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The Yellow Hypergiant – B[e] Supergiant Connection

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Abstract. B[e] supergiants and yellow hypergiants share a number of common properties regarding their circumstellar environments. Using the forbidden [O I] and [Ca II] lines as disk tracers, we suggest the presence of a Keplerian disk or ring around the yellow hypergiant V509 Cas and confirm the pole-on inner disk around V1302 Aql. These findings indicate a change in mass-loss behavior from spherical in cooler yellow hypergiants to axisymmetric in the hotter ones during the passage through the Yellow Void. The accumulation of material in the equatorial plane reminds of the disks of B[e] supergiants, supporting the suggestion that yellow hypergiants might appear as B[e] supergiants after they reach the blue edge of the yellow instability domain.

1. Introduction

During their post-main-sequence evolution massive stars pass through several short-lived phases of enhanced mass loss. Yellow hypergiants (YHGs) and B[e] supergiants (B[e]SGs) are well-known groups in such transition phases. The ejected material typically accumulates in either shells, rings, or disk-like structures. Rich emission line spectra of such objects provide information on the structure and kinematics of the circumstellar matter. Forbidden emission lines of singly ionized or neutral metals, such as [Ca II] and [O I], serve as particularly valuable tracers for their formation regions, carrying information on kinematics and physical conditions. It has been shown (Aret et al. 2012; Aret, Kraus, & Šlechta 2016) that the appearance of these lines requires high-density environments combined with large emitting volumes. Such conditions are met in the innermost regions of Keplerian rotating disks around B[e]SGs, where [Ca II] lines are formed closest to the star, followed by the [O I] λ5577 line and the [O I] $\lambda\lambda$6300, 6364 lines further out.

YHGs are massive stars that have passed through the red-supergiant (RSG) phase and evolve back bluewards in the Hertzsprung-Russell diagram. Enhanced mass loss and eruptions in YHGs are ascribed to increased pulsation activity (see the overview by de Jager 1998). Although physical mechanisms causing build-up of massive disks around B[e]SGs are unknown, it has been suggested that pulsations might play a role as well (Kraus et al. 2016). Controversial results have been obtained concerning the evolutionary state of B[e]SGs. While the enrichment in ^{13}C in their disks favors a pre-RSG state (Oksala et al. 2013), their massive dusty environments indicate a post-RSG evolutionary phase. Similarities in the circumstellar environments of YHGs and B[e]SGs support the latter case and the suggestion by Davies, Oudmaijer, & Sahu (2007) that YHGs may be evolving toward the B[e]SG phase.

2. Observations

During the years 2010–2015, we carried out an optical spectroscopic survey of a large sample of Galactic northern emission-line stars. The survey includes four YHGs: V1302 Aql (A2-F8 Ia), V509 Cas (A7-G5 Ia), ρ Cas (F0-G7 Ia), V1427 Aql (F3-G5 Ia), and two B[e]SGs: V1478 Cyg (B0-B1.5 I) and 3 Pup (A2.7 Ib). The B[e]SGs were discussed in detail in Aret et al. (2016).

Spectra were obtained using the Coudé spectrograph attached to the Perek 2-m telescope at Ondřejov Observatory (Šlechta & Škoda 2002) in three wavelength regions: around H α (6250–6760 Å, $R \simeq 13\,000$), in the region of the [Ca II] $\lambda\lambda$7291, 7324 lines (6990–7500 Å, $R \simeq 15\,000$), and in the region of the Ca II infrared triplet (8470–8980 Å, $R \simeq 18\,000$). The H α region also encloses the two [O I] $\lambda\lambda$6300, 6364 lines.

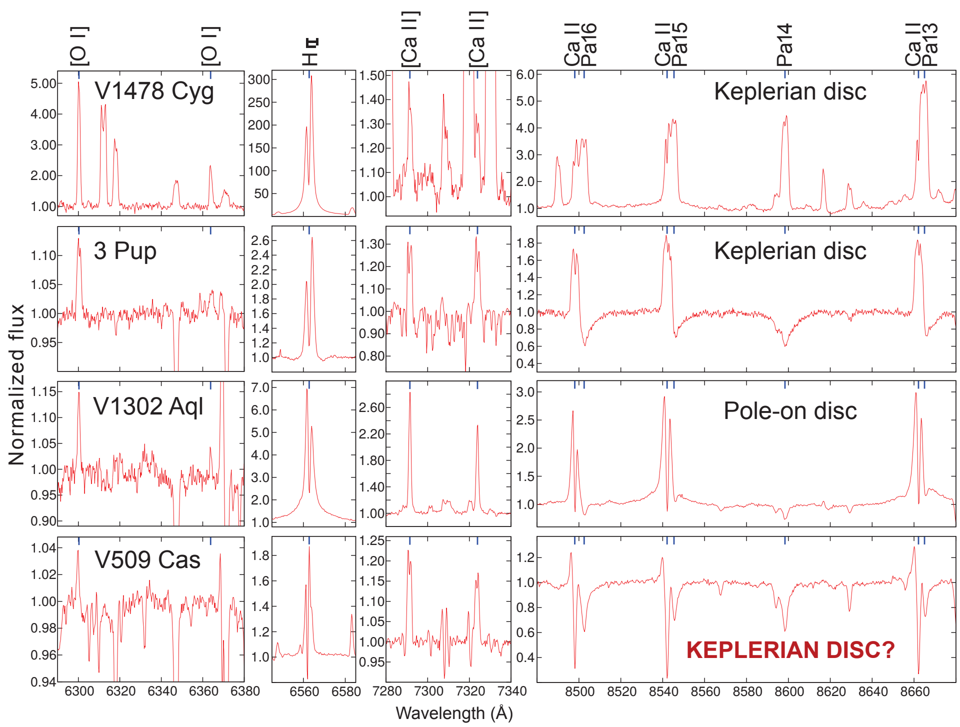

Figure 1. Spectra of the B[e]SGs compared to the two hotter YHGs.

3. Results and Conclusions

Both the [Ca II] and [O I] lines were identified in the spectra of the B[e]SGs V1478 Cyg and 3 Pup, and of the hotter YHGs V1302 Aql and V509 Cas (Figure 1), while in the cooler YHGs ρ Cas and V1427 Aql only the [Ca II] lines were present, but not the [O I] lines. Also the infrared Ca II triplet lines are in emission in B[e]SGs and the hotter YHGs, while in the cooler YHGs we see them in absorption. This indicates a difference in excitation mechanisms of the [Ca II] lines in hotter and cooler environments.

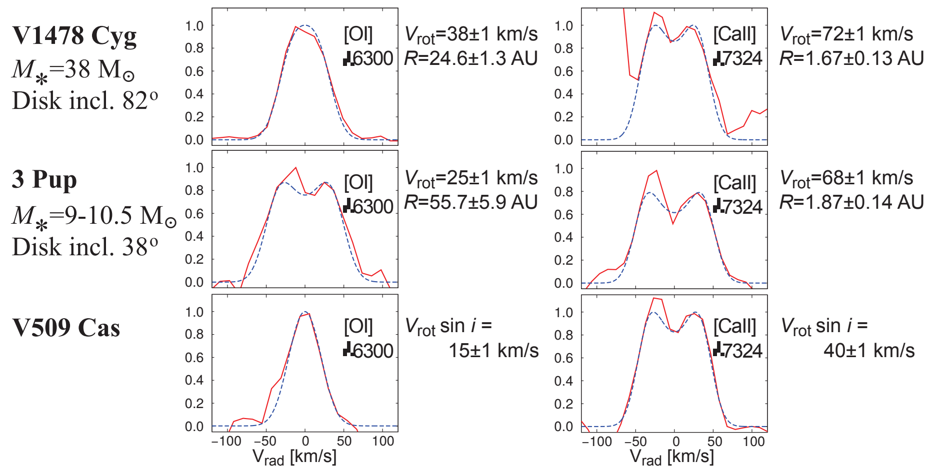

Figure 2. Kinematic model fits (dashed blue) to the observed profiles (solid red) of the forbidden lines. Shown are the obtained rotational velocities and the corresponding radii of the emitting rings assuming Keplerian rotation.

Both B[e]SGs are known to possess a disk (see Aret et al. 2016). We obtained rotational velocities from the line profiles of these B[e]SGs using a simple kinematic model, assuming that the emission originates from a narrow Keplerian rotating ring. We calculated the profile shape considering only the rotational velocity projected to the line of sight and the resolution of the spectrograph (Figure 2).

The presence of both sets of forbidden lines in the two hot YHGs indicates that the physical conditions in their environments could be similar to those in the B[e]SGs. The profiles of the forbidden emission lines of V1302 Aql are single peaked (Figure 1) and display no kinematical broadening beyond spectral resolution. Such profiles are in agreement with their formation in the nearly pole-on seen disk (Castro-Carrizo et al. 2007; Tiffany et al. 2010). Not much is currently known concerning the structure of the small-scale environment of V509 Cas. The forbidden lines in our spectra show clearly double-peaked profiles for the [Ca II] lines. The [O I] lines appear as broad but single peaked features at our spectral resolution, however, modeling of the profile reveals significant rotational broadening of the lines, as for V1478 Cyg (Figure 2). This kinematical picture is typical for B[e]SGs (Kraus et al. 2010; Aret et al. 2012; Maravelias et al. 2016). Thus, V509 Cas is the second YHG with clear indication for an inner disk.

In both cooler YHGs the profiles of the [Ca II] lines are very narrow single-peaked. They provide no information on the kinematics in their [Ca II] line-forming regions, but are consistent with an origin from a spherically symmetric shell.

The presence of disks around the hotter YHGs might indicate a drastic change in the mass-loss behavior from spherical to axisymmetric during the evolution through the Yellow Void, as was suggested by Davies et al. (2007). As pulsations are believed to be the main mechanism responsible for enhanced mass loss and eruptions in YHGs (de Jager 1998), this would require a change in the pulsation habit of the stars when they approach the blue boundary of the "first" instability region (Figure 3). During their passage through the second part of the Yellow Void, more material might still accumulate in the equatorial plane and at the blue edge of the Yellow Void the stars might appear as B[e]SGs. Such a scenario was already suggested for V1302 Aql by

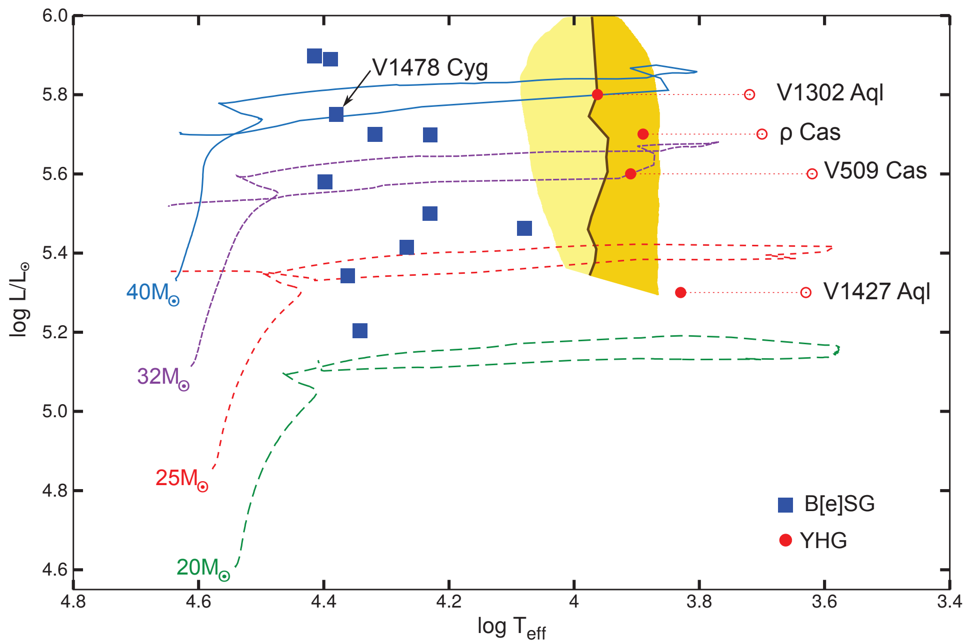

Figure 3. Upper part of the HRD illustrating a possible evolutionary link between YHGs and B[e]SGs. For the YHGs horizontal excursions due to $T_{\rm eff}$ variations are shown. Evolutionary tracks are from Ekström et al. (2012). The Yellow Void is as in de Jager & Nieuwenhuijzen (1997), the "first" instability region is darker and its high-temperature boundary is marked by the solid line (Nieuwenhuijzen et al. 2012).

Zickgraf (1998) and Davies et al. (2007). It might also apply to V509 Cas and even to a larger sample of hot YHGs, which is worth being investigated in more detail.

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