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THE NATURE OF THE ECLIPSING BINARY LD 328

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LD 328 (GSC 3256-0458, $00^{\rm h}26^{\rm m}49\overset{\rm s}{.}09$, $+49^\circ40'35\overset{''}{.}7$ (USNO A2.0)) was discovered as an eclipsing binary by Dahlmark (1999). An analysis of the historical photographic observations, Dahlmark's data, and recent visual and CCD observations shows that the star is an Algol variable with a period of $1\overset{\rm d}{.}0838485$, increasing at, $\dot{P}/P = 5.6 \times 10^{-7}$ yr^{-1} (Lloyd et al. 2001). In this paper the CCD observations are described in more detail and are used to model the system.

The CCD observations have been calibrated using a comparison sequence derived from $BV(RI)_{\rm C}$ observations from the USNO Flagstaff Station 1.0-m telescope and a SITe/Tektronix 1024 × 1024 CCD (see Table 1). LD 328 was observed at two phases which provide multi-colour photometry at secondary eclipse and out of eclipse (see Table 2). The comparison stars were calibrated on one photometric night and have an estimated zero point error of $0\overset{\rm m}{.}02$. Additional field photometry is available at

ftp://ftp.nofs.navy.mil/pub/outgoing/aah/sequence/ld328.dat.

Further CCD observations in V only have been made by Hager, Lubcke and Kaiser using 0.25-m, 0.28-m and 0.35-m SCTs respectively, all equipped with ST-9E CCDs, and together with the Flagstaff observations they cover the complete light curve. Observations around primary eclipse were also made by James using an unfiltered Starlight Xpress SX CCD on a 0.30-m telescope. These have been calibrated using the R magnitudes of the comparison stars. The light curves in V and R are shown in Figures 1 and 2 respectively, using the current period given above

Very little is known about LD 328. There is no spectral type available and the only accurate photometry is that presented here. It is possible to estimate the unreddened colours of the primary from the $B-V$, $V-R_{\rm C}$ and $R-I_{\rm C}$ colours derived at secondary minimum, assuming that it lies on the main sequence, and that the secondary component makes no significant contribution at this phase. Values for the unreddened main sequence have been taken from AQ4 (Cox 1999). The contribution of the secondary is obviously small as the star is only slightly bluer at secondary minimum compared to the out of

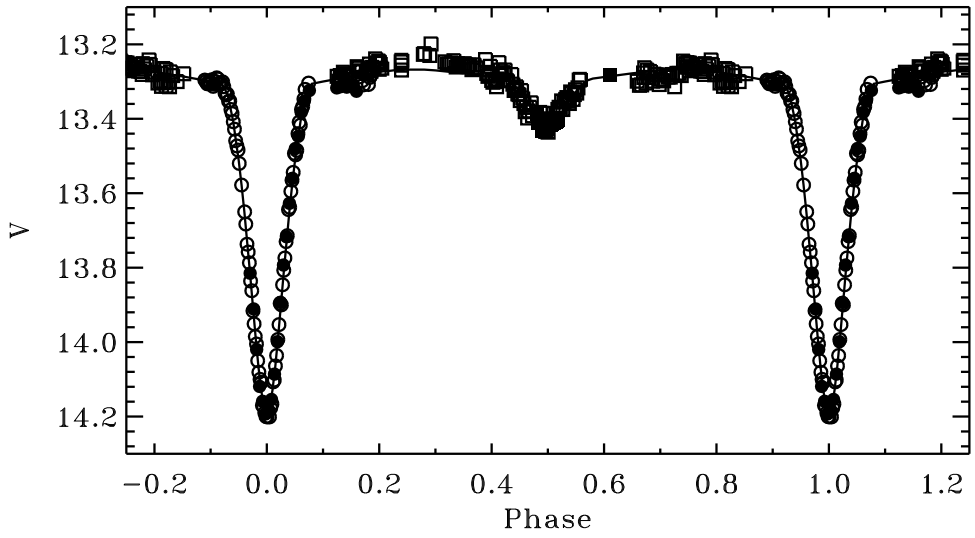

Figure 1. The phase diagram of the CCD V-band data showing the individual observations of Lubcke (filled circles), Kaiser (open circles), Henden (filled squares) and Hager (open squares). The modelled light curve has been over plotted

eclipse colours. Unfortunately the unreddened colours are poorly constrained and are consistent with main-sequence stars of spectral type A or F. Any contribution from the secondary will tend to make the primary appear of a later spectral type.

The V-band light curve of the system has been modelled using the LIGHT2 code (see Hill et al. 1989). A grid of models has been calculated covering a range of temperatures for the primary component, $6\,500 < T_1 < 15\,000$ K corresponding approximately to spectral types F5 to B5, and a range of mass ratios, $0.2 < q < 1.0$. For each model the program has solved for the relative radii of both components, R_1/a, R_2/a, the temperature of the secondary, T_2 and the inclination, i. A series of models was also run with the secondary radius, R_2/a, fixed at the Roche lobe radius, and the results are collected in Table 3.

The relative radii and the inclination are similar for all the solutions and they all produce very similar fits to the light curve, so there is no clearly preferred solution. For the smallest mass ratio, $q = 0.2$, the solutions with the secondary radius fixed or floating are essentially identical, but for larger mass ratios the secondary lies within its Roche

Table 1: Comparison star photometry near LD 328

Star	RA (2000) Dec	V	$B-V$	$V-R_C$	$R-I_C$
GSC3256-0691	$0^h27^m02\overset{s}{.}28$ +49°38arcm49″.8	12.486	0.552	0.327	0.341
GSC3256-0138	0 27 12.08 +49 43 06.6	13.511	0.533	0.332	0.340
GSC3256-0274	0 26 44.72 +49 45 59.6	12.736	0.542	0.331	0.328

Table 2: Multi-colour photometry of LD 328

HJD	Phase	V	$B-V$	$V-R_C$	$R-I_C$
2451930.6207	0.611	13.283	0.523	0.336	0.342
2451931.5851	0.501	13.428	0.478	0.308	0.316

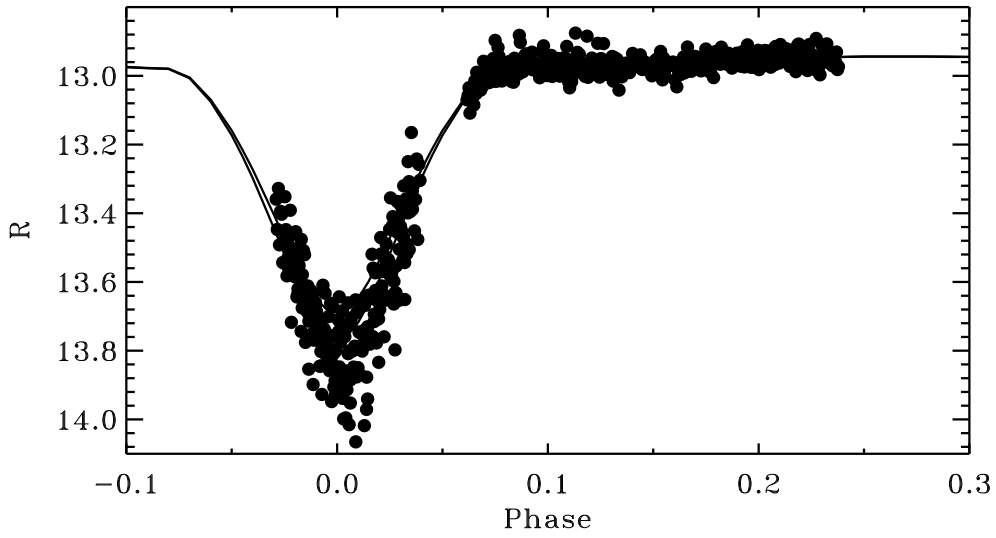

Figure 2. The unfiltered CCD observations around primary eclipse calibrated using the comparison star R magnitudes, with the modelled $R_{\rm C}$ and $I_{\rm C}$ light curves over plotted

lobe. For these, when the secondary radius is fixed at the Roche lobe radius, the fits to the data are only marginally poorer, but the solutions produce much smaller primaries and cooler secondaries.

Table 3: Photometric model of LD 328

T_1^*	T_2	R_1/a	R_2/a	i	q	$R_1/R_\odot$
15 000	8 200	0.23	0.26	81	1.0	2.4
15 000	8 400	0.22	0.26	80	0.5	2.1
15 000	7 700	0.16	0.30†	77	0.5	1.5
15 000	8 300	0.23	0.23†	82	0.2	2.0
10 000	6 200	0.23	0.26	80	1.0	1.9
10 000	6 300	0.23	0.25	81	0.5	1.7
10 000	5 800	0.16	0.30†	76	0.5	1.2
10 000	6 300	0.23	0.23†	81	0.2	1.6
8 000	5 200	0.24	0.25	81	1.0	1.7
8 000	5 400	0.24	0.25	81	0.5	1.5
8 000	4 900	0.17	0.30†	75	0.5	1.1
8 000	5 600	0.24	0.23†	82	0.2	1.4
6 500	4 600	0.22	0.26	80	1.0	1.3
6 500	4 600	0.25	0.24	81	0.5	1.4
6 500	4 300	0.17	0.30†	75	0.5	0.9
6 500	4 800	0.24	0.23†	82	0.2	1.2

* T_1 fixed; † R_2/a fixed at the Roche lobe radius

The models can also be used to estimate the change in colour with phase for comparison with the observed values (Table 2). Unfortunately there is a lack of consistency which makes it difficult to draw any firm conclusions. The agreement tends to be better with the cooler, lower mass ratio solutions, but it is still not as good as might be expected.

The relative radii, R_1/a, have been converted to absolute values by adopting consistent values of M_1 and T_1 for main-sequence stars. For the higher mass ratios the radii derived in this way are too small for the type of star assumed. Solutions with R_2/a fixed are even less consistent with the spectral type. A consistent set of values for the mass and radius occur for a primary of spectral type later than A7, ($T_1 < 8\,000$ K) making the secondary a low-mass, late G- or K-type star. The secondary is probably filling its Roche lobe, as the photometric solutions, the colours and the increasing period, all point in this direction.

In conclusion, LD 328 appears to be a relatively cool Algol binary with the secondary filling its Roche lobe. Much of the uncertainty in the photometric model would evaporate with a good spectral classification. LD 328 is potentially a very useful system as it is has relatively deep eclipses and a well determined rate of period change, and would benefit from a more detailed photometric and spectroscopic study.

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