Spatially and spectrally resolved velocities in the atmosphere of evolved stars

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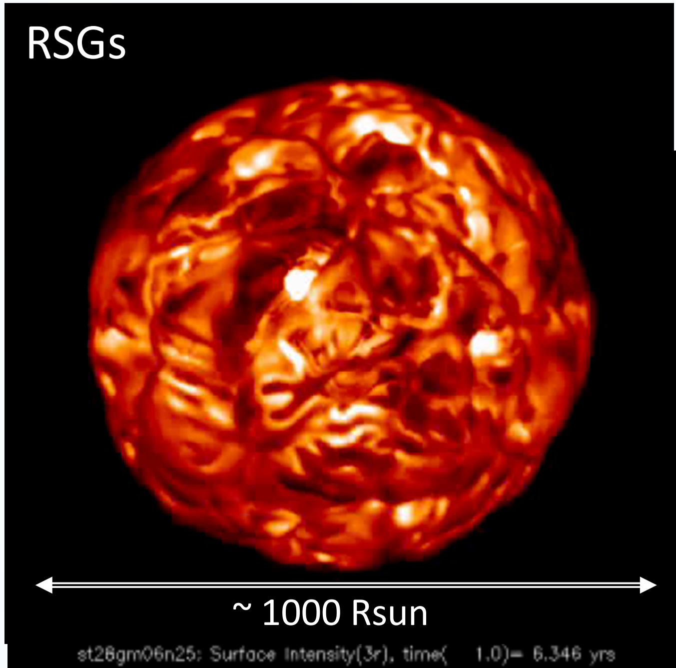
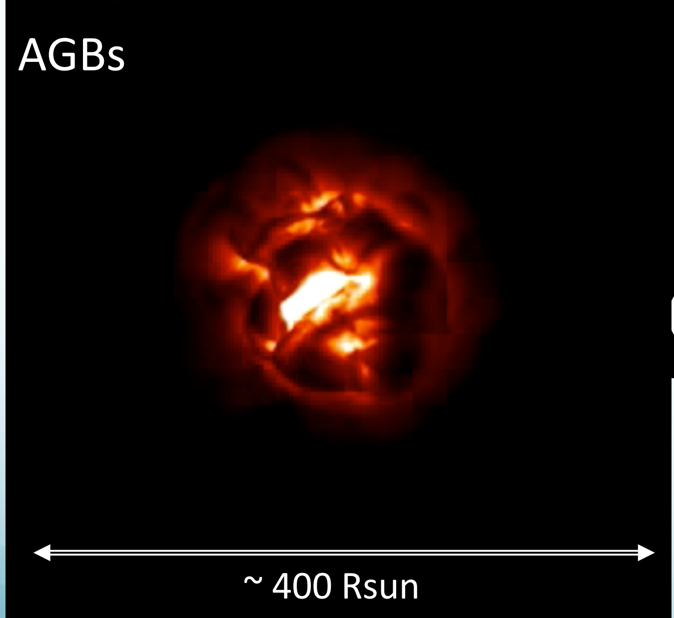
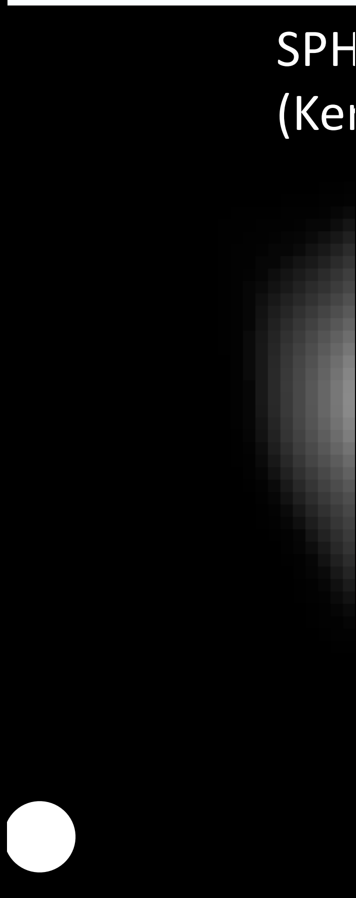
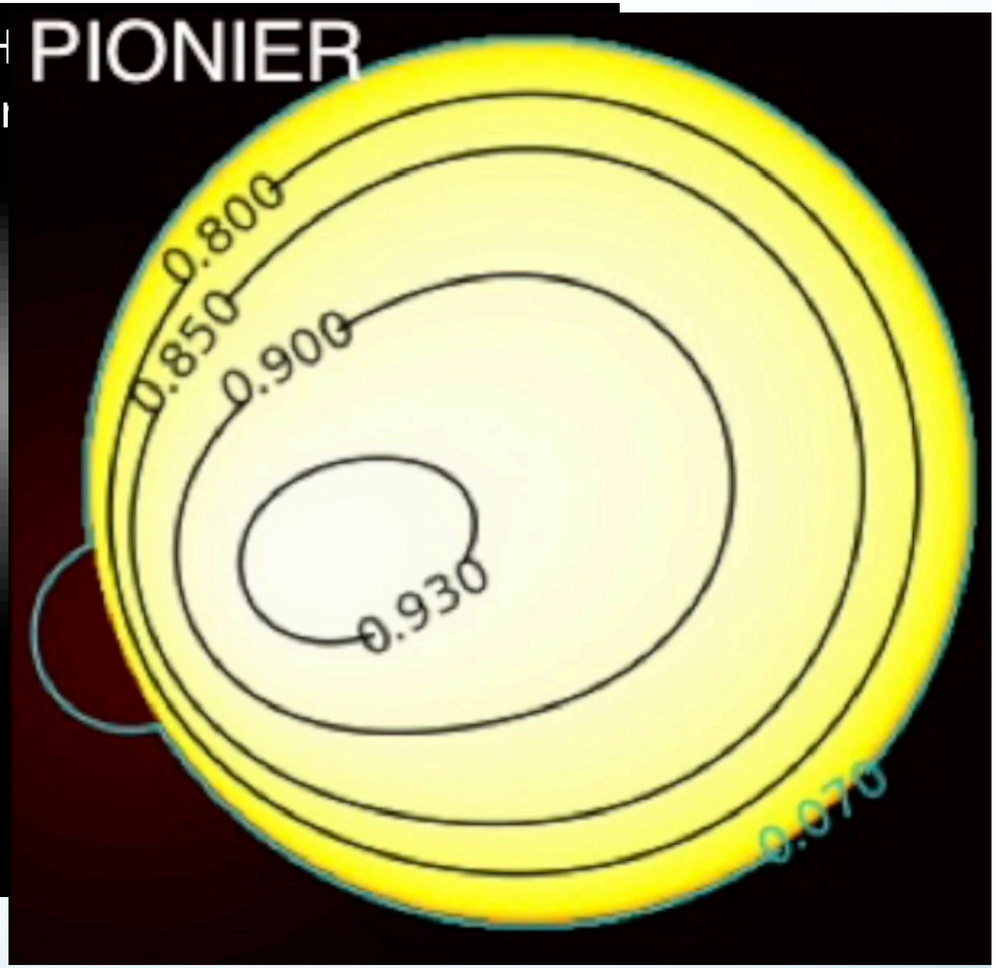
IONIER, MIRC, ALMA, AMBER, IOTA… (Montarges et al. 2014, 2016, 2018; Kervella et al. 2016; Chiavassa et al. 2017)









Strong synergy between observations and simulations to attack the mass-loss, dynamics, and stellar parameters determination of these stars

ISM/circumstellar → Surface

PNPS 2014-2018: Chiavassa, Kervella, Montarges,Lagadec, Perrin, Haubois

3D hydrodynamical simulations of stellar atmosphere

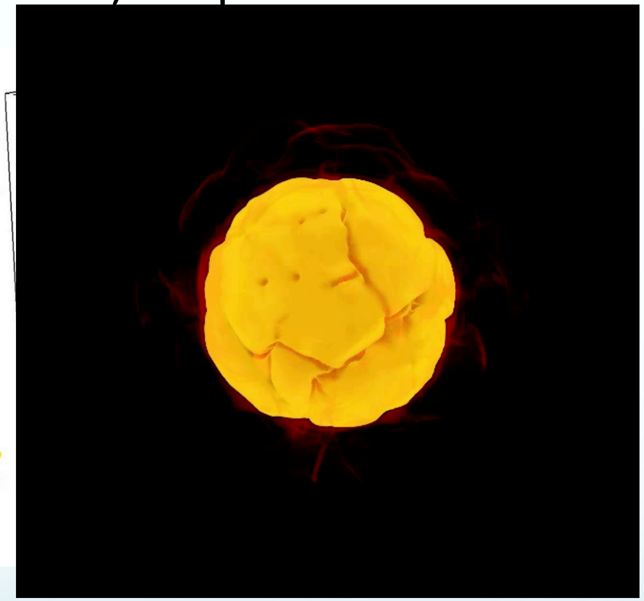
We use the stellar convection simulation computed with CO5BOLD code (Freytag et al. 2012)

→ 3D models = **Very realistic! → deeply checked versus observations**

- **Hydrodynamics 3D** (Grid: 200^3 - 300^3 - 500^3), time dependent
- Solution to the equations for the compressible hydrodynamics (conservation of mass, energy, and momentum) coupled with non-local transport of radiation with detailed opacities

Global simulations

Red supergiants and AGBs

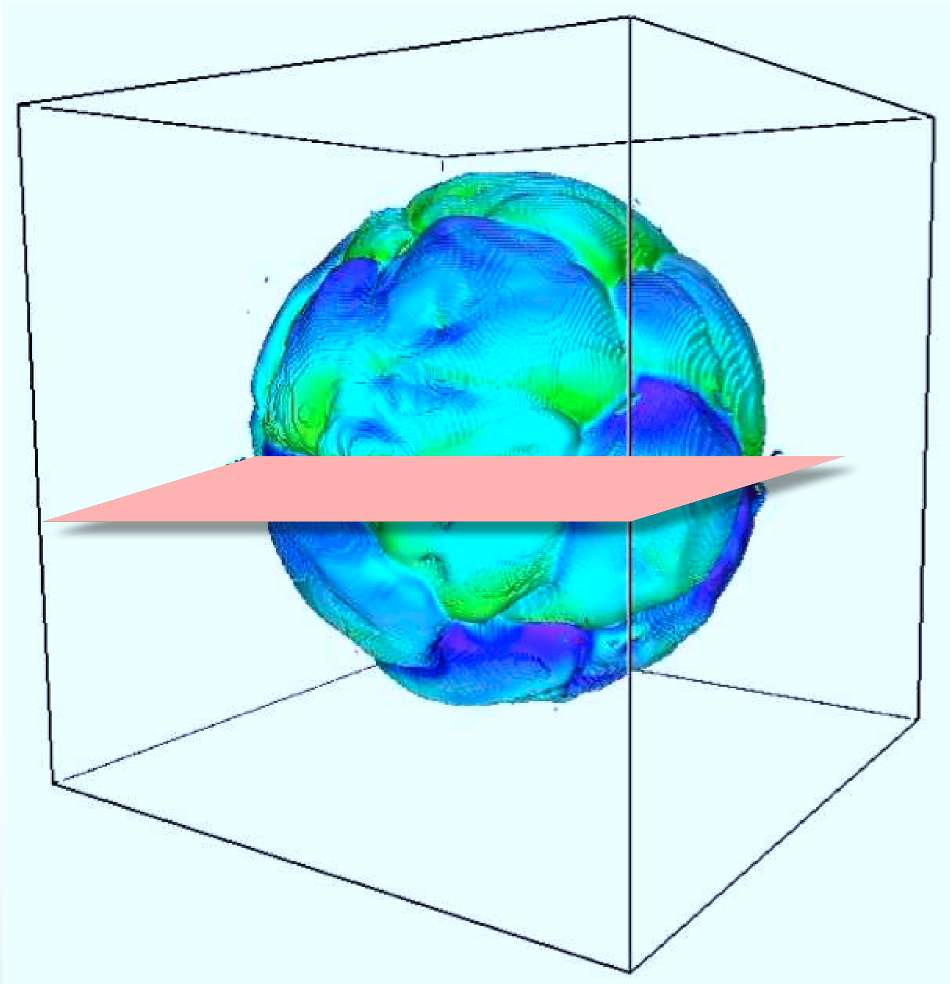


Local simulations

Main Sequence stars and red giants

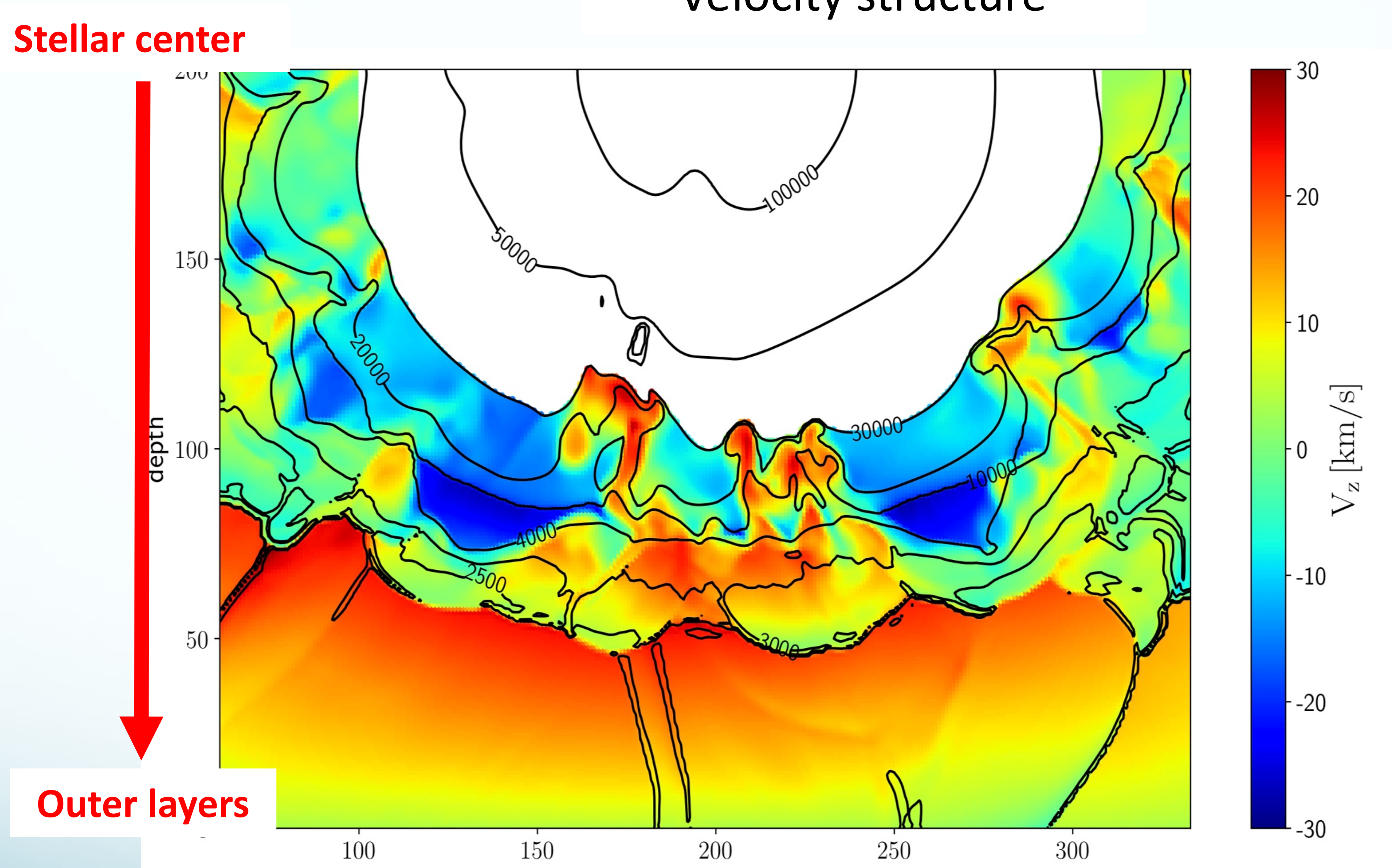
- Detailed (billions of atomic and spectral lines) and fast (computational time slightly larger than 1D computation) post processing of 3D simulations with OPTIM3D (Chiavassa, Plez, Josselin, Freytag 2009)

3D hydrodynamical simulations of stellar atmosphere



3D hydrodynamical simulations of stellar atmosphere

Velocity structure



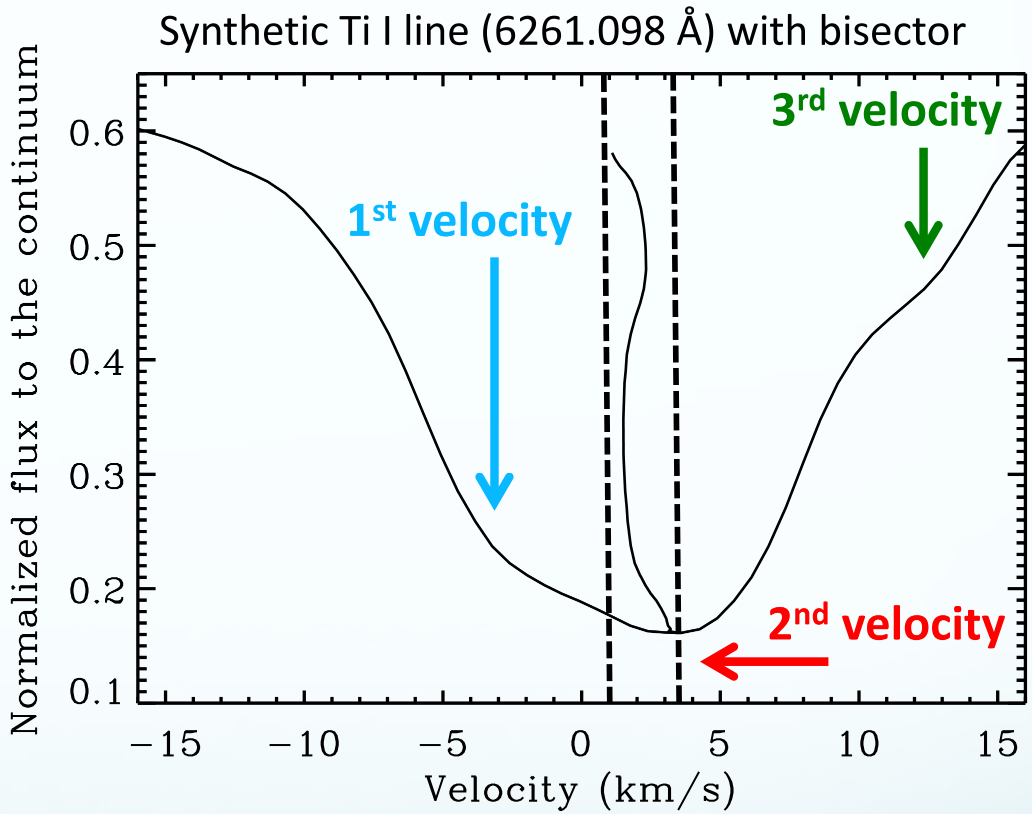
- Velocity field is not-homogeneous
- Temperature (and density) structure permeated by random shocks

3D hydrodynamical simulations of stellar atmosphere

Bisector values range ≈ 2-3 km/s

- Extremely heterogeneous velocity field (2-3 components)
- Same behaviour in the infrared

→ **Very complicated to measure Radial velocities!**



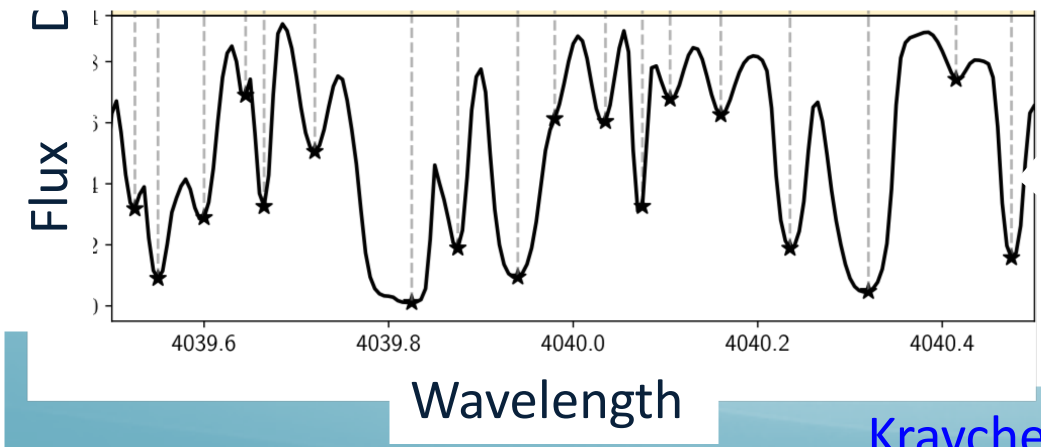
Tomography method

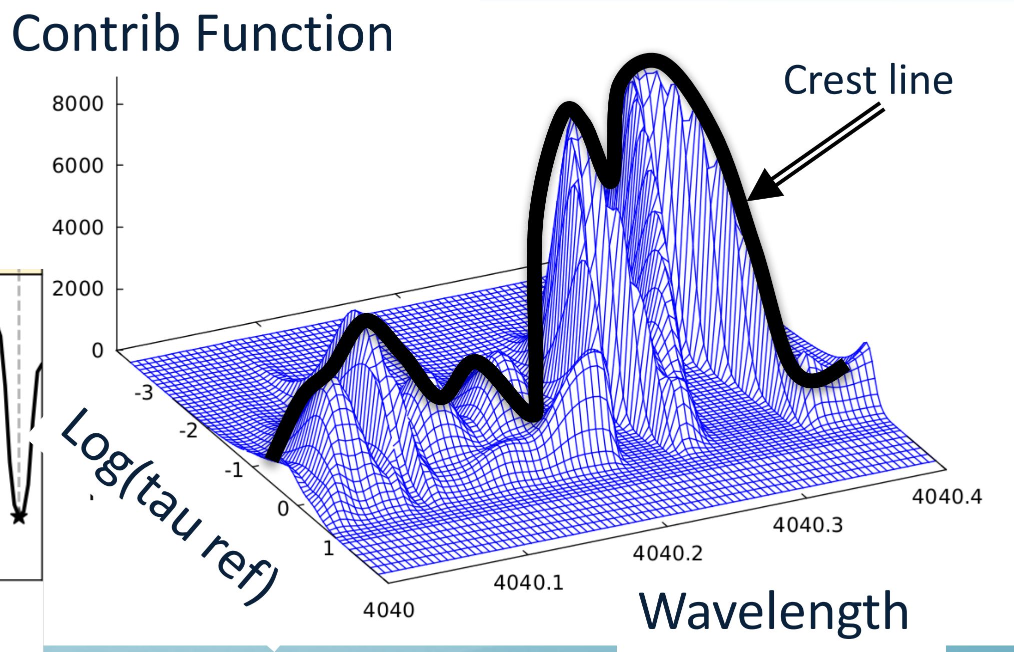
AIM: Retrieve the vertical component of the velocity field as a function of depth in the stellar atmosphere (Alvarez+ 2001 and Josselin & Plez 2007)

HOW:

(i) computing contribution function to absolute line depression

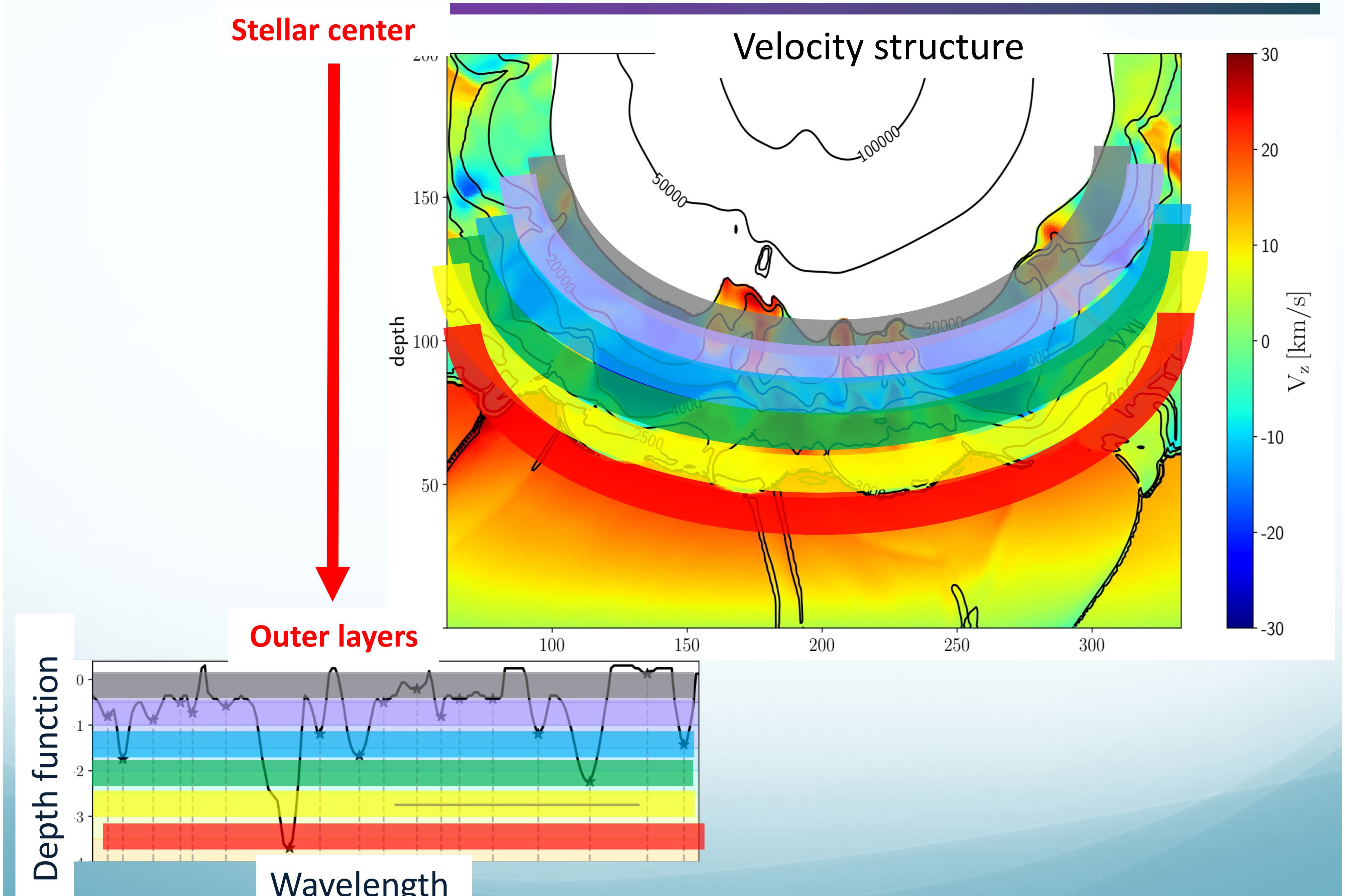
(ii) Sorting spectral lines according to their formation depth (which is expressed in an optical depth scale computed at the reference wavelength λ = 5000 A)





Kravchenko et al. (2018, A&A, 610, A29)

Tomography method



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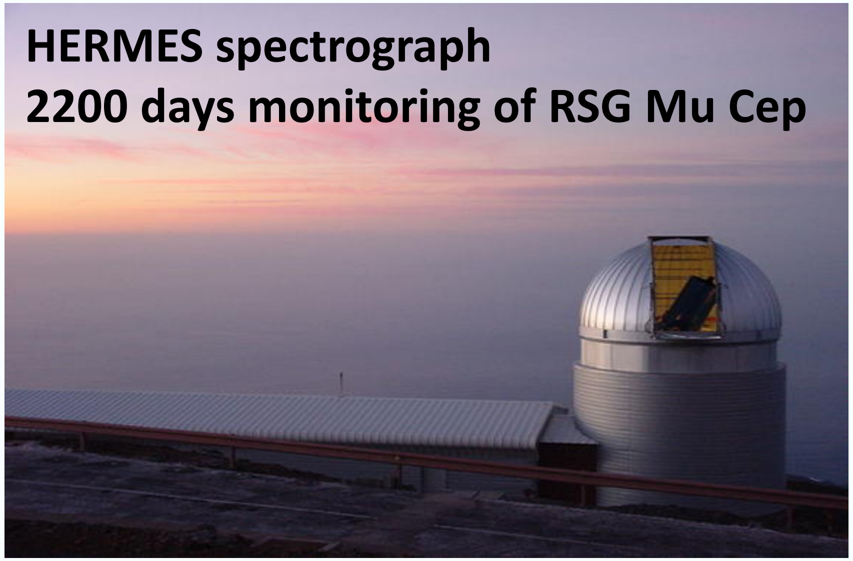
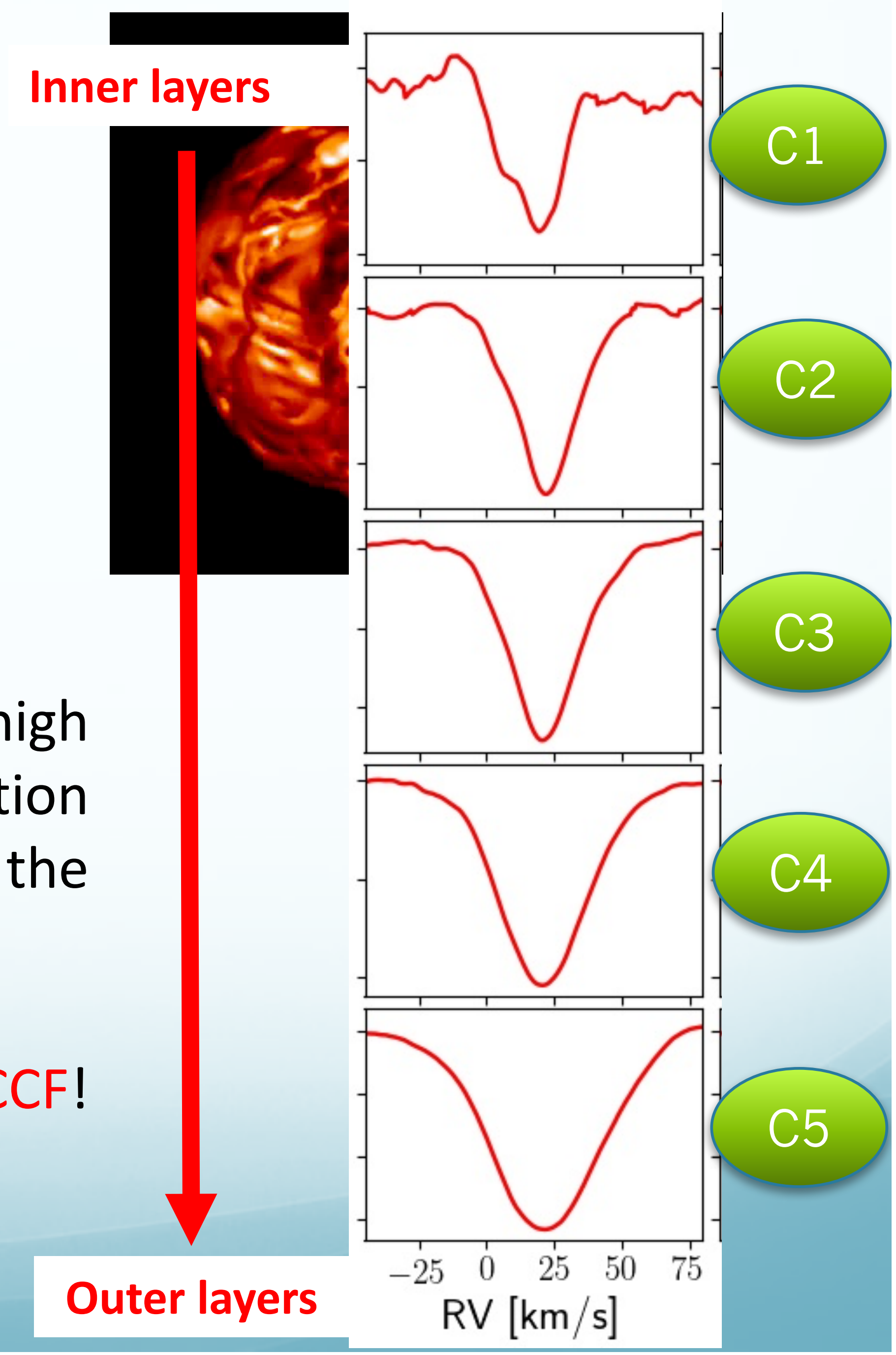
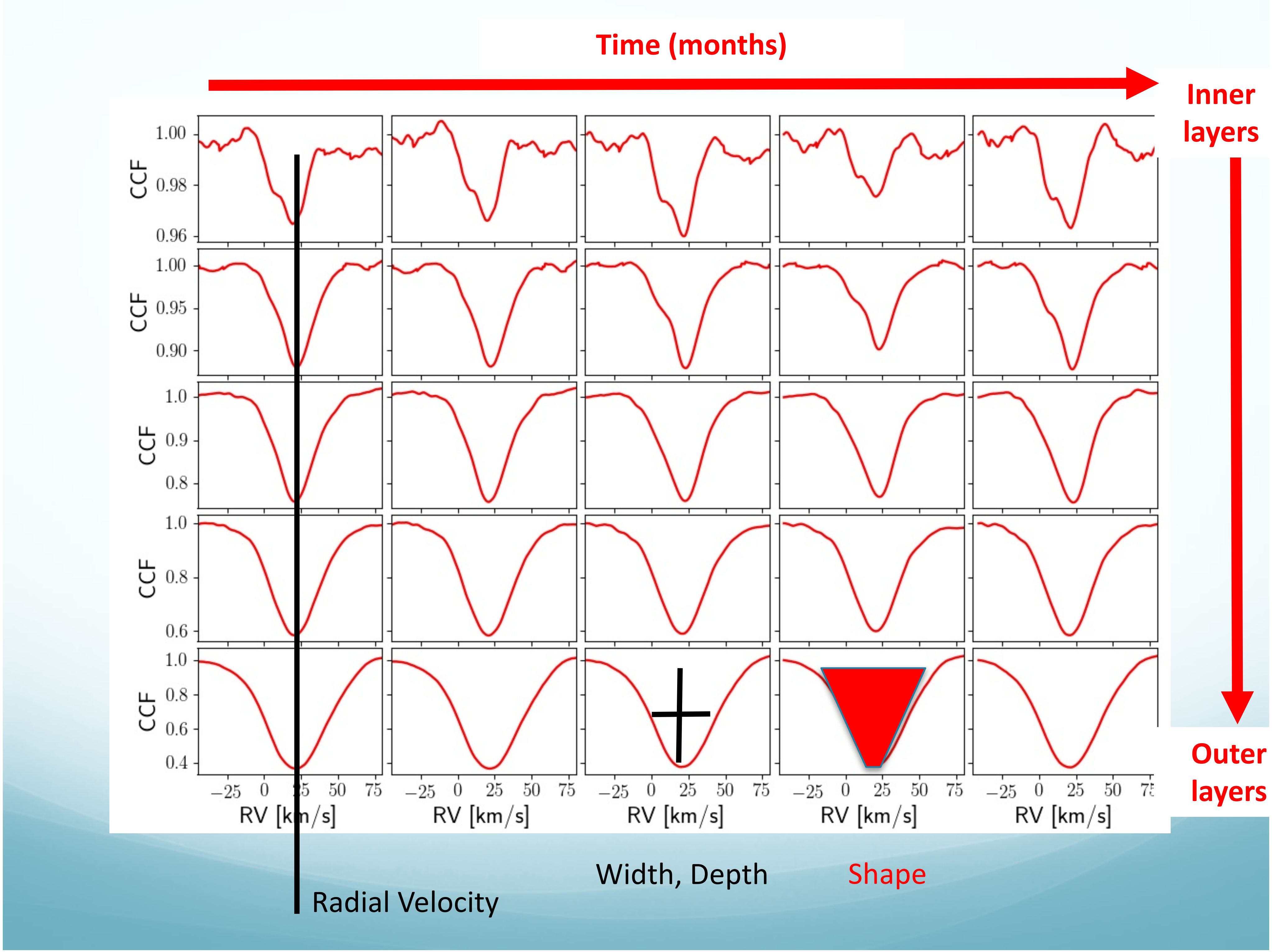
Cross-correlation function

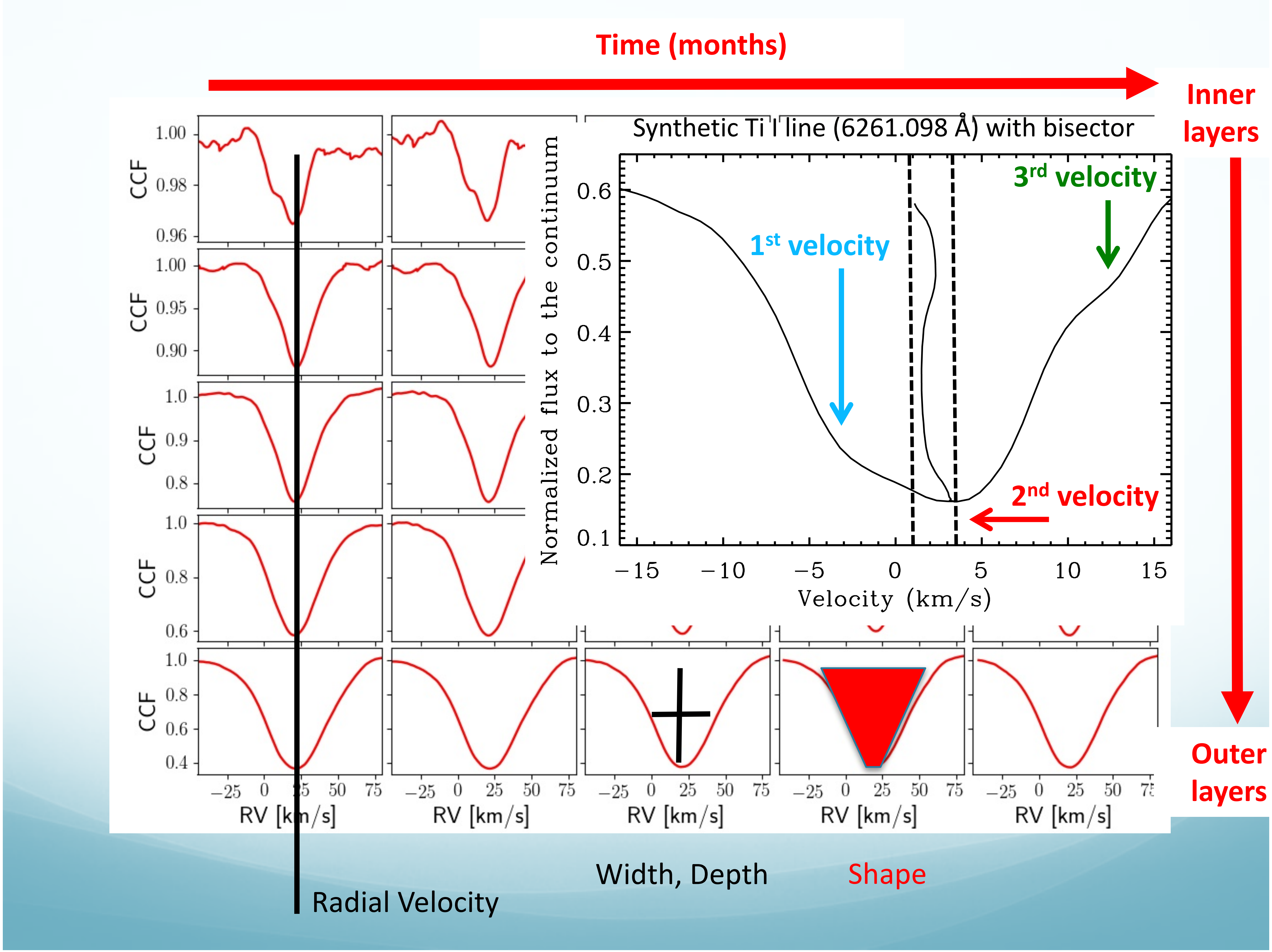


- Cross-correlation (CCF) of high resolution spectra from observation and simulations with the thomographic masks

- Shape, shift, radial velocity from CCF! Important information of dynamics

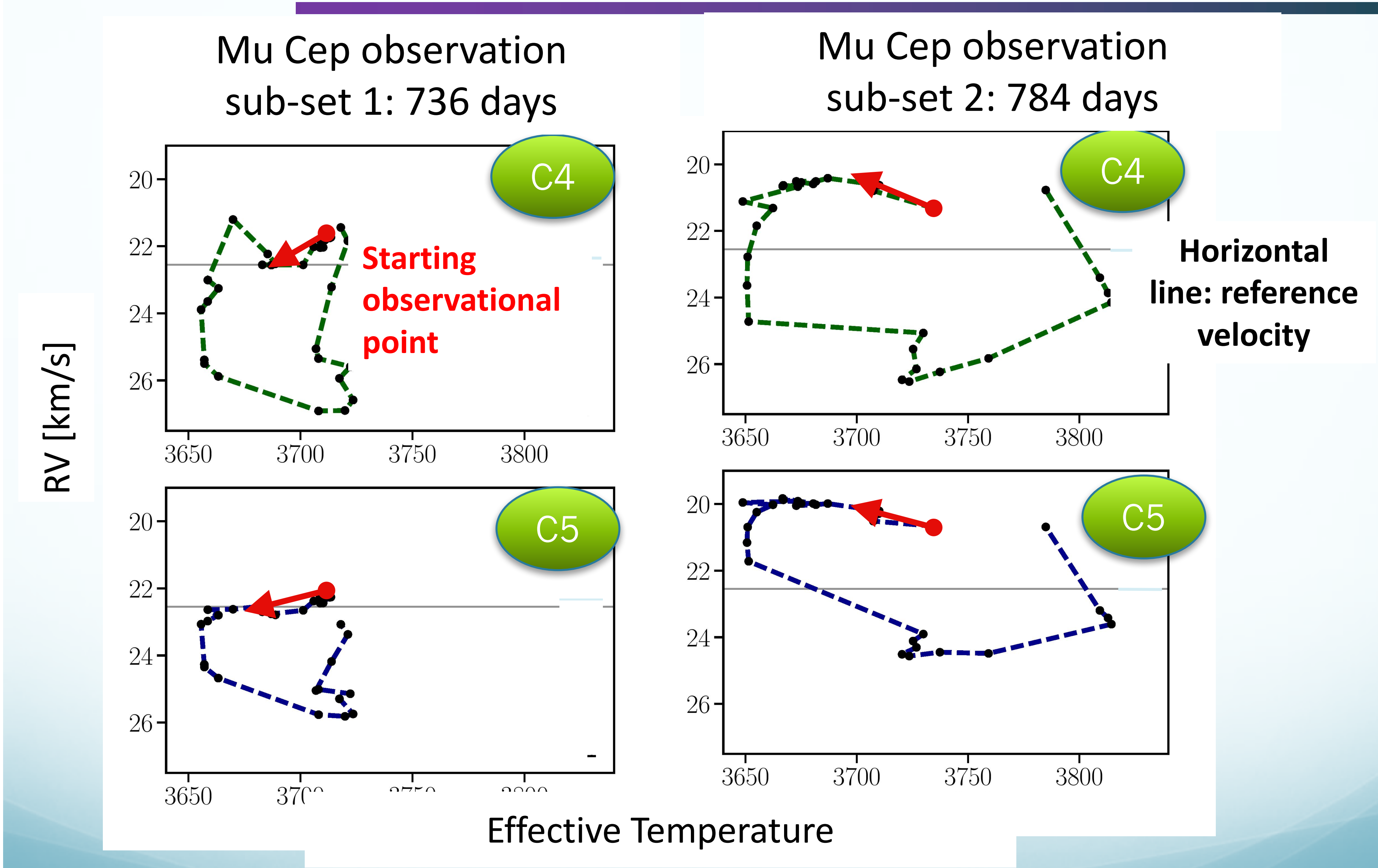



Time (months)
Inner layers
Outer layers
CCF
RV [km/s]
Radial Velocity
Width, Depth
Shape



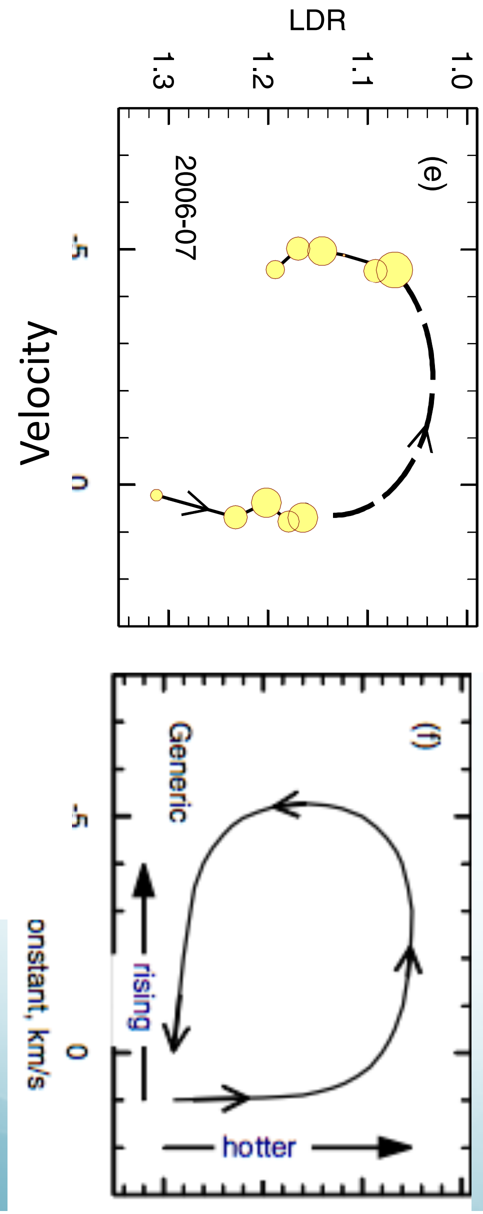
Time (months)
Inner layers
Outer layers
Synthetic Ti I line (6261.098 Å) with bisector
1st velocity
2nd velocity
3rd velocity
Normalized flux to the continuum
Velocity (km/s)
CCF
RV [km/s]
Radial Velocity
Width, Depth
Shape

Observations…



Very close to the (short) period found by Kiss 2006 for Mu Cep (860 days)

Working in progress: Kravchenko, Chiavassa, Van Eck et al. (in prep.)

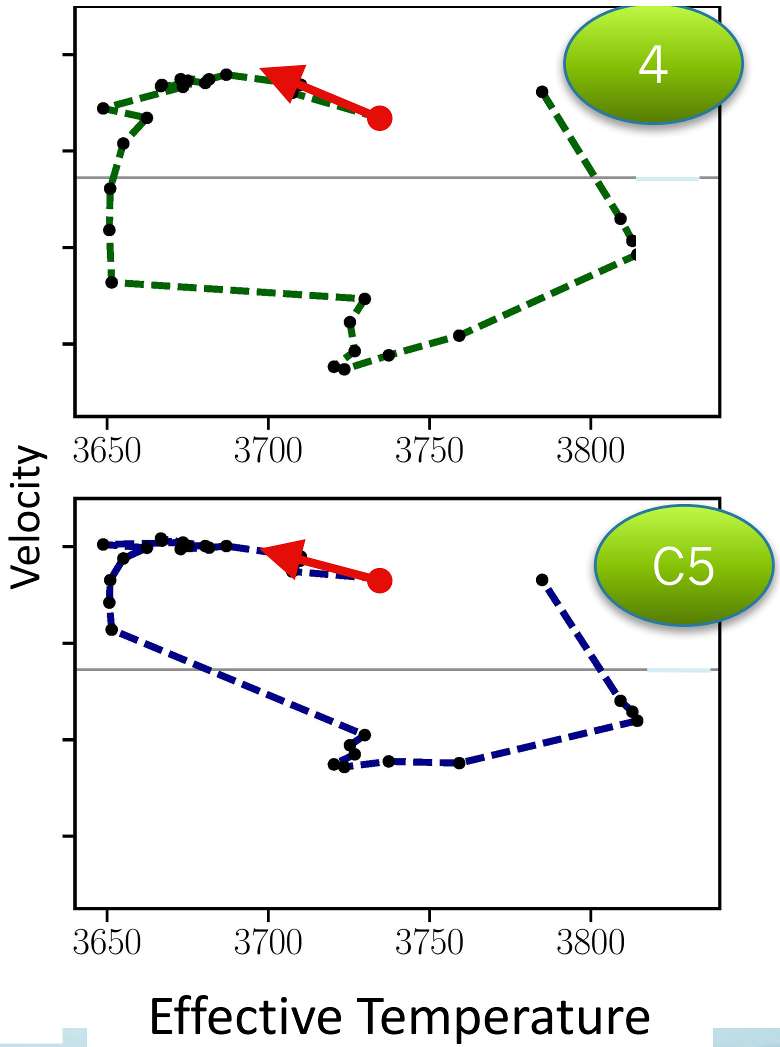


line depth ratio (T indicator)

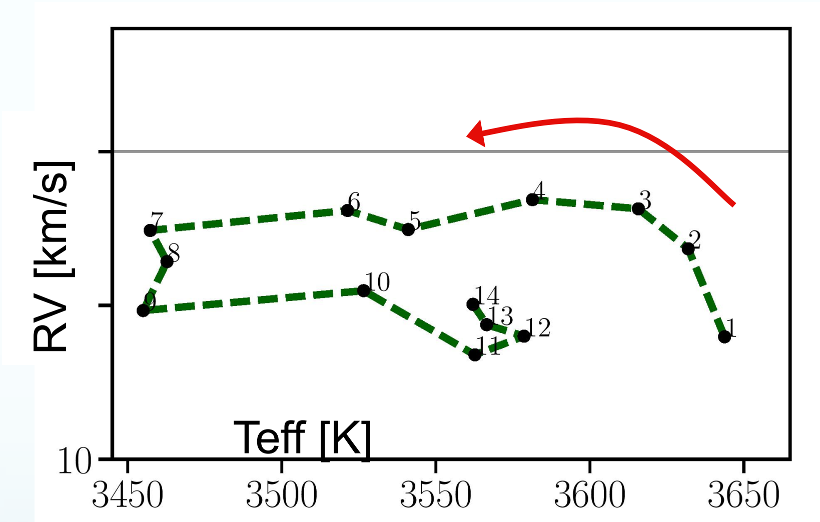
Gray 2008 found a similar behaviour for Betelgeuse (period of 400 days) with a different analysis.

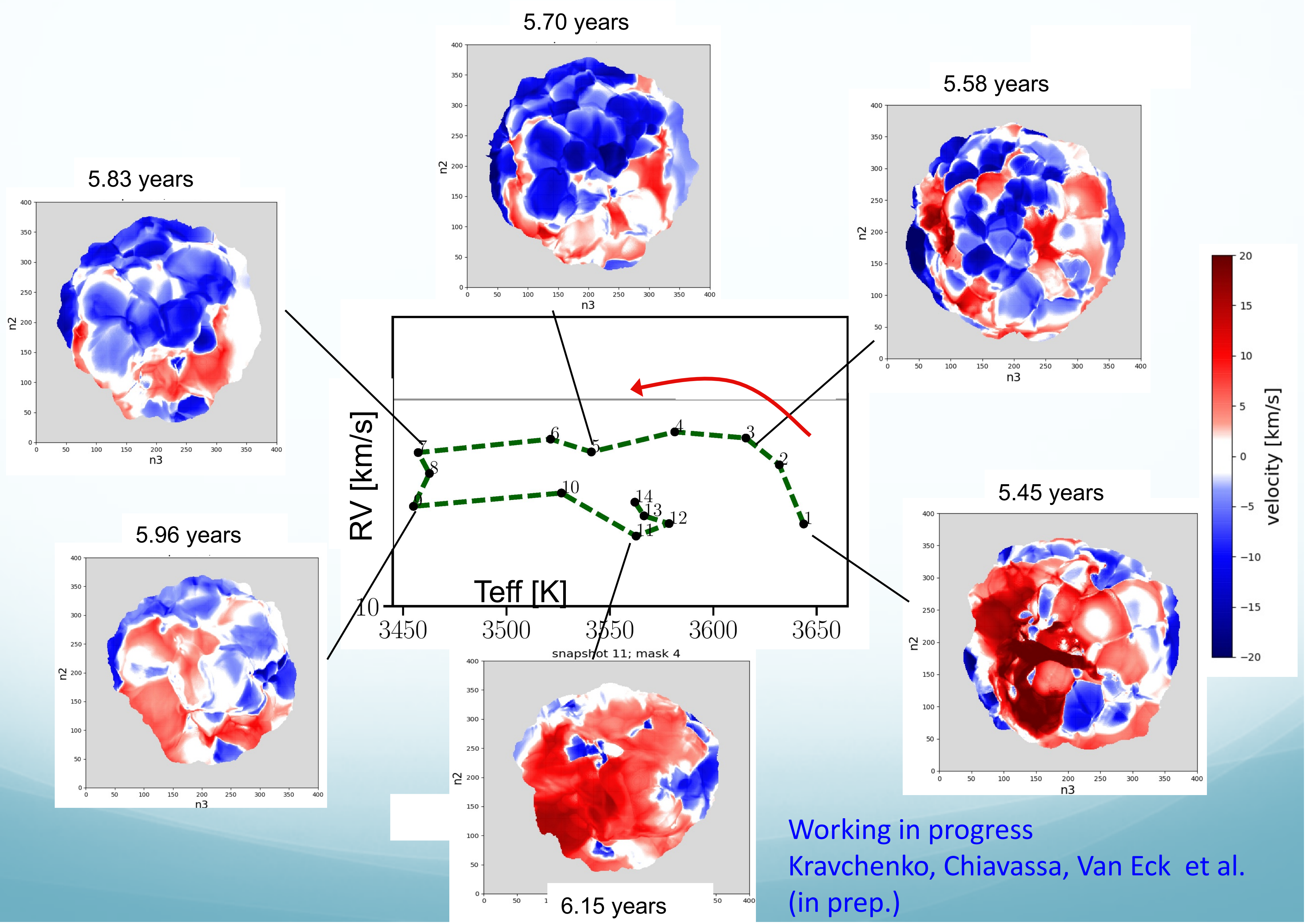
Signature of stellar convection!

Mu Cep observation sub-set 2: 784 days



… versus simulations

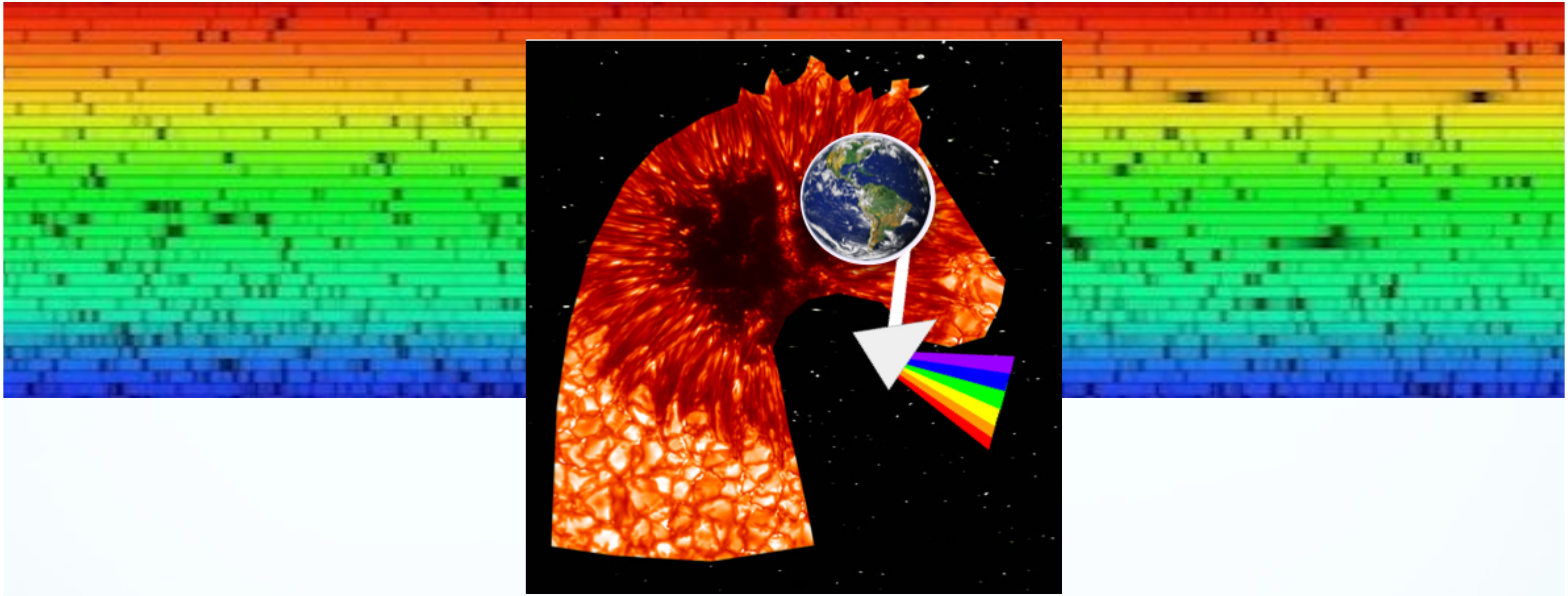




Working in progress
Kravchenko, Chiavassa, Van Eck et al.
(in prep.)

Conclusions

- Implementation and validation of tomography technique in 3D RHD simulations. The velocity field is recovered as a function of depth in the stellar atmosphere.
- Mu Cep shows the signature of convection? Is the convection period resolved?
- New observing constraints for velocity versus surface brightness maps (interferometry – PIONIER, MATISSE, MIRC; and spectropolarimetry – A. Lebre talk)



HoRSE : High Resolution Spectroscopy for Exoplanet atmospheres and their host Stars

1-5 Oct 2018 Nice (France)

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