Radial Velocities of Six OB Stars

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ABSTRACT. We present new results from a radial velocity study of six bright OB stars with little or no prior measurements. One of these, HD 45314, may be a long-period binary, but the velocity variations of this Be star may be related to changes in its circumstellar disk. Significant velocity variations were also found for HD 60848 (possibly related to nonradial pulsations) and HD 61827 (related to wind variations). The other three targets, HD 46150, HD 54879, and HD 206183, are constant-velocity objects, but we note that HD 54879 has Hα emission that may originate from a binary companion. We illustrate the average red spectrum of each target.

Online material: extended table

1. INTRODUCTION

Radial velocity measurements exist for many of the bright OB stars because of their usefulness for binary mass determination and cluster dynamics. However, of the 227 stars listed by Mason et al. (1998) in a survey of the multiplicity of bright O stars, 17 lacked sufficient radial velocity data to determine whether or not they were members of spectroscopic binaries. We observed six of these targets with unknown spectroscopic duplicity in two extended observing runs of high dispersion and high signal-to-noise ratio (S/N) spectroscopy at the Kitt Peak National Observatory (KPNO) coude’ feed telescope in 2000. We have already reported on discoveries made during these runs, of new single-lined spectroscopic binaries (HD 14633, HD 15137; Boyajian et al. 2005) and double-lined spectroscopic binaries (HD 37366, HD 54662; Boyajian et al. 2007). Here we present our results on the six stars with mainly “unknown” spectroscopic binary status from the list of Mason et al. (1998). We describe the observations, measurements, and analysis in § 2 and then discuss the individual targets in detail in § 3. Our results are summarized in Table 2 of § 2.

2. OBSERVATIONS AND RADIAL VELOCITIES

Red spectra were collected with the KPNO 0.9 m coude’ feed telescope during two observing runs in 2000 October and December. The spectra were made using the long collimator, grating B (in second order, with order-sorting filter OG 550), camera 5, and the F3KB CCD, a Ford Aerospace 3072 × 1024 device. The setup yielded a resolving power of $R = \lambda/\delta\lambda \approx 9500$, with a spectral coverage of 6440–7105 Å. The exposure times were less than 30 minutes, yielding a S/N ≈ 200 pixel−1. We obtained between 22 and 62 spectra of each star.

The spectra were extracted and calibrated using standard routines in IRAF,6 and then each continuum-rectified spectrum was transformed onto a uniform heliocentric wavelength grid for analysis. We removed atmospheric lines by creating a library of spectra from each run of the rapidly rotating A star ζ Aql, removing the broad stellar features from these, and then dividing each target spectrum by the modified atmospheric spectrum that most closely matched the target spectrum in a selected region dominated by atmospheric absorptions.

We measured radial velocities in two ways. For targets with absorption lines, we formed a cross-correlation function (CCF) between a given spectrum and a single reference spectrum of the star (usually the first observation). These relative velocities were then transformed to an absolute velocity scale by adding a mean velocity measured by parabolic fits to the lower halves of the absorption lines in the reference spectrum. Two of the targets have spectra dominated by emission lines, and in these cases we measured bisector velocities for the extreme line

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TABLE 1

| Star Name | Date (HJD −2,450,000) | V₂ (km s⁻¹) | σ (km s⁻¹) |
|-----------|-----------------------|-------------|------------|
| HD 45314  | 1817.942              | −31.3       | ...        |
| HD 45314  | 1818.945              | −32.2       | ...        |
| HD 45314  | 1819.936              | −31.2       | ...        |
| HD 45314  | 1820.931              | −32.0       | ...        |
| HD 45314  | 1821.931              | −32.2       | ...        |
| HD 45314  | 1822.926              | −31.9       | ...        |
| HD 45314  | 1823.866              | −32.0       | ...        |
| HD 45314  | 1823.987              | −32.5       | ...        |

Note.—Table 1 is published in its entirety in the electronic edition of the PASP. A portion is shown here for guidance regarding its form and content.

Fig. 1.—Mean red spectrum of HD 45314 in the rest frame. Line identifications are marked by vertical lines.

3. NOTES ON INDIVIDUAL STARS

3.1. HD 45314

The star HD 45314 (O9 pe, Conti 1974; B0 IVe, Negueruela et al. 2004) has a speckle interferometric companion at a separation of 50 mas (corresponding to a period of ≈30 yr; Mason et al. 1998). The average red spectrum illustrated in Figure 1 shows that Hα and He i λλ6678, 7065 are double-peaked emission lines. This suggests that the emission forms in a disk and that the line wings form in the gas closest to the star. Thus, we can use measurements of the Hα wings as a proxy for the motion of the underlying star. We measured radial velocities using the wing bisector method of Shafter et al. (1986).

Our results indicate that there was a significant change in velocity from −32.0 ± 0.9 to −21.6 ± 1.9 km s⁻¹ between the runs. This may indicate that the Be star is a spectroscopic binary with a period of months. However, the emission profiles changed in shape between the runs (see Fig. 2 for the Hα averages from each run), so it is also possible that the changes in bisector velocity result from physical changes in the gas distribution in the disk rather than orbital motion. We rec-
ommend a program of blue spectroscopy of this star to distinguish between the binary and disk variation explanations.

3.2. HD 46150

The spectroscopic binary status of HD 46150 (O5 V(f); Underhill & Gilroy 1990) remains inconclusive, even though it has a history of radial velocity measurements spanning eight decades (Plaskett 1924; Abt 1970; Conti et al. 1977b; Garmany et al. 1980; Liu et al. 1989, 1991; Underhill & Gilroy 1990; Fullerton 1990; Stickland & Lloyd 2001). The measured radial velocities fall in the range of $-51$ km s$^{-1}$. Stickland & Lloyd (2001) suggest that this range is significantly larger than expected for diverse measurements of a single star. The most extensive analysis of this star by Garmany et al. (1980) covered four observing seasons, with a mean of $-100$ km s$^{-1}$ and a range of 26 km s$^{-1}$. They conclude that the scatter results from atmospheric rather than orbital variations (see also Underhill & Gilroy 1990).

The mean red spectrum in Figure 3 shows a strong He ii spectrum associated with a very early type star. We measured CCF velocities of the H$\alpha$, He i $\lambda\lambda6678, 7065$, and He ii $\lambda\lambda6683, 6890$ features. The error in the mean velocity from closely spaced pairs is $I = 1.3$ km s$^{-1}$, while the standard deviation among the mean velocities is $E = 3.8$ km s$^{-1}$. A standard $F$-test (Conti et al. 1977a) indicates that a temporal variation this large is expected from random variations with a probability of 0.6%; i.e., the observed variation is probably significant. However, most of the variance comes from the first run, in which there appear to be relatively large night-to-night variations that are absent in the second run. This may indicate that the observational errors were larger in the first run compared to our estimate of $I$ from the scatter in measurements from the second run (also consistent with the larger line-to-

3.3. HD 54879

The target HD 54879 (B3 V, Neubauer 1943; O9.5 V, Morgan et al. 1955; B0 V, Claria 1974) has only a few spectroscopic measurements over the past century. The mean spectrum shown in Figure 4 indicates that it has H$\alpha$ emission and is thus a Be star, which has historically never been observed in emission until now. We made CCF velocity measurements using the lines He i $\lambda\lambda6678, 7065$, C ii $\lambda\lambda6578, 6583$, and Si iv $\lambda\lambda6667, 6701$.

Our $V_r$ measurements show no evidence of Doppler shifts in the absorption lines over both short and long timescales. The external error $E = 1.4$ km s$^{-1}$ is somewhat larger than the
internal error $I = 0.6$ km s$^{-1}$. The $F$-test indicates that a scatter between observations of this size is expected with a probability of 3.1%, so this star is radial velocity constant over the duration of the run. The only other radial velocity measurement on record, $V = 15.6 \pm 1.4$ km s$^{-1}$, from Neubauer (1943), is smaller than our mean of $V = 35.4 \pm 1.4$ km s$^{-1}$. We caution that this discrepancy may be caused by measuring different lines in the blue part of the spectrum, or by long-term changes in the spectrum.

The mean spectrum has very narrow lines of He i, C ii, N ii, O ii, and Si iv. These apparently sharp absorption lines are unexpected in Be stars that are normally rapid rotators with broad lines. One possibility is that HD 54879 is a rare Be star that is seen almost pole-on, so that the rotation is tangential to the line of sight and the lines do not suffer rotational broadening. Another possibility is that HD 54879 is a Be shell star in which the narrow absorptions form in a circumstellar disk that is projected against the star. The star might have a strong magnetic field that controls the gas outflow and has spun down the star. Finally, the spectrum may be that of a long-period binary consisting of a bright, narrow-lined B star and a fainter Be star (although no companion was found in the speckle survey by Mason et al. 1998). This explanation is supported by the fact that the Hα emission does vary in strength and shape on short and long timescales in our observations, while the absorption lines are constant.

### 3.4. HD 60848

The star HD 60848 is another Be-type object (O9.5 IVe; Negueruela et al. 2004) that may be a runaway star because of its position well out of the Galactic plane (de Wit et al. 2005). It was recently observed with moderate-dispersion blue spectra by McSwain et al. (2007), who found no evidence of velocity variability. We observed this star only during the second run, but with a higher sampling rate (as frequent as 15 minute intervals during some nights). The mean red spectrum (Fig. 5) shows that Hα and He i λ6678,7065 all display double-peaked emission.

We measured relative radial velocities by determining CCF offsets from the first spectrum for the He i λ6678 region, and these were then placed on an absolute scale by finding the bisector velocity of the profile in the first spectrum, using the method from Shafter et al. (1986). The external error of $E = 3.2$ km s$^{-1}$ is larger than the internal error of $I = 1.0$ km s$^{-1}$, and the $F$-test indicates that this scatter has a probability of 0.3% for an origin in random variations. Furthermore, there is clear evidence of systematic trends within some nights. We used the CLEAN algorithm from Roberts et al. (1987) to find evidence of two periodic signals with periods of $3.51 \pm 0.03$ and $3.74 \pm 0.03$ hr (both with peak power far above the 1% false-alarm probability defined by Scargle 1982). These periods are much too small to be related to binary motion. They may be due to changes in disk density or illumination caused by nonradial pulsations in the underlying star (Rivinius et al. 2003).

### 3.5. HD 61827

The star HD 61827 (O8–9 Ib, Houk 1982; B3 Iab, Garrison et al. 1977; B3 Ia, Turner 1977) is a luminous object in an association surrounding the cluster NGC 2439 (Turner 1977). We found no evidence of a prior radial velocity measurement in the literature. The star’s red spectrum (Fig. 6) shows Hα in emission, as is often the case for B supergiants. The lack of He i λ6683 and the relative strength of C i λ6578, 6583 support the later subtype adopted by Garrison et al. (1977) and Turner (1977). We used the C i λ6578, 6583 and He i λ6678, 7065 absorption lines in the CCF to determine radial velocities.
for this star. The ratio of the external to the internal error indicates that the star is a velocity variable.

Our spectra show dynamic Hα emission changes, with variable red and blue peaks appearing to vary on a timescale of 5–10 days. We suspect that these variations are related to structures in the stellar wind that are modulated by rotation and temporal changes in the outflow. These emission variations in Hα appear to affect the velocities measured for the absorption lines of C II and He I through subtle effects of emission filling that are not apparent to the eye. For example, during the first run, we observed the emergence of a strong redshifted Hα peak during the time when the absorption velocities attained their minimum value, and the appearance of a strongly blueshifted Hα peak occurred at the time when the absorption velocities reached a maximum. This correlation indicates that the absorption lines we measured (C II and He I) are probably also partially filled in by weak emission that shifts the line center away from the location of the emission. Thus, we suggest that the apparent velocity variations in HD 61827 are due to the effects of variations in the star’s wind.

3.6. HD 206183

HD 206183 (O9.5 V; Daflon et al. 2003) resides in the Tr 37 cluster in the Cep OB2 association. Mason et al. (1998) list two visual companions but assign the star to the “unknown” status as a spectroscopic binary, since only one other velocity measurement exists (Sanford & Merrill 1938). The average red spectrum (Fig. 7) shows that the lines are narrow ($V \sin i = 19.2 \pm 1.9$ km s$^{-1}$; Daflon et al. 2003). We measured CCF radial velocities for HD 206183 using Hα and He I $\lambda\lambda 6678, 7065$. The mean velocities show no evidence for velocity variability over the two runs.

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