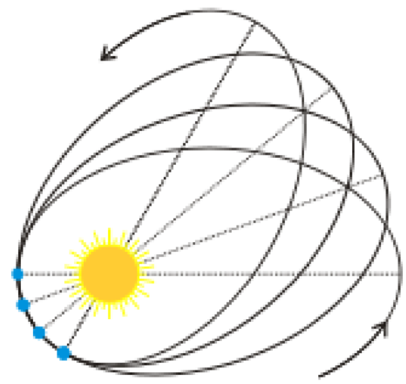
Eclipsing binary systems with eccentric orbits

Eccentric eclipsing binaries are a subgroup of detached binary stars that have provided new and important information for the study of internal stellar structure. Eccentric systems display the phenomenon of Apsidal motion. In particular, apsidal motions in this type of binary systems has proven to be highly rewarding during the past decades, allowing to get valuable astrophysics parameters of the binary system.

Currently there are more than a hundred eccentric eclipsing systems known. Many of them still require extensive observations for creation of reliable astrophysical models of their systems. Below one can read a short overview of this kind of systems and their examples

The apsidal motion effect

The study of apsidal motion effect in detached eclipsing binary systems with eccentric orbits (EEB) is an important source of information on the stellar internal structure as well as for the possibility of verification of the theory of General Relativity (Claret & Gimenez 1993; Claret 1997). It is the rotation of the line of apses of the orbit of an eccentric or elliptical two body system. The rate of motion of the apsis is dependent on the internal structure of each component. Determination of the characteristics of a binary thus provides an observational test of the theory of stellar structure and evolution.



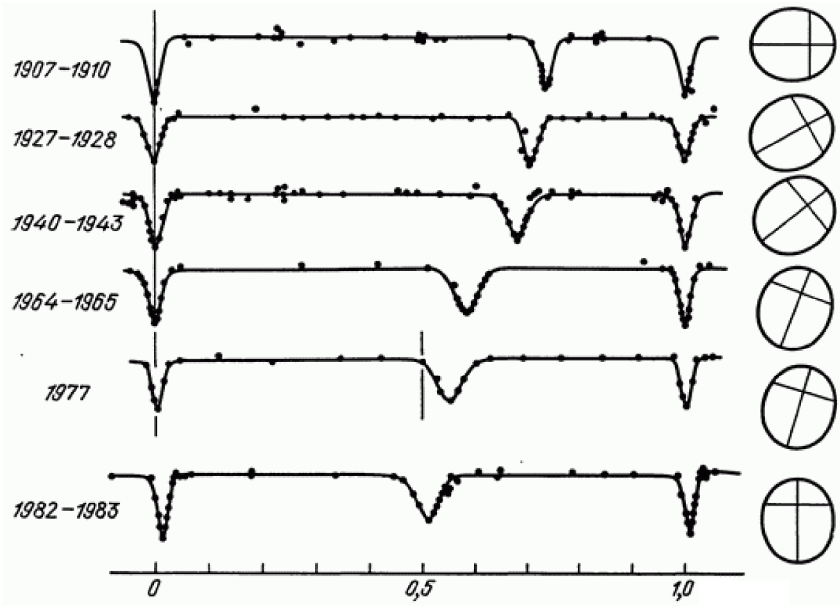


***Fig.1.** The light curve evolution of RU Mon between 1907 and 1983, due to the apsidal motion effect (right). Schematic model of the line of apsides rotation (top).*

The first theoretical explanation of apsidal motion (the precession of an eccentric orbit in its own plane) extends back to the beginning of the 20th century. The history of apsidal motion studies based on observations of times of minima of eclipsing binary stars is long and interesting. It began with the recognition by Dunér (1892) that there were two separate types of minima of Y Cyg with significantly different periods, and he correctly atrributed this effect to a rotating line of apsides. This massive binary is one of the best-known cases of apsidal motion among eclipsing binaries.

The initial idea to measure the motion of the periastron of binary stars in order to have some insight into their internal structure was given by Russell (1928). In eccentric binaries, the behavior of the orbit is influenced by the distortion of the components. This is a function of the internal density concentration as well as the mass ratio and the separation of the components. Stellar distortion, or deviation from the point-like behavior, is responsible for the secular movement of the periastron and its observational measurement should obviously lead to an empirical measurement of the level of the density concentration. A fairly good historic introduction can be found in (Gimenez, 2006).

From the observational point of view, the study of this effect requires a more or less continuous monitoring of times of minimum light of the candidate systems. The necessarily long time basis of the observations requires a careful preparation of programs and targets.

This means that a large amount of observing time is generally needed which is not available at large instruments. Since only accurate timings of relatively deep eclipses are needed, a moderate or even small telescopes equipped with a photoelectric photometer or a CCD camera can be perfectly suited to this kind of project.

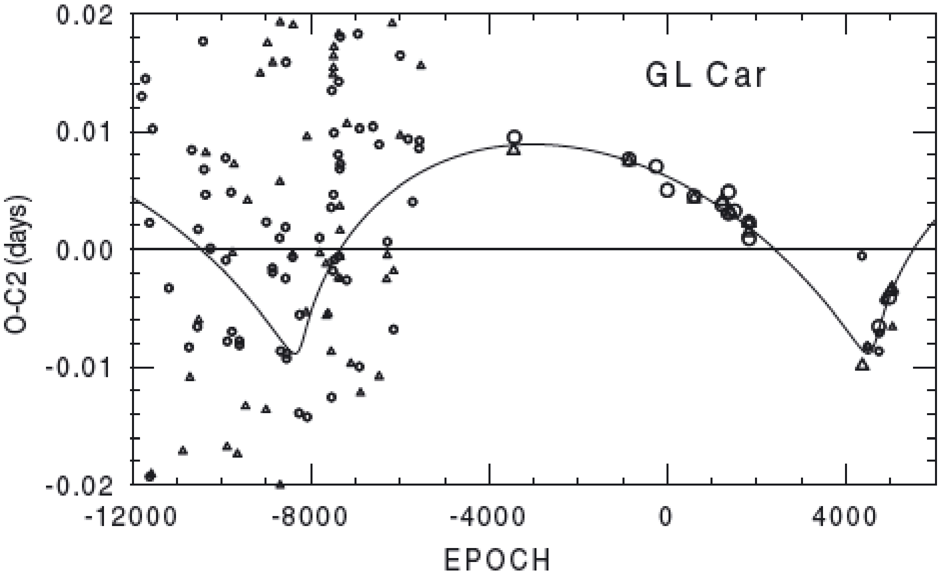


Fig. 2. *The O–C2 diagram for the times of minima of GL Car after subtraction of the apsidal motion. The curve represents a light-time effect for the possible third body eccentric orbit with a period of about 90 yr and an amplitude of about 13 min. The individual primary and secondary minima are denoted by circles and triangles, respectvely (*Wolf et al., 2008).

There are some advantages and disadvantages of the use of this effect (Hegedüs et al. 2005):
Advantages:

- its basic study requires only very simple techniques (timing of eclipsing minima).
- the effect includes information not only about the internal mass distribution, but the gravitational theory itself as well.

Disadvantages:

- generally one needs to wait for quite a long time until the effect can be revealed;
- by the study of minima time observations (or by changes in the spectroscopic orbital elements), because the typical periods of this effect are from several hundred to several thousand years;
- the individual internal structure parameters remain unknown, only the weighted average of the two components can be determined.

A detailed analysis of the period variations can be performed using times of minimum light observed throughout the apsidal motion cycle, and from this both the orbital eccentricity and the period of rotation of the periastron can be obtained with a high accuracy. Moreover, this provides independent information for the analysis of the light curves (Giménez, 1994).

Similar photometric studies of apsidal motion in EEB's were published regularly during the seventies by Helmut Busch, Hartha observatory, and later e.g. by Kh. F. Khaliullin, Moscow University, or J. V. Clausen, Copenhagen University (Wolf et al., 2004). A catalogue of eclipsing binaries that are suitable for photometric monitoring was provided by Hegedüs (2000) while a catalogue of known binaries with apsidal motion was published by Petrova & Orlov (1999).

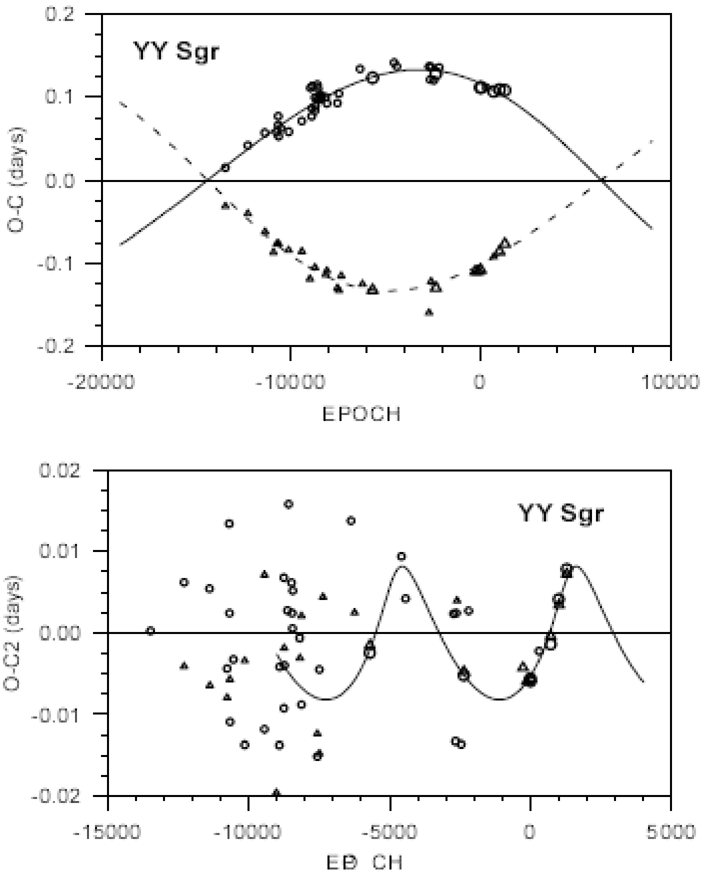


Fig. 3. *O − C residuals for the times of minimum of YY Sgr with respect to the linear part of the apsidal motion equation. (top). Below is the O − C2 diagram for the times of minimum of YY Sgr after substraction the terms of the apsidal motion. The curve represents a light-time effect for the third body orbit with a period of 44 years with and an amplitude of about 0.008 days. (Wolf, 2000)*

The theory behind the effect

Suitable numerical methods for the apsidal motion analysis were described by Gimenez & Garcıa-Pelayo (1983), Lacy (1992), and Wolf & Šarounová (1995).

Below some basic concepts behind the core of the theory are provided just to recap of the method. There are five independent variables (T_0, P_s, e, ω_1, ω_0) determined in this procedure. e represents the eccentricity of an orbit. The periastron position ω at epoch E is defined by the famous linear equation:

$$\omega = \omega_0 + \omega_1 {}^* E,$$

where ω_1 is the rate of periastron advance (in degrees per sidereal cycle or in degrees per year), and the position of periastron for the zero epoch T_0 is denoted as ω_0. On a shorter timescale, the precession of an eccentric orbit in its own plane can produce an observable rate of change in the longitude of periastron:

$$\omega_1 = d\omega / dt.$$

The sidereal and anomalistic periods of the binary, P_s and P_a, are connected by the following equation:

$$P_s = P_a \, (1 - \omega_1 / 360^\circ),$$

and the period of apsidal motion can be represented via

$$U = 360^\circ P_a / \omega_1$$

The rate of motion of the apsis is dependent on the internal structure of each component. Determination of the characteristics of a binary thus provides an observational test of the theory of stellar structure and evolution. The apsidal motion in relatively close binary systems can be studied by means of an O–C diagram analysis (for details see, e.g., Wolf *et al.* 1996, 1997).See Fig.2 and Fig.3 as examples of this kind of research.

In the case of deep, narrow eclipses the rate of apsidal motion can be determined by the analysis of primary and secondary eclipse timings and by measuring the change in the displacement of the secondary minimum from the half point (0.5 phase) according to

$$D = (t_2 - t_1) - P / 2$$

where t_2 and t_1 are times of secondary and primary minima, respectively (GM85). D, in turn is related to the longitude of periastron ω by the formula given by Sterne (1939, a, b):

$$D = \frac{P}{\pi}\left[\tan^{-1}\left(\frac{e\cos\omega}{(1-e^2)^{1/2}}\right) + \frac{e\cos\omega}{1-e^2\sin^2\omega}(1-e^2)^{1/2}\right]$$

For a short recap of the method: the individual equations for computing the time of primary and secondary minima are given in Giménez & García-Pelayo (1983). This is a weighted least squares iterative procedure, including terms in the eccentricity up to the fifth order.

Eclipsing Binary with Eccentric Orbits Catalog

In 2007 there was a catalog containing a list of binary systems with eccentric orbits published (Bulut+). The catalog lists the physical parameters (including apsidal motion parameters) of 124 eclipsing binaries with eccentric orbits. In addition, the catalog also contains ***a list of 150 candidate systems***, about which fewer details are known at present.

The catalog can be found at http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/MNRAS/378/179

J/MNRAS/378/179 - Eclipsing Binary with Eccentric Orbits Catalog (Bulut I., Demircan O., 2007)

References for further reading:

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Appendix 1. Examples of Eclipsing Binary Systems with Eccentric Orbits


V889 Aquilae, HD 181166


CW Cephei, SAO 20401


DI Herculis, SAO 86544


NY Cephei, SAO 20351


MZ Lacertae, SAO 12870


V402 Lacertae, SAO 51698


VW Pegasi, GSC 02753-00649


AR Cassiopeiae, SAO 35478

Object Designation		RA (J2000)	DEC (J2000)	Eccentricity	Period (days)	Mag. Range
V889 Aql	SAO 104708, HD 181166	19 18 49.8	+16 15 00	0.375	11.120879	8.52 - 9.1 V
AR Cas	SAO 35478, HIP 115990	23 30 01.9	+58 32 56	0.24	6.0663309	4.82 - 4.96 V
CW Cep	SAO 20401, HIP 113907	23 04 02.2	+63 23 48	0.29	2.72914	7.6 - 8.04 V
EY Cep	BD+80 112	03 40 04.0	+81 01 09	0.442	7.971438	9.8 – 10.57 V
NY Cep	SAO 20351, HIP 113461	22 58 39.8	+63 04 37	0.48	15.275727	7.4 - 7.55 V
Alpha CrB	SAO 83893, HIP 76267	15 34 41.3	+26 42 52	0.37	17.359907	2.21 - 2.32 B
V541 Cyg	GSC 02656-03703	19 42 29.4	+31 19 40	0.48	15.33779	10.2 - 10.9 p
V1143 Cyg	SAO 31850, HIP 96620	19 38 41.2	+54 58 25	0.54	7.6407613	5.85 - 6.37 V
NN Del	SAO 126201, HIP 102545	20 46 49.2	+07 33 10	0.518	99.2684	8.40 - 8.95 V
DI Her	SAO 86544, HIP 92708	18 53 26.2	+24 16 41	0.489	10.550168	8.39 - 9.11 V
LV Her	GSC 02076-01042	17 35 32.4	+23 10 30	0.61	18.435935	10.9 - 11.3 p
MZ Lac	SAO 12870, HIP 17257	22 28 01.7	+53 41 00	0.42	3.158795	11.2 - 12.1 p
V345 Lac	GSC 03986-02900	22 18 43.3	+54 40 33	0.456	7.491862	11.1 - 11.7 p
V402 Lac	SAO 51698, HIP 109354	22 09 15.2	+44 50 47	0.379	3.7820	6.7 - 6.99 Hp
V2283 Sgr	HD 321230	18 04 38.8	-36 54 52	0.488	3.4714231	10.23 -11.03 V
RU Mon	BD-07 1623, HIP 33163	06 54 12.3	-07 35 45	0.396	3.584749	10.33 -11.18 V
FT Ori	SAO 78120, HD 42858	06 13 58.1	+21 25 39	0.405	3.150415	9.1 - 9.9 V
VW Peg	GSC 02753-00649	22 56 23.6	+33 13 43	0.39	21.071749	9.9 - 10.6 V
V436 Per	SAO 22690, HIP 8704	01 51 59.3	+55 08 50	0.388	25.9359	5.49 - 5.85 V
EQ Vul	HD 337188, SON 4475	19 58 23.2	+28 01 08	0.359	9.297164	11.79 - 12.5 B