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THE ORBITAL PERIOD CHANGES OF YY Eri

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YY Eri ($V = 8\overset{\rm m}{.}05$–$8\overset{\rm m}{.}80$, $P = 0\overset{\rm d}{.}3125$) is a W UMa type eclipsing binary, whose orbital period variations have been argued by several authors. For example, Kim (1992) suggested that observed times of minima of YY Eri can be fitted to a non-linear ephemeris with a sinusoidal term. Maceroni and van't Veer (1994) claimed, however, that some later observations including ones of their own were deviating substantially from Kim's (1992) non-linear ephemeris. More recently, Kim et al. (1997) made an extensive study of the period variations of YY Eri, analyzing all the available photoelectric and CCD minima down to 1996 and some visual and photographic minima before 1950. They suggested that the most plausible mechanism would be a cyclic magnetic activity modulation of the primary star combined with a continuous mass transfer. They proposed two non-linear ephemerides, both of which have a periodic and a quadratic term, considering that the alternative period variations of YY Eri may be periodic ones rather than real abrupt changes.

In this study, we carried out photoelectric and CCD photometry of YY Eri with V filter from November 1992 through February 2000. Gunma University (GU) group covered three primary and four secondary minima using a 25-cm telescope plus an SBIG ST-7, while Variable Star Observers League in Japan (VSOLJ) group obtained two primary and two secondary minima using a 20-cm telescope plus a photoelectric photometer (Hamamatsu R647), a 25-cm telescope plus an SBIG ST-6, and a 6-cm/10-cm telescope plus SBIG ST-5. The times of these observed minima were determined with Kwee and van Woerden's (1956) method. VSOLJ group also covered another ten minima of YY Eri, which have been reported in *VSOLJ Var. Star Bull.*

In addition to 86 photoelectric and CCD minima listed by Kim et al. (1997), we collected another 31 photoelectric and CCD minima including those determined in this study, as shown in Table 1. The table also gives $(O-C)_1$ and $(O-C)_3$ residuals and their epochs E for these minima, which will be mentioned below. Among these data, we re-determined the three minima of *VSB 23* to four places from the original individual data using Kwee and van Woerden's (1956) method because they are given to three places of decimals in the source. We marked one (HJD 2451126.0528) of the minima of *VSB 33*

Table 1: Times of minima of YY Eri collected in this study.

HJD 2400000 +	E (cycles)	$(O-C)_1$ (days)	$(O-C)_3$ (days)	Method	Source**
46026.1049*	+38596.5	−0.0346	−0.0357	pe	AAS 136
46026.2641*	+38597	−0.0362	−0.0372	pe	AAS 136
46027.2304*	+38600	−0.0344	−0.0354	pe	AAS 136
46028.1945*	+38603	−0.0348	−0.0358	pe	AAS 136
46028.3558*	+38603.5	−0.0342	−0.0352	pe	AAS 136
48948.0655	+47685	−0.0001	+0.0002	pe	This study (VSOLJ)
50046.1407	+51100.5	+0.0023	+0.0018	CCD	This study (VSOLJ)
50049.1939*	+51110	+0.0033	+0.0007	CCD	VSB 23
50050.1586*	+51113	+0.0025	+0.0009	CCD	VSB 23
50071.0544	+51178	+0.0010	−0.0008	CCD	This study (VSOLJ)
50443.9947*	+52338	+0.0056	−0.0002	CCD	VSB 23
50481.2888	+52454	+0.0061	−0.0001	CCD	BAV-M 102
50758.4211	+53316	+0.0087	−0.0006	pe	IBVS 4670
50759.5467	+53319.5	+0.0091	−0.0003	pe	IBVS 4670
50819.9885	+53507.5	+0.0096	−0.0004	CCD	VSB 33
50823.3630	+53518	+0.0084	−0.0017	CCD	BAV-M 111
50829.9538	+53538.5	+0.0086	−0.0016	CCD	VSB 33
50834.9382	+53554	+0.0098	−0.0005	CCD	VSB 33
50843.9400	+53582	+0.0097	−0.0007	CCD	VSB 33
51126.0528:*	+54459.5	+0.0097:	−0.0039:	CCD	VSB 33
51129.1100	+54469	+0.0127	−0.0010	CCD	VSB 33
51200.9643	+54692.5	+0.0126	−0.0019	CCD	VSB 37
51496.427	+55611.5	+0.021	+0.003	CCD	BBSAG 122
51499.1572	+55620	+0.0180	−0.0000	CCD	This study (GU)
51533.0764	+55725.5	+0.0194	+0.0010	CCD	This study (GU)
51534.0411	+55728.5	+0.0196	+0.0012	CCD	This study (GU)
51535.9672	+55734.5	+0.0167	−0.0017	CCD	This study (VSOLJ)
51537.0941	+55738	+0.0184	−0.0001	CCD	This study (GU)
51538.0594	+55741	+0.0192	+0.0007	CCD	This study (GU)
51598.9842	+55930.5	+0.0205	+0.0013	CCD	This study (GU)
51599.9478	+55933.5	+0.0197	+0.0004	CCD	This study (GU)

* see text

* AAS 136: Yang & Liu (1999); BBSAG 122: *BBSAG Bull.*, **122**, 4, BAV-M 102: *BAV Mitteilungen*, Nr. 102; BAV-M 111: *BAV Mitteilungen*, Nr. 111; IBVS 4670: Selam, Gürol & Müyesseroğlu (1999); VSB 23: *VSOLJ Var. Star Bull.*, **23**, 2; VSB 33: Nagai (1999); VSB 37: Nagai (2000)

with a colon and will not use it in our discussion, because this minimum is found not free from somewhat large observational scatters in our re-examination of the original data.

Now, we will briefly discuss the orbital period variations of YY Eri based on all the photoelectric and CCD minima available to us. Figure 1 shows the $O - C$ diagram of YY Eri constructed with the following linear ephemeris

$$\text{Prim. Min} = \text{HJD } 2433617.51983 + 0.321496212 \times E$$

which is given by Kim et al. (1997, Eq. (1) in their paper).

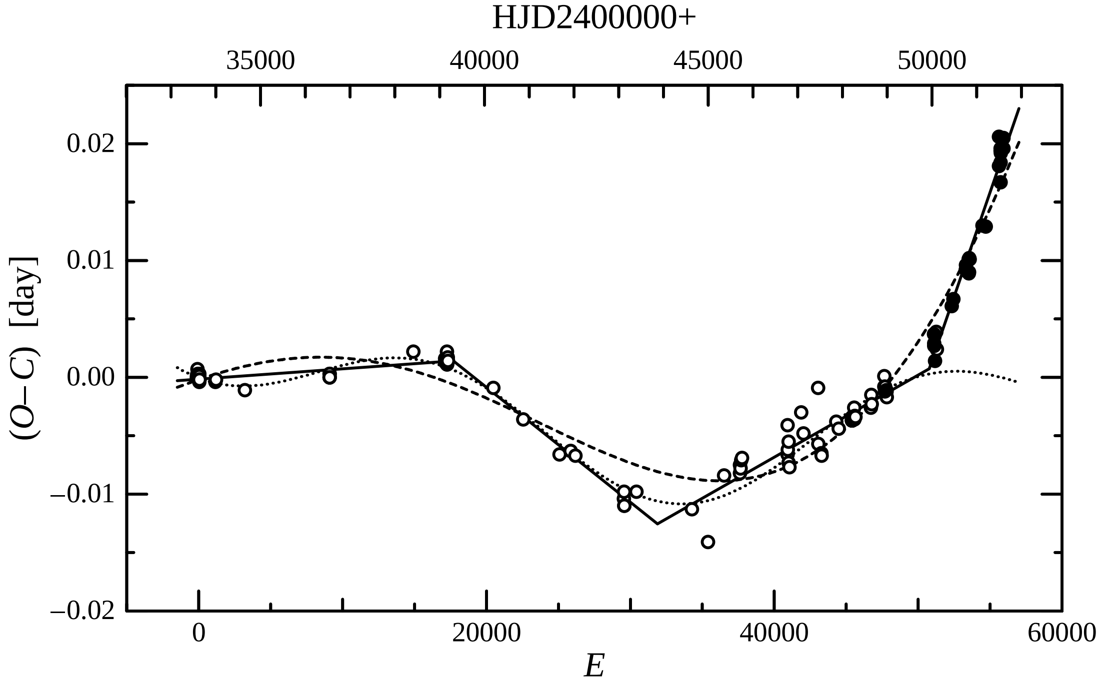

Figure 1. $O - C$ diagram of YY Eri constructed with the linear ephemeris of Kim et al. (1997, Eq. (1) in their paper). The open circles are the minima used by Kim et al. (1997) while filled circles are those collected in this study. The dotted line indicates the non-linear ephemeris of Kim et al. (1997, Eq. (2) in their paper), and the broken line represents the "best-fit" ephemeris with a sinusoidal and a quadratic term. The segments of solid straight lines show a combination of linear ephemerides listed in Table 2.

It turns out that the $O - C$ values of five minima of *AAS 136* (Yang and Liu, 1999) are systematically smaller than those of nearly same epochs by $0\overset{d}{.}03$–$0\overset{d}{.}04$. Since the discrepancy is unacceptably large, we will not take account of these minima in our discussion. It is noted, however, that the $O - C$ values became satisfactorily consistent with those of nearly the same epochs if exactly one day is added to each of these minima.

The dotted line in Figure 1 shows one of the two non-linear ephemerides proposed by Kim et al. (1997, Eq. (2) in their paper), which has a sinusoidal and a quadratic term. Figure 2a displays the $(O - C)_1$ residuals from this non-linear ephemeris. They are also listed in Table 1. This ephemeris represents the overall $O - C$ variation of YY Eri fairly well except for the last few thousand cycles, where $(O - C)_1$ residuals increase rapidly, suggesting that the ephemeris of Kim et al. (1997) can be applied no longer for these epochs. It is also found that the same is true of the case of the other non-linear ephemeris of Kim et al. (1997, Eq. 3 in their paper), although no line for the ephemeris is drawn in Figure 1.

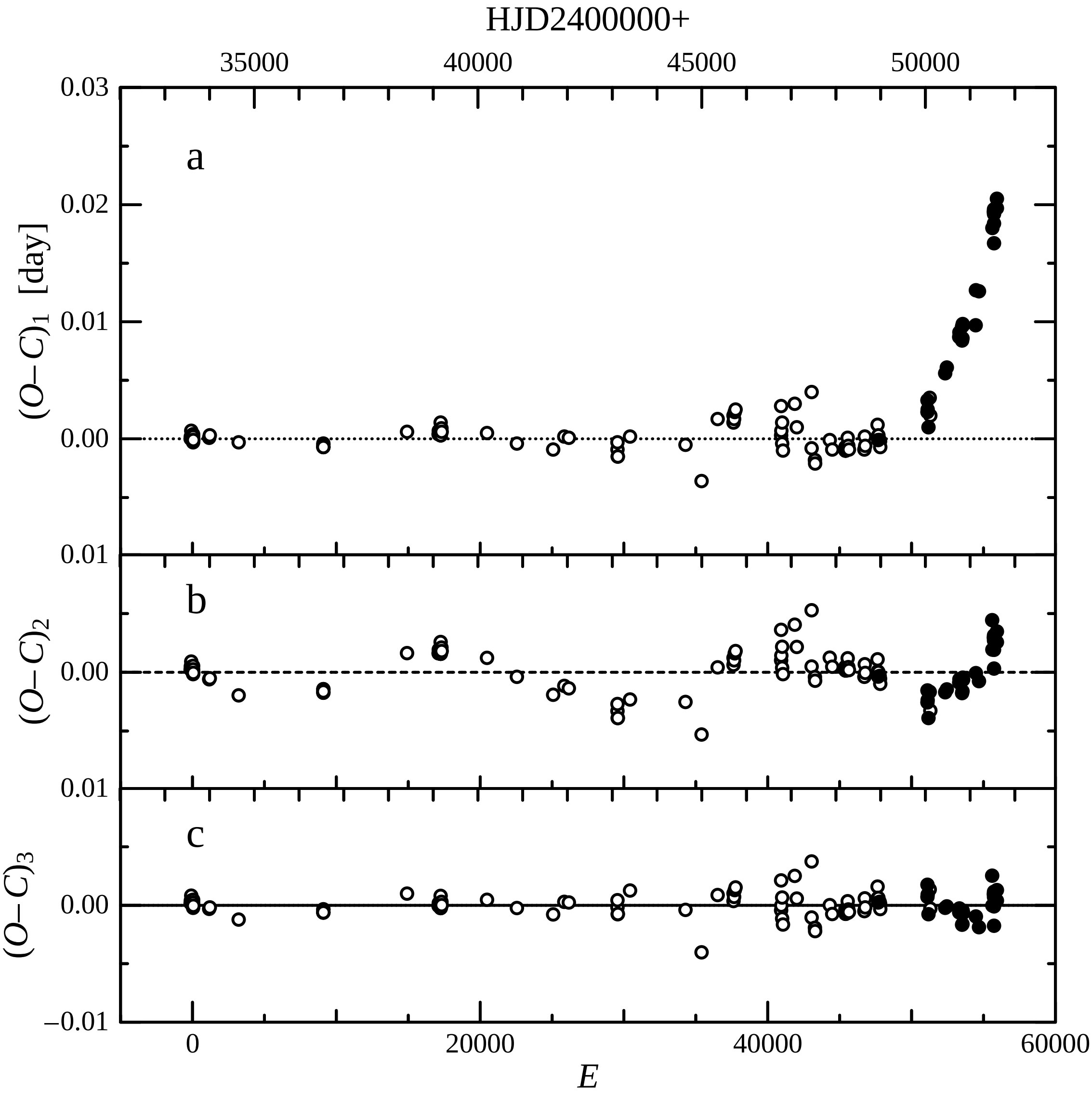

Figure 2. (a) $(O-C)_1$ residuals from Eq. (2) in the paper of Kim et al. (1997). (b) $(O-C)_2$ residuals from the non-linear ephemeris with a sinusoidal and a quadratic term fitted to all the data. (c) $(O-C)_3$ residuals from a combination of the linear ephemerides given in Table 2.

Table 2: Linear ephemeris of YY Eri for each interval

Interval Division & Duration	Linear Ephemeris Primary Min.	Period Change $\Delta P/P$
$\geq$ 5700 days	HJD $2433574.4392 + 0.32149630 \times (E + 134)$	
	± 1 ± 1	
HJD 2439300		$-3.3{\times}10^{-6}$
4600 days	HJD $2440201.1179 + 0.32149523 \times (E - 20478)$	
	± 3 ± 5	
HJD 2443900		$+5.2{\times}10^{-6}$
6000 days	HJD $2444636.1486 + 0.32149692 \times (E - 34273)$	
	± 3 ± 4	
HJD 2449900		$+8.9{\times}10^{-6}$
$\geq$ 1700 days	HJD $2450045.9782 + 0.32149979 \times (E - 51100)$	
	± 3 ± 9	

Assuming that the ephemeris of YY Eri is still represented by an equation having a sinusoidal and a quadratic term over the cycles down to the latest minimum, we obtain the "best-fit" solution which is shown by the broken line in Figure 1. However, the obtained ephemeris, whose parameters are not presented here, does not represent the overall $O-C$ variation so well. In fact, as seen in Figure 2b, the $(O-C)_2$ residuals from this ephemeris show a somewhat wave-like pattern rather than a random scattering around $(O-C)_2 = 0$. It is also noticed that the deduced periodicity ($\sim$ 76 yr) of the periodic term is much longer than the time span ($\sim$ 49 yr) covered with the photoelectric and CCD minima available to us. Therefore, at the moment, no strong evidence seems to exist that the ephemeris of YY Eri should have a periodic term.

Next, we assume that YY Eri has experienced only abrupt period changes. Dividing the observationally covered span ($\sim$ 49 yr) into four constant period intervals, we computed a linear ephemeris for each interval with the least square method, which is shown in Table 2 and also in Figure 1 with a segment of straight solid line. Although Kim et al. (1997) also derived such a combination of linear ephemerides for YY Eri, we adopt different intervals from theirs. For example, we separated the span $E = -133.5 - (+47685)$ into three constant period intervals, while they divided it into five intervals. Keeping in mind that observed times of minima are more or less affected by measured errors in observations and by possible fluctuant effects due to stellar "activity", we believe that, to investigate the nature of the overall $O-C$ variation, the least divisions would be more reasonable as far as no appreciably systematic residuals are presented. It is also noticed that there exists a significant discontinuity between the two linear ephemerides of Kim et al. (1997) around $E \simeq 36000$ (see Fig. 2 in their paper), which is unacceptable unless another two period jumps are supposed to have occurred around there. The $(O-C)_3$ residuals from the linear ephemerides obtained in this study are given in Table 1 and also in Figure 2c, where we see no significant wave-like pattern as found in Figure 2b.

In conclusion, the observed orbital period variations of YY Eri are more likely to be approximated by abrupt changes than by periodic ones. Kim et al. (1997) claimed that abrupt period changes are less plausible for YY Eri because no evidence of anisotropic mass ejection had been reported. There are some binaries, however, whose abrupt period changes are considered due to a cyclic magnetic activity of the component(s) (e.g. Šimon, 1997a, 1997b). Therefore, an abrupt period change approximation does not necessarily exclude the possibility of a cyclic magnetic activity mechanism for YY Eri.

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