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THE R BAND LIGHT CURVES OF ECLIPSES OF U Gem IN OUTBURST

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U Gem is one of just a few known eclipsing dwarf novae (e.g. Krzeminski, 1965). Large variations of the eclipse profiles in quiescence and outburst offer a unique opportunity to study the changes in the disk and the interaction of the disk with the mass stream (bright spot). Here we report an analysis of the R band CCD observations of eclipses which occurred during the peak of the outburst. As far as we know, no photometric observations of eclipses of U Gem in the red spectral region during outburst were published previously.

The R-filter CCD images were obtained by Maksutov 180/1000 mm, SBIG ST-6 in the Astronomical Institute in Ondřejov during the February 2002 outburst and covered three eclipses. The exposure times were 90 and 70 sec. The star USNO-A2.0 1050-05472483 was used as the comparison star while USNO-A2.0 1050-05473287 served as the check star. The variable, the comparison star and the check star were placed on the same image. These CCD data are available at the IBVS website as `5453-t2.txt`.

The position of our CCD observations is shown in Fig. 1. The one-day means of the visual observations from the AFOEV database (CDS, Strasbourg, France) are superimposed and show that the CCD data were obtained during the peak of the outburst.

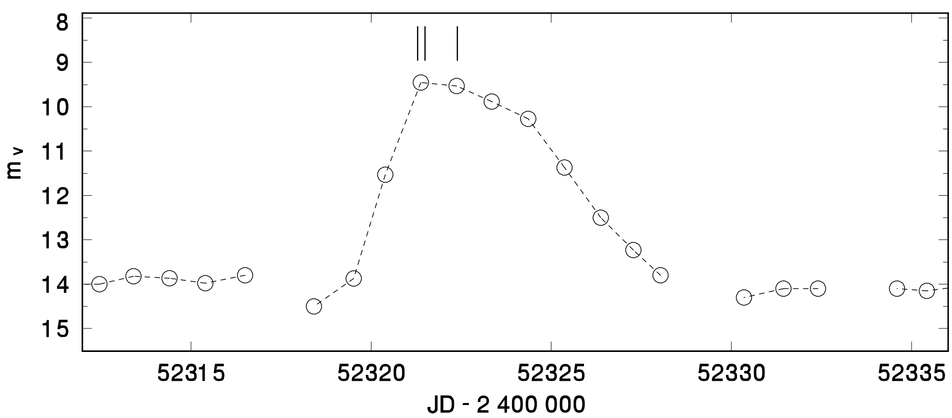

Figure 1. The profile of the February 2002 outburst of U Gem. The empty circles represent the one-day means of the AFOEV visual observations. The vertical lines mark the centers of the series of the R band CCD observations.

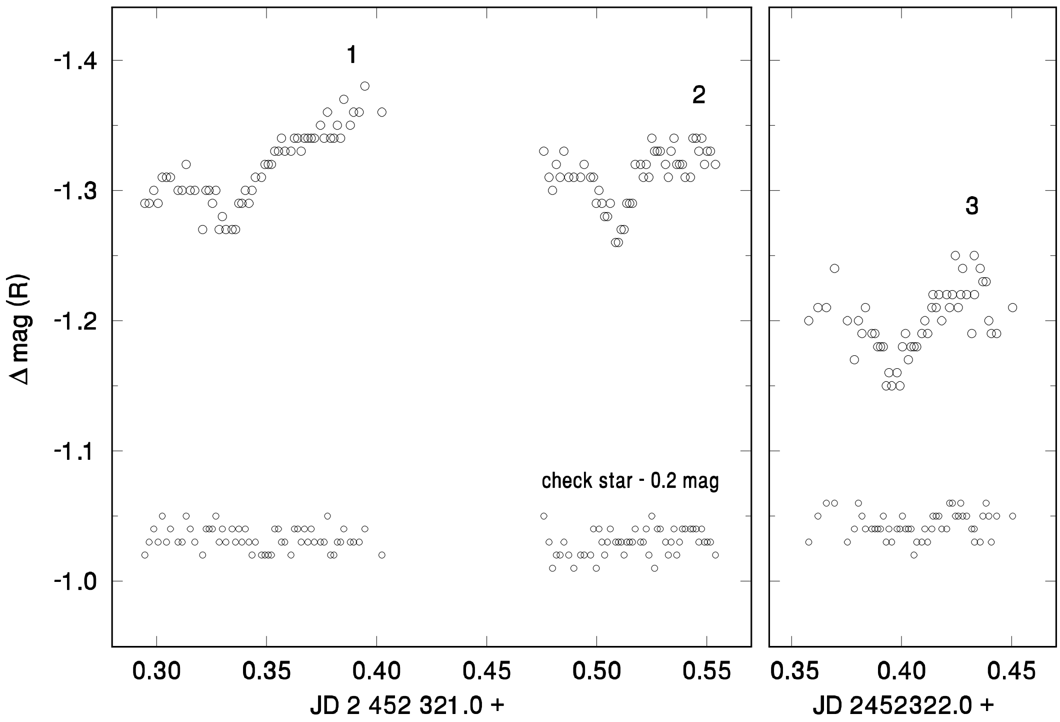

Figure 2. The profiles of the eclipses observed in the R band during the top of the February 2002 outburst of U Gem. The relative magnitudes for both the variable and the check star are plotted.

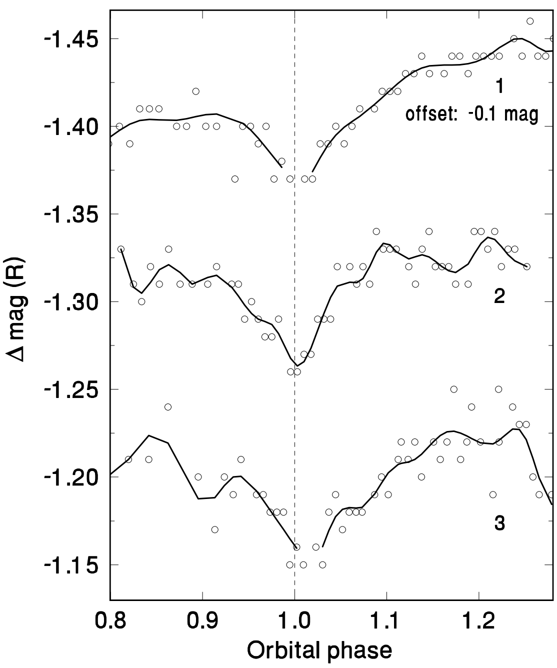

Figure 3. The details of the profiles of the eclipses observed during the February 2002 outburst of U Gem. The number at each curve refers to the label in Fig. 2. The smooth curves represent the fits by the code `HEC13`. The ephemeris of Smak (1993), valid for the moment of the mid-eclipse of the bright spot in quiescence, was used.

The profiles of the eclipses observed in the R band are shown in Fig. 2. The first eclipse might occur during the very late rise to the outburst maximum because a trend of an increasing brightness is superposed. The depth of the eclipses is very small, of the order of 0.05 mag(R). The light curves were therefore smoothed by the code HEC13, written by Dr. P. Harmanec and based on the method of Vondrák (1969 and 1977). This method can fit a smooth curve to a complicated course of the data. The descending and ascending branches of eclipses 1 and 3 were fitted separately.

The fits to the profiles of the individual eclipses are shown in detail in Fig. 3. The orbital phases were calculated according to the ephemeris of Smak (1993):
$T_{\rm min} = 2\,437\,638.82627 + 0.1769061898\ E$, which is valid for the moment of the mid-eclipse of the bright spot in quiescence.

We determined the timings of the three eclipses by the method of bisectors to take the asymmetry of the profiles into account. The minima determined from the observed and smooth curves, representing mainly the middle part of the eclipse depth, were in good agreement. A difference of approx. -0.005 days was found only for the first eclipse. The values of $O-C$ in Table 1 were calculated using the ephemeris of Smak (1993).

Table 1. Minima timings of U Gem determined from the smooth curves

JD	Epoch	$O-C$ (days)
2452321.3327	82996	0.0003
2452321.5097	82997	0.0004
2452322.3960	83002	0.0022

In quiescence, the deep, narrow eclipse of U Gem with a steep ingress and egress (Krzeminski, 1965) is caused by an occultation of the bright spot by the secondary star while the white dwarf and the inner disk region are not eclipsed (Warner and Nather, 1971). On the contrary, the profiles of the eclipses obtained at the peak of the 2002 outburst in the R band appear to be very broad, often with extended wings. In addition, there is no sign of a bump characteristic for the interval of the best visibility of the bright spot, which is very prominent in quiescence. This behaviour bears some resemblance to that observed in the V band by Naylor and la Dous (1997) during the 1995 April outburst.

Fig. 3 shows that the full width of eclipse can be as large as 0.2 phases. The very broad wings of the eclipses are characteristic for an eclipse of an expanded, highly brightened accretion disk. Nevertheless, the phases of mid-eclipse (Table 1) are close to the phase of the eclipse of the spot, not of a disk. The moment of the superior conjunction of the white dwarf in U Gem (i.e. when the mid-eclipse of the disk should occur) advances the moment of the mid-eclipse of the bright spot by 0.025 ± 0.005 phase in quiescence (Smak, 2001). The moment of minimum occurs earlier during outburst than in quiescence (Krzeminski, 1965). However, our observations show that the minima during outburst occur systematically later than suggested by the ephemeris of Smak (1993), and later than the course of the $O-C$ values in his Fig. 1. This can be explained by a recent increase of the period length $P_{\rm orb}$. We note that the minima observed by Naylor and la Dous (1997), when recalculated according to the ephemeris of Smak (1993), have negative $O-C$'s during the 1995 April outburst and $O-C \approx 0.0012$ day in the 1996 February quiescence.

Significant cycle-to-cycle changes of the modulation, mainly the slope of the ascending branches of the consecutive eclipses 1 and 2 and a sharper bottom part of eclipse 2, were detected. A similar asymmetry is apparent also in one night of the 1995 April outburst (Naylor and la Dous, 1997). Small changes of the disk profile can give rise to the asymmetry of a grazing eclipse. A comparison with the in-outburst Doppler tomography of He II λ4686 (Groot, 2001) reveals that the part of the disk on which a spiral shock arm is developing lies between the white dwarf and the observer between phases $\sim 0.0 - 0.15$. Large changes of the profile of the disk, connected with a non-uniform brightness distribution, may occur there. Another possibility could be a deformation of the disk around the impact of the stream (emerging from eclipse), caused by an increase of the mass outflow from the donor star due to an irradiation during outburst (Smak, 1995). Nevertheless, the spiral arms are a more likely explanation because they appear sooner than the heating of the donor (Fig. 2 in Groot, 2001). Variable, vertically extended structures of unclear origin are really known to be present in U Gem and to give rise to the X-ray dips at phases 0.15 and 0.7 (Mason et al., 1988) and UV dips at phase 0.1 (Naylor and la Dous, 1997). The spiral structure of the disk may be the common cause of the variations observed in various spectral regions during outburst but simultaneous multiwavelength observations are highly desired in this respect.

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