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MULTICOLOR OBSERVATIONS OF THE PRIMARY AND SECONDARY ECLIPSES OF OW GEMINORUM

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OW Gem is a unique, long-period, well-detached, eclipsing binary system, composed of two evolved supergiant stars. Their spectroscopic orbits are well known (Griffin & Duquennoy, 1993). The orbital period derived from observations of 11 eclipses between 1902 and 1991 is 1258.59 days, *i.e.* about 3.45 years (Williams & Kaiser, 1991). Griffin (1993) described 8 similar long-period systems, containing two comparable giants with known spectroscopic orbits, but only OW Gem shows eclipses, thus it remains the only system with precisely known masses for both components.

Terrell et al. (1994) mounted an international photoelectric campaign to observe this star during primary and secondary eclipses in 1995. We answered their appeal but unfortunately, the analysis of this campaign exclude our photometric data (Kaiser et al., 2002). In 1995 we observed OW Gem in *UBVri* bands with the 60 cm Cassegrain reflector at Piwnice Observatory near Toruń (Poland). We used a single-channel diaphragm photometer with an unrefrigerated EMI 9558B photomultiplier. Our *UBV* response curves were very close to the standard Johnson's system, whereas our broad *ri* bands had significantly shorter mean wavelengths: 6390Å and 7420Å, respectively. HDE 258848 was chosen as a comparison star and GSC 1332:0578 as a check star, both suggested by Terrell et al. (1994). The accuracy of our measurements was about $\pm0\overset{m}{.}03$ in U, $\pm0\overset{m}{.}02$ in BVr and $\pm0\overset{m}{.}01$ in i bands. Our observations during the primary eclipse in 1995 are presented in Fig. 1. Unfortunately, we only obtained a few observational points around the secondary eclipse in late 1995.

One year ago, Derekas et al. (2002) reminded us again of this star by their observations of the primary eclipse at the turn of 2001/2002. So we decided to observe the secondary eclipse, which took place only a few months later, in October 2002, thanks to the large orbital eccentricity ($e = 0.52$). Before the publication of Kaiser et al. (2002), only three V measurements, $0\overset{m}{.}1$ below the average brightness of the star outside the eclipse (Williams, 1989), were known as photometric signs of the secondary eclipse.

In 2002, we made 24 measurements during 22 nights between Sept. 2 and Dec. 9 which gave quite a good time coverage of the secondary eclipse. The data were obtained with the same telescope equipped with a cooled Burle/RCA C31034 photomultiplier. The standard Johnson-Cousins $UBV(RI)_C$ system and two intermediate-band interference filters (FWHM ≈ 100Å), "h"(located at H_β) and "c"(located in the continuum around 4804Å) were used.

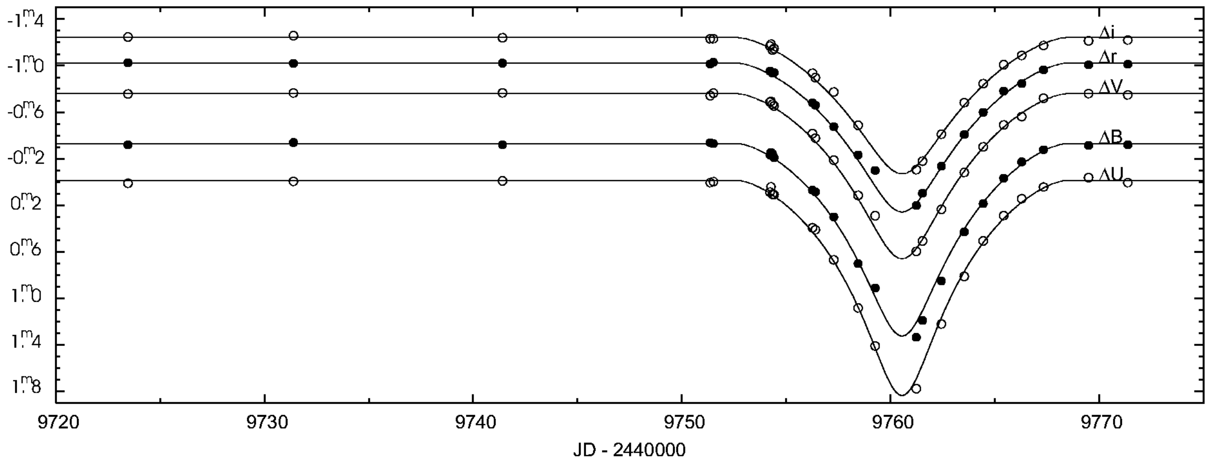

Figure 1. The *UBVri* light curves of OW Gem during the primary eclipse in 1995 with the best fit model ($T_{hot} = 7100\mathrm{K}, T_{cool} = 4950\mathrm{K}, i = 89°$). The neighbouring curves are shown with different (filled and open) circles for clarity.

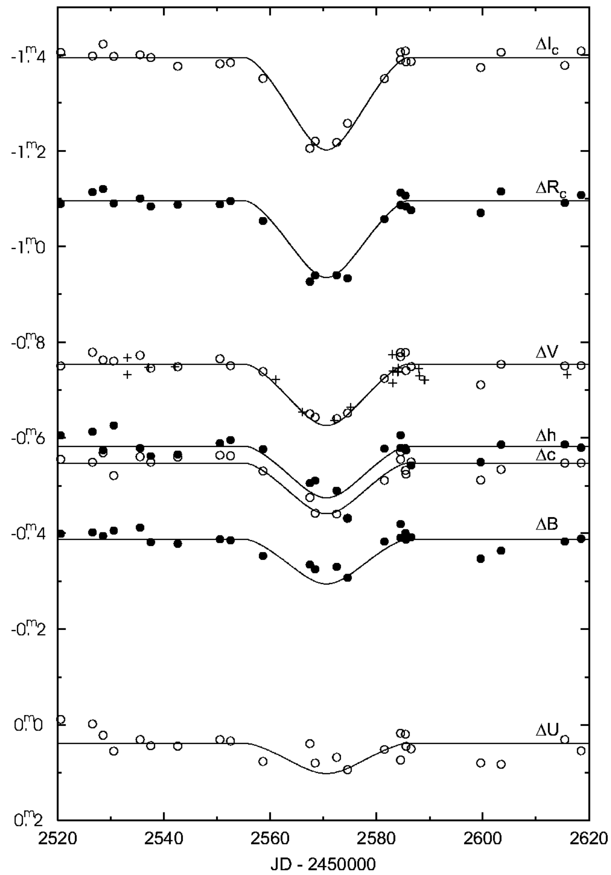

Figure 2. The *UBV(RI)*$_C$ light curves of OW Gem during the secondary eclipse in 2002 with the best fit model ($T_{hot} = 7100\mathrm{K}, T_{cool} = 4950\mathrm{K}, i = 89°$). The neighbouring curves are shown with different (filled and open) circles. Crosses in the *V* light curve correspond to Williams' (1989) observations shifted to epoch 2002 with period $1258^{\mathrm{d}}.59$.

The accuracy of our measurements was $\pm 0\overset{m}{.}03$ in "h" and "c", $\pm 0\overset{m}{.}02$ in $UBVR_C$ and $\pm 0\overset{m}{.}01$ in I_C bands. The same comparison and check stars were utilized as in 1995. Fig. 2. presents our light curves of the secondary eclipse. The time of the mid-eclipse was in an agreement with the ephemeris given by Williams (1989). The depth of the eclipse increases with increasing wavelength from about $0\overset{m}{.}08$ in the B up to $0\overset{m}{.}2$ in the I_C. Our data obtained during the primary eclipse in 1995 (Fig. 1) and especially during the secondary eclipse in 2002 (Fig. 2) are good complements of the observations previously collected by Kaiser et al. (2002) and Derekas et al. (2002).

We have tried to fit a very simple model to our light curves. The sizes of both stars were fixed at values given by Griffin & Duquennoy (1993): $R_{hot} = 30R_\odot$ and $R_{cool} = 35R_\odot$. The limb darkening was neglected and stellar fluxes were approximated as blackbodies. The adjustable parameters were the effective temperatures of the hotter (T_{hot}) and the cooler (T_{cool}) components and the impact parameter D which measures the projected distance between the centres of stellar discs in the mid-eclipse point. We took the timings from Kaiser et al. (2002): JD 2449760.6 for the primary in 1995 and JD 2452570.9 for the secondary in 2002.

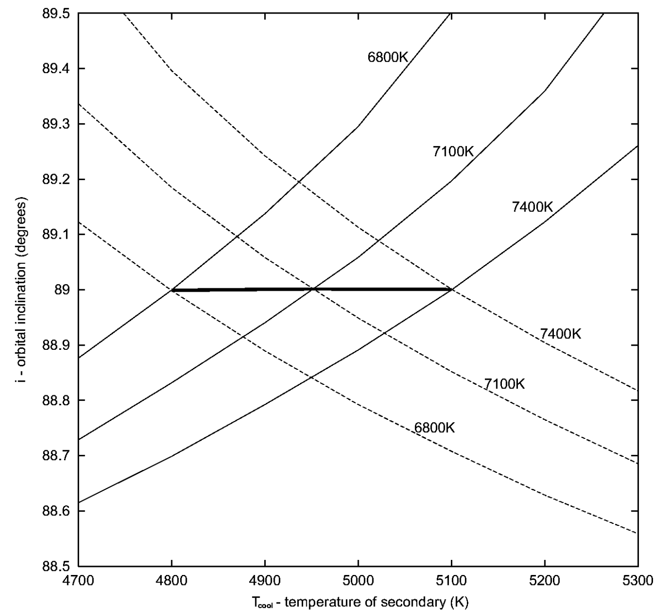

Figure 3. The best fits of orbital inclination $i = i_{oc}$ found for the primary (continuous lines) and $i = i_{tr}$ for the secondary (dashed lines) eclipses. Particular lines are signed by the temperature of the hotter component T_{hot}. The most probable solutions (thick line) are denoted by intersections between lines corresponding to opposite eclipses (when temperatures and inclination derived from both minima are the same).

We have adopted three reasonable temperatures T_{hot} for the F2 Ib-II component: 6800K, 7100K, 7400K. The temperature of the G8 IIb component T_{cool} has been changed from 4500 K to 5500 K with a step of 100K. For each pair of such temperatures we have found an impact parameter D giving the best fit to our observation in all $UBVri$ or $UBV(RI)_C$ bands simultaneously. As a best fit criterion we used the minimum of the sum of normalized standard deviations in five bands $\sigma^e_U/\sigma^o_U + \sigma^e_B/\sigma^o_B + \sigma^e_V/\sigma^o_V + \sigma^e_{r/R_C}/\sigma^o_{r/R_C} + \sigma^e_{i/I_C}/\sigma^o_{i/I_C}$, where indices '$e$' and '$o$' correspond to fits during and outside the eclipse, respectively. The narrow filters h and c were omitted in these calculations in order to keep the same weights for both minima.

The spectroscopic orbit of Griffin & Duquennoy (1993) gives the distance between the stars during transit to be about twice that during the occultation: $r_{oc} = 0.553a$ and $r_{tr} = 1.096a$, where a is semi-major axis. The orbital inclination i can be derived separately for each eclipse:

$$\tan i_{oc} = \frac{r_{oc} \sin i}{D_{oc}} = \frac{0.553a \sin i}{D_{oc}}$$
$$\tan i_{tr} = \frac{r_{tr} \sin i}{D_{tr}} = \frac{1.096a \sin i}{D_{tr}}$$

where D_{oc} and D_{tr} are impact parameters during the occultation and transit, respectively. Adopting a projected semi-major axis $a \sin i = 1052 R_\odot$ (Griffin & Duquennoy, 1993) we have found the inclination for different stellar temperatures fitted to both eclipses separately (Fig. 3). Of course, the inclination obtained from primary and secondary eclipses must be the same, *i.e.* $i = i_{oc} = i_{tr}$. This requirement corresponds to that shown in Fig. 3 at the intersection between the solutions $i = i_{oc}(T_{hot}, T_{cool})$ and $i = i_{tr}(T_{hot}, T_{cool})$ for occultation (primary) and transition (secondary), respectively. As a result, the orbital inclination $i = 89^\circ$ is almost constant and independent of the stellar temperatures . This is a consequence of arbitrary assumed stellar dimensions from Griffin & Duquennoy (1993) who found the same inclination. They also estimated temperatures of both components of 7100K and 4800K. Nevertheless, our calculations show the temperature ratio $T_{hot}/T_{cool} \approx 1.43 \pm 0.01$, which is significantly smaller than $7100/4800 \approx 1.48$. Based on our values the secondary component is likely to be hotter (about $4900 - 5000$K) which agrees with the suggestion by Derekas et al. (2002). Synthetic light curves for our most probable parameters are presented together with observations in Figs. 1 and 2.

We will search for better radii of both stars with the Wilson-Devinney code, including limb darkenings and models of stellar atmospheres for the calculations. Unfortunately, we need more and better observations outside the eclipses, in particular, close to the periastron where small deformations of stars cannot be excluded. Additionally, hot and cool spots on the supergiants' convective surfaces are very likely, which can significantly affects the solutions.

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