

ACCURATE FUNDAMENTAL PARAMETERS OF ECLIPSING BINARY STARS

The study of detached eclipsing binaries is one of the most powerful ways to investigate the properties of individual stars. The analysis of light curves and radial velocity curves allows us to find the masses, radii and surface gravities of two different stars of the same age and chemical composition. Effective temperatures can be derived from spectral analysis or from photometric calibrations.

The resulting astrophysical data can be used to test theoretical stellar evolutionary models and the physics which they contain (Southworth, Maxted & Smalley, 2004a). The characteristic properties of several types of peculiar stars can also be investigated if such a star is found in a detached eclipsing binary, for example slowly pulsating B stars (e.g., V539 Arae; Clausen, 1996), and metallic-lined stars (e.g., WW Camelopardalis; Lacy et al., 2002).

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The metallic-lined eclipsing binary WW Aurigae

WW Aurigae is a double-lined detached eclipsing binary with an orbital period of 2.52 days and an accurate Hipparcos parallax. It was discovered to be an eclipsing binary in 1918. Etzel (1975) observed excellent photoelectric light curves in the Stromgren *uvby* filters, containing one thousand observations in each filter (see Southworth et al., 2004d, for details).

The rotational velocities of the components were found to be 35 and 55 km s⁻¹ from CCD spectra by Abt & Morrell (1995), who also classified the stars as Am (A2, A5, A7) where the bracketed spectral types have been obtained using the Ca II K lines, Balmer lines, and metallic lines.

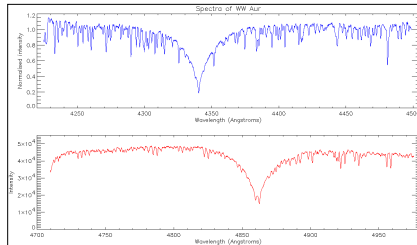


Figure 1. Spectra of WW Aur. Top: H γ spectrum observed when the stars had a small velocity separation of 20 km s⁻¹. Bottom: H β spectrum observed when the stars were separated by 200 km s⁻¹.

Grating spectra were obtained using the IDS spectrograph on the 2.5 m Isaac Newton Telescope on La Palma. Radial velocities were determined from the observed spectra using the two-dimensional cross-correlation algorithm TODCOR (Zucker & Mazeh, 1994). In this algorithm two template spectra are simultaneously cross-correlated against each observed spectrum for a range of possible radial velocity differences for each template.

Spectra from seven standard stars with spectral types between A0 IV and F5 V were selected and used as templates in the TODCOR analysis. Example spectra are shown in Figure 1. The final spectroscopic orbit allows the masses of the two stars to be determined to accuracies of 0.3%, and is shown in Figure 2.

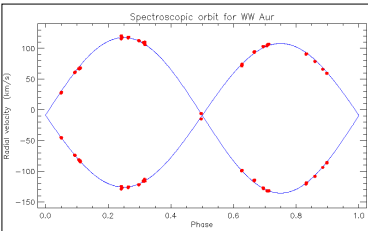


Figure 2. Spectroscopic orbit of WW Aur with individual radial velocity determinations indicated by filled circles.

The light curves of Etzel (1975) were analysed using the EBOP code (Popper & Etzel, 1981). Each light curve was analysed separately to find the best-fitting stellar radii, light ratio and linear limb darkening coefficients (Figure 3). Uncertainties in the values of the photometric parameters were evaluated using Monte Carlo simulations (Southworth, Maxted & Smalley, 2004b); the best fit was evaluated at the phases of observation and Gaussian noise added. The resulting light curve was fitted and this process was repeated ten thousand times.

Individual Strömgren photometric indices were evaluated using the light ratios found during the light curve analysis. Effective temperatures of 8350 ± 200 and 8170 ± 300 K were found for the stars using the calibration of Moon & Dworetzky (1985).

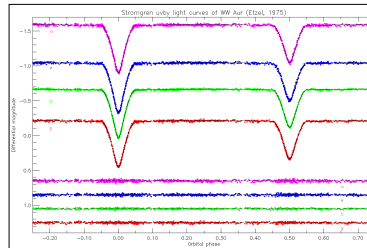


Figure 3. Photoelectric *uvby* light curves of WW Aur from Etzel (1975) with the EBOP best fits shown by black lines. The residuals of the fit are shown at the base of the figure.

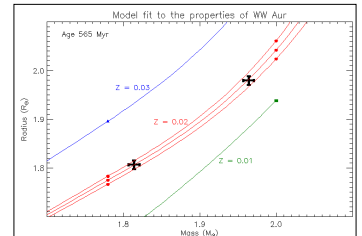


Figure 4. Comparison between the masses and radii of the components of WW Aur and the predictions of the Granada theoretical evolutionary models (Claret, 1995) for several different metal abundances, Z.

The Z = 0.01 and 0.03 isochrones are shown for 565 Myr and the Z = 0.02 predictions are shown for 550, 565 and 570 Myr.

The physical parameters of the component stars of WW Aurigae are:

Mass = 1.964 ± 0.007 1.814 ± 0.007 M
 Radius = 1.980 ± 0.007 1.807 ± 0.009 R
 log (g) = 4.160 ± 0.007 4.165 ± 0.007
 T_{eff} = 8350 ± 200 8170 ± 300 K

In Figure 4 the masses and radii of the stars are compared to the predictions of the Granada stellar evolutionary models. A normal helium abundance was adopted. The Z = 0.02 (approximately solar metal abundance) isochrone fits the masses, radii, effective temperatures and surface gravities well for an age of 565 ± 15 Myr.

HD 23642 and the distance to the Pleiades

HD 23642 is a detached eclipsing binary, with an orbital period of 2.46 days, composed of an A0 V star and an Am star. It was recently studied by Munari et al. (2004), who determined its distance, and so the distance of the Pleiades open cluster, using a method incorporating theoretical bolometric corrections. However, their use of two different solar absolute bolometric magnitudes caused a systematic error in the distance, of about the same size as the quoted uncertainty.

We have reanalysed the *BV* light curves of Munari et al. (2004) to redetermine the radii of the two stars. We have also undertaken Monte Carlo simulations to determine reliable uncertainties on the derived quantities (Southworth, Maxted & Smalley, 2004c)

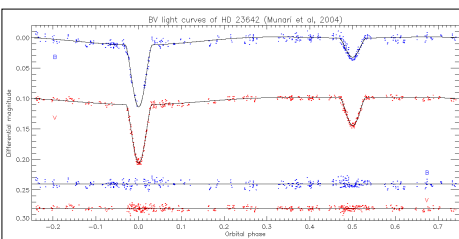


Figure 5. The *BV* light curves of Munari et al. (2004) with our best-fitting EBOP model light curves shown by solid black lines. The residuals of the fit are shown at the bottom of the figure.

The traditional method of finding the distance of an eclipsing binary is to calculate the luminosities of each star from their radii and effective temperatures. The resulting absolute bolometric magnitudes are corrected to absolute visual magnitudes using model-dependent bolometric corrections. Then the absolute and the apparent visual magnitudes of the system are compared to find the distance.

An alternative is to determine the angular diameters of the stars using calibrations of surface brightness. As the linear radii are known, this gives the distance directly and without the use of theoretical calculations. Kervella et al. (2004) recently provided relations between surface brightness and effective temperature. If infrared *JHK* apparent magnitudes are used, the uncertainty in reddening is negligible.

Using the surface brightness method we determine a distance to HD 23642, and so to the Pleiades, of 139 ± 4 pc, where the biggest contributor to the uncertainty is the apparent *K*-filter magnitude of the system given by 2MASS. This distance is in disagreement with the Hipparcos distance of 120 ± 3 pc, but in good agreement with the distance determined by main sequence fitting, ground-based and HST parallaxes and study of the astrometric binary Atlas (see Southworth, Maxted & Smalley, 2004c, for references and details).

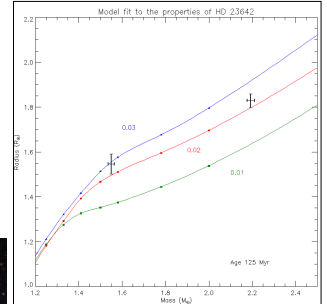


Figure 6. Comparison between the masses and radii of the components of HD 23642 and the predictions of the Granada theoretical stellar evolutionary models. Normal helium abundances and an age of 125 Myr (Stauffer et al., 1998) have been adopted for the Pleiades.

Astrophysical parameters of HD 23642:

Mass = 2.19 ± 0.02 1.55 ± 0.02 M
 Radius = 1.83 ± 0.03 1.55 ± 0.05 R
 log(g) = 4.25 ± 0.02 4.25 ± 0.03
 T_{eff} = 9750 ± 250 7600 ± 400 K