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

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Resumen / LHA 120-S 73 es un objeto peculiar de tipo espectral B8 que se encuentra en la Nube Mayor de Magallanes. Es una estrella supergigante rodeada por gran cantidad de material que forma una estructura tipo disco, vista aproximadamente en la dirección polar. En dicho disco tiene lugar la formación de moléculas y polvo. En este trabajo estudiamos la estructura, cinemática, y propiedades físicas del disco en base a observaciones espectroscópicas de alta y media resolución en la región del óptico e infrarrojo. Usamos diferentes trazadores tales como las líneas en emisión de [O I] y [Ca II] para la región gaseosa más interna y las bandas en emisión de la molécula de CO para el borde interno del disco molecular. Buscamos además la presencia de otras moléculas en la región del infrarrojo cercano y estudiamos la emisión del polvo en el infrarrojo medio.

Abstract / The Large Magellanic Cloud hosts the peculiar B8-type star LHA 120-S 73. Belonging to the B[e] supergiant group, this star is surrounded by large amounts of material which forms a circumstellar disk-like structure, seen more or less pole-on. Within its dense and cool circumstellar disk, molecules form and dust condensates. Based on medium and high-resolution optical and infrared spectroscopic data, we study the structure, kinematics and physical properties of the disk using different tracers, as the emission lines of [O I] and [Ca II] for the innermost gaseous atomic region and the first-overtone bands of CO for the inner border of the molecular disk. We also analyze near-infrared mid-resolution spectra to search for the presence of other molecules and mid-infrared low-resolution spectroscopic observations to study the composition of the dust component.

Keywords / stars: early-type — circumstellar matter — stars: individual: LHA 120-S 73

1. Introduction

B[e] supergiants (B[e]SGs) are massive stars in a short-lived phase of their post-main sequence evolution. This phase is characterized by strong mass ejections rather than a smooth mass loss via a stellar wind. The ejected material accumulates in dense rings or disk-like structures, in which a complex chemistry takes place, resulting in the formation of molecules and dust. Recent observations have revealed that this circumstellar material displays variability, not only in density but also in the kinematical properties.

In this context, we decided to study the structure and kinematics of the circumstellar material of some B[e]SGs, based on the analysis of different optical and infrared spectral features that can trace the disk at different distances from the star. In the optical range forbidden lines such as [O I] and [Ca II] are used to constrain the density and temperature structure of the inner atomic disk regions, while molecular emission arising in the infrared range is a good tracer of the molecular disk.

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. In this work we focus on the star LHA 120-S 73 and present our preliminary results.

2. About LHA 120-S 73

LHA 120-S 73 (= RMC 66; $V = 10.66$) is a peculiar star that belongs to the LMC. It was classified as a B8-type supergiant by Stahl et al. (1983) and Stahl & Wolf (1986) who detected the presence of dust. Zickgraf et al. (1986) derived its stellar parameters: $T_{\rm eff} = 12\,000$ K, $M_{\rm bol} = -8.9$, $R = 125\,{\rm R}_\odot$, $M = 30\,{\rm M}_\odot$, $E(B-V) = 0.12$ and reported its B[e] nature. Intrinsic polarization due to dust was detected suggesting a non-spherically symmetric distribution for it (Magalhaes, 1992). Molecular emission from CO bands was detected in the near-infrared (McGregor 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 polycyclic aromatic hydrocarbons 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

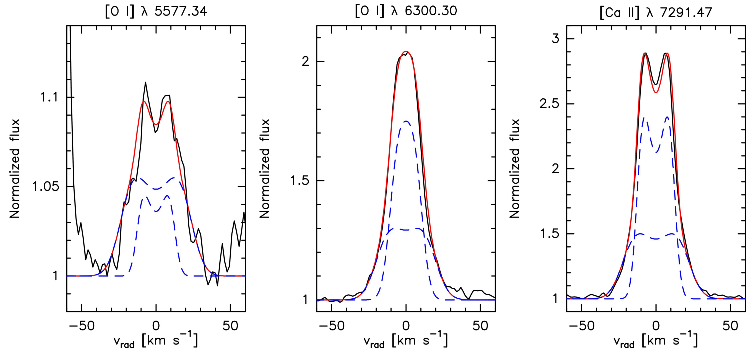

Figure 1: Model fit (red) to the observed (black) [O I] and [Ca II] lines of LHA 120-S 73 in the 1999 spectrum. In blue are shown the contributions of two different rings to the whole profile of each line.

curve were found by 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 in Keplerian rotation and seen at an inclination angle of $\sim 28°$.

3. Observations

High-resolution optical spectra ($R \sim 48\,000$) in the range 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, 2014, and 2015 (program ID 076.D-0609(A)).

Using the Phoenix spectrograph, attached to the 8-m telescope at Gemini South (Chile), we obtained high resolution near-infrared spectra ($R \sim 40\,000$) in the ranges 2.288–2.296 μm and 2.320–2.329 μm, under different observing runs during 2004, 2010 and 2011 (program IDs: GS-2004B-Q-54 and GS-2010B-Q-31).

Low resolution mid-infrared spectra ($R \sim 100$) in the range 8–13 μm were acquired with the T-ReCS spectrograph at Gemini South (Chile) attached to the 8-m telescope in 2012 (program ID: GS-2012B-Q-90).

4. Results

4.1. Forbidden lines

Several forbidden emission lines, such as [O I] $\lambda\lambda$5577 and 6300 and [Ca II] λ7291, can be used to trace the neutral and ionized 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 the FEROS spectra, we found that the [O I] λ5577 and [Ca II] λ7291 lines originate from about one ring with a velocity of ~ 40 km s^{-1} and another one with a velocity of 23 km s^{-1}. The [O I] λ6300 line also has the contribution of two rings, one with a velocity of 34 km s^{-1} that co-exists with the CO gas and another one with a velocity of 17 km s^{-1} (Fig. 1). The velocities have been corrected for the stellar heliocentric velocity.

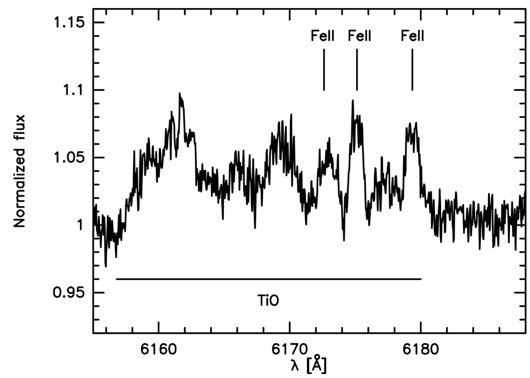

Figure 2: Detection of TiO band emission in 2014 FEROS spectrum.

4.2. TiO emission bands

A broad emission feature extending from 6158 Å to 6180 Å is detected (Fig.2). 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). Thus, LHA 120-S 73 is the fourth object with clear signatures of TiO band emission. It is worth noting that all stars with TiO emission also show emission from CO bands (e.g. Oksala et al., 2013).

4.3. CO emission bands and their variability

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

Our Phoenix spectra clearly resolve the structure of the first and second band head emission as well as individual double-peaked CO roto-vibrational lines in front of the second band head (Fig. 3). This allows us to constrain the physical parameters of the CO gas very well. The blue shoulder and the red peak of the band head are typical characteristics of emission from a rotating ring or disk (Najita et al., 1996; Kraus et al., 2000).

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 $T_{\rm CO} = 2850 \pm 100$ K, $N_{\rm CO} = (6 \pm 1) \times 10^{20}$ cm^{-2} and a rotational velocity

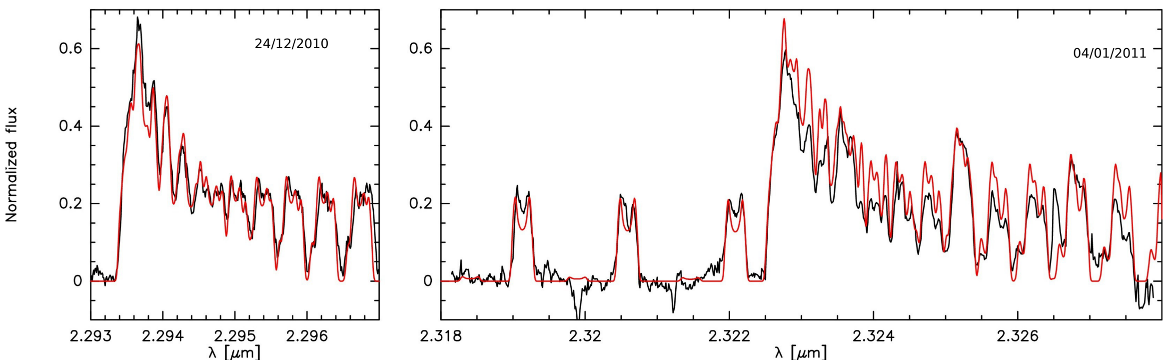

Figure 3: Model fit (red) to the observed (black) first and second CO band heads.

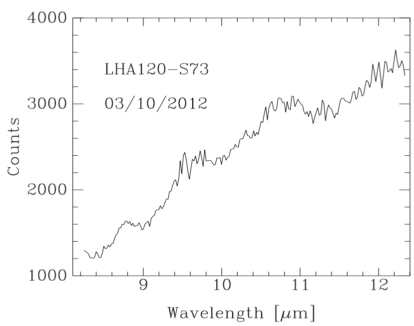

Figure 4: T-ReCS spectrum of LHA 120-S 73. The spectrum is not flux calibrated.

of 34 km s^{-1} (see Fig. 3). No contribution from Pfund emission lines is seen in our data. Noticeable Pfund lines in LHA 120-S 73 arise at longer wavelengths (Liermann et al., 2010; Oksala et al., 2013).

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. The latter implies that the rotation velocity of the 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.

4.4. Dust emission

The T-ReCS spectrum shows two prominent emission features around 9.5 μm and 10.8 μm (Fig. 4) that resemble the ones shown by Kastner et al. (2006), indicative of a mixture of small and large silicate grains.

5. Conclusions and future work

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.

We have still 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. We also intend to estimate the stellar parameters using the BCD method (Chalonge & Divan, 1977) and study in more detail the mid-infrared spectrum of LHA 120-S 73.

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