

HIGH VELOCITY SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES: BD+20 5152, A POSSIBLE TRIPLE SYSTEM

J. Sperauskas¹, A. Bartkevičius², R. P. Boyle³ and V. Deveikis¹

¹ *Vilnius University Observatory, Čiurlionio 29, Vilnius, LT-03100, Lithuania*

² *Institute of Theoretical Physics and Astronomy, Vilnius University, Goštauto 12, Vilnius, LT-01108, Lithuania*

³ *Vatican Observatory Research Group, Steward Observatory, Tucson, AZ 85721, U.S.A.*

Received 2010 January 21; revised July 1; accepted October 26

Abstract. The spectroscopic orbit of a high proper motion star, BD+20 5152, is calculated from 34 CORAVEL-type radial velocity measurements. The star has a slightly eccentric orbit with a period of 5.70613 d, half-amplitude of 47.7 km/s and eccentricity of 0.049. The center-of-mass velocity of the system is -24.3 km/s. BD+20 5152 seems to be a triple system consisting of a G8 dwarf as a primary component and of two K6–M0 dwarfs as secondary and tertiary components. This model is based on the analysis of its *UBVRI* and *JHK* magnitudes. According to the SuperWASP photometry, spots on the surface of the primary are suspected. The excessive brightness in the Galex FUV and NUV magnitudes and a non-zero eccentricity suggest the age of this system to be less than 1 Gyr.

Key words: stars: binaries: spectroscopic, individual (BD+20 5152)

1. INTRODUCTION

The star BD+20 5152 (J2000: RA = $22^{\text{h}} 26^{\text{m}} 14^{\text{s}}$, DEC = $+21^{\circ} 32' 10''$) has been included in the program of radial velocities of Population II stars (Bartkevičius & Sperauskas 2005a) owing to its high proper motion, $\mu_{\alpha} = 186.4$ and $\mu_{\delta} = 151.0$ mas/yr (SIMBAD), and significant ultraviolet excess, $\delta(U-B) = 0.22$, detected by Sandage & Kowal (1986). As a high proper motion star it was spotted by Luyten (1957) and included in his catalog as LTT 16569. This star is also known as G 127-31 in the Lowell Proper Motion Survey (Giclas et al. 1971). From 280 Å/mm dispersion objective prism spectra Lee (1984) has classified BD+20 5152 as K0.

The variability of BD+20 5152 with a period of 2.8894 d and amplitude of $\sim 1\%$ has been detected (SuperWASP survey, Norton et al. 2007). In that survey the star has a designation 1SWASP J222614.44+213209.6. The positional coincidence between this star and the ROSAT X-ray source 2RXP J222613.9+213219 was also noted. However, due to uncertainties in the positions of ROSAT (2000) sources, such match might be ambiguous. For example, Flesch & Hardcastle (2004) have identified the same X-ray source as a quasar with $B = 17$ mag. Furthermore, BD+20 5152 was not included as a X-ray source in the ROSAT all-sky survey

catalogs compiled by Voges et al. (1999, 2000). The star also turned out to be a radial velocity variable. Seven measurements of its radial velocity obtained by Fouts (1987) are spread over a range of +22.8 to -74.5 km/s.

In this paper, orbital parameters for the primary component of the spectroscopic binary BD+20 5152AB are obtained from 34 new radial velocity measurements. This continues publishing spectroscopic orbits for the stars selected as candidates for Population II objects (Bartkevičius & Sperauskas 2005b, 2006; Bartkevičius, Boyle & Sperauskas 2008). Dr. A. J. Norton (2009) has kindly provided us with opportunity to analyze yet unpublished photometric data from the SuperWASP project (Pollacco et al. 2006) collected in 2006 and 2007. We will discuss these data in Section 4, in connection with the rotation of BD+20 5152.

2. RADIAL VELOCITY MEASUREMENTS AND ORBITAL SOLUTION

Radial velocities were measured with a CORAVEL-type spectrometer of the Vilnius University Observatory. This instrument and data reduction techniques are described in Usgren, Sperauskas & Boyle (2002). Thirty-four radial velocities were obtained from 2005 October 5 to 2009 October 15 with the 0.63 m and 1.65 m telescopes of the Molėtai Observatory, Lithuania, and with the 1 m and 2.3 m (Kuiper) telescopes of the Steward Observatory, Arizona.

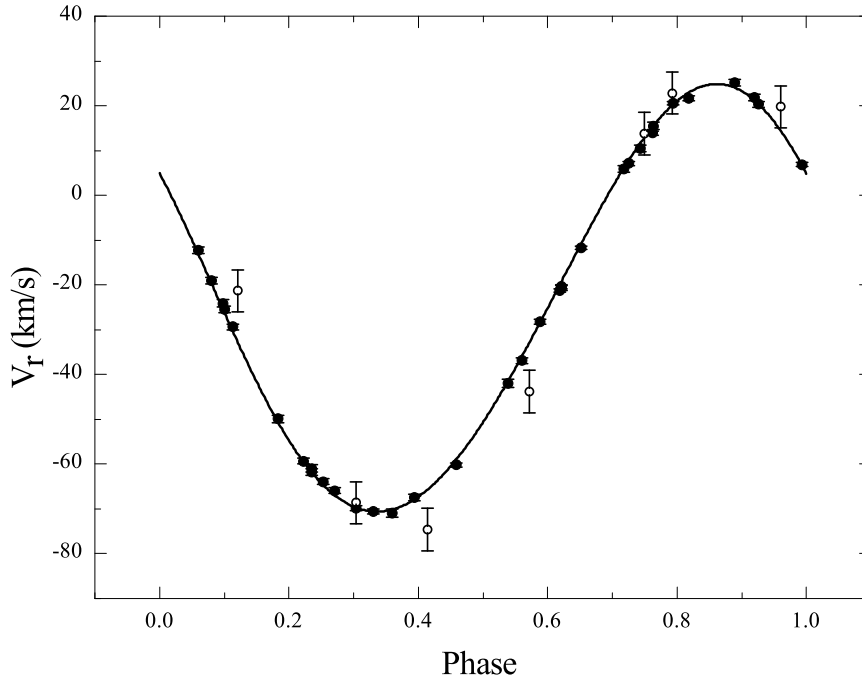


Fig. 1. Radial velocity curve of BD+20 5152. CORAVEL measurements are marked by solid dots. Open circles are the velocities obtained by Fouts (1987).

The measured radial velocities are given in Table 1, together with heliocentric dates, phases and residuals $O-C$ calculated from the orbital elements presented in Table 2.

Table 1. Radial velocity measurements.

HJD-2400000 days	Phase	V_r km/s	$O-C$ km/s	σ km/s	HJD 2400000+ days	Phase	V_r km/s	$O-C$ km/s	σ km/s
53649.450	0.223	-59.3	-0.29	0.7	53706.281	0.183	-49.9	-0.10	0.7
53650.428	0.394	-69.7	0.60	0.7	53707.293	0.360	-70.9	-0.67	0.9
53651.378	0.561	-36.9	-0.27	0.7	53708.312	0.538	-42.0	0.34	0.9
53652.273	0.718	5.9	0.55	0.7	53985.486	0.113	-29.4	0.12	0.7
53652.421	0.744	10.5	-0.62	0.7	54045.620	0.652	-11.7	-0.01	0.4
53653.249	0.889	25.1	0.93	0.7	54056.668	0.588	-28.2	1.15	0.5
53653.425	0.919	21.9	0.40	0.7	54057.660	0.761	13.9	-0.80	0.5
53654.224	0.060	-12.3	-0.16	0.7	54061.634	0.458	-60.2	-0.60	0.5
53654.341	0.080	-19.0	-0.23	0.7	54063.686	0.818	21.7	-0.93	0.6
53654.443	0.098	-24.1	0.48	0.8	54066.610	0.330	-70.6	-0.06	0.5
53655.229	0.236	-61.0	0.40	0.8	54074.569	0.725	7.1	0.02	0.4
53655.329	0.253	-63.9	0.36	0.7	54357.472	0.304	-69.8	-0.25	0.6
53655.427	0.270	-65.9	0.65	0.7	54747.283	0.618	-21.2	-0.25	0.4
53672.345	0.235	-61.8	-0.47	0.7	54747.297	0.621	-20.4	-0.14	0.4
53675.359	0.764	15.5	0.49	0.8	54748.288	0.794	20.6	0.65	0.4
53676.285	0.926	20.3	-0.41	0.7	54764.414	0.621	-20.7	-0.37	0.5
53677.281	0.100	-25.5	-0.15	0.7	55120.322	0.994	6.0	-0.37	0.5

Table 2. Orbital elements of BD+20 5152.

Parameter	Value
Orbital period	$P = 5.70613 \pm 0.00003$ d
Center-of-mass velocity	$V_{\odot} = -24.29 \pm 0.08$ km/s
Half-amplitude	$K = 47.7 \pm 0.1$ km/s
Eccentricity	$e = 0.049 \pm 0.002$
Longitude of periastron	$w = 53 \pm 2$ deg
Date of conjunction	$T_{\text{conj}} = 2455120.36 \pm 0.04$ d
Projected semimajor axis	$a \sin i = (3.739 \pm 0.008) 10^6$ km
Function of mass	$f(m) = 0.0641 \pm 0.004 M_{\odot}$
Standard deviation of residuals	$\sigma(O - C) = 0.51$ km/s

Table 3. Intrinsic *UBVRIJHK* magnitudes of BD+20 5152.

<i>U</i>	<i>B</i>	<i>V</i>	<i>R</i>	<i>I</i>	<i>J</i>	<i>H</i>	<i>K</i>	E_{B-V}
10.813 ± 0.027	10.637 ± 0.022	9.886 ± 0.019	9.465 ± 0.022	9.104 ± 0.022	8.402 ± 0.035	7.914 ± 0.027	7.848 ± 0.024	0.013

Figure 1 shows the radial velocity curve of BD+20 5152. The diameter of points in the figure is almost equal to the mean error of observations (± 0.7 km/s). Radial velocities measured by Fouts (1987) are also plotted for comparison, but owing to their large errors (± 4.7 km/s), these values have not been used for the orbital solution. It is intriguing that BD+20 5152, supposed to be an old Population II star, has a short orbital period, 5.7 d, with the eccentricity significantly different from zero ($e = 0.049$). According to the Goldman & Mazeh (1991) approximation to tidal circularization of orbits of short-period binaries, the time scale of this process is proportional to the 10/3 power of the period. Thus, the circularization time should be only 0.7 Gyr for a binary star with $P = 5.7$ d.

3. THE COMPONENTS

Using the 280 Å/mm dispersion spectra, obtained with a 4° objective prism, Lee (1984) has classified BD+20 5152 as a K0-type star without any note about its possible binary nature or similarity to subdwarfs. Our CORAVEL radial-velocity measurements indicate no secondary component by any dip in the cross-correlation curve. So, this can mean that the secondary component is at least 2.5 mag fainter than the primary. Using the *Hipparcos* parallax 12.21 ± 1.88 mas (van Leeuwen 2007) and V and E_{B-V} values given in Table 3, we obtain $M_V = 5.3 \pm 0.3$ mag for the main component. This means that the primary is a main sequence G5–G8 star of mass 0.95 to 0.90 $M_\odot$. Then, according to the mass function for a binary system, the minimum mass of the secondary is 0.48 $M_\odot$, its spectral class earlier than M2 and $M_V < 10$ mag. For these evaluations the calibration of MK spectral type in terms of M_V and $M_\odot$ is taken from Straizys (1992).

Additional evaluation of components of the system was made by comparing its *UBVRIJHK* magnitudes with the same magnitudes for different MK spectral types taking into account the following.

(1) The weighted mean colors derived from Sandage & Kowal (1986) *UBV* photometry and Rossello et al. (1988) *UBVRI* photometry. The latter photometric results are based on the Neckel & Chini (1980) standards with R and I magnitudes slightly different from Johnson’s standards (Bessell 1983; Taylor et al. 1989). Therefore, $V-R$ and $R-I$ colors have been reduced to the standard Cousins system by means of Taylor’s equations (8) and (13).

(b) 2MASS *JHK_s* photometry (Cutri et al. 2003) was transformed to the Bessell & Brett homogenized system by the relations given by Carpenter (2001).

(c) $E_{B-V} = 0.045$, the value of extinction along the line of sight, derived by the Schlegel et al. (1998) method¹. This value was reduced to 0.013 mag using the Abt & Golson (1962) factor $1 - \exp(-H \cdot r \cdot \sin(b))$, where $r = 82$ pc is the star distance taken from van Leeuwen (2007), a constant $H = 0.008$ pc⁻¹ determined by Bond (1980) and b is the Galactic latitude of the star.

Intrinsic *UBVRI* colors for MK spectral types were taken from Straizys (1992) and *JHK* colors from Bessell & Brett (1988). MK spectral types for the components of BD +20 5152 were selected by using the criterion $\Delta_{\min} = ((\sum(m_i(\text{MK}) - m_i(\text{star}))^2)/(N - 1))^{0.5}$.

Three different cases are investigated: (1) only the primary component is considered, i.e., the secondary component is much fainter and its flux can be neglected, (2) the system is composed from two stars of different spectral types, and (3) the

¹<http://irsa.ipac.caltech.edu/applications/DUST/>

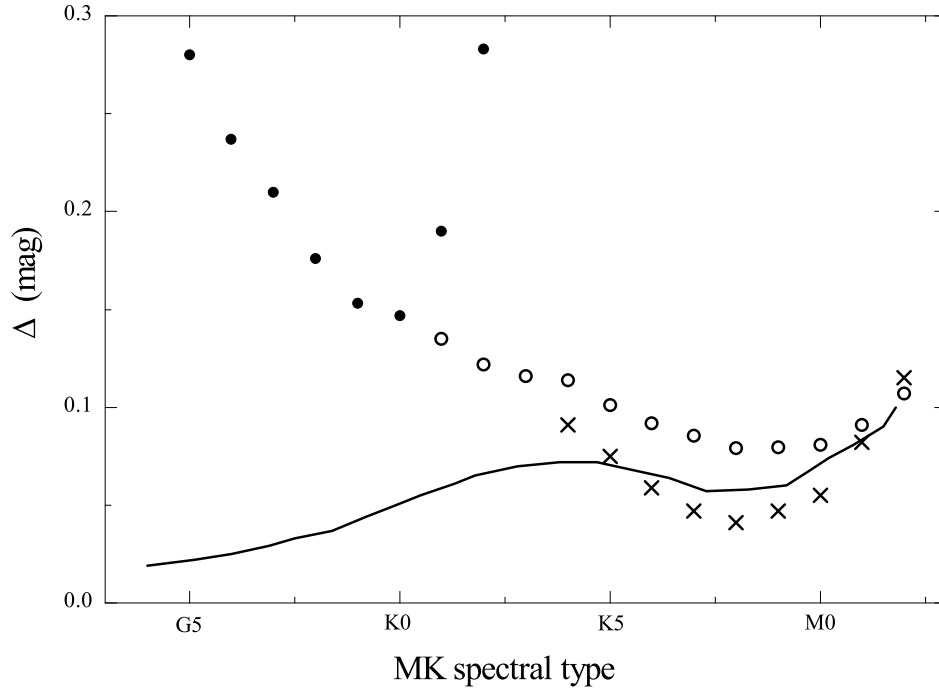


Fig. 2. Δ values obtained by comparing *UBVRJHK* magnitudes of BD+20 5152 with analogous magnitudes for various MK spectral types. Dots – only the primary is considered, open circles – a binary system with a G6 V type primary, crosses – a triple system with a G8 V type primary.

star is treated as a triple system. The last case was considered due to the conclusion by Tokovinin et al. (2008) that about 70% of spectroscopic binaries with periods close to 6 days are members of triple systems.

The results of magnitude comparison in different wavelengths are given in Figure 2, where the solid line corresponds to the values of $\Delta_{\min}$ obtained by summing the errors in measured magnitudes of the star (Table 3) and the magnitude errors originating from uncertainty of MK spectral types. The latter errors are accepted as differences in magnitudes corresponding to differences in spectral type of 0.5 subclass. It is obvious that this line indicates a limit of the validity of the $\Delta_{\min}$ criterion due to the magnitude errors.

As we can see from Figure 2, the best fit of BD+20 5152 photometry to the model is achieved when this star is treated as a triple system consisting of a G8 V star as the primary and two K6–M0 V stars as the secondary and tertiary components.

In Figure 3 we plot the two-color *FUV–NUV* vs. *NUV–V* diagram based on the GALEX All-Sky Survey photometry² and the magnitude *V* for the following types of stars: (1) white dwarfs taken from Lajoie & Bergeron (2007); (2) main-sequence stars (MK standards) in the interval of spectral classes G2–G8 and colors $B-V = 0.61$ – 0.77 from the list of Garcia (1989) and measured by GALEX; (3) two

²<http://galex.stsci.edu/GR4/>

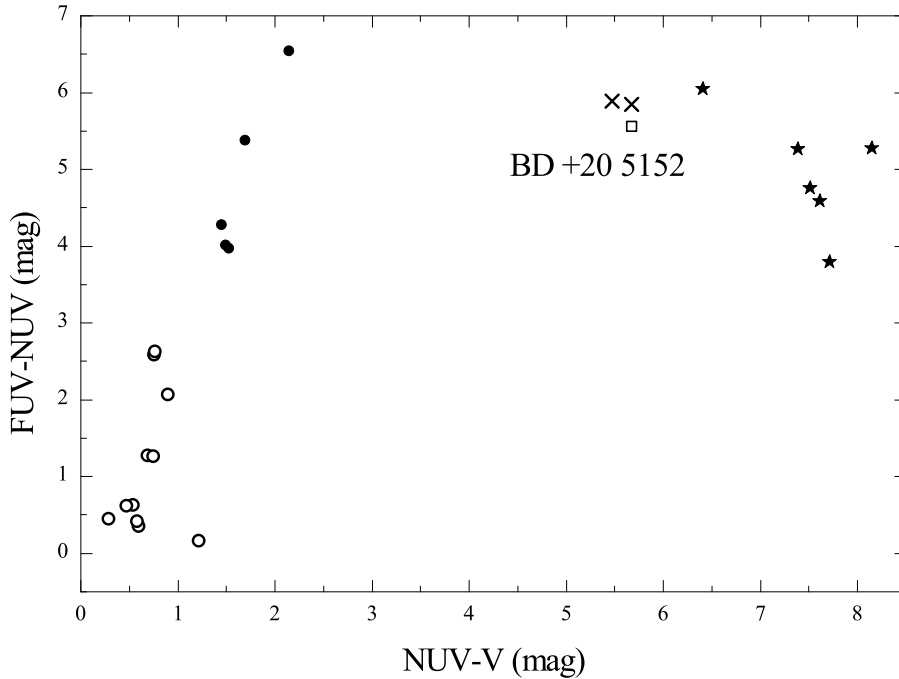


Fig. 3. The GALEX $FUV-NUV$ vs. $NUV-V_{UBV}$ diagram. Standard G2–G8 stars are plotted as asterisks. Two Hyades cluster dwarfs are denoted by crosses. White dwarfs with $T_{\text{eff}} = 10500\text{--}13500$ K are marked by open circles and those with $T_{\text{eff}} = 7300\text{--}8500$ K by dots.

Hyades cluster dwarfs, HD 26736 ($B-V = 0.66$) and HD 26756 ($B-V = 0.70$) from Smith et al. (1991). For these two stars a high level of chromospheric activity has been indicated by a low value of index $I(\text{MgII})$ derived from the IUE spectra. In the $FUV-NUV$ vs. $NUV-V$ diagram, BD+20 5152 is located in close vicinity of chromospherically active stars and far from normal G-type stars. Closest to it is the standard G2.5-type star, HD 140538, which was also classified as a high activity variable star (Hall et al. 2007). An excess of ultraviolet flux of BD+20 5152 cannot be explained by the presence of a cool white dwarf, since for the distance modulus $V-M_V = 4.5$ its NUV and FUV magnitudes should be ~ 4 mag fainter than those measured by GALEX: $NUV = 15.56$ mag and $FUV = 21.12$ mag. Consequently, we conclude that the ultraviolet excess originates in the star itself, possibly due to chromospheric activity.

4. VARIABILITY AND ROTATION

During the first run of SuperWASP photometry carried out in 2004, Norton et al. (2007) identified BD+20 5152 as a variable star with a period of 2.8894 d and amplitude of about 1%. Observations of this star continued in 2006 and 2007 and in total more than 16 000 data points were collected. Exposure time of individual measurement was 30 s only, and on each observable night from several to more than 100 measures were made. A detailed description of the WASP project is given in Pollacco et al. (2006).

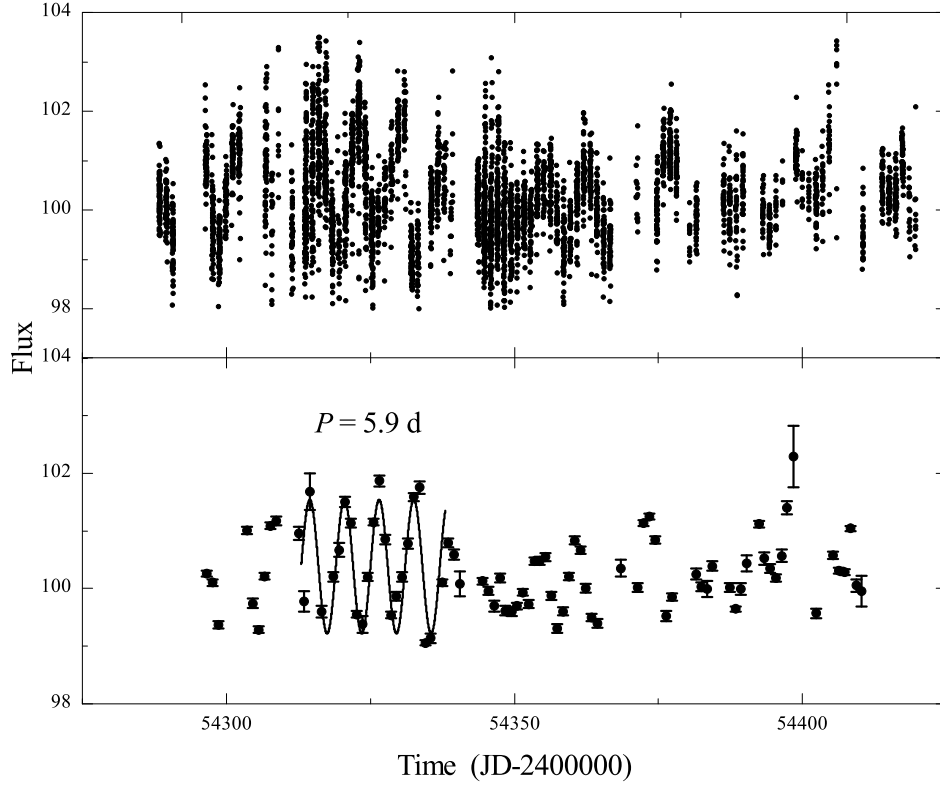


Fig. 4. SuperWASP photometry of BD+20 5152 obtained in 2007. In the upper panel, individual measures are given. The lower panel shows the averaged fluxes for each night and the fitted curve during the period of strongest variability.

In the Norton dataset, time intervals with a high level of variability, lasting several tens of nights, can be identified. In the upper panel of Figure 4 we show all measurements of 2007. In the lower panel we show a sinusoidal curve fitted to the individual measurements obtained during 25 successive nights, when the variability was quite strong, and the average fluxes for each night. The parameters of the curve are: $P = 5.88 \pm 0.04$ d and $A = 1.12 \pm 0.02$ in the flux with a S/N amplitude ratio of 4.1, determined by Fourier analysis in the software package Period04 (Lenz & Breger 2005). The S/N amplitude ratio calculated with a period of 2.9 d is about twice lower than the limit value of 4.0 evaluated by Breger et al. (1993) at which the frequencies of intrinsic variability can be distinguished from noise. Comparable parameters we also obtained for the observations during 31 nights in 2006: $P = 5.9 \pm 0.03$ d and $A = 0.97 \pm 0.02$. It is possible that such a variability could be generated by the presence of spots on the star surface, modulated by axial rotation of the star with a period close to 6 days. This rotation causes the broadening of cross-correlation functions (CCF) measured with the Coravel, and this makes possible to use the width (FWHM) of CCF to estimate the rotation velocity (Baranne et al. 1979).

For this purpose in Figure 5 CCF of BD+20 5152 is compared with those of two standard MK stars, G5 V (HD 135101) and K0 V (HD 185144). The $v \sin i$

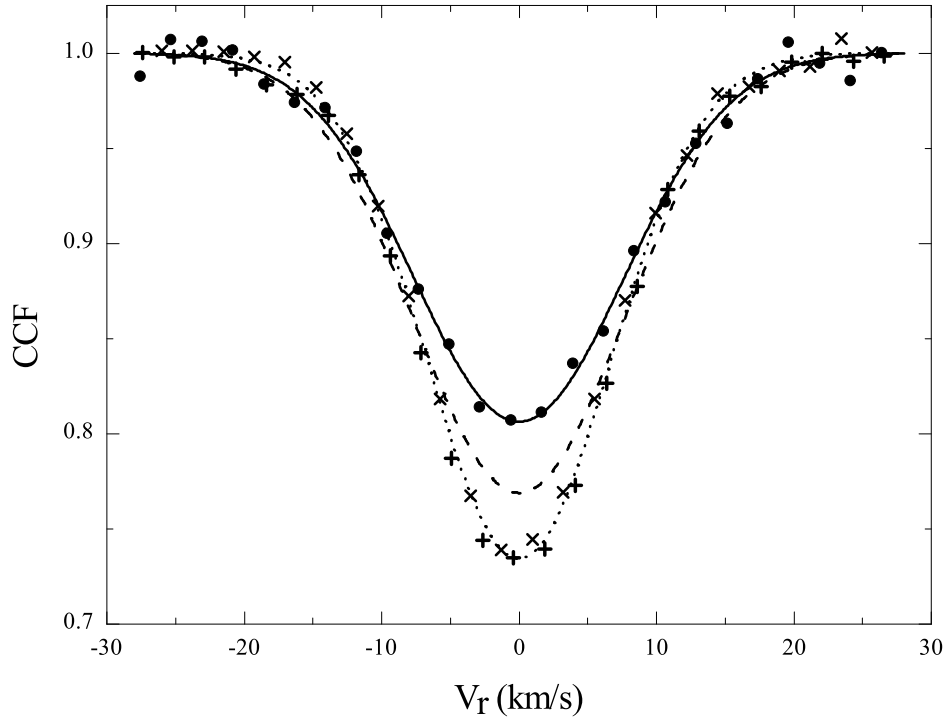


Fig. 5. Cross-correlation functions of BD+20 5152 (dots) and the standard stars G5 V, $v \sin i = 1.8$ km/s (crosses), and K0 V, $v \sin i = 1.4$ km/s (pluses). The solid and short-dashed lines are the Gaussians fitted to the observations. The dashed line is a fit to the corrected measurements of BD+20 5152 (see the text).

values of these two stars are 1.8 km/s and 1.4 km/s, respectively (Valenti & Fischer 2005). The FWHM of the Gaussian fits to the measured CCF is 15.3 ± 0.1 km/s and 15.6 ± 0.1 km/s for G5 V and K0 V stars respectively, and 18.3 ± 0.4 km/s for BD+20 5152. In the case of BD+20 5152, the FWHM was also calculated after eliminating the influence of the radiation from the two other components. Two K8 V type stars, as secondary and tertiary components, increase the total brightness of the system by about 0.15 mag. Therefore the measured CCF by such amount decreases. As a result, the FWHM of BD+20 5152 increases by about 20% in comparison with slowly rotating standard stars. In accordance with our preliminary calibration of FWHM in $v \sin i$, the projected rotational velocity is 8.5 ± 2 km/s. In the case of $i = 90^\circ$, the star rotates with the period $P = 8 \pm 2$ d. This value is quite close to the period of variability detected from SuperWASP photometry. For G5–K5 dwarfs the area of the dip of CCF only marginally depends on temperature, but remains strongly dependent on metallicity. The area of the dip for BD+20 5152, 4.45 ± 0.2 km/s, is almost of the same size as for the standard stars G5 and K0: 4.38 ± 0.1 and 4.53 ± 0.05 km/s, and we conclude that the metallicity of these stars is also similar.

5. CONCLUSIONS

Using 34 radial velocity measurements we calculated the following orbital parameters for the spectroscopic binary BD+20 5152AB: $P = 5.70613$ d, $K_1 = 47.7$ km/s, $e = 0.049$ and $a \sin i = 5.37 R_\odot$. Modeling of spectral energy distribution of the star with *UBVRI* and *JHK* photometry suggests that BD+20 5152 is probably a triple system consisting of a G8 V type star as the primary component and two K6–M0 V stars as the secondary and tertiary components. Accepting masses $0.93 M_\odot$ and $0.58 M_\odot$ for these types of stars from Straižys (1992) and using the mass function calculated for the spectroscopic binary, we estimate its orbit inclination $i = 65^\circ$ and a distance of $15.4 R_\odot$ between A and B components.

Radial velocities of this system were monitored during a four year period. The fitted curve shows no deviations larger than 2σ . Consequently, no effects of the motion of the AB system in the outer orbit (the binary system and the third component) were detected. In the case of circular orbit and $P > 2\Delta T$ yr, the semi-major axis of the outer orbit is $a > 6$ AU or > 70 mas and $A_{ab} < 6$ km/s. Such high amplitude of radial velocity variation should be easily detected. Therefore, either the semi-major axis of the third component is much larger than 6 AU or the inclination angle of the orbit is rather small. The flux excess of BD+20 5152 in the *NUV* and *FUV* passbands, the variability similar to that of the spotted stars, and the slightly eccentric orbit – all this give strong arguments in favor of this system being rather young and chromospherically active, with the age ≤ 1 Gyr.

ACKNOWLEDGMENTS. We are grateful to Andrew J. Norton for the permission to use the unpublished WASP photometric data and to Andrei Tokovinin for his valuable comments. We also thank Julija Bagdonaite for her help in analysis of the WASP data. We wish to thank the Steward Observatory for observing time on Mt. Lemmon and Mt. Bigelow telescopes. The use of the Stellar Data Center (CDS), NASA Bibliographic Data Center (ADS), the NED database, Astrophysics preprint archive facilities and the Washington Visual Double Star Catalog (WDS) are acknowledged. J. Sperauskas thanks the Jesuit Community of the Vatican Observatory at Tucson for hospitality. We are also grateful to Roger Griffin for valuable comments.

REFERENCES

- Abt H. A., Golson J. C. 1962, *ApJ*, 136, 363
- Baranne A., Mayor M., Poncet J. L. 1979, *Vistas in Astronomy*, 23, 279
- Bartkevičius A., Sperauskas J. 2005a, *Baltic Astronomy*, 14, 511
- Bartkevičius A., Sperauskas J. 2005b, *Baltic Astronomy*, 14, 527
- Bartkevičius A., Sperauskas J. 2006, *Baltic Astronomy*, 15, 539
- Bartkevičius A., Boyle R., Sperauskas J. 2008, *Baltic Astronomy*, 17, 103
- Bessell M. S. 1983, *PASP*, 95, 480
- Bessell M. S., Brett J. M. 1988, *PASP*, 100, 1134
- Bond H.E. 1980, *ApJS*, 44, 517
- Breger M., Stich J., Garrido R. et al. 1993, *A&A*, 271, 482
- Carpenter J. M. 2001, *AJ*, 121, 2851
- Cutri R. M., Skrutskie M. F., Van Dyk S. et al. 2003. *The 2MASS All-Sky Catalog of Point Sources*; CDS catalog No. II/246
- Flesch E., Hardcastle M. J. 2004. *An All-Sky Optical Catalogue of Radio / X-ray*

- Sources (QORG catalog)*, A&A, 427, 387; CDS catalog No. J/A+A/427/387
- Fouts G. 1987, PASP, 99, 986
- Garcia B. 1989, Bull. Inform. CDS, No. 36, 27
- Giclas H.L., Burnham Jr. R., Thomas N.G. 1971. *Lowell Proper Motion Survey: 8991 Stars with $m > 8$, $\mu > 0.26''$ /year in the Northern Hemisphere*, Lowell Observatory, Flagstaff; CDS catalog No. I/79
- Goldman I., Mazeh T. 1991, ApJ, 376, 260
- Hall C. J., Lockwood G. W., Skiff B. A. 2007, AJ, 133, 862
- Lajoie C.-P., Bergeron P. 2007, ApJ, 667, 1126
- Lee S.-G. 1984, AJ, 89, 702
- Lenz P., Breger M. 2005, Comm. in Asteroseismology, No. 146, 53
- Luyten W. J. 1957. *A catalogue of 9867 stars in the Southern Hemisphere with Proper Motions Exceeding 0.2'' annually*, University of Minnesota, Minneapolis
- Neckel Th., Chini R. 1980, A&AS, 39, 411
- NED, 2008. The NASA/IPAC Extragalactic Database. Galactic Extinction Calculator; <http://nedwww.ipac.caltech.edu/forms/calculator.html>
- Norton A. J., Wheatley P. J., West R. G. et al. 2007, A&A, 467, 785; CDS catalog No. J/A+A/467/785
- Norton A. J. 2009, private communication
- Pollacco D. L., Skillen I., Cameron A. C. et al. 2006, PASP, 118, 1407
- ROSAT. 2000, *The Second ROSAT Source Catalog of Pointed Observations*, ROSAT Consortium, ROSAT News No. 72; CDS catalog No. IX/30
- Rosselo G., Figueras F., Jordi C. et al. 1988, A&AS, 75, 21
- Sandage A., Kowal C. 1986, AJ, 91, 1140
- Schlegel D. J., Finkbeiner D. P., Davis M. 1998, ApJ, 500, 525
- Smith G. H., Burstein D., Wu C.-C. 1991, AJ, 101, 655
- Straižys V. 1992, *Multicolor Stellar Photometry*, Pachart Publ. House, Tucson, Arizona (available in pdf format at www.itpa.lt/MulticolorStellarPhotometry)
- Taylor B. J., Joner M. D., Johnson S. B. 1989, AJ, 97, 1798
- Tokovinin A., Thomas S., Sterzik M., Udry S. 2008, Multiple Stars Across the H-R Diagram, ESO Astrophysics Symposia, Springer-Verlag, 2008, p. 129
- Ugoren A. R., Sperauskas J., Boyle R. P. 2002, Baltic Astronomy, 11, 91
- Valenti J. A., Fischer D. A. 2005, ApJS, 159, 141
- van Leeuwen F. 2007, *Hipparcos, the New Reduction of the Raw Data*, Springer
- Voges W., Aschenbach B., Boller Th. et al. 1999. *The ROSAT All-Sky Survey Bright Source Catalogue*, A&A, 349, 389; CDS catalog No. IX/10A/1rxs
- Voges W., Aschenbach B., Boller Th. et al. 2000. *ROSAT All-Sky Survey Faint source catalogue*, IAUC 7432; CDS catalog No. IX/29/rass_fsc