LHA 115-S 23, from B[e] to A[e]: A highly precessing system or a chemically peculiar object ?

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Abstract: We report on the variation of the rapidly rotating SMC supergiant star LHA 115-S 23 (AzV 172) for which we found a decrease in effective temperature from 11000 K to 9000 K and a simultaneous increase in rotation velocity from 110 km/s to 150 km/s (the latter corresponding to 75% of its critical velocity) within a period of 11 years. Such a behaviour cannot be explained by stellar evolution, especially not the fast cooling of the star. We therefore discuss possible scenarios that can lead to both, an apparent cooling and a speed up of the rotation velocity. The most plausible ones are either a highly precessing system, or a star with an inhomogeneous surface abundance distribution due to e.g. hot spots. If the latter scenario is true, our target would be the first post-main sequence object with such a peculiar surface abundance pattern.

B[e] Phenomenon and LHA 115-S 23

The B[e] phenomenon was defined by the presence in the optical spectra of B-type stars (Conti, 1997) of:

(a) Strong Balmer Emission Lines;
(b) Permitted emission lines of mainly low ionization metals, e.g. FeII;
(c) Forbidden emission lines of [FeII] and [OI];

and also a strong near or mid-infrared excess due to hot circumstellar dust.

Based on Lamers et al. (1998), there are different types of objects presenting the B[e] phenomenon: pre-main sequence HAeBe stars, compact planetary nebula, symbiotic objects, hot supergiants – *the most popular class with confirmed members in Magellanic Clouds* - and finally unclassified objects whose evolutionary stage is still unknown.

LHA 115-S 23, hereafter S 23, is a SMC star and was classified as a B8 supergiant by Azzopardi & Vigneau (1982). Later Zickgraf et al. (1992), hereafter ZSW, included this star in the group of B[e] supergiants and derived its parameters. In this work, we are presenting, based on new spectroscopic data, a revised analysis of this object *(more details can be seen in Kraus, Borges Fernandes, Kubát & de Araújo, 2008, astroph/0806.3208, in press A&A).*

Observations

We obtained optical spectra with the ESO 1.52-m telescope in La Silla (Chile) using the high-resolution spectrograph FEROS (R=55000, around 6000 Å). The spectra was taken on 14/10/2000, covering a sky area of 2 arcsec and a wavelength range from 3600Å to 9200Å.

Spectroscopic Analysis of LHA 115-S 23

From our high-resolution FEROS spectra, we have derived:

(a) *Spectral type and effective temperature:* based on the line strength ratio of MgII (λ4481) over HeI (λ4472). Since the HeI lines are not present in our spectra (Fig. 1), differently than seen in the spectra of ZSW, we have derived a lower limit for this ratio and compared to the value from ZSW data. We have found a spectral type A0 or later for this star (Fig. 2).

Fig.1 – Parts of the rectified FEROS spectrum (dashed line). For a better comparison, we convolved the FEROS data to a resolution of R=4900 similar to ZSW data.

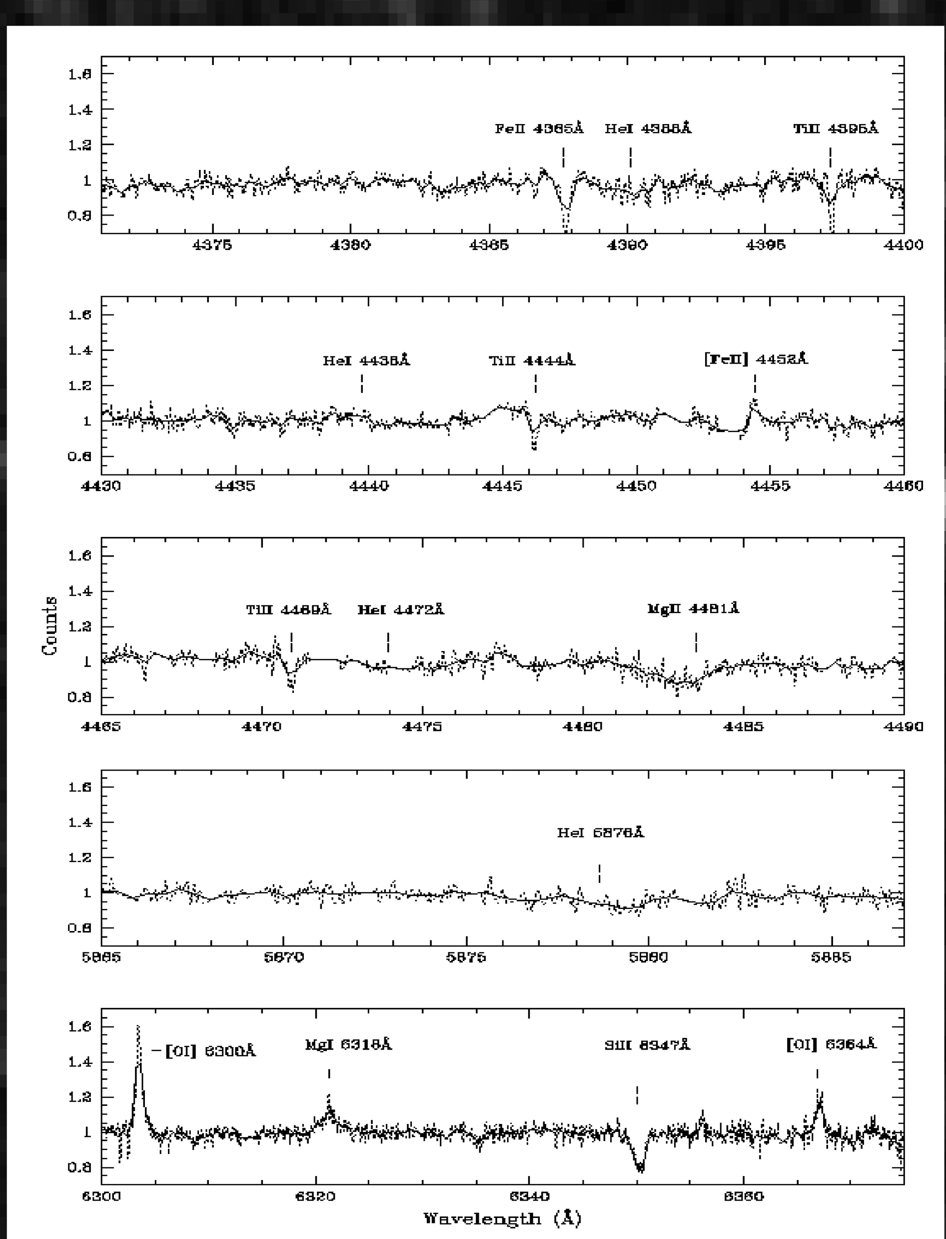
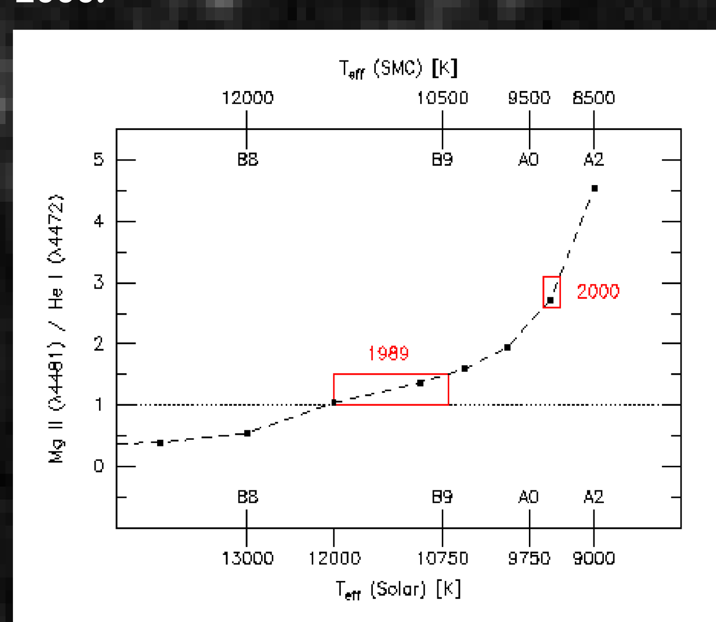


Fig.2 – Effective temperature dependence of the line ratio MgII λ4481 over HeI λ4472 calculated from model stellar atmospheres with log g =2.5 at solar abundances (also valid for SMC based on Lennon, 1997). The spectral types and related effective temperatures are indicated in the bottom label for solar abundance and in top label for SMC one (Evans & Howarth, 2003). The two boxes correspond to the observed ratios with their errors for the ZSW data taken in 1989 and our spectra taken in 2000.



(b) *Interstellar and Circumstellar Extinction plus the Luminosity Class:* from photometric data in the literature, we saw that UBV data changed substantially from 1972 until 1999. We decided to use the data taken in 1999 (only one year earlier than our FEROS spectra) to derive the interstellar extinction and also the luminosity class considering the spectral type obtained from our spectra. However, we got different values of E(B-V) from (B-V) and (U-B). The explanation is:

Extinction and emission from the stellar wind!

We test the influence of the wind to the UBV band fluxes by modeling a spherically symmetric isothermal wind (Kraus et al. 2008a, b) and we have found the best scenario for an A1Ib star – *the first A[e] star identified* - with T_{eff} = 9000K, mass loss rate of 3 x 10^{-6} M /yr and interstellar extinction with E(B-V) ≈ 0.03. *It seems that within 11 years, the star has cooled ~ 2000K*!

Table 1 – The set of parameters derived from our analysis compared to the ZSW one. From the comparison with stellar evolutionary tracks for SMC stars (Charbonnel et al., 1993) an initial mass of 9.5-11 M is estimated.

	ST and LC	T_{eff} (K)	E(B-V)	Log (L/L)
ZSW	B8-9 Ib	11000	0.1	4.46
Our Analysis	A1 Ib	9000	0.03	4.30

(c) *Projected Rotational Velocity:* modeling the line profile of the MgII (λ4481) line using the FWHM method, we could estimate *v sin i* considering the presence of macro-turbulence, from our spectrum (Fig. 3) and also from the ZSW data.

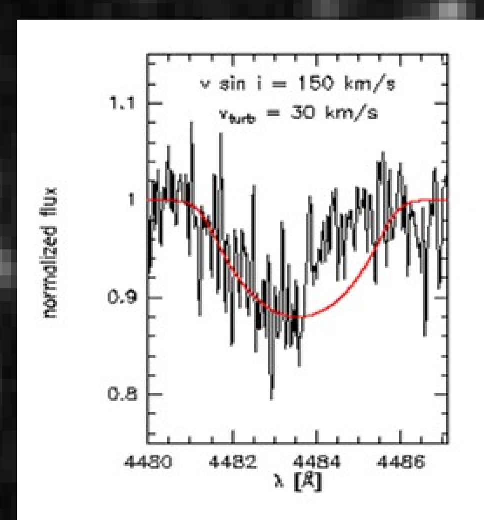


Fig.3 – Fit of the MgII λ4481 line with a profile consisting mainly of stellar rotation plus some macro-turbulence.

S 23 is the fourth B[e] supergiant with confirmed high v sin i (≈ 150 ± 5 km/s). Based on our set of stellar parameters, it is rotating with at least 75% of its critical velocity. A tentative derivation from the ZSW data gives v sin i ≈ 110 ± 10 km/s, so there is an increase of its v sin i in 11 years!

How can we explain the cooling and the increasing of projected rotational velocity in just 11 years ?

1 - Stellar Evolution: NO!
The stellar evolution theories predict cooling associated to decreasing of *v sin i* or when the star contracts, it heats up and increases *v sin i* . In addition, it takes 5000 yr for such a star to cool from 11000K to 9000K (Meynet, private communication).

2 - Precession of the star related to the line of sight: POSSIBLE!
Due to a rapid stellar rotation, the stellar surface suffers from a deformation in the form of flattening (Fig. 4). Thus, the polar regions become much hotter than the equatorial region (depending on the fraction of the rotation velocity to the critical velocity). Other stellar parameters will also change from one region to other.

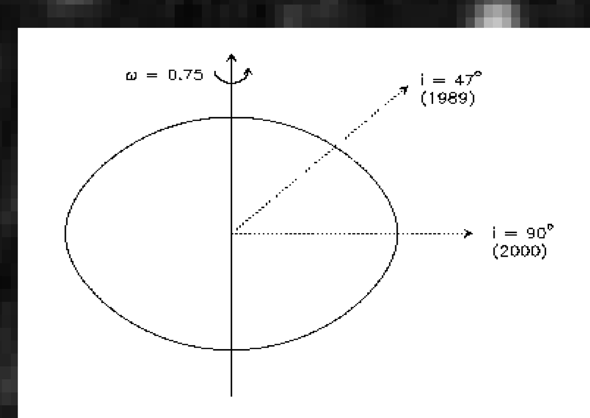


Fig.4 – The shape of *S 23* rotating with 75% of its critical velocity. Assuming this value, we can derive the inclination of the observer related to the rotation axis of the star in the periods of our observations and of ZSW. In 2000, we would see a region that is cooler, but with a higher *v sin i*, on the other hand, in 1989, it was possible to see contributions from hotter regions, but it was seen a lower *v sin i*.

3 – A Rapidly Rotating Star with Surface Inhomogeneities: POSSIBLE!
It is known that chemically peculiar (CP) stars at or close to the main sequence present surface abundance inhomogeneities or spotty surface patterns. Since these stars rotate, variations in HeI line profiles are observed (Smith, 1996). The reason of these inhomogeneities might be associated to variations in the magnetic field of these stars (Khokhlova et al. 2000). A co-existence of abundance and also temperature inhomogeneities has recently been claimed by Lehmann et al. (2007). Even knowing that *S 23* is not a main sequence star and no such inhomogeneities have been reported for a supergiant, we cannot discard this scenario to explain the variations seen in this star.

ATTENTION: Only an observational campaign to monitor the variations in the HeI lines and also to measure the projected rotational velocity from the MgII lines can give more hints concerning the nature of this curious object. This campaign can take several years to confirm the precession scenario or just some rotational periods to prove the surface inhomogeneities scenario.

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