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THE ROTATIONAL VELOCITY AND MASS RATIO OF 5 CETI

Five Ceti (HR 14=HD 352) is a single-lined spectroscopic binary containing a K giant (Christie 1933). In spite of its 96-day period, Lines and Hall (1981) have found it to be an ellipsoidal variable, possibly with shallow eclipses. Superficially, the light curve resembles that of the W UMa-type contact binary AW Ursae Majoris (Paczyński 1964). The similarity must be only apparent, however, for if the mass ratio of 5 Cet were small enough for it to be a completely eclipsing contact system, its long period and large radial velocity variations (K = 24.3 km/s; Beavers and Salzer 1985) would give it a prohibitively large total mass. Nevertheless, the light curve indicates that the K giant must be filling or nearly filling its Roche lobe. Ultraviolet spectra show a somewhat warmer component (~ spectral type F) with rather broad lines. For a better understanding of the nature of this hot component, we will need to know the stars' masses, hence the mass ratio of the system.

Since the optical light curves appear to be produced by a contact binary of low mass ratio, most of their amplitude must be due to ellipsoidal variation, and it is possible that the system does not even eclipse. Thus the light curves provide only poorly defined limits on the mass ratio ($q = M_2/M_{gK}$) and orbital inclination, although they seem to require the K star nearly to fill its Roche lobe. However it is possible to restrict the value of q by comparing the rotational velocity of the K giant with its orbital velocity, provided this star is nearly in contact with its Roche lobe.

Table 1

HIGH-DISPERSION SPECTRA OF 5 CETI

DATE	EPOCH $JD_{\odot}$-2440000	PHASE*	RADIAL VELOCITY (km/s)
20 Sep 1984	5963.8780	18.54	9.4 ± 0.3
8 Oct 1984	5981.9042	18.73	24.0 ± 0.8
19 Nov 1984	6023.7171	19.16	-21.0 ± 0.3

* Phases are on the ephemeris of Lines and Hall (1981).

As part of a comprehensive study using ultraviolet observations to analyze the hot companion, we have obtained three spectra of 5 Cet at high dispersion with the coudé feed telescope at Kitt Peak National Observatory (operated by AURA, Inc., under contract with the NSF). Epochs of the observations and results are given in Table 1. The first two observations were obtained by Barden during programs to study line profiles of active late-type stars. The third spectrum was obtained for us by Darryl Willmarth on a Kitt Peak request night at roughly twice the resolution of the other two observations. In addition, a wavelength calibration source was observed with this same instrumental setup, as were spectra of the K giant stars HD 8949 (K1 III), ε Tau (KO III), and α Tau (K5 III), chosen as rotational velocity standards. These stars should be excellent standards for slow rotation, since all single K giants are expected to have Vsinι less than a few km/s (Gray 1982). In fact, we have found accurate rotational velocities for two of these stars in the literature ε Tau (Vsini = 3.0 km/s; Baliunas, Hartmann, and Dupree 1983) and α Tau (Vsini = 2.7 km/s; Smith and Dominy 1979). The spectrum of 5 Cet has lines decidedly broader than those of the slowly rotating comparison stars. In addition, the strength of metallic lines in the Hα region is consistent with a spectral type in the range K2-K4. Absorption lines in 5 Cet are decidedly stronger than in HD 6734 (KO III) but are weaker than in α Tau (K5 III).

The three spectra of 5 Cet were analyzed by Barden with standard computer programs developed to fit the spectra of binary stars with combinations of spectra of single stars (e.g., Barden 1984). The resulting rotational velocity is 22 ± 3 km/s; the derived radial velocities agree well with the velocity curve of Beavers and Salzer (1985).

For a star in contact with its Roche lobe, the radius in terms of orbital separation varies as $1/(1+q^{0.5})$ while the radius of its orbit about the center of mass goes as $q/(1+q)$. This gives a relation between Vsini and K of the form

$$V\sin i/K = Cq^{-1}\{(1+q)/(1+q^{0.5})\} \qquad (1)$$

where C is at worst a slowly varying function of q and orbital phase. We note that J. S. Gallagher (1984; private communication) has previously used this reasoning to measure mass ratios of cataclysmic variables. The term C is a complicating factor, since the stars are severely distorted tidally, and we have evaluated it in the following manner.

We can define an effective radius for the star r_{eff} and and a constant C_1

such that

$$C_1 = \sum(x/R)\delta L/\sum\delta L = r_{eff}/R_1. \qquad (2)$$

Here, x is the orthogonal distance on the plane of the sky from the star's rotation axis to a point on its surface, and R is its maximum projected radius. But for a synchronously rotating component of a binary system we likewise have

$$C_2 = \sum(x/a)\delta L/\sum\delta L = r_{eff}/(a_1+a_2). \qquad (3)$$

where the a's are the semi-major axes. Thus

$$C_2/C_1 = R_1/(a_1+a_2) = qR_1/\{a_1(1+q)\} \qquad (4)$$

Since $R_1 \sim V\sin i$ while $a_1 \sim K_1$,

$$\frac{V\sin i}{K} = \frac{1+q}{q}\,\frac{C_2}{C_1}. \qquad (5)$$

C_1 can be evaluated analytically for spherical stars and numerically for rapidly rotating stars. For an undarkened circular disk $C_1 = 0.42$, while if the limb-darkening coefficient is $x=0.6$, $C_1 = 0.37$. For synchronously rotating members of contact binary systems seen at conjunction, we find $C_1 \approx 0.40$. Thus we will adopt $C_1 = 0.40 \pm 0.02$. C_2 has been calculated for a contact component of a binary seen at phase 0.16. The resulting values of C_2 and Vsini/K are listed in Table 2. They correspond to $C = 0.78$ in Eq. (1).

Table 2
Vsini/K vs. q FOR A
CONTACT COMPONENT

q	C_2	Vsini/K
1.2	0.150	0.69
1.0	0.156	0.78
0.833	0.163	0.90
0.71	0.168	1.01
0.625	0.173	1.13
0.50	0.183	1.37

The best values of Vsini and K available thus give Vsini/K = 0.91 ± 0.13. This corresponds to the mass ratio $q = M_2/M_{gK} \leq 0.82 \pm 0.14$. The inequality derives from the possibility that Star 1 might not actually fill its Roche lobe, in which case our procedure would overestimate q.

These values of K and q lead to plausible masses for the two components only if the inclination is relatively low. The mean radial velocity of 5 Cet is small, suggesting that the system is not a high velocity star of low metallicity and extreme age. Thus the mass of the more evolved component, conceivably the K giant, should be about 1.0 $M_\odot$ or greater. We achieve this with $i < 70°$. Such a small inclination is also consistent with the amount of ellipsoidal distortion of the light curve, provided the K giant is in contact with its Roche lobe.

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