On the nature of the $\delta$ Scuti star HD 115520

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Abstract. Observing Delta Scuti stars is most important as their multi-frequency spectrum of radial pulsations provide strong constraints on the physics of the stars interior; so any new detection and observation of these stars is a valuable contribution to asteroseismology. While performing uvby-beta photoelectric photometry of some RR Lyrae stars acquired in 2005 at the Observatorio Astronómico Nacional, México, we also observed several standard stars, HD115520 among them. After the reduction this star showed indications of variability. In view of this, a new observing run was carried out in 2006 during which we were able to demonstrate its variability and its nature as a Delta Scuti star. New observations in 2007 permitted us to determine its periodic content with more accuracy. This, along with the uvby-beta photoelectric photometry allowed us to deduce its physical characteristics and pulsational modes.

1. Introduction
In [1] confirmed the membership of HD 115520 to the $\delta$ Scuti class. It had been considered as a standard star in a 2005 observing run. From the relatively large scatter shown, [2] considered it to be variable candidate. With this in mind, new data were acquired in two new nights in 2006 which established it as a $\delta$ Scuti star. In the present paper we present new observations which were performed in 2007 with the same instrumentation over a period of four nights and which have served to determine its periodic content. The frequencies found explain the behavior of both seasons separated by more than one year.

2. Observations
These were taken at the Observatorio Astronómico Nacional, México using the 1.5 m telescope to which a spectrophotometer was attached. The observing season was carried out on four consecutive nights in March and April, 2007. The following observing routine was employed: a multiple series of integrations was carried out, consisting of five 10 s integrations of the star to which one 10 s integration of the sky was subtracted. Two reference stars were also observed C1: HD116879 and C2: HD114311. These were observed in the following sequence to optimize
the time coverage of the variable: V, sky, C1, V, V, C2, V. A series of standard stars was also observed at the beginning and at the end of each night to transform the data into the standard system. The Strömgren system [3] is an intermediate band width system that overcomes many of the shortcomings of the $UBV$ system and provides astrophysically important information. The color indices in the Strömgren system are very useful quantities. Because both the $b$ and $y$ filters are relatively free from blanketing, the index ($b - y$) is a good indicator of color and effective temperature. A color index is essentially the slope of the continuum. In the absence of blanketing, the continuum slope would be roughly constant and ($b - y$) approximately equals ($v - b$). Because ($v - b$) is affected by blanketing, the difference between these two indices indicates the strength of blanketing. Hence a metal index, $m_1$, can be defined as

$$m_1 = (v - b) - (b - y).$$

To determine how the continuum slope has been affected by the Balmer discontinuity, the index $c_1$ is defined as

$$c_1 = (u - v) - (v - b).$$

This index measures the Balmer discontinuity, nearly free from the affects of line blanketing.

The absolute photometric values of the 2007 campaign are provided in an archive. The accuracy of the season is deduced from the differences between the reduced and the previously reported values of the standard stars. Due to the fact that the last night was of lower quality, and hence, less accurate, the mean values of the differences are calculated only from the standards of the first three nights. They are: 0.015, 0.008, 0.007, 0.011 mag for $V$, ($b - y$), $m_1$, and $c_1$, respectively.

However, since the amplitude of the star is typical of a $\delta$ Scuti star ($\sim 20$ mmag, see Figure 4 and in Figure 2 of [1]), we preferred to analyze the data for the periodic content through differential photometry in the $y$ filter for which use was made of the reference stars C1 and C2 to increase the accuracy of the photometry to thousands of magnitude. A magnitude value of the reference stars was interpolated at the time of the variable and the final values, to which the average value of each night was subtracted.

3. Frequency determination

With the relatively few data points acquired in the 2006 season (only two short nights) we were able to demonstrate the star’s variability and found evidence of at least two close frequencies which might explain the resulting beating behavior of the light curve. Since the new photometric data is constituted of four long consecutive nights, we are now able to determine the pulsational frequencies with greater precision. Two numerical packages were utilized: Period04 [4] and ISWF [5]. With Period04 the first run examined gave a frequency of 17.8643 c/d with an amplitude of 0.0140 mag in the frequency interval between 0 and 30 c/d with a step rate of 0.0150. On the other hand, the ISWF package yielded the following frequencies (in c/d) listed in diminishing amplitudes (in parentheses, in mmag) 17.850 (13.877); 14.7786 (10.334); 17.4527 (6.415); 13.5217 (4.236) and 18.1831 (3.973).

In the 2006 season we obtained 18.82 and 14.63 c/d. Given the complex window function of observations on only two nights from only one observatory, we might consider them the same. On the other hand, when the whole set was utilized with a step rate of 0.00015, Period04 yielded peaks at 17.8373 and 14.7537 c/d, (see Figure 1 and Table 1). The rest of the frequencies might be disregarded because they do not significantly improve the residuals. Their peaks are indistinguishable from each other due to the aliasing caused by the window function. Therefore, we will consider as definitive only the first two frequencies listed in Table 1. Figure 2 shows the light curves of the six observed nights.
Figure 1. Periodograms of all the observed nights. From top to bottom, window, first frequency obtained at 17.8375 c/d, periodogram after prewhitening this with a resulting peak at 14.7537 c/d, and finally the prewhitened histogram of the two previously determined frequencies with a peak at 16.5121 c/d.

Table 1. Frequencies, amplitudes and phases derived

| Frequency (c/d) | Amplitude (mag) | Phase  |
|----------------|-----------------|--------|
| F1 17.8375     | 0.0131          | 0.1028 |
| F2 14.7537     | 0.0108          | 0.2612 |
| F3 16.5121     | 0.0070          | 0.5646 |

4. Physical parameters

As it has been already described in [1], we carried out a well-known procedure to determine reddening as well as unreddened colors using the photometric mean $uv$ values reported in Table 3. Table 4 lists the reddening, the unreddened indexes, the absolute magnitude, and the distance. Its position on the $[m_1] - [c_1]$ diagram established it to be an A8V star. Its temperature and log of surface gravity can be determined by locating HD 115520 in the $(b - y)_0$ vs. $c_0$ grids of [6] (Figure 3); the values we determine are 7700 K and 4, respectively. As was stated in Paper I, we compared our results with those in a paper by [7] who found an effective temperature $T_{\text{eff}}$ of 8199 (+449,-317), a log g 4.63 (+0.34,-0.23), an [Fe/H] 0.62 (+-0.13) and a stellar type membership to the main-sequence for this star. Although [7] has evaluated physical parameters for this star, and his numerical values coincide with ours, we feel that we have more data to determine the physical characteristics. Nevertheless, we have employed his reported metallicity of HD 115520 to discriminate between the models that explain the star’s behavior.

5. The evolutionary status of HD 115520

The determination of the evolutionary stage of a field star requires precise estimates of its global parameters. In the case of HD 115520 the distance as determined from Strömgren photometry is 140 pc which leads an $M_V$ of 2.86 mag by using the calibrations of [8]. On the other hand, the distance value of 130 pc estimated from a parallax of 3.29 ± 0.97 mas provided by the Hipparcos
Figure 2. Light curves of HD 115520 for the years 2006 and 2007 obtained at SPM Observatory. 
y shows the magnitude variation (dots) in magnitudes, X axis is time.

Table 2. Mean values of the uv photometry of HD 115520 from the two seasons

|        | average | sigma | N   |
|--------|---------|-------|-----|
| V (mag)| 8.4305  | 0.0178| 579 |
| (b - y) (mag)| 0.1334 | 0.0070| 584 |
| m₁     | 0.1701  | 0.0051| 580 |
| c₁     | 0.8068  | 0.0139| 584 |
| β      | 2.8108  | 0.0133| 67  |

catalogue [9] yields an $M_V$ of 1.02 mag which is quite different from the photometric one. This ambiguity can be explained by the uncertainties in the determination of each measured distance. The large relative error ($\sigma(\pi)/\pi \sim 0.30$) of the Hipparcos parallax for HD 115520 implies an $\sigma(M_V) > 0.5$ mag, whereas in the present paper the uncertainty in the apparent magnitude derived as explained in [2] from the standard deviation of 579 data points of the two seasons gives an $m_V = 8.4305 \pm 0.0178$ (see Table 2) and an $\sigma(M_V) < 0.1$ mag. Although this latter value does not include the uncertainty in $M_V$ due to the photometric calibrations which can be as large as 0.3 mag for early type stars (e.g. [10]), we think that the photometric distance is more reliable than the trigonometric one because different photometric calibrations ([10] and [11]) lead to similar distance values for HD 115520. Furthermore, similar values of $m_V$ for HD 115520 have already been reported in previous papers ([12], [13], [1]). Therefore, we will use the photometrically determined distance to try to establish the evolutionary status of HD 115520.

Figure 4 shows the observed position of HD 115520 (asterisk) in the HR diagram and its associated uncertainty (cross upon the asterisk). PMS and post-MS evolutionary tracks giving a range of masses between 1.45-1.60 $M_\odot$ for HD 115520 are shown with dotted and continuous lines respectively. These evolutionary sequences were computed by using the CESAM evolution code [14] with an input physics appropriate to δ Scuti stars and a chemical initial composition of $Z = 0.013$ and $Y = 0.28$. Also shown are the theoretical pre-MS instability strip boundaries of the first three radial modes obtained by [15].
Figure 3. Location of the photometric data of HD 115520 in the grids of LGK86.

Table 3. Reddening and unreddened parameters of HD 115520

| $E(b - y)$ | $(b - y)_0$ | $m_0$ | $c_0$ | $V_0$ | $M_v$ | $DM$ | dst (pc) |
|------------|-------------|-------|-------|-------|------|------|---------|
| 0.000      | 0.135       | 0.170 | 0.807 | 8.43  | 2.68 | 5.75 | 141     |

According to the models depicted in Fig. 4 HD 115520 could either be in pre-MS stage with an age between 15-20 Myr or post-MS stage with an age between 500-700 Myr. In the former case, the age was estimated as the time spent by the star travelling from the birthline to the ZAMS in the HR diagram according to the isochrones given by [16].

As shown by [17] non-radial oscillation spectra in the low frequency domain can be used to discriminate between the pre- and post-MS stage. In the present case, however, this is seldom possible since the two detected peaks in HD 115520 are most likely due to radial oscillations. In fact, we have tried to reproduce the observed periods computing linear adiabatic pulsation models of HD 115520 for some selected pre- and post-MS models located within the error box in Figure 4, but no satisfactory fit between observed and theoretical frequencies was found. Therefore, more observational efforts are required to establish the true nature of this interesting object.

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Figure 4. Position of HD 115520 in the HR diagram.

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