Accurate properties of low mass stars: masses and radii of CM Draconis

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Summary. Eclipsing binaries provide the only high-accuracy (\textasciitilde 1-2\%) measures of stellar masses and radii, making them suitable to carry out tests of the models of structure and evolution of stars. In this work we have studied CM Draconis. Its components are very similar, with masses and radii of about 0.23 M\textsubscript{\odot} and 0.25 R\textsubscript{\odot}, respectively. We have analysed light curves in the R and I bands to calculate its fundamental properties with accuracies better than 1\%. With these results we plan to carry out a thorough test of stellar 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 and the small eccentricity of the orbit have led to the detection of apsidal motion providing a further check on models through the determination of the internal structure of the stars.

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 [4]). This system is composed of two similar main sequence stars of spectral type dM4. The orbital period is about 1.268 days and the eclipses have almost equal depths. As many other close binary systems the two components are in synchronized orbital motion. CM Dra is at a distance of 15 pc and it has a maximum visual magnitude of 12.9. The star components are active as can be deduced from the signature of spots as a \textasciitilde 0.01 magnitude modulation on the light curves.

In general, the orbital parameters and the masses and radii of the components of eclipsing binary systems can be computed using light curves in several bands and radial velocity curves. There are specific codes, such as Wilson-Devinney [8] (WD), to fit these parameters to light and radial velocity curves.
Fig. 1. Magnitude modulation induced by spots: (a) single I band FCAPT light curve (1997) and (b) R band Sleuth light curve (2004).

with enough accuracy to test stellar models. Recent results [7] indicate that low mass star models predict \( \sim 10\% \) smaller radii and \( \sim 5\% \) larger temperatures for a given mass although the predicted and observed luminosities are in agreement. Such discrepancies are significantly larger than the accuracy level of \( \sim 1\% \) reached in the calculation of the fundamental properties of the stars. A hypothesis put forward to explain the differences between models and observations is the high magnetic activity level of low mass close binary systems that cause the appearance of spots on the surface of the star, so part of the outgoing internal energy is blocked and the structure may be modified to reach equilibrium [7]. This hypothesis is currently under study.

An important feature of the components of CM Dra is that the standard models predict them to be fully convective, so the magnetic dynamo mechanism is different from that of more massive stars with radiative cores [2]. In contrast, some authors show that the introduction of magnetic fields in the models predicts the existence of radiative cores down to 0.1-0.2 \( M_\odot \) stars [6]. Accurate investigation of the components of CM Dra will shed more light to discern the correct scenario. An additional feature of this system is its small orbital eccentricity. 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 stars.

2 Available data and analysis procedure

We have more than 20000 I and R band measurements of the CM Dra system coming from different sources: an I band light curve from Lacy (1975), R and I band light curves from the Four College APT (1996-2001) and an R band light curve from the Sleuth telescope (2004).

The first step in the analysis has been the correction of the modulation induced in 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. Their effect can be removed from the light curves by combining a solution with spots and a synthetic one without spots. Despite the possibility of computing both the system and spot parameters at the same time, we removed the spot effect in order to combine light curves from different epochs that show different modulations (Figure 1). After combining some of such light curves and computing out-of-eclipse normals to reduce the number of data points, we end up with four of them, two in both R and I bands, covering a time interval of 29 years of observations. The spectroscopic elements of CM Dra have been adopted from [5]. Modeling of the observations has been done with the WD code using time as independent variable.

More than 150 observed times of minima of CM Dra spanning over 30 years are also available. 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. These variations are due to the presence of tidal interactions between the system and can be used to study the internal structure of the components.

3 Results

3.1 Stellar properties

Our analysis using the WD code has provided good fits (Figure 2) to the observations and therefore accurate determinations of the orbital and physical parameters (see Table 1). However, further very accurate data with dense time sampling combined with a refined spectroscopic analysis will be used to corroborate and redefine these properties in order to carry out a critical test of stellar structure models.

The comparison of our results with the stellar models of [1] indicates discrepancies on radii of about 3% and 6% for the primary and secondary components, respectively. These discrepancies, go in the same direction as reported
Table 1. Orbital and physical properties of the system. * from Metcalfe et al. (1996).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (days)</td>
<td>$1.268389921 \pm 0.00000006$</td>
</tr>
<tr>
<td>Epoch (HJD)</td>
<td>$2442893.93200 \pm 0.00004$</td>
</tr>
<tr>
<td>$e$</td>
<td>0.0064 $\pm 0.0005$</td>
</tr>
<tr>
<td>$\omega$ (°)</td>
<td>$104 \pm 7$</td>
</tr>
<tr>
<td>$d\omega/dt$ (*/day)</td>
<td>$(0.5 \pm 0.4) \times 10^{-3}$</td>
</tr>
<tr>
<td>$i$ (°)</td>
<td>$89.65 \pm 0.06$</td>
</tr>
<tr>
<td>$M_2/M_1$*</td>
<td>0.926 $\pm 0.006$</td>
</tr>
<tr>
<td>$a$ (R⊙)</td>
<td>$3.75 \pm 0.01$</td>
</tr>
<tr>
<td>$T_2/T_1$</td>
<td>$0.993 \pm 0.002$</td>
</tr>
<tr>
<td>$L_2/L_1$ (R band)</td>
<td>$0.902 \pm 0.005$</td>
</tr>
<tr>
<td>$L_2/L_1$ (I band)</td>
<td>$0.908 \pm 0.006$</td>
</tr>
<tr>
<td>$r_1$ &amp; $r_2$</td>
<td>$0.0665 &amp; 0.0646 (\pm 0.0001)$</td>
</tr>
<tr>
<td>$R_1$ &amp; $R_2$ (R⊙)</td>
<td>$0.250 &amp; 0.242 (\pm 0.001)$</td>
</tr>
</tbody>
</table>

before for other low mass stars, although they appear smaller. We plan to explore the effects of magnetic activity to assess the origin of these differences.

### 3.2 Apsidal motion

The WD code can fit a linear variation of the argument of periastron, and from the analysis of the CM Dra light curves we have observed that the best fits are obtained with this parameter free. Nevertheless, we have used the times of minima in order to further define its value in a more accurate way. With these data, we have found a preliminary apsidal motion rate of about $4.0 \times 10^{-4}$deg day$^{-1}$.

This apsidal motion rate is related to the internal structure of stars by means of the internal structure constant $k_2$ [3], giving a further test to the stellar models. The accurate computing of the apsidal motion using times of minima and the study of the internal structure constant compared with theoretical models is under way.

**Acknowledgements**

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**References**