A viewpoint on stellar atmospheres

Andrea Chiavassa

LAGRANGE

Observatoire de la CÔTE d'AZUR

Are stars smooth?

Brightness variability

Stellar contamination: M dwarf stars

Conclusions

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Brightness variability

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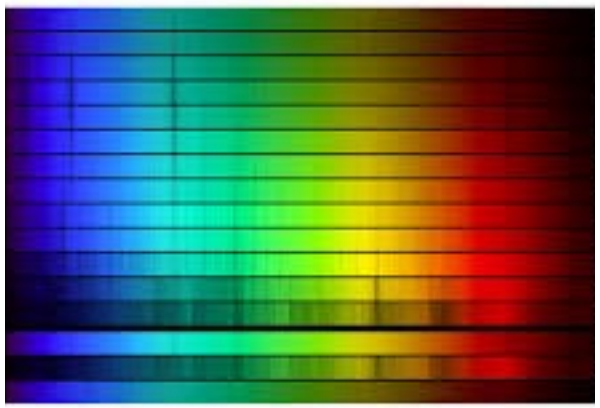
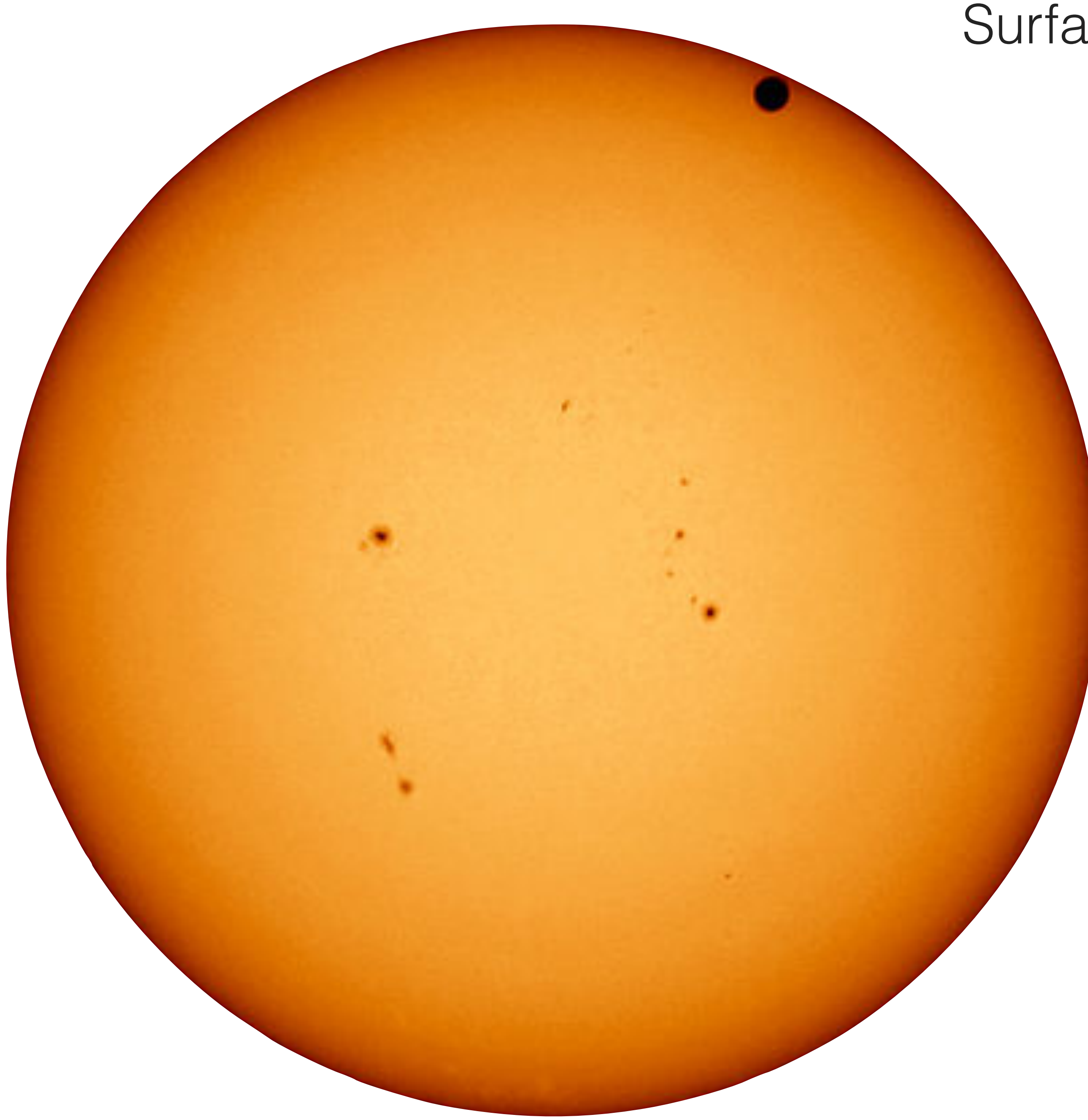
Conclusions

Are stars really smooth?

Stellar parameters:
Effective Temperature, radius,
Surface Gravity, Age…

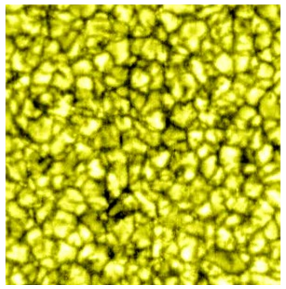
Chemistry/NLTE



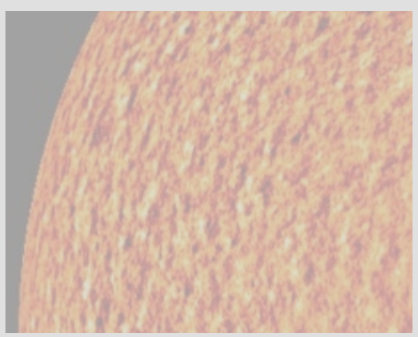


Are stars really smooth?

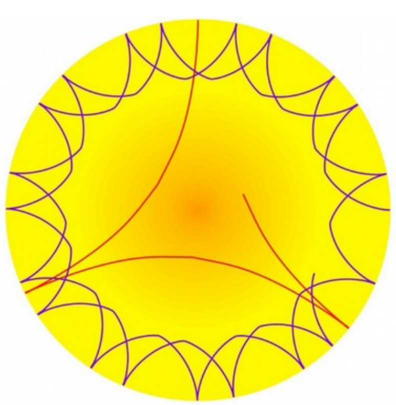
Granulation

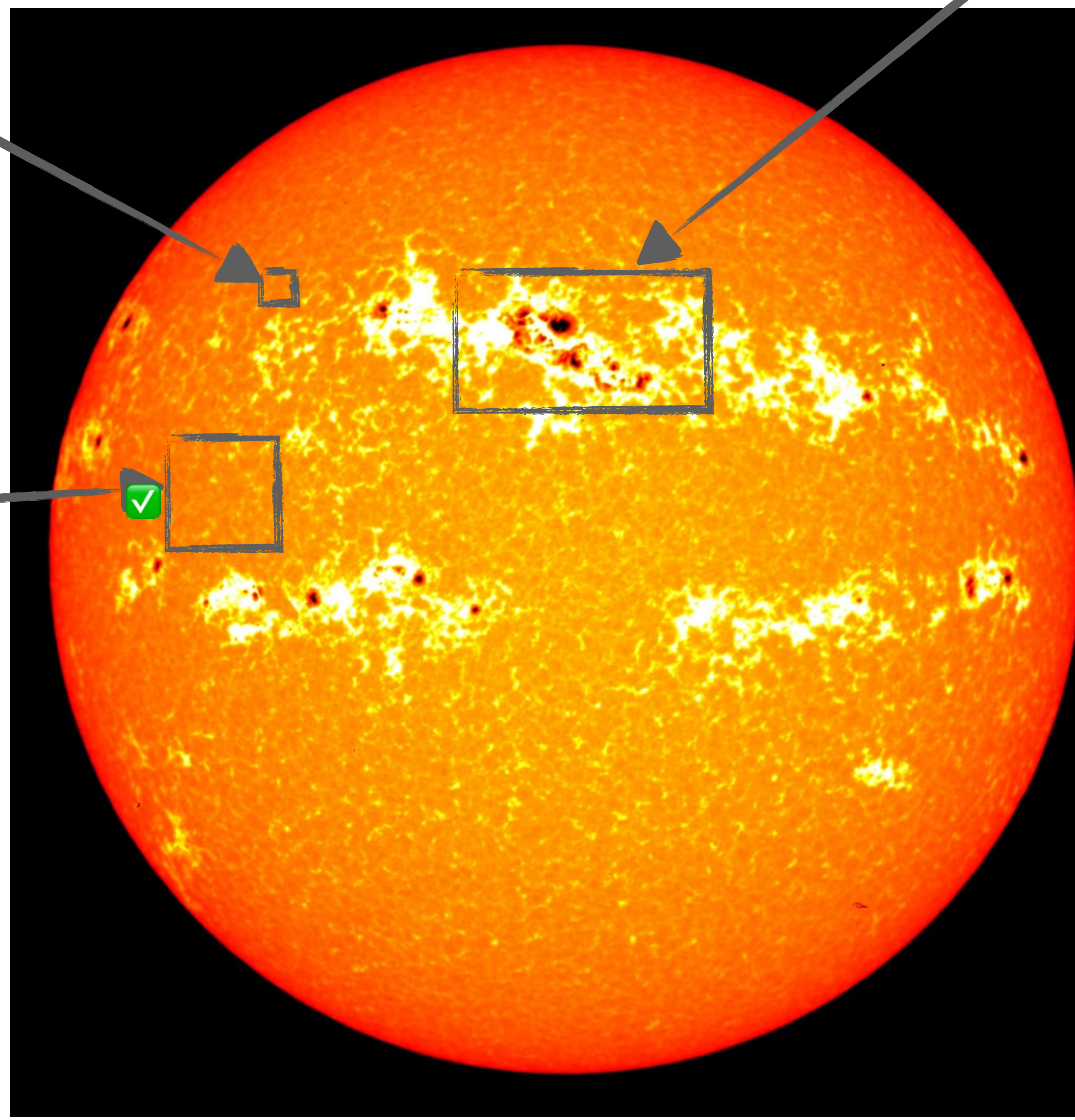


Super granulation



Oscillations

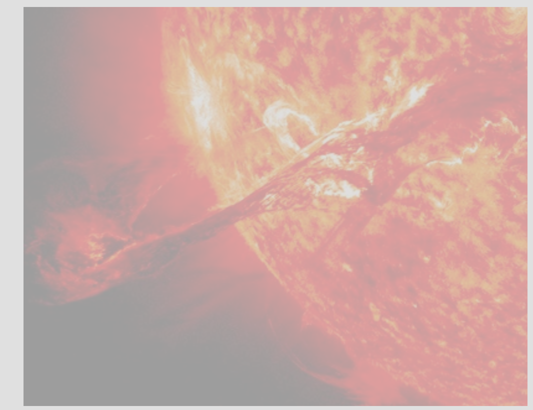




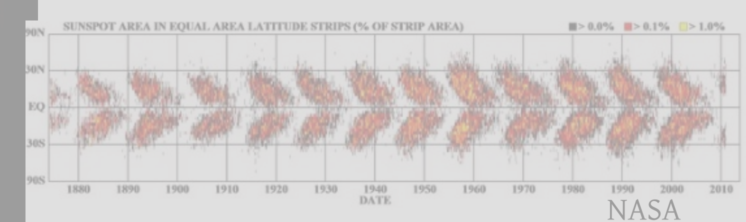
High solar activity: 28 marche 2001, NASA

Starspots and faculae

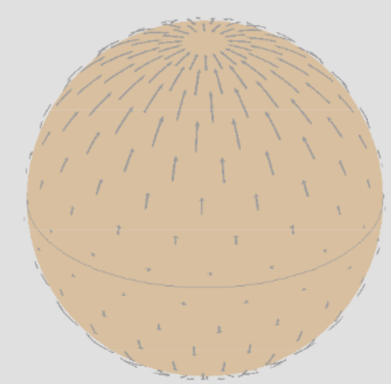
Flares



Cycles



Meridional circulation



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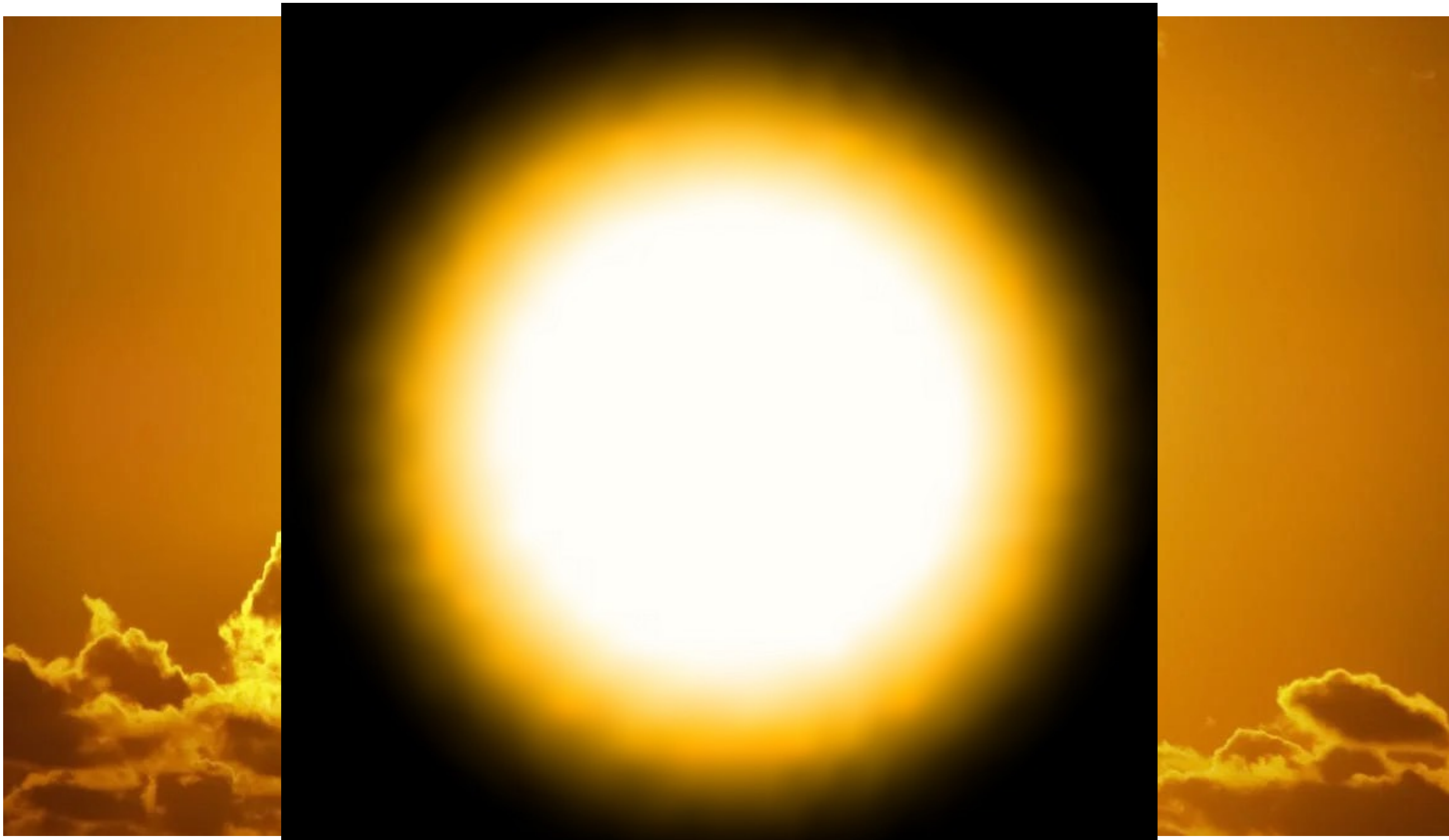

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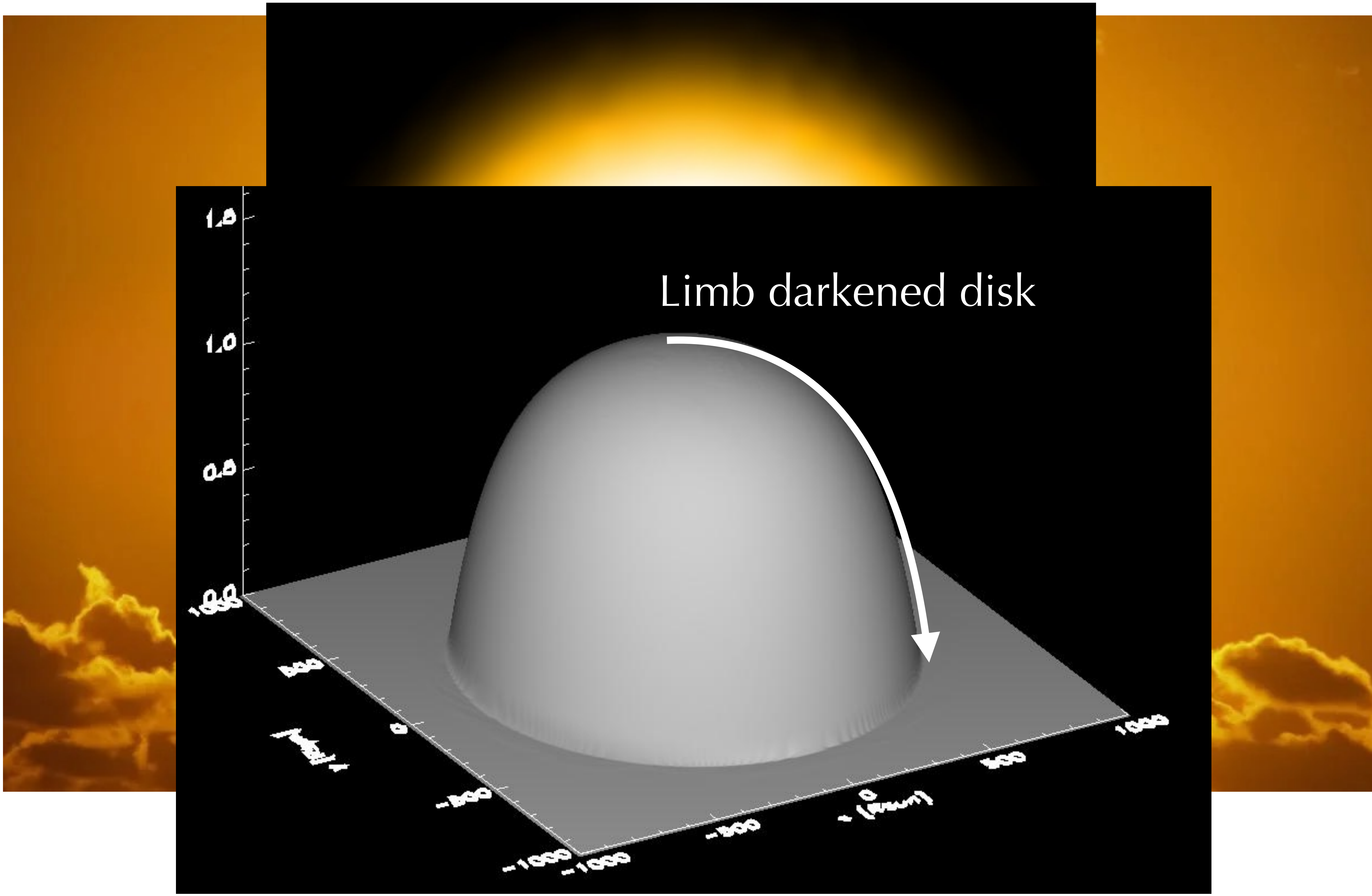

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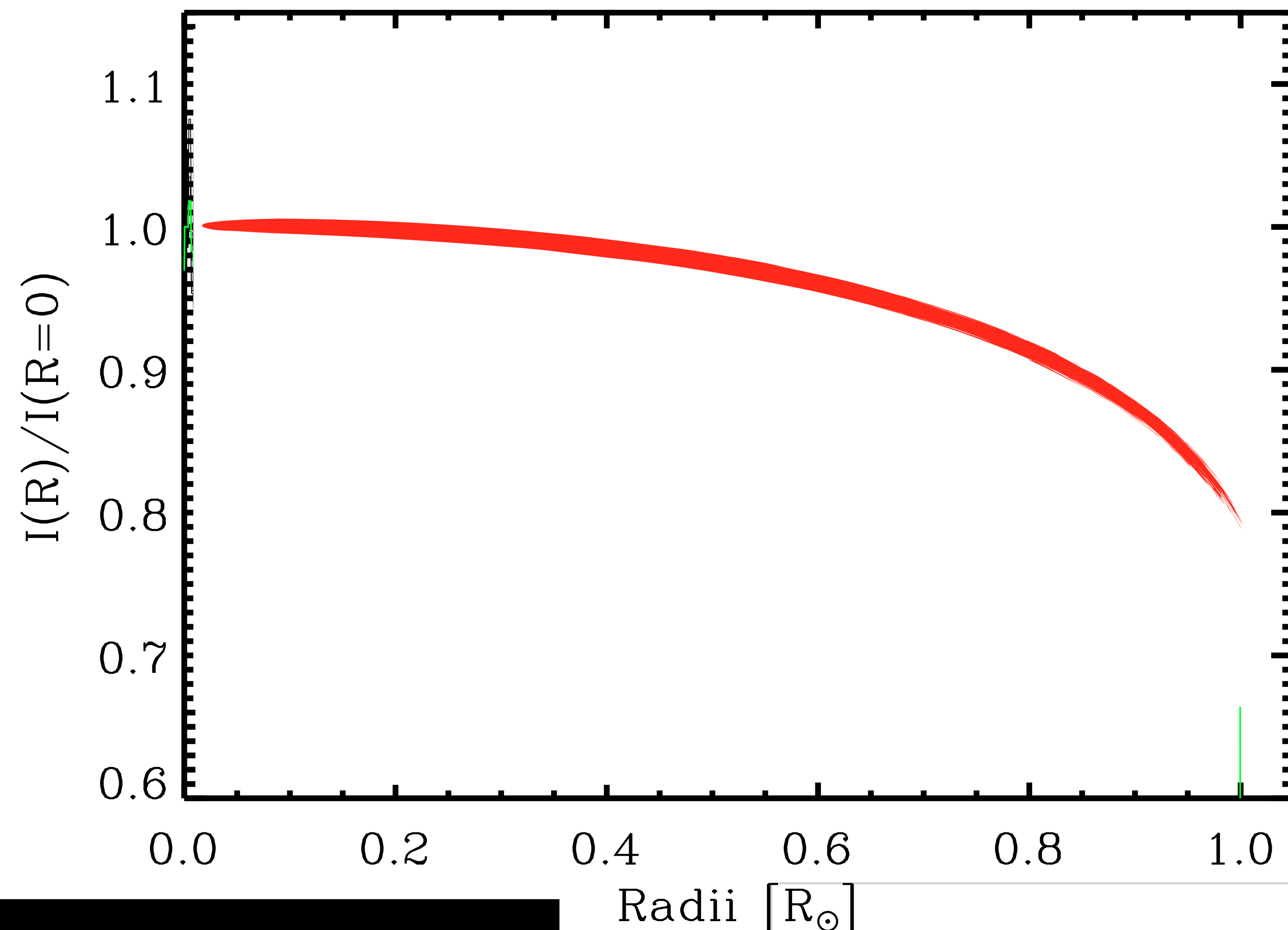

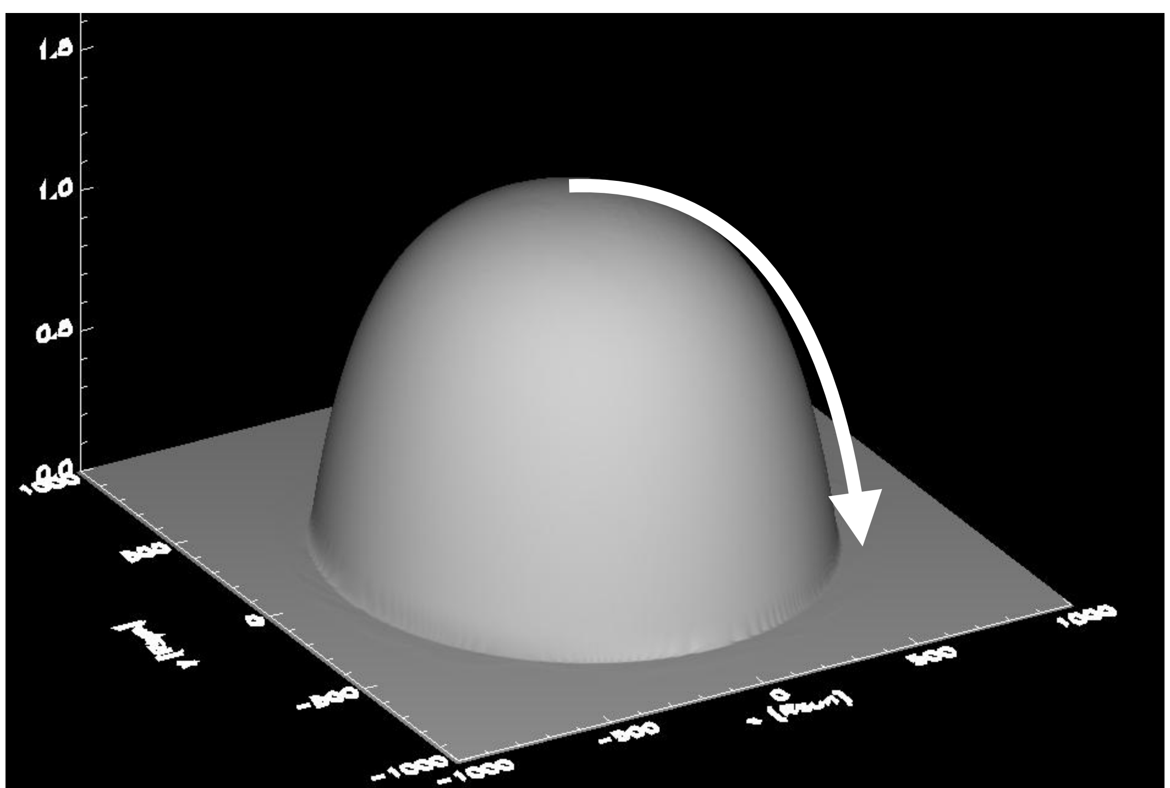

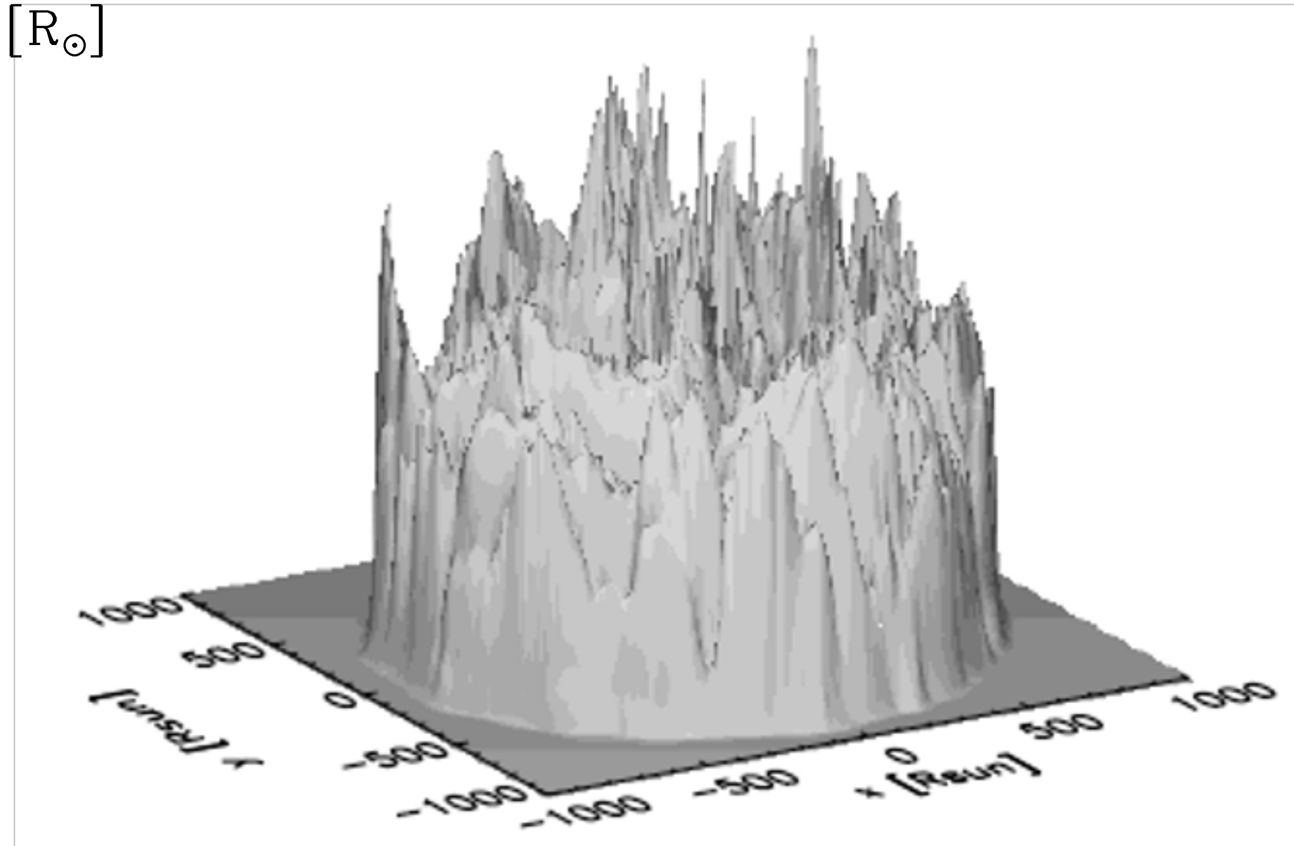

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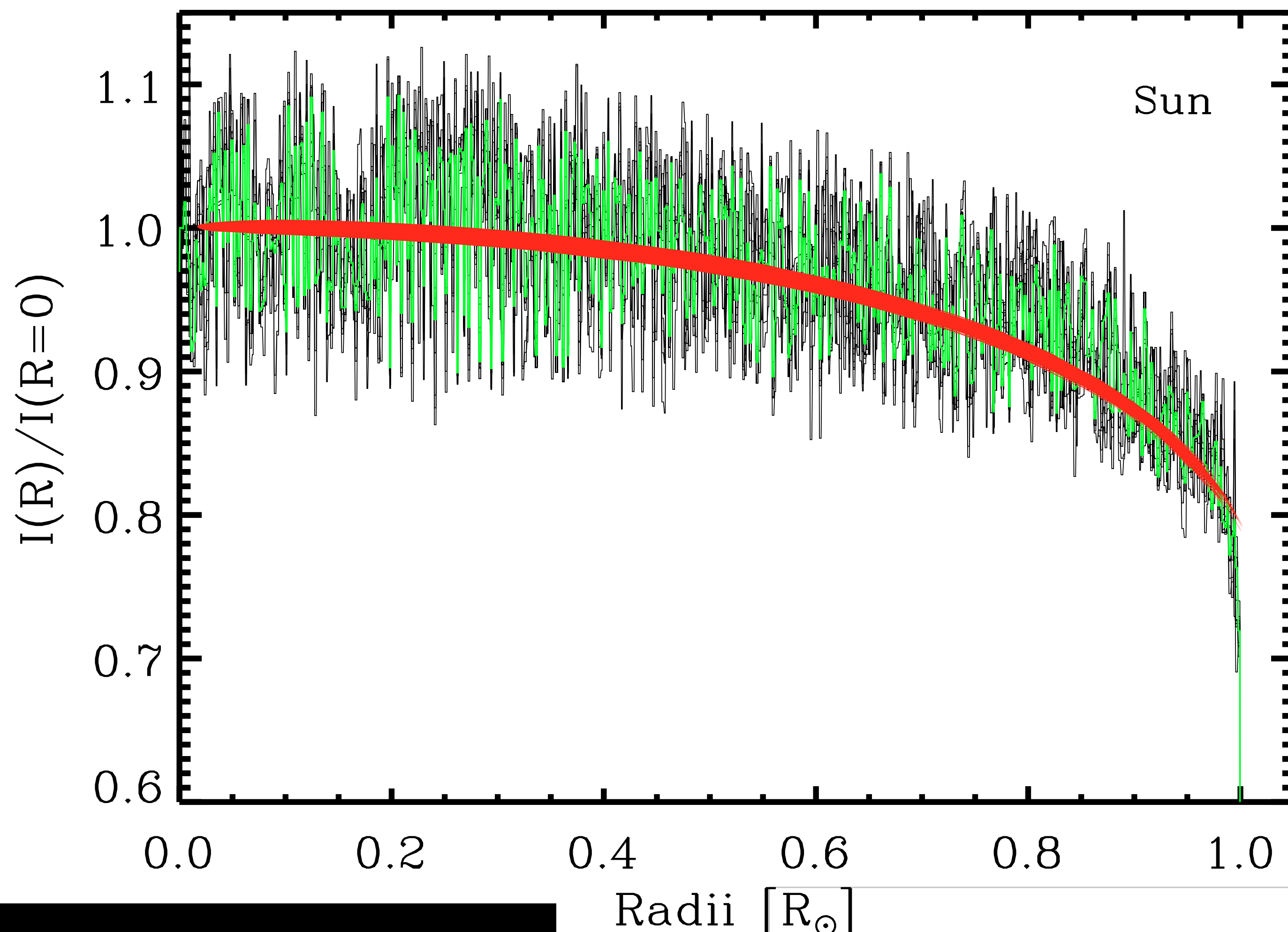

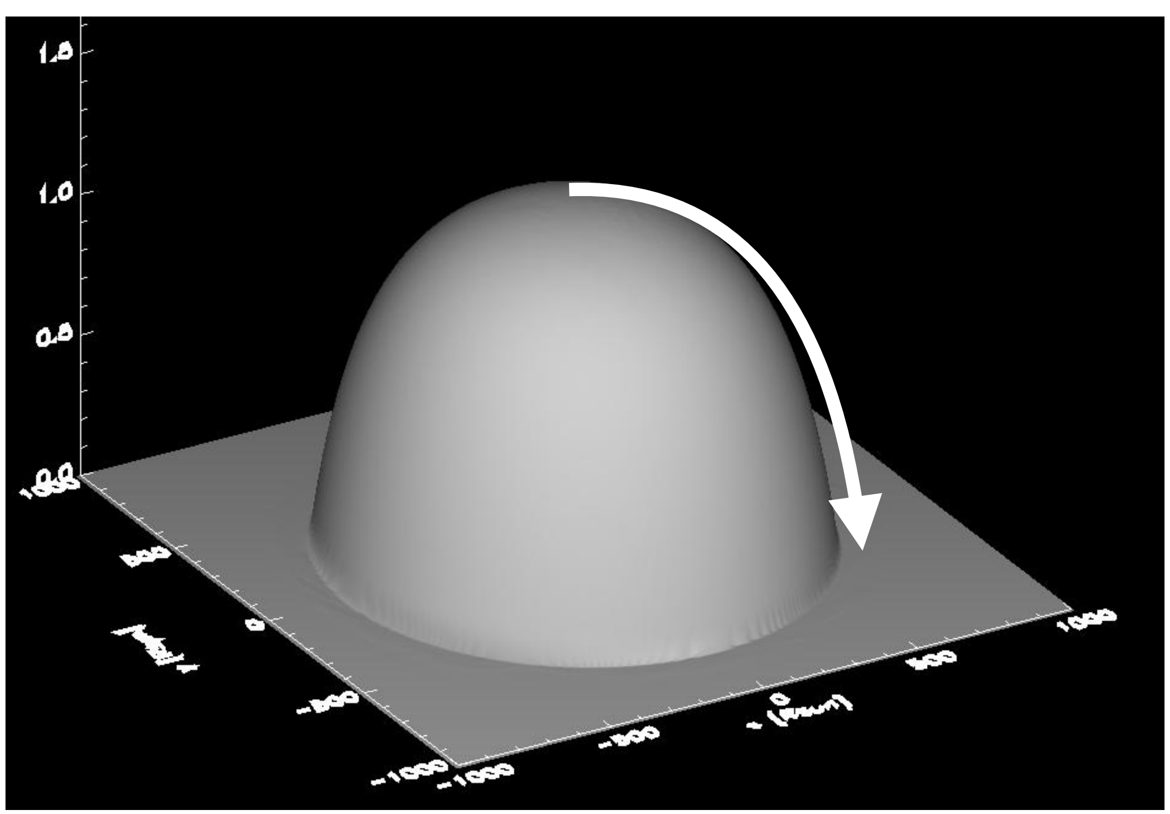

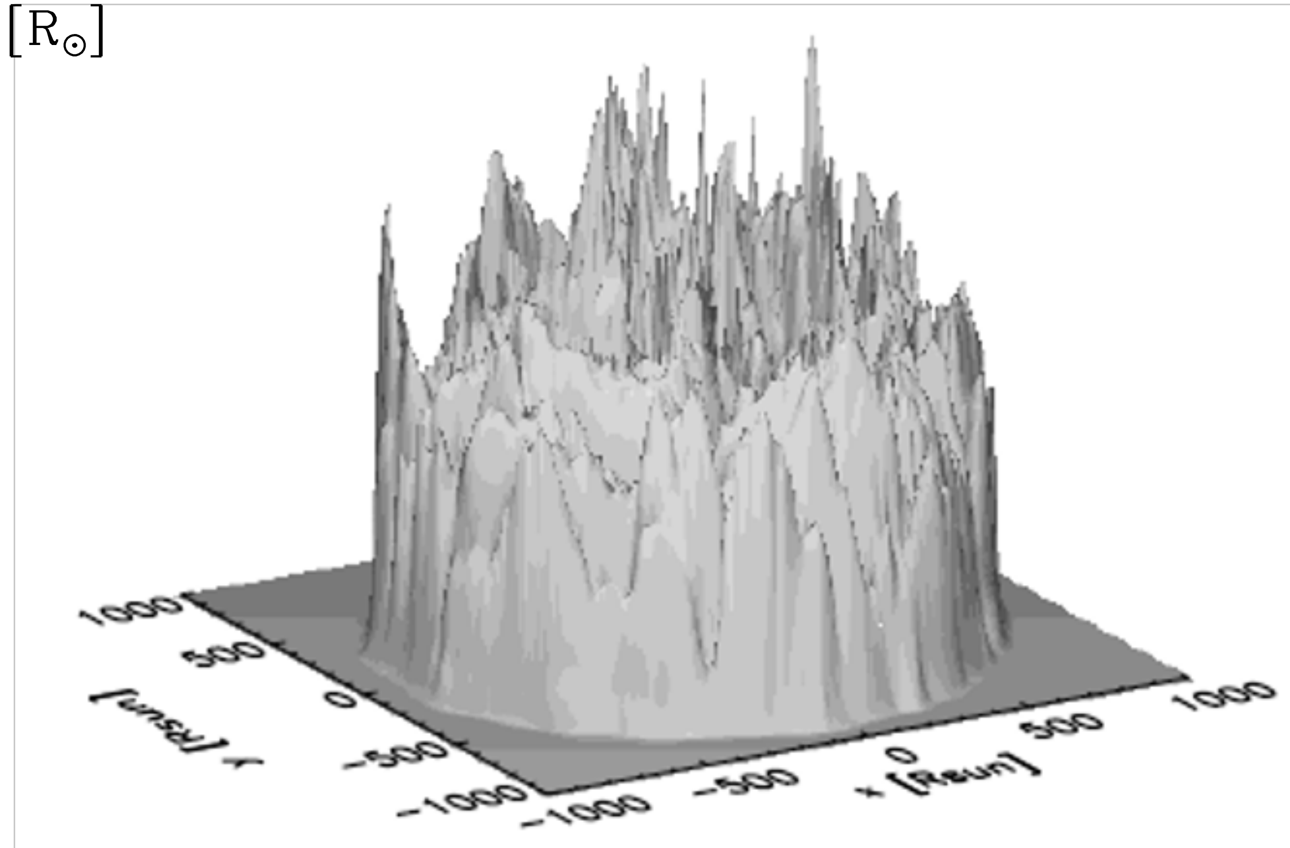

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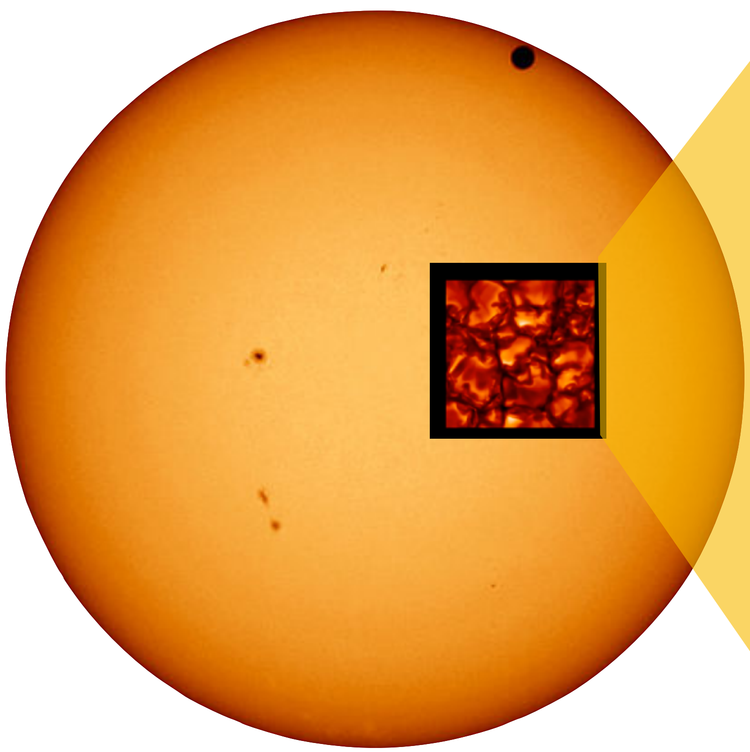
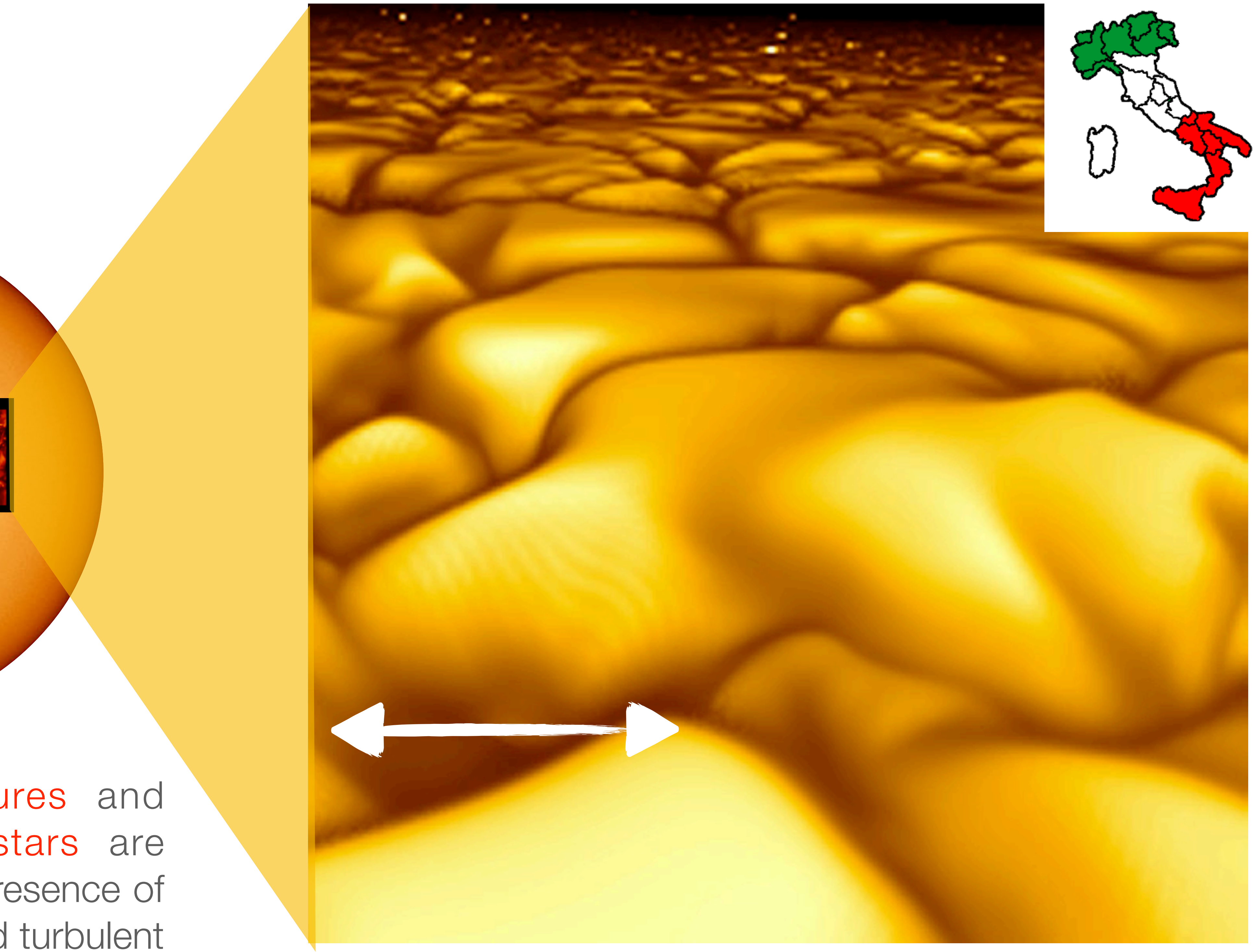


The surface structures and dynamics of cool stars are characterised by the presence of convective motions and turbulent flows which shape the emergent spectrum.

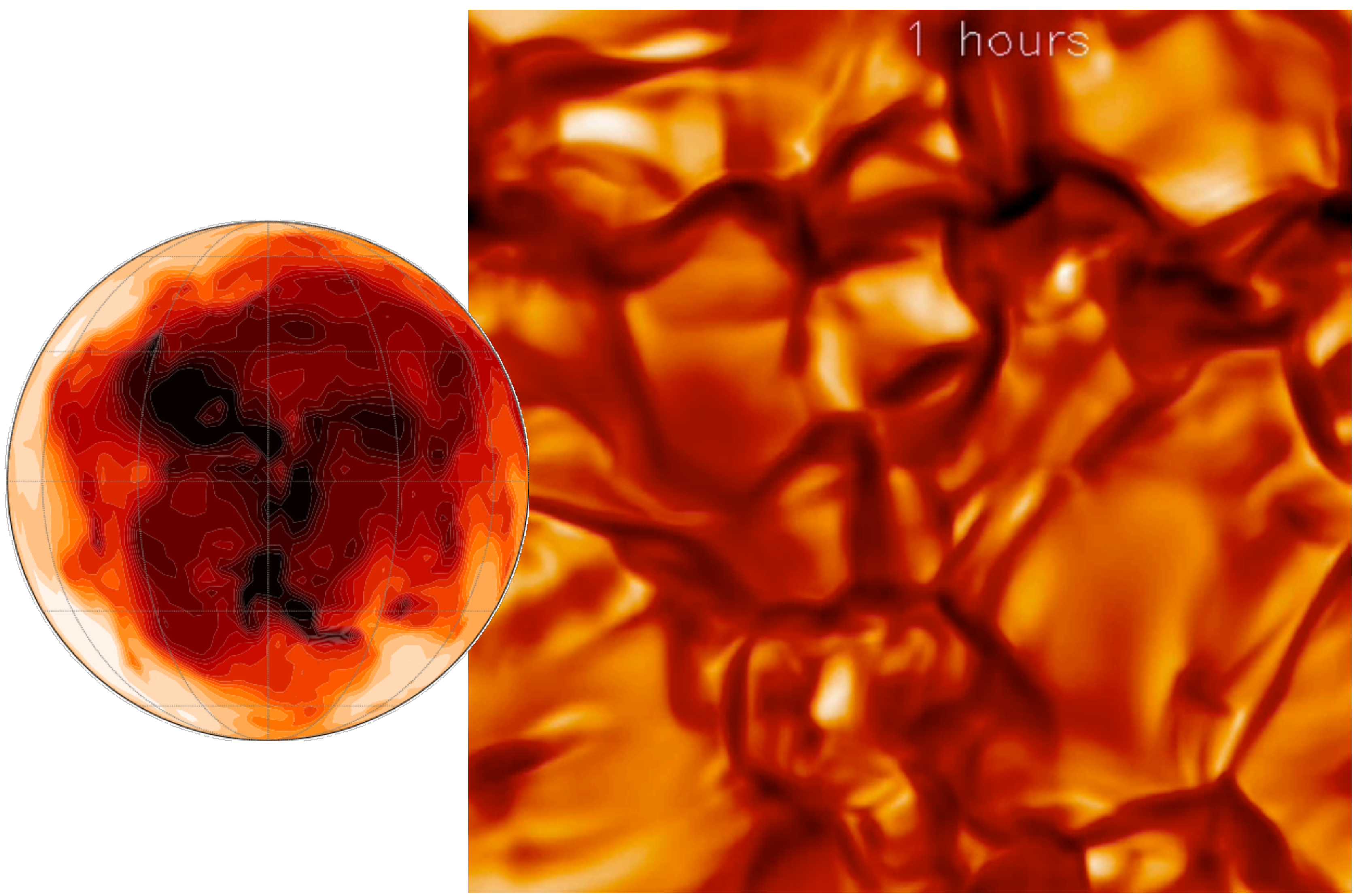


For the Sun, about 1000 km, about 5 minutes
(synthetic data, video from M. Carlsson)

Are stars really smooth?

What is the impact of stellar granulation on the observed planetary signal?

- Photometric transits
- Brightness and velocity variability
- High spectral resolution



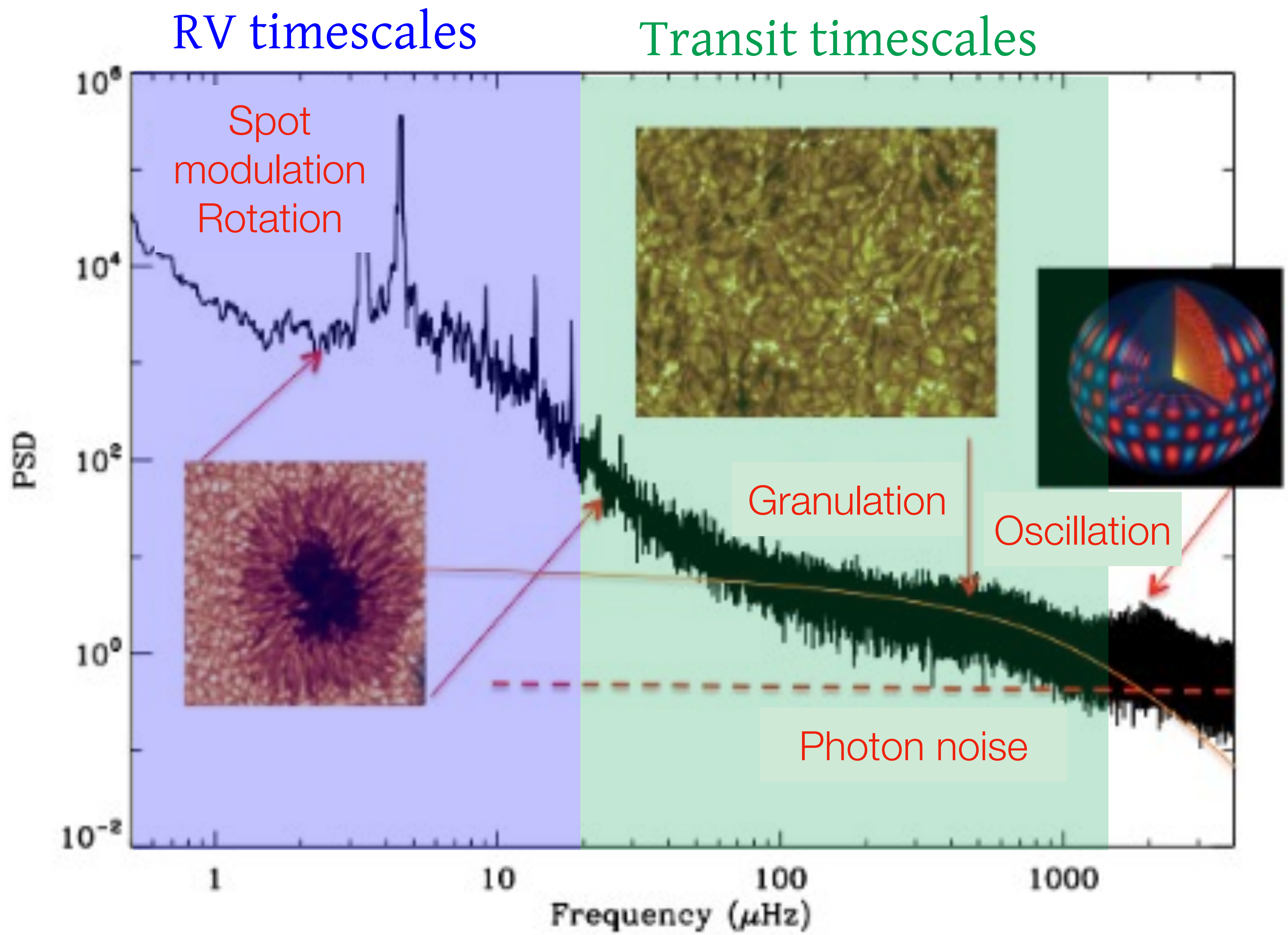
Are stars smooth?

Brightness variability

Stellar contamination: M dwarf stars

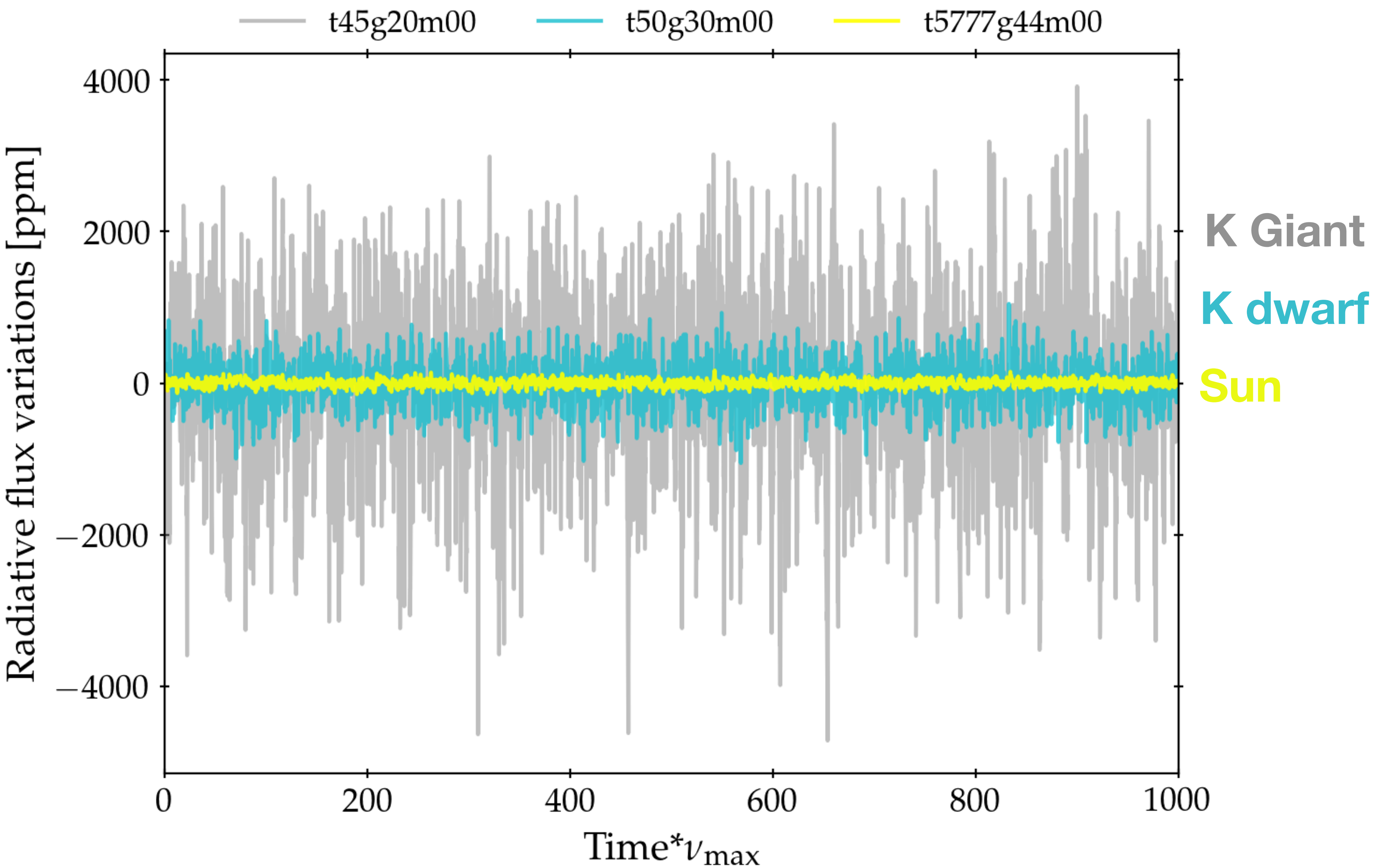
Conclusions

Pulsating stars



KIC 3733735 (F5iV-V star), figure adapted from Garcia et al. 2014

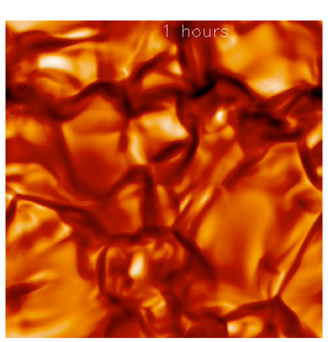
Brightness variations



Detecting an Earth
- 12 hours transit
- 9 m/s in amplitude
- 84 ppm

Perryman 2018

Sun granules



∼1 Mm in size
- 5-10 minutes in time
- 40-80 cm/s in amplitude
- 10-300 ppm

Rodríguez Díaz et al. 2022
Chiavassa et al. 2018

K Giant granules

∼600 Mm in size
- hours to days in time
- 200-300 m/s in amplitude
- 1000-2000 ppm

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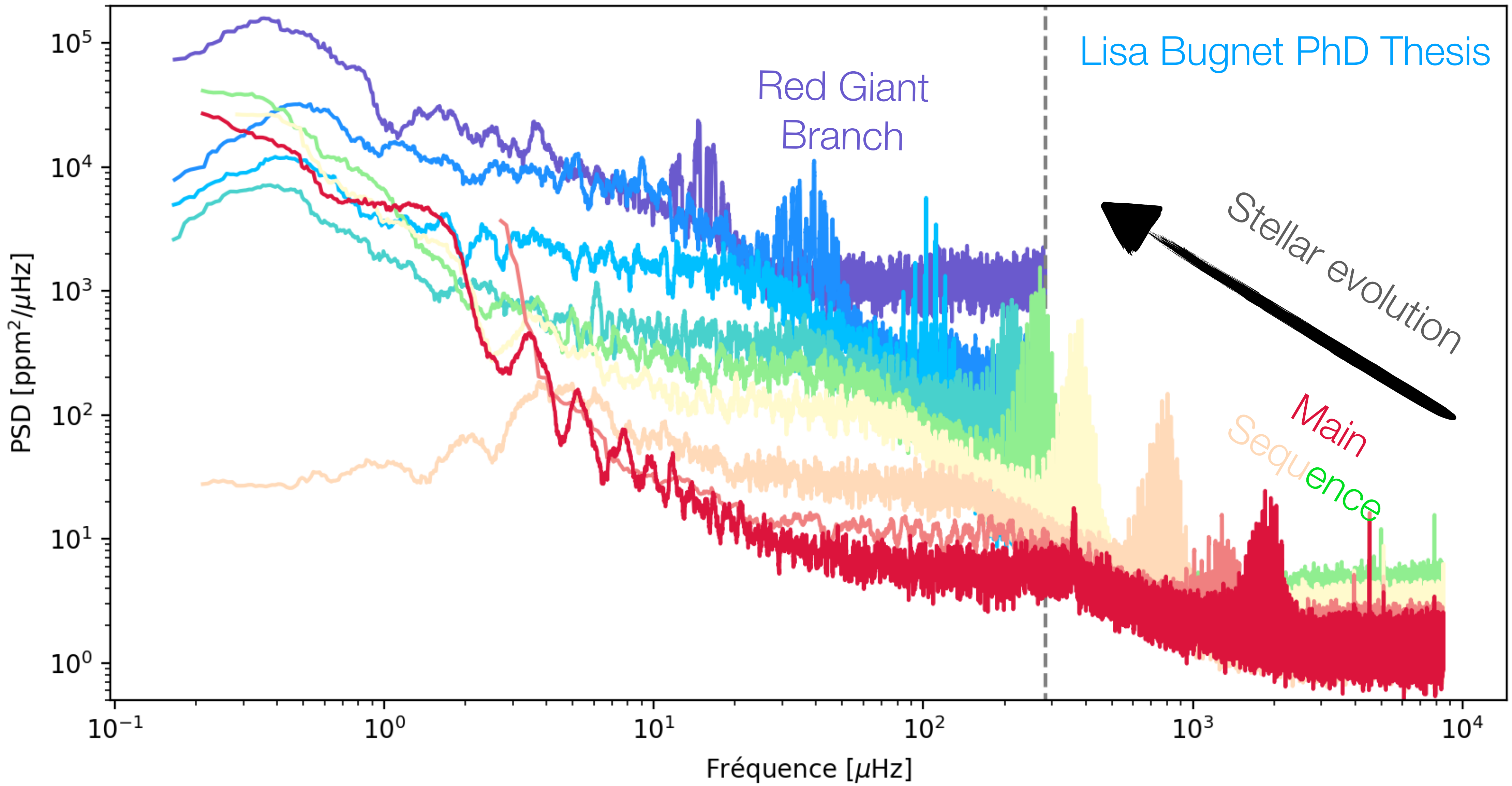

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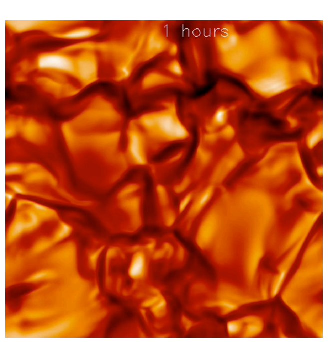

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Granule sizes depend on pressure scale height and, in particular, on surface gravity

Rodríguez Díaz et al. 2022
Chiavassa et al. 2018

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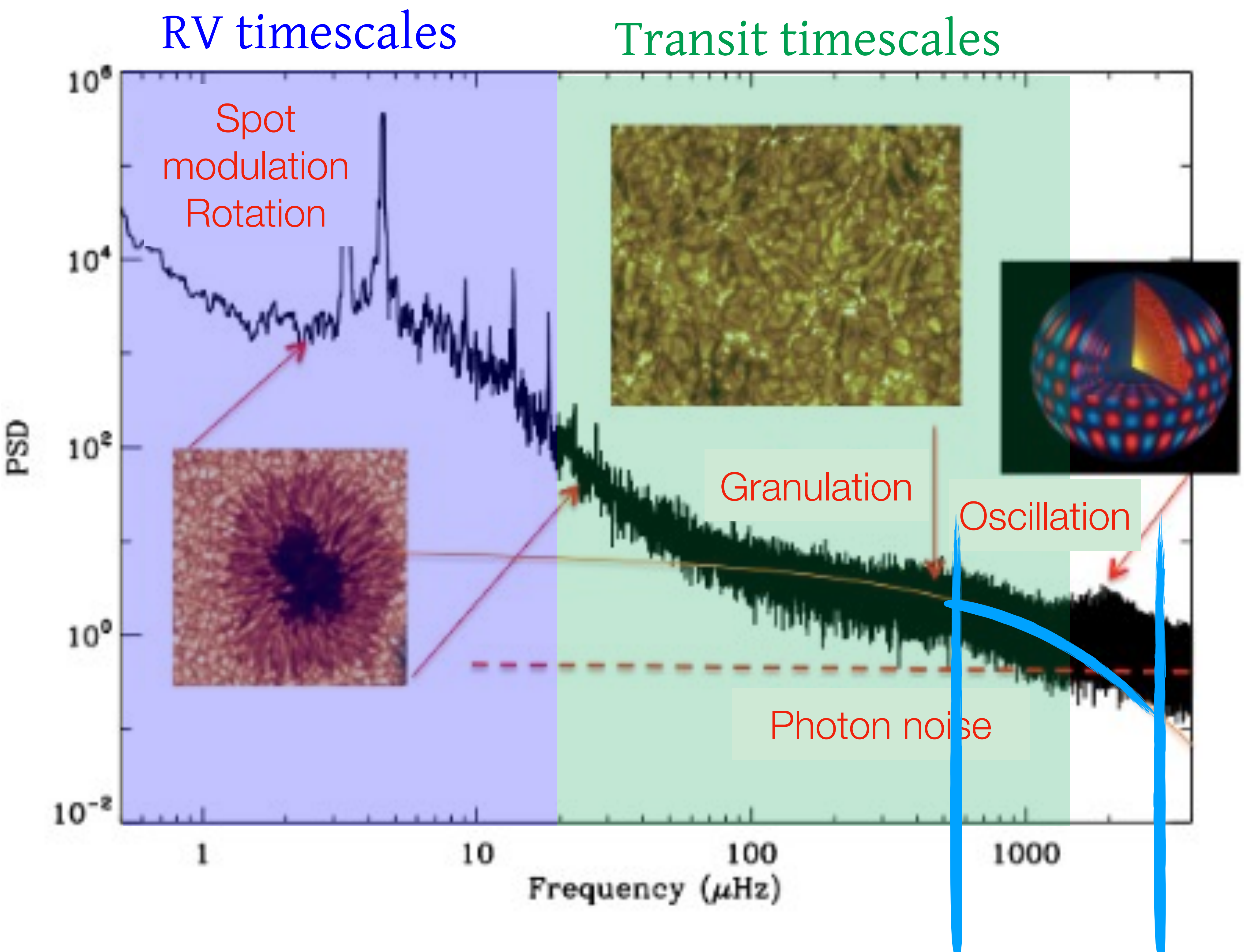

Sulis et al. 2023

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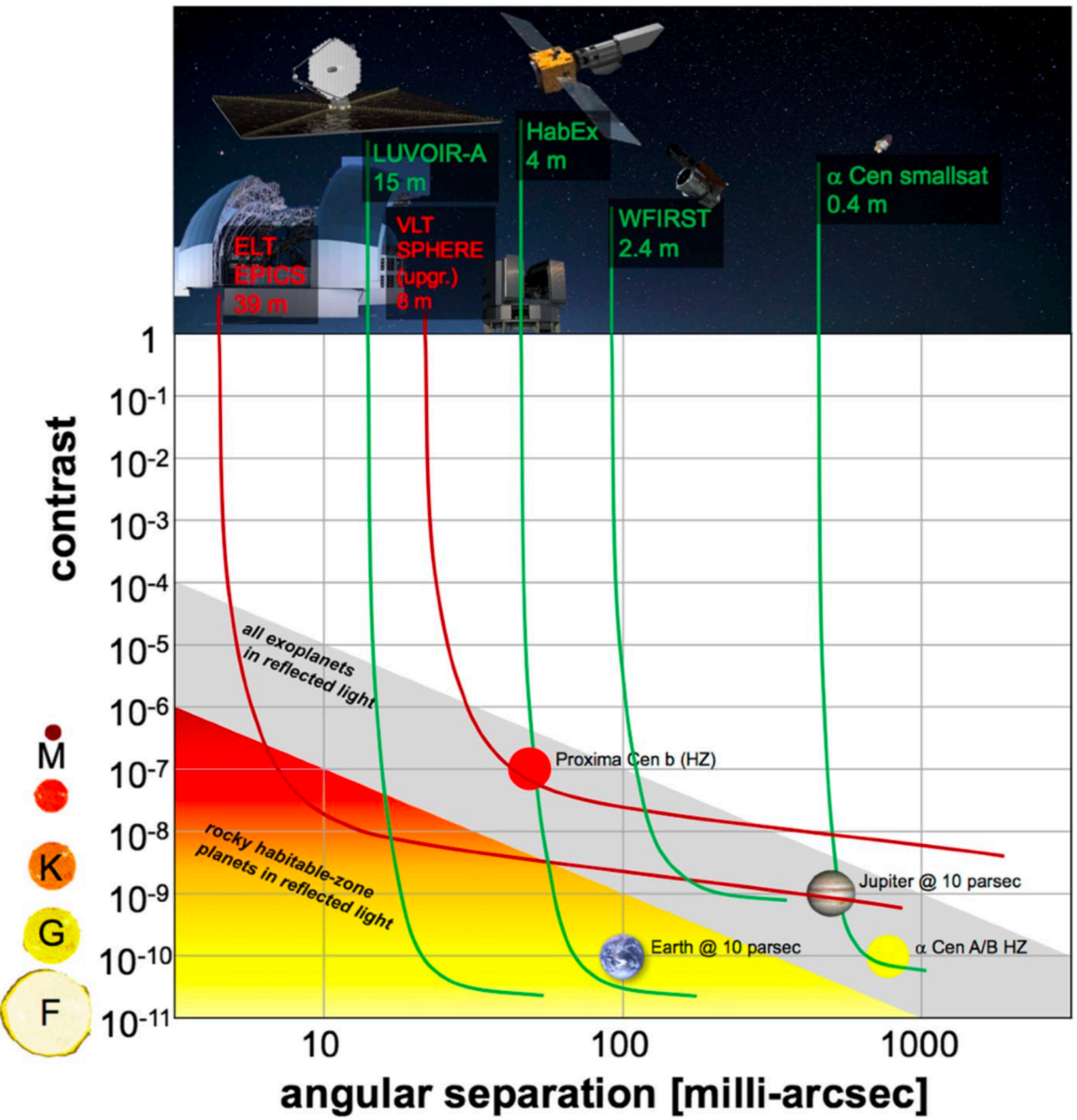
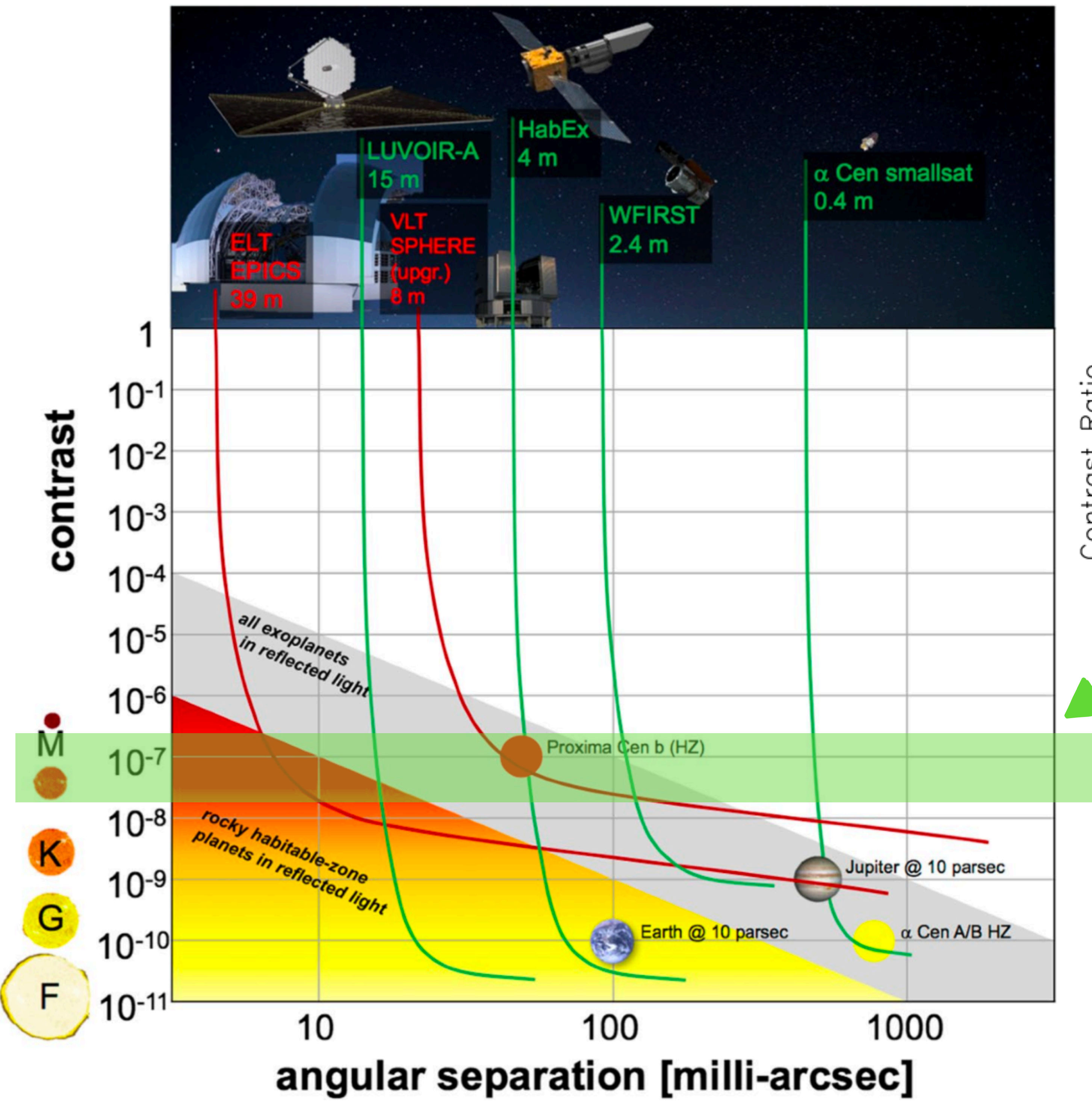
Combining high-dispersion spectroscopy with high contrast imaging



Snellen et al. 2022 (to be updated)

Combining high-dispersion spectroscopy with high contrast imaging



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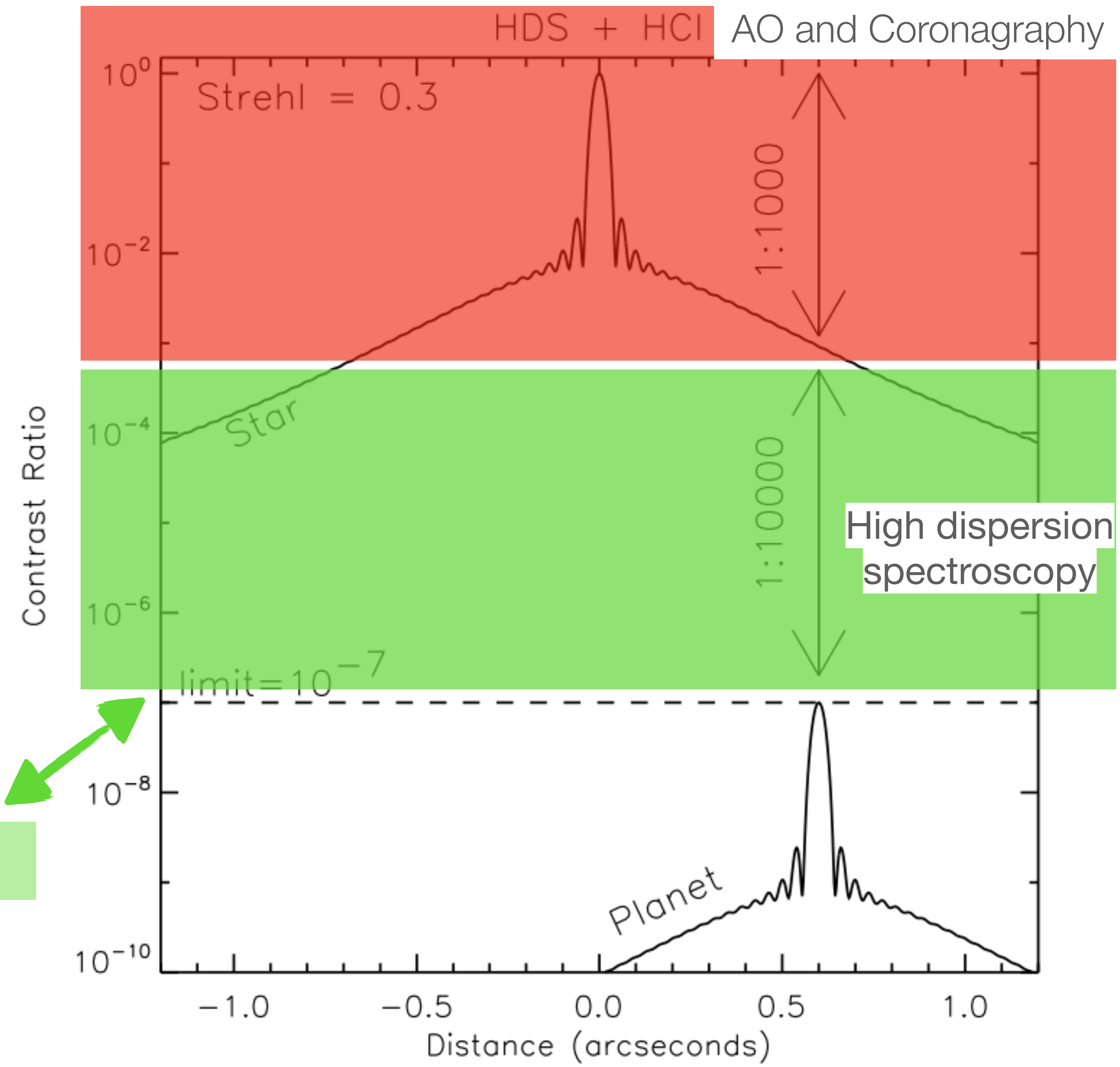
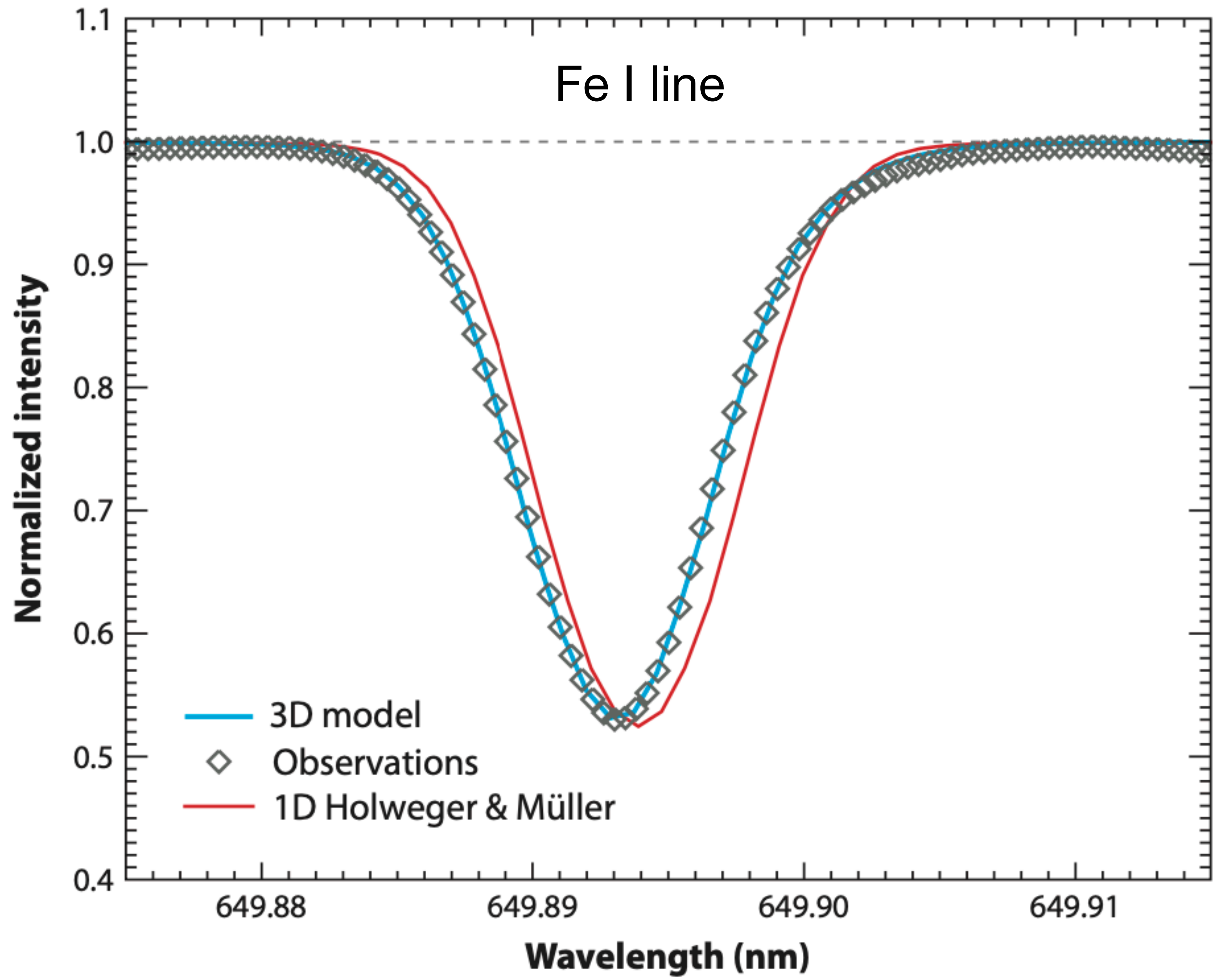


Snellen et al. 2015

Hosting star: precise stellar characterisation

Measurements of solar (stellar) abundances that you likely use in your codes or plotting reference for the Sun



There is not a complete agreement on the abundances. Which one has to be taken?
The differences are not negligible (up to 20% for some elements)

Critical importance of chemical analysis of the host star

Asplund et al., 2009, 2020	Caffau et al., 2011	Amarsi et al., 2021	Magg et al., 2022
Stagger-code (3D LTE)	Co5bold (3D LTE)	Stagger-code 3D LTE (new analysis on molecules)	1D/<3D> NLTE analysis

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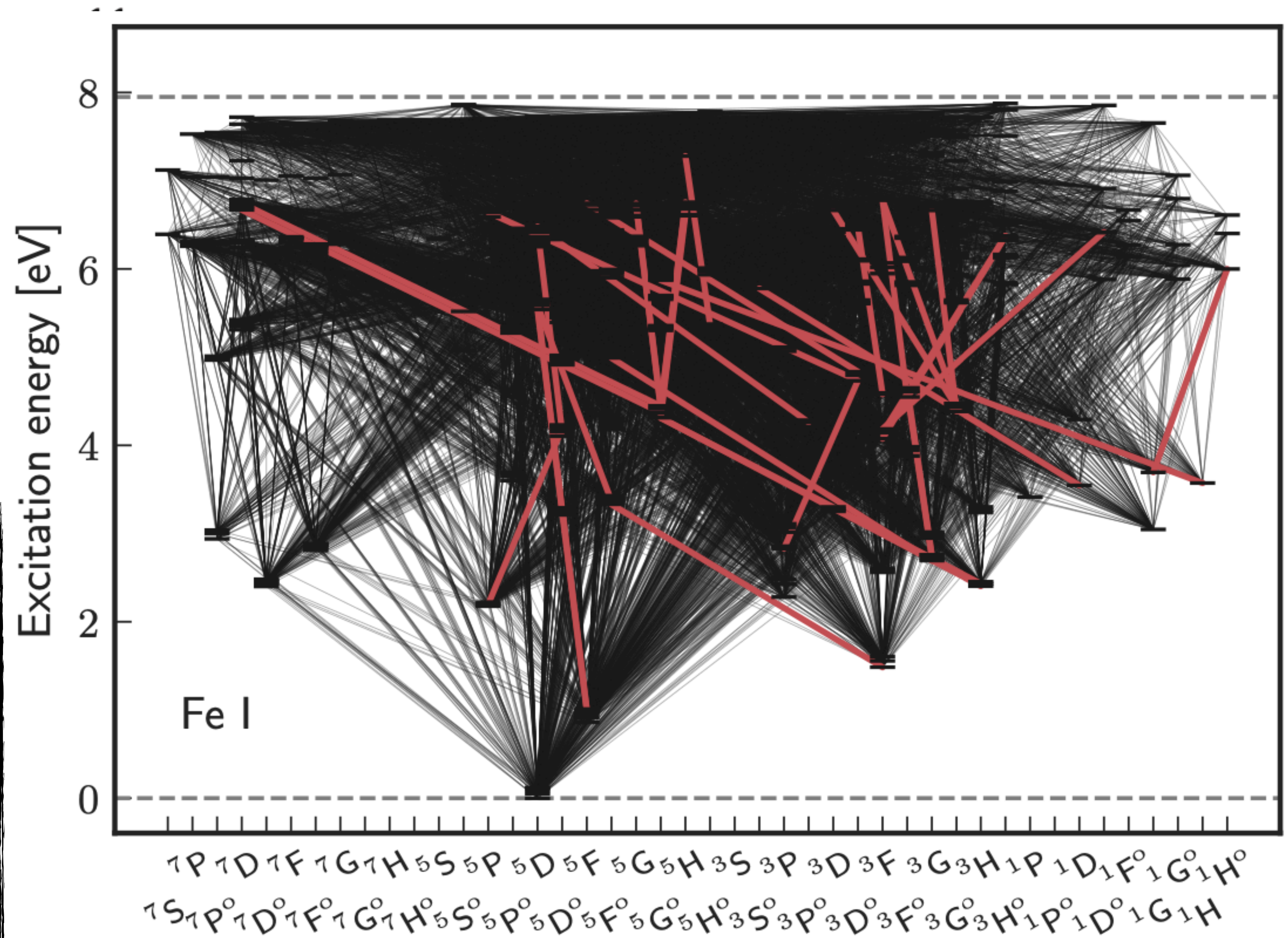

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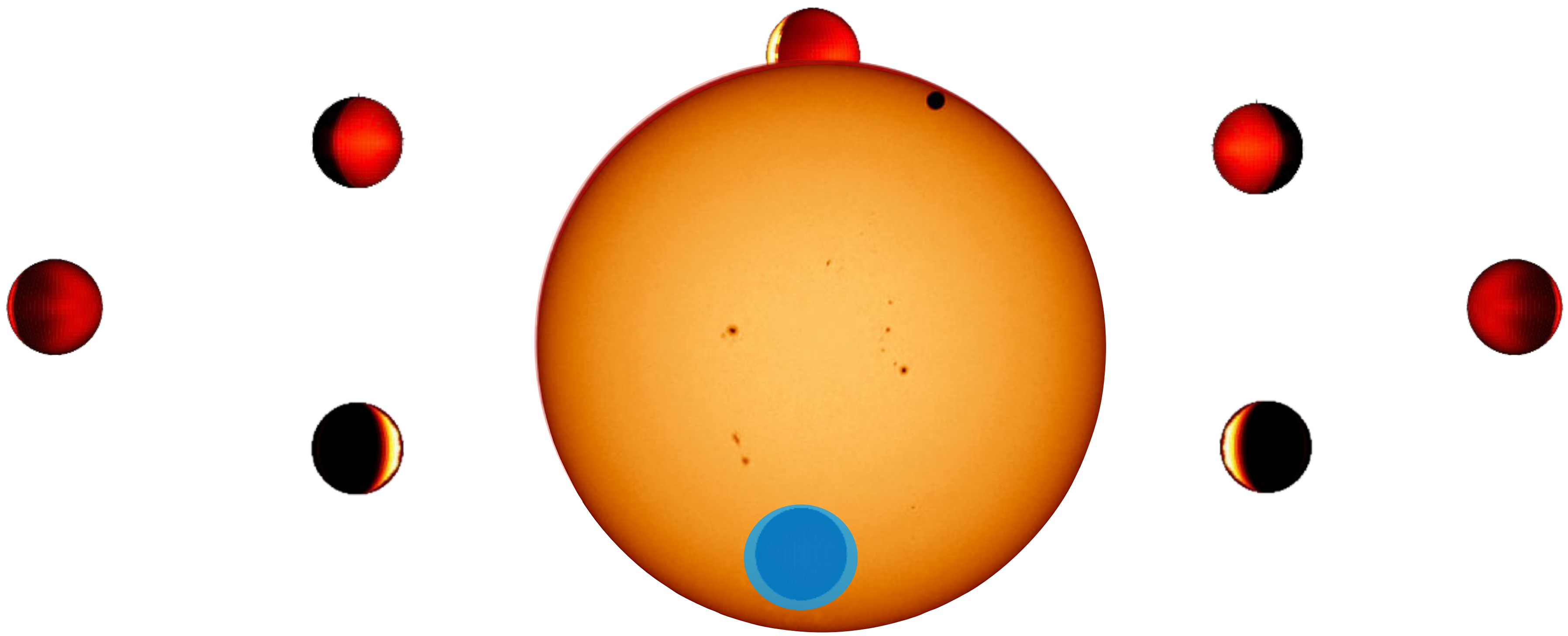
1D/<3D> NLTE
analysis

Stellar contamination

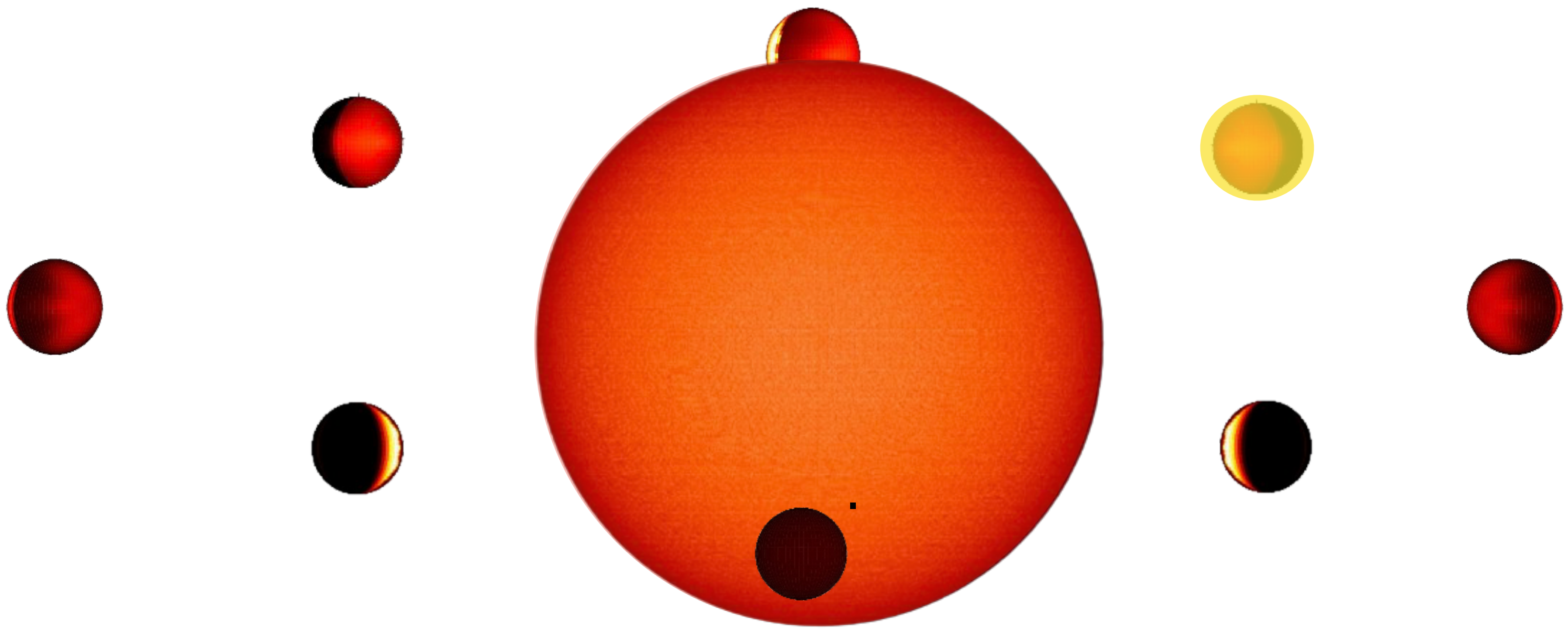


Atmosphere characterisation (N_2, CO_2, H_2O, CH_4…)

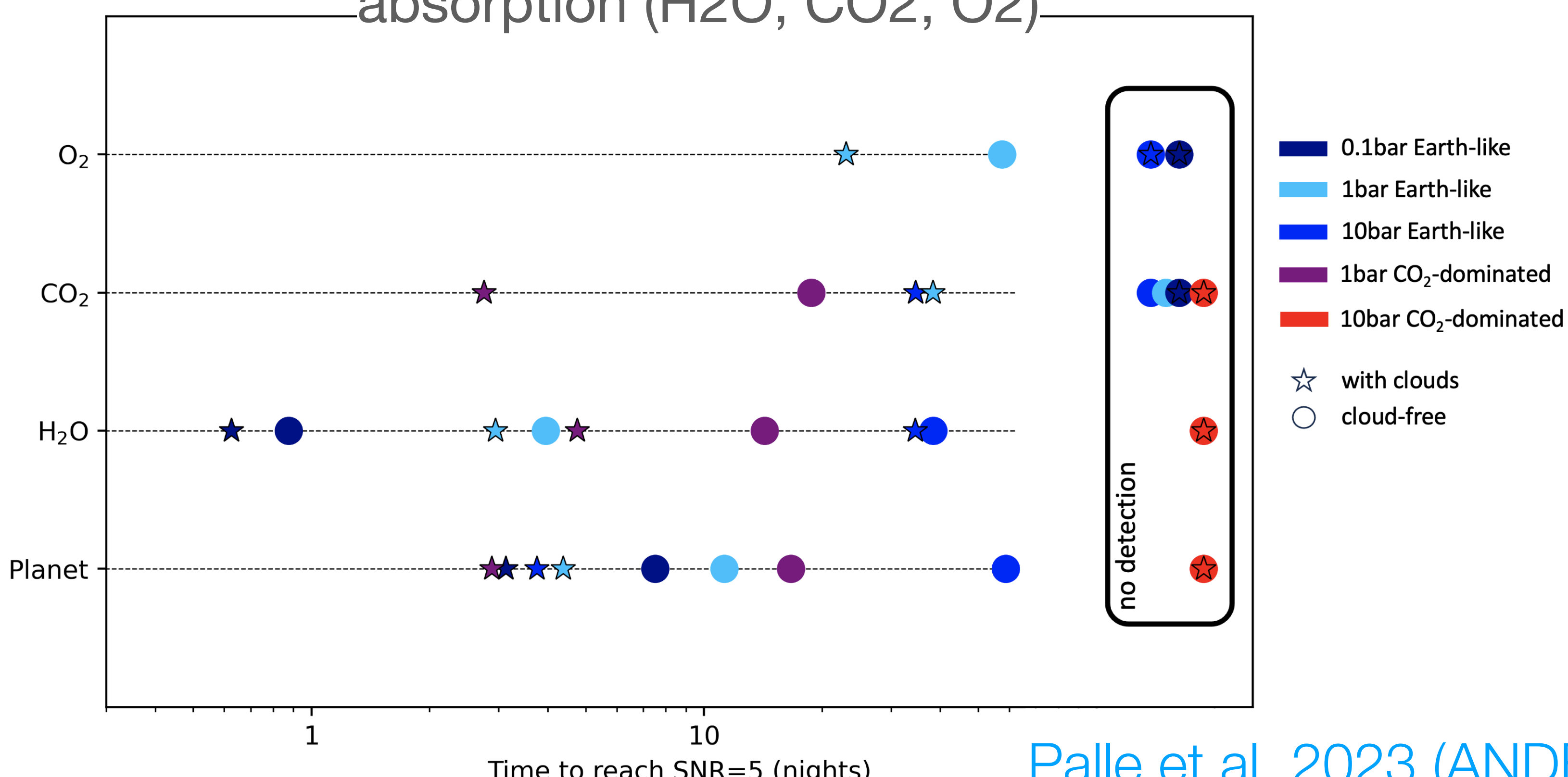
Transmission for Sun-Earth-like system is about 0.2 ppm

Transmission for M dwarf-Earth-like system is about 40 ppm

Stellar contamination



Stellar lines reflected on the planet or molecular absorption (H2O, CO2, O2)

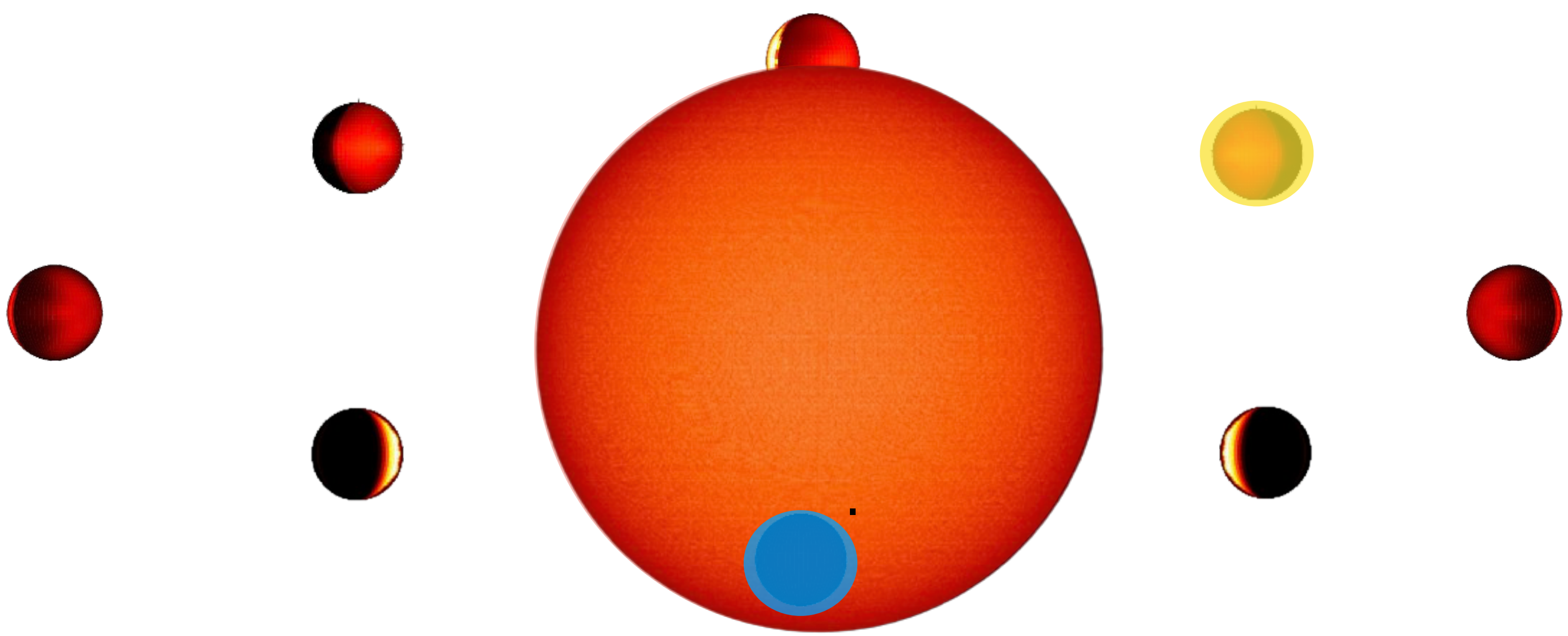


Palle et al. 2023 (ANDES paper)

Atmosphere characterisation (N2, CO2, H2O, CH4, O2)

Planetary albedo: reflective layers on the surface (ice, oceans) and in the atmosphere (clouds)

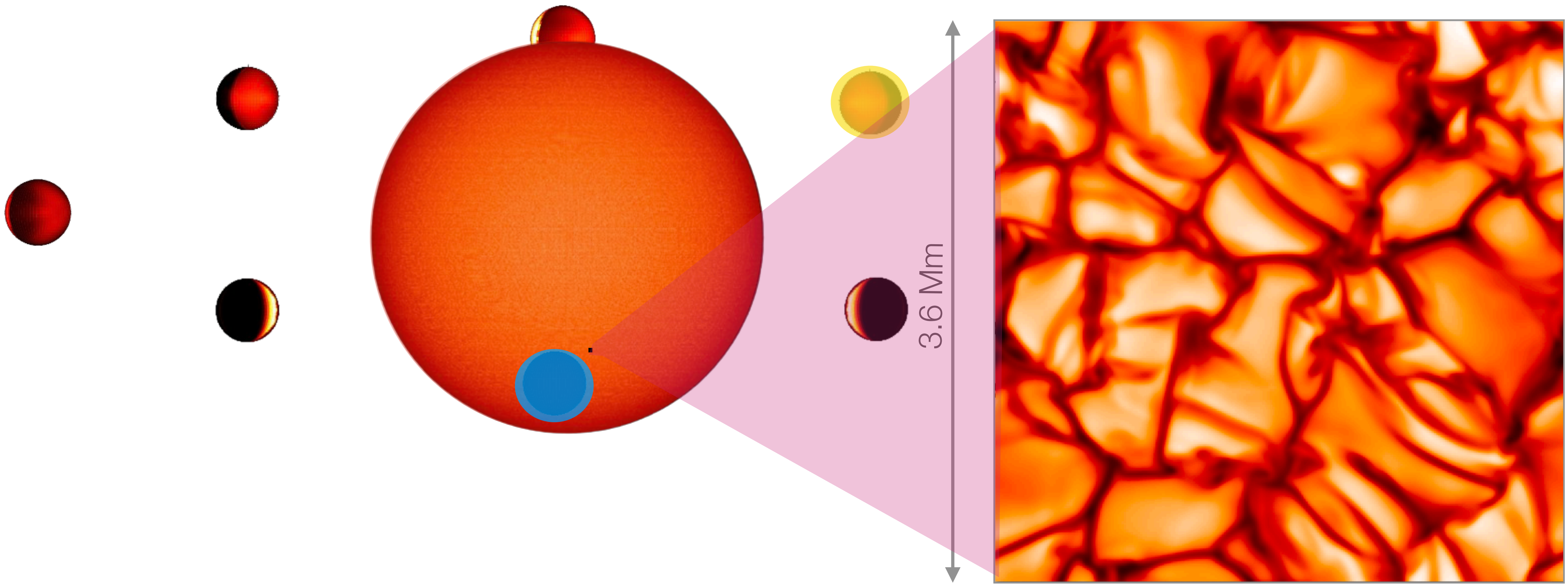
Stellar contamination



Best case scenario: M dwarf + Earth like system

Stellar activity
Molecular absorption
Stellar variability
Stellar parameters

Stellar contamination



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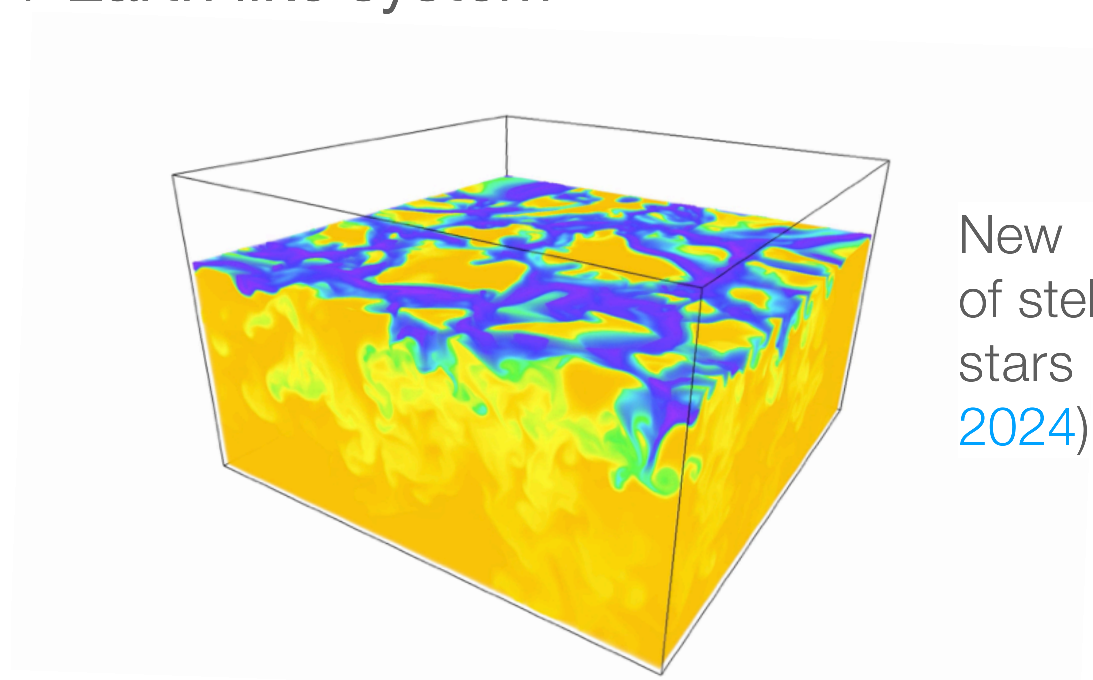
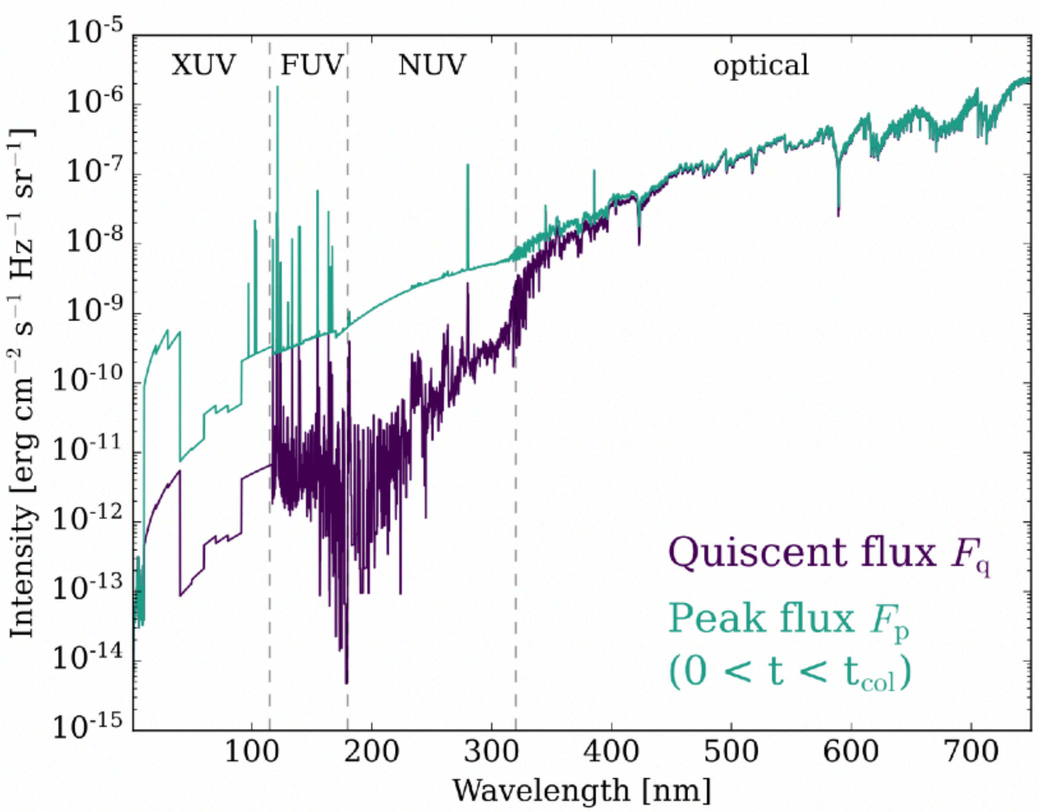


New state-of-the-art simulation of stellar convection for M dwarf stars (Rodriguez Díaz et al. 2024)

Stellar contamination: Stellar activity

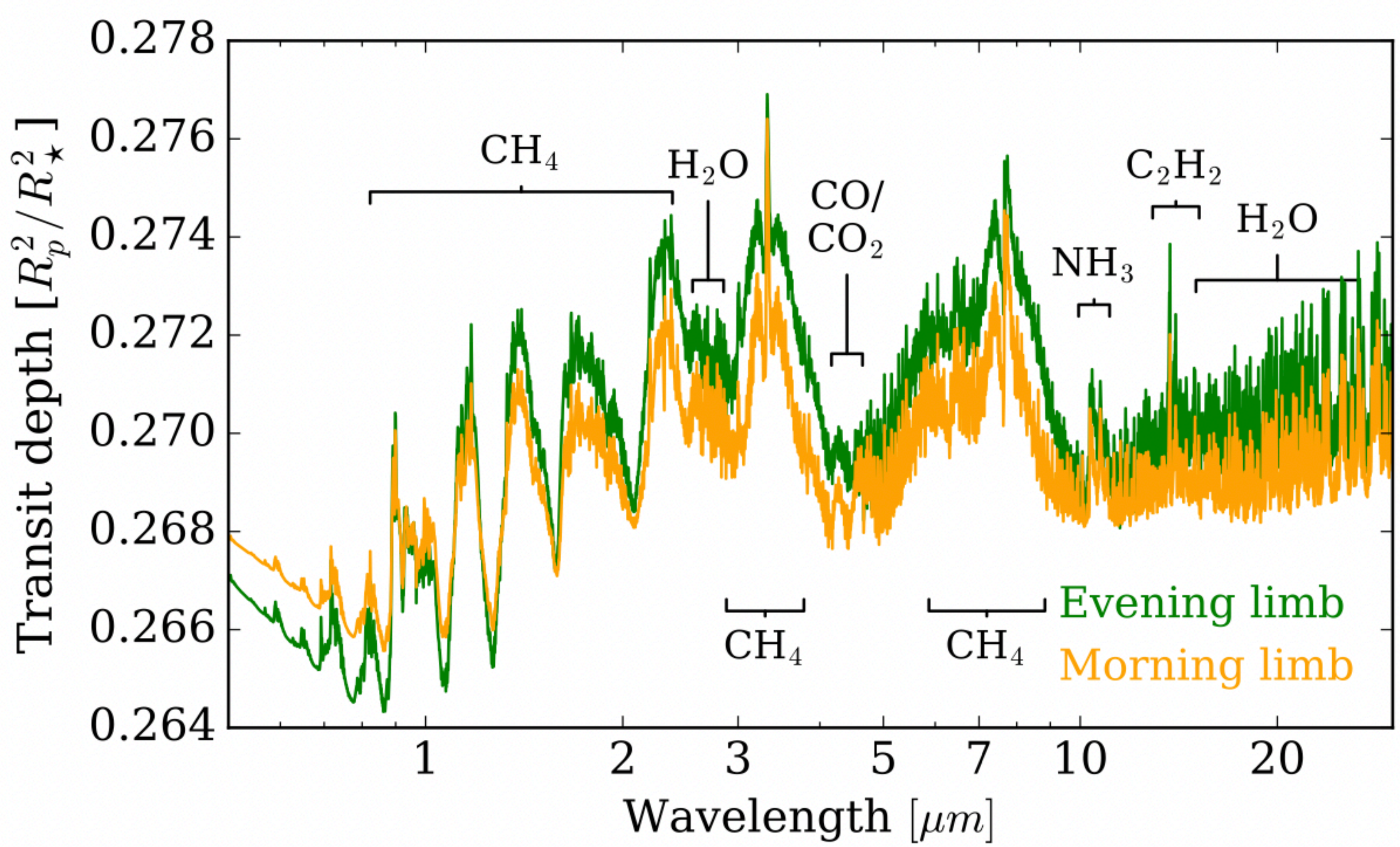
Synthetic flare of a M dwarf star



Impact on the (close-orbiting) gaseous planet atmosphere

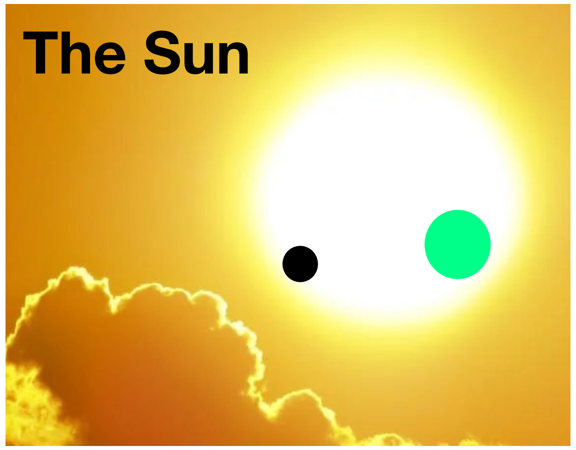
Several hundred of ppm

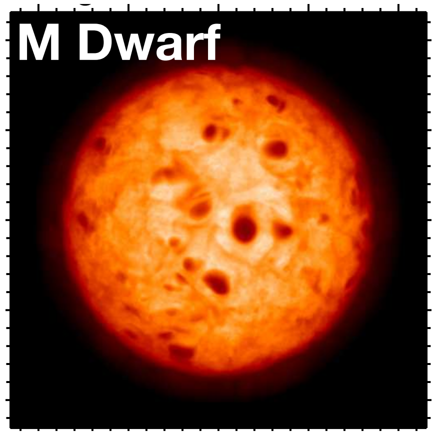
Happening up to several days after the flares

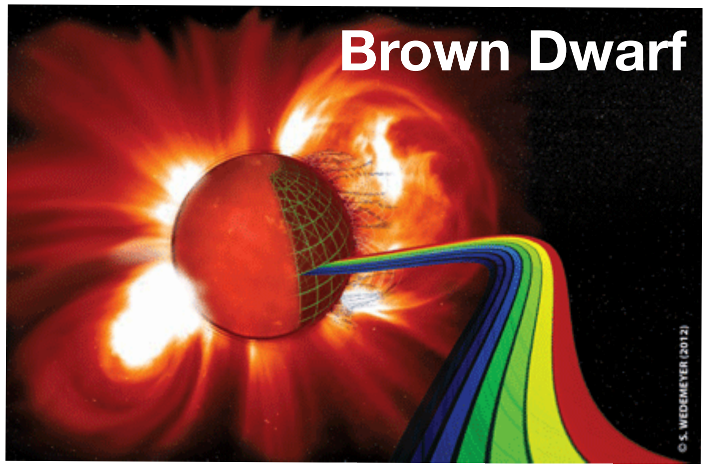


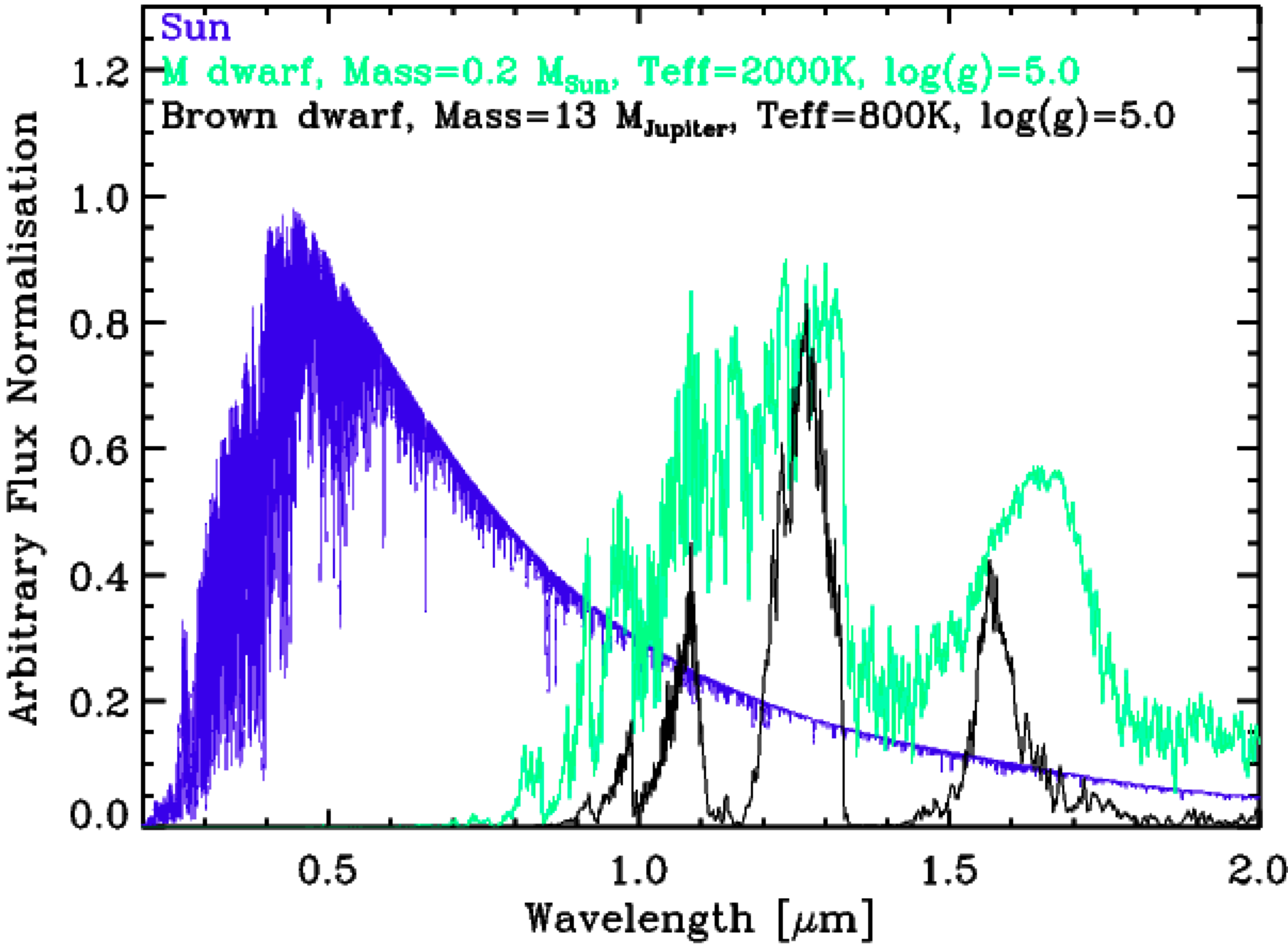
Konings et al., 2022

Stellar contamination: Molecular absorption









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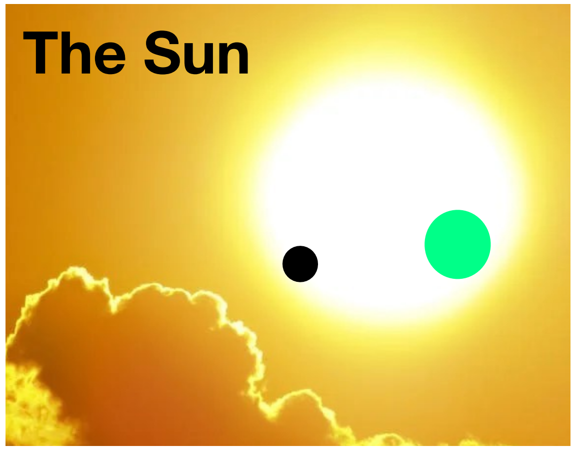
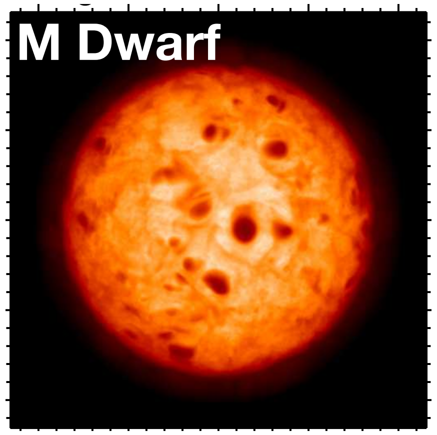
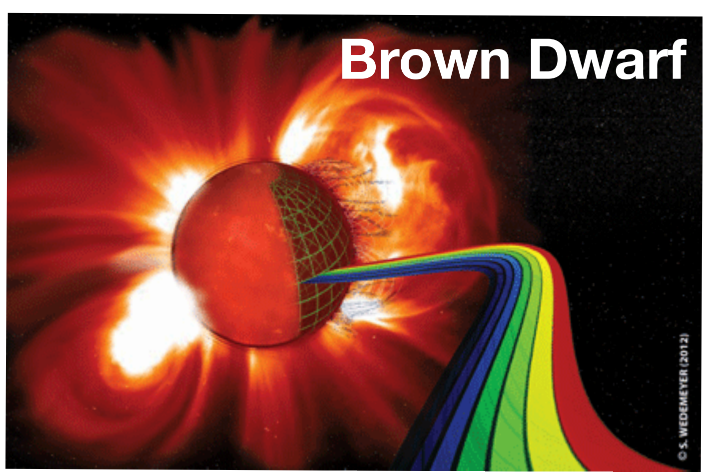
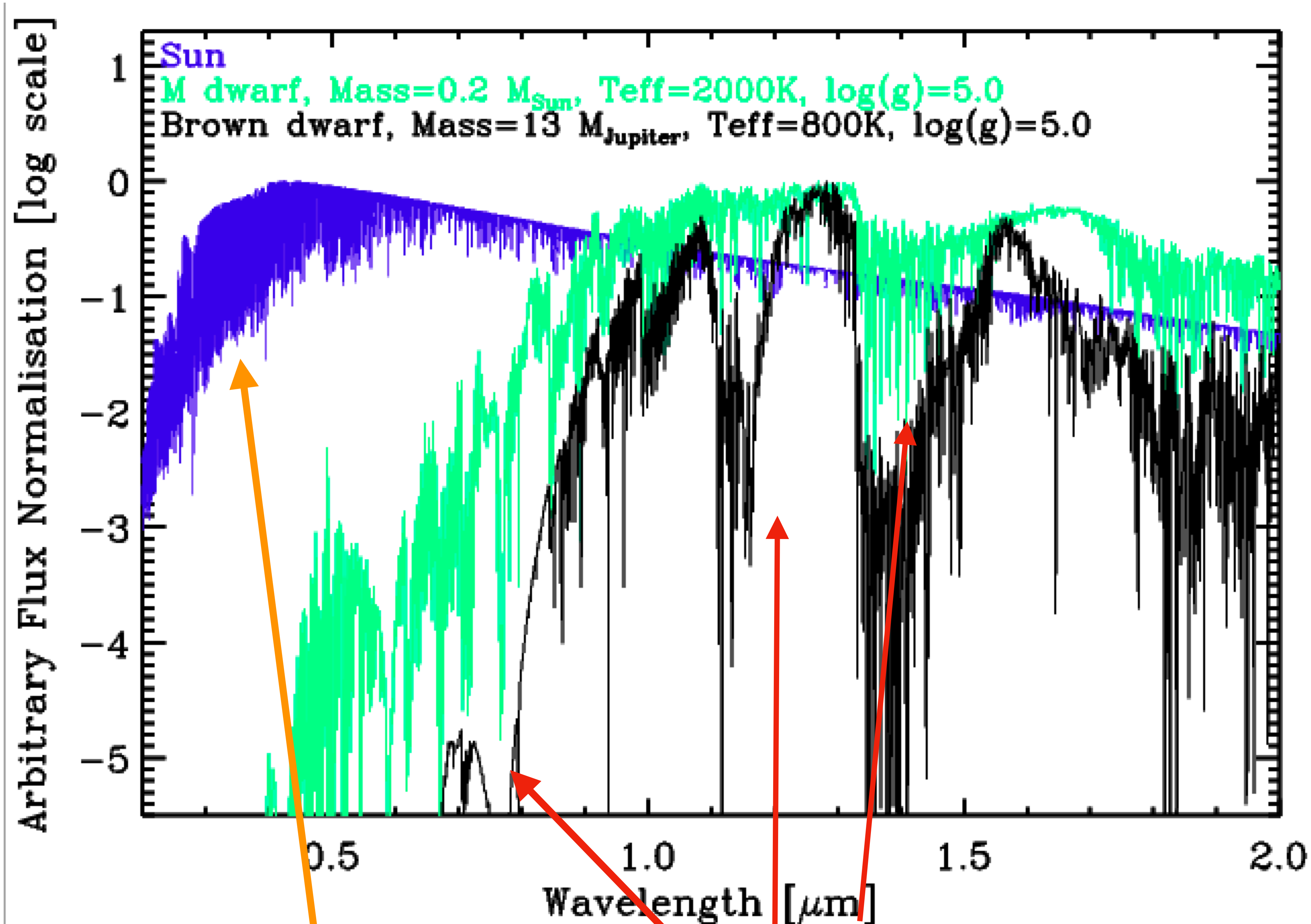




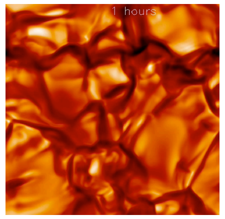




Molecular transitions
(e.g., TiO, VO, CO, H2O, …)

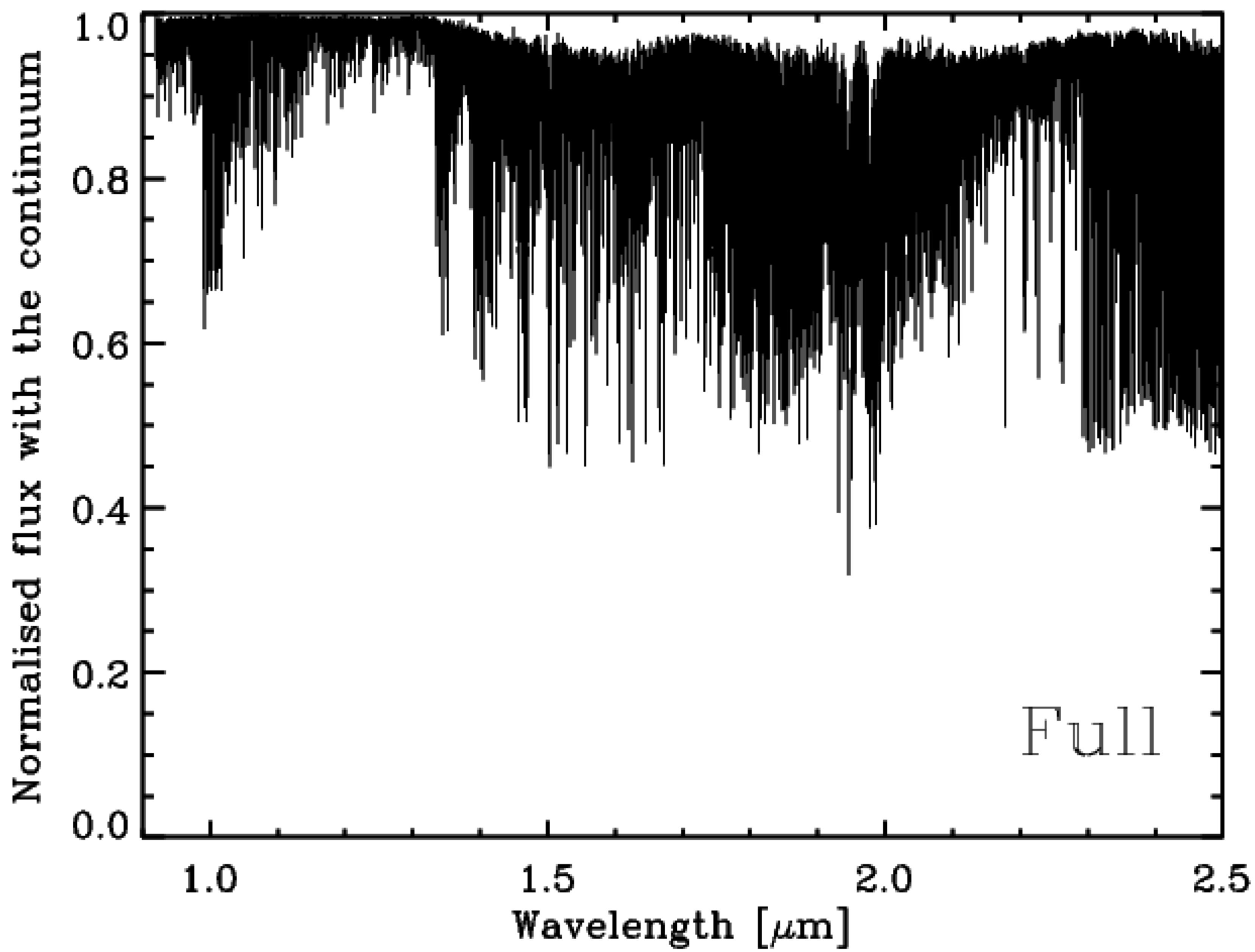
Atomic transitions

Stellar contamination: Molecular absorption



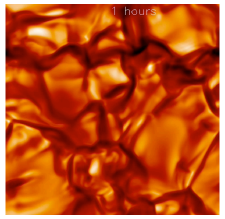
M dwarfs regime

Teff=3500K, logg=4.5, [Fe/H]=0



Chiavassa, Brogi, Bigot et al., in prep.

Stellar contamination: Molecular absorption



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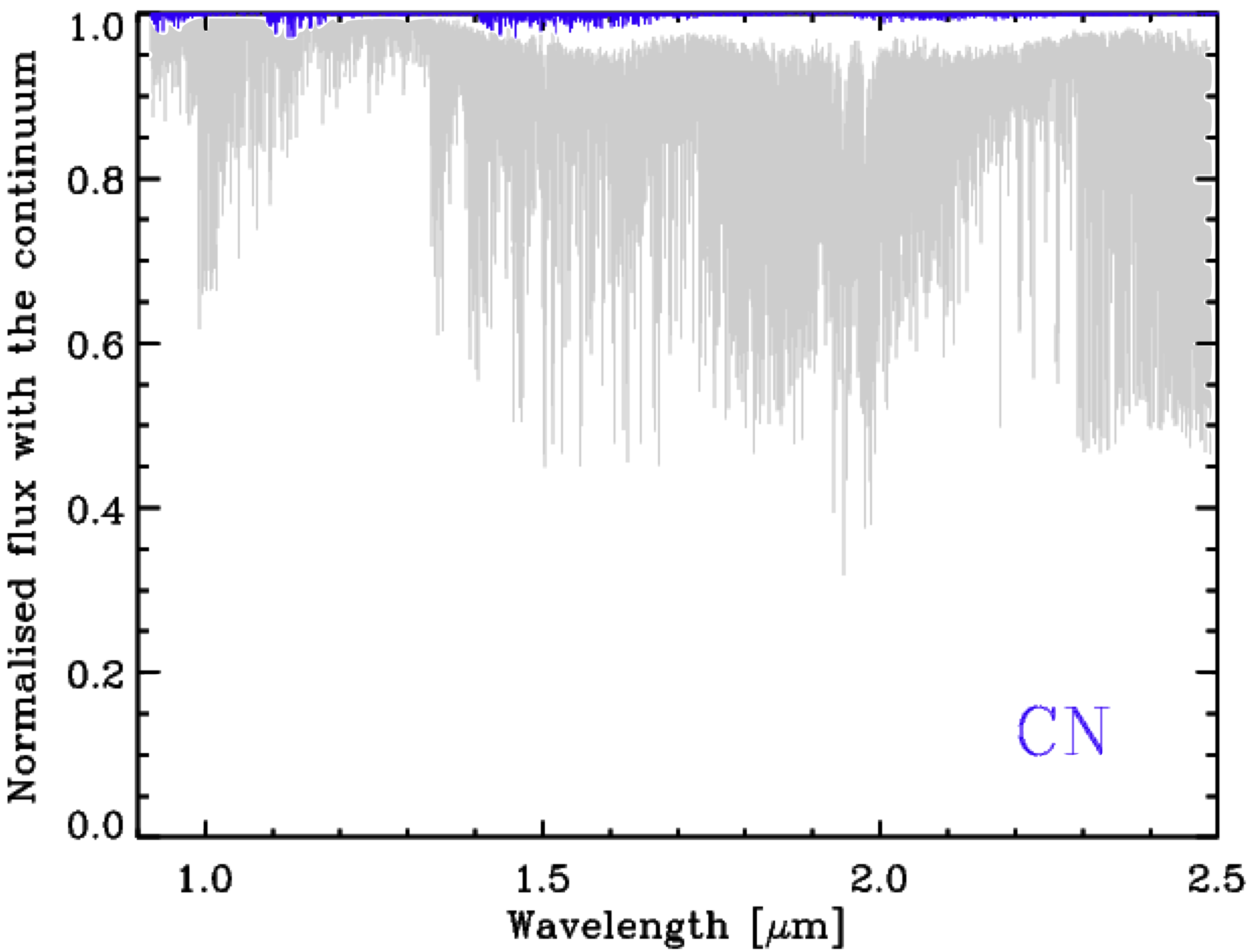
Low contributor

CN

Intermediate contributor

Large contributor



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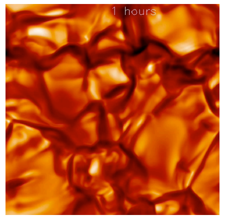

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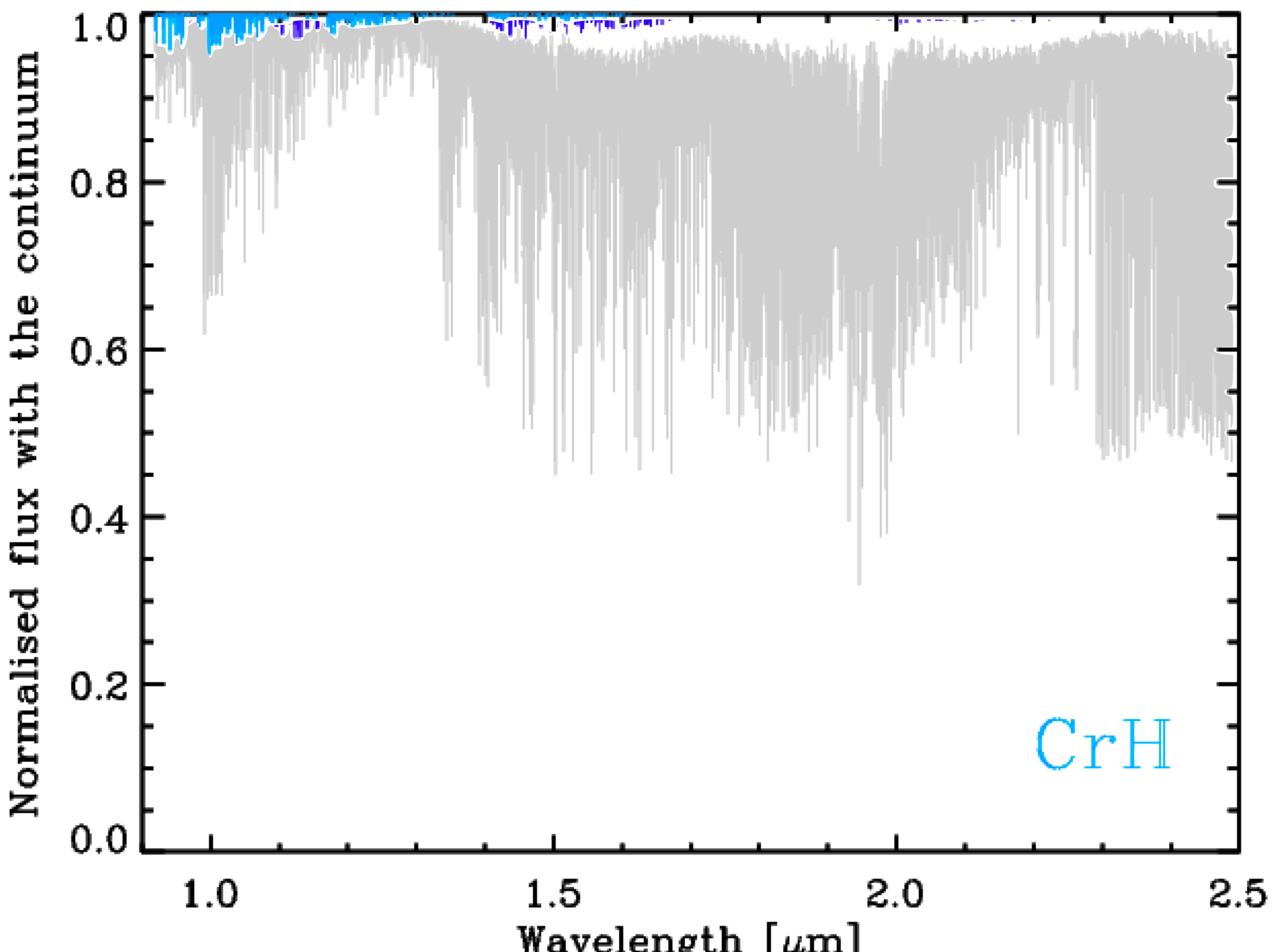

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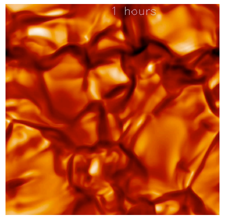

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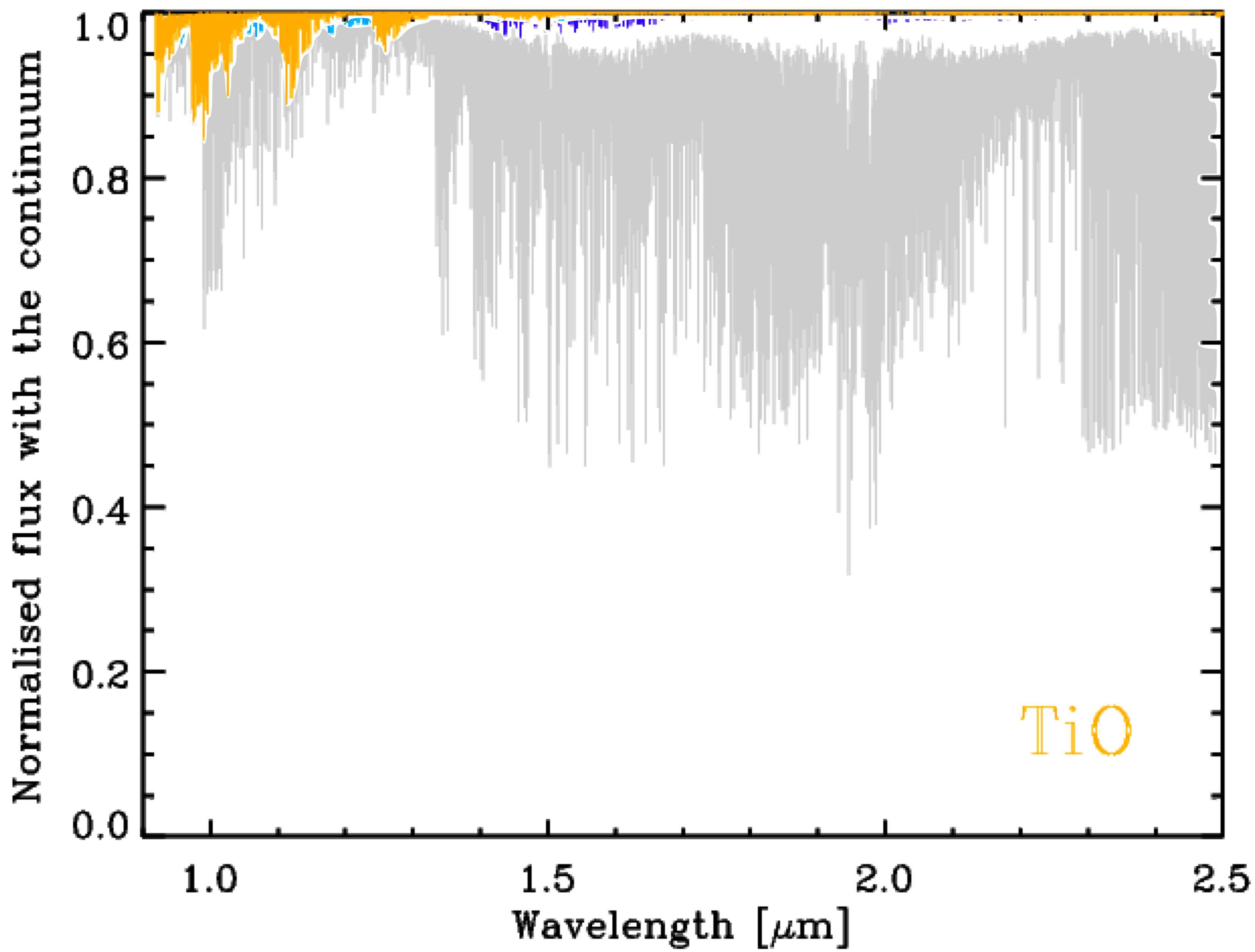
Large contributor



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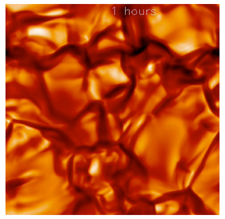

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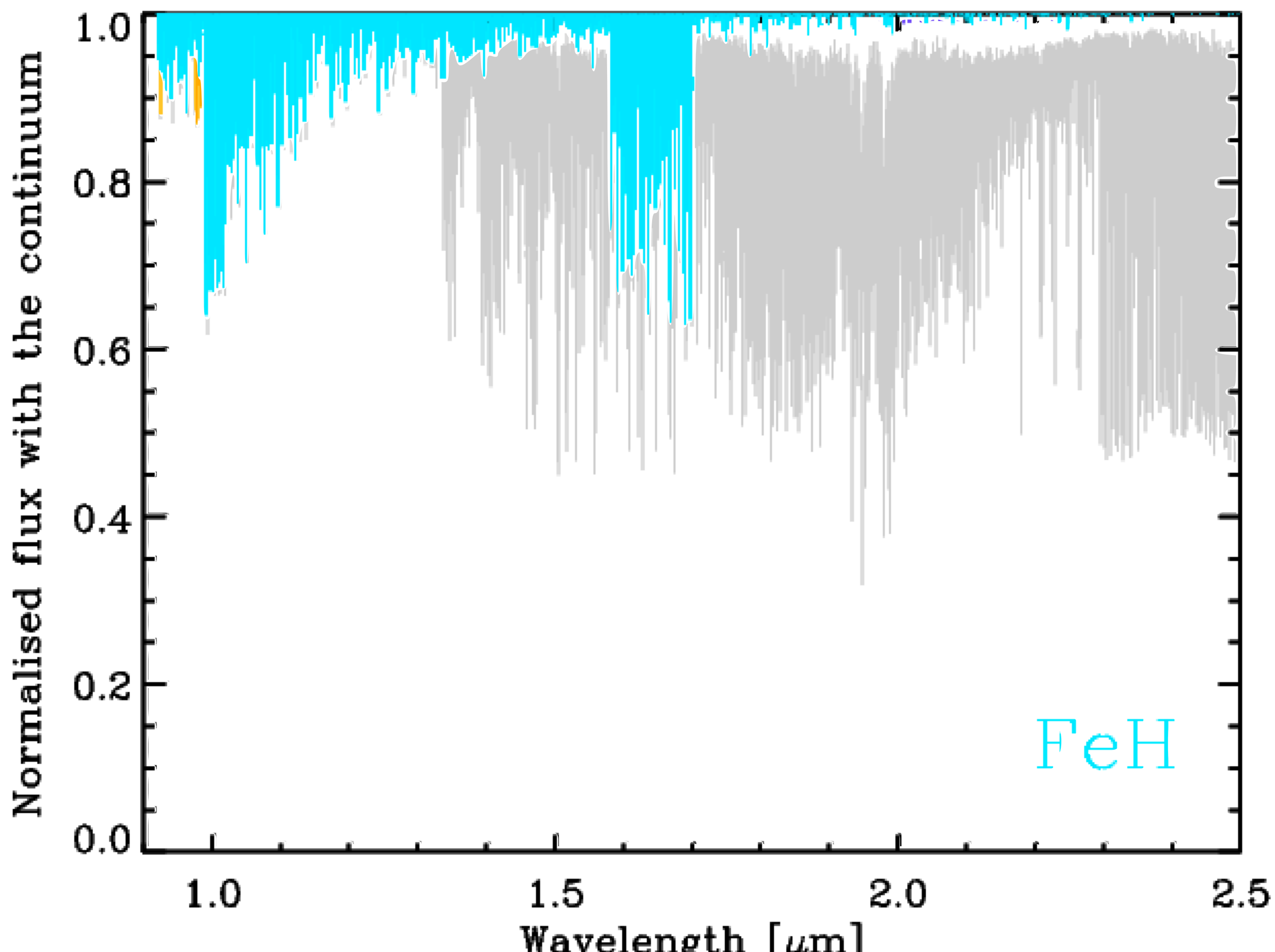

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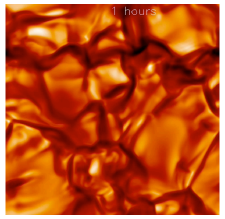

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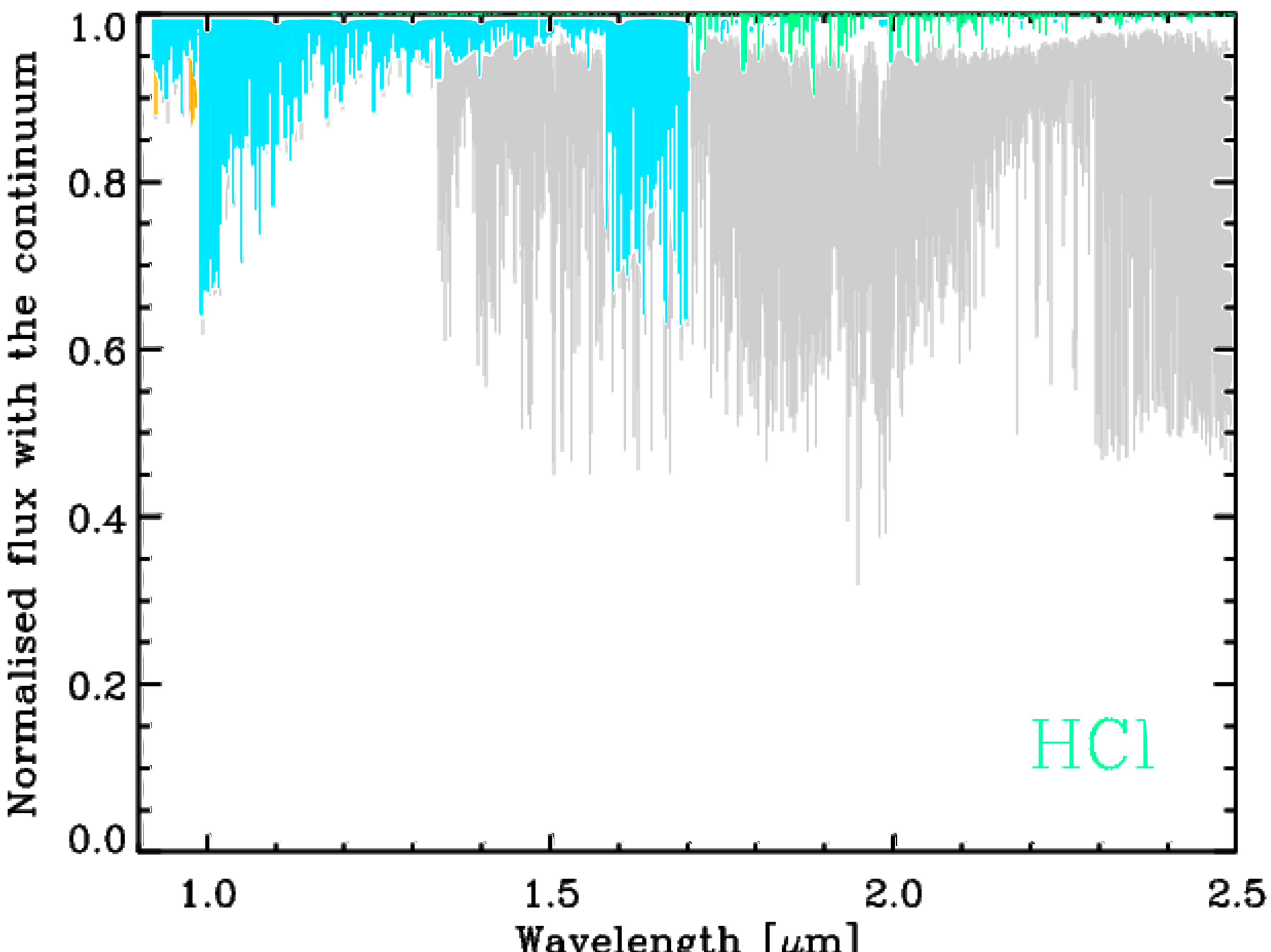

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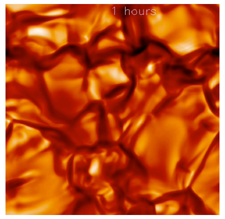

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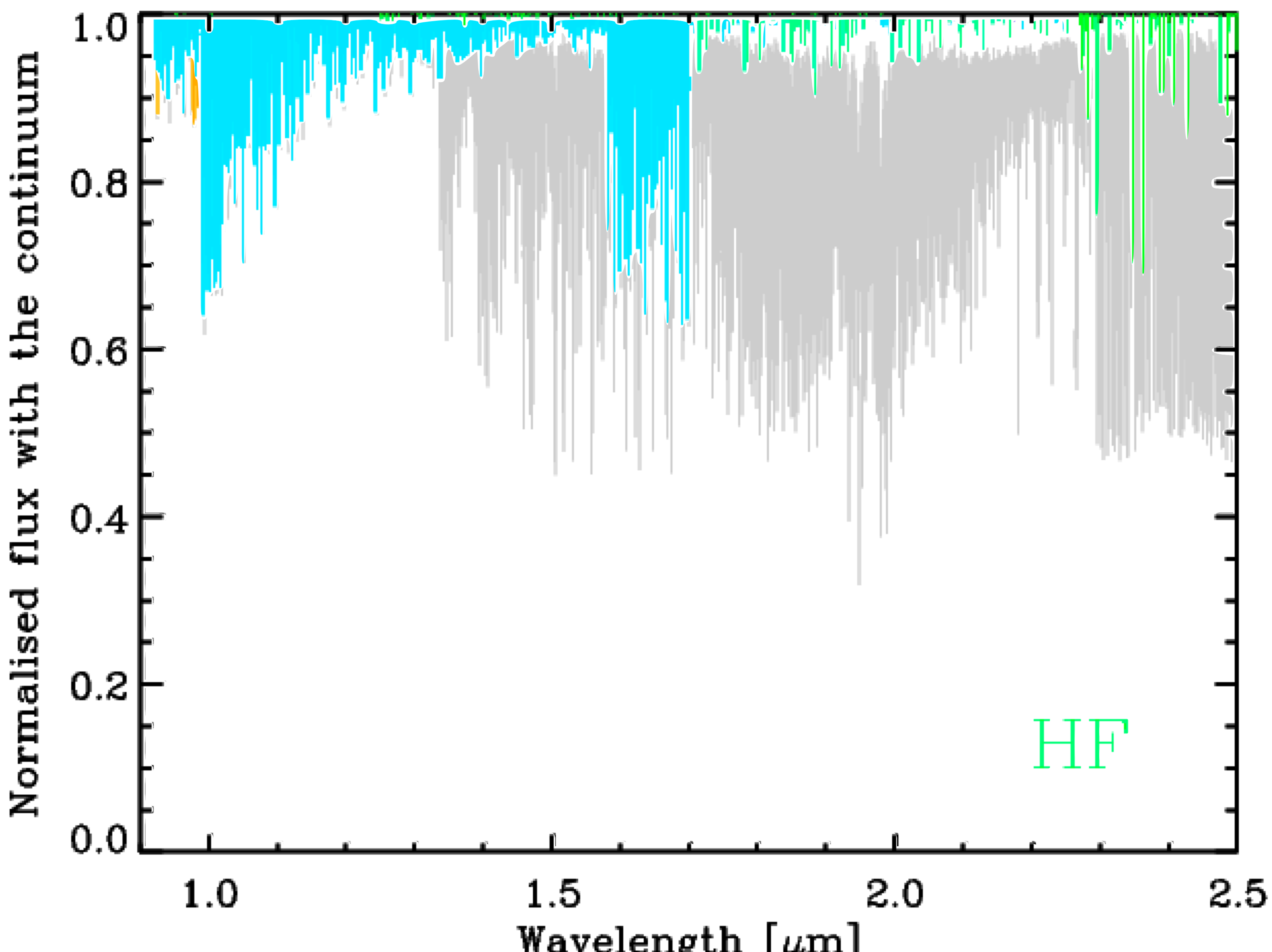
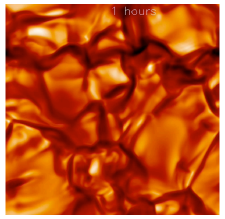
TiO FeH

Large contributor



Chiavassa, Brogi, Bigot et al., in prep.

Stellar contamination: Molecular absorption



M dwarfs regime

Teff=3500K, logg=4.5, [Fe/H]=0

Low contributor

CN CrH HCl

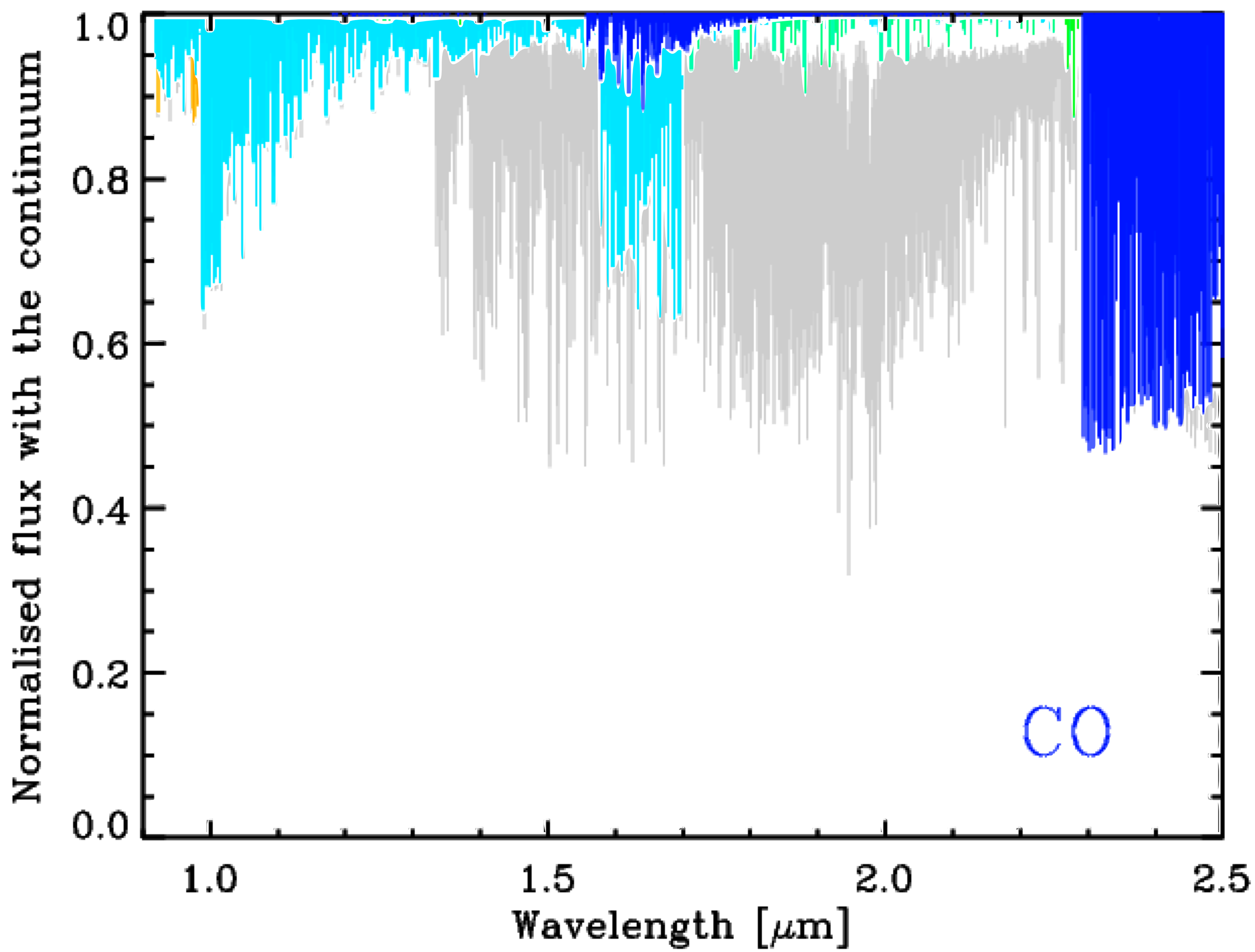
HF

Intermediate contributor

TiO FeH

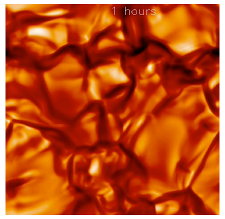
Large contributor

CO



Chiavassa, Brogi, Bigot et al., in prep.

Stellar contamination: Molecular absorption



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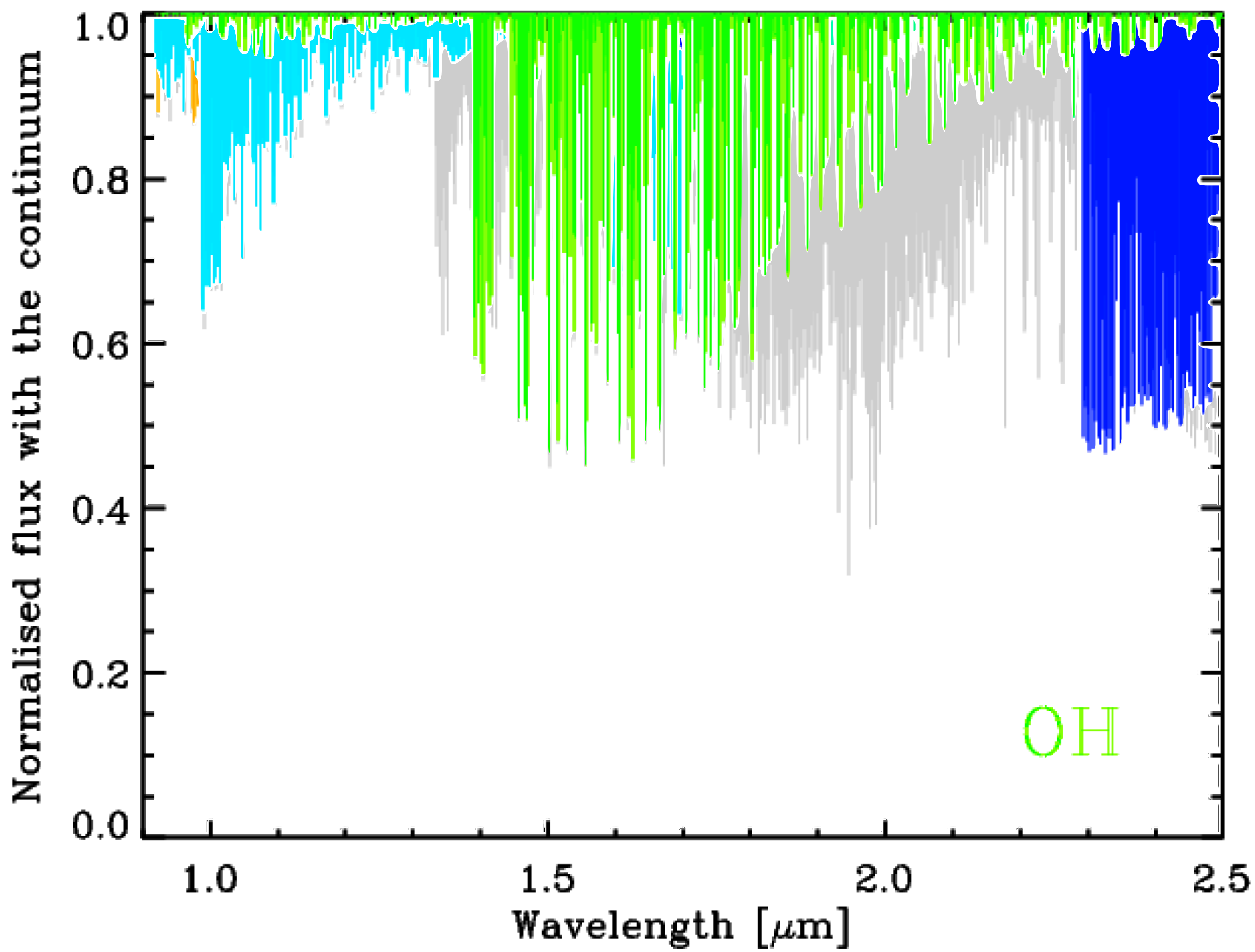
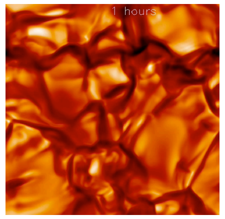


Chiavassa, Brogi, Bigot et al., in prep.

Stellar contamination: Molecular absorption



M dwarfs regime

Teff=3500K, logg=4.5, [Fe/H]=0

Overlaps with lines in the planet/stellar spectrum (H2O, CO…) used in cross-correlation

Low contributor

CN CrH HCl

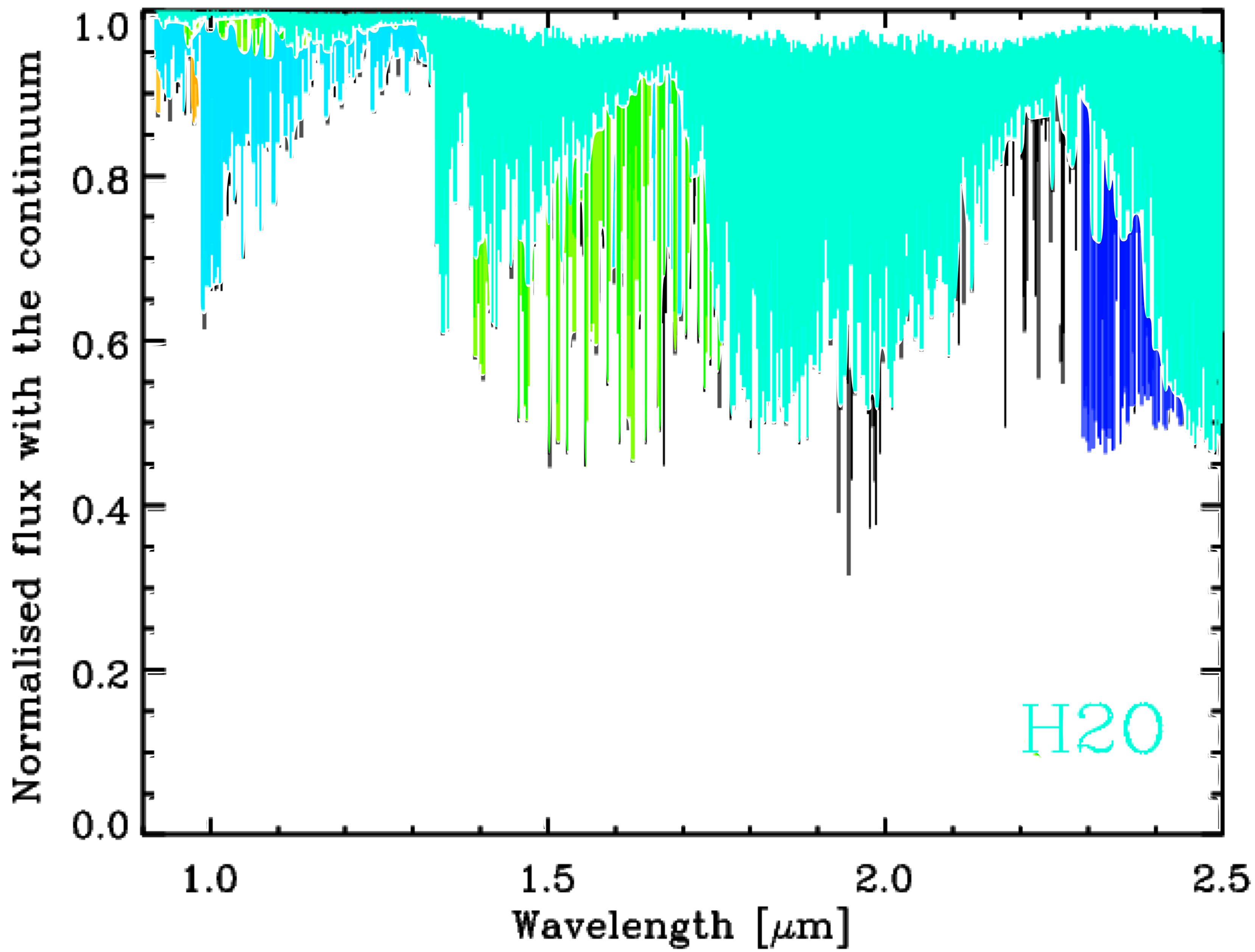
HF

Intermediate contributor

TiO FeH

Large contributor

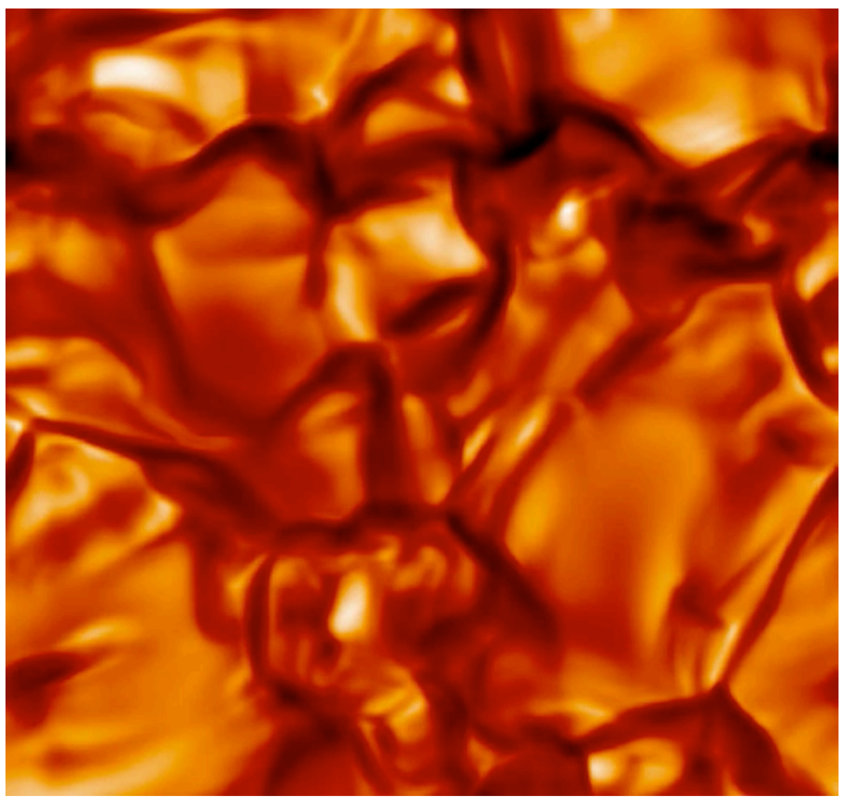
CO OH H_2O



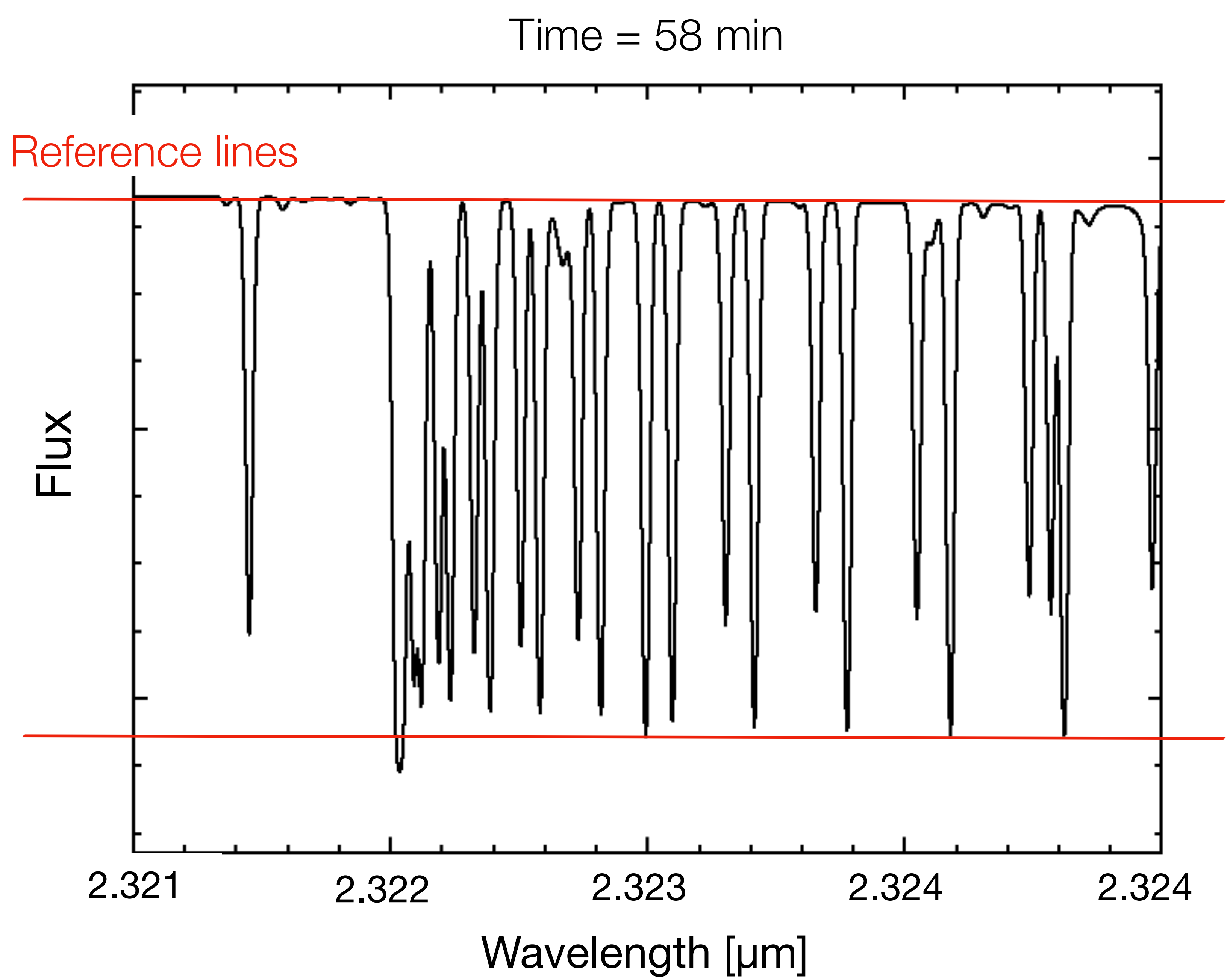
Chiavassa, Brogi, Bigot et al., in prep.

Stellar contamination: Stellar variability

Temporal fluctuations

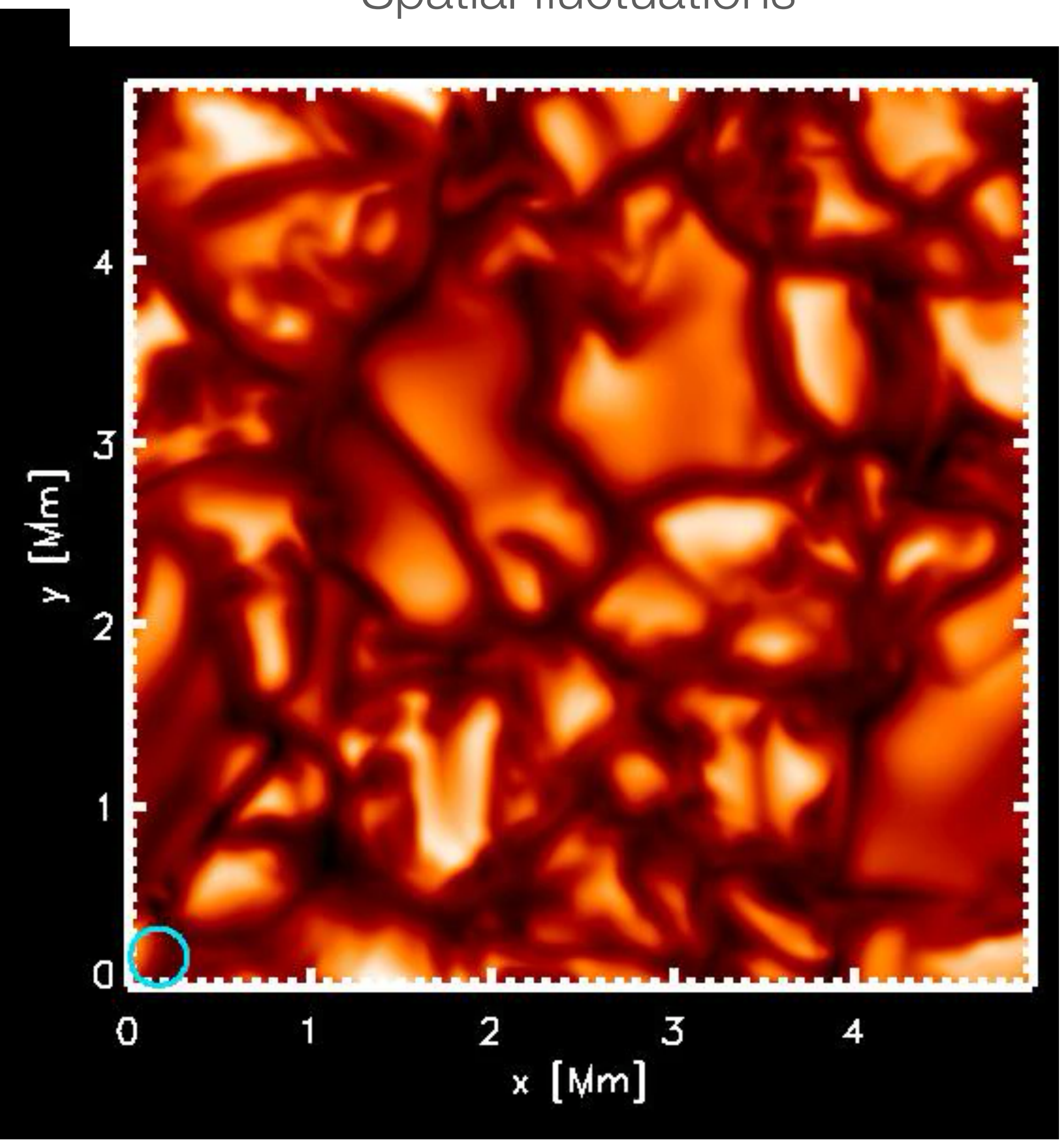


CO K-band wavelength region

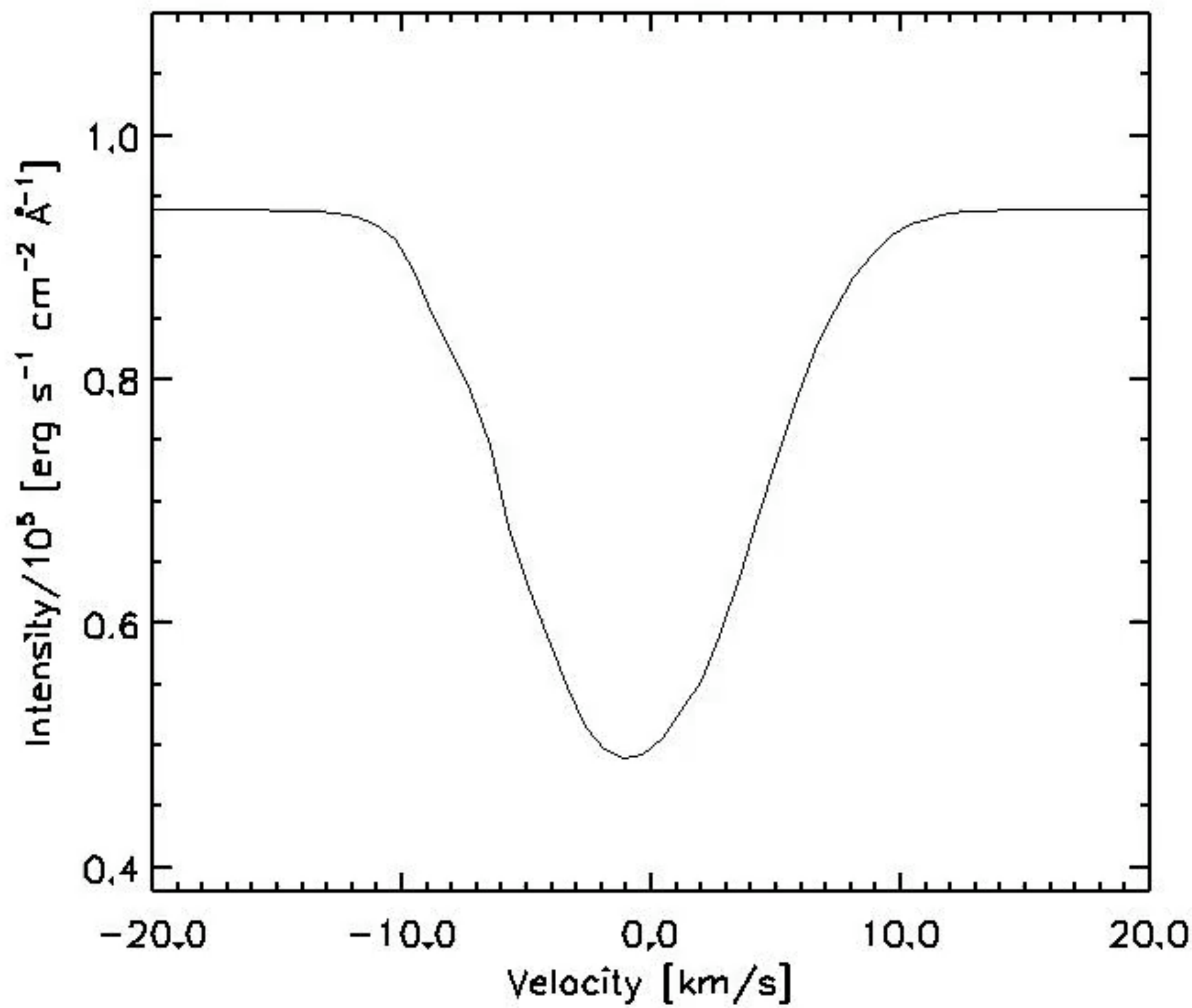


Stellar contamination: Stellar variability

Spatial fluctuations



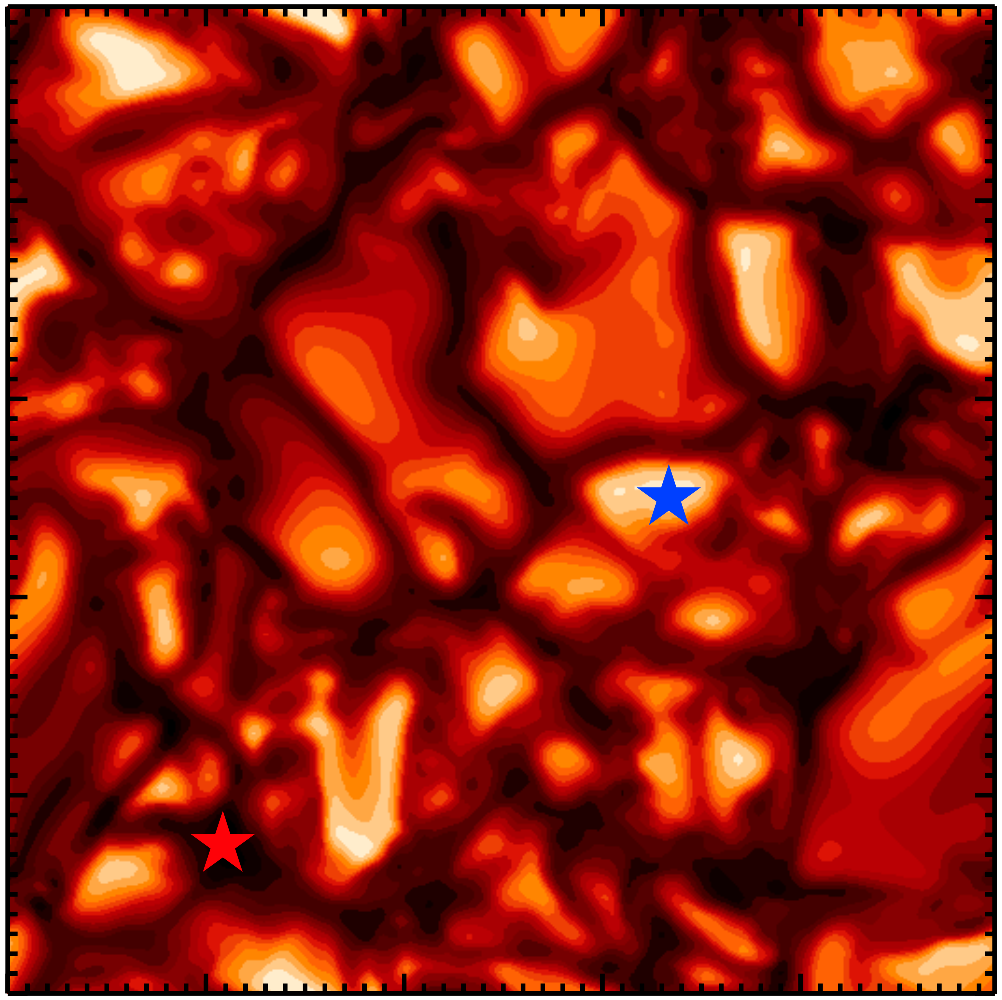
CO line (λ = 23 015.002 Å)



Chiavassa & Brogi, 2019

Stellar contamination: Stellar variability

Spatial fluctuations



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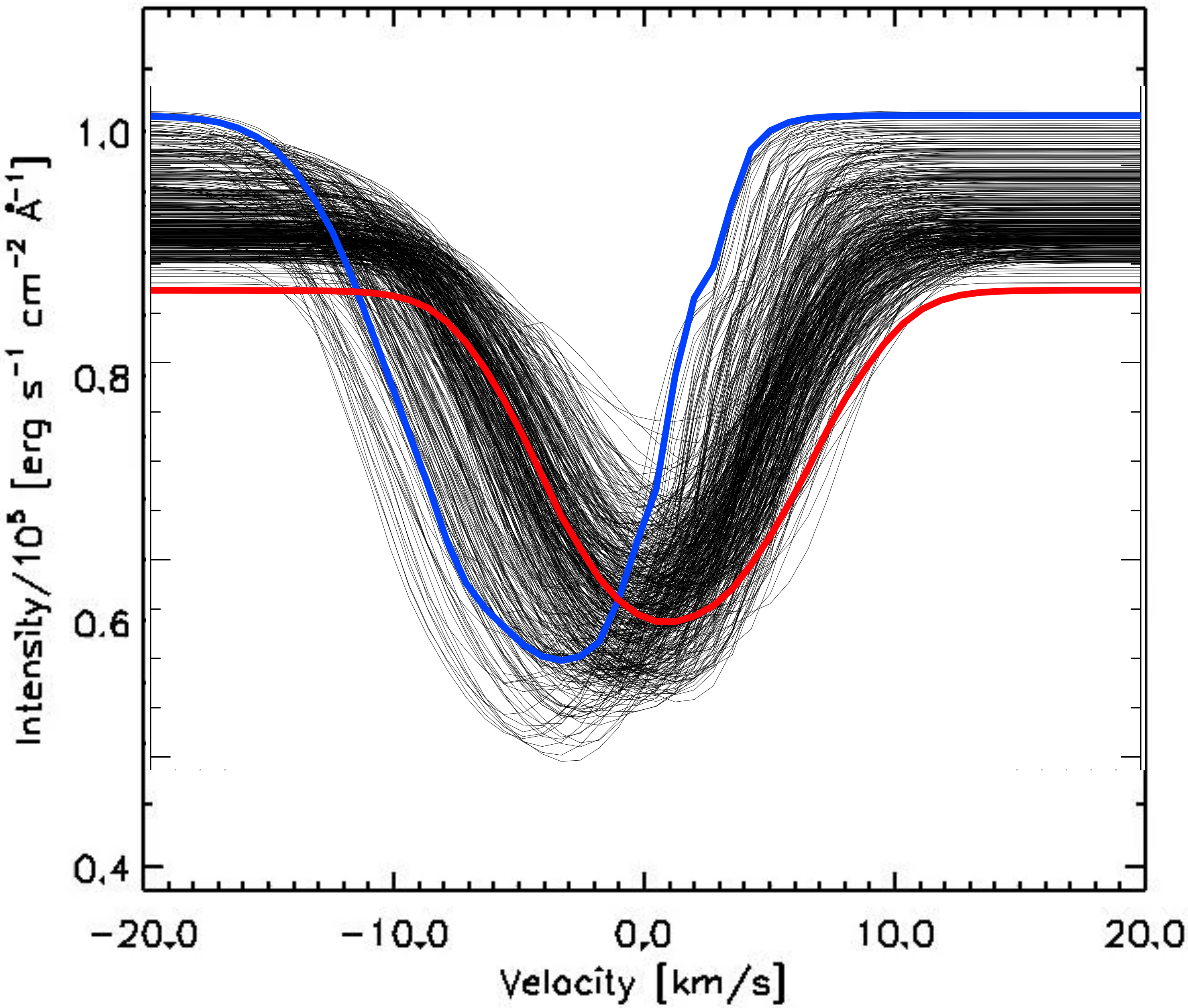

Full convective stars result into a large spatially/temporally contamination the signal

Chiavassa & Brogi, 2019

Are stars smooth?

Brightness variability

Stellar contamination: M dwarf stars

Conclusions

In conclusion …

From the planet point of view:

- the star is the noise, and the stellar spectra need modelling to be processed

From the stellar point of view:

- the “noise” is the signal of stellar dynamics and key point for studying its physical properties
- the planet transits represent and relevant source of information for the star

Stellar atmospheres are dynamics, depending on their stellar parameters —> not negligible impact on all observables (planetary detection, radius, density, composition, dynamics…)

M-dwarf hosts are the optimal target as their spectra have more lines to detect, thus boosting the detection strength of the cross-correlation. However, this requires accurate models of M-dwarfs spectra

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