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INCREASED MULTIPLICITY OF 77 CYGNI, V815 HERCULIS, AND HD 140122

Francis C. Fekel[1]

RESUMEN

Mediante observaciones espectroscópicas de alta dispersión de 77 Cygni, V815 Herculis, and HD 140122 se ha detectado por lo menos una componente adicional en cada sistema. La nueva componente en 77 Cyg tiene un período de 35.48 días. V815 Her es un sistema triple con períodos de 1.810 y 2300 días, o 6.3 años. Las dos componentes visuales de HD 140122 son a su vez binarias espectroscópicas de corto período, con períodos de 10.879 y 15.770 días, respectivamente.

ABSTRACT

High-dispersion spectroscopic observations of 77 Cygni, V815 Herculis, and HD 140122 have resulted in the detection of at least one additional component in each system. The newly identified component of 77 Cyg has a period of 35.48 days. V815 Her is a triple system with periods of 1.810 and 2300 days or 6.3 yr. The two visual binary components of HD 140122 are short-period spectroscopic binaries with periods of 10.879 and 15.770 days.

Key Words: **BINARIES: CLOSE — BINARIES: SPECTROSCOPIC**

1. INTRODUCTION

Several years ago Tokovinin (1997) compiled a multiple star catalog, the current version of which contains over 800 physical systems. Of course, as he noted, any such catalog is incomplete due to a variety of biases. Nevertheless, additional components to binaries can be discovered from surveys or through luck and/or perseverance. Using my skill with the latter two methods, I have increased the number of known components in three systems.

2. OBSERVATIONS AND REDUCTIONS

High-resolution spectroscopic observations were obtained with the Kitt Peak National Observatory (KPNO) coudé feed telescope, coudé spectrograph, and a TI CCD detector. Nearly all of the spectrograms were centered in the red at 6430Å. They have a resolution of 0.21Å, cover a wavelength range of about 80Å, and have typical signal-to-noise ratios of 200.

Radial velocities were determined in the 6385–6444 Å region with the IRAF cross-correlation program FXCOR (Fitzpatrick 1993). The IAU radial-velocity standards β Virginis, HR 5694, HR 7560, and ι Piscium were used as reference stars. Radial velocities of 4.4, 54.4, 0.0, and 5.6 km s^{-1}, respectively, were adopted from Scarfe, Batten, & Fletcher (1990). The star β Aquilae was used as the reference star for the velocities of V815 Her. From my unpublished results, it has a radial velocity of −40.2 km s^{-1}.

3. MULTIPLE STARS

3.1. *The great mistake: 77 Cygni = HR 8300 = HD 206644 = Kui 108 AB*

The star 77 Cygni is a close visual double with a period of 26.5 yr and semimajor axis of 0.″15 (Hartkopf & Mason 2000). Abt (1981) classified the combined system as A0 V. One of the two visual components is a double-lined binary for which Harper (1926) computed an orbit with a period of 1.729 days. Spectrograms around 4500 Å show lines of three components. Comparison with various early-type reference stars suggests that the spectral class of both short-period binary components is A1, while that of the broad-lined star is B8. Although lines of the B8 star are so broad that accurate velocities can not be measured, I obtained some spectra of the system in an attempt to improve the orbit of the short-period pair.

During a typical observing run, most of my spectra are acquired at red wavelengths. At most only one night is set aside for blue-wavelength observations. With my mind in an early morning fog, I inadvertently got a spectrum of 77 Cyg at my usual 6430 Å region. A quick look at the raw spectrum confirmed my expectation, there were no measurable lines in this wavelength region. I castigated

[1]Center of Excellence in Information Systems, Tennessee State University, Nashville, TN, USA.

myself for the waste of time and continued with the rest of my observing program. Nevertheless, I later processed the spectrum and compared it with the spectrum of an F-type radial velocity standard. To my surprise, very weak, narrow absorption lines appeared to be present. My great mistake resulted in the detection of the secondary of the broad-lined star, making the system quadruple!

3.2. *Orbit*

¿From 1997 July to 2001 September, 36 spectra were obtained. A period search resulted in a period of 35.48 days. The orbital elements are given in Table 1. Despite the moderately long period, the orbit is nearly circular, having an eccentricity of 0.027 $\pm$ 0.004. Of particular interest is the very large mass function of 1.34 $M_\odot$, which, since this is the orbit of the secondary, corresponds to the minimum mass of the primary. If the F star secondary has a mass of 1.1 $M_\odot$, the mass of the B8 primary is 2.7 $M_\odot$ for an orbital inclination of 90°. Figure 1 shows a comparison of the radial velocities and the computed orbit.

TABLE 1

ORBITAL ELEMENTS OF 77 CYG Ab

Parameter	Value
P (days)	35.473 $\pm$ 0.005
T (HJD)	2,451,087.3 $\pm$ 0.9
γ (km s^{-1})	-21.6 ± 0.2
K (km s^{-1})	71.5 $\pm$ 0.3
e	0.027 $\pm$ 0.004
ω (deg)	261.1 $\pm$ 9.5
$a \sin i$ (km)	34.9 $\pm$ 0.2 x 10^6
$f(m)$ ($M_\odot$)	1.34 $\pm$ 0.02

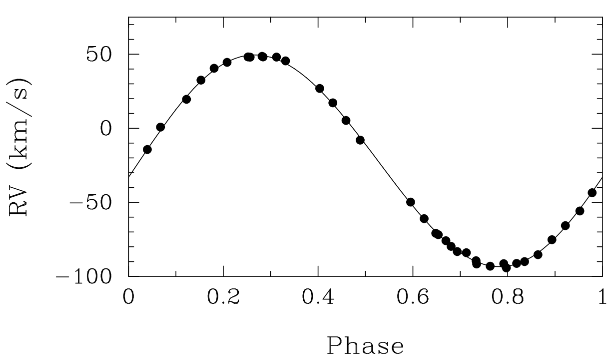

Fig. 1. Comparison of radial velocities and computed orbit for 77 Cyg Ab.

TABLE 2

SHORT-PERIOD ELEMENTS OF V815 HER

Parameter	Value
P (days)	1.809827 $\pm$ 0.000002
T_0 (HJD)	2,450,204.583 $\pm$ 0.001
γ (km s^{-1})	variable
K (km s^{-1})	54.1 $\pm$ 0.2
e	0.00 adopted
ω (deg)	undefined
$a \sin i$ (km)	1.346 $\pm$ 0.005 x 10^6
$f(m)$ ($M_\odot$)	0.0297 $\pm$ 0.0004

3.3. *The unexpected expected result: V815 Herculis = HD 166181*

Early in my career I obtained two spectra of V815 Herculis, a 1.810-day, chromospherically active binary with an orbit previously determined by Nadal et al. (1974). In 1992 Bob Dempsey acquired 13 additional spectra at KPNO. He soon found that his velocities did not fit the orbit of Nadal et al. (1974). There was an 11 km s^{-1} difference between the center-of-mass velocities of the two orbits (Dempsey et al. 1996). He asked me if the difference might result from a third component in the system. I told him that such a large velocity zero-point difference between observatory systems was very unlikely, and so the system was almost certainly triple.

As a result of Bob's work, I made new spectroscopic observations to determine the long-period orbital elements of this presumed triple system. My observations soon showed that the system was indeed triple, although lines of neither the short-period secondary nor the third star were detectable at 6430 Å. After several years the time span of my coverage was great enough so that elements for the long-period orbit could be determined. When I added the velocities of Nadal et al. (1974) to the orbit, the large center-of-mass velocity difference, noted by Dempsey et al. (1996), remained! It was not the result of third body motion but rather, velocity zero-point differences. Nevertheless, this unexpected cause had led to the discovery of the expected result, the multiplicity of V815 Her.

3.4. *Orbits*

The short-period component has an orbital period of 1.810 days (Dempsey et al. 1996). Velocity residuals to this orbit were solved to produce preliminary long-period orbital elements. Adopting a circular short-period orbit, both orbits then were solved

TABLE 3

LONG-PERIOD ELEMENTS OF V815 HER

Parameter	Value
P (days)	2300 ± 20
T (HJD)	2,450,505 ± 46
γ (km s^{-1})	−7.0 ± 0.8
K (km s^{-1})	13.4 ± 0.4
e	0.75 ± 0.08
ω (deg)	297 ± 8
$a \sin i$ (km)	281 ± 9 x 10^6
$f(m)$ ($M_\odot$)	0.17 ± 0.02

simultaneously. The long period is 2300 days or 6.3 yr. Table 2 lists the short-period orbital elements while Table 3 presents those of the long period orbit. The elements are preliminary since the rapid rise from minimum to maximum velocity in the long-period orbit has not been covered well (Figure 2).

3.5. *A multiple mess: HD 140122 = A 2176 = ADS 9747*

HD 140122 is a close visual double consisting of a pair of A stars with a period of 54.0 yr and a semimajor axis of 0″.15 (Baize 1994). Abt (1981) classified the combined spectrum as an Am star of spectral type A1/A4IV/F2. My first spectroscopic observations of it were obtained with photographic plates when I was a graduate student. From those spectra I found that one of the visual components was a spectroscopic binary with a period of 10.86 days. Over the next two decades I made additional observations at red wavelengths with CCD detectors. However, my orbital ephemeris did not produce the expected results. The CCD spectra, which have much higher signal-to-noise ratios than the plate spectra, sometimes showed two sets of partially blended lines of similar strength, while at other times there was a set of strong lines and one of very weak lines, a multiple mess. Eventually the light dawned, both visual components must be spectroscopic binaries, one double-lined and one single-lined.

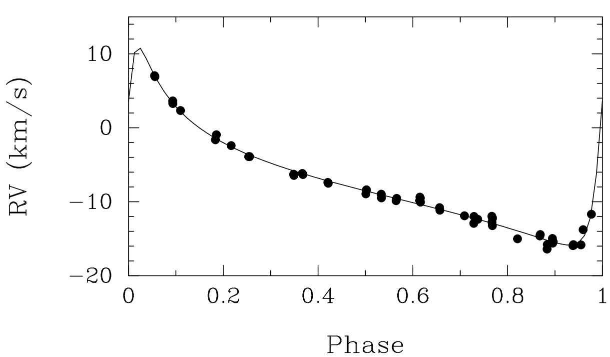

Fig. 2. Comparison of radial velocities and computed long-period orbit of V815 Her. The short-period velocity variation has been removed.

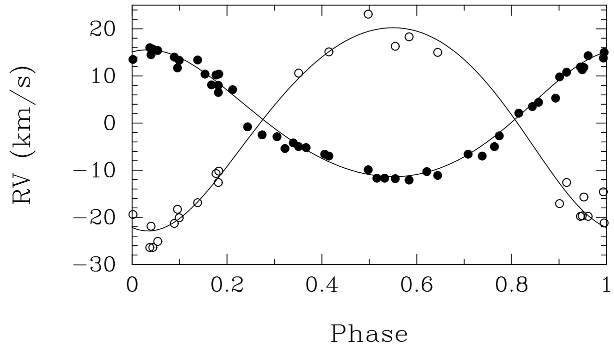

Fig. 3. Radial velocities of HD 140122 compared with the computed orbit. Solid circles represent Aa, open circles, Ab.

3.6. *Orbits*

The very small velocity amplitudes of the two components with the strongest lines made disentangling the velocities difficult. Using the least blended velocities, I was able to find a period of 10.879 days for component Aa, a value quite similar to the result from my photographic-plate velocities. Table 4 presents orbital elements for components Aa and Ab. The extremely small minimum masses of 0.03 and 0.02 $M_\odot$ for the components indicate that the inclination of this orbit is quite low, about 15°. The orbit of both components is shown in Figure 3.

The orbital period of Ba is 15.770 days, and like component Aa, component Ba has a low velocity am-

TABLE 4

ORBITAL ELEMENTS OF HD 140122 Aa,Ab

Parameter	Value
P (days)	10.880 ± 0.001
T (HJD)	2,452,015.0 ± 0.9
γ (km s^{-1})	0.7 ± 0.6
K_{Aa} (km s^{-1})	13.5 ± 0.3
K_{Ab} (km s^{-1})	21.6 ± 1.5
e	0.10 ± 0.06
ω_{Aa} (deg)	345 ± 33
$a_{Aa} \sin i$ (km)	2.00 ± 0.09 x 10^6
$a_{Ab} \sin i$ (km)	3.21 ± 0.30 x 10^6
$m_{Aa} \sin^3 i$ ($M_\odot$)	0.030 ± 0.005
$m_{Ab} \sin^3 i$ ($M_\odot$)	0.018 ± 0.002

TABLE 5

ORBITAL ELEMENTS OF HD 140122Ba

Parameter	Value
P (days)	15.770 ± 0.003
T (HJD)	2,452,537.5 ± 0.7
γ (km s^{-1})	3.1 ± 0.6
K (km s^{-1})	7.0 ± 0.6
e	0.29 ± 0.8
ω (deg)	283 ± 19
$a \sin i$ (km)	1.6 ± 0.1 x 10^6
$f(m)$ (M$_\odot$)	0.0007 ± 0.0002

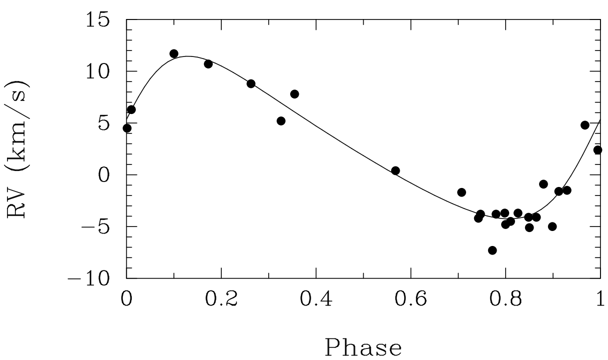

Fig. 4. Radial velocities of HD 140122 Ba compared with the computed orbit.

plitude, causing the lines of the two spectroscopic binary primaries rarely if ever to be resolved. The elements given in Table 5 are preliminary as is the computed velocity curve shown in Figure 4.

With a new velocity ephemeris for the Aa,Ab system, and one for the Ba system, observations obtained when the components are least blended should result in improved orbital elements. After 25 years of observation I soon hope to be finished with this multiple mess.

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DISCUSSION

Scarfe – What would be your best guess on the inclinations of the components of the last of your three multiple systems? Are they likely not to be coplanar?

Fekel – The visual orbit inclination of HD 140122 is 37.5^o, rather low. The minimum mass for the primary of the double-lined pair is quite small, 0.03 $M_\odot$. If the primary is a mid-A star its mass is about 1.7 $M_\odot$. Thus, the inclination of the orbit is about 15^o and it is not coplanar with the visual orbit. The mass function of the second system is also small, suggesting a low inclination.

Francis C. Fekel: Center of Excellence in Information Systems, Tennessee State University, 330 10th Avenue North, Nashville, TN 37203, USA (fekel@evans.tsuniv.edu).