HIGH VELOCITY SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES: BD +30 2129 A

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\textbf{Abstract.} The spectroscopic orbit of a high proper motion visual binary system BD +30 2129 component A is determined from 22 CORAVEL-type radial velocity measurements. A period of $P = 32.79$ days and a moderate eccentricity $e = 0.29$ are obtained. The visual system AB has a projected spatial separation $\sim 580$ AU. The system’s barycenter velocity $V_0 = -35.95$ km/s and the transverse velocity $V_t = 132.2$ km/s. The Galactic spatial velocity components $U = +76.7$ km/s, $V = -110.4$ km/s, $W = -26.6$ km/s, and a large ultraviolet excess give evidence that the star belongs to thick disk population of the Galaxy.

\textbf{Key words:} stars: binaries: spectroscopic, visual, individual (BD +30 2129)

1. INTRODUCTION

Some time ago we initiated a program of photoelectric measurements of radial velocities of Population II single and binary stars (Bartkevičius et al. 1992; Sperauskas & Bartkevičius 2002; Bartkevičius & Sperauskas 2005\textsuperscript{a,b} and references therein). This is the second publication devoted to spectroscopic binary orbits of high velocity stars using radial velocities, obtained by one of us (J.S.) with a CORAVEL-type spectrometer.

As a moderate high-proper-motion star ($\mu = 0.187''$/yr), BD +30 2129 was most probably first recorded by Luyten in his Bruce Proper Motion catalog (Luyten 1960) as BPM 87250. Respectively, the star is also included in the Luyten NLTT (Luyten 1979) catalog. As a visual binary it was discovered by Hipparcos (ESA 1997).

2. IDENTIFICATION

Equatorial coordinates of the binary components, taken from the Hipparcos Catalogue Double and Multiple Systems Annex (DMSA), part C (ESA 1997), are (ICRS, epoch J1991.25):

A: $\text{RA} = 11^{h}17^{m}3.5272^{s}$, $\text{DEC} = +29^\circ 19' 26.307''$,
B: $\text{RA} = 11^{h}17^{m}3.3515^{s}$, $\text{DEC} = +29^\circ 19' 29.534''$. 
Due to the fact that component A is comparatively bright and the distance between the components is only 4", in all photographic sky surveys and even in the 2MASS survey component B is blended by the large and saturated image of component A.

An interesting fact is that the successive BD star in the declination zone +30°, BD +30 2130, at the angular distance of ~15′, is also a moderately high-proper-motion star (G 147-36, $\mu = 0.198''$/ yr). It is also a short period ($P = 6.57206$ d) metal-deficient spectroscopic binary (Latham et al. 2002).

The identification chart from the second blue Palomar Sky Survey (POSS II J) is presented in Figure 1. Identifiers of the star taken from the CDS Simbad, and retrieved using the Wizier and other sources, are presented in Table 1. It is obvious that Simbad gives only a part of identifiers.

**Table 1. Identifiers of the binary components.**

| Component | Identifier                  | Component | Identifier                  |
|-----------|-----------------------------|-----------|-----------------------------|
| A         | BD +30 2129                 | AB        | WDS J11171+2919             |
| AB        | HIP 55115                   | A         | BPM 87250                   |
| A         | TYC 1983-1992-1             | A         | NLTT 26848                  |
| B         | TYC 1983-1992-2             | A         | FONAC 956397                |
| AB        | HDS 1608                    | A         | GSC2.2 N201302235           |
| A         | GSC 01983-01992             | AB        | TDSC 31153                  |
| AB        | CCDM J11171+2919            | A         | ASCC-2.5 683301             |
|           |                              | B         | ASCC-2.5 683300             |
|           |                              | A         | USNO-B1.0 1193-0187375      |
|           |                              | B         | USNO-B1.0 1193-0187372      |
|           |                              | A         | UCAC BS 50077892            |
|           |                              | B         | UCAC BS 50077891            |

### 3. PHOTOMETRY

Only one ground-based photoelectric photometry publication is known (Figueiras et al. 1990). The color indices $V-R$ and $V-I$ are in the Neckel & Chini (1980) system. Although the authors do not indicate, both components probably are measured together, since the distance between the components A and B is rather small. As was mentioned above, *Hipparcos* has resolved components A and B. A new reduction in the *Tycho 2* catalog (Hog et al. 2000) presents very different $B_T$ and $V_T$ values for component A, in comparison to those given in *Hipparcos* DMSA-C. As *Tycho 2* presents more precise and more consistent photometry with the ground-based data of Figueiras et al. (1990), we use only the *Tycho 2* values for component A. Photometry of the components estimated and reduced to the standard systems is given in Table 2. The methods of estimation and reduction are commented in the notes to Table 2. The components have been measured in 2MASS (Skrutskie et al. 2006), but those measurements suffered from very strong blending and are unreliable, especially for component B.

*UBV* photometry indicates a considerable ultraviolet excess for the combined light of AB, the same as it is estimated for component A, and the main component Aa of the spectroscopic binary. Prior to the determination of ultraviolet excesses
\[ \delta(U-B) \], color indices were corrected for a small interstellar reddening \( E_{B-V} \approx 0.01 \) mag. \( \delta(U-B) \) is determined from the \( U-B \) vs. \( B-V \) diagram, using the mean main sequence line (Bartkevičius 1980). For both cases, AB and A, the normalized ultraviolet excess \( \delta(U-B)_{0.6} \), extrapolated using the Sandage (1969) Table 1A, is 0.19 mag. Using the Karatas & Schuster (2006) relation (Eq. 6) we obtain [Fe/H] = -1.1.

### Table 2. Photometry

| Comp. | \( B_T \) | \( \sigma_{B_T} \) | \( V_T \) | \( \sigma_{V_T} \) | \( B_T-V_T \) | \( \sigma_{(B_T-V_T)} \) | \( H_p \) | \( \sigma_{H_p} \) | Notes |
|-------|-----------|-----------------|-----------|-----------------|----------------|-----------------|-----------|-----------------|-------|
| A     | 10.566    | 0.036           | 10.112    | 0.039           | 0.454          | 0.053           | 10.151    | 0.015           | 1     |
| B     | 10.625    | 0.040           | 9.992     | 0.033           | 0.633          | 0.052           | 13.133    | 0.234           | 1     |

| Comp. | \( B \) | \( \sigma_B \) | \( V \) | \( \sigma_V \) | \( B-V \) | \( \sigma_{(B-V)} \) | Notes |
|-------|--------|--------------|-------|--------------|--------|-----------------|-------|
| A     | 10.474 | 0.033        | 9.927 | 0.032        | 0.547  | 0.046           | 3     |
| B     | 13.126 | 0.232        | 0.305 | 0.105        | 0.180  | 9.180           | 3     |

| Comp. | \( V \) | \( \sigma_V \) | \( B-V \) | \( \sigma_{(B-V)} \) | \( U-B \) | \( \sigma_{(U-B)} \) | Notes |
|-------|--------|--------------|--------|-----------------|--------|-----------------|-------|
| AB    | 9.890  | 0.015        | 0.573  | 0.034           | -0.087 | 0.019           | 4     |
| A     | 9.93   | 0.56         | -0.10  | -0.18           | 6a     |                 | 5     |
| Aa    | 10.257 | 0.52         | -0.18  | 6b              |        |                 | 5     |
| Aa    | 9.94   | 0.53         | -0.12  | 6b              |        |                 | 5     |
| B     | 13.04  |              |        |                 |        |                 | 5     |

| Comp. | \( (V-R)_{NC} \) | \( \sigma_{(V-R)_{NC}} \) | \( (V-I)_{NC} \) | \( \sigma_{(V-I)_{NC}} \) | \( (R-I)_{NC} \) | \( \sigma_{(R-I)_{NC}} \) | Notes |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------|
| A     | 0.47            | 0.36            | 0.83            | 0.36            | 4               |                 | 5     |

| Comp. | \( (V-I)_{IC} \) | \( (R-I)_{IC} \) | Notes |
|-------|-----------------|-----------------|-------|
| AB    | 0.35            | 0.35            | 8     |
| A     | 0.32            | 0.32            | 5     |
| Aa    | 0.30            | 0.31            | 6a    |
| Aa    | 0.30            | 0.30            | 6b    |

**Notes to Table 2.**

1. Hipparcos DMSA-C;
2. Tycho 2;
3. ASCC-2.5 (Kharchenko 2001);
4. Figueras et al. (1990);
5. \( V \) and \( B-V \) of component A are obtained by averaging: (a) component A photometry obtained from ground-based combined AB photometry (Figueras et al. 1990), assuming \( \Delta V(AB) = 3.1 \) mag and using a F7V spectral type for component A and a K5 V spectral type for component B; energy distributions were taken from Sviderskienė (1988) and intrinsic color indices from Straizys (1992), (b) the values of \( V \) and \( B-V \) of component A published in ASCC-2.5, (c) the values of \( V \) and \( B-V \) reduced from Tycho 2 \( B_T \) and \( V_T \) (using the Hipparcos equations [1.3.33] and [1.3.26]), (d) the same as in (c), but using reductions from Table 2 of Bessell (2000). The color indices \( U-B, (V-R)_{NC} \) and \( (V-I)_{NC} \) of component A are obtained using only by the above condition (a). Here NC means color indices from Neckel & Chini (1980).
6. Very approximate magnitudes and color indices of spectroscopic binary primary component Aa are obtained from component A photometry, assuming (a) \( \Delta V(AaAb) = 1.1 \) mag, F6 V spectral type for component Aa and G5 V type for component Ab, or (b) \( \Delta V(AaAb) = 4.1 \) mag, F6 V spectral type for component Aa and K7 V type for component Ab.
7. The magnitude for component B is obtained by averaging the value from ASCC-2.5 and the value reduced from \( H_p \), magnitude, using the \textit{Hipparcos} and Bessell (2000) relations.

8. Reduction of Neckel & Chini (1980) color indices \((V-R)_{\text{NC}}\) and \((V-I)_{\text{NC}}\) to the Cousins (1980) system was done by the Taylor et al. (1989) relations.

4. DISTANCE, ABSOLUTE MAGNITUDES AND KINEMATICS

For the star \textit{Hipparcos} recorded a parallax of moderate precision (37%), \( \pi = 6.88 \pm 2.56 \) mas. This corresponds to a distance to the system of \( r = 145 \pm 54 \) pc. Interstellar reddening was obtained from the Schlegel et al. (1998) maps, using the NED database extinction calculator. For BD +30°2129 at \( \ell = 201.4^\circ \) and \( b = +69.1^\circ \), we got the total line-of-sight reddening \( E_{B-V} = 0.018 \) mag. This reddening was reduced by the exponential law taking into account the Galactic latitude and the distance (as described by Anthony-Twarog & Twarog 1994, p. 1583), and the values \( E_{B-V} = 0.012 \) and \( A_V = 0.04 \) were obtained for the star. Adopting the \textit{Hipparcos} parallax, \( A_V = 0.04 \), \( V_0(A) = 10.0 \) mag and \( V_0(B) = 13.0 \) mag, we obtain absolute magnitudes \( M_V = 4.2 \pm 0.8 \) and \( 7.2 \pm 0.8 \) for A and B components. These absolute magnitudes correspond to spectral types F8 V and K5 V for solar chemical composition stars (according to the calibration from Straižys 1992, App. 2). The color index \( B-V \) for component A from Table 2, with a small reddening correction, is also consistent with the F8 V spectral class. Using the results of photometry and the mean weighted proper motion value \( \mu(A+B) = 0.19188 \pm 0.00054''/\text{yr} \), we calculated the following approximate reduced proper motion values \( H_V \): 11.4 and 14.4. These \( H_V \) and the estimated \((B-V)_0\) values place both components in the subdwarf region, close to the subdwarf and the main sequence border.

The \textit{Hipparcos} parallax, proper motion components from ASCC-2.5 and our value of spectroscopic binary barycenter radial velocity were used to calculate kinematical parameters of the system. The procedure of computation is the same as in Bartkevičius & Gudas (2001, 2002). The velocity component \( U \) is directed to the Galactic center, \( V \) – to the direction of Galactic rotation and \( W \) – to the North Galactic Pole. The velocity components were corrected due to the Solar motion with respect to the Local Standard of Rest \( U = 10.0 \pm 0.4 \) km/s, \( V = 5.2 \pm 0.6 \) km/s and \( W = 7.2 \pm 0.4 \) km/s (Binney & Merrifield 1998). The calculated kinematical parameters and the data used for their calculations are given in Table 3. Evidently, the binary system belongs to the thick disk population.

| \( \ell \) | \( b \) | \( \pi \) | \( \sigma_\pi \) | \( \sigma_\theta/\pi \) | \( \mu(\text{RA}) \) | \( \sigma_\mu(\text{RA}) \) | \( \mu(\text{DEC}) \) | \( \sigma_\mu(\text{DEC}) \) | \( \mu''/\text{yr} \) | \( \sigma_{\mu''/\text{yr}} \) |
|-------|-----|-----|-------|----------|---------|---------|---------|---------|---------|---------|
| 201.35 | 69.13 | 0.00688 | 0.00256 | 0.372 | 0.02763 | 0.00355 | -0.18988 | 0.00059 |
| \( \mu''/\text{yr} \) | \( \sigma_\mu'' \) | \( \sigma_\mu''/\mu \) | \( V_t \) | \( \sigma_{V_t} \) | \( V_0 \) | \( \sigma_{V_0} \) | \( U \) | \( \sigma_U \) |
| 0.19188 | 0.00059 | 0.003 | -35.95 | 0.15 | 132.2 | 49.2 | 76.7 | 15.0 |

| \( V \) | \( \sigma_V \) | \( W \) | \( \sigma_W \) | \( V_{\text{tot}} \) | \( \sigma_{V_{\text{tot}}} \) |
|------|-------|------|-------|--------|--------|
| -110.4 | 13.7 | -26.6 | 0.7 | 137.0 | 47.5 |
5. RADIAL VELOCITY MEASUREMENTS

Radial velocities were measured by one of the authors (J.S.) with a CORAVEL-type spectrometer constructed at the Vilnius University Observatory. A description of the spectrometer, the measurements and data reduction procedures are presented in Upgren, Sperauskas & Boyle (2002). 22 individual radial velocities for BD +30 2129A were obtained during four observing runs. During the first run (2000 March 15, JD 2451618 – 2000 April 24, JD 2451658) the 2.3 m, 1.5 m and 1.5 m telescopes of the Steward Observatory were used. During the second run (2002 April 4, JD 2452369 – 2002 May 9, JD 2452404), the third run (two measurements at 2003 May 26 and 28, JD 2452786 and JD 2452788) and the fourth run (2006 March 6, JD 2453800 – 2006 May 10, JD 2453866) the 1.65 m and 0.63 m telescopes of the Molėtai Observatory were used. These measurements were spread over the period of 2248 days. Standard single-measurement errors range from 0.7 to 1.1 km/s, with a mean value of 0.9 km/s. Individual radial velocity measurements are listed in Table 4 together with the Heliocentric Julian Days and phases, calculated from the orbital elements, measurement errors and residuals.

Table 4. Radial velocity measurements.

| HJD 24+ | Phase | V_r (km/s) | σ_V_r (km/s) | O-C (km/s) | HJD 24+ | Phase | V_r (km/s) | σ_V_r (km/s) | O-C (km/s) |
|---------|-------|------------|--------------|------------|---------|-------|------------|--------------|------------|
| 51618.867 | 0.561 | -46.0 | 1.0 | -1.9 | 52385.310 | 0.935 | -49.4 | 0.9 | -0.1 |
| 51633.754 | 0.015 | -27.5 | 0.9 | -0.8 | 52386.325 | 0.966 | -41.1 | 0.9 | 0.2 |
| 51657.695 | 0.745 | -57.5 | 0.8 | 0.8 | 52398.415 | 0.335 | -22.0 | 0.8 | 0.9 |
| 51658.629 | 0.774 | -59.4 | 0.7 | 0.3 | 52399.408 | 0.365 | -24.3 | 0.8 | 1.5 |
| 52369.440 | 0.451 | -34.6 | 0.8 | -0.5 | 52403.348 | 0.485 | -36.8 | 0.9 | 0.4 |
| 52375.395 | 0.633 | -50.6 | 0.8 | -0.3 | 52404.441 | 0.519 | -39.9 | 0.9 | 0.4 |
| 52376.385 | 0.664 | -52.9 | 0.8 | -0.1 | 52786.368 | 0.166 | -10.6 | 1.0 | -1.0 |
| 52377.371 | 0.693 | -55.2 | 0.8 | -0.2 | 52788.983 | 0.228 | -14.2 | 1.0 | -1.0 |
| 52382.361 | 0.845 | -60.4 | 0.9 | -0.1 | 53800.593 | 0.997 | -10.3 | 0.8 | 0.4 |
| 52383.385 | 0.876 | -58.5 | 0.9 | -0.1 | 53865.381 | 0.073 | -13.7 | 1.1 | -0.1 |

6. ORBIT SOLUTION

The obtained radial velocity curve is plotted in Figure 2. The calculated orbital elements are given in Table 5. The system has a moderate center-of-mass radial velocity and orbit eccentricity.

Table 5. Orbital elements of BD +30 2129A.

| Parameter | Value |
|-----------|-------|
| Orbital period | P = 32.790±0.002 days |
| Center-of-mass velocity | V_0 = -35.95±0.13 km/s |
| Half-amplitude | K = 25.8±0.2 km/s |
| Eccentricity | e = 0.289±0.007 |
| Longitude of periastron | ω = (278.5±1.7)° |
| Date of conjunction | T_{con} = 2453863.0±0.2 HJD |
| Projected semimajor axis | a \sin i = (11.15±0.08) \times 10^6 km |
| Function of the mass | f(m) = 0.0513±0.0001 M_☉ |
| Mean square error of one observation | σ(O-C) = ± 0.60 km/s |
7. PARAMETERS OF THE VISUAL BINARY SYSTEM

As was mentioned in Introduction, BD +30 2129, as a visual binary system, was discovered by Hipparcos and included in the Hipparcos Catalogue Double and Multiple Systems Annex (DMSA), part C (systems resolved into distinct components) (ESA 1997). This catalog gives the angular distance $d = 3.962''$ between the components and the position angle $PA = 325.0^\circ$ at epoch 1991.25. However this is marked as an ambiguous double-star solution. An alternative solution for AB is also given: $PA = 16^\circ$ and $d = 0.29''$. The new reductions in the Tycho 2 catalog, the measurements in the 2MASS infrared survey and the visual observations during radial velocity measurements, all definitely confirm the results of principal solution. The mean values using the Tycho, Tycho 2 and 2MASS solutions are: $PA = 324.7^\circ$ and $d = 4.00''$. The minimum spatial distance between components A and B, adopting the apparent separation $d = 4.00''$ and the Hipparcos parallax $\pi = 0.00688''$, is 581 AU. The period of the AB system, estimated by Kepler’s third law, assuming circular face-on orbit, apparent separation and parallax is 14000 or 8400 years. The first value of the period is for the accepted mass sum of the triple system 1 $M_\odot$ (this corresponds to a metal-deficient system) and the second value is for 2.8 $M_\odot$ (this corresponds to a solar chemical composition system). The mean radial velocity of component B, $V_r = -34.8 \pm 1.0$ km/s, based on two measurements, confirms a binary nature of the visual system.

8. CONCLUSIONS

On the ground of 22 CORAVEL-type radial velocity measurements, a spectroscopic orbit of moderate eccentricity ($e = 0.29$) with a period of $P = 32.79$ days is obtained for component A of a high velocity ($V_{tot} = 137.0$ km/s) visual binary system BD +30 2129. The projected spatial separation of components of the visual binary AB is found to be $\sim 580$ AU. Likely, the system is metal-deficient ([Fe/H] $\approx -1$). The Galactic spatial velocity components $U = +76.7$ km/s, $V = -110.4$ km/s, $W = -26.6$ km/s, and a large ultraviolet excess give evidence that
the system belongs to thick disk of the Galaxy. The estimated period of the visual system is about 10 000 years.

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