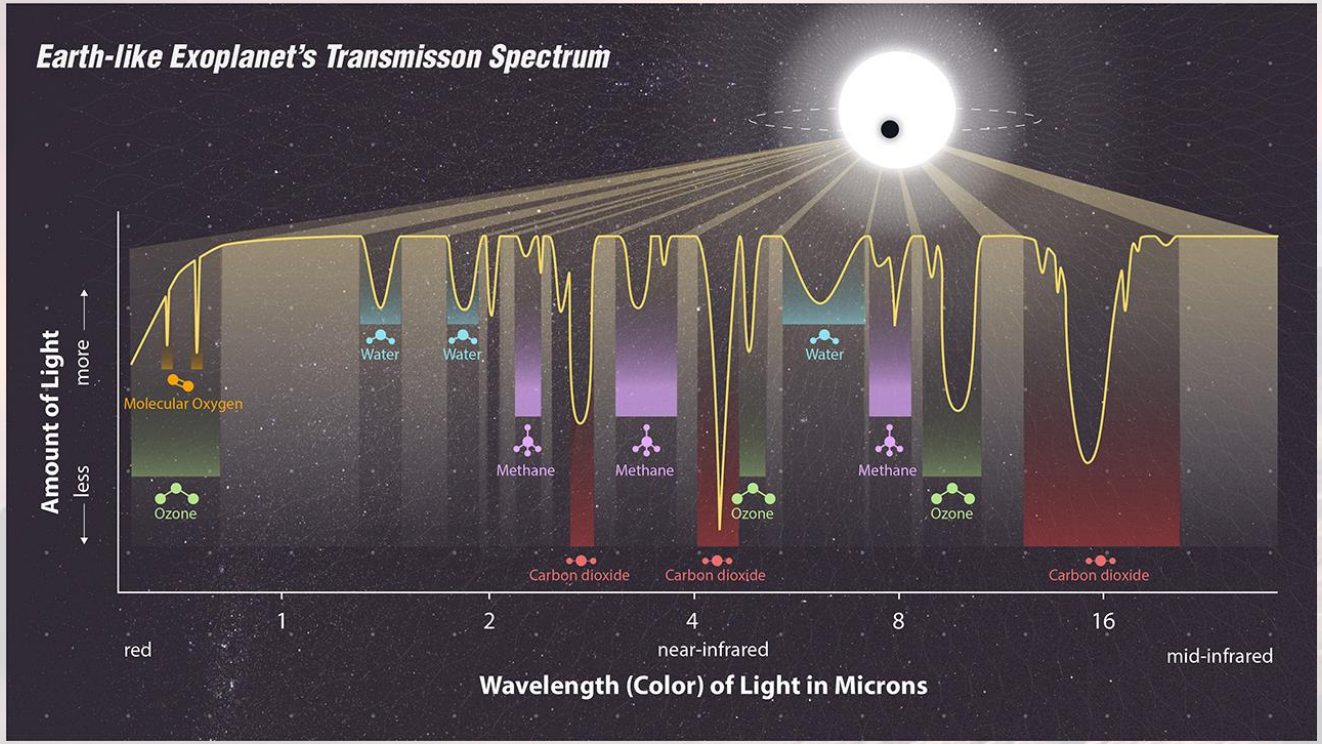
ELT/ANDES: BREAKING DEGENERACIES AND PROBING ATMOSPHERIC ESCAPE AND DYNAMICS IN EXOPLANETS

14 – 05 – 2026

Federico Biassoni

EXOPLANETARY TRANSIT

- During a transit, **the stellar light is filtered** by the planetary atmosphere producing **unique absorption lines** of atoms and molecules composing it.



- **Credits: Image,** NASA, ESA, CSA, STScI, Joseph Olmsted (STScI)

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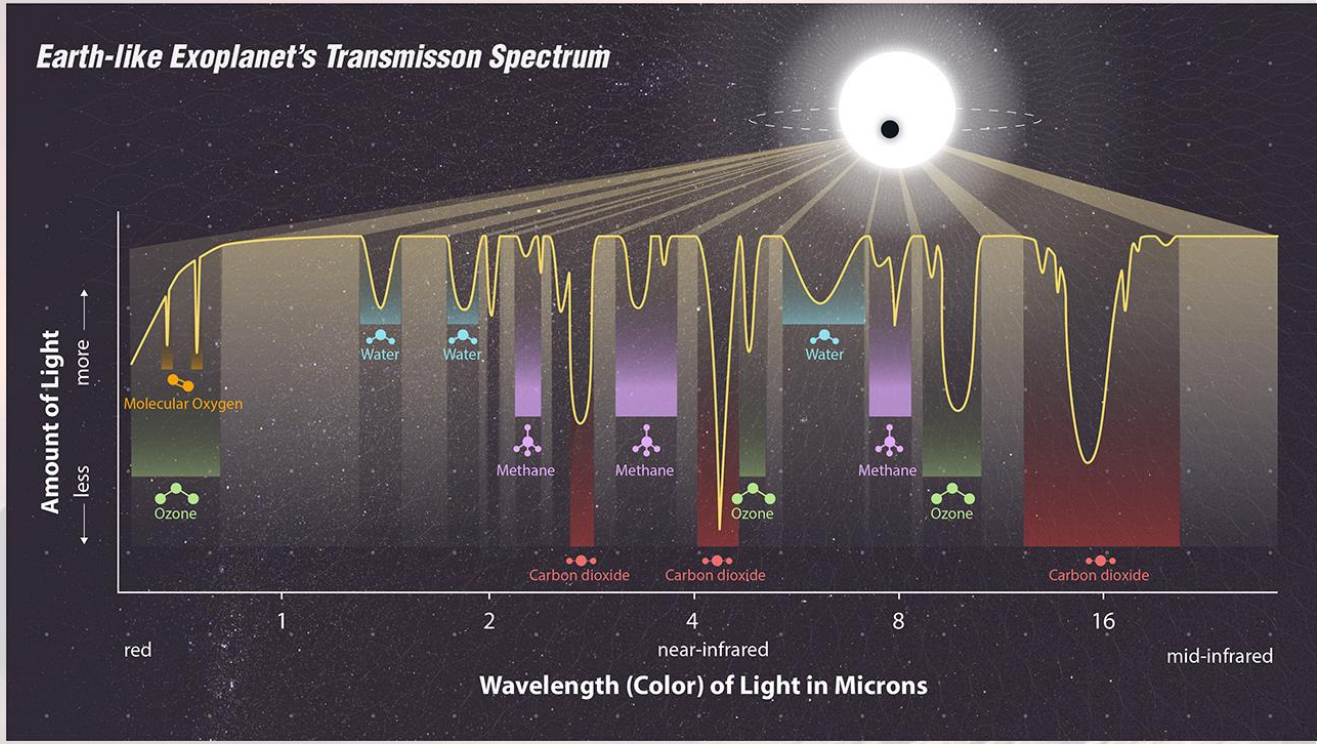
- However, only **high resolution (R>50000) spectrographs** are able to fully resolve these absorption lines.



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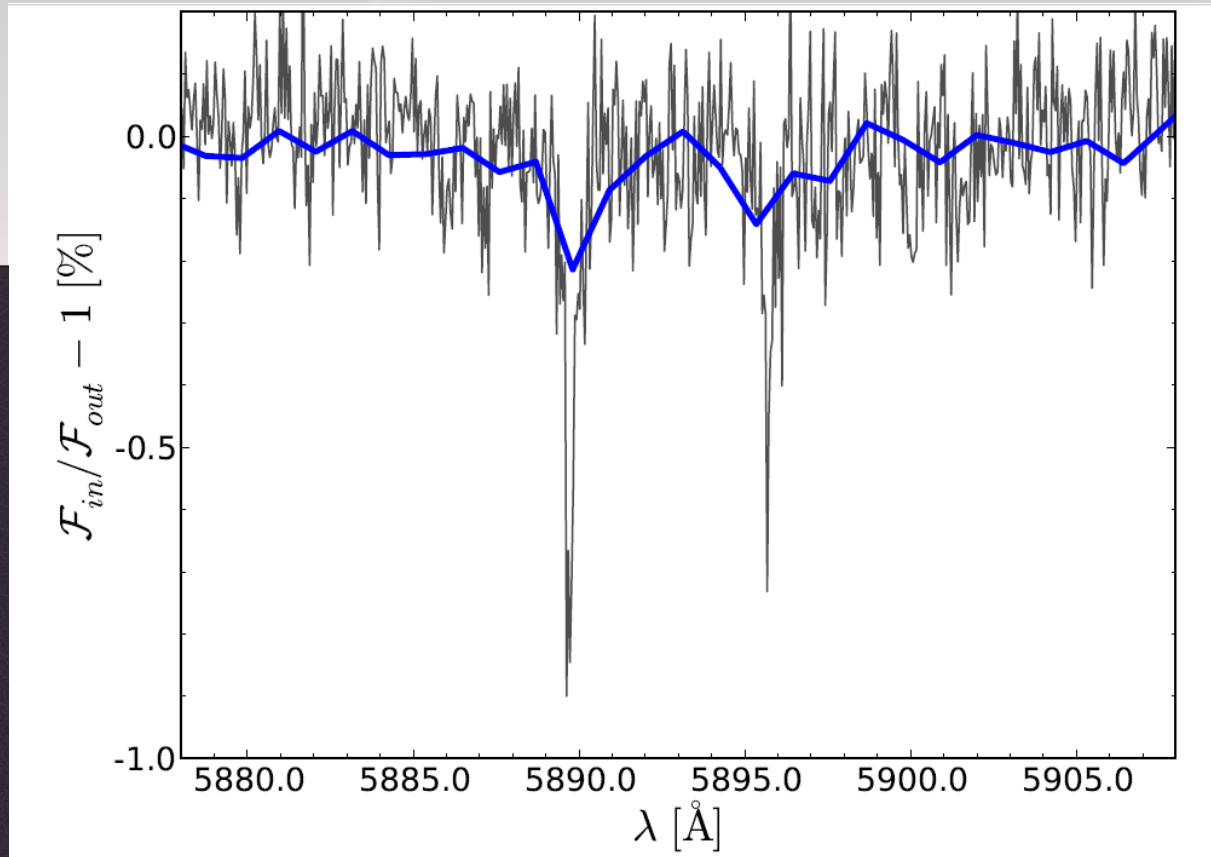

Fig. 7. Comparison of the transmission spectra around the Na I doublet obtained by the HST/STIS instrument (Huitson et al. 2012, in blue) and by the HARPS spectrograph (binned by 5×, in black).

- Figure and caption from Wyttenbach+15

HYDRODYNAMIC ESCAPE

- **Jupiter** and **Neptune** like exoplanets having a **close-in orbit** (period of 1-10 days; 0.01-0.1AU) are **preferred target** for atmospheric characterisation, **even with 8-10m class telescope**, due to their **extended atmosphere**. The scientific community refers to them as **hot Jupiters** and **warm Neptunes**.

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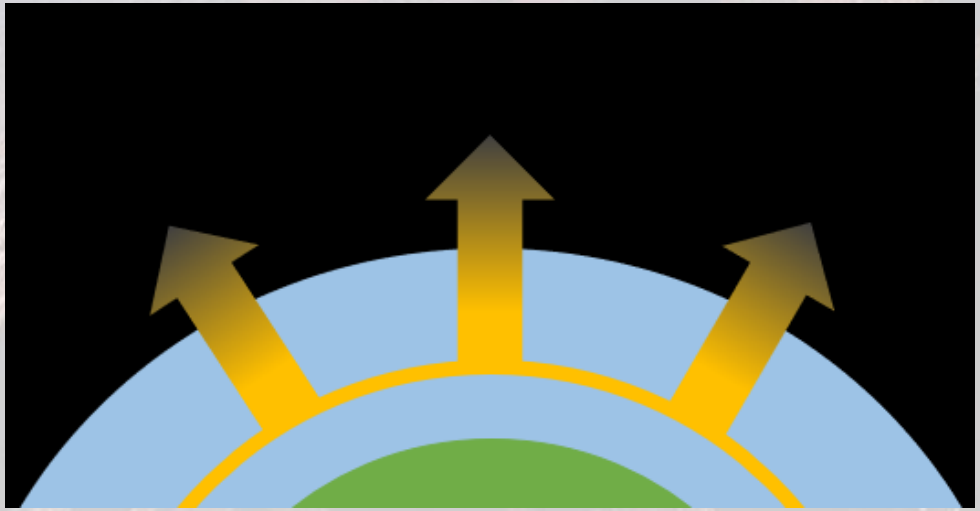
- Due to their proximity to the host star, their equilibrium temperature can reach values above 2000K, resembling in an **inflated atmosphere** with a scale heigh $\gtrsim$ 100 km.
- Exposure to **intense** stellar X-ray and UV (**XUV**) **irradiation** is bound to cause physical and chemical **atmospheric evolution and expansion** in close-in orbit exoplanets.
- The process in which the planet absorbs and converts the stellar energy into **expansion work** is called:

PHOTOEVAPORATION



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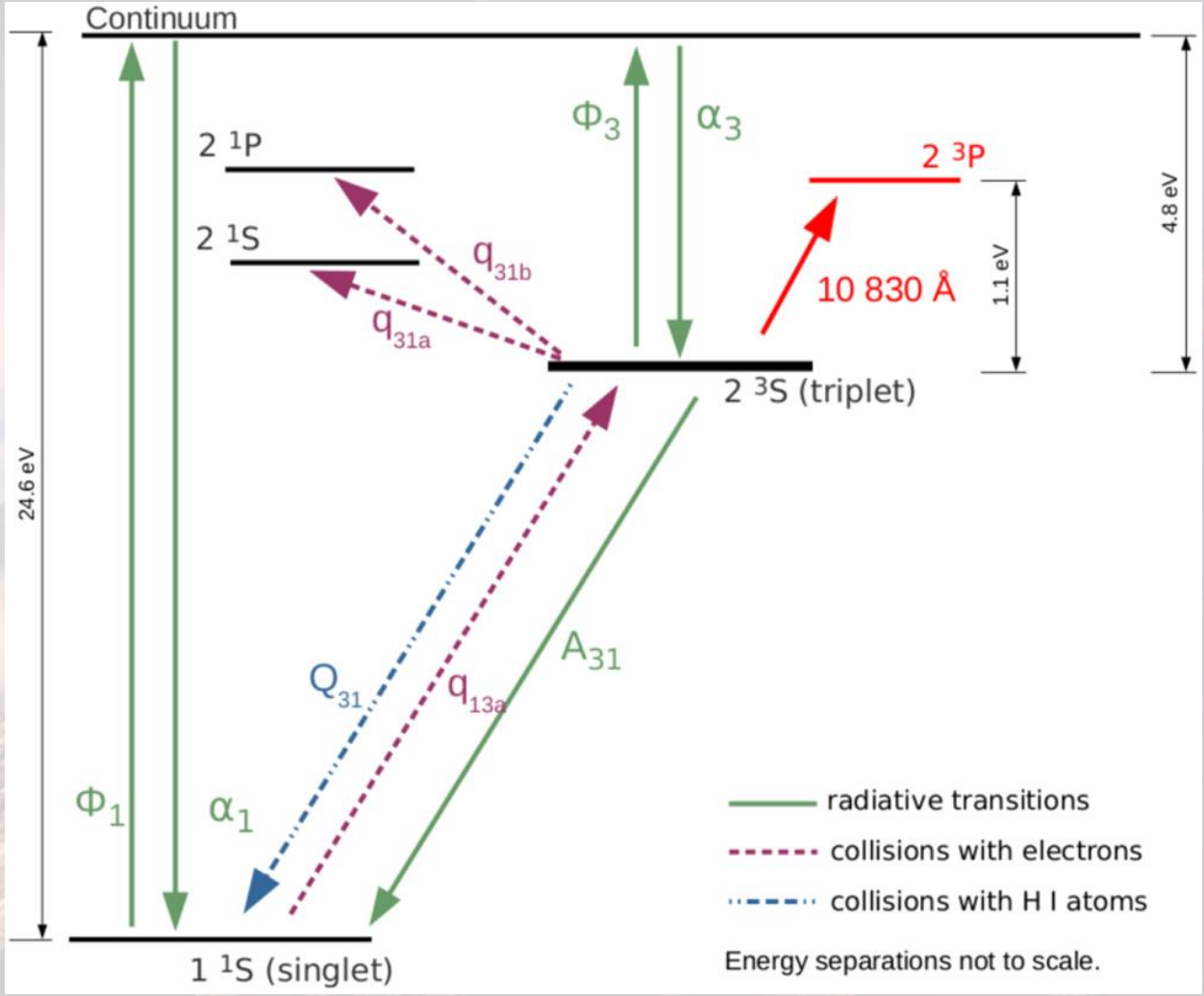

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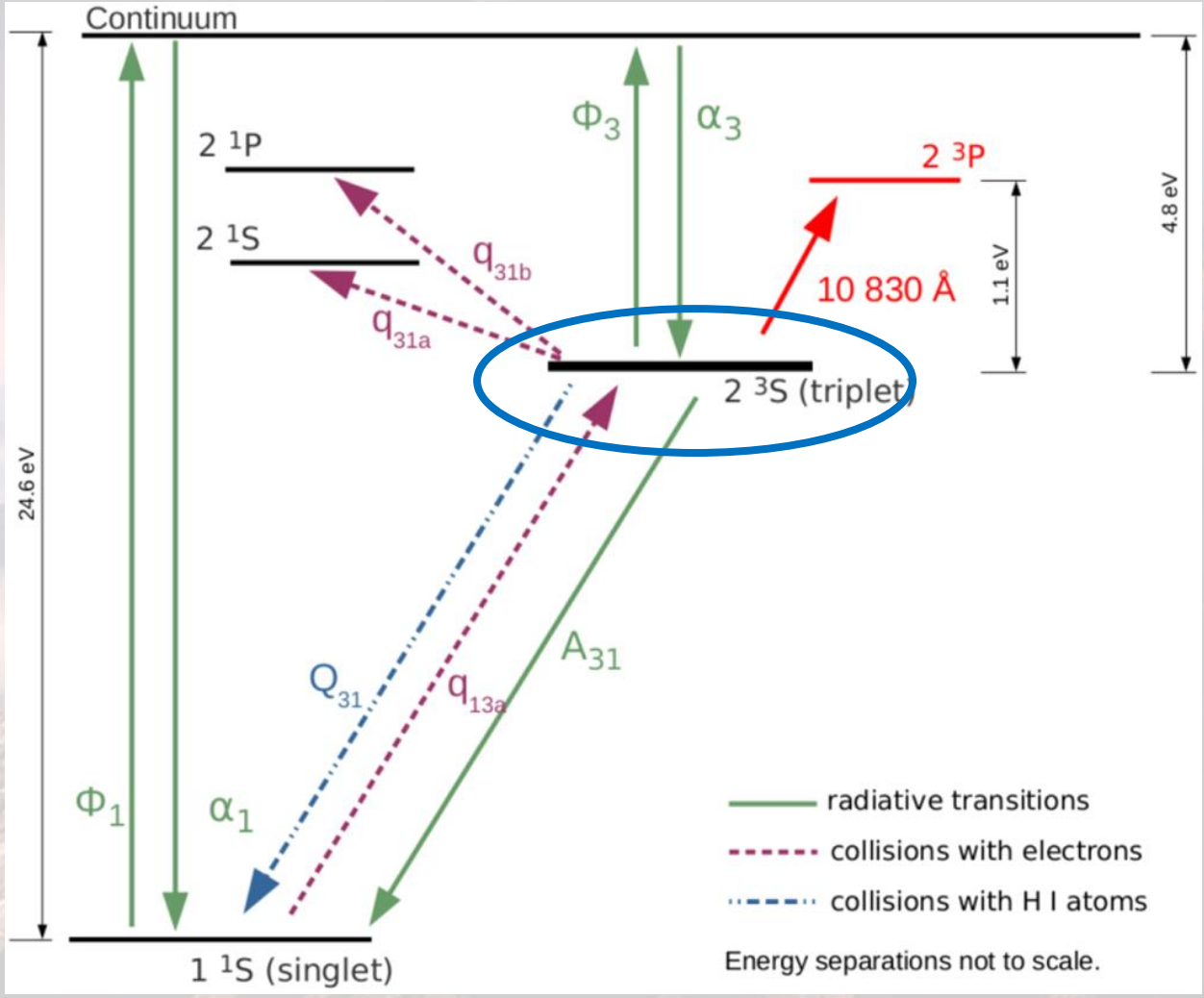
- The HeI(2^3S) nIR absorption lines are not affected by ISM and can be detected by **high-resolution** ground based facilities.



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ATM. ESCAPE SIMULATIONS

ATmospheric **ES**cape code (Caldiroli+21)[1].

- Fast 1D hydro photo-ionisation code.
- Atmospheric parameters, T, P, v, ρ in a **self-consistent** way, derives $\dot{\mathbf{M}}$.

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Astronomy & Astrophysics manuscript no. Exoplanet_paper_1_2021
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Irradiation-driven escape of primordial planetary atmospheres I. The ATES photoionization hydrodynamics code⋆

Andrea Caldiroli[1,2], Francesco Haardt[1,3,4], Elena Gallo[5,6], Riccardo Spinelli[1,4], Isaac Malsky[5], and Emily Rauscher[5]

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- We developed a Transmission Probability Module (**TPM**; Biassoni+23)[1] to simulate the **HeI(2^3S) absorption profile** during a planetary transit.
- In this way, it is possible to **compare the simulation** results **with observations** and infer fundamental planetary paramters.

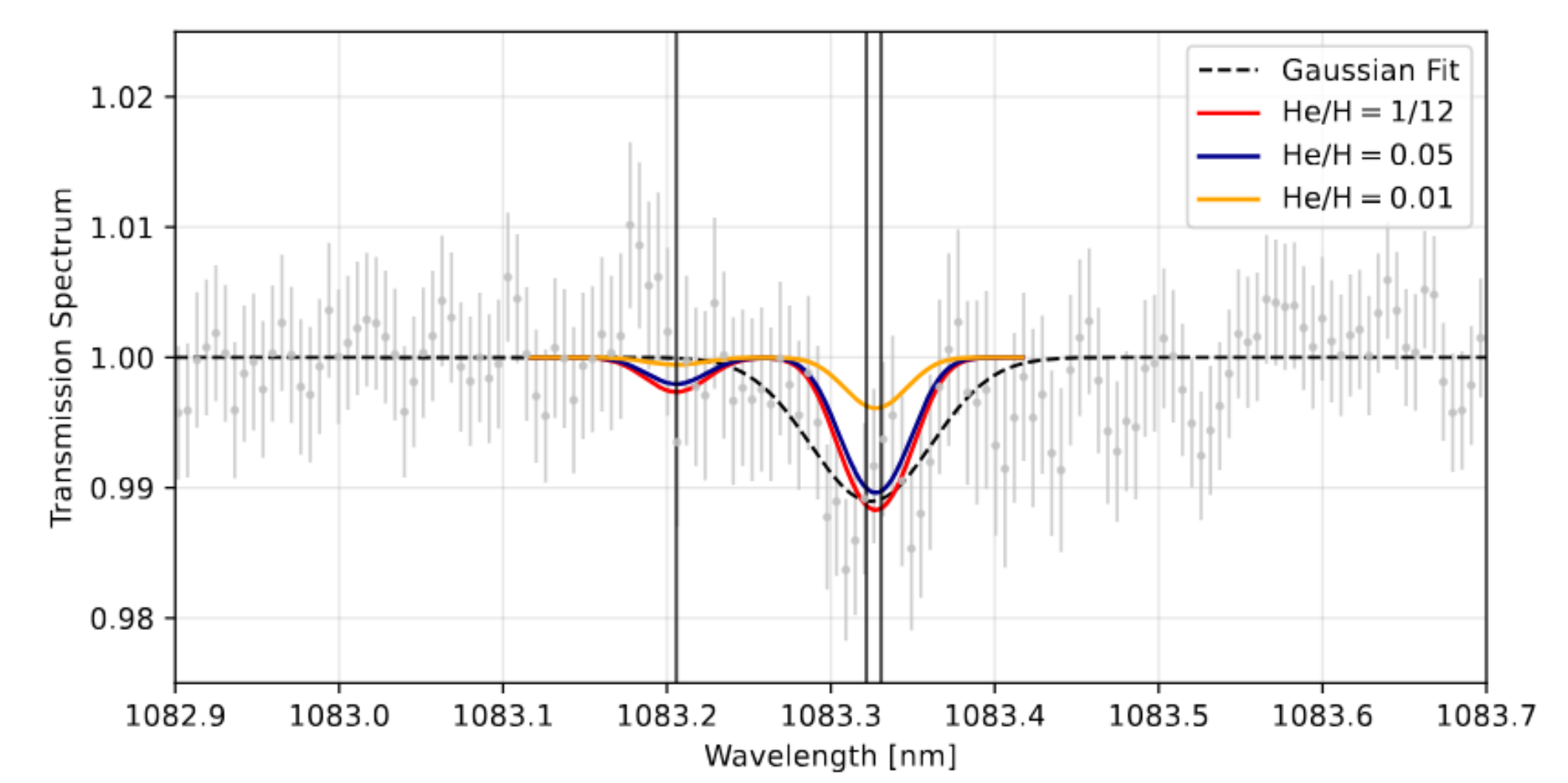
Astronomy & Astrophysics manuscript no. Arxiv
October 23, 2023

Self-Consistent Modeling of Metastable Helium Exoplanet Transits

Federico Biassoni[1,2], Andrea Caldiroli[3], Elena Gallo[4], Francesco Haardt[1,2,5], Riccardo Spinelli[6], and Francesco Borsa[2]

ATM. ESCAPE SIMULATIONS

- Example between different simulations of the HeI(2^3S) absorption profile obtained with ATES+TPM for the hot Jupiter KELT-18b. Figure from Chella+26, A&A sub.



HeI(2^3S) DEGENERACY

- HeI(2^3S) is produced by **ionisation** (24.6 eV = 504 Å) and **recombination** of the HeI.
- Hence, the stellar **EUV** (100 – 912 Å) **fluxes** and SED **shapes** are fundamental for our simulations.
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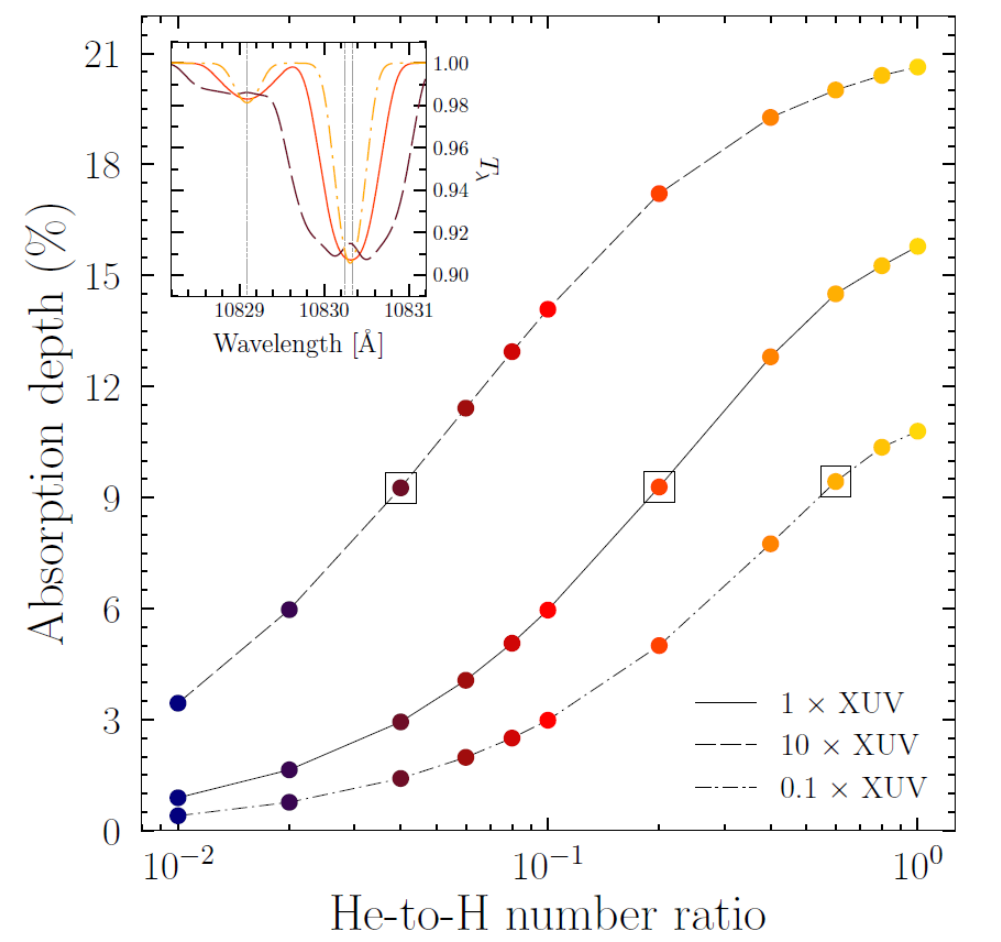
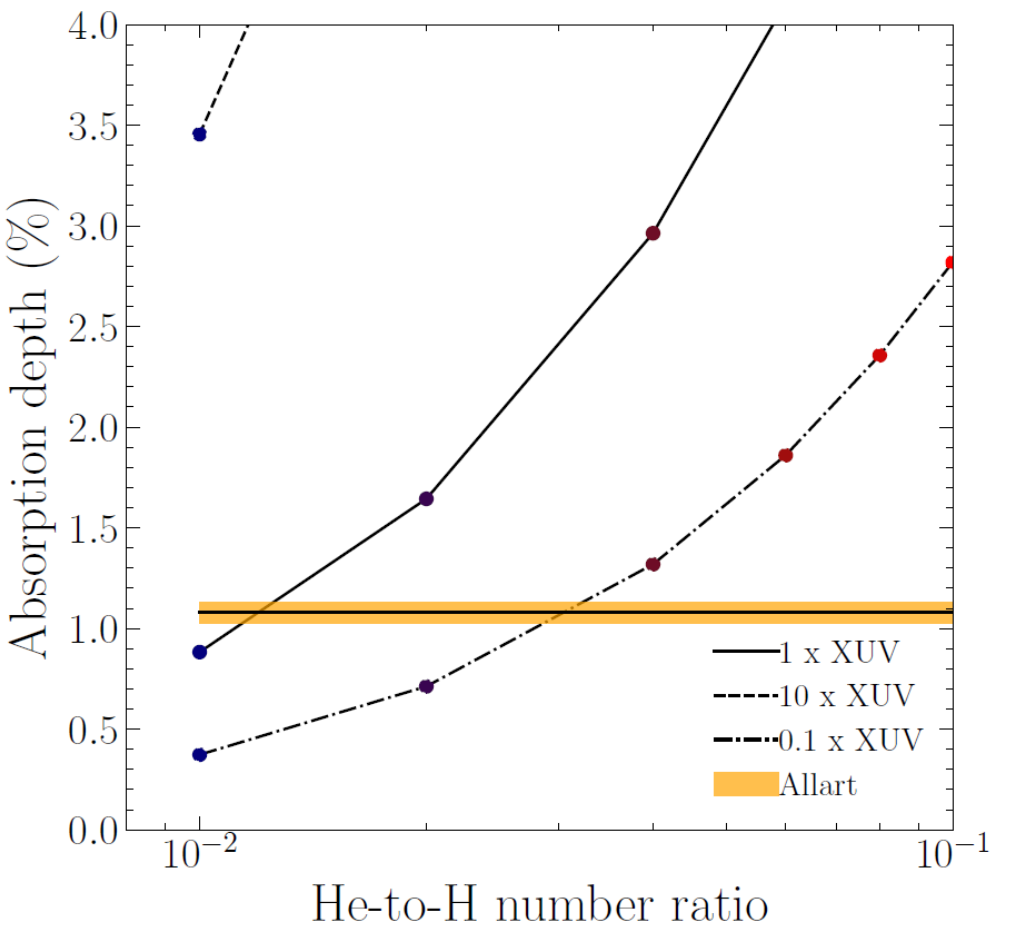
- However, we do not know a priori the exact He/H value.
- Furthermore, the **unknown** He/H number density ratio is **strongly degenerate** with the stellar **EUV flux**.

TWO SOURCES OF UNCERTAINTY

HeI(2^3S) DEGENERACY

- The **same absorption depth** could be obtained changing both the He/H number density and the stellar EUV.
- ATES+TPM simulations obtained varying the stellar EUV flux and planetary He/H ratio for the planet HAT-P-11b, compared with HeI(2^3S) detection by Allart+18.





BREAK THE DEGENERACY

- It is possible to **break** this degeneracy by observing **SIMULTANEOUSLY** the HeI(2^3S) triplet and the Balmer Hα line at 6563Å at **high-resolution**.

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- Unlike helium, Hα is **less sensitive** to the He/H ratio but **strongly depends** on the stellar EUV flux.

- By **jointly modelling** Hα and HeI(2^3S) and compare them with simultaneous **high-resolution** observations, it becomes possible to first **constrain the stellar EUV flux** and subsequently derive the **atmospheric helium abundance**.

THE ANDES SUPREMACY

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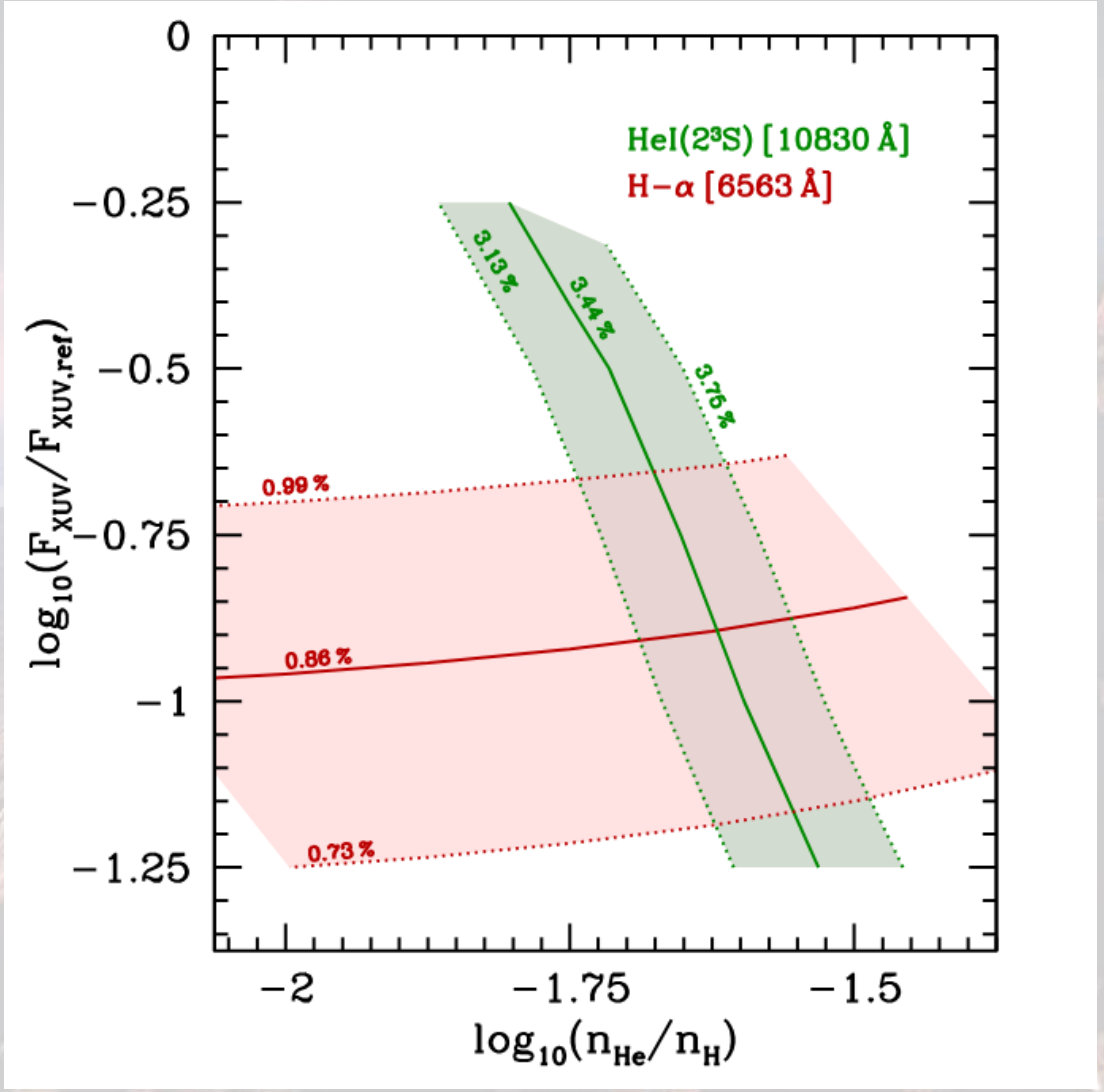
- Example of a grid of simulations obtained with ATES+TPM and CLOUDY (Ferland+17) after including the Hα for the planet WASP-52b.



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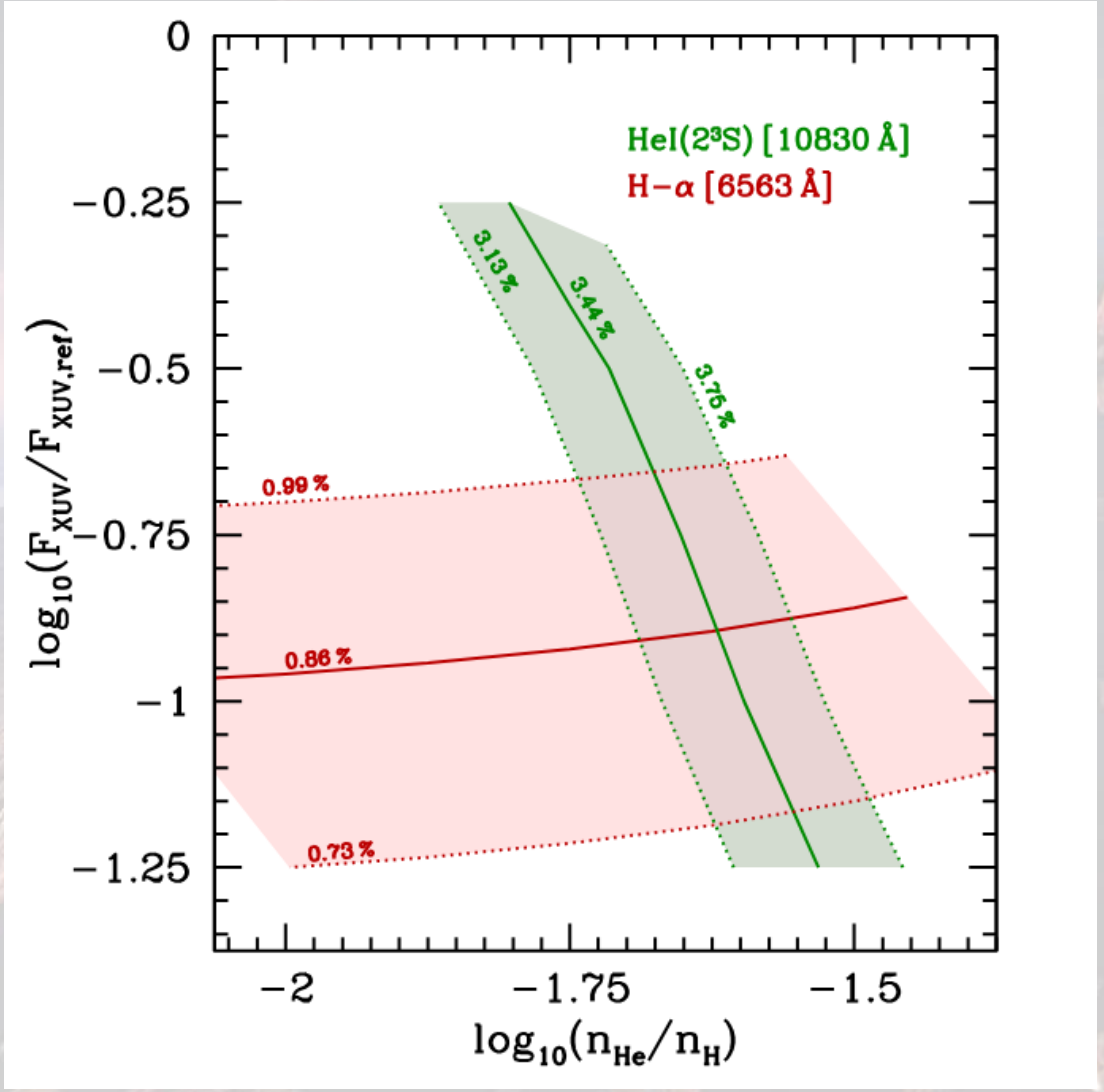
- Example of a grid of simulations obtained with ATES+TPM and CLOUDY (Ferland+17) after including the Hα for the planet WASP-52b.
- **Current facilities** (e.g. CARMENES, GIARPS) **do not achieve** the precision required to a simultaneously and robust detection.



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- However, **stellar activity** like flares, faculae, plagues, and spots, **can mimic** an extra HeI(2^3S) planetary absorption during a transit or produce a high Hα emission feature (see e.g., Guilluy+24).

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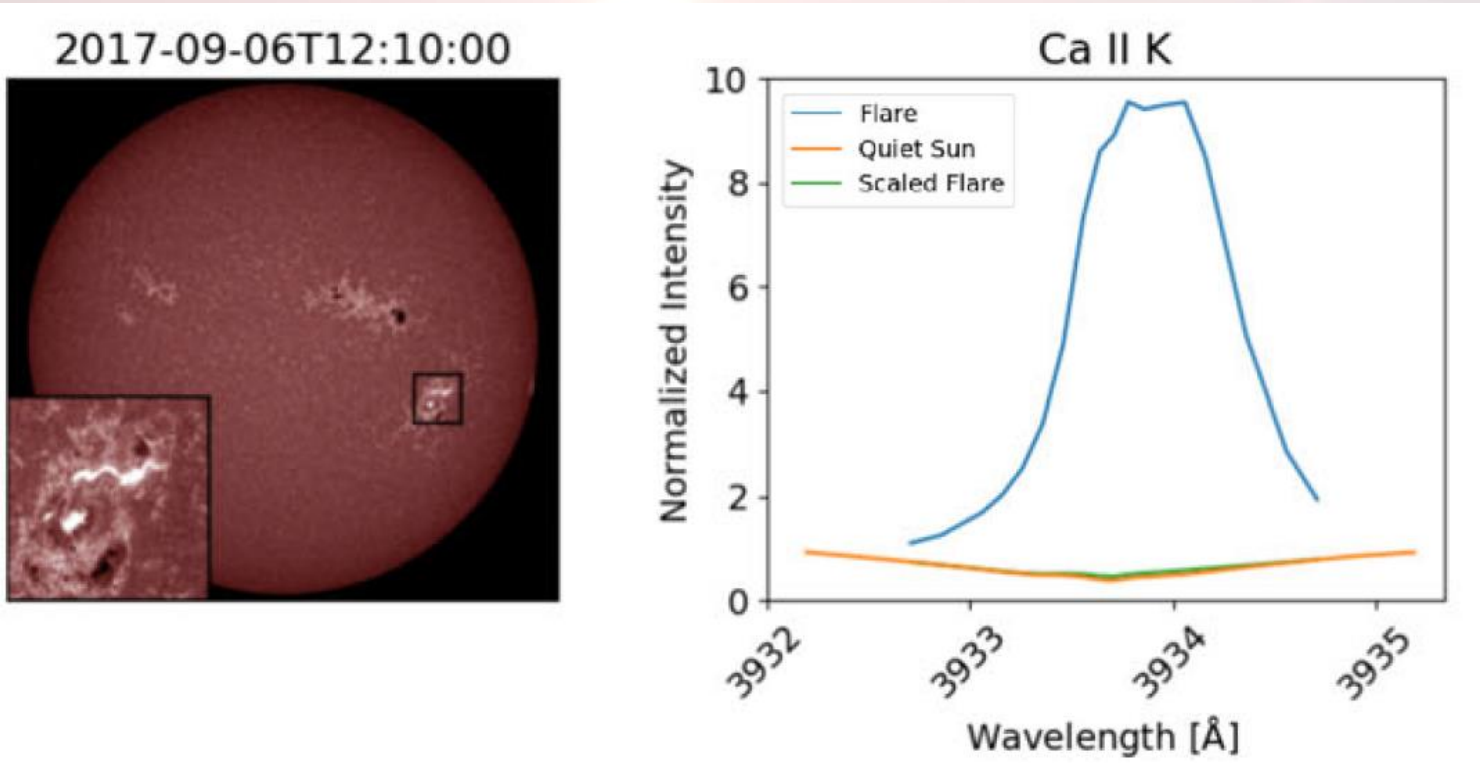
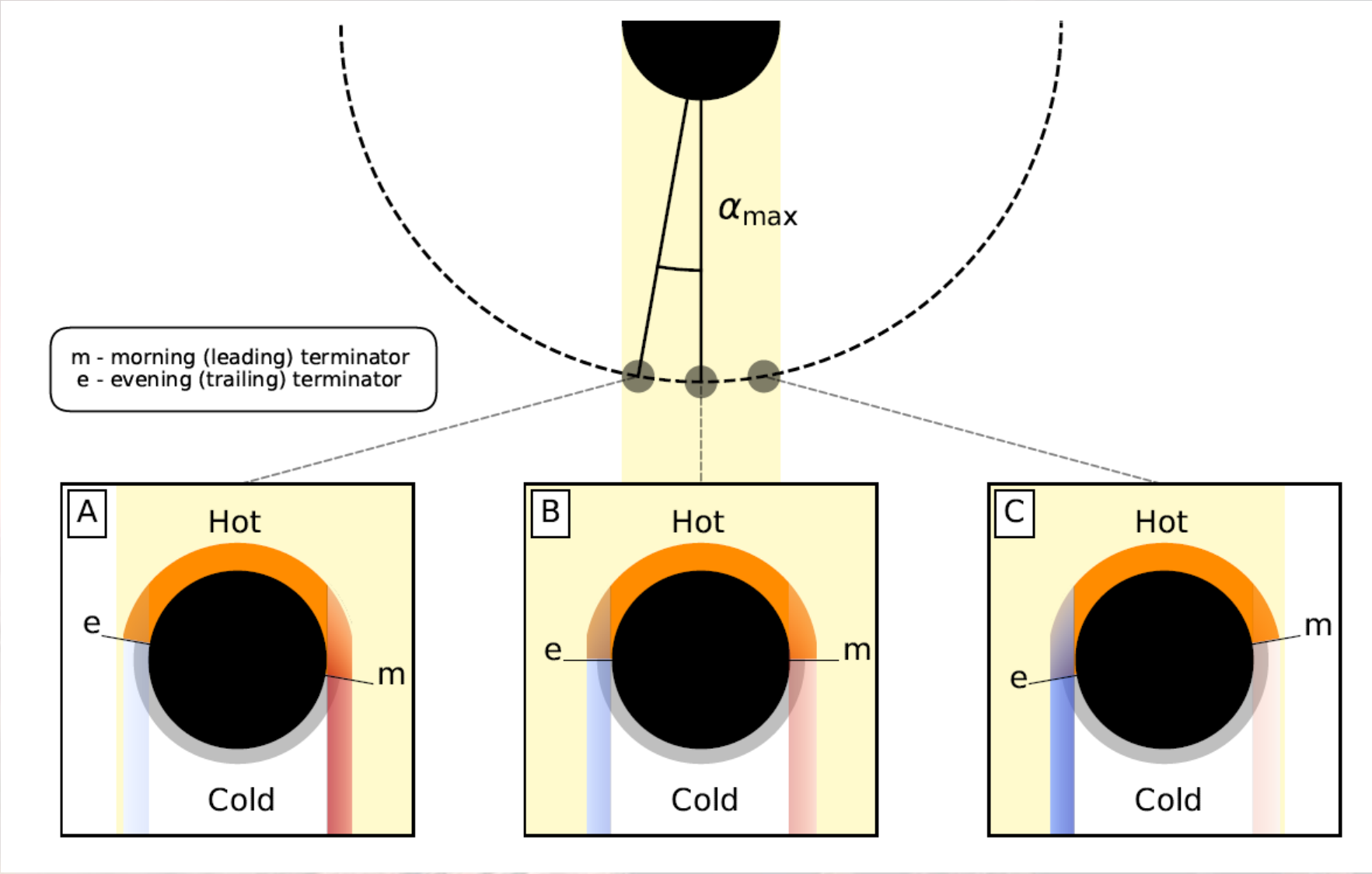
- But, ANDES will **overcome** this problem, thanks to its **U band** => direct observations of the **CaII H** (3968 Å) and **CaII K** lines (3933 Å) => derivation of the activity index R_{HK} .



- Comparison of the response of the CaII K line to changes in solar activity. Figure adapted from Pallé+25.

ATMOSPHERIC DYNAMICS

- During the transit we observe **different planetary limb** having different properties: the **morning** and the **evening side** of the **terminator**. Figure from Prinoth+23.



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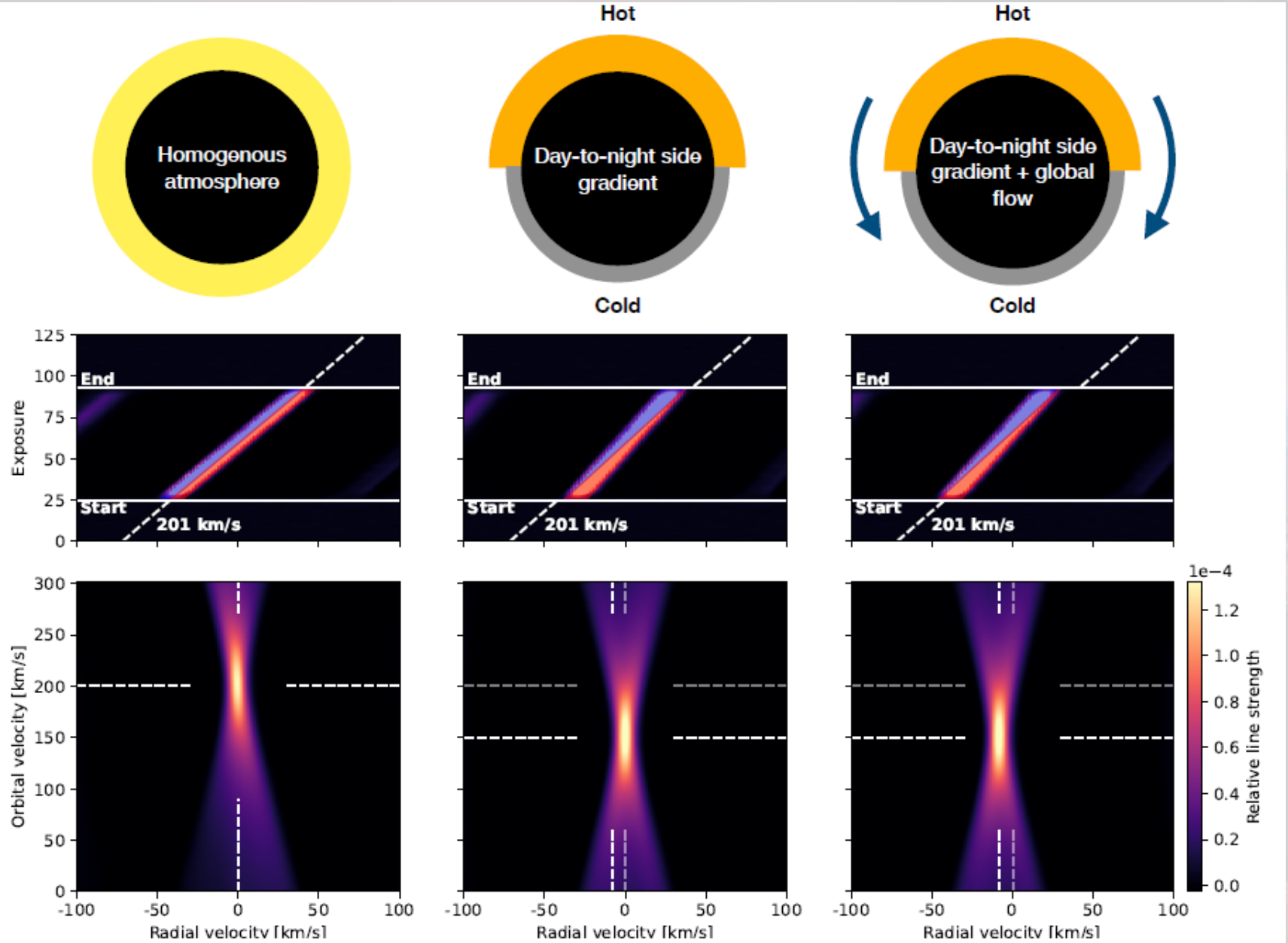
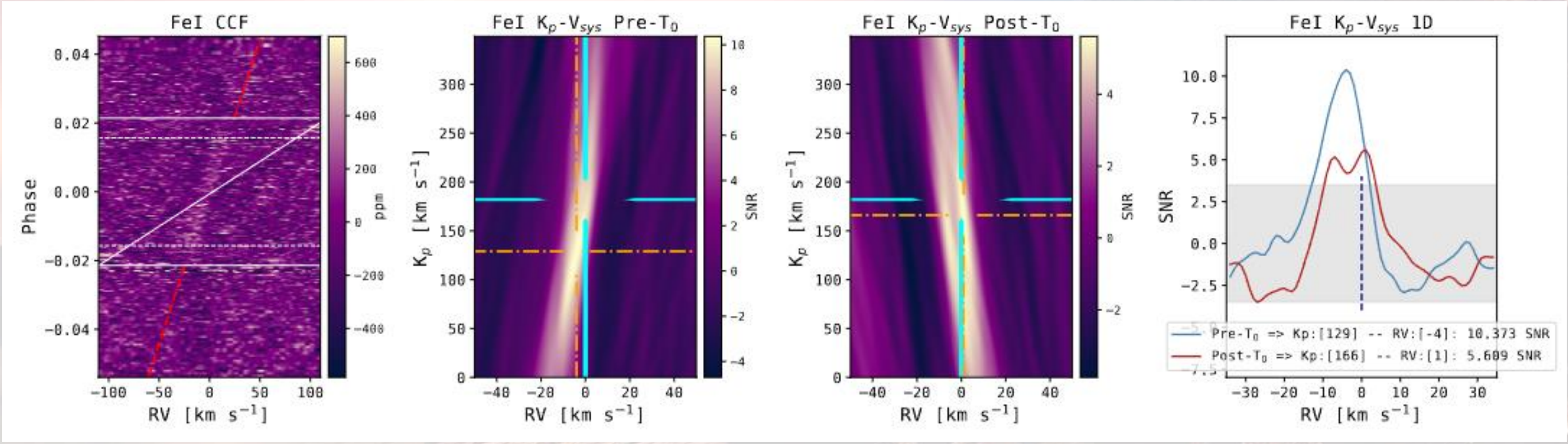


- Using the **CCF** technique (Snellen+10) it is possible to detect exoplanetary signals.
- **Atmospheric winds** shift the signal.
- Figure adapted from Prinoth+23.

ATMOSPHERIC DYNAMICS

- It is possible to **split the transit** into two parts: the morning and evening side **searching for differences** in the detected signals. However, today **we are limited by SNR**.
- In this example, **we used 7 transits** obtained with HARPS-N to see an average difference in the hemispheres at an adequate SNR for the hot Jupiter KELT-20b.
- The double peak observed weighting the post-T_0 exposures may be associated to **equatorial jet** combined with an **attenuated signal from polar regions**. Figure from Biassoni+26 A&A sub.



ATMOSPHERIC DYNAMICS

- Thanks to ANDES+ELT and the **high-resolution**, it will be possible to reach enough SNR **even with a single transit**, and the **single exposures** can be used to detect differences between hemispheres, instead of weighting half transit to reach the adequate SNR.

- In this way, it will be possible to **detect longitudinal, latitudinal and zonal winds**.

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- Due to its **extreme wavelength coverage** from U to H band at **high-resolution**, ANDES will delve **atmospheric properties** for different species living at **different altitudes** e.g., ionic or atomic species at high altitudes (which absorption lines dominate the VIS band) and molecules at lower altitudes (predominantly in the nIR), giving information about **vertical structure, pressure, temperature and winds**.

- Finally, ANDES+ELT not only will have the properties to analyse at such high precision atmospheric dynamics of hot Jupiter but also **will extend these characterisation also to sub Neptunes and super Earth like planets**.