Characterization of the Variability of the B-Supergiant HD 14134

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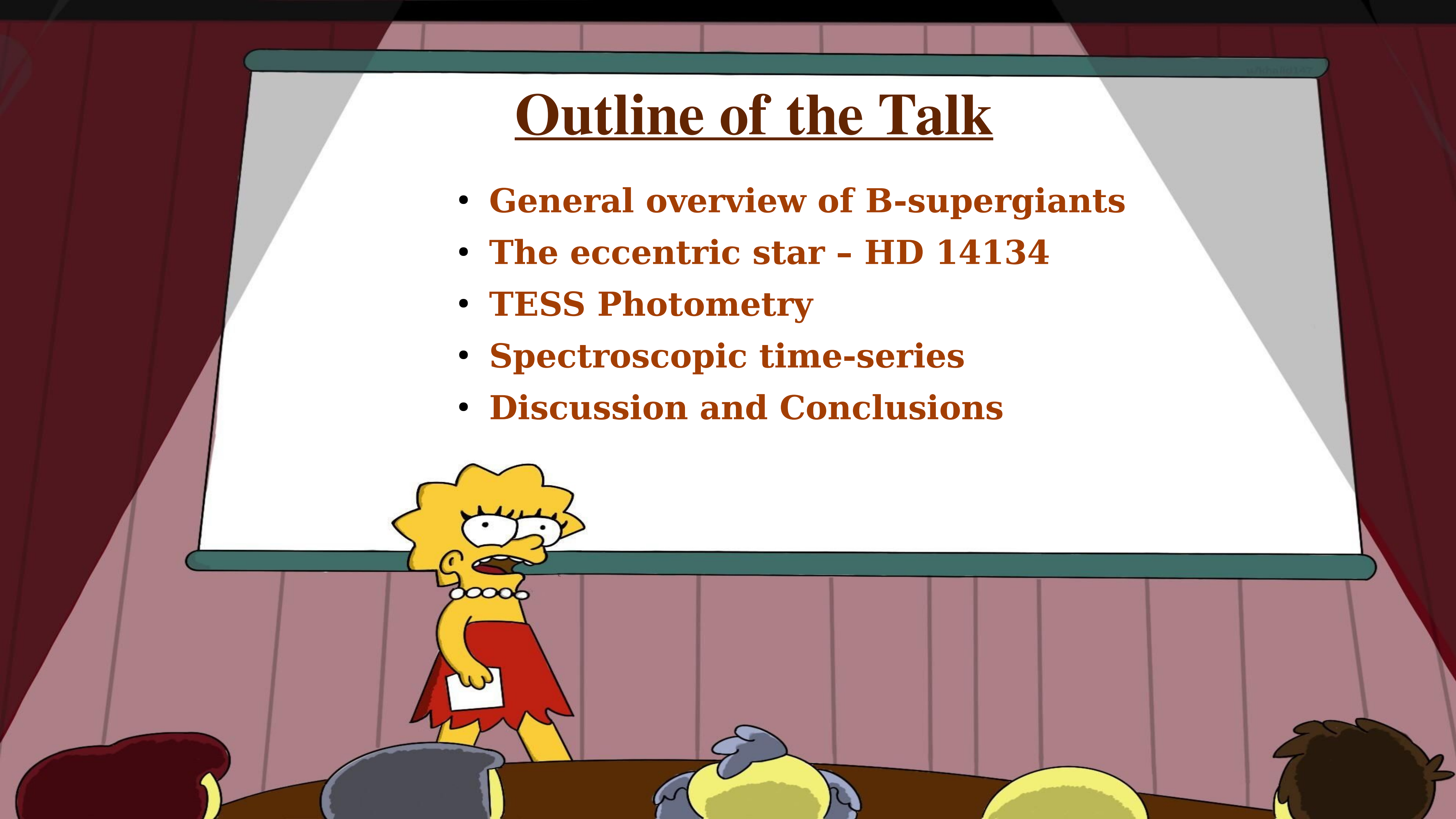
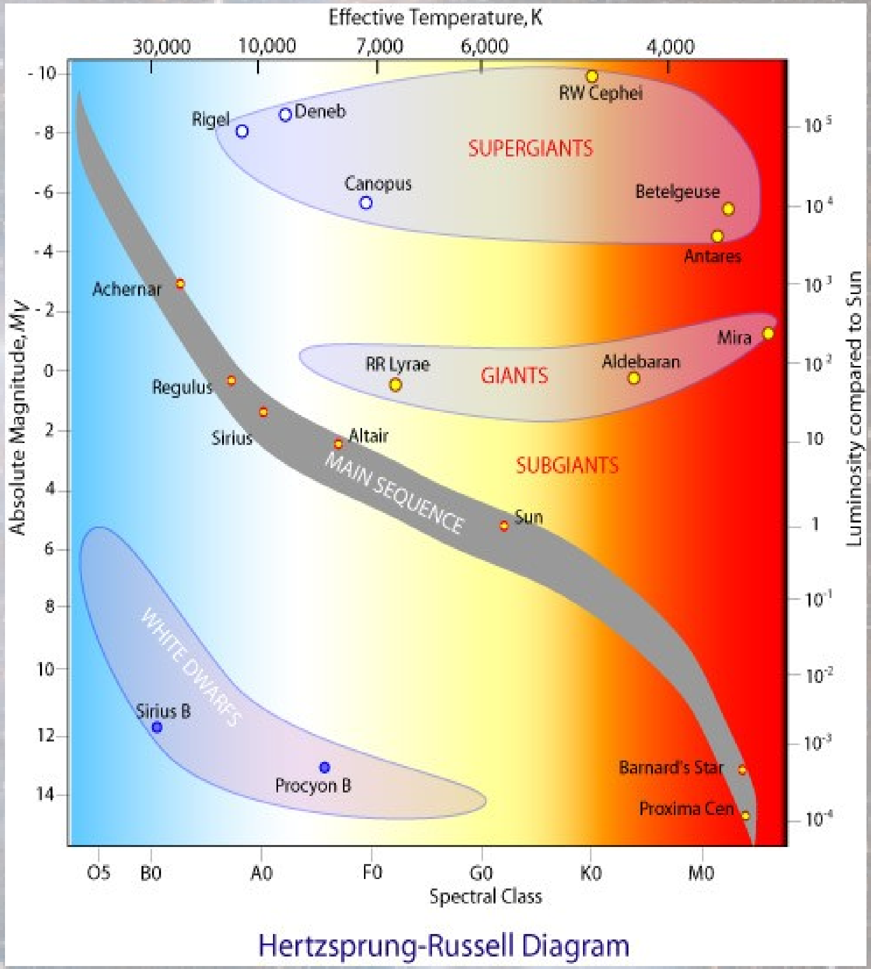

Outline of the Talk
General overview of B-supergiants
The eccentric star – HD 14134
TESS Photometry
Spectroscopic time-series
Discussion and Conclusions

General overview of B-supergiants

- This class of massive stars belongs to the spectral type- B and luminosity class – Ia or Ib.

- In general, supergiant stars occupy the top region of the Hertzsprung–Russell diagram but only B-supergiants occupy the region where the effective temperature ranges from 10,000K to 25,000K.



The eccentric star - HD 14134

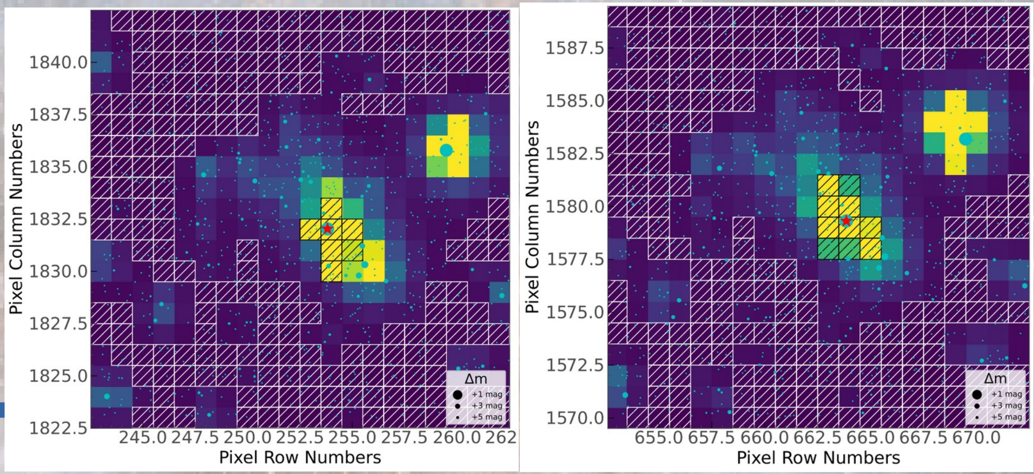
- V520 Persei or HD 14134 is a blue supergiant member of NGC 869, one of the Perseus Double Clusters (Merrill & Burwell 1933).
- **V:** 6.5678 mag
- **Spectral type:** B3Ia, its spectral appearance in the optical blue region (Lennon et al. 1992) .
- HD 14134 is also known for its variability:
  (i) in radial velocity measured in various photospheric lines (Kontizas & Kontizas 1981),

  (ii) in photometry (Adelman et al. 2000; Koen & Eyer 2002; Lefèvre et al. 2009; Laur et al. 2017),

(iii) its Hα line which displays a diversity of profile shapes such as P Cygni, inverse P Cygni, pure emission, pure absorption and complete absence of the profile, i.e. compensation of absorption with emission (Morel et al. 2004; Maharramov & Jahangirova 2017; Maharramov 2017).

Photometric data

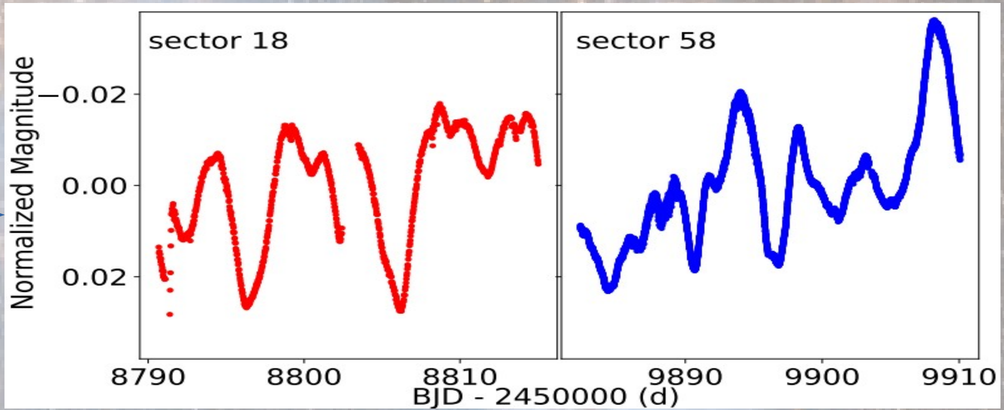
TESS light curves have been extracted for the two sectors (Sector 18 and 58) available. Apertures were chosen such that contamination from nearby sources is excluded.



TPF

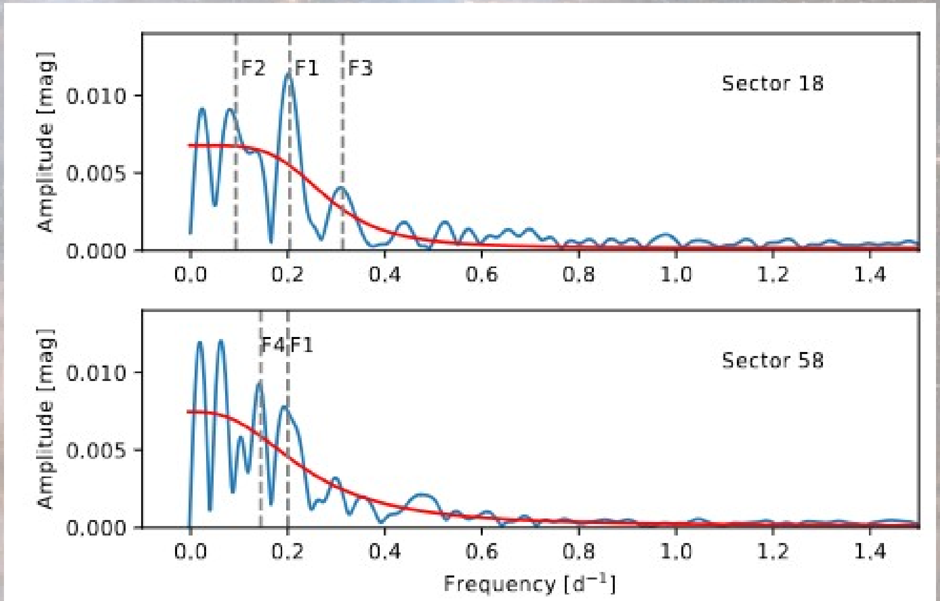
TESS 'Lightkurve' package

Final product

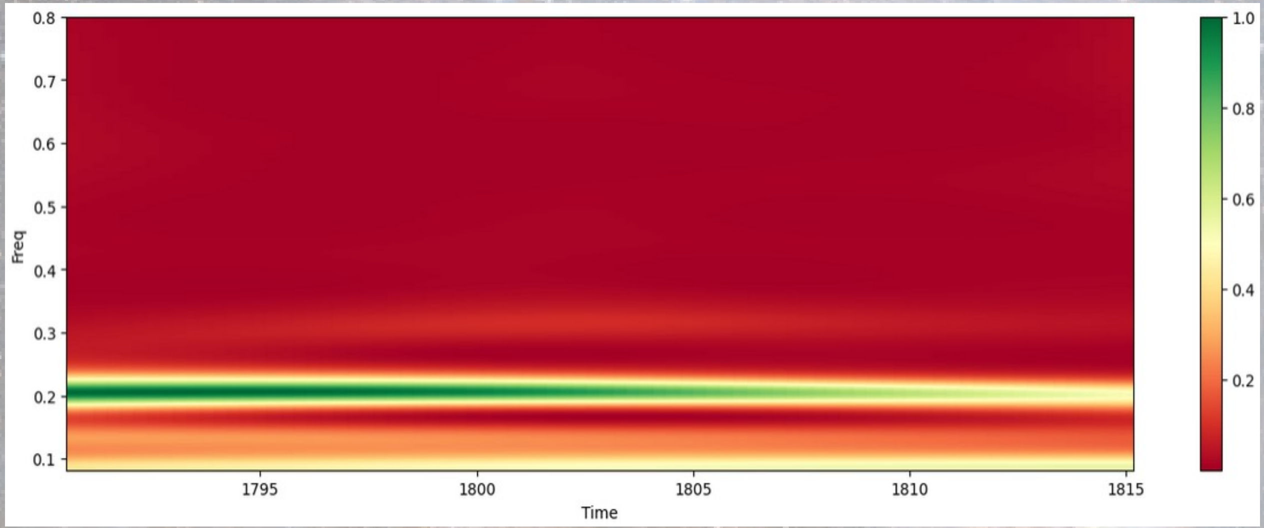


Analysis of Photometric light curves

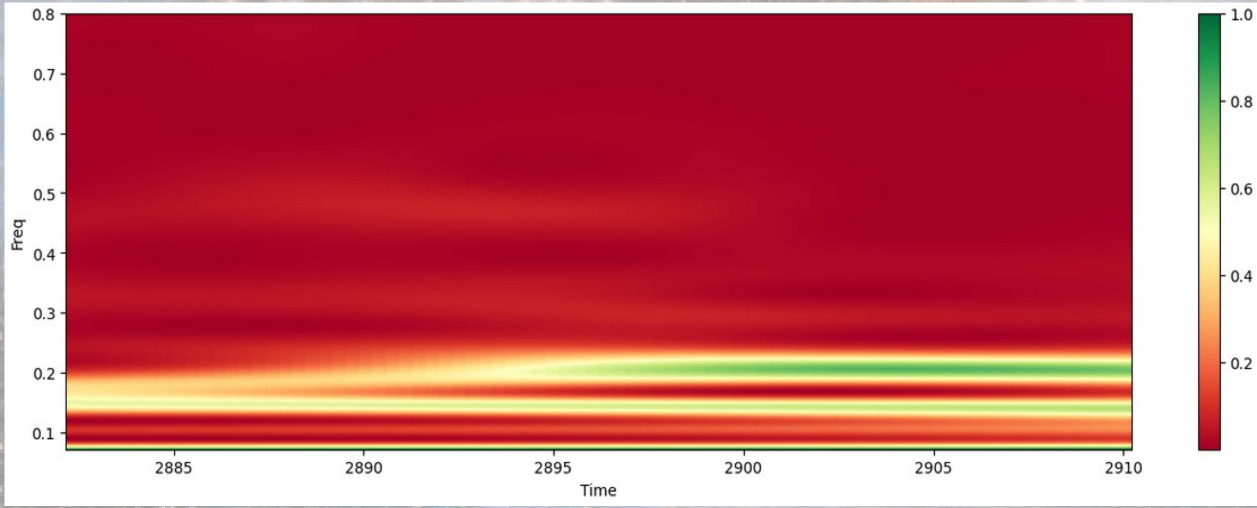
IDs	Frequency [d^{-1}]	Amplitude [mmag]	SNR
Sector 18			
F1	0.2042	12.311	8.50
F2	0.0927	10.155	6.47
F3	0.3129	3.757	2.89
Sector 58			
F4	0.1443	9.175	4.28
F1	0.2000	8.143	4.07



- The dominant frequency F1 is changing its amplitude from one sector to another.
- Although the SNR of F3 is quite low but if we include them in our list then we notice, $F1$-$F2 \approx F3$-$F1$.
- The other harmonics we found are, $F1 \sim 2F2$, F3~ $3F2$
- Furthermore from **Saio et al. (2013)** if the star (with initial mass between 20-25⊙) has effective temperature between ~10000-25000K it is possible to find radial pulsation modes with periods between 3.16-63.09 days. Thus, the period that our photometric study shows (5 days), may represent a radial mode of pulsation.



Sector - 18



Sector - 58

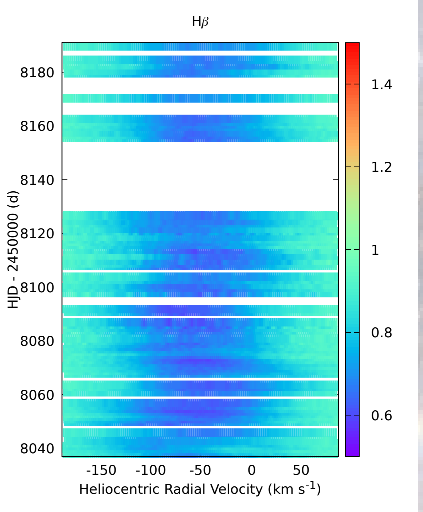
Scalograms to study the change in frequency and amplitude over Time :

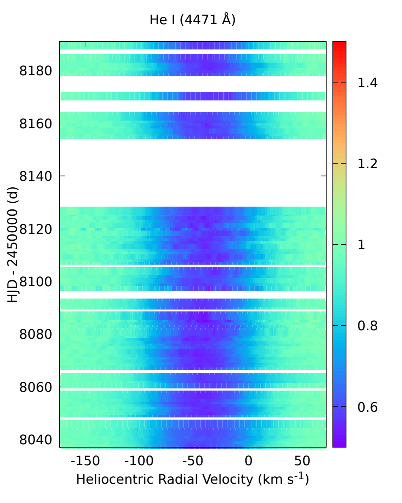
Fourier analysis demonstrates that the primary frequency F1 in sector 18 appears with lower amplitude than F4 suggesting a transient nature of this frequency. To verify this, we performed wavelet analysis on the light curves of both sectors. Periods across time can be studied with the use of the Weighted Wavelet Z-Transform (WWZ).

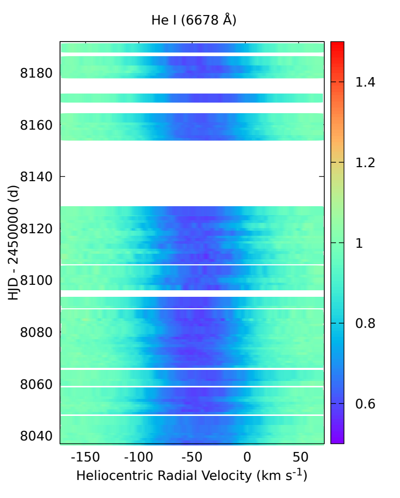
Foster et. al. (1996)

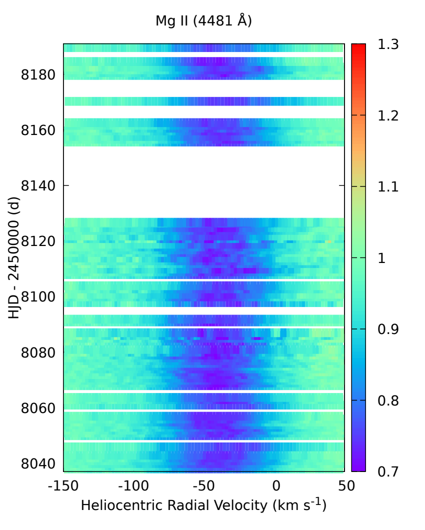
Spectroscopic time series

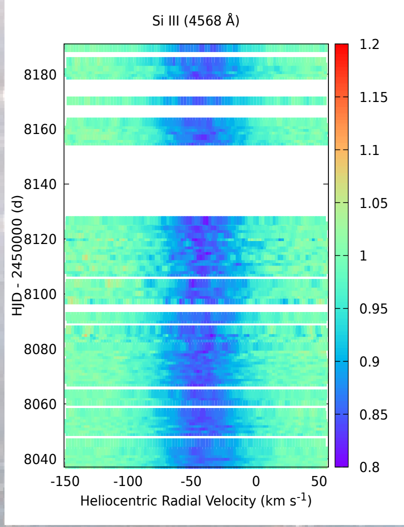
- 73 high-resolution spectra (R = 40000, a wavelength coverage from 3900 - 7100 Å) were collected with the Poznan Spectroscopic Telescope at the Winer Observatory in Arizona for HD 14134 between October 2017 and March 2018 with signal-to-noise ratios between 30 to 110.
- Dynamic plots for the lines Hβ, He I, Si II, Si III and Mg II. The color code represents the flux normalized to the continuum value.
- Profile changes in width, depth, and radial velocity have been detected.
- No periodic variability.

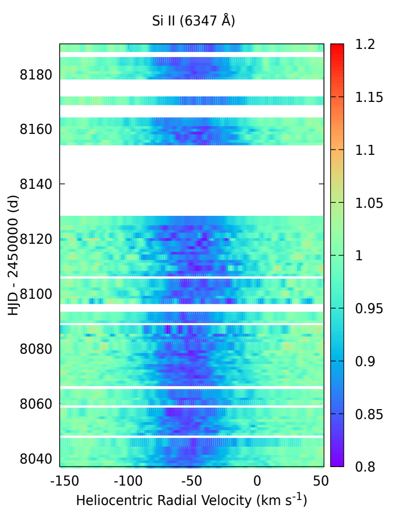








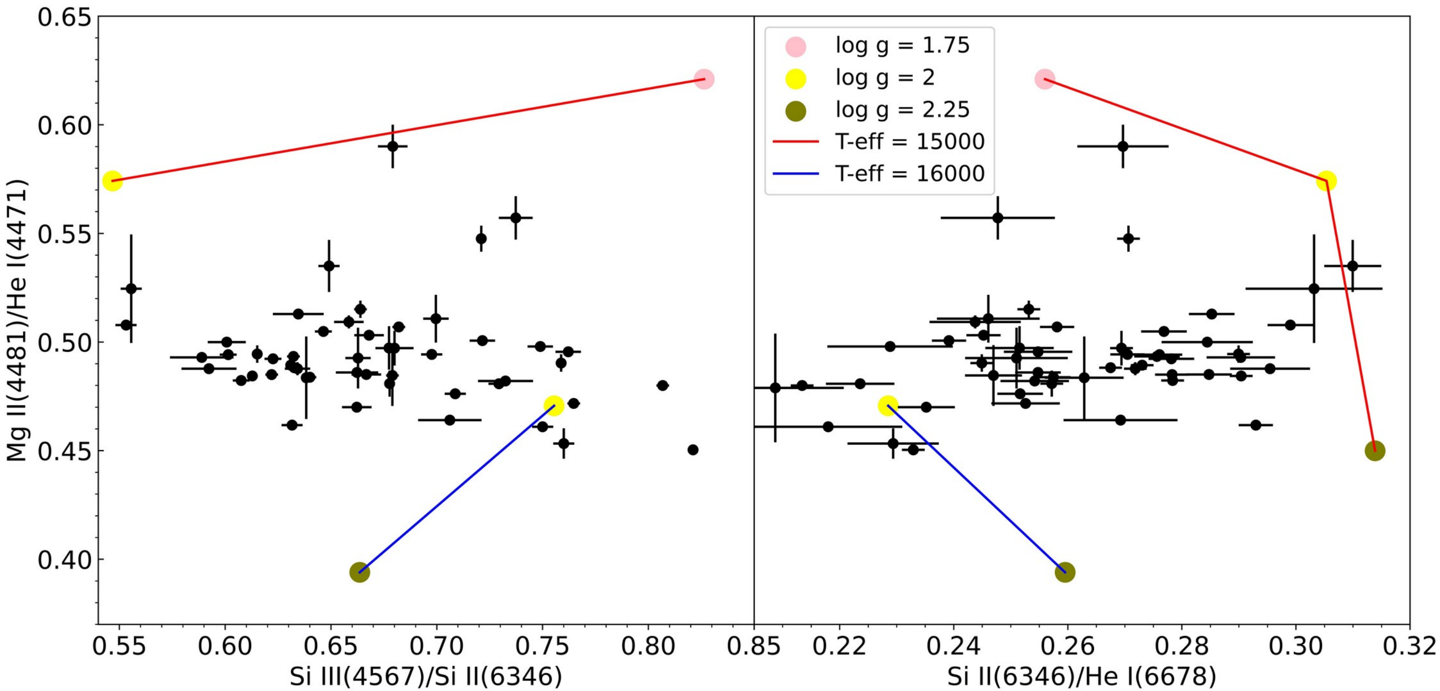




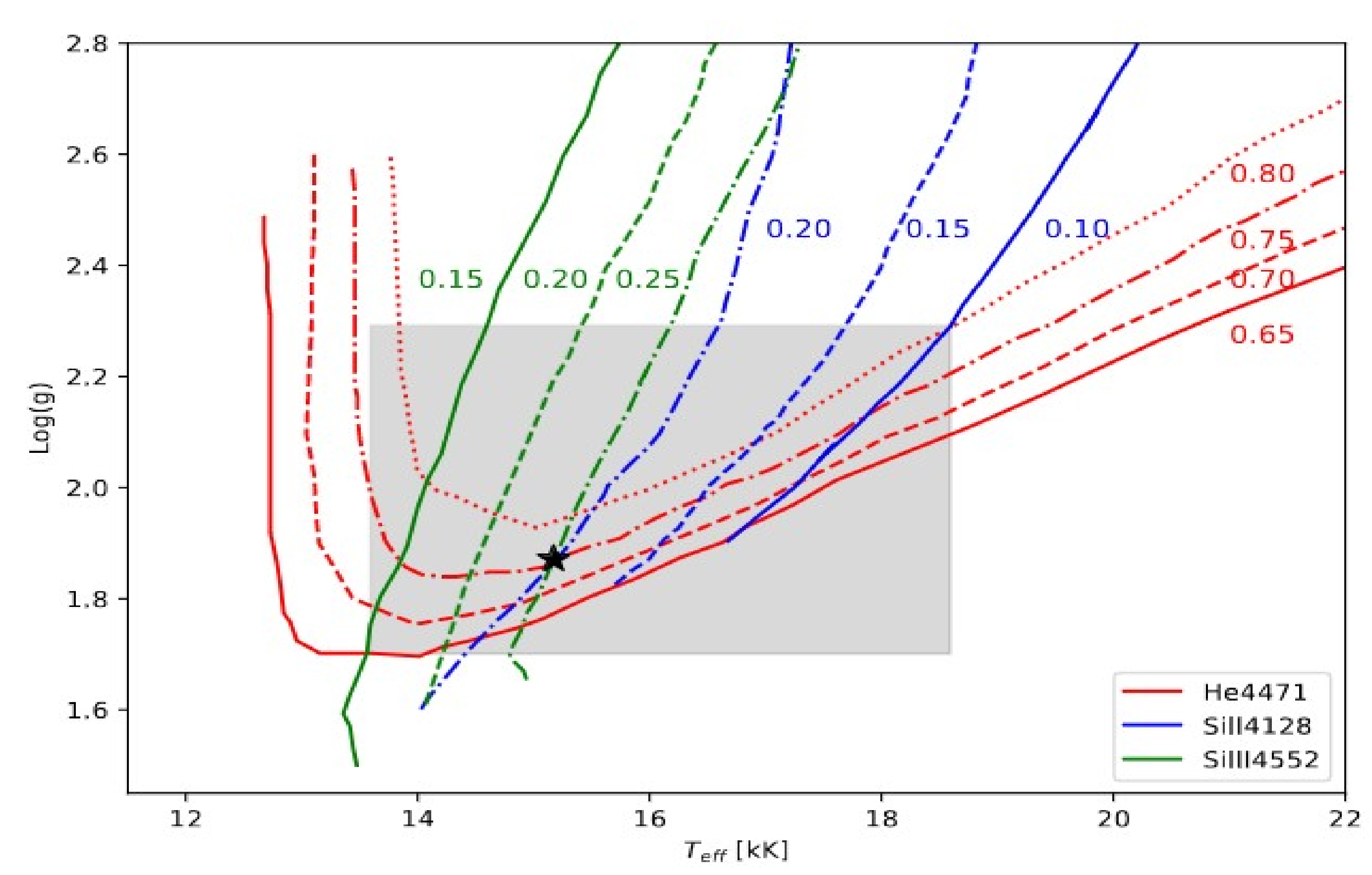
Comparison of EW measurements with predictions from TLUSTY-SynSpec

- We measured equivalent width (EW) ratio of temperature sensitive photospheric lines.

- The observed values spread between the theoretical lines of constant effective temperature with lower and upper limits of 15000K (red) and 16000K (blue), respectively, and between the values of log $g = 2$ and 2.25 dex. This range in values of log g agrees with previous works **(Kudritzki et al. 1999; Crowther et al. 2006).**



- The errorbars of the individual EW ratios are considerably lower than the spread of the data points, suggesting real temperature variations as expected from (radial) pulsation activity.



- Comparison of averaged EWs of several photospheric lines with predictions from FASTWIND models computed by Lefèvre et al. (2009).
- We have a common convergence at T_{eff} = 15180 K and log g = 1.87, denoting the most likely equilibrium state of the star.

Moment Analysis and confirmation of the trace of pulsation

$$\langle v^j \rangle_{f*g} \equiv \frac{\int_{-\infty}^{+\infty} v^j p_{\mathrm{theo}}(v)\,\mathrm{d}v}{\int_{-\infty}^{+\infty} p_{\mathrm{theo}}(v)\,\mathrm{d}v} = \frac{\int_{-\infty}^{+\infty} v^j (f*g)(v)\,\mathrm{d}v}{\int_{-\infty}^{+\infty} (f*g)(v)\,\mathrm{d}v}$$

Aerts et al. (1992), Aerts (1996)

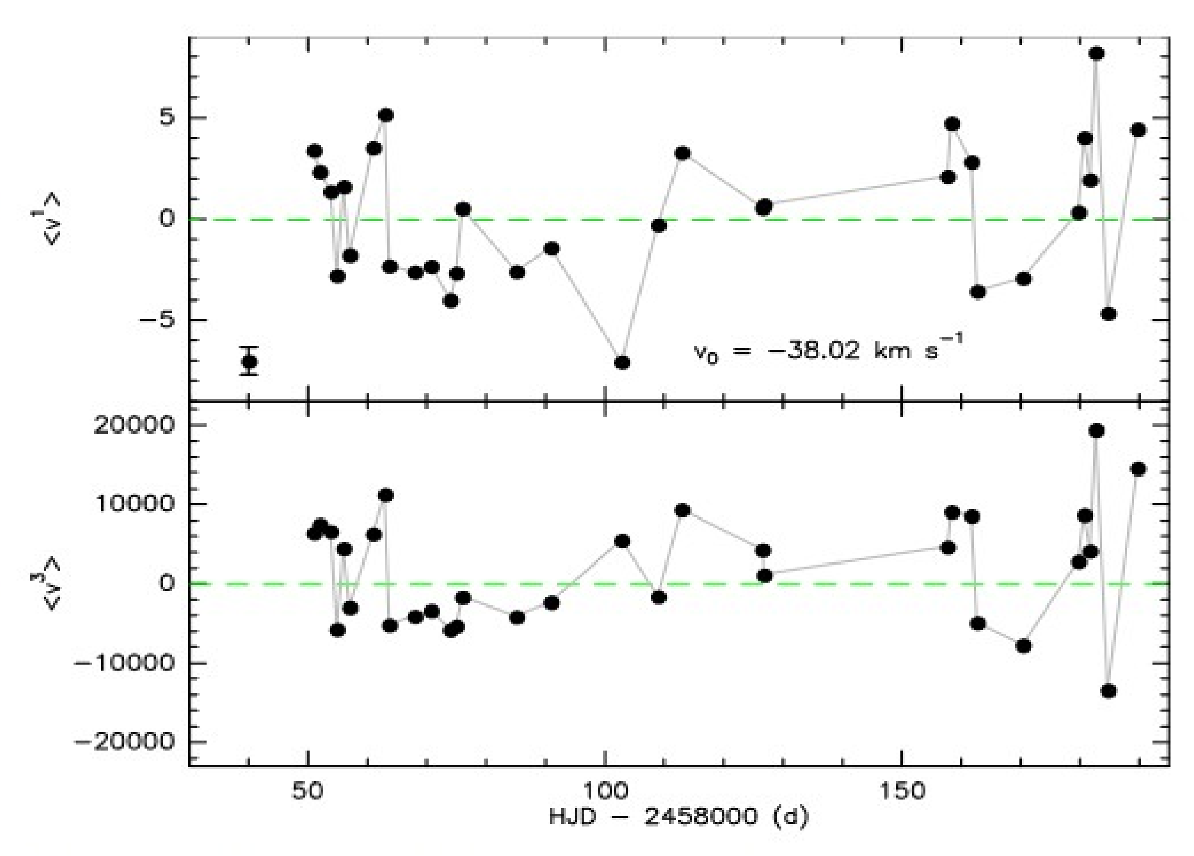
first three velocity moments are connected to the specific property of the line profile:

i) the first moment <v^1> is the centroid of the line profile in a reference frame with origin at the stellar centre;

ii) the second moment <v^2> is a measure of the width of the line profile;

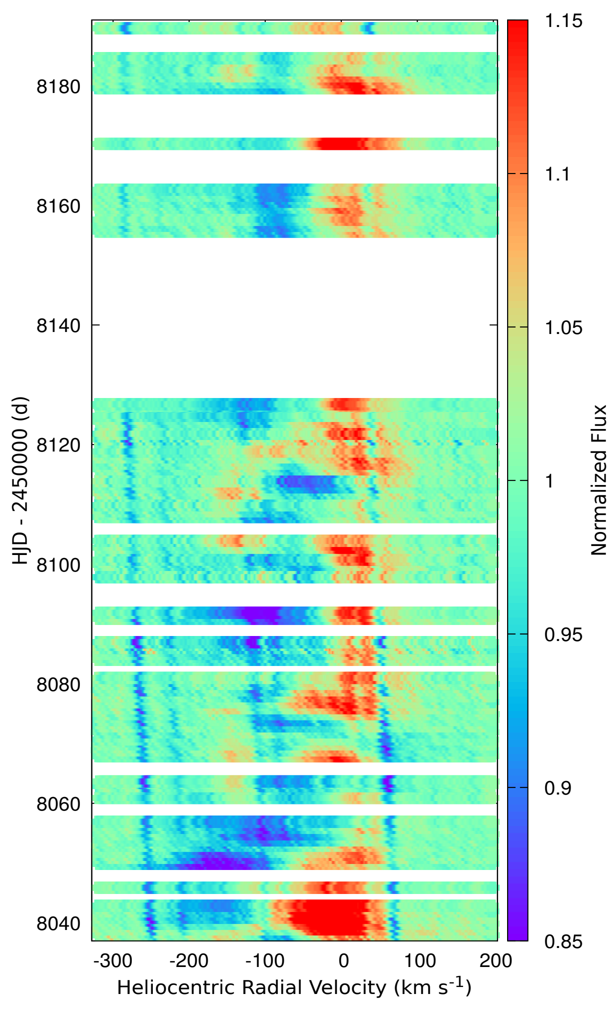
iii) the third moment <v^3> is a measure of the skewness of the line profile

Analysis of the Si III line shows that the first and third moment vary in phase, which is a strong indication for pulsations as cause of the line-profile variability.



First (top panel) and third velocity moments (bottom panel) of the Si III λ4568 line profile. v_0 denotes the systemic velocity of the star.

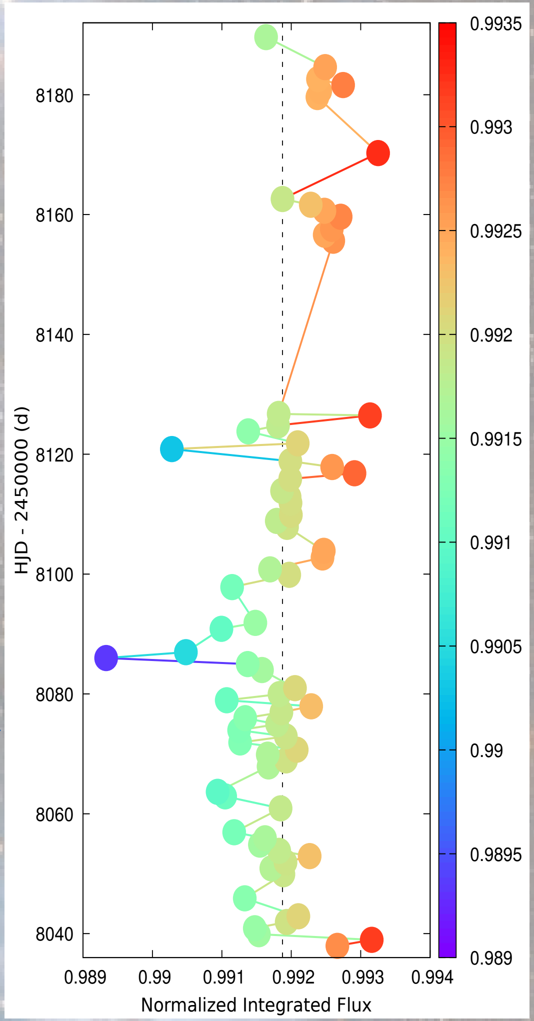
Hα and its imprints



- The temporal evolution of the Hα profile. The color coding is such that yellow-red marks emission and blue marks absorption.
- The variation in Hα profile depicts the strong wind variation and variable mass-loss rate

- The impact of wind variability on normalized broad-band flux, integrated between 4500 Å and 6850 Å

$$F[\lambda_1,\lambda_2]=\frac{\int_{\lambda_1}^{\lambda_2} F_\lambda \, d\lambda}{\int_{\lambda_1}^{\lambda_2} d\lambda}$$



Discussion and Conclusion

- Variability has been detected in both spectroscopic and photometric time-series of HD 14134. The main frequency derived from the TESS light curves displays significant amplitude variations over time.
- Our detected 5-day period contradicts the findings of **Morel et al. (2004)**, who proposed a periodicity of 12.8 days. Our spectroscopic data did not reveal any clear periodicity.
- The Fourier analysis of TESS light curves of massive stars is usually hampered by the presence of red noise contaminating especially the low-frequency domain of the amplitude spectrum.
- While the physical mechanism behind the red noise is not yet unambiguously identified, we wish to raise awareness that wind variability, imprinting its footprint onto photometric signals, likely contributes to it.