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The light and period changes of RT Andromedae

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Abstract. The nature of the long-term orbital period variation and the light level variation of RT And was studied based on all available photometric observations. The (O–C) diagram formed by all available times of eclipse minima could be either of a quasi-sinusoidal form superimposed on a parabolic form, or a long period sinusoidal form. The quasi-sinusoidal form with an amplitude of ∼0.002 days and a period of ∼65 years could be due to a cyclic magnetic activity modulation on the orbital period of the system. Applegate's theory (Applegate 1992), in this case, predicts an ∼3 kG mean subsurface magnetic field for the primary component of the system. The parabolic form corresponds to a secular period decrease of about 3×10^{-9} $m_{\odot}$ yr^{-1} caused by mass loss from the system, and the long-period sinusoidal form with an amplitude of ∼0.02 days and a period of ∼105 years corresponds to a secular period change caused by the light-time effect due to an unseen third star in the system. It was estimated that the unseen third star should be a low mass (lower than 0.6 $m_{\odot}$) and faint (∼$5\overset{\rm m}{.}$ fainter than the system RT And) star, whose detection is almost impossible. Future data will add information on the nature of the secular (O–C) variation. Secular light level variation of the system was found to be irregular and no correlation was detected with the orbital period variation.

Key words. stars: binaries: eclipsing – stars: individual: RT And

1. Introduction

RT And (BD +52°3383A, HIP 114484), as an interesting eclipsing binary, has a long observational record. It belongs to the short-period RS CVn type binaries (Hall 1976). Its first photoelectric observations were made by Gordon (1948, 1955). She reported a variable and asymmetric peculiar light curve.

Later observations proved the substantial variability in all phases of the light curve (Milano et al. 1981; Zeilik et al. 1989; Pribulla et al. 2000; among others). The asymmetry in the light curve has been interpreted as being produced by large cool star spots on the primary star (Zeilik et al. 1989; Pribulla et al. 2000).

The period variation of the system was studied many times in the past. First, Payne-Gaposchkin (1946) noted that previously published periods were too long to satisfactorily reflect the 1579 Harvard patrol plates. A few years later, Gordon (1955) found that the period found by Payne-Gaposchkin was too long to fit her observations. Kristenson (1967), Williamon (1974) and Dean (1974) discussed the abrupt period changes around 1914, 1940 and 1964. The often-observed asymmetry of the minima and the different light levels both during and outside of eclipse, expected by related period jumps, were thought to be caused by discontinuities in the mass exchange between the two components, as first suggested by Wood (1950). Hall & Kreiner (1980) and Milano et al. (1981, 1986) considered continuous period variation and derived quadratic elements. Milano et al., however, noted that it is not possible to ascertain, from their data, if the period variation is continuous or formed by abrupt changes. They guessed the presence of a wave with a period of about 44 years, superimposed on the parabolic (O–C) diagram.

Later period studies of RT And by Borkovits & Hegedüs (1996), Albayrak et al. (1999), and Pribulla et al. (2000) with more and more extended data were all considered continuous period variations. Borkovits & Hegedüs claimed that an unambiguous identification of a third component is not possible for RT And, although they represented the data very well with two light-time orbits (P_1 = 110 yr and P_2 = 51 yr). Albayrak et al. represented the data by a single light-time orbit (P = 108 yr) as the most possible cause of the cyclic period change. Finally, Pribulla et al. represented the data equally well by two period jumps in 1936 and 1966, a continuous period change combined with a light-time orbit, and by two combined light-time orbits.

On the other hand, the possible relation between the long-term asymmetry variation of the minima or different

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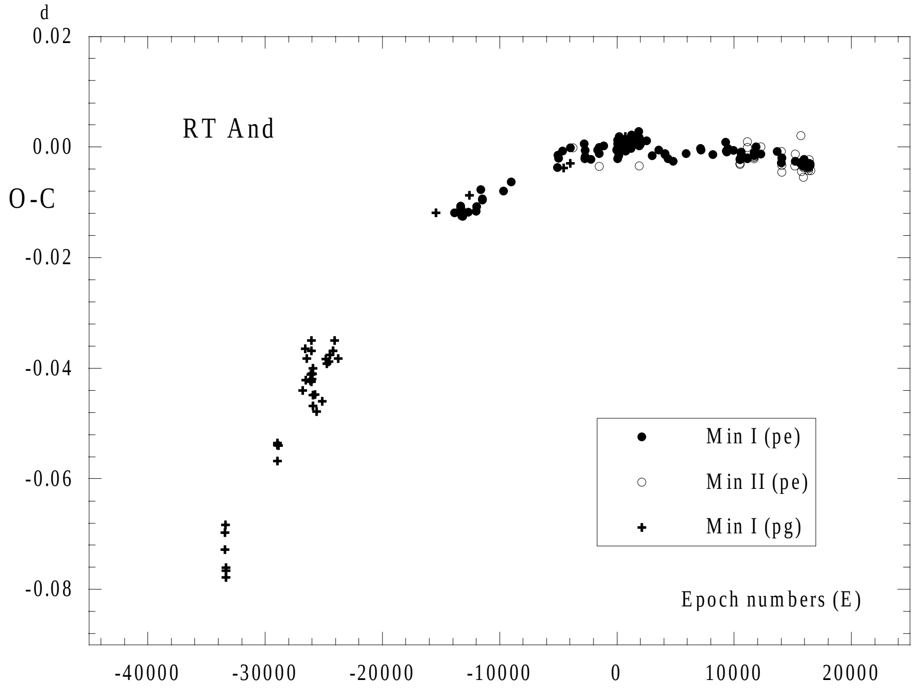

Fig. 1. The (O–C) diagram of RT And formed by using Kholopov et al.'s (1985) linear light elements (see Eq. (1)).

light levels of the light curves and the period variation of RT And was suggested in the past but never studied based on the observed data.

The aim of the present paper is to reconsider the long-term period variation and the light curve asymmetry or the light level variation of the system with the extended data and to search for a possible correlation between them.

2. Orbital period change

2.1. (O–C) diagram

We have used all photographic and photoelectric minima from the list compiled by Pribulla et al. (2000), except for the corrected value of 51 178.3440 instead of 51 179.3440 (Agerer & Hübscher 2000). We had to add only some photoelectric minima observed recently by Nelson (2000) and Bíró & Borkovits (2000). The weights used for different data were the following: photographic = 1 and photoelectric = 5.

As a first step, the (O–C) residuals were calculated by using the light elements given by Kholopov et al. (1985); as

$$\mathrm{Min\,I\,(HJD)} = 2\,441\,141.88901 + 0\overset{\mathrm{d}}{.}628929513 \times E. \quad (1)$$

From the (O–C) diagram in Fig. 1, the system's orbital period change could be suggested to be parabolic or sinusoidal.

We have considered three possible mechanisms to explain the orbital period change of the system: (i) mass loss from the system, (ii) a light time effect due to a third body in the system, and (iii) a period modulation due to the magnetic activity cycle of a component star. We shall investigate the suggested models in turn.

2.2. The mass loss from the system

The quadratic light elements of the system have been estimated by the weighted least squares method as follows:

$$\begin{aligned}\mathrm{Min\,I\,(HJD)} = {} & 2\,435\,454.47199(8) \\ & + 0\overset{\mathrm{d}}{.}628930798(9) \times E \\ & - 4\overset{\mathrm{d}}{.}65(4) \times 10^{-11} \times E^2.\end{aligned} \quad (2)$$

The quadratic fit and the O–C residuals from the parabola (as given by Eq. (2)) are plotted in Fig. 2. The quadratic term in Eq. (2) shows that the orbital period of RT And is continuously decreasing. The period decrease is found to be about 0.467 ± 0.004 s per century.

In binaries with solar type components, a continuous period decrease may indicate that the binary is undergoing magnetic breaking. In other words, if the outflowing mass is constrained by magnetic fields to co-rotate with the mass-loosing star out to an Alfvén radius which is sufficiently large, then the orbital period will decrease because a large amount of angular momentum per unit mass is removed from the system. This physical phenomenon has been discussed in Hall & Kreiner's (1980) paper for RT And together with 31 RS CVn type binaries and more recently in Demircan's (1999) paper.

In Hall & Kreiner's (1980) model, the cooler component star is assumed to be mass losing by a convectively driven stellar wind mechanism. The estimated mass loss rate is about $3 \times 10^{-9}\ m_{\odot}\ \mathrm{yr}^{-1}$ for the observed orbital period decrease of RT And system. Demircan (1999) has obtained the semi-empirical formula for the orbital period evolution of the RS CVn type binaries by using the empirical relations between the orbital angular

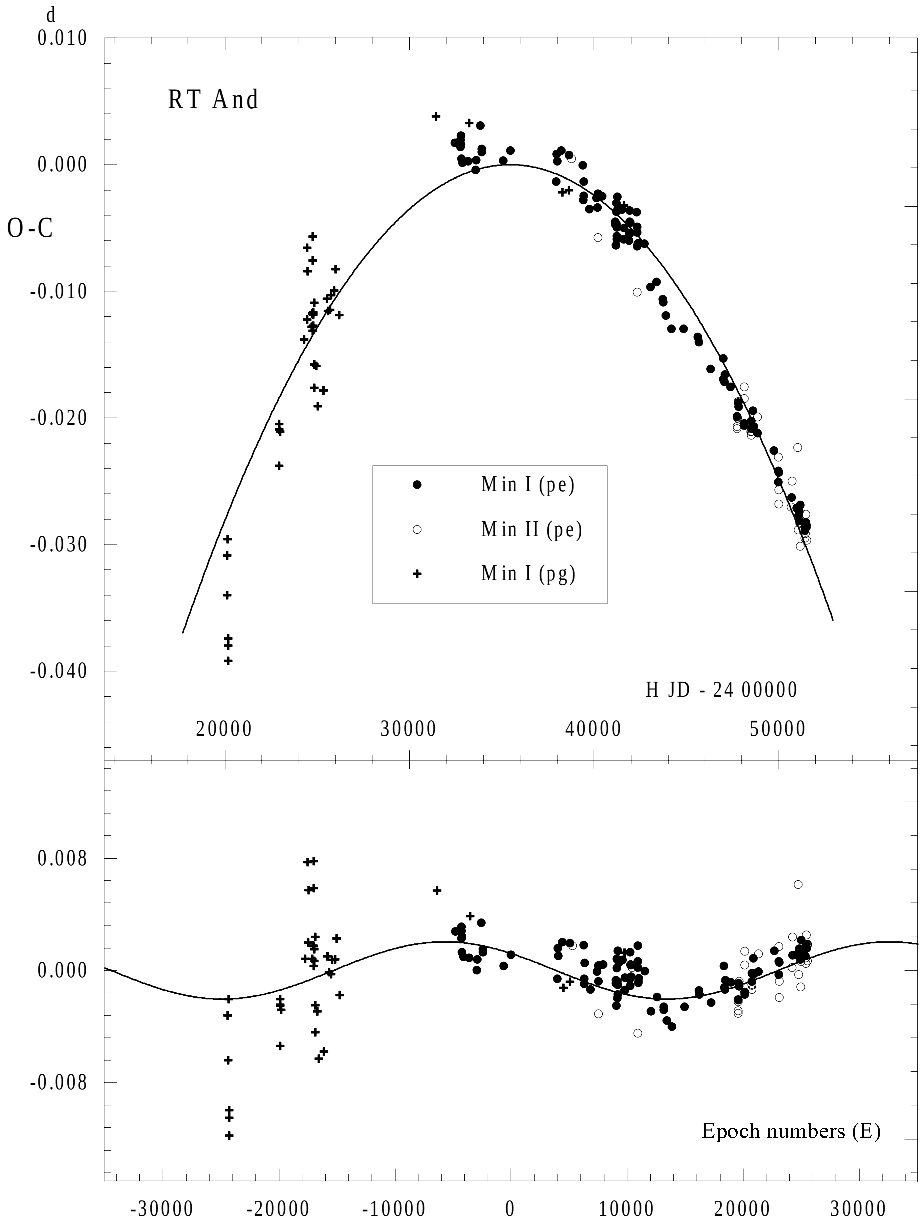

Fig. 2. a) The parabolic representation of the (O–C) data, and **b)** the residuals from the parabolic curve.

momentum loss, mass loss and period variation. According to his semi-empirical formula (e.g. his Eq. (7)), the mass loss rate of the system can be estimated to be about $4.7 \times 10^{-9}\ m_{\odot}\ \mathrm{yr}^{-1}$ for the observed orbital period decrease of RT And system. However, the mass loss consideration in Hall & Kreiner (1980) and Demircan (1999) is not vectorial, thus whether the magnetic wind can be polar or equatorial is not known.

2.3. Third body interpretation

The parabolic variation of the (O–C) diagram in Figs. 1 and 2 can well be a part of a sinusoidal form. So, a reasonable fit to (O–C) variation can be achieved by using a sinusoidal ephemeris instead of a parabolic form (cf., e.g. Irwin 1959):

$$(\mathrm{O{-}C}) = \frac{K}{\sqrt{1-e'^2\cos^2\omega'}}\left\{\frac{1-e'^2}{1+e'\cos\nu'}\sin(\nu'+\omega') + e'\sin\omega'\right\}, \quad (3)$$

where

$$K = \frac{a'_{12}\sin i'\sqrt{1-e'^2\cos^2\omega'}}{2.590\times10^{10}}, \quad (4)$$

is the semi-amplitude of the light-time effect (in days), a_{12} is the semi-major axis of the absolute orbit of the center of mass of the eclipsing pair around that of the whole system (in km), 2.590×10^{10} is the speed of light

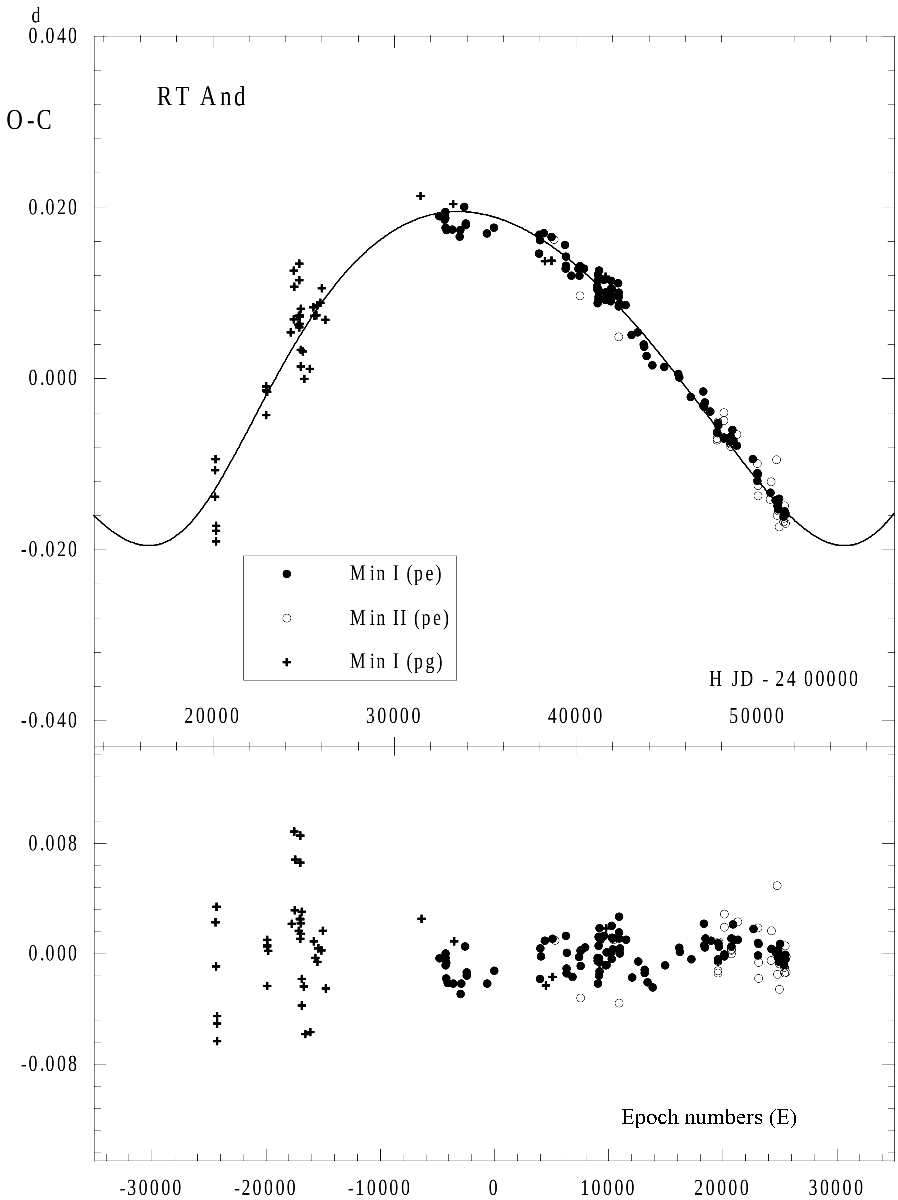

Fig. 3. a) The tilted (eccentric) sinusoidal representation of the (O–C) variation, and **b)** the residuals from the best fit curve (solid line).

(in km/day), i' is the inclination, e' is the eccentricity, ν' is the true anomaly, ω' is the longitude of periastron passage of the orbit of the three body system. T' and P_{12}, which are the secret parameters in Eq. (3), are the epoch of the periastron passage and the period of this orbit, respectively.

A weighted least squares solution of the T_0, P, $a_{12}\sin i'$, e', ω', T' and P_{12} parameters found are given in Table 1. The sinusoidal best fit curve and the residuals were plotted against epoch number in Fig. 3.

The most possible cause of the sinusoidal variation (if real) of the (O–C) diagram is known to be the existence of an unseen third star in the system. The parameters given in Table 1 show that the eclipsing pair revolves around a center of mass of the three-body system with a long period of 105 ± 10 yr. The projected distance of the center of mass of the eclipsing pair to the center of mass of the triple system should be 3.44 ± 0.22 AU. These values lead

Table 1. Parameters of the three-body orbit.

Parameter	Value	Standard deviation
T_0 HJD	35 454.4554	0.0009
P (day)	0.62893095	0.00000009
$a_{12}\sin i'$ (AU)	3.44	0.22
e'	0.31	0.05
ω' (°)	306	15
T' HJD	19 071	177
P_{12} (year)	105	10

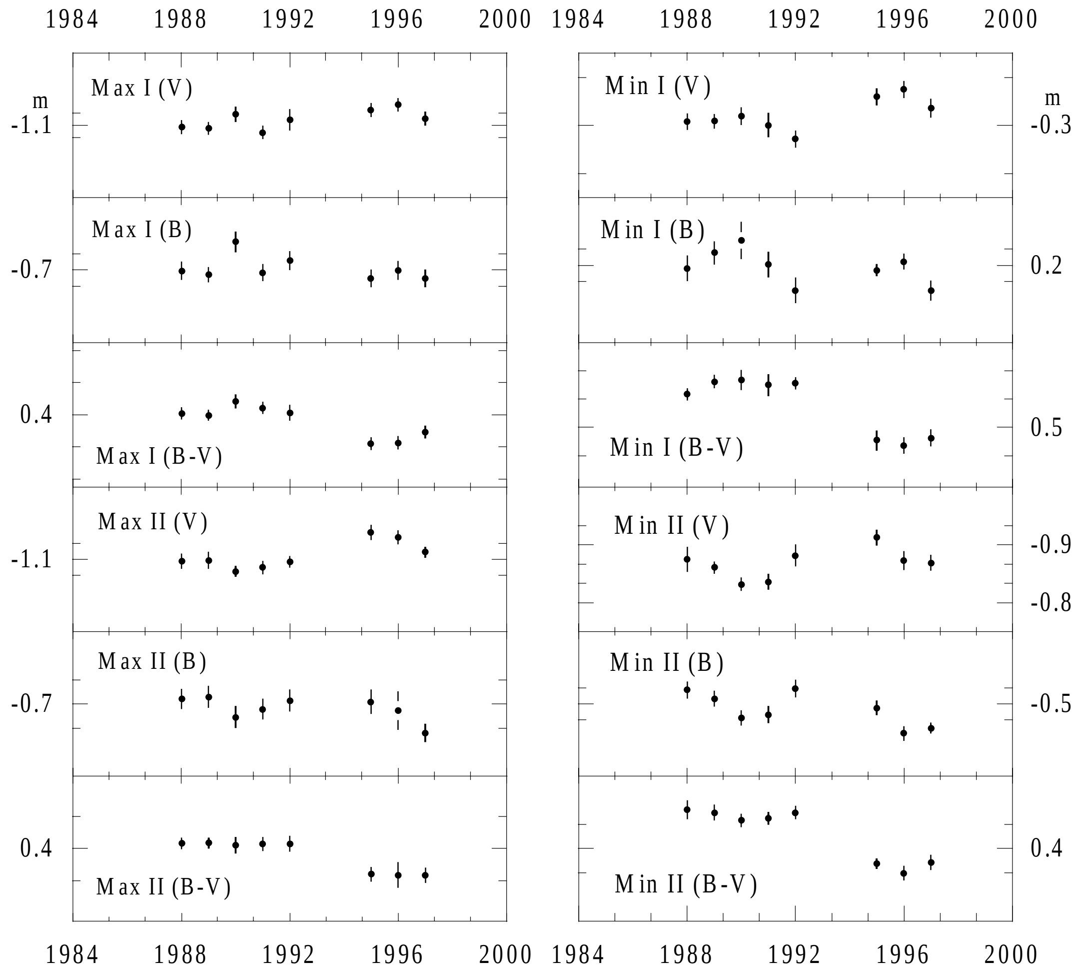

Fig. 4. The light level variation of RT And. The data were obtained from the selected light curves, where the same comparison star were used. The estimated error bars of the observational data in the figure were, also, plotted.

to a small mass function of $f(m_3) = 0.0037\ m_\odot$ for the hypothetical third body. So, the estimated mass of the third body ranges from $0.57\ m_\odot$ for $i' = 30°$ to $0.26\ m_\odot$ for $i' = 90°$.

If the third body orbit is co-planar with the systemic orbit, the semi-major axis a_3 of the third body orbit around the center of mass of the triple system would be about 25 AU. This value shows that the third body, if it exists, lies far beyond the outer Lagrangian points of RT And, and its orbit should be stable.

If the third body is a main-sequence star, the mass-luminosity function ($M_{\rm bol} = 5.84 - 6.54 \log m(m_\odot)$) for the main-sequence stars with $m < 0.7\ m_\odot$ given by Demircan & Kahraman (1991) gives the bolometric absolute magnitude of the third body as $M_{\rm bol} = 9\overset{\rm m}{.}7$, whereas the bolometric absolute magnitude of the system RT And is found to be about $4\overset{\rm m}{.}06$ in Pribulla et al.'s (2000) work. So, the third body would be about $5\overset{\rm m}{.}0$ fainter than RT And, which is too faint for photometric or spectroscopic detection. The semi-amplitude of the radial velocity of the center of mass of the eclipsing pair, relative to the mass center of triple system, turns out to be 1.03 km s^{-1}, which is too small for spectroscopic detection. The maximum angular separation between the hypothetical third body and the eclipsing pair would be about $0\overset{''}{.}006$, which is also too small for observational detection.

2.4. Magnetic activity interpretation

The cyclic magnetic activity effect on the orbital periods of RS CVn systems seems quite possible, since the components of these systems are late type and they display spin-orbit coupling. So, as an alternative explanation for cyclic changes of the orbital periods of RS CVn systems, Applegate's (1992) gravitational quadrupole coupling mechanism deserves attention. If the magnetic activity can change the quadrupole moment of a star, the cyclic exchange of angular momentum between the inner and outer parts of the star can change the star's oblateness and radial differential rotation. Any change in the rotational regime of a binary star component due to magnetic activity would be reflected in the orbit, as a consequence of the spin-orbit coupling. Finally, the cyclic magnetic activity can modulate the orbital period of the close binary system (Applegate 1992).

The residuals from the parabolic representation as plotted in Fig. 2b indicate a low amplitude (∼0.002 day) and a long period (∼65 years) oscillation. Using these parameters and the absolute dimensions of RT And from Pribulla et al. (2000), in Applegate's (1992) formulation we estimated the mean subsurface magnetic field of the primary component to be about 3 kiloGauss, which is provided by the periodic change of angular momentum between the inner and outer part of the star.

As it was noted by Applegate (1992), such oscillations in the orbital period should be connected to the long-term light level variations.

3. Luminosity variations

In order to look for any long-term light variations of RT And, we obtained 27 photoelectric light curves from Pribulla et al. (2000). These data were obtained between 1948 and 1999. In the observational data of the eight light curves between 1988 and 1997, the same comparison star was used. We considered, in every light curve, the light levels at mid-primary and mid-secondary eclipses (Min I and Min II) and Max I and Max II after primary and secondary eclipses. Each of the light levels of four characteristic phases were estimated on both B and V light curves. The scatter diagrams of the light levels at maxima and minima indicate no periodicity. However the data from selected light curves indicate short-term (a few years) fluctuations (Fig. 4), which are clearly not correlated with the period variation of the system.

4. Summary and discussion

All possible characters of the (O–C) variation formed by all available observed times of minima of RT And were interpreted in terms of the orbital period variation and possible causes. Most probably, the cyclic magnetic activity of the primary component, mass loss from the system and an unseen third star in the system play important roles in the orbital period (and thus (O–C)) variation. No sign of the expected correlation between orbital period variation and the light variation was found from the presently available data.

The last 85 years of data from RT And were found to be insufficient to decide on the character of the secular (O–C) variation; parabolic or sinusoidal. The present data in Fig. 1, in fact, are slightly better represented (see Fig. 3) by a tilted (eccentric) sinusoidal which strengthens the arguments for the presence of a third body revolving around the binary in an eccentric orbit. Future observations over next 20 years may help us decide about the character of the variation. Such new data will also be important in determining the sinusoidal long-term modulation of the (O–C) variation.

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