# Monitoring variable stars observed by INTEGRAL-OMC

The following material was developed to support the *Observe variable stars with your own telescope* project which forms part of ESA's *Explore the high-energy Universe* competition.

Introduction

The Optical Monitoring Camera (OMC) on INTEGRAL is a small refractive telescope (5 cm aperture) that detects the visible emission associated with the gamma ray sources being observed by INTEGRAL's main instruments, the spectrometer SPI and the imaging camera IBIS. In addition to observing the high-energy targets, the OMC also monitors continuously all potentially variable stars within its large field of view (5 x 5 degrees). In operation since 2002, the OMC has observed thousands of different celestial objects.
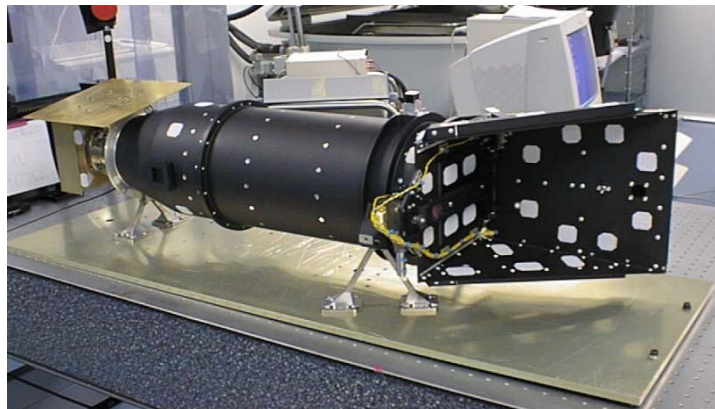
INTEGRAL's Optical Monitoring Camera pictured, during integration, in the laboratory at INTA, Spain

The light curves of these variable stars are processed and made available to the public via the OMC database (http://sdc.cab.inta-csic.es/omc/), where they can be downloaded by filling in a very simple search form.

The high-energy sources observed by INTEGRAL are frequently very variable at all wavelengths, including in visible light. The comparison of the light curves at different wavelengths (or energies) gives important clues about the physical properties of the emitting source, such as its size (determined by the delay between variations at different energies) and origin (accretion onto a black hole or a compact object).

Observing the stars

Equipment required:

- The stars provided in the 'Observing List' for the *Explore the high-energy Universe* competition can be observed using any standard telescope with an aperture larger than 6" (15 cm), however a minimum aperture of 8" (20 cm) is highly recommended.
- Standard CCD camera
- Star finder charts (if your telescope doesn't have a star finder device)
- Observation log, torch with red light, and notebook and pen

Planning observations

You should plan your observations thoroughly before you go out to observe. You need to select stars to observe from the 'Observing list' provided (see Observing_list.pdf). When choosing the stars you would like to observe, remember to consider their visibility from your observing location at the time you will be making your observations. It is up to you how many stars you choose to observe but a minimum of 1 star must be studied.

You are required to make light curves for the stars you observe. Therefore you will need to observe each star during many different phases of its variability to be able to reproduce as complete a light curve as possible - the period for each star is provided in the 'Observing list'. You will need to prepare an 'Observation log' to record your observing sessions.

To obtain the most accurate measure of the visible magnitude for the stars you are observing you will need to calibrate your measurements after you have made the observations. To do this you will need to get rid of the effects related to differences in sky transparency from one night to the other, different altitudes of the star above the horizon and so on.

It can be difficult to derive a calibrated visible magnitude for the star that you are observing. If you are uncertain how to calibrate your observations you can simply observe a reference star at the same time as you observe your target variable star. The reference star will have a known visible magnitude that can be found in astronomical catalogues. Your results will be even more accurate if you observe more than 1 reference star.

You can use the CDS Simbad database to help you to identify reference stars that are close to your target stars:

http://simbad.u-strasbg.fr/simbad/sim-fid.

Search for your target variable star using the "Basic Query" option and then click on "query around". This option allows you to identify all stars around your target. Adjust the "Output options" button to make sure that the V magnitude and the spectral type of the surrounding stars are included in the list.

Locating stars

If your telescope is equipped with a star locator device, stars can be located using their celestial coordinates (Right Ascension (RA) and Declination (DEC)). Alternatively, you can use a star finder chart; these can easily be created using freely available tools, such as:

The online digitized sky survey: http://archive.eso.org/dss/dss

Recording observations

Record all the steps you have taken during your observing session and fill in your observation log. Remember to make a note of the quality of your view of the sky. You might

include information about clouds, wind, light pollution levels and other contaminating light sources.

You should also note if an observation session ended, was interrupted or postponed for any reason, such as, bad weather conditions and technical problems. These are also normal circumstances for professional observatories.

Image processing software

To process your images you will need a simple image processing tool. You could use the software that came with your CCD camera. Alternatively, software is available to download for free from the internet. (Professional processing software, like IRAF or MIDAS, run on LINUX and Mac machines and can also be downloaded freely from the internet).

A complete list of astronomy software, both free and commercial, can be found at:

http://midnightkite.com/software.html.

Processing images using a reference star

To calculate the visible magnitude of your target variable star you need to compare the counts measured for your star to the counts of the reference star. You need to use the following formula (as a first approximation):

$$V^* - V_0 = -2.5 \log (flux^*/flux_0)$$

Where:
V^* = visible magnitude of your target star
V_0 = the catalogued V (visible) magnitude for the reference star
Flux* = counts (in any units) you have measured using the image processing software for your target star
Flux$_0$ = counts (in any units) you have measured for the reference star

The flux is a measure of the counts made by the CCD camera over a given time. To measure the flux you should follow the specific procedure for the image processing system you are using.

Further notes:
The visible, or V, filter of the Johnson photometric system is centred in the middle of the visible window, at 550 nm (5,500 Å), and has an effective width of 89 nm (890 Å). Your measurements will be more accurate if:

- A filter with a similar passband (range of wavelengths) is used. Nevertheless, this is not strictly required.
- The reference stars are selected with a spectral type (which defines the temperature of the star, and therefore the slope of its emission) which is similar to the spectral type of your target star.

Light curves – times units

Light curves are fundamental tools for variable star astronomy. They are a graph of apparent brightness (magnitude), plotted on the y-axis, verses time, plotted on the x-axis.

The time is usually in Julian Date (JD), or a variation of it. The Julian Date is a method that is used in astronomy and space science when continuous day counts are needed. JD counts days (and fractions of a day) from noon on January 1, 4713 B.C. For INTEGRAL data, time information is given in terms of INTEGRAL Julian Date (IJD), which is defined as JD − 2,451,544.5.

For the observing project of the *Explore the high-energy Universe* competition, "Barytime" should be used. This is the Barycentric Dynamical Time (TDB) in the INTEGRAL Julian date, and is the time given in the x-axis of the OMC light curves.

To be able to compare light curves from your observations with those from the OMC onboard INTEGRAL you will need to use the same time system. You must convert the time (and date) of your observation into Barytime. This can be done in the following way:

- First you need to calculate the "Barycentric Julian Dates in Barycentric Dynamical Time" (BJD_TDB) for your observations. The applet at the link below will do this for you. All you need to enter is the date and time that you made your observations, as well as your geographical location. The time should be in UTC, the Coordinated Universal Time, which is the primary time standard by which the world regulates clocks:

http://astroutils.astronomy.ohio-state.edu/time/utc2bjd.html

The following equation can then be used to calculate the Barytime

$$\text{Barytime} = \text{BJD\_TDB} - 2{,}451{,}544.5$$

Where:
BJD_TDB = Barycentric Julian Dates in Barycentric Dynamical Time (as you obtained using the above applet)

Light curves – periods and phases

Light curves are often displayed as "folded" where phase rather than a specific date or time unit is displayed on the x-axis. The phase is the fraction (ranging from 0.0 to 1.0) of the period at the time of the observation.

You can see in Figures 1 and 2 that it is difficult to identify any feature in a light curve that is extended over several years. In contrast, when you fold it according to the period, most of the subtle details of the variations become evident.
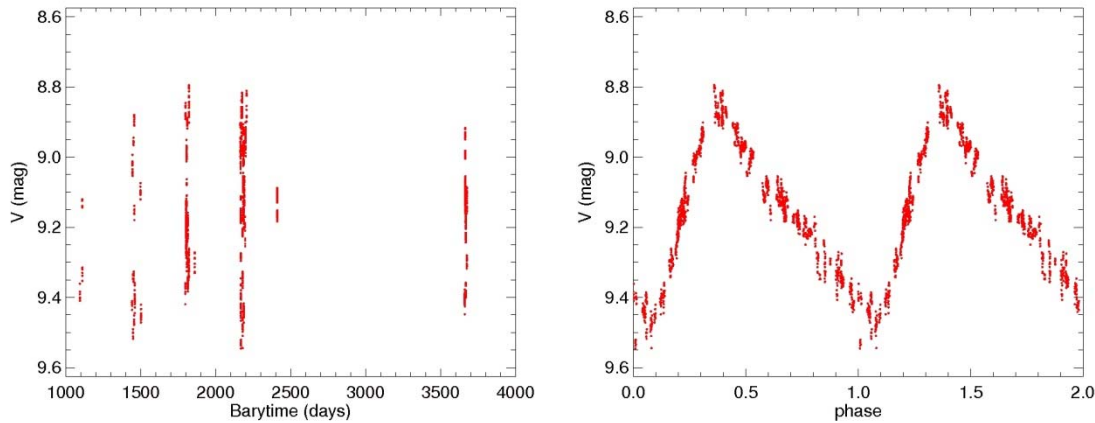
Figure: 1
The OMC light curve of a pulsating star is shown in the left panel (brightness, expressed in V magnitude, vs. Julian date). In the right panel, the V magnitude has been folded according to its period.
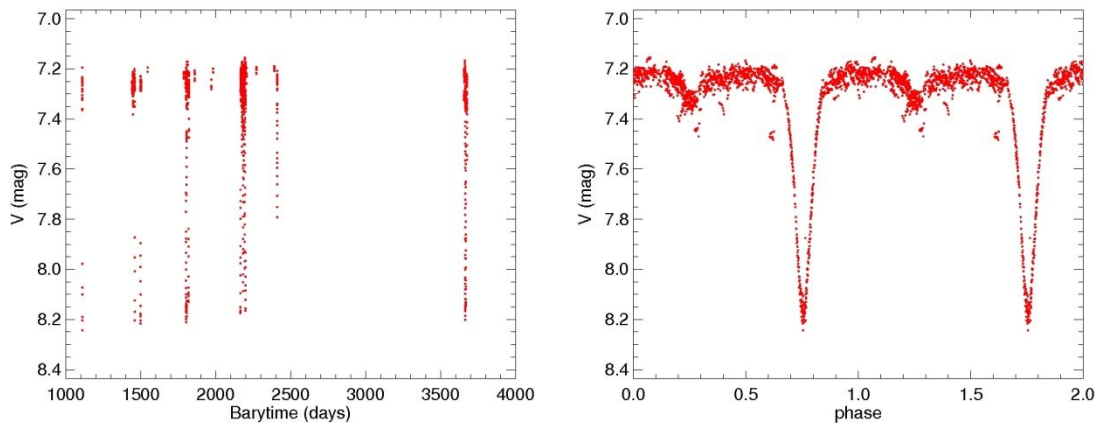
Figure 2:
Light curve of an eclipsing binary. The two minima are clearly detected in the folded light curve shown in right panel.

It is relatively easy to generate a table of phase values using a spreadsheet program, such as Microsoft Excel, just using the formula:

$$\text{phase}(T) = \text{mod}((T-T_0)/P)$$

Where:
T = the time of the observation
T_0 = the reference epoch
P = the period (in days)

In this way, your observations do not have to be taken during a single observing session; you can combine data taken on different dates to build a folded light curve by applying the above formula. Of course, the more often you monitor the star, the less scatter and the higher the accuracy you may obtain.

Once you have created your folded light curve, you could add your data to observations made by the OMC, using the provided data. You could check to see whether the period could be improved by including your observations.

The best way to do this is to slightly modify the period and then examine, by eye, whether the resulting folded light curve shows more or less scatter; repeat until you derive your optimum value.

We recommend you plot your data in different colours when combining with the OMC points, to be able to compare them easily.

Optical photometry is never an easy task. Don't be surprised if you find several points which clearly diverge from the average light curve. The data in the files that have been provided to you for the *Explore the high-energy Universe* competition have already been cleaned from all the effects of different problems, such as, cosmic ray hits and readout noise.

Support

The INTEGRAL OMC team, at the Centro de Astrobiología (INTA-CSIC), Madrid, Spain, will be pleased to provide advice for this project.

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