The visible arm of the GAPS 2.0 atmospheric characterization programme

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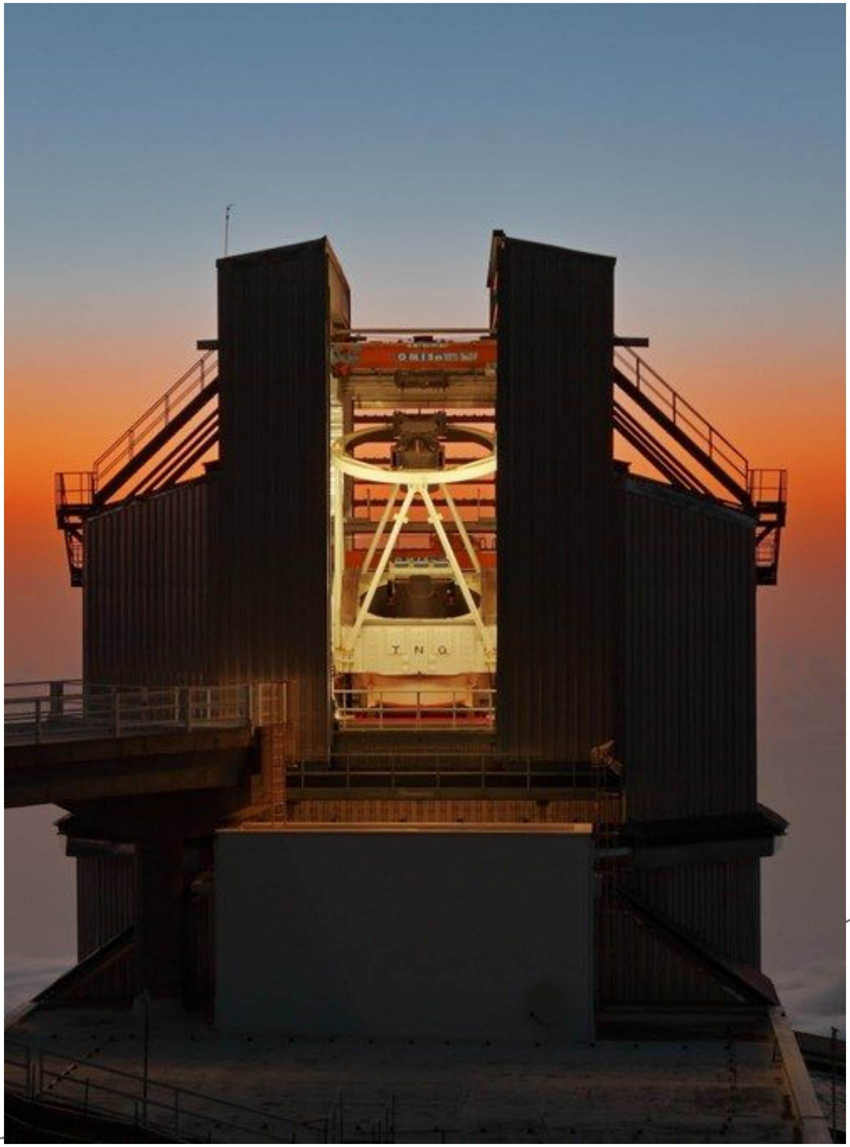
GAPS

OUTLINE

- GIARPS@TNG: the instrument and its performances
- GAPS-2.0: timeline and main science case(s)
- GAPS/AT (planetary atmospheres): techniques and challenges
- GAPS/AT status and first results



HARPS-N + GIANO-B = GIARPS

- Simultaneous use of HARPS-N (0.38-0.69 μm; R~115,000) and GIANO (0.95-2.45 μm R~50,000) through a dichroic, at the Nasmith-B platform of the TNG; GIANO moved from Nasmith-A and upgraded (now slit-based)
- High-resolution VIS-NIR spectra, high-precision radial velocity
- Management: Italian Exoplanetary community through the *Premiale WOW*, with a particular effort by the GAPS team (funds, manpower, observing time)

GIARPS: a timeline

- 2012: HARPS-N available at TNG
- 2014: GIANO-A Science Verification at TNG
- 2014: WOW proposed to use them together
- 2015 – 2016: Feasibility study and HW realization
- Aug/Sep 2016: Commissioning of the new GIANO preslit and Autoguider
- Oct/Nov 2016: GIANO in Nasmyth-B: Commissioning of GIANO-B and new GUI (HARPS-like)
- Feb/Mar 2017: Mounting of the dichroic, GOFIO online, GIARPS Commissioning
- April 2017: GIARPS available at TNG (shared risk)

GIARPS: the science

GIARPS was originally design with many science cases in mind to exploit its nearly unique combination of spectral coverage and resolution:

1) **Exoplanets**: atmospheric characterization; emission/transmission spectroscopy; phase curves
2) **Exoplanets**: radial velocity studies
3) **Solar system** (planets, dwarf planets, minor bodies (NEOs, comets,...)
4) **Other science**: Young Stellar Objects; x-ray binaries and magnetic stars; CVs and novae; transients; GRB and SN

A new beginning: GAPS-2.0

- GAPS-2 is a 5-yr long-term program at TNG building up to the experience gained within the previous GAPS collaboration. Same instrument (GIARPS), same collaboration, more focused science case
- **GAPS-2 has been approved starting from AOT37 (40 nights/semester); observing time will be granted on a year-by-year basis (annual report);**
- GAPS-1 (2012-2017) was oriented toward the «*exploration of the diversity of the architectures of planetary system*». We have found an astonishing diversity in the architectures of planetary systems as well as in exoplanet orbital and physical parameters.
- GAPS-2 (2017-2022) is focused on the next step: «*What are the origins of this diversity?*»

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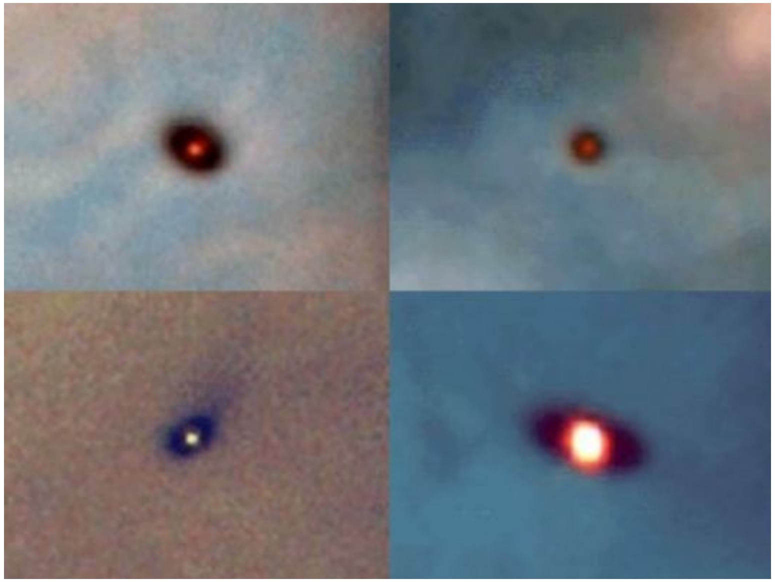
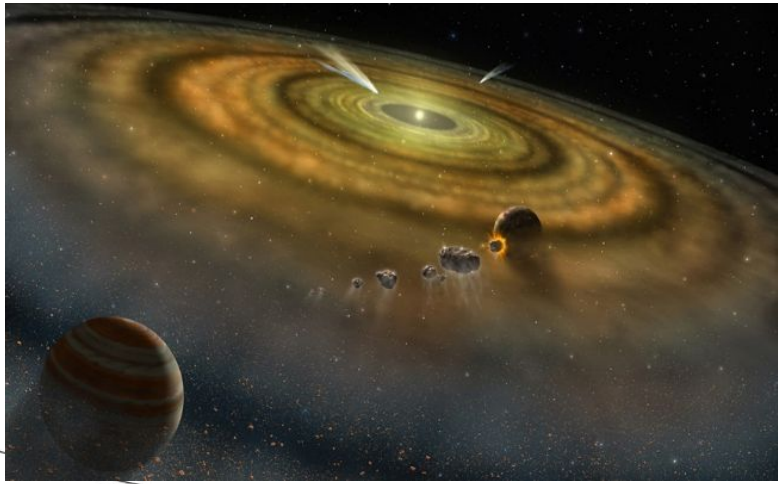
What is the origin of planetary diversity?

Planet formation in different environments

(discs with different mass and metallicity, stellar multiplicity, crowded or isolated environments, etc.)





Planet migration/evolution

(interactions of planets with the disc and planetesimals, planet-planet dynamical interactions, star-planet tidal interactions)

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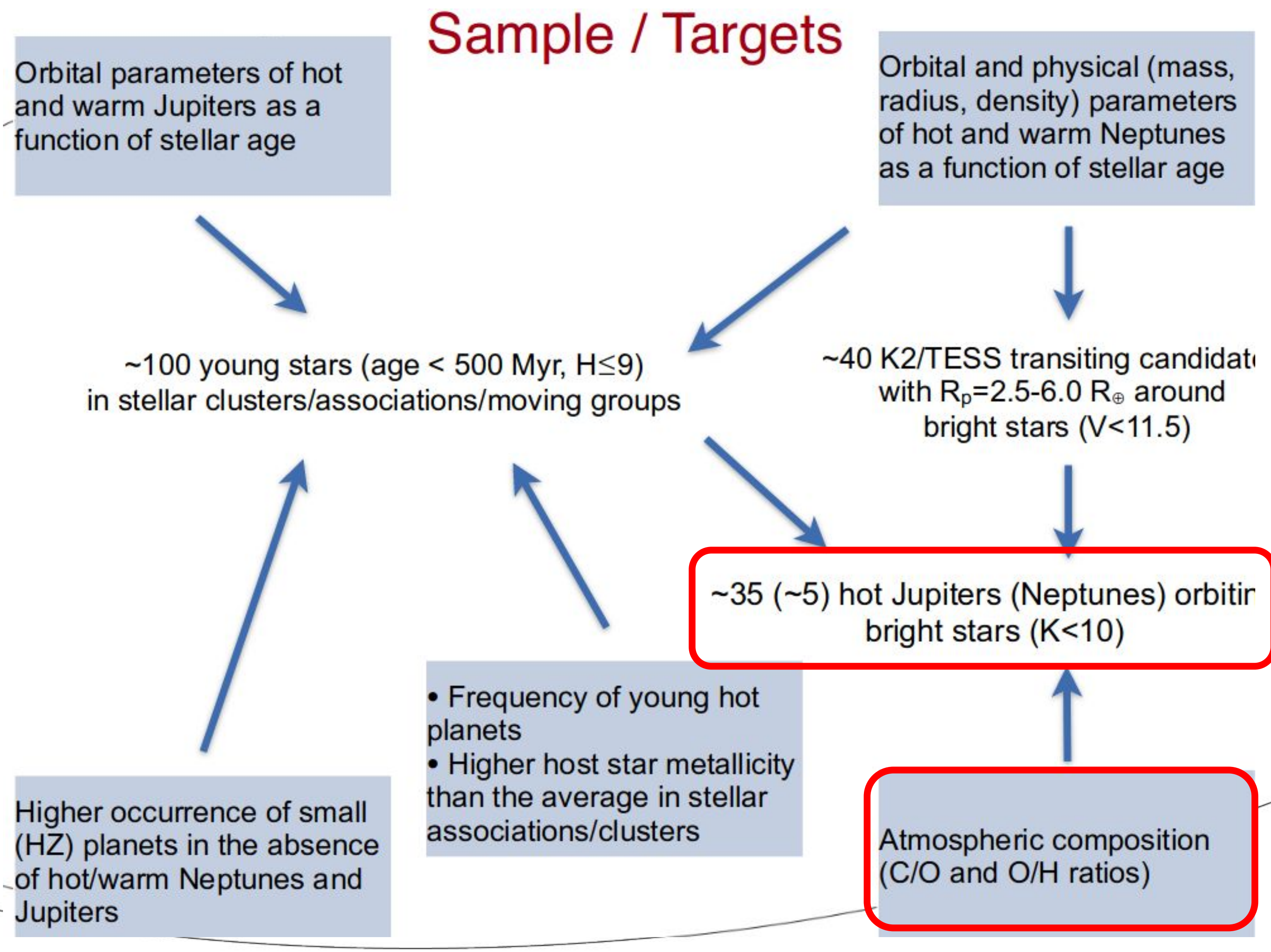
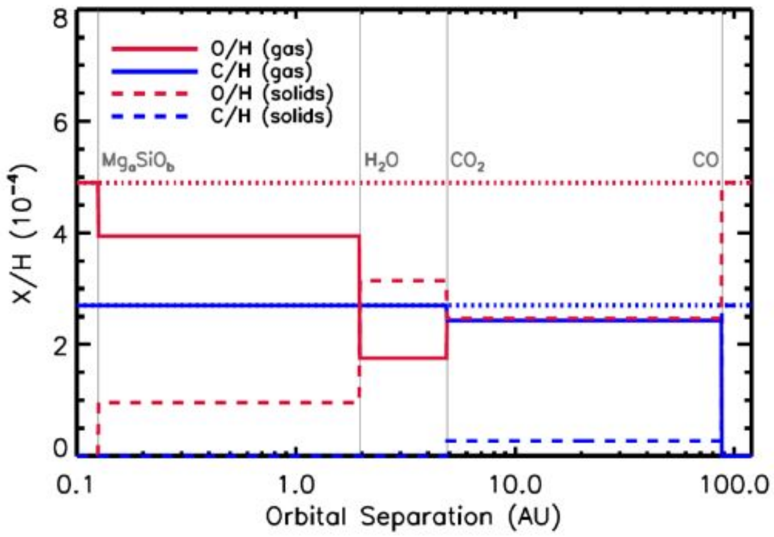
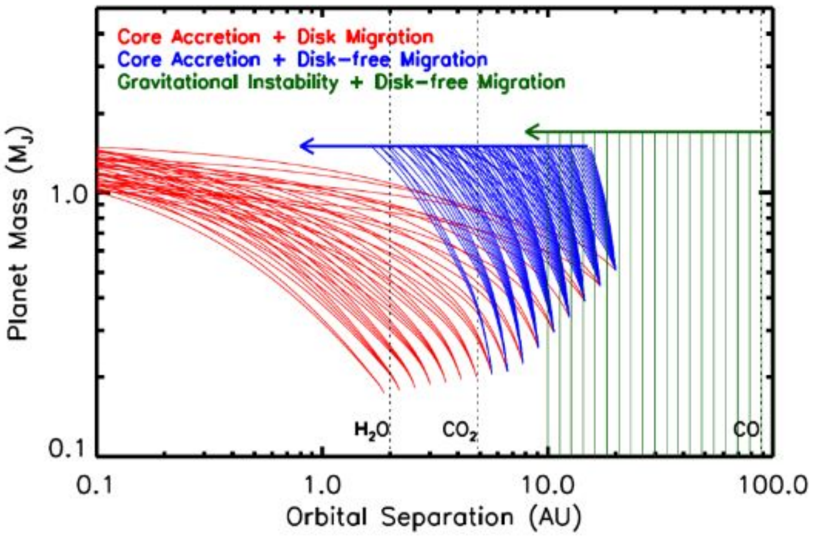
What is the origin of planetary diversity?



The GAPS/AT subprogram

- Crucial information about the environment where planets **formed**, their subsequent **migration**, and their **interaction** with the host star is somehow encoded in the present physical state and chemical composition of their atmospheres.
- In particular, the relative **abundance ratios** of key elements such as [C/O] are predicted to be important tracers of the formation and evolution history of gaseous giants (Madhusudan+ 2014); while other elements (alkali metals) are excellent tracers of **atmospheric escape** and evaporation





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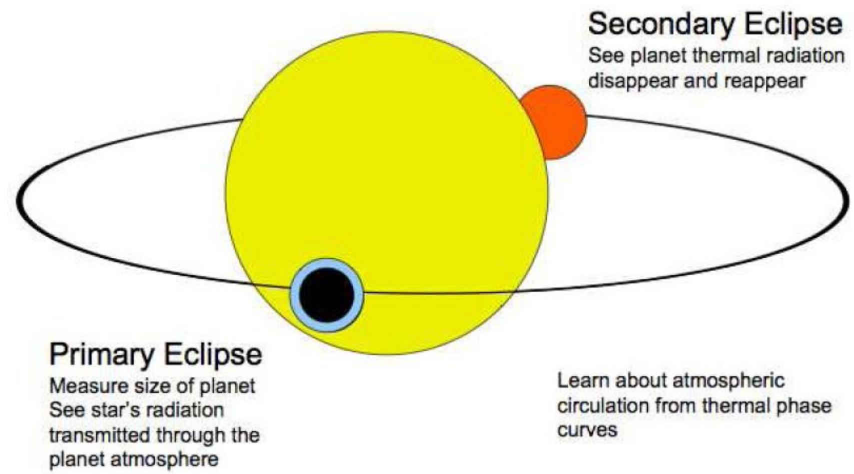
How to detect exoplanetary atmospheres

Spectroscopy of combined light (star+planet) is a powerful tool to probe atomic and molecular species in exoplanetary atmospheres

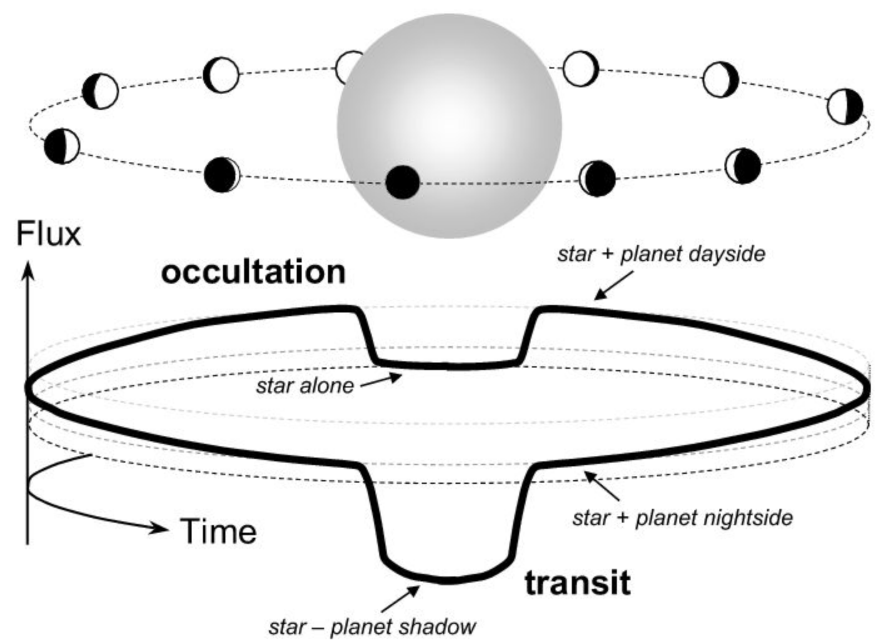
Transmission spectroscopy (TS) during transits is able to probe the terminator region up to several scale heights

Emission spectroscopy (ES) probes the day-side hemisphere of the planet and is more sensitive to the lowest layers. ES does not always require a transiting geometry!

TS and ES are highly **complementary** as they probe different chemical/physical environments and are subject to different biases and limitations. Other complementarities arise from the different spectral range investigated (e.g., IR vs. VIS)



Adapted from Seager



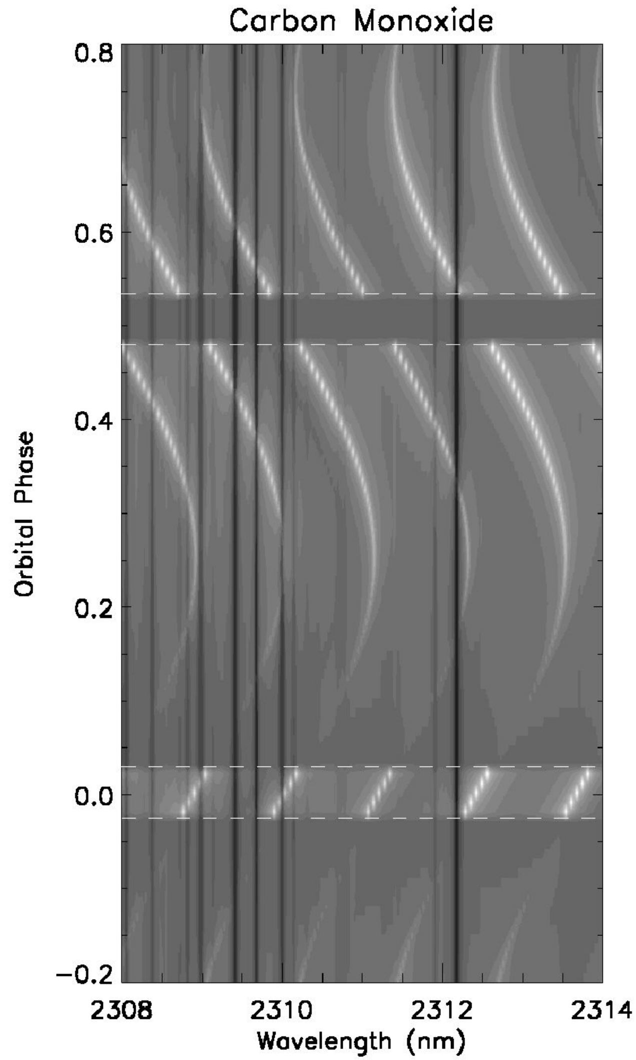
Winn+ 2011

Advantages of high spectral resolution

At R ≳ 20,000-30,000 the individual molecular lines begin to be resolved and can investigate the fine structure of atomic lines. Advantages of high-*R* transmission spectroscopy:

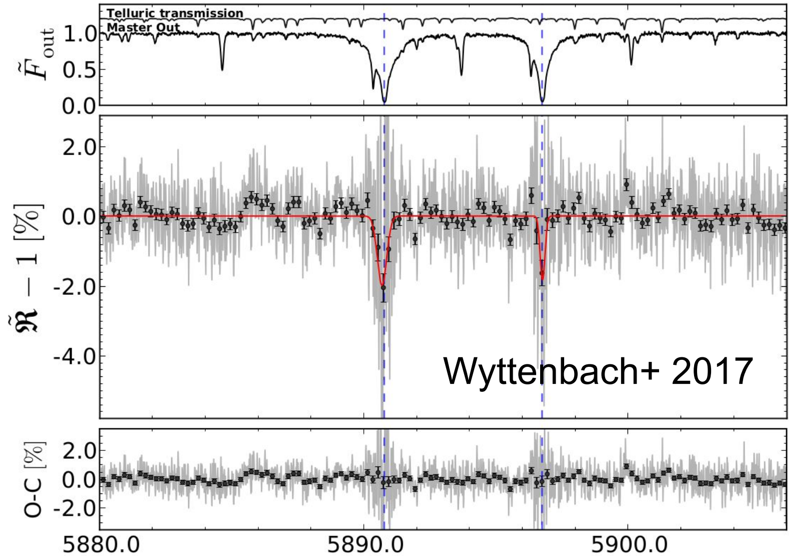
- Disentangling the stellar, planetary, and telluric signal by their radial velocity shift;
- Co-adding the weak signal of individual molecular lines by cross-correlating lots of them over a wide spectral range;
- Tracing a pressure-temperature (P-T) profile of the atmosphere (through the fine shape of the lines)
- Detecting super-rotation of the atmosphere (through the broadening of the line profiles) and high altitude winds (through the blue-shift of the lines).
- Study the Rossiter-McLaughlin (RML) effect and its λ dependence

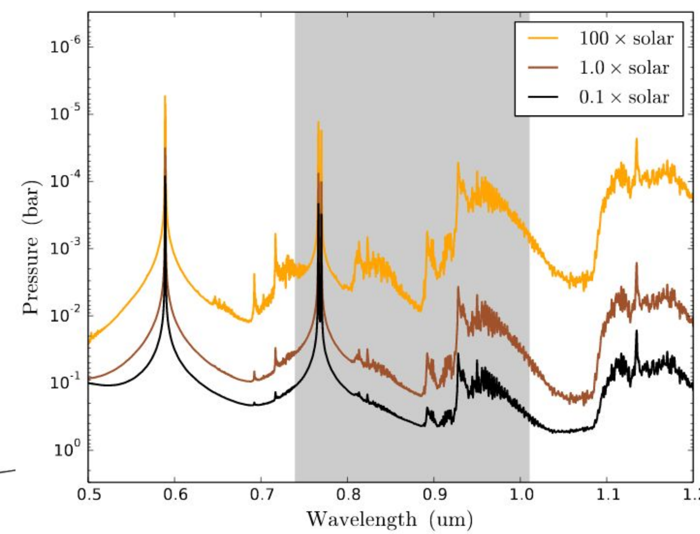
It takes a stable, high-resolution spectrograph possibly with a large spectral range: GIARPS!



1) Alkali metals (Na + K)

- Among alkali metals only Na is accessible by GIARPS (K is at ~7699 Å)
- Due to its huge cross-section the core of Na lines (observed at HR) allow us to probe down to very low pressures (external layers)
- Even in very cloudy HJs Na can be detected well above the cloud layer (*tens of H*; WASP-49b, Wyttenbach+ 2017, Cubillos+ 2017)
- Highly complementary with LR observations (e.g., HST or ground-based spectrophotometry; Brogi+ 2017; Pino et 2017)

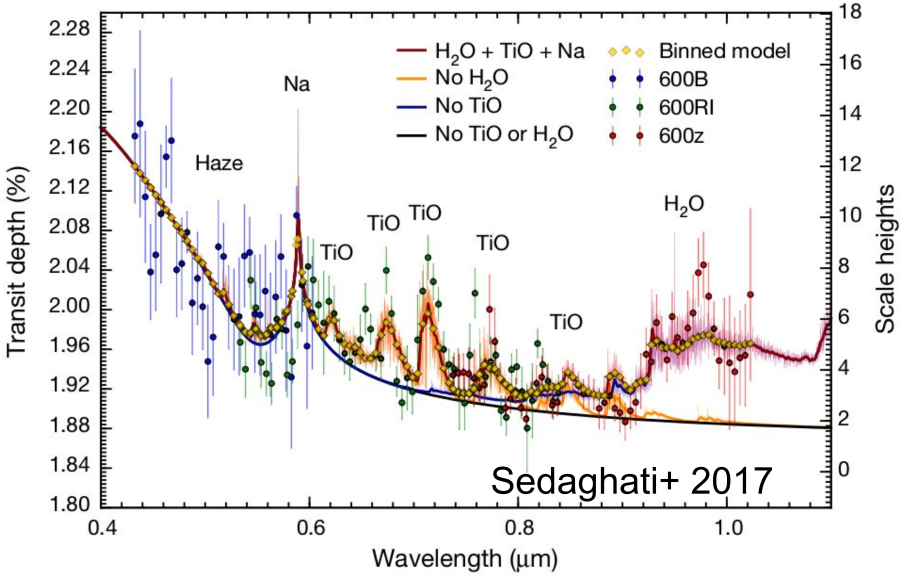


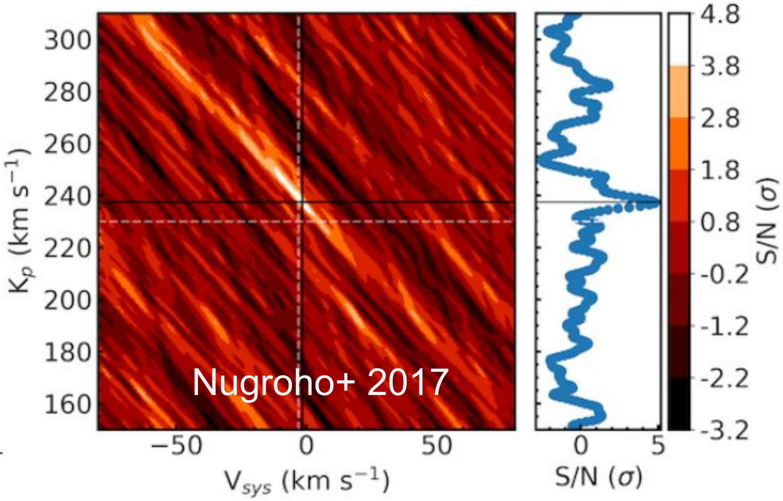


Cubillos+ 2017

2) Titanium Oxide

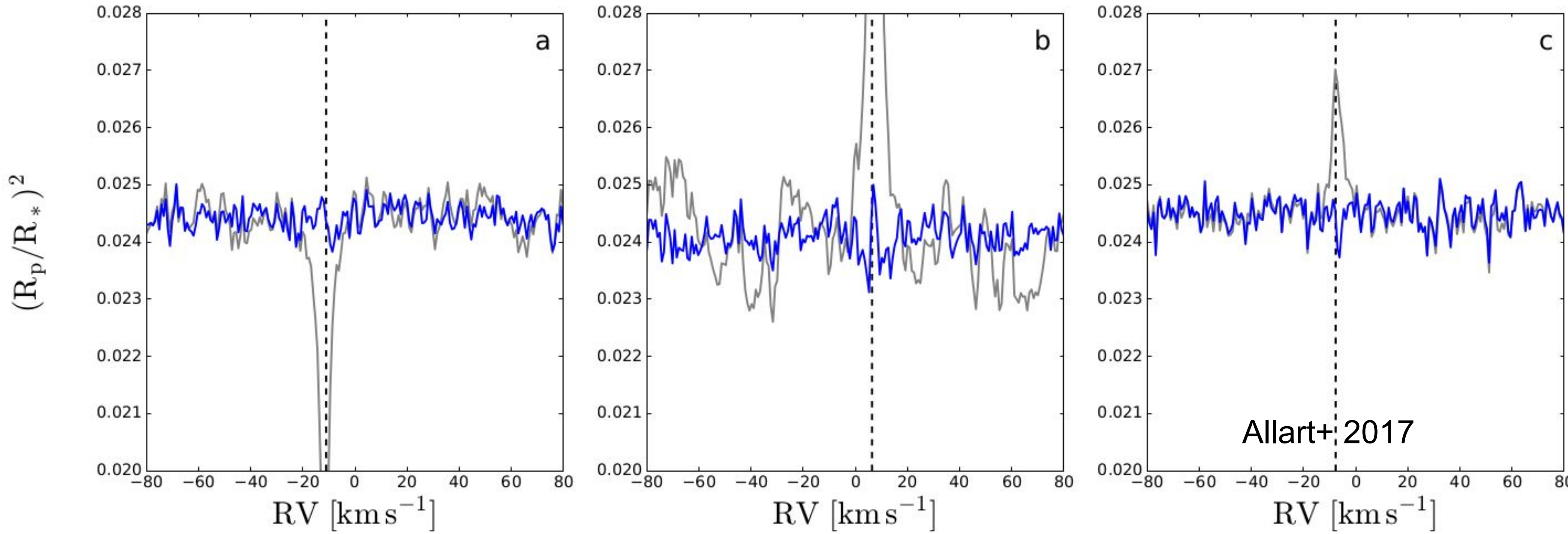
- Thought to be main optical absorber for extremely irradiated planets (T_{eq}>1900 K); crucial to explain T-P inversions (Fortney+ 2008)
- First detected by Sedaghati+ (2017) on WASP-19; LR ground-based TS (FORS2)
- First detected in emission by Nugroho+ (2017) on WASP-33b
- Requires accurate TiO line lists in HR spectroscopy (Hoeijmakers+ 2015); old ones do not x-correlate bluewards of 6300 Å.





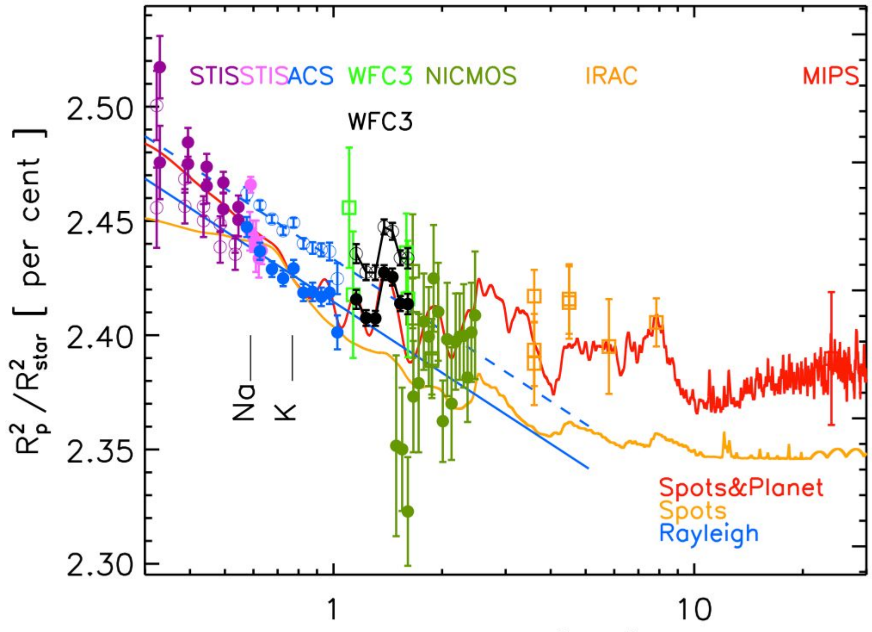
3) “Optical” water

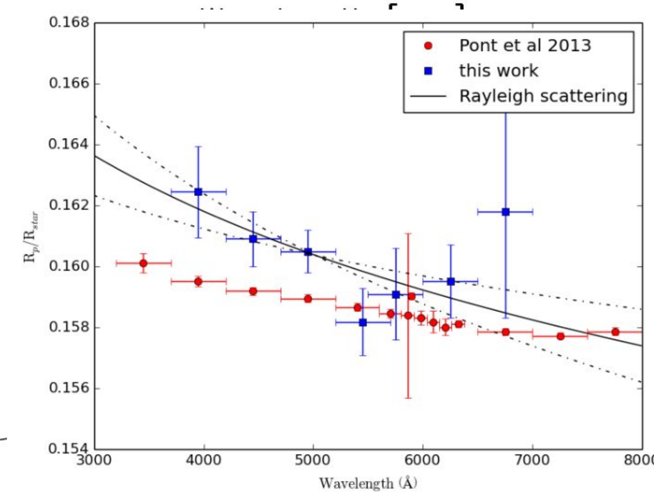
- The strongest H_20 molecular band are in the NIR region, but the first weaker bands appears redward of ~5900 Å (within the HARPS-N range)
- Allart+ (2017): first attempt to find H_2O on HD189733b by x-correlating an HARPS spectrum (three nights). Null detection (100-ppm water band at Å) rejected at 5σ, but space-like accuracies at ~20 ppm demonstrated



4) Rayleigh/Mie scattering

- Slope affecting the continuum, especially the blue region due to the λ^{-4} dependence of the Rayleigh x-section. Due to H_2 or aerosols (many candidates proposed)
- Crucial to estimate the *H*, the size and nature of the scattering particles, and to lift degeneracies between the molecular abundances estimated from the NIR TS and the presence of aerosols
- Usually not accessible by HR TS (continuum is lost by its "doubly differential" approach), but: chromatic Rossiter effect (Snellen+ 2004) on some specific target. *Possible GIARPS opportunity for HJ hosted by bright and fast-rotating stars.* And: measuring the H_20 contrast ratio on different bands





Di Gloria+ 2015

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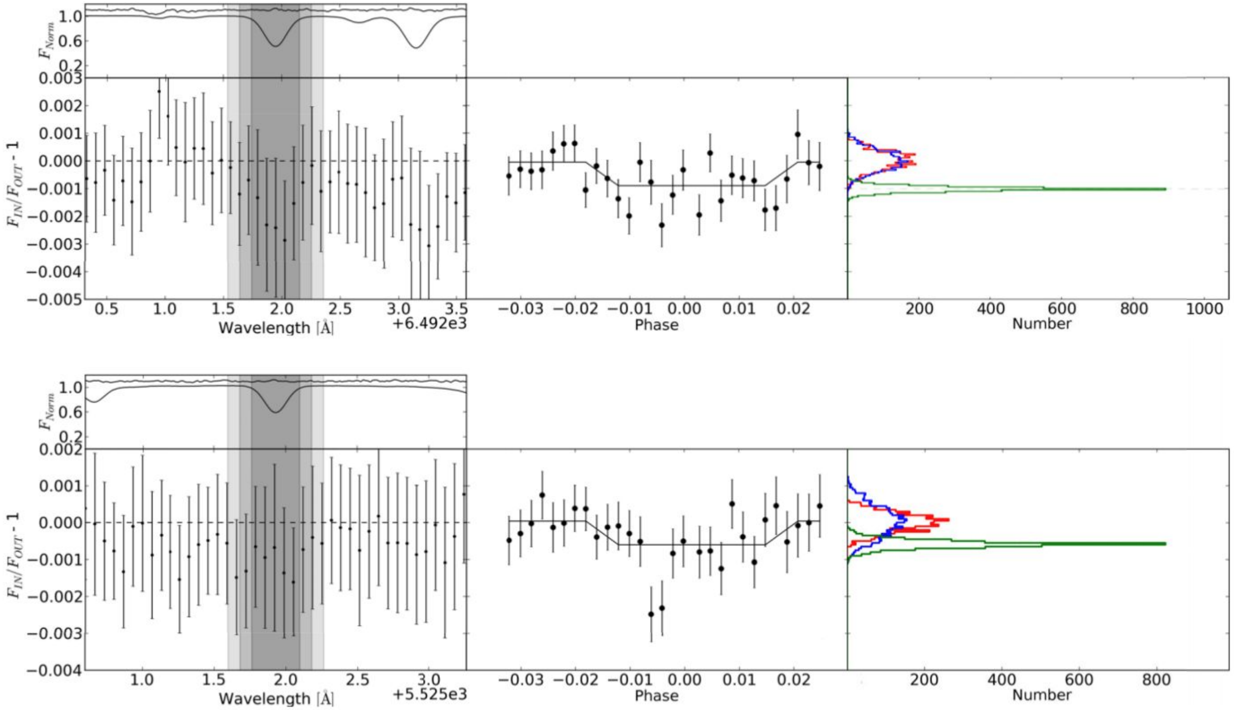
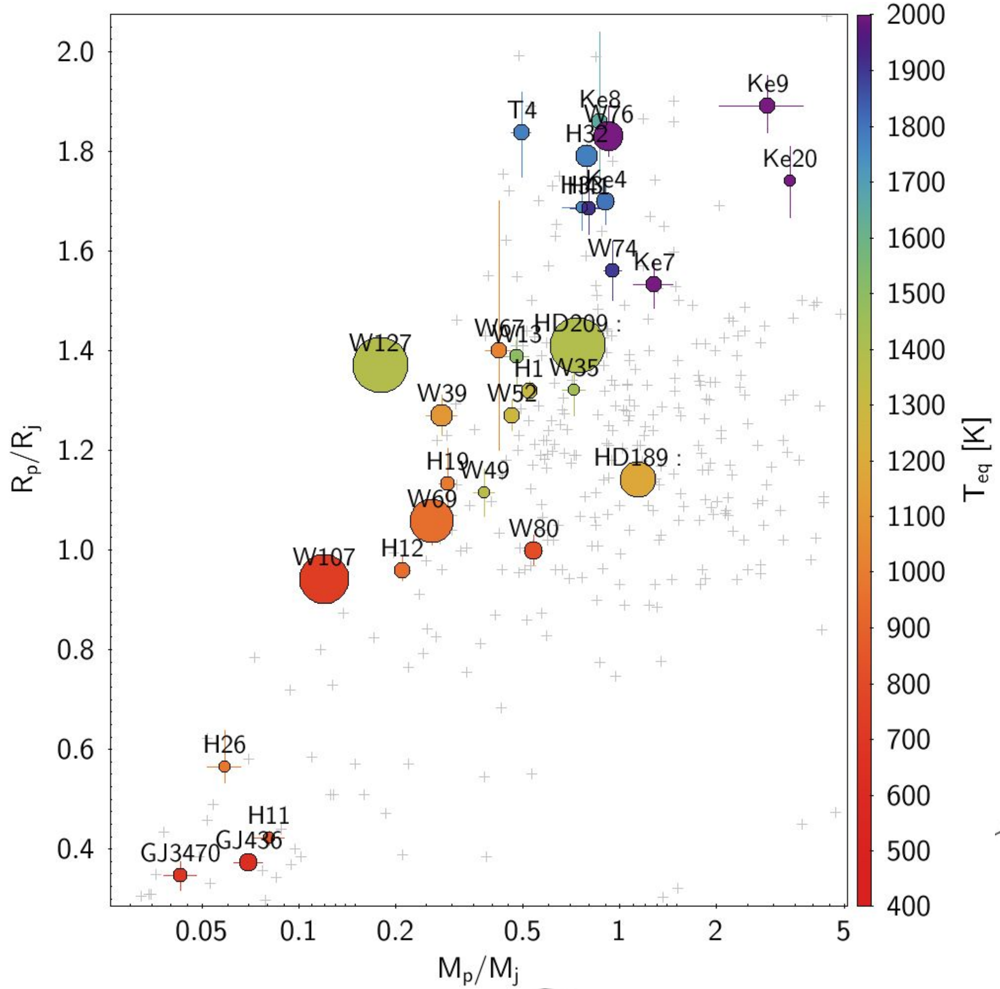
5) Other “exotic” features

- **Halpha/CaII absorption**. Claimed on HD189733b (Jensen+ 2012; Barnes+ 2016), WASP-12b (Fossati+ 2013) among other. Still unknown if it is of stellar or planetary origin (Cauley+ 2017a, 2017b, 2017c), or possibly both?
- **Other metals** (?). Calcium and Scandium (Astudillo-Defru+ 2013). Lithium (Casasayas-Barris+ 2018). Difficult interpretation (CLV? Yan+ 2017)



Status of GAPS/AT

- Target list: 26 **Hot Jupiters** covering a wide range in the parameter space (density, age, host star type…) selected according to observability plus a small sample of “easy” **Neptunians**
- Twelve targets observed during the first year of operations
- **Technical problems**: many failures especially on the NIR channel, mostly solved now; one third of nights lost due to bad weather / seeing condition. At least three transit required for a robust detection
- Scientific issues: many transmission signals discovered/confirmed but difficult to reproduce; unexpected telluric emission; observing strategy fine-tuned



First results of GAPS/AT

Tomographic transmission spectroscopy of VHJs (KELT-9b) with a clear detection of both doppler shadow and atmospheric signal (Borsa+ 2019, A&A 631, 34)