Vertical wind shear of KELT-20b hints at magnetically damped circulation

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Credit:
NASA, ESA, CSA, J. Olmsted (STScI)

OBSERVATOIRE DE LA CÔTE D'AZUR

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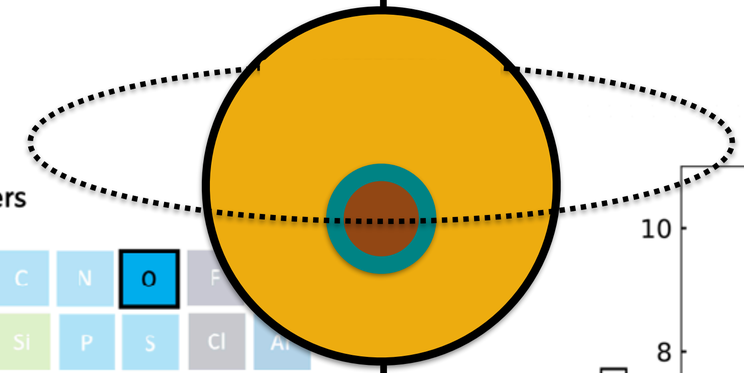
LAGRANGE

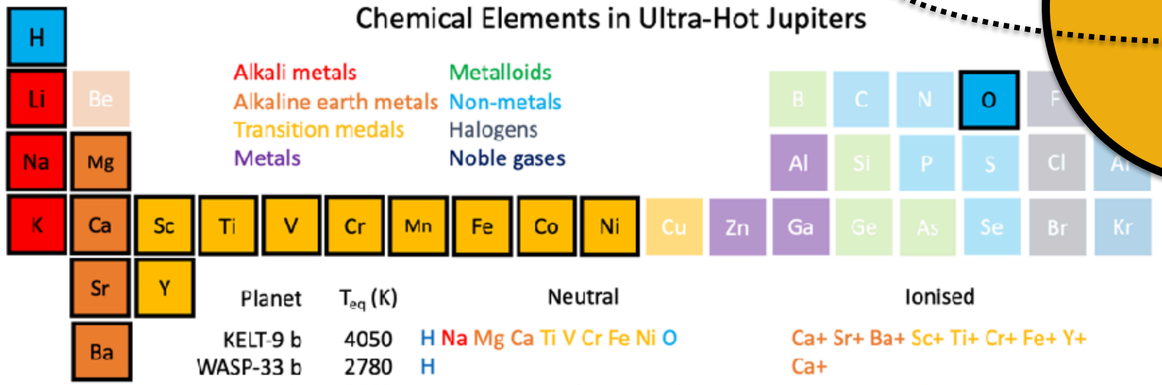
25/06/2026

Hot Jupiter Spectroscopy

Snellen 2025

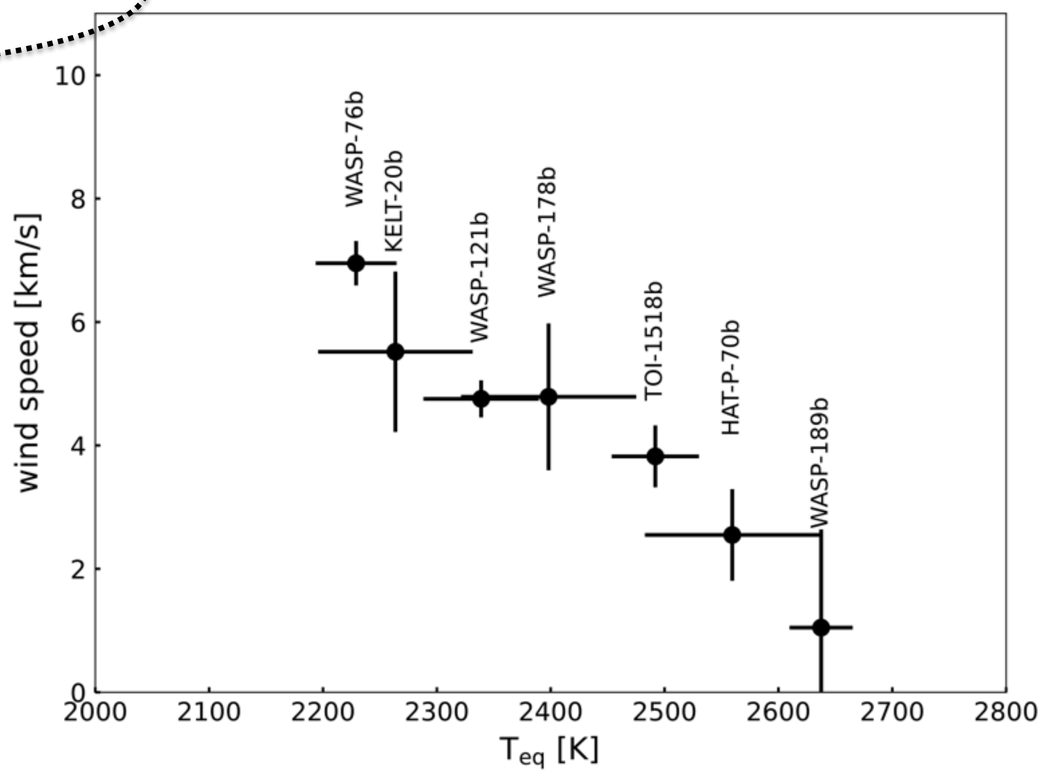


Chemical Elements in Ultra-Hot Jupiters



Planet	T_{eq} (K)	Neutral	Ionised
KELT-9 b	4050	H Na Mg Ca Ti V Cr Fe Ni O	Ca+ Sr+ Ba+ Sc+ Ti+ Cr+ Fe+ Y+
WASP-33 b	2780	H	Ca+
WASP-189 b	2640	H Na Mg Ca Sr Ti V Cr Fe Ni	Ca+ Sr+ Ba+ Ti+ Fe+
HAT-P-70 b	2550	H Na Mg Ca V Cr Fe	Ca+ Fe+
WASP-121 b	2450	H Li Na K Mg Ca V Cr Mn Fe Co Ni	Ca+ Sr+ Ba+ Sc+ Ti+ Fe+
MASCARA-4 b	2400	H Na Mg Ca Sr V Cr Mn Fe	Ca+ Ba+ Ti+ Fe+
MASCARA-2 b	2260	H Na Mg Ca Cr Mn Fe	Ca+ Cr+ Fe+
WASP-76 b	2180	H Li Na K Mg Ca V Cr Mn Fe Ni O	Ca+ Ba+ Fe+
HAT-P-67 b	1930	H Na He	Ca+

Seidel+ 2026



Chemical composition

Wind speed

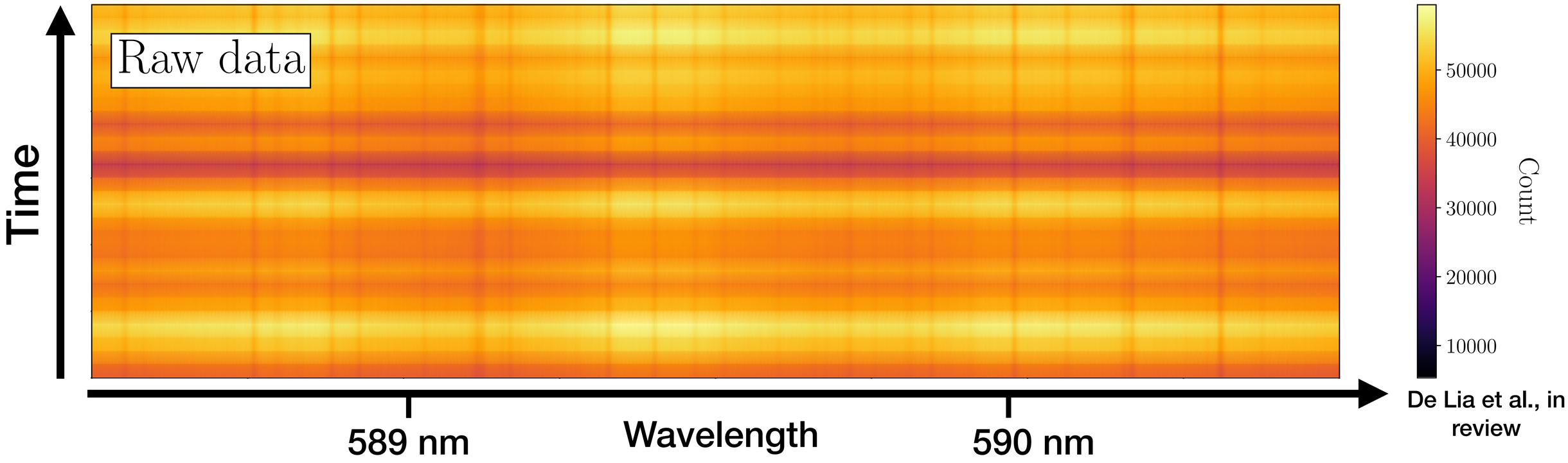
The EXOWIND Program

anr agence nationale de la recherche	Teq (K)	Period (days)	Radius (Rjup)	Tstar (K)	Transit (hours)	N transits	Scaled SNR	Total time
HAT-P-70b	2552	2.7	1.87	8450	3,48	2	1.55	8,96
TOI-1518b	2492	1.9	1.87	7300	2,74	2	0.99	7,48
KELT-20b	2255	3.5	1.741	8720	3,10	1	1.6	4,1
KELT-7b	2049	2.7	1.53	6789	3,51	4	0.85	18,04
KELT-4Ab	1821	2.9	1.699	6206	3,46	4	0.9	17,84

Goal : Investigate winds of (Ultra) Hot Jupiters

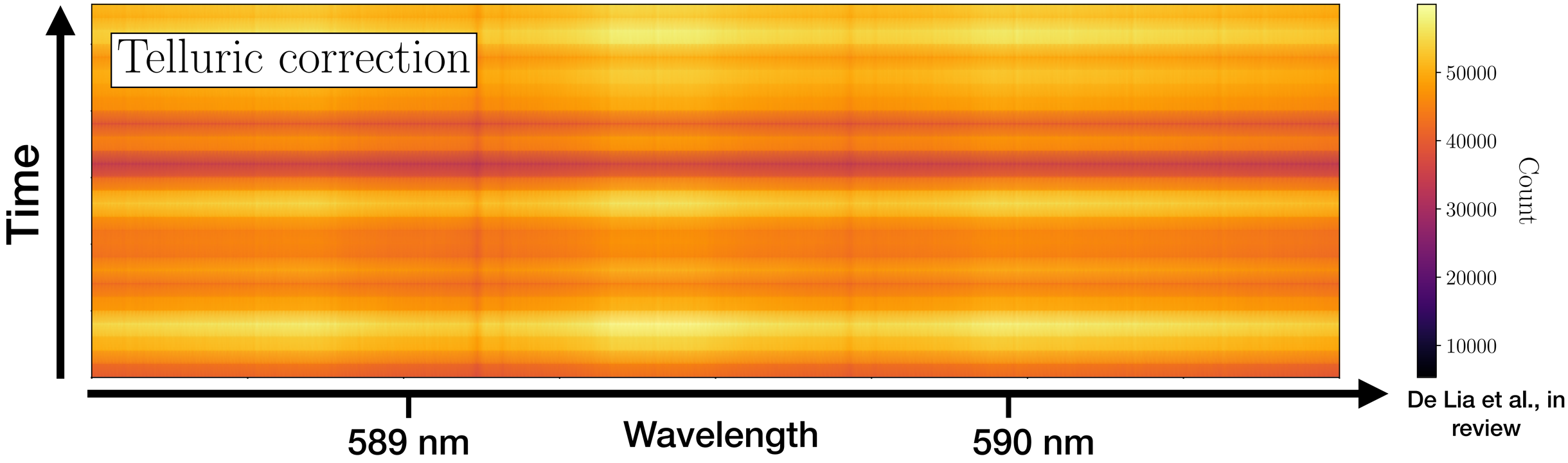
- Gemini North : 8 meter
- MAROON-X : Optical spectrograph
- High Resolution ~ 80 000

Data reduction



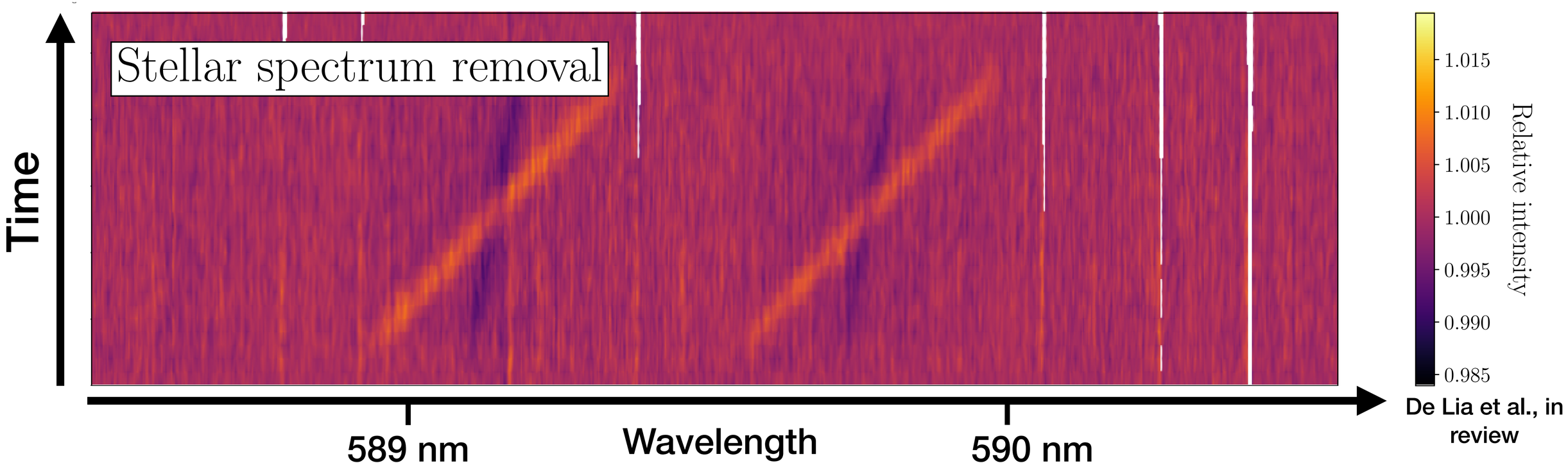
Echelle grating : only showing 1 out of 61 orders

Data reduction



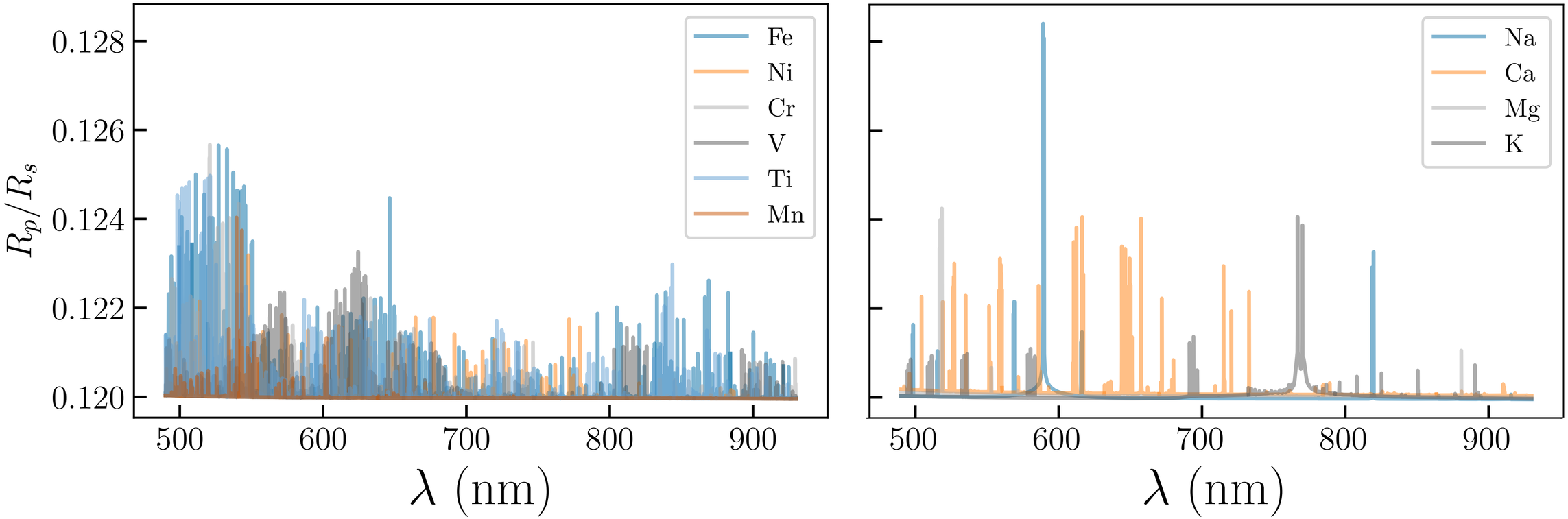
Telluric correction with Molecfit

Detection of Sodium



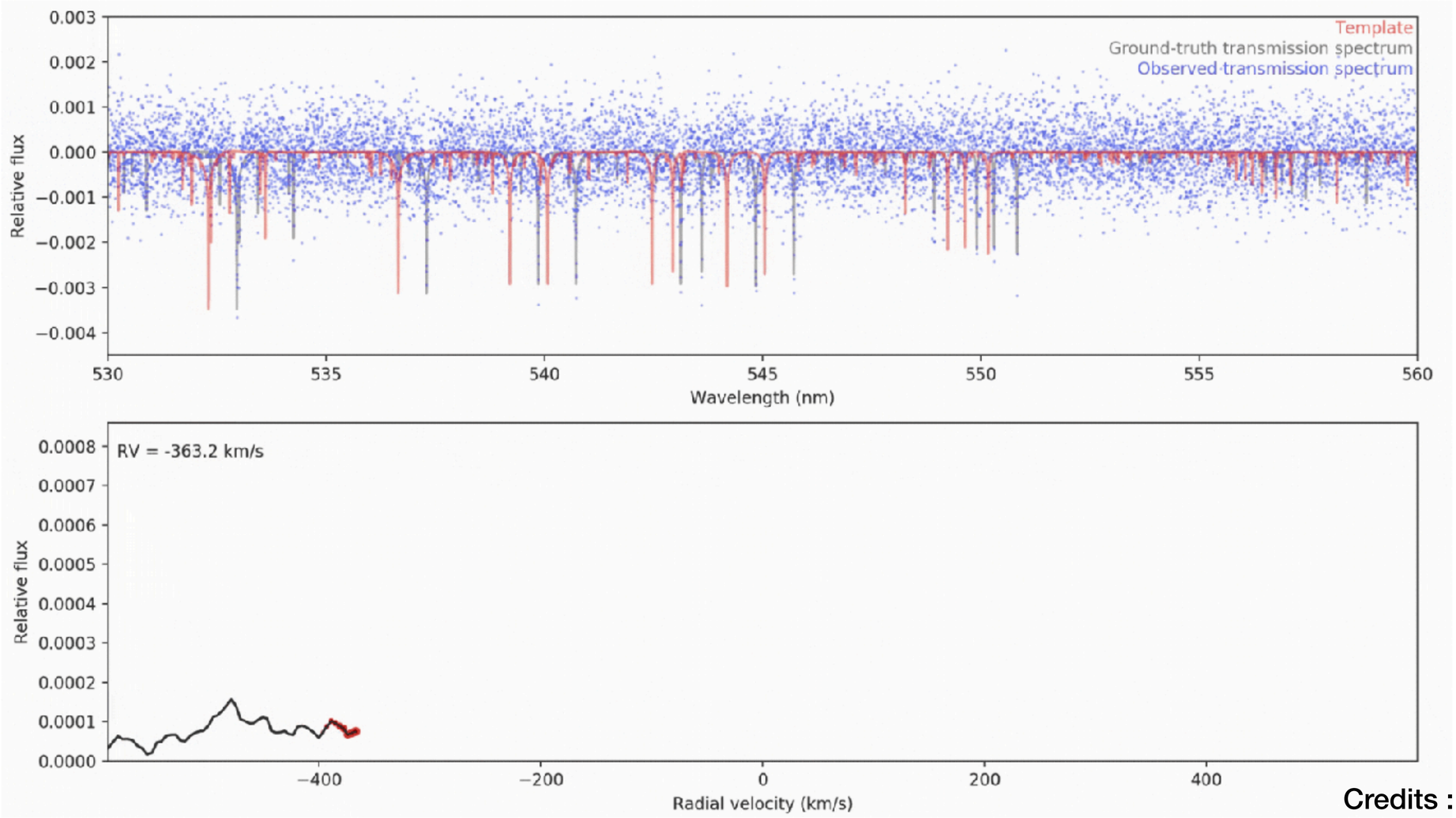
We already see the planet features in absorption

Species Templates



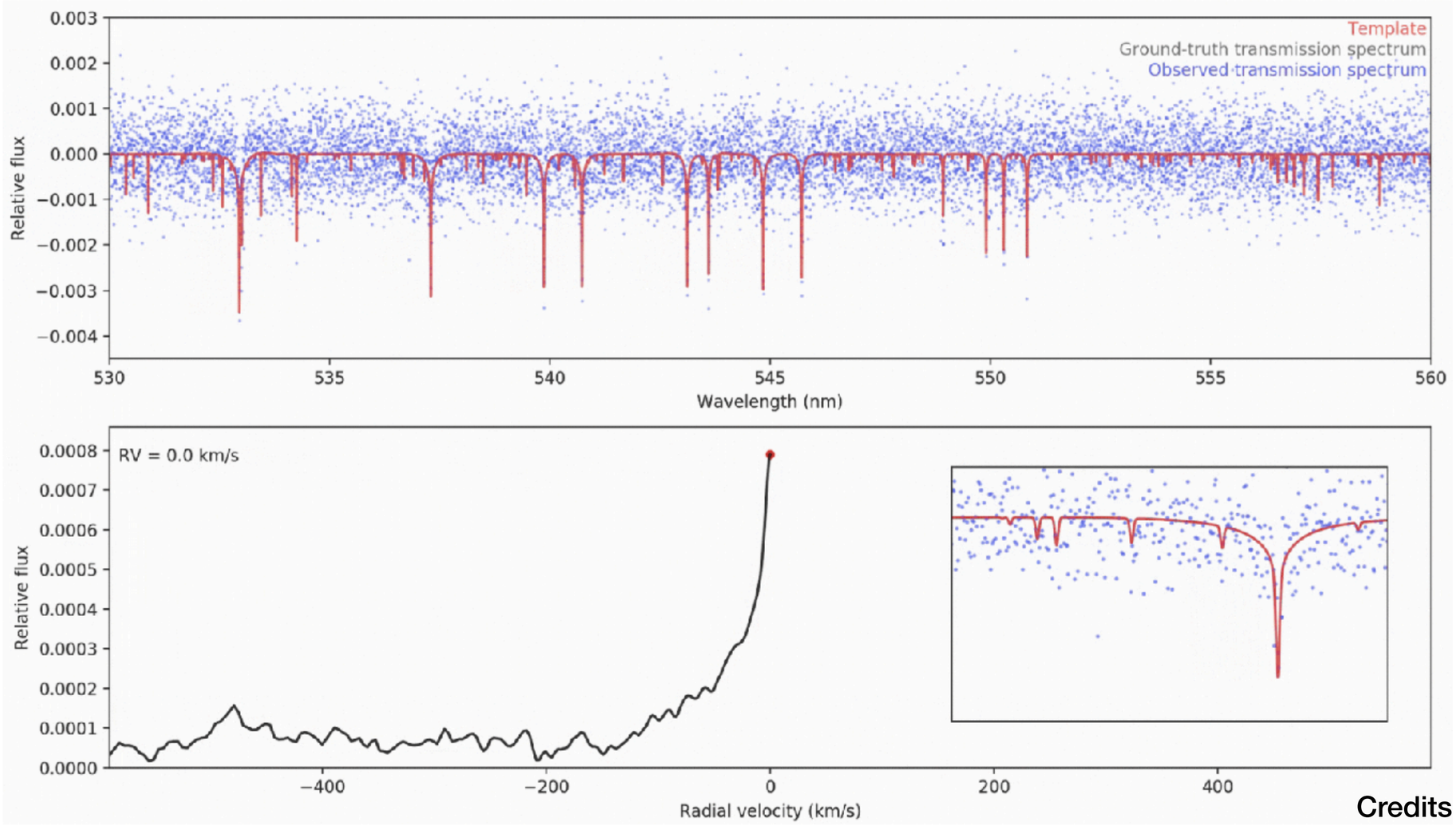
Single lines are usually not seen directly

Cross-Correlation



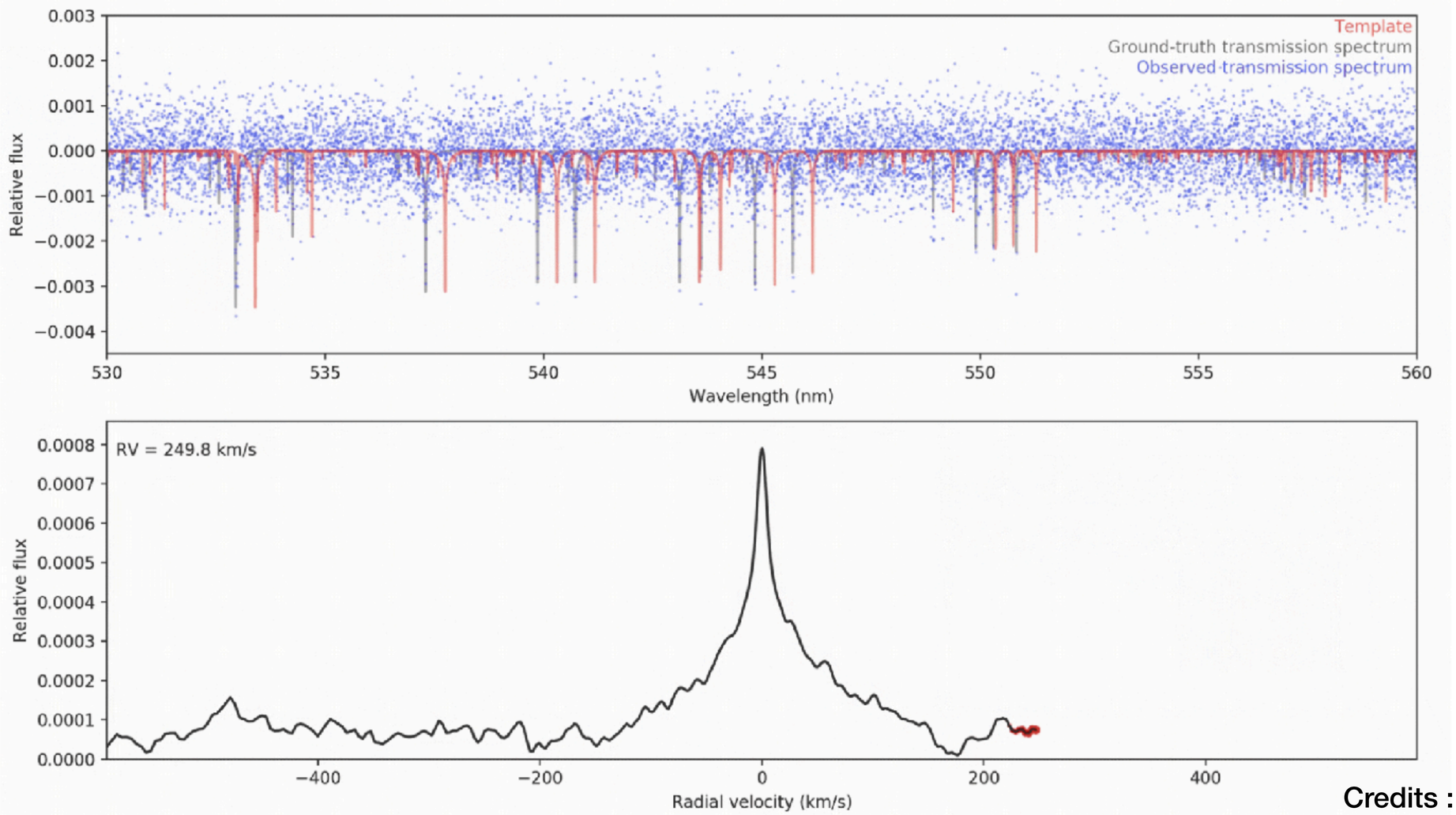
Credits : J. Hoeijmakers

Cross-Correlation



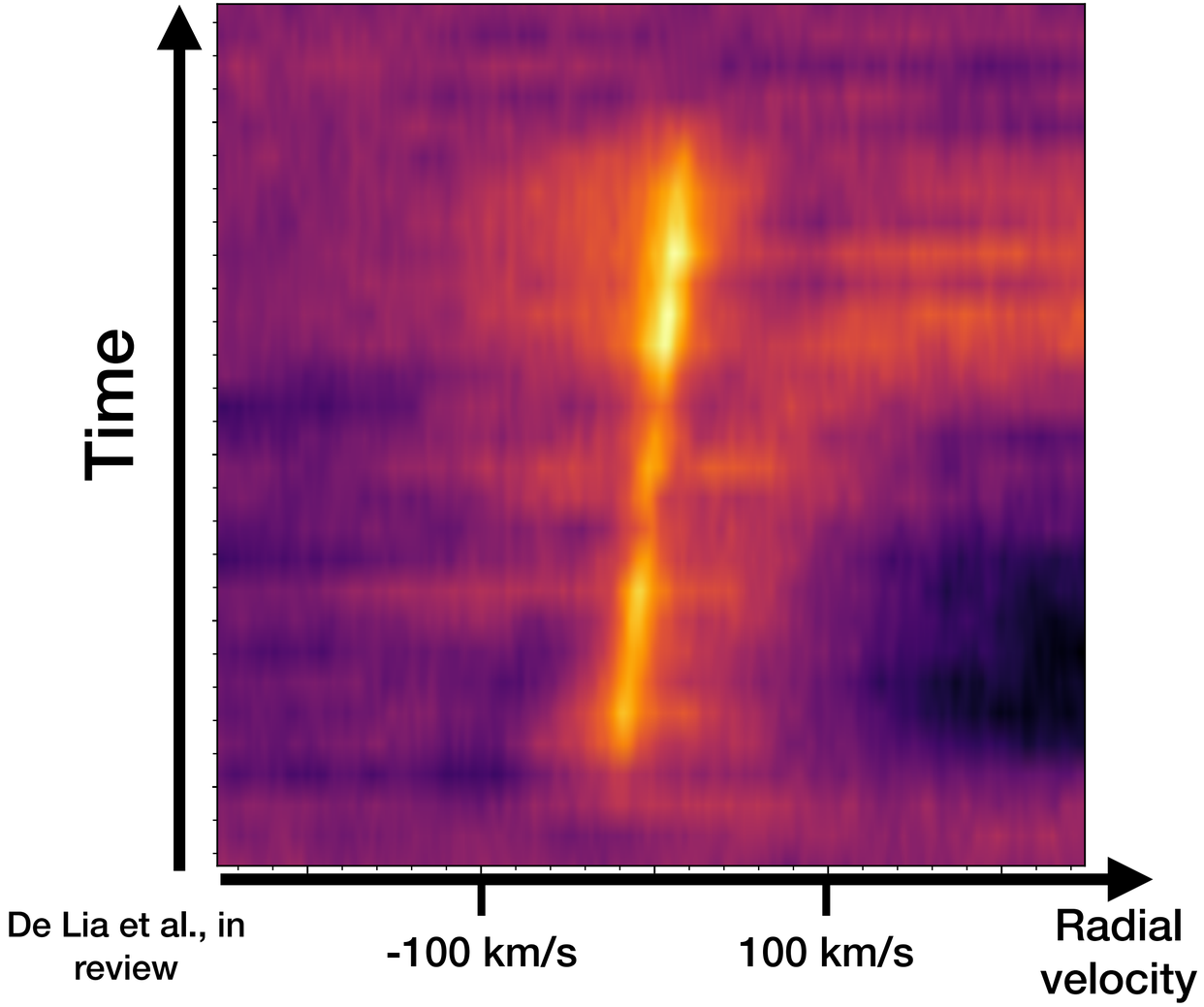
Credits : J. Hoeijmakers

Cross-Correlation



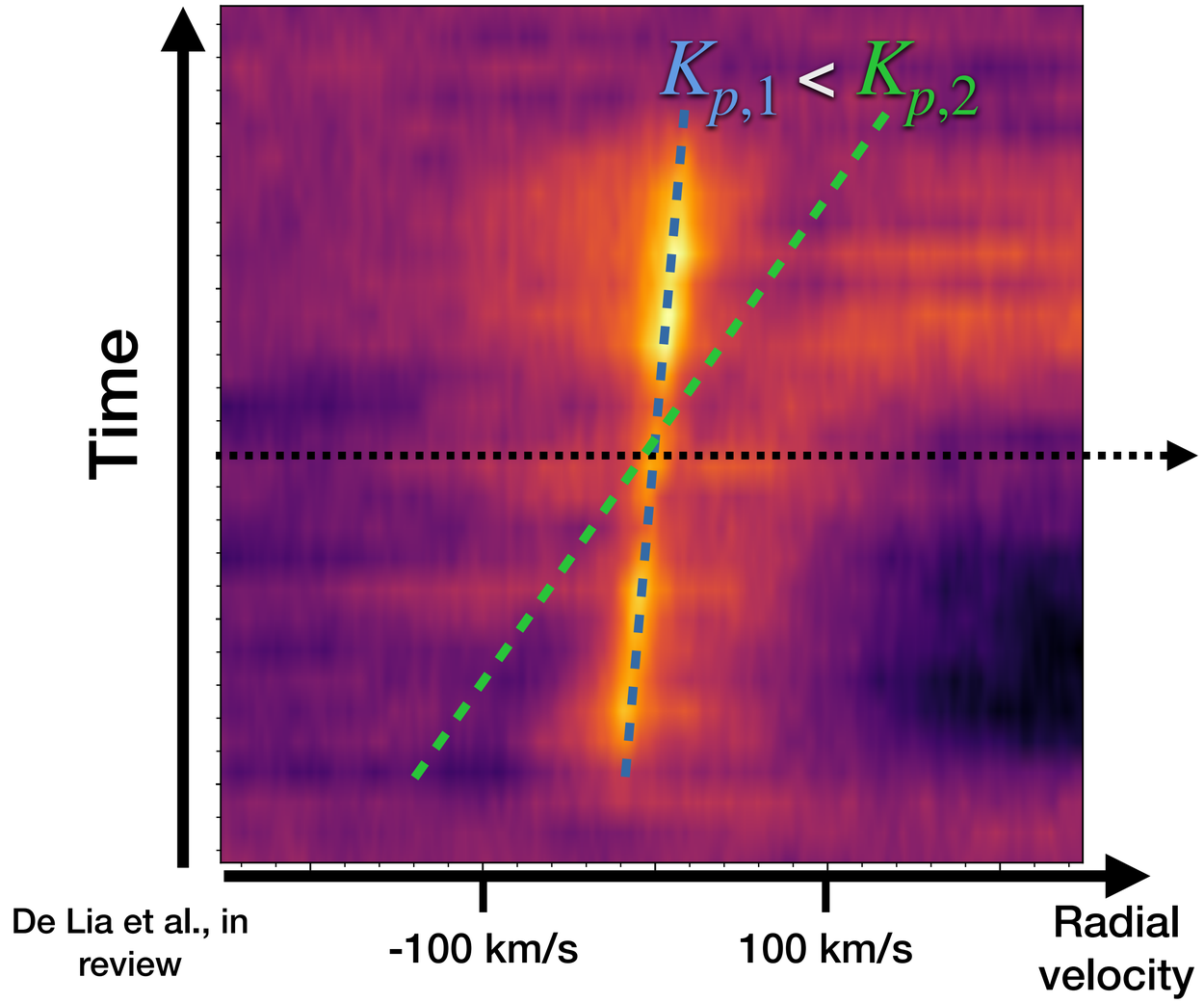
Credits : J. Hoeijmakers

$K_p - v_{sys}$ maps



De Lia et al., in review

$K_p - v_{sys}$ maps

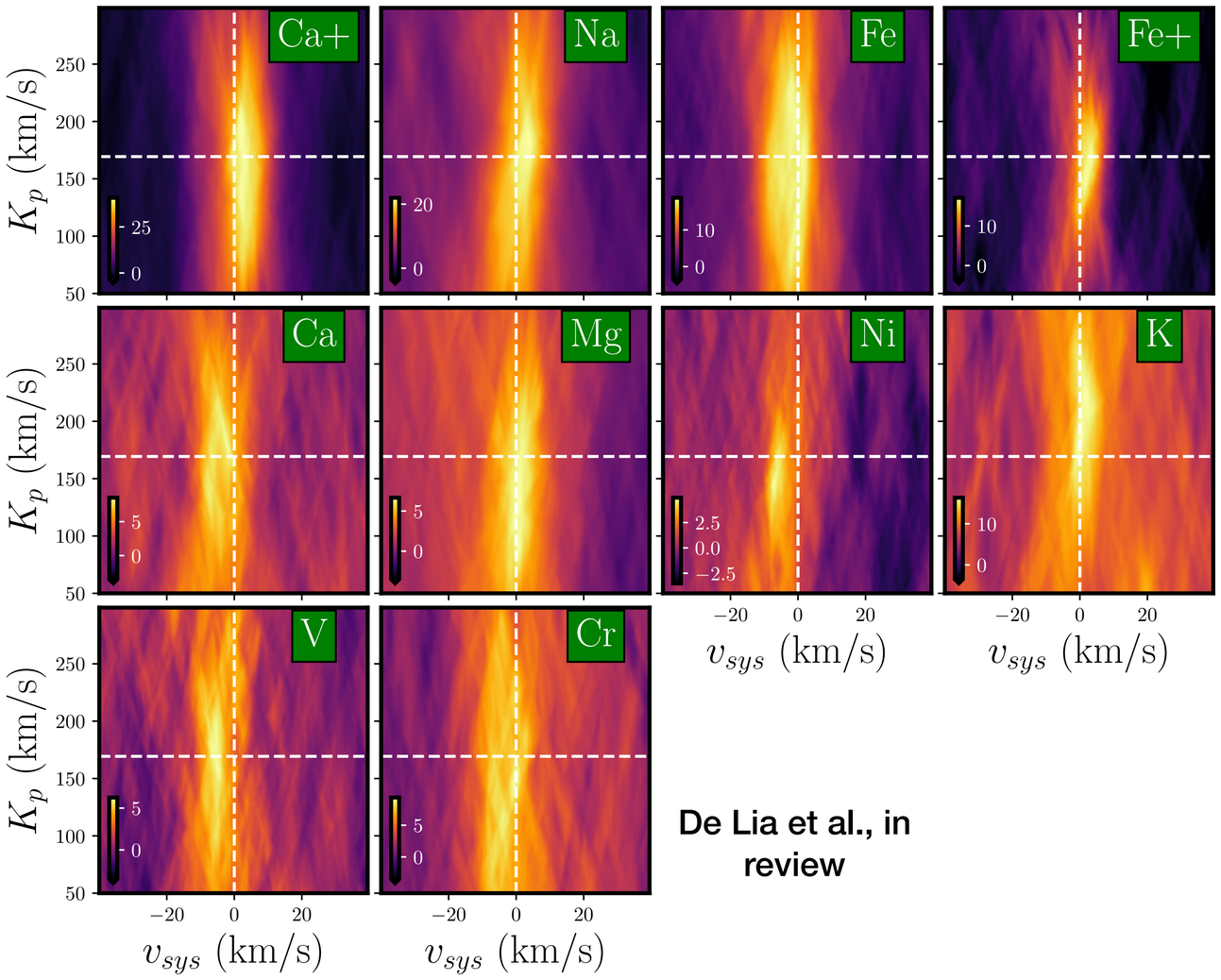


Integration along circular orbits :

$$V_{orb} = K_p \sin(2\pi\phi) + v_{sys}$$

$K_p - v_{sys}$ detection maps

Detection maps



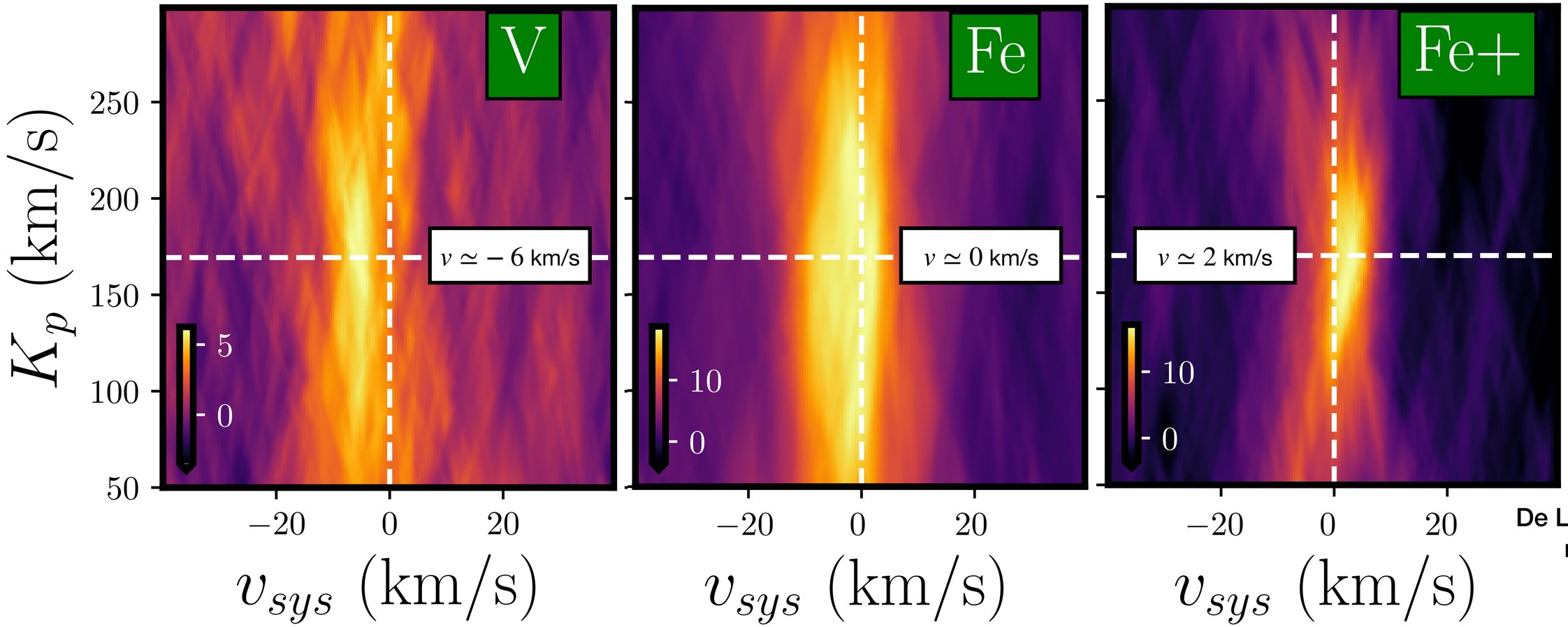
De Lia et al., in review

10 detections at 5 sigma

Chemical diversity of Ultra Hot Jupiters

See also WASP-121b (Prinoth+ 2025) or WASP-76b (Kesseli+ 2022)

A whole lotta dynamics



De Lia et al., in review

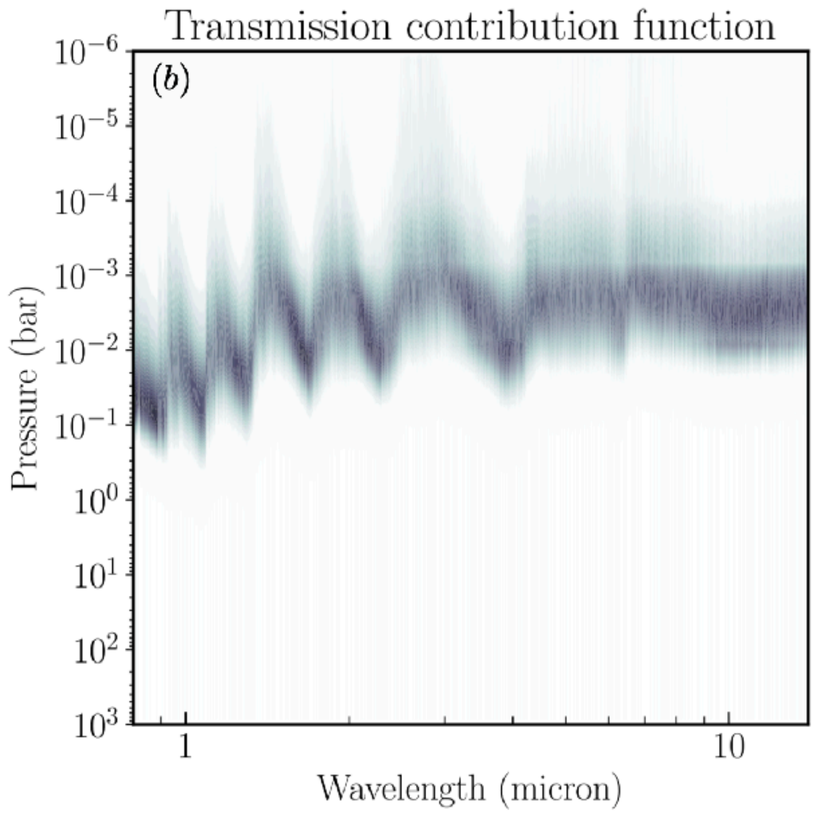
All species are shifted… but not the same way !

Goal of this work

Can we quantitatively measure the vertical gradient of wind using high-resolution spectroscopy ?

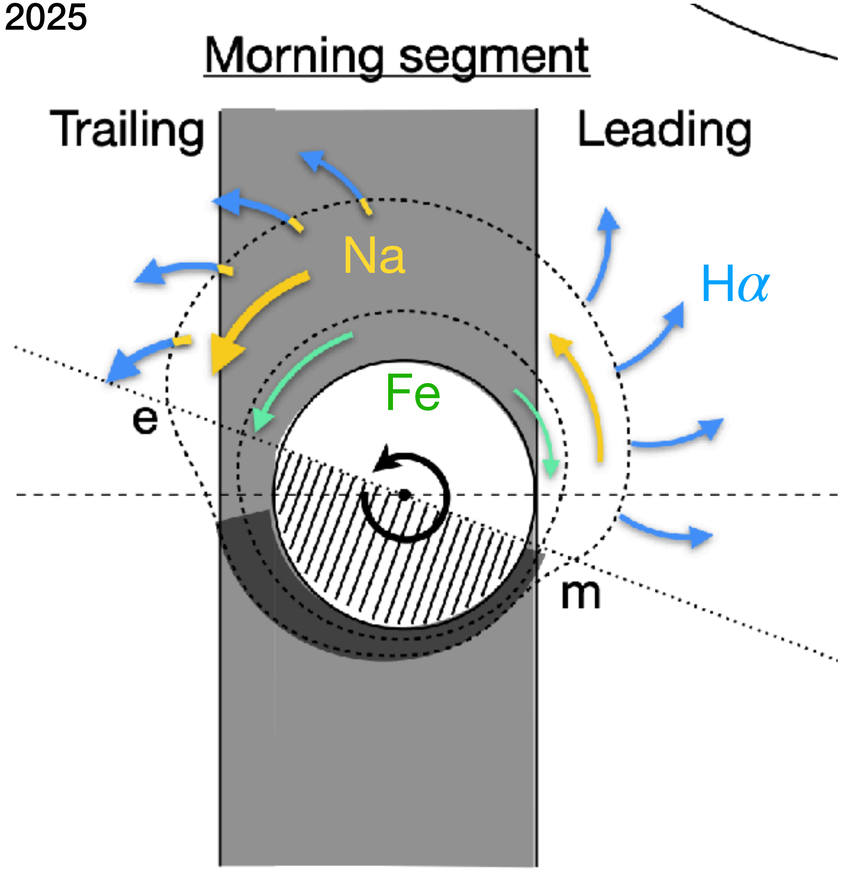
Vertical variation of winds

Mollière+ 2019



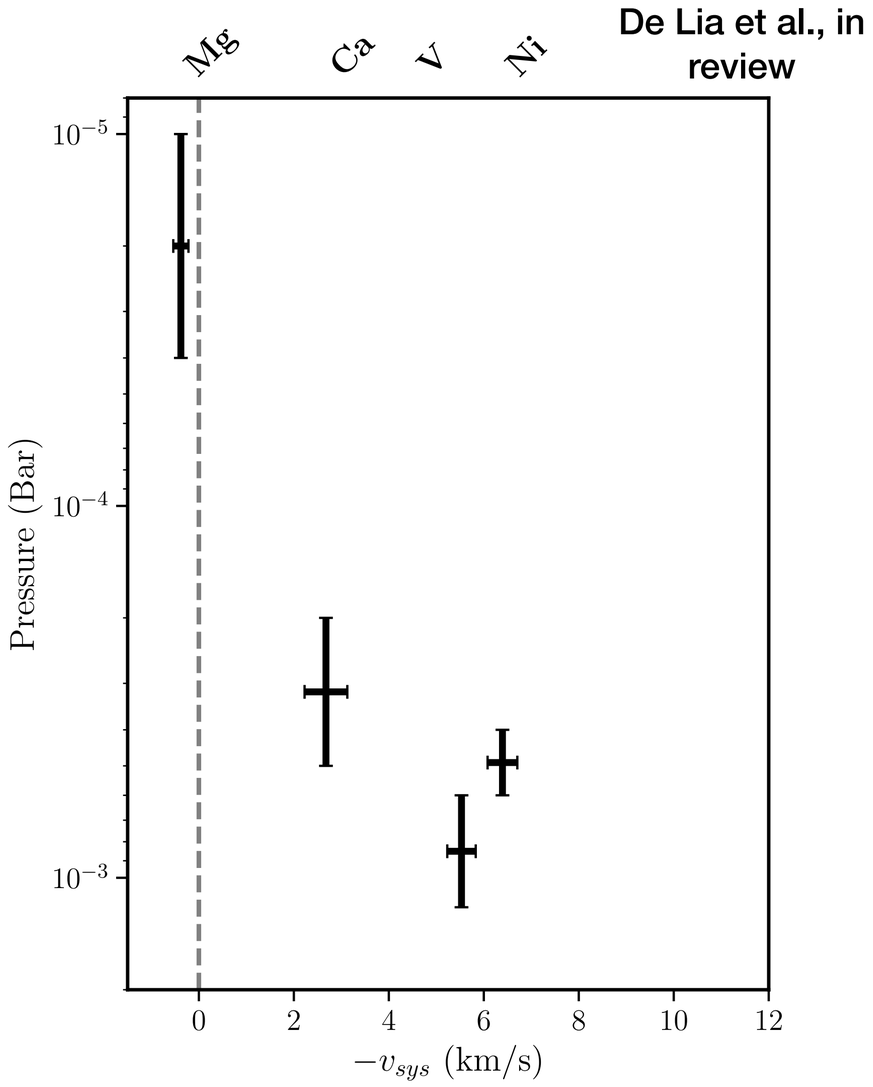
At low resolution : we know species probe different pressures

Seidel+ 2025



Seidel+ 2025 :
Vertical information exists in High-Res

Pressure-velocity profile

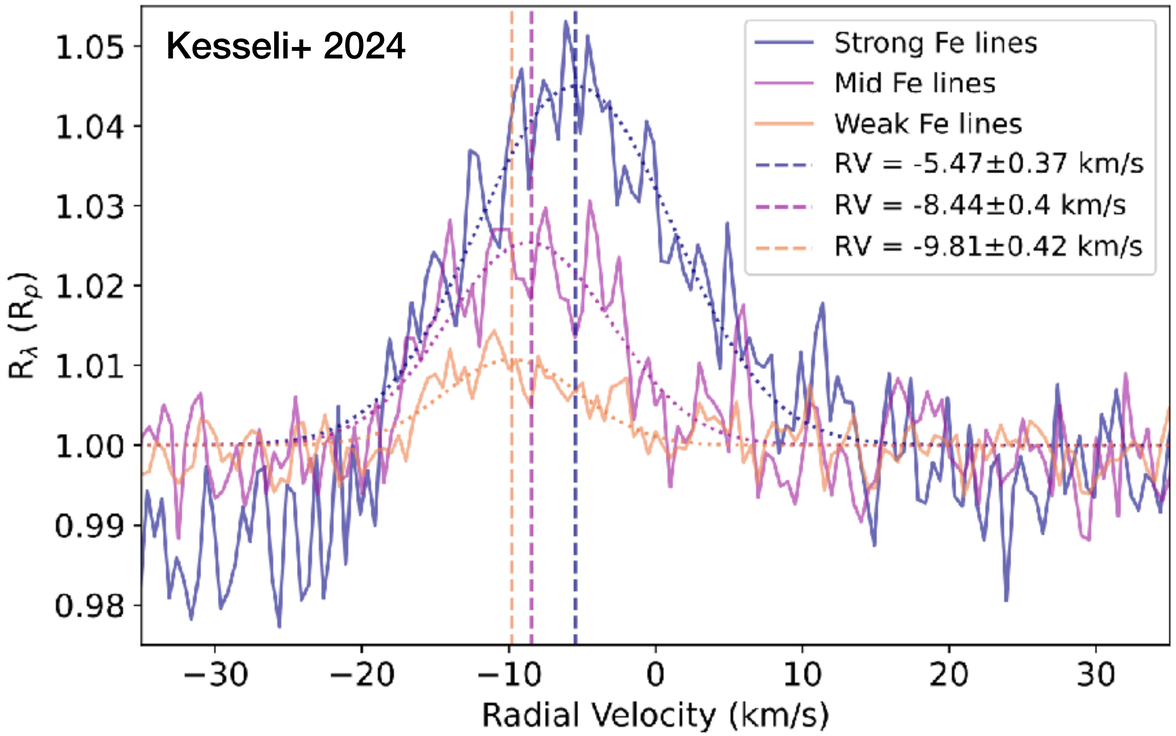


Wind speed seems to decrease with altitude

KELT-20b orbital configuration limits biases :

- Low rotational velocity of ± 2 km/s
- Aligned system with low impact parameter $b = 0.5$

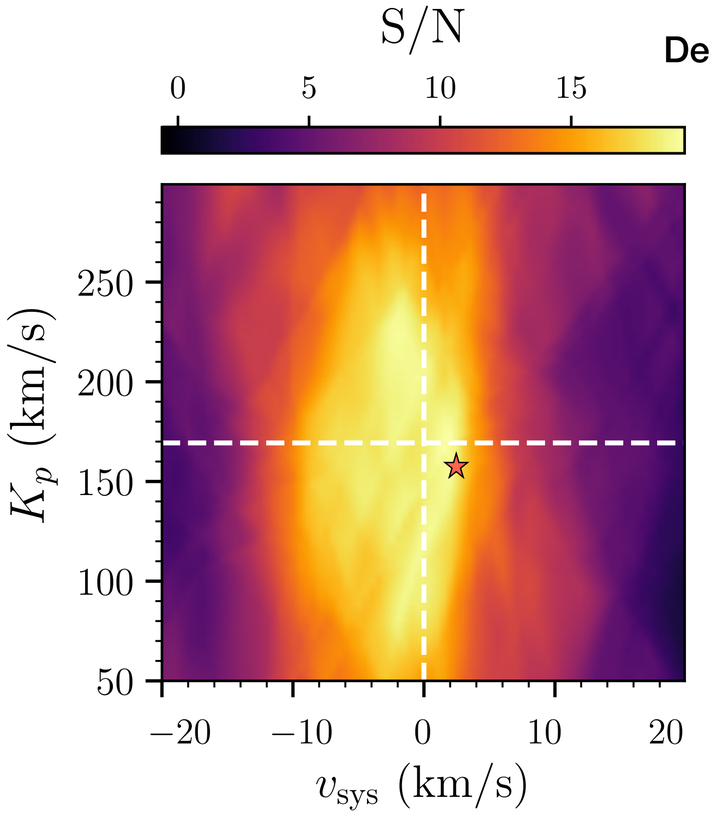
Separating spectral lines



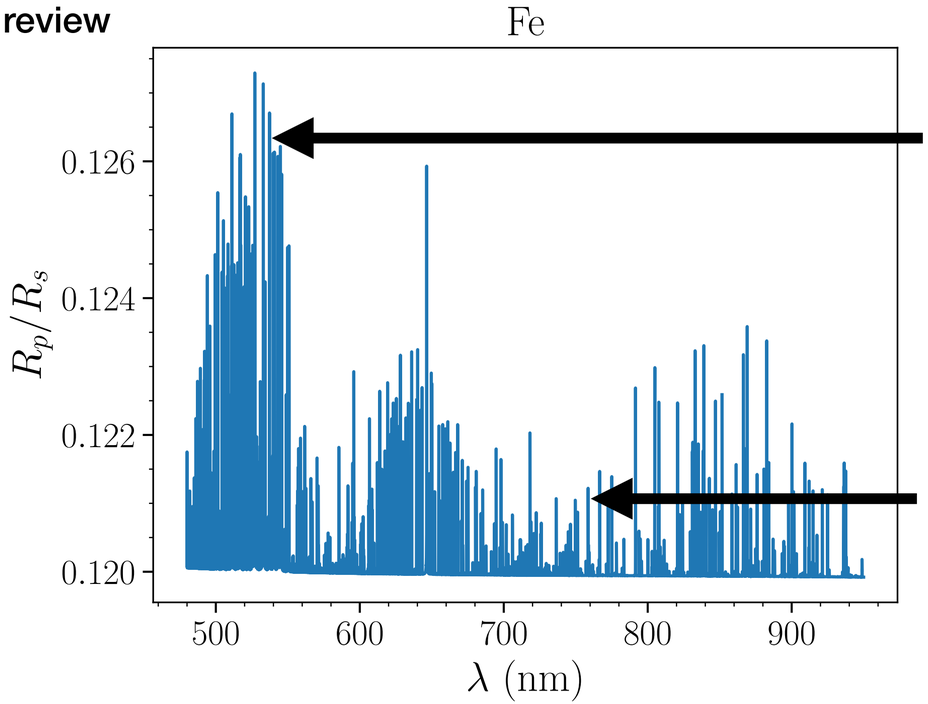
Kesseli+ 2024, Kempton & Rauscher 2012 :
Splitting lines in templates

Can we separate the template to get vertical information ?

Separating spectral lines



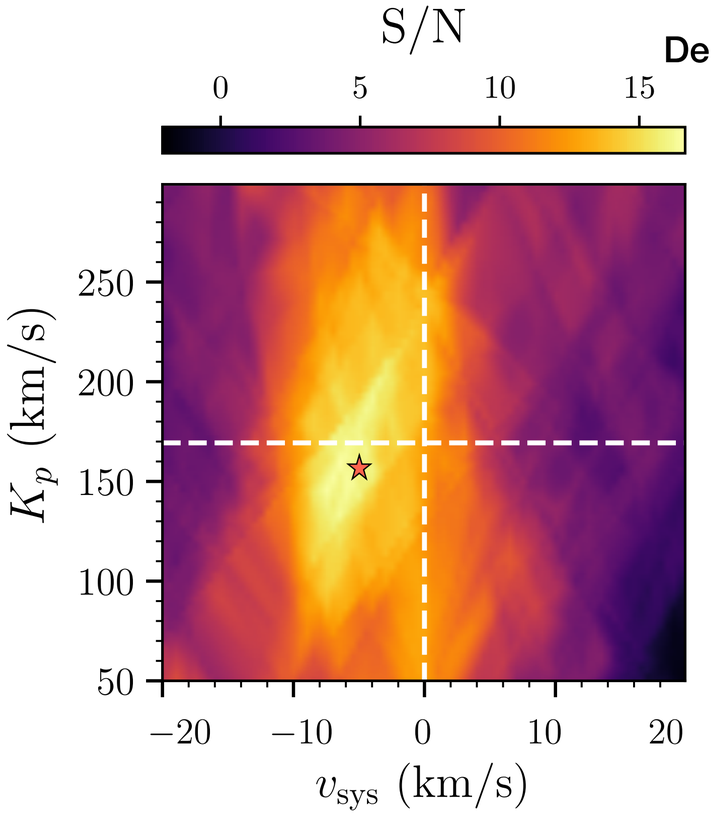
De Lia et al., in review



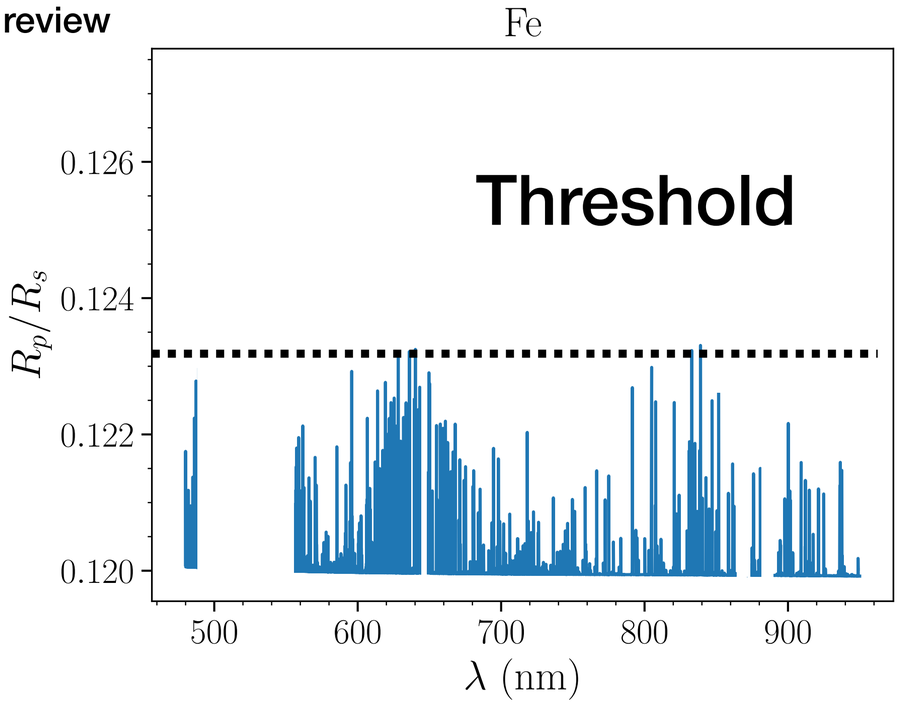
Strong spectral lines

Weak spectral lines

Separating spectral lines



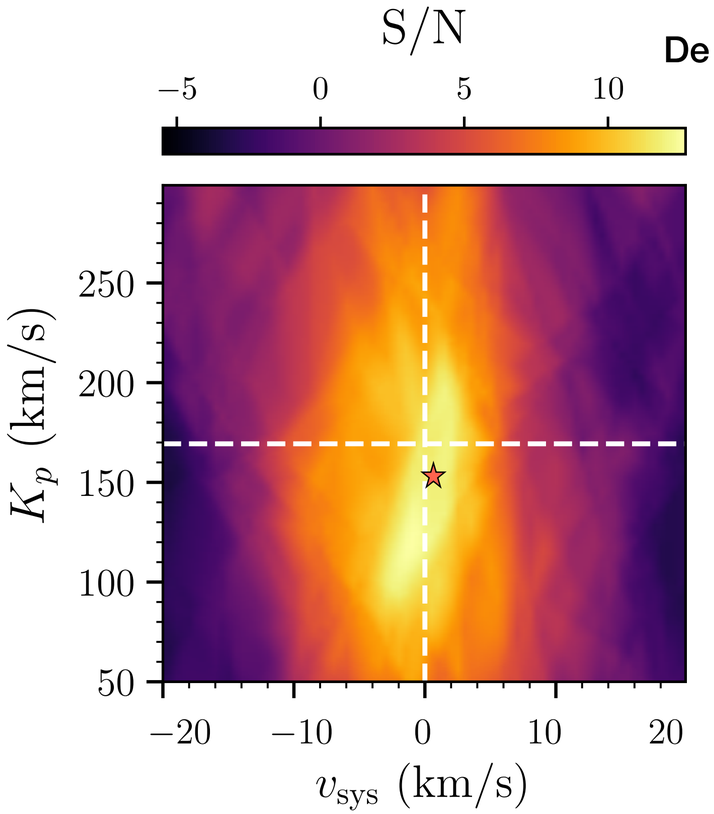
De Lia et al., in review



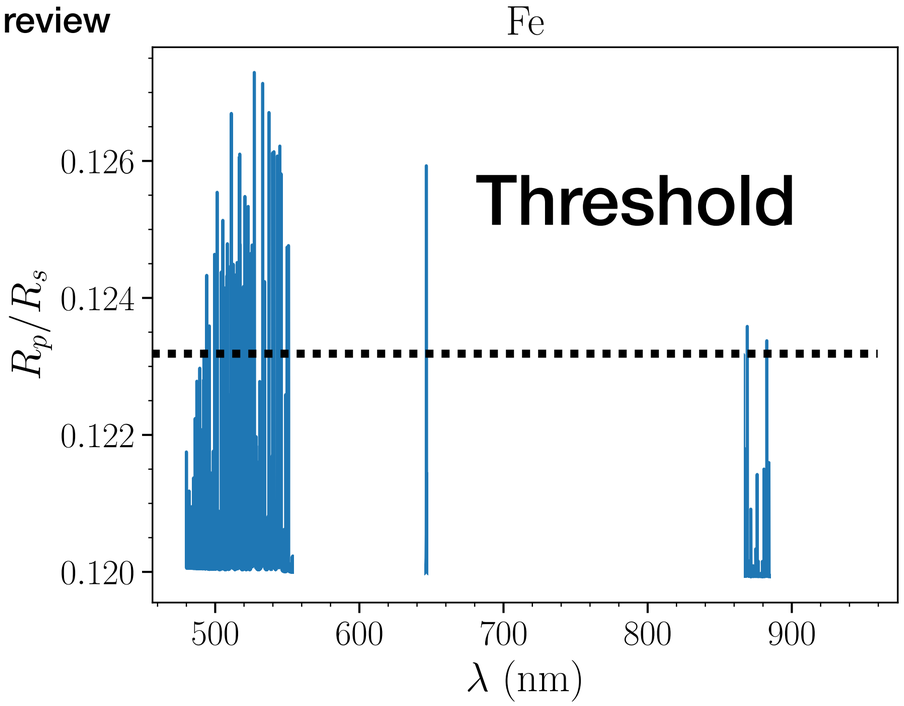
The detection shape changes !

Weak lines probe higher velocities

Separating spectral lines



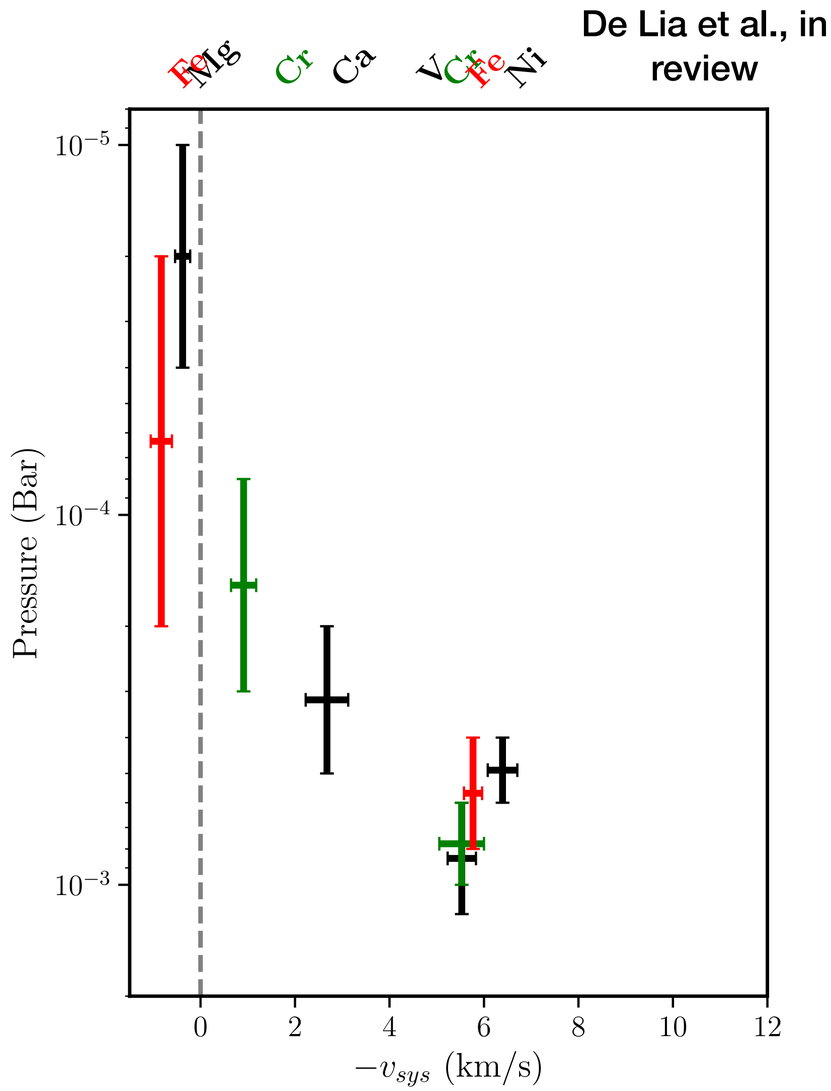
De Lia et al., in review



The detection shape changes !

Strong lines probe lower velocities

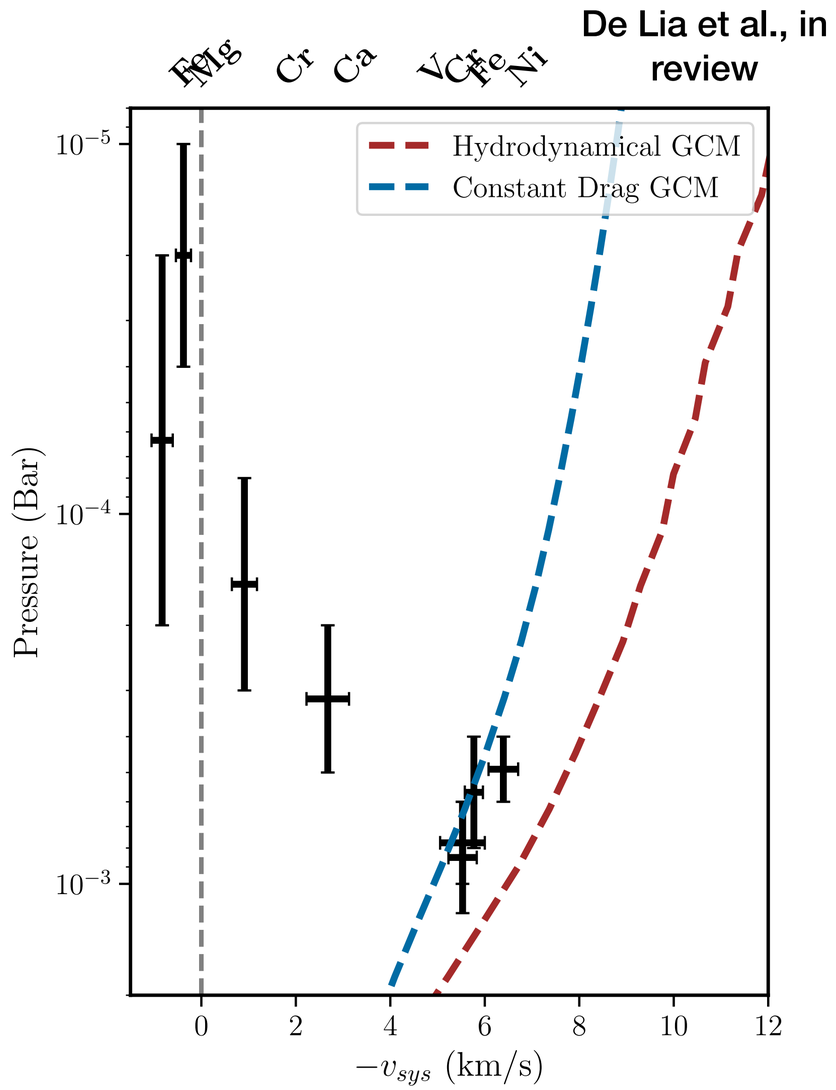
Pressure-velocity profile



Two complementary methods :

- Different species probe different heights
- Single species can also probe different heights

Pressure-velocity profile

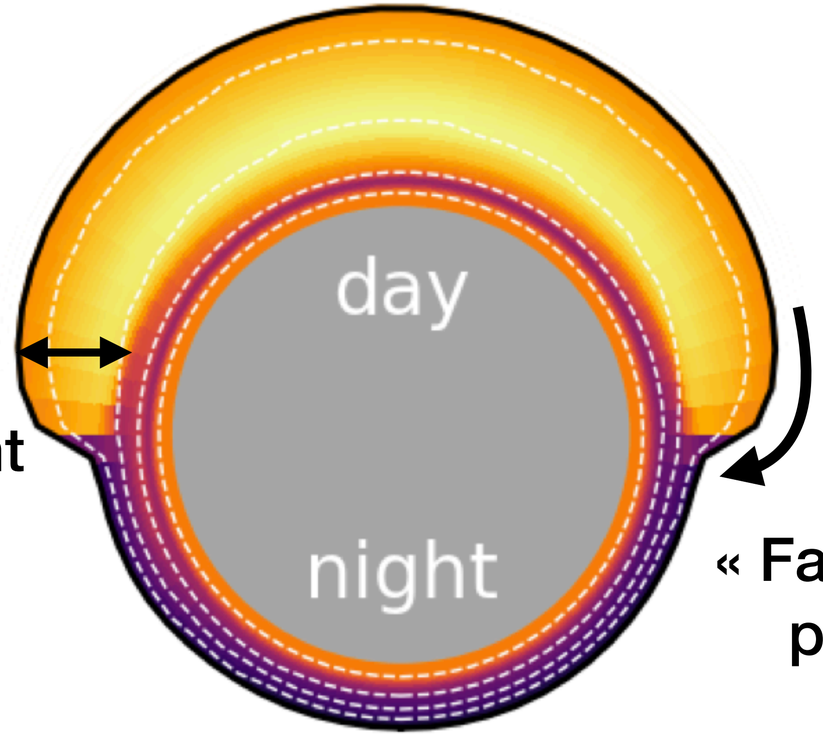


Hydrodynamics or constant drag GCMs are not sufficient

We need a drag that varies with altitude

Magnetic Models

Komacek & Showman 2016



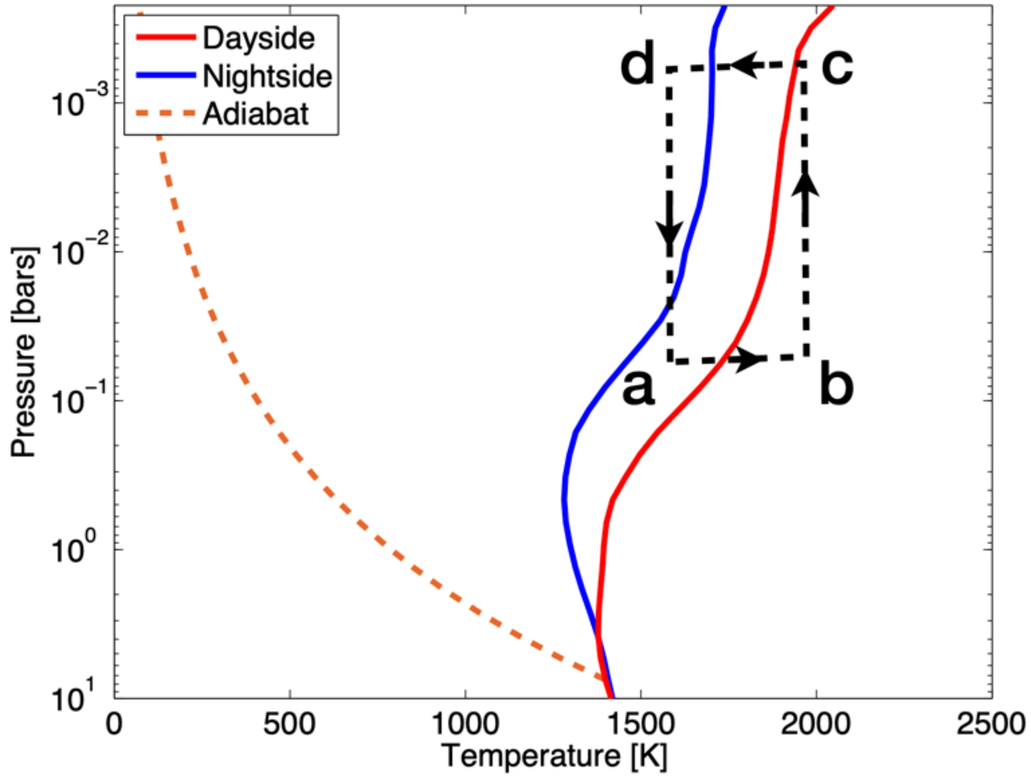
Scale height different

« Falling » path

From Wardenier+ 2023

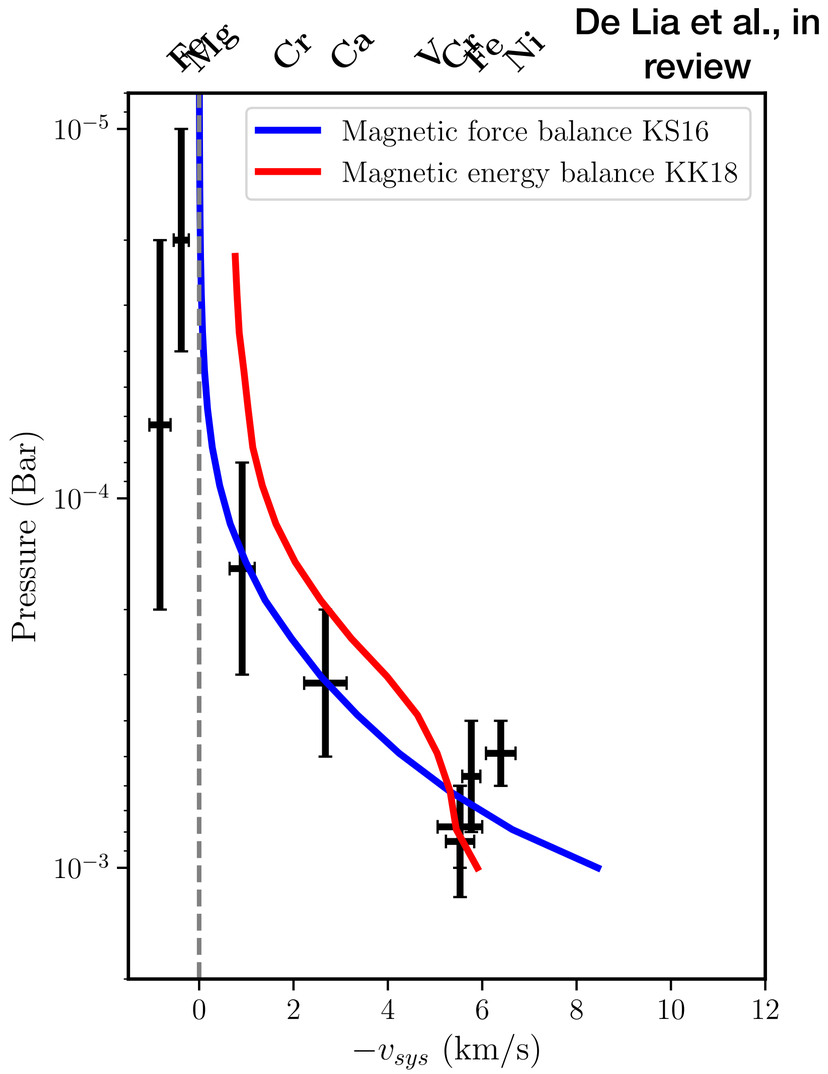
Force balance :
Magnetic drag = Geopotential gradient

Koll & Komacek 2018



Energy balance :
Magnetic dissipation = Heat engine work

Pressure-velocity profile



Simple magnetic models allow to reproduce the trend

These models have limitations :

- Simplified 1D models
- No full MHD equations

Conclusion

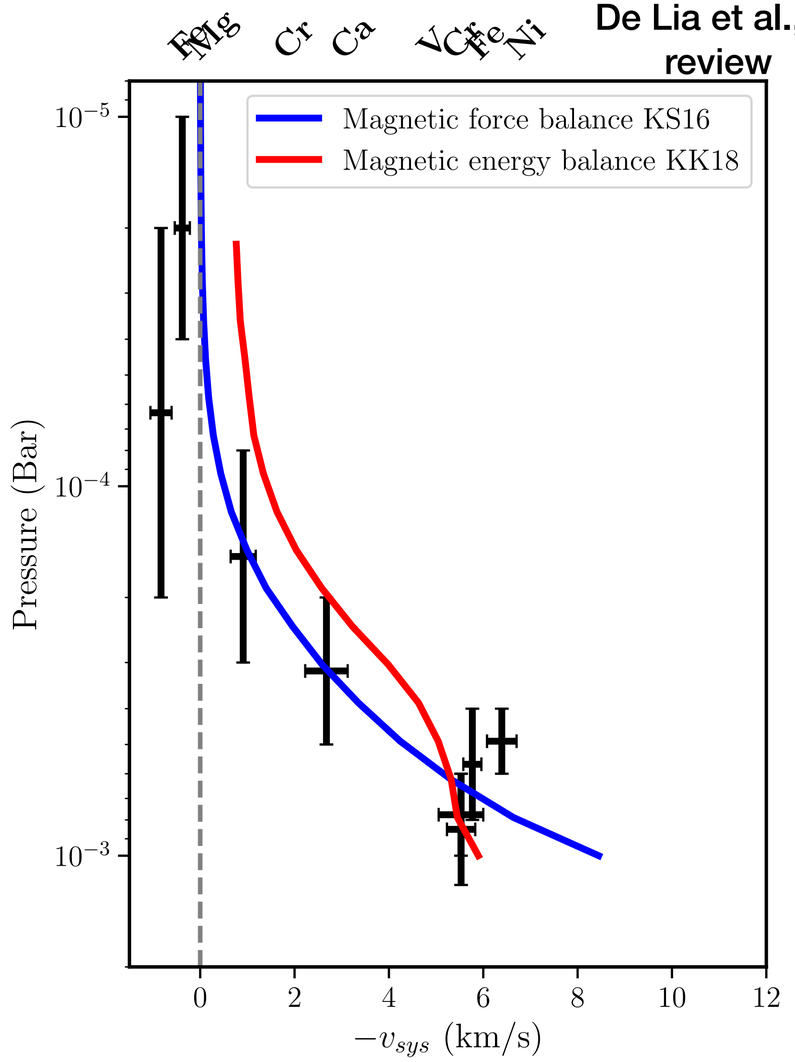
Astronomy & Astrophysics manuscript no. output
May 25, 2026

Vertical wind shear hints at magnetically damped circulation on the Ultra-Hot Jupiter KELT-20b

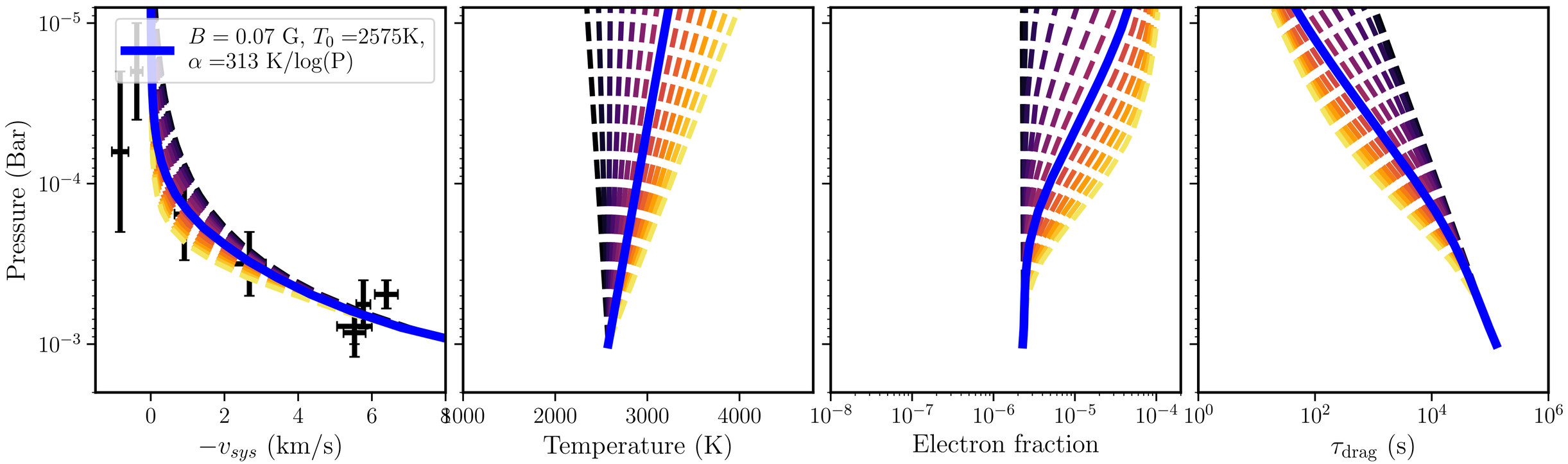
V. De Lia[1], V. Parmentier[1,], J.V. Seidel[1,2], R. Van Den Broeck[1], H. Beltz[3], B. Prinoth[4,5], T. D. Komacek[6], E.Rauscher[7], T.Hood[1], J. L. Bean[8], M. Brogi[9,10], A. Simonnin[5], and L. Pino[11]

- High resolution allows to get the vertical wind structure
- Both single species and multi-species can lead to estimation of the vertical wind shear
- Hints at magnetically affected circulation, but models are limited

De Lia et al., in review

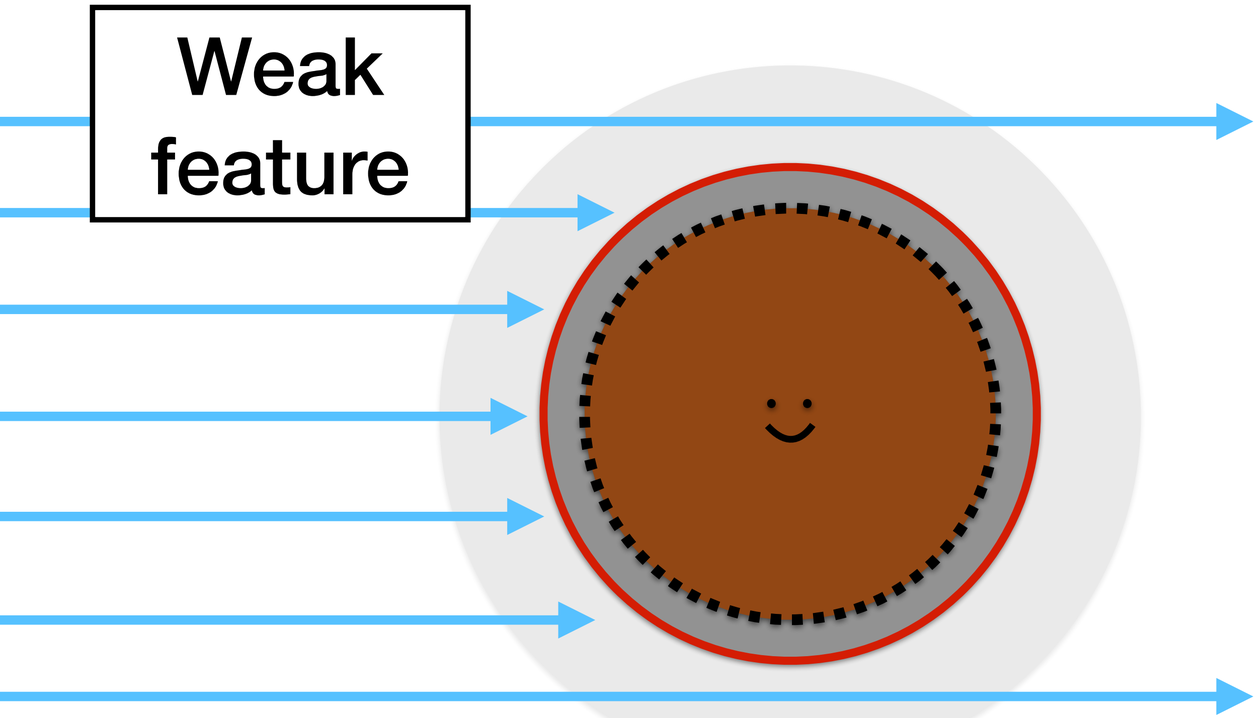


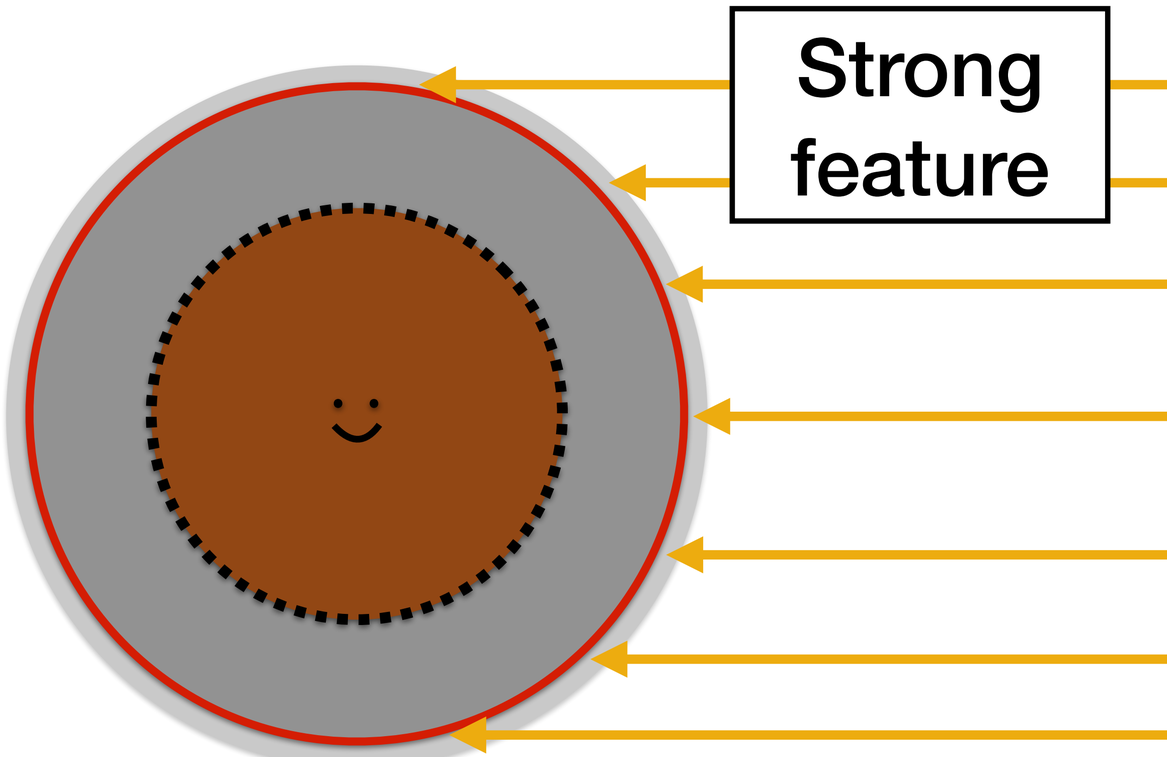
Model parameters



We likely constrain the gradient of ionization in the atmosphere

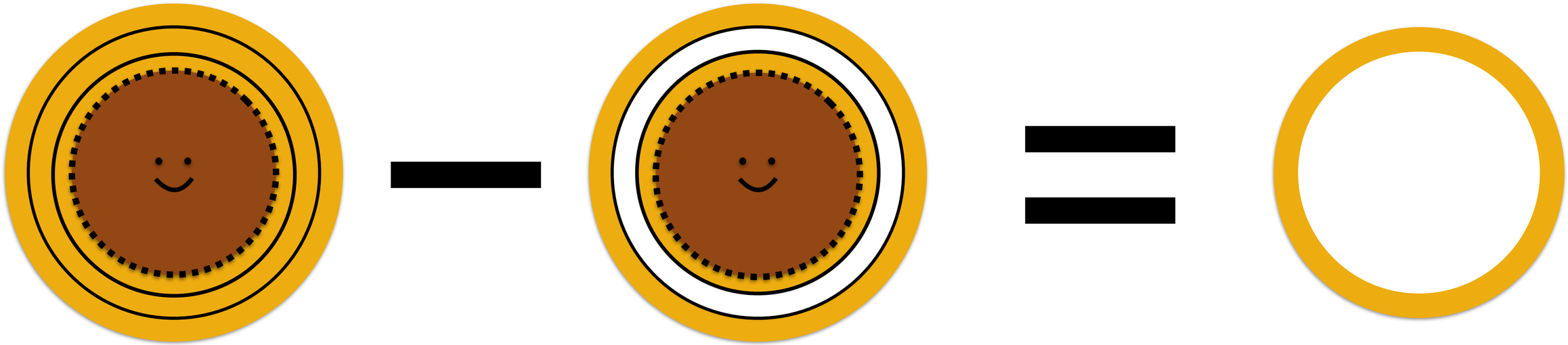
Contribution functions





We can estimate the pressure layers that contribute to the Doppler shift

Contribution functions

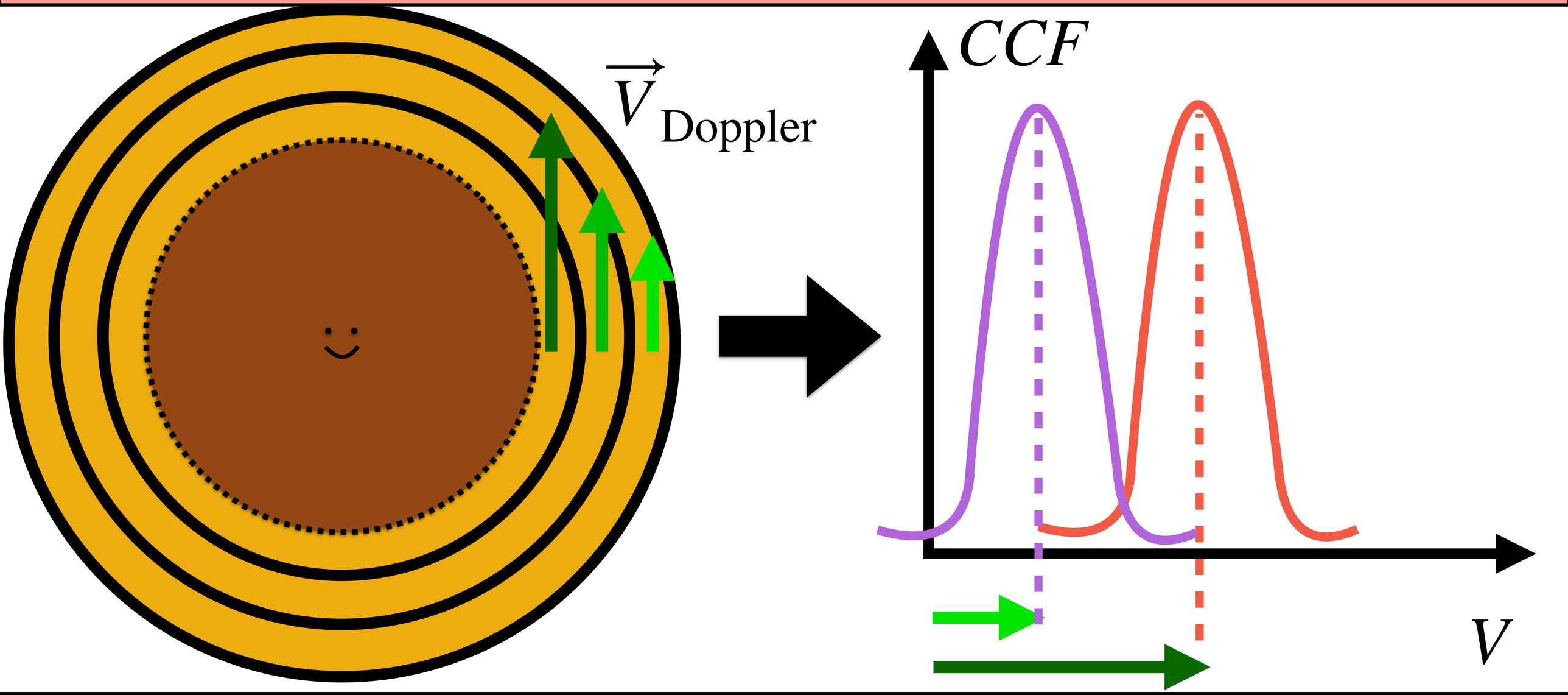


Reference simulation

Same, with $\rho_{\text{layer}} = 0$

Layer contribution

Contribution functions



Contribution functions

New methods
(Velocity based)

Usual method
(Density based)