

High-resolution, near-infrared observations of B[e] supergiants

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Resumen / Las estrellas supergigantes B[e] están rodeadas por discos formados por material eyectado por la estrella central. Para describir las propiedades de estos discos, pueden usarse distintos trazadores en las regiones espectrales del óptico y del infrarrojo. La emisión molecular de CO es particularmente valiosa, ya que define la región de transición entre el gas atómico y el molecular. Recientemente, hemos comenzado con una campaña de observación, para obtener espectros de alta resolución en el infrarrojo cercano de una muestra de estrellas B[e] supergigantes con emisión molecular de CO confirmada. En este trabajo, presentamos espectros obtenidos con GEMINI/IGRINS de CD-57 3107 y HD 62 623 y los parámetros físicos de sus discos moleculares que derivamos a partir del modelado detallado de su emisión en CO. Además, reportamos la detección de emisión de ^{13}CO en ambos espectros, reforzando la hipótesis de la naturaleza evolucionada de estos objetos.

Abstract / B[e] supergiants stars are surrounded by disks formed from material released from the central object. To trace the properties of these disks, diverse emission features in the optical and near-infrared can be used. CO band emission is particularly valuable, because it defines the transition region between the atomic and molecular gas. We have recently started a campaign to obtain high-resolution near-infrared spectra for B[e] supergiant stars with confirmed CO emission. In this work, we present GEMINI/IGRINS spectra of CD-57 3107 and HD 62 623 and the physical parameters of their molecular disks obtained from detailed modeling of their CO band emission. Moreover, we report on the detection of ^{13}CO emission in both stars, reinforcing the evolved nature of these objects.

Keywords / stars: early-type — circumstellar matter — stars: emission-line, Be

1. Introduction

B[e] supergiants (B[e]SGs) are massive and luminous evolved B-type stars that exhibit a hybrid spectrum with strong Balmer emission lines, narrow low-excitation emission lines of permitted and forbidden transitions (indicative of a cool and slowly expanding medium), and a strong near and mid infrared excess (indicative of hot circumstellar dust) (Lamers et al., 1998). Resonance lines of highly ionized elements in their UV spectrum also reveal a hot and fast line-driven wind (Kraus & Lamers, 2003).

As a result of the mass lost during the B[e]SG phase, these stars are surrounded by a cool and dense complex circumstellar environments, where atomic, molecular and dusty regions are found in disk-like structures (Kraus, 2019).

Investigation of the kinematics within the gaseous disk region often reveals that it is consistent with Keplerian rotation (Aret et al., 2012; Cidale et al., 2012; Kraus et al., 2013). However, recent observations showed that the circumstellar material is located in detached disks or rings, favoring a scenario in which mass loss happens episodically rather than smoothly. In some cases, these disk or ring structures are found to be highly variable in density and kinematics (e.g. Torres et al., 2012; Kraus et al., 2016). The nature of the disk was also suggested to be circumbinary, at least in some cases, as some Galactic B[e]SGs were found to be in binary systems (Maravelias et al., 2018).

While in the optical spectral range forbidden emission lines of [O I] and [Ca II] can be used as ideal tracers for the neutral and ionized atomic disk regions close to the star (e.g. Torres et al., 2018; Condori et al., 2019), in the near-IR spectral region, emission from molecules such as CO, are excellent indicators for the disk conditions at larger distances (Kraus et al., 2000). CO bandheads in emission around 2.3 μm, have proven to be major indicators for the disk dynamics. These molecular bands give evidence of a cool and dense circumstellar region and usually trace the inner rim of a molecular disk.

In this work we present high-resolution near-IR spectra of two B[e]SGs and we derive the kinematics and physical properties of their molecular disk from modeling of their CO band emission.

2. Targets and Observations

We have selected two B[e]SG stars, CD-57 3107 and HD 62 623, which both have been reported to display CO band emission based on low- and medium-resolution

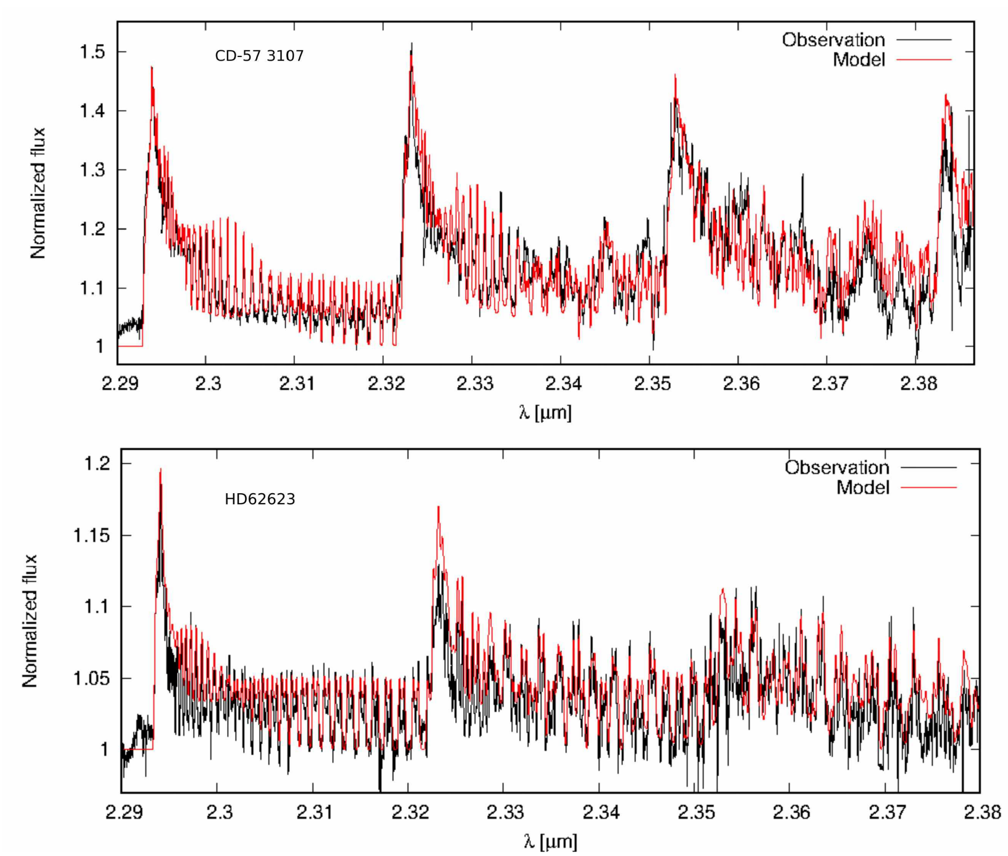

Figure 1: Best model fitting to: the first four CO bandheads observed in the high-resolution spectrum of CD-573107 (*top panel*) and the first three CO bandheads for HD 62 623 (*bottom panel*).

spectra, respectively (McGregor et al., 1988; Maravelias et al., 2018). We performed spectroscopic observations using the GEMINI/IGRINS echelle spectrograph. This instrument provides a very high resolution (R $\approx$ 40 000) and covers a wide spectral range (1.9-2.5 μm).

3. CO molecular emission modeling

The observations were acquired under the program GS-2020A-Q-138. Spectra were reduced using standard tools, paying special attention to the telluric correction, that is a difficult task due to the high resolution of the spectra. CO band emission is clearly detected in our high-resolution spectra of both stars (black lines in Fig. 1). CO molecular bands were modeled using the code developed by Kraus et al. (2000) for ^{12}CO band emission from a rotating disk, which was improved by Kraus (2009) to include the isotope ^{13}CO. This code has been advanced by Vallverdú et al. (2021, in press) by implementing further molecules whose emission can now be computed simultaneously. The CO molecular emission spectrum was calculated assuming local thermodynamic equilibrium and ^{12}CO as well as the ^{13}CO isotope were considered.The parameters of the model are the temperature, the column density, the abundance of the different isotopes, the inclination and the rotational velocity of the disk. As this emission arises commonly from a narrow region, it is a good approximation to assume constant temperature, density and rotational velocity.

Rotation, as in Keplerian disks, results in a characteristic band head shape, displaying a blue shoulder and a red peak, and the separation between these two corresponds to twice the rotational velocity projected to the line of sight. Therefore, the first bandhead, when observed in high resolution, provides already a good guess of the kinematics of the CO gas. However, reliable physical parameters of the band formation regions require the full emission spectrum with at least 3-4 band heads.

The high resolution provided by IGRINS is essential to reliably determine the kinematics of the CO emitting region as it allows to resolve even small rotational speeds. And the full spectral coverage is vital for precise determinations of the gas temperature and column density. High-resolution spectra are also necessary to detect and adequately model the ^{13}CO bandheads, that are useful to help us distinguish between a pre- or post-main sequence evolutionary state.

During the evolution of the star, the ^{13}C isotope is produced in the stellar core and mixed to the surface, from which it is released via stellar winds. Therefore, the detection of measurable amounts of ^{13}C, locked into ^{13}CO molecules, is an unambiguous tracer for chemically enriched material (Kraus, 2009; Liermann et al., 2010) based on which the evolutionary phase of B[e] stars with uncertain nature can be pinned down (e.g. Muratore et al., 2015; Kraus et al., 2020).

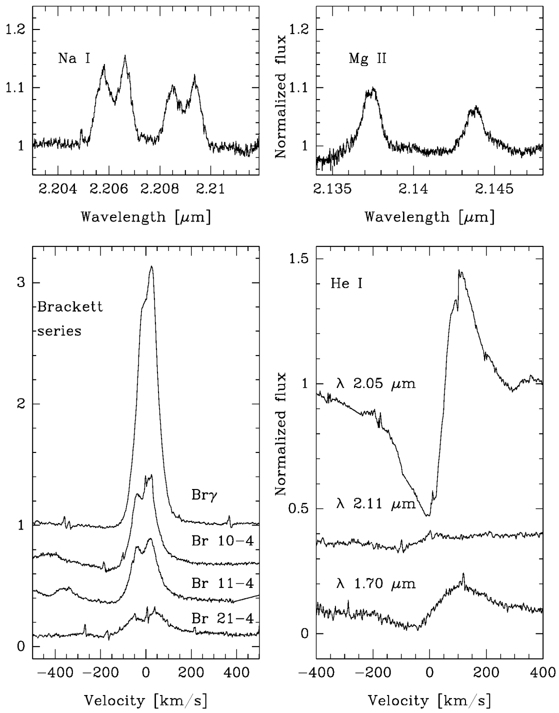

Figure 2: CD-57 3107 near-infrared emission features.

4. Results

CD-57 3107 (Hen 3-394, α = 10:15:21 δ = -57:51:42): This star is a Galactic B[e]SG. Besides CO, its infrared spectrum also displays emission from SiO bands (Kraus et al., 2015). From interferometry, Domiciano de Souza et al. (2011) located the dust envelope further than 11 AU.

Our best-fitting model to the observed CO emission, is shown in red in (Fig. 1, top) and was achieved for a molecular gas temperature $T_{CO} = 2\,800$ K and a column density of $N_{CO} = 5 \times 10^{21}$ cm^{-2}. Considering that the emission originates from a rotating ring seen under an inclination of i = 60° (Domiciano de Souza et al., 2011), we obtained a rotation velocity of $V_{rot} = 124$ km s^{-1}.

The spectrum displays clear emission from^{13}CO, and we obtain a ^{12}CO/^{13}CO ratio of ∼19 indicating ^{13}CO enrichment of the circumstellar material, characteristic of an evolved object.

In addition to CO emission, the near-IR spectrum displays double-peaked lines of Na I, which form in a similar region than CO lines, and arise from warm dense material. Moreover, we found hydrogen double-peaked lines with incipient P Cygni line profiles and with the red peak stronger than the blue one, He I P Cygni lines, that reveal the presence of a dense wind, and Mg II emission lines (see Fig. 2).

HD 62 623 (3 Pup, α = 07:43:48 δ = -28:57:17): Due to its slightly lower effective temperature, HD 62 623 is classified as an A-type star. It is the only known Galactic A[e] supergiant (Chentsov et al., 2010). Recently, Miroshnichenko et al. (2020) confirmed that HD 62 623 is a binary system in a circular orbit with a period of 137.4 days and a semi-major axis of 1.11 AU, which suggests that the circumstellar gaseous disk is circumbinary. Considering evolutionary tracks of mass-transferring binaries, they derived masses for the gainer and donor around 8.8 $M_\odot$ and 0.75 $M_\odot$, respectively.

Our best fitting model for the CO molecular emission (Fig. 1, bottom) has the parameters: $T_{CO} = 2\,000$ K, $N_{CO} = 3 \times 10^{20}$ cm^{-2}, $V_{rot} = 53$ km s^{-1} and i = 38°. The ^{12}CO/^{13}CO ratio is ∼ 19, giving evidence of a circumstellar enriched medium and indicating an evolved nature of the A-type component. The obtained values are in good agreement with those determined by Maravelias et al. (2018) using a lower resolution spectrum.

5. Conclusions

We could precisely determined the kinematics and physical parameters of the circumstellar disks of two B[e]SG candidates by means of CO modeling, reiforcing the need of high-resolution near-IR spectroscopy in order to study the environments of these kind of objects. In addition, we detected clear ^{13}CO emission from both stars, confirming their evolved nature.

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