ORBITS OF FOUR YOUNG TRIPLE-LINED MULTIPLE SYSTEMS

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ABSTRACT
Each of the nearby triple systems HIP 7601, 13498, 23824, and 113597 consist of solar-type dwarfs with comparable masses, where all three components are resolved spectrally, while the outer pairs are resolved both visually and spectrally. These stars are relatively young (between 100 and 600 Myr) and chromospherically active (X-ray sources), although they rotate slowly. I determine the spectroscopic orbits of the inner subsystems (periods 19.4, 14.1, 5.6, 20.3 days) and the orbits of the outer systems (periods 1.75, 51, 27, 500 years, respectively). For HIP 7601 and 13498, the combined spectro-interferometric outer orbits produce direct measurement of the masses of all of the components, allowing for a comparison with stellar models. The 6708 Å lithium line is present and its strength is measured in each component individually by subtracting the contributions of the other components. The inner and outer orbits of HIP 7601 are nearly circular, likely co-planar, and have a modest period ratio of 1:33. This study contributes to the characterization of hierarchical multiplicity in the solar neighborhood and provides data for testing stellar evolutionary models and chronology.

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

Supporting material: machine-readable tables

1. INTRODUCTION

Binary and multiple stars attract interest for various reasons. Historically, they have served as excellent calibrators of stellar masses, radii, and other parameters, e.g., for testing and refining evolutionary models. Multiple systems also host interesting processes such as dynamical interactions, mass transfer, mergers, etc. Multiplicity statistics and studies of certain key objects inform us concerning the processes of star formation. The objects featured in this work are interesting from several points of view.

The radial velocities (RVs) of nearby solar-type multiple systems were monitored in 2014 and 2015 to determine the frequency of spectroscopic subsystems in visual components and to follow their orbital motion. The resulting statistics were reported in Tokovinin (2015), while a detailed analysis of the individual systems was deferred to future publications. This paper is the first of this series. It deals with four triple-lined spectroscopic binaries (SB3s). These solar-type multiple systems (Table 1) are relatively young, as inferred from their chromospheric activity (all are X-ray sources) and the presence of lithium. The first two objects were identified as SB3s by Wichman et al. (2003) in a spectroscopic follow-up of ROSAT. The wide, common-proper-motion pair HIP 113579 and 113597 belongs to the AB Doradus association (Torres et al. 2006); its fainter component is the SB3. In all four SB3s, the outer subsystems are spatially resolved; their orbits in the plane of the sky are computed or updated here together with the spectroscopic orbits of the inner subsystems.

In this work, I designate the individual components of hierarchical multiples by sequences of letters such as A, Ab, or AB; a component may contain one or several stars. The binary systems are designated by joining components with a comma, e.g., Aa,Ab. The designation A,B stands for a binary system with two components A and B, while the designation AB stands for one component, e.g., an unresolved binary in a system AB,C.

The observational material and data analysis are presented in Section 2. Sections 3–6 are devoted to the individual systems and follow the same template: bibliography, orbits, and estimation of the component’s parameters. In Section 7, the results are used to discuss the mass–luminosity relation, the strength of the lithium line, and the origin of hierarchical triple-lined systems. Finally, Section 8 summarizes the paper.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Spectroscopic Observations

Most spectra used here were taken with the 1.5 m telescope located at the Cerro Tololo Interamerican Observatory in Chile, which is operated by the SMARTS Consortium. The observing time was allocated through NOAO (programs 14B-0009, 15A-0055, 15B-0012). The observations were made with the fiber-fed echelle spectrograph CHIRON (Tokovinin et al. 2013) by the telescope operators in service mode. The spectra taken in the slicer mode have a resolution of $R = 80,000$ and a signal-to-noise ratio (S/N) of at least 20. They cover the range from 415 to 880 nm in 53 orders. Thorium–argon calibrations were recorded for each target. A few spectra taken in 2010 at the same telescope with the Fiber Echelle (FECH) with a resolution of $R = 44,000$ (Tokovinin et al. 2015c) are also used here. Most (but not all) of the individual RVs were published in Tokovinin (2015), where preliminary orbital periods were also announced.

2.2. RVs by Cross-correlation

The reduced and wavelength-calibrated spectra delivered by the CHIRON pipeline were retrieved from the SMARTS center at Yale University. The availability of this service has greatly enhanced this program by allowing for rapid analysis of the RVs and flexible scheduling of new observations when needed.

1 http://www.astro.yale.edu/smarts/

2 http://www.ctio.noao.edu/noao/content/chiron
The spectra were cross-correlated with a digital binary mask (template) based on the solar spectrum stored in the NOAO archive (see Tokovinin et al. 2015c, for more details). The cross-correlation function (CCF) $C(v)$ is computed over an RV span of $v = \pm 200 \text{ km s}^{-1}$ in the spectral range from 4500 to 6500 Å. CCFs of all orders are simply summed up and normalized by the median value. Portions of the CCFs within $\pm 2.35 \sigma$ of each dip are approximated by Gaussian curves. After the first iteration, the centers and dispersions are determined, and in the second iteration the fitting area is adjusted accordingly. The CCF model with three Gaussians is

$$C(v) = 1 - \sum_{j=1}^{3} a_j \exp\left[-(v - v_j)^2/2\sigma_j^2\right];$$

(1)

this model contains nine free parameters ($v_j, a_j, \sigma_j$). CCFs with overlapping (blended) dips were processed by fixing amplitudes $a_j$ or dispersions $\sigma_j$ to the values determined on other nights from well-resolved CCFs, like those in Figure 1.

I do not provide formal errors for the RVs or other parameters resulting from the CCF fits, as they are very small and do not characterize the real precision of the results. The RV precision is dominated by systematic effects and is estimated from residuals to the orbits at $\sim 0.1 \text{ km s}^{-1}$. The velocity zero point relies on the wavelength calibration and on the mask derived from the solar spectrum, rather than on standard stars.

### 2.3. Estimation of Rotation Velocity

The CCF width $\sigma$ depends on the spectral resolution, correlation mask, and intrinsic width of the stellar lines. The latter are broadened by rotation, macro-turbulence, and other factors. When rotation dominates, the CCF shape deviates substantially from Gaussian, but for moderate or slow rotation the CCF is well modeled by a Gaussian with increased dispersion $\sigma$. I calibrated the relation between the projected rotation speed $V \sin i$ and $\sigma$ using a digital solar spectrum. It was broadened by a Gaussian PSF corresponding to the spectral resolution $R = 80,000$ $(3.75 \text{ km s}^{-1})$ and rotation (e.g., Diaz et al. 2011), assuming a linear limb darkening law with a coefficient of 0.65. The broadened spectrum was correlated with the mask. After accounting for solar rotation of $2 \text{ km s}^{-1}$, the results can be fit by the formula

$$V \sin i \approx 1.80 \sqrt{\sigma^2 - \sigma_0^2},$$

(2)

where $\sigma_0 = 3.4$ and all of the values are in km s$^{-1}$. This relation is valid for $\sigma < 12$ and is accurate to $\pm 0.4$, as long as line broadening factors other than rotation are the same as in the Sun. In the fiber mode of CHIRON, which is not used here,

### Table 1

| HIP   | HD   | WDS (J2000) | Spectral Type | $V$ (mag) | $B - V$ (mag) | $\mu_x^a$ (mas yr$^{-1}$) | $\mu_y^a$ (mas yr$^{-1}$) | $\%\mu a$^a |
|-------|------|-------------|---------------|----------|---------------|---------------------------|---------------------------|--------------|
| 7601  | 10800| 01379–8258  | G1V           | 5.87     | 0.62          | +122                      | +120                      | 36.52 ± 0.28  |
| 13498 | 18198| 02539–4436  | KOIII?        | 7.73     | 0.69          | +107                      | +56                       | 14.09 ± 0.73  |
| 25824 | 35877| 05073–8352  | F8V           | 6.80     | 0.57          | +57                       | +147                      | 20.81 ± 0.48  |
| 113579| 217343| 23005–2619 | G5V           | 7.47     | 0.64          | +7                        | –108                      | 32.51 ± 0.71  |
| 113597| 217379| 23005–2619 | K7V           | 9.65     | 1.34          | +14                       | –157                      | 32.74 ± 2.03  |

Note.

a Proper motions and parallax from HIP2 (van Leeuwen 2007).

Figure 1. CCFs of triple-lined systems HIP 7601 (upper curve, shifted by 0.2) and HIP 13498 (lower curve). The letters mark components corresponding to each CCF dip.

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### 2.4. Speckle Interferometry

Information on the resolved outer subsystems has been retrieved from the Washington Double Star Catalog (WDS; Mason et al. 2001). It is complemented by recent speckle interferometry from the SOAR telescope. The latest publication (Tokovinin et al. 2015b) contains references to the previous papers of this series. Observations made in 2015 and 2016 are not yet published.

### 2.5. Orbit Calculation

Orbital elements and their errors were determined by the least-squares fits with weights inversely proportional to the adopted data errors. The IDL code orbit was used. It can fit spectroscopic, visual, or combined visual/spectroscopic orbits. The formal errors of the orbital elements are determined from these fits. The errors of the masses and orbital parallax derived from the combined orbits are computed by taking into account correlations between individual elements.

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http://www.ctio.noao.edu/~atokovin/orbit/
Orbits of the subsystems were determined iteratively. Knowing the semi-amplitudes $K_1$ and $K_2$ in the inner orbit Aa,Ab, I estimate the RV of A (center of mass) as the weighted sum, $V_A = (K_2 V_{Ab} + K_1 V_{Aa})/(K_1 + K_2)$. These RVs, together with the RVs of the secondary component B and the speckle measurements, define the outer orbit. The $V_A$ resulting from the motion in the outer orbit is then subtracted from $V_{Aa}$ and $V_{Ab}$ in the next iteration of the inner orbit, and so its center-of-mass velocity $\gamma$ is zero by definition.

The spectroscopic orbital elements derived in this work are listed in Table 2 and the visual orbits are assembled in Table 3, using common notation. For a circular orbit, $\omega = 0$ means that the element $T$ corresponds to passage through the node (maximum RV). The last two columns of Table 2 provide the weighted rms residuals to the spectroscopic orbits and the total number of RVs for both components. The last column of Table 3 contains the number of astrometric measures. The combined orbits are featured in both tables, duplicating overlapping elements. In combined orbits, the longitude of periastron $\omega_\Lambda$ corresponds to the primary, and the position angle of the visual orbit $\Omega_\Lambda$ is chosen accordingly to describe the motion of the secondary. The weights of the positional measurements and RVs are balanced, so that each data set has $\chi^2/N \sim 1$, where $N$ is the number of degrees of freedom.

The observations used in the orbit calculations are listed in two tables, published in full as supplemental material. Table 4 gives, for each date, the RVs of the primary and secondary components $V_1$ and $V_2$, their errors used for relative weighting, and the residuals to the orbit $O-C$. The first column contains the Hipparcos number and the second column identifies the system. For the inner subsystem of HIP 7601, the velocities $V_1$ and $V_2$ are relative to the center of mass $V_A$ (motion in the visual orbit is subtracted). In the outer orbits, $V_1$ refers to the center of mass of the subsystem. The last column of Table 4 specifies the data source. The RVs of the non-variable component HIP 113597B are also listed in this table.

The resolved astrometric measurements are listed in Table 5 in a manner similar to the RVs, with the first two columns identifying the system, followed by the date, position angle $\theta$, separation $\rho$, position error $\sigma_\rho$ used for weighting, residuals to the orbit, and reference.

2.6. System Modeling

The individual magnitudes of the components are computed from the relative areas of their CCFs, which are proportional to the product $\sigma_\gamma$. Although the spectral types of all of the components in SB3s are similar, a small correction is needed to account for the dependence of the line strength on the effective temperature. Using synthetic spectra (Bertone et al. 2008), I found that the CCF surface depends on the effective temperature $T_e$ almost linearly, proportional to $1 - 3.27(T_e/6000 - 1)$ for $4000 < T_e < 6500$. At lower $T_e$, the surface decreases. The measured CCF areas are corrected for this factor, assuming a reasonable $T_e$, to split the combined $V$-band flux between the components. Resolved photometry of visual pairs is used as an independent check. The CCF parameters and magnitudes of individual components are given in Table 6.

The Hipparcos distance modulus provides the absolute magnitudes of the components, so that their masses are estimated using standard relations (e.g., Henry & McCarthy...
The guesswork of matching the data and models cannot replace the actual measurement of stellar parameters. However, it is useful for detecting discrepancies and for estimating parameters which are not measured directly, such as the effective temperatures and colors of individual components. To distinguish model-dependent (estimated) parameters, they are marked by asterisks in the tables.

2.7. The Lithium Line

The presence of the resonance lithium doublet at 6707.761 and 6707.912 Å (average wavelength 6707.82 Å) in the spectra of solar-type stars is a sign of their relatively young age (Soderblom et al. 1993). Unfortunately, this line is located near the end of the CHIRON echelle order. Its quantitative analysis in SB3s is complicated because the line is a blend of three components in orbital motion. The following procedure was used.

The echelle order containing the lithium line was normalized by the fitted continuum. The nominal positions of the 6707.82 Å line corresponding to each component were computed using their measured RVs and the barycentric correction. The expected profiles of the lithium-line blend computed with preliminary estimates of its amplitudes and widths for each component matched the individual spectra quite well. Then, I reconstructed the line profile of each component by subtracting the contributions of the other two components from each spectrum, shifting the resulting spectrum to the rest-frame wavelength, and averaging all of the spectra with weights proportional to the flux. The primary component with the strongest lithium line is processed first, using preliminary estimates for the other two components.

Dotter et al. 2008, assuming that the stars are on the main sequence. Effective temperatures and individual magnitudes in different filters are then derived from the masses with the help of the same standard relations, and the combined photometry resulting from the system model is compared to the actual combined magnitudes. This provides a check on the temperatures. The modeled masses are compared to the dynamical mass sum from the visual orbit or to the actually measured masses from the combined orbit. Adjustments to the model are made iteratively to achieve a better match between the observed and modeled properties of each system; the details are different, depending on the available data.

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Then, the line profile of the second component is reconstructed in the same way, using the refined estimate of the primary. Finally, the weakest component is retrieved by subtracting the first two.

The lithium line in the co-added spectrum of each component is fit by a Gaussian curve to measure its amplitude $a_{Li}$, width $\Delta a_{Li}$, equivalent width $EW_{Li}$, and wavelength $\lambda_{Li}$. The latter shows that the lines are indeed not shifted from the assumed rest-frame wavelength of 6707.82 Å. The measured EWs are divided by the relative flux of each component $f_R$ to make the result comparable to the line strength in single stars. The $R$-band magnitudes derived from the system models are used for this correction. Note that the lithium line is wider than the CCF, as it is a blend of two lines spaced by 6.7 km s$^{-1}$.

3. HIP 7601 (HD 10800)

The G1V star HIP 7601 (HR 512) is located at a distance of 27 pc from the Sun; it is designated as GJ 67.1 in the catalog of nearby stars. According to Wichman et al. (2003), it is a young SB3 system and an X-ray source. Nordström et al. (2004) recognized it as a double-lined binary. There is extensive literature concerning this bright star. Its chromospheric activity was measured by Henry et al. (1996): $\log R'\sin(i) = -4.6$. These authors noted that the star is slightly more active than normal, but not very active. There is no obvious emission in the core of the H$\alpha$ line. Torres et al. (2006) detected the lithium line 6707.8 Å and measured an equivalent width of 70 mA, which is indicative of a young age. Based on the IRAS photometry, a mid-IR excess at 25 $\mu$m was detected, suggesting a debris disk. However, further observations at the VLT have shown no mid-IR excess at 11.59 and 18.72 $\mu$m (Smith et al. 2008). Incidentally, there were no other faint stars within the 19$''$ field of view. Trilling et al. (2008) also found no energy excess in the Spitzer passbands; the flux at 70 $\mu$m was even less than predicted by the photospheric model.

Physical parameters of the star were derived from high-resolution spectra by several authors, apparently disregarding its multiplicity. Maldonado et al. (2012) determined the metallicity $[\text{Fe/H}] = -0.11$ and age $\log i = 9.09$. Ammler-von Eiff & Reiners (2012) found the projected rotational velocity $V \sin i = 1.8 \pm 0.6$ km s$^{-1}$. Casagrande et al. (2011) give $T_e = 5905$ K, $[\text{Fe/H}] = -0.13$, and $\log g = 4.06$, while Saffe (2008) determined $T_e = 5901$ K, $\log g = 4.84$, and $[\text{Fe/H}] = +0.09$. The triple-lined nature of the spectrum could potentially bias these results.

All three dips in the CCF are narrow, differing in their contrast (Figure 1). The dip amplitudes of Aa, B, and Ab (strongest to weakest) and the widths of their CCFs $\sigma$, determined only from the triple-lined (not blended) spectra and averaged, are listed in Table 6. The $\sigma$ correspond to a $V \sin i$ of 3.0, 4.3, and 1.8 km s$^{-1}$ in Aa, B, and Ab, respectively (see Section 2.3).

The outer system was resolved by speckle interferometry at SOAR in 2014 and was given the WDS designation J01379−8259 or TOK 426 (Tokovinin et al. 2015b). The archival speckle observation made in 2011, distorted by telescope vibrations, was reprocessed and used here in the orbit calculation, as well as the recent, yet unpublished, speckle measures. The median magnitude difference is 0.79 mag at both the 540 and 770 nm wavelengths. The relative photometry is based on 4 and 5 measurements in each band, with rms scatters of 0.12 and 0.09 mag. The $V$ magnitudes in Table 6 correspond to $\Delta V_{AB} = 0.77$ mag, which is in agreement with the speckle photometry.

In the ESO archive, I found 11 spectra of HIP 7601 taken with HARPS in the period from 2009 to 2012 (program 088C.513 and its continuation). The spectral resolution is very similar to that of CHIRON: $R = 80,000$. The reduced spectra were retrieved from the archive and cross-correlated with the solar mask to derive the RVs. The use of these additional data does not increase the time base, but reduces the errors of the orbital elements. I applied a correction of $-0.25$ km s$^{-1}$ to these RVs, determined from the $\gamma$-velocity of Aa,Ab fit solely to the HARPS data. RVs derived from blended CCFs are not used in the determination of the inner orbit and are given a low weight (large errors in Table 4) in the outer orbit. The adopted errors of the RVs match the actual rms residuals, yielding $\chi^2/N \sim 1$.

The orbit of the inner subsystem Aa,Ab is shown in Figure 2, and the combined spectro-interferometric orbit of the outer pair AB is featured in Figure 3. In the final iteration of the outer orbit, I added, with a low weight, the RVs from Wichman et al. (2003) measured in 2000, $-5.4$, $-20.6$, $+18.4$ km s$^{-1}$ for Aa,Ab, and B, respectively. The spectrum taken in 2008 (Tokovinin et al. 2015c) was also used, although it shows only two double lines (two components were blended). The rms residuals to the SOAR speckle measures are 1$''$0 in angle and 1.2 mas in separation. The 1.75 year outer period is determined with a relative error of 0.027%, or just 4 hr.

The combined orbit of A,B leads to an orbital parallax of $37.10 \pm 0.45$ mas, which is in good agreement with the HIP2 parallax of 36.52 $\pm 0.28$ mas. The HIP2 parallax corresponds to a mass sum of $3.25 \mathcal{M}_\odot$, while the orbital masses of A and B are $2.033 \pm 0.049$ and $1.033 \pm 0.026 \mathcal{M}_\odot$. Using the mass ratio $q = 0.841$ in the inner orbit, the masses of Aa and Ab are determined to be $1.104 \pm 0.027$ and $0.929 \pm 0.022 \mathcal{M}_\odot$. The uncertainty of the orbital inclination $i_{A,B}$ contributes to the errors of the orbital masses and parallax.
By comparing the sum of the orbital masses of Aa and Ab with $M \sin^3 i = 1.00 \, M_\odot$ in the inner orbit, its inclination $i_{Aa,Ab} = 51.9^\circ$ is derived. It is similar to the inclination of $47.4^\circ$ in the outer orbit; thus, the two orbits could be close to coplanarity. The ratio of periods is $32.970 \pm 0.009$. Its difference from the integer number 33 is small, although formally significant. An almost integer period ratio and orbits with low eccentricities that are likely co-planar make this system similar to HD 91962, that is, the “planetary” quadruple with a period ratio of 19.0 (Tokovinin et al. 2015a).

The masses and $V$ magnitudes of all three stars are measured, the distance is known, and so too are the absolute magnitudes $M_V$ known. They match well the empirical relations between the mass and absolute magnitude $M_V$, while the Dartmouth isochrones predict $M_V$ that are 0.2 mag too bright (see Section 7.1). To evaluate the effective temperatures and colors, I interpolated the solar-metallicity isochrone using masses reduced by 5%. The resulting parameters are listed in Table 7, and are marked by asterisks to show that they are guessed at rather than measured. They lead to combined $B - V$ and $V - K_s$ colors of 0.60 and 1.44 mag, respectively, while the actual colors are 0.62 and 1.47 mag. The flux-weighted $T_e = 5939$ K is close to the value of $T_e \approx 5900$ K reported in the literature. This agreement indicates that the guessed-at temperatures of the stars are close to reality.

The profiles of the lithium line in the individual components (Figure 4) are symmetric (no apparent blends) and are not shifted in wavelength with respect to their expected position. The nine individual spectra summed in the combined profile have a total flux of 45,000 electrons per pixel, and hence the S/N of 210. The sum of the EWs is 63.4 mÅ, which is in good agreement with the value of 70 mÅ measured by Torres et al. (2006). In the last line of Table 7, the measured EWs are divided by the relative flux of each component $f_R$, making the result directly comparable to single stars. The component Ab is measured with the largest error being due to the small amplitude of its lithium line and the large correction.

### Table 7

| Parameter | Aa | B | Ab |
|-----------|----|---|----|
| Mass ($M_\odot$) | 1.10 | 1.03 | 0.93 |
| $M_V$ (mag) | 4.45 | 4.89 | 5.55 |
| $T_e^\star$ (K) | 6131 | 5879 | 5524 |
| $(B - V)^\star$ (mag) | 0.50 | 0.64 | 0.79 |
| $\lambda_{Li}$ (Å) | 6707.82 | 6707.82 | 6707.83 |
| $\sigma_{Li}$ | 0.137 | 0.058 | 0.019 |
| $\sigma_{Li}$ (km s$^{-1}$) | ±0.003 | ±0.002 | ±0.002 |
| EW$_{Li}$ (mÅ) | 40.3 | 18.6 | 4.5 |
| EW$_{corr}$ (mÅ) | 91.3 | 56.7 | 20.6 |

### Figure 3

[Combined orbit of the outer system HIP 7601 A,B. Top (a): orbit in the plane of the sky, with primary component A at the coordinate origin and scale in arcseconds. Bottom (b): the RV curve (squares for the center-of-mass A, triangles for B). RVs with low weight are plotted as crosses.]

### Figure 4

[Average spectrum in the region of the lithium line for each component of HIP 7601, with the other two components subtracted. The curves (top to bottom, shifted vertically for clarity) correspond to Ab, B, and Aa. Full lines show the spectra, and dashed lines are Gaussian fits. Statistical errors are ±0.005.]
The spatial velocity of HIP 7601 calculated using the $\gamma$-velocity of A,B is $(U, W, V) = (-20.0, -2.4, -9.6) \text{ km s}^{-1}$ (the $U$ axis points away from the Galactic center). It corresponds to the kinematics of the young disk. The velocity is accurate to better than 1 km s$^{-1}$. The object does not belong to any known kinematic group. The closest kinematic neighbor is probably the Castor group with $(U, W, V) = (-10.7, -7.5, -8.8) \text{ km s}^{-1}$. According to Klutsch et al. (2014), the probability of HIP 7601’s membership in the Castor group could be around 20%, considering the velocity dispersion of its known members.

4. HIP 13498 (HD 18198)

The star has a spectral type of G8/K1III+3: in SIMBAD (Houk 1978), while in fact it consists of three main-sequence dwarfs. Its color is $B-V = 0.69$ mag. The HIP2 parallax is $14.09 \pm 0.73$ mas, while the original HIP1 parallax is $14.87 \pm 1.13$ mas. It is a visual binary 1 1480 (WDS J02539-4436) with an orbital period of 52 year, a semimajor axis of 0.73 mas, while the original HIP1 parallax is $14.87 \pm 1.13$ mas. There are no other visual components in the WDS. Wichman et al. (2003) discovered double lines and concluded that there is a spectroscopic subsystem. They measured the lithium line with an equivalent width of 110 mÅ (sum of both components) and computed the relative X-ray flux to be log $L_X/L_{bol} = -4.76$. Double lines were also noted by Nordström et al. (2004). Tokovinin et al. (2015c) detected triple lines, implying that all three components have comparable luminosities. The physical parameters were derived from high-resolution spectra, apparently disregarding the multiplicity, by Casagrande et al. (2011), who give $T_e = 5925 \text{ K}$, $[\text{Fe}/\text{H}] = 0.14$, and $log g = 4.03$.

The relative photometry of the outer system A,B by speckle interferometry at SOAR gives median magnitude differences of 1.52 and 1.49 mag at 540 and 782 nm, respectively. Wichman et al. (2003) list the resolved Tycho photometry of A and B reduced to the standard $B, V$ system: $V = (7.97, 9.54)$ mag and $B - V = (0.67, 0.79)$ mag, while $\Delta H_p_{AB} = 1.58$ mag. The resolved photometry indicates that the component B is slightly redder than A. The $V$ magnitudes in Table 6 correspond to $\Delta V_{AB} = 1.53$ mag.

After the initial orbital solutions were derived from the CHIRON data, I included the RVs measured in 2008 (Tokovinin et al. 2015c), with a correction to account for the visual orbit and a correction of +0.5 km s$^{-1}$ for the instrument zero point. The 14 day orbit of Aa,Ab is determined quite reliably, with rms RV residuals of 60 and 100 m s$^{-1}$ for Aa and Ab, respectively.

Using the available micrometer and speckle measurements, as well as the RVs of A (center-of-mass of Aa,Ab) and B, I computed the combined visual/spectroscopic orbit of A,B (Figure 6). The node of the visual orbit is now defined. The weighted rms residuals in angle and separation are 0.66 and 3 mas, respectively, while the weighted RV residuals for A and B are 35 and 33 m s$^{-1}$. The spectrum obtained by Wichman et al. (2003) on 2000.829 (JD 2451847.307) has a strong line with $RV = 12.9 \text{ km s}^{-1}$ (apparently a blend of Aa and B) and a weaker line at 31.2 km s$^{-1}$ that corresponds to Ab. Due to the unresolved blending, this observation is of little help for orbit refinement; it is used with a low weight for the orbit of A,B.

The periastron of the A,B orbit in 2007.3 has not yet been covered, either by speckle observations (back then, time allocation committees denied access of speckle instruments to 4 m telescopes) or by RVs (I have not found any spectra in the ESO archive). The next periastron passage will occur in 2058, when the RV difference between A and B will reach 23 km s$^{-1}$.

Available data loosely define the RV amplitudes because the shape of the RV curve is poorly constrained. Decreasing the element $\omega_B$ by only 2° increases the mass sum by 0.6 $M_\odot$. The unconstrained orbit in Tables 2 and 3 yields the orbital parallax $\pi_{AB} = 14.8 \pm 0.8$ mas and the masses $M_A = 2.16 \pm 0.40 M_\odot$ and $M_B = 0.87 \pm 0.25 M_\odot$. This is close to the HIP1 parallax, which I adopt here. The HIP2 parallax leads to the dynamical mass sum of 3.5 $M_\odot$, which appears to be too large, given the combined color and magnitude.

Considering the uncertainty of the orbital masses, I adopt mass estimates that are compatible with the measurements and match the expected relation between the mass and absolute magnitude. Starting with the mass sum of 3.0 $M_\odot$ and the well-measured mass ratio of 0.862 in the inner orbit, I fix the mass ratio in the outer orbit at $q_{AB} = 0.45$ (compatible to its measurement within the uncertainty) and obtain the component’s masses listed in Table 8. A smaller value of $q_{AB}$ would imply that the component B is too bright for its mass.

The effective temperatures are estimated from the Dartmouth 1 Gyr isochrone using the above masses reduced by 5%. They match the combined color of the system and the “blended” $T_e = 5925 $ K given by Casagrande et al. (2011). The modeled combined color $V - K_s = 1.48$ mag agrees with the measured combined color $V - K_s = 1.49$ mag; the model predicts $B - V = 0.63$ mag, which is slightly bluer than the measured value of 0.69 mag. Of course, the adopted $T_e$ remain only a plausible guess until a more detailed analysis is performed to separate the individual spectra and actually measure $T_e$.

The lithium line is detected in Aa and Ab, and is below the detection threshold in B. The line profiles (with the contribution of other components subtracted) are provided in Figure 7 (total count 17,000 electrons, $S/N = 130$). A weak Fe I line at 6707.44 Å is noticeable, as well as some asymmetry of the lithium line itself. The parameters of the Gaussian fits to the lithium line are listed in Table 8.
The inner orbit corresponds to the mass sum \( M \sin^2 i = 0.91 \, M_\odot \). The adopted masses imply an orbital inclination of 49°, which is similar to the 51.5° inclination of the outer orbit. The two orbits could be nearly coplanar, although this cannot be established without resolving the inner subsystem and determining the orientation of its orbit in the sky.

The spatial velocity of HIP 13498, which is calculated using the \( \gamma \)-velocity of Aa,Ab, is \( U = -37.5, -21.8, -4.3 \) km s\(^{-1} \), placing the object in the Hyades moving group with \( U, W, V = (-39.7, -17.7, -2.4) \) km s\(^{-1} \) (see Klutsch et al. 2014).

5. HIP 23824 (HD 35877)

The star has a spectral type F8V, \( B - V = 0.57 \) mag. It is a visual binary HDS 669 with an orbital period of 26.5 year (Tokovinin et al. 2015b). The relative photometry of the outer system Aa,Ab by speckle interferometry at SOAR gives median magnitude differences of 2.65 and 2.20 mag at 540 and 782 nm, respectively, while \( \Delta H_p = 2.53 \pm 0.25 \) mag. The \( V \) magnitudes in Table 6 correspond to \( \Delta V_{aB} = 2.72 \) mag.

Double lines were noted by Nordström et al. (2004), suggesting a spectroscopic subsystem. The orbit of the subsystem Aa,Ab (Figure 8) is determined from several triple-lined CHIRON spectra. A circular orbit is forced, considering the short period; I did not subtract the outer orbit here.

The visual orbit of the outer system Aa,Ab (Figure 9) is only slightly revised by adding three recent measures to the latest published solution; all of the measures, except for the first Hipparcos resolution, come from SOAR. The spectroscopic elements are tentative owing to the lack of RV coverage. No additional useful RV data were found in the literature or in the archives. I used the \( \gamma \)-velocity of Aa,Ab as a single measure (the CHIRON data span only 1.15 years), while the individual velocities of B show a small positive trend that is in agreement with the orbit. The data are not sufficient to determine the RV amplitudes and masses. Instead, I fixed \( \gamma_{AB} = 4.6 \) km s\(^{-1} \) to obtain the expected mass ratio, \( q_{AB} = 0.38 \). Unfortunately, the periastron passage in 2014.3 was not covered by spectroscopy; otherwise, the masses could have been measured.

The HIP2 parallax of 20.8 \( \pm \) 0.5 mas leads to a mass sum of 3.15 \( M_\odot \), while the RV amplitudes in the orbit of Aa,Ab correspond to a mass sum of 2.8 \( M_\odot \). In the following, I adopt a mass sum of 3.0 \( M_\odot \), or a dynamical parallax of 21.2 mas. The HIP2 parallax is consistent within its error; it could be biased by the orbital motion.

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Table 8 Components of HIP 13498

| Parameter | Aa | Ab | B |
|-----------|----|----|---|
| Mass (\( M_\odot \)) | 1.11 | 0.96 | 0.93 |
| \( M_V \) (mag) | 4.17 | 5.22 | 5.38 |
| \( T^\circ \) (K) | 6103 | 5558 | 5443 |
| \( (B - V)^+ \) (mag) | 0.51 | 0.78 | 0.82 |
| \( \lambda_{Li} \) (Å) | 6707.83 | 6707.83 | ... |
| \( \alpha_{Li} \) (km s\(^{-1} \)) | 0.193 | 0.053 | <0.01 |
| \( \delta_{Li} \) (km s\(^{-1} \)) | ±0.005 | ±0.005 | ... |
| \( E_{Li} \) (mA) | 65 | 18 | <2 |
| \( f^* \) | 0.52 | 0.26 | 0.22 |
| \( EW_{Li} \) (mA) | 125 | 69 | <9 |

The inner orbit corresponds to the mass sum \( M \sin^2 i = 0.91 \, M_\odot \). The adopted masses imply an orbital inclination of 49°, which is similar to the 51.5° inclination of the outer orbit. The two orbits could be nearly coplanar, although this cannot be established without resolving the inner subsystem and determining the orientation of its orbit in the sky.

The spatial velocity of HIP 13498, which is calculated using the \( \gamma \)-velocity of A,Ab, is \( (U, W, V) = (-37.5, -21.8, -4.3) \) km s\(^{-1} \), placing the object in the Hyades moving group with \( (U, W, V) = (-39.7, -17.7, -2.4) \) km s\(^{-1} \) (see Klutsch et al. 2014).
The system model is adjusted to the data in the same way as for HIP 13498. Starting with the mass sum of 3.0 $M_\odot$ and the well-measured mass ratio of 0.888 in the inner orbit, I fix the mass ratio in the outer orbit at $q_{AB} = 0.38$ and obtain the component’s masses listed in Table 9. The modeled combined color $V - K_s = 1.40$ mag equals the measured one; the model predicts $B - V = 0.55$ mag, which is slightly bluer than measured. The adopted masses imply an inner orbital inclination of 48°6, while the inclination of the outer orbit is 62°.

The lithium line is detected in Aa and Ab, while it is below the detection threshold in B, just as in HIP 13498. The parameters of the Gaussian fits to the lithium line are listed in Table 9.

The spatial velocity of HIP 23824 calculated using the $\gamma$-velocity of A,B is $(U, W, V) = (-29.4, -18.5, -4.2)$ km s$^{-1}$. A correction of ($-5.8, -4.0$) mas yr$^{-1}$ was applied to the HIP2 proper motion to subtract the photocenter motion in the visual orbit. Eggen (1985) believes that this triple system belongs to the Hyades moving group, although the agreement for its velocity is not as good as for HIP 13498.

6. HIP 113597 (HD 217379)

This K6.5Vke star is a known 1°9 visual binary RST 1154 (WDS 23005–2619AB) and an X-ray source. A brighter star HIP 113579 (HD 217373) at 581° distance on the sky (projected separation 18 kau), along with HIP 113597, forms a comoving wide pair, and both objects belong to the AB Doradus group of young stars in the solar neighborhood (Zuckerman et al. 2004). The very faint companion found by Chauvin et al. (2010) at 5°4 from HIP 113579 remains unconfirmed, and is possibly not real. The WDS denotes the brighter star as C, while the visual components of RST 1154 are denoted as A and B. To avoid further confusion, I keep here the current WDS designations C, A, and B in decreasing brightness order; the unresolved photometry and spectroscopy of HIP 113597 refers to AB (C, A,B were designated hierarchically as A, Ba, and Bb in Tokovinin 2014a). Table 1 lists the basic properties of this multiple system. The photometry of AB and its spectral type are from Weis (1993). As the parallaxes of AB and C are equal within errors, in the following I adopt the average parallax of 32.6 mas.

High-resolution spectroscopy revealed HIP 113597 to be a triple-lined system. This was discovered independently by Elliott et al. (2014) and Tokovinin (2015); both works are based on the echelle spectra taken in 2010 with VLT/UVES and 1.5 m/FECH, respectively. Earlier spectroscopic studies did not recognize the triple-lined nature of this object. For example, Malo et al. (2014) provide RVs of C and AB as 7.3 ± 0.3 and 6.6 ± 0.3 km s$^{-1}$, respectively, from single spectra taken with Phoenix at Gemini-South. Zuckerman et al. (2004) detected a strong lithium 6707.8 Å line in the component C and noted its absence in AB (this is confirmed in the CHIRON spectra). Nordström et al. (2004) measured the constant RV(C) = 6.10 km s$^{-1}$ over 2135 days; they did not observe AB.

The visual binary AB was last measured in 2015.73 with the speckle camera at SOAR, yielding a position of 239°3, 2°30 and the magnitude difference $\Delta V = 0.79$ mag. Its previous measurement by Hipparcos in 1991.25 is 235°7, 1°839 and

| Parameter | Aa | Ab | B |
|-----------|----|----|---|
| Mass$^a$ ($M_\odot$) | 1.15 | 1.02 | 0.83 |
| $M_V$ (mag) | 3.89 | 4.72 | 6.20 |
| $T_e$ (K) | 6227 | 5766 | 5111 |
| $(B - V)^0$ (mag) | 0.48 | 0.69 | 1.02 |
| $\sigma_{UB}$ | 0.119 | 0.044 | <0.02 |
| $\sigma_{U}$ (km s$^{-1}$) | ±0.005 | ±0.005 | ... |
| EW$_{Li}$ (mÅ) | 49 | 20 | <8 |
| $f_{Li}^*$ | 0.57 | 0.33 | 0.10 |
| EW$_{core}$ (mÅ) | 86 | 62 | <80 |

The visual binary AB was last measured in 2015.73 with the speckle camera at SOAR, yielding a position of 239°3, 2°30 and the magnitude difference $\Delta V = 0.79$ mag. Its previous measurement by Hipparcos in 1991.25 is 235°7, 1°839 and...
\( \Delta H_p = 0.79 \) mag. All three components Aa, Ab, and B have comparable brightness and color, and so \( \Delta m \) is apparently independent of the wavelength.

All three dips in the CCF are narrow (Figure 10). The central, stationary component belongs to the visual secondary B, while the two moving components belong to the spectroscopic subsystem Aa, Ab. The relative amplitudes of the dips are variable. This happens because the 2.52 separation between A and B is comparable to the 2.7" diameter of the CHIRON fiber projected on the sky. Depending on centering, guiding, and seeing, the fraction of light from each component that enters the fiber is variable. In the spectra taken with FECH in 2010, the CCF area (EW) of B is half the sum of Aa and Ab, as expected from the relative photometry of the visual binary A,B. In most spectra taken in 2015 with CHIRON, the EW(B) is comparable to the sum EW(Aa)+EW(Ab). Both instruments have the same acquisition and guiding unit; the difference in relative intensities could be caused by a different offset of the object position on the fiber.

To determine the relative fluxes in the V band, I use the ratio \( \text{EW}(Aa)/\text{EW}(Ab) = 0.68 \pm 0.02 \), which has been measured reliably, and assume that it reflects the light ratio (the CCF area does not depend on effective temperature at \( T_e \sim 4000 \) K). Assuming \( \Delta V_{AB} = 0.79 \) mag from Hipparcos photometry, I computed the apparent magnitudes of B, Aa, and Ab as listed in Table 6.

The spectroscopic orbit of the inner subsystem is plotted in Figure 11. The mass ratio of the inner pair is 0.95, while the spectroscopic masses \( M \sin^3 i \) are 0.48 and 0.45 \( M_\odot \). I used the RVs measured by Elliott et al. (2014) on JD 2455341.4055 with a correction of +6.15 km s\(^{-1}\). The correction was derived by computing the center-of-mass velocity \( V_A = (V_1K_2 + V_2K_1)/(K_1 + K_2) = 1.41 \) km s\(^{-1}\); it must equal 7.56 km s\(^{-1}\) according to my orbit. An RV bias is expected when a semi-resolved (blended) visual binary is observed with a slit spectrograph like UVES, as guiding is made on the combined light and the individual components are no longer centered in the slit.

Knowing the absolute visual magnitudes of the components (distance modulus 2.43 mag), I estimated their masses by assuming that they are on the main sequence (the bright star C is actually on the main sequence). The result is given in Table 10. The combined magnitudes of AB in the J and K\(_s\) bands derived from this model are 7.17 and 6.33 mag, respectively. They compare well with the 2MASS magnitudes of 7.05 and 6.27. The model leads to a \( B - V \) color of 1.39 mag, while the measured color is 1.34 mag (Weis 1993). The good agreement between the modeled and actual colors shows that the system indeed consists of three main-sequence stars of \( \sim 0.6 \) \( M_\odot \) each. The model implies the effective temperatures given in the last line of Table 10. The mass ratio in the subsystem Aa, Ab is 0.95 according to the model, which matches the measured ratio. The orbital inclination of Aa, Ab is \( \sim 70^\circ \).

The pair A,B has opened up from 0.6" to 2.5" since its discovery by Rossiter (1955) in 1930. We know the distance to the system and its estimated mass sum, 1.8 \( M_\odot \). The observed motion can be represented by a visual orbit matching this mass sum (Figure 12). This orbit is not uniquely constrained by the data, and so the errors of its elements are undetermined. It is computed only to show that the motion is compatible with a Keplerian orbit and to get an idea of the period. Owing to the long period, no substantial improvement of this orbit is expected in the following decades.

The average RV(B) is 7.05 km s\(^{-1}\) with an rms scatter of 0.54 km s\(^{-1}\) (see Table 4). The two measurements in 2010 average at 8.0 km s\(^{-1}\), while the 13 measurements in 2015 have an average value of 6.76 km s\(^{-1}\) with an rms scatter of 0.16 km s\(^{-1}\). It is unlikely that the difference is attributable to the different spectrographs, FECH and CHIRON, as the RVs of Aa and Ab measured from the same spectra do not show
instrument-related systematics. Motion in the visual orbit is too slow to explain the RV change over five years. Elliott et al. (2014) measured $RV(B) = 5.5 \text{ km s}^{-1}$ in 2010, with an uncertain bias (see above). I cannot exclude a low-mass (possibly planetary) companion to B modulating its RV. The outer orbit of A,B leaves ample room for such a putative subsystem.

The positive RV difference $RV(A)−RV(B)$ in 2015 confirms the correct choice of ascending node in this provisional orbit. I measured in 2010 $RV(C) = 7.03 \text{ km s}^{-1}$ (Tokovinin 2015), which is in agreement with Nordström et al. (2004). Analysis of this bright component C (HIP 113579) is outside the scope of this work.

The measured RV of the component A, together with the known distance and proper motion, leads to a Galactic velocity of $(U, V, W) = (−3.0, −25.5, −15.1) \text{ km s}^{-1}$. A correction for the motion in the orbit A,B is not applied here; it should be small, $<1 \text{ km s}^{-1}$. According to Malo et al. (2014), the AB Doradus group has a spatial velocity of $(U, V, W) = (−7.1, −27.2, −13.8) \text{ km s}^{-1}$.

The 10 year photometric monitoring of HIP 113597 by ASAS (Pojmanski 1997)\(^5\) shows a constant brightness of $V = 9.58 \text{ mag}$ with an rms scatter of 0.036 mag; it is not identified as a variable star in the ASAS database.\(^6\) Young 0.6 $M_\odot$ dwarfs are expected to be active, but no flares have been detected so far. The H\(\alpha\) line has a low contrast, possibly being filled by emission. The projected rotation velocity of all three components is moderate, from 7.2 to 8.8 $\text{ km s}^{-1}$. It is faster than the estimated pseudo-synchronous rotation in the inner pair, $3.6 \text{ km s}^{-1}$.

\(^5\) Slow variability of HIP 9642 and 113597 in ASAS has been noted by R. Barba (2016, private communication).

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**Figure 12.** Tentative orbit of the pair HIP 113597 A,B (RST 1154). Visual measurements are plotted as empty squares, the Hipparcos and speckle data as filled squares. The insert shows the “shift-and-add” image in the $I$ band obtained in 2015.7 at SOAR.

**Figure 13.** Relation between mass and absolute magnitude for HIP 7601 and 13498. The standard relations are traced by the dashed line (Dotter et al. 2008, solar metallicity), full line (Henry & McCarthy 1993), and dotted line (Tokovinin 2014a).

7. DISCUSSION

7.1. Masses

The masses of the components of HIP 7601 are measured from the combined outer orbit with an accuracy of 2.5%. The masses of HIP 13498 are constrained by the orbit and parallax only to within $\sim10\%$, while the masses of HIP 23824 and 113597 are not measured directly. Figure 13 plots the absolute magnitude versus mass for the first two systems. The data match empirical relations such as those of Henry & McCarthy (1993) and Tokovinin (2014a). On the other hand, the Dartmouth 1 Gyr isochrone for solar metallicity is $\sim0.2 \text{ mag}$ brighter; the discrepancy is even larger for $\text{[Fe/H]} = −0.15$. The agreement with the isochrone would be better for a larger-than-solar metallicity. Spectroscopic measurements of $\text{[Fe/H]}$ could have been biased by the unrecognized multiplicity.

7.2. Lithium and Rotation

The equivalent widths of the lithium line in HIP 7601 and HIP 23824 are comparable to stars of similar color in the Hyades (Soderblom et al. 1993), as illustrated in Figure 14, suggesting an age of $\sim0.6 \text{ Gyr}$. However, large scatter of the lithium abundance and activity indicators among stars in the Hyades makes this estimate rather uncertain. The lithium line in HIP 13498 is stronger than in the Hyades, although the system may belong to this group kinematically.

The components of both HIP 7601 and 13498 have slow axial rotation ranging from 1.8 to 4.3 $\text{ km s}^{-1}$, as inferred from the width of their CCFs. Assuming that the components of the inner subsystems are synchronized and aligned with the orbits, I estimate projected synchronous velocities of 2.0 and 2.7 $\text{ km s}^{-1}$. They are close to the actual $V \sin i$ of the secondary components Ab, 1.8 and 2.8 $\text{ km s}^{-1}$ in HIP 7601 and 13498, respectively. The primary components Aa and the visual secondaries B rotate slightly faster. If the lines are broadened by additional factors compared to the Sun, then the above estimates are upper limits. In the closest inner binary HIP 23824 Aa,Ab, the synchronous speed of Aa, estimated at $V \sin i = 7.3 \text{ km s}^{-1}$, matches its measured rotation of 7.1 $\text{ km s}^{-1}$, while B rotates much slower at $V \sin i = 1.6 \text{ km s}^{-1}$.
By definition, triple-lined systems have all three components of comparable masses and luminosities. If their components were chosen randomly from the stellar mass function, then SB3s would be exceptionally rare. The four nearby SB3s studied here do not appear exceptional, demonstrating that stars with similar masses are commonly assembled together in hierarchical systems. It is legitimate to ask how these objects were formed, given that the initial size of a solar-mass protostellar core, on the order of the Jeans length ($\sim 10^4$ au), is much larger than the size of those multiples.

It is currently believed that binaries forming by the fragmentation of cores or circumstellar disks have relatively large initial separations, no less than $\sim 50$ au, owing to the opacity limit to fragmentation (Low & Lynden-Bell 1976). Subsequent accretion shrinks the binary, while its components grow in mass. The binary separation decreases roughly as $M^{-2}$ (Bonnell & Bate 2005). The secondary grows faster than the primary, which naturally leads to close pairs of comparable-mass stars. To explain the origin of a hierarchical SB3, we have to admit that the inner pair formed first and became closer, while the outer component formed later. If this triple system later gained substantial mass and this mass was accreted preferentially by the distant companion, then one expects that the former tertiary would become nearly as massive as the close pair, converting itself into a primary. Such triple systems are indeed common (e.g., $\alpha$ For, Tokovinin 2013). However, in the case of SB3s, the growth of the outer component had to be regulated in such a way that all three stars end up with similar masses. The challenge of explaining the formation of SB3s may lead to new insights on star formation in general.

All four systems studied here are structured in a similar manner, with an inner spectroscopic pair and a tertiary companion. The orbits of those tertiaries, however, have quite different periods ranging from 1.75 to $\sim 500$ years. In three systems, the inclinations of the inner orbits are close to the inclinations of the outer orbits, suggesting coplanarity. The inner orbit in the closest triple, HIP 7601, has a small eccentricity of $e = 0.1$. This also argues for approximate coplanarity in this system because, otherwise, the Kozai-Lidov cycles (Kiseleva et al. 1998) would have increased the inner eccentricity.

On the other hand, the inner orbits in HIP 13498 and 113597 are moderately eccentric. The separations at periastron in these inner binaries correspond to equivalent circular orbits with $P_{circ} = P(1 - e)^{3/2}$ of 7.8 and 8.7 days, respectively. These periods are shorter than the 10 day circularization period of solar-type stars (Mayor et al. 2010), meaning that the components tidally interact at periastron. The Kozai-Lidov mechanism cannot be ruled out. In any case, the inner orbits will eventually become circular. These triple systems are relatively young and still evolve dynamically toward circular inner orbits. The inner binary in HIP 23824 is already circularized.

The triple system HIP 7601 holds the record of the shortest outer period (639 days) among the 4847 F- and G-type dwarfs within 67 pc of the Sun (Tokovinin 2014b). The outer periods of multiple systems in this sample are all longer than $\sim 1000$ days. This means that shorter outer periods are rare. Nevertheless, such systems certainly exist. For example, VW LMi contains four solar-type stars packed in the outer orbit with a period of only 355 days (Pribulla et al. 2008). Several triple stars with short outer periods were recently found by Borkovits et al. (2016) in the *Kepler* sample of eclipsing binaries.

If the orbit of the tertiary component shrinks, then at some point it starts to interact dynamically with the inner pair, even when the orbits are co-planar (no Kozai-Lidov cycles). Such interaction should start at moderate period ratios (on the order of a few tens) and may take the form of mean motion resonances (integer period ratios). The period ratio in HIP 7601 is close (although not quite equal) to an integer number. The ratio of inner periods in the hierarchical quadruple system HD 91962 is also an integer number 19.0 (Tokovinin et al. 2015a). The absence of the dust disk and outer companions for HIP 7601 imply that its outer orbit is no longer shrinking.

8. SUMMARY

The orbital elements of four hierarchical systems have been determined here, based on the original RVs and complemented by published and new resolved measurements. All of the objects are relatively young, as inferred from the chromospheric activity (X-ray sources), the presence of lithium, and the kinematics. Measurements of masses, luminosities, and rotation provide interesting material for calibrating the evolution of solar-type stars and their ages.

The system HIP 7601 is most interesting, as it is the closest, the brightest, and has an accurately determined outer orbit and masses. The accuracy of masses can be further improved by accumulating more data and/or by using better instruments. The semimajor axis of the inner 19 day subsystem is 6 mas, making it an easy target for long-baseline interferometers such as VLTI. Only a few observations are needed to establish the relative orbit orientation, confirming or refuting their suggested co-planarity. New data will also improve the accuracy of the measured masses and period ratio.

I thank the operators of the 1.5 m telescope for executing observations of this program and the SMARTS team at Yale for scheduling and pipeline processing. This work used the SIMBAD service operated by Centre des Données Stellaires (Strasbourg, France), bibliographic references from the Astrophysics Data System maintained by SAO/NASA, the

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Figure 14. Equivalent width of the lithium line in the components of HIP 7601 (squares), 13498 (asterisks), and 23824 (triangles) vs. their $B - V$ color. The solid line is a schematic trend for the Hyades from Figure 4 of Soderblom et al. (1993).

7.3. Origin

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If the orbit of the tertiary component shrinks, then at some point it starts to interact dynamically with the inner pair, even when the orbits are co-planar (no Kozai-Lidov cycles). Such interaction should start at moderate period ratios (on the order of a few tens) and may take the form of mean motion resonances (integer period ratios). The period ratio in HIP 7601 is close (although not quite equal) to an integer number. The ratio of inner periods in the hierarchical quadruple system HD 91962 is also an integer number 19.0 (Tokovinin et al. 2015a). The absence of the dust disk and outer companions for HIP 7601 imply that its outer orbit is no longer shrinking.

8. SUMMARY

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The system HIP 7601 is most interesting, as it is the closest, the brightest, and has an accurately determined outer orbit and masses. The accuracy of masses can be further improved by accumulating more data and/or by using better instruments. The semimajor axis of the inner 19 day subsystem is 6 mas, making it an easy target for long-baseline interferometers such as VLTI. Only a few observations are needed to establish the relative orbit orientation, confirming or refuting their suggested co-planarity. New data will also improve the accuracy of the measured masses and period ratio.

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Washington Double Star Catalog maintained at USNO, and products of the 2MASS survey. HIP 113597 was discussed with P. Elliott. Data from the ESO archive (program 088C.513 and its continuation) were used. Comments by anonymous Referee helped to improve the paper.

**Facilities:** CTIO:1.5m, SOAR.

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