Tracing the mass-loss history of B[e] supergiants

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1. Motivation

The post-main sequence evolution of massive stars encompasses several phases with strong, often eruptive mass-loss events, including the puzzling B[e] supergiants (B[e]SGs). Stars in this group are surrounded by disks which are cool and dense, and give rise to a complex chemistry, producing molecules and dust. The original idea was that these disks had been formed via a steady, but slow, high density equatorially confined wind. However, recent observations revealed that the circumstellar material is located in detached disks or rings, sometimes even multiple rings, favouring a scenario in which mass loss happens episodically rather than smoothly. Furthermore, time-resolved observations of these disk or ring structures indicated a high variability in density and kinematics. Some Galactic B[e]SGs were recently found to be in binaries, and in a few cases, the disks are circumbinary instead of circumstellar. We have initiated an observing campaign using high-resolution optical and near-infrared spectroscopy aimed at studying the structure and kinematics of the circumstellar material of B[e]SGs. While in the optical spectral range several forbidden emission lines can be used as ideal tracers for the ionized and neutral atomic disk regions close to the star, near-infrared spectra host band emission from molecules such as CO, which are excellent indicators for the disk conditions at larger distances. Here we present and discuss first results.

2. Optical and near-infrared spectroscopy

- Optical high-resolution spectra ($R \sim 48\,000$) were obtained in April and December 2005 and December 2008 using the FEROS spectrograph attached to the 2.2m-telescope at ESO in La Silla (Chile).
- High-resolution ($R \sim 50\,000$) near-infrared spectra were obtained in April and August 2010 and January 2011 with the Phoenix spectrograph attached to the 8m-telescope at Gemini-South (Chile). The spectra cover the second CO band head region.
- A high-resolution ($R \sim 50\,000$) near-infrared spectrum of the B[e]SG HD 327083, covering the second CO band head, was taken from the ESO archives. It was obtained on 2010 June 28 with CRIRES attached to an ESO 8m-telescope at Paranal (Chile).
- Data reduction, telluric, and heliocentric velocity corrections were performed using ESO pipelines and standard IRAF tasks.

3. Modeling of the CO band emission

- CO bands were calculated in LTE using the disk code of Kraus et al. (2000).
- CO band emission arises typically from a narrow ring region, justifying the assumptions of constant temperature, density, and rotational velocity.

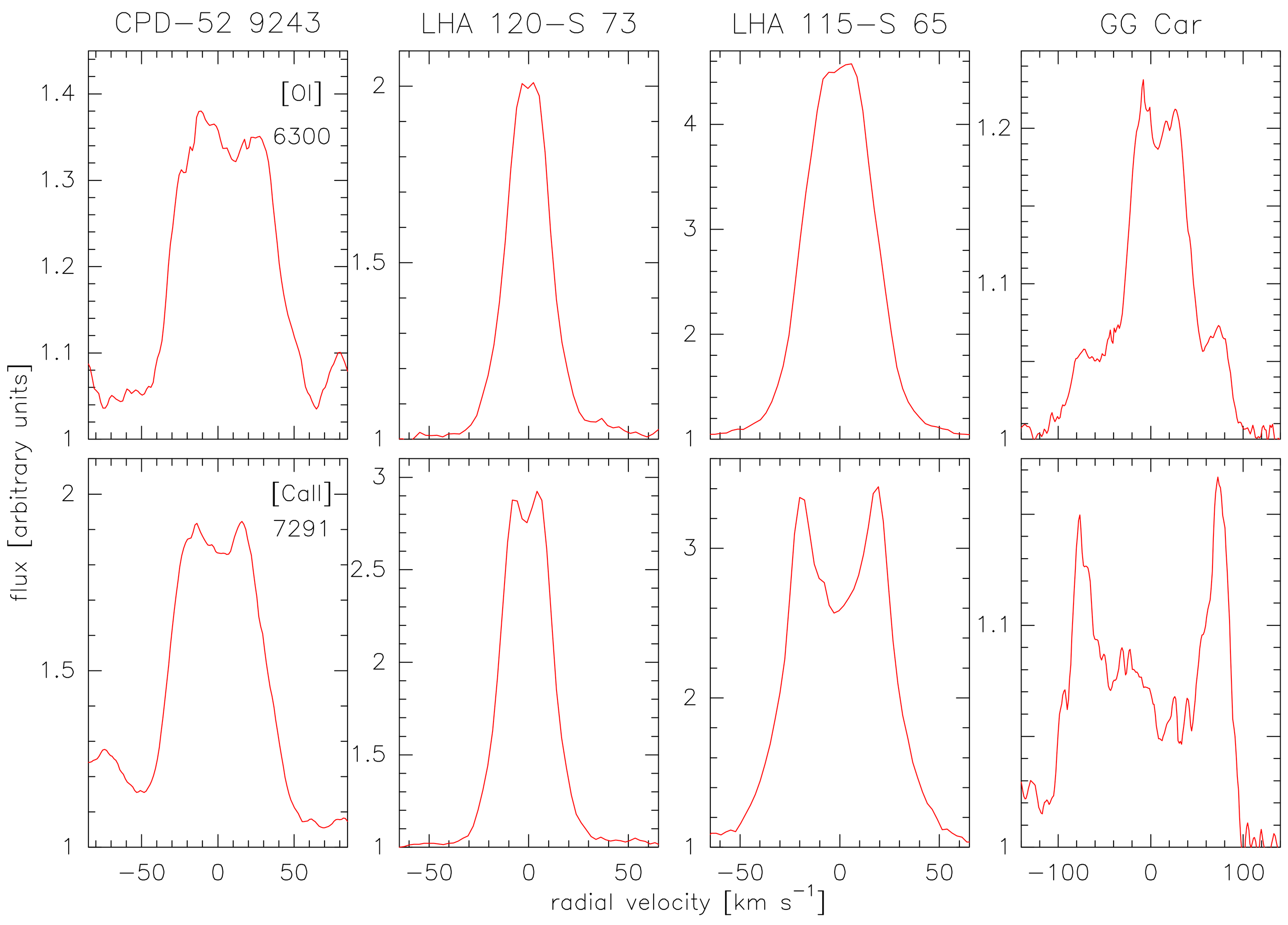

Figure 1: Profiles of forbidden emission lines of [OI] (top) and [CaII] (bottom) displaying double-peaks, characteristic for rotational broadening.

4. Kinematics from forbidden lines

- Forbidden lines (Fig. 1) form over a much larger disk region than CO bands.
- Max (min) velocities in Table 1 refer to wing (peak) separation values.
- [CaII] lines typically form in higher density regions than [OI] lines.
- [CaII] lines indicate higher velocities than [OI] lines

⇒ Keplerian rotation in the disk is traced from inside out:

[CaII] ⇒ [OI] ⇒ CO

- Work in progress: Modeling of the forbidden lines to constrain density and temperature structure of the disks.

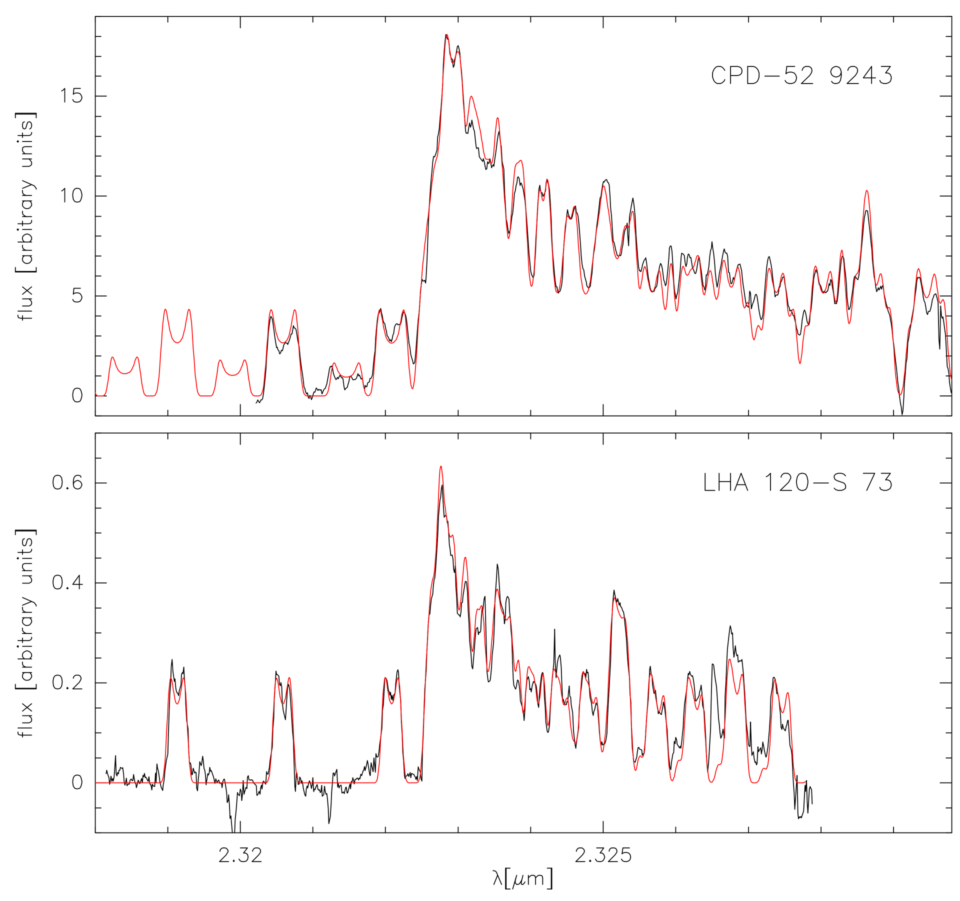

Figure 2: Fits (red) to the observed CO bands (black) of a Galactic (top) and an LMC B[e]SG (bottom). v sin i values are obtained from the fully resolved individual CO lines blueward of the band head.

5. Selected B[e]SGs with kinematically resolved CO bands

⇐ Model fits to the observed second CO band heads of two B[e]SGs (Fig. 2). The clearly double-peaked, fully resolved individual CO lines on the blue side of the band head indicate rotational broadening.

Table 1: Velocities projected to the line of sight, obtained from the different tracers.

Object	i	Ref.	v sin i [CaII] [km/s] max	min	[OI] [km/s] max	min	CO [km/s]	Ref.
	[°]							
CPD-52 9243	46± 7	(1)	40	20	40	20	25.5± 0.5	(2,1)
LHA 120-S 73	28± 1	(3)	30	6	25	3	15.5± 0.5	(2)
LHA 115-S 65	84± 6	(3)	50	20	40	5	unknown	(2)
HD 327083	∼ 48.5	(4)	n.a.	n.a.	n.a.	n.a.	55.5± 1.0	(2)
GG Car	63± 9	(5)	100	75	90	20	80.0± 1.0	(2,6)

References: (1) Cidale et al. (2012); (2) This work; (3) Aret et al. (2012); (4) Wheelwright et al. (2012a); (5) Marchiano et al. (2012); (6) Kraus et al. (2013).

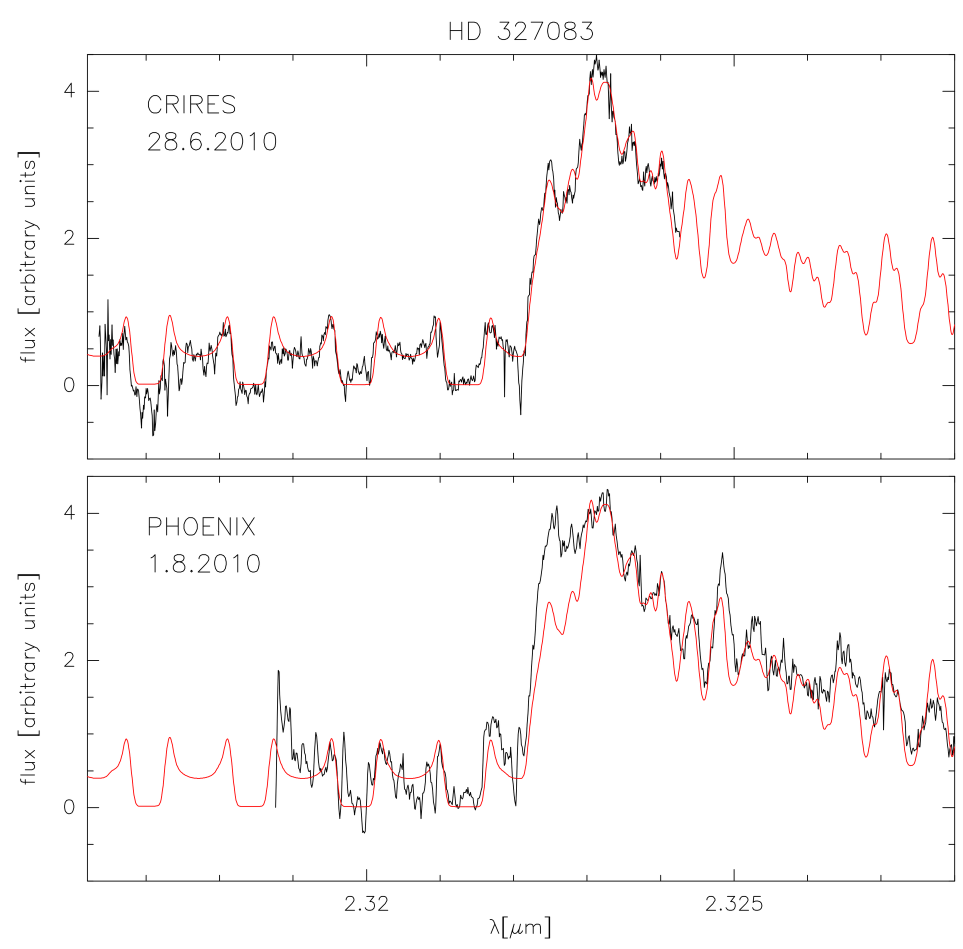

Figure 3: Fit (red) to the observed CO bands of the Galactic B[e]SG HD 327083 taken with CRIRES (black, top). The same model cannot fit the Phoenix spectrum (black, bottom) taken only about one month later.

6. Variability in CO emission in peculiar B[e]SGs

⇐ CO bands of the Galactic B[e]SG HD 327083 (Fig. 3). The best-fit model to the CRIRES spectrum does not fit the Phoenix data taken ~ 1 month later. Contrary to the postulation of Wheelwright et al. (2012b), we do see strong variability in CO emission, implying an inhomogeneous density distribution in the circumbinary disk (Andruchow et al. in prep.).

No CO band emission was seen in the SMC B[e]SG LHA 115-S 65 for several decades. The sudden, strongly blueshifted appearance of the CO bands (Fig. 4, Oksala et al. 2012, 2013) indicates recent mass ejection. ⇒

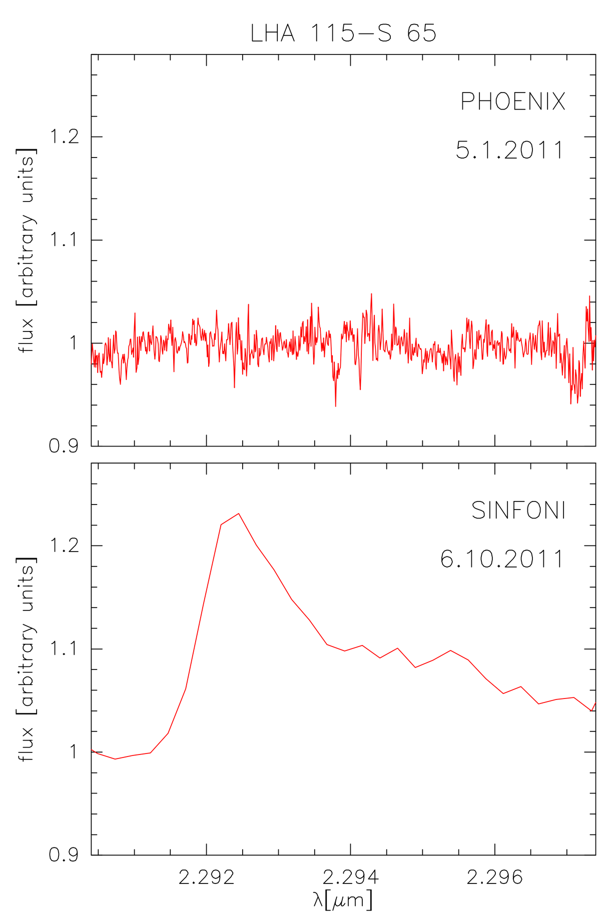

Figure 4: Sudden (within nine months) appearance of CO band emission in the SMC B[e]SG LHA 115-S 65.

7. Results and outlook

- Many B[e]SGs show indication for multiple (LBV-like?) mass ejections.
- Mass accummulates typically in Keplerian rotating circumstellar rings.
- Two Galactic B[e]SGs (GG Car and HD 327083) were found in close binary systems with circumbinary disks; the primary component of GG Car was possibly a normal Be star during its main-sequence evolution (for details see Kraus et al. 2013).
- Detailed kinematical studies are needed (and in progress) to trace the mass-loss history of all B[e]SGs.

References

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