Exploring the circumstellar disk-like structure of the B[e] supergiant LHA 120-S 73

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Motivation

B[e] supergiant (B[e]SG) stars are post-main sequence massive stars which are surrounded by cold and dense rings or disk-like structures where a complex chemistry takes place, forming molecules and dust. These objects are in a short-lived phase characterized mainly by strong mass ejections, rather than a smooth mass loss via stellar wind. Recent observations have revealed that these circumstellar structures are highly variable, not only in density but also in their kinematic properties. In this context, we decided to study the structure and kinematics of the circumstellar material of some B[e]SGs, in particular LHA 120-S 73, based on the analysis of different optical and infrared spectral features that can trace the disk at different distances from the star.

Increasing our knowledge of the properties of B[e]SGs and their disks could shed light on the physical mechanism(s) causing this poorly understood transitional phase in the evolution of massive stars.

About LHA 120-S 73

- LHA 120-S 73 (= RMC 66; m_v = 10.66) is a peculiar star that belongs to the LMC.
- It was classified as a B8-type supergiant by Stahl et al. (1983, 1986) who detected the presence of dust.
- Zickgraf et al. (1986) derived its stellar parameters: T_{eff} = 12000 K, M_{bol} = -8.9, R = 125 R_{sun}, M = 30 M_{sun}, E(B-V) = 0.12 and reported its B[e] nature.
- Molecular emission from CO bands was detected in the near-infrared (Mc Gregor et al. 1988, Liermann et al. 2010, Oksala et al. 2013), with apparent stability in both ^{12}CO and ^{13}CO.
- Emission features from amorphous and crystalline silicates and PAHs were observed in the mid-infrared region (Kastner et al. 2006). Notable far-infrared emission was also observed (van Loon et al. 2010).
- Variations in its light curve were also found (van Genderen & Sterken 2002).
- The existence of a circumstellar disk (seen close to pole-on) was proposed by Zickgraf et al. (1986) and Muratorio & Friedjung (1988) to explain the simultaneous observation of many narrow permitted and forbidden emission lines of low ionized metals and broad P Cygni absorption components.
- Based on the kinematic analysis of [O I] and [Ca II] lines, Aret et al. (2012) found that the disk is a Keplerian rotating disk seen at an inclination angle of ~28°.
- Intrinsic polarization due to dust was detected suggesting a non-spherically symmetric distribution for it (Magalhaes 1992).

Observations

- Optical spectra (R~48000, 3600-9200 Å) were obtained using the FEROS spectrograph at ESO in La Silla (Chile) attached to the 1.52-m telescope in 1999 and to the 2.2-m telescope in 2005 and 2014.
- Near-infrared spectra (R~40000, 2.288-2.296 μm, 2.320-2.329 μm) were acquired with the Phoenix spectrograph at Gemini-South (Chile) attached to the 8-m telescope in 2004, 2010 and 2011.
- Mid-infrared spectra (R~100, 8-13 μm) were acquired with the T-Recs spectrograph at Gemini-South (Chile) attached to the 8-m telescope in 2012.

Preliminary results

In the near infrared

CO emission bands

Band emission from molecules are excellent indicators for the disk conditions at larger distances from the star. A special role play CO bands, because they mark the transition from the atomic to the molecular region.

The Phoenix spectra display clearly resolved individual double-peaked CO ro-vibrational lines in front of the second band head (Fig. 1). Hence, the physical parameters of the CO gas (velocity, temperature, density) are very well constrained. Using the CO disk code of Kraus et al. (2000) and the disk inclination angle of i= 28° (from Aret et al. 2012), the best fit is obtained for T_{CO} = 2850 ± 100 K, N_{CO} = (6 ± 1) x 10^{20} cm^{-2} and a rotational velocity of 34 km/s. No contribution from Pfund emission is seen in our data. Visible Pfund lines in LHA 120-S 73 arise at longer wavelengths (Liermann et al. 2010; Oksala et al. 2013)..

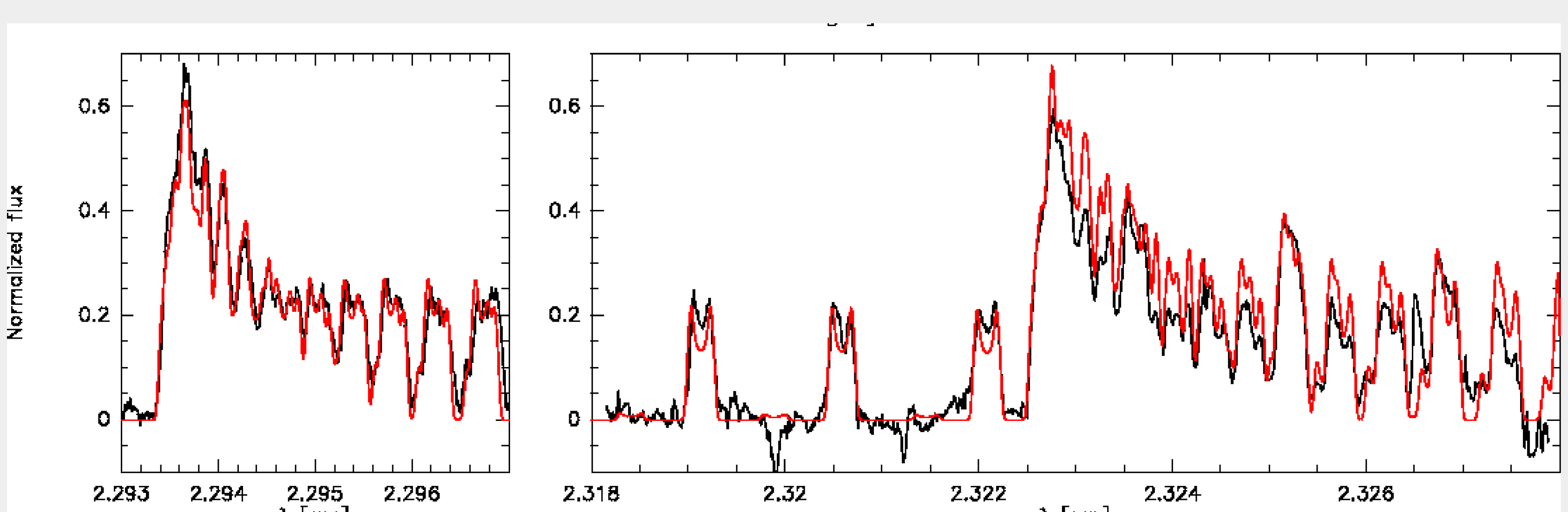

Figure 1: Model fit (red) to the observed (black) first and second CO band heads.

Variability

While the optical lines in the FEROS spectra are very stable over the 15 years covered by the data, the intensity of the emission of the CO band head was lower in 2010 than in 2004 but the width of the band head did not change (Fig. 2). The latter implies that the rotation velocity of CO gas did not change, while the former suggests a change in the column density. We interpret this variation as due to density inhomogeneities in the CO ring.

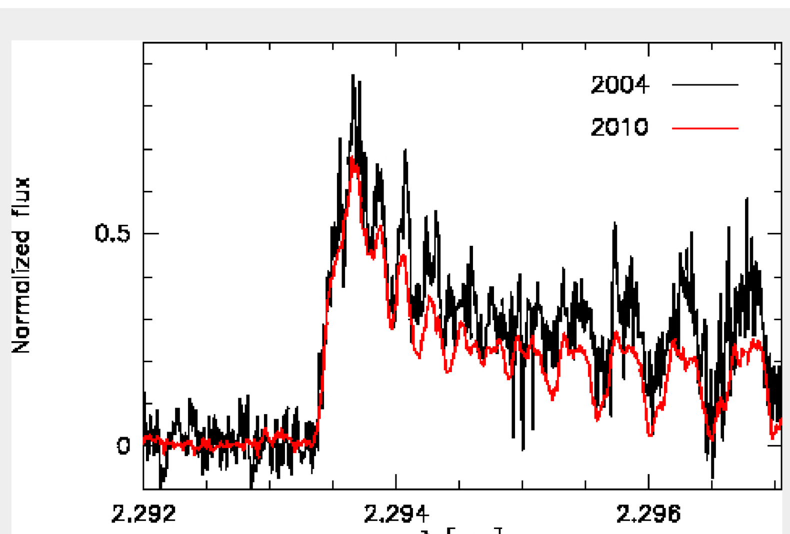

Figure 2: Comparison of the intensities of the first CO band head observed with Phoenix in 2004 and 2010.

In the mid-infrared

The T-Recs spectrum shows two prominent emission features around 9.5 μm and 10.8 μm (Fig. 3) that resemble the ones previously presented by Kastner et al. (2006).

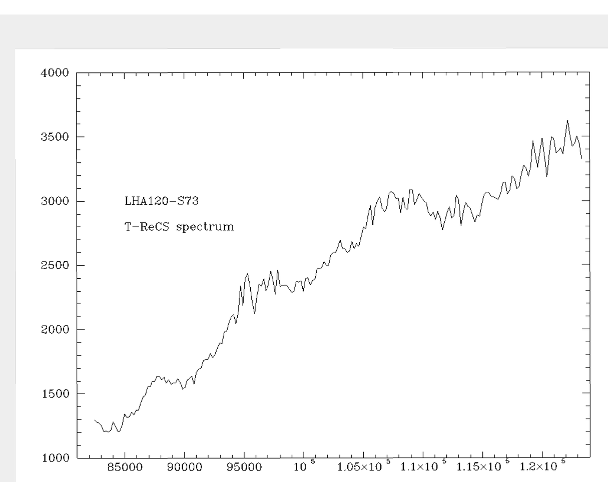

Figure 3: T-Recs spectrum (arbitrary units).

In the optical

Forbidden lines

Several forbidden emission lines, such as [O I] λλ5577 and 6300 and [Ca II] λ7291 lines, can be used to trace the ionized and neutral atomic disk regions close to the star. Modeling of these lines is helpful to constrain the kinematics of their formation regions.

Based on model fits to FEROS spectra, [O I] λ5577 and [Ca II] λ7291 lines originate from about one ring with a velocity of ~40 km/s and another one with a velocity of 23 km/s. [O I] λ6300 line also has the contribution of two rings, one with a velocity of 34 km/s that co-exists with the CO gas and another ring at a velocity of 17 km/s (Fig. 4).

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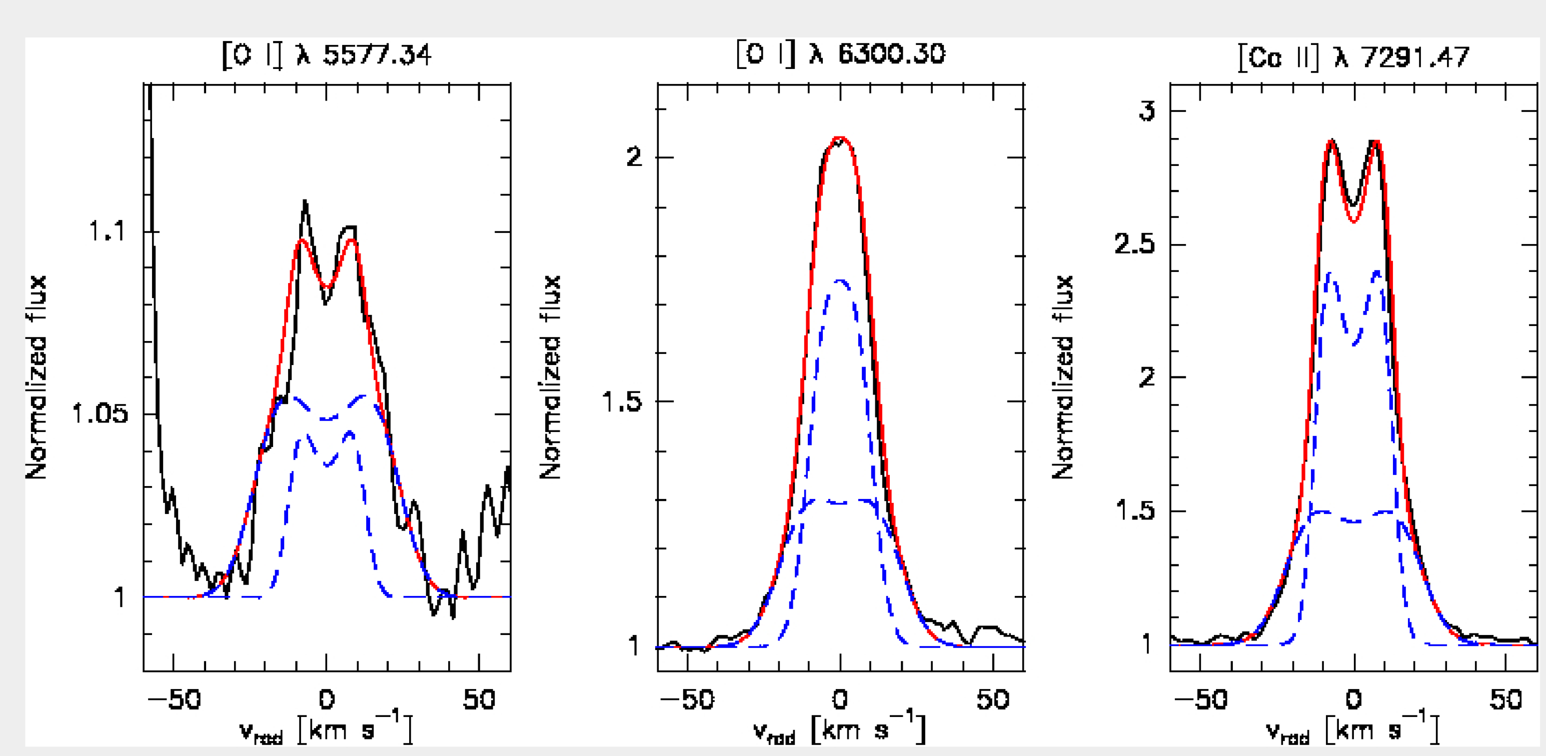

Figure 4: Model fit (red) to the observed (black) [O I] and [Ca II] lines of LHA 120-S 73 in the 1999 spectrum. In blue are shown the contributions of two different rings to the whole profile of each line.

TiO emission band

A broad emission feature extending from 6158 Å to 6180 Å is detected (Fig. 5). Very similar structures were clearly seen in three more B[e]SGs and were assigned to TiO band emission (Zickgraf et al. 1989, Torres et al. 2012).

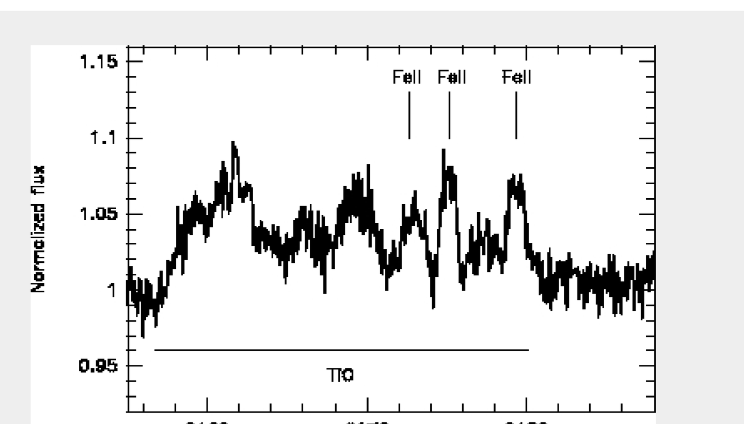

Figure 5: TiO band emission

Conclusions

The results from our data analysis suggest that multiple rings of atomic and molecular gas revolve LHA 120-S 73 on Keplerian orbits. The CO bands display clear indications for density inhomogeneities of yet unknown origin.

Near future work

- To analyze the whole sample of optical observations to complement/improve the study already done of the tracers of the inner part of the disk.
- To estimate the stellar parameters using the BCD method (Chalonge & Divan, 1977).
- To study the mid-infrared spectrum of LHA 120-S 73 in detail.

References

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