PHOTOMETRIC AND SPECTROSCOPIC VARIATIONS
OF THE BE STAR HD 112999

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1 Introduction

Be stars were defined as ‘A non-supergiant B-type star whose spectrum has or had at
time, one or more Balmer lines in emission” by Jaschek et al. (1981). This class of stars
have circumstellar disks that originate hydrogen, helium, and/or metal lines in emission.
The main causes that are thought to generate these disks are: rapid rotation and/or
binarity, combined with non-radial pulsations (Huat et al., 2009; Neiner et al., 2012).
These phenomena can take place as a stage in the evolutionary life of hot B-type stars.

One of the most intriguing properties of Be stars is their long-term variability, which
seems to be related to disk growth or loss events (Hubert & Floquet, 1998). These events
have spectroscopic and photometric effects, i.e. changes from emission to absorption line
(and vice versa), and also flux and color variations. Given the great variety of observed
events, many open questions on the Be stars remain (see the review by Porter & Revinius,
2003, and references therein), which raises the importance of studying these objects. More-
over as the same authors state “Be stars are in a unique position to make contributions
to several important branches of stellar physics, e.g., asymmetric mass—loss processes,
stellar angular momentum distribution evolution, asteroseismology, and magnetic field
evolution”.

The primary goal of this work is to show the analysis carried out on a new possible
transient Be star, labelled HD 112999 (αJ2000 =13:01:35, δJ2000 = −60:40:16). This star
was observed by one of us (MAC) while trying to identify possible members of the Cen-
taurus OB1 (CenOB1) stellar association (Corti & Orellana, A&A in press). The spectral
classification of this star presents some discrepancies in the available bibliography. It
was first reported as Be star by Bidelman & MacConnell (1973). Other authors reported
different spectral types, i.e. Cannon & Pickering (B8; 1920), Houk & Cowley (B6 III (N); 1975), and Garrison et al. (B6 V; 1977). Nowadays, HD 112999 is listed in the BeSS
catalogue\(^1\) as B6 III ne (Neiner et al., 2011). As our optical spectrum, taken on 2009, was very different from those classified before, the star deserved careful consideration. We searched spectral and photometric databases and found that HD 112999 is a variable Be star which seems to have experimented disk – loss and growth – events over the last decades. In the following sections, we describe these facts.

2 Observational Data

2.1 Spectroscopic data

The observational material belongs to different-programs runs obtained at the Complejo Astronómico El Leoncito (CASLEO\(^2\)), Argentina and La Silla Observatory, Chile. In these runs were used different instrumental configurations which are detailed in Table 1.

For CASLEO observations, comparison arc images were observed at the same sky position as the science targets as the stellar images immediately after or before the stellar exposures, being Th−Ar for the echelle mode of the REOSC spectrograph, Cu−Ar for the simple mode, and He−Ne−Ar if the B&C was used. Moreover, bias frames, standard stars of radial−velocity, and spectral−type (the last during the run B only) were observed every night. We have also taken the spectrum of the standard of rotational−velocity, \(\tau\) Sco (Slettebak et al., 1975), during run C. These spectra were processed and analysed with IRAF\(^3\) routines.

The spectrum retrieved from the ESO database, was acquired with the FEROS spectrograph and processed with the MIDAS pipeline. The radial velocities were obtained by simple crosscorrelation of the echelle orders of the object and of the simultaneous calibration fiber with respect to a corresponding reference spectrum.

2.2 Photometric data

The photometric data were taken from two sources: the Epoch Photometry Annex of Hipparcos Astrometry Mission (Perryman & ESA, 1997) and The All Sky Automated Survey (ASAS) (Pojmanski, 1997).

The Hipparcos data consist of 214 observations made between December 1989 and January 1993. The measurements are in the interval 7.31 < \(H_p\) < 7.48, while the errors of the individual measurements ranges from 0.007 to 0.020 mag. According to the criteria adopted when Hipparcos data were analyzed, this star was classified as an “unsolved variable”\(^4\). Following the Hipparcos calibration for a star with colour index \(V-I = 0.070,\)

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\(^1\)http://basebe.obspm.fr

\(^2\)Operated under agreement between CONICET and the Universities of La Plata, Córdoba and San Juan, Argentina.

\(^3\)IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

\(^4\)cf. The Hipparcos and Tycho Catalogues, Vol. 1, Introduction and Guide to the Data, Sec. 1.3 App. 2.
as in this case, the relation $H_p - V_J = 0.025$ should hold, where $V_J$ is the magnitude in the $V$ filter of the Johnson photometric system.

The ASAS data include 1030 magnitude determinations obtained between November 2000 and December 2009. ASAS provides aperture photometry with several apertures. For this study, the aperture labeled as MAG 1 in the dataset was selected because larger apertures could be contaminated by a neighbor star. The errors of individual measurements are up to 0.120 mag, with a typical value $\text{err}_{\text{ASAS}} = 0.040$ mag. Since $\text{err}_{\text{ASAS}} > (H_p - V_J)$, no zero-point correction was applied to compare both datasets.

3 Results

3.1 Spectral Analysis

The FEROS spectrum (labelled A in Table 1) shows typical Be features as the Balmer lines $H_\gamma$, $H_\beta$ and $H_\alpha$ in emission (see Fig 2). In it, it is possible to see at least 1 additional emission line, Fe I $\lambda 4328$ bluer than $H_\gamma$ and 2 additional emission lines, Fe I $\lambda 4849$ and Fe I $\lambda 4875$ of $H_\beta$. It also presents others metallic lines, i.e. O II, Fe II, Cr II, Ti III, C III, etc, as weak emissions, some of them shown in Fig 1. All of these emission lines could be originated in a disk. The double structure observed in $H_\alpha$ emission lines is thought as originated by the Be star seen with mid inclination angle. The rotation of the disk plus possible absorption ("reversal" of the emission) against the edge of the star or disk cause such profiles. Other features as He I, $\lambda 4009$, 4026, 4144, 4387, 4471, 4921, 5875, 6678 and 7065, Si II $\lambda\lambda 4128-30$ and Mg II $\lambda 4481$ are present in absorption. We interpreted that these lines are originated in the stellar photosphere. This composite spectrum indicates that HD 112999’s disk was thick and extended during 2008 May.

![Figure 1. Some metallic emission lines in the FEROS spectrum.](image)

Our B spectrum, obtained about one year later than the A one, shows the emission contribution very weak in the $H_\beta$ profile and almost marginal in the $H_\gamma$ line. The metallic lines (seen as weak emissions in A) are not detected in this spectrum. We think that this is not due to the B spectrum has poorer S/N ratio than the A one. The absorption lines, identified as arising in the stellar photosphere in the A spectrum, are also present here.
Table 2: Radial velocities measured in the high resolution spectra

| Line          | run A [km s\(^{-1}\)] | run B [km s\(^{-1}\)] | run C [km s\(^{-1}\)] |
|---------------|------------------------|------------------------|------------------------|
| He I 4026     | -20                    | 5                      | 7                      |
| He I 4471     | -35                    | -15                    | -31                    |
| Mg II 4481    | -92                    | -5                     | -2                     |
| He I 5876     | -20                    | 36                     | -19                    |
| Na I 5890-96  | 4.5                    | 5.5                    | 2.5                    |

Three years later, the C spectrum presents the Balmer lines H\(\gamma\) and H\(\beta\) as pure absorption, i.e. there are no traces of the emission contribution (see Fig 2).

The D spectrum was obtained by one of us (WAW) to see the profile of the H\(\alpha\) line, as none of B and C spectra included it in their spectral ranges. Thus, we proved that H\(\alpha\) is a conspicuous absorption line in the spectrum taken during April 2012 (see Fig 2).

The E spectrum is the one we have been able to obtain more recently (shown in Fig 3). It shows the same absorption spectral lines than the other spectra, plus a very narrow absorption line at 4233 Å, which we identified as Fe II. We consider this line was originated in a shell because of its FWHM is \(\sim 2.5\) Å compared to the FWHM \(\sim 8\) Å of the photospheric He I absorption lines. This assumption is in good agreement with the already proved by Arias et al. (2006) that the forming region of Fe II lines is located close to the central star.

We classified the Be-type spectra A, B, and E as B2–3 V, following the criteria of Walborn & Fitzpatrick (1990), i.e. the ratio between Si III \(\lambda 4552\) and Si IV \(\lambda 4089\), the declining strengths of the C III+O II blends at \(\lambda\lambda 4070\) and 4650, and the weakness of all the Si II-III features. From the spectral type B2 to B3, Si II \(\lambda\lambda 4128-30\), C II \(\lambda 4267\) and Mg II \(\lambda 4481\) increase in prominence. The very large He I \(\lambda\lambda 4144/4121\) ratio is a characteristic of the B2 V spectra. The principal luminosity criterion is Si III \(\lambda 4552/\) He I \(\lambda 4387\).

An important parameter to know in this class of star is the projected rotational velocity \((v\sin i)\). To estimate this parameter, we have used the spectrum of the star \(\tau\) Sco. It was convolved with rotation line profiles calculated for different projected rotational velocities and the FWHM of the absorption line He I \(\lambda 5015\) was measured for each velocity. Then, a linear relation between FWHM and the \(v\sin i\) was fitted. This empirical relation was used to translate the FWHM of the line in the spectrum of HD 112999 into a \(v\sin i\) estimation. In this way we obtained \(v\sin i = 170 \pm 40\) km s\(^{-1}\), being the error so large because of the low S/N ratio of the spectrum and the weakness of the line.

On the other hand, the emission of the star could be the result of disk instabilities caused by the spun up by binarity mass transfer (McSwain et al., 2009); thus, the B star becomes a Be star of rapid rotation. We measured the radial velocities in the three high-resolution spectra (A, B, and C). For this, we fit Gaussian profiles to selected spectral lines, i.e. He I \(\lambda\lambda 4026, 4471,\) and 5876, and Mg II \(\lambda 4481\) as well as the interstellar lines of Na I. On comparing the values of Na I, no systematic difference is obtained among the spectrographs used (within an error of 3 km s\(^{-1}\)). However, the He I and Mg II \(\lambda 4481\) absorption lines present variations of more than five times the expected error. Although, this result is not enough to confirm the binary nature of HD112999. We provide the radial velocity measurements in Table 2 for future reference.
Figure 2. Variations of H$\gamma$, H$\beta$ and H$\alpha$ lines from spectra obtained in different runs (see Table 1). Other emission lines are also present. We identified them as Fe $i$ $\lambda$ 4328 (in the H$\gamma$ region), Fe $i$ $\lambda$ 4849 and $\lambda$ 4875 (H$\beta$ region), and Fe $i$ $\lambda$ 6574 (H$\alpha$ region).
3.1.1 BCD fundamental parameters

![Graph showing spectral lines and discontinuities](image)

**Figure 3.** Balmer discontinuity: D is the first Balmer jump for normal B star, d is the second discontinuity, in absorption, which indicates the presence of the circumstellar envelope.

We derived some physical properties from the E spectrum of HD 112999 using the BCD (Barbier-Chalonge-Divan) spectrophotometric system (Chalonge & Divan, 1973, 1977). A detailed description of this method is presented in Zorec et al. (2009, Appendix A) and further applications to Be stars were done by Zorec et al. (2005) and Aidelman et al. (2012). This method is ideal for studying peculiar stars, and in particular Be stars, due to the fact that the parameters defined by the method are not affected by interstellar extinction and absorption/emission from the circumstellar envelope (Zorec & Briot, 1991). Then, we determined a B3 spectral type (with one subtype error) of luminosity class III, an effective temperature $T_{\text{eff}} = 17500 \pm 1000$ K, a surface gravity $\log g = 3.3 \pm 0.5$, an absolute magnitude $M_V = -2.5 \pm 0.5$ mag, and a color excess $E_{B-V} = 0.11 \pm 0.07$ mag.

The presence of the second Balmer discontinuity, in the E spectrum, indicates that a circumstellar envelope is still present (Divan, 1979). Fig 3 shows this spectrum in the Balmer discontinuity region, the first jump, D, corresponds to a normal B star, while the second one, d, is originated by the envelope.

We estimated the distance to HD 112999, using its extreme V magnitudes, i.e. $7.3 \leq V \leq 7.5$ (see Fig. 4), corrected by colour excess $E_{B-V} = 0.11 \pm 0.07$ mag and considering the standard selective absorption coefficient, $R_v = 3.1$ (Schultz & Wiemer, 1975). We obtained a distance modulus of $9.5 \pm 0.5$ mag ($790 \pm 180$ pc) and $9.7 \pm 0.5$ mag ($870 \pm 200$ pc), respectively. These estimated distance values with its respective errors are slightly larger than the Hipparcos distance (654 pc). Then, HD 112999 results closer than the Cen OB1 association, $V_0 - M_v = 12$ mag (2500 pc) (Corti et al., 2012).
3.2 Light curve analysis

The collected photometric data were analyzed together and the resulting light curve is shown in Fig. 4, HD 112999 presents two kinds of variabilities: a short-term (1.302 days; Hubert & Floquet, 1998) and a long-term one (∼ years). The former, smaller than 0.1 mag, is present in the Hipparcos data (see Fig. 5), and it is the reason why this star was included in the General Catalogue of Variable Stars (Samus et al., 2009) and classified as BE⁵.

The long-term variation can be better observed in the ASAS data. To enhance and show it more clearly, we represent unweighted averages (calculated within intervals of ∼114 days) with filled circles. In Fig. 4, we identified the light maximum reached on ∼ HJD 2454200 (ASAS data).

4 Discussion

The collected spectra show important variations, very noticeable in the Balmer lines, i.e. their emission profiles decrease in intensity from May 2008 to June 2012 (A to E). This kind of variability resembles the one already detected in other Be stars like MG 31 and MG 119 in NGC 3766 (McSwain et al., 2008); Pleione and κ Dra Hubert & Floquet, 1998) and 66 Ophiuchi (Floquet et al., 2002).

⁵In the cases when a Be variable cannot be readily described as a Gamma Cassiopeiae variable (GCAS) star, (Samus et al. 2009) give simply BE for the type of variability.
The relation between the photometric and spectroscopic data is shown in Fig. 4. The capital letters are the same defined in Table 1. The light curve and the spectra obtained in A and B runs, are well correlated in the sense that as the star fades, the Balmer emissions decrease their intensities (Fig. 2). This behavior is related to disk dissipation. The lack of photometric data after 2009 August prevents us to determine if the star reached the minimum between B and C runs or it will be reached later.

The singular behavior observed in HD 112999 led us to search in the existing literature in order to become familiar with the information already known about this star. Thus, we learned that the unique Be spectrum of HD 112999 was obtained in the period 1967–1969 by Bidelman & MacConnell (1973)\(^6\). Unlikely, they did not provide a precise date of observation, which enables us to relate it with the date of the FEROS spectrum. As said in Section 1, other authors have reported different spectral classifications for HD 112999. We adopted the B2–3 V spectral–type for HD 112999, determined following the criteria of Walborn & Fitzpatrick (1990).

5 Summary

The analysis of the spectroscopic and photometric data of HD 112999 allowed us to identify a long–term variability in its V light curve and the change of the profiles of the Balmer lines from emission to absorption. The declining on V–magnitudes between 2007 and 2009 is related with the disappearance of emission lines, very noticeable in some Balmer lines. We propose that the reported changes are originated in the loss of the disk. Photometric data were not sufficient to search for long-term periodicities, thus we encourage other researchers to monitor this star in the future. We classified our spectra as B2–3, the luminosity class should be clarified with further observations.

\(^6\)This observation was the reason to be included in the Catalogue of Be Stars (Jaschek & Egret, 1982)
We took advantage of the observations obtained on different observing programs to measure some important parameters as the projected rotational velocity, and the distance modulus. Also, our last (E) spectrum, obtained on 2012 June, was analyzed via the BCD method and noted that a circumstellar envelope is still present. Hence, further spectra should be obtained to determine if HD 112999 will reach a normal B–type.

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