

Ups...! We did it again...

New observational evidence for HVA events

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Introduction

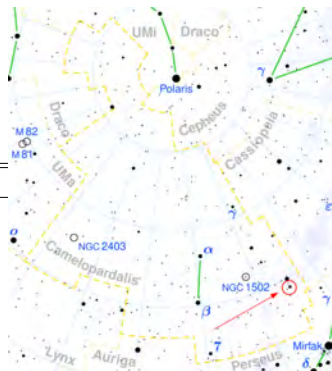
- variability of $H\alpha$ line of late B– and early A–type supergiants
- what is HVA?
- hypothesis that may explain the source of HVA and why do we observe only 8 early type supergiants showing those extraordinary events
- new observational evidence of HVA

HD 21389

Physical Characteristics

- A0 type supergiant star
- member of Cam OB1 association
- belongs to α Cyg variables
 - ▶ low amplitude variability in brightness and radial velocities

Parameters	Values	References
$M [M_{\odot}]$	19.3	Verdugo et al. 1999b
M_V [mag]	-7.56	
T_{eff} [K]	9730	Verdugo et al. 1999b
$R [R_{\odot}]$	97	Verdugo et al. 1999b
$\log L/L_{\odot}$	4.87	de Jager et al. 1988
$\log g$ [cgs]	1.7	Takeda 2000
v_{∞} [km \cdot s $^{-1}$]	218	Talavera & Gómez de Castro 1987
\dot{M} [$M_{\odot} \cdot$ yr $^{-1}$]	$-4.2 \cdot 10^{-7}$	Barlow and Cohen 1977



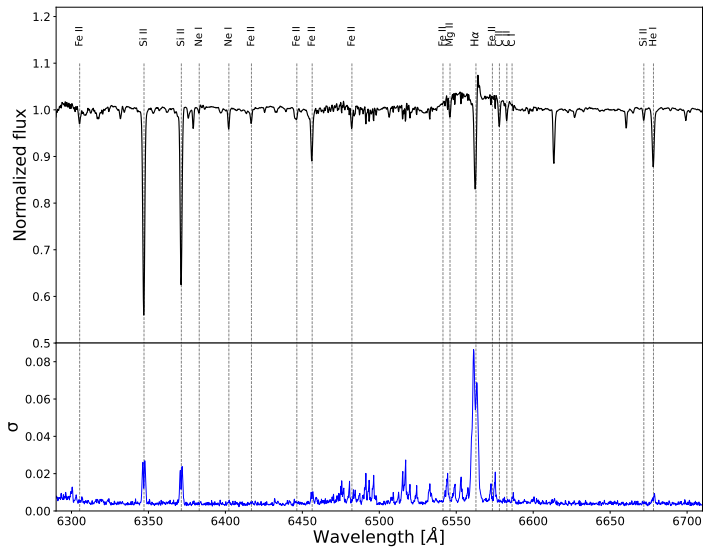
HD 21389

Previous Observation

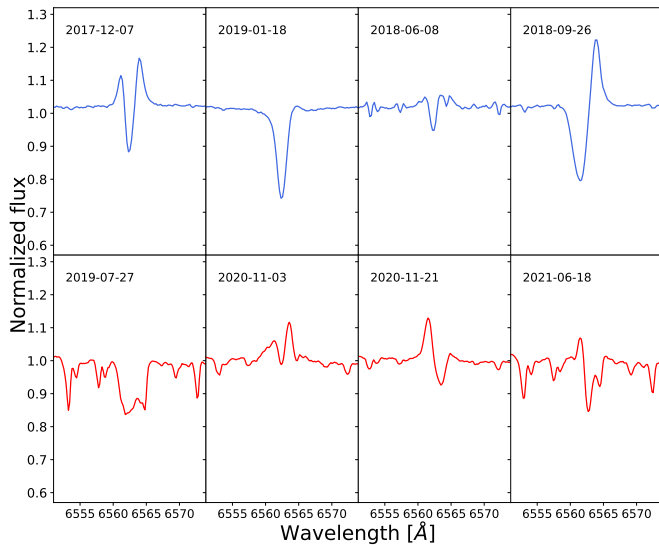
- suspected as a spectroscopic binary (Campbell et al. 1911)
- presents variability in Balmer lines (strongest in $H\alpha$)
 - ▶ and in other metallic lines (both in lines' profile and radial velocities)
 - associated with its active and quiescent phases
- member of rare group showing High Velocity Absorption events (HVA)



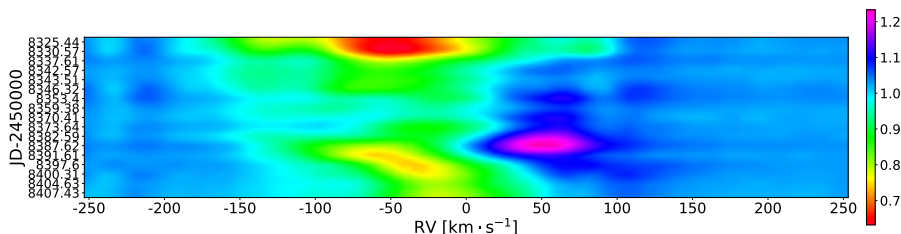
Temporal Variance Spectrum (TVS)



H α line

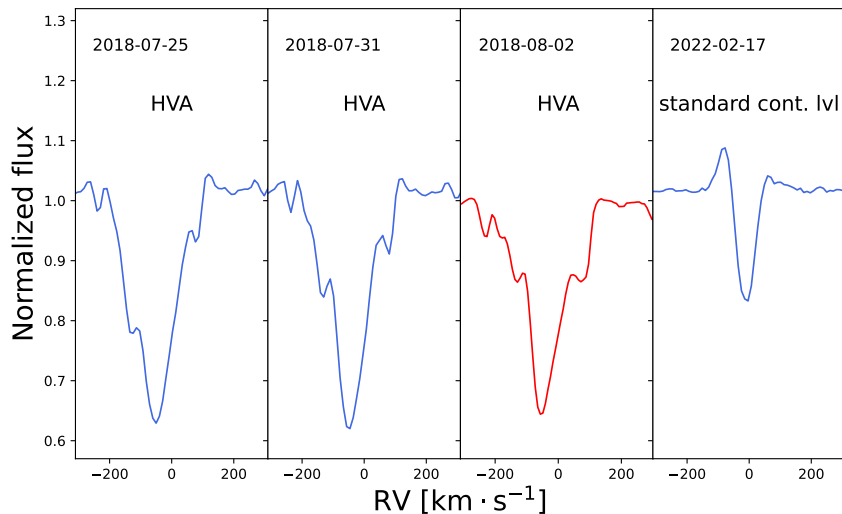


H α line – HVA event

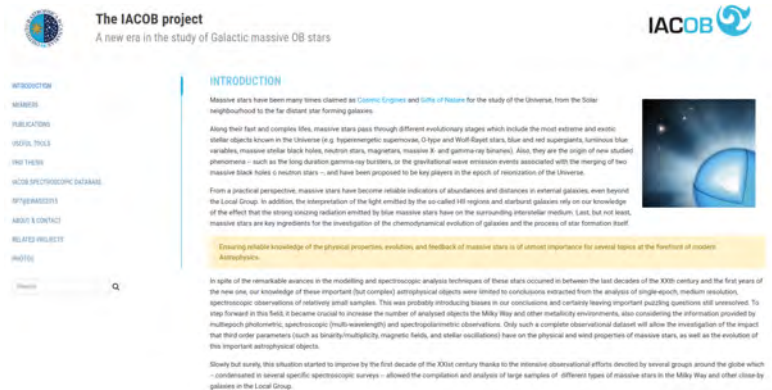


Dynamic spectrum intercepting final phase of HVA that HD 21389 underwent in July 2018. Color scale represents the flux. The reddest part corresponds to HVA event.

H α line – HVA event



Lines' profile appearance during HVA event.



The IACOB project
A new era in the study of Galactic massive OB stars

INTRODUCTION

Massive stars have been many times claimed as *Cosmic Engines* and *Gifts of Nature* for the study of the Universe, from the Solar neighbourhood to the far distant star forming galaxies.

Along their fast and complex lives, massive stars pass through different evolutionary stages which include the most extreme and exotic stellar objects known in the Universe (e.g. hyperenergetic supernovae, O-type and Wolf-Rayet stars, blue and red supergiants, luminous blue variables, massive stellar black holes, neutron stars, magnetars, massive X- and gamma-ray binaries). Also, they are the origin of new studied phenomena – such as the long duration gamma-ray bursts, or the gravitational wave emission events associated with the merging of two massive black holes or neutron stars – and have been proposed to be key players in the epoch of reionization of the Universe.

From a practical perspective, massive stars have become reliable indicators of abundances and distances in external galaxies, even beyond the Local Group. In addition, the interpretation of the light emitted by the so-called HII regions and starburst galaxies rely on our knowledge of the effect that the strong ionizing radiation emitted by blue massive stars have on the surrounding interstellar medium. Last, but not least, massive stars are key ingredients for the investigation of the chemodynamical evolution of galaxies and the process of star formation itself.

Ensuring reliable knowledge of the physical properties, evolution, and feedback of massive stars is of utmost importance for several topics at the forefront of modern astrophysics.

In spite of the remarkable advances in the modelling and spectroscopic analysis techniques of these stars occurred in between the last decades of the XXth century and the first years of the new one, our knowledge of these important (but complex) astrophysical objects were limited to conclusions extracted from the analysis of single-epoch, medium resolution, spectroscopic observations of relatively small samples. This was probably introducing biases in our conclusions and certainly leaving important puzzling questions still unresolved. To step forward in this field, it became crucial to increase the number of analysed objects the Milky Way and other metallicity environments, also considering the information provided by multi-epoch photometric, spectroscopic (multi-wavelength) and spectro-polarimetric observations. Only such a complete observational dataset will allow the investigation of the impact that third order parameters (such as binarity/multiplicity, magnetic fields, and stellar oscillations) have on the physical and wind properties of massive stars, as well as the evolution of this important astrophysical objects.

Slowly but surely, this situation started to improve by the first decade of the XXIst century thanks to the intensive observational efforts devoted by several groups around the globe which – condensed in several specific spectroscopic surveys – allowed the compilation and analysis of large samples of different types of massive stars in the Milky Way and other close-by galaxies in the Local Group.

Figure: IACOB project webpage

How many of them behave the same way?

- now we know about 8 of them
- why?

Supergiants showing HVA

HD 213989

HD 21291

Rigel

Deneb

HD 199478

HD 91619

HD 96919

HD 207260

Do they have something in common?

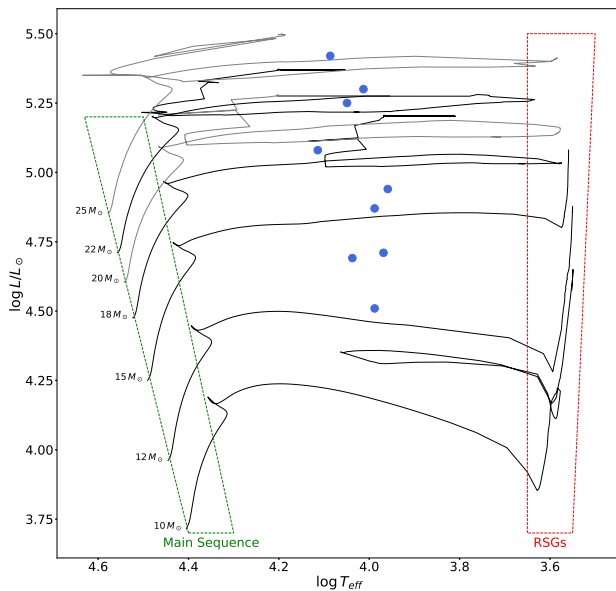
Do they have something in common?

YES, but not much at least
what we know :(

Variability type

- all of them belongs to α Cyg type variables
 - ▶ pulsating stars
 - ▶ low amplitude variability
 - ▶ variability in line profiles is typical
 - ▶ mainly in $H\alpha$ line

Evolutionary status



Evolutionary status

all objects showing HVA are α Cyg variables:

- **Deneb**

- ▶ evolving from the main sequence towards the right to RSG branch (Schiller 2007)
- ▶ **BUT:** referred to be in the post-red supergiant stage by Przybilla et al. 2010

- **Rigel**

- ▶ pulsational characteristics implies that Rigel already underwent RSG stage and evolving blue-wards (Saio, Georgy & Meynet 2013)

- **HD 21389**

- ▶ sun-like abundances (N/C, N/O) \rightarrow evolving right in its first crossing (Corliss, Morrison & Adelman 2015)

Results for HD 21389

- variability on different time scales
- most interesting behavior in $H\alpha$ line
- weak X strong HVA event
- we have only(mainly) observational data

- physical causes of HVA – comparison of observed profiles with models
- would it be possible to find more of them?

Evidence for new HVA events

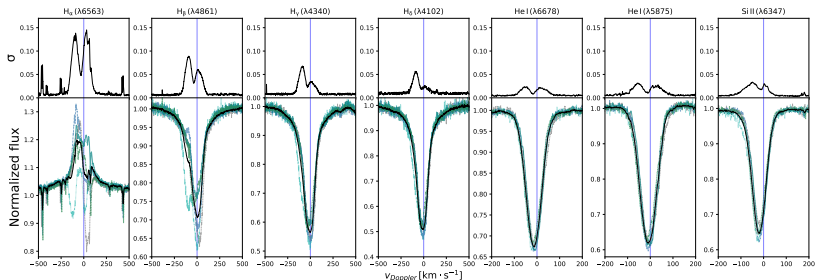


Figure: TVS of HD 199478. Highly blue-shifted H α lines' profile has been taken during HVA event.

Evidence for new HVA events

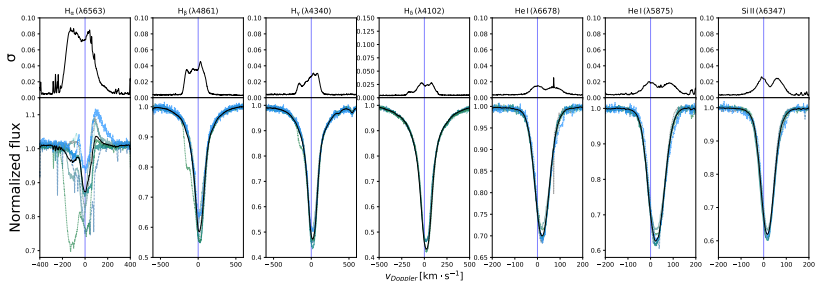
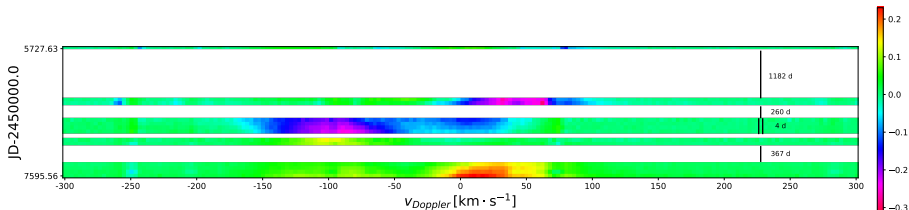


Figure: TVS of HD 34085. Highly blue-shifted H α lines' profile has been taken during HVA event.

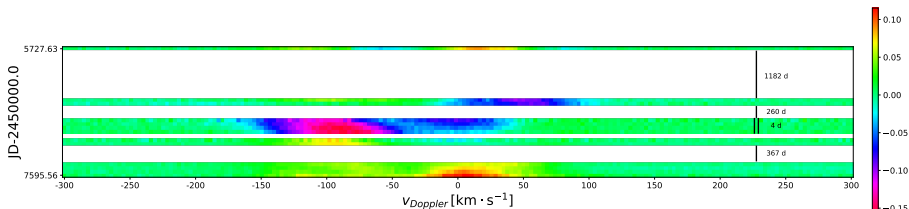
So, what's going on during HVA?

- HUGE macro structures may explain the depth of $H\alpha$ HVA profiles
- HUGE macro structures ($\geq R_{\odot}$) = **clumps** moving towards OR away from the observer may explain the shift in $v_{Doppler}$ / RV of line cores / RV of absorption components
- can they be formed in the very upper layers of the atmosphere?
 - ▶ because there is an evidence of imprint of HVA in photospheric lines (Ismailov [2020](#), Ismailov [2021](#))
- HVE??? (High Velocity Emission events)
 - ▶ caused by geometry $\rightarrow v \sin(i)$?
 - ▶ or...?

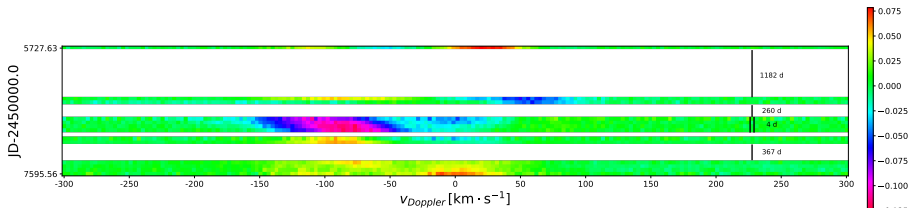
HD 199478



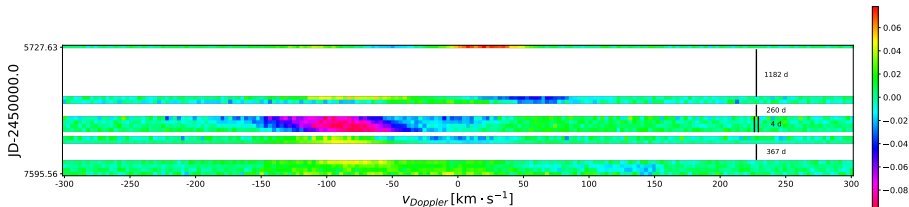
(a) Residual dynamic spectrum of H α line.



(b) Residual dynamic spectrum of H β line.



(c) Residual dynamic spectrum of H γ line.



(d) Residual dynamic spectrum of H δ line.

So, what's going on during HVA?

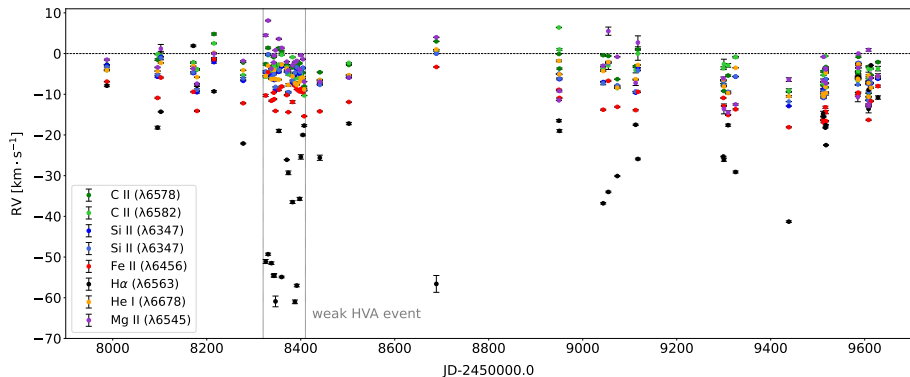


Figure: No imprint in photospheric lines.

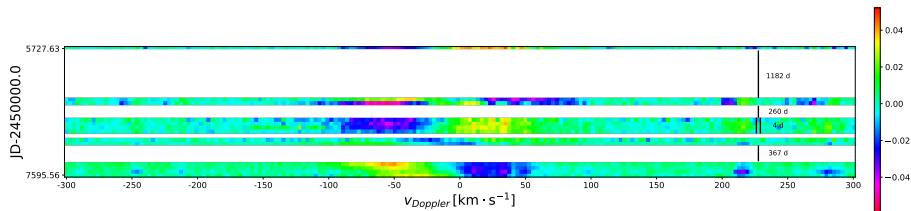


Figure: Residual dynamic spectrum of He I ($\lambda 5876$) line.

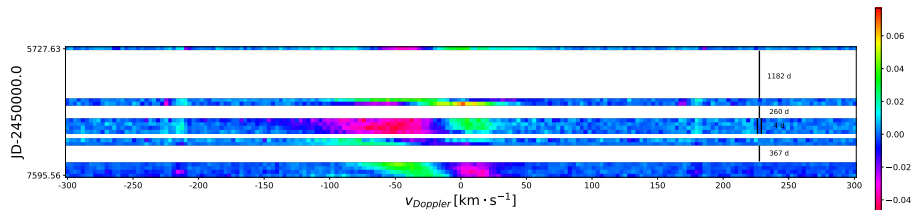


Figure: Residual dynamic spectrum of Si II ($\lambda 6347$) line.

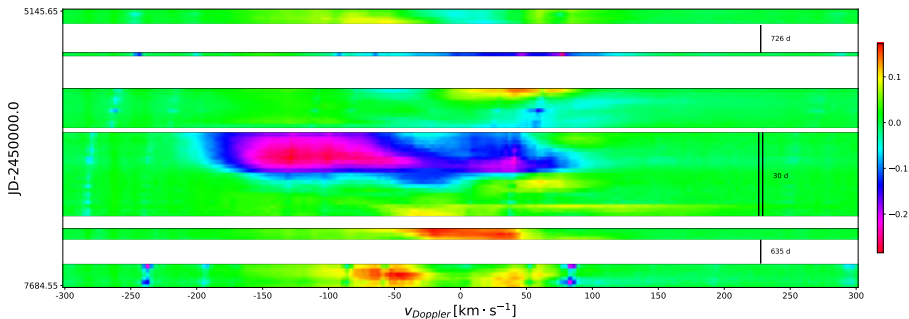


Figure: Residual dynamic spectrum of H α line.

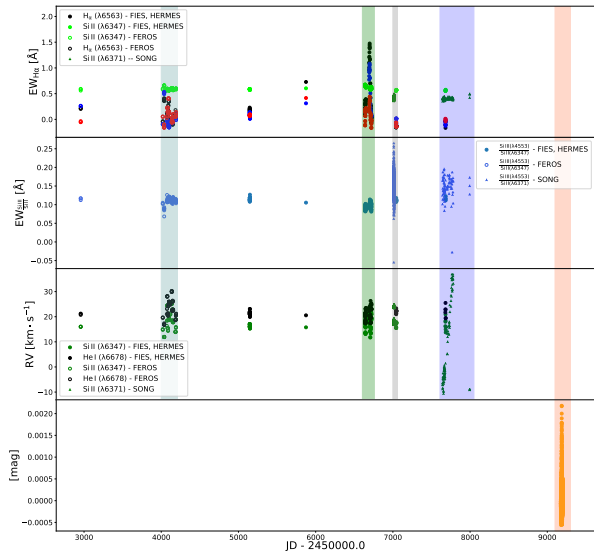


Figure: RV and EW of selected lines of Rigel.

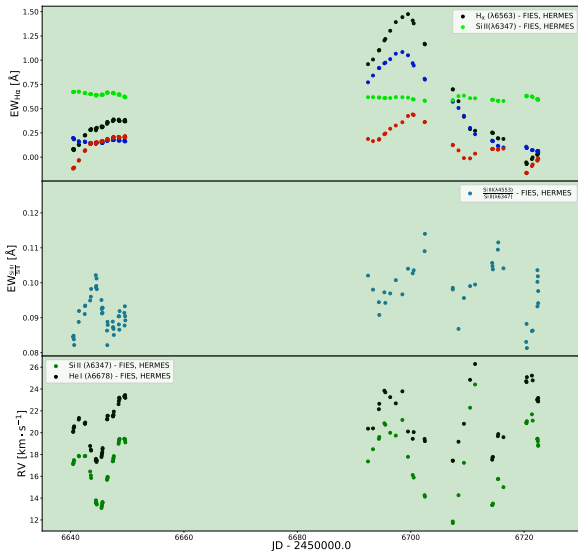


Figure: Zoomed part of previous figure I.

Evidence for HVA events - Rigel

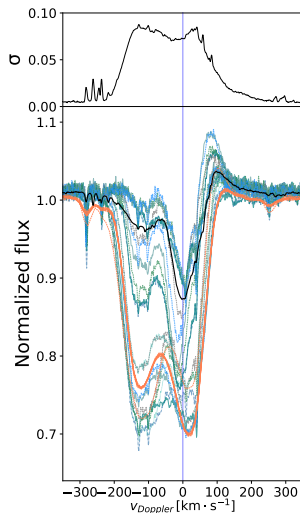


Figure: TVS of HD 34085. Highly blue-shifted H α lines' profile has been taken during HVA event.

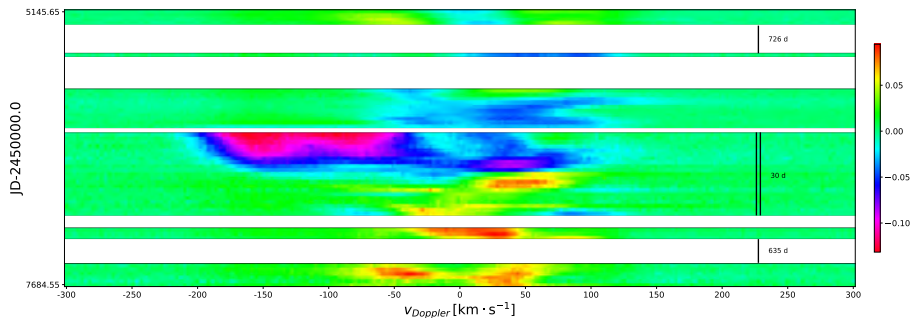


Figure: Residual dynamic spectrum of $H\beta$ line.

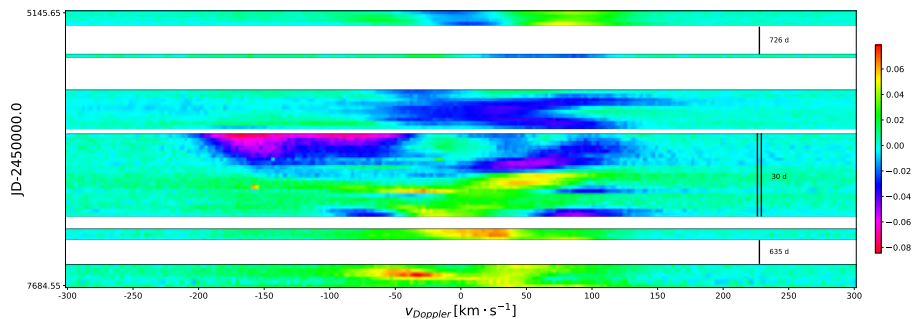


Figure: Residual dynamic spectrum of H γ line.

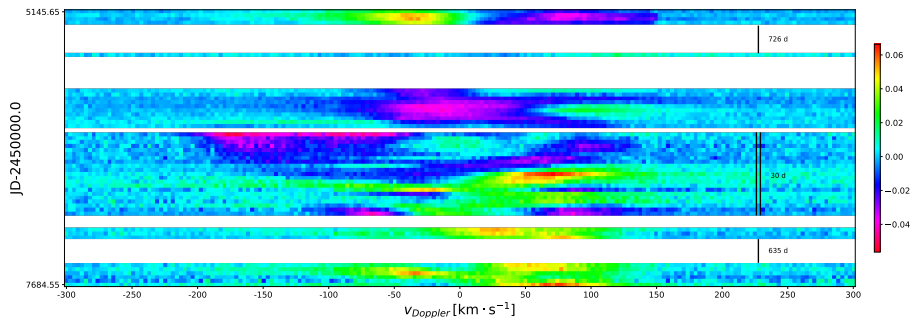


Figure: Residual dynamic spectrum of H δ line.

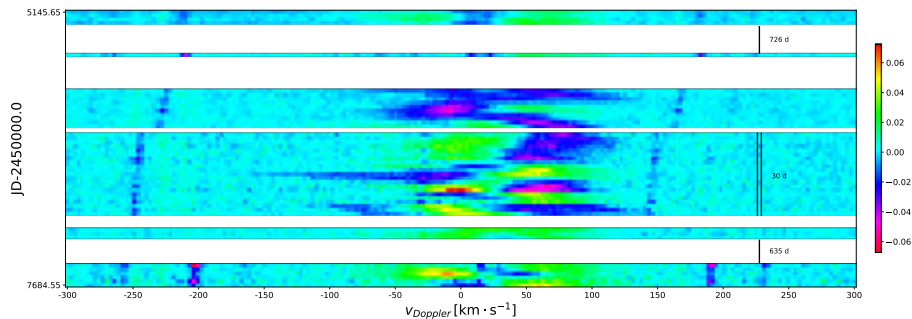
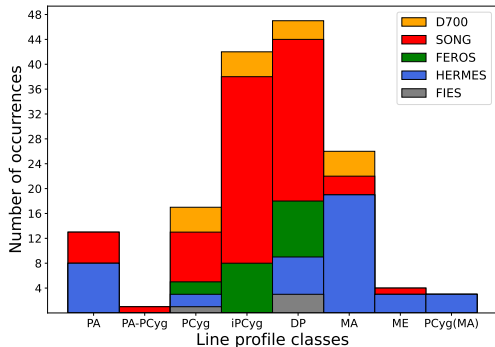


Figure: Residual dynamic spectrum of Si II ($\lambda 6347$) line.



PA - pure absorption profile

PA-PCyg - pure absorption profile turning smoothly to PCyg

PCyg - PCyg type profile

iPCyg - inverse PCyg type profile

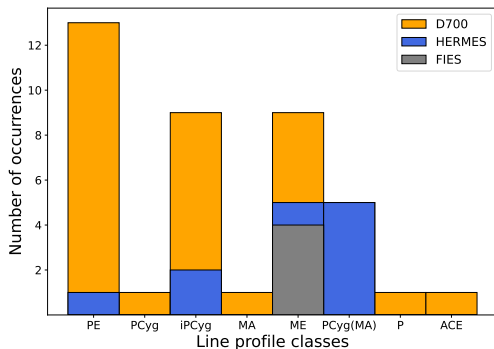
DP - double-peaked profile

MA - absorption profile with multiple components

ME - emission profile with multiple components

PCyg(MA) - PCyg type profile with multiple absorption components

Figure: Morphology histogram of $H\alpha$ line profiles.



PE - pure emission profile

PCyg - PCyg type profile

iPCyg - inverse PCyg type profile

DP - double-peaked profile

MA - absorption profile with multiple components

ME - emission profile with multiple components

PCyg(MA) - PCyg type profile with multiple absorption components

P - peculiar profile

ACE - absorption profile with central emission components

Figure: Morphology histogram of $H\alpha$ line profiles.

Future insights

- how long does the HVA take? - in average
- comparison with the rotational period
- do the macro structures survive more than one rotational period?
- estimation of RV during the maximum → comparison with v_{∞}
- is there contribution of other effects (eg. binarity or pulsations)?
- **do the results correspond to the hypothesis???**
- is it possible to see HVA in light curves?
- would it be possible to say (based on the hypothesis) why do we observe just a few of them?

Thank You for Your Attention!