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Progress Report on New Spectroscopic Orbits of Potential Interferometric Binaries

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Abstract. We discuss the status of a program to obtain radial velocities from high-resolution, red-wavelength spectra to improve the orbits of bright known spectroscopic binaries that are potential targets of ground-based interferometers. Most of the 28 orbits still to be published are for solar-type stars or late-type giants. Of the 51 systems that have been extensively observed in this project, four or 8% have been found spectroscopically to have a long period companion, making the systems at least triple. Of the remaining 28 systems, we have detected the secondary of a dozen former single-lined spectroscopic binaries. The combination of spectroscopy and astrometry from interferometric observations will result in three-dimensional orbits and will produce many additional systems with mass uncertainties less than 1% and well determined distances. Orbital inclinations for some of our stars can also be obtained with astrometry from the GAIA mission.

1. Introduction

Over the past decades the intersection of the visual and spectroscopic binary domains has expanded significantly. This increased overlap is primarily the result of improved optical and near-infrared interferometers (Quirrenbach 2001) but also the product of high-resolution spectrographs and high quantum efficiency CCDs that result in high signal-to-noise red and infrared wavelength spectra.

The combined analysis of astrometric and spectroscopic observations can produce a complete three-dimensional binary orbit, enabling precise masses and the distance to the system to be determined. Torres et al. (2010) summarized the recent situation, noting that there are more than 20 interferometric binaries with mass uncertainties $\leq$3%. The astrometric and spectroscopic data can also provide additional basic parameters such as absolute magnitudes, luminosities, rotational velocities, and abundances enabling valuable comparisons with stellar evolutionary theory (e.g., Hummel et al. 2001; Boden et al. 2006; Fekel et al. 2009).

In 2002 we began a program to enhance the spectroscopic orbit precision of potential interferometric binaries (Fekel & Tomkin 2004). A search of the Eighth Catalogue of the Orbital Elements of Spectroscopic Binary Systems (Batten et al. 1989) identified bright, field binaries that could be resolved with current interferometers but had spectroscopic orbits that needed improved precision to significantly reduce their mass uncertainties. Obtaining radial velocities of previously analyzed spectroscopic binaries at a substantially different epoch can also result in the discovery of a third component, increasing the known multiplicity of systems (e.g., Duquennoy & Mayor 1991). Such information is needed for the statistics of multiple systems and an understanding of their origin (Tokovinin 2008). A third objective of this binary star program is the spectroscopic detection of previously unseen secondary components, turning single-lined binaries into much more useful double-lined binaries. The binary mass ratio distribution, for example, is an important diagnostic for assessing models of binary formation (e.g., Halbwachs et al. 2003).

2. Observations

Red wavelength spectra have been obtained at three observatories. Initially, many of the spectra were acquired at McDonald Observatory and the Kitt Peak National Observatory (KPNO). We made observations at McDonald with the 2.1 m telescope, Sandiford Cassegrain echelle spectrograph (McCarthy et al. 1993), and a Reticon CCD. Those spectra cover the wavelength range 5600–7000 Å and have a resolving power of 60,000. At KPNO we collected observations with the KPNO coudé feed telescope, coudé spectrograph, and usually a TI CCD. Those spectra are centered at 6430 Å, cover a wavelength range of 84 Å, and have a resolving power of about 30,000.

We are now exclusively observing with and have obtained the majority of our spectrograms with the Tennessee State University 2 m Automatic Spectroscopic Telescope (AST) and fiber-fed echelle spectrograph (Eaton & Williamson 2004, 2007), situated at Fairborn Observatory in southeastern Arizona. Initially, the detector was a SITe ST-002A CCD with 15 μm pixels that produces a resolving power of about 35,000. Those AST echelle spectrograms have 21 orders that span the wavelength region 4920–7100 Å. Because of the low throughput and noise problems of that system, upgrades occurred in 2010 and 2011 when we replaced the fiber, dewar, and CCD (Fekel et al. 2013a). The new detector is a Fairchild 486 CCD having a 4096×4096 array of 15 μm pixels. Echelle spectrograms with that detector have 48 orders that range from 3800–8260 Å. We primarily acquire our AST spectra with a 200 μm diameter fiber that produces a resolving power of 25,000 at 6000 Å. Signal-to-noise ratios of the spectra are typically 100–250.

Complimentary astrometric observations with the CHARA interferometric array at Mount Wilson Observatory have been obtained for 10 of our spectroscopic binary systems.

3. Results

To date we have published eight papers, the most recent being Fekel et al. (2013b), for 23 systems in our series on new precision orbits of bright double-lined spectroscopic binaries. The minimum masses ($m_1 \sin^3 i$ and $m_2 \sin^3 i$) of the binary components have accuracies of 1% or better. The spectral types of the primaries are primarily A or F dwarfs with orbital periods that range from 5 to 134 days. While our initial papers have concentrated on earlier type stars, most of the remaining stars in our program are solar-type stars or late-type subgiants and giants. Of the remaining 28 systems, 21 have late-type star primaries. The orbital periods of those 28 binaries range from 3.3 to 926 days.

Of the 51 binaries that we have extensively observed for this project, from our radial velocities we have identified tertiary components for four systems, HD 103478, HD 108642, HD 110318, and HD 178619, or 8% of our sample. The long orbital periods of those systems are 845, ∼5500, ∼3140, and 424 days, respectively.

Building on the work of Stockton & Fekel (1992), who searched for the secondary features of previously known single-lined spectroscopic binaries that had relatively large mass functions, we have acquired high signal-to-noise CCD spectra at red wavelengths of a number of such systems. Of the remaining 28 binaries for which we have extensive spectroscopic observations, we have detected the secondary lines in 12 former single-lined binaries or 43% of those systems. While in most of the 12 binaries the secondary features are easily visible in our high signal-to-noise red wavelength spectra, for three systems, HD 54371, HD 54563, and HD 79028, the secondary features are not obvious in our spectra. However, we extended our search for spectral evidence of the secondary components. For our spectra of those three systems we subtracted the averaged spectrum of the regions around the primary lines, appropriately shifted so that all the primary lines from spectrum to spectrum were aligned. This subtraction resulted in residual spectra that show an extremely weak average summed profile that corresponds to the secondary component (Fig. 1).

Thus, we have successfully measured the radial velocities of the secondary components, turning those 12 single-lined systems into more useful double-lined spectrocopic binaries. In Table 1 we provide some basic data for those 12, including our newly determined mass ratios, the smallest of which is 0.50.

Torres et al. (2010) compiled a list of eclipsing binaries with very accurately determined masses and radii and a second list of systems with accurate masses from astrometry and spectroscopy. They noted that the types of systems with well determined basic properties that are underrepresented include those with stars less massive than the Sun as well as those with evolved giants. Our list of systems with orbits still to be published contains nine binaries that have at least one component that is a late-type subgiant or giant. The five with subgiant components are listed in Table 1, while the systems with giants in them are HD 40084, HD 106677, HD 185734, and HD 218527. Binaries with low mass ratios or components in very different evolutionary states provide the most leverage in comparisions with evolutionary models.

4. Future Observations

Two binaries for which we have not been able to detect the secondary are the solar-type stars HD 14214 (Fekel et al. 2007) and HD 131511. In both cases the unseen companions are likely early M dwarfs. However, as shown by Mazeh et al. (2002, 2003) it is possible to detect such low-mass companions in infrared spectra. In collaboration with the University of Florida, we are currently commissioning an infrared echelle spectrograph, FIRST, on our 2 m AST at Fairborn Observatory (Muterspaugh et al. 2014). This will allow us to detect the very late-type companions of HD 14214 and HD 131511 and other stars that have mass ratios less than 0.5.

To turn the minimum masses from a spectroscopic orbit into actual masses, an orbital inclination is required. In addition to ongoing interferometric astrometry, the GAIA satellite mission will produce orbital inclinations from astrometry that, when combined with our new double-lined spectroscopic orbits, are precise enough to determine masses to 1% accuracy as well (Halbwachs & Arenou 2009).

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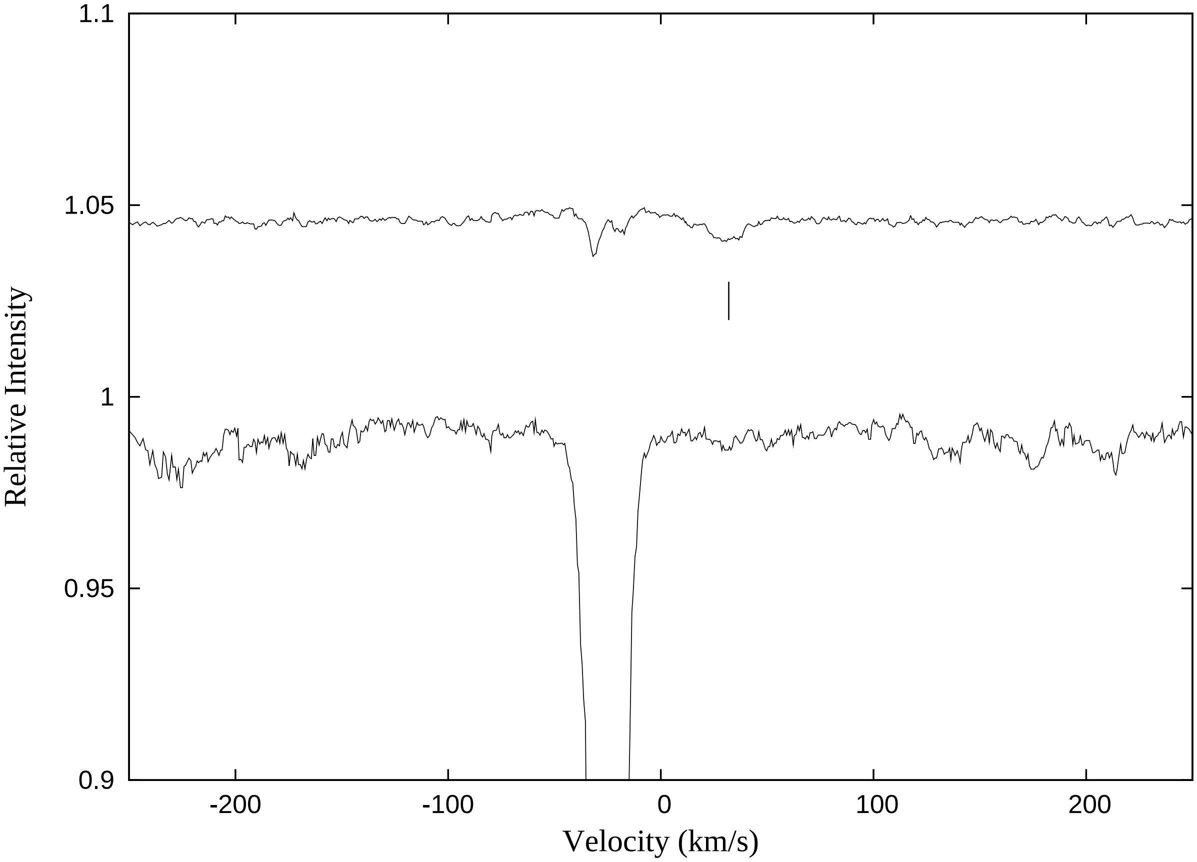

Figure .1: From an AST spectrum of HD 54563, the lower solid line is the average profile of the components, summed over 168 spectral regions. The upper line, arbitrarily vertically shifted for visibility, is the remainder after the average region around the primary component from all useful spectra has been removed from the lower line. The position of the secondary is indicated with a tick mark below the summed residual spectrum.

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Table 1. Basic Properties of New Double-Lined Binaries

HR	HD	Spectral Type[a]	V (mag)	$B-V$ (mag)	Parallax[b] (mas)	Period (days)	Mass Ratio m_2/m_1
...	9312	G8IV	6.78	0.929	17.32	36.52	0.77
...	9313	G8IV	7.82	0.972	9.03	53.51	0.71
976	20210	F0m	6.25	0.290	16.41	5.54	0.61
...	54371	G5V	7.09	0.700	39.73	32.81	0.50
2692	54563	G8IV	6.43	0.880	21.82	113.35	0.64
3648	79028	F9V	5.18	0.605	51.10	16.24	0.55
...	96511	G0IV	7.15	0.700	21.88	18.89	0.76
4536	102713	F7IV	5.73	0.467	14.40	32.86	0.80
4564	103578[c]	A3IV	5.53	0.116	6.59	6.62	0.64
4750	108642[c]	A7m	6.52	0.215	11.69	11.78	0.55
4822	110318[c]	F5V	5.17	0.432	12.67	44.51	0.51
...	120005	F6V	6.51	0.491	22.87	39.28	0.58

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[a] Spectral type of the combined system

[b] van Leeuwen (2007)

[c] Triple system

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