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# Photometric study of two $\beta$ Lyr-type binaries: DD Aqr and RR Lep

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## HIGHLIGHTS

- Light curves of DD Aqr and RR Lep were solved.
- Physical parameters of the components were estimated.
- Period changes were analysed and interpreted using possible mechanisms.

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## ABSTRACT

This paper presents detailed analysis of photometric observations of two eclipsing binary systems, DD Aqr and RR Lep. The *V* light curve of the neglected binary star DD Aqr from the All Sky Automated Survey was solved for the first time. The 1982–1987 *UBV* light curves of RR Lep from Vyas and Abhyankar (1989) were re-analysed. The final solutions give these two $\beta$ Lyr-type binary stars as having near contact configurations in which the secondary components almost fill their Roche limiting lobes. Using *O-C* residuals formed by the updated minima times, orbital period changes of the systems were analysed. The *O-C* diagram of DD Aqr displays a cyclic variation, while that of RR Lep shows a quasi-sinusoidal variation superimposed on a downward parabolic form. The parabolic variation, which suggests a secular orbital period decrease in RR Lep, was interpreted in terms of the combined effect of mass transfer and loss. The cyclic *O-C* variations were interpreted in terms of the light travel time effect due to unseen components in these two systems. The absolute parameters of the components of the systems were estimated, and their present evolutionary status is also discussed.



## 1. Introduction

Studying near contact binaries (NCBs) is important for an understanding of the formation and evolution of close binaries. The term NCB was first suggested by Shaw (1990) who defines NCBs as systems having components that are very close to filling their Roche lobes or with one component filling its Roche lobe while the other component is almost filling its lobe. Many NCB systems show $\beta$ Lyr-type light curves. The spectral types of the primary and secondary components of NCBs are A or F and G or K, respectively. Orbital periods of NCBs are generally less than one day, and their components have strong tidal interactions (e.g. Shaw, 1990; 1994; Hilditch, 2001). It is well-known that once a component fills its Roche lobe, a mass transfer from the lobe-filling component to the other component will occur. The mass transfer and/or mass loss in a close binary star can cause its orbital period to change. Therefore, observations of NCBs are also important for studying mass transfer in close binary stars. For this reason, the aim of this paper is to contribute to our knowledge of NCBs by studying two typical but under-researched NCB systems.

DD Aqr (AN 189.1935, GSC 00568-01178, ASAS J224553 + 0102.9, $V$=10.68 mag) was announced to be a variable star by Hoffmeister (1935). After its discovery, unfortunately, DD Aqr was neglected. There has been no detailed photometric/spectral study on DD Aqr up to now, although new minima times and new ephemerides of DD Aqr have been given by many authors in the literature. Only estimated general properties were reported in several catalogues.

RR Lep (BD -13 1086, HD 33789, GSC 05342-00258, 2MASS J05121050-1311585, $V$=10.14 mag) was discovered to be a variable star by Hoffmeister (1931). Photometric light curves of RR Lep and their solutions have been given by several authors (e.g. Samec et al., 1989; Vyas and Abhyankar, 1989; Liakos and Niarchos, 2013). Recently, Liakos and Niarchos (2013) confirmed that RR Lep is a classical Algol-type binary system with its primary component showing $\delta$ Scuti-type pulsations. They suggested that the primary component is an evolved main-sequence star and the secondary component is a rather more evolved star located above the

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**Table 1**
Summary of minima times used.

| System | Data Interval | Visual | | F & P | | CCD & Pe | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Min I | Min II | Min I | Min II | Min I | Min II | |
| DD Aqr | 1936–2013 | 24 | 3 | 8 | – | 39 | 7 | 81 |
| RR Lep | 1933–2014 | 46 | 1 | 11 | – | 31 | 4 | 93 |

F: photographic, P: photovisual, and Pe: photoelectric minima times.

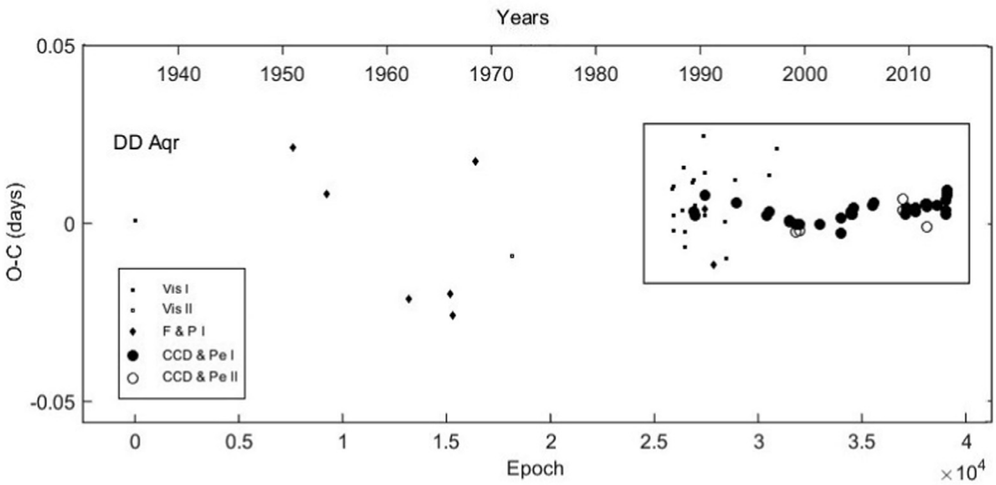


**Fig. 1.** *O-C* diagram of DD Aqr.

TAMS. They also proposed that RR Lep has a constant orbital period. There has been no *O-C* based period analysis of the system so far.

## 2. Orbital period analysis

In order to investigate the orbital period variations of DD Aqr and RR Lep, the *O-C* method was used. Observational minima times (eclipse timings) of these two eclipsing binaries were obtained from the list compiled by Kreiner et al. (2001). Adding some new minima times published in the literature, the updated data, summarized in Table 1, were used and can be requested in electronic or printed format from the authors. Almost all observational data were used, especially for RR Lep, although the earlier data (mostly visual, photographic and photovisual) have relatively less accuracy. Disregarding these, however, would result in a loss of information when the system was only able to be observed visually, photographically and/or photovisually, especially in early epochs. Since most of the older minima times have no published standard errors, the individual minima times were weighted according to the type of observation rather than their standard errors. Therefore, since the visual and photovisual (weak images on photographic plate) minima times and photographic (photographic series of exposures) minima times were published to two or three decimal places, their weights were chosen to be 1 and 5, respectively. On the other hand, since the CCD and photoelectric minima times were given to four or five decimal places, their weights were chosen to be 10.

The *O-C* (observed minus calculated) values of minima times of DD Aqr and RR Lep were calculated using the following linear ephemeris in Eqs. (1) and (2), respectively, given by Kreiner et al. (2001):

$$C_{1,\mathrm{DD\ Aqr}}\ (\mathrm{MinI/MinII}) = \mathrm{HJD}\ 2428395.1586 + 0^{\mathrm{d}}.72101091 \times E, \quad (1)$$

$$C_{1,\mathrm{RR\ Lep}}\ (\mathrm{MinI/MinII}) = \mathrm{HJD}\ 2430377.1532 + 0^{\mathrm{d}}.91542823 \times E. \quad (2)$$

Then, the *O-C* residuals were plotted against the epoch number ($E$) and observation years in Figs. 1 and 3 for DD Aqr and RR Lep, respectively. The CCD and photoelectric data in the box in the *O-C* diagram of DD Aqr in Fig. 1 display a quasi-periodic oscillation. However, the *O-C* diagram of RR Lep in Fig. 3 appears to be either a downward parabola or part of a sinusoid. Under the assumption of parabolic *O-C* variation, the weighted least-squares method was applied to each *O-C* data set of RR Lep to find its quadratic ephemeris. Furthermore, in order to show that the symmetric parabola at the vertex with $E$ (epoch number) = 0, the conjunction time ($T_0$) of RR Lep was changed. The resulting parameters and their standard deviations are as follows:

$$C_{2,\mathrm{RR\ Lep}} = \mathrm{HJD}\ 2444226.6650(40) + 0^{\mathrm{d}}.9154270(40) \times E - 0^{\mathrm{d}}.95(49) \times 10^{-10} \times E^2 \quad (3)$$

in which the parentheses contain the standard errors in units to the last decimal place. The new $O\text{-}C_2$ values and theoretical best-fitting curves, and also the residuals, are plotted against the epoch number and observation years in the second and third panels of Fig. 3. The quadratic term in Eq. (3) suggests that the orbital period of RR Lep is continuously decreasing at a slow rate of 0.65(±0.34) seconds per century. Standard errors of the quadratic term and period decrease were calculated to be a little large due to scattered data, especially before 2000.

RR Lep is a near contact binary system in which the secondary component is very close to filling its Roche limiting lobe (see Section 3). If mass transfer occurs from the secondary component to the primary component, the orbital period of the system should increase, as the mass-losing secondary component is less massive than the mass-gaining primary component. On the other hand, as is well known, if mass loss occurs from the system, the orbital period should decrease. Therefore, we considered the combined