Leibniz-Institut für Astrophysik Potsdam

High-resolution transmission spectroscopy of the super-Earth 55 CNC e

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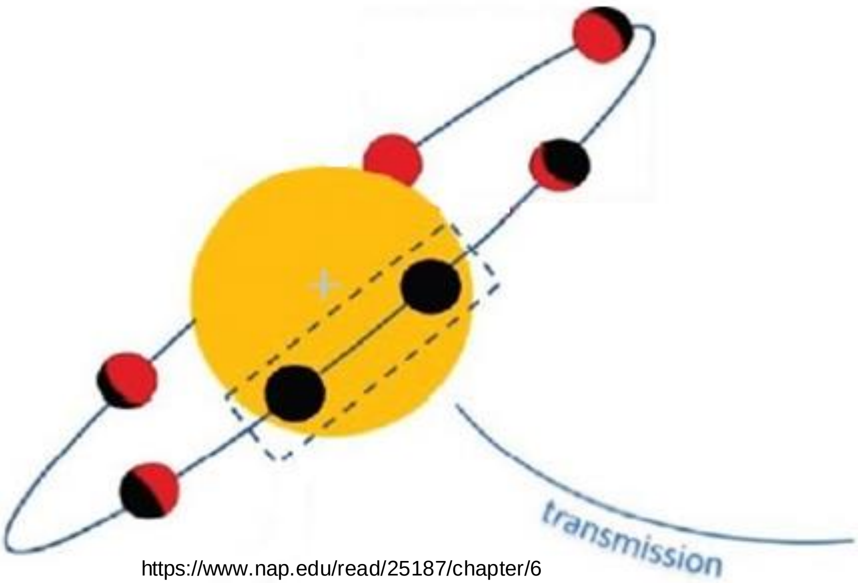
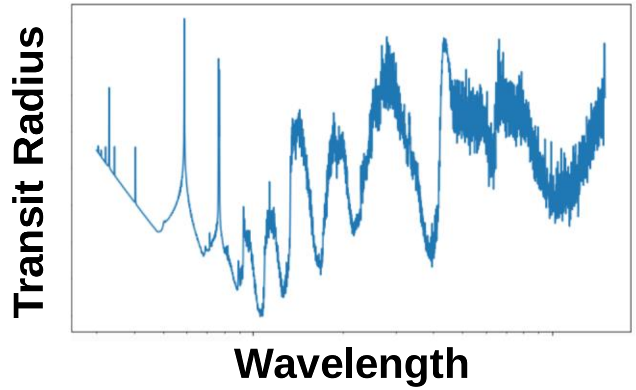
Atmospheric characterization

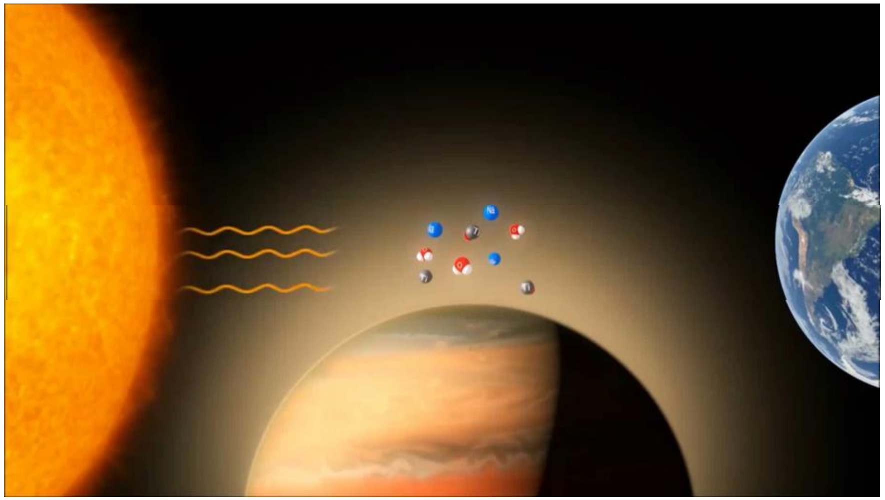
Detecting atmospheric spectral signature of exoplanets during transit



https://www.nap.edu/read/25187/chapter/6



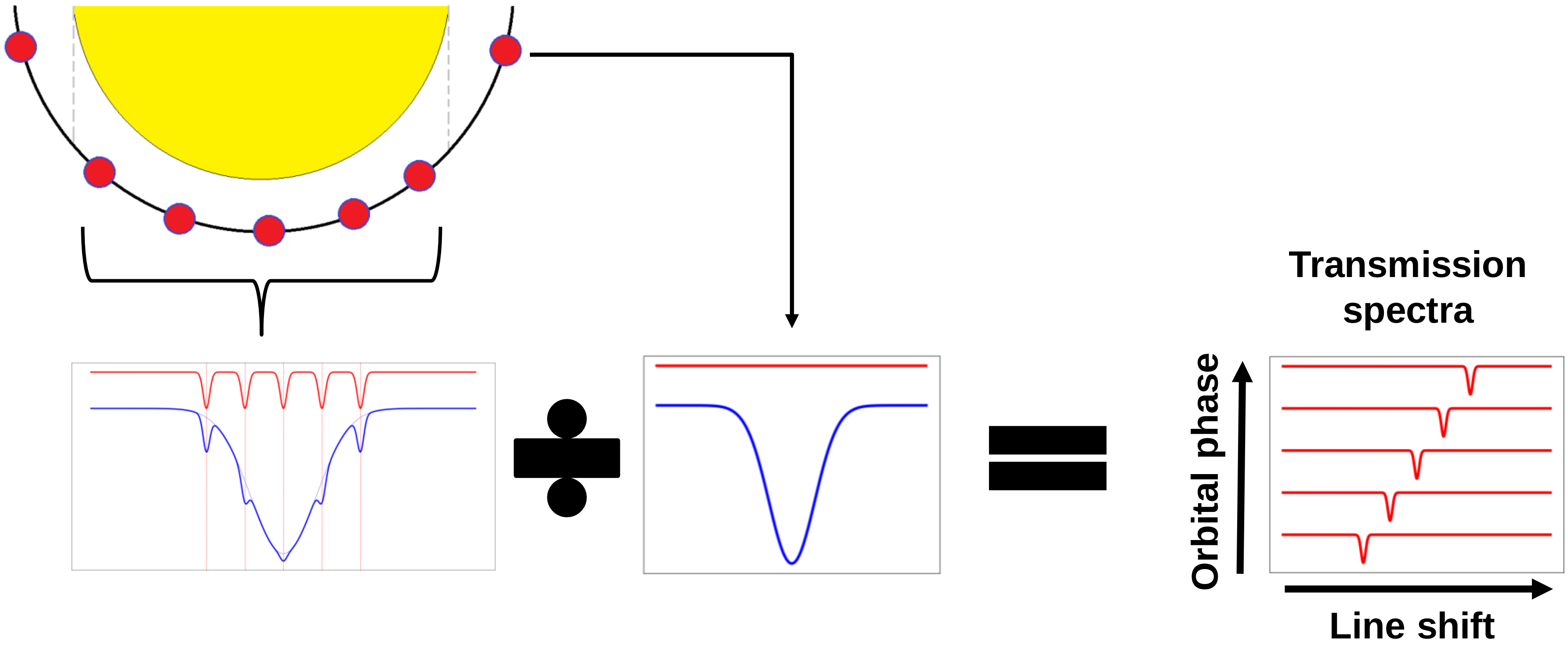
https://petitradtrans.readthedocs.io/en/latest/content/notebooks/getting_started.html



https://elt.eso.org/public/videos/eso1729c/

Extracting atmospheric absorption

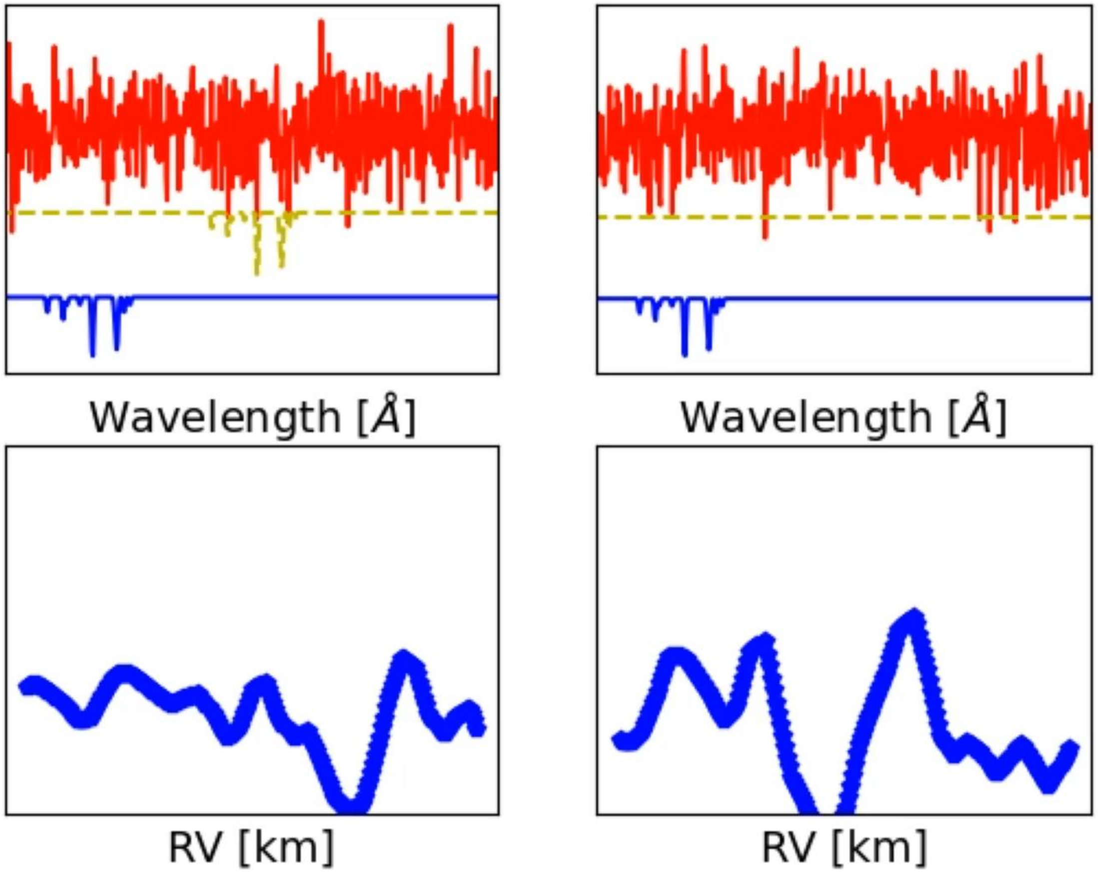
The planetary absorption arise shifted according to its orbital phase velocity on top of the stellar lines



Dividing the in-transit stellar line by the out-of-transit line removes the stellar contribution showing the shifted planetary absorption!

Extracting atmospheric absorption - the cross correlation method

For weak absorption lines, the cross-correlation method allows to combine a large amount of lines and compare templates with the observations:

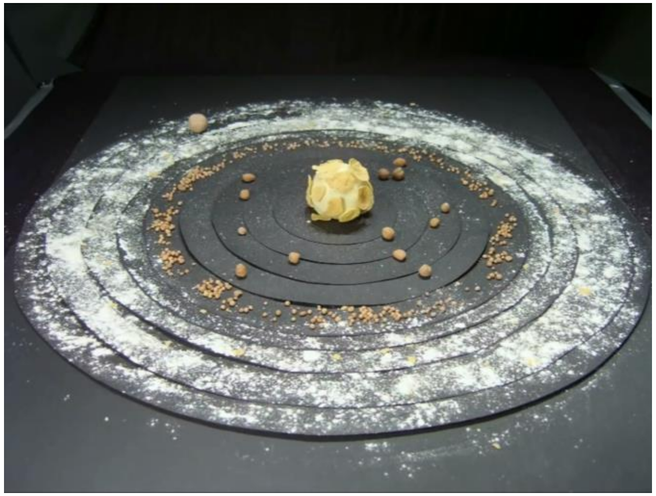


Observation with noise level

CC function

Why do I care about the atmospheres ?

The comparison of exoplanet atmospheres with the solar system planet ones can give clues about planetary evolution processes

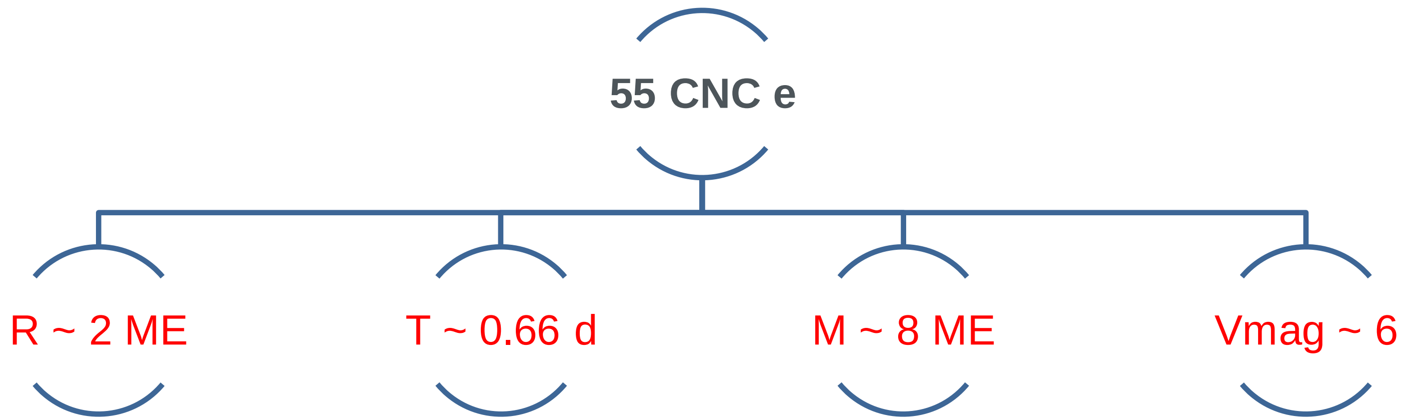


www.youtube.de

The super-Earth 55 Cnc e

Absorption signature from gaseous exoplanets have been resolved in high- resolution observations, but the Holy Grail is located towards the direction of terrestrial ones!

The super-Earth 55 CNC e seems to be one of the best candidates

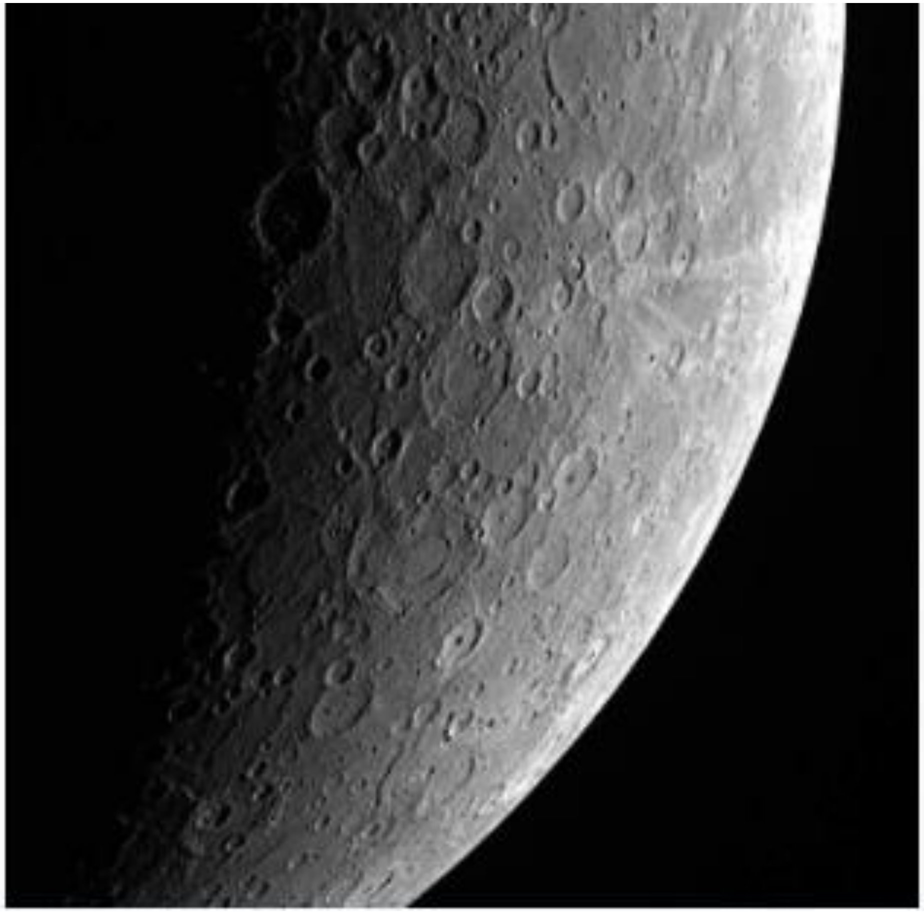


Example: Mercury

Sputterring by solar irradiation leads to an exosphere that consists of of different species

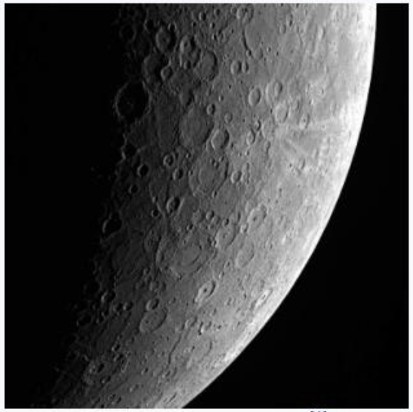
Species	CD,[n 1] cm^{-2}	SD,[n 2] cm^{-3}
Hydrogen (H)	$\sim 3 \times 10^9$	~ 250
Molecular hydrogen	$< 3 \times 10^{15}$	$< 1.4 \times 10^7$
Helium	$< 3 \times 10^{11}$	$\sim 6 \times 10^3$
Atomic oxygen	$< 3 \times 10^{11}$	$\sim 4 \times 10^4$
Molecular oxygen	$< 9 \times 10^{14}$	$< 2.5 \times 10^7$
Sodium	$\sim 2 \times 10^{11}$	1.7–3.8×10^4
Potassium	$\sim 2 \times 10^9$	~ 4000
Calcium	$\sim 1.1 \times 10^8$	~ 3000
Magnesium	$\sim 4 \times 10^{10}$	$\sim 7.5 \times 10^3$
Argon	$\sim 1.3 \times 10^9$	$< 6.6 \times 10^6$
Water	$< 1 \times 10^{12}$	$< 1.5 \times 10^7$
neon, silicon, sulfur, iron, carbon dioxide, etc.		

1. ^ Column density
2. ^ Surface density



https://en.wikipedia.org/wiki/Atmosphere_of_Mercury

Comparing atmospheric properties of 55 Cnc e with Mercury



Atmosphere of Mercury[1]

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https://en.wikipedia.org/wiki/Atmosphere_of_Mercury

Concentrating here on atomic species, **for 55 CNC e**:

→ A primary atmosphere seems to be ruled out

- → Non-detection of Hydrogen (Ehrenreich et al. 2012; Tabernero et al. 2020)
- → Non-detection of Helium (Zhang et al. 2021)

→ Evidence of Sodium absorption ?

- → Tentative detection of Na (Ridden-Harper et al. 2015)
- → Non-detection of Na (Tabernero et al. 2020)

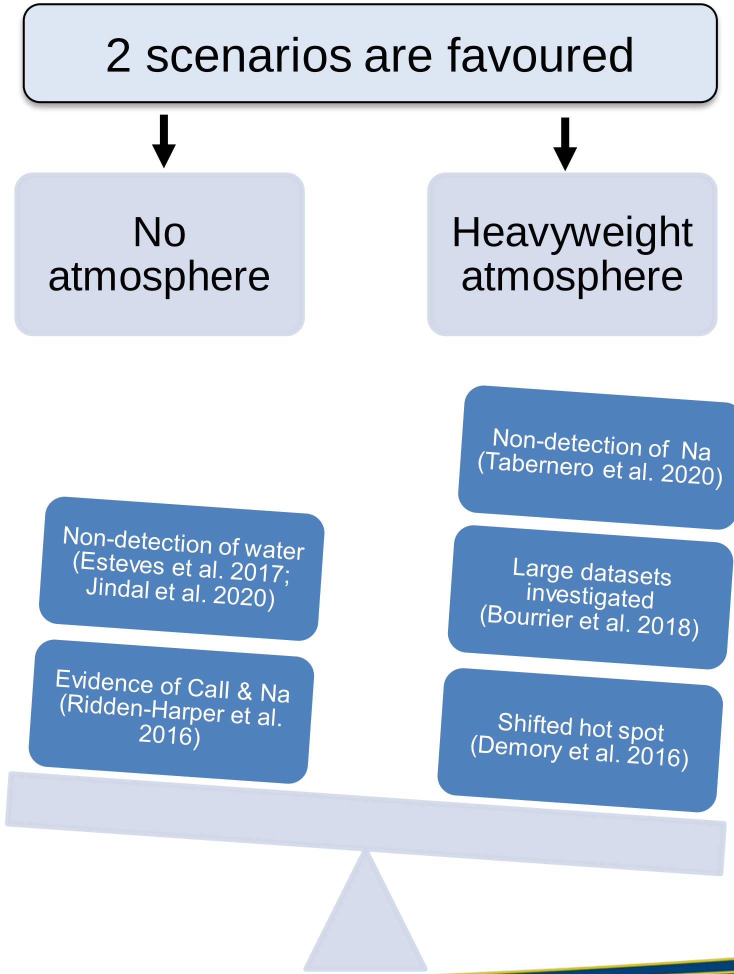
→ Evidence of ionized Calcium?

- → Tentative detection of Ca H&K (Ridden-Harper et al. 2015)

→ Other major atomic species are not investigated yet: O, K, Mg, …

Big Picture

55 CNC e is most probably the best studied terrestrial exoplanet to date, but its atmospheric conditions are still puzzling



We want to add another puzzle piece !

Science Question

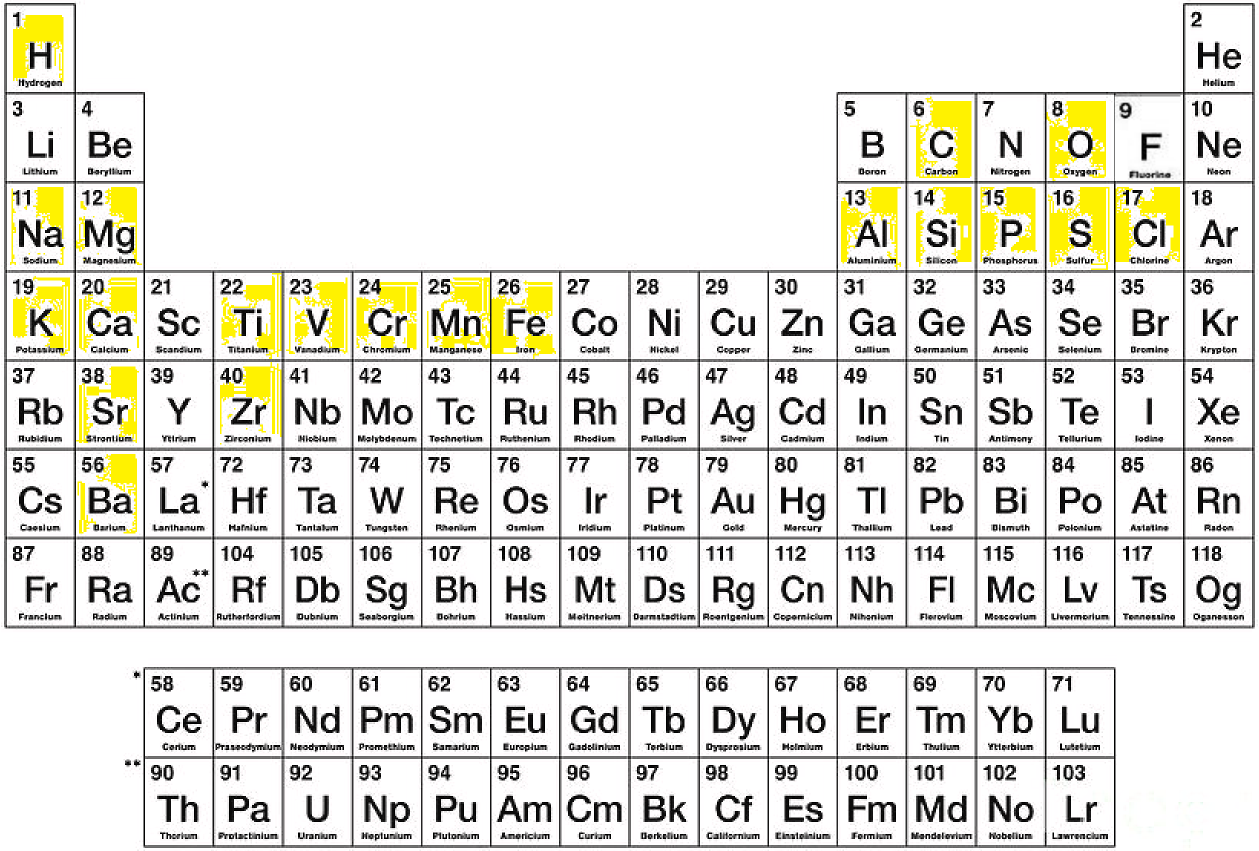
Does 55 CNC e has an exosphere full of sputtered species arising from a rocky surface

The immediate aim

We search for absorption by different atomic and ionic species due to sputtering or released by a magma ocean assuming an **Earth-like crust composition** :

David R. Lide (Hrsg.): *CRC Handbook of Chemistry and Physics*, 85. Auflage. CRC Press, Boca Raton, Florida, 2005. Section 14, Geophysics, Astronomy, and Acoustics; Abundance of Elements in the Earth's Crust and in the Sea.

Species	Composition in %
O	46,1000
Si	28,2000
Al	8,2300
Fe	5,6000
Ca	4,1500
Na	2,3600
Mg	2,3300
K	2,0900
Ti	0,5650
H	0,1400
P	0,1050
Mn	0,0950
F	0,0585
Ba	0,0425
Sr	0,0370
S	0,0350
C	0,0200
Zr	0,0165
Cl	0,0145
V	0,0120
Cr	0,0102

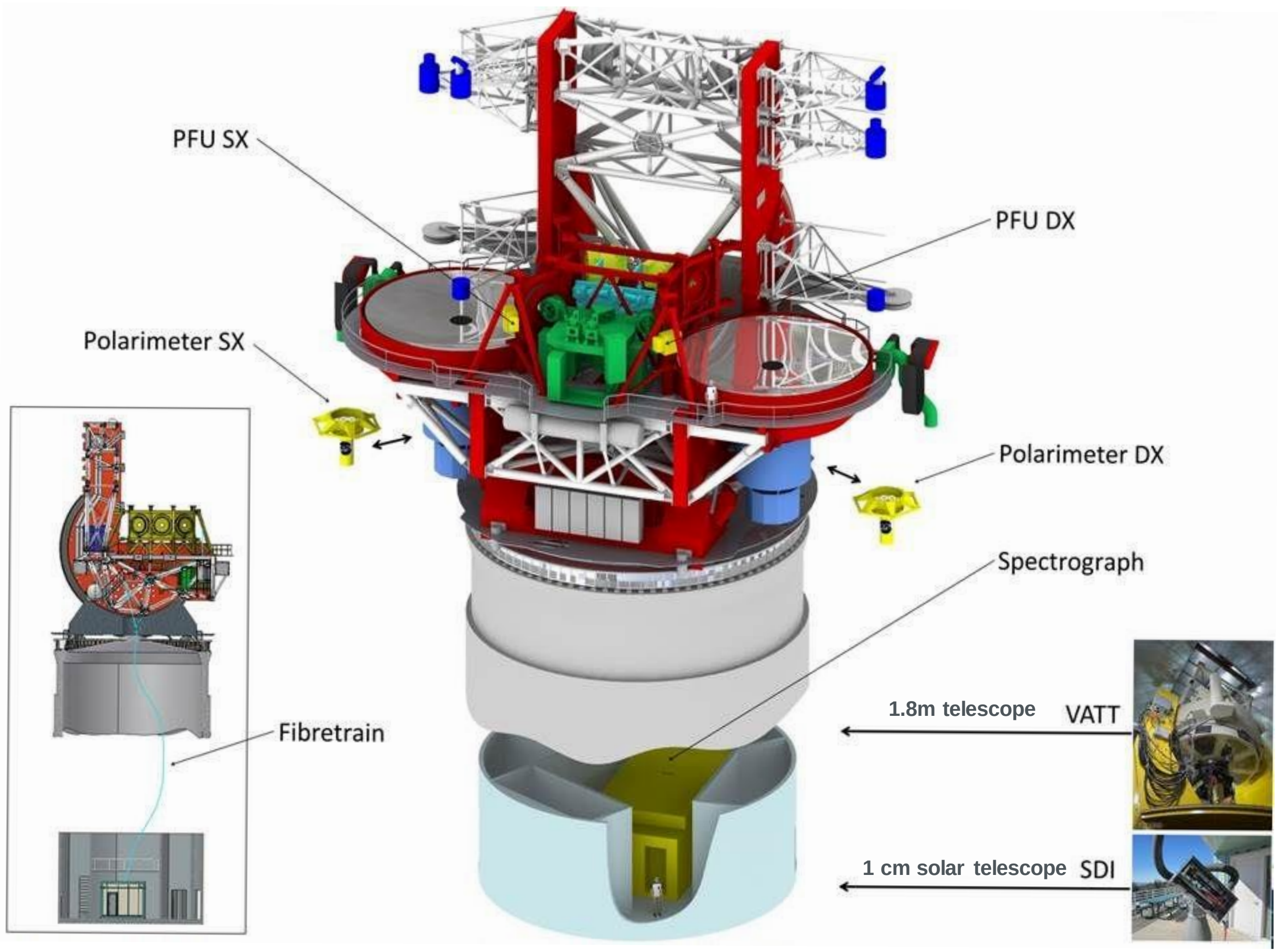


→ Their presence would confirm the rocky-planet scenario and their absence would hint towards the heavyweight scenario!

The transit observation of 55 Cnc e

Observation tool

The LBT (Large Binocular Telescope) and PEPSI (Potsdam Echelle Polarimetric and Spectroscopic Instrument) are used to observe one transit !



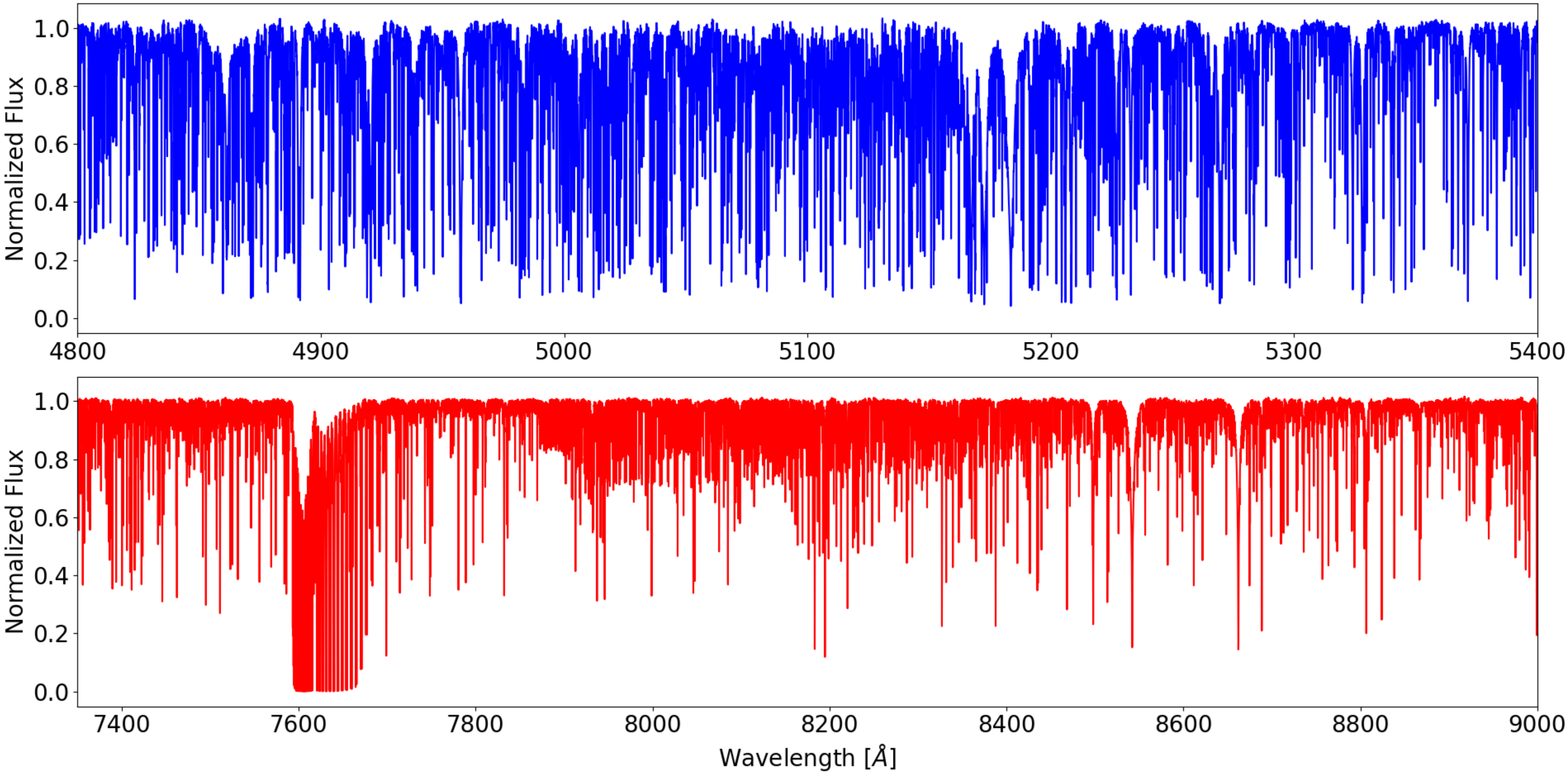
Strassmeier et al. (2015)

Our setup:

- 2 x 8.4m mirrors
- R = ~120 000
- λ_1 = 480 - 540 nm
- λ_2 = 730 - 900 nm
- Exp.time = 90 s

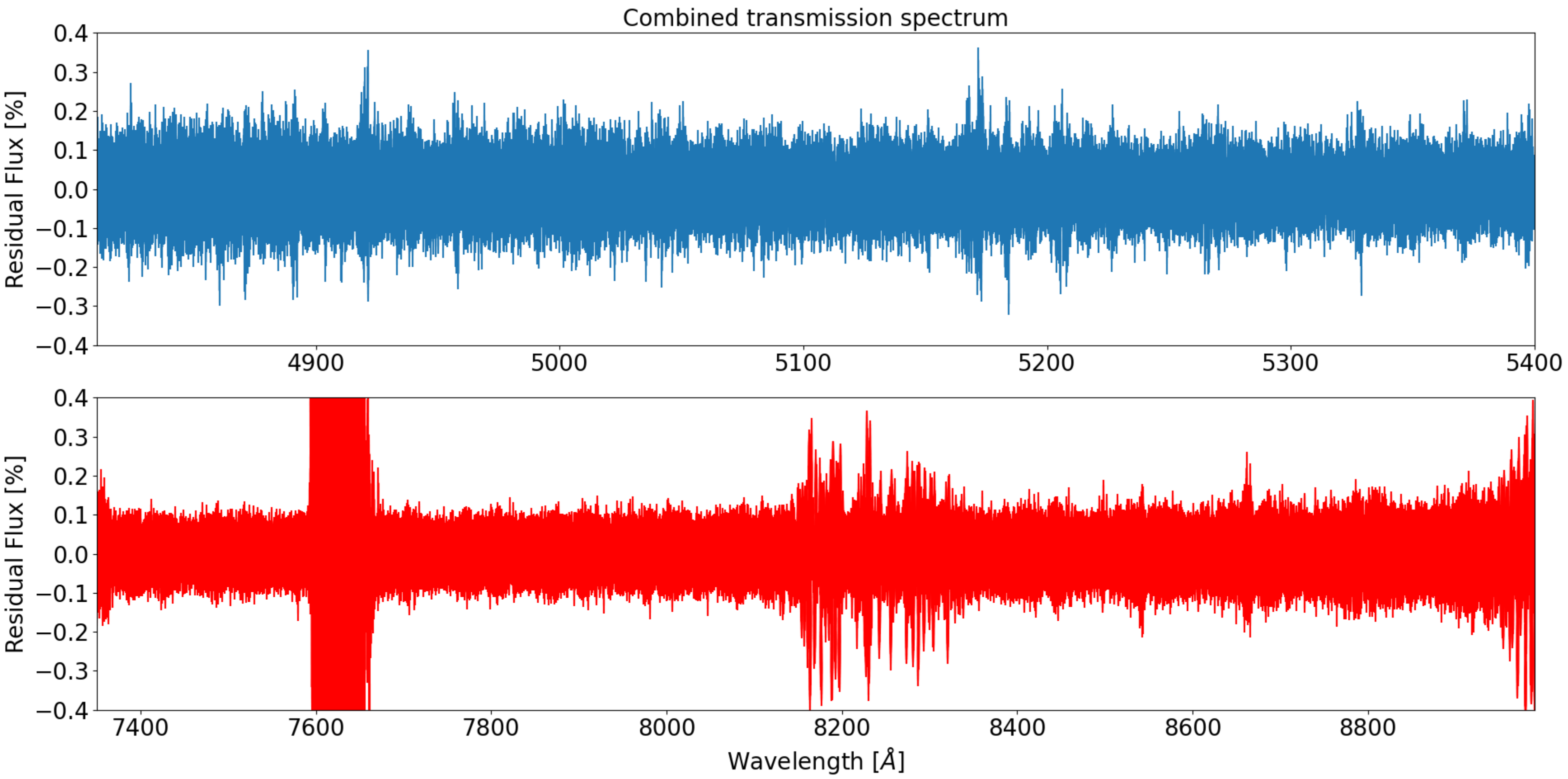
The Observation

One example spectrum of the observed wavelength range:

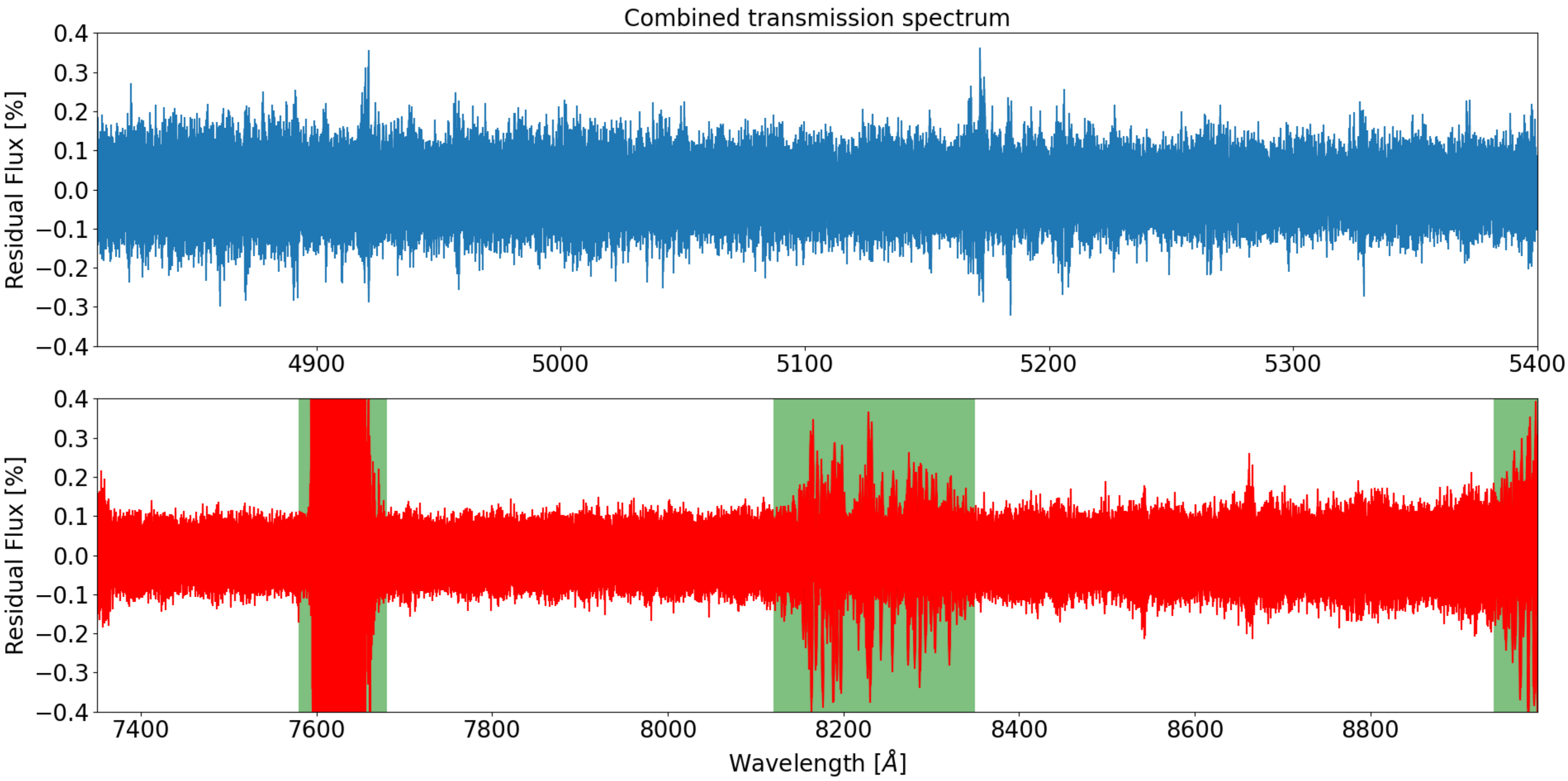


→ 41 in-transit & 42 out-of-transit spectra with continuum S/N ~ 500 and S/N ~ 700 per pixel

The combined transmission spectrum



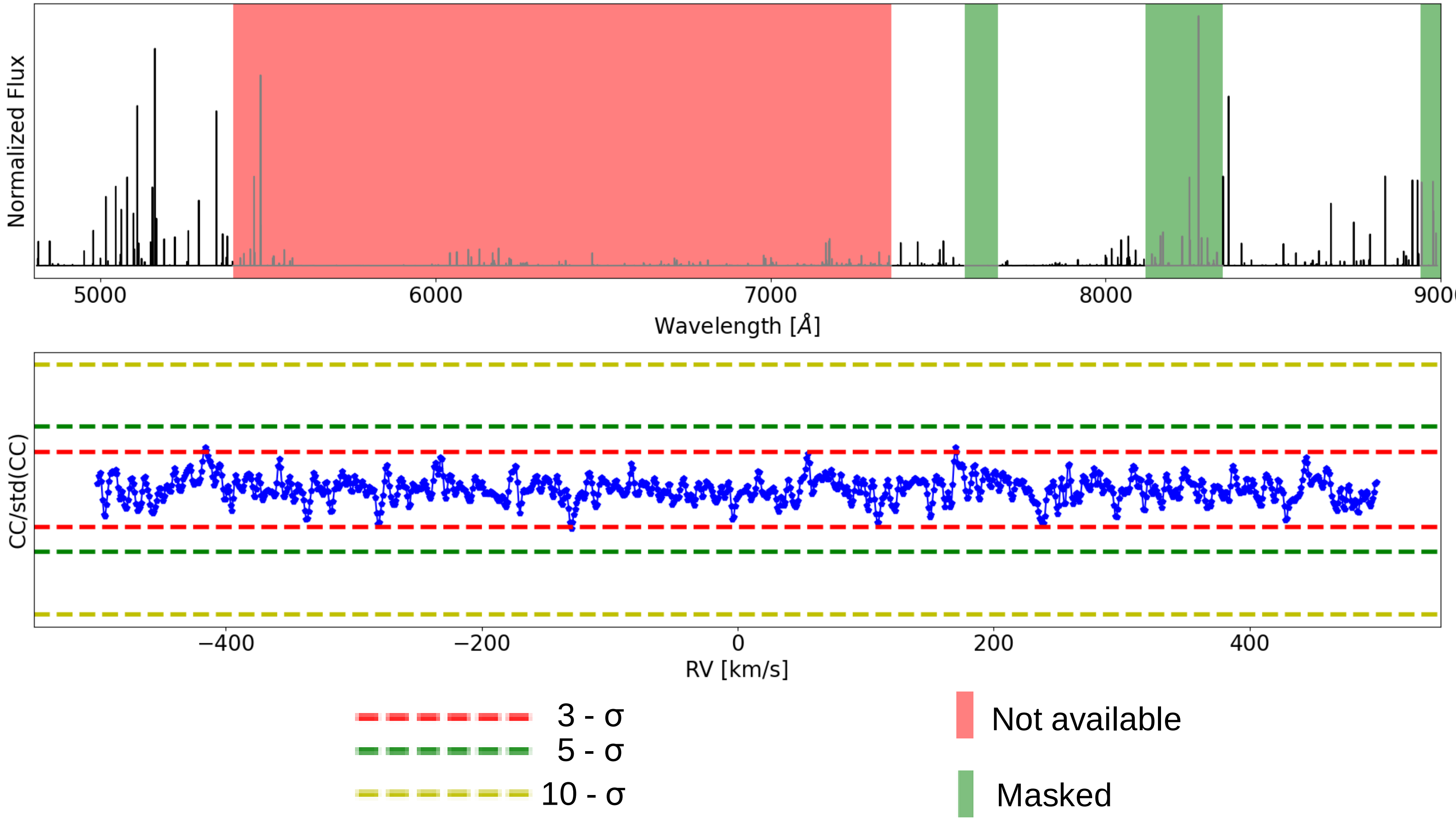
The combined transmission spectrum



→ Masking the regions with strong telluric lines !

Results

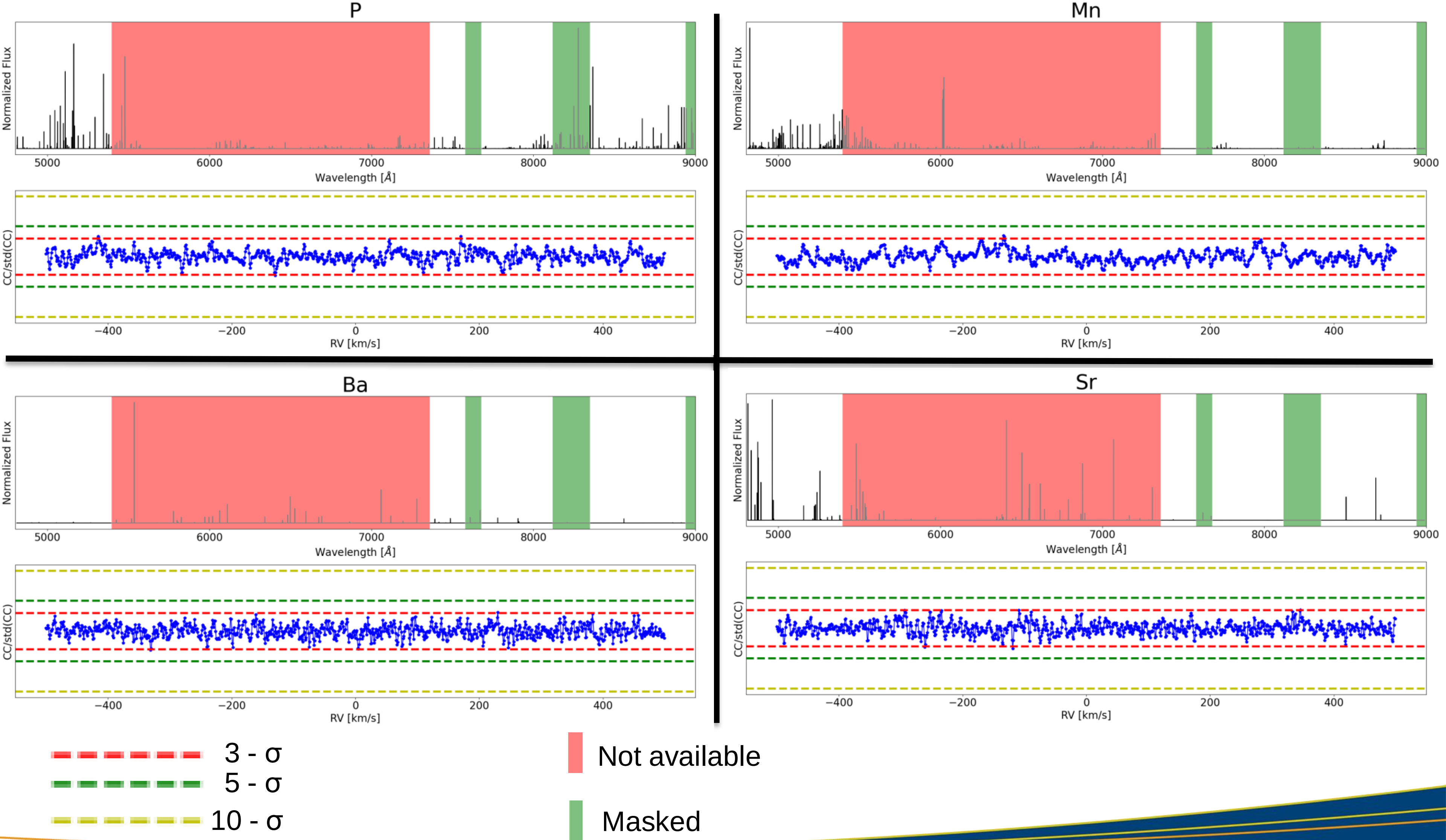
Showing transmission spectra and cross - correlation functions for different atomic and ionic species



→ Ongoing investigation, thus only **preliminary** results !

Results: Looking for atomic species on 55 CNC e

Let´s start the investigation with the less abundant atoms: **P, Mn, Ba, Sr,** S, C, Zr, Cl, V, Cr



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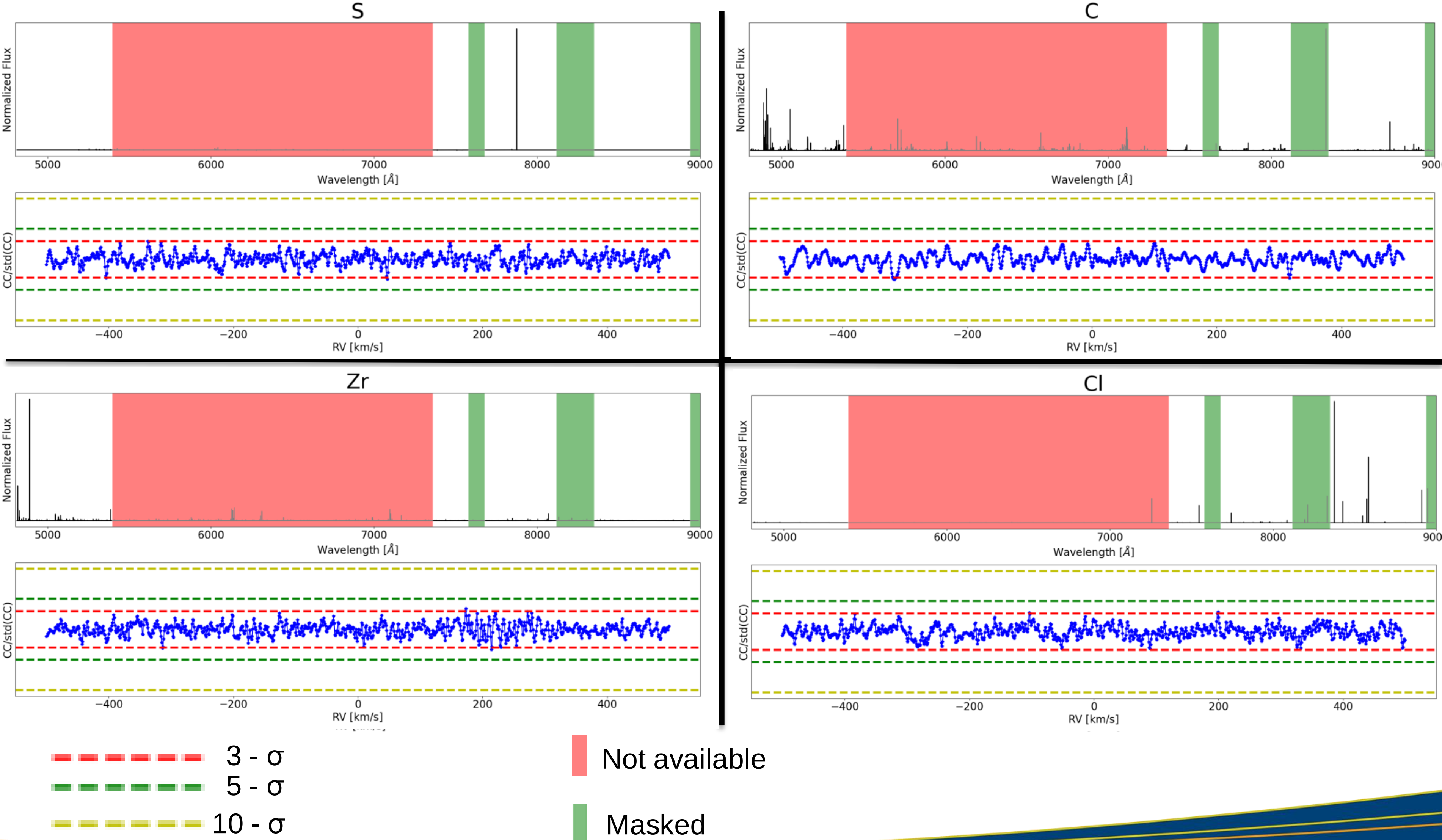

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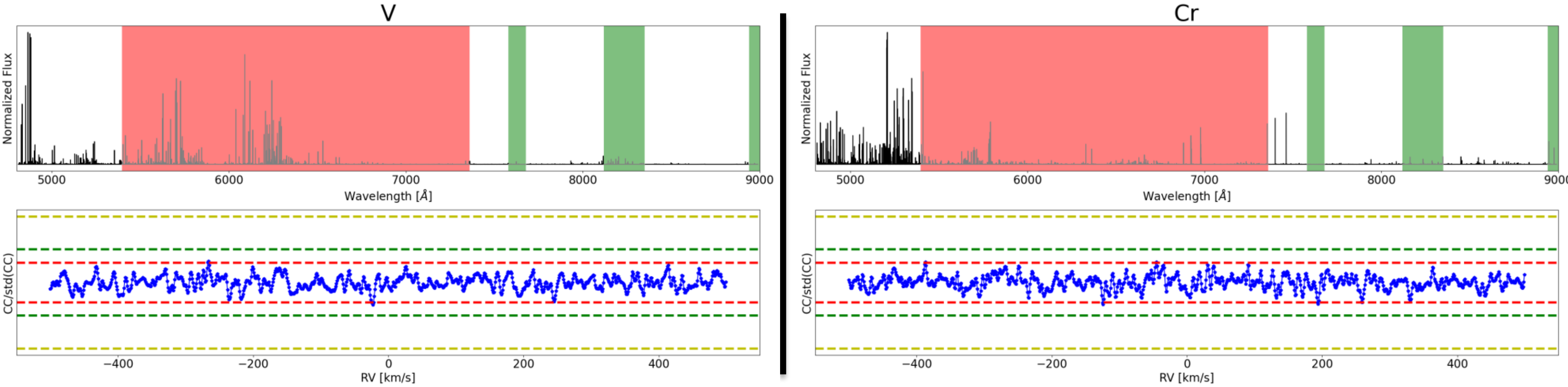


→ The less abundant species do not show absorption

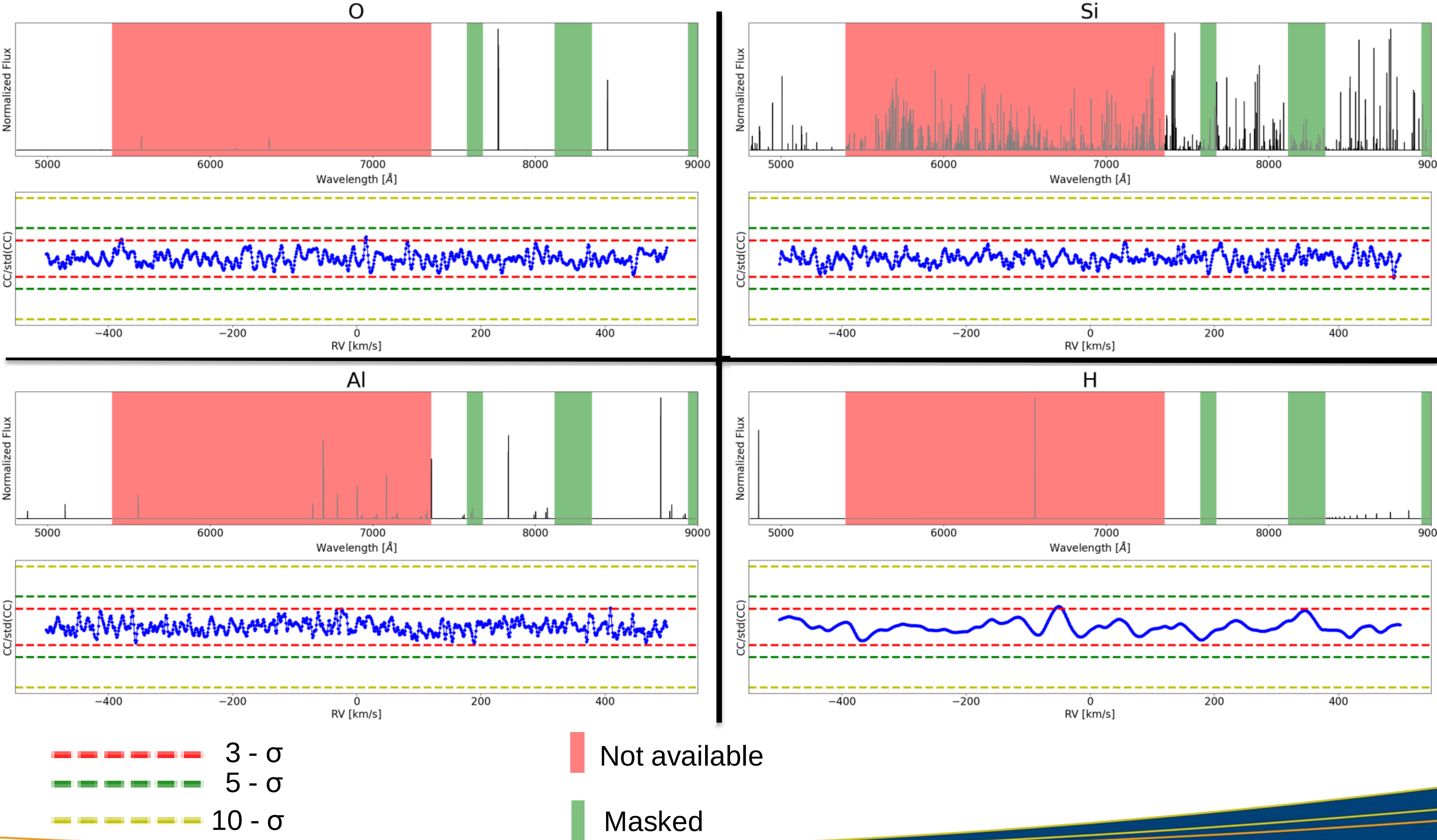
3 - σ
5 - σ
10 - σ

Not available

Masked

Results: Looking for atomic species on 55 CNC e

The more abundant atoms: **O, Si, Al, H**, Fe, Ca, Ti, Na, K, Mg



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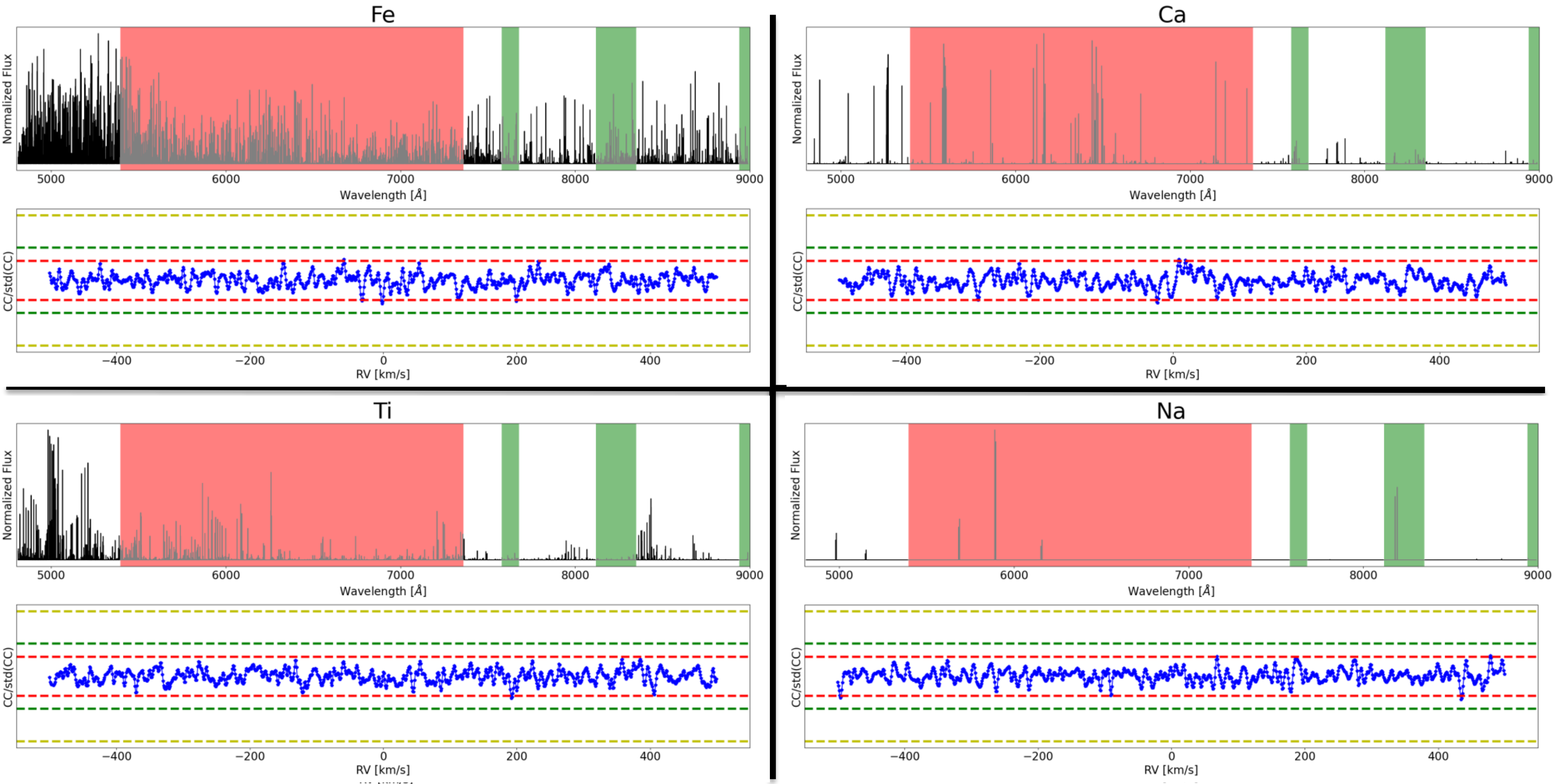

3 - σ
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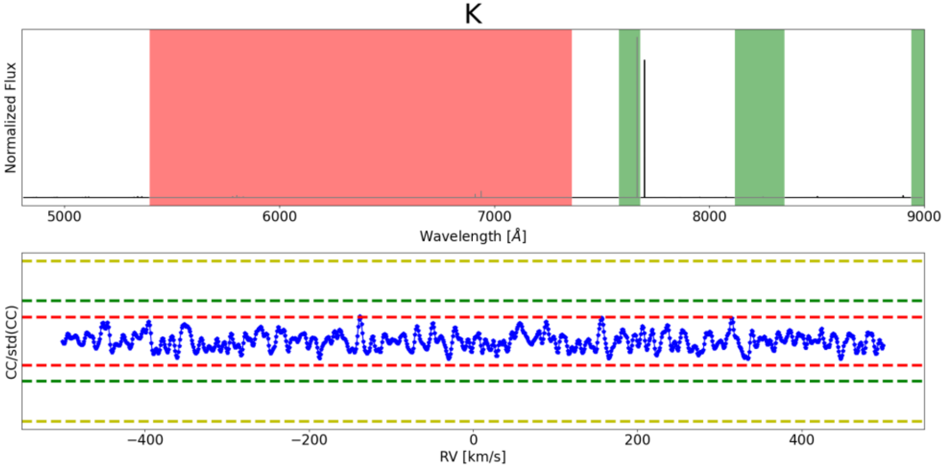
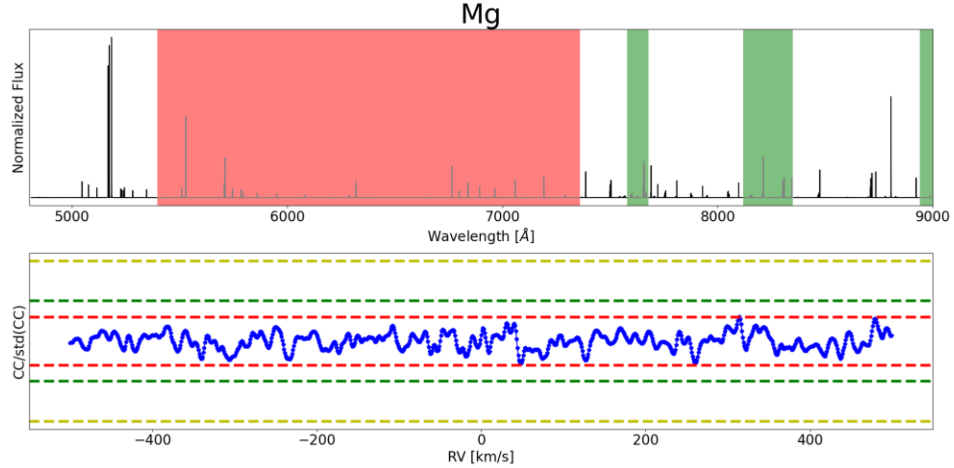




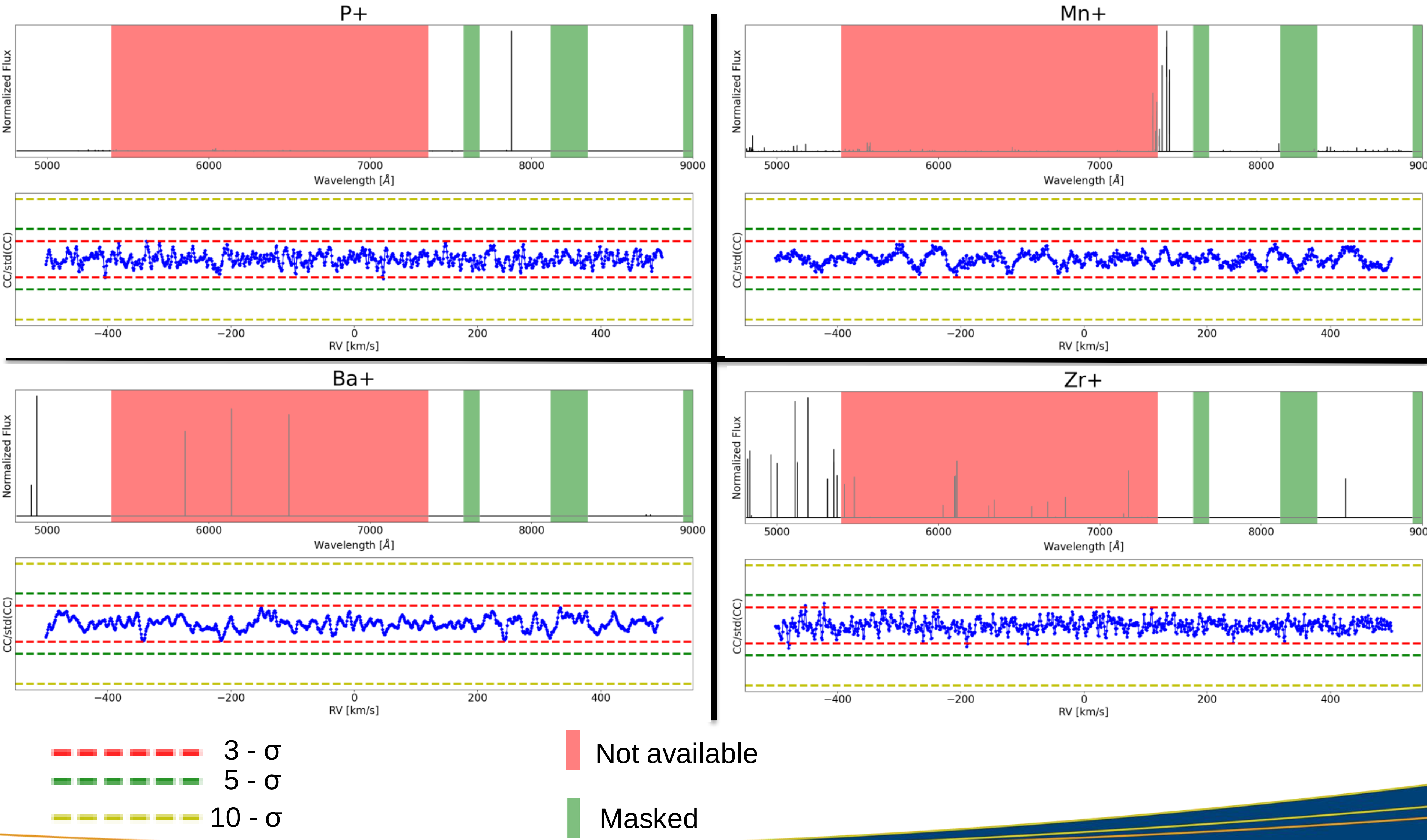
3 - σ
5 - σ
10 - σ

Not available

Masked

Results: Looking for ionized species on 55 CNC e

Let´s continue the investigation with the less abundant ions: **P+, Mn+, Ba+, Zr+,** V+, Cr+



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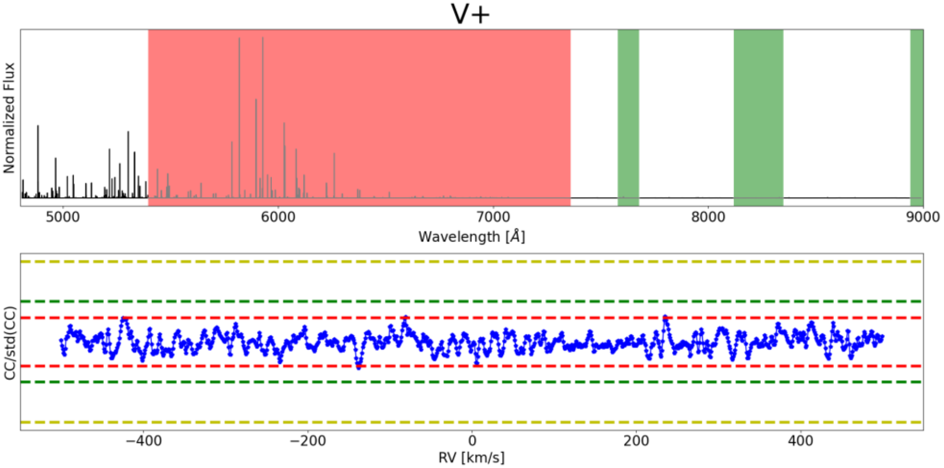
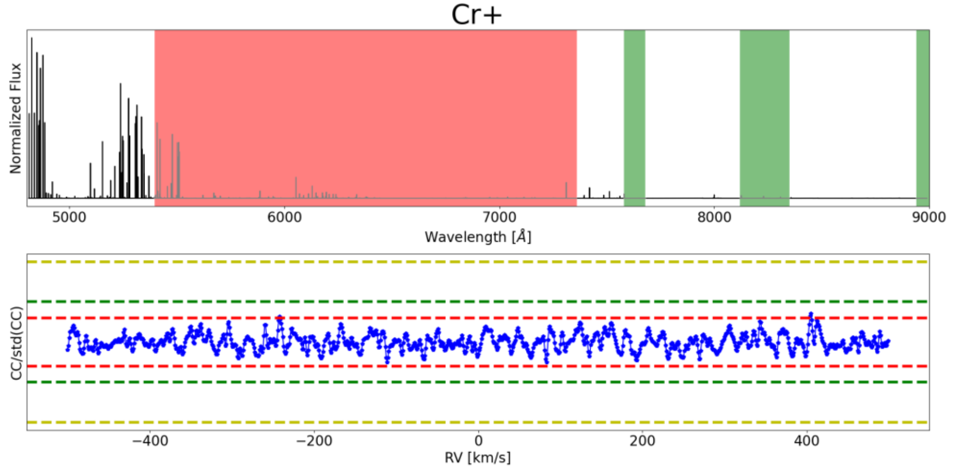




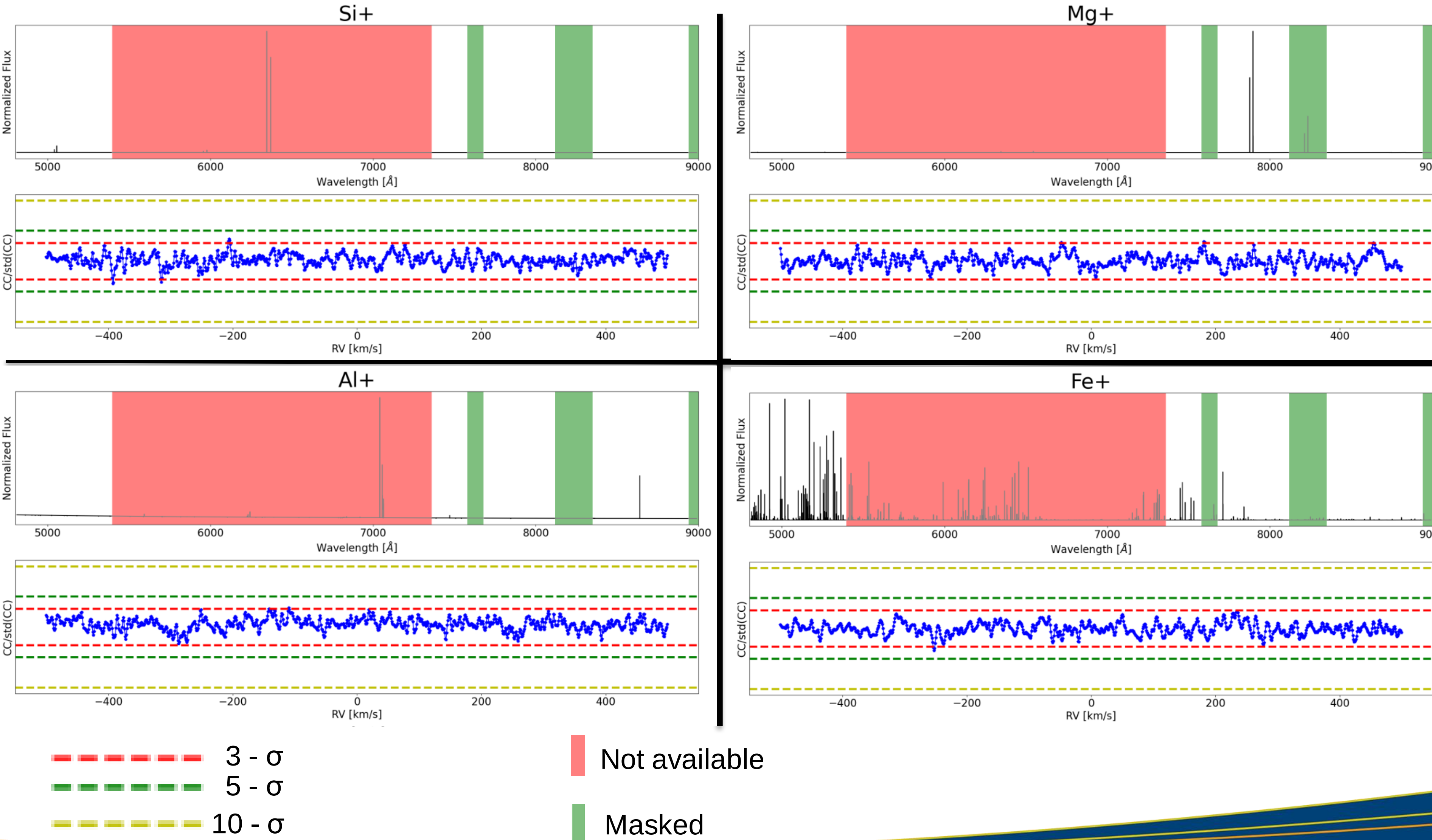
3 - σ
5 - σ
10 - σ

Not available

Masked

Results: Looking for ionized species on 55 CNC e

The more abundant ions: **Si+, Mg+, Al+, Fe+,** Ti+, Ca+



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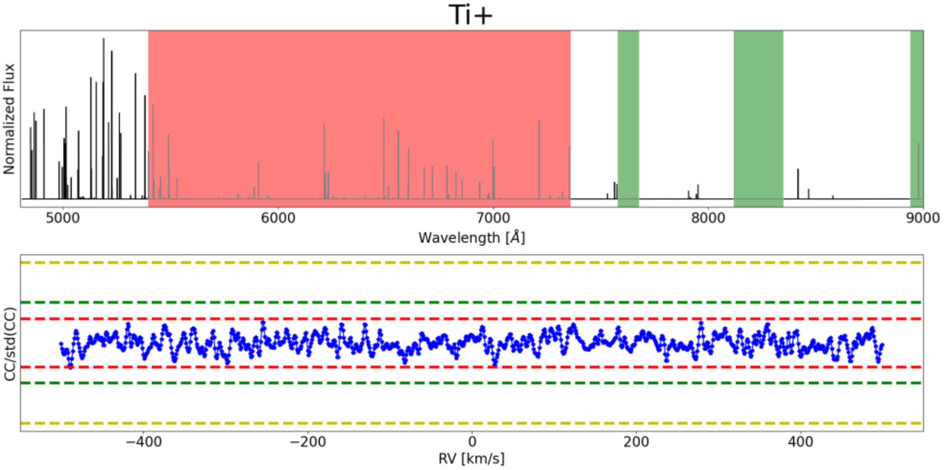
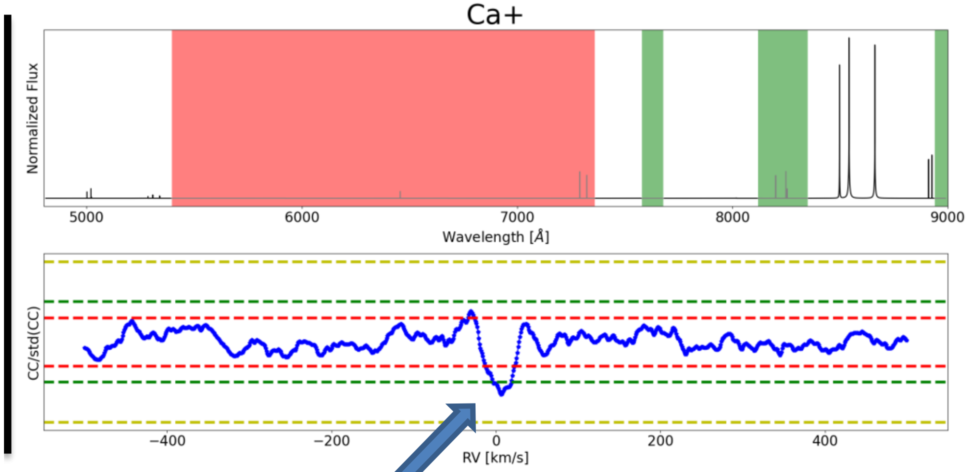




What´s going on there ?

Negative sign would hint on emission ! But the signal is very broad, thus probably has no planetary origin… needs further invetigation !

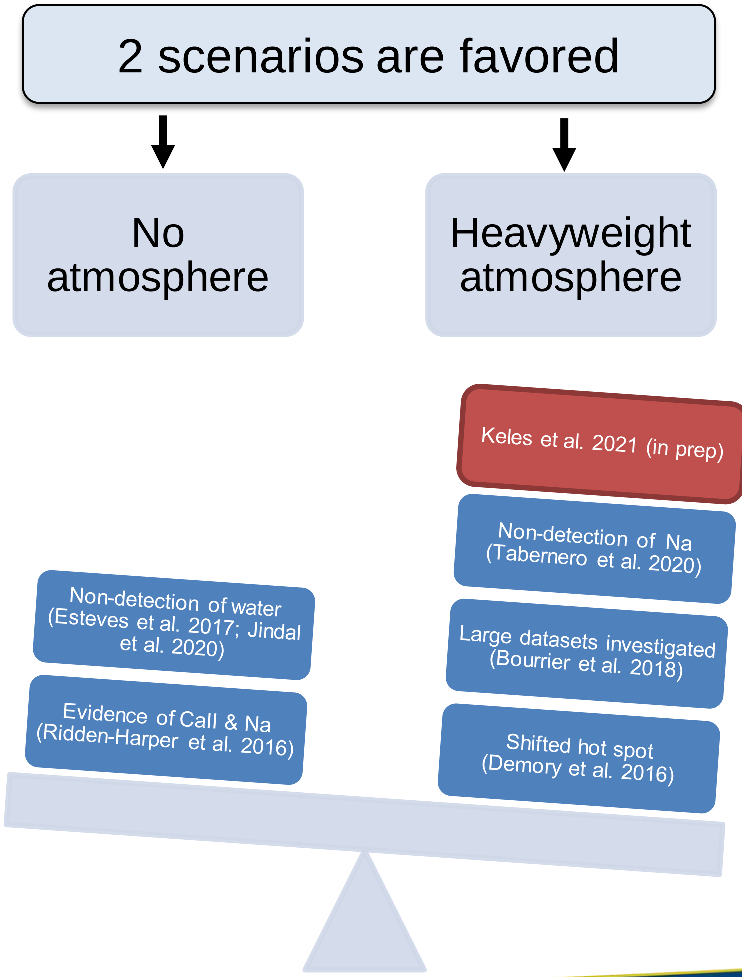
3 - σ
5 - σ
10 - σ

Not available

Masked

Conclusion

No absorption by species available in the Earth´s crust found in the transmission spectrum of the super-Earth 55 Cnc e, **hinting** on a heavyweight atmosphere!



Note, that all authors do not exclude either one of these scenarios !

Both scenarios still remain possible…