Clumping in Hot Star Winds
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Hα line profile variability in the B8Ia-type supergiant Rigel (β Ori)

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Hα observations of Rigel obtained on 184 nights during the past ten years with the 1-m telescope and échelle spectrograph of Ritter Observatory are surveyed. The line profiles were classified in terms of morphology. About 1/4 of them are of P Cygni type, about 15% inverse P Cygni, about 25% double-peaked, about 1/3 pure absorption, and a few are single emission lines. Transformation of the profile from one type to another typically takes a few days. Although the line stays in absorption for extended intervals, only one high-velocity absorption event of the intensity reported by Kaufer et al. (1996a) was observed, in late 2006. Late in this event, Hα absorption occurred farther to the red than the red wing of a plausible photospheric absorption component, an indication of infalling material. In general, as the absorption events come to an end, the emission typically returns with an inverse P Cygni profile. The Hα profile class shows no obvious correlation with the radial velocity of C II λ6578, a photospheric absorption line.

1 Introduction

Rigel is a hot, luminous star that is well known to show mass loss. Studies of the Mg II resonance lines have shown its terminal wind speed to be about 230 km s^{-1} (Kaufer et al. 1996b). According to Gilheany (1991), Mg II in this star shows episodes of increased mass-loss rate and edge velocity, as well as DAC-like behavior. Hα is also well known to be highly variable, with profile morphologies ranging from P Cygni to double-peaked to inverse P Cygni (Kaufer et al. 1996b, Israelian et al. 1997).

A non-LTE, line blanketed model atmosphere analysis by Przybilla et al. (2006) derived $T_{\rm eff} \simeq 12,000$ K, $\log g \simeq 1.7$, and $L \simeq 2 \times 10^5 L_\odot$. Thus, the star is in a physical regime where the wind is partially ionized. Accordingly, the number of neutral H atoms, and hence the strength of Hα absorption, can be expected to be sensitive to density perturbations, because of not only column density effects but also ionization effects. Therefore, this physical regime is a particularly interesting one for the study of structure in stellar winds.

The purpose of this report is to make an initial survey of the results of more than ten years of spectroscopic monitoring of this star.

2 Observations and reductions

The observations were made with the 1-m telescope, fiber-fed échelle spectrograph, and Wright Instruments CCD camera of Ritter Observatory (U. Toledo, OH, USA). The CCD encompasses a 70-Å range around Hα, plus 8 other such ranges. The entrance slit width gives a resolution element about 4.3 pixels wide, which corresponds to $\lambda/\Delta\lambda = 26,000$. The spectra have signal-to-noise ratios ranging from about 30 to several hundred per pixel and have not been smoothed. Figure 1 shows a typical spectrum. Experience with this instrumentation shows that the underlying continuum is linear; the apparent curvature of the local continuum in this and similar stars is due to broad Hα emission wings that are thought to be a non-LTE effect (Hubeny & Leitherer 1989).

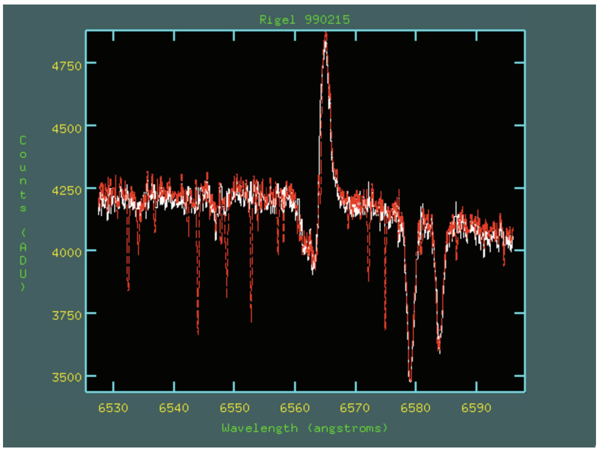

Figure 1: A typical Hα spectrum of Rigel taken on 15 Feb. 1999 (UT), before continuum normalization. The red overplot shows the spectrum before removal of telluric lines.

Data reduction was carried out by standard procedures with IRAF. Telluric water lines were removed, and the spectra were normalized to a linear fit to the apparent continuum at the ends of the spectral range observed. The Hα profiles were classified visually into seven morphological classes: P Cygni, inverse P Cygni, absorption (in which weak emission wings may be present), pure emission, double emission, double absorption, and triple absorption. In the last of these, the spectrum just reaches the continuum between the absorption components.

Our data set consists of 193 observations made on 184 nights during 1996–2007. During each observing season, a typical 20-night interval includes 4 observations.

3 Results

The radial velocity of C II λ6578 was measured from the same data. It is variable with an amplitude of about 10 km s^{-1} and a mean of +21.5 km s^{-1}, which we adopted as the systemic radial velocity. There is no obvious correlation between the C II radial velocity and the Hα profile class.

Figure 2 shows examples of an inverse P Cygni, a double-peaked, and a P Cygni profile. It illustrates the behavior, previously noted by Kaufer et al. (1996b), that the blue and red peaks rise and fall while remaining approximately stationary. In keeping with this behavior, our results show a tendency for the Hα absorption velocity to be more negative than the systemic velocity, except that it is more positive than systemic when the profile morphology is inverse P Cygni.

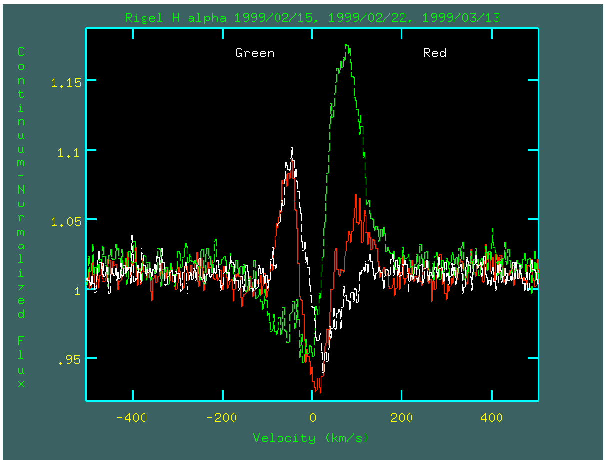

Figure 2: Typical examples of an inverse P Cygni (white), a double-peaked (red), and a P Cygni profile (green). In this and later figures, the abscissa is heliocentric radial velocity.

Hα often appears in pure absorption, sometimes symmetrical and near systemic velocity. Occasions when, on the other hand, it is asymmetric or blueshifted, we call "absorption events." Absorption events tend to be followed by inverse P Cygni profiles.

Figure 3 shows the number of occurrences of each profile class. About 2/3 of the time, the profile is in one of the three emission states. On the other hand, if all the absorption-type profiles are counted together, they become the most numerous class.

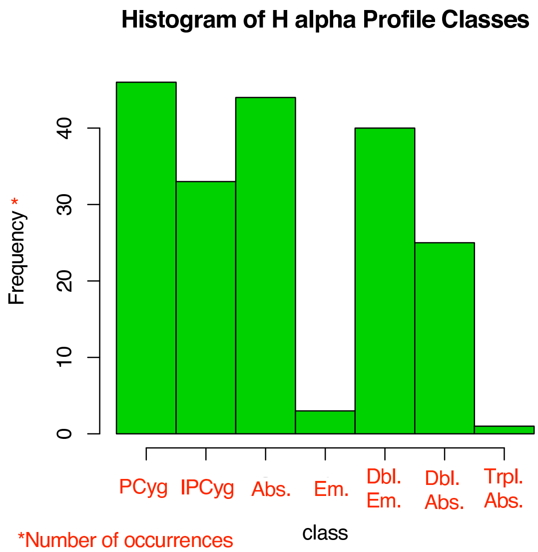

Figure 3: Frequency of each Hα profile class.

We estimated the persistence times of the various profile classes from sequences of observations that were densely sampled enough to exclude the profile changing to another type and back again during the sequence. The P Cygni and inverse P Cygni profile classes have a median persistence time of 5 days or less, compared to 10 to 13 days for the other profile classes, but the ranges of values of persistence time for all the profile classes overlap.

We also studied the time scale for Hα profile variations to occur. No significant differences were observed between spectra obtained during the course of one to two hours. Minor changes were sometimes observed during the course of 24 hours, while significant morphological changes occur in 2 to 3 days or more. These time scales are much shorter than the relevant physical time scales, which are the rotation period, $P/\sin i = 164 \pm 13$ d (based on Przybilla et al. 2006), and the dynamical time scale of the wind, 20 to 60 d (Kaufer et al. 1996a). Therefore, they indicate that the wind has structure on a scale that is small compared to the volume of the wind and/or is rapidly changing.

In addition to several weaker absorption events exhibiting lower absorption velocities, we observed one strong, high-velocity absorption event of the intensity reported by Kaufer et al. (1996a). Our one spectrum taken during this event is shown in Figure 4. For comparison is shown a sample photospheric model profile—not fully realistic for this star, since it comes from a model that is 3,000 K hotter.

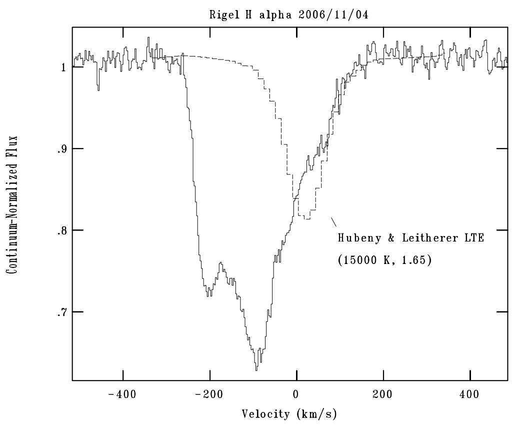

Figure 4: Full line: spectrum obtained during a high-velocity absorption event. Dashed line: fiducial photospheric profile, shifted upward to match the local continuum.

On the basis of Hα profiles similar to that shown in Figure 5, Israelian et al. (1997) claimed infalling material, which they proposed is due to control of the wind by magnetic loops. In a weak wind, however, redshifted absorption could be caused by the wind being translucent at that wavelength, so that the photospheric absorption shows through. In order to demonstrate the existence of infall, one has to show that the absorption on the red wing is deeper than any likely photospheric profile at that wavelength. This condition is fulfilled in Figure 5 unless the true photospheric profile is significantly deeper and wider than the example shown here.

4 Conclusions and future work

Although the spectrum of this star is often depicted in the literature to have P Cygni emission in Hα, most of the time the line has another emission profile type or is in absorption. It is reasonable to conclude that the wind is highly variable in structure, with significant departures from spherical symmetry. Accordingly, the star's mass-loss rate may be lower than commonly estimated.

In future work, we plan to search for (quasi)periodic behavior in the Hα profile.

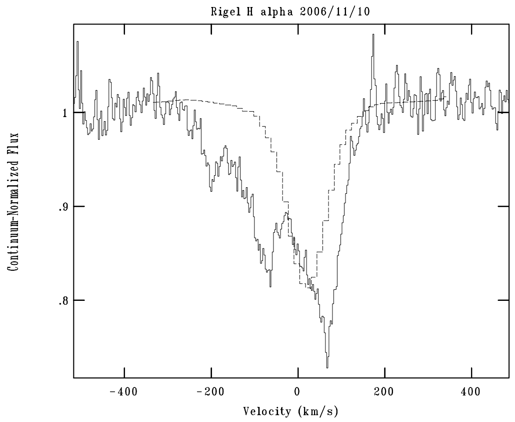

Figure 5: Spectrum that may show evidence for infalling material. The dashed line is as in Figure 4.

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References

Gilheany, S. 1991, Vistas Astron., 34, 249

Hubeny, I. & Leitherer, C. 1989, PASP, 101, 114

Israelian, G., Chentsov, E., & Musaev, F. 1997, MNRAS, 290, 521

Kaufer, A., Stahl, O., Wolf, B., Gäng, Th., Gummersbach, C. A., Jankovics, I., Kovács, J., Mandel, H., Peitz, J., Rivinius, Th., & Szeifert, Th. 1996a, A&A, 314, 599

Kaufer, A., Stahl, O., Wolf, B., Gäng, Th., Gummersbach, C. A., Kovács, J., Mandel, H., & Szeifert, Th. 1996b, A&A, 305, 887

Przybilla, N., Butler, K., Becker, S. R., & Kudritzki, R. P. 2006, A&A, 445, 1099

Prinja: Do you see any evidence that the high-velocity absorptions in Hα are correlated in some way with disturbances (velocities, strength) in the photospheric lines such as C II λ 6578?

Morrison: In the present data, which I showed in the boxplot, the correlation is very weak, if any. If we cross-correlate with a time lag, we may find a stronger relationship.

Moffat: 1. Are there any variations that are cyclic on a rotation period? 2. Has this star been looked at using spectropolarimetry?

Schner: We did observe this star spectro-polarimetrically occasionally. At least we can say that there is no strong magnetic field present.

Puls: The predicted deep-seated photospheric emission in Hα is usually reduced (though not destroyed) if you include winds into the atmospheric models (Hubeny's calculation is based on hydrostatic models.).

Morrison: Thank you. When we observe this star with our new, larger-format CCD camera, we will be better able to determine the continuum level and hence the amplitude of the scattering wings.