Optical spectroscopy of stars with disks

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1. Introduction

During their evolution, stars pass through several phases, in which they are surrounded by dense envelopes of circumstellar material.

Pre-main sequence objects, such as Herbig Ae/Be stars, and their less massive counterparts, T Tauri and FU Orionis stars, are usually surrounded by dense accretion disks hiding the central object.

Massive stars in post-main sequence stages, such as the red supergiants (RSGs), yellow hypergiants (YHGs), luminous blue variables (LBVs), and B[e] supergiants (B[e]SGs) expel large amounts of material, which accumulates in a shell or nebula, or in a disk-like structure.

Observed emission features of stars with disks in quite diverse evolutionary stages appear very much alike, meaning that they must have comparable physical conditions in their environments.

While molecular and dust spectroscopy provides information about the outer disk, optical emission lines are good probes of hot gaseous regions close to the star. Besides the emission in the hydrogen Balmer series, emission in the Ca II infrared triplet (IR-triplet) $\lambda\lambda$8498, 8542, 8662 lines serves as an important indicator for circumstellar material and has been reported for a diversity of objects. The lower energy levels, to which the calcium IR-triplet lines decay, are the upper levels of the two forbidden transitions of [Ca II] $\lambda\lambda$7291, 7324.

Forbidden emission lines are especially valuable disk tracers, because they are optically thin, and therefore their profiles reflect the kinematics within their formation region. The forbidden [O I] line at 6300 Å has been used for gas diagnostics after Acke et al. (2005) reported detection of this line in a sample of Herbig Ae/Be stars. Recently, Aret et al. (2012) discovered emission in [Ca II] $\lambda\lambda$7291, 7324 lines from the disks of B[e] supergiants.

The [Ca II] lines trace very high-density regions, hotter and denser than the [O I] line-forming region.

We have started **a spectroscopical survey** of stars surrounded by dense environments, to study **the frequency and origin of [Ca II] lines** in stars with circumstellar disks and to obtain **constraints on the physical conditions** under which these lines appear.

2. Observations

Our sample consists of 9 B[e] stars, 4 YHGs, a post-AGB star and 2 peculiar objects with dense disks, 9 pre-main-sequence stars, 3 emission-line stars of O–B types and 30 Be stars (Table 1).
Observations were obtained during 2011–2012 using the Coudé spectrograph attached to the 2m-telescope at Ondřejov Observatory (Šlechta & Škoda, 2002).
Spectra were taken in three wavelength regions:

- H_α : 6250–6760 Å, $R \simeq 13\,000$
- [Ca II] : 6990–7500 Å, $R \simeq 15\,000$
- Ca II IR-triplet : 8470–8980 Å, $R \simeq 18\,000$

The data were reduced using standard IRAF tasks. Telluric corrections were performed using telluric standard stars observed each night. Spectra were corrected for heliocentric and systemic velocities and normalized.

3. Results

None of the observed Be stars displayed forbidden lines in their spectra, neither [O I] nor [CaII], even though they were selected based on their sometimes rather prominent CaII IR-triplet emission (e.g. 28 Tau in Fig 1). This indicates that the disks of Be stars are not dense enough to create detectable emission in the forbidden lines.

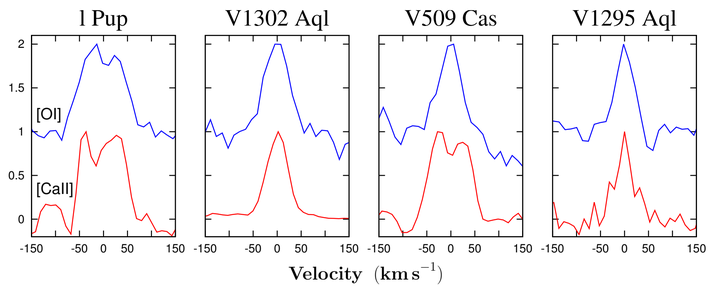

Figure 2: Kinematically broadened line profiles of [Ca II] (red) compared to [O I] (blue).

Most B[e] stars have [O I] emission, and those which display [CaII] lines in their spectra also show strong emission in the CaII IR-triplet, but not vice versa.
All yellow hypergiants from our sample show emission in [CaII], however, emission in the CaII IR-triplet does not seem to be a prerequisite of the appearance of the forbidden lines. Emission in the IR-triplet requires the population of higher excited states than emission in the forbidden lines, and the circumstellar material around cooler stars is not hot enough to populate them.
T Tau and FU Ori stars show wide multicomponent emission in the forbidden lines of calcium and oxygen arising from regions with complicated and very different kinematics like from a disk and jets.

Modeling of the emission lines is in progress. This will help us to constrain the physical conditions of the circumstellar environments.

Table 1: Spectral features of observed stars

Star	Class	[Ca II]	[O I]	Ca II IR
V1478 Cyg	B[e]SG cand	+	+	em
OY Gem	B[e](cPNe)	+	+	em
l Pup	B[e]SG	+	+	em
CI Cam	B[e]SG	–	–	em
V1972 Cyg	B[e]SG cand	–	+	em
V743 Mon	B[e]	–	+	em
BD+23 3183	B[e]	–	+	–
HD 281192	B[e]	–	+	–
V1429 Aql	B[e]SG cand	+	?	em
V1302 Aql	YHG	+	+	em
V509 Cas	YHG	+	+	em/abs
V1427 Aql	YHG	+	–	abs
ρ Cas	YHG	+	–	abs
IRAS 19343 +2926	Post-AGB	+	+	em
XX Oph	Peculiar	+	+	em
υ Sgr	Peculiar	+	–	em
V380 Cep	Herbig	–	+	em
AB Aur	Herbig	–	+	em
HD 31648	Herbig	–	–	em
V1295 Aql	Herbig	+	+	em
HD 179218	Herbig	–	+	–
RW Aur	T Tau	+	+	em
DG Tau	T Tau	?	+	em
V1331 Cyg	T Tau	+	+	em
V1057 Cyg	FU Ori	+	+	P-Cyg
alp Cam	Em	–	–	–
HD 209296	Em	?	?	em
HD 76868	Em	–	–	em

References

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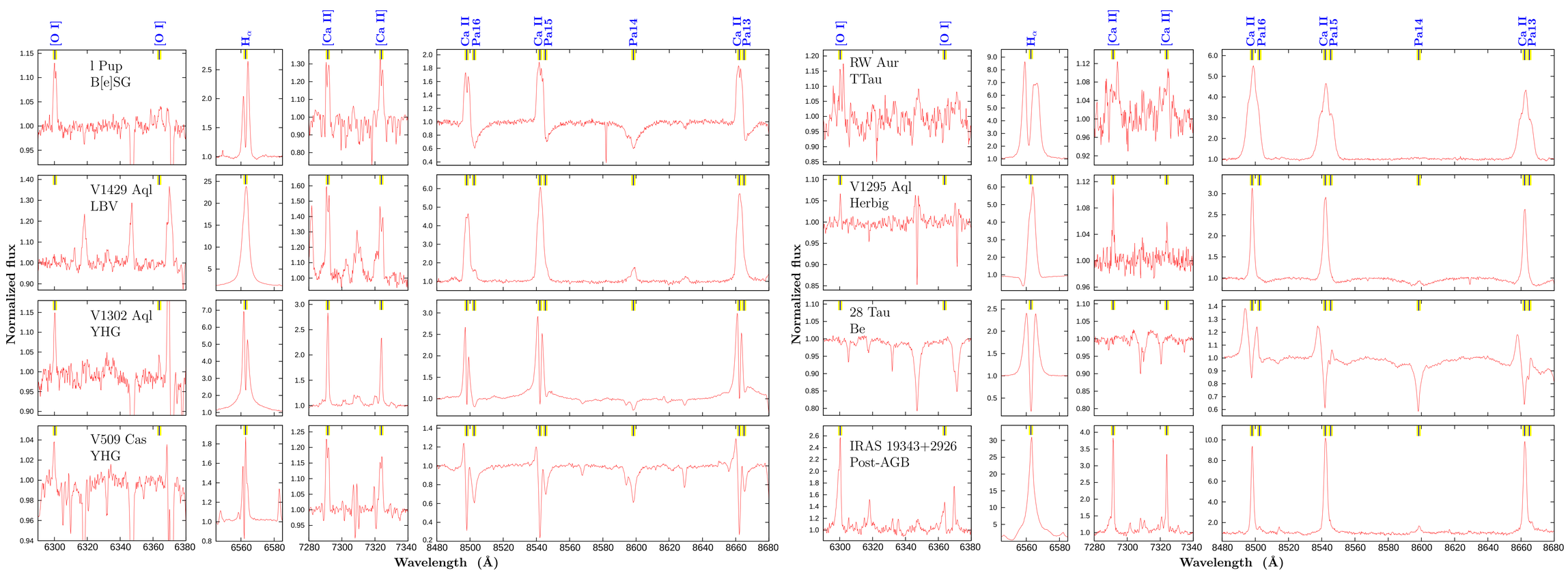

Figure 1: Portions of the optical spectra around the lines of interest for a sub-sample of objects.