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Tartu Observatory

# Spectroscopic and photometric variability of the blue supergiant $\rho$ Leo

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In collaboration with:

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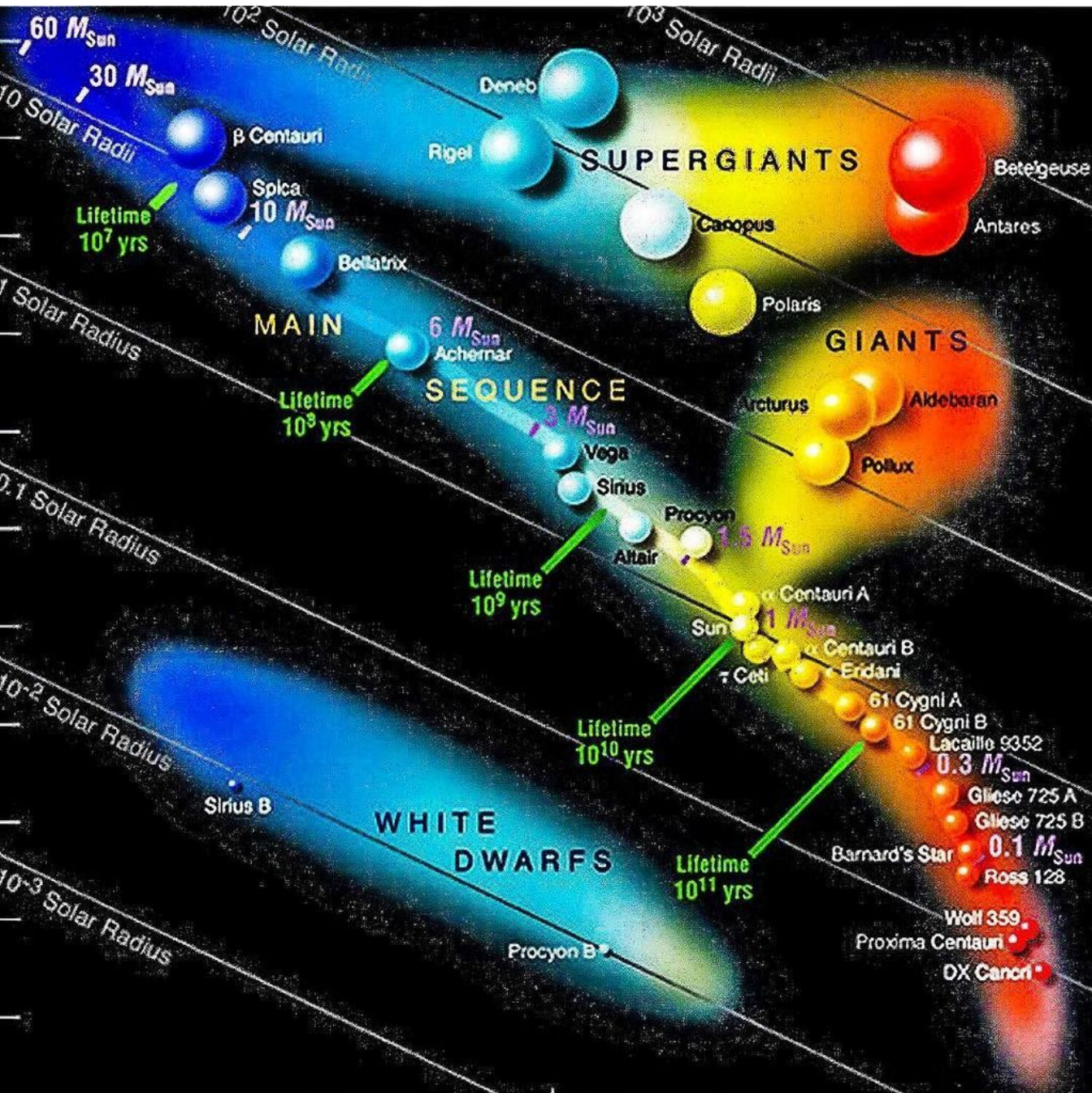


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# Research objects



Blue supergiant (**BSG**) stars — post-main-sequence massive stars

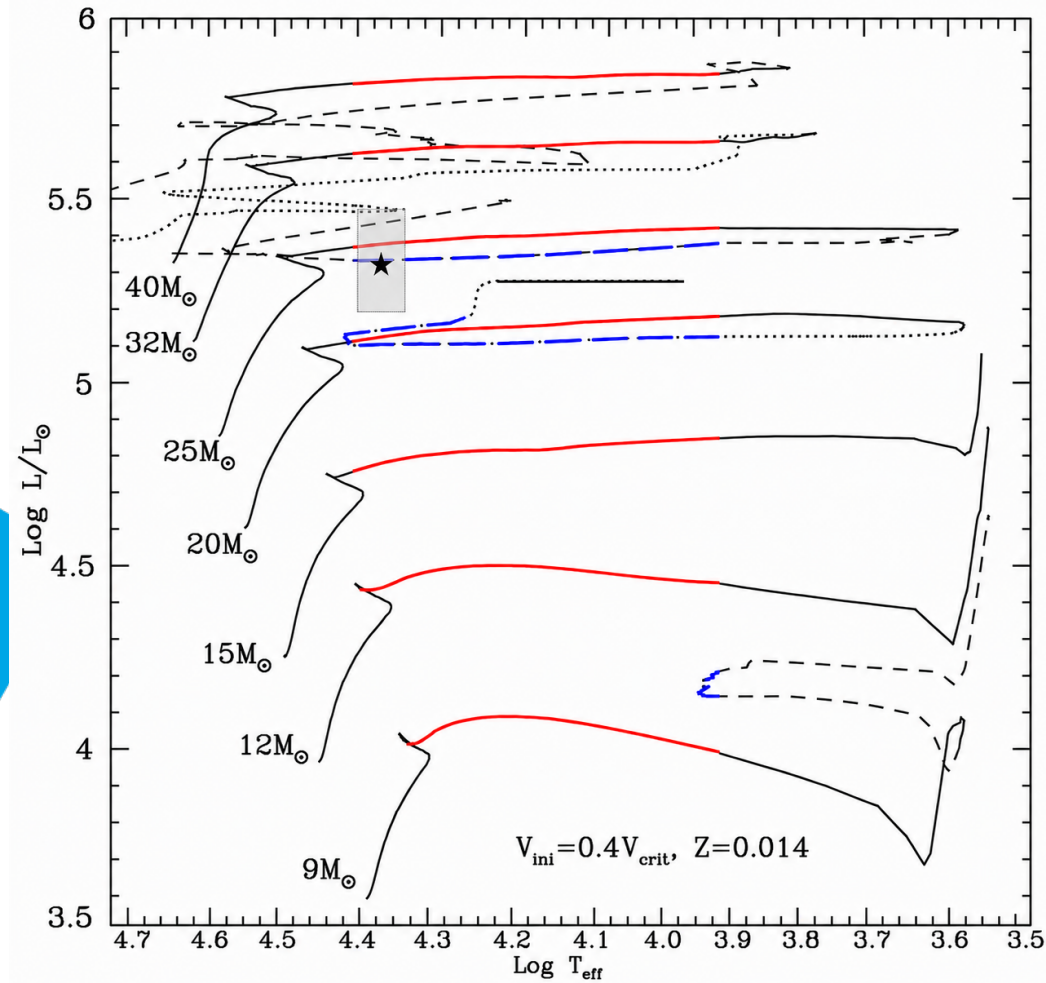
## Characteristics:

- Mass 8 - 50  $M_{\odot}$
- Radius 10 - 100  $R_{\odot}$
- Luminosity  $L$  10 000 - 300 000  $L_{\odot}$
- Effective temperature  $T_{\text{eff}}$  10 000 – 30 000 K
- Strong variability
- Strong variable stellar wind

## Why do study the BSG?

- \* BSGs are immediate SN progenitors
- \* Uncertain internal structure
- \* Variability probes stellar interiors

# Blue supergiant $\rho$ Leo



Berlanas+ 2018

## Physical parameters of $\rho$ Leo:

- Spectral type B1 labNstr [1]
- $M, M_{\text{Sun}}$  22 - 27 [1, 5]
- $R, R_{\text{Sun}}$  32 - 37.4 [1, 5]
- $T_{\text{eff}}, \text{K}$  23 000 [this work]
- $\text{Log } g$  2.6 [this work]
- $V, \text{mag}$  3.87 [2]
- Distance, pc 660 (Gaia) - 900 (spec)
- Variable type  $\alpha$  Cyg [1]
- Suspected binarity [3, this work]
- $V_{\text{rad}}, \text{km/s}$  +40.6 - 42 [this work, 4]
- Rotation-axis inclination, deg 21.7 [this work]

[1] Crowther+ 2006  
 [2] Oja 1993  
 [3] Weißmayer 2023  
 [4] Kharchenko+ 2007  
 [5] Morel+, 2004



## Observations

### 1.5-meter mirror telescope AZT-12

- Long-slit spectrograph ASP-32  
320-1100 nm wavelength range  
Cassegrain focus
- I used 1800 lines/mm diffraction grating:
  - wavelength range **6300 - 6730 Å**
  - resolution  $R \approx 10\,000$
  - signal-to-noise ratio (S/N)~400

**11.5** years spectroscopy monitoring of  $\rho$  Leo:

2014-01-20 – 2025-05-31

~**3500** spectra

163 nights

The longest time-series ~4h 40m



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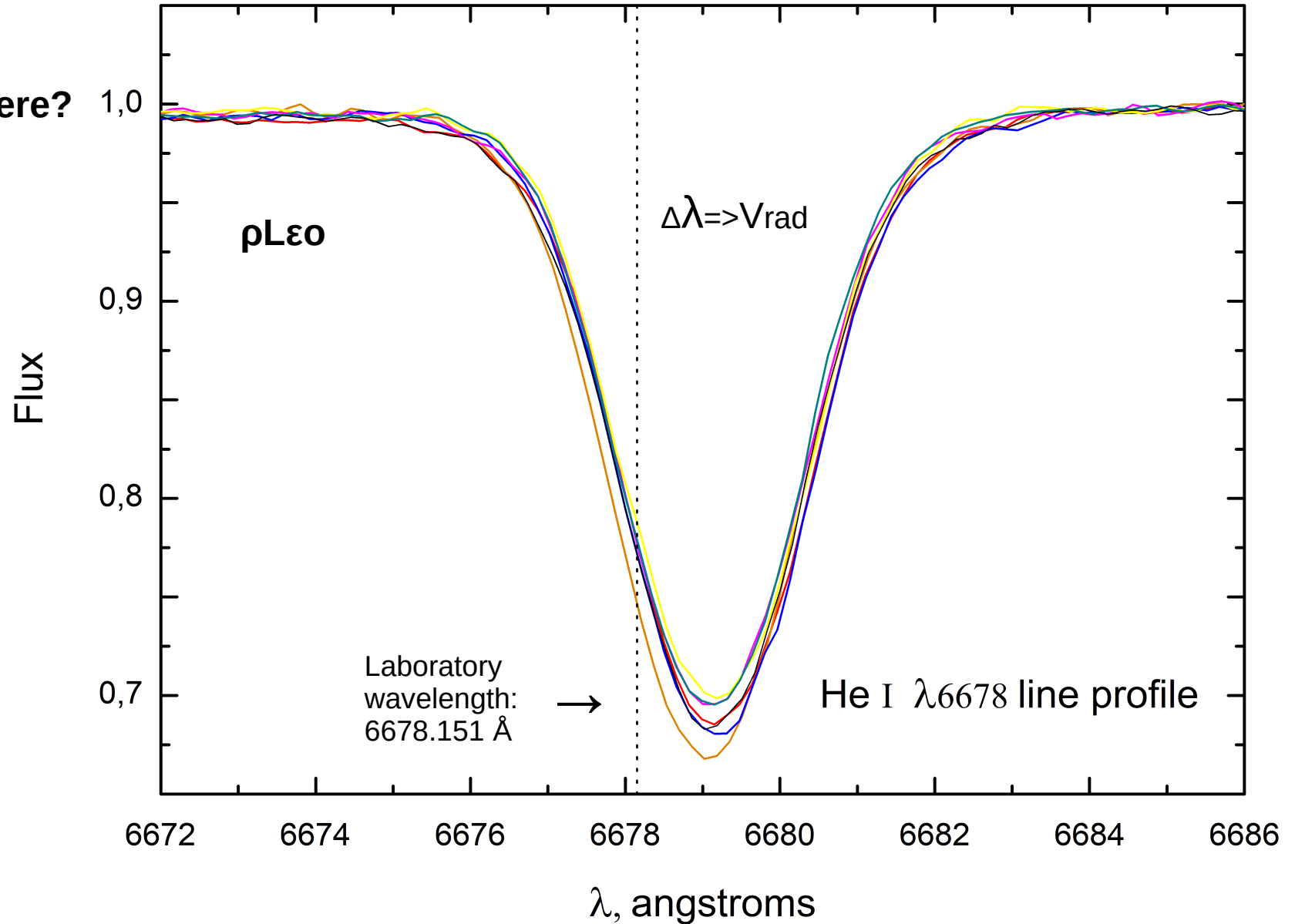


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# Spectrum variability and analysis

What can we know from here?

- ☀ Moment analysis
- ☀ Frequency analysis
- ☀ Wavelet analysis



# Moments analysis

$$M_0 = \sum_{i=1}^N (1 - F_i) \Delta x_i,$$

$$M_1 = \sum_{i=1}^N (1 - F_i) (x_i - x_0) \Delta x_i,$$

$$M_2 = \sum_{i=1}^N (1 - F_i) (x_i - x_0)^2 \Delta x_i,$$

$$M_3 = \sum_{i=1}^N (1 - F_i) (x_i - x_0)^3 \Delta x_i.$$

← Equivalent width

← Radial velocity

← Width

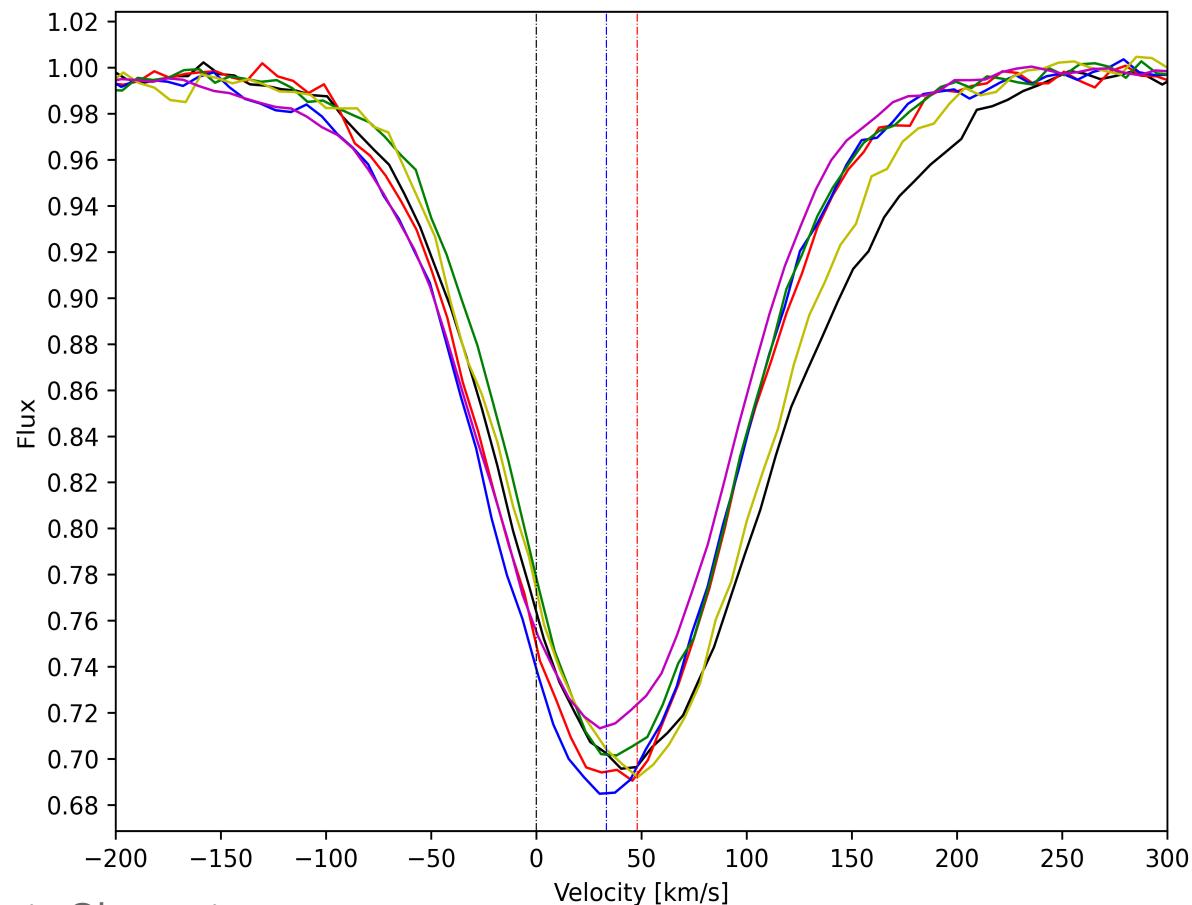
← Skewness

$$V_{rad} = \frac{\lambda - \lambda_0}{\lambda_0} \cdot c \Rightarrow$$

$x_0$ :  $V_{rad}$  (system)

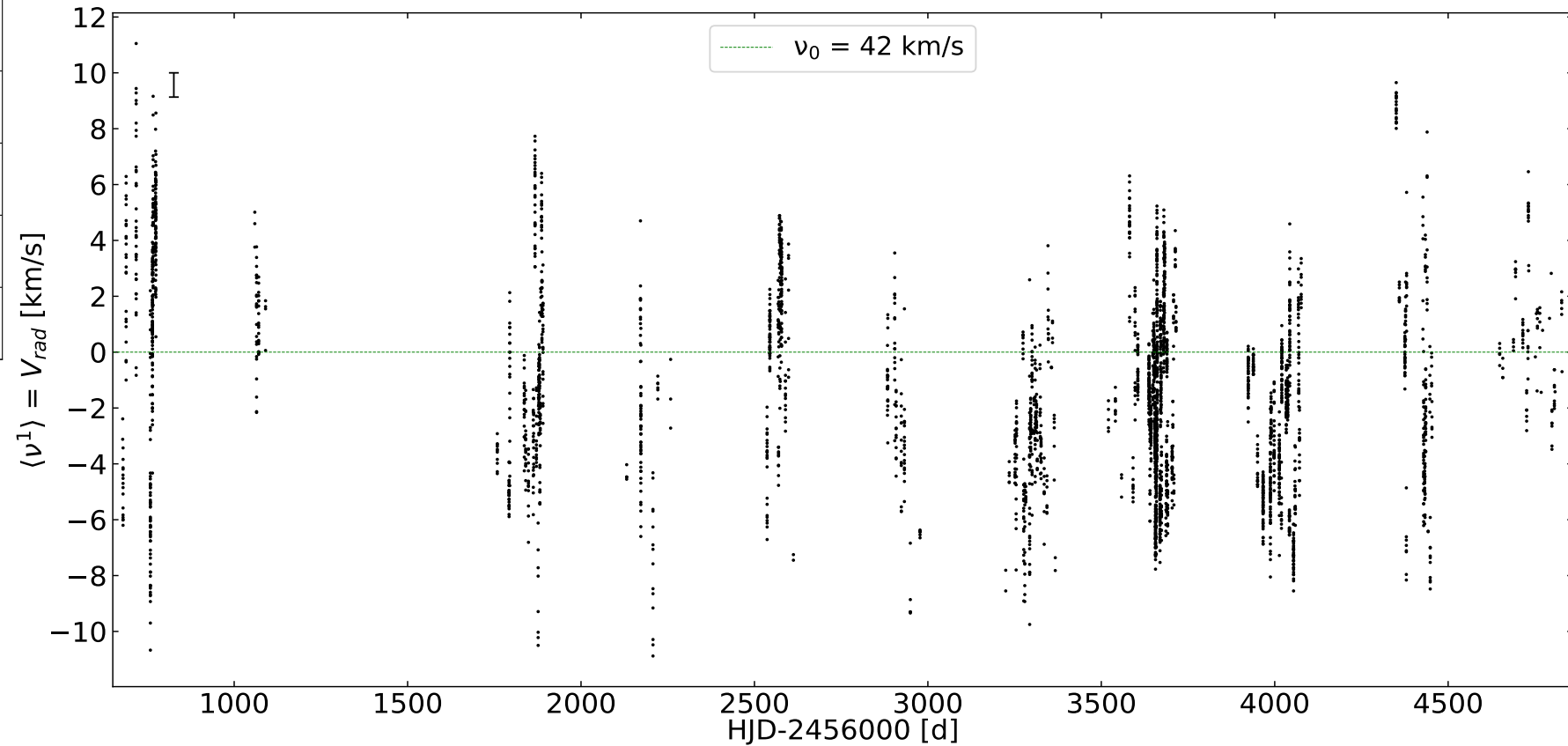
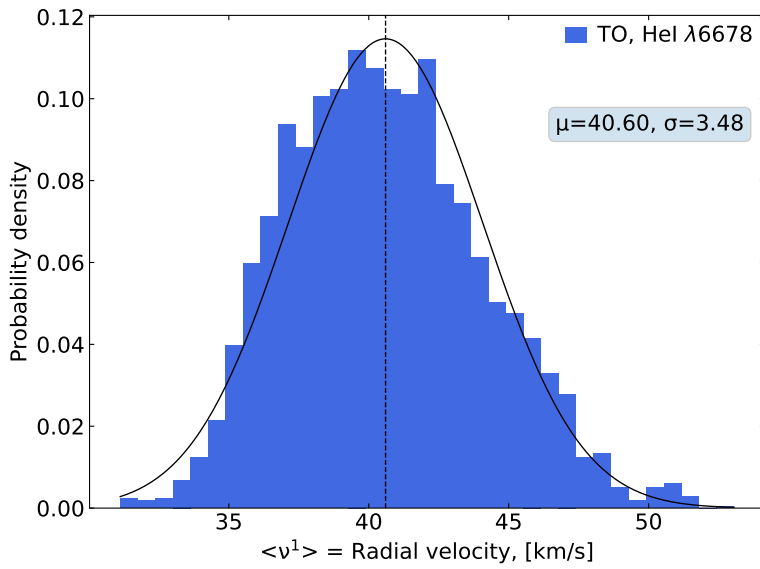
$x_i$ : velocity corresponding to  $\lambda_i$

$F_i$ : flux value measured at wavelength  $\lambda_i$  for pixel  $i$

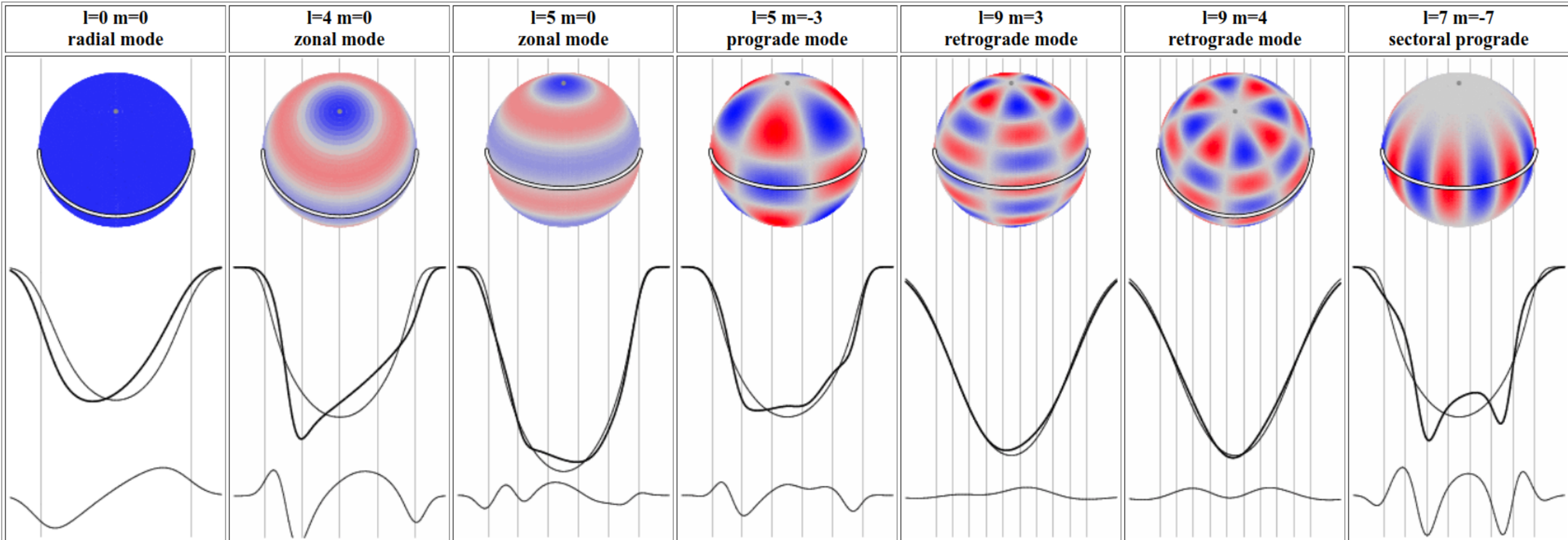




# TO spectroscopic data – 11.5 years of observations, first moment of HeI line (radial velocity)



# Possible origin: non-radial pulsations



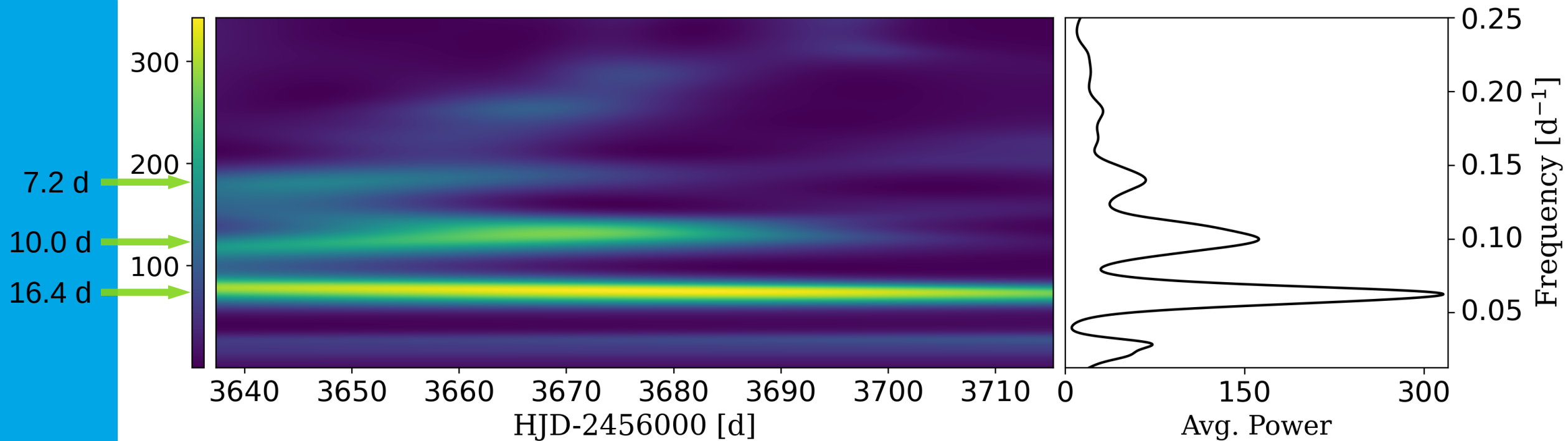
John Telting. NRP animation creator <http://staff.not.iac.es/~jht/science/nrpform/>

$l$  – number of node lines  
 $m$  – azimuthal number  
 $n$  – radial order

# Weighted wavelet Z-transform of the season 2022



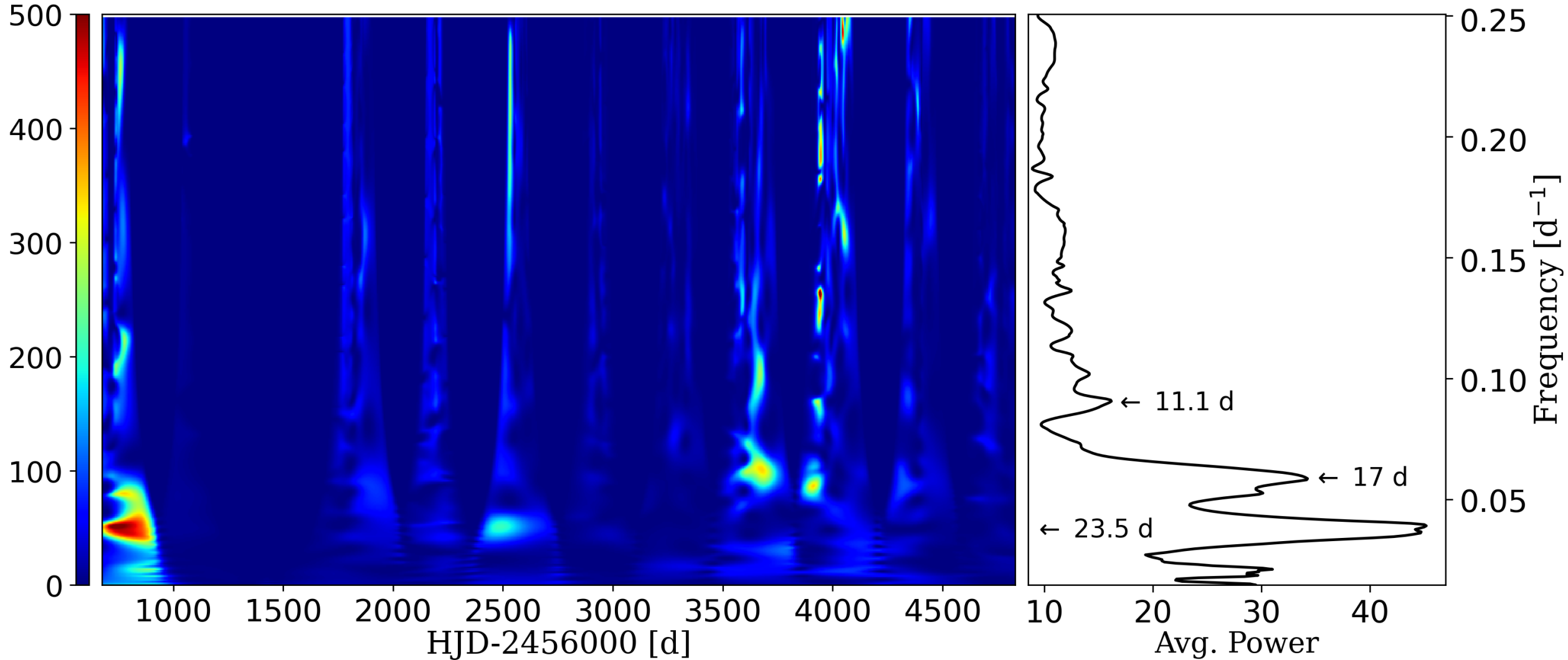
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# Wavelet analysis of the first moment, 11.5 years of observations



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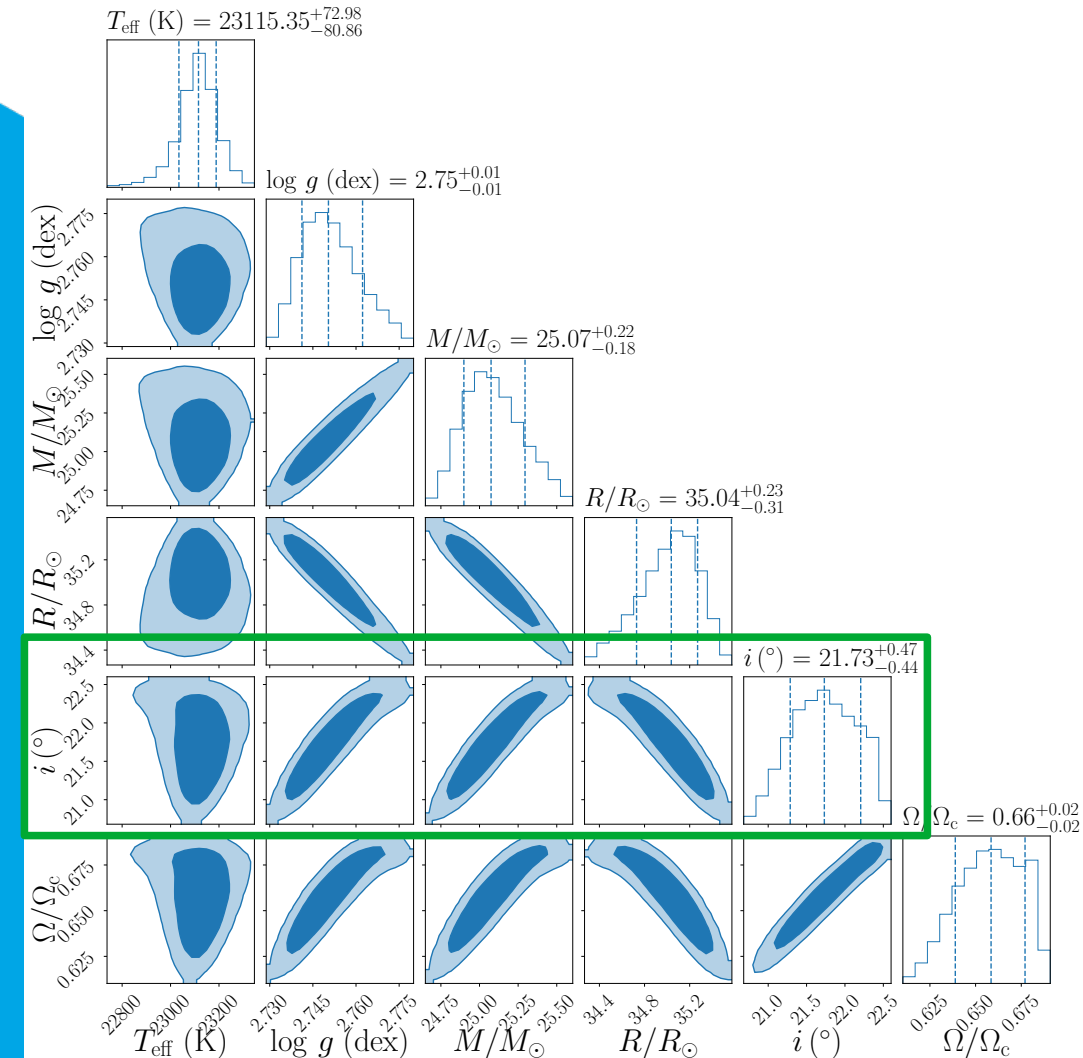
# Inclination angle => rotation period



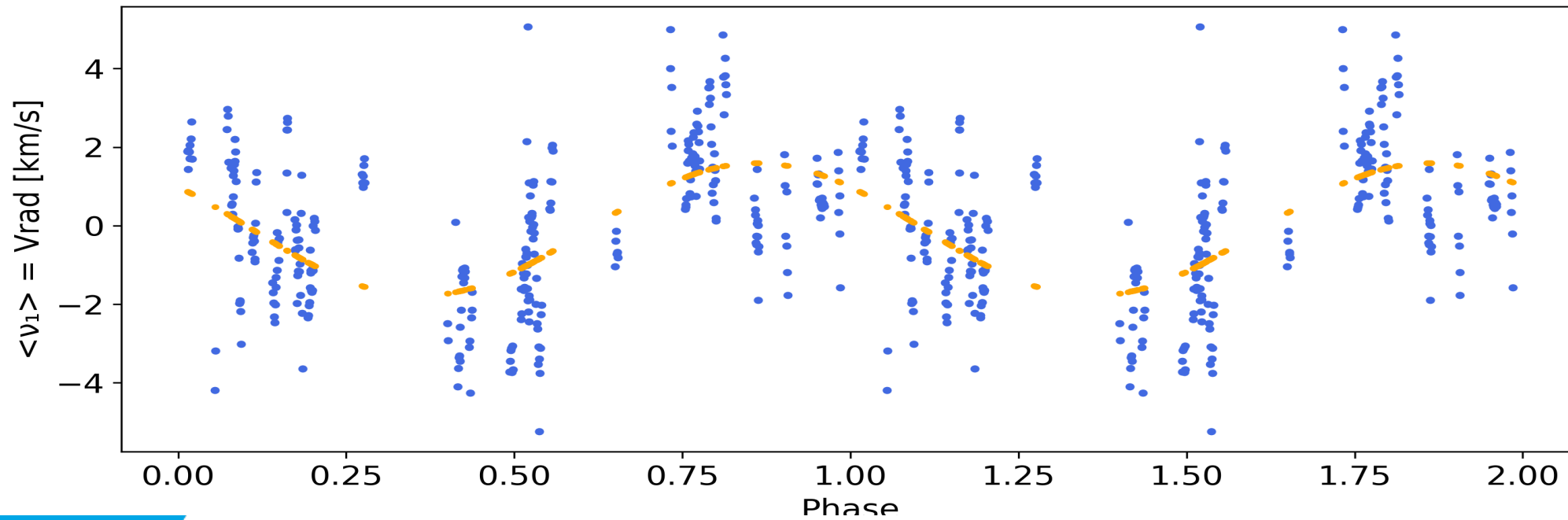
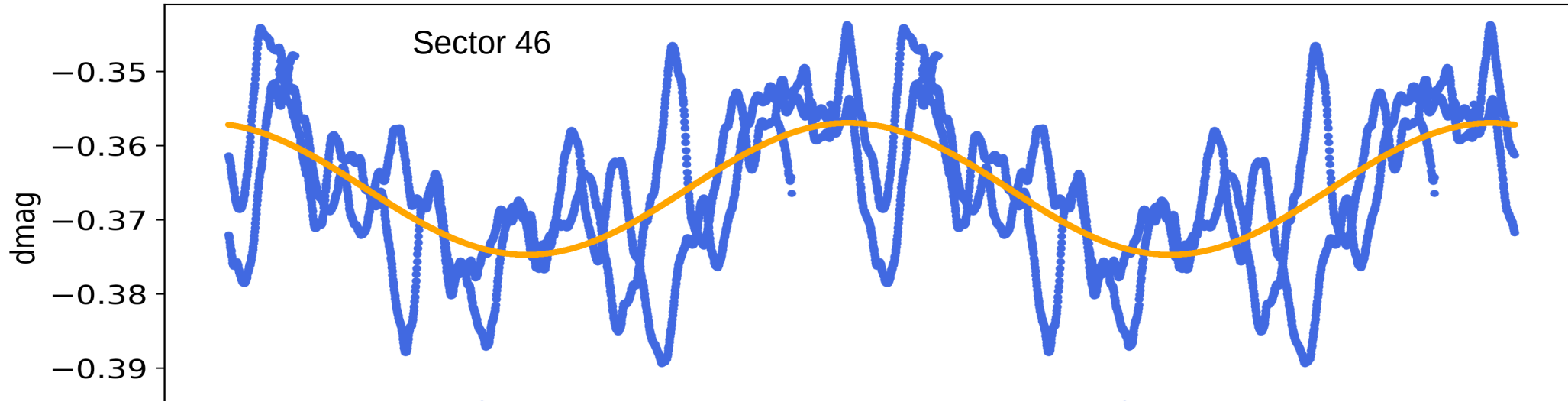
Results of the fittings of the observed HeI 4026 Å line profile with the **ZPEKTR** models using a Hamiltonian Monte Carlo (HMC) inference with STAN (Carpenter et al. 2017; Duane et al. 1987). For this, the HARPS spectrum observed on 12 February 2006 was used.

The best angle of inclination obtained in this analysis is **21.7°**.

By incorporating the stellar radius and the projected rotational velocity into the calculations, we estimate a rotation period of **12.5 ± 0.7 days**.



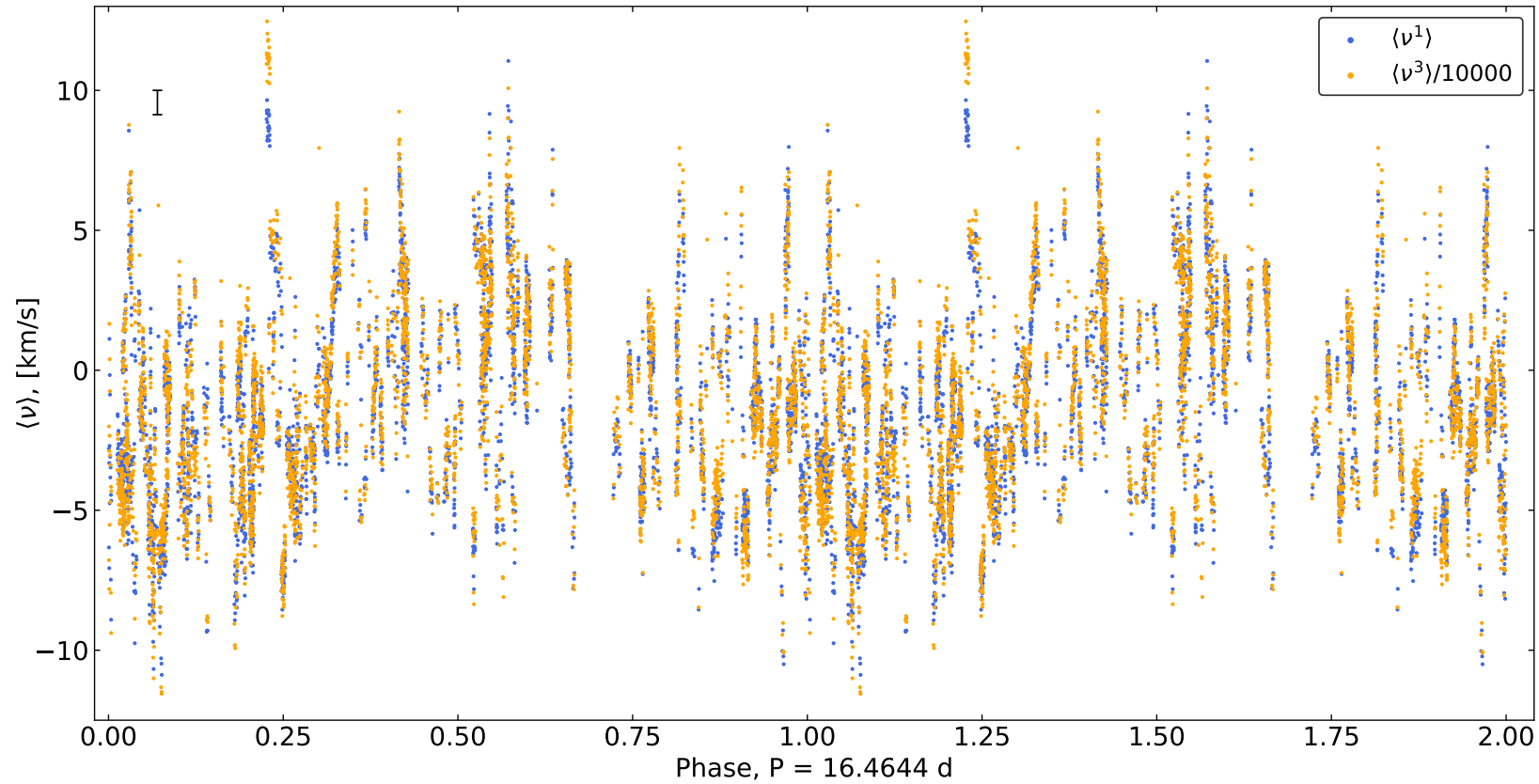
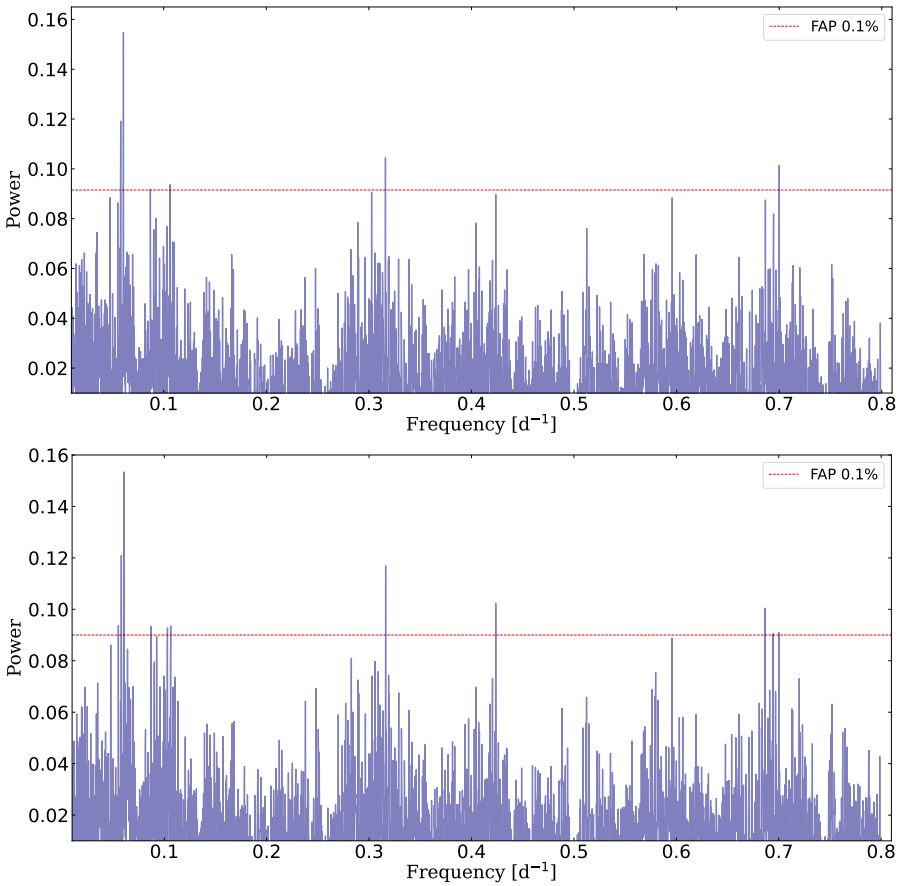
TESS photometry+season 2021 spectroscopy, period 12 days - rotation



# The first (radial velocity) and the third (skewness) moments, full TO dataset



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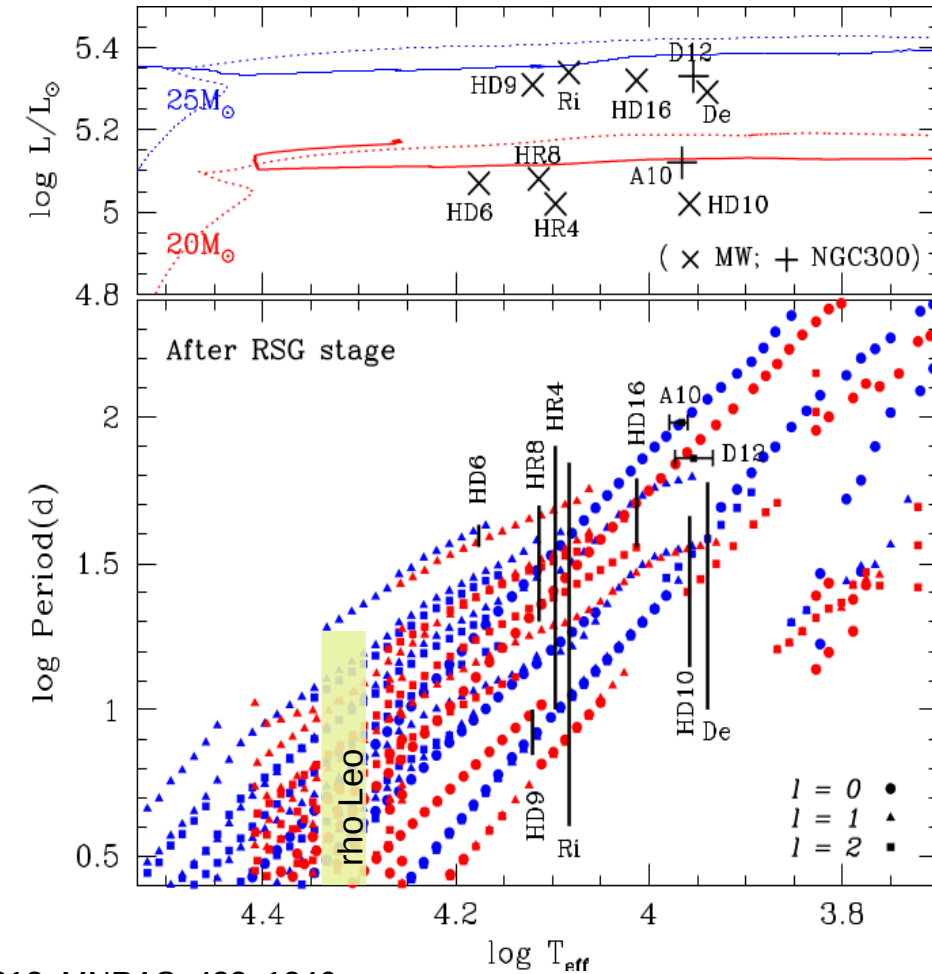
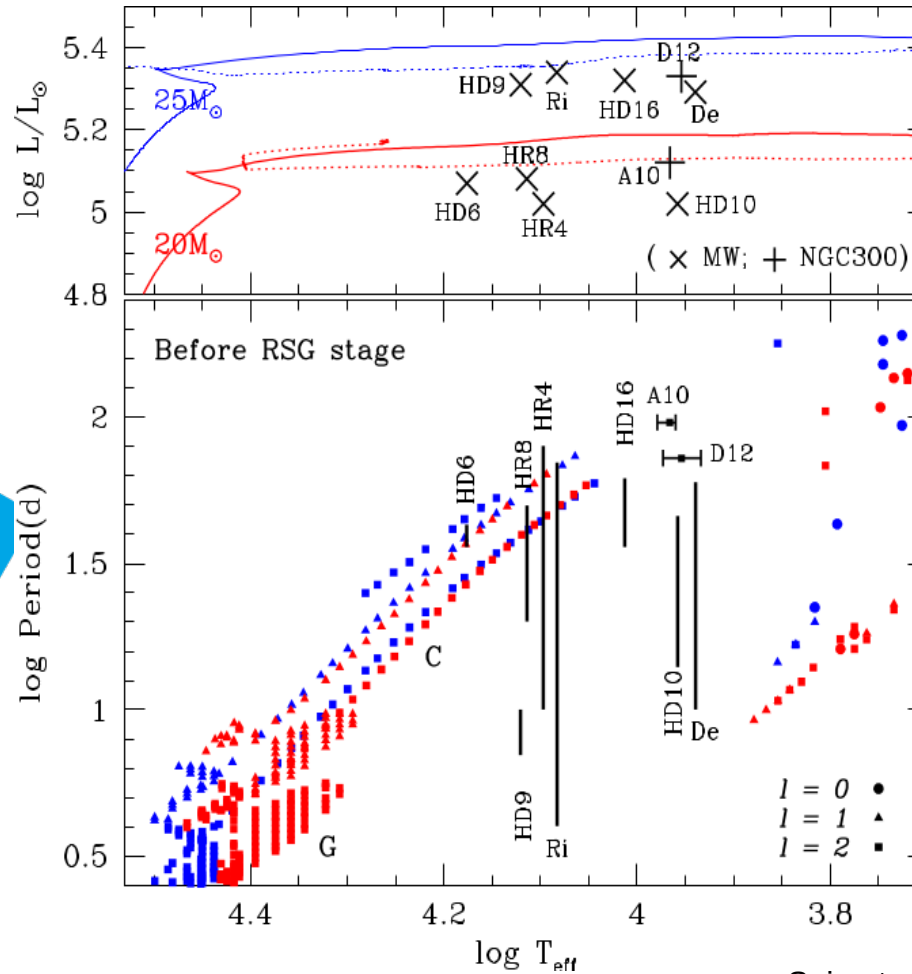


Lomb-Scargle periodograms for the 1<sup>st</sup> and the 3<sup>rd</sup> moments.

# Scenario 1 – radial + non-radial pulsations



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Saio et al. 2013, MNRAS, 433, 1246

## Scenario 2 – $\rho$ Leo is a binary system



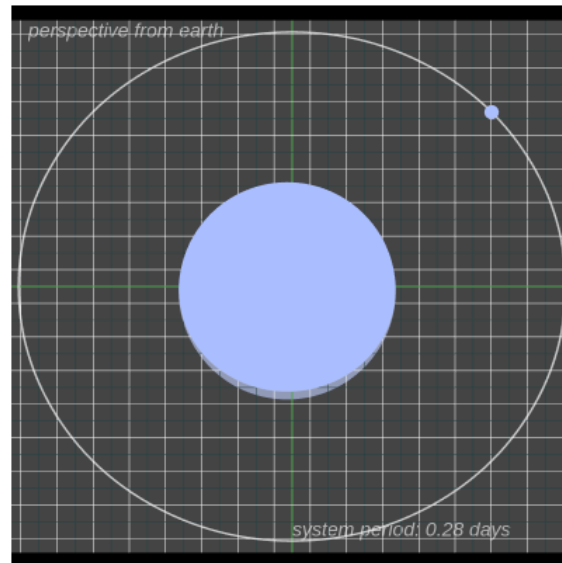
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Input data:

1. Period 16.5 d
2. Amplitude 3.94 km/s
3. Incl. angle 21.7 degrees
4.  $M_{\text{primary}}$  22  $M_{\odot}$
5. Distance 700 pc

Result:

$M_2 \approx 0.52 M_{\odot}$   
 $a \approx 0.358 \text{ a.u. } (\approx 2.4R_1)$   
 $\theta_{\text{max}} \approx 0.51 \text{ mas}$



# Conclusions



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1. Multiple stable and quasi-stable periods.
2. Rotation period of  $\rho$  Leo is  $12.5 \pm 0.7$  days.
3. Identified stable period of  $\sim 16.5$  days is due to
  - \* **pulsations**
  - \* possible **binarity**.
4. The star is on the blue loop of evolution, after the red supergiant stage.

## Future work



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Developed methodology will be applied to other BSGs monitored at TO combining our spectroscopic time series and high-cadence space photometry.

Thank you for your attention!

LOOKING FOR POSTDOC

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### BSG monitoring list 2014 - 2026

Object	m	spectral type
V1768 Cyg	5.66	B1
P Cyg	4.82	B1-2_la-0_ep
V2118 Cyg	7.12	B1.5la
Deneb	1.25	A2lae
55 Cyg	4.86	B3lae
HD 199478	5.73	B8lae
HD 202850	4.26	B9lab
HD 208501	5.81	B8lb
V639 Cas	6.22	B2.9lab
HD 2905	4.19	B1lae
HD 12301	5.62	A0lb
HD 13267	6.35	B5la
HD 13854	6.50	B1labe
HD 14134	6.54	B3la
HD 14143	6.65	B2la
HD 14818	6.27	B2lae
HD 14956	7.24	B2la
HD 21389	4.54	A0la
Rigel	0.13	B8lab
HD 37128	1.70	B0lab
HD 38771	2.05	B0lab
62Ori	4.65	B2I
PU Gem	5.75	B2.5lb
HD 87737	3.51	A0lb
<b>pLeo</b>	<b>3.84</b>	<b>B1lab</b>
HD 164353	3.97	B5lb