COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5554

Konkoly Observatory
Budapest
6 August 2004

HU ISSN 0374 – 0676

PHOTOMETRIC ANALYSES OF THE CONTACT BINARIES FZ ORIONIS AND AH TAURI

BYBOTH, K. N.[1,2]; MARKWORTH, N. L.[1,3]; BRUTON, W. B.[1,4]

[1] Department of Physics and Astronomy Stephen F. Austin State University, Nacogdoches, TX 75962 USA

[2] e-mail:krisbyboth@yahoo.com

[3] e-mail:nmarkworth@sfasu.edu

[4] e-mail:astro@sfasu.edu

Hoffmeister (1934) discovered variability in the light of **FZ Orionis** (HD 288166, GSC 119 01014, $\alpha(2000) = 05^{\rm h}41^{\rm m}21^{\rm s}$, $\delta(2000) = +02^\circ 36' 23''$). Kippenhahn (1953) classified the system to be of the type β Lyr, and estimated the period to be 1.597 days. Figer (1983) and Le Brogne *et al.* (1984) suggested the system was instead of the type W UMa and reported a period of 0.3999860 days. El-Bassuny Alaway(1993) and Rukmini *et al.* (2001) suggested that the variability in the light curve could be due to the presence of a third body and/or mass loss from the system.

Shapley *et al.* (1934) discovered variability in the light of **AH Tauri** (HBV 6187, CSI 24 3442, $\alpha(2000) = 03^{\rm h}47^{\rm m}12^{\rm s}$, $\delta(2000) = +25^\circ 7' 0''$). Photographic observations were made by Binnendijk (1950) and Romano (1962), Binnendijk classified the system as W UMa, while Romano classified the system to be of the type β Lyr. Further photometric observations were made by Bookmyer (1971) and Liu *et al.* (1991). Bookmyer indicated a spectral type of around G5. Liu gives a complete Wilson-Devinney solution.

Our photometric observations of FZ Ori were made on the nights of December 21 and 22, 2003, and of AH Tau on the nights of December 24, 30, and 31, 2003, using the 46-cm telescope with attached SBIG ST-8XE CCD camera equipped with standard Johnson UBVRI filters. The images were calibrated and the magnitudes extracted using standard image reduction procedures with MIRA. Differential magnitudes in the natural system are available upon request of author NLM. Approximately 200 observations were made in each of the R, I, and V filters of FZ Ori and 130 observations in these same filters of AH Tau. The comparison and check star data for FZ Ori were as follows: comparison star (GSC 00119-00214, $\alpha(2000) = 05^{\rm h}41^{\rm m}17\overset{\rm s}{.}6$, $\delta(2000) = +02^\circ 35' 30\overset{''}{.}0$); check star (GSC 00119-00771, $\alpha(2000) = 05^{\rm h}41^{\rm m}05\overset{\rm s}{.}1$, $\delta(2000) = +02^\circ 37' 12\overset{''}{.}0$). These stars are labeled in Figure 1 as C and K with the variable star denoted by V. The comparison and check star data for AH Tau were as follows: comparison star (GSC 01804-02470, $\alpha(2000) = 03^{\rm h}47^{\rm m}0\overset{\rm s}{.}0$, $\delta(2000) = +25^\circ 5' 29\overset{''}{.}0$); check star (GSC 01804-02485, $\alpha(2000) = 03^{\rm h}47^{\rm m}20\overset{\rm s}{.}0$, $\delta(2000) = +25^\circ 8' 36\overset{''}{.}0$). These stars are labeled in Figure 2 in the same sense as Figure 1.

We observed one primary and two secondary minima for FZ Ori and two primary and one secondary minima for AH Tau. The mean epochs of minimum light were determined from these eclipses using the results of parabolic fits. Table 1 contains the average times of minima for the three observed colors. Additional times of minima for FZ Ori were recorded by El-Bassuny, Le Brogne *et al.*, and Nelson (2004). Additional times of minima for AH Tau were recorded by Liu *et al.*. A linear ephemeris was calculated using the last 18,000 orbits (FZ Ori) and the last 39,000 orbits (AH Tau) given by Nelson (2004). Qian and Ma (2001) suggest a parabolic ephemeris for FZ Ori based on the previous suggestion of El-Bassuny Alawy (1993). We have examined the O-C diagram (Qian and Ma 2001) for FZ Ori. Many of the minima given were determined visually or photographically, giving a large scatter. We do not find the argument for a nonlinear ephemeris compelling. The Heliocentric Julian Day of the primary minima can be computed by the following formula.

FZ Ori

$$\text{HJD Tmin I} = 2452950.09329 \ + 0.399984 \text{ d} \times \text{E}. \tag{1}$$

AH Tau

$$\text{HJD Tmin I} = 2451824.00832 \ + 0.33267174 \text{ d} \times \text{E}. \tag{2}$$

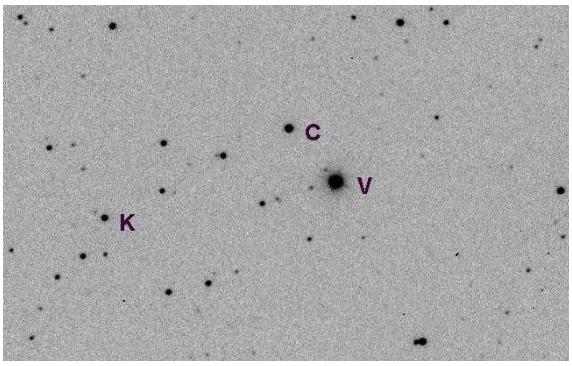

Figure 1. Finder Chart FZ Ori

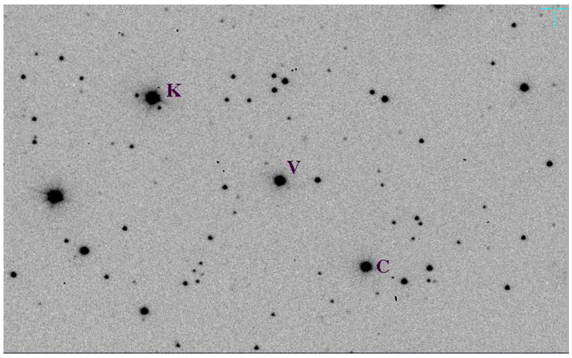

Figure 2. Finder Chart AH Tau

Table 1. Times of Minimum Light

Star	JD Hel. 2450000+	Min	O−C (days)
FZ Ori	2994.6868	II	-0.0048
FZ Ori	2995.6863	I	-0.0051
FZ Ori	2995.8865	II	-0.0050
AH Tau	2997.6735	I	-0.0007
AH Tau	3004.8272	II	0.0005
AH Tau	3005.6595	I	0.0012

We have calculated models for the light curves of both stars using the Wilson-Devinney code (Wilson 1993, henceforth WD). Common parameters that were varied include inclination of the orbit (i), temperature of the secondary star (T_2), modified potential of the stars ($\Omega_1 = \Omega_2$), mass ratio (q), relative luminosity of the primary star (L_1), and monochromatic linear limb darkening coefficient of the primary star ($x_1 = x_2$). Both stars were assumed to be contact binary systems (Mode 3). The values of gravity brightening and bolometric albedo were set at their suggested values for convective atmospheres (Lucy 1968), i.e., $G_1 = G_2 = 0.32$, $A_1 = A_2 = 0.5$. Synchronous rotation was assumed for each star ($F_1 = F_2 = 1.0$). Linear limb darkening coefficients were initialized at the model atmosphere values of Carbon and Gingerich (1969). The model atmosphere option was employed for each star.

A previous WD solution for FZ Ori has been published (Rukmini, et al. 2001). We used their value of T_1 and did not vary it. The two solutions compared very well, except in the value of the mass ratio (0.92 compared to our 0.792). Their value was based upon numerical experiments in which q was varied within a range. Their data have considerable scatter and we find evidence of a star spot. We ran the stellar spot model for FZ Ori and found that the presence of a hot spot on the primary star resulted in an accurate fit of the observed light curve. Table 2 presents our WD solution including the spot parameters.

AH Tau also has a previous WD solution (Liu, *et al.* 1991). We fixed the value of T_1 using a combination of the solution of Liu, et al. (1991) and the spectral type given by Bookmyer (1971) in conjunction with the calculations of Schmidt-Kaler (1982). Differences occur between our solutions in the values of L_1 (0.657 compared to our 0.574), q (0.503 compared to our 0.773), and i ($84\overset{\circ}{.}3$ compared to our $80\overset{\circ}{.}7$). Differences in the mass ratio also results in a difference in the modified potentials. The larger inclination in their solution produced larger stars to account for the depth and duration of the eclipses. Solution space for contact systems is filled with local minima, making accurate solutions difficult to obtain. The solutions presented here come from careful examination of the matrix of correlation coefficients and the use of the method of multiple subsets (Wilson and Biermann 1976). Both of these solutions for AH Tau call for component stars which are virtually identical and very close to solar values. It is difficult to see how two stars so nearly identical in their properties could be different by a factor of two in their masses. We also note that our mass ratio falls in a gap in the mass ratio grid of Liu, *et al.* Our WD solution for AH Tau is presented in Table 3.

The errors listed in Tables 2 and 3 are the formal errors of the partial differential least squares technique employed in the WD method. The values of the errors are used as a guide in determining the number of decimal places each parameter is given. We should note that the actual errors of the parameter determination may be higher.

Table 2. Wilson-Devinney Solution for **FZ Ori**

Wavelength Independent Parameters - Mode3

i	T_1	T_2	Ω_1	Ω_2	q	F_1	F_2	G_1	G_2	A_1	A_2
66.88	6108 K	6043 K	3.334	3.334	0.792	1.00	1.00	0.32	0.32	0.5	0.5
±0.12		±11	±0.007		±0.004						

Wavelength Dependent Parameters

Band	L_1	L_2	x_1	x_2
Vis	0.562	0.438	0.61	0.61
	±0.001		±0.05	
Red	0.561	0.439	0.60	0.60
	±0.001		±0.05	
IR	0.560	0.440	0.59	0.59
	±0.001		±0.04	

Spot Parameters

Co-Latitude	Longitude	Size	Temperature Factor
1.8 rad	6.1 rad	0.27 rad	1.17
±0.7	±0.5	±0.11	±0.06

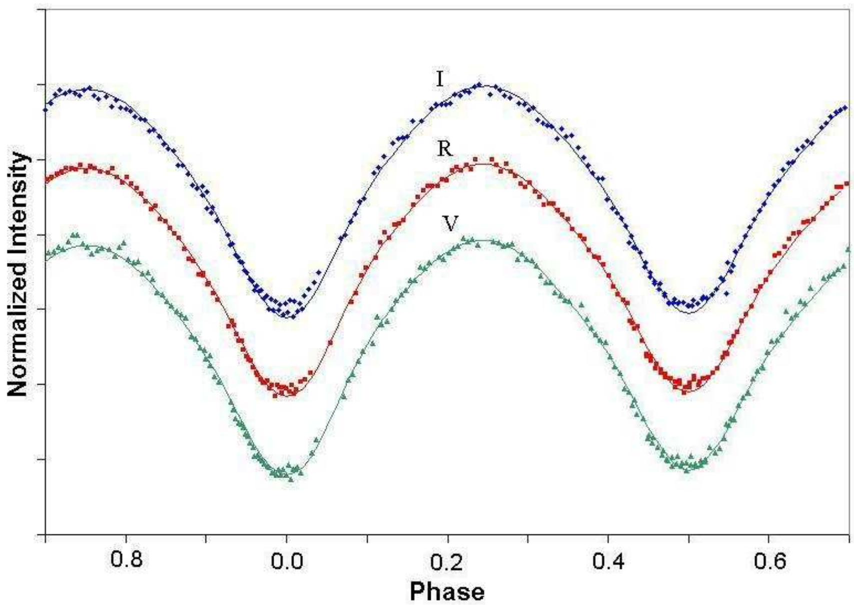

Figure 3. Light curves for FZ Ori
Solid curves are the Wilson-Devinney solution given below

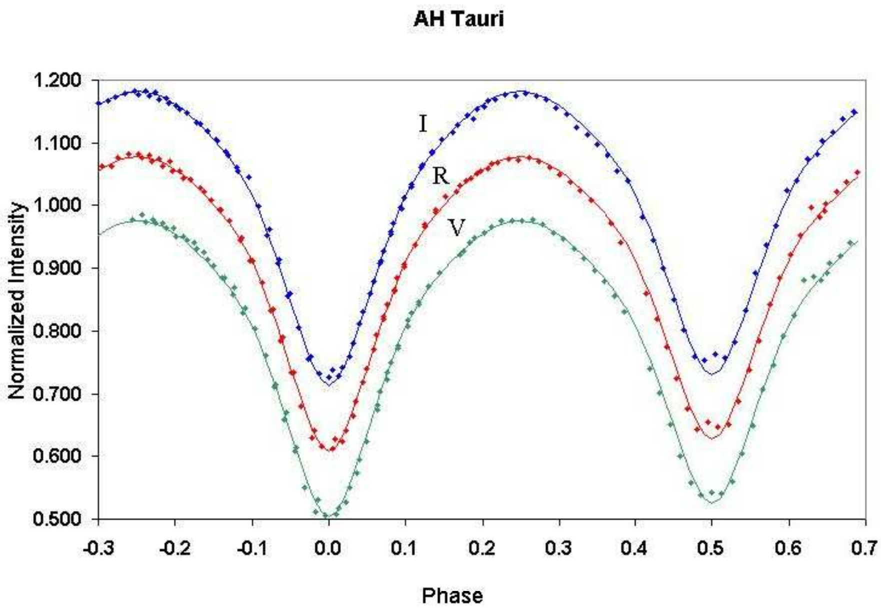

Figure 4. Light curves for AH Tau
Solid curves are the Wilson-Devinney solution given below

Table 3. Wilson-Devinney Solution for **AH Tau**

Wavelength Independent Parameters - Mode3

i	T_1	T_2	Ω_1	Ω_2	q	F_1	F_2	G_1	G_2	A_1	A_2
80.73	5900 K	5815 K	3.330	3.330	0.773	1.00	1.00	0.32	0.32	0.5	0.5
±0.12		±11	±0.009		±0.004						

Wavelength Dependent Parameters

Band	L_1	L_2	x_1	x_2
Vis	0.574	0.426	0.60	0.60
	±0.001		±0.07	
Red	0.571	0.429	0.60	0.60
	±0.001		±0.06	
IR	0.569	0.431	0.60	0.60
	±0.001		±0.06	

References:

Binnendijk, L. 1950, *B.A.N.* **11**, 209.

Bookmyer, Beverly B. 1971, *Pub. Astron. Soc. Pacific*, **83**, 211.

Carbon, D.F. and Gingerich, O. 1969, in *Theory and Observation of Normal Stellar Atmospheres*, ed. O. Gingerich, Cambridge, Mass, MIT Press, p. 377.

El-Bassuny Alawy, A.A. 1993, *Ap&SS*, **207**, 171

Figer, A. 1983, *GEOS Circular on Eclipsing Binaries* **8**.

Hoffmeister, C. 1934, *Astron. Nachr*, **253**, 195.

Kippenhahn R. 1953, *Astron. Nachr.*, **281**, 153.

La Brogne, J.F., Figer, A, and Dumont, M. 1984, *IBVS*, **2566**.

Liu, Qing-yao, Yang, Yu-lan, Zhang, Yun-lin, and Wang, Bi, 1991, *Chinese Astronomy Astrophysics*, **15**, 143.

Lucy, L.B. 1968, *Ap. J.*, **151**, 1123.

Nelson, B. 2004, *Eclipsing Binary O-C Files*, from `http://www.aavso.org/observing/programs/eb/omc/nelson_omc.shtml`

Qian, Shengbang and Ma, Yuan 2001, *Pub. Astron. Soc. Pac.* **113**, 754.

Romano, G. 1962, *Mem. Soc. Astr. Italiana*, **33**, 17.

Rukmini, J., Rao, P. Vivekananda, and Ausekar, B.D. 2001, *Bull. Astr. Soc. India*, **29**, 323.

Schmidt-Kaler, Th. 1982, "Physical Parameters of the Stars," *Landolt-Börnstein Numerical Data and Functional relationships in Science and Technology*, New Series, Group VI, Volume 2b, Springer-Verlag, Berlin.

Shapley, H. and Hughes, E. 1934, *Harvard Ann.* **90**, 168.

Wilson, R.E. 1993, in *New Frontiers in Binary Research*, ed. K.C. Leung and I.S. Nha, *A.S.P. Conf. Ser*, **38**, 91.

Wilson, R.E. and Biermann, P. 1976, *Astr. and Ap.* **48**, 349.