# Photometric studies of bright southern binary systems: $\epsilon$ Cra and $\psi$ Ori

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**Abstract.** We present results from detailed analyses of new data combined with previously published light curves of $\epsilon$ Cra and $\psi$ Ori. Based on the shape of the secondary minimum of $\epsilon$ CrA we found that the discrepancy between the photometric and spectroscopic mass ratio, although marginal, is statistically significant. We propose a third light as a possible solution and derive the absolute parameters of components. The physical parameters of components of an early-type binary system $\psi$ Ori were also obtained from the light curve modelling. Our solution indicate that $\psi$ Ori is a detached, grazing-eclipse system.

**Keywords:** binary stars, eclipsing

## 1. Introduction

Between 1991 and 2001 many observations were obtained of bright eclipsing or ellipsoidal binary stars which may also be observed with the Sydney University Stellar Interferometer, SUSI. The purpose of this program was to obtain photometry to enable some parameters to be fixed during the complex analysis of the SUSI data. The observations were taken using the 24-inch telescope of the Australian National University at Siding Spring Observatory (hereinafter referred to as SSO). The new data will be referred to as *SSO V* magnitudes. The datails about the observing programme and the equipment was given by Shobbrook (2004).

$\epsilon$ CrA (HD155813) is the brightest ($4.73^m$) W UMa-type system, with period P=$0.59^d$ discovered by Cousins & Cox (1950). UBV observations were reported by Tapia (1969) and those in RI passbands by Hernandez (1972). The UBVRI set was analyzed with the Wilson-Devinney (W-D) code by Twigg (1979) who photometrically determined the mass ratio to be very small: q=0.113. The spectroscopic orbit of $\epsilon$ Cra was published by Goecking & Duerbeck (1993). The following

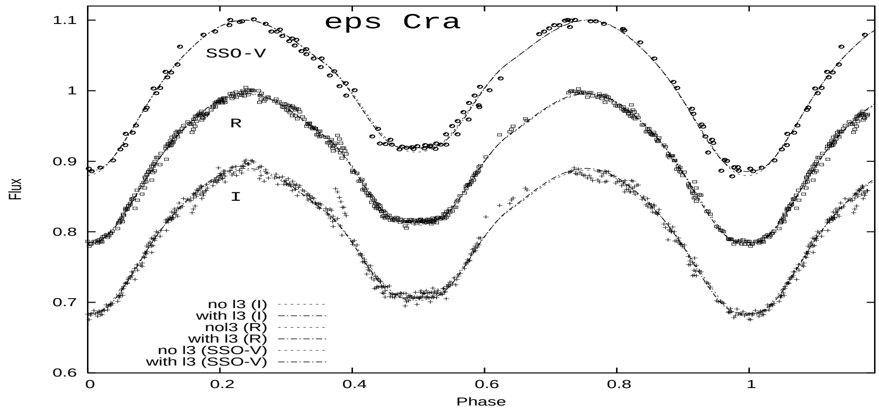


*Figure 1.* Comparison between theoretical and observed light curves of $\epsilon$ Cra. Observations are shown by squares and theoretical curves by lines.

orbital elements were obtained: $K_1$=34.5 km/s, $K_2$=266.9 km/s and $\gamma$=57.9 km/s.

$\psi$ Ori (HD 35715, V=4.6$^m$) was found to be a spectroscopic binary with period of 2.5 days by Frost & Adams (1903). The most recent orbital solution made by Telting et al. (2001) resulted in the following orbital elements: $K_1$=144.6±0.5 km/s, $K_2$=237±4 km/s, $\gamma$=+19±5 km/s, e=0.053±0.001, and $\omega$=172±5°. The light curve of $\psi$ Ori, as shown by Percy (1969), is typical of an ellipsoidal variable. The depths of the minima in the SSO data are approximately 0.035$^m$ and 0.020$^m$. The U and B light curves have been analyzed by Hutchings & Hill (1971). The authors found an orbital inclination of 58±8° and derived the absolute parameters: $M_1$=14.2 $M_\odot$, $M_2$=8.6 $M_\odot$, $R_1$=6.1 $R_\odot$, $R_2$=4.7 $R_\odot$.

## 2. Results from the light curve modelling

In order to obtain the physical parameters of each system we used the W-D code (Wilson (1979)) supplemented with the Monte Carlo search procedure. The theoretical values of both albedo and gravity darkening coefficients were used. The limb darkening coefficients were adopted as functions of the temperature and wavelength from the Díaz-Cordovés et al. (1995) and Claret et al. (1995) tables. For both systems we fix two crucial parameters, the temperature appropriate for the spectral type and the mass ratio, as determined from the radial velocity curves.

Solution of $\epsilon$ Cra was done using the Hernandez's (1972) RI light curves and the new SSO V-filter observations. We fixed the mass ratio at $q$=0.129 obtained by Goecking & Duerbeck (1993) and the temperature of the primary star at 6700 K (F2V). We obtained convergence relatively quickly but the fit was not satisfactory. It was not possible to achieve the flat bottom of the secondary minimum. We therefore made two additional computations: one, adding light from a third source as a free parameter and, two, assuming that there is no third light but letting the mass ratio be a free parameter. Both trials converged to much better fits, with the theoretical light curve resembling almost perfectly the shape of the observations. We were thus able to obtain a good fit either if a third light was included in the list of free parameters, resulting in the third light contribution to the total light of 10-15 %, or for a mass ratio value $q$=0.106±0.003, smaller than that derived from spectroscopy.

In our light curve modelling of $\psi$ Ori we used the Toronto data (U and B filters), the Kitt Peak B data, the data collected by the Hipparcos mission and the new SSO V observations. We fixed the temperature of the primary component at 26000 K (B1 spectral type), the mass ratio value at $q$=0.61 and the eccentricity $e$=0.053, as obtained by Telting et al. (2001). We assumed that there is no third light in this system.

The theoretical light curve along with observations are shown in Figs. 1 and 2 for $\epsilon$ Cra and $\psi$ Ori, respectively. The final physical parameters for the components are: $M_1$=1.74±0.06 $M_\odot$, $M_2$=0.21±0.02 $M_\odot$, $R_1$=2.14±0.03 $R_\odot$, $R_2$=0.86±0.03 $R_\odot$ for $\epsilon$ Cra and $M_1$=12.09±0.35 $M_\odot$, $M_2$=7.37±0.18 $M_\odot$, $R_1$=4.09±0.08 $R_\odot$, $R_2$=2.59±0.26 $R_\odot$ for $\psi$ Ori.

For $\epsilon$ Cra we found the contact configuration with an fill-out factor of 63 %. To obtain a good fit, we found it necessary either to reduce the the mass ratio by 0.02, or to postulate the existence of a third light in the system. We conclude that there is still a small discrepancy between the spectroscopic and photometric mass ratio for $\epsilon$ Cra and, if there are no systematic errors in the determination of the radial velocities (especially those of the fainter componennt possibly due to line blending), it can be removed only by adding a third light.

$\psi$ Ori has a detached configuration with the primary, more massive, component being closer to its Roche lobe. Our model suggests that the light curve of $\psi$ Ori has a very shallow eclipse also observed by Waelkens & Rufener (1983). Unfortunately, the phases around the minima have not been covered by earlier U and B observations. These phases definitely deserve more observers' attention to improve the solution for this early type binary.

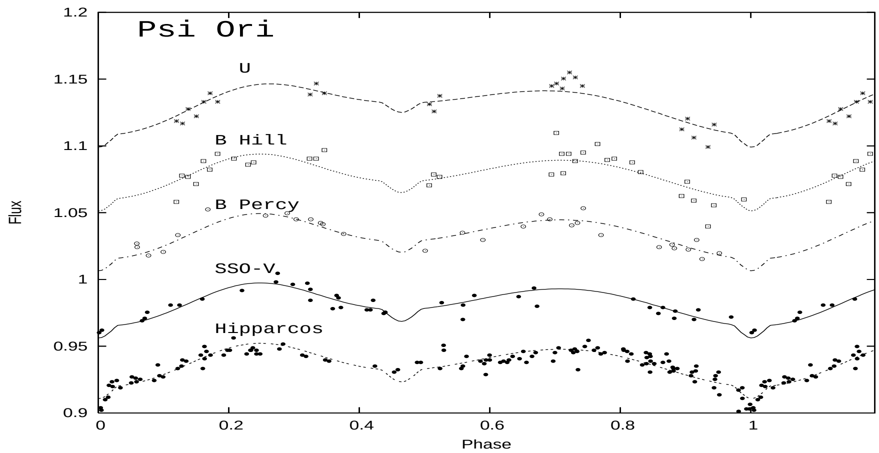


*Figure 2.* Comparison between theoretical and observed light curves of $\psi$ Ori. Individual observations are shown by squares and theoretical light curves by lines.


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