# The MPO Users Guide

A Companion Guide to the

MPO Canopus/PhotoRed

Reference Manuals

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# MPO Users Guide

The purpose of this guide is to provide direct examples of how to use Canopus and PhotoRed for astrometry and photometry.

It will begin with a set of tutorials that cover elements common to whatever task you are trying to accomplish. From there, there will be a set devoted to astrometry, which is finding the position of an asteroid or other object in an image. Some of what you learn in these lessons will be used in the following set of lessons to determine the rotation period of an asteroid using images from two nights. After this group comes a number of lessons, each geared towards a specific goal or task. For example, how to import and export data from other programs, how to find moving objects or variable stars in a set of images, and how to find the transforms for your system so that you can do all-sky photometry.

This plan is not so much different from earlier versions of the Users Guide but there will be noticeable differences. First among them is that even the early-on lessons will not be literal step-by-step instructions. This style required many hours, even days, to write up just one lesson, and worked at a level that should be far below the average user. It should not be necessary to give detailed steps in lieu of “click on star X in the image” when there is a sample showing which one is “star X”. However, to make sure no user is left behind, there will some very quick lessons at the start of this Guide that cover such basics but still not in over-stated detail.

What will also be different is the number of lessons. This Guide contains many more than previous versions. Some of them are offered in lieu of providing the same details in the Canopus/PhotoRed Reference Manual. The exclusive purpose of the Manual is to explain the details of user input fields and the general operations and theories behind the programs so that they are not pure “black boxes” about which you have no understanding of data generation and manipulation. Step-by-step or even broad tutorials have been removed from the Reference Manual. All such material is to be found here.

*The Canopus/PhotoRed Reference Manual are combined into a single Adobe PDF document (Canopus_PhotoRedV10.PDF). By default, it is installed in \MPO\DOCS. If you installed the MPO software to a different base directory, look for the DOCS directory in that location.*

## Before You Start

Obviously, you want to get going as quickly as possible and Canopus/PhotoRed have been written to make astrometry and photometry as easy as possible. However, keep in mind that accurate results and good science require careful work. This does not always come easy and certainly not without understanding the limitations of the data and the program’s ability to manipulate them.

Bar far, astrometry is easier than photometry. While there are many considerations to obtain accurate astrometry, there are many more involved in photometry. The color of stars and the target, for the most part, is not important in astrometry but critical in photometry. One can easily compare astrometric results with others but combining data from several photometric observers requires more effort to generate an accurately merged set of data.

Canopus/PhotoRed provide routines that minimize the considerations in photometry but, admittedly, the learning curve is not shallow, especially when it comes time to determine the period of an asteroid’s lightcurve. If it’s any consolation, even the professionals admit to learning even after years of practice and still then, using a little “black magic” to make the final determination.

## The Reference Images

The MPO DVD contains dozens of images on which to practice astrometry along with many more to be used for determining the lightcurve amplitude and period of an asteroid. In addition, there is a series of images of M67 and other reference fields to be used for the PhotoRed tutorials that show how to derive photometric transforms as well as images that demonstrate the moving object and variable star search routines in Canopus.

*It is strongly recommended that you install the example images since they are reference throughout the Users Guide. Attempting to use your own images when first leaning may mean some things are lost in translation and the learning curve will be a vertical cliff.*

The images for lightcurve determinations were “dark framed” but not flat-fielded. The absence of flat-fields had no adverse affect on the determination of a lightcurve. In fact, a very clean, smooth curve was obtained. This will not always be the case and the use of flat-fields for all work is strongly encouraged.

After installation (assuming you selected the default destination of \MPO), the astrometry images are located in

\MPO\EXAMPLES\ASTMTRY

The lightcurve photometry examples are in

\MPO\EXAMPLES\LTCURVES

There are subdirectories below these with images from separate nights.

The photometry reduction examples are in several directories under

\MPO\EXAMPLES

The Moving Object Search images are in

\MPO\EXAMPLES\MOVINGOBJECTSEARCH

The Variable Star Search images are in

\MPO\EXAMPLES\VARIABLESTARSEARCH

All the images are “real world”, i.e., they were measured in Canopus and/or PhotoRed and the results, when appropriate, submitted. In the case of the astrometry images, the results went to the Minor Planet Center. The photometry results were published in the *Minor Planet Bulletin*. At the Palmer Divide Observatory, more than 600 lightcurves have been measured and then published in the *MPB* using Canopus. Other observers using Canopus have contributed hundreds of curves and the number is growing with each quarterly publication. In other words, it can be done. All you need is a little practice, patience, and, of course, Clear Skies!

*To avoid saying “default directory” or “C:\MPO” repeatedly throughout the guide, all references to file paths will be given on the assumption that the MPO software was installed into a directory \MPO off the root of a hard drive. If you installed to a different location, substitute “\MPO” for the path where you installed the software.*

# Keystroke and Mouse Commands

| ***Command*** | ***Meaning*** |
|---|---|
| <Key> <button> | Press the key (or button) indicated within the brackets. For example, <F9> means to press function key F9. |
| Click | Press and release the left mouse button. |
| Right-click | Press and release the right mouse button. |
| Shift+click | Press and hold down either shift key and click the left mouse button. Release the shift key after the click. |
| <Ctrl+Key> | Press and hold down either Ctrl key and press then release the indicated key or mouse button. Then release the Ctrl key. For example, <Ctrl+3> means to hold down the Ctrl key and press the “3” key on the main keyboard (*not number pad*)<br><br>If the key is a capital letter, the lower case version is OK, i.e., don’t hold down the Shift key unless it’s specifically part of the keystroke command. For example, if told to press <Ctrl+Alt+I>, don’t hold down or even press the Shift key as part of the keystroke combination. |
| Drag | Depress the left mouse button and, while keeping it depressed, move the mouse cursor to a specified location, e.g., to a list in a box.<br><br>In some cases, you depress the right mouse button. This is not common and will be specifically mentioned. If no mouse button is specified, use the left button.<br><br>Some mice have features that allow dragging by pressing a single or special button. Consult the mouse’s user manual or on-line help. |

When asked to enter a string, e.g., “Examples”, enter the value in the appropriate field without the quotes – unless specifically told to do so.

## Mac Users

Canopus and PhotoRed are Windows/Intel (Wintel) programs. They will run on a Mac that is running a virtual machine that loads the Windows operating system, e.g., Parallels. There is no provision made for Mac-specific needs or requirements and it is presumed that you are familiar with running programs under Windows.

*You must have files on a local drive or, if on a network drive, that drive must be mapped to a local drive letter. You cannot, for example, load an image via a URL (\\remotemache\remotedirectory\Afile.FIT). While the image will load, the Auto-Match routine will likely fail with a “120” error.*

## Inverted Images

The charts and images in the tutorials are often inverted (dark stars, light sky) even though this may not be the normal appearance in the program. This is done to make seeing fine details a little easier as well as to improve printing quality. Large areas of black do not always print well, especially if there are fine details within the area, such as stars.

Instead of noting every instance where the chart and/or image has been inverted for this Users Guide, you should presume that a screen shot (or part of it) has been inverted when you see, for example, dark (black) stars on a light (white) sky. *Do not be concerned that the screen shot is not an exact match for what you see if the only difference is white on black versus black on white.*

## The Forest and the Trees

The results you get in many of the lessons may be different from those in this guide. ***Don't get bogged down by minor differences that can be the result of many factors.*** Unless the results are significantly different or things don't work "as advertised", concentrate on the process and see if maybe you missed a step or took a wrong turn and that's the reason for the discrepancies.

## MPO Software Support Group

Don't forget the MPO Software group on Yahoo

http://tech.groups.yahoo.com/group/MPOSoftware

If you have any questions or problems, post a message there. I monitor it constantly as do a large number of users. Experience is the best teacher so, when you can, draw on the pool of real-world experience of Canopus/PhotoRed users.

# Core Operations

The following lessons cover things that you will use at one time or another regardless of the task you are running. These include loading and scaling images, setting the configuration, adjusting the apertures for astrometry and photometry (the areas used to measure the target and sky background), and so on. You should be thoroughly familiar with these concepts before trying to move on to a specific task.

As noted in the introduction, none of these tutorials contain “blow-by-blow” instructions to the level of how to click on a star in an image. That is a basic Windows function that you are presumed to know.

*It will be helpful to follow the tutorials in this section in order. In some cases, a given lesson presumes that you’re familiar with information from a previous tutorial.*

# 1. Critical Configuration Settings

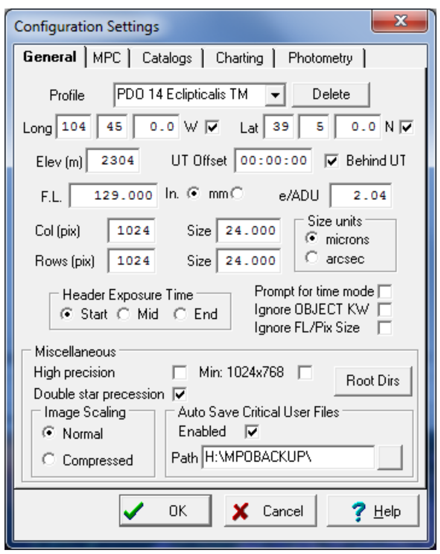
Several of the settings in the configuration form are important for making astrometry and photometry easier and accurate. In some cases, it means the difference between getting and not getting the program to match the image to a set of reference stars, what's called an AutoMatch.

See the "Configuration" section in the Canopus Reference Manual for details on the individual settings. It is important that you understand each value, how it is used, and – in some cases – how it interacts with other values in ways that allow the programs to work as intended or prevent them from doing so.

*The configuration form allows you to save multiple configurations under different names. The settings are stored in the Windows registry. Once created and saved, you can quickly recall the settings for a given telescope/camera/preferences combination by selecting the previously saved profile.*

## Critical Values – General Tab

This tutorial highlights those settings most critical to basic operations. This does not mean that you should ignore the others but, if you use the defaults, the programs should work as expected.




1. Open the Configuration form by clicking the configuration speed button on the top tool bar, using the keyboard combination of <Shift+Ctrl+S>, or selecting "File | Configuration" from the main menu.
2. The Configuration form has several tabs, each with a specific purpose. Go to the "General" page by clicking on its tab.
3. Enter a profile name in the "Profile" field or select one from the drop down list.
4. Enter your longitude, latitude, and elevation (in meters). 1 foot = 0.3048 meters.
5. Enter the UT Offset value.

*This is* **not** *the difference between your computer clock and Universal Time. It is the difference between the time in the FITS headers and UT. Under most circumstances, this value is 00:00:00, meaning the time obtained from the FITS header is in UT.*

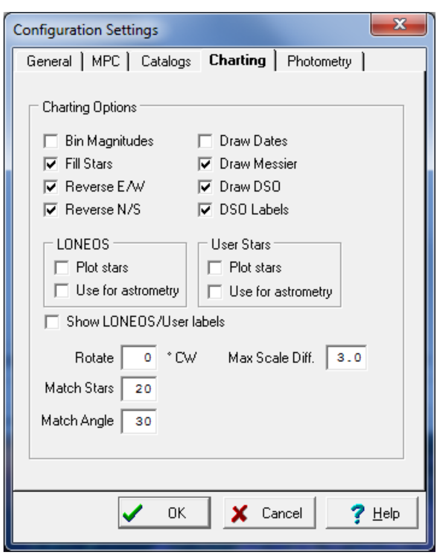
6. Enter the focal length. Use the radio buttons immediately to the right of this field to indicate if the value is inches or millimeters.
7. Enter the eADU value. This should be a positive, non-zero number that is the conversion factor from electrons to ADU as given by the camera manufacturer. Enter 2.3 if you don't know the value.
8. Enter the number of columns (Cols) and rows (Row) in the images. The program usually reads these from the FITS header but it is a good idea to enter the correct values regardless.
9. Enter the pixel sizes in microns or arcseconds. Use the radio button group to specify the units. See the Canopus Reference Manual for additional information.
10. Select the appropriate Header Exposure Time. This is usually "Start", meaning that the time taken from the FITS header is the exposure start time.
11. If you have trouble getting the programs to AutoMatch, check "Ignore OBJECT KW" and/or "Ignore FL/Pix Size". If you do this, the values for focal length and numbers for Col, Row, and pixel sizes must be accurate.

## Critical Values – MPC/Catalogs

The default settings on the MPC and Catalog values are not usually critical to the basic operation of the program. However, the values on those tabs should be set to reflect your setup. For example, those on the MPC tab are used when generating an astrometry report for the Minor Planet Center and so should include *your* information, not the default.

## Critical Values – Charting

Some of the settings on this tab affect the ability of the program to match an image to a chart of reference stars.



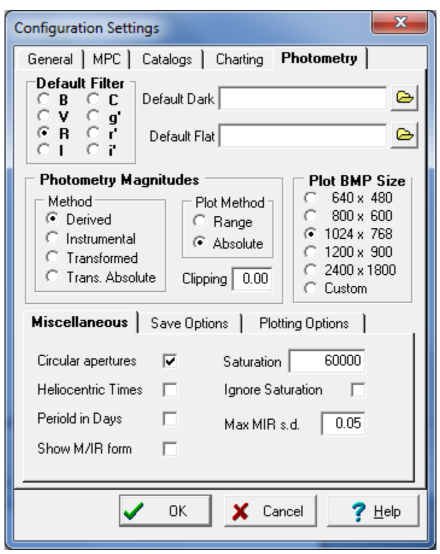
1. Go to the Charting page by clicking on the "Charting" tab.
2. Check the "Reverse E/W" and "Reverse N/S" boxes and enter an appropriate value in the "Rotate" field so that a chart generated by the program matches the approximate scale and orientation of your images. Usually, all that's needed is to set the two check boxes as needed. However, if using an AO or other device that affects the image in one axis but not the other, it may be necessary to set the chart rotation as well.
3. The "Max Scale Diff" setting may affect if you can get an AutoMatch. After an initial AutoMatch, Canopus and PhotoRed check the original scale of the chart (in degrees per side) versus the value after the match and find the ratio of the smaller value to the largest (meaning the ratio is always 1.0 or greater). If the ratio exceeds this value, then the AutoMatch is forced to fail.

   If the configuration is set correctly and/or Canopus can get the needed values form the FITS header, then the scale ratio should be in the range of 1.0 to 1.5. It's recommended that you don't go less than 2.0, which would account for a difference of having an image binned at 1x1 but the configuration set to pixel sizes that are equal to 2x2 binning.

*This "Max Scale Diff" setting is a "safety valve" in that a very bad mismatch between the derived and true plate scales can make the program appear to hang (or actually do so). For example, the original scale might be 0.3 degrees per side but the derived scale was 12 degrees per side. This could mean tens of thousands of stars are being added to the chart and Canopus has to work its way through all of them. That can take a long time.*

## Critical Values – Photometry

The default values on the Photometry tab generally work. There are many settings that should be changed depending on the type of work you are doing.




1. Confirm the "Max MIR s.d." setting is to your liking.

When doing an AutoMatch Canopus establishes what's called the Magnitude/Intensity Relationship (*M/IR from here on*). This allows it to compute the magnitude of any object in the image based on its measured instrumental magnitude. As part of finding the M/IR, Canopus automatically removes stars with excessive residuals (the computed magnitude versus the catalog magnitude). The "Max MIR s.d." is the level used to remove any given star. If the residual exceeds this amount, the star is removed from the M/IR solution.

Experimentation will tell you what works best for your needs. If you set the value too low, e.g., 0.01 mag, you may not get enough stars for a good solution. If you set it too high, e.g., 0.2 mag, then the standard deviation of the overall solution goes up dramatically.

*This setting is important when using TrueMags for analysis (these will be covered in later tutorials). You want to keep the overall standard deviation as low as possible to reduce the scatter in the derived data.*

2. Check the "Ignore Saturation" box if you want Canopus to measure and use stars that are above the "Saturation" value. *This is not recommended* unless you have good reason and are aware of the potential consequences. The program cannot find an accurate centroid or magnitude for a star that is in the non-linear response of the camera or full saturated.

## *About Saturation*

Having the right saturation value is critical to some operations in Canopus, e.g., when doing photometry using magnitudes based on the Magnitude/Intensity Relationship (M/IR, see the Reference Manual and tutorial in the Photometry chapter). If you set the value too high, so that stars that are in the non-linear response of your camera, or are actually saturated, then the MI/R solution can be off significantly and your results badly skewed. When in doubt, underestimate the value and never assume that it is the maximum allowed by your camera's ADU converter. Just because the ADU is 16-bit doesn't mean that the camera is linear all the way up to 65535 ADU counts.

*Note that the preceding assumes 16-bit images, usually the native output of cameras. If you're using processed images, they may be 32-bit (integer or float) or 64-bit (float) and so the saturation number will be on the order of 2 billion for 32-bit integer images. If you're working with 32 or 64-bit images, check "Ignore Saturation." The odds of any pixel actually reaching the maximum value for these images are extremely remote – unless the images are the result of stacking several 16-bit images and a given star was non-linear or saturated on one or more of those images.*

## Saving Changes

Click <OK> to save the current settings.

Click <Cancel> to close without saving changes and revert to the settings before the form was opened.

*Some of the tutorial sets, e.g., astrometry and lightcurve photometry, include short tutorials that set certain fields to specific values. What was covered here are the core values that MUST be set or at least considered in order for the programs to work properly.*

# 2. Opening Images

Canopus can load FITS (Flexible Image Transport System), SBIG, BMP, and JPG files. However, FITS and SBIG are the only two that allow you to AutoMatch an image and for which you should use for science work with FITS the “standard” format.

*It should be noted now that there are many FITS “standards”. MPO software does its best to adhere to those whose definition can be found at http://fits.gsfc.nasa.gov/fits_home.html.*

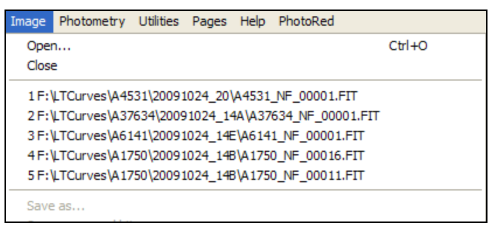
*The Canopus/PhotoRed manual has an appendix of recognized keywords, i.e., names for values that are found in FITS/SBIG headers. Many programs add “keywords” to the header to define other values or use “standard” values in a way not expected. Canopus/PhotoRed may or may not recognize them or use them properly. The only “guarantee” is that every effort will be made to have the MPO programs work within the standards defined on the above link and the keywords listed in the Reference Manual appendix.*

To open an image in Canopus/PhotoRed for measuring or AutoMatch, you can

1. Select “Image | Open image” from the main menu or press (<Ctrl+O>, the letter, not the number). This displays a Windows file open dialog where you can select the image to be loaded.

   A list of the five most recently opened images is found on the Image menu. Use this to reload one of those images without having to navigate through the Windows file open dialog.

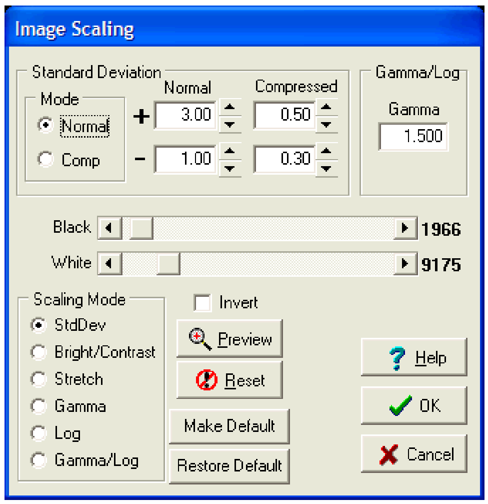
2. Select Image from the main menu and chose a previously opened image from the MRU (most recently used) file list.



# 3. Scaling/Inverting an Image

Canopus and PhotoRed provide some basic image manipulation to make it easier to see faint targets or bring out details in other ways.

*The scaling does NOT change the original data. It simply modifies the way the image data are displayed. You can save the modified display as a BMP or PNG but the underlying FITS data does not change.*




1. Open an image in Canopus
2. Right-click over the image and choose “Image scaling” from the pop-up menu to display the Image Scaling form.
3. Select a method of scaling and adjust the values to get the desired effect.
4. Click <OK> to close the form and keep the settings.

## Setting a Default Scaling

You can apply a set of scaling settings to all images opened after you make the settings for a given image. For example, if you have a set of images with a bright star that dominates the scaling such that you can’t see faint objects, you can open one of those images, set the scaling so you can see faint objects, and then have the scaling settings be applied to any other image opened afterwards.

1. Open an image in Canopus.
2. Right-click over the image and select “Image scaling” from the pop-up menu to display the scaling form.
3. Set the scaling so that the image is displayed to your liking.

   If necessary, click <Preview> to force the current image to use the scaling settings. Click <Reset> to restore settings to the values when the form was opened and force the image to use those settings.
4. Click <Make Default>.
5. Click <OK> to close the form.

*All images opened after setting a default use those settings. Some images may not scale well with the default values, showing as all black, all white, or with extremely high contrast. You should use custom scalings carefully and remember that they could make some images worse than better.*

## Invert the Image – One Time

Some find it more convenient to view an image when the stars are dark and the sky background bright. To toggle the current image between “normal” (white stars, dark sky) and “inverted” (dark stars, light sky):

1. Right-click the over the image and select “Invert” from the pop-up menu.

or

2. Open the scaling form and check the “Inverted” box.

Each time you select Invert, the display is set to the opposite state.

## Make Inverted the Default

To force Canopus/PhotoRed to open all images with dark stars and light sky:

1. Select “Image | Sticky Invert” from the main menu.

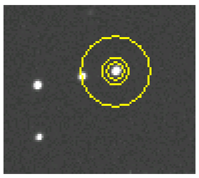
If an image is open, it is set to dark stars, light sky. If it is already set to “inverted”, it does not switch to “normal” mode.

## Aperture Colors

Even when an image is inverted, the aperture color settings are retained. See the tutorial on setting aperture sizes and colors (pg. 15).

# 4. Setting the Apertures

The measuring apertures are used to define the areas on the image used to find the brightness of a star, asteroid, or other object – what will be called “the target” – and the brightness of the nearby sky. There three apertures, centered on a common point and concentric with one another. The screen shot below shows a sample set of apertures.

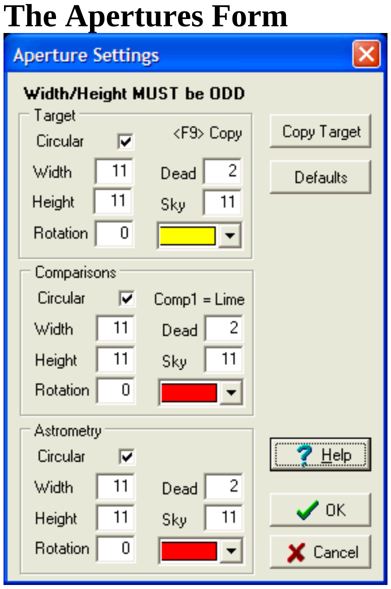


The inner-most circle is the “target aperture.” Pixel values from within this region define the brightness of the target.

Just outside that is another circle that forms an annulus with the target aperture. The area of this annulus is called “the dead zone”. Pixels within this region are ignored entirely. It’s a buffer zone between the region that defines the target and the region that defines the sky background so that pixels within the annulus are not counted twice.

The outer-most circle defines the outer boundary of the “sky annulus” with the dead zone aperture defining the inner boundary. The pixels within this area are used to compute the sky background. The average value is then subtracted from the value of every pixel in the target aperture so that what remains is the result of the only the target and not the target + sky.

## The Apertures Form




To set the measuring apertures before measuring images:

1. Click <Apertures> on the main form tool bar to display the apertures form.
2. Change the settings as desired and then click <OK>.

*The height and width values can be different but both must be odd numbers, e.g., 3, 7, etc.*

## Some Apertures Hints

1. You can define aperture sets for three types of objects: the target (e.g., an asteroid or variable star being measured for time-series work), the comparison stars (when using the lightcurve wizard and transform wizards), and astrometry (when measuring field stars during an AutoMatch).
2. The “Width” and “Height” settings for a given object type are for the “target” aperture, the inner-most aperture. The “Dead” and “Sky” settings are for the width of the given zone. For example, assume the target aperture is 11x11 pixels. A “Dead” setting of 2 means the dead zone is two pixels wide and so has a total width of 13 and radius of 2 + 5, or 7 pixels. Keep in mind that because of the forced odd number of pixels in the target aperture of 11 pixels there are five pixels on either side of the “center” column (or above/below the center row). A “Sky” setting of 11 means the outer aperture has a radius (assuming circular apertures) of 11 + 2 + 5, or 18 pixels.
3. You can set the target apertures independently of the comparisons apertures. This is useful if working a fast moving object and so the target and/or the comparisons are trailed.
4. The apertures for a given object type do not have to be symmetrical, i.e., round or square. They can have different heights and widths. All the apertures (target, dead zone, sky) for a given object type are the same shape since the latter two are defined in terms of the target aperture.
5. You can set the rotation angle of a non-symmetrical aperture set. For example, if using elliptical apertures, where the height and width are not the same, you can rotate the ellipse to match the trailed image of a fast moving object.
6. You can use different colors for each object type, e.g., yellow for the target and red for comparisons.

*When using the Lightcurve and Photometry wizards in Canopus and PhotoRed where you are measuring a series of images in which an “anchor star” is used to find all other objects, the “anchor star” (one of the Comparisons group) always uses bright green (lime) apertures. You should select a color for the Comparisons other than lime and that used for the Target type so that you can easily spot the “anchor star.”*

7. You can copy the “Target” type aperture set to the “Comparison” and “Astrometry” types by pressing <F9> or clicking <Copy Target>.

See the set of Astrometry and Photometry tutorials for examples of setting the apertures.

# 5. AutoMatch

One of the most common and important operations when using Canopus and PhotoRed is *AutoMatch*. This is where the program reads the information from the FITS/SBIG header and/or configuration settings, generates a star chart centered on the presumed center of the image, and matches the chart's center, rotation, and scaling to the image. In more specific terms, the chart is created so that for any given star in the image, the corresponding star in the chart is at the same distance and angle from the chart center. Mathematically, the star has the same polar coordinates in the image and chart, both of which have the same origin point in the sky.

When this is done, so-called "plate constants" are found. These allow converting an X/Y coordinate on the image to an RA and Declination, thus allowing, for example, Canopus to determine the coordinates of an asteroid to be sent to the Minor Planet Center. Also found during an AutoMatch is what's called the Magnitude-Intensity Relationship (M/IR). This converts the measured total ADU count for an object in the image to a magnitude based on those taken from the one or more catalogs used to generate the chart.

*The reliability of M/IR-derived magnitudes depends on the catalog used to generate the chart. If you use the MPOSC and set the default magnitudes to Sloan r', the results – while in r' magnitudes – will be fairly consistent and reliable. This is because those magnitudes are taken from the CMC-14 and Sloan catalogs, which have a high-degree of internal consistency. If you use the MPOSC3's BVR magnitudes (derived from 2MASS J-K values) the consistency is not as good and so there can be a much larger scatter in data based on these values.*

## AutoMatch Fundamentals

The Canopus Reference Manual contains details on the AutoMatch process such as how the programs read the header to get the necessary information and when/if those values are superseded by the configuration settings. On the assumption that the necessary values are available, it is important that you have a basic idea of how the AutoMatch works. For the sake of brevity, the following steps assume Canopus is being used. The core AutoMatch code is used in all MPO programs and so a general description applies to all.

1. Canopus reads the FITS header and determines the approximate RA and Declination of image center as well as the scale (degrees/pixel) and orientation (e.g., north up, east left) for the chart.
2. Using the EXTRACT program in \MPO\UTILS (based on SExtractor), Canopus extracts the stars from the image. This includes an instrumental magnitude and X/Y coordinates. The star data are sorted by magnitude and a fixed number of the brightest stars are collected into a "constellation."
3. The chart is generated and the star data sorted to find a fixed number of the brightest stars (the chart's "constellation").
4. Canopus forms a number of two-star pairs using the image constellation and compares each pair to every possible two-star combination among the chart constellation.

*During the AutoMatch process, you will see a set of colored lines on the chart. These represent the pairs that Canopus uses to try to find a match.*

5. For each comparison, the chart data is translated, rotated, and scaled so that the separation and angle of the test pair from the chart matches the pair from the image.

6. Canopus then checks how many matches can be made between the new X/Y coordinates of the chart constellation to the image constellation.

7. The chart pair that results in the most number of matches to the image is used redraw the entire chart and attempt to find an astrometric solution that has an acceptable error. That error is found by back-fitting the derived plate constants to find the RA/Declination of the chart stars and comparing them to their catalog positions. The mean error and standard deviation of the comparisons are used to determine if the solution is acceptable.

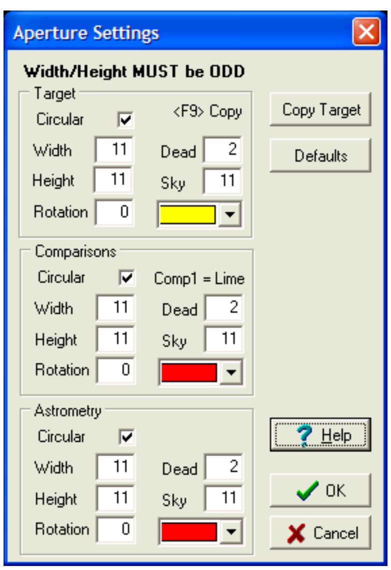
8. If Canopus can read the FITS header such that it knows that it was approximately centered on a given asteroid, it will use the plate constants to find the asteroid on the image and automatically measure it (*AutoMeasure*). This simulates the actions of clicking on the asteroid in the image, which derives the RA/Declination from the plate constants, right clicking over the image and selecting "Set Asteroid Position" from the pop-up menu.

*If Canopus cannot AutoMatch the image, it is usually because the configuration settings (those affecting scale and orientation) are such that the initial chart is so far off from that of the image that the pair matching fails. The other main reason for AutoMatch to fail is that Canopus cannot read or reads incorrectly the FITS header information and so determines a chart center that is significantly different from that of the image.*

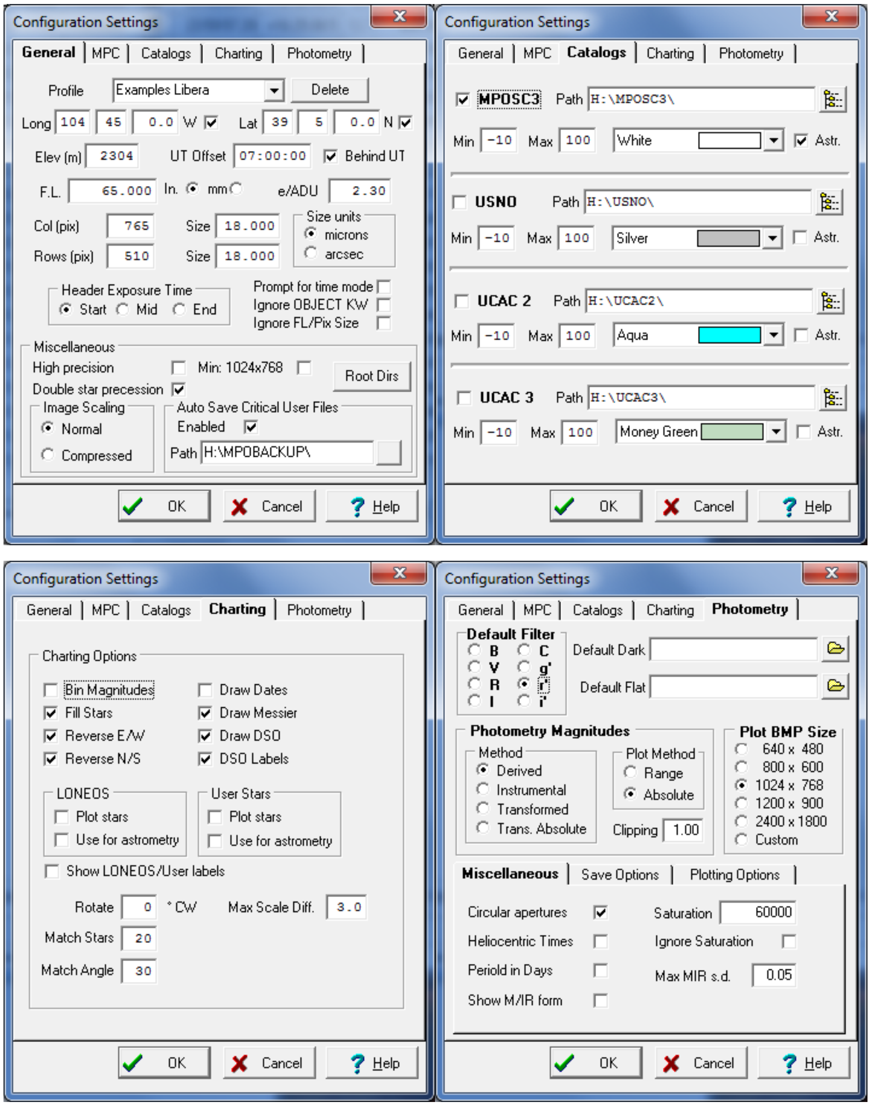
## AutoMatch Tutorial

The following steps will take you through an AutoMatch. These general steps apply to any image. Where the details may change is the configuration and aperture settings.

1. Open the Apertures form and duplicate the settings in the screen shot below.



2. Open the Configuration form, duplicate the settings shown below, and save the changes. The name you give the profile is not important.



The presumption is that you installed the MPOSC3 catalog but not UCAC2 or UCAC3 and that you do not have the 10/11 CD set of the USNO-A catalog. Even if you did, you should generally use only one catalog at a time, assuming that there are enough stars in the catalog for the field of view being covered.

*When doing astrometry, the UCAC2 or 3 catalog is the one of choice. For photometry in Canopus, use MPOSC3 since it contains data from the CMC-14 and SDSS catalogs. Where available, the Sloan r' magnitudes are much more internally consistent over the BVRI magnitudes derived from a 2MASS to BVRI conversion (Warner, 2007; Minor Planet Bulletin **34**, 113-119).*

*Note that the Sloan r' magnitudes were chosen on the "Photometry" tab for this exercise. In this case, it is OK because there are a sufficient number of stars in the field with r' magnitudes. This fact will be used to demonstrate an important feature in Canopus for doing lightcurve photometry. In other cases, you may want to – or have to – choose another photometric band.*

3. Load the following image

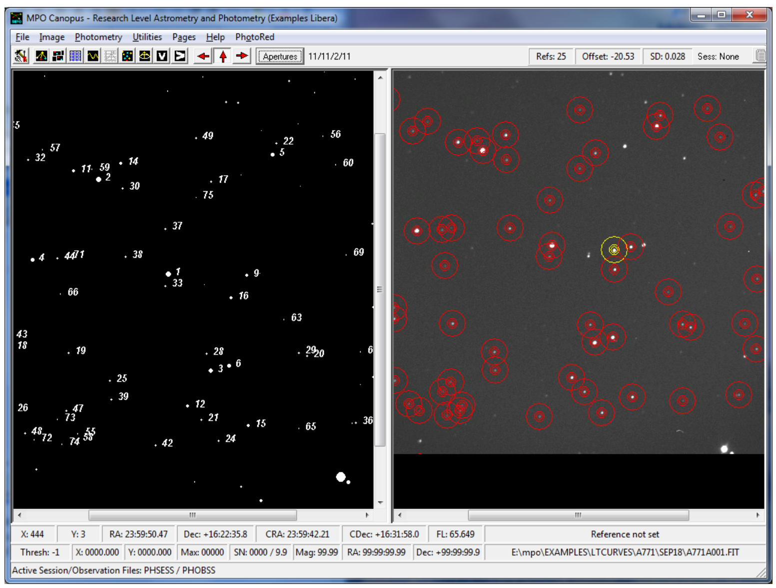
   \MPO\EXAMPLES\LTCURVES\A771\SEP18\A771A001.FIT

4. Invoke AutoMatch by:

   A Keyboard: <Ctrl+ A>

   B Menu: "Image | Auto match/measure"

5. You will see a set of colored lines on the chart. After a few seconds, those go away and are replaced by numbers. On the image, a set of measuring apertures are displayed. One set, those about the asteroid, is in yellow.




6. Look at the upper right of the Canopus form. You'll see the summary of the M/IR solution in a tool bar giving the number of the stars in the solution, the M/IR offset, and the standard deviation of that offset. See the Reference Manual for additional information.

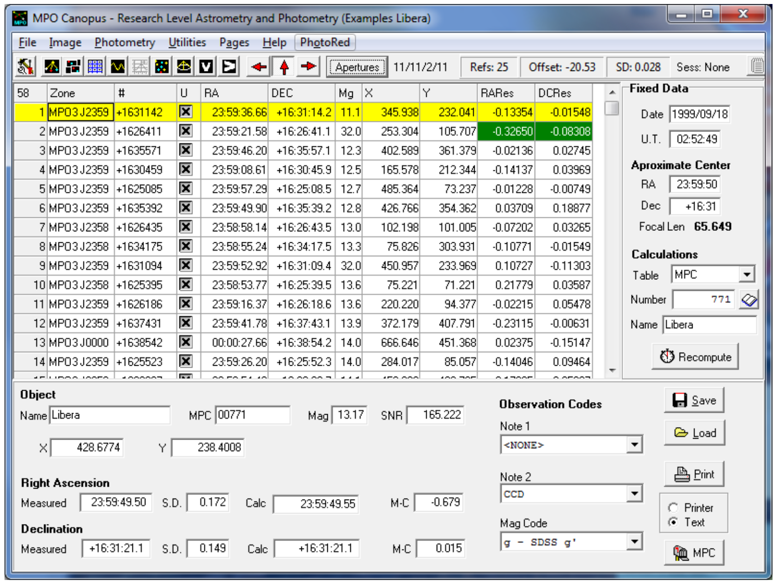
*The Refs number may not match the number of stars used in the astrometric solution, which determines the "plate constants" that allow computing the RA and Declination of a star based on its X/Y coordinates on the image.*

7. Go to the Reductions page:

   A Select "Pages | Reductions" from the main menu

   B Click <Reductions> on the tool bar at the top of the Canopus form (it has an icon that resembles a spread sheet or table).

C  Press <Ctrl+3>




8. This page shows the derived position for the asteroid at the bottom of the page. The table shows the data for the reference stars used to find the plate constants. The numbers in the far left column of the table correspond to the numbers on the chart back on the Measurements page. The RARes/DCRes values are the differences between the catalog position and the one computed from the plate constants and are given in arcseconds. The standard deviations of these residuals are shown in the S.D. fields at the bottom of the form. In this case, the match is very good, with the deviations ~0.15 arcseconds.

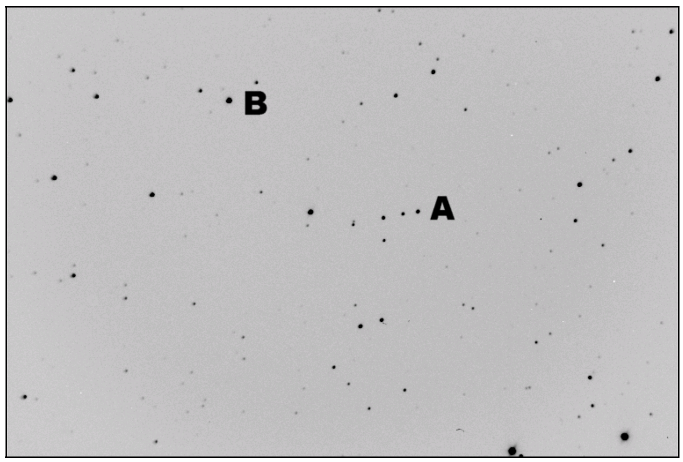
*As you'll see in a later tutorial, the M-C values are the differences between the measured and calculated position.* ***The absolute value of these numbers is not as important as the trend of the numbers when comparing results from a number of images taken on the same night.***

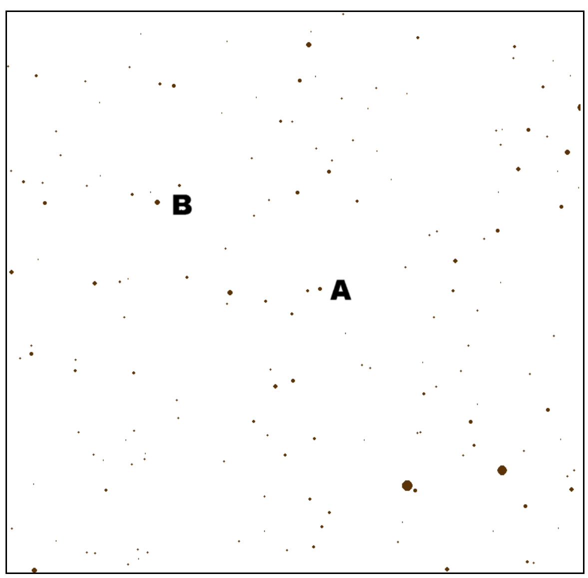
## AutoMatch in PhotoRed

In PhotoRed, you go through the same basic steps as above. The difference is that after an AutoMatch, there is no Reductions page and you won't see the apertures on the image. Instead, a simple message appears that says "AutoMatch Successful."

# 6. Manual Matching

Sometimes Canopus cannot perform an AutoMatch. This can for several reasons, usually because it cannot interpret information from the FITS header correctly and so cannot determine the approximate center of the image or approximate scale and/or orientation for drawing the chart. When you encounter such a case, you can still get Canopus to match the image and so get the plate constants and M/IR solutions needed for other things.




The following steps refer to these two screen shots. The top one is the CCD image while the bottom is a chart drawn by Canopus that approximately matches the image.

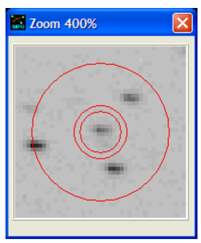
To do a manual match requires that you first have Canopus draw a chart that approximately matches the scale and orientation of the image. From there, you will do manually what Canopus does automatically, indicate a pair of stars on the chart that correspond to the same stars on the image. From there, Canopus can do the rest.

Note that the chart is square. Regardless of the image aspect ratio, the chart is always square with the sides being the larger dimension of the image.

## Opening the Zoom Box

When trying to place the mouse cursor over an object in an image, it often helps to see a magnified view of the area of the image under the cursor. This is provided by the "Zoom Box" feature.

1. After you open an image, right click over it and select one of the three Zoom items from the popup menu. Each one provides a different level of magnification, 200%, 300%, or 400%. You can also display the form by pressing <Ctrl+Shift+2> (200%), <Ctrl+Shift+3> (300%), or <Ctrl+Shift+4> (400%).




2. Move the box to a convenient location on the screen so that it doesn't get in the way of doing things.

Note that the box also shows the current set of apertures. If you change the aperture settings (sizes), the box automatically updates. The apertures are always red.

*If you open the configuration form, the box is closed and you have to open the box again.*

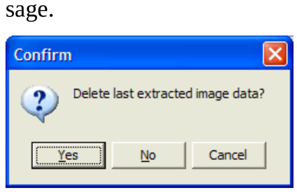
## Manual Chart Matching

This tutorial uses the configuration profile and aperture settings that you created for the AutoMatch tutorial (pg. 17).

1. Load this image

   \MPO\EXAMPLES\LTCURVES\A771\SEP18\A771A001.FIT

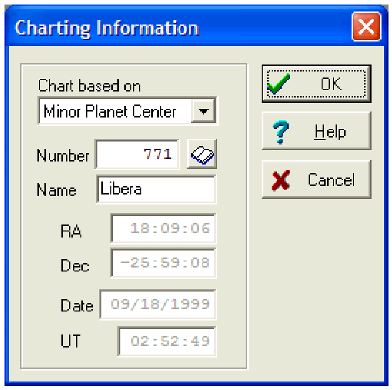
2. Select "Image | Generate manual chart" from the main menu. This displays a message.




3. Click <No>.

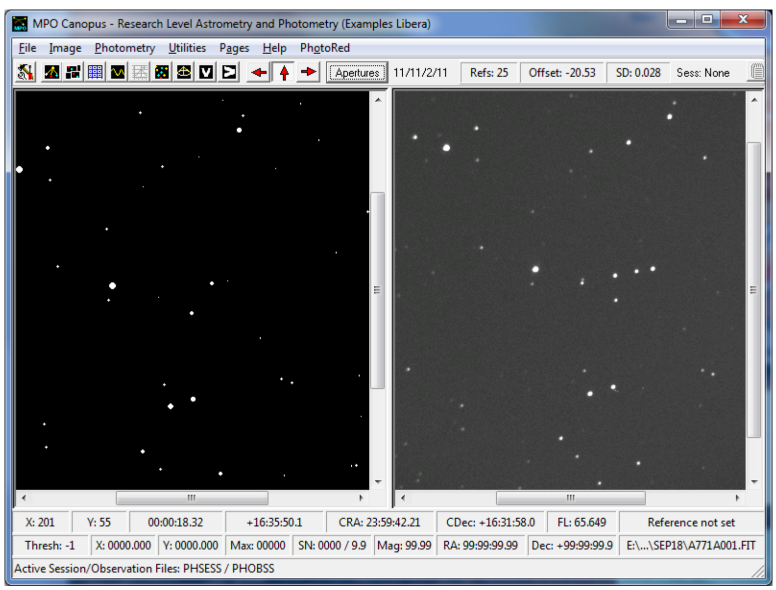
*If you do an AutoMatch, it generates a file that has data on the stars in the image that was measured. You may want to generate the chart for that image again but not do an AutoMatch. Also, that file might still be needed for some other functions. By answering "No", that file is not deleted. Of course, the presumption is that you'll be working with the same image from which the data file was created. If you change images, then that file is no longer valid and you should delete it.*

4. After you click < No>, the chart generation form appears.




If possible, Canopus fills in the fields for you. In this case, it was able to determine that the image was of 771 Libera and set the form accordingly.

5. Click <OK> to generate the chart. Your screen should look similar to this:




6. Using the reference images at the beginning of this tutorial, locate star "A" on the image and click on it. You should see a set of measuring apertures centered on it.

7. Right-click over the image and select "Select Image Star | Add Star 1" from the popup menu.

8. Find star “A” on the chart. Center the mouse cursor over the star and right-click.
9. Select “Set chart star | Add Star 1” from the popup menu.
10. Repeat these steps for Star ‘B’, ***except*** that you select “Add Star 2” from the two popup menus.

*When selecting the two stars to be used in this process they should be 1) as far apart as possible but not too close to the edge and 2) not be on a vertical or horizontal line, i.e., a line joining the two would not be nearly parallel to the vertical or horizontal edges of the image. Following these guidelines improves the accuracy of the match.*

11. Right-click over the *chart* and select “Match to Image | Auto measure” from the popup menu.

After a few moments, you should see something similar to what followed an AutoMatch in that tutorial: a number of aperture sets about stars on the image and reference numbers next to a number of stars on the chart.

What you see after this match may not match the screen shot of the AutoMatch exactly, i.e., a different set of stars may have been used in the final solution. That could be due to the AutoMatch finding a different star pair that had a larger separation (or angle) that produced a solution with smaller residuals. The main point is that you do see the apertures and reference numbers and when you go to the Reductions page that you see something similar to what followed in the AutoMatch tutorial.

# 7. Blinking Images

There may be times when you want to compare two or more images to see if there is an unexpected moving object in your image or to check a reference image of a galaxy against a more recent image to see if a supernova may have occurred. The Moving Object Search (MOS) utility in Canopus can search for moving objects in a number of sets of images but that is overkill for a simple check to make sure you know where an asteroid is or to locate unexpected targets. This is where the Blinker in Canopus comes in handy.

The idea behind the blinker is simple: two or more images are aligned and then each one is shown in quick succession. All non-moving objects that are in every image appear to stand still while a moving object changes location from image to image. It was a similar concept that was used by Clyde Tombaugh to discover Pluto, but he was using large photographic plates and a mechanical device.

## Using the Blinker

For this exercise, it's better to maximize the Canopus form so that it occupies the full screen.

1. Go to the Blinker page using one of three options:
    - Select "Pages | Blinker" from the main menu
    - Click <Blinker> on the top tool bar
    - Press <Ctrl+2> on the keyboard


2. Click <Open> and load a file. For this tutorial, locate and open

    \MPO\EXAMPLES\LTCURVES\A771\SEP18\A771A001.FIT

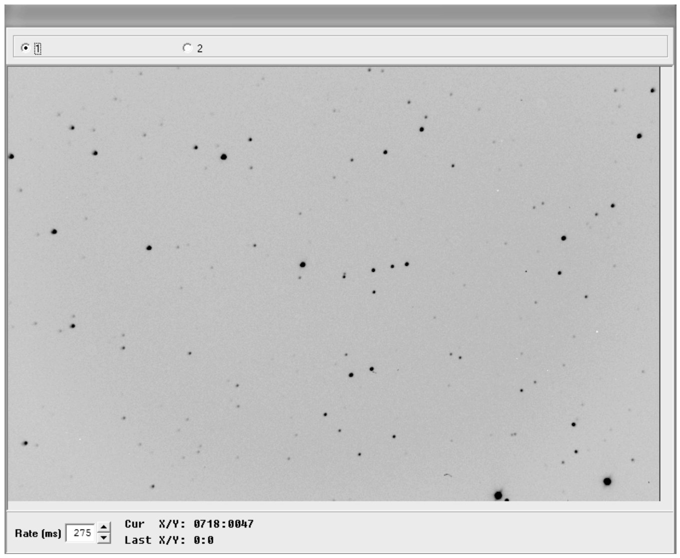
3. Repeat step 2, loading

    \MPO\EXAMPLES\LTCURVES\A771\SEP18\A771A006.FIT

The image windows are cascaded so that you can see all (or most) of one image and the caption bars of the other images underneath.

*You can load more than one image at a time. When the file open dialog appears after clicking <Open>, select as many files as you want (be reasonable) using the standard Windows techniques for selecting multiple files.*

4. On the first image, click on a brighter star near the middle of the image.
5. Click the caption bar of the second image to bring it to the front and then click on the same star on that image.
6. If you want to view the images inverted (dark stars and light sky), which can help finding fainter objects, click <Invert> on the Blinker page (it's immediately to the left of the "Clear" button).
7. Click <Start>. This minimizes the two images and presents a new window where the images are alternately displayed. The caption on the button changes to "Pause."




Unless you picked the asteroid (it's happened), all the stars in the image should be stationary while one star – the asteroid – appears to move back and forth.

You can change the rate at which the two images are displayed by changing the value in the "Rate (ms)" field by entering a value directly or using the spinner control.

If you click <Pause>, the blinker stops on the current image (and the caption reverts to "Start.") Use the radio buttons at the top of the form to select which image is displayed.

If one or fewer images are open, the Start/Pause button is disabled.

Use <Clear> to close all images. The button is disabled while the blinker is operating.

You can close a window and open one or more others to use for blinking. Make sure that you click on the same reference star in each image before starting the blinker. If not, the images are not aligned and you could get dizzy as the blinker displays those misaligned images.

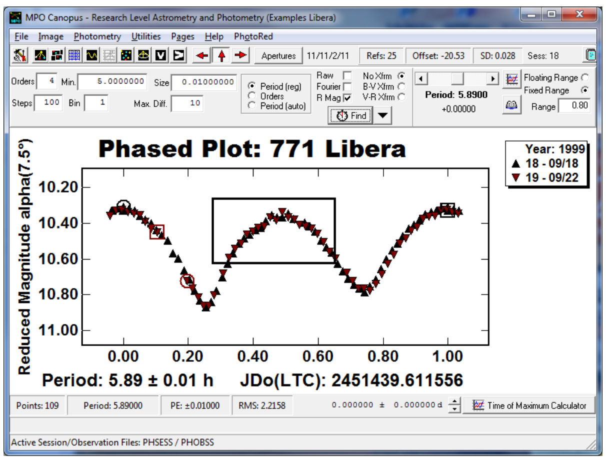
# 8. Working with Plots

## Saving Plots

All plots can be saved using a menu option or button provided for that purpose. The default is to save as a PNG since these are much smaller than BMP files and have very little compression loss. When a file dialog appears, select type of file before saving. Regardless of the extension you give the file, MPO software forces the extension to the selected file type.

## Pan and Zoom

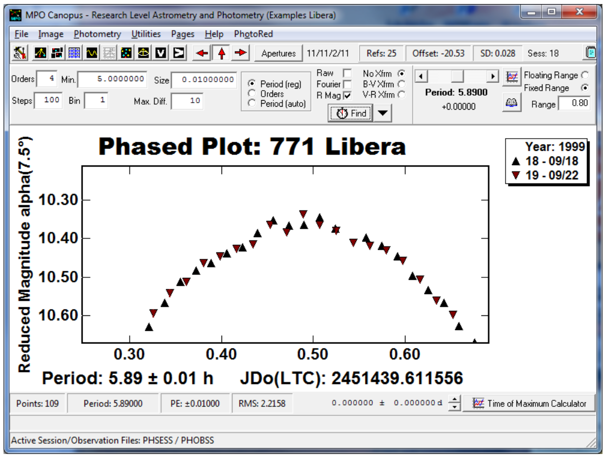
Many of the plots presented in Canopus and PhotoRed allow zooming in to see a portion of the plot in detail and then, while still zoomed in, to pan around the entire plot to look at other regions up-close.




Here is a screen shot of Canopus after generating the lightcurve of an asteroid. The box has been added to indicate the approximate region on which we want to zoom.

### *Zooming In*

1. Move the mouse cursor a little above and to the left of the region that you want to see zoomed.
2. Drag the mouse cursor a little below and to the right of the region and then release the mouse button.




Now you see the region filling the entire plot area.

You can zoom in as much as you want. If you want to zoom in some more, just repeat the process of selecting a region but on the zoomed plot. It is not necessary to reset the plot to zoon in more.

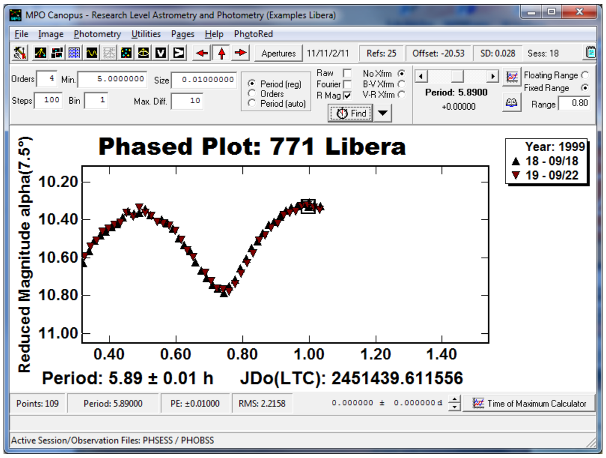
## *Zooming Out*

1. To zoom back to normal view, reverse the process, i.e., place the mouse cursor anywhere on the plot area, drag up and to the left a few pixels, and release the mouse. The plot returns to normal scaling.

## *Panning*

"Panning" means to move the entire set of data in any direction. You can pan the plot regardless of the zoom level.

1. Move the cursor anywhere on the plot and drag using the *right mouse button instead of the left.*




This screen shot shows the original plot after panning to the right.

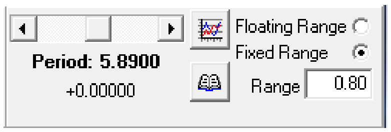
*The most common use of panning it to move about the data set after zooming in.*

### *Reset Panning*

Use the same procedure to reset the plot as you did for zooming out, i.e., drag up and to the left from anywhere on the plot and then release the left mouse button.

## Working with Lightcurve Plots

There are several features available specific to the plots on the Lightcurve Analysis page.




### *Floating and Fixed Range*

The preferred practice in publishing asteroid lightcurves is to have the vertical scale such that 0.6 to 0.8 magnitudes is about as high as the phase between 0 and 100 (or 1.0) is wide. The default in Canopus is forces the vertical range to 0.8 magnitude.

The reason for keeping such a scale is to avoid having small changes in the lightcurve appear to be much larger than they are in proportion to the overall curve. For example, one can get the false impression that the asteroid is more elongated than it really is. Of course, if the amplitude is very small, forcing the range may make the curve essentially flat and so all detail is lost. Then it is OK to expand the vertical scale to see the details, but the expansion should be kept to a minimum.

#### Floating Range

Check this radio button to have Canopus scale the vertical axis such that the curve is about 70-80% of the plot area height, but with no less than ~0.12 mag total height.

#### Fixed Range

Check this radio button and enter the vertical range of the plot. If the amplitude of the curve exceeds the range, Canopus automatically switches internally to use the floating range option but the setting does not change on the tool bar.

Click <Replot>, immediately to the right of the period slider bar, to replot the data if you make any changes to the range settings.

### *Changing the Period Dynamically*

You can see the effects of changing the period solution on the phased plot (where the data are folded to fit between 0.0 and 1.0 of the period) without having to click <Find> again.

1. Move the slider bar left or right of center. As you do, you'll see the new period value and the amount of change in the labels below the slider.
2. Click <Replot> to see the effects of the change.

This is a handy tool for getting an estimate of the true period error. The one reported by Canopus is the formal error, which should often be increased to provide a more reasonable error estimate. If you change the period by 0.01 h and the plot "falls apart" or the data noticeably no longer line up, then you can put an upper limit on the period error at 0.01 h.

### Changing the Range of the Period Slider

By default, the period slider range is ±0.1 h. If you're working a long period asteroid, this is too little. If you're working a short period asteroid and would like to test very small changes, it is too much.

1. Click on the slider's "thumb" (button) and press one of the number keys *on the main keyboard* (not the number pad). This resets the slider to the middle and changes the total range.

| Key | Range (hours) |
|---|---|
| 1 | ±5.000 |
| 2 | ±1.000 |
| 3 | ±0.500 |
| 4 | ±0.200 |
| 5 | ±0.100 |
| 6 | ±0.067 |
| 7 | ±0.050 |
| 8 | ±0.033 |
| 9 | ±0.025 |
| 0 | Reset to default (±0.100) |

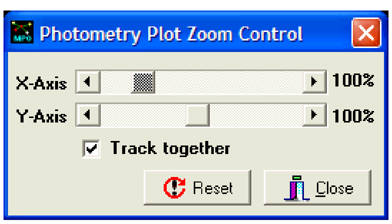
*Clicking <Find> resets the slider range and position to its defaults.*

## *Plotting Options*

Click <Options> (immediately below the <Replot> button) to see a menu with several options. Most of the menu options are toggles, meaning if you select one, it goes from off to on or vice versa.

### Zoom

This is a special implementation of zooming the lightcurve.




Use the slider bars to change the vertical and or horizontal scaling of the plot. If the "Track together" box is checked, the sliders move in unison. Uncheck the box to change the scaling independently.

You can save the rescaled plot as long as you don't close the zoom form or click <Reset>.

### Show Legend

This menu item toggles the legend on the lightcurve plot. When publishing the lightcurve, you should include the legend. Use a graphics program to move the legend within the data area. This makes for a much better presentation.

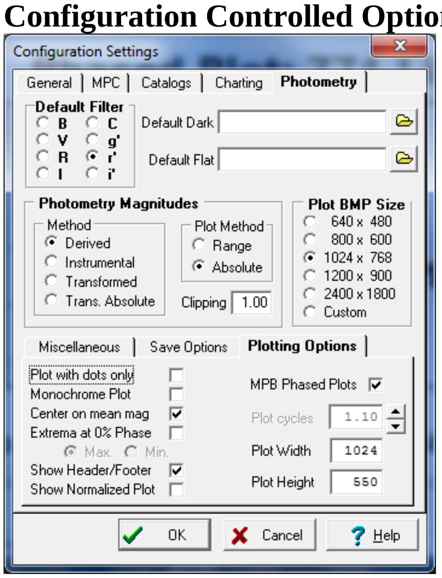
### Show Header and Footer
This menu item toggles the header and footers of the plot. When publishing the lightcurve, generate the plot with the header and footer enabled. You can copy and paste as needed for the final version. See an example below.

### Flip Y-axis
Lightcurves should be presented so that the object is brightest when the data points are at the top. If you've been given data where the asteroid is brightest at the bottom, use this option to present the lightcurve correctly.

### Show Errors
This toggles the error bars on the data points in the plots.

### Save LC Plot
Click this to display a file dialog. Plots can be saved as PNG or BMP files.

## Configuration Controlled Options




The Reference Manual covers the details of the plotting options controlled on the "Configuration | Photometry | Plotting Options" tab.

One worth mentioning here is the ability to generate custom-sized plots. This is useful for when publishing your lightcurves in a journal such as the *Minor Planet Bulletin, Journal of the AAVSO* (*JAAVSO*), and so on. Another is to plot the data showing more than one cycle (the data are repeated when going past the first cycle). The "MPB Phased Plots" forces the phase range from -0.05 to +1.05 cycles. Some journals want a wider range. If you uncheck the "MPB Phased Plots" box, you can set the range from 1.0 – 2.0 cycles. These custom-phased plots always start at 0.0 phase.

# 9. The MPO Server

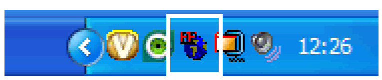
The MPO Server is a Windows program that runs automatically whenever you start an MPO program (MPO Canopus, Connections, MPO Viewing Guide, or MPO LCInvert). The server is one side of what's called a "client-server" database system. The MPO programs are the clients and, of course, the MPO Server is the server.

The idea is that the client applications never access data file directly. Instead, they send a request to the server, which then accesses the files, and returns the requested data. When editing or adding data, the server is the one that does the actual modifying, using the data supplied from the client. Think if the server as a bank teller who takes and gives you money from the bank's vault (I'm showing age by assuming that not all people use electronic banking).

You should almost never have to worry about the MPO server application. However, there may come a time when you need to start and restart it. For example, if one of the MPO client programs shuts down unexpectedly or in a way not intended, the server may "keep a hold" on one or more files such that when the client application tries to access the file again, the server says that it's not available. The teller is waiting to get the manager's approval to release your funds.

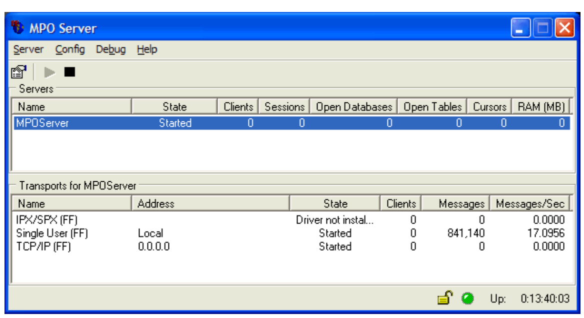
You will get error messages on occasion that tell you specifically to stop and restart the MPO server or that a certain action cannot be done. The latter is usually when trying to make a backup of the main files as Canopus closes. Should you suspect that the teller is being stingy, it's easy to get the manager's approval and conduct your transactions.

1. ***Make sure all MPO client programs are closed.***
2. On the far right of the Windows task bar, usually at the bottom of your screen, is the *icon tray*..

   This holds the icons of programs that are running in the background, e.g., a virus scanner. Among the icons you should see is one that looks like an Earth globe with "FF" superimposed. A white box has been added to the screen shot above to indicate the MPO Server icon.

3. Double-click the icon to display the MPO Server application.

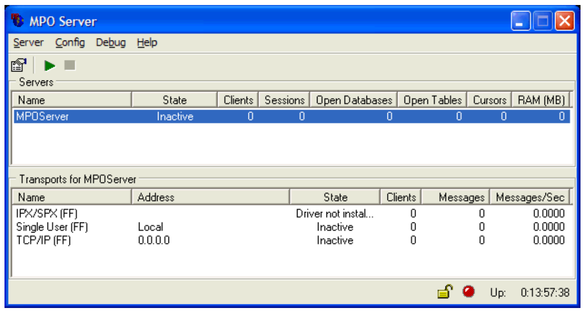
   
   

   Note the green "LED" at the bottom right of the server form.

***Do not change any options or settings on the MPO Server unless instructed in this Guide or by technical support.***

4. Click the black square at the upper left. This stops the MPO Server.
5. Wait until the black square becomes disabled (turns gray) and the button to its left displays a green, right-pointing arrow. The "LED" should now be red.

☞ *It can take ten or more seconds for the MPO Server to stop.*




6. Click the green arrow and wait until it turns gray, the square is black, and the "LED" is back to green. This should take only a few seconds at the most.
7. Click the "X" at the far upper right of the form. This does not close the application but simply returns it to the icon tray.

## Warning

As noted above, do not change any options or settings in the MPO Server without being told to do so by technical support. Otherwise, the MPO client programs may no longer work.

# Astrometry in Canopus

The following sections cover the steps used in Canopus to measure the position of an asteroid (or other target) using the AutoMatch feature. As seen in the core lesson on AutoMatch, Canopus also attempts to locate an asteroid based on information in the FITS header and automatically measure its position and magnitude as well. It does not and cannot measure multiple targets in the same field. You must measure additional items separately. That will be covered in a subsequent tutorial. Targets other than asteroids, e.g., variable stars, also are not measured automatically after an AutoMatch. Some tutorials in the Photometry section of this guide cover measuring such objects.

As part of the AutoMatch, Canopus automatically measures the reference stars on the image and eliminates those that have excessive residuals. You can override the set of reference stars that Canopus selects and the position that it uses for the asteroid. With practice and a field that is not overly crowded, you can go through the entire process of measuring an image in less than 10 seconds.

The tutorials in this section assume that you have gone through the core lessons and understand the basics of setting the configuration, setting aperture sizes and colors, and how to AutoMatch an image (or, if necessary, do a manual match).

The objectives of the tutorials are to:

1. Teach the basics of doing astrometry, which is the measuring of an object's position and, as a secondary goal, its brightness.
2. Understanding the results and, if necessary, working with the data set to get the best possible answer.
3. Reporting your results to the Minor Planet Center or other institution or person.
4. Practicing the core functions of opening images, setting the configuration, and doing an AutoMatch of an image.

## Never Trust a Computer

Every effort has been made in Canopus to provide the "right" results. However, no program is absolutely perfect and sometimes there is no perfect "right" result. For example, if you're working an asteroid in a crowded field, Canopus may not place the target aperture exactly where it should when measuring the position of the asteroid automatically. Always confirm the results by visual inspection where possible and review the numerical results to make sure they make sense. "Black boxes", no matter how well designed, can provide the wrong results under real-world circumstances.

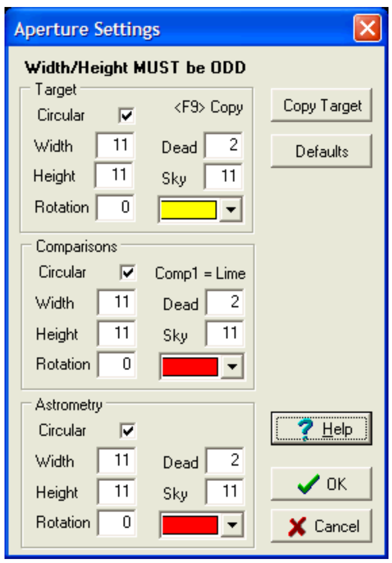
# 1. Measuring an Asteroid - I

The purpose of this tutorial is to measure the position of an asteroid. It is essentially the same as the AutoMatch tutorial (pg. 17). The difference is that you'll use different images.

Be sure to keep Canopus open after running this lesson so that you can move immediately to the subsequent lessons on reviewing and manipulation the results and then to generating a report for the Minor Planet Center.

1. Open the configuration form and duplicate the settings on the next page. If you did the AutoMatch tutorial in the Core Operations section, you would just select the profile that you created for that tutorial from the drop down list but confirm that the settings match all pages.

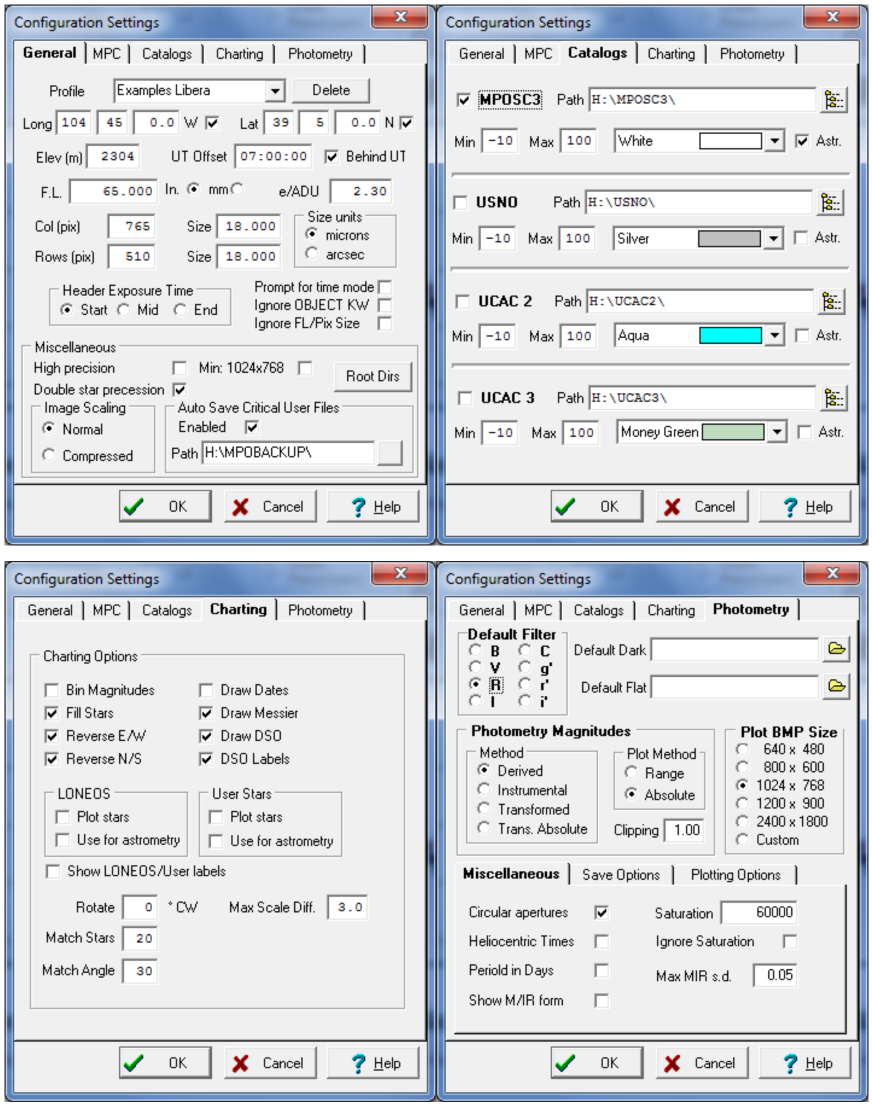
2. If necessary, open the apertures form and set the apertures as shown in the screen shot.

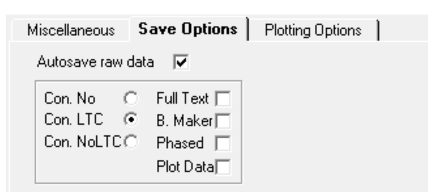



3. Open the image

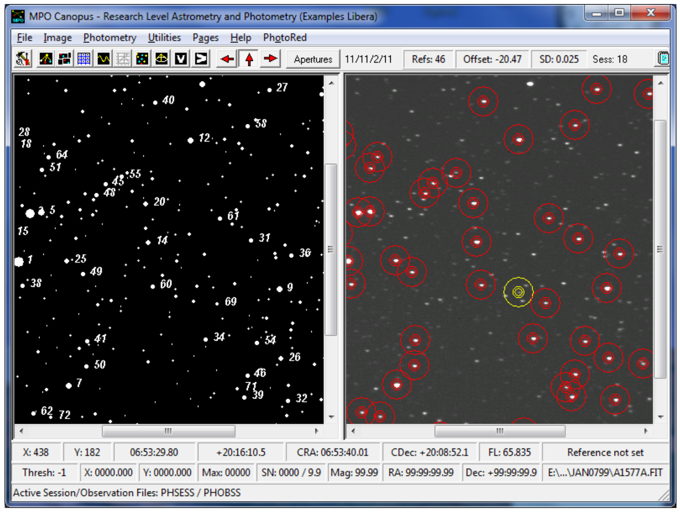
   \MPO\Examples\ASTMTRY\JAN0799\A1577A.FIT

4. Do an AutoMatch (press <Ctrl+A> on the keyboard). You should see something similar to this screen shot.

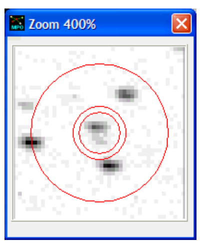



*The bottom screen shot is of the "Save Options" subtab on the "Photometry" tab of the configuration form.*

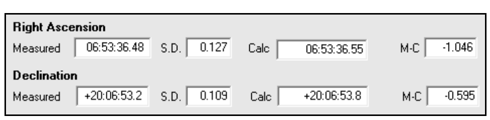



5. If not already, open the Zoom box at 400% and move the mouse cursor over the asteroid (yellow apertures in the screen shot) so that the mouse cursor is centered on the inner aperture (the “measuring” aperture). ***Do not click on the asteroid***.




6. If you look closely, you’ll see that there is a very faint star just below the asteroid. The screen shot of the zoom box shows a highly-processed section of the image. The asteroid is the brighter (darker) of the two objects within the aperture while the star is the smaller (fainter) object.

7. Switch over to the Reductions page (press <Ctrl+3>) and look at the bottom part of the form, where the M-C values are reported.




8. Since the asteroid and star were both within the measuring aperture, the derived position is not that of the asteroid but that of the combined objects. You would not to submit these results as-is, unless you also indicated that the measurement was affected by a field star.

## Cheating the System

In some cases, you can “fix” this problem by manually overriding the measurement.

9. Switch back to the measurements page (<Ctrl+1>).

10. Open the apertures form and change the target aperture settings to use a ***width of 9 pixels and height of 5 pixels***. Click <OK> to save the changes.

*This causes the apertures on the image to disappear. If you don't remember where the asteroid was, do another AutoMatch.*

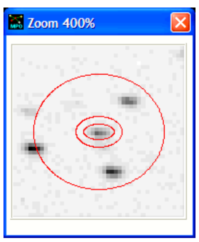
11. Using the zoom box to help locate the mouse cursor, click on the asteroid.

## *Fine-tuning the Mouse Cursor Location*

If you have trouble placing the cursor exactly where you want (e.g., the mouse movement is jerky), click on the image as close as possible where you want the apertures to be for the final measurement.

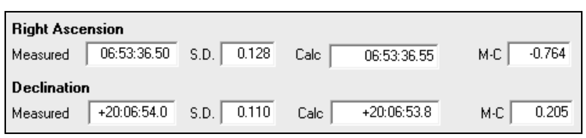
While looking at the zoom box, use the Up/Down/Left/Right keys on the keyboard to move the cursor one pixel per each keystroke.

Once the cursor is where you want it, press <Spacebar>. This is the equivalent of clicking the mouse but means you don't have to touch the mouse to do it and so possibly move the cursor off the desired location.




The screen shot above shows the placement of the elliptical aperture before clicking on the image to get an updated position.

12. After clicking on the asteroid in the image with the new apertures, go back to the Reductions page (<Ctrl+3>) and look at the revised data for the asteroid.




13. Note that the RA and Declination have changed significantly and that the residuals are much smaller.

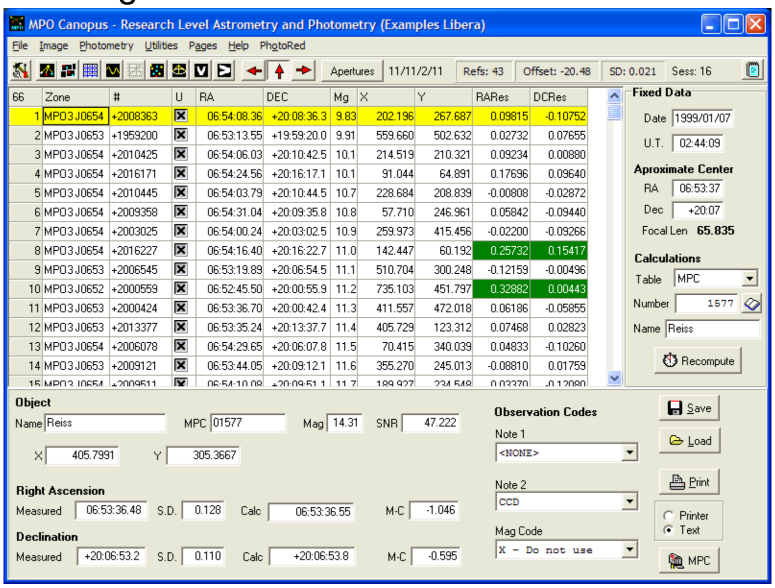
14. ***Before going on, restore the target aperture height and width to 11 pixels each***.

## *Don't Do the Crime if You Can't Do the Time*

We "cheated" in this case by changing the measuring aperture for the target and finding its position again by manually placing the mouse cursor and recording new position data. In reality, there is probably still a small bit of that faint star part of the measurement. It's hard to believe, but the laws of optics dictate that the brightest (not saturated) and faintest stars on an image are the same size, you just can't see the outer parts of the faint stars because they are very close to the sky background level.

Be very careful when trying to cheat the system and understand that by changing the apertures, you also change photometric results, not just astrometric.

# Saving the Results




If you want to generate a report for the MPC or someone else, you must save the results. These include not just the position of the object but all the information on the Reductions page. This allows you to load the file in the future and generate a new report or check the results.

15. If not there, go to the Reductions page (<Ctrl+3>).

16. Assuming that your results from the AutoMatch are still there, click <Save> on that page. This displays a Windows file dialog.

17. By default, the program assigns a file name based on the number or name of the object plus an auto-incremental number. For example, A1577_0001.AST where the leading "A" indicates an asteroid. It's recommended that you change the name to include the date of the observations, e.g., A1577_19990107_0001.AST would show that the observations were made on 1999 January 7.

    The program uses a default path of \MPO\CANOPUS\ASTFILES. You can change this but it's recommend that you keep all astrometry data this directory, which was created when you installed Canopus.

18. Click <Save> on the file dialog to save the file.

19. Proceed immediately to the next tutorial, where you'll measure a second image of the same asteroid and we'll take a more detailed look at the results.

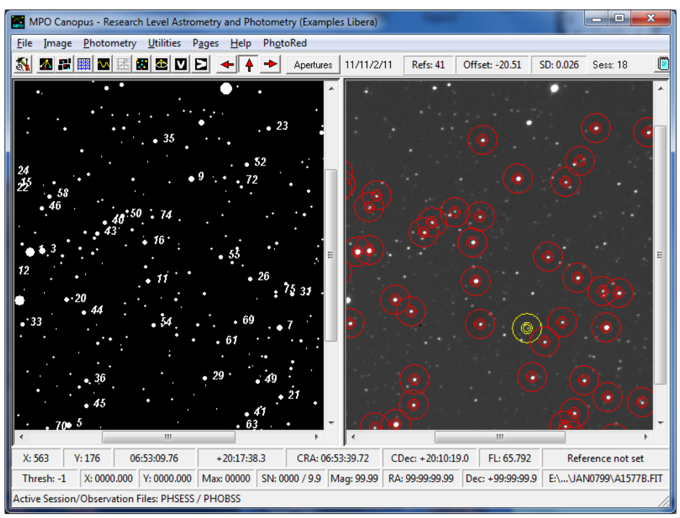
# 2. Measuring an Asteroid – II

The previous tutorial gave us a "statistic of one," meaning that we have one position for an asteroid with specific measured versus computed residuals. What happens if we measure a second image? Do we get the same approximate errors or something completely different? What if we measure two more images taken on a different night and compare the residuals to those from the first night? Most important of all, do we know that the residuals are even remotely correct? The answer to that last question might surprise you.

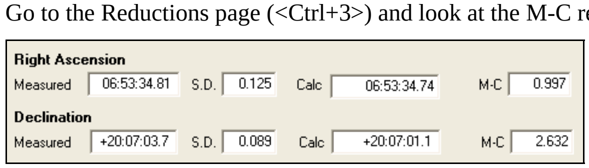
This tutorial will also take a closer look at analyzing the results on the Reductions page, beyond just those for the asteroid, and what they tell you about the overall quality of the solution.

1. Confirm that you are using the same configuration and initial aperture settings that you used at the start of the previous tutorial.
2. Load the following image

   \MPO\Examples\ASTMTRY\JAN0799\A1577B.FIT
3. AutoMatch the image.

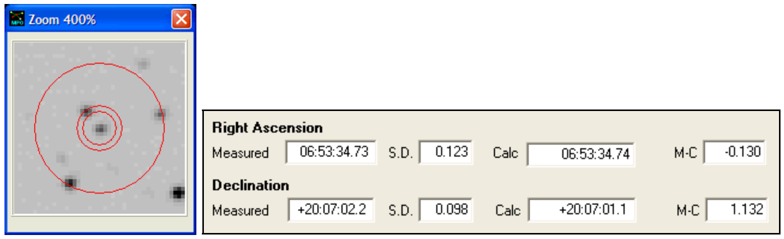



4. If you look carefully, you'll see that the yellow set of apertures, those for the asteroid, are slightly off-center from the asteroid. That's because a nearby star encroached into the aperture and skewed its placement.
5. Go to the Reductions page (<Ctrl+3>) and look at the M-C residuals.



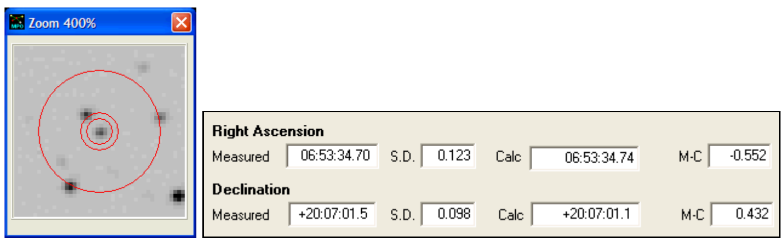

   Note the large M-C value in Declination, no doubt due to including part of that star above the asteroid.
6. We're going to try "cheating" as we did in the previous tutorial. Reset the height and width of the target aperture to 9 pixels. Do not change any other settings.

7. Do an AutoMatch on the image. It is not necessary to reload it first.




8. The star is still just on the edge of the measuring aperture for the target but notice how the M-C residuals have gone down considerably. Also note the significant difference in the measured RA and Declination.

9. You can see that there appears to be plenty of sky around the asteroid with the aperture set to 9x9. So, reset the apertures to 7x7 and do the AutoMatch again.




10. The star is no longer affecting the asteroid and so this is as good as we're going to get. The residuals are much smaller and the position, especially in Declination has changed yet again.

    This is as far as you want to go. As noted earlier, you can't really see the entire stellar profile and so to go smaller might mean cutting off a significant portion of the "wings" of the asteroid's image.

11. Save the results under a unique name. ***Do not overwrite the results from the previous tutorial***.

*Do not close Canopus or do another AutoMatch. You want the current results available for the next tutorial.*

## One More Cheat

Sometimes it's possible to position the target apertures a little off-center of the target so that you keep a field star from interfering with the measurement. The centroiding algorithm in Canopus/PhotoRed can handle this and still generate a reasonably accurate position and brightness (assuming that none of the star is encroaching into the measuring area.

*There's a saying that "It's not cheating if you don't get caught." Cheating is cheating and to quote the famous phrase, "There's no such thing as a free lunch." When you use the off-center technique, be aware that the centroiding algorithm has to work overtime and that you may not really be cutting off the interfering star completely. Both of these can affect the final results to one degree or another. However, sometimes, there is no alternative and so you must accept the "tainted" results or have none at all.*

## About Position Residuals

Before moving to the next lesson, let's compare the M-C residuals from the two lessons. Remember, your numbers may be slightly different.

| Lesson | RA M-C | Dec M-C |
|---|---|---|
| 1 | -0.764 | +0.205 |
| 2 | -0.552 | +0.432 |

What is important here is not so much the actual values but the trend of the values. In this case, both of the residuals in RA are negative and *approximately* 0.5 arcseconds. The Declination values are both positive and are centered on about 0.3 arcseconds. If we had a third image for the night, we would hope to get residuals that are similar, i.e., about -0.5 arcseconds for RA and +0.3 arcseconds for Declination.

The M-C values are affected by many things. For example, you may not have the most recent orbital elements from the Minor Planet Center and so the calculated position is not right. Your longitude and latitude settings may be off, which affects the correction from geocentric positions to topocentric (from the surface of the Earth at your location). This correction can be significant for asteroids very close to Earth.

It's also possible that the times in your FITS header are wrong and so you'll get a larger error along the line of the asteroid's path. If this is the case, then when you submit your report to the Minor Planet Center, no doubt you'll get a return message asking you to check your measurements, including the times.

Again, the important consideration is the trend of the residuals. If a third set showed the RA residual to be +0.5, then that should cause you to recheck the results. If they are the same and you can find no reason for the difference, report the data any way. It is often worse not to report what appears to be strange data than to hold onto it. There are many cases in history where the "unusual" proved to be real and "normal" to be wrong.

### *Proof of Concept*

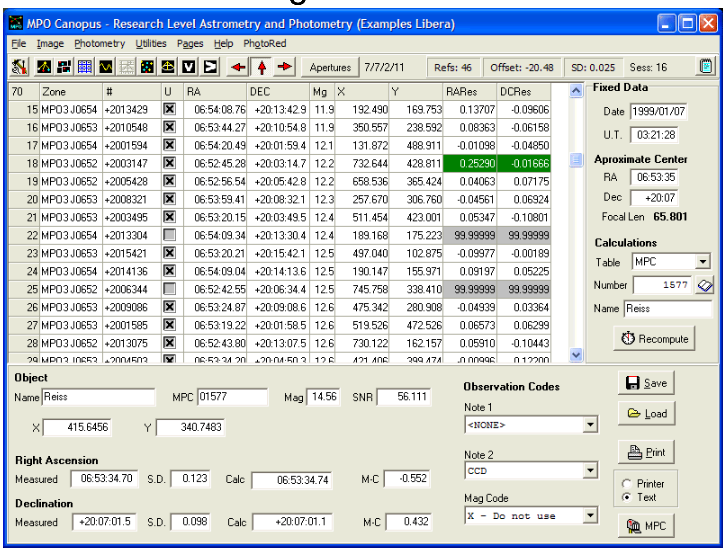
To explore these concepts, repeat the two tutorials using images of the same asteroid from a second night. These are found in

\MPO\Examples\ASTMTRY\JAN0899

Try using apertures of 11x11 to start. If necessary, use the techniques described above to reduce the interference from any field stars.

Save your results and compare them to those from this and the previous lessons. What do you find? If the trends are not similar, check for faint field stars.

# 3. Measuring an Asteroid – III




This lesson covers aspects of the Reductions page not covered in detail in the previous two tutorials, most important, how to improve the astrometric solution.

*To restate what was mentioned in the introduction of the Users Guide, your results may vary some from what you see in this lesson. Do not get hung up on the fact that the numbers are not exactly the same. The point here is how to interpret and manipulate the results to get the best possible solution. Naturally, if your results are significantly different, you should double check your steps to make sure that you have followed along as expected.*

1. Assuming that you still have the results from the previous tutorial, or that rerun it, go to the Reductions page (<Ctrl+3>)

2. Note the number in the upper-left corner of the table. This is the number of stars used in the astrometric solution. Canopus limits the number to 75. This is *more than enough* to get a good solution. Keep an eye on this number throughout the tutorial.

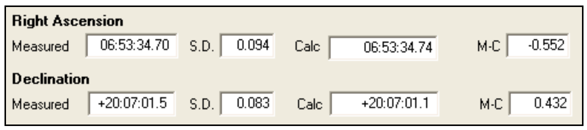
3. If you scroll down the table, you may see one or more rows where the RARes and/or DCRes cells have green, blue, or red backgrounds. These indicate that the RA and Declination for the star that is found from the astrometric solution differs a significant amount from the catalog RA and Declination.

   Green difference of 0.25 < x < 0.5 arcseconds.
   Blue difference of 0.5 < x < 0.75 arcseconds.
   Red difference of x > 0.75 arcseconds.

4. If you see a row with colored cells, click on the cell in the "U" (used) column so that the "X" goes away. As you do, keep an eye on the Measured position, the S.D. (standard deviation of backfit residuals), and M-C values. Usually, you'll see very little change in these values. Those of primary concern are the S.D. values. The lower these values, the "better" the astrometric solution. As mentioned in the previous tutorial, the trend of the M-C values and not their actual values should be taken as a whole over several images.

5. Note that the number of stars in the upper-left corner has changed as have the RARes and DCRes values. The latter two are now 99.99999, indicating that the star is not part of the calculations. If you move off the row, you'll see that these cells have a gray background, providing another visual cue about the star's status.

6. Locate other rows that have colored cells and remove those stars from the calculations and compare the S.D. values to what they were when you started.




These are the results found running this tutorial. Note that the M-C values are the same as those at the end of the previous tutorial. However, the S.D. values have gone down by about 0.04 arcseconds in RA and Declination. That's not a significant difference, but it shows how removing a few "bad" objects affects the overall solution. The number of stars in the final solution, that number in the upper-left corner of the table, is 56, meaning 9 stars were removed from the initial solution.

## Hitting a Moving Target

As you eliminated stars from the solution, you may have noticed that another star, one that was good – no colored cells, suddenly became "bad." The solution is highly-dependent on every data point and so adding or removing one affects the residuals of all the others.

When Canopus first does the astrometric solution, it goes through a process much like you just did but going only so far. At the worst, it stops when there are only 8 stars left in the solution.

## Other Things

The Reference Manual covers the rest of this page in more detail. For the moment, note the three drop down lists under "Observation Codes." Usually, you should not change these, most important of all, "Note 2" which is set to "CCD" and so indicates the observations were made from CCD images.

If you cannot completely eliminate a field star from the observation, you can use the "Note 1" drop down list and select 'I' – involved with star.

The "Mag Code" defaults to "Do not use", meaning the derived magnitude that is reported in the "Mag" field on the page is not included. However, if you use the MPOSC3 or UCAC catalogs as the source for magnitudes, it may be appropriate to set this field to the photometric band defined by "Configuration | Photometry | Default Filter".

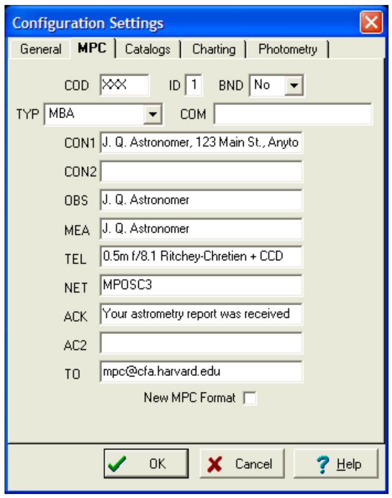
*If you didn't already, be sure to save the final results (see the previous tutorials in this section).*

# 4. Generating an MPC Report

The ultimate goal of doing the previous lessons is to generate a report for the Minor Planet Center and then submit it.

*Do NOT submit the results from these tutorials to the Minor Planet Center.*

1. Open the Configuration form and go to the MPC tab.




2. Change the selection in the TYP drop down list to MBA.

   The Reference Manual explains this page in more detail. You should also review the Minor Planet Center's rules for data submission. In many cases, they prefer that you do NOT specify the type of object, using "unidentified." They will do the linking of the positions to known orbits, if any.

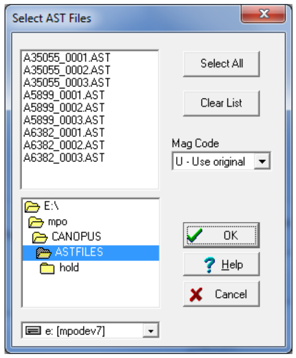
   An exception may be when *every* object in the report is of a particular type, usually main belt (MBA) or a near-Earth Object (NEO). There are two NEO entries in the list. The "NEOP" option is for objects listed on the NEOCP (NEO Confirmation Page) of the Centers web site.

*The settings in the screen shot above (except the TYP field) are the defaults immediately after installation. Before you actually submit a report to the Minor Planet Center, be sure to enter correct values in all the fields on this tab and save them.*

3. Assuming that you saved the results from the previous tutorials, go to the Reductions page (<Ctrl+3>).
4. Click <MPC>. This displays a Windows file dialog where you give the name for the report (text) file. All such files are forced to use the extension "TXT".
5. Enter a name for the file.

*The default directory for the files is \MPO\CANOPUS\EMF. It is recommended that you keep all files in this directory.*

6. Click <Save> on the file dialog. This displays a custom file selection form.

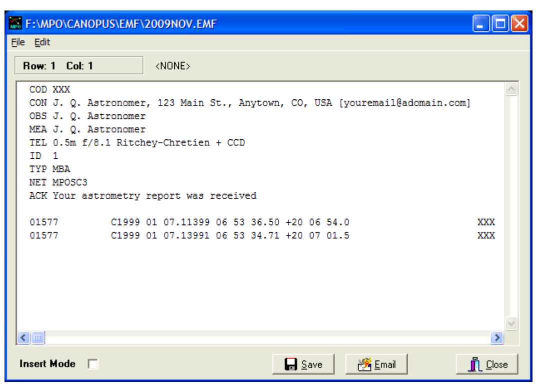



This form is filtered for AST files, which are created when you save the results on the Reductions page. This is a typical Windows multi-select form where you can select one or more files, contiguous or non-contiguous within the list.

*Note the dropdown list box "Mag Code". This allows you to force using magnitudes in the MPC report with a specific band, not using magnitudes at all, or having each file determine how its magnitude data are written. Generally, you'll select "U – use original" on the presumption that you saved the original file with the magnitude and band setting that you wanted to be used for that data.*

7. Select the files that will be used to generate the MPC report. In this case, select the files you created as part of the tutorials in this section and then click <OK>. This presents the MPC Report form.

*If you have TYP on the configuration form (see Step 1) set to "Unidentified", a small form appears after you click <OK> in Step 7 asking for additional information. See the Reference Manual*




8. The form contains a memo (text) control that you can change if necessary. The control comes up in "overwrite" mode so that you do not change the columns in which each data field in the report lines starts.

*Be very careful when editing this report. You **must** keep data in their correct columns.*

9. The file automatically saved automatically as the form appeared. If you make changes, then click <Save>.

10. Click <Email> to invoke your default email program and start a new message. The “To” address is automatically set to the “To” email setting on the “Configuration | MPC” tab.
11. Attach the just created file and send the message to the MPC.

# Photometry in Canopus

The primary goal of photometry in Canopus is to measure asteroid (or variable star) magnitudes in dozens if not hundreds of images and then to determine the period and amplitude of the lightcurve. The process can be broken in to two steps.

- Measure the series of images
- Find the lightcurve characteristics (period and amplitude)

At first, the number of steps and detail required might seem daunting but, again, accurate photometry is neither simple nor simply done. Go through each step carefully, refer to the Reference Manual if you have questions about "why", and before long the hard part will be waiting to get the next series of images and not the processing of measuring them.

Once again, it's important that you follow the steps below in order. You can't measure images before you tell Canopus how to determine magnitudes and you can't determine a lightcurve until you measure images.

There are other goals within the photometry features, for example, finding the color index of an object or finding the transforms for your system for all-sky photometry or higher-precision/accuracy work. These will be covered as well.

## A Matter of Magnitudes

Canopus always records the "instrumental" magnitude of a comparison or target. This is computed directly from the sum of the ADU counts for the object and then normalized to a 1-second exposure. This means that even images with different exposure times can be directly compared among one another, assuming the same system was used.

*The instrumental magnitude is independent of any catalog used. It is strictly a function of the system that took the image.*

Canopus can also record a true magnitude (*TrueMag* from here on). This is based on a solution using the measured instrumental magnitude versus the catalog magnitude for up to 75 images in the star. For each star, the difference between instrumental magnitude and catalog magnitude is computed (m-M). The mean and standard deviation of these results comprise what is called the Magnitude/Intensity Relationship (*M/IR* from here on). If you think about it for a moment, in a perfect world, the instrumental magnitude should vary in direct proportion to catalog magnitudes, e.g., a star that is one magnitude brighter in a catalog should have an instrumental magnitude that is also one magnitude brighter. Of course, this is not the case.

Errors in the catalog values, measurement of the instrumental magnitudes, and differences in the color of the stars used in the data set contribute to some degree of uncertainty. These are all wrapped up into the standard deviation of the mean of the m-M differences, or at least to a first order approximation. These are only the "internal" factors. External conditions such as variable observing conditions mean that the solution for one image may not be the same as for another image, e.g., if a slight haze moves in, the instrumental magnitudes are all fainter, and so the "offset" (m-M) is different.

The MPOSC3 catalog provided with MPO software includes a large subset of the Carlsberg Meridian Catalog (CMC-14) as well as from the Sloan Digital Sky Survey (SDSS). More specifically, the catalogs strongly favor stars that about the same color as the Sun. These magnitudes are mostly SDSS r' with some g' and i' when available. Almost all stars in MPOSC3 also have BVRI magnitudes derived from 2MASS J-K magnitudes (see

Warner, 2007; *Minor Planet Bulletin* **34**, 113-119). These have an internal consistency of ~0.05 mag for V and 0.03 mag for R. Many tests have been run using the magnitudes from the MPOSC3 catalog, mostly to link data sets from many nights. Generally, individual sessions "fall into line" to within 0.02 mag when using a calibration method involving the Comparison Star Selector and instrumental magnitudes.

*"Catalog-based" magnitudes are those referenced to the magnitudes within a given catalog (or standard photometric system). This term is used instead of "absolute" to avoid confusion with the standard definition of "absolute magnitude", which is the brightness of an object (usually a star or galaxy) when it is 10 parsecs from Earth.*

## How Does Canopus Work?

There are three basic approaches in Canopus. Two involve differential photometry.

### *Differential Photometry*

This is where the difference between a target and comparison (or average of several comparisons) is found for each image. It is this differential value that is used in analysis.

Since, in most cases, any variations caused by external factors are the same across the entire image, this approach nullifies those factors. What remain are the internal factors, the differences in color between the object and comparison stars usually dominating things.

*You must take care not to use stars that are beyond the linear response of the camera, let alone that are saturated – even if it's only one pixel out of dozens.*

### *Instrumental Photometry*

For MPO software, this will mean that instrumental magnitudes are used for *differential photometry and that no offset is applied to put the differential values on a standard system*. These will be called *Instrumental* in this Guide.

### *Catalog-based Photometry*

This approach uses the M/IR to compute the magnitude of the target directly and ignores the comparisons altogether. If the M/IR is computed image by image, then this reduces but does not eliminate external factors. Under good conditions, this approach produces good catalog-based magnitudes. However, one cannot be sure if "good conditions" prevailed throughout a session. These will be called *TrueMags* in this Guide.

### *A Hybrid Approach (Derived Magnitudes)*

Another approach, one that Canopus can use and is ***strongly*** recommended is a hybrid of the two methods. It's one that's long been used by the AAVSO for submitting CCD observations. Here, Canopus finds the instrumental magnitude difference between the target and comparison ($m_t$ – $m_c$) and then adds the catalog magnitude of the comparison ($M_c$). The result is a catalog-based magnitude for the target. If multiple comparisons are used, then there are multiple values for the target. The mean of those values and standard deviation of that mean are used for the final value for the target. These values will be called *DerivedMags* in this Guide.

That standard deviation incorporates the uncertainty in the measurement of the target and each comparison, the uncertainty in the catalog value, the uncertainty in the correction for color differences (if used), and so on. It is not a perfect predictor of the error budget, but it is better than much simpler methods.

*The DerivedMags method is the recommended approach for almost all measuring for time-series photometry. It gives catalog-based values while retaining the (considerable) virtues of differential photometry using instrumental magnitudes.*

## Selecting the Analysis Method in the Configuration

When you want to use simple differential instrumental magnitude values (*Instrumental*), you will select “Configuration | Photometry magnitudes | Method | Instrumental”.

If you want to use *DerivedMags*, select the “Derived” method

If you want to use the “pure M/IR” magnitudes (*TrueMags*) that ignore the comparison star set entirely, select “Transformed”.

*All three of these methods will include corrections for changing geometry and/or phase (if appropriate) when doing period analysis. These corrections are mandatory in order to do proper analysis. The “Transformed Absolute” method does not include these corrections.*

## A Step Beyond: Applying Transforms On-the-fly

When using instrumental magnitudes in the process, either the *Instrumental* or *DerivedMags* methods, Canopus allows you to apply corrections to the differential magnitudes as they are computed for use in the analysis engine. This same approach is used in the AAVSO Batch Processing routines in PhotoRed. This produces *Transformed data*.

Before you select any option that would produce *transformed data*, you *must* find the transforms for your system using PhotoRed. This involves taking images in two filters, usually B and V or V and R, of a standard reference field so that PhotoRed can determine the corrections needed to convert an instrumental magnitude difference to one on a standard system.

Those transforms rely on catalog magnitudes, i.e., standard magnitudes such a B and V or V and R, and not instrumental magnitudes. For example, the transform for the R filter might be

$$R = m_o + T_r(V-R) + Z_o$$

| | | |
|---|---|---|
| Where | $m_o$ | instrumental magnitude of star (usually corrected for air mass) |
| | $T_r$ | system transform for R filter |
| | V-R | color index; the difference between the V and R standard magnitudes |
| | $Z_o$ | Nightly zero point offset |

*When using the Comp Star Selector (covered in the tutorials), Canopus can transfer the B-V or V-R color indices of the comparisons from the MPOSC3, making them available for applying transforms on-the-fly. As for the target, that is taken from the current PhotoRed transforms data. This is covered in more detail in the tutorials on finding a lightcurve.*

## *The Differentials*

Let's go a step further and look at the internal workings of Canopus when computing the instrumental magnitude difference between the target and a comparison star. A subscript of "t" indicates the target and one of "c" indicates the comparison. The "o" subscripts in the formula above are presumed. CI represents the chosen *catalog* color index, e.g., V-R, for the target or comparison.

$$\Delta m = (m_t - m_c) + T_r(CI_t - CI_c) + (Z_t - Z_c)$$

Obviously, the Z values are identical on a given night and so that differential is 0 and drops out. This leaves only the difference in the instrumental magnitudes plus the correction for the difference in the color indices of the target and comparison which, as noted above, can be transferred into the current session when using the Comp Star Selector. The net result is that Canopus computes the catalog color index differential and applies it to the difference in instrumental magnitudes to derive a *transformed differential magnitude*.

Don't let this confuse you too much. The tutorials will demonstrate these principles. What's important to understand is that by taking the time to find the transforms for your system (if you have the necessary filters), you can increase the accuracy of your results and, within some limits, have a little more flexibility when choosing comparison stars by not having to keep them as close to the same color (same color index) as the target.

## Deprecated Methods

The "Transformed" and "Transformed Absolute" methods have been retained in the current version of Canopus but should be considered "deprecated", meaning that they are no longer recommended and used very infrequently. The main reason for retaining them is to work with data that has been converted to standard magnitudes in PhotoRed and then imported back into Canopus. In those cases, you do not want to make further use of the comparison star set since that was done in the PhotoRed processing.

As mentioned above, you should use the "Transformed" method if working with the *TrueMags* found during AutoMatch (see below).

➪ *Applying transforms on-the-fly is almost identical to the process in PhotoRed, thus saving you the effort of moving your data into PhotoRed, transforming it, and the exporting for use in Canopus. The main difference is that you are relying on the catalog color index (e.g., V-R) in Canopus instead of finding it directly. Keep in mind that the catalog magnitudes in the MPOSC3 are derived from empirical formulae based on the 2MASS J-K magnitudes and can have significant errors, which will migrate into your results. When the AAVSO APASS catalog is available (and supported by MPO software), the catalog values will be internally consistent to 0.02 mag or so, thus removing a significant source of error in the transformation of data.*

## AutoMatch while Measuring

If you want to use or at least have reasonable M/IR magnitudes for every image, you must use the AutoMatch option when measuring images (this is covered in the tutorials). Doing this takes much longer since the stars from each image must be extracted and matched to a chart from the catalog of the same field of view, assuming that the images can be AutoMatched at all.

➪ *Remember, instrumental magnitudes are* **always** *measured.*

The advantage to this approach is if the tracking isn't very good or you deliberately dithered around the target. In this case, Canopus may not be able to find the set of comparisons and target. The AutoMatch routine "knows" the RA and Declination of what's called the *anchor star* (see the first tutorial in this chapter). After an AutoMatch, it can find that star and, using that as the reference point, the remaining comparisons and target.

### *To Match or not to Match*

If you need to get images measured in a hurry, do not use the AutoMatch feature. If you will have to reset the comparison star locations on a large number of images or you want to "walk away" so that you can get breakfast before dashing off to work while Canopus measures images, then use the AutoMatch feature.

➪ *Remember: you do not have to use the resulting catalog magnitudes for the target for analysis. Since the instrumental magnitudes are measured regardless, you can use the Instrumental or DerivedMags methods. The main (really, only) reason for the AutoMatch processing is to let you do other things on a different computer or away from the processing computer while Canopus is measuring images. You should not try to do things on the processing computer during auto-processing since the program is constantly trying to "get focus."*

## The Comp Star Selector (CSS)

The Comp Star Selector (CSS) was introduced in later versions of 9.5. This feature allows you chose comp stars when doing differential photometry that are similar in color to the target. This improves the overall quality of the measurements since the comparisons and target will be affected about the same by changing extinction (remember that blue stars "fade faster" than red stars as the field gets closer to the horizon).

### Make it a Habit

You should ***always*** use the Comp Star Selector. The most important reason is that it records the catalog magnitudes of the comparison stars and can transfer those into Canopus so that they become available for using *DerivedMags* approach. If doing *Instrumental* analysis, the average of the comparison star catalog magnitudes can be used to set the nightly zero point for each set of data. Linking sessions via this approach has been quite successful in work on very long period asteroids.

Finally, while you may *hope* to use *TrueMags*, those many external factors mentioned earlier may come into play such that non-differential photometry produces very poor results. With the *DerivedMags* approach, you still get catalog-based magnitudes that are much more reliable and stable.

➪ ***The benefits of the CSS are many while the time to set it up it is minimal. Use it!***

## The Concept of Sessions

Probably the most confusing concept to first-time Canopus users is that of a *session*. Simply put, a *session* is a set of observations taken of the same object on the same date using the same filter and the same comparison stars. For a variable star or slow-moving asteroid, you will usually have one session for a given night (unless you shoot the target in multiple filters). If you're working a fast-moving asteroid such that you have to change the field of view once or many times over a single night (and so define a new set of comparison stars for each field), then you will have a separate session for each field (set of comparisons).

Why have separate sessions? It's to account working the general case of a moving target (I think of variable stars as a special case where the object is not moving – which can be approximately true for an asteroid near one of its stationary points). In the general case, you're not assured of using the same comparison stars each night, sometimes over the course of single night. Since the target magnitude on each image is based on the comparison star set one way or another, any shift in the comp star set average value affects the target magnitudes throughout out the session. Even if you are using the same comparison star set, many factors – including just bad luck (aka "Murphy") – can mean a slight shift in the data from session to session. This is called *zero point shift*.

By having separate sessions, you can set the zero point for each session separately and so account for minor variations in the zero point over the duration of the observations.

➪ *When using the* DerivedMags *method with SDSS magnitudes, especially if applying color corrections, it is rare to have to apply any correction to the zero points. If so, it's on the order of 0.01-0.02 mag. When using the 2MASS to BVRI values, the shifts are usually on the order of < 0.05 mag, though 0.1 mag is not impossible. This demonstrates the importance of using "native" catalog magnitudes that have a good internal consistency.*

The second important reason behind sessions is the most critical when working asteroids. All other things being equal, an asteroid changes brightness as its distances from the Sun and Earth change. Canopus can correct for these changes so that all magnitudes are based on the notion that the average magnitude of the asteroid is always the same, no matter how much it fades or brightens due to changing distance.

Asteroids also change brightness with changing phase angle, which is the apparent separation of the Earth and Sun as seen from the asteroid. For example, when the asteroid is at opposition and the Earth and Sun are in a line with the Earth on the asteroid side of the Sun, the phase angle is 0°. There is a very distinct change in rate of change of the magnitude as the asteroid phase angle is near opposition (the *opposition effect*). This is most pronounced with phase angles less than about 7°. The relationship is complex and calculated using the *H* (absolute magnitude) and *G* (phase slope parameter) values that you find the Minor Planet Center's MPCORB file (or Lowell Observatory's ASTORB, among others). Canopus computes the correction due to changing phase and adjusts the object's magnitude accordingly. You can even use a custom value for *G* should it be determined by measurements or to test the affect of different values on period analysis.

As you might have guessed by now, the phase correction varies constantly and so a new value is needed for each session. The issue is even more complex than what's been explained before. See the Reference Manual for additional information.

A third reason, related more to processing observations than making them, is that separate sessions are needed for observations in different filters for proper processing in PhotoRed. Such processing will be covered in later tutorials.

Just remember: "one object on one night using one filter and one set of comparison stars equals 1 session" and you'll be on your way to understanding sessions and why they are necessary.

➪ *The concept of sessions still holds even if using DerivedMags or TrueMags. The corrections for changing distance and phase must still be included in order to do period analysis. What you don't have to worry about is the different values for the comparison star set average. Even so, you may still have to "tweak" the zero point a little because of the inherent errors in the catalog magnitudes for the comparisons, among other things.*

# 1. A First Lightcurve

This tutorial will take you through finding the lightcurve of an asteroid on a single night. At times, you'll have several forms open at once. Position them the best you can so that you can see as much of each one as possible.

Remember that *DerivedMags* is the recommended method for analyzing data. This tutorial will generate the necessary data to use that method or instrumental magnitudes (both still taking advantage of differential photometry). AutoMatch will not be used here so that you get data as quickly as possible. When working the second night of data for this asteroid, AutoMatch will be used, first to demonstrate its use and, second, because the field of view jumped around considerably that night and you'd be resetting the location of comparison star apertures a number of times. In the end, it would still take less time to work without AutoMatch but the "frustration factor" and being able to have the measurements take place unattended after they are started are both worth considering.

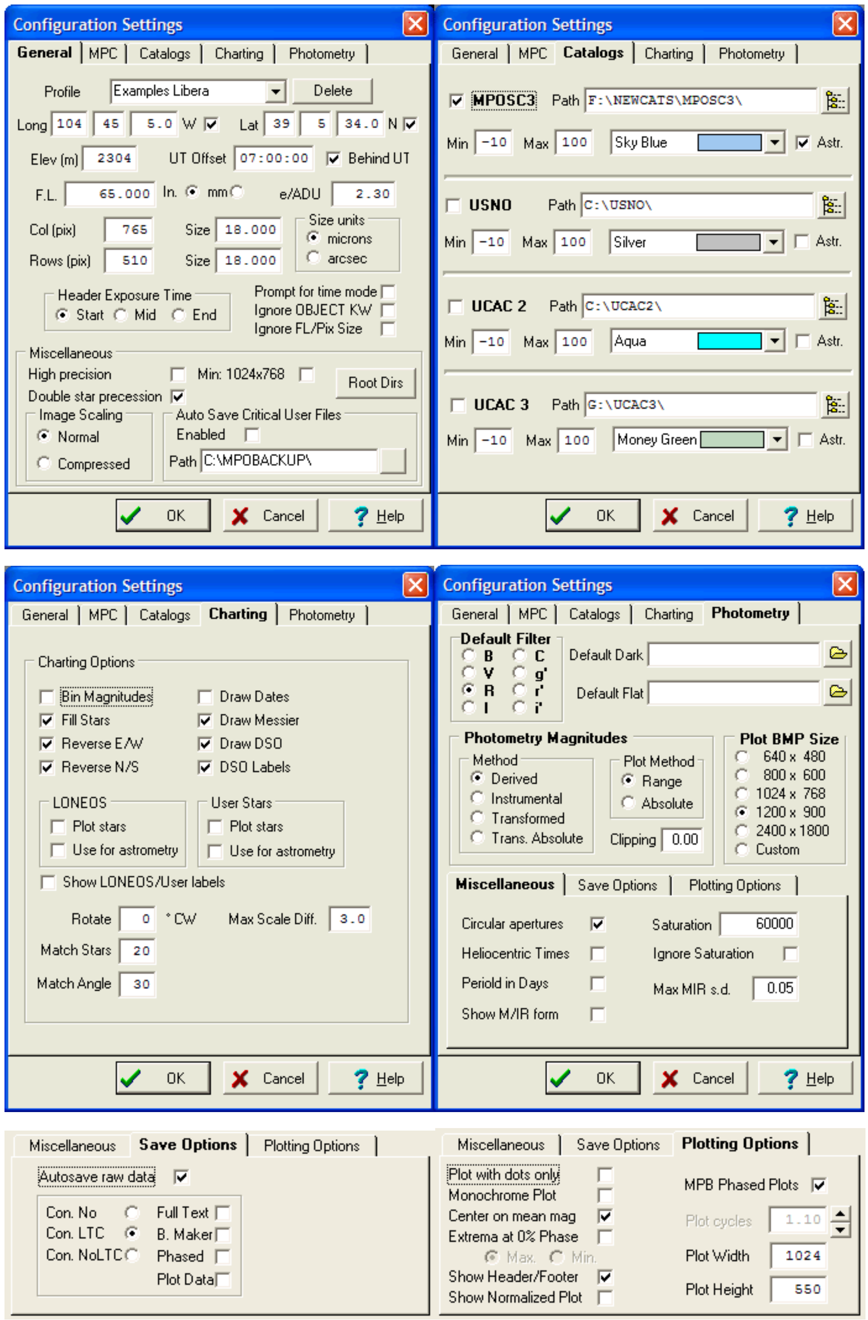
## *The Prime Example*

This tutorial goes into more detail than some that follow, featuring more screen shots and descriptive text (however, don't expect a literal blow-by-blow account). It also forms the foundation for following tutorials that eventually lead to finding the rotation period of the asteroid.

For these reasons, work through it carefully and make sure you understand the fundamentals of using the lightcurve wizard, Comp Star Selector, and StarBGone. Following tutorials assume that you worked through this one and have sound footing in those fundamentals.

*There are several options when measuring images that affect what data are available for analysis. With such flexibility comes complexity. Take your time and try to understand the "why" and much as the "what" that are covered in this and following tutorials.*

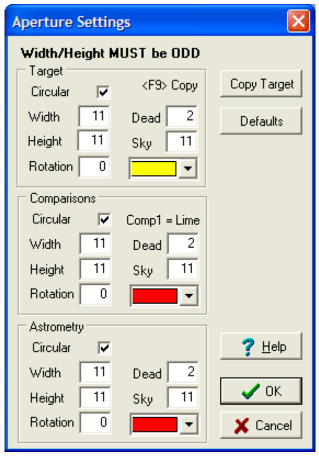
1. Open the configuration form and match the settings on the screen shots (the profile name can be different if you want).




Note this last screen shot is of the "subtab" on the Photometry tab of the configuration form. This subtab includes options that control the plotting of the data when analyzing a lightcurve.

Note also that "Plot Method | Range" is selected. Many publications prefer that the magnitude scale be given as range, i.e., plus or minus form an average value, instead of catalog-based magnitudes. The choice is yours.

2. Set the apertures to use 11x11 for target, comparisons, and astrometry.




3. Open the first image for the first night for 771 Libera from the Examples folder, \MPO\Examples\LTCURVES\A771\SEP18\A77A001.FIT

*In general, the image you open just before creating a session and running the light-curve wizard* ***must*** *be the first image that you will use in the lightcurve wizard. The image does not have to be the first image that will eventually measure. This is explained in more detail later in this tutorial.*

*There is another important consideration for the first image. It should be of higher quality (good guiding, no clouds, etc). This is particularly important if you will be using the star subtraction feature (StarBGone) since you need to be able to see and select all potential subtraction stars.*

4. AutoMatch the image (<Ctrl+A>)

   If you get an AutoMatch (you should), display only the image by manually moving the splitter bar to the left, using the left-pointing red arrow on the toolbar (to the left of the "Apertures" button, or pressing <Ctrl+Alt+I>.

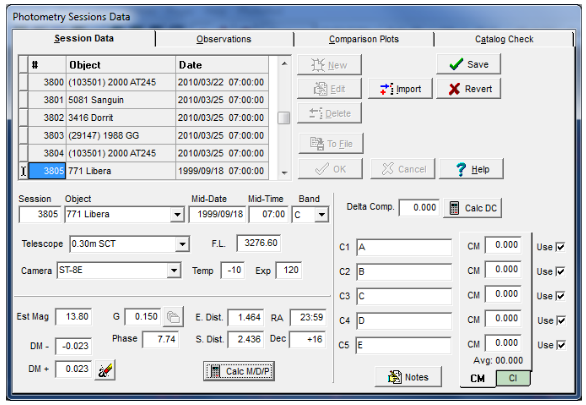
   <Ctrl+Alt+S> positions the splitter evenly between the image and chart.

   <Ctrl+Alt+C> moves the splitter so that only the chart is seen on the Measurements page.

***You should always AutoMatch the first image to be measured just before creating a session.*** *The plate constants are used to find the asteroid on the images opened in the Lightcurve Wizard (see below) and allow using the Comp Star Selector. It also allows data about the M/IR to be transferred to the sessions* Notes *field.*

5. Open the Zoom window to 300 or 400% (<Ctrl+Shift+3> or <Ctrl+Shift+4>)

6. Open the Photometry Sessions form (<Ctrl+Shift+S>) or "Photometry | Sessions" from the main menu.




Reference the screen shot above for the following steps.

7. Click <New> to the right of the table to create a new session.

8. Enter “771 Libera” (remember, without the quotes) in the Object field. The drop down list contains up to the last ten objects worked, but you can also type in the name of a new object.

*It is very important that you use the exact same name for a given object for all sessions. Canopus groups sessions by name. The grouping is not case-sensitive (so Fred and FRED will be in the same group) but it is sensitive to any other differences.*

9. The Mid-Date should already be set to 1999/09/17. This was taken from the FITS header. Unfortunately, the header was not written in UT and so the date is off by one day.

   ***Change the date to 1999/09/18.***

*Generally, all date fields in Canopus use ANSI format, yyyymmdd (year, month, date), always with four-digit years. Time fields always use 24-hour format, e.g., 13:05 and not 1:05 PM.*

10. The Mid-Time field indicates the *approximate* middle UT of the observations to be made. Don’t get caught up on having this value exactly the middle. Somewhere close is “good enough.”

    This field defaults to 07:00 UT, which is reasonable for data taken in the continental U.S. and good for this tutorial.

11. Enter information in the “Telescope” and “Camera” fields (or use the drop down list if there are previous entries).

12. The F.L. (focal length) can be given in millimeters or inches. This is an informational field and is not used elsewhere.

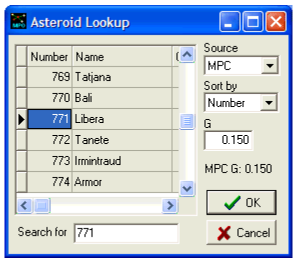
13. The Temp is the CCD operating temperate (in °C). This is an informational field and not used elsewhere.

14. The Exp is the exposure in seconds. If available, Canopus takes this from the FITS header of the image that is open when the sessions form is opened.

15. Select the C filter in the drop down list.

*If you are going to apply transforms on-the-fly, be sure to select the filter that was used to take the images and that you have good transforms for that filter. Canopus reads this field to determine which transforms from the PhotoRed transforms data to use.*

16. Click <Calc M/D/P>. This displays a form where you pick the asteroid being measured.




*If you're not working an asteroid, you should still enter the RA and Dec values. See below.*

17. Locate the asteroid in question by scrolling down the table or using the search controls on the right side and bottom of the form.

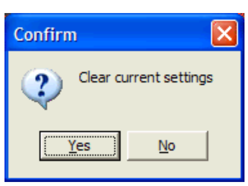
18. Once the asteroid is highlighted, click <OK>. This automatically enters data in the fields within the same area as <Calc M/D/P>. The values in these fields are used to correct for changing distances and phase angle, light-time travel, and to compute the air mass of the field on-the-fly since the AIRMASS FITS keyword is not assumed to be available. See the Reference Manual for additional information.

19. If you used the Asteroid Lookup form or are working a variable star, check the entries in the RA and Dec fields. This is the approximate RA and Declination of the center of the field being worked. The data are used to compute air mass and, for a variable star, the heliocentric JD. See the Reference Manual.

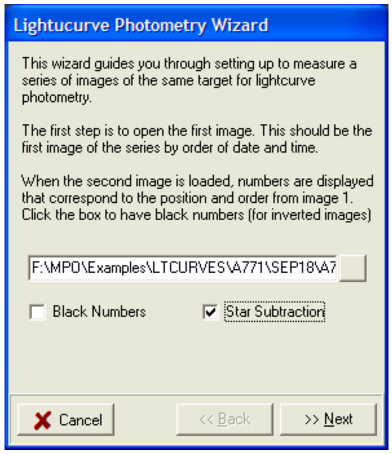
20. Click <Save> to save the changes.

21. Click <OK> to close the sessions form and make the newly created session the *default session*. The default session is the one to which any new data are added or in which existing observations are edited.

22. Open the Canopus Lightcurve Wizard (<Ctrl+Shift+W>) or "Photometry | Lightcurve wizard" from the main menu. This displays a dialog which is a "It's 2 AM and the operator may doing something that he really doesn't want to do" warning.




23. Click <Yes>. This displays the first page of the Lightcurve Photometry Wizard (called "the wizard" or "lightcurve wizard" for the rest of the Canopus photometry tutorials).

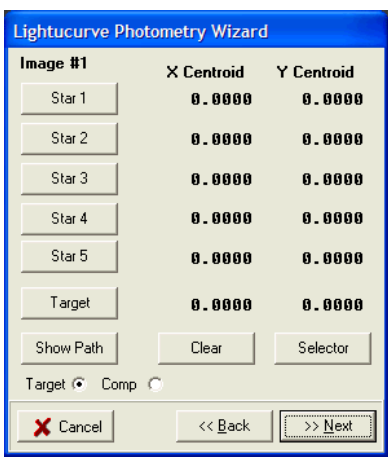



The wizard has several pages, some of which have entry controls, informational text, or both. You maneuver through the wizard by using the “Back” and “Next” buttons.

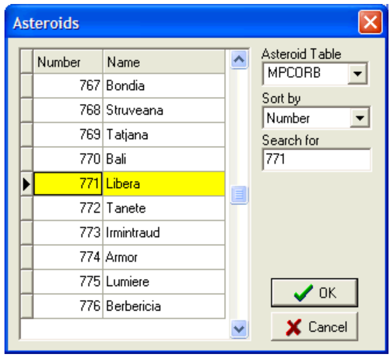
24. Even thought it is already open, click the button next to the top entry field and load \MPO\Examples\LTCURVES\A771\SEP18\A771A001.FIT.

25. Check the “Star Subtraction” box. Make a habit of doing this if working a moving target. In the end, the target may not go near any field stars and so star subtraction is not needed. It’s easy to change your mind after you know for certain that you won’t need to use star subtraction (This feature is called “StarBGone” in the Reference Manual; be sure to read that section).

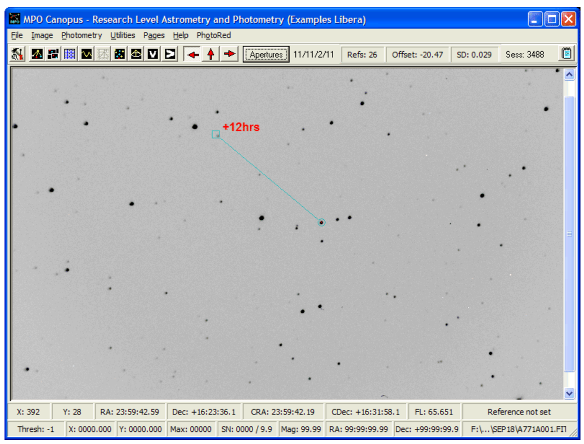
26. Click <Next> to see a page of informational text. Click <Next> again to get to the page where you define the comparison stars on the first image.




27. Click <Show Path>. This displays a form similar to the one used in the Sessions form to pick an asteroid.




28. Locate 771 Libera in the table and click <OK>.

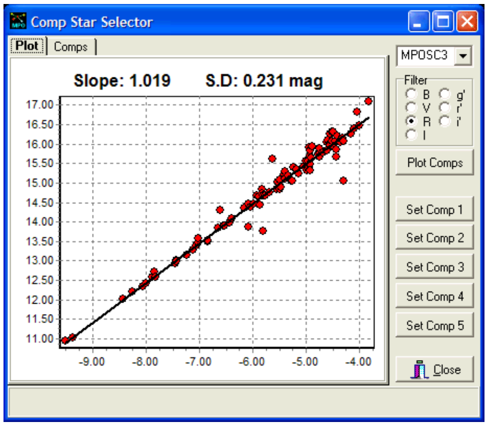



29. You should see something similar to above, i.e., a small circle around the asteroid and a line off in one direction. At the end of the line is the length of the line, in hours of asteroid motion.

*Make a habit of using the Show Path feature. It's most important use is picking the comparison star set on the first image so that you won't pick comparisons that are too close to the asteroid's path. Also, you cannot show the path on the second image unless you've activated it on the first image. You must have done an AutoMatch on the image being used for Image 1 for the Show Path feature to work.*

30. Click on the asteroid, the "star" at the end of the line, surrounded by a small circle, and away from the "+12hrs" label.
31. Click <Target> on the wizard form.
32. Click <Selector> the wizard. This displays the Comp Star Selector (CSS from here on).

Reference the screen shot below for the next few steps.




33. Select "MPOSC3" in the drop down list and "R" in filter.

## *Applying Transforms On-the-Fly*

If you're going to apply transforms to the data, you must select the standard filter for which the transform was computed. For example, if you're using an R filter, you almost certainly found the transform to convert R instrumental magnitudes to R standard magnitudes and, most likely, based it on the V-R color index. In this case, you must select the R filter.

If you're working with images taken with a Clear or no filter at all, you'll see that there is no C option in the group of filters. In this case, you must select the standard magnitudes for which you found the transform for the Clear (no) filter. This is usually V. However, you may have found the transform to convert Clear to R. In this case, you must select R.

*If you are you're going to use TrueMags and the "Transformed" method, then it's very important that you select the same filter as the "Default Filter" on the "Configuration | Photometry" tab. The configuration setting determines which catalog magnitudes are used to establish the M/IR (magnitude/intensity relationship). You want to pick comp stars based on the same photometric band.*

If you're using *Instrumental* or *DerivedMags* but haven't found or don't want to apply transforms, the "Default Filter" and the filter you select here should be the same and come closest to the band of your system. For example, if using the Clear filter, many systems using the Kodak chips (KAF series) come close to matching the R band. So the R filter is probably a good choice.

*If at all possible, use the r' magnitudes for unfiltered systems. These are much more consistent and you will get "tighter" results (lower standard deviation). Unfortunately, the SDSS and CMC-14 catalogs do not cover the entire sky and so you may be forced to use the 2MASS to BVRI magnitudes.* ***Which ever you chose, make sure to use the same setting for every session for the object.*** *Otherwise you will have unpredictable zero point shifts that can and will affect period analysis.*

*The Clear filter has a significant color dependency and so it is critical that you use comparisons that match the color of the target as closely as possible.*

Put another way, the transform for a given filter is 0 for a perfect match to the standard system, meaning that there is no difference in the color correction over a wide range of colors. ***This is not true for the Clear filter.*** A typical example at my location is $T_c \sim 0.3 *$ (V-R). So, if the differential color index between target and comparison is only 0.1 mag, the error by not applying a transform will be 0.03 mag (0.3 * 0.1). This can be and often is a significant error when trying to get consistent data and linking data from one night to another night.

### *Continuing On*

34. Click <Plot Comps>. This finds stars in the chart that was generated during the AutoMatch done just before staring the wizard. If you don't do an AutoMatch, you'll get an error message about there not being enough stars (you'll also get that warning if you pick a magnitude band for which values are available for very few, if any, stars in the field.

35. You should see a plot similar to the one above. A perfect world solution would be a slope of 1.000 and S.D. of 0.000 mag. That never happens.

## Tricks of the CSS and Picking Comparisons

If you click on a data point on the plot, Canopus automatically places a set of measuring apertures over the star in the image that corresponds to that data point and measures the star. Also, the status bar at the bottom of the CSS displays information about the star.

If you click on a star on the image that has a data point in the plot, that data point changes to green and you again see the star's information in the status bar. If the star doesn't have a counterpart in the plot, all plot points revert to red and the status bar goes blank to let you know that the star is not valid as far as the CSS is concerned.

You want to pick stars whose plot points are close to the solid black line and have a color index similar to the target. If you're working asteroids, then use B-V = 0.8 or V-R = 0.45 as guides. The star values don't have to be exactly the same, but try to keep them within 0.2 mag of the target color index if at all possible.

### *Fixing a Bad CSS Solution*

If there are some way-off outliers on the plot such that it may be difficult to determine which stars really are close to the line (with a good solution), you can remove those points from the calculations.

<Ctrl+Click> on a bad point and answer "Yes" to the confirmation message to remove the point from the calculations. This automatically updates the solution and plot. Don't worry about removing stars at the far lower left. These are the very bright, and often saturated, stars. It is mostly points about half-way and towards the faint end that – when significantly bad – can make things difficult.

### *The Anchor Star*

The first comparison star (Comp1) is the "anchor star" and is *critical* in all that follows and in many other features of Canopus and PhotoRed. It needs to be chosen carefully. The primary use of the anchor star, beyond its roles as one of the comparison stars for differential photometry, is the reference point from which the positions of the other comparisons, the target, the StarBGone reference, and subtraction stars are reckoned. All those positions are derived as offsets from the anchor star.

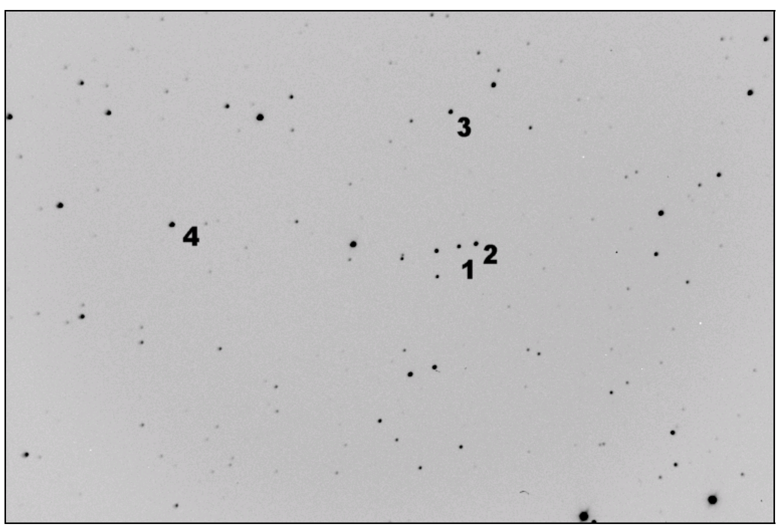
A good anchor star has one critical trait:

- It is on all images to be measured

All comparison stars should have these traits:

- It is below the non-linear roll-over point of the camera's response (or saturation, which ever is lower).
- It has a good SNR, preferably > 100.
- It does ***not*** have to be about the same brightness as the target. You don't want to use a 16.0 magnitude comparison just because you have a 16.0 magnitude target.
- It should have a similar color to the target.
- It should ***not*** have any close companions. Otherwise, Canopus may have trouble isolating it from nearby stars as it ploughs through dozens of images.
- If working a moving target, it should not be so close to the object's path such that the two merge or very nearly so.
- Its position on the image should favor a moving target's direction of motion. You want the target to move towards the comparison set, not away from it. This should be done within reason. It's really best to have the comparisons surround the target over the entire session. That is not always possible.

If possible pick the maximum of five comparison stars but never less than two. Having more comparisons lowers the noise in the average value and gives you some flexibility should one of the comparisons you picked happened to be variable.



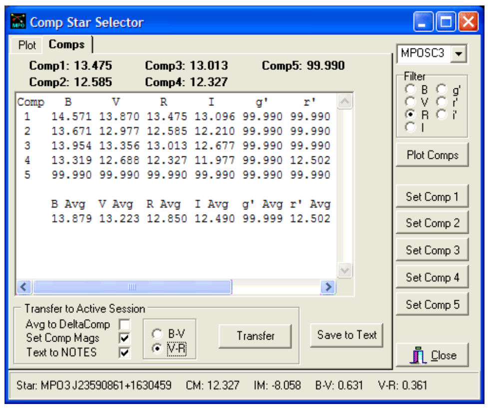

36. Using the screen shot above, ***for each numbered comparison***

    Click on the star. Note if one of the plot data points turns green and the star information.

    Click <Set Comp X> (X is a number from 1 to 5) on the CSS. Start with <Set Comp 1> and go through <Set Comp 4> (comp 5 is not used).

*Note that as you click one of the CSS comp buttons, the X/Y location of the star is recorded in the lightcurve wizard fields as well. Do NOT click <Star X> buttons on the wizard. While the X/Y position will be recorded, the magnitude information that the CSS would retrieve is not recorded.*

37. After you have measured the fourth comparison star, click the “Comps” tab at the top of the CSS notebook control. This displays the magnitude data for the chosen comparisons.




## Canopus Transfer

It’s just a good idea to keep a permanent but handy record of all the contents of the CSS comps memo. For example, if you are doing *Instrumental* photometry and it turns out that one of the comparisons is variable, you must first eliminate that comparison from the calculations and then find a new average magnitude for the comparisons to use in the sessions DeltaComp field. If you have the CSS data available, this is very easy to do.

The CSS can transfer the average value to the DeltaComp field, the individual magnitudes of the comparisons to the respective CM and CMCI (catalog magnitude, color index) fields, and the contents of the CSS memo to the Notes field of the current session without having to go back to the Canopus main form and opening the sessions form.

38. Do ***not*** check the “Avg to DeltaComp” box. This is because we’re using the *DerivedMags* method. If we were using the *Instrumental* method, then you *would* check this box.

39. Check the “Set Comp Mags” box.

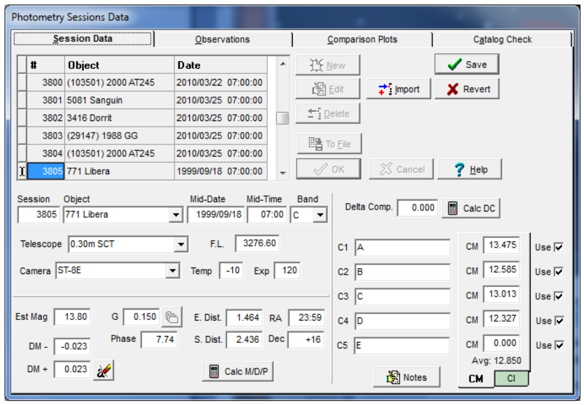
40. Check the “Text to NOTES” box.

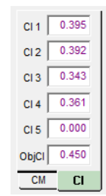
41. Check the “V-R” button. This transfers the V-R magnitudes to the sessions form. If you did (or will do) transforms based on B-V, then you would check that button.

*If you are applying transforms, you **must** select the color index that you used for finding the transform. For example, if when finding the transform for the Clear filter you used V-R catalog magnitudes, then you must select V-R here. **Making a selection does not automatically mean that transforms will be applied;** it means only which values are used should you chose to apply transforms.*

If you chose the wrong color index, don't worry. By doing this transfer, both sets of data are placed in the NOTES field and you can easily import them into the fields on the sessions form later. Having worked a day job and then doing photometry all night too many times, I've built in many "It's 2 AM and the operator is half-awake" safeguards.

42. Click <Transfer>. This displays a confirmation message that the data were transferred or, if not, the nature of the problem.




In case you're curious, the screen shots above show the session form just after the transfer. The C1-C5 names have not yet changed (they will when you close the wizard) but the individual catalog magnitudes for the selected comps have been entered. Since only four comparisons are being used, the C5 catalog magnitude is 0.0. The "Use" box is still checked, but will be cleared when you finish the wizard.

The small form to the right is the second tab of the catalog magnitudes and shows the color index values that were transferred. The 0.45 for the "ObjCI" came from the PhotoRed transforms data and is the approximate default V-R for solar-colored objects.

*Do not edit the Sessions form manually at this time. Finish the wizard before making any changes.*

## *Notes about the Transfer*

Do not switch active sessions while working with the Comp Star Selector. Data could end up in the wrong place or, worse, overwrite existing data.

The transfer to the Notes field looks for an existing section in the Notes data that starts with "COMP START SELECTOR DATA" and ends with a string of dashes terminated with an asterisk, i.e., "----*". Do not change any lines, including the header and terminating line, in this section of the Notes field. Otherwise, Canopus cannot find it and replace it with revised data from the CSS.

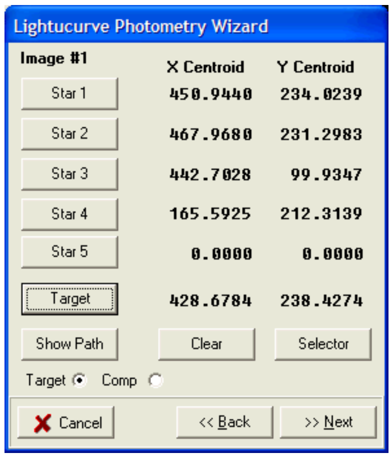
43. Click <Save to Text> on this page of the CSS. This saves the contents of the memo field to a text file with the default directory being the same as where the image was found.

    This is somewhat redundant to transferring the text to the session Notes field, but it does provide a second copy in a separate file that you could send to another observer.

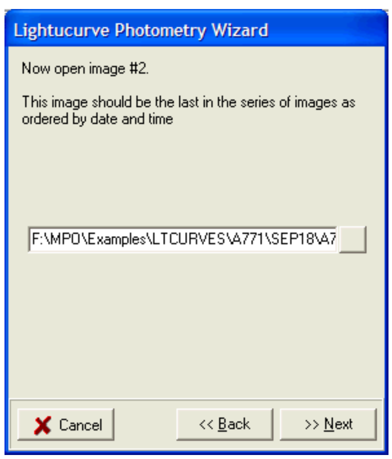
*Make a habit of saving the CSS data* ***and*** *saving the data in the separate text file. You will need it more often than you think and the only way to get it back if you don't save it one place or another is to run the wizard again.*

## Moving On

44. After you close the CSS, the wizard should look something like this.




45. Click <Next> to get to the next page of the wizard.




46. Use the speed button next to the entry field to bring up a Windows file dialog and load \MPO\Examples\LTCURVES\A771\SEP18\A771A045.FIT.

### *Choosing the Second Image*

The second image in the wizard is used to compute a moving target's rate of motion and the rate of rotation of the images (e.g., due to a poor polar alignment). Once these are known, Canopus can compute the position of the target and other comps in reference to the anchor star location for every image. If necessary, you can override the placement of target apertures, but if you chose the second image carefully, this is not usually necessary.

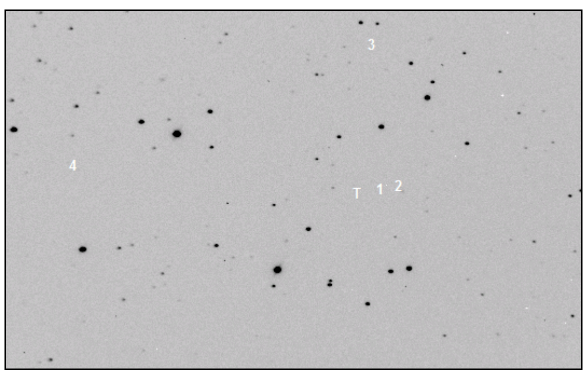
Given these considerations, the second image should meet these criteria.

- It must contain the anchor star which, in turn, should not be too near an edge.
- It should contain all selected comparison stars.
- It should be towards the end of the session in order to maximize the accuracy of predicting a moving target's rate of motion and the rate of image rotation.
- If there is extreme image rotation from the start to the end of the observing run, pick an image about half-way through the run for the second image. This requires more extrapolation than might be preferred but it also means that the wizard can correctly locate comps 2-5 when doing underlying calculations required to measure all images.

47. When the second image appears, a set of numbers and "T" appear superimposed. Numbers 2 and higher and "T" are located in reference to the number 1 star (the anchor) based on the offsets in X and Y measured in the first image.

    Many times, the labels will not be exactly next to the stars and target. This is particularly true if you repositioned the telescope during the observing run to the asteroid near center. This is not a problem and is easily fixed.

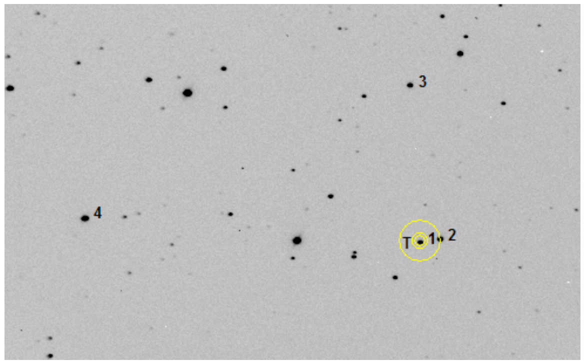
*If you invert the images in the wizard, it may be a good idea to select "Black numbers" so that the labels are easier to see. If you have trouble seeing the numbers in this exercise, you can use the Back button to get to the first page, check that box, and then return to this page ("Image #2") of the wizard.*




48. As you can see, the numbers are not next to their corresponding comparison stars. You can reposition the entire set of apertures by moving the mouse cursor over the anchor star (Comp 1) and then <Ctrl+Click>. Note how all the labels move to their now positions.

    This provides a visual check that you have correctly identified the anchor star on the second image, i.e., all the labels – except the "T" for a moving target – should be next to their respective comparison stars. Why is "T" not next to the target? The target moved!

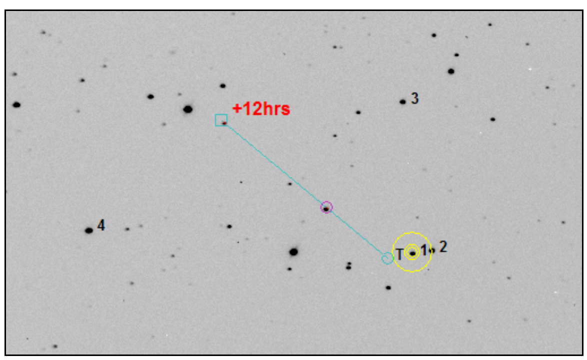
*Sometimes a label may be on top of the anchor star and you won't be able to click on the star (the cursor disappears as you move over the star). Click the speed button to the right of the "Clear" button so that it appears raised (it should appear depressed). This hides the labels so that you can click on the anchor star.*




The screen shot above shows the target apertures around the anchor star and labels next to their respective comparisons.

49. Click <Star 1> button on the wizard (make sure you are on the “Image #2” page). Note how not just the anchor star position is entered but those of the other comparisons as well. These will be updated a little (to account for image rotation) before the final results are derived.

50. Where is the target? Click <Show Path>. As with Image 1, a line appears that shows the path of the asteroid but this time there is a small circle at a point along the path where Canopus predicted the asteroid would be. See the screen shot below.




51. Click on the asteroid to measure the target position.

52. Click <Target> on the wizard. The X/Y values are entered on the wizard.

53. Click <Next>. This displays information about star subtraction because you checked that box on the first page. If you did not check that box, then the following steps can be skipped. In fact, you must skip them because the relevant wizard pages will not be displayed.

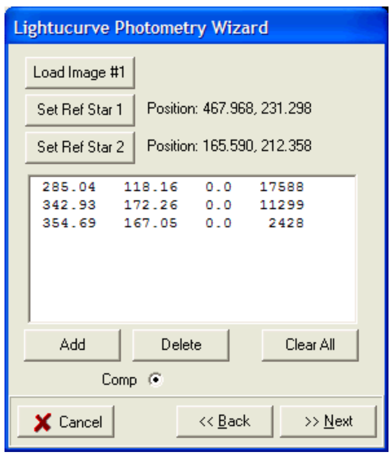
## Star Subtraction (StarBGone)

StarBGone is a feature of Canopus that removes faint field stars so that you can measure an asteroid over a larger number of images than you might be able to otherwise. If those stars intrude into the measuring area of the target aperture, then you will get inaccurate results. StarBGone has literally saved hundreds of images from the electronic trash can.

*If after reviewing the paths from "Show Path" in the previous steps you determine that the moving target does not come close to any field stars, you can either go through these steps and specify a random star as the subtraction star (don't make it a comp star!) or go back to the first page of the wizard and uncheck "Star subtraction." Then click <Next> to get to the final page of the wizard to close it out.*

See the Reference Manual for additional information on StarBGone.

*StarBGone does not have infinite power. It cannot remove a $10^{th}$ magnitude star as the $16^{th}$ magnitude asteroid goes over it. Statistics of random noise will show that at some point the noise in a given star's measurement is equal to or greater than the entire contribution of the target. Do not expect major miracles with StarBGone but do expect to recover data in a number of cases you thought might not be possible.*




54. Click <Load Image 1> to load the same image that was used as Image 1 earlier in this tutorial.

55. A line appears going through the target that is derived from the positions you gave for it on the first and second image. Any field star that touches this line or lies sufficiently close to it should be marked for subtraction.

*It is much easier to see faint field stars when you invert the image (black stars, light background).*

## *Choosing the StarBGone Reference Stars*

As each image is opened, Canopus finds Reference Star 1 and scales it to match each subtraction star in proportion to its relative brightness to the reference star on the original image. The scaling is done on several levels in order to get the best possible match, i.e. total intensity and the contribution of each pixel to the total intensity. This allows Canopus to do a good match on images that are trailed as well as perfectly guided.

The reference star requirements are:

- It is on every image to be measured
- It is not saturated or in the non-linear range of the camera.
- It is isolated (no close companions)

- For Reference Star 1, it is about as bright as the brightest star that can be *reasonably* subtracted. This is a hard criterion to specify exactly. Remember that StarBGone can do only so much. This is a case where trial and error (and, hopefully, success) is the best guide.

- For Reference Star 1, it is also recommended that it be one of the comparison stars. The reason for this is that you can plot the comparison star magnitudes during the session and determine if one or more is variable. It will not do to have a variable reference star for star subtraction!

- For Reference Star 2, it should be well-removed from Reference Star 1 in order to allow the most accurate calculation of image rotation and scaling. It should not be on a line joining it and Star 1 that is nearly parallel to the edges of the image. If, for example, they have the same Y-axis value, then Canopus cannot accurately determine how much image rotation has taken place and so overlay the scaled Reference Star 1 correctly.

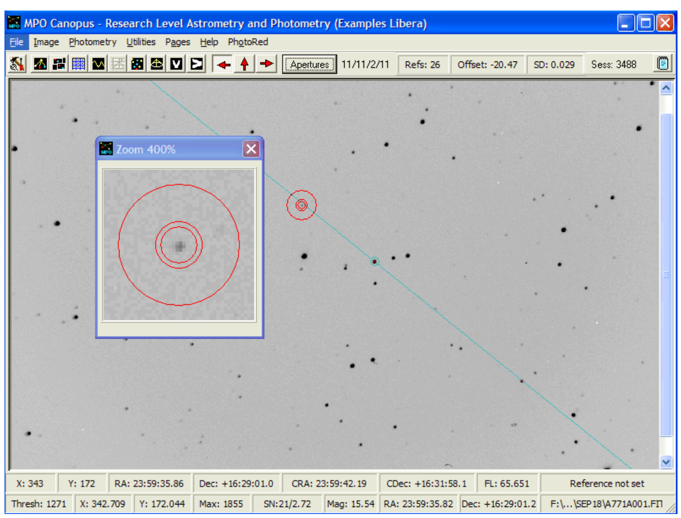
56. Click on comparison star 2 on the image and then click <Set Ref Star 1> on the wizard.

57. Move the mouse cursor to X = 220, Y = 94. This is a star near a brighter star, the latter of which is close to the asteroid path.

58. Click on the star and then click <Set Ref Star 2>.

59. If it isn't still open, display the zoom box. This helps see faint stars along the asteroid path and position the cursor.

60. Locate stars near the path. For each one, click on the star and then click <Add> on the wizard. To delete an entry, click on it in the list, and then click <Delete>.

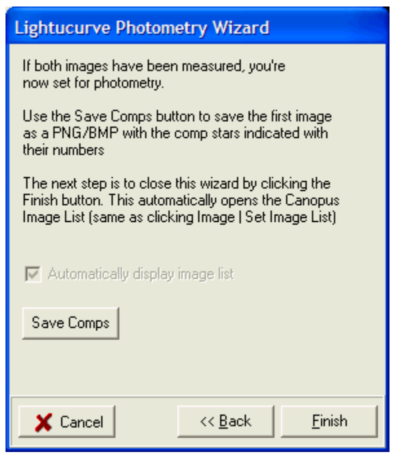



The screen shot above shows an example of marking a subtraction star.

*You do not have to mark every star near the path for subtraction, only those that are close enough that they might intrude into the measuring area of the target aperture. The sky background algorithm in Canopus can handle fairly bright stars that fall into the sky aperture. However, it can't hurt to mark somewhat brighter stars that would intrude into the sky annulus in order to reduce the stress on the algorithm.*

*There is no point in trying to remove an excessively bright star. Simply skip those images where the target and star are too close.*

61. After you have marked all the subtraction stars, click <Next> to go to the final page of the wizard.

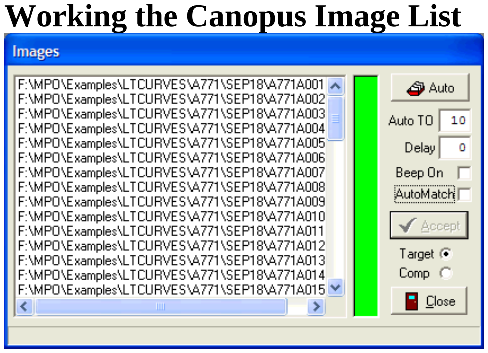



62. Click <Save Comps>. This saves a copy of Image 1 with the number labels included as either a PNG or BMP file. This gives you a quick visual guide to the comparisons that you selected. The default directory is the same as for Image 1.

63. Click <Finish>. This displays a Windows file dialog.

64. Select all the A771*.FIT image in F:\MPO\Examples\LTCURVES\A771\SEP18. When you accept the selection, this displays the Canopus Image List after a few moments. The delay is caused by Canopus sorting the selected image in increasing date/time order after getting the date/time from the FITS header, not the Windows file date/time stamp.

## Working the Canopus Image List



The Canopus Image List provides the interface to measuring the selected images. The "Target" and "Comp" buttons determine which set of apertures are used when you click on an image while processing is paused. In most cases, you will use "Target" since you'll be "tweaking" the position of the target apertures if they begin to wander away from the target.

A quick note on the "Beep On" control. If checked, Canopus sounds a short beep after an image is measured. This can be both comforting and annoying. You can check or uncheck the box at almost any time.

## *A Bit of Philosophy*

Before describing the various measuring methods available, let it be said that "fully-automated software" has never been the goal or philosophy of Canopus. It is a good idea to review every image at least quickly before it is measured and, if not up to standards, reject it. If one trusts the computer without question, this could result in a set of data with numerous "bad" points that must be reconciled one way or another. By reviewing the measuring process and maintaining at least some control, you can reduce the number of outlier data points considerably and so proceed to lightcurve analysis much sooner and with a greater confidence in the data set and subsequent results.

## *Full Manual – Without and With AutoMatch*

In this mode, you double-click on the first image in the list. It is loaded and Canopus places the measuring apertures where it thinks it will find the comparisons and target. If the placement is good, you click <Accept> (or press <Enter> if the form has focus). Canopus records the data and then loads the next image.

If you do not check "AutoMatch", then the M/IR is not computed as each image is loaded and so only the instrumental magnitudes are valid for analysis, meaning that either *Instrumental* or *DerivedMags* methods can be used. You will not be able to use *TrueMags*.

Even if measuring hundreds of images, things move along very quickly in most cases. However, clicking <Accept> or pressing <Enter> gets rather tedious. Also, if Canopus cannot find the anchor star within ±5 pixels of the expected position, it displays a warning message and does not measure the image. You must either reposition the measuring apertures or move to the next image.

If you check "AutoMatch", then Canopus does an AutoMatch as each image is loaded. This makes the process much slower but, except for rare cases, Canopus automatically finds the anchor star and you don't have to reposition the measuring apertures. You still have to click <Accept> (or press <Enter>) to load the next image.

## *Semi-Auto – With and Without AutoMatch*

This is identical to the above with the exception that you click <Auto> on the Image List, tell the program to use the "Simple" auto processing, and it takes over by clicking <Accept> for you. The delay between images, in seconds, can be set by the "Delay" field. Even a delay of 0 has a slight delay to allow Windows to process messages properly.

➪ *Semi-Auto, Without AutoMatch is recommended for most cases. Second would be Semi-Auto, With AutoMatch.* ***When all is said and done, unless you have to reposition apertures for almost every image, it will take much less time to measure images if you do <u>not</u> use AutoMatch.***

The AutoTO field changes the default timeout, in seconds, allowed for Canopus to extract the stars from an image and do an AutoMatch. This is needed for cases where an image was very badly guided and so the AutoMatch generates a chart that is way out of scale to the image and has thousands of stars. This works in conjunction with the "Configuration | Charting" option for "Max Scale Diff" to avoid the program appearing to hang during an AutoMatch.

*Make sure that you don't set the timeout so short that your computer can't extract the stars from a crowded field before the timeout occurs.*

### *Full Auto – Forced AutoMatch*

This is the "walk away" mode. Once you start it, error message are no longer displayed nor does the process stop. If an image fails for whatever reason, the error information is stored and the program moves to the next image automatically. Any errors are displayed after the last image is handled.

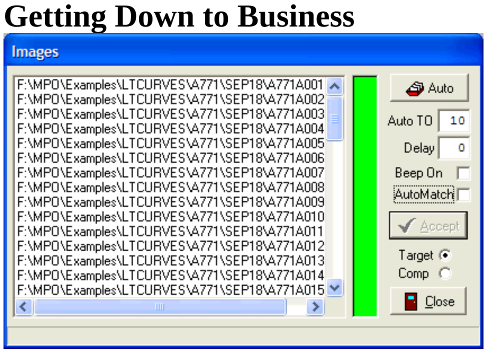
AutoMatch is forced so that Canopus can find the anchor star and measure the comps and target (save when clouds rolled in or an alien spacecraft was hovering in the field of view).

### *Some Image List Tricks*

If you need to reload an image to check it or have it measured again then, while not auto-processing, double-click on the name of the image in the list.

Canopus checks the date/time of the image (not the file date/time stamp) before deciding whether to add a new observation record or edit an existing one. If the observation being processed by the Image List has the same session number as an existing session and is within 2 seconds of an existing observation, then Canopus presumes that it should edit the record and not add it as a new one. You can remeasure an image 20 times (assuming the same default session) and it appears as a single observation.

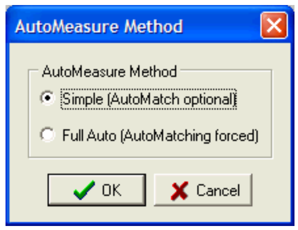
## Getting Down to Business




65. Position the Image List and zoom box so that you can see the middle part (if not all) of an image as it is loaded by the Image List.
66. Click (not double-click) on the first file in the list.
67. Match the settings in the screen shot immediately above. Make sure that the AutoMatch box is ***not checked***.

*If you have doubts that the images can be extracted and matched in 10 seconds, increase the value in the AutoTO to something you think is reasonable.*

68. Click <Auto>. This displays a form that allows you to select the auto-processing mode.

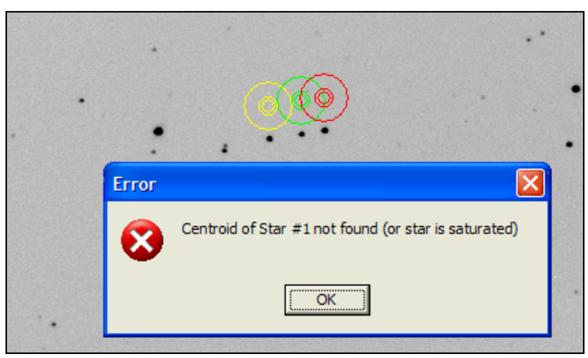



69. Check the “Simple (AutoMatch optional) radio button and then click <OK>.

*Note that the “Auto” button caption changes to “Abort” while an image is being loaded and measured. If you want to top auto-processing, click the button to display a confirmation message. Click <Yes> to abort processing.*

70. The first image should load and be measured automatically. After the second image is loaded, you should see an error message. As you can see from the screen shot immediately below, the apertures are no longer centered on the stars and target.

*The green-colored (lime) aperture set represents the anchor star. The other apertures represent the target (default yellow) and comparisons 2-5 (default red).*




71. Click <OK> to clear the message.

72. Click on the anchor star in the image. The apertures should all move in unison such that they are centered on the comparisons and target again.

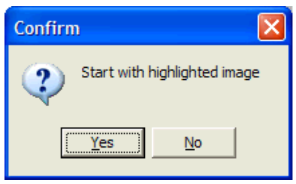
*If the anchor and other comparison star apertures are well-positioned but the target aperture is not, <Ctrl+Click>* ***on the target*** *on the image. This repositions only the target apertures.*

*If you accidentally click on the wrong star for the anchor star, double-click the image's name in the Image List files list. This reloads the image so that you can click on the correct star.*

*Do not click on the star again without reloading the image. This does not reposition the other apertures.*

73. The highlight in the files list should be on the second image. If so and the apertures are all where they need to be, click <Auto> again. You will see the same query form as before. Check "Simple (AutoMatch optional)."

74. Since the highlight is not on the first image in the list, you see a new confirmation message.




75. Click <Yes> to start with the second (highlighted) image. If you click <No>, the processing starts with the first image in the list.

Continue as above until all images are measured. You will have to reposition the apertures a few times but, for the most part, Canopus will measure merrily along.

*Do not check the AutoMatch box during this tutorial, e.g., when paused to reposition apertures.*

76. Once the last image is processed, click <Close> on the Image List.

## More on Resetting the Apertures

While measuring, especially if not using AutoMatch, an image may come up where the field shifted enough that Canopus cannot find the anchor star and/or target. If this is the case, the following:

- If necessary, stop AutoProcessing.
- Turn off AutoMatch
- Double-click on the image name in the list to reload it.
- If the anchor star aperture is wrong and, therefore, so are the comparisons, click on the anchor star in the image. This should reset the apertures to their correct positions.
- If the target aperture is not right, even after resetting the anchor star, <Ctrl+Click> on the star on the image. This rests the target aperture.
- Click <Accept> to update the internal settings and have Canopus measure the image using the revised aperture positions. This loads the next image.
- If you were AutoMatching, check that box and double-click on the highlighted image in the list to reload it and have Canopus AutoMatch.

- If you were auto-processing, set AutoMatch as desired, click on the next file to be measured and then click <Auto>. Otherwise, double-click on the next image to be measured so that the Image List loads it and places the apertures.

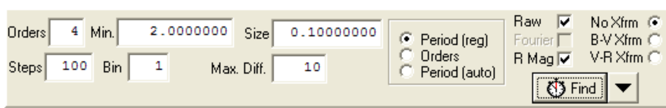
## Aborting Auto-processing

If you need to stop auto-processing, for example, the target aperture is drifting away from the target and needs to be reset, click <Abort>. When you click <Abort>, a message appears confirming if you want to abort. Click <Yes>. If you have AutoMatch turned on, the processing may not stop until after the match is performed.

## Taking a Quick Look

It's your birthday and you want to open the presents. In this case, look at the results of your measurements. This will not be the tutorial on how to do a period search. That is usually not reasonable until you get a second night.

77. Go to the Lightcurve Analysis page (<Ctrl+4>); or select "Pages | Lightcurve analysis" from the main menu; or click the lightcurve analysis speed button on the Canopus tool bar).




78. Enter these settings in the analysis fields that are found at the top left of the Analysis page.

### *Reduced Magnitudes*

*Reduced magnitudes*, for the purposes of Canopus in this case, are those that have been corrected to *unity distances at a fixed phase angle*, i.e., the magnitude that the object would have if it were at 1 AU from the Sun and 1 AU from the Earth at the given phase angle. Sometimes, this would not be physically possible, but by using the standard correction of

$$-5 * \log(rR)$$

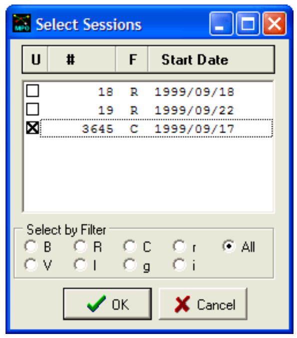
where r is the Earth-asteroid distance and R is the Sun-asteroid distance, all magnitudes can be referenced to an independent fixed distance.

The resulting magnitudes may be considerably different from the *sky magnitude*, the apparent brightness as measured using the M/IR offset, but they are directly comparable to one another in terms of removing the effects of changing distance.

If you choose not to use *reduced magnitudes*, Canopus still applies a distance correction to all sessions but the reference point ("zero points") is the distances at the time of the first session.

*Even when using Reduced magnitudes, the correction for phase angle is included based on the value for the phase slope parameter (G) that's entered in the sessions form.*

79. Click <Find>. This displays a Select Sessions form.




80. Make sure the “All” button is checked. Otherwise, you see only those sessions where the Filter was set in the sessions from to the filter selected here.

81. Check the session in which you’ve been working (the current default session).

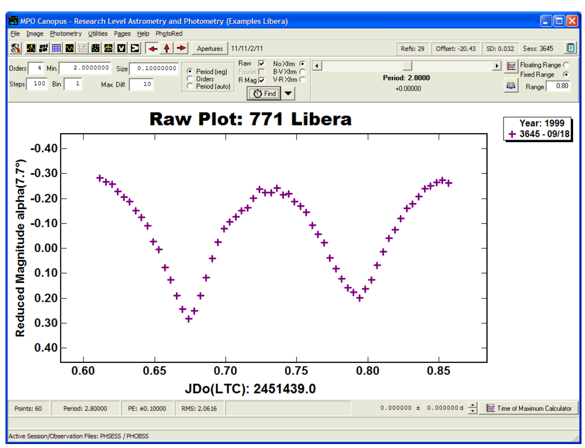
    If this is the first time you’ve measured an object with the name you used in the Object field of the sessions form, there will be only one item. If you’ve done other measurements, more than one item appears. Select (check) only those sessions you want to analyze.

    This is a typical Windows multi-select list where you use click, Shift+Click, and/or Ctrl+Click to select one or more items.

*This shows the importance of giving the same name in the Object field on the sessions form for observations involving the same object. Canopus uses the Object field to search for all sessions involving a given target. Only those that match the name in the Object field of the default session are found.*

82. Once you select the session on which we’re working, click <OK>.

83. After a few moments, you will see something like this.




Two other forms are also displayed. These are not shown or discussed here. We’ll look at those in detail in a following tutorial. Close those forms for now.

This is a plot of the raw data, meaning that no attempt has been made to fit the data to a specific period. Since this is a raw plot, the period is not displayed.

## *Phase Angle (alpha)*

*Note that the Y-axis is labeled “Reduced Magnitude alpha(7.7°).*

Phase angle, the angle between the Sun and Earth as seen from the asteroid, is designated with the Greek letter $\alpha$ (“alpha”). Since there’s no assurance that the character will be properly displayed, it is spelled out on the plot. This value tells you the reference phase angle for all observations.

Remember that all data must be corrected to remove effects not only of changing distance but changing phase angle. The corrections are calculated using the value for *G* (phase slope parameter) entered in the sessions data and a complex formula that predicts magnitude based on that value. The phase angle for the first session is the “zero point” for all other corrections – all data are corrected to this phase angle. Correcting to 0° requires accurate knowledge of *G*, which is not often available.

If the phase angle for the first session (usually earliest by date) has not be computed, then “?” replaces the value in parentheses.

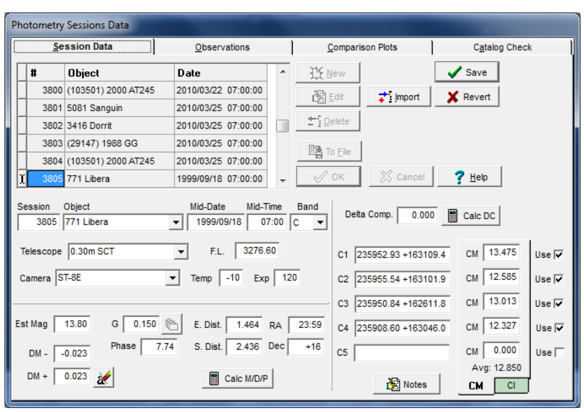
*Since Reduced magnitudes were selected, the title includes “Reduced”. Had that box not been checked before clicking <Find>, the title would have been just “Magnitude” plus the phase angle information.*

*The “industry standard” for Reduced magnitudes is the V band. If you do not use V magnitudes, be sure to note which band was used when you publish your results (you DO publish your results, don’t you?).*

## Checking the Comparison Stars

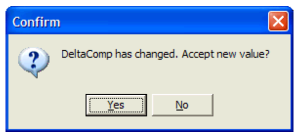
Immediately after you measuring images for a session, you should check that none of the chosen comparisons is variable. Don’t assume this is the case. For all you know, a comparison that has been used for years for variable star work may have suddenly gone into its once-every-50-years eclipse.

84. Click <Notepad> (notepad icon) at the far upper right of the Canopus main form. This displays the sessions form in edit mode on the current default session.



*Before moving on, note that the C1-C4 names were changed from “A”, “B”, etc. They are now a combination of the RA and Declination of their respective positions without the field delimiters. This allows you find those comps on any image (since their X/Y values may change) or in an on-line search. C5 has been set to blank and the “Use” box is no longer checked.*

85. On the Session Data tab, click <Calc DC>. This may display a message (it shouldn’t in this case if you’ve followed the instructions carefully).



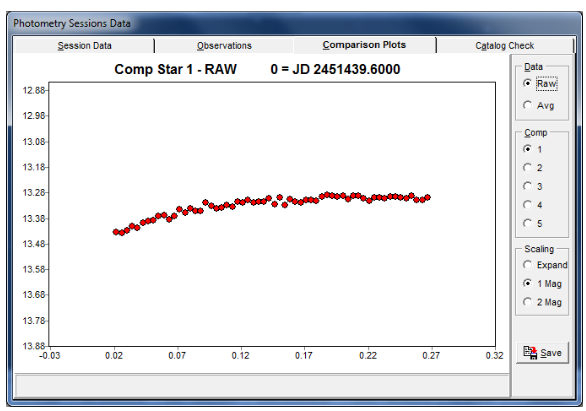

86. Click <No>. This causes Canopus to recompute some internal values regarding the comparison star set so that you can plot their data.

    In most cases, click <No>. You may have spent some time finding the correct value for the DeltaComp value. You don’t want to override it without first being asked.

*The DeltaComp values are used with differential photometry (when using* Derived-Mags *or* Instrumental *methods) to correct for the difference in the average magnitude of the comparison star set from one session to another.*

87. Click on the “Comparison Plots” tab of the sessions form.

88. If necessary, click on the “Data | Raw” and “Comp | 1” radio buttons on the right side of the form. You should see something similar to the screen shot below.

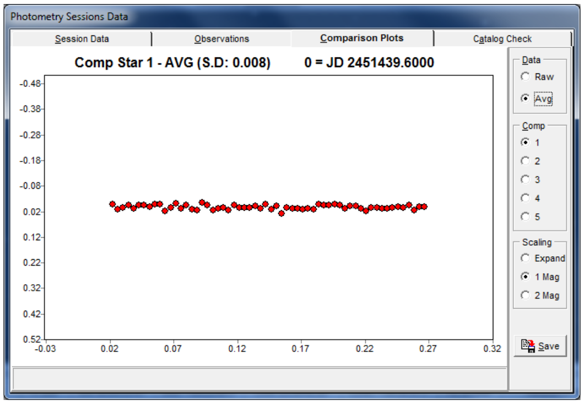



89. Click on the other Comp radio buttons to see the raw data for the other comparisons.

    Note that the data are tight, there is little scatter, but that they are not flat. Instead they rise and then level off. This is normal. You are seeing the effect of extinction that causes a star to get brighter as the field rises higher above the horizon. Near the meridian, the magnitude changes very little. If the session had gone longer, the curve would have started going down.

    As with M-C values in astrometry (see those tutorials), you are looking for a similar trend among all the comparisons. If they all show about the same scatter and trend, then all is good.

90. You can confirm the quality of the comparison star data further by clicking the "Data | Avg" radio button. The plot will change slightly (in this case).




91. Now you see (as you would hope) the data on a nearly flat, horizontal line.

Here the program is plotting the differences between the instrumental magnitude of the select comparison and the average instrumental magnitude of the remaining comparisons. This is akin to the old C-K values that showed the stability of the measurements.

At the top of the plot, you see the "S.D: 0.007" (in this example). This is the standard deviation, in magnitudes, of the average of all the data points. You want something on the order of 0.01 mag. Here, it's even better. Sometimes, however, when conditions are not ideal, you get a larger scatter. This is reflected in the data for the target.

## *Fixing Things*

If plotting the "Avg" and the line is not flat but, for example shows a sinusoidal shape or obvious eclipse, you have used a variable star for a comparison! If you select other stars, the trend will reverse itself for those stars as the variable becomes part of the average of the "remaining comparisons."

*These steps should not be necessary for this tutorial.*

- Go back to the Session data tab and uncheck the "Use" box next to the comparison star that is variable.
- Click the <Calc DC> to recompute the internal values.
- Click <No> to resetting the DeltaComp Value

### Instrumental Method

If you are working the *Instrumental* method, you must change the DeltaComp value to the average of the catalog magnitudes of the comp stars still being used. If you transferred the magnitudes to the session when using the Comp Star Selector, this is very easy to do.

- As you check or uncheck the "Use" box on the "Session Data", the average of the catalog magnitudes is displayed immediately below the "C5 CM" entry field. Enter that value in the DeltaComp field.

- Go to the Comparison Plots tab and repeat the exercise to be sure that no other star is a variable.

If you did not transfer the values but did save the Comp Star Selector data to the NOTES field:

- Click <Notes> to display the Notes field editor.
- Write down the appropriate catalog values for the comps (all of them so that you do this once).
- Enter the values in the CM fields. Proceed as described immediately above.

### DerivedMags Method
All that is necessary is to uncheck the “Use” box of the offending comparison. You should leave the DeltaComp value at 0.000, or whatever the value is after you did some “tweaking” to align sessions.

### Working with *TrueMags*
In this case, the average of the comp star set is not being used and so you should keep the DeltaComp value as it is, usually 0.000 unless you’ve done some fine-tuning in previous analysis.

## *Another Fix (Bad Data Points)*
Even if all the comp star average plots show a relatively flat line, there may be one or more data points that are well above or below the line. These outliers can be due to many things, e.g., a cosmic ray hit, hot or cold pixel, and so on.

As long as you keep in mind that no data point should be removed without good reason, you can eliminate individual data points (images) from the calculations.

- <Ctrl+Click> on the data point on the comparison star plot. This displays a confirmation message.
- Click <Yes>.
- Repeat as necessary, checking each “Avg” plot for each comparison individually.

As you remove each point, it is removed from the calculations and the comparison star data and plot are refreshed. This includes the standard deviation displayed at the top of the plot.

*The data points are not deleted from the data table, just excluded from being used. You can restore data points (or exclude them) by going to the “Observations” tab and either checking or unchecking the Use box for a given observation.*

92. Once you are satisfied with the comp star data, return to the “Session Data” tab, click <Save> and then click <OK>.
93. Click <Find> on the Lightcurve Analysis page of Canopus and repeat the steps from above. The plot reflects the changes.

## Removing Bad Data Points on the Analysis Page
Just as you could with the comparison plots in the sessions form, you can exclude one or more data points by clicking on the lightcurve.

- <Ctrl+Click> on an outlier data point. This displays a confirmation message.
- Click <Yes> to exclude the point. The period and new lightcurve are automatically re-computed.

*If you just click on a point, information about it appears on the lower status bar. This includes the JD (light-time corrected or Heliocentric JD) and the session number from which the data point was taken. The latter is handy if you are plotting data from more than one session.*

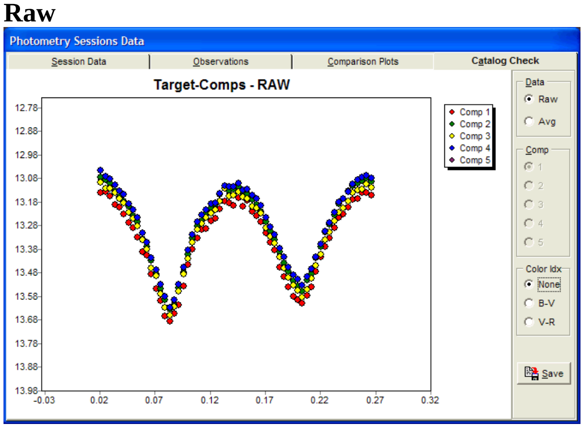
## A Second Check of the Comparisons

The above checks show only the stability of the comparisons among one another. They do not show the quality of the *DerivedMags* solutions. For example, one of the stars may have a catalog value that is off by several tenths of a magnitude. This increases the error in the mean of the *DerivedMags* value and can make it so the session doesn't match other data – it's on a different zero point.

*This feature can be used whether using Instrumental or DerivedMags but only if you transferred from the Comp Star Selector or manually entered the catalog magnitudes for the comparisons in the "CM" field so on the sessions form.*

94. Click on the "Catalog Check" tab to display the DerivedMags data in a different way.

**Raw**

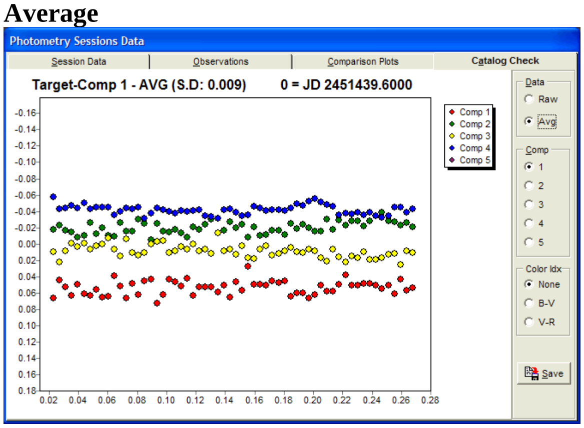



This screen shot shows the Raw view of the Catalog Check. Here, the Y-values are the derived magnitude for the asteroid when using one of the comparisons. In a perfect world, the plots would like exactly on top of one another since the derived magnitude for the asteroid should be the same regardless of which comparison is used. If the plots are not well-aligned, that indicates, mostly likely, that the catalog magnitude for the corresponding comparison is bad.

In this case, it appears that Comp1's catalog magnitude is a little too low since its curve is below the others, but only slightly.

*Note that the "Color Idx" button is set to "None." If you were applying transforms, you would want to check the appropriate color index. However, this is just for the sake of comparisons here. You must still check the appropriate Transforms button when finding a lightcurve to apply the color corrections during period analysis..*

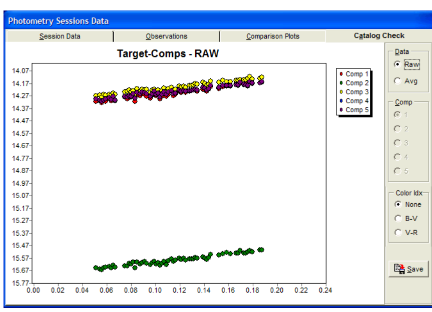
**Average**

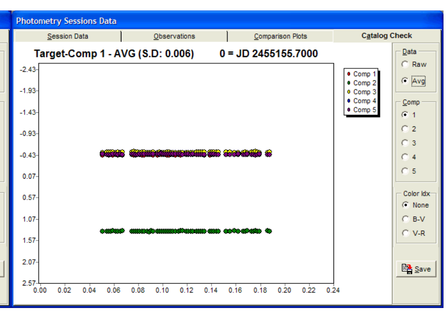



The average plot shows the data for each comparison as the difference between the derived magnitude using the selected comparison star catalog magnitude minus the average of the derived magnitudes for the object using the remaining comparisons. Here again, in that perfect world the plots would sit exactly on top of one another.

The normal vertical scale is ±2.5 magnitudes, so these plots did appear to be superimposed until the zoom capability was used to expand the vertical scale. The data for comps 2-4 are reasonably close to being at the same level. Comp1's data are about 0.06 magnitude below Comp 3. This slight mismatch could make this session be too high or low in comparison to another session. It would probably be best to drop Comp 1 from the calculations by unchecking its "Use" box on the "Session Data" tab.

A dramatic example of how this feature can spot "bad" comparisons is shown in the screen shots below when working a different asteroid. Three comparison star data sets lie very close to one another but the one for Comp 2 is way below the others.

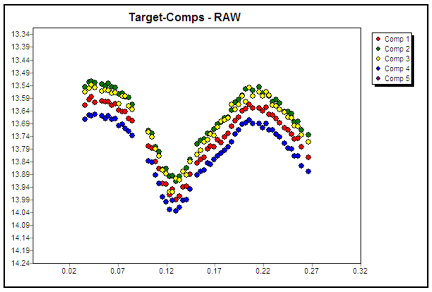


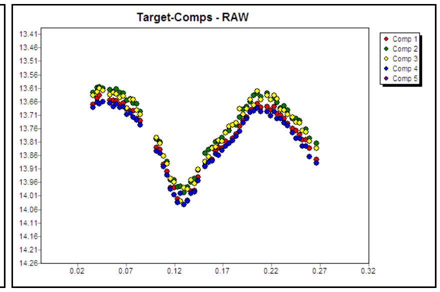




With Comp 2 used in the calculations, the DeltaComp for this session had to be changed considerably from 0.00 to make it mate with sessions from the same night. When Comp 2 was removed, the session lined up perfectly with the others when DeltaComp was set to 0.00.

## How Does Applying Transforms Change Things?

In this case, the R magnitudes matched the Clear filter images very closely and the comparison stars were close enough in color so that there really was no difference when checking the "B-V" or "V-R" color indices (it's also because there were reasonable transforms available). Here is an example where transforms were again available and applying them *did* make a difference.




On the left is the Raw plot with no color correction included. On the right, the V-R color index correction has been applied. You can see that the five curves come much closer to matching and so the benefit of using transforms, assuming that good color index values and transforms are available.

## In Conclusion

This concludes this tutorial. It's been long but, I hope, productive. The data stored here is used in a following tutorial, so be sure not to delete this session.

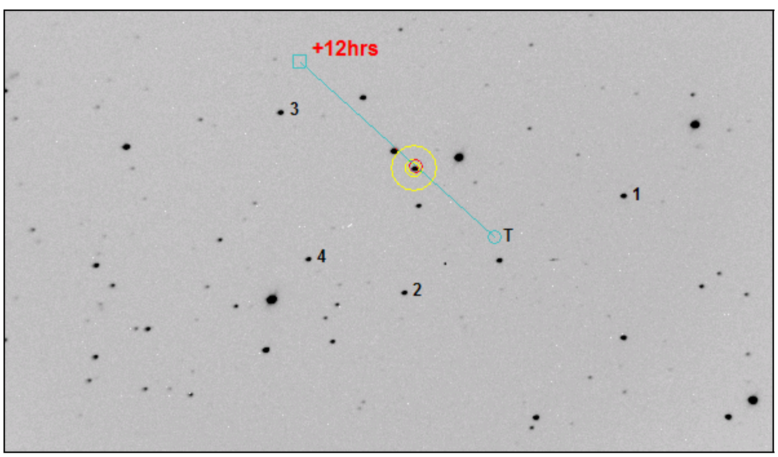
Check the Reference Manual for more details about specific fields or methods demonstrated here. Once you understand the process and get comfortable with it, you'll find that you can measure a night's set of images in a very short order. If the target is cooperative, period analysis goes just as quickly, maybe even faster.

## 2. Using AutoMatch (Night 2)

This tutorial measures the second night of images of 771 Libera. The process is nearly identical to what was described in the previous tutorial in this chapter. The main difference is that AutoMatch is used in order to demonstrate its use and also because the field of view jumped around quite a bit the second night and you would have to reset the apertures a number of times.

*Even when having to reset the measuring apertures when not using AutoMatch, it would take much less time to go through this tutorial. AutoMatch is handy but definitely not for the impatient or those with limited time.*

1. If necessary, open the configuration and select the profile created in the second tutorial, the one used for looking at *DerivedMags* values. If you forget, it is not important as long as the profile is one of the two created in the first two tutorials. You can switch just before doing the analysis. The main point is to make sure that Canopus had the right information so that it can AutoMatch images.
2. Open \MPO\Examples\LTCURVES\A771\SEP22\A771001.FIT.
3. AutoMatch the image.
4. Create a new session. Make sure you that you:
   - Use the exact same name in the Object field as in the first two tutorials.
   - ***Set the date to 1999/09/22. Do this before the next step.***
   - Click <Calc M/D/P> and compute the data for 771 Libera.
5. Run the lightcurve wizard, making sure to use the Comp Star Selector.
6. Using star subtraction is optional (it won't be needed). However, you should make a habit of checking that box on the first page of the wizard so that you have the option of using it should a moving target come close to field stars. See Lesson 1 in this chapter and the Reference Manual for additional information.




Reference this screen shot for the next few steps

7. Use \MPO\Examples\LTCURVES\A771\SEP22\A7710001.FIT for the first image in the wizard and \MPO\Examples\LTCURVES\A771\SEP22\A7710045.FIT for the second image.

8. Use the comparisons indicated in the screen shot.

9. When you run the Comp Star Selector,

   - Do ***not*** check “Avg to DeltaComp”.
   - Check “Set Comp Mags” and check “Text to NOTES”
   - Click <Transfer> to send the selected values to the sessions form
   - Click <Save Text> and save the CSS data to a text file.

*Get in the habit transferring data to the sessions form and saving the CSS data to a text file. It’s easier to delete a text file no longer needed that to go through the steps to recreate it.*

10. Save the Image 1 comps reference image when you get to the last page of the wizard.

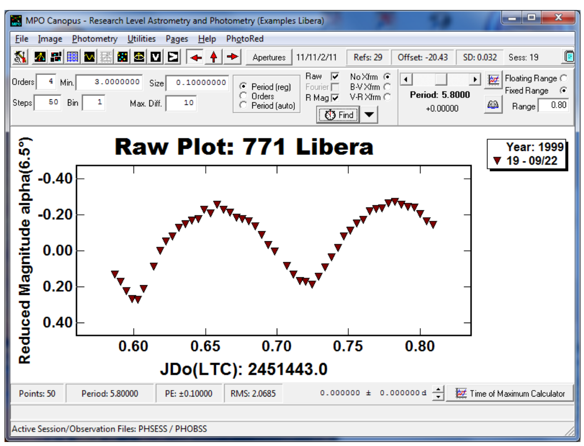
11. After finishing the wizard, select all the A771 images in

    \MPO\Examples\LTCURVES\A771\SEP22\

12. When the Image List appears,

    - Check the “AutoMatch” box
    - Click <Auto> and select “Simple (AutoMatch optional)” for the method. If not, see the previous tutorial for instructions on how to reset apertures when auto-processing.

13. Canopus should get through all the images without stopping to have you reset apertures.




Yes, that’s all there is to implementing AutoMatch, unless it can’t find the comps. If you had selected “Full Auto (AutoMatch Forced)”, then even if there is a problem, the process will not stop but a memo form appears after all images have been processed that displays which images failed and why.

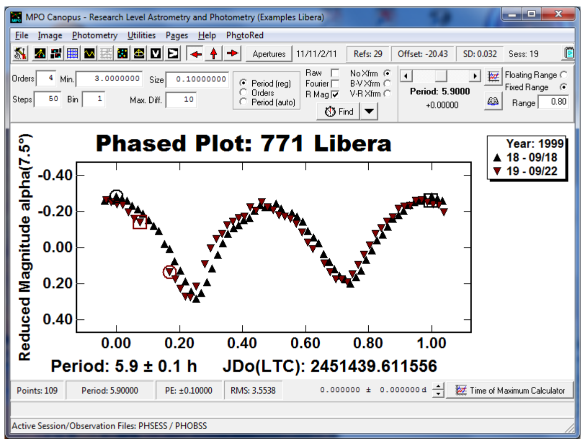
14. Go to the Lightcurve Analysis page and plot the raw data (check the “Raw” box) for ***this session only***.

15. Uncheck the “Raw” box.

16. Set the period search values to the settings shown in the screen shot immediately above.

*Experience teaches you a likely period search range for an initial search. For one, asteroid lightcurves with an amplitude > 0.3 mag are almost always "bimodal", meaning that they have two maximums and minimums per rotation (think of a spinning potato). The raw lightcurve covered almost a full bimodal cycle over about five hours. So, we made sure that a period between 5-7 hours was covered.*

17. Click <Find> again, this time selecting this session and the one created in the second tutorial, the one that also was the result of using AutoMatch.




This shot shows the results of the period search when running this tutorial. The match is close and the good news is that the two sessions agree very closely vertically. You may see something a little different.

Remember that the error in the MPOSC3 catalog is ~ ± 0.03 mag for R. In addition, we're using Clear filter and no transforms. It won't be unusual to see slight displacements, but they should be 0.05 or less if you make sure to use comparisons of the same color (same color index) as the target.

## *Quirks in Period Analysis*

As a quick aside into period searching, the Fourier analysis likes to find a solution with the minimum RMS error between the modeled curve and actual data. Sometimes this occurs by not having *any* overlap of the data by stacking sessions end-to-end (which has zero or nearly zero overlap). With "just so" period search parameters, the analysis of the tutorial data can find a better solution by just this means.

It's not just minor changes in the search parameters that can make a difference. Sometimes it takes nothing more than removing one point from the data set to find an entirely different period. This is what makes period analysis "fun" and challenging.

# 3. The Essentials of Period Analysis

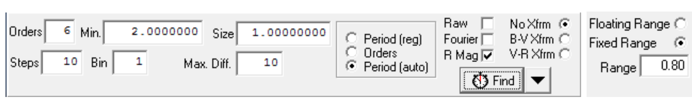
Many books and papers can be (and have been) written on period analysis. You'll find a chapter on it in my book, *A Practical Guide to Lightcurve Photometry and Analysis* (Springer, 2006; available on Amazon and Barnes&Noble and may other sites).

Canopus uses the FALC (Fourier Analysis for Lightcurves) algorithm developed by Alan Harris. The algorithm in the "industry standard" for asteroid period analysis. Petr Pravec modified it to do both additive and non-additive period analysis. The former works for finding the orbital period of a binary system and the rotation period of the satellite. Tumbling asteroids have complex curves that can be analyzed only by the non-additive routines such as Pravec's. Canopus includes the additive dual period analysis. There is a tutorial on finding the orbital period of a binary asteroid in this Guide.

For now, we will concentrate on a "simple" case where there is only one period, the curve is relatively symmetric, the data are of high quality, the amplitude is fairly large, and the period is reasonably short. If you work with an asteroid with such characteristics, consider yourself lucky. Of the more than 600 that I've done to date, less than 100 fit that entire set of characteristics.

*This tutorial presumes that you have run the previous three in this chapter and that you have TrueMags data for two nights on 771 Libera.*

1. Open the sessions form and select one of the two sessions that contain the *DerivedMags* data generated in Lessons 1 and 2.
2. Go to the Lightcurve Analysis page (<Ctrl+4>) and enter the search parameters shown in the screen shot below.




## The Search Parameters

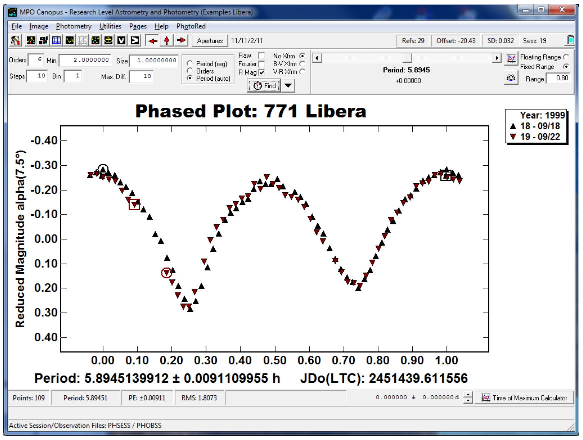
The individual settings are covered in detail in the Reference Manual. Here is a brief description of each to satisfy your immediate curiosity.

| | |
|---|---|
| Orders | The number of harmonic orders in the Fourier analysis |
| Min | The minimum period in the search |
| Size | The size of the steps in the search. This is hours or days depending on the setting on the Configuration Photometry tab. |
| Steps | The number of steps in the search. |
| Bin | How many contiguous points to combine into a single point. |
| Max Diff | The maximum difference between two contiguous points. |
| Period | Period (reg): Steps increment arithmetically by Step Size |
| | Orders: The period is held constant but the number of orders ranges from Min to Min + Steps. Canopus is limited to 15 orders maximum. |
| | Period (auto). The step size increases geometrically in proportion to the start period and original step size. This helps avoiding the search skipping over the "correct" solution. |

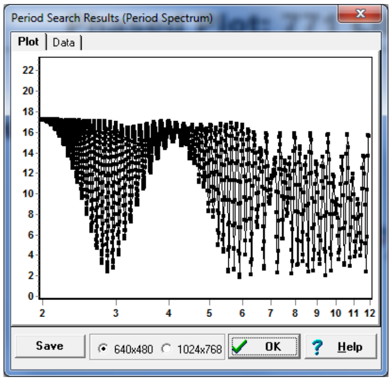
*See the Reference Manual for a more detailed explanation of the relation between the search type, Min, Size, and Steps fields.*

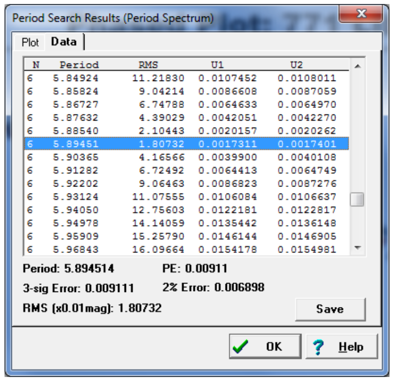
## *The Analysis*

3. Click <Find>. The result from running this tutorial is shown below.




4. Note the small form that also appeared. This is the “Comp Adjust” form and will be covered in a moment. Another form also appeared.




This is the “Period Spectrum” form. It has two tabs. The first is a plot of the results of the period search. The period (hours or days) is the X-axis and the RMS error (in units of 0.01 mag) is the Y-axis. A lower RMS error indicates a more likely period solution, with some caveats.

The second tab displays the data in a table and shows three error values:

PE (Probable Error): This is the error directly out of the Fourier analysis. It is often “too optimistic”.

3-sig Error: This is the 3-sigma error, i.e., 3x the probable error and more conservative and one often quoted.

2% Error: This is the error that would cause the last data point in the set (by date order) to be shifted by 2% (or, an error of about 7° rotation). It uses a formula similar to the one used to estimate the period error when doing spin and shape axis modeling.

The main lightcurve plot always shows the Probable Error.

## Which Error Value to Use

It is difficult to say that any one of the errors is *the* one to report in your final analysis. You need to use some common sense and review the amount of data, the total time span of the observations, and the fit of the data to the Fourier curve. If nothing else, it is better to be conservative rather than liberal.

## What is Right?

Asteroid lightcurve analysis has been called a bit of science and a bit of black magic. There are many possibilities to consider. We can cover only the basics here.

First, asteroid lightcurves *tend* to be bimodal, meaning that they have two maximums and two minimums per rotation. If you picture a spinning potato ("Spuds in Space!"), you can see why this would be the case – assuming that you were seeing the potato with its spin axis nearly perpendicular to the line of sight. However, if you're looking down on one of the "potato poles", then you won't see a bimodal curve but more likely one that is monomodal and has a very low amplitude.

If the asteroid is at a very high phase angle, all bets are off. You can have very complex curves with three or more maximums and minimums.

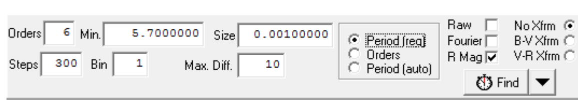
As a general rule of thumb, if the phase angle is low, the asteroid is near opposition, and the amplitude is < 0.10 mag, then you probably *cannot* say with certainty whether or not a monomodal or bimodal solution, the latter having a period about double that of the monomodal curve, is correct. If the amplitude is 0.10 – 0.20 mag, then the tendency is towards accepting a bimodal solution. As the amplitude increases, it is more likely that a bimodal solution is correct, especially with amplitudes of more than 0.3 mag.

If you look at the period spectrum plot, you see a number of solutions between 2.5 – 3.25 h and another set centered on about 5.7 h. That first group represents monomodal solutions, which have a period about one-half that of the bimodal solution. This fact can be put to good use, as will be shown later.

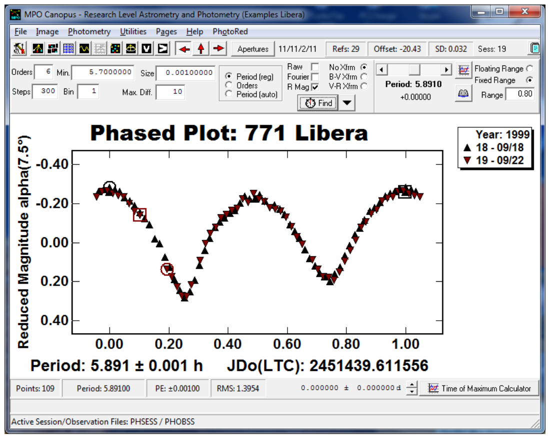
*Remember, these are all rules of thumb and you could end up all thumbs if you accept them as absolute. Fans of a certain series of movies will recognize the line, "We consider them to be more of a set of guidelines."*

5. In the first solution, a period of about 5.7 h was found with a bimodal lightcurve. Since the amplitude of the curve is more than 0.3 mag, we will presume that a bimodal solution is correct and what needs to be done is refine the search.

6. Reset the search parameters as shown here. Note that the period method has been switched to "Period (reg)."




7. Click <Find>. The results are show here.



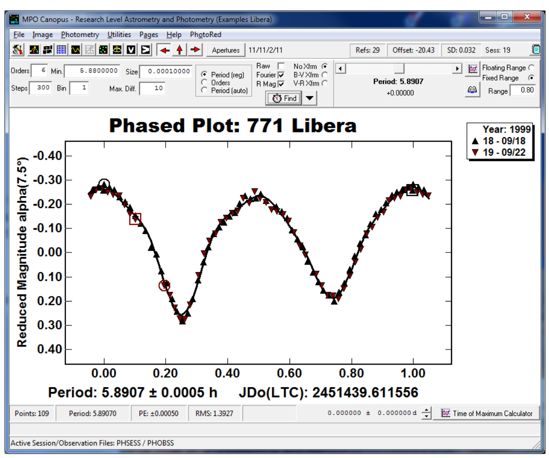

The phasing of the curves is almost perfect. We are very close.

8. When the error in the period (shown at the bottom of the plot) is equal to the step size, it is not a bad idea to refine the search a little more by setting the minimum period and a smaller step size that centers the new search on the period that was just found.

9. Set Size to 0.0001 h and the Min to 5.880 h. Leave Steps at 300.

10. Check the “Fourier” box. This is available only if you do not have the “Raw” box checked.

11. Click <Find>. Here are the results.




12. This is about the best you can do with the available data. If you want to experiment a little, try changing to higher and lower values for Orders. You’ll see that Orders = 8 gives a slightly better fit to the Fourier curve and higher precision (0.0006 h versus 0.0007 h).

13. Congratulations! You are now a steely-eyed lightcurve analyst!

***Do not close Canopus just yet. Move immediately to the next tutorial to explore using Instrumental magnitudes and the Comp Adjust form.***

# 4. The Comp Adjust Form

This tutorial covers using the *Instrumental* method and the Comp Adjust form. Even when using *DerivedMags* or *TrueMags*, the data from various sessions may not agree perfectly. There are several reasons. For example, there is the inherent error in the catalog magnitudes or the M/IR solution is not exactly the same for every image. Another may be color differences between the bulk of the stars used to find the M/IR and the target.

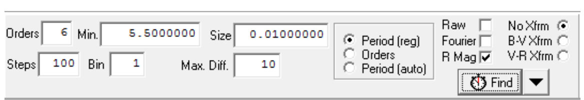
If you recall, Canopus corrects data from a given session to make it directly comparable to the first session. These corrections are based on using a specific value for the phase slope parameter, *G*. In most cases, *G* = 0.15 is used. This is not always correct and under extreme circumstances, one can get a better fit of the data by changing the assumed value of *G* and recalculating the corrections. The sessions form stores the value for *G* to be used to compute the corrections and so you can change that value and see if it makes for a better fit.

*All sessions involving the same target must use the same value of G. If you change one, you must change them all to agree with the first session for that target.*

The Comp Adjust form is used to change the DeltaComp values in sessions on-the-fly and visually so that you can immediately see the effect of changing the value for one session on the overall solution.

1. Open the configuration form and select the profile that you created in Lesson 1 of this chapter and change from the “Photometry Magnitudes | Method” from “Derived” to “Instrumental”.

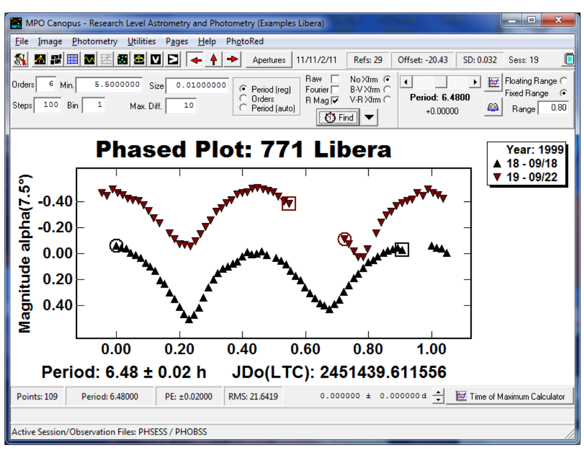
2. Go to the Lightcurve Analysis page (<Ctrl+4>) and set the search parameters as shown below. ***Make sure that the Fourier box is not checked.***

   We’re going to cheat by using parameters that are close to the final solution since we have a good idea of that final solution. In real life, you would start with the auto search as we did in the previous tutorial.

3. Click <Find>.

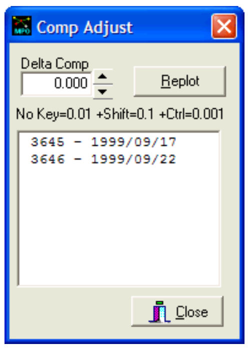
4. Select the sessions you created in the first tutorials of this chapter.



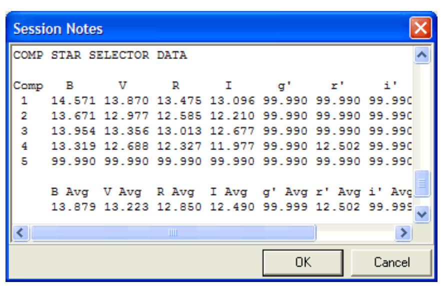
What happened?!

Remember that Canopus uses the DeltaComp values to correct differences in the comparison star average among sessions. DeltaComp = 0.0 for this initial search. We are using the average of the *instrumental magnitudes* of the comparison stars to find the differential value. Since we are using a different set of comparisons on the two nights, the average instrumental value for the two sets is not the same.

Normally, you would be sure to set the DeltaComps on the same "scale", i.e., 0.000 if using *DerivedMags* or *TrueMags* and the average of the comparisons found by the Comp Star Selector for *Instrumental*. You can change these values after the fact using the Comp Adjust form.




5. Open the Sessions form
   - Select the first session being used
   - Click <Edit>.
   - Click <Notes>. This displays the Notes editor.

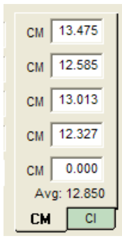



   - Scroll down until you find the CSS data and note the average R magnitude for the comparisons. In this case, it is 12.850.
   - Enter that value in the DeltaComp field.
   - Click <Save>.
   - Highlight the second session and find/enter its average R magnitude (13.453 when running this tutorial)

6. Click <OK> to close the sessions form after you have saved the changes for the second session.

## An Alternate Method

You may have noticed by now that the average of the comparison magnitudes is immediately available on the Sessions form; it's shown just below the five comp star values.




If you manually change any of the values or change the status of the "Use" box for a comparison, the average is updated immediately.

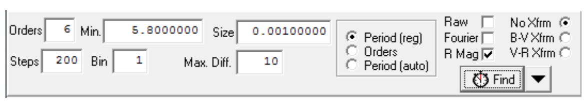
Instead of opening the notes form, you can simply enter the average value into the DeltaComp fields.

*If you should enter values for a comparison star directly, e.g., after finding more accurate values or finding them from another source, make sure you enter 0.000 for any star that is not used at all. Then, even if you check the "Use" box for the star, it does not affect the average. However, it* **still** *affects the calculations for the object during period analysis if "Use" is checked.*

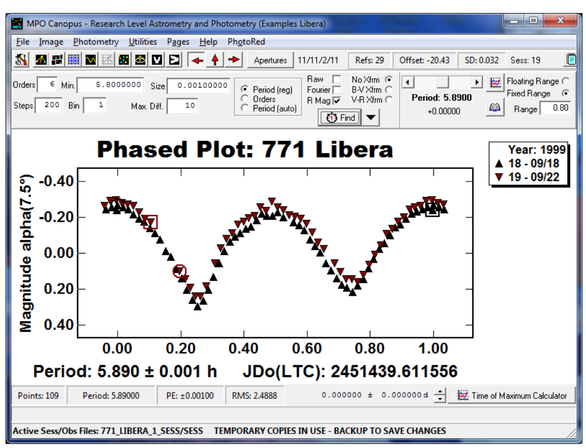
## Review the Results

Before finding the period again, remember that in the previous tutorial we found the period was about 5.88 hours.

7. Change the search parameters so that the search is about centered on that value.



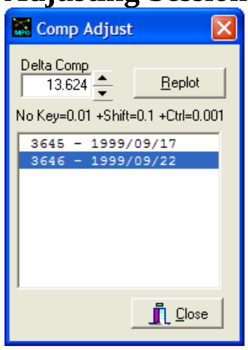

8. Click <Find> to redo the search.




Things are looking *much* better.

The two sessions don't match as well as in the previous tutorial, mostly because the vertical alignment (the zero point adjustment as reflected in the DeltaComp value) is not quite right.

## Adjusting Sessions with the Comp Adjust Form




The spinner control next to the "DeltaComp" field can be used to change the value in that field, or you can enter a new value directly. The spinner is easier since you can use the mouse all the time.

The legend just above the list of sessions tells how to change the amount the DeltaComp changes for each mouse click. Clicking on the spinner changes DeltaComp by 0.01 mag. <Shift+Click> causes DeltaComp to change by 0.1 mag while <Ctrl+Click> causes DeltaComp to change by 0.001 mag.

A given session always moves in the direction of the arrow, regardless if using *TrueMags* or instrumental magnitudes for analysis. So, if you click <Up>, all the data in the selected session move up.

You must click <Replot> to have the change take affect.

### *Changing DeltaComp for Several Sessions at Once*

You can change the DeltaComp values for two or more sessions in one step.

- Select two or more sessions. Note that when at least two sessions are selected, the "Delta Comp" entry field, its spinner, and the "Replot" button are disabled.
- Right-click over the list and use the popup menu to shift all the sessions up or down by 0.01, 0.05, 0.1, or a custom amount. If you select "Custom" from the popup menu, a small form appears where you enter the amount of the shift (from 0.001 to 99.999 mag). The value you enter is always positive. Canopus determines automatically if the data need to go up or down.
- The selection does not change after the multi-shift. However, the value in the "DeltaComp" changes to show the new value for the first item in the selection.

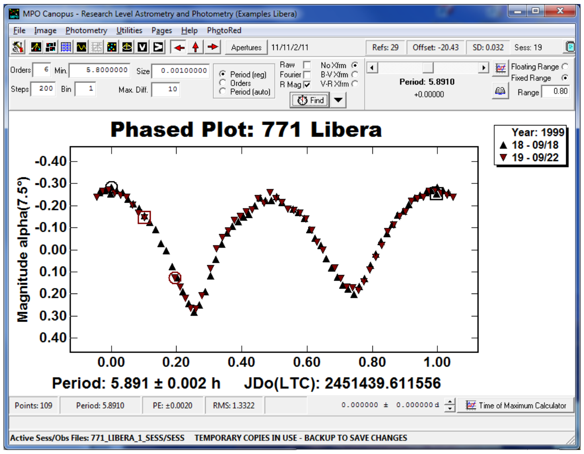
### *Restoring Values*

You can restore original values *as long as you do not click <Find> again*. Right-click over the sessions list and choose from the popup menu to restore the highlighted or all DeltaComps to their original values. Canopus automatically replots the data with the restored values – you do not have to click <Replot>.

## Changing the Second Session

9. The second session appears to be a little too high against the first session. So, highlight the second session in the Comp Adjust list and click the *down* arrow 3 or 4 times (do ***not*** hold down the Shift or Ctrl key).

10. Click <Replot>.




Now the two sessions are almost exactly on top of one another and the period solution has a much better precision.

You are now a steely-eyed lightcurve analyst with honors!

## *Keeping Changes to a Minimum*

By using more reliable native catalog values (not those derived from conversion formulae) and keeping the comps similar in color to the target, you can keep zero point shifts to a minimum. If you're working a long period amplitude object that might be tumbling, you really need 0.01 to 0.03 mag, agreement of the zero points.

You can come closer to achieving this if you use the SDSS r' magnitudes instead of R (or other BVRI filter) from the MPOSC3. The problem is that the sky coverage of the CMC-14 and SDSS surveys are not complete and so you may have fields that have no or not enough stars with r' magnitudes. You should ***not*** mix magnitude bands when establishing the M/IR or in the CSS for a given target over its entire run and so you may be forced to use R (or other BVRI filter) for your work. In the future, there promises to be a catalog with 0.02 precision data over the entire sky covering 10-17 magnitude. This "APASS" catalog, being developed by Arne Henden at the AAVSO, should make color differences the prime source of zero point shifts in the future.

## In Conclusion

An adjustment of < 0.05 mag (in other terms, < 0.05 mag agreement between nightly zero points) is very good. If you get < 0.03 mag shifts (not uncommon) then the results are excellent. Most people doing all-sky photometry under *average* conditions can't do much better, at least consistently. Of course, there are those who achieve much better results but usually in above average locations and only with very careful work. Our goal here is not to derive magnitudes for high-precision work but to get "good enough" agreement among sessions for proper period analysis.

As mentioned before, you should have the DeltaComp values in the sessions approximately right before you begin analysis. For *DerivedMags* or *TrueMags* analysis, this means 0.000 for all DeltaComps. For instrumental magnitudes, use the average of the comp stars found by the Comp Star Selector.

Of course, images and processes for tutorials are carefully chosen to provide easily obtained results without considering all the variations and considerations. Many subtleties were not covered in this chapter. Check the Reference Manual for additional information and above all, practice, practice, practice using the methods described here with your own images and data.

# Using PhotoRed

PhotoRed is a utility program that helps you perform a variety of special photometric calculations:

- Determination of your system's transformation coefficients, which convert your instrumental magnitudes to the standard Johnson-Cousins BVRI or Sloan (SDSS) g'r'i' systems.
- Determination of first and second order extinction terms.
- Determination of color indices.
- Determination of the nightly zero point.
- Conversion of instrumental magnitudes to exoatmospheric standard magnitudes.
- Automated observations of variable stars for submission to the AAVSO.

A detailed discussion of photometry and the derivation of the routines to derive the transformation values is beyond the scope of this Guide and even the Reference Manual. Readers should refer to the several excellent references listed in the Credits section of the Canopus/PhotoRed Reference Manual.

*PhotoRed and Canopus support Johnson/Cousins B, V, R, and I (and C as a special case) as well as Sloan (SDSS) g', r', and i' for reductions to standard magnitudes. They do not handle U or any other filters.*

## A Diminishing Need

PhotoRed was written in large part to provide the necessary steps to convert instrumental magnitudes taken during time-series work to standard magnitudes. By reducing to standard magnitudes, results can be directly related to other such data and make it easier for some studies since all data would be on a common, well-defined system.

With the *TrueMags* method in Canopus, all of this *almost* becomes moot when using *DerivedMags* or *TrueMags*, especially if using the SDSS magnitudes in MPOSC3. However, there are instances where a more detailed and rigorous process is necessary.

- Since the *TrueMags* method does not do differential photometry, it is still subject to variations due to changing conditions (more so than, for example, changing extinction). When differential photometry using instrumental magnitudes produces better results, then – if the observer requires – the data can still be put on a standard system.
- Until an all-sky, well-calibrated catalog is available, the *DerivedMags* and *TrueMags* values can still have some significant errors. That catalog is coming but it's not here yet.
- For *DerivedMags* and AAVSO batch processing, you can apply color corrections (based on the color index of the target and a given comparison star). These improve the quality of the data by making them conform better to the standard system and help remove scatter (errors) caused by color differences.

The need for PhotoRed may not be as great as before, but there is still enough need such that it is worth your time to work through some quick tutorials if for no other reason than to understand the basics of calibrated photometry.

## Save the Lesson Data

In the lessons that follow, many depend on observation data measured in a previous lesson (so that you don't have to re-measure images). This is one of the main advantages of PhotoRed; you can measure a set of images once and use the same data to find several different sets of values required for the transformation process. Save early and save often!

## Some Background Reading First

Before you begin these lessons, please read the opening sections of the PhotoRed Reference Manual, specifically those discussing the relationship between Canopus and PhotoRed. In addition, review the general discussions about first order extinction (FOE), transforms, color indices, and the overviews of the reduction methods. While some of the material may not make complete sense without the full examples to follow, at least you will have a good idea about what you should expect for results and some insight into the "why" of the steps you're taking.

The sections "First Order Extinctions – Is This Trip Necessary?" and the one that follows in the PhotoRed Reference Manual are very important. They may take more than one read. However, the better you understand the interrelation of the first order extinction and transforms values, the better you'll understand the overall process and master PhotoRed. In the lessons that follow, I will assume that you understand some of this material in order to avoid excessive repeating of background information.

## A Note about the Lessons and Images

As you go through the lessons, you may note that the images were not all taken on the same night with the exact same setup. Normally, this is not the way you should do things and this will affect the results in one or more lessons. *Do not let this point keep you from working through the lessons nor accept it as common practice*. The goal of these lessons is to learn the process and not to duplicate results exactly. Where and when necessary, the Guide will tell you how things could and should have been better.

Of course, should your results when working with "real" data appear to be in contradiction to what's reasonable, then you should re-examine your work. If your results don't change and you can account for no reason for the deviation, then you should report them and, if possible, why you think they are accurate.

## Lesson on Extinction by Comp Star – Don't Skip It

There is a tutorial on finding first order extinction values using the comparison star method. This approach is not generally recommended because it relies on highly stable conditions for long periods. This is not usually possible for most sites. Therefore the tendency is to skip this lesson, especially after reading the PhotoRed Reference Manual, which also discourages the comp star method. Avoid this temptation.

The first part of the lesson details the use of the Differential Photometry Wizard. The Wizard was created so that you would not have to measure images in Canopus just to find the color index and standard magnitudes of the comparisons and target as well as the standard magnitudes of the comparisons. These values are required in PhotoRed to reduce the target instrumental magnitudes to standard magnitudes. There's a built-in quiz in the lesson that you shouldn't miss.

# 1. Transforms and Modified Hardie First Order Extinction

There's no point in repeating steps when not necessary. This is best demonstrated by the fact that the Transforms and Modified Hardie First Order Extinction (MHFOE) methods can be run using the data obtained from a single combined set of images taken of two reference fields.

As covered in the opening sections of the PhotoRed Reference Manual, the MHFOE method relies on having transforms. This is backwards to most people's thinking but it really does work. The transforms value for a given filter is the slope of a linear regression using the instrumental magnitudes in that given filter versus the standard (catalog) color indices of the stars that were measured. It turns out that the transform values (slopes) *are independent of first order extinction.* If you change the FOE values when finding transforms, the only thing affected is the zero point of the linear regression.

Furthermore, the only way the MHFOE method can work is to use the transforms against standard color index values for the stars being used in the analysis. This converts the instrumental magnitudes close to the standard system, on which Hardie's original method relied. The MHFOE method provides poor results at best if this is not true.

The above are very important concepts in PhotoRed. Understanding them makes understanding and using PhotoRed *much* easier. See the "First Order Extinctions – Is This Trip Necessary?" and the following section in the PhotoRed Reference Manual for a detailed explanation.

The Modified Hardie First Order Extinction (MHFOE) method is preferred over the comparison star method for several reasons.

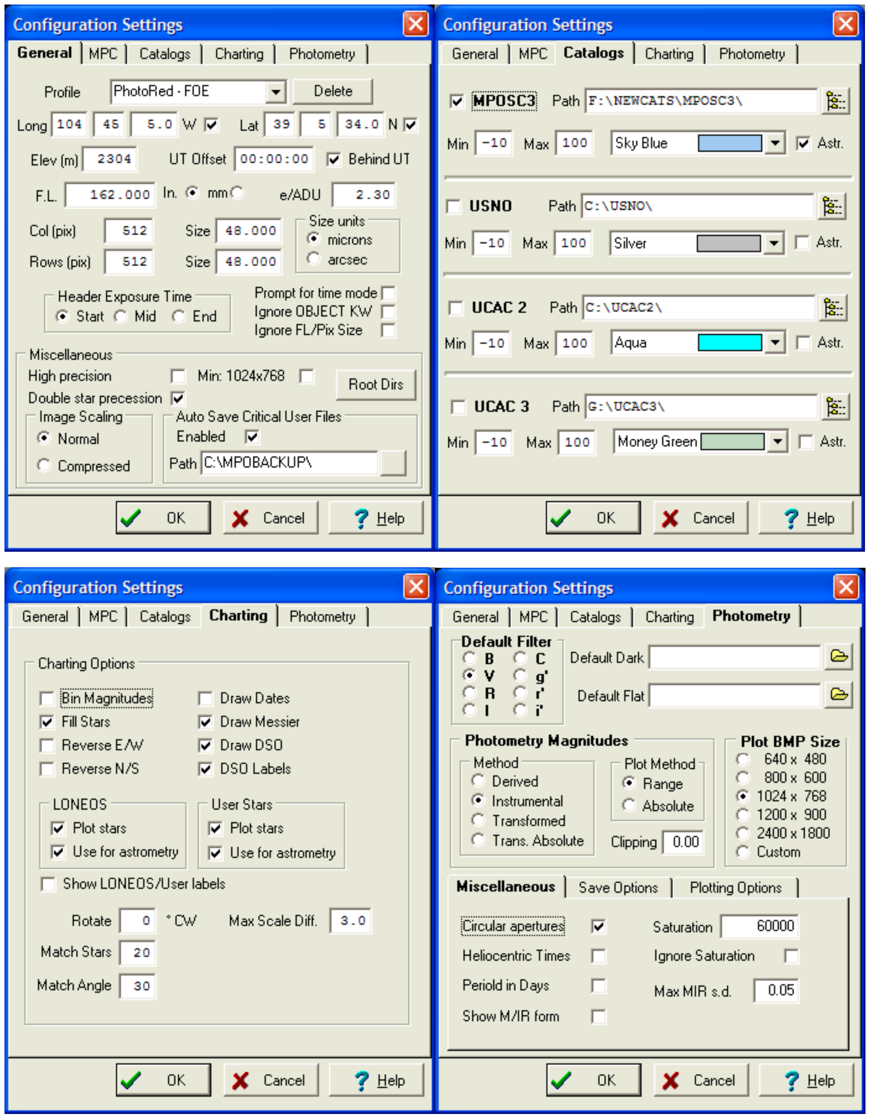
- It takes only a few minutes, thus leaving more time for observing the program field.
- It avoids problems with changing photometric conditions through the night.
- It uses standard (or near standard) stars, so the catalog values are well known.

## Getting Started

In this tutorial, you'll use some images taken of a field at air mass 1.06 and another at 2.0.

1. Open the configuration form in Canopus and match the settings on the screen shots below. PhotoRed does not allow you to create or change the profile setting, so you must make sure you have the settings entered in Canopus first. The reason for this restriction is because more than one instance of Canopus can be started at a time. The currently selected profile name in Canopus is used to keep track of settings among the multiple instances.

*Note that you're creating a new profile name in this tutorial. You won't necessarily create a new profile name each time you run the program. You're creating this one so that the settings match the system used to take the images you're about to measure. If you have several setups, creating a separate profile makes using Canopus and PhotoRed much easier. Instead of changing values on one or more page of the configuration form when you measure images taken with a given system, you can simply select a profile of preset values.*




*Turn off (uncheck) "Autosave raw data" on the "Save Options" subtab on the Photometry page.*

2. Once you have matched the settings, click <OK> to save the new configuration.

3. Switch over to PhotoRed by selecting "PhotoRed | Launch PhotoRed" from the Canopus main menu. If you want, you can hide the Canopus main form by selecting "Canopus | Hide Canopus" from the PhotoRed main menu.

## Measuring Field 1

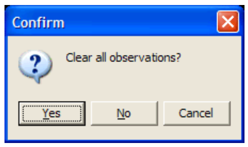
4. Set the apertures to 11x11/2/11 for target, comps, and astrometry. See "Setting the Apertures" tutorial in the Core Operations chapter.

5. Select “Image | Open” from the main menu and open the file

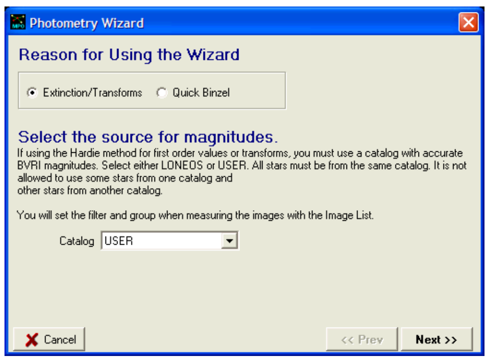
   \MPO\EXAMPLES\PHOTORED_FOE\AK_GEM_REF_C_00001.FIT

6. Select “Image | Auto match/measure” from the main menu (<Ctrl+A>). The program matches the chart to the image.

7. Select “Photometry | Photometry Wizard | Transforms” (or <Alt+W>) to start the Photometry Wizard. This displays a confirmation message.

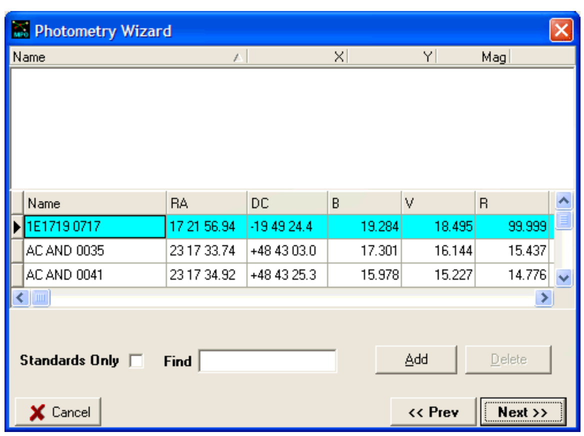



8. Select Yes. This displays the first page of the Transforms Wizard.

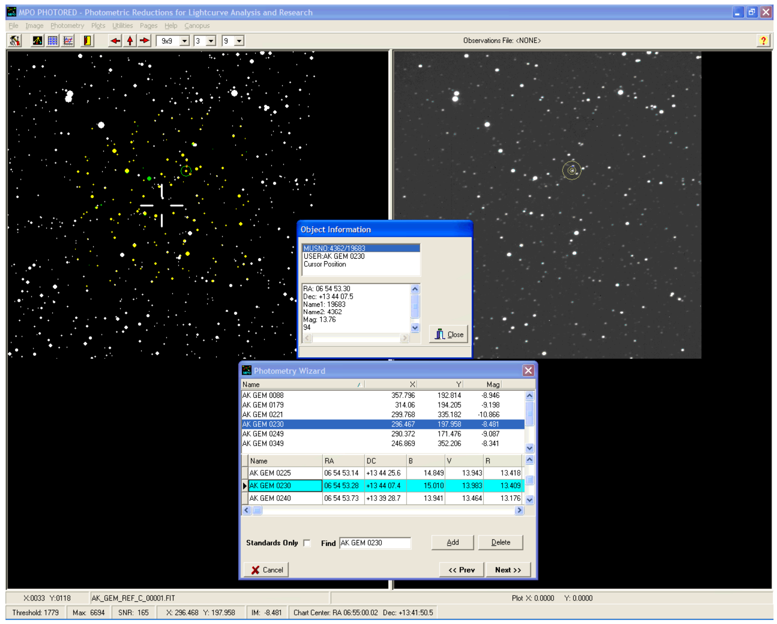



9. Select “Extinction/Transform” in the radio group and “User” in the “Catalog” drop down list.

10. Click <Next>. This displays another page of explanatory text. After you’ve read the text, click <Next>. This displays the USER catalog embedded in the Photometry Wizard. The goal from here is to measure the several USER stars in the image.



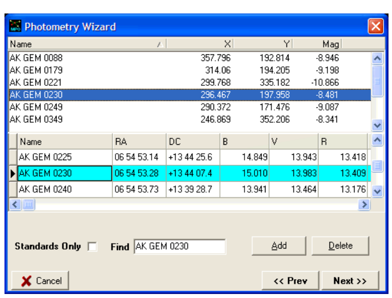

Use the screen shot below as a guide for the new few steps.



*You're about to have the PhotoRed form, the Wizard, and one other form on the screen. Arrange things as you need. Use the zoom box. It helps seeing faint companions near potential candidate stars.*

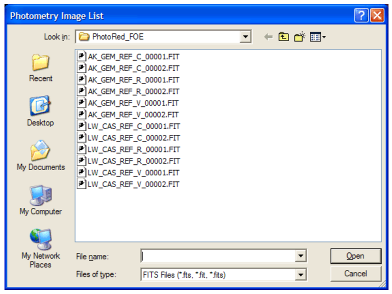
11. <Ctrl+Click> on the star in the image that has apertures around it.
12. Note that in the "Find" field of the Wizard, the table has been automatically positioned to the star and that its name is in the "Find" field.
13. Click <Add> on the Photometry Wizard. The data for the star appears in the list on the Wizard.
14. Repeat steps 14 through 16, using a different star each time, until you have at least five stars, more is preferred. If you click on a star that is not in the UserStar catalog, the program beeps. If you select a star that is already in the list and then click <Add>, the program displays a message and does not add the star again.

*When selecting stars, avoid those that have close companions and/or are very faint. This helps avoid "bad data" points later on.*

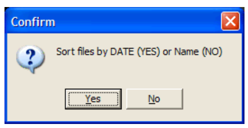



The screen shot above shows the wizard after a number of stars have been added.

15. Click <Next> to display the final page of the wizard and then click <Finish>. This displays a file selection list.

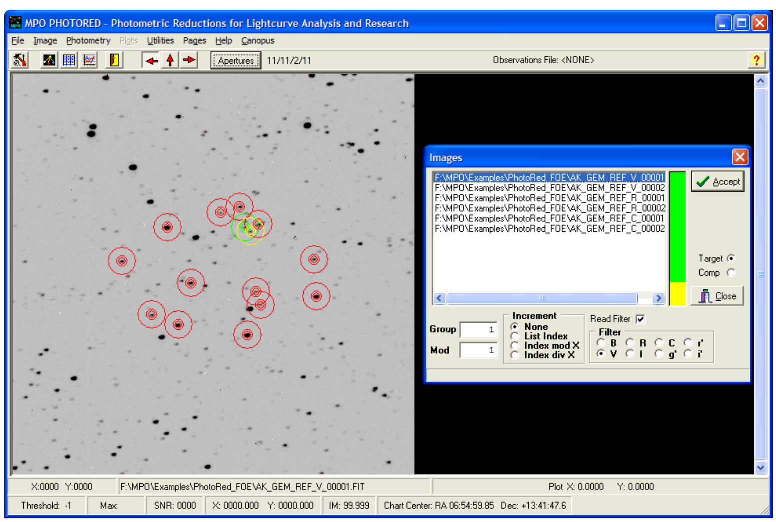



16. Select all the images for AK GEM and then click <Open>. This displays a confirmation message.




17. Click <Yes>.

*Since the images were taken so that all of those of one filter were taken back-to-back, the selected images are grouped by filter regardless of your choice. However, this will not always be the case and which option you chose can have a profound affect on the final results. See the Reference Manual for additional information.*




18. Double-click on the first image in the list. You should see something like the screen shot above for the image.

*You may have selected different stars, so the number and placement of apertures may be different. The important point is that you see the "anchor star" surrounded by green (lime) apertures.*

19. Set the controls as shown in the screen shot above.

*By setting Group to "1" and selecting "Increment | None", all the images will be put into the same group, i.e., Group 1. See the Reference Manual for additional information about groups.*

*The Read Filter feature (activated by checking the "Read Filter" box) requires that the FILTER key word be used in the FITS header and that the values assigned to that key word use the standard names for BVRIC filters, i.e., B(lue), V(isual), R(ed), I(nfrared), and C(lear). For SDSS filters, the entries need to be g', r', or i'. Your imaging software must follow these conventions when writing data to the FITS header. MPO Connections does include the FILTER key word and allows the names to be mapped to meet the naming requirements.*

20. The apertures should be centered over the stars. If they are not, click on the anchor star. This should reposition all the apertures so that they are centered over their respective stars.

21. Click <Accept>. This measures the image and automatically loads the next image in the list, which is the second V image.

22. For each successive image, confirm that the apertures are centered after the image is loaded. If not, reposition them. Confirm that the "Filter" radio button setting matches the filter for the image (the name of the sample files contains the filter). Then click <Accept>.

23. Repeat until all images are measured.

24. Click <Close>.

25. The file save box appears as soon as you close the wizard. This helps assure that you do not forget to save your data. Save the file under the name

    PHOTORED_LESSON1.OBS

Of course, you can select about any name you want but future lessons will refer to this specific filename.

## Measuring Field 2

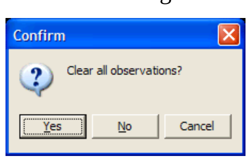
26. Select "Image | Open" from the PhotoRed main menu and open the file

    \MPO\EXAMPLES\PHOTORED_FOE\ LW_CAS_REF_C_00001.FIT

27. Set the apertures to 9x9/2/11. These images have much better seeing and the available stars have closer companions that can be excluded by slightly smaller apertures.

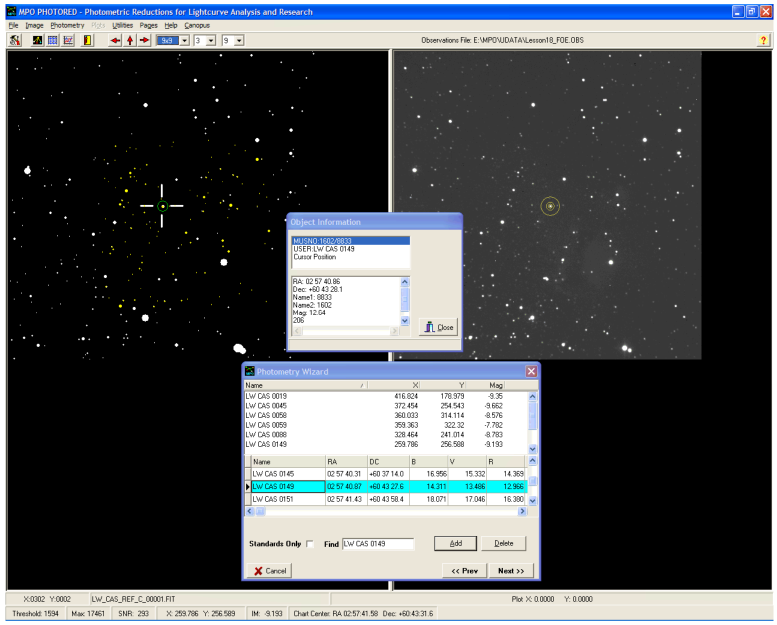
28. AutoMatch the image.

29. Start the Photometry Wizard as you did for the first image. This displays the confirmation message.




30. ***Click <No>***. You want to add the observations you're about to measure to those from the first field. If you click <Yes>, the observations from the first field are deleted.

Use the screen shot below for the next few steps.

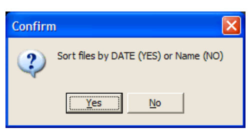


31. <Ctrl+Click> on the star on the image that has apertures around it. This is your anchor star for the second set of images.

32. As you did with the first image, select an additional set of stars with no less than five stars and preferably 10 or more.

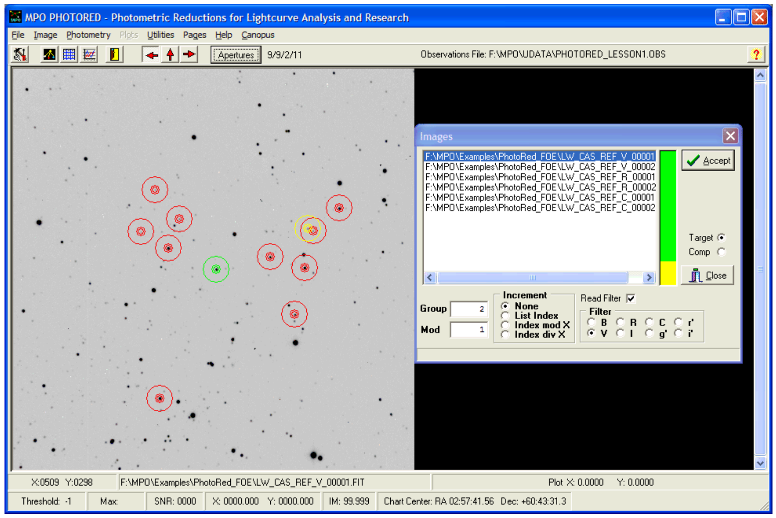
33. When done defining the stars to be used, click <Next> to the last page of the Wizard and then click <Finish>. This presents the file dialog.

34. Select all the images for LW CAS.




35. Click <Yes> on the confirmation message.

Use the screen shot below for the next few steps.




36. Double-click on the first file in the list. This loads the image and displays the measuring apertures. Again, you may have selected different stars. Make sure that the anchor star has the green (lime) apertures.

37. ***Set the Group number to 2.***

38. As you did for the first set of images, as each image is loaded confirm that the measuring apertures are centered and reposition them if necessary. Also confirm that the “Filter” radio button matches the filter for the image (the filter is included in the file name).

39. Click <Accept> to record the data and move to the next image.

40. Repeat until all images are measured.

41. Click <Close>.

42. The file save box comes up as soon as you close the wizard. Save the file under the same name you previously saved the data, i.e.,

    PHOTORED_LESSON1.OBS

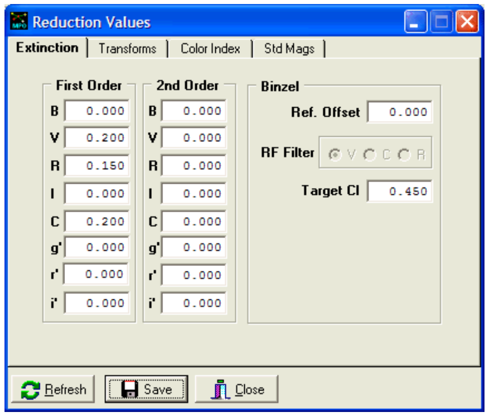
PhotoRed warns that you are about to overwrite the file. Click <Yes> to overwrite the file, which now contains the data for both images.

You can take a break here if you want. However, you’re just a few seconds away from seeing the results of your efforts so far. You may have a little work to do, e.g., removing some bad stars from the solution set, but that won’t take long either.

## Transforms First

Contrary to some conventions and for the reasons discussed at the start of this lesson, we’ll find the transforms first. The assumption is that you have not previously measured images for the night and so must use assumed first order extinction values when finding the transforms.

43. From the PhotoRed main menu, select “Photometry | Transforms values” (or <Ctrl+T>). This opens the transforms form.

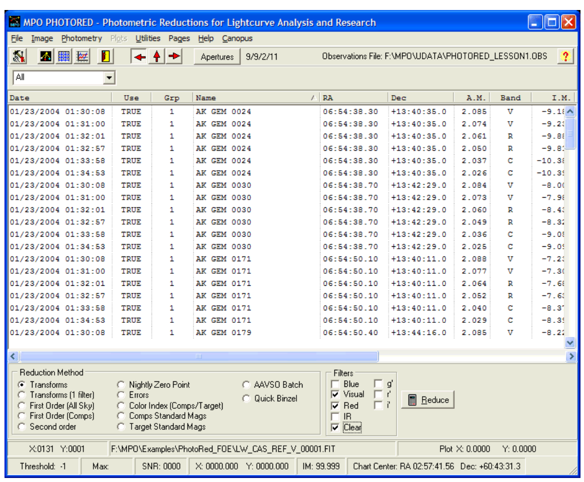



44. Go to the "Extinction" page and enter the values shown above for the First Order V, R, and C fields. These are just estimates. Don't worry about the other values on the tab.

*When entering assumed values, the V and C extinctions should be similar while the R should be a little less than V, so that V-R is a small positive number on the order of 0.05mag.*

45. Click <Save> and then click <Close>.

46. If not there, go to the Reductions Page (<Ctrl+2>).




*Remember that your data may not be exactly the same since you may have picked different reference stars.*

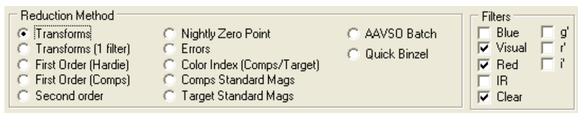
47. Click on the "Grp" column header so that the data is sorted by group number. If Group 2 is at top, click the column header again.

48. Make sure you are scrolled all the way to the top of the data list and then click on the first observation.

49. Without clicking on the data list, scroll down until you see the first observation in Group 2.

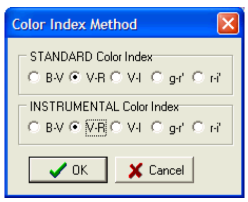
50. <Shift+Click> on the last observation in Group 1. This should highlight all observations in Group 1, which should be the lower field and have an air mass value near 2.0.

51. Right-click over the data area and select "Set Use to False" from the popup menu. You should see the entries in the "Use" column of the table change to *False* for the selected observations.




52. Select the "Transforms" method under "Reduction Method" and check the boxes for Visual, Red, and Clear.

53. Click <Reduce>. This displays a form asking which color index to use.

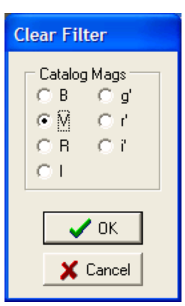



54. Select V-R for the color index in both sections.

*Normally, you would think that because you took images in V and R that you would automatically select V-R for the "Standard Color Index", and you'd be right. However, strange as it seems, PhotoRed allows finding a standard color index different from the filters used, say B-V versus v-r. This mixing of color indices is not generally recommended because of secondary extinctions and other factors. However, tests have shown that good to excellent results – judged by comparisons to reduced magnitudes of stars in reference fields – can be obtained. See the PhotoRed Reference Manual for additional information.*

***Very Important!*** *Even though you can select an "off-color index", there must still be catalogs magnitudes for the filters for which you are trying to find transforms. For example, the program uses r-R (instrumental minus catalog) magnitude when finding the R transform. It cannot use B, or V, or any other magnitude to find the transform for R.*

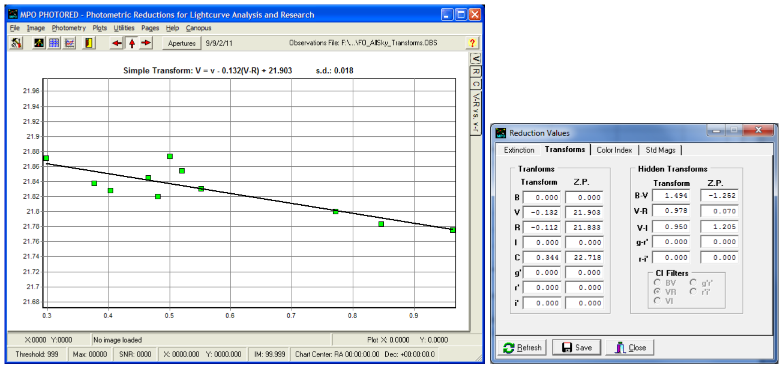
55. Click <OK>. This displays another selection form.




56. Select the "V" radio button.

*When transforming Clear observations, you can have them referenced to any one of the supported filters. Usually, this is "V" and so PhotoRed would find the transform that converts a Clear instrumental magnitude to standard V. Regardless of your choice, and as noted above, there must be catalog values for which ever filter you chose.*

57. This displays the V plot and Transforms form.




58. Using the data measured for this tutorial, the standard deviation for the linear regression line is 0.018 mag.

59. Click on the "R" and "C" tabs at upper right to display the results for those filters.

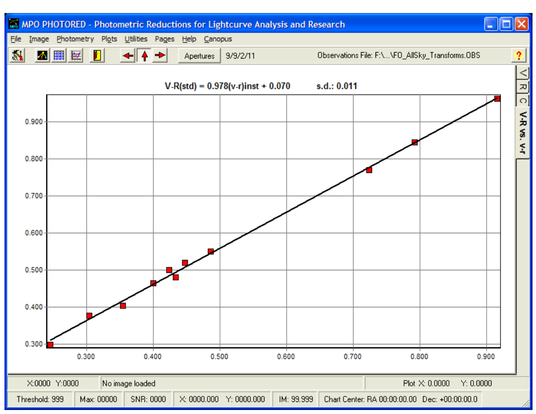
## Fixing the Data

If you have a data point that is significant off the line and affecting the solution dramatically, click on that point.

The name of that star along with its group number and X/Y values appears at the bottom right. Use this information to go back to the Reductions page and set the "Use" flag to *False* for the observations in the given filter for the star and re-run the method. You may not have to remove the star (set the "Use" flag to *False*) for all observations in all filters. Maybe just one filter was bad or even just one observation.

## The Hidden Transform (Instrumental CI to Standard CI)

60. Click the "V-R vs. v-r" tab.



This shows the so-called "hidden transform" that allows PhotoRed to convert a known instrumental color index into a standard color index. In this case, v-r to V-R. The slope of this line should be close to 1.00, which would indicate a perfect color match of your system to the standard system. You also want a small standard deviation.

Also important is that the v-r values (the X-axis) cover as large a range as possible. As with any linear regression solution, confining the values on the X-axis can produce bad results by forcing extrapolation to smaller and/or larger values. This will be clearly seen when finding the first order extinction using comparison stars.

61. If you're satisfied with the results, click <Save> on the Transforms form and then click <Close>.

62. Make sure that you save the observations data again if you made any changes, e.g., marked the "Use" flag some stars to *False*.

## *A Look at the Results*

When running this tutorial, these results were obtained.

| Filter | k' | Tx(V-R) | ZP |
|---|---|---|---|
| V | 0.200 | -0.132 | 21.903 |
| R | 0.150 | -0.112 | 21.833 |
| C | 0.200 | +0.344 | 22.718 |

At the end of the lesson, you'll see how the $T_x$ value (transform for a given filter) does not change (or very little) but the $ZP_x$ (zero point value) does when actual first order extinction values are used instead of the assumed values.

## Finding the First Order Extinction (FOE) Values

Assuming that you've saved the data and the transforms, you can take a break if you want. However, you're very close to being done, so hang in there.

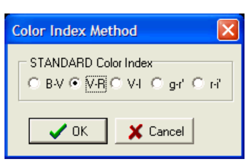
63. Go back to the Reductions page (<Ctrl+2>).

64. If you changed the sort order of the data for some reason, click on the "Grp" column header until the observations for Group 1 are at the top of the data list.

65. Select all the observations for Group 1 and use the popup menu to change the "Use" column back to *True*.

66. Select "First Order (Hardie)" in the Reduction method and confirm that only the Visual, Red, and Clear boxes are checked.

67. Click <Reduce>.

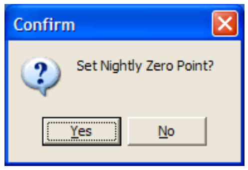



68. Select "V-R".

This method uses only catalog magnitudes and so it is not necessary to select which instrumental color index to use.

*You must have observations in the two filters of the selected color index and there must be catalog values for those filters for this method to work.*

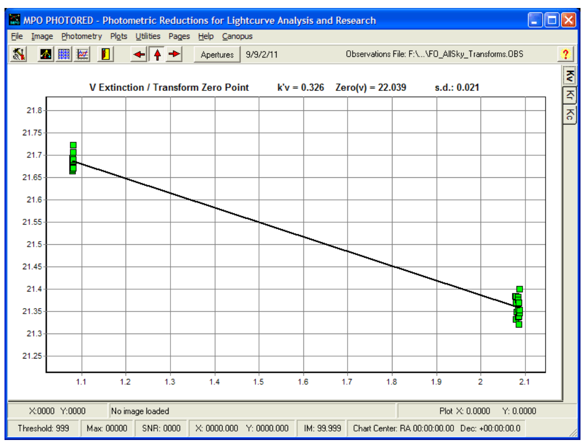
69. Click <OK>. You are asked if you want to set the nightly zero points.




70. Click <Yes> to display the Transforms form and V plot.

71. As before, you're asked which standard filter magnitudes to use for the Clear filter. Click <V> for Visual.

*Remember that finding the transforms earlier also found nightly zero points based on the assumed FOE values. Since we are finding the true FOE values, which – in this case – are not the same as those assumed values, we must accept the new nightly zero points. Otherwise, all the reduced standard magnitudes will be in error. See Appendix A of this Guide where this lesson is repeated and you do not set the nightly zero points.*




Again, your results may be different. Note the tight grouping of the data at each end. The group on the right is the data from the high air mass (lower) field while the data at upper left is from the low air mass (higher) field. If the data are spread widely at either end, you may have some "bad" data points and need to remove them from the calculations as described above.

72. The standard deviations in the derived values were on the order of 0.02 mag, which is very good for my location.

    The $k'_{V\text{-}R}$ was +0.063. This is good because it means that the V first order extinction is greater than for R and that the two are similar. Remember that this value should be on the order of +0.05.

73. Click on the "R" and "C" tabs to review their solutions.

74. If satisfied with the results, click <Save> on the Transforms form and then close that form.

# 2. Transforms Errors

This lesson assumes you did the previous tutorial and saved the observations data from that tutorial. Here, we'll presume you saved the data under the name

\MPO\UDATA\PHOTORED_LESSON1.OBS

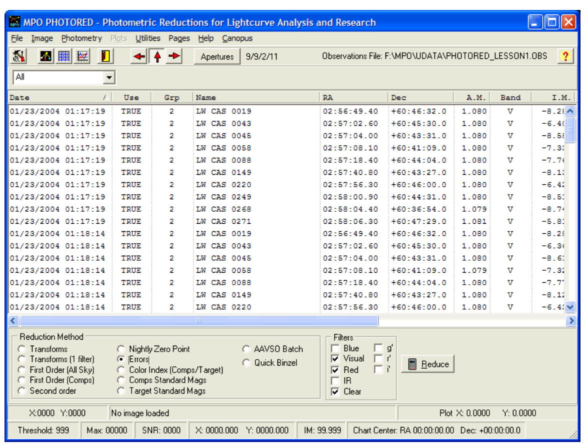
The point of this tutorial is to allow you to review the quality of the transforms and zero points you found earlier by using them against the original data. In a perfect world, using those transforms and zero points against the original data should produce standard magnitudes that exactly match the catalog values.

You don't have to run this routine every time you find transforms but it's a good idea to do "spot checks" from time to time, just to be sure your results are valid. If nothing else, this routine helps spot a "bad" star that might be adversely affecting the transforms values.

*You won't be measuring any images in this lesson, so you don't need to worry about configuration settings.*

1. If you closed PhotoRed after the previous tutorial, you need to open PhotoRed and load the data. If you've moved directly here from the previous lession, you can skip to step 5.

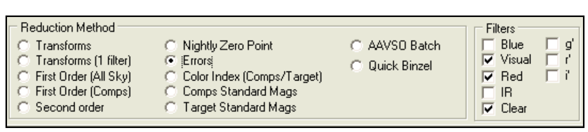
2. To load a PhotoRed OBS file, select "Photometry | Load observations" from the PhotoRed main menu. This opens a Windows file dialog. Locate and open the appropriate file.




3. Remember that the data are for two fields, one high and one low, and that you found the transforms using only the higher field.

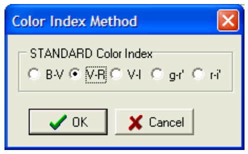
4. Click on the "Grp" column header to sort the data by group number.

5. Select all the data from Group 1 and use the popup menu to set the "Use" flag to *False*.




6. Set the Reduction Method and select the filters as shown in the screen shot above.

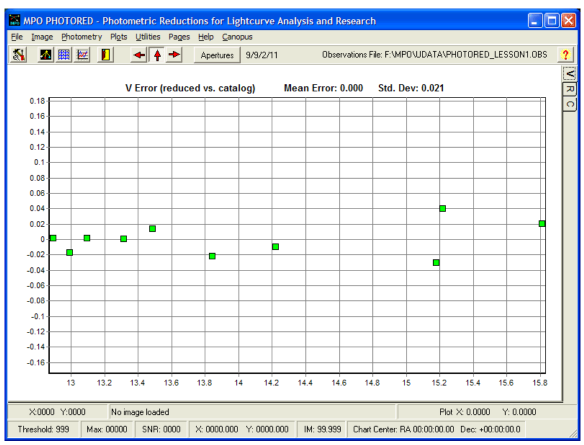
7. Click <Reduce>. This displays the form to select a color index.




8. Select “V-R” since this is color index that you used to find the transforms.
9. Click <OK>. This displays the form to select to which filter to convert Clear magnitudes.
10. Select “V” since that is what you used when finding the transforms.

*In this and other reduction methods when you are offered a choice of color index or Clear to “X” filter, you* **must** *select the same values that you did when finding the transforms. It will not do to find transforms in terms of B-V and later select V-R.*

11. Click <OK>. This displays the Plots page.




Remember that your results may be different. The point here is to check the mean value – it should be 0.000 or very close to it – and the standard deviation of the errors. In this case, it is 0.021 mag for the V filter (R had 0.014 mag and Clear had 0.019 mag standard deviations).

12. Click the “R” and “C” tabs to see the results.

*If you don’t use Landolt standard fields for finding transforms, be sure to document which field you did use*

## Check Again

It’s not really valid to run the errors test on the same data used to find the transforms. Try running the test on the data for the lower field by setting the “Use” flag to *True* for the Group 1 stars *only*. Here are the filters, mean errors, and standard deviations found when running this tutorial

V: 0.006 ± 0.021 R: 0.009 ± 0.015 Clear: 0.013 ± 0.022

Given the large air mass of the lower field, these results are very good.

# 3. First Order Extinction – Comp Star II

One of two methods of getting data into PhotoRed is outlined here. In either case, the general approach requires that you follow a target field over a large range of air mass values in order to determine first order extinction (FOE from here on; I'm tired of typing "first order extinction"). Changing conditions for all but the best sites often makes getting a usable value difficult.

The Modified Hardie First Order Extinction (MHFOE) method, covered in the previous lesson, is preferred for finding first order extinction values. The comparison star method requires that conditions be not only stable but "photometric" quality for the duration of the run. This occurs very rarely for most sites, especially "backyard observatories".

## Don't Save Anything

Do not save the FOE values found in this lesson. Read the steps at the end of the lesson carefully. If you save the FOE values, those found in the previous lessons are lost. In this case, you will have to go through the reductions part of the transforms tutorial again (assuming you saved the data from that lesson) so that you can complete future lessons with the correct transforms, first order extinction, and zero point values.

You can save the observations data if you want, but they are not used in other lessons.

## Two Roads Converge

You can find FOE values using a comparison star by two means in PhotoRed. One involves using PhotoRed directly while the other takes advantage of data from Canopus that you created for time-series analysis. Eventually, the two methods reach a common point, which is where you have several groups of observations that cover a large range of air mass.

As discussed in the PhotoRed Reference Manual, a group is set of observations that are treated as if the images were taken at the same time. If you take a set of filtered images of the target field every half hour for the specific intent of finding the FOE for each filter, then each of those sets would be assigned its own, unique group number.

Whether you use PhotoRed or Canopus depends on the images you have. If you took a time-series in one or more filters and plan to measure them in Canopus so that you can do period analysis as well as convert to standard magnitudes via PhotoRed, then you should import that data from Canopus. That process is covered in the next tutorial.

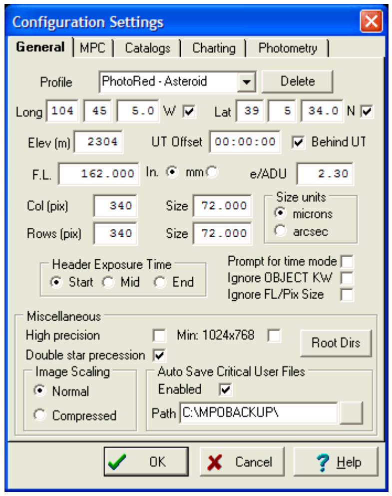
If during the night you periodically returned to a given field so that you could get data over a range of air mass values and will not be measuring those the images from that field in Canopus, then you should use the method outline in this lesson in which you measure images only in PhotoRed.

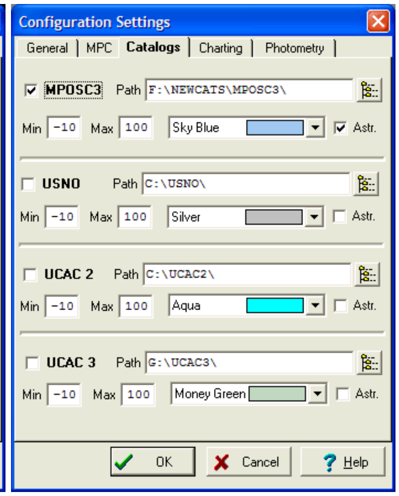
The method in this and the following lesson use the same configuration settings since you'll be measuring the same images for both exercises.

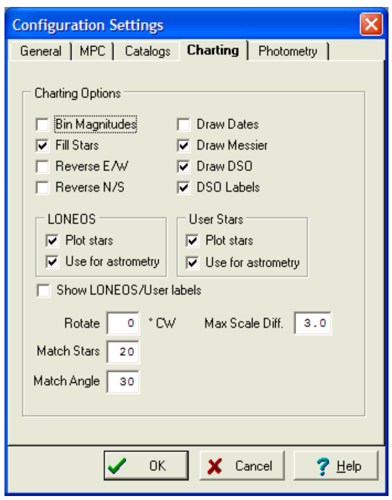
### *Setting the Configuration*

You'll create a new profile in this tutorial. Remember that all you need to do is open the Configuration form and type a new name into the "Profile" combo box, set the values on the various tabs as desired, and then click <OK> to save the new profile.

1. Open the configuration form *in Canopus* and match the settings in the screen shots below.




2. Switch back to PhotoRed and, if you want, use "Canopus | Hide Canopus" on the PhotoRed main menu to hide the Canopus form.

## Running the Differential Photometry Wizard

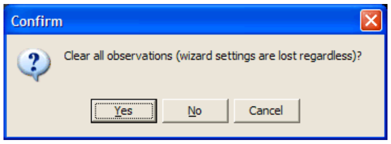
The next step is to run the Differential Photometry Wizard. This gives PhotoRed information about the comparison stars and asteroid (or other target) on a series of images. After this, you'll be able to run the FOE routine. If you have images in more than one filter, you'll also be able to determine the instrumental color index of the comps and target.

3. Use the blinker in Canopus with the following two images to determine which "star" is the asteroid.

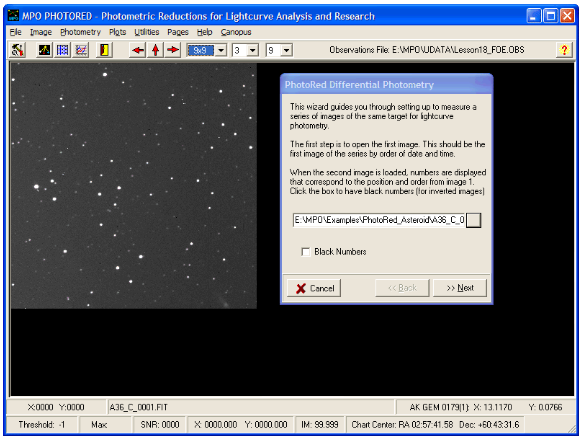
   \MPO\EXAMPLES\PHOTORED_ASTEROID\A36_C_0001.FIT
   \MPO\EXAMPLES\PHOTORED_ASTEROID\A36_C_0124.FIT

4. Set the PhotoRed apertures to 9x9/2/11

5. Start the Differential Photometry Wizard in PhotoRed (<Ctrl+W> or "Photometry | Photometry wizard | Differential Photometry" from the main menu). This displays a message.

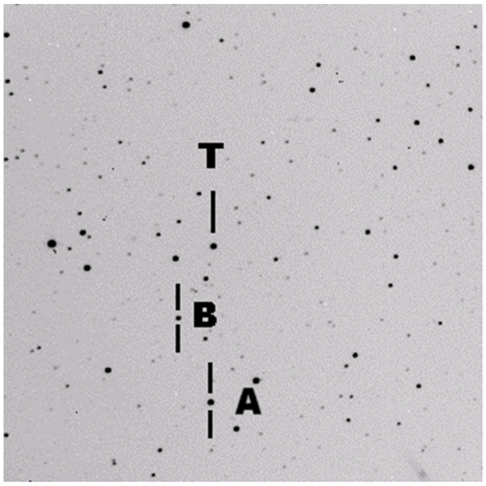



6. Click <Yes>. This displays the first page of the Differential Photometry Wizard.



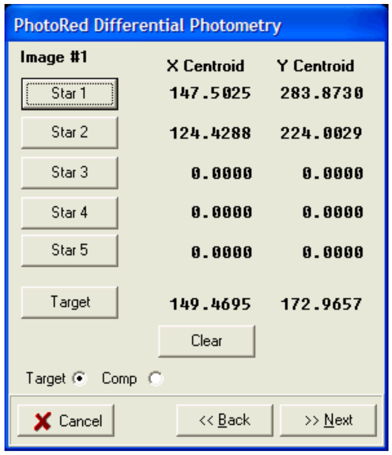

This wizard works identically to the one you used in the Photometry chapter to set up measuring images to find an asteroid's lightcurve in Canopus.

7. Load \MPO\EXAMPLES\PHOTORED_ASTEROID\A36_C_0001.FIT
8. Click <Next> until you get to the page to select the comparisons for Image 1.




Use the reference image above for the next few steps.

9. Set the two comparison stars and target on the wizard by clicking on each one and then the appropriate button on the page. You should see something like this:



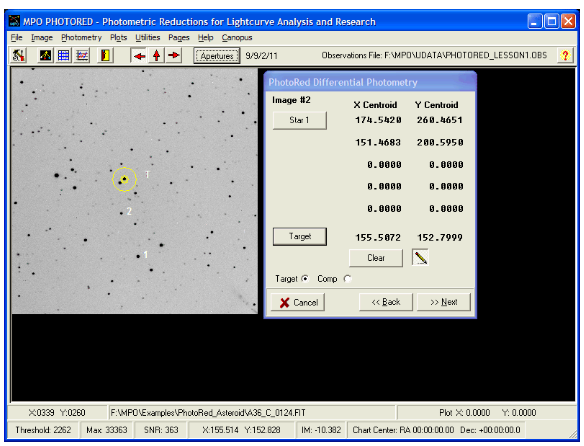

☞ *The Comp Star Selector is not available on this wizard.*

10. Click <Next> to go to the next page and load the second image,

    \MPO\EXAMPLES\PHOTORED_ASTEROID\A36_C_0124.FIT

11. Click <Next> until you get to the page to set the comparisons and target on the second image.

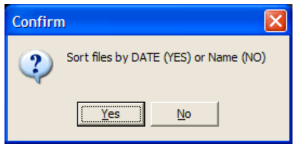
12. Set the positions for the comparisons and target.




13. Click <Next> until you get to the end of the wizard and then click <Finish> to display a Windows file dialog.

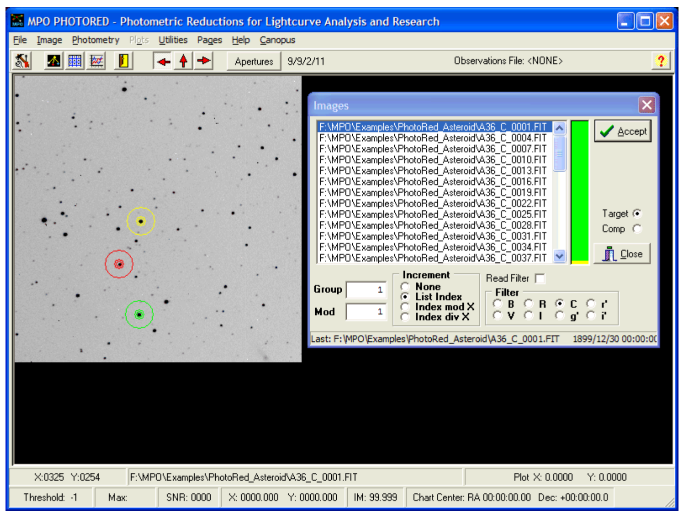
14. Select all the Clear (A36_C_*.FIT) files ***except*** A36_C_0124 and A36_C_0127. The asteroid is too close to a field star for those images to be used.

15. Click <Open> on the file dialog. This displays a message.




Depending on how the file names are created by your imaging program, the images you select for measuring in PhotoRed may not always be in chronological order or grouped by filter (if the program includes the filter in the file name). This option allows you to try to sort the files in the list so that they make measuring as easy as possible by not having to switch filters on the Images List about to come up. Experience will tell you how to answer this question for a given situation.

16. Click <Yes>. This displays the Images List form.




17. Check the “Increment | List Index” radio button. This automatically assigns the Group number to the list index + 1 (the list index starts with 0. Since 0 is not a valid group number, PhotoRed automatically adds 1 to the list index).

18. Do ***not*** check “Read Filter”. The images do not have the FILTER key word in the header and so PhotoRed cannot automatically make the filter selection.

19. Select the “C” filter.

*AutoMatch and auto-processing are not available on the PhotoRed Image List.*

20. Double-click on the first image in the list. This loads the image and automatically measures the comps and target, as shown in the screen shot above. Note that the “Group” box now shows “1”.

21. If the apertures are centered on the appropriate objects, click <Accept> (or press <Enter> if the Image List form has focus). This records the data for the observation and automatically loads the next image.

***Proceed carefully in the next step****. If you make a mistake and click <Accept> with the apertures in the wrong place, you can still double-click on the mismeasured image in the list, position the apertures, and then click <Accept>. However, unlike Canopus, PhotoRed always appends data and so it will not overwrite the bad data with good. When you go to reduce the data, you will need to delete the offending observation or set "Use" to* False.

22. Repeat until all the images are measured. If the apertures are not properly centered, click on the anchor star ("A" in the reference image) to reposition them.

23. After you have measured the last image, click <Close>. This causes a file save form to appear. Save the file so you don't lose your data. For this tutorial, use the file name

    \MPO\UDATA\PHOTORED_LESSON3.OBS

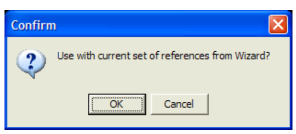
*The data from this lesson are not required for future lessons but you should get in the habit of saving your observations data. The one time you don't is the one time you really should have.*

## Measuring the V and R Images

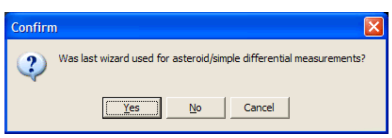
You will now measure the V and R images. This is a slight difference from what you did above, but only for the first few steps. Once you get to the point of running the wizard, the only difference will be which files to measure and making sure to select the proper filter.

*Do NOT start the Wizard again.*

24. Select "Photometry | Open image list" from the PhotoRed main menu. This presents a message.



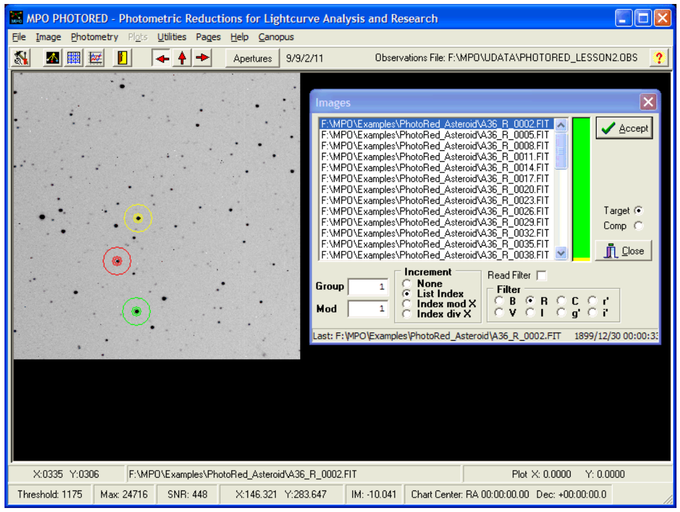

25. Click <OK>. We're using the same comps and target but a different set of images. Another message appears.




26. Click <Yes>. The PhotoRed Reference Manual gives more information on the available choices and when you'd use each one. The Image Selection list is displayed as before.

27. Select all the R (red) images up to and including A36_R_0119.FIT.

28. Sort the files by Date (click <Yes> on the message that appears). This displays the PhotoRed Image List.




29. Select “List Index” and set the “R” radio button. Do ***not*** check “Read Filter.”

30. As you did before, measure all the images, making sure to reset the apertures if necessary.

31. Save the data into the same file as before, i.e.,

    \MPO\UDATA\PHOTORED_LESSON3.OBS

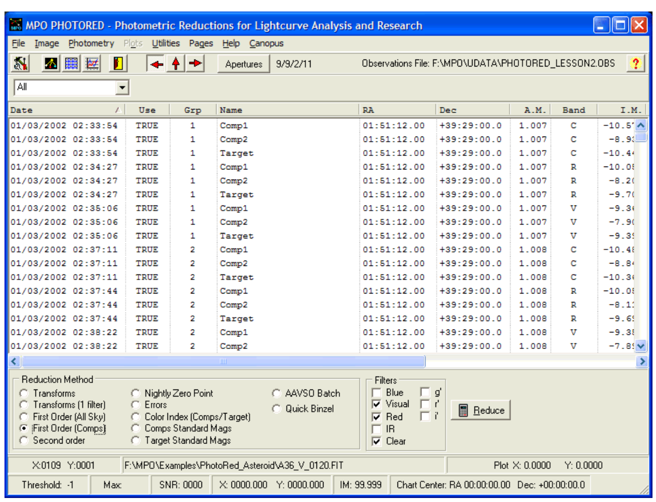
*Do not run the wizard again.*

32. Repeat steps 24 through 31, using the V images, A36_V_0003.FIT through A36_V_0120.FIT.

    ***Be sure to set the filter to “V” on the image list.***

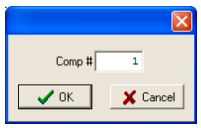
33. Once you’ve measured all the V images, save the observations again into \MPO\UDATA\PHOTORED_LESSON3.OBS.

34. Go to the Reductions page <Ctrl+2>



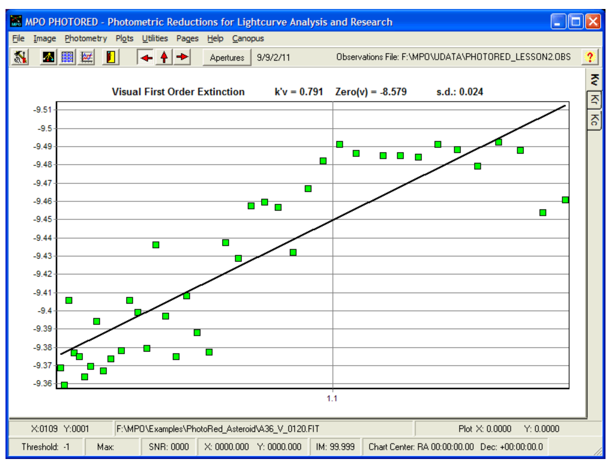
35. Click the "Grp" column header to sort the observations by group number until Group 1 is at the top of the list.


36. Select "First Order (Comps) and check the Visual, Red, and Clear boxes, then click <Reduce>. This displays a small form that allows you to choose which comparison star to use for the calculations. The default is 1.




You can enter a number from 1 to 5 but, of course, there must be a corresponding comparison star. For example, if you have only two comparisons, as in this case, only "1" or "2" is a valid entry.

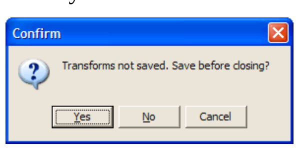
37. Click <OK>. This displays the Plots page.




☞ ***Do not click <Save> on the Transforms form.*** *These are* ***very bad*** *results. You'll see why in a moment.*

38. Use the tabs at the upper right of the plot to switch to those for the R and C filters.

39. When you close the Transforms form, you'll see a warning.




40. Click <***No***>.

## What Went Wrong?

The extinction values seem unreasonably high. More important, there is something seriously wrong. Remember that a star's *instrumental* magnitude gets more negative as it gets brighter – just like the magnitude system for stars. In this case, the comparison star got brighter as its air mass got larger, meaning *the star got brighter as it got lower!* This is backwards. If you re-run the reduction using a different comparison, you'll see the same trend.

The answer lies in the fact that the data cover a very small range of air mass and the change in the instrumental magnitude over the entire time was only 0.12 mag at most. If you remember your high school algebra and least squares solutions, you need as large a range in X values as possible. What we've done here is take a small sampling that happens to have a fair amount of noise. *"Garbage in: garbage out."*

This points out how the comparison star method can lead you astray if you're not careful and, even more important, emphasizes the rule, *"Never Trust a Computer."* You should *never* accept the results from a program without question. Computers can always generate results. You have to make sure they are *reasonable* results.

If you did the Photometry chapter lessons on 771 Libera to find its lightcurve, you have other data available. The next tutorial shows you how to use that data to find the first order extinction. You'll have data for only one filter, Clear, but the principle is the same for data from any filter.

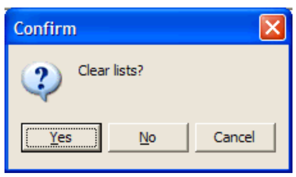
# 4. First Order Extinction – Comp Star II

This lesson teaches you how to import data from Canopus for additional processing in PhotoRed, usually to convert Canopus instrumental magnitudes to standard magnitudes on the Johnson-Cousins or Sloan system.

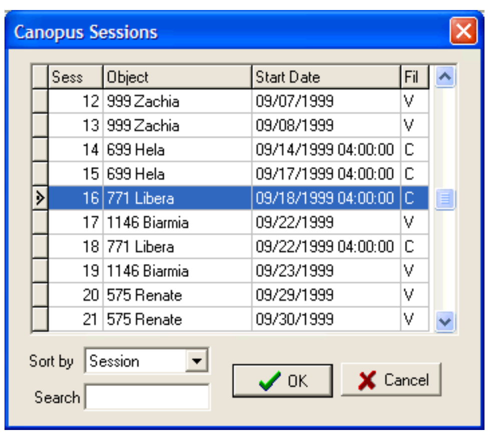
> *Given the* DerivedMags *method available in Canopus, especially when the AAVSO's APASS catalog is fully on-line, PhotoRed's future lies mostly in finding the color index of unknown objects and batch processing of variable star observations for the AAVSO.*

For this tutorial, you will use the data from the first lesson of the Photometry chapter where you measured images for 771 Libera to find its lightcurve. Since instrumental magnitudes are always measured and saved in Canopus, the data from any one of those lessons can be used.

1. Select "Utilities | Import Canopus session | from PHSESS" from the PhotoRed main menu. If there are observations on the data page, a confirmation message is displayed.




2. Click <Yes>. This displays the sessions selection form.



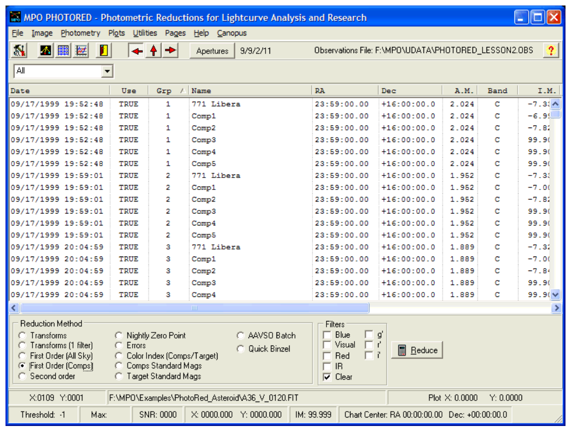

This is a multiselect form, meaning that you can select more than one session. This would make sense only if the sessions were from the same night. They might be with different filters or the result of having to create several sessions because of a fast moving object.

In this case, we're going to select one and only one session.

3. Locate the session Sept. 18, 1999, session for 771 Libera and click on it. This highlights the session (the session number in the "Sess" column may not be the same as shown above).

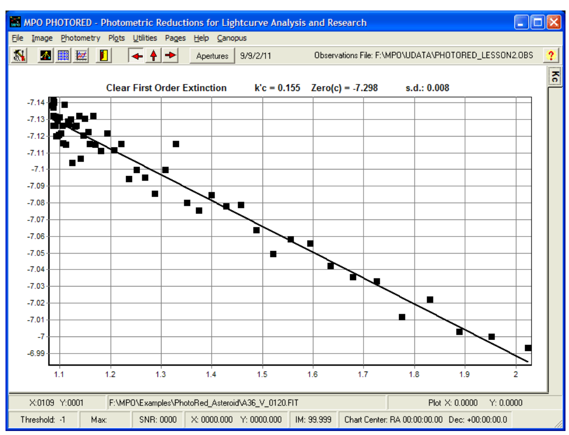
4. Click <OK>. The cursor changes to an hourglass (or whatever your "Wait" cursor is) while the data are imported. This may be so fast that you don't see the cursor change.

5. Go to the Reductions page (<Ctrl+2>). The observations should be available.




6. Select "First Order (Comps)" and check the Clear filter box.

7. Click <Reduce> and select Comp 1 in the form that appears. This displays a plot similar to the one below.




Note that the comp star does what it should, get brighter with lower air mass. The range of air masses is also much larger than before, going from nearly 1.0 to just over 2.0. This helps assure a good liner regression solution.

☞ *Something that should be quickly apparent is that if you follow a field all night, going from eastern horizon to western, is that the preponderance of data will be at lower air masses. The air mass changes quickly when near the horizon but more slowly when the field is near the meridian. If you want a good range of air masses for this method, make sure that you get a number of images when the field is only 30-40° high.*

A later lesson will show you how to export the data from PhotoRed to files that can be read by Canopus.

# 5. Second Order Extinction

Second order extinction is a term that is dependent on both air mass and color. You're probably familiar with the concept of how objects near the horizon are redder than when seen overhead. This change in color (due to scattering) affects the correction to the raw instrumental magnitudes to make them *exoatmospheric*, i.e., as seen from outside the Earth's atmosphere.

By definition, second order extinction (SOE) is zero for the V and R filters. Most tests have indicated that this is true. However, you should confirm it for your system and, if for some reason it is not, try to figure out why and – if necessary – apply it as needed.

The B and Clear filters do have second order terms that cannot be ignored. Keeping all comparisons and the target (and check) similar in color can reduce the correction to insignificant amounts but if you're finding the standard magnitudes of comparisons to generate your own sequence, then you should consider second order terms.

The most effective way to determine SOE is to follow a pair of stars over a wide range of air mass. These stars should be significantly different in color, one being red and the other blue, in order to give the largest possible difference and so make for a more accurate determination of SOE.

## The Sample Images

The sample images for this exercise were taken with the SDSS g', r', and i' filters. For the SDSS colors, you will use the standard g'-r' standard magnitudes color index (not instrumental). However, you can relate SOE to any standard color index.

The files are found in \MPO\EXAMPLES\PHOTORED_SOE. The full path will not be given in the following steps, just the file names. Look in the above directory (assuming you used the default installation path) for the images.

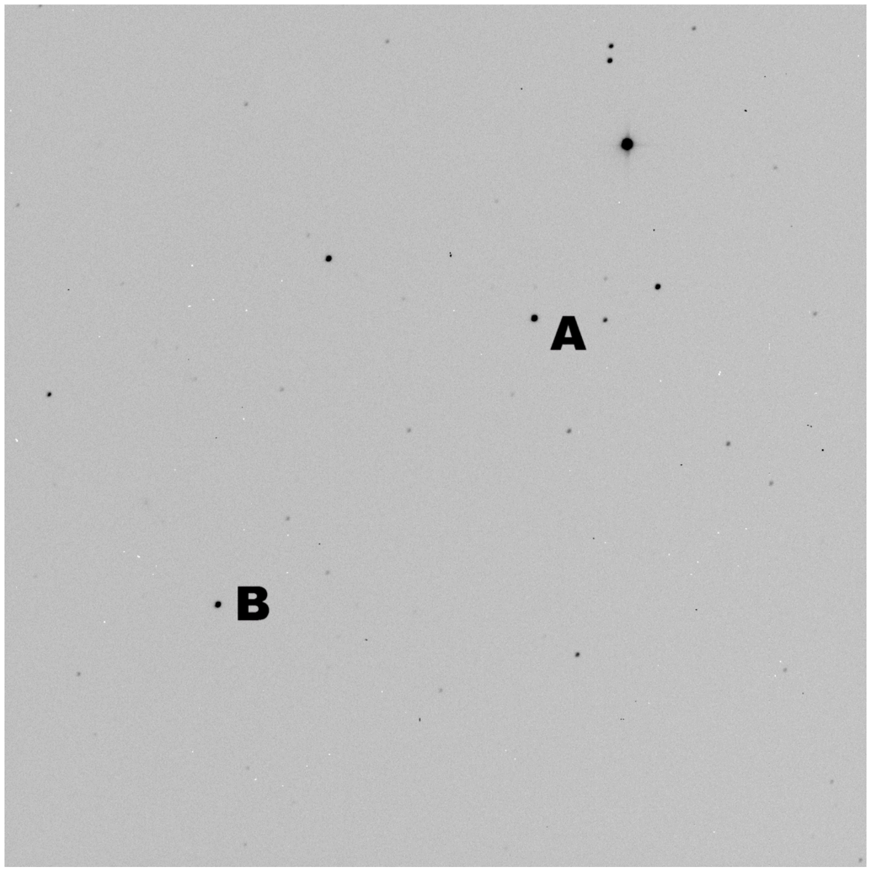
## Cheating the System

The SOE term is usually in units of air mass and *instrumental* color difference. If you have measurements in two colors, then SOE can be determined directly. What if you are working in only one filter, e.g., Clear? What then? PhotoRed "cheats" by using the standard color index, e.g., V-R, and a slightly different method called the *slope of slopes* developed by Robert Buchheim. In this approach, PhotoRed finds the slope of the instrumental magnitude versus air mass, just as is done for first order extinction (in reality, this finds a solution that includes FOE *and* SOE). This is done for a number of stars with their standard color index saved as well. The final solution finds a least square solution using the slopes as the Y-axis and color index as the X-axis. The slope of this line, the *slope of slopes*, is the second order extinction. The Y-intercept is the first order extinction (averaged due to the several different values based on color).

As always, the solution is more reliable if you include as many stars as possible that cover a wide range of colors and the data extend over a wide range of air mass, preferably getting close to 2.0 at the "low" end.

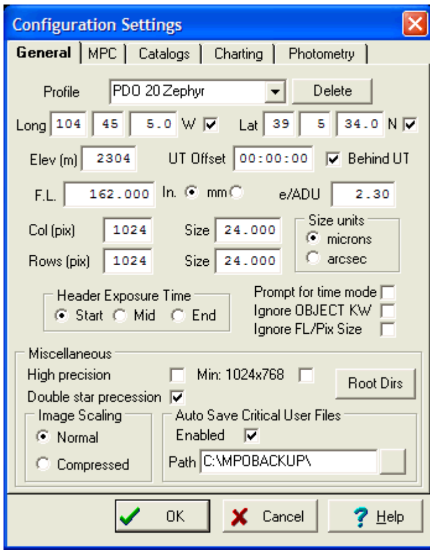
## Reference Image

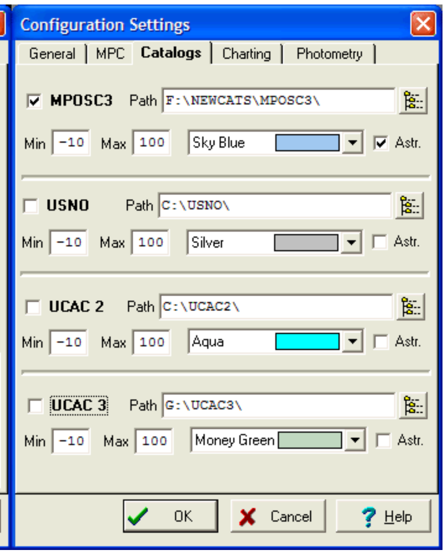
Use the screen shot below for reference in the tutorial.

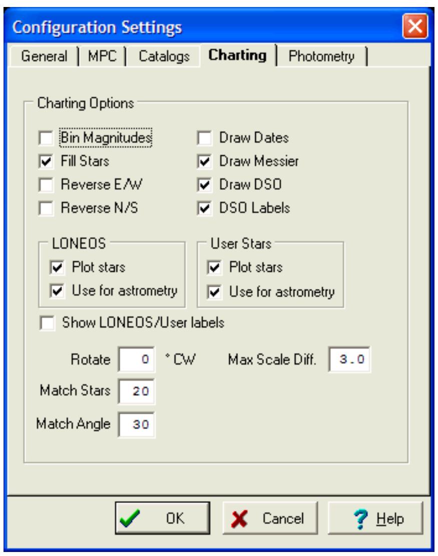



## Finding SOE

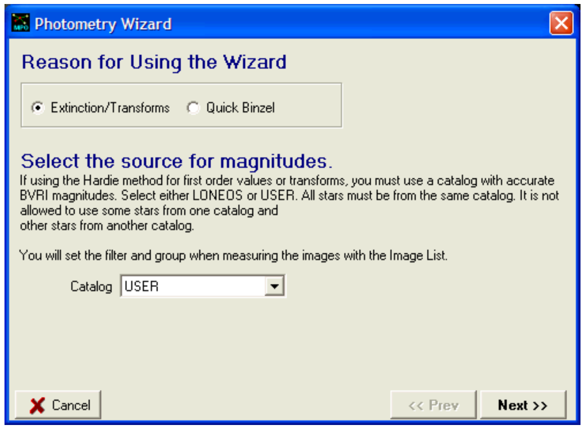
1. Set the configuration to match the shots below. The only items of actual interest on the General tab are the Header time information (to determine mid-exposure), the focal length, and pixel sizes. The name of the profile is not important save to make it easy for you to know why it was created.



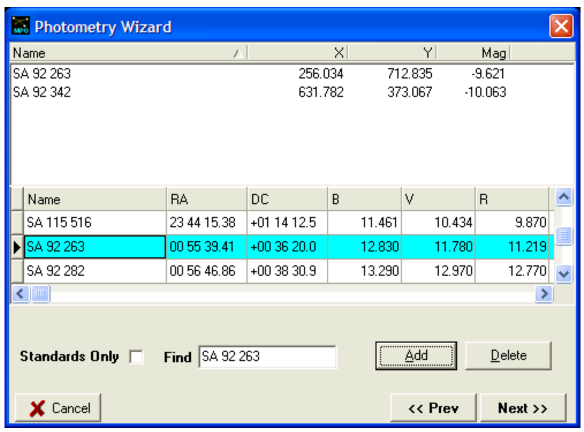




2. Set the target, comparison, and astrometry apertures to 15x15, 2, 11.
3. Open SDSS_RB_SA92_G'_00017.FIT
4. AutoMatch the image.
5. Run the Photometry Wizard (<Alt+W>).
6. Select "Extinction/Transforms" for the purpose and "User" catalog in the drop down list on the first page.

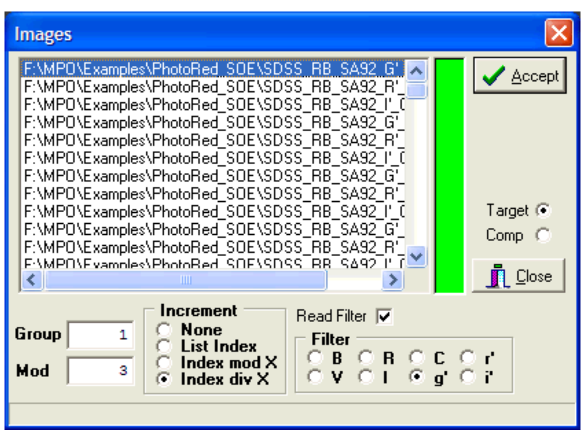



7. Add stars “A” and “B” from the reference image to the list of targets.




8. Finish the wizard. When the file selection dialog appears, select *all* SDSS*.FIT files.

9. ***Sort the files by Date. This is important.***



10. Set up the Image List as shown above, specifically, make sure to select “Index DIV X” and set “Mod” to 3.

    One image in each filter was taken per set. Sets were taken throughout the night in order to follow the field over a wide range of air mass. You want the images in the each set to have the same group number. By sorting by date, the first three images in the list are each filter in the first set, the second three in the list are the three images – one in each filter – for the second set, and so on.

    The DIV operator combined with Mod = 3, means that the first three images will be in group 1, the second in group 2, etc. because DIV returns the integer part of X/Y and so, 1 div 3 = 0, 5 div 3 = 1 and likewise down the list.

➯ *The group number is actually (X div Y) + 1 since Group 0 is not allowed.*

    The headers in these images have the FILTER keyword and value set so that the Image List can read them and so set the “Filter” radio button as needed. Otherwise, you would have to change the filter for every image. With almost 75 images to be measured, that would be very tedious.

11. Double-click on the first image, confirm the apertures are correctly placed, and click <Accept> (or press <ENTER> if the Image List has focus). This automatically loads the next image. Continue until all images are measured.
12. Save the observations data set before running the reductions routine.

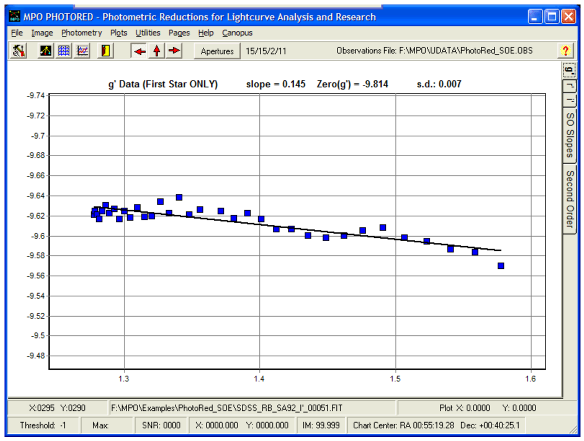
➯ *Proceed slowly. You may have to reset the apertures a number of times during the measuring.*

## *No Do-overs*

Unlike the Canopus Image List, with the PhotoRed Image List you cannot re-measure an image and have the new data replace the old. If you make a mistake, reload the image that was mis-measured (double-click on it in the list), reset the apertures, and then click <Accept>. You will have a “bad” data point in the set that you can usually spot by the SNR of the stars being dramatically lower compared to the “correctly” measured image or by an outlier data point on the plots.

# Running the Second Order Method

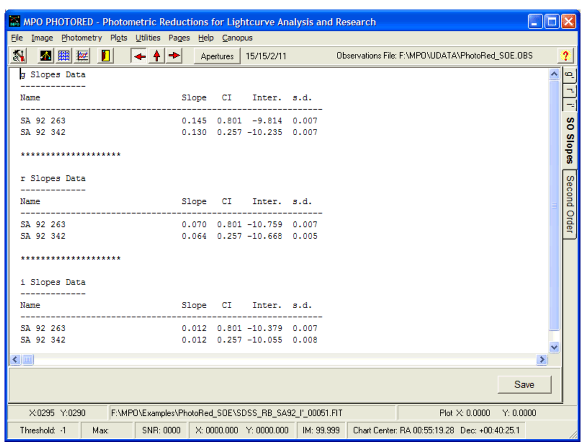
13. Check the “Reduction Method | Second order” radio button.
14. Check the g’, r’, and i’ filter boxes. Do not check the Clear filter box at this time.
15. Click <Reduce>.
16. Select the g’-r’ standard color index for the reductions.




For each filter, PhotoRed plots the raw data for the first star in the list. This lets you check that the overall data appear to be good and that there are no outlier points throwing off the solution.

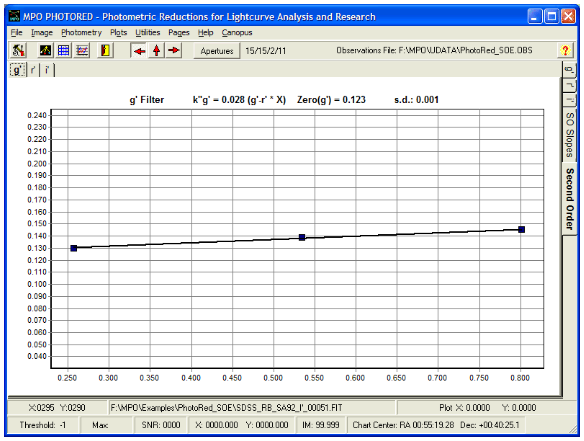
17. Review the plots for the first star for the three filters. They should all be reasonably good. The standard deviation for all three was 0.007 mag when this tutorial was run.

18. Click the "SO Slopes" tab (right side of the form).




This tab displays the intermediate and final results. For each star, you see the slope of the raw data (instrumental magnitude versus air mass), the standard color index, and the standard deviation of the least squares solution for the raw data.

19. Click the "Second Order" tab.




This tab shows the plots for the three filters with the X-axis being the standard color index of the star and the Y-axis the slope of the raw data least squares analysis.

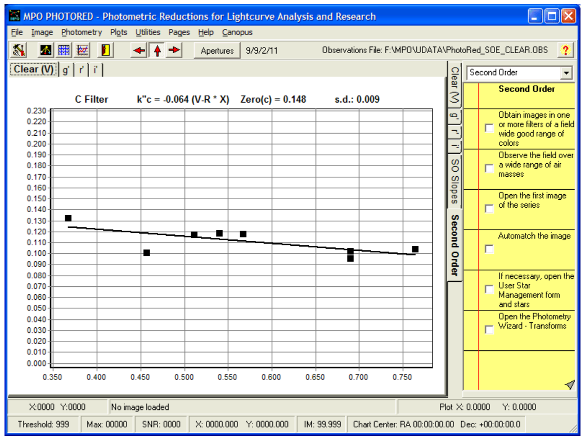
What you hope to see is a value of 0.0 for the second order slope. This would mean that there is no color dependency in extinction for the given filter.

For the g’ filter, SOE = +0.03. This is a little strange since it implies that red stars fade faster. That is obviously not the case. When you get a strange result, and even in general, you should get data from additional nights and confirm what you’re getting and take an average. This may have been an “off night” that needs verification. However, that is not the point to this tutorial.

*When there are only two data points (stars), as in this case, PhotoRed adds an artificial point that is the average of the two points. This is required in order to get a least squares solution with standard deviation. The slope (*SOE *term) does not change as a result.*

## *Don’t Forget the Clear Filter*

The Clear filter has a very broad response, about equal to your camera’s response. It’s bound to have a second order term that should be included. This was verified in another exercise using different images.




Here are the data from that reduction

| Star | Slope | B-V | Inter. | s.d. |
|---|---|---|---|---|
| 1 | 0.101 | 0.457 | -7.841 | 0.008 |
| 2 | 0.118 | 0.540 | -8.606 | 0.008 |
| 3 | 0.096 | 0.690 | -7.971 | 0.011 |
| 4 | 0.117 | 0.511 | -8.641 | 0.007 |
| 5 | 0.118 | 0.567 | -8.610 | 0.013 |
| 6 | 0.102 | 0.690 | -7.584 | 0.011 |
| 7 | 0.104 | 0.764 | -7.845 | 0.009 |
| 8 | 0.132 | 0.367 | -8.681 | 0.010 |

These results are more in line with what is expected by showing that blue stars fade faster than red stars as they near the horizon.

# 6. Finding Color Indices

The underlying approach to PhotoRed for finding standard magnitudes for a target relies on knowing the *standard* color index of the comparisons and target beforehand. To make the final step to standard magnitudes for the target, the standard magnitudes of the comparisons must be known. The next two lessons are dedicated to finding those values.

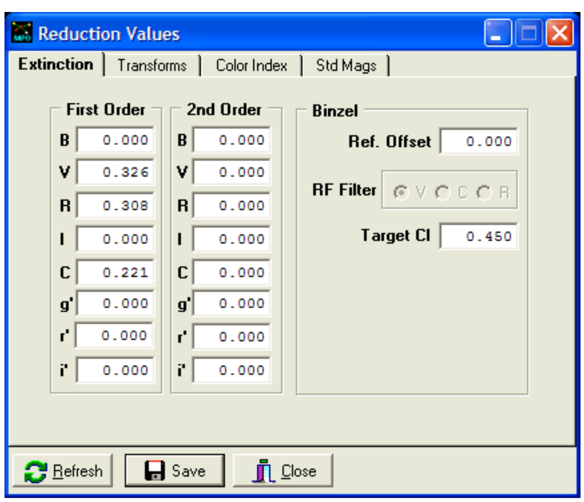
In case your curiosity is up, the final reductions use a differential photometry formula (based on a paper by Richard Miles of the BAA), that accounts for the difference in the standard color index of the target and a given comparison star. If more than one comparison is involved, PhotoRed finds the derived standard magnitude differential value between the target and a given comparison and applies the derived standard magnitude for that comparison. The average of the derived standard magnitudes of the target is then reported as the final value.

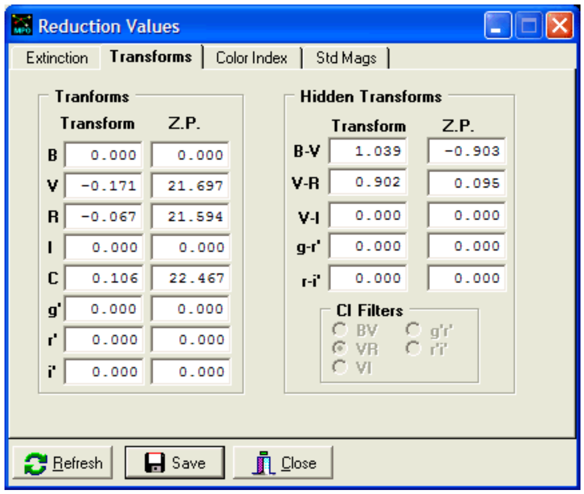
Since “Practice makes perfect” (better yet – “Perfect practice makes perfect”), you’re going to repeat many of the steps in the first part of a previous lesson except on a different set of images and with a slightly different but *critical* difference. You’ll also learn a trick that save you lots of time for the next lesson, which is finding the standard magnitude of the comparisons.

## *Measuring the Images*

The presumption in this tutorial is that you are familiar with the Differential Photometry Wizard in PhotoRed, which is very similar to the Lightcurve Wizard in Canopus. If not, review the tutorials in the Photometry chapter and the earlier lesson in this chapter, “First Order Extinction – Comp Star I.”

1. Check that you are using the profile created in PhotoRed Lesson 3 (First Order Extinction – Comp Star I”). That lesson called the profile “PhotoRed – FOE.” If you didn’t run that lesson, go to it now and create a profile with the settings shown in that lesson.
2. Set the PhotoRed measuring apertures to 9x9/3/11.
3. Select “Photometry | Transforms values” (<Ctrl+T>) to open the Transforms form.






4. Set the values on the Extinction and Transforms tabs as shown in the two screen shots immediately below and then click <Save>.

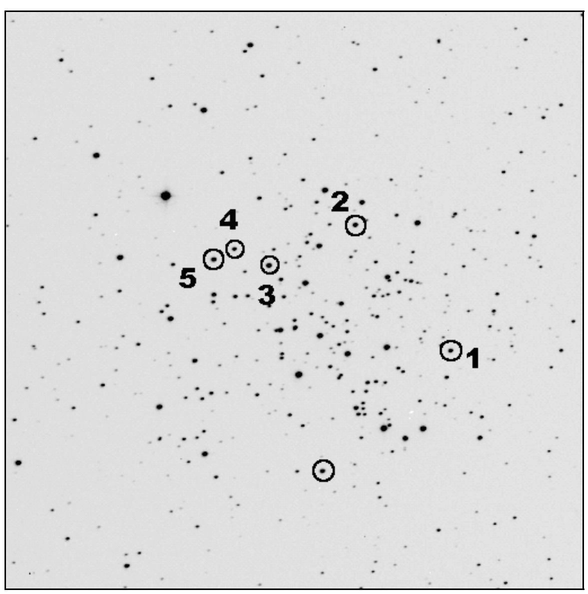
*The values were determined "off-line" using the same set of images and the modified Hardie method.*

5. Click <Close> to close the form.

6. Select "Photometry | Photometry wizard | Differential Photometry" (or <Ctrl+W>).

7. Click <Yes> on the confirmation message to clear all observations. The wizard then appears.

8. Load \MPO\EXAMPLES\PHOTORED_M67\M067_C_0001.FIT and click <Next> until you get to the wizard page to set the comparisons for Image 1.

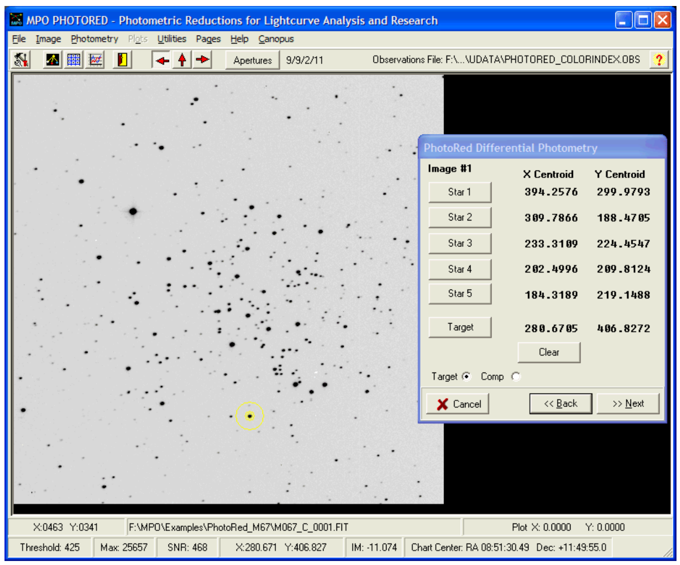


Reference the screen shot above for the next few steps. The five numbered stars are the comparisons. The circled but un-numbered star is the “target.”

*Comp 1 has a close companion, so be careful.*

9. For each of the numbered stars (the comparisons), click on the star on the image and then click the same numbered button. For example, click on star 1 and then click <Star 1> on the wizard. Do this for all five comparisons.

10. Set the position for the “target” by clicking on it on the image and then click <Target> on the wizard. You should see something similar to this.



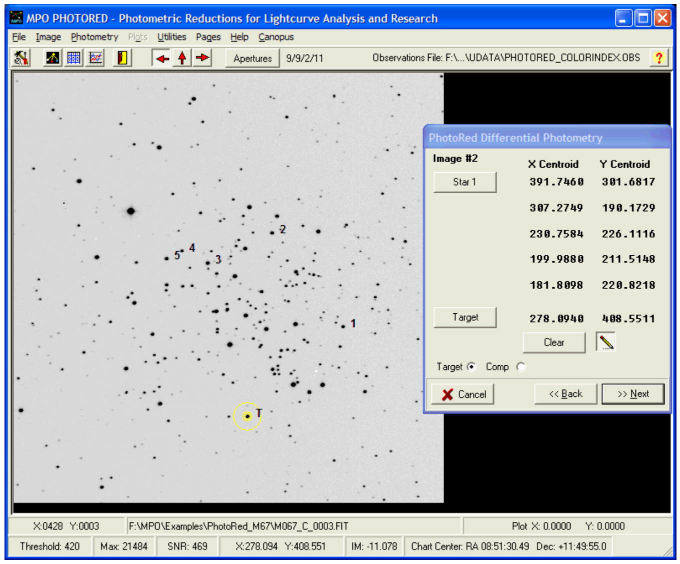

*The X/Y coordinates may be slightly different in the third or fourth decimal place.*

11. Click <Next> on the wizard and load the second image,

    \MPO\EXAMPLES\PHOTORED_M67\M067_C_0003.FIT.

12. Click <Next> until you get to the page to set the positions on the second image

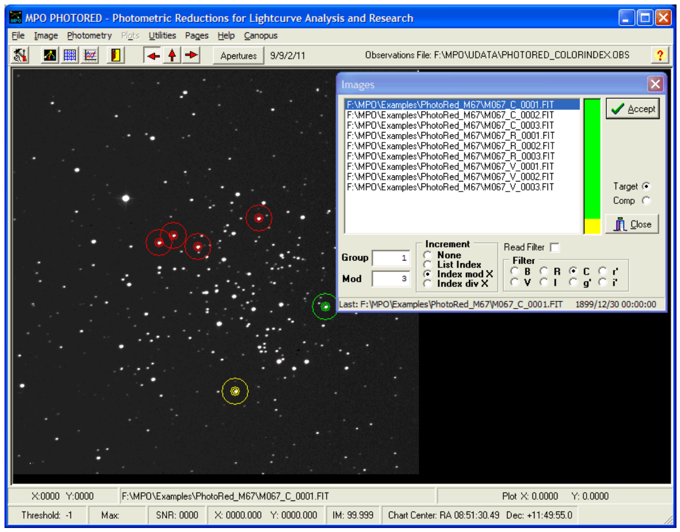
13. Set the positions for the comps and target on the second image. Your results should look similar, *but maybe not exactly*, as these:




14. Click <Next> once. This takes you to the final page where the button is now called “Finish”.
15. Click <Finish>. This closes the wizard and displays a Windows file dialog.
16. Select *all* the M67 image in the \MPO\EXAMPLES\PHOTORED_M67\ directory.
17. Click <Yes> to the question about sorting the files by date or name.

*Depending on how the file names are created by your imaging program, the images you select for measuring in PhotoRed may not always be in chronological order or grouped by filter (if the program includes the filter in the file name). This option allows you to try to sort the files in the list so that they make measuring as easy as possible by not having to switch filters on the Images List. Experience will tell you how to answer this question for a given situation.*

18. Enter “3” in the Mod entry field (without the quotes).
19. Check the “Increment | Index mod X” radio button. The combination of these two settings allows you to measure all the images without having to change the Group number manually. As you'll see, each of the three images for a given filter is assigned to a different group.
20. Check the “C” radio button (assuming the first image is as shown in the screen shot below).
21. ***Do not check the “Read Filter” box***. These images do not have the FILTER key word in the header.
22. Double-click on the first file name in the list. This loads the image into the program. The measuring apertures should be centered on the comparisons and target.



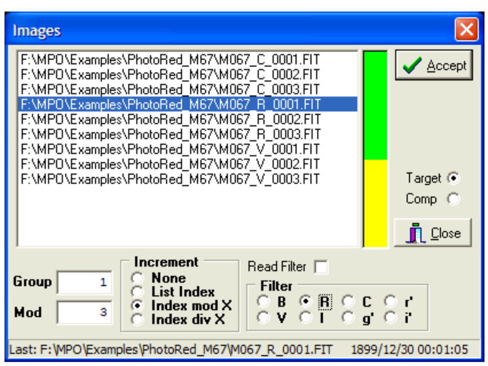

***Proceed carefully from here on. The following steps assume that the files are in the order seen in the screen shot.***

23. Measure the three Clear images by clicking <Accept>. Reposition the apertures if necessary.

*Note how the value in the group number automatically increases as each Clear image is loaded*

24. ***When the first R (red) image is loaded, do not immediately click <Accept>, even if the apertures are aligned.***

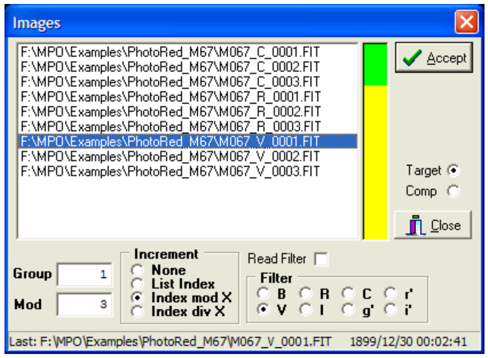
25. Change the filter to R (not r') and note that the Group field has gone back to "1". This is as it should be.




*When running the tutorial, it was necessary to click on Comp 1 (the anchor star) for each R image since the apertures were slightly off center. This may or may not be necessary for you.*

26. Measure the three R images.

27. ***Pause again when the first V (visual) image is loaded and set the Filter to V.***



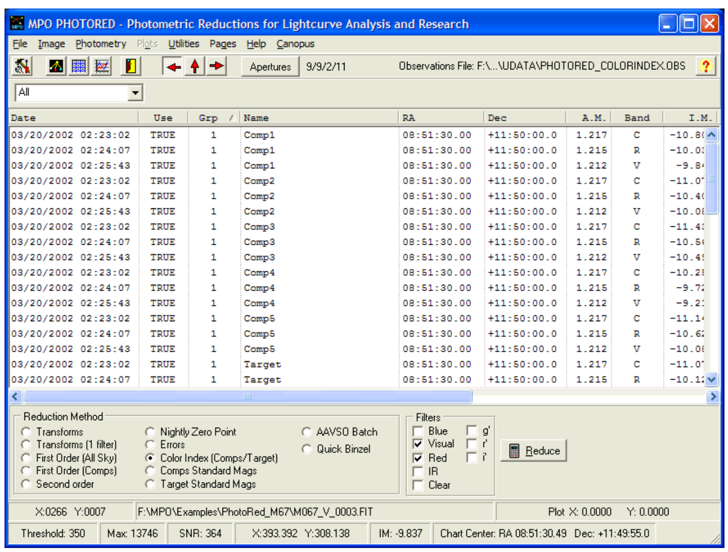

28. Measure the three V images.

29. Click <Close>. This displays a file save form. Save the file as

    PHOTORED_COLORINDEX.OBS

*It is not necessary to enter the OBS extension. PhotoRed forces the file to have that extension when the file is saved. This is required since, when trying to load previously saved files, the file dialog looks only for OBS files.*

30. Go to the Reductions page (<Ctrl+2>)



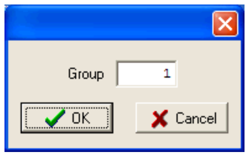

## A Stitch in Time…

Here comes a time-saving trick. The Color Index (Comps/Target) method requires three groups of data in order to calculate a standard deviation of the derived values. On the other hand, the Comps Standard Mags method, *which uses the exact same data*, must have the data arranged so that there is one and only one group but with at least three observations in each filter per group to compute the standard deviations. You don't want or need to remeasure the images, where you would force the group number to "1".

31. Click on the “Grp” column header on the data list until the data is sorted by group number with all Group 1 data at the top of the list.

32. Select all the observations in the list.

33. Right-click over the data list and select “Set group number” from the popup menu. This displays an entry form.




34. Enter “1” and click <OK>. All the data should have the group number set to 1.

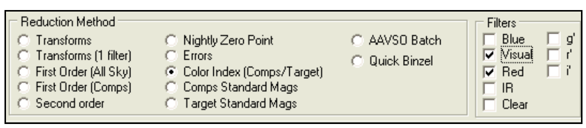
35. Select “Photometry | Save Observations” from the PhotoRed main menu and save the data under the name PHOTORED_CMPSTDMAG.OBS.

## Finding the Color Index Values

Before you can find the color index values, you need to get the original data back, where the observations are in three groups.

36. Select “Photometry | Load Observations” and load the original data that was saved under PHOTORED_COLORINDEX.OBS

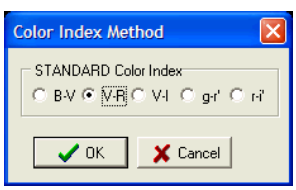
37. Go to the Reductions page (<Ctrl+2>).




38. Set the Reduction Method and filters as shown.

*Clear is not a standard filter, so you do not check that box. If you do, PhotoRed ignores it.*

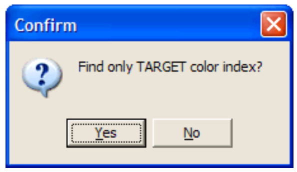
39. Click <Reduce>. This displays the Color Index Method form.




40. Select “V-R” since this is the color index you used to find the transforms and FOE values.

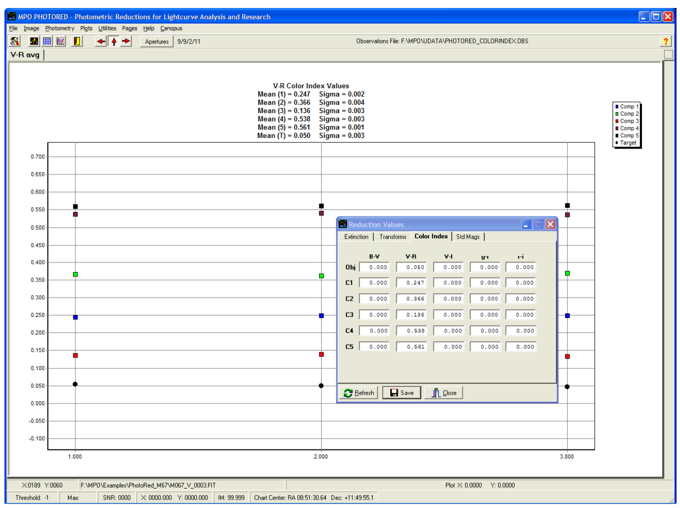
***This is important!*** *You* **must** *select the same color index that you used in finding the transforms and first order extinction (if you used the modified Hardie method). You also* **must have** *observations in the two filters involved in the color index and those two filters must be checked in the Filters section.*

41. Click <OK>. This displays a confirmation message.




42. Click <No>. This displays the Plots and Transforms form.

*PhotoRed allows you to enter the standard color index values for the comparison stars into the Transforms form if they are known beforehand, as might be the case when working a variable with calibrated field stars. If this were the case, you would not need to find the color index values for the comparisons but only the target. In this case, we assume that none of the values is known.*




The results in listed in the Transforms form as well as at the top of the plot. The "Sigma" values are the standard deviations of the average V-R for each comparison and the target. When running this tutorial, all the sigmas were 0.005 mag or less.

43. Click <Save> on the Transforms form and then click <Close>.

## *Comparing Results.*

How good are the results? Here's a comparison of the derived versus Henden catalog values for the five stars and target.

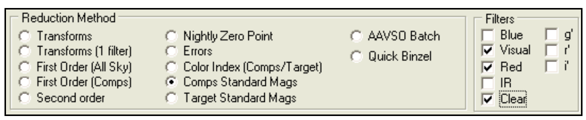
| Object | Henden V-R | Derived V-R | Diff. H-D |
|---|---|---|---|
| Comp1 | 0.249 | 0.247 | +0.002 |
| Comp2 | 0.355 | 0.366 | -0.011 |
| Comp3 | 0.141 | 0.136 | +0.005 |
| Comp4 | 0.532 | 0.538 | -0.006 |
| Comp5 | 0.568 | 0.561 | +0.007 |
| Target | 0.049 | 0.050 | -0.001 |

# 7. Standard Magnitudes – Comparisons

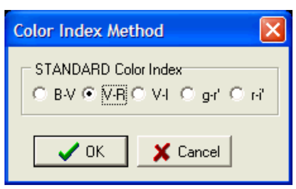
The final step before finding target standard magnitudes is to find the standard magnitudes of the comparisons. This is done by combining all the values found so far, i.e., transforms nightly zero points, extinction, and standard color indices. Once the standard magnitudes of the comparisons are known, then the color corrected differential magnitude between each comparison and the target are found and applied against the comparison's standard magnitude to give a reduced standard for the target.

*To repeat one more time, you should try to use a reference field close to the target field, maybe a couple of degrees or less. Also, if you use reference and comparison stars that are similar in color to the target, then the extinction and color index values are of little or no consequence in the final reductions. The reason you've learned how to find those values is because you can't always have a reference field nearby or have the luxury of finding reference and/or comparison stars that sufficiently match the color of the target.*

1. From the PhotoRed main menu, select "Photometry | Load observations". Load the PHOTORED_CMPSTDMAG.OBS that you created in the previous lesson.
2. Go to the Reductions page (<Ctrl+2>).



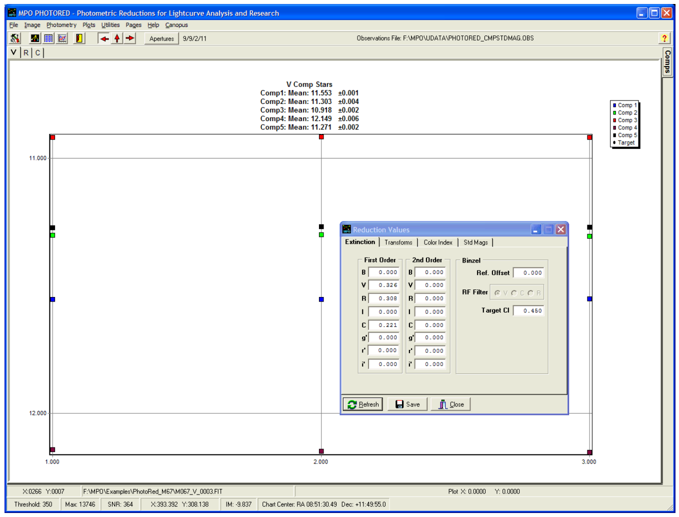

3. Select "Comps Standard Mags" and check the Visual, Red, and Clear filter boxes.
4. Click <Reduce>. This displays the Color Index Method form.




5. Select "V-R".

*Remember that you must use the same color index throughout the process, from transforms to target standard magnitudes.*

6. Click <OK>. This displays the Plots page and Transforms form.



7. Click the “R” and “C” tabs to review the plots.

8. Click <Save> on the Transforms form and then click <Close>.

Internally, the standard deviations are less than 0.01m for each comparison. Let’s compare results against catalog values again. “H” stands for the Henden magnitude while “P” stands for the PhotoRed derived magnitude.

| Obj | VH | VP | RH | RP | CH(v) | CP(v) | Vp-Cp |
|---|---|---|---|---|---|---|---|
| Comp1 | 11.546 | 11.544 | 11.297 | 11.297 | 11.546 | 11.547 | -0.003 |
| Comp2 | 11.284 | 11.290 | 10.924 | 10.925 | 11.284 | 11.295 | -0.005 |
| Comp3 | 10.929 | 10.912 | 10.788 | 10.778 | 10.929 | 10.907 | +0.005 |
| Comp4 | 12.123 | 12.131 | 11.590 | 11.593 | 12.123 | 12.128 | +0.003 |
| Comp5 | 11.242 | 11.250 | 10.692 | 10.689 | 11.242 | 11.242 | +0.008 |
| | Err: | -0.001 +0.011 | Err: | -0.000 ±0.002 | Err: | +0.001 ±0.013 | +0.002 ±0.005 |

These results will do for many cases. The standard deviations of for the errors are a little large; you’d prefer them to be more on the order of 0.01 mag and not 0.02 mag. The good news is that the Clear-to-V reduction shows the magnitudes to be nearly identical to the directly reduced V magnitudes, which are acceptably close to the Henden values.

# 8. Standard Magnitudes – Target I

In the final step, you're going to find the standard magnitude of the target from the last lesson. The approach of using the data from the Color Index measurements, i.e., a limited number of images, is not uncommon. As previously mentioned, you might visit a target field only once or twice in a night to keep tabs on a long period variable or some other project. In this case, you wouldn't need a protracted time-series and there's no need to clutter the Canopus sessions data table with a number of sessions with very few observations in each.

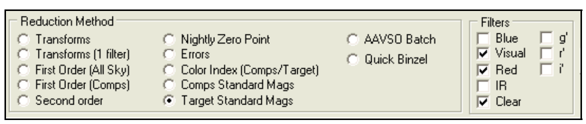
*It's assumed for this tutorial that you did the lessons in the Photometry chapter where you measured the images for 771 Libera on two nights.*

The results that you get here will be meaningless. This is because there were no images in V and R of Libera to find the true color indices of target and comparisons or the standard magnitudes of the comparisons. Once again, the goal is not to reproduce a set of results exactly but to learn the processes in PhotoRed well enough to use them on your own images.

1. Select "Photometry | Load Observations" from the PhotoRed main menu and load PHOTORED_COLORINDEX.OBS created in the "Color Indices" tutorial.

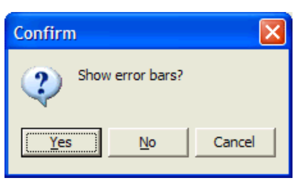
*By using the data where the observations were split into three groups, you can get an average and valid standard deviation for the target. If you were to use the data in with all the data in Group 1, you would get an average but the reduction routine could not find a valid standard deviation.*

2. Go to the Reductions page (<Ctrl+2>).

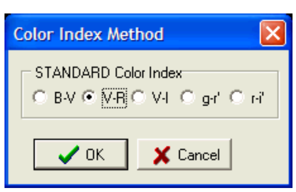



3. Set the Reduction Method to "Target Standard Mags" and check the Visual, Red, and Clear filters.

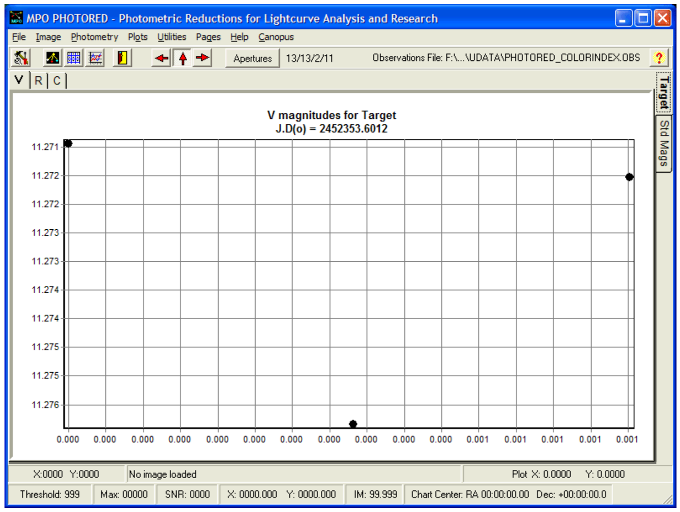
4. Click <Reduce>. This displays a confirmation message.



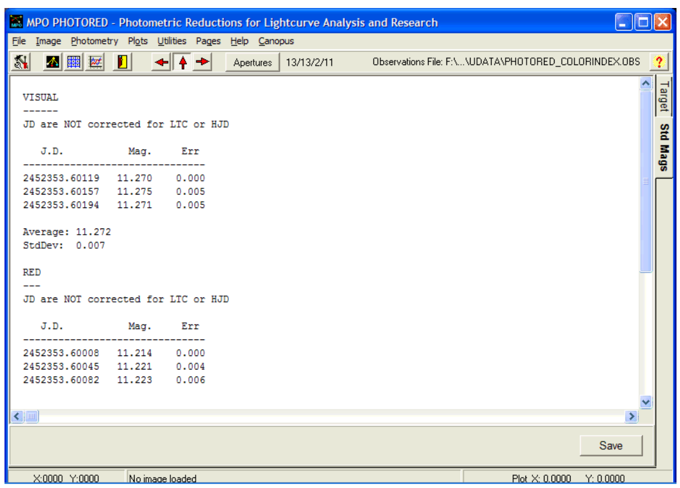

5. Click <No>. The errors are going to be "above average" (or what you hope is average) and so the error bars will only fill the plot needlessly.




6. As before, select "V-R" since that is the color index that has been used up to this point. This displays the V plots page, which should show three data points.




7. Click on “R” and “C” tabs at upper left to see the plot for those filters.
8. Click the “Std. Mags” tab to display a text file with the data broken out by filter.




9. You can click <Save> at lower right to open a file save form and save the text file, which can then be used in a spreadsheet or sent to other observers who might not have Canopus.

The standard V and R magnitudes from the Henden catalog for the target star are 11.267 and 11.218. PhotoRed found 11.272 (+0.005 mag difference) and 11.219 (+0.001 mag difference) respectively. The Clear-to-V reduction found 11.265, or –0.002 from the Henden value and –0.007 mag from the PhotoRed V value.

# 9. Standard Magnitudes – Target II

This tutorial is going to use a very important "trick" within PhotoRed in order to get reasonable results. This trick is good to know if you already know the standard magnitudes and color indices for the comparison stars, which is often the case when working a variable star field that has comps that have been well-calibrated. We'll use an average V-R value for asteroids since there no images available to determine its true value.

The images of 771 Libera were taken with an entirely different system from those used to find the transforms, and so the color corrections will not be exact. Don't let all this stop you from getting comfortable with the process. When you get your own data, then you can concentrate on the absolute certainty of the results.

## Forcing the Issue

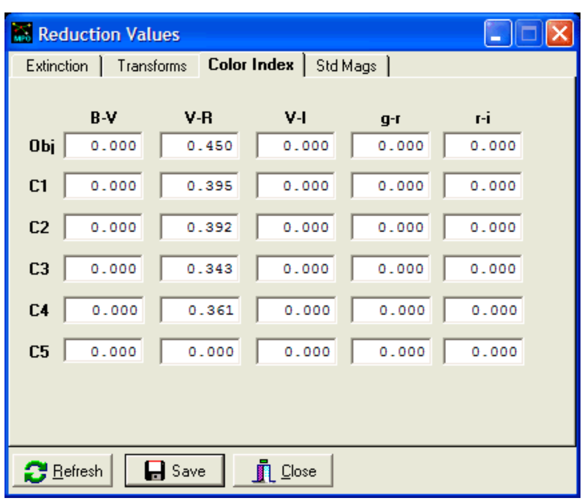
Before you begin, you want to make a backup of the data in the Transforms form. This is different from clicking <Save> on the form. Each profile has its own set of Transforms values and when you click <Save>, you're just overwriting the data for that profile. If you make a backup, then you can restore previous results into the current profile.

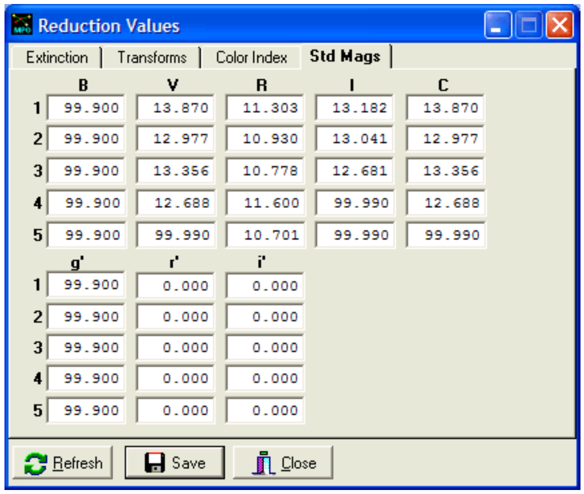
1. Select "Photometry | Backup saved transforms" from the PhotoRed main menu. This displays a Windows file dialog. Save the current set of Transforms under any name you like, e.g., TUTORIAL_TRANSFORMS_1.PRR. The PRR extension is forced when you save the file name.

*You can restore these transforms to the Transforms form (make them the "current" Transforms) by selecting "Photometry | Restore to saved transforms" and loading the file that you just saved.*

What you're going to do is enter known color index and standard magnitude values for the comparisons. Again, you're working a field where such data are available, you can skip all the steps used to find the color indices and standard magnitudes for the comparisons and just enter as them as you're about to do. The only step you would have to take, and only if the data are not available or a reasonable guess is not "good enough", is to find the color index of the target.

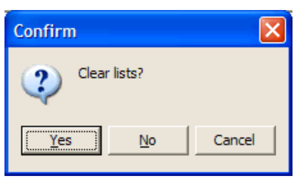
2. Open the Transforms form (<Ctrl+T>).



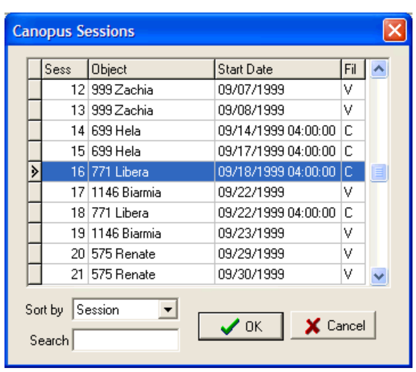



*The values you're entering were found in Canopus by doing an AutoMatch on the first image of the set and then clicking on the comp stars on the chart. This displays the Object Info form which includes, among other things, the BVRI magnitudes derived from the 2MASS J-K magnitudes. The inherent errors in those values migrate through to this exercise and so increase the overall error of each data point.*

3. On the Color Index tab, enter the values shown above in the V-R column.
4. On the Std Mags tabs, enter the values shown for the V and C columns.
5. Click <Save> so that the changes become the active set of Transforms and then click <Close>.
6. Select "Utilities | Import Canopus data | from PHSESS" from the PhotoRed main menu. This displays a confirmation message.




7. Click <Yes>. This displays a sessions selection form.



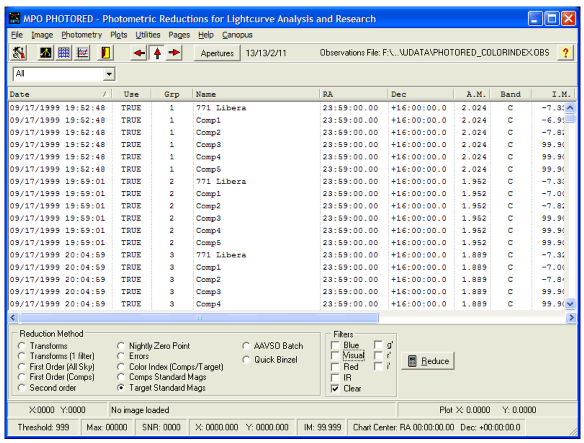
This is a multiselect form, meaning you could select more than one session. This would make sense only if the sessions were from the same night. They might be with different filters or the result of having to create several sessions because of a fast moving object.

In this case, we're going to select one and only one session.

8. Locate the session Sept. 18, 1999, session for 771 Libera and click on it. This highlights the session and changes the symbol in the far left, fixed column to a combined arrow and dot. This indicates that not only is the highlighted row the current row but also has been "selected". If the highlighted row has no symbol in the column, it has not been selected.

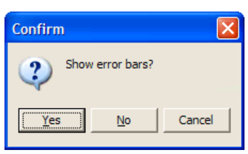
9. Click <OK>. The cursor changes to an hourglass (or whatever your "Wait" cursor is) while the data are imported.

10. Go to the Reductions page (<Ctrl+2>). The observations should be available. Remember: it may not be exactly the same as what you have but should be close.



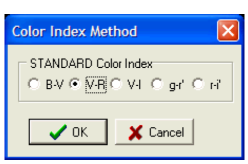

11. Select "Target Standard Mags" for the reduction method and check only the Clear filter box.

12. Click <Reduce>. This displays a confirmation message.

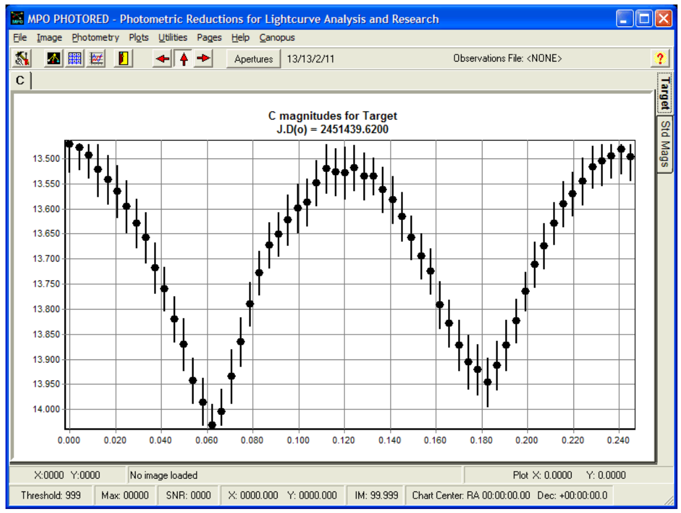



13. Click <Yes>. This displays the select color index form.

*You can click <Yes> because you "cheated" by manually entering comparison star data and an assumed V-R for the asteroid in the Transforms form.*




14. Select "V-R" (why?) and click <OK>. This displays the plot.




Now you have a real lightcurve with standard magnitudes. These are V magnitudes since the Clear transforms were to the V band. The average magnitude from this plot is about 13.75. The predicted magnitude based on data from the Minor Planet Center was 13.81, or 0.06 mag fainter.

Don't necessarily write this off due to errors in the reduction process. That predicted magnitude is based on two values: *H* (absolute magnitude) and *G* (phase slope parameter). A slight error in either one or both could make up a large part of the different here. Checking the accuracy of the *H-G* parameters is one of the reasons for reducing data to the standard system.

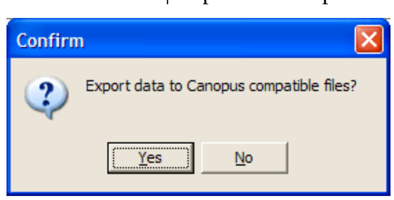
In this case, however, the inherent errors in the 2MASS conversions and the fact that the transforms were found using data from a different telescope/camera combination had more to do with the error, which is still not excessive.

15. Click the "Std. Mags" tab to review and, if you want, save the text file for experimenting with another program.

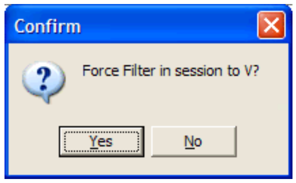
## Return to Sender

16. Had this not been a test, you would normally want to export the data back to Canopus export files (also called "saved session files") where you could do further period analysis or more detailed plotting or send them to another Canopus user.

17. Select "Utilities | Export to Canopus". This displays a confirmation message.



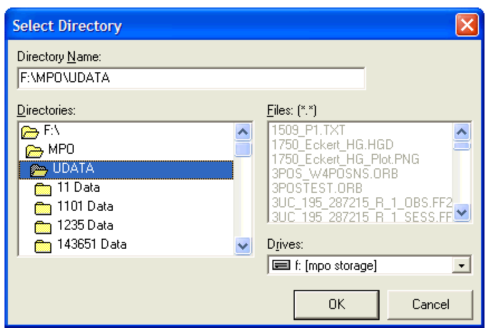

18. Click <Yes>. This displays another message.




If the data you import from Canopus has only V and/or C measurements that were converted to V in PhotoRed, then you want to force the session information in the exported files to indicate that the V filter was used. In this case, click <Yes>.

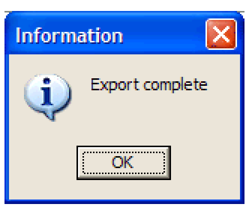
If you have observations in other filters or the Clear transform converts the Clear instrumental magnitudes to a band other than V, you should click <No>, otherwise the sessions file carries the wrong filter information.

19. Click <Yes>. The cursor changes to the "wait" condition while the data are written to the hard drive. When the export is complete, a Windows select directory dialog appears.




The default is \MPO\UDATA. You can save the files here or any other directory, including one that you create on-the-fly. It is recommended that you store all export files in \MPO\UDATA or a subdirectory of it.

20. Once you have selected an existing directory or entered the path to a new one, click <OK>. This displays a confirmation message.




21. Click <OK>.

## *What's in a Name?*

Note the naming convention used when creating the files.

First is the object name as listed in the Object field of the Canopus Sessions form (up to a maximum of 30 characters). This is followed by _X_ where X is the filter for the given session, and then by an assigned number so that you could export additional files, e.g., from a second night. For example, the exported files from this tutorial were named

771_LIBERA_V_1_SESS.FF2
771_LIBERA_V_1_OBS.FF2

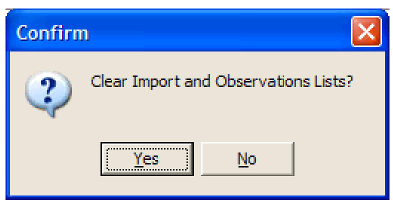
***The _OBS.FF2 and _SESS.FF2 that end the file name are mandatory**. If you change the name of the files, you must keep these ending characters and maintain the FF2 extension. Otherwise, Canopus cannot work with the files.*

*Furthermore, what precedes these two mandatory suffixes must also be identical. For example, if the OBS file in the files above had "V_2" instead of "V_1", Canopus would not be able to import the observations. In short, change file names with great care and only if you know what you're doing.*

Whenever you're working with imported Canopus data, many of the menu items under Photometry on the PhotoRed main men are disabled. While the data appear to be "normal" in relation to what you've seen in most of the lessons, there are some underlying differences important enough to have PhotoRed try to prevent some actions. Before you can work with PhotoRed generated data, you must clear the Canopus data.

## Cleaning Up

22. From the PhotoRed main menu, select "Utilities | Clear Lists". This displays a confirmation message.




23. Click <Yes>. This clears the data lists and you can work with PhotoRed generated data again.

Of course, it does little good to create these files if you don't know how to use them or pass them around to other Canopus users. Data Importing and Exporting are a vital part of the Canopus/PhotoRed system and so a separate set of tutorials is devoted to those tasks.

# 10. AAVSO Batch Processing

AAVSO Batch Processing allows you to measure a number of images for a non-moving target automatically and find the standard magnitude of a target based on differential photometry using pre-known comparison stars. This is the approach taken by the AAVSO in its CCD reporting format. In previous times, there would be one and only one comparison, a check star, and the target. That has changed in that more than one comparison can be used and the check star's role has changed when more than one comparison is used in ensemble photometry.

Before, the role of the check star was to subtract its magnitude from that of the comparison star. The constancy and scatter of that differential was a measure of the quality of the target observations and to assure that the comparison was not variable.

The new role of the check under ensemble photometry is as a "control target." Just as with the target, the magnitude of the check star is found for each comparison. The average of the derived magnitudes of the check and standard deviation of the average are used for the check star value in the report. If all is well, the reduced magnitude will match the adopted magnitude of the check. If the reduced magnitude does not match the adopted value, then the AAVSO or future researcher can apply the difference to the target magnitude to get the "true" value. Of course, the derived value for the check should be consistent, even if it's not exactly equal to its adopted value. Also, should the adopted magnitude of the check change, then the difference can be factored into the target values.

*MPO PhotoRed always presumes ensemble photometry in the reduction method. This affects how you go about the process of measuring images and reducing the data. See below.*

## Process Overview

The process of measuring images for AAVSO work (or any non-moving target) is as follows.

1. Take images of the target field in one or more standard filters or Clear.
2. If you're going to transform the values, i.e., apply color corrections, you'll need to find the transforms for your system. See the PhotoRed tutorials in this Guide and the PhotoRed Reference Manual for more information.

*Since AAVSO Batch Processing relies strictly on differential photometry, the nightly zero points and first order extinction terms are not critical. What is important is that the difference in the first order extinction be about right. For example, if relying on V-R color index, then $k'_{vr}$ should be about +0.05.*

*The only remaining terms of importance are the transforms and second-order corrections. The latter are usually negligible for differential work and in small fields. This leaves the transforms, which allow PhotoRed to correct for color differences between the target and comparisons.*

3. Create a Batch Reference File for the field. This specifies the location and magnitudes of the target, check, and one or more comparison stars.
4. Create a Batch Definition File. This is a list of objects to be measured with each item in the list using a Batch Reference File and measuring a specific set of files.
5. Reduce the data.
6. Generate reports as needed.

## Creating a Batch Reference File

The following tutorial measures about 100 images, 50 from each of two nights, of an RR Lyr type variable. The magnitudes will be on the standard Johnson V system. At the end of the tutorial, you will generate a report compatible with the AAVSO CCD reporting format that, if it were ”live data”, could be emailed or uploaded to the AAVSO “as-is.”

You will be working with images in two subdirectories under

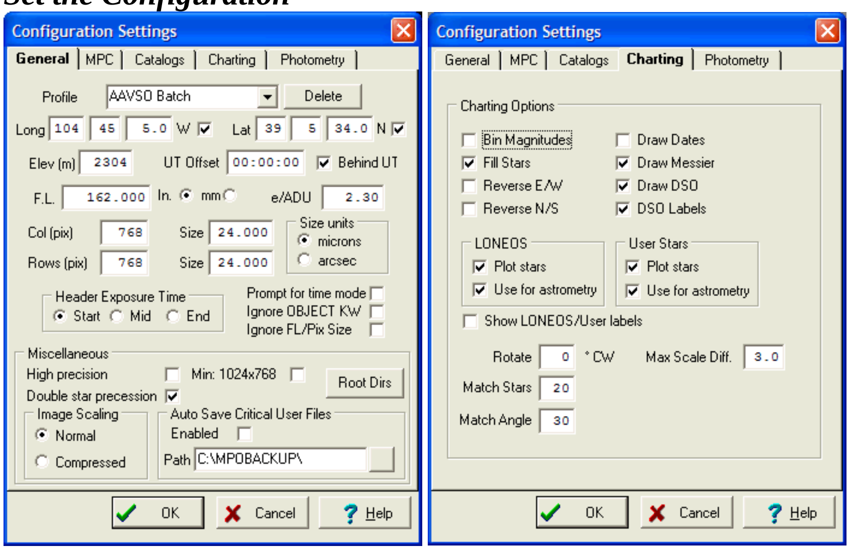
\MPO\EXAMPLES\AAVSO_Batch\ET_PER

***Since the path name is long, and more so after adding one of two subdirectories and a file name, the path to files will be shortened to, for example,***

**\..\20071023**

***With \..\ representing* \MPO\EXAMPLES\AAVSO_Batch\ET_PER**

### *Set the Configuration*




1. Set the Canopus configuration to match the two screen shots.

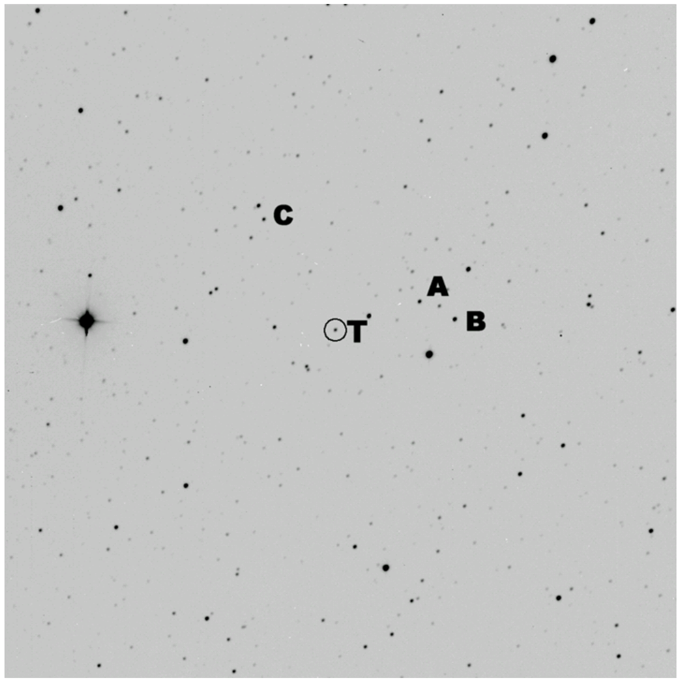
*Remember that you cannot create a new profile in PhotoRed. If the profile doesn’t exist, go to Canopus and create it there, using the values shown. The name you give the profile is not important.*

2. Set the PhotoRed apertures to 13x13/2/11

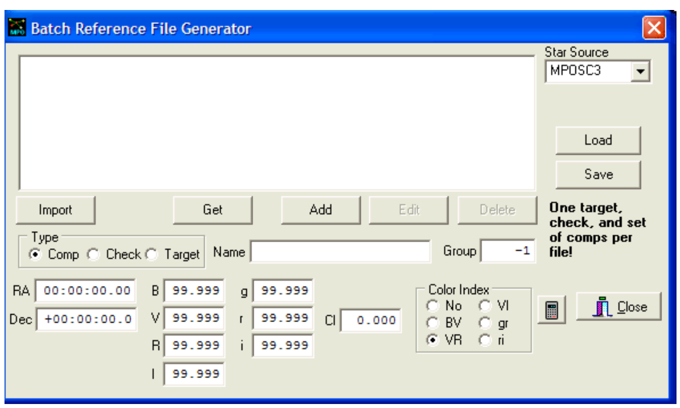
3. Open and AutoMatch the image

   \..\20071023\ ET_PER_VISUAL_00001.FIT

Use the screen shot below for reference.




4. Select “Utilities | Generate batch reference file” from the main menu. This displays the Batch Reference File Generator (*called the “Generator” from here on*).




5. Select the MPOSC3 catalog from the drop down list.

6. Check the VR Color Index radio button.

7. <Ctrl+Click> on star “C” on the image. This displays the Object Information form.

8. Click <Get> on the Generator. This puts the star’s information into the entry fields.

*The magnitudes are from the 2MASS J-K conversion (see Warner, 2007,* Minor Planet Bul. ***34****, 113-119). However, the reduced magnitudes using the PhotoRed reduction methods found different values for the stars to be used. Those values will be used instead.*

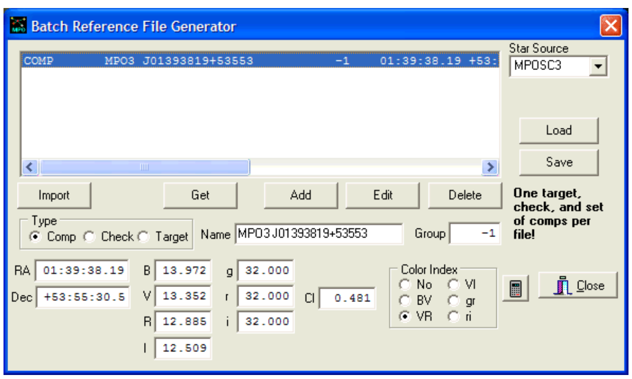
Changing the catalog values will not be uncommon. If the AAVSO chart for the field has adopted magnitudes for comparisons, you must use those instead. The main advantage of using this approach is that the Generator automatically enters the correct RA and Declination for you, thus avoiding a critical error.

*A tutorial in the Supplemental chapter shows how to import AAVSO data downloaded from their web site and so bypass measuring images entirely in order to create a batch reference file.*

9. Change the V magnitude to 13.352 and the CI (Color Index) magnitude to 0.481.
10. There is no AUID (AAVSO Unique Identifier) for any of the stars in the field (except the variable, of course), so leave the Name field alone. A comment entry in the batch processing file lets the AAVSO know these are 2MASS identifiers.

*Do NOT change the group number. It must be -1 for this exercise.*

11. Check the “Comp” radio button and then click <Add>. The information is placed into the list.




*When you click <Add>, all the entry fields are set to default values that the Generator recognizes as “no star”. To see the values in the fields for an item, click on that item in the list.*

12. <Ctrl+Click> on star “B”. Change the data to the values below and add the star to the list.

    V = 12.319
    CI = 0.381
    Type = CHECK

13. <Ctrl+Click> on star “T” (the target) and repeat the steps for adding the star to the list, using these values in the Generator *before you add the star.*

    V = 99.999
    CI = 0.486
    Type = TARGET
    Name = ET PER

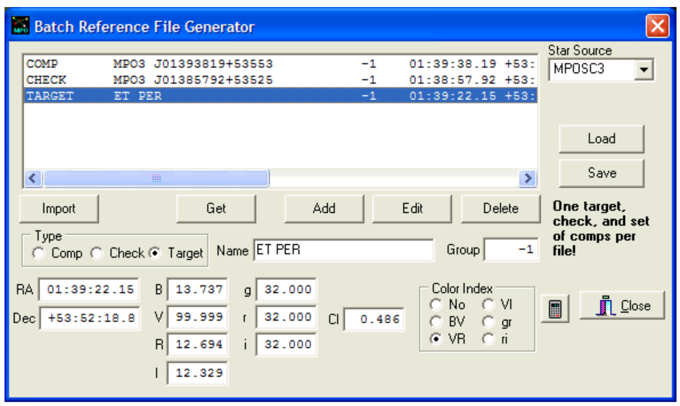
You set V = 99.999 only as a reminder that the magnitude is unknown. 99.999 could be entered for the B, R, and I magnitudes as well in the steps above to indicate that they are unknown or not to be used.

*The three Sloan values are set to 32.000 to indicate "no value".*

Naturally, if you are working a target where one or more of the other magnitudes are known in other bands for the comps and/or check, and you are going to find reduced magnitudes in those bands, you want to enter the proper values in the appropriate fields.

Many variables change color as they vary. You can chose to enter a compromise value, which introduces a maximum error about one-half the total range of color index values, or create different Batch Reference Files for maximum, mid-range, and minimum. This would imply, of course, that you know where on its cycle the star was when you measure a set of images.

14. Your final result should look something like this.




15. Click <Save> and save the file in the default directory of \MPO\UDATA. For this lesson, use the name

    ET_PER_TUTORIAL.TXT

The Batch Reference Files are simple text files that can be edited in a text editor. See the PhotoRed manual for the formatting of the.

16. Click <Close> to close the Generator.

This completes this part of the process. The next step is to create a Batch Definition File that uses this information.

## Creating a Batch Definition File

The Batch Differential Photometry form (*called the "Batch form" from here on*) is used to create a list of batch definitions. Each definition refers to a unique Batch Reference File, indicates the name of the object, filter used, and a list of images to be measured. This allows you to measure with a single processing pass not only images of the same target in different filters but many objects on one or many nights. Each item in the list is treated as a single "session" as defined by MPO Canopus. That's why you must break out the observations of a single target by filter and/or date.

*Never create a definition that measures images using different filter and/or taken on different dates or of different targets.* ***The strict rule is for a definition is: one target, one filter, one date per definition****. The good news is that you can use the same Batch Reference file for all definitions involving the same target, regardless of filter or date, just as long as the comps, check, and target information do not change.*

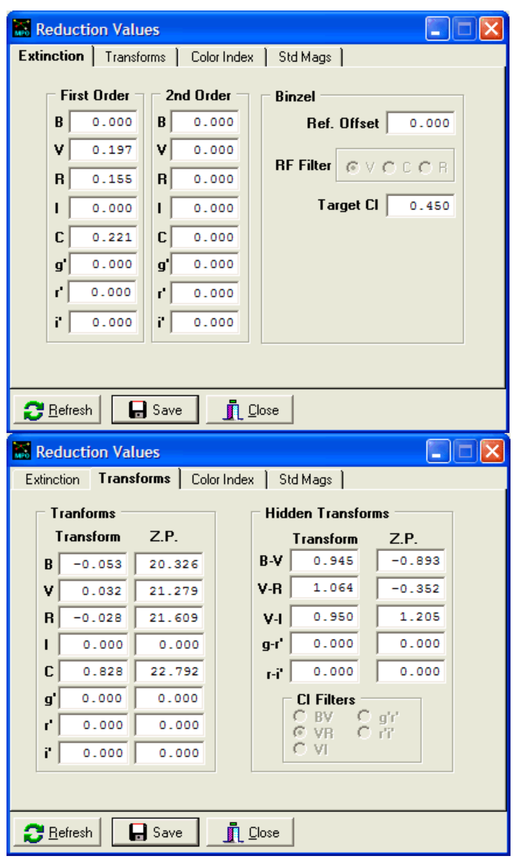
This tutorial is going to use transforms, i.e., apply color corrections to account for different color indices for the target, comp, and check stars. This is not a required step and should be done only if you know you've established good transforms for your system.

*The derived magnitudes are based on differential photometry, so the absolute first order extinction (*FOE*) and nightly zero point values are not critical. However, it is important to have* FOE *values such that the difference between k'v and k'r is accurate. Otherwise, the correction based on color index will not be right.*

17. If you want to save whatever transforms values you have, select "Photometry | Backup saved transforms" from the main menu before proceeding. You can reload the original transforms when needed.

18. Select "Photometry | Transform values" (or <Ctrl+T>) to open the Transforms form.

19. Match the screen shots below for V and R FOE and the V and R transforms (including "hidden").

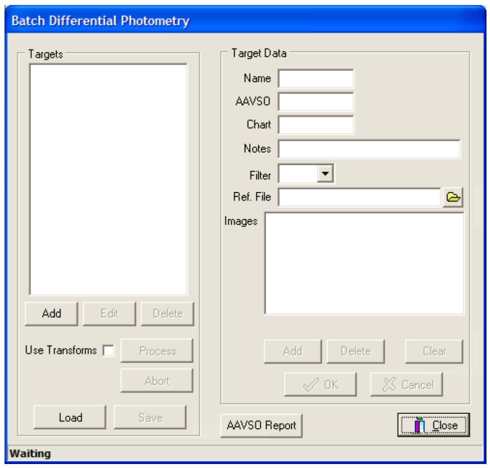


20. Save the changes and then close the form.

21. Set the measuring apertures to 13x13/2/11.

22. Go to the Reductions page (<Ctrl+2>) and select “AAVSO Batch” for the reduction method.

23. Click <Reduce>. This displays the Batch form.




24. Click <Add> on the form. This puts it into edit mode and places the cursor in the “Target Data | Name”.

25. Enter the following information

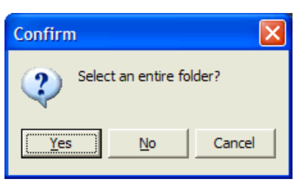
    Name: ET PER 1
    AAVSO: ET PER
    Chart: 071023
    Notes: Warner sequence, 2MASS identifiers
    Filter: V

*The Name field is not the AAVSO name but a unique identifier for the batch definition. You could use anything that makes sense to you.*

See the PhotoRed Reference Manual for details on each entry field.

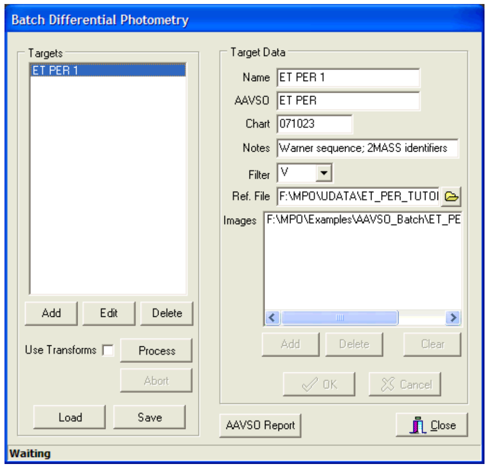
26. Click the button next to “Ref. Field” to open a file open dialog. Locate and select the Batch Reference File you created in the previous section. The name of the file appears in the entry field.

27. Click <Add> under the Images field (a list box). This displays a message.




28. Click <Yes>. This displays the Windows directory selector. Locate and select \..\20071023. Remember that \..\ is short-hand for the path to the example images.

29. Click <OK>. This creates an entry in the Targets list.



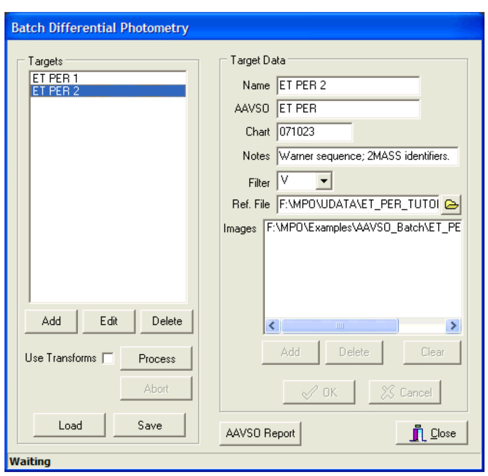

## Saving Time

Selecting a folder instead of a specific set of images can save you a considerable amount of time by not having to edit the batch definitions every time you measure images of the same target. For example, say you regularly observe ET PER. You may save the images for a given night, maybe even filter, in separate directories. However, if you move the images to be measured even temporarily to a work directory, e.g., ETPER_WORK, you can specify this temporary directory in the batch definition. Measure the images and then move them to their permanent location. Unless something else changes about the definition, you need to create it only once.

## Adding a Second Definition

30. Repeat the above steps above to add a new definition. Keep all information the same except:

Name: ET PER 2
Images: \..\20071026 (click <Yes> to “Select an entire folder?”).

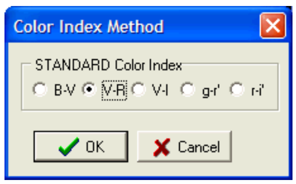


31. Click <Save>. Save the definition in the default directory, \MPO\UDATA\, using the name

    ET_PER_TUTORIAL.BFD

## Measuring Images

32. Check “Use Transforms”.
33. Click <Process> to start measuring images.
34. Since “Use Transforms” was checked, a confirmation message appears.



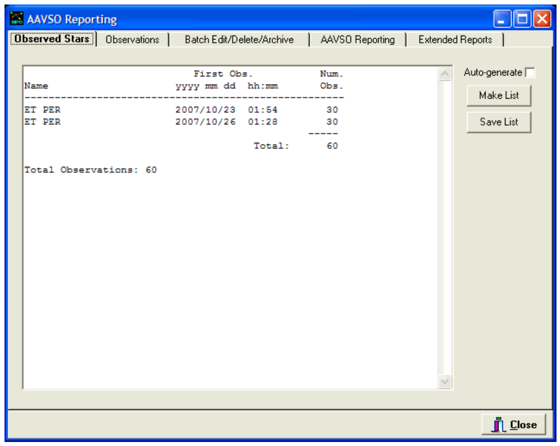

35. Select “V-R” (remember it was V-R magnitudes that were entered in the Batch Reference File) and then click <OK>. This starts batch process.
36. The batch processing takes some time since each image must be opened, the stars extracted, and then PhotoRed does an AutoMatch. This is why is important to have the correct configuration settings. PhotoRed extracts the stars in the first pass for each definition and then does the AutoMatch. PhotoRed uses the plate constants and the positions in the Batch Reference File to find the target, check, and comparison and then measure their magnitudes.

*Do not disturb the program during batch processing. You can try to work on other things as long as they do not involve MPO files, e.g., you can do email. However, as each image is loaded and AutoMatch invoked, PhotoRed “grabs focus” from any other program. The best thing to do is sit back, keep an eye on things, and have a cup of coffee.*

*Remember that you’re processing two sets of images, so don’t think things are done after the first set of extractions and measurements.*

*Monitor the bottom status line of the Batch form. It tells you which image is being processed and the image count versus total image count.*

37. After all the images have been processed, the AAVSO Report form should appear.




38. If the first tab is blank. Click <Make List>. This generates a summary of all observations, showing the name of each star, the date, and number of observations on that date. It does not subdivide by filter.

39. Click <Save List> to save the text file to your hard drive.

*The setting of "Auto-generate" is remembered each time you run the program. It is off by default since generating the list can take some time if you have thousands of observations. This is something that you can and should avoid. See the Data Import/Export chapter for lessons on managing the AAVSO tables. Later in this tutorial, you'll export data for use in Canopus. The Archiving functions (located on the "Batch Edit/Delete/Archive" tab) are covered in tutorials in the Data Import/Export or Supplemental chapters.*

## Generating an AAVSO Report

40. Click on the "AAVSO Reporting" tab. You should see your data (and more if this is not the first object you've measured).

41. Set the entry fields as follows

| | |
|---|---|
| Name: | ET PER |
| Start: | 2007/10/23 |
| End: | 2007/10/27 |
| V: | Checked |
| Observer Code: | XXX |
| Delim: | \| - pipe |

*The search for the Name field is case-sensitive, so entering ET Per would not find any records in this case. If you do not enter a name, then all records within the start-end range are included.*

### *About Date Formats and Ranges*

Generally, Windows programs set the date and time formats to those specified in the Windows regional settings. However, Canopus and PhotoRed force ANSI date format, yyyymmdd (year, month, date), and 24-hour time. This helps assure that dates written to text will be in a known format and so can be used in certain routines without having to worry if the format in the text matches the Windows settings.

Note that the End date is Oct 27, when the last data are actually from Oct. 26. The Start is the earliest date for observations, starting at 00:00 UT. The End is the latest date at 00:00 UT. If you set the End to Oct 26, then none of the observations from that date would be included.

☞ *All data you want to include in the report must fall on or between the two dates at 00:00 UT.*

42. Click <Generate>. This displays a file dialog with a default name of

    AAVSO_REPORT_<yyyymmdd>.TXT

    Where yyyymmdd is the current date in ANSI format.

☞ *The default directory is the last one used when saving a file. If there is no previous default, \MPO\UDATA is the default.*

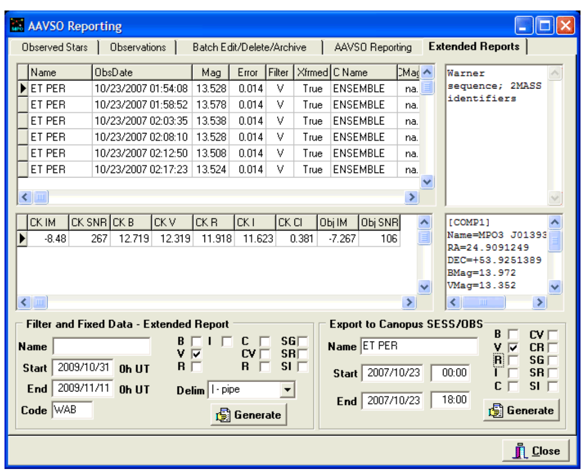
43. Save the file. This is the file you would email or upload to the AAVSO if this were "live" data.

As a check, the data were imported into a spread sheet where the mean magnitude and standard deviation of the Check star were found: V = 12.312 ± 0.012. Remember that the Check star had a catalog value of 12.319, or a difference of 0.007 m. This provides another check on the quality of the data and accuracy of the results. Should the check star actually be a different magnitude, the difference between its true and adopted values can be applied to the target magnitudes to improve the accuracy of those results.

## Exporting to Canopus Export (Saved Session) Files

You can create Canopus export files that can be imported into Canopus for period analysis and plotting. If you have data from more than one date, you must export files multiple times, once for each date. You can export data from multiple filters on the same date in one step however.

44. Click the "Extended Reports" tab.



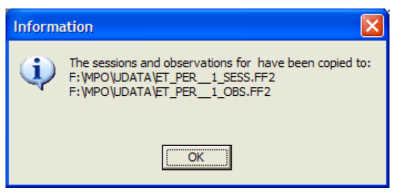
45. In the Export to Canopus SESS/OBS section, set the entry fields as follows.

| | | |
|---|---|---|
| Name: | ET PER | |
| Start: | 2007/10/23 | 00:00 |
| End: | 2007/10/23 | 18:00 |
| V: | Checked | |

The start and end date/times are in UT. The start and end dates can be different but the total time between the combined start date/time and end/date time must be less than 24 hours.

*Keep in mind the rules for a Canopus session: one target, same comparisons, same filter, same date. The last is a little flexible since many locations will have data from a single run that cross dates, e.g., those in the Eastern Hemisphere who start observing before 00:00 UT and keep observing until after 00:00 UT the next day.*

46. Click <Generate> to export the data to a pair of export files (SESS/OBS).




*PhotoRed generates a unique base name for the pair, so previous exports, even if of the exact same data set, are not overwritten. Your file names may be different.*

47. Repeat the steps above in this section, with the following exception

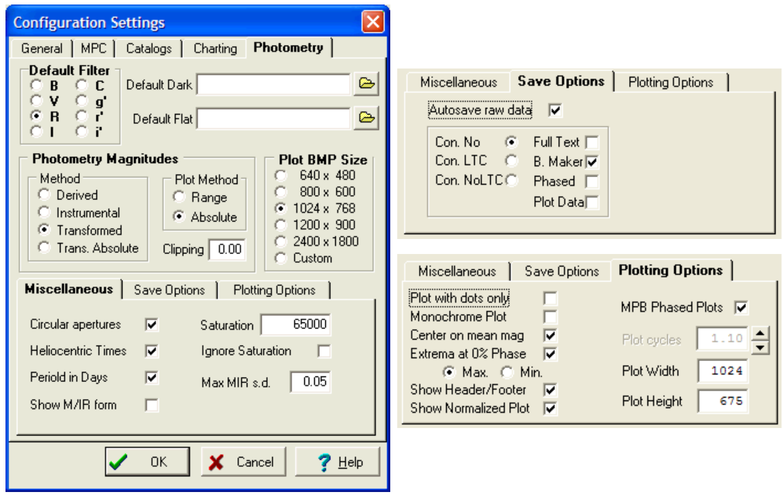
| | | |
|---|---|---|
| Start: | 2007/10/26 | 00:00 |
| End: | 2007/10/26 | 18:00 |

48. Close PhotoRed but leave Canopus open.

## Importing and Analyzing AAVSO Data

Now it’s time to see if the data from the two runs line up and to do some period analysis.

49. Open the Canopus configuration form and go to the “Photometry” tab and match the settings on the sub-tabs as show below. Save the revised settings.



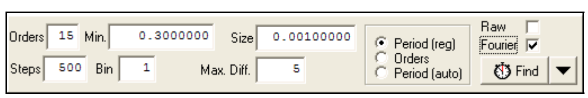

50. Select "Photometry | Load saved session(s)" from the Canopus main menu and load the first of the two export file sets you created in the previous section.

51. Select "Photometry | Import into saved session | from file" from the Canopus main menu and import the second set of export files from the previous section of this tutorial.

52. You'll see a warning message that you are working with a temporary copy. If you want to save the combined set, select "Utilities | Backup current sessions/observations" and save the combined set. They will be saved with the same name as the first files you loaded but you can save them to a different directory.

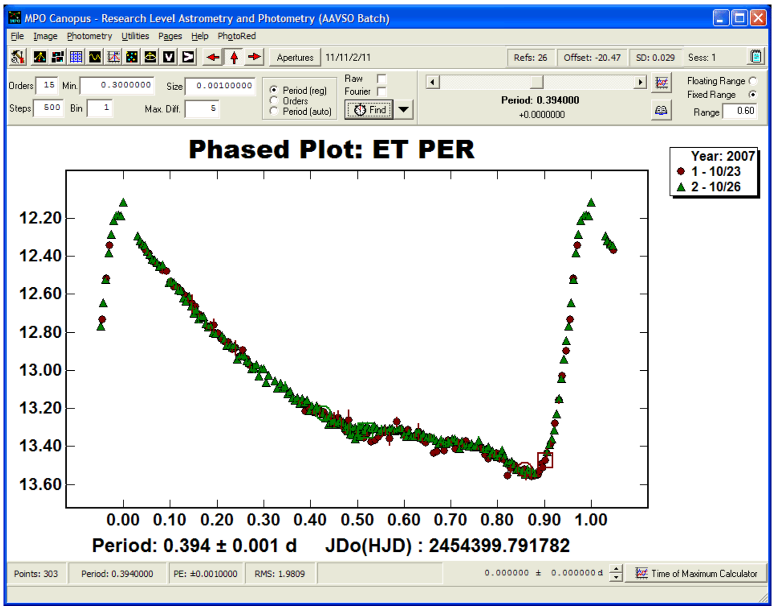
53. Go to the Lightcurve analysis page (<Ctrl+4>).

54. Set the period search parameters as follows as shown below.




Why set the orders so high? As you'll see, this is an RR Lyr star that has a very fast rise from minimum to maximum. The higher number of orders allows the Fourier curve to follow that sharp rise and rapid "roll-over" towards minimum more closely as well as a small "bump" towards minimum. If this were a typical contact binary star, you could use lower orders. An Algol-type variable would also probably require higher orders since they, too, have relatively sharp rises and falls during the primary eclipse.

55. Click <Find> and select both sessions. After a few seconds, you should see a plot similar to this.




56. You can try to refine the period search by setting the Min to something a little less that 0.394 and decreasing the step size. The full data set for this star included more than 700 data points and led to finding a very precise period.

## In Conclusion

As you've seen, PhotoRed can process large numbers of images on any number of targets from a given night. You can generate reports to submit to the AAVSO (ET PER was one of those submitted), and do period analysis in Canopus.

# 11. The Quick Binzel Reduction Method

The Quick Binzel method is designed to use a small number of images in two standard filters, V and R, to find the V magnitude of an asteroid or other object as well as the V-R of that target. Its primary use is to obtain V magnitudes over a range of phase angles to determine the H and G parameters of an asteroid.

This tutorial does not include detailed step-by-step instructions. See previous tutorials on using the Photometry Wizard for Transforms for a general description of how to match an image and select stars from a catalog using the matched image.

### *Why QuickBinzel and not AutoMatch?*

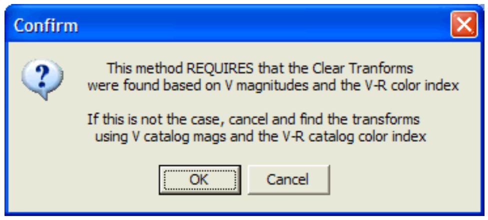
The "Max MIR s.d." setting on the Canopus configuration affects only Canopus. Also, this method allows you to measure images in two filters to find the color index at the same time you find the *color-corrected* reduced V magnitude of a target. You can also be more selective about which stars are included in the solution. While a little more time-consuming, the net result is usually a better solution than what you get from the M/IR solution in Canopus.

## Running the Quick Binzel Method

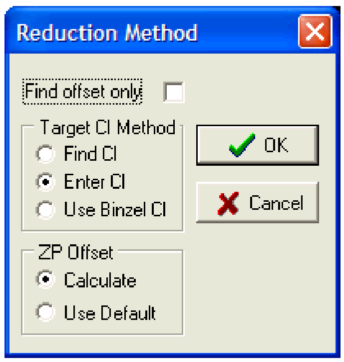
Make sure that you have found the v-r to V-R hidden transform and first order extinction for V and R such that the differential value between these two is approximately correct, usually 0.02-0.07 mag.

If finding V-R for the target, obtain images in V and R of the field. Three is a good number but it should be no less than two.

1. Open the first image to be measured and do an AutoMatch.
2. In PhotoRed select "Photometry | Photometry wizard | Transforms/Quick Binzel" from the main menu (or <Alt+W).
3. Select "Quick Binzel" on the first tab of the wizard and "MPOSC3" from the drop down list for the catalog.
4. Select as many reference stars from the catalog as possible that are on the image. Try to avoid excessively faint stars (low SNR) or those that are non-linear or saturated. Also try to avoid those with close companions such that a one pixel error in the placement of the aperture would change the reading of the star.
5. Measure the target's position on the initial image. In "Quick Binzel mode", the wizard includes a separate page where you set the target name and location.
6. Measure the images. Put all data into Group 1, making sure that the correct filter is selected on the image list before you click <Accept>.
7. Save the observation data.
8. Run the Quick Binzel reduction method. If you select the Clear filter, you'll see a warning message.




9. If it’s OK to proceed, click <OK>. This displays the Options form.




See the Reference Manual for information about the options.

10. Uncheck the “Find offset only” box so that PhotoRed can find the average difference between instrumental and catalog magnitudes.

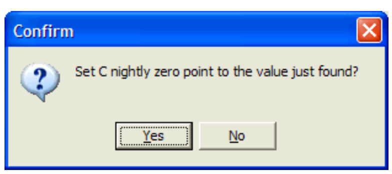
11. Check the “Enter CI” radio button.

12. Check the “ZP Offset | Calculate” radio button.

13. Click <OK>. Since you checked “Enter CI”, an entry form appears.

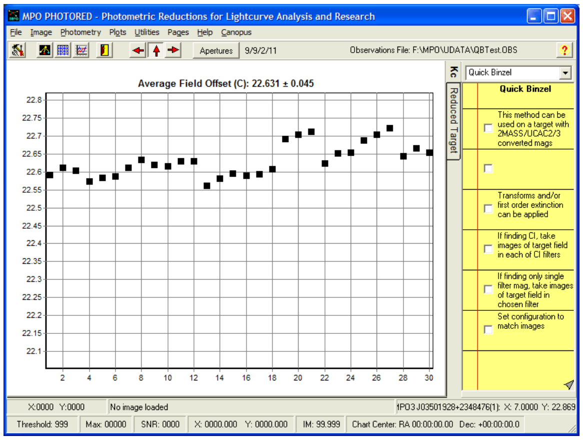
14. Enter the color index of the objects. The default is 0.45, the average V-R for asteroids.

15. Click <OK>. This displays another message.



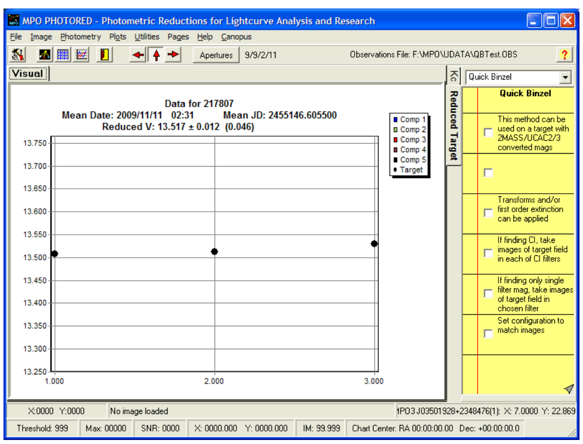

This option allows you to reset the nightly zero point used for the transforms and all-sky photometry. It uses the current value for first order extinction to calculate the result.

16. Click <Yes>. The results are displayed Plots page of PhotoRed.




The plot above shows the individual c-V values for each star in each image. In this case, there were 11 stars and 3 images. You can click on a given data point to see which star produced the data point. The above data is acceptable, with a standard deviation of 0.034 mag. If using the LONEOS or User Star catalogs, you can usually get this down to 0.02 mag or less.

The “Reduced Target” tab shows the reduced V magnitude of the target.




Since there were three images, PhotoRed found the V magnitude of the target three times by applying its corrected instrumental magnitude (for color and extinction) to the Average Field Offset value shown above. The three values are plotted as are the average of the three values and the standard deviation.

If you had measured V and R images, you could have obtained the V-R value for the target. You don’t see this page because you chose to enter the value manually. Had those images been available, the V-R would have been computed by making three pairs of v-r instrumental magnitudes (corrected for extinction) and applying the hidden transform to each v-r value. The average of these three and the standard deviation are shown in the header of the plot along with the average JD of the set of images and the reduced V magnitude of the target.

Note the error for the reduced magnitude. The error given immediately after the magnitude is the standard deviation of the three measurements. The value in the parentheses is the combined error of the measurements formed by adding in quadrature the standard deviation of the offset average and the standard deviation of the reduced magnitude.

# Data Import/Export Tutorials

Sometime it is necessary to share your data with other observers during a campaign or with researchers who need your data. Canopus has been designed to make data sharing as easy and flexible as possible. Since there many variations on this theme, not every possibility can be covered. The follow tutorials serve to get you started and to give you ideas on how to go about data sharing.

These tutorials are aimed at Canopus data only. They do not include PhotoRed nor AAVSO data.

## Canopus Export (Saved Sessions) Files

Canopus requires two files for data analysis, a session file (with SESS at the end of the name) and an observation file (with OBS at the end of its name). The primary files are PHSESS.FF2 and PHOBS.FF2, which are found in the \MPO\COMMON directory. These store the data that you create with the lightcurve wizard or import from other users.

It is recommended that only *your* data be kept in these two files. If you're working in collaboration with others and want to incorporate their data into a single data set, then you should work with a different set of files. These are the Canopus "*export files*" even though you may be importing the data from them.

When exporting to *export files*, Canopus creates two files using SESS and OBS in the file name. The two files together are an ***export set***. For example, if you are working 771 Libera and that is the entry in the "Object" field of the sessions form, then the files will be given default names of

> 771_LIBERA_X_SESS.FF2
> 771_LIBERA_X_OBS.FF2

Where X is an auto-incrementing number so that existing files are never overwritten. As you might presume, the SESS file contains the data for one or more sessions and the OBS file contains all the observations for all the sessions.

> *It is extremely important that you not change the names of the files or, if you do, that the base file name is exactly the same for both files and that you keep the _SESS.FF2 and _OBS.FF2 endings..*

Canopus relies on the SESS file name to find the corresponding OBS file. You cannot specify them separately when loading data into Canopus. For example, in the examples above, if the SESS file was named 771_LIBERA_1_SESS.FF2 and the OBS file was 771_LIBERA_2_OBS.FF2, Canopus would not be able to find the OBS file.

The file names are not case-sensitive. Otherwise, they must follow these rules.

## Text Files

As you'll see in the tutorials, you can export to and import from text files. Certain information must be available for at least the OBS file (the observations data). You will have to create the SESS file or use an existing one. This is covered in the tutorials.

## Working with Export Sets from Earlier Versions

Version 10 of Canopus automatically converts version 9.x export files (including PHSESS/PHOBS) as the program attempts to load them.

Once the files are converted, you can return them to a person using v9.x. However, some of the fields available in v10 are not available to the other users. If he returns the fields to you again, Canopus will still be able to load them (v9.x does not "uncovert" the file) but some data may be missing or not updated because v9.x has no knowledge of the new data fields.

*Version 10 cannot convert data from v8.x and before on-the-fly. Those data files must be converted to v10 using the CONVERT10 program found in \MPO\PROGRAMS. See the CONVERT10 documentation and Installation Guide for additional information.*

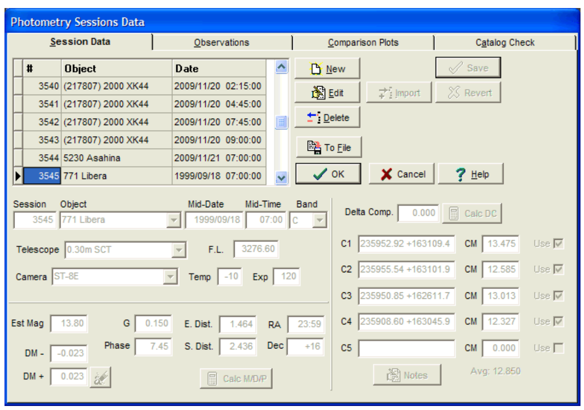
# 1. Creating an Export Set

It is very easy to create a Canopus *export set* from data in your PHSESS/PHOBS files. You would create an *export set* for a number of reasons.

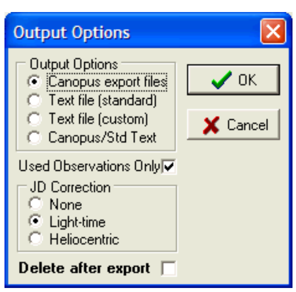
- For archiving purposes so that you have the data for a given object in its own files.
- To share with other Canopus users who want to incorporate your data into their data sets.
- To create a “Master” export set that will be used to import data from other users in a collaboration. This keeps the data for the given object isolated from your data set and allows you to resend the merged set back to the other Canopus users.

*The easiest way to exchange data among Canopus users is with export sets. Sending text files requires additional work and can lead to errors.*

1. Open the sessions form (<Shift+Ctrl+S>).




2. Select the first session for the object for which you want to export data. In the example above, it is 771 Libera.
3. Click <To File>. This displays the Output Options form.




4. For this tutorial, we want on only Canopus *export files* (an *export set*), so check the “Canopus export files” radio button.
5. Check the “Used Observations Only” box.

   If you’ve excluded observations for one reason or another, checking this box prevents the unused observations from being included in the *export set*.

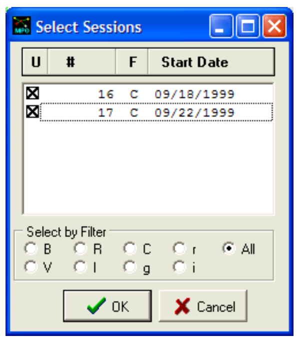
*The “JD Correction” setting has no meaning for an export set. The “raw dates” are exported so that the receiver can have Canopus apply or not apply corrections as he wants. By never applying an corrections in an* export set, *there is never any confusion about whether or not the Julian Dates have been adjusted for light-time correction or to heliocentric JD.*

*A later tutorial brings this setting into consideration.*

6. ***Do not*** check the “Delete after export” box! If you do, you will get a warning message that allows you back out before you *permanently* remove the data from the PHSESS/PHOBSS files.

***The “Delete after export” option should be used VERY carefully. The “Delete” button on the sessions form accomplishes the same goal, but one session at a time.***

7. Click <OK>. This displays the (what should be) familiar Select Sessions form.




8. Select the “All” radio button so that all sessions, regardless of filter setting in the sessions, are included in the output.

   If you select another filter, then only those sessions with that filter are included in the list and will be in the *export set*.

9. Click <OK>. This displays a Select Directory form. The default is \MPO\UDATA, but you can store the files in another directory if you want.

10. After you select the directory, you should see a confirmation message that the files were saved.

11. Use Windows explorer to check the directory for the two files in the *export set*. If you were to repeat the process above selecting sessions with the same “Object” name, you would get a separate set of export files with the auto-increment number one higher.

*If sending to another Canopus user, be sure to send both files of an export set.*

# 2. Exporting to a Text File – I

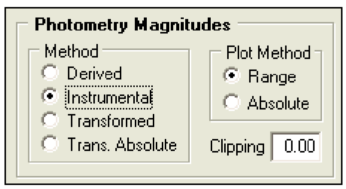
Not every person with whom you work will be using Canopus. You can still provide them with as much or as little of the information within the SESS and OBS files as you want to send or they need to receive.

*When exporting to a text file, the "raw data" are output, meaning that no corrections for phase angle or distance are included.*

This tutorial will be very brief, since it follows the same steps as the previous lesson up to the point where you get to the Output Options form.

## *Selecting the Output Magnitudes*

1. Open the configuration form and set the type magnitudes to be used when calculating the average of the comparisons and the differential magnitude of the target.




The "Method" is what's used for the calculations. The "Plot Method" setting as no effect.

*If you select "Derived" make sure that you have magnitudes entered in the "CM" field for each comparison that is used. Otherwise, you will get exaggerated errors.*

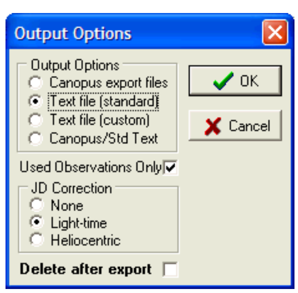
Do not select the deprecated "Transformed" or "Transformed Absolute" method.

2. For this tutorial, select "Instrumental", which is also the choice you should make if catalog magnitudes are not entered in the "CM" fields for the comparisons on the sessions form.

## *Exporting the Data*

3. Open the sessions form and select the first session for the object for which you want to export data.

4. Click <To File> to display the Output Options form.




5. Select the options as shown above.

This time, the “JD Correction” is important. Choose the option that is right for your situation. The header of the file will indicate which correction, if any, was applied.

6. Click <OK> to display the Select Sessions form.
7. Select the sessions to included and click <OK>. This presents a file dialog so that you can change the default name and path if you want.
8. Save the file. If successful, you will see a confirmation message giving the full file name.

## What’s in the File?

The file begins with the header for the first session. This contains the essential data for that session from the PHSESS file, including the entire contents of the Notes field, which can contain information about the M/IR solution, the catalog magnitudes of the comparisons, and StarBGone data as well. For example (less the Notes section):

```
Session #3511
Details for: 1750 Eckert

Start Date: 2009/11/11 07:00:00
Color Band: C
Delta Comp: 0.00
Delta Dist: 14.47
Sun Dist:   1.609
Earth Dist: 0.704

Telescope: 0.35m f/9.1 SCT
Focal Len: 3276.60
Camera:    SBIG STL-1001E
Temp (C):  -30
Exp. (s):  240
Phase Slope: 0.15
Phase/Dist Corr (-/DAY): +0.005
Phase/Dist Corr (+/DAY): -0.005

JD CORRECTED FOR LIGHT-TIME: 0.004063 days

ERROR CALC: The magnitude error is calculated by the following:
            Err = sqrt(sqr(ERR[target]) + sqr(Err[Comps]))
            where Err[Target] = 1.0857/SNR[target]
                  Err[Comps]  = sqrt(sqr(1.0857/SNR[Comp1])...+
                  sqr(1.0857/SNR[CompN])) / N
            The factor of 1.0857 converts flux to magnitudes (Howell)

Comp1: 011546.19 +464250.6          14.230  Y
Comp2: 011524.53 +464234.2          13.716  Y
Comp3: 011546.39 +464430.3          14.334  Y
Comp4: 011551.63 +464420.4          14.187  Y
Comp5: 011541.68 +464106.1          14.302  Y
```

*Note the header includes a line regarding JD correction. In this case, the JD values were corrected for light-time, the time light took to go from the asteroid to the Earth (in days). The JD values for this session were all corrected by* **subtracting** *0.004063 days from the raw JD. Light-time correction is always subtracted from the raw JD.*

This is followed by a detailed listing of the observation data, with the instrumental magnitude for the target and each comparison. At the far right of each line are three columns that give data based on the Photometry Method setting.

If "Instrumental", the columns are the average of the comparisons that are used (CAvg), the Object-CAvg magnitude (the differential), and the estimated error in magnitudes.

If "Derived" the column headings are the same but the CAvg is 0.000 since the magnitudes for the target are presumably on the same zero point as the comparisons. Therefore, the values are the *DerivedMags* for the target. The error is the standard deviation, in magnitudes of the mean of the DerivedMags value. Here are samples of the last three columns, the left-hand is when "Instrumental" was selected and the right-hand when "Derived" was selected.

```
   CA    O-CAvg   Err            CA    O-CAvg   Err
 --------------------          --------------------
 -8.065  +0.242  0.003          0.000 +14.396  0.068
```

The errors can be considerably larger with the *DerivedMags*, mostly because of inconsistencies within the catalog and color differences between each comp star and the target. The *Instrumental* errors are based solely on the 1.0857/SNR conversion for each comparison and target.

At the end of the output file is a "condensed" listing that gives the JD, differential (or *DerivedMags*) value, and error.

```
Condensed Observation Data for Session: 3511
---------------------------------------------
  U      J.D.         Obj-CAvg      Err
----------------------------------------
  Y 2455146.85369      +0.242      0.003
  Y 2455146.85679      +0.228      0.003
```

## Export Set and Text in One Pass

Now that you're familiar with both export set and text file exporting, you can save time if you need both by choosing "Canopus/Std Text" on the Output Options form. This generates the same files as described in this and the previous tutorial in one step.

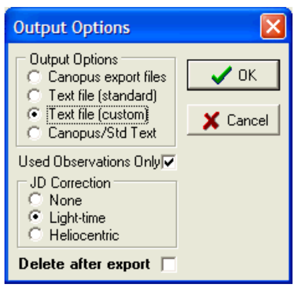
# 3. Exporting to a Text File - II

The previous tutorial covered exporting the session and observations data for an object to a text file using a fixed format. While this usually works in most cases, you can also output the data in a custom format should a collaborator want the data in specific format. The custom output generator provides a considerable amount of flexibility in this regard but, of course, cannot possibly account for every contingency.

If you have not run the previous tutorial on exporting to a text file, at least read the introductory material.

1. You do not have to select the Photometry Magnitudes method before running a custom report. The Custom Output form allows you to make that selection.

2. Open the sessions form (<Shift+Ctrl+S>) and highlight a session of the object for which you are exporting data. Click <To File>. This displays the Output Options form.

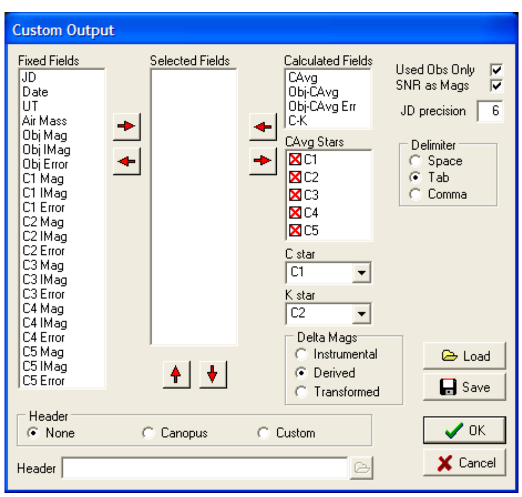



3. Select “Text file (custom)” radio button.

4. Check the “Used Observations Only” box. This setting can be overridden on the Custom Output form.

5. Select the “JD Correction | Light-time” option for this tutorial. Your needs may require a different selection.

6. Click <OK> to display the Select Sessions form. Select one more sessions and then click <OK> on that form to display the Custom Output form.



On the left is a list of *stored* data fields. These are values that are stored in the OBS file. The lists and combo boxes to the right of the form are *calculated* fields that can be included in the report. The middle list is the fields, *stored* and *calculated* that have been selected, the Select Fields list.

See the Reference Manual for details about the individual fields.

## *Moving Fields to and From the Selected Fields List*

To move an item from the “Fixed Fields” list to the “Selected Fields” list, highlight the item in the “Fixed Fields” list and click the right-pointing arrow button located between the two lists. This removes it from the Fixed Fields list.

To move the item back to the “Fixed Fields” list, highlight it in the “Selected Fields” list and click the left-pointing arrow button located between the two lists.

In a like manner, you can move items to and from the “Calculated Fields” list using the arrows between those two lists to move an item in the direction the arrow on the button is pointing.

You can select more than one item in any list since they are multi-select Windows list boxes that use the common rules for selecting contiguous or non-contiguous items.

If you attempt to move an item from the “Select Fields” list to the wrong list, e.g., CAvg to “Fixed Fields” instead of “Calculated Fields”, the program sounds a beep and rejects the move.

## *Selecting Output Fields*

7. Using the instructions above, move the “JD” and “Obj IMag” fields from the “Fixed Fields” list to the “Selected Fields” list.
8. From the “Calculated Fields” list, select “CAvg” but do not move it just yet.

*When using CAvg, you must also select which comp stars to use in building the average. This is done by selecting one or more items in the “CAvg Stars” list. If you select a star that is not used, it is ignored.*

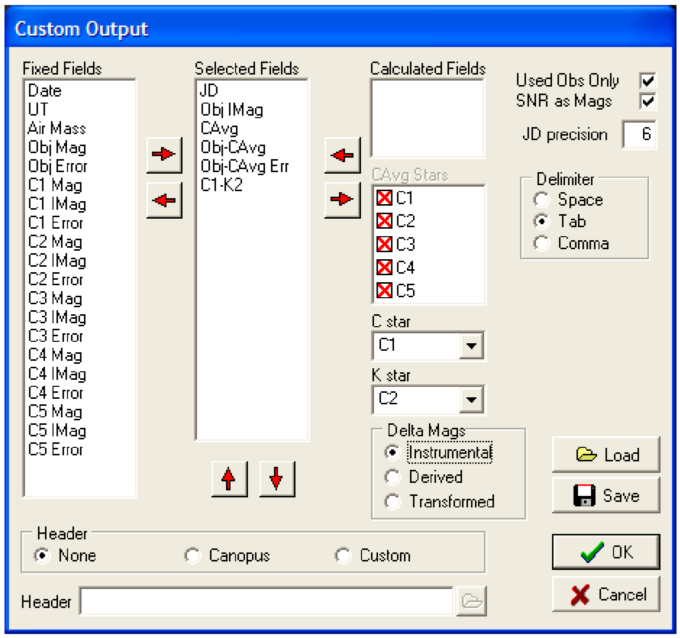
9. Select all the stars in the “CAvg Stars” list.
10. Move “CAvg” to the “Selected Fields” list.
11. Move “Obj-CAvg” and “Obj-CAvg Err” to the “Selected Fields” list using a single move (select both items before moving).
12. Select “C1” in the “C Star” drop down box.
13. Select “C2” in the “K Star” drop down box.
14. Move “C-K” to the “Selected Fields” list.

*Many people like to have a K-C magnitude as a check on the quality of the night. If the value, which is the difference between two selected comp stars, is stable, then the observations can be considered trustworthy.*

15. Select “Delta Mags | Instrumental”. This means only the instrumental magnitudes are used in computing the CAvg, Obj-CAvg, Obj-CAvg Err, and C1-K2 values.

*If you select "Derived", the CAvg value is 0.0. Obj-CAvg value is found by first computing the instrumental difference between the target and the comparison's catalog magnitude to get a derived magnitude for the target. This is repeated for each comparison. The Obj-CAvg value is the mean of those derived magnitudes and the error is the standard deviation of the mean.*

If "Transformed" is selected, the C-K value uses the M/IR derived value for the comparisons.




16. Set the remaining options to match those in the screen shot above.
17. Click <Save> to save these settings when the Windows file dialog appears. The file is a simple text file using the Windows INI file structure.
18. Click <OK> to run the report. When done, a Windows file dialog appears. Save the file. The default name is the entry in the "Object" field of the sessions with "Custom" included to indicate that it is not a standard output format text file.

Here is a short section of the file generated when running this tutorial on data for 1750 Eckert.

```
Observation Data Fields: JD,Obj IMag,CAvg,Obj-CAvg,Obj-CAvg Err,C1-K2

Observation Data for Session: 3511
----------------------------------
2455146.853691        -7.823     -8.065     +0.242     +0.004     +0.501
2455146.856792        -7.866     -8.094     +0.228     +0.004     +0.502
2455146.859926        -7.806     -8.038     +0.232     +0.004     +0.508
2455146.863077        -7.715     -7.961     +0.246     +0.005     +0.494
```

The first line gives the names of the columns. If more than one session had been selected, each session would be in its own block.

The non-data lines can easily be removed before the receiver imports the data. They are put there to “document” the data, which should always be done to one degree or another.

### *A Custom Header*

Sometimes a research requests a particular bit of information at the top of the file, something different from the standard Canopus header. If that is the case, you can create a text file that has the header information that’s needed and then specify “Header | Custom” on the Custom Output form. You would also enter the full name of the file before generating the report. You can use the speed button next to the “Header Options” radio button group to locate the custom header file and enter its full name into the field.

# 4. Importing Export Sets

Importing *export sets* is relatively easy and straightforward. Where the trick likes is planning a routine when working in collaboration with other Canopus users. For example, if you are the "primary", then all data comes to you. As mentioned earlier, you really don't want to merge other people's data into your PHSESS/PHOBS files. Here is just one possible outline of how you would proceed.

- Create an *export set* that includes all your sessions and observations for the target.
- Rename the files to indicate they are the *master files*. For example, say your export files had the original names

  771_LIBERA_1_SESS.FF2
  771_LIBERA_1_OBS.FF2

  Rename them to

  771_LIBERA_MASTER_SESS.FF2
  771_LIBERA_MASTER_OBS.FF2

  It's also a good idea to create a new subdirectory under \MPO\UDATA to hold all files that you'll be getting, e.g., \MPO\UDATA\771_DATA.

*The total length for each of the two export set files, excluding path, cannot exceed 32 characters. This is a limit of the data base engine. If you try to load files with file names that are too long, the engine, via Canopus, reports an error and the data are not loaded.*

- If you make additional observations, continue putting them into the PHSESS/PHOBS files so that you have a complete record of your work.
- Load the master set and import the new data from your PHSESS/PHOBS files and collaborators, be it their export data sets or text files.

The following tutorials show you how to do handle all these basic steps.

### Avoid Duplication

If you or your collaborators will be sending new data from time-to-time, it is very helpful if there is no duplication of data. For example, say you get an *export set* from your collaborator that has data from Nov. 1 and you have incorporated that data into your master set. He then observes on Nov. 3. Make sure that when he creates the *export set* to send you that he selects *only* the Nov 3 session, not both. Otherwise, Canopus loads both sessions as new data, meaning that you'll have two sessions from Nov 1 from your collaborator.

The same applies if you're creating export sets to send to someone else. Select only new data each time you create a new export set. Remember that Canopus automatically creates new export sets with unique base names by using an auto-increment number.

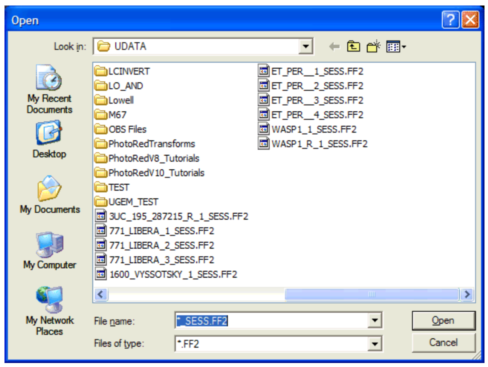
You want to be careful if collecting sets from others. They may send you files that have the same file name as some on your computer. I put all incoming files into a temporary directory, immediately rename the two files in the set, often including the initials of the observer in the new name, and then move the renamed files to the working directory.

## Temporary Data

In many cases when working with *export sets*, you are not working on the original files but a temporary copy. If you do not backup the files (covered in the tutorials), then you will lose all changes when you close Canopus.

## Importing an Export Set

1. Assuming that you are not already working with an export set, select "Photometry | Load export set" from the Canopus main menu. This displays a Windows file dialog that is filtered to show only those files that end with _SESS.FF2.

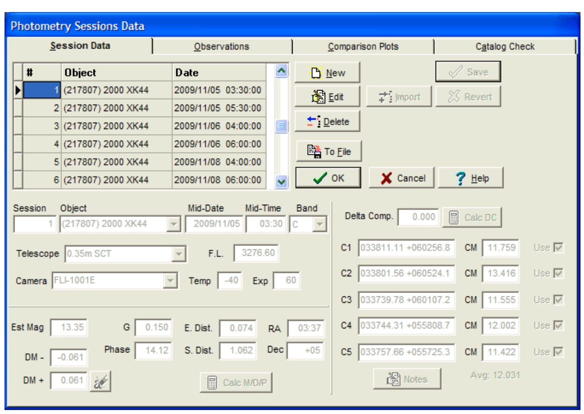



If you did the tutorials on creating an asteroid lightcurve and then exporting the export set for those sessions, there should be at least one _SESS.FF2 file in the dialog somewhere on your hard drive.

2. Select a file from the dialog and click <Open>.

If there is at least one session with data in the file, Canopus automatically sets the first session as the default session. If there are no sessions, an error message appears and no sessions are available.

3. Open the sessions form (<Shift+Ctrl+S>).




All the sessions are (or should be) for the same object. If there sessions with slightly different names, this suggests that you received a file that included data from several observers that had been created by steps that are outlined in the tutorials to follow. Before you continue working on the data sets, you should set the "Object" field entry to the same for all sessions.

## Some Tricks of the Sessions Form

There are several handy keystroke combination or features of the sessions form that may come in handy when working with export files and in general.

*You cannot be editing an existing record or adding a new one to use these features.*

### Searching for a Session by "Object" Field

- Click on the table.
- Press <Ctrl+F>. This displays an entry form where you can enter all or part of the name that appears in the "Object". The search is not case-sensitive, so "Fred" and "FRED" will be found. The search looks for the search string anywhere within a name, so "1503" will find "(21503) Beksha" or "1503 Kuopio"
- If no match is found, the table is positioned on the last session.

### Filtering by "Object" Field

If you want to show only those sessions involving a specific target,

- Located a session for that target.
- Press <Shift+Ctrl+F>. Only sessions have the same "Object" field entry appear in the table. The background of the table goes from light gray (technically, "button face") to light green. This is a visual cue that the table is filtered.
- To remove the filter, press <Shift+Ctrl+F> again.

### Finding by Session Number

To find a specific session number

- Press <Ctrl+G>. This displays an entry form where you enter the session number.

### Going into Edit Mode

You can go into edit mode one of two ways

- Click <Edit>.
- Press <F2> (function key <F2>)

You do not have to click on the table before pressing < F2> to go into edit mode.

*You cannot edit the table entries directly. You must use the entry fields below the table.*

## Clearing an Export Set

Before you can load another *export set* or to return to using the PHSESS/PHOBS files, you must clear the current export set.

4. Select "Photometry | Clear session" from the Canopus main menu. This clears the *export set* and makes PHSESS/PHOBS the default photometry files. It also resets

internal flags such that there is no default session. You must reselect a session from the sessions form as the default session

*The default session is the one to which new observations are appended or existing data are edited. Its "Object" field serves as the filter when selecting sessions for doing period analysis or exporting data.*

# 5. Merging Export Sets

As outlined earlier in this chapter, if you are the “primary” in a collaboration of several observers, it is best to work with a master *export set* and not import data from several observers into your primary PHSESS/PHOBS files. This tutorial presumes that you have already loaded that master *export set* and now want to add additional data.

The first case is where you are in collaboration with yourself. That’s not as strange as it sounds. There are some Canopus users who operate out of more than one observatory and work with a copy of Canopus at each location. In this case, they have one computer where they tend to do most of the work, the “master”, and create *export sets* on the computers to copy to the master where they can create a merged data set. This iscovered in the first part of this tutorial.

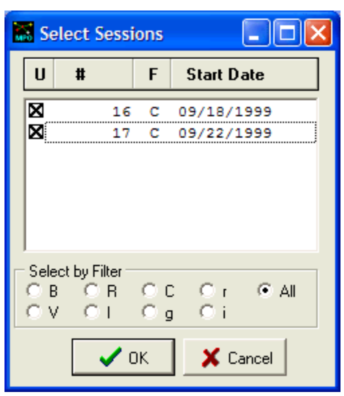
The second, and more likely case, is where you are brining in data from other Canopus observers who have sent you one or more *export sets*. This is covered in the second part of this tutorial

## Merging from PHSESS/PHOBS

An example of when you would use this approach is when you’ve been working with a master *export set* that includes data from several observers, including yourself, that you get more data for the collaboration that is put into your PHSESS/PHOBS files (the primary photometry data files). You could export the new data to an *export set* and then merge that set into the master set, but that’s one too many steps. Instead, you can go directly from your PHSESS/PHOBS files into the master *export set*.

1. Load an *export set*, e.g., the “master” being used in a collaboration where the data from several observers are being merged. For this lesson, an *export set* from the 771 Libera lightcurve tutorials (see the Photometry chapter) was loaded.

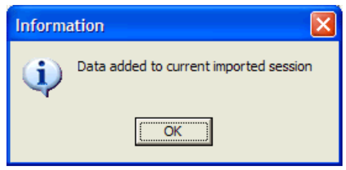
2. Select “Photometry | Import into export set | from PHSESS” from the Canopus main menu. This displays the Select Sessions form.



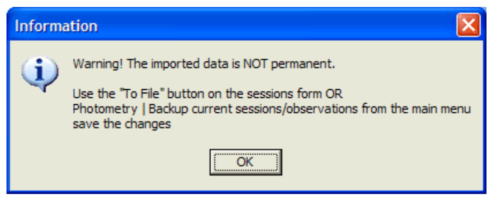

   The form lists only those sessions from the PHSESS file that have the same name as that in the “Object” field of the currently active session from the master *export set*.

3. Select one or more sessions and click <OK>. You will see some information messages as sessions and observations are imported and renumbered. Canopus assures that there are no sessions with duplicated session numbers since those uniquely identify a given session.

4. If all went well, you'll see a confirmation message.




5. Click <OK>. This displays a warning message.




6. Open the sessions form (<Ctrl+S>) and confirm that the correct data were imported and that things look OK.
7. If so, close the sessions form and immediately select "Utilities | Backup current sessions/observations" from the Canopus main menu. This displays a select directory dialog.

   If you want, you can save the updated export set to the original directory. If you select that directory, a warning message appears that the files already exists. Click <Yes> to overwrite the existing files.
8. After the files are saved, a confirmation message is shown that gives the path to which they were saved.

You can now work with the master set just as would the PHSESS/PHOBS files.

### *Backup before Leaving*

Even though you did a backup after you first loaded the additional data, you are still working with temporary files and so the originals will not have any changes that you make while working with the data.

***Select "Utilities | Backup current sessions/observations files" before you clear the session or exit Canopus. Otherwise your changes will be lost.***

## Merging from Export Sets

The steps are essentially the same to import data from *export sets* on your system as outlined in the steps above. There is only one difference.

1. Load the master *export set.*
2. Select "Photometry | Import into export set | from file" from the Canopus main menu. This displays a Windows file dialog that filters to show only files ending with _SESS.FF2.

*You can select one and only one export set per merge.*

3. Select the SESS file to merge and follow the steps outlined above, including backup the merged data set.

4. If you have additional *export sets* to merge, repeat the steps above.

***Be sure to backup the export set after you have imported all additional data.***

## Exporting Merged Sets

The steps for exporting the data from a merged *export set* are the same as when working with the PHSESS/PHOBS files. The exception is small and not common, that being the when working with a merged *export set*, all sessions are very likely of the same object.

*There is no rule against merging sets that cover different objects. You would work with the merged, multi-object set just as you do the PHSESS/PHOBS files.*

# 6. Importing from Text Files

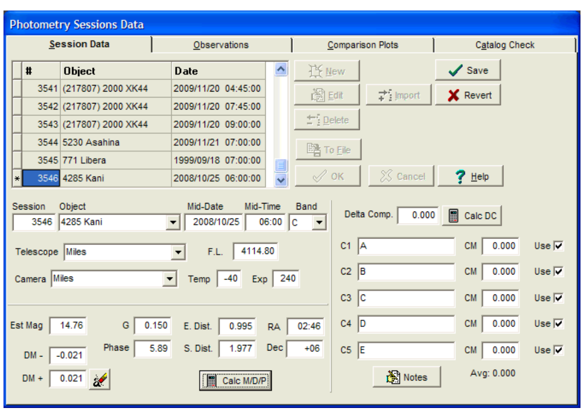
Many times you will need to import lightcurve data that did not come from Canopus. Since that data can be in many forms, this requires a specialized import process. However, it's not hard and can be easily learned.

## *Some Basic Requirements*

- There must be at least a date (JD or calendar date/time) and magnitude for each observation.
- The import file must be simple ASCII text and have one and only one observation per line.
- If there are header lines (non-data), those must be removed before trying to import the data.
- The magnitudes can be instrumental or on a standard system.
- Data must be imported into an existing, empty session.
- If there are data for multiple nights, you must create a separate session for each night. If necessary, parse the data file into several files, each one having the data from one and only one night.

*Two sample files are available for this tutorial. They are found in \MPO\EXAMPLES\DATAIMPORT. Only the file names (without this path) will be given in the tutorial. These were for the asteroid 4265 Kani and kindly supplied by Richard Miles of the British Astronomical Association*

1. Open the sessions form (<Shift+Ctrl+S>) and click <New> to create a new session.



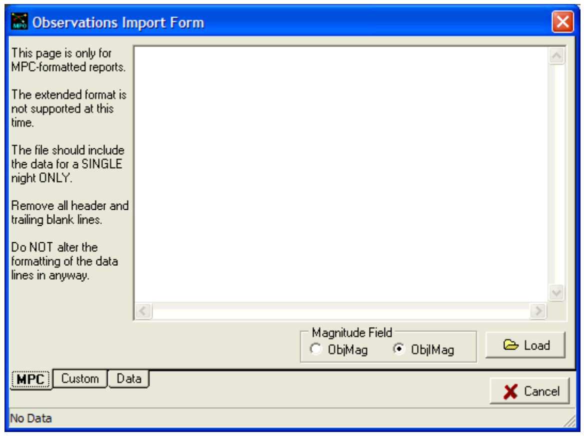

   The only critical information that's needed is the "Object", "Mid-Time", "Band", and distance/phase data.

2. Match the settings for these critical items as shown above. To get the distance/phase data, you need to click <Calc M/D/P> and locate 4265 in the look up list.

3. Click <Save> to save the session data but do not close the sessions form.

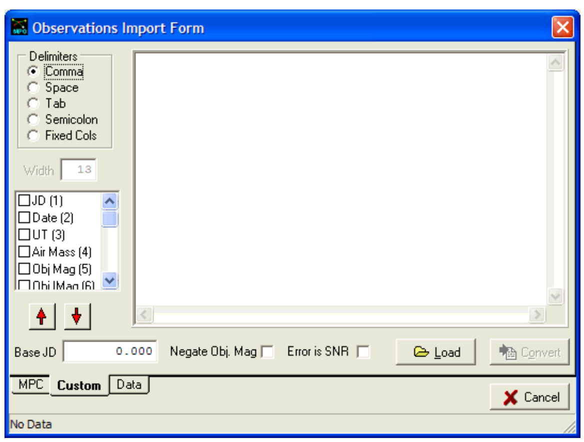
*Because of internal structures, you cannot import the data while creating a new session. So, you must save the session and then go immediately into edit mode.*

4. Click <Edit> to edit the session you just created.
5. Click <Import>. This displays the Observations import form (the *Import* form).




The Import form allows you to import data from two sources: MPC-compliant reports such as you create when you generate an MPC report from astrometry files (see the Astrometry chapter) or Custom, meaning you specify the format of the incoming data.

6. Click the “Custom” tab.




The left side of the form is where you define the incoming data.

7. Select the “Delimiters | Tab” button since the incoming data use tabs between the values in a given line.

*It is important that one and only one tab be used between fields. See the Reference Manual for additional details on delimiters in the data file.*

8. Check “JD” in the fields list since that is one of the fields in the incoming data.

9. Locate "Obj IMag" and <Ctrl+Click> on it. If you click, you will lose the "JD" selection since this is a typical Windows multi-select list box.

10. Use the up arrow below the list to move "Obj IMag" just below "JD".

11. Located "Obj Error" in the list, <Ctrl+Click> on it, and move it to just below "Obj IMag".

*You don't have to move the items in the list. This is just so that you see all the checked items at the top and don't forget to select a field that you want.*

12. Set the "Base JD" to 2450000.0. The data in the file are Julian Date – 2450000.0, so you need to add that constant to the data so that the correct JD are stored in the file.

13. Do not check either of the two check boxes. The data are such that the object is brightest at minimum value and the errors are in magnitudes.

## Which Object Magnitude?

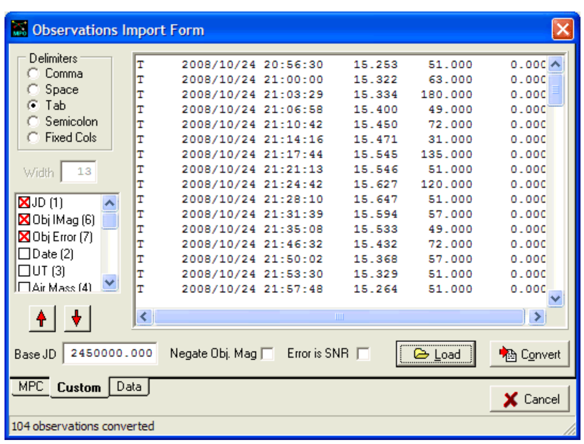
"Obj IMag" was chosen because analysis is being done using *Instrumental* mode (see the tutorials in the Photometry chapter). Since there is only one magnitude per line in the file, you need to put in the magnitude field in the observations file that will be used during the analysis.

*If using "DerivedMags" you would still select the "Obj IMag" field. This is because that method reads the "Instrumental" magnitude field in the observations file to do the calculations. Only the "Transformed" or "Transformed Absolute" photometry methods would use the Obj Mag field.*

If we had selected "Obj Mag", the data would go into the "true" magnitude field in the observations file. Then, if you try to do analysis in the *Instrumental or Dervied* mode, there would be no data in the instrumental magnitude field and you get a blank plot along with a complaint about no data.

14. Click <Load>. This opens a Windows file dialog. Locate and open

    A4265_20081025.TXT

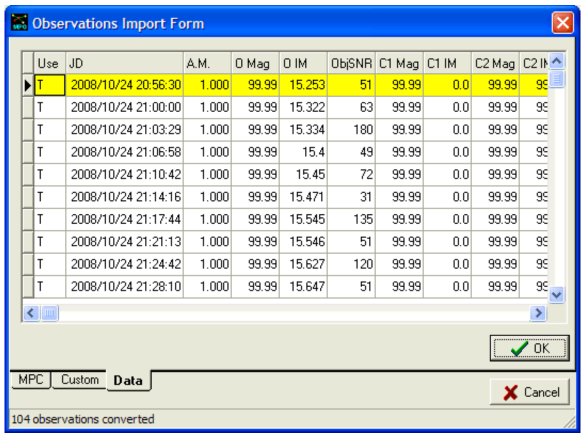



You should see something like the screen shot above.

*If you don't see any data in the memo form, look at the status line at the very bottom of the form. It will likely say something about an incorrect number of fields. This is usually caused by setting the wrong delimiter or indicating more fields than there actually are.*

*If you get an error about a bad date (probably a negative one), you forgot or improperly set the "Base JD" value.*

15. Click on the "Data" tab.




You should see something like the screen shot above. Note the "O Mag" and "O IM" columns. The "O Mag" column stores the "true" magnitude value. Here it 99.99 since we did not import data into that field. The "O IM" column holds the data even though, in this case, the data look to be *DerivedMags* values. Again, the *DerivedMags* photometry method reads the *instrumental* magnitude values from the observations file to generate a final "catalog magnitude" for the target.

This goes back to section above about selecting a magnitude for the input data. Canopus does not combine data from these two columns during analysis; it's one or the other. When merging data sets that include instrumental differential values and "true" magnitudes, this means working with the DeltaComp values in the sessions form to get the sessions to merge properly.

16. Click <OK>.

17. You will see a message asking you to confirm that you want to import the data. Click <Yes>.

18. After a second or two, you should see a confirmation message saying that 104 of 104 records were imported. Close that message (click <OK>). This returns you to the sessions form.

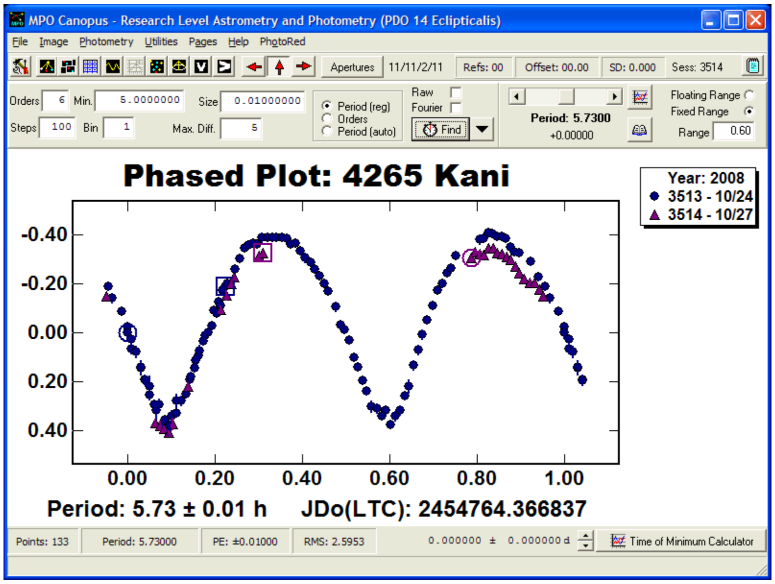
19. Click <Save> to save the session information.

## *Second Verse, Same as the First*

Repeat the process, starting with creating a new session. The differences are:

- The Mid-Date is 2008/10/28
- Load A4265_20081025.TXT for the data file.

- You should import 29 of 29 records.




Here is a plot of the data after doing a period search and before “tweaking” the nightly zero points.

If you have a large number of data sets to import, this process can get tedious. However, it is the only way to get it done within Canopus. A special utility program, the Lightcurve Analysis Engine, shipped with MPO Canopus, allows importing large number of data sets into the PHSESS/PHOBS files or, preferred, new export sets.

A tutorial on the LAE is forthcoming. In the meantime, consult the on-line help file for the program.

# Supplemental Tutorials

The tutorials that follow provide insights into using specialized features of MPO Canopus and PhotoRed. Among these are the dual-period search in Canopus when working with binary asteroids and the AAVSO-driven methods in PhotoRed.

The supplemental tutorials are designed for “advanced” users in the sense that they do not walk through procedures literally step-by-step, down to individual keystrokes, mouse clicks, and menu selection. It’s assumed the user is familiar with the Windows operating system and doesn’t need detailed instructions when told to open a given image, to select a range of items in a list box, or save a set of data. Furthermore, it’s assumed the user has a solid familiarity with the MPO programs, enough so that they are able to find menu items on their own and have a good grasp of the fundamentals of how to open and measure images using the various wizards. The tutorials in the main section of this Users Guide provide somewhat more detailed steps to acquire this familiarity and should be run not only on the sample images and data but on the user’s data as well. Throughout, however, it is assumed that the user is comfortable with the Windows operating system and its common controls, e.g., file dialogs, multi-select lists, and so on.

By not going into the greater detail of the main tutorials (which takes considerable time to document), it’s hoped that this Users Guide will expand over time to include many more supplemental tutorials that allow you a more complete understanding of MPO Canopus and PhotoRed. This will let you get the most benefit and enjoyment from what I consider to be an extremely powerful toolbox for research on asteroids, variable stars, and double stars, among others.

The tutorials are offered in no particular order of importance. You get to decide which ones matter most to you.

Brian D. Warner

Palmer Divide Observatory

2010 April

# 1. Dual Period Search

MPO Canopus incorporates Alan Harris' FALC program, a Fourier analysis algorithm that has become the "industry standard" for asteroid lightcurve period analysis when only a single period is involved. With the discovery of binary asteroids, the need for finding two or more periods within an asteroid lightcurve was required. That capability has now been added, but still using the FALC routines as the underlying engine.

For more complete details about binary period analysis, refer to the paper by Pravec et al. (2006) in *Icarus*. A *brief* outline follows here. It is not meant to be even slightly comprehensive or thorough in all details.

In a typical asynchronous binary system, a small satellite rotates about the primary asteroid, its rotation period being tidally locked to the orbital period, like the Earth's moon, but this is not always the case. The primary spins at a faster rate. For NEAs, the average primary rotation rate is between 2 and 5 hours with the orbital periods of the satellite going from 12 to 40 hours. In some cases, careful analysis of the lightcurve shows that the satellite contributes a small amount of variation on top of that of the primary as it rotates when the satellite is not tidally locked to the period of its orbit or if it is locked but is sufficiently elongated so that the "out of eclipse" time shows a upward hump. Those who work certain types of eclipsing variable stars are familiar with this behavior.

If the viewing aspect is just right, occultations and eclipse events can be seen in the lightcurve as unexpected drops in the overall brightness. If there are events, then you'll be finding the primary rotation and, most likely, orbital periods since those will dominate the data. You can then try to find the rotation period of the secondary, but keep in mind that it may not be rotating independently of its orbital period and/or the amplitude of the lightcurve is too small in comparison to the average scatter of the data.

If there are no events, then you'll find the primary rotation period and can then try to find a secondary rotation period due to the rotation of the satellite. Again, it may be too small in comparison to the scatter of the data or be tidally locked.

Complicating matters even more is if the phase angle is large enough, conditions may be right such that the shadow of the satellite on the primary is visible independently, in whole or in part, of the satellite itself. Observers of Jupiter's four largest satellites are familiar with the difference between a transit of the moon and the transit of its shadow.

In MPO Canopus, the search for the various periods and amplitudes within the total lightcurve is an iterative process that proceeds as follows:

- Using the "standard" procedure, an initial primary period is found and that curve is subtracted from the data, leaving only the variations due to the satellite and events. Unless the data are of high quality, the low amplitude lightcurve of the satellite is lost in the noise of the data. However, the event data should dominate what's left after subtraction and so allow finding of the orbital period.

- The secondary period is subtracted from the data, allowing a refinement search for the period of the primary. Once that is found, the Fourier coefficients are again saved and used to subtract the primary curve from the data.

- The secondary period is again analyzed, with the final results being saved.

- Once the primary and orbital lightcurve Fourier coefficients have been found, a search can be made for the satellite's curve. The depth of the events can be used to derive an estimate of the size ratio of the two objects, given as $D_2/D_1$ and in the range of $0 < x < 1$.

The following is not a detailed step-by-step set of instructions but does try to explain the process of searching for the primary and orbital period of the binary system 5477 from November 2005. You'll be using the sample files found in \MPO\EXAMPLES\DUALPERIODSEARCH

5477_1989_UH2_C_MASTER_SESS.FF2
5477_1989_UH2_C_MASTER_OBS.FF2

There are two other files in that directory, for (6265) 1985 TW2, kindly supplied by David Higgins, Hunters Hill Observatory, Australia. Do not load those files at this time. They are there for additional practice. See the end of this tutorial.

*Again, as you step through this lesson, your results may not exactly match those presented. They should be very similar if you follow the instructions carefully. Keep your eye on the "big picture", which is to learn the concepts behind and the steps used in a dual period search.*

## Change the UT Offset

It is ***vital*** that the UTOffset in the configuration be correct before you start these tutorials. This value is used to convert the date/time in the FITS header to Universal Time. If you have the wrong UTOffset, then some of the calculations will fail, most notably, when defining *exclusion sets*. These are data points with each session that you want to subtract from the observations when doing period analysis because they are part of "mutual events" (occultations and/or eclipses involving a satellite).

Before starting this tutorial, open the Configuration form and make sure the UTOffset is 00:00:00. Create a new profile if you want or, as in the examples here, temporarily change the UTOffset of the "Examples Libera" profile. This is because the data in the *export set* that you'll be using were based on a UTOffset of 0.0 (the data in the FITS headers were UT and not local).

## Getting Started

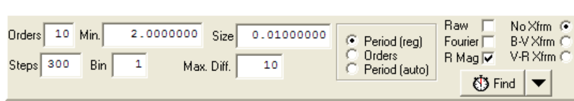
1. On the "Configuration | Photometry" tab, check "Instrumental" for the photometry magnitudes method and "Range" for the plot method.

2. As noted above, make sure the UTOffset is 00:00:00. Save the changes if necessary.

*If the UTOffset for the profile is not normally 00:00:00, be sure to reset this value to its original state after you're done with this tutorial.*

3. Load the SESS/OBS files for the asteroid using "Photometry | Load export set" on the Canopus main menu

4. On the Photometry page (where you do period searches) set the initial search parameters to the following:



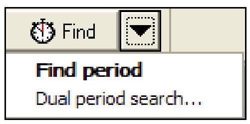

5. The reason this period range was select is that visual inspection of the raw plots showed that after accounting for obvious events, the period was very likely around 2-4 hours. A search going further out does find a very strong solution at 6.05 hours. However, the curve is dominated by the presumed events and forms

an unlikely-shaped curve. Of course, little is impossible and one needs to keep an open mind that the object may have an unusual shape and, therefore, an unexpected lightcurve.

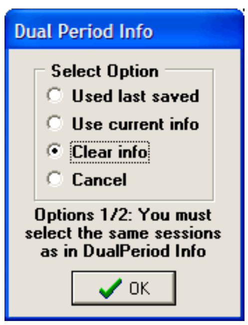
6. Use a high number of orders when doing a dual period search. This helps by allowing the Fourier solution to “cling tighter” to the actual data.

*You can check the “Fourier” box on the period search page when finding the primary curve and there is sufficient data to fill in the curve. You should not check the box when doing the initial searches for the orbital period since missing data and high orders often result in very “wild” Fourier curves that greatly expand the vertical range of the plot. Once you start narrowing in on things, you can elect to include the Fourier curve for one or both curves as appropriate.*

7. Click the down arrow button next to the Find button. This displays a submenu:




8. Select “Dual period search.” The “Find period” is bold because that is the menu item selected if you just click <Find>. You should see a confirmation message.




*Should you have the dual period search form open and click <Find> or select the “Find period” menu button, you’ll see a warning message that asks if you want to close the Dual Search Parameters form and do a single period search.*

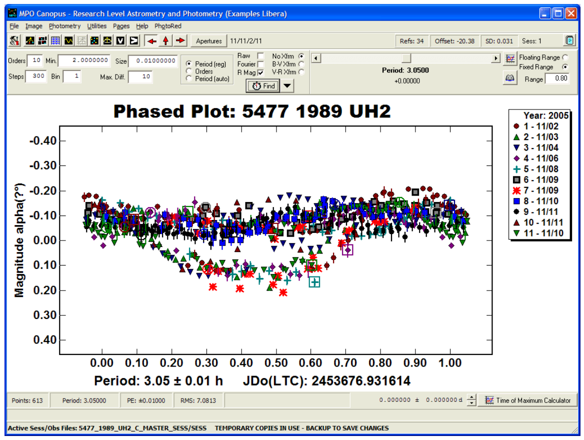
9. Select the “Clear Info” option.

*See the Reference Manual for an explanation of the options.*

10. Click <OK>. This displays the Select Sessions form.

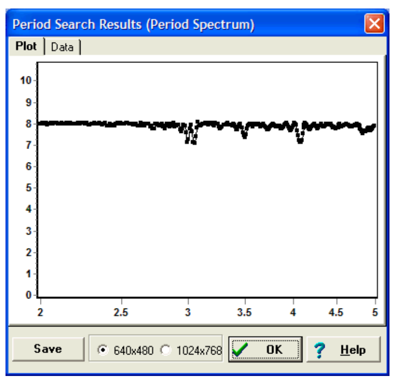
11. Select all available sessions (there should be 11 sessions).

12. After a few moments, Canopus computes the period and presents the plot, which should look something like the one below.




Presuming this is a binary asteroid, the eclipse/occultation events (or just "events") are fairly obvious. We can't get a good solution until those are removed from consideration.

13. Before going on, take a look at the period spectrum plot on the Period Search Results form.

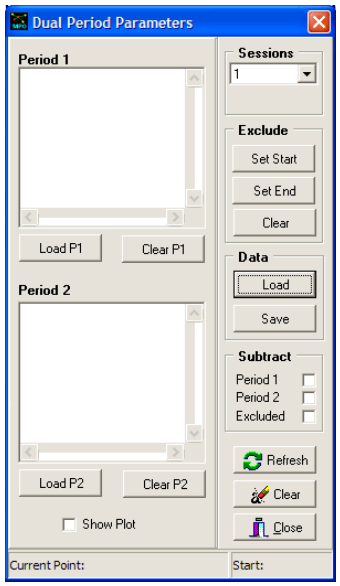



There are three or four possible solutions, obviously none of them very outstanding since they show as only slight dips below the rest of the data.

Which one, if any, is correct? In this case, go with the period suggested by Canopus but keep in mind for the future that the data due to events influences the period solution, sometimes dramatically. In the lightcurve plot, you can clearly see the data points that might be due to eclipse/occultation events.

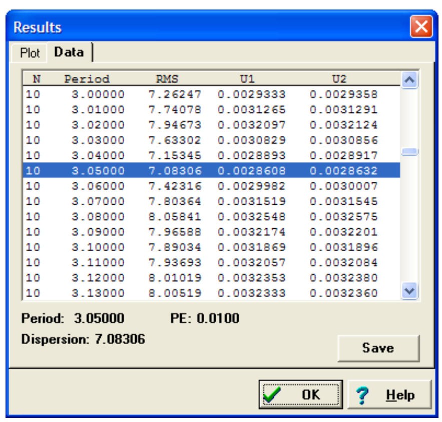
*From here on, the Period Search Results form will be called just Results form.*

14. In addition to the Results form you see when finding a period, the Dual Period Parameters form now appears.




15. This form remains open unless you deliberately close it. Don't do that right now. Note that it is "empty". That will also soon change.

16. Going back to the Results form, click on the "Data" tab.

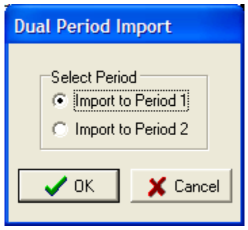



17. Click <Save>. The default directory is \MPO\UDATA but you can save the file anywhere. For this tutorial, use the name

    A5477_P1.TXT

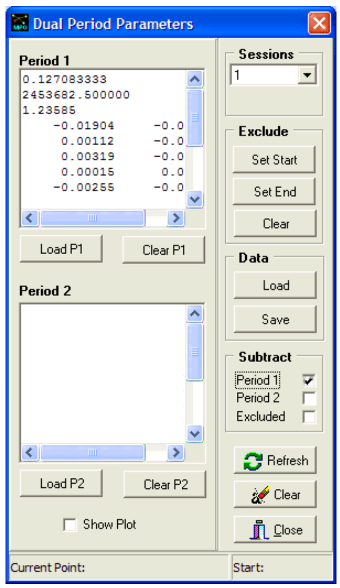
    This convention tells you the name of the asteroid (or number) and that the data are for Period 1.

18. After you click <Save>, another form appears since you have the Dual Period Parameters form open (DPP for short).




19. This form allows you to load the Fourier values directly into the DPP, assigning them to either Period 1 or Period 2.

20. Check “Import to Period 1”, click <OK>, and then look at the DPP.




Note that the Period 1 memo field now has the Fourier values.

*As with almost all tutorials in the Users Guide, don’t worry if your results are not exactly the same. As long as they are “in the ballpark”, keep moving ahead. The goal is to learn the process, not duplicate results. Unlike a chemistry professor I had, you don’t get a reduced grade for not getting exactly the same results he did – even when the grad student confirmed my observations.*

21. Check the “Subtract | Period 1” radio button and then click <Data | Save>. Save the DPP data as

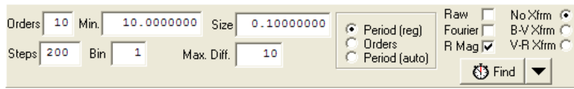
A5477_ALL.TXT

22. Click <OK> on the Results form to get it out of the way. Move the DPP to some convenient location.

*You can also double-click on the DPP caption bar to “roll it up” – reduce it to just the caption bar and maybe a small bit of the form under it. Double-click the caption bar again to restore the form to its normal size.*

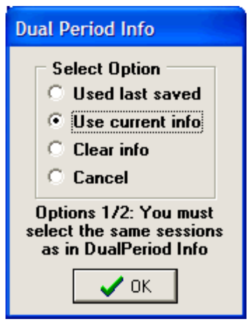
***Do not click <Close> on the DPP at this time.***

23. Set the period search parameters as follows



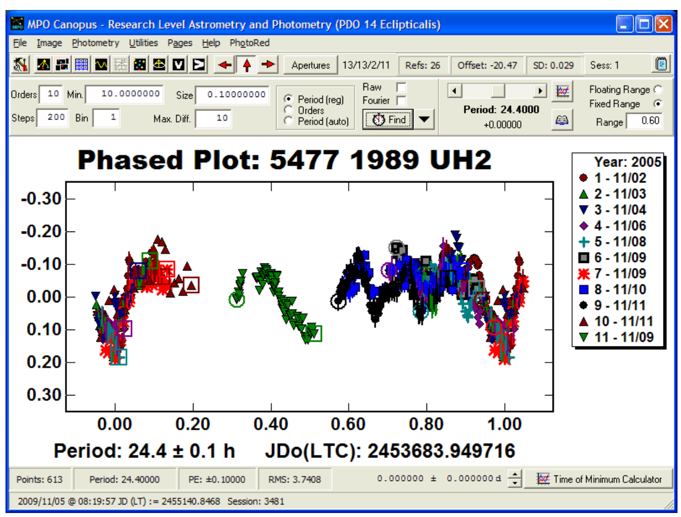

24. Confirm that the “Subtract | Period 1” button is checked. This subtracts the theoretical curve defined by the Period 1 Fourier coefficients from the data before the period search is started.

25. Click the down arrow next to <Find> and select “Dual period search” from the drop down menu. This displays the Dual Period Info options form.




26. Select “Use current info”. This uses the information in the DPP form and subtracts Period 1 from the data set.

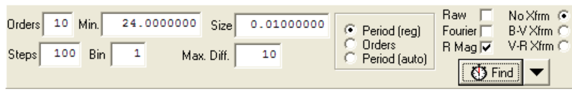
27. Select all sessions in the Select Sessions form and click <OK>. You should see results similar to these.



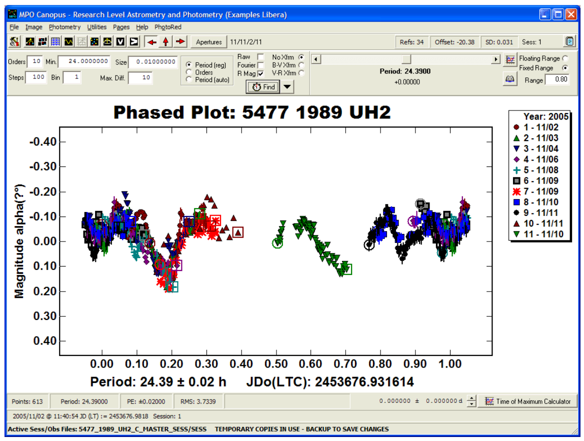

The events are better defined, though there is still some oscillation outside the events. This is a possible clue that you have not locked onto the true primary period.

28. Since we’re “in the neighborhood,” click <OK> on the Results form to clear it.

29. Set the period search parameters to the following and re-run the dual period search.




30. You'll see a plot similar to the one above, but the period may be slightly different. When running this exercise, the new period was 24.39 ± 0.02 hr.

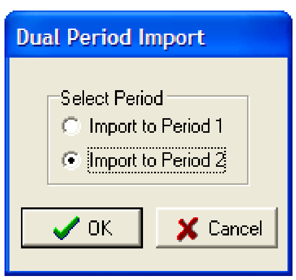



Don't try to go with higher precision for now; we need to be sure of the primary period.

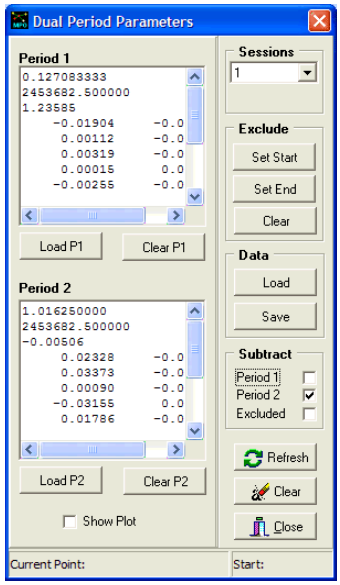
31. Go to the Data tab on the Results form and save the Fourier values using the name

A5477_P2.TXT

This displays the Dual Period Import form (*Import form* from here on).




32. Select "Import to Period 2" and click <OK>. Note how the values are now in the Period 2 memo field on the DPP.

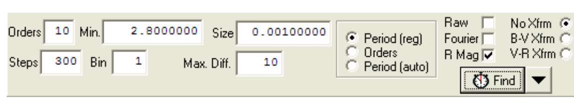



33. Check the “Subtract | Period 2” box and uncheck the “Subtract | Period 1” box.
34. Click <Save> and save to A5477_ALL.TXT, overwriting the original file.
35. Click <OK> on the Results form.

## Refining the Primary Period

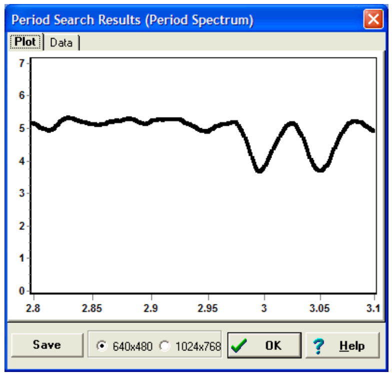
It’s time to refine the primary period by subtracting out the data based on the longer period.

36. Set the period search parameters as follows and run a dual period search, selecting “Use current info” and all sessions.



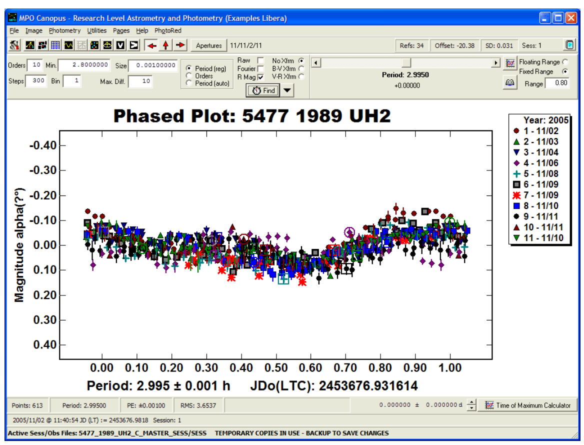

*Why these parameters? First they include the initial primary period of about 3.05 hours. However, they also include a period that was almost as good that was at around 2.99 hours. Remember that the initial period was influenced by the then unsubtracted event data. When this is the case, the “true” period is often a little less that what is initially found, especially if the event data are strong.*

37. The period spectrum shows that the 2.99 hour solution is now favored but by the slightest amount.




*When you encounter this situation, i.e., two periods very close to one another, it's best to include both periods in future searches to see which one eventually prevails.*

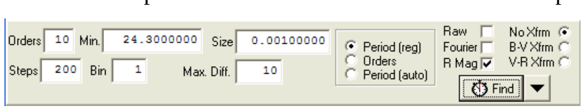
Again, because the secondary data period may not be "perfect" at this time, it doesn't hurt to presume the shorter period due to the influence of the event data on the solution (makes it longer than it might be). Here is the plot of the data at this point.



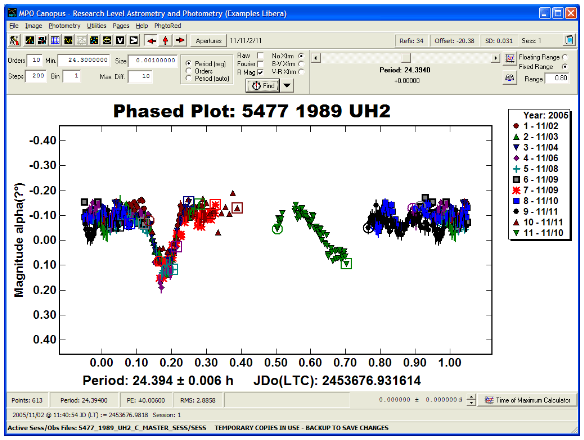

38. Once again, save the Fourier values from the Data tab on the Results form and import them into the DPP, making sure to select "Period 1". Save the data under the previous name, i.e., A5477_P1.TXT

39. Check "Subtract | Period 1", uncheck "Subtract | Period 2", and save the DPP data under the previous name, i.e., A5477_ALL.TXT.

40. Set the search parameters as follows and do another dual period search.




41. Here are the results from running this exercise

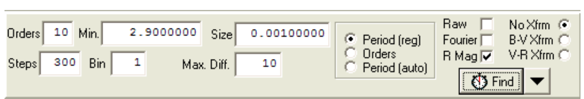



42. Save the Fourier values in the Results form, import them into “Period 2” on the DPP, check “Period 2”, uncheck “Period 1”, and Save the DPP data.

*You should be starting to get into the rhythm of switching between which period to search and saving the results after each search.*

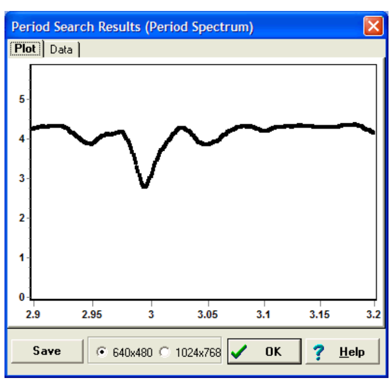
43. This will be the last pass at finding the primary. The secondary period does not need to be examined again, unless additional data are available.

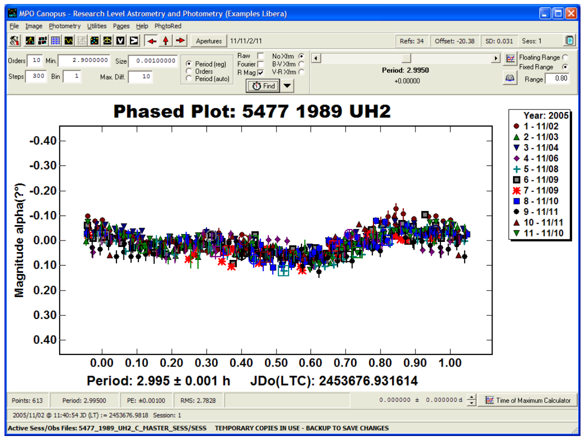
44. Set the period search parameters as follows and do the dual period search.




45. Make sure that you save the Fourier data from the Results form, import it into the DPP, and then save the DPP data set.

***Do not close the DPP after the search***



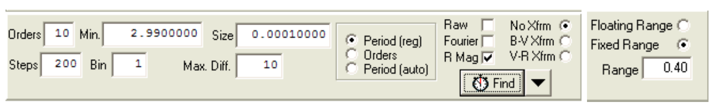



There is no longer any ambiguity! The 3.05 hour solution is now a relatively minor blip. In the sense of full disclosure, the search can be very sensitive to very minor changes in either period. If too precise of a solution for the second period had been tried, it may have been entirely possible that the longer period near 3 hours prevailed.

*To repeat, when you have two solutions that are very close to one another and one or the other appears to be "the truth." you should keep working on refinements until you can eliminate one or the other with as much certainty as possible.*

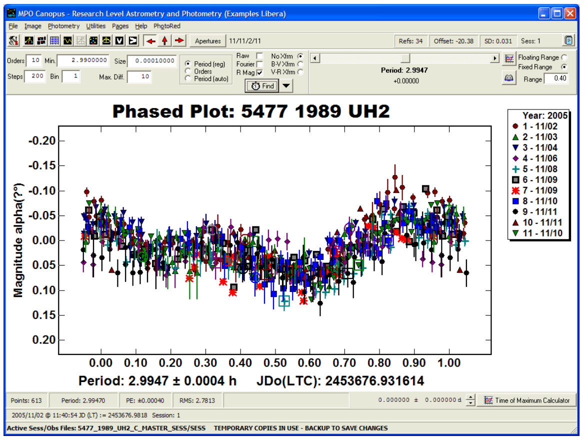
46. Again, there is no real need to work on the second period again. However, you can see if you can get a slightly better solution on the primary period.

47. Leave DPP settings as they were, i.e., subtracting Period 2, and do a dual period search using these search parameters:




*Note that the plot range (at the far right of the parameters tool bar, has been reset to 0.40. This expands the plot's vertical scale so that you can see the curve in more detail. In general, you want to keep the value at 0.8 so that 1 magnitude in amplitude is about the same scale as 1 cycle of the lightcurve. This avoids giving a false impression of amplitude changes in the curve, which can be interpreted – incorrectly – as having significant physical meaning.*

Here are the final results.

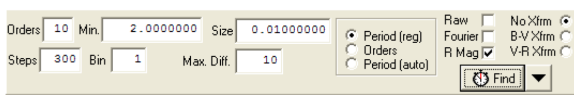



The precision is as low as you can go. Note that there are still some data points from sessions that might have had events. Manual elimination of these points, at least temporarily, might improve things but doing so would take more effort that resulting gain and would be based at least on some guesswork.

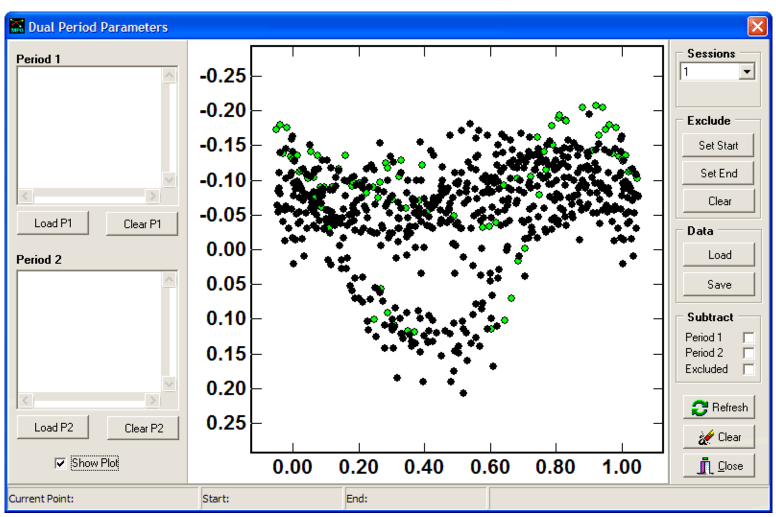
## Exclude, Then Search

If the event data are sufficiently strong, you can speed up the initial search for the primary period by excluding the event data before doing the initial period search.

48. Start the search fresh using the initial search parameters, selecting "Clear info", and selecting all sessions.




49. When the Dual Search Parameters form appears, check the "Show Plot" box towards the lower left.



50. If necessary, move the form so that you can see all of it, including the plot.

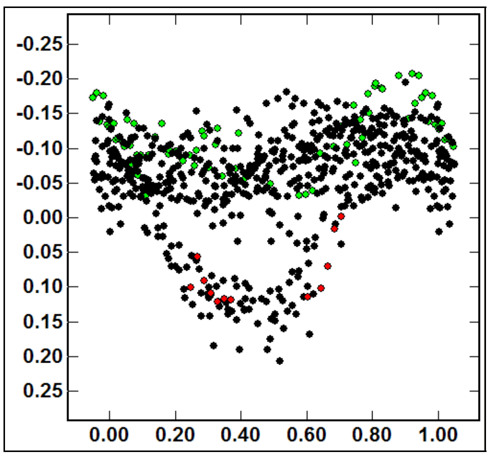
51. The plot shows all the data as black dots, except for those associated with the session selected in the drop down list at upper right. As a quick aside, change the selection in the list and see how the plot changes.

52. In the screen shot above, the event data is very apparent in the form of data well below the general curve and that some of the data points from session 1 are probably due to an event. We want to eliminate these from the solution.

53. Click on the left-most green data point that is in the “event area”. Then click <Set Start>. The status bar at the bottom shows the date/time of that data point.

54. Click the right-most green data point that is in the “event area.” This is not always obvious but make the best estimate you can.

55. Click <Set End>. If the end point you selected is later in time than the start point, the end date and time are shown in the status bar and the two data points and all those that were in between are changed to red. The screen shot below shows the results of excluding points from session 1.




*You may get a warning message that the end date is before the start date. This is a phased plot, so data points are not necessarily in chronological order. Keep working to find the two end points that exclude the most number of event data points.*

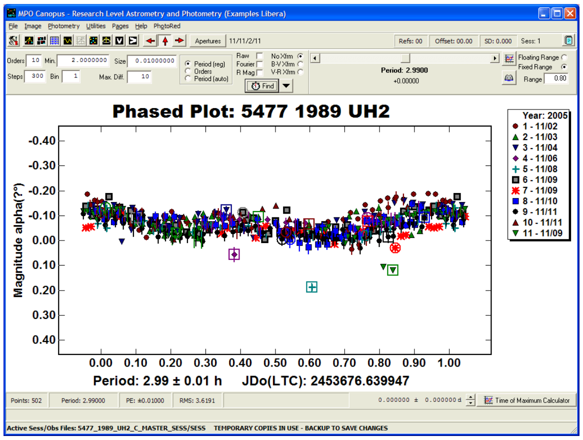
56. Repeat the process for all sessions. Note that not all sessions have event data. Do not exclude data from those.

57. Once you have reviewed all sessions, click <Save> to save the entire set.

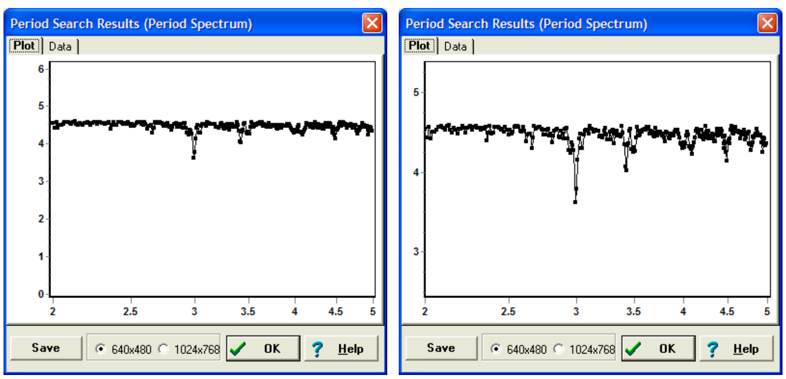
*Use a different file name for the ALL set, e.g., A5477_ALL_WEXCLUDE.TXT so that you won’t lose the results of what’s been done until now.*

58. Uncheck the “Show Plot” box to shrink the form and then check ***only*** the “Excluded” box. This ignores the excluded data points when doing the period search (this is not the same as subtracting them).

59. Run the dual period search again without changing the search parameters, ***making sure to select “Use current info” and all sessions***. Here’s the resulting plot.




60. If you did a good job picking the event data points, there will be none or only a few below the general plot of the rest of the data. Note that the period found is 2.99 hr. By eliminating the event data, the period search was able to find the approximate correct period on the first try. Here's the period spectrum.




These are the same plots. The one on the right is "zoomed" a little to show the differences better.

*See the Core Operations tutorial on zooming and panning plots.*

61. The alternate 3.05 hr period value is significantly higher though not completely lost in the noise.

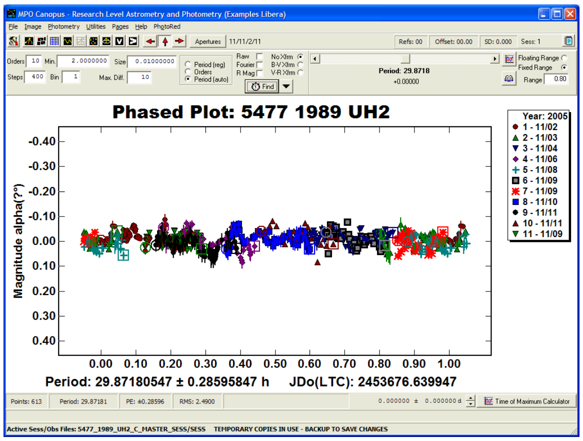
62. To find the orbital period, you want to uncheck the "Excluded" box so that the event data are available for analysis and then check the "Period 1" box to subtract that information from the data set.

## Finding the Rotation Period of the Satellite (P2)

To find the rotation period of the satellite, presuming that it's not tidally locked to the primary, you must remove the effects of the primary rotation and the events, if any. In the previous section, the event data were excluded to find the primary period. Presumably, you could then subtract Period 1 and exclude the event data and try to find the value of P2. If you are careful about selecting the event data to exclude so that there are no points remaining, or just not select sessions with events, this is an acceptable approach.

However, if there are data points from the events still being used, then the period search can "latch onto" those points because they are a more significant part of the overall amplitude than the P2 lightcurve and so you end up finding the value of Porb instead. This was the case when following through with the results of the previous section.

The other option is to find P1 and Porb, as you did in the first part of this tutorial and then run the search again after checking the "Period 1" and "Period 2" boxes. This subtracts the two curves from the data and analyzes what's left. The screen shot below shows the results of taking that second approach.




In this case, the period was close to the orbital period. However, there's nothing significant in this solution since the data are fairly noisy. In the analysis by Petr Pravec of a more complete data set, P2 was not found, indicating either the satellite was tidally locked to the primary or that the amplitude of the curve was too small to be reliably detected.

## Estimating the Size Ratio

The one remaining thing to do that is reasonably possible is estimate the size ratio, i.e., $D_2/D_1$. In the Pravec paper, he shows a relationship between $C_1$ and $C_2$, the averages in the Fourier solutions and the size ratio. However, Pravec works in flux units and, more important, the data are probably all standardized such that the values are against a common zero point. This is not necessarily the case here. In fact, using the Pravec formula with the values of $C_1$ and $C_2$ found in this exercise provides some bizarre results.

So, the alternate method is to use the depth of the *shallower* event to estimate the size ratio. Presumably, the shallower event is when the satellite goes in front of the primary. The amount of light from the primary is reduced by the ratio of the flux of the two objects, which can be assumed to be directly related to the projected area of the two objects. The areas are proportional to the squares of the radii.

When using this method, there is also the presumption that this is a total event. If partial, then using the drop in magnitude only sets a lower limit to the size ratio.

$D_2$/D1 can be found by

$$D_2/D_1 = [1 - 10^{(-0.4m)}]^{1/2}$$

Where m is the depth of the shallower event in magnitudes.

If one takes a value of 0.16 mag for the shallower event, then this becomes

$D_2/D_1 \quad = [1 - 10^{(-0.4 * 0.16)}]^{1/2}$

$\quad = [1 - 0.8630]^{1/2}$

$\quad = 0.37 \pm 0.02$

The error is approximately the same as the error in magnitude.

## A Second Try

As mentioned at the start of this tutorial, there is a second set of files available in

\MPO\EXAMPLES\DUALPERIODSEARCH

These are for 6265 1985 TW2, another binary asteroid discovered by David Higgins, Hunters Hill Observatory, Australia, who provided his original data.

This set is cleaner than that for 5477 and should provide an excellent second chance at finding the primary and orbital periods. The steps won't be covered here, nor will the final results so that you don't have any preconceptions. Besides, you can find the values on the Internet. It won't hurt to give you a clue: the primary period is about 1/6 the orbital period and the orbital period is less than a day.

## A Final Thought

All of the discussions have presumed an asynchronous system where the satellite is tidally locked to the orbit or is maybe spinning at a rate independent of the orbital period. Also, the primary in the system has a period in the range of 2-5 hours and the orbital period is 15-40 hours. These are not absolute limits. A discovery at the Palmer Divide Observatory in late 2009 of revealed what is probably a binary asteroid of unusual type. Here the primary has a period of almost 600 hours and the secondary has a period of about 2.5 hours. The amplitude of the primary is ~0.40 mag while that of the secondary is ~0.04 mag. The orbital period is unknown since there were no mutual events.

In short, it never hurts to look for two additive periods in lightcurve data if there are signs of such. In the end, the second period may be due to nothing more than the analysis latching onto noise. However, it just may be evidence of something real and lead to a new discovery.

# 2. The Moving Object Search

The Moving Object Search allows you to search for moving objects in your images. For those hunting new asteroids, it's an ideal tool and beats using the blinker and having to stare at the images, especially if you have dozens of image to review.

The basic principle is to take a set of three images, align and stack them, and the remove any object that is the same place on all three images. Anything that remains is a potential candidate. However, what remains may not be a real object but clumps of noise, hot pixels, and so on. The MOS looks at the remaining objects for such things as being on all three images, the position change between images 1 and 2 and then images 2 and 3 is proportional to the time changes between images, and that the three points lie close to a line.

You can set various parameters to determine how faint the search goes, the maximum motion allowed, and how close to a line the three points must lie. When done, you are presented with the results in visual and text form. This allows you to confirm that what the MOS found is real. The MOS also generates an MPC-ready report that you can edit as needed before sending it to the Minor Planet Center.

No search engine is going to be perfect. It's going catch some things it shouldn't and miss some things it shouldn't. Protecting against the former is why there is the visual inspection tool. Unfortunately, there is no tool that finds excluded objects. In this case, you make the search parameters less restrictive knowing that you will get more false hits than before. At some point, you have to decide on the cutoff point between catching as many new targets as possible and spending lots of time rejecting false hits.

The number of images is fixed at three. In the future it may be possible to use additional images (you don't want to use less than three).

### *For Best Results*

The images that you measure should be pre-processed with flats and darks (and bias frames if needed). This will remove much of the noise that might otherwise be seen as moving objects by the MOS.

### *File Location*

The files for this tutorial are found in

\MPO\EXAMPLES\MOVINGOBJECTS

which will be referred to as the "MOS directory" from here on.

The Moving Object Search form will be called "the MOS" from here on.

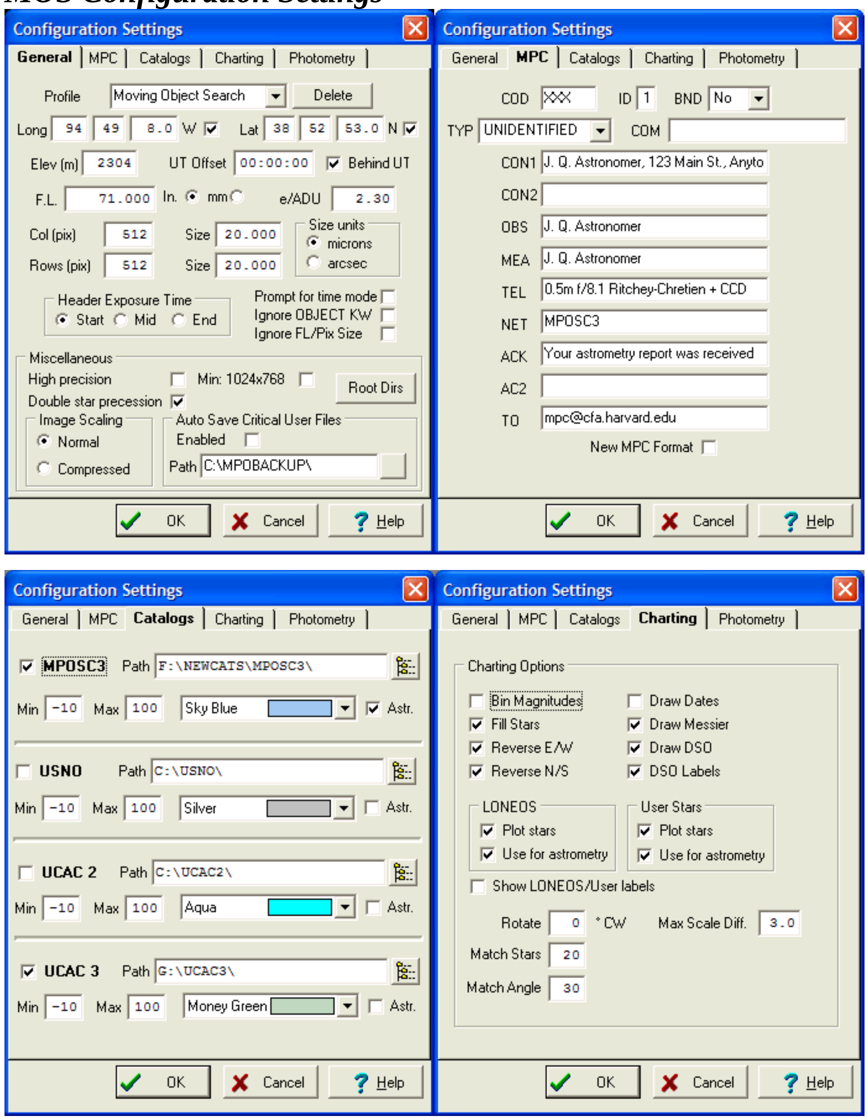
☞ *The images used in this tutorial were kindly supplied by Larry Robinson of Sunflower Observatory, Olathe, KS. They have been processed with darks and flats.*

### Setting the Configuration

1. Open the configuration form and create a profile with the settings shown below.

☞ *You can access the MPC tab on the configuration form directly by clicking <MPC> on the MOS form. The other pages are also available. You should confirm the MPC settings before running any search.*

## MOS Configuration Settings




## MPC Settings

The “Typ” on the “MPC” page of the configuration affects the MPC report that is generated. What you select is not always straightforward. Generally, the Minor Planet Center likes to make the identifications and so you indicate all targets as “unidentified”. In this case, all the fields are of known main-belt objects, and so the “MBA” option in the drop down list is not inappropriate.

The NET field is set to MPOSC3. This tells the MPC which catalog was used for finding positions and magnitudes. Since the MPOSC3 astrometry is from the 2MASS catalog, you could also enter “2MASS”, which is more recognized by the MPC.

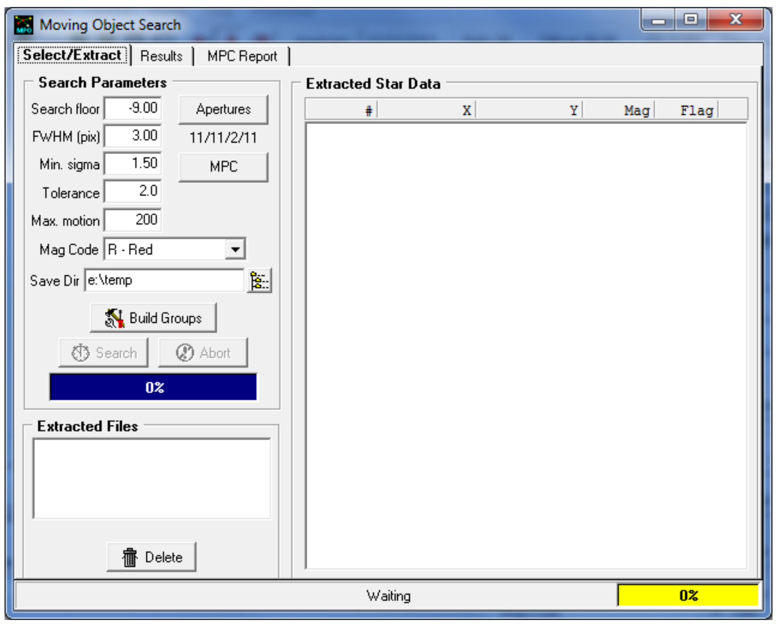
*Regardless of which type you select, the MOS doesn't know which object you're measuring, especially if it's a new one. So, it uses a base name with sequential numbers to identify all objects in the report. The base name changes based on the option you select. If necessary and desired, you can edit the MPC report so that it identifies the specific object.*

*Consult the Minor Planet Center web site's astrometry guide for additional insights.*

The settings on the other pages and tabs are not critical to this tutorial.

2. Open the MOS by selecting "Utilities | Moving Object Search" from the Canopus main menu, or press <Shift+Ctrl+M>.

3. Copy the settings seen in the screen shot below, ***except the "Save Dir" field***.

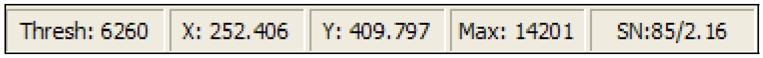



The MOS uses AutoMatch to extract the star data and stores the extracted data for each image in its own file that can be read for the extraction process. The files are stored in the "Save Dir" location.

The "Mag Code" drop down list includes the most common supported filters. If you want to include magnitude estimates in the report, set this value to match the instrumental band of the catalog magnitudes (the "Default Band" setting on the Canopus "Configuration | Photometry" tab). If using a Clear filter, "R" is probably the best choice for most Kodak (KAF) blue-enhanced chips.

*You can also select "Do not use", but this means the magnitudes are not included at all. It's easier to delete them in the editor if you change your mind than it is to go through the search again. So, it's recommended that you select an appropriate filter when doing a search.*

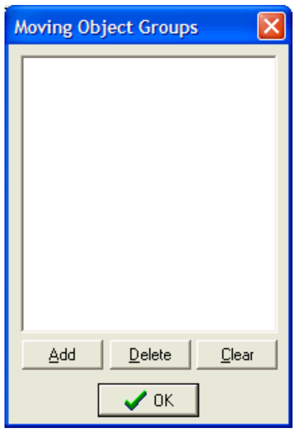
The "FWHM" setting is in pixels. If you're not sure of the value, move the MOS aside and open one of the images. Click on a non-saturated star and review the statistics in the bottom status bar of the Canopus form.




The “SN:85/2.16” in this example indicates the star has a signal-to-noise ratio (SNR or SN) of 85 and the full width-half max of the star profile is 2.16 pixels. Click on several stars and use a mental average to enter into the “FWHM” field. It’s OK to go a little larger. Some of the images in the examples have slightly greater FWHM and so 3.0 was used as a “one size fits all” estimate.

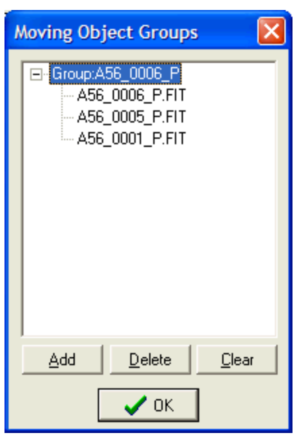
4. Manually enter a valid directory in the “Save Dir” field or use the speed button next to the field to display a directory selector.

5. Click <Build Groups>. This displays a small form.



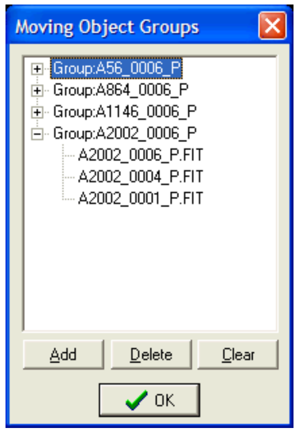

6. Click <Add>. This displays a Windows file dialog that allows you to select more than one file at a time.

7. Locate the MOS directory and select the three files with a base name of A56. The MOS Groups form should look something like this.




Click <+> or <–> next to the group name to expand or collapse the tree that shows which files are in the group.

8. Repeat adding groups for all the images in the MOS directory. When done, you should have something like the screen shot below.




*Make sure that each group has exactly three images and that the three images are of the same target (they have the same base name).*

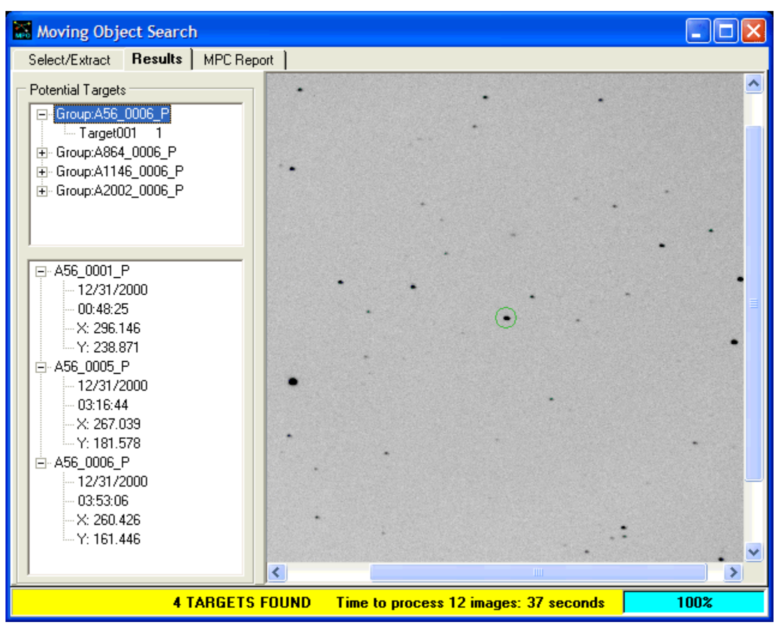
*Don't worry if the files in the group aren't in increasing date order. The MOS sorts the files before doing the search.*

9. Click <OK> to close the Groups form.

10. Click <Search> on the MOS to start the search.

    Each group is handled separately.

    Progress meters and the status bar at the bottom of the MOS keep you informed during the measuring process.




The screen shot above shows the results of running this tutorial.

11. Click on the name of a group in the top list. This changes the image to the first one in that group.

12. Click <+> next to a group in the top list to show the targets in that group. The numbering within the group starts at 1 but the number to the right is an incrementing number that corresponds to the objects in the MPC report.

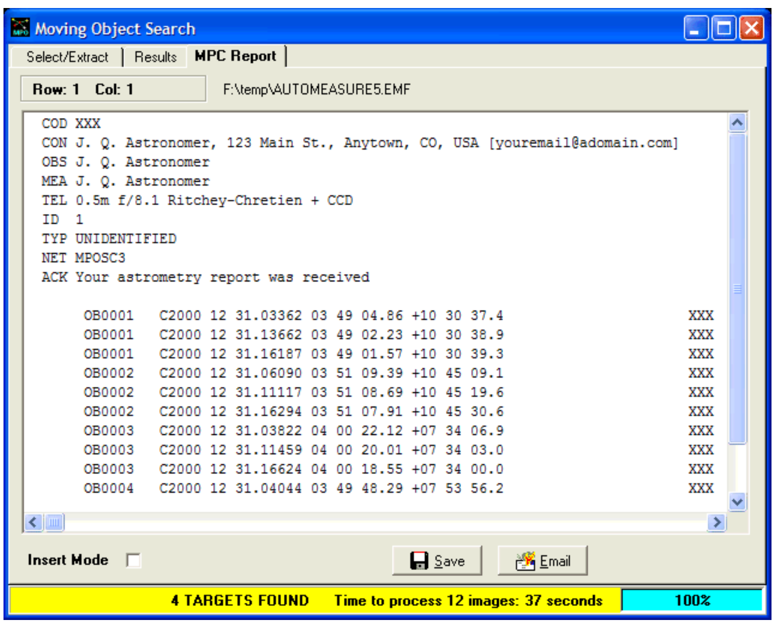
13. If there is more than one target in the group, clicking on each target loads the first image of the group and the image is updated to show the position of the selected target.

    As you change targets in the top list, the bottom list is updated to show the three images in the group. For each image, the date and time are displayed along with the X/Y coordinate of the target on that image.

14. Click on the name of a file in the bottom list to show its image and have the green aperture re-center on the target.

## *Reviewing the MPC Report*

15. Click on the “MPC Report” tab.




16. The information at the top of the report is taken from the MPC tab in the configuration form.

*The memo can be edited and the form comes up in overwrite mode. This means that if you start typing, you will replace existing characters and not force the characters to the right of cursor to push right. This helps assure that you do not change the structure of the data lines, which MUST have the data in specific columns.*

17. Note that the file has already been saved using the name given at the top of the page. This is the file that you would attach if you click <Email> to send the report.

The “OB000X” items indicate the specific object back on the Results page. Canopus gave them this default name as a result of the configuration setting for the TYP field on the configuration MPC page. You could change these to the actual numbers of the asteroid since they are known, but you would enter the numbers starting with column 1 and using leading zeros to pad to five characters. If you do change to the actual numbers, the then “TYP” line in the report should be changed to MBA.

*See the Minor Planet Center’s web site for its Astrometry guide and the details of this report format.*

## Search Recommendations

Don’t set the search floor too low (closer to 0). Otherwise almost every bit of noise might show up as a potential target.

Keep “Min sigma” at 1.0 or greater. This is the degree to which a pixel rises above the general background. If you set it below 1.0, you quickly start adding noise as potential targets.

Keep the tolerance at 2-3 pixels. Anything more from a straight line or away from the predicted position on the image (part of the check for a real target), and you might get false hits, especially in crowded fields.

The “Max motion” is for the full range of time among the images. For example, if the first and last image are one hour apart, the object must move less than “Max. motion” pixels over that time. If the images are 512 pixels on a side, a setting of 200 means the object moves no more than about 2/5 the field over that hour.

## Running a New Search

If you get too many hits or not as many as you think you should, change the search parameters and rerun the search. The star data must be extracted again since some of the changes may affect which stars are included in the extracted files.

## Deleting DAT Files

Unless you need to the debug problems, you click <Delete> under the “Extracted Files” box before starting a search (if there are items in the box).

If there are any items in the box when you close the MOS, you are asked if you want to delete the DAT files. Again, unless you have a particular need to save them, delete the files. The files do no harm but if you work with the MOS frequently, the number of files will grow significantly.

# 3. The Variable Star Search

The Variable Star Search (VSS) is another example of putting images taken for one purpose to use for another. The images that are used in this tutorial were taken to generate the lightcurve of an asteroid. The VSS was used to see if any of the stars in the field happened to be variable. If so, then it would be possible to work them further and generate lightcurves and periods for them and even publish the results if worthwhile. As it turns out, there was at least one previously unreported variable and a couple of other potential candidates.

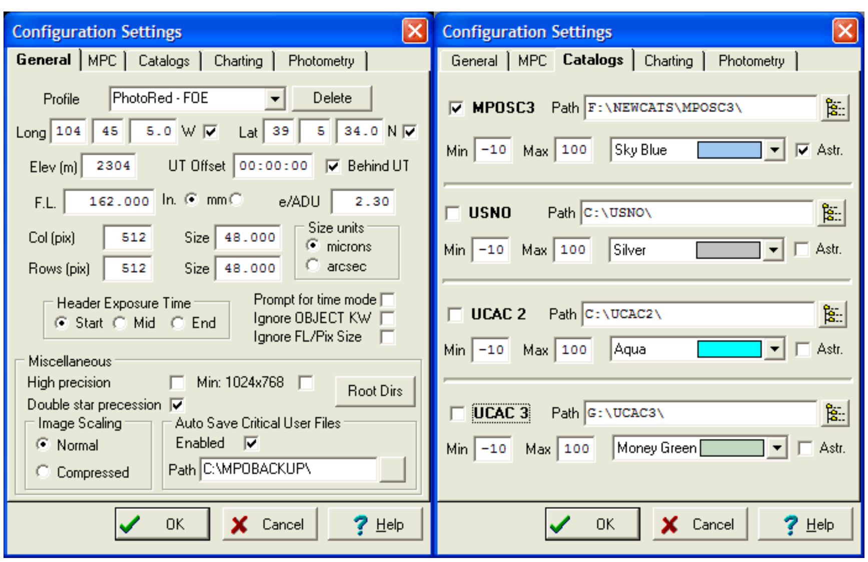
The concept of the VSS is similar to the Moving Object Search (MOS) in the previous tutorial: start with a series of images, match them, and – in this case – look only for stars that *don't* move and then auto-generate a lightcurve for every star on the images that meets the initial search criteria. Those that show variability of a minimum level are reported for visual inspection.

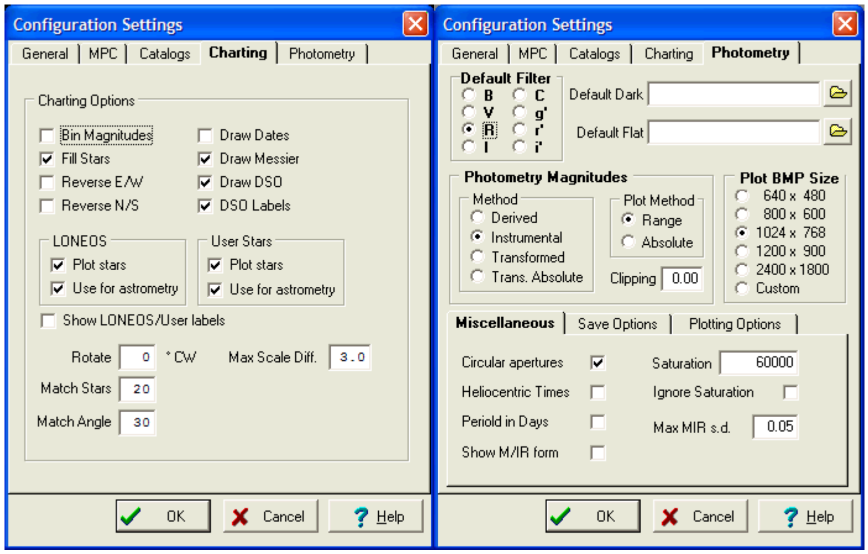
You can give the profile any name you want. Note that it's the same profile that was used in the PhotoRed tutorial for finding first order extinction using the Modified Hardie method. If you ran that tutorial, these settings should be the same, or very close to it.

The only setting on note on the "Photometry" page is for "Circular apertures." This exercise does not worry about the types of magnitudes since they won't be stored in the observations file. If you're interested, the instrumental magnitudes of the stars as extracted from the image are used for analysis.

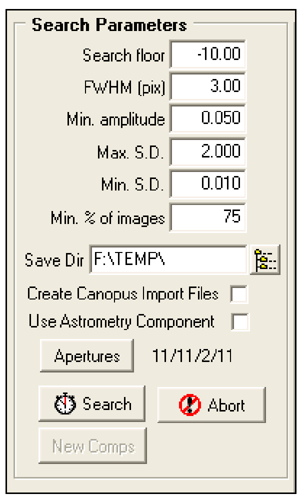
This utility has been used to find at least a dozen new variable stars, some of which lead to a published paper. It was inspired by talks with Robert Koff, Antelope Hills Observatory, Bennett, CO, as we drove from Colorado to California for the annual Society for Astronomical Sciences meeting (http://www.SocAstroSci.org).

1. Set up a configuration profile that matches the screen shots below.






2. Open the VSS (<Ctrl+Shift+V>) or select "Utilities | Variable star search" from the Canopus main menu.



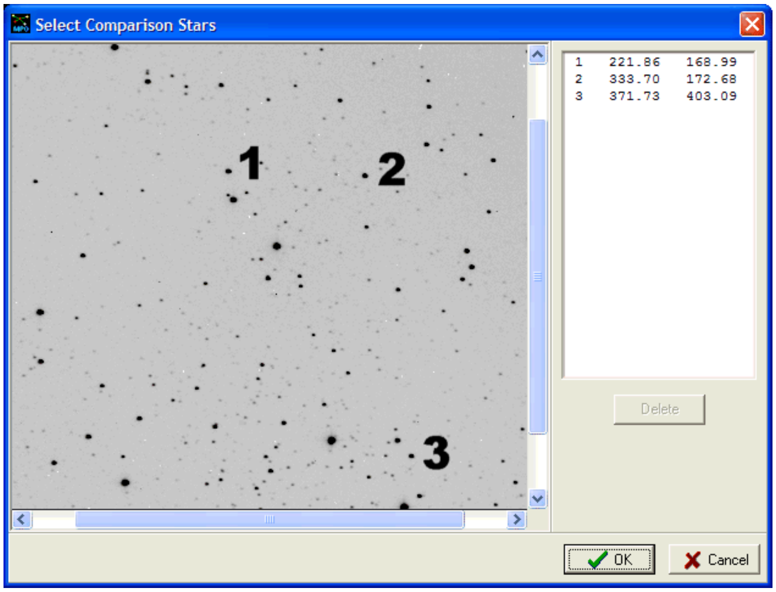

3. Match the search parameters that you see above in that section on the VSS, ***except the "Save Dir"***. Manually enter or use the speed button to the right of the field to select a valid directory for the temporary files.

   See the Reference Manual for a discussion on each of the parameters.

*Unlike the MOS, these files can be used again during the same VSS session to do a follow up search with different search parameters or comparisons.*

4. Click <Search>. This displays a Windows file dialog.

5. Select all the files in the \MPO\EXAMPLES\VARIABLESTARSEARCH directory. This starts the search where the data are extracted from the images and moving objects are removed.




6. When the data extraction is done, the Select Comparison Star form appears. Use the screen shot above as a guide.

7. Click on each of the numbered stars. As you do, its X/Y coordinates appear in the list at right. If you click on the wrong star, highlight the entry in the list and click <Delete>.

## *Picking Comps*

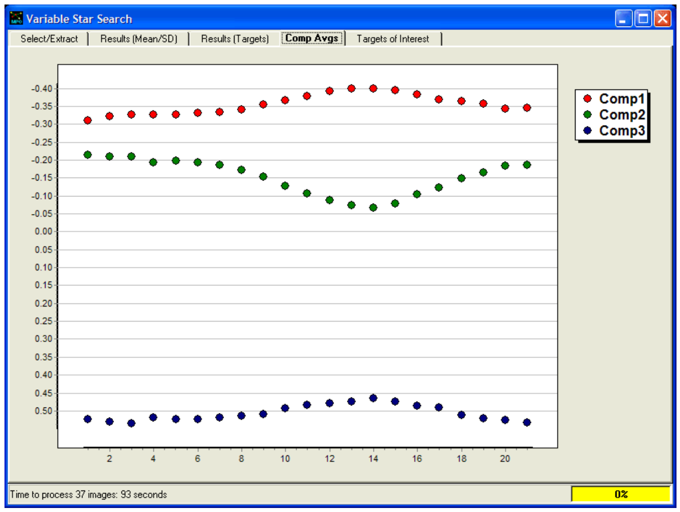
Unless you know the field for some reason, you really don't have an idea of which stars are variable and which are not. It is very possible when picking these three stars that one or more is variable. The VSS provides a way to check, which is covered below.

For a general rule, try to pick isolated stars that are reasonably bright but not near saturation or non-linearity.

8. Click <OK> to proceed.

*Depending on the number of images and stars in each image, it may take a few seconds for the VSS to find potential variables and report back.*

9. Click on the "Coms Avg" tab. This displays the raw instrumental magnitudes of each comparison star against the average of the other comparisons.



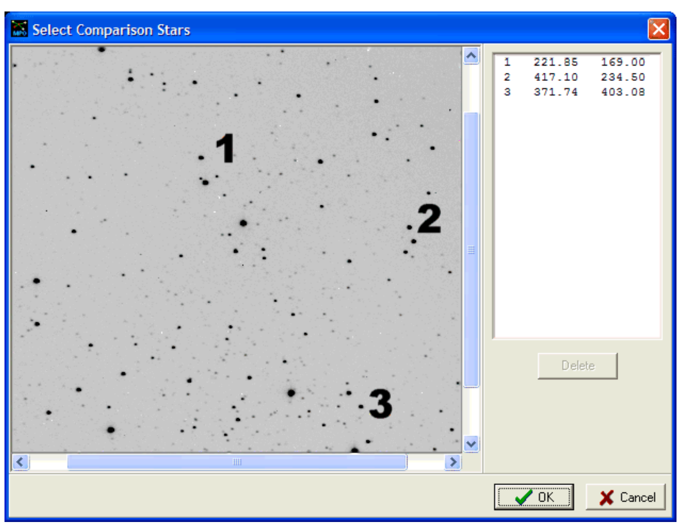

Oops! One of the stars appears to be variable! All three lines should be flat. Instead, Comp 2 goes a different direction from the other two. It is the most likely culprit.

## Running a Second Search

Fortunately, you do not have to run a new search but only chose a new set of comparisons.

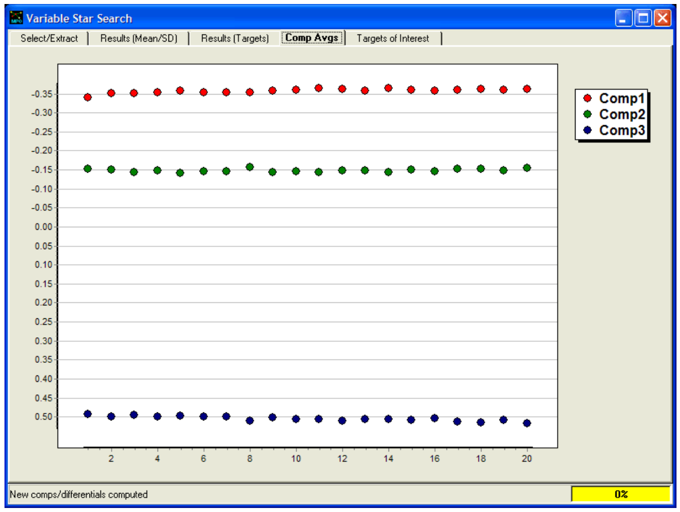
10. Click on the “Select/Extract” tab.

11. Click <New Comps>. This displays the same form that you used before to select comparison stars.



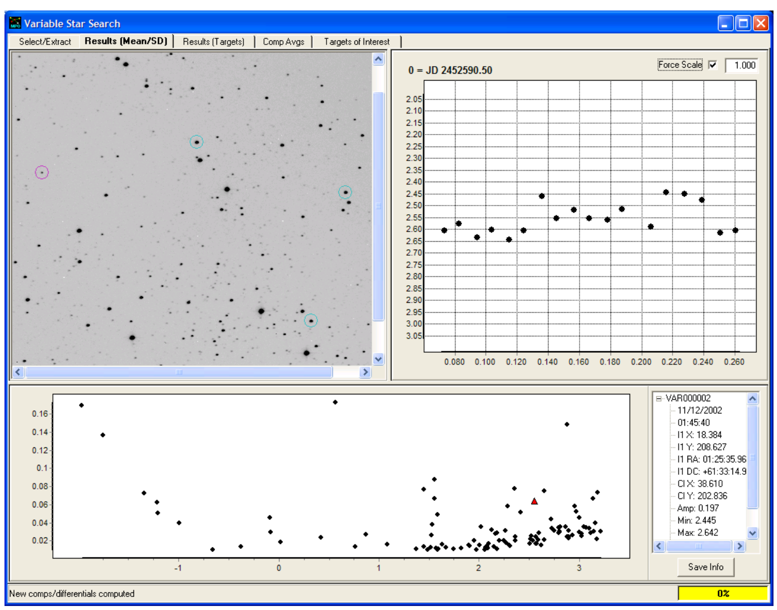

12. Select the new set of comps (only #2 changes) and click <OK>. This time the search is much shorter because all the original star data are still intact. The only thing new is to compute the differential magnitudes between the comps and stars.

13. Return to the “Comps Avg” page.




Now you have a good set of comparison stars!

14. Click on the “Results (Mean/SD)” tab. This displays the search results using the Max/Min S.D. parameters in the search parameters, meaning that the standard deviation of the average magnitude of each candidate was between the two limits (in magnitudes).




At the upper left is the first image in which the variable appeared (it may not always be the first image in the set if the field of view changes significantly during the run). The comparison stars are surrounded by red circles (cyan on an inverted image) and the target surrounded by a green circle (magenta on inverted image). At the upper right is a plot of the “variable star”. Below is a plot (*SD Plot*) of the

Mean Magnitude (X-axis) and the standard deviation (Y-axis) for each candidate. At the lower right are the stats for the selected star.

## *Working the Results (Mean/SD) Page*

In principle, stars with higher standard deviations (higher on the vertical axis) are potential candidates. However, stars at the far left of the SD Plot are the brightest stars in the image and often show a high standard deviation because they are non-linear or saturated. At the far right are the faintest stars where the standard deviation is high because the star is close to the background level. So don't be fooled thinking that every star with a high standard deviation is a variable. That is why the individual lightcurves are plotted as well.

*You can zoom and pan the SD Plot, which is often necessary to see individual data points in crowded plots.*

Note in the screen shot above that one of the stars in the SD Plot is a red triangle. This is the currently selected star.

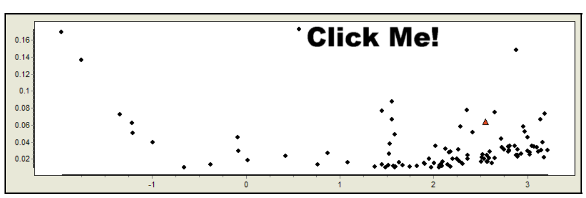
15. Click on any point in the SD Plot; that point turns into a red triangle and the previous one returns to a black diamond. The image is reloaded and the newly selected star's location is indicated.

    The lightcurve plot changes to show the selected star's data and the stats box at lower right is updated to reflect the new data.

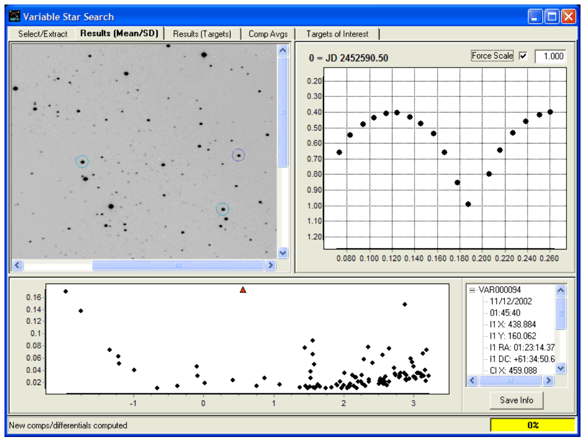
16. If not already, check the "Force Scale" box above the lightcurve plot after you set the value to 1.000 in the entry field next to it. This forces the lightcurve to have a 1-magnitude vertical scale. You do this when reviewing plots in order to avoid seeing what are really small amplitude changes as being significant.

*As you review the candidates, you will see general trends that repeat in the lightcurves, e.g., they all have a "bump" about half way through or have about the same amount of scatter. Those that follow the trend are most likely not variables. Those that show unusual behavior deserve closer attention.*

17. In the plot shows in the screen shot above, the lightcurve is relatively flat. This is probably not a variable.

18. Now click the data point to the left of "Click Me!"



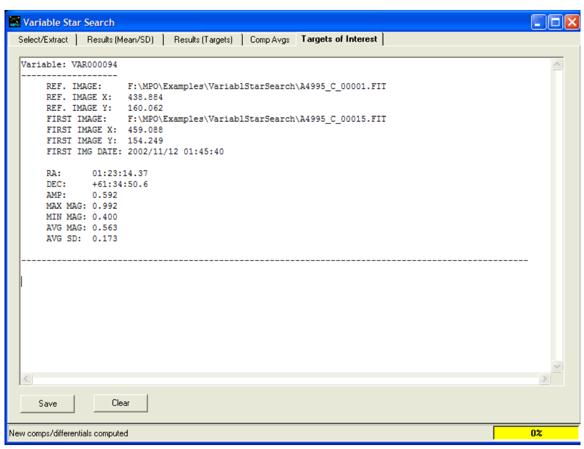

Now you have something that appears to be legitimate! As it turns out, this was a previously unreported variable star. Additional data were obtained and a model was generated in David Bradstreet's *Binary Maker 3.0*.

Note that the image was scrolled so that you could see the variable at the far right of the image.

19. Click on the "Results (Targets)" page. You should see the same lightcurve.

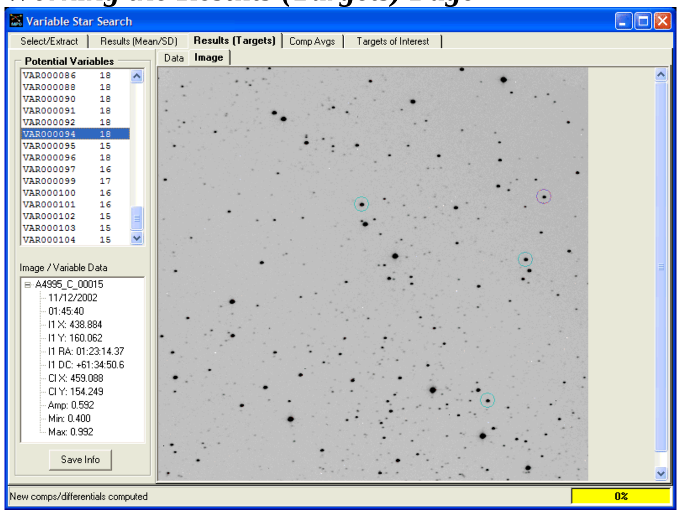
20. Go back to the "Results (Mean/SD)" page and click <Save Info>.

21. Go to the "Targets of Interest" page.




You can save this a text file for later reference. After you've reviewed the search results, you can use the information in this file to relocate the stars and do proper lightcurve photometry in Canopus. This is often necessary if you have a target that is borderline case. The more accurate tools in Canopus will determine for certain if the star is variable and, if so, allow you to do a period analysis on the data.

## Working the Results (Targets) Page




As you saw, when you select a target on the Mean/SD page, it is also selected on the Targets page. This reverse is true as well: when you select a target in the upper list on the left of the page, it is selected on the "Mean/SD" page.

The screen shot above shows the "Targets" page with the Image tab selected. This allows you to view an image just as before.

22. Click on an item in the upper list on the "Data" tab. As you pick different objects, their information appears in the bottom list and the lightcurve changes.

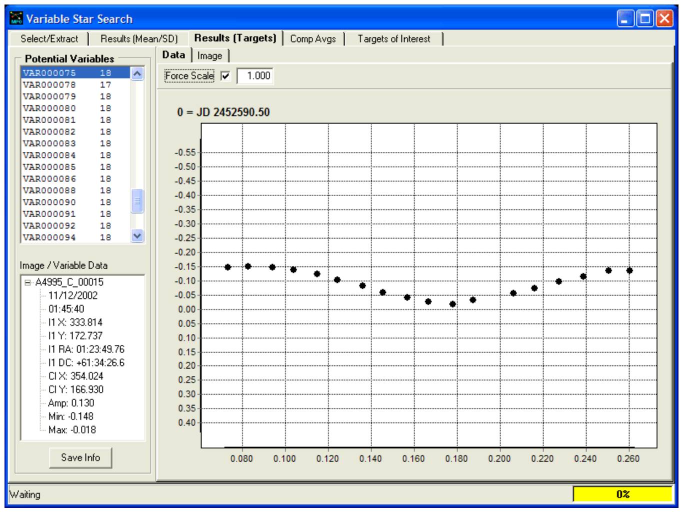
    As before, look for general trends among lightcurves and then take a close look at those that don't follow the trend.

23. Click on the "Image" tab on the "Targets" page.

24. If necessary, refer back to the beginning of the tutorial where the first set of comp stars was selected, the set where the second comp was variable.

25. Click on that star on the image. The selected item in the list changes and the information in the bottom list is updated.

26. Click on the "Data" tab. You should see the lightcurve for that star.




While not as dramatic as the previous variable, the lightcurve on this star is smooth. This is very likely a variable star.

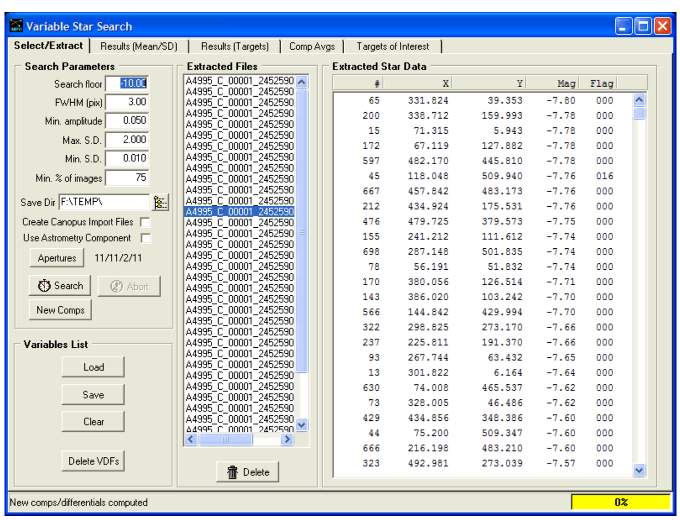
Note that the information includes the RA and Declination of the star. You can use the International Variable Star Index (VSX) on the AAVSO web site (http://www.aavso.org) to look for known stars based on coordinates.

A search on the VSX found that the star is AX CAS, an Algol-type eclipsing binary. The magnitude range of the star is given at 0.5 mag. The dip here was only 0.15 mag so I happened to be lucky and caught the secondary eclipse.

## Additional Searches with the Same Data

Go back to the Select/Extract page.

27. Double-click on a file in the “Extracted Files” list.



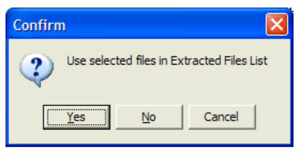
You can sort the data that appears in the “Extracted Star Data” list by clicking on the “X”, “Y”, or “Mag” column headers.

28. Click on the “Mag” header until the values closest to zero (the faintest stars) are at the top of the list. The instrumental magnitudes are usually lower (fainter) than the floor you set. This is because all stars are extracted, regardless of the floor setting, which controls which stars are included in a search.

    This means that you can use the same data for multiple searches, changing the floor, minimum amplitude, and/or standard deviation ranges. This is different from just selecting a new set of comparison stars because one is variable. Once you have a good set of comparisons, use them again for different search parameters.

29. Select all the files in the “Extracted Files” list.

30. Click <Search>. Since you have one or more files in that list select, a message appears.




31. Click <Yes> to use the extracted data. If you click <No> then the VSS will extract the data from the images again.

## Saving and Loading Results

You can save the entire set of results of the last search so that you can later reload the data and review the results.

*The extracted star data are not saved, so you cannot rerun searches with different parameters. However you can use a different set of comparison stars* **provided** *the image that was used to select the comparisons is still available in the same location as when you ran the initial search.*

32. Click <Save> on the “Select/Extract” page. This presents a Windows file dialog. Enter a file name and save the data. The extension is forced to “VDF”. The files can be fairly large (by some standards). The file for this tutorial was about 2 MB.

33. Click <Load> to reload the file. There are no files in the “Extracted Files” list, but you are able to review the previous results and select a new set of comparisons, if that original image is available.

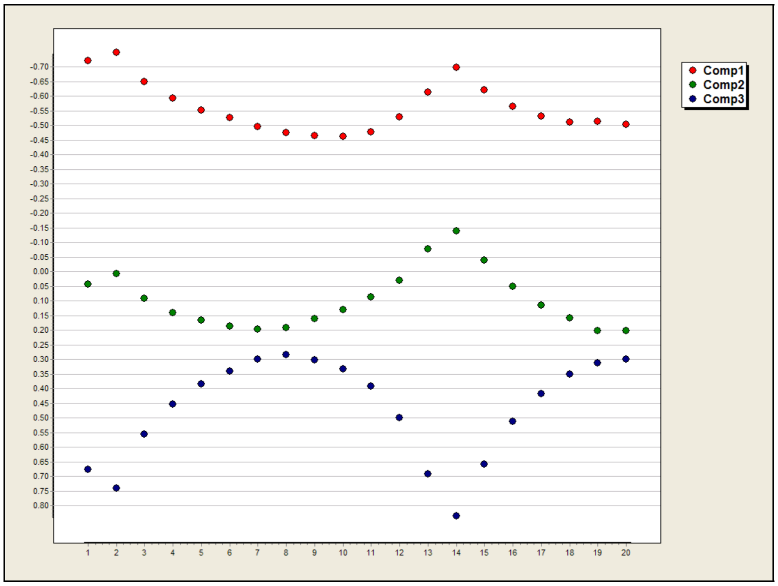
*You will not able to see the images unless they are available in the same location as when the original search was run.*

If you click <Search> after loading a VDF, the VSS will try to do a full search by asking for a set of images. The original data files are no longer available, so the VSS must recreate the data.

### *Saving the Comps Plot*

Right-click over the plot on the “Comps Avg” page and select “Save comps plot” from the popup menu. This displays a file dialog. You can force the file to be saved as a PNG or BMP.

For "fun", I selected a new set of comps after loading the VDF for this tutorial using the two known variables and one "constant."



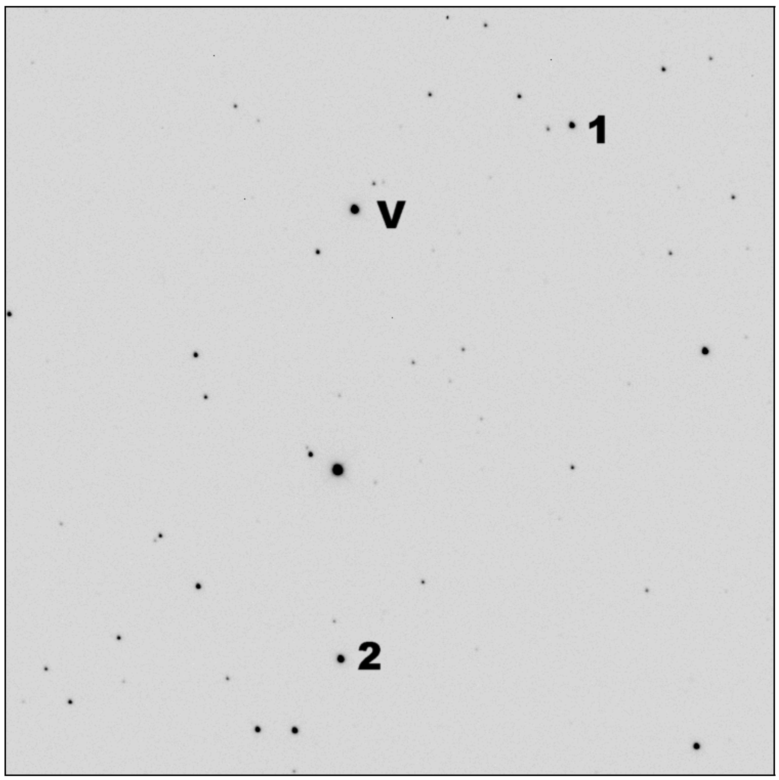

This is when you know that you've picked some very bad comparisons.

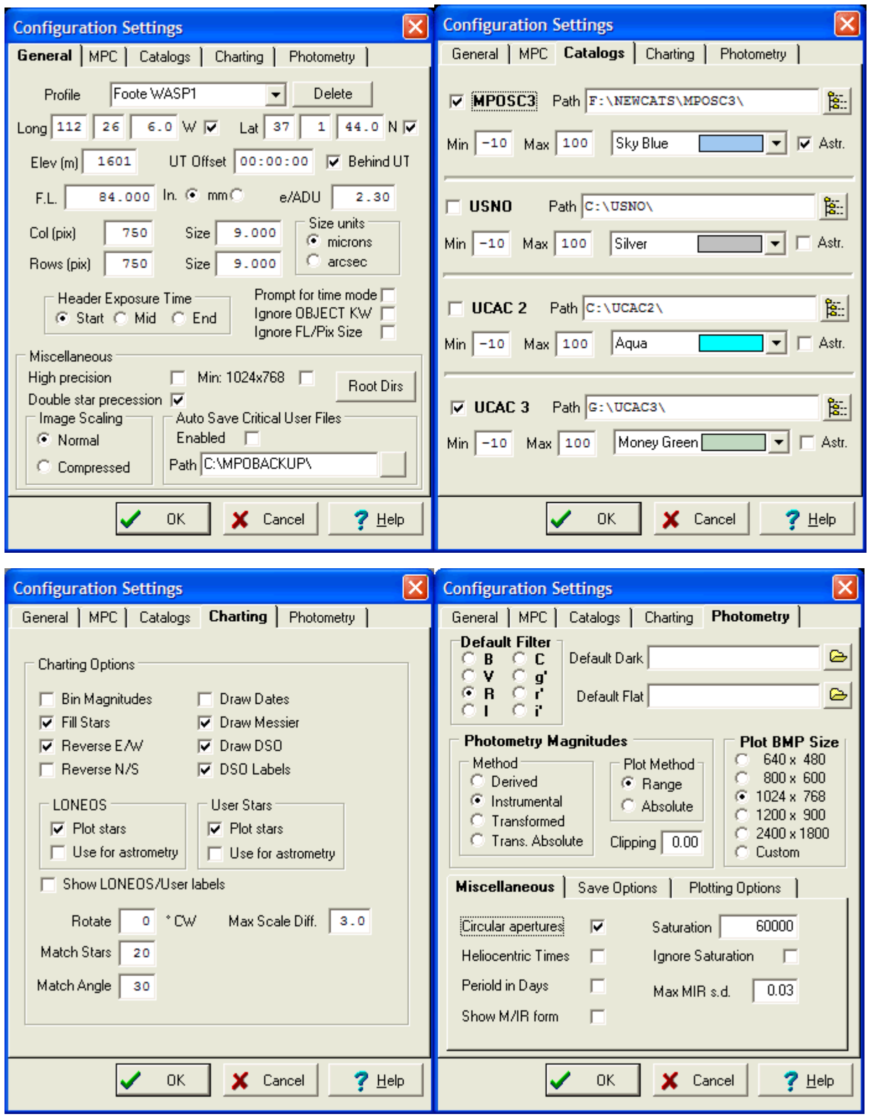
# 4. Exoplanet Lightcurve

Exoplanets are big news these days. More than 400 have been found as of this writing. This tutorial is nearly identical in concept to the one where you found the lightcurve of an asteroid and so will not go into great detail on the individual steps, except to direct you to the necessary files and configuration settings.

*The images for the exoplanet, WASP-1, were donated by Cindy and Jerry Foote. Cindy is a noted "backyard astronomer" who has contributed to the discovery of several exoplanets. The original images were cropped using the "Crop" function the Batch Image Processor of Canopus.*

Use the image below to identify the two comparisons and variable (exoplanet).






1. Set the configuration in Canopus to match the settings above. You can give the profile any name that you want.
2. Set the apertures to 17x17/2/11.
3. The files to be measured are found in

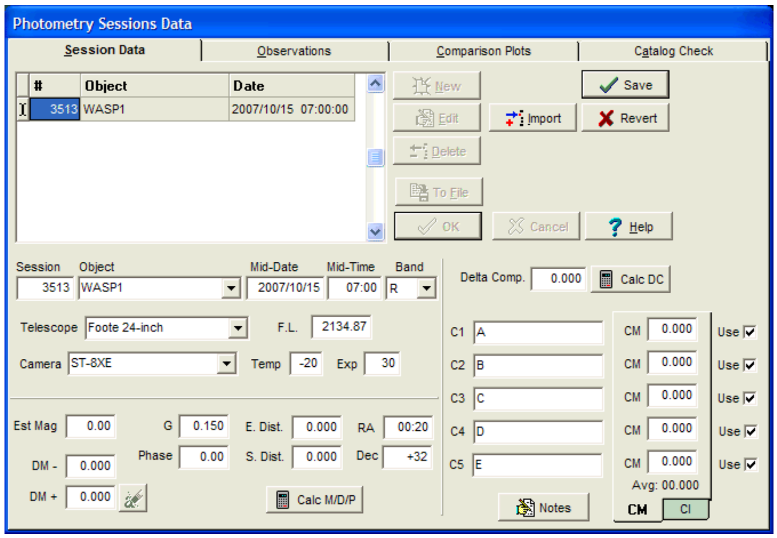
   \MPO\EXAMPLES\WASP1

*From here on, only a file name will be given when needed and "the WASP directory" will refer to the above path.*

4. Open WASP1_R_00001.FIT and AutoMatch.

With the configuration settings, there were 10 reference stars in the M/IR solution with a standard deviation of 0.021 mag.

5. Create a new session in Canopus (<Shift+Ctrl+S>). Match the settings in the entry fields as shown below.




## When You Work upon a Star

Note that the "E. Dist" and "S. Dist" fields are set to 0. This is because you are working a star and not an asteroid. So, there are no corrections for phase and distance. With these values at 0, there is no light-time correction applied to the Julian Dates stored in the observations file.

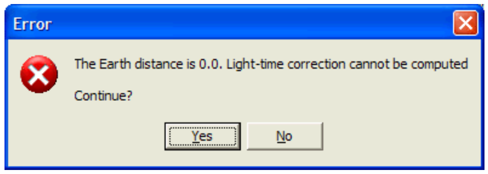
Also note that the approximate RA and Dec have been entered (Canopus was able to take them from the FITS header; it the values are not available, you must enter them). These are used to compute the air mass of the field on-the-fly based on the longitude and latitude and UTOffset values in the configuration. Canopus does not assume that the AIRMASS keyword is present in the FITS header. The RA and Dec are also used to compute Heliocentric Julian Dates.

*When working a variable star, heliocentric JD values are preferred, thus referencing all observations to when the distant star's light reaches the sun. If not used, timing errors of greater than 16 minutes can occur.* ***Canopus always stores the raw JD based on the FITS header.*** *It is only when doing period analysis or when you export data asking for such that either light-time or HJD corrections are applied.*

You can tell Canopus to use HJD by selecting that option on the Photometry page of the configuration.

## Run the Wizard

6. Click <Save> and then <OK> after you have made the entries into the sessions form. Since the two distance fields are 0, a warning message is displayed.

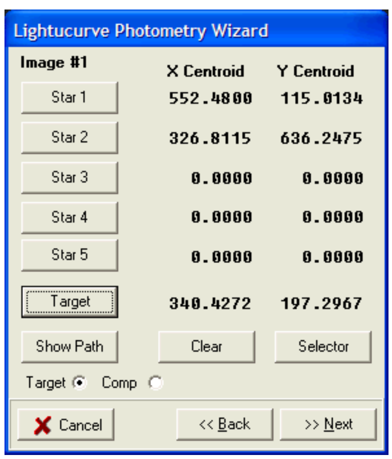


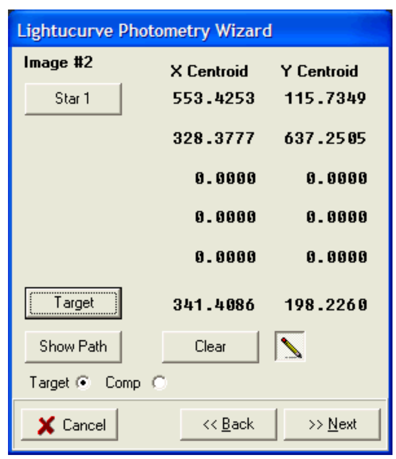

7. Click <Yes> to continue. This message is more for those working asteroids who forgot to click <Calc M/D/P> while creating the new session.

8. Run the Lightcurve wizard (<Shift+Ctrl+W>).

   - Do not run the Comp Star Selector. We're going to use instrumental magnitudes for the highest accuracy. Since the star itself is not stable, there is no need to worry about trying to match multiple sessions.
   - Use the two stars marked with "1" and "2" in the reference image above as the comparisons.
   - Do not check "Star Subtraction". The object is not moving.
   - Use WASP1_R_00001.FIT for the first image and WASP1_R_00075.FIT for the second image. Since the target is not moving, you could actually use the same image for Image 1 and 2 in the wizard.

   The Wizard should look something like these after you select the comps and target on the first and then second image.



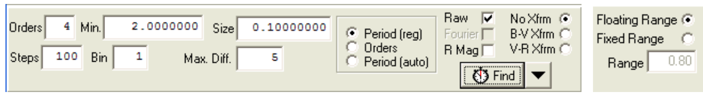

9. Finish the wizard and select all the WASP1_R*.FIT images in the WASP1 directory.

10. Turn off AutoMatch in the Canopus Image List (uncheck the box) and select the "Auto | Simple" method.

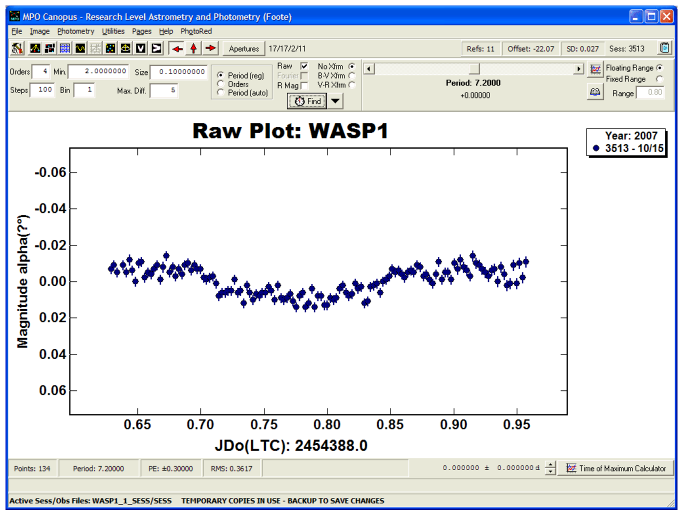
*It took about 90 seconds to measure all the images on the tutorial machine, an older one with only 512 MB of RAM running XP SP3.*

11. Go to the Lightcurve analysis page (<Ctrl+4>).

12. Set the period search parameters as shown.

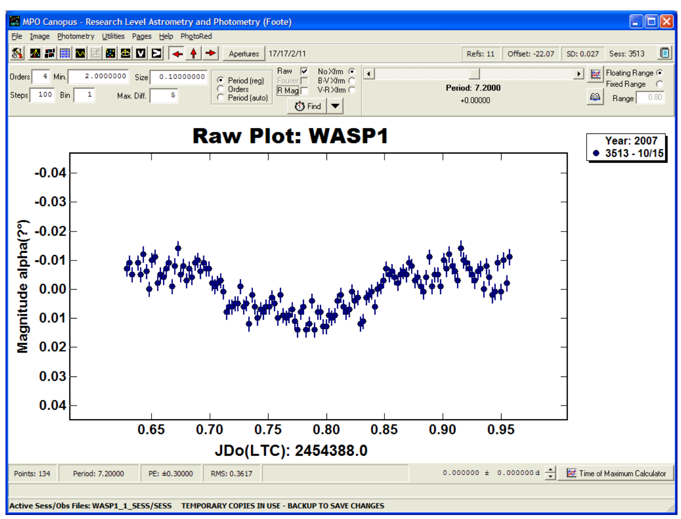



*Note the switch to "Floating Range". The amplitude of the lightcurve is so small that the default setting of Fixed Range = 0.8 mag shows a flat line.*

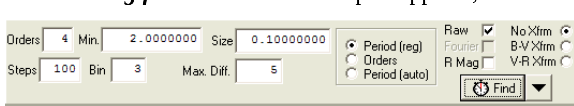


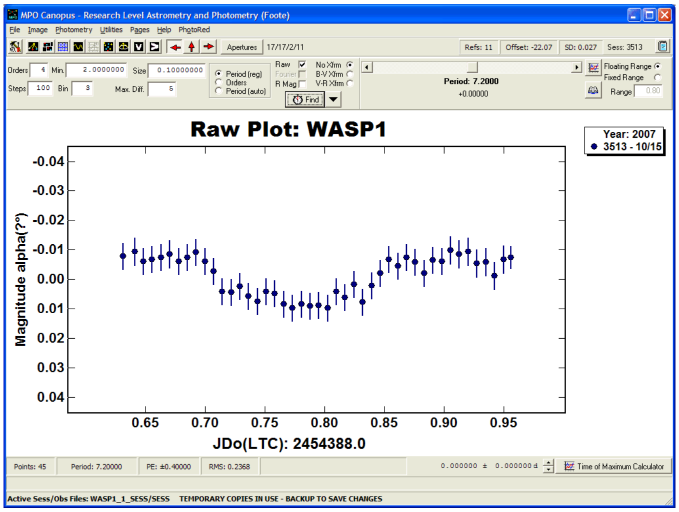

You can clearly see the "dip" in the lightcurve caused by the exoplanet.

13. Zoom in on the chart to see the curve in more detail.




14. Reset the zoom to show the plot normally and rerun the search, ***but change the "Bin" setting from 1 to 3.*** After the plot appears, zoom in again.





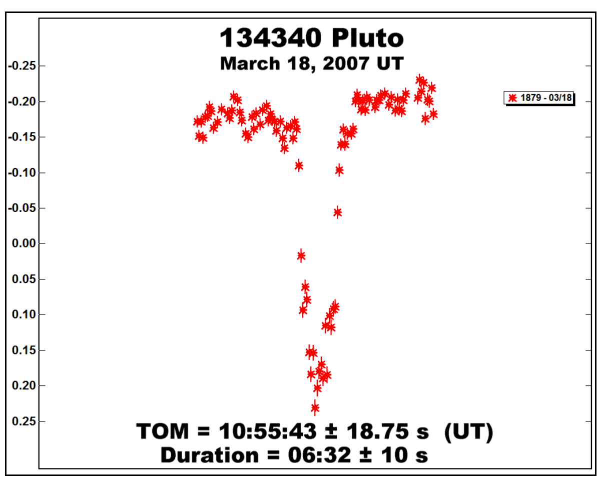

The “Bin” feature finds the average of Bin-successive data points with each point no more than “Max Diff” minutes between the points in the bin.

*This is not a running average binning. No given data point is used more than once.*

15. Before you move on, be sure to reset the “Bin” field to 1. It’s easy to overlook this and then be wondering what’s wrong when you start plotting your next target.

## *A Special “Asteroid” Occultation*

Canopus was used to record the occultation of a star in 2007 by one of the newest “small solar system bodies”: Pluto. If one accepts the premise (just for fun) that something that is a planet but not a major planet is a “minor planet” and minor planets are asteroids, then this was the first ever asteroid occultation that I observed.




The pair was less than 30° above the horizon on a not so good night and so the data are noisier than I might have gotten otherwise given the brightness of the two.

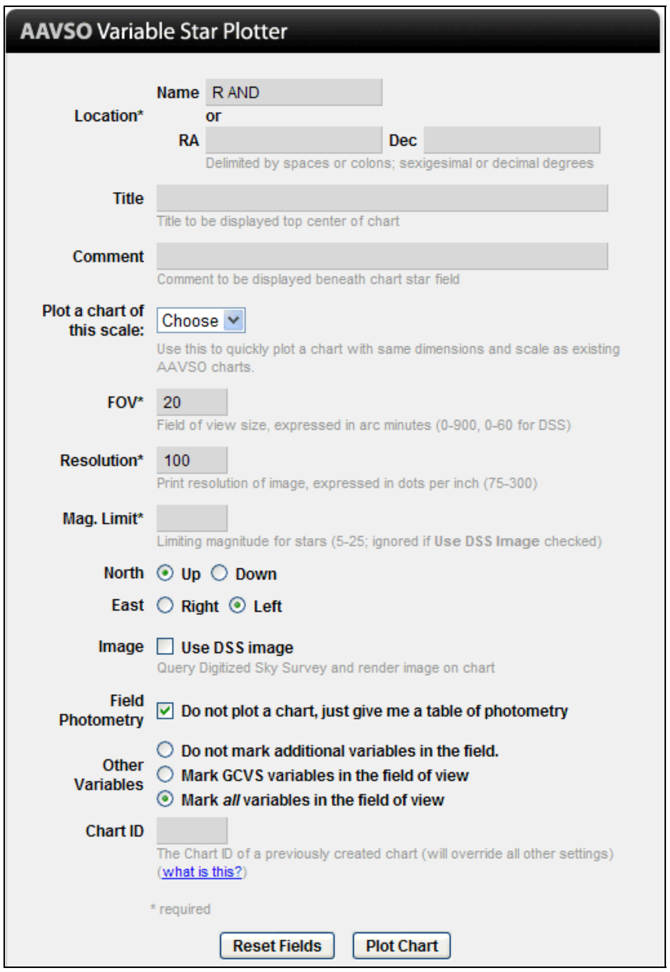
# 5. AAVSO VSP Data Import

In the PhotoRed chapter, the AAVSO Batch Processing tutorial takes you through the steps to get data into the Batch Reference File Generator (the *Generator*) using an image of the variable's field and catalog values from the MPOSC3 or other source.

If you're working a variable with an established sequence of comparisons, one that you can retrieve from the AAVSO's Variable Star Plotter (*VSP*) then you can capture that data and import it into the Generator in a few simple steps. This makes for much quick work and assures that you're working with accepted and adopted values for comparison stars.

1. Go to the VSP site: http://www.aavso.org/observing/charts/vsp/

*All web site URLs are subject to change. If nothing else, go to the AAVSO home page and look for the variable star plotter page.*




For this tutorial, we'll retrieve data for R AND. Not all stars will have a photometric sequence. The AAVSO is working on that as fast as they can.

2. Enter “R AND” (without the quotes) in the “Name” field.
3. Enter 20 for the FOV (field of view). This is the approximate FOV, in arcminutes, for the telescopes at my location. You would normally enter a value appropriate to the system that you are using.
4. Check the “Do not plot a chart, just give me a table of photometry” box.
5. Since you’re not generating a chart for this tutorial, the other settings don’t matter. However, if you want to generate a chart afterwards, at the least set the two orientation buttons so that the chart matches your images.

*It’s a good idea to generate and save the chart (uncheck the “Do not plot…” box and run the search after getting the photometry data). This way you can compare the “Comp” and “Check” assignments made by PhotoRed and change them if necessary.*

6. Click <Plot Chart>. This generates a photometry sequence table.

**Field Photometry For R AND From the AAVSO Variable Star Database**

Data includes all comparison stars within 0.166666666666667° of RA: 0:24:01.90 (6.00792) & Decl.: 38:34:37.00 (38.57694).

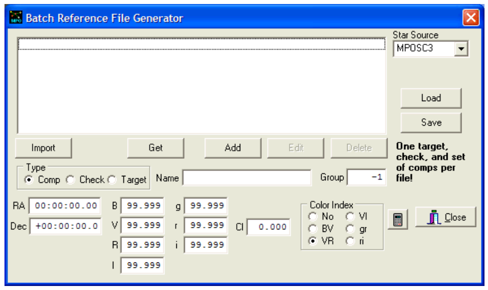
| AUID | RA. | Dec. | Label | U | B | V | Rc | Ic | J | H | K | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000-BBB-629 | 0:24:50.51 [6.21046d] | 38:44:19 [38.73861d] | **97** | - | 10.038 (0.043)[18] | 9.718 (0.030)[18] | 9.542 (0.036)[18] | 9.361 (0.036)[18] | 9.050 (0.016)[8] | 8.891 (0.014)[8] | 8.856 (0.013)[8] | |
| 000-BBB-566 | 0:23:32.51 [5.88546d] | 38:34:49.7 [38.58047d] | **99** | - | 10.010 (0.075)[1] | 9.891 (0.054)[16] | 9.743 (0.073)[18] | 9.618 (0.079)[18] | - | - | - | |
| 000-BBB-590 | 0:24:02.31 [6.00962d] | 38:31:33.7 [38.52603d] | **115** | - | 12.600 (0.023)[18] | 11.496 (0.009)[18] | 10.899 (0.021)[18] | 10.359 (0.026)[18] | - | - | - | |
| 000-BBB-596 | 0:24:06.28 [6.02617d] | 38:33:30.8 [38.55856d] | **119** | - | 13.095 (0.024)[18] | 11.916 (0.007)[18] | 11.307 (0.013)[18] | 10.768 (0.015)[18] | 9.923 (0.017)[8] | 9.369 (0.013)[8] | 9.232 (0.031)[8] | |
| 000-BBB-608 | 0:24:17.01 [6.07088d] | 38:30:09.7 [38.50269d] | **123** | - | 13.288 (0.092)[18] | 12.330 (0.012)[18] | 11.781 (0.016)[18] | 11.274 (0.020)[18] | 10.526 (0.017)[8] | 10.003 (0.015)[8] | 9.918 (0.013)[8] | |
| 000-BBB-618 | 0:24:30.43 [6.12679d] | 38:35:06.8 [38.58522d] | **127** | - | 13.485 (0.025)[18] | 12.666 (0.009)[18] | 12.194 (0.017)[18] | 11.768 (0.021)[18] | 11.171 (0.017)[8] | 10.790 (0.015)[8] | 10.696 (0.015)[8] | |
| 000-BBB-555 | 0:23:15.18 [5.81325d] | 38:38:56.1 [38.64891d] | **128** | - | 13.538 (0.018)[18] | 12.776 (0.013)[18] | 12.351 (0.019)[18] | 11.958 (0.020)[18] | 11.424 (0.028)[8] | 11.097 (0.029)[8] | 10.999 (0.028)[8] | |
| 000-BBB-624 | 0:24:37.14 [6.15475d] | 38:34:06.8 [38.56856d] | **134** | - | 14.513 (0.020)[18] | 13.364 (0.007)[18] | 12.679 (0.013)[18] | 12.115 (0.014)[18] | 11.340 (0.016)[8] | 10.794 (0.018)[8] | 10.651 (0.015)[8] | |
| 000-BBB-600 | 0:24:09.59 [6.03996d] | 38:39:11.9 [38.65331d] | **136** | - | 14.253 (0.009)[18] | 13.648 (0.007)[18] | 13.279 (0.018)[18] | 12.943 (0.022)[18] | 12.501 (0.019)[8] | 12.213 (0.017)[8] | 12.145 (0.020)[8] | |
| 000-BBB-599 | 0:24:09.14 [6.03808d] | 38:31:19.6 [38.52211d] | **137** | - | 14.392 (0.035)[18] | 13.702 (0.013)[18] | 13.318 (0.021)[18] | 12.943 (0.030)[18] | 12.444 (0.019)[8] | 12.119 (0.017)[8] | 12.071 (0.020)[8] | |
| 000-BBB-573 | 0:23:44.87 [5.93696d] | 38:32:17 [38.53806d] | **139** | - | 14.873 (0.035)[18] | 13.871 (0.013)[18] | 13.320 (0.026)[18] | 12.811 (0.028)[18] | 12.057 (0.019)[8] | 11.546 (0.017)[8] | 11.443 (0.017)[8] | |
| 000-BBB-602 | 0:24:11.09 [6.04621d] | 38:30:23.9 [38.50664d] | **140** | - | 14.591 (0.032)[18] | 13.970 (0.016)[18] | 13.613 (0.033)[18] | 13.255 (0.036)[18] | 12.786 (0.020)[8] | 12.486 (0.019)[8] | 12.412 (0.023)[8] | |
| 000-BBB-570 | 0:23:39.45 [5.91437d] | 38:33:18.9 [38.55525d] | **142** | - | 14.958 (0.030)[18] | 14.236 (0.020)[18] | 13.819 (0.036)[18] | 13.436 (0.038)[18] | 12.864 (0.017)[8] | 12.531 (0.022)[8] | 12.491 (0.028)[8] | |
| 000-BBB-582 | 0:23:54.61 [5.97754d] | 38:31:19 [38.52195d] | **145** | - | 15.278 (0.082)[18] | 14.489 (0.019)[18] | 14.059 (0.035)[18] | 13.681 (0.040)[18] | 13.170 (0.019)[8] | 12.874 (0.022)[8] | 12.770 (0.023)[8] | |
| 000-BBB-578 | 0:23:50.03 [5.95846d] | 38:36:33.3 [38.60925d] | **147** | - | 15.145 (0.045)[18] | 14.703 (0.025)[18] | 14.449 (0.053)[18] | 14.211 (0.057)[18] | 13.917 (0.024)[8] | 13.700 (0.032)[8] | 13.639 (0.057)[8] | |
| 000-BBB-579 | 0:23:51.57 [5.96488d] | 38:34:52.8 [38.58133d] | **150** | - | 16.027 (0.065)[18] | 15.022 (0.015)[18] | 14.447 (0.023)[18] | 13.908 (0.032)[18] | 13.100 (0.028)[8] | 12.596 (0.030)[8] | 12.538 (0.034)[8] | |

Report this sequence as: **1432gfq** in the *chart* field of your observation report.

- **AUID** is the AAVSO Unique Identifier for the star. When reporting a problem, please include this AUID.
- Coordinates are in J2000 sexagesimal format, followed by decimal degrees
- Click here for a search of variable stars in this field via VSX
- **Label** is that star's label when plotted on an AAVSO chart, this is usually (but not always) its V magnitude rounded to the tenths.

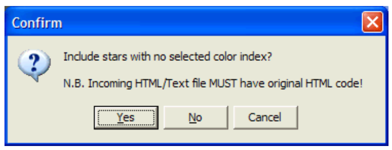
*Note that the table does not list the variable’s data other than name (if the chart was generated by name) and RA and Declination. There are no magnitudes for the variable, which means that its color index will be set to 0.000.*

7. Use your browser’s options to ***save this page as an HTM/HTML file***. Do not save it as a simple text file.
8. Close or minimize the browser and open the Generator in PhotoRed (“Utilities | Generate batch reference file” from PhotoRed main menu).




9. Set the Color Index to “V-R”. If your transforms were found using a different color index, select the one you used. If you’re not going to apply transforms, this setting doesn’t matter but you should get in the habit of selecting something.

10. Click <Import>. This displays a message.

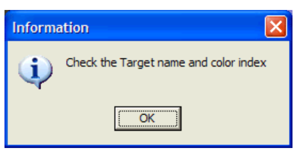



This gives you the option of including stars that do not have magnitudes in both of the bands in the color index you selected.

11. Click <No>, indicating that you want only stars that have both V and R magnitudes. A Windows file dialog is displayed.

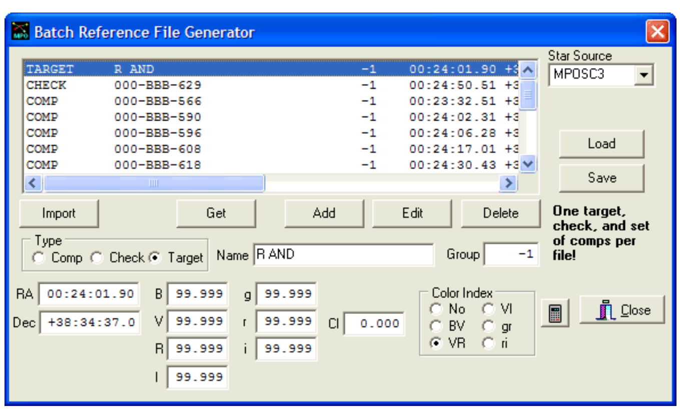
12. Locate and load the html file that you saved.

13. If all is successful, you’ll see a final message.




This is a reminder that the target name may not have been found, e.g., you generated the chart by position, and that the color index for the target is was not set.

14. Click <OK> to see the imported data.



15. The Group should be -1. The “Star Source” setting is not important since you’re not working with an image and PhotoRed generated chart.

## About the Imported Data

The Target data, if it could be retrieved, are the first item in the list. Remember that the color index has not been set since, by design, there are no magnitudes given for the target in the photometry table. This means, also by design, that the magnitudes for the target have been set to 99.999.

By default, the first star in the table is the “Check” star for ensemble photometry. All remaining stars are set to be a “Comp” and, as such, form the ensemble.

*Always confirm the imported data. Parsing HTML code can be tricky, and there’s always a chance that the format of the output file can change.*

# 6. Measuring Double Stars

Canopus includes enhanced features for measuring double stars, saving the results, and reporting those results. The summary reports can even reduce the saved raw instrumental magnitudes in different filters into standard magnitudes, greatly increasing the scientific value of your observations.

Here's an outline of what you do.

- Use the Double Stars List to select all the images you want to measure. This List is easier than having to use the "Image | Open" and locating the next file after each measurement.
- For each image, specify the reference (primary) star, specify the secondary star, and then add the information to the DoubleStarsManagement table.
- After all images have been measured, use the Double Stars Measurements form to review the data and generate a report of the raw information for all data or that matching a name and/or date range, or a summary report that can combine observations of a given star/filter/date into a single observation with errors and reduced standard magnitudes.

*Canopus must be able to AutoMatch the images (or you will have to match them manually). This is so it has the plate constants to convert X/Y positions to RA and Declination. See the Reference Manual for how Canopus looks for certain FITS keywords in order to generate a chart centered on the image center.*

## *How Double Stars Are Measured*

When you do an AutoMeasure for an image, this generates a set of "plate constants" that allow converting an X/Y position to RA/Declination. Canopus stores the measured RA/Declination for the primary and secondary and then computes the distance and position angle using standard formulae found in "Astronomical Algorithms" by Meeus and "Observing and Measuring Visual Double Stars" by Argyle.

This is a more rigorous method than simply computing the X/Y positions and applying plate scales (arcsec/pixel) to find the distance since it also accounts for the cos(Declination) factor in the RA and positions near the pole.

## *No Samples*

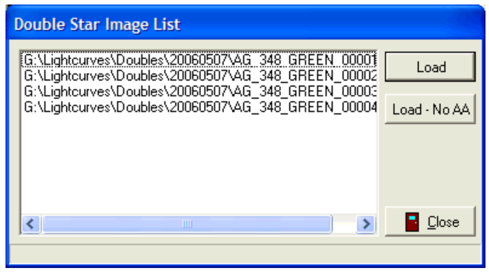
There are no example images for double star measurements. These tutorials will be "read along" only but the process is fairly simple and straightforward and should be easily applied to your images.

## Measuring the Images

1. Double star measuring requires using AutoMatch, so open the configuration form if necessary and create or select a profile that fits the images you will be measuring, e.g., the charting orientation is approximately correct and the core values on the General tab match the focal length and pixels for the system.
2. Set the measuring apertures as needed. You can change them while measuring, if necessary.

3. Select “Utilities | Double stars | Set double star list” from the Canopus main menu (or press <Shift+Ctrl+L>). This displays a Windows file dialog.

4. Select one or more images to be measured. When done, the Double Stars List (the *List*) is displayed.




5. Double-click on the first file in the list (or highlight it and click <Load>). This loads the image into Canopus. Each time an image is loaded, the highlight automatically moves to the next item in the list so that once you've measured the just selected image, you can quickly load the next image in the list.

   If successful, you’ll see the typical apertures around a number of stars on the image and numbers next to stars on the chart. If not successful, you will have to match the chart manually. See the tutorials in the Core Operations chapter.

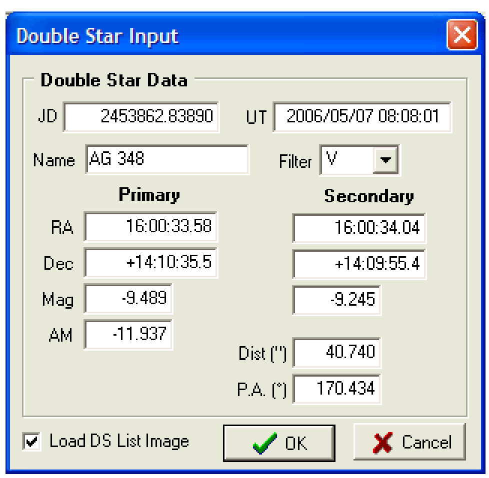
*To clear the astrometry apertures so that you can see things better, right-click over the image and select “Toggle AA boxes” from the popup menu.*

6. Once the image is matched, <Alt+Click> on the primary star on the image. This prevents the Object Info box from appearing but still measures the star’s position.

7. Right-click over the image and select “Set Dist/PA reference” from the popup menu.

8. <Alt+Click> on the secondary star.

9. Right-click over the image and select “Save Dist/PA Data” from the popup menu to display the Double Stars Input form.



10. Enter the name for the double star in the “Name” field and select the appropriate filter from the “Filter” drop down list.

11. Check the “Load DS List Image” box if you want to have Canopus automatically load the next image in the double star list.

    In most circumstances, you want this box checked, which is the default, when using the Double Stars List. The exception would be when you have a multiple star on a set of images, e.g., an AB, AC, and BC pair. In this case, uncheck the box so that when you add a measurement, the current image remains loaded with its astrometric solution still valid.

    For example, if you set the A star as the reference and measured the B as the secondary, you can then measure the C component as the secondary without having to reset the A as the reference. Just be sure to change the entry in the Name field to match which pair is being measured. For the B-C pair, you would have to reset the B star as the reference and the C as the secondary.

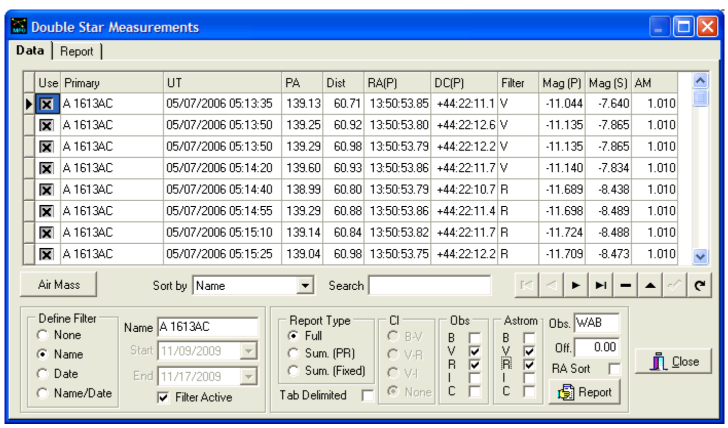
12. Repeat the steps above until the last image has been measured.

## Generating a Double Stars Report

The Double Star Measurements form allows generating one of three types of reports, one fixed and two summary. The two summary reports should provide all the information needed for publication, including errors (standard deviations) and the values used to reduce to standard magnitudes.

*See the Reference Manual for a discussion of the report types.*

13. Press <Shift+Ctrl+D> to display the Double Stars Measurements (the *DSM form*).




The data were previously entered using the Double Stars list. Again, there are no sample images, so you won’t be able to perform these steps directly until you get your own images and have you own data.

For this tutorial, we’ll generate a full report for “A 1613AC”.

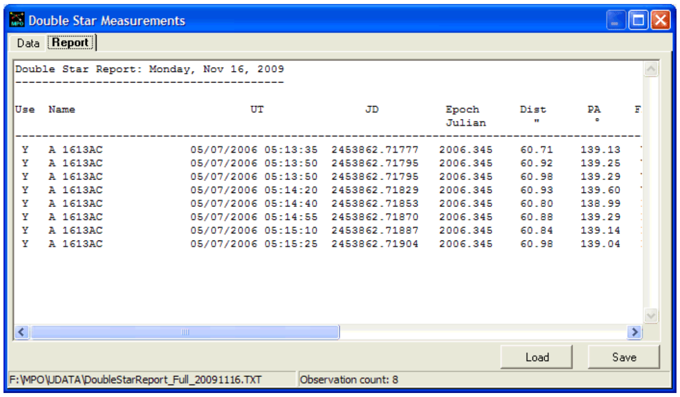
14. Check “Define Filter | Name”. This allows filtering the report by double star name.

15. Enter “A 1613AC” (without the quotes) in the “Name” field and then check the “Filter Active” box.

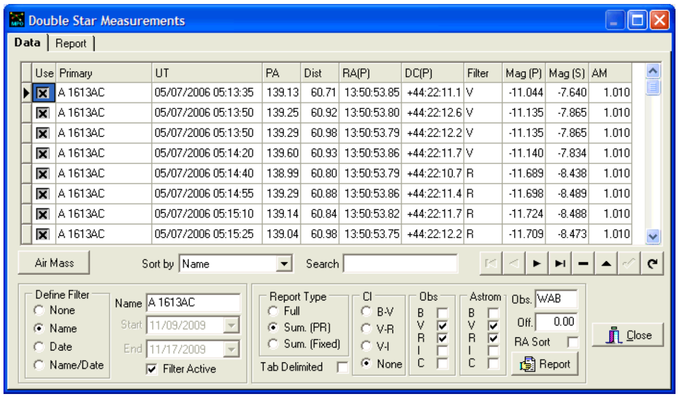
16. Set the other controls as shown. The “WAB” in the “Obs” field is mine. You would use another identifier for your observations.

17. Click <Report>. This generates the text file and presents a Windows file dialog so that you can change the name and or path where the file is stored.

18. Save the file. This displays the report on the Report page of the DSM form.



19. Go back to the Data page and match these settings.



In this case, a summary report is being generated that applies PhotoRed transforms to the instrumental magnitudes to find the standard magnitudes for the measured stars. This report also finds the mean and standard deviation of the position angle (PA, degrees) and separation (Dist, arcseconds).

20. Click <Report>. Save the file and then review the results on the Report page.

This data set found PA = 139.2 ± 0.19° and Dist = 60.88 ± 0.094”

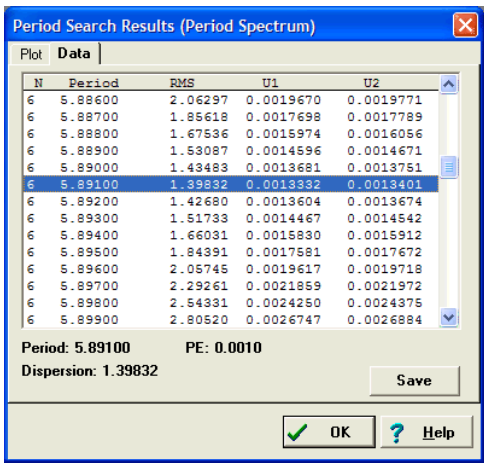
There are many combinations to generate reports. This tutorial was designed to give you an introduction into this useful tool that can used for simple but very important research.

# 7. The Lightcurve Ephemeris

After finding a reasonably good solution for a lightcurve, you can use the data generated when finding the period to generate a lightcurve for a future date. This is very helpful if you're trying to fill in a specific part of the curve or planning observations around a maximum or minimum. The Lightcurve Ephemeris tool (the *LCE*) in Canopus provides this capability

This tutorial presumes that you did the lightcurve lessons in the Photometry chapter and so have data for 771 Libera.

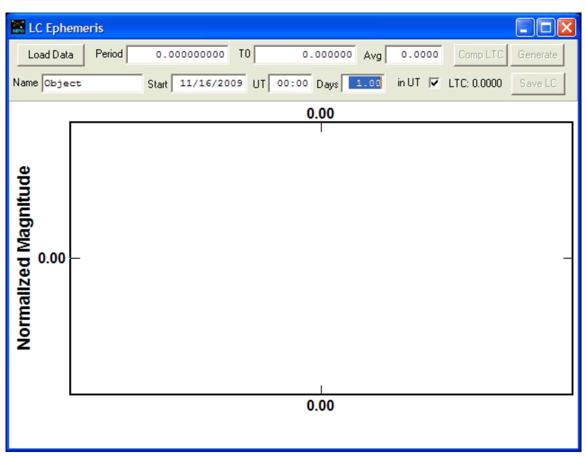
1. Before you can run the LCE, you must do a period search and save the Fourier data.



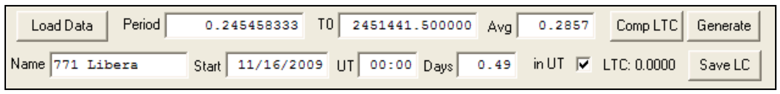

2. Click <Save> on the Period Search Results form and save the file. I recommend a name that includes "Fourier", e.g., Libera_Fourier.txt.

*Do not change the contents of the file in any way. Otherwise, Canopus may not be able to read it correctly.*

3. Press <Shift+Ctrl+E> in Canopus ("Utilities | Lightcurve ephemeris" from the main menu). This displays the LCE.



4. Click <Load Data>. Locate and load the Fourier data file that you saved.
5. If the file is successfully loaded, the entry fields should change to reflect the data in the file.



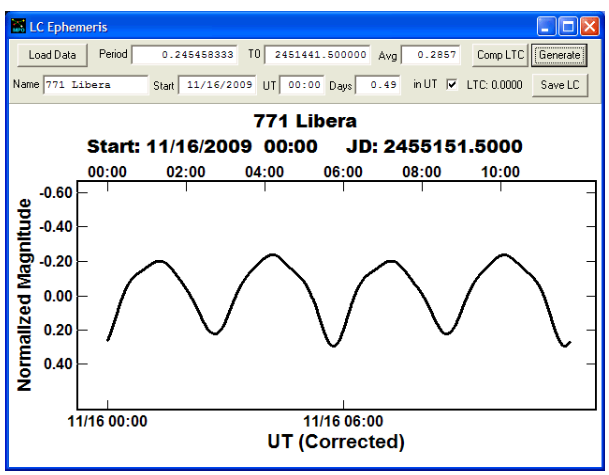

6. Enter “771 Libera” in the “Name” field, which is not automatically changed when you load the data.

*The “Days” field is set to generate approximately two complete cycles as based on the period.*

No matter how well the period has been determined, it is not reasonable (for an asteroid at least) to generate a predicted lightcurve many years after the fact. For one, the period you find for an asteroid is synodic, meaning that it will change slightly depending on viewing aspects. Another is that even the slightest error can quickly amount to a significant difference over time. This tool is intended to be used during a current campaign to plan observations.

However, you can turn things around and see how close the prediction comes to reality. This may allow you to correct the original period by increasing the precision some. This is what variable star people do all the time. Again, however, asteroids do not have constant synodic periods (and some even have changing sidereal periods) and so you must keep things in perspective.

7. Check the “in UT” box. This makes the horizontal axis in time instead of lightcurve phase.
8. Click <Generate>. This displays the predicted lightcurve starting at the current date and extending for about 0.5 days.




9. Click <Save> to save the plot. This forces the LCE to full screen and then presents a Windows file dialog. After you save the file, the LCE returns to its original state.

See the Reference Manual for additional information on the LCE.

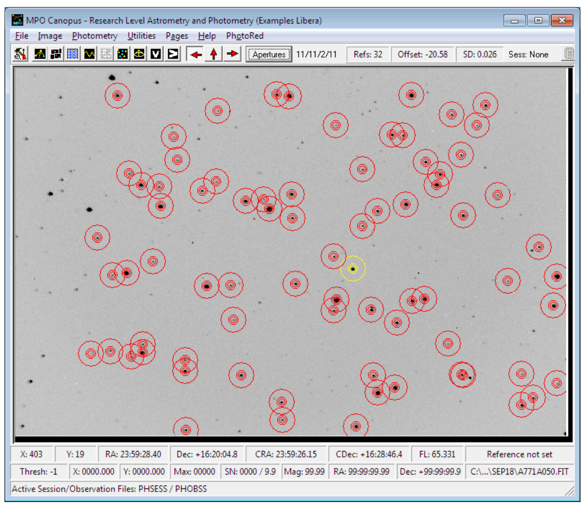
# 8. Finding Other Asteroids (AutoMatch)

After you've done an Automatch to find an asteroid (see the "AutoMatch" tutorial on page 17), you may wonder if there are any other asteroids in the image. You could use the Moving Object Search (MOS) utility (see page 227) but there is a faster way to do a preliminary check. This check can also be used to cross-check the MOS results. For example, you may have the overall "sensitivity" of the MOS too low and are overlooking some asteroids.

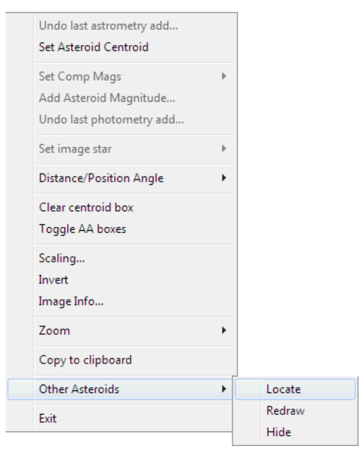
1. Run the AutoMatch tutorial with the exception of using

   \MPO\EXAMPLES\LTCURVES\A771\SEP18\A771A050.FIT

   for the AutoMatch (this image has two asteroids – did you spot the second one while you were doing the photometry tutorial?)



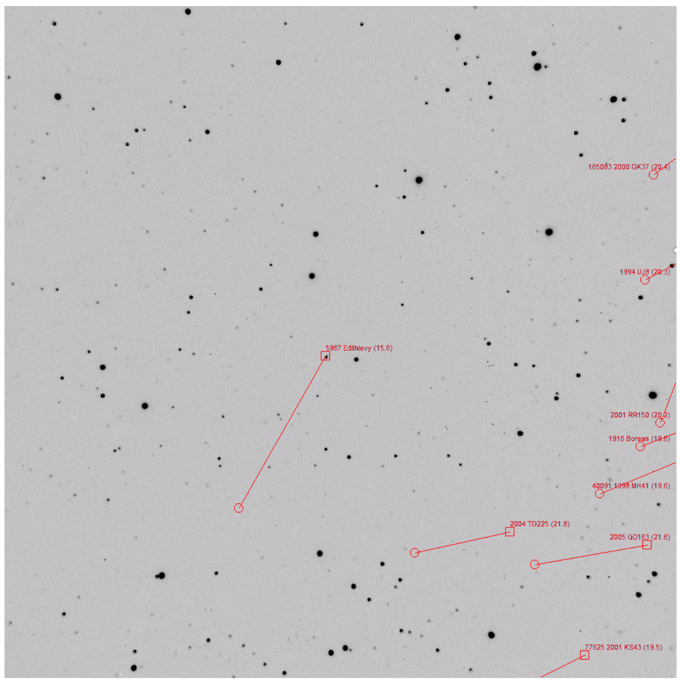

2. Once you have the AutoMatch, right-click over the image to display the image popup menu and select "Other Asteroids | Locate"




3. This automatically starts looking at every asteroid in the MPCORB_EX file (compressed version of the MPCORB table). If the asteroid can reach at least magni-

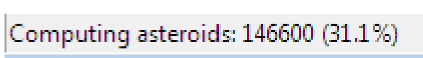
tude 22.0 (V), its position is found without accounting for perturbations or numerical integration. If the position is within 5x the side of the matched chart (in degrees) of the center of the matched chart, the asteroid's is position is recomputed using full integration and perturbations as well as including light-time and parallax corrections.

*Actually, two positions are found in that final computation. The first is for the mid-exposure of the image and the second is for 6 hours (0.25 day) later. If one or both of the positions are on the image, the asteroid is plotted.*

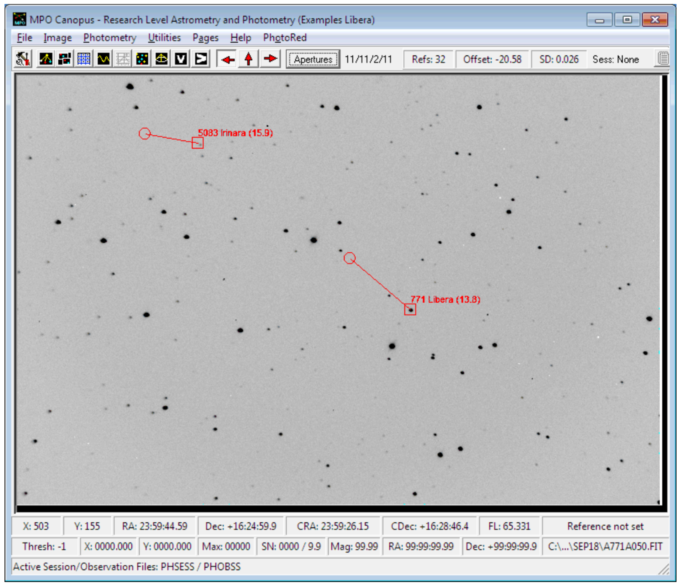



Here's an example of an image that had several asteroids enter or leave the field of view between the time the image was taken and six hours later.

During the search, the bottommost status bar shows the progress.




On a Win7 64-bit machine, the search of almost 500,000 asteroids took less than 20 seconds.




4. The screen shot above shows the final results. For each asteroid, the initial position is indicated by a square with the number (if not 0), name, and estimated V magnitude above the square. If the square is too close to the top, the text is below the square.

   The +6 hour position is indicated by a circle. A line between the two shows the path. In some cases, both markers may not be shown, the asteroid either leaving or entering the image field of view over the 6 hours. In either case, the ID text appears above or below the one end marker that is shown.

## Computed but Not Measured

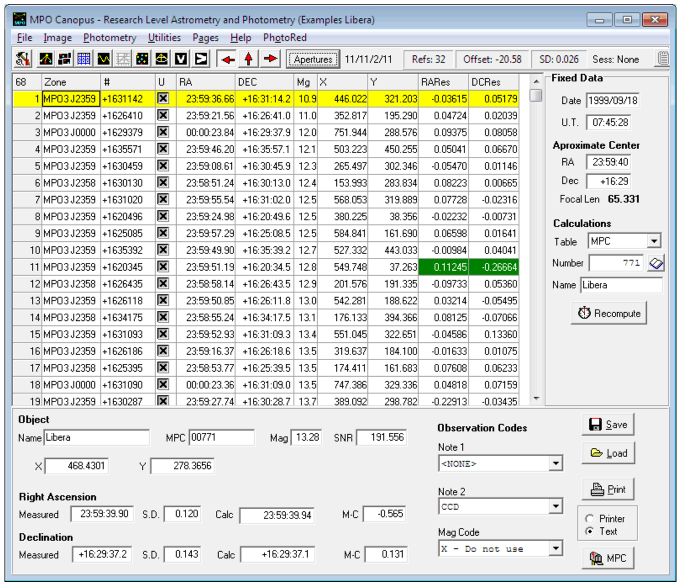
It's very important to understand that locator utility only finds asteroids that are computed to be in the image field of view. ***The position of any asteroid that is found is not actually measured.***

You must confirm that a given asteroid is actually within the square end marker (if shown) by using the blinker. Do not assume that any "star" within the square is the actual asteroid. Since the search limit is V ~ 22.0, it's very possible for a number of asteroids to be in the field of view but far below the limiting magnitude of your image.

The quick way to confirm if the asteroid is actually present is to use the Blinker with at least three images and see if you spot the asteroid moving. You can also use the Moving Object Search utility. However, if that is not set properly, it may miss very faint asteroids. In fact, using this utility is a way to check to see if the MOS is finding every possible asteroid.

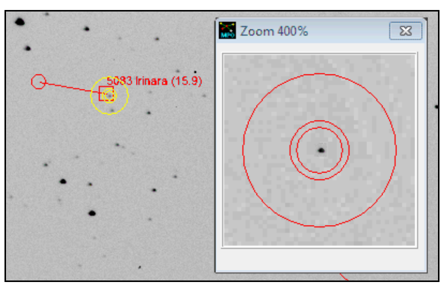
## Measuring the Other Asteroids

When you did the AutoMatch, Canopus was able to find 771 Libera and automatically measured it. If you review the Reductions page, you'll see that its X/Y coordinates along with measured and computed positions were entered.




If you want to keep this information for an astrometry report, click <Save> (see the tutorial on astrometry). Now you can measure and save the data for the other asteroid in the image.

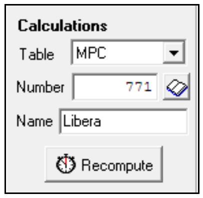
1. Return to the Measurements page and click on the other asteroid that is within the rectangle (this "star" was confirmed to be moving with the Blinker).



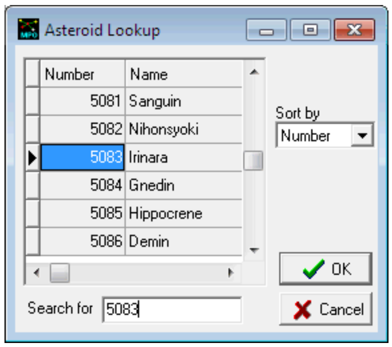

*Note that the information in the status bars at the bottom update to show the object's SNR and measured coordinates and position.*

2. Right-click over the image and select "Set Asteroid Centroid" from the popup menu.

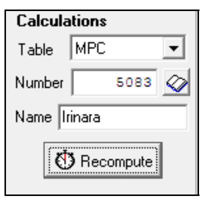
3. Go to the Reductions page. Note the "M-C" values. They are *huge*. That's because the computed position is not for the newly selected asteroid. You need to update the information, including the name and MPC ID.




4. In the “Fixed Data” section of the Reductions page, click the button next to “Number” field, which currently has 771. This displays the asteroid picker.

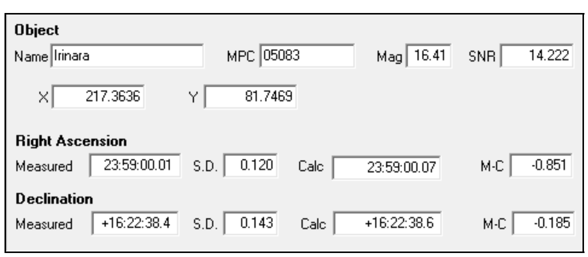



5. Make sure the “Sort by” combo box is set to “Number” and then type “5083” (without the quotes) in the “Search for” field. Let the table reposition to that asteroid (there’s about a 0.25 second pause after you stop typing) and then click <OK>.




6. Click <Recompute>.

*The information on the Reductions page is not automatically updated after you pick a new asteroid. You must click <Recompute> to complete the calculations and update the Object section data fields.*




7. Review the information in the “Object” section. Note that the name and MPC fields have been updated as have the magnitude and computed SNR. Most important is to note that the “M-C” values are *much* better.

8. As you did earlier, click <Save> and save the new data. By default, Canopus should use a base name of "A5083" for the file. Confirm this is the case so that you know which asteroid is represented in the new data file.

*If you had an image with several asteroids, measure the position and save the data for each one following the steps above.*

## *Hiding and Re-displaying the Markers*

You can hide the markers and lines by selecting "Other Asteroids | Hide" from the image popup menu. To redisplay them, select "Other Asteroids | Redraw."

## *Copy to Clipboard*

If you select "Copy to Clipboard" from the image popup menu while the markers are displayed, the markers are included.

## Lost List

Since the marker positions are very specific to the image and chart following an AutoMatch (or manual match), the asteroids list is cleared every time you generate a chart on the Measurements page (either due to an AutoMatch attempt or generating the chart manually from the menu) or if you load an image. It doesn't matter if the image is the same image or the chart is for the same image on which you did the match. To keep bookkeeping to a minimum, Canopus takes the blunt approach and clears the list.

# 9. Batch Editing of the G Parameter

The exact value for the Phase Slope Parameter (*G*) in the *H-G* magnitude system can have an effect when finding the period of an asteroid's lightcurve. When several sessions in Canopus are combined, the data are "normalized" the phase angle of the asteroid at the time of the first (usually earliest) session. To do this requires using the *G* parameter. So, if the wrong value is used, the correction can be seriously affected.

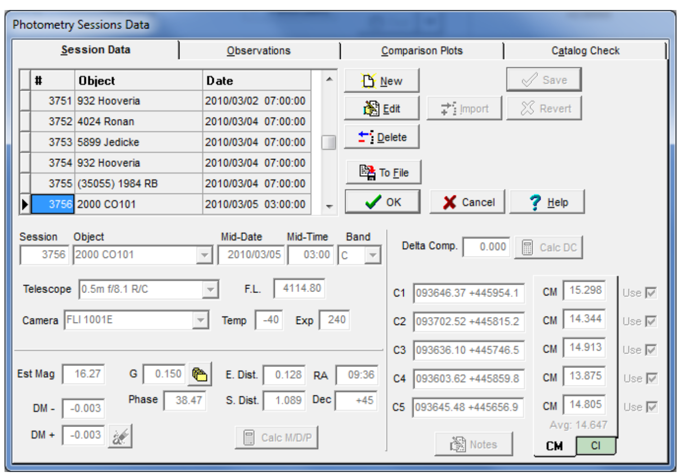
The default value of *G* is 0.15. This is sufficient for most asteroids but some asteroids have considerably different values of *G*. For example, high albedo objects (those of type E, V, and R) have *G* ~ 0.43. Very dark objects (low albedo) have low values of *G*, ~0.12 for C, D, P, etc.

If the actual value of *G* becomes available after you've created a number of sessions for a given object, it's a good idea to enter the revised value and recheck the period analysis. It can also help in period analysis if using the default value of *G* initially to try other values and see if that improves the solution, e.g., better RMS fit. If you a have number of sessions, it can be very tedious, and prone to error, to edit each session manually. This is where the batch editing feature for changing the value of *G* comes in handy.

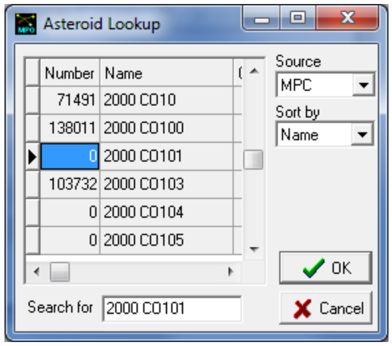
*Remember that the G parameter is not used for variable stars. Use this feature only if the sessions involve an asteroid.* ***Every session for a given object must use the same value of G.***

1. Open the sessions form (<Ctrl+Shift+S> or "Photometry | Sessions" on the Canopus main menu.

*Do not click <Edit> or <New>. You cannot use the batch edit feature while creating a new session or editing an existing one.*

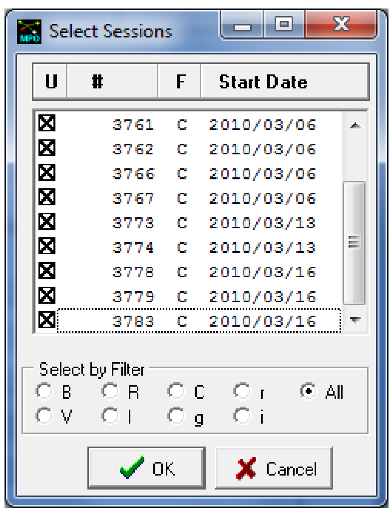



2. Locate one of the sessions for the asteroid in question.
3. Click the button next to the "G" entry field in the session data section of the session form. This displays the asteroid selection form.



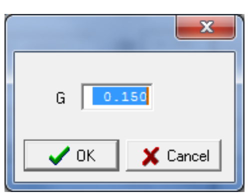

While it’s possible that Canopus might be able to determine the asteroid from the entry in the “Object” field, there are too many possibilities and not enough certainties of how that field is managed to assure the correct interpretation. This is why the Asteroid Lookup form is displayed.

4. Locate the same asteroid as that in the session and click <OK>. This displays the sessions selection form.




5. Select ***all*** sessions for the asteroid and click <OK>. This displays a data entry form.

*Remember! **All** sessions for a given asteroid **must** use the same value of G for analysis. The asteroid’s physical properties cannot and do not change from one night to the next!*



The initial value that appears in the entry field is the value of G in the session that you highlighted in step 2.

6. Enter the new value of *G* and click <OK>.

   For guidance, here are some typical values of *G* (taken from Warner et al. (2009), *Icarus* **202**, 134-146).

| | |
|---|---|
| C, G, B, F, P, T, D | 0.12 ± 0.08 |
| M | 0.20 ± 0.07 |
| S, Q | 0.24 ± 0.11 |
| E, V, R | 0.43 ± 0.08 |

The larger scatter in S, Q is because the various sub-classes of the S type each have their own values of G. See the Icarus paper for a more detailed breakout.

*An important point to remember: There is sufficient scatter in the values for G among similar classes and within a base class, e.g., S, that you* **cannot** *use the G parameter alone to determine a spectral type, with the* **possible** *exception, of having a large value of G. Even then, you can only say that the value for G is* **consistent with** *a taxonomic type or albedo group, e.g., G = 0.4 is consistent with a type E and/or a high-albedo object.*

7. After you click <OK> on the value entry form, Canopus updates the value for *G* for all the selected sessions ***and recomputes the estimated magnitude and DeltaMag values***. This is why you had to select the specific asteroid.

From here, you can redo the period analysis to see what effect, if any, changing the value of *G* had on the data. Since the period solution can change significantly with different values of *G*, be sure to do a search on an appropriate range of periods. Don’t presume that the new solution will be within a few percent of the old solution.