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CM Draconis: Masses and Radii of Very Low Mass Stars

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Abstract. In this work we have studied CM Draconis, one of the least massive eclipsing binaries known. Its components are very similar, with masses and radii of about 0.23 $M_\odot$ and 0.25 $R_\odot$. We have analysed light curves in the R and I bands to calculate the fundamental properties of this system with accuracies better than 1%. With these results we plan to carry out a thorough test of the models, which have been found to predict smaller radii and larger effective temperatures than observed for these low-mass stars. This will also be especially interesting in the case of CM Dra since the mechanism driving magnetic activity is thought to be different from that of more massive stars. In addition, the extended time-span of the observations has led to the detection of apsidal motion. This provides a further check on models through the determination of the internal structure of the stars.

Keywords. Binaries: eclipsing, binaries: spectroscopic, stars: fundamental parameters, stars: individual (CM Dra), techniques: photometric

1. Introduction

The eclipsing binary CM Draconis is one of the least massive stellar binary systems known since its discovery by C. Lacy in 1975 (see Lacy, 1977). This system is composed of two main sequence stars of spectral types dM4. Both eclipses have nearly equal depths since the two components are quite similar. The orbital period is about 1.268 days, short enough to keep the two components in almost synchronized orbital motion. Its distance is 15 pc and it has a maximum visual magnitude of 12.9. The presence of the signature of spots as a ~0.01 magnitude modulation on the light curves indicates that the system components have active regions on their surfaces.

Eclipsing binary systems have the powerful feature that, using light curves in several bands and radial velocity curves, the orbital parameters and the masses and radii of the components can be derived. This is accomplished by using fitting codes such as Wilson-Devinney (Wilson & Devinney, 1971; WD). In this way, the calculated stellar properties are accurate enough to test stellar models. Recent results (Ribas, 2006) indicate that low-mass stellar models predict ~10% smaller radii and ~5% larger temperatures for a given mass than observed, although the predicted and measured luminosities are in good agreement. The discrepancies are significant when compared to the accuracy level of ~1%

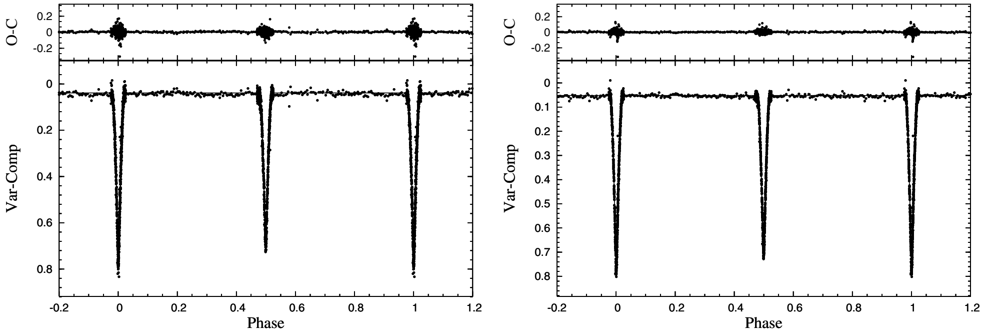

Figure 1. Fitted light curves in R- (left) and I- (right) bands of the data from FCAPT. Normal points have been computed in the out-of-eclipse phases.

reached in the calculation of the fundamental properties of the stars. The differences between models and observations seem to be due to the high magnetic activity level of low mass stars in close binary systems, but this still needs to be investigated.

The main feature of CM Dra is that the masses of its components are low enough to be fully convective, so the magnetic dynamo mechanism is different from that of more massive stars with radiative cores (Chabrier & Küker, 2006). In contrast, it has been proposed that the inclusion of magnetic fields in the models predicts radiative cores down to 0.1–0.2 $M_\odot$ stars (Mullan & MacDonald, 2001). Accurate investigation of the components of CM Dra will shed more light to discern the correct scenario. A small orbital eccentricity is an additional feature of this system. Variations in the times of minima have led us to detect apsidal motion, which provides a further test to the models because its rate depends on the internal structure of the stars.

2. Available data and analysis procedure

The available data for CM Dra comes from different sources: an I-band light curve from Lacy (1975), six R and I seasonal band light curves from the Four College APT (1996-2001) and an R-band light curve from the Sleuth telescope (2004).

The first step has been the correction of the modulation induced on the light curves by the spots present on the surface of the stars. This can be done by adjusting several spot parameters within the WD code for each seasonal light curve. After combining some of the datasets, we end up with four light curves, two in both R and I bands, covering a time interval of 29 years of observations (Figure 1). The spectroscopic elements of CM Dra have been adopted from Metcalfe *et al.* (1996). Modeling of the observations has been done with the WD code using time as independent variable.

Also available, there are more than 150 observed times of minima of CM Dra spanning over 30 years. Times of minima can be measured with high accuracy (∼10 s) for CM Dra and therefore subtle variations in the occurrence of eclipses are detectable.

3. Results

3.1. *Stellar properties*

One of the goals of this study is to obtain accurate measures of the stellar properties of the components of CM Dra, i.e., masses and radii. Our analysis using the WD code has provided good fits to the observations and therefore accurate determinations of the orbital

Table 1. Orbital and physical properties of the system.

Parameter	Solution 1	Solution 2
P (days)	$1.268389919 \pm 0.000000006$	
Epoch (HJD)	$2442893.93200 \pm 0.00004$	
e	0.0024 ± 0.0005	0.0019 ± 0.0005
ω (°)	231 ± 7	132 ± 4
$d\omega/dt$ (°/day)	$(-0.3 \pm 0.4)\cdot 10^{-3}$	$0.4\cdot 10^{-3}$ (fixed)
i (°)	89.68 ± 0.06	89.66 ± 0.05
$M_2/M_1{}^*$	0.926 ± 0.006	
a ($R_\odot$)*	3.75 ± 0.01	
T_2/T_1	0.9953 ± 0.0016	0.9943 ± 0.0016
L_2/L_1 (R-band)	0.862 ± 0.005	0.880 ± 0.006
L_2/L_1 (I-band)	0.865 ± 0.006	0.885 ± 0.006
r_1 & r_2	0.0669 & 0.0629 (± 0.0001)	0.0664 & 0.0637 (± 0.0002)
R_1 & R_2 ($R_\odot$)	0.251 & 0.236 (± 0.001)	0.249 & 0.239 (± 0.001)

* from Metcalfe *et al.* (1996).

and physical properties (see Table 1). However, there exists an ambiguity that is due to the very small eccentricity of the orbit (~0.002). While the separation of the primary and secondary eclipses, which is a function of $e\cdot\cos\omega$, is computed with high precision, the width of the eclipses, which is related to $e\cdot\sin\omega$, is much more difficult to measure. Therefore, we have derived two good-fitting complementary solutions with ω=132° and ω=231° (see Table 1). The difference in the width of the eclipses of these solutions is ~30 s, and even with our large datasets, they are indistinguishable. Further very accurate data with dense time sampling combined with a refined spectroscopic analysis will be used to solve this ambiguity.

When comparing our results with the predictions of the stellar models of Baraffe *et al.* (1998) we find that the observed radii are larger by about 3.3% in solution 1 and 2.5% and 4.5% for the primary and secondary components, respectively, in solution 2. These discrepancies, go in the same direction as reported before for other low mass close binary stars, although they appear smaller. We plan to explore the effects of magnetic activity to assess the origin of the differencies observed.

3.2. *Apsidal motion*

The analysis of the light curves has also led to the detection of apsidal motion and we have used the times of minima in order to further define its value. We have found preliminary rates of about $-4\cdot 10^{-4}$ deg day^{-1} and $5\cdot 10^{-4}$ deg day^{-1} for solutions 1 and 2.

The sign of the apsidal motion is different depending on the configuration of the system, the confirmation of solution 1 would indicate the presence of a third body in the system since this would best explain this negative apsidal motion rate. The interpretation of the apsidal motion data is currently underway.

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