Application of a New Non-Linear Least Squares Velocity Curve Analysis Technique for Spectroscopic Binary Stars

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Abstract

Using measured radial velocity data of nine double lined spectroscopic binary systems, NSV 223, AB And, V2082 Cyg, HS Her, V918 Her, BV Dra, BW Dra, V2357 Oph, and YZ Cas, we find corresponding orbital and spectroscopic elements via the method introduced by Karami & Mohebi (2007a) and Karami & Teimoorinia (2007). Our numerical results are in good agreement with those obtained by others using more traditional methods.

Key words. stars: binaries: eclipsing — stars: binaries: spectroscopic

1 Introduction

Determining the orbital elements of binary stars helps us to obtain fundamental information, such as the masses and radii of individual stars, that has an important role in understanding the present state and evolution of many interesting stellar objects. Analysis of both light and radial velocity (hereafter RV) curves, derived from photometric and spectroscopic observations, respectively, yields a complete set of basic absolute parameters. One historically well-known method to analyze the RV curve is that of Lehmann-Filhés (cf. Smart, 1990). In the present paper we use the method introduced by Karami & Mohebi (2007a) (=KM2007a) and Karami & Teimoorinia (2007) (=KT2007), to obtain orbital parameters of the nine double-lined spectroscopic binary systems: NSV 223, AB And, V2082 Cyg, HS Her, V918 Her, BV Dra, BW Dra, V2357 Oph, and YZ Cas. Our aim is to show the validity of our new method to a wide range of different types of binary.

The NSV 223 is a contact system of the A type and the mass ratio is believed to be small (Rucinski et al. 2003a,b). The large semiamplitudes, $K_i$, suggest that the orbital inclination is close to 90°. The spectral type is F7V and the period is 0.366128 days (Rucinski et al. 2003a,b). The AB And is a contact binary. The spectral type is G8V. The period is 0.3318919 days. It is suggested that observed period variability may be a result of the orbital motion...
in a wide triple system. The third body should then have to be a white dwarf (Pych et al. 2003, 2004). V2082 Cyg is most probably an A-type contact binary with a period of 0.714084 days. The spectral type is F2V (Pych et al. 2003, 2004). V2082 Cyg is most probably an A-type contact binary with a period of 0.714084 days. The spectral type is F2V (Pych et al. 2003, 2004). In HS Her, the effective temperatures were found to be $T_1 = 15200 \pm 750K$ and $T_2 = 7600 \pm 400K$ for the primary and secondary stars, respectively (Cakirli et al. 2007). The secondary component appears to rotate more slowly. The presence of a third body physically bound to the eclipsing pair has been suggested by many investigators. The two component are located near the zero-age main sequence, with age of about 32 Myr (Cakirli et al. 2007). It is classified as an Algol-type eclipsing binary and single-lined spectroscopic binary. The spectral type of more massive primary component is $B4.5V$. The effective temperature is about $15200 \pm 750K$ for the primary component and $7600 \pm 400K$ for the secondary component. The period is 1.6374316 days (Cakirli et al. 2007).

The V918 Her is an A-type contact binary. The spectral classification is A7V. The period of this binary star is 0.57481 days (Pych et al. 2003, 2004). The BV Dra and BW Dra have a circular orbit. From spectrophotometry the components of BV Dar are classified as F9 and F8 while the components of BW Dra are G3 and G0. The period of BV Dra is 0.350066 days and for BW Dra is 0.292166 days (Batten & Wenxian 1986). The V2357 Oph was classified as a pulsating star with a period of 0.208 days. The spectral type is G5V (Rucinski et al. 2003a, b). The spectral type of primary component of YZ Cas is A1V and for the secondary is F7V. The period of this binary is 4.4672235 days (Lacy 1981).

This paper is organized as follows. In Sect. 2, we give a brief review of the method of KM2007a and KT2007. In Sect. 3, the numerical results are reported, while the conclusions are given in Section 4.

2 A brief review on the method of KM2007a and KT2007

One may show that the radial acceleration scaled by the period is obtained as

\[ P \ddot{Z} = \frac{-2\pi K}{(1 - e^2)^{3/2}} \sin \left( \cos^{-1} \left( \frac{\dot{Z}}{K} - e \cos \omega \right) \right) \times \left\{ 1 + e \cos \left( -\omega + \cos^{-1} \left( \frac{\dot{Z}}{K} - e \cos \omega \right) \right) \right\}^2, \]

where the dot denotes the time derivative, $e$ is the eccentricity, $\omega$ is the longitude of periastron and $\dot{Z}$ is the radial velocity of system with respect to the center of mass. Also

\[ K = \frac{2\pi}{P} \frac{a \sin i}{\sqrt{1 - e^2}}, \]

where $P$ is the period of motion, $a$ is the semimajor axis of the orbit and inclination $i$ is the angle between the line of sight and the normal of the orbital plane.

Equation (1) describes a nonlinear relation, $P \ddot{Z} = P \ddot{Z}(\dot{Z}, K, e, \omega)$, in terms of the orbital elements $K$, $e$ and $\omega$. Using the nonlinear regression of Eq. (1), one can estimate the parameters $K$, $e$ and $\omega$, simultaneously. Also one may show that the adopted spectroscopic elements, i.e. $m_p/m_s$, $m_p \sin^3 i$ and $m_s \sin^3 i$, are related to the orbital parameters.

3 Numerical Results

Here we use the method of KM2007a and KT2007 to derive both the orbital and combined elements for the nine different double lined spectroscopic systems NSV 223, AB And, V2082
Cyg, HS Her, V918 Her, BV Dra, BW Dra, V2357 Oph, and YZ Cas. Since the paper has become very much lengthened by a large number of very similar diagrams and tables, hence only the result for NSV 223 is presented here and the results of other systems are reported in Karami et al. (2008). Using measured radial velocity data of the two components of NSV 223 obtained by Rucinski et al. (2003a,b), the fitted velocity curves are plotted in terms of the photometric phase in Fig. 1. For other systems, see Figs. 2 to 9 in Karami et al. (2008).

Figures 2 to 3 shows the radial acceleration scaled by the period versus the radial velocity for the primary and secondary components of NSV 223. For other systems, see Figs. 12 to 27 in Karami et al. (2008). The solid closed curves are results obtained from the non-linear regression of Eq. (1), which their good coincidence with the measured data yields to derive the optimized parameters $K, e$ and $\omega$. The apparent closeness of these curves to ellipses is due to the low, or zero, eccentricities of the corresponding orbits. For a well-defined eccentricity, the acceleration-velocity curve shows a noticeable deviation from a regular ellipse (see Karami & Mohebi 2007b).

The orbital parameters, $K, e$ and $\omega$, obtaining from the non-linear least squares of Eq. (1) and the combined spectroscopic elements including $m_p \sin^3 i$, $m_s \sin^3 i$, $(a_p + a_s) \sin i$ and $m_p/m_s$ obtaining from the estimated parameters $K, e$ and $\omega$ for NSV 223 are tabulated in Tables 1 to 2. For other systems, see Tables 3 to 18 in Karami et al. (2008). The velocity of the center of mass, $V_{\text{cm}}$, is obtained by calculating the areas above and below of the radial velocity curve. Where these areas become equal to each other, the velocity of center of mass is obtained. Tables 1 to 2 show that the results are in good accordance with the those obtained by Rucinski et al. (2003a,b) for NSV 223.

4 Conclusions

Using the method introduced by KM2007a and KT2007, we obtain both the orbital elements and the combined spectroscopic parameters of nine double lined spectroscopic binary systems. Our results are in good agreement with the those obtained by others using more traditional methods. There are some awareness about very close or contact binaries which show some anomalies from more general (detached) binaries. Systematic differences are sometimes found from standard Keplerian models. Even so, the results which are obtained appear comparable to those found by other authors using other methods. This does not mean that all these results are correct. It just implies that where systematic differences appear they affect the results found by different methods of analysis in similar ways. There are also some awareness about the complication binaries which do not behave in an ideal way. For example, active RS CVn type binaries with spots and the non-uniform surface flux distribution should affect the radial velocities.

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Figure 1: Radial velocities of the primary and secondary components of NSV 223 plotted against the photometric phase. The observational data have been deduced from Rucinski et al. (2003a,b).

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Figure 2: The radial acceleration scaled by the period versus the radial velocity of the primary component of NSV 223. The solid curve is obtained from the non-linear regression of Eq. (1). The plus points are the experimental data.

Figure 3: Same as Fig. 2, for the secondary component of NSV 223.
Table 1: Orbital parameters of NSV 223.

| Parameter | This Paper | Rucinski et al. (2003a,b) |
|-----------|------------|---------------------------|
| Primary   |            |                           |
| $V_{cm}$ ($km s^{-1}$) | $-21.31 \pm 0.98$ | $-21.66(2.15)$ |
| $K_p$ ($km s^{-1}$) | $42.56 \pm 0.03$ | $40.39(2.64)$ |
| $e$       | $0.004 \pm 0.001$ | —                        |
| $\omega$ ($^\circ$) | $279.40 \pm 12.04$ | —                        |
| Secondary |            |                           |
| $V_{cm}$ ($km s^{-1}$) | $-21.31 \pm 0.98$ | $-21.66(2.15)$ |
| $K_s$ ($km s^{-1}$) | $300.76 \pm 0.04$ | $297.98(4.18)$ |
| $e$       | $e_s = e_p$ | —                        |
| $\omega$ ($^\circ$) | $\omega_s = \omega_p - 180^\circ$ | —                        |

Table 2: Spectroscopic elements of NSV 223.

| Parameter | This Paper | Rucinski et al. (2003a,b) |
|-----------|------------|---------------------------|
| $m_p \sin^3 i/M_\odot$ | $1.3447 \pm 0.0007$ | —                        |
| $m_s \sin^3 i/M_\odot$ | $0.1903 \pm 0.0002$ | —                        |
| $(a_p + a_s) \sin i/R_\odot$ | $2.4834 \pm 0.0005$ | —                        |
| $m_s/m_p$ | $0.1415 \pm 0.0001$ | $0.136(10)$ |
| $(m_p + m_s) \sin^3 i/M_\odot$ | $1.535 \pm 0.001$ | $1.47(9)$ |