



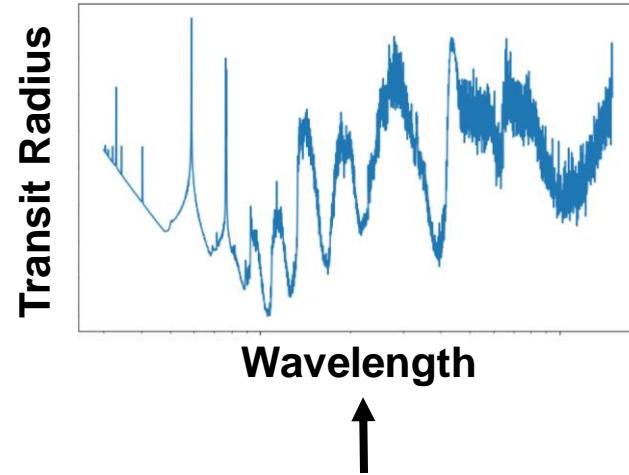
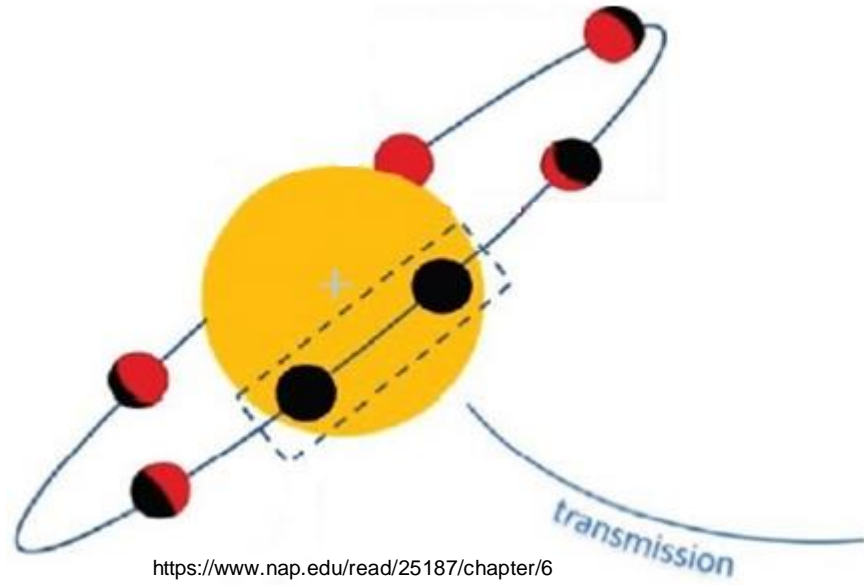
Leibniz-Institut für
Astrophysik Potsdam

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

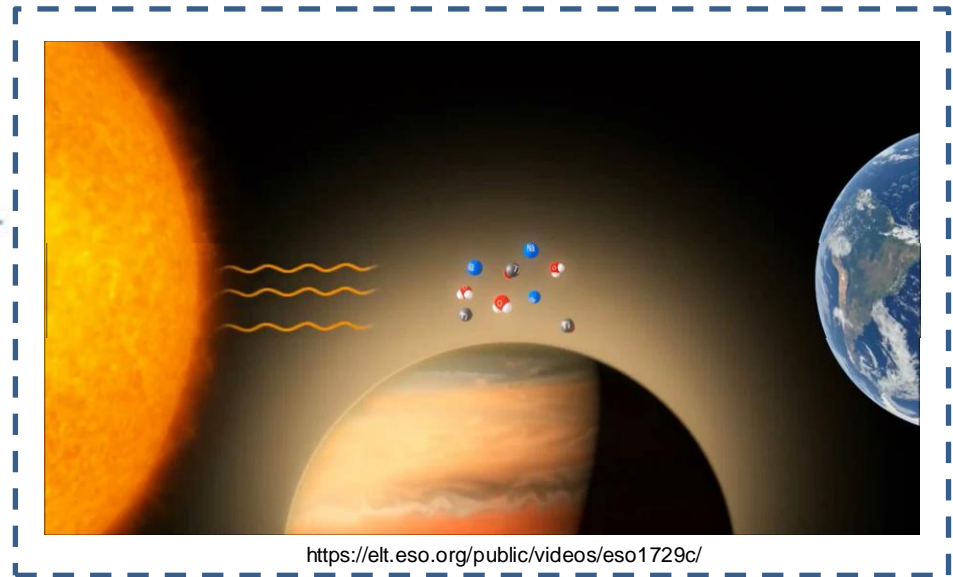
Engin Keles, Matthias Mallonn, Katja Poppenhaeger, Julian Alvarado Gomez, Laura Ketzer,
Daniel Kitzmann, Thorsten Carroll, Ilya Ilin, Xanthippi Alexoudi, Klaus Strassmeier

Atmospheric characterization

Detecting atmospheric spectral signature of exoplanets during transit

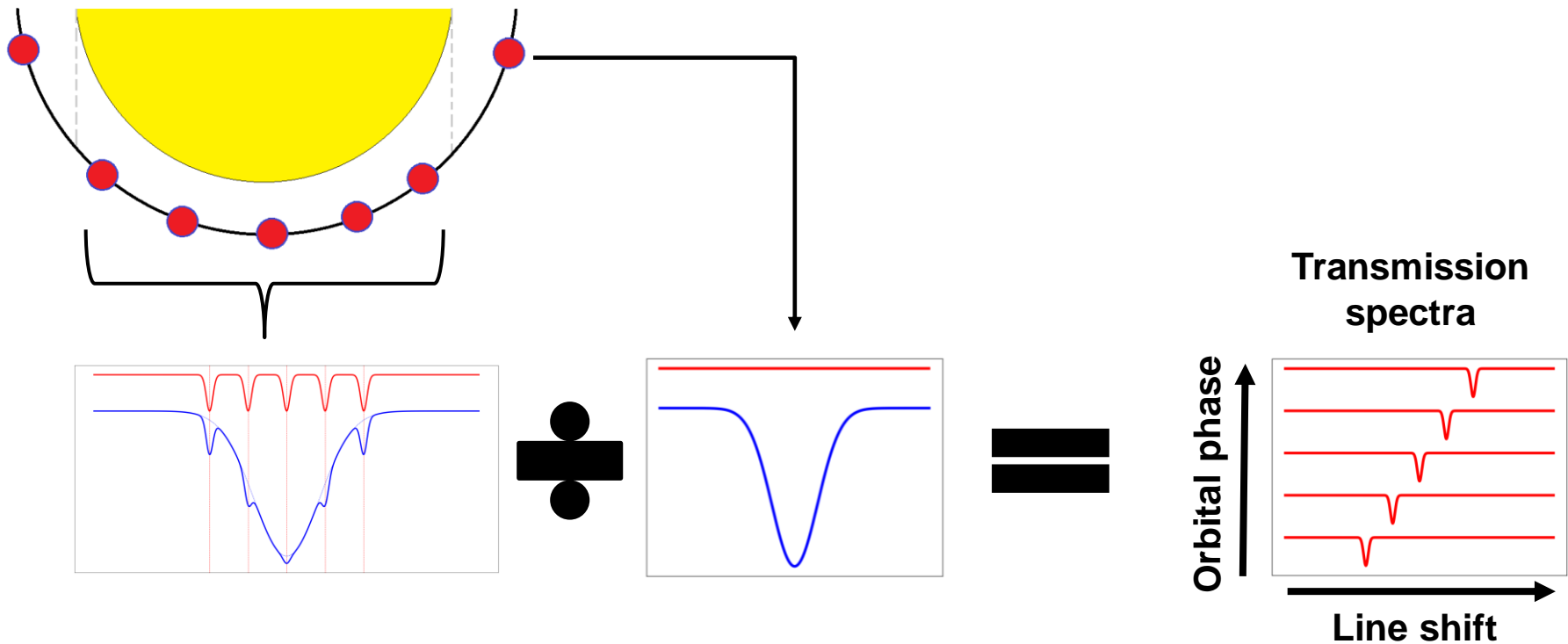


https://petitradtrans.readthedocs.io/en/latest/content/not_ebooks/getting_started.html



Extracting atmospheric absorption

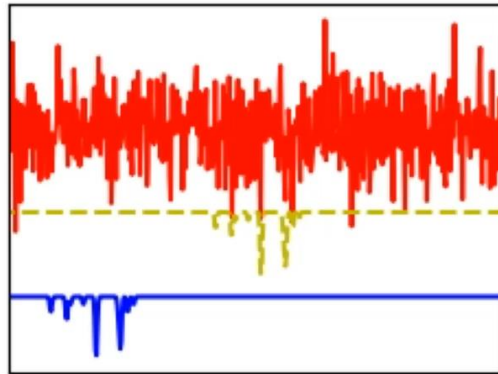
The **planetary absorption** arise shifted according to its orbital phase velocity on top of the **stellar lines**



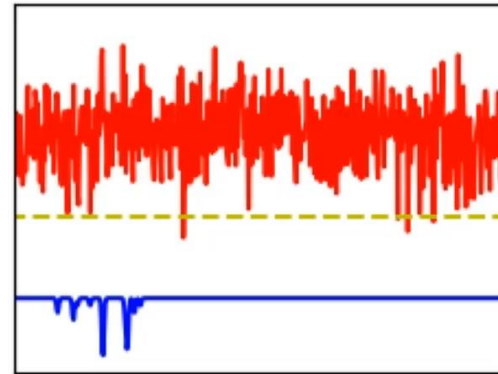
Dividing the in-transit stellar line by the out-of-transit line removes the stellar contribution showing the shifted planetary absorption!

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**:

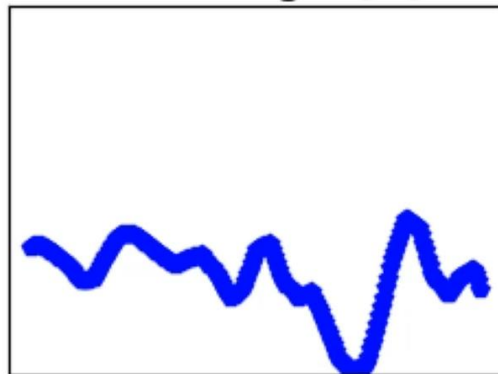


Wavelength [\AA]

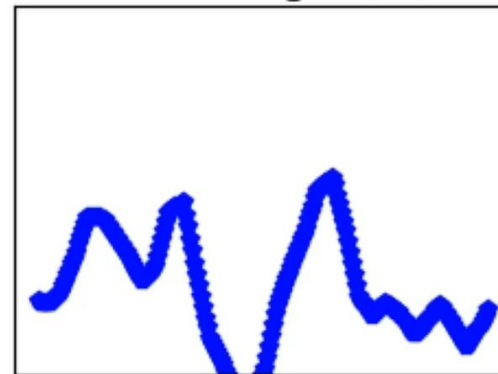


Wavelength [\AA]

Observation with
noise level



RV [km]

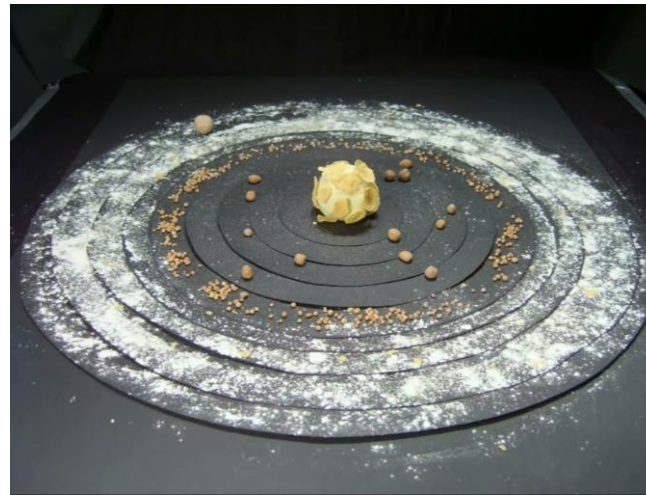


RV [km]

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

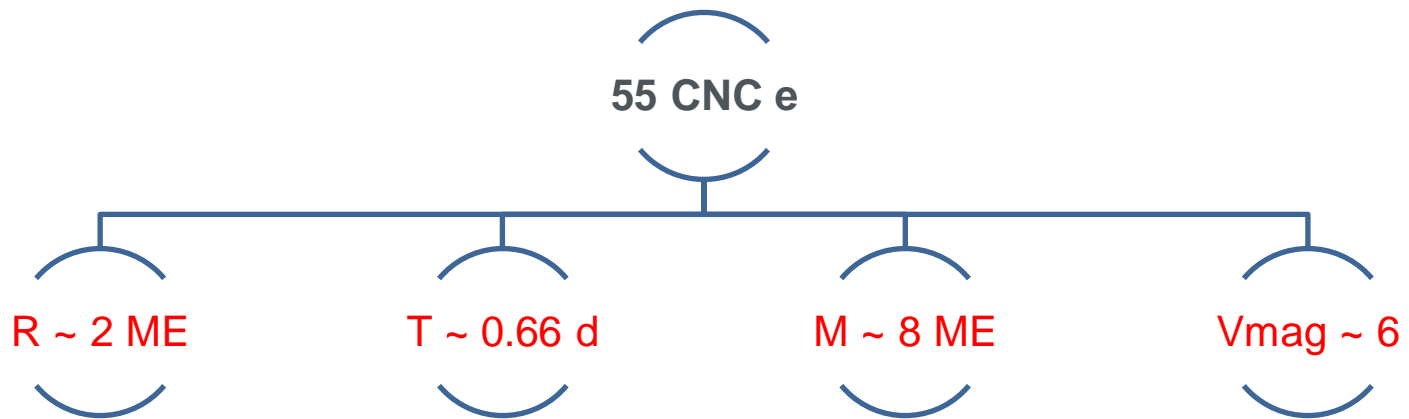


www.youtube.de

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

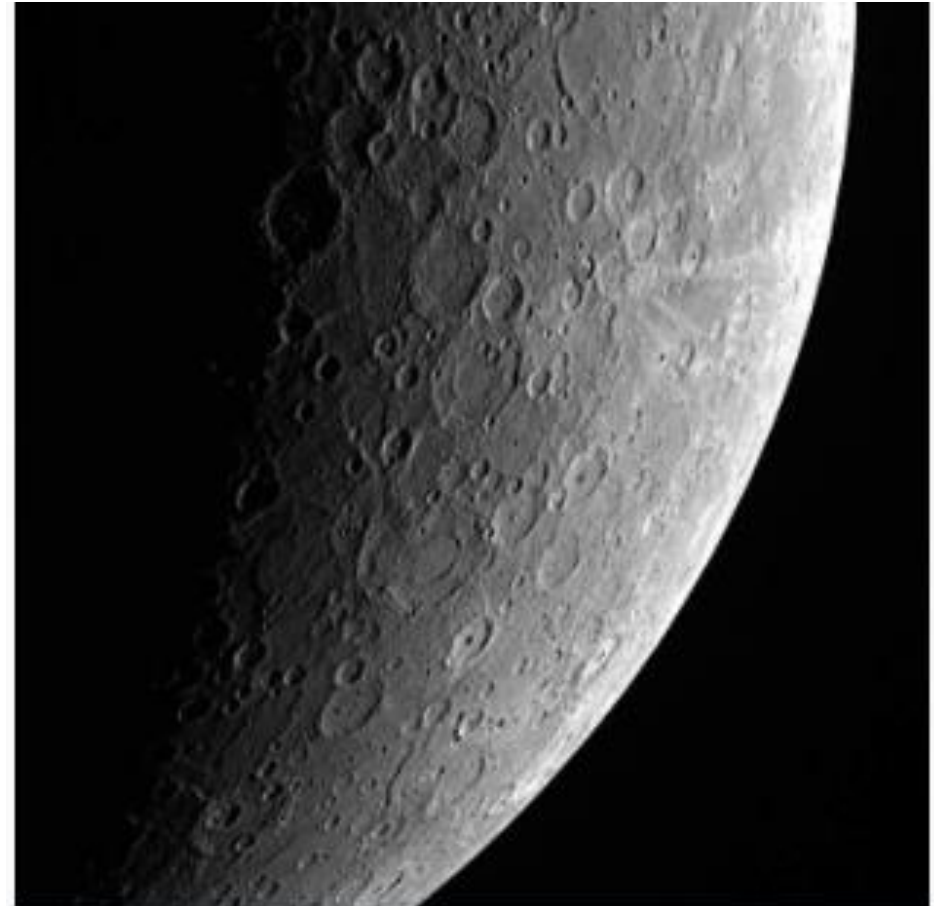


Example: Mercury

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

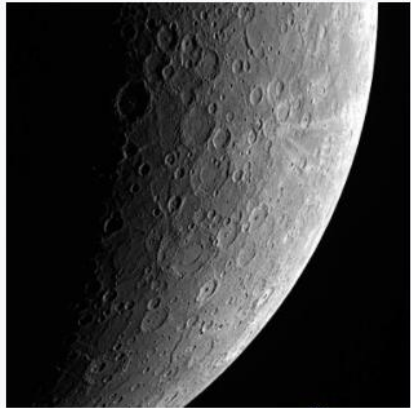
Species	CD, ^[n 1] cm ⁻²	SD, ^[n 2] cm ⁻³
Hydrogen (H)	$\sim 3 \times 10^9$	~ 250
Molecular hydrogen	$< 3 \times 10^{15}$	$< 1.4 \times 10^7$
Helium	$< 3 \times 10^{11}$	$\sim 6 \times 10^3$
Atomic oxygen	$< 3 \times 10^{11}$	$\sim 4 \times 10^4$
Molecular oxygen	$< 9 \times 10^{14}$	$< 2.5 \times 10^7$
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]

Species	CD, ^[n 1] cm ⁻²	SD, ^[n 2] cm ⁻³
Hydrogen (H)	$\sim 3 \times 10^9$	~ 250
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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)

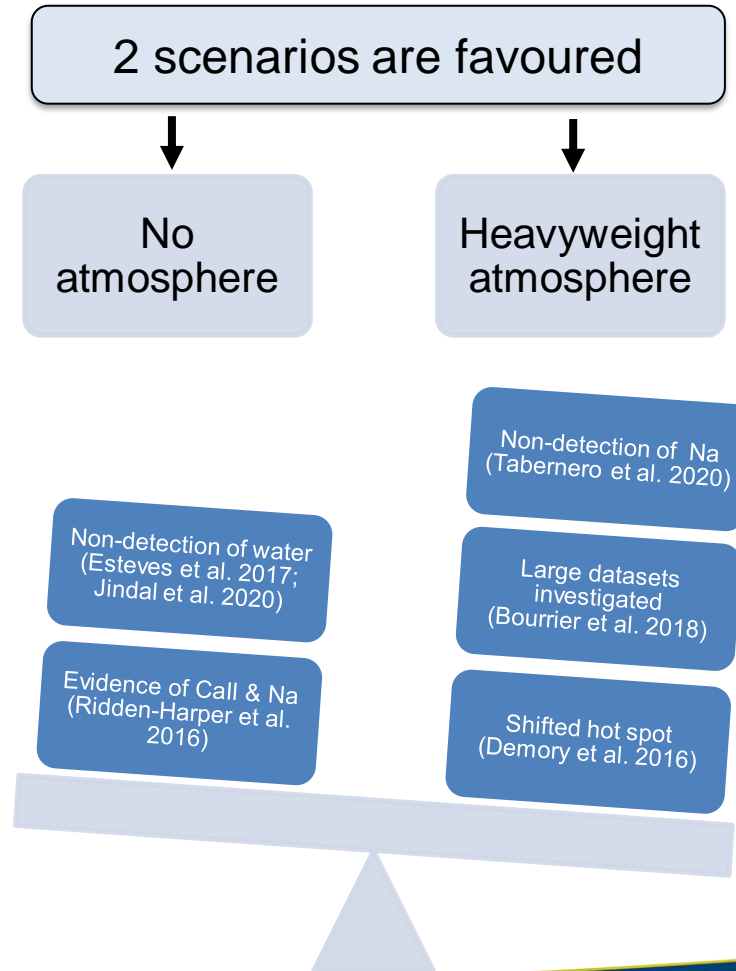
→ Evidence of ionized Calcium?

- 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 !

This work

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** :

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

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson
* 58 Ce Cerium																	
59 Pr Praseodymium																	
60 Nd Neodymium																	
61 Pm Promethium																	
62 Sm Samarium																	
63 Eu Europium																	
64 Gd Gadolinium																	
65 Tb Terbium																	
66 Dy Dysprosium																	
67 Ho Holmium																	
68 Er Erbium																	
69 Tm Thulium																	
70 Yb Ytterbium																	
71 Lu Lutetium																	
** 90 Th Thorium																	
91 Pa Protactinium																	
92 U Uranium																	
93 Np Neptunium																	
94 Pu Plutonium																	
95 Am Americium																	
96 Cm Curium																	
97 Bk Berkelium																	
98 Cf Californium																	
99 Es Einsteinium																	
100 Fm Fermium																	
101 Md Mendelevium																	
102 No Nobelium																	
103 Lr Lawrencium																	

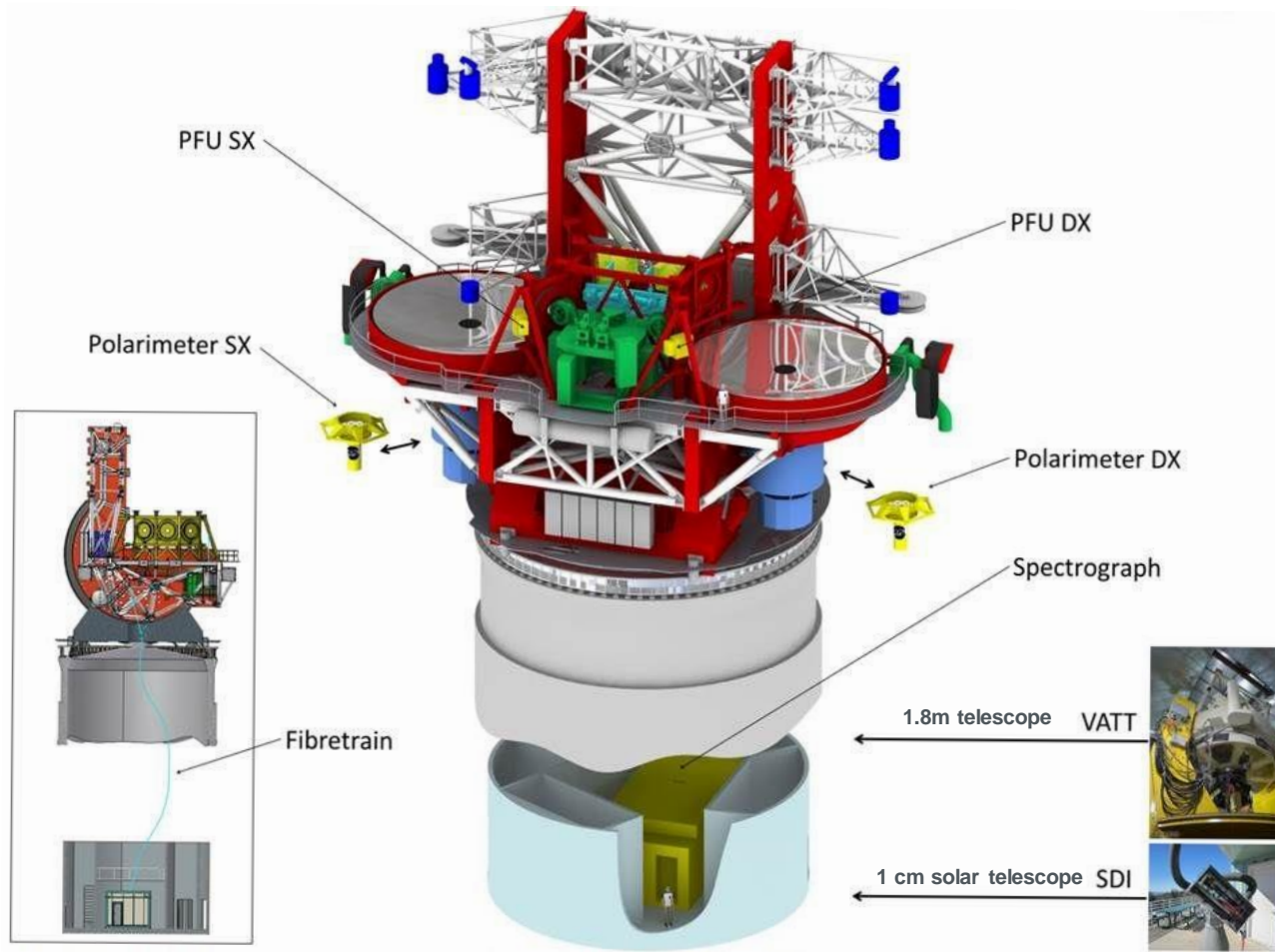
→ Their presence would confirm the rocky-planet scenario and their absence would hint towards the heavyweight scenario!

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 !



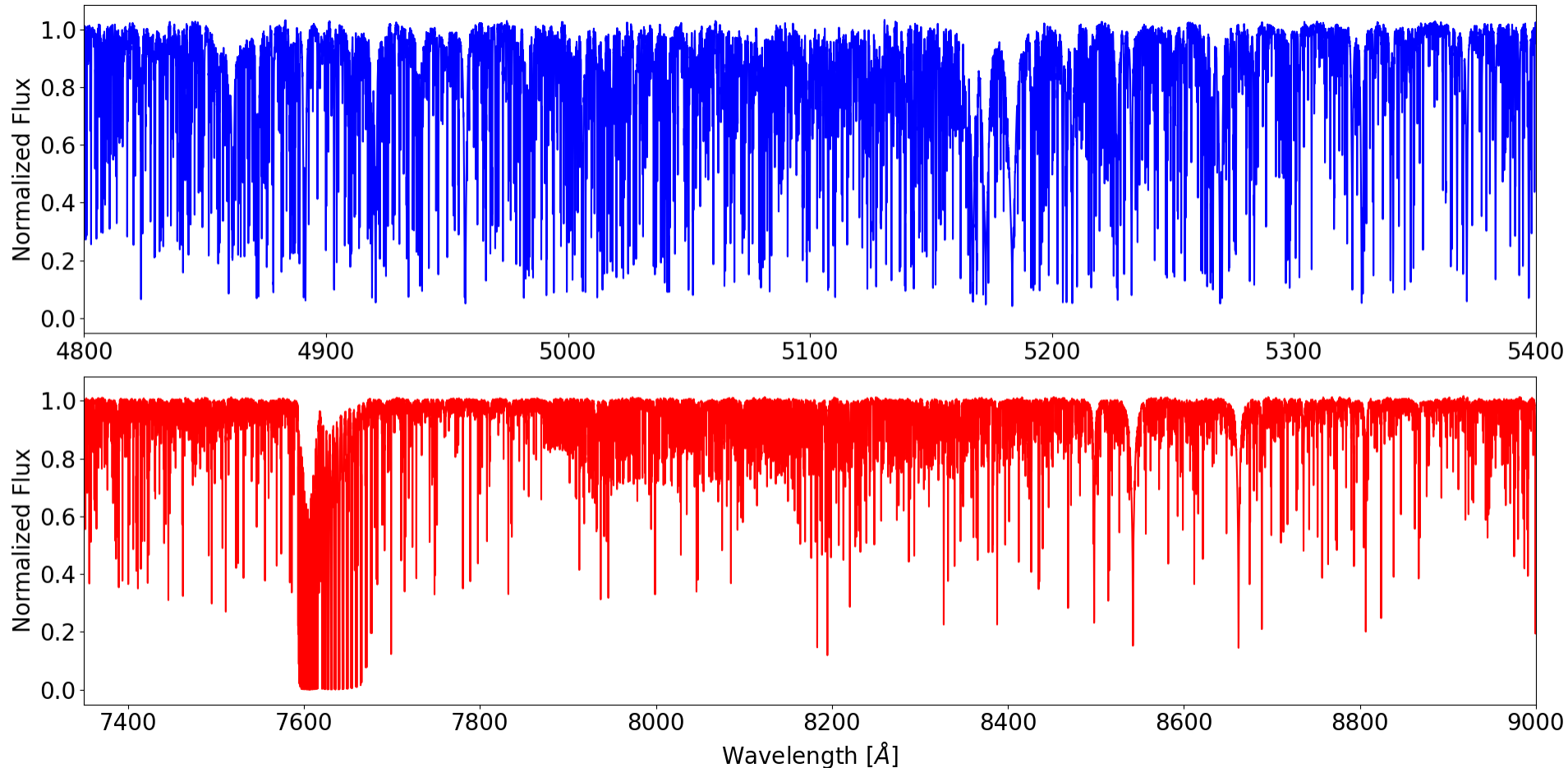
Strassmeier et al. (2015)

Our setup:

- 2 x 8.4m mirrors
- $R = \sim 120\,000$
- $\lambda_1 = 480 - 540\text{ nm}$
- $\lambda_2 = 730 - 900\text{ nm}$
- Exp.time = 90 s

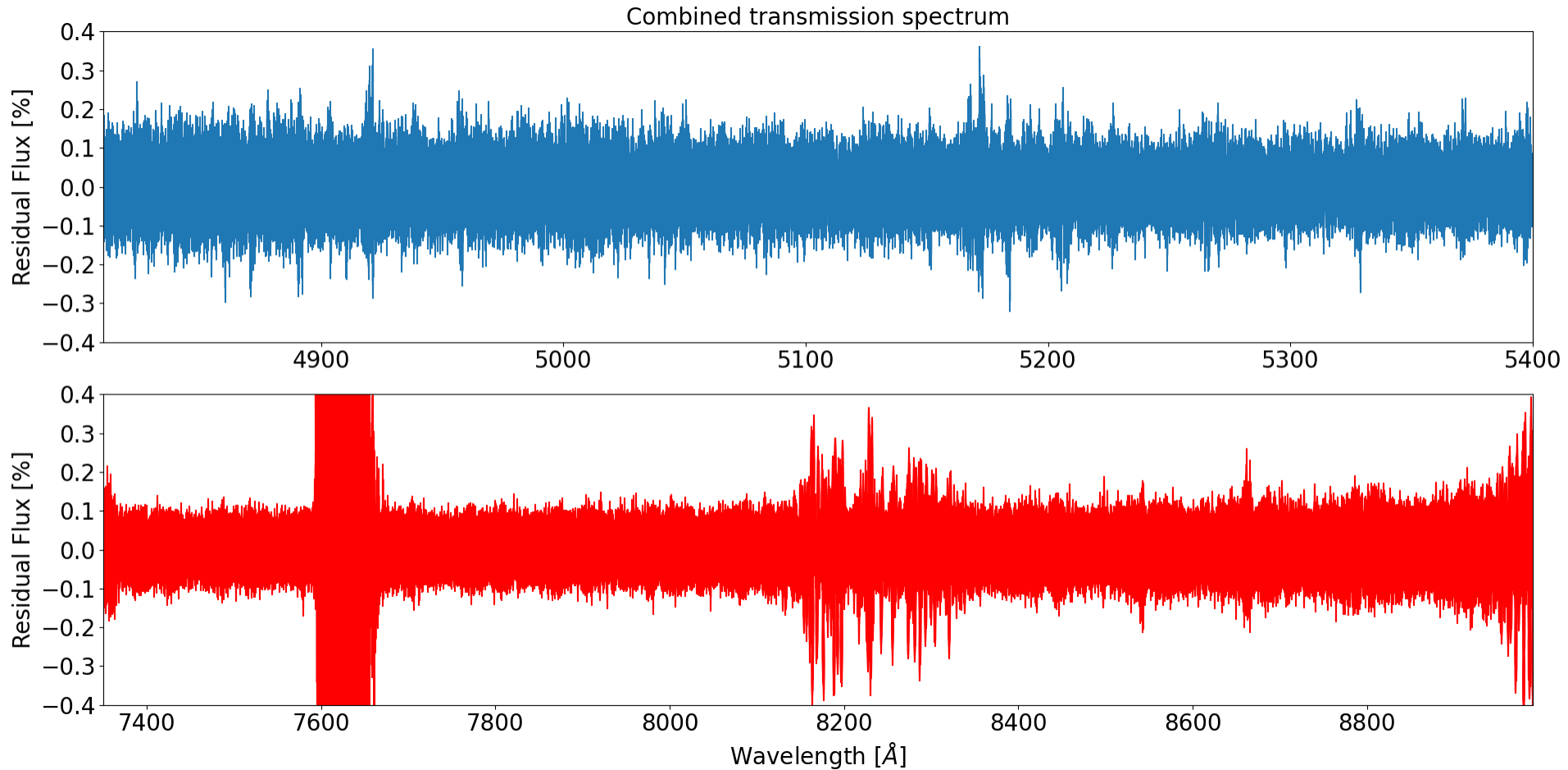
The Observation

One example spectrum of the observed wavelength range:

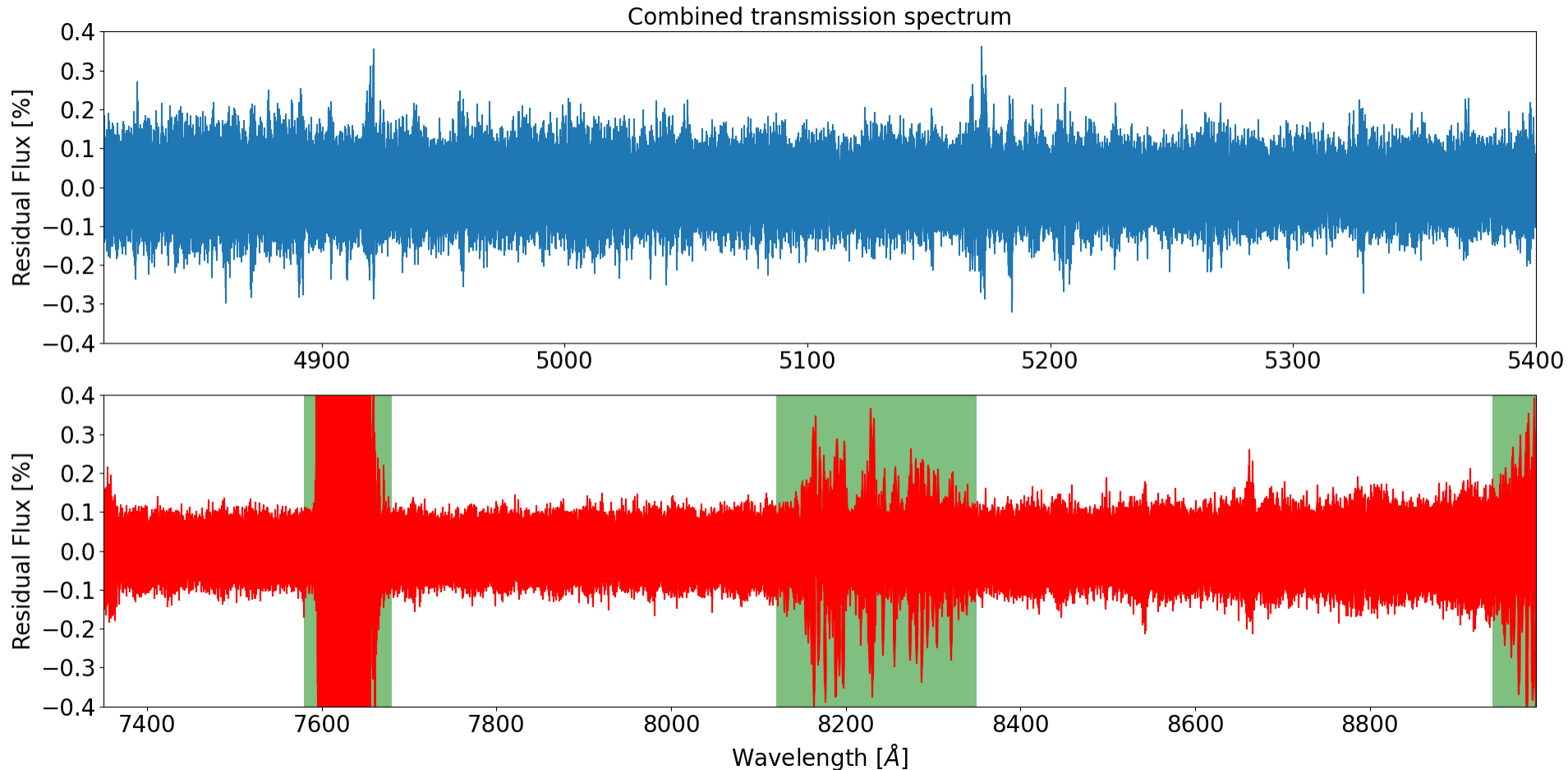


→ 41 in-transit & 42 out-of-transit spectra with continuum $S/N \sim 500$ and $S/N \sim 700$ per pixel

The combined transmission spectrum



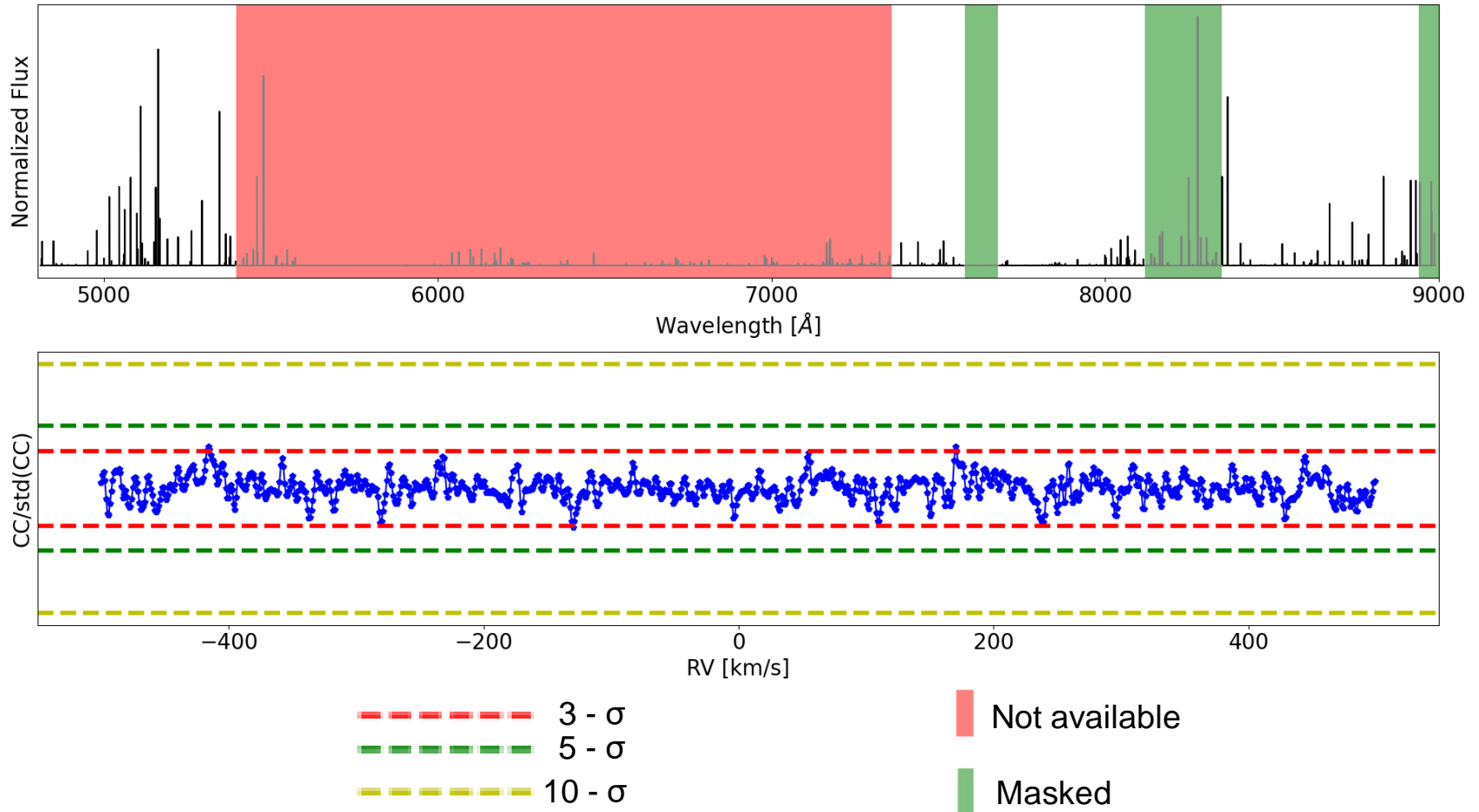
The combined transmission spectrum



→ Masking the regions with strong telluric lines !

Results

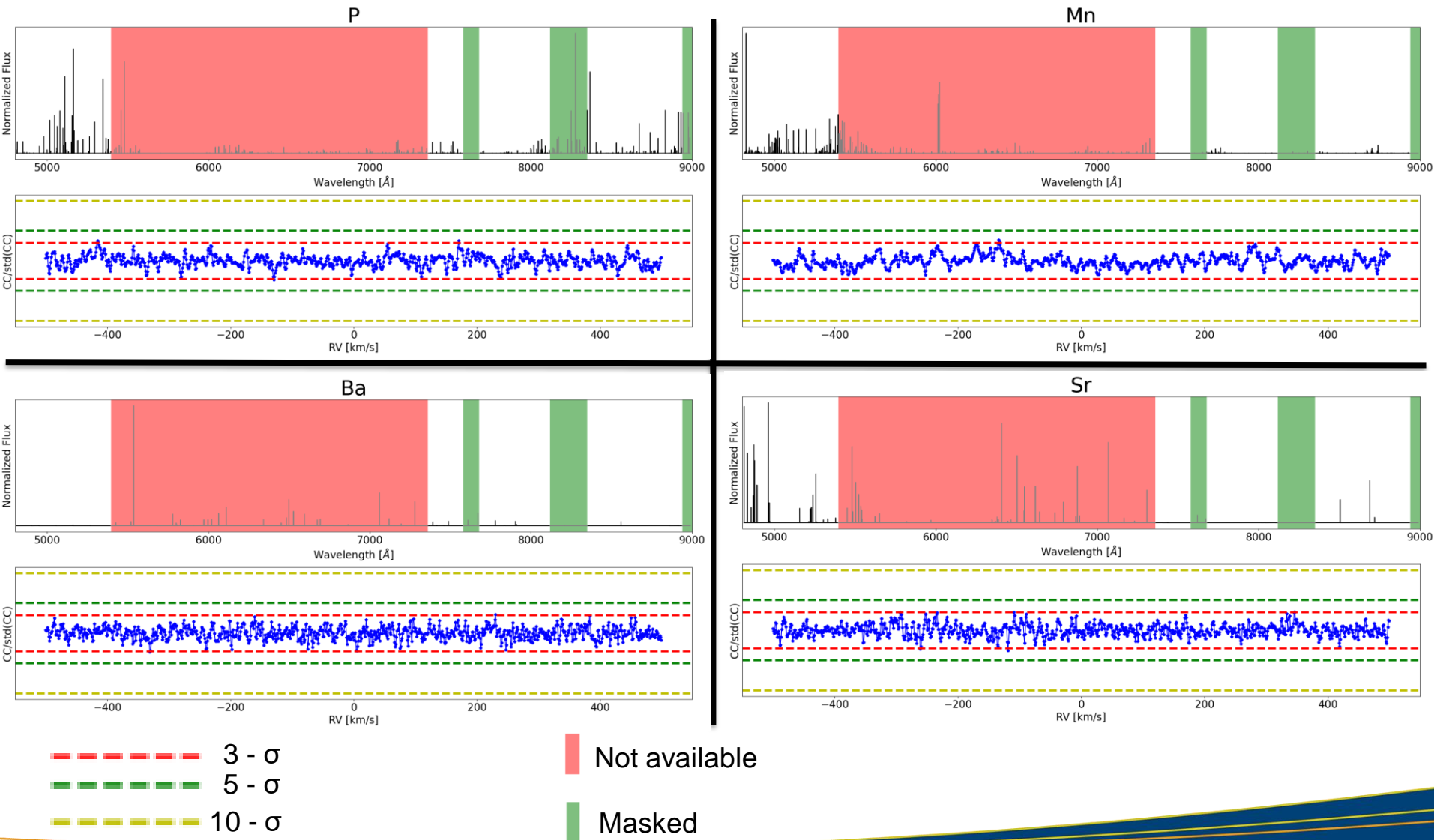
Showing transmission spectra and cross - correlation functions for different atomic and ionic species



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

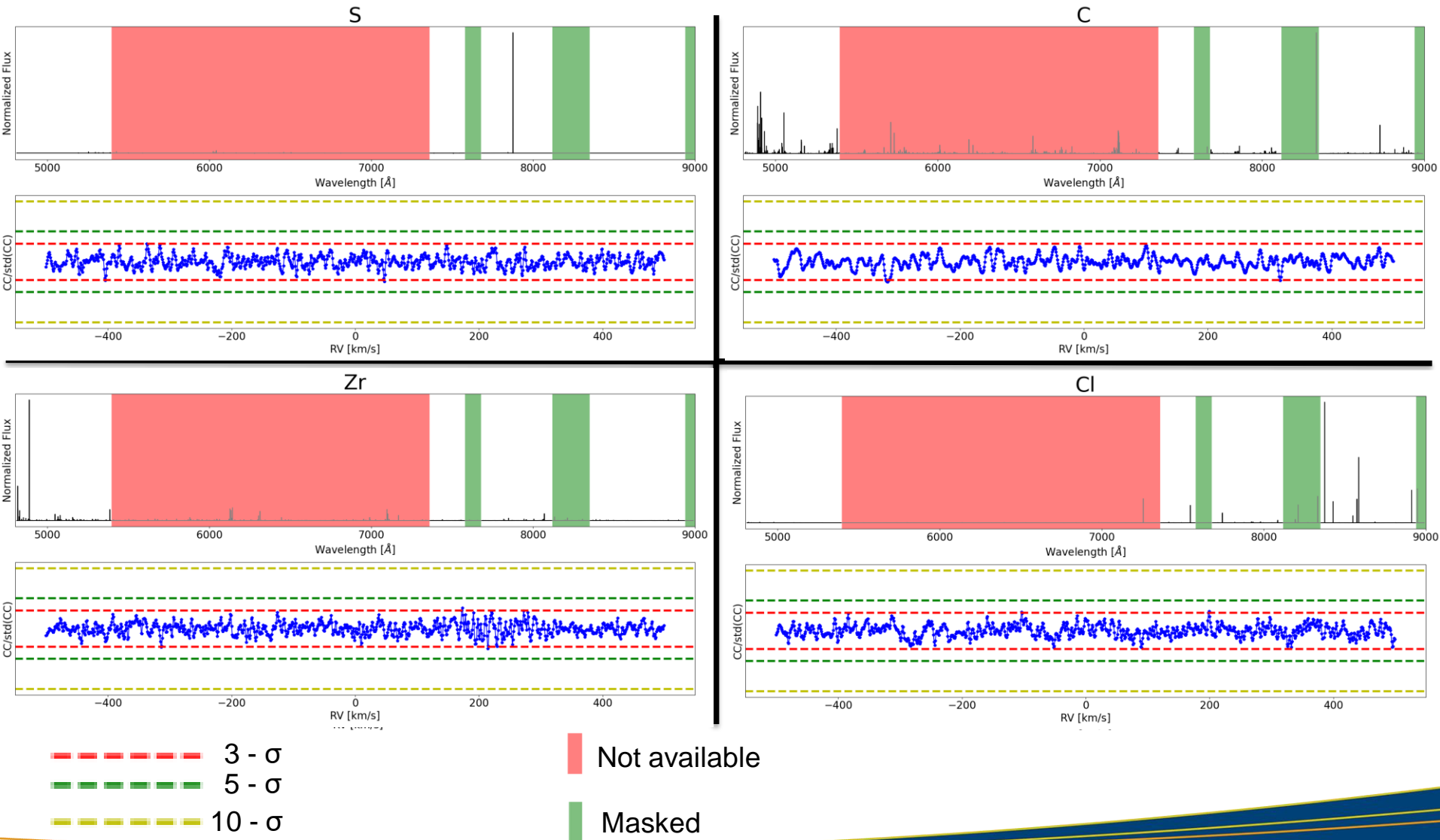
Results: Looking for atomic species on 55 CNC e

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



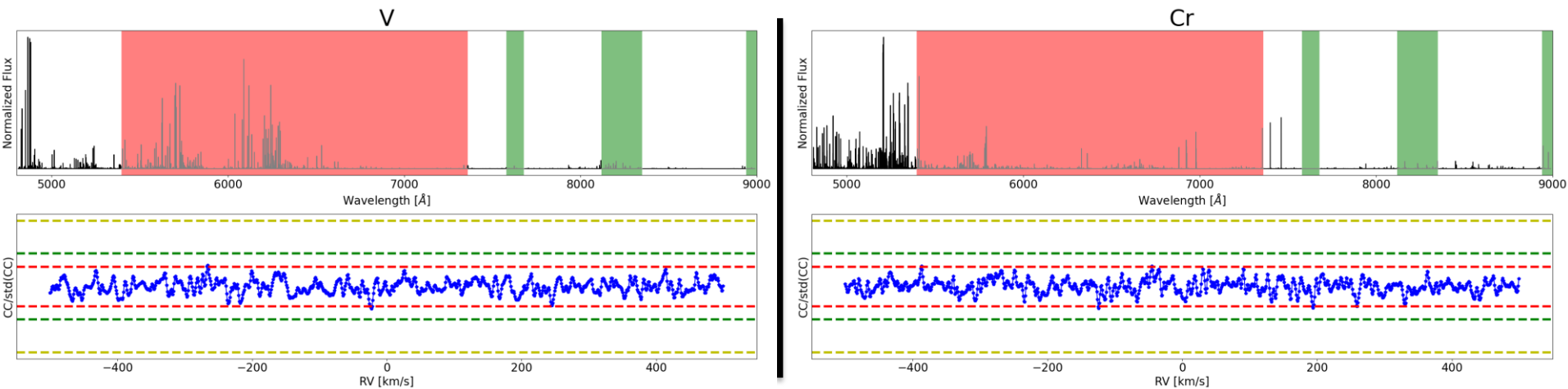
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Let's start the investigation with the less abundant atoms: P, Mn, Ba, Sr, **S**, **C**, **Zr**, **Cl**, V, Cr



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**

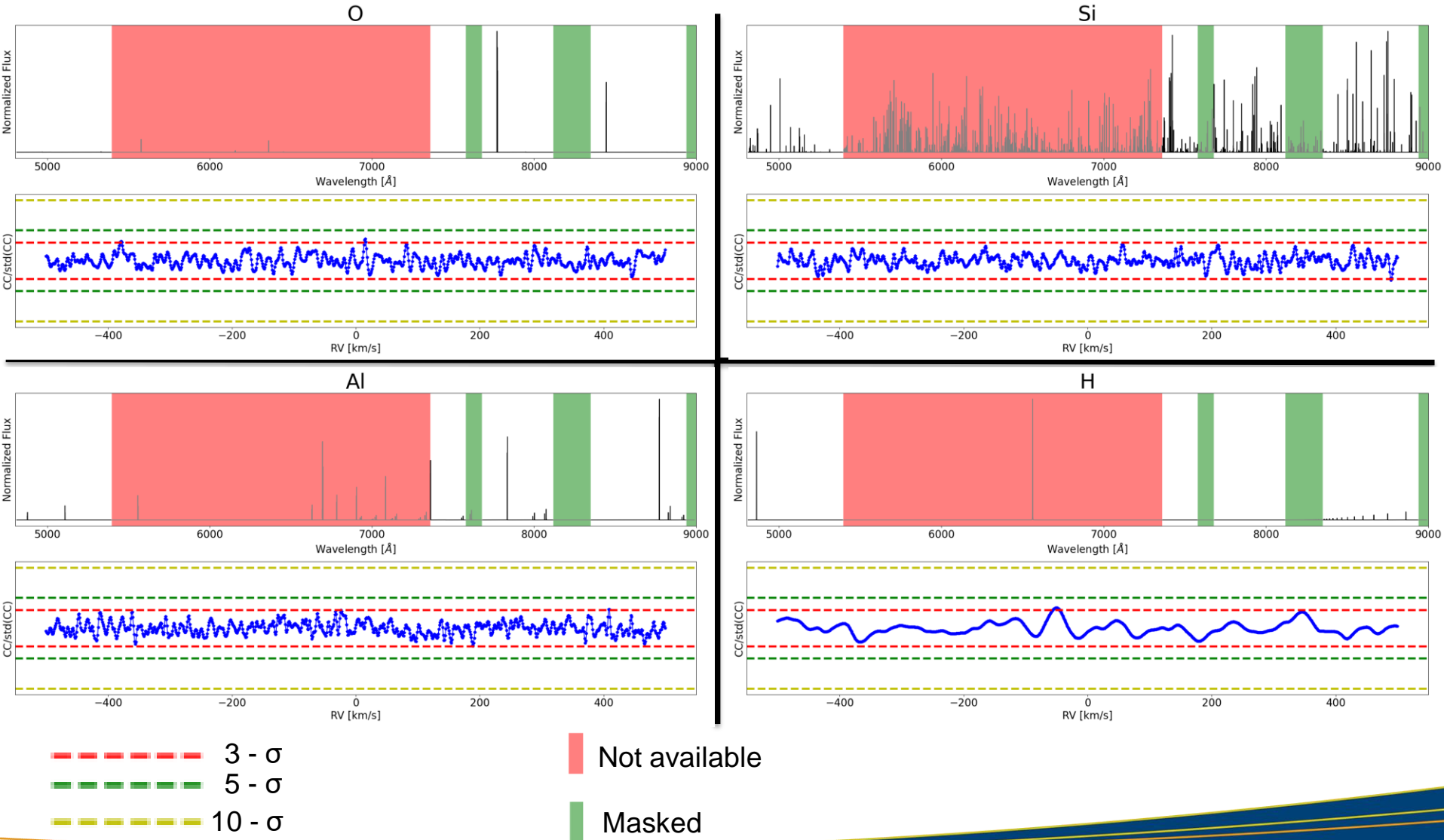


→ The less abundant species do not show absorption



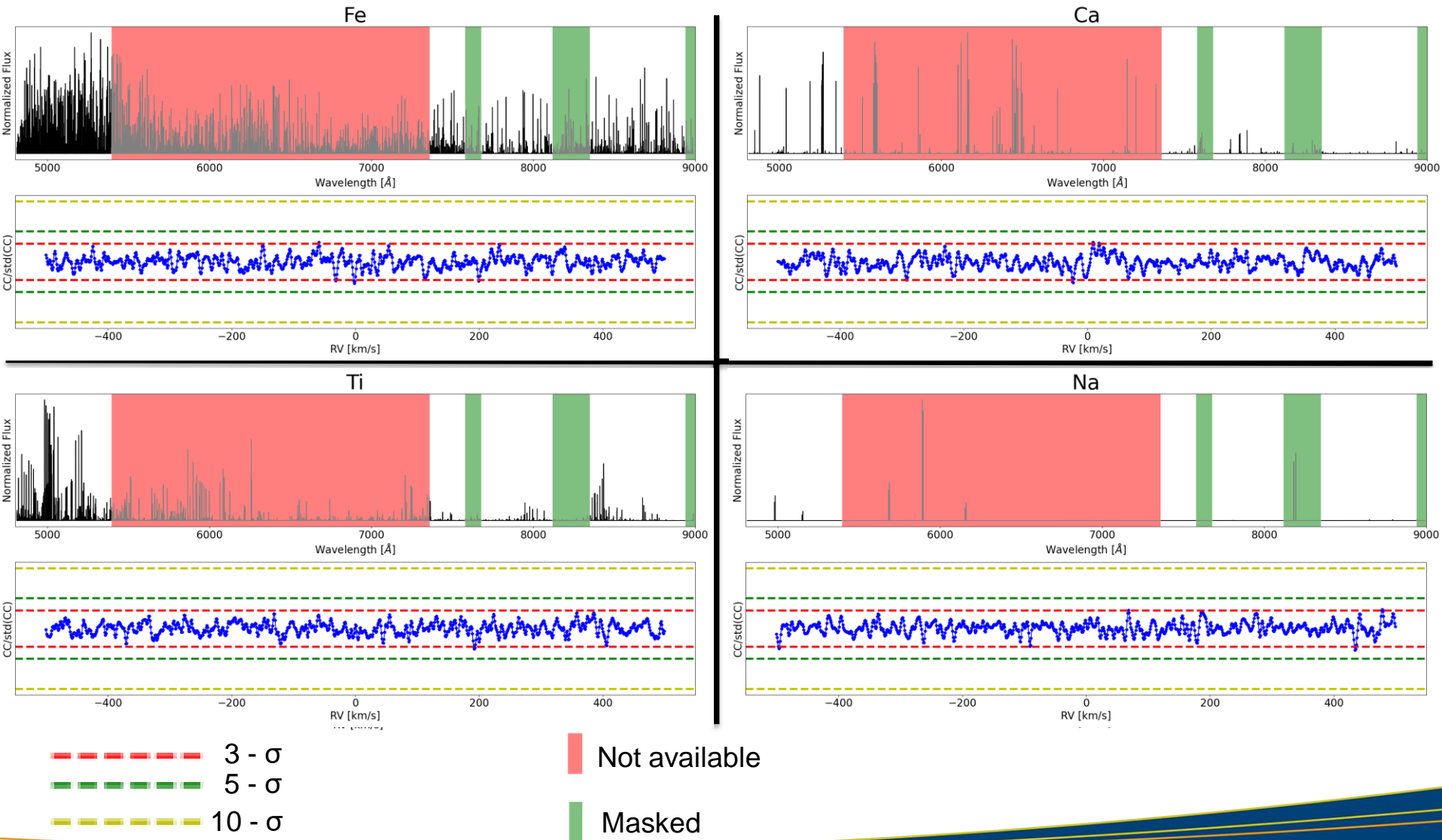
Results: Looking for atomic species on 55 CNC e

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



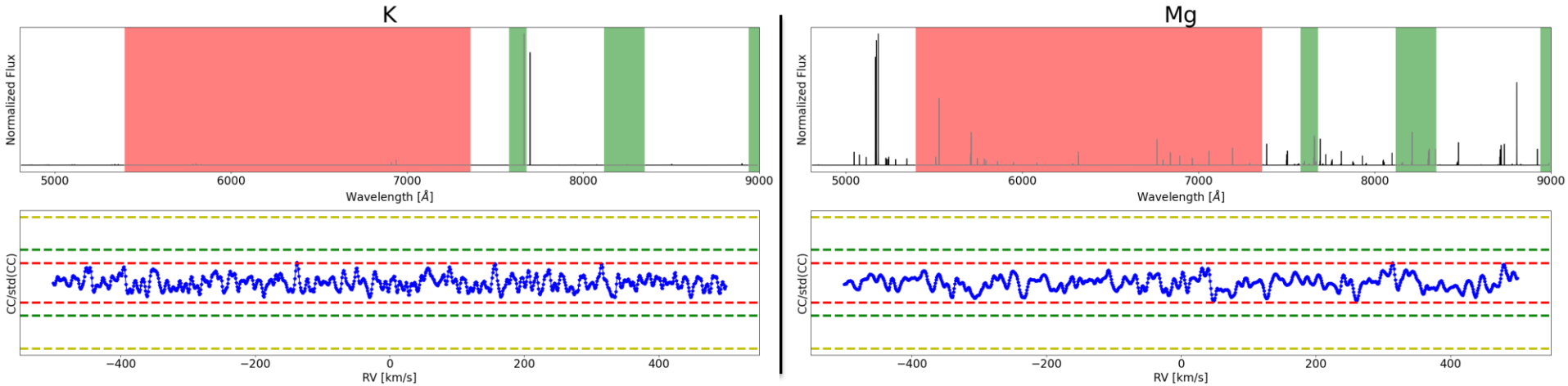
Results: Looking for atomic species on 55 CNC e

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



Results: Looking for atomic species on 55 CNC e

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

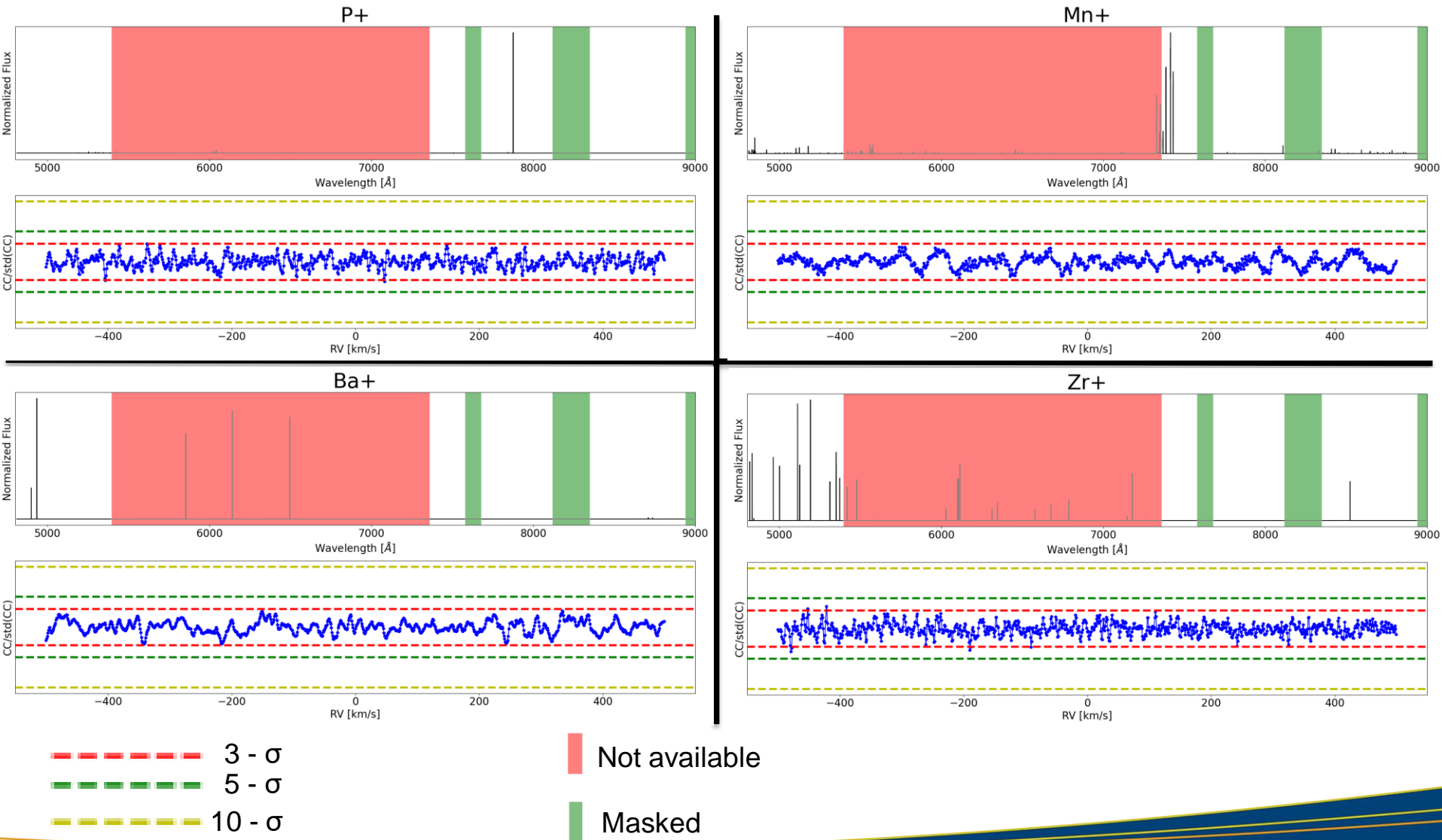


--- 3 - σ
--- 5 - σ
--- 10 - σ

Not available
Masked

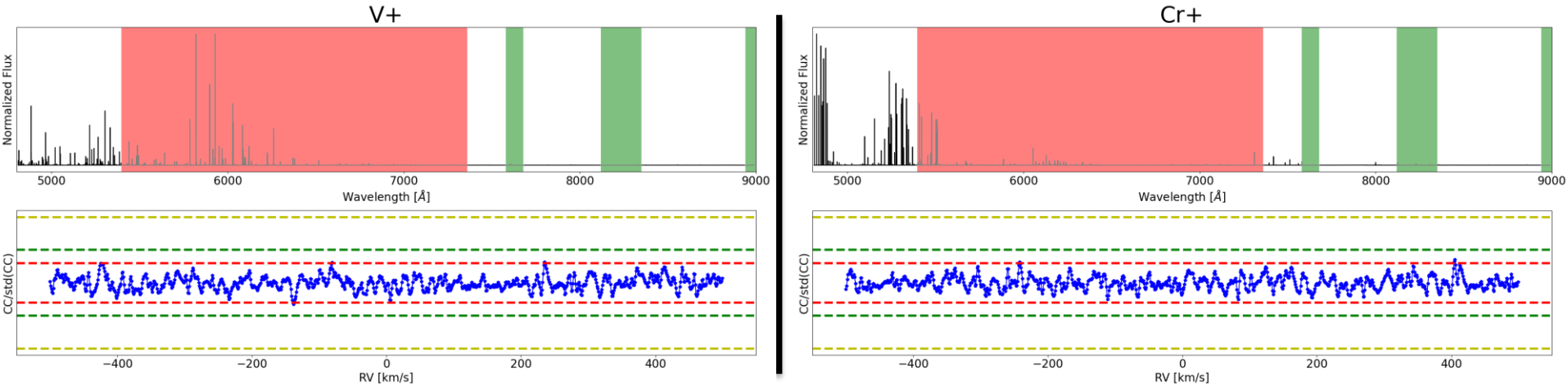
Results: Looking for ionized species on 55 CNC e

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



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+

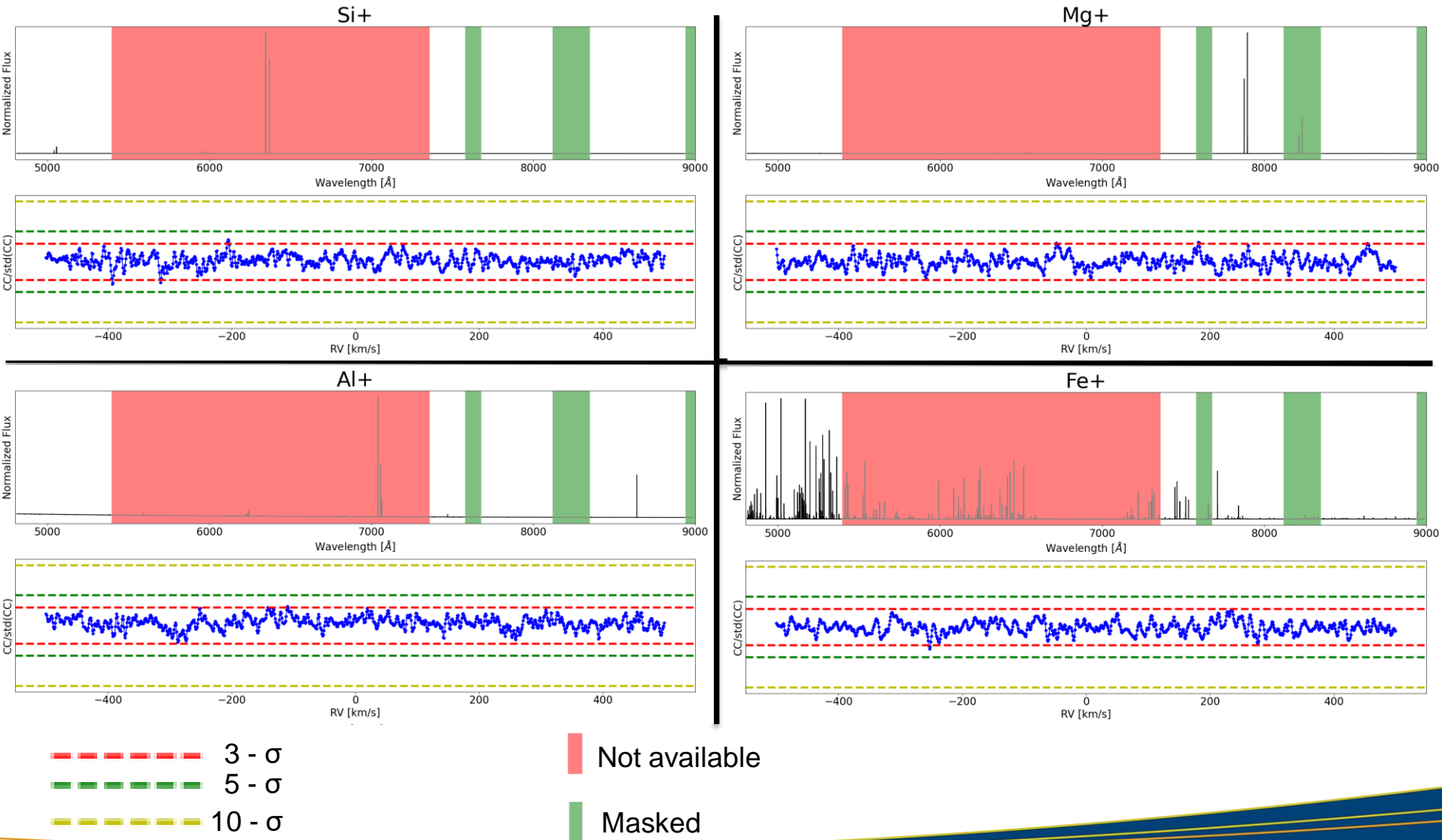


--- 3 - σ
--- 5 - σ
--- 10 - σ

■ Not available
■ Masked

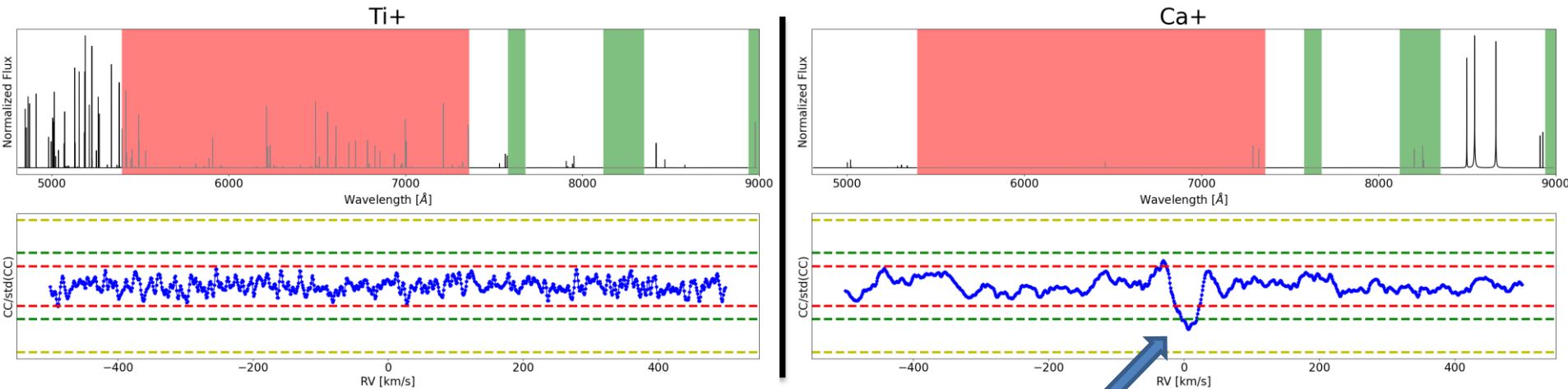
Results: Looking for ionized species on 55 CNC e

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



Results: Looking for atomic species on 55 CNC e

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



What 's going on there ? 🧐

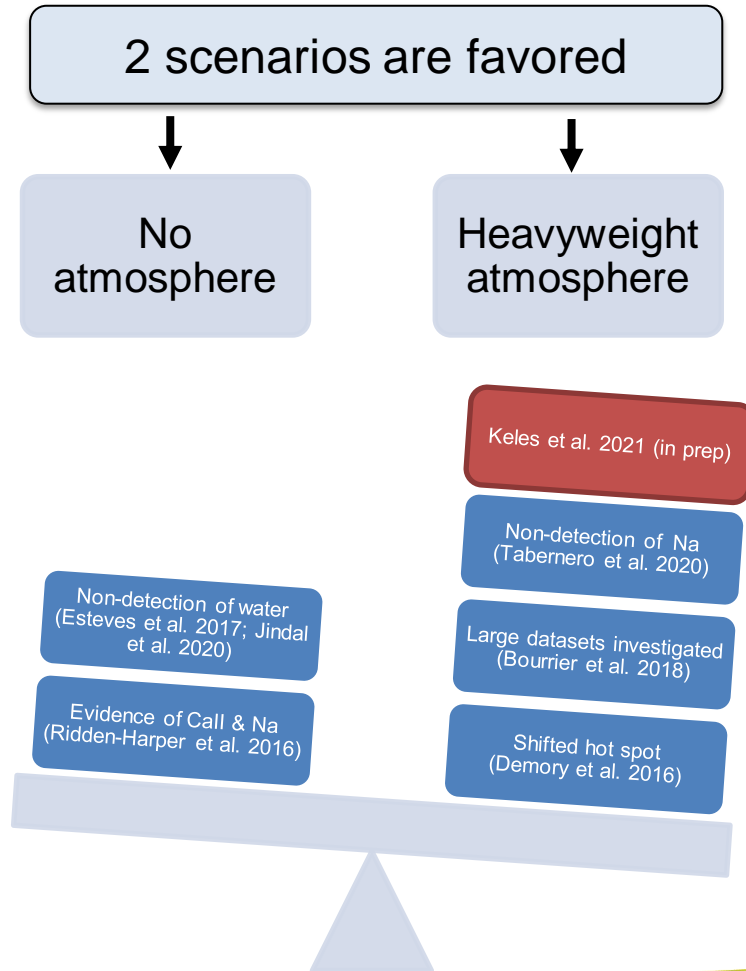
Negative sign would hint on emission ! But the signal is very broad, thus probably has no planetary origin... needs further investigation !

--- 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...