FULL TITLE
ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION**
NAMES OF EDITORS

Toward Mapping the Detailed Density Structure of Classical Be Circumstellar Disks

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Abstract. We present the preliminary results of near contemporaneous optical and infrared spectroscopic observations of select classical Be stars. We find strong evidence of oppositely oriented V/R hydrogen line profiles in the optical versus infrared spectra of zeta Tau, and briefly discuss how sustained contemporaneous optical and infrared spectroscopic observations might enable us to trace the detailed density structure of classical Be circumstellar disks.

1. Introduction

Asymmetrical double-peaked line profiles are often observed in classical Be stars. The ratio of the violet (V) to red (R) intensities in these profiles, i.e., the V/R ratio, has been observed to vary in a quasi-periodic manner on time-scales of several to 10 years (Okazaki 1997), and these features are most commonly interpreted as evidence of one-armed spiral density waves in these stars' circumstellar disks. While all line profiles in any given observation of a classical Be star are expected to exhibit the same V/R orientation (see Figure 1), Waters & Marlborough (1992) predicted on theoretical grounds that the different optical depths probed by optical versus infrared hydrogen lines might produce oppositely oriented V/R ratios in contemporaneous observations of these different wavelength regimes. Thus observing such a phenomenon and/or observing the temporal evolution of these line profiles could enable one to map the detailed density distribution of classical Be circumstellar disks, hence determine if these these disks do exhibit density waves. To our knowledge, Clarke & Steele (2000) have offered the only tentative observational evidence of such a phenomenon, when they reported that the H I Brackett γ and He I 2.058 μm lines in an observation of a classical Be star in their dataset had oppositely oriented V/R ratios. These authors postulated that either a discrete mass ejection, i.e. a μ Cen-like event, had recently entered the disk from a non-radial pulsation event or they that were probing a one-armed density wave a different disk radii, e.g. the phenomenon predicted by Waters & Marlborough (1992).

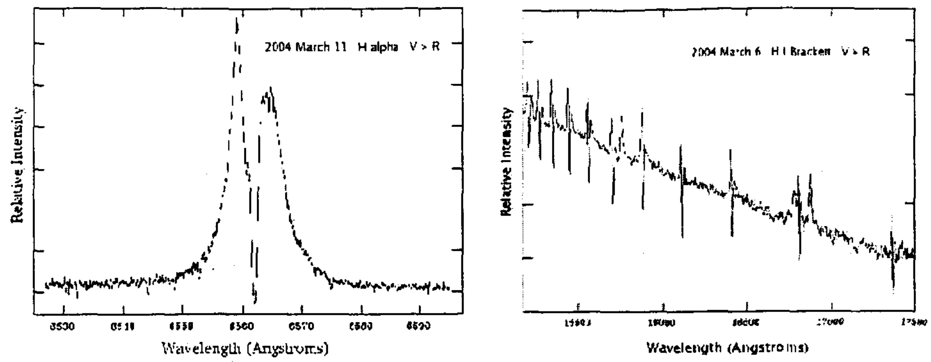

Figure 1. *Left:* The Hα spectrum of 48 Librae observed on 11 March 2005 exhibits an asymmetrical profile characterized by V > R. *Right:* A near contemporaneous infrared spectrum obtained on 6 March 2005 also exhibits hydrogen Brackett lines having asymmetrical profiles with V > R. The agreement between the orientation of these line profile morphologies is the standard scenario expected in observations of classical Be stars.

2. Observations

The Hα spectra presented in this preliminary study were obtained with the echelle spectrograph (R $\sim$ 26,000) at the University of Toledo's Ritter Observatory 1m telescope, as part of a long-term monitoring program of classical Be stars. Our infrared spectra were obtained on 5-6 March 2004 at NASA's Infrared Telescope Facility (IRTF) using its SpeX instrument, with a 0.3 x 15 arc-second slit, providing R $\sim$ 2000 from 0.8 to 2.4 μm. Although these latter data were not obtained under photometric conditions, the overall shape of all line profiles presented in this report as well as their relative strengths should not be affected by this calibration uncertainty.

3. Initial Results and Future Work

Similar to Clarke & Steele (2000), our infrared spectrum of the classical Be star NGC 2439:WBBe 1 (Wisniewski 2005) (not pictured here) shows suggestive evidence of oppositely oriented line profile morphologies: several Fe II lines in this spectrum exhibit evidence of asymmetry with V > R structure, while numerous hydrogen Brackett lines exhibit evidence of asymmetry with V < R morphologies. More convincing evidence of such a phenomenon occurring is present our near contemporaneous optical and infrared spectroscopic observation of the classical Be star zeta Tau, shown in Figure 2. From these data, it is clear that while the Hα line profile is characterized by an asymmetry with V < R, both in observations prior to and following our infrared observation, all of the hydrogen Brackett series line profiles exhibit asymmetrical morphologies with V > R. We suggest that the simplest explanation of this observational phenomenon is that we are observing different optical depths in zeta Tau's disk in our optical versus infrared spectra, i.e. these different wavelength regimes are probing the spiral density wave present in zeta Tau's disk at different radial depths of the disk (Waters & Marlborough 1992).

These data represent the initial results of a long-term contemporaneous optical and infrared spectroscopic monitoring program we have initiated to trace the evolution of this observational phenomenon in zeta Tau, as well as in a much larger sample of classical Be stars. We plan to model the evolution of these profiles with the 3-D NLTE Monte Carlo code of Bjorkman & Carciofi (2005) in an effort to constrain the detailed density profiles of these circumstellar disk systems.

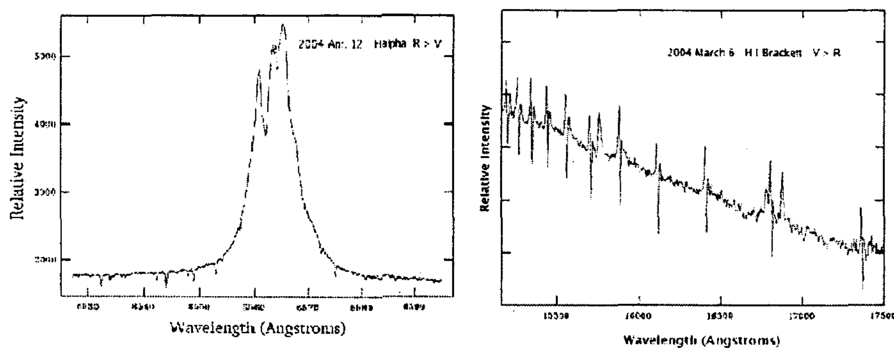

Figure 2. *Left:* The Hα spectrum of zeta Tau observed on 12 April 2005 exhibits an asymmetrical profile characterized by V < R. An earlier Ritter spectrum of this object, obtained on 28 February 2005, also exhibits this same type of asymmetrical profile. We therefore infer that zeta Tau exhibited a similar Hα line profile morphology at the time of our infrared observations. *Right:* In contrast, the infrared spectrum of zeta Tau observed on 5 March 2004 exhibits asymmetrical hydrogen Brackett line profiles characterized by V > R.

Acknowledgments. Portions of this research were supported by a NASA LTSA grant to KSB (NAG5-8054), a Research Corporation Cottrell Scholar award (KSB), a NASA GSRP Fellowship to JPW (NGT5-50469), a Sigma Xi Grant-in-aid of Research to JPW, and the NSF REU program at the University of Toledo (AFK). JPW and KSB further acknowledge financial support provided by the conference organizers and JPW acknowledges travel support provided by an AAS international travel grant.

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