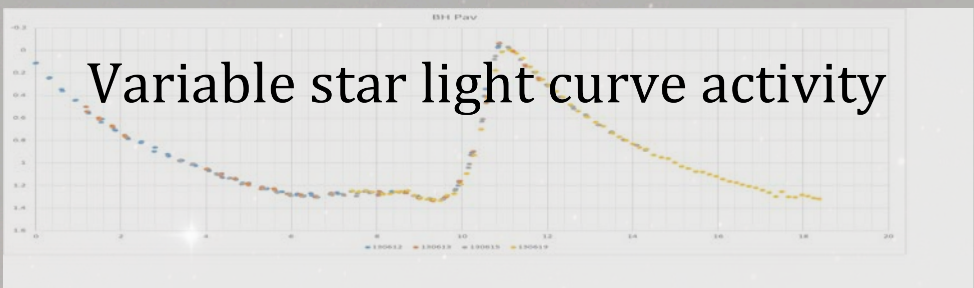
SPIRIT

SPICE-PHYSICS-ICRAR
REMOTE INTERNET TELESCOPE

Variable star light curve activity



spice
secondary teachers enrichment program

Table of Contents

1 Introduction and package contents

This document package comprises information and activities that provide experienced users of *SPIRIT* the means to create photometric light curves of variable stars. The package contains 4 key items:

1. Background information on targeting and imaging variable stars with *SPIRIT*.
2. An image analysis activity that familiarises participants with software tools used in the photometric analysis of stars and generation of light curves.
3. An activity that uses data obtained by participants to create light curves of short period variable stars of the type RR Lyrae.
4. Appendices and supporting information.

1.1 Requirements

This activity assumes basic astronomical knowledge and experience using *SPIRIT* to acquire images. Additional prerequisites include:

- Basic knowledge of variable stars and the importance of their study.
- Familiarity with planetarium software such as *Stellarium* for planning and visualising targets.
- Familiarity with *SPIRIT's* advanced imaging options. The use of 'plans' to automate the acquisition of data will be used in later activities.
- A basic understanding of time series graph interpretation.
- Access to, and experience in the use of *Microsoft Excel* for data presentation and graphing (optional).

1.1.1 Processing software

The data analysis component of this activity uses the image processing and analysis software *MaxIM DL*. Trial download and purchasing details are available from *Diffraction Limited*[1]. Experience in the use of *MaxIM DL* is not required.

1.2 Workflow:

The basic sequence of activities is as follows:

1. Selecting and imaging a number of targets at different exposures from a provided list of southern RR Lyrae variable stars.
2. Preliminary use of *MaxIM DL* to gain experience in analysis of images and use of basic photometry tools. Concepts such as 'saturation' and 'signal to noise' are examined. Images of RR Lyrae stars acquired in step 1 are analysed in order to determine the exposure requirements for collecting light curve data.
3. Collecting data for extended light curve analysis over one or more nights.

[1] http://www.cyanogen.com
[2] "Short Period" refers to a light curve for which the interval between successive occurrences of the same

4. Performing photometry in *MaxIM DL* and creating a basic light curve.

2 Targeting and imaging variable stars

A light curve is a time-series plot displaying the magnitude (brightness) variation of an object over time. Light curves are used by astronomers to study the physical properties of transient astronomical objects such as asteroids, variable stars and supernovae.

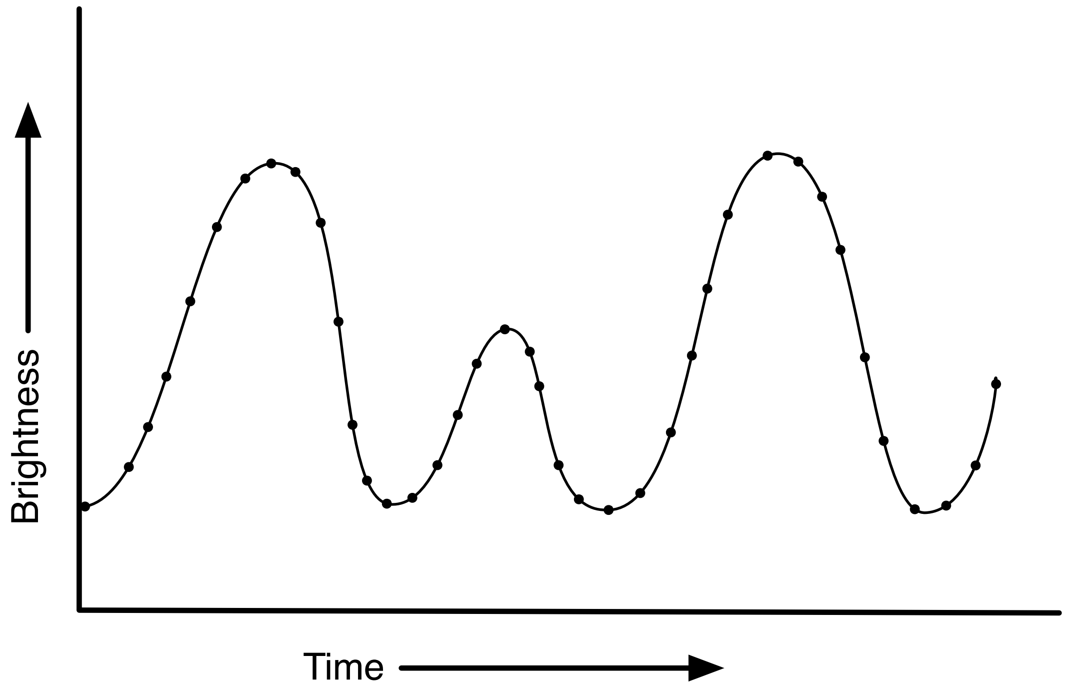


Figure 1: Observations of an astronomical object over several hours show it brightening and dimming over successive periods

Many images (often dozens) of a specific target are acquired over one or more nights and are used collectively to create a light curve. In the case of short period[2] variable stars such as RR Lyrae stars, the images required to create a complete light curve can be acquired in less than one or two nights.

2.1 Targeting tips

To maximise the number of images that can be acquired in a given night, always select targets that are east of the meridian at nightfall. A target that is visible at nightfall 4 hours east of the meridian can be observed for at least 8 hours. In the case of *SPIRIT*, selecting targets in the southern sky will also increase the available observation time. The list provided in Appendix C has been customised for use with *SPIRIT.*

[2] "Short Period" refers to a light curve for which the interval between successive occurrences of the same point is comparatively short. In Astronomy this is typically hours or days, versus weeks, months or even years.

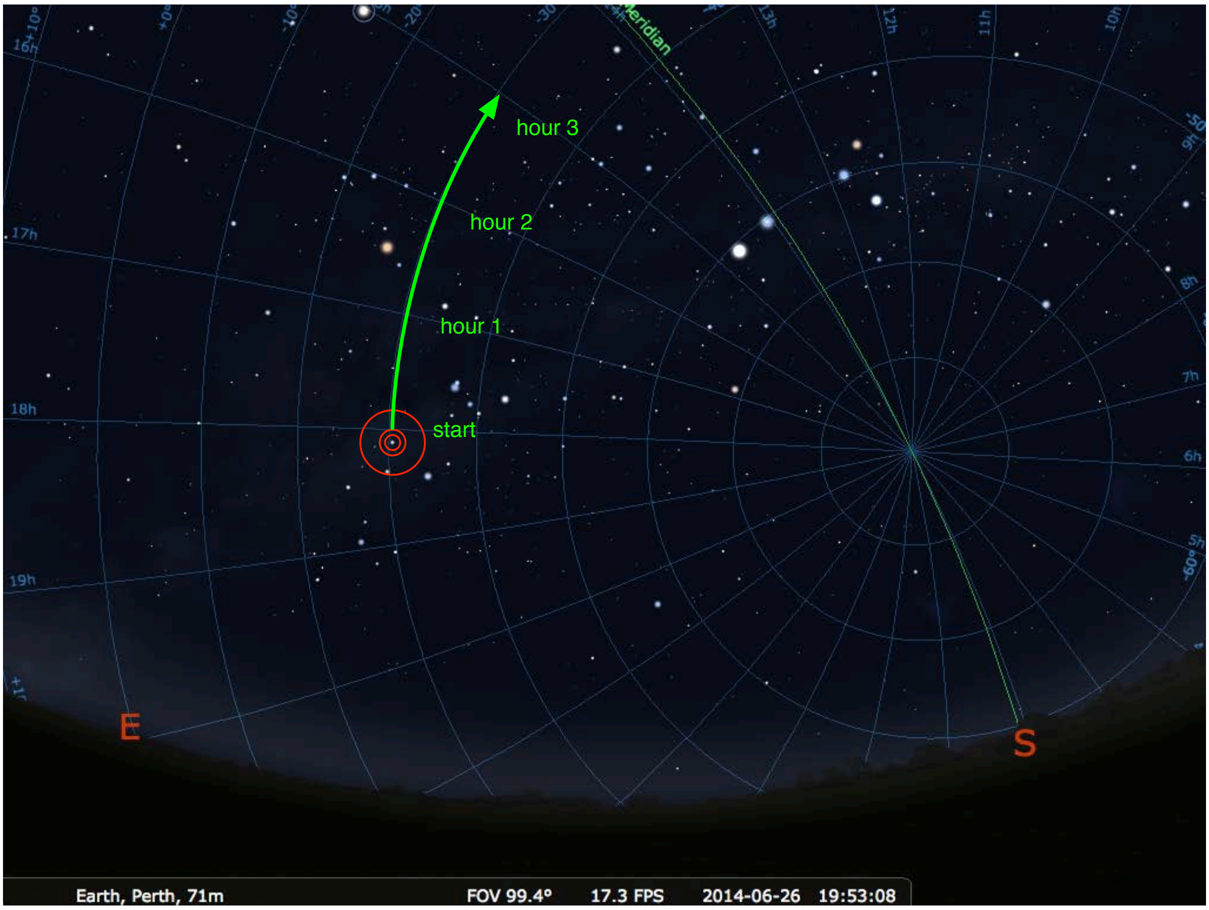


Figure 2-2: The night sky 'rotates' from east to west. Choose targets in the east at nightfall to maximise the number of individual observations that can be undertaken over the course of the night.

Multiple target lists should be ordered by RA, so that targets that are ‘higher’ in the sky are imaged first.

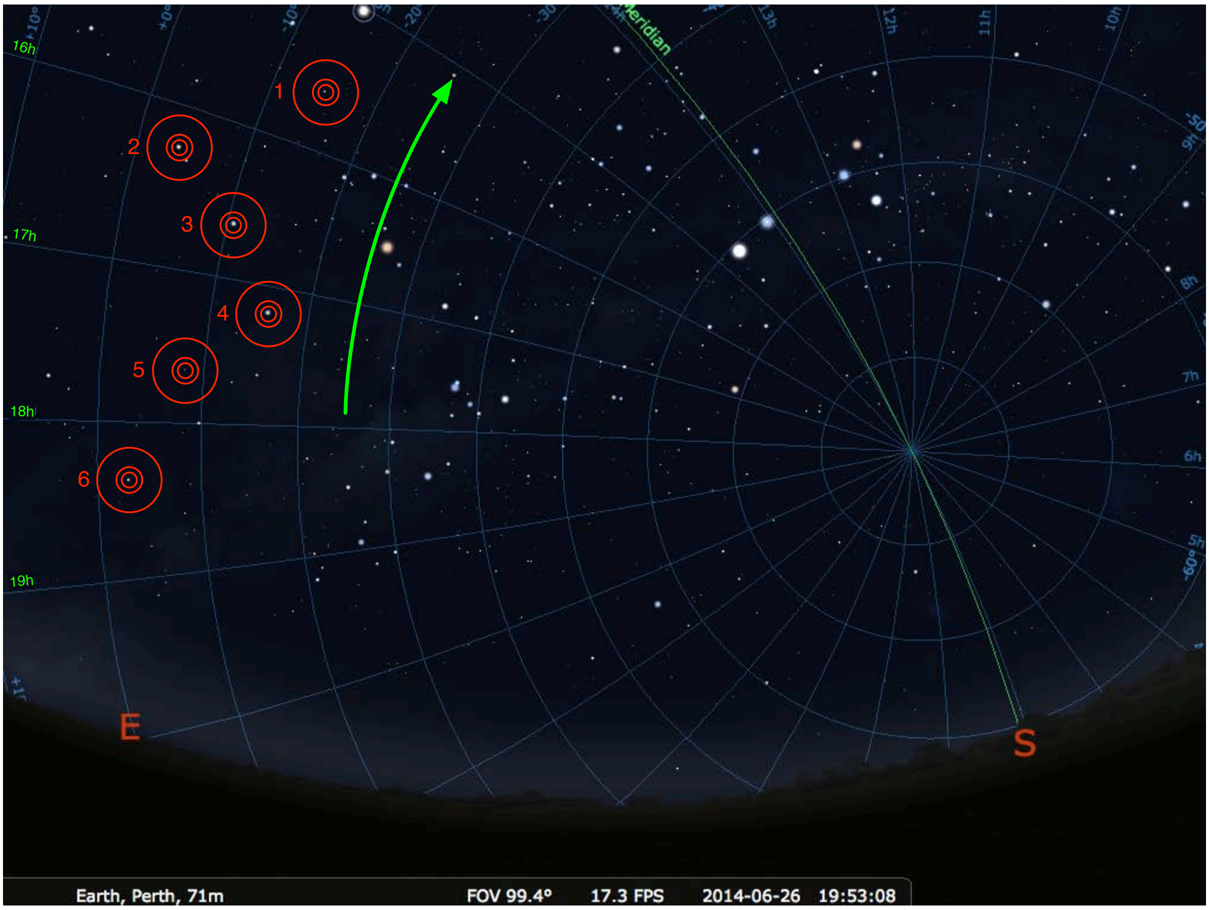


Figure 2-3: Targets that are higher in the sky should be imaged first.

Very crowded fields can prove challenging when it comes time to perform photometry. Choosing a target that is easily distinguished in a field of view will make analysis easier. Planetarium software can help visualise the field before imaging.

Figure 2-4: Crowded fields can be more challenging when it comes time to perform photometry. If possible, choose targets that are easily identified.

2.2 Target magnitude and exposure

Choosing bright variable stars will allow shorter exposure times. This means that more targets can be scheduled over a given time period. However, accurate photometry is sensitive to exposure, and *very* bright variable stars place more demands on determining the optimum exposure. As a general rule, choose stars that produce unsaturated data within a 10 to 60 second exposure through the V filter[3]. Test images should be acquired on a preceding night to help characterise the imaging system before a dedicated light curve data acquisition run (see section 3).

2.3 Automation and data acquisition tips

Collecting data over an entire night or more requires use of *SPIRIT's* advanced imaging options. *ACP Planner* can be used, or the templates provided in Appendix B can be modified to suit. Pay careful attention to the total acquisition time of an ACP Plan and book sufficient telescope time accordingly.

Always take at least two images of a target in succession to help mitigate the risk of artefacts, such as satellites or clouds, affecting a single image[4].

A typical list may contain five or more targets. Two images of each target are taken sequentially for all targets in the set, and repeated over the course of the night using an appropriate time interval between sets. If you are imaging only one or two targets, this interval may be 15 minutes or more. A variable star's magnitude may show little change within a short time frame, and an unnecessarily large number of images will increase the amount of time it takes to download, process and analyse data. A good starting point is to allow 15 minutes between images of a single target. Large lists of a dozen or so targets may require no interval between sets (by the time the last target is imaged sufficient time will have passed to allow the first target to be imaged again).

Target lists should be ordered by RA so that objects that are higher in the sky are imaged first.

Finally, avoid target imaging below 30° in altitude. The atmosphere at these low altitudes will adversely affect the accuracy of your photometry.

3 Activity: Using MaxIM DL to analyse stellar profiles

MaxIM DL includes a number of tools well suited for scientific analysis of astronomical images. This activity will familiarise you with those tools as well as verify the suitability and exposure details of your proposed targets.

[3] The standard photometric V filter is preferred for photometric observations as it provides a baseline from which data can be transformed for scientific use.
[4] In addition, image processing software can be used later to combine pairs of short-exposure images by averaging to reduce noise and improve image quality.

3.1 Data acquisition

Choose a small number of RR Lyrae variable stars according to the selection criteria outlined in section 2.1. Obtain exposures of your proposed target stars through the V filter.

Take at least two images at each of the following exposures:

10, 15, 20, 30, 45, 60 seconds.

Time your image acquisition to correspond with the favourable viewing of each target (e.g. high in the sky on a clear, preferably moonless night).

3.2 Image inspection and target verification

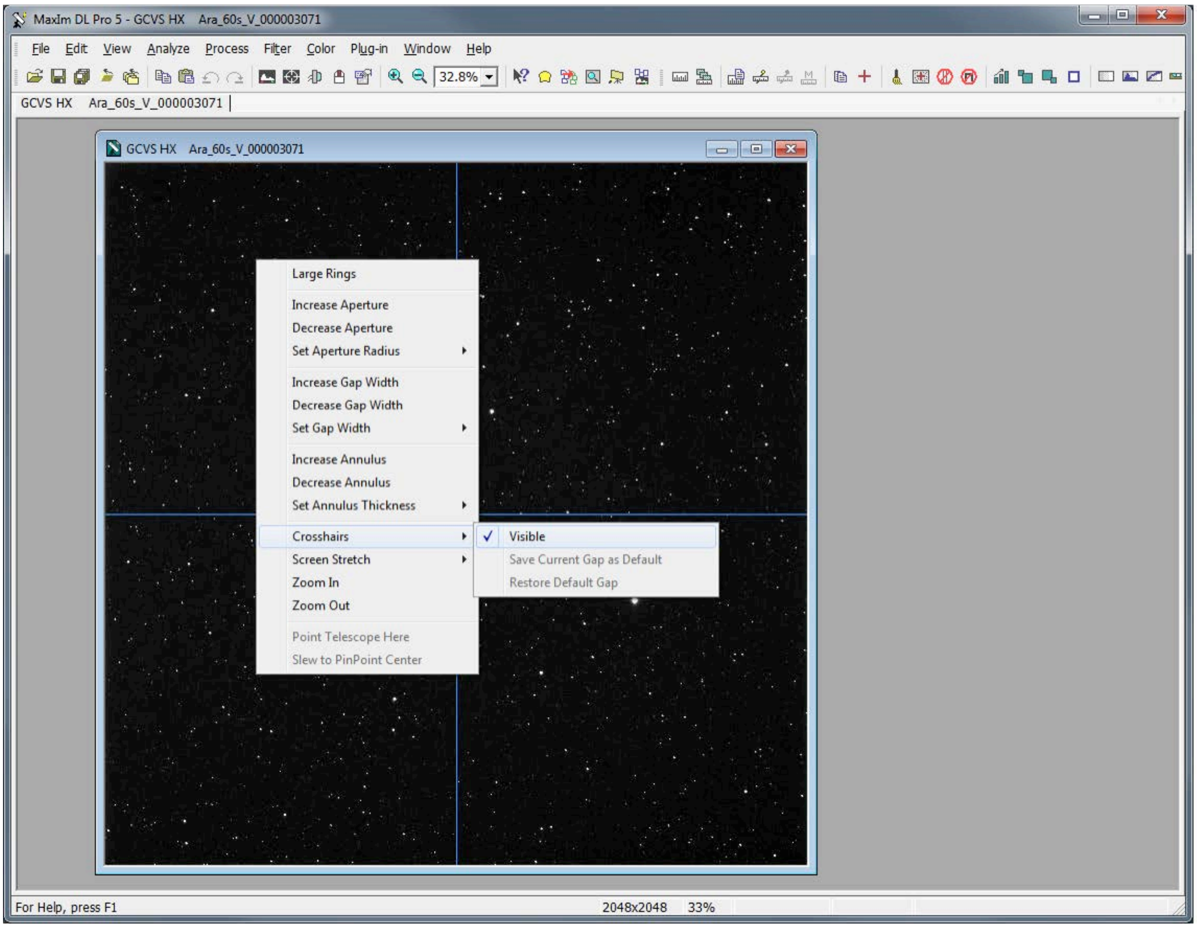
Download the calibrated FITS images.

Start *MaxIM DL* and open one of the 30 second exposures taken through the V filter.

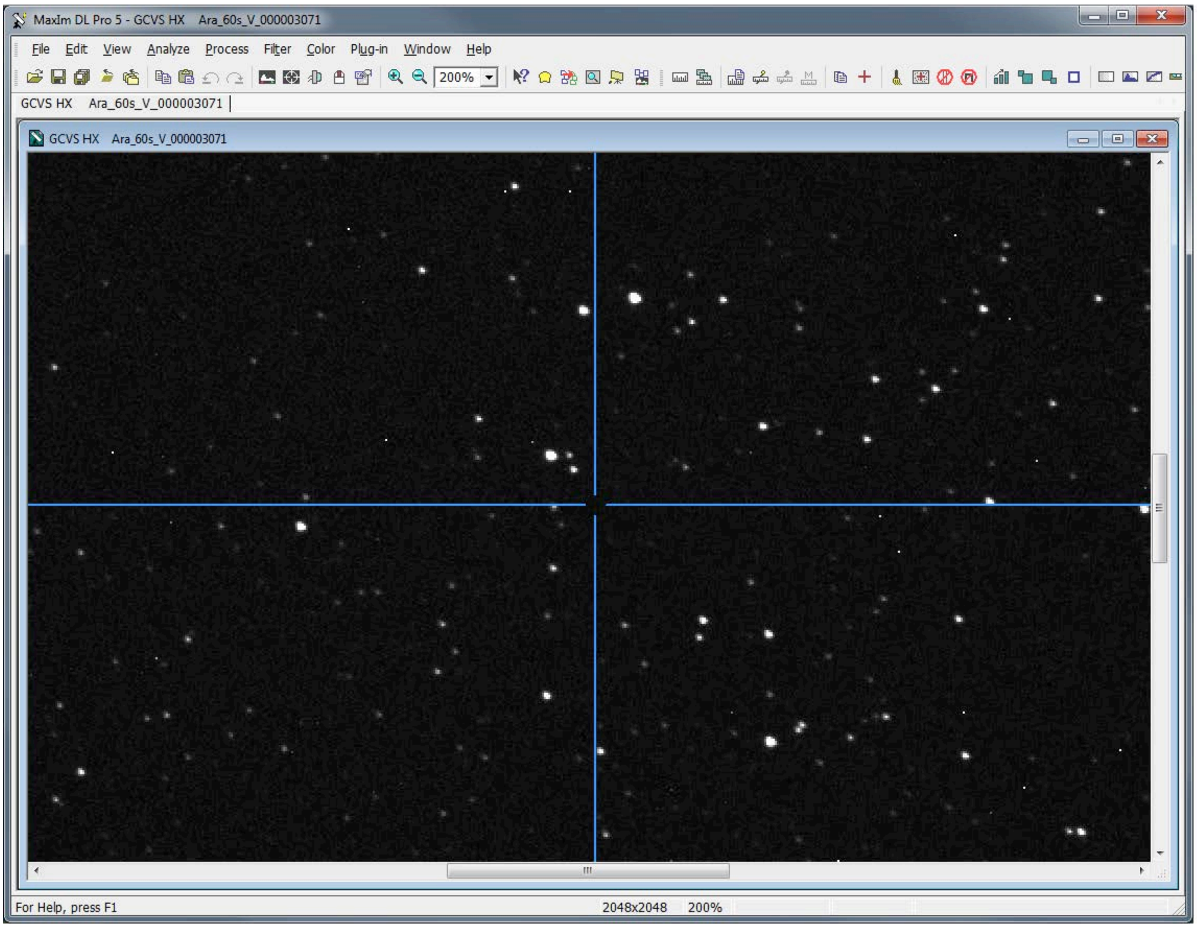
3.2.1 Finding your variable star

Your first task is to verify which of the many stars in your field is the target variable star. *SPIRIT's* accurate targeting means that there is a very good chance it is centred in the frame.

Right click anywhere on the image then select **Crosshairs / Visible** to provide a guide to the centre of the image.



Zoom in on the centre of the image using the mouse wheel or 'Zoom' tool.



Despite SPIRIT's accurate targeting, there is still no way of knowing which of the stars near centre is the variable star. There are a number of ways to verify the target.

1. Planetarium programs.
   Basic planetarium applications such as *Stellarium* are of limited use, unless the target star exists in the software database. In addition, the default stellar databases in basic planetarium software may not include sufficient stars to perform a comparison with your image.
2. Image linking in advanced planetarium programs.
   Some advanced planetarium applications[5] include image linking features that allow a FITS image to be inserted and aligned onto the screen. However, such applications are usually expensive.
3. Finder charts available online from the American Association of Variable Star Observers (AAVSO). The AAVSO includes a number of resources that allow visitors to download finder charts and comparison images via the VSX service[6].
4. On-line survey images and interactive sky atlases such as *Aladin*.

Refer to Appendix A for a detailed description of how to use Aladin to verify a target variable star in a FITS image.

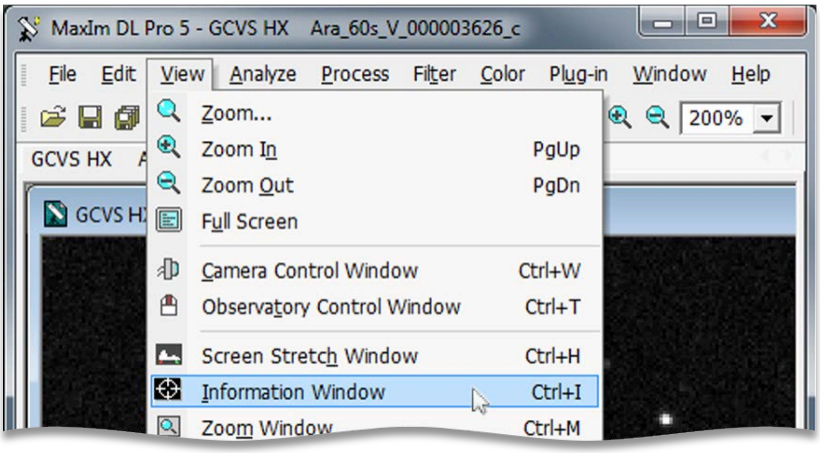
[5] Eg, TheSkyX Pro, available from http://www.bisque.com
[6] http://www.aavso.org/vsx/

Once you have confirmed without doubt the target variable star in your image, you are ready to perform some analysis.

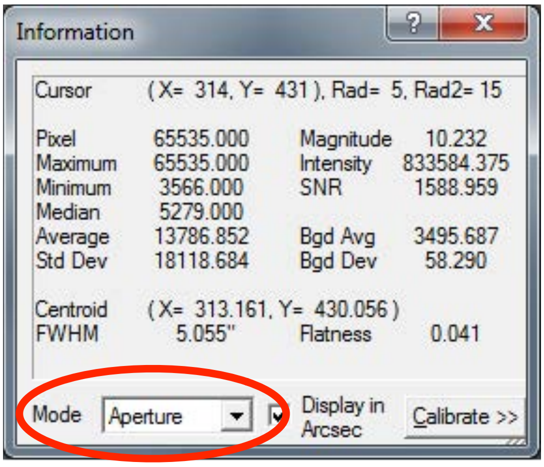
3.3 Analysis using MaxIM DL: The 'Image Information' tool

The image information tool provides a set of useful features for analysing stellar profiles and performing basic photometry. It can be used to gain an understanding of the 'quality' of the data, and provide a guide for setting correct exposure when it comes time to collect light curve data.

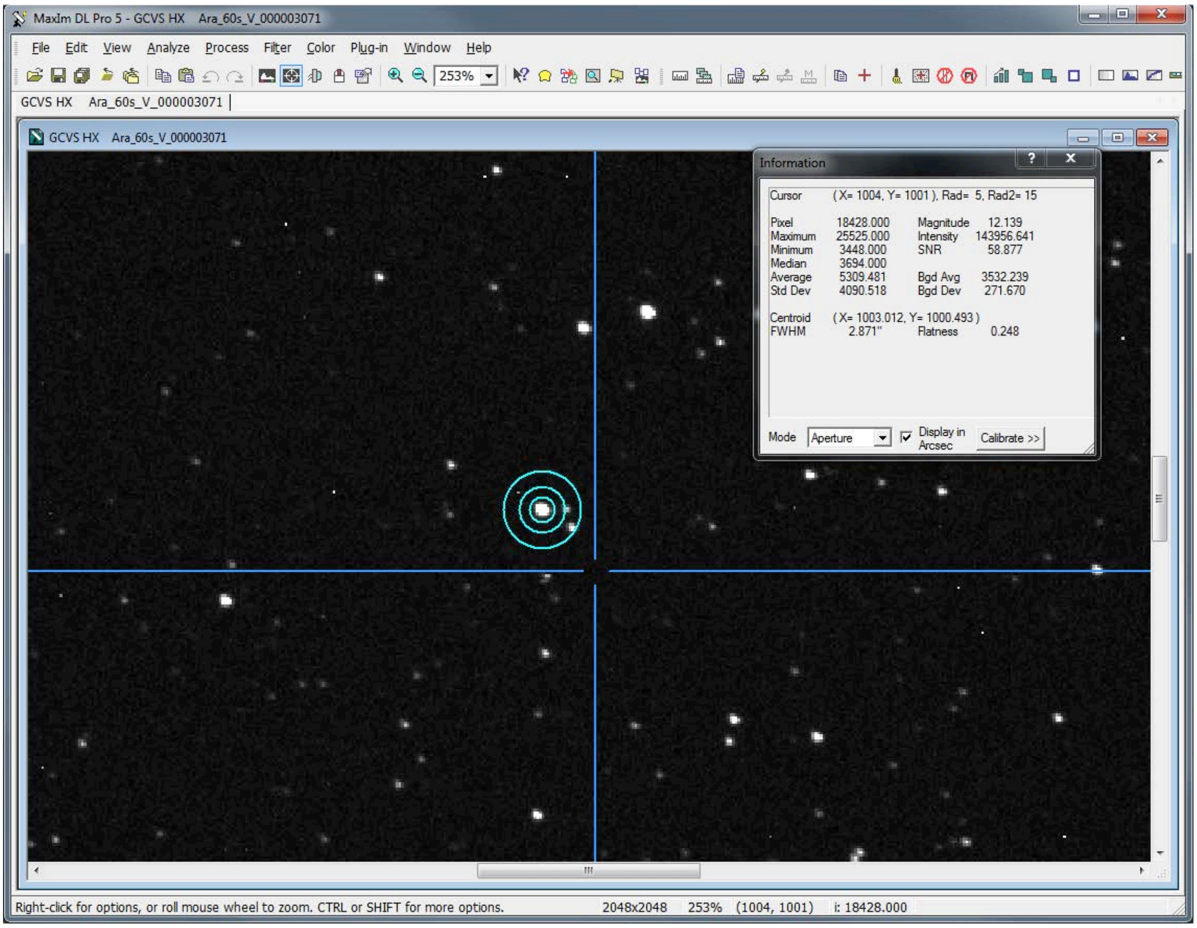
Open the Information Window available under View / Information window or by using the keyboard command *Ctrl+I*.



Ensure the Mode selected is 'Aperture'.



As you move around the image with your mouse, you will see various pixel values change on the Information screen. Position the mouse target over the target variable star. The target star can be 'snapped' in place by double clicking it.



It is important to ensure that the target star is completely contained within the innermost circle (the *aperture*).

To adjust the size of the aperture, right click anywhere on the screen and select **Set Aperture Radius**.

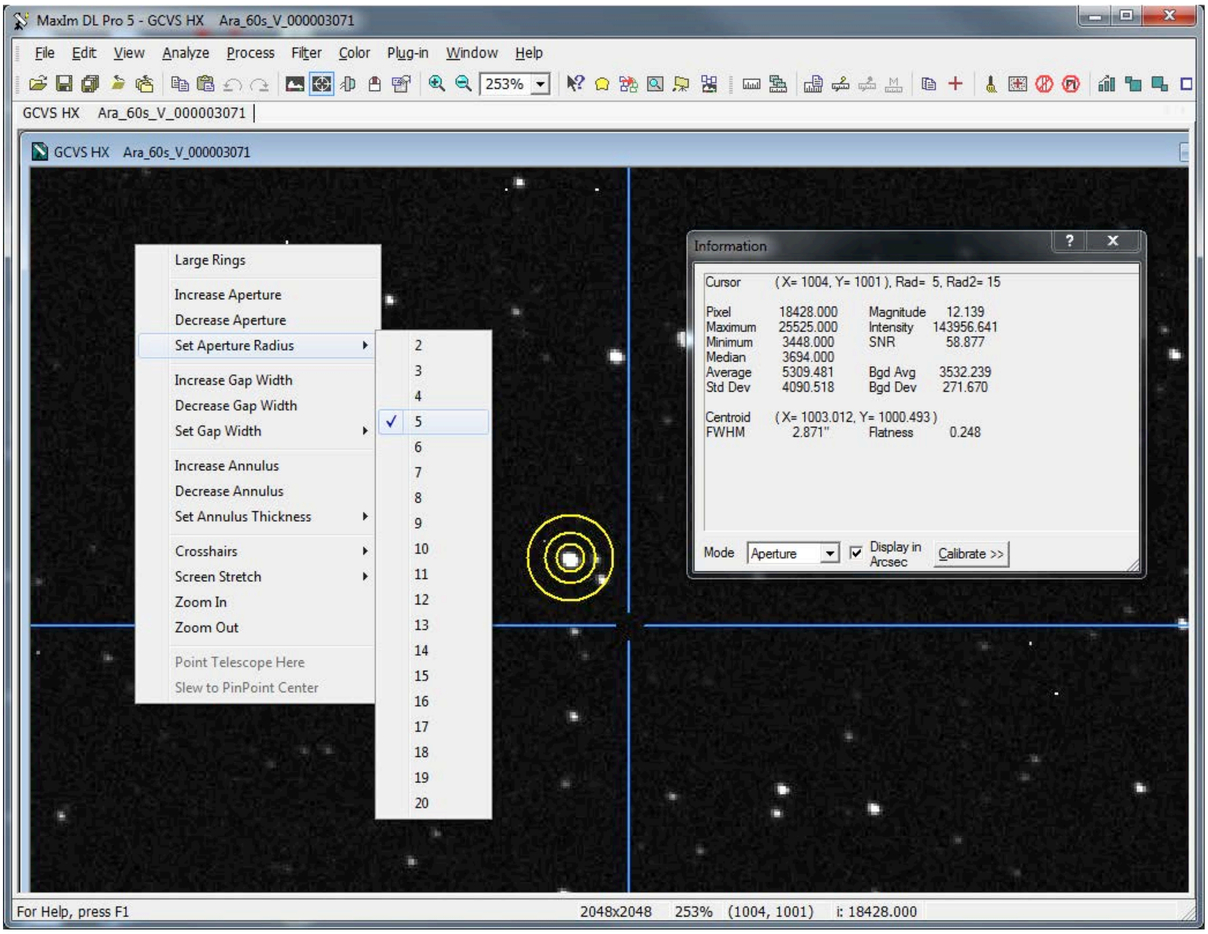


Figure 3-1: Right click on the image to set the aperture radius

3.3.1 Saturation and signal

The maximum pixel value of the selected star should not exceed 55,000. If your target star has a maximum pixel value approaching 65,535 the star profile will be over exposed or *saturated*, and produce unreliable photometric data. If your target star is saturated, close the image and open one with a shorter exposure, e.g. 15 seconds.

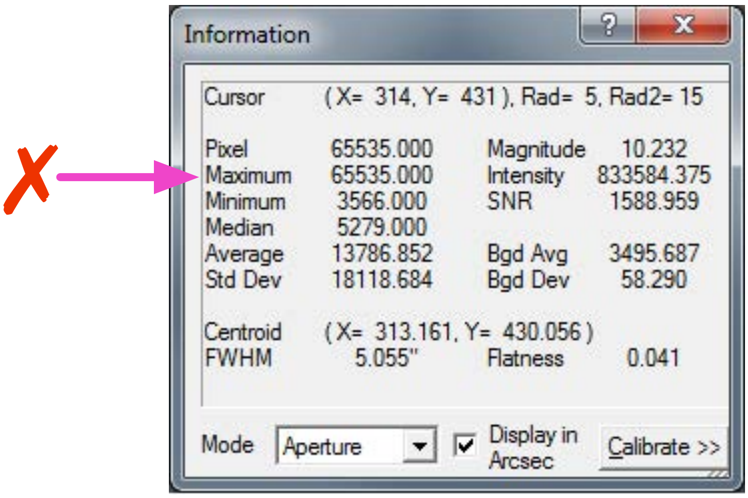


Figure 3-2: Saturated target star resulting from an exposure that is too long

But what if the star is too dim? If your target star has a very low maximum pixel value (less than 5000) then the photometric data may be unreliable due to excessive noise. Check the value for SNR (signal to noise). For *SPIRIT* a value lower than 30 should be avoided. If this is the case, close your image and open one with a longer exposure, e.g. 45 seconds.

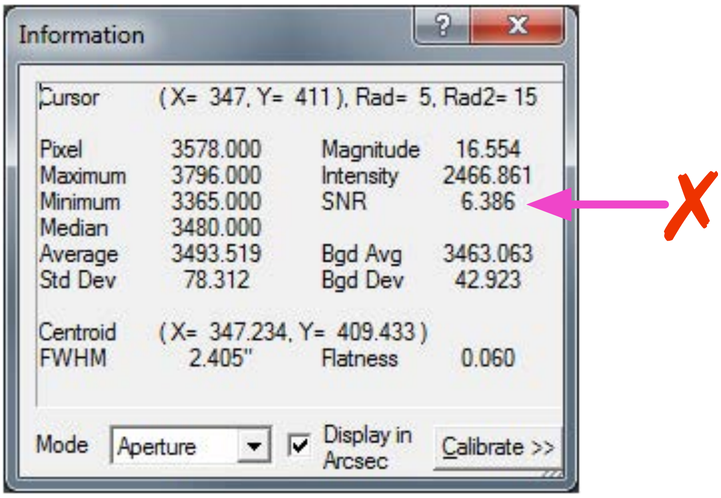


Figure 3-3: Low signal to noise ratio resulting from an exposure that is too short

Hint: Aim for a maximum pixel value of between 20,000 and 40,000 and a SNR greater than 100.

Having taken a variety of test images at different exposures, you will be able to determine the *best* exposure for your target when it comes time to collect light curve data with *SPIRIT.*

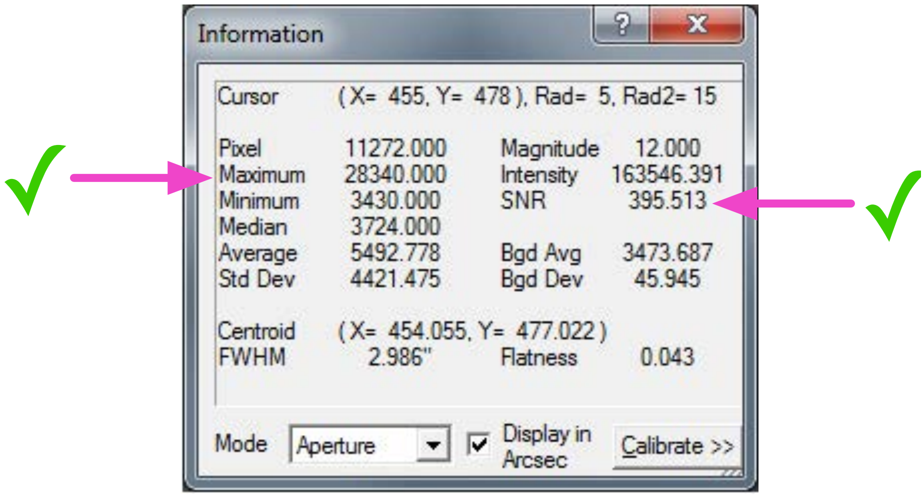


Figure 3-4: Unsaturated star showing good signal

Make a note of the 'best' exposure for each of the targets imaged for use in future data acquisition.

4 Activity: Light curve analysis of RR Lyrae variable stars

In this activity one or more RR Lyrae stars will be imaged over the course of many hours. The acquired data will be used to create light curves for the observed targets.

4.1 Prerequisites

This activity assumes familiarisation with the image processing and analysis software *MaxIM DL* as used in the *SPIRIT* activity *Using MaxIM DL to analyse stellar profiles*. Knowledge of advanced image acquisition techniques for time series work covered in section 2 is also assumed.

4.2 Workflow

1. Create a list of targets for which position and exposure details have been predetermined in the activity outlined in section 3.3.
2. Create an ACP plan that allows the list of targets to be imaged repeatedly over the course of one or more nights.
3. Acquire data on a night of good seeing.
4. Download and organise the calibrated FITS files by target name.
5. Undertake photometry using *MaxIM DL* on each of the targets and create light curves.
6. Output the data for further analysis and presentation in *Microsoft Excel* (optional).

4.3 Photometry and light curve creation using *MaxIM DL*.

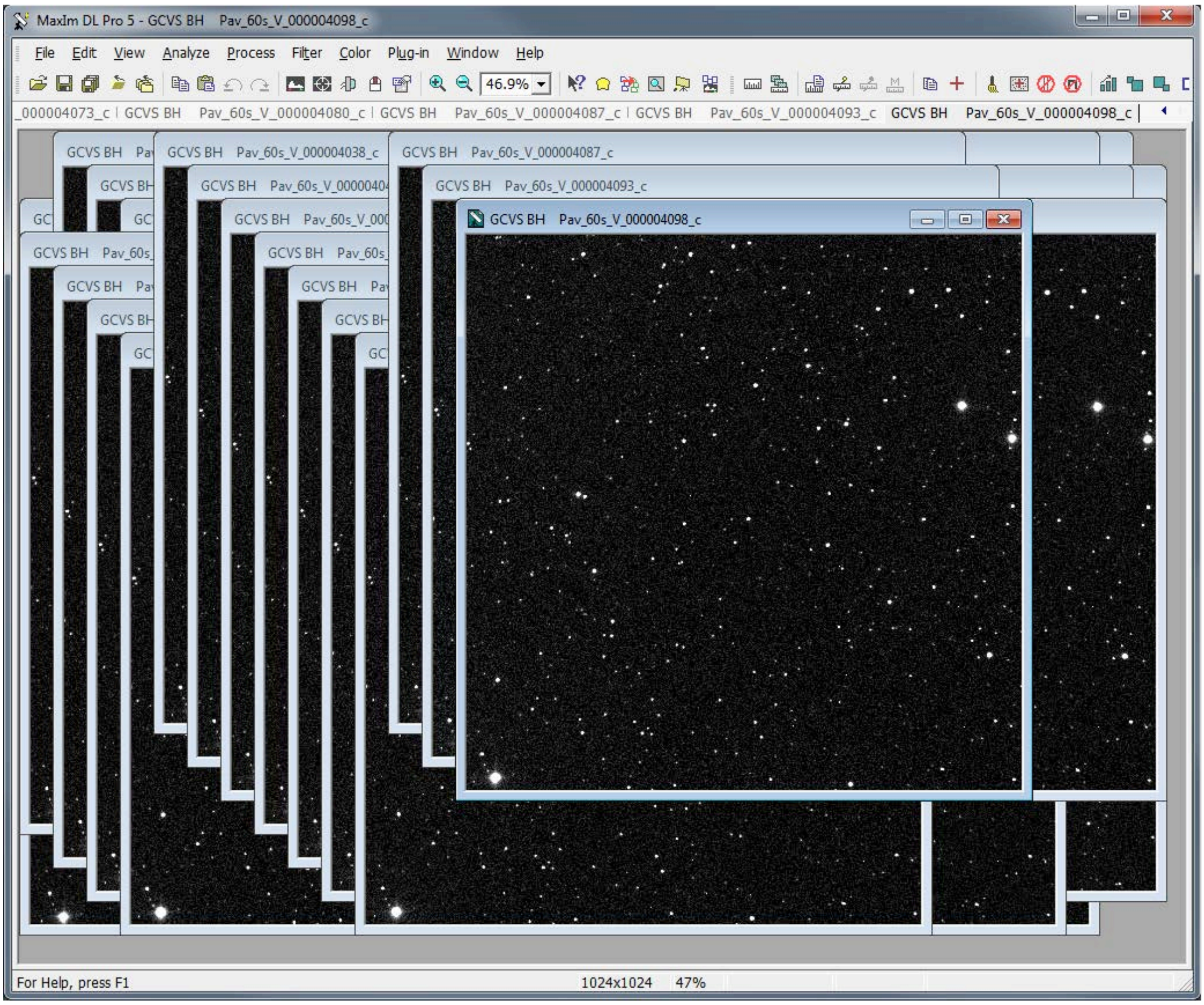
MaxIM DL includes a photometry analysis tool that streamlines processing large numbers of images of a target. It can be used effectively to generate and view the light curve of a variable star from dozens of images and includes the means to export raw data for use in other software.

4.3.1 Open your images

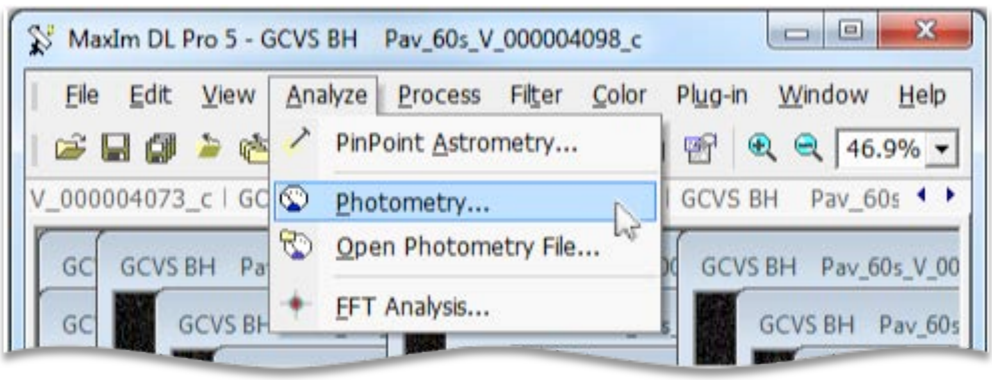
Your images should be in FITS format, and stored in a dedicated folder for each target.

Start *MaxIM DL* and use the **File / Open** command to open a set of images of a single target by selecting multiple files.[7]

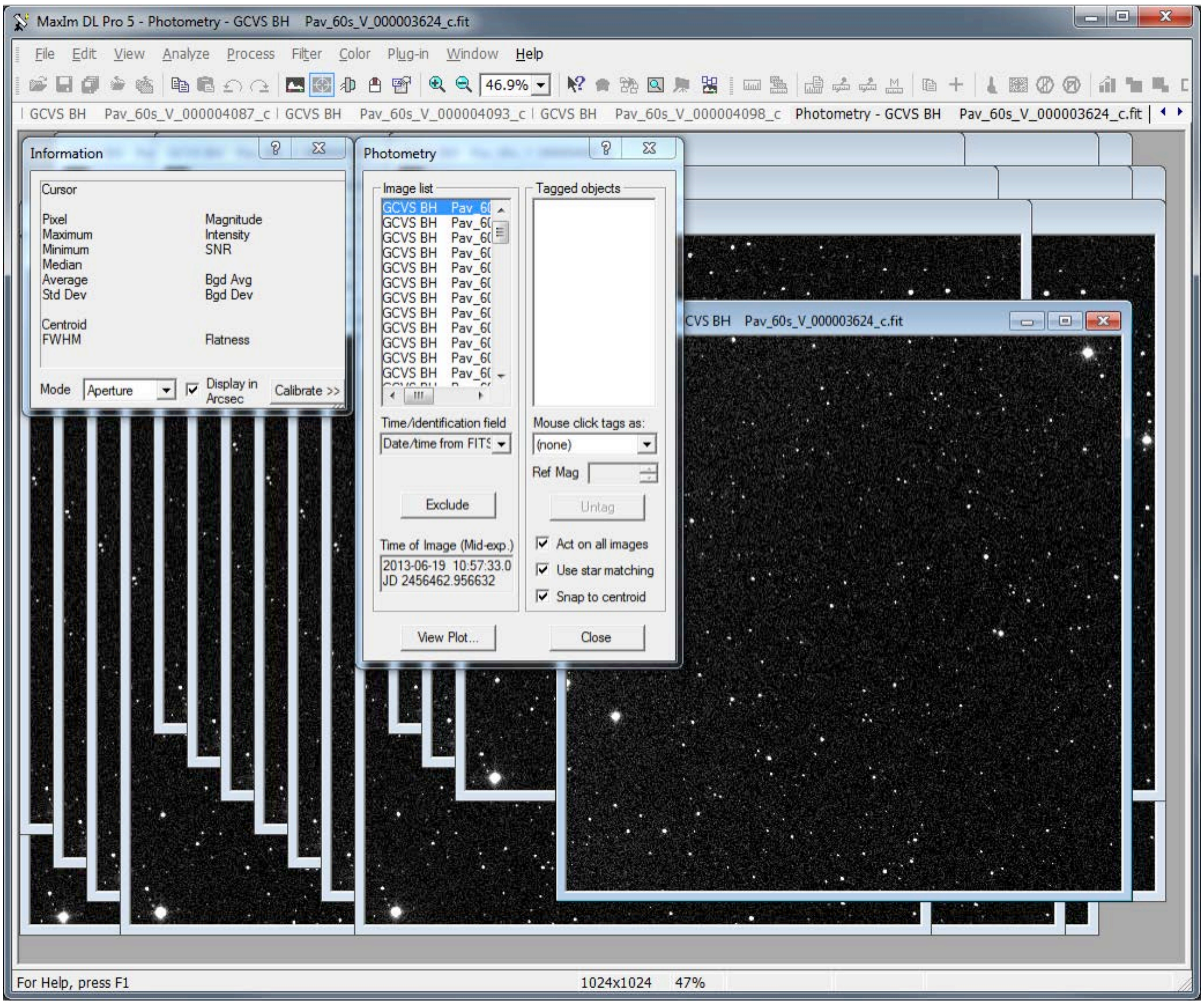
[7] Depending on CPU power and available memory, this may take some time. *MaxIM DL* may struggle to process a large number of images on an old computer or one with insufficient memory. If this is the case, process fewer images at a time and build up the light curve piece by piece.



Select **Photometry** from the **Analyze** menu



The Image Information and Photometry tools will appear on the screen.



4.3.2 Photometry in *MaxIM DL*

MaxIM DL's photometry tool provides the means for efficient examination of a large set of images, and the ability to specify and analyse a target of interest across that set. Fixed magnitude or 'reference stars' can be defined so that the light curve of a target of interest can be created.

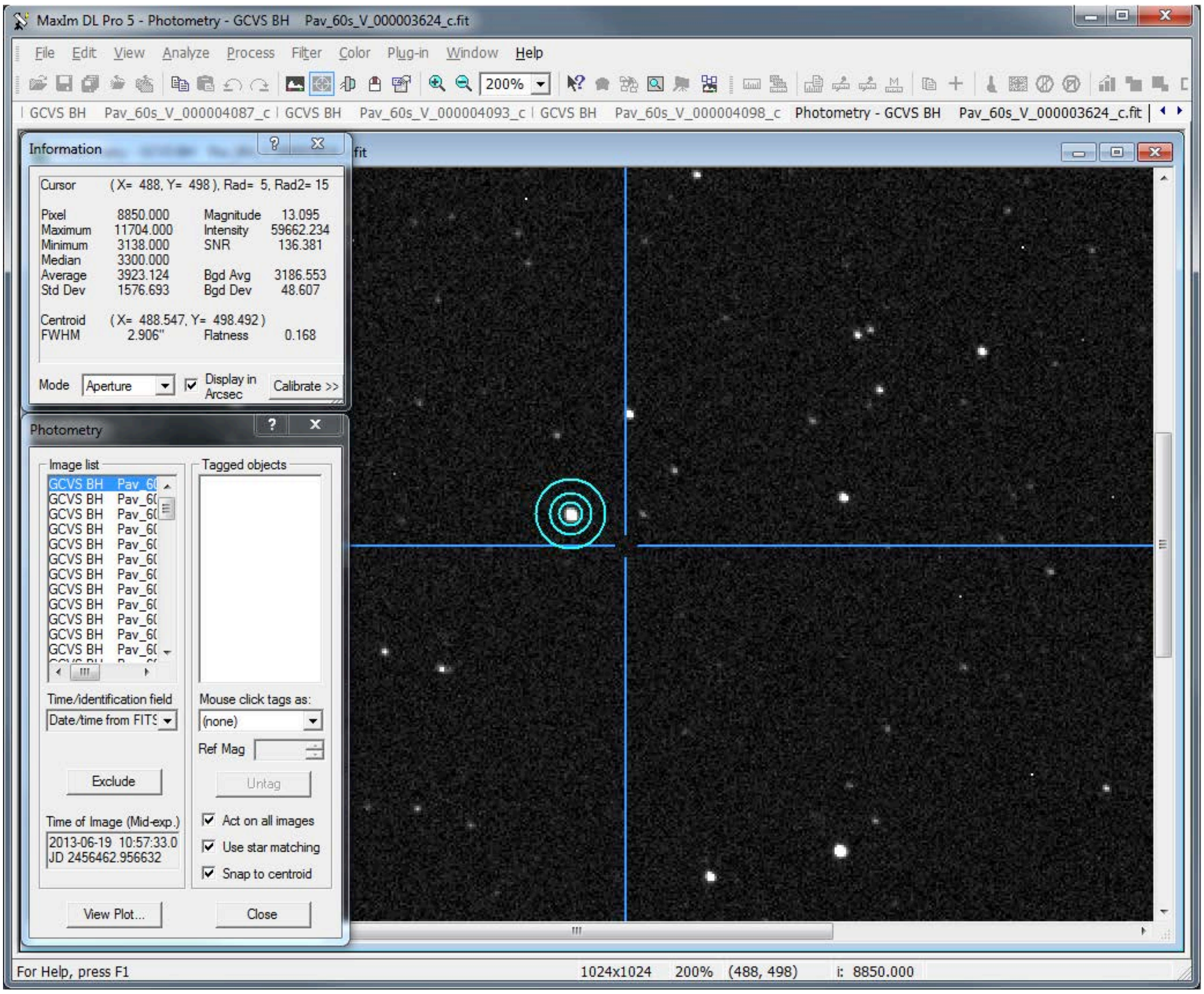
Images can be quickly examined, included and excluded by selecting them under **Image list**. The Image Information tool is also active and can be used to examine stellar profiles by positioning the mouse cursor over an object of interest (see section 3.3.).

4.3.3 Creating a light curve

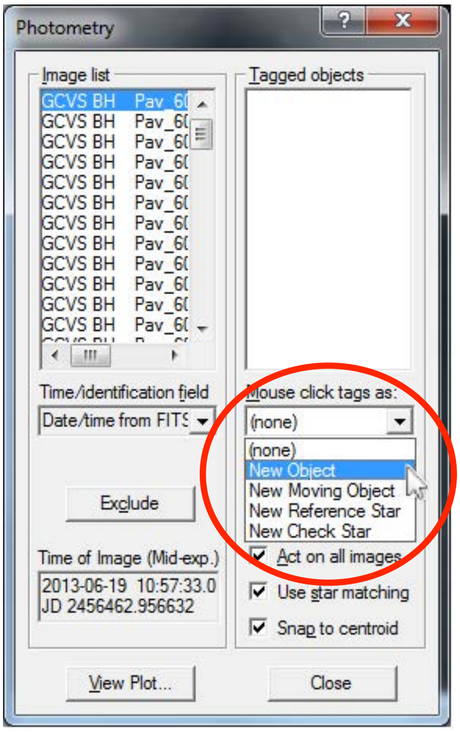
The creation of a basic light curve involves 4 steps.

1. Identify and define the target variable star.

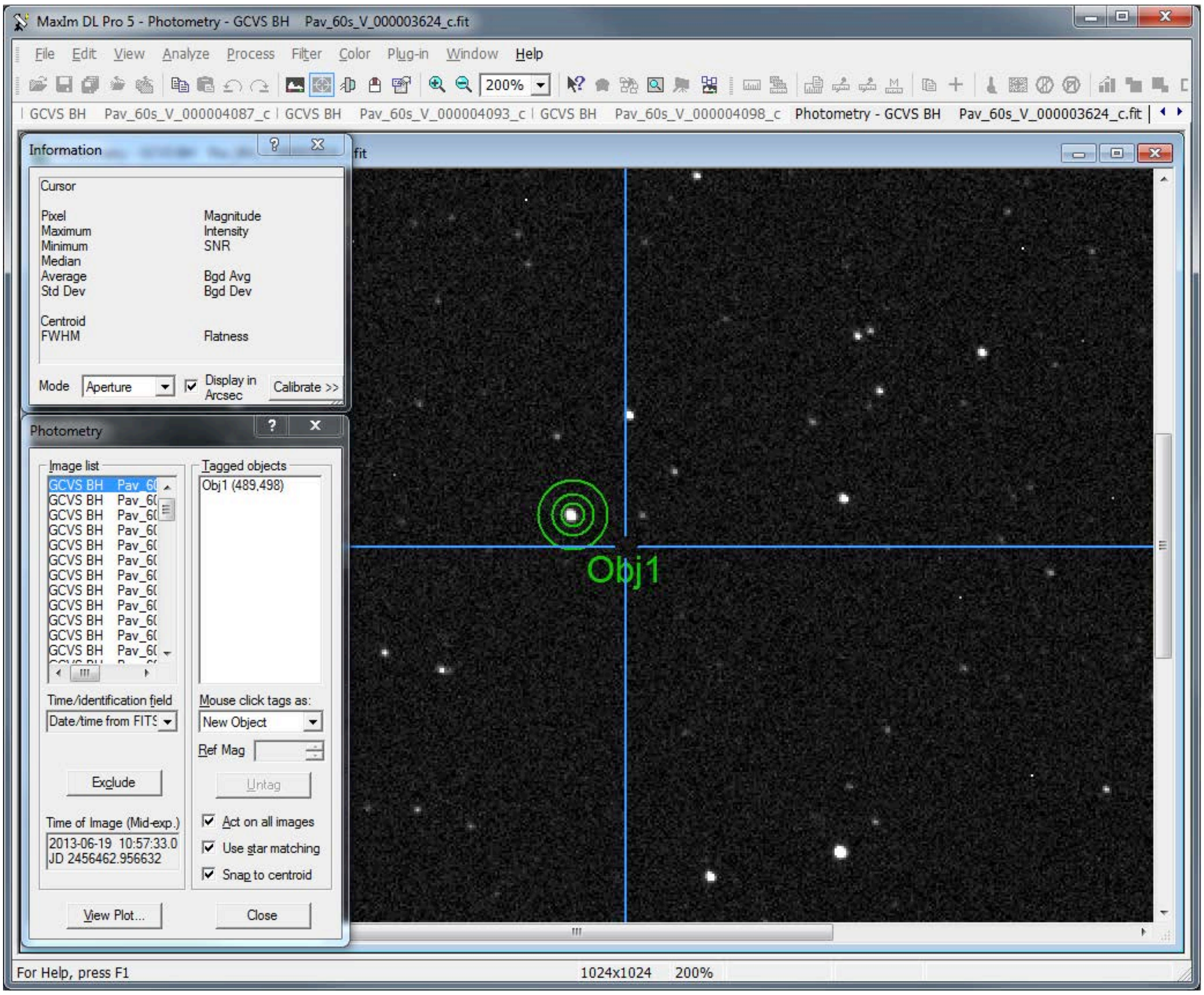
Zoom in and examine one of the open images. Use an appropriate method to accurately verify the target variable star (see section 3.2.1 for detailed information). Be sure that the photometry aperture completely encompasses the target, adjusting its size if necessary (see Figure 3-1).



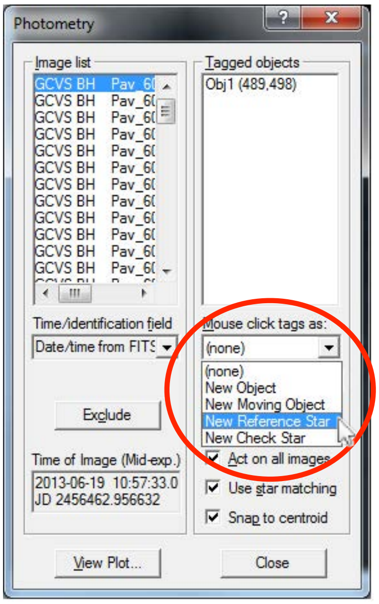
Select **New Object** from the target 'tags' drop down dialog in the photometry tool.



Position the aperture over the target variable star and select it. *MaxIM DL's* photometry routine will process all files, automatically finding the same star in each image. It will handle images that are not aligned, or that are rotated with respect to one another.[8] This can be verified by viewing other images in the image list once the process is complete.

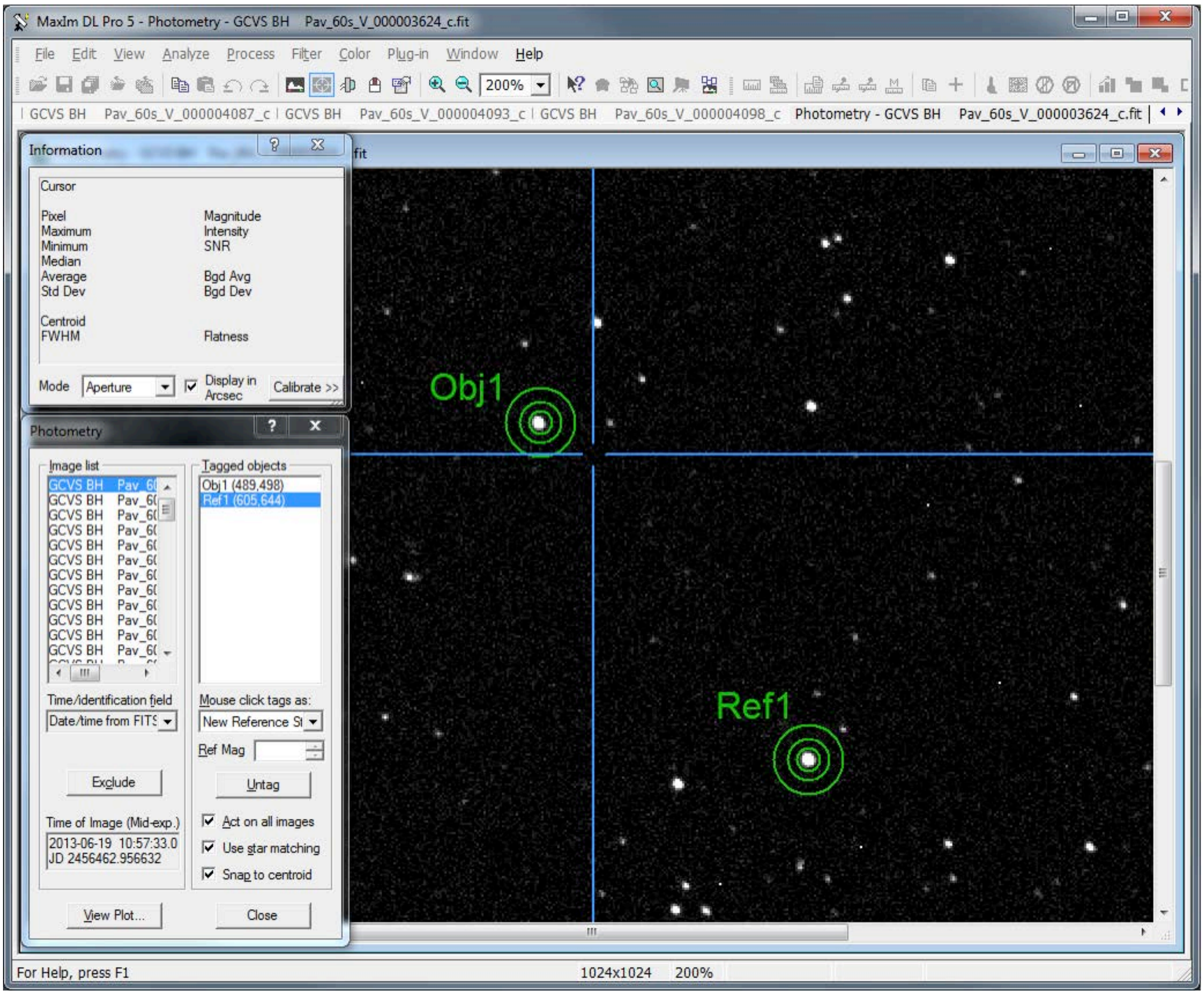


2. Select **New Reference Star** from the target 'tags' drop down dialog.

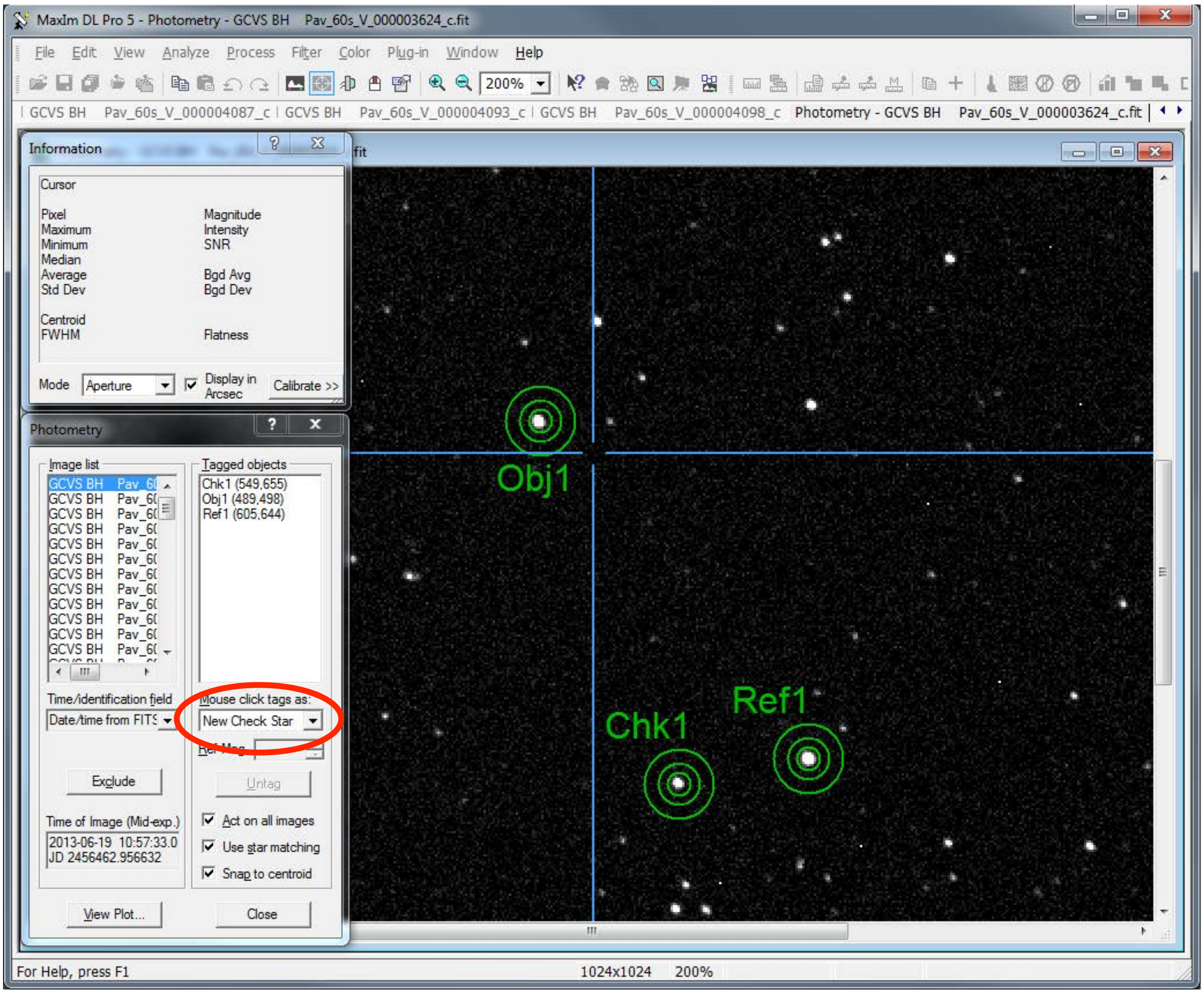


[8] This assumes that the images have been 'plate solved' which is always the case with *SPIRIT* images. Under rare circumstances it may be necessary to rotate some images manually if the photometry routine fails.

Centre the aperture over a star similar in brightness to the target variable star and preferably in the same region. The star should not be saturated, and have good SNR (see section 3.3.1). Once selected, *MaxIM DL* will automatically identify the same reference star in all images.



3. Repeat the process this time selecting **New Check Star** as the tag type. Check stars are used by the software to ensure that the reference star itself is not variable.



At the end of step 3, you should have defined and selected your variable star (Obj1) a reference star (Ref1) and a check star (Chk1). It's now time to create the light curve.

4. Select **View Plot** on the Photometry tool. This will produce a time-series plot of the three objects. The variable star's light curve should be very obvious. If it isn't you may need to check that you have chosen the correct target. Selecting a different reference star may also be necessary if the reference and check stars deviate from the horizontal in an extreme way.

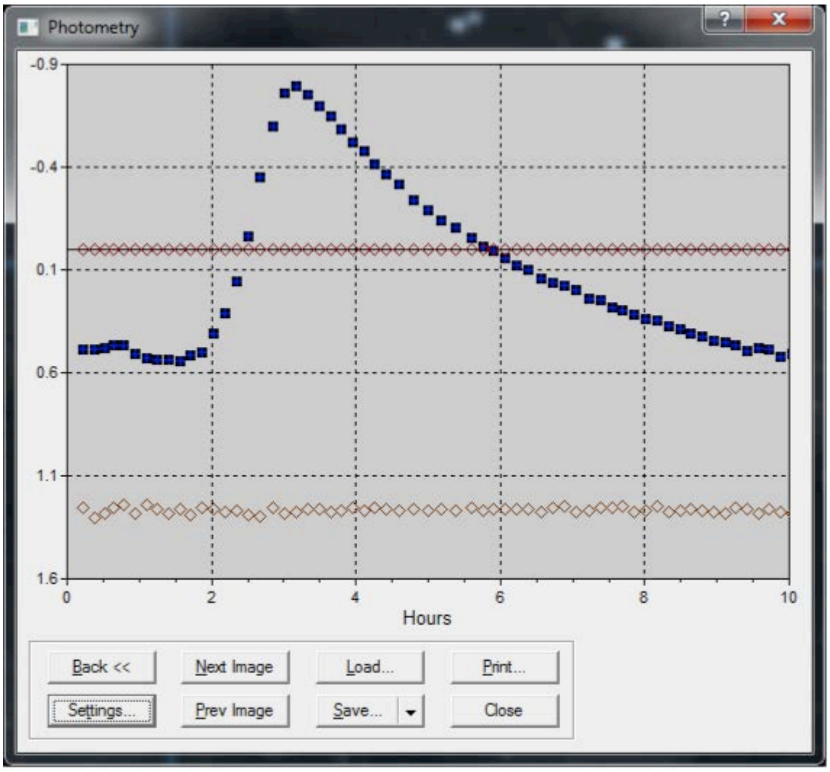


Figure 4-1: Light curve of variable star BH Pav

The graph above shows the magnitudes[9] (vertical axis) of all three objects; Obj1, Ref1 and Chk1 over the duration of imaging – in this case some 10 hours (the horizontal axis). The reference and check stars show constant magnitudes over this time frame. By comparison, the variable star shows a sudden rise in magnitude early in the plot, followed by a gradual decrease in magnitude over the following 7 hours. Another interesting feature is the 'shock bump' near minimum – a characteristic of this type of RR Lyrae star. This pattern will repeat with a constant 'period' of approximately 11 hours.

Congratulations! You have just created your first light curve. Select **Settings** to change the appearance of the plot. The data can also be saved as a CSV file for use in applications such as *Microsoft Excel*.

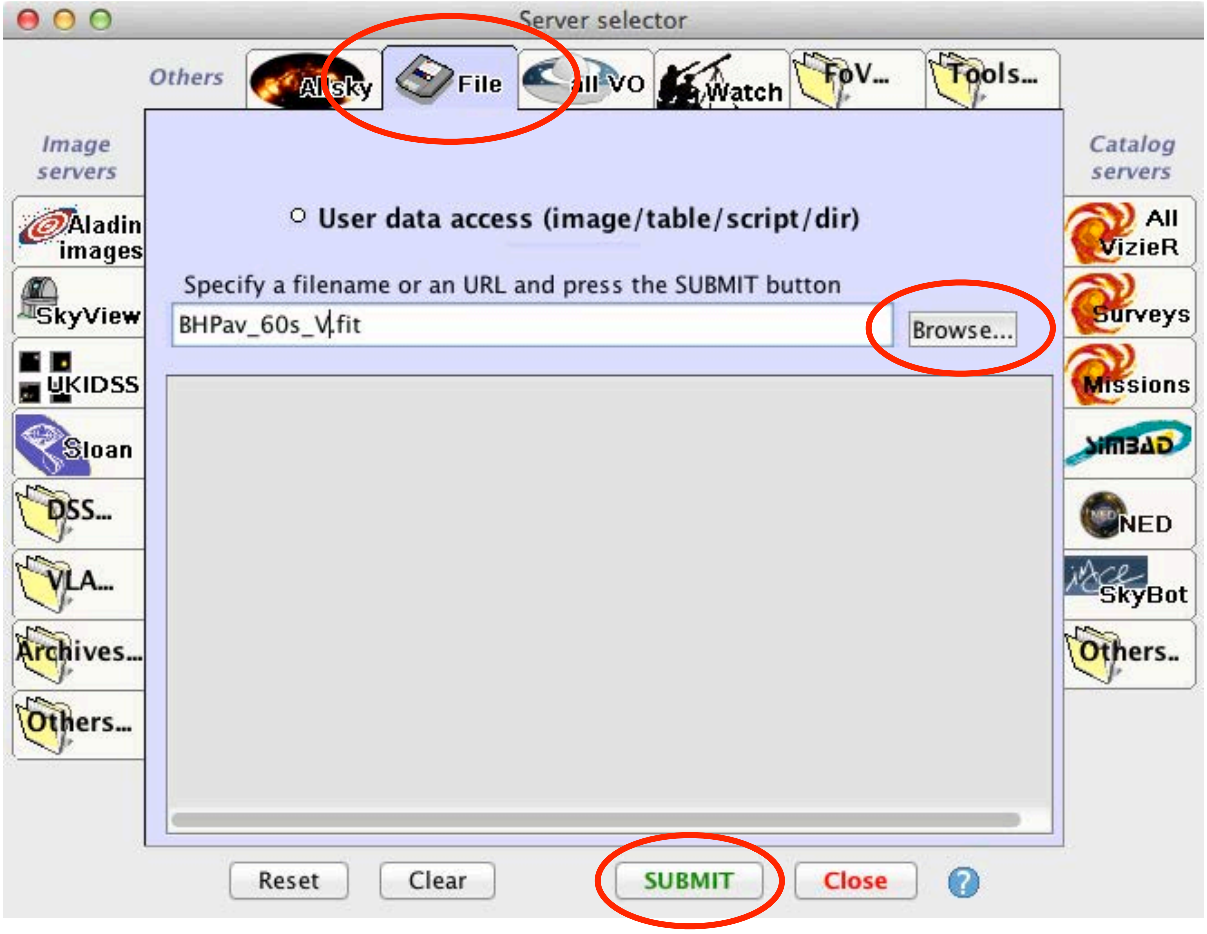
[9] The magnitude value is arbitrary in differential photometry and does not represent the actual or 'absolute' magnitude of the star. A description of the transformations required to place the magnitude measurements on a standard scale is beyond the scope of this activity.

Appendix A: Using *Aladin* to verify a target variable star

Aladin[10] is a free interactive sky atlas that uses professional on-line astronomical data sources. It can be used to quickly verify the target star in your field.

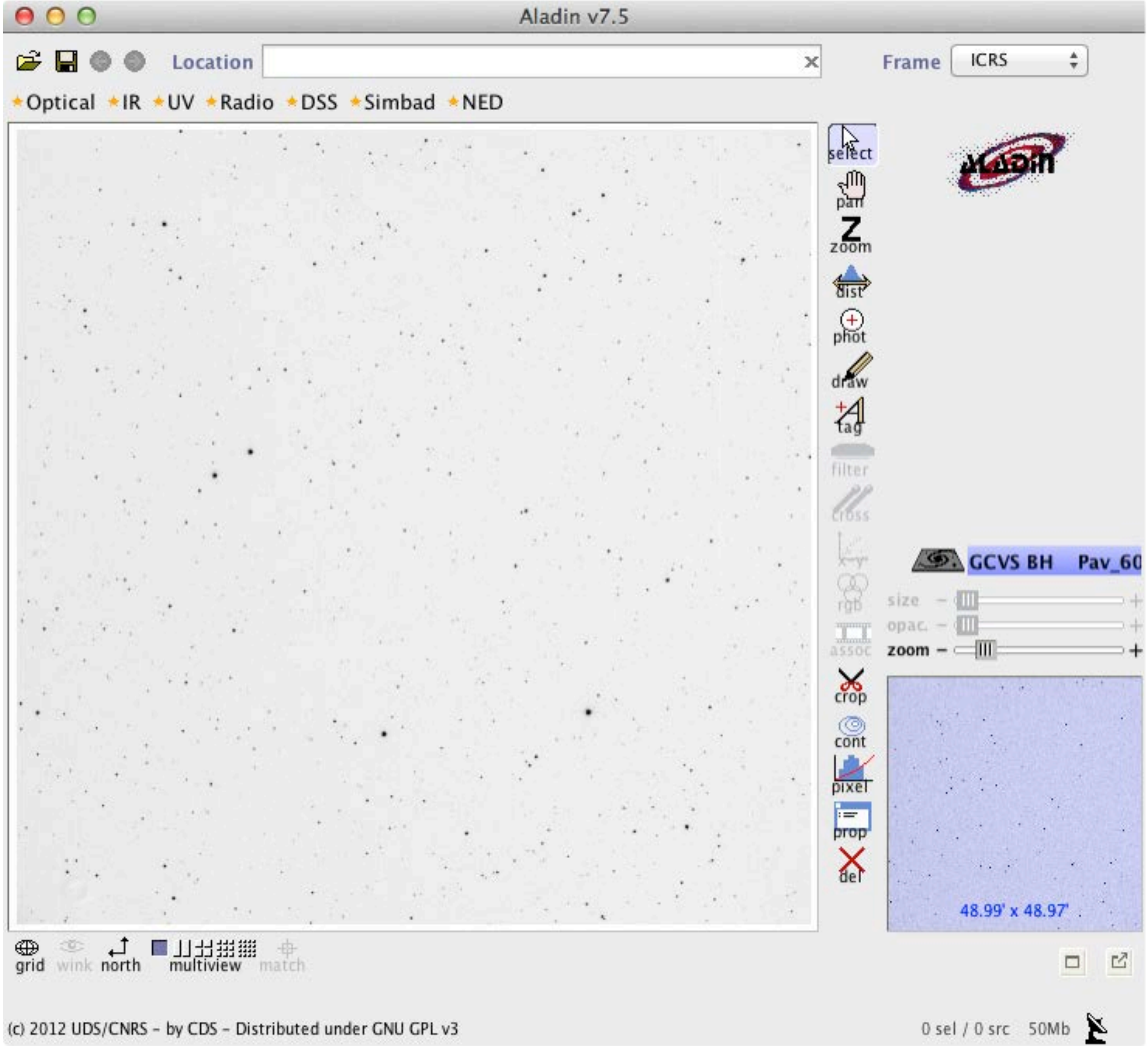
Start *Aladin*, and select **File / Open.**

Select the **File** tab, navigate to your FITS image and then select **SUBMIT.**

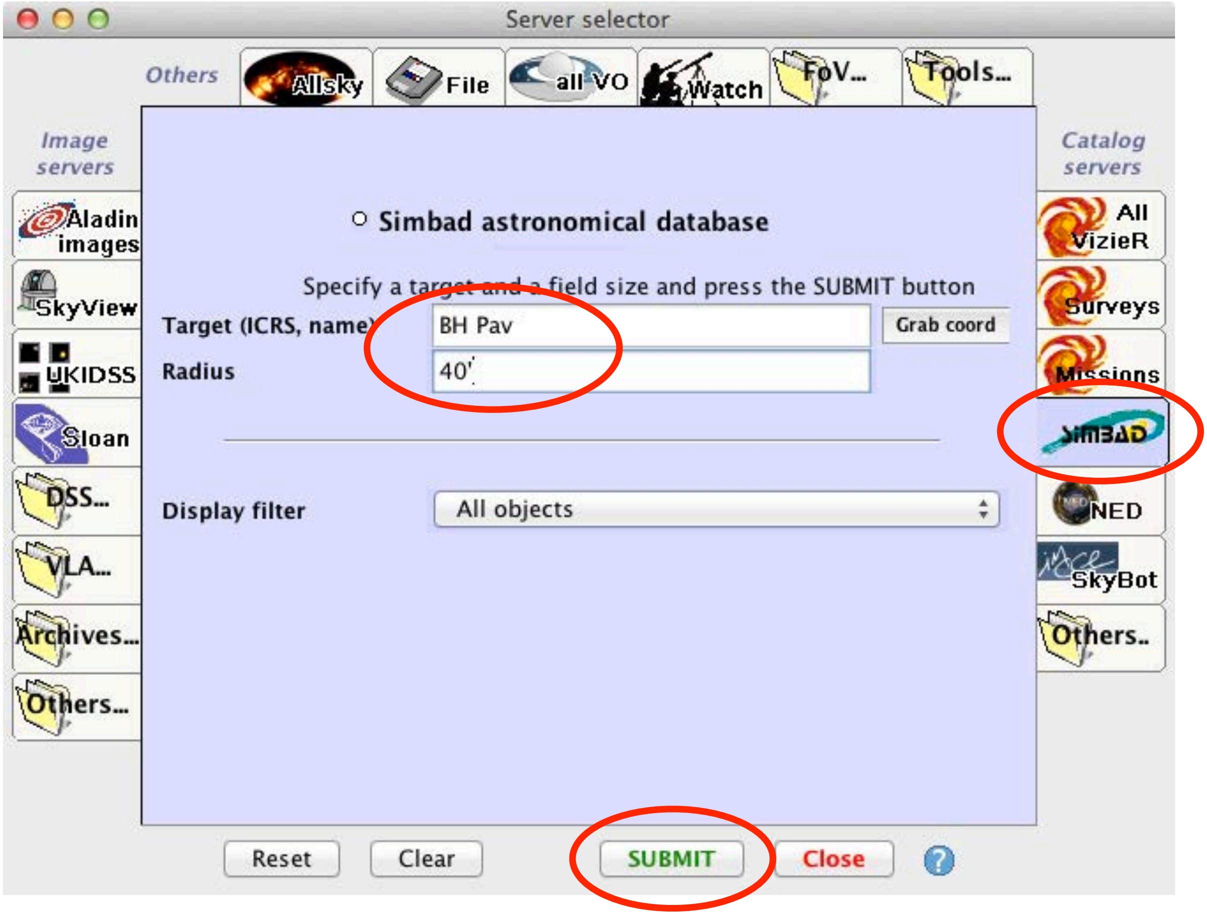


[10] Available for download from http://aladin.u-strasbg.fr/

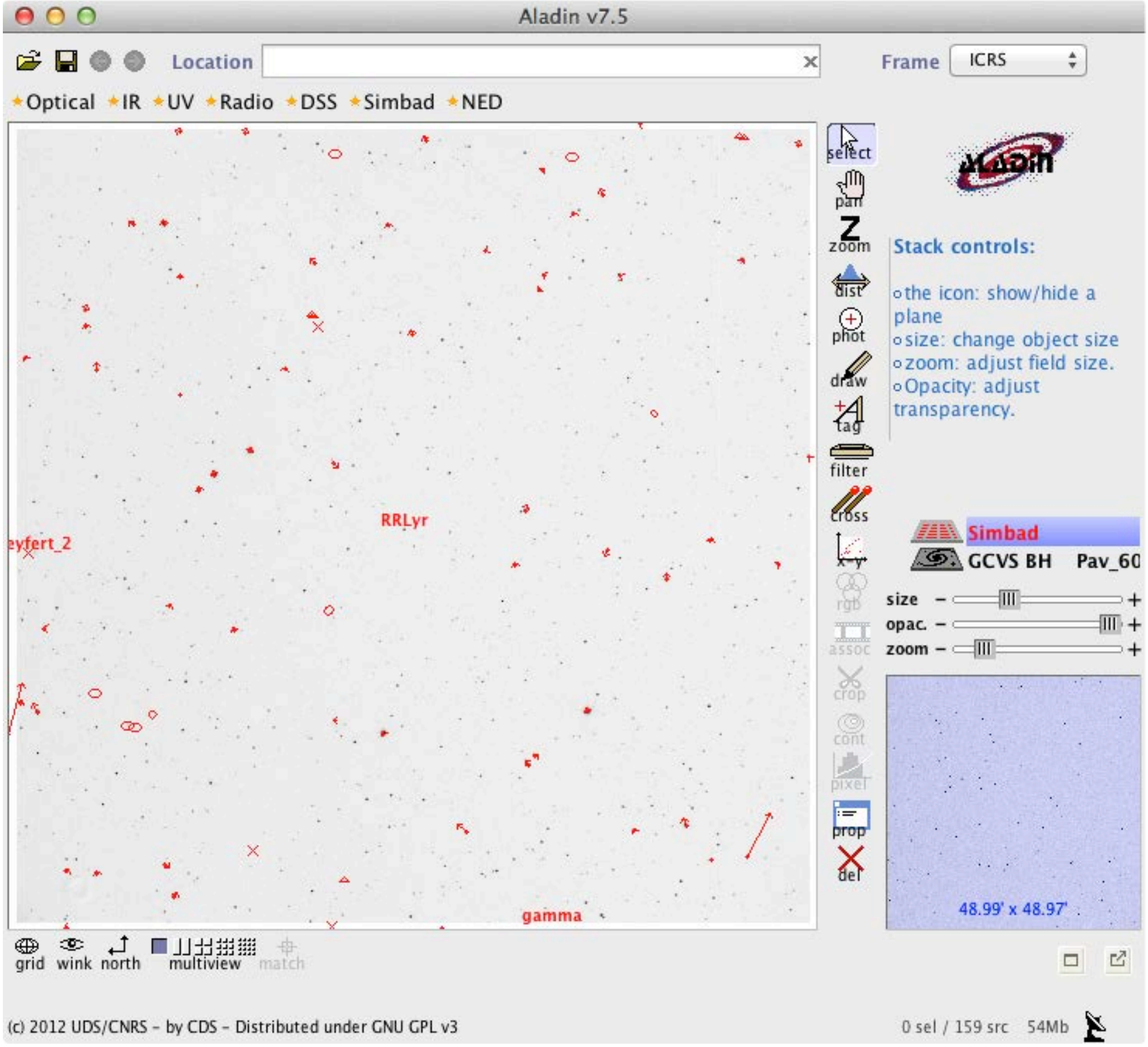
Take a moment to inspect your image. The **zoom** tool can be used to zoom in on the centre of the image.



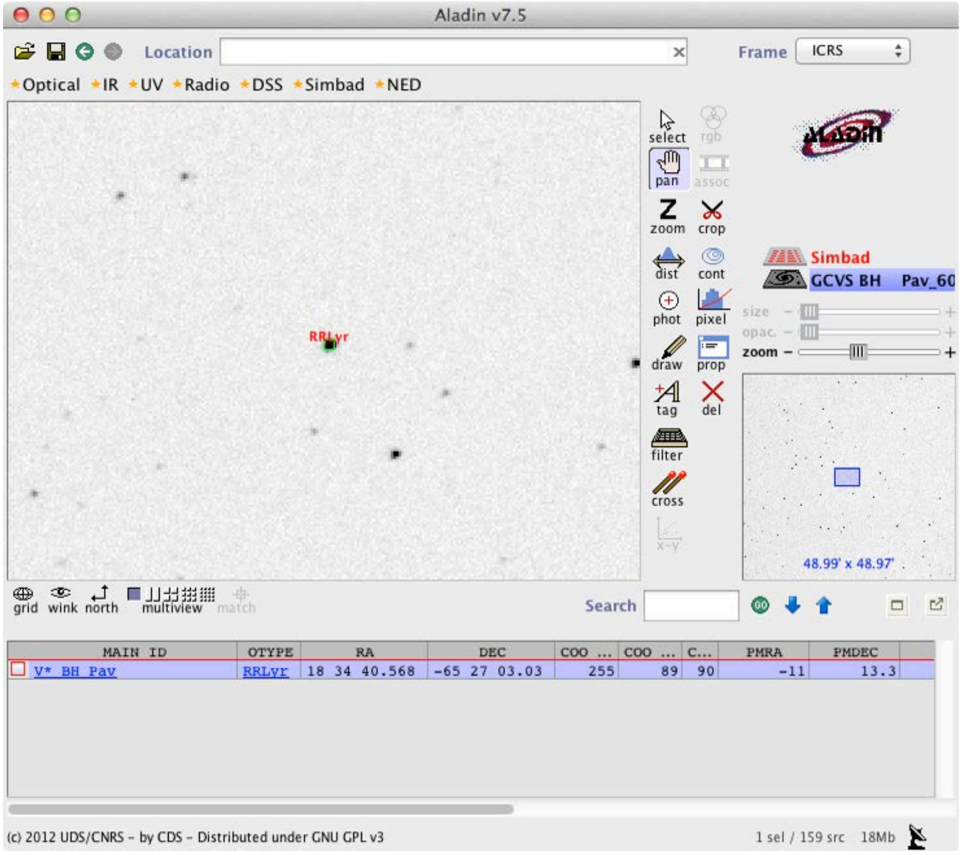
Select **File / Open** again. This time, choose the **SIMBAD** tab from the options available below 'catalog servers'. Type the name of your target and a radius that corresponds roughly to the field of view of your image. Select **SUBMIT.**

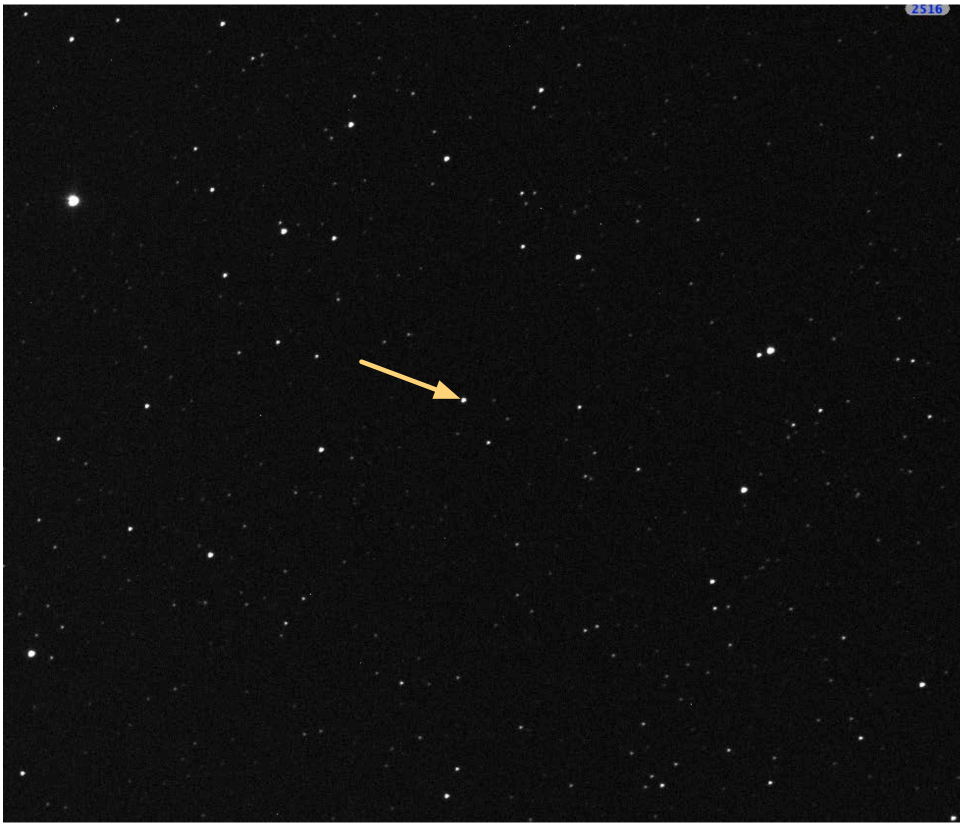


Aladin will display an overlay of objects that will allow you to determine with certainty which of the stars near centre is the target variable star.



Zoom in and verify the target by selecting it. Then refer back to your open image in *MaxIM DL* and check that you can identify the same star.





The orientation of your image with that of a finder chart or reference image may differ. MaxIM DL includes tools available under the **Edit** menu that allow your image to be rotated, or you can rotate the finder chart or image in *Aladin* to match the view in *MaxIM DL*.

Appendix B: ACP Plan templates

The templates on the following pages provide examples of ACP plans that can be modified to automate the acquisition of data for variable star light curve work.

Specifications for exposure and filter are the same for each plan.

The timing and repeat directives differ, providing some options for the frequency of image acquisition, and the duration of the run.

The list of targets is specified last in all cases, and can be exchanged for a different list of targets to suit.

RR Lyrae variable stars cannot be specified by name using the *SPIRIT* interface. Celestial coordinates for each star must be manually specified in the plan using tab delimited field spacing following the convention *object <tab> RA <tab> Dec*. The name can be anything useful, and can include spaces. Coordinates should be J2000.

New plans should be checked using *SPIRIT's* plan checker, and monitored or tested before a run is left unattended.

Plan Template 1: Repeating targets.

This basic plan will take two images of each target in succession and then repeat 25 times. It is important to calculate the approximate time that each set will take, so that you can maximise the amount of data acquired during your booking. As such, this plan does not suit lists of two or three targets, where the time between sets may not be sufficient to show a measurable change in magnitude.

The plan below contains 7 targets that are imaged twice per set, using 60 second exposures. This adds up to 14 minutes of imaging time, but if we allow for image download and for the telescope to slew between targets, this gives a total imaging time somewhere around 20 - 25 minutes per set. Total imaging time is just over 8 hours. Each target will have 25 data points, which may or may not be sufficient to create a complete light curve.

```
; RR Lyrae Plan 1
; Paul Luckas
; 14th June, 2013
; SPIRIT I
;
; The first section sets up the default image parameters
;
#INTERVAL 60		; exposure of 60 seconds
#FILTER V		; using the photometric V filter
#COUNT 2		; two images of each target per set
#SETS 25		; repeated 25 times
;
; The next section specifies the targets, using tab delimited field spacing between name, RA and Dec
;
V0487 Sco	17 35 05.83	-34 23 45.0
V0494 Sco	17 40 48.48	-31 32 31.8
WY   Pav	17 56 12.37	-57 09 43.4
V0690 Sco	17 57 38.65	-40 33 27.2
HX    Ara	17 58 44.91	-55 16 24.0
MS    Ara	18 03 04.29	-52 43 20.6
BH    Pav	18 34 40.57	-65 27 03.0
;
; End of Plan
```

Plan Template 2: Repeating targets at set intervals.

This plan assumes that the total imaging time for each set is less than the interval between sets. There are 7 targets for which 2 exposures of 60 seconds will be acquired for each target within each set. The interval between each set is 30 minutes, so there should be plenty of time for each set to finish before the next is scheduled to start.

This plan, destined for *SPIRIT II* also contains some other useful features:

- Binning has been set to 2 from the default bin mode 3. This provides a pixel scale more suitable for photometry when using *SPIRIT II.*
- A subframe has been specified to reduce the large field of view of *SPIRIT II*, making it more suitable for single star photometry. File size is reduced, as is the burden on CPU when it comes time to process a large number of images.

```
; RR Lyrae Plan 2
; Paul Luckas
; 15th June, 2013
; SPIRIT II
;
#INTERVAL 60                ; 60 second exposures of each
#COUNT 2                    ; Take 2 images of each target at a time
#FILTER V                   ; Using the the photometric V filter
#BINNING 2                  ; Sets the binning mode to bin 2
#SUBFRAME 0.5                       ; Reduces the field of SPIRIT II to half
#SETS 16                    ; Repeated 16 times over the course of the night
#WAITUNTIL 1, 12:30                 ; First set starts at 1230 UT
#WAITUNTIL 2, 13:00         ; Second set starts 30 min later
#WAITUNTIL 3, 13:30                 ; Next set starts 30 min after that
#WAITUNTIL 4, 14:00         ; etc
#WAITUNTIL 5, 14:30
#WAITUNTIL 6, 15:00
#WAITUNTIL 7, 15:30
#WAITUNTIL 8, 16:00
#WAITUNTIL 9, 16:30
#WAITUNTIL 10, 17:00
#WAITUNTIL 11, 17:30
#WAITUNTIL 12, 18:00
#WAITUNTIL 13, 18:30
#WAITUNTIL 14, 19:00
#WAITUNTIL 15, 19:30
#WAITUNTIL 16, 20:00
;
V0487 Sco   17 35 05.83   -34 23 45.0
V0494 Sco   17 40 48.48   -31 32 31.8
WY    Pav   17 56 12.37   -57 09 43.4
V0690 Sco   17 57 38.65   -40 33 27.2
HX    Ara   17 58 44.91   -55 16 24.0
MS    Ara   18 03 04.29   -52 43 20.6
BH    Pav   18 34 40.57   -65 27 03.0
;
; End of Plan
```

Appendix C: List of southern RR Lyrae targets for use with *SPIRIT*

The following provides a list of RR Lyrae stars well suited for *SPIRIT*. The list is ordered by RA, and includes targets optimally positioned in the southern sky.

NAME	RA	DEC
UU Cet	00 04 05.1	-16 59 52
AO Tuc	00 04 06.3	-59 29 06
RY Psc	00 11 41.1	-01 44 55
UY Scl	00 14 45.8	-39 14 36
RX Cet	00 33 38.3	-15 29 15
FX Cet	00 45 06.1	-18 54 15
AE Tuc	00 50 00.6	-62 38 08
W Tuc	00 58 09.7	-63 23 44
RU Cet	01 00 40.3	-15 57 28
AE Scl	01 07 25.8	-32 18 35
CS Phe	01 09 49.5	-44 18 53
VW Scl	01 18 15.0	-39 12 45
AM Tuc	01 18 30.6	-67 55 05
RV Scl	01 19 42.6	-26 51 55
VX Scl	01 35 23.7	-35 07 43
SV Scl	01 44 59.7	-30 03 33
RV Cet	02 15 14.9	-10 48 01
RZ Cet	02 28 32.4	-08 21 30
BB Hyi	02 33 18.8	-73 36 43
SW For	03 01 08.7	-38 07 43
RX For	03 11 13.2	-26 28 59
X Ret	03 25 20.1	-65 03 19
SX For	03 30 22.3	-36 03 14
U Pic	04 50 06.6	-50 39 25
U Cae	04 53 14.4	-37 49 16
BB Eri	04 53 37.5	-19 26 01
XX Dor	04 59 13.6	-69 35 43
SU Col	05 07 47.0	-33 51 54
V0964 Ori	05 07 54.5	-02 08 49
RY Col	05 15 07.8	-41 37 42
AO Lep	05 24 14.6	-14 06 03
RT Dor	05 29 44.7	-64 17 13
AV Col	05 56 50.6	-27 40 02
RW Col	06 03 38.6	-31 35 25
VW Dor	06 07 45.7	-66 58 39
RX Col	06 13 14.7	-37 15 01
IU Car	06 53 07.5	-59 35 44
HH Pup	07 20 35.6	-46 42 30
OP Pup	07 39 21.5	-17 20 49
HK Pup	07 44 46.8	-13 05 56

NAME	RA	DEC
V0895 Mon	07 50 21.4	-01 14 31
KZ Pup	07 52 36.5	-17 23 01
AN Vel	08 06 09.9	-43 39 53
XX Pup	08 08 28.2	-16 32 00
IU Pup	08 14 30.7	-41 38 57
BB Pup	08 24 22.6	-19 32 31
ET Hya	08 35 04.2	-08 50 10
SV Vol	08 48 32.6	-71 39 15
DG Hya	08 58 06.3	-05 26 26
DH Hya	09 00 14.8	-09 46 44
XX Hya	09 09 49.5	-15 35 59
SZ Hya	09 13 48.8	-09 19 09
IV Hya	09 22 20.6	-13 38 49
BK Ant	09 44 14.8	-39 39 41
CD Vel	09 44 38.2	-45 52 37
BN Ant	09 57 06.0	-39 17 26
WZ Hya	10 13 24.1	-13 08 17
WY Ant	10 16 04.9	-29 43 42
BT Ant	10 32 02.6	-30 10 37
FS Vel	10 46 00.3	-43 59 17
RV Sex	10 46 41.8	-08 22 33
AF Vel	10 53 02.5	-49 54 23
TV Leo	11 11 21.9	-05 53 31
BI Hya	11 11 48.2	-32 22 54
V0590 Cen	11 12 25.2	-36 52 46
W Crt	11 26 29.6	-17 54 52
SS Leo	11 33 54.5	-00 02 00
BI Cen	11 45 54.6	-59 22 40
X Crt	11 48 56.2	-10 26 29
V0753 Cen	11 51 15.3	-55 48 16
DT Hya	11 54 00.2	-31 15 40
SW Cru	11 59 06.4	-60 18 19
EM Mus	12 35 55.5	-72 53 00
AS Vir	12 52 45.9	-10 15 36
AT Vir	12 55 10.5	-05 27 32
AM Vir	13 23 33.3	-16 39 58
AU Vir	13 24 48.0	-06 58 45
FX Hya	13 27 58.9	-27 05 52
WW Vir	13 28 23.9	-05 17 09
V0671 Cen	13 40 09.7	-37 26 28

NAME	RA	DEC
RV Oct	13 46 31.8	-84 24 06
FY Hya	13 53 35.4	-29 34 49
V0499 Cen	13 55 14.8	-43 14 25
V0674 Cen	14 03 24.1	-36 24 20
CW Lup	14 20 23.0	-44 31 59
ST Vir	14 27 39.1	-00 54 06
Y Oct	14 29 04.4	-88 38 44
DO Vir	14 38 46.0	-05 19 31
TY Aps	14 48 50.0	-71 19 42
XZ Aps	14 52 05.4	-79 40 47
XX Lib	15 07 10.0	-25 59 52
YZ Aps	15 10 00.8	-78 23 03
V0372 Ser	15 17 35.0	-01 05 17
TV Lib	15 18 21.8	-08 27 43
AZ Lib	15 20 38.4	-22 17 29
AP Lup	15 21 45.2	-48 45 37
LQ Lib	15 26 01.1	-15 32 46
CG Lib	15 35 16.8	-24 20 13
VY Lib	15 51 17.0	-15 45 03
PQ Lup	15 55 53.2	-40 41 44
VX Aps	15 59 56.3	-75 13 20
BS Aps	16 20 51.5	-71 40 16
V0445 Oph	16 24 41.2	-06 32 30
V0413 Oph	16 25 11.0	-10 31 26
V0680 Ara	16 43 07.6	-61 05 42
RW TrA	17 00 46.7	-66 39 50
ST Oph	17 33 59.4	-01 04 51
V0487 Sco	17 35 05.8	-34 23 45
V0494 Sco	17 40 48.5	-31 32 32
V0756 Sgr	17 48 48.9	-21 52 52
EX Aps	17 51 45.0	-69 20 05
WY Pav	17 56 12.4	-57 09 43
V0690 Sco	17 57 38.6	-40 33 27
HX Ara	17 58 44.9	-55 16 24
MS Ara	18 03 04.3	-52 43 21
V0592 CrA	18 26 20.8	-44 59 50
BH Pav	18 34 40.6	-65 27 03
V3859 Sgr	18 38 32.2	-27 42 05
V0413 CrA	18 47 57.6	-37 44 23
AF Sct	18 48 26.7	-13 57 48
V1130 Sgr	19 20 32.5	-20 32 20
HH Tel	19 33 20.3	-45 39 49
GZ Tel	19 36 46.1	-50 47 40
HN Tel	19 37 04.1	-52 58 19

NAME	RA	DEC
BN Pav	19 38 03.4	-60 36 40
V0796 Sgr	19 46 39.9	-40 27 23
V1356 Aql	19 46 58.9	-02 04 34
FO Pav	19 51 42.2	-62 44 08
DN Pav	19 52 10.9	-63 40 25
V4424 Sgr	19 54 01.9	-30 15 10
SW Pav	19 57 25.7	-66 46 48
BP Pav	19 58 00.2	-65 44 10
V2232 Sgr	20 07 27.3	-43 49 10
HY Tel	20 08 13.5	-55 14 02
V1644 Sgr	20 09 14.9	-29 33 22
V1645 Sgr	20 20 44.5	-41 07 06
V1646 Sgr	20 23 08.8	-31 17 42
V2279 Sgr	20 27 03.4	-40 40 14
CH Aql	20 33 42.2	-05 38 49
IV Pav	20 34 44.9	-72 36 55
AA Aql	20 38 15.1	-02 53 25
VX Ind	20 41 51.4	-47 06 43
BT Aqr	20 57 48.3	-05 41 07
RV Cap	21 01 28.9	-15 13 46
CP Aqr	21 10 12.9	-01 43 16
Z Mic	21 16 22.7	-30 17 03
YZ Cap	21 19 32.4	-15 07 01
SS Gru	21 28 06.3	-37 09 35
Z Gru	21 34 37.1	-49 07 29
RY Oct	21 36 09.4	-77 18 14
YZ PsA	21 42 06.2	-25 28 29
SS Oct	21 53 35.4	-82 46 44
TZ Aqr	22 01 55.5	-05 36 03
BV Aqr	22 02 54.0	-21 31 32
YZ Aqr	22 14 30.5	-10 55 47
GP Aqr	22 25 39.1	-07 56 28
BN Aqr	22 27 48.7	-07 29 02
HH Aqr	22 41 31.5	-06 28 39
RW Gru	22 42 07.0	-44 09 12
XZ Gru	22 47 34.7	-39 03 33
BO Aqr	22 54 08.3	-12 21 38
YY Tuc	23 11 00.6	-58 20 07
DN Aqr	23 19 17.2	-24 12 59
UZ Scl	23 22 47.0	-30 07 10
RV Phe	23 28 31.5	-47 27 13
BR Aqr	23 38 32.9	-09 19 07

Appendix D: Contributing and sharing photometric data

The photometric measurement and monitoring of variable stars, including RR Lyrae stars, is an important on-going endeavour. Amateur astronomers represent a dominant group in both data collection and analysis, and their work is well regarded by professional astronomers.

A number of organisations exist that allow amateur astronomers to participate in scientifically useful variable star projects. The most famous of the ‘pro-am’ initiatives is the American Association of Variable Star Observers (AAVSO). AAVSO provides the ‘clearing house’ for variable star observations as well as a comprehensive set of on-line resources for both amateur and professional astronomers.

More information can be found at the following link:

http://www.aavso.org/

Southern hemisphere observers are well represented by the Variable Stars South (VSS) organisation.

Further information on VSS can be found at the following link:

http://www.variablestarssouth.org/