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HD 172189: an eclipsing and spectroscopic binary with a δ Sct-type pulsating component in an open cluster

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Abstract. We present a study based on more than 2500 *ubvy*-measurements collected on HD 172189, a new eclipsing binary system with a δ Sct-type pulsating component that belongs to the open cluster IC 4756. The great interest of this object lies in that three important characteristics coexist: cluster membership, binarity and pulsation. Its binarity and the δ Sct-type pulsations of one component were detected in the course of several Strömgren photometric campaigns. The frequency analysis of all the *ubvy* out-of-eclipse data reveals a clear frequency of 19.5974 cd^{-1} as well as the existence of other high values in the range 18–20 cd^{-1} . We have also carried out a first evaluation of the binary parameters and determined a value of 5.702 d for the orbital period. An additional potential interest of HD 172189 resides in its location in the field of view of the COROT mission and, therefore, this star is an excellent candidate for becoming a target for asteroseismology.

Key words. stars: binaries: eclipsing – stars: oscillations – stars: variables: δ Sct – Galaxy: open clusters and association: IC 4756

1. Introduction

The existence of stellar pulsation in an eclipsing binary system is a very interesting phenomenon for the theoretical study of the variable component because binarity provides useful information on its stellar parameters and pulsation modes (Reed et al. 2002). However, few objects of this type have been discovered to date. Several examples of δ Sct pulsators in stellar systems can be found in Lampens & Boffin (2000). More recently, Rodríguez et al. (2004) reported a complete list of δ Sct stars detected in eclipsing binary systems. In addition, if binarity and intrinsic variability are favourable conditions that contribute to a better knowledge of the pulsational behaviour, the fact that the star belongs to an open cluster implies additional advantages. The stellar parameters (age, chemical composition and distance), which are shared by all the member stars of a cluster, place constraints on stellar models, enhancing our knowledge from the oscillation modes. RS Cha is the only example of an eclipsing binary with a δ Sct component in a cluster reported in the literature. This star is an A-type double-lined eclipsing binary belonging to the new young open cluster η Chamaeleontis (Luhman & Steeghs 2004, and references therein). Long before its membership to this cluster was established, RS Cha was

discovered to be an eclipsing binary by Strohmeier (1964). A *ubvy* study to determine the parameters of the system was carried out by Clausen & Nordstrom (1980) but the authors were not able to conclude whether the detected δ Sct variations correspond to only one or both components. Recently, Gáspár et al. (2003) have discovered a δ Sct star in an eclipsing binary in the field of the cluster NGC 2126 using CCD photometric observations. However, their astrometric study suggests non-membership to the cluster.

HD 172189 is classified as an A2-type star with a *V* magnitude of 8.85. Several studies using proper motions demonstrate that this object belongs to the open cluster IC 4756 (star 93 in the numbering system of Kopff 1943). The binarity of HD 172189 was discovered in the summer of 1997 during an observing campaign carried out for detecting γ Doradus pulsating stars in the cluster IC 4756 (Martín 2000; Martín 2003). With a time span of 10 nights, only one minimum of light was detected. In order to determine the orbital period of the binary system, new observing campaigns were carried out in following years. From these measurements, new light minima and δ Sct-type oscillations were detected.

Furthermore, HD 172189 is located in the summer field of view of the forthcoming COROT mission (Baglin et al. 2002).

Lying close to the main target HD 171384, it represents an excellent candidate for being selected as secondary target (Poretti et al. 2005).

2. Observations

The *uvby* photometric observations presented in this letter were obtained in different campaigns during 1997, 2003 and 2004, lasting for a total of 48 nights. In the years 1997 and 2003, the *uvby* measurements were performed using the 90-cm telescope at Sierra Nevada Observatory (SNO, Spain) and later, during the summer of 2004, a two-site campaign was carried out together with the 1.5-m telescope at San Pedro Mártir Observatory (SPMO, Mexico). In both sites, twin six-channel simultaneous Strömgren photometers were used. We employed HD 172365, SAO 123720, HD 173369, HD 181414 as comparison and check stars for the different observing runs. In the 2004 coordinated campaign, only one comparison star (HD 172365) was observed because the results derived from the first observations did not show any sign of variability. In total, more than 2500 measurements in each of the four filters *uvby* have been obtained.

Moreover, two closely time spaced, high-resolution ($R = 48\,000$) spectra were collected in June 2, 2004 using the FEROS spectrograph attached to the ESO 2.2 m-telescope at La Silla (Chile). The spectra were obtained in the framework of the preparation of the GAUDI archive (Solano et al. 2005) for the COROT mission.

3. The membership of HD 172189 to the cluster IC 4756

The first reference to the open cluster IC 4756 dates from 1943, when Kopff (1943) carried out a detailed study of the clusters NGC 6633 and IC 4756 and provided spectral types for 203 stars using photographic photometry and spectroscopy. Several photometric studies have been published with estimations of the cluster's age, distance or colour excess (Alcaino 1965; Schmidt 1978; Smith 1983; Martín 2000). However, the number of studies on the membership of the observed stars is smaller. Preliminary proper motions and *UBV* photometry were obtained by Seggewiss (1968), whose values were updated by Herzog et al. (1975). In this latter work, the membership of HD 172189 to the open cluster IC 4756 was negative according to the *UBV* photometry. Only those stars located within twice the standard error of the photographic photometry to the ZAMS and giant branches in the two-colour and the colour-magnitude diagrams simultaneously were considered as members. Schmidt (1978) later obtained Strömgren photometric measurements of HD 172189 ($b - y = 0.258$, $m_1 = 0.123$, $c_1 = 1.055$, $\beta = 2.820$) and derived a colour excess of $E(b - y) = 0.159$ and a true distance modulus of 7^m11 . This distance modulus value is considerably smaller than the cluster average 8^m05 in spite of the reddening value being similar to what was expected for the corresponding part of the cluster where HD 172189 is located (~ 0.15 mag). The conclusions of both investigations about the membership of HD 172189 to the cluster based on photometry should thus be revised. The effects

of the binarity we claim may modify such conclusions since apparent magnitudes as well as colour indices were considered as representing those of a single star.

The opposite situation is found when considering the analysis of the membership from proper motion measurements. Firstly, Herzog et al. (1975) reported a probability of 0.92 of HD 172189 belonging to IC 4756. More recently, the membership of this star was confirmed by Missana & Missana (1995) who re-studied this cluster through a specific statistical method. Their results, obtained with the χ^2 criterion and those obtained by Herzog et al. (1975) from the criterion of the maximum likelihood of Sanders (1971) are in concordance, reporting for HD 172189 a probability of 0.95 for cluster membership.

4. The binary system

The light curves from the data collected for HD 172189 show three light minima due to eclipses. Only one of the eclipses was followed past the minimum in brightness. We carried out a period search using the method of Schwarzenberg-Czerny (1996). From the analysis we obtained the ephemeris $T(\text{min I}) = \text{HJD } 2\,452\,914.644(3) + 5.70198(4)$ d. The Strömgren *v*-filter differential magnitude phased with the orbital period of 5.70198 d is depicted in the bottom panel of Fig. 1. The observed primary eclipse depth is of approximately 0.12 mag.

We used the May 2003 version of the Wilson-Devinney program (Wilson & Devinney 1971) for a first modelling of the photometric light curve. We fitted the orbital parameters to reproduce the depth of the primary eclipse, the lack of a secondary minimum and the out-of-eclipse variations. The solutions call for a system with a moderate orbital eccentricity of $e \approx 0.24$, a longitude of the periastron of $\omega \approx 68^\circ$ and an inclination of $i \approx 73^\circ$. The best fit is obtained with two components of quite different radii ($r_2/r_1 \approx 0.6$) but similar temperatures ($T_{\text{eff}2}/T_{\text{eff}1} \approx 1.05$), although the temperature ratio is a poorly constrained parameter. It is worth noting that the absence of a secondary minimum is likely caused by the geometric orbital configuration (i.e., different relative separations at the two eclipse phases) rather than by the components having very unequal temperatures. This lack of a secondary eclipse makes the determination of e and ω still tentative because these parameters are fully determined by the subtle out-of-eclipse variations. In Fig. 1 we show our best fit to the Strömgren *v* light curve, with an rms of 0.0057 mag, and the phased (O-C) residuals.

The available high-resolution spectra were used to measure the radial velocities of the two components since double lines are clearly visible (SB2). We employed the two-dimensional cross-correlation algorithm TODCOR (Zucker & Mazeh 1994) with synthetic spectrum templates computed for a temperature of 8000 K. We obtained velocities of about 63 km s^{-1} and -127 km s^{-1} for the primary (i.e., more luminous) and secondary components, respectively. Unfortunately, the two spectra were taken very close in time and in the same orbital quadrature and thus the direct determination of the component mass ratio is not possible. Nevertheless, a rough estimation of the mass ratio can be made if we assume the mean radial velocity of the cluster ($\sim -26 \text{ km s}^{-1}$; Mermilliod & Mayor 1990) as the systemic velocity of the binary. We obtain a value of

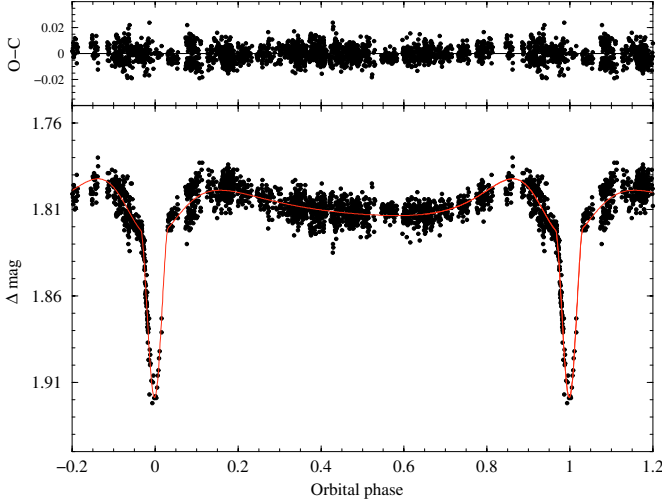


Fig. 1. Strömgren differential v light curve of HD 172189 for all data with a preliminary fit (see text). The upper panel shows the (O–C) residuals.

$M_2/M_1 \approx 0.9$, which suggests that the two components are quite similar in mass. In addition, our analysis yields a luminosity ratio of the two components of $L_2/L_1 \approx 0.5$, which, when combined with the mass ratio, would indicate a rather evolved system. According to the ephemeris listed above, the spectra were taken around phase 0.83. However, because of the still uncertain values of e and ω , we cannot make a reliable prediction of the individual stellar masses at this point. A complete radial velocity curve, as well as multi-wavelength and dense light curves, are needed to achieve a full description of the binary system.

Finally, a possible alternative explanation for the observation of only one eclipse in the light curve is the presence of identical eclipses separated by 0.5 phase (i.e., zero eccentricity). In this case, the orbital period of the binary system would be about 11.4 d. Note, however, that this scenario results in a light curve with out-of-eclipse variations that cannot be easily explained with fitting programs. Moreover, from the measured radial velocities, $K_1 + K_2 \gtrsim |RV_1 - RV_2| = 190 \text{ km s}^{-1}$ can be estimated, with K_1 and K_2 being the velocity semi-amplitudes. Using Kepler's Third law, the total mass of the system in this case would be greater than $8 M_\odot$, predicting components with masses significantly higher than expected for a δ Sct star. We thus strongly favour the scenario with $P = 5.702 \text{ d}$.

5. The pulsating component

The short period variability caused by pulsations during out-of-primary-eclipse observations is shown in Fig. 2. This differential light curve in the v filter corresponds to the last two-site campaign in the summer of 2004. Very small-amplitude oscillations around a few thousandths of a magnitude are observed in most of the nights. The deviations with respect to the average magnitude are produced by the variations of the orbital phase of the binary pair. As can be seen, this magnitude difference becomes more evident near the primary eclipses, for instance, around HJD 2 453 228.4–2 453 228.8 and HJD 2 453 233.4.

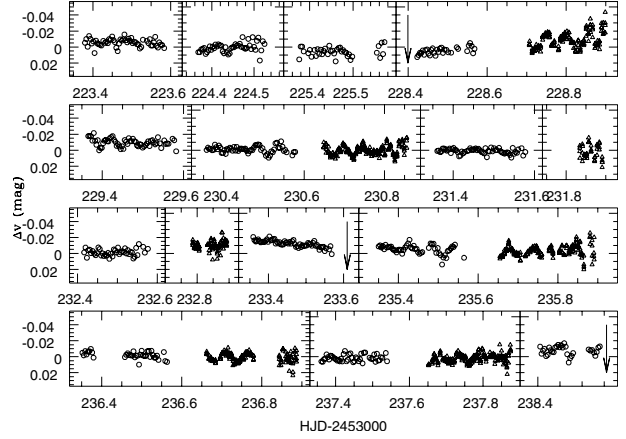


Fig. 2. v -band differential light curves obtained from the two-site campaign. The primary eclipse phases have not been plotted. The open circles and triangles correspond to the SNO and SPMO data, respectively. The vertical arrows mark the positions of the three observed primary minima (HJD-2 453 000 = 228.174, 233.875 and 239.578).

As to the identity of the pulsating component, there is no reliable evidence at this point. However, the oscillations are probably related to the primary component since it contributes $\sim 70\%$ of the total light. To determine the oscillation modes of the pulsation a frequency analysis has been performed using all out-of-primary-eclipse measurements. The method used is the same as in Rodríguez et al. (1998), where single frequency and multiple frequency techniques are combined using both Fourier and multiple least squares algorithms.

To ensure consistent results, the analysis has been made in the three filters (vby) where the precision of the measurements is better. In addition to the frequency $f_1 = 0.17541 \text{ cd}^{-1}$ corresponding to the orbital period, we have detected a set of peaks in the typical δ Sct region of $18\text{--}19 \text{ cd}^{-1}$, with $f_2 = 19.59740 \text{ cd}^{-1}$ and $f_5 = 18.87939 \text{ cd}^{-1}$ corresponding to the frequencies with the highest amplitudes. Figure 3 shows the power spectra in the filter v before (top panel) and after prewhitening the orbital period, f_2 and f_5 (middle and bottom panels), respectively. The bottom panel represents the residuals. After this cleaning procedure, several peaks remain in high frequencies with semi-amplitudes below 2 mmag.

Our analysis not only shows peaks corresponding to the high modes but also reveals the presence of low frequencies – $f_3 = 1.55425 \text{ cd}^{-1}$ and $f_4 = 0.05995 \text{ cd}^{-1}$ – not shown in Fig. 3. In contrast to f_2 and f_5 , these frequencies were different in all filters. Such values appear as a consequence of the binary effects, not completely removed by the f_1 term, together with a high number of measurements collected from only one site and the existence of the numerous gaps between the different observing periods. For the purpose of verifying the nature of f_3 and f_4 , a second frequency analysis has been carried out with only the data set observed during the 2004 two-site campaign. The results confirm the orbital period obtained considering all the measurements in addition to new frequencies very close to f_2 (19.5960 and 19.4887 cd^{-1}). The number of peaks in low frequencies, as well as the number of aliases, decreases. Therefore, the values f_3 and f_4 have been excluded from the

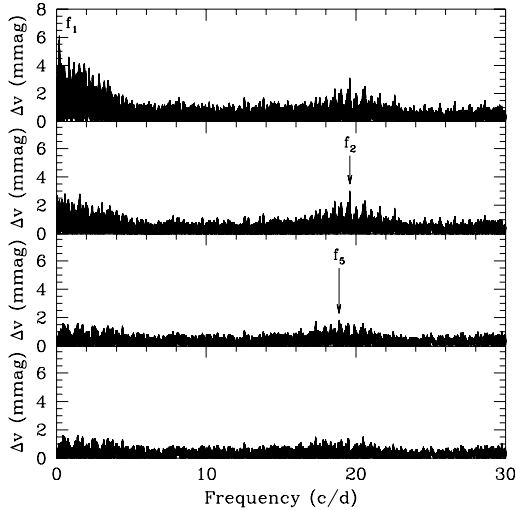


Fig. 3. Power spectra in the v filter before and after prewhitening the following frequencies: $f_1 = 0.17541 \text{ cd}^{-1}$, $f_2 = 19.59740 \text{ cd}^{-1}$ and $f_3 = 18.87939 \text{ cd}^{-1}$.

final solution. The spectral region in which peaks from the binarity variation and data sampling appear, is sufficiently far from that of the δ Sct variation as to not to affect our analysis of the pulsations.

6. Conclusions

Photometric measurements collected over several years have allowed us to discover the binary nature and δ Sct pulsation of HD 172189. The first minimum in brightness was observed during the summer of 1997. To detect a second eclipse, new campaigns were carried out in 2003, which also unveiled small amplitude oscillations in the light curves. The orbital period of the binary system could not be determined until the two-site campaign in 2004 took place. The most important preliminary results of these observations are:

1. An orbital period of 5.702 d and an eclipse depth in the primary minimum of about 0.12 mag have been estimated.
2. Preliminary simulations of the binary solution suggest that this object is a classic eclipsing binary system with an eccentric orbit. The components likely have similar masses and are at a rather evolved evolutionary stage.
3. Frequencies have been detected in the region of 18–20 cd^{-1} when analyzing the out-of-eclipse data. Within this range, the frequencies of 19.59740 and 18.87939 cd^{-1} are those with higher amplitudes (less than 5 mmag).

With high probability, HD 172189 is a binary system belonging to the IC 4756 open cluster that also shows δ Sct-type pulsations. We have presented a preliminary analysis of the currently available data but more photometric and spectroscopic observations are required to verify the physical parameters

of this eclipsing binary system. Measurements obtained during the eclipses could be very useful in typifying the oscillation modes of the pulsating component. Actually, HD 172189 offers a unique possibility in the δ Sct scenario, especially when considering the possible COROT pointing. Indeed, the complete characterization of this important system will permit detailed investigations of stellar structure and evolution thanks to the many constraints provided by binarity and cluster membership.

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