Photometric Analysis of Wide and Narrow Hα Band Observations of R Canis Majoris

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Abstract.

Wide and narrow Hα lightcurves of R CMa were analysed using Wilson-Devinney (WD) and Information Limit Optimisation Technique (ILOT) approaches. A range of mass ratios, tested by both methods, led to an optimal estimate of around 0.45, at variance with the spectroscopic value. The distortion on the light curve affects the modelling, and so, in a second fitting, this was represented by a 'hot spot', associated with mass transfer effects. A semi-detached configuration was then derived. This is supported by the form of the Hα index variation, which has also been modelled. Although thus appearing as a 'classical Algol' system, R CMa retains its inherent peculiarity of low mass ratio *with* low period, which cannot be reconciled with conservative evolution scenarios.

1. Introduction

In this paper[1] we concentrate on analysis of photometric data for one of the best observed and historically well documented systems of Algol-like general type — R CMa — a bright (mag 6) partially eclipsing binary, with the short period of 1.1359 days (Guinan and Ianna, 1983, Edalati *et al.*, 1989). We apply both Wilson-Devinney (WD) (1971) and information limit optimization (ILOT) techniques.

An inherently peculiar group of 'R CMa stars' once was postulated (Kopal, 1959). Although, part of the peculiarity was later removed after detailed studies (cf. eg. Okazaki, 1978), a problem remains that Algols with very low mass ratios can exist *at low periods.* R CMa is in a very odd position in this respect (Budding, 1985). Edalati *et al.*'s (1989) recent Hα wide and narrow data were examined, and, as the value of the mass ratio q is a key issue, we sought its 'photometric' value.

2. Photometric Analysis

The (WD) light curve programs LC and DC ('Mode 2') were used to produce best fit solutions to the Hα wide band data for a range of values of q. Limb darkening values were taken from Al-Naimiy (1981). The lowest sum of deviations was at $q = 0.4$. DC was then rerun with q among the variable parameters. It remained at 0.40, however, we did not establish that our best parameter *absolutely* minimizes Σ. The narrow band data were processed in a corresponding way, with the same subset of varied parameters. The final convergent DC solution for this gave $q = 0.48$.

[1] A more detailed version can be supplied on request.

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TABLE I
Parameter sets from ILOT fits to a 'cleaned' data set

Primary Luminosity L_1	=	$96.1 \pm 0.6\%$
Primary radius r_1	=	0.324 ± 0.002
Secondary radius r_2	=	0.218 ± 0.002
Inclination i	=	81.7 ± 1.7 deg

The ILOT modelling approach (Banks and Budding, 1990; Budding and Zeilik, 1987) was next applied along similar lines. Derived stellar radii were slightly less than those of WD, while the inclination and primary luminosity slightly higher. A run was made with q variable, producing a determinate result for the mass ratio (0.45) — within error of that derived by WD for the same data. This agreement supports the parallelism of the separate methodologies reported previously (Banks *et al.*, 1990), but it runs counter to the spectroscopic mass ratio of Tomkin (1985).

We relate the disparity to the photometric irregularities of R CMa, regarding these as due to interactive effects, and modelled the difference between the data and initial theoretical fit as a mass transfer 'hot spot' on the on the K3 $\pm$ 2 secondary (Guinan and Ianna, 1983). Our ILOT-type program uses the formalism of Budding (1977), and also generates an undistorted residual light curve. An arbitrary ratio of two for the spot to photospheric flux was assumed, with the spot site being equatorial. The hot spot was placed at longitude 19.6 ± 3.7 deg, with radius 9.6 ± 0.1 deg. This ties in with the impact location of a mass transferring stream, deflected to the following hemisphere of the primary in the standard Roche lobe overflow scenario (cf. Lubow and Shu, 1975). A subsequent best fitting to the residual light curve (Figure 1a) produced the parameters of Table 1. The new secondary radius (0.218) corresponds to a semi-detached configuration at $q = 0.15$ (Kopal, 1959), thus confirming the usual view of the system in recent literature.

The adopted parameters of Table 1 differ, by ~5%, from those given by Guinan (1977), but they are within the ~7% error limits of the absolute parameter determination of Tomkin (1985). The large secondary overluminosity ($\sim 0.5 L_\odot$) for a star of only $0.17 M_\odot$ is a conspicuous feature of the system, which the evolved Algol scenario has a natural explanation for.

Algol systems show a characteristic pattern of variation for the Hα narrow – wide difference (the Hα index), through the primary eclipse, related to mass transfer effects (cf. Khan and Budding, 1986). Such a variation can be simply modelled by an emitting disk-like structure about the primary star, in keeping with more detailed physical representations (eg. Prendergast and Taam, 1974). In the comparable cases of U Cep and U Sge electron densities in the range 10^{10} – 10^{11} were derived in structures of mass around 5×10^{20} g. There also tends to be some asymmetry, with more emitting material towards the following hemisphere of the primary.

The Hα data for R CMa confirm our general expectations, though the quality of the data is not exemplary, and not suitable for detailed modelling. The broad

Figure not submitted

Fig. 1. (a)ILOT fitting to the R CMa photometric data after accounting for the effects of a 'hot spot'. (b) Theoretical variation of Hα index compared with observed data.

features are: (i) a significant rise in the index just after primary minimum — consistent with the eclipse of a region where emitting matter is concentrated; (ii) a minimum coincident with the main eclipse, due to the relatively increased contribution of the later star in the combined effect at this phase; (iii) a 'normal' level — approximated by the index values well away from primary eclipse.

In Figure 1b we show a theoretical curve passing through the data, corresponding to the model discussed in Khan and Budding (1986). The disk model parameters are the same as given for U Cep, except that the fractional extent h was reduced to 0.4 for R CMa, and the equivalent widths are 1Å for ingress and 4Å for egress.

From this, we estimate electron densities of order 3.10^{10} (on average) in the weak accretion structure around primary equator whose net mass is some 2×10^{18}g. This is only of the order of 1% that found for the weak disks of U Cep and U Sge, due mainly to the much smaller volume for R CMa. The sense of the Hα index asymmetry is apparently greater for R CMa, probably because of the greater proportional size of the primary star in comparison to its Roche Lobe.

3. Conclusions

Photometric analysis of the system R CMa is inherently not well defined, because the eclipses are only partial, and also there are irregularities in the light curve — probably varying with time, and related to binary interactive effects.

Initial modelling of the data of Edalati *et al.*, (1989), by both WD and ILOT procedures, indicated R CMa to be a detached binary. This is plausible for a pair of unevolved Main Sequence dwarfs, but contrasts with the semi-detached configuration supported by the spectroscopic mass ratio and photometric irregularities.

The data can be reconciled with a classical Algol by first removing the effect of a 'hot spot', whereupon a semi-detached configuration fits the residual light curve. The Hα index variation through the primary eclipse also supports the Algol model.

We are still left with the combination of low masses and low period — necessitating a complex previous history if we are to retain the present picture (cf. Tomkin and Lambert, 1989, for a detailed discussion). Any conservative scenario would require a minimum separation of the two mass centres of just $1.2R_{\odot}$. The external Lagrangian points are then $0.84R_{\odot}$ away from the mass centres, ie. at distances comparable to the unevolved radii of $0.7M_{\odot}$ stars. It seems inevitable that systemic mass loss would then occur. The implied loss of angular momentum suggests that, in any case, a substantial proportion (perhaps ~80% (Tomkin, 1985)) of the present secondary's mass was somehow lost from the system — rather atypically larger than most classical Algols require. We are thus still far from a complete understanding of R CMa, and urge continued efforts at observation and interpretation.

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