

O-C diagrams basics

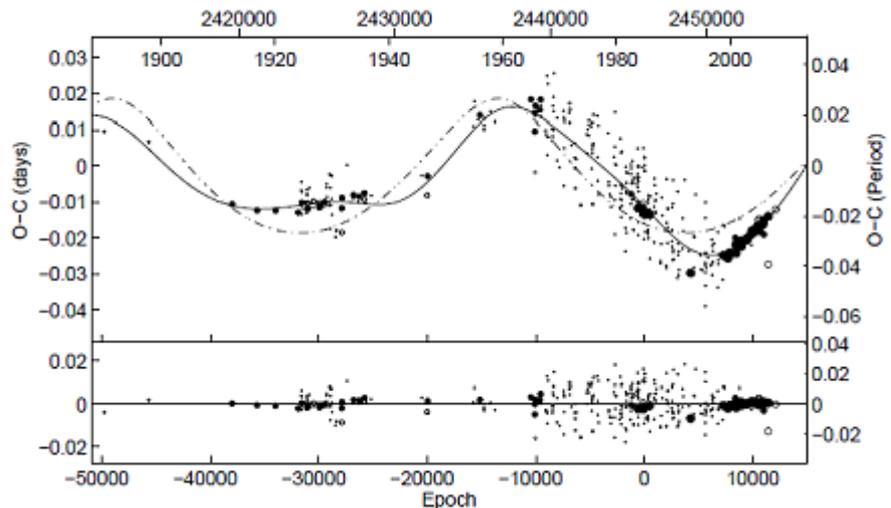
Most variable stars change its brightness over a cycle. O-C diagrams compare the actual timing of an event (e.g. the mid-point of an eclipse or a pulsation cycle peak) to the moment we expect this event is occurred in a case of constant periodicity. These period variations are usually delicate. By building Observed-minus-Calculated (O-C) diagrams one can measure very subtle changes in the period happening with the star.

O-C diagrams is a powerful diagnostic tool in the natural sciences. Basic period analysis consists of finding a reliable ephemeris of the main periodic variation and modelling of the first order effects. The basic mechanisms of the periodic or nearly periodic stellar variability are the rotation of an anisotropically radiating star, the orbital motions of components in stellar systems, and pulsations or oscillations of various kinds (Mikulášek et al., 2011).

The O-C diagram is a plot showing the observed times of maximum light (O) minus those calculated according to an adopted ephemeris (C) as a function of time. The horizontal axis of the an O-C diagram most often represent time, usually expressed in days. Scientists principally use the Julian Date (JD) of the observation. It can also be cycles or phase. The vertical axis is the "O-C" part which gives the diagram its name and its interpretive power. For each observed event one takes the observed time of the event (that's the "O" part) and subtracts the time predicted from the existing data or model of the star. The difference, Observed minus Calculated or "O - C", is plotted on the vertical axis of the graph. The pattern that shows up in the O - C diagram can tell if your predictions (or model) are valid.

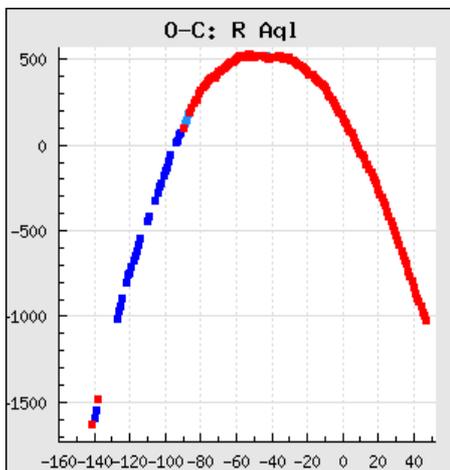
For a star with no measurable change in the period (or in a case of constant period), points on the O-C diagram will scatter about a straight horizontal straight line across the graph. The size of the scatter is an indication of the accuracy of the observed times of maximum. The O-C method, basically, assumes the use of a stable and accurate clock. The credibility of obtained astrophysical information strictly depends on the reliability of observation times and their uncertainties. If the period of the star is changing at a slow constant

rate ($P(t) = P_0 + Bt$, where B is a small), then a good approximation of the O-C diagram can be represented by a parabola.



The O-C diagram of WZ And (upper part), where the solid line represents the theoretical LITE variation caused by a 3rd body and the O-C residuals obtained after the subtraction of LITE (lower part). For details, please refer to (Zasche, Liakos et al., 2009)

Note that in order to interpret an O-C diagram correctly, you have to know a number of cycles have elapsed between observed extremums. This is not always the case, since there may be large gaps between observations. Other problem is when the period has been changed significantly between observations.



The longer the time interval (in cycles) over which the data have been collected, the higher will be the resulting accuracy of the solution. If your period is slightly off, the discrepancy will accumulate as times goes on. In that case, the O-C diagram will look like an inclined straight line.

If the O-C diagram turns out to be curved, the period of the system is changing slowly. Imagine the middle horizontal line of the graph as a zero-level. Then positive is up and negative is down. A curve leading downwards indicates a shortening period: the events are happening earlier and earlier than predicted. If it curves upward, the events are happening later and later than expected, so the period is increasing.

Left: O-C diagram for R Aql (by Thomas Karlsson, <http://var.astronet.se>)

The appearance of an O-C diagram is strongly dependent on the ephemeris formula used to construct it. Traditional analysis ways of an O-C diagram use basic method listed below (Batten, 1973; Tsessevich, 1973).

- 1) a linear approximation, where the time of the primary minimum is given by a linear relation:

$$MinI = t_0 + P_{orb} \times E$$

- 2) a quadratic least square fitting, which uses the average period value over the elapsed time interval (\bar{P}):

$$(O - C) = 1/2(dP_{orb}/dt)\bar{P}E^2$$

- 3) which is sometimes combined with a sinusoidal periodic variation.

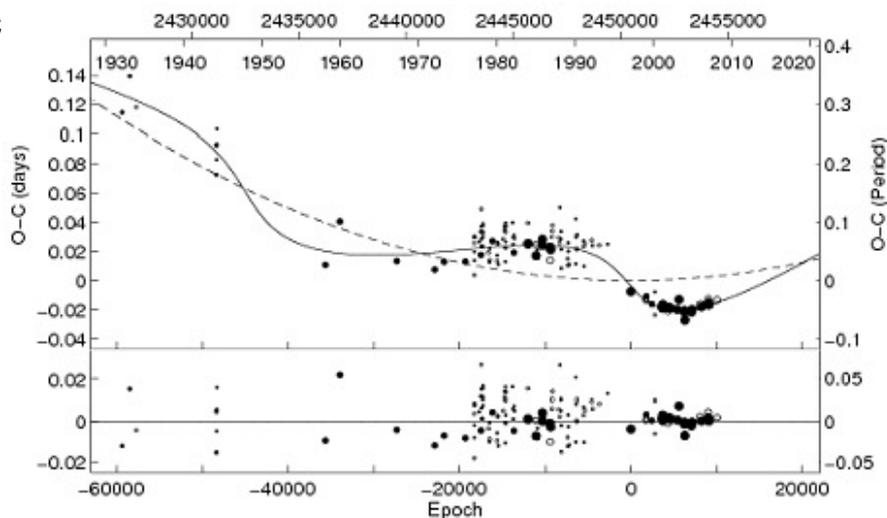
$$MinI = t_0 + PE + 1/2(dP/dt)PE^2 + \alpha \sin(2\pi E/P_* + \phi)$$

There were three new ways of O-C diagram treatment proposed in the mid-90s:

- the higher order polynomial method (HOP), or the first continuous method (Kalimeris et al., 1994);
- the state-space statistical model (SSM), proposed by (Koen, 1996);
- the second continuous method (Jetsu et al., 1997).

For methods detail, please refer to the following paper: "The (O-C) Diagrams of Eclipsing Binaries: Traditional and New Ways of Treatment" (Rovithis-Livaniou, 2001).

To get even more information on methods for O-C diagrams and errors accounting, please follow the publication: "The O-C Diagram: Basic Procedures" (Sterken, 2005).



The O-C diagram of FZ Ori (upper part), where the solid line represents the theoretical LITE variation caused by a 3rd body and the O-C residuals obtained after the subtraction of LITE (lower part). For details, please refer to (Zasche, Liakos et al., 2009)

Useful links and web sources:

O-C diagrams for a selection of Mira stars, with the observations data table behind it (compiled by Thomas Karlsson).

<http://var.astronet.se/mirainfooc.php>
<http://var.astronet.se/mirainfooper.php>

An Atlas of O-C diagrams of Eclipsing Binary
<http://www.as.up.krakow.pl/o-c/>

Eclipsing Binaries Minima Database
http://www.oa.uj.edu.pl/ktt/krttk_dn.html

Kepler Eclipsing Binary Catalog
<http://keplerebs.villanova.edu/>

3400 O-C files of Eclipsing Binaries (compiled by Bob Nelson)
<http://www.aavso.org/bob-nelsons-o-c-files>

Photoelectric Minima of some Eclipsing Binary Stars (compiled by Tom Krajci)

<http://www.konkoly.hu/cgi-bin/IBVS?5690>

References for further reading:

- Sterken, C.; 2005; The Light-Time Effect in Astrophysics, Proceedings of ASP Conference Series, Vol. 335, p. 3
- Mikulášek et al., 2011; IAU Symposium, 282, 391
- Zasche, P., Liakos, A., et al.; 2009, New Astronomy, 14, 121
- Rovithis-Livaniou H., 2001, Odessa Astron. Public., 14, 91
- P. Zasche, A. Liakos, et al., 2008
- Kalimeris et al., 1994, a&a, 282, 775
- Koen, C., 1996; MNRAS, 283, 441
- Jetsu, L., Pagano, I. et al., 1997, A&A, 326, 698

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