δ Scuti Stars in Stellar Systems: the interest of HD 220392 and HD 220391

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Abstract. The very wide double star CCDM 23239-5349 is an interesting study case of a pulsating star within a common origin pair or wide binary. Both stars are located in the δ Scuti instability strip. Based on data obtained at La Silla (Chile), at the Swiss 0.7m and the ESO 0.5m telescopes, we found two periodicities of about 4.7 and 5.5 cycles per day (cpd) with amplitudes of 0.014 and 0.011 mag, respectively, for HD 220392, the brightest member of the system. The most dominant periodicity was also detected in the Hipparcos Epoch Photometry data. A similar period search on the (smaller) dataset obtained for the 1 mag fainter B-component, HD 220391, however shows no periodic behaviour with an amplitude significantly above the noise level of the data (about 0.006 mag).

1. Introduction

The double star CCDM 23239-5349 is a wide visual system consisting of two bright stars (with Δm ≃ 1 mag and an angular separation of 26.5 arcsec) having similar proper motions as well as compatible parallaxes. This classifies it as a wide binary (see Sect.4.1).

Regular short-period light variations on a time scale of ≃ 5 hr have been detected for the brightest component of the system (Lampens 1992). The detailed investigation of the difference in variability and physical properties between two components of a stellar pair is particularly interesting when both companions are located in the same area of the colour-magnitude diagram: in this case both stars are situated in the δ Scuti instability strip. The aim of this study is to search for clues to understand which factors determine the pulsation characteristics such as modes and amplitudes among δ Scuti stars. A more extensive discussion will appear elsewhere (Lampens, Van Camp, & Sinachopoulos 2000).

1Based on observations done at La Silla (ESO, Chile) and on data obtained by the Hipparcos astrometry satellite.
2. Observations and reduction

The photometric data have been gathered during three campaigns at La Silla: two campaigns performed at the 0.7m Swiss telescope (P. Lampens) plus one at the 0.5m ESO telescope (D. Sinachopoulos). In Table 1 we display the amount of data taken for the targets HD 220392 (396 data) and HD 220391 (245 data). All Geneva data are absolute measurements in the filters UBVB1B2V1G of the Geneva Photometric System acquired with standard star measurements and obtained via a centralized reduction method (Rufener 1988). This centralized processing has not been applied to the ESO data taken in the UBV photometric system. The reduction of the October data implied using a check-star HD 220729 (V=5.52, sp. type F4V) whose measurements were interpolated between the two other ones. We have verified the constancy of this star ($H_p = 5.6197 \text{ mag}, \sigma_{H_p} = 0.0005 \text{ mag}$) in the Hipparcos Catalogue (ESA 1997) and we have fitted a 5th degree polynomial to the check-star observations for each night separately. This polynomial was then subtracted from the data of both programme stars in order to suppress as well as possible common variations. The ESO data are thus interpreted as differential measurements only.

In addition we made use of the data in the Hipparcos Epoch Photometry Catalogue (ESA 1997).

3. Period analyses

3.1. HD 220392

We combined the 3 nights of ESO V data with the Geneva V magnitudes into a total of 396 V data with a time base of 866 days by adjusting the mean value of the ESO (differential) data to the mean Geneva V magnitude. We made use of PERIOD98 (Sperl 1998) for the frequency analyses and tested different combinations with the abovementioned dataset which confirm the results obtained with the Geneva data only. The results of these analyses are displayed in Tables 2b (Fourier fit) and 3 (frequency search) (Lampens, Van Camp, & Sinachopoulos 1999). Two alternative solutions are mentioned. After prewhitening for 4.67 cpd, a second frequency of 5.52 cpd was chosen as the next most dominant frequency because of a slightly higher reduction of the residual standard deviation of the largest dataset. The mean light curves presented in Figure 1 have amplitudes of 0.014 and 0.011 mag respectively: left is a plot of all the data against a frequency of 4.67439 cpd (after having taken the 5.52 cpd variation into account) while right shows the same but against a frequency of 5.52234 cpd. The residual dispersion after two prewhitenings amounts to 0.006 mag, which is of the order of the noise level in the data.

The Hipparcos Epoch Photometry Catalogue lists 183 measurements of HD 220392 (HIP 115510). The note in the Main Catalogue however mentions that the “data are inadequate for confirmation of the period from Ref. 94.191” (ESA 1997). The reason for this are the quality flags that all are equal to or larger than 16, meaning “possibly interfering object in either field of view”. The effective width of the aperture is 38 arcsec, so companions at angular separations between 10 and 30 arcsec may interfere significantly during the measurement. We rejected some suspicious data (Lampens et al. 1999). Fourier analysis of the
remaining 176 data then revealed $4.6743 \pm 0.0001$ cpd, the same frequency as found in all former datasets. The amplitude associated with $f_1$ is 0.013 mag large but the second frequency (5.52 or 6.52 cpd) remained below detection as a two-frequency fit attributed an amplitude of only 0.003 mag to $f_2$.

3.2. HD 220391

Data were obtained during the last two seasons only. The standard deviation of the 245 measurements is less than half the one of the previously discussed dataset. A frequency search was performed in a similar way as for HD 220392: one peak at the frequency of 0.42 cpd was found but the associated amplitude of 0.005 mag is below the expected noise level and the reduction of the standard deviation is too small.

The Hipparcos Epoch Photometry catalogue lists 182 measurements of HD 220391 (HIP 115506). Again all quality flags are equal to or larger than 16. We selected 172 data by applying the same conservative criteria as above. Fourier analysis between 0. and 23. cpd displayed a peak at $\sim 11$ cpd (with an associated amplitude of 0.013 mag!). This artifact frequency of order 2 hr$^{-1}$ is introduced by the rotation period of the satellite.

4. Astrophysical considerations

4.1. The nature of the association

From the mean Geneva colour indices and the corresponding calibrations for A-F type stars in the Geneva Photometric System (Künzli et al. 1997; Kobi & North 1990) we derived the physical parameters presented in Table 2. The Hipparcos astrometric data are useful to establish the nature of the association: the relative proper motion between the two components of this wide system is quite small ($\Delta \mu_{\alpha,B-A} \simeq -2.44$ milli-arcsec/yr (mas/yr), $\Delta \mu_{\delta,B-A} \simeq +1.57$ mas/yr with errors of the same order) while the parallaxes are compatible to better than 1.5σ ($\pi_A = 6.79 \pm 1.43$ mas, $\pi_B = 9.19 \pm 2.44$ mas). In the left part of Figure 2, all stars within 1.3° on the sky with proper motions from the Simbad database have been plotted to illustrate the concordance of the proper motions for both stars. These data confirm the common proper motion status and the probable physical association of the pair (van de Kamp 1982). Radial velocities would be very useful but such information is lacking for component B. Both components also share an identical projected rotational velocity.

We used the absolute magnitudes to fit a model of stellar evolution of solar chemical composition (Schaller et al. 1992) in a theoretical H-R diagram. The same isochrone with an estimated age of $\approx 10^9$ years for the system appears to fit both stars well (right part of Figure 2). This conclusion holds even after removal of the effects of rotation at the rate of half the break-up velocity (Pérez Hernández et al. 1999), as illustrated by the filled symbols in the same figure. We conclude that both stars thus form a common origin pair and probably even a true binary system.
4.2. The nature of the variability

The mean \((d, B_2-V_1)\)-values place both stars well within the \(\delta\) Scuti instability strip as observed in the Geneva Photometric System. We note the interesting situation where two physically associated stars with similar characteristics behave quite differently from the variability point-of-view. In the previous sections we have shown that the brightest component behaves as a \(\delta\) Scuti variable with a total amplitude of 0.05 mag while the fainter component presents no short-period variability of amplitude larger than 0.01 mag. What could the causes be for the difference in variability between both? From the Geneva colour indices, it appears that the brightest component has \(\Delta d > 0.100\), thus it is more evolved than its companion. From the isochrone fit, one may also notice the probable core hydrogen burning phase of HD 220391 and the overall contraction or shell hydrogen burning phase of the brightest component, HD 220392. Evolution appears in this case to be the probable cause for the observed diversity in variability.

From the properties listed in Table 2, the pulsation constants can be computed but there is no clear conclusion at present: one of the frequencies \((f_2)\) may possibly correspond to the fundamental radial mode \((F)(Q = 0.037\) or 0.032 days). Additional photometric observations for this interesting couple of stars is certainly recommended. The already obtained data are neither sufficiently numerous nor of sufficient quality to allow unambiguous solutions or to solve for the multiple frequencies. Radial velocities would be needed too.

5. Conclusion

What factors actually determine the pulsation characteristics, i.e., the amplitudes and modes of pulsation in the \(\delta\) Scuti instability strip? This question cannot be addressed on the basis of a single case. But it could be approached as illustrated here. Binary systems with pulsating variable components offer a unique opportunity of coupling the information obtained by astrometric means (association type - parallax - total mass) to the astrophysical quantities (luminosity ratio - colours - pulsation characteristics). For example, the detailed investigation of differences in variability between the components of a binary may provide relevant clues with respect to their pulsation characteristics. Differences in origin and age can be ruled out as well as differences in overall chemical composition. In this case the short-period pulsating component is easily identified and the information obtained on the variability can be coupled to the astrophysical parameters of each component. It would be even better to investigate such characteristics in a visual binary for which basic information on the orbital motion can be derived. This would allow one to obtain a direct estimation of the stellar mass, independent of any choice of modelisation. The derivation of the pulsation constant would be more straightforward too (the error on the mass defines the accuracy of \(Q\)).

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Table 1. Photometric data available for HD 220392 and HD 220391

| Identifier | Instrument 1 | Instrument 2 | Epoch 1          | Epoch 2          | Number of data 1 | Number of data 2 | Time base     |
|------------|--------------|--------------|------------------|------------------|------------------|------------------|--------------|
| HD 220392  | 0.7mGEN      | 0.7m+0.5mESO | June 90-Sept. 91 | June 90-Oct. 92  | 124              | 396              | 464          |
|            |              |              |                  |                  |                  |                  |              |
| Hipparcos  |              |              | Nov. 89-Mar. 93  |                  | 176              |                  |              |
|            |              |              |                  |                  |                  |                  |              |
| HD 220391  | 0.7mGEN      | 0.7m+0.5mESO | Sept. 1991       | Sept. 91-Oct. 92 | 98               | 245              | 19.1         |
|            |              |              |                  |                  |                  |                  |              |
|            |              |              |                  |                  | 172              |                  | 41 months    |

Figure 1. Phase diagrams for the HD 220392-data against the frequencies of 4.67439 cpd (after removal for the 5.52 cpd variation) (left) and of 5.52234 cpd (after removal for the 4.67 cpd variation) (right)

Figure 2. Proper motion distribution in the sky area around HD 220392/1 (left) and isochrone fit in the HR diagram (Z=0.020) (right). Filled symbols refer to the locations after the correction for rotation.
Table 2. Physical parameters derived for HD 220392/1

| Identifiers | HD 220392 | HD 220391 | Source |
|-------------|-----------|-----------|--------|
| Hip         | 115510    | 115506    |        |
| CCDM        | 23239-5349A | 23239-5349B |        |

| Sp. Type | F0IVn | A9Vn | GG89 |
|----------|-------|------|------|
| $m_v$    | 6.124 ± 0.014 | 7.103 ± 0.007 | |
| $U$      | 1.608 | 1.538 | |
| $V$      | 0.647 | 0.662 | G    |
| $B_1$    | 0.958 | 0.954 | E    |
| $B_2$    | 1.422 | 1.426 | N    |
| $V_1$    | 1.364 | 1.379 | E    |
| $G$      | 1.769 | 1.790 | V    |
| $d$      | 1.314 | 1.259 | A    |
| $B_2-V_1$| 0.058 | 0.047 |      |
| $M_V$    | +0.83 ± 0.15 | +1.62 ± 0.15 | |
| $M_{bol}$| +0.87 ± 0.15 | +1.66 ± 0.15 | FL96 |
| $\log T_{eff}$ | 3.856 ± 0.008 | 3.867 ± 0.009 | |
| $[M/H]$  | -0.05 ± 0.09 | -0.12 ± 0.10 |      |
| $\log g$ | 3.77 ± 0.07  | 4.06 ± 0.07  |      |
| $M$      | 2.3 ± 0.2    | 1.8 ± 0.2    | NO96 |
| $v\sin i$ | 165          | 140          | LE75 |
| $\pi_{phot}$ | 8.7 ± 1      | 8.0 ± 1      |      |
| $\pi_{Hip}$ | 6.79 ± 1.43  | 9.19 ± 2.44  | E    |
| $\mu_{\alpha}$ | 0.073        | 0.071        | S    |
| $\mu_{\delta}$ | -0.035       | -0.033       | A    |