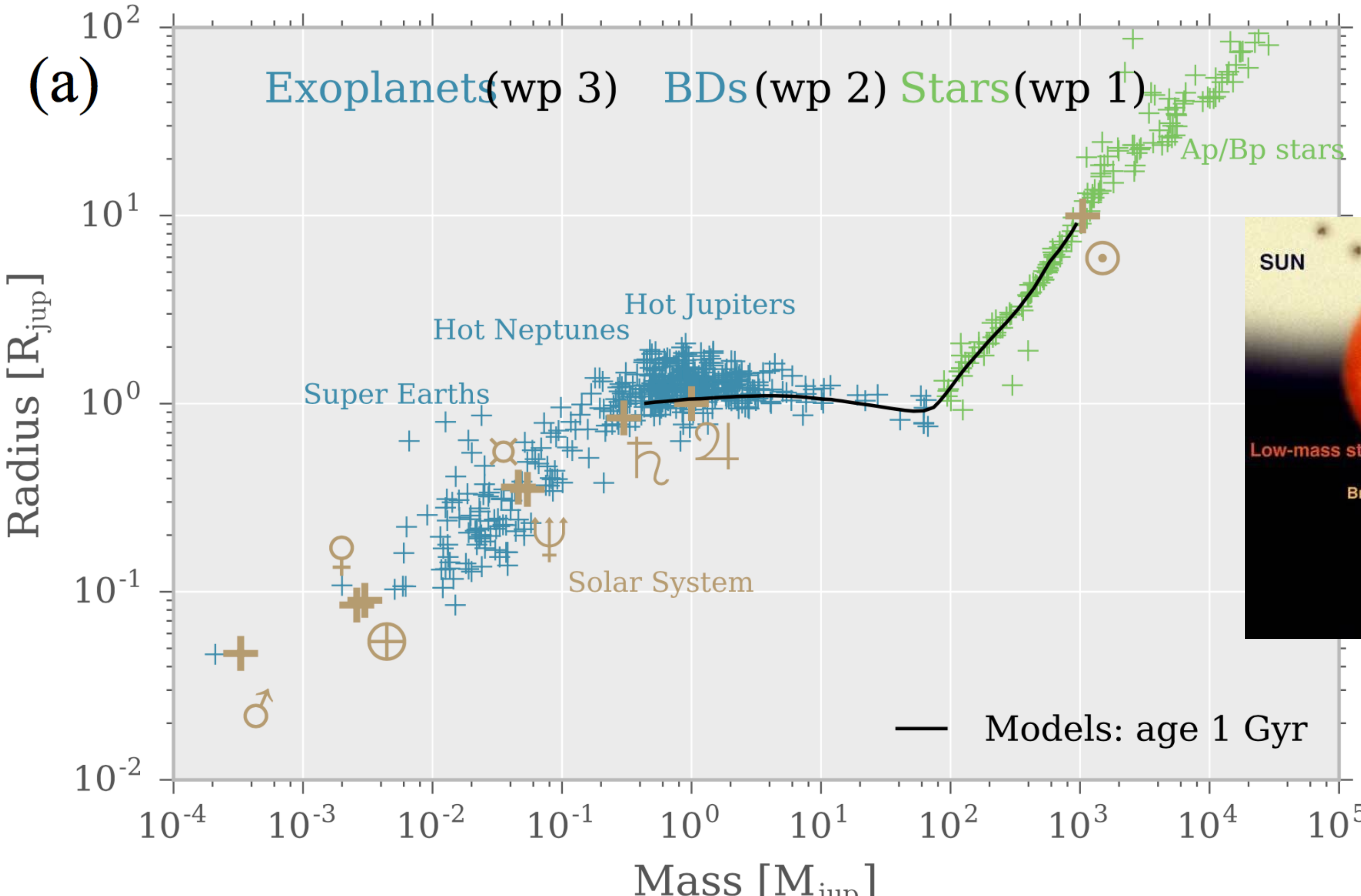
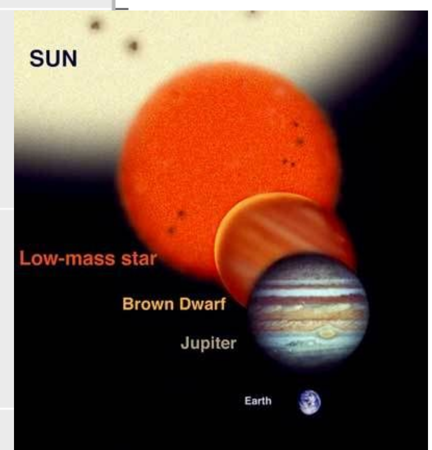
Exoplanet atmospheres

Pascal Tremblin
Pierre-Olivier Lagage
Sébastien Fromang

Exoplanet detection

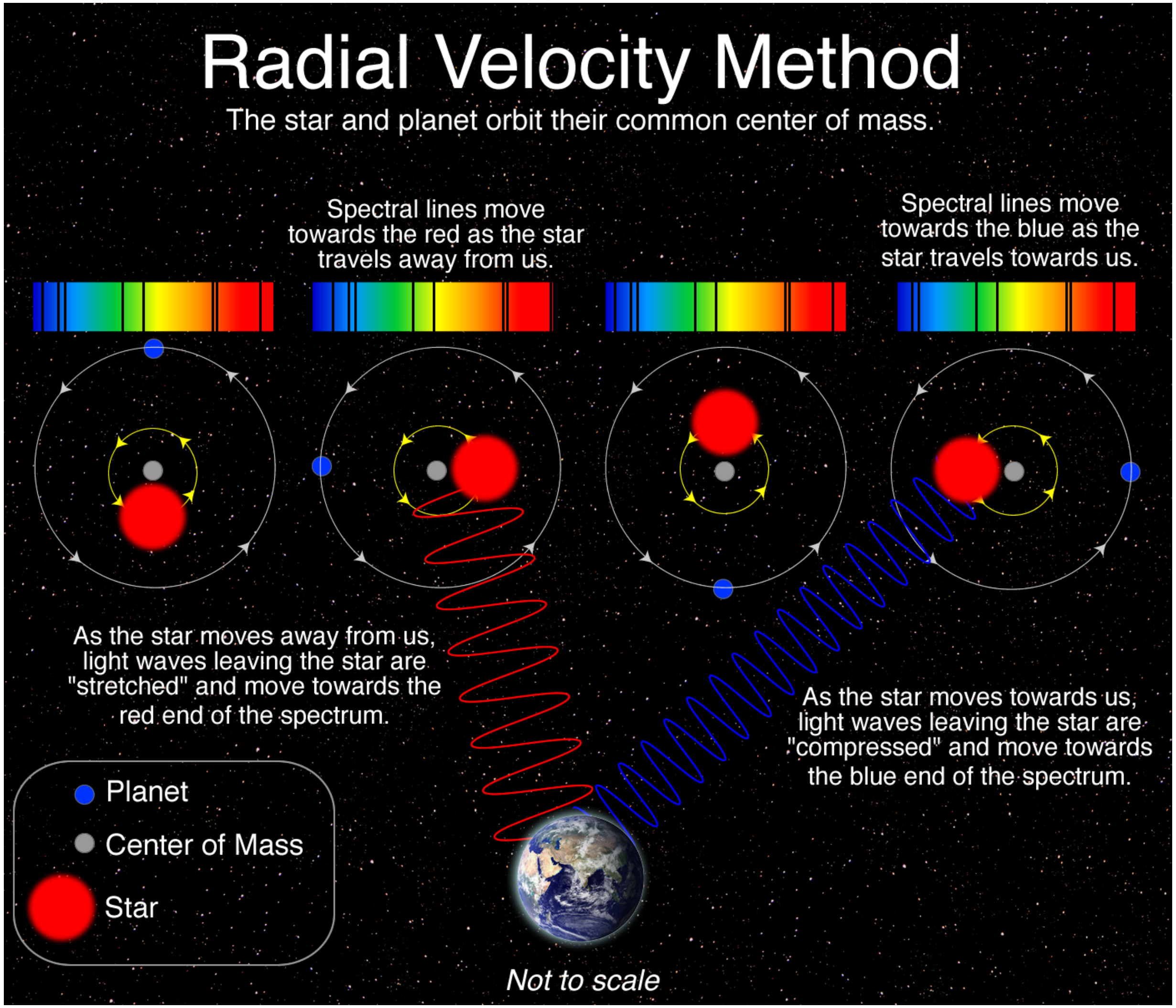
- An exoplanet is a planet that does not orbit around the Sun but around another star (well sort of…)





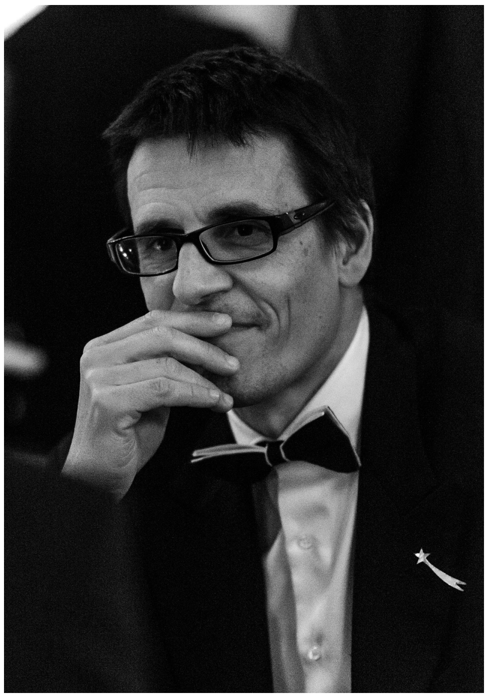
Exoplanet detection

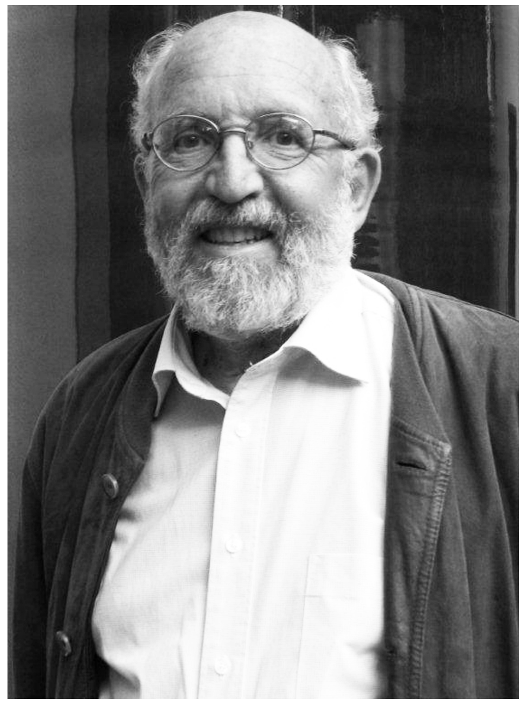
– Astronomers have imagined an undirect detection method: the radial-velocity method



➢ A bit of history…

– In 94/95, Didier Queloz and Michel Mayor were actually analysing their data on the fly with the Elodie spectrograph at Observatoire de Haute Provence.

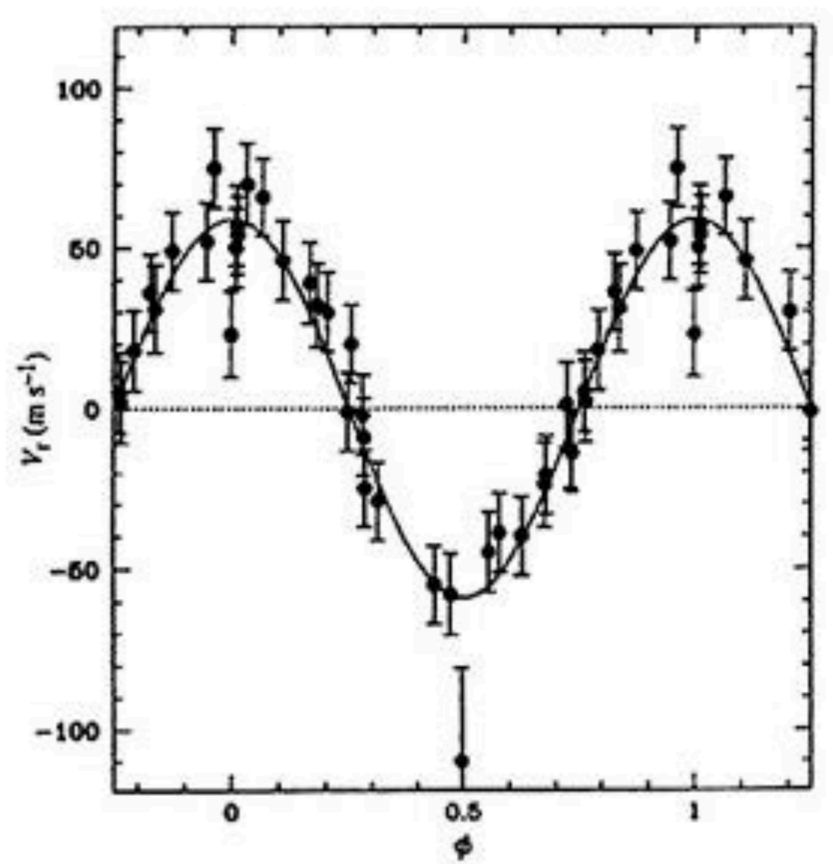




– … and found a tiny signal in their data…

➢ A bit of history…

- After almost one year checking their data, they extract this signal from the star 51 Pegasus



- … and found that an object (51 peg b) is orbiting with a period of only **4.2 days**

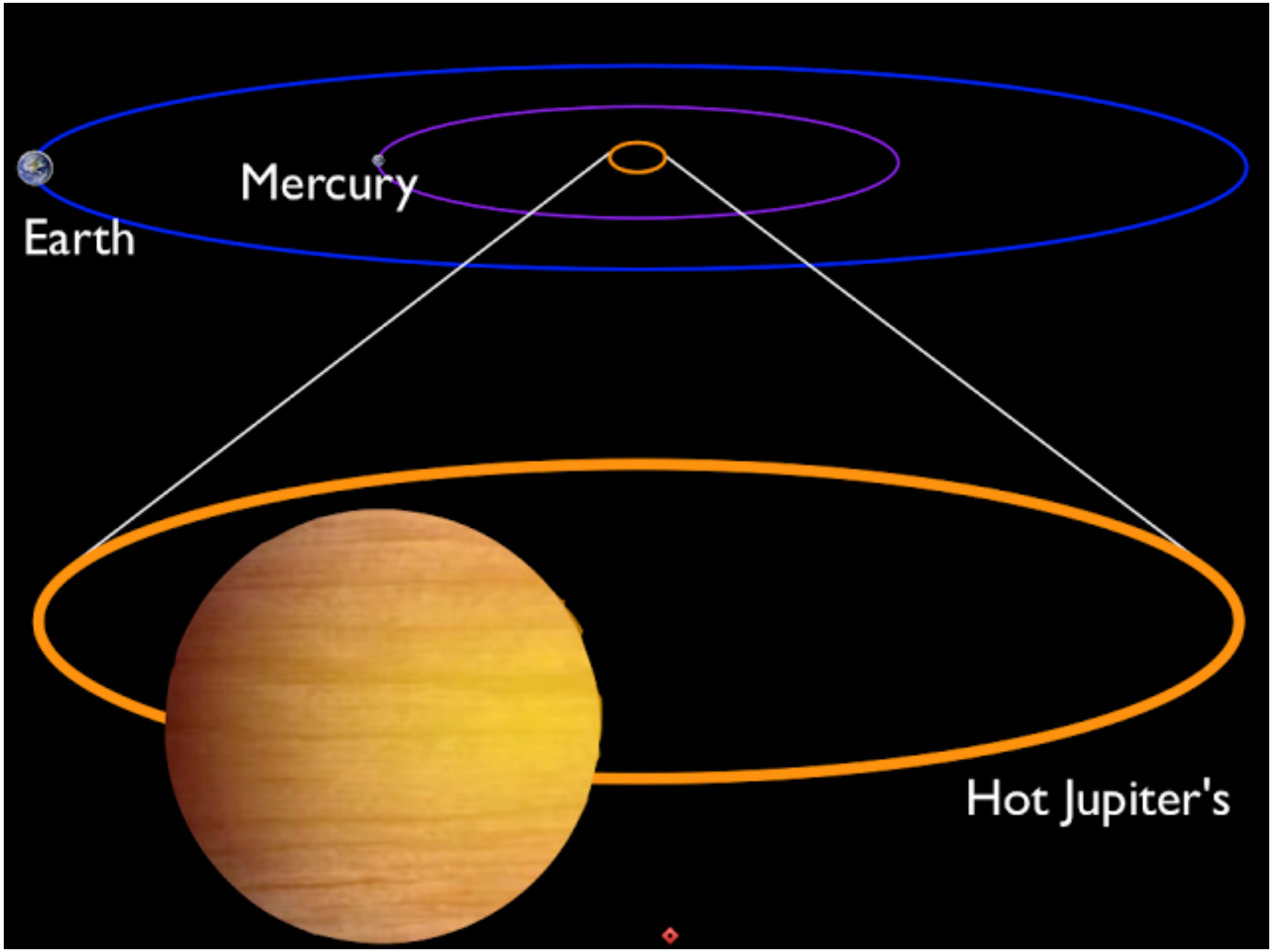
A bit of history…

- How do we get the orbit of the object?

- How do we get the mass of the object?

➢ A bit of history…

- Minimum mass of 0.5 mass of Jupiter orbiting at 0.05 au of the star…
- Strongly irradiated by the star: **Hot Jupiter**



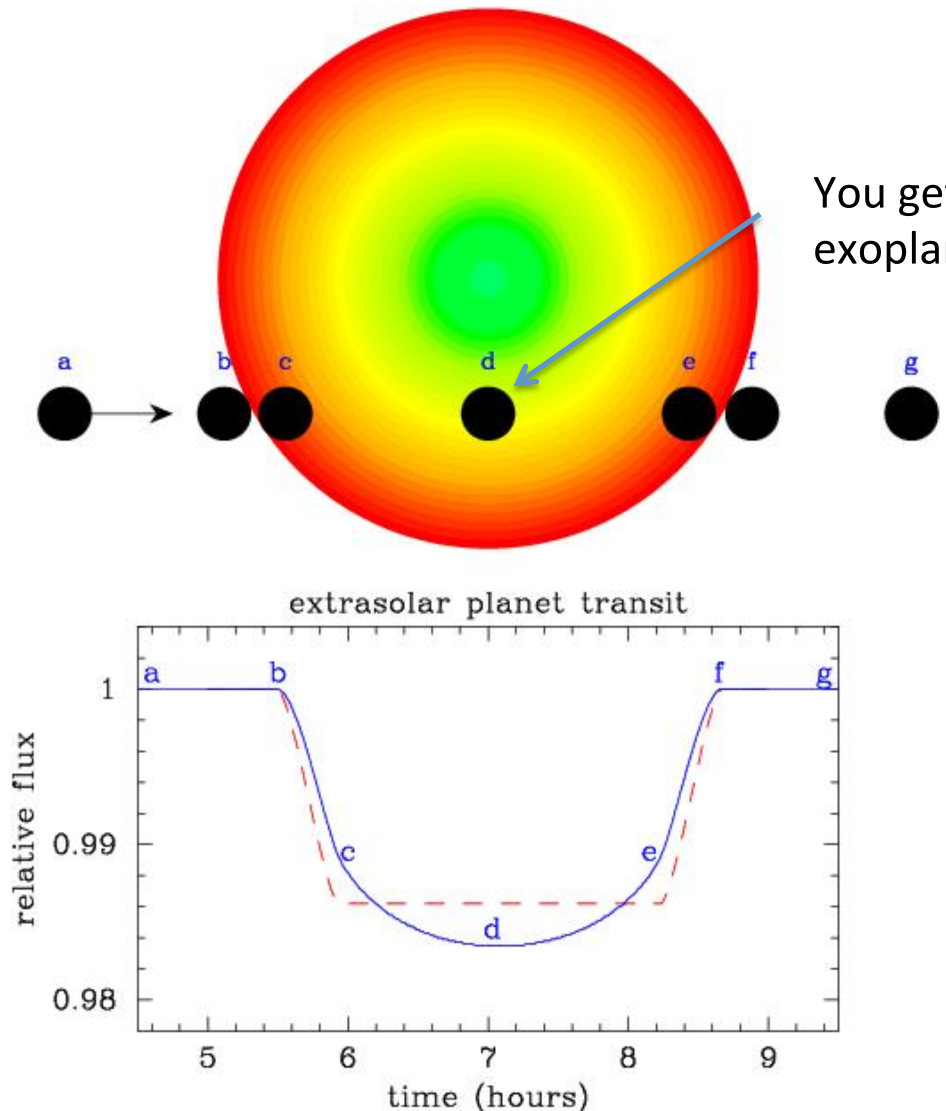
A bit of history…

- Nobody has ever predicted this kind of planets to exist: a huge part of the astrophysics community (and the press) was not ready to accept this detection:

  - Instrumental error? (the signal around 51 peg was immediatly confirmed by competitors, Marcy's group)
  - Astrophysical artifact? E.g. from the atmosphere of the star? star spots ?
  - A binary star?

➢ A bit of history… part 2

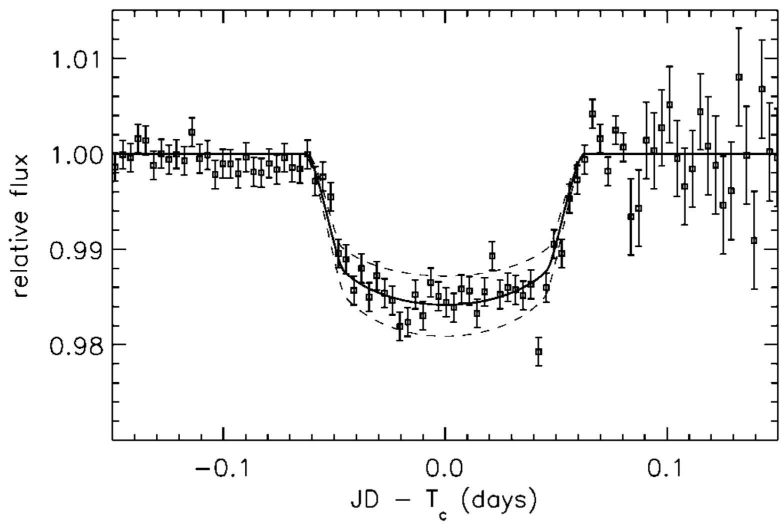
- Astronmers have imagined a second undirect detection technique: the transit method



You get the radius of the exoplanet

➢ A bit of history… part 2

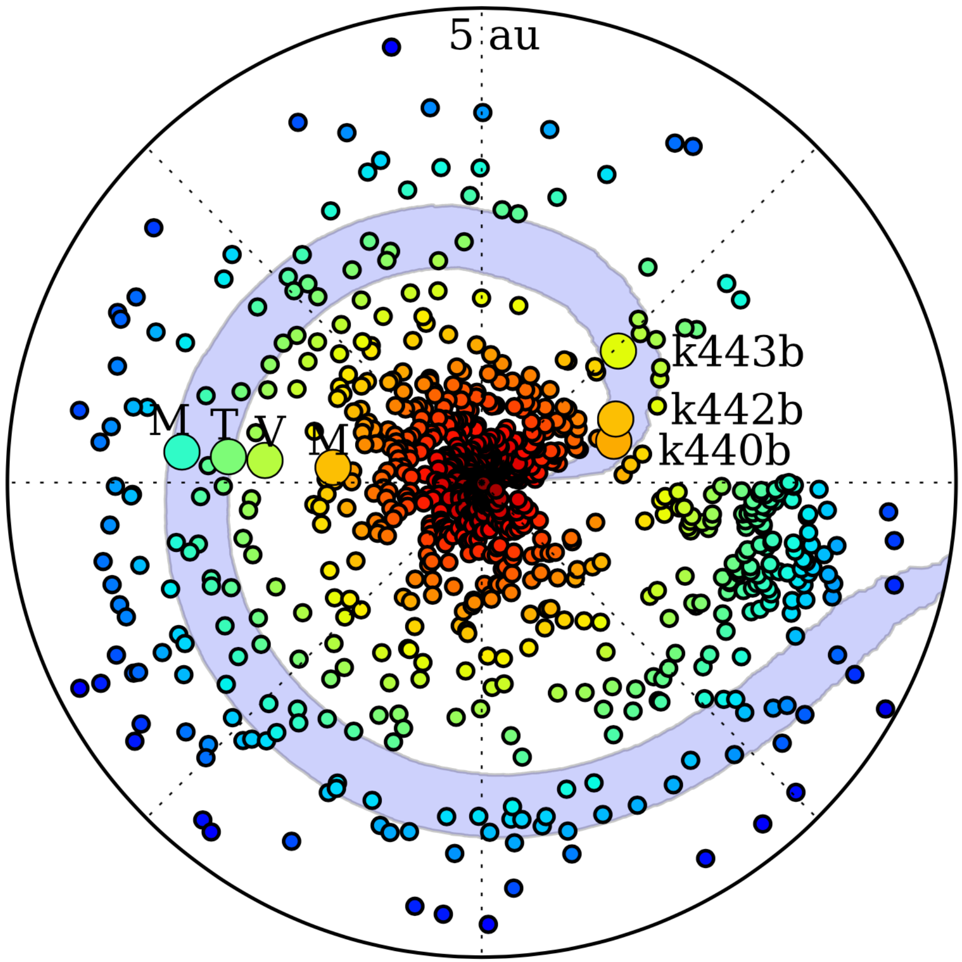
– Astronomers had to wait until 1999 for the first detection by this method, a 0.7 Jupiter-mass hot jupiter called HD209458b



– Finally confirming the existence of exoplanets !

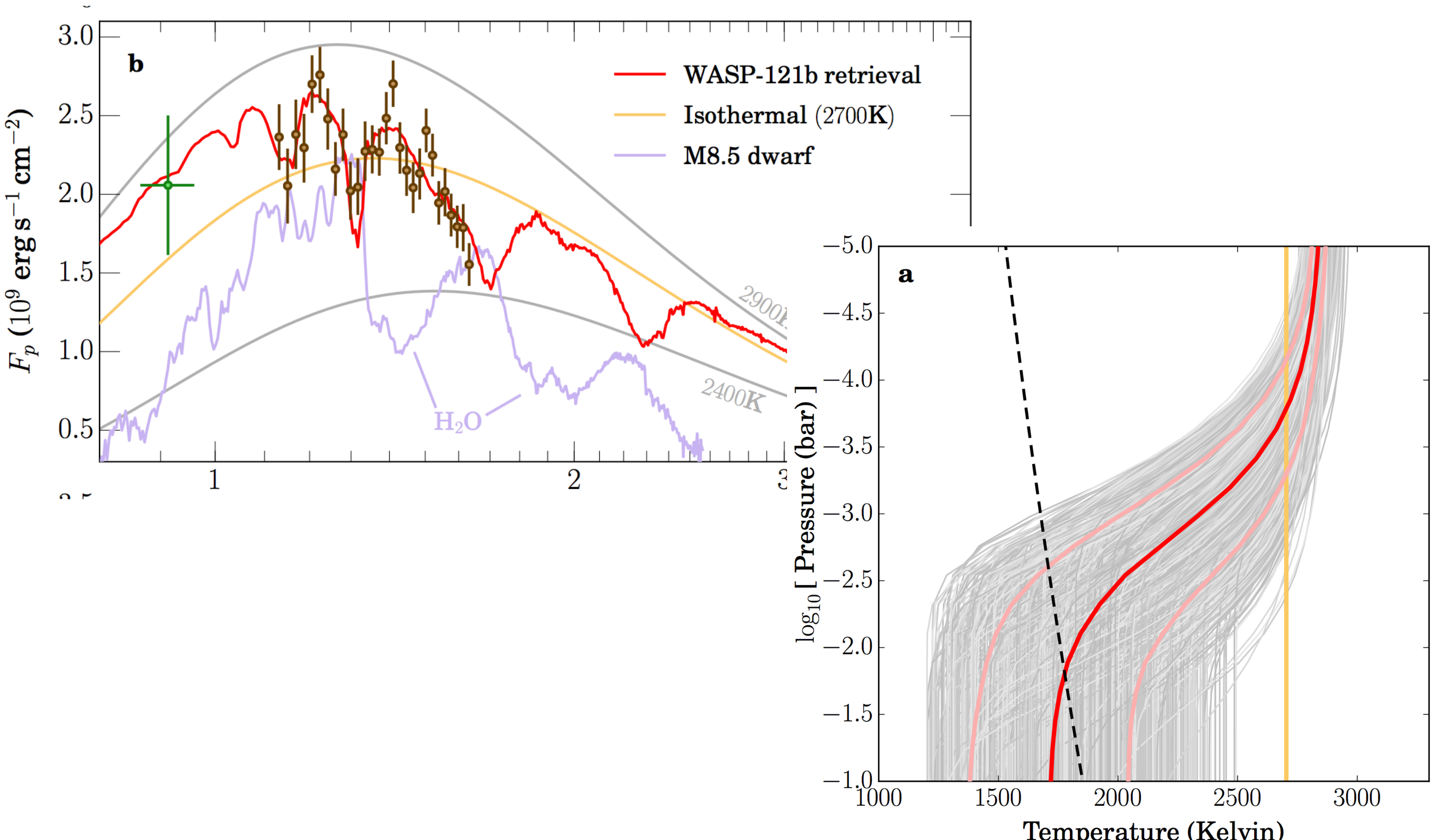
A bit of history… part 2

- Since then astronomers have observed up to **3500 exoplanets** with an important diversity in terms of mass, radius, orbits, etc… with a few rocky planets in the habitable zone of their parent stars:



➢ Characterization of the atmospheres

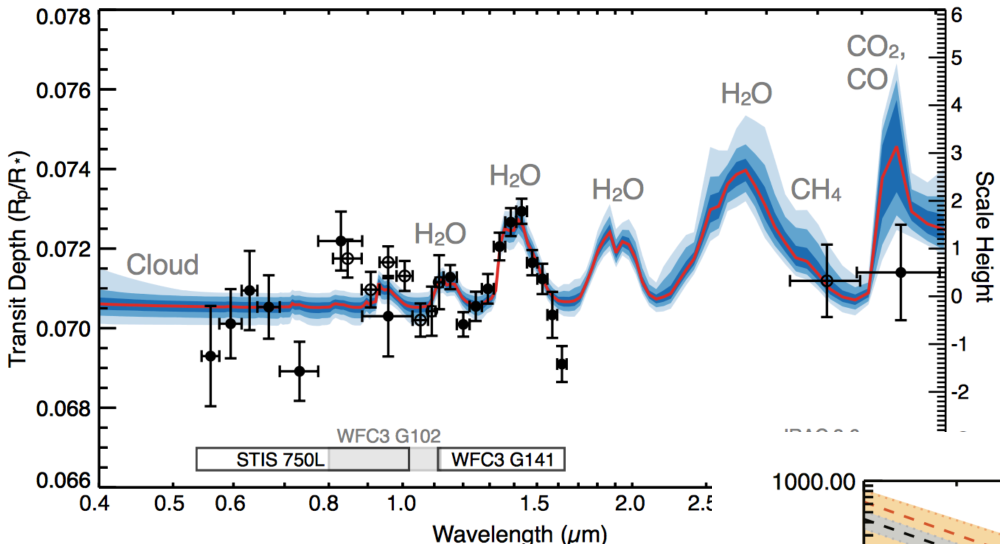
- Use 1D model to get the abundances of molecules in Emission spectra
- Evans et al. 2017 (in press): detection of a stratosphere in a hot Jupiter

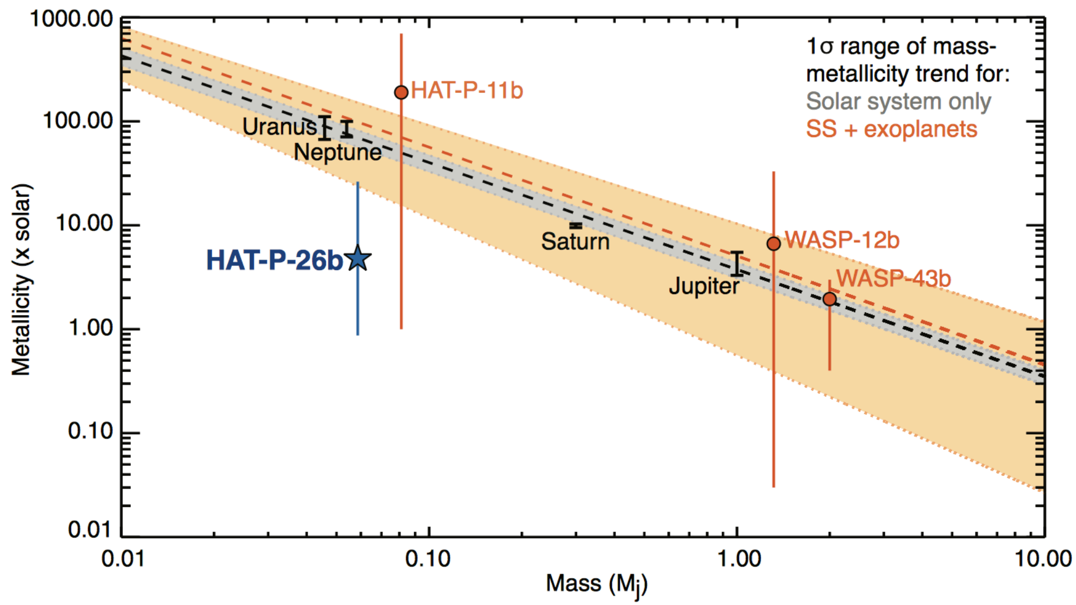


➢ Characterization of molecular abundances

– Use 1D model to get the abundances of molecules in transmission spectra

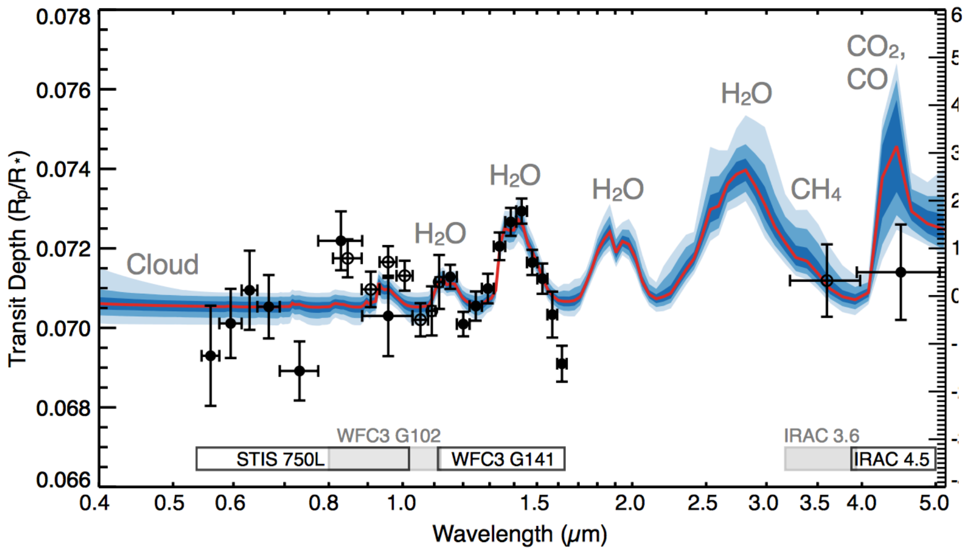
– Wakeford et al. 2017: low-metallicity hot neptune





Characterization of molecular abundances

– Huge breakthrough thanks to JWST upcoming observations !



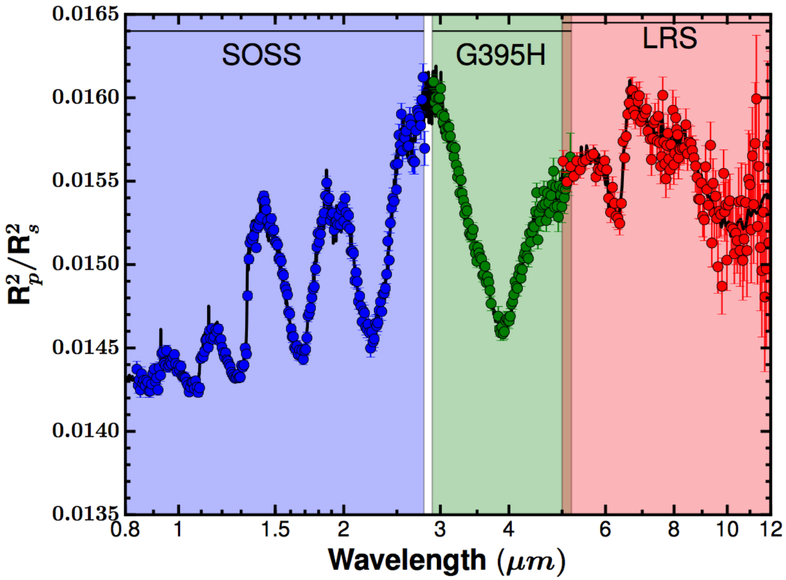


Figure 27. Figure showing ATMO best fit model transmission spectra (transit depth) for WASP-17b simulated with PandExo for JWST observations. Shaded regions indicate different JWST instrument modes, red shaded region indicates NIRISS SOSS mode, blue indicates NIRSpec G395H mode and green indicates MIRI LRS mode

Exoplanet atmospheres

	Description	Date	People in charge	Deliveries
1	Benchmarking of atmospheric exoplanet models	2016	P. Tremblin . P-O. Lagage + MIRI consortium exoplanet modeling group	1 paper (ApJ)
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Exoplanet atmospheres

- We want to get the structure of the atmosphere:
  - The pressure profile
  - The temperature profile

- For that we need to solve the stationnary conservation laws:
  - The Hydrostatic balance
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dP/dz=rho g

Radiative Flux + Convective Flux = cst

- Radiative transfer

Need the gas/cloud opacity i.e. abundances

- Chemistry

Exoplanet atmospheres

- We want to get the structure of the atmosphere:
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  - The temperature profile

- Emission transmission spectra

- Atmospheric composition

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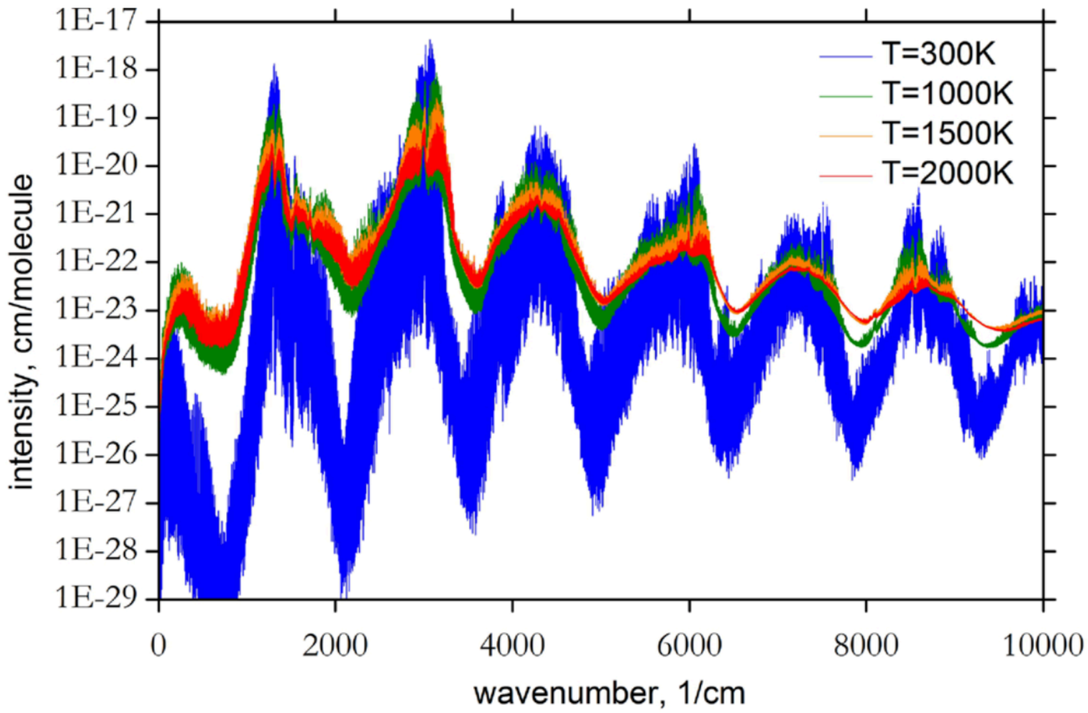
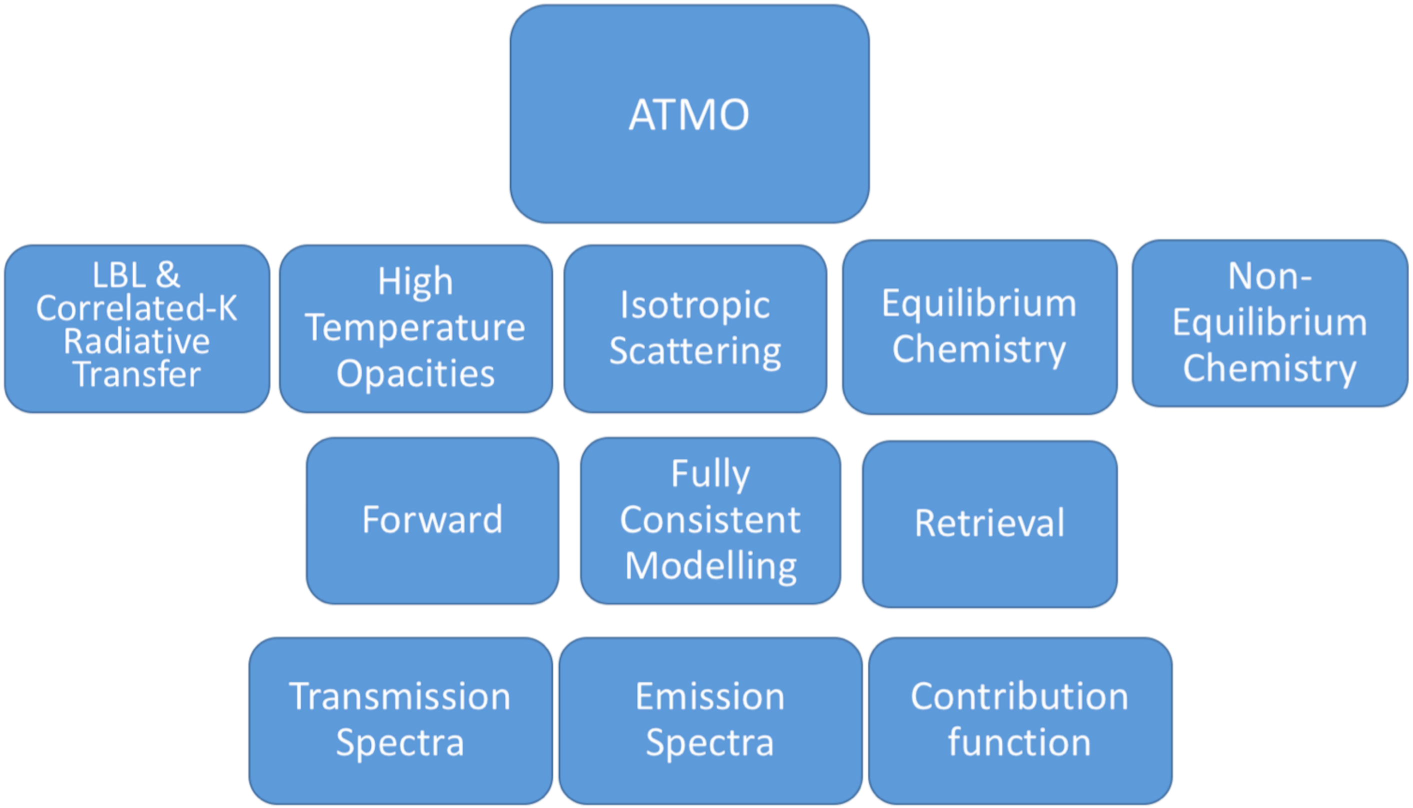
Exoplanet atmospheres

- Why is it complicated?



- Need sophisticated radiative transfer schemes (e.g. correlated K)

Exoplanet atmospheres



- Need a benchmark!

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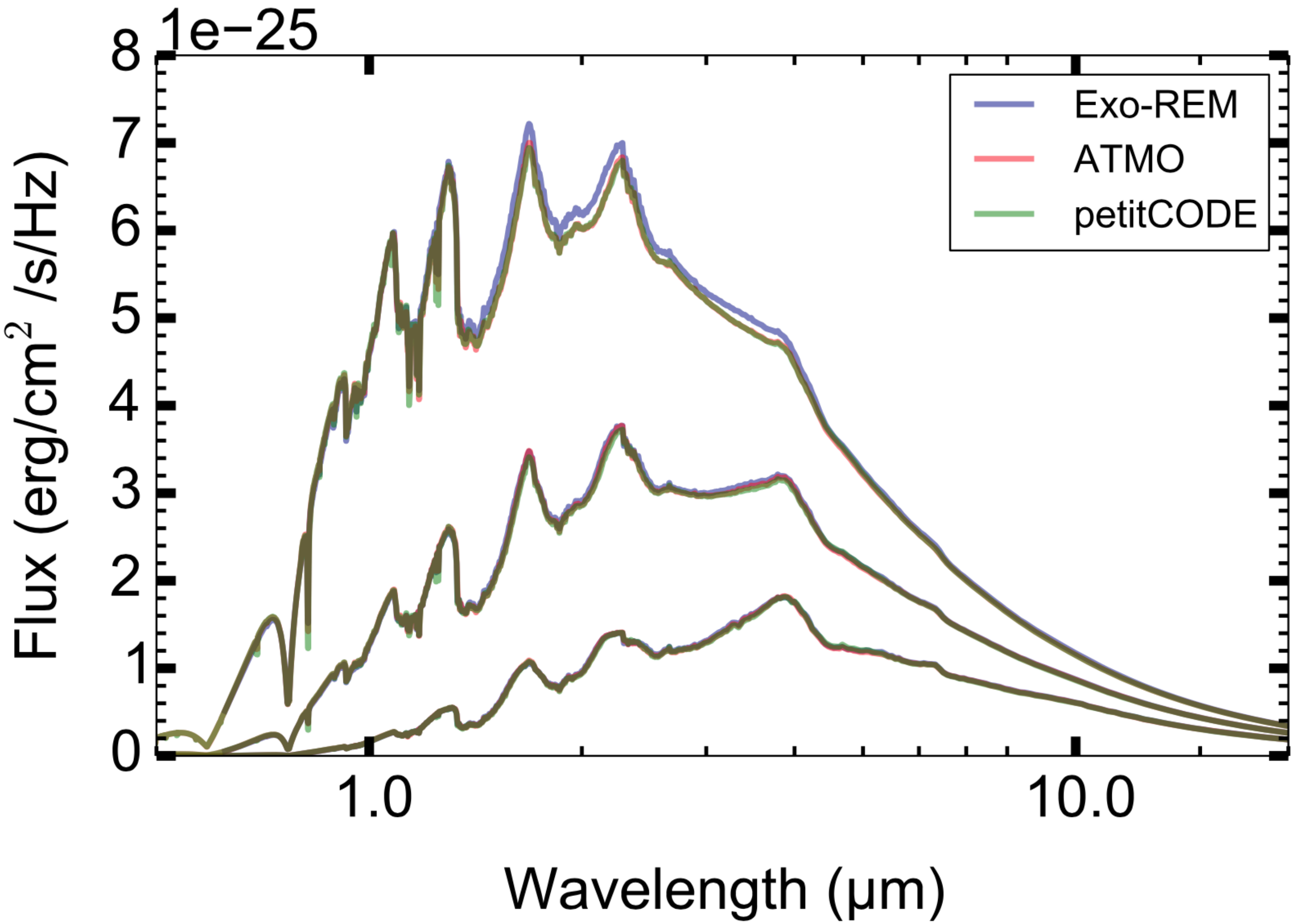
TOWARD THE ANALYSIS OF JWST EXOPLANET SPECTRA: BENCHMARKING ATMOSPHERIC MODELS

Jean-Loup Baudino,[1,2,3] Paul Mollière,[4] Olivia Venot,[5,6] Pascal Tremblin,[7,8]
Bruno Bézard,[9] and Pierre-Olivier Lagage[1,2]

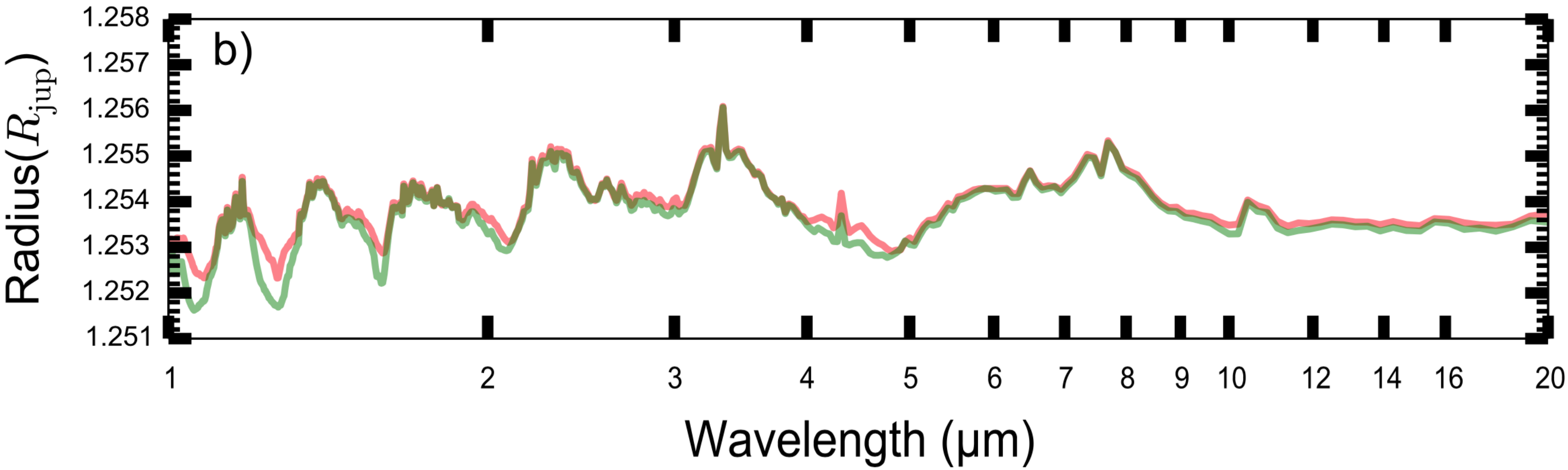
Submitted to ApJ

Abstract

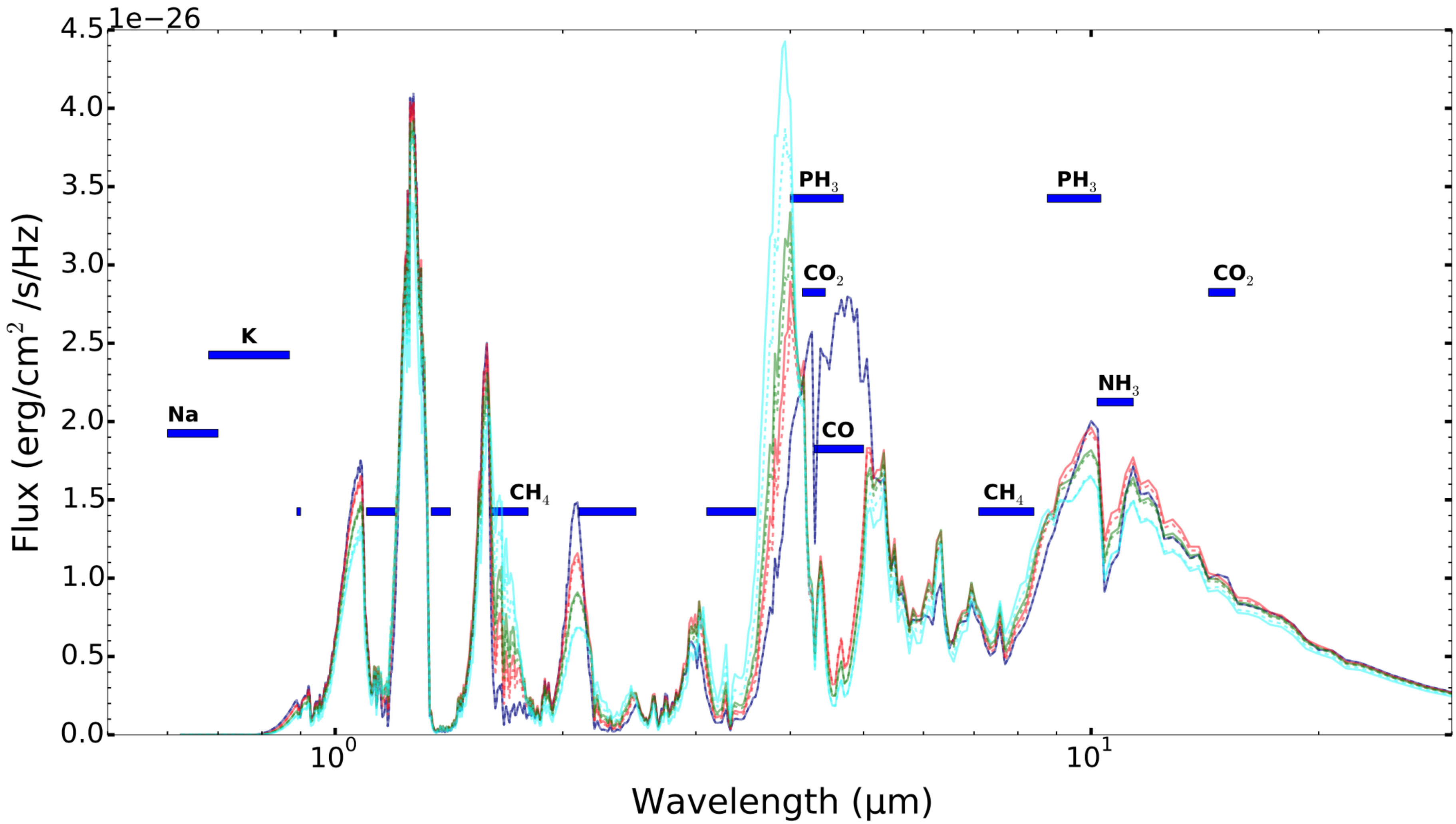
Given the forthcoming launch of the James Webb Space Telescope (JWST) which will allow observing exoplanet atmospheres with unprecedented signal-over-noise ratio, spectral coverage and spatial resolution, the uncertainties in the atmosphere modelling used to interpret the data need to be assessed. To do so, we compare three 1D models developed independently : *ATMO*, *Exo-REM* and *petitCODE*. We define a benchmark protocol. We show that it is mandatory to use the most up-to-date molecular linelists to compute the opacity of the atmosphere. We also show the limitation in the precision of the models due to uncertainties on the way to deal with the alkali and molecule far wing lineshapes. We compare two chemical models which do not lead to significant differences in the emission or transmission spectra. We discuss the observational consequences of using equilibrium or out-of-equilibrium chemistry. Each of the models has benefited from the benchmarking activity and has been updated. The protocol developed in this paper and the online results can constitute a test case for other models.



- Obtain a good agreement… after we converge on:
  - Input parameters (elementary abundances, molecular species, …)
  - Modeling issues (def. of the planet radius, def of the mean molecular weight, …)



- But still some differences:
  - Importance of up-to-date opacity linelists



- But still some differences:
  - Chemistry model
  - + other modeling uncertainties remaining (alkali lines, line shapes, etc)

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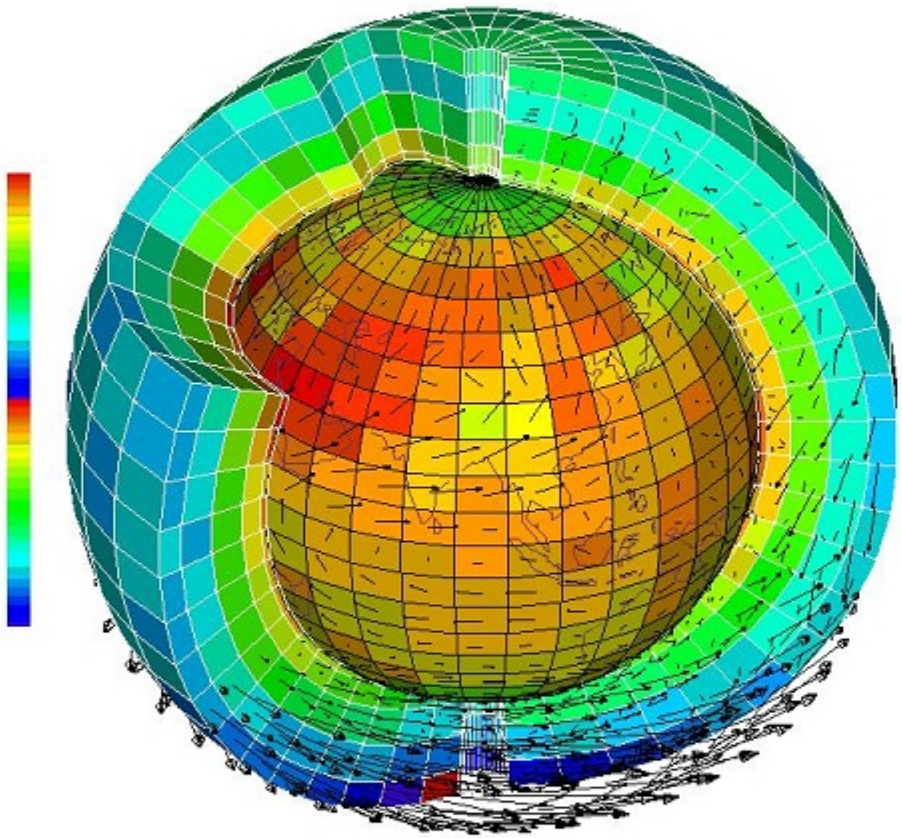

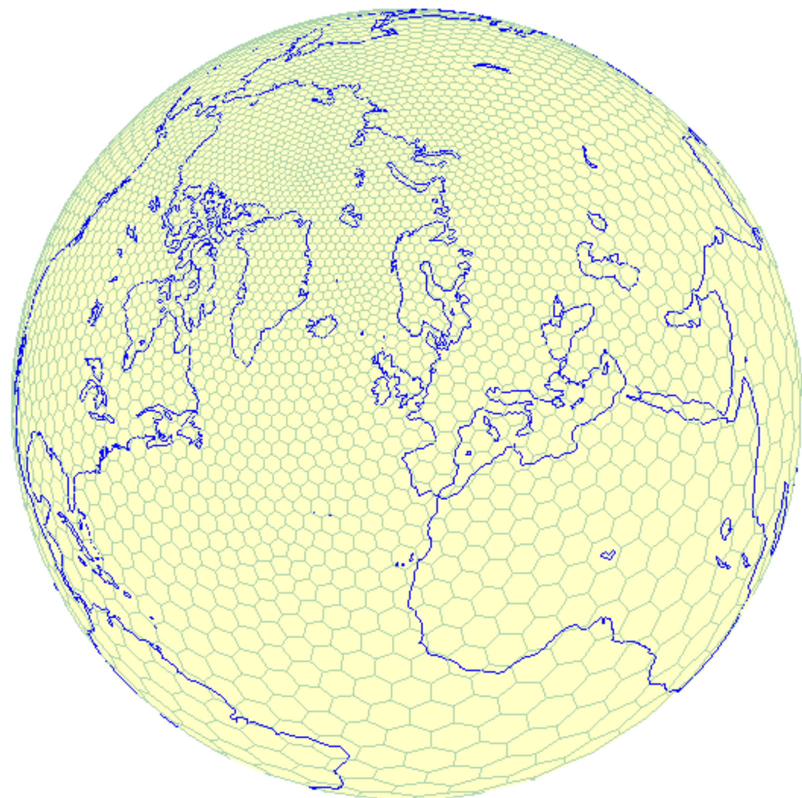

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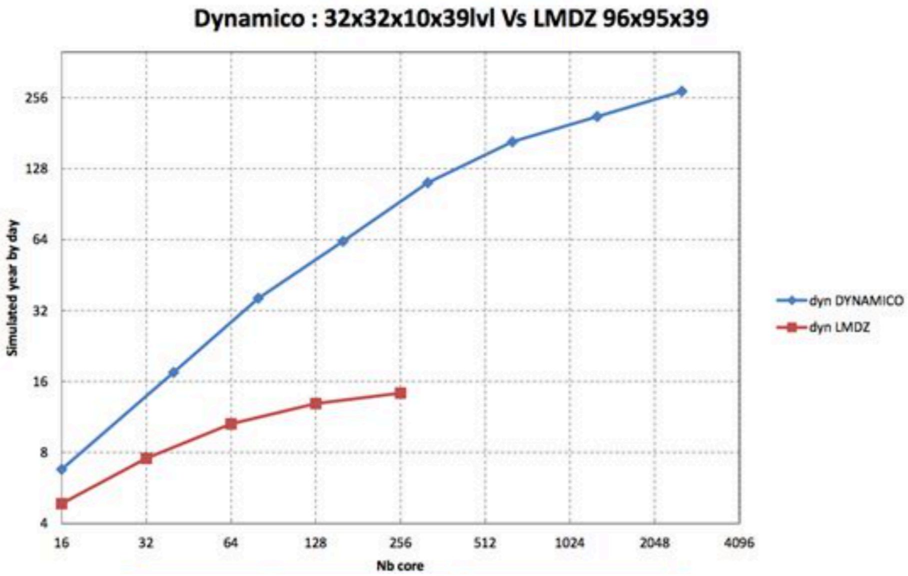
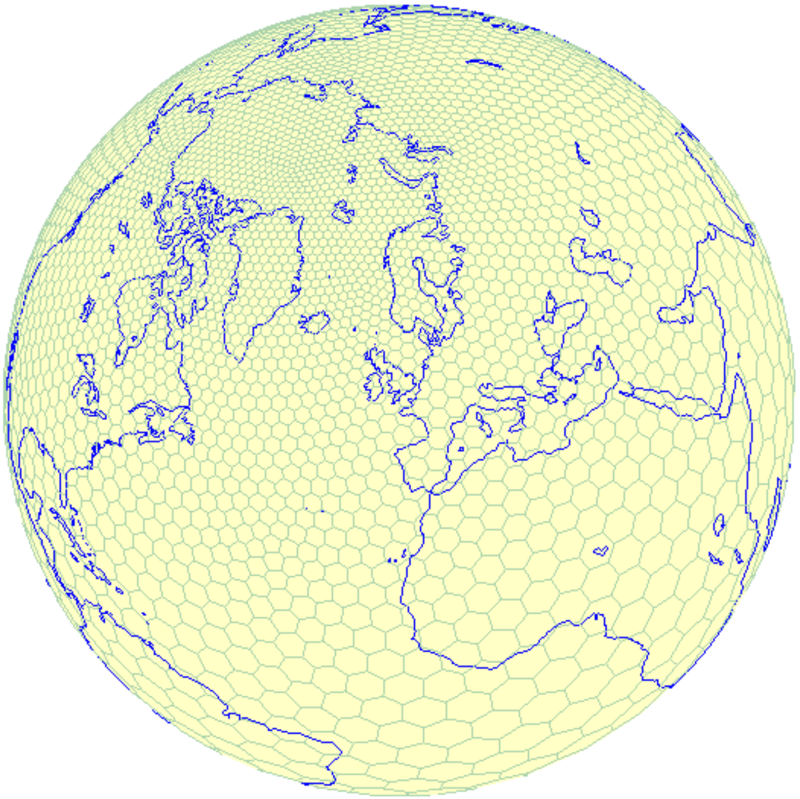
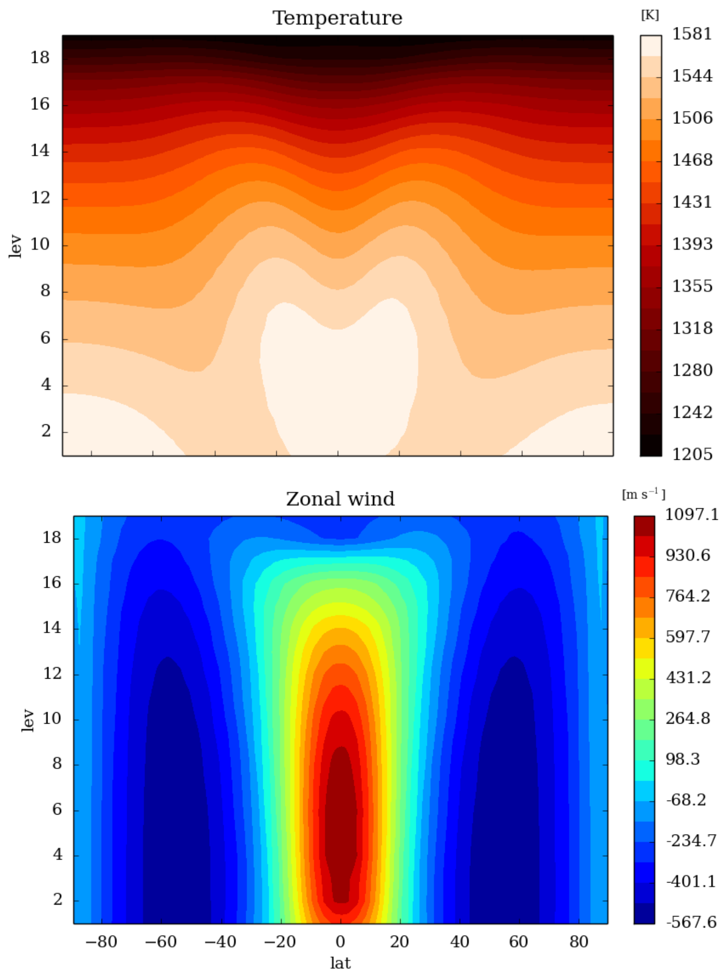




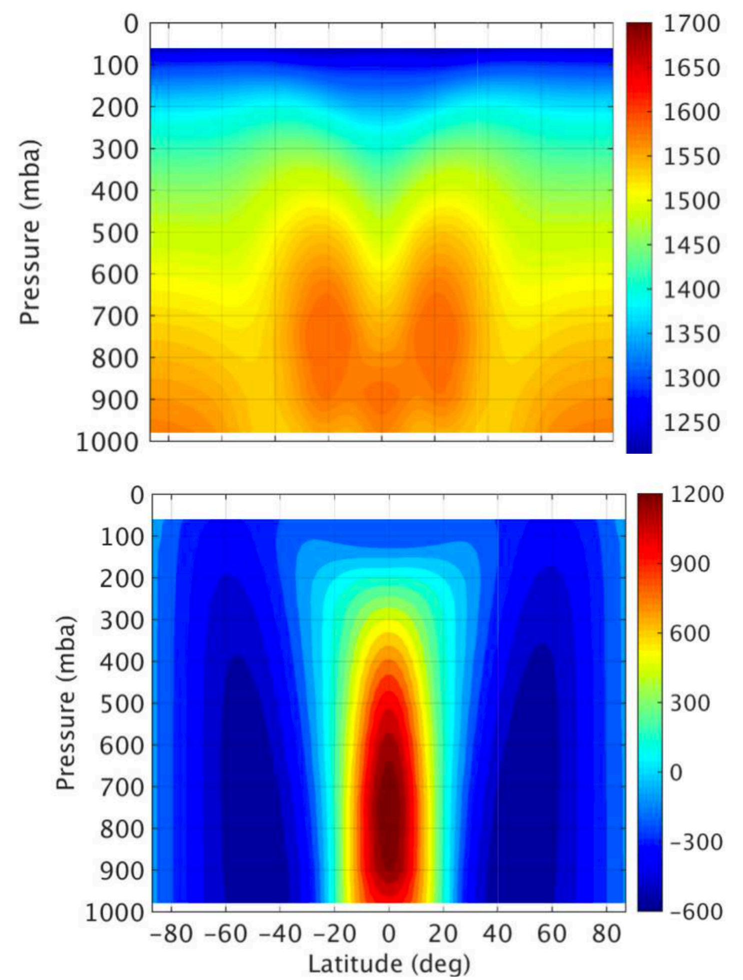
Exoplanet atmospheres

- Adaptation to Hot jupiters: S. Fromang

Shallow hot jupiter DYNAMICO model



(comparison to Mendonça et al. 2016)



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