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

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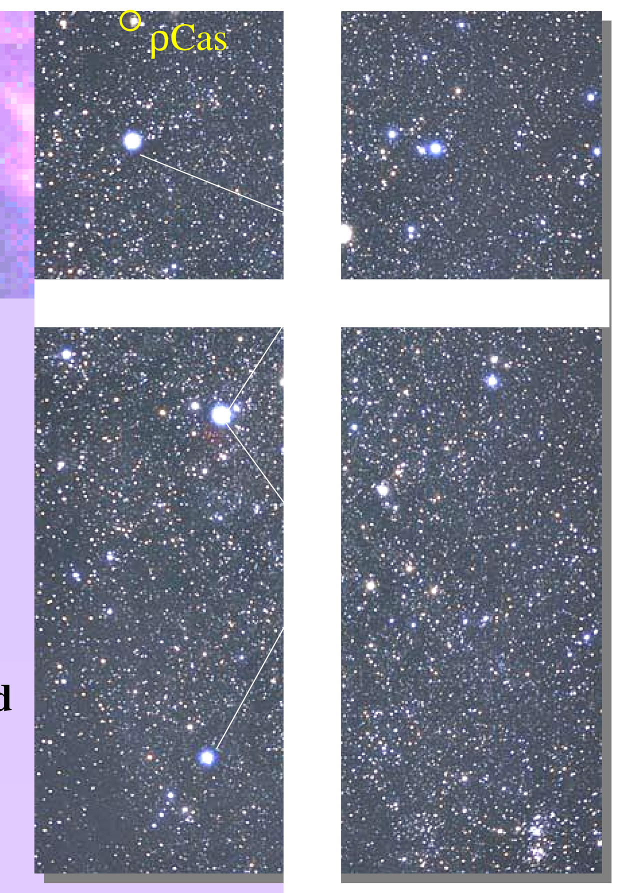
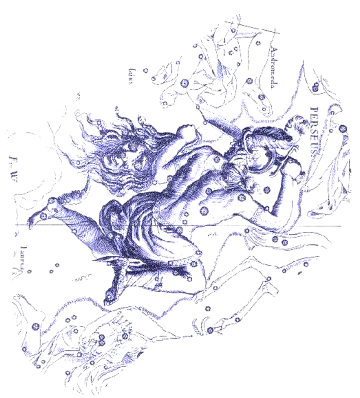
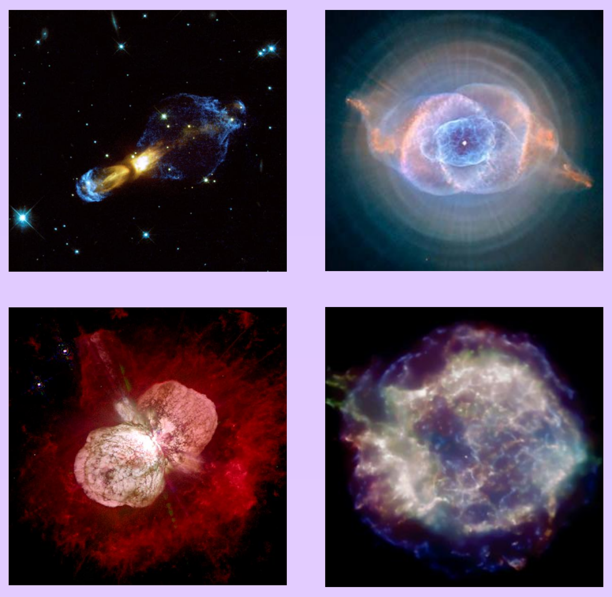




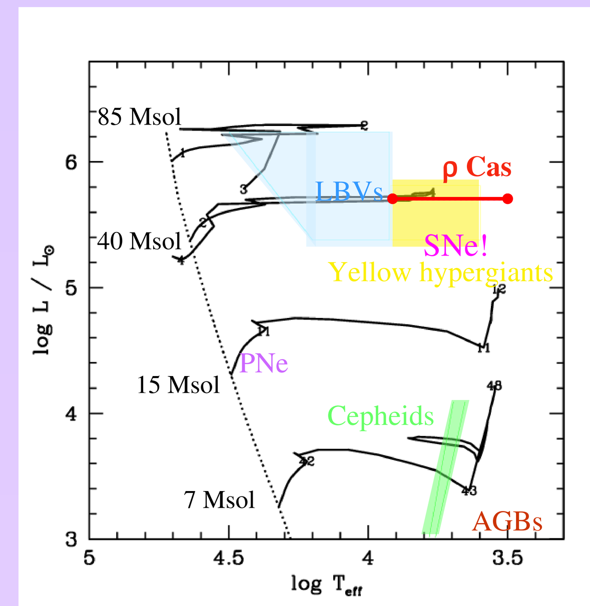
Introduction

1. Not just simple light-bulbs!



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 balls, 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.

2. And what star are you talking about?



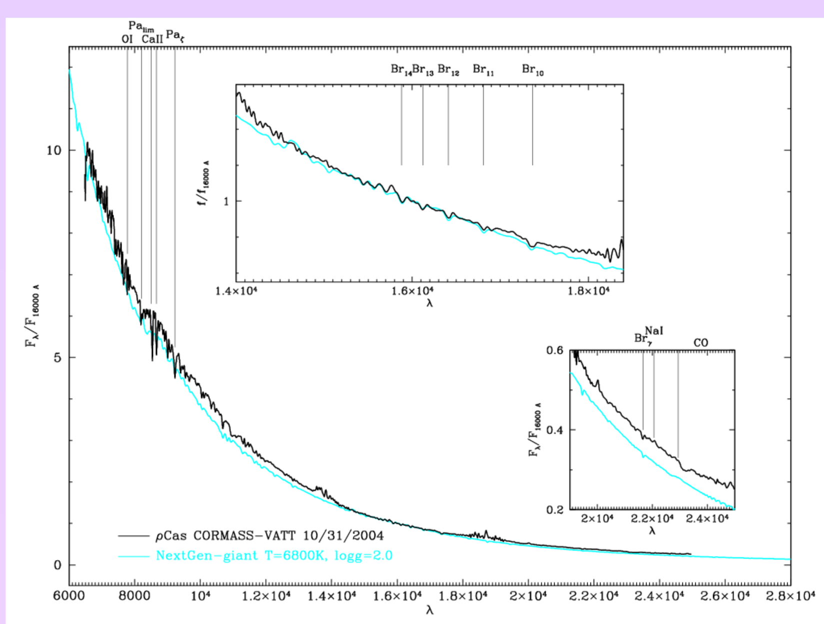
This plot shows where the most massive stars live on the HR diagram. According to Geneva tracks, **ρ Cas** is a ~30 Msol yellow hypergiant (F8I+), and a good **candidate to the SNII progenitor!** It is a semi-regular pulsating star which once in ~50 years goes into an outburst – turns into M hypergiant and ejects a shell worth 5% Msol!

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

Observations

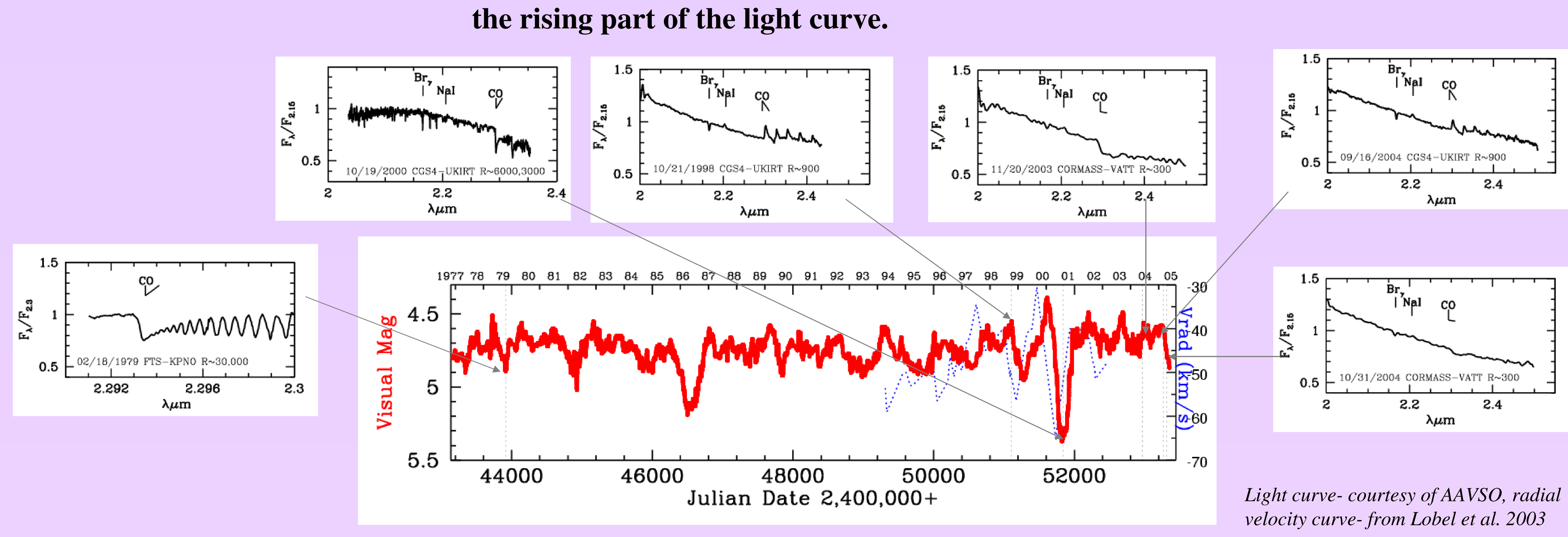
3. A CO molecule in an F star? That's odd!

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 0.87μ triplet, as expected for an **F-G supergiant** (compare to the model spectrum by Phoenix group below). Amazing fact however that it also shows a **CO 2.3μm feature**, characteristic of much cooler K-M stars!



4. Wow - it correlates with pulsations!

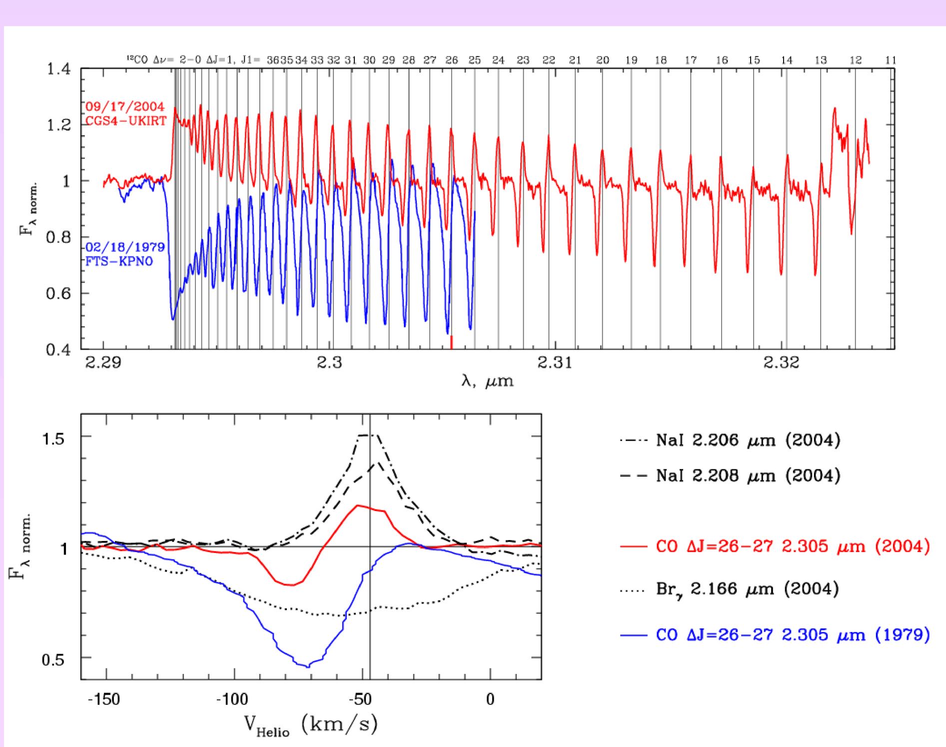
We collected another CORMASS spectrum in Oct 2004, moderate resolution SpeX spectrum on IRTF (R~2,000, going to 4.1μm) in Sep 2004, retrieved a CGS4 UKIRT archival spectra from 1998 and 2000 (in outburst), and obtained through the service mode a high-resolution (R~30,000) echelle spectrum in Sep 2004. In addition we considered the first CO spectrum taken by Lambert at 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.



Light curve- courtesy of AAVSO, radial velocity curve- from Lobel et al. 2003

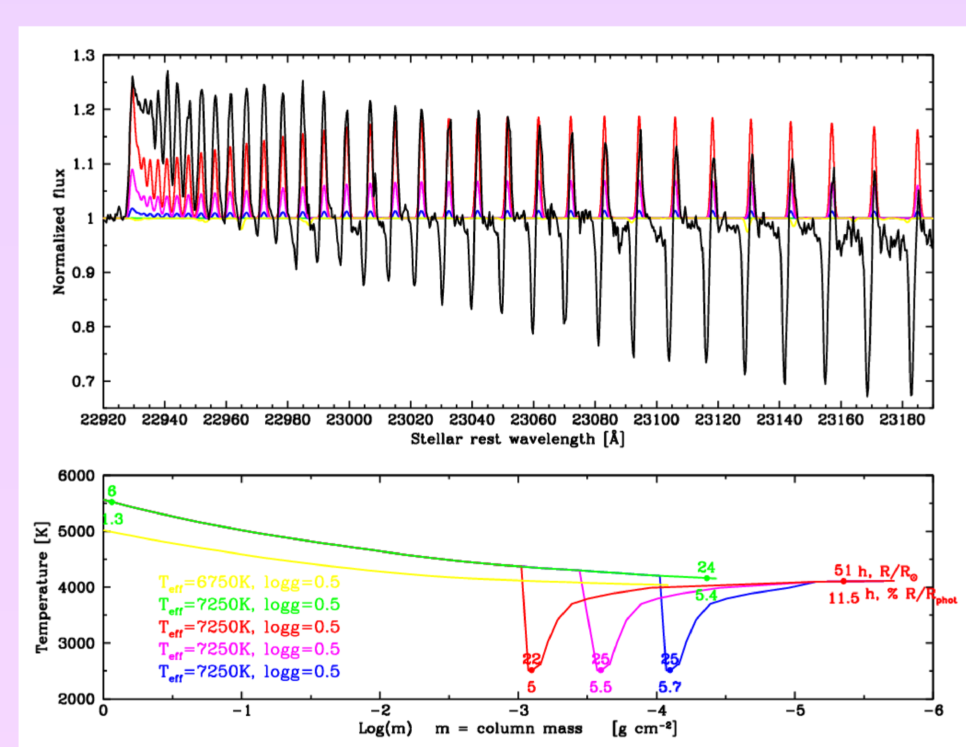
Modeling

5. P Cyg profiles? Probably not!



The plot on the left, top panel, compares the bandhead of the 2.3μu 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 Br_γ 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!

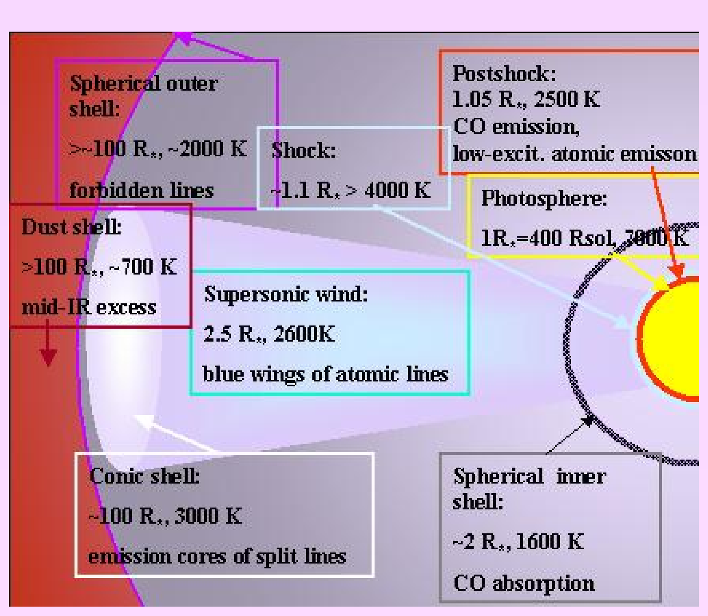


We first verified that the CO absorption can not be produced in the normal photospheric model with Teff > 6500 K, even at the small gravities of hypergiants (yellow and green curves on the left). Therefore, **absorption** must be attributed to the cool **remote shell**.

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).

Reconstruction

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). Were CO lines truly PCyg and therefore optically thin in emission, due to similar oscillator strengths (Kurucz database) they whould have similar strengths, which is not observed. We therefore think that the **two different systems** are observed- an absorption one, originating in the remote shell at distance ~ few stellar radii (see Lambert et al. 1981) 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).

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 warm 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.



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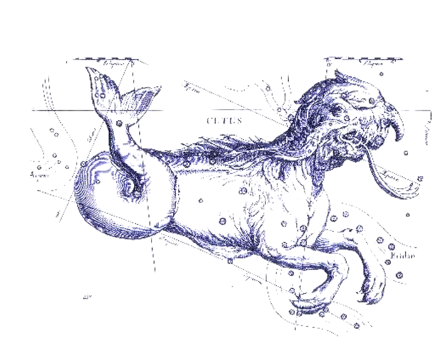

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