Spectroscopic orbits of 10 nearby solar-type dwarfs

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ABSTRACT

Several nearby solar-type dwarfs with variable radial velocity were monitored to find their spectroscopic orbits. Orbital elements of HIP 179, 1989, 2981, 5276, 6439, 11218, 21443, 96434 are determined, as well as tentative orbits for HIP 28678 and 41214. We discuss each of those objects. Three of the four double-lined binaries are twins with nearly equal components. All four orbits with periods shorter than 10 d are circular, the remaining orbits are eccentric.

Key words: binaries: spectroscopic – stars: solar-type.

1 INTRODUCTION

Current interest in nearby solar-like stars is largely driven by search of exoplanets. These stars are also ideally suited for the study of binary statistics, which gives clues to the origin of stellar and planetary systems. The 25-pc sample of Raghavan et al. (2010) was recently extended to a larger volume to increase the significance of binary statistics and to access the statistics of higher order hierarchies (Tokovinin 2014b).

Extensive data on F- and G-type stars within 67 pc of the Sun are available in the literature and cover the full range of orbital periods. The detection of spectroscopic binaries is mostly based on the Geneva–Copenhagen Survey (GCS) by Nordström et al. (2004). They addressed about 80 per cent of the sample, typically with two or three radial velocity (RV) measurements per star. However, many spectroscopic binaries discovered by GCS from variable RV or from the appearance of double lines have no orbits determined so far. This leaves their periods and mass ratios indeterminate and adds uncertainty to the multiplicity statistics. A large number of these binaries were followed by D. Latham at Center for Astrophysics, its limitations can be found e.g. in Tokovinin & Gorynya (2001). The RV precision reaches 0.3 km s$^{-1}$, but it is worse for stars with shallow correlation dips and/or fast axial rotation.

2 OBSERVATIONS

The observations were conducted in 2012 and 2013 at the 1-m telescope of the Crimean Astrophysical Observatory sited in Simeiz, Crimea. Radial velocities were measured by the CORAVEL-type echelle spectrometer, the Radial Velocity Meter. This instrument is based on analogue correlation of spectrum with a physical mask, where slits correspond to the spectral lines (Tokovinin 1987). The RVs are measured by fitting Gaussian curves to the observed correlation dips, with the zero-point determined from observations of RV standards. Further information on the observing method and its results can be found e.g. in Tokovinin & Gorynya (2001). The RV precision reaches 0.3 km s$^{-1}$, but it is worse for stars with shallow correlation dips and/or fast axial rotation.

3 NEW ORBITS

Identifications and basic parameters of stars with orbital solutions are assembled in Table 1. Orbital elements and their errors are listed in Table 2 in standard notation. Its last columns contain the total number of RV measurements, the rms residuals to the orbit, and mass estimates. For double-lined binaries, we provide Msin$i^2$, for single-lined binaries the minimum secondary mass $M_{\text{min}}$ is listed, computed from the mass function and the estimated primary mass $M_1$ by solving the equation $M_{\text{min}} = 4.695 \times 10^{-3} K_1 P^{1/3} (1 - e^2)^{1/3} (M_1 + M_{\text{min}})^{2/3}$. Individual measurements and their deviations from the orbits are listed in Table 3, available in full electronically. Its columns contain the heliocentric Julian day JD, RV and its error $\sigma$ in km s$^{-1}$, residual to the orbit O–C, and, for double-lined binaries, the component identification (‘a’ for the primary, ‘b’ for the secondary). The RV curves are plotted in Figs 1 and 2. In the orbital fits, RVs are weighted as $1/(\sigma^2 + 0.3^2)$, where $\sigma$ are individual RV errors determined by the Gaussian fits of the correlation dips, with instrumental error of 0.3 km s$^{-1}$ added in quadrature. RVs derived from the unresolved blended dips of double-lined binaries are given a very low weight by artificially increasing the errors by few tens.
of km s$^{-1}$. Otherwise, the double dips are fitted by two Gaussian curves. The formal errors are also increased by 1 or 2 km s$^{-1}$ for stars with fast rotation and shallow correlation dips. For circular orbits, we fix the elements $e = 0$ and $\omega = 0$ (asterisks in Table 2) and fit the remaining four elements $P, T, K_1, \gamma$.

### 4 COMMENTS ON INDIVIDUAL OBJECTS

We discuss now each star individually. The masses of the primary components were derived from their apparent $V$ magnitudes and trigonometric parallaxes, using standard relations for main-sequence dwarfs (corrections were made for magnitudes of double-lined binaries). The existence of additional (tertiary) visual components was noted.

HIP 179 has a well-defined double-lined orbit with $P = 10.65$ d and nearly equal RV amplitudes, leading to the mass ratio of $q = M_2/M_1 = 0.982$ (GCS estimated $q = 1.00 \pm 0.01$). This binary is therefore a twin with identical components. The star is elevated above the main sequence by about 1.5 mag, more than 0.75 mag expected for a twin binary. Either the components are slightly evolved (subgiants), or the parallax is larger than measured by Hipparcos.

| HIP  | HD  | $V$  | Spectral type | $\tau_{\text{HIP}}$ (mas) | $M_1$ (M$_\odot$) |
|------|-----|------|---------------|-------------------------|------------------|
| 179  | 224974 | 6.90 | G0V          | 15.3                    | 1.32             |
| 1989 | 2085 | 7.89 | F5           | 16.8                    | 1.22             |
| 2981 | 3454 | 7.53 | F5           | 22.0                    | 1.17             |
| 5276 | 6611 | 7.24 | F5           | 19.4                    | 1.29             |
| 6439 | 8321 | 7.16 | F5           | 20.1                    | 1.29             |
| 11218 | 14938 | 7.20 | F5           | 18.0                    | 1.35             |
| 21443 | 28907 | 8.61 | G5           | 15.5                    | 1.11             |
| 28678 | 41255 | 7.47 | F9V          | 15.8                    | 1.21             |
| 41214 | 70937 | 6.03 | F2V          | 15.8                    | 1.61             |
| 96434 | 184962 | 7.12 | F8           | 18.5                    | 1.20             |

Table 2. Orbital elements.

Table 3. Individual radial velocities and residuals (fragment).

The semimajor axis of the spectroscopic orbit is about 2 mas. The star was observed and not resolved by speckle interferometry (Mason et al. 2001a) and by Robo-AO (Riddle et al., in preparation). We do not see any systematic RV trend within a year. The existence of any additional tertiary components thus appears unlikely, unless they have low mass and escaped direct resolution.

HIP 1989 has a circular orbit with $P = 7.35$ d with a relatively massive secondary ($M_{\text{min}} = 0.56$ M$_\odot$). The object is on the main sequence. This star is on the exoplanet programme at the Keck telescope (Isaacson & Fischer 2010) and shows the RV jitter of 3.4 m s$^{-1}$ superposed on the orbital RV variation. The four RV measurements from Keck kindly provided by Fischer (private communication) match our orbit, but are not included in the solution, adding little to its improvement. To our knowledge, no spectroscopic orbit was published. SIMBAD lists the RV of $-47.4$ km s$^{-1}$, while the true centre-of-mass velocity is $-6.6$ km s$^{-1}$. Observations with Robo-AO (Riddle et al., in preparation) exclude tertiary components within the detection limit of that instrument.

HIP 2981 has an 8.25-d period. The circular orbital solution was imposed, as expected at such short periods. The object is on the main sequence. The star is slightly metal deficient, [Fe/H] $= -0.58$, and has no additional known companions.

HIP 5276 has a preliminary orbit with $P = 74$ d. In two observing seasons, we could not achieve a good phase coverage, but observed the ascending branch of the RV curve three times, fixing the period securely. Nidever et al. (2002) published a single RV measurement.
of $-6.08$ km s$^{-1}$ made on JD 245 1026; curiously, they included the object in their list of constant-velocity stars. We used this measurement in the orbital solution presented in Fig. 1 (see the lowest data point).

The primary mass of $1.29$ M$_\odot$ implies a minimum secondary mass of $0.56$ M$_\odot$. The system is triple, it has a visual companion B in the 2MASS catalogue at 6.17 arcsec, 335.4. This companion was confirmed as physical (comoving) with Robo-AO (Riddle et al. 2014). With a proper motion (PM) of 131 mas yr$^{-1}$, the companion would have moved if it were a background star. The mass of the visual companion B estimated from its photometry is about $0.3$ M$_\odot$.

HIP 179 is similar to the previous object in that the coverage of the RV curve is far from perfect, but observations in two seasons establish the 34-d period quite well. The primary component is on the main sequence, the minimum mass of the spectroscopic secondary is $0.27$ M$_\odot$. The visual companion at 71 arcsec listed in the WDS (Mason et al. 2001b) as STTA 16 is optical because its observed motion is opposite to the PM of A. The existence of other tertiary components was probed by speckle interferometry at SOAR (Hartkopf, Tokovinin & Mason 2012) and with Robo-AO (Riddle et al., in preparation), none were found.

HIP 11218 has a circular orbit with $P = 4.32$ d. It is about 1.1 mag above the main sequence. Fast stellar rotation synchronized with the orbit likely causes the increased chromospheric activity, explaining why the object was detected in X-rays by ROSAT. It has no additional visual companions, as far as we know. SIMBAD lists metallicity $[\text{Fe/H}] = -0.25$.

HIP 21443 is flagged in the GCS as a single-lined binary. Guillout et al. (2009) confirm the fast RV variability and relate it to the detection of this star by ROSAT (their two RV measurements are included in the present orbit with an offset of $+7$ km s$^{-1}$). The lithium line and $H\alpha$ emission indicate that HIP 21443 is young. Fast rotation matches the 2-d period found here, although the orbit is based on only 12 RV measurements.

The 2MASS catalogue contains a star at 5.′′3, 12.◦6 from the main target. This companion was measured with Robo-AO at similar position. However, the PM of HIP 21443 is small, 20 mas yr$^{-1}$, and the field is rather crowded. It remains to be established whether the 2MASS companion is bound or is just a background star.

HIP 28678 shows double lines. In two seasons, we covered only a small fraction of its RV curve, so the present orbit with $P = 163$ d is rather tentative. The mass ratio $q = 0.98$ found here is close to $q = 0.947$ estimated in the GCS from 11 observations. The orbital period implies a semimajor axis of 12 mas, so the binary could be marginally resolvable by speckle interferometry. It was observed with speckle interferometry at the 4.1-m SOAR telescope in 2010.9 and 2014.05 and found unresolved (Hartkopf et al. 2012). In the light of the present orbit, we re-examined the speckle data and found a slight asymmetry indicative of marginal resolution, although no measurement of the separation could be made.
The spectral type is F9V, the star is moderately elevated above the main sequence owing to its binarity. No additional visual companions are listed in the WDS.

**HIP 41214** (HR 395) is a double-lined binary. The data do not yet constrain the orbit well. The 28-d period suggested here represents the observations, but may be not a unique solution. The orbit implies $q = 0.77$, while GCS estimated $q = 0.86$ from two observations. The star appears slightly evolved. It is monitored at Keck for exoplanets (Isaacson & Fischer 2010). Note that the primary mass of 1.73 M$\odot$ slightly exceeds 1.61 M$\odot$ estimated from the luminosity (a magnitude difference of 0.85 mag was adopted to subtract the light of the secondary). This means high orbital inclination. This star is not identified as a variable in the ASAS data base (Pojmanski 1997). Although the ASAS photometry does hint on occasional minima, they do not follow the 27.9-d periodicity.

**HIP 96434.** In two seasons, we were able to derive a double-lined orbit with a 30-d period and moderate eccentricity. The RV errors are large because the correlation dips are shallow. The components are nearly equal in mass, $q = 0.96$. The GCS recognized the double-lined nature of this binary but did not estimate its mass ratio. The semimajor axis of 4.5 mas puts this pair beyond the reach of speckle interferometry, even at 8-m telescopes. The WDS companion H 5104 at 39", 138° is optical, as evidenced by its relative motion which simply reflects the PM of the main target. No additional components were found with Robo-AO (Riddle et al., in preparation).

5 CONCLUSIONS

The data base on solar-type binaries within 67 pc (Tokovinin 2014a) suffers from the missing data (periods and mass ratios) on 260 spectroscopic binaries discovered by the GCS. Our work reduced this number by 4 per cent; its results are already included in the statistical analysis of this sample (Tokovinin 2014b). Several other stars with variable RV and/or double lines were observed, but do not have yet sufficient data to derive their orbits. We plan to continue the observations.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 3. Individual radial velocities and residuals (fragment) (http://mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stu743/-/DC1).

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