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# SPECTROSCOPIC AND PHOTOMETRIC SOLUTION OF THE BINARY SYSTEM BD+14°5016

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BD+14°5016 (SAO 108714, GSC 01720-00658) was discovered as a variable of W UMa type by Maciejewski et al. (2002). It is recorded in SIMBAD database as a $V{=}9\overset{\mathrm{m}}{.}50$ magnitude star of F2 spectral type, with $B-V{=}0\overset{\mathrm{m}}{.}31$. Photometric measurements from Tycho-2 Catalogue give $B-V{=}0\overset{\mathrm{m}}{.}34$ which is more consistent with the spectral type. The binary shows a light curve with an amplitude slightly smaller than 0.5 mag and with unequal minima and maxima. Up to the present the classification of variability type has based on a light-curve morphology, typical for contact binaries. The presented three spectral observations show lines of both components and allow to determine preliminary radial velocity amplitudes and hence mass ratio of component stars. That quantity together with photometric data allows us to find preliminary solution of the system.

The spectroscopic observations were collected at the David Dunlap Observatory (DDO), University of Toronto, with the 1.9 m telescope and the Cassegrain spectrograph giving a dispersion of 10.8 Å mm$^{-1}$, corresponding to about 0.2 Å pixel$^{-1}$ or about 12 km s$^{-1}$ pixel$^{-1}$. The spectra were centered at 5185 Å with a spectrum coverage of 210 Å. The exposure time of 20 min was used for all spectra. For reduction standard IRAF†, procedures were employed. The velocity determinations were done with broadening function algorithm (Rucinski 1999) against a sharp-line standard star used as a template.

The radial velocity data are listed in Table 1. For every spectrum the Heliocentric Julian Date of the exposure, phase and radial velocity measurements with errors are given. The phase was calculated according to ephemeris given in Maciejewski et al. (2002). Because of light curve peculiarities (described below) the ephemeris for a secondary minimum was taken. As a template the star HD 89021 with radial velocity of $V_t = 18.1$ km s$^{-1}$ (Evans, 1967) was used. Radial velocities were transformed to the solar system barycenter.

**Table 1.** Radial velocities measurements for BD+14°5016

| HJD | Phase | $V_1$ [km s$^{-1}$] | $V_2$ [km s$^{-1}$] |
|---|---|---|---|
| 2452571.698462 | 0.2410 | $-47.1 \pm 1.5$ | $238.7 \pm 0.7$ |
| 2452572.629192 | 0.7024 | $62.1 \pm 0.5$ | $-219.0 \pm 1.2$ |
| 2452576.711157 | 0.1116 | $-44.6 \pm 0.2$ | $155.8 \pm 1.2$ |

†IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

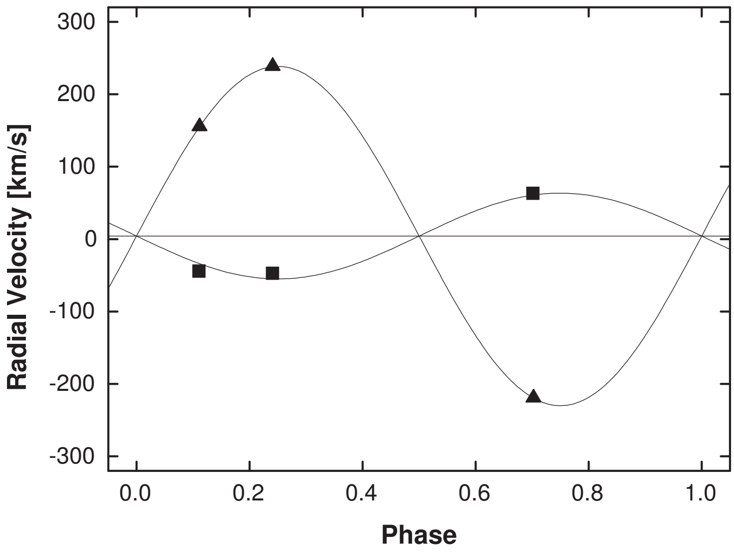


**Figure 1.** Radial velocities of BD+14°5016 plotted versus orbital phase.

The radial velocity orbits were solved by least squares fitting of a sinusoid for each component from the form $V(\phi) = \gamma + K_i \sin\phi$, with $\phi$ being the phase, $\gamma$ – the velocity of system's barycenter and $K_i$ – the velocity amplitude. The results are shown in Figure 1. The sine curves and the straight line denote circular-orbit fits and the average radial velocity $\gamma$, respectively. The derived orbital elements: the velocity amplitudes $K_1$ and $K_2$, average radial velocity $\gamma$, mass ratio $q$, orbit dimensions $a$, $a_1$, $a_2$ and component masses $m_1$, $m_2$ are presented in Table 2.

**Table 2.** Spectroscopic orbital elements of BD+14°5016

| Element | | Value |
|---|---|---|
| $K_1$ | [km s$^{-1}$] | $59.2 \pm 7.9$ |
| $K_2$ | [km s$^{-1}$] | $234.2 \pm 0.2$ |
| $\gamma$ | [km s$^{-1}$] | $4.2 \pm 0.8$ |
| $q = m_2/m_1$ | | $0.253 \pm 0.034$ |
| $a \sin i$ | [$R_\odot$] | $3.69 \pm 0.11$ |
| $a_1 \sin i$ | [$R_\odot$] | $0.74 \pm 0.10$ |
| $a_2 \sin i$ | [$R_\odot$] | $2.947 \pm 0.003$ |
| $m_1 \sin^3 i$ | [$M_\odot$] | $1.33 \pm 0.08$ |
| $m_2 \sin^3 i$ | [$M_\odot$] | $0.34 \pm 0.12$ |

The photometric data were adopted from Maciejewski et al. (2002). The observations were obtained on 16 nights during September-November 2002 with the 135 mm f/2.8 semi-automatic CCD camera operating at the Piwnice Observatory of the Nicholas Copernicus University. From the original CCD $V$-band light curve a few bad points have been excluded. The final light curve, composed of 255 data points marked with crosses, is plotted in Figure 2. The different brightness maxima heights suggest the presence of a spot on the surface of one of the components (O'Connell effect). The primary minimum and brighter maximum are shifted in phase and falls in phase 0.98 and 0.23, respectively. The brighter maximum seems to be relatively broader at the side of primary minimum.

The data were analyzed with the Wilson-Devinney (WD) light and radial velocity curves analysis code (Wilson and Devinney, 1971; Wilson, 1979, 1990). The synthetic light curve was computed using the light curve (LC) program and the differential corrections procedure was performed with the DC program. WD software was operated in Mode 3. The temperature of the primary component $T_1$ was set at 6900 K, typical for dwarfs of F2 spectral type. That value places the primary below a boundary of 7200 K between stars with convective and radiative envelopes, therefore the convective model was finally considered. We also developed a radiative model, however the obtained solution turned out to be less consistent with data. Standard values of bolometric albedos, $A_1 = A_2 = 0.5$, and gravity darkening coefficients, $g_1 = g_2 = 0.32$ (Lucy, 1967), for convective envelopes were used. Limb darkening values for logarithmic law were interpolated from van Hamme's tables (van Hamme, 1993). The central wavelength for a near-Johnson $V$ filter was assumed to be 5400 Å. Because of the light-curve peculiarities we assumed a spot solution from the beginning.

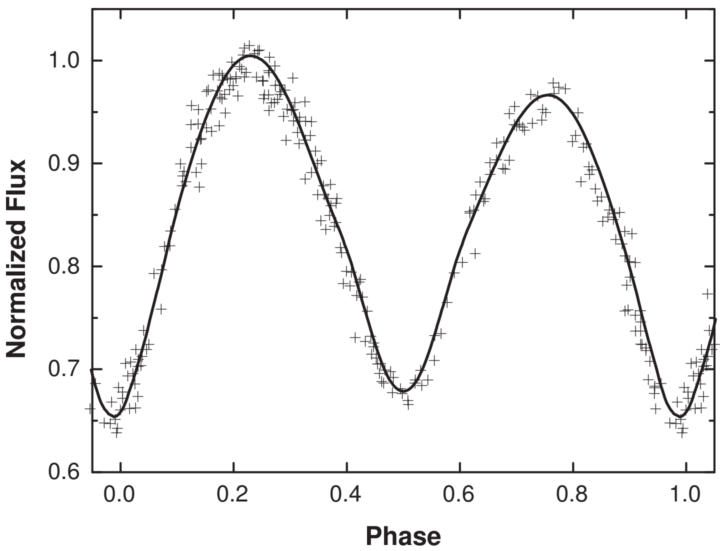


**Figure 2.** Observed (crosses) and computed (solid curve) light curve of BD+14°5016.

The calculated final light curve is displayed in Figure 2 (solid curve). The best results were obtained with a model including a hot spot located on the surface of the more massive component, near the neck connecting both stars. This superluminous region may be interpreted as a place where the gas stream from the secondary component strikes the surface of the primary. The final solution parameters are listed in Table 3 and the geometric representation of the model is shown in Figure 3. The system is in a large degree of overcontact of about 54%. The primary minimum is a transit indicating that BD+14°5016 is an A-type W UMa system. That is in agreement with its early spectral type.

**Table 3.** Solution parameters of BD+14°5016

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $g_1 = g_2$ | $0.32^\dagger$ | $r_1$ (pole) | 0.493 |
| $A_1 = A_2$ | $0.50^\dagger$ | $r_1$ (side) | 0.540 |
| $x_1 = x_2(V)$ | $0.694^\dagger$ | $r_1$ (back) | 0.573 |
| $y_1 = y_2(V)$ | $0.286^\dagger$ | $r_2$ (pole) | 0.275 |
| $x_1 = x_2$ (bol) | $0.638^\dagger$ | $r_2$ (side) | 0.290 |
| $y_1 = y_2$ (bol) | $0.252^\dagger$ | $r_2$ (back) | 0.356 |
| $i$ [°] | $72.6 \pm 0.3$ | $M_1$ [$M_\odot$] | 1.53 |
| $T_1$ [K] | $6900^\dagger$ | $M_2$ [$M_\odot$] | 0.39 |
| $T_2$ [K] | $6571 \pm 25$ | $R_1$ [$R_\odot$] | 2.076 |
| $\Omega_1 = \Omega_2$ | $2.255 \pm 0.005$ | $R_2$ [$R_\odot$] | 1.181 |
| Spot Latitude [°] | $90^\dagger$ | $L_1/(L_1 + L_2)$ | $0.791 \pm 0.003$ |
| Spot Longitude [°] | $333 \pm 1$ | $L_2/(L_1 + L_2)$ | $0.209 \pm 0.003$ |
| Spot Radius [°] | $7.8 \pm 0.4$ | $M_{bol1}$ [mag] | 2.43 |
| Spot Temp. Factor | $1.55 \pm 0.05$ | $M_{bol2}$ [mag] | 3.87 |

$^\dagger$ assumed and unadjusted

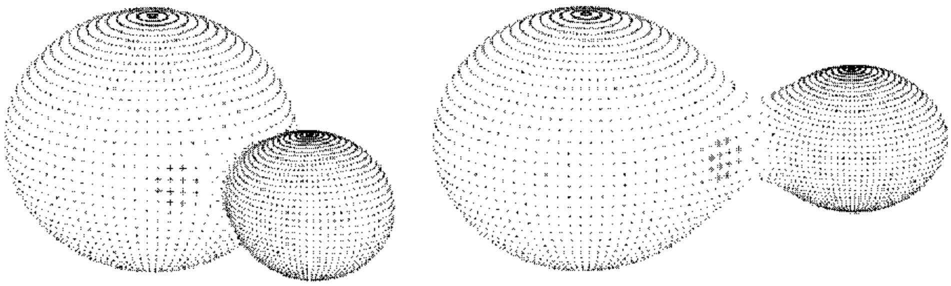

**Figure 3.** A three-dimensional model of BD+14°5016 for phases 0.1 and 0.25.

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