ON THE SHORT-TERM ORBITAL PERIOD MODULATION OF Y LEONIS

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Abstract. The orbital period variation of the oEA system Y Leonis is investigated using observational data covering a relatively short time base, but whithout large time gaps. The aim of the present approach is to focus our attention on the short-term variability phenomena occurring in this system. The results of this study emphasize the intricate behaviour of the orbital period of Y Leo at the considered time scale.

Key words: variable stars – eclipsing binary systems – data analysis.

1. INTRODUCTION

The variable star Y Leonis (HIP 47178) is an A3 + K4 IV / K5 EA/SD eclipsing binary system (Giuricin et al. 1980, 1983). Though Giuricin et al. (1983) concluded that Y Leo is an "*ordinary semi-detached system, probably free of complications*", the results obtained during the last decade seem to contradict this conclusion. Thus, Yoon et al. (2004) found some Hα line profile variations in Y Leo. Later, Pop (2005) emphasized the multiperiodic character of the orbital period variability of Y Leo. Turcu et al. (2008) discovered the low amplitude and short period pulsations of the primary component of Y Leo. Recently, Turcu et al. (2010) established the Wilson-Devinney solution of the light curve of Y Leo on the basis of 7217 CCD observations obtained during 2009 observing season. They also emphasized some photometric variability during primary minima, possibly related to partial visibility of the primary component's pulsations, the presence of some variable accretion structures (e.g., Richards and Albright 1999; Richards 2004),

and/or patterns of stellar activity of the cool, late type secondary component (e.g., Hall 1989; Applegate 1992). In a recent paper, Pop et al. (2010a) resumed the study of the orbital period variation of Y Leo. They succeed to describe the multiperiodic behaviour of the $O - C$ curve considering: (i) a long-term modulation of 85.65 yr, which could also be part of a longer-term secular trend related to mass transfer and/or mass loss phenomena, and (ii) five short-term modulations with periodicities of: 25.10 yr, 10.521 yr, 7.645 yr, 9.231 yr, and 18.07 yr, respectively (in the descending order of their amplitudes). The possible causes taken into account by Pop et al. (2010a) were: the presence of some low mass stellar companions, and magnetic cycles of the secondary component according to Applegate's (1992) mechanism. The analyses performed by Pop (2005), and Pop et al. (2010a) supplied evidences for the possible presence of a low level stochastic variability of the orbital period.
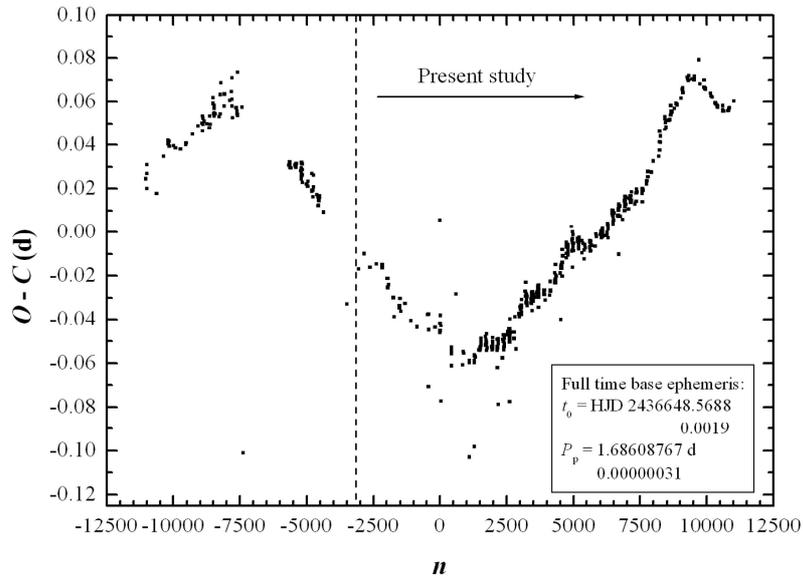

Fig. 1 – The preliminary $O - C$ diagram of Y Leonis based on all available data covering a time base of 101.8 yr.

The goal of the present approach was to perform a study of the short-term variability of the orbital period of Y Leo, using a subset of the available data covering about the last 63 yr of the whole data set. The main advantages of this choice are: the lack of long time gaps, and the presence of timing data with better quality, both from the viewpoint of the light detector used (photoelectric and CCD data), and the accuracy of the data processing methods. Our results are presented in Figs. 1–5.
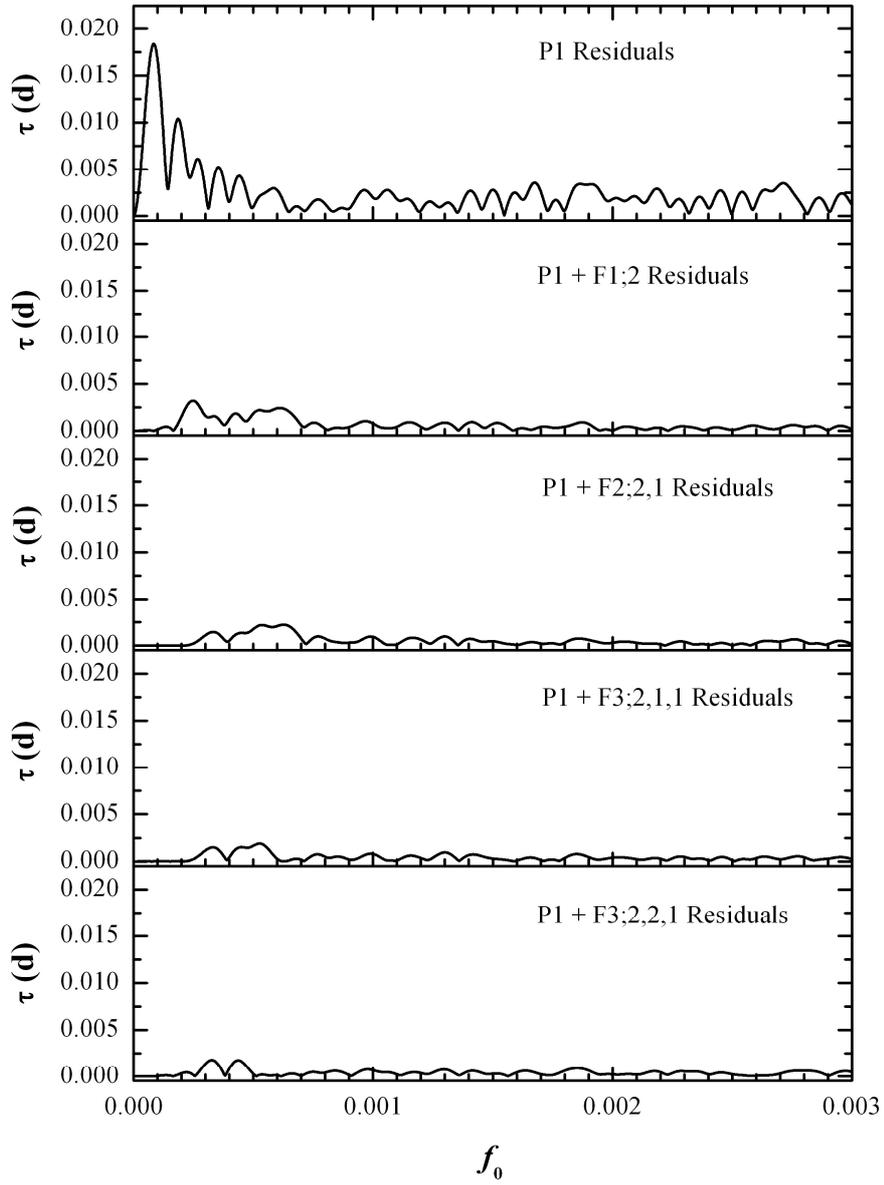
Fig. 2 – Amplitude spectra corresponding to different stages of prewhitening of the $O - C$ curve.
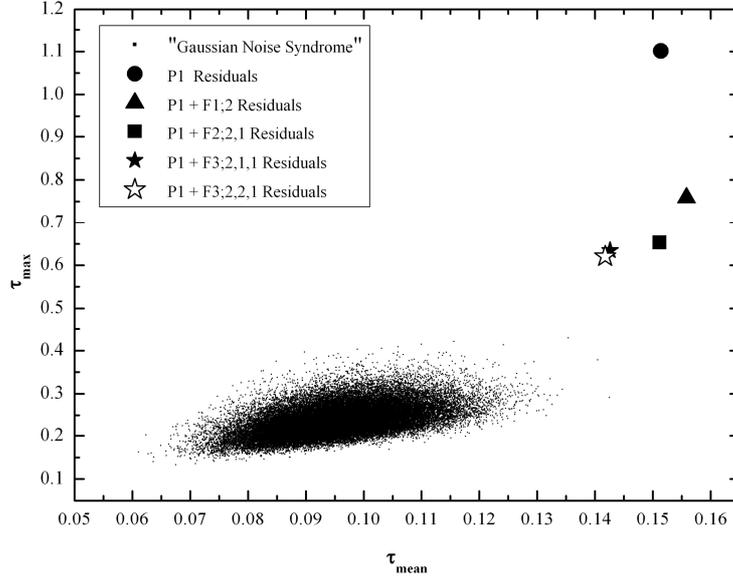
Fig. 3 – The different stages of the prewhitening process in the plane $(\tau_{mean}, \tau_{max})$ with respect to the cluster of simulated data points (see also Pop et al. 2010a).

2. OBSERVATIONAL DATA AND ANALYSIS METHODS

A complete description of the collection of times of minimum light used in this study is given by Pop et al. (2010a). From the initial data set containing 544 minimum light times, we obtained 403 data points without outliers and multiple observations performed at the same primary eclipse. According to the aim of the present approach, we took into account the last 336 times of minimum light (see Fig. 1). As we already mentioned, this subset of the whole data set covers a time base of 63 yr, does not display significant time gaps, and also contains good quality data.

The methods used for the $O - C$ curve analysis and modeling were previously described by Pop (1996, 2000) and Pop et al. (2003). The mathematical model for the ephemeris describing the temporal repartition of minimum light time

$$t_n = t_0 + \sum_{k=1}^{K} \tau_k n^k + \sum_{l=1}^{L} \sum_{m=1}^{M_l} \tau_{lm} \sin(2\pi m f_{0l} n + \Phi_{lm}),$$

where $\tau_1 \equiv P_p$, and $f_0 = P_p / P_{sl}$. To simplify the details of our results, we used the

following notation: $P[K] + F[L]; [M_1], [M_2], \ldots, [M_L]$, where P refers to the polynomial term, while F refers to the sum of truncated Fourier series.
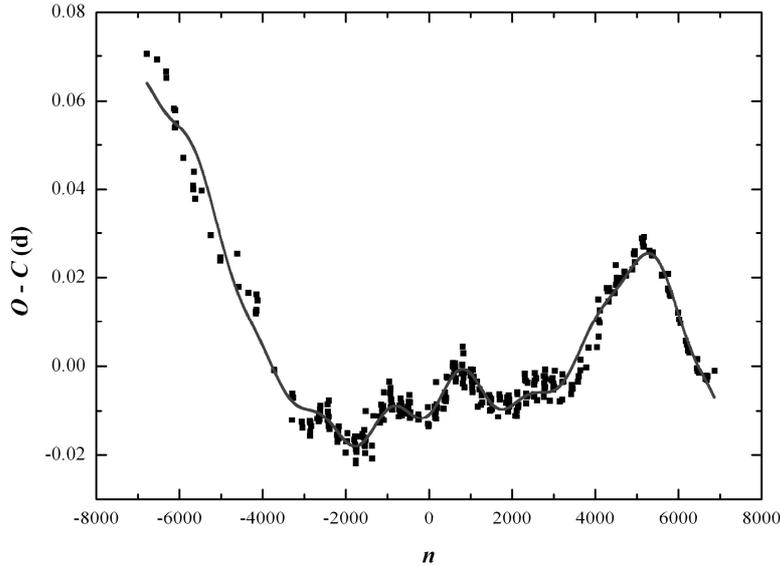

Fig. 4 – The final multiperiodic model of the $O - C$ curve of Y Leonis.

The alternate behaviour of the $O - C$ curve of Y Leo was investigated adopting a strategy which joins the $O - C$ curve modelling, periodicity detection techniques in the amplitude spectrum through Monte Carlo simulations (Pop 2005; Pop et al. 2010b, and references therein). The possible stochastic and/or irregular variability of the $O - C$ residuals is analysed using the self-correlation method (Percy et al. 1981; see also Percy et al. 1993, 2003), which is able to provide a „profile" of the respective variability phenomenon.

3. RESULTS AND CONCLUDING REMARKS

Three periodicities have been finally considered: 55.71 yr (fundamental + first harmonic), 17.96 yr (fundamental + first harmonic), and 7.486 yr. Because of the shorter time base considered with respect to the previous approach (Pop et al. 2010a), the longest period component ($P_{s1} = 55.71$ yr) fits the long-term behaviour of the $O - C$ curve, but without having a correct correspondence with that estimated in our previous approach

(P_{s1} = 85.65 yr). We have to note that, as in the case of taking into account all observational data (see Pop et al. 2010a), the secular trend cannot be described by a polynomial trend.

The above two shorter periodicities correspond to two of the periodicities pointed out by Pop et al. (2010a): 18.07 yr, and 7.645 yr.
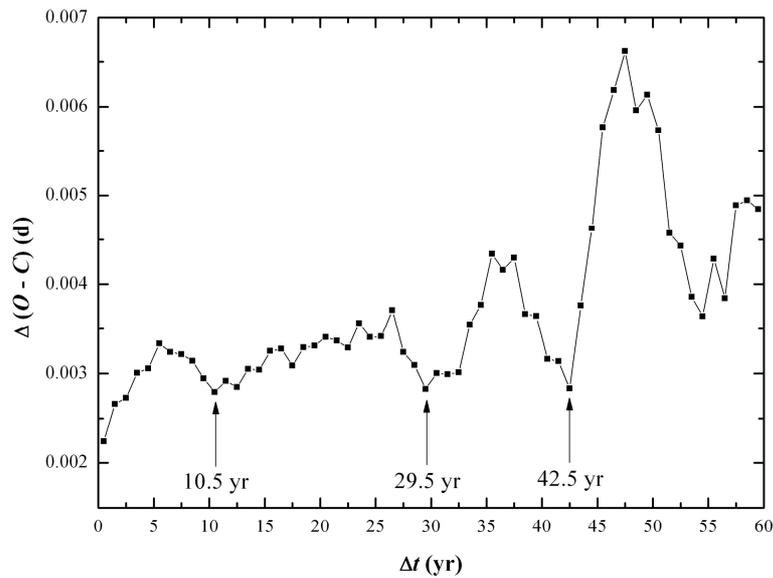

Fig. 5 – Self-correlation diagram of the final $O-C$ residuals.

The spectrum of the residuals obtained after removing the first periodicity displays (see Fig. 2, P1 + F1;2 residuals), in the (dimensionless) frequency range between 0.0002 and 0.0007, an intriguing group of close overlapping peaks.

The spectrum of the final residuals (P1 + F3;2,2,1) reveals the presence of two close peaks with similar amplitudes and significant frequencies (see Fig. 2, and see also Fig. 3). The model improvement process through differential corrections method, taking into account these two frequencies, failed.

The final $O-C$ curve model (Fig. 4) describes quite well the run of the $O-C$ residuals, but some misfits can be remarked.

The analysis of the P1 + F3;2,2,1 residuals with self-correlation method confirmed their intricate behaviour (Fig. 5, see also Fig. 3).

Both performed analyses (Pop 2005; Pop et al. 2010b; and Percy's self-correlation analysis) revealed the presence of a significant amount of noise (with respect to the

Gaussian noise, or to the observational errors), as well as the possible presence of some further periodic components.

We remark in the self-correlation diagram (see Fig. 5) the occurrence of the first minimum at the period value of 10.5 yr, which is another periodicity found by Pop et al. (2010a) (10.521 yr). It is interesting to observe that the second minimum appears at a periodicity close to three times the previous one, and relatively close to the period of 25.10 yr also emphasized by Pop et al. (2010a).

The present analysis of the short-term variability of the orbital period of Y Leonis, based on data covering a 63 yr time base, emphasized the intriguing behaviour of this oEA system. From the point of view of time series analysis, two important questions remain to be solved:

(i) what is the actual shape of the secular trend of the $O - C$ curve; and

(ii) nature of the above mentioned group of close overlapping peaks that appear in the amplitude spectrum of the P1 + F1;2 residuals (see Fig. 2), as well as their physical explanation.

Possible relations between the involved frequencies cannot be ruled out. Obviously, the observational and theoretical study of Y Leo has to be continued during the following observing seasons.

REFERENCES

Applegate, J. H.: 1992, *Astrophys. J.*, **385**, 621.
Giuricin, G., Mardirosian, F., Mezzetti, M.: 1983, *Astrophys. J. Suppl. Ser.*, **52**, 35.
Giuricin, G., Mardirosian, F., Predolin, F.: 1980, *Inf. Bull. Var. Stars*, No. 1786.
Hall, D. S.: 1989, *Space Sci. Rev.*, **50**, 219.
Percy, J. R., Hosick, J., Leigh, N. W. C.: 2003, *ASP Conf. Ser.*, Vol. **292**, p. 159.
Percy, J. R., Ralli, J. A., Sen, L. V.: 1993, *Publ. Astron. Soc. Pacific*, **105**, 287.
Percy, J. R., Shyam, M. J., Matthews, J. M.: 1981, *Astron. J.*, **86**, 53.
Pop, A.: 1996, *Rom. Astron. J.*, **6**, 147.
Pop, A.: 2000, *Metode de analiză şi interpretare a variabilităţii stelare*, Ed. Casa Cărţii de Ştiinţă, Cluj-Napoca.
Pop, A.: 2005, *ASP Conf. Ser.*, Vol. **335**, p. 263.
Pop, A., Liteanu, V., Moldovan, D.: 2003, *Astrophys. Space Sci.*, **284**, 1207
Pop, A., Turcu, V., Marcu, A.: 2010a, submitted to *Astrophys. Space Sci.*
Pop, A., Vamoş, C., Turcu, V.: 2010b, *Astron. J.*, **139**, 425.
Richards, M.: 2004, *Astron. Nachr.*, **325**, 229.

Richards, M. T., Albright, G. E.: 1999, *Astrophys. J.*, **123**, 537.
Turcu, V., Pop, A., Moldovan, D.: 2008, *Inf. Bull. Var. Stars*, No. 5826.
Turcu, V., Pop, A., Marcu, A., Moldovan, D.: 2010, *Astrophys. Space Sci.* DOI 10.1007/s10509-010-0432-9 (in press).
Yoon, T. S., Lee, J. A., Byeon, J. G., Kim, K. M., Kim, J. H., Yoo, K. H., Kim, S. H.: 2004, *New Astron. Rev.*, **48**, 759.

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