Absolute Parameters for the Very Young, Hot Eclipsing Binary V684 Mon in NGC 2264

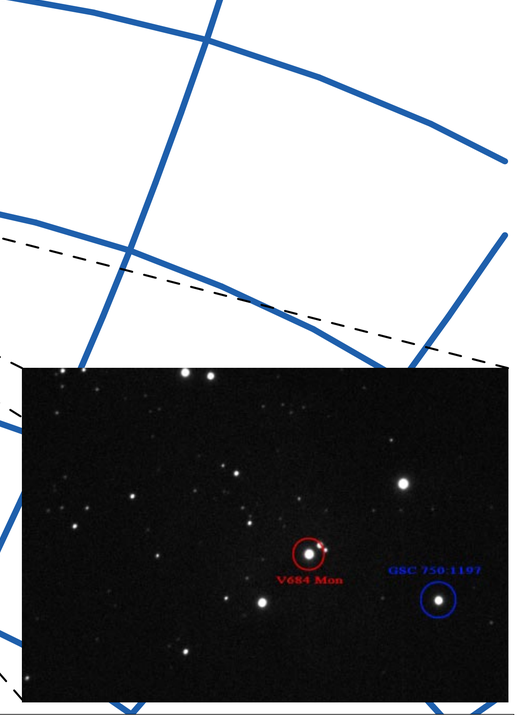
The Bradstreet Observatory at Eastern University

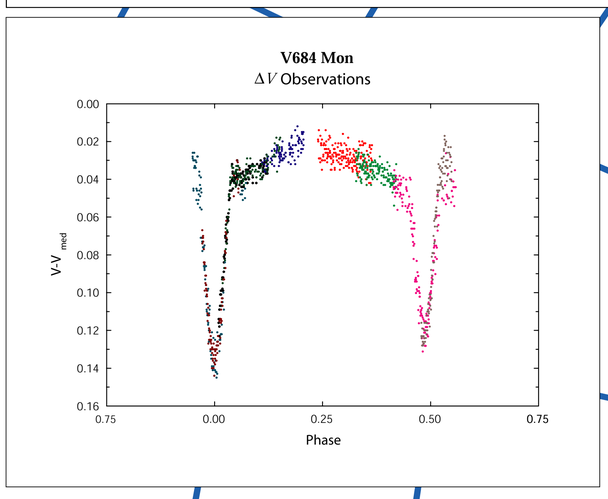
David H. Bradstreet[1], J. R. Hargis[1], S. J. Sanders[1], A. Prsa[2], P. B. Etzel[3]

[1]*Eastern Univ.*, [2]*Villanova Univ.*, [3]*San Diego State Univ.*

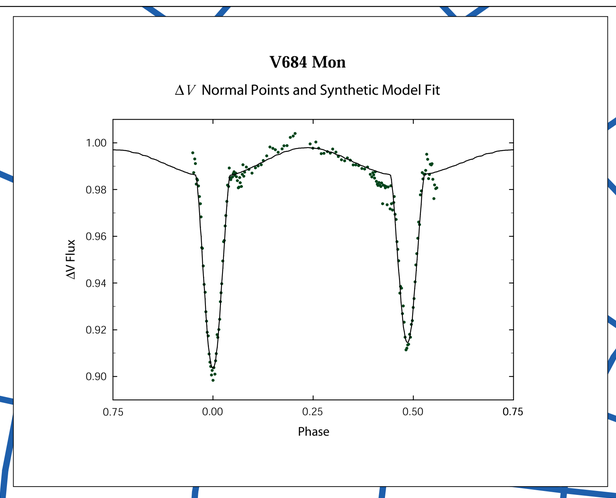
V684 Mon (HD 47755, W74, vM37, VSB52) is a young, hot (B4V, B4V; V = +8.51) close eclipsing binary (P = 1.851 d) in the open cluster NGC 2264 (cluster age 3-4 Myr). Walker (1956) noted that this star exhibited double lines, but no published radial velocity curve exists. Koch *et al.* (1986) discovered that the system eclipsed, but the system was observed over a limited timescale, obtaining only one minimum with enough coverage to generate a reliable timing. Because of the potential for investigating a very young pair of main sequence B-stars in a cluster of known age, this star was put on the observing program at the Bradstreet Observatory at Eastern University and a preliminary light curve analysis was given by Bradstreet *et al*. (1999). Since 1999 we have been photometrically monitoring V684 Mon in order to obtain times of minimum light as well as to investigate previously observed light curve subtleties which suggested a slightly eccentric orbit and intrinsic variability. New precision BVR light curves have been obtained in 2007 using a 40-cm telescope and a SBIG ST10-XME CCD camera. The O-C diagram seems to indicate that the period of V684 Mon is increasing at a relatively rapid rate.This determination may be complicated by a possible advance in the angle of periastron, but further observations will be needed to resolve this matter. Our light curve data confirms the orbital eccentricity, as the derived ephemeris clearly phases the secondary eclipse at 0.485P. The existence of an eccentricity in such a close binary further commends the idea that this system is very young, *i.e.*, that V684 Mon is a cluster member of NGC 2264. Forty-nine spectra of V684 Mon were obtained using the 1.0-m telescope at Mt. Laguna Observatory in 2002 and the system has been confirmed to be double-lined. Radial velocities were determined via the TODCOR algorithm (Zucker & Mazeh 1994), where synthetic spectra from TLUSTY (Hubeny & Lanz 1995) were used as templates.

The light and radial velocity curves were simultaneously modelled using the PHOEBE suite of software (Prsa & Zwitter 2005) based on the latest WD code (Wilson & Devinney 1971) with Kurucz model atmospheres. Given the constraints of a mass ratio from the radial velocity curve, the orbital eccentricity and the observed outside-of-eclipse light varations (due to tidal distortions from the small orbital separation), the model is well constrained to the parameters given below. Note that the errors quoted are the formal errors of the solution. Multiple parameter-space iterations confirmed the robustness of this model. It was determined from the radial velocity curve that the secondary eclipse is actually the eclipse of the more massive star, hence the subscripts listed in the parameter table below are reversed from the usual sense (note the mass ratio greater than unity). Given the derivation of the absolute parameters from the solution, we are able to compare the measured masses and radii with the theoretical ZAMS. The stars are slightly undersized for their masses, but they are definitely main sequence stars. The cluster membership of this binary has been questioned in the past (*e.g.* Walker 1956; Vasilevskis *et al.* 1965) due to proper motions discordant with those of other cluster members. However the binary's brightness and color placed it where one would expect in the cluster's color magnitude diagram if it were a cluster member (see plot below). Recent TYCHO proper motions (Dias *et al.* 2001) have confirmed that V684 Mon is a cluster member. Our derived distance of 880 ± 60 pc to the binary further supports this as indirect distance measurements have ranged from 650-950 pc. Thus V684 Mon is definitely not a foreground binary as previously believed. This distance measurement will be refined when the B and R photometry are analyzed and a more definite effective temperature for the stars is derived.

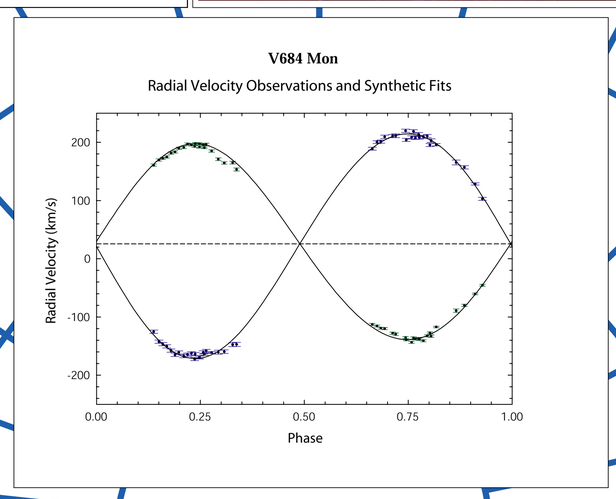




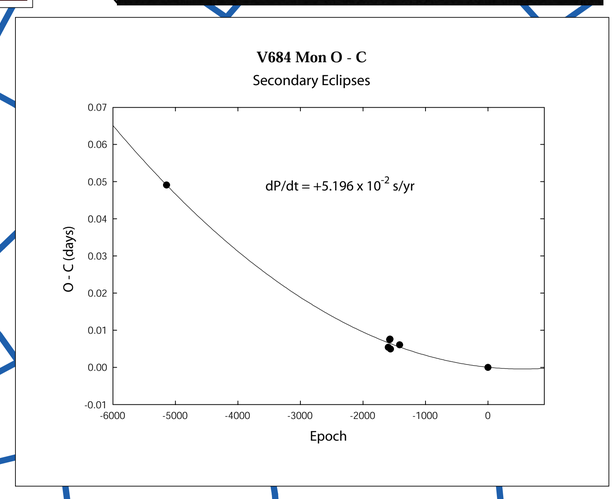
Individual V observations of V684 Mon. Each color represents a different night of data. The differential magnitudes were determined using ensemble photometry techniques. The shallower eclipse, *i.e.*, phase = 0.485P, actually turned out to be the eclipse of the hotter, more massive star.



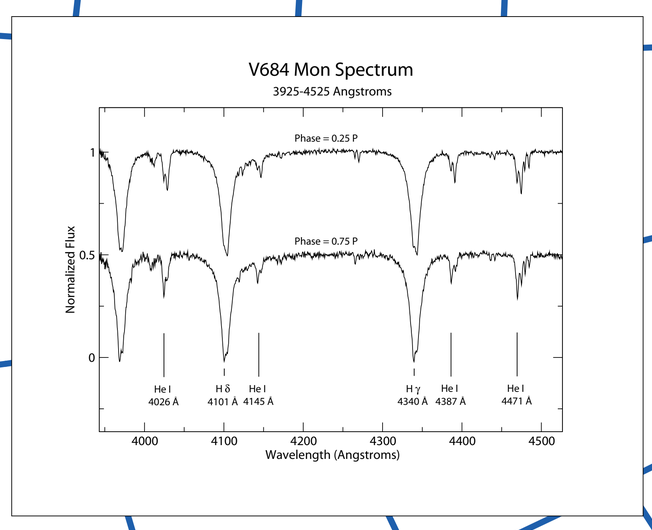
Wilson-Devinney fit (solid curves) to the ΔV normal points of V684 Mon



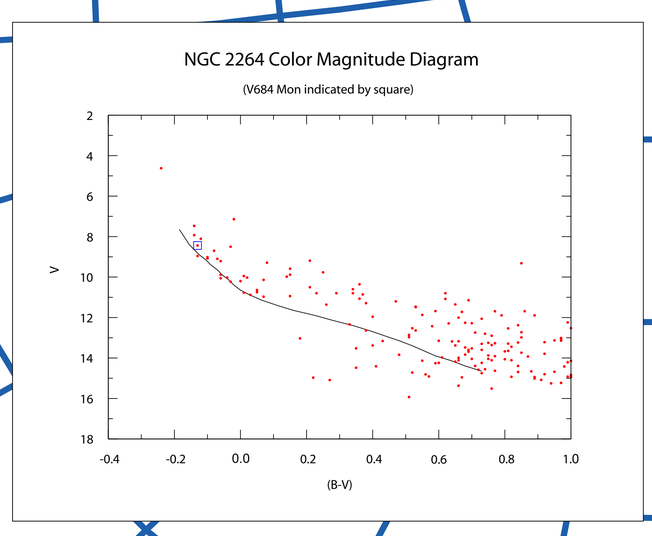
Radial velocity observations from Mt. Laguna Observatory in 2002 plotted against Wilson-Devinney synthetic fits. The green data points represent the more massive star and the blue data points the less massive star.



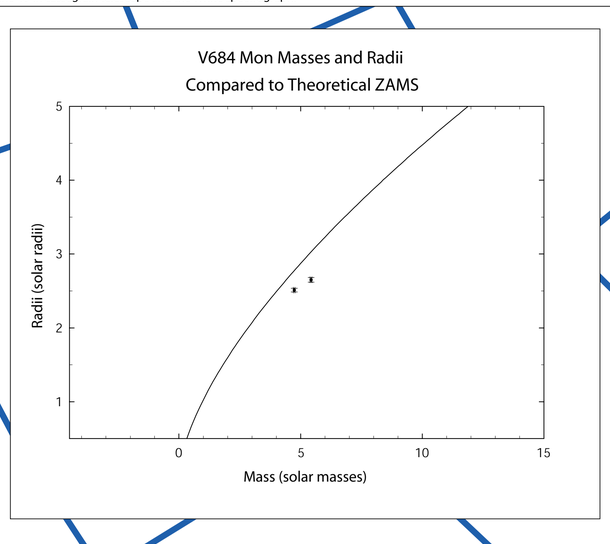
O-C residuals of V684 Mon implying a period increase for the system over the past 26 years. The figure shows an example of a quadratic fit to the data, although the number of observed minima currently does not allow unanimous determination of the trend.



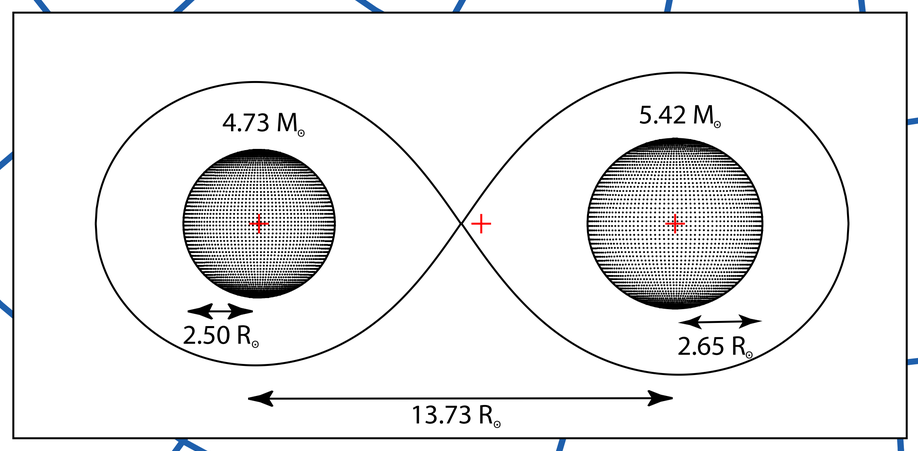
Sample specta of V684 Mon taken at opposite quadratures. Prominent double lines are indicated. These along with 47 others were obtained at the Mt. Laguna Observatory of San Diego State University from January-March 2002 using the 40-in cassegrain telescope and the White spectrograph.



Color magnitude diagram for NGC 2264 from Vasilevskis et al. (1965) showing position of V684 Mon. The solid curve represents the ZAMS corrected for the reddening of Walker (1956) and preliminary distance modulus derived from the absolute parameters of V684 Mon which gives a distance of ~880 ± 60 pc.



The derived masses and radii for the components of V684 Mon plotted against the theoretical ZAMS. The error bars indicate the formal errors of the solution. The stars appear to be slightly undersized for their masses.



Cross-sectional diagram to scale of the components of V684 Mon.
The plus sign in between the stars represents the barycenter of the system

Light Curve Parameters for V684 Mon

(Formal probable errors given in parentheses)

Mass ratio	= 1.146 (0.004)
Inclination	= 74.°17 (0.13)
Ω_1	= 6.6767 (0.0545)
Ω_2	= 6.9226 (0.0600)
T_1	= 16500 K (265)
T_2	= 16578 K (267)
$Albedo_1 = Albedo_2$	= 1.0 (assumed)
$Luminosity_1 = L_1$ (5500 Å)	= 0.4709 (2)
$Luminosity_2 = L_2$ (5500 Å)	= 0.5291 (2)
Gravity brightening $g_1 = g_2$	= 1.0 (assumed)
$F_1 = F_2$ (rotation)	= 1.0 (assumed)
Eccentricity	= 0.028 (0.002)
Phase shift	= -0.0073 (0.0003)
Argument of periastron	= 141.°(4.°)
Gamma velocity	= 25.739 km/s (0.322)
K_1	= 192.8 km/s
K_2	= 168.2 km/s

Stellar Radii

r_1 back = 2.514 (0.025)	r_2 back = 2.666 (0.032)
r_1 side = 2.490 (0.024)	r_2 side = 2.637 (0.032)
r_1 pole = 2.474 (0.024)	r_2 pole = 2.617 (0.030)
r_1 point = 2.521 (0.026)	r_2 point = 2.676 (0.033)

Absolute Parameters

Star 1	Star 2
M_1 = 4.726 $M_\odot$ (0.034)	M_2 = 5.417 $M_\odot$ (0.039)
R_1 = 2.500 $R_\odot$ (0.025)	R_2 = 2.650 $R_\odot$ (0.032)
L_1 = 387.26 $L_\odot$ (0.17)	L_2 = 440.55 $L_\odot$ (0.18)
$M_{1\,Bol}$ = -1.77	$M_{2\,Bol}$ = -1.91
$Log_1\ g/g_0$ = 4.338 (0.091)	$Log_2\ g/g_0$ = 4.347 (0.108)

Semi Major Axis = 13.730 $R_\odot$ (0.028)