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Variability in B supergiant star HD91316 (ρ Leo)

Vitalii Checha

<u>In collaboration with:</u>
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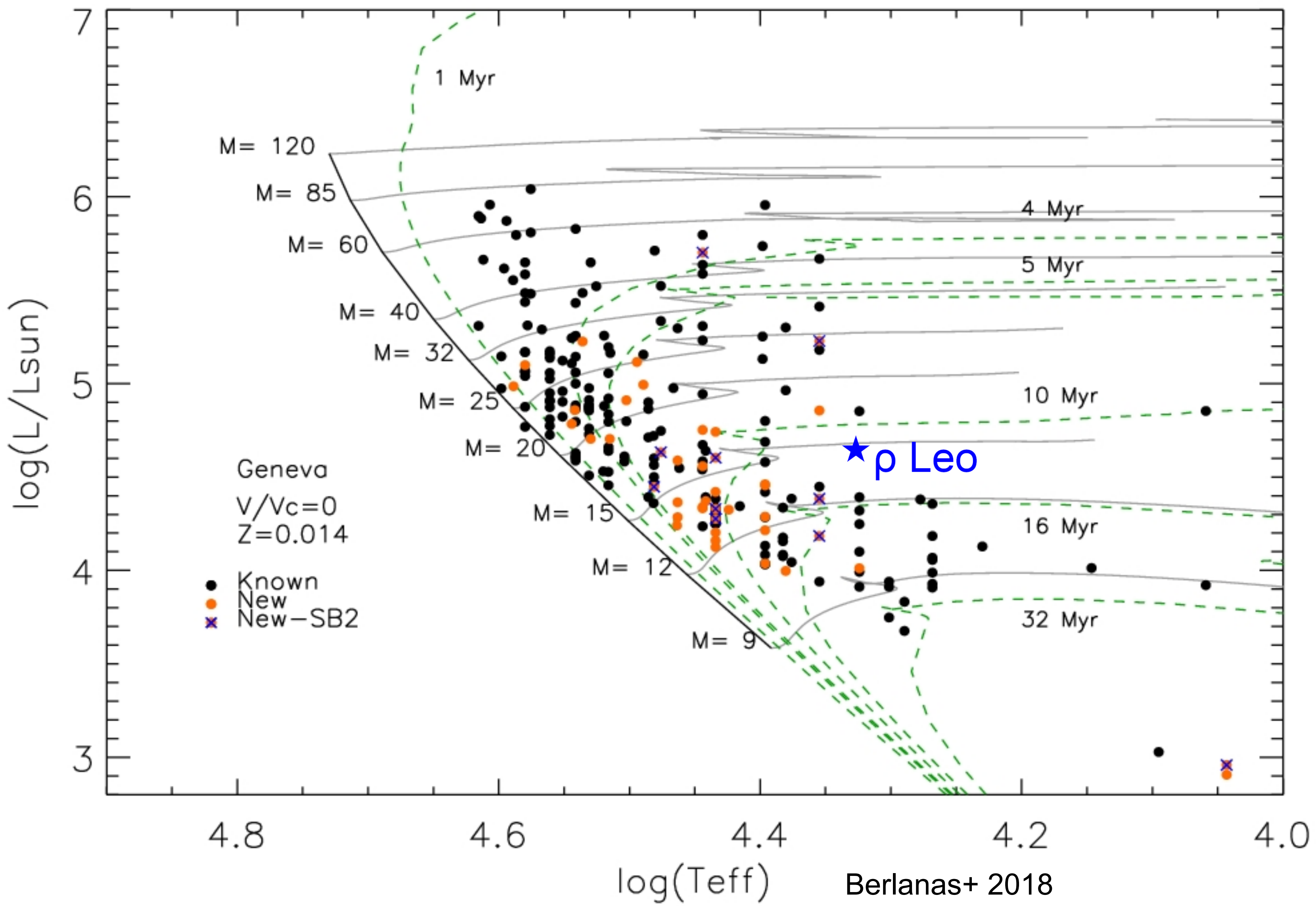
Funded by
the European Union

Blue supergiant - ρ Leo



Berlanas+ 2018

Physical parameters of ρ Leo:

- Spectral type B1 Iab [1]
- Teff , K 22000 [1]
- M, M⊙ 22 [2]
- R, R⊙ 32 [1]
- L, L⊙ 45600 [1]
- Vrad, km/s +40.5 [this work]
- V, mag 3.85 [1]
- Variable type α Cyg [1]
- Binary star [3]

[1] Crowther+ 2006
[2] Morel+ 2004
[3] Wilson 1941

FASTWIND best fit model
for rho Leo (Ignacio Araya)

Observed spectrum: HARPS 2006-02-12
ESO Archive

He=0.2 (not in ISOSCELES yet)

Teff= 23 000 K

logg= 2.6

R= 37.4 Rsun

Mdot= 0.35E-6 Msun/year

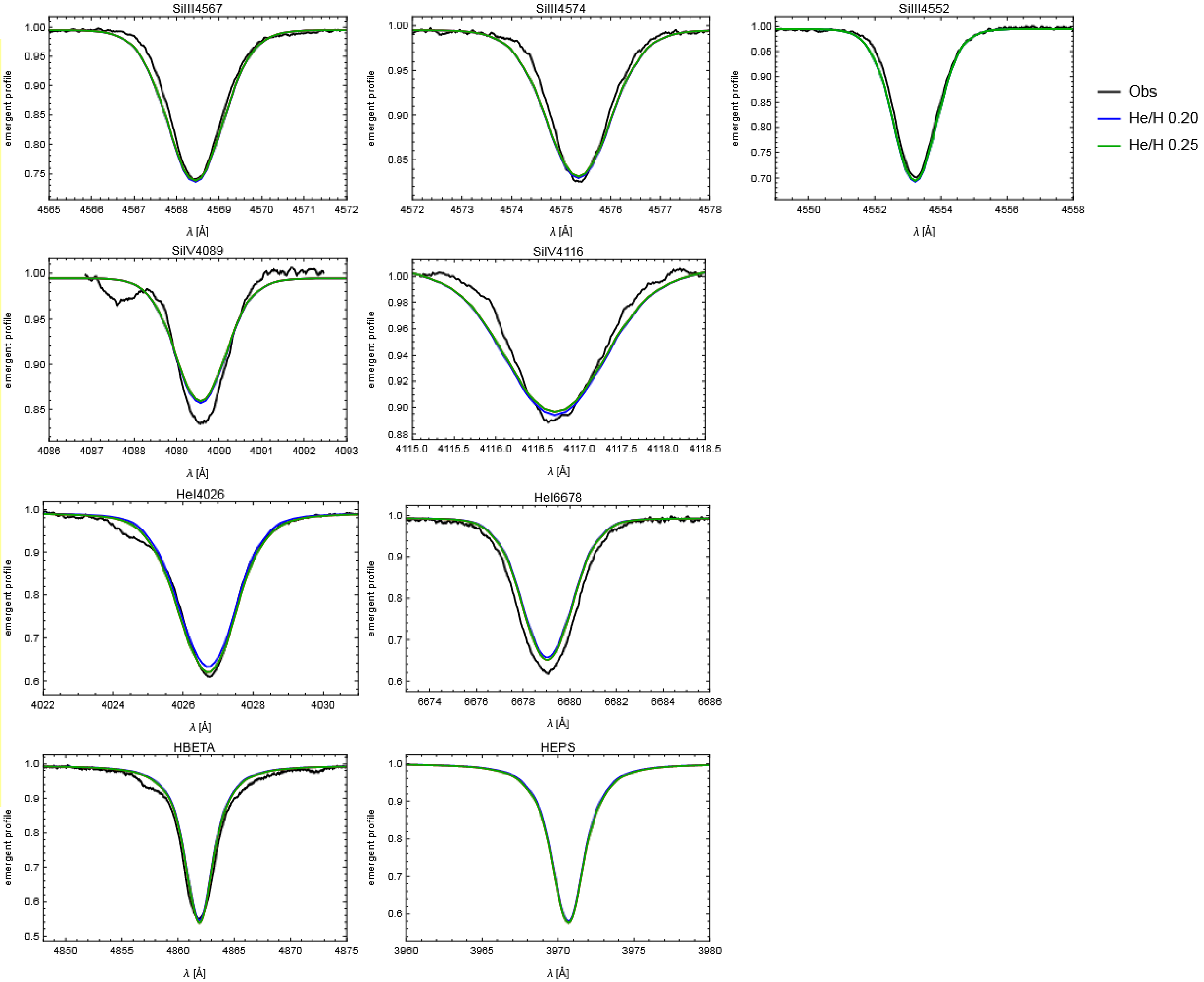
vinf= 1110 km/s

beta= 1.0

vmicro= 15 km/s

vsini= 48 km/s

vmacro= 76 km/s



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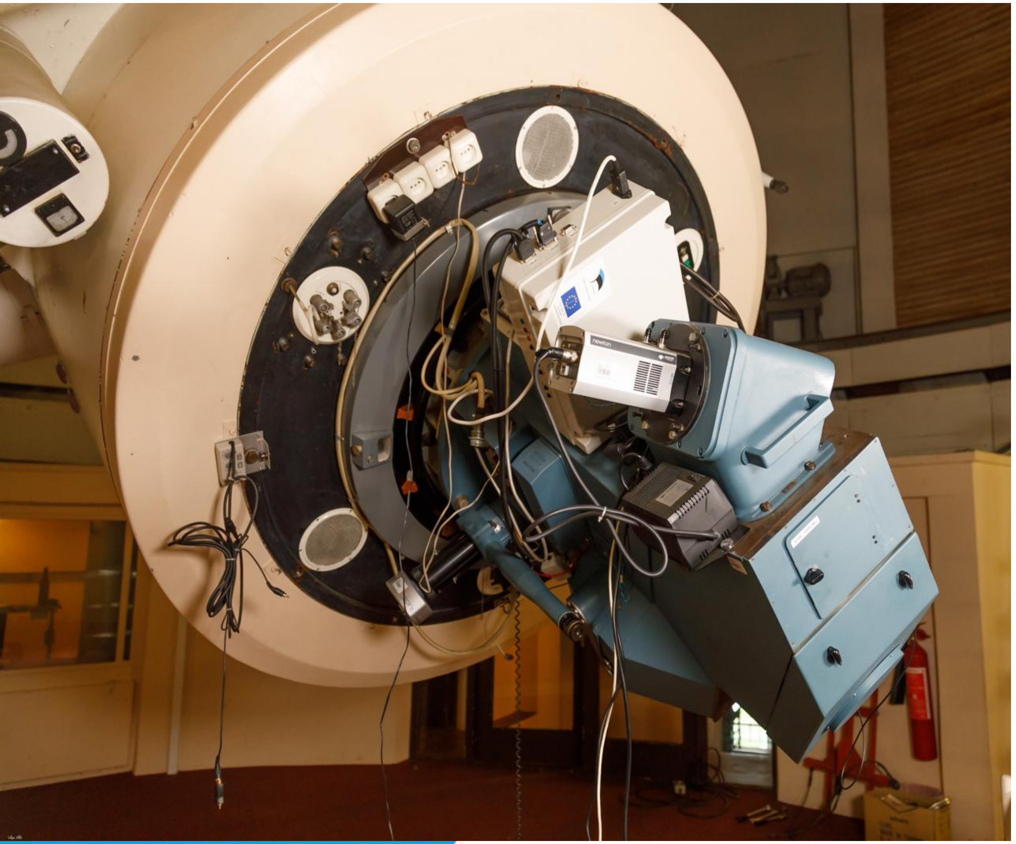

1.5-meter mirror telescope AZT-12

→ 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 ≈ 10 000
- signal-to-noise ratio (S/N)~400

ρ Leo monitoring

2017-01-04 – 2023-05-11

3014 spectra

132 nights

The longest time-series ~4h 40m

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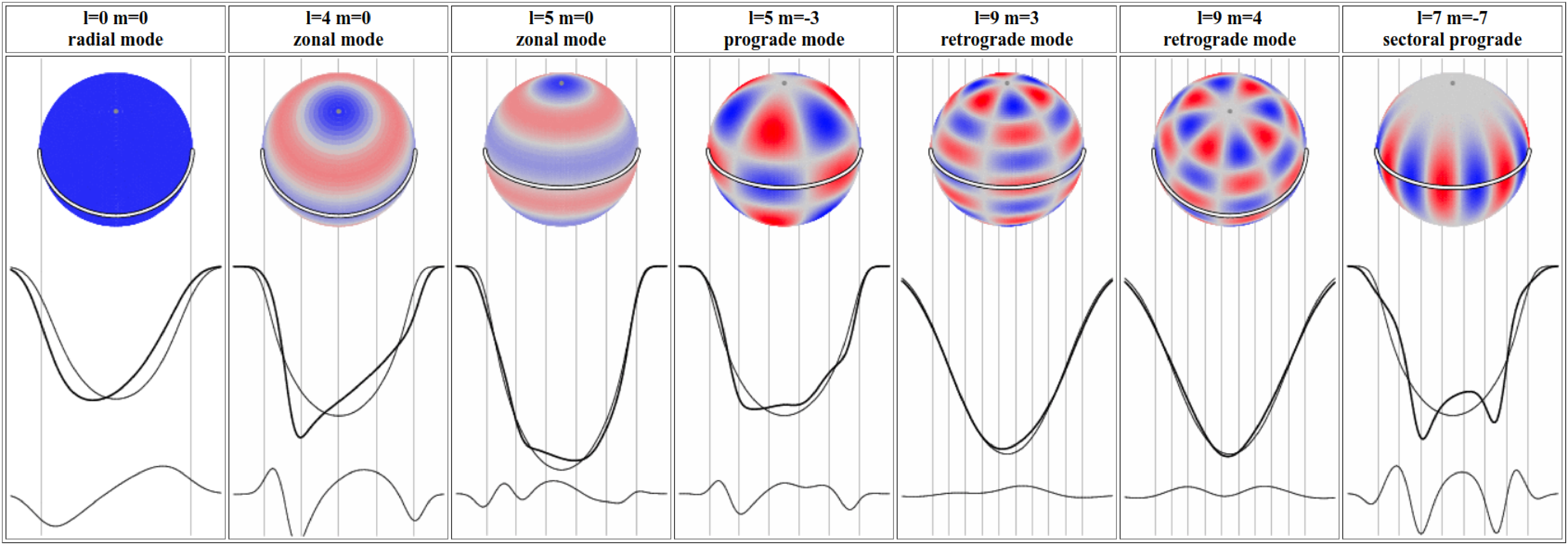
the European Union

Pulsations modes



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

l = 0
m = 0

l = 1
m = 0

l = 1
m = 1

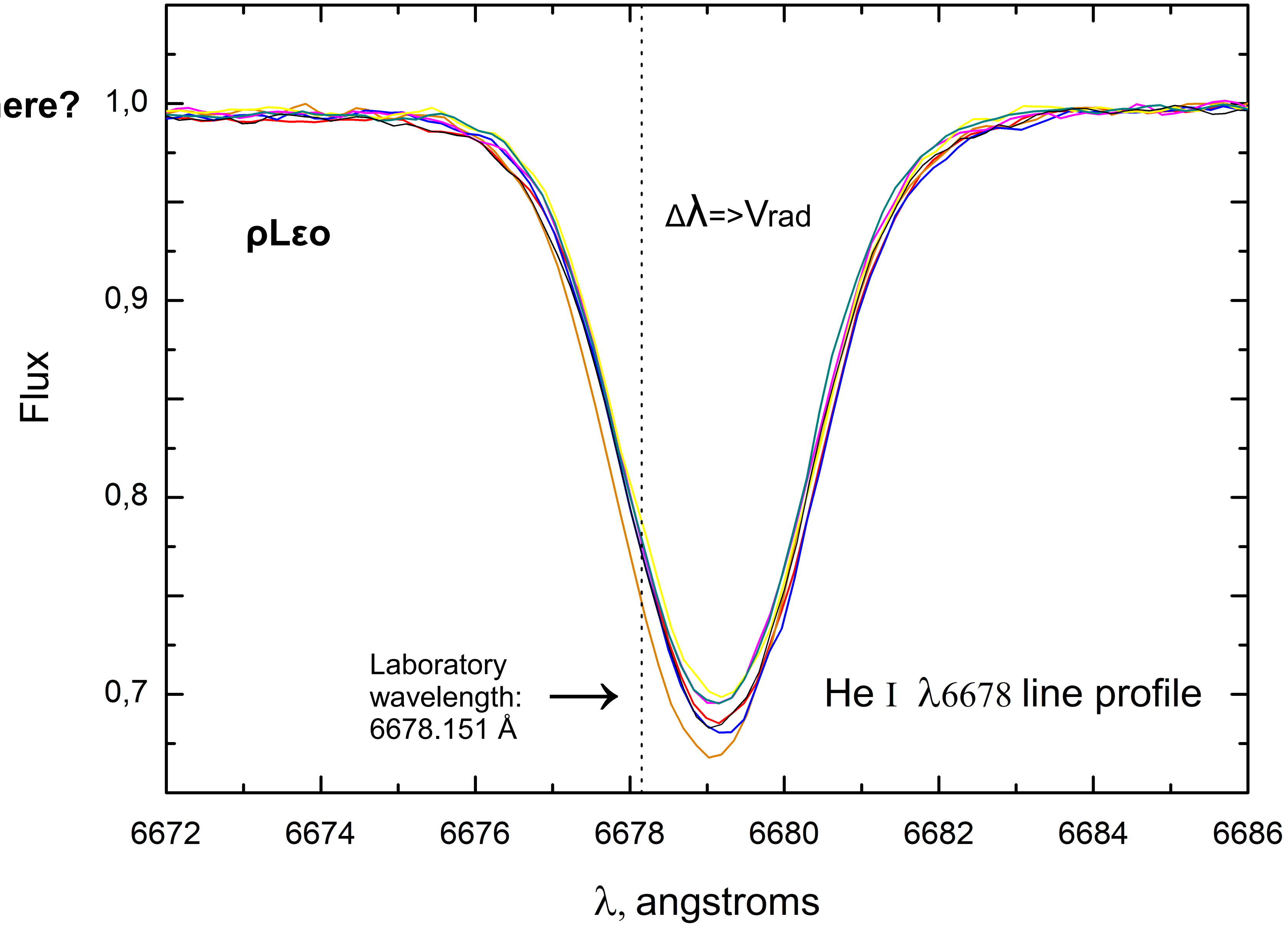
l = 2
m = 1

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

Spectrum variability and analysis

What can we know from here?

- **Moment analysis**
- Frequency analysis
- Wavelet analysis



Moment analysis

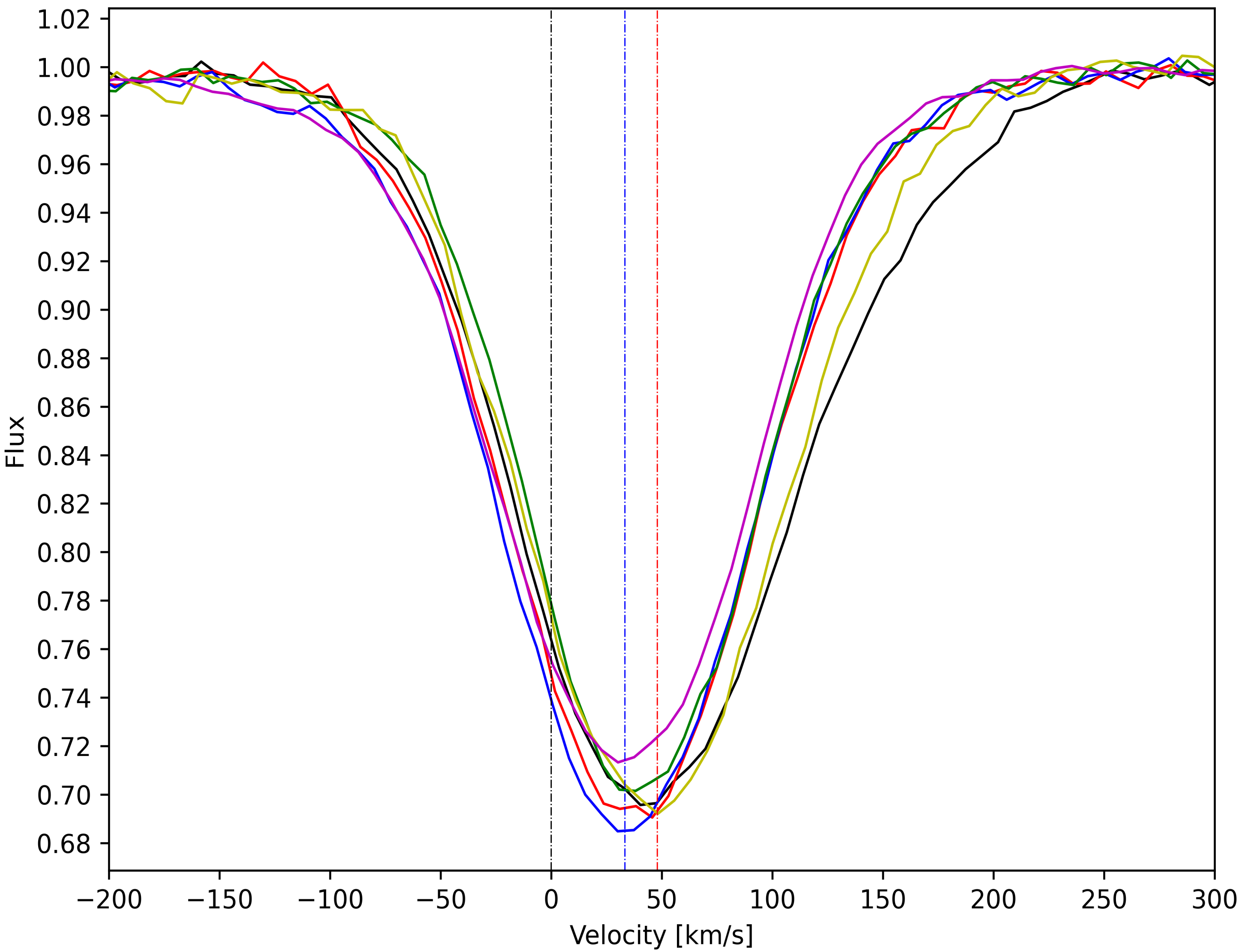
$$M_0 = \sum_{i=1}^{N} (1 - F_i)\Delta x_i,$$

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

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

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

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



Xo: Vrad(system)

Xi: velocity corresponding to λi

Fi: flux value measured at wavelength λi for pixel i

Spectral data

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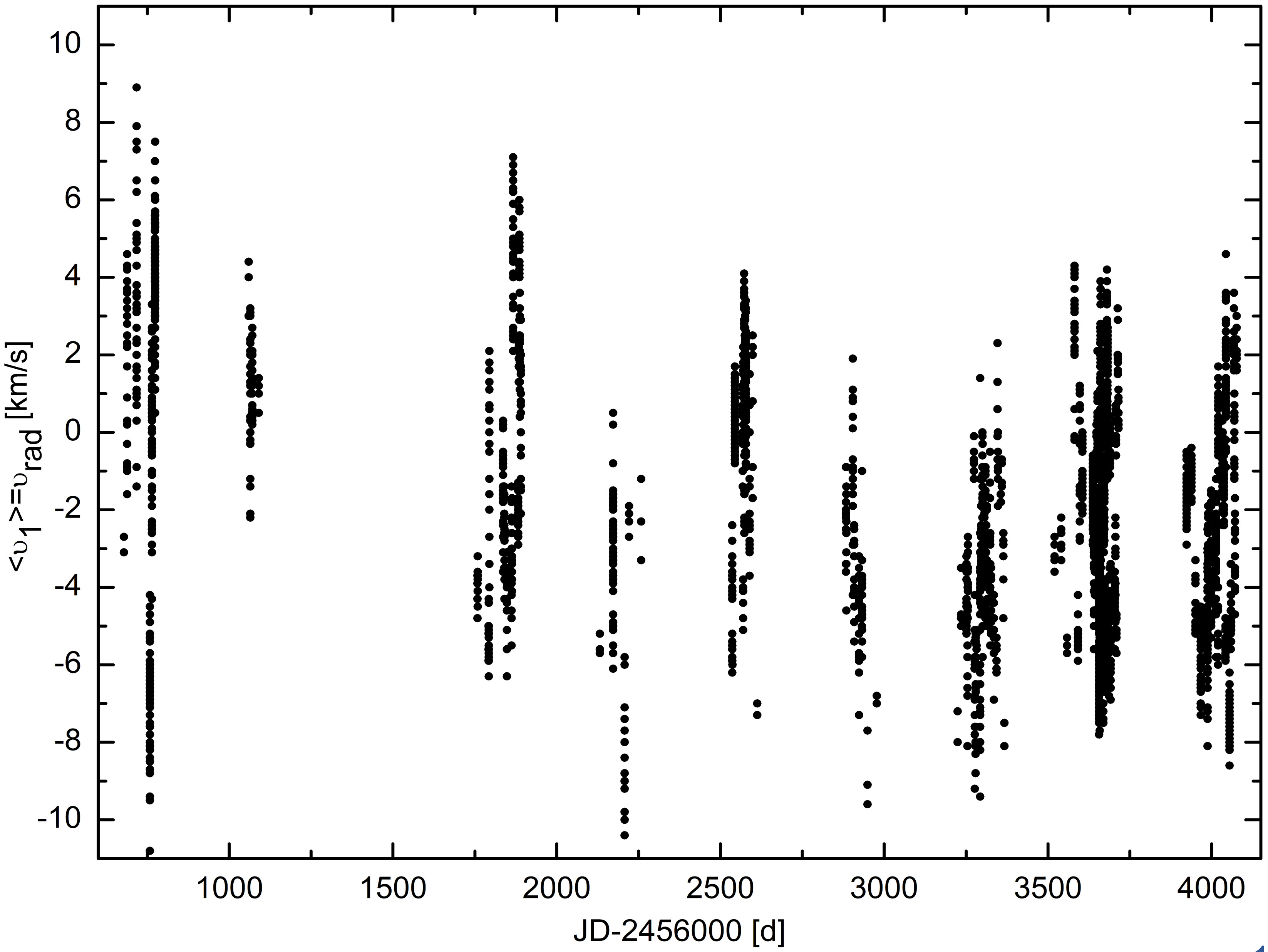
Observational data for blue supergiant **ρLεο**

From 2017-01-04

To 2023-05-11

Spectra – 3014

Nights – 132
The longest time-series ~4h 40m



Season 2022

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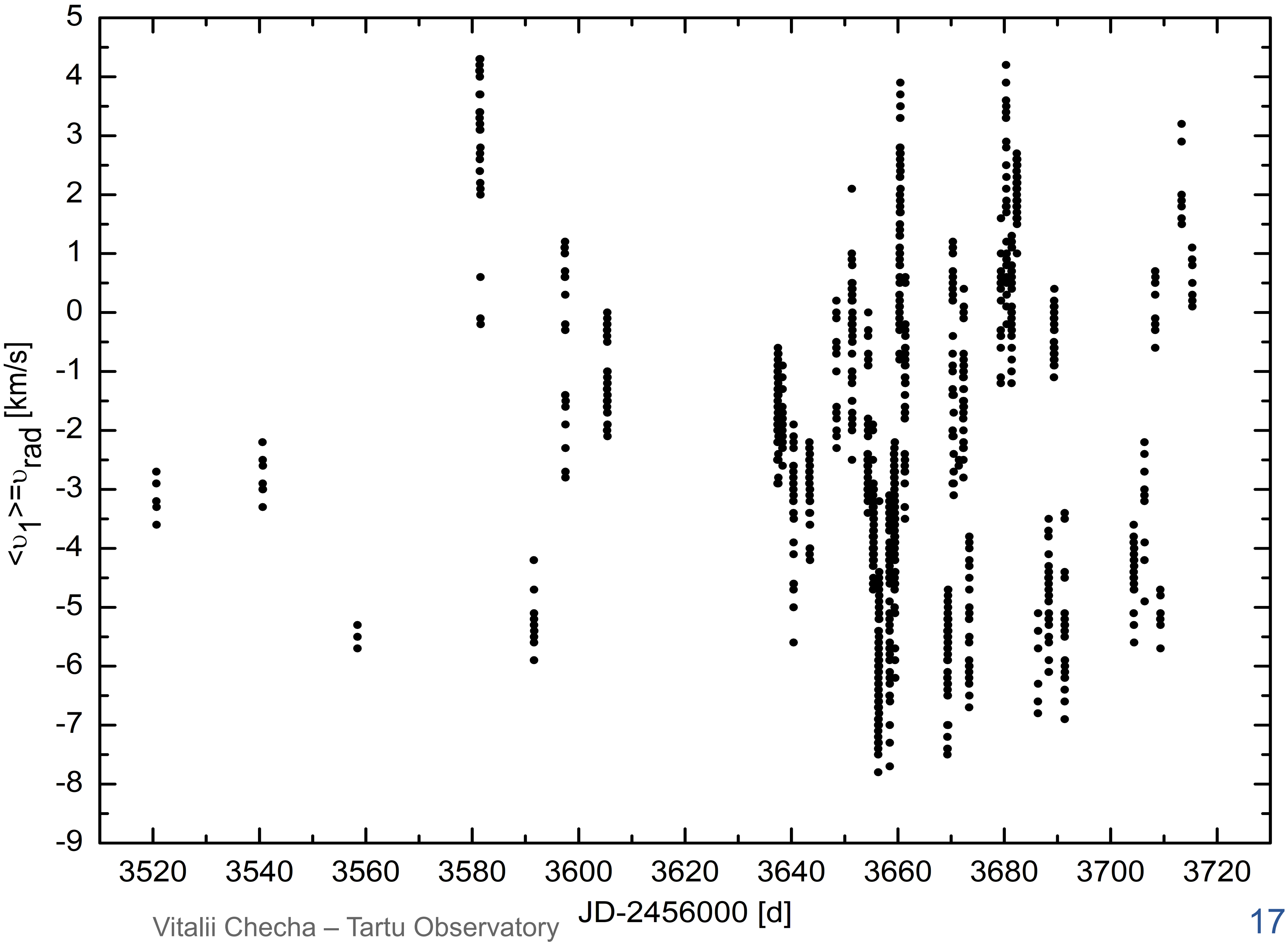
Observational data for blue supergiant **ρLεo**

From 2021-11-01

To 2022-05-15

Spectra – 1111

Nights - 39



Season 2022 – one night

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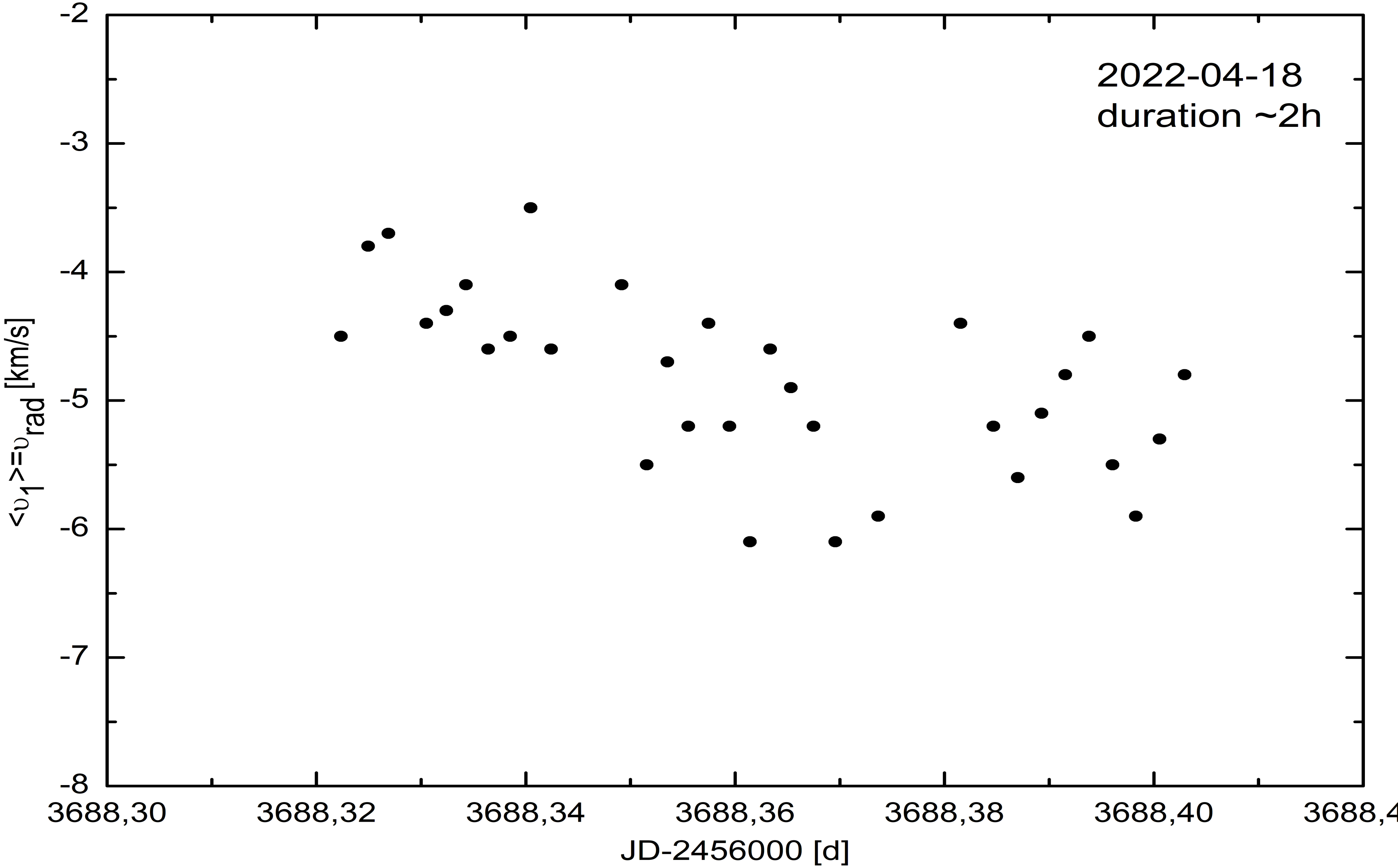
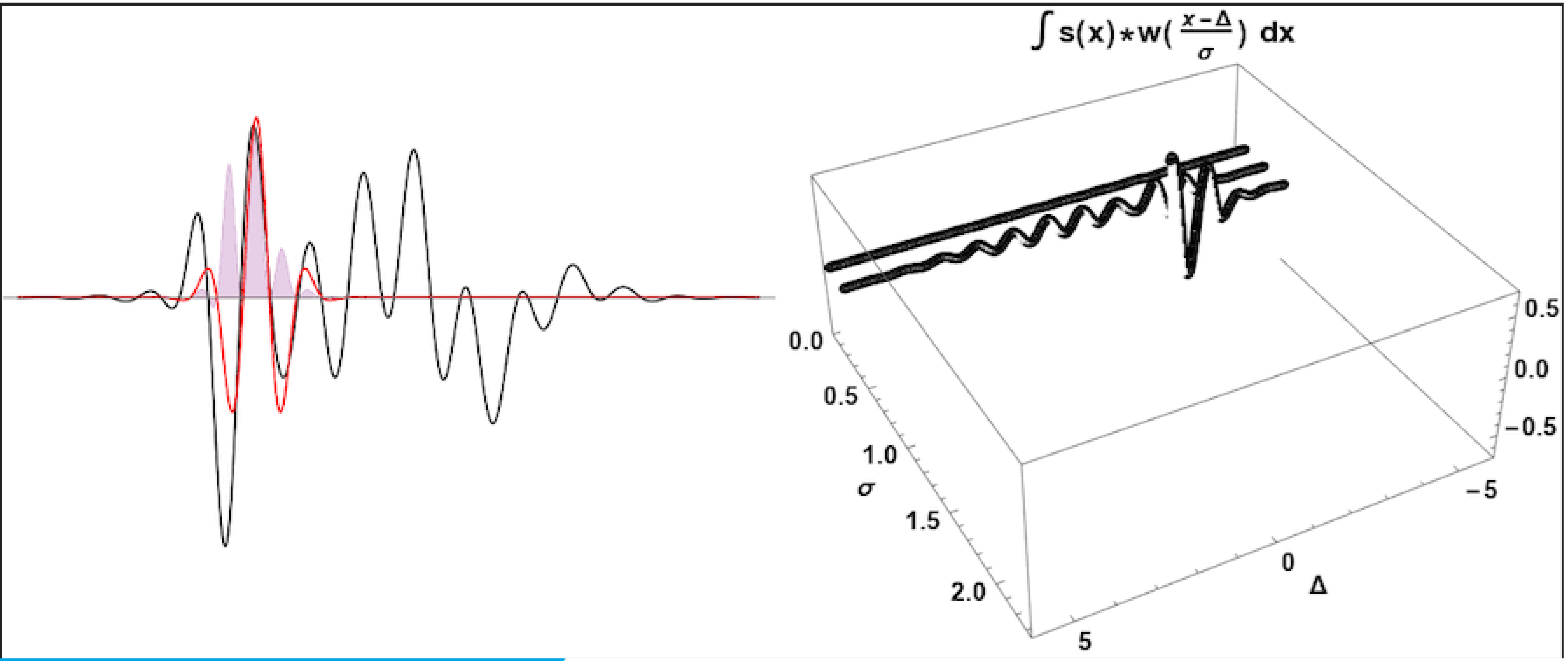
Observational data for blue supergiant **ρLεo**

Night 2022-04-18

Spectra – 33



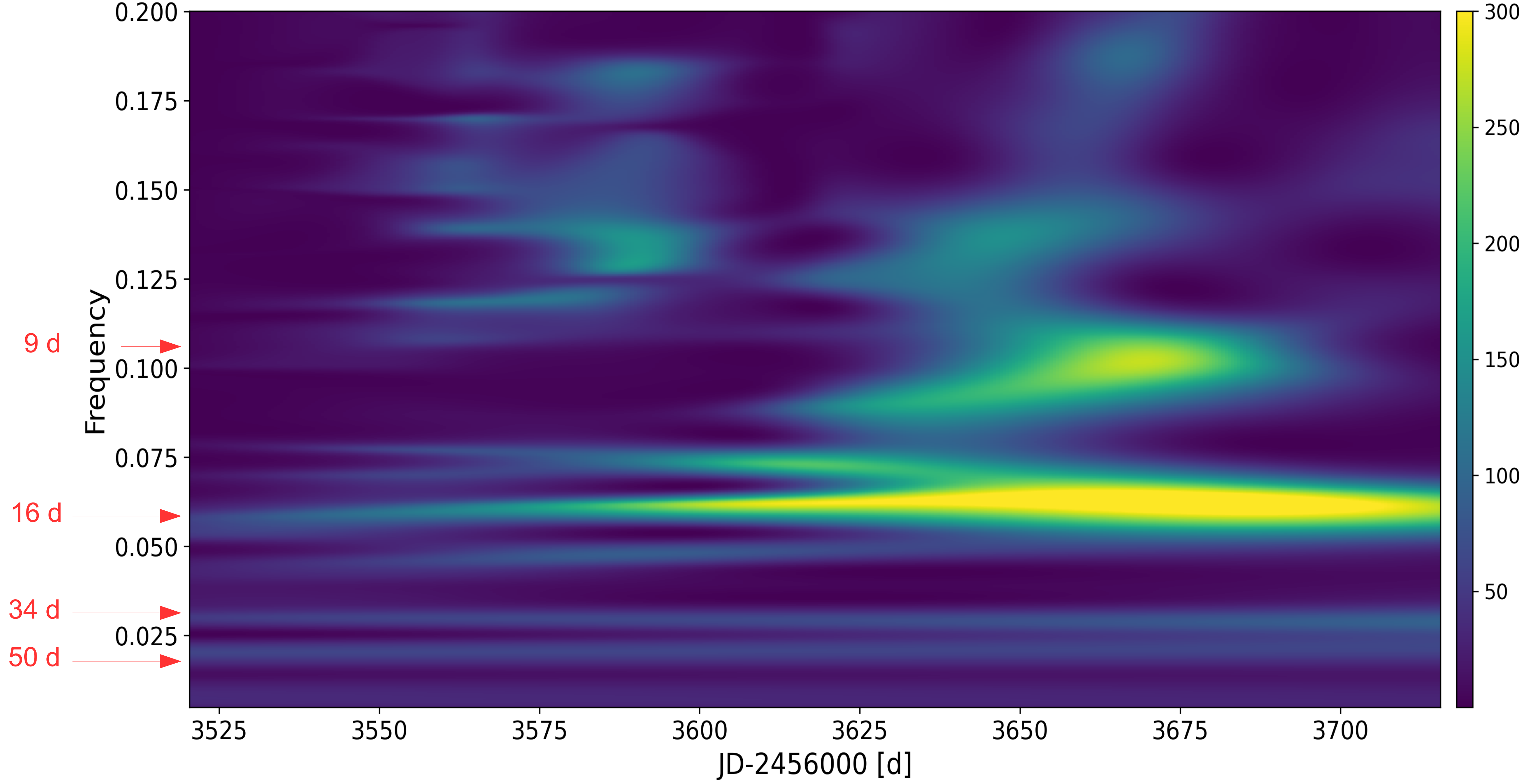
Weighted Wavelet Z-transform



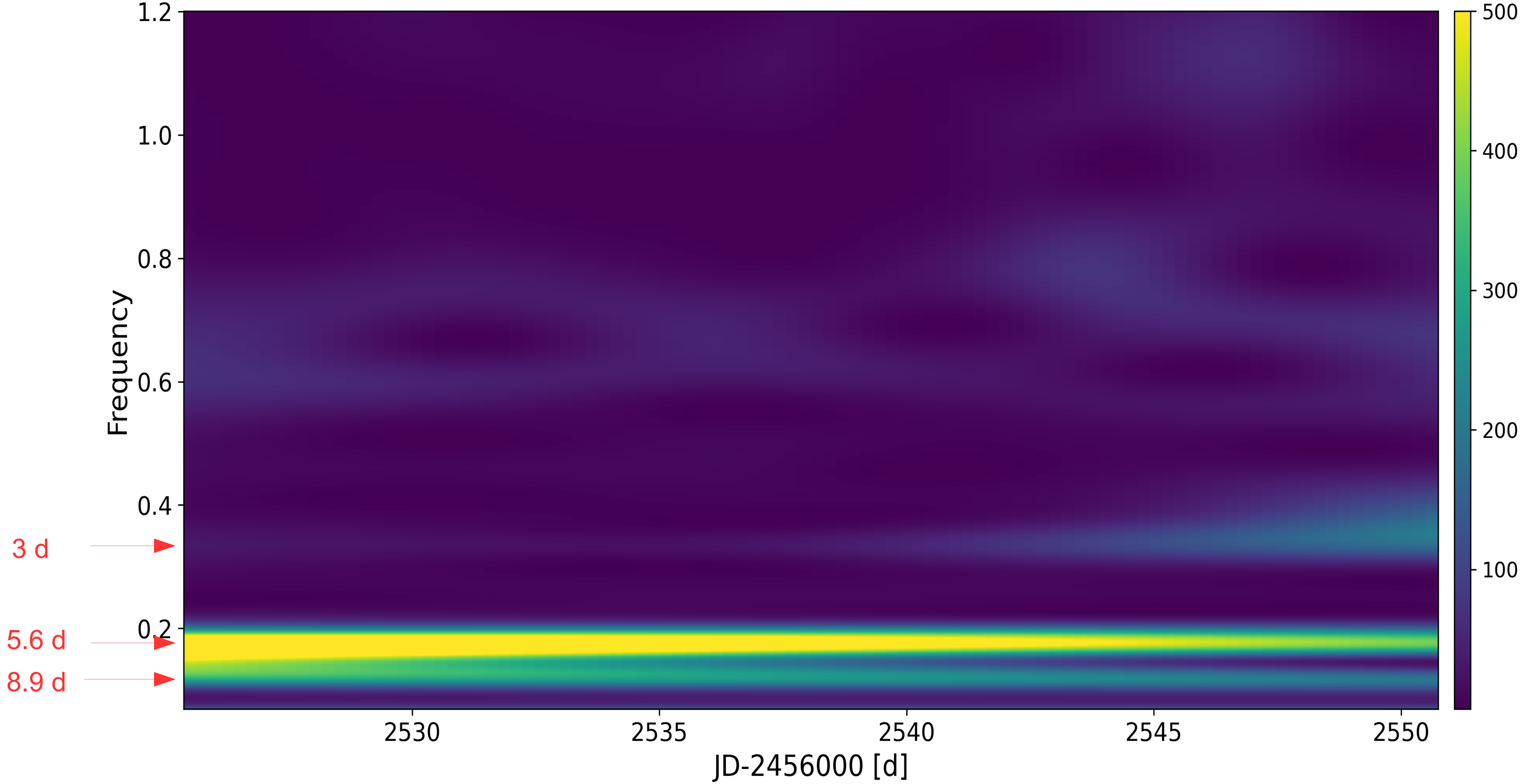
https://twitter.com/j_bertolotti/status/1224296204173021184

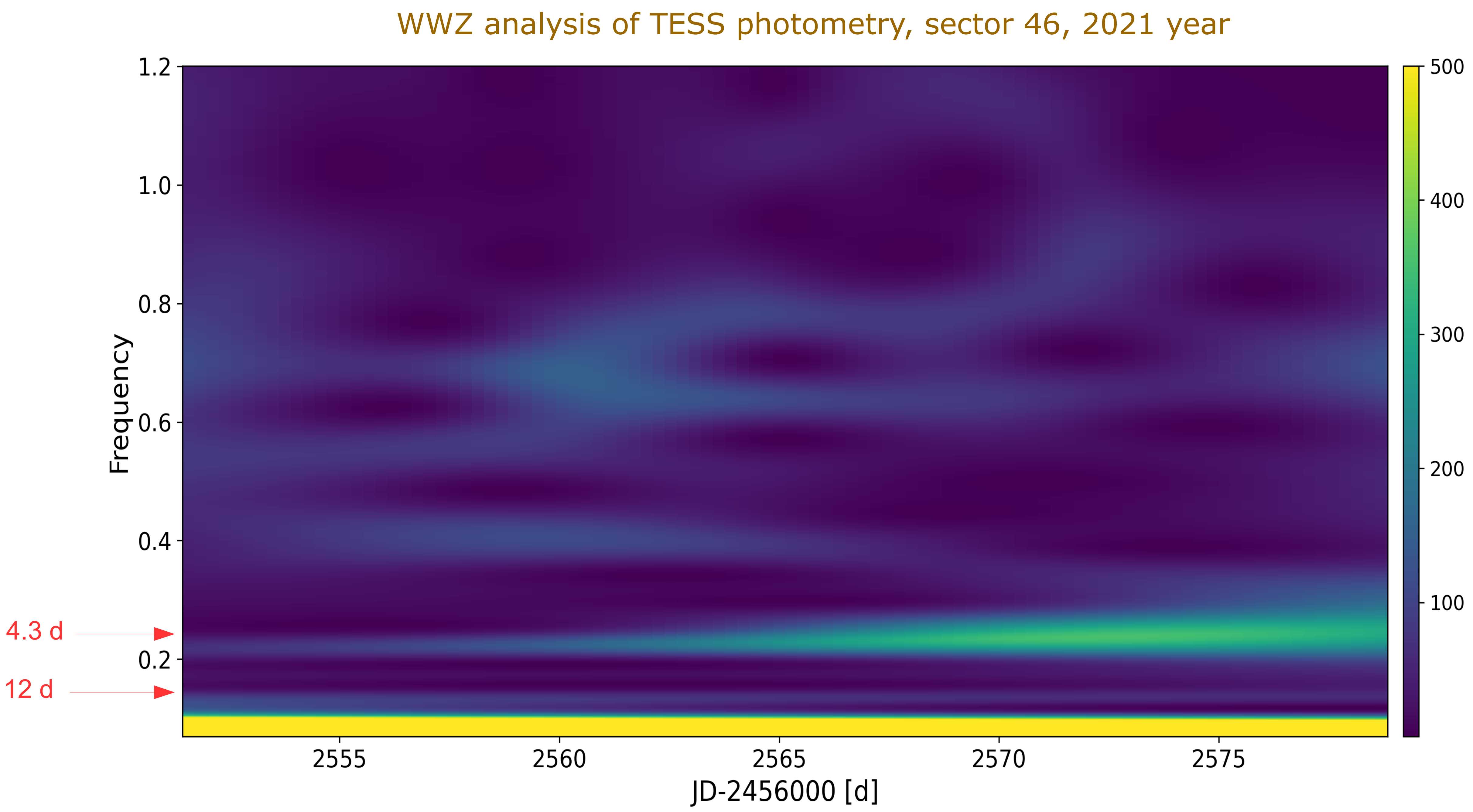
- The WWZ method is a time-frequency analysis method, exploring both the frequency domain and the time domain.
- Method produces output for a range of frequencies and time, plots the response as a function of two variables → 3D plot
- The WWZ performs a wavelet transform using a wavelet function, which includes both a periodic, sinusoidal test function and a Gaussian window function.

Weighted Wavelet Z-transform, spectra of season 2022



WWZ analysis of TESS photometry, sector 45, 2021 year





WWZ analysis of TESS photometry, sector 46, 2021 year
Frequency
1.2
1.0
0.8
0.6
0.4
0.2
4.3 d
12 d
2555
2560
2565
2570
2575
JD-2456000 [d]
500
400
300
200
100

Lomb-Scargle periodograms, spectra of season 2022

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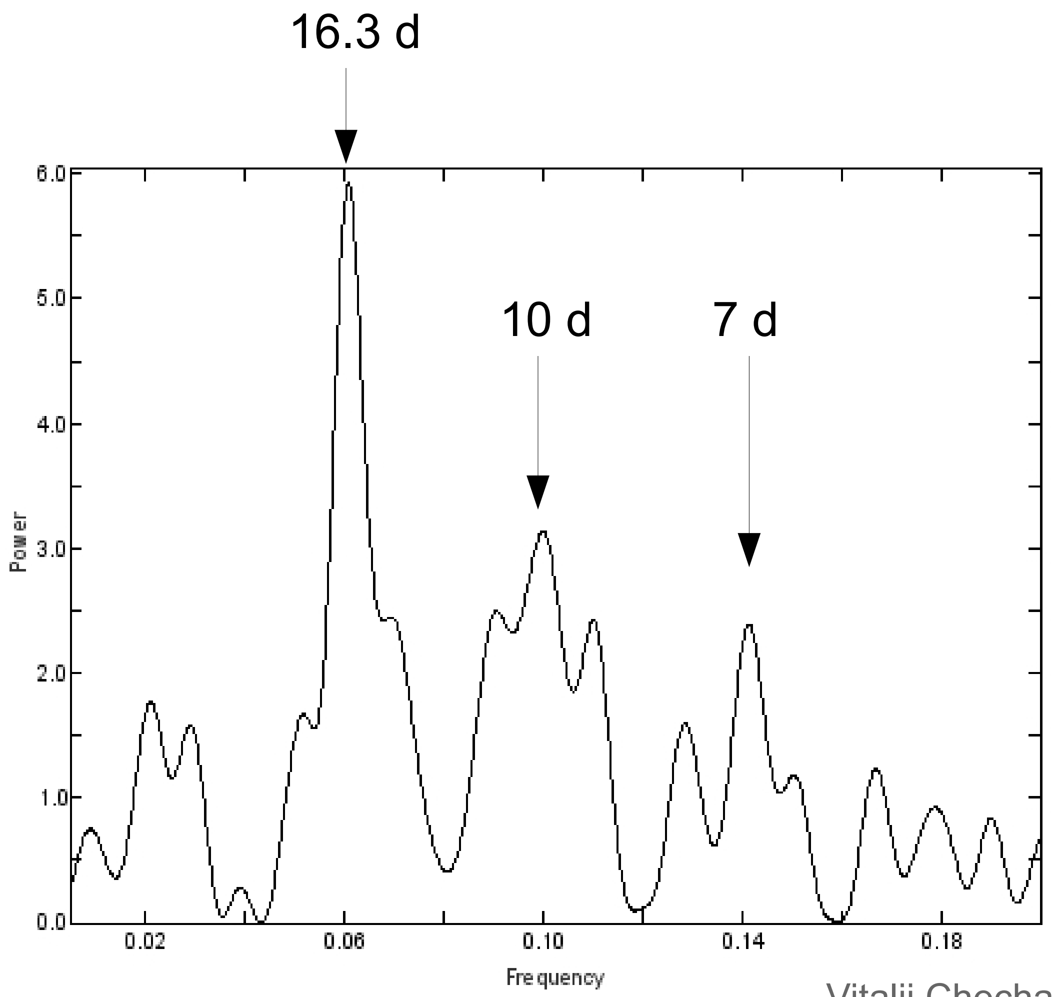
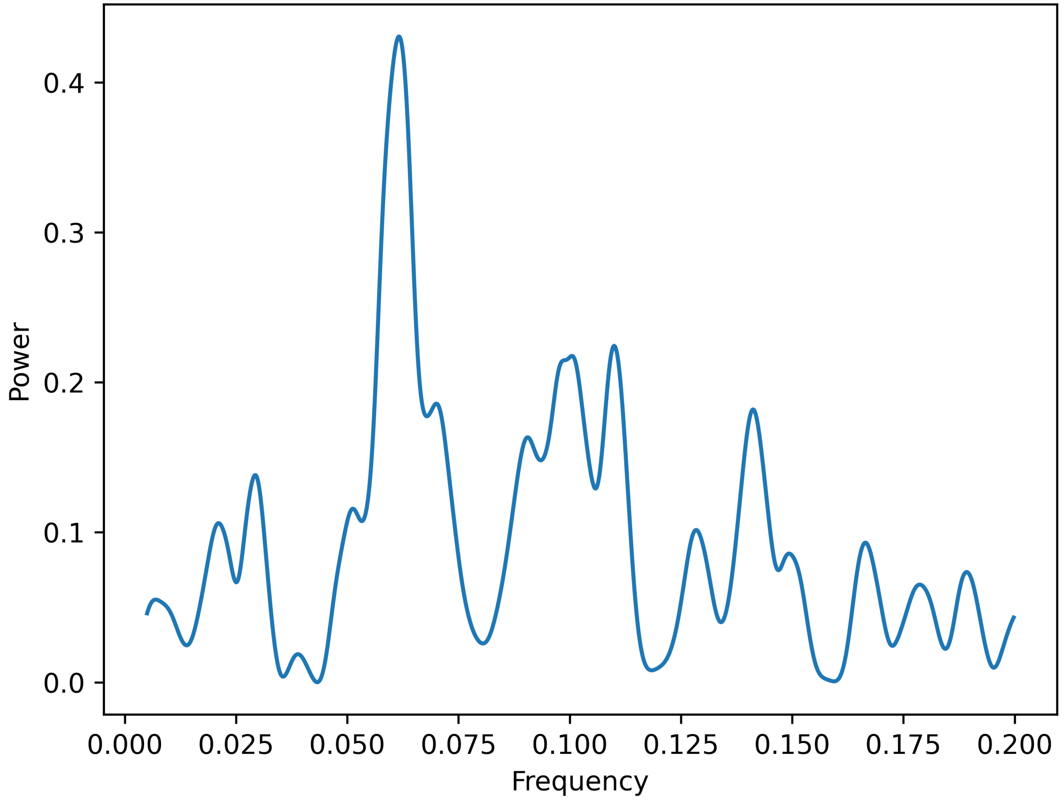
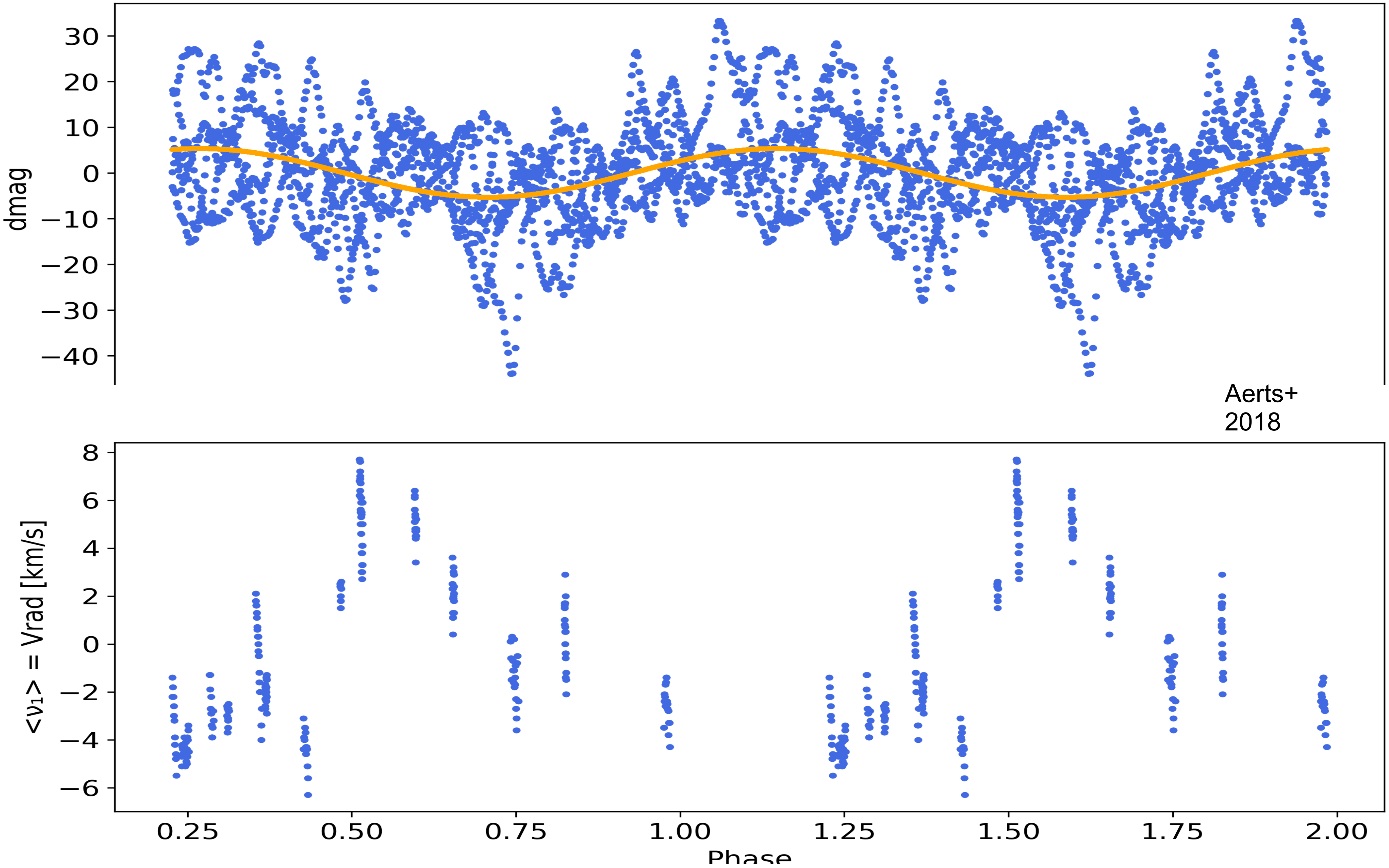
Whitened Lomb-Scargle (Period04)



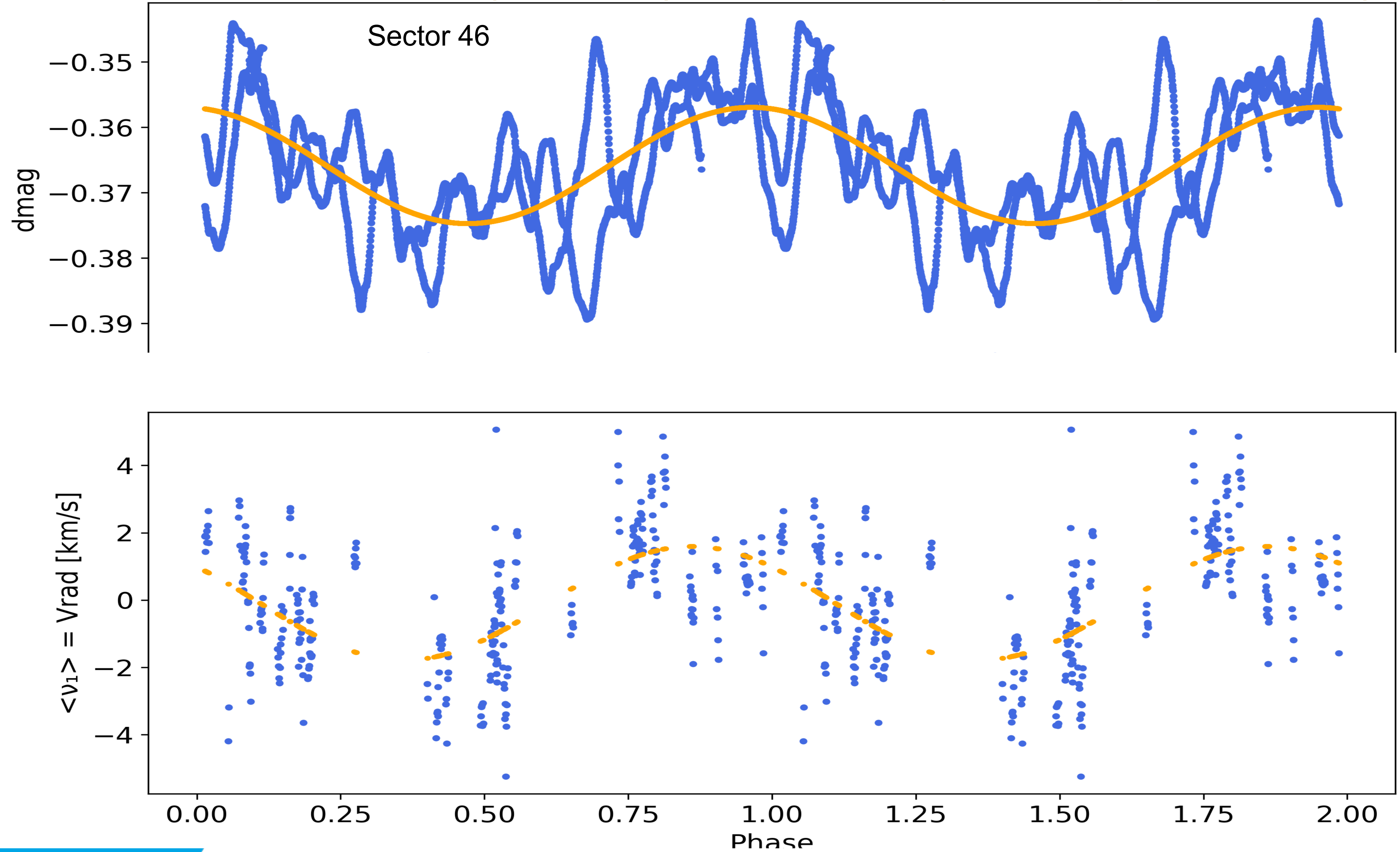
Generalized Lomb-Scargle (Python)



K2 photometry+season 2017 spectroscopy, period 17 days



TESS photometry+season 2021 spectroscopy, period 12 days



Results of frequency analysis

Freq.	Period, days	2017	K2	2019	2020	2021	TESS Sect 45	TESS Sect 46	2022	2023
f1	~17	17.5	16		17				16.2	
f2	~12	11.2	24.7		12.6			12	11.2	21
f3	~9						8.9		9	
f4	~7	6.6, 7	7.1							[illegible]
f5	~5.5		5.5				5.6		6	
f6	~4					4.5		4.3	4.7	[illegible]
f7	~3	2.8		3.3	3.4		3			[illegible]
f8	~1.5			2		1.4				
f9	~0.9	0.9		0.8	0.9	0.9			0.9	0.9

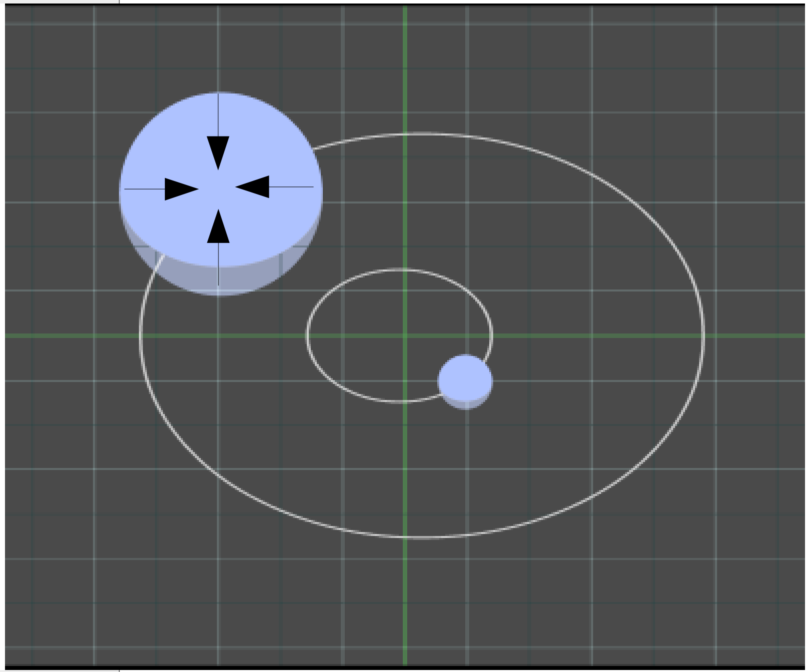
Combinations:

$f_1 + f_2 = f_4$

$f_6 + f_7 = f_8$

$f_2 – f_1$ = 50 days (from WWZ)

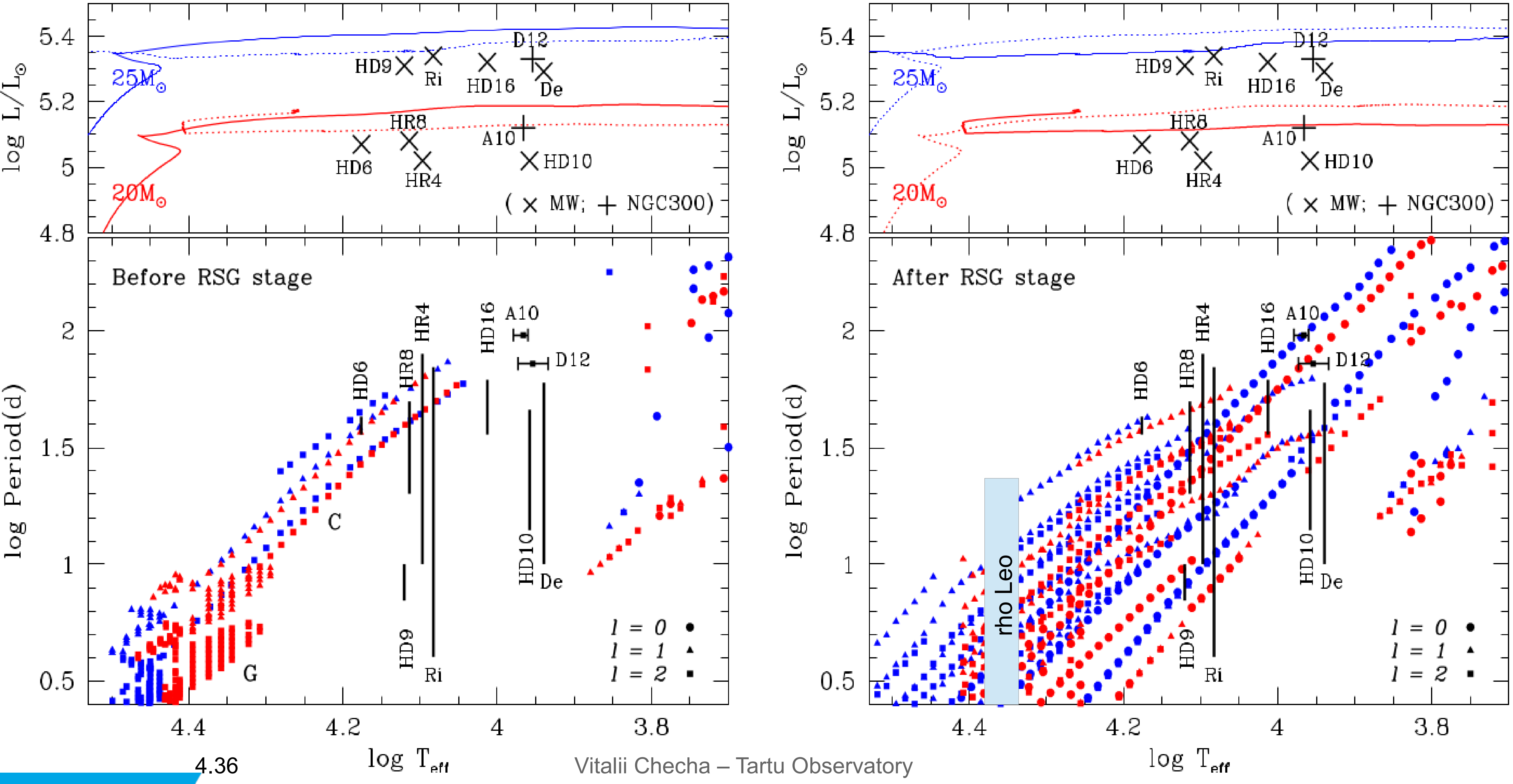
Shibahashi & Kurtz 2012



http://ccnmtl.github.io/astro-simulations/eclipsing-binary-simulator

Saio et al. 2013, MNRAS, 433, 1246

Pulsation period predictions for B supergiants



BSG monitoring list 2014 - 2024

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Object	m	spectral type
V1768 Cyg	5.66	B1
P Cyg	4.82	B1-2_Ia-0_ep
V2118 Cyg	7.12	B1.5Ia
Deneb	1.25	A2Iae
55 Cyg	4.86	B3Iae
HD 199478	5.73	B8Iae
HD 202850	4.26	B9Iab
HD 208501	5.81	B8Ib
V639 Cas	6.22	B2.9Iab
HD 2905	4.19	B1Iae
HD 12301	5.62	A0Ib
HD 13267	6.35	B5Ia
HD 13854	6.50	B1Iabe
HD 14134	6.54	B3Ia
HD 14143	6.65	B2Ia
HD 14818	6.27	B2Iae
HD 14956	7.24	B2Ia
HD 21389	4.54	A0Ia
Rigel	0.13	B8Iab
HD 37128	1.70	B0Iab
HD 38771	2.05	B0Iab
62Ori	4.65	B2I
PU Gem	5.75	B2.5Ib
HD 87737	3.51	A0Ib
ρLeo	**3.84**	**B1Iab**
HD 164353	3.97	B5Ib

POEMS

Conclusions

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1. Combination of different frequency analysis methods is necessary for investigation of quasi-periodic variability of BSGs.

2. Certain periods almost always exist, while others appear and disappear.

3. We suggest that the detected period of **12** days is the binary orbital period, while period the **17** days is due to radial pulsations.

4. Set of periods (quasi-periods) and their harmonics obtained from analysis of rho Leo spectral time series indicates that the star is on the blue loop of evolution, after the Red Supergiant stage.

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

6. It would be interesting to explore the circumstellar environments - for the presence of remnants of the slow and dusty winds on RSG stage.

References

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Berlanas et al. 2018, A&A, 612, A50

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Morel et al., 2004, MNRAS 351, 552

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Wilson R.H., 1941, Publications of the University of Pennsylvania, Astronomical series vol.V, part IV