The VSS Southern Eclipsing Binaries Programme

Tom Richards

Yes, astronomy is fascinating and exciting to read about. And yes, it's fascinating and exciting to see the denizens of the sky through a telescope or to capture them with an image. But how about doing some astronomy; contributing to the science instead of just absorbing it? Eclipsing binaries offer a way in that's simple, un-demanding of equipment, doesn't need you outside all hours of the night, produces exciting results out of every night's imaging, and can even be done on a computer instead of a telescope. The Southern Eclipsing Binaries Programme of Variable Stars South is designed to provide all of that to the beginner in astronomical research, as well as keeping the experts very busy. A 2013 RASNZ Conference paper.

Astrophysical Research for Beginner to Expert

The SEB Programme is a multi-purpose and ongoing campaign to observe and analyse bright eclipsing binary (EB) stars accessible to Southern Hemisphere observers. Despite their importance and easy observability, large numbers of them have had little or no observational work done on them since discovery, and many more require follow-up work to extend and check existing studies. Very bright EBs such as R Ara which used to be the province of visual observers now need monitoring with DSLRs, which are 10 to 100 times more accurate in magnitude estimation and provide well-timed rapid time-series data through a night – necessary for eclipse timing. For a summary of the importance of EB research, especially by amateurs, including many valuable suggestions for projects, see (Guinan, Engle & Devinney, 2012).

What does an observer need to work on EBs? At the simplest level, basic to all aspects of the Programme, nothing more than a telescope of any size that can automatically track a target star for many hours (so you can go to bed), a CCD or DSLR camera for imaging, and photometry software. The Programme provides target selection and observing advice via its pages on the VSS website, making preparation just too easy.

The Programme stresses data analysis and astrophysical research as much as observation. This differentiates our work strongly from AAVSO and CBA programmes. All observational data will be studied within the Programme to achieve our research goals, rather than just archiving them in an online variable star database and leaving the research to others. Analysts sitting at computers using spreadsheets and other software are as central to the Programme as observers at their telescopes.

The primary output of the Programme is refereed articles in research journals, with everyone in the Programme who has made a significant contribution appearing in the author list. In addition, all observational data will be made publicly available after we have published or otherwise completed our analysis. All figures in this article come from VSS SEB research unless otherwise stated. You can find out more about this Programme in the SEB area of the VSS website – see (Richards, 2013)—hereafter 'our website').

The Programme's Research Goals

The Programme has a number of research goals that require varying levels of equipment for adequate observation and varying levels of sophistication in computer analysis.

Goal 1. Obtaining Times of Minimum

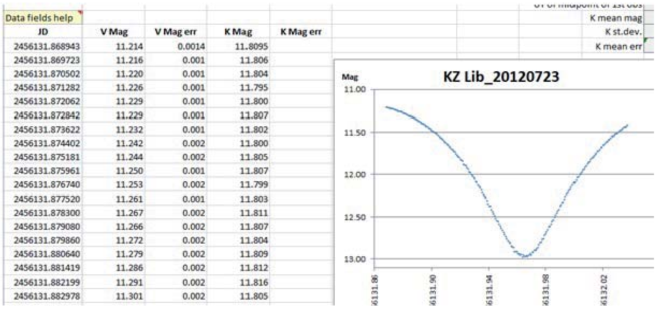
Finding out exactly when eclipses occur – or more precisely, measuring their times of minimum (ToM) – is most important in its own right, and provides the basis for all our further research, as I'll explain below. Our goal is normally to obtain at least three well-timed primary or secondary eclipses for each target in its observing season.

To obtain the observational data you need a telescope that can track accurately, with a CCD or DSLR camera. You should also synchronise your computer clock to a local NTS time server. Photometric filters are not needed, but data obtained using them can be used in more advanced research – see below. For this reason, we recommend always using a Johnson V filter if you have it.

How do you choose your targets from the myriad in the southern sky? Our website has a list of target EB systems and the comparison and check stars to use for each. To select a suitable target on a given night, download David Motl's freeware Ephemerides program (Motl, 2010) and use our ephemeris file, available on our website. This will list eclipses visible from your site each night.

You obtain images of the target variable for several hours around the predicted ToM; then calibrate them in the usual way, and use an aperture photometry package that comes with most imaging and image-processing software to obtain a light curve of the target. You enter your results onto an Excel Observation Report Form (see Figure 1) which then goes to the analyst for that target. At this stage you will also be given mentoring comments on your work and how to improve it (You don't want to see my early photometry work – nor do I!)

Each target EB in the Programme is assigned to an analyst, who receives the completed Observation Report Forms for the target. As an analyst you enter data from the Observation Forms into a PERANSO file for the target (Vanmunster, 2004)



Data fields help				
JD	V Mag	V Mag err	K Mag	K Mag err
2456131.868943	11.214	0.0014	11.8095	
2456131.869723	11.216	0.001	11.806	
2456131.870502	11.220	0.001	11.804	
2456131.871282	11.226	0.001	11.795	
2456131.872062	11.229	0.001	11.800	
2456131.872842	11.229	0.001	11.807	
2456131.873622	11.232	0.001	11.802	
2456131.874402	11.242	0.002	11.800	
2456131.875181	11.244	0.002	11.805	
2456131.875961	11.250	0.001	11.807	
2456131.876740	11.253	0.002	11.799	
2456131.877520	11.261	0.001	11.803	
2456131.878300	11.267	0.002	11.811	
2456131.879080	11.266	0.002	11.807	
2456131.879860	11.272	0.002	11.804	
2456131.880640	11.279	0.002	11.809	
2456131.881419	11.286	0.002	11.812	
2456131.882199	11.291	0.002	11.816	
2456131.882978	11.301	0.002	11.805	

Figure 1: Part of a completed Observation Report Form for the Programme binary KZ Lib showing the typical results of a night's work. The light curve appears automatically, computed from the date and magnitude columns.

and use its facilities to measure minima – see Figure 2. There are actually several ways of measuring a minimum – and doing it by eye is not one of them! Your results are placed on our website, accessible by all members of the EEB Programme. As more Observation Forms arrive, you update this Excel Results File.

As the analyst for a particular target, you have the responsibility to guide the research on it. For example you might ask observers to obtain some secondary minima in this observing season, or advise you have all the primary minima data you need for the season, or request some more sophisticated type of observation for one of the more advanced Programme goals. Of course, you may not wish to take your analysis work beyond the basic Goal 1 level, but if you do there is a wealth of research to carry out. Your comfort zone is up to you.

Goal 2. Deriving Light Elements

What do we do with these ToMs? One fundamental use is to find the orbital period P of the system, essentially by measuring intervals between minima.

This is a job just for the analyst. When you have three or more well-timed minima in a season for a particular target, you can derive the binary's Light Elements (P plus one well-timed minimum to set as the zero epoch, E_0). A target's Results file, referred to above, contains an automatic linear regression routine that derives LEs from the minima measurements. From the LEs any other minimum can be predicted. Whilst LEs exist in the literature for all our Programme's targets, they are often very poor or badly out of date. Even if they're good, it is only

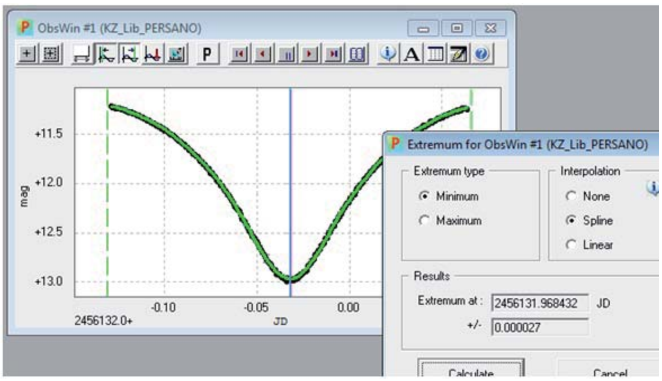


Figure 2: Measurement of the Time of Minimum of KZ Lib in PERANSO.

by continually updating minima times and LEs that we can see if a target system's period is changing – a most interesting phenomenon that's discussed below.

Goal 3. Obtaining a Full Phased Light Curve

The light curve of an eclipse is only part of a binary's entire light curve. For many lines of research a full light curve is needed, covering all phases of the orbit of the stars around each other, from primary eclipse through to secondary eclipse and back again to primary. Figure 3 is an example. From such a light curve much can be deduced about the nature of the two stars. Relative depths of the primary and secondary eclipses, for example, tell you the relative luminosities of the two stars. A curved out-of-eclipse portion can indicate the stars are tidally distorted by their mutual gravitation, or that one is reflecting the light of the other.

To get photometry for a full light curve you really need to use photometric filters – especially Johnson B and V. It is also very desirable at this stage to apply transformation coefficients to the photometry, as transformed data in two filter bandpasses

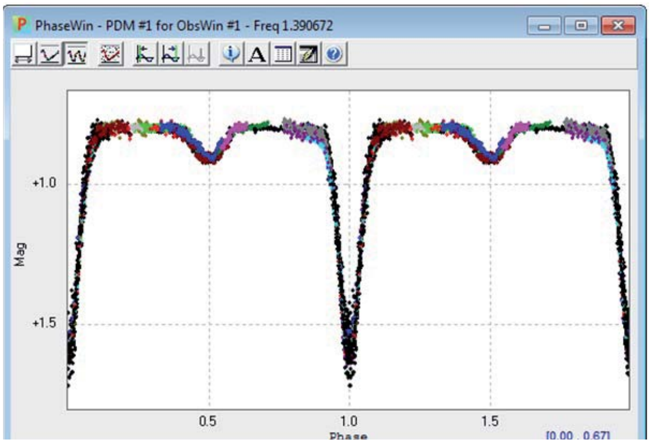


Figure 3: A phased light curve for the Programme binary CU Hya derived from time series observations by many observers – each night's observation set is a different colour.

can reveal more about the stars, such as their colour indices and hence temperatures. (TCs are factors you apply to the magnitudes you measure through filters to make them agree with the definitions of the standard photometric system. See (Cohen, 2003.))

Observers won't obtain complete light curves – periods are too long. So the analyst has to cobble together the portions sent in by observers, as was done in Figure 3.

Goal 4. Obtaining Spectra

For many purposes, as well as their intrinsic interest, it is valuable to obtain spectra of eclipsing binaries. This is a rather specialized task, though many amateurs now use sophisticated spectrographs and are skilled at spectral analysis. Quite amazingly, the bulk of southern EBs have little or no spectral data, and when they do it is just a spectral classification often derived indirectly by statistical means. Deriving a spectral classification from study of a spectrum is crucial for a lot of the more advanced analysis work described below. Figure 4 is an example. Where equipment and the target permit, it is useful to

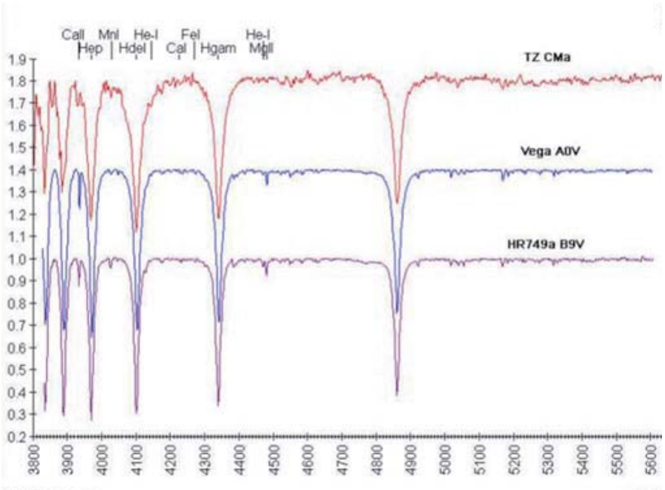


Figure 4: Spectrum of the Programme binary TZ CMa together with two comparison spectra.

compare spectra at primary and secondary minimum and out of eclipse — differences can provide specific information about the component stars. Radial velocity data, though crucial to a full astrophysical modelling of the binary system (Goal 5) is beyond amateur spectrographic equipment. From the measured radial velocity of the brighter star coming and going, and knowing the period P, it is trivial to calculate its orbital radius. You do need to know the orbital inclination as well, which can be derived from the light curve - see Goal 5. Then the sizes of the stars can be calculated, using the widths of the eclipses. If we can make a sufficiently important case for a particular system, we will seek time on a large professional telescope to obtain radial velocity data.

Goal 5. Light Curve Analysis and System Modelling

This is primarily a job for the analyst, where complete phased light curves in two or more bandpasses have been obtained; though with suitable assumptions it is possible to carry out light curve analysis on an un-transformed light curve in one bandpass - see e.g. (Zasche, 2009).

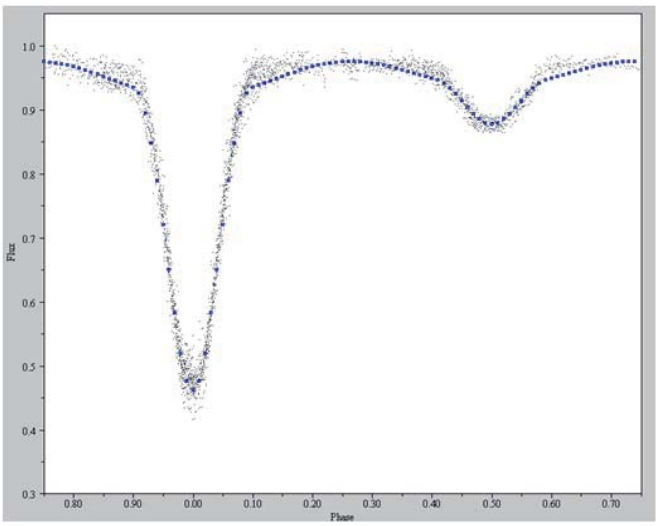


Figure 5: A synthetic light curve (dots) fitted to the observed light curve for CU Hya.

The aim here is to infer a range of astrophysical parameters about the system from analysis of the light curve and using the spectral classification. Some of these are the orbital inclination to our line of sight, the radii of the stars relative to the orbital radius, their shapes, the ratios of their masses, luminosities and temperatures. The way to do this is to feed assumed values for these parameters into a program that can generate the light curve of an EB using those parameter values, then to adjust until the generated light curve matches the observed one. Figure 5 is an example. Two commonly used programs here are PHOEBE (e.g. Prša & Zwitter, 2005) based on the Wilson-Devinney code (Wilson 1994) and BinaryMaker 3 (Bradstreet, 2005). Both are highly recommended.

Goal 6. Investigate O-C

This also is a job just for the analyst, and includes searching the literature. An O-C diagram (see Figure 6) shows the extent to which Observed ToM data points (HJDs of primary minima) diverge from those Calculated from some set of linear LEs over time. To do this properly, all recorded ToMs in the literature from the discovery date onwards are needed, as well

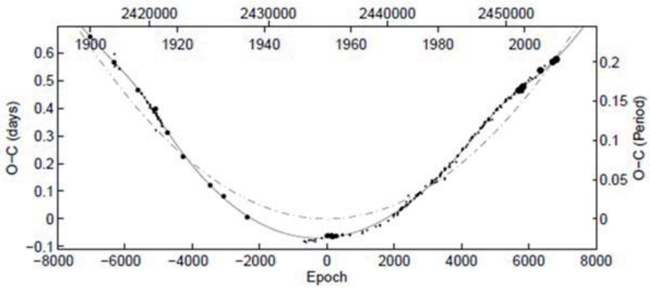


Figure 6: O-C diagram of RR Dra. The abscissa is epochs (orbital cycles counting from a chosen E_0). The ordinate shows the difference between an observed ToM and that calculated for that epoch, in days. The upward-opening parabolic shape shows that the orbital period is decreasing.
From (Zasche et al, 2008).

as those recorded in this Programme - perhaps over some years. Inspection of a regression along the plotted points can show if the assumed period is right, wrong, or is changing over time. If it is changing in any way, the acceleration may be constant or the O-C diagram may reveal a sudden change in period. Such changes can indicate mass transfer between the two stars or mass loss from the system or some sudden adjustment in one star. Along with light curve analysis (Goal 5) this provides important astrophysical information about the system.

Goal 7. Search for a Third Body (including the VSS SPADES Project)

Light curve analysis can reveal the presence of a “third light” contaminating the light received from the eclipsing pair. Where this is not a faint background star inside the photometry measurement aperture, it may be due to a third star orbiting in the binary system, which like the primary pair cannot be seen individually.

More significantly, an O-C diagram can show oscillations with a fixed period, indicative of the presence of a third, invisible body in the system such as a star orbiting the eclipsing pair

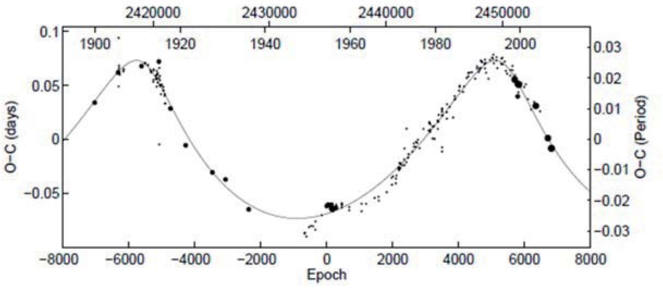


Figure 7: When the best-fit parabola is subtracted from the O-C curve in Figure 6, a periodic curve is revealed, indicating the presence of a third body in the system.

From (Zasche et al, 2008)

in the same plane. This third body is shifting the visible pair periodically closer to us then further away, and so advancing or delaying the time the light of an eclipse takes to reach us (the so-called Light Time Effect). See Figure 7. If the physical parameters of the eclipsing pair are known, it is possible to derive orbital and mass information about the third body. It may turn out to be a star, a brown dwarf, or even a planet, though detecting the low-amplitude oscillations of a planet requires high quality ToM measurements in the first place. The SPADES Project (Search for Planets Around Detached Eclipsing Stars) within the SEB Programme is aimed at detecting such planets, which would be very difficult to find using other planet-finding techniques such as radial velocity, transits, or microlensing. As one example, two planets have been found around the Eclipsing Binary HW Vir by this method (Lee et al, 2009).

Goal 8. Unexpected Opportunities

The SEB Programme is particularly interested in targets of opportunity that can arise from time to time, as well pro-am collaborative campaigns and the study of unusual or particularly important EBs when the occasion arises. SPADES is an example. Some EBs such as V685 Cen and R Ara are evolving rapidly yet are poorly monitored. Others such as Z Cha and VZ Scl are cataclysmic or novalike variables or otherwise given to irregular or eruptive behaviour. These are frequent campaign targets and anyway should be monitored closely. Even the routine monitoring of poorly observed EBs can yield important surprises, such as the discovery of a pulsating component or a significant change in the light curve. Even Algol has not had its light curve checked for several years!

These sorts of systems and campaigns will usually require specialised observing and analysis methods, and may require close collaboration with a professional team. Any suggestions for a campaign on such targets of opportunity should be sent to me.

How Can You Take Part?

This is a research programme open to anyone. At the elementary stages such as Goal 1 - finding minima - only elementary skills are needed, but these underlie all more advanced work, to which you can progress as your equipment and research skills permit. For example, your observing equipment may limit you just to the basic Goal 1 photometry, but your interest in research and analysis may take you all the way to the fascinating business of light curve modelling - Goal 5 - and writing a paper about it. To join in, send me an email telling me about your equipment and what you'd like to do in the project. You'll be assigned a mentor and given pointers to get going. But first, I suggest you read all the project documentation on our website.

Wishing you clear skies and a high bandwidth!

Annotated References

Bradstreet, D., 2005. SASS 24, 23-37. BinaryMaker 3. (*www.binarymaker.com)* is a straightforward and powerful EB modelling package, with a live 3D graphical rendering of the system model. Widely used by professionals and amateurs alike. Comes with an outstanding User Guide, which includes a wealth of information about the astrophysics of binaries and advice for successful modelling.

Cohen, Lou, 2003. "Computing and Using CCD Transformation Coefficients". Available from *http://ara.roma.it/files/uploads/Ccdcoeff.pdf*. A hands-on account of how to derive and apply TCs, with little theory. Highly recommended for the beginner.

Guinan, E.F., Engle, S.G. & Devinney, E.J., 2012. *JAAVSO* **40**, 467-480. Discusses the current importance of EB research, research emphasis particularly for amateurs, and interesting projects.

Lee, J.W. et al, 2009. "The sdB+M Eclipsing System HW Virginis and its Circumbinary Planets." *AJ* **137**, 3181.

Motl, D., 2010. Ephemerides. *http://www.motl.cz/dmotl/predpovedi/*. An elegant little freeware program for predicting eclipses.

Prša, A., Zwitter, T., 2005. ApJ 628, 426. PHOEBE. (PHysics Of Eclipsing BinariEs, believe it or not!) *http://phoebe.fmf.uni-lj.si/*. It is a sophisticated but user-reasonably-friendly EB modelling package, using the Wilson-Devinney light curve analysis code with an intelligent front-end. The program is freeware, downloadable from *http://sourceforge.net/projects/phoebe/*. Rather an industry standard now.

Richards, T., 2013. Southern Eclipsing Binaries Programme. *www.variablestarssouth.org*, go to Research > Southern Eclipsing Binaries.

Vanmunster, T., 2004. PERANSO Light Curve and Period Analysis Software. *http://www.peranso.com*. Very well designed software, widely used with an excellent user guide.

Wilson, R.E., 1994. "Binary Star Light-Curve Models". *Publ. Ast. Soc. Pacific*, **106**, 921. Landmark paper on the history and problems of light-curve modelling.

Zasche, P., 2008. "Period changes in six semi-detached Algol-type binaries."*New Astronomy* **13**, 405-428.

Zasche, P., 2009. *New Astronomy* **14**, 129-132. Derives system models from EBs observed by INTEGRAL. The modelling involved can use only un-transformed V photometry, and the paper discusses how to do this in PHOEBE.

SEB Programme Coordinator
Director, Variable Stars South

tom.richards@variablestarssouth.org