How to interpret LPV in roAp stars

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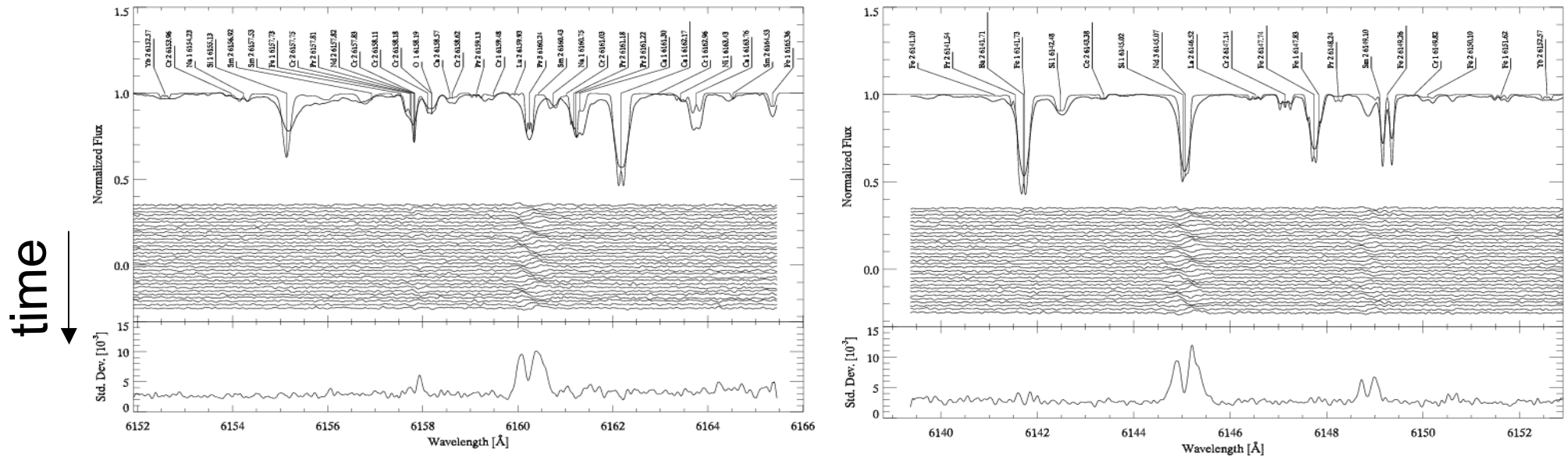[2] Centre for Astrophysics, University of Central Lancashire, Preston PR1 2HE, UK
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Recent spectroscopic observations of roAp stars with high spectral resolution and high time resolution show line profile variations (LPV) which seem to be similar to those seen in rapidly rotating B-type line-profile variables. At first glance these line profile variations seem to be in disagreement with the mode identification based on the photometric observations. We propose an interpretation according to which the observed line profile variations are a manifestation of a shock wave in the high atmosphere near the magnetic polar regions, and show that the line profile variations can be still understood in the framework of the oscillation mode being still consistent with the photometric observations.
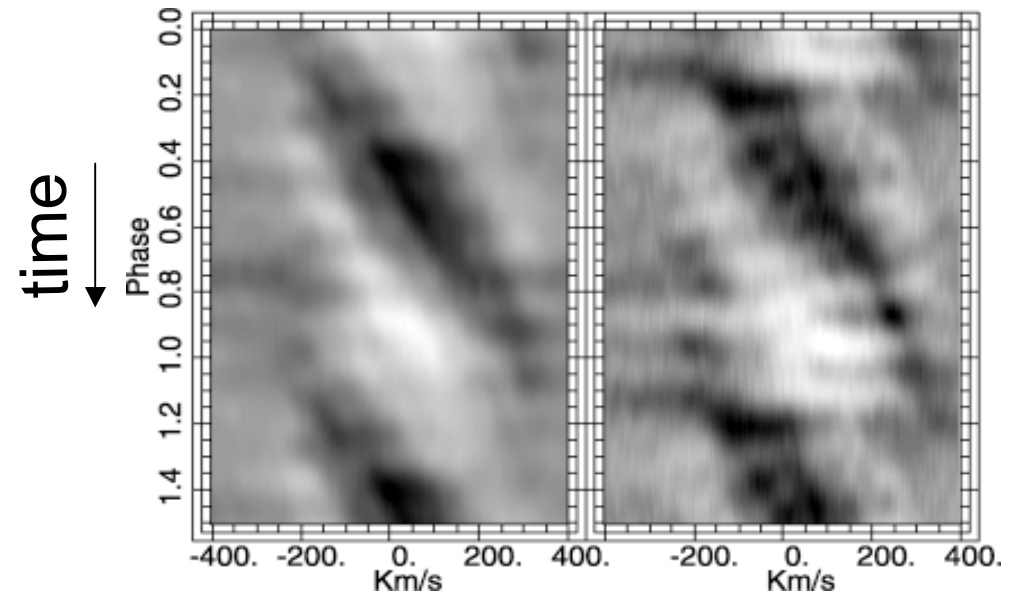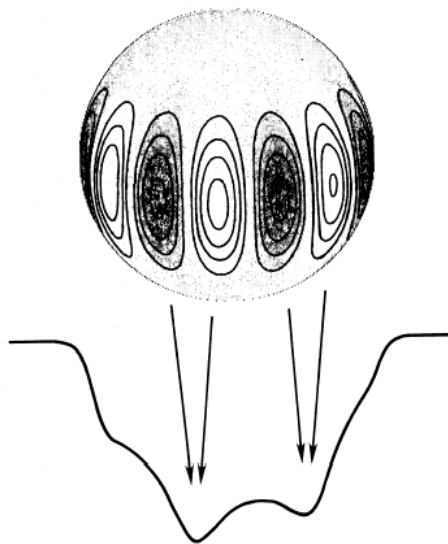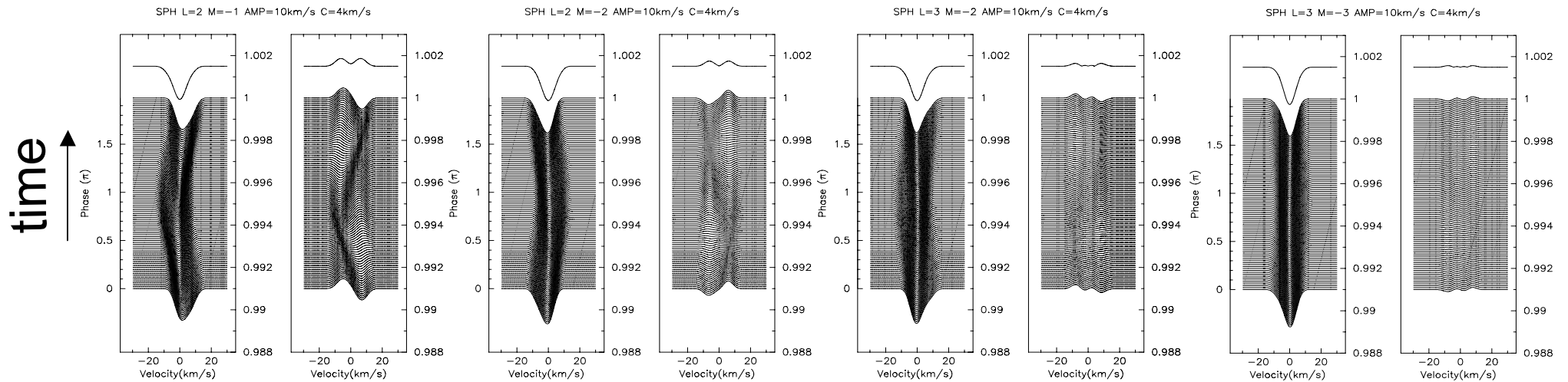
So what's the problem?

- Kochukhov & Ryabchikova (2001, A&A, 374, 615) showed in the extremely slowly rotating (P_{rot} > 70 yrs) roAp star, γ Equ, spectacular line profile variations (LPV) in lines of Nd III and Pr III that they interpreted as being caused by oblique pulsation modes of ℓ = 2 or 3 and $m = -\ell$ or $-\ell +1$.

- The LPV move only from blue-to-red.

- Similar LPV are also seen in some other roAp stars in lines of ND III and Pr III, which are believed to be formed in the upper atmospheric layer.

- However, the other photospheric lines do not show such monotonic blue-to-red shift.

Case of the rapidly rotating B stars

- This blue-to-red shift pattern is observed in rapidly rotating B stars pulsating in intermediate ℓ sectoral modes ($\ell = m \sim 4\text{-}8$). This is a manifestation of absorption bumps travelling across a rotationally broadened profile from blue to red (bottom left).

- As a typical example, see a gray-scale plot (bottom right) for 19 Mon ($v \sin i = 350$ km s^{-1}) from Balona et al. (2002, MNRAS, 333, 952) .

- But γ Equ has virtually no rotation ($P_{rot} > 70$ yr), so this interpretation cannot be applicable to this star.

Here is what LPV for low-ℓ , *m*= ℓ or ℓ -1 NRP [$Y_l^m \exp(i\sigma t)$] look like

time

SPH L=2 M=−1 AMP=10km/s C=4km/s   SPH L=2 M=−2 AMP=10km/s C=4km/s   SPH L=3 M=−2 AMP=10km/s C=4km/s   SPH L=3 M=−3 AMP=10km/s C=4km/s

- In the case of γ Equ, there is no rotation to broaden the spectral lines and distinguish the blue approaching wing from the red receding wing.

- The LPV go back-and-forth, blue-to-red-to-blue.
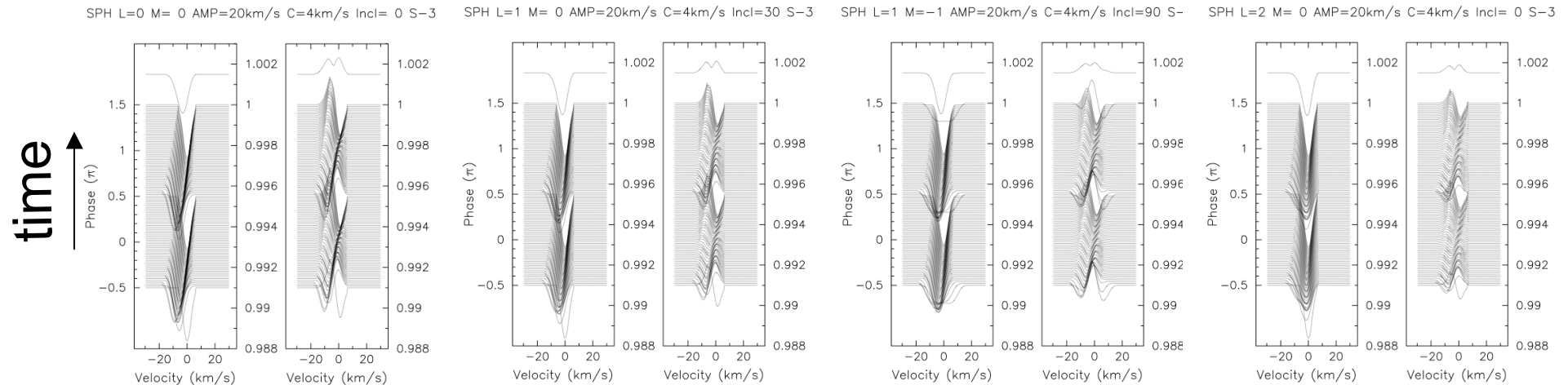
- They do not just go blue-to-red.

A new interpretation: shock wave?

- Why do the LPV in Nd III and Pr III show such monotonic blue-to-red movement, while the photometric observations imply axisymmetric dipole oscillations, from which blue-to-red-to-blue LPV are expected?

- The Nd III λ6145 line-forming layer is moving with a maximum speed of 18 km s^{-1} in one pulsation cycle. This maximum speed is much higher than the radial velocity pulsation amplitudes so far detected from other spectral lines in other roAp stars -- of the order of 1 km s^{-1} or less. This is possible if the Nd III λ6145 line is formed in a high layer where the density is very low.

- This maximum speed seems to be faster than the sound speed of the atmosphere. The pulsation amplitude in velocity is expected to increase with the decrease of the density with height. So the amplitude in velocity naturally exceeds the sound speed at a certain level, and a shock wave is generated.

- When this shock wave propagates through the layer under consideration, the layer is suddenly kicked upward by the shock wave and then falls down after reaching the peak height, at which the speed of the layer is zero. This process repeats and the resultant variation in the Doppler shift is qualitatively in agreement with the observed one in Nd line.

Prediction based on this model

- This picture may be consistent with the mode identification from the photometric observations, which imply the axisymmetric dipole modes whose symmetry axis coincides with the magnetic axis being inclined to the rotation axis of the star (the oblique pulsator model).

- The LPV should be sinusoidal for the spectral lines formed in layers where the wave motion is subsonic.

- The LPV should be sinusoidal for chemical elements that are not concentrated in the magnetic polar regions, so their pulsation velocities remain subsonic.

- The LPV should show monotonic blue-to-red motion only for the lines formed in the high atmosphere near the magnetic polar regions.

Here is LPV for the current model

- Eigenfunction is given as $Y_l^m(\theta,\varphi)$, but its temporal variation is assumed to be not sinusoidal but saw-toothed; --- $Y_l^m(\theta,\varphi) \, \Sigma \, n^{-1}\exp(in\sigma t)$.
- LPV for ℓ =0 or ℓ =1 & m=0 or ℓ =1 & m=1 with a large inclination angle i or ℓ =2 & m=0 with i~0 are in agreement with the observed LPV in lines of Nd III and Pr III.
- Note that the mode identification ℓ =1 & m=0 is consistent with that deduced from photometric observations (the oblique pulsator model).