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A MULTIPERIODIC EPHEMERIS FOR RZ CEPHEI

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In a recent paper Todoran & Roman (1999) resumed the problem of the period variability of the RRc type star RZ Cephei. The $O-C$ curve displayed therein and covering about 120000 pulsation cycles, has an obvious alternate character. Geyer (1958) proposed for the first time a periodic ephemeris with a period of about 46 yr. This alternate behavior was later discussed by Cester & Todoran (1976) and Firmanyuk (1980, 1982). In what follows, we will present our results concerning the modelling of the run of this $O-C$ curve. They represent a continuation of our preliminary approach (Pop, 1998).

In our study we used 284 individual times of maximum light from the following sources: Florja (1939), Spinrad (1959), Todoran (1974), Cester & Todoran (1975, 1976), Maintz (1992), Seifert (1993) and Todoran & Roman (1999). The timespan of these data is about 102 yr.

We calculated the $O-C$ residuals with elements that are different from those of Todoran & Roman:

$$t_n = \text{HJD } 2430591.499 + 0\overset{\text{d}}{.}30867359\, n. \tag{1}$$

We took as initial epoch that moment which is the closest to the middle of the data set. Such a choice prevents cycle count errors. Being given the value of this parameter, we determined (through exhaustive search) that value of the pulsation period which minimizes the standard deviation of the $O-C$ residuals.

The next step in our analysis was to establish an adequate ephemeris according to the intricate behavior of the $O-C$ curve:

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

where t_0 is the initial epoch, the second term describes a polynomial trend, while the last one is a multiperiodic term with $f_{0l} = P_p/P_{sl}$, $P_p \equiv \tau_1$, P_p being the unperturbed pulsation period, and P_{sl} is the period of the l^{th} modulator signal. The fitting methodology of such a complex model to a given $O-C$ curve has been described in our previous paper (Pop (1996), see also Pop et al. (1996)). The preliminary fitting through linear least squares method for fixed values for frequencies, were followed by an improvement of all parameters using the differential correction method. In addition, we used the t statistical criterion of Student in order to keep only significant terms in Eq. (2) (see e.g. López de Coca et al., 1984). Our numerical tests lead us to an ephemeris with $K = 2$, $L = 2$, $M_1 = 2$, and $M_2 = 3$. The values of the computed parameters together with those of the corresponding standard errors are given in Table 1. The run of the observed data as well as that of the computed model are displayed in Figure 1.

Finally, we are able to formulate some conclusions:

1. According to the results listed in Table 1, the $O-C$ curve contains a parabolic trend, caused by a slow, linear decrease of the pulsation period, which may be related to evolutionary structural changes. In the same time, the standard error of τ_2 is quite large. That is why new observations are needed in order to confirm the existence of this trend.
2. The multiperiodic character of the determined ephemeris agrees with the shape of the observed $O-C$ curve, which is typical of a beat phenomenon. Its shape is caused by the interaction of two modulator signals. This result represents a quantitative confirmation of Todoran's (1976) assertion about the multiperiodicity of RZ Cep variability. Future observational and theoretical studies are needed in order to elucidate the nature of the involved physical mechanisms. It is interesting to note here that the longer periodicity (54.03 yr) is very close to the value of the median cycle length (55 yr) established by Hall (1990) for a sample of 21 variables of RR Lyr type, displaying alternate period changes. Could the appearance of the $O-C$ curve be the result of the interaction between pulsation and cyclic magnetic activity (according to the hypothesis of Stothers (1980))?
3. The amplitude of the second harmonic of the shorter periodicity (i.e., $l=2$, $m=3$) is below the level of the observational noise, whose standard deviation is about 0.023 d. Its reality has to be verified on the basis of new and more accurate observations.
4. A more precise estimate of the $O-C$ curve amplitude is about 0.51 d. Such a large value is a consequence of more or less rapid, but long-term and alternate cycle-to-cycle changes of the pulsation period.

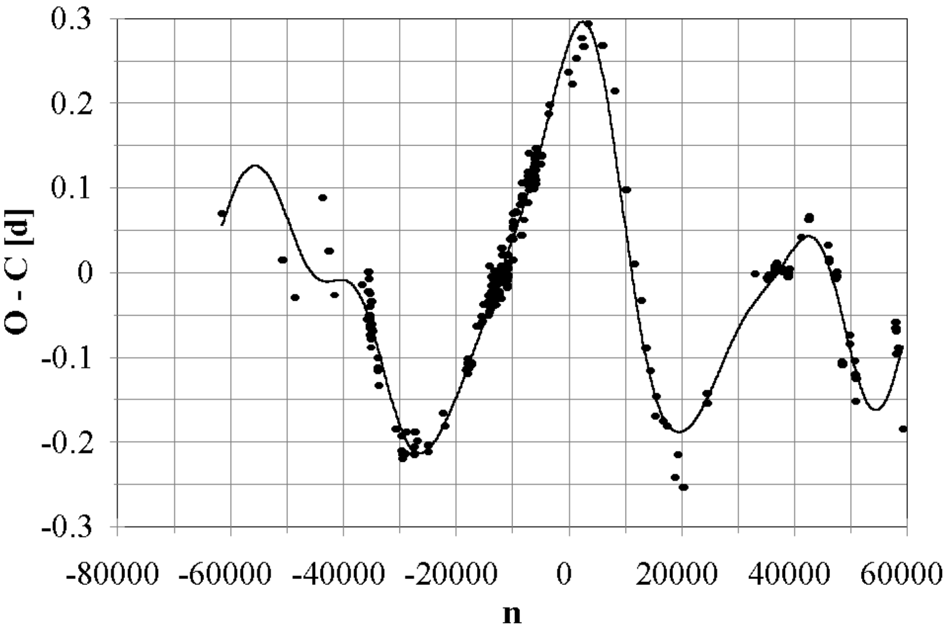

Figure 1.

Table 1

$t_0 = \mathrm{HJD}\ 2430591.2692$ ± 0.0043	
$\tau_1 \equiv P_p = 0.308673143$ d ± 0.000000081	
$\tau_2 = -9.8 \times 10^{-12}$ d/c $\pm 4.4 \times 10^{-12}$	
$f_{01} = 1.564 \times 10^{-5}$ $\pm 0.018 \times 10^{-5}$	$P_{s1} = 54.03$ yr ± 0.62
$\tau_{11} = 0.1244$ d ± 0.0044	$\Phi_{11} = 1.359$ rad ± 0.031
$\tau_{12} = 0.0578$ d ± 0.0039	$\Phi_{12} = 0.634$ rad ± 0.084
$f_{02} = 2.420 \times 10^{-5}$ $\pm 0.015 \times 10^{-5}$	$P_{s2} = 34.92$ yr ± 0.21
$\tau_{21} = 0.1180$ d ± 0.0029	$\Phi_{21} = 2.013$ rad ± 0.034
$\tau_{22} = 0.0403$ d ± 0.0027	$\Phi_{22} = 0.248$ rad ± 0.077
$\tau_{23} = 0.0076$ d ± 0.0027	$\Phi_{23} = 5.92$ rad ± 0.33

We hope that our attempt to decipher the period variability phenomenon of RZ Cep, together with the previous paper of Todoran & Roman (1999), will stimulate the interest in observing this pulsating star.

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