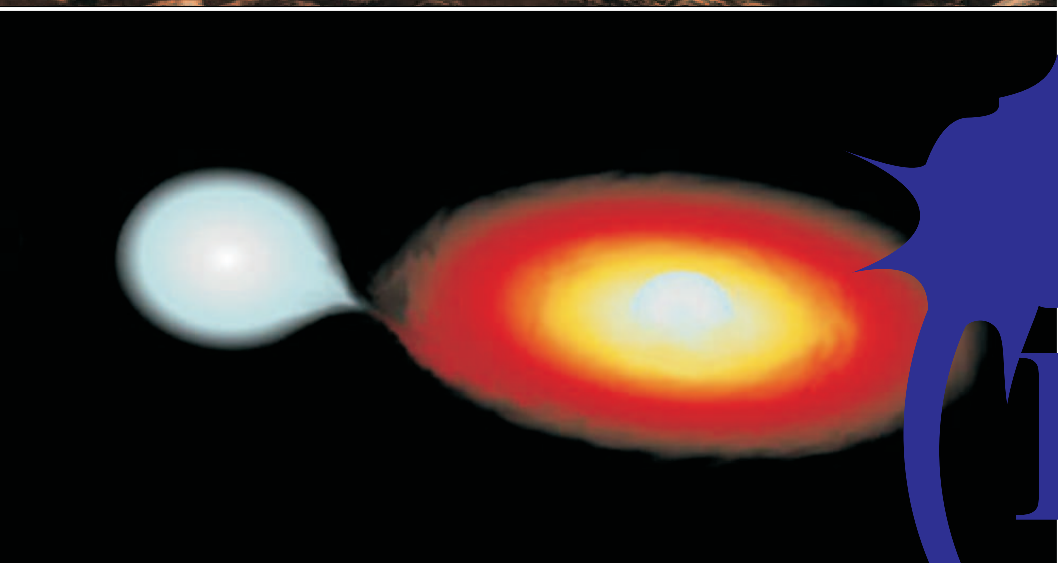


British Astronomical Association

Eclipsing Binary Observing Guide

BAA

British Astronomical Association

Eclipsing Binary Handbook

Second Edition

A Beginner's Guide to making observations of Eclipsing Binary Star Systems

Contents

Acknowledgements: Drew Taylor for Algol and W UMa portrayals: Steve Bowers, Orion's Arm Universe Project, for Zeta Aur portrayal, Georg Domogala for Beta Lyrae portrayal, Dr B Hufnagel for diagram on p 6, Professor J Kreiner for RZ Cas diagram on p 18, DTerrell for Beta Lyrae light curve on p10 as used in Van Hamme, Wilson and Guinan, Astronomical Journal, vol 110, page 1350 (1995).

Foreword

It is often said that astronomy is one of the few remaining sciences where amateurs can still contribute to research, and the study of variable stars is one of the fields regularly cited to exemplify that this is the case. Members of the BAA Variable Star Section (VSS), often equipped with only modest equipment, have contributed important observations that have helped push back the frontiers of variable star science for more than 130 years. The VSS observations database in fact extends back to 1840, some fifty years before the Association was founded, and at the time of writing contains around four million observations.

This Handbook focuses on eclipsing binary stars. These are variable stars, not because the light of the individual components varies, but because of the eclipses that occur when one star gets in the way of the other star as seen from our viewpoint on Earth. Thus, the light curve of an eclipsing binary is characterised by periods of practically constant light, with periodic drops in intensity when one star passes in front of the other.

Studying how eclipsing binaries behave can give us important insights into their stellar components. For example, binary star systems are very important in astrophysics because calculations of their orbits allow the masses of their component stars to be measured, which in turn allows other stellar parameters, such as radius and density, to be indirectly estimated. Observing eclipsing binaries also gives insights into how one star affects the other: if they are sufficiently close and massive, their tidal forces will distort each other's shape, information about which can be obtained from the light curve. Moreover, as the stars evolve, this can affect the interval between eclipses, the time of which can be measured precisely by the observer.

Eclipsing binaries can be studied with a range of techniques, from simple naked eye observations of some of the brighter systems, through using binoculars or small telescopes, via imaging with DSLR cameras, all the way to sophisticated electronic imaging systems. This Handbook provides the observer with a guide to observing these objects. It covers the basic categories of eclipsing binaries, which stars the beginning observer might like to follow, how to interpret the resulting light curve and extract the all-important "time of minimum", corresponding to mid eclipse.

The original Handbook was written by Des Loughney, the VSS Eclipsing Binary Secretary, in 2011. I'm extremely grateful to Des for preparing this revised edition which contains much updated information. Both Des and I are also grateful to Dr. Chris Lloyd for revising the list of target stars on the VSS eclipsing binary programme.

Readers are advised to visit the BAA VSS web site regularly to obtain the latest charts, news and information. They are also welcome to subscribe to the VSS Circulars, which regularly contain features on eclipsing binaries. These are available free of charge – please contact the VSS Director if you wish to receive future copies.

Jeremy Shears,

Director, British Astronomical Association - Variable Star Section

Bunbury, Cheshire, 2021

1. What are Eclipsing Binaries?

A Binary star system is one in which two stars orbit around a common centre of gravity. It is estimated that over 50% of all stars are in binary systems, possibly as much as 65%. Eclipsing Binaries are those Binary systems in which the orbital plane of the system is almost side on as seen from the Earth so that as the stars move around the common centre of gravity there are eclipses. Stars in an eclipsing binary system are usually so close together that they cannot be separated even in the most powerful telescopes. We deduce that they are in an eclipsing system because of the way the light from the system varies in a regular and characteristic pattern. An eclipsing binary allows scientists to find out a lot about how binary systems evolve and thus the fate of most stars.

A primary eclipse occurs when the brighter star is eclipsed by the fainter star. The secondary eclipse occurs when the fainter star is eclipsed by the brighter star. If the two stars are of the same brightness then both eclipses will be equal.

If one of the stars is much fainter than the other then the secondary eclipse may not be readily observed by visual observers. If the orbits of the two stars are circular then the secondary eclipse will occur midway between primary eclipses. If the orbits are elliptical the secondary eclipse may occur earlier or later than midway.

A primary eclipse is said to be total if one star is completely obscured by the other star for a period of time. The period of minimum light can be minutes, days or in one case two years! If a star is not totally obscured then the eclipse is described as partial. In that case there is no prolonged period of minimum light. There can also be a prolonged period of minimum light with an annular eclipse.

2. Why Observe Eclipsing Binaries?

Studying the light variations of an Eclipsing Binary system allows us to learn a lot about the stars that comprise the system and about the way stars evolve. This is of great significance given that 50% of all stars are in such systems.

The time between the mid-points of two sequential primary minima is called the (orbital) period of the system. The period of a system is not necessarily constant. If the stars are close together the period can change due to mass transfer between the two stars. Small changes in the period can build up over many orbits so that visually observed times of the eclipse clearly varies from the predicted time of mid-eclipse. Amateur astronomers can detect these changes over months, years and decades and provide valuable information on the evolution of the systems.

The work done by visual amateur astronomers is an important supplement to the more accurate and detailed work that can be done photometrically by professionals and advanced amateurs with a CCD or DSLR camera.

The achievable accuracy of plus or minus 0.1 magnitude in visual estimations can be sufficient to allow very good calculations of the mid-point of an eclipse and thus to monitor the period of the system.

It is possible for visual observers to pick up other variations in the light output which may be due to star spots or effects linked to accretion disks.

An eclipsing binary system that has a period of 1.5 days will eclipse about 240 times a year. If the period was changing by just 1 second per orbit then the difference between the predicted time and actual time of mid-eclipse will be four minutes after a year. Changes on this scale can be detected by visual observers.

Some 'fast' eclipses can be dramatic astronomical events which can be well observed with a telescope or binoculars. The eclipse of the RW Tau system results in a drop of 3.4 magnitudes to primary minimum from 8.1 to 11.2 magnitude. Just before minimum the light drops two magnitudes in an hour. The Z Draconis system drops from 10.8 magnitude to 14.1 magnitude. The drop from around 11 to 14.1 takes place in about 45 minutes.

The physics of two stars in orbit around a common centre of gravity, using data provided by visual observers, instrumental observers, spectroscopists and professionals allows a great deal of information to be obtained about the stars. The mass, size, temperature and luminosity (brightness) of each star can be determined and thus the distance of the system from the Sun.

3. Types of Eclipsing Binary

There are three basic types of Eclipsing Binary which are classified on the shape of their light curves. The light curve will be the observed magnitudes over the whole period of the system.

EA Systems - Algol Type Systems

These are systems in which the light curve shows little variation outside of eclipses. If there is a significant difference in brightness between the two stars the primary minimum will be marked whereas the secondary minimum may not be observable visually. RW Tau is an EA system where the drop to primary minimum is 3.1 magnitudes. RZ Cas is also an EA system where the drop is 1.5 magnitudes. The stars in an EA system are spherical and may be well separated or 'detached'. They may also be 'semi-detached'. In this case there will usually be a mass transfer taking place between the stars of the system.

The periods of an EA system can vary from a fraction of a day to years. Below (figure 1) is a diagram of an EA system. Note that the primary minimum occurs when the brighter but smaller star is eclipsed.

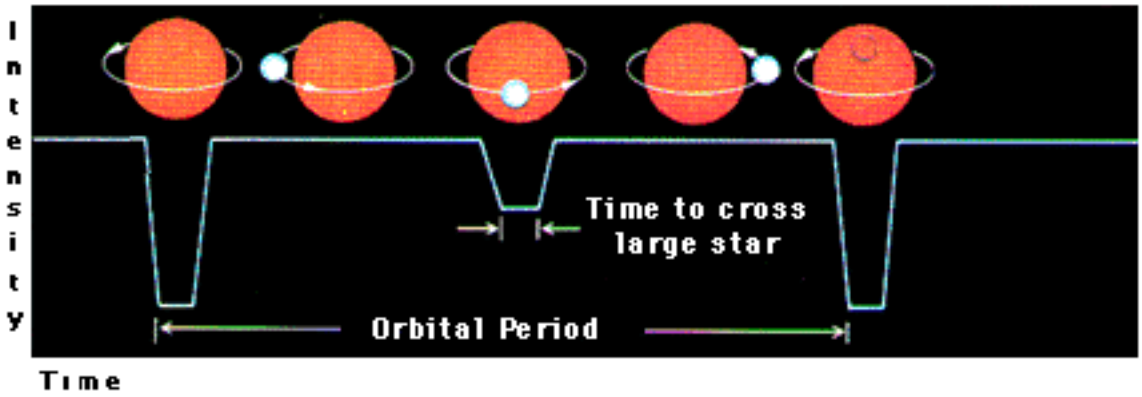


Figure 1 EA System

EB Systems - Beta Lyrae type systems

These are systems in which the stars are close enough to have gravitationally distorted each other. The stars are ellipsoids rather than spheres. As a result light variations occurs between eclipses so that the exact start and end of eclipses cannot readily be determined. However, in these systems, the primary eclipse is quite marked and can involve a drop of up to 2 magnitudes.

There is no time of constant light between primary and secondary eclipses. These systems are invariably semi-detached.

EW Systems - W UMa type systems

These are eclipsing binaries in which the stars are in contact or almost in contact. The stars are distorted and may share a common envelope of material. It is impossible to specify the onset and end of eclipses. The light curve is always varying. The amplitude of the eclipses is usually less than 0.8 magnitudes. The stars are so close that the orbital period can be just a few hours.

These systems can be satisfying to study because as the magnitude is always changing they can be usefully observed at any time.

Sub - Systems

There are a number of sub systems. Probably the most important is the RS type. This type is named after the eclipsing binary RS Canum Venticorum. These systems have light variations that are produced by large star spots (the sun spots of stars). The changes can be up to 0.2 magnitude which means they can be detected instrumentally but are difficult to detect by visual observers.

In international databases such as the General Catalogue of Variable Stars (GCVS) a system may be followed by a notation such as EB/SD/RS which means that it is a semi detached EB type which shows light variations due to star spots.

4. Which Eclipsing Binaries to Start With?

We have selected five eclipsing binaries for beginners to practise on. They are systems that can be studied with binoculars or the naked eye. Observing these systems allows the refinement of techniques that can then be fruitfully applied to observing more challenging systems with telescopes or instrumentally (CCD/ DSLR cameras). There are many more binocular systems.

The five systems all have a range in excess of half a magnitude. Less than that range is not suitable for visual observing because the margin of error (plus or minus 0.1 magnitude) makes it very difficult to construct light curves that enable a reasonable estimation of the time of mid-eclipse. But, using a DSLR camera , for example, can allow effective study of a system in which the range of variation is less than 0.2 magnitude because a margin of error of plus or minus 0.02 can be achieved.

Once the techniques have been mastered there are many, many, interesting systems that can be observed including those on the BAAVSS Eclipsing Binary Programme.

BAAVSS charts of the five stars are included with this Guidebook. The charts show the position of the eclipsing binary system and the comparison stars that can be used to follow the changes in brightness during the eclipse. To allow a reasonable estimation of mid-eclipse at least five estimations have to be made of the fade and five estimations of the rise from eclipse. Estimates are usually made every fifteen minutes timed to the nearest minute. Sometimes estimates every ten minutes can be useful near the bottom of the eclipse.

At the start of an evening's observing it is advisable to calibrate a time piece so that it is accurate to under a minute.

Predictions of eclipses are on the Krakow database (see 9.3 'Atlas of Eclipsing Binary Stars').

The methods used for making a recording of observations are the same for eclipsing binaries as for other types of variable star. For further details see the BAA VSS publication: "Observing Guide to Variable Stars".

One of the main challenges of observing Eclipsing Binaries (EBs) is to take advantage of an extended clear period during the night which allows for the several hours of observation that are necessary to fully cover an eclipse.

Observing Tips

- you will inevitably be aware of your previous observations when making your next observation. Try and be careful not to allow your earlier observations to influence your next observation;

- only be aware of the general time of an eclipse - the approximate hour rather than the exact minute;

- do not assume that during a fade each successive estimate will be fainter than the previous one and that during the rise each successive estimate will be brighter than the previous one;

- do not assume that the observed minimum brightness will match the catalogued value;

- do not assume that the observed minimum magnitude will be the same in every eclipse;

- do not assume that estimates will be symmetrical around the midpoint of an eclipse. Most are but some are not;

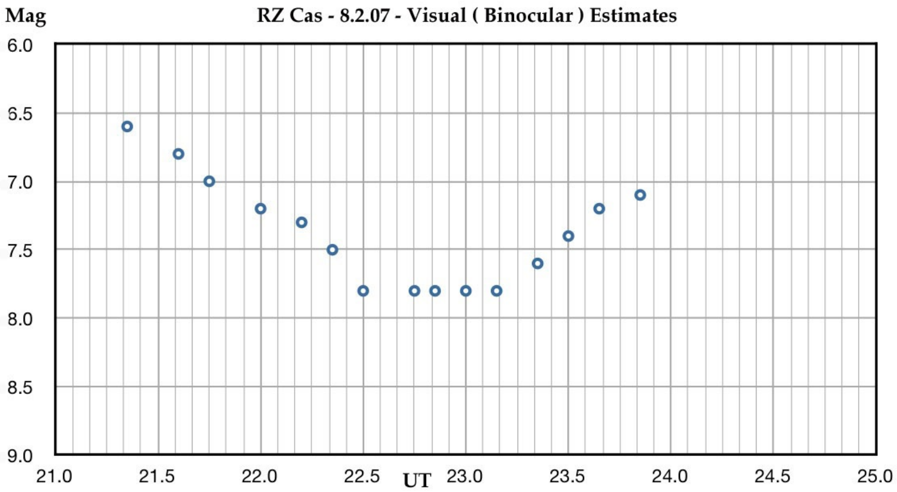
- be patient. After a couple or more hours of observing be just as careful in studying the rise. Resist the urge to be in a hurry for an eclipse to end so that you can go to bed!

4.1 RZ Cassiopeia

This is a good system to start with. It is easily visible in binoculars and has primary eclipses that are 1.5 magnitudes in depth. The secondary eclipses are only 0.1 magnitude in depth and therefore cannot be observed visually. The system varies from 6.2 to 7.7. It is classed as EA/SD.

Other good reasons to look at this system are that it is circumpolar from British latitudes and with a current period of 1.1952503 days eclipses occur very frequently.

Although many eclipses are of the same depth and estimates are symmetrical about the time of mid-eclipse this is not always the case. In a semi-detached system (SD) mass will be transferring from one star to another. Sometimes an accretion disk can build up which can reduce the usual magnitude at mid-eclipse or at points on the fade or rise.



Your estimates should be plotted on ruled paper on which the vertical axis is magnitude and the horizontal axis is time, or in a spreadsheet such as Microsoft Excel . Above are my estimates of 8th February 2007.

RZ Cas was the BAAVSS's Variable Star of the Year in 1999. The article that appeared in the BAA's Annual Handbook can be seen at: <http://www.britastro.org/vss/vsoty_rzcas_1999.pdf>.

4.2 Beta Persei - Algol

Algol was one of the first variable stars to be recognised in the 17th century. It's variation can be seen with the unaided eye. In January 1999 it was named as the AAVSO (American Association of Variable Star Observers) Variable Star of the Season. Information on the system can be studied at <http://www.aavso.org/vsots_betaper> . If you google "Algol Star" you can study many artists impressions of the system and several animations.

Algol's out of eclipse magnitude is 2.1 with a primary minimum at 3.4 magnitude. It has a current period of 2.8673043 days. The whole eclipse lasts a few hours. It is a partial eclipse and therefore does not have a flat bottom.

The partial eclipse of the dimmer star only results in a fade of 0.1 magnitude which is too small to be detected visually.

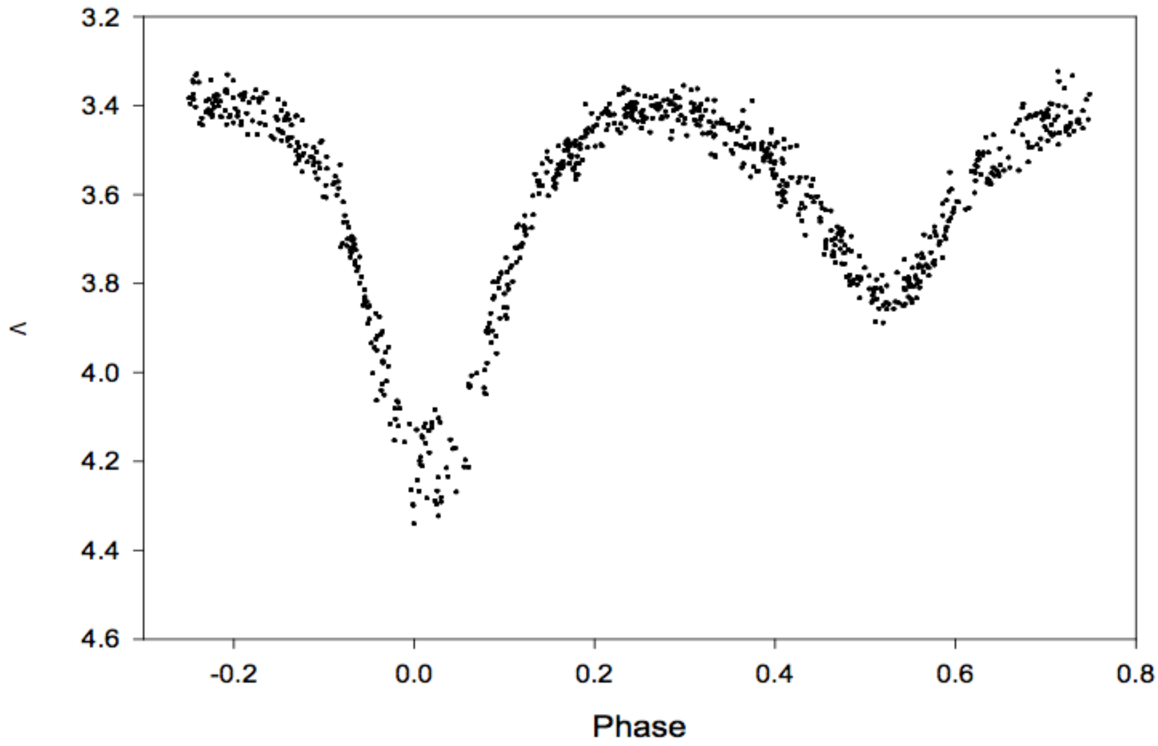
One of the stars in the system fills what is called it's Roche Lobe. This is the volume of space which is dominated by its gravitational field. When the Roche Lobe is filled the star loses material to its companion. The change in the relative masses, due to the ongoing mass transfer, results in the gradual period change.

A careful study of the system has shown that it is actually a triple star system. The eclipsing binary pair is separated by 0.062 AU and the other separated by an average of 2.69 AU. AU represents an Astronomical Unit which is the average distance of the Earth from the sun.

4.3 Beta Lyrae

This was the AAVSO's Variable Star of the Season in 2005 (<http://www.aavso.org/vsots_betalyr>). It is a well known eclipsing binary that was discovered to be a variable star in 1784. Its changes can, like Algol, be followed by the naked eye. It varies from 3.3 magnitude to 4.4 magnitude over a period of about 12.9 days.

Unlike Algol there is no out of eclipse flat maximum. The stars of the system are sufficiently close to produce tidal distortion. The primary star bulges towards the secondary star. The primary star is losing mass to the secondary in such a way that the secondary is almost totally obscured by a cloud of gas and dust. When the primary is hidden in the primary eclipse the magnitude drops by 1.1. When the secondary is obscured the magnitude drops by about 0.6. The light curve of the system is illustrated below.



The system's magnitude always varies. The stars are themselves sufficiently separated for there to be a period of no eclipse but the cloud of dust and gas is large enough to give the impression that the two stars are almost in contact and thus in constant eclipse. Therefore the system can be observed at any time and all estimates are useful. The fastest change in magnitude is around the primary eclipse.

Note that the system has a significant secondary eclipse which in contrast with RZ Cas and Algol can be easily picked up visually.

The diagram plotted above is called a phase diagram. The vertical axis is for magnitude. The horizontal axis represents the decimalised period of the system (12.9 days). In this type of diagram 0 is the midpoint of the primary eclipse; 0.5 the midpoint of the secondary eclipse and 0.25 and 0.75 the midpoints of the two maxima. When a system has a period of 12.9 days it is impossible for one observer to get a complete light curve within one period because, of course, much of the period will be within daylight and unobservable due to the weather.

Sometimes observers will combine as part of an international campaign to construct a light curve covering one period.

A phase diagram is the depiction of estimates over a couple of months to get a comprehensive light curve. A phase diagram works on the assumption that the period of a system will not change within two or three months. This is generally the case. Later on in this Handbook there will be a detailed description of how a phase diagram is constructed. It is a very useful technique given UK weather.

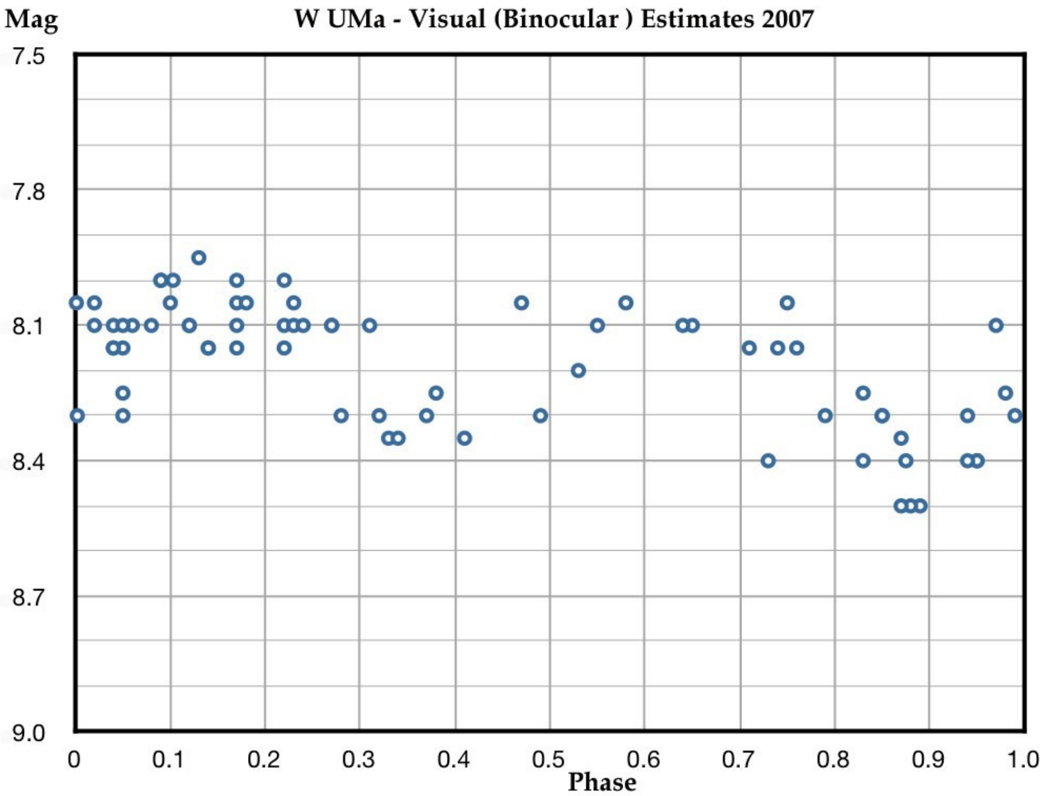
4.4 W Ursae Majoris

This is another famous eclipsing binary which is the prototype of its class of eclipsing binaries where two stars are actually in contact and share a common envelope. Being so close these systems have very short periods. In W UMa's case the period is about 8 hours.

It varies from 7.8 magnitude to 8.5. The primary minimum is 0.7 magnitude in depth and the secondary magnitude is 0.6 magnitude in depth.

Like Beta Lyrae this class of systems always varies in magnitude and so can be observed at any time. All estimations are useful. Although the light curve of W UMa is usually symmetrical there can be bumps/ shoulders due to the presence of large star spots. These are much bigger than sunspots because the close proximity of the stars can produce larger, more complex and intense magnetic fields.

Below is a plot of binocular estimates of W UMa at the end of 2007 and the beginning of 2008. This is an example of the characteristic light curve. This light curve is a phase diagram and is a combination of observations over many nights. It will be seen that there is some scatter in the estimates although the overall curve is clear.



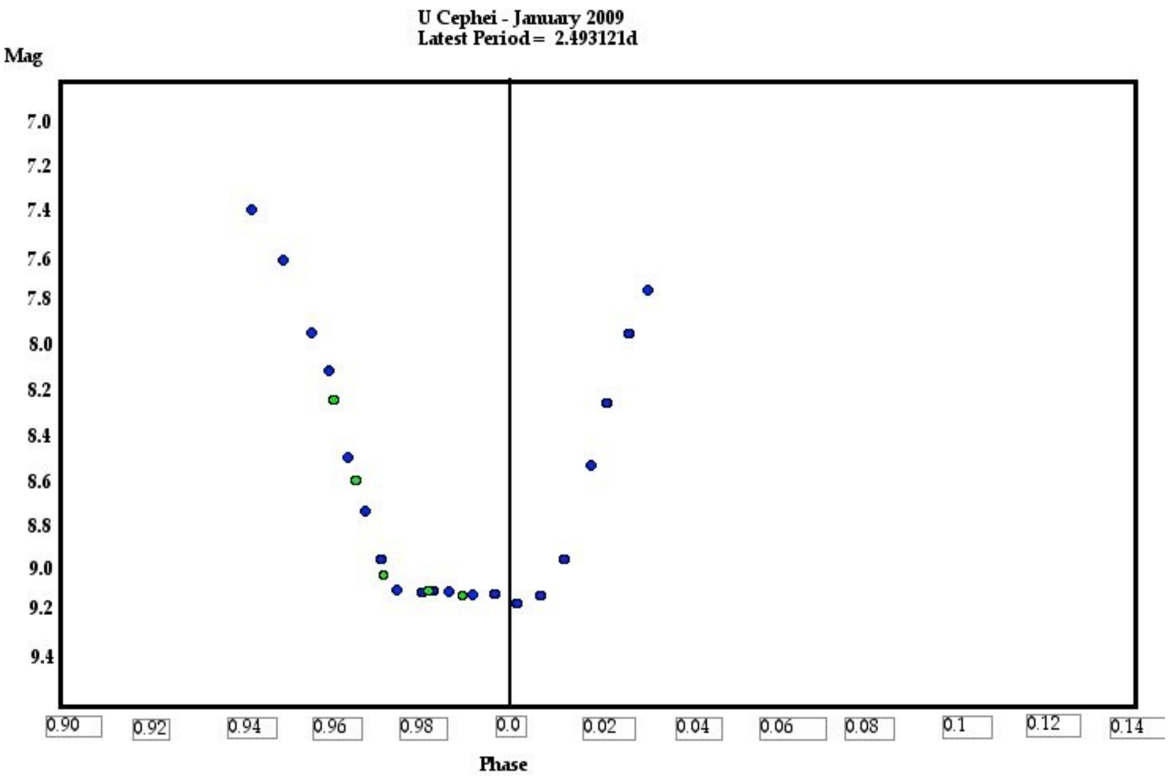
The scatter may be due to the inherent error in the form of observation. The scatter may also be genuine due to large star spots.

4.5 U Cephei

This system was the BAAVSS's Variable Star of the year in 2006 (<http://www.britastro.org/vss/VSOTY_ucep_2006.pdf>). Lying at high declination, less than 10 degrees away from Polaris, it varies between magnitudes 6.7 and 9.4.

The period is nearly two and half days. The primary star is much brighter than the secondary star and, as a result, whereas we see a dip in brightness of nearly 2.7 magnitudes when the primary star is eclipsed by the secondary, the dip in brightness that occurs when the primary eclipses the secondary is too small to be seen visually.
The primary is believed to be a B type main sequence star of around 4 solar masses. The secondary is an evolved G type giant star of around 3 solar masses that is very slowly losing mass to the primary. This transfer of mass very slowly alters the orbital period of the system. Consequently over a period of time, the eclipses slowly move away from the times predicted by the GCVS. By monitoring the times of eclipses and seeing how their times compare with GCVS predictions we can detect these changes.

Eclipses of U Cephei last approximately 9 hours. By making brightness estimates every 15 minutes or so, a few hours either side of the predicted times, you can follow the course of the eclipse, seeing it fade to minimum, stay at a flat minimum for around 2 hours and then brighten again. The flat minimum indicates that the eclipse is total.



Above are estimates of U Cephei made in January 2009. They have been used to construct a light curve which is fairly symmetrical. Now and then the system undergoes phases of larger mass transfer which alter the appearance of the accretion disk surrounding the secondary star. 12.In these circumstances the light curve is not symmetrical. Amateur astronomers may be the first observers to pick up these changes. They can render a real service to science by alerting the professional community,

4.6 Other Eclipsing Binaries

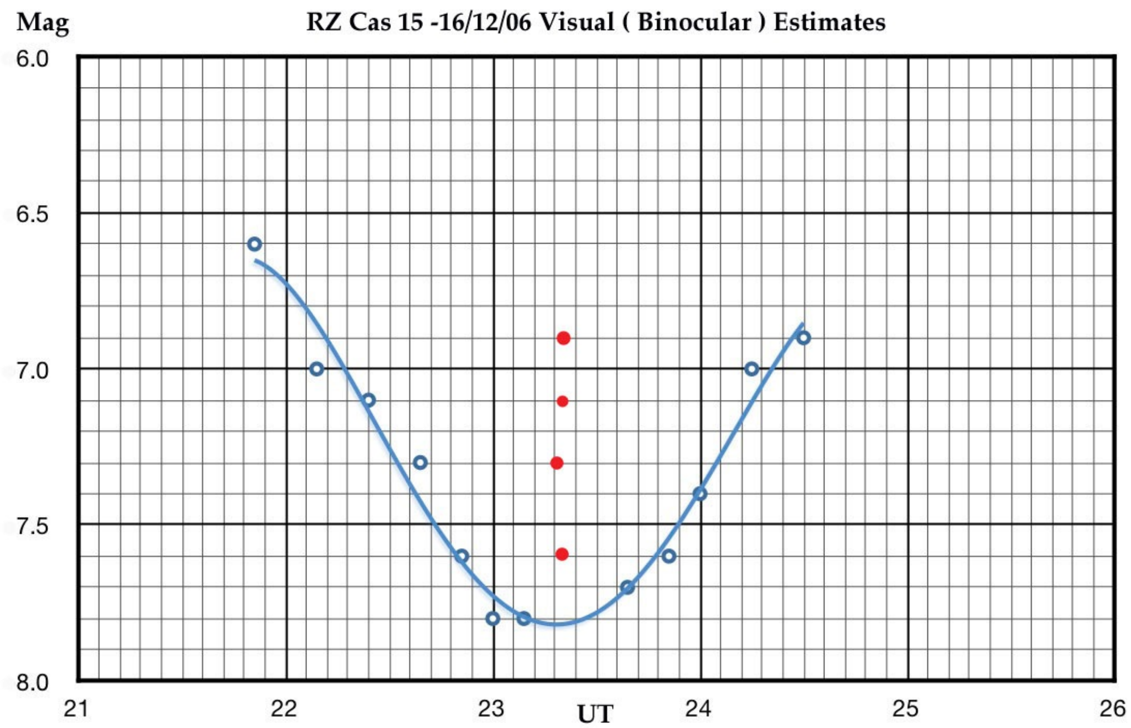
Once you have trained on the above five systems there are many others to look at. There are 61 Eclipsing Binaries on the BAAVSS's list of interesting systems that may do something unexpected. In any case all of these systems are worth monitoring. The whole list is contained within an appendix to this Handbook. For the most up to date information see the Section's website.

MORE ADVANCED MATTERS:

5. Estimating mid-eclipse from a light curve.

When you have made your first observations of an eclipse you will hopefully have made at least five estimates of the fade and five of the rise. Ideally you should aim for seven.

Using graph paper or a computer graphics programme, or the chart facility within a spreadsheet programme such as Excel, you construct a diagram where magnitude is the vertical axis and time is the horizontal axis. Magnitude has been estimated to the nearest tenth and time to the nearest minute. So that we can compare results across time zones by time we mean Universal Time (UT) and not British Summer TIme (BST).



Above is a diagram of RZ Cas observations where magnitude is plotted against time. It can be seen that the main time divisions are the hours in Universal Time.

A quick look of the plotted estimates will give an idea of the symmetry of the eclipse and a good indication of the minimum and the mid point of the minimum.

Studying the plotted estimates, using a pencil, the next step is draw, by eye, a best fit curve that will link all the estimates. A pencil (and a rubber) is used as several attempts may have to be made before the best fit curve is finalised. In all attempts it has to be borne in mind that visual estimates can have an error of plus or minus 0.1 magnitude.

Once the light curve has been drawn, lines are drawn, as in the figure above between points of equal magnitude. This line is called a chord. A ruler is used to mark the mid point of the chord (red). You will therefore have a series of mid points. The average of these points becomes your estimate of mid-eclipse. This method of determining mid-eclipse is called the bisected chord method. Using the bisected chord method the time of mid-eclipse was estimated to be 23.33 hours or about 23 hours and 20 minutes.

It may seem a bit rough and ready but should determine a mid point to within plus or minus three minutes. This method becomes especially useful when an eclipsing binary has not been studied for some years. The difference between the observed time and the predicted time can easily be half an hour after a gap of years and this can be picked up by a visual observer. There have been occasions when two or three BAA members have been able to observe the same eclipse on the same night. This can allow, by comparing all three estimations of mid-eclipse, a refined overall estimate to be made. Team work in the field of eclipsing binaries can produce good science.

5.1 Julian Date

The Julian day system was introduced by astronomers to provide a single system of dates that could be used when working with different calendars and to unify different historical chronologies.

The actual **Julian date** (JD) is the interval of time in days and fractions of a day, since January 1, 4713 BC Greenwich noon. This means that 18.00 UT on 8th June 2011 becomes JD 2455721.25. A shortened form of expressing this date and time would be JD 5721.25 (omitting the first 245). The horizontal time axis on a light curve can be expressed in Julian Date (JD) terms.

The Julian Date is most useful when compiling observations from different observers around the world.

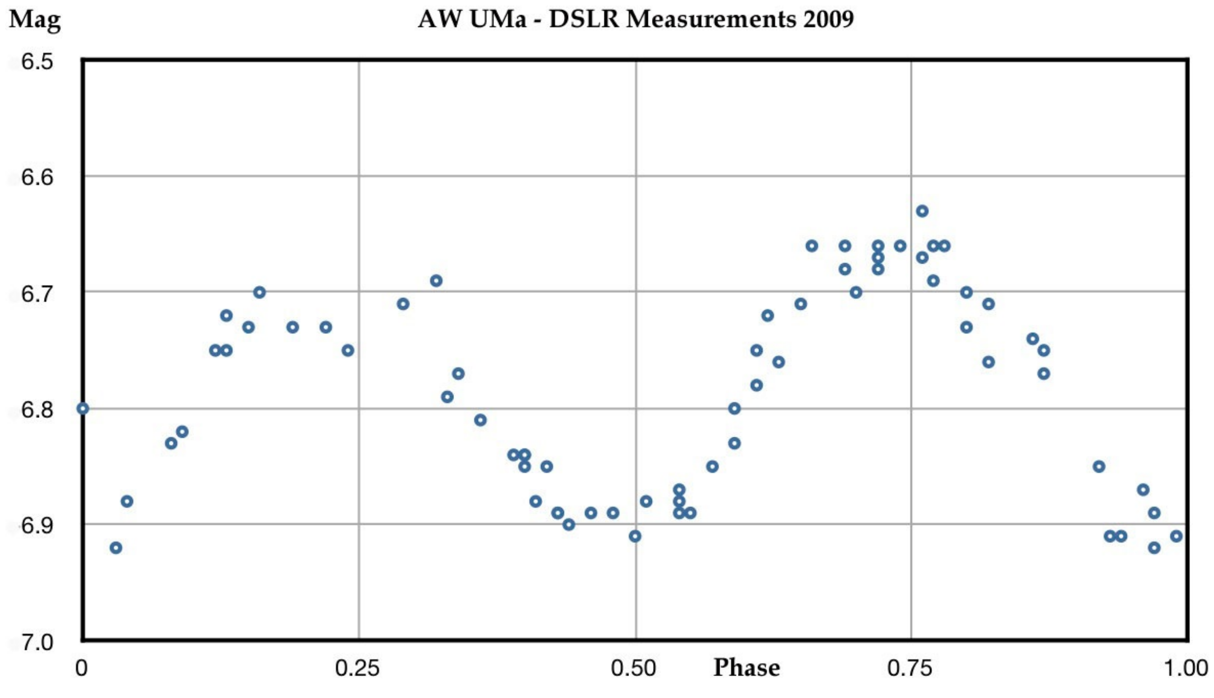
6. Combining Estimates From Different Nights - Using a Phase Diagram.

A phase diagram is a modification of a light curve diagram that presents estimates of an eclipsing binary that were made over several nights, sometimes over a period of a couple of months.

Phase diagrams are used because it is often impossible to observe a full eclipse in one night for a number of reasons: changing weather conditions, too low down in the sky at either start or finish, twilight intervenes or the eclipse is simply too long to observe in one night. Some systems such as Beta Lyrae are always in eclipse. To get a full light curve (and to gradually account for the part taking place in daylight) it is inevitable that several eclipses will have to be observed.

Phase diagrams are constructed on the assumption that the period of the system is unchanging or has not changed significantly. That is usually an acceptable assumption if the estimates are made over a period of about two months or less.

Below is a phase diagram constructed in 2009. It incorporates estimates of the eclipsing binary system AW UMa (EW class) over a period of two months. The vertical axis is still magnitude.



The horizontal axis represents the decimalised period of the system where 0 is the time of the primary mid-eclipse and 0.5 the time of the secondary mid-eclipse. 0.25 and 0.75 are the times of mid maxima.

The conversion of the time of an observation to a phase value is usually done with a spreadsheet. This is the quickest method as steps in the calculation can be automated with simple formulae.

Before we start the calculation we have to know the current period of the system (P1) and the latest listed Heliocentric Julian Date (HJD) (see appendix 9.7) time of the mid-eclipse (T1). These two values can be obtained from the Krakow website, <http://www.as.up.krakow.pl/o-c/>. At the site click on 'Constellation List', then 'Cyg', then 'V367', then 'current minima and phase' to be found two thirds of the way down the page, then look at Light Elements which has a period of 18.59778 days (P1). Then, under 'Computed times of minima' and HJD is the latest time and date of a predicted primary eclipse (T1).

The steps in the calculation are:

V367 Cyg	Date	JD	T	JD+T	Elapsed Time	Phase	P	Magnitude
P=18.59778	17 May 2010	5334	23.40	5,334.4750	15.3670	0.8263	0.83	-7.02
Base=5319.108	23 May 2010	5339	0.15	5,338.5063	19.3983	1.0430	0.04	-7.24
	23 May 2010	5339	0.75	5,338.5313	19.4232	1.0444	0.04	-7.24
	24 May 2010	5340	0.15	5,339.5063	20.3983	1.0968	0.10	-7.05
	23 Jul 2010	5401	23.10	5,401.4625	82.3545	4.4281	0.43	-7.28
	27 Jul 2010	5405	22.40	5,405.4333	86.3253	4.6416	0.64	-7.10
	31 Jul 2010	5409	23.80	5,409.4917	90.3837	4.8599	0.86	-7.17
	4 Aug 2010	5413	22.40	5,413.4333	94.3253	5.0718	0.07	-7.38
	5 Aug 2010	5414	22.20	5,414.4250	95.0000	5.1081	0.11	-7.20
	9 Aug 2010	5418	23.30	5,418.4708	99.3628	5.3427	0.34	-7.17
	14 Aug 2010	5423	22.85	5,423.4521	104.3440	5.6105	0.61	-7.21
	15 Aug 2010	5424	22.65	5,424.4438	105.3358	5.6638	0.66	-7.13
	18 Aug 2010	5427	22.00	5,427.4167	108.3087	5.8237	0.82	-7.07
	20 Aug 2010	5429	22.30	5,429.4292	110.3212	5.9319	0.93	-7.44
	21 Aug 2010	5430	22.30	5,430.4292	111.3212	5.9857	0.99	-7.73

1. Calculate the Julian Date of your observation (T2) when hours/ minutes are a decimalised part of a day. The JD of 9.11 pm on the 10th June 2011 is 2455722.38263.

2. Calculate the time that has elapsed since the last listed mid minimum: (T2-T1)=T3

3. Calculate the period/ periods that have elapsed since T1. T3 is divided by P1. In the resulting value the numbers after the decimal point represents the phase value. If the value was 5.1378 then the magnitude would be plotted at 0.1378 on the horizontal axis.

Below are some actual calculations of the measurements of the system V367 Cyg (EB Class) using a spreadsheet. The magnitude is expressed as a minus number in order to make it easier to plot a chart on the Mac programme 'Numbers'.

Within the above spreadsheet:

The current period (P1) is 18.59778 days.

JD +T is the time of the observation (T2). It is the Julian Day (Column C) plus the decimalised Universal Time (Column D). From the figure in the D column is subtracted 12 (as the Julian Day starts at midday and not midnight). The resultant figure is divided by 24 to arrive at the fraction of the Julian Day which is stated in Column E.

Elapsed time, column F, is the time since the chosen time of the predicted primary eclipse (T2-T1). T1 is a predicted time of primary eclipse prior to the observations in 2010. On the Krakow website the chosen time of eclipse, prior to the measurements, was 2455319.108. For our purposes the first three figures can be ignored. The calculations within the spreadsheet are performed using the number 5319.108.

Phase (Column G) is the elapsed time (column F) divided by the period (P1).

'P' (Column H) is the decimal part of the period that the observation was made.

Magnitude (Column I) is, of course, the observed magnitude of the star. It is expressed to two decimal places as the observations were the result of DSLR photometry and were not visual.

After a couple of months of perhaps 50 estimates a good light curve should emerge. If the period stated on an international database is correct then the mid point of the primary maxima will be clearly centred on 0. If it is not then the period of the system has changed. Secondary maxima will be centred on 0.5.

* ***Note that a phase diagram is a way of combining not only your observations on different nights but also the observations of many observers on different nights.***

* ***Sometimes partial phase diagrams are constructed which record estimates around the time of primary eclipse. Such a diagram may run from 0.8 to 1/0.0 to 0.2. Partial diagrams are used for EA systems with longer periods. Outside of eclipses the system may be constant and of limited interest.***

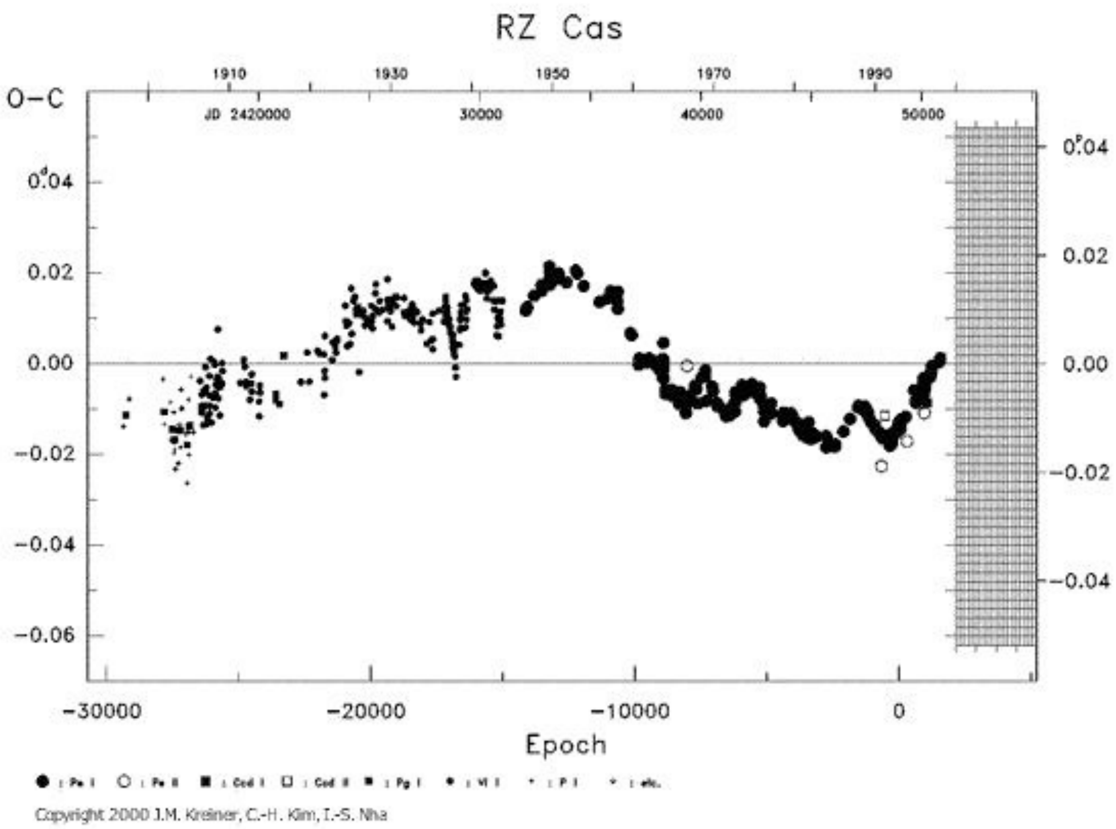
7. Tracking Period Changes

The study of the period changes of an eclipsing binary system can be of great importance. For semidetached and contact systems it can cast light on mass transfer rates. Period changes can be evidence of stellar evolution or reveal the presence of a third component in the system.

To illustrate the changes a diagram is constructed in which a horizontal axis is time and the vertical axis is a fraction of a day. On the diagram is plotted the difference between the observed (O) time of mid-eclipse and the calculated (C) time of mid eclipse (according to an international database). Such a diagram is called an O/C Diagram.

If the period is longer than the calculated period the plots will slope upwards. If the period is shorter it will slope downwards. Abrupt changes in slopes illustrate sudden changes in period. Gradual changes take the form of a gradual curve.

Taken from the Krakow database is an O/C diagram for RZ Cas. Note that the time axis covers over a 100 years. It can be seen that there are broad trends and there are also short term variations when the period may increase or decrease. The grid on the right is there so that you can print off the diagram and accurately add your observation to see how it fits in with recent trends.



8. Predictions.

Once you have practised with the five eclipsing binaries that we have suggested you can move on to study many more. Printed predictions of Algol, RS CVn and RZ Cas are available in the BAA Annual Handbook.

The BAA Variable Star Section Circular is produced every three months and contains a regular Eclipsing Binary News which highlights interesting systems and (international) campaigns to observe a specific system or systems.

Predictions of a large number of EBs can be obtained from the Krakow website at< https://www.as.up.krakow.pl/ephem/>. For RZ Cas, when you reach the website, click on constellation, then Cas, then RZ and, finally, 'current minima and phase' (see also p15 4th paragraph). It should be noted that predictions on the Krakow website are calculated based on your computer time.

The Eclipsing Binary Secretary of the BAA VSS is always willing to make suggestions of systems to observe.

This is a beginners's guide so we have not dealt with more challenging observations. We can support and guide those observers who wish to tackle these.

If you have a telescope you may prefer to observe fainter systems, where the minima may go below magnitude 13. Similarly, if you have a CCD camera your observation can be more accurate and reveal subtle features in the light curve as well as reaching even fainter magnitudes.

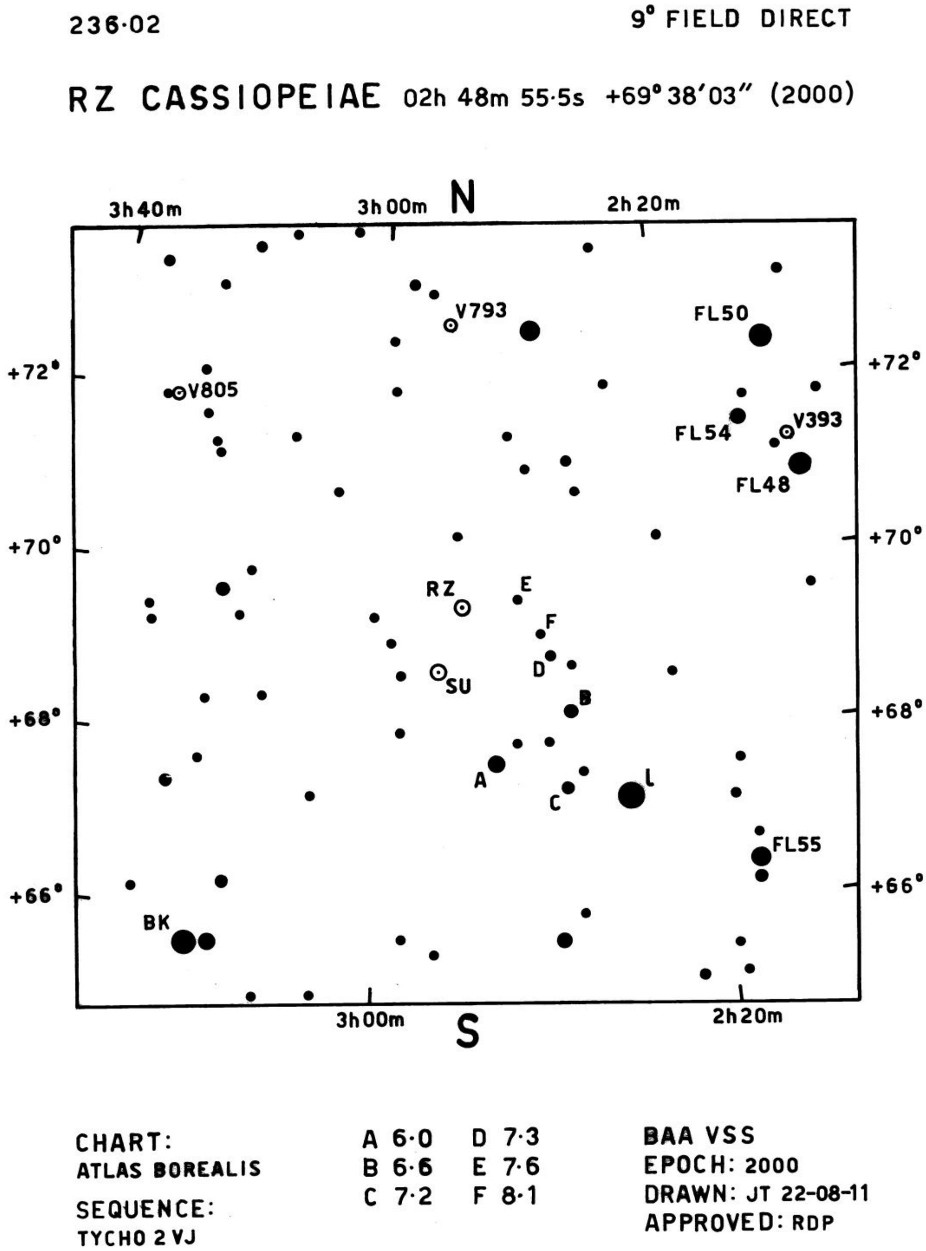
In addition, with a DSLR camera you will be able to see more subtle changes in the light curve although you'll probably be limited to stars no fainter than a visual observer can see with just a pair of binoculars. An undriven DSLR camera can do good photometry down to magnitude 9.5 with exposures of 5 seconds. A DSLR camera attached piggy back on a driven telescopic mount can be used down to magnitude 11.5 with exposures of 30 seconds.

All your observations should be submitted to the BAAVSS database. If you have done enough observations to calculate the current time of mid eclipse of a system then the time (expressed as Heliocentric Julian Date) can be submitted to the Krakow database where it will be used to refine predictions.

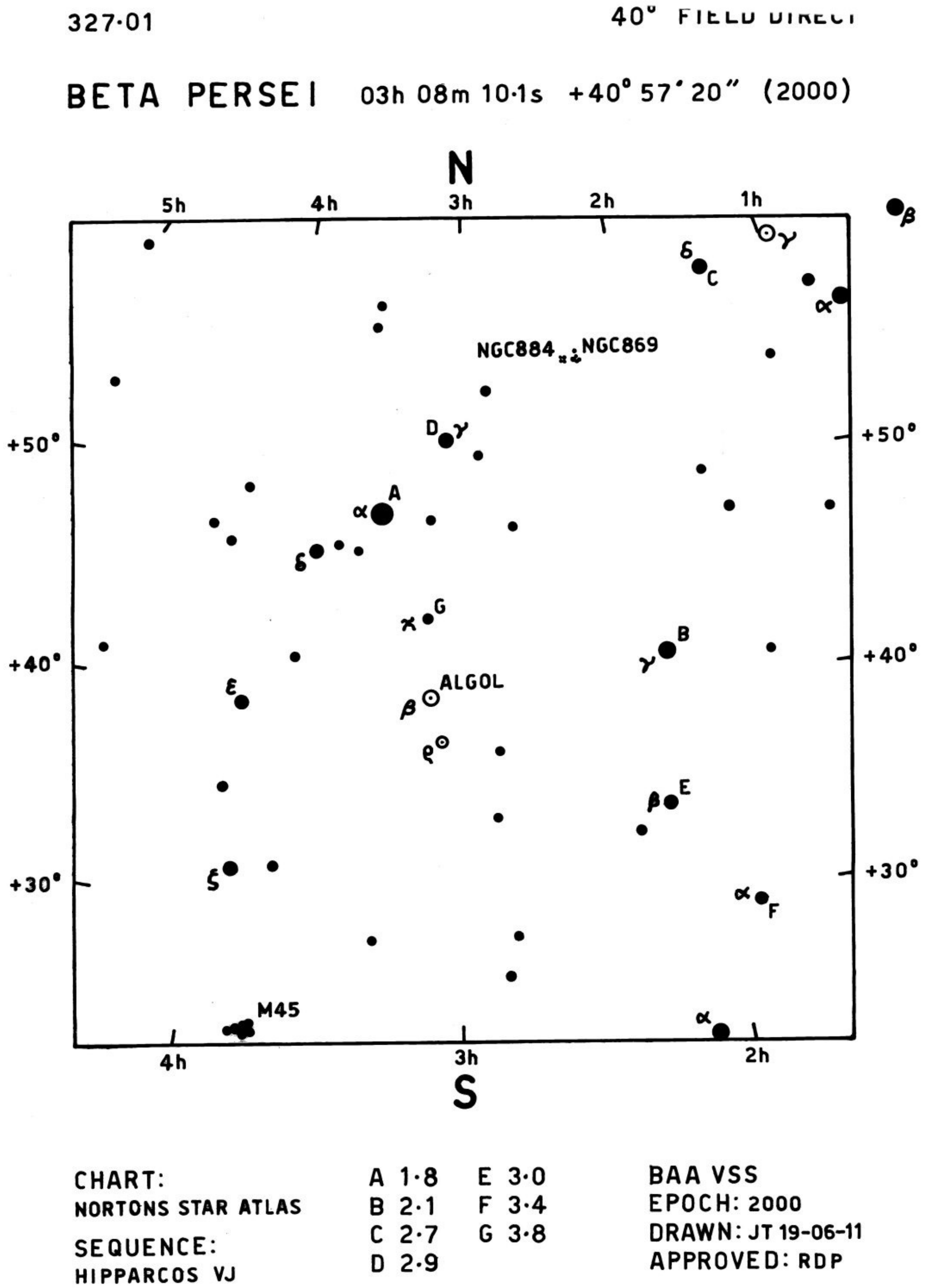
9. APPENDICES

9.1 The Five Charts

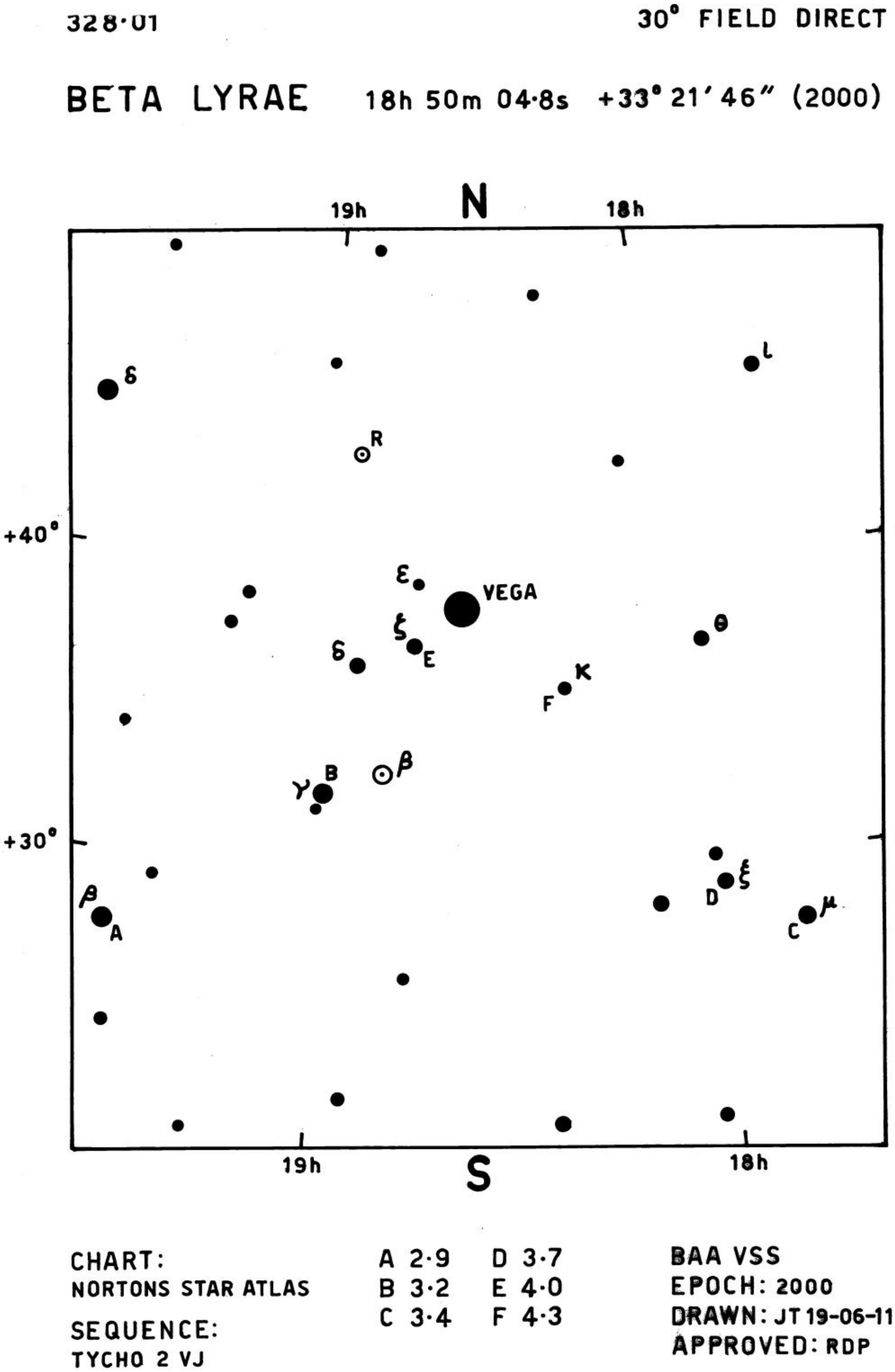
9.1.1 - RZ Cas



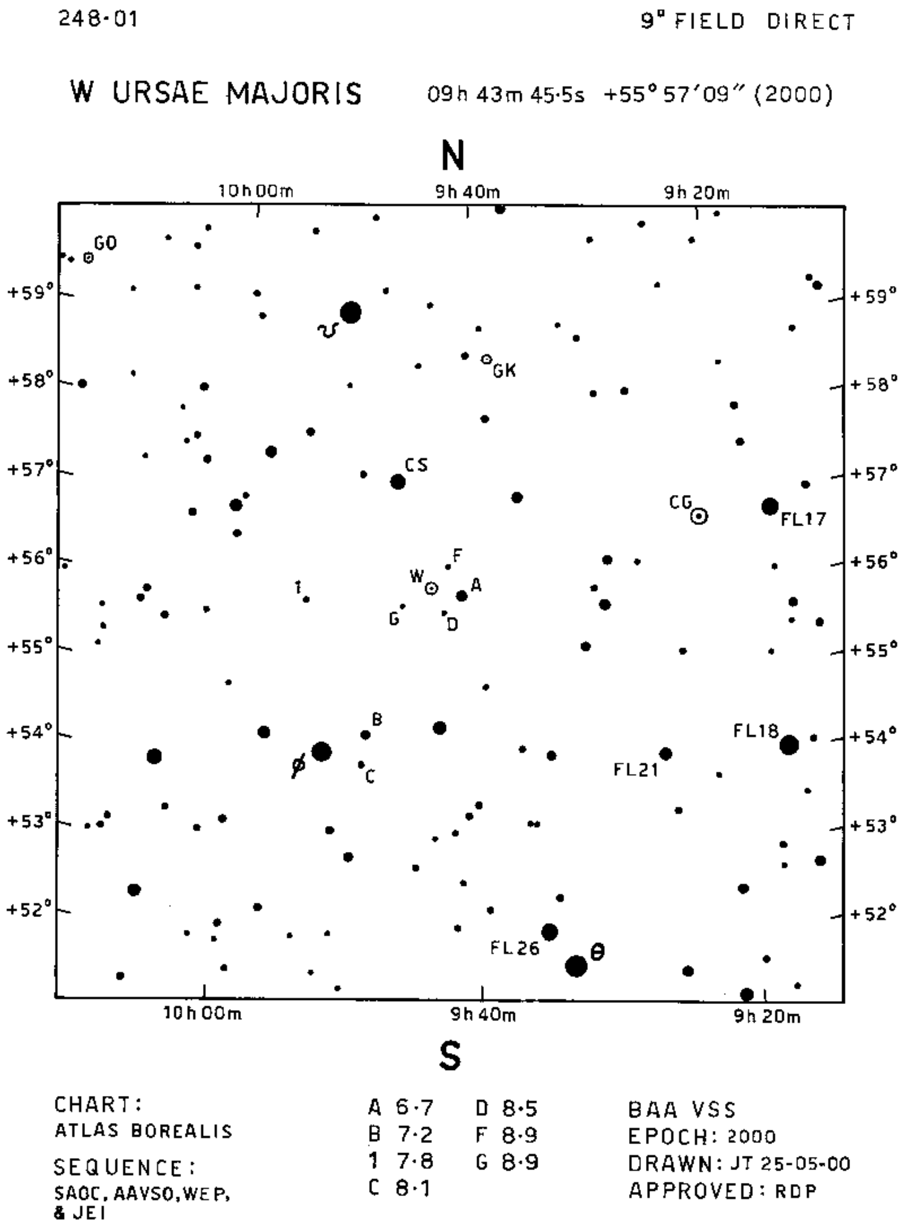
9.1.2 Beta Persei - Algol



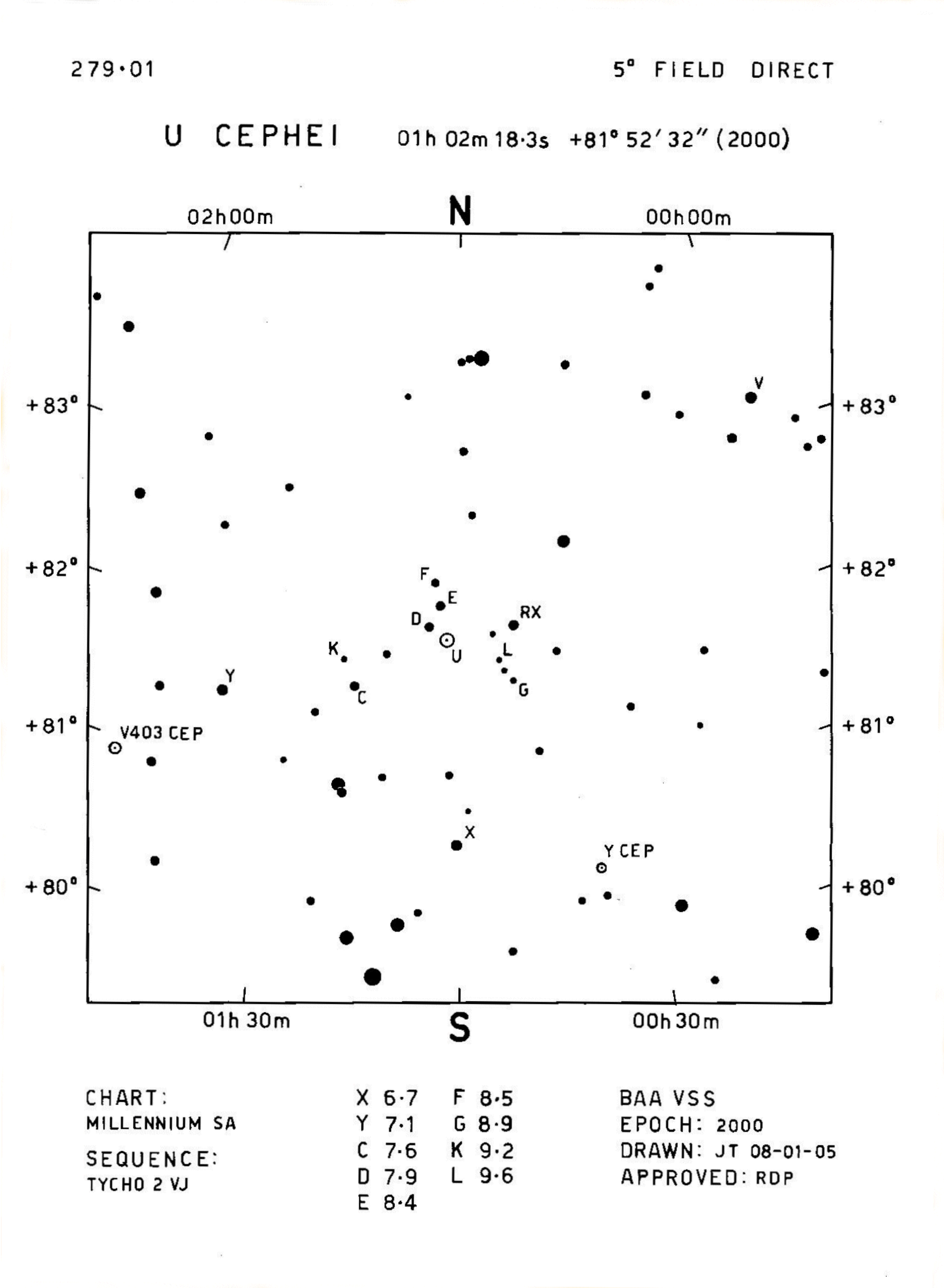
9.1.3 Beta Lyrae



9.1.4 - W Ursae Majoris



9.1.5 - U Cephei



279·01
5° FIELD DIRECT
U CEPHEI 01h 02m 18·3s +81° 52′ 32″ (2000)
N
02h00m
00h00m
+83°
+82°
+81°
+80°
F
E
D
RX
K
U
L
G
Y
C
V403 CEP
X
Y CEP
V
01h 30m
00h 30m
S
CHART:
MILLENNIUM SA
SEQUENCE:
TYCHO 2 VJ
X 6·7
Y 7·1
C 7·6
D 7·9
E 8·4
F 8·5
G 8·9
K 9·2
L 9·6
BAA VSS
EPOCH: 2000
DRAWN: JT 08-01-05
APPROVED: RDP

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9.2

The BAAVSS Eclipsing Binary Programme

The information here has been expanded compared with the first edition of this Handbook. Thanks to Chris Lloyd the tables contain under the name of the star a link to SIMBAD; under Chart a link to the BAAVSS website where a chart can be downloaded; under VSX a link to information on the star on the AAVSO website.

The 'Max' and 'Min' magnitudes are all visual.

In the Eclipsing Binary Program list, the Period column is in days (d), the 'D' column gives the duration of the eclipse in hours. This is only well-defined for Algol type (EA) stars. 'EB' or 'EW' in this column indicates that the star is a Beta Lyrae or W UMa star.

Beginner's Eclipsing Binaries

Star	RA	Dec	Max	Min1	Min2	Period (d)	D (h)	Chart	VSX	VAR Type	Range
beta Lyr	18 50	33 21	3.3	3.9	4.4	12.945272	EB	328.01	18631	EB	1.05
beta Per	03 08	40 57	2.1	2.2	3.4	2.86736	10	327.01	26202	EA/ SD	1.2
RZ Cas	02 48	69 38	6.18	6.3	7.72	1.195247	5	236.02	6348	EA/ SD	1.54
U Cep	01 02	81 52	6.75	6.9	9.24	2.493087	9	279.01	8356	EA/ SD	2.49
W UMa	09 43	55 57	7.8	8.4	8.48	0.3336375	EW	248.01	37110	EW/ KW	0.73

Priority Eclipsing Binaries

Star	RA	Dec	Max	Min 1	Min2	Period (d)	D (h)	Chart	VSX	VAR Type	Range
OO Aql	19.48	9.18	9.2	9.9	9.9	0.506792	EW	1984 Dec23	1441	EW/ DW	0.7
AR Aur	05 18	33 46	6.15	6.7	6.82	4.134695	7	283.01	3833	EA/ DM	0.67
EO Aur	05 18	36 38	7.6	7.9	8.13	4.065637	12	283.01	3920	EA/ DM	0.57
IM Aur	05 15	46 24	7.9	8.1	8.51	1.247296	6	1972 Feb04	3992	EA	0.61
LY Aur	05 29	35 22	6.66	7.3	7.35	4.0024932	EB	283.01	4035	EB/ SD	0.69
ZZ Boo	13 56	25 55	6.8	7.4	7.44	4.991744	7	253.01	4357	EA/ DM	0.65
TV Cas	00 19	59 08	7.22	7.3	8.22	1.8125997	8	1982 Aug16	6359	EA/ SD	1.00
TW Cas	02 45	65 43	8.3	8.4	8.98	1.428324	5	273.01	6360	EA	0.66
U CrB	15 18	31 38	7.66	7.7	8.79	3.4522013	11	254.01	10603	EA/ SD	1.13
RS CVn	13 10	35 56	7.93	8.2	9.14	4.797887	13	253.01	5028	EA/ AR/ RS	1.21

Star	RA	Dec	Max	Min1	Min 2	Period (d)	D (h)	Chart	VSX	Var Type	Range
V367 Cyg	20 47	39 17	6.67	7.2	7.6	18.59773	EB	1986Jul06	11287	EB/KE	0.93
Z Dra	11 45	72,14	10.8	11	14.1	1.357456	5	1993Jan10	13681	EA/SD	3.3
TW Dra	15 33	63 54	7.4	7.5	9.9	2.806847	11	274.01	13702	EA/SD	2.5
AI Dra	16 56	52 41	7.1	7.2	8.1	1.1988146	5	284.01	13735	EA/SD	1.04
BH Dra	19 03	57 27	8.4	8.5	9.3	1.8172386	5	285.01	13758	EA/SD	0.89
S Equ	20 57	05 04	8.35	8.4	10.4	3.436106	11	286.01	13954	EA/SD	2.05
68 u Her	17 17	33 06	4.7	4.9	5.37	2.051027	14	1971Aug27	15899	EA/SD	0.68
Z Her	17 58	15 08	7.3	8.2	8.18	3.9928077	11	1972Feb06	14820	EA/ AR/RS	0.88
AR Lac	22 08	45 44	6.08	6.4	6.77	1.983192	7	1971Feb13	16660	EA/ AR/RS	0.69
UV Leo	10 38	14 16	8.9	9.5	9,56	0.6000873	3	1987Nov	17066	EA/ DW	0.66

Star	RA	Dec	Max	Min1	Min 2	Period (d)	D (h)	Chart	VSX	Var Type	Range
V566 Oph	17 56	04 59	7.46	7.9	7.96	0.4096457	EW	1972Jun11	21052	EW/ KW	0.50
EE Peg	21 40	09 11	6.93	7.1	7.51	2.6282142	6	245.01	25271	EA/DM	0.58
IQ Per	3.59	48 09	7.72	7.9	8.27	1.7435701	5	246.01	25758	EA/DM	0.55
U Sge	19 18	19 36	6.45	6.7	9.28	3.3806193	14	287.01	27345	EA/SD	2.83
lambda Tau	04 00	12 29	3.37	3.91	3.5	3.9529478	14	1993Oct22	36240	EA/DM	0.54
RW Tau	04 03	28 07	7.98	8.1	11.59	2.768804	9	1984Dec18	35032	EA/SD	3.61
HU Tau	04 38	20 41	5.85	5.9	6.68	2.0562997	7	247.01	35238	EA/SD	0.83
TX UMa	10 45	45 33	7.06	7.1	8.8	3.063295	9	288.01	37135	EA/SD	1.74
Z Vul	19.21	25 34	7.25	7.6	8.9	2.454934	11	255.01	38184	EA/SD	1.65

Star	RA	Dec	Max	Min 1	Min 2	Period (d)	D (h)	Chart	VSX	Var type	Range
TW And	00 03	32.51	8.8	8.9	10.9	4.122834	13	AAVSO 122901	30	EA	2.08
AD And	23 36	48.40	11.2	11.6	11.82	0.986202	EB	1984 Dec22	58	EB	0.62
IU Aur	05 27	34 46	8.19	8.7	8.83	1.8114754	EB	1984 Dec24	4000	EB/ SD	0.64
SX Aur	05 11	42.19	8.38	8.9	9.14	1.2100802	EB	1984 Dec23	3786	EB	0.76
BM Cas	00 54	64.05	8.78	9	9.31	197.28	EB	1986 Jul05	6420	EB	0.53
DO Cas	02 41	60 33	8.39	8.6	9.01	0.684666	EB	1986 Jul05	6468	EB/ KE	0.62
EG Cep	20 15	76 48	9.31	9.6	10.21	0.5446218	EB	AAVSO 0801	8503	EB	0.9
GK Cep	21 30	70 49	6.89	7.4	7.37	0.936157	EB	1971 Dec02	8545	EB/ KE	0.48
V448 Cyg	20 06	35 23	7.9	8.4	8.72	6.5197162	EB	1986 Jul06	11368	EB/ SD	0.82
V477 Cyg	20 05	31 58	8.5	8.7	9.34	2.3469906	4	1972 Feb05	11397	EA/ DM	0.84
RX Her	18.30	12 36	7.28	7.7	7.87	1.7785724	6	1972 Jun12	14827	EA/ DM	0.59
SW Lac	22 53	37 56	8.51	9.3	9.49	0.3207152	EW	1987 Nov	16612	EW/ RS	0.98
AP Leo	11 05	05 09	9.32	9.9	9.91	0.430358	EW	1987 Nov	17100	EW/ KW	0.59
TZ Lyr	18 15	41 06	10.87	10.8	11.85	0.528827	EB	1987 Nov	18073	EB	0.98
V505 Mon	06 45	02 29	7.15	7.6	7.65	53.7805	EB	1971 Aug22	19333	EB/ GS/ D	0.50
CD Tau	05 17	20.07	6.77	7.3	7.34	3.435137	7	1972 Feb04	35122	EA/D	0.57

Low Amplitude Eclipsing Binaries

Here is a selection of ten low amplitude eclipsing binaries. These will have been neglected by visual observers because of their low amplitude. They are, however, suitable targets for DSLR photometry. Charts and comparisons can be obtained by contacting the BAA Eclipsing Binary Secretary.

Star	RA	Dec	Max	Min 1	Min 2	Period(d)	Class	Chart	VSX	Var Type	Range
AO Cas	0.17	51.25	6.07	6.3	6.24	3.523487	ELL/KE		6398	ELL	0.17
YZ Cas	0.45	74.59	5.71	6.05	6.12	4.4672224	EA		6383	EA/DM	0.41
CC Cas	3.14	59.33	7.06	7.25	7.30	3.368753	EB		6434	EB/DM	0.24
CQ Cep	22.36	56.54	8.63	9.12	9.27	1.641249	EB		8469	EB/DM/WR	0.49
CW Cep	23.04	63.23	7.60	8.04	8.04	2.72914	EA		8475	EA/DM	0.44
VW Cep	20.37	75.36	7.38	7.78	7.68	0.2783089	EW	1972 Mar21	8393	EW/KW	0.40
AH Cep	22.47	65.03	6.88	7.08	7.08	1.7747505	EB		8414	EB/DM	0.29
V1425 Cyg	21.11	55.19	7.70	8.13	8.03	1.252387	EB		12345	EB/KE	0.45
AW UMa	11.3	29.57	6.83	7.13	7.03	0.4387299	EW		37180	EW/KW	0.30
V1061 Tau	4,58	24.29	7.95	8.45	8.33	1.385217	EB		36078	EB/KE	0.5

9.3 Useful Reading and References

Observing Guide To Variable Stars - BAAVSS (2004)

This can be obtained from the British Astronomical Association, Burlington House, Piccadilly, London W1J 0DU. <https://britastro.org>.

Webb Society Deep Sky Observer's Handbook - Volume 8 Variable Stars by John Isles (1990) ISBN 0-89490-208-3

This can be obtained from the British Astronomical Association, Burlington House, Piccadilly, London W1J 0DU. <https://britastro.org>.

Understanding Variable Stars by J R Percy (2007) CUP ISBN 978-0-521-23253-1

Observing Variable Stars - A Guide For the Beginner by D H Levy (1989) CUP ISBN 0-521-32113-1

An Atlas of O-C Diagrams of Eclipsing Binary Stars: Mt Suhora Astronomical Observatory, Cracow Pedagogical University:<http://www.as.up.krakow.pl/ephem>.

Binary Stars - A Pictorial Atlas: Terrell, Mukherjee and Wilson: (1992) Kreiger Publishing Company ISBN 0-89464-698-2

Observing Variable Stars, Novae and Supernovae - Gerald North (2004) CUP ISBN 0-521-82047-2

Measuring Variable Stars Using a CCD Camera - A Beginners Guide - BAAVSS (2006)

This can be obtained from the British Astronomical Association, Burlington House, Piccadilly, London W1J 0DU: <https://britastro.org>.

BAAVSS Circulars - published every three months - contact the Circulars Editor (see BAAVSS Officers).

9.4 Useful Websites

The British Astronomical Association Variable Star Section: <http://www.britastro.org/vss>

American Association of Variable Star Observers: www.aavso.org

General Catalogue of Variable Stars:<http://www.sai.msu.su/gcvs/gcvs/index.htm>

Bundesdeutsche Arbeitsgemeinschaft fur Veränderliche Sterne: www.bav-astro.de/index.php?sprache-en

Wikipedia: http://en.wikipedia.org/wiki/Binary_star

9.5 BAAVSS Officers

Director: Professor Jeremy Shears, Pemberton, School Lane, Tarporley, Cheshire CW6 9NR. Tel: 07795 223869, <**bunburyobservatory@hotmail.com**>

Assistant Director: Roger Pickard, 3 The Birches, Shobdon, Leominster, Herefordshire HR6 9NG. Tel: 01568 708136 E-mail: <**roger.pickard@sky.com**">.

Secretary: Bob C Dryden, 21 Cross Road, Cholsey, Oxon. OX10 9PE.
Tel: 01491 652006, visual.variables@britastro.org

Chart Secretary: John Toone, Hillside View, 17 Ashdale Road, Cressage, Shewsbury SY5 6DT. Tel: 01952 510794, Email: <**enootnhoj@btinternet.com**>.

Pulsating Stars Coordinator: Shaun Albrighton, 4 Walnut Close, Hartshill, Nuneaton, Warwickshire, CV10 0XH. Tel: 02476 397183 Email: <**shaunalbrighton93@gmail.com**>.

Nova/ Supernova Secretary: Guy M Hurst, 16 Westminster Close, Basingstoke, Hants RG22 4PP, Tel and Fax: 01256 471074, Email: **guy@tahq.org.uk**>.

Eclipsing Binary Secretary: Des Loughney, 113 Kingsknowe Road North, Edinburgh EH14 2DQ. Tel: 0131 477 0817, Email: desloughney@blueyonder.co.uk

Database Secretary: Andy Wilson, 12 Barnard Close, Yatton, Bristol B44 0QE.
Tel: 01934 830 683. Email: andyjwilson_uk@hotmail.com

CV's and Eruptive Stars Co-ordinator, Circulars Editor & Webmaster: Gary Poyner, 67 Ellerton Road, Kingstanding, Birmingham B44 0QE. Tel: 07876 077855, Email: <**garypoyner@gmail.com**>.

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Email: office@britastro.com
Website: www.britastro.org

9.6 General Catalogue of Variable Stars: Classification of Eclipsing Binaries

The following section has been taken from the GCVS web site at: <http://www.sai.msu.su/gcvs/gcvs/iii/vartype.txt>

Close Binary Eclipsing Systems

We adopt a triple system of classifying eclipsing binary systems: according to the shape of the combined light curve, as well as to physical and evolutionary characteristics of their components.

The classification based on light curves is simple, traditional, and suits the observers; the second and third classification methods take into account positions of the binary-system components in the (MV ,B-V) diagram and the degree of inner Roche lobe filling. Estimates are made by applying the simple criteria proposed by Svechnikov and Istomin (1979). The symbols for the types of eclipsing binary systems that we use are given below.

a) Classification based on the shape of the light curve

E Eclipsing binary systems. These are binary systems with orbital planes so close to the observer's line of sight (the inclination i of the orbital plane to the plane orthogonal to the line of sight is close to 90 deg) that the components periodically eclipse each other. Consequently, the observer finds changes of the apparent combined brightness of the system with the period coincident with that of the components' orbital motion.

EA Algol (Beta Persei)-type eclipsing systems.

Binaries with spherical or slightly ellipsoidal components. It is possible to specify, for their light curves, the moments of the beginning and end of the eclipses. Between eclipses the light remains almost constant or varies insignificantly because of reflection effects, slight ellipsoidality of components, or physical variations. Secondary minima may be absent. An extremely wide range of periods is observed, from 0.2 to >= 10000 days. Light amplitudes are also quite different and may reach several magnitudes.

EB Beta Lyrae-type eclipsing systems.

These are eclipsing systems having ellipsoidal components and light curves for which it is impossible to specify the exact times of onset and end of eclipses because of a continuous change of a system's apparent combined brightness between eclipses; secondary minimum is observed in all cases, its depth usually being considerably smaller than that of the primary minimum; periods are mainly longer than 1 day. The components generally belong to early spectral types (B-A). Light amplitudes are usually <2 mag in V.

EW W Ursae Majoris-type eclipsing variables.

These are eclipsers with periods shorter than 1 days, consisting of ellipsoidal components almost in contact and having light curves for which it is impossible to specify the exact times of onset and end of eclipses. The depths of the primary and secondary minima are almost equal or differ insignificantly. Light amplitudes are usually <0.8 mag in V. The components generally belong to spectral types F-G and later.

b) Classification according to the components' physical characteristics

GS Systems with one or both giant and supergiant components; one of the components may be a main sequence star.

PN Systems having, among their components, nuclei of planetary nebulae (UU Sge).

RS RS Canum Venaticorum-type systems. A significant property of these systems is the presence in their spectra of strong Ca II H and K emission lines of variable intensity, indicating increased chromospheric activity of the solar type. These systems are also characterized by the presence of radio and X-ray emission. Some have light curves that exhibit quasi sine waves outside eclipses, with amplitudes and positions changing slowly with time. The presence of this wave (often called a distortion wave) is explained by differential rotation of the star, its surface being covered with groups of spots; the period of the rotation of a spot group is usually close to the period of orbital motion (period of eclipses) but still differs from it, which is the reason for the slow change (migration) of the phases of the distortion wave minimum and maximum in the mean light curve. The variability of the wave's amplitude (which may be up to 0.2 mag in V) is explained by the existence of a long-period stellar activity cycle similar to the 11-year solar activity cycle, during which the number and total area of spots on the star's surface vary.

WD Systems with white-dwarf components.

WR Systems having Wolf-Rayet stars among their components (V 444 Cyg).

c) Classification based on the degree of filling of inner Roche lobes

AR Detached systems of the AR Lacertae type. Both components are subgiants not filling their inner equipotential surfaces.

D Detached systems, with components not filling their inner Roche lobes.

DM Detached main-sequence systems. Both components are main-sequence stars and do not fill their inner Roche lobes.

DS Detached systems with a subgiant. The subgiant also does not fill its inner critical surface.

DW Systems similar to W UMa systems in physical properties (KW, see below), but not in contact.

ELL Systems in contact or nearly in contact where the components are ellipsoidal and this can be seen in the light curve.

K Contact systems, both components filling their inner critical surfaces.

KE Contact systems of early (O-A) spectral type, both components being close in size to their inner critical surfaces.

KW Contact systems of the W UMa type, with ellipsoidal components of F0-K spectral type. Primary components are main-sequence stars and secondaries lie below and to the left of the main sequence in the (MV,B-V) diagram.

SD Semidetached systems in which the surface of the less massive component is close to its inner Roche lobe.

The combination of the above three classification systems for eclipsers results in the assignment of multiple classifications for object types. These are separated by a solidus ("/") in the data field. Examples are: E/DM, EA/DS/RS, EB/WR, EW/KW, etc.

9.7 Heliocentric Julian Date

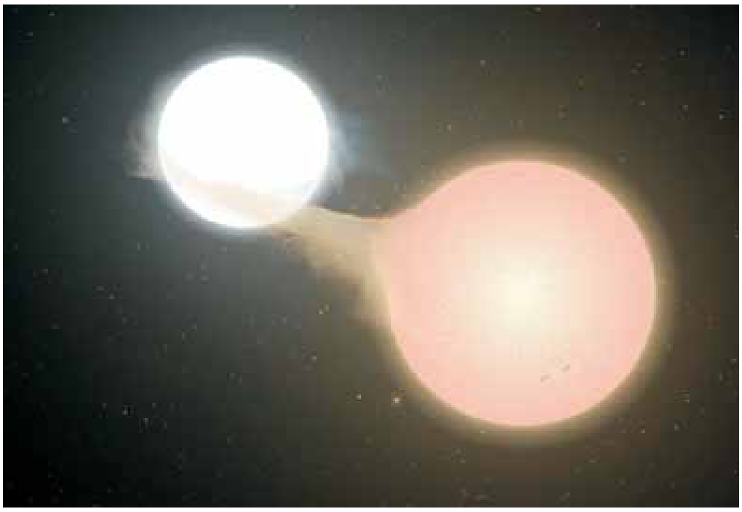
The Heliocentric Julian Date (HJD) is the same as the Julian day, but adjusted to the frame of reference of the Sun, and thus can differ from the Julian day by as much as 8.3 minutes, that being the time it takes the Sun's light to reach Earth.

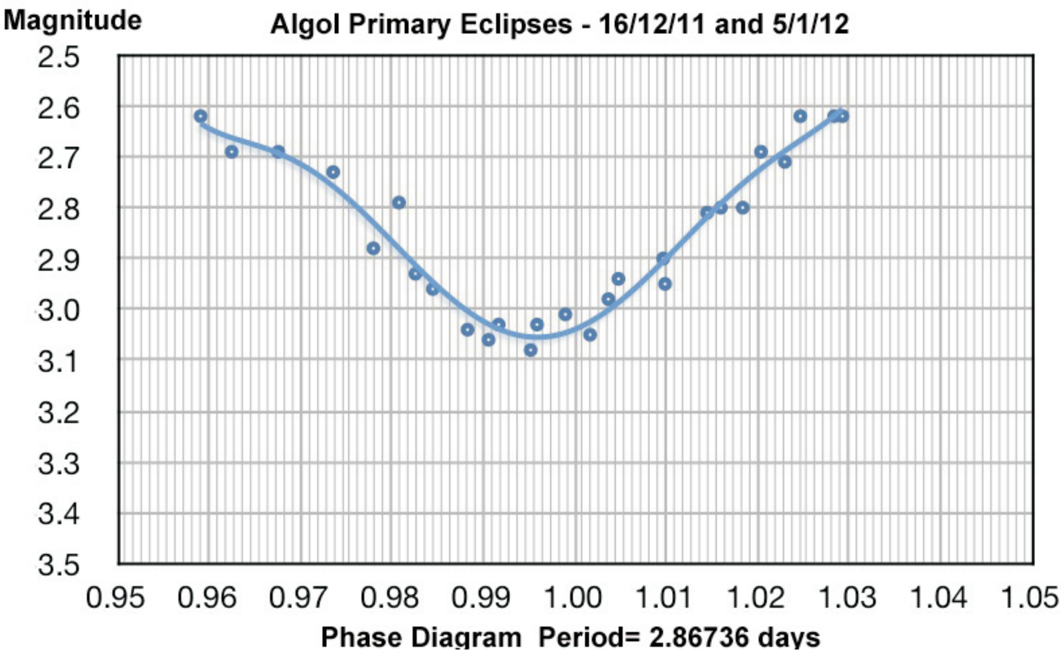
The official time of a mid-eclipse of an eclipsing binary is usually stated as a HJD. Otherwise the time of mid-eclipse, even if the period of an eclipsing binary is unchanging can seem to vary by 16.6 minutes if we observe the system six months apart ie on opposite sides of the Earth’s orbit around the Sun.

An estimate of mid-eclipse, for submission to the BAAVSS and international databases should be expressed as a HJD date. The HJD can be calculated using specialist websites and a specialist Excel programme. The specialist website that is often used is:

<http://www.physics.sfasu.edu/astro/javascript/hjd.html>

On the 31st May 2009 an eclipse of AI Draconis was observed. By the bisected chord method the time of mid-eclipse was estimated to be 23 hours and 48 minutes. The JD date was 4982.4917. The HJD date was 4982.4880. The HJD of mid-eclipse that was predicted by the major international database was HJD 4982.4933. The eclipse apparently took place about seven minutes early.





Algol - the first eclipsing binary to be discovered.

It's variability was recorded in 1667. John Goodricke, in 1783, thought that it was an eclipsing system with a dark body eclipsing Algol. In 1881 Pickering confirmed that it was an eclipsing binary system.'

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