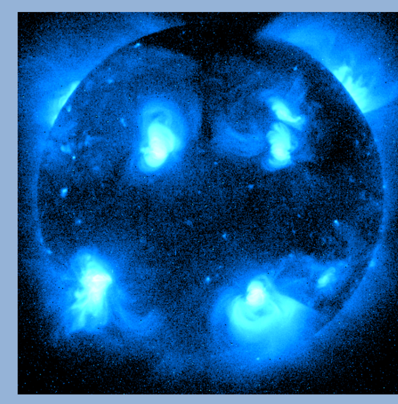
Multiple, short-lived "stellar prominences" on the O giant ξ Persei: a magnetic star?

Natallia P. Sudnik, Pedagogical University, Minsk, Belarus

Huib F. Henrichs, University of Amsterdam, Netherlands



Any similarities with reality is a mere coincidence...

Abstract

Many spectral lines in OB stars show unexplained variability on a rotational timescale, which is cyclical, but not periodic. This occurs in the so-called discrete absorption components (DACs) both in UV-wind line profiles and in many optical lines. Typical upper limits of ≈ 300 G for a magnetic field are found in these stars. Here we search for the rotation period of the O giant ξ Persei in the N IV 1718 wind line in 12 y of IUE data. We also analyzed time-resolved optical spectra using the same simplified model as earlier for λ Cephei, in terms of multiple spherical blobs attached to the surface, called stellar prominences (Sudnik and Henrichs 2016). These represent transient multiple magnetic loops on the surface, for wich we search for the lifetimes. We find:

- The rotation period is 2.0406 d, in contrast to ~4 days in earlier work.

- Model fits of He II 4686 spectra in 1989 give lifetimes of the prominences of mostly less than 5 h.

- We predict that ξ Per has a magnetic dipole field, with superposed variable magnetic prominences.

ξ Persei

Adopted stellar parameters

- Spectral type: O7 III(n)((f))
- V = 4.0
- Vrad = +65 km/s (Runaway)
- d = 416 pc [revised]
- $\log(L/L_{\odot}) = 5.2$
- Teff = 34500 K
- $R \approx 11.2\ R_{\odot}$
- *vsini* = 230 km/s
- *i* = 56°
- Rotation period: 2.0406 d
- Non radial pulsations, p mode: *l* = 3, *P* = 3.5 h
- $M \approx 26\ M_{\odot}$

1. UV wind and Hα observations

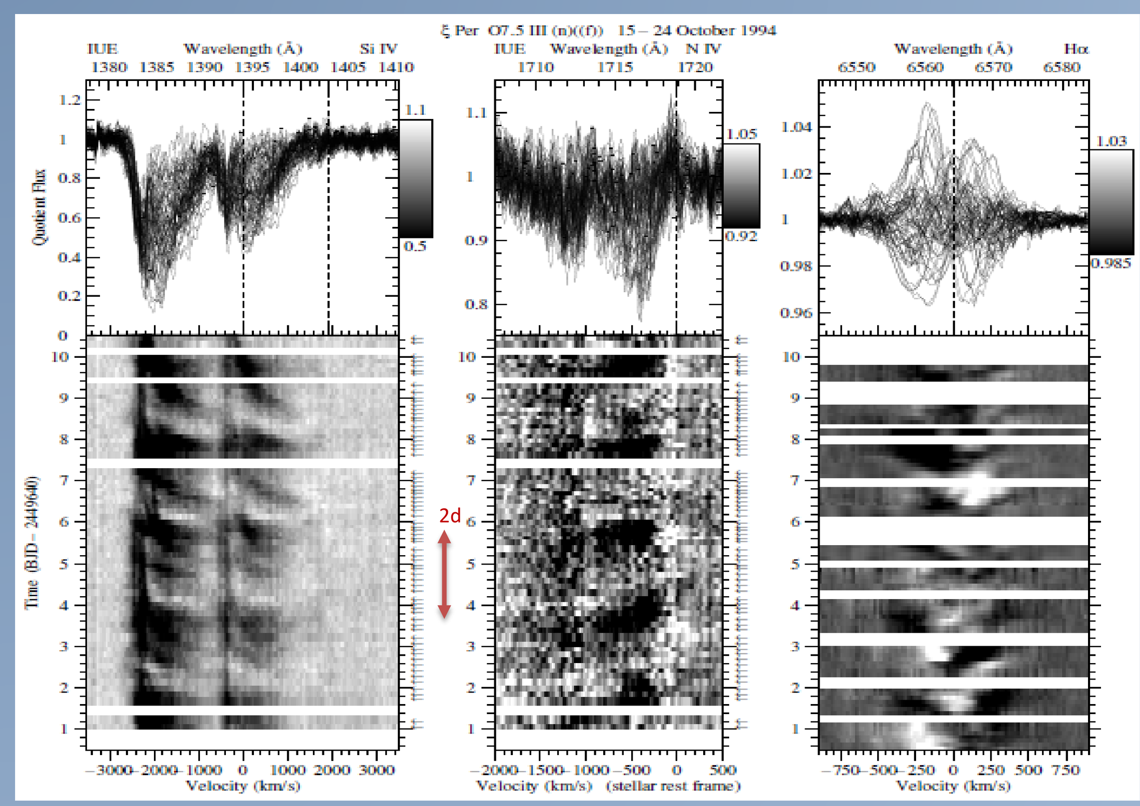


Fig. 1 – Discrete Absorption Components (DACs) during 10 days in 1994 (de Jong et al 2001), shown as progressing dark features in quotient spectra of Si IV (left) and NIV (middle) and Hα (right). The 2 d periodicity (see section 2) is clearly visible, which we identify as the rotation period.

- DACs are explained by CIRs: Corotating Interacting Regions, which start near the surface
- The unanswered research question is whether these DACs stem from a magnetic pole
- Between the strongest DACs, (identified in the N IV line), there are intermediate DACs in Si IV
- The cyclical behavior on a ~2d timescale is present in all three lines
- There are blue to red moving Hα absorptions at positive velocity, indicating an intermediate inclination angle

2. Rotation period from NIV 1718

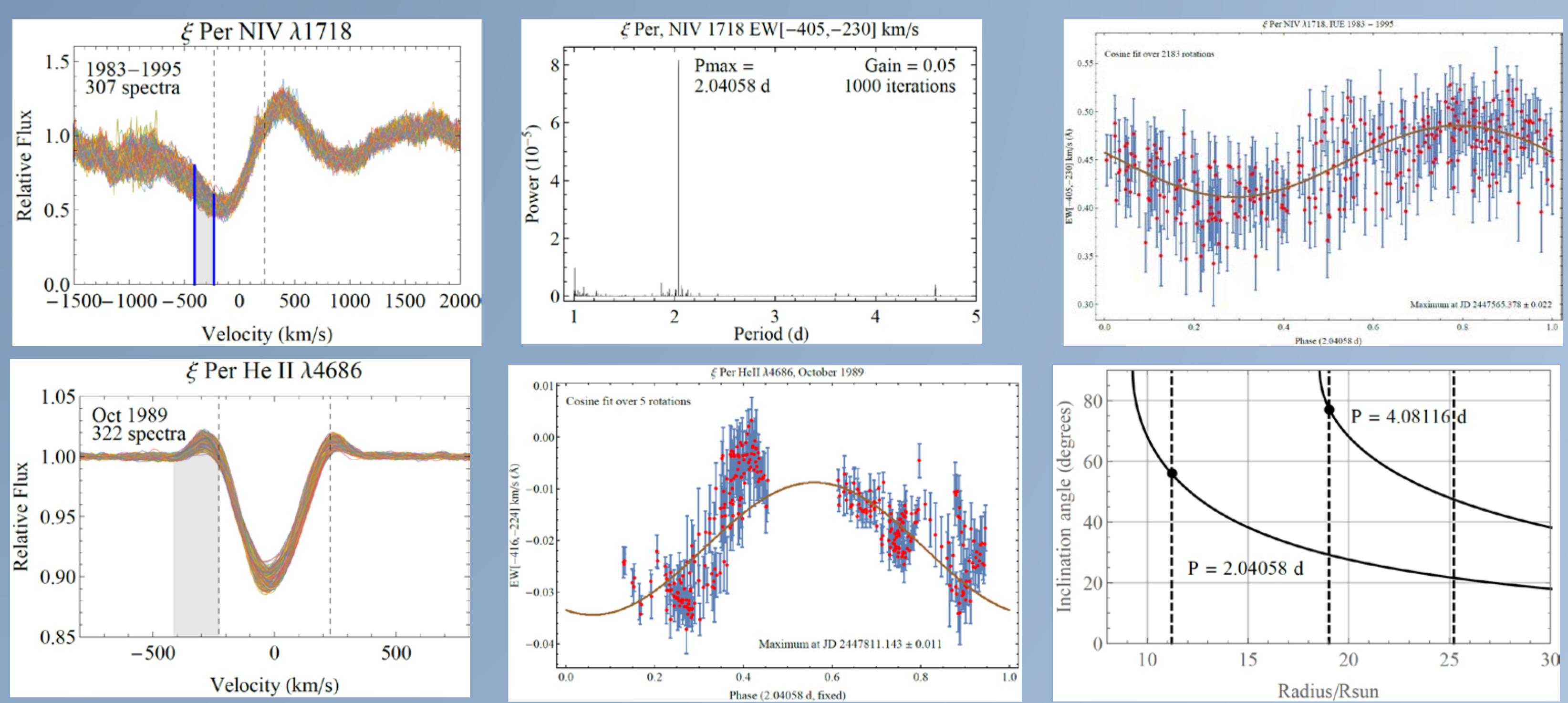
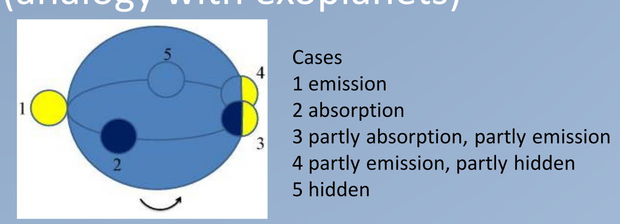


Fig. 2 –Equivalent widths of selected regions in NIV 1718 and He II λ4686. Note that the two emission peaks in the He II line are at the *vsini* value of the star (dashed lines), strongly suggesting a rotation effect. From the power spectrum we derive P = 2.04058 d as the rotation period. Phase folded data over 12 years shows a very strict periodicity, similar to the folded He II equivalent widths. Twice this value can be excluded as the rotation period because of the constraining stellar radius.

3a. Model

- Each prominence is represented by a corotating optically thin spherical blob of gas attached to the surface.
- Fit profile: $F(v)_{\rm b} = \exp\left[-A\tau e^{-\frac{1}{2}((v-v_{\rm b})/w)^2}\right]\exp\left[(\pi r^2 - A)\tau e^{-\frac{1}{2}((v-v_{\rm b})/w)^2}\right]$
- Each blob with radius *r* has central optical depth τ, width *w,* and is centered around v_0 as a function of velocity *v*
- The parameter $A \leq \pi r^2$ takes into account the transient and eclipsing geometry (analogy with exoplanets)



- v_0 is determined by corotation
- Superposition of line profiles of *n* blobs
- Because the line profile itself is not known, we work with subsequent quotient spectra

3b. Fit Strategy

- Construct subsequent quotient spectra → remove the overall line shape to isolate relative changes
- Take equal blobs with initial values r = 0.2 R*, τ = 0.2, and w = 70 km/s
- Constrain the rotation period by the inclination angle, radius and *vsini*
- Fit by eye the first two quotient spectra and try to include the next quotients until no satisfactory fit is found by varying the location and number of the blobs
- Take these parameters as input for a least-squares nonlinear model fit
- Repeat for all quotient spectra for all datasets, with equal period
- If no fit can be achieved, start with new number of blobs with different parameters

3c. Model fit example

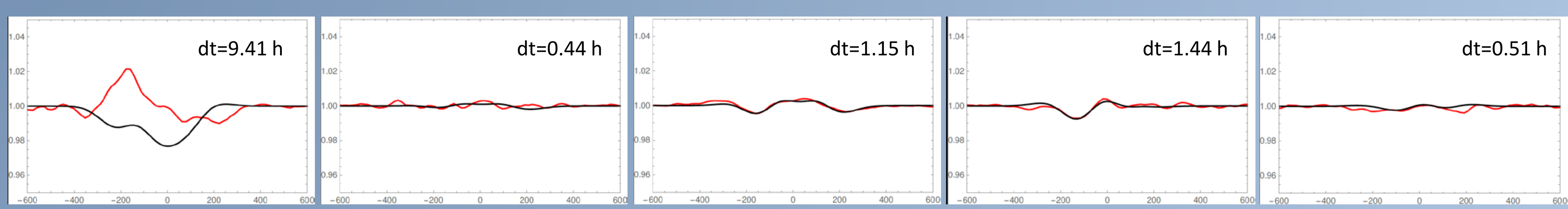


Fig. 5 – Model fit (black) to subsequent quotient He II 4686 spectra in velocity space of 1989 (red) with 5 blobs (τ = 0.15, w = 72 km/s) and period = 2.04 d, implying *i* = 56°. See Fig. 6 for their relative orientation. The time lapse between the quotient spectra is indicated. The figure shows three accepted fits (panel 2, 3 and 4) over 3.03 h, but with these parameters the fits in the previous 9.41 hours and 0.51 hours later are not acceptable. This constraints the the life time of the configuration.

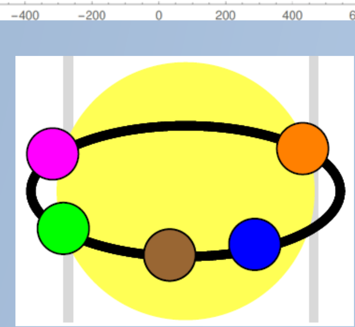
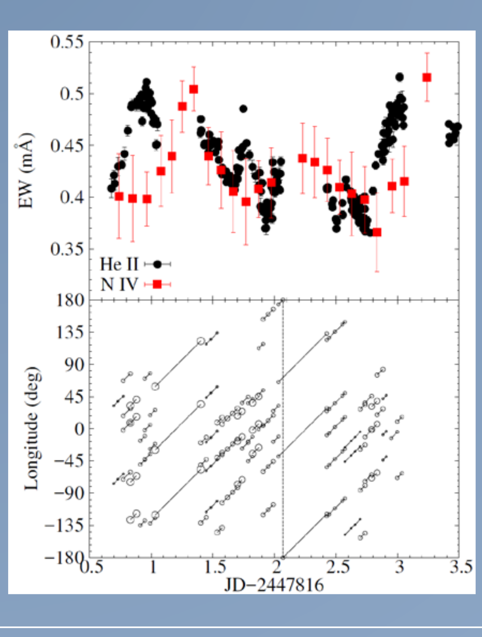
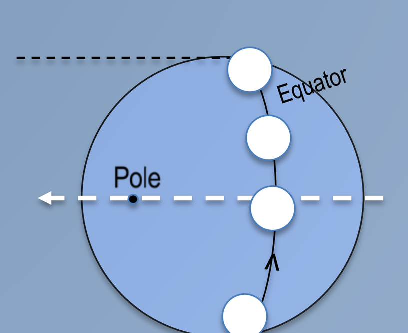


Fig. 6 (right) – Blob configuration as result of the model fit of panels 2, 3 and 4 of Fig. 5.

4. Covariability of UV, optical variations and model results



- Simultaneous He II 4686 and N IV 1718 EW, as measured between v = *vsini* =-230 km/s km/s and -400 km/s and arbitrarily scaled to the same amplitude. These lines are likely formed in the same region, and indeed show a similar trend, like in Fig. 1.
- Fit results are not unique: more periods can fit the same dataset



- Model fits to quotient spectra need multiple (at most 5) features with lifetimes up to 5 h
- The lifetime as a function of the number of blobs derived from the fits is in the order of hours, much smaller than the rotation period

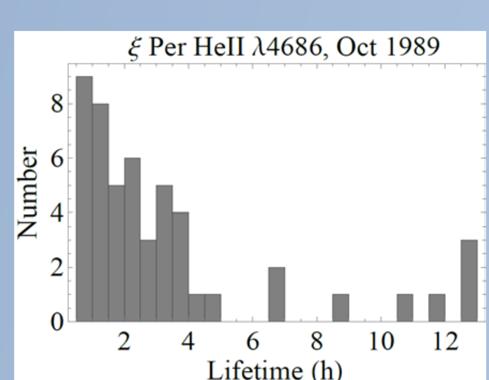


Fig. 7 – *Top:* Overplot of scaled equivalent widths of UV N IV and optical He II λ4686 line. The similar trend suggests that the cyclical variability of the wind and of the optical lines are tied.
– *Bottom:* Model fit results of He II quotient spectra displayed as circles located at the fitted stellar longitude (0° = line of sight). Sizes are proportional to the fitted optical depth (0.08 < τ < 0.38). The number of model blobs is between 1 and 5. Trends are caused by the rotation.
– *Right:* Schematic stellar surface with adopted inclination angle 56° and example blobs with radius 0.2 R*

5. Conclusions

- The rotation period is 2.04058 d.
- A ~4 d period would not be consistent with the adopted radius of ~$11R_{\odot}$ (Markova, 2004), as opposed to earlier work.
- This periodicity predicts that ξ Per has a dipolar like field, with the footpoints of strong DACs at only one of the magnetic poles.
- This field could be detected with the derived ephemeris.
- With the implied *i* = 56°, and only one pole visible, β should be near ~ 90° - *i* = 34°.
- The superimposed variable magnetic prominences can be interpreted by our model fits.
- We propose (in analogy to solar prominences) that multiple (1 - 5) magnetic loops are present on the surface, with a short life time (~hours), which we call prominences
- These prominences are proposed to be at the footpoints of weaker intermediate DACs.
- Cancellation effects may make magnetic detection of these prominences difficult (Kochukhov and Sudnik 2013).
- To (dis)proof this model we propose simultaneous high-precision photometry (like by Ramiaramanantsoa et al 2014) and spectroscopy with continuous coverage during more than one rotation period, and Zeeman Doppler Imaging.
- Similar λ Cep data could be fit with the same model, which suggests a common phenomenon among O stars

Natallia Sudnik snata.astro@gmail.com
Huib Henrichs huib.henrichs@gmail.com