Apsidal Motion in Eclipsing Binaries

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Abstract

Eclipsing binaries provide the most accurate fundamental stellar parameters. Eccentric systems displaying the phenomenon of Apsidal motion can also provide data to test directly theoretical stellar structure models. In this paper the astrophysical reasons for and consequences of apsidal motion will be discussed, as will the observations required to make use of this phenomenon.

It is hoped that this paper will stimulate interest in eclipse monitoring observing programmes.

1 What is Apsidal Motion?

Apsidal motion is, at least conceptually, a straight-forward physical process. It describes the motion of the line of apses of the orbit of an eccentric – or elliptical – two body system, such as a star and a planet (e.g. the Sun and Mercury) or two stars. It is the rotation of the system as a whole, on top of the individual orbital and axial rotations of the two bodies of the system. Figures 1 and 2 show schematic representations of the same binary star system seen at two different epochs, such that the apsidal motion of the system has carried the major-semi-axis of the system through 90°.

2 What causes Apsidal Motion?

In typical 'close'[1] binary systems, the dominant cause of apsidal motion is the departure of the structure of the component stars from effective point masses.

[1] Here close can be defined as meaning that the two stars are close enough to each other that their relative proximity will have a significant bearing on their long term evolution. In particular, at some point in time, because they are in the binary system their evolution will differ from what would result were each star an isolated single star.

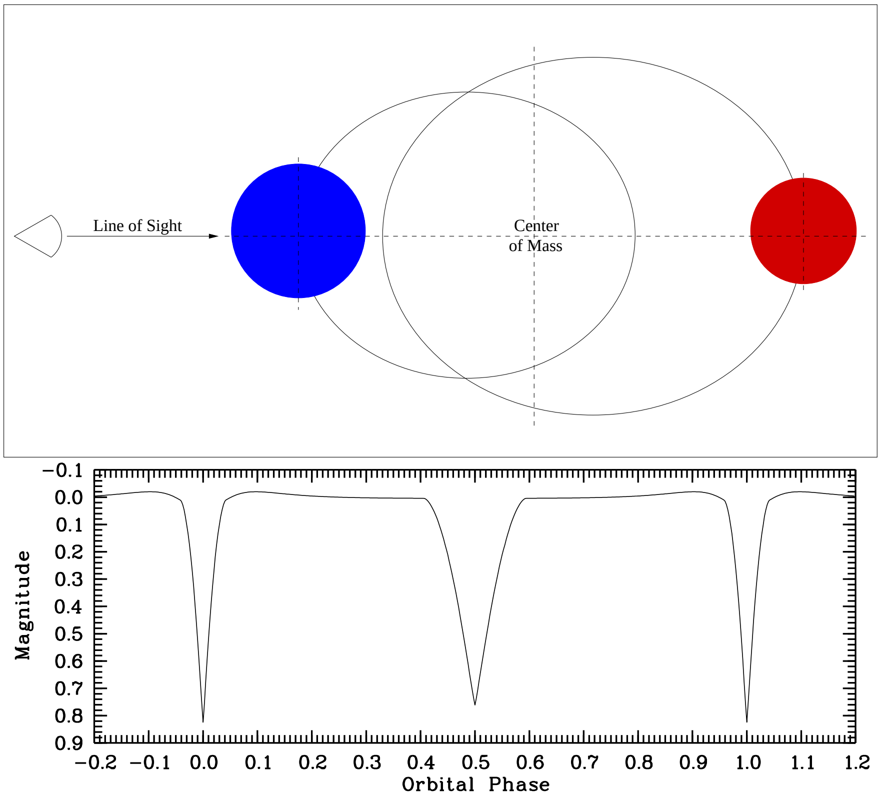

Figure 1: Schematic of an eccentric eclipsing binary and corresponding light curve. The binary is depicted at a *longitude of periastron* of 90°. Due to the variable speed of the two components through their orbital motions the light curve shows two eclipses of quite different duration.

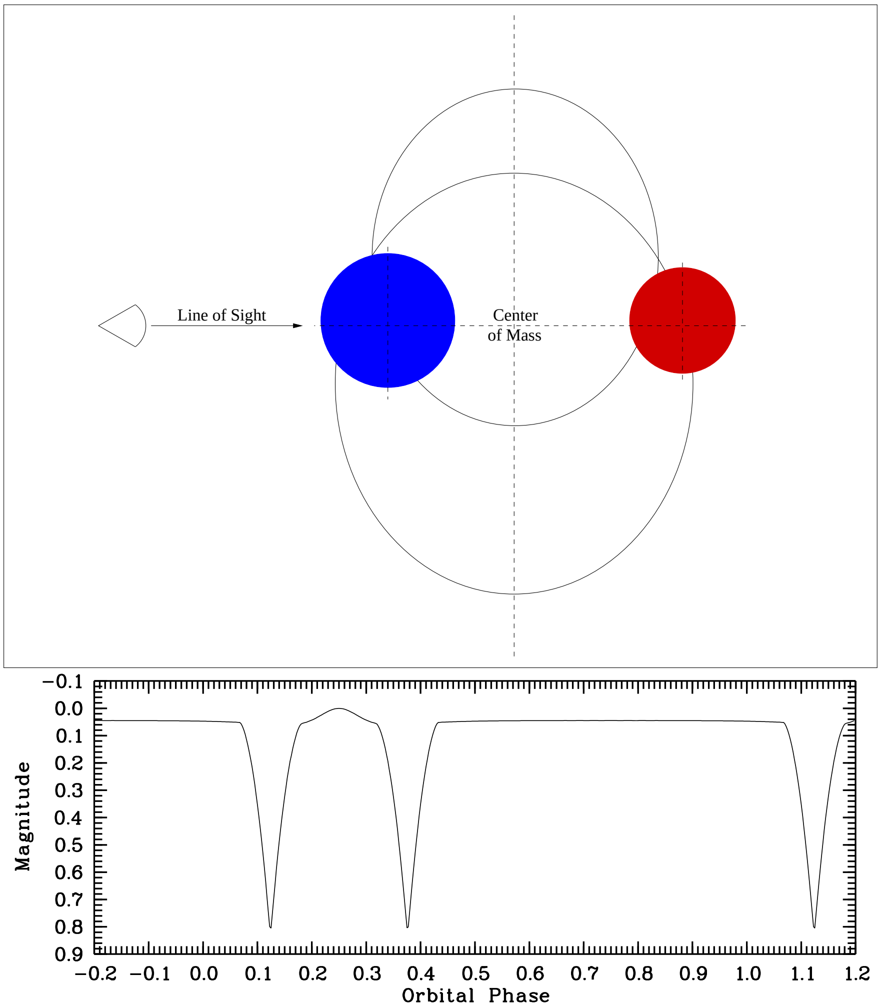

Figure 2: Schematic of the same eccentric eclipsing binary as seen in figure 1. Here the binary is depicted at a *longitude of periastron* of 180°. Due to the variable speed of the two components through their orbital motions the corresponding light curve shows two eclipses of equal duration but separated in time (or orbital phase) by markedly different periods.

Tidal interactions between the components and the rotational motion of the individual components of a binary system deforms the two stars into 'egg-shaped' volumes. These deformations of course affect the entire structure of the stars, not only their surface geometry. A complete mathematical description of the process is well beyond the scope of this article. A complete (and very mathematical) review of the subject is presented by Kopal (1959).

3 Why is Apsidal Motion useful?

Because apsidal motion is caused by the departures of stellar structure from effective point masses, apsidal motion can be used as a probe of stellar structure. This is an important test for verifying the validity of theoretical models for stellar structure and stellar evolution. Ensuring that our understanding of stellar structure and evolution is accurate has far reaching consequences; in particular, all stellar ages – which are, for example, often compared with the age of the Universe – are estimated via comparison with theoretical evolutionary models. In order to have complete faith in the predictions of these models, they must accurately reproduce *all* the observable properties of stars.

Until recently there has been a significant systematic disagreement between the observed degree of central condensation of the mass in stars and that predicted by theoretical models. Claret and Giménez (1993) however were able to obtain good agreement between the observed stellar structure, or at least the degree of central condensation, and that predicted by theory for the majority of a sample of 14 eccentric eclipsing binary systems, i.e. 28 individual stars. They achieved this by using the (then) most up-to-date opacity tables (Rogers and Iglesias, 1992) and incorporating the effects of stellar rotation and convective core overshooting. Some uncertainty however still surrounds the most evolved stars included in their sample.

There is also a General Relativistic contribution to the apsidal motion. But for most detached eccentric eclipsing binaries, the General Relativistic contribution is generally and order of magnitude or more smaller and it is the contribution due to the tidal and rotational distortions of the component stars which dominates.

4 How is Apsidal Motion observed?

As is clearly shown in figures 1 and 2, one of the effects of apsidal motion is to cause the orbital phase of the primary and secondary minima to oscillate about their 'mean' positions of 0. and 0.5 respectively. This effect is clearly, and easily, observable simply by observing the precise times of minima. By way of example, the star HV 982 in the Large Magellanic Cloud whose light curve is similar to those in figures 1 and 2, has a sidereal period[2] of 5.335220 ± 0.000003 days, an eccentricity of 0.155 ± 0.002 and an apsidal period of 206 ± 6 yr (Pritchard et al., 1997). The maximum deviation of the minima in orbital phase is ~ 0.05 or equivalently 6 hr, 24 min.

5 Observing Programmes

My main purpose in presenting this paper at the 1997 Annual Conference of the Royal Astronomical Society of New Zealand was to try to generate some interest among the the members of the society and affiliated societies in an observing programme centered on the eclipse monitoring of eccentric eclipsing binary stars.

I am therefore very interested in making contact with anyone who is interested in observing eclipsing binary minima with a view to obtaining accurate timings from which accurate parameters for apsidal motion can be determined. Giménez (1994) discusses such a programme and presents a list of more than one hundred systems with orbital periods ranging from ~ 1 to ~ 27 days and V magnitudes ranging from 3.9 to ~ 14.0. A successful observing programme would probably require either a photoelectric photomultiplier or a CCD camera for accurate photometry.

6 Acknowledgements

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7 References

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[2]The sidereal period is the mean time interval between successive primary (or secondary) minima.

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