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Monitoring Changes in Eclipsing Binary Orbits

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Abstract

Times of light minimum were determined from observations of seven eclipsing binaries, EP AND, WZ AND, AH TAU, HP AUR, ZZ AUR, GO CYG and UV LEO. Based on these new times of minimum and those collected from the literature, changes in the orbital period of the systems were found and are presented. The literature contains hundreds of papers, which include proposed explanations for these period changes. Most involve apsidal motion, motion around another star (third body), mass transfer between stars, mass loss, magnetic cycles, and braking and angular momentum loss. When identifying an orbital period change in these systems and one of these common mechanism appears to be a feasible or satisfactory hypothesis, we applied the explanation to the occurring orbital changes where system parameters were available.

1. Introduction

Times of light minimum have been acquired on seven eclipsing binaries. Three are EA-type, one is EW-type, one is detached, and two have been classified near contact or EB-type. See the systems listed in Table 1. Four of the systems have been neglected binaries either because they have been recently discovered or overlooked. Enough times of minima on these systems were found in the literature such that, when combined with the times acquired in this paper, we have determined orbital period changes. See Table 2 for all the reference sources for times of light minima and Table 4 lists the times of light minimum obtained this paper. Times of light minima using photographic, photoelectric and CCDs observations were used at numerical value and not weighted. With these changes we can provide estimates of mass transfer and angular momentum loss (AML), which are predicted by theoretical work. We computed O–C curves with the acquired times of light minimum as these diagrams best reveal period changes. The O–C differences for each system have been calculated according to an earlier ephemeris minimum found in the previous written works on each system. The O–C values are computed in days and presented graphically against epoch or orbit numbers. A least squares polynomial is used to describe the period change or changes resulting in a parabola. The equation for this parabola curve is then added to the earlier ephemeris minimum to obtain a quadratic ephemeris and all errors noted are standard errors for the least-squares fit. The residuals from the quadratic equation were then plotted in a second O–C diagram and a polynomial fit of the fifth order applied.

2. Observations

At the Paradise View Observatory a Meade 14” LX200GPS used an STL-1301E SBIG camera at 2007mm (79”) focal length, giving an effective field of view of 1.49 arcsec/pixel (Figure 1). At the Kings Canyon Observatory, an ST-9XE SBIG camera attached to a 12” Meade LX200 classic with a 1920mm (75.6”) focal length gave an effective pixel field of view of 2.18 arcsec/pixel (Figure 2).

All times of light minimum were obtained in the VR color system approximating the standard Johnson photometric system. Reduction, charting and computations of the data were accomplished using the software programs listed in Table 3. 72 times of minima were acquired and are listed in Table 4.

Figure 1. Paradise View Observatory

Figure 2. Kings Canyon Observatory

System	Type	Spectral Type	Mag V / R	AML sec $year^{-1}$ Observed
EP AND	EW	-/-	11.9/11.3	$+1.4^{-12}$
WZ AND	Near Contact	F5/G2	11.6/-	+0.019
AH TAU	Semi-Detached	G5/-	11.8/10.76	+0.002
HP AUR	Near Contact	G2V/G8V	11.3/10.22	-0.016
ZZ AUR	Semi-Detached	A7/	11.4/11.1	-0.006
GO CYG	Semi-Detached	AOV/	8.67/8.65	+0.009
UV LEO	Detached	F8/	10.06/9.59	+0.003

Table 1. List of Eclipsing Binary Systems studied. AML = Angular Momentum Loss

(EBMD) Eclipsing Binaries Minima Database	http://www.oa.uj.edu.pl/ktt/
Bob Nelson's O – C files	http://binaries.boulder.swri.edu/binaries
Simbad	http://simbad.u-strasbg.fr/
AAVSO Web	http://www.aavso.org/
Up-To-Date Linear Elements of Eclipsing Binaries	www.as.ap.krakow.pl/ephem/

Table 2. List of Databases used.

Binary Maker 3	Light Curve Synthesis Program
Software Bisque – CCDSoft5	Image Processing and CCD Camera Control Software
Software Bisque - TheSky6	Planetarium Program
Microsoft – Excel	Spreadsheet Software
MPO Software - Canopus & PhotoRed	Data Processing
MPO Software – Connections	Telescope and Camera Control Program
PERANSO	Period Analysis Software
PSI-Plot	Technical Plotting and Data Processing

Table 3. List of software programs used for observations and data reduction.

OBJECT	HJD +2,400,000	Sd ^-3	FIL	TYPE	OBJECT	HJD +2,400,000	Sd ^-3	FIL	TYPE
EP AND	53686.891459	2.63	V	II	WZ AND	53691.907000	4.21	V	II
EP AND	53686.892174	5.85	R	II	WZ AND	53694.691000	6.43	V	II
EP AND	53687.699875	2.81	V	II	WZ AND	53694.691231	7.57	R	II
EP AND	53687.702979	3.91	R	II	HP AUR	53771.817123	3.02	V	I
EP AND	53688.712826	5.29	R	I	HP AUR	53771.816250	1.56	R	I
EP AND	53688.713270	0.423	V	II	HP AUR	53774.662767	2.43	V	I
EP AND	53688.910711	6.72	V	I	HP AUR	53774.661715	3.94	R	I
EP AND	53688.916564	9.87	R	I	ZZ AUR	53779.66503	2.21	V	I
EP AND	53689.720745	2.58	R	II	ZZ AUR	53779.66522	1.63	V	I
EP AND	53689.924354	3.07	V	II	ZZ AUR	53779.66728	2.29	R	I
EP AND	53689.926210	5.67	R	I	GO CYG	53610.838511	1.84	R	I
EP AND	53690.730717	3.74	V	II	GO CYG	53615.856026	3.38	V	I
EP AND	53690.732234	5.32	R	I	GO CYG	53615.856028	4.62	R	I
EP AND	53690.934733	2.74	V	II	GO CYG	53615.861034	1	V	I
EP AND	53690.935283	5.32	R	II	GO CYG	53615.862008	0.98	R	I
EP AND	53691.740136	5.11	R	I	GO CYG	53615.865305	3.64	V	I
EP AND	53691.740367	3.64	V	I	GO CYG	53633.813420	5.27	V	I
EP AND	53692.750290	5.27	V	I	GO CYG	53633.812944	5.11	R	I
EP AND	53692.752596	8.28	R	I	GO CYG	53674.718971	3.91	R	I
EP AND	53694.770288	7.45	R	I	GO CYG	53674.720455	2.79	V	I
EP AND	53694.770604	7.44	R	I	UV LEO	53776.821289	1.82	V	II
EP AND	53694.771004	6.23	V	I	UV LEO	53776.824667	2.81	R	II
EP AND	53694.773560	1.44	V	I	UV LEO	53779.822497	3.64	V	II
WZ AND	53687.730698	2.93	V	I	UV LEO	53779.822860	2.57	R	II
WZ AND	53687.734200	4	R	II	AH TAU	53689.806815	8.14	R	II
WZ AND	53688.772500	46.5	V	II	AH TAU	53689.806920	1.02	R	II
WZ AND	53688.776217	4.38	R	II	AH TAU	53688.807730	1.84	V	II
WZ AND	53689.821571	11.65	R	I	AH TAU	53688.807385	3.38	R	II
WZ AND	53689.823000	14.9	V	II	AH TAU	53689.807335	5.87	V	II
WZ AND	53690.861157	4.8	V	I	AH TAU	53689.807245	5.26	V	II
WZ AND	53690.863880	8.35	R	I	AH TAU	53689.970529	4.6	V	I
WZ AND	53691.903600	7.59	R	II	AH TAU	53689.972385	0.98	R	I
AH TAU	53692.799690	0.01	R	II	AH TAU	53694.795025	3.33	R	II
AH TAU	53692.800870	5.48	V	II	AH TAU	53694.795445	1.84	V	II
AH TAU	53692.966240	1.48	V	I	AH TAU	53694.961573	2.95	R	I
AH TAU	53692.966876	2.09	R	I	AH TAU	53694.962003	1.88	V	I

Table 4. Target Stars with Times of Minima. Type I = primary minimum. Type II = secondary minimum.

3. Case Studies

3. 1. EP AND

This system was discovered in 1972 but has been neglected. Only 13 reference papers were listed on Simbad since 1986. The binary is a contact system. We had only found 38 times of light minimum before we acquired the 23 times for this paper as shown in Figure 3. The O–C diagram is produced from the data set with the linear ephemeris, Eq. 1.

$$HJD = 2442638 + 0^d.40411057\ E \qquad (1)$$

With only 53 data points plotted it showed a discontinuously changing period with step variations but at a constant rate. We were fortunate to locate the Bob Nelson database and were able to acquire a total of 304 times of light minimum. We plotted all the O–C points, applied a parabolic least squares to the residuals to obtain the quadratic Eq. 2.

$$\begin{aligned} HJD &= 2442638.5109 && \pm 0.00066 \\ &+ 0^d.40411057\ E && \pm 1.6^{-7} \\ &+ 9.00901496^{-21}\ E^2 && \pm 5.85^{-12} \qquad (2) \end{aligned}$$

A second O–C diagram, (Figure 4), was plotted using equation 2 and a sinusoidal curve in the O–C residuals is evident. This shows a secular period change. Where a sinusoidal curve appears, a third body orbiting around the binary system can produce it. These periodic variations in the minima timing are caused by the light travel-time difference.

With the quadratic term it is possible to estimate the theoretical amount of angular momentum loss in the system from the equation given by Bradstreet (2000):

$$\begin{aligned} dP/dt &= 2 * (+9.00901496^{-21}) && \text{Quad. Term} \\ &* (1/.40411057) && \text{Period} \\ &* (86400) * (365.25) && \text{sec/day day/year} \\ &= +1.407^{-12}\ \text{seconds year}^{-1} && (3) \end{aligned}$$

The AMG, Angular Momentum Gain (dP/dt) observed = +1.407-12 seconds/year.

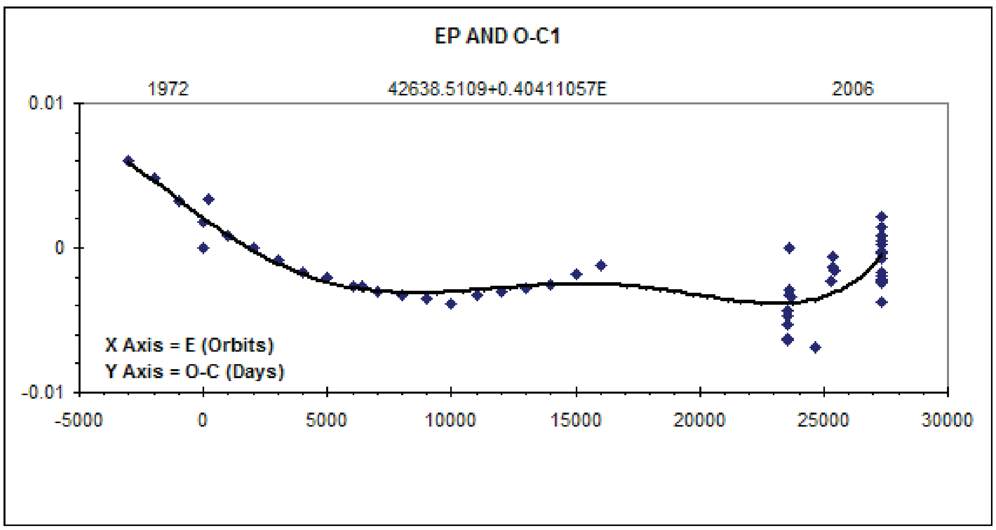

Figure 3.

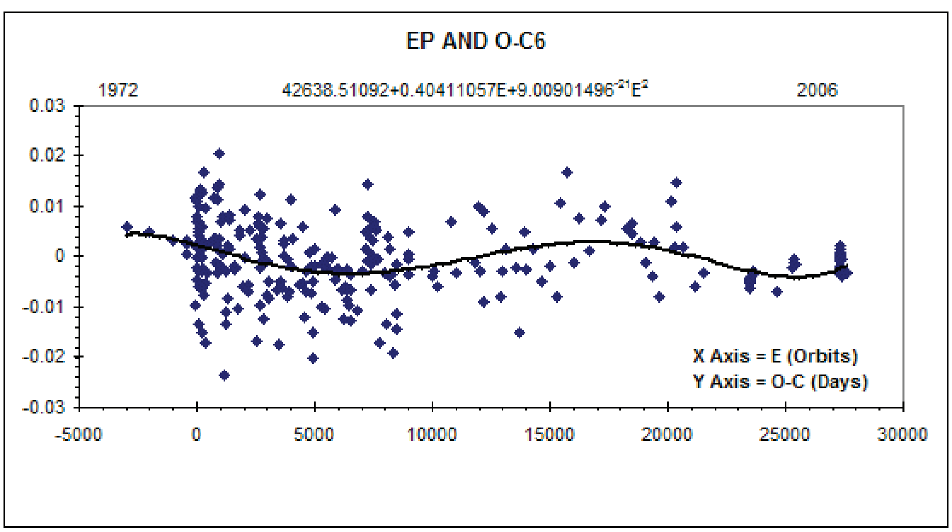

Figure 4.

3. 2. WZ AND

This is a near contact system with both stars convective, F5+G2. From the literature, 199 times of light minimum were gathered and 19 were obtained, this paper. The O-C chart, Figure 5, containing 218 points was computed from the linear ephemeris:

$$HJD = 2445963.8078 + 0^{d}.069565936\ E \qquad (4)$$

As explained in the introduction, a current ephemeris containing a quadratic term was computed:

$$\begin{aligned} HJD &= 2445963.80785 && \pm 0.0006 \\ &+ 0.^{d}695658345\ E && \pm 1.94^{-7} \\ &+ 2.129257^{-10}\ E^{2} && \pm 2.31^{-11} \qquad (5) \end{aligned}$$

The polynomial fitted residual from Eq. 5 is shown in Figure 6. The continual steady increase in the orbital period is shown and the minima this paper confirm the period is still increasing. The AMG, Angular Momentum Gain, Eq. 3, (dP/dt) observed = +0.019 seconds/year. The period and AMG has been continuous for the last 35 years.

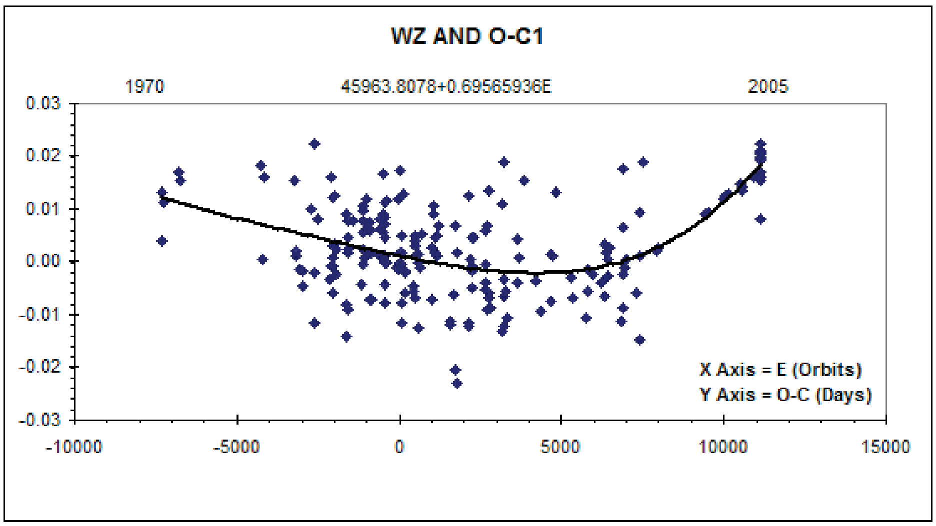

Figure 5.

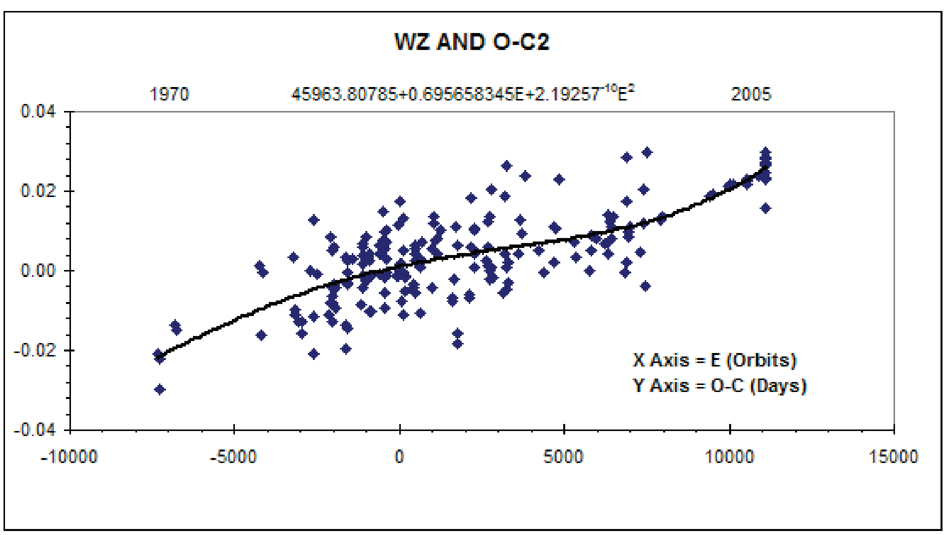

Figure 6.

3. 3. AH TAU

A semi-detached system with the primary star a G5. The secondary spectral type is unknown. A total of 126 times of light minima were used in Figure 7 and 8, 16 acquired by this paper. Both diagrams show a recent abrupt increase in the period of the orbit around 2001 and are confirmed by this paper using the linear ephemeris:

$$HJD = 2447000.2689 + 0.^{d}33267164\ E \qquad (6)$$

When a quadratic term

$$\begin{aligned} HJD &= 2447000.26777 && \pm 0.0006 \\ &+ 0.^{d}332671802\ E && \pm 5.97^{-7} \\ &+ 1.09848^{-11}\ E^2 && \pm 4.42^{-12} \end{aligned} \qquad (7)$$

was applied a sinusoidal trend was evident, Figure 8. The feasibility of a third body around the system is possible. The AMG observed using Eq. 3, (dP/dt) = +0.002 seconds/year.

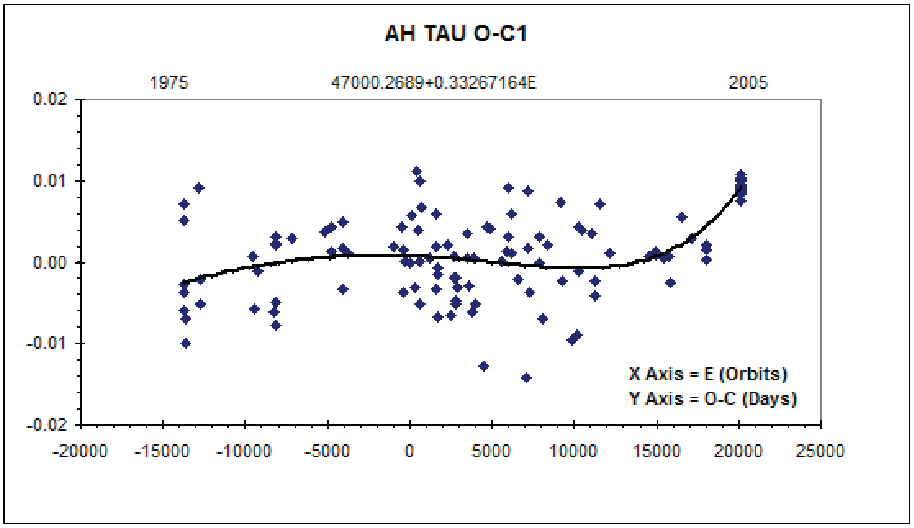

Figure 7.

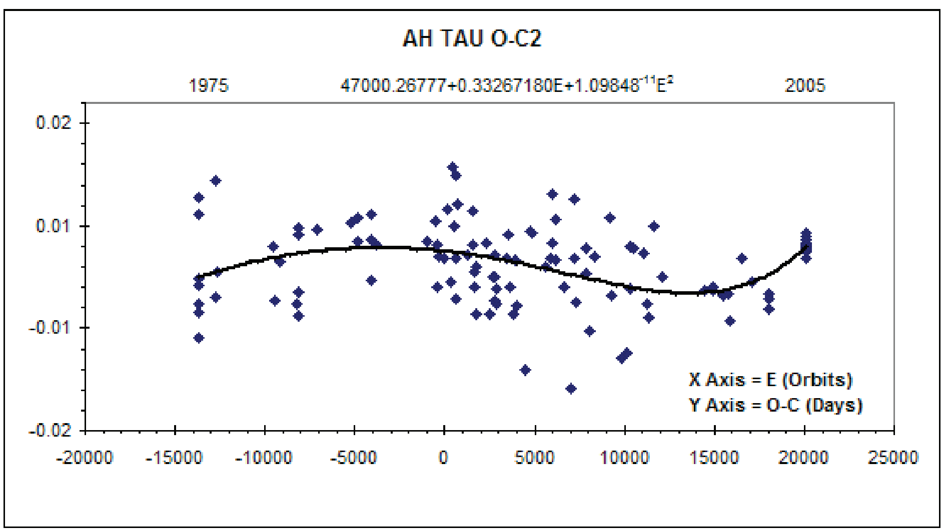

Figure 8.

3. 4. HP AUR

This is a near contact system with two late-type stars, G2V + G8V. A total of 70 times of light minima O-C are plotted, 4 from this paper, covering 30 years. Eq. 8 linear ephemeris was used to compute the O-C points, Figure 9.

This system had some orbit changes prior to 2001 but since that time the diagrams using Eq. 8 and 9 display slight changes, if any at all, Figure 10.

$$HJD = 2446008.9135 + 1.^{d}42281854\ E \qquad (8)$$

$$\begin{aligned} HJD &= 2446008.91495 && \pm 0.001 \\ &+ 1.^{d}422821051\ E && \pm 7.04^{-7} \\ &- 3.57509682^{-10}\ E^{2} && \pm 1.29^{-10} \qquad (9) \end{aligned}$$

The scatter of the points prior to 2001 is due to the type of observations used. Visual and photographic observations prior and CCD type after. The AML observed using Equation 3, (dP/dt) = –0.016 seconds/year.

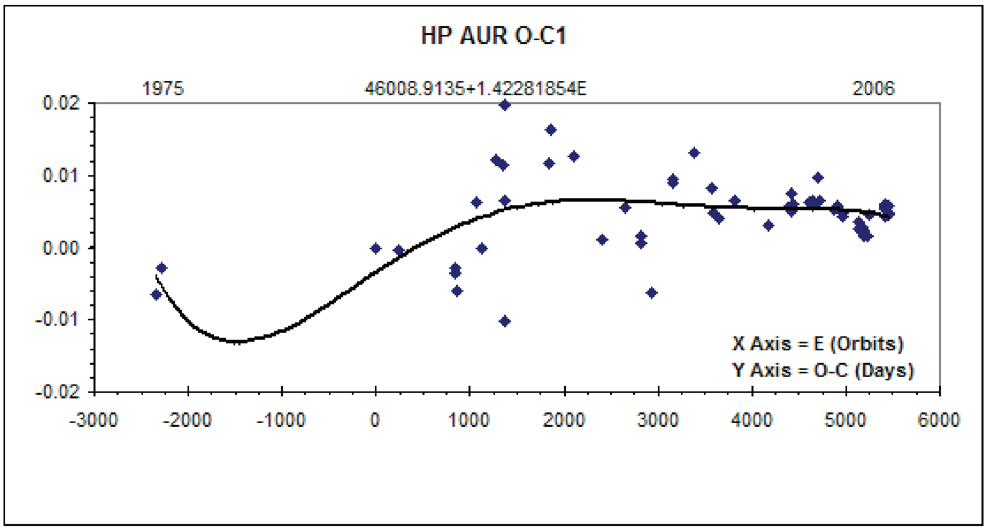

Figure 9.

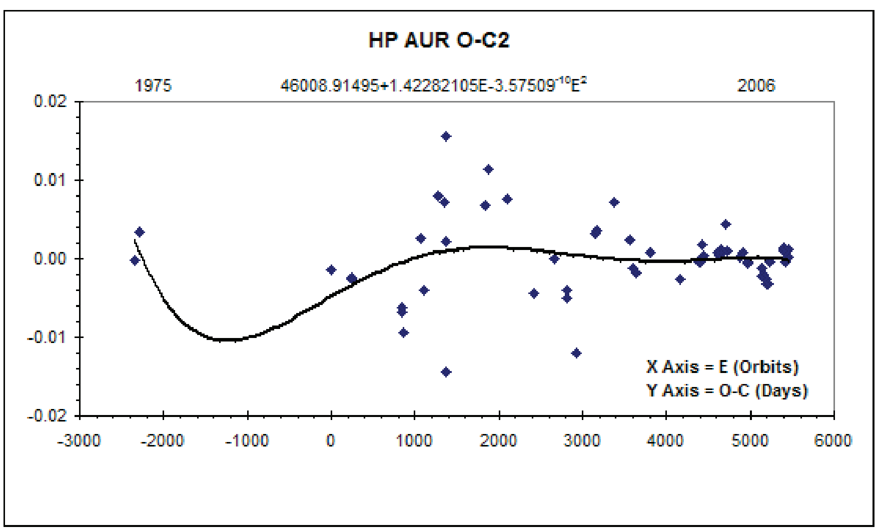

Figure 10.

3. 5. ZZ AUR

A semi-detached system with the primary a type A hot star. The spectral type of the secondary is unknown. A least-squares fit using the linear ephemeris (10) is plotted in Figure 11.

$$\text{HJD} = 244962.2221 + 0.^{d}601217202\ E \qquad (10)$$

Figure 11 displays a steady increase in the orbital period but when a second O–C diagram, Figure 12, was plotted using Equation 10 a sinusoidal trend is apparent. This shallow sine curve with small amplitude would indicate Keplerian motion caused by a third object.

$$\begin{aligned} \text{HJD} \; &= 2444962.22827 && \pm 0.0007 \\ &+ 0.^{d}601217202\ E && \pm 2.65^{-7} \\ &- 6.10504338^{-11}\ E^{2} && \pm 2.026^{-11} \qquad (11) \end{aligned}$$

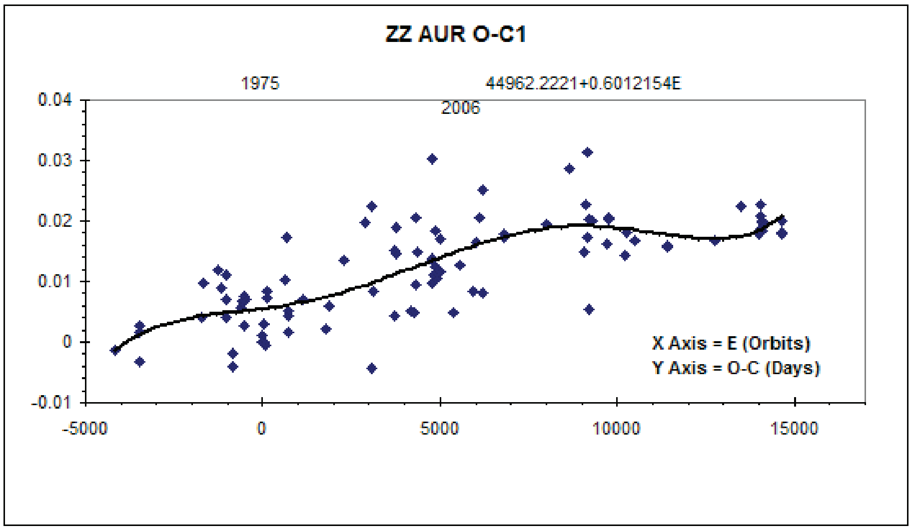

Figure 11.

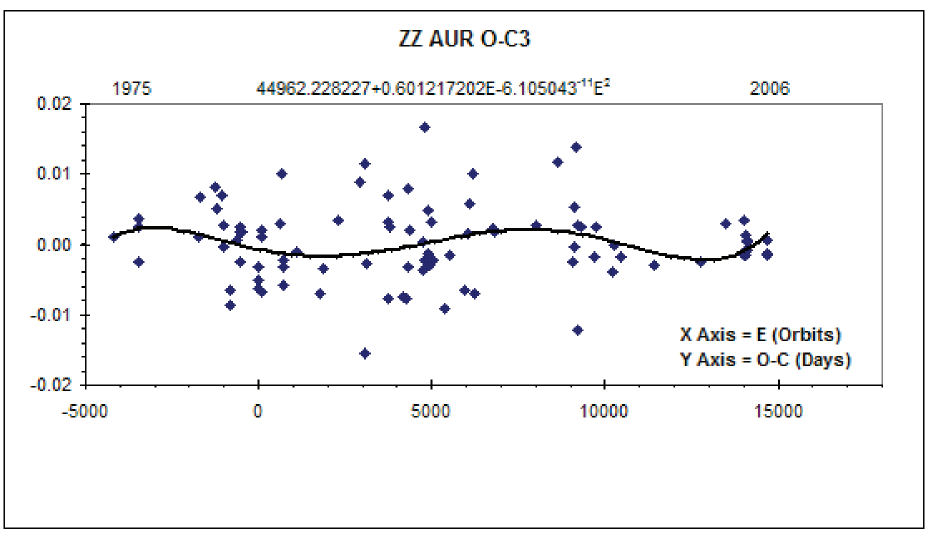

Figure 12.

3. 6. OO CYG

With 144 times of light minima used, 21 of them are this paper. The span of time covers 74 years from 1931. This system is semi-detached, the primary being a hot type A0V which has made it difficult to determine the spectral type of the secondary. The linear ephemeris

$$HJD = 2433930.40561 + 0.^{d}71776382\ E \qquad (12)$$

was used to compute the O–C chart, Figure 13. The O-C diagram, figure 14 was plotted using the quadratic Eq. 13

$$\begin{aligned} HJD &= 2433930.407925 && \pm 0.0009 \\ &+ 0.^{d}717763632\ E && \pm 1.21^{-7} \\ &+ 9.961248^{-11}\ E^2 && \pm 4.94^{-12} \qquad (13) \end{aligned}$$

which shows the true trend of the changes of the orbital period. This period was decreasing since 1931 until an abrupt increase in 1972. This increase continued until 1995 when an abrupt decrease occurred. A paper, Jones (1994a), showed a previously unreported sine curve trend in the residuals. Since that time, October 1993, 52 more times of light minima have been obtained and instead of a smooth sine curve, the wave displays the abrupt decrease that is continuing today. Using the quadratic term the AMG, Eq. 3, (dP/dt) observed = +0.009 seconds/year.

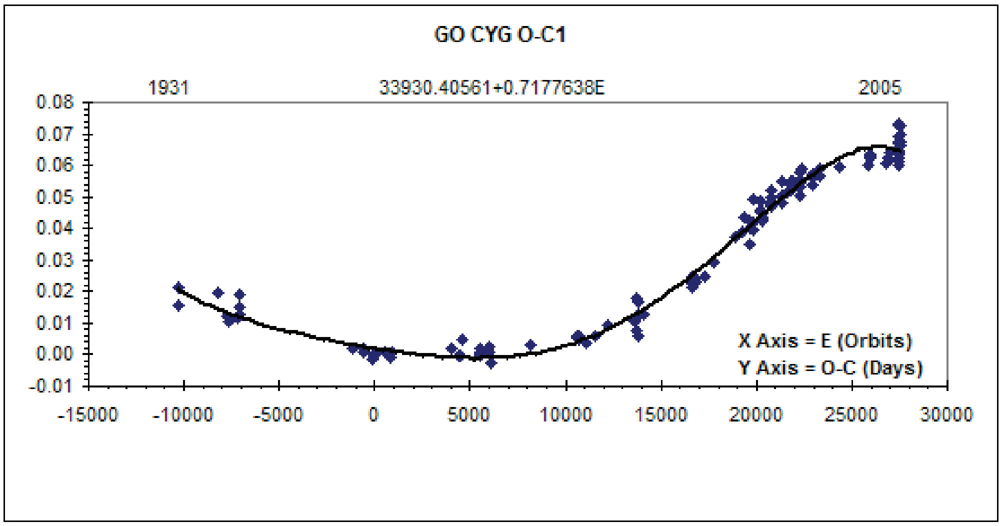

Figure 13.

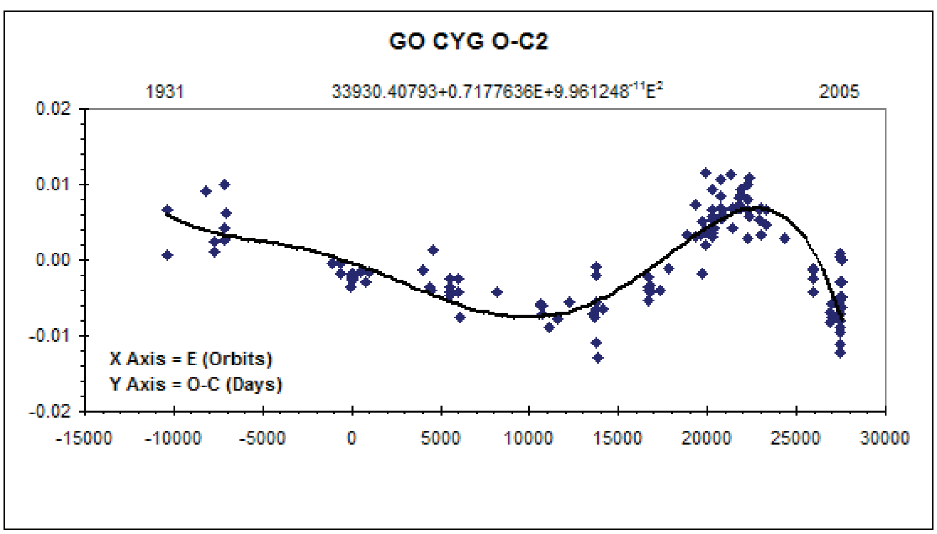

Figure 14.

3. 7. UV LEO

This is a short-period detached eclipsing binary with two late-type convective stars, G0 + G2, Popper (1997). We were able to locate 220 published times of light minima and added 4 times with this paper. The linear ephemeris (Eq. 14) was used to compute the O-C chart in Figure 15.

$$HJD = 2438440.72525 + 0.^{d}600085011\ E \quad (14)$$

The computed quadratic ephemeris (Eq. 15)

$$\begin{aligned} HJD &= 2438440.726259 && \pm 0.0002 \\ &+ 0.^{d}600085128\ E && \pm 2.41^{-8} \\ &+ 2.73603731^{-11}\ E^2 && \pm 1.46^{-12} \end{aligned} \quad (15)$$

was applied to the O-C numbers and the residuals plotted in Figure 16. The linear and quadratic plot both show a steady increase in the orbital period since 1939. Using the quadratic term the AMG, Equation 3, (dP/dt) observed = +0.003 seconds/year.

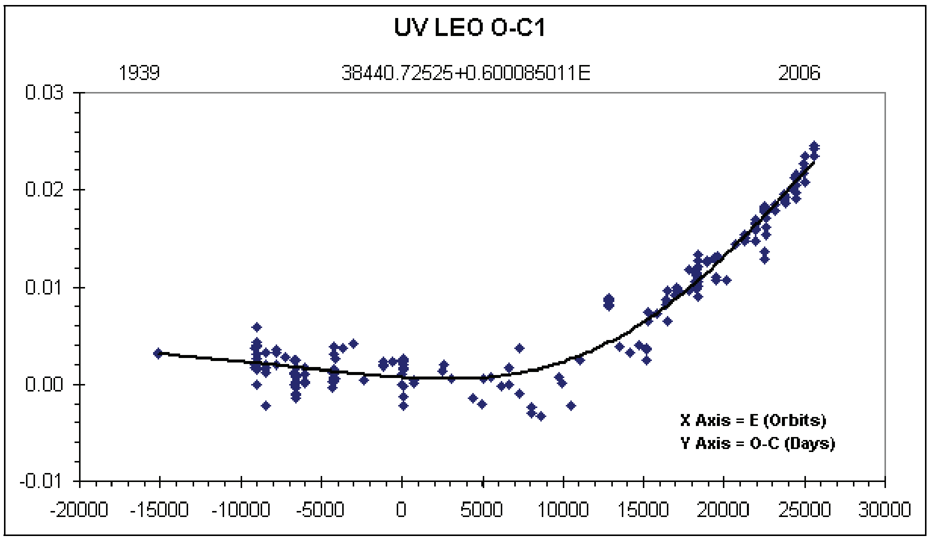

Figure 15.

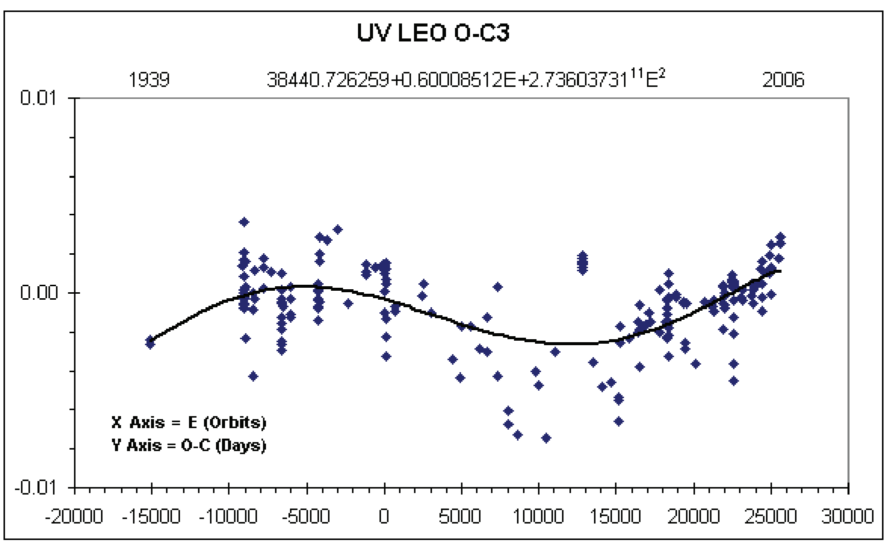

Figure 16.

4. Conclusion / Discussion

We have displayed the fundamental properties of the orbits of seven eclipsing binaries using observed times of light minima and compared them with the computed times, O-C. Despite some gaps in the observed times, the O-C charts have clearly exposed the main features of changes in the orbital periods. No attempt was made to analyze the light curves of the systems or try to determine if apsidal motion is present. A number of proposed mechanisms are in the literature to explain the period changes involving angular-momentum transfer, magnetic coupling, mass transfer and third body effect on the system.

An inferred light-travel time effect demonstrated by a smooth sinusoidal trend in the O-C diagrams is evident in four systems, EP AND, AH TAU, ZZ AUR and UV LEO, Figures 4, 8, 12, and 16 respectively. Of note, three of the systems are close contact or semi-close binaries and one, UV LEO, is detached. The orbital period changes caused by the light-travel time effect must be secular and appear to be independent of the modulated period variations exposed in sections of the fitted polynomial in the O-C diagrams, the so-called step variations.

In the three-body theory for period changes, to compute the mass of the third body, $M_{3,}$ and the size of the orbit about the system's barycentre, a, the total mass of the binary, M_b, needs to be known. For AH TAU, $M_b = 1.61\ M_O$, Yang (2002). We could not find such data for EP AND and ZZ AUR. Using the O-C diagram in Figure 8 and using the timing difference between extremes of the O-C curve and the peak amplitude of the sinusoid, Van Buren (1986), we determined a radius of 0.61 ±0.03 AU for the motion of the binary around the barycenter. The sine curve has a period of 25.1 ±1.29 years and this puts $M_3 = 1.59 \pm 0.02\ M_O$. The 0.61 AU represents the distance between the far and near side of the binary orbit about the system's barycentre. These numbers can be considered plausible and the third-body orbit could cause the orbital period changes.

We did not compute the orbit of a triple system for UV LEO since the sine curve in Figure 16 is asymmetrical. Snyder (1998) reported a more pronounced and symmetrical sinusoid, with the binary's motion about the barycentre of the triple of 0.32 AU and a period of 40.1 years.

We found that the short-term variations are easy to detect because of their short time scale in contrast to long-term changes, which are difficult to expose because of their small amplitude.

We are hoping to research detached systems like UV LEO displaying a light-travel time sine curve which would be free of the other effects inherent with contact and near-contact systems. We computed the Angular Momentum Loss/Gain observed for the seven systems, Table 1, since it required the quadratic term we had already computed to construct the O-C charts.

We would like to present a warning: It was Dugan who said, "Period changes frequently occur after publication of a careful study."

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