C-Munipack Documentation

Release 2.1.32

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CHAPTER ONE

PREFACE

At the beginning of the 21st century, astronomical photometry has changed a lot. Instead of visual and photoelectric observation, the observers began to use CCD cameras. The CCD cameras became cheaper and therefore more affordable even for amateur astronomers. This gave rise to the demand for a software tool for processing the CCD-data, which would be affordable for an amateur astronomer, provide a simple and user-friendly graphical interface and provide robust algorithms.

In April 2003 the C-Munipack project was started; its goal was to supply the astronomers with a powerful but also user-friendly tool for processing their CCD-data. At the time, the two similar tools existed: MuniDOS, a text-mode program, which was somewhat limited by the user interface. Additionally, according to the authors, the program is not using modern algorithms, and no future development is planned. The other available was Munipack, written partly in Fortran and partly in C. Munipack is a modern and still maintained tool, but there were several disadvantages: the users of Windows operating system would have severe problems with its compilation from the source code (no binaries were provided), and the graphical interface, that program offers, is available only for unix-based operating systems. Of course, there are some commercial products available on the market, some of them are really good, but these products are not affordable for amateur astronomers, since they have to pay for everything by themselves.

About this document

This manual is an official user manual and a reference of the C-Munipack software. The document consists of several parts. The first, introductory, part gives a reader a basic information about the software, its authors, features and internet resources that are related to the project. *The second part* describes in details its graphical user interface, the Muniwin application, which is the way that the most users uses for their daily work all the time. *The third part* contains detailed description of a set of user commands, the C-Munipack toolkit, these commands can be used to build automated shell scripts. The detailed description of the algorithms and file formats is found in *the fourth part* of this document.

If you are a novice user, please read the chapter *Getting started* first. This chapter is a simple tutorial that guides your through a basic CCD frame processing work-flow using a set of sample frames that are available on the project's home page. The basic concepts of the software are also explained there.

Acknowledgement

I would like to thank to all my colleagues, who contributed with their ideas, advice, and suggestions, to this program. Namely to Filip Hroch for sharing the Munipack source code, and for his help with porting it from Fortran to C, to Lukas Kral for sharing his Varfind source code, to Miloslav Zejda, Ondrej Pejcha, Petr Svoboda, Volkan Bakis for their help with testing and valuable suggestions to the user interface and also to Jitka Kudrnacova and Petr Lutcha for their help with the user manual.

The user manual contains CCD frames of GSC 2750 854 (courtesy of Vyskov observatory) and CCD frames of 268 Adorea (courtesy of ProjectSoft HK & Astronomical Institute of the Charles University in Prague)

CHAPTER

TWO

INTRODUCTION

The software package C-Munipack presents the complete system for reduction of images carried out by a CCD or DSLR camera, oriented at observation of variable stars. The specific programs of reduction process can be called from a command line or via an intuitive graphical user interface.

The project is based on the previous Munipack package, the command-line programs have the same name, but to the contrary to Munipack, the C-Munipack software is coded in the C/C++ language and it contains several new functions and tools in addition. Assignment of the command-line parameters and the configuration files is similar in the both projects, exceptions are described in the project documentation.

The graphical user interface, which was build upon the portable GTK+ toolkit, should be familiar for Munidos users, but it takes full advantage of the graphical environment, and therefore the interface is more comfortable and enables a user an improved control over the reduction process in comparison with the original interface of Munidos.

2.1 Features and capabilities

The following list is a short overview of the key features that the C-Munipack software provides:

- Powerful graphical user interface that runs on the most up-to-date platforms and operating systems
- Conversion of CCD frames from several input formats (see below) into the standard FITS format
- Conversion of several RAW formats produced by DSLR cameras into the standard FITS format
- Color channel separation for color DSLR images
- Extensive set of the calibration tools: correction of observation time, bias-frame correction, dark-frame correction, flat-flat correction and heliocentric correction
- Aperture photometry using a fully configurable set of apertures of different sizes
- Automatic finding corresponding stars on a set of frames
- Tracking of moving targets, such as minor Solar System bodies
- Easy-to-use making light curves for selected stars; either differential curves or instrumental magnitudes for further post-processing
- Ensemble photometry using unlimited number of comparison stars
- Semiautomatic detection of new and unknown variable stars on a view field
- Computation of air mass coefficient
- Combining a set of bias, dark and flat frames into high quality master-bias, master-dark and master-flat correction frames
- Exports light curve as: CSV file, ASCII file, MCV compatible format, AVE compatible format

- Exports light curve in the AAVSO Extended Format
- All data processing and scientific routines are placed in a public ANSI C library that can be used to create a tailor-made photometry software
- A complete set of user (shell) commands that can be used for automatic surveys

The following input formats are supported:

- The FITS format with many date and time formats
- The SBIG's ST-x compressed and uncompressed formats
- The OES Astro format
- Selected models of DSLR camera raw format: CRW, NEF[1]

2.2 What can NOT the software do?

- It doesn't control a camera or a telescope of any manufacturer.
- It doesn't compute celestial coordinates of objects (astrometry)

2.3 Authors

The project manager David Motl is also the author of the most part of the source codes. Some small pieces of the sources originate from the Munipack package, coded by Filip Hroch. The algorithms for aperture photometry originate from the Daophot software by P. B. Stetson. The Munifind algorithm originates from the Varfind tool coded by Lukas Kral. The code of the lossless JPEG decoder incorporated in the DSLR image reader originates from Dave Coffin's dcraw utility. The matching algorithm using Phi-LogR space originates from Nick Kaiser's imcat software.

The package uses the following third party software:

- FITSIO library, written by Dr. William Pence, NASA
- EXPAT library, written by James Clark's
- GTK+ toolkit, developed by the The GTK+ Team
- Sphinx documentation generator
- WCSLIB library, writter by Mark Calabretta
- FFTPACK library, written by Paul Swarztrauber, NCAR
- The windows binaries are compiled using MSVC 2010 Express edition
- The installer is built using Nullsoft Scriptable Install System (NSIS)

[1] Please read the *Photometry using a DLSR camera* article before using the C-Munipack software to process snapshots from a DSLR camera.

2.4 License and copying

This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License version 2 as published by the Free Software Foundation.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the LICENSE file for more details.

2.5 Where can I get the latest version?

The project is hosted by SourceForge. The latest version of the binaries, the source codes and the documentation is available on the following address:

http://c-munipack.sourceforge.net/

2.6 Supported platforms

MS Windows

The binaries provided on the website are compatible with MS Windows XP SP3 and later (32-bit or 64-bit).

The C-Munipack software is developed on MS Windows 7. The distributed binaries are compiled using the MSVC 2010 Express edition.

Note: Since C-Munipack version 2.1, MS Windows 2000 are no longer supported.

Other platforms

The software must be compiled from the source code; it should compile on any POSIX-compliant system, provided that the following libraries/packages have been installed.

Minimum requirements:

- C/C++ compiler (such as gcc)
- cfitsio 3.x (http://heasarc.gsfc.nasa.gov/fitsio/)
- expat (http://expat.sourceforge.net/)
- GTK+ 2.x (http://www.gtk.org/)

Optional dependencies:

- gstreamer (http://gstreamer.freedesktop.org/)
- wcslib (http://www.atnf.csiro.au/people/mcalabre/WCS/)

The software build is tested on Debian 7.7 and 8.2. It is known to compile also on *Mac OS X*.

2.7 What's new in version 2.1

The main goal of this version was to provide 64-bit binaries for MS Windows platform along with the 32-bit version. The installer package for MS Windows comes with the both versions and the installer chooses the binaries that are appropriate for the host platform. The GKT+ library was updated to the version 2.24 and therefore Windows 2000 are no longer supported.

The software can also read WCS coordinates, if they are stored in the source FITS files. I thought that I could use them to get reliable matching for difficult cases, like glubular clusters, but this effort was fruitless so far. The only result from this effort is that if the source FITS files comprises the WCS data, the frame preview window shows RA/Dec coordinates of objects.

There are also two new plot types - *CCD temperature* plot which shows temperature variations over time; such plot can be used to monitor performace of the camera cooling sub-system. The new *Object properties* plot can be used to check for changes in de-focus (FWHM), weather conditions through a plot of instrumental magnitudes of a constant object or sky background level.

The version 2.1 also introduces a new matching tool that can track an object that moves with respect to the stars, such as minor Solar System bodies, the software is not designed to measure accurate position of the objects, it can be used to observe changes in the brightness in time.

CHAPTER THREE

INSTALLATION AND UNINSTALLATION

The latest version of the binaries and the source code can be obtained from the C-Munipack project home page: http://c-munipack.sourceforge.net/. Choose the binary or source package according to your platform and download it.

3.1 Using the installer on MS Windows

Note: Since C-Munipack version 2.1, MS Windows 2000 are no longer supported.

Download the installer (.exe file) from the project home page and execute it. Follow the instructions in the installation wizard. By default, the files are installed to the Program Files folder. The software itself doesn't require the write access to the installation path and it doesn't read or modify the windows registry. All configuration files and other temporary files are stored in user's Application Data folder.

The installer package comprises of the both 32-bit and 64-bit executables. The installer automatically chooses the executables which are appropriate to the host platform.

Uninstallation

To uninstall the software open the Control Panel, then open the Add/Remove programs tool. Select the C-Munipack 2.1 item and click on the "Remove" button.

3.2 Building from the source code on POSIX-compliant systems

Download the source code archive to your computer and unpack it using the tar command. The software comes with the GNU automake configuration scripts.

Run the 'configure' script

First, run the configure script that is stored in the root directory. The script takes a while to finish. It automatically checks the dependencies and makes a set of Makefiles that in turn are called to build and install the binaries and the data files. Here is the list of the most frequently used command-line options that the configure script accepts.

`--help`
: Print the complete set of command-line options.

`--prefix=path`
: Install the software in subdirectories below prefix. The default value of prefix is /usr/local.

The following options extends the default configure's set:

`--disable-gui`
: Do not build the graphical user interface (Muniwin).

`--disable-toolkit`
: Do not build the set of user commands (toolkit).

`--disable-sound`
: Do not build the software with the support for sounds that are played when a process is finished. Use this option if you do not have the gstreamer library.

`--disable-wcs`
: Do not build the software with the Woorld Coordinate System (WCS) support. Use this option if you do not have the wcslib library.

Build and install

Run 'make'. Once you have successfully compiled the software, run 'make install'.

Note: On some systems, it is necessary to run 'ldconfig' after 'make install'.

Files and directories

The 'make install' command installs a the binaries, the data and the user manual to the destination directory, the files is installed into following directories. In the list below, the prefix stands for the installation path, the default prefix is /usr/local.

`prefix/bin`
: The binaries

`prefix/lib`
: The libraries that are used to build applications using the C-Munipack API

`prefix/include`
: The header files that are used to compile applications using the C-Munipack API

`prefix/man`
: The Unix-style man pages

`prefix/share/c-munipack-2.0`
: The icons, sounds and documentation

The configuration files are stored per user within the directory that is reserved for the user-specific application configuration information. The path is determined using the mechanisms described in the XDG Base Directory Specification.

`$HOME/.config/C-Munipack-2.0`
: The configuration files

`$HOME/.local/share/C-Munipack-2.0`
: The default directory for catalog files, projects, etc.

CHAPTER

FOUR

GETTING STARTED

The following text describes the basic procedure for processing an observation of a short-periodic eclipsing variable stars by means of the Muniwin software, the graphical user interface which comes with the C-Munipack software.

The package with the demonstration data used in the example is available on the project home page. Download and unzip the archive to an empty folder (e.g. `~/c-munipack/sample`). The archive has the following structure:

`dark / 20s / masterdark.fts`
: master-dark frame (20 seconds exposure)

`dark / 20s / raw / dark*.fts`
: set of raw dark frames (20 seconds exposure)

`flat / v / masterflat.fts`
: master-flat frame (optical filter V)

`flat / raw / flat-v*.fts`
: set of raw flat frames (optical filter V)

`data / v / frame*.fts`
: sample CCD frames (optical filter V)

4.1 General overview

The reduction of CCD observation can be described in general as a process that takes a time sequence of source frames of the same view field and a set of calibration frames and makes a table of brightness values of a selected object with respect to the time of observation, called a light curve.

The process of reduction of a CCD observation in the Muniwin software consists of the several steps:

1) Creating a new project and populating it with input files (source CCD frames)
2) Calibration of the source frames
3) Photometry and matching
4) Selection of stars
5) Selection of aperture

4.2 Start Muniwin

Launch the **Muniwin** program - a way how to launch an application depends on your operating system and desktop environment. For example, on the MS Windows platform, the Muniwin program can be run from the menu *Start* → *Programs* → *C-Munipack 2.1* folder. On POSIX-compliant platforms, execute the command `muniwin` in a terminal window. A *main application window* appears.

See also:

Main window.

4.3 Create a new project

In the Muniwin application, open the main menu, select item *Project* → *New*. A new dialog appears.

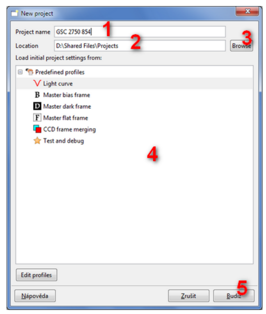


Fig. 1: The dialog for making a new project.

Fill in a name that will be assigned to the project (1). Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >. In our example, let us use the designation of the variable star `GSC 2750 854`.

The field *Location* (2) shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button (3) to select a directory in a separate dialog.

The dialog also displays a list of available project types, called the profiles. The profile is used to specify initial settings for a new project. The installation package comes with a set of factory-provided profiles, which are listed under the section *Predefined profiles*. Later on, when you tune your own set of configuration parameters that you want to use repeatedly, you can create your own profiles, called *User-defined profiles*. See the section *Profiles* in the manual for instructions how to create and edit the user-defined profiles.

In this introductory demonstration tour, we will make a light curve for an eclipsing binary. Please, select the item *Light curve* in the section *Predefined profiles* in the table (4).

The dialog is closed and you should see the main application window again now. The table of input files shown there is empty.

See also:

New project (dialog).

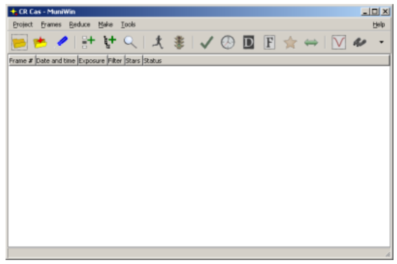


Fig. 2: The main application window with the table of input files, now empty.

4.4 Selecting source frames

Now, we're going to populate the project with source files. Open the *Frames* menu and click on *Add frames from folder*. Go to the folder which contains the source CCD frames. The source CCD frames from the demonstration data are stored in the `data/v` subfolder. You should see the list of files in the center navigation pane. This dialog allows you to add all frames from folders and subfolders. If you need to specify only a subset of files from a particular folder, you the *Add individual frames* choice.

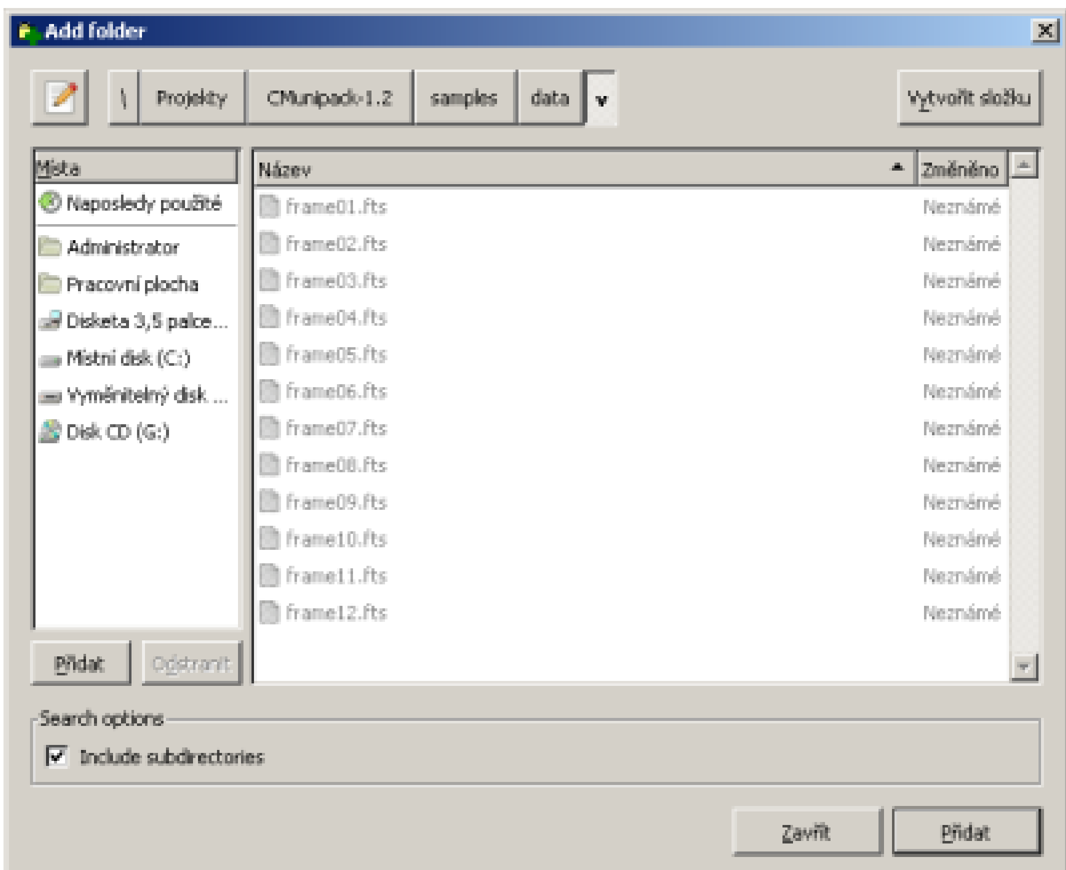


Fig. 3: The dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

Push the *Add* button. If you want to process data taken in several nights at once, use the same procedure to add those files to the table. After inserting all the files you want to process, close the dialog by pushing the *Close* button.

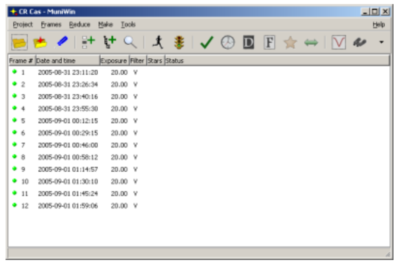


Fig. 4: The main application window with the sample frames inserted.

See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*.

4.5 Frame reduction

Reduction of CCD frames is a process that takes the source CCD frames, performs their conversion and calibration, detects stars on each frame and measures their intensity and finally finds correlation (match) between objects that were found in the data set. The process of reduction prepares the data that are necessary for making a light curve or a variable star.

The reduction consists of the four steps - conversion, calibration, photometry and matching. Although they can be invoked step-by-step manually, the preferred way is to use the *Express reduction* dialog that allows to perform these steps in a batch. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. The dialog has several options aligned to the left, each of them relates to an optional step in the reduction process.

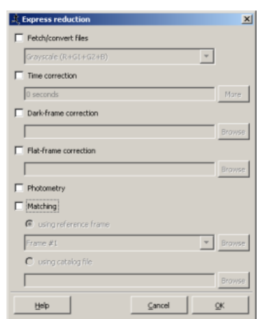
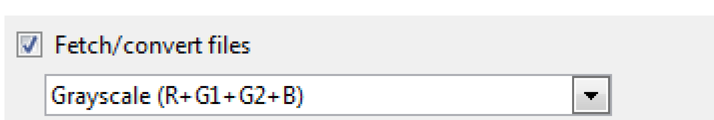
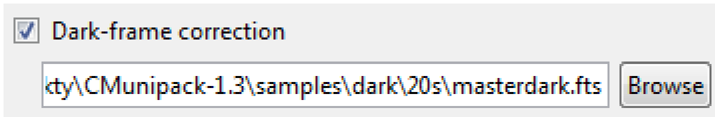


Fig. 5: The dialog for setting parameters of the reduction process

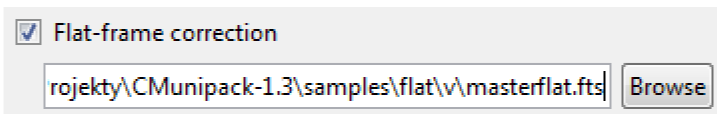
Check the *Fetch/convert files*. In this step, the program makes copy of the source CCD frames. This is necessary, because the following calibration steps will modify them and we don't want the program to change our precious source data.



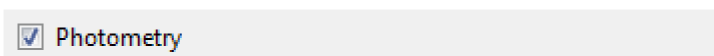
A raw CCD frame consists of several components. By the calibration process, we get rid of those which affect the result of the photometry. In some literature, the calibration is depicted as the peeling of an onion. There are three major components which a raw frame consists of - the current made by incident light, current made thermal drift of electrons (so-called dark current) and constant bias level. In standard calibration scheme, which we will demonstrate here, the dark-frame correction subtracts the dark current and the also the bias. Because of the nature of the dark current, it is necessary to use a correction frame of the same exposure duration as source files and it must be carried out on the same CCD temperature, too. Thus, the properly working temperature regulation on your CCD camera is vital. Our sample data needs to perform the dark-frame correction, so check the *Dark-frame correction* option. Click the *Browse* button and find the file with the dark frame. For the sample data, use the file `dark / 20s / masterdark.fts`.



Then, we have to compensate the spatial non-uniformity of a detector and whole optical system. These non-uniformities are due to the fabrication process of a CCD chip and they are also natural properties of all real optical components, lenses in particular. The flat-frame correction uses a flat-frame to smooth them away. The flat-frame is a frame carried out while the telescope is pointed to uniformly luminous area. In practice, this condition is very difficult to achieve, the clear sky before dusk is usually used instead. Our sample data needs to perform the flat-frame correction too, so check the *Flat-frame correction* option. Click the *Browse* button and find the file with the flat frame. For the sample data, use the file `flat / V / masterflat.fts`.



The photometry is a process that detects stars on a CCD frame and measures their brightness. Unlike the previous steps, the result is saved to a special file, so-called the photometry file. There are a lot of parameters which affect the star detection and also the brightness computation. In this example, the default values work fine, but I would suggest you to become familiar with at least two of them - FWHM and Threshold - before you start a real work. Check the *Photometry* option.



The previous command treated all source files independently. As a result of this, a star #1 in one file is not necessarily the same as a star #1 in another file. The matching is a process which finds corresponding stars on source frames and assigns an unique identifier. Check the *Matching* option.

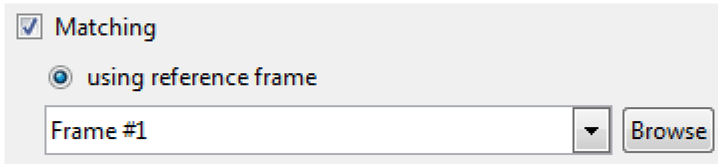
It is necessary to select one frame from the set of source frames that all other frames are matched to, this frame is called a reference frame. In my experience, the frame with the greatest number of stars works the best. Back to our example, let's pick up the first one.

In previous steps, we have configured parameters of the reduction process and we are ready to start it. Click the *OK* button. During the execution a new window appears displaying the state of the process; all the information is also presented there. This window will be automatically closed after finishing the process. Wait for the process to finish.

After finishing, the icon in the file table changes; the information about the time of observation, the length of the exposition and the used filter is filled in. In case some of the frames could not be processed successfully, the entry is be marked with a special icon and in the *Status* column the error message is indicated.

See also:

Express reduction (dialog).



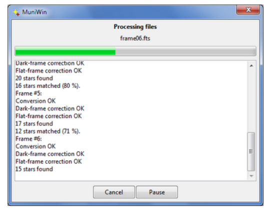


Fig. 6: The dialog displayed during time demanding operations.

4.6 Making a light curve

The sample data is the observation of an eclipsing binary star. For most of such observers, the goal is to make a light curve. A light curve is usually represented as a table, which consists of at least two columns - time stamps expressed as Julian dates and differential instrumental brightness of a variable star in magnitudes. The magnitudes are called differential, because they are differences between two stars - a variable star and a comparison star. A variable star is a star that is subject of brightness variation and a comparison star is supposed to be constant. To check that the comparison star is really constant, it's advisory to use one or two additional stars, so-called check stars. They are supposed to be constant too and thus the difference between any check star and the comparison star should be constant.

The Muniwin program is designed to guide you through the process of making a light curve. Open the *Make* menu and select the *Light curve* item. A new dialog appears, all fields in this dialog are optional, they allows you to include only subset of frames to the curve, apply the heliocentric correction or include the air mass coefficients to the output. Let all options unchecked and just confirm the dialog by the OK button.

Another dialog appears. The next dialog allows you to pick up a variable star, a comparison star and one or more check stars. In this dialog, the reference frame is displayed. Find a variable star and click on it using the left mouse button (1). A context menu appears. Select the *Variable* item. The star is drawn in red color now and the label `var` is placed near to it. Using the same procedure, select one comparison star (2) and one or more check stars (3 and 4). I would recommend you to use two check stars. If you are using the sample data, use the stars according to the following screenshot. Confirm the selection by the *OK* button.

In the next dialog, we have to choose the aperture. You can image the aperture as a virtual circular pinhole, placed on each star on a frame to measure its brightness. All pixels that are inside the pinhole are included in computation leaving out the background pixels. The best aperture should be big enough to include most of the star's light, on the other hand, the bigger aperture is used the more background is included and the more noisy the result is. Because of this, the photometry process computes the brightness of each star in a set of predefined apertures of radius in the range

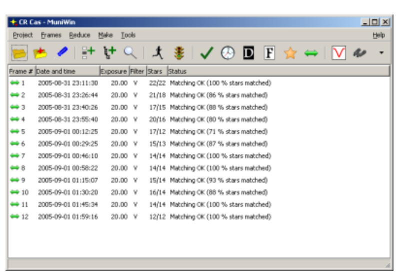


Fig. 7: The main application window after the recution.

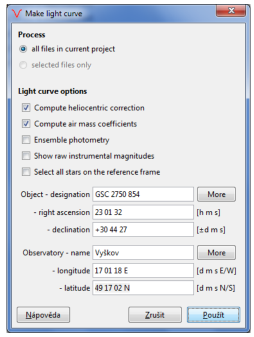


Fig. 8: The dialog for making a light curve.

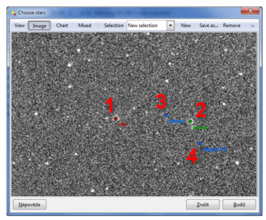


Fig. 9: The dialog for selection of a variable star (red), a comparison star (green) and check stars (blue).

of 2 and 30 pixels.

The programs allows you to select an aperture in the following dialog, the program displays a graph of standard deviation of data for each aperture. The curve has U-like shape usually and the best aperture is in the minimum of the curve (5). For the sample data, select the aperture #2 and confirm the dialog by the *OK* button.

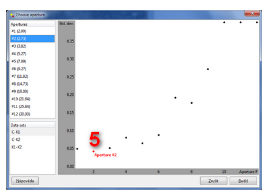


Fig. 10: The dialog for selection of an aperture.

Now the program has got enough information to make a light curve of the selected variable star. The light curve is presented in a new window. Please keep in mind that the magnitudes displayed in the light curve are differential with respect to the selected comparison star.

See also:

Light curve.

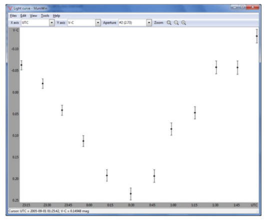


Fig. 11: The dialog with a light curve graph.

4.7 Exporting a light curve to a file

The light curve can be exported to a file in several formats.

See also:

Export light curve in AAVSO format

CHAPTER

FIVE

USING MUNIWIN

5.1 Projects

The concept of projects was introduced to retain the products of the CCD frame calibration and reduction even when another data sets were processed; it allows one to revert back to the data that have been already processed without necessity of processing them again.

The project consists of:

- Project settings - a set of configuration parameters
- Image files - one image file per frame. These are created as copies of the source frames, they are modified during the reduction process by applying various transformations and calibration steps.
- Photometry files - one photometry file per frame. The photometry files contain the list of detected objects and their properites - coordinates, brightness, etc.

5.1.1 Project settings

All configuration parameters that affect the data processing are retained in the project, allowing one to work with multiple configurations efficiently. When the projects settings are changed, the program updates the project. There is one exception to this rule - if the project is opened in the 'read-only' mode, the new settings are kept in the memory, but the project file is not changed.

When a new project is created, the initial project settings is loaded from a template, called the *profile*. The installation package comes with a set of predefined profiles, but the user can save his own ones. See the *Profiles* section for more information.

The description of the individual parameters can be found in *this chaper*.

5.1.2 Project types

The project type was introduced to optimize the user interface when a specific task is performed - for example, when one is making a master flat frame, some of the tools, like the light curve dialog or the find variables dialog, can be kept from the menus and the toolbar, because they are not used in this context. The *Project settings dialog* is affected by the choice of the project type, too. The dialog presents only the parameters that are used in the selected task.

5.1.3 Managing projects

The Muniwin program allows one:

- To create a new project - *New project (dialog)*
- To open an existing project - *Open project (dialog)*
- To rename the opened project using the *Project settings dialog*
- To make a copy of a project - *Export project (dialog)*
- To import data from old C-Munipack into a new project - *Import project (dialog)*

5.1.4 Files and directories

Regarding the data storage, the program is not limited to any specific folder. The user's folder for application data is supplied just as a default location (actual folder depends on the operating system). A user can choose any folder that suits him. There is no special configuration option that needs to be adjusted, the *New project (dialog)* allows one to choose any location for the new project and the *Open project (dialog)* also allows one to choose a project in any folder. The data can be stored on an external drive or shared using a network storage. In case of a network storage, the program takes uses a locking mechanism (see below) to ensure that two users does not make changes to a project at the same time.

Example of the default location on Windows:

`C:\Users\your name\Application data\C-Munipack-2.0\Projects`

A project consists of two components: a project file - it can be recognized by the extension 'cmpack', e.g. 'GSC 2750 854.cmpack' and a related folder that consists of the calibrated images, photometry files, etc. This folder has the same name as the project file plus the extension '-files', e.g. 'GSC 2750 854.cmpack-files'. These two (file + folder) must always go together. All references inside a project are relative, therefore you can move or copy a project or a bunch of projects just by moving or copying it's folder to any location.

5.1.5 Project sharing

When a project is opened more than once, the program detects this situation and notifies a user. It allows one to open the project in the 'read-only' mode; in this mode, it is allowed to make outputs, e.g. light curve, but operations that would change the data files are disallowed. The file-based locking mechanism used should work over the network in most situation, although this is not guaranteed in all configurations.

See also:

Profiles, *Project settings (dialog)*, *New project (dialog)*, *Load profile (dialog)*

5.2 Profiles

The profile provides a set of configuration parameters that are used to process the data. Unlike the *project*, it does not contain the data - image files and photometry files. The profiles are used to transfer the configuration parameters between projects. Once you invent the best configuration parameters for your observations, save them as a user-defined profile. Next time, when you are going to do the same task with another frame set, choose the profile in the *New project* dialog; the project is created with settings restored from the profile. When you process the data from multiple instruments, you can create multiple user-defined profiles, each of which fits the particular instrument.

The description of the individual parameters can be found in *this chaper*.

5.2.1 Creating user-defined profiles

A new profile can be created using the following steps:

(1) Start with a project - create a new project or open an existing one. Set up the project settings.

(2) From the main menu select *Project* → *Edit properties*.

(3) Go to the root page (called *Project . . .*).

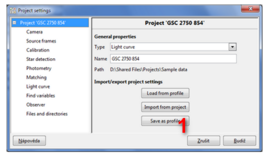


Fig. 1: Project settings dialog

(4) Click the *Save as profile* button (1). A new dialog appears. Enter the name of the profile (2).

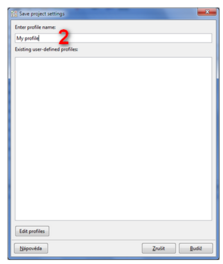


Fig. 2: Save as profile dialog

(5) Confirm the dialog.

5.2.2 Using user-defined profiles to create a new project

The projects settings for a new project can be restored from the user-defined profile:

From the main menu select : *Project* → *New*. A new dialog appears.

(1) Enter a project name.

(2) Adjust location of the new project if necessary.

(3) List of existing profiles is shown in the table. The profiles are divided into two sections -
user-defined profiles and predefined profiles. Choose the profile and confirm the dialog.

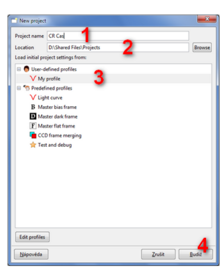


Fig. 3: New project dialog

5.2.3 Editing user-defined profiles

The user-defined profiles can be edited and managed by the *Edit profiles* dialog.

(1) From the main menu select *Tools* → *Edit profiles*. A new dialog appears.

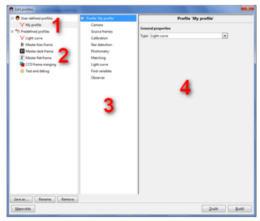


Fig. 4: Edit profiles dialog

The dialog is divided into three sections. The table on the left presents a list of existing profiles. They are divided into two parts - used-defined profiles (1) and predefined profiles (2). Unlike the user-defined profiles, the predefined profiles are created at the program installation and they cannot be modified.

When a profile is selected, the rest of the dialog shows the configuration parameters of the selected profile. The central sections of the dialog (3) shows a structure of pages which the parameters are divided to. Select a page to show the configuration parameters (4).

Each page has got the *Set defaults* button on it. Click the button to reset the parameters on the current page to the default values.

5.2.4 Loading settins from a profile to an existing project

To load a the settings from a profile to an existing project:

(1) From the main menu select *Project* → *Edit properties*. A new dialog appears.

(2) Go to the root page (called *Project* . . .).

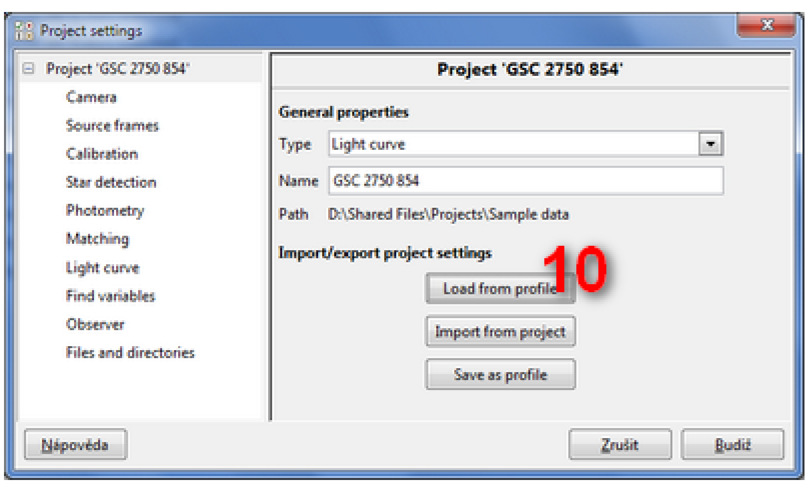


Fig. 5: Project settings dialog

Click the *Load from profile* button (10). A new dialog appears. Choose the profile that shall be loaded into the current project. Confirm the dialog.

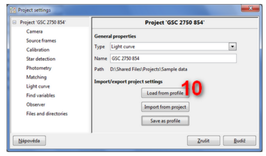


Fig. 6: Load profile dialog

5.2.5 Files and directories

The user's folder for application data is supplied just as a default location for the user-defined profiles (actual folder depends on the operating system). Each profiles is stored as a separate file.

Example of the default location on Windows:

`C:\Users\your name\Application data\C-Munipack-2.0\Projects`

You can change the path using the *Environment options* dialog, the section *Files and directories*:

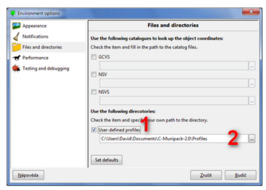


Fig. 7: Environment options dialog

Check the option (1) to tell the software to use user-supplied path to the directory with user-defined profiles. Specify the path to the edit box below (2). If the option is not checked, the program uses the default location (see above).

See also:

Projects, *Project settings (dialog)*, *New project (dialog)*, *Load profile (dialog)*, *Save project settings (dialog)*, *Edit profiles (dialog)*, *Import project settings (dialog)*

5.3 Light curve

The light curve is a graph of intensity of an object (a variable star in most cases), as a function of time. The light curve of the observered object is usually presented in a form of a graph that has time on the independent axis and the intensity in magnitudes on the other axis. Each point in the graph represents single measurement, which in simple cases corresponds to a single input CCD frame.

To make a light curve of an observed object, we need a set of photometry files with cross-reference information (matched photometry files). An user have to the program which stars are variable stars and comparison stars. In case of aperture photometry, he also have to choose an aperture.

The Muniwin program allows an user to apply further corrections and include additional information to a light curve, all of which will be discussed later in the text.

This chapter explains how to make a light curve of stationary objects, such as variable stars and exoplanets. For a guide on making a light curve of moving objects (minor Solar System bodies) follow *this link*.

5.3.1 Before you start

Before you start the reduction of your own CCD frames, you may need to perform several pre-processing steps. Though it isn't necessary, combining the several correction frames into so-called "master" ones is advisory, because it reduces the noise and makes the result more precise. The method of making master correction frames is described in separate chapters.

See also:

Master-dark frame and *Master-flat frame*

5.3.2 Creating a new project

First of all, we will create a new *project*. To begin with processing of a variable star observation, we create a new project. To do so, open the *Project* menu and activate the *New* item. A new dialog appears.

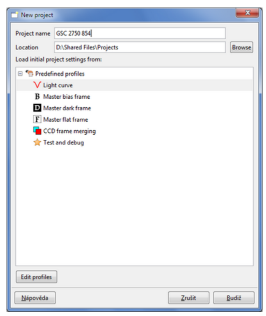


Fig. 8: The dialog for making a new project.

Fill in a name that will be assigned to the project. Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >.

The field *Location* shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button to select a directory in a separate dialog.

The dialog also displays a list of available profiles. A profiles provides an intial set of configuration parameters into a new project. When you confirm the dialog, you should be in the main window again now. The table of input files shown there is empty.

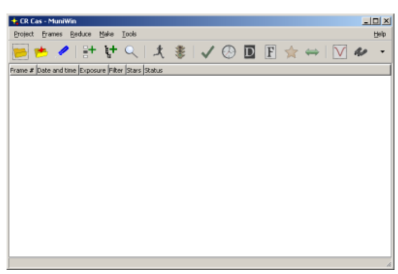


Fig. 9: The main application window with the table of input files, now empty.

See also:

New project (dialog) and *Main window*.

5.3.3 Input files

Now, we are going to tell the program which files we are going to work on. These files are called the input files. Their list is displayed in the table in the main application window. When the application is closed, the list of files are saved to the disk and it is restored back when the program is launched again.

Supposing that the table now consists of files from your previous task, let's get rid of them. Please, use *Files* → *Clear files* to start a new task instead of just removing the files from the table. Besides the clearing the table of input files, this function resets all internal variables, too.

Now, we need to populate the table with the CCD frames we're going to reduce. There are two methods how to achieve that - adding a individual files or adding all files from a folder. Which way is the best for you depends on organization of your observations on the disk. I'd suggest you to make a folder for each year, a folder for each night in it, the a subfolder for a name of object or another view field identification and finally a subfolder named upon the color filter (if you use more of them). In this case, the "Add frames from a folder" method is more convenient.

Click on *Files* → *Add frames from folder* in the main menu. A new dialog appears. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. Enter the folder with the input files - you should see them in the middle pane. Then, click on the *Add* button to add files to the table of input files. The program shows the number of added files in the separate dialog. The *Add frames from folder* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

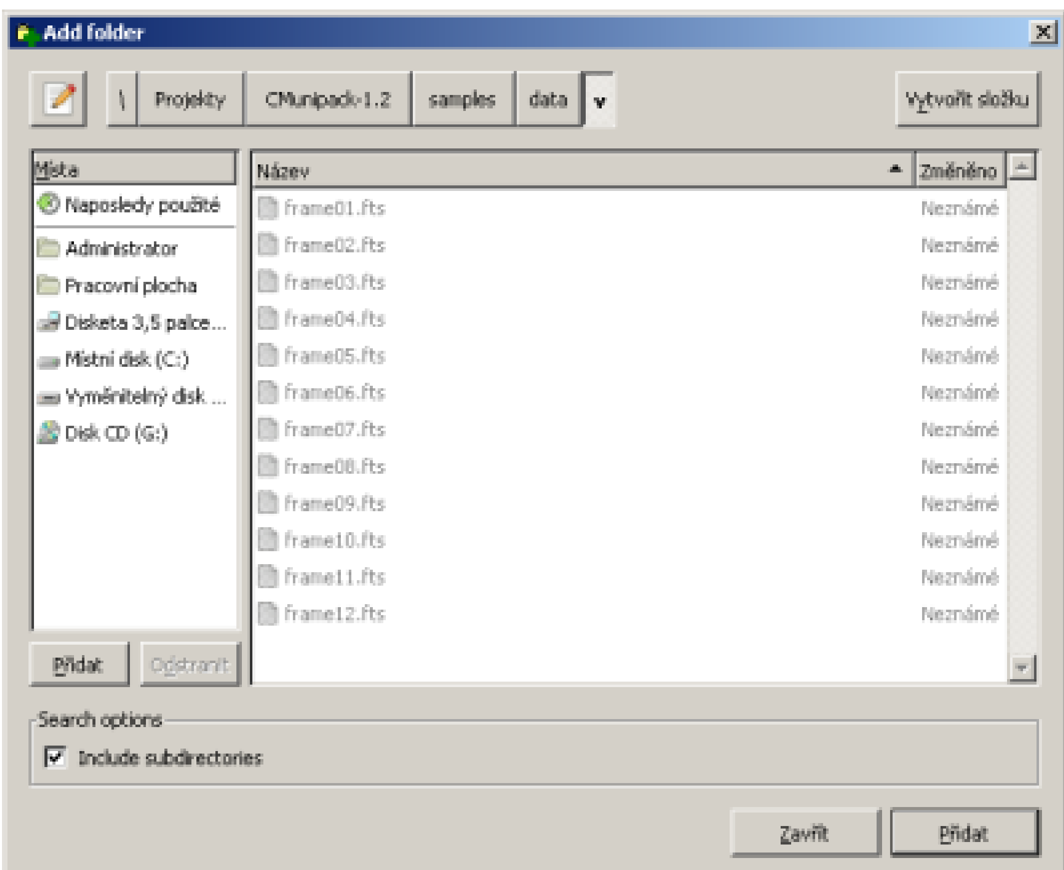


Fig. 10: The "Add folder" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

If you want to reduce only a subset of files from a folder, click on *Files* → *Add individual frames* in the main menu. A new dialog appears, similar to the previous one. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. In the middle pane, select the files using the `Ctrl` modifier to include and exclude a single file and the `Shift` modifier to include a range of files. Then, click on the *Add* button to add selected files to the table of input files. The program shows the number of added files in the separate dialog. The *Add individual frames* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

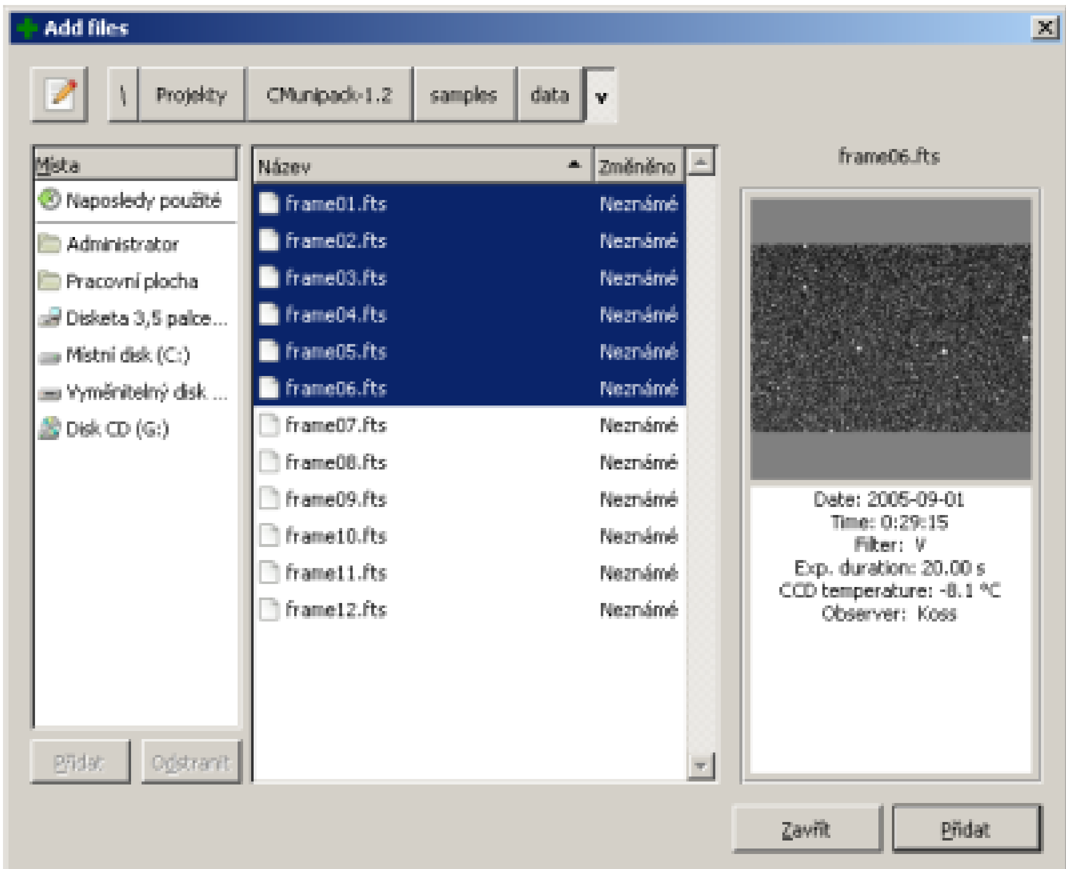


Fig. 11: The "Add files" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*.

5.3.4 Frame reduction

Reduction of CCD frames is a process that takes source CCD frames, performs their conversion and calibration, detects stars on each frame and mearures their intensity and finally finds correlation (match) between objects that were found in the data set. The process of reduction prepares the data that are necessary for making a light curve or a variable star.

The reduction consists of several steps - conversion, calibration, photometry and matching. They can be invoked step-by-step manually. The preferred way is to use the *Express reduction* dialog that allows to perform these steps in a batch. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. The dialog has several options aligned to the left, Each of them relates to an optional step in the reduction process.

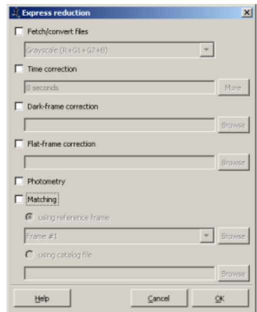
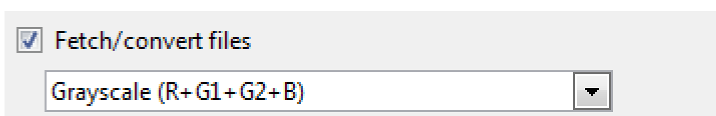


Fig. 12: The dialog for setting parameters of the reduction process

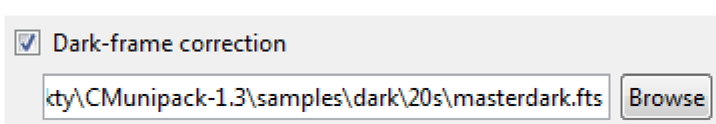
Fetch/convert files

Check the *Fetch/convert files*. In this step, the program makes copy of the source CCD frames. This is necessary, because the following calibration steps will modify them and we don't want the program to change our precious source data.



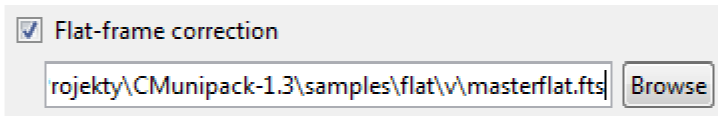
Dark-frame correction

A raw CCD frame consists of several components. By the calibration process, we get rid of those which affect the result of the photometry. In some literature, the calibration is depicted as the peeling of an onion. There are three major components which a raw frame consists of - the current made by incident light, current made thermal drift of electrons (so-called dark current) and constant bias level. In standard calibration scheme, which we will demonstrate here, the dark-frame correction subtracts the dark current and the also the bias. Because of the nature of the dark current, it is necessary to use a correction frame of the same exposure duration as source files and it must be carried out on the same CCD temperature, too. Thus, the properly working temperature regulation on your CCD camera is vital.



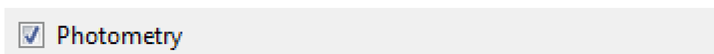
Flat-frame correction

Then, we have to compensate the spatial non-uniformity of a detector and whole optical system. These non-uniformities are due to the fabrication process of a CCD chip and they are also natural properties of all real optical components, lenses in particular. The flat-frame correction uses a flat-frame to smooth them away. The flat-frame is a frame carried out while the telescope is pointed to uniformly luminous area. In practice, this condition is very difficult to achieve, the clear sky before dusk is usually used instead.



Photometry

The photometry is a process that detects stars on a CCD frame and measures their brightness. Unlike the previous steps, the result is saved to a special file, so-called the photometry file. There are a lot of parameters which affect the star detection and also the brightness computation. In this example, the default values work fine, but I would suggest you to become familiar with at least two of them - FWHM and Threshold - before you start a real work. Check the *Photometry* option.



FWHM
The FWHM parameter specify the expected width of stars on a frame. The value is the Full Width at Half Maximum in pixels. The parameter controls the behavior of the low-pass digital filter, which is used in the star detection algorithm.

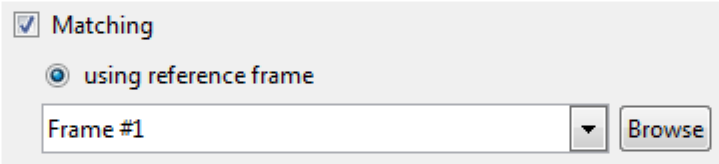
Threshold
The Threshold parameter specify the lowest brightness of detected stars. Fainter objects are considered to be background artifacts and thus sorted out. The value is dimensionless coefficient.

Once you tune up the parameter for your environment, usually it is not necessary to adjust them for every task, unless the quality of your images varies considerably. In the first iteration, you can use the default values (FWHM = 3.0 and Threshold = 4.0) and do the photometry. Click on the *Reduce* → *Photometry* item in the main menu and confirm the new dialog by the *OK*. Then, by double click on a frame in the main window open the preview window and check the results. If there are stars which have been detected as a close binary although it is not true, you should increase the *FWHM* value. If the stars you are interested in are not detected, try decrease the *Threshold* value. If it doesn't help, decrease the *FWHM*. If there is a lot of background artifacts detected as a real stars, increase the *Threshold*. By several iterations, adjust the parameters, so all the stars you are interested in are detected and there are no false binaries.

Matching

The previous command treated all source files independently. As a result of this, a star #1 in one file is not necessarily the same as a star #1 in another file. The matching is a process which finds corresponding stars on source frames and assigns an unique identifier. Check the *Matching* option.

It is necessary to select one frame from the set of source frames that all other frames are matched to, this frame is called a reference frame. In my experience, the frame with the greatest number of stars works the best. Back to our example, let's pick up the first one.



Invoking the reduction process

In previous steps, we have configured parameters of the reduction process and we are ready to start it. Click the *OK* button. During the execution a new window appears displaying the state of the process; all the information is also presented there. This window will be automatically closed after finishing the process. Wait for the process to finish.

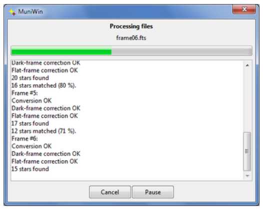


Fig. 13: The dialog displayed during time demanding operations.

After finishing, the icon in the file table changes; the information about the time of observation, the length of the exposition and the used filter is filled in. In case some of the frames could not be processed successfully, the entry is be marked with a special icon and in the *Status* column the error message is indicated.

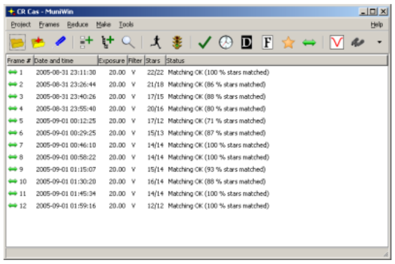


Fig. 14: The main application window after the recution.

See also:

Express reduction (dialog).

5.3.5 Making a light curve

Reduce the source CCD frames (see the chapter “Reduction of CCD frames”). Then click on the *Plot* → *Light curve* item in the main menu. A new dialog appears. The dialog allows an user to set up the options for the light curve. If you want only a subset of frames from the project to be included in the curve, check the selected files only option in the box. The program can also include several corrections and coefficients to the output file, these features are discussed later in the text.

Confirm the dialog by the *OK* button.

See also:

Plot light curve (dialog)

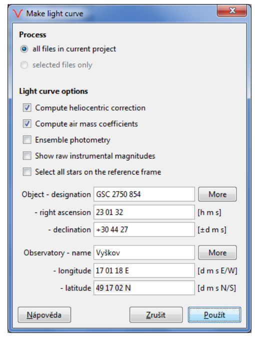


Fig. 15: The dialog for making a light curve.

5.3.6 Selecting the stars

The next dialog shows the reference frame and allows an user to select variable, comparison and check stars. The detected stars are highlighted. Click on the variable star using left mouse button. A context menu opens. Select the *Variable*. The star is now drawn in red color now and the label "var" is placed near to it. Using the same procedure, select one comparison star and one or more check stars. I would recommend you to use two check stars. Confirm the selection by the *OK* button.

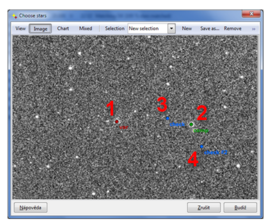


Fig. 16: The dialog for selection of a variable star (red), a comparison star (green) and check stars (blue).

See also:

Choose stars (dialog)

5.3.7 Choosing an aperture

Now, we have to choose the aperture. You can image the aperture as a virtual circular pinhole, placed on each star on a frame to measure its brightness. All pixels that are inside the pinhole are included in computation leaving out the background pixels. The best aperture should be big enough to include most of the star's light, on the other hand, the bigger aperture is used the more background is included and the more noisy the result is. Because of this, the photometry process computes the brightness of each star in a set of predefined apertures of radius in the range of 2 and 30 pixels.

To select the best aperture, we can take advantage of a comparison and check stars - providing that they are constant, we can compute the differential magnitudes between each couple of them on each other and then compute the variance or standard deviation from the mean level. For the best aperture, the deviations are minimal.

In the next dialog, the graph shows the standard deviation for each aperture. Find the aperture with the minimal deviation and click on it using the left mouse button. A context menu appears. Select the *Select aperture* item. The point is drawn in red color now and the label is placed near to it. Confirm the selection by the *OK* button.

See also:

Choose aperture (dialog)

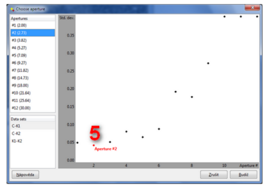


Fig. 17: The dialog for selection of an aperture.

5.3.8 Plotting a light curve

Now, the program has got enough information to make a light curve. It is presented in a new window which appears automatically.

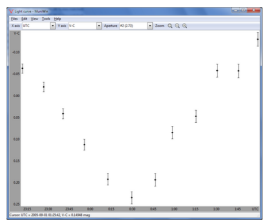


Fig. 18: The dialog with a light curve graph.

See also:

Light curve (dialog)

5.3.9 Saving a light curve to a file

In the window with a light curve, click on the *File* –> Save` item in the local menu. A new dialog appears. Locate the folder where you want to save the results and fill in the name of the output file. Confirm the dialog by the *Save*.

The light curve is saved to a text-based file. On its first line, the names of the columns are stored. The second line shows the aperture and color filter used. The data are stored on the following lines. Each line corresponds to a single source frame. In the first column, there is a time of observation (center of exposure) expressed as a Julian date. The second column consists of differential instrumental brightness of the variable stars with respect to the comparison star in magnitudes (V-C). The error estimation is stored in the next column. Following columns consist of differential magnitudes of comparison star and check stars and their error estimations.

It is also possible to save a light curve in other formats.

See also:

Export light curve in AAVSO format

5.3.10 Heliocentric correction

While the Earth orbits the Sun, the distance between the observed object and the observer changes during a year. Although the amplitude of these changes is negligible with respect to the mean distance, it becomes significant when you are interested in a time interval between two events, like times of minimum of a eclipsing variable star. In this case, the finite speed of light is not unimportant. The value of the heliocentric correction is the time that the light needs to travel from the Earth's actual position to the center of the Earth's orbit. The value may be either positive, when the Earth is nearer to the object than the Sun, or negative in the opposite case.

It is possible to make a light curve that includes the value of the heliocentric correction for each measurement in a separate column. Optionally, it is also possible to save the output table which has heliocentric Julian date in its first column.

To compute the heliocentric corrections for an existing light curve, click on the *Edit → Properties* in the local menu in the light curve window. A new dialog opens. Check the option *Compute heliocentric correction*. When you are making a new light curve, it is also possible to turn this feature on (see above). Confirm the dialog by the *OK* button.

When the heliocentric correction is turned on, you have to fill the object's celestial coordinates to the appropriate edit boxes in the dialog, the fields may be filled automatically if the input CCD frames or a catalogue file unsed in the matching step contain such information.

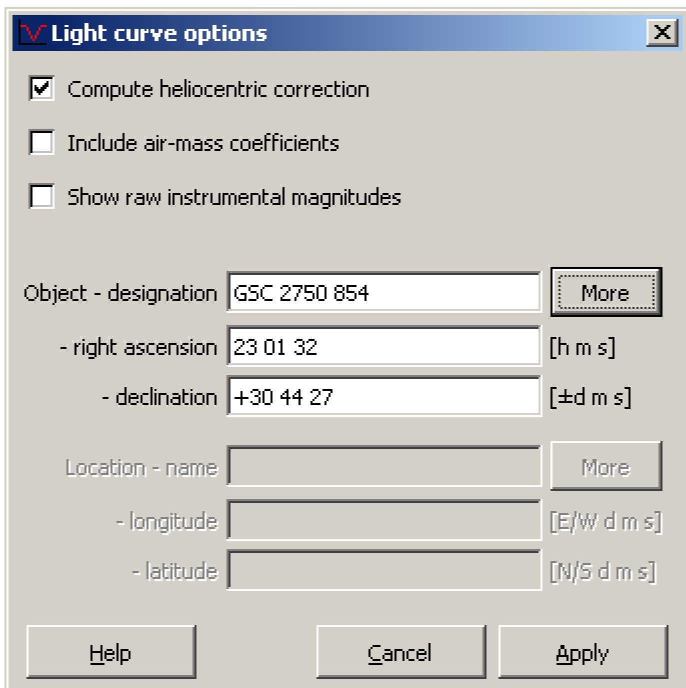


Fig. 19: Light curve properties dialog (heliocentric correction)

Only one value of Julian date per each row can be exported to the file. You can choose between the geocentric and heliocentric J.D. in the "Save light curve" dialog - there is an appropriate option in the section "Export options". However, in both cases, the file will contain the column *HELCOR* with values of the heliocentric correction for each observation.

There are other options how to obtain the object coordinates. For more options, click on the *More* button. A new dialog appears. In this dialog you can make your table of favorite objects. For known variable stars, the program provides a tools for searching the common variable star catalogs (GCVS, NSV and NSVS).

5.3.11 Air mass coefficients

The air mass coefficient characterizes the attenuation of the star's signal after it has traveled through the Earth's atmosphere. While this effect is strongly dependent on the light's wavelength (color), it must be taken account in computation of the color index (temperature) of an observer object. The attenuation also becomes significant when the color index of the variable and the comparison star are not close. The air mass coefficient is always positive value, it defined as 1.0 when the object is in the zenith and greater than one when the object is somewhere between the horizon and the zenith. The program also presents the value of altitude of the object above the horizon in degrees. Please note, that the value is positive to indicate altitude above the horizon while a negative value of altitude means that the object is below the horizon - it indicates that either times of observation, object coordinates or observer coordinates are wrong.

Although the C-Munipack program doesn't perform any corrections to the measured intensity. It can compute the value for coefficient for each measurement and put those values into the output file to a separate column.

To compute the air mass coefficients for an existing light curve, click on the *Edit* → *Properties* in the local menu in the light curve window. A new dialog opens. Check the option *Compute air mass coefficients*. When you are making a new light curve, it is also possible to turn this feature on (see above). Confirm the dialog by the *OK* button.

When the heliocentric correction is turned on, you have to fill the object's celestial coordinates and observer's geographic coordinates to the appropriate edit boxes in the dialog, the fields may be filled automatically if the input CCD frames or a catalogue file unsed in the matching step contain such information.

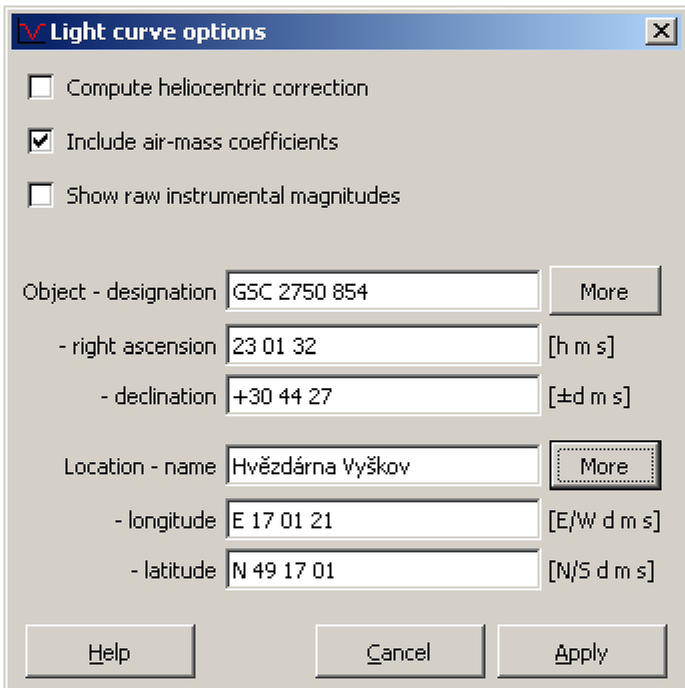


Fig. 20: Light curve properties dialog (air mass coefficients)

When you save the light curve to a file, it will contain the column *AIRMASS* with values of the air mass coefficient and the column *ALTITUDE* with values of altitude of the object above the horizon in degrees.

There are other options how to obtain the object and observer coordinates. For more options, click on the *More* button. A new dialog appears. In this dialog you can make your table of favorite objects and locations. For known variable stars, the program provides a tools for searching the common variable star catalogs (GCVS, NSV and NSVS).

5.3.12 Intensities (fluxes)

In some cases when further processing of the photometric data is involved, ensemble photometry for example, it is neccesary to get intensity (brightness) values of individual stars instead of the standard differential magnitudes. Some programs call such value the flux. The intensity is defined as integral of the light in an aperture minus contribution of a local background. The intensity can be transformed into magnitudes using Pogson's law and a reference intensity. In the C-Munipack software, this value is called the raw instrumental magnitude.

The Muniwin software provides a special output mode called 'Raw instrumental magnitudes'. If this mode is enabled, the light curve will contain a pair of values for each selected star and frame. The first value in pair is the intensity of a star expressed in magnitudes and the second value is its error estimation. The reference intensity was set to 10^10. Please look into the separate document 'Theory of operation' section 'Aperture photometry' on the conversion between the raw instrumental magnitude and the intensity.

To show the raw instrumental magnitudes for an existing light curve, click on the *Edit* → *Properties* in the local menu in the light curve window. A new dialog opens. Check the option *Show raw instrumental magnitudes*. Confirm the dialog by the *OK* button. When you are making a new light curve, it is also possible to turn this feature on (see above) in the *Make light curve* dialog.

5.3.13 Trimming outliers from the curve

Is is possible to manually trim outlying observations from the curve. You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. There are two options: When you select the option *delete from data set*, the selected measurements are removed from the current light curve, the data will be shown when you make another light curve or *Rebuild* the actual curve. The other option *remove from project* means that the frames corresponding to the selected measurements are removed permanently from the list of input files (see: Main application window) and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

5.4 Master-dark frame

The master-dark frame is an image made of several dark images. The dark image is used in a process of CCD image calibration. To reduce a noise of a result, it is advisory to make a number of raw dark frames and combine them into one correction frame. The Master-dark tool in the Muniwin program provides a simple method how to do that.

5.4.1 Creating a new project

First of all, we will create a new *project*. To begin with processing of a variable star observation, we create a new project. To do so, open the *Project* menu and activate the *New* item. A new dialog appears.

Fill in a name that will be assigned to the project (1). Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >.

The field *Location* (2) shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button to select a directory in a separate dialog.

Select a profile (3) to specify an intial set of configuration parameters into a new project. When you confirm the dialog, you should be in the main window again now. The table of input files shown there is empty.

See also:

New project (dialog) and *Main window*

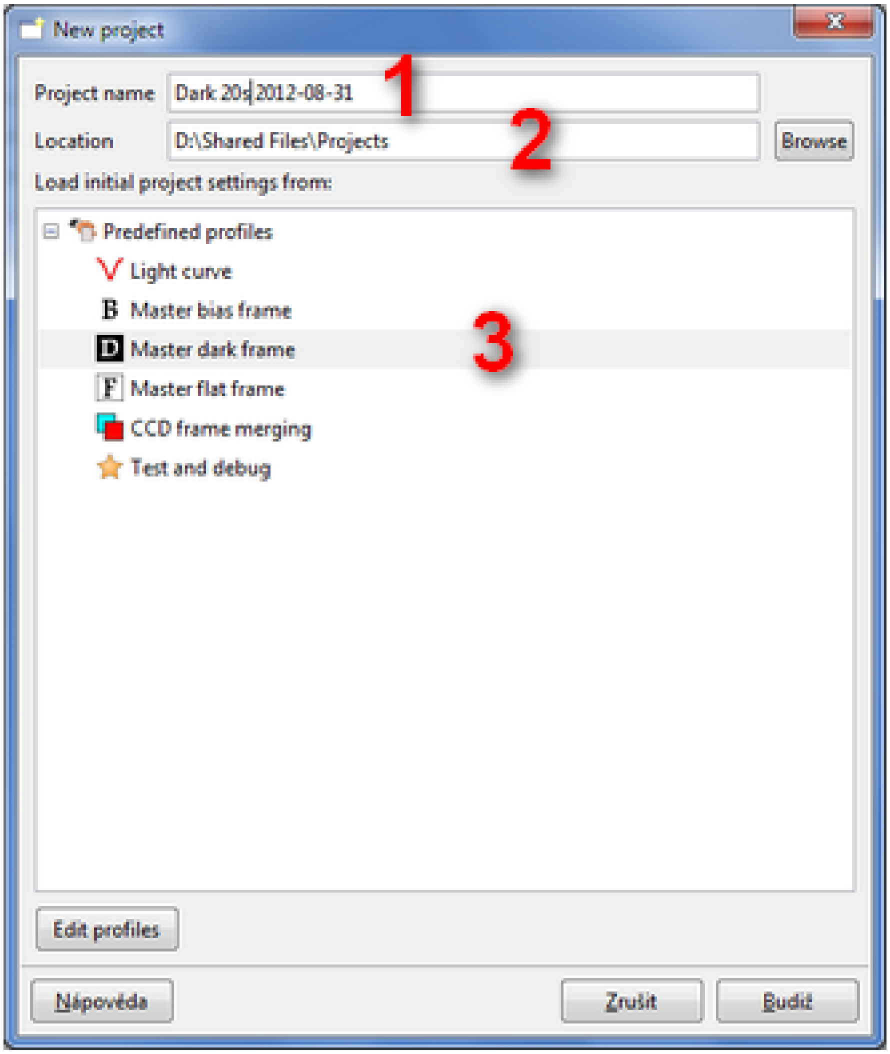


Fig. 21: The dialog for making a new project.

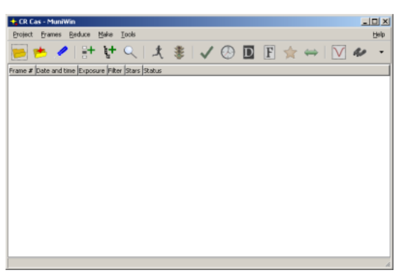


Fig. 22: The main application window with the table of input files, now empty.

5.4.2 Input files

Now, we are going to tell the program which files we are going to work on. These files are called the input files. Their list is displayed in the table in the main application window. When the application is closed, the list of files are saved to the disk and it is restored back when the program is launched again.

Supposing that the table now consists of files from your previous task, let's get rid of them. Please, use *Files* → *Clear files* to start a new task instead of just removing the files from the table. Besides the clearing the table of input files, this function resets all internal variables, too.

Now, we need to populate the table with the CCD frames we're going to reduce. There are two methods how to achieve that - adding a individual files or adding all files from a folder. Which way is the best for you depends on organization of your observations on the disk. I'd suggest you to make a folder for each year, a folder for each night in it, the a subfolder for a name of object or another view field identification and finally a subfolder named upon the color filter (if you use more of them). In this case, the "Add frames from a folder" method is more convenient.

Click on *Files* → *Add frames from folder* in the main menu. A new dialog appears. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. Enter the folder with the input files - you should see them in the middle pane. Then, click on the *Add* button to add files to the table of input files. The program shows the number of added files in the separate dialog. The *Add frames from folder* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

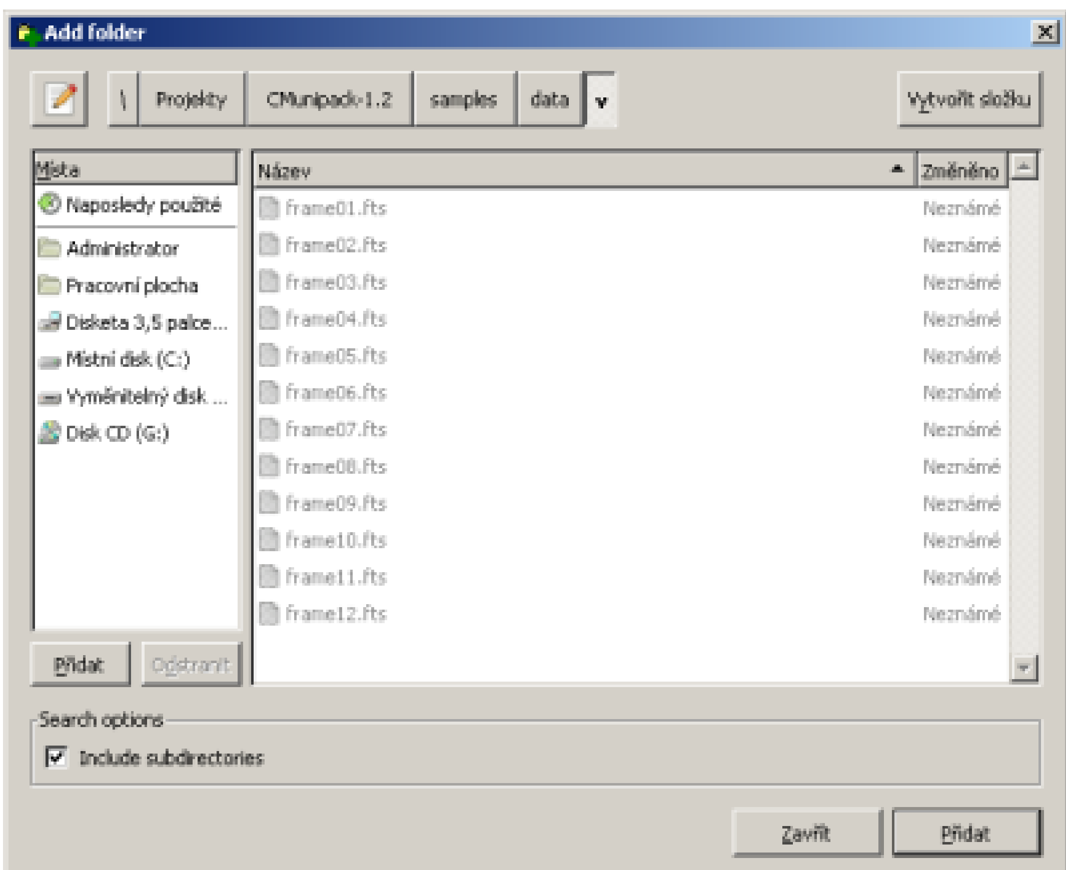


Fig. 23: The "Add folder" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

If you want to reduce only a subset of files from a folder, click on *Files* → *Add individual frames* in the main menu. A new dialog appears, similar to the previous one. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. In the middle pane, select the files using the `Ctrl` modifier to include and exclude a single file and the `Shift` modifier to include a range of files. Then, click on the *Add* button to add selected files to the table of input files. The program shows the number of added files in the separate dialog. The *Add individual frames* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

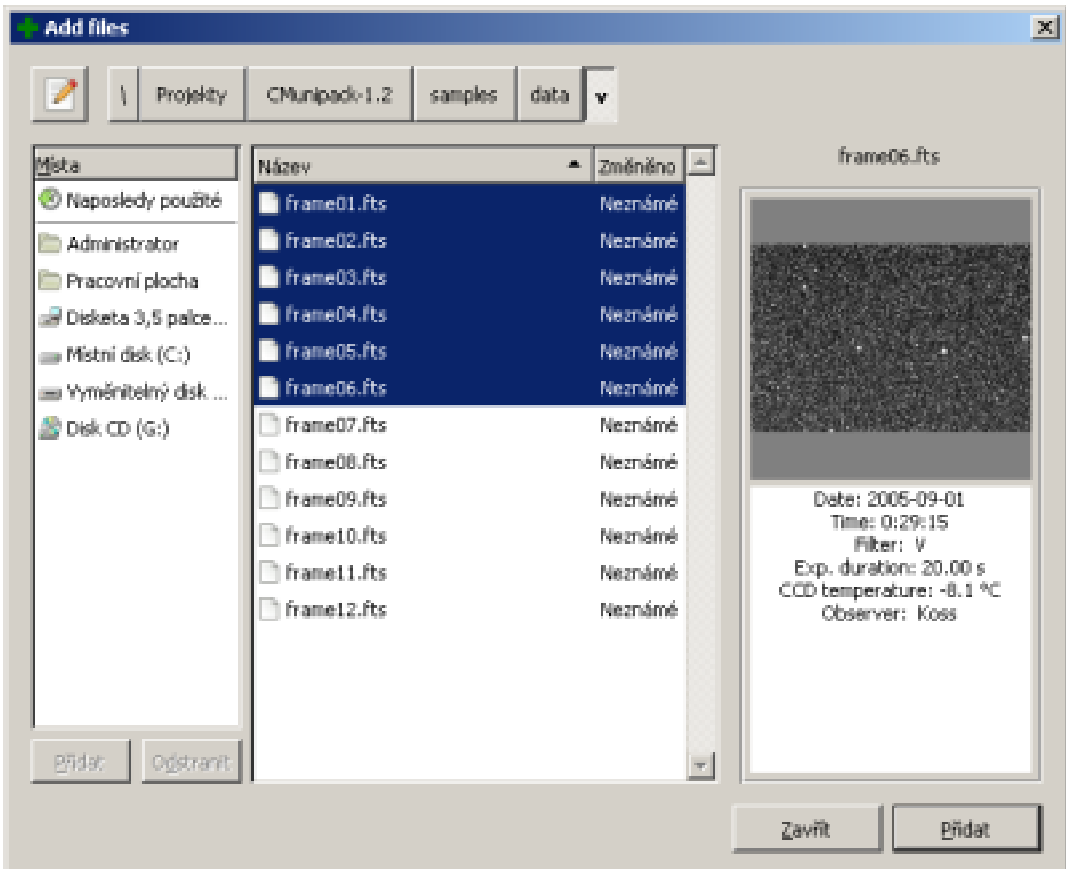


Fig. 24: The "Add files" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

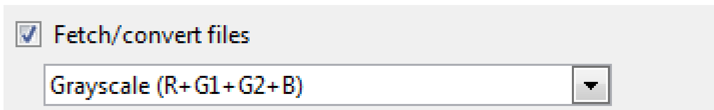
See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*

5.4.3 Frame reduction

The next step is called the reduction process, even though there is no real “reduction” of the data. This is to keep the general scheme of data processing the same for all project types. In the standard calibration scheme, it is necessary to perform just one step - conversion of the source CCD frames into a working format, no calibration or photometry is required.

We will use the same *Express reduction* dialog as in the section *Light curve*. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. Check the option *Fetch/convert files* and let other options unchecked.



See also:

Express reduction (dialog)

5.4.4 Making master dark frame

Open the menu *Make* and select the item *Master-dark frame*. A new dialog appears. In the dialog, specify whether all files shall be processed or only the selected ones. Confirm the dialog. In the following dialog select a directory and enter the name of output file where a new master-dark frame shall be saved to. Press the *Save* button.

When a task is finished, a new preview window appears. A new master-dark frame is displayed in a separate window.

See also:

Master dark frame (dialog)

5.5 Master-flat frame

The master-flat frame is an image made of several flat images. The flat image is used in a process of CCD image calibration. To reduce a noise of a result, it is advisory to make a number of raw flat frames and combine them into one correction frame. The separate correction frame has to be used for each filter, if the color filters are used. Avoid eventual camera rotation on its mount.

5.5.1 Creating a new project

First of all, we will create a new *project*. To begin with processing of a variable star observation, we create a new project. To do so, open the *Project* menu and activate the *New* item. A new dialog appears.

Fill in a name that will be assigned to the project (1). Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | ” < and >.

The field *Location* (2) shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button to select a directory in a separate dialog.

Select a profile (3) to specify an intial set of configuration parameters into a new project. When you confirm the dialog, you should be in the main window again now. The table of input files shown there is empty.

See also:

New project (dialog) and *Main window*

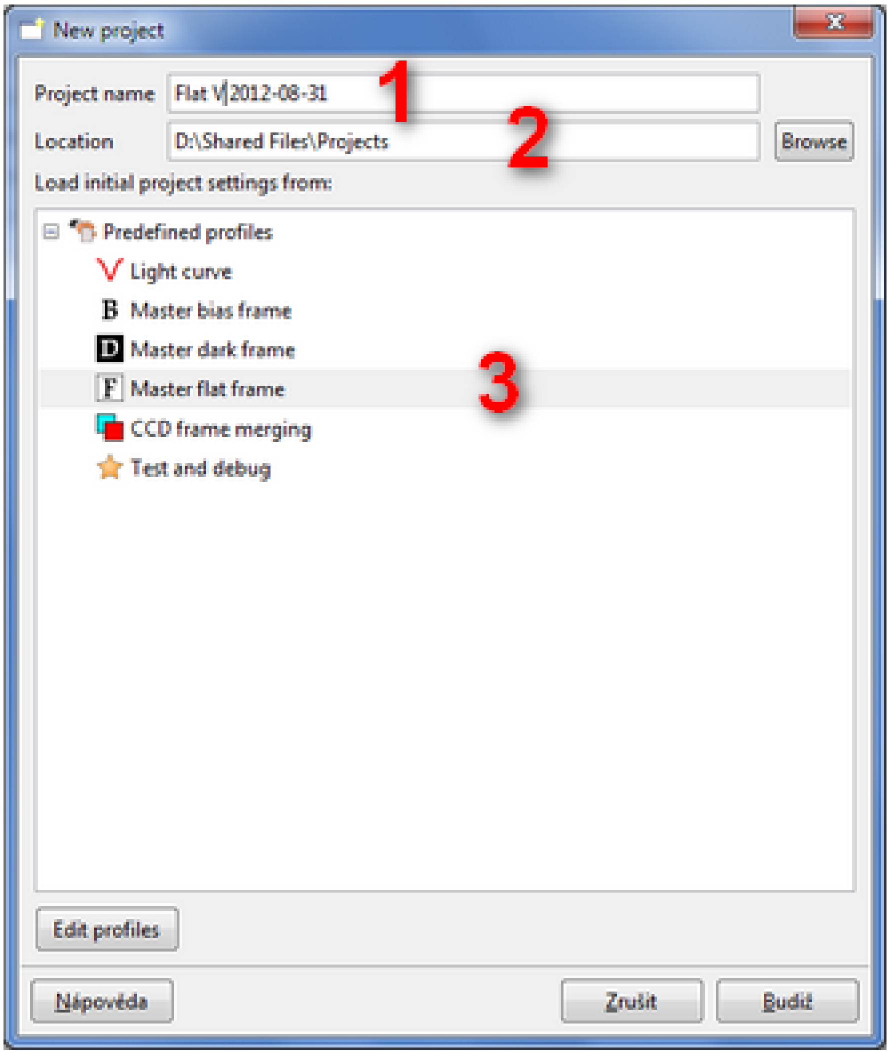


Fig. 25: The dialog for making a new project.

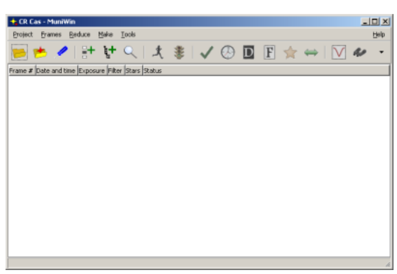


Fig. 26: The main application window with the table of input files, now empty.

5.5.2 Input files

Now, we are going to tell the program which files we are going to work on. These files are called the input files. Their list is displayed in the table in the main application window. When the application is closed, the list of files are saved to the disk and it is restored back when the program is launched again.

Supposing that the table now consists of files from your previous task, let's get rid of them. Please, use *Files → Clear files* to start a new task instead of just removing the files from the table. Besides the clearing the table of input files, this function resets all internal variables, too.

Now, we need to populate the table with the CCD frames we're going to reduce. There are two methods how to achieve that - adding a individual files or adding all files from a folder. Which way is the best for you depends on organization of your observations on the disk. I'd suggest you to make a folder for each year, a folder for each night in it, the a subfolder for a name of object or another view field identification and finally a subfolder named upon the color filter (if you use more of them). In this case, the "Add frames from a folder" method is more convenient.

Click on *Files → Add frames from folder* in the main menu. A new dialog appears. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. Enter the folder with the input files - you should see them in the middle pane. Then, click on the *Add* button to add files to the table of input files. The program shows the number of added files in the separate dialog. The *Add frames from folder* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

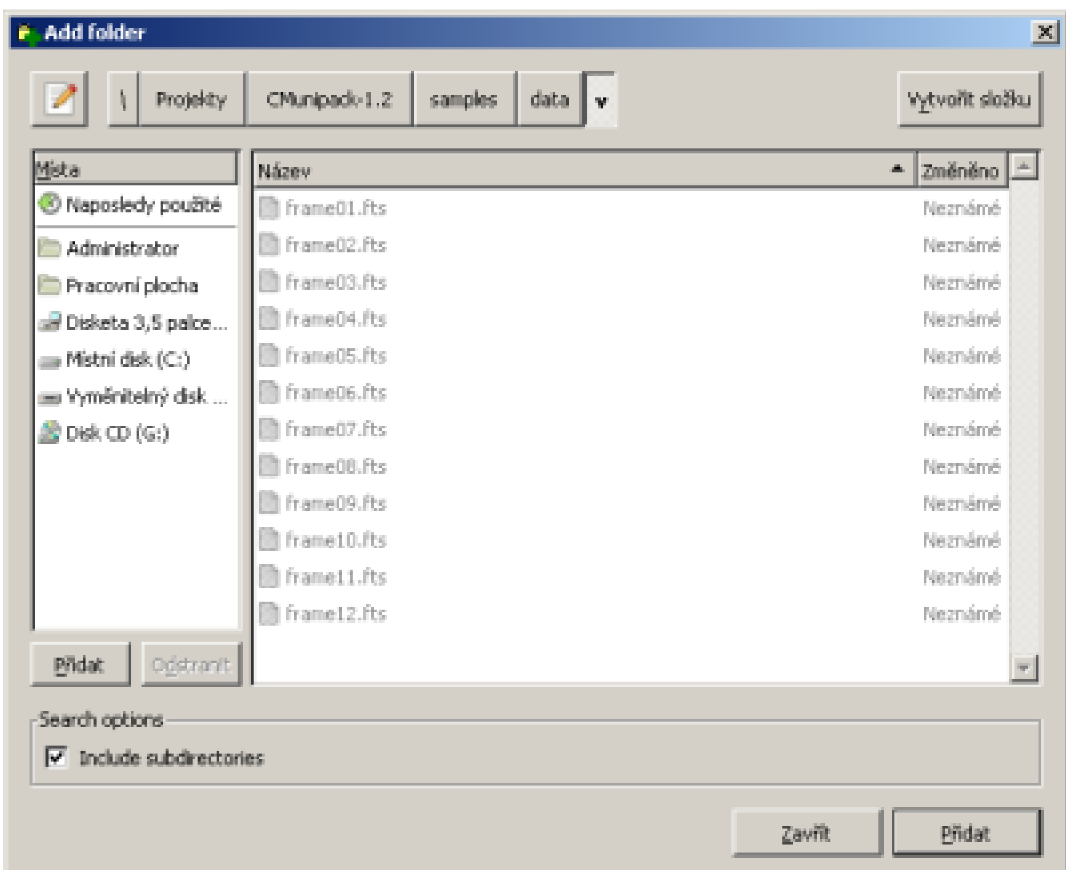


Fig. 27: The "Add folder" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

If you want to reduce only a subset of files from a folder, click on *Files* → *Add individual frames* in the main menu. A new dialog appears, similar to the previous one. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. In the middle pane, select the files using the `Ctrl` modifier to include and exclude a single file and the `Shift` modifier to include a range of files. Then, click on the *Add* button to add selected files to the table of input files. The program shows the number of added files in the separate dialog. The *Add individual frames* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

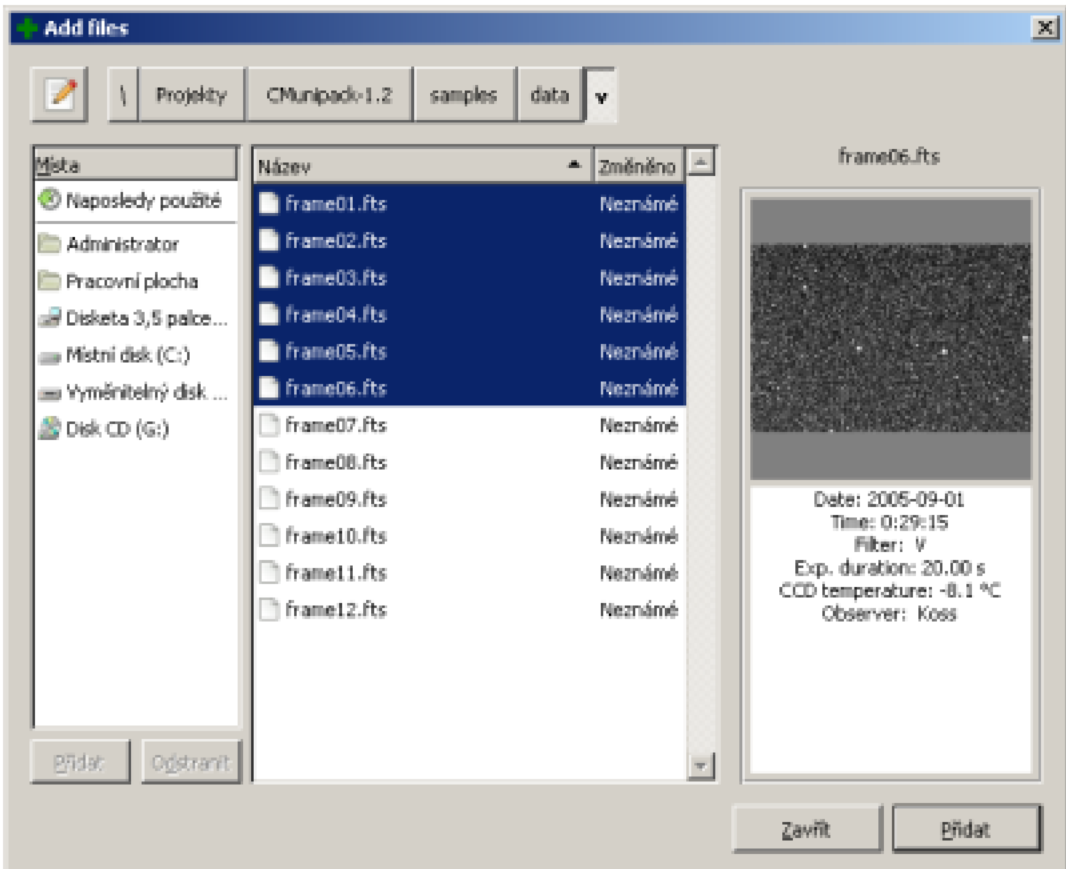


Fig. 28: The “Add files” dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

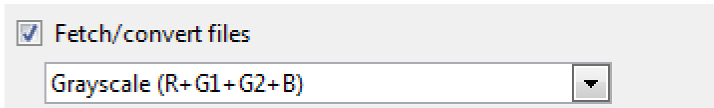
See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*

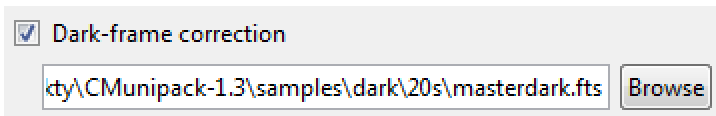
5.5.3 Frame reduction

The next step is called the reduction process, even though there is no real “reduction” of the data. This is to keep the general scheme of data processing the same for all project types. In the standard calibration scheme, it is necessary to perform just two step - conversion of the source CCD frames into a working format and dark frame correction.

We will use the same *Express reduction* dialog as in the section *Light curve*. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. Check the option *Fetch/convert files*.



Check the *Dark-frame correction* option. Click the *Browse* button and find the file with the dark frame.



See also:

Express reduction (dialog)

5.5.4 Making master flat frame

Click on the *Make* → *Master-flat frame* item. A new dialog appears. In the dialog, specify whether all files shall be processed or only the selected ones. Confirm the dialog. In the following dialog select a directory and enter the name of output file where a new master-flat frame shall be saved to. Press the *Save* button.

When a task is finished, a new preview window appears. A new master-flat frame is displayed in a separate window.

See also:

Master flat frame (dialog)

5.6 Finding variables

The CCD observation allows to measure brightness of all stars occurring in the field of the telescope. It may happen, that on a series of frames that apart from observed star there occurs also another variable star. By the following steps, you can perhaps discover a new variable star.

The *Find variables* dialog is the useful tool that provides semi-automatic scanning of variable stars in the series of source files. It is based on the relation between the standard deviations of the brightness of the stars and their mean brightness. The program reads all photometry files and compute the mean brightness and standard deviations of brightness of all stars. The algorithm automatically removes stars that are missing on majority of source frames. For the star of lower magnitude the deviation of brightness exhibits higher value than deviation for stars with a higher brightness.

First follow all steps of observed frames reduction through matching of the photometry files. Click on the *Tools* → *Find variables* item in the main menu. The program show a simple dialog which allows you to specify a source of data. It is possible either to use all frames that are listed in the project or to use only frames that are currently selected in the main window. The last option allows you to process the data stored in an external file. Confirm the dialog by “OK” button.

The program computes all stars brightness data at all frames and selects one comparison star. The dialog window opens. At top left area a graph of standard deviation of brightness vs. mean brightness or an object is shown. On the

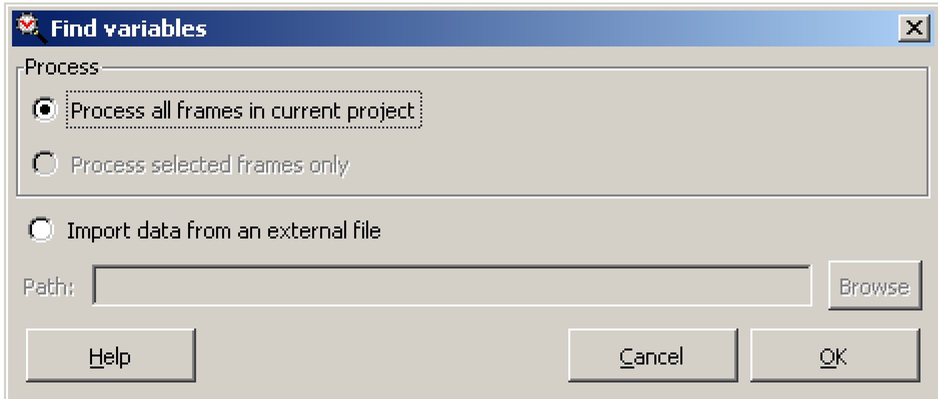


Fig. 29: The dialog for selecting the data source for Find variables tool.

right part the identification chart with variable star marked up is presented. Also the selected star light curve graph is shown.

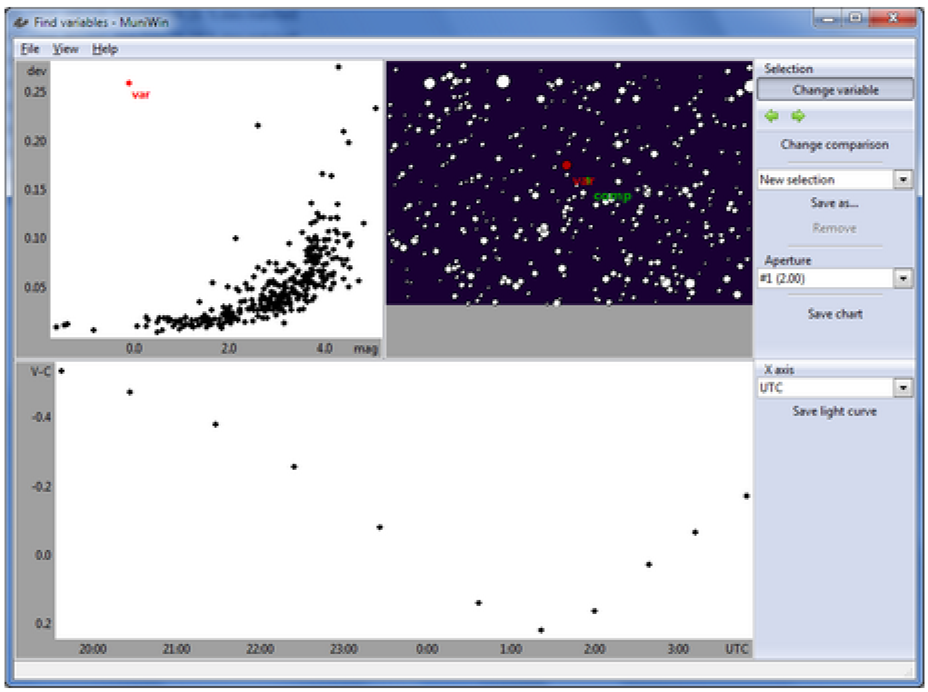


Fig. 30: The dialog for semi-automatic finding of variable stars.

In the top left area of the dialog, there is the graph of standard deviation of brightness vs. mean brightness of an object. According to the law of statistics, if all stars were constant, all objects would be located close to the parabola-like shape that goes from the left bottom corner of the graph to the right and turns up to its right top corner. If object's brightness changes, the standard deviation is higher than the deviation of object of the same mean brightness - these objects are usually located above the curve.

Click at any point of the graph left. The program marks the point with red circle with the *var* label. The same way, the corresponding star is marked up on the identification chart. In the bottom part of the dialog window, the light curve graph of the star is plotted. Sequentially indicate all stars, you suspect to be a variable star.

It may happen, that the comparison star automatically chosen is not good - it might not be constant. In this case the mag-dev curve has different character:

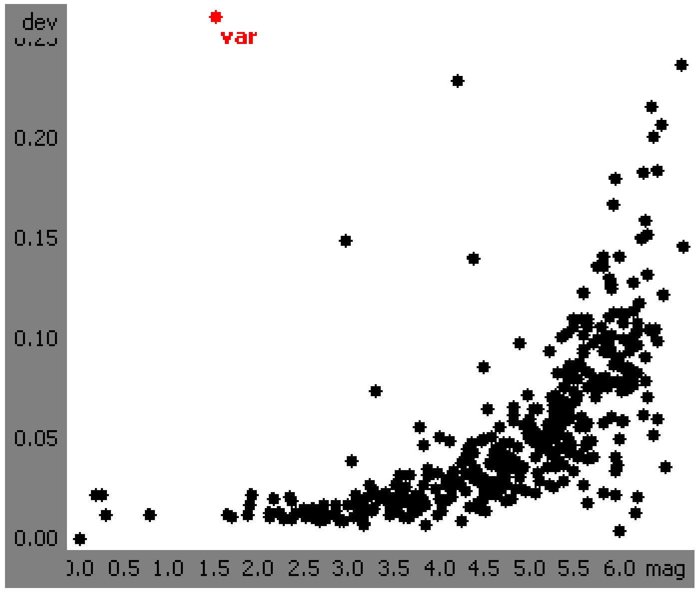


Fig. 31: The detail of the mag-dev curve with a variable star highlighted.

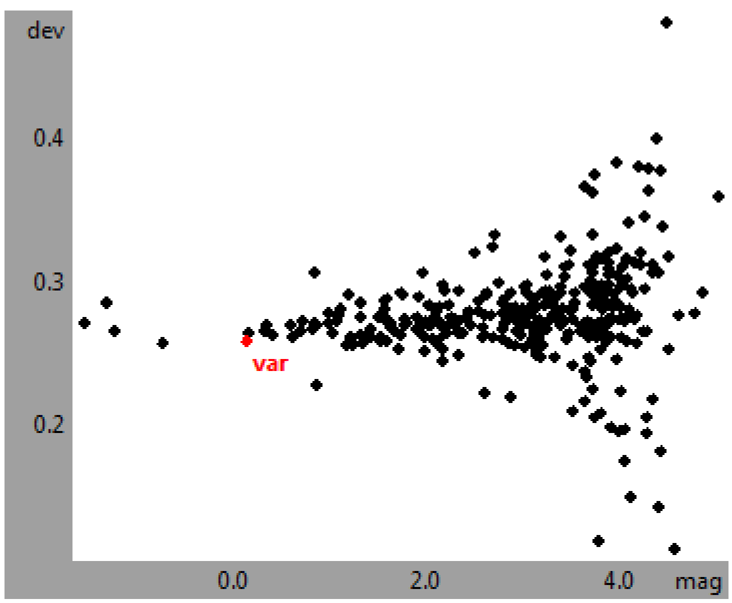


Fig. 32: The detail of the mag-dev curve when the comparison star is not constant.

The comparison star is marked on the chart with green circle with the *comp* label. To change the comparison star manually, click on *Comp* button on the control panel and select the star on the identification chart. When done, click on the *Var* button to switch back to variable selection mode.

By the help of the buttons on the panel, the graph, chart or the light curve can be saved as data or image file.

5.6.1 Exporting data

The program also provides means of exporting the brightness data of all stars for all frames to a single text file. It is possible to import the data to the Find variables tool later or process the file in an external program.

To export the data to a file, click on the *Save data* button on the right side of the dialog. In the following dialog select a directory and enter the name of output file where the data shall be saved to. Press the *Save button*.

5.6.2 Processing data from an external file

The "Find variables" tool is capable of reading the data from an external file. Such file can be created by the same tool from a set of reduced CCD frames (see section Exporting data) or by an external program.

To import the data from a file, click on the :menuselection :*Tools –> Find variables* item in the main menu. It the following dialog, check the appropriate option and enter the path to the data file into the following edit box. Confirm the dialog by *OK* button.

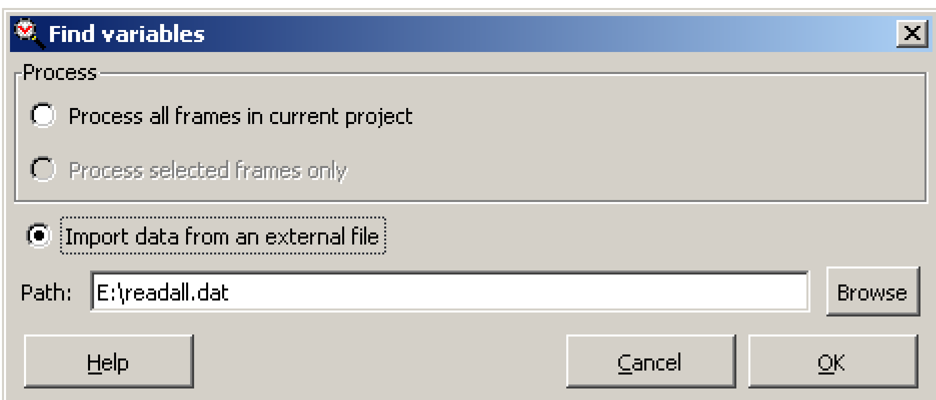


Fig. 33: Find variables - importing data from an external file.

5.6.3 Known variable stars

If the source frames contain World Coordinate System (WCS) data, the software can show positions of known variables on the frame. You have to specify paths to the catalog files in the program settings (see *Environment options (dialog)*). For each catalog, the toobar on the right side of the window contains one check box that turns the catalog on and off. By clicking on the icon, a standard color selection dialog appears.

See also:

Find variables (dialog), *Environment options (dialog)*.

5.7 Catalog files

Catalog files speed up your work in case you often observe particular star field, for example in long-term monitoring of a variable star. In a standard work flow, you would have to mark the stars again and again. The catalog file's structure is similar to that of the photometry file, except it includes the selection of stars. When you use the catalog file as a reference frame in the matching phase, the program will match the photometry files against it and the selection of stars is restored as well. Then, when you make a light curve, the variable, comparison and check stars are already marked.

The first observation you process by standard procedure, using one frame from a set as a reference file. When you have finished, you can make a catalog file. Click on the *Tools* → *Make catalog file* item in the main menu. A new dialog appears that allows you to select a variable star, a comparison star and optionally check one or more check stars. If you have made a light curve before, the stars are automatically selected.

Confirm the selection dialog by the *OK* button to proceed to the next step. Another dialog appears. In its left part, fill in the edit fields, you have to fill in the name of the catalogue file (first entry), all other fields are optional and you can left them blank. Confirm the dialog by the *Save* button.

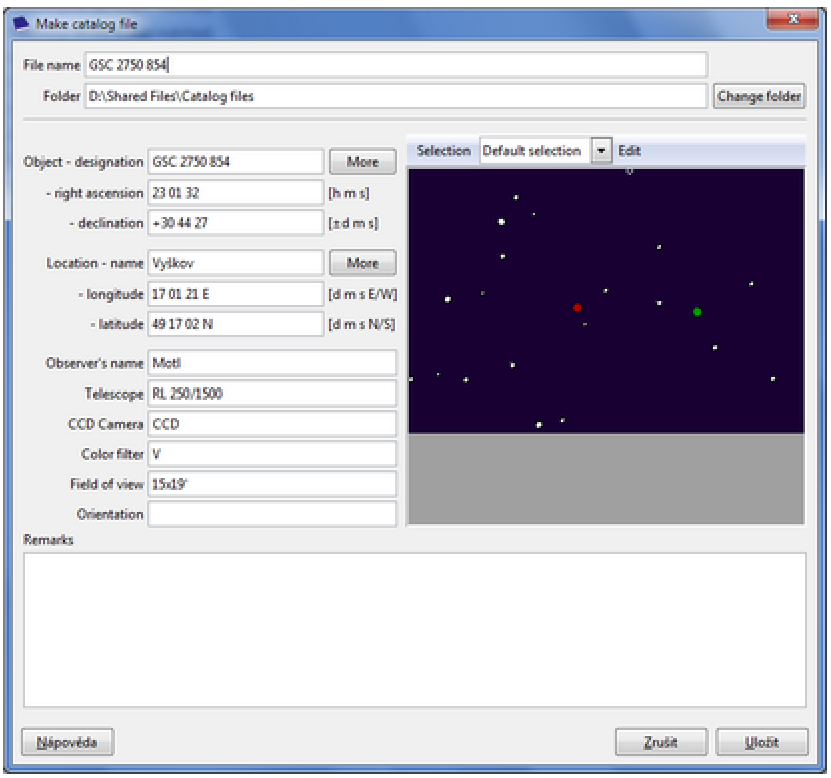


Fig. 34: The dialog for making a catalog file.

See also:

Make catalog file (dialog) and *Match stars (dialog)*

5.8 Frame merging

The frame merging makes one or more resulting CCD frames by combining a set of source frames. This function is usable for example when the very faint objects are observed, thus demanding very long exposure durations to obtain desired accuracy. The exposure duration is limited in practice due to inaccuracy of the telescope driving. The merging can virtually extend the attainable exposure time, because the image shift can be corrected.

The implementation used in the current version of the C-Munipack project requires calibratted source frames and corresponding photometry files with information about frame offsets. These are produced by the matching process, no special option is required.

Corresponding pixels are summed and the result is divided by the total number of source frames. Pixels, which are not covered by all source frames or which contain bad pixels, are set to zero. The exposure duration is computed as sum of the durations of source frames. The observation time is computed as arithmetic mean of times of source frames. The Muniwin program allows automatized or manual splitting of the set of input files and making a single or a set of result frames.

5.8.1 Before you start

Before you start the reduction of your own CCD frames, you may need to perform several pre-processing steps. Though it isn't necessary, combining the several correction frames into so-called "master" ones is advisory, because it reduces the noise and makes the result more precise. The method of making master correction frames is described in separate chapters.

5.8.2 Creating a new project

First of all, we will create a new *project*. To begin with processing of a variable star observation, we create a new project. To do so, open the *Project* menu and activate the *New* item. A new dialog appears.

Fill in a name that will be assigned to the project. Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >.

The field *Location* shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button to select a directory in a separate dialog.

Select a profile (3) to specify an intial set of configuration parameters into a new project. When you confirm the dialog, you should be in the main window again now. The table of input files shown there is empty.

See also:

New project (dialog) and *Main window*

5.8.3 Input files

Now, we are going to tell the program which files we are going to work on. These files are called the input files. Their list is displayed in the table in the main application window. When the application is closed, the list of files are saved to the disk and it is restored back when the program is launched again.

Supposing that the table now consists of files from your previous task, let's get rid of them. Please, use *Files* → *Clear files* to start a new task instead of just removing the files from the table. Besides the clearing the table of input files, this function resets all internal variables, too.

Now, we need to populate the table with the CCD frames we're going to reduce. There are two methods how to achieve that - adding a individual files or adding all files from a folder. Which way is the best for you depends on organization

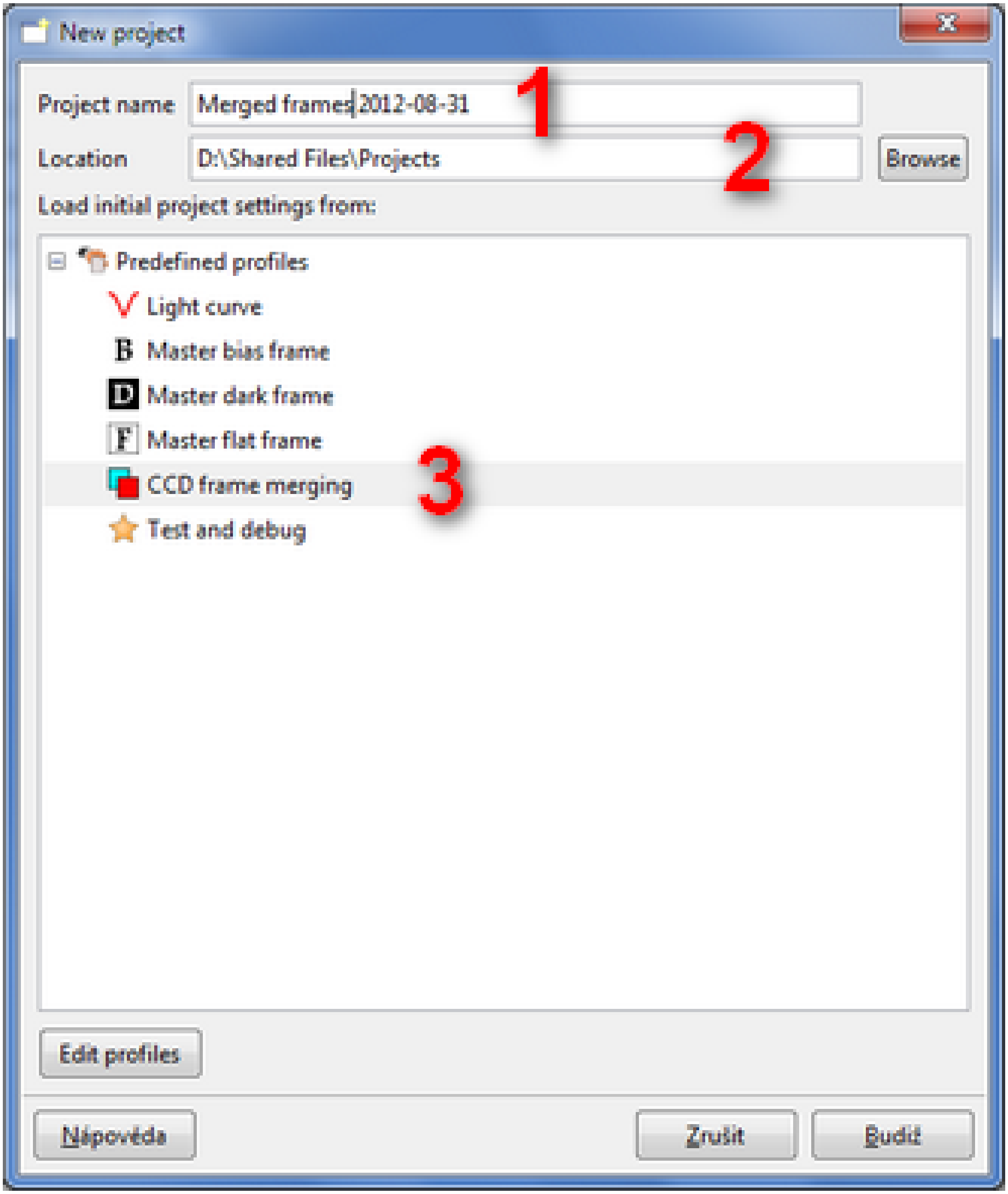


Fig. 35: The dialog for making a new project.

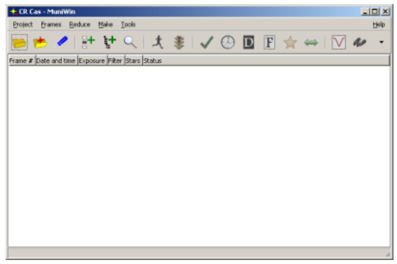


Fig. 36: The main application window with the table of input files, now empty.

of your observations on the disk. I'd suggest you to make a folder for each year, a folder for each night in it, the a subfolder for a name of object or another view field identification and finally a subfolder named upon the color filter (if you use more of them). In this case, the "Add frames from a folder" method is more convenient.

Click on *Files* → *Add frames from folder* in the main menu. A new dialog appears. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. Enter the folder with the input files - you should see them in the middle pane. Then, click on the *Add* button to add files to the table of input files. The program shows the number of added files in the separate dialog. The *Add frames from folder* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

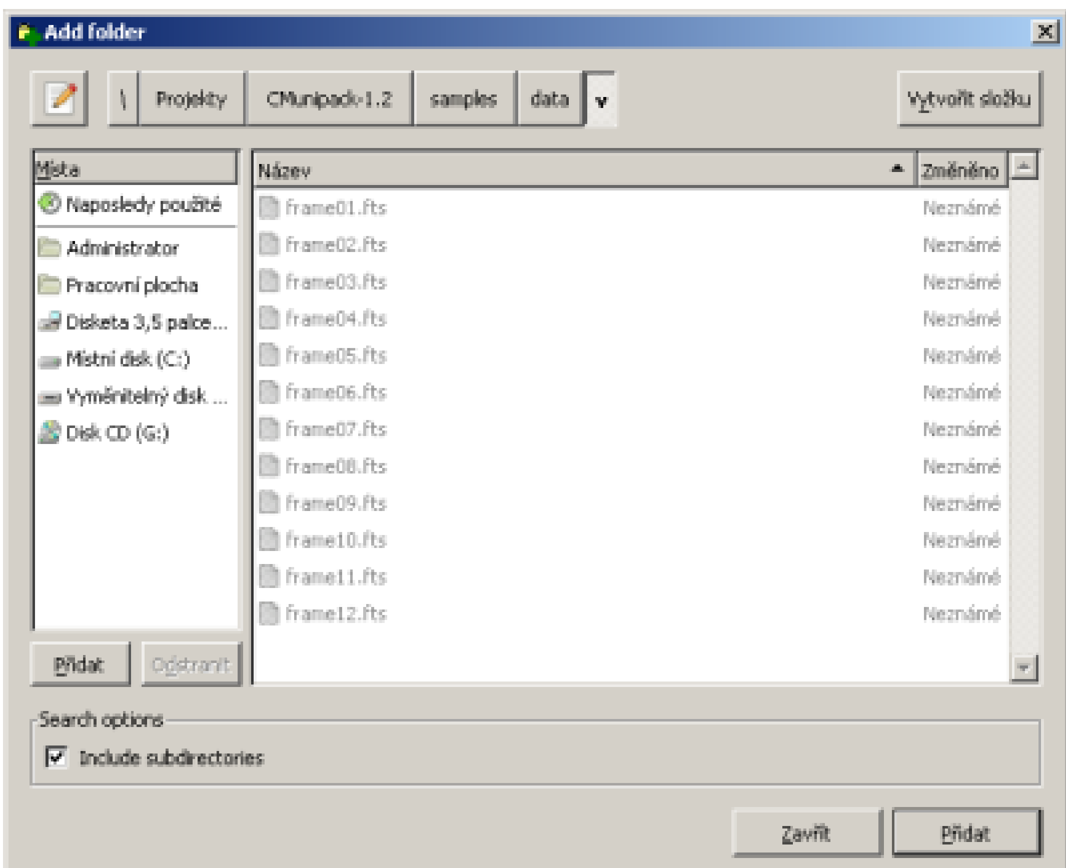


Fig. 37: The "Add folder" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

If you want to reduce only a subset of files from a folder, click on *Files → Add individual frames* in the main menu. A new dialog appears, similar to the previous one. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. In the middle pane, select the files using the `Ctrl` modifier to include and exclude a single file and the `Shift` modifier to include a range of files. Then, click on the *Add* button to add selected files to the table of input files. The program shows the number of added files in the separate dialog. The *Add individual frames* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

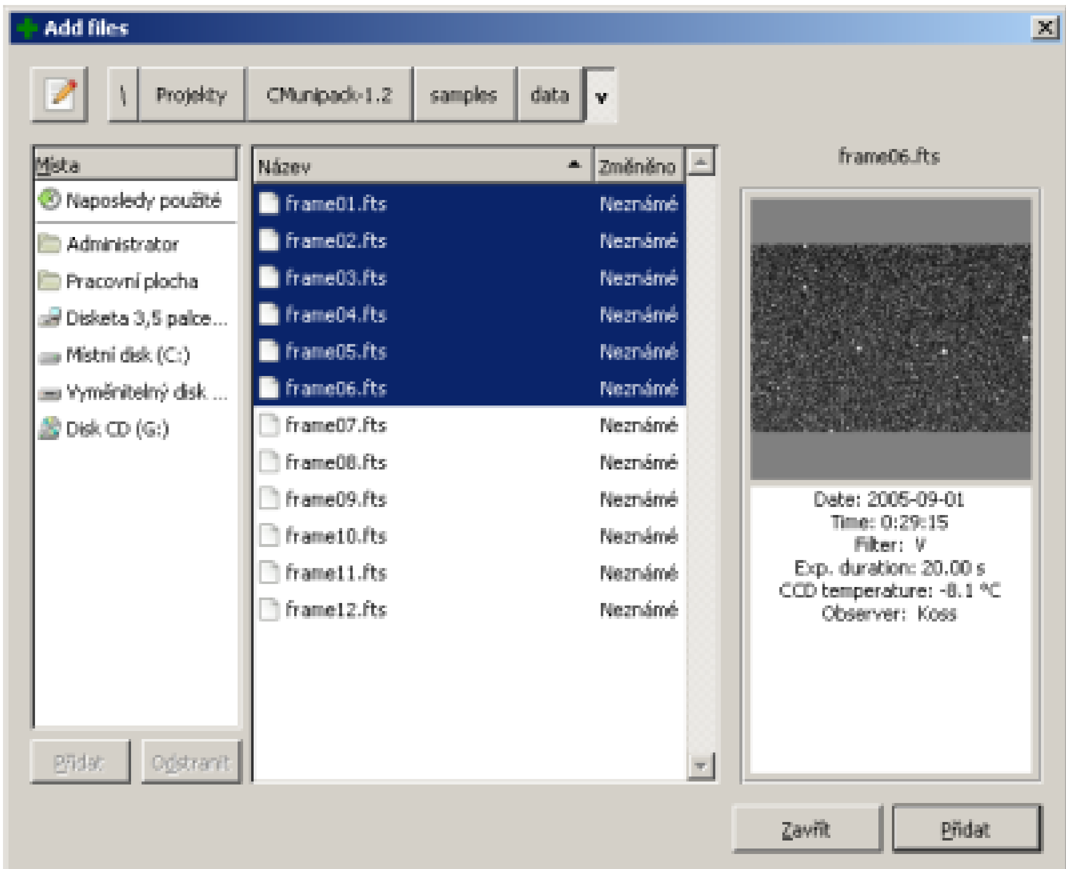


Fig. 38: The "Add files" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*

5.8.4 Frame reduction

Reduction of CCD frames is a process that takes source CCD frames, performs their conversion and calibration, detects stars on each frame and mearures their intensity and finally finds correlation (match) between objects that were found in the data set. The process of reduction prepares the data that are necessary for making a light curve or a variable star.

The reduction consists of several steps - conversion, calibration, photometry and matching. They can be invoked step-by-step manually. The preferred way is to use the *Express reduction* dialog that allows to perform these steps in a batch. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. The dialog has several options aligned to the left, Each of them relates to an optional step in the reduction process.

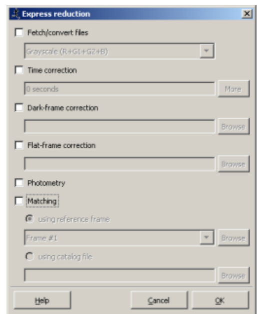
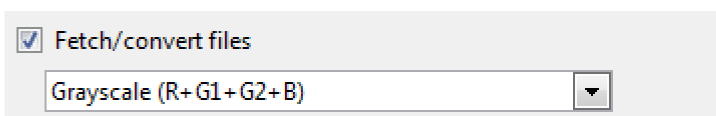


Fig. 39: The dialog for setting parameters of the reduction process

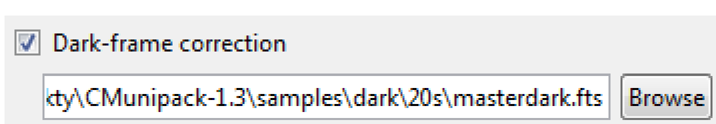
Fetch/convert files

Check the *Fetch/convert files*. In this step, the program makes copy of the source CCD frames. This is necessary, because the following calibration steps will modify them and we don't want the program to change our precious source data.



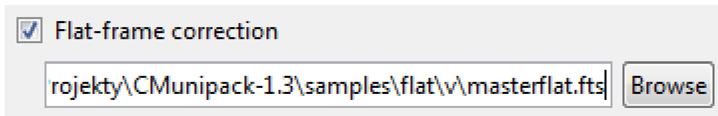
Dark-frame correction

A raw CCD frame consists of several components. By the calibration process, we get rid of those which affect the result of the photometry. In some literature, the calibration is depicted as the peeling of an onion. There are three major components which a raw frame consists of - the current made by incident light, current made thermal drift of electrons (so-called dark current) and constant bias level. In standard calibration scheme, which we will demonstrate here, the dark-frame correction subtracts the dark current and the also the bias. Because of the nature of the dark current, it is necessary to use a correction frame of the same exposure duration as source files and it must be carried out on the same CCD temperature, too. Thus, the properly working temperature regulation on your CCD camera is vital.



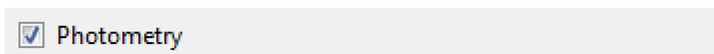
Flat-frame correction

Then, we have to compensate the spatial non-uniformity of a detector and whole optical system. These non-uniformities are due to the fabrication process of a CCD chip and they are also natural properties of all real optical components, lenses in particular. The flat-frame correction uses a flat-frame to smooth them away. The flat-frame is a frame carried out while the telescope is pointed to uniformly luminous area. In practice, this condition is very difficult to achieve, the clear sky before dusk is usually used instead.



Photometry

The photometry is a process that detects stars on a CCD frame and measures their brightness. Unlike the previous steps, the result is saved to a special file, so-called the photometry file. There are a lot of parameters which affect the star detection and also the brightness computation. In this example, the default values work fine, but I would suggest you to become familiar with at least two of them - FWHM and Threshold - before you start a real work. Check the *Photometry* option.



FWHM
: The FWHM parameter specify the expected width of stars on a frame. The value is the Full Width at Half Maximum in pixels. The parameter controls the behavior of the low-pass digital filter, which is used in the star detection algorithm.

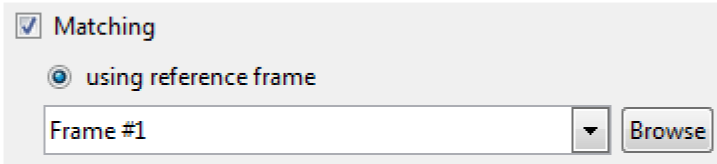
Threshold
: The Threshold parameter specify the lowest brightness of detected stars. Fainter objects are considered to be background artifacts and thus sorted out. The value is dimensionless coefficient.

Once you tune up the parameter for your environment, usually it is not necessary to adjust them for every task, unless the quality of your images varies considerably. In the first iteration, you can use the default values (FWHM = 3.0 and Threshold = 4.0) and do the photometry. Click on the *Reduce* → *Photometry* item in the main menu and confirm the new dialog by the *OK*. Then, by double click on a frame in the main window open the preview window and check the results. If there are stars which have been detected as a close binary although it is not true, you should increase the *FWHM* value. If the stars you are interested in are not detected, try decrease the *Threshold* value. If it doesn't help, decrease the *FWHM*. If there is a lot of background artifacts detected as a real stars, increase the *Threshold*. By several iterations, adjust the parameters, so all the stars you are interested in are detected and there are no false binaries.

Matching

The previous command treated all source files independently. As a result of this, a star #1 in one file is not necessarily the same as a star #1 in another file. The matching is a process which finds corresponding stars on source frames and assigns an unique identifier. Check the *Matching* option.

It is necessary to select one frame from the set of source frames that all other frames are matched to, this frame is called a reference frame. In my experience, the frame with the greatest number of stars works the best. Back to our example, let's pick up the first one.



Invoking the reduction process

In previous steps, we have configured parameters of the reduction process and we are ready to start it. Click the *OK* button. During the execution a new window appears displaying the state of the process; all the information is also presented there. This window will be automatically closed after finishing the process. Wait for the process to finish.

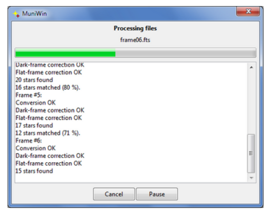


Fig. 40: The dialog displayed during time demanding operations.

After finishing, the icon in the file table changes; the information about the time of observation, the length of the exposition and the used filter is filled in. In case some of the frames could not be processed successfully, the entry is be marked with a special icon and in the *Status* column the error message is indicated.

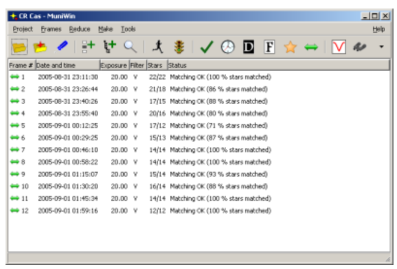


Fig. 41: The main application window after the recution.

See also:

Express reduction (dialog)

5.8.5 Making combined frames

Open *Make* menu, select the *Merge frames* item. A new dialog window appears. If you are going to make a set of resulting frames, select the *Split frames and process each group separately* option. Set the parameters for automatic splitting frames to groups; one resulting frame will be made for each particular group. Fill the maximum number of frames in a group to the *Merge every … frames* field. Set the maximum time span between the first and the last frame in a group. Enter the minimum number of frames (*Min. frames*). Confirm the dialog by the *OK* button. The standard dialog for saving files is opened. Find a directory, where the output files shall be stored to and enter the file name prefix. For example, if you enter the crcas prefix, the resulting files will be named `crcas00001.fts`, `crcas00002.fts`, etc. Close the dialog by the *Save* to start the merging.

It is possible to split the files manually. In the *Input files* table, select the frames, which shall be combined to a single resulting frame. In the *Make* menu, select the *Merge frames* item. The same dialog window as in previous case is opened. In the upper part of the dialog, select the *Process selected files only* option and in the lower part, select the *Merge all source frames to a single output frame* item. Confirm the dialog by the *OK* button. The standard dialog for saving files is opened. Find a directory, where the output file shall be stored to and enter the its name. No numbers are added to the name in this case. Close the dialog by the *Save* to start the merging. Repeat the action subsequently for all input files.

If the frames have been aligned (transformed) already, you can run this step after the frame conversion. You have to check the option “Do not transform the source frames”. If this option is checked, the software does not attempt to do any alignment of the frames, so if they do not match, the objects will be deformed or copied on the combined frames.

See also:

Merge frames (dialog)

5.8.6 Processing merged frames

Merged frames can be processed in the same way as common CCD frames with an exception that no calibration (bias, dark and flat correction) is applied to them. Follow instructions in the *Light curve* section.

5.9 Incremental processing

The incremental processing is a feature that allows an user to merge new files into an existing project. The new frames are automatically reduced using the same settings as the frames that are already in the project. It is particularly useful in an observation of short-period variables. Using this tool, it is possible to monitor the variable behavior during the observation and eventually decide, by checking a light curve, whether to resume or stop it.

During the first run, process the CCD frames by the standard procedure up to the selection of stars and produce a light curve. After acquiring a set of new frames, click on the *Reduce* → *Process new files* item in the main menu. A new dialog window appears. Select the option *process new files in the directory* and in the *Directory* field, select the directory which the new files are stored in. You can also setup file filtering conditions using the fields in the bottom part of the dialog. Only files that meet those conditions will be merged into the project.

If you check the option *Periodically check…*, the program will monitor the specified path on background and whenever new files turn up, the program automatically appends them to the list and processes them.

See also:

Process new frames (dialog)

5.10 Fields with multiple variable stars

The Muniwin software provides several features that simplifies the processing of a frame set that includes multiple variable stars on one star field. The software allows a user to create a set of selections of objects, each of which is consisting of choice of variable star, comparison star(s) and check star(s). These selections can be exported to a catalog file and reused in the next observation of the same star field.

5.10.1 Defining a set of object selections

- Create one project for your frame set
- Reduce your observation in a normal way, create a light curve for the first variable star and save it to the file.
- Start making a light curve for the next variable (*Plot* → *Light curve*). In the *Choose stars* dialog, the software always shows the most recently used selection of objects. Click on the *Save as…* button (10) on the toolbar. A new dialog appears. Enter a name of the first variable.

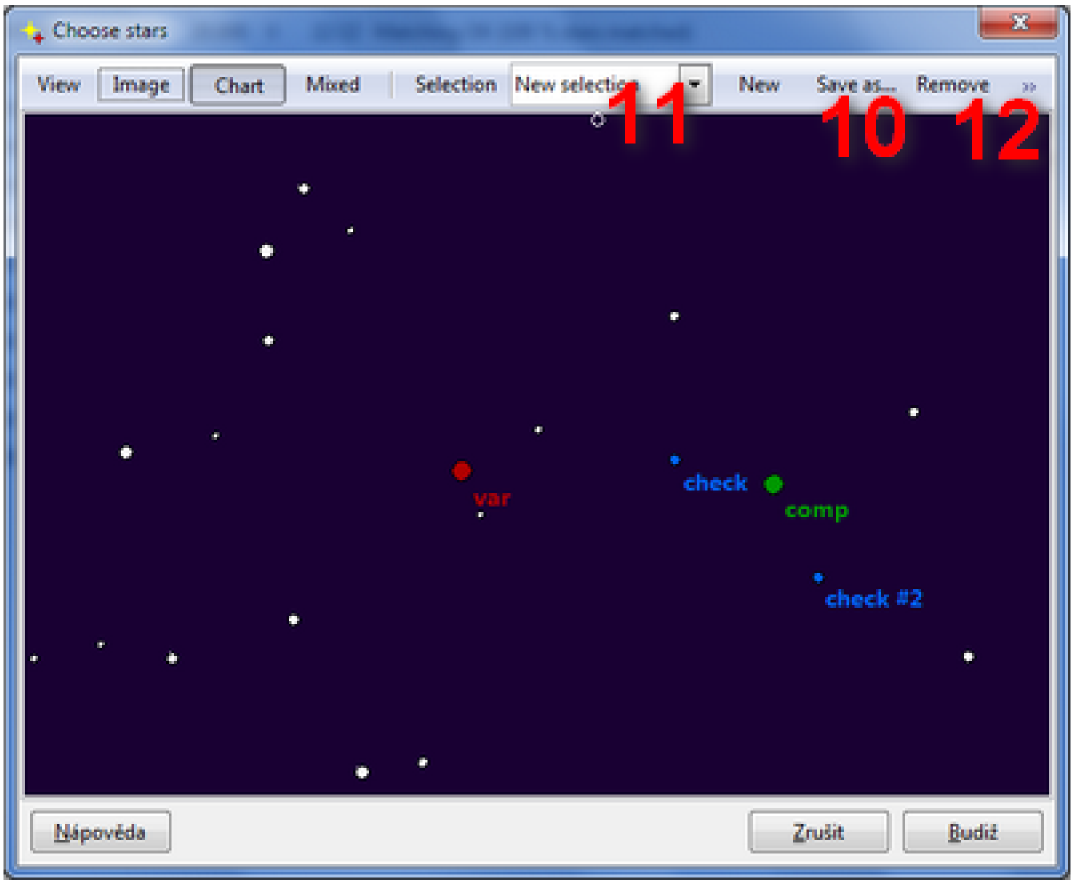


Fig. 42: The dialog for selecting a variable star, a comparison star and check stars

- Change the selection of the variable stars, you can also choose another comparison or check stars if needed. Confirm the dialog and continue. Save the light curve for the second variable.
- Use the same steps to make light curve for third, fourth, … variable.

To revert back to the selection that was previously saved, use the selection field (11) on the toolbar.

5.10.2 Multiple variables in the catalog file

The selections of objects that were saved using the steps described above are preserved when you make a *catalog file*. The dialog *Make catalog file* allows you to inspect and edit the selections before you create the new catalog file.

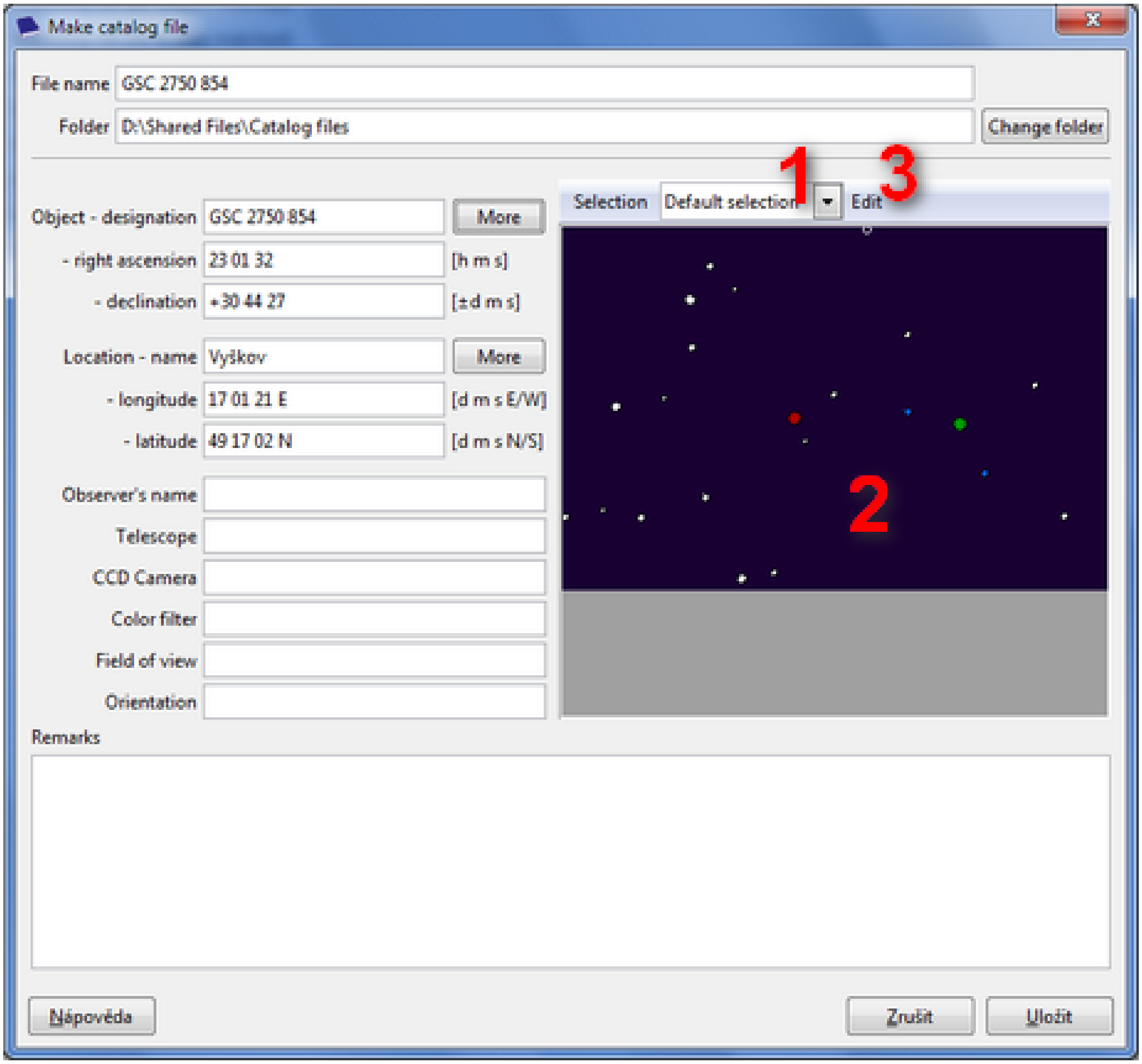


Fig. 43: Make catalog file dialog

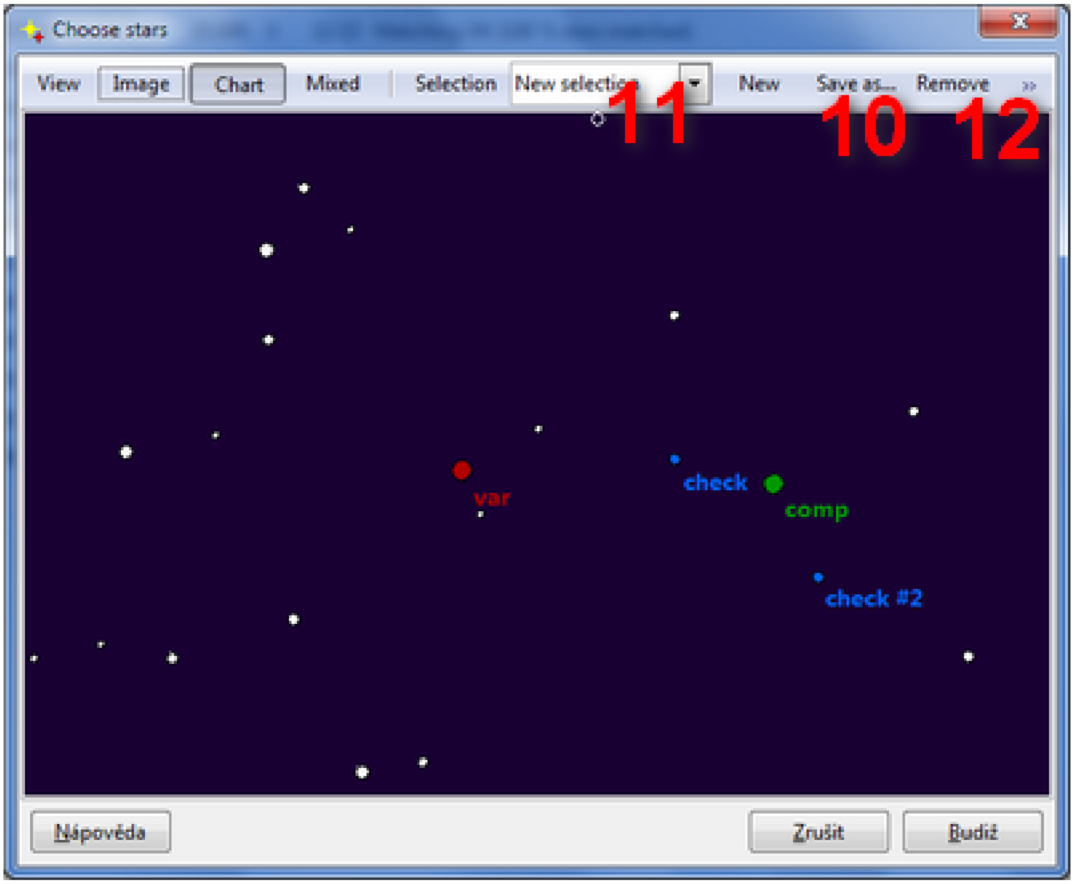
(1) Select the name of the selection. The selection is shown in the preview area (2).

(3) Click the *Edit* button to edit the selections.

5.10.3 Using catalog files with multiple object selections

The catalog file that was created using the previous steps can be used in the next observation of the same star field as a reference for frame matching in the same way as any other catalog file. All the object selections that were saved to the catalog files are restored.

When you are about to choose the stars when making a light curve for the first variable, click on the selection field (11) in the *Choose stars* dialog and select the named that you specified for the selection of objects for the first variable.



Use the same procedure for the second, third, fourth, etc. variable star.

See also:

Match stars (dialog), *Choose stars (dialog)*, *Make catalog file (dialog)*

5.11 Ensemble photometry

The ensemble photometry is a technique of a light curve construction which utilizes measurements of multiple comparison (constant) stars in order to reduce the random errors. The method implemented in the C-Munipack software can be called "strict" ensemble photometry, because it requires that *all* stars from the comparison star set are present on every frame, if this is not satistifed, the frame is discarded from the light curve. Fluxes (not magnitudes) of the comparison stars are summed up to get instrumental magnitude of an "artificial" comparison star which is than used to find out differential brightness of a variable star.

See also:

Light curve

5.12 Advanced calibration scheme

The standard calibration of CCD frames uses single dark frame and single flat frame. To obtain reasonable results, it is necessary to use dark frame of the same exposure duration as the scientific images. If you observe several objects during a night and those objects have different magnitude, different exposure durations are often used. But in this case you will need to carry out as many sets of dark frames as the number of exposures you have chosen. This task may be quite time consuming work. This disadvantage can be solved by advanced calibration, which involves scalable dark frames. The reduction process in this case is a bit more complicated than standard one, so it is recommended to experienced users only.

5.12.1 Calibration procedure

1. Acquire a set of bias frames. They are carried out by the similar way as the dark frames, the exposure duration should be minimal (zero in ideal case). I use 100 frames. The bias frames can be reused till some change to the camera hardware was made, so you need to acquire the set only once.
2. Acquire a set of flat frames. An easy way is to acquire frames of short exposure duration during dusk with a telescope pointed towards east, not very low altitude. Move the telescope during exposure rapidly. The pixels on a flat frame shouldn't have overexposed pixels and you should not see stars (bright lines if you move the telescope during exposure) on them when you check them in the preview window. I take 20 frames, one second each.
3. Each night, acquire the set of dark frames using long exposure duration. It is recommended to carry out dark frames on the end of observation, when the camera is enough uniformly cooled. I take ten frames, 120 seconds each.
4. Create a new project of *Master bias frame* type. Add your bias frames, convert them and make a master bias frame. Save it to a file.
5. Create a new project of *Master dark frame* type. Open menu *Project → Edit properties*. Select the *Calibration* page and check the option *Advanced calibration scheme*. Add your dark frames, convert them, apply master bias frame and make a master dark frame. Save it to a file.
6. Create a new project of *Master flat frame* type. Open menu *Project → Edit properties*. Select the *Calibration* page and check the option *Advanced calibration scheme*. Add your flat frames, convert them, apply bias and dark corrections and make a master flat frame. Save it to a file.
7. Create a new project of *Light curve* type. Open menu *Project → Edit properties*. Select *Calibration* page and check the option *Advanced calibration scheme*. Add your sky frames, apply bias, dark and flat corrections.

Continue in reduction of source images by standard way.

5.12.2 Remarks

- The scalable dark frame is automatically detected using the information stored in the file header. For all other frames which are not considered to be scalable ones, the standard calibration is used.

See also:

Bias correction (dialog), *Master bias frame (dialog)*, *Dark correction (dialog)*, *Master dark frame (dialog)*, *Project settings (dialog)*

5.13 Photometry using a DLSR camera

The C-Munipack software can decode RAW images produced by selected DSLR cameras. Because the DSLR cameras have not been designed to be used for the photometry, there are several potential pitfals that you may stumble upon. As in any other scientific work, it is recommended to be careful and to check if your results are correct before using or publishing them. In case of the 'raw' images, you should know, that the available documents on the 'raw' format are imcomplete, chaotic and often inconsistent.

5.13.1 Color components

The most common mistake is that the color components are not in correct order. Almost all commercial DSLR cameras have a single array of light sensitive elements. Before the array, there is a color filter mosaic, most of them is a *Bayer filter <http://en.wikipedia.org/wiki/Bayer_filter>*. Color components are distributed in a repeating pattern:

```
R   G   R   G   R   G   ...
G   B   G   B   G   B   ...
R   G   R   G   R   G   ...
...
```

The problem is, that in the first cell of the first row, some models have red (R) component and others starts with the blue (B) or green (G) component.

To check if the software decodes the components correctly I recommend to perform an easy test: take an image of any colorful object or objects that contain easily distinguished pathes of three basic colors (red, green and blue) on a black background. Save this image in the 'raw' format and load them into the C-Munipack software and perform *Fetch/convert* reduction steps with different selection of the color channel each time. After each conversion, show the resulting frame and check if the patches of the selected color component are bright and patches of other colors are dark.

See also:

Bayer filter
see http://en.wikipedia.org/wiki/Bayer_filter

RGB color components
see http://en.wikipedia.org/wiki/Additive_color

RAW format
see http://en.wikipedia.org/wiki/RAW_format

5.14 Photometry of minor Solar System bodies

The major challange in photometry on minor Solar System bodies is the tracking of the moving object of interest in the view field. The matching procedure, as it is used for a variable star, would not work without modifications, because the object changes its position between the frames with respect to surrounding stars. Also, the stars moves between the frames, as a result of mechanical inaccuracy of a telescope mount and its clockdrive.

This chapter explains how to make a light curve of a moving object, such as a minor Solar System body. For a guide on making a light curve of stationary objects (variable stars or exoplanets) follow *this link*.

The procedure of making a light curve of a moving object is the same as the process in case of a variable star except the matching step. The matching process is different here; a user has to specify at least three frames, called `key frames` and mark the moving object on each of them.

5.14.1 Before you start

Before you start the reduction of your own CCD frames, you may need to perform several pre-processing steps. Though it isn't necessary, combining the several correction frames into so-called "master" ones is advisory, because it reduces the noise and makes the result more precise. The method of making master correction frames is described in separate chapters.

See also:

Master-dark frame and *Master-flat frame*

5.14.2 Creating a new project

First of all, we will create a new *project*. To begin with processing of a set of source frames, we create a new project. To do so, open the *Project* menu and activate the *New* item. A new dialog appears.

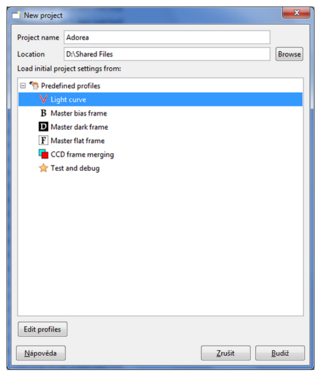


Fig. 44: The dialog for making a new project.

Fill in a name that will be assigned to the project. Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >.

The field *Location* shows a path to the directory where a new project will be created. Edit the path to change the location, you can also click the *Browse* button to select a directory in a separate dialog.

The dialog also displays a list of available profiles. A profiles provides an intial set of configuration parameters into a new project. When you confirm the dialog, you should be in the main window again now. The table of input files shown there is empty.

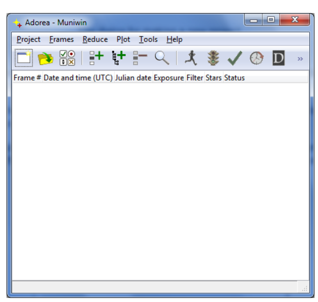


Fig. 45: The main application window with the table of input files, now empty.

See also:

New project (dialog) and *Main window*.

5.14.3 Input files

Now, we are going to tell the program which files we are going to work on. These files are called the input files. Their list is displayed in the table in the main application window. When the application is closed, the list of files are saved to the disk and it is restored back when the program is launched again.

Supposing that the table now consists of files from your previous task, let's get rid of them. Please, use *Files → Clear files* to start a new task instead of just removing the files from the table. Besides the clearing the table of input files, this function resets all internal variables, too.

Now, we need to populate the table with the CCD frames we're going to reduce. There are two methods how to achieve that - adding a individual files or adding all files from a folder. Which way is the best for you depends on organization of your observations on the disk. I'd suggest you to make a folder for each year, a folder for each night in it, the a subfolder for a name of object or another view field identification and finally a subfolder named upon the color filter (if you use more of them). In this case, the "Add frames from a folder" method is more convenient.

Click on *Files → Add frames from folder* in the main menu. A new dialog appears. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. Enter the folder with the input files - you should see them in the middle pane. Then, click on the *Add* button to add files to the table of input files. The program shows the number of added files in the separate dialog. The *Add frames from folder* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

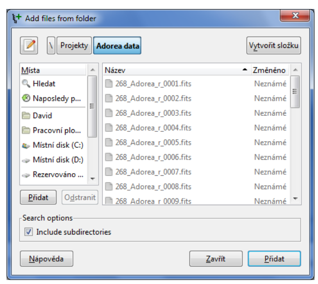


Fig. 46: The "Add folder" dialog with the place selection box (left), the file selection box (right)

If you want to reduce only a subset of files from a folder, click on *Files → Add individual frames* in the main menu. A new dialog appears, similar to the previous one. In the dialog, find a folder where the inputs files are stored in. Click on an entry in the *Places* pane to go to one of a preselected folders, double click in the middle pane enters the folder. The buttons in the upper part of the dialog shows your current position in the directory tree, you can use them to go to one of the parent folders. In the middle pane, select the files using the `Ctrl` modifier to include and exclude a single file and the `Shift` modifier to include a range of files. Then, click on the *Add* button to add selected files to the table of input files. The program shows the number of added files in the separate dialog. The *Add individual frames* dialog is not closed automatically and allows a user to continue. Click on the *OK* button to close the dialog and return to the main window.

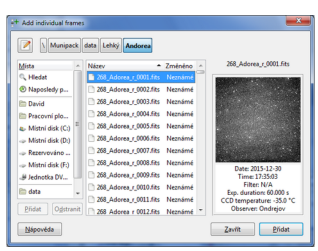


Fig. 47: The "Add files" dialog with the place selection box (left), the file selection box (middle) and the preview panel (right).

See also:

Add frames from folder (dialog) and *Add individual frames (dialog)*.

5.14.4 Frame reduction

Reduction of CCD frames is a process that takes source CCD frames, performs their conversion and calibration, detects stars on each frame and mearures their intensity and finally finds correlation (match) between objects that were found in the data set. The process of reduction prepares the data that are necessary for making a light curve.

The reduction consists of several steps - conversion, calibration, photometry and matching. They can be invoked step-by-step manually. The preferred way is to use the *Express reduction* dialog that allows to perform these steps in a batch. Using the menu, activate the *Reduce* → *Express reduction* item. A new dialog appears. The dialog has several options aligned to the left, Each of them relates to an optional step in the reduction process.

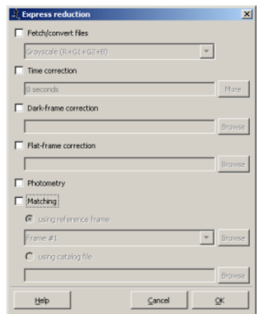
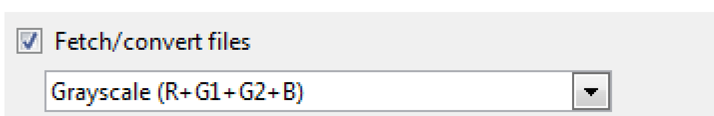


Fig. 48: The dialog for setting parameters of the reduction process

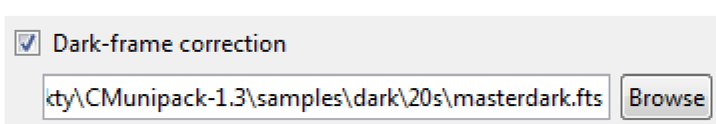
Fetch/convert files

Check the *Fetch/convert files*. In this step, the program makes copy of the source CCD frames. This is necessary, because the following calibration steps will modify them and we don't want the program to change our precious source data.



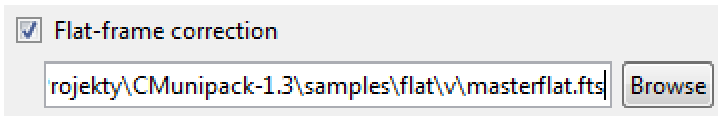
Dark-frame correction

A raw CCD frame consists of several components. By the calibration process, we get rid of those which affect the result of the photometry. In some literature, the calibration is depicted as the peeling of an onion. There are three major components which a raw frame consists of - the current made by incident light, current made thermal drift of electrons (so-called dark current) and constant bias level. In standard calibration scheme, which we will demonstrate here, the dark-frame correction subtracts the dark current and the also the bias. Because of the nature of the dark current, it is necessary to use a correction frame of the same exposure duration as source files and it must be carried out on the same CCD temperature, too. Thus, the properly working temperature regulation on your CCD camera is vital.



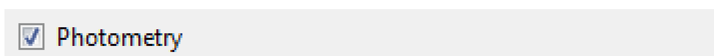
Flat-frame correction

Then, we have to compensate the spatial non-uniformity of a detector and whole optical system. These non-uniformities are due to the fabrication process of a CCD chip and they are also natural properties of all real optical components, lenses in particular. The flat-frame correction uses a flat-frame to smooth them away. The flat-frame is a frame carried out while the telescope is pointed to uniformly luminous area. In practice, this condition is very difficult to achieve, the clear sky before dusk is usually used instead.



Photometry

The photometry is a process that detects stars on a CCD frame and measures their brightness. Unlike the previous steps, the result is saved to a special file, so-called the photometry file. There are a lot of parameters which affect the star detection and also the brightness computation. In this example, the default values work fine, but I would suggest you to become familiar with at least two of them - FWHM and Threshold - before you start a real work. Check the *Photometry* option.



FWHM
: The FWHM parameter specify the expected width of stars on a frame. The value is the Full Width at Half Maximum in pixels. The parameter controls the behavior of the low-pass digital filter, which is used in the star detection algorithm.

Threshold
: The Threshold parameter specify the lowest brightness of detected stars. Fainter objects are considered to be background artifacts and thus sorted out. The value is dimensionless coefficient.

Once you tune up the parameter for your environment, usually it is not necessary to adjust them for every task, unless the quality of your images varies considerably. In the first iteration, you can use the default values (FWHM = 3.0 and Threshold = 4.0) and do the photometry. Click on the *Reduce* → *Photometry* item in the main menu and confirm the new dialog by the *OK*. Then, by double click on a frame in the main window open the preview window and check the results. If there are stars which have been detected as a close binary although it is not true, you should increase the *FWHM* value. If the stars you are interested in are not detected, try decrease the *Threshold* value. If it doesn't help, decrease the *FWHM*. If there is a lot of background artifacts detected as a real stars, increase the *Threshold*. By several iterations, adjust the parameters, so all the stars you are interested in are detected and there are no false binaries.

Matching (skipped)

In case of observation of moving object of intereset, do not perform the matching now; keep the *Matching* option unchecked. The matching process requires user input, but this can be done only when photometry of the source frames has been finished.

Invoking the reduction process

In previous steps, we have configured parameters of the reduction process and we are ready to start it. Click the *OK* button. During the execution a new window appears displaying the state of the process; all the information is also presented there. This window will be automatically closed after finishing the process. Wait for the process to finish.

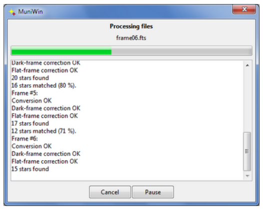


Fig. 49: The dialog displayed during time demanding operations.

After finishing, the icon in the file table changes; the information about the time of observation, the length of the exposition and the used filter is filled in. In case some of the frames could not be processed successfully, the entry is be marked with a special icon and in the *Status* column the error message is indicated.

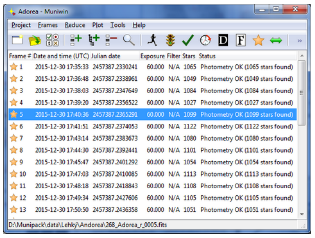


Fig. 50: The main application window after the photometry step

See also:

Express reduction (dialog).

5.14.5 Matching the frames and tracking the object of interest

The object is expected to move along a smooth curve in time. We pick up at least three frames, called key frames, and we mark the object of interest on each of the key frames. It is recommended to start with one key frame at the beginning, one key frame in the middle and one key frame at the end of the set. The key frames define three points and a curve is fitted between them. The curve is used to determine expected position of the object in observation time of any other frame and an unidentified object found on a non-key frame close to the expected position is matched as the object of interest.

Click on the *Reduce* → *Match stars* item in the main menu. A new dialog appears.

In the dialog, check the option *Moving target* (20). List of source frames is presented in the table (21). In the table, select a frame that will be used as the first key frame. The first key frame has got the same function as a reference frame in the matching process for stellar objects; all frames are matched against this frame and it is also used as a background in object selection dialogs. When you select a frame, it is shown in the preview area (22). Click the *Add key frame* button. A new dialog appears.

Find the object of interest and click on it (31). Confirm the dialog (32). You get back to the previous dialog. In the table of frames (21), the key frames gets an icon of a red key before the frame number (24).

Repeat this step until there are at least three key frames. The other key frames are marked by a white key icon (25). The red key icon indicates the frame that is used as a reference key frame in the matching process. Then, click on the *Apply* button to start the matching process.

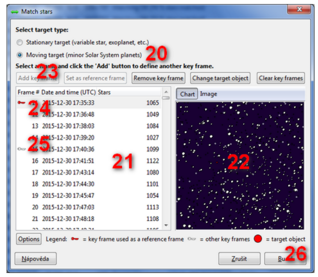


Fig. 51: The Matching dialog in the moving target mode

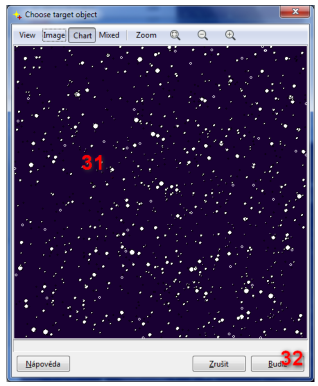


Fig. 52: The Select target dialog

The process now runs automatically. The selected key frames are processed first, the positions of the selected object of interest on the key frames are used to find the path which the object follows by fitting a polynomial function to them. Then, the rest of the frames are processed; the fit is used to find out an expected position of the object in an observation time and an object close to the expected position is marked as the object of intereset on the frame.

See also:

Match stars (dialog)

5.14.6 Making a light curve

Click on the *Plot* → *Light curve* item in the main menu. A new dialog appears. The dialog allows you to set up the options for the light curve. If you want only a subset of frames from the project to be included in the curve, check the selected files only option in the box. The program can also include several corrections and coefficients to the output file, these features are discussed later in the text.

Confirm the dialog by the *OK* button.

See also:

Plot light curve (dialog)

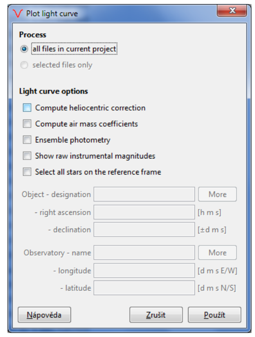


Fig. 53: The dialog for making a light curve.

5.14.7 Selecting the stars

The next dialog shows the reference frame and allows you to select the object of interest, the comparison and the check stars. All detected objects are highlighted. Click anywhere on the frame with the right mouse button to open a context menu. Select the item *Set moving target as a variable*. The object of interest is now drawn in red color and the label "var" is placed near to it (1). Pick up a star that shall be used as a comparison star and click on it using left mouse button. Select the item *Comparison*, the object is now drawn in green color and the label "comp" is placed near to it (2). I would recommend you to pick up also two check stars. Confirm the selection by the *OK* button (3).

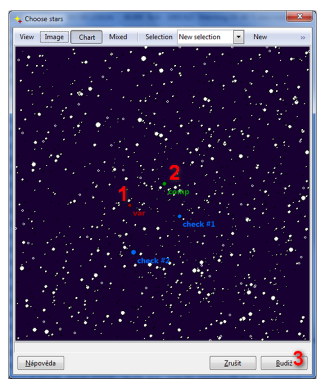


Fig. 54: The dialog for selection of an object of interest (red), a comparison star (green) and check stars (blue).

See also:

Choose stars (dialog)

5.14.8 Choosing an aperture

Now, we have to choose the aperture. You can image the aperture as a virtual circular pinhole, placed on each star on a frame to measure its brightness. All pixels that are inside the pinhole are included in computation leaving out the background pixels. The best aperture should be big enough to include most of the star's light, on the other hand, the bigger aperture is used the more background is included and the more noisy the result is. Because of this, the photometry process computes the brightness of each star in a set of predefined apertures of radius in the range of 2 and 30 pixels.

To select the best aperture, we can take advantage of a comparison and check stars - providing that they are constant, we can compute the differential magnitudes between each couple of them on each other and then compute the variance or standard deviation from the mean level. For the best aperture, the deviations are minimal.

In the next dialog, the graph shows the standard deviation for each aperture. Find the aperture with the minimal deviation and click on it using the left mouse button. A context menu appears. Select the *Select aperture* item. The point is drawn in red color now and the label is placed near to it. Confirm the selection by the *OK* button.

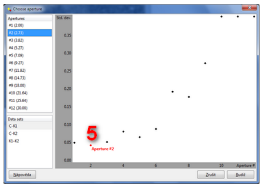


Fig. 55: The dialog for selection of an aperture.

See also:

Choose aperture (dialog)

5.14.9 Plotting a light curve

Now, the program has got enough information to make a light curve. It is presented in a new window which appears automatically.

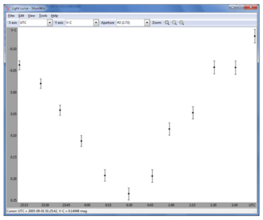


Fig. 56: The dialog with a light curve graph.

See also:

Light curve (dialog)

5.14.10 Trimming outliers from the curve

Is is possible to manually trim outlying observations from the curve. You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. There are two options: When you select the option *delete from data set*, the selected measurements are removed from the current light curve, the data will be shown when you make another light curve or *Rebuild* the actual curve. The other option *remove from project* means that the frames corresponding to the selected measurements are removed permanently from the list of input files (see: Main application window) and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Note:

CCD frames of 268 Adorea:
BlueEye600, RiLA 0.60-m f/5 Ritchey-Chretien + CCD G4-4000BI
(ProjectSoft HK & Astronomical Institute of the Charles University in Prague)

5.15 Export light curve in AAVSO format

The AAVSO Extended format is one of the export formats supported by the Muniwin application. The format is used to submit the CCD or DSLR to the American Association of Variable Star Observers (AAVSO).

5.15.1 General overview

In order to save your observation in the format that the AAVSO accepts, take the following steps:

1) Process your observation data and create a light curve. The light curve should consists of differential magnitudes; this is the default for the standard light curve generation process in the Muniwin application.
2) Open the dialog for saving the light curve: *File* → *Save*.
3) Select the *AAVSO Extended Format* as the file type. Choose a directory where the file shall be stored to and fill in the name of the file. Confirm the dialog.
4) A new dialog appears. The dialog allows you to fill in the information about the observation and the observer. Follow the steps in the dialog and fill in the data. When its last page is confirmed, the file is generated.

5.15.2 Detailed description

Process your observation data and create a light curve. The light curve should consists of differential magnitudes; this is the default for the standard light curve generation process in the Muniwin application. A detailed description of these steps can be found in the chapter *Light curve*.

The following steps are optional:

- If you check the option to compute the heliocentric correction, you will have the choice to save heliocentric Julian dates to the exported file. You need to fill in celestial coordinates of the variable star.
- You can also check the option to include the air mass coefficient values as well. If you do so, the values will be saved to the file. You have to fill in celestial coordinates of the variable star and also geographic coordinates of the observation location.

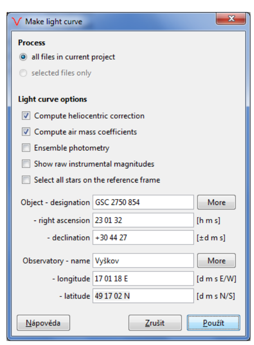


Fig. 57: Make a light curve

In the next dialog, select the stars. If you follow the standard photometry scheme with one comparison star, you have to mark at least the variable star and one comparison star. It is recommended to pick up one check star, which helps you to choose an optimum aperture.

The enseble photometry mode is also supported. In this mode, you combine several comparison stars together; in this case, marking at least one check star is mandatory. More about this mode can be find in the chapter *Ensemble photometry*.

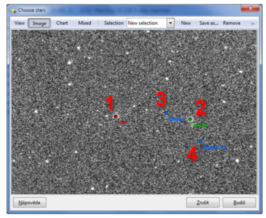


Fig. 58: Mark the variable star (red), comparison star (green) and check stars (blue).

In the next dialog, select the aperture. If you marked at least one check star, the dialog shows a graph of standard deviation between the comparison star and the check star vs. the aperture size. Usually it is a V-like curve. Choose the aperture with minimum value and select it.

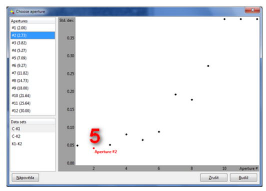


Fig. 59: Select an aperture with minimum value

A new dialog shows a light curve:

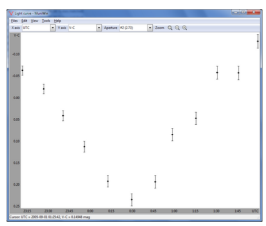


Fig. 60: Light curve of the variable star. Please note, that the magnitudes are differential (V-C).

In the window with a light curve, click on the *File* –> Save` item in the local menu. A new dialog appears. Locate the folder where you want to save the results (1) and fill in the name of the output file (2). Choose the file type to be *AAVSO Extended Format* (3). If you checked the option to compute heliocentric correction, you have the choice to export Julian dates helicentric or geocentric (4). Confirm the dialog by the *Save* button (5).

A new dialog appears:

Fill in the observation data:

(1) Star identification - use the AAVSO Designation, the AAVSO Name, or the AAVSO Unique Identifier, but NOT more than one of these.

(2) Observer code - the official AAVSO Observer Code for the observer which was previously assigned by the AAVSO.

(3) Observation type - specify type of the camera - CCD or DSLR.

(4) Filter - click the *Browse* button to choose the color filter used.

(5) Chart - please use the sequence ID you will find in red at the bottom of the photometry table. If a non-AAVSO sequence was used, please describe it as clearly as possible.

(6) Notes - comments or notes about the observation. Leave this field blank if you don't want to specify any notes.

Click the *Next* button to continue. The dialog is switched to the next page.

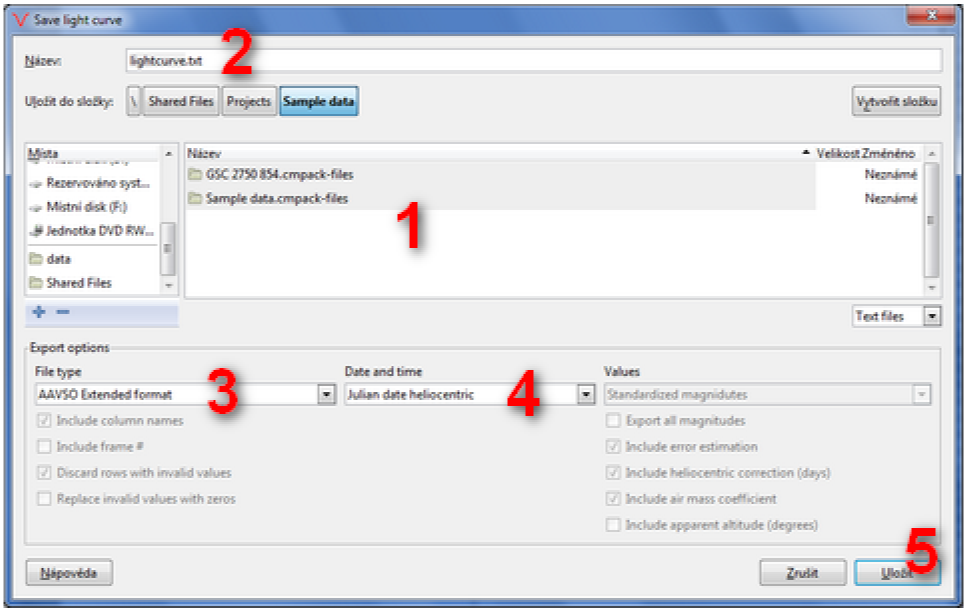


Fig. 61: Specify directory and file name, choose the correct file type.

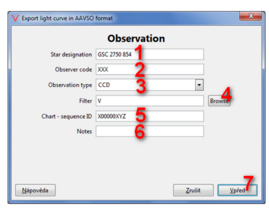


Fig. 62: Fill in the observation data (page 1)

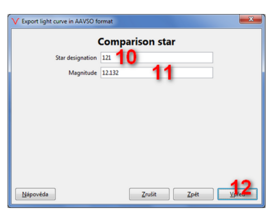


Fig. 63: Fill in the observation data (page 2)

The next page is designated to fill in the data about the comparison star. Provide the comparison star identifier (usually an integer number) and brightness of the comparison star according to the filter you used. Click the *Next* button to continue.

In case of the ensemble photometry, you don't need to fill in anythink on this page, just click the *Next* button to continue.

The dialog is switched to the next page.

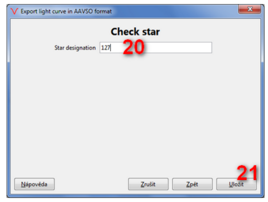
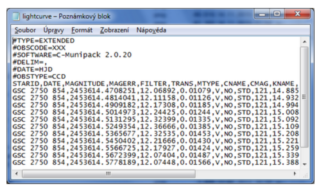


Fig. 64: Fill in the observation data (page 3)

The last page is shown only if you selected a check star. Please note, that in case of the ensemble photometry, using the check star is mandatory. Provide the check star identifier (20). Click the *Save* button to finish the dialog. When the dialog is finished the file is generated.

You can review the content of the file using a text editor:




```
#TYPE=EXTENDED
#OBSCODE=XXX
#SOFTWARE=C-Munipack 2.0.20
#DELIM=,
#DATE=HJD
#OBSTYPE=CCD
STARID,DATE,MAGNITUDE,MAGERR,FILTER,TRANS,MTYPE,CNAME,CMAG,KNAME,
GSC 2750 854,2453614.4708251,12.06892,0.01079,V,NO,STD,121,14.885
GSC 2750 854,2453614.4814041,12.11158,0.01126,V,NO,STD,121,14.932
GSC 2750 854,2453614.4909182,12.17308,0.01185,V,NO,STD,121,14.994
GSC 2750 854,2453614.5014973,12.24425,0.01244,V,NO,STD,121,15.008
GSC 2750 854,2453614.5131295,12.32399,0.01335,V,NO,STD,121,15.092
GSC 2750 854,2453614.5249354,12.36666,0.01385,V,NO,STD,121,15.109
GSC 2750 854,2453614.5365677,12.32535,0.01453,V,NO,STD,121,15.208
GSC 2750 854,2453614.5450402,12.21666,0.01430,V,NO,STD,121,15.221
GSC 2750 854,2453614.5566725,12.17927,0.01424,V,NO,STD,121,15.259
GSC 2750 854,2453614.5672399,12.07404,0.01487,V,NO,STD,121,15.339
GSC 2750 854,2453614.5778189,12.07448,0.01566,V,NO,STD,121,15.388
```

Fig. 65: Generated file with exported observation in the AAVSO Extended Format shown in the Notepad application.

5.15.3 Standardized magnitude

Under the AAVSO Extended format, the brightness of a variable star is reported in the form of the standardized magnitude, defined as:

$$V_{std} = (V_{ins} - C_{ins}) + C_{std}$$

where V_{ins} and C_{ins} are the instrumental magnitude of the variable and the comparison, respectively, and C_{std} is the chart magnitude for the comparison. The $(V_{ins} - C_{ins})$ part is the $V - C$ value that you find in the (differential) light curve created in the software. You specify C_{std} values for your comparison in the export settings (see above).

See this page for the original description.

Unlike the variable, which is reported as a standardized magnitude, the brightness of the comparison and the check star is reported in form of the instrumental magnitude - C_{ins}. Please note, that there is a different in reporting comparison and check star magnitude in the standard (single comparison star) and the ensemble photometry (multiple comparison stars).

5.15.4 Ensemble photometry

When multiple stars are used to stand in for a comparison, the value of C_{std} needs be computed from chart magnitudes of all stars which are incorporated in the ensemble. The C-Munipack software uses flux averaging, so the instumental magnitude of the comparison C_{ins} is replaced in the above equation by the following formula.

$$C_{ins} = -2.5log_{10}(\frac{1}{N}\sum 10^{-0.4C_{ins,i}})$$

where N is a number of stars in the ensemble, and $C_{ins,i}$ is the instrumental magnitude of *i*-th star in the ensemble.

Similarly, we define the chart magnitude of the comparison C_{std}:

$$C_{std} = -2.5log_{10}(\frac{1}{N}\sum 10^{-0.4C_{std,i}})$$

where $C_{std,i}$ is the chart magnitude of *i*-th star in the ensemble.

See also:

AAVSO Extended Format
see https://www.aavso.org/aavso-extended-file-format

AAVSO Observer Code
see https://www.aavso.org/where-do-observer-codes-come

AAVSO Unique Identifier
see https://www.aavso.org/aavso-unique-identifier

Standardized magnitude
see https://www.aavso.org/standardized-magnitude

5.16 Export light curve in BAAVSO format

TBD.

5.17 Checking the telescope mount

A track curve is a graph of spatial offset of CCD frames, as a function of time. Such curve is used to monitor the stability and precision of telescope mount and its clock drive.

You can use the C-Munipack software to make a track curve from a set of CCD frames of a star field. As a result of the matching step during the reduction of input frames, an offset relative to a reference file in axes X and Y are stored to photometry files. The track curve tools uses this information to make a graph of offset in X and Y axis respectively, as a function of time.

5.17.1 How to make a track curve

1. Process source CCD frames by normal way of reduction till star matching.
2. In the *Plot* menu, select the *Track curve* item. A new dialog window with a graph appears. The Julian date is on the horizontal axis of the graph and the offsets in pixels are on its vertical axis.

The graph consists of two data columns:

- *OFFSETX* - offset in horizontal direction, positive values mean the shift to the right, negative to the left.

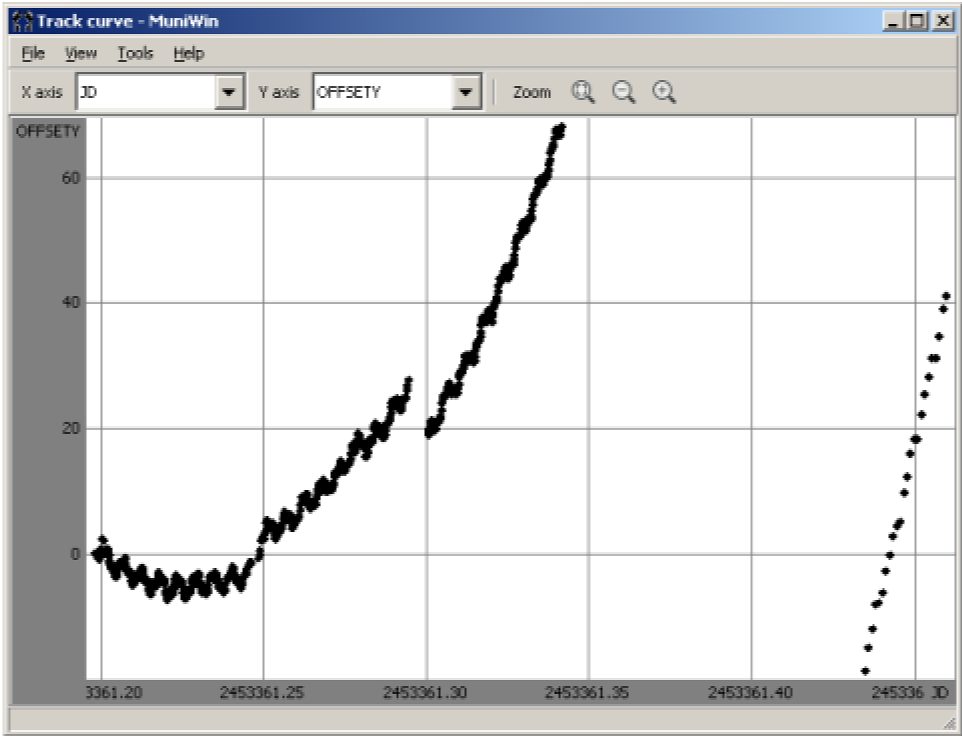


Fig. 66: The track curve

- *OFFSETY* - offset in vertical direction, positive values mean the shift to the bottom, negative to the top.

The track curve shows the periodic error of the telescope mount. The periodic error is caused by eccentricity of a tooth wheel and demonstrates itself as a sinusoidal signal in the track curve. Note that several superimposed sinusoidal signals are present on the picture, each with different period and amplitude. By finding the period of the signal, you can tell which tooth well is eccentric.

See also:

Plot track curve (dialog)

5.17.2 Trimming outliers from the curve

Is is possible to manually trim outlying observations from the curve. You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. There are two options: When you select the option *delete from data set*, the selected measurements are removed from the current curve, the data will be shown when you make another track curve or *Rebuild* the actual curve. The other option *remove from project* means that the frames corresponding to the selected measurements are removed permanently from the list of input files (see: Main application window) and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

See also:

Track curve (dialog)

5.18 Project settings

This chapeter provides a complete list of project settings and the description of each parameter.

Camera

Camera parameters

- Read noise - readout noise in electrons, you should enter the proper value stated in the camera's documentation. Default: 15.0
- Gain - number of electrons per ADU, you should enter the proper value stated in the camera's documentation. Default: 2.3

Source frames

Source frame conversion and processing parameters

- Min. pixel value - lowest value of pixel in ADU. All pixels, which are equal to or less than specified value are considered to be invalid, by default: 0
- Max. pixel value - highest value of pixel in ADU. All pixels, which are equal to or greater than specified value are considered to be overxposed, by default: 65535.
- Image data format - pixel data format in which the working files are stored. If the "Autodetection" is selected, the program keeps the format of original source files. Otherwise, the data are transformed during the Fetch/Convert operation. Default: Autodetection
- Binning - reduction of frame size. When this feature is enabled, the program will sum the pixel values from groups of neighboring pixels making one pixel for each group in the working frame. This transformation is performed in the Fetch/Convert operation. This is useful for processing images from the hi-resolution DSLR and CCD cameras. Please note, that the sum of pixel values are computed (not average), so you when you enable binning, you will probably need to increase the "Max. pixel value". Default: No binning
- Border - skip invalid parts of the source frames. Set up frame borders to nonzero if you need to remove parts of the frames from the processing. Default: 0

Calibration

Parameters for bias, dark and flat corrections.

- Standard calibration - in the standard calibration scheme, only two correction frames are used - a dark frame, which also includes the bias, and a flat frame. The standard calibration scheme is simpler to follow, but it requires that the dark frame must be of the same exposure duration as source frames.
- Advanced calibration - in the advanced calibration scheme, all three correction frames are applied separately - a bias frame, a dark frame and a flat frame, in that order. The dark frame must not contain a bias, such dark frame is called scalable dark frame, because it need not to be of the same exposure duration as source frames.

Star detection

Parameters for detection of objects on a frame. This step is done during the Photometry operation.

- Filter width (FWHM) - full width at half maximum of the Gaussian filter. The low-pass filter is applied to the source image before searching for local maxima. If profile of objects on frames roughly corresponds to the Gaussian function, the good value for the filter width is the FWHM of objects. You can use the Quick Photometry tool in the Preview window to measure the FWHM of objects. In case the profile of objects is not a Gaussian function and the program splits stars into two or more objects, you need to raise this value. Default: 3.0
- Detection threshold - the level which a brightness enhancement must have above the background level to be considered as a real object. The value is given in standard deviations. The best starting point is the default value 4.0. Process a set of frames and check the results. If you need to detect fainter object, reduce it. If many background artefacts are considered as stars, raise it. Run the photometry again and repeat the steps until the results are satisfactory. Please note, that the filter width also affects the detection capabilities. Default: 4.0
- Minimum and maximum sharpness - minimum and maximum value of sharpness which a brightness enhancement must have to be considered a real object. The main purpose is to eliminate bad pixels, it may also help to eliminate blurred objects such as nebulaes and galaxies. Defaults: 0.2 and 1.0
- Minimum and maximum roundness - minimum and maximum value of roundness which a brightness enhancement must have to be considered a real object. This test is intended to eliminate bad rows and columns, it may also help to eliminate galaxies or cosmic particle traces. Defaults: -1.0 and 1.0
- Max. stars - maximum number of objects. This parameter is used to limit the photometry file to a reasonable number of objects. The stars are sorted by their magnitudes and specified number of stars from the top of the list is preserved, the rest is discarded. Default: 10000

Photometry

Parameters for aperture photometry.

- Aperture - the program computes brightness of stars in all defined apertures. It is possible to define at most 12 apertures. An user can select one of them when making output data, a light curve for example. The aperture is defined by its radius in pixels.
- Inner and outer radius - local background level is measured in an annulus that is centered on the object. These parameters define its inner and outer radius in pixels. Defaults: 20.0 and 30.0.

Matching

Parameters for matching stars.

- Standard algorithm - identifies similar polygons of stars and find the best match. It works well if a source frame is scaled, rotated or even mirrored with respect to the reference frame. The limitation is that it requires at least three stars on a frame.
- Algorithm for sparse fields - this algorithm can match frames which contain at least one star. Scale, tilt and position of a source frame with respect to the reference frame should be close. Otherwise, it leads to a false match.
- Algorithm for dense fields - this algorithm works well on very dense fields containing multitude of objects of similar magnitude, like globular clusters. It is slower that the standard algorithm.

Standard algorithm parameters

- Read stars - if a source or reference file contain more than given number of stars, the program reads only that number of brightest stars. This limit speeds up the computation. Default: 10
- Identification stars - a number of stars that are identified in each iteration. More information is given in the theory of operation. Default: 5
- Clipping factor - tolerance used during the iterative evaluation of the transformation coefficients. Default: 2.5

Parameters of sparse-fields algorithm

- Max. offset - maximum offset between a source frame and a reference frame in pixels. It is intended to eliminate false matches. This parameter should as high as the highest offset of an object of frames, but no higher. Default: 2.0

Parameters of dense-fields algorithm

- Clipping factor - tolerance used during the iterative evaluation of the transformation coefficients. Default: 2.5

Master bias

Parameters for making a master bias frame.

- Output data format - pixel data format in which the master bias frame is stored. If the “Autodetection” is selected, the program keeps the format of working files. Otherwise, the data are transformed into specified format. Default: Autodetection

Master dark

Parameters for making a master dark frame.

- Make scalable dark frame - make a master dark frame that can be scaled to match the exposure duration of a source frame and a dark correction frame (see the advanced calibration scheme for further information). When you check this option, you have to subtract a bias frame from your dark frames before you make a master dark frame.
- Output data format - pixel data format in which the master dark frame is stored. If the “Autodetection” is selected, the program keeps the format of working files. Otherwise, the data are transformed into specified format. Default: Autodetection

Master flat

Parameters for making a master flat frame.

- Output data format - pixel data format in which the master dark frame is stored. If the “Autodetection” is selected, the program keeps the format of working files. Otherwise, the data are transformed into specified format. Default: Autodetection
- Output mean level - the program normalizes the master flat frame so its mean level is equal to a given value. If it is set too high, the output frame has many overexposed pixels. On the other hand, too low value raises the noise when a integer pixel format is used, because pixel values in a frame are rounded to the nearest integer values. Default: 10000

Merge frames

Parameters for frame merging.

- Output data format - pixel data format in which the merged frame is stored. If the "Autodetection" is selected, the program keeps the format of working files. Otherwise, the data are transformed into specified format. Default: Autodetection

Find variables

Parameters for finding new variables.

- Clipping threshold - minimum share of valid brightness measurements that a star must have to be included in the mag-dev graph. This test is intended to eliminate stars that have few valid measurements only and their position in the mag-dev graph more or less random. Default: 60

Observer

Observer's geographic coordinates.

- Name - any text identifying the observing location, i.e. name of the town
- Longitude - observer's longitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'E' character at the first position in a string to indicate that the location is on the eastern hemisphere or 'W' character for locations on a western hemisphere.
- Latitude - observer's latitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'N' character at the first position in s string to indicate that the location is on the north hemisphere or 'S' character for locations on a southern hemisphere.

See also:

Projects, *Profiles*, *Environment options (dialog)*, *Project settings (dialog)*, *Edit profiles (dialog)*

CHAPTER

SIX

MUNIWIN REFERENCE MANUAL

6.1 Main menu

Here is the list of all items that can be displayed in the main menu. Please note, that some items may be hidden according to the actual project type. See *Projects* topic for details.

- Menu *Project*
  - *New* - start a new project; see *New project (dialog)*.
  - *Open* - open an existing project; see *Open project (dialog)*.
  - *Recent projects* - open one of the most recently used projects.
  - *Export* - make copy of the current project to another location; see *Export project (dialog)*.
  - *Close* - close current project.
  - *Edit project settings* - change project settings - name, type, processing parameters, etc.; see *Project settings (dialog)*.
  - *Exit* - close the project and the main window.
- Menu *Frames*
  - *Add individual frames* - add one or more frames from a folder; see *Add individual frames (dialog)*.
  - *Add frames from folder* - add frames from a folder and its subfolders; see *Add frames from folder (dialog)*.
  - *Remove selected frames* - remove selected frames from the project.
  - *Remove all frames* - remove all frames from the project.
  - *Show selected frame* - open selected frame in a preview window; see *Frame preview window*.
  - *Show properties* - show properties of a selected frame.
- Menu *Reduce*
  - *Express reduction* - conversion, calibration, photometry and matching done at in a batch; see *Express reduction (dialog)*.
  - *Process new frames* - process frames that were appended to the project, apply the same rules as to the frames that had been already processed; watch periodically for new frames in a folder, append them to the project and process them; see *Process new frames (dialog)*.
  - *Fetch/covert files* - make working copy of the source frames, convert them if necessary; see *Fetch/convert files (dialog)*.
  - *Bias correction* - apply bias correction; see *Bias correction (dialog)*.
  - *Dark correction* - apply dark correction; see *Dark correction (dialog)*.

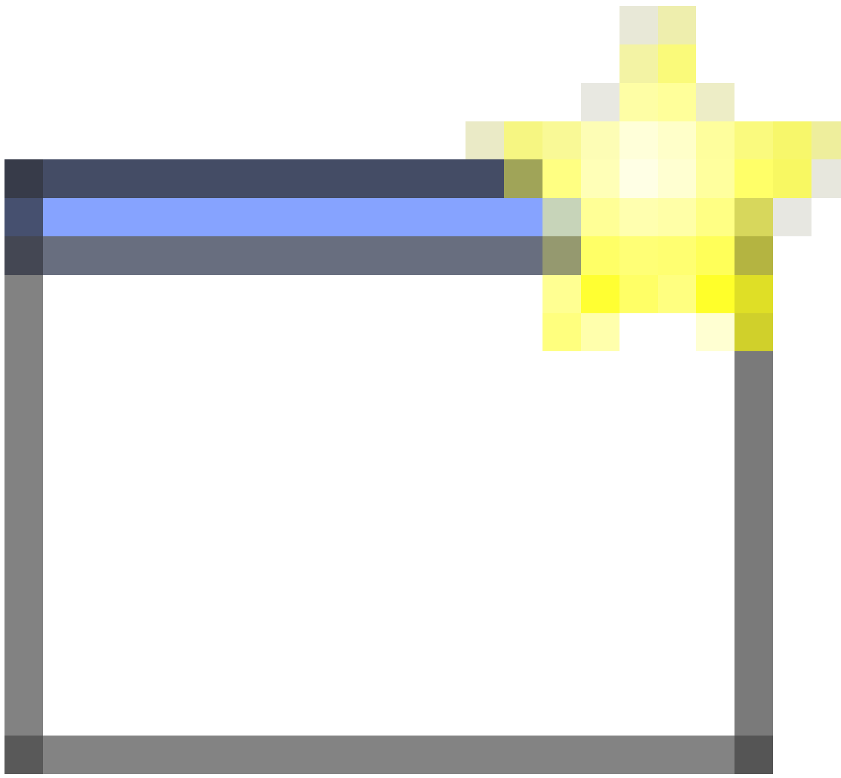
  - *Flat correction* - apply flat correction; see *Flat correction (dialog)*.
  - *Photometry* - run photometry; see *Photometry dialog (dialog)*.
  - *Match stars* - find cross-references between stars on the frames; see *Match stars (dialog)*.
- Menu *Plot*
  - *Light curve* - make light curve (magnitude vs. time) for a variable; see *Plot light curve (dialog)*.
  - *Track curve* - make track curve (frame offset vs. time); see *Plot track curve (dialog)*.
  - *Air mass* - make air mass curve (air mass vs. time); see *Plot air mass (dialog)*.
  - *CCD temperature* - make CCD temperature curve (temperature vs. time); see *Plot CCD temperature (dialog)*.
  - *Object properties* - plot object properites (position, de-focus (FWHM), instrumental magnitude, …); see *Plot object properties (dialog)*.
- Menu *Make*
  - *Master bias frame* - make master bias frame; see *Master bias frame (dialog)*.
  - *Master dark frame* - make master dark frame; see *Master dark frame (dialog)*.
  - *Master flat frame* - make master flat frame; see *Master flat frame (dialog)*.
  - *Merge frames* - merge frames to make combined frames; see *Merge frames (dialog)*.
- Menu *Tools*
  - *Find variables* - semi-automatic search for variable stars; see *Make find variables dialog*.
  - *Make catalog file* - make a catalog file (a reference frame for the field); see *Make catalog file (dialog)*.
  - *Show thumbnails* - show small previews of all frames in the projects; see *Thumbnails (dialog)*.
  - *Show message log* - show detailed report from the last process; see *Message log (dialog)*.
  - *Open file* - open CCD frame, photometry file or curve in a preview window; see *Image file (window)*, *Photometry file (window)*, *Catalog file (window)* and *Graph (window)*.
  - *Recent files* - open one of the most recently used files.
  - *Import data from C-Munipack 1.x* - import data from a folder that contains C-Munipack 1.x files; see *Import project (dialog)*.
  - *JD converter* - convert a Julian date into a Gregorian calendar date; see *JD converter (dialog)*.
  - *Heliocentric correction* - compute heliocentric correction for given Julian date and object corrdinates; see *Heliocentric correction (dialog)*.
  - *Air mass coefficient* - compute air mass coefficient for given Julian date, object corrdinates and observer coordinates; see *Air mass coefficient (dialog)*.
  - *Edit profiles* - open dialog for editing user-defined profiles; see *Edit profiles (dialog)*.
  - *Environment options* - change user interface settings; see *Environment options (dialog)*.
- Menu *Help*
  - *Show help* - show help for the main application window.
  - *User's manual* - open the user manual at the top-level table of contents.
  - *About Muniwin* - information about version of the software and libraries, license and authors.

See also:

Main window, *Main toolbar*

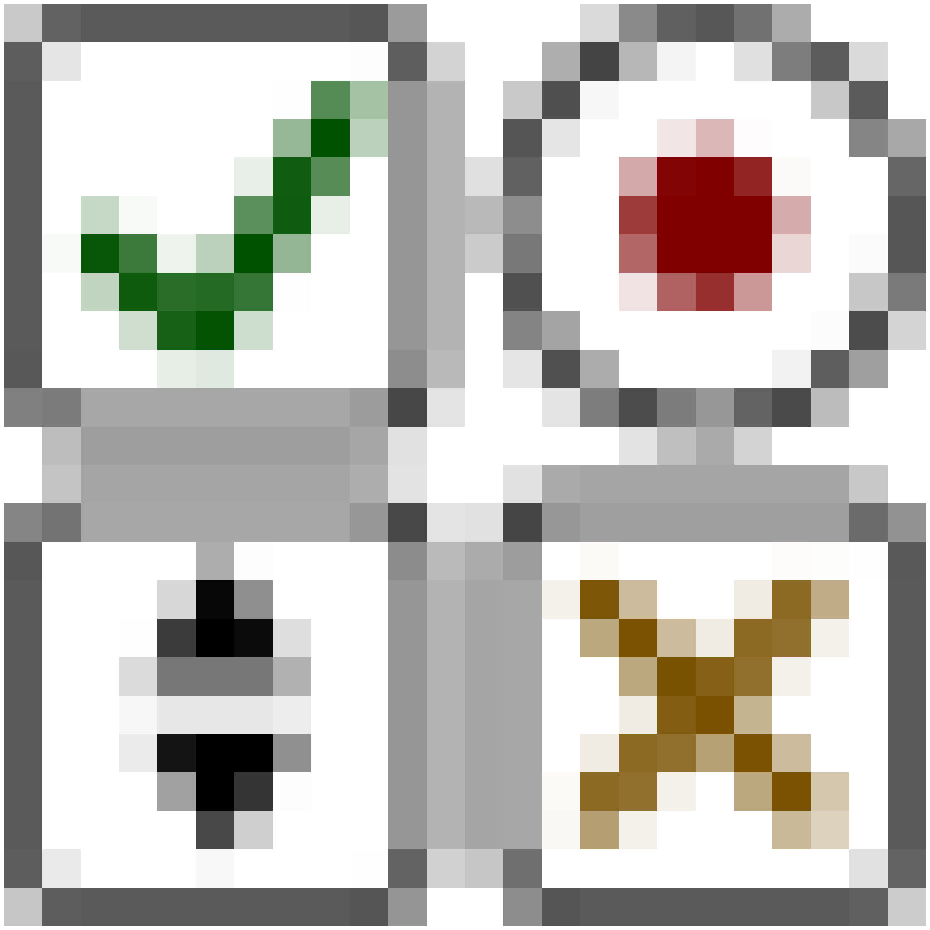
6.2 Main toolbar

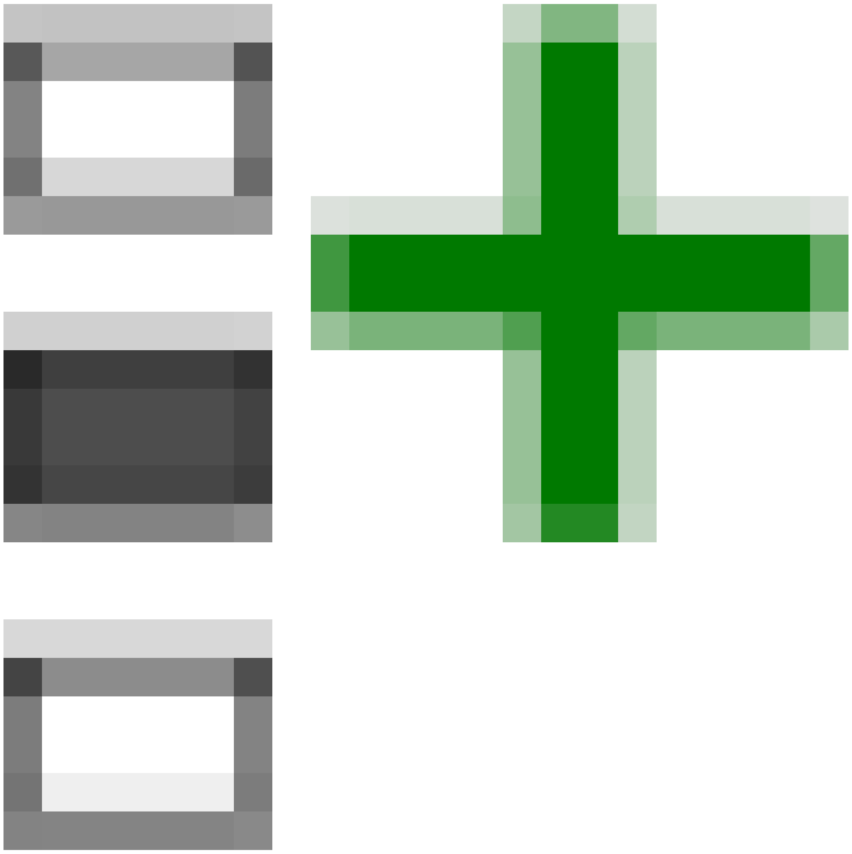
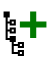
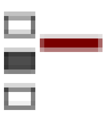
Here is the list of all items that can be displayed in the main toolbar. Please note, that some items may be hidden according to the actual project type. See *Projects* topic for details.

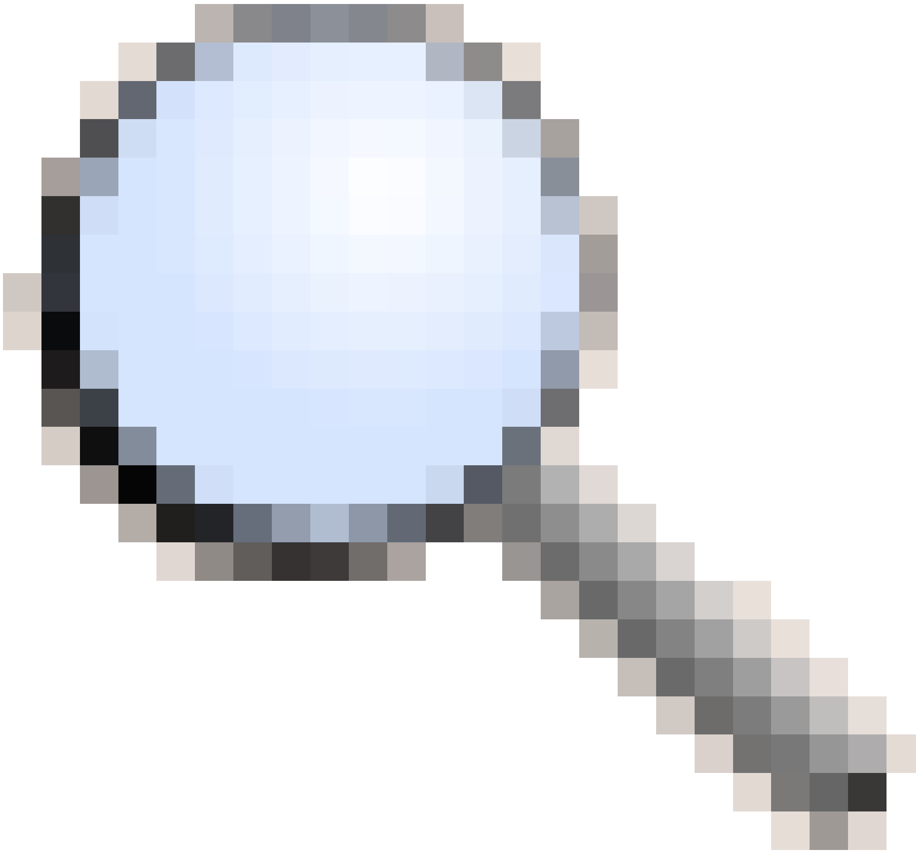
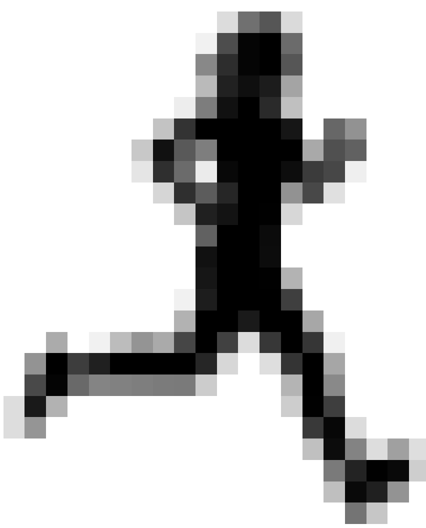


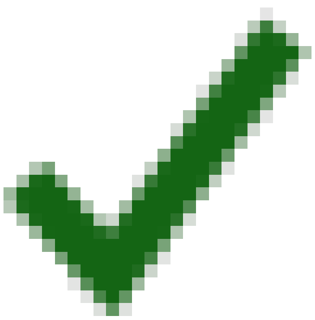
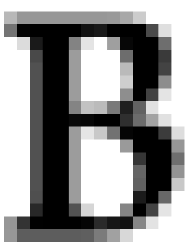
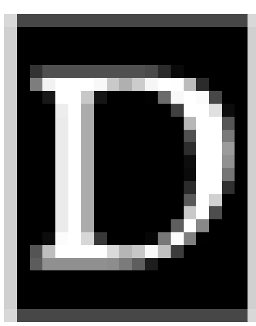
- - start a new project; see *New project (dialog)*.

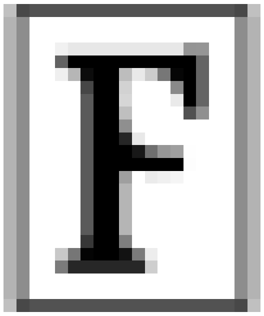
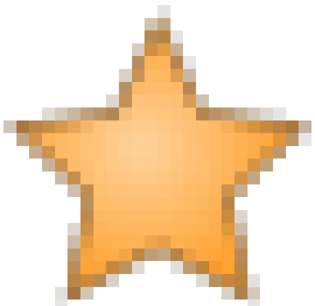
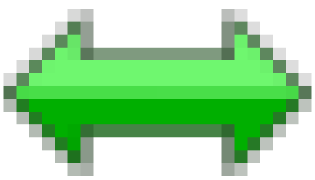
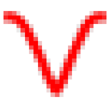
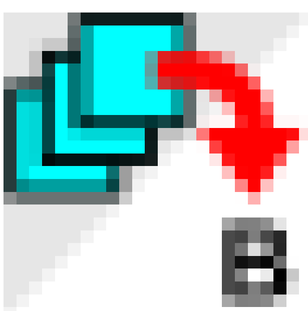
-  - open an existing project; see *Open project (dialog)*.

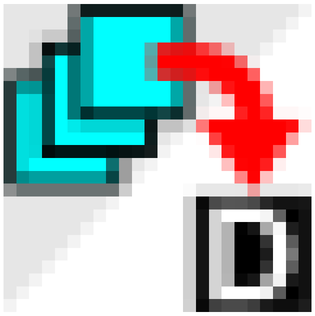
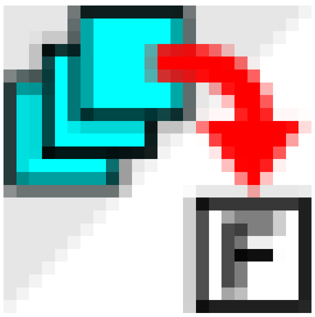
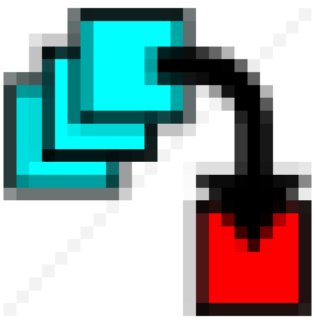
-  - change project settings - name, type, processing parameters, etc.; see *Project settings (dialog)*.

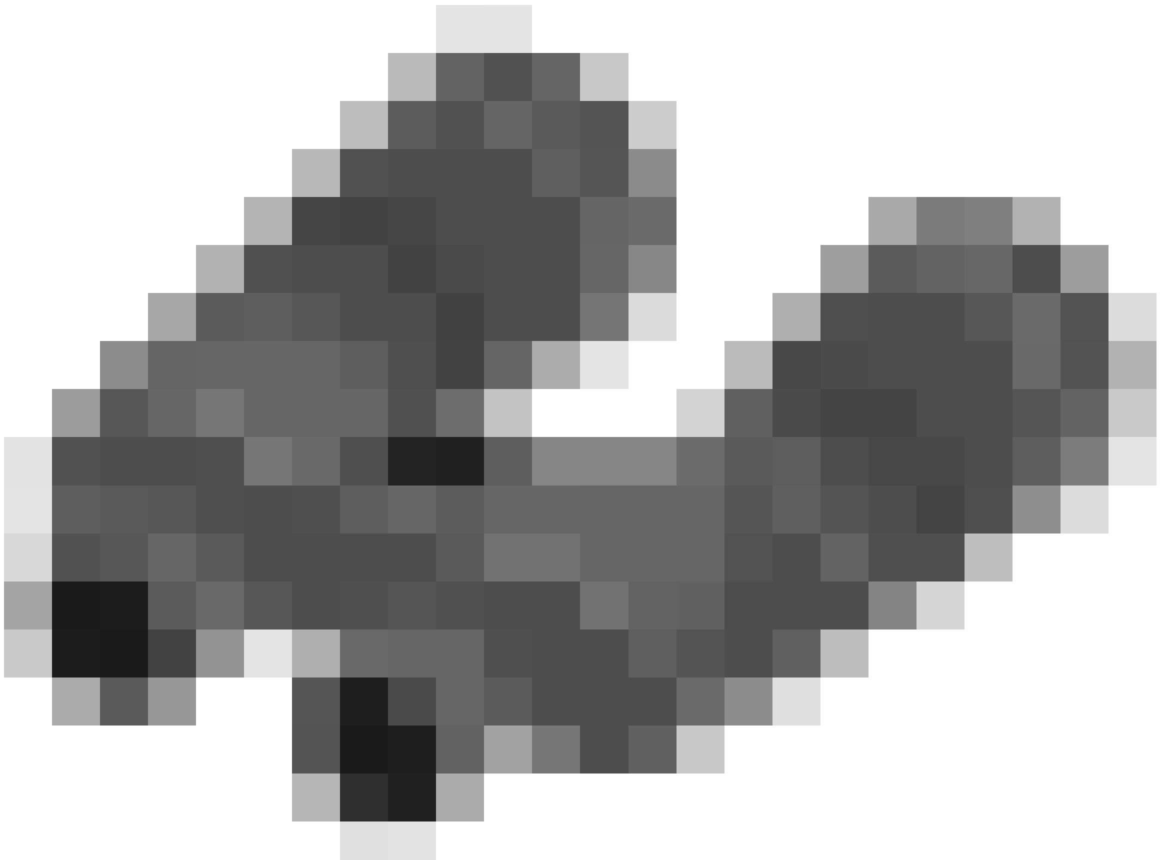
-  - add one or more frames from a folder; see *Add individual frames (dialog)*.
-  - add frames from a folder and its subfolders; see *Add frames from folder (dialog)*.
-  - remove selected frames from the project.

-  - open selected frame in a preview window; see *Frame preview window*.
-  - conversion, calibration, photometry and matching done at in a batch; see *Express reduction (dialog)*.

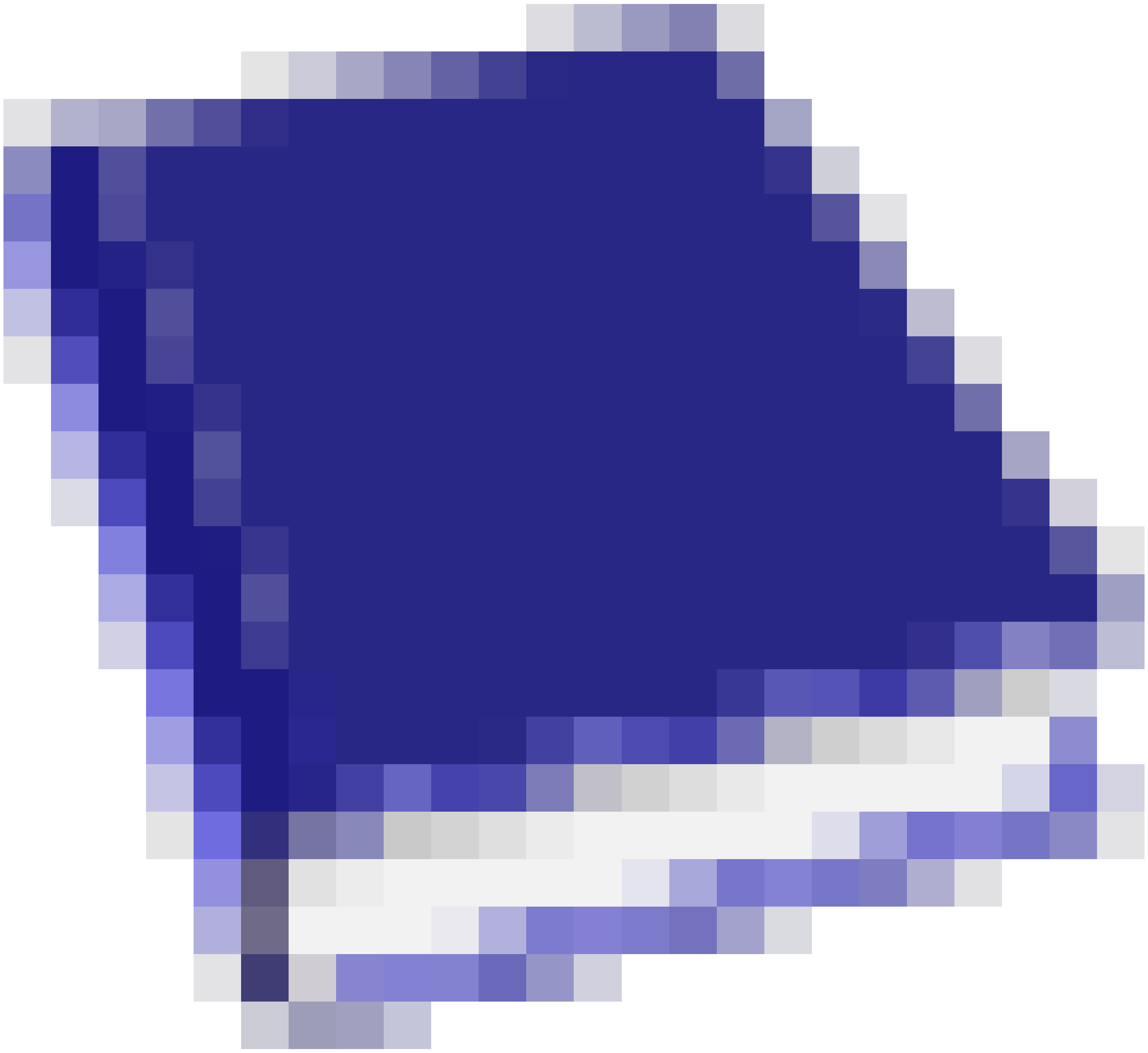
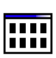
-  - process frames that were appended to the project, apply the same rules as to the frames that had been already processed; watch periodically for new frames in a folder, append them to the project and process them; see *Process new frames (dialog)*.
-  - make working copy of the source frames, convert them if necessary; see *Fetch/convert files (dialog)*.
-  - apply bias correction; see *Bias correction (dialog)*.
-  - apply dark correction; see *Dark correction (dialog)*.

-  - apply flat correction; see *Flat correction (dialog)*.
-  - run photometry; see *Photometry dialog (dialog)*.
-  - find cross-references between stars on the frames; see *Match stars (dialog)*.
-  - make light curve (magnitude vs. time) for a variable; see *Plot light curve (dialog)*.
-  - make master bias frame; see *Master bias frame (dialog)*.

-  - make master dark frame; see *Master dark frame (dialog)*.
-  - make master flat frame; see *Master flat frame (dialog)*.
-  - merge frames to make combined frames; see *Merge frames (dialog)*.



- -
  semi-automatic search for variable stars; see *Make find variables dialog*.

-  - make a catalog file (a reference frame for the field); see *Make catalog file (dialog)*.
-  - show small previews of all frames in the projects; see *Thumbnails (dialog)*.

See also:

Main window, *Main menu*

6.3 Dialogs and tools

6.3.1 About Muniwin (dialog)

The “About Muniwin” dialog shows the version, the authors and the licence of the software.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Help* → *About Muniwin*.

See also:

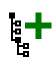
Introduction, *Getting started*

6.3.2 Add frames from folder (dialog)

The “Add frames from folder” dialog is used to add source frames into the current project. Unlike the closely related dialog “Add individual frames”, it takes all files from a selected folder and optionally its subfolders.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Frames* → *Add frames from folder*.
2. from the main toolbar: 

File browsing

The button “Type a file name” (1) shows and hides the “Location” text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the “Location” text box (2) you can type a path to a folder. If you don’t type any path, the name of the selected folder will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of folders names beginning with these letters will be displayed.

The path to the current folder is displayed at the top of the dialog (3). You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the “Add” or the “Add to Bookmarks” option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Right-clicking a folder name opens a context menu.

(7) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

Check the option “Include subdirectories” (8) to instruct the program that it shall also search for CCD frames in the subfolders of the current folder.

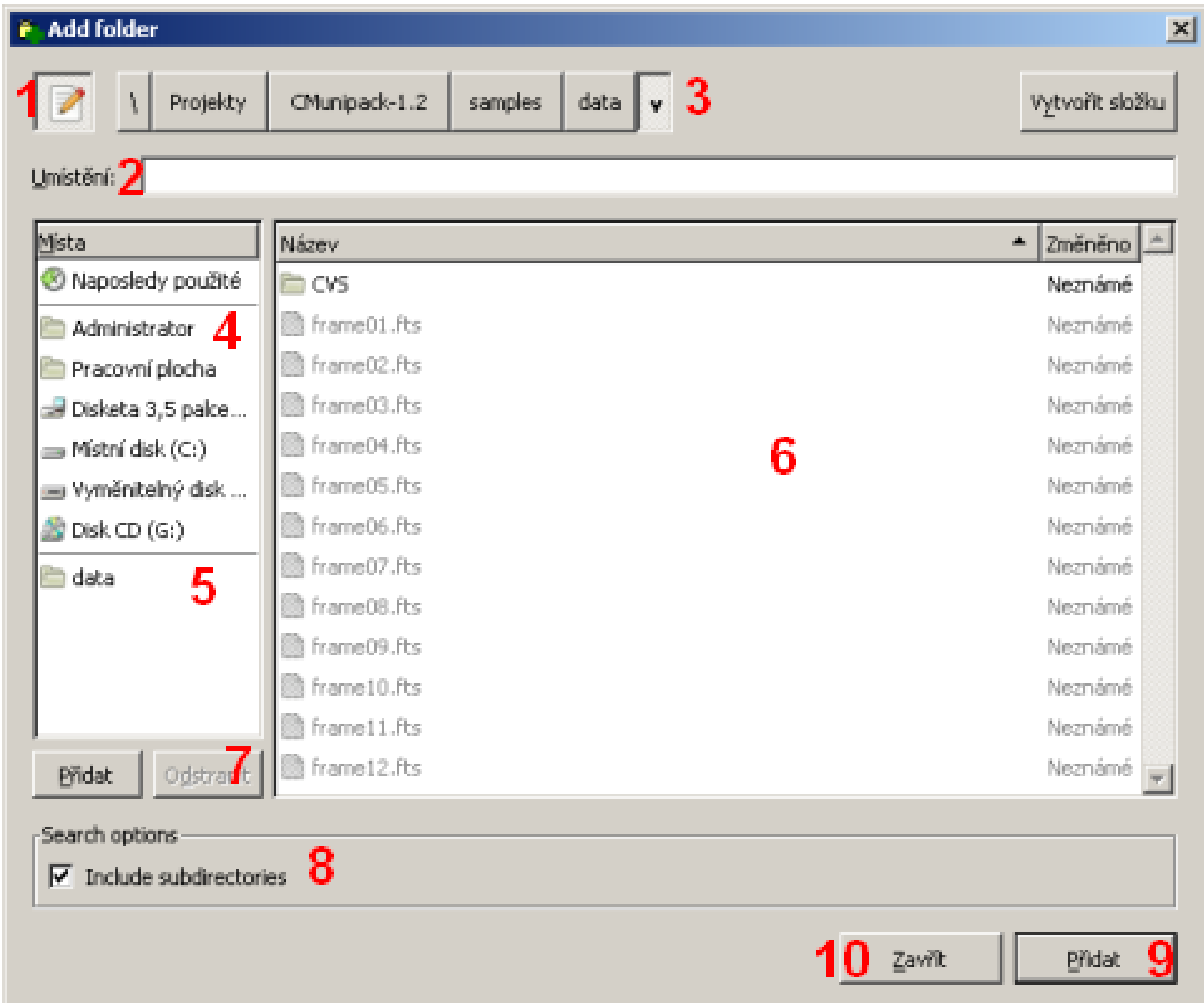


Fig. 1: The dialog for adding multiple files to the project.

Including files the project

To add the files from the current folder, click the "Add" button (9). The program searches it for available files. Several situations may occur:

- If the file is not a valid CCD frame, it is ignored.
- If the file is already included in the project, it is ignored.
- If there are multiple files left and they have different color filter name, the program shows a new dialog and asks an user to select which filters shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.
- If there are multiple files left and they have different exposure duration, the program shows another dialog and asks an user to select which exposures shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.
- If there are multiple files left and they have different object designation, the program shows another dialog and asks an user to select which objects shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.

When the action is completed, the dialog is not closed; you can go on to add files from another folder or close the dialog by the "Close" button (10).

See also:

Add individual frames (dialog), *Main window*

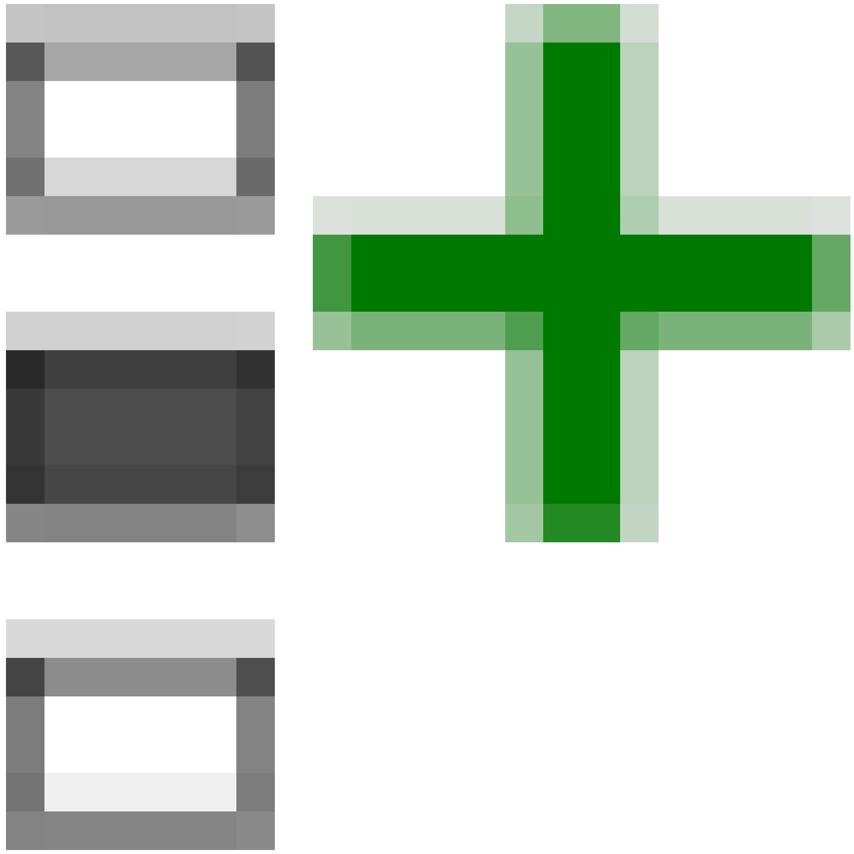
6.3.3 Add individual frames (dialog)

The "Add individual frames" dialog is used to add source frames into the current project. Unlike the closely related dialog "Add frames from folder", it allows an user to select individual files.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Frames* → *Add individual frames*.



2. from the main toolbar:

File browsing

The button "Type a file name" (1) shows and hides the "Location" text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

The path to the current folder is displayed at the top of the dialog (3). You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. You can use Shift and Ctrl modifiers to select multiple files. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

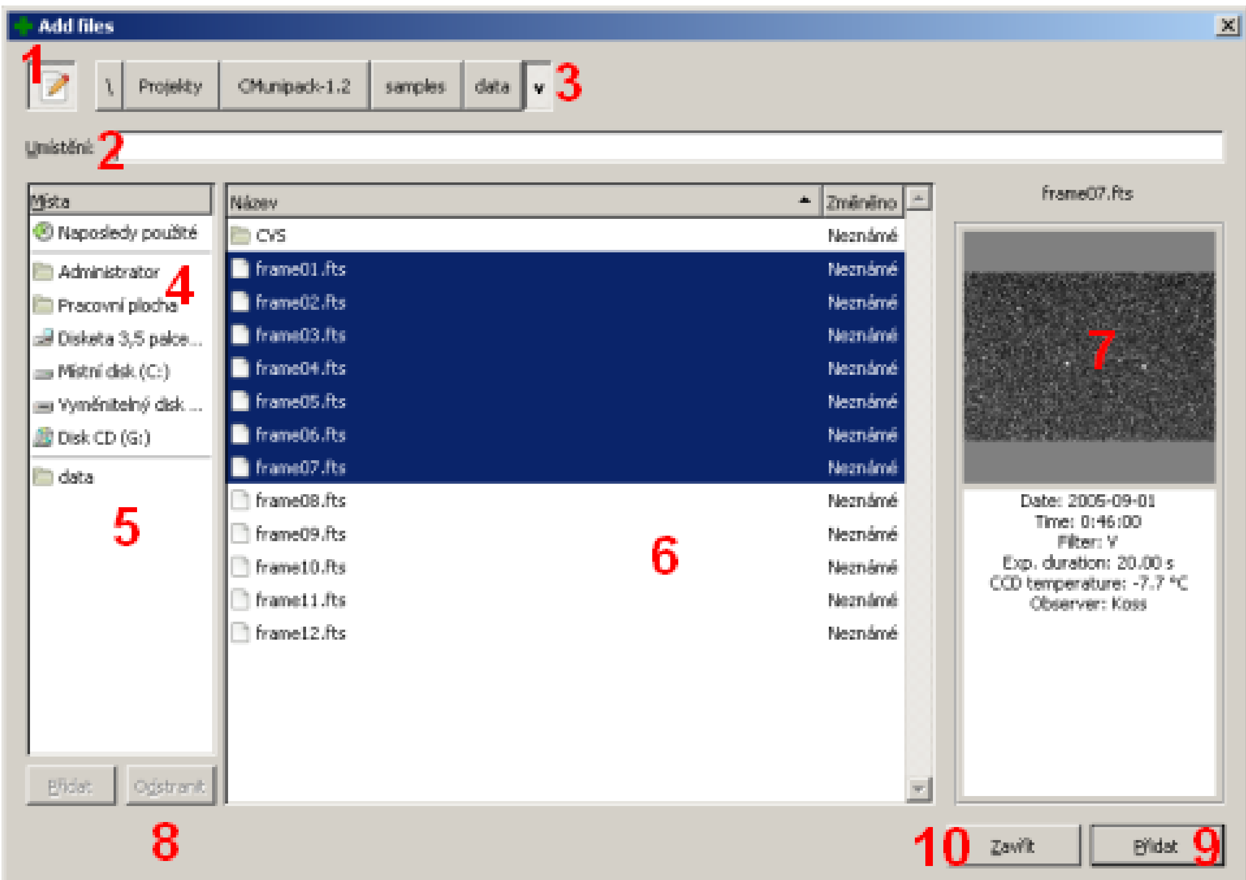


Fig. 2: The dialog for adding individual files to the project.

Including files the project

To add the selected files to the project, click the "Add" button (9). The program checks the selected files. Several situations may occur:

- If the file is not a valid CCD frame, it is ignored.
- If the file is already included in the project, it is ignored.
- If there are multiple files left and they have different color filter name, the program shows a new dialog and asks an user to select which filters shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.
- If there are multiple files left and they have different exposure duration, the program shows another dialog and asks an user to select which exposures shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.
- If there are multiple files left and they have different object designation, the program shows another dialog and asks an user to select which objects shall be added to the project. You can use the "All files" option or select one or more items in the box, other files will be ignored.

When the action is completed, the dialog is not closed; you can go on to add files from another folder or close the dialog by the "Close" button (10).

See also:

Add frames from folder (dialog), *Main window*

6.3.4 Air mass coefficient (dialog)

The "Air mass coefficient" allows an user to compute air mass coefficient for specified star, location and date of observation. The object's altitude in degrees is also presented.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools → Air mass coefficient*.

Computing air mass coefficient and object's altitude

Enter object's right ascension to the text box (1) in hours. Use the hexagesimal format, separate the fields by a space character.

Enter object's declination to the text box (2) in degrees. Use the hexagesimal format, separate the fields by a space character.

Click the ellipsis button (3) to retrieve object's coordinates from a table of predefined objects or a catalog of variable stars.

Enter observer's longitude to the text box (4) in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'E' character at the first position in a string to indicate that the location is on the eastern hemisphere or 'W' character for locations on a western hemisphere.

Enter observer's latitude to the text box (5) in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'N' character at the first position in s string to indicate that the location is on the north hemisphere or 'S' character for locations on a southern hemisphere.

Click the ellipsis button (6) to retrieve observer's coordinates from a table of predefined locations.

Fig. 3: Computing air mass coefficient and object's altitude

Enter a Julian date into the text box (7) or date and time into the text box (8). As you type in the data, corresponding value of air mass coefficient and altitude is updated in the last two text boxes (9, 10).

See also:

JD converter (dialog), *Heliocentric correction (dialog)*

6.3.5 Air mass curve (dialog)

The "Air mass curve" dialog is used to display a curve of air mass coefficients and altitudes as a function of time. These values to useful in data post-processing to compute the extinction coefficients.

Activating the dialog

The dialog can be activated:

- from the main menu: *Plot* → *Air mass*.

The "Plot air mass" dialog appears. Fill in the object coordinates and the observer coordinates. Confirm the dialog.

Air mass dialog

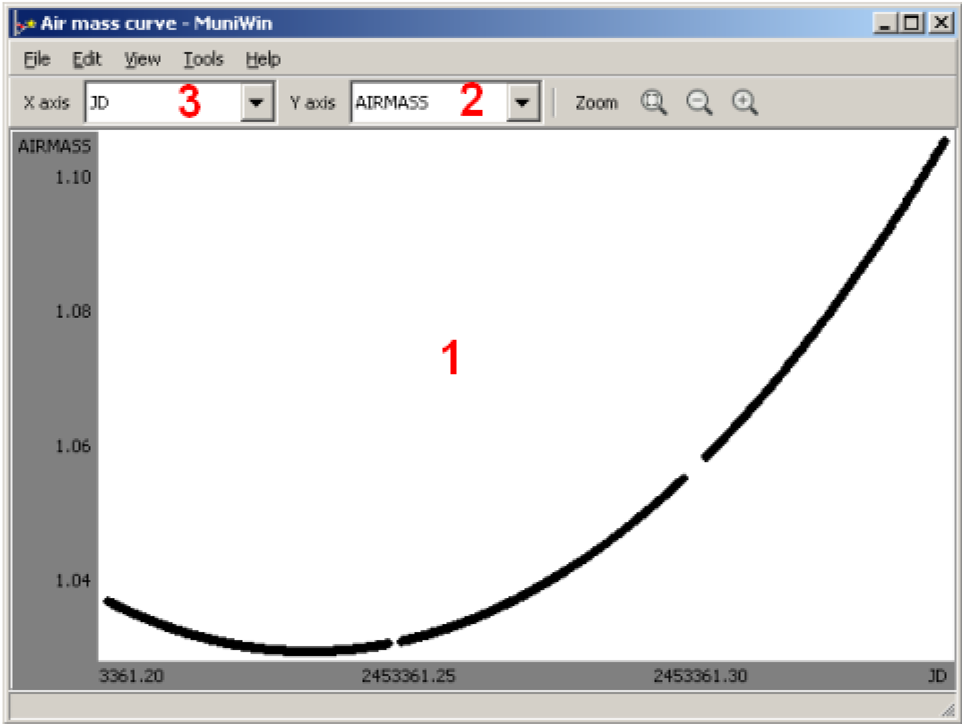


Fig. 4: Air mass

(1) The actual data set is shown here.

(2) The list of available data sets is displayed here.

(3) You can switch the labels on the X axis between Julian date (JD) or date and time (UTC).

Data sets

The following data sets are available:

- *AIRMASS* - The air mass coefficient
- *ALTITUDE* - The apparent altitude in degrees; positive values above the horizon, negative values below the horizon

Context menu

You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. It provides following functions:

- Show frame - it shows a preview to a selected frame. It is not allowed when more than one frame is selected.
- Show properties - it opens a new dialog with properties of selected frame. It is not allowed when more than one frame is selected.
- Delete from data set - selected measurements are removed from the current curve, the data will be shown again when you make a new curve or *Rebuild* the actual curve.

- Remove from project - source frames corresponding to the selected measurements are removed permanently from the list of input files and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Statistics

The *Statistics* is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

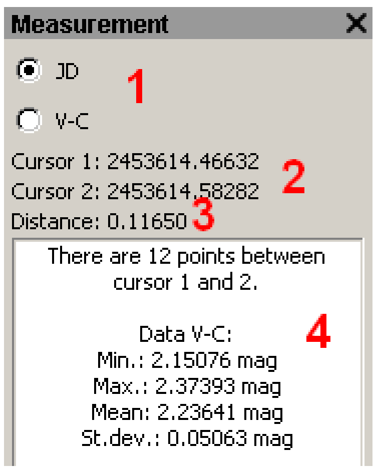
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Light curve (dialog), *Track curve (dialog)*, *Object properties (dialog)*, *CCD temperature (dialog)*

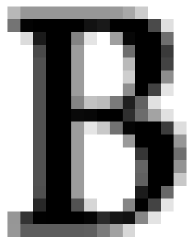
6.3.6 Bias correction (dialog)

The "Bias correction" dialog is used to select a bias frame during the calibration of the source files. The bias-frame calibration is used only in the advanced calibration scheme.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Bias correction*.



2. from the main toolbar:

File browsing

The button "Type a file name" (1) shows and hides the "Location" text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

(3) The path to the current folder is displayed. You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. You can start the operation by clicking on the Execute button or by a double left click on a file. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) By clicking the Add button, you add the selected folder to bookmarks.

By clicking the Remove, you remove the selected bookmark from the list.

(9) It is possible to apply the operation on all source files in the project or on the files that are currently selected in the table of input files.

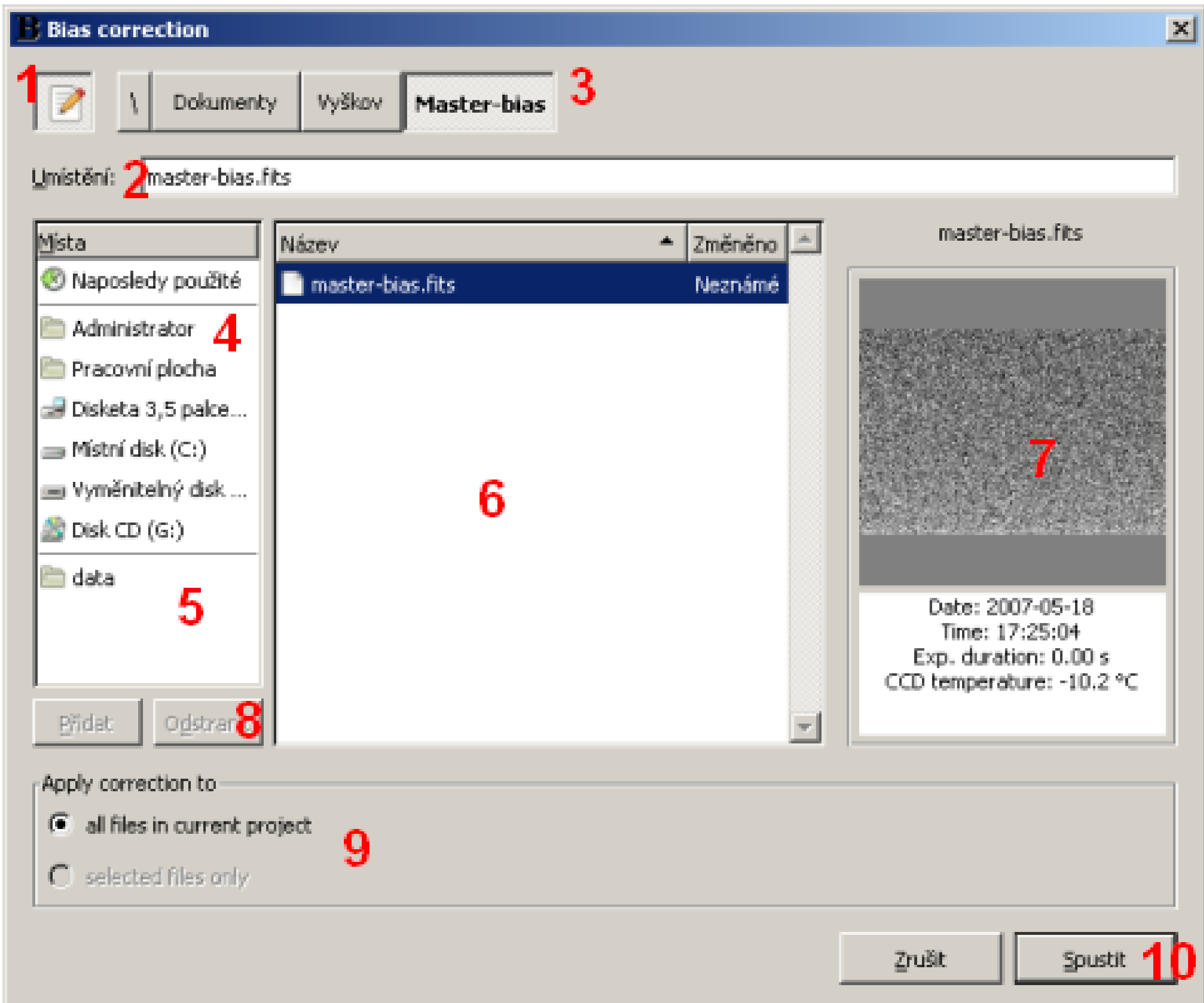


Fig. 5: The dialog for selecting a bias frame

Applying the bias correction

Click the "Execute" button (10) to start the operation. The bias correction is applied to a working copy of source files. The working copy is replaced by corrected frames.

- A working copy of source frame must be made before the bias correction.
- The bias correction can be applied to each frame only once.
- The bias correction must be applied before the dark correction, the flat correction and the photometry.

If you make a mistake, you can revoke the step by making a fresh copy of source frames by means of the "Fetch/convert files" function.

See also:

Master bias frame (dialog), *Advanced calibration scheme*

6.3.7 Catalog file (window)

This preview window is used to display the content of a catalog file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Open file*.

When a file is opened, the program checks its content and decides which kind of preview window will be activated. Each file is presented in a separate window.

Dialog controls

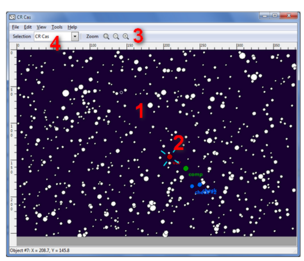


Fig. 6: Preview window for catalog files

(1) The chart is displayed in the preview area. It is possible to switch between two rendering modes - displying file as a chart or as a table of objects.

(2) When you place a cursor over an object, the position and brightness (if available) is displayed in the status bar.

(3) You can zoom the preview in and out using the icons on the toolbar.

(4) If the catalog file was saved with multiple object selections, use this control to to review the other selections.

The local menu bar provides following functions:

- Menu File:
  - Open - open another file, this is an equivalent to selection *Tools* → *Open file* from the main window.

  - Save as - save the catalogue file to a file.
  - Export - depending on the current display mode:
    * If a chart is shown, the function export the chart or image to a file in the PNG or JPEG format. The save dialog provides several options, that allows adjusting the size of the resulting image.
    * If a table is shown, the function export the table to a file in the CSV or TEXT format. The save dialog provides several options, that allows adjusting the content of the file.
  - Show properties - display the further details about the file. Full header preview is available in separate window.
  - Close - close this window
- Menu Edit:
  - Edit properties - edit descriptive information stored in the catalog file (observer, location, user remarks, . . .)
  - Change selected stars - enter editing mode for objects (variable, comparison and check stars)
- Menu View:
  - Chart - show the objects as a chart
  - Table - show the table of objects
  - Rulers - turn on/off the rules that are shown on the top and left side of the preview area
- Menu Tools:
  - **Object inspector - if this tool is activated, left-click an object to display**
    its properties. The information is presented in the right part of the dialog.

Object inspector tool

The Object inspector tool is a tool which displays that the program registers about an object on a frame. The main purpose of this tool is for testing and debugging. Unlike the Quick Photometry, the Object Inspector shows results, that has been obtained during the "full" photometry. Because of this, calibration and photometry must be performed first. The results are more relevant.

To activate the tool:

1. From the local menu, select *Tools* → *Object inspector*. A new panel on the right side of the preview window appears.

Using the left mouse button, click on the image (1), to select an object. The object is highlighted and its properties are displayed in the right panel (2).

The following object parameters are presented:

- Object # - object's ordinal number on the current frame.
- Reference ID - object's ordinal number on a reference frame.
- Center - coordinates of the object's centroid
- Brightness - instrumental brightness of the object in magnitudes.
- Error - error estimation of brightness in magnitudes.

Several dimensions are presented in the image area (3):

- Two blue circles show the annulus which is used to estimate the background properties.

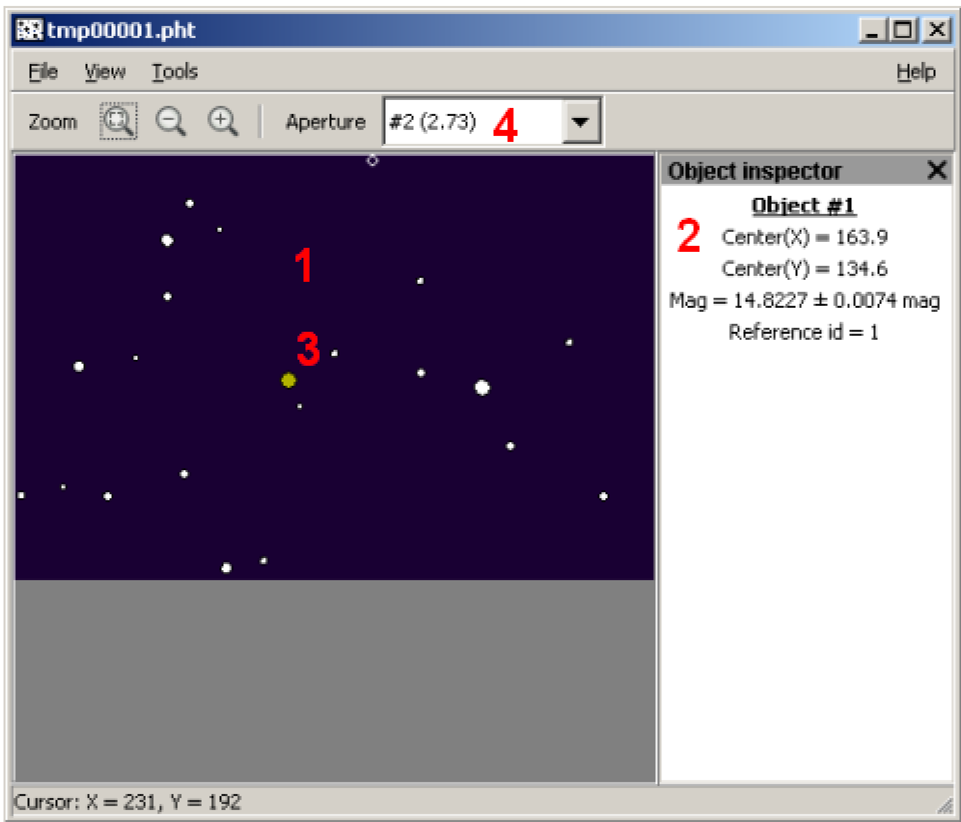


Fig. 7: Object Inspector tool

- A green circle shows the size of the aperture.

(4) Here, you can change the current aperture.

Editing object selections

How to edit object selections (variable, comparison and check stars) in an existing catalog file.

In the preview window use the local menu *Edit → Change selected stars*. A stripe which indicates that you the editing mode has been activated appears between the preview area and the toolbar (1).

Now, you can change the roles of objects in the same way as in the dialog *Choose stars*. Click on an object (2) in the preview area. A context menu appears. Select an item to change the role of the object.

(3) Using the toolbar controls, you can switch between existing selections and create, update and remove them.

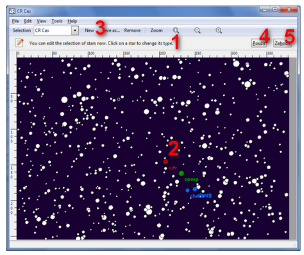


Fig. 8: Preview window for catalog files in edit mode

When you have finished the changes, click the *Apply* button on the stripe (4). If you want to discard changes, click the *Discard* button (5). By this action you leave the editing mode.

See also:

Open file (dialog)

6.3.8 CCD temperature (dialog)

The "CCD temperature" dialog is used to display a table or a plot of CCD temperature as a function of time. The plot is useful to check the performance of the camera cooling sub-system.

Activating the dialog

The dialog can be activated:

- from the main menu: *Plot → CCD temperature*.

The "Plot CCD temperature" dialog appears. Confirm the dialog.

CCD temperature dialog

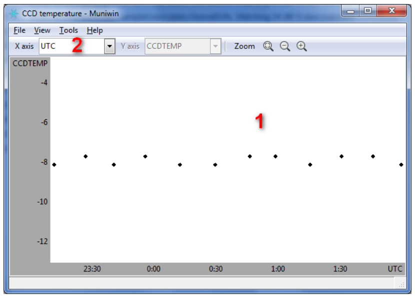


Fig. 9: CCD temperature

(1) The actual data set is shown here.

(2) You can switch the labels on the X axis between Julian date (JD) or date and time (UTC).

Data sets

The following data set is available:

- *CCDTEMP* - Temperature of the CCD chip as reported in the source files; in centigrades

Context menu

You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. It provides following functions:

- Show frame - it shows a preview to a selected frame. It is not allowed when more than one frame is selected.
- Show properties - it opens a new dialog with properties of selected frame. It is not allowed when more than one frame is selected.
- Delete from data set - selected measurements are removed from the current curve, the data will be shown again when you make a new curve or *Rebuild* the actual curve.
- Remove from project - source frames corresponding to the selected measurements are removed permanently from the list of input files and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Statistics

The *Statistics* is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

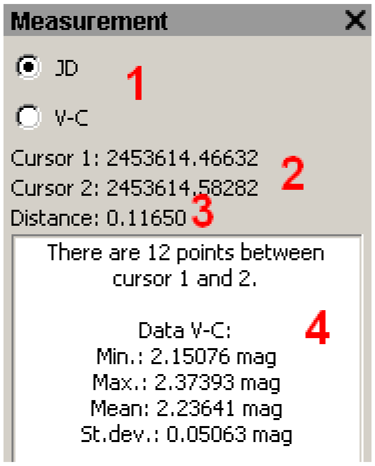
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Air mass curve (dialog), *Light curve (dialog)*, *Track curve (dialog)*, *Object properties (dialog)*

6.3.9 Chart (dialog)

The "Chart" dialog is used to make a chart of selected stars that were used to make a light curve.

Activating the dialog

The dialog can be activated:

1. From the *Light curve (dialog)* dialog: *View* → *Chart*.

Dialog controls

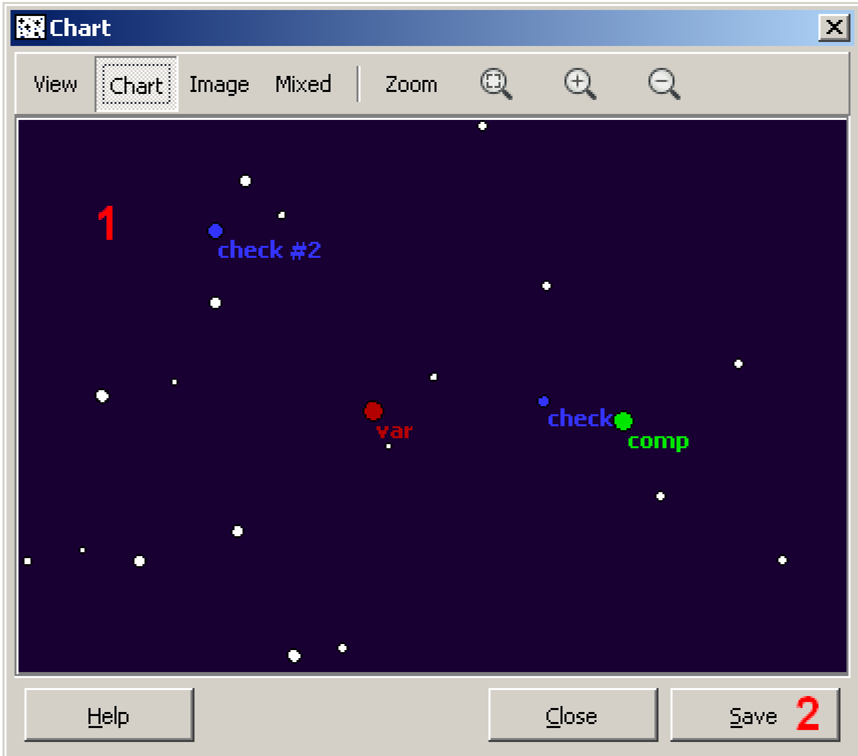


Fig. 10: Chart dialog

(1) The reference frame is displayed in the dialog. The actual variable star, comparison star and check stars are highlighted.

Click the "Save" button (2) to save the chart to the file.

Tags

Any object on the reference frame can have user-defined short string, so called *tag*. Tags are used to provide additional identification to objects on an exported charts. For example, when you assign a tag with GCVS name to your variable star; the caption 'var' and the GCVS name will be printed on the chart next to the star. Please note, that objects that are not selected can have tags, too.

Tags are stored to a *catalog file* and they are loaded to the project when you use the catalog file as a reference frame in the *matching* step.

To assign a tag to an object or edit existing tag, place a mouse cursor over a detected object, it is highlighted with a cross hair (3). Open a context menu with a single click, and select *Edit tag*. A new dialog appears. Enter a text (single line) and confirm the dialog. The text should appear next to the selected star.

Tags can be removed from the same context menu.

See also:

Light curve (dialog)

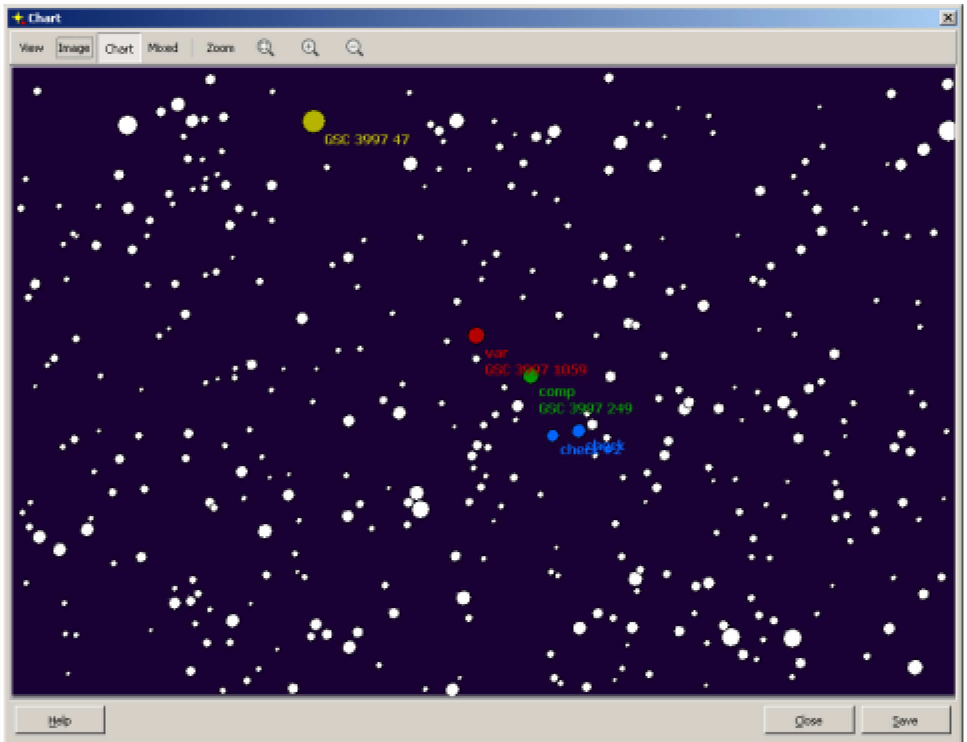


Fig. 11: Chart dialog with tags

6.3.10 Choose aperture (dialog)

The "Choose aperture" dialog is used to select an aperture. During the photometry, each object is measured using a set of predefined apertures of different sizes. The best aperture size depends on width of objects and background noise level, these parameters vary for each run.

Selecting the aperture

(1) The table of defined apertures is displayed here.

(2) The list of available data sets are available is shown here. Separate data sets are made for each couple of a comparison star (C) and a check star (K1, K2, etc.).

The graph of curve of deviations as a function of aperture index (3) is shown in the right part of the dialog. The point that corresponds to the currently selected aperture is highlighted.

Left click on a point in the graph selects the aperture.

Click the "OK" button (4) to save the selection.

- Usually the best aperture corresponds to the minimum of the curve.
- The matching must be applied before the matching.
- At least one comparison and one check star must be selected before the dialog is activated.

See also:

Choose stars (dialog), *Light curve (dialog)*

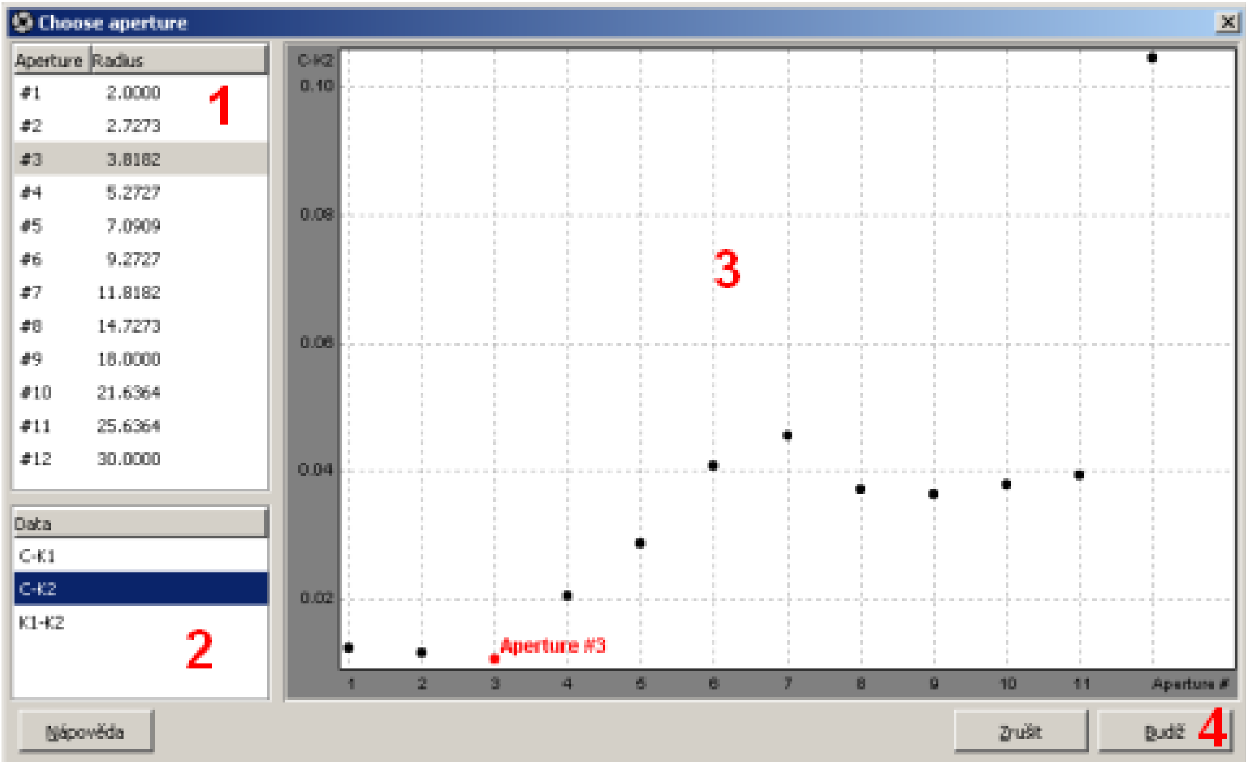


Fig. 12: The dialog for selecting an aperture

6.3.11 Choose stars (dialog)

The "Choose stars" dialog is used to select variable, comparison and check stars. This information is required to make a light curve. One can also assign tags to objects, e.g. GSC numbers, these tags are printed on displayed and exported charts.

Selecting the stars

The image shows a reference frame or a catalog file (1), it depends what kind of file you have chosen in the Match stars dialog.

(2) It is possible to switch the display mode between an image, a chart or both of them.

When you place a mouse cursor over a detected object, it is highlighted with a cross hair (3). Open a context menu with a single click, select an option from a menu to select or deselect it.

(3) Click the *New* button to clear the current selection.

Click the *OK* button to confirm the selection.

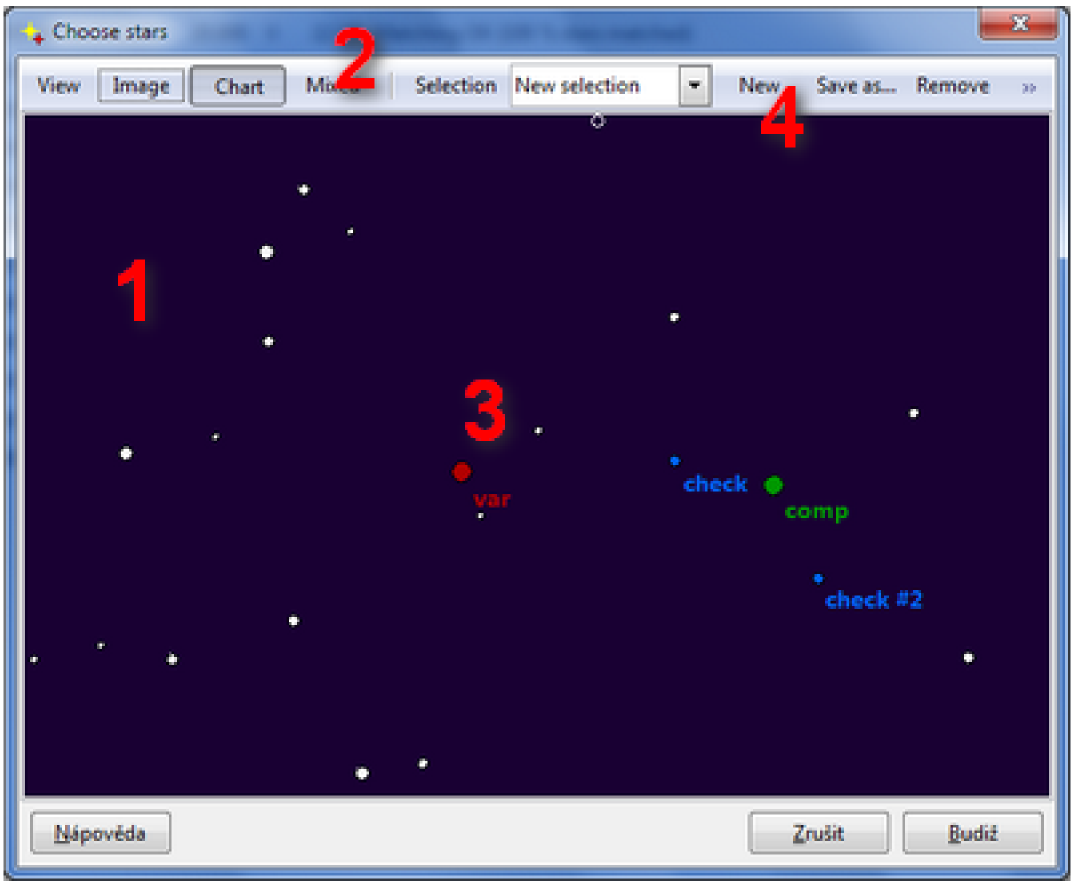


Fig. 13: The dialog for selecting a variable star, a comparison star and check stars

Saving the selection of objects

If you want to save the current selection of objects for further reference, click the *Save as…* button (10) on the toolbar. A new dialog appears. Enter a name of the selection, e.g. name of the variable star. This feature is useful in a case there are *multiple variable stars* on one star field.

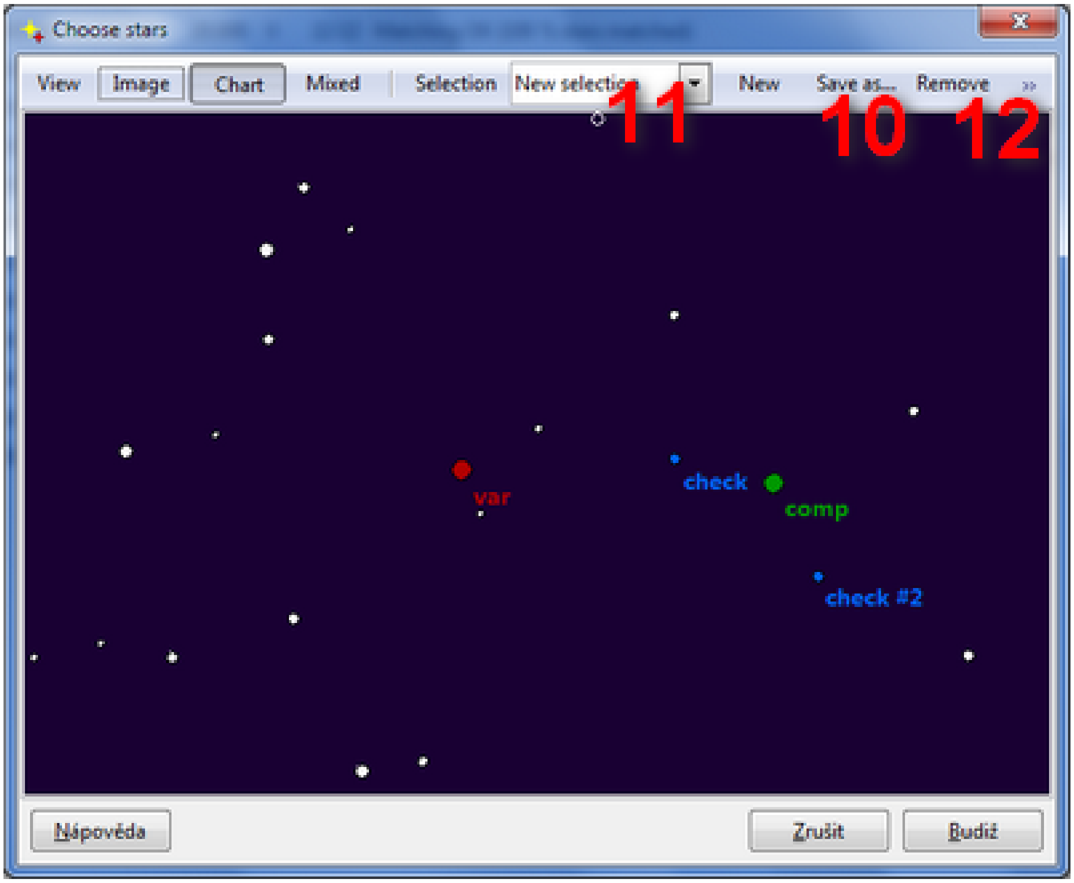


Fig. 14: The dialog for selecting a variable star, a comparison star and check stars

To restore the selection that was saved, use the selection control (11) on the toolbar. You can remove the selection using the *Remove* button (12).

Tags

Any object on the reference frame can have user-defined short string, so called *tag*. Tags are used to provide additional identification to objects on an exported charts. For example, when you assign a tag with GCVS name to your variable star; the caption 'var' and the GCVS name will be printed on the chart next to the star. Please note, that objects that are not selected can have tags, too.

Tags are stored to a *catalog file* and they are loaded to the project when you use the catalog file as a reference frame in the *matching* step.

To assign a tag to an object or edit existing tag, place a mouse cursor over a detected object, it is highlighted with a cross hair (3). Open a context menu with a single click, and select *Edit tag*. A new dialog appears. Enter a text (single line) and confirm the dialog. The text should appear next to the selected star.

Tags can be removed from the same context menu.

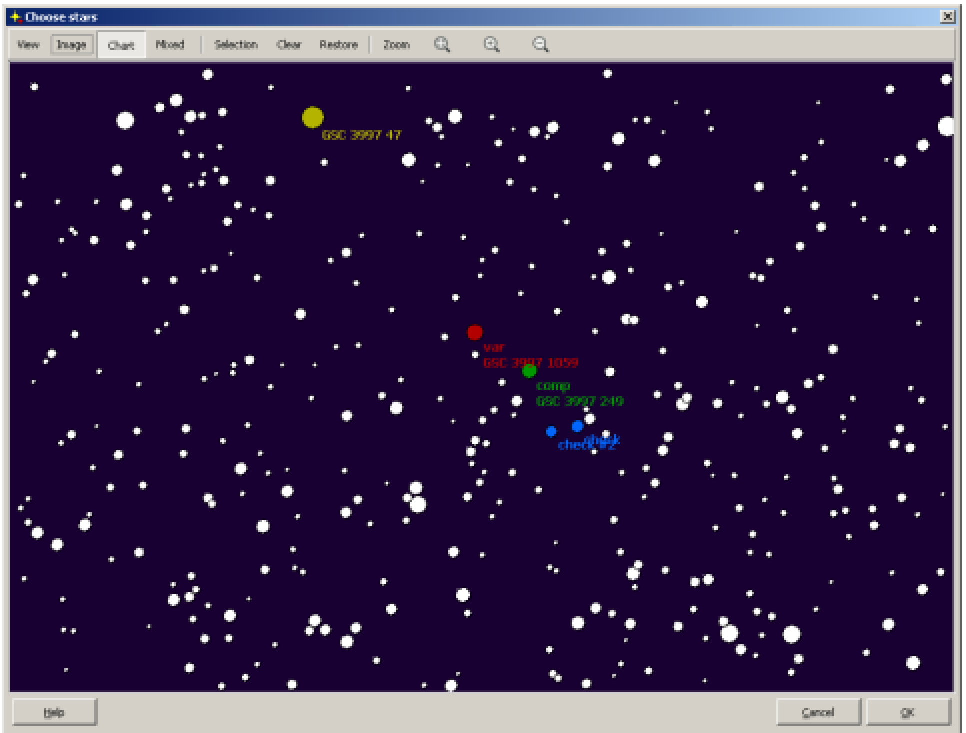


Fig. 15: The dialog for selecting stars, with tags

Known variable stars

If the source frames contain World Coordinate System (WCS) data, the software can show positions of known variables on the frame. You have to specify paths to the catalog files in the program settings (see *Environment options (dialog)*). For each catalog, the toobar contains one check box that turns the catalog on and off. By clicking on the icon, a standard color selection dialog appears.

See also:

Match stars (dialog), *Choose aperture (dialog)*, *Light curve (dialog)*, *Environment options (dialog)*.

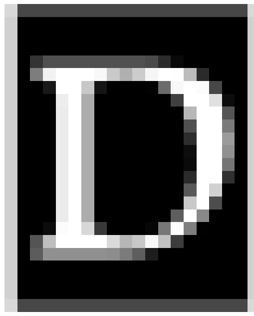
6.3.12 Dark correction (dialog)

The "Dark correction" dialog is used to select a dark frame during the calibration of the source files. The dark-frame calibration is used in the standard and the advanced calibration scheme.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Dark correction*.

2. from the main toolbar: 

File browsing

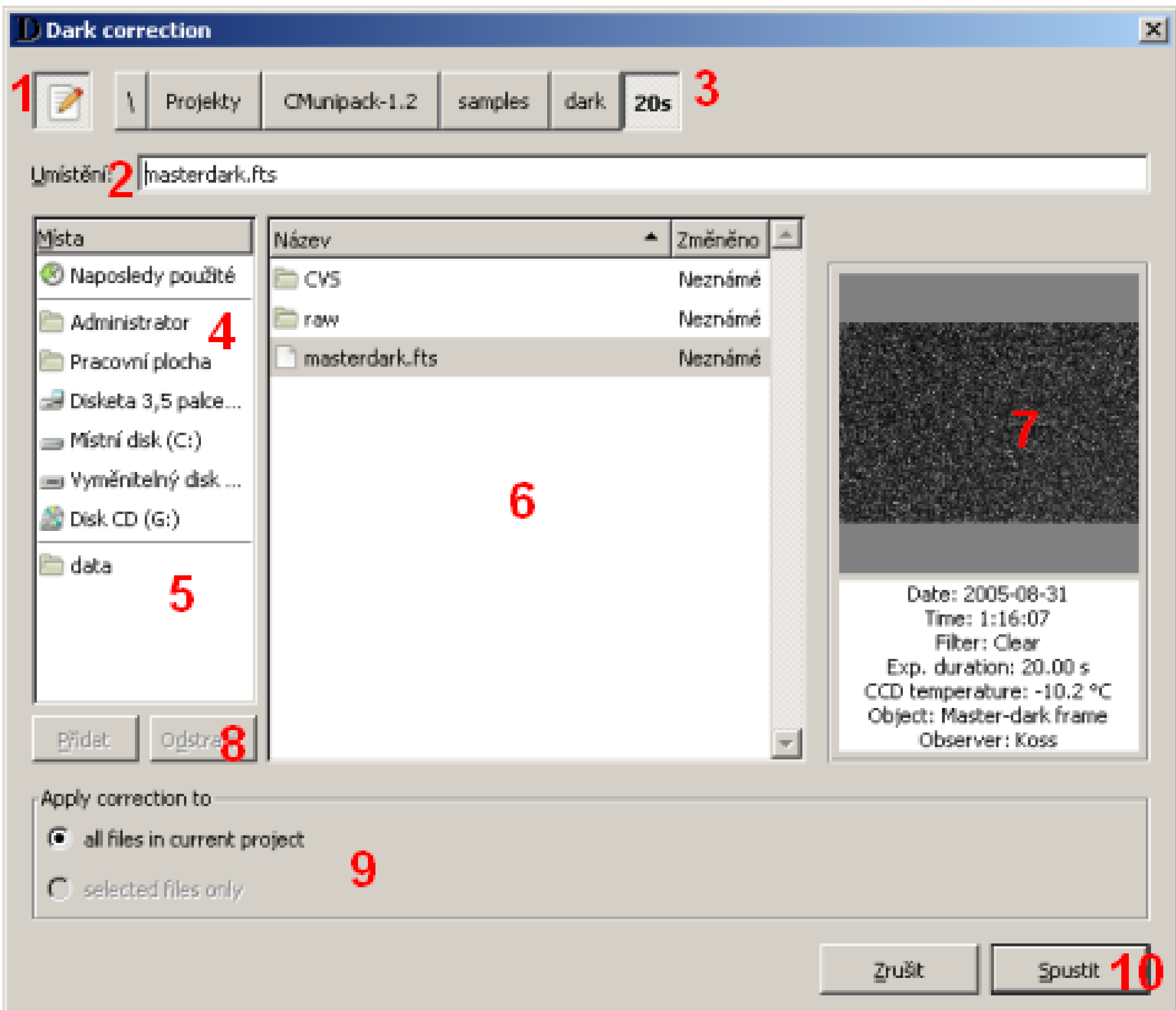


Fig. 16: The dialog for selecting a dark frame

The button "Type a file name" (1) shows and hides the "Location" text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

(3) The path to the current folder is displayed. You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. You can start the operation by clicking on the Execute button or by a double left click on a file. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) y clicking the Add button, you add the selected folder to bookmarks.

By clicking the Remove, you remove the selected bookmark from the list.

(9) It is possible to apply the operation on all source files in the project or on the files that are currently selected in the table of input files.

Applying the dark correction

Click the "Execute" button (10) to start the operation. The dark correction is applied to a working copy of source files. The working copy is replaced by corrected frames.

- A working copy of source frame must be made before the dark correction.
- In the advanced calibration scheme, the bias correction must be applied before the dark correction.
- If the dark correction has been applied to the source frame already, you can skip it. (Some camera controlling software does it automatically.)
- The dark correction can be applied to each frame only once.
- The dark correction must be applied before the flat correction and the photometry.

If you make a mistake, you can revoke the step by making a fresh copy of source frames by means of the "Fetch/convert files" function.

See also:

Main window, *Master dark frame (dialog)*, *Advanced calibration scheme*

6.3.13 Edit profiles (dialog)

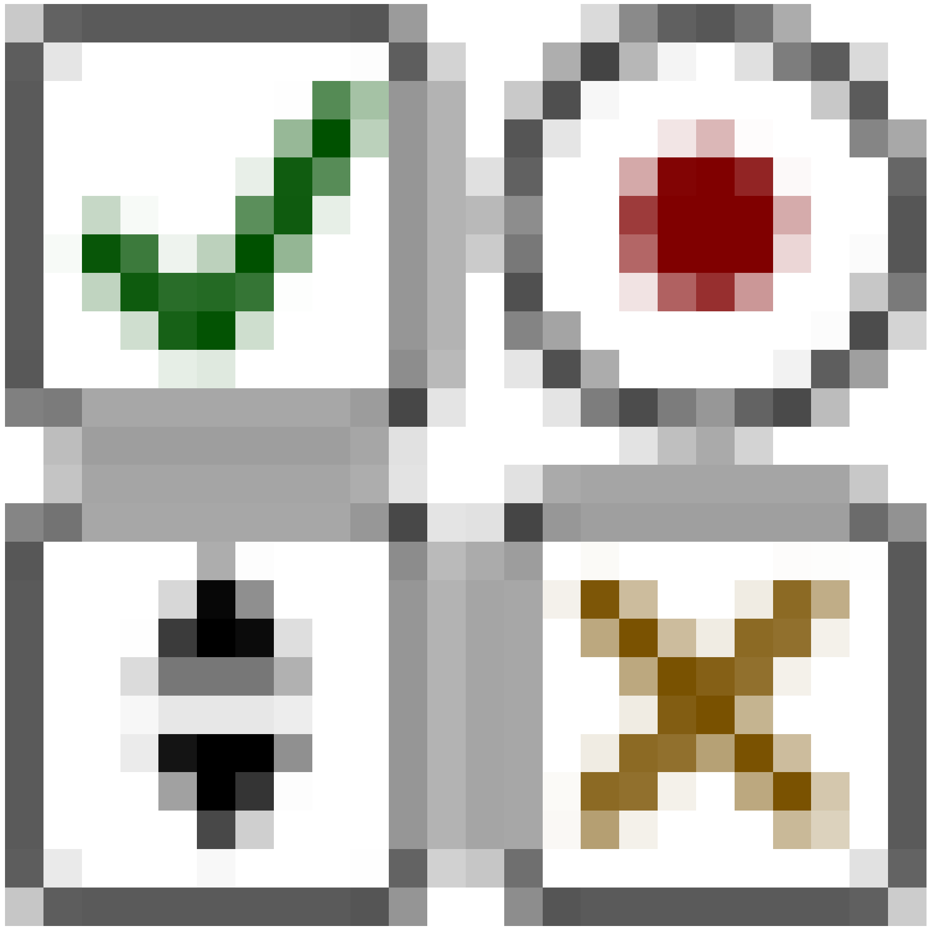
The "Project settings" dialog is used to set up the parameters of the data processing and output. User interface options that do not affect the data processing are places in the separate dialog "Environment options".

Among many parameters of the aperture photometry procedure a special attention should be payed to the following: Filter width and the Detection threshold. These parameters control mainly the detection of stars on the CCD frames. By decreasing the Filter width value the fainter stars will be found. It is to be pointed out, that too small value may take the artefacts on the background as regular stars. The Detection threshold value sets the distance between the finest stars detected and the background sky noise. The value is entered in multiplies of background standard deviations.

The description of the individual parameters can be found in *this chaper*.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Project* → *Edit properties*.
2. from the main toolbar: 

The dialog controls

(1) Select a category.

Parameters in the selected category are shown on the right pane (2).

Click "Set defaults" button (3) to set the parameters in the selected category to the default values.

Click the button (4) to save the settings as current configuration.

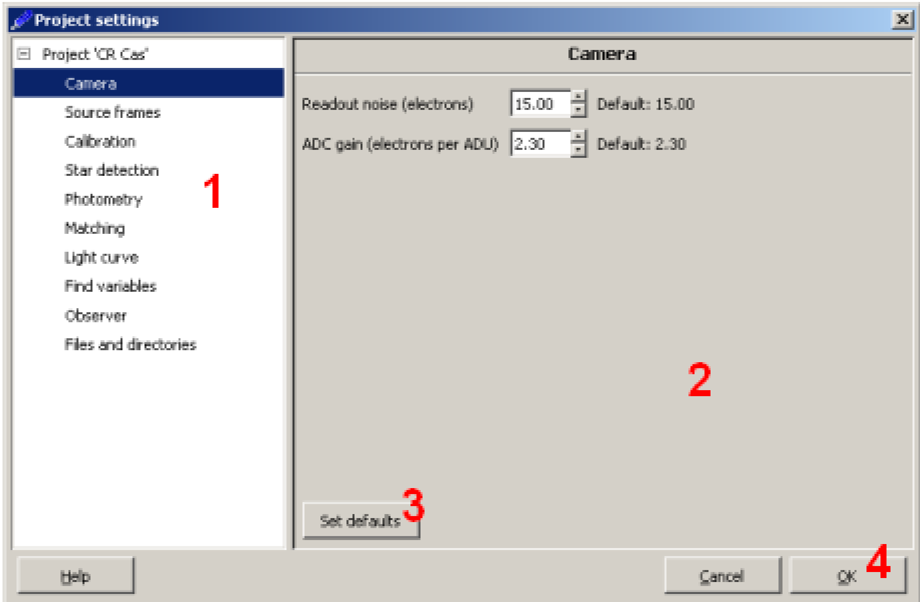


Fig. 17: The "Project options" dialog

Configuration profiles

If you process the data from multiple cameras or telescopes, you will need to adjust the project options for each setup. The program allows to store the configuration to a file and then load it back.

To save the current settings to a file, click on the "Save to profile" button. A standard save dialog appears. Enter a name of the file, you can also change the target direcory. Confirm the dialog.

To restore the settings from a file, click on the "Load from profile" button. A standard open dialog appears. Look up the file with saved project options and confirm the dialog. Please note, that your current project settings will be overwritten by this action.

See also:

Projects, *Profiles*, *Project settings*, *Environment options (dialog)*

6.3.14 Environment options (dialog)

The "Environment options" dialog is used to customize the user interface. These options do not affect the data processing. The data processing parameters are placed in the separate dialog "Project options".

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Environment options*.

Customizing the user interface

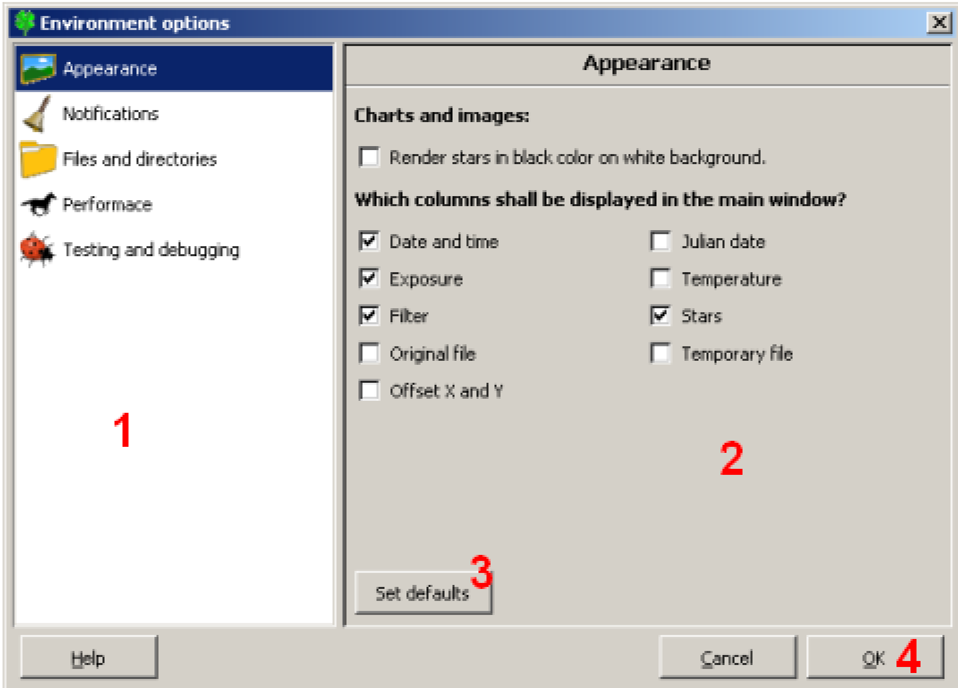


Fig. 18: The "Environment options" dialog

(1) Select a category.

Options in the selected category are shown on the right pane (2).

Click "Set defaults" button (3) to set the options in the selected category to the default values.

Click the button (4) to save the settings.

See also:

Project settings (dialog)

6.3.15 Export project (dialog)

The "Export project" dialog is used to specify a target location and name of the new project that is created as a copy of the current project.

Since the original (source) files are not considered to a part of a project, the source files are not duplicated. A project references to source files by their path, the export function does not change the paths to the source files.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Project → Export*.

The basic dialog

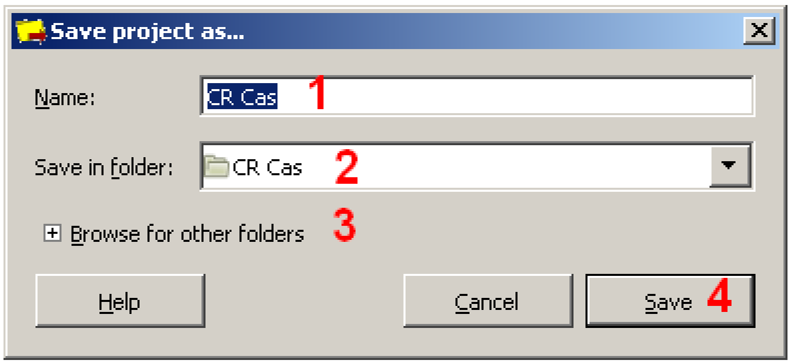


Fig. 19: The "Export project dialog" dialog (basic form)

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

Click on the "Save" button (4) to copy the project file and the acompanying files.

Browsing the directories

(10) Here, you can access to your main folders and to your store devices.

(11) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(12) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(13) Enter the file name of the new image file here.

(14) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (15) to shrink the dialog to its basic form.

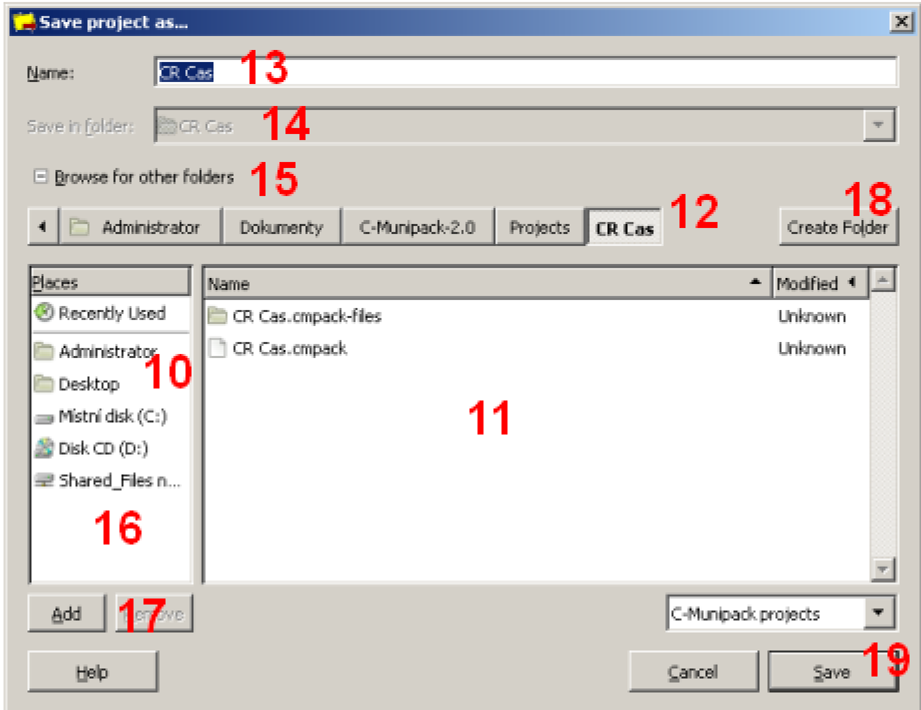


Fig. 20: The "Export project dialog" dialog (with browser)

(16) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

(17) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (18) and following the instructions.

Click on the *Save* button (19) to copy the project file and the acompanying files.

See also:

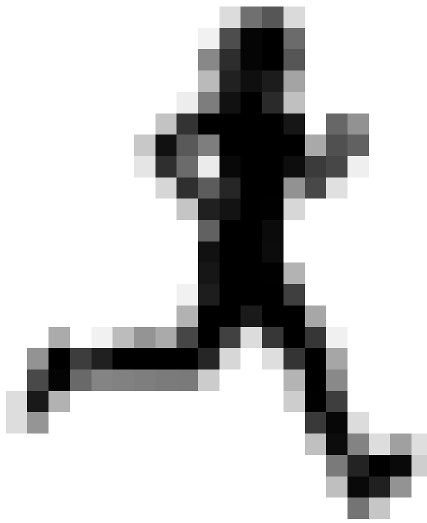
Projects, *New project (dialog)*, *Open project (dialog)*

6.3.16 Express reduction (dialog)

The “Express reduction” dialog provides a simple way how to go through the whole reduction process in one step. Using the standard way, the user has to proceed the reduction step by step manually. The asks an user for all necessary information first and then controls the reduction automatically.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Express reduction*.
2. from the main toolbar: 

Setting up the reduction process

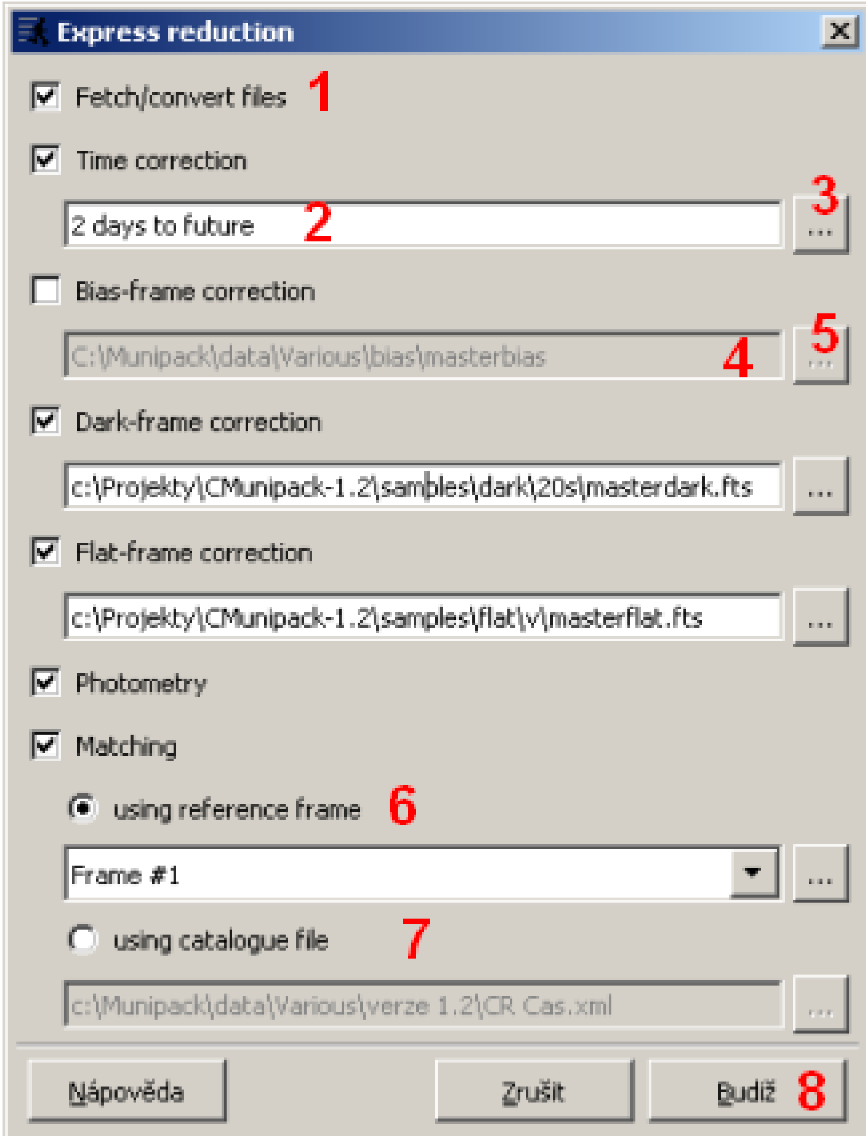


Fig. 21: The "Express reduction" dialog

(1) Each check box on the left side of the dialog corresponds to one reduction step. Check the option to perform the corresponding operation. For example, to start the reduction with a fresh copy of the source frames, check the "Fetch/convert files" option.

If the time correction is turned on, the actual time shift is displayed in the text box (2). Click on the ellipsis button (3) to open a new dialog for specifying the time shift.

For the bias, dark and flat corrections, the path and name of the correction frame is displayed below the check box (4). You can use the ellipsis button (5) to open a new dialog that allows you to browse the files and folders.

If the matching is turned on, you can choose as a reference either one frame from a set of source frames (6) or a catalog frame (7). The matching step cannot be used for moving target, in this case use the Express reduction dialog to do the processing up to the photometry and run the matching tool manually.

Click on the "Execute" button (8) to start the reduction.

It is possible to apply the operations on all source files in the project or the files that are currently selected in the table of input files. Please note, that the matching step cannot be applied on a subset of frames - that's why this option is not available when the operation shall be performed only to selected frames.

See also:

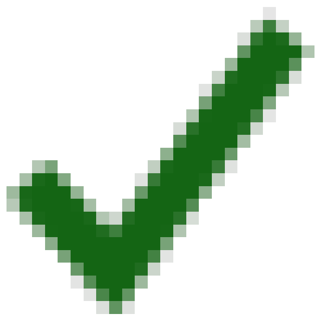
Fetch/convert files (dialog), *Time correction (dialog)*, *Bias correction (dialog)*, *Dark correction (dialog)*, *Flat correction (dialog)*, *Photometry dialog (dialog)*, *Match stars (dialog)*

6.3.17 Fetch/convert files (dialog)

The "Fetch/convert files" dialog is used to make a copy of the source files. At first look, this step might seem to be redundant, but it allows an user to start again with a fresh copy whenever one makes a mistake during the calibration of the source frames.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Fetch/convert files*.
2. from the main toolbar: 

Copying the source files

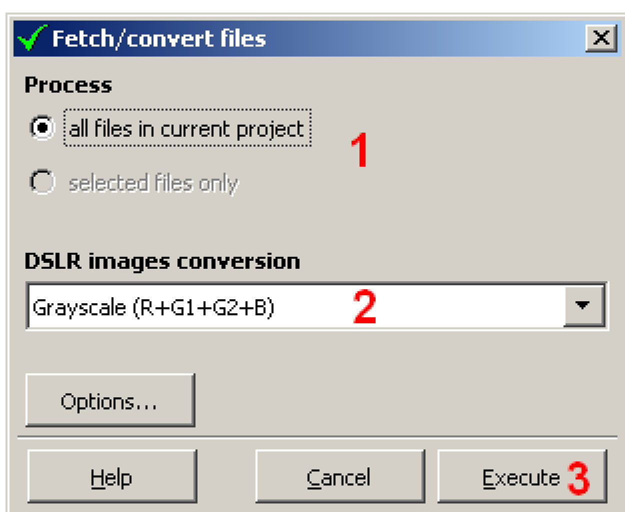


Fig. 22: The dialog for making a working copy of source files.

(1) You can either make a fresh copy of all source files in the project or make a copy of the files that are currently selected in the table of input files.

(2) When you process DSLR images, select a transformation for RAW images to gray scale. This option is ignored if the source frames are already in gray scale.

- Grayscale - the program sums all four pixels in Bayer mask. The resulting image have half the resolution of the RAW image and its range is four times higher than the range of the original picture.
- Red / blue - the program takes only red and blue pixels respectively. The resulting image have half the resolution of the RAW image and its range is the same as the range of the original picture.
- Green - the program takes only two green pixels on diagonal, sums them and the result divides by two. The resulting image have half the resolution of the RAW image and its range is the same as the range of the original picture.

To start the action, click the “Execute” button (3).

See also:

Main window, *Express reduction (dialog)*

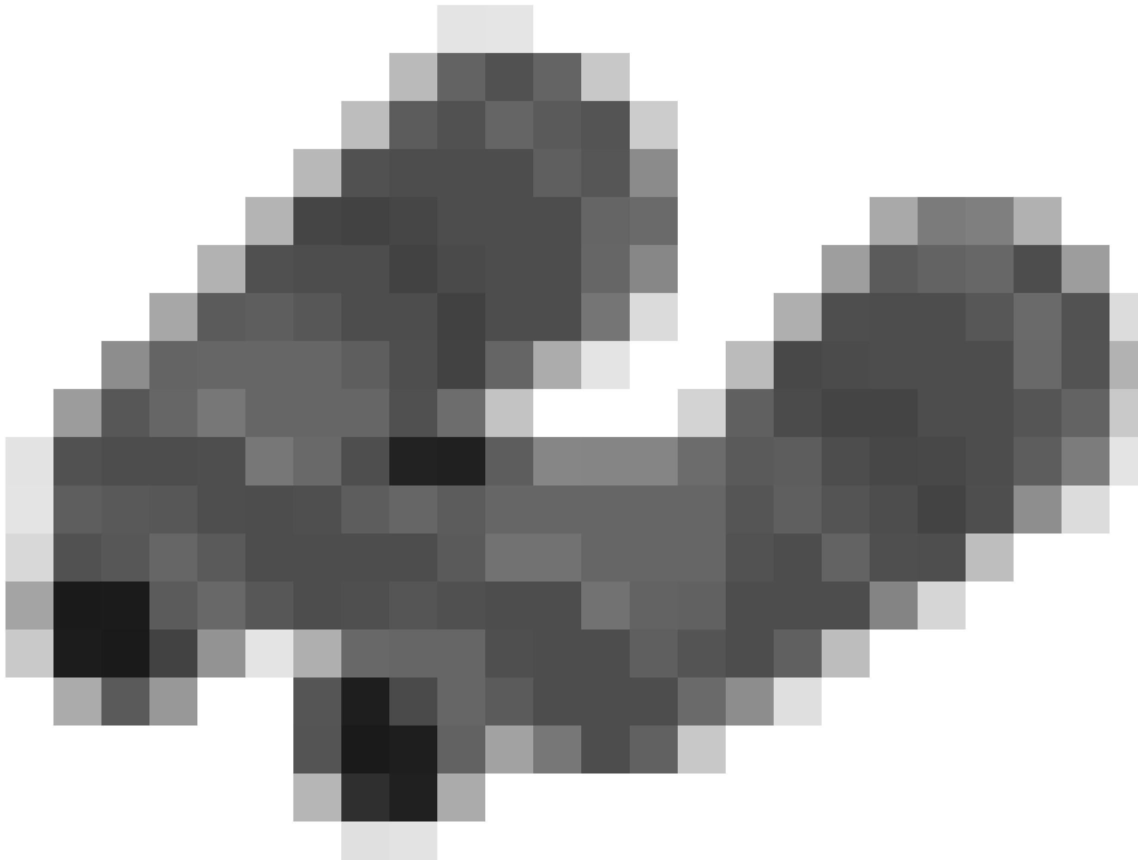
6.3.18 Find variables (dialog)

The “Find variables” dialog is used to find objects that significantly change their brightness.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Find variables*.



2. from the main toolbar:

The dialog controls

(1) The mag-dev graph is presented here. Each point in the graph corresponds to an object. Left click on a mag-dev graph to select a star. The selected star is highlighted and marked as “var”. Its position is shown on the chart (3) and its light curve is shown below (2).

(3) Position of the variable star and the comparison star are marked on the chart. You can also select an object by using the left button. The object is highlighted and marked as “var”. The corresponding point on the mag-dev curve is shown on the graph (1) and it light curve is shown below (2).

When the dialog is opened, it works in the variable selection mode. A suitable comparison star is determined automatically and kept fixed. When you click on the chart or mag-dev curve, you change the object that represents the variable star. To change the comparison star, click on the *Change comparison* button (5). When the button is pressed, you can change the comparison star by selecting the object on the chart or mag-dev curve. Click the *Change variable* button (4) to switch back to the variable star selection mode.

Check the *Ensemble photometry* to allow selection of multiple comparison stars. Click on the icon with the plus sign

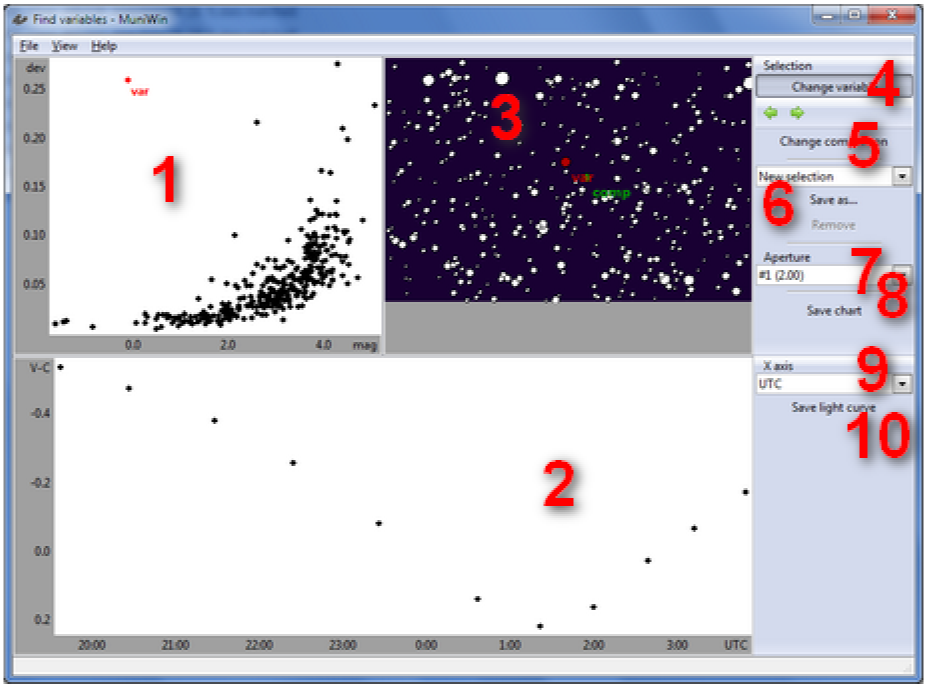


Fig. 23: The dialog for finding new variable stars

and click on an object on the chart or the mag-dev curve to add the object to the set of comparison stars. Click on the icon with minus sign and click on a comparison star on the chart to remove the object from the set.

(6) You can save the current selection of comparion and variable star for further inspection. Click the *Save as…* button. A new dialog appears. Enter a caption that the current selection will be identified with. Using the selection field, you can browse the saved selections and using the *Remove* button, you can remove the current item from the list.

(7) Using this selection field, you can change the current aperture.

Click the *Save chart* button (8) to save the chart to a file.

(9) The labels on the X axis can be switched between Julian date (JD) and date and time (UTC).

The magnitudes can be switched between two modes:

- Adaptive - the magnitude scale of the light curve changes when you change the selection of the variable or the comparison star. The program sets the scale to correspond to the range of data points in the actual light curve for the selected comparison and variable stars. If the range of data points is less than 0.05 mag, the scale is set to cover that range.
- Fixed - the magnitude scale of the light curve does not change when you change the selection of the variable star. The program makes light curves for the chosen comparison star and all other objects and finds the maximum range D (difference between maximum and minimum magnitude of data points). If D is less than 0.05 mag, it is set to this value. When a user selects a variable star, the light curve is made. The vertical scale of the graph is set to cover the fixed range D and the light curve is shown at the center of the graph area.

Click the "Save light curve" button (10) to save the light curve to a file.

The menu bar that is attached to the dialog provides following functions:

- Menu File:
  - Save mag-dev curve - exports table with mag-dev curve to a text file.
  - Save chart - save the chart to a file.

- Save light curve - save the light curve to a file.
- Export varfile data - exports magnitudes of all stars for all source frames to a single file.
- Export mag-dev curve as image - exports the graph with mag-dev curve to an image file
- Export light curve as image - exports the graph with light curve to an image file
- Rebuild - reloads the data from the project
- Close - close this window

• Menu View:
  - Image only - show only CCD image (if available) and hide objects.
  - Chart only - show only objects and hide the CCD image.
  - Chart and image - show CCD image on the background and objects as an overlay.

See also:

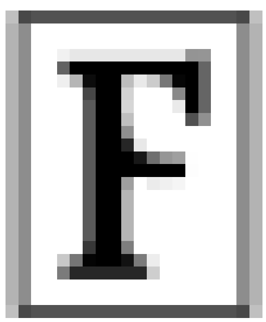
Finding variables, *Choose stars (dialog)*, *Light curve (dialog)*

6.3.19 Flat correction (dialog)

The "Flat correction" dialog is used to select a flat frame during the calibration of the source files. The flat-frame calibration is used in the standard and the advanced calibration scheme.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce → Flat correction*.
2. from the main toolbar: 

File browsing

The button "Type a file name" (1) shows and hides the "Location" text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

(3) The path to the current folder is displayed. You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

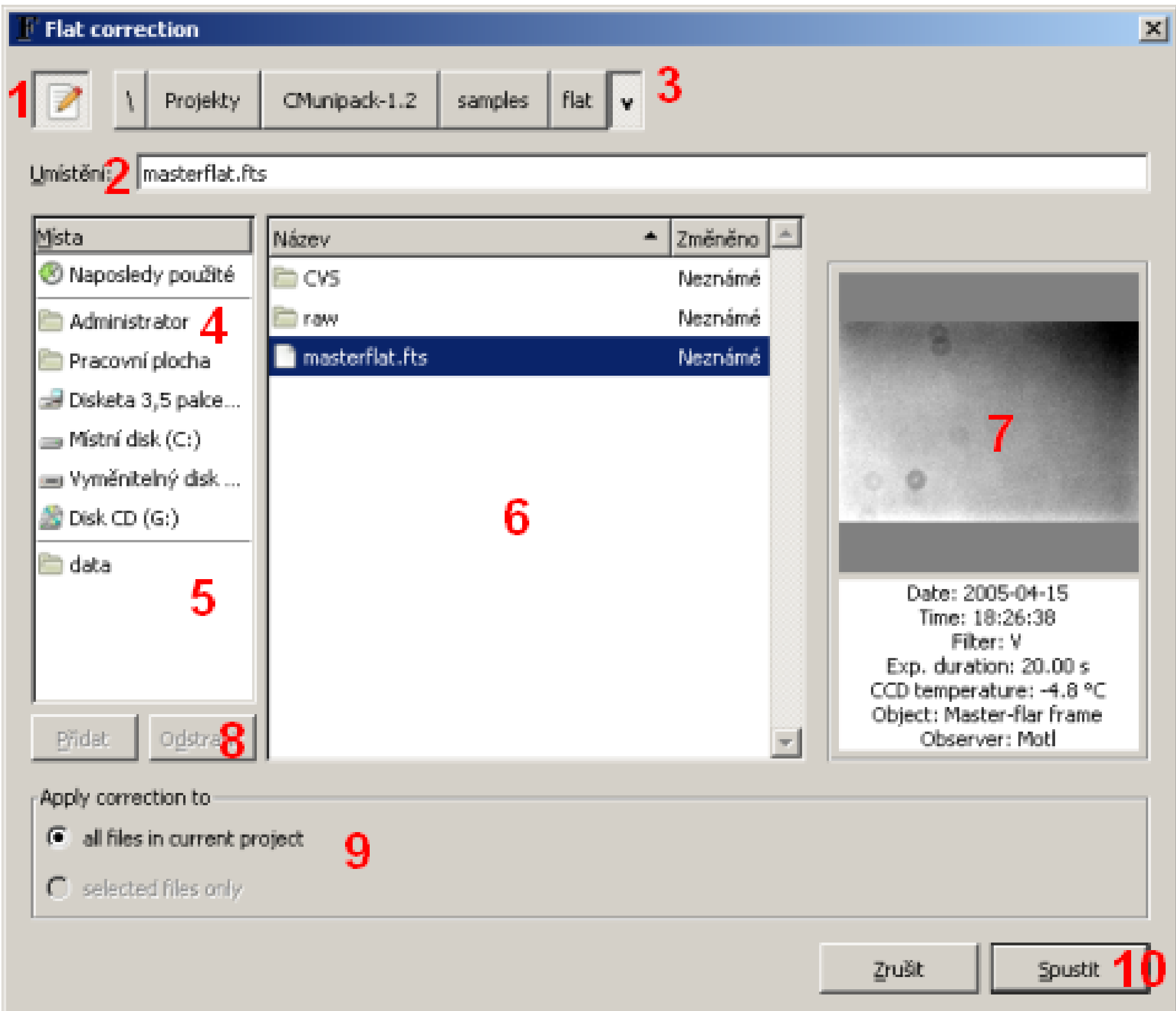


Fig. 24: The dialog for selecting a flat frame

(5) Here, you can add bookmarks to folders, by using the “Add” or the “Add to Bookmarks” option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. You can start the operation by clicking on the Execute button or by a double left click on a file. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) By clicking the Add button, you add the selected folder to bookmarks.

By clicking the Remove, you remove the selected bookmark from the list.

(9) It is possible to apply the operation on all source files in the project or on the files that are currently selected in the table of input files.

Applying the flat correction

Click the “Execute” button (10) to start the operation. The flat correction is applied to a working copy of source files. The working copy is replaced by corrected frames.

- A working copy of source frame must be made before the flat correction.
- The bias and the dark correction must be applied before the flat correction, if necessary.
- The flat correction can be applied to each frame only once.
- The flat correction must be applied before the photometry.

If you make a mistake, you can revoke the step by making a fresh copy of source frames by means of the “Fetch/convert files” function.

See also:

Main window, *Master flat frame (dialog)*

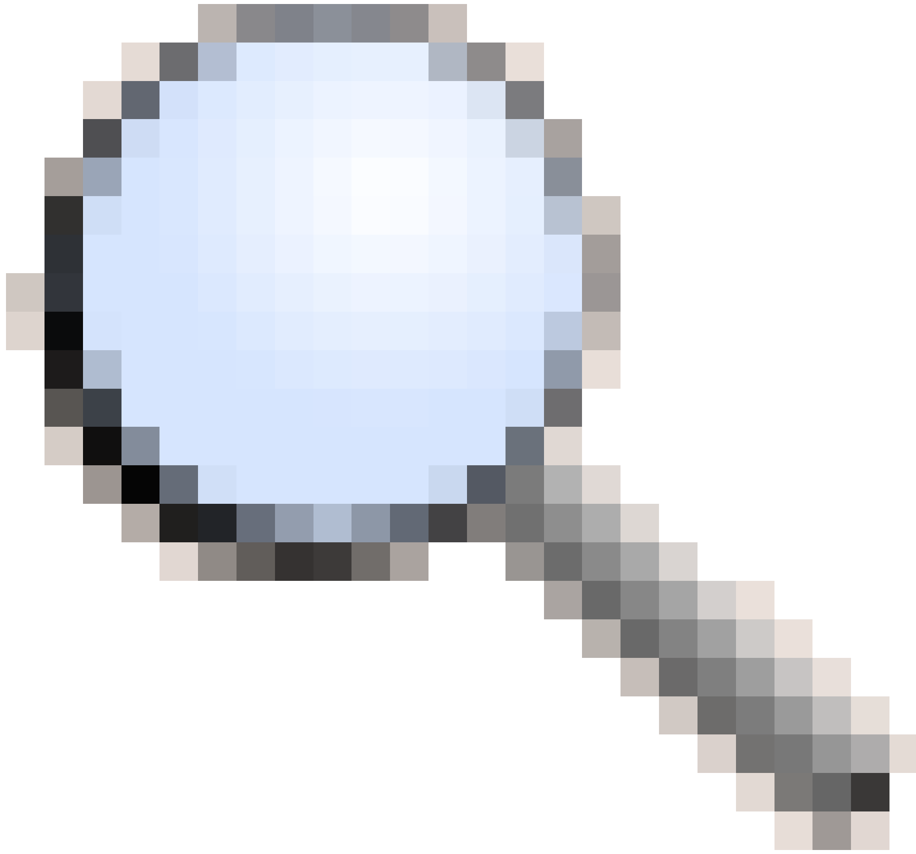
6.3.20 Frame preview window

This window is used to display a source frame and all information related to this frame.

Activating the dialog

The dialog can be activated:

1. double left click on an item in the table of source files.
2. right click on an item in the table of source files, from the context menu select *Open preview*.
3. from the main menu: *Project* → *Show selected frame*.



4. from the main toolbar:

Each file is presented in a separate window.

Dialog controls

(1) The image and chart are displayed in the preview area. It is possible to switch between several rendering modes.

(2) You can easily jump to the previous and next frame in the table by means of the left/right arrow icons on the toolbar. The ordinal number of displayed frame and total number of frames in the text box as a fraction.

(3) You can zoom the preview in and out by means of the zoom icons on the toolbar.

(4) It is possible to change the current aperture for which the object's brightness is displayed in the chart and the information box.

(5) The local menu bar provides following functions:

- Menu Frame:
  - Show properties - display the further details about the frame. Full header preview is available in separate window.
  - Remove from project - remove this frame from the project. It has the same effect as removing the frame from the main application window.
  - Close - close this window
- Menu View:
  - Image only - show only a CCD image and hide objects

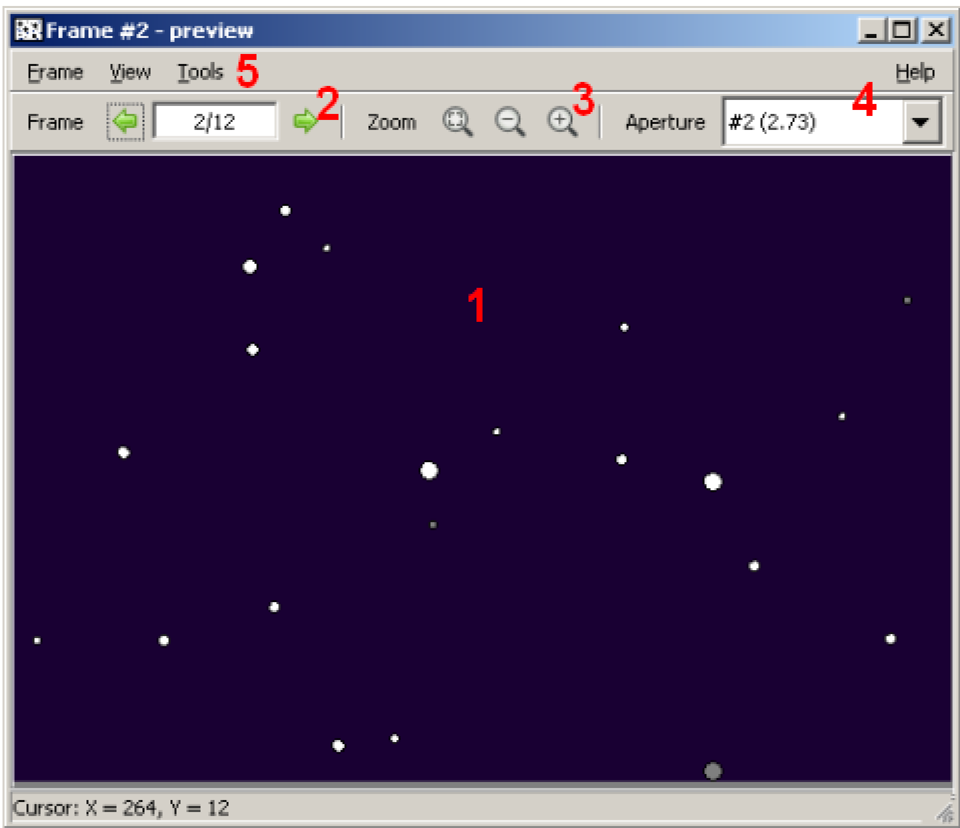


Fig. 25: Preview window for source frames

  - Chart only - show only objects and hide a CCD image
  - Chart and image - show a CCD image on the background and objects as an overlay
  - Table - show a table of detected objects
  - Calibrated image - show the current calibrated frame
  - Original image - show original uncalibrated image
  - Pseudo-color image - switch between rendering of pixel intensities in pseudo-color scale and a gray scale.
  - Rulers - show rules with pixels
  - Moving target trace - show a trace of a moving target. The curve spans from the point where the moving object is supposed to be for a minimum observation date to a point for a maximum observation date. The minimum and maximum date is determined from all frames in the dataset. A mark (short line perpendicular to the trace) highlights a point where the moving target is supposed to be at the observation date of the current frame.

- Menu Tools:
  - Gray scale - show a gray scale or a pseudo-color scale on the right side of the dialog.
  - Object inspector - show the Object inspector tool - explained below.
  - Quick photometry - show the Quick photometry tool - explained below.

Browsing the image

In the local menu, select *View* → *Image only* to hide the objects.

When you place a cursor over the image area, the coordinates and the pixel value are displayed in the status bar.

Quick Photometry tool

The Quick Photometry tool is a tool which computes basic photometric properties of an object on a frame. The main goal of this tool is to provide an estimation of the FWHM value (the important input parameter of the photometry process).

Because this tool does simplified version of aperture photometry, the results are informative only and shouldn't be used elsewhere. Also, it doesn't require a proper calibration to be performed first.

To activate the tool, select *Tools* → *Quick photometry* from the local menu. A new panel on the right side of the preview window appears.

Using the left mouse button, click on the image (1), close to an object. The program automatically finds the nearest local maximum, so you don't need to be accurate. The computation stars automatically and the results are displayed the the right panel (2).

The following object parameters are presented:

- Center - coordinates of the local maximum.
- Max - pixel value in local maximum
- Background - mean background level, computed as a robust mean of pixels in the sky annulus.
- Noise - background noise level, computed as a standard deviation of pixels in the sky annulus.
- FWHM - object's width, computed full width at half maximum.
- Aperture - aperture radius used for computing the object's signal.

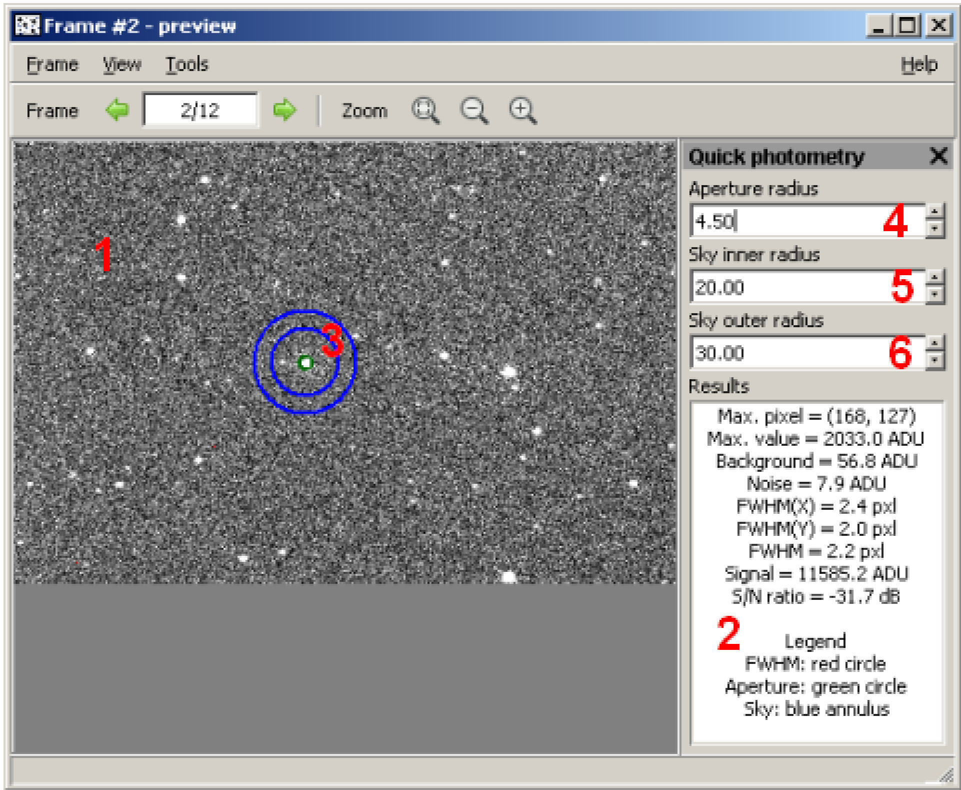


Fig. 26: Quick photometry tool

- Signal - object's signal, sum of pixels in the aperture, mean background level is subtracted.
- S/N ratio - signal to background noise ratio, displayed in decibels: SNR = 10.log(S/N).
- (3) Several dimensions are presented in the image area.
- Two blue circles show the annulus which is used to estimate the background properties.
- A red circle shows the object's average FWHM.
- A green circle shows the size of the aperture.

It is also possible to change some parameters:

- (4) Aperture radius in pixels
- (5) Inner radius of the sky annulus in pixels
- (6) Outer radius of the sky annulus in pixels

Profile tool

The Profile tool is used to check the shape of objects. It shows a curve of pixels values along a line.

To activate the tool, select *Tools* → *Quick photometry* from the local menu. A new panel on the bottom of the preview window appears.

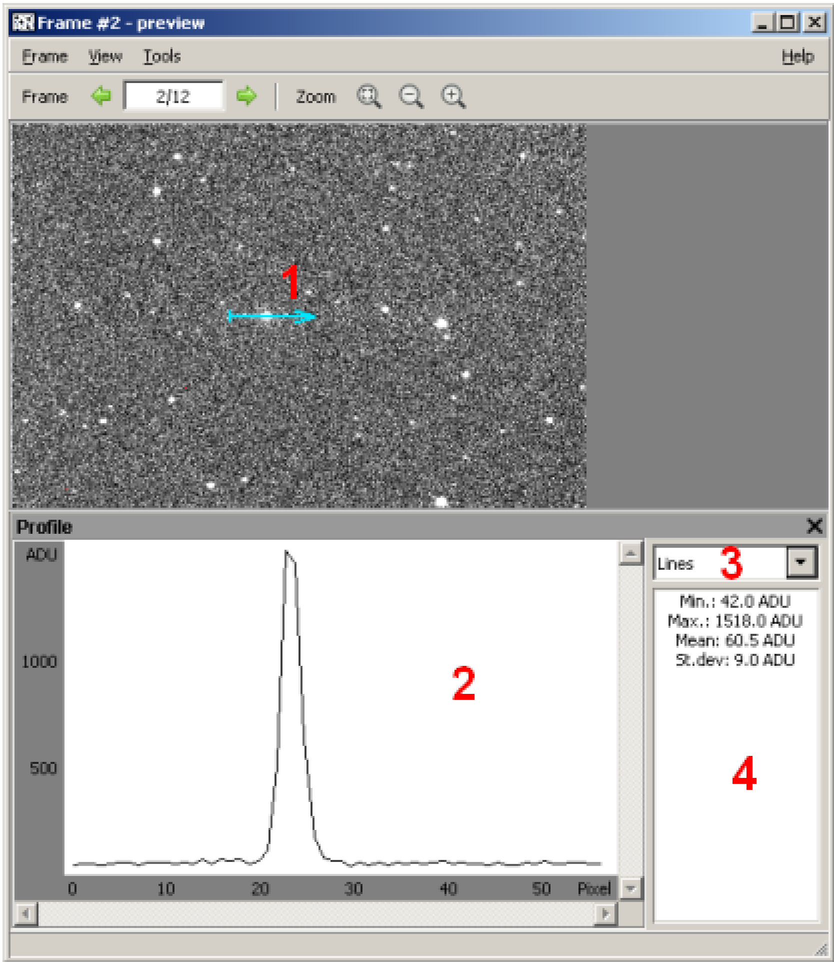


Fig. 27: Profile tool

Using the left mouse button, draw a line on the image (1), crossing the center of an object. The profile is drawn in the graph (2). You can adjust the graph style (3). The following parameters are displayed in the information box (4):

- Min - minimum pixel value.
- Max - maximum pixel value
- Mean - mean pixel value of pixels in the profile.
- St. dev. - standard deviation of pixels in the profile.

Histogram tool

The Histogram tool shows a histogram of pixel values and some related statistics.

To activate the tool, select *Tools* → *Histogram* from the local menu. A new panel on the bottom of the preview window appears.

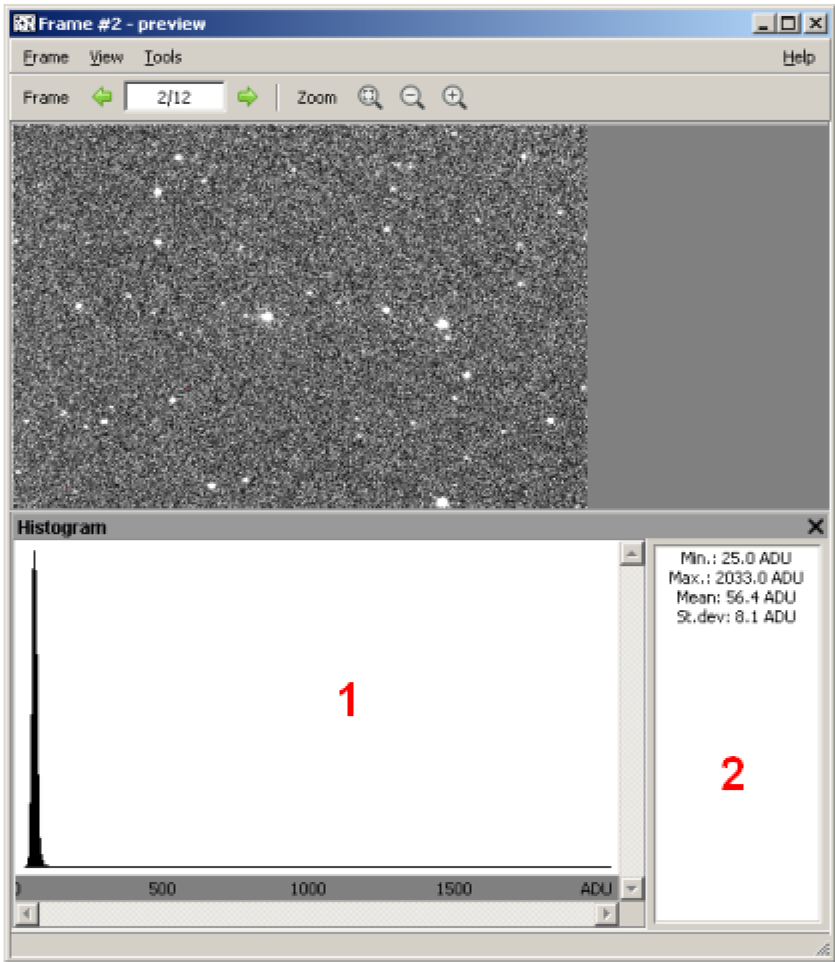


Fig. 28: Histogram tool

The histogram is shown in the left part (1) of the tool. The following parameters are displayed in the text area on its right side (2):

- Min - minimum pixel value
- Max - maximum pixel value
- Mean - mean pixel value of all pixels
- St. dev. - standard deviation of all pixels

Browsing the objects

In the local menu, select *View* → *Chart only* or *Image and chart* to show the objects.

When you place a cursor over an object in the image area, its coordinates and other properties are displayed in the status bar.

Objects that were not identified on the reference frame (see Matching) are rendered in a gray color.

Objects that were not measured successfully (see Photometry) are drawn in red color and not filled.

Objects that were not measured and not matched are draw in gray color and not filled.

The brightness for each object is rendered using the selected aperture.

Object inspector tool

The Object inspector tool is a tool which displays that the program registers about an object on a frame. The main purpose of this tool is for testing and debugging. Unlike the Quick Photometry, the Object Inspector shows results, that has been obtained during the "full" photometry. Because of this, calibration and photometry must be performed first. The results are more relevant.

To activate the tool:

1. From the local menu, select *View* → *Chart only* or *Image and chart* to show the objects.
2. From the local menu, select *Tools* → *Object inspector*. A new panel on the right side of the preview window appears.

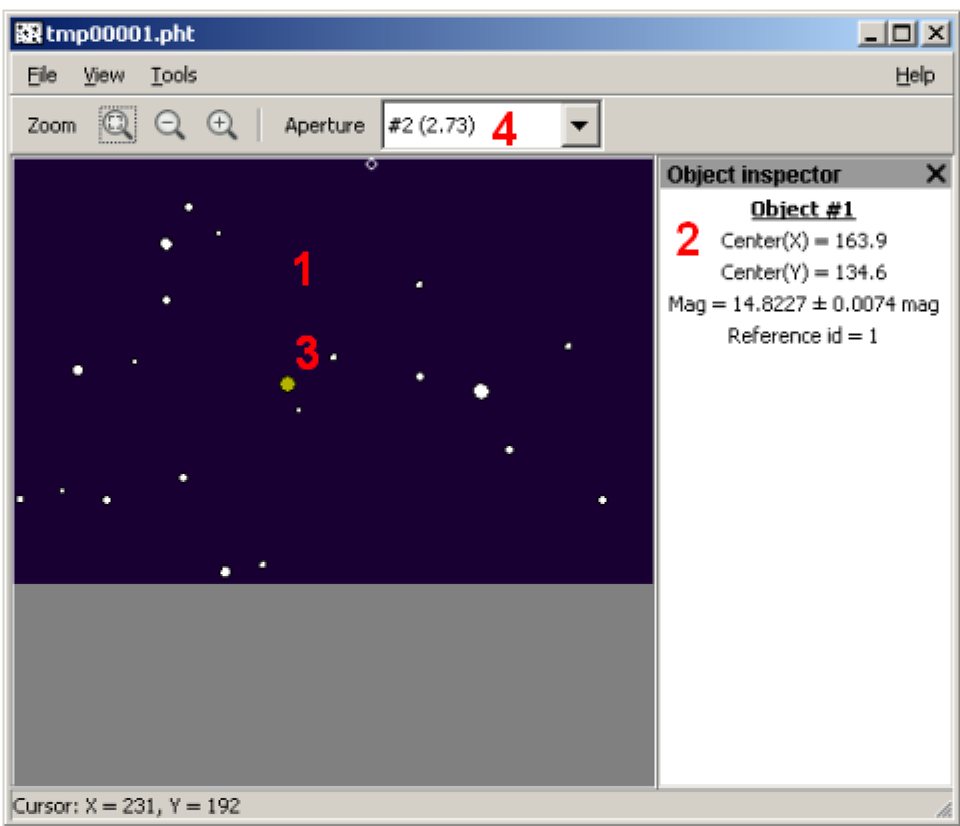


Fig. 29: Object Inspector tool

Using the left mouse button, click on the image (1), to select an object. The object is highlighted and its properties are displayed in the right panel (2).

The following object parameters are presented:

- Object # - object's ordinal number on the current frame.
- Reference ID - object's ordinal number on a reference frame.
- Center - coordinates of the object's centroid
- Brightness - instrumental brightness of the object in magnitudes.
- Error - error estimation of brightness in magnitudes.

Several dimensions are presented in the image area (3):

- Two blue circles show the annulus which is used to estimate the background properties.
- A green circle shows the size of the aperture.

(4) Here, you can change the current aperture.

See also:

Main window

6.3.21 Graph (window)

This preview window is used to display the content of an external file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Open file*.

When a file is opened, the program checks its content and decides which kind of preview window will be activated. Each file is presented in a separate window.

Dialog controls

(1) The data are displayed in the preview area. It is possible to switch between two rendering modes - displying file as a graph (plot) or as a table.

(2) When you place a cursor over a data point, the values are displayed in the status bar.

(3) You can zoom the preview in and out by means of the zoom icons on the toolbar.

If the file contains multiple columns, you can use the controls (4) and (5) to switch the displayed data.

The local menu bar provides following functions:

- Menu File:
  - Open - open another file, this is an equivalent to selection *Tools* → *Open file* from the main window.
  - Export - depending on the current display mode:
    - If a graph is shown, the function export the graph to a file in the PNG format.
    - If a table is shown, the function export the table to a file in the CSV or TEXT format. The save dialog provides several options, that allows adjusting the content of the file.

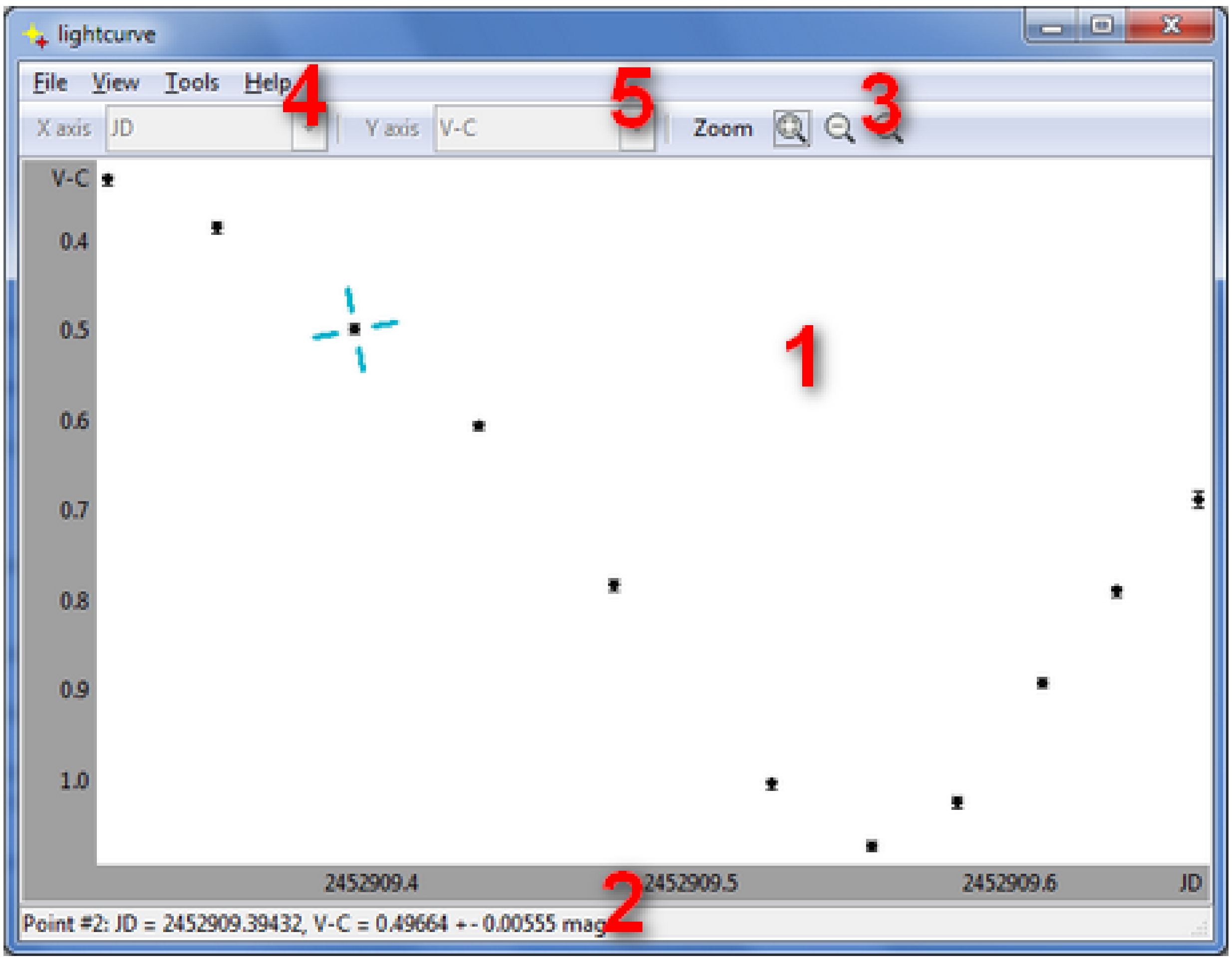


Fig. 30: Preview window for light curves, track-lists, etc.

- Show properties - display the further details about the file. Full header preview is available in separate window.
- Close - close this window

- Menu View:
  - Graph - show the data as a graph (plot)
  - Table - show the data as a table
  - Show errors - turns on and off the error bars (if available).
  - Grid - turn on and off the horizontal and vertical grid
- Menu Tools:
  - Statistics - turns on and off the 'Statistics' tool - see below.
  - Measurement - the tool allows measuring distances using two cursors.

Statistics

The Statistics is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

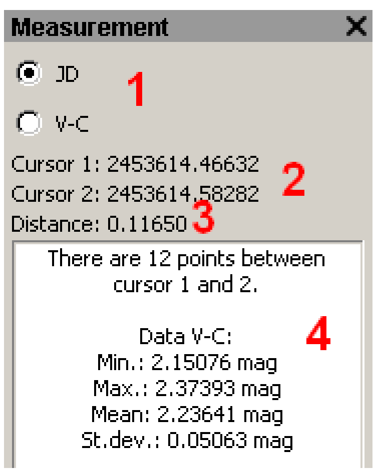
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Open file (dialog)

6.3.22 Heliocentric correction (dialog)

The "Heliocentric correction" allows an user to compute heliocentric correction for specified star and date of observation. It can also convert the geocentric date into heliocentric one and vice versa.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Heliocentric correction*.

Computing heliocentric correction

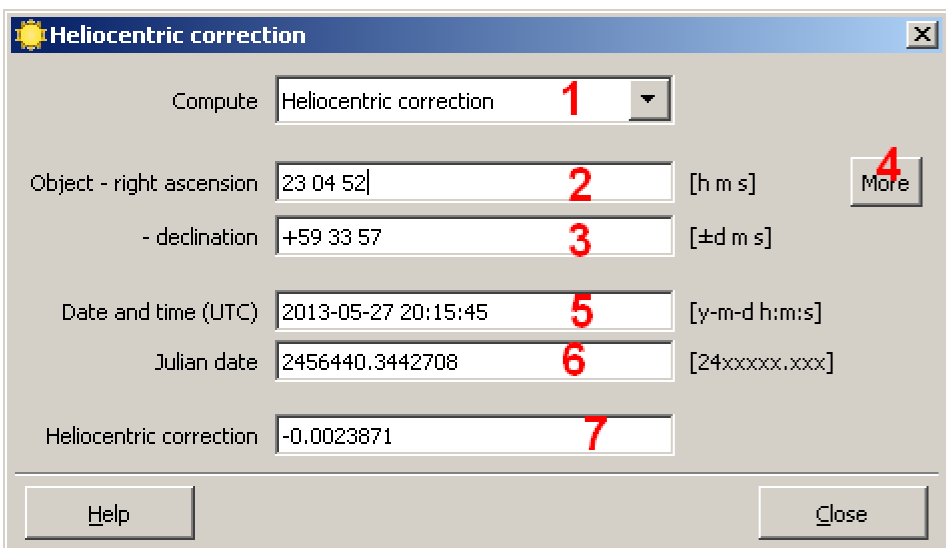


Fig. 31: Computing heliocentric correction

(1) Select the desired output value.

Enter object's right ascension to the text box (2) in hours. Use the hexagesimal format, separate the fields by a space character.

Enter object's declination to the text box (3) in degrees. Use the hexagesimal format, separate the fields by a space character.

Click the ellipsis button (4) to retrieve object's coordinates from a table of predefined objects or a catalog of variable stars.

Enter a Julian date into the text box (5) or date and time into the text box (6). As you type in the data, corresponding value of heliocentric correction in days is updated in the last text box (7).

Computing heliocentric Julian date

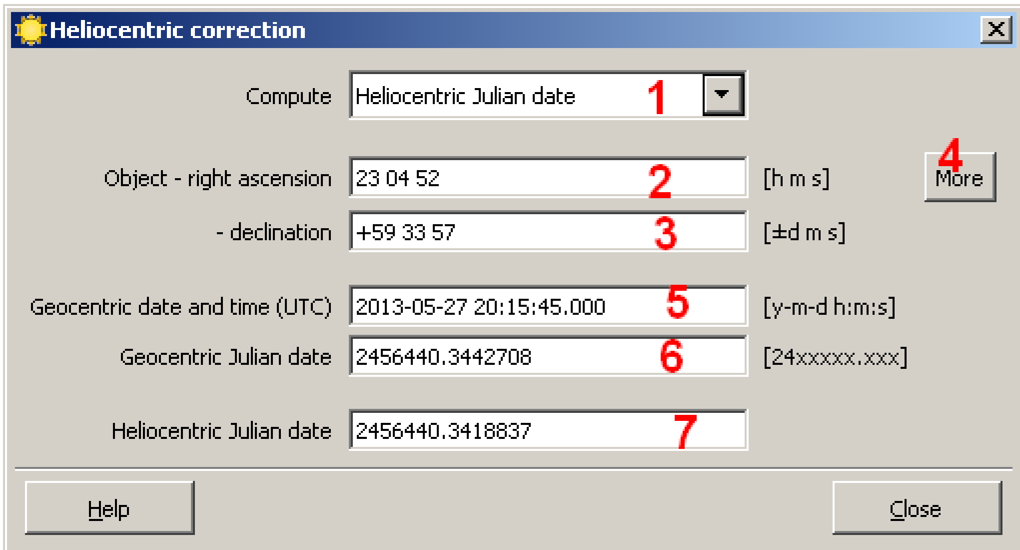


Fig. 32: Computing heliocentric Julian date

(1) Select the desired output value.

Enter object's right ascension to the text box (2) in hours. Use the hexagesimal format, separate the fields by a space character.

Enter object's declination to the text box (3) in degrees. Use the hexagesimal format, separate the fields by a space character.

Click the ellipsis button (4) to retrieve object's coordinates from a table of predefined objects or a catalog of variable stars.

Enter a geocentric (observed) Julian date into the text box (5) or the date and time into the text box (6). As you type in the data, corresponding value of heliocentric Julian date is updated in the last text box (7).

Computing geocentric Julian date

(1) Select the desired output value.

Enter object's right ascension to the text box (2) in hours. Use the hexagesimal format, separate the fields by a space character.

Enter object's declination to the text box (3) in degrees. Use the hexagesimal format, separate the fields by a space character.

Click the ellipsis button (4) to retrieve object's coordinates from a table of predefined objects or a catalog of variable stars.

Enter a heliocentric Julian date into the text box (5) or date and time into the text box (6). As you type in the data, corresponding value of geocentric (observed) Julian date is updated in the last text box (7).

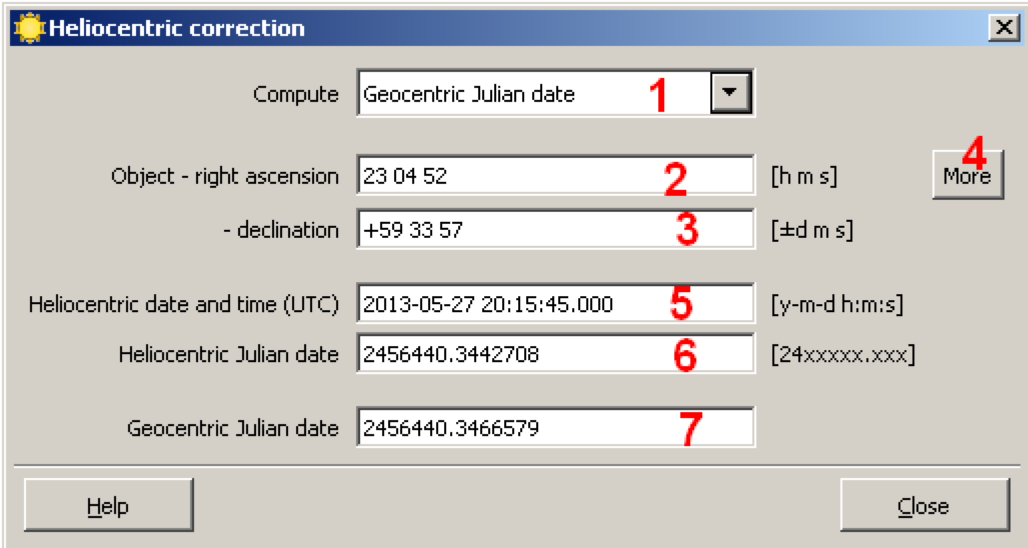


Fig. 33: Computing geocentric Julian date

See also:

JD converter (dialog), *Air mass coefficient (dialog)*

6.3.23 Image file (window)

This preview window is used to display the content of an external image file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Open file*.

When a file is opened, the program checks its content and decides which kind of preview window will be activated. Each file is presented in a separate window.

Dialog controls

(1) The CCD image is displayed in the preview area. It is possible to switch between positive and negative style in the "Preferences" dialog.

(2) When you place a cursor over an image, the coordinates and the pixel value is displayed in the status bar.

(3) You can zoom the preview in and out by means of the zoom icons on the toolbar. The actual magnification is shown here.

(4) The local menu bar provides following functions:

- Menu File:
  - Open - open another file, this is an equivalent to selection *Tools* → *Open file* from the main window.
  - Save as - save the image to a file in FITS format. To export the image in one of common raster image formats, use the 'Export'.

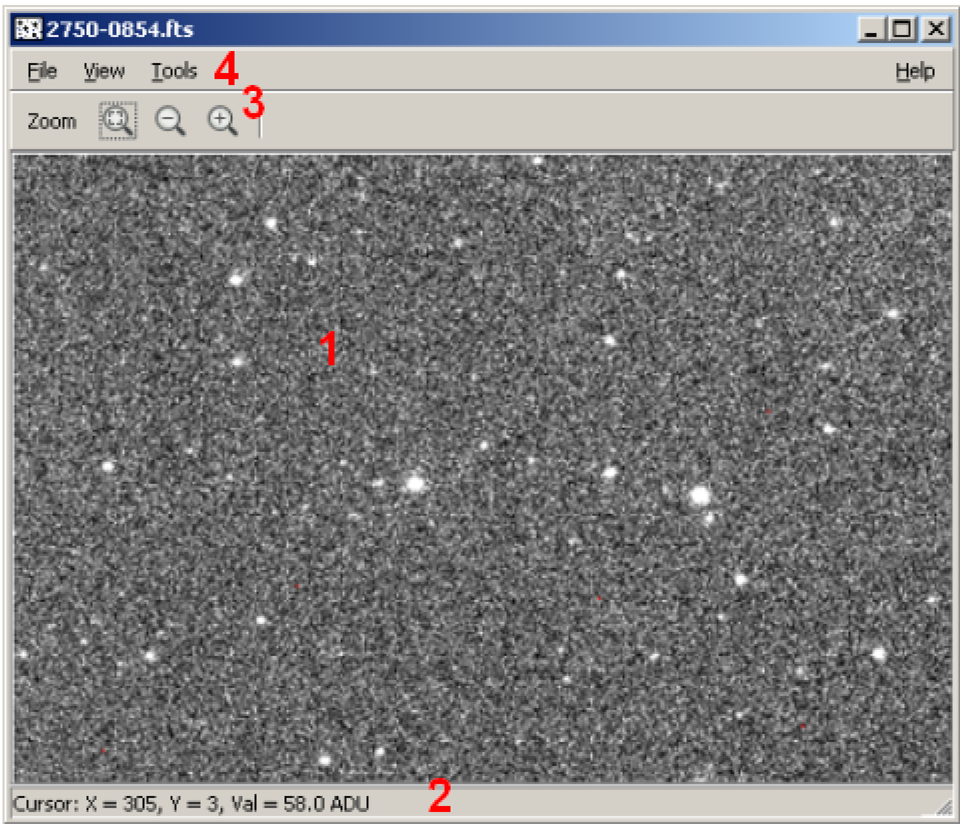


Fig. 34: Preview window for CCD image files

- Export - export the image to a file in one of common raster image formats, currently the PNG and JPEG formats are supported. It is possible to adjust the size of the resulting image.
- Show properties - display the further details about the file. Full header preview is available in separate window.
- Close - close this window

- Menu View:
  - Rulers - turn on/off the rules that are shown on the top and left side of the preview area
  - Pseudo-color image - switch between rendering of pixel intensities in pseudo-color scale and a gray scale.
- Menu Image:
  - Horizontal flip - flip image from left to right
  - Vertical flip - flip image from top to bottom
- Menu Tools:
  - Gray scale - show a gray scale or a pseudo-color scale on the right side of the dialog.
  - Quick photometry - show the Quick photometry tool - explained below.
  - Profile - show the Profile tool - explained below.
  - Histogram - show the histogram and statistics.

Quick Photometry tool

The Quick Photometry tool is a tool which computes basic photometric properties of an object on a frame. The main goal of this tool is to provide an estimation of the FWHM value (the important input parameter of the photometry process).

Because this tool does simplified version of aperture photometry, the results are informative only and shouldn't be used elsewhere. Also, it doesn't require a proper calibration to be performed first.

To activate the tool, select *Tools* → *Quick photometry* from the local menu. A new panel on the right side of the preview window appears.

Using the left mouse button, click on the image (1), close to an object. The program automatically finds the nearest local maximum, so you don't need to be accurate. The computation stars automatically and the results are displayed the the right panel (2).

The following object parameters are presented:

- Center - coordinates of the local maximum.
- Max - pixel value in local maximum
- Background - mean background level, computed as a robust mean of pixels in the sky annulus.
- Noise - background noise level, computed as a standard deviation of pixels in the sky annulus.
- FWHM - object's width, computed full width at half maximum.
- Aperture - aperture radius used for computing the object's signal.
- Signal - object's signal, sum of pixels in the aperture, mean background level is subtracted.
- S/N ratio - signal to background noise ratio, displayed in decibels: SNR = 10.log(S/N).
- (3) Several dimensions are presented in the image area.
- Two blue circles show the annulus which is used to estimate the background properties.

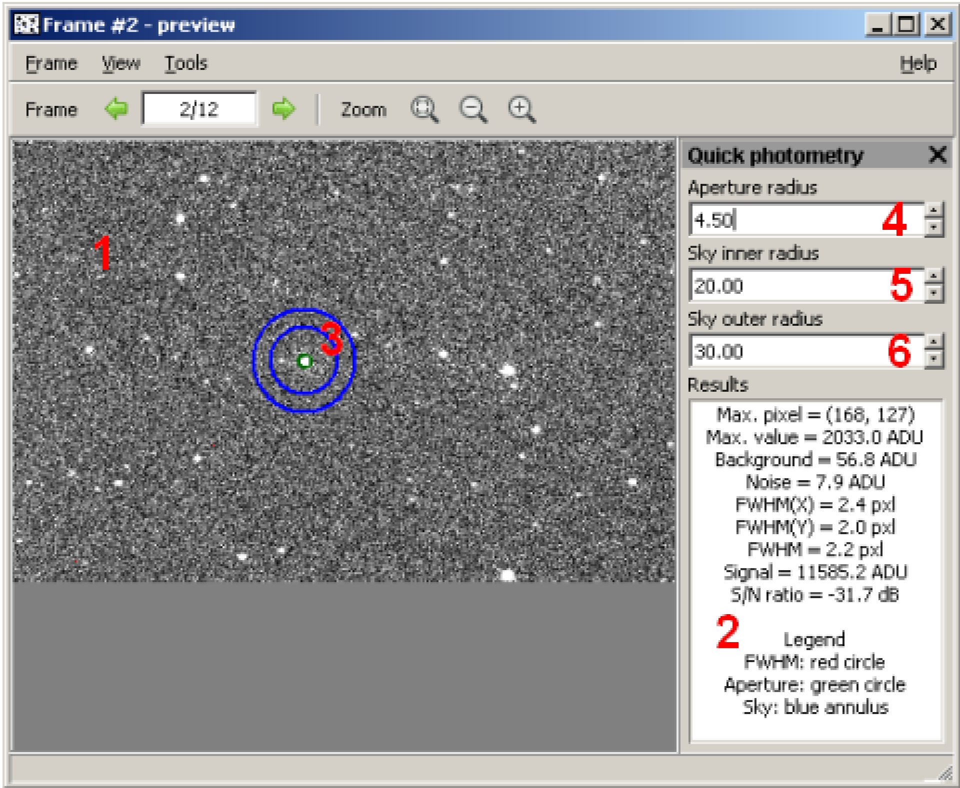


Fig. 35: Quick photometry tool

- A red circle shows the object's average FWHM.
- A green circle shows the size of the aperture.

It is also possible to change some parameters:

- (4) Aperture radius in pixels
- (5) Inner radius of the sky annulus in pixels
- (6) Outer radius of the sky annulus in pixels

Profile tool

The Profile tool is used to check the shape of objects. It shows a curve of pixels values along a line.

To activate the tool, select *Tools* → *Quick photometry* from the local menu. A new panel on the bottom of the preview window appears.

Using the left mouse button, draw a line on the image (1), crossing the center of an object. The profile is drawn in the graph (2). You can adjust the graph style (3). The following parameters are displayed in the information box (4):

- Min - minimum pixel value.
- Max - maximum pixel value
- Mean - mean pixel value of pixels in the profile.
- St. dev. - standard deviation of pixels in the profile.

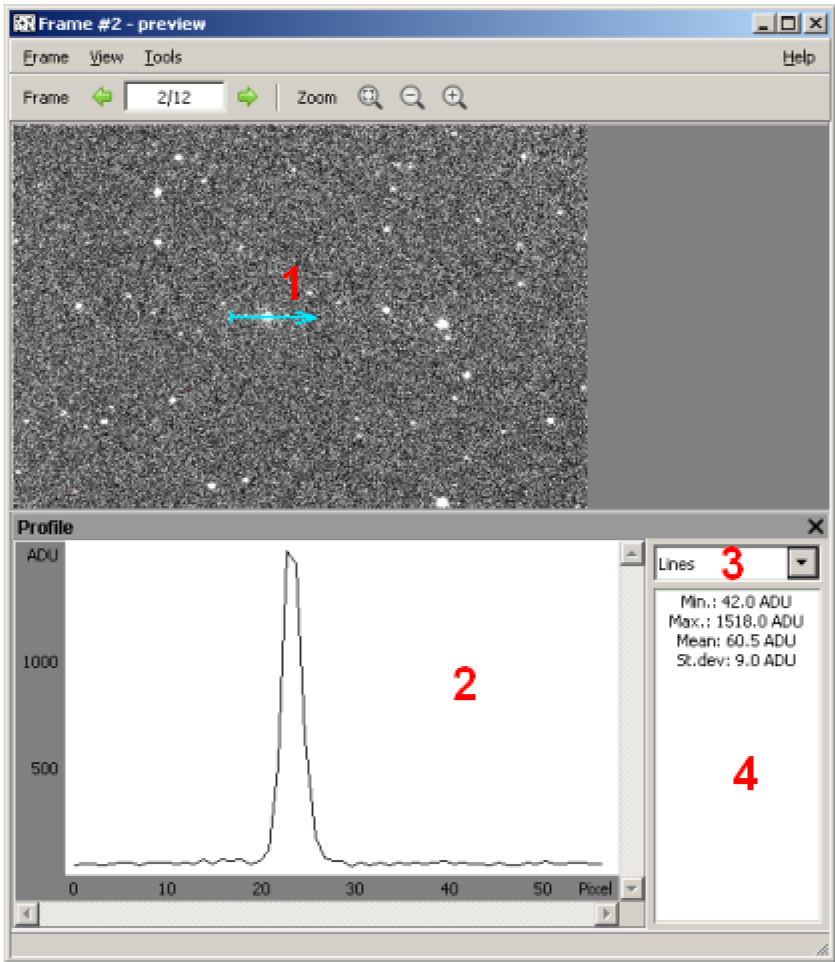


Fig. 36: Profile tool

Histogram tool

The Histogram tool shows a histogram of pixel values and some related statistics.

To activate the tool, select *Tools* → *Histogram* from the local menu. A new panel on the bottom of the preview window appears.

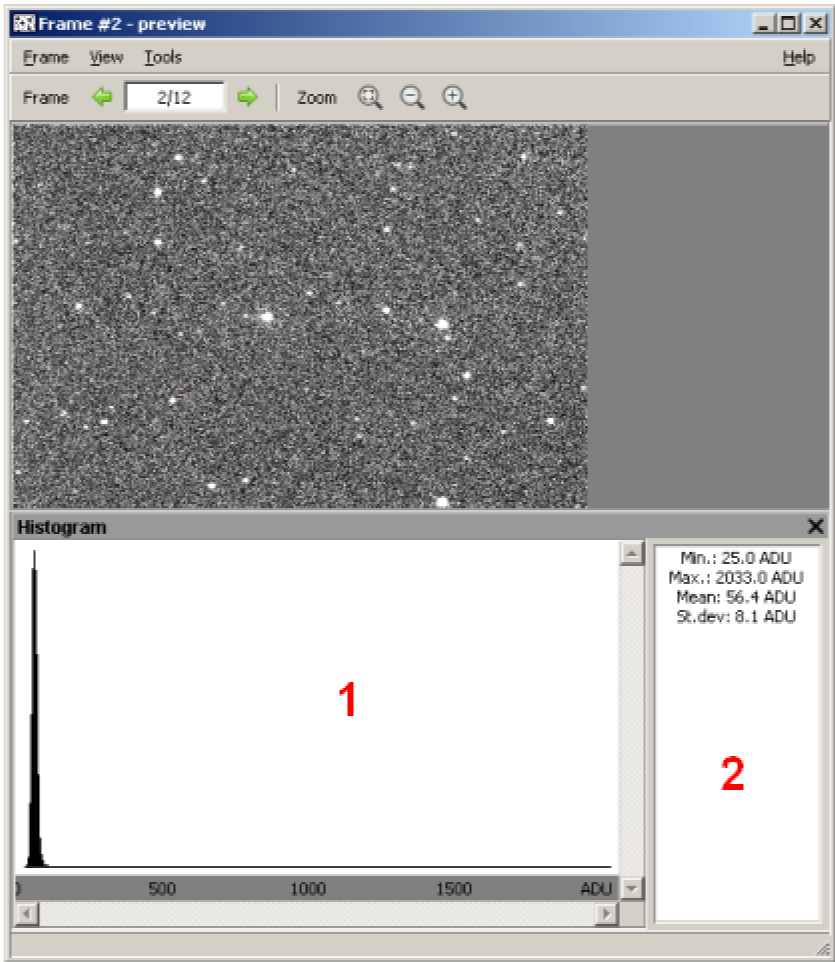


Fig. 37: Histogram tool

The histogram is shown in the left part (1) of the tool. The following parameters are displayed in the text area on its right side (2):

- Min - minimum pixel value
- Max - maximum pixel value
- Mean - mean pixel value of all pixels
- St. dev. - standard deviation of all pixels

See also:

Open file (dialog)

6.3.24 Import project settings (dialog)

The *Import project settings* dialog is used to copy settings from an existing project to the current project. When you do this on regular basis, consider using *Profiles*.

Activating the dialog

The dialog can be opened from the *Project settings (dialog)*, the root page, using the *Import from project* button.

The dialog controls

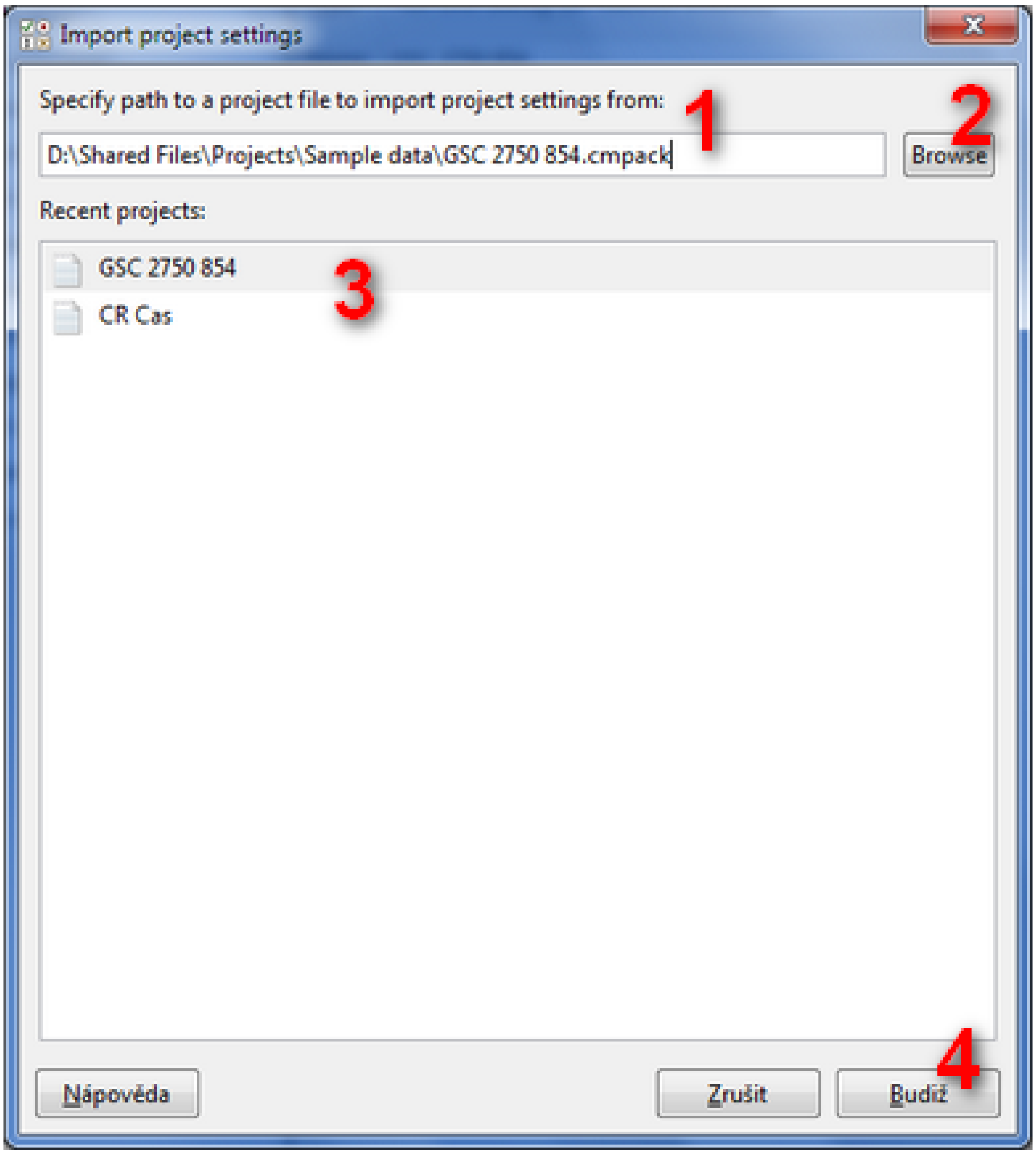


Fig. 38: Import project settings dialog

(1) Specify a path to the project which the settings shall be imported from.

(2) Click the *Browse* button to open a standard file selection dialog.

(3) The table shows the most recetly used projects. When you select an item, the projest's path is filled in to the edit field.

Click the button (4) to confirm the dialog.

See also:

Project settings (dialog)

6.3.25 Import project (dialog)

The *Import project* dialog is used to enter a location of a directory containing files to be imported into a new project. This tool allows one to transform a project from an old version of C-Munipack into a new one.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Import data from C-Munipack 1.x.*

File browsing

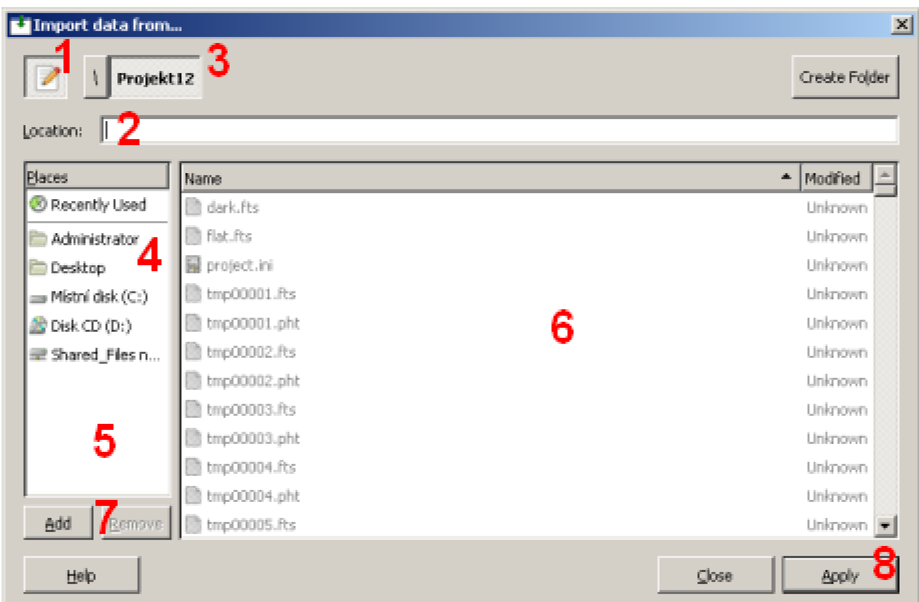


Fig. 39: The dialog for making a project from files originating from an old C-Munipack software.

The button (1) shows and hides the *Location* text box. The keyboard shortcut `Ctrl+L` key combination does the same action.

In the *Location* text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

The path to the current folder is displayed at the top of the dialog (3). You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the *Add* or the *Add to Bookmarks* option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Right-clicking a folder name opens a context menu.

(7) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

Click the "Apply" button (8) to continue; this dialog is followed by the *New project (dialog)*.

6.3.26 JD converter (dialog)

The "JD converter" dialog allows an user to convert a Julian date into a Gregorian calendar date (common date and time) and vice versa.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *JD converter*.

Converting Gregorian calendar date to Julian date

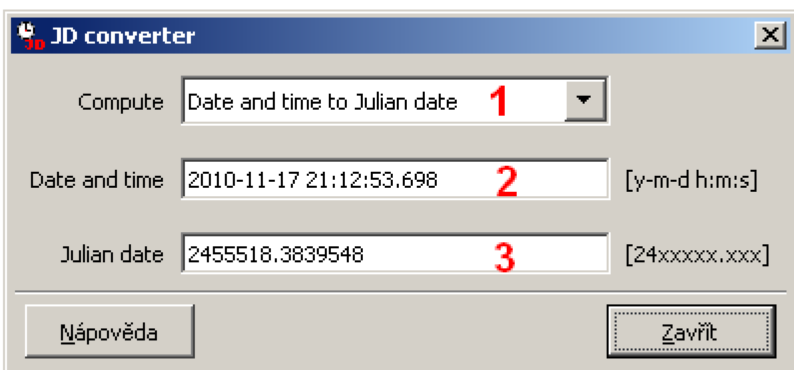


Fig. 40: Gregorian calendar date to Julian date

(1) Select the direction of the conversion

Enter the Gregorian calendar date to the text box (2) in the following form: year-month-day hour:minute:second. The time part is optional. Seconds can contain a fractional part. As you type in the data, corresponding Julian date is updated in the third text box (3).

Converting Julian date to Gregorian calendar date

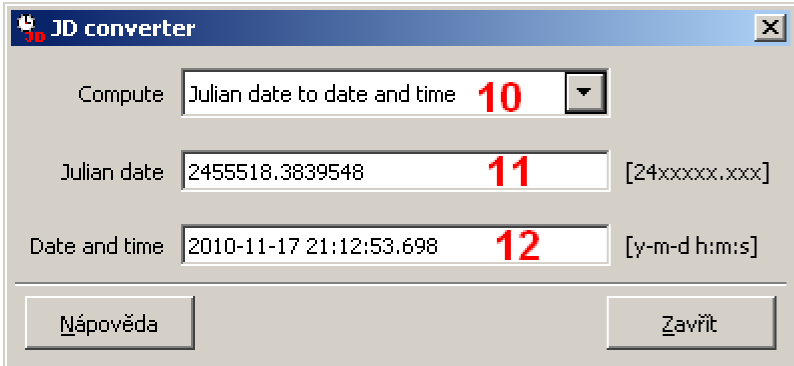


Fig. 41: Julian date to Gregorian calender date

(10) Select the direction of the conversion

Enter the Julian date to the text box (11). As you type in the value, corresponding Gregorian calender date is updated in the third text box (12).

See also:

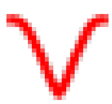
Heliocentric correction (dialog), *Air mass coefficient (dialog)*

6.3.27 Light curve (dialog)

The "Light curve" dialog is used to make a light curve of an object. The light curve is common output of the reduction of CCD frame.

Activating the dialog

The dialog can be activated:

- from the main menu: *Plot* → *Light curve*.
- from the main toolbar: 

The "Plot light curve" dialog appears. Check the options. Fill in the object coordinates and the observer coordinates, if necessary. Confirm the dialog.

Light curve dialog

(1) The actual data set is shown here.

(2) You can switch the labels on the X axis between Julian date (JD) or date and time (UTC).

(3) It is also possible to switch between apertures.

(4) The list of available data sets is displayed here.

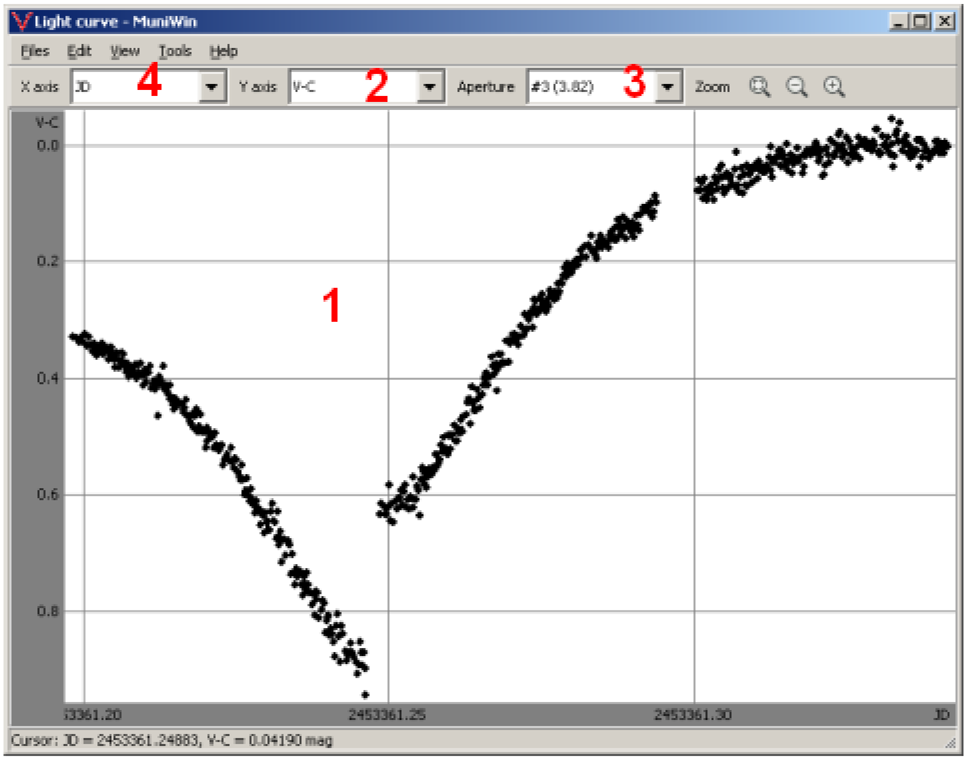


Fig. 42: Light curve

Data sets

Depending on the type of the light curve and the status of the options, the following data sets are available:

Differential magnitudes

- *V-C* - Differential magnitude of the variable star w.r.t. the comparison star
- *V-Kn* - Differential magnitude of the variable star w.r.t. the n-th check star
- *C-Kn* - Differential magnitude of the comparison star w.r.t. the n-th check star

Ensemble photometry

- *V-C* - Differential magnitude of the variable star w.r.t. the artificial comparison star
- *V-Kn* - Differential magnitude of the variable star w.r.t. the n-th check star
- *Cm-Kn* - Differential magnitude of the m-th comparison star w.r.t. the n-th check star

Instrumental magnitudes

- *V* - Instrumental magnitude of the variable star
- *C* - Instrumental magnitude of the comparison star
- *Kn* - Instrumental magnitude of the n-th check star

All stars (differential)

- *IDnnn-C* - Differential magnitude of the object with ID = *nnn* w.r.t. the comparison star

All stars (instrumental)

- *IDnnn* - Instrumental magnitude of the object with ID = *nnn*

Auxilliary data sets

The following data sets are optional:

- *HELCOR* - The heliocentric correction; in days
- *AIRMASS* - The air mass coefficient
- *ALTITUDE* - The apparent altitude in degrees; positive values above the horizon, negative values below the horizon

Context menu

You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. It provides following functions:

- Show frame - it shows a preview to a selected frame. It is not allowed when more than one frame is selected.
- Show properties - it opens a new dialog with properties of selected frame. It is not allowed when more than one frame is selected.
- Delete from data set - selected measurements are removed from the current curve, the data will be shown again when you make a new curve or *Rebuild* the actual curve.
- Remove from project - source frames corresponding to the selected measurements are removed permanently from the list of input files and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Statistics

The Statistics is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

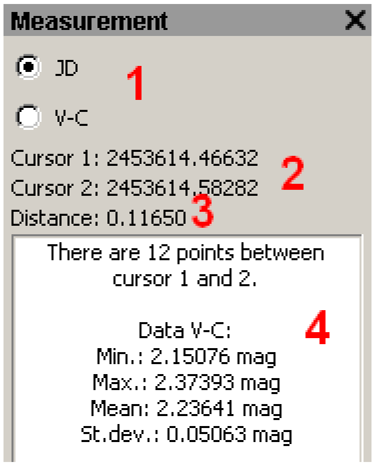
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Chart (dialog), *Export light curve in AAVSO format*

6.3.28 Load profile (dialog)

The dialog is used to load settings from a profile into the current project.

Activating the dialog

The dialog can be opened from the *Project settings (dialog)*, the root page, using the *Load from profile* button.

The dialog controls

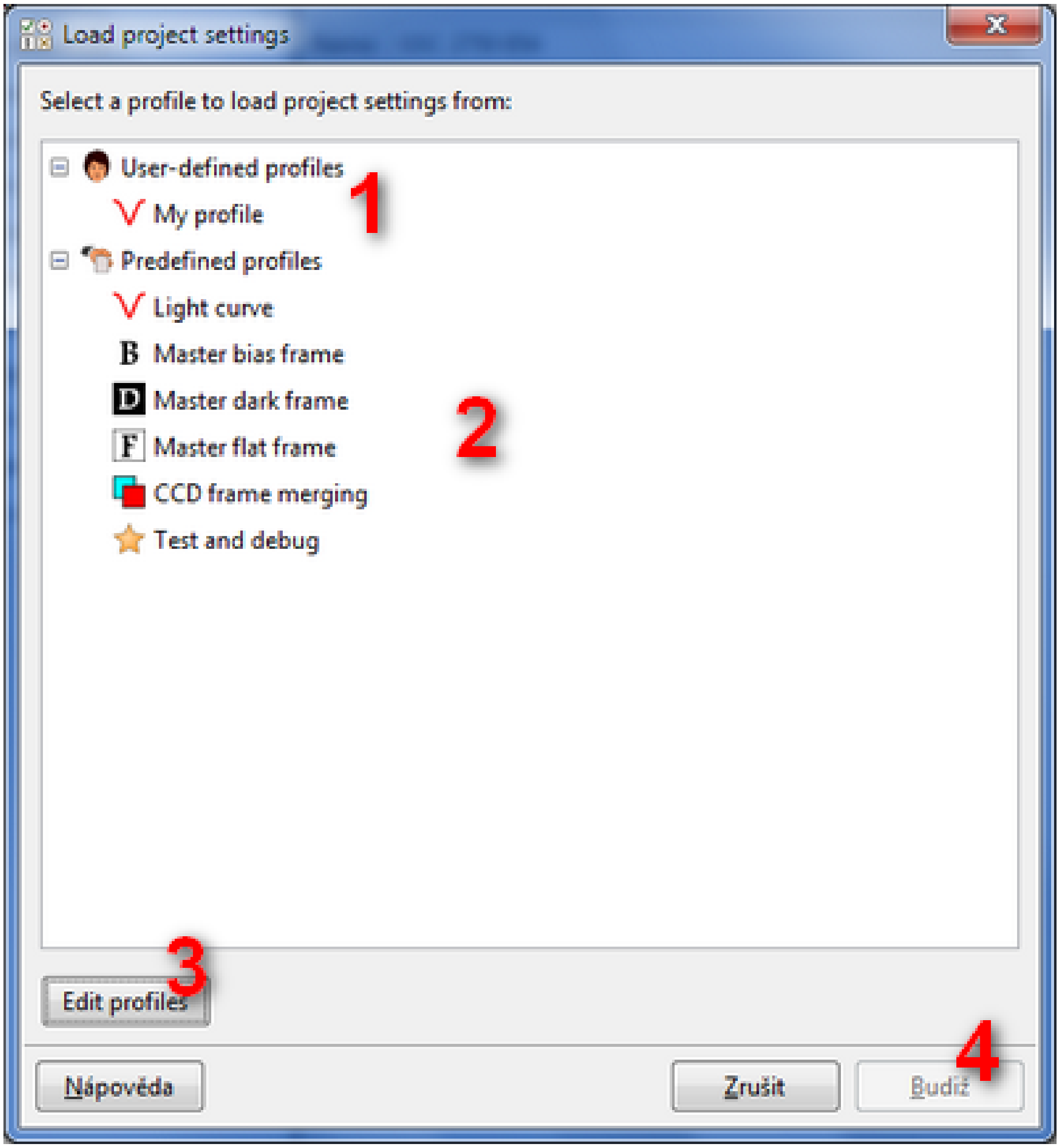


Fig. 43: Load project settings dialog

List of existing profiles is shown in the table. The profiles are divided into two categories - user-defined profiles (1) and predefined profiles (2).

Click the *Edit profiles* button to open the *Edit profiles (dialog)*.

See also:

Project settings (dialog), *Edit profiles (dialog)*, *Save project settings (dialog)*

6.3.29 Main window

The "Muniwin" window is a main application window. The list of source files is presented in the table. The *Main menu* a *Main toolbar* allow an user to access all features of the program.

Browsing the source files

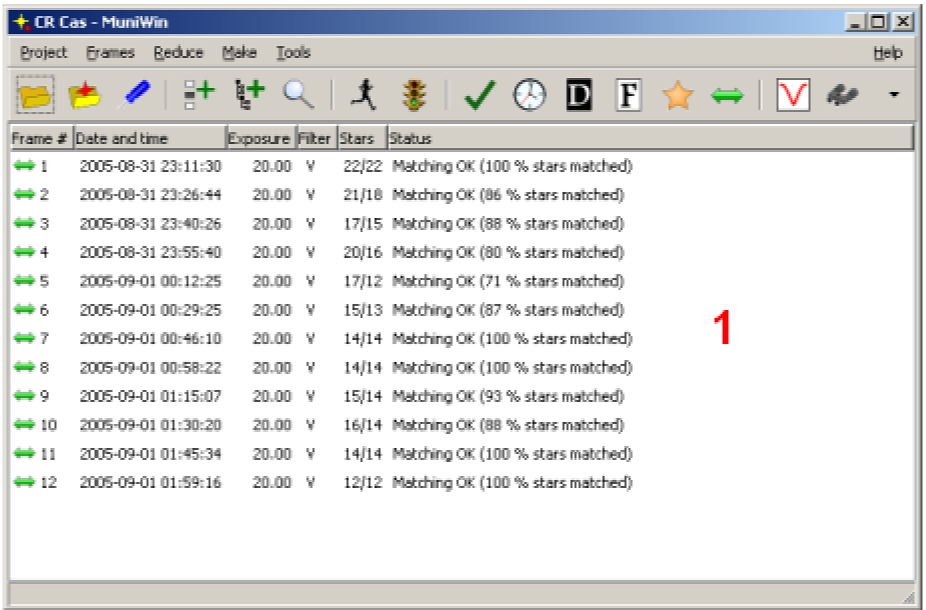


Fig. 44: Main window

(1) The list of source frames are presented in the table. For each frame, the icon on the left indicates its status. Next to the icon, there is the ordinal number assigned to a frame. Most of the fields can be turned on and off in the "Preferences" dialog.

- Frame # - assigned ordinal number of the frame
- Date and time - Gregorian calender date and time of the center of exposure
- Julian date - Julian date of the center of exposure
- Exposure - exposure duration in seconds
- Temperature - CCD temperature in centigrade degrees
- Filter - name of the color filter
- Stars - after the photometry, the number of detected stars is displayed here. After the matching, two numbers are shown. The first value is a number of matched stars, the second value is a number of detected stars.
- Original file - full path to the original image file.
- Temporary file - name of the temporary image file.
- Status - the result of the last operation is displayed

Double left-click on an item to open a preview to the selected frame in a separate window. Right-clicking a folder name opens a context menu.

See also:

Add individual frames (dialog), *Add frames from folder (dialog)*, *Frame preview window*, *Main menu*, *Main toolbar*

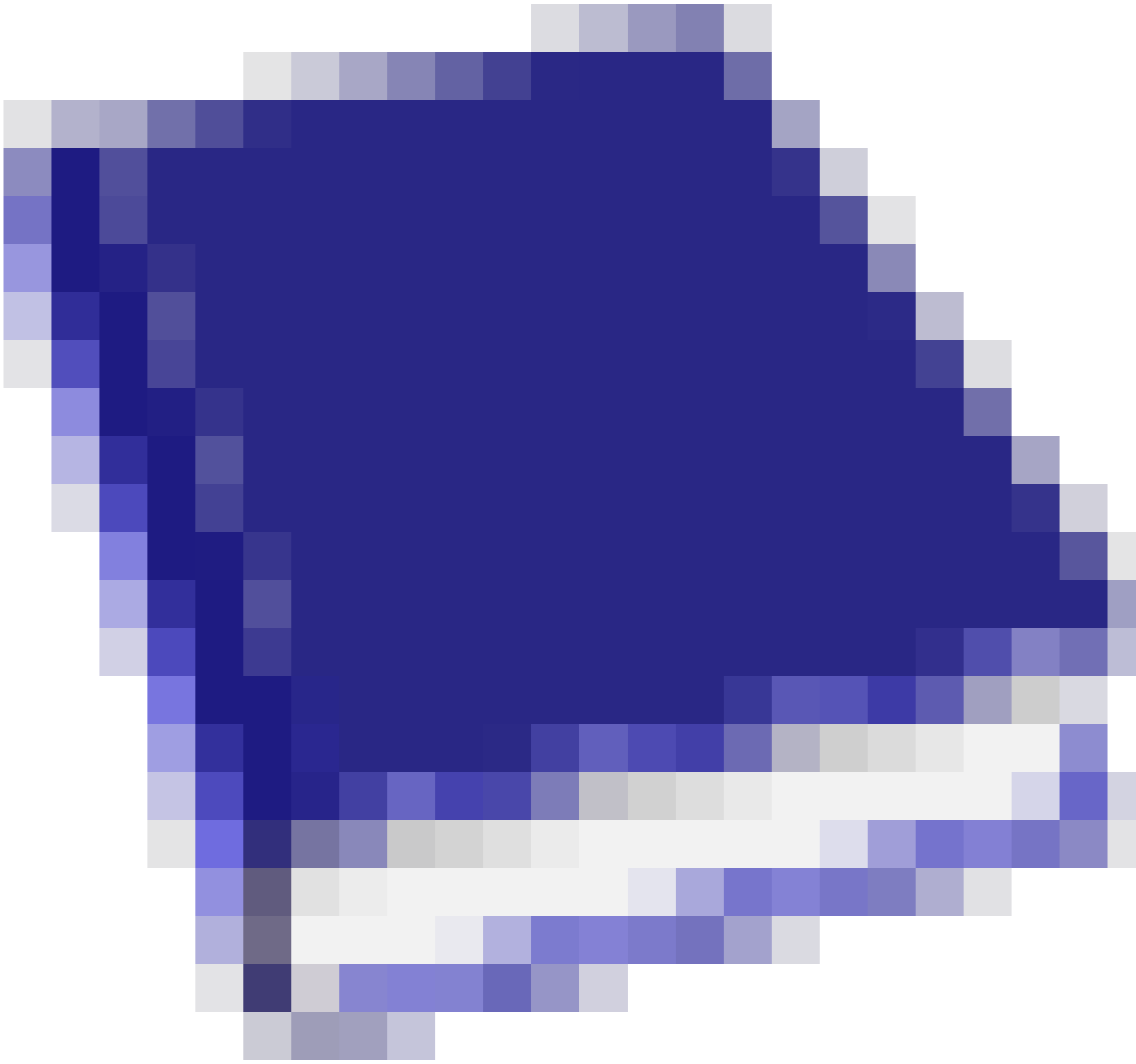
6.3.30 Make catalog file (dialog)

The "Make catalog file" dialog allows an user to fill in the information that he wants to save to a new catalog file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Make catalog file*.



2. from the main toolbar:

Filling up the form

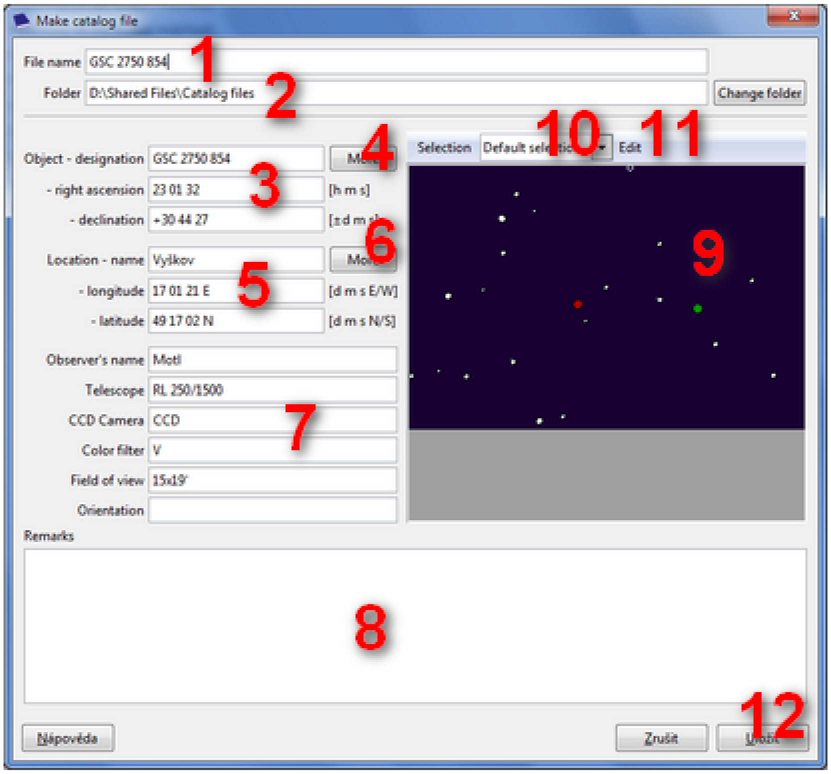


Fig. 45: The "Make catalog file" dialog

(1) Enter a name of the catalogue file. The string can't include the characters that are not allowed in the file name, i.e. colon, slash, backslash, asterisk, question mark, etc.

(2) This field shows a path to the folder where the new catalog file will be saved to. Click on the "Browse" button to change the folder.

(3) If you make light curves with heliocentric JD or air mass coefficients, you can fill in the object's position. The coordinates will be restored when you use the catalog file as a reference file in the matching. Click on the button (4) to retrieve the coordinates from a list of user-defined objects or a catalog of variable stars.

(5) If you make light curves air mass coefficients, you can fill in the observer's location. The coordinates will be restored when you use the catalog file as a reference file in the matching. Click on the button (6) to retrieve the coordinates from a list of user-defined locations.

(7) These fields are optional. There are no formatting rules for these fields.

(8) If you want to provide more information, you can write it here.

(9) The preview area shows the default selection of objects. The variable star is marked with red color, the comparison star is green and check stars are rendered in blue color. Use the selection field (10) to review the defined selections. All the selections that are presented here, will be saved to the catalog file. Click the *Edit* button (11) to edit the selections.

Click the button (12) to proceed.

See also:

Match stars (dialog)

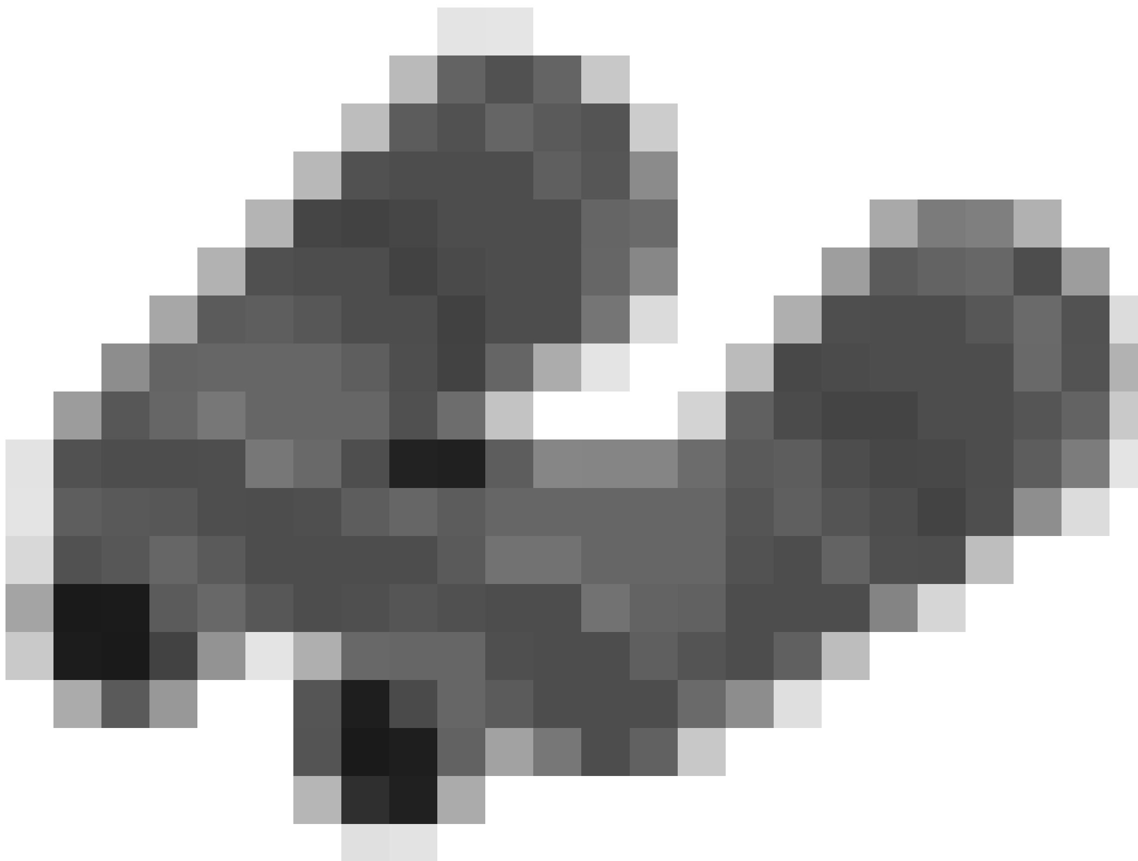
6.3.31 Make find variables dialog

The "Make find variables" dialog is used to select the data source for the *Find variables (dialog)*. Basically, there are two options - the data can be construed from the current project or loaded from a varfind file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Find variables*.



2. from the main toolbar:

The dialog controls

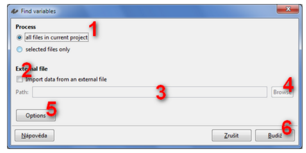


Fig. 46: "Make find variables" dialog

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

(2) To load the data from an external varfind file, check this option. The path to the file must be specified into the edit field (3). Click the *Browse* button to open a standard file selection dialog.

Click the button (4) to proceed.

See also:

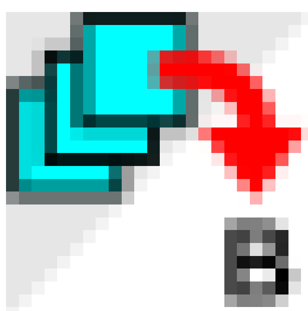
Finding variables, *Find variables (dialog)*

6.3.32 Master bias frame (dialog)

The "Master bias frame" dialog is used to enter a name and a directory for a new master bias frame. You can find more information about bias frames in the chapter "Advanced calibration scheme".

Activating the dialog

The dialog can be activated:

1. from the main menu: *Make* → *Master bias frame*.
2. from the main toolbar: 

The basic dialog

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

(4) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

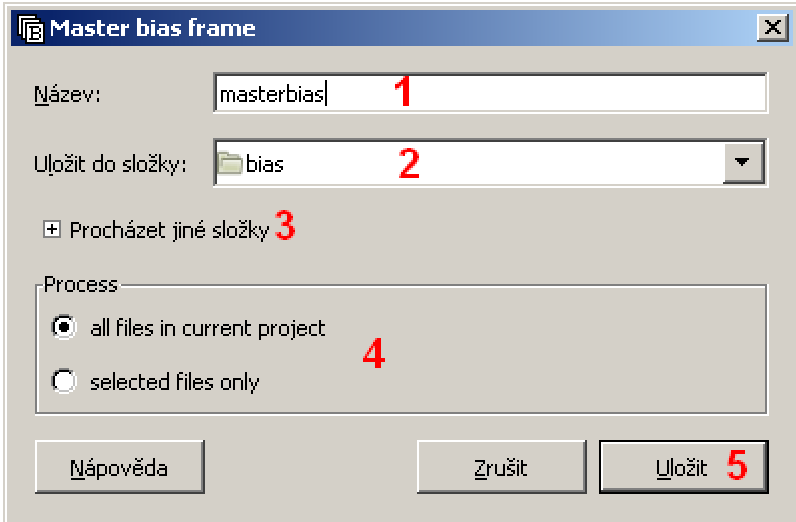


Fig. 47: The "Make master bias frame" dialog (basic form)

Browsing the directories

(11) Here, you can access to your main folders and to your store devices.

(12) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(13) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(14) Enter the file name of the new image file here.

(15) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (16) to shrink the dialog to its basic form.

(17) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

(18) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (19) and following the instructions.

(20) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

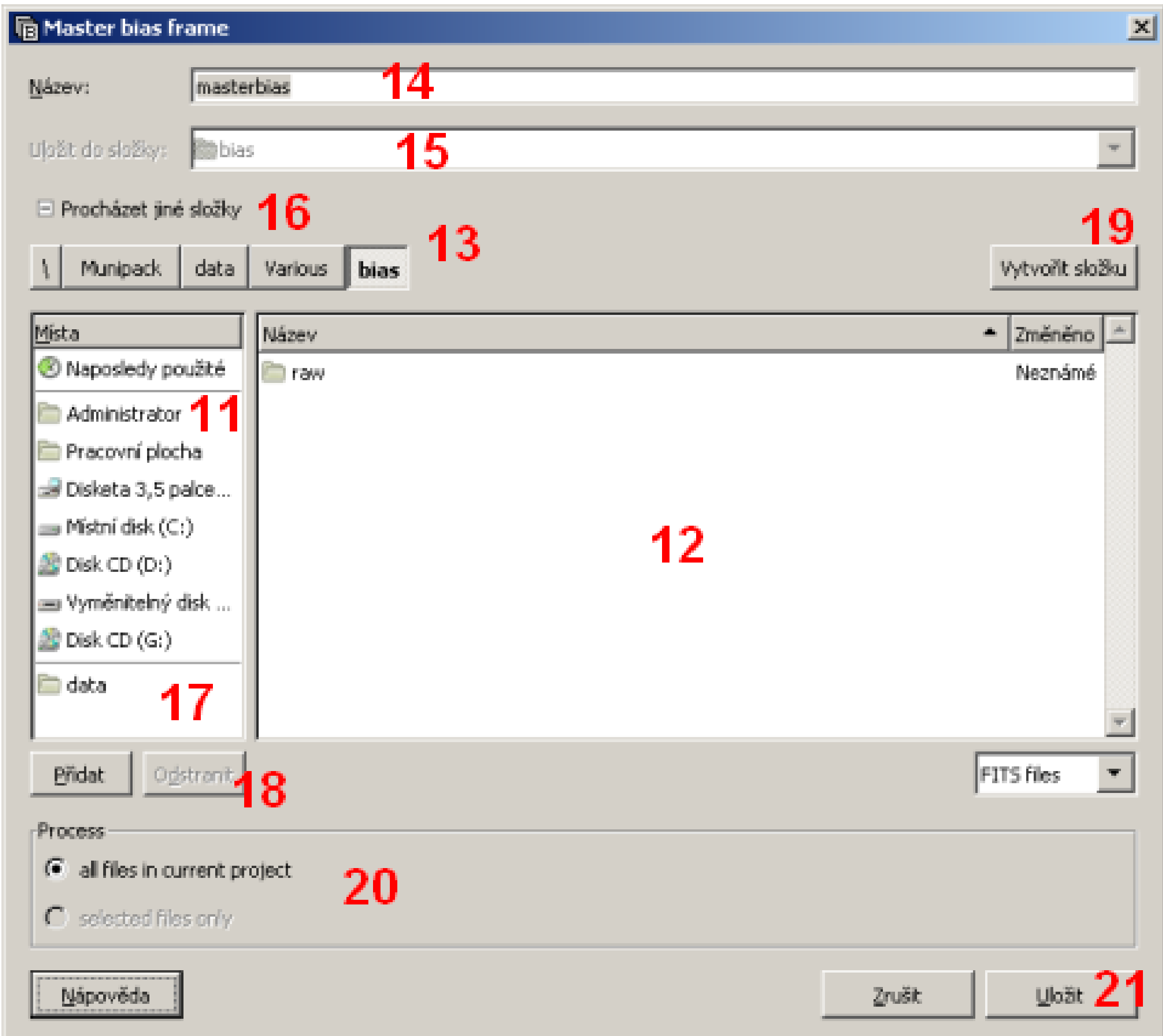


Fig. 48: The "Make master bias frame" dialog (with browser)

Making the master bias frame

Click on the "Save" button (5 or 21) to start the operation.

- A working copy of source frame must be made before making a master bias frame.
- Do not apply any calibration (bias, dark or flat corrections) to source frames.
- Bias correction frame are used in the "Advanced calibration scheme" only.

See also:

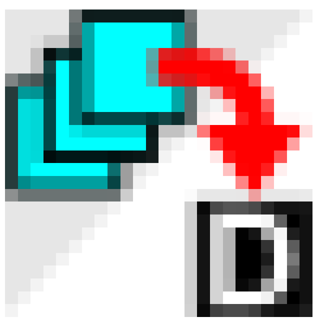
Bias correction (dialog), *Advanced calibration scheme*

6.3.33 Master dark frame (dialog)

The "Make master dark frame" dialog is used to enter a name and a directory for a new master dark frame. You can find more information about dark frames in the chapter "Standard calibration scheme".

Activating the dialog

The dialog can be activated:

1. from the main menu: *Make* → *Make master dark frame*.
2. from the main toolbar: 

The basic dialog

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

(4) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

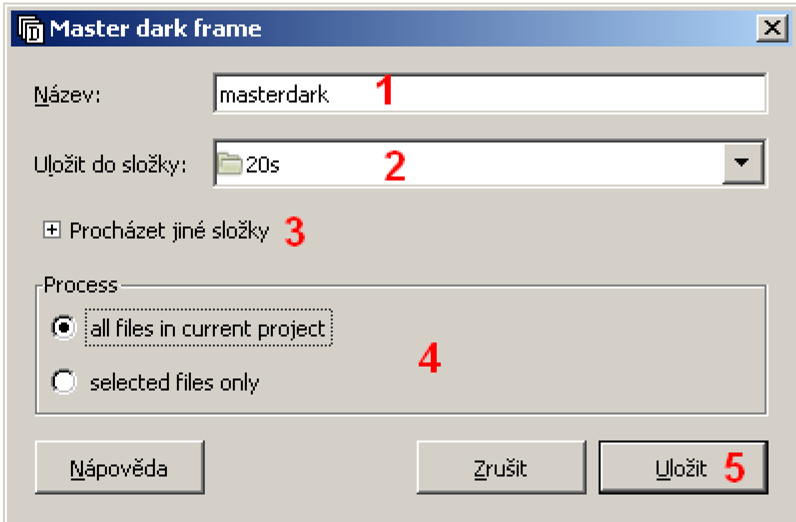


Fig. 49: The "Make master dark frame" dialog (basic form)

Browsing the directories

(11) Here, you can access to your main folders and to your store devices.

(12) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(13) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(14) Enter the file name of the new image file here.

(15) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (16) to shrink the dialog to its basic form.

(17) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

(18) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (19) and following the instructions.

(20) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

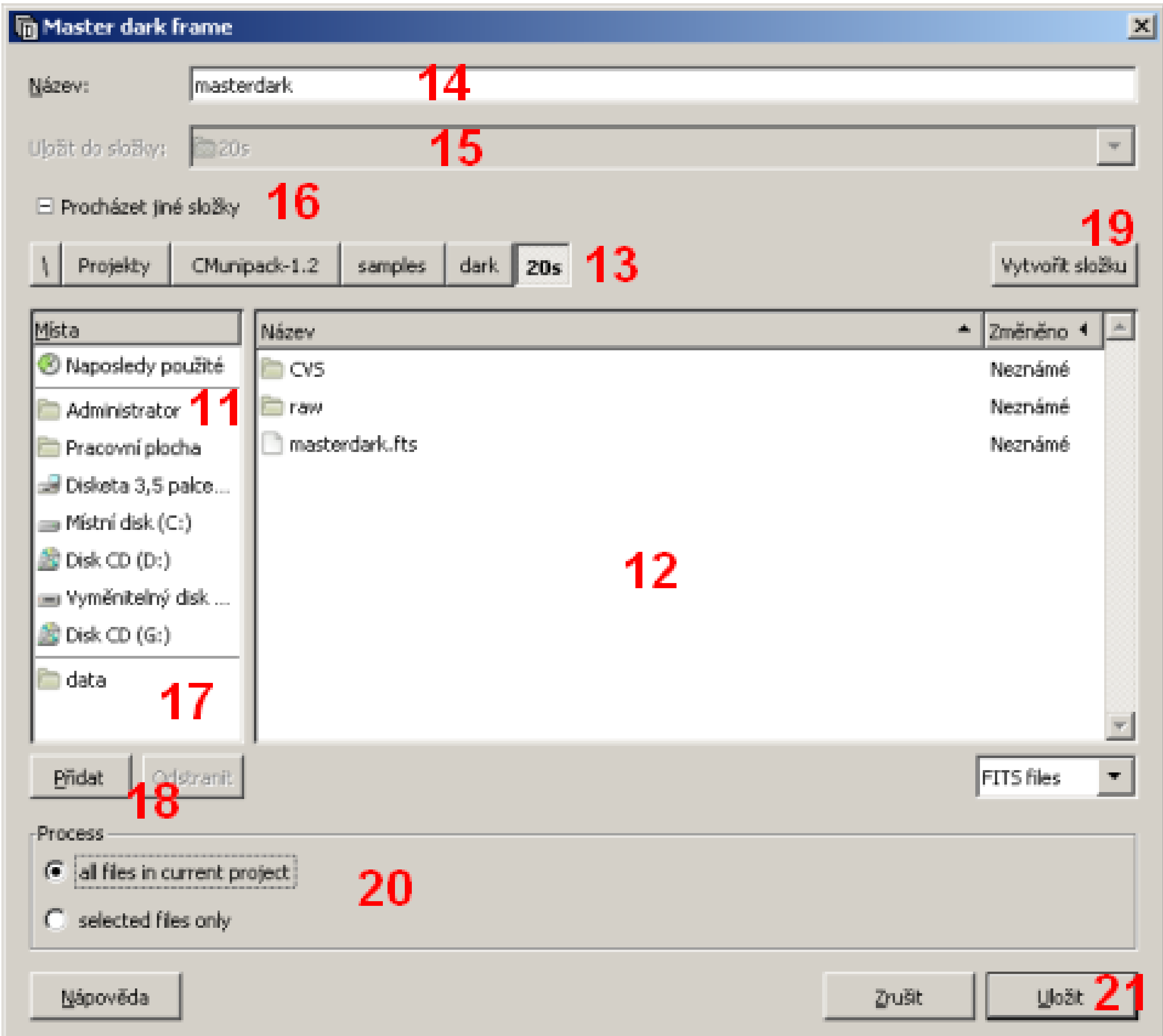


Fig. 50: The "Make master dark frame" dialog (with browser)

Making the master dark frame

Click on the "Save" button (5 or 21) to start the operation.

- A working copy of source frame must be made before making a master dark frame.
- In the *standard* calibration scheme, do not apply any calibration (bias, dark or flat corrections) to source frames.
- In the *advanced* calibration scheme, the bias correction must be applied before making a master dark frame, if necessary.

See also:

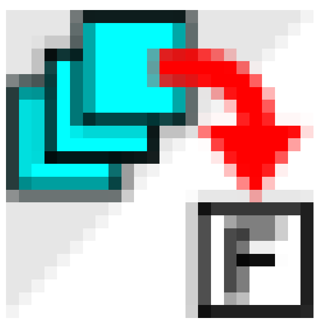
Dark correction (dialog), *Advanced calibration scheme*

6.3.34 Master flat frame (dialog)

The "Master flat frame" dialog is used to enter a name and a directory for a new master flat frame. You can find more information about flat frames in the chapter "Standard calibration scheme".

Activating the dialog

The dialog can be activated:

1. from the main menu: *Make* → *Make master flat frame*.
2. from the main toolbar: 

The basic dialog

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

(4) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

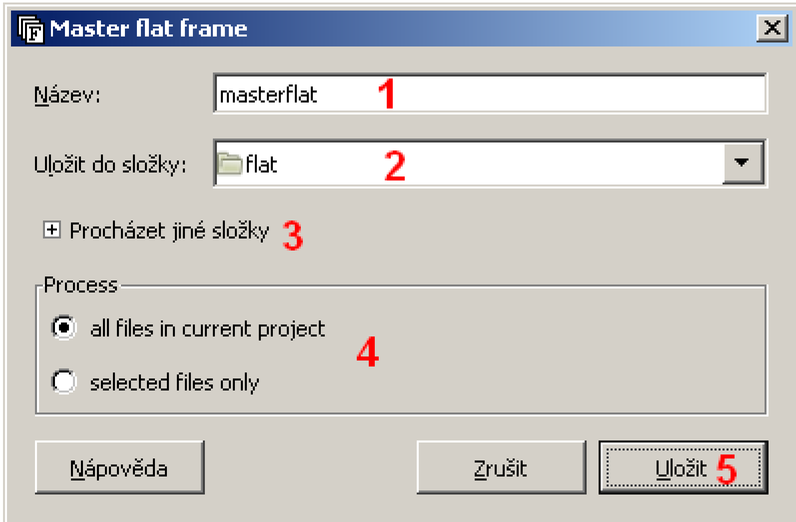


Fig. 51: The "Master flat frame" dialog (basic form)

Browsing the directories

(11) Here, you can access to your main folders and to your store devices.

(12) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(13) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(14) Enter the file name of the new image file here.

(15) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (16) to shrink the dialog to its basic form.

(17) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

(18) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (19) and following the instructions.

(20) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to make a master frame using a subset of source files only.

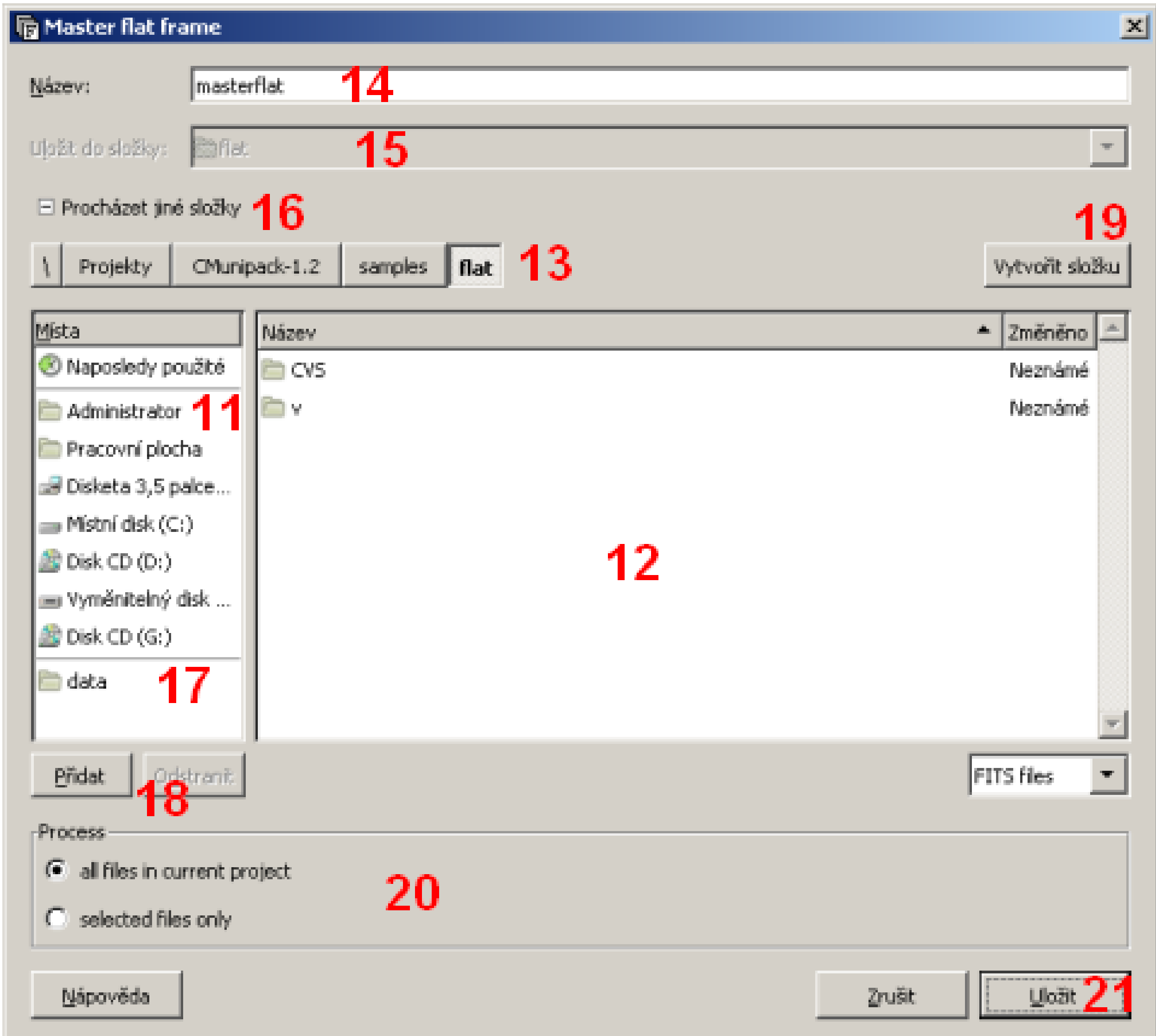


Fig. 52: The "Master flat frame" dialog (with browser)

Making the master flat frame

Click on the "Save" button (5 or 21) to start the operation.

- A working copy of source frame must be made before making a master flat frame.
- The bias and the dark correction must be applied before making a master flat frame, if necessary.

See also:

Flat correction (dialog), *Advanced calibration scheme*

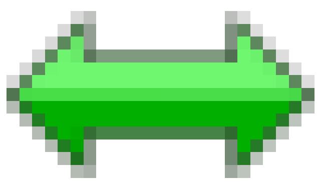
6.3.35 Match stars (dialog)

The "Match stars" dialog is used to select a frame that shall be used during the matching process as a reference. The matching process finds corresponding stars on each source frame with respect to the reference frame.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Match stars*.



2. from the main toolbar:

Stationary vs. moving targets

The first choice is about the character of the object of interest:

1. Stationary target - choose this option for objects that do not move during the observation with respect to the surrounding stars - variable star, exoplanet, etc. The software will ask you to pick up one of the frames as a reference frame; you can also use a catalog file that you prepared while processing a previous observation of the same view field.
2. Moving target - choose this option for objects that changes significantly its position during the observation with respect to the surrounding stars - minor Solar System body, for example. The software will ask you to select at least three frames, called key frames, and you will also need to mark the object on each of the key frames.

Reference frame vs. catalog file

If you process observation of a stationary object, you have also option what to use as a reference for the matching process:

1. To pick one frame out of the source frame and use it as a reference. This frame is then referred to as a reference frame. There is no simple rule which frame you shall choose, selecting a frame with the greatest number of measured objects is usually a good starting point, though. The important idea is that the program can deal with a situation when a measured object is not present on all frames, but it must be present on a reference frame. Thus, make sure that at least the variable star and the comparison star are present of a reference frame.
2. To use a catalog file that has been made during processing of previous run of the same field. When you observe a particular variable star on regular basis, it's tedious to manually select stars and enter the position for every run. Utilizing the catalog files makes it simpler, because the application restores the information from a persistent file.

Stationary object - selecting a reference frame

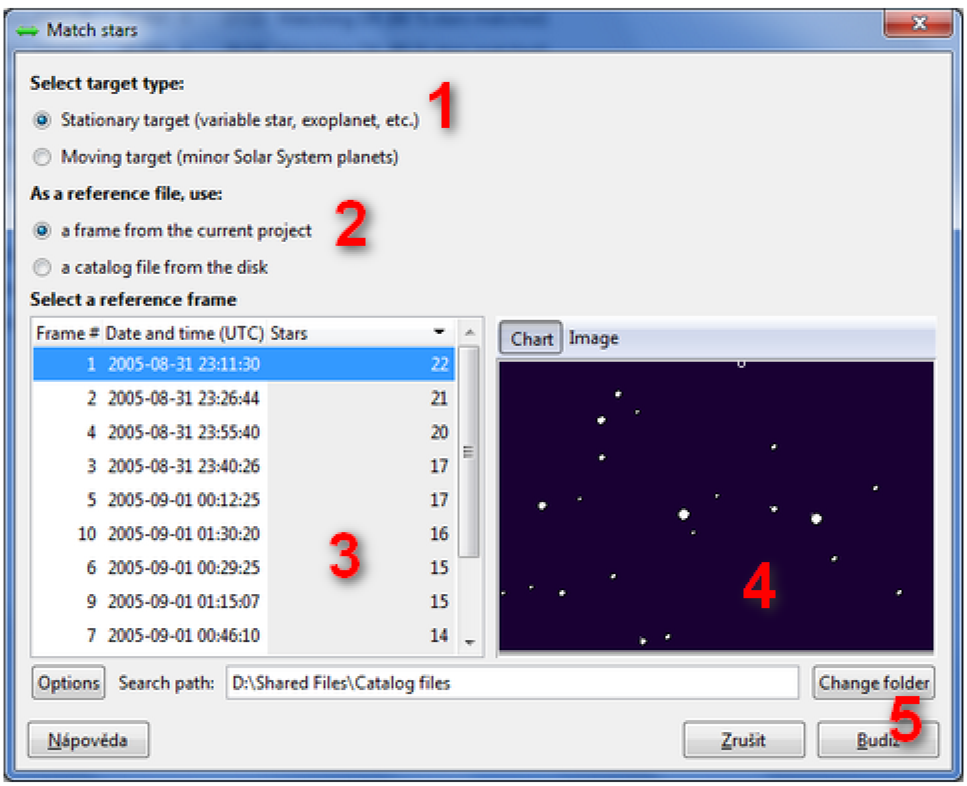


Fig. 53: The dialog for selecting a reference frame

Check the option (1). The list of valid source frames is displayed here (2).

(3) When you select a frame, the preview and short info is displayed here. Double click on the preview to show a larger preview in a separate dialog.

Select a frame.

Click the "Execute" button (4) to start the matching.

Stationary object - browsing the catalog files

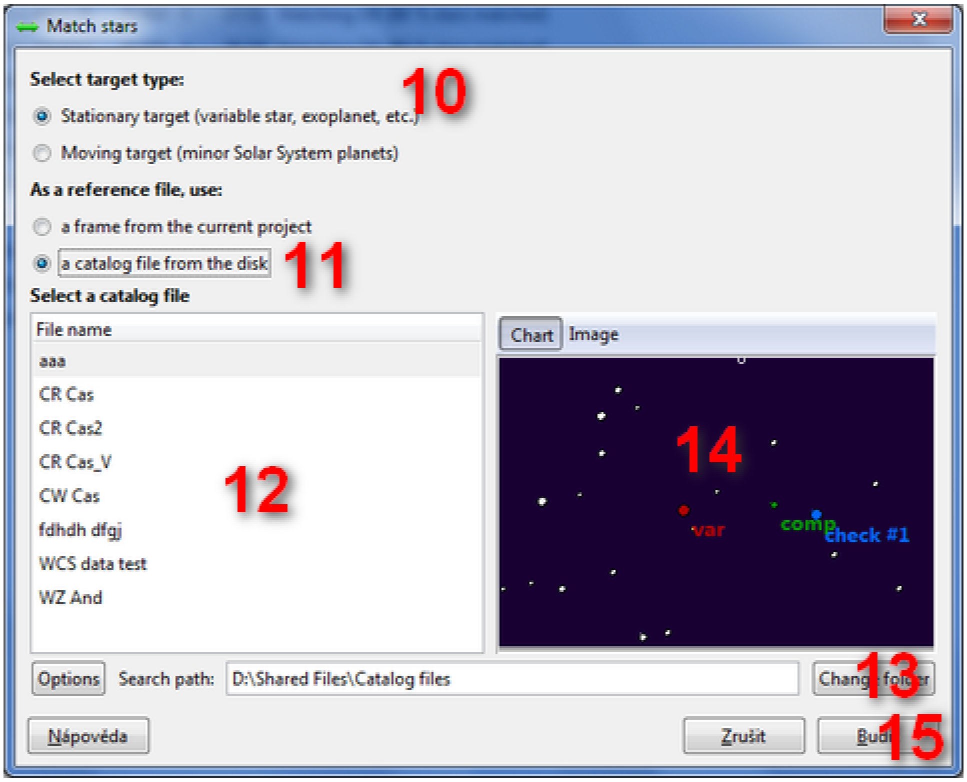


Fig. 54: The dialog for selecting a catalog file

Check the option (10). The list of predefined catalog files is displayed here (11).

(12) You can change the folder in which the files are looked for.

(13) When you select a frame, the preview and short info is displayed here. Double click on the preview to show a larger preview in a separate dialog.

Select a file. It is recommended to use a file that was carried out with the same color filter as your source files, this is not required, though.

Click the "Execute" button (14) to start the matching.

Moving target - defining key frames

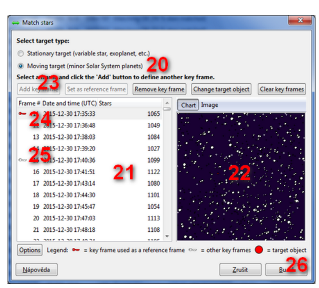


Fig. 55: The Matching dialog in the moving target mode

In the dialog, check the option *Moving target* (20).

List of source frames is presented in the table (21).

When you select a frame, the preview is displayed in the preview area (22).

Click the *Add key frame* button (23) to add the selected frame to the list of key frames.

Use the *Set as a reference frame* button to define which key frame is used as a reference frame. The reference frame is always marked with a red key icon (24), while other key frames are marked with a white key icon (25).

Click the *Remove key frame* to remove the selected frame from the list of key frames.

If you need to change the marked object on one of the key frames, click the *Change target object*.

Click the *Clear key frames* to clear the list of key frames and start again.

Click the "Execute" button (26) to start the matching.

Executing the matching

Click the "Execute" button to start the matching.

- The photometry must be applied before the matching.
- The matching can be applied several times, the old cross-reference data are overwritten.

See also:

Make catalog file (dialog), *Photometry dialog (dialog)*

6.3.36 Merge frames (dialog)

The *Merge frames* dialog is used to start the process of merging CCD frames.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Make* → *Merge frames*.
2. from the main toolbar: 

Setting up the parameters

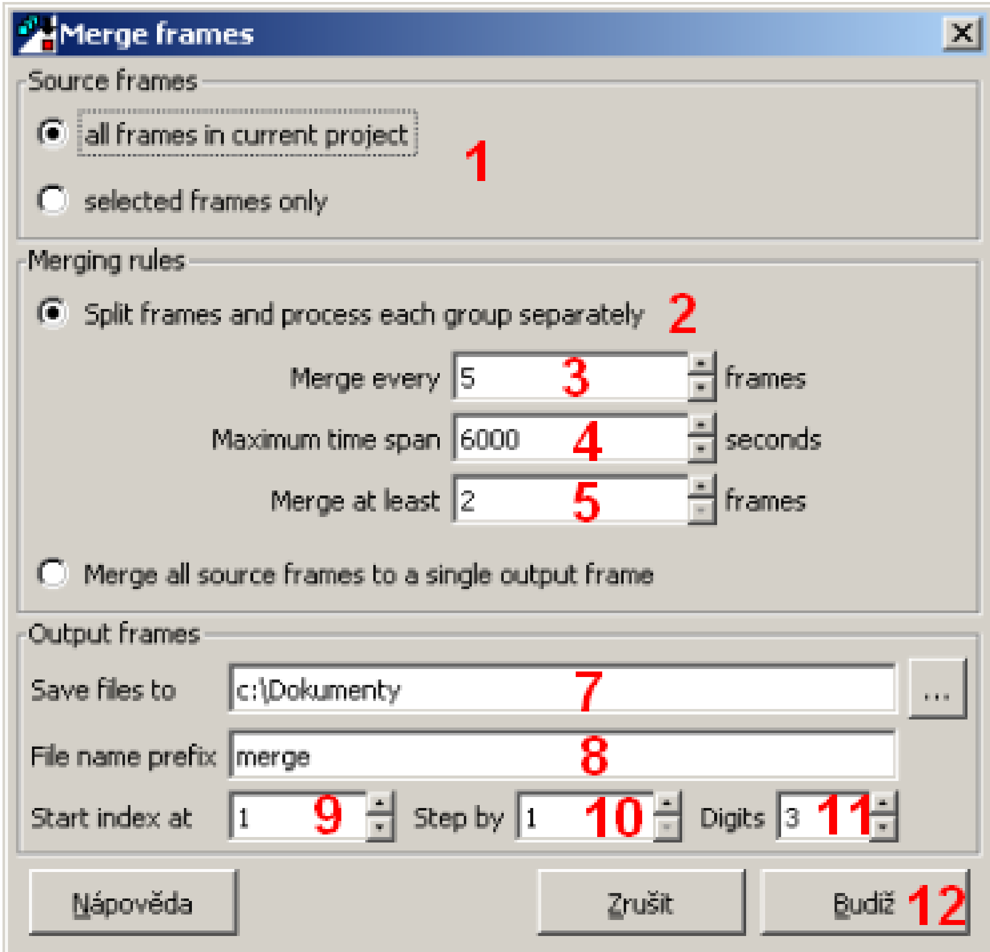


Fig. 56: The "Merge frames" dialog

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files. By means of this option, it is possible to split frames manually by processing a subset of source files at a time.

(2) Check this option to let the program split source frames automatically. Next parameters in the middle pane sets the merging rules. (3) Specify maximum number of source frames merged into a single output frame. (4) Specify maximum time interval between any two frames that can be combined into a single frame. (5) Specify minimum number of source frames. If the there are less frames than this value, the output frame won't be made. This situation may happen if the time interval is too short.

(6) Check this option to make a single output frame.

(7) Enter a path to the directory where output files shall be saved to. You can use the ellipsis button to open a new dialog that allows you to browse the files and folders.

(8) Enter a string that the new files shall begin with. The prefix is followed by a dot, ordinal number of a frame (see below), a dot and 'fts' extension.

(9) Enter an ordinal number of the first output frame. (10) Enter a step increment for ordinal numbers of frames. The ordinal number is left-padded with zeroes to specified number of digits (11).

Merging frames

Click on the "Execute" button (12) to start the operation.

- All calibration steps (bias, dark and flat correction), photometry and matching must be made before merging frames.

6.3.37 Message log (dialog)

The "Message log" shows all messages from the last process. You can check the result of the last process (photometry, matching, . . .) here.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Show message log*.

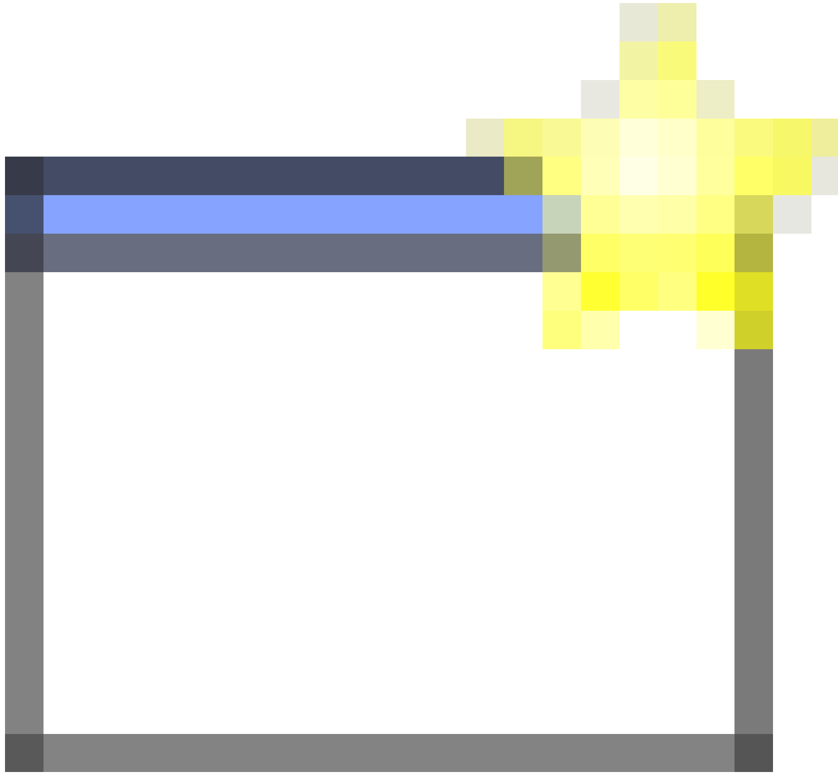
6.3.38 New project (dialog)

The *New project* dialog is used to enter name, location and select a type of a new project.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Project* → *New*.



2. from the main toolbar:

The dialog controls

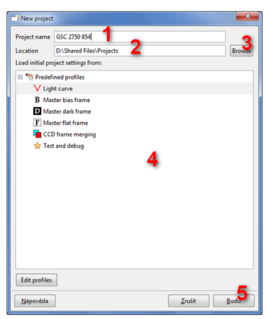


Fig. 57: The "New project" dialog

(1) Enter a project name. Because the name of the file that keeps track of the data related to the project, the project file, is derived from the name, some characters cannot appear in the project name, do not use: / ? % * : | " < and >.

The entry (2) shows a path to the directory where a new project will be created. You can edit the path directly in the entry field or you can also click the *Browse* button (3) to select a directory in a separate dialog.

(4) List of existing profiles is shown in the table. The profiles are divided into two categories - user-defined profiles and predefined profiles.

Click the button (5) to proceed.

See also:

Projects, *Profiles*, *Load profile (dialog)*.

6.3.39 Object coordinates (dialog)

The "Object coordinates" dialog is used to specify the celestial position of the observed object. This information is necessary to compute the heliocentric correction and the air mass coefficient.

Sources of coordinates

There are several possibilities how to enter the object celestial position:

- To enter equatorial coordinates manually to edit fields in the dialog.
- To pick out an item from a table predefined positions. A user can add records to the table and edit them.
- To search out the position in a catalog of variable stars. The GCVS, NSV, NSVS and BRKA catalogs are supported. They are not included in the installation and must be installed and configured separately.
- To get the position from the reference frame, i. e. a source frame or a catalog file that has been used for the matching.

Specifying the position manually

Select the source of coordinates (1).

(2) Enter object designation here. Although this field is not required, it is recommended to fill in a meaningful object identification.

Enter object right ascension to the text box (3) in hours. Use the hexagesimal format, separate the fields by a space character.

Enter object declination to the text box (4) in degrees. Use the hexagesimal format, separate the fields by a space character.

(5) Source and Remarks are optional fields. You can enter any information that you find useful. There are no formatting rules for these fields.

Click on the "Add" button (6) to add an object into the table of predefined objects (7).

Click the "OK" button (8) to save the coordinates.

Using the table of predefined position

Select the source of coordinates (10).

The table of predefined positions is displayed in the table (11). Right-clicking a table opens a context menu.

Select an item in the table with a single left click to recall the data. The data are shown in the text boxes above the table (12).

Click the "Add" button (13) to make a new item to the table with data filled in the text boxes. Click the "Save" (14) button to update selected record. Click the "Remove" button (15) to remove the selected record from the table.

Click the "OK" button (16) to confirm the dialog.

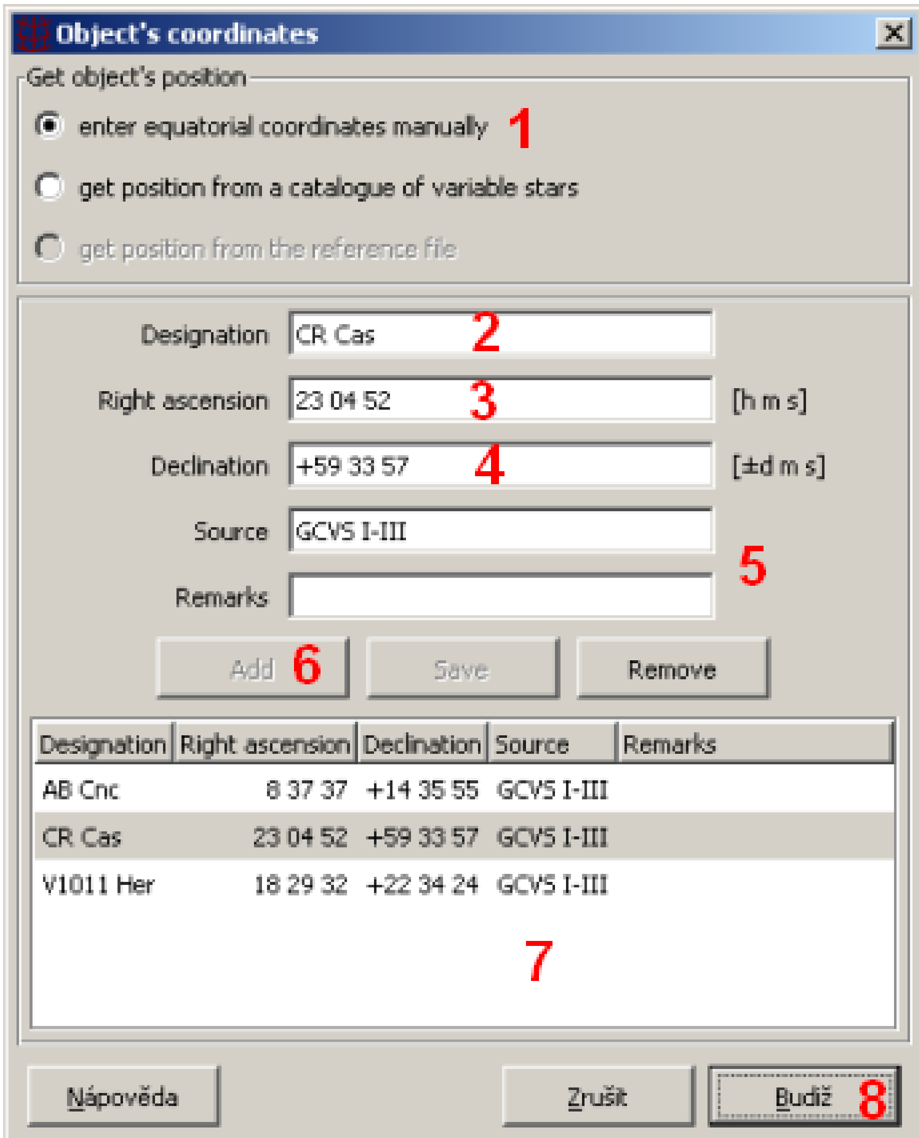


Fig. 58: Specifying the object position manually

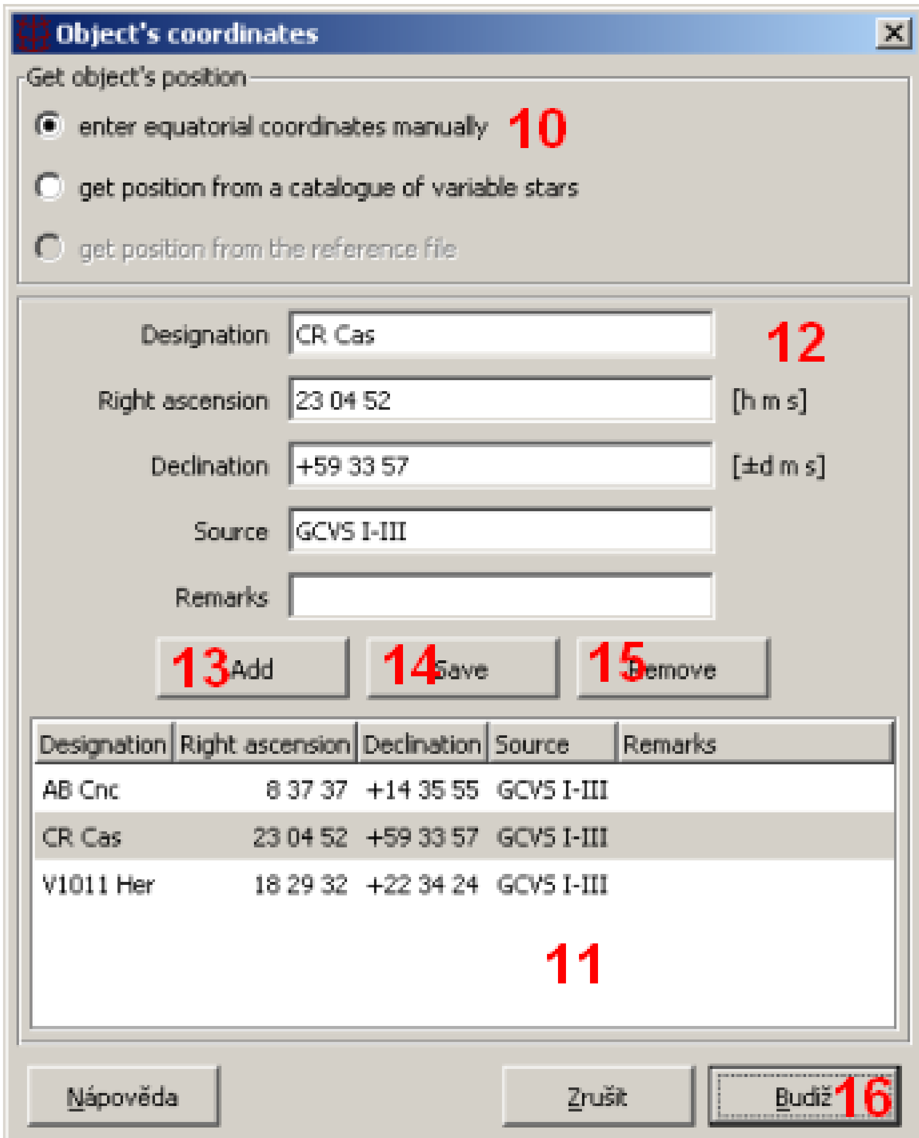


Fig. 59: Getting the object coordinates from the table of predefined positions

Searching in a catalog of variable stars

The catalog files are not included in the program's installation package. You have to download and install them separately.

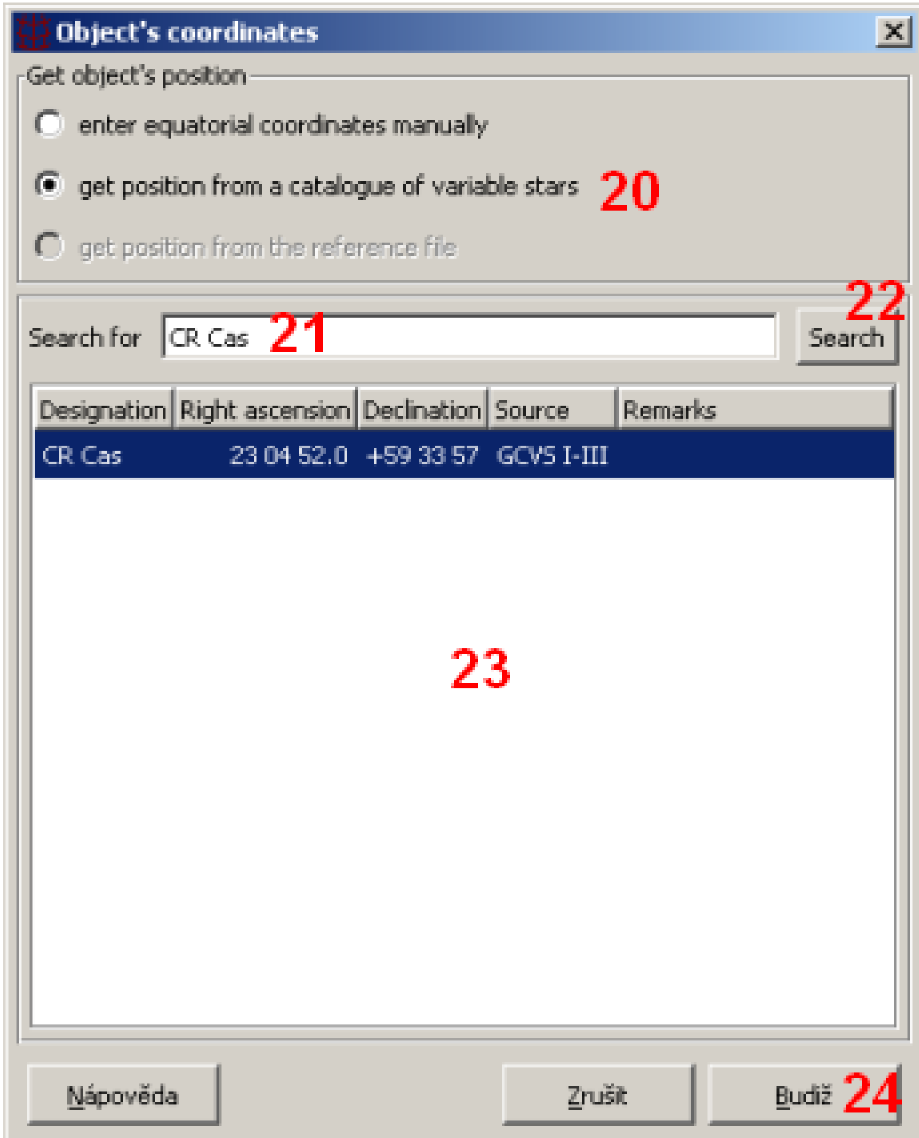


Fig. 60: Searching the variable star catalogs

Select the source of coordinates (20).

Enter the variable star designation into the text box (21). The search is not case sensitive.

Click the "Search" button (22) to start the search. The records that match are displayed in the table below (23).

Select an item in the table with a single left click. Right-clicking a table opens a context menu.

Click the "OK" button (24) to save the coordinates.

Using position from the reference frame

This option is available only when the reference frame includes the information about the position of the object.

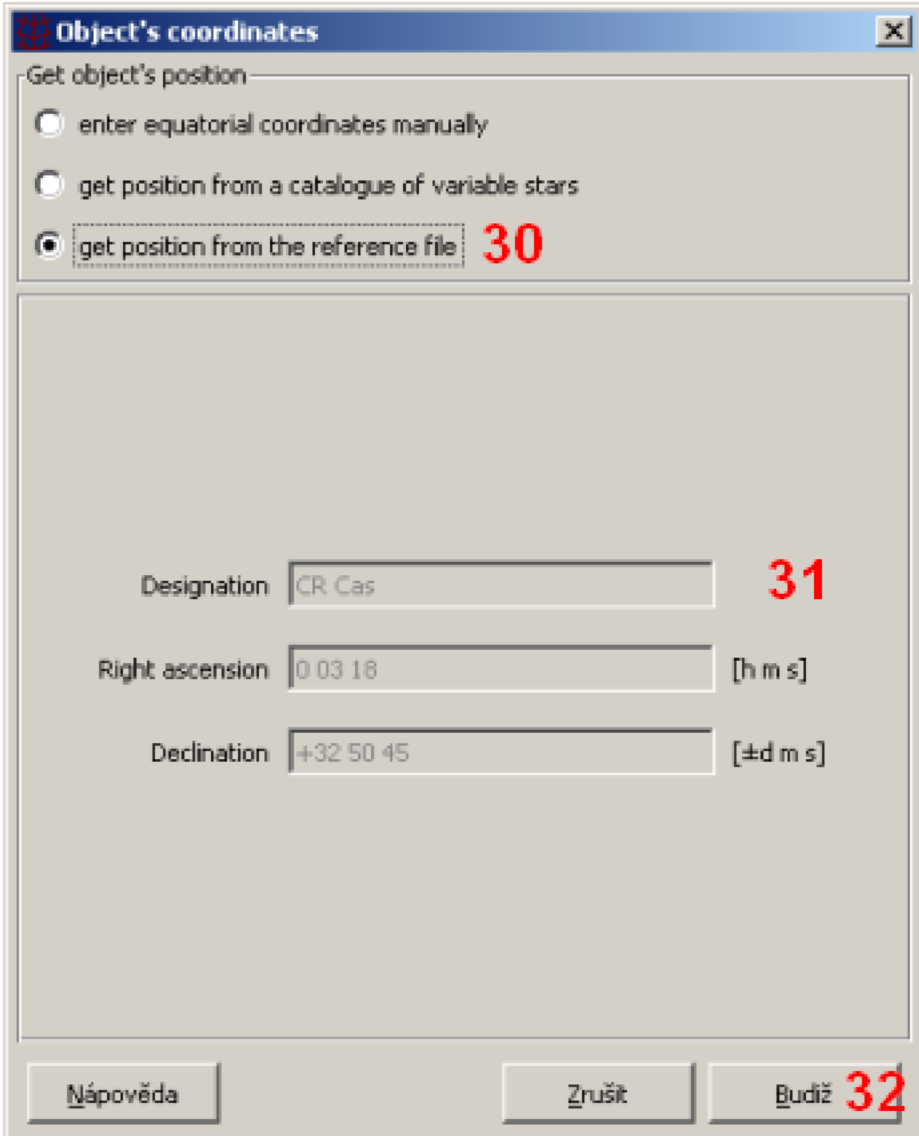


Fig. 61: Object coordinates from the reference frame

Select the source of coordinates (30).

(31) The equatorial coordinates of the object is displayed in the text boxes.

Click the "OK" button (32) to save the coordinates.

See also:

Match stars (dialog), *Make catalog file (dialog)*

6.3.40 Object properties (dialog)

The "Object properties" dialog is used to display a table or a plot of various object properties as a function of time.

Activating the dialog

The dialog can be activated:

- from the main menu: *Plot* → *Object properties*.

The "Plot object properties" dialog appears. Confirm the dialog.

Object properties dialog

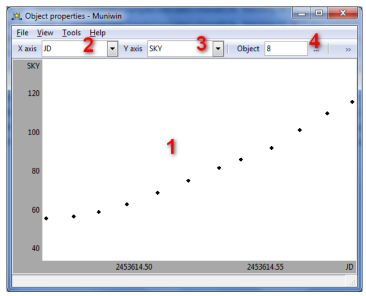


Fig. 62: Object properties

(1) The actual data set is shown here.

(2) You can switch the labels on the X axis between Julian date (JD) or date and time (UTC).

(3) The list of available data sets is displayed here.

(4) The ID of the selected object is shown here. Click the ellipsis button (. . .) to check the chart or select another object.

Data sets

The following data sets are available:

- *X* - The horizontal position of the object's center w.r.t. the frame border; in pixels
- *Y* - The vertical position of the object's center w.r.t. the frame border; in pixels
- *SKY* - The mean local background level computed in the "sky annulus"; in ADU
- *FWHM* - The estimated de-focus of the object expressed as the Full Width at Half Maximum value; average from the two values measured in the horizontal and the vertical direction; in pixels
- *MAG* - Absolute instrumental brightness of the object; in magnitudes

Context menu

You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. It provides following functions:

- Show frame - it shows a preview to a selected frame. It is not allowed when more than one frame is selected.
- Show properties - it opens a new dialog with properties of selected frame. It is not allowed when more than one frame is selected.
- Delete from data set - selected measurements are removed from the current curve, the data will be shown again when you make a new curve or *Rebuild* the actual curve.
- Remove from project - source frames corresponding to the selected measurements are removed permanently from the list of input files and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Statistics

The *Statistics* is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

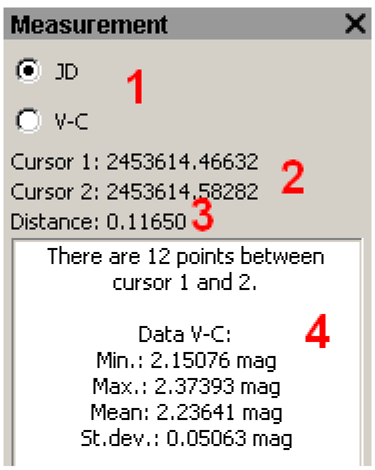
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Air mass curve (dialog), *CCD temperature (dialog)*, *Light curve (dialog)*, *Track curve (dialog)*

6.3.41 Observer coordinates (dialog)

The "Observer coordinates" dialog is used to specify the geographic coordinates of the observed object. This information is necessary to compute the air mass coefficient.

Sources of coordinates

There are several possibilities how to enter the observer geographic location:

- To enter geographic coordinates manually to the edit fields in the dialog.
- To pick out an item from a table predefined locations. A user can add records to the table and edit them.
- To use the default location. The default location can be changed in the "Preferences" dialog.
- To get the location from the reference frame, i. e. a source frame or a catalog file that has been used for the matching.

Specifying the location manually

Select the source of coordinates (1).

(2) Enter location designation here. Although this field is not required, it is recommended to fill in a meaningful object identification.

Enter observer longitude to the text box (3) in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'E' character at the first position in a string to indicate that the location is on the eastern hemisphere or 'W' character for locations on a western hemisphere.

Enter observer latitude to the text box (4) in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'N' character at the first position in s string to indicate that the location is on the north hemisphere or 'S' character for locations on a southern hemisphere.

(5) Remarks is an optional field. You can enter any information that you find useful. There are no formatting rules for this field.

Click on the "Add" button (6) to add an object into the table of predefined objects (7).

Click the "OK" button (8) to save the coordinates.

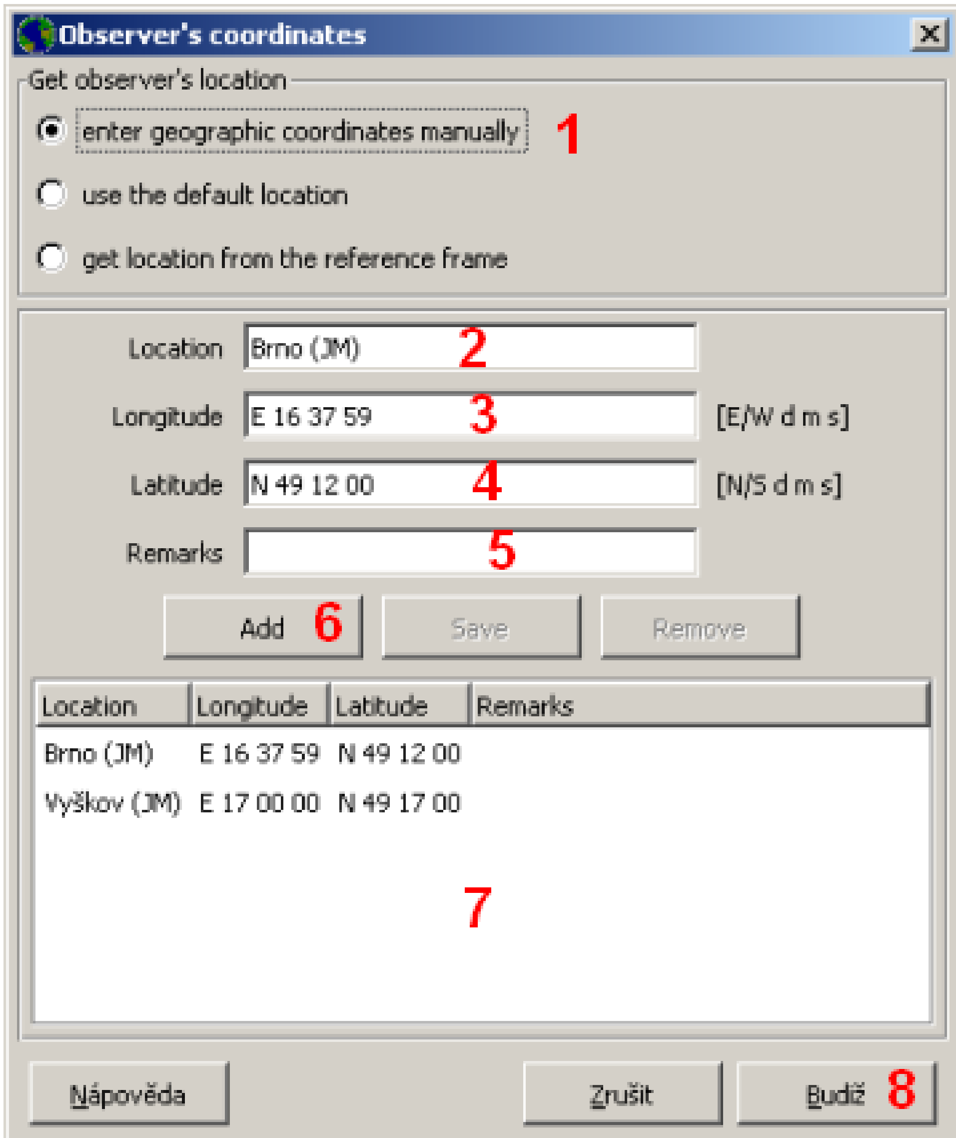


Fig. 63: Specifying the observer location manually

Using the table of predefined locations

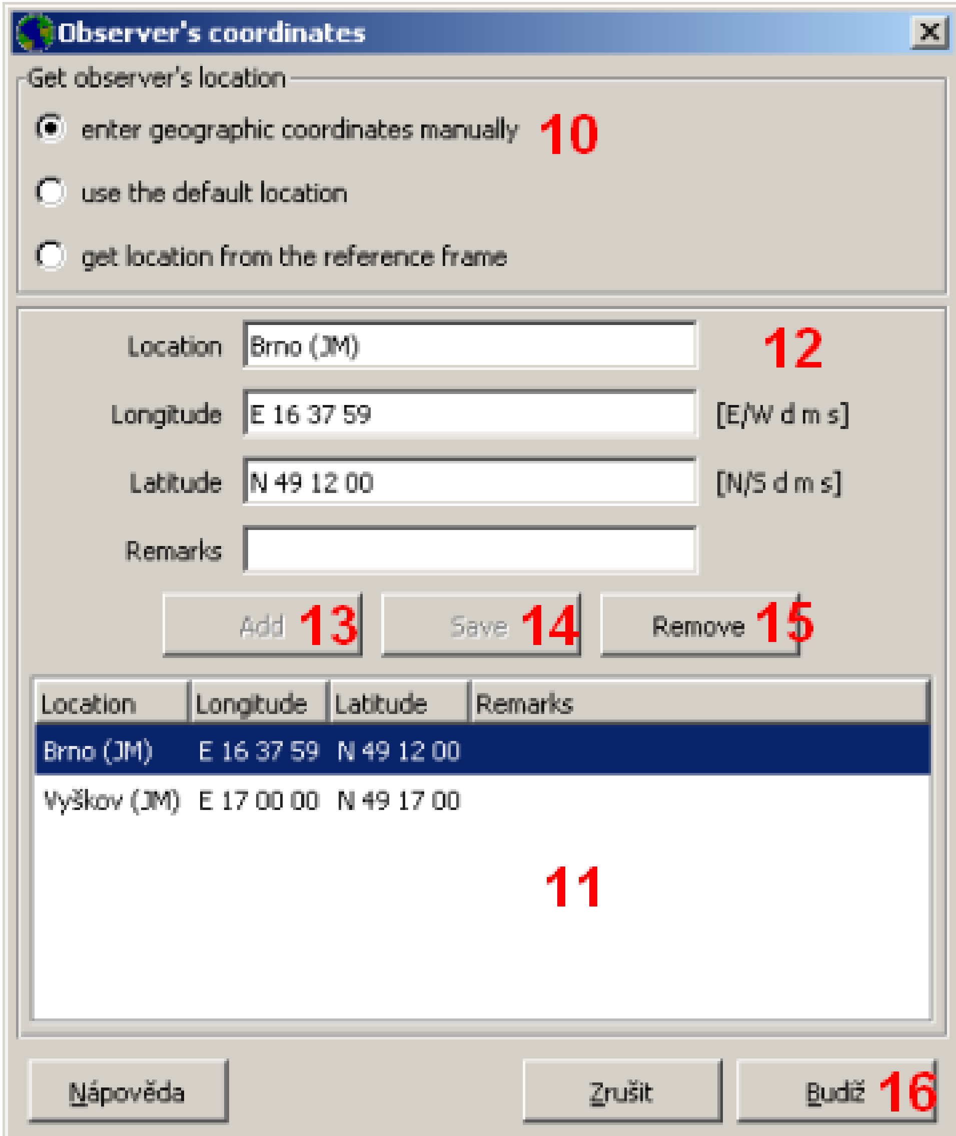


Fig. 64: Getting the observer coordinates from the table of predefined locations

Select the source of coordinates (10).

The table of predefined locations is displayed in the table (11). Right-clicking a table opens a context menu.

Select an item in the table with a single left click to recall the data. The data are shown in the text boxes above the table (12).

Click the "Add" button (13) to make a new item to the table with data filled in the text boxes. Click the "Save" (14) button to update selected record. Click the "Remove" button (15) to remove the selected record from the table.

Click the "OK" button (16) to confirm the dialog.

Using the default location

The default geographic coordinates can be adjusted in the "Preferences" dialog.

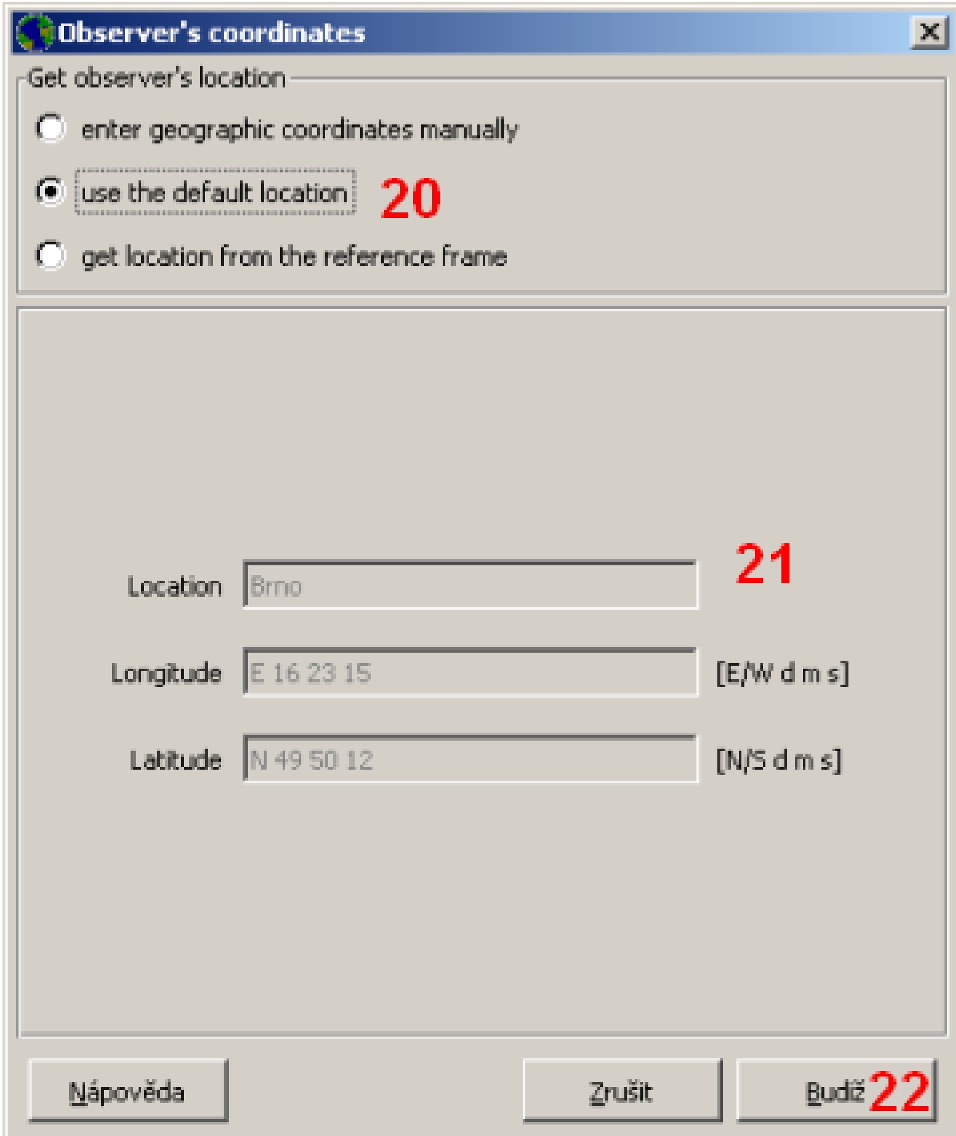


Fig. 65: Using the default geographic location

Select the source of coordinates (20).

(21) The default geographic coordinates are displayed in the text boxes.

Click the "OK" button (22) to save the coordinates.

Using location from the reference frame

This option is available only when the reference frame includes the information about the location of the observer.

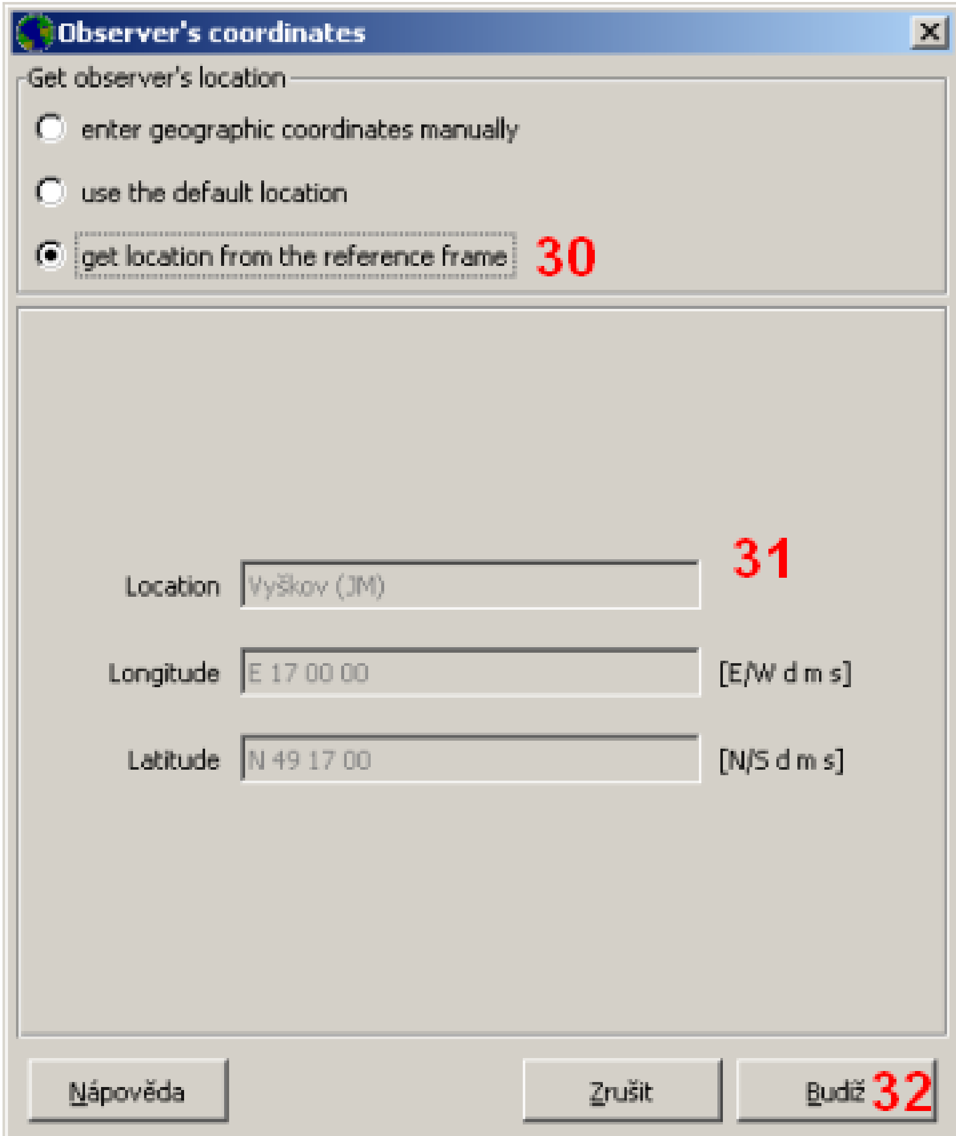


Fig. 66: Observer coordinates from the reference frame

Select the source of coordinates (30).

(31) The geographic coordinates of the observer is displayed in the text boxes.

Click the “OK” button (32) to save the coordinates.

See also:

Match stars (dialog), *Make catalog file (dialog)*

6.3.42 Open file (dialog)

The "Open file" dialog is used to show content of an external file. A file is displayed in a separate preview window.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Open file*.

File browsing

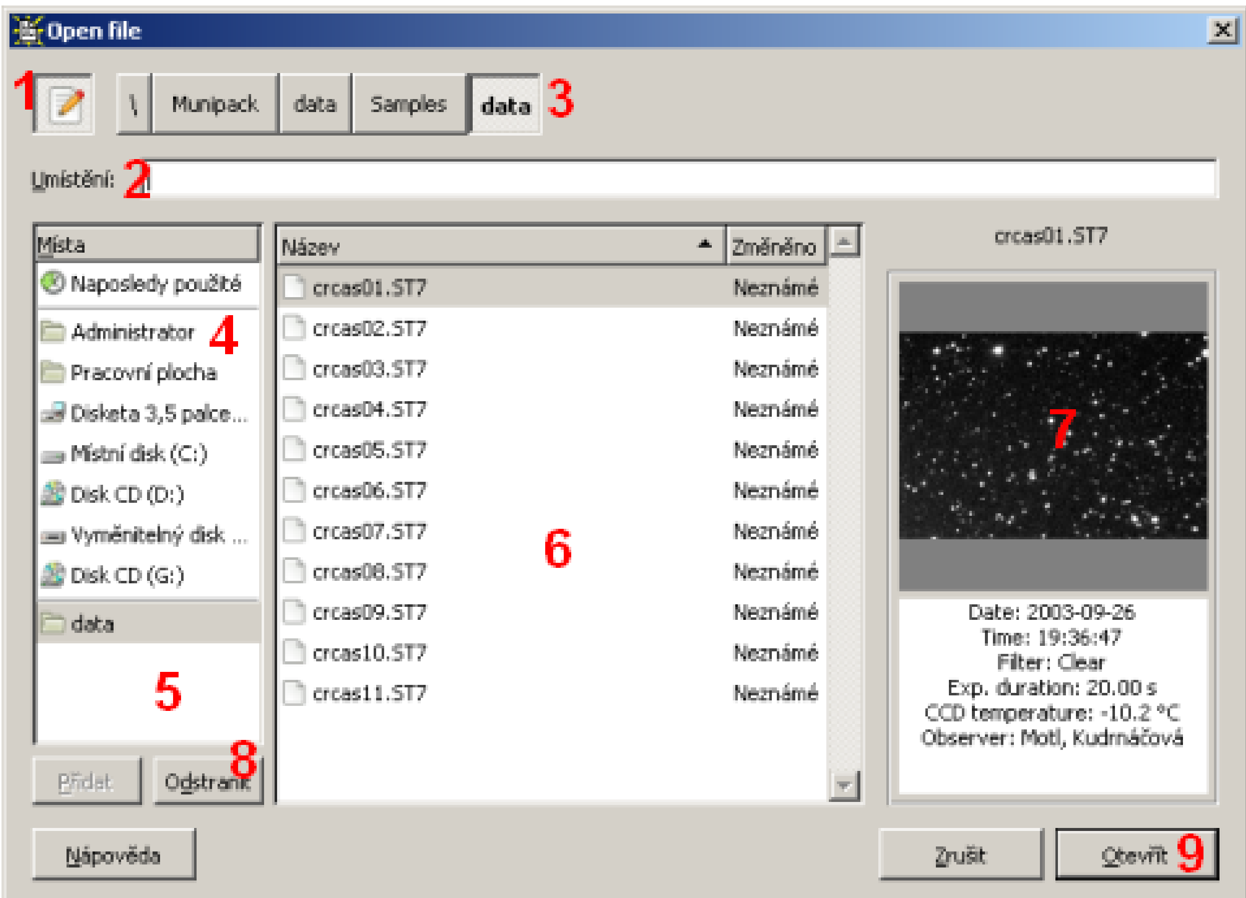


Fig. 67: The dialog for browsing files

The button "Type a file name" (1) shows and hides the "Location" text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

The path to the current folder is displayed at the top of the dialog (3). You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

Click the "Open" button (9) to open a file in a separate window.

See also:

Image file (window), *Photometry file (window)*, *Catalog file (window)*, *Graph (window)*

6.3.43 Open project (dialog)

The "Open project" dialog is used to load an existing project into the *Muniwin* program.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Project* → *Open* → *Project*.

2. from the main toolbar:

File browsing

The button (1) shows and hides the *Location* text box. The keyboard shortcut Ctrl+L key combination does the same action.

In the "Location" text box (2) you can type a path to a file. If you don't type any path, the name of the selected file will be displayed. You can also type the first letters of the name: it will be auto-completed and a list of file names beginning with these letters will be displayed.

The path to the current folder is displayed at the top of the dialog (3). You can navigate along this path by clicking on an element.

(4) Here, you can access to your main folders and to your store devices.

(5) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

The contents of the selected folder is displayed here (6). Change your current folder by double left clicking on a folder in this panel. Select a file with a single left click. You can use Shift and Ctrl modifiers to select multiple files. Right-clicking a folder name opens a context menu.

If the selected file is a file recognized by the C-Munipack, the preview and short info is displayed in the right part of the dialog (7). Double click on the preview to show a larger preview in a separate dialog.

(8) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

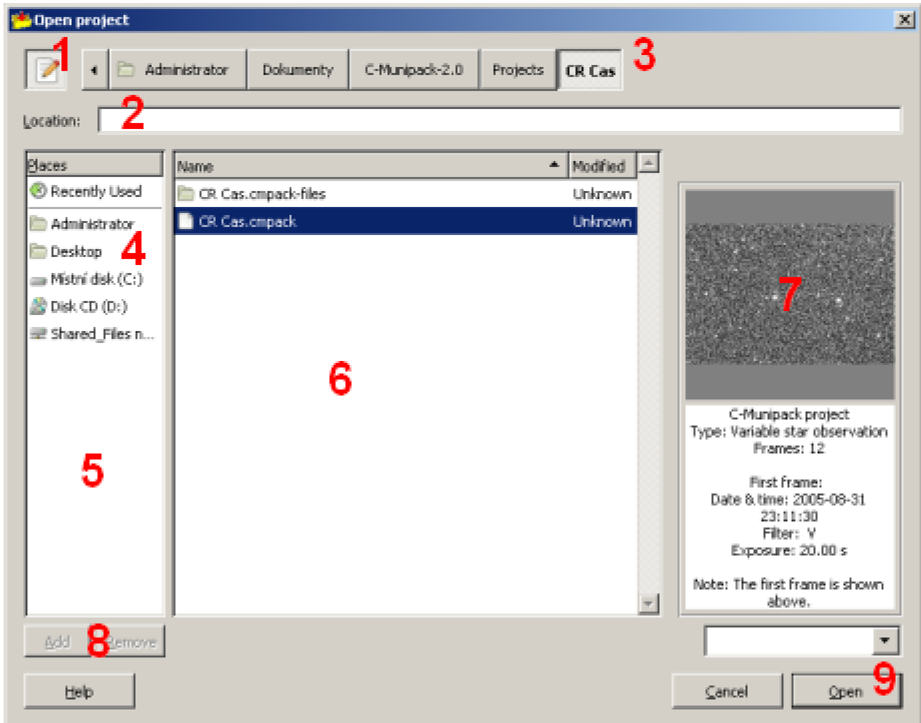


Fig. 68: The dialog for loading an existing project

See also:

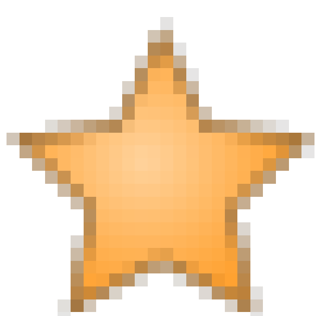
Projects, *New project (dialog)*, *Open file (dialog)*, *Export project (dialog)*

6.3.44 Photometry dialog (dialog)

The "Photometry" dialog is used to start the photometry process. The photometry takes the calibrated working copy of the source frames, detects the objects and measures their brightness and other parameters. Results are stored to separate files, which are called photometry files.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Photometry*.
2. from the main toolbar: 

Running photometry

Any frame calibration steps (bias, dark, flat and time correction) must be applied before the photometry.

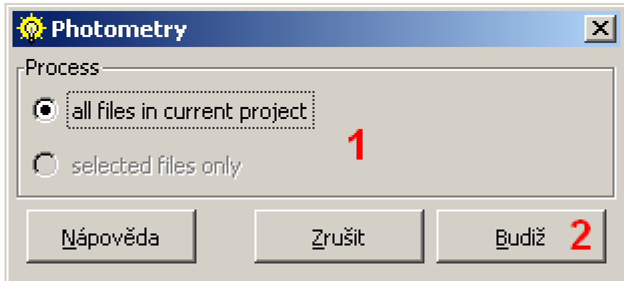


Fig. 69: The dialog for starting the photometry

(1) It is possible to apply the operation either on all source files in the project or on the files that are currently selected in the table of input files. This option is useful when you are finding the ideal values of the photometry settings. It is strongly recommended to use a single set of settings for all frames in a set.

Click the "Execute" button (2) to start the operation.

- All calibrations (bias, dark, flat and time correction) must be applied before the photometry.
- The photometry can be applied several times, the old photometry files are overwritten.

Photometry on aligned frames

If the source frames have been already aligned, for example when they were creating by merging frames, you can alternatively use a *special photometry and matching mode*.

See also:

Match stars (dialog), *Express reduction (dialog)*, *Photometry dialog (aligned frames)*

6.3.45 Photometry dialog (aligned frames)

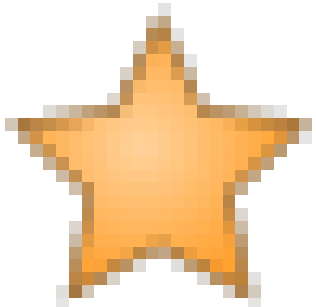
The "Photometry" dialog is used to start the photometry process. Unlike the *Standard photometry dialog*, this dialog is shown when the project type is set to "Light curve (aligned frames)". In this mode, the input frames needs to be aligned. For example, thay can be created by *merging frames*. The user is expected to mark objects on interest manually. The software skips the object detection phase and continues with measuring brightness of specified objects. Results are stored to separate files, which are called photometry files. The user does not need to run the *matching process*.

Activating the dialog

You have to set the project type to "Light curve (aligned frames)" - see *here*.

The dialog can be activated:

1. from the main menu: *Reduce* → *Photometry*.

2. from the main toolbar: 

Running photometry

Usually, it is not neccessary to perform any frame calibration steps (bias, dark, flat and time correction) in this mode. The calibration takes places before frame merging.

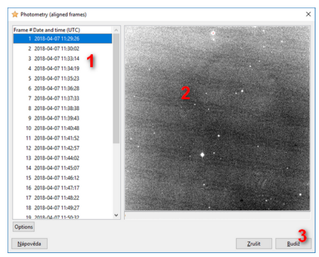


Fig. 70: The dialog for the photometry of aligned frames

(1) Choose one of the source frames

(2) Right click on an image to create an object on a place of mouse cursor. From the menu, select object type. Right click on an object to change its type or remove it.

Click the “Execute” button (3) to start the operation.

- The photometry can be applied several times, the old photometry files are overwritten.
- No frame matching is needed, you can proceed to making a light curve.

Known variable stars

If the source frames contain World Coordinate System (WCS) data, the software can show positions of known variables on the frame. You have to specify paths to the catalog files in the program settings (see *Environment options (dialog)*). For each catalog, the toobar contains one check box that turns the catalog on and off. By clicking on the icon, a standard color selection dialog appears.

See also:

Light curve (dialog), *Photometry dialog (dialog)*, *Environment options (dialog)*

6.3.46 Photometry file (window)

This preview window is used to display the content of a photometry file.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools* → *Open file*.

When a file is opened, the program checks its content and decides which kind of preview window will be activated. Each file is presented in a separate window.

Dialog controls

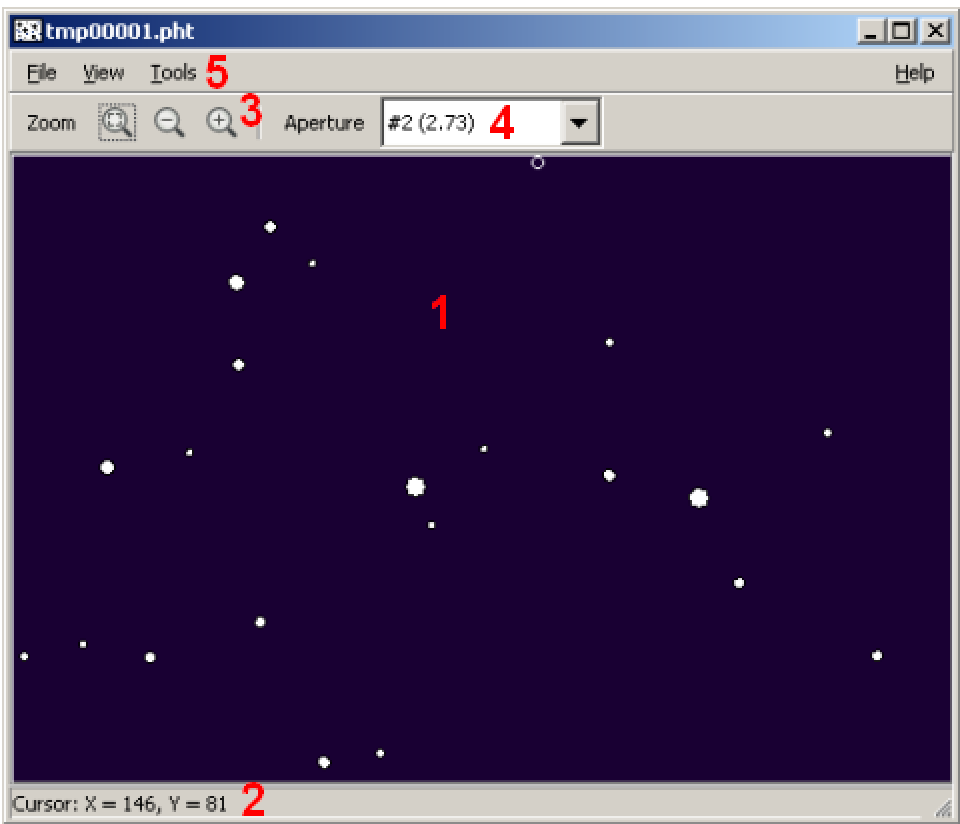


Fig. 71: Preview window for photometry files

(1) The chart is displayed in the preview area. It is possible to switch between two rendering modes - displying file as a chart or as a table of objects.

(2) When you place a cursor over an object, the position and brightness (if available) is displayed in the status bar.

(3) You can zoom the preview in and out by means of the zoom icons on the toolbar.

(4) You can change the aperture for which brightness of objects are rendered.

(5) The local menu bar provides following functions:

- Menu File:

  - Open - open another file, this is an equivalent to selection *Tools* → *Open file* from the main window.
  - Export - depending on the current display mode:
    - If a chart is shown, the function export the chart or image to a file in the PNG or JPEG format. The save dialog provides several options, that allows adjusting the size of the resulting image.
    - If a table is shown, the function export the table to a file in the CSV or TEXT format. The save dialog provides several options, that allows adjusting the content of the file.
  - Show properties - display the further details about the file. Full header preview is available in separate window.
  - Close - close this window
- Menu View:
  - Chart - show the objects as a chart
  - Table - show the table of objects
  - Rulers - turn on/off the rules that are shown on the top and left side of the preview area
- Menu Tools:
  - **Object inspector - if this tool is activated, left-click an object to display**
    its properties. The information is presented in the right part of the dialog.

Object inspector tool

The Object inspector tool is a tool which displays that the program registers about an object on a frame. The main purpose of this tool is for testing and debugging. Unlike the Quick Photometry, the Object Inspector shows results, that has been obtained during the "full" photometry. Because of this, calibration and photometry must be performed first. The results are more relevant.

To activate the tool:

1. From the local menu, select *View* → *Chart only* or *Image and chart* to show the objects.
2. From the local menu, select *Tools* → *Object inspector*. A new panel on the right side of the preview window appears.

Using the left mouse button, click on the image (1), to select an object. The object is highlighted and its properties are displayed in the right panel (2).

The following object parameters are presented:

- Object # - object's ordinal number on the current frame.
- Reference ID - object's ordinal number on a reference frame.
- Center - coordinates of the object's centroid
- Brightness - instrumental brightness of the object in magnitudes.
- Error - error estimation of brightness in magnitudes.

Several dimensions are presented in the image area (3):

- Two blue circles show the annulus which is used to estimate the background properties.
- A green circle shows the size of the aperture.

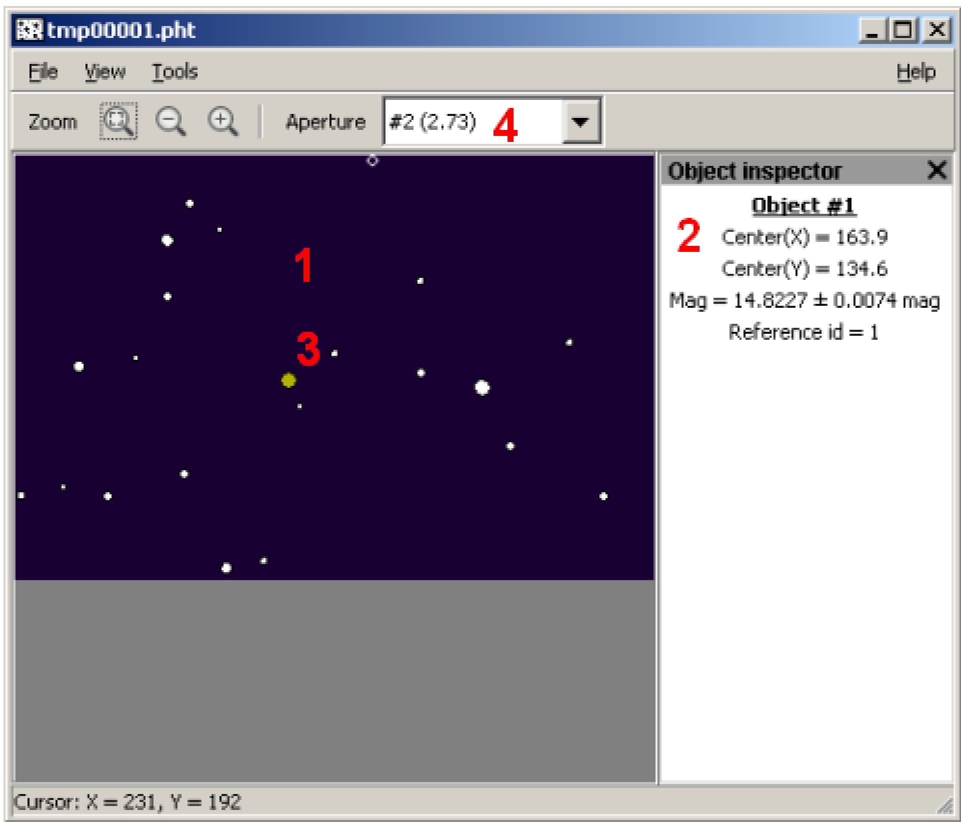


Fig. 72: Object Inspector tool

(4) Here, you can change the current aperture.

See also:

Open file (dialog)

6.3.47 Plot air mass (dialog)

The “Plot air mass” dialog is used to create a curve of air mass coefficients and altitudes as a function of time. These values to useful in data post-processing to compute the extinction coefficients.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Plot* → *Air mass*.

Making a plot of air mass

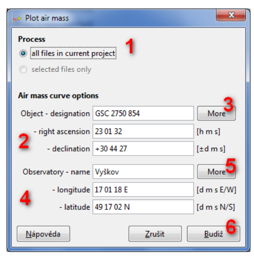


Fig. 73: Plot air mass (dialog)

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

(2) Specify object’s designation and object coordinates into the edit fields. Enter object’s right ascension in hours. Use the hexagesimal format, separate the fields by a space character. Enter object’s declination in degrees. Use the hexagesimal format, separate the fields by a space character. Click the button (3) to retrieve object’s coordinates from a table of predefined objects or a catalog of variable stars.

(4) Specify observer’s geographic coordinates into the edit fields. Enter observing location designation (i.e. city name). Enter the longitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter ‘E’ character at the first position in a string to indicate that the location is on the eastern hemisphere or ‘W’ character for locations on a western hemisphere. Enter observer’s latitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter ‘N’ character at the first position in s string to indicate that the location is on the north hemisphere or ‘S’ character for locations on a southern hemisphere. Click the button (5) to retrieve observer’s coordinates from a table of predefined locations.

Click the button (6) to proceed.

See also:

Air mass curve (dialog)

6.3.48 Plot CCD temperature (dialog)

The "Plot CCD temperature" dialog is used to set up the initial parameters for a new plot of CCD temperature.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Plot* → *CCD temperature*.

Making a plot of CCD temperature

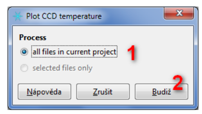


Fig. 74: Plot CCD temperature (dialog)

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

Click the button (2) to proceed.

See also:

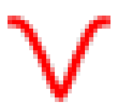
CCD temperature (dialog)

6.3.49 Plot light curve (dialog)

The "Plot light curve" dialog is used to set up the initial parameters for a new light curve.

Activating the dialog

The dialog can be activated:

- from the main menu: *Plot* → *Light curve*.
- from the main toolbar: 

Making a light curve

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

(2) Set up the light curve options:

- *Compute heliocentric correction* - is option if you want to include the heliocentric Julian date and heliocentric correction of the observed object to the resulting data. If so, you have to fill in the object's coordinates below.
- *Compute air mass coefficients* - check this option if you want to include the air mass coefficient and apparent altitude of observed object to the resulting data. If so, you have to fill in the object's celestial coordinates and observer's geographic coordinates below.

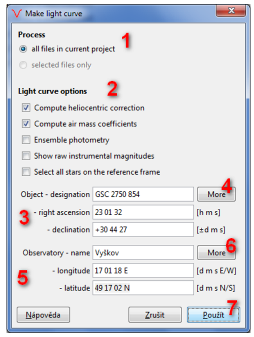


Fig. 75: Plot light curve (dialog)

- *Ensemble photometry* - if this option is enabled the *Ensemble photometry* method is used to reduce the random errors of the resulting light curve by combining measurement from multiple comparison (constant) stars.
- *Show raw instrumental magnitudes* - by default the light curve consists of differential magnitudes (differences between two objects). If this option is checked, the light curve will consists of raw instrumental magnitudes, as they were determined in the aperture photometry. Please note, that the instrumental magnitudes does not correspond to absolute magnitude of objects and without further processing, these values are meaningless.
- *Select all stars on the reference frame* - check this option to create a light curves for all objects on the reference frame. If the differential magnitudes shall be computed, you will have to select at least one comparison star. This option is useful if you want to export complete photometry data for further processing.

Note: If you want to save your data in AAVSO extended format, make a light curve with differential magnitudes for one variable star - in simple way: do *not* check the last two options.

(3) Specify object's designation and object coordinates into the edit fields. Enter object's right ascension in hours. Use the hexagesimal format, separate the fields by a space character. Enter object's declination in degrees. Use the hexagesimal format, separate the fields by a space character. Click the button (4) to retrieve object's coordinates from a table of predefined objects or a catalog of variable stars.

(5) Specify observer's geographic coordinates into the edit fields. Enter observing location designation (i.e. city name). Enter the longitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'E' character at the first position in a string to indicate that the location is on the eastern hemisphere or 'W' character for locations on a western hemisphere. Enter observer's latitude in degrees. Use the hexagesimal format, separate the fields by a space character. Enter 'N' character at the first position in s string to indicate that the location is on the north hemisphere or 'S' character for locations on a southern hemisphere. Click the button (6) to retrieve observer's coordinates from a table of predefined locations.

Click the button (7) to proceed.

See also:

Light curve (dialog)

6.3.50 Plot object properties (dialog)

The "Plot object properties" dialog is used to set up the initial parameters for a new plot of object properties.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Plot* → *Object properties*.

Making a plot of object properties

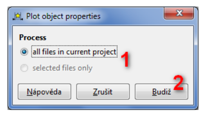


Fig. 76: Plot object properties (dialog)

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

Click the button (2) to proceed.

See also:

Object properties (dialog)

6.3.51 Plot track curve (dialog)

The "Plot track curve" dialog is used to set up the initial parameters for a new track curve.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Plot* → *Track curve*.

Making a plot of track curve

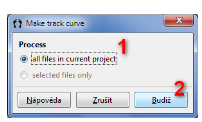


Fig. 77: Plot track curve

(1) It is possible to include all source files in the project or the files that are currently selected in the table of input files.

Click the button (2) to proceed.

See also:

Track curve (dialog)

6.3.52 Process new frames (dialog)

The "Process new frames" dialog is used in the incremental processing. This feature allows an user to reduce a small set of frames and when this set is enlarged by adding a new files into the project, the same rules can be applied to the new files without much user interaction.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Process new files*.
2. from the main toolbar: 

The dialog controls

Check the option (1) if the new files has been already added to the project. If the second option is checked (2), the program will search for new frames in a directory and add them to the project.

(3) Enter path to the directory where the program shall search for new files. You can use the ellipsis button to open a new dialog that allows you to browse the files and folders.

(4) Check this option to include all subdirectories when searching for new files.

You can also specify the constraints, which files must meet:

(5) Check this option to include files whose names start with a certain string. Enter the file name prefix to the text box. Files that begin with the string are processed. The replacement characters "*" and "?" are not supported here.

(6) Check this option to include frames which has been carried out with specified color filter. Enter the filter name to the text box, search is not case sensitive.

(7) Check this option to include frames with 'object name' field equal to specified string. Enter the object name to the text box, search is not case sensitive.

(8) Check this option to start a background process that periodically checks the specified path and processes new files that turn up in the path.

Click the "OK" button (9) to start the operation.

See also:

Express reduction (dialog), *Bias correction (dialog)*, *Dark correction (dialog)*, *Flat correction (dialog)*, *Photometry dialog (dialog)*, *Match stars (dialog)*

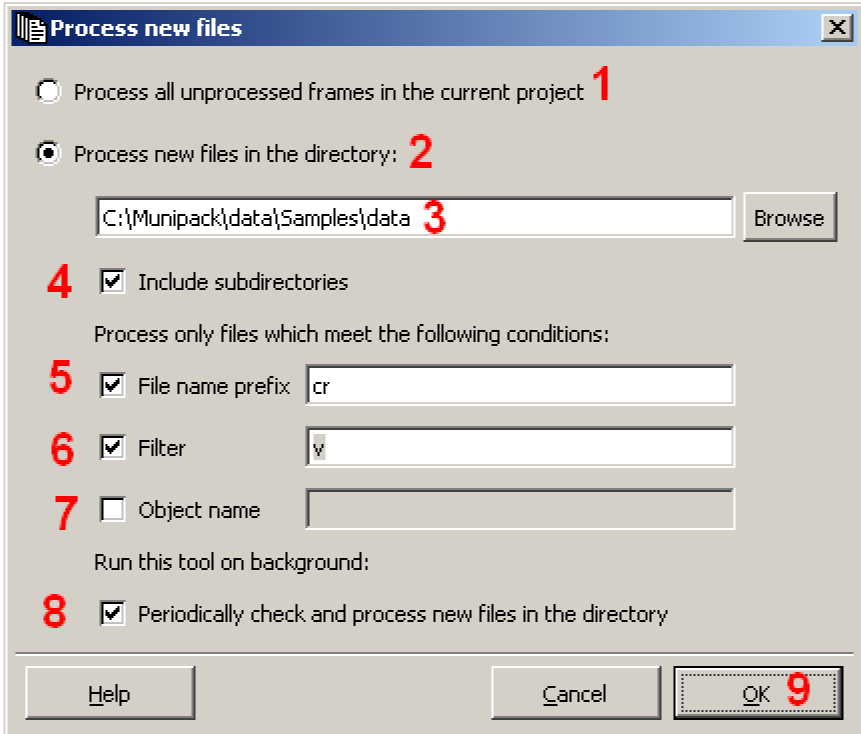


Fig. 78: The "Process new files" dialog

6.3.53 Project settings (dialog)

The "Project settings" dialog is used to set up the parameters of the data processing and output. User interface options that do not affect the data processing are places in the separate dialog "Environment options".

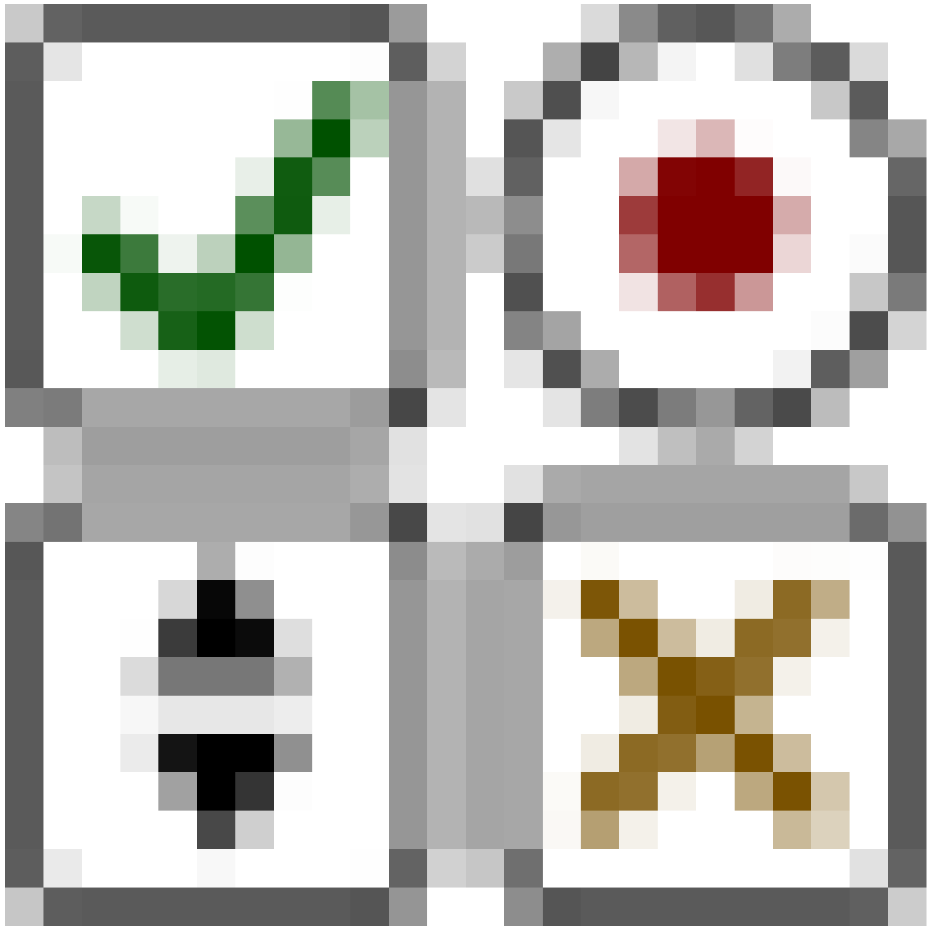
Among many parameters of the aperture photometry procedure a special attention should be payed to the following: Filter width and the Detection threshold. These parameters control mainly the detection of stars on the CCD frames. By decreasing the Filter width value the fainter stars will be found. It is to be pointed out, that too small value may take the artefacts on the background as regular stars. The Detection threshold value sets the distance between the finest stars detected and the background sky noise. The value is entered in multiples of background standard deviations.

The description of the individual parameters can be found in *this chaper*.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Project* → *Edit properties*.

2. from the main toolbar: 

The dialog controls

(1) Select a category.

Parameters in the selected category are shown on the right pane (2).

Click “Set defaults” button (3) to set the parameters in the selected category to the default values.

Click the button (4) to save the settings as current configuration.

Configuration profiles

If you process the data from multiple cameras or telescopes, you will need to adjust the project options for each setup. The program allows to store the configuration to a file and then load it back.

- To save the current settings to as a user-defined *profile*, click on the “Save as profile” button. A new dialog appears. Enter a name of the file. Confirm the dialog.
- To restore the settings from a profile, click on the *Load from profile* button. A new dialog appears. Select one the displayed profiles and confirm the dialog. Please note, that your current project settings will be overwritten by this action.
- To copy the settings from another project, click on the *Import from project* button. A standard open dialog appears. Look up the project that the settings shall be imported from and confirm the dialog.

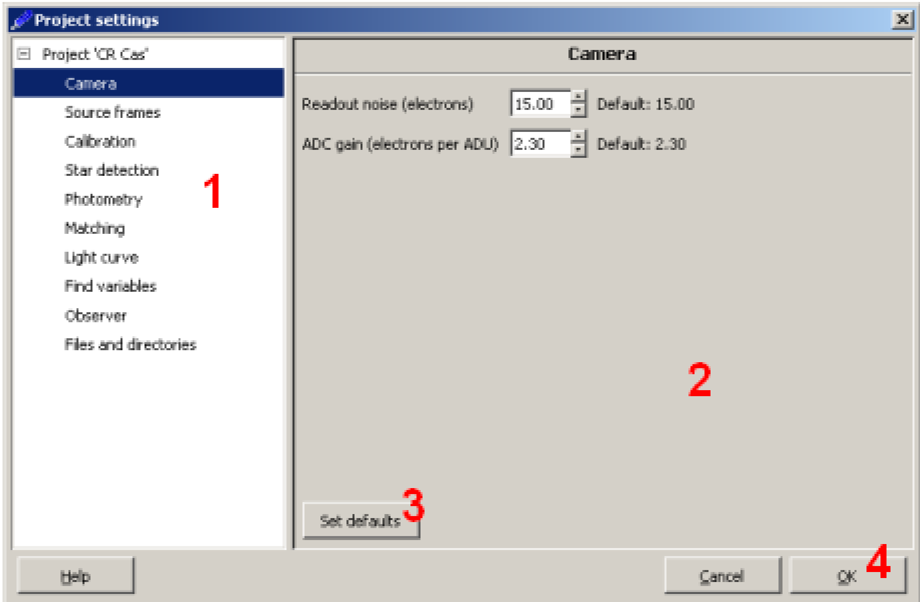


Fig. 79: The "Project options" dialog

See also:

Projects, *Profiles*, *Project settings*, *Environment options (dialog)*, *Load profile (dialog)*, *Save project settings (dialog)*, *Import project settings (dialog)*

6.3.54 Save chart (dialog)

The "Save chart" dialog is used to enter a name and a directory for a new image file.

Activating the dialog

The dialog can be activated:

1. from the "Chart" dialog: button "Save".

The basic dialog

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

(4) You can specify the size of the new image. You can either specify the size as a percentage of the original CCD image (5) or you can specify the width (6) and height (7) of the new image in pixels.

Click on the "Save" button (8) to make an image file.

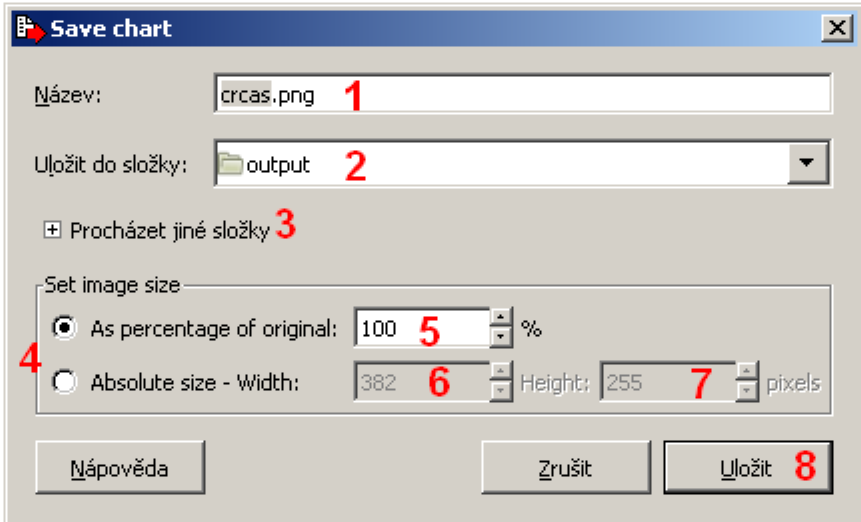


Fig. 80: The "Save chart dialog" dialog (basic form)

Browsing the directories

(10) Here, you can access to your main folders and to your store devices.

(11) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(12) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(13) Enter the file name of the new image file here.

(14) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (15) to shrink the dialog to its basic form.

(16) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

(17) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (18) and following the instructions.

(20) You can specify the size of the new image. You can either specify the size as a percentage of the original CCD image (21) or you can specify the width (22) and height (23) of the new image in pixels.

Click on the "Save" button (24) to make an image file.

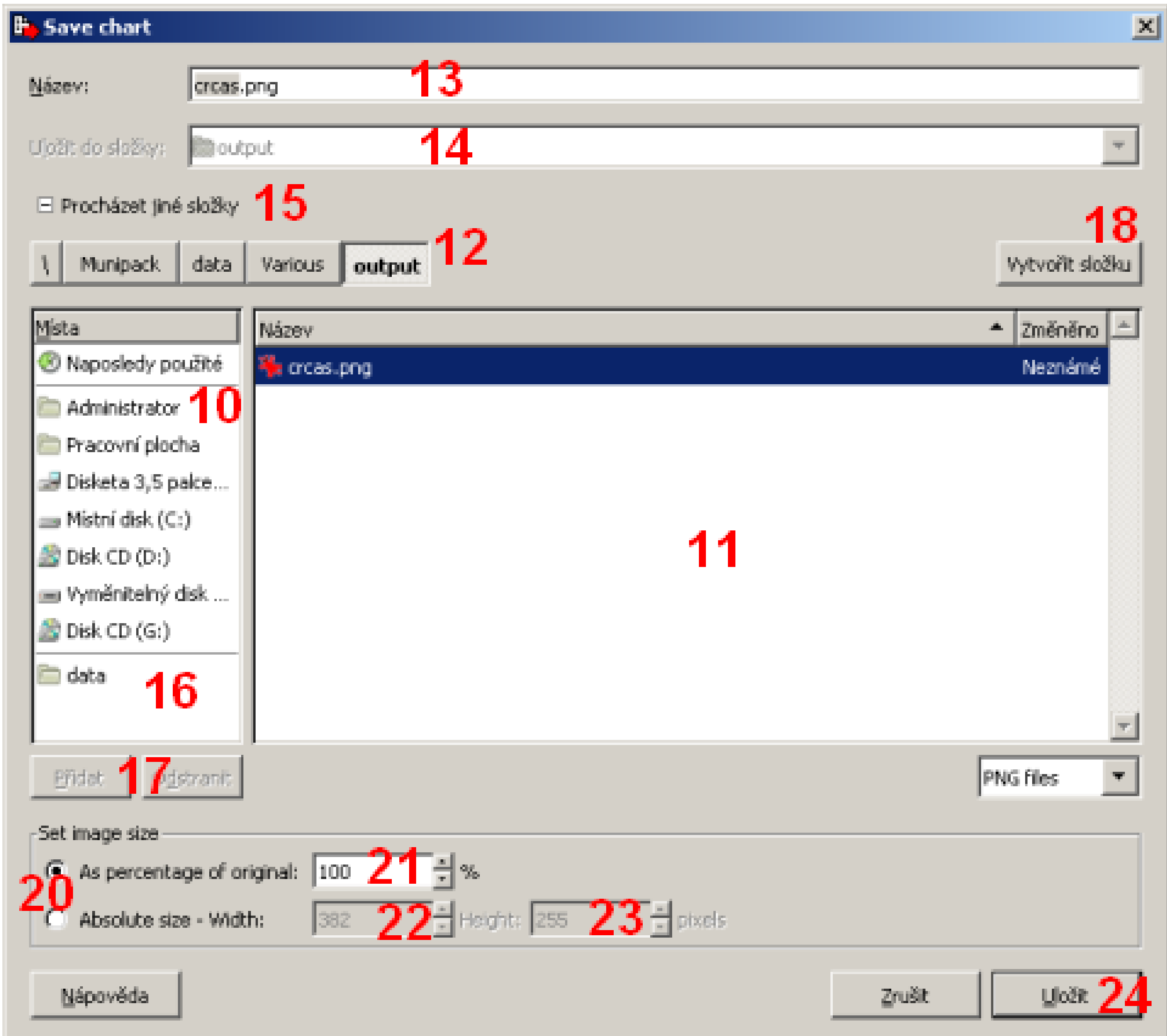


Fig. 81: The "Save chart dialog" dialog (with browser)

6.3.55 Save graph (dialog)

The "Save graph" dialog is used to enter a name and a directory for an exported graph.

Activating the dialog

The dialog can be activated:

1. from the "Air mass curve" dialog: menu *File* → *Export*.
2. from the "Light curve" dialog: menu *File* → *Export*.
3. from the "Track curve" dialog: menu *File* → *Export*.

The basic dialog

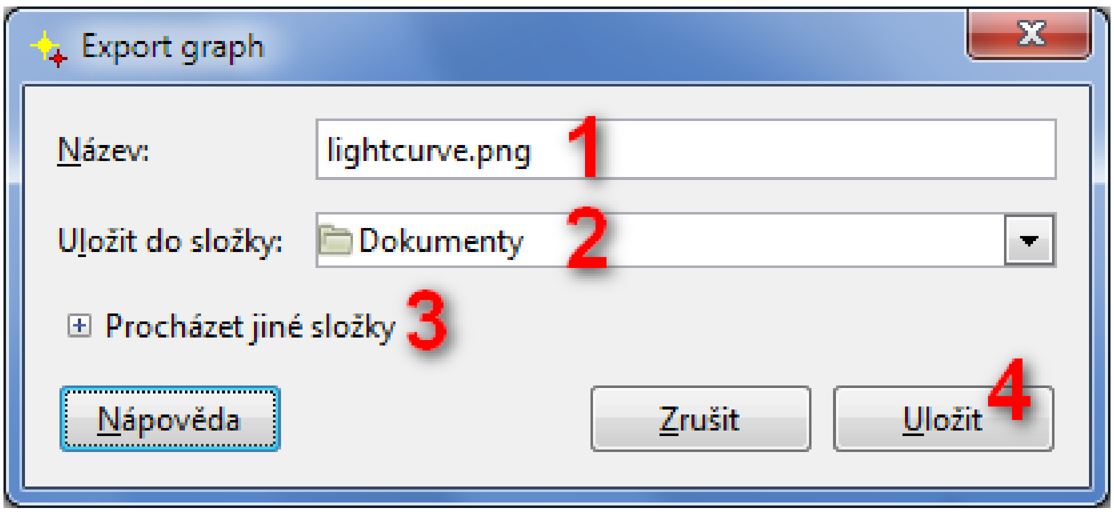


Fig. 82: The "Save graph dialog" dialog (basic form)

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, and a drop-down list of bookmarks (2) to select a directory to save it in.

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (3) to expand the dialog to its full form.

Click on the "Save" button (4) to continue.

Browsing the directories

(10) Here, you can access to your main folders and to your store devices.

(11) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(12) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

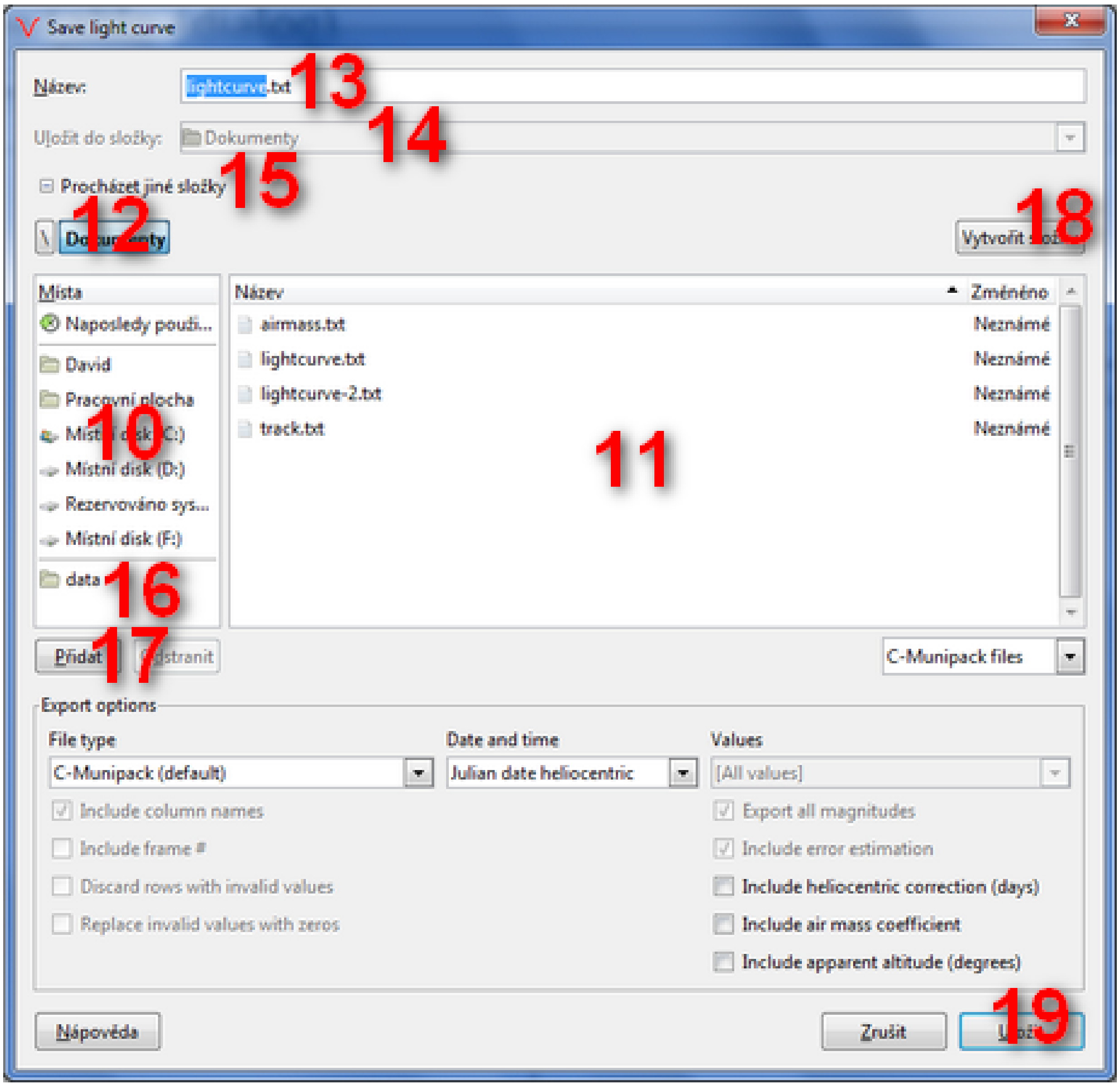


Fig. 83: The “Save graph dialog” dialog (with browser)

(13) Enter the file name of the new image file here.

(14) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on “Browse for other folders” button (15) to shrink the dialog to its basic form.

(16) Here, you can add bookmarks to folders, by using the “Add” or the “Add to Bookmarks” option you get by right-clicking a folder in the central panel, and also remove them.

(17) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn’t yet exist, you can create it by clicking on “Create Folder” button (18) and following the instructions.

Click on the “Save” button (19) to continue.

6.3.56 Save project settings (dialog)

The dialog is used to save settings from the current profile as a user-defined profile. The profile is used to define an initial settings for a new project, see *Profiles* for more details.

Activating the dialog

The dialog can be opened from the *Project settings (dialog)*, the root page, using the *Save as profile* button.

The dialog controls

(1) If you want to create a new user-defined profile, enter its name to the edit field.

(2) To update an existing profile, select it in the table.

(3) Click the *Edit profiles* button to open the *Edit profiles (dialog)*.

Confirm the dialog using the button (4) to continue.

See also:

Project settings (dialog), *Edit profiles (dialog)*

6.3.57 Save table (dialog)

The “Save table” dialog is used to enter a name and a directory for an exported table.

Activating the dialog

The dialog can be activated from various dialogs that provides the data that can be exported in tabular form, for example a light curve, table of objects, etc.

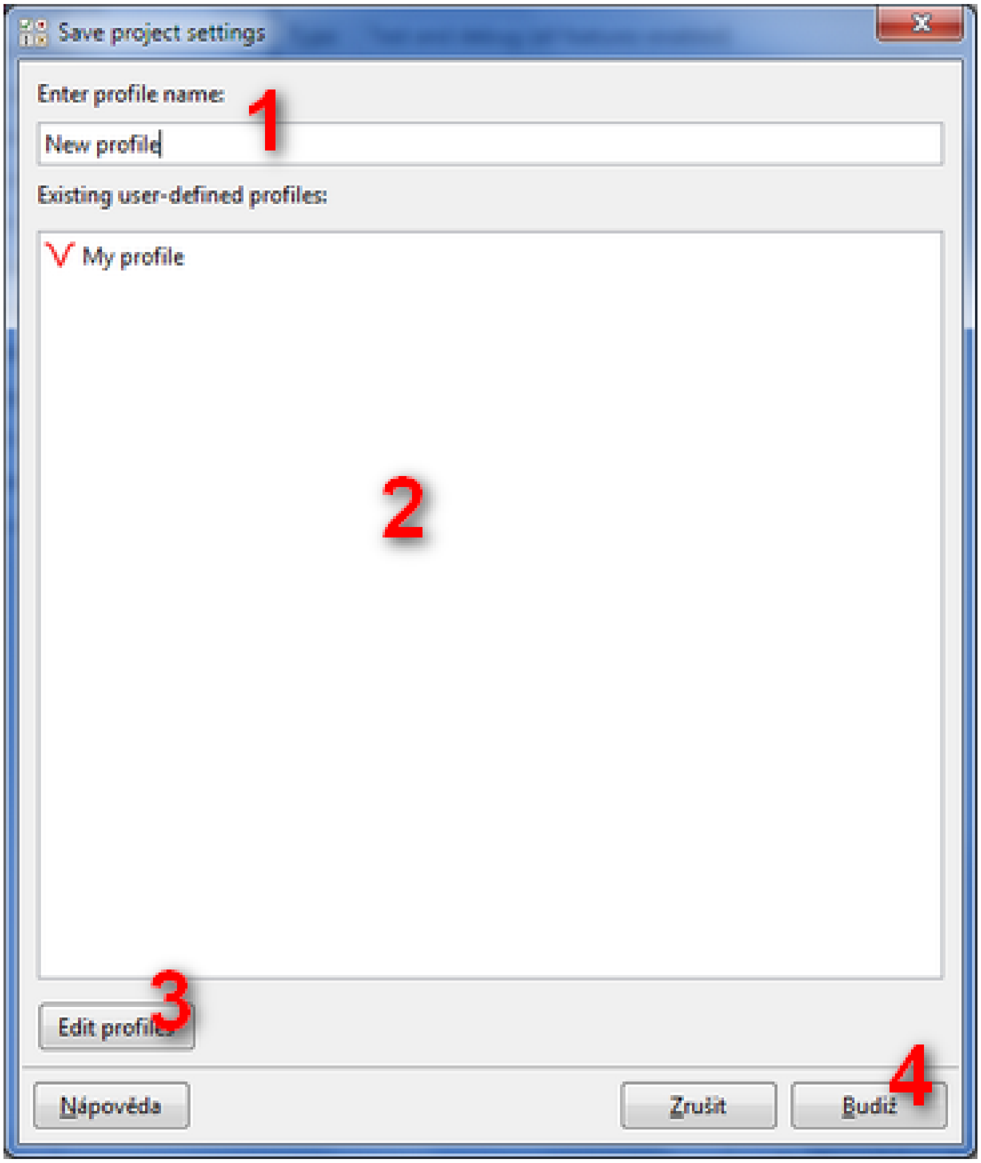


Fig. 84: Save project settings dialog

The basic dialog

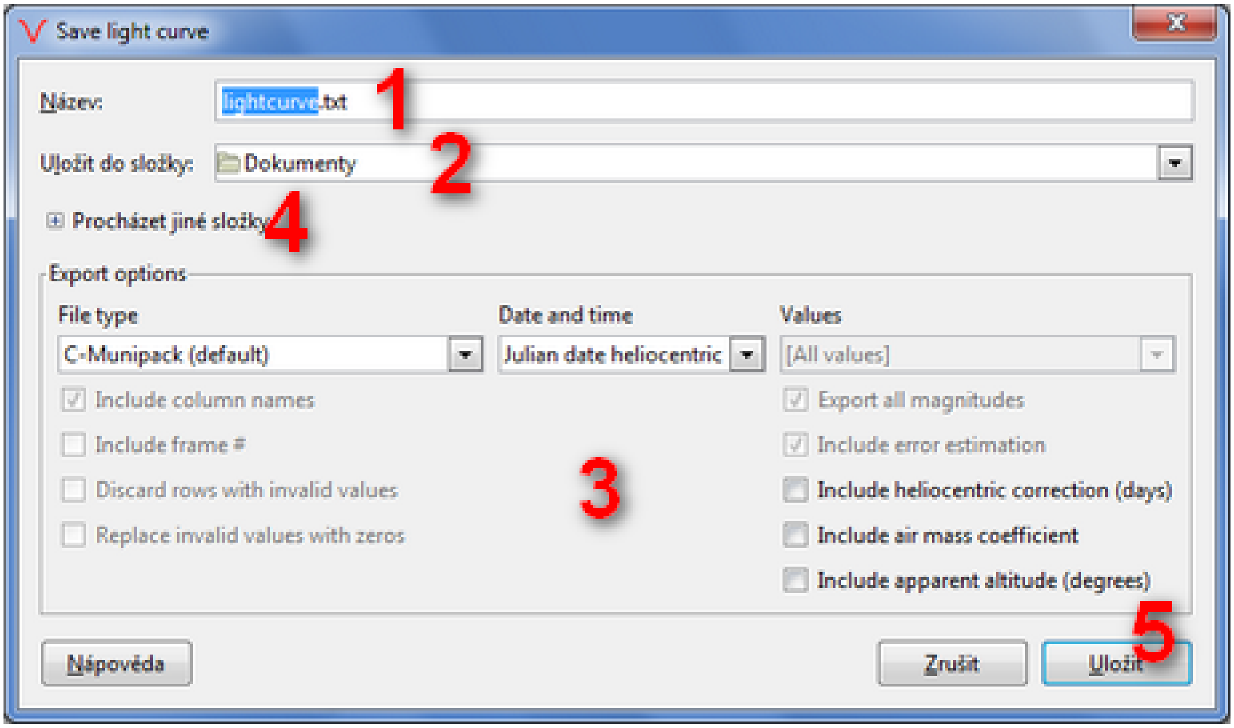


Fig. 85: The "Save table dialog" dialog (basic form)

In its basic form, as shown above, the dialog consists of a text box (1) to assign a name to the file, a drop-down list of bookmarks (2) to select a directory to save it in and a group of export options (3).

If the directory you want is not in the list of bookmarks, click on "Browse for other folders" button (4) to expand the dialog to its full form.

Click on the "Save" button (5) to continue.

Browsing the directories

(10) Here, you can access to your main folders and to your store devices.

(11) The middle panel displays a list of the files in the current directory. Change your current directory by double left-clicking on a directory in this panel. Select a file with a single left click. You can then replace the file you have selected by clicking on the Save button. Note that a double left click start the operation.

(12) Above the middle panel, the path of the current directory is displayed. You can navigate along this path by clicking on one of the buttons.

You can right click on the middle panel to access the "Show Hidden Files" command.

(13) Enter the file name of the new image file here.

(14) This drop-down list is only available in the basic form of the dialog. It provides a list of bookmarks for selecting a directory in which to save your file. click on "Browse for other folders" button (15) to shrink the dialog to its basic form.

(16) Here, you can add bookmarks to folders, by using the "Add" or the "Add to Bookmarks" option you get by right-clicking a folder in the central panel, and also remove them.

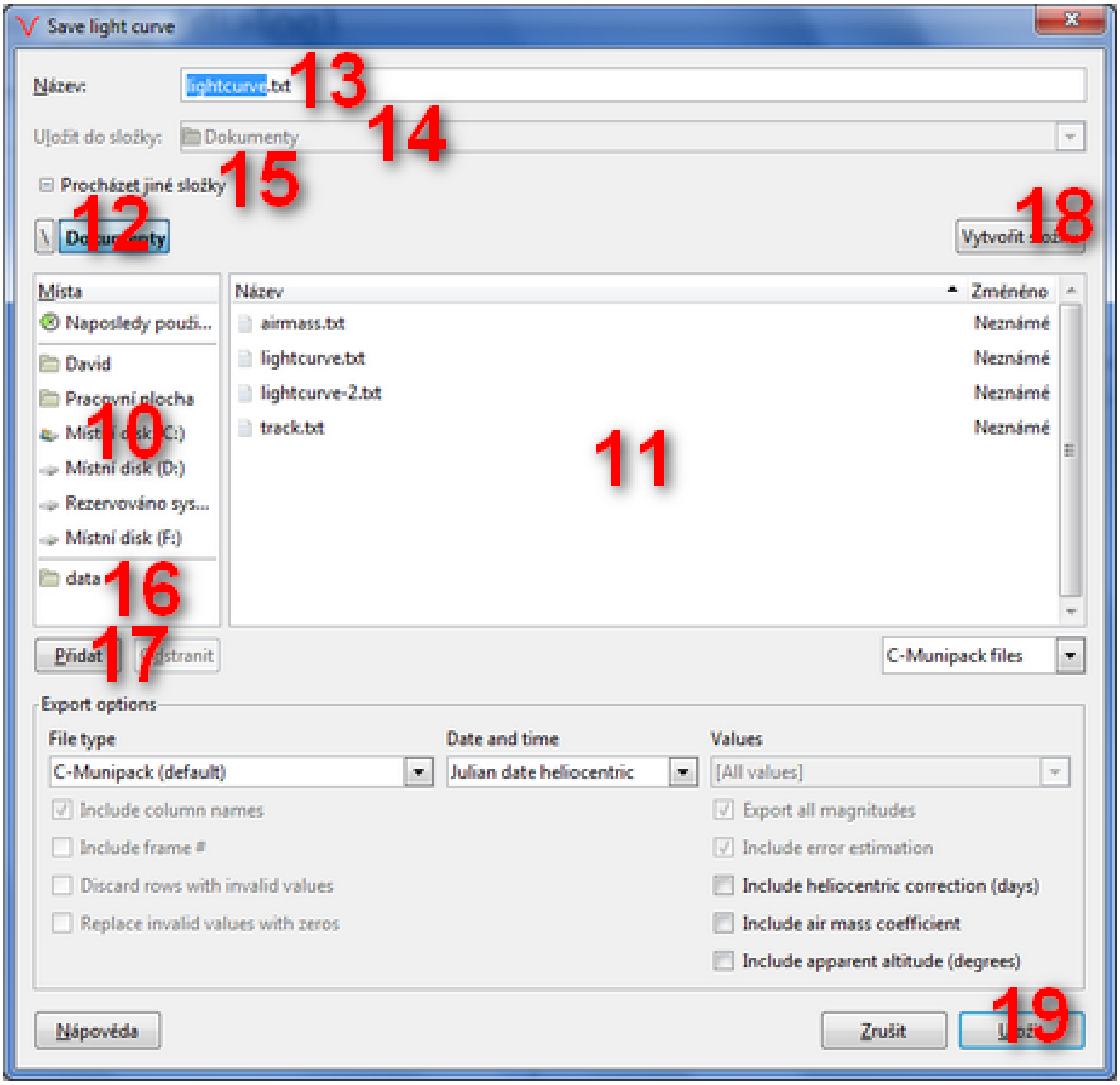


Fig. 86: The "Save table dialog" dialog (with browser)

(17) By clicking the Add button, you add the selected folder to bookmarks. By clicking the Remove, you remove the selected bookmark from the list.

If you want to save the image into a folder that doesn't yet exist, you can create it by clicking on "Create Folder" button (18) and following the instructions.

Click on the "Save" button (19) to continue.

Export options

The current version of the software supports the following export formats. Please note, that in some situations not all format are available.

- C-Munipack - this is the default format for saving tables using the Muniwin software. It is also supported by some other astrophotometry programs, i.e. (original) Munipack, Munidos, etc. Basically, it is a text file with two-line header and fields separated by a single space.
- AVE compatible - a format for exporting light curves that can be processed by the AVE software. Basically, it is a text file without a headers and two columns - JD and differential magnitude of a variable.
- MCV compatible - a format for exporting light curves that can be processed by the MCV software. Basically, it is a text file without a headers and two columns - JD and instrumental absolute magnitude of a variable.
- Text - a common format for exporting tabular data. It is a text file, each row is stored on a separate line. The file may include a header, which consists of a single line with column names. The optional header is immediately followed by table data, individual fields are separated by a single space. Such files can be processed by common plotting tools, i.e. gnuplot.
- CSV - a common format for exporting tabular data. It is a text file, each row is stored on a separate line. The file may include a header, which consists of a single line with column names. The optional header is immediately followed by table data, unlike the Text format, the individual fields are separated by a single comma character. Such files can be easily imported into common spreadsheet processors, i.e. Apache OpenOffice Calc.

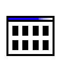
The selection of other export options that are available in a particular situation depends on the type of the data being exported as well as on the selected file format. The options are self-explanatory.

6.3.58 Thumbnails (dialog)

The "Thumbnails" dialog is used to conveniently review all frames that are included in the project. The dialog allows an user to manually check the source frames and remove bogus ones from the further processing.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Tools → Show thumbnails*.
2. from the main toolbar: 

Browsing the frames

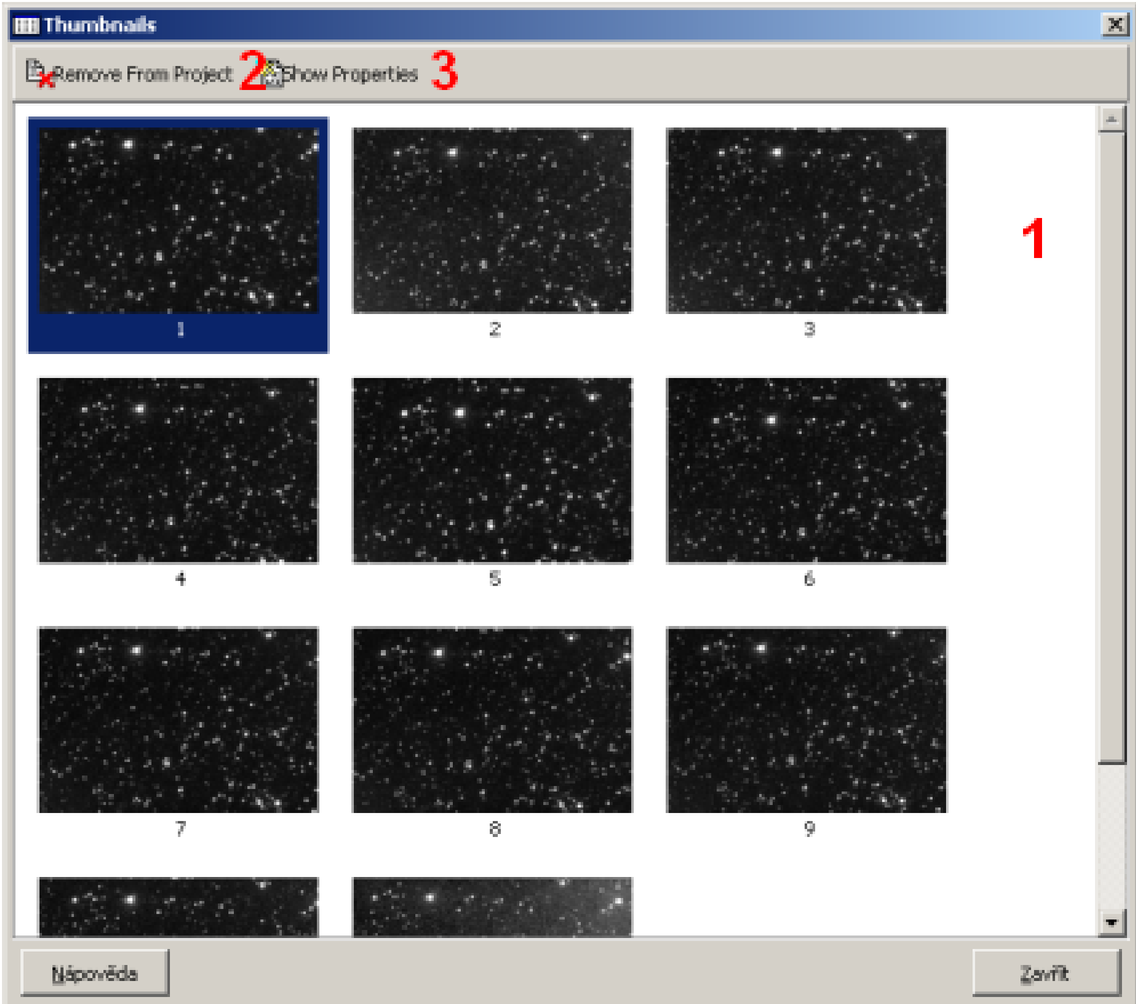


Fig. 87: The "Thumbnails dialog

(1) The source frames are displayed here. The caption corresponds to the ordinal number of a frame. Select a file with a single left click. You can use Shift and Ctrl modifiers to select multiple files. Right-clicking a folder name opens a context menu.

Click on the "Remove from Project" button (3) to remove selected frame from the table of source frames.

Click on the "Show Properties" button (2) to show further details about a selected frame.

See also:

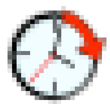
Main window

6.3.59 Time correction (dialog)

The "Time correction" dialog is used to fix the date and time observation of the source files in case the computer time was misaligned to the real time during the observation.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Reduce* → *Time correction*.
2. from the main toolbar: 

Specifying the time shift

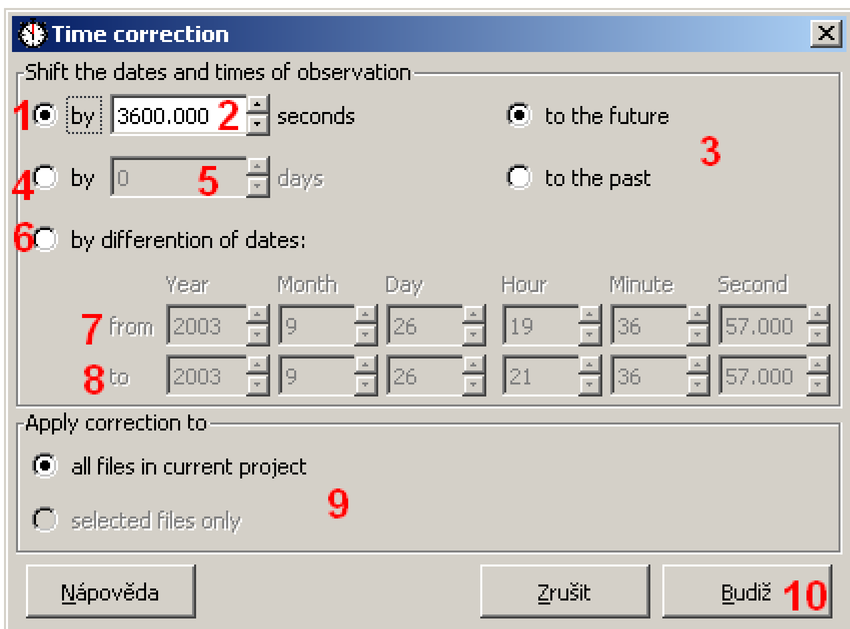


Fig. 88: The dialog for specifying the time shift

There are three possibilities how to specify the time shift: constant number of seconds, days or difference between two dates.

To change time of observation by a constant number of second, check the first option (1) and enter the number of seconds to the text box (2). The value should be always positive, here (3) you can specify if the time shall be shifted either to the future or to the past.

To change date of observation by a constant number of days, check on the second option (4) and enter the number of seconds to the text box (5). The value should be always positive, here (3) you can specify if the date shall be shifted either to the future or to the past.

The third option (6) provides more elaborate control over the time shift. You are expected to specify a pair of dates. The first one is the original (bad) date (7), the second one is the new (correct) date (8). The difference between these two dates gives a time shift, that will be applied to all frames. It is not required that the specified original date corresponds to a source frame.

(9) It is possible to apply the operation on all source files in the project or on the files that are currently selected in the table of input files. By means of this option, it is possible to apply a correction to a subset of source files only.

Applying the time correction

Click the “Execute” button (10) to start the operation. The time correction is applied to a working copy of source files.

- A working copy of source frame must be made before the time correction.
- The time correction can be applied several times to a frame, effect of this function is cumulative.
- The time correction must be applied before the photometry.

If you make a mistake, you can revoke the step by making a fresh copy of source frames by means of the “Fetch/convert files” function.

See also:

Main window, *Express reduction (dialog)*

6.3.60 Track curve (dialog)

The “Track curve” dialog is used to display spatial offsets of the source frames as a function of time. This curve is used to check the precision of a telescope mount. The offsets are relative to the reference frame, they are computed separately in X and Y direction.

Activating the dialog

The dialog can be activated:

1. from the main menu: *Plot* → *Track curve*.

Track curve dialog

(1) The actual data set is shown here.

(2) You can switch the labels on the X axis between Julian date (JD) or date and time (UTC).

(3) The list of available data sets is displayed here.

Data sets

The following data sets are available:

- *OFFSETX* - The horizontal offset of the frame w.r.t. the reference frame or the catalogue file; in pixels
- *OFFSETY* - The vertical offset of the frame w.r.t. the reference frame or the catalogue file; in pixels

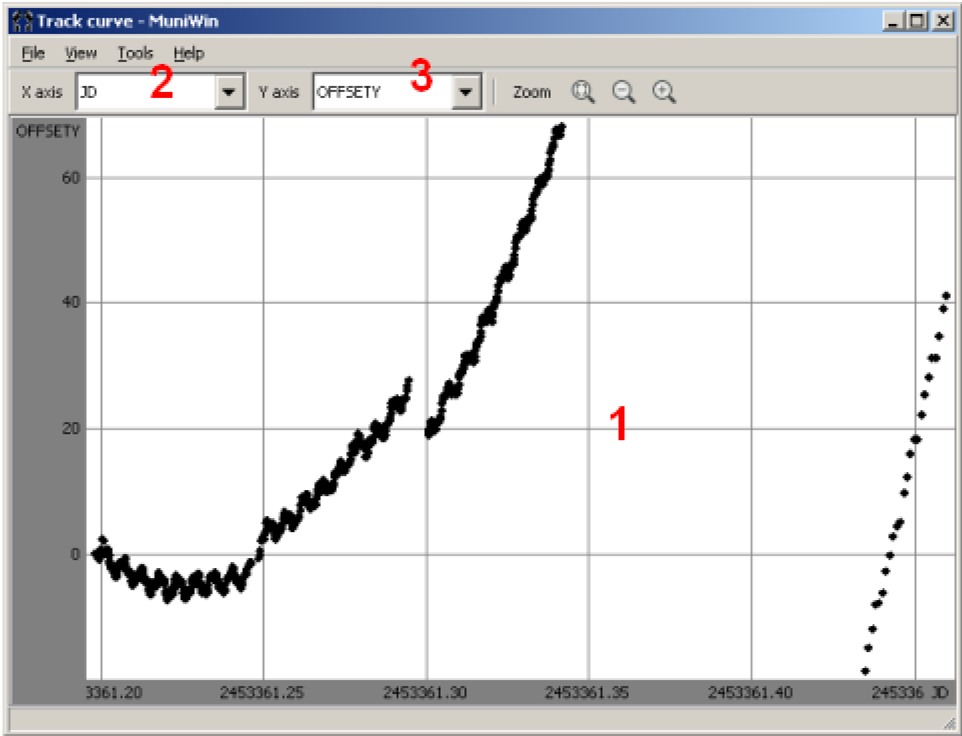


Fig. 89: Track curve dialog

Context menu

You can select an individual point by a right click, you can also select more than one point by pressing a Shift key and left mouse button and drawing a rectangle in the graph. Then, click the right mouse button on a point in the selection to open the context menu. It provides following functions:

- Show frame - it shows a preview to a selected frame. It is not allowed when more than one frame is selected.
- Show properties - it opens a new dialog with properties of selected frame. It is not allowed when more than one frame is selected.
- Delete from data set - selected measurements are removed from the current curve, the data will be shown again when you make a new curve or *Rebuild* the actual curve.
- Remove from project - source frames corresponding to the selected measurements are removed permanently from the list of input files and such measurements won't be included in any other output. It is not allowed to remove a reference frame.

Statistics

The Statistics is a tool that computes and shows the minimum, maximum, sample mean and standard deviation.

To activate the tool:

1. From the local menu, select *Tools* → *Statistics*. A new panel on the right side of the preview window appears.

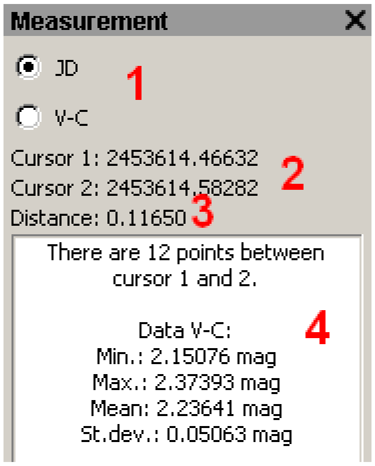
If no points are selected, all points in the data set are included in the computation. To restrict the data for the statistics, press and hold the Shift key and draw a rectangle in a graph while you keep the left mouse button pressed down.

Measurement

The *Measurement* tool displays two cursors in the graph. The cursors can be adjusted by dragging them using the left mouse button. The position of each cursor, their distance and statistics for the data between cursors is presented.

To activate the tool:

1. From the local menu, select *Tools* → *Measurement*. A new panel on the right side of the preview window appears.



Measurement tool

(1) Choose the axis you want to measure.

(2) Positions of the cursor 1 and 2 are displayed here.

(3) Distance between cursor 1 and 2.

(4) When cursors are defined on the independent (X) axis, number of points (frames) between cursor 1 and 2 are displayed and also minimum, maximum, mean value and sample deviation are presented.

See also:

Light curve (dialog)

CHAPTER SEVEN

COMMAND LINE TOOLS (TOOLKIT)

The C-Munipack toolkit provides a complete set of tools for reduction of images carried out by a CCD camera, aimed at the observation of variable stars. It provides a powerful set of commands called directly from a shell or a command-line interpreter. They are ready for use in custom-built shell scripts or batch files.

The toolkit has been developed as a part of the C-Munipack project. See the project's home page for more information about the project and other interfaces.

7.1 Using command-line tools

The following text describes the basic procedure for processing an observation of a short-periodic variable star by means of the C-Munipack toolkit.

The package with demo data used here is available on the project's web pages. Unzip the archive to an empty folder at your hard disk (e.g. ~/c-munipack/sample), open a shell or command-line window and make the folder your current working directory. The archive has got the following structure:

`dark / 20s / masterdark.fts`	master-dark frame (20 seconds exposure)
`dark / 20s / raw / dark*.fts`	set of raw dark frames (20 seconds exposure)
`flat / v / masterflat.fts`	master-flat frame (optical filter V)
`flat / raw / flat-v*.fts`	set of raw flat frames (optical filter V)
`data / v / frame*.fts`	sample CCD frames (optical filter V)

The reduction of CCD data has the following general scheme:

1. Conversion of input files to a working format
2. Calibration
3. Photometry and matching
4. Making output

Most of widely used CCD camera controlling software save the data in FITS format, which has virtually became the standard in this field. This is also a working format for all tools from the C-Munipack project - it means, that they expect the FITS files on their input and saves the output in this format, too. There is one exception to this rule, the **konve** command, which reads several different formats and convert them to FITS. See the documentation for the **konve** command for the list of supported formats. If your files are not in FITS format, use this command to convert your source files to the FITS format.

```
mkdir tmp
konve -o tmp/frame???.fts your-files/\*.st7
```

Even if your input files are saved in the FITS format, I would suggest you to make a local copy, because it's always advisory to play safe and make sure you don't tamper your original data with a misprint in a command. You can use the **konve** command or just simple **cp** command for this job, but I will use the former to demonstrate its use.

```
mkdir tmp
konve -o tmp/frame???.fts data/v/\*.fts
```

First command makes a new folder, that we will use for storing all temporary files hereafter. The second line makes a copy of all sample frames to it.

A raw CCD frame consists of several components. By the calibration process, we get rid of those which affect the result of the photometry. In some literature, the calibration is depicted as the peeling of an onion. There are three major components which a raw frame consists of - the current made by incident light, current made thermal drift of electrons (so-called dark current) and constant bias level. In standard calibration scheme, which we will demonstrate here, the dark-frame correction subtracts the dark current and the also the bias. Because of the nature of the dark current, it is necessary to use a correction frame of the same exposure duration as source files and it must be carried out on the same CCD temperature, too. Thus, the properly working temperature regulation on your CCD camera is vital. The dark-frame calibration is made by means of the **darkbat** command.

```
darkbat -o tmp/dark???.fts dark/20s/masterdark.fts tmp/frame*.fts
```

Then, we have to compensate the spatial non-uniformity of a detector and whole optical system. These non-uniformities are due to the fabrication process of a CCD chip and they are also natural properties of all real optical components, lenses in particular. The flat-frame correction uses a flat-frame to smooth them away. The flat-frame is a frame carried out while the telescope is pointed to uniformly luminous area. In practice, this condition is very difficult to achieve, the clear sky before dusk is usually used instead. The **flatbat** has very similar syntax to the previous one.

```
flatbat -o tmp/flat???.fts flat/v/masterflat.fts tmp/dark*.fts
```

The source files are calibrated now. We are ready to detect a stars on each frames and measure their brightness. This process is called the photometry and unlike the previous commands, the result is saved to a XML based file, so-called photometry file. There are a lot of parameters which affect the star detection and also the brightness computation. In this example, the default values work fine, but I would suggest you to become familiar with at least two of them - FWHM and Threshold - before you start a real work.

```
muniphot -o tmp/frame???.pht tmp/flat*.fts
```

The previous command treated all source files independently. As a result of this, a star #1 in one file is not necessarily the same as a star #1 in another file. The process called matching finds correspondences between them and a unique identifier is assigned to each star. Before we do so, we have to choose one frame, which shall be used as a reference frame. In my experience, the frame with the greatest number of stars works the best. For our example, let's pick up the third frame - `frame003.pht`.

```
munimatch -o tmp/match???.pht tmp/frame003.pht tmp/frame*.pht
```

The sample data is the observation of an eclipsing binary star. For most of such observers, the goal is to make a light curve. A light curve is a table, which consists of at least two columns - time stamp expressed as a Julian date and difference between two stars - a variable star and a comparison star. A variable star is a star that is subject of brightness variation and a comparison star is supposed to be constant. Before we go on, we have to find out the identifiers of at the variable star and the comparison star. This task is very difficult to perform on a command-line, so I will skip it for the present. If you followed the previous step, the variable star is #1 and the comparison is #2.

Now, we have got all information we need to make a light curve. This is done by means of the **munilist** command.

```
munilist -v 1 -c 2 output.txt tmp/match*.pht
```

Let's have a look on the output file. The first several line should look like this:

```
JD V-C s1
ApertureIndex = 1
ApertureRadius = 2.0000
Filter =  V

2453614.46632 -0.1058 0.0110
2453614.47054 -0.0952 0.0108
...
```

The first line is a table header. It consists of names of table columns separated by a space. The following lines up to the single empty line form the file header. They provide the descriptive information about the data stored in the file. Each line consists of a keyword, the equal sign an the value. After an empty line, the table data follows. Each row is written on a separate line and columns are divided by a space.

7.2 Program arguments

The user command accept a list of command-line arguments, that provides requisite information for its execution. They are used to specify names of input files, values of configuration parameters etc. Some arguments are obligatory, others are optional only.

The syntax of command-line arguments follows in general the GNU/POSIX conventions. The arguments are separated by a single space character, in case an argument itself contain a space, it must be enclosed in double-quotes. Refer to the documentation of your shell for more details.

There are two types of command-line arguments - options and positional parameters. Options are optional, while positional parameters are always obligatory.

The options are used to provide extra information to customize the execution of a command. Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option. Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

All arguments that are not options nor option values are regarded as positional parameters. First such argument specify value of the first positional parameter and so on. Some parameters take variable number of arguments, usually list of input files. This case is indicated in the synopsis by an ellipsis (. . .) following the parameter name. It means that it takes all following positional parameters.

All following user commands are equivalent:

```
prog --option-a --option-b xyz --option-c=123 file1 file2
prog -a -b xyz -c123 file1 file2
prog -abxyz -c123 file1 file2
```

7.3 Using configuration files

The configuration files provide extra information to customize the execution of a command. Unlike the command-line options, they can be prepared once and reused repeatedly. By means of them, the number of command-line arguments can be significantly reduced.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: <replaceable>name</replaceable> = <replaceable>value</replaceable>, all other lines are silently ignored. Parameter names are always case-sensitive. A hash character starts a comment string, all following content is ignored up to the end of the present line.

The `-p` option must be used to instruct the program to read and process the configuration file. Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

Example of configuration file:

```
# Sample configuration file
right-ascension = `23.0253`        # GSC 2750 854
declination     = `30.7408`
longitude       = `16.6667`        # Brno
latitude        = `49.2167`
```

7.4 Batch processing

Repetitive challenge with reduction of CCD observation is in treating a large number of files. To do this job effectively, it is necessary to execute each reduction step for all frames in subsequent manner. This issue is inconsiderable namely for calibration of CCD frames - the calibration data should be fetched into the memory only once and then applied to all frames. Thus one need to execute an user command for a large set of input files.

One straightforward way in processing large batch of frames is writing the names of input files as separate command-line arguments. More shrewd users would use the wild-card notation, but it doesn't work in more complicated situation. There is yet another way - using directory files.

The directory file is a simple text file. Each line consists of a file path or name. Such file can be obtained using simple command.

On GNU/Linux:

```
ls ??? &gt; dirfile.txt
```

On Windows:

```
dir /b *.st7 &gt; dirfile.txt
```

If the files are placed not in the current working directory, you have to specify the proper path in full or shortened form relative to the current working directory. It is not allowed to use the wild-card notation here. Use the `-i` option to instruct the program to read the file.

When a program produces a number of files, it is also necessary to assign a distinct name for each output file. By default, the output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. By means of the command-line options, it is possible to override this behavior.

The `-o` option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to at least the same number of decimal places as the number of the question marks. By means of the `-i` option, you can modify the ordinal number of the first frame.

The following command writes its output to files `out010.fts`, `out011.fts` and `out012.fts`:

```
darkbat -o out???.fts -i 10 dark.fts in001.fts in002.fts in003.fts
```

If you are going to use the files produced by one command as the input files of the subsequent operation, you can ask the former to make a directory file for you by including the `-g` option followed by a file name.

CHAPTER

EIGHT

TOOLKIT REFERENCE

8.1 Commands

The following command line programs are installed as a part of the C-Munipack software:

8.1.1 airmass (command)

utility for computing air mass coefficient

Synopsis

airmass [options] *input-files* …

airmass [options] -j *julian-date*

Description

The **airmass** command computes value of air mass coefficient (X) for given Julian date, object's coordinates and observer's coordinates. It may also append the values to a set of measurements stored in a text file.

When the -j option is present on the command line, the value of air mass coefficient is printed to the standard output stream.

If one or more file names are present on the command line, each source file given is processed line by line, the program expects the JD value in the first column, which must be divided at least one of common used dividers (semicolon, comma, space, tab char, …). The JD value can be in full (2453xxx.x) or short (53xxx.x) form. Decimal places must be separated by point, not comma. The value of air mass coefficient is computed and appended to the end of the line. If the line starts with the text `JD`, it is considered to be a table header and the text `AIRMASS` is appended to the end of the line. All other lines which do not fit to any of previous rules are copied to the output file without modification.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-j, --julian-date <jd>
: compute and print air mass coefficient for given Julian date. Do not combine this option with input file names.

-a, --right-ascension <hhmmss>
: right ascension of object in hours, minutes and seconds

-d, --declination <ddmmss>
: declination of object in degrees, minutes and seconds

-l, --longitude <dddmmss>
: longitude of observer in degrees, minutes and seconds; positive values for a location to the east of the Greenwich meridian, negative values for a location to the west of the Greenwich meridian.

-b, --latitude <ddmmss>
: latitude of observer in degrees, minutes and seconds; positive values for a location to the north of equator, negative values for a location to the south of equator.

--altitude
: compute and print also the altitude of the object in degrees.

-s, --set <name=value>
set value of configuration parameter

-i, --read-dirfile <filepath>
read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
set output file mask (default=:file:*amass????.dat*), see the *Output files* section for details.

-c, --counter <value>
set initial counter value (default=1), see the *Output files* section for details.

-p, --configuration-file <filepath>
read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
print list of command-line parameters

-q, --quiet
quiet mode; suppress all messages

--version
print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

right-ascension = hhmmss
right ascension of object in hours, minutes and seconds

declination = ddmmss
declination of object in degrees, minutes and seconds

longitude = dddmmss
longitude of observer in degrees, minutes and seconds; positive values for a location to the east of the Greenwich meridian, negative values for a location to the west of the Greenwich meridian.

latitude = ddmmss
latitude of observer in degrees, minutes and seconds; positive values for a location to the north of equator, negative values for a location to the south of equator.

Examples

```
airmass -l164000 -b491300 -a182932 -d223424 -j2452763.5670
```

The command computes and prints value of air mass coefficient to the standard output. The object's coordinates are R.A. = 18h 29m 32s, DEC. = +22d 34m 24s, the observer's coordinates are LON. = 16d 40m to the east of the Greenwich meridian and LAT. = 49d 13m to the north of the equator. Julian date of observation is 2452763.5670.

```
airmass -l164000 -b491300 -a182932 -d223424 -oamass.dat table.dat
```

The command adds values of air mass coefficient to the table stored in `table.dat` file and the resulting table stores in `amass.dat` file. The object's and observer's coordinates are the same as in previous example.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.2 autoflat (command)

utility for making master-flat frames

Synopsis

autoflat [options] *output-file input-files* …

Description

The **autoflat** command compose a set of flat frames and makes one flat frame called 'master-flat'. Applying this function, you can achieve high quality correction frame and thus reducing the noise of a result.

All source frames must be in the FITS format and of same dimensions. Frames of the same exposition duration and color filter should be used, avoid eventual camera rotation on its mount. The output file is written in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
: set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

bitpix = value
: output data format (0=Auto)

level = value
: average level of output frame in ADU

Examples

```
autoflat out.fts in1.fts in2.fts in3.fts
```

The command computes the master-flat frame from the input files `in1.fts`, `in2.fts` a `in3.fts`; the resulting frame is stored to output file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.3 biasbat (command)

utility for bias correction

Synopsis

biasbat [options] *bias-file input-files* …

Description

The **`biasbat`** command applies bias correction to a set of source frames. The bias correction is applied in advanced calibration scheme only, please refer to documentation about the calibration of CCD frames.

The source frames and the bias frame must be in the FITS format and of same dimensions. The output file is written in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*bout????.fts*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Examples

```
biasbat -oout.fts bias.fts in.fts
```

The command applies the bias correction to the input file `in.fts` using the file `bias.fts` as a correction frame. The output is written to the output file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.4 darkbat (command)

uility for dark correction

Synopsis

darkbat [options] *dark-file input-files …*

Description

The **darkbat** command applies dark correction to a set of source frames. The source frames and the dark frame must be in the FITS format and of same dimensions. The output file is written in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
set value of configuration parameter

-i, --read-dirfile <filepath>
read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
set output file mask (default=:file:*dout????.fts*), see the *Output files* section for details.

-c, --counter <value>
set initial counter value (default=1), see the *Output files* section for details.

-p, --configuration-file <filepath>
read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
print list of command-line parameters

-q, --quiet
quiet mode; suppress all messages

--version
print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

scaling = value
dark-frame scaling (0=disabled, 1=enabled)

Examples

```
darkbat -oout.fts dark.fts in.fts
```

The command applies the dark correction to the input file `in.fts` using the file `dark.fts` as a correction frame. The output is written to the output file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.5 flatbat (command)

utility for flat-frame correction

Synopsis

flatbat [options] *flat-file input-files …*

Description

The **flatbat** command applies flat-field correction to a set of source frames. It means, that it divides the source frames by the flat frame pixel-by-pixel and the result is multiplied by median value of the flat frame. The resulting image is written to output file. The source frames and also flat frame must be in FITS format and of same dimensions. The output file is in FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*fout????.fts*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Examples

```
flatbat -oout.fts flat.fts in.fts
```

The command applies flat correction to `in.fts` using `flat.fts` as a correction frame. The output is written to `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.6 helcor (command)

utility for computing heliocentric correction

Synopsis

helcor [options] *input-files*

helcor [options] -j *julian-date*

Description

The **helcor** command computes value of heliocentric correction for given Julian date and object's coordinates. It may also append the values to a set of measurements stored in a text file. When the -j option is present on the command line, the value of heliocentric correction is printed to the standard output stream.

If one or more file names are present on the command line, each source file given is processed line by line, the program expects the JD value in the first column, which must be divided at least one of common used dividers (semicolon, comma, space, tab char, . . .). The JD value can be in full (2453xxx.x) or short (53xxx.x) form. Decimal places must be separated by point, not comma. The Julian date is replaced by a corrected date and the value of correction may be optionally appended to the end of the line. If the line starts with the text `JD`, it is considered to be a table header and it is changed to `JDHEL` or `JDGEO`. The text `HELCOR` is optionally appended to the end of the line. All other lines which do not fit to any of previous rules are copied to the output file without modification.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-j, --julian-date <jd>
: compute and print heliocentric correction for given Julian date. Do not combine this option with input file names.

-a, --right-ascension <hhmmss>
: right ascension of object in hours, minutes and seconds

-d, --declination <ddmmss>
: declination of object in degrees, minutes and seconds

-s, --set <name=value>
: set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*hcor????.dat*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

`right-ascension = hhmmss`
: right ascension of object in hours, minutes and seconds

`declination = ddmmss`
: declination of object in degrees, minutes and seconds

Examples

```
helcor -a182932 -d223424 -j2452763.5670
```

The command computes and prints value of heliocentric correction to the standard output. The object's coordinates are R.A. = 18h 29m 32s, DEC. = +22d 34m 24s. Julian date of observation is 2452763.5670.

```
helcor -a182932 -d223424 -ohcor.dat table.dat
```

The command performs the heliocentric correction to the table stored in `table.dat` file and the resulting table stores in `hcor.dat` file. The object's coordinates are the same as in previous example.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.7 kombine (command)

utility for making combining CCD frames

Synopsis

kombine [options] *output-file input-files* …

Description

The **`kombine`** command combines a set of CCD frames to a single CCD frame. The source frames should be corrected already. The source frames are shifted by the offset stored in the corresponding photometry file with offset values. The photometry files are products of the **`Munimatch`** utility. Then, the resulting values are computed pixel by pixel by means of the mean algorithm (sum divided by total number of frames). Pixels in those regions, which are not covered by all frames, are set to zero. Pixels, which are zero on at least one of the source frames, are set always to zero. Pixels, which are overexposed on one the source frames, are set always to maximal value (655535 ADU).

All source frames must be in FITS format and of same dimensions. Frames of the same color filter and exposition duration should be used. The output file is in FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
: set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

bitpix = value
: output data format (0=Auto)

Examples

```
kombine ouptut.fts test1.fts test2.fts test3.fts
```

The command computes the combined frame from the files `test1.fts`, `test2.fts` a `test3.fts`; the resulting frame is stored to `output.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.8 konve (command)

utility for conversion of CCD frames to the FITS format

Synopsis

konve [options] *input-files* …

Description

The **konve** command converts CCD frames from the format used by camera controlling software to FITS format. The correction of time of observation or image flipping can be applied also.

The program can be run in several modes, the mode is selected by command-line parameters. Besides the usual conversion mode, it allows printing header information of source files in short or detailed form. You can convert header only while not copying the image. Additional information, which shall be written to the output files can be given in parameter file.

Current version of program supports reading SBIG (ST-xx) compressed and uncompressed files and the FITS files also. Note, that you can use FITS to FITS conversion for gathering files from many locations into one directory. It will solve the file name collisions.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-n, --print-info
: print short info about frames; don't make any output file.

-e, --print-header
: print content of the header; don't make any output file.

-s, --set <name=value>
: set value of configuration parameter

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*kout????.fts*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

flip-image = xy
flip image (value can be 'x', 'y' or 'xy')

time-corr = secs
time correction in seconds (>0 = to future, <0 = to past)

Examples

```
konve -oout?.fts test1.st7 test2.st7 test3.st7
```

The command converts the files `test1.st7`, `test2.st7` and `test3.st7` and writes the output to the files: `out1.fts`, `out2.fts` and `out3.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.9 meanbias (command)

utility for making master-bias frames

Synopsis

meanbias [options] *output-file input-files …*

Description

The `meanbias` command compose a set of bias frames and makes one bias frame called 'master-bias'. Applying this function, you can achieve high quality correction frame and thus reducing the noise of a result. The bias correction is applied in advanced calibration scheme only, please refer to documentation about the calibration of CCD frames.

All source frames must be in the FITS format and of same dimensions. The output file is written in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
: set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified directory file; see the *Input files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

bitpix = value
: output data format (0=Auto)

Examples

```
meanbias out.fts in1.fts in2.fts in3.fts
```

The command computes the master-bias frame from the input files `in1.fts`, `in2.fts` a `in3.fts`; the resulting frame is stored to output file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.10 meandark (command)

utility for making master-dark frames

Synopsis

meandark [options] *output-file input-files …*

Description

The **meandark** command compose a set of dark frames and makes one dark frame called 'master-dark'. Applying this function, you can achieve high quality correction frame and thus reducing the noise of a result.

All source frames must be in the FITS format and of same dimensions. Frames of the same exposition duration should be used. The output file is written in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
: set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

bitpix = value
: output data format (0=Auto)

scalable = value
: make scalable dark-frame (0=No, 1=Yes)

Examples

```
meandark out.fts in1.fts in2.fts in3.fts
```

The command computes the master-dark frame from the input files `in1.fts`, `in2.fts` a `in3.fts`; the resulting frame is stored to output file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.11 munifind (command)

utility for finding unknown variable stars

Synopsis

munifind [options] *output-file input-files …*

Description

The **munifind** command reads matched photometry files and creates the table of standard deviations of magnitudes in the dependence on a mean magnitude. Such table is used to detect unknown variable stars on a set of CCD frames. The table is written to a output file in text format.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set <name=value>
: set value of configuration parameter

-a, --aperture <value>
: Aperture identifier (default=1)

-c, --comparison-star <star>
: identifier of the comparison star or negative value for automatic detection (default=-1)

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

aperture = value
: Aperture identifier (default=1)

comp = star
: identifier of the comparison star or negative value for automatic detection (default=-1)

threshold = value
: cfraction of good measurements required, in percents (default=60)

Examples

::
: munifind output.dat test1.mat test2.mat test3.mat

The command makes table of brightness of the star #2 (stored on second position in photometry files) relative to the star #3 for photometry files `test1.mat`, `test2.mat` a `test3.mat`; the resulting frame is stored to `output.dat`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.12 munilist (command)

utility for making listings from a set of photometry files

Synopsis

munilist [options] *output-file input-files …*

Description

The **`munilist`** command reads files generated by other commands and generates a table according to the format specified using command line parameters or a configuration file. The basic mode is creating a light curve where the munilist utility is used to read matched photometry files and creates the table of magnitudes of selected stars in the dependence on a time. The table is written to a output file in text format. The format of the table depends on given parameters and on the number of selected stars. It is usually the last step of reduction process. Other modes are designed to print a table of objects from a reference photometry file or a catalogue file.

The list of stars is given on command line, the stars are identified by index number according to their cross-reference identifiers.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

`--light-curve`

make a light curve (default)

`--chart`

make a table of objects from a photometry file or a catalogue file. Only the first input file is processed.

--obj-plot:
takes an object identification using the 'object' parameter and makes a table containing object properties (e.g. FWHM) from each given input photometry file.

--track-list
make table of frame offsets w.r.t. the reference frame or a catalogue file. The table contains relative offsets in X and Y axis of the frame center in pixels.

--diff-mag
make table of differential instrumental magnitudes (default)

--inst-mag
make table of absolute instrumental magnitudes

--object <star>
object identifier for 'obj-plot' output

-s, --set <name=value>
set value of configuration parameter

-a, --aperture <value>
Aperture identifier (default=1)

-v, --variable-stars <star,star,...>
comma separated list of identifier(s) of the variable star(s)

-c, --comparison-stars <star,star,...>
comma separated list of identifier(s) of the comparison star(s)

-e, --check-stars star...
comma separated list of identifier(s) of the check star(s)

-i, --read-dirfile <filepath>
read list of input files from specified file; see the *Input files* section for details.

-p, --configuration-file <filepath>
read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
print list of command-line parameters

-q, --quiet
quiet mode; suppress all messages

--version
print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

aperture = value
: Aperture identifier (default=1)

var = star,star,...
: comma separated list of identifier(s) of the variable star(s)

comp = star,star,...
: comma separated list of identifier(s) of the comparison star(s)

check = star,star,...
: comma separated list of identifier(s) of the check star(s)

Examples

::

munilist output.dat test1.mat test2.mat test3.mat

The command makes table of brightness of the star #2 (stored on second position in photometry files) relative to the star #3 for photometry files `test1.mat`, `test2.mat` a `test3.mat`; the resulting frame is stored to `output.dat`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.13 munimatch (command)

utility for finding matching photometry files

Synopsis

munimatch [options] *reference-file input-files …*

Description

The **munimatch** command finds corresponding stars in two photometry files. One file is referred to as a reference file, the second one is called source file. The output of the matching process is the photometry file, which the stars from source file is written in, but their order is changed, so corresponding stars are on the same indexes in output and reference files. Instead of a reference file, which is usually one frame from a sequence being processed, a catalog file in XML format can be used.

The source and output files have to be in photometry file format. The reference file should be in photometry or catalog file format, optionally. If a set of files is processed, then the reference file is common for all sources.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set `<name=value>`
: set value of configuration parameter

-i, --read-dirfile `<filepath>`
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile `<filepath>`
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask `<mask>`
: set output file mask (default=:file:*%.mat*), see the *Output files* section for details.

-c, --counter `<value>`
: set initial counter value (default=1), see the *Output files* section for details.

-p, --configuration-file `<filepath>`
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
quiet mode; suppress all messages

--version
print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

max_stars = value
Max. number of input stars

vertices = value
Number of polygon vertices

clip_thresh = value
Clipping threshold

sp_fields = value
Matching method

sp_maxoffset = value
Max. offset for sparse fields

Examples

```
munimatch -oout.mat ref.pht in.pht
```

The command matches file `in.pht` as a source file and `ref.pht` as reference file and the writes output to `out.mat`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.14 muniphot (command)

utility for photometry of CCD frames

Synopsis

muniphot [options] *input-files* ...

Description

The **muniphot** command applies photometry to a single frame or a set of CCD frames. The output is written to so-called photometry files. Current version uses aperture photometry algorithm only. All source frames must be in the FITS format.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-s, --set `<name=value>`

set value of configuration parameter

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*kout????.fts*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-p, --configuration-file <filepath>
: read parameters from given configuration file. See the *Configuration file* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
: print software licence

--verbose
: verbose mode; print debug messages

Configuration file

Configuration files are used to set the input parameters to the process that is going to be executed by a command. Use the -p option to instruct the program to read the file before other command-line options are processed.

The configuration file consists of a set of parameters stored in a text file. Each parameter is stored on a separate line in the following form: name = value, all other lines are silently ignored. Parameter names are case-sensitive.

readns = value
: Readout noise

gain = value
: ADC gain

minvalue = value
: Min. pixel value in ADU

maxvalue = value
: Max. pixel value in ADU

fwhm = value
: Expected FWHM in pixels

thresh = value
: Detection threshold

minsharp = value
: Low sharpness cutoff

maxsharp = value
: High sharpness cutoff

minround = value
: Low roundness cutoff

maxround = value
: High roundness cutoff

skyinner = value
: Inner radius of sky aperture

skyouter = value
: Outer radius of sky aperture

apertures = value,value,...
: Comma separated list of radii of star apertures

Examples

```
muniphot -oout?.pht test1.fts test2.fts test3.fts
```

The command performs photometry to the files `test1.fts`, `test2.fts` and `test3.st7` and writes the output to the files: `out1.pht`, `out2.pht` and `out3.pht`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

8.1.15 timebat (command)

utility for time correction

Synopsis

timebat [options] *time-corr input-files* …

Description

The **timebat** command applies time correction to a set of source frames. It means, that it adds given amount of time to the times of observation. The program does not touch neither the image data nor other parameters in header. The source frames must be in the FITS format. The output file is in the FITS format too.

Input files

Names of input files can be specified directly on a command-line as command arguments; it is allowed to use the usual wild-card notation. In case the input files are placed outside the working directory, you have to specify the proper path relative to the current working directory.

Alternatively, you can also prepare a list of input file names in a text file, each input file on a separate line. It is not allowed to use the wild-card notation here. Use the -i option to instruct the program to read the file.

Output files

By default, output files are stored to the current working directory. Their names are derived from the command name followed by a sequential number starting by 1. Command options allows a caller to modify the default naming of output files.

The -o option sets the format string; it may contain a path where the files shall be stored to. Special meaning has a sequence of question marks, it is replaced by the ordinal number of a file indented by leading zeros to the same number of decimal places as the number of the question marks.

By means of the -i option, you can modify the initial value of a counter.

On request, the program can write a list of output files to a text file, use the -g option to specify a file name.

Options

Options are used to provide extra information to customize the execution of a command. They are specified as command arguments.

Each option has a full form starting with two dashes and an optional short form starting with one dash only. Options are case-sensitive. It is allowed to merge two or more successive short options together. Some options require a value; in this case a value is taken from a subsequent argument. When a full form is used, an option and its value can also be separated by an equal sign. When a short form is used, its value can immediately follow the option.

Whenever there is a conflict between a configuration file parameter and an option of the same meaning, the option always take precedence.

-i, --read-dirfile <filepath>
: read list of input files from specified file; see the *Input files* section for details.

-g, --make-dirfile <filepath>
: save list of output files to specified file, existing content of the file will be overwritten; see the *Output files* section for details.

-o, --output-mask <mask>
: set output file mask (default=:file:*tout????.fts*), see the *Output files* section for details.

-c, --counter <value>
: set initial counter value (default=1), see the *Output files* section for details.

-h, --help
: print list of command-line parameters

-q, --quiet
: quiet mode; suppress all messages

--version
: print software version string

--licence
print software licence

--verbose
verbose mode; print debug messages

Examples

```
timebat -oout.fts 43.512 in.fts
```

The command shifts time of observation of CCD frame stored in the file `in.fts` by 43 seconds and 512 miliseconds to the future. The output is written to file `out.fts`.

Exit status

The command returns a zero exit status if it succeeds to process all specified files. Otherwise, it will stop immediately when an error occurs and a nonzero error code is returned.

CHAPTER

NINE

C-MUNIPACK LIBRARY (API)

The C-Munipack library provides an extensive set of functions with a simple application programming interface (API) for reduction of images carried out by a CCD or DSLR cameras, aimed at observation of variable stars.

The library has been developed as a part of the C-Munipack software. See the project home page for more information about the project and other interfaces.

9.1 Sample program

The following text describes implementation of a very simple application, which performs photometry of a single CCD frame using functions from the C-Munipack library. It is supposed, that you have got the C-Munipack library and its headers installed.

The source code

Let's start - make a new project in your favorite IDE and make a big mug of coffee for yourself. First of all, we need to include some standard headers:

```
#include <stdio>
#include <stdlib>
```

The declarations from the C-Munipack library are sorted into several header files, but all we need to include just one header file, which in turn includes all other public header files:

```
#include <cmunipack>
```

We will use command-line arguments to specify name of an input CCD frame and name of an output file. Because of this, our declaration of the `main` function looks like this:

```
int main(int argc, char *argv[])
{
        CmpackPhot *lc;
```

The `lc` variable is called a context. The context stores the configuration parameters and keeps internal data used during photometry process. It allows a caller to process multiple frames in different threads without interference between each other. The context is a trick that makes all functions from the library *re-entrant*; you can safely call functions from different threads without any synchronization or locking features provided that those threads uses different contexts. There are two exceptions to that rule. The initialization routine must be called before any other call from the C-Munipack library and the clean-up routine must be called as the last call.

At the beginning of our sample program, we call the initialization routine:

```
/* Library initialization */
cmpack_init();
```

The next piece of code checks the command line parameters. This demo expects two parameters, the first one is a name of an input file with a source frame, the second one is a name of an output file:

```
/* Command line checking */
if (argc!=3) {
            fprintf(stderr, "Syntax: test <ccd frame> <photometry file>");
            return 1;
}
```

Before we do any real work, we need to create a new photometry context. This is a opaque data structure that keeps the configuration parameters required to perform a photometry on a frame. The context is created by calling the `cmpack_phot_init` routine. This function creates a new photometry context, sets all parameters to default values, sets the reference counter to one. A pointer to the context is returned. The caller becomes an owner of the context and when we don't need it anymore, we should release the reference by calling the `cmpack_phot_free` function which decrements the reference counter and destroys the context.

Let's set up at least two most important configuration parameters – the filter half-width and the detection threshold. We let all other parameter to the default values.

```
/* Create context */
lc = cmpack_phot_init();
cmpack_phot_set_fwhm(lc, 2.5);
cmpack_phot_set_thresh(lc, 4.0);
```

Now everything is ready to do a real work. The photometry is executed by calling the `cmpack_phot`, which takes the context as its first parameter, the names of the input and output files as the second and third parameter. The fourth parameter is NULL.

```
cmpack_phot(lc, argv[1], argv[2], NULL);
```

Before we finish the program, we should destroy our reference to the photometry context and since this is the last reference, the context and all data that are stored within the context is destroyed as well.

```
/* Destroy context */
cmpack_unref(lc);
```

Before terminating the program, you should call the library clean-up function.

```
        /* Library cleanup */
        cmpack_cleanup();

        return 0;
}
```

Compiling and linking

The C-Munipack library comes with a configuration file for pkg-config. If your system supports pkg-config, this is the easiest way how to pass all options that are necessary to compile and link an application against the C-Munipack library.

Otherwise, you have to set up all the options on the command line. Here is an example that builds our source code on Debian 4 using the gcc compiler.

```
gcc main.c -I -lcmunipack-1.2 -lexpat -lcfitsio -lm
```

9.2 Memory allocation

In the C-Munipack library, all dynamic memory allocation are performed by means of a group of routines which correspond to the C standard library memory handling function.

When you build your own application using the C-Munipack library, please check the API Reference to make sure when the caller is responsible to free the allocated memory blocks. To do so, you have to call the `cmpack_free` routine, otherwise, the behavior of the program is unpredictable.

Detecting memory leaks

When the C-Munipack library is compiled with `_DEBUG` symbol defined, the memory handling function keep track of blocks allocated on the heap. When the application calls the `cmpack_clean` routine, the list of blocks that are still allocated is printed to the standard output. This feature is designed to detect memory blocks that were allocated but not freed.

Detecting out-of-block modifications

When the C-Munipack library is compiled with `_DEBUG` symbol defined, the memory handling function check for out-of-block modifications. When a memory block is requested, the function allocates 8 bytes more and writes a 4 bytes of constant data at the beginning of the block and 4 bytes of constant data at the end of the block. The function returns a pointer of a memory after the first four bytes, so from caller's perspective, everything is transparent.

When a memory block is freed or reallocated, the program checks if the leading and trailing data were not modified. In such case, an assertion is issued to stop execution of the program.

9.3 Objects and reference counting

Most of the structures that are published by the C-Munipack library are opaque. They can be referenced by pointers, but their internal structure and content can be accessed only by calling appropriate functions. This slows down an execution of the resulting program, but provides a compatibility of binary code that were dynamically compiled against the library.

To help binding into other languages, the structures contain reference counters reference counting that can be incremented and decremented and when the last reference to a structure is lost, the structure is freed automatically. For each structure that support reference counting, there are two functions:

A function that has the `reference` suffix increments the reference counter of an object given as an argument. Its return value is a copy of the argument. A function that has the `free` suffix decrements the reference counter of an object given as an argument and when the reference counter reaches zero it destroys the object and frees allocated memory.

9.4 Initialization and clean-up

The library initialization routine `cmpack_init` must be called prior to any other call to the library. It initializes the static data and when the library was compiled with `_DEBUG` symbol defined, the data required by the memory leak detection is also initialized.

The library initialization routine `cmpack_cleanup` can be called before the program terminates, though it is not necessary, if you don't care about memory leaks, which is a bad idea in general. The clean-up code releases any memory allocated in static data. When the library was compiled with `_DEBUG` symbol defined, it prints out to the standard output a report about any memory blocks that were allocated but not freed. Please note that only memory blocks that were handled by library's allocation/free routines are threated by the leak detector.

9.5 Thread safety

Functions from the C-Munipack library are *re-entrant*. It means, that you can call them from different threads without any external synchronization and locking if they are called on different data. The data that are used inside a function call are stored on a stack, the data that are passed between function calls are stored in an memory allocated on a heap, called a context.

On the other hand, functions from the library are not *thread-safe*. When you call a function on the same context (data) from two threads at the same time, the behavior of the program and the results are unpredictable.

For example, it is safe to perform a photometry on two frames in two threads simultaneously, but you have to make two photometry contexts (instances of *CmpackPhot* type).

There are two exceptions to this rule, the library initialization routine `cmpack_init` and the clean-up routine `cmpack_cleanup`. These routines are not re-entrant nor thread-safe.

CHAPTER

TEN

THEORY OF OPERATION

This section of the user manual give a reader a detailed explanation how the data are processed in the C-Munipack software, how the output data are computed and how the temporary and the output data are formatted. The text is divided into the two sections; the description of the algorithms incorporated in the software is provided in the first part of the section, the second part comprises the specifications of the file formats.

10.1 Algorithms

The algorithms involved in the C-Munipack software at the various stages of the data processing are described in detail in this section. Its purpose is to explain to a curious reader how the source frames and the photometry files are handled, what the numbers and graphs mean and how exactly they are derived. I do not claim that I have invented the algorithms, whenever possible, proper references to the original materials are given.

In the following text, reference is often made to "bad" and "overexposed" pixels. A pixel is regarded as a bad pixel if its value is equal to or less than the value of the first configurable parameter "Minimum pixel value". Usually this parameter is set to zero, the lowest possible value that can be stored in a source image. An overexposed pixel has a value equal to or greater than the value of the second configurable parameter "Maximum pixel value". This configuration parameter should be set to a value at which the analog-to-digital converter saturates, but can be set to a lower value to exclude a higher part of the intensity range where response of a detector is not linear enough. In the correction algorithms, both bad and overexposed pixels are excluded from the computations.

10.1.1 Dark-frame correction

There is a choice of two calibration schemes for the dark-frame correction: the standard calibration scheme and the advanced calibration scheme.

Standand calibration scheme

In the "standard calibration scheme", the dark-frame correction is a subtraction of a dark frame *D* from a source frame *X* to generate an output frame Y. The following formula is applied to each pixel at coordinates *(x, y)* independently:

$$Y(x,y) = X(x,y) - D(x,y) \tag{10.1}$$

Bad and overexposed pixels require special treatment:

- If a pixel is bad at either source frame or dark frame, it must be marked as bad on a corrected frame.
- If a pixel is overexposed on the source pixel, it must stay overexposed after the correction.
- If a pixel is overexposed on the dark frame, it is marked as bad on the corrected frame.

Advanced calibration scheme

In the "advanced calibration scheme", a scalable dark frame, that was acquired with exposure duration $t_S D$ is scaled to match the exposure duration t_X of a source frame *X*. Then, the dark frame is subtracted from a source frame to generate an output frame *Y*.

$$Y(x, y) = X(x, y) - \frac{t_X}{t_S D} SD(x, y) \tag{10.2}$$

The program makes sure that the dark frame is a scalable dark frame by checking the status of the *SCALABLE* flag, which is stored in the file's header.

10.1.2 Flat-frame correction

The flat-frame correction is a division of a source frame *X* by a flat frame *F* and multiplying it by a constant *k*. The constant *k* is determined such that the range of pixel values and the gain factor (number of photons per ADU) are roughly preserved. The constant *k* is computed as a mean value of the correction frame *F* by means of the robust mean algorithm, see the chapter *Robust mean*.

$$Y(x, y) = X(x, y) - k\,\frac{X(x, y)}{F(x, y)} = X(x, y) - \bar{F}\,\frac{X(x, y)}{F(x, y)} \tag{10.3}$$

Bad and overexposed pixels require special treatment:

- If a pixel is bad in either source frame or dark frame, it must be marked as bad on the corrected frame.
- If a pixel is overexposed on the source pixel, it must stay overexposed after the correction.
- If a pixel is overexposed on the flat frame, it is marked as bad on the corrected frame.

10.1.3 Bias-frame correction

The bias-frame correction is a subtraction of a bias frame *B* from a source frame *X* to generate an output frame *Y*. Unlike the dark correction, scaling is not applied, because the bias is independent of exposure duration. The bias-frame correction is applied only in the *advanced calibration scheme*.

$$Y(x, y) = X(x, y) - B(x, y) \tag{10.4}$$

The following statements describe how bad and overexposed pixels are treated:

- If a pixel is bad in either source frame or bias frame, it must be marked as bad on the corrected frame.
- If a pixel is overexposed in the source frame, it must stay overexposed after the correction.
- If a pixel is overexposed on the bias frame, it is marked as bad on the corrected frame.

10.1.4 Master dark frame

A master dark frame is created from a set of raw dark frames. The robust mean algorithm (see *Robust mean*) is applied on a pixel-by-pixel basis, while leaving out bad and overexposed pixels. If there are enough source frames, the robustness of the algorithm ensures that an accidental artifact (e.g. cosmic ray particle) is ruled out and does not affect the mean value. If a pixel has an invalid value on all source frames, it is marked as a bad pixel on the resulting frame.

The source dark frames must have the same exposure duration, otherwise the resulting frame is not correct.

A scalable dark frame is computed in the same way as a master dark frame. The program checks that the bias-frame correction was applied to all source frames and sets the *SCALABLE* flag in the file's header. The status of this flag is checked in the dark correction, see chapter *Dark-frame correction*.

10.1.5 Master flat frame

A master flat frame is created from a set of raw flat frames. Unlike the dark frame, we normalize the source frames first to ensure equal mean value for all of them. This is correct, because the mean level of a flat frame depends on the intensity of the light source that was used to illuminate the camera. What we are seeking here is a ratio of sensitivity of a detector pixel to the mean sensitivity of all pixels. It would be natural to normalize the flat frames to a mean value of 1.0, but if we attempted to store such a normalized frame to a file storing each pixel value as an integer number, the quantization noise would destroy all our efforts. Therefore, we have to choose a value which is high enough the reduce the quantization noise. On the other hand, the allowed range of values that can be stored to a file is limited and depends on the number of bits reserved for each pixel. If we put the mean intensity too high, some of the pixels would be out of range. The value which the flat frames is normalized to is a configurable parameter, its default value of 10,000 provides a trade-off between quantization noise and the limited range, and it is appropriate in the vast majority of cases.

The steps are as follows: First, take each of the source frames, apply the robust mean algorithm (see chapter *Robust mean*) to compute its mean intensity, then normalize the frame by dividing each pixel value by the mean value and multiplying by the required mean value of 10,000. Next, apply the robust mean algorithm to normalized frames on pixel-by-pixel basis, while leaving out bad and overexposed pixels. If a pixel has an invalid value on all source frames, it is marked as a bad pixel on the resulting frame.

10.1.6 Master bias frame

A master bias frame is created from a set of bias frame. The robust mean algorithm (chapter *Robust mean*) is applied on a pixel-by-pixel basis, while leaving out bad and overexposed pixels. If there are enough source frames, the robustness of the algorithm ensures that an accidental artifact is ruled out and does not affect the mean value. If a pixel has an invalid value on all source frames, it is marked as a bad pixel on the resulting frame.

10.1.7 Star detection

Star detection is an algorithm that finds stellar objects on a CCD frame. The input of the algorithm is a calibrated CCD frame F; that is, the bias, dark and flat corrections have already been applied to the source image data. The output of the algorithm is a table of x and y coordinates that correspond to the centers of detected stellar objects. For practical use, the robustness of the detection is a crucial property, because the signal to noise ratio of real images tend to be low, and there are often artifacts present.

The algorithms that are in the C-Munipack software follow the algorithms from the Stetson's *FIND* routine - see [**?**] for the documentation of the original code.

Estimation of overall background level and noise level

In the prologue of the star detection, the overall background mean level and noise level is determined. These values are required in the following phases. The robust mean algorithm, described in the section *Robust mean*, is used to determine the mean level and standard deviation of the background. It is assumed, that majority of pixels are not stars; in this case the pixels that are covered by stars are rejected by the robust mean as outliers, but if the field was almost covered by stars, the background estimate would be biased.

Not all pixels are included in the computation of the robust mean, the program filters out pixels that belongs to the user-defined border and also bad and overexposed pixels.

Fitting Gaussian function

Because of the noise, the shapes of stars are not regular. Especially for faint stars, the maximum pixel need not be located at its center. When the telescope was slightly de-focused during the exposure, the profiles of stars has a depression in its center caused by a projection of the secondary mirror on the detector. Insufficient filtering at this stage causes multiple detections of a single object.

The low-pass filter is implemented by fitting a function *y* to each pixel using several pixels in its neighborhood. The function *y* is a linear combination of a sampled two-dimensional Gaussian function $g(i, j)$ that represents an image of a stellar object and a constant function that represent a local background level. The linear least squares method is used to determine the two coefficients *h* and *s* of fitted function *y*:

$$y(i, j) = h\, g(i, j) + s = h\, e^{-\frac{(i-i_0)^2+(j-j_0)^2}{2c^2}} + s \tag{10.5}$$

where i_0 and j_0 are coordinates of a central pixel and *c* is computed from the configurable parameter *FWHM*, which determines the width of a Gaussian function and the filter's frequency response. The parameter *c* is related to the *FWHM* parameter according to:

$$FWHM = 2\sqrt{2\log 2}\, c \tag{10.6}$$

The linear least squares find values of free parameters *h* and *s* which minimizes a sum of squared residuals between original image data $F(i, j)$ and its model $y(i, j)$

$$S(h, s) = \sum (y(i, j) - F(i, j))^2 \rightarrow min. \tag{10.7}$$

The Gaussian function as well as the constant function are contiguous and indefinite, for practical implementation we have to restrict the integration space to the pixel's neighborhood. We determine the half-length of a filter using the *FWHM* parameter:

$$\text{filter half-length} = \max(2, \lfloor 0.637 * \text{FWHM} \rfloor) \tag{10.8}$$

For practical use, we define *n* as a width and height of a square matrix as $n = 2 * \text{filter half-length} + 1$ and also a value of *N* as a number of pixels in the pixel's neighborhood $N = n^2$.

From a solution of a linear least squares we get the following formula for the coefficient *h* that multiples the Gaussian function.

$$h = \frac{N \sum gf - \sum f \sum g}{N \sum g^2 - (\sum g)^2} \tag{10.9}$$

Equation (**??**) is applied to each pixel of a source frame *F* independently, leaving out pixels that are too close to the border, less that filter half-length. Computed values of the *h* coefficient for each pixel are stored in a new auxiliary frame *H*.

Finding star candidates

The object candidates are found by searching for local maxima in the auxiliary frame *H*. The neighborhood of each pixel at coordinates *x* and *y* is checked out to the radius equal to the filter half-length. If the pixel in the center has a greater value than all pixels in its neighborhood, we have found a candidate.

The candidates are subjected to several subsequent tests. Each test was designed to be sensitive to specific class of artifacts.

Checking minimum brightness

The height of the fitted two-dimensional Gaussian function stored in the filtered frame *H* of a candidate with local maximum at coordinates *x* and *y* must be equal to or greater than minimum height, *hmin*:

$$hmin = \text{THRESHOLD} * relerr * \sigma_F^2 \tag{10.10}$$

where *THRESHOLD* is the detection threshold parameter, adjustable in the configuration of the program.

The *relerr* term in the equation is determined as:

$$\frac{1}{relerr} = \sqrt{\sum G^2 - \frac{(\sum G)^2}{N}} \tag{10.11}$$

where *N* is a number of pixels in the matrix *G*.

The σ_F^2 term is an estimation of random noise per pixel in ADU. The random noise has two independent sources. The first one is the Poisson statistics that applies to a number of photons that hit the detector during the exposure (number of discreet events that occurred in a fixed time). The variance σ^2 of the Poisson random variable with mean value of λ is $\sigma^2 = \lambda$. If we know the number of photons per ADU, the gain *p* of the detector, and the mean level *s* of the background, the mean number of photons λ that hit the detector is $p.s$.

The variance of the random error per pixel in ADU σ_{ADU}^2 is determined from the formula

$$\sigma_{ADU}^2 = \frac{s}{p} \tag{10.12}$$

The second source of noise is the preamplifier and A/D converter σ_{RN}^2, usually referred to as the read-out noise. This parameter should be given by a manufacturer in the camera's data sheet, however, this value is stated for a single frame and when a processed frame has been made by summing or averaging of multiple raw frames, a corresponding transformation of the specified value of the read-out noise must take place. This applies namely when one is processing DSLR images or combined CCD images.

If the processed frame has been made as a *sum* of *N* raw frames, then

$$\sigma_{RN}^2 = (\text{READOUT\_NOISE})^2 * N \tag{10.13}$$

where *READOUT NOISE* is a read-out noise value in A/D units per frame (from the data sheet).

If the processed frame has been made as a *average* (arithmetic mean) of *M* raw frames, then

$$\sigma_{RN}^2 = (\text{READOUT\_NOISE})^2 / M \tag{10.14}$$

These sources are independent, therefore from the error propagation rules we determine the overall noise σ_F^2 as:

$$\sigma_F^2 = \sigma_{ADU}^2 + \sigma_{RN}^2 \tag{10.15}$$

Sharpness of an object

This test is intended to leave out diffuse objects, traces of cosmic particles, etc. The sharpness value of a candidate must be within configurable limits. Sharpness is defined as a ratio of height of best-fitting Gaussian function and best-fitting sampled two-dimensional δ function.

$$\delta(i,j) = \begin{cases} 1, & \text{if } i = i_0 \text{ and } j = j_0 \\ 0, & \text{otherwise} \end{cases} \tag{10.16}$$

The first value, the height of best-fitting Gaussian function has already been determined in advance – it is stored in the auxiliary frame *H*. The procedure of fitting the delta function is the same as for the two-dimensional Gaussian function. We model the image as a linear combination of the delta function δ and the constant function.

$$S(d,t) = \sum (d.\delta(i,j) + t - F(i,j))^2 \to min. \tag{10.17}$$

We limit the fitting of the delta function to the same number of neighboring pixels as we did for fitting the Gaussian function. By solving the linear equations to find a value of free parameters *d* and *t* that minimizes the sum of squared residuals between the model *y(i,j)* and original frame F we get a height of best-fitting delta function as a value of *d*:

$$d = \frac{N\sum \delta f - \sum f \sum \delta}{N\sum \delta^2 - (\sum \delta)^2} = \frac{N f(i_0,j_0) - \sum f}{N-1} = f(i_0,j_0) - \frac{\sum f - f(i_0,j_0)}{N-1} \tag{10.18}$$

The last form of the equation is easy to implement. It says: take the central pixel and subtract the average of all surrounding pixels.

Roundness of an object

This test rules out candidates that have a width along the x-axis much different than along the y-axis. Such local maxima do not correspond to real stars, but to artifacts caused during the read-out of the CCD chip.

The roundness parameter is defined as the relative difference between height of the best-fitting Gaussian in x and y axes. Please note, that unlike the previous steps, we fit the image data to a one-dimensional Gaussian function. Therefore, we need to reduce the dimensionality of the image data. The distribution of the signal is modeled after a 2D Gaussian function. We take advantage of a fact that an integral of the 2D Gaussian function *G(x,y)* in *x* is 1D Gaussian function *G(y)* and vice versa.

First, we sum the image data in the neighborhood of the local maxima by rows to a vertical profile of an object and we fit the result with a linear combination of a one-dimensional Gaussian function and a constant function. From the least squares fit we get the height of Gaussian h_x. Second, we sum the image data by columns to get a horizontal profile of an object and by the same way we get a value h_y. The roundness parameter is derived as the difference between those two values divided by their average.

$$\text{ROUNDNESS} = 2\,\frac{h_x - h_y}{h_x + h_y} \tag{10.19}$$

If the heights of both Gaussian functions are equal, the value of roundness is zero. If one the Gaussian functions has zero height, the value is 2 or -2. The default allowed range for the roundness is -1 and 1.

Finding center of the object

Up to this point, we have worked with the data as if the center of the object was located in the center of the brightest pixel. In this step, we derive the position of the object by estimating an offset vector of the centroid of the brightness enhancement to the brightest pixel.

The offset vector is derived in two subsequent steps, its d_x and d_y components are computed separately. The value of d_x is computed by fitting the first derivative of a one-dimensional Gaussian function $G'(x)$ to the difference between image data $F(x)$ and the best-fitting Gaussian function $G(x)$. We use the same horizontal profile of the object as we used in the computation of the roundness parameter and we subtract the best-fitting Gaussian function $h_xG(x)$ that we have already derived. Then we fit the result of subtraction by the linear combination of the function $G'(x)$ and a constant function using the linear least squares method.

$$S_x(j_x,k_x) = \sum ((j_x.G'(x) + k_x) - (F(x) - h_x.G(x)))^2 \to min. \tag{10.20}$$

We find the value of j that minimized the sum in equation (**??**). The value is then used to estimate the offset between the central pixel and the centroid of the brightness enhancement using the equation (**??**). *Proof?*

$$d_x = \frac{j}{1 + |j|} \tag{10.21}$$

The same method is used to derive the offset d_y in the vertical direction.

The object's center $\vec{o}$ is computed as a sum of coordinates of central pixel $\vec{x}$ and the offset vector $\vec{d} = (d_x, d_y)$.

10.1.8 Aperture photometry

Aperture photometry determines brightness of a stellar object by integrating the signal in a small area on a frame. This area, usually called the aperture, is chosen in such a way that it includes all pixels that were exposed by the light from the measured object, but not the light from another source.

The point spread function that represents the spatial distribution of the signal from an ideal stellar object is rotationally symmetric, so the aperture has circular shape. The conditions described above define requirements of the ideal aperture size. If it were too small, a non-negligible part of the signal would be omitted; on the other hand, the bigger the aperture the bigger is the chance that another object appears in the area.

Supposing the frames were properly calibrated, the frame contains the superposition of two sources - the sky background and the signal from objects. When we sum the pixel values in an aperture, the sum contains these both of these. To get a signal from the object only, we need to subtract the background level.

It is not possible to measure the background at the positions of the objects directly. We need to estimated local background level from neighboring pixels. For this estimation we use another aperture that has an annular shape. Its center is aligned to the same point as the integrating aperture. The central blank part of the annulus masks the signal from the measured object. The mean value of pixels in the annulus is used to estimate background level at its center. In an ideal case, the annulus would contain only pixels that represent the background, without objects. In practice this is not generally the case, therefore a robust algorithm for estimation of the mean level must be applied - such an algorithm must effectively reject pixels exposed by stellar objects in the annulus. See the chapter *Robust mean* for its implementation in the C-Munipack software.

The C-Munipack software uses the same algorithm for aperture photometry as Stetson's DAOPHOT software. You can see [**?**] for the documentation that comes with the original code.

Deriving brightness of an object

We have stated that the sum *S* of pixels in a small area *A* around an object is a sum of the object's net intensity *I* plus background intensity $B\,.\,A$:

$$S = I + B\,.\,A \tag{10.22}$$

The values of *S* and *B* are derived from the source frame, the area *A* is determined as the area of circle of radius *r*, where *r* is the size of the aperture in pixels. It is then easy to compute the net intensity *I* of an object in ADU:

$$I = S - B\,.\,A \tag{10.23}$$

Supposing that the net intensity *I* is proportional to the observed flux *F*, we can derive the apparent magnitude *m* of the object, utilizing the Pogson's law:

$$m = -2.5 \log_{10} \left(\frac{I}{I_0} \right) \tag{10.24}$$

where I_0 is a reference intensity from an object of some chosen reference flux F_0. The ratio between flux and intensity is not known, however it is legitimate to choose any reference intensity I_0 value, providing only the magnitude difference between two objects is required - the difference is independent of choice of the reference intensity I_0. In the C-Munipack software, the reference intensity was set to 10^{10} ADU.

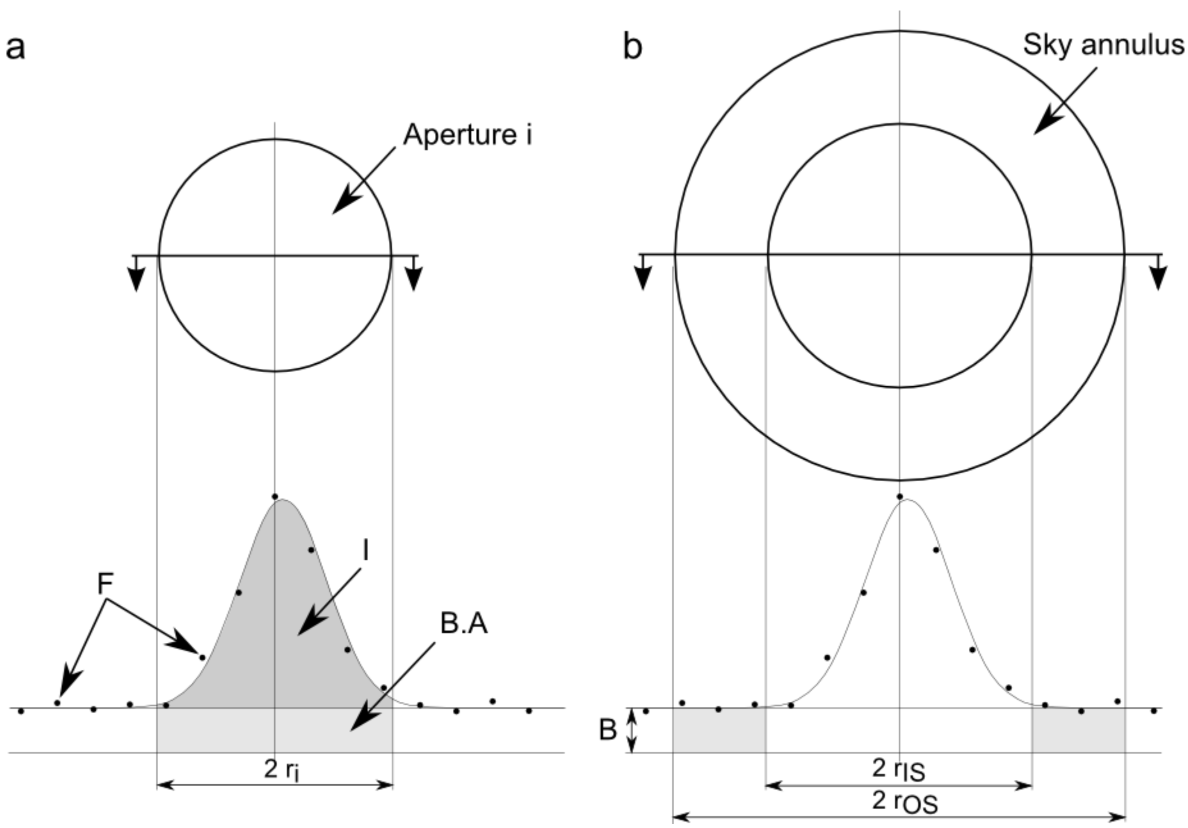


Fig. 1: Aperture photometry. (a) Aperture *i*: *F* – image data samples, *I* – net intensity of a stellar object, *B,.,A* – background signal, *r_i* – aperture radius; (b) Sky annulus: *B* – background mean level, r_{IS} – inner radius of sky annulus, r_{OS} – outer radius of sky annulus.

When the brightness cannot be measured?

In some situations, brightness of an object cannot be measured:

- The distance between the object's center and the image border is smaller than the aperture radius.
- There is an overexposed pixel or a bad pixel inside the aperture.
- The net intensity I is zero or negative.

When the output data are saved to an DAOPHOT-compatible photometry file, unmeasured objects are indicated by brightness value 99.9999. The reader should recognize any brightness greater than 99.0 magnitudes as an invalid measurement.

Estimating the measurement error

Once we have derived the raw instrumental brightness of an object, we will try to estimate its standard error. First of all, we will recall a few general rules that apply to the standard error and its propagation. This is a general rule for error propagation through a function f of uncertain value X:

$$\mathrm{Var}(f(X)) = (\frac{df}{dx})^2\,\mathrm{Var}(X) \tag{10.25}$$

Using this general rule, we derive two laws of error propagation. In the first case, the uncertain value X is multiplied by a constant a and shifted by a constant offset b. This law can also be used in the case where only a multiplication or only an offset occurs.

$$\mathrm{Var}(aX + b) = a^2\,\mathrm{Var}(X) \tag{10.26}$$

The second law defines the error of a logarithm of uncertain value X:

$$\mathrm{Var}(\log(\pm bX)) = \frac{\mathrm{Var}(X)}{\bar{X}^2} \tag{10.27}$$

Please note, that the *log* function here is the natural logarithm, while the Pogson's formula (see above) incorporates the base-10 logarithm. The following equation helps us to deal with this difference:

$$\log_b(x) = \frac{\log_k(x)}{\log_k(b)} \tag{10.28}$$

Putting these two equations together we get:

$$\mathrm{Var}(\log_{10}(\pm bX)) = \frac{\mathrm{Var}(X)}{\bar{X}^2\,\log(10)^2} \tag{10.29}$$

If we have two uncorrelated uncertain variables X and Y, the variance of their sum is the sum of their variances, this equation is known as Bienaym'{e} formula.

$$\mathrm{Var}(X + Y) = \mathrm{Var}(X) + \mathrm{Var}(Y) \tag{10.30}$$

From this formula, we can also derive the standard error of a sample mean. If we have N observations of random variable X with sample-based estimate of the standard error of the population s, then the standard error of a sample mean estimate of the population mean is

$$SE_{\bar{X}} = \frac{s}{\sqrt{N}} \tag{10.31}$$

Armed with this knowledge, we can start thinking about the estimation of standard error of object brightness. We will consider the following three sources of uncertainty: (1) random noise inside the star aperture that includes the thermal noise of the detector, read-out noise of the signal amplifier and the analog-to-digital converter, (2) Poisson statistics of counting of discreet events (photons incident on a detector) that occur during a fixed period of time and (3) the error of estimation of mean sky level.

For the estimation of mean sky level, we have used the robust mean algorithm. It allows to estimate its sample variance σ^2_{pxl}. This is a pixel-based variance and because we have summed together *A* pixels in the star aperture, the Bienaym'{e} formula applies, the sum *S* is a sum of *A* uncorrelated random variables, each of which has variance σ^2_{pxl}. For the variance of the first source of error we get:

$$\sigma_1^2 = A\,\sigma^2_{pxl} \tag{10.32}$$

where *A* is a number of pixels in the star aperture.

From Poisson statistics we can derive a variance that occur due to counting of discreet events, photons incident on a detector, that occur during a fixed period of time, the exposure. We will again need to use the gain *p* of the detector to convert a intensity in ADU to a number of photons. If the measured net intensity of an object is *I* we compute the mean number of photons $lambda$ as

$$\lambda = I\,p \tag{10.33}$$

Then, the variance of intensity due to Poisson statistics is equal to its mean value.

$$\sigma^2_{ph} = \mathrm{Var}(\mathrm{Pois}(\lambda)) = \lambda = I\,p \tag{10.34}$$

The variance is in photons, we have to convert it back to ADU to get the variance in units ADU^2.

$$\sigma_2^2 = \frac{\sigma^2_{ph}}{p^2} = \frac{I\,p}{p^2} = \frac{I}{p} \tag{10.35}$$

We have derived the sky level as a sample mean of pixel population in the sky annulus. Because each pixel in the annulus has variance σ^2_{pxl}, the variance of sample mean is

$$s^2_{sky} = \frac{\sigma^2_{pxl}}{n_{sky}} \tag{10.36}$$

where n_{sky} is the number of pixels in sky annulus.

From equation (**??**) we compute the variance of object's intensity as

$$\sigma^2_{ADU} = \sigma_1^2 + \sigma_2^2 + A^2\,s^2_{sky} \tag{10.37}$$

Note, that in equation (**??**) the sky level is multiplied by *A*, so we have to multiply its variance by A^2 - see the equation (**??**). Now, we use the law of error propagation for the logarithm adopted to match the formula of the Pogson's law.

$$\sigma^2_{mag} = (\frac{-2.5}{I\,\log(10)})^2\,\sigma^2_{ADU} \tag{10.38}$$

Putting equations (**??**) and (**??**) together, we can derive the standard error of the object's brightness in magnitudes as

$$\sigma_{mag} = \frac{1.08574}{I}\,\sqrt{\sigma^2_{ADU}} \tag{10.39}$$

Intensities

In some cases when further processing of the photometric data is involved, ensemble photometry for example, it is necessary to get intensity (brightness) values of individual stars instead of the standard differential magnitudes. The intensity I_{ADU} is defined as integral of the light in an aperture minus contribution of a local background. The intensity can be transformed into magnitudes using Pogson's law and a reference intensity. In the C-Munipack software, this value is called the raw instrumental magnitude.

The net intensity *I* in ADU can be computed from the raw instrumental magnitude *m* using an inversion of the Pogson's law (see (**??**)). As was stated above, the reference flux was set to 10^{10} ADU. The resulting relation is:

The error estimation σ_I for the net intensity *I* can be computed from the error estimation σ_{mag} using an inversion of the equation (**??**):

$$\sigma_{ADU} = \frac{I}{1.08574} \sigma_{mag} \tag{10.40}$$

10.1.9 Frame matching

Note: I'd like to point out, that I did not invent the algorithm presented below. I reimplemented the algorithm that was part of the original Munipack software. According to the original source code, Filip Hroch is the author, but I haven't found any paper regarding this method. In case you know about it, please let me know.

Up to this point, the source frames are processed independently. To make a light curve of a particular object, we need to trace that object throughout the set of frames. This step is called *matching* in the C-Munipack software. It takes two or more lists of stellar objects (result of photometry) and determines which objects on one list are the same physical object on the rest of the lists.

The matching algorithm implemented in the C-Munipack software is an extension of the algorithm published by Valdes [**?**]. The main difference is that it builds polygons of $n \geq 3$ vertices instead of triangles. The text follows the terminology of Valdes wherever possible. The matching algorithms based on similarity of triangles were described and implemented also by Stetson [**?**] and Groth [**?**].

The algorithm works on two catalogs of objects, each object is described by its coordinates in some local coordinate system and its brightness. We assume that the coordinate systems of these catalogs are shifted, scaled, rotated or even inverted. To make it even more difficult, the catalogs can overlap only partially; objects from one catalog need to be present in the second catalog and vice versa. Problems with separation of close objects might cause that objects present in one catalogs are missing in the other catalogs. In addition to that, due to random and field distortions to position of objects are subject of noise and thus they are known only imprecisely.

The matching algorithm works in three subsequent phases. In the first phase, possible transformations between the coordinate systems of two catalogs are found. Then, the best transformation is chosen and last a relation between the objects from the two catalogs is established.

Although the method in its basic form works on a pair of catalogs only, its extension to an arbitrary number of frames is obvious. One frame from the set of source frames is chosen as a reference catalog and all other source frames are matched against the reference one. The alternative is to use any other catalog of the same field and match the source frames against it.

Similar triangles

A catalog of objects can be seen a large number of triangles - it is possible to create a triangle for every combination of three objects. If the coordinate systems of two catalogs are shifted, scaled, rotated or inverted (flipped) to each other and two catalogs show at least partially the same set of physical objects, there must be many triangles that have the similar shape in both catalogs, because the said operations do not change the their shape. Not all triangles from one catalog have their counterparts in the other one. Also, due to the noise component in position measurements and field distortion, the triangles are never exactly the same.

Following Stetson [**?**], shape of a triangle is described by two shape indices which form a point in two-dimensional *triangle space* (x_t, y_t) defined as:

$$u = \frac{\text{length of second longest side}}{\text{length of longest side}} \tag{10.41}$$

and

$$v = \frac{\text{length of shortest side}}{\text{length of longest side}} \tag{10.42}$$

It can be shown, using the law of sines, that if a triangle is made by shifting, rotation, scaling, inversion or their combination from an original triangle, it projects to the same point in the triangle space. The Euclidean distance in the triangle space is used to measure similarity of two triangles. If it is lesser than some value ϵ, the triangles match.

Building polygons

The algorithm implemented in the C-Munipack software follows the method described by Valdes. It sorts the objects by the brightness in decreasing order and takes up to N_{obj} objects from both catalogs. But it does not stop when it find a pair of triangles that match. It continues to build up a pair of polygons of *N* vertices from them by taking one of the sides and finding two objects that would form yet another similar triangles. On success, it adds the objects to the list to make a quadrilateral and so on up to a polygon with *N* sides. The value *N* is a configurable parameter. A constant value $\epsilon = 0.005$ is used to check if two triangles match.

Reducing the number of false matches

The following optimization reduces the number of false matches. When a pair of objects *(A, B)/ and *(A', B')* is takes, their distances $d = |AB|$ and $d' = |A'B'|$ are computed. The ratio *d:d'* is used as a scale between the two frames. Also, points in half between these points *P* and *P'* are determined. For any point *C* from the first catalog, its distance to the point *P* is divided by *d:d'* to get expected distance of a desired object *C'* to the point *P'*. Then, it is possible to restrict the search to objects of distance to *P'* not very far from the expected value. Quick sort algorithm is used to sort objects by distance from the point *P'*, which allows to stop search when the distance is above upper limit.

From polygon to transformation

By means of the algorithm described in the previous section, two similar polygons *P_1* and *P_2* were found, each of which has *N* vertices. The next step is to find the best-fitting transformation between coordinates of vertices of *P_1* and *P_2*. The scale factor is estimated first. Next, the inversion is determined. Finally, the linear least squares (LLSQ) method is applied to find the values of the rest of the parameters.

The estimation of the *scale* factor *s* between the two polygons *P* and *P'* is estimated as the robust mean of ratios between corresponding vertex distances of the two polygons. The mean value is determined using the robust mean algorithm (see *Robust mean*).

The *inversion* is represented by value *m = 1* if mirroring does not occur (local coordinate systems are of the same handedness) or *m = -1* if it does. To determine the value *m*, first two vertices of polygons *P* and *P'* are used to make oriented lines and we check whether the third vertices in *P* and *P'* are on the same side of the oriented lines. The test can be performed in 3-D space by comparison of sign of z-coordinate of crossproduct of the vectors $\vec{AB}$ and $\vec{AC}$ to the sign of z-coordinate of crossproduct of the vectors $\vec{A'B'}$ and $\vec{'A'C}$. The value *m = 1* if the signs are equal, *m = -1* otherwise.

The *rotation* and *offset* between the two frames are estimated by determining coefficients *A*, *B*, *X_0* and *Y_0* by means of the LLSQ method.

The first estimation of the transformation matrix *M_0* is created by combining the scale factor, the *m* value and the results of the LLSQ fitting. The variance :math`sigma_0^2` of the solution is determined using the minimized value of the sum of squares *S*:

$$\sigma_0^2 = \frac{S}{2N-4} = \frac{1}{2}\frac{S}{N-2} \tag{10.43}$$

The denominator, *2N-4*, is the statistical degrees of freedom; *2N* is the number of equations (each vertex gives two equations) and there are four free parameters. The variance will be used to determine allowed displacement between expected and observed position of a star.

Refining the transformation

The transformation found using polygon vertices only is further refined in the second stage by including stars from *S* and *S'*. It was stated above, that not all stars from S* and *S'* must necessarily have corresponding objects on the other frame, thus it is necessary to use a robust approach and rule such stars out.

For each star from a set *S*, its coordinates are transformed into the second frame using the matrix *M_0* (first estimation). Then, a star from the set *S'* with minimum distance to the computed location is found, and if its distance is less than maximum displacement *t*, the two stars are included in the second estimation. The value *t_0* is determined using the variance σ_0^2:

$$t_0 = \sigma_0.\text{clip}.\sqrt{6} \tag{10.44}$$

The stars from the set *S* that were successfully identified in *S'* are used in the LLSQ method (same as in the first iteration) in order to determine a second estimation of the transformation matrix *M_1*. The scale and mirror value are kept unchanged. Also, the new value of sample variance σ_1^2 is determined.

Number of identified stars and the sum of squares from the second iteration are used to select a best-fitting solution.

Vote array

The vote array is organized as a map, where keys are unordered sets of polygon vertices and it stores number of matches, stars that were identified in the second stage, sum of squares and the transformation matrix. When a new candidate is identified, the program compares the set of polygon vertices with existing keys in the vote array. When there is a matching item, its match counter is incremented by one. If not, a new record is added to the vote array and its match counter is initialized to one.

The selection of the best-fitting solution is based on the number of matches. If the vote array contains multiple records with the maximum match count, the first one wins.

Cross-reference table

The result of the matching algorithm applied to a set of source frames is a cross-reference table which represents relations between objects detected on the source frames. The table should allow to efficiently find the measurements for a particular physical object. In the C-Munipack software, each detected object on a single source frame is assigned a unique integer number at the final stage of the photometry step; these identification numbers are frame-wise.

The cross-reference table is a map where keys are frame identification and frame-wise object identifier and the values are global object identifiers. If the matching is done against one of the source frames, object identifiers on that source frame are used as global identifiers. If a catalog file is used, the object identifiers in the catalog are used as global identifiers.

The table is stored in a distributed form, each object on each frame has got an attribute that defines if the object was found on a reference frame or a catalog file and if so, what the global identification was.

10.1.10 Tracking a moving target

The process of matching frames, based on features that are preserved under certain transformations, as it was described in the *previous chapter*, works well for stellar objects; detected stars form the same pattern on each frame. Mismatch between any two frames is change in spatial offset, scale and rotation, in some cases also a mirror operation applies. The task of matching a set of frames is about finding a set of equations (matrix) that transforms coordinates of any vector (point) on one frame to a vector in a reference coordinate system.

In case of moving targets, such as minor Solar System bodies, in additional to the mismatch desribed above, another source of mismatch is introduced - an object of interest, having its own radial movement, changes its position with respect to surrounding stars between the frames (in time). Therefore, if a pattern used for the frame matching would include such an object, it would not match. The challange in reduction of an observation of minor bodies is in founding an image of the object of interest on each source frame. Fortunately, it can be reasonably expected, that such an object does not move randomly, but follows a simple trajectory that can be fitted using a simple polynomial function or spline.

The C-Munipack software approaches this task with help of a user. He picks up a small set of frames, called key frames, and on each frame he indicates an object that corresponds to the target. As in the frame matching for stellar objects, a user also chooses one frame to be a reference frame. The rest of the process does not require any further interaction.

The key frames are processed first. The object indicated by the user as the target is left out from the reference frame and the key frame. Then, the same frame matching process as in case of a stellar object is applied to those two frames. This is repeated for each key frame and the equations that transforms frame coordinates into reference coordinates are preserved.

The software keeps an observation time and position of the target object from each key frame and transforms those positions into the reference coordinate system. Then, using linear least squares method, the transformed positions are interpolated using two second order polynomial function of time t:

$$x(t) = A_x + B_x.t + C_x.t^2 \tag{10.45}$$

and

$$y(t) = A_y + B_y.t + C_y.t^2 \tag{10.46}$$

Using the functions $x(t)$ and $y(t)$ a position of the target in the reference coordinate system can be determined an any given time t.

Subsequently, the matching process continues with processing all other frames. The software reads an observation time t of a frame and using the functions $x(t)$ and $y(t)$, determines the position of the target in reference coordinate system in time t. Then, the target object's position on the reference frame is changed to values $x(t)$ and $y(t)$ and a standard frame matching process is applied. If the fit is correct, an object close to the expected position of the target is found, the pattern of objects on the reference frame and the pattern on source frame match and an identification of the target object is found as a result of the standard frame matching process.

10.1.11 Artificial comparison star

The artificial comparison star is used to enhance a quality of a light curve by utilizing multiple stars that are used to compute differential magnitudes of a variable star.

A new virtual comparison star is created from a set of stars and its brightness in magnitudes and error estimation are derived for each frame. Then, a normal course of light curve construction is followed. The brightness of an artificial star is computed by averaging the intensities (not magnitudes) of stars from a set. The same set of stars must be incorporated in the average on each frame, otherwise the results were incorrect. Therefore, if there is missing measurement for one of stars, it is not possible to compute the brightness of a comparison star for this frame.

Deriving brightness of the artificial comparison star

First, we use inverse Pogson's law to convert brightness in magnitudes *m_i* into intensity *I_i* for each star *i* from the set.

$$\frac{I_i}{I_0} = 10^{-0.4\, m_i} \tag{10.47}$$

Next, intensities are combined by means of arithmetic mean. Please note, that the factor *1/N* is used to keep the brightness in the same range as the source data.

$$\frac{I}{I_0} = \frac{1}{N} \sum \frac{I_i}{I_0} \tag{10.48}$$

Then, the intensity is converted back to magnitudes:

$$m = -2.5 \log_{10} \left(\frac{I}{I_0} \right) \tag{10.49}$$

Estimating the measurement error

The inverse equation (**??**) can be used to transform the error estimation from magnitudes to intensity unit. Supposing that noise sources are independent, we can compute the variance of *I* as:

$$\sigma_I^2 = (\frac{1}{N})^2 \sum \sigma_{I_i}^2 \tag{10.50}$$

The equation (**??**) is used to convert the resulting variance back to magnitudes. Putting all three formulas together we get the following formula for the error estimation of the resulting brightness of a artificial comparison star in magnitudes:

$$\sigma_m = \frac{\sqrt{\sum (\frac{I_i}{I_0} \sigma_{m_i})^2}}{\sum \frac{I_i}{I_0}} \tag{10.51}$$

10.1.12 Finding variables

The *Find variables* tool is based on the dependency of noise level to mean brightness. The fainter an objects is, the smaller is the signal-to-noise ratio and the more noisy is the measurement of the object. It can be shown that two objects of similar brightness which do not vary in brightness during the observation also have similar noise levels, which is computed as the sample standard deviation. If one of the objects changes its brightness due to reasons other than measurement noise, for example it is an eclipsing binary, its sample standard error is greater than a constant object of the same mean brightness. Using this idea, we can make a graph of sample standard deviation vs. mean brightness of all objects detected on a frame set. Supposing the majority of objects are constant, the graph will reveal a curve, which grows towards lower brightness. Any outlying point located above the curve denotes an object that has brightness variations other than measurement noise and thus it might be a variable star.

The *Find variables* tool does not find variable stars automatically. It presents the graph described above and provides a means of selecting any object on the graph and showing its light curve. The decision whether an object is a variable or not is left to the user.

Making the mag-dev graph

A list of source frames is analyzed and raw instrumental magnitudes stored in memory. Each detected object must be uniquely identified across all the frames. One star is chosen as the comparison star and we assume that this star was constant during the observation.

However, an object might not be measured correctly on all frames in a frame set. If the comparison star has an invalid measurement on one or more frames, we cannot derive a differential magnitude for any object on those frames, so we have to reject these frames as whole. For the rest of the frames, it may happen that an object does not have a valid measurement on one or more frames. In this case we cannot derive a differential magnitude of that particular object on those frames.

Let us denote *N* as the number of source frames and *N_C* as the number of frames where a comparison star has valid measurements. For each object *i* we can derive a number of frames *N_i* where both the object and the comparison star has valid measurements. If *N_i* is less than a minimum number of frames N_{min}, we will rule out the object from the output. The minimum number of frames N_{min} is calculated from *N_C* and configurable threshold *t* in units of percent.

$$N_{min} = \lfloor \frac{t}{100} N_C \rfloor \tag{10.52}$$

For each object *i* that has a valid measurement on frame *j*, we compute the differential magnitude $m_{i,j}$:

$$m_{i,j} = mag_{i,j} - mag_{C,j} \tag{10.53}$$

where $mag_{i,j}$ is instrumental magnitude of the object *i* and $mag_{C,j}$ is instrumental magnitude of the comparison star *C* on frame *j*. Then, the mean value $\overline{m_i}$ is computed by means of the robust mean algorithm and the sample standard variance s_i^2 is also determined. Please note, that although the robust mean algorithm is used to compute mean brightness of an object, all valid measurements should be taken into account in the computation of the sample variance. Otherwise for a variable star, some of its valid measurements would be unjustly rejected as outliers, resulting in lower variance. The term $\frac{N_i}{N_i - 1}$ is known as Bessel's correction.

$$s_i^2 = \frac{N_i}{N_i - 1} \frac{1}{N_i} \sum_{j=1}^{N_i} (m_{i,j} - \overline{m_i})^2 = \frac{1}{N_i - 1} \sum_{j=1}^{N_i} (m_{i,j} - \overline{m_i})^2 \tag{10.54}$$

Figure *1* shows a scatter graph of stars that were measured in the field of eclipsing binary CR Cassiopeiae showing the relationship between the stars' mean magnitude *x_i* versus their sample standard deviations *s_i*.

Choosing a comparison star

If the user does not pick a comparison star, the program uses the following algorithm to choose one and uses it to make a mag-dev curve. There are several criteria that the program can use to determine the suitability of an object to be a comparison star. A good comparison star should be 1) on the greatest number of frames to avoid more data rejection than necessary, 2) it should not vary in brightness and 3) the noise of its measurements should be low to reduce a noise of differential magnitudes and the resulting data.

Let us take all objects that were found on a reference frame. We assign a number of frames *F_i* which each object i has been successfully identified on. The maximum of values *F* is determined and all objects that have the maximum value of *F* are kept on the list, the others are removed.

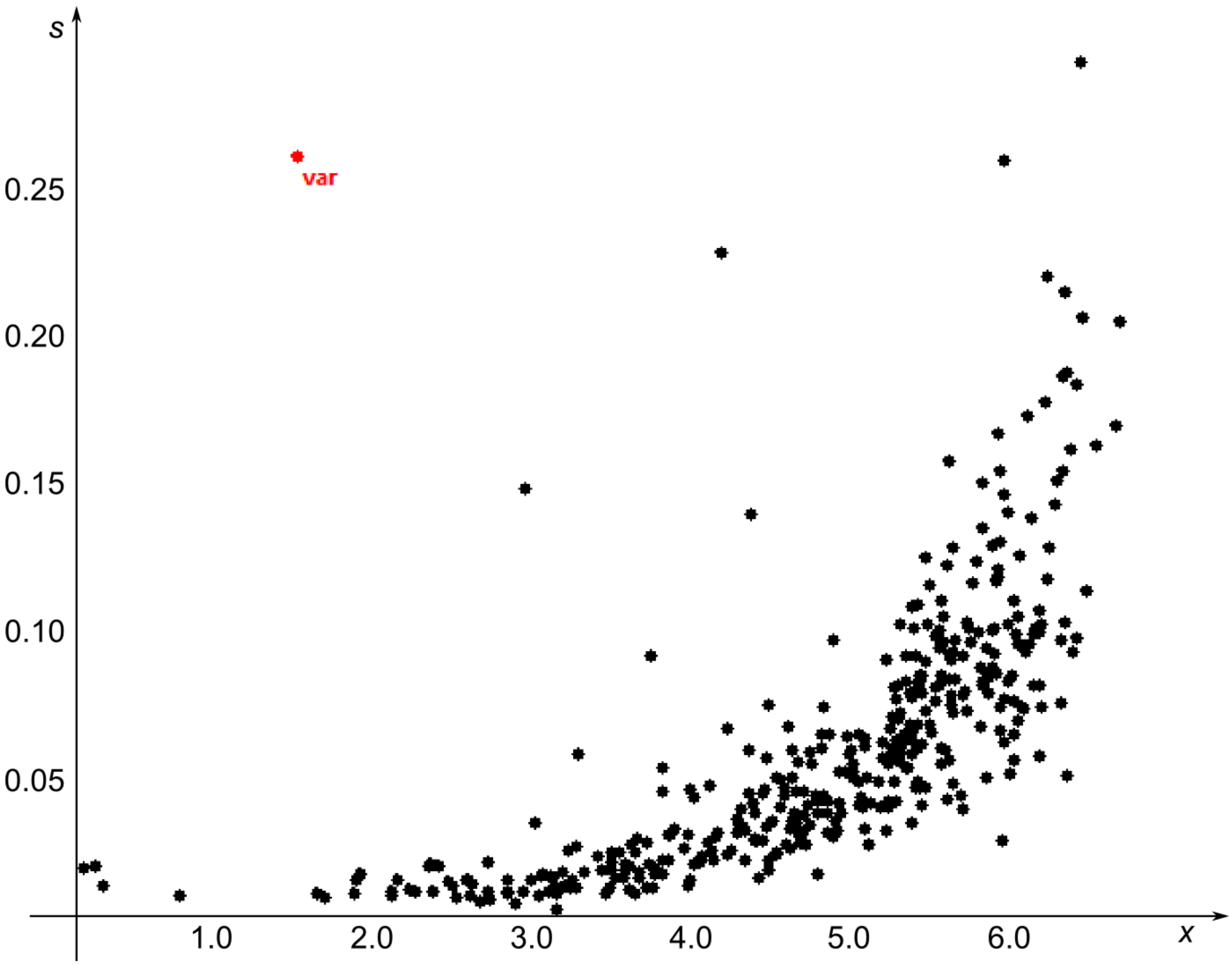


Fig. 2: Mag-dev graph of stars in the field of eclipsing binary CR Cas. The majority of stars are constant forming a typical "background" curve. The variable star CR Cas, labeled *var*, has greater standard deviation than stars of similar mean magnitude.

For each $\frac{N(N-1)}{2}$ pairs of objects that were left on the list, a differential light curve is derived and a robust mean and a sample standard deviation is computed for the light curve data. Finally, the star that has the lowest sum of standard deviations is picked as the comparison star.

Please note, that although the robust mean algorithm is used to compute mean brightness, all valid measurements should be taken into account in the computation of the sample standard deviation. If there were a variable star on the list of candidates, some of its valid measurements would be unjustly rejected as outliers, resulting in lower deviation.

10.1.13 Frame merging

Frame merging is a technique which uses averaging to combine multiple CCD frames into one frame. In a naive implementation the mean value of corresponding pixels of source frames could be computed. However it wouldn't work well in practice since the sky is revolving around the celestial pole throughout the night and in most cases even perfectly adjusted motorized compensation does not track the stars with sufficient precision.

Therefore, in tasks where frame merging is performed, the reduction is done in two phases. First, the original frames are reduced up to the matching step to get the information about their relative offsets. Then, the original frames are aligned to one reference frame by means of the shift transformation. The frames are divided into groups, and for each group one combined frame is made. In this way we get a set of combined frames, which are processed in the second phase. Unlike the first phase, calibration is not applied to the combined frames since the images were already calibrated in the first phase.

10.1.14 Heliocentric correction

The heliocentric correction compensates for the differences in the observer's distance to the observed object due to movement of the Earth around the Sun. When we measure the time that elapsed between two events and the time span is in the order of days or more, we may need to compensate for the timing due to the finite speed of light. A common approach is to transform the observation time as it would be observed from the center of the Sun, which is considered to be fixed with respect to the object. The Julian date JD is transformed into Heliocentric Julian date HJD. The difference between those two dates is called the heliocentric correction HC and usually it is expressed in days.

$$HJD = JD + HC \tag{10.55}$$

Figure 1 illustrates the situation. The heliocentric correction HC is the time that light needs to cover the distance $\|\vec{r}\|$. The vector $\vec{r}$ can be thought of as a projection of the Earth-Sun vector $\vec{s}$ into the direction of Earth-object unit vector $\vec{n}$.

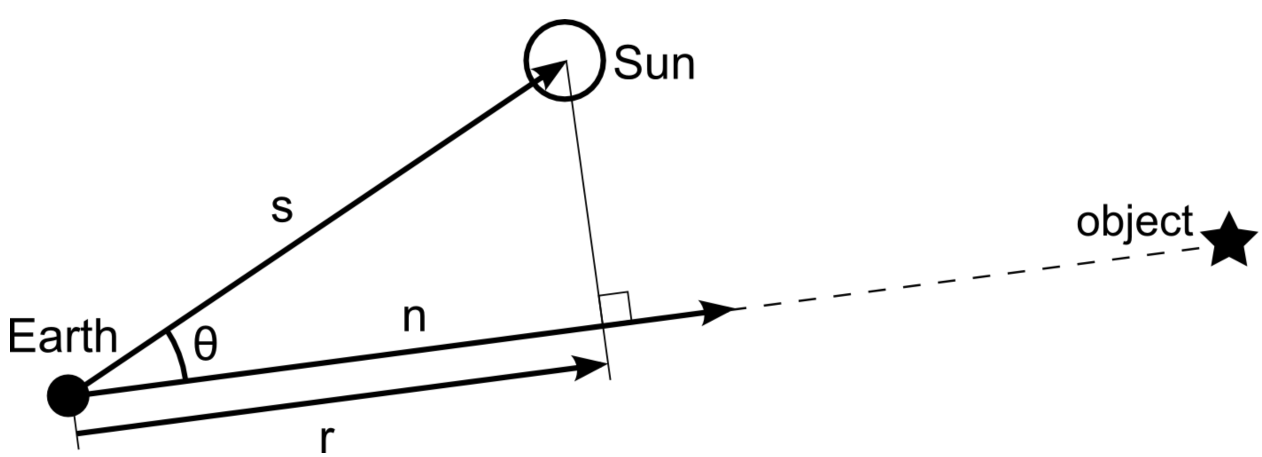


Fig. 3: Vectors used to derive heliocentric correction. *s*: Earth-Sun vector; *n*: Earth-object unit vector; *r*: projection of *s* into direction of *n*

The length of the vector $\vec{r}$ can be computed as:

$$\|\vec{r}\| = \|\vec{s}\| \cos\theta \tag{10.56}$$

The cosine of angle θ can be derived from the expression for dot product of two vectors:

$$\vec{a} \cdot \vec{b} = \|\vec{a}\| \, \|\vec{b}\| \, \cos\theta \tag{10.57}$$

When we put the two equations together, we get

$$\|\vec{r}\| = \|\vec{s}\| \frac{\vec{s} \cdot \vec{n}}{\|\vec{s}\| \, \|\vec{n}\|} \tag{10.58}$$

the length of vector $\vec{s}$ cancels out and because the vector $\vec{n}$ is a unit vector, its length is equal to 1. Then we can simplify the previous equation to

$$\|\vec{r}\| = \vec{s} \cdot \vec{n} \tag{10.59}$$

Vector $\vec{s}$ is computed using Flandern's formulas for Earth-Sun distance *R_S* and Sun's ecliptic longitude λ_S (see [**?**]).

The object's position is specified by two equatorial coordinates - right ascension α and declination δ. These coordinates must be transformed into the ecliptic coordinate system to get object's ecliptic longitude λ and latitude β.

The easiest way to compute the dot product of two vectors in polar coordinates is to transform them into the 3-D Cartesian system first, using a trigonometric identity for cosine of the sum of two vectors we get

$$\|\vec{r}\| = R_S \, \cos\beta \, \cos(\lambda - \lambda_S) \tag{10.60}$$

Using a speed of light $c = 299,792,458$ meters per second we can derive the formula for the Heliocentric correction. Please note, that it is necessary to convert the units to get the value in days.

$$HC = \frac{R_S}{c} \, \cos\beta \, \cos(\lambda - \lambda_S) = -0.00577552 \, R_S \, \cos(\beta) \, \cos(\lambda - \lambda_S) \tag{10.61}$$

10.1.15 Air mass coefficient

Air mass is the length of an optical path that light from an observed object travels through the Earth's atmosphere. Along this path, the light is attenuated by scattering and absorption. The greater is the air mass, the greater is the attenuation. This is illustrated in Figure 1, objects near the horizon appear less bright than when they are at the zenith.

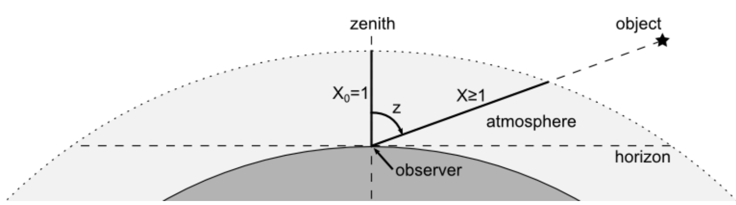


Fig. 4: Air mass. z – zenith angle of the object. By definition, the air mass coefficient is equal to 1 at zenith ($z=0$).

The air mass coefficient *X* is the air mass relative to that at the zenith. So, its value is 1 when the object is at zenith, and increases as the zenith angle z grows, reaching approximately 38 at the horizon.

Versions 1.2.21 and older

In versions 1.2.21 and older, the air mass coefficient *X* was computed using the approximation published by Hardie in 1962 (see [**?**]). This gives usable results for zenith angles up to about 85 degrees. For greater zenith angles, the program returned a negative value, to indicate that air mass cannot be computed.

Versions 1.2.22 and newer

Since version 1.2.22, the air mass coefficient *X* is computed using the approximation published by Pickering in 2002 (see [**?**]). The formula (**??**) works well even for zenith angles up to 90 degrees. The program stores a negative value to indicate a situation when an object is below a horizon.

$$X = \frac{1}{\sin(h + 244/(165 + 47h^{1.1}))} \tag{10.62}$$

where *h* is apparent altitude $(90° - z)$ in degrees.

10.1.16 Robust mean

The computation of robust mean is based on a re-descending *Psi* type M-estimator, that uses Hampel's influence function, see [**?**] and [**?**]:

$$\Psi(x) = \begin{cases} x & \text{if } 0 \le |x| \le a \\ a \operatorname{sign}(x) & \text{if } a \le |x| \le b \\ \frac{a(c-|x|)}{(c-b)} \operatorname{sign}(x) & \text{if } b \le |x| \le c \\ 0 & \text{if } c \le |x| \end{cases} \tag{10.63}$$

where *a = 1.7*, *b = 3.4* and *c = 8.5*. The function $\Psi(x)$ and its first derivative $\Psi'(x)$ is plotted on Figure *Hampel's influence function. (a) influence function \Psi; (b) first derivative \Psi'*.

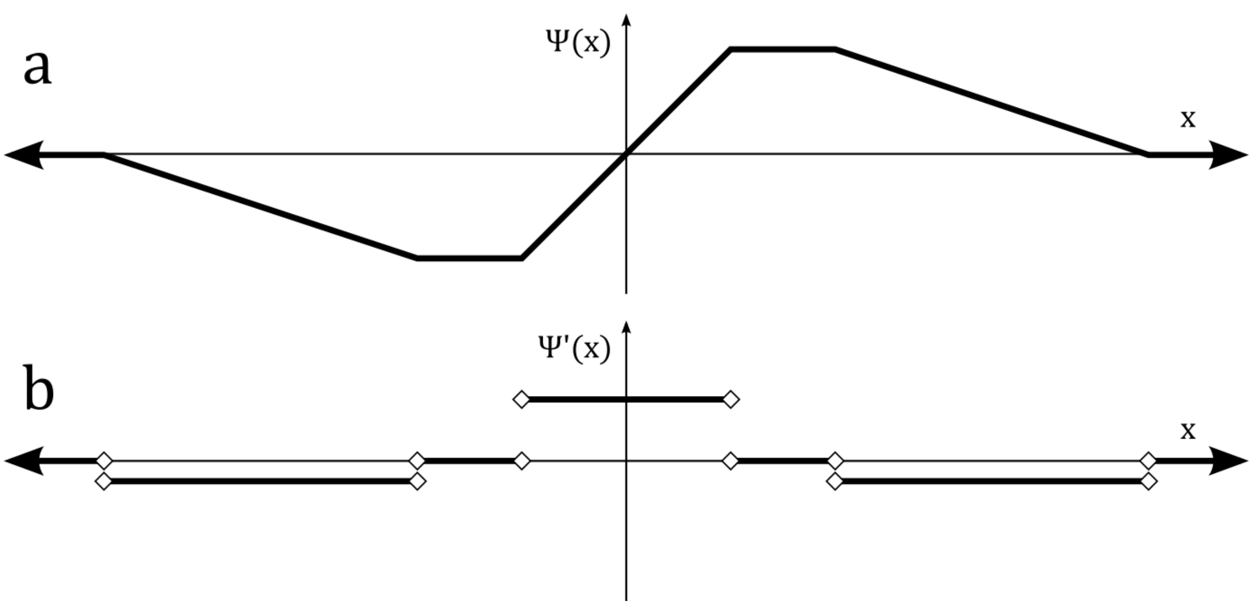


Fig. 5: Hampel's influence function. (a) influence function Ψ; (b) first derivative Ψ'

The starting point for iterations is determined by median as an estimate of location and median of absolute deviations (MAD) for an estimation of scale *s*.

$$s = MAD(X)/0.6745 \tag{10.64}$$

The optimum solution is found by means of the Newton-Raphson optimizing algorithm. In iteration j a new estimation of location μ_j is determined using the following formula:

$$\mu_j = \mu_{j-1} + s\,\frac{\sum \Psi(r_i)}{\sum \Psi'(r_i)} \tag{10.65}$$

where r_i is a residual

$$r_i = \frac{x_i - \mu}{s} \tag{10.66}$$

If the input vector has normal distribution, the estimation of variance is:

$$\sigma^2 = \frac{n}{n-1}\,n\,\frac{\sum \Psi^2(r_i)}{(\sum \Psi'(r_i))^2} \tag{10.67}$$

where *n* is the number of samples. The term $\frac{n}{n-1}$ is Bessel's correction.

The iterations are stopped when one of the following conditions is satisfied:

- The number of iterations exceed 100 or
- the absolute difference $|\mu_j - \mu_{j-1}|$ is less than $10^{-4}\sigma$, where σ is an square root of variance σ^2 computed at each step or
- the absolute difference $|\mu_j - \mu_{j-1}|$ is less than 10^{-7}.

See also: [**?**] and [**?**].

10.2 File format specification

In this chapter, you will find the description of file formats that are created and used by the C-Munipack software.

All keywords and invariant phrases, which are included directly in the files are printed in *cursive font*. Names of files and directories are printed in `teletype face`. Default values of parameters are places in the [square brackets].

10.2.1 Photometry files

The photometry files are produced by the photometry process. The file consists of a table of detected objects and their properties.

The photometry files are stored as binary streams in order to get optimum performace, because it does not require analyzing any kind of language and decoding the values.

The binary format of photometry files was introduced to latter versions of C-Munipack 1.2, because it has turned out that the XML-based formats are too slow to parse.

Multi-byte data is stored in little-endian format (Intel). Real numbers are stored in the *binary64* format of IEEE 754-1985.

File header

The general structure of binary photometry file is given in table *1*.

Table 1

Offset	Type	Length	Description
0	char[]	28	Format identifier
28	long	4	Format revision number
32	long	4	Length of metadata in bytes

The format identifier must be the following text:

```
C-Munipack photometry file\r\n
```

Current format revision number is **4**.

Metadata

The metadata block immediately follows the file header. The parameters are stored on fixed offsets. The length of the header is 540 bytes. See the table *2* for description of header fields.

Table 2

Offset	Type	Length	Description
0	long	4	unused
4	long	4	Frame width in pixels
8	long	4	Frame height in pixels
12	binary64	8	Julian date of observation
20	char[]	70	Optical filter, right-padded with spaces
90	binary64	8	Exposure duration in seconds
98	binary64	8	CCD temperature in Centigrades
106	char[]	70	Reduction software
176	short	2	Date of creation (year)
178	byte	1	Date of creation (month)
179	byte	1	Date of creation (day)
180	byte	1	Date of creation (hour)
181	byte	1	Date of creation (minute)
182	byte	1	Date of creation (second)
183	byte	1	unused
184	binary64	8	Lowest good pixel value
192	binary64	8	Highest good pixel value
200	binary64	8	Gain in electrons per ADU
208	binary64	8	Readout noise in ADU
216	binary64	8	Expected FWHM of objects
224	binary64	8	Mean FWHM of objects
232	binary64	8	Standard error of FWHM of objects
240	binary64	8	Detection threshold
248	binary64	8	Low sharpness cutoff
256	binary64	8	High sharpness cutoff
264	binary64	8	Low roundness cutoff

continues on next page

Table 1 – continued from previous page

Offset	Type	Length	Description
272	binary64	8	High roundness cutoff
280	long	4	Matching status: 0=not matched, 1=matched
284	long	4	Number of stars used in matching
288	long	4	Number of polygon vertices
292	long	4	Number of matched stars
296	binary64	8	Clipping threshold
304	binary64	8	Offset in X axis to the ref. frame in pixels
312	binary64	8	Offset in Y axis to the ref. frame in pixels
320	char[]	70	Object's designation, right-padded with spaces
390	binary64	8	Object's right ascension
398	binary64	8	Object's declination
406	char[]	70	Observer's location designation, right-padded with zeros
476	binary64	8	Observer's longitude
484	binary64	8	Observer's latitude
492	binary64[]	48	Transformation matrix (xx, xy, x0, yx, yy, y0)

Object's right ascension - the reader must interpret a value that is outside range of 0 and 24 as undefined value. The writer is recommended to use DBL_MAX value to indicate an undefined value.

Object's declination - the reader must interpret a value that is outside range of -90 and 90 as undefined value. The writer is recommended to use DBL_MAX value to indicate an undefined value.

Observer's longitude - the reader must interpret a value that is outside range of -360 and 360 as undefined value. The writer is recommended to use DBL_MAX value to indicate an undefined value.

Observer's latitude - the reader must interpret a value that is outside range of -360 and 360 as undefined value. The writer is recommended to use the DBL_MAX value to indicate an undefined value.

Transformation matrix

The transformation matrix holds an affine transformation, such as a scale, rotation, shear, or a combination of those. The transformation of a point (x, y) is given by:

$$
\begin{aligned}
x_{new} &= x_x * x + x_y * y + x_0 \\
y_{new} &= y_x * x + y_y * y + y_0
\end{aligned}
\tag{10.68}
$$

WCS data

The WCS data block immediately follows the metadata block. The first four bytes (long type) specify the length of the block in bytes, the data starts at offset 4. The WCS data are encoded as a FITS header.

Table of apertures

The table of apertures immediately follows the WCS data block. The first four bytes (long type) specify a number of records in the table, the first record starts at offset 4, records have 12 bytes each. The description of fields in the table of apertures is given in table *3*.

Table 3

Offset	Type	Length	Description
0	long	4	Aperture identifier
4	binary64	8	Radius in pixels

Table of objects

The table of objects immediately follows the table of apertures. The first four bytes (long type) specify a number of records in the table, the first record starts at offset 4, records have 48 bytes each. The description of fields in the table of objects is given in table *4*.

Table 4

Offset	Type	Length	Description
0	long	4	Object identifier within a file (starts with 1 for valid entries)
4	long	4	Global identifier (assigned in matching), zero or negative value if the objects was not matched (*)
8	binary64	8	X-coordinate of position of the object
16	binary64	8	Y-coordinate of position of the object
24	binary64	8	Local mean background level in ADU
32	binary64	8	Std. deviation of local background level
40	binary64	8	Full width at halt maximum (FWHM) in pixels

(*) It is recommended to assign valid object identifiers from the range of 1 to 2,147,483,647 (MAX_INT). The reader should interpret zero or negative value of object identifier as an invalid entry; the record should be silently ignored. The reader should interpret zero or negative value of global identifier (a result of matching) as a non-matched object. The writer is recommended to use the value (-1) to indicate invalid entries and non-matched objects.

Table of measurements

The table of measurements immediately follows the table of objects. The number of records is not given explicitly, but it is always number of objects multiplied by number of apertures. Objects and apertures are stored in the same order as they appear in the tables of objects and table of apertures, respectively. The first records that specify measurement data for the first object and aperture stars at offset 0, the second record specify measurement data for the first object and second aperture, etc. Each record has 12 bytes. Unlike previous fields, magnitude and its error is stored in 24.8 format with fixed decimal point. The value `0x7FFFFFFF` means undefined value. The description of fields in the table of measurements is given in table *5*.

A non-zero integer value at offset 8, introduced in revision 3, specify a reason why the object was not measured. The table *6* gives a list of possible values and their meaning.

Table 5

Offset	Type	Length	Description
0	long	4	Raw instrumental brightness in magnitudes, 8.24 fixed point format
4	long	4	Error estimation of brightness, 8.24 fixed point format
8	long	4	A value indicating the reason why the object was not measured

Table 6

Value	Description
0	The object was measured successfully
1014	Computed magnitude is outside the range of -99 and 99 magnitudes
1600	The net intensity in the aperture is zero or negative (*)
1601	The aperture size has an invalid value
1602	The aperture is too close to the frame border
1603	There are overexposed pixels in the aperture
1604	There are pixels of invalid value in the aperture
1605	There are not enough pixels with valid value in the sky annulus

(*) The net intensity is defined as sum of pixel values in the aperture minus mean background intensity multiplied by aperture area.

10.2.2 Catalog files

Using catalog files can speed up your work, in case you often observe particular star field, for example long-term monitoring of a variable star. The structure of the data stored in a file is very similar to a photometry file, but it contains the selection of stars (variable star, comparison star, etc.). When a catalog file is used instead of a reference file in matching phase of reduction, the selection is automatically restored from that file.

Catalog files are saved as XML documents. The EXPAT library has been used for reading the files in XML based formats, see the *References* section for details.

Description of elements

cat_file

The root element of XML document

Attributes

None

Model

(info?, selection*, taglist?, stars?)

Description

The *cat_file* element is a root element of the document. The document consists of meta-data (file header), arbitrary number of object selections, a table of object tags and a table of objects.

info

The file header

Attributes

None .. rubric:: Model

(object | ra2000 | dec2000 | observer | observatory | telescope | camera | filter | fov | orientation | comment)*

Description

The *info* element is a container for catalog file meta-data. The parameters are given as child elements, parameter values are stored in child elements' content. The order of child elements is not significant. The description of parameters is given in *Table 1*.

Table 1

Element name	Presence	Description
object	optional	Object's designation
ra2000	optional	Object's right ascension
dec2000	optional	Object's declination
observer	optional	Observer's name
observatory	optional	Observer's location designation
longitude	optional	Observer's longitude
latitude	optional	Observer's latitude
telescope	optional	Designation of the telescope
camera	optional	Camera manufacturer and model
filter	optional	Optical filter
fov	optional	View field size
rotation	optional	View field orientation
comment	optional	User comments

selection

The table of selected objects

Attributes

name

Model

(select*)

Description

The *selection* element is a container for elements that specify an object role (variable, comparison and check stars) to make a light curve. Since the version 2.0.11, the catalog file is capable of including an arbitrary number of object selections - the main purpose of this is to support multiple variable stars on a single star field.

Each *select* element define one object and its role. If there are more roles for a single object, the result is undefined. The optional attribute *name* specify a caption that is used to provide a list of available object selections. If it is not present, it is recommended to use the file name of the catalog file (without extension) instead.

select

A selected star and its role

Attributes

id, label

Model

Empty

Description

The *select* element assigns a role and caption to one star. The mandatory attribute *id* specify object's identifier, it must be one of object identifiers that appears in the table of star. The attribute *label* is a description of the object. It starts with a prefix, which must be either 'var' for a variable star, 'comp' for a comparison star and 'chk' for a check star. When there are more stars of the same role, the ordinal number is appended to the prefix to give them unique labels.

selection

A list of tabs

Attributes

None

Model

(tag*)

Description

The *taglist* element is a container for elements that specify user-defined strings (tags) for objects. Each *tag* element define a tag for a single object. If there are more tags for a single object, the result is undefined.

tag

A star's tag

Attributes

id, value

Model

Empty

Description

The *tag* element assigns a tag to one star. The mandatory attribute *id* specify object's identifier, it must be one of object identifiers that appears in the table of star. The attribute *value* is a string assigned to it.

stars

A table of all stars on the frame

Attributes

width, height

Model

(s*)

Description

The *stars* element is a container for stars, each child element *s* specify a single star. The mandatory attributes *width* and *height* define a frame size in pixels. If there are multiple definitions with the same identifier, the result is undefined.

s

The position and brightness of a star

Attributes

id, x, y, m, e

Model

Empty

Description

The *s* element defines an object. The mandatory attribute *id* is the object's identification, it must be unique within the file. The mandatory attributes *x* and *y* stores the position of the object within the frame, the coordinates are specified in pixels, the origin is the left top corner of the frame. The attributes *m* and *e* specifies raw instrumental brightness in magnitudes and its error estimation.

10.2.3 Light curve files

Light curves (dependency of brightness on observation time) are usually final product of the reduction process. A light curve table consists of observation time in Julian date form followed by magnitudes and their errors of all selected stars. Two basic output working modes are provided: in differential mode, magnitudes stored in the table are differences between each pair of the stars. On the other hand, instrumental mode allows you to print out raw values computed by photometry. Note, that instrumental magnitudes cannot be compared to absolute ones, which is found in the photometry catalogs, without further post-processing.

Format C-Munipack (default)

Output files are stored in the ASCII format; the end of the line is represented by `CR+LF` in the DOS/MS Windows environment and by `LF` in the Unix/Linux environment. First line contains always a list of column names separated by single space character. Second line consists of additional information (aperture, filter, etc.) and has no special formatting, it must not start by number, though.

On the following lines, the table values are stored. The values are separated by tab character or single space, rows are separated by the end-of-line character (see above). Parsers must ignore all additional white characters. Empty lines indicates, that the corresponding frame was not successfully processed and thus a brightness of a variable or a comparison star could not be determined. See table *1* for short description of columns.

Table 1

Keyword	Description
JD	Geocentric Julian date of observation
JDHEL	Heliocentric Julian date of observation
V-C	Difference of variable and comparison star
s1	Error of V-C value
V-K1	Difference of comparison and check star #1
s2	Error of C-C1 value
…	…
V	Brightness of variable star (abs. instr. magnitude)
s1	Error of V value
C	Brightness of comparison star
s2	Error of C value
K1	Brightness of check star #1
s3	Error of K1 value
…	…
IDnnn-C	Difference of object with ID nnn and the comparison star
…	…
IDnnn	Brightness of object with ID nnn (abs. instr. magnitude)
…	…
HELCOR	Heliocentric correction in days
AIRMASS	Air mass coefficient
ALTITUDE	Altitude (elevation) in degrees above horizon

Format AVE compatible

The “AVE compatible” file format allows to save a light curve with differential magnitudes to the AVE software [**?**]. The output file is an ASCII text file. Each frame is stored on a separate line, lines begin with a Julian date of observation, followed by a space and followed by a brightness of a variable star in magnitudes. Frames where a variable was not measured are omitted. The file does not contain any header.

Format MCV compatible

The “MCV compatible” file format allows to save instrumental magnitudes of selected stars in a file that can be processed in the MCV software [**?**]. The output file is an ASCII text file. Each frame is stored on a separate line, lines begin with a Julian date of observation, followed by instrumental magnitude for each selected star. Fields are separated by a space character. A zero value stored instead of a valid magnitude indicates missing or invalid data. The file does not have any header.

See also:

Light curve, *Light curve (dialog)*, *Export light curve in AAVSO format*

10.2.4 Track curve files

Track lists (dependency of frame shift on observation time) are usually used for determining the value of periodic error of the telescope mount. A track curve table consists of observation time in Julian date form followed by shifts in the horizontal (X) and the vertical (Y) axes in pixels relative to the reference frame.

Output files are stored in the ASCII format; the end of the line is represented by `CR+LF` in the DOS/MS Windows environment and by `LF` in the Unix/Linux environment. First line contains a list of column names separated by single space character. Second line consists of additional information and has no special formatting, it must not start by number, though.

On the following lines, the table values are stored. The values are separated by tab character or single space, rows are separated by the end-of-line character (see above). Parsers must ignore all additional white characters. Empty lines indicates, that the corresponding frame was not successfully processed and thus shift values could not be determined. See table *1* for short description of columns.

Table 1

Keyword	Description
JD	Geocentric Julian date of observation
OFFSETX	Relative shift in horizontal direction
OFFSETY	Relative shift in vertical direction

10.2.5 Air mass curve files

The table of air mass coefficients is stored in the ASCII format; lines are separated `CR+LF`, `LF` or `CR` character. The writer can choose any separator, it is recommended to use a separator native to the writer's environment. The reader must correctly handle any separator. The first line contains a list of column names separated by a single space character. Second line is left empty.

On the following lines, the table values are stored. The values are separated by a space character, rows are separated by an end-of-line character (see above). Parsers must ignore all additional white characters between fields, at the beginning and at the end of a line. See table *1* for the description of the columns.

Table 1

Keyword	Description
JD	Geocentric Julian date of observation
AIRMASS	Air mass coefficient
ALTITUDE	Apparent altitude in degrees above horizon

10.2.6 Varfind curve format

The Varfind (mag-dev) curve file consists of table of indexes, mean magnitudes and standard deviations for all detected stars. Such data is intended for detecting variable stars on a set of CCD frames. Magnitudes are always in differential form, they are relative to the comparison star.

Output files are stored in the ASCII format; the end of the line is represented by `CR+LF` in the DOS/MS Windows environment and by `LF` in the Unix/Linux environment. First line contains a list of column names separated by single space character. Second line consists of additional information and has no special formatting, it must not start by number, though.

On the following lines, the table values are stored. The values are separated by tab character or single space, rows are separated by the end-of-line character (see above). Parsers must ignore all additional white characters. See table *1* for short description of columns.

Table 1

Keyword	Description
INDEX	Ordinal number of a star in the reference file
MEAN_MAG	Mean relative magnitude of a star
STDEV	Standard deviation of previous value
GOODPOINTS	Number of measurements used for computation

10.2.7 Readall file format

This 'Read all' file is used to export the measurement data of all objects and a set of frames to one file. Its name originates from the old 'readall' utility. In the C-Munipack software such file can be created by the 'Find variables' tool and this tool can also import data from such file.

The readall file is a text file. Lines are separated by `CR+LF`, `CR` or `LF` character. The writer can use any line separator, the reader should correctly handle any of these. Fields are separated by a space character, the reader should ignore any additional space characters between fields, at the beginning of a file or between the last field and following line separator.

The first line is used to identify the file. It should contain the following text:

```
# JD, instrumental mags and standard deviations of all detected stars}
```

The seconds line starts with a hash character and it is followed by an aperture identifier and color filter name. Third and following lines consists of measurement data.

The first field of each line is a Julian date of observation. The following fields contain raw instrumental brightness of objects followed by an error estimation. The data are organized in such a way that one object occupy always the same fields on each line. Invalid magnitudes are represented as values '99.99999' and invalid error estimations are represented as values '9.99999'.

The length of a line is not limited. Because each line carries measurement data for a entire frame, the reader must be designed to correctly handle very long lines.

CHAPTER

ELEVEN

TIPS AND TRICKS

11.1 I need to move my projects to another drive

In case the current folder where the projects are stored in does not suit you, do the following steps:

1. Close the program
2. Move the content of the current folder with the existing projects into another location.
3. Next time you create a new project using the *New project (dialog)*, change the location for the new project.

The is no special configuration option that needs to be adjusted to change the location of your project files.

11.2 How to back up a project

No special action is necessary to make a copy of a project; copy a project file, a directory with the "-files" suffix and all files that resides in it.

Restoring is also easy; just copy the files and directories to a folder and make sure that you have the 'read-write' access to the project file, the directory with "-files" suffix and also to all files that resides in it. When you open a project from a read-only location, e.g. DVD, the program detects the situation and gives a warning; you can open a project in 'read-only' mode; in this mode, it is allowed to make outputs, e.g. light curve, but operations that would change the data are not allowed.

CHAPTER

TWELVE

GLOSSARY

Air mass coefficient
The air mass coefficient characterizes the attenuation of the light when it travels through the atmosphere. Because the atmosphere is not equally transparent for all wavelengths, this effect becomes important when you want to compute the absolute magnitudes for measured objects. The coefficient equals to 1.0 when the object is in the zenith by definition and it is greater than one for altitudes between the zenith and the horizon. It is not defined for objects at or below the horizon.

Altitude
Altitude is one of the coordinates of the horizontal coordinate system. It is used for computation of the air mass coefficient. To compute the object's altitude at a time of observation, the date and time of observation, object's equatorial coordinates and observer's geographical coordinates must be known.

Aperture photometry
The aperture photometry is a method for measurement of brightness of a star on a CCD frame. After image calibration, the frame consists of two components - sky background level and a signal from a star. To measure star's brightness, we have to separate these two components.

The algorithm of aperture photometry was developed from a method used for a observations made by means of a photomultiplier. Unlike this, the aperture photometry for digital images carried out by means of a CCD camera uses the digital image processing algorithms. The algorithm uses two apertures - an annular shaped one to measure the background level in vicinity of a star and a circular one to measure the total flux from a star. The background is subtracted from a star's signal. The brightness of a star is defined as a ratio of its signal to a fixed reference value. Such value, expressed in magnitudes, is called instrumental absolute brightness.

Bias frame
A bias frame is an image obtained from the CCD camera when all light is blocked and the exposure is indefinitely short (in ideal case). It represents the constant bias level, that is preset in the camera's electronics that reads out the image data. For ideal CCD camera, the level should be constant for pixels and the bias could be represented by a single value. In practice, there are small differences between pixels.

In the standard calibration scheme, the bias is included in the dark frame and thus it is subtracted during the dark-frame correction. In the advanced calibration scheme, the bias must be subtracted from a scientific frame before the dark-frame calibration is applied.

The bias frame is used in the bias-frame correction phase of the reduction process. To reduce noise, a master bias frame is often used instead of a raw bias frame.

Bias-frame correction
The bias-frame correction subtracts the bias component from a CCD frame. This step is a part of the reduction process of CCD frames. It is used only in the advanced calibration scheme.

To apply the correction to a set of frames, a bias frame is required.

Catalog file
A catalog file is a file that consists of a list of stars (their positions and magnitudes). Unlike a photometry file, it

can contain identification of variable, comparison and check stars.

A catalog file can be made by means of the Muniwin user interface and it is used as a reference file in the matching process. In this case, the software restores the selection of stars from a file and an user don't need to select the stars again. It is useful if you repeatedly observe the same field.

Dark frame
A dark frame is an image obtained from the CCD camera when all light is blocked. The image represents the thermal current accumulated in a CCD device during an exposure. The mean value of the thermal current is proportional to the CCD temperature and exposure duration. For an ideal CCD camera, the thermal current would be the same for all pixels and it could be represented by a single value. In practice, some of the CCD elements are much more sensitive to the thermal current than the rest. These pixels, which appear as a bright dots on a dark frame, are called hot pixels. Depending on the calibration scheme, the dark frame may also contain the bias level.

The dark frame is used in the dark-frame correction phase of the reduction process. To reduce noise, a master dark frame is often used instead of a raw dark frame.

Dark-frame correction
The dark-frame correction subtracts the thermal component from a CCD frame. This step is a part of the reduction process of CCD frames. In the standard calibration scheme, this bias components is subtracted as well, because the bias is included in the dark frame. To apply the correction to a set of frames, a dark frame is required.

Ensemble photometry
The ensemble photometry is a technique of a light curve construction which utilizes measurements of multiple comparison (constant) stars in order to reduce the random errors. The method implemented in the C-Munipack software can be called "strict" ensemble photometry, because it requires that *all* stars from the comparison star set are present on every frame, if this is not satistifed, the frame is discarded from the light curve. Fluxes (not magnitudes) of the comparison stars are summed up to get instrumental magnitude of an "artificial" comparison star which is than used to find out differential brightness of a variable star.

Flat frame
A flat frame is an image obtained from the CCD camera when a telescope is pointed towards a luminous area of uniformly distributed intensity across the field of view. The image represents the spatial distribution of the sensitivity not only of the CCD elements but whole device. It records the response of the entire optical system - the telescope, filters, camera's window, cover glass and CCD chip itself - to a uniform source of light. Most significant effects that affect a flat frame are vignetting and sensitivity variations of CCD elements.

The flat frame is used in the flat-frame correction phase of the reduction process. To reduce noise, a master flat frame is often used instead of a raw flat frame.

Flat-frame correction
The flat-frame correction equalizes sensitivity variations of the whole optical system (telescope + filter + camera). This step is a part of the reduction process of CCD frames.

To apply the correction to a set of frames, a flat frame is required.

Flexible Image Transport System
FITS
The Flexible Image Transport System is a file format designed specifically to store scientific images and data. Since its first publication in 1981 in has become the most frequently used file format for storing and manipulating of images that were carried out by means of the astronomy CCD cameras.

In the C-Munipack project, the FITS format accepts the FITS images on its input and it uses the format to store the results of operation that produce a CCD image as an output.

Full Width at Half Maximum
FWHM
Full Width at Half Maximum is used in the C-Munipack software to express a diameter or width of a star-like objects. The width is measured in the middle between background level and the maximum value.

Heliocentric correction

The heliocentric correction fixes the variations of the distance between the observer (Earth) and observed object which occur because the Earth orbits around the Sun. This effect is not negligible especially in observation of eclipsing variable stars or exoplanet transitions, when you need to measure the time interval between two events, that occurred few weeks or months apart. The heliocentric correction transforms the times in such a way that they are related to a virtual fixed point placed in one focus of the Earth's orbit (close to the Sun).

The heliocentric correction is optionally performed during construction of a light curve. Object's equatorial coordinates are required.

Heliocentric Julian date
HJD
JD(hel.)

The heliocentric Julian date is a time of an event (a particular observation, time of minimum) with the heliocentric correction applied.

Julian date
JD

The Julian date (JD) is the interval of time in days and fractions of a day since January 1, 4713 BC Greenwich noon. It is widely used and recommended by International Astronomical Union to express the time of an event, for example a particular observation, minimum of a variable star, etc.

You can use the Muniwin program to convert the Gregorian calendar date to Julian date and back.

Light curve

A light curve is a graph of brightness of a star, as a function of time. The light curve is one of the products of the C-Munipack software. It is used especially in the observation of variable stars. The brightness of a star is expressed in magnitudes, usually as a difference between two objects - a variable star and a comparison star. One or more check stars are used in addition. Absolute intensities are used sometimes, another post-processing step outside the C-Munipack software is required in this case.

Depending on a type of the light curve, a user must choose a variable star, a comparison star and optionally one of more check stars. Object's equatorial coordinates or observer's geographical coordinates may be required, too.

Master bias frame

A master bias frame is a combined CCD frame made from a set of bias frames. By means of the robust mean algorithm, the noise of the resulting image is reduced.

The master bias frame is used in the bias-frame correction phase of the reduction process.

Master dark frame

A master dark frame is a combined CCD frame made from a set of dark frames. By means of the robust mean algorithm, the noise of the resulting image is reduced.

The master dark frame is used in the dark-frame correction phase of the reduction process.

Master flat frame

A master flat frame is a combined CCD frame made from a set of flat frames. By means of the robust mean algorithm, the noise of the resulting image is reduced.

The master flat frame is used in the flat-frame correction phase of the reduction process.

Matching

The matching is the last step in the standard CCD image reduction scheme. It process a set of photometry files of a same view field and finds a relation between individual stars on the frames. For example, the star on position (100, 100) on frame 1 is the same one as star on position (120, 95) on frame 2 etc. Each star is then assigned a unique identifier, which is the same for the same star on all frame in the project.

To perform the matching, one frame must be given as a reference frame. The reference frame is usually one frame from a set of input frames, but another frame may be used - see catalog files.

Photometry
The photometry is a process performed during the CCD image reduction. It takes a calibrated CCD image and detects stars on it. For each star, the brightness is determined. The results are saved to a file, which is called the photometry file.

Current version of the software uses the aperture photometry method to measure brightness of an object.

Profile
The profile provides a set of configuration parameters that are used to process the data. Unlike the project, it does not contain the data - image files and photometry files. The profiles are used to transfer the configuration parameters between projects.

Project
The project in the C-Munipack software is a container that retains the products of the CCD frame calibration and reduction process. The project consists of project settings, image files and photometry files. The projects are used to keep the products when the user switches between various data sets.

Reduction of CCD frames
The reduction of CCD frames is a process which takes raw frames carried out by means of a CCD camera and produces a set of photometry files, one file for each input frame. The photometry file consists of a set of stars. For each star, the derived brightness is stored. An unique identifier assigned to each star is used to identify a particular star between frames.

Depending on a reduction scheme, the reduction consists of the following three steps: calibration (bias-frame correction, dark-frame correction, flat-frame correction and time correction), photometry and matching.

Reference file
A reference file is a photometry file which is used in the matching process. It is either a photometry file for one of source frames or a catalog file of the same field.

The matching algorithm takes two photometry files at a time and find corresponding stars on them. To match more than two scientific frames, one frame from the set is chosen as a reference file and all source frames are matched one by one against the reference.

Scalable dark frame
A scalable dark frame is a special case of the dark frame. It is used in the advanced calibration scheme that allows to use a dark frame of exposure duration different from scientific images for the dark-frame correction.

The scalable dark frame can be made from a dark frame by subtracting a bias frame. Thus, the scalable dark frame contains only components that are linearly dependent on exposure duration.

Time correction
The time correction fixes the time of observation of source frames. This step of the reduction process is optional and depends on particular situation. For example, you can use the correction to fix the bias of the PC's system clock in regards to the UTC.

Time of observation
In the C-Munipack software, the time of a particular CCD frame is always related to a center of the exposure.

Track curve
A track curve is a graph of spatial offset of CCD frames, as a function of time. Such curve is used to monitor the stability and precision of telescope mount and its clock drive.

CHAPTER

THIRTEEN

HISTORY

13.1 Change log

Version 2.1.37

January 11, 2024`

- Added an option to select if positive longitude is east or west of Greenwich meridian.

Versions 2.1.27 - 2.1.36

- Bug fixes

Version 2.1.26

June 18, 2023`

- Added an option to disable alignment on local maxima in the Quick photometry tool.

Version 2.1.35

March 29, 2023

- Added support for date & time format using UT field, the value is specified in seconds.

Version 2.1.32

December 11, 2021

- Added support for CR3 raw files

Version 2.1.27

May 21, 2020

- Added new date & time format (prefixed with date name)
- Added new date & time format (QHY8L camera)
- Added an option to show and hide tags for known variables
- Fixed random crash when frames in the main window are sorted by property other that date and time

Version 2.1.23

December 18, 2017

- Added new file format - Nikon D5500

Version 2.1.22

December 07, 2017

- New feature - copy WCS coordinates of selected object to clipboard (context menu on right click)
- New feature - sorting of frames in the main window
- Minor fix - sign of SNR values

Version 2.1.21

July 30, 2017

- Fix for frames with zero exposure time
- Fix chart preview in the Find variables tool - the image + chart mode did not work.
- Fix highlighting a variable star in the Find variables tool

Version 2.1.20

June 3, 2017

- Minor change - Find variables - highlight all variable stars from user-defined selections (known variables)
- Minor change - default file name for light curve and chart is set to a name of a current user-defined selection
- Minor change - if a label on a chart is located beyond the right / bottom edge, draw it on the left / above the object.

Version 2.1.19

March 29, 2017

- Fixed error - Minimum pixel value could not be set below zero.
- Fixed crash that occurred when creating a light curve when project's path contains characters with diacritics

Version 2.1.18

March 11, 2017

- New date & time format (DATE-OBS with dots as separators)
- Fixed build issue with 32/64-bit long integer numbers.
- Fixed bug in AAVSO export - column names must start with a hash character
- Show wcslib's version identifier in the About dialog

Version 2.1.17

March 4, 2017

- New date & time format (CTRLTIME field)
- Increased buffer sizes to avoid crashes due to buffer overrun.
- Removed include of "malloc.h" header, error when building for Mac.

Version 2.1.16

February 8, 2017

- Fixed error when saving a profile - 'No such file or directory' error message is shown when the 'Profiles' directory does not exist.
- New date & time format in FITS files - hours without a leading zero.

Version 2.1.15

January 2, 2017

- Fixed error in BAA VS export - columns VarAbsMag and VarMag were the wrong way round.

Version 2.1.14

October 11, 2016

- Added new date & time format (PI VersArray)

Version 2.1.13

August 7, 2016

- Ensemble (multiple comparison stars) photometry in the Find variables tool

Version 2.1.12

July 6, 2016

- Added new date & time format - 'UTC' field

Version 2.1.11

June 18, 2016

- New matching algorithm for very dense fields
- Fixed random crash in the 'Find variables' tool

Version 2.1.10

May 21, 2016

- Munilist command can make a table of objects from a photometry file or a catalogue file

Version 2.1.9

May 15, 2016

- Fixed crash in making light curve
- Fixed crash in Find variables tool
- Fixed crash in the 'munilist' command line tool
- Do not clear parameters stored in a project on 'Remove all frames' command

Version 2.1.8

May 8, 2016

- Message log reverted to its original state (more messages)
- Frame preview dialog - when switching between frames, keep a selected object on its place
- Frame preview dialog - optionally show a track of a moving target
- DLSR processing - fixed error in reading/writing of "frames summed" parameter to FITS files

Version 2.1.7

March 6, 2016

- Fixed minor GUI issues related to moving targets
- Fixed minor bug in frame matching for moving targets
- The tool "Process new frames" did not work with moving targets

Version 2.1.6

February 28, 2016

- Updated user manual

Version 2.1.5

February 22, 2016

- Matching for moving targets
- Fixed issues with 'Max. stars' parameter
- Improved error reporting capabilities

Version 2.1.4

January 9, 2016

- Fixed program crash in the photometry

Version 2.1.3

December 30, 2015

- The installation package for MS Windows includes 64-bit executables
- Updated GTK+ toolkit; MS Windows 2000 are no longer supported
- Added new plot - CCD temperatures
- Added new plot - object properties (position, de-focus (FWHM), instumental magnitude, …)
- 'Save project' renamed to 'Export project'
- The option 'Ensemble photometry' added to the 'Make light curve' dialog
- Support for World Coordinate System (WCS) data; show RA/Dec coordinates of objects
- Renamed columns "Vnnn" in the light curve if the option "Select all stars on the reference frame" is checked to "IDnnn"
- Added new date & time format - 'DATE' field

Version 2.0.21

November 16, 2015

- Fixed bug in creating a light curve with heliocentric correction
- Fixed bug in AAVSO export for the ensemble photometry.
- Added manual topic about creating an AAVSO report.

Version 2.0.20

November 11, 2015

- Export a light curve in the AAVSO Extended format
- Fixed program crash in the Find variables tool

Version 2.0.19

November 3, 2015

- Added option in making a light curve - show all objects on the reference frame
- Maximizing the main window on startup is default, but it can be turned off in the Environment settings

Version 2.0.17

March 8, 2015

- Fixed saving of CCD files - message "Invalid dimensions of the image".

Version 2.0.16

November 17, 2014

- Fixed program crash in Express reduction tool (selection of reference frame)
- The program can read 'Instrument' and 'Telescope' fields from the FITS frames.
- More formats when reading object celestial coordinates from FITS files.
- Fixed compatibility issues when compiling software on Debian 7.

Version 2.0.15

October 27, 2014

- Time correction can be applied at any time (after photometry and matching)
- Find variables - uses median filtering to remove sporadic outlaying measurements
- Julian dates are printed with 7 digits after the decimal point
- Improved exporting of tables, all tables can be exported in CSV format
- Minor bug fixes

Version 2.0.14

July 19, 2014

- Fixed bug in light curve - errors bars were always shown
- Find variables - added "custom" range of magnitudes in the light curve
- Fixed crash in find variables - program crashed when an image was shown instead of a chart

Version 2.0.13

July 13, 2014

- Fixed crash in matching
- Find variables - fixed or adaptive range of magnitudes in the light curve

Version 2.0.12

July 04, 2014

- Fixed saving of light curves

Version 2.0.11

June 15, 2014

- Graphs and charts now respect the system color scheme (Set the Windows to high contrast theme to switch to a "night" mode).
- Fixed bug - the photometry did not work properly if the frame borders were used
- Python module - cmpack.PhtFile now exports FWHM of an object
- Frame preview - the 'Object inspector' tool shows reason why an object was not measured
- Frame preview can show a table of objects
- Light curve, track curve and air mass curve can show a table of measurements. The table can be exported to a CSV file.
- Changed dialog for creating new project, loading and saving profiles.
- It is possible to save multiple selections of objects (multiple variable stars on one view field)
- Option if the first line in the FITS file is displayed at the top or the bottom of the window
- Added possibility of constant time offset that is always applied to all frames in the project.
- Fixed creating 32-bit master flat frames

Version 2.0.10

July 7, 2013

- Fixed bug in catalog files - var, comp and check stars were not restored in the 'Matching' tool.
- Fixed minor problem with range checking in the Autocontrast routine
- It is possible to edit user-defined object tags in a catalogue file
- Object inspector shows net intensity in ADU for a selected object
- Quick photometry - 'Signal' renamed to 'Net intensity'

Version 2.0.9

May 23, 2013

- Graphs can alternatively display date and time (UTC) and Julian date (JD)
- Fixed bug - when 'Mater bias' project was open, the 'Make' menu was hidden
- When frames are removed from the project, the associated temporary files are deleted
- Fixed bug - matching algorithm for sparse fields required at least 5 stars
- When one wants to save a chart, the program suggests the same name as for the light curve
- When Ctrl key is held while mouse wheel is rotated, the zoom in X axis is preserved.
- The 'Help' menus are aligned to the left
- Exposure duration is shown with 3 decimal places

Version 2.0.8

January 14, 2013

- Fixed bug - program crashed in the dark correction procedure

Version 2.0.7

January 13, 2013

- Fixed bug - when multiple bias/dark/flat correction frames was applied inside a single set of source frame, the corrections were not applied correctly. The first correction frame was applied always.
- Updated document *Theory of operation* - added detailed description of the matching algorithm
- Merge frames - correct handling of a case where the merged frames are rotated
- Choose stars dialog - variable star was sometimes not displayed
- All dialog controls have tooltip texts
- Fixed master flat tool - failed in case where source frames were stored in signed 16-bit format.

Version 2.0.6

November 17, 2012

- User defined tags for objects on charts.
- New Python interface for C-Munipack library.
- Fixed bug - time correction did not work in the Express reduction dialog.
- Fixed doxygen configuration file.

Version 2.0.5

October 28, 2012

- New 'Measurement' tool.
- Find variables - it is possible to manually remove individual objects from the mag-dev curve
- Do not show items in recent lists if they do not exist.
- Minor bug fixes
- Updated user's manual

Version 2.0.4

October 4, 2012

- The 2.0 .. rubric:: Version is now released as a current stable .. rubric:: Version.
- List of recent projects and list of recent files are shown in the main menu.
- New *Statistics* tool that shows minimum, maximum, mean and standard deviation.
- Express reduction can be applied to selected frames only.
- Support for CSLR camera Cannon 1100D
- Minor bug fixes
- Updated user's manual

Version 2.0.3

September 21, 2012

- Optimized main menu items
- Better icons
- Updated user's manual

Version 2.0.2

September 1, 2012

- Added support for QHY cameras
- Updated icons
- Updated user's manual

Version 2.0.1

August 19, 2012

- Fixed bug in processing entered object's and observer's coordinates.

Version 2.0.0

August 12, 2012

- First public release of the 2^{nd} generation of the C-Munipack software

CHAPTER

FOURTEEN

TROUBLESHOOTING

The Muniwin tells that my FITS files are not correct

Usually, this is a problem with the format of the date and time of observation. See bellow for more information.

The Muniwin tells that it cannot open/find files even if they are there.

If a path to files contains non-ASCII characters, like u with german umlaut, depnding on your system, the program might not be able to cope with such paths. I'm aware of this limitation, but I'm not able to fix that in short term. Meanwhile, please avoid using non-ASCII characters in paths.

The Muniwin cannot read the date and time correctly

Unfortunately, there is not any standard how to save a date and time of observation to FITS file, so every program uses its own special format. Although current version of C-Munipack can read many different formats, it may happens, that your program uses the another one. Send me one frame or two as sample (see *Bug reports, new feature requests*) and I will add it to the sources promptly.

The Muniwin does not run after 'make install'

When the program is run from a command line it complains about missing shared library 'libcmunipack-2.0.so.xxx'.

Run 'ldconfig' after 'make install'. Although 'make install' should do the trick, on some systems it does not.

CHAPTER

FIFTEEN

BUG REPORTS, NEW FEATURE REQUESTS

If you find a bug in the software or if you miss some feature, please don't hesitate to send me an email. Please include at least the following information to your report:

1. The version of the C-Munipack software you use.
2. Your operating system.
3. If the program shows an unexpected error message, an exact copy of the message. A screenshot is always more helpful then just the text.
4. Does this bug occur always, randomly but often or seldom?
5. Can you tell the minimum steps that leads to the failure?

Thanks!

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CHAPTER

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