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THE HIERARCHICAL TRIPLE SYSTEM HD 109648

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ABSTRACT. We present observations of the hierarchical triple-lined spectroscopic triple system HD 109648. Using an extended version of a new two-dimensional cross-correlation technique, TODCOR, we derive radial velocities independently for each component of the system. From a simultaneous orbital solution for hierarchical triple systems, we determine orbital elements for the inner and outer orbits. With a very short outer orbital period, and a small outer-to-inner period ratio, HD 109648 is one of the best candidates in which to observe evolution in the orbital elements of a hierarchical triple system.

Key Words: stars: binaries – techniques: radial velocities

1. INTRODUCTION

Due to stability considerations, triple star systems are almost always observed to be hierarchical, with a distant third star orbiting a closer pair. This type of system can be approximated as the combination of two binary systems: an "inner" or "close" binary consisting of the two nearby stars (labeled Aa and Ab, with Aa being the brighter of the two) and an "outer" or "wide" binary, consisting of the center of mass of the inner binary (labeled A) and the third star (labeled B). Of course, this approximation is only valid when the mean separation of the inner binary is much smaller than that of the outer binary.

In this paper, we examine the triple-lined spectroscopic triple system HD 109648, $\alpha = 12^h\ 35^m\ 59^s$, $\delta = +36^\circ\ 15'\ 30''$ (J 2000). This system is located in what was identified by Upgren and Rubin (1965) as an old open cluster, Upgren One, consisting of seven bright F stars. Thus this system also has the designation of Upgren One, Star 6. Whether this group of stars is in fact associated is the subject of some discussion (Upgren, Philip and Beavers 1982, Gatewood et al. 1988 and Stefanik et al. 1996).

2. OBSERVATIONS AND REDUCTION

125 observations were made of HD 109648 over a period of roughly 2000 days, using the 1.5 m Wyeth reflector at Oak Ridge Observatory in Harvard, Massachusetts, a part of the Harvard-Smithsonian Center for Astrophysics. The observations are part of a radial velocity survey undertaken in 1980, though the telescope has been in operation since 1933.

For these observations, an echelle spectrograph is used in conjunction with an intensified photon-counting Reticon detector. In normal procedure, the detector covers a 50 Å window centered at 5187 Å. Details regarding the instrumentation can be found in Latham (1992). Various calibrations are also performed, including flatfielding, wavelength solution by comparison exposures from a Thorium-Argon emission lamp and zero-point velocity determination via sky and standard star exposures.

A new two-dimensional cross-correlation technique, called TODCOR, has been developed by Zucker and Mazeh (1994) to determine component radial velocities in double-lined spectroscopic binaries. We have employed a three-dimensional extension of TODCOR for use with triple-lined systems, as detailed by Zucker, Torres and Mazeh (1995), to obtain radial velocities for the components of HD 109648.

Whereas standard techniques to determine component radial velocities in multiple systems generally use a cross-correlation against a single template (for instance, Kurtz et al. 1992), the key to TODCOR is the use of a composite template spectrum. This allows one to determine the radial velocity of each component of the system simultaneously and independently. Use of Fast Fourier Transform (FFT) methods allows the cross-correlation to be computed in a time-efficient manner.

The TODCOR technique works extremely well in determining the radial velocities of the individual components of a multiple system. This is especially important in cases where standard approaches fail, for instance, when two components have nearly the same radial velocity, causing a blended peak in a standard one-dimensional cross-correlation analysis. TODCOR is also useful in determining light ratios (i.e., luminosity contributions) of the components of a system, as well as determining radial velocities when the components differ significantly in their individual spectra.

3. ORBITAL SOLUTION

Once velocities are obtained for the three components in the system, periodicity can be determined by means of a periodogram analysis (Scargle 1982, Horne and Baliunas 1986). For HD 109648, this analysis clearly indicated the hierarchical nature of the system, showing an inner period of roughly 5.5 days, and an outer period of approximately 120 days.

A first attempt at an orbital solution treated the inner two stars as an isolated double-lined spectroscopic binary, and the outer star as an isolated single-lined binary, making use of existing code. Though this method provided a promising solution, the scatter in the data points was much larger than the error expected. The reason for this is that by considering the inner binary as isolated, we neglect the periodic motion of the center of mass of the inner binary in the outer orbit.

Thus, to obtain an orbital solution correctly, one must solve the motions simultaneously. A code to do this was specially developed, dramatically improving the results. The beautiful orbital solution derived is shown in Fig. 1. The upper panel shows the solution for the inner binary; the filled circles show the motion for the brighter of the two inner stars (Aa) and the open circles show the motion of the fainter one (Ab). The outer orbit is displayed in the lower panel; here the circles represent the motion of the center of mass of the inner binary, and the triangles show the motion of the third star (B). The motion of the inner two stars are thus the sum of their common center of mass motion and their individual inner orbital motion.

From the solutions of the inner and outer orbits, we can determine standard orbital elements for the two binary motions, given in Table 1. The system as a whole possesses an overall radial velocity given by γ, which is important in determining whether or not HD 109648 is associated with other stars in Upgren One (Stefanik et al. 1996).

4. DISCUSSION

The solution of this system shows the necessity for a simultaneous orbital solution of both orbital motions. In addition, the efficacy of TODCOR in

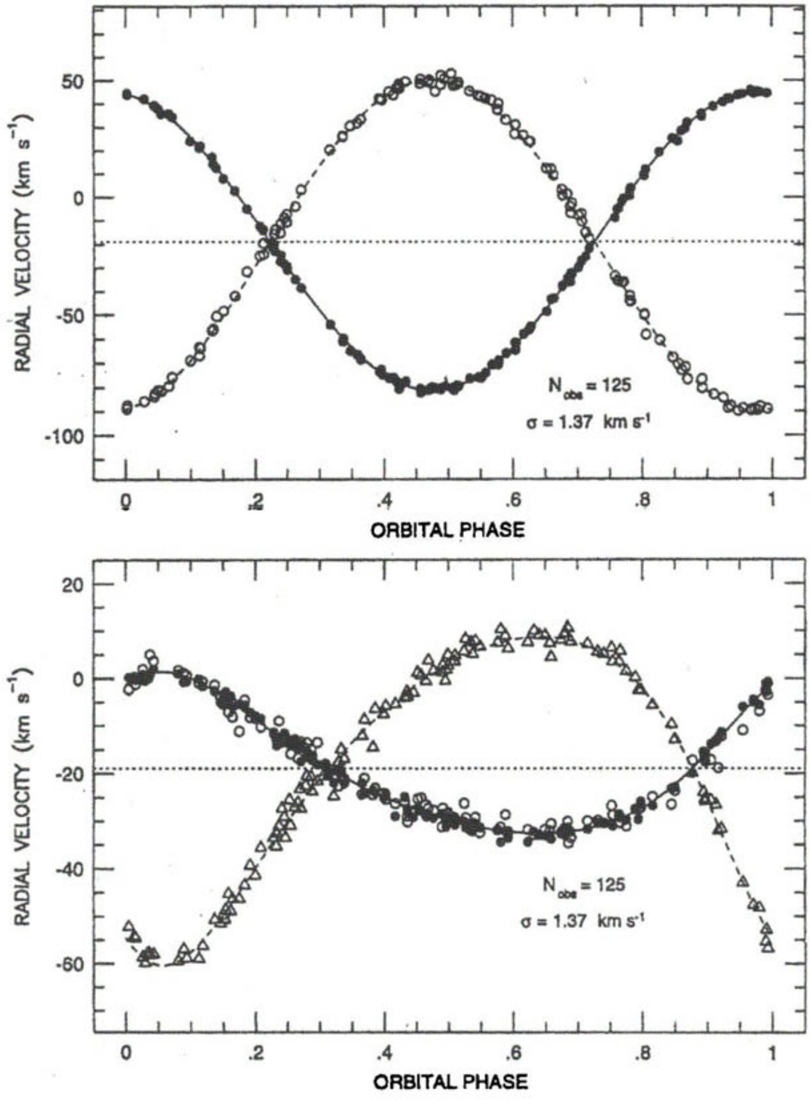

Fig. 1. Simultaneous orbital solution for HD 109648. The motions of Aa (filled circles) and Ab (empty circles) are separated into two parts: their center of mass motion (shown in the lower panel) and their inner orbital motion (upper panel). The lower panel also shows the orbit of the third star B (triangles).

TABLE 1. HD 109648 orbital elements

Inner Orbital Elements	
P_A	5.478425±0.000012 days
K_{Aa}	63.16±0.07 km/s
K_{Ab}	70.04±0.13 km/s
e_A	0.0125±0.0016
ω_A	9.0±8.2°
T_A	2448461.82±0.13 HJD
$a_{Aa}\sin i_A$	4.758±0.010 Gm
$a_{Ab}\sin i_A$	5.276±0.017 Gm
$m_{Aa}\sin^3 i_A$	0.7053±0.0049 $M_{\odot}$
$m_{Ab}\sin^3 i_A$	0.6360±0.0033 $M_{\odot}$
Outer Orbital Elements	
P_{AB}	120.549±0.015 days
K_A	17.00±0.12 km/s
K_B	34.54±0.27 km/s
e_{AB}	0.240±0.005
ω_{AB}	326.5±1.2°
T_{AB}	2448410.49±0.40 HJD
$a_A\sin i_{AB}$	27.36±0.19 Gm
$a_B\sin i_{AB}$	55.58±0.43 Gm
$m_A\sin^3 i_{AB}$	1.048±0.020 $M_{\odot}$
$m_B\sin^3 i_{AB}$	0.516±0.008 $M_{\odot}$
Systemic Elements	
γ	-18.94±0.07 km/s

accurately determining radial velocities for components of multiple systems is also evidenced.

Furthermore, the system itself is of key interest in studying orbital evolution in hierarchical triple systems. Since the separation of the motion into two binary systems is only an approximation, we expect the elements of these binary motions not to remain constant, but vary with time. Mazeh and Shaham (1976, 1977, 1979) describe several evolutionary effects that should occur in hierarchical triple systems, including a periodic modulation of the inner eccentricity, and a precession of the two orbital planes, consequently modulating the two angles of inclination.

The timescale for such modulation is directly proportional to the product of the outer period and the outer-to-inner period ratio (Mazeh and Shaham 1976; Mazeh, Krymolowski and Latham 1993). Thus, for evolution to occur on short timescales, a system should have a short outer period and a small outer-to-inner period ratio. This system, with an outer period of about 120.55 days and a period ratio of only 22, leads to predicted evolution with a period on the order of 20 years. This makes HD 109648 one of the best systems in which to study these evolutionary effects, as it possesses one of the shortest evolutionary timescales known. Work is presently underway to look for observational evidence of such evolution, as well as numerical simulations to constrain the motion of the system.

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