The origin and variability of the CO near-IR band in the yellow hypergiant ρ Cas

Nadya Gorlova1, Alex Lobel1, Adam Burgasser2, George Rieke1, Nick Woolf3

ngorlova@as.arizona.edu

Adam Burgasser
2 Univ. of Arizona, 2-CFA, 3-AMNH

The origin and variability of the CO near-IR band in the yellow hypergiant ρ Cas

The AAVSO international database is acknowledged for the visual light curve.

Acknowledgements

M. Andersen, C. Corbally, J. Greissl, D. McKenna, M. Meyer, J. Nelson, R. Smith at the U. of Arizona/VATT;

We can’t directly image surfaces of stars yet, except for our Sun which is a good example how complicated things can be!
The HST & Chandra images on the left show a low mass and a high mass stars near the end of their evolution - they are sufficiently hot to light up light up stuff in their close vicinity. The intricate details in the shredded matter tell us that stars are not just simple light bulbs, but posses powerful dynamical engines near their surfaces capable to produce these beautiful shapes.

Spectroscopy allows to indirectly “see” even closer to the star, and at the earlier stages of evolution.

1. Not just simple light-bulbs!

2. And what star are you talking about?

This plot shows where the most massive stars live on the HR diagram. According to Geneva tracks, ρ Cas is a ~30 Msol yellow hypergiant (FM+), and a good candidate to the SNF progenitor! It is a semi-regular pulsating star which once in ~50 years goes into an outburst – turns into M hypergiant and ejects a shell worth 5% Msol!

Check this website to learn more about ρ Cas and other curious supergiant stars: http://aobel.freeshell.org

3. A CO molecule in an F star? That’s odd!

In Nov 2003 we first obtained a near-IR spectrum of ρ Cas on the Vatican telescope (Arizona), using a low-resolution echelle spectrograph CORMASS. The spectrum is dominated by the H lines and the CaII 8542 triplet, as expected for an F-G supergiant (compare to the model spectrum by Phoenix group below). Amazing fact however is also a CO 2.3µm feature, characteristic of much cooler K-M stars!

4. Wow - it correlates with pulsations!

We collected another CORMASS spectrum in Oct 2004, moderate resolution SpeX spectrum on IRTF (R~2,000, going to 4.1µm) in Sep 2004, retrieved a CGS4 UKHRT archival spectra from 1998 and 2000 (in outburst), and obtained through the service mode a high-resolution (R~30,000) echelle spectrum in Sep 2004. In addition we considered the first CO spectrum taken by Lambert et al. in 1979 with the FTS on the 4m KPNO. We have discovered that the CO band goes in emission during the fast expansion phase near the maximum light, and turns back into absorption on the rising part of the light curve.

5. P Cyg profiles? Probably not!

The plot on the left, top panel, compares the bandhead of the 2.3µm 1st overtone CO transition in Feb 1979 (pure absorption) and in Sep 2004 (P Cyg-like profiles). The lower panel shows a representative J=26-27 CO line profile compared to NaI and Brγ line profiles (also obtained on Sep 2004), in heliocentric velocity scale. The CO emission component is close the radial velocity of the star (~47km/s), while absorption component seems blueshifted with the blue wing extending to the relative velocity as high as ~100 km/s.

6. Temperature minimum needed!

We first verified that the CO absorption can not be produced in the normal photospheric model with Teff > 6500 K, even at the small gravities of hypergiants (yellow and green curves on the left). Therefore, absorption must be attributed to the cool remote shell.

We further managed to roughly reproduce the emission part of the CO band by inserting in the photospheric models a cool layer (T=2500K) at just ~20 solar radii above the photosphere (red line).

7. Putting things together: shocks and other cool stuff

P Cyg profiles haven’t been observed in the optical and near-IR spectra of ρCas (Lobel et al. 1998). We therefore think that the two different systems are observed: an absorption one, originating in the remote shell at distance ~ few stellar radii (see Ayres et al. 2002) and the emission one, originating in the layer just above the photosphere of the star, in the region of temperature minimum, which is perhaps similar to the transitional region below chromosphere in the Sun (Ayres 2002). This cool layer can potentially be produced in the wake of the pulsation-driven shock, similar to the low-excitational emission lines observed in the optical (Lobel et al. 2003).

Conclusion

Similar spectroscopic behavior have been previously observed in the less massive semi-regular variables (Gillett et al. 1989, Oudmaijer et al. 1995). ρ Cas is only the second yellow hypergiant, and the first non-binary one (after HR 8752 which has hot companion), where this phenomenon is being discovered. Our work is also the first modeling attempt to interpret it in terms of pulsation-driven shock. It adds a new component to the known structure of the extended atmospheres of the massive stars, and opens a new range of possibilities for the interpretation of the long-standing problem of the wind-driving mechanism in supergiants.

On the left is our not-to-scale cartoon with temperatures and distances from the center of the star reconstructed from the different spectroscopic features.

References