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Giant Convection Cells, Where Are You?

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Abstract. High-resolution high S/N observations of photospheric lines in the spectrum of Betelgeuse are devoid of the structure one would expect if only a few giant convection cells dominated the surface of the star.

1. The Hypothesis of Giant Convection Cells

The possibility of giant convection cells was suggested by Schwarzschild back in 1975. More recently, 3D hydrodynamical calculations have lent support to this concept (e.g., Freytag 1999). The idea of giant convection cells is qualitatively in agreement with the pattern of variation of macroturbulence (derived from the widths of spectral lines) and granulation (related to the asymmetries of spectral lines) across the HR diagram (Gray 1988), where both increase in strength toward higher luminosities. Betelgeuse, a bright supergiant M star, offers itself as a testing ground where we can look for and possibly study granulation having extremely large cell dimensions. By extremely large, I mean not only in absolute dimensions, but also compared to the star itself. Some of the models of Freytag (1999) actually show only three or four cells on the stellar disk! Now if a cell has any coherence, it will emit a spectrum with a net Doppler shift corresponding to the projected radial velocity of the cell. Three or four distinct spectra, each corresponding to one of the giant cells, and each having its own Doppler shift, should then dominate the spectrum we see and record. This implies structure or lumpiness in the profiles of the spectral lines. So, what do the observations of Betelgeuse actually show?

2. The Observations

Data were taken at the University of Western Ontario Elginfield Observatory using the coude spectrograph (Gray 1986, Gray et al. 2000) armed with a 200 by 4096 CCD. These data span the 17 months from 1999 Oct 6 to 2001 Feb 27. Figure 1 illustrates the very large line broadening of Betelgeuse (solid line in upper panel). For comparison, a more "normal" star is shown, α Lyn. Although α Lyn is a bit hotter than Betelgeuse, it is close enough for us to recognize the same spectral lines. To bring the point home, also shown in Figure 1 is the α Lyn spectrum (dashed line in upper panel) convolved with a Gaussian having a dispersion of 15 km s^{-1}. I don't expect an exact match, but it's close enough to show that Betelgeuse has a Doppler-shift distribution with a

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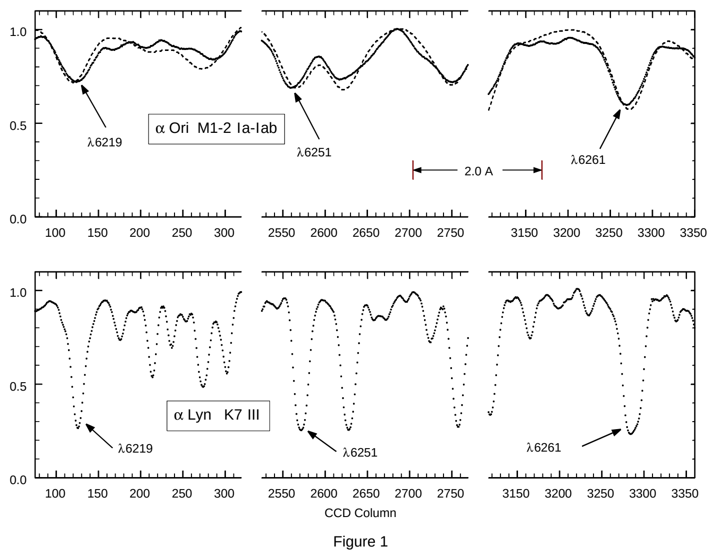


Figure 1. Coude spectra of Betelgeuse (M1-2 Ia-Iab) and α Lyn (K7 III). .

dispersion not far from 15 km s^{-1}, and that means that the full span of velocities across the Betelgeuse profiles is in excess of 55 km s^{-1}. These velocities are much larger than the 5 km s^{-1} rotation rate (Uitenbroek et al. 1998) or the $\sim$ 5 km s^{-1} velocity of sound. But the striking thing to realize is that the profiles, and therefore the Doppler-shift distribution that has broadened them, is extremely smooth. There is no structure or lumpiness. In other words, we do not see three or four giant-cell spectra shaping these lines. Betelgeuse shows all kinds of variations. The line depths vary in concert with the brightness of the star (see Gray 2000). The radial velocity varies. There are episodes of mass ejection. There is a bright spot or spots that come and go. Through all of these activities, the Doppler-shift distribution remains remarkably constant! Figures 2 and 3 illustrate what I mean. The variable line depths have been taken out by normalizing the core depth to a standard exposure. Once that is done, the profiles are almost invariant.

Figure 2 shows exposures for a dozen nights in October 1999, while Figure 3 shows mean profiles from seven time blocks spaced over 16 months of observation. The time scales covered by these data run from a fraction of an hour to the full 16 months. Yes, there are some tiny differences. Some of these will arise from variations in the line blending as the star runs through its repertoire of contortions. Others seem to stem from true variations in the Doppler-shift distribution. The two cases can be distinguished by looking at more than one line. Doppler-shift changes can be expected to appear in all lines, while blends will be line-specific. By this criterion, the differences seen in Figure 3 arise from line blends. However, a significant change in the Doppler-shift distribution did occurred in March 2000, when the line widths became narrower by $\sim$4% for some three weeks. In Fig. 4, I have plotted the full half-depth widths of

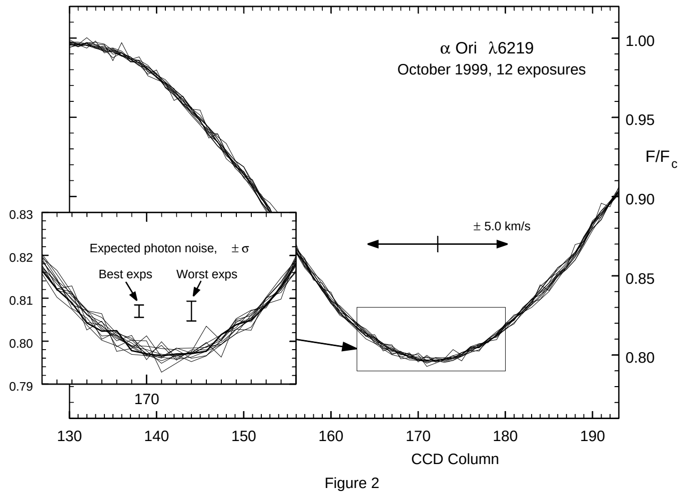


Figure 2. Comparison of α Ori λ6219 profiles obtained in 1999 October.

two lines (panels b & c). The top panel shows the variation in line depths during this time interval. The scatter of the half widths is consistent with the measuring errors. All of a sudden, about a quarter of the way through 2000, the blurring of the spectrum became less, i.e., the Doppler-shift distribution was narrower. This narrowing seems to be unrelated to the variations of brightness and line depths, and the profiles remain smooth and without structure during this episode. Perhaps the narrowing was merely a statistical variation in the distribution of convection cells. If this were true, then poison statistics would imply $\sim$600 cells on the visible hemisphere.

3. Preliminary Conclusions

Additional material and a more complete discussion will appear in the Publications of the Astronomical Society of the Pacific. It is premature to draw any hard conclusions against giant convection cells, but so far the classical picture in which the spectral lines are broadened by the statistical ensemble of Doppler shifts of hundreds of convection cells seems more in agreement with the Betelgeuse photospheric observations.

So, I'll put together in a nut shell
the whole thing I'm up here to tell:
Though giant cells have been suggested,
it's only an idea and must be tested.
So off to the telescope we go
to get some evidence to show.

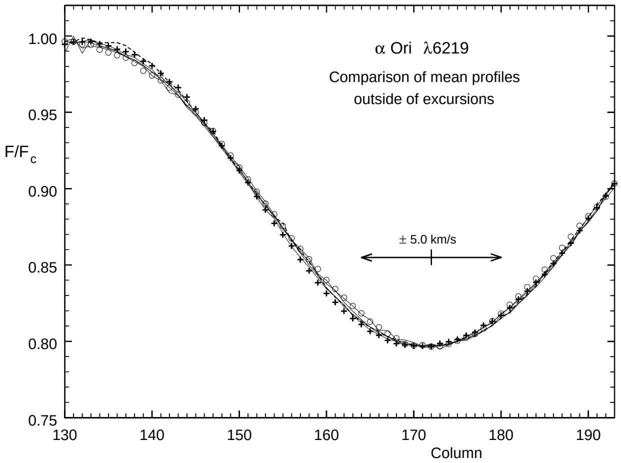
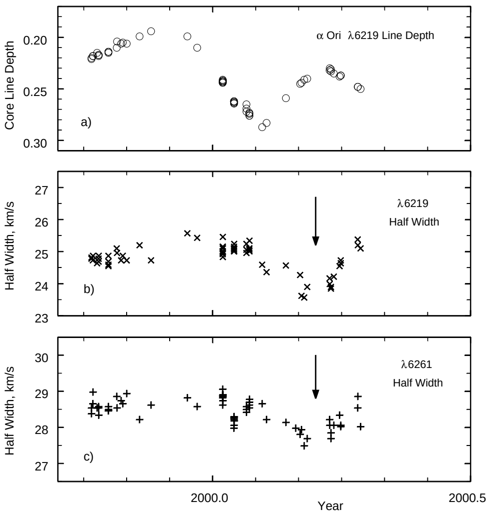


Figure 3

Figure 3. Comparison of α Ori $\lambda 6219$ profiles obtained over sixteen months.



Excursion 2

Figure 4

Figure 4. Long-term changes in line profiles.

And what do we find, like it or not?
Well that grand idea is not so hot!
Those spectral lines, where bumps are expected,
show instead great smoothness perfected.
The case is not proven beyond doubt,
so let's take care not to shout.
For detailed models we'll have to wait,
and then judge the giant-cells' fate.

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