Modelling the Atmosphere of Hot Jupiter-like Exoplanets using a Global Climate Model

Rencontre Jeunes Physicien.ne.s
2 Novembre 2022

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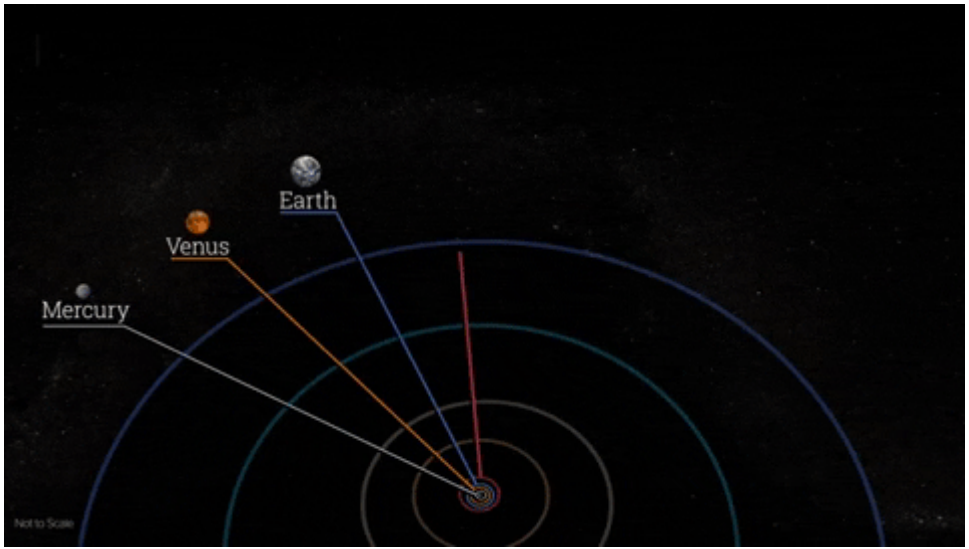
Outline

- ➔ Context: Planetary atmospheres.
- ➔ Context: Exoplanets and Hot Jupiters.
- ➔ Observation: How and what do we see ?
- ➔ Model: *Generic PCM*
- ➔ Upgrades: Effects of clouds on observables
- ➔ Take Home Messages

Context: Planetary Atmospheres of the Solar System

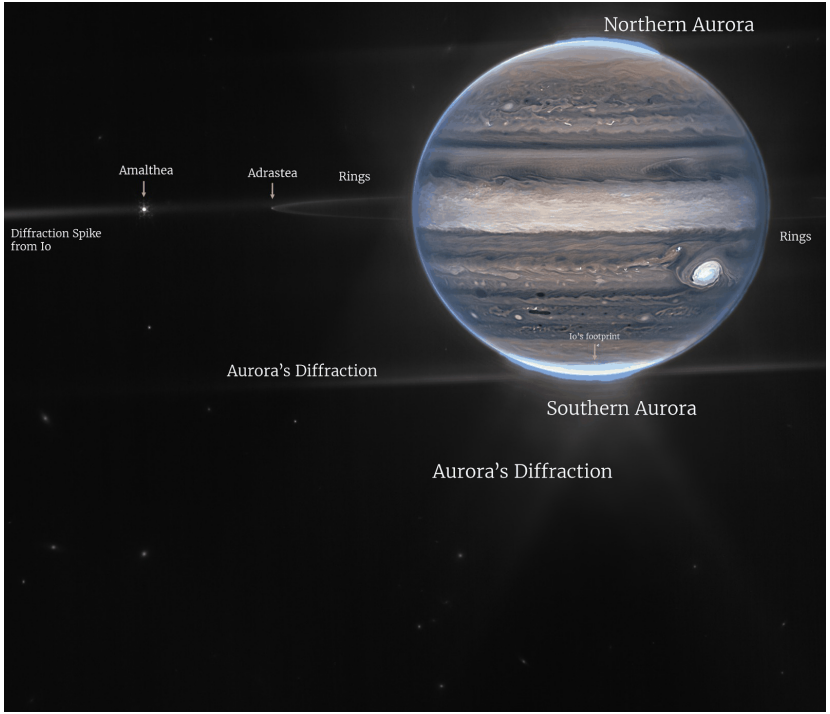
- ➔ 8 planets in our Solar System.
- ➔ 4 rocky planets close to the Sun.
- ➔ 4 gaseous planets orbiting outward.
- ➔ Only Mercury (closest to the Sun) doesn't have an atmosphere.
- ➔ Gaseous planets are **big** ! Jupiter is ~ 11x larger than Earth, ~ 400 time more massive.
- ➔ Jupiter is mainly made of H and He.



Credis: Nasa website

Context: Focus on Jupiter's atmosphere

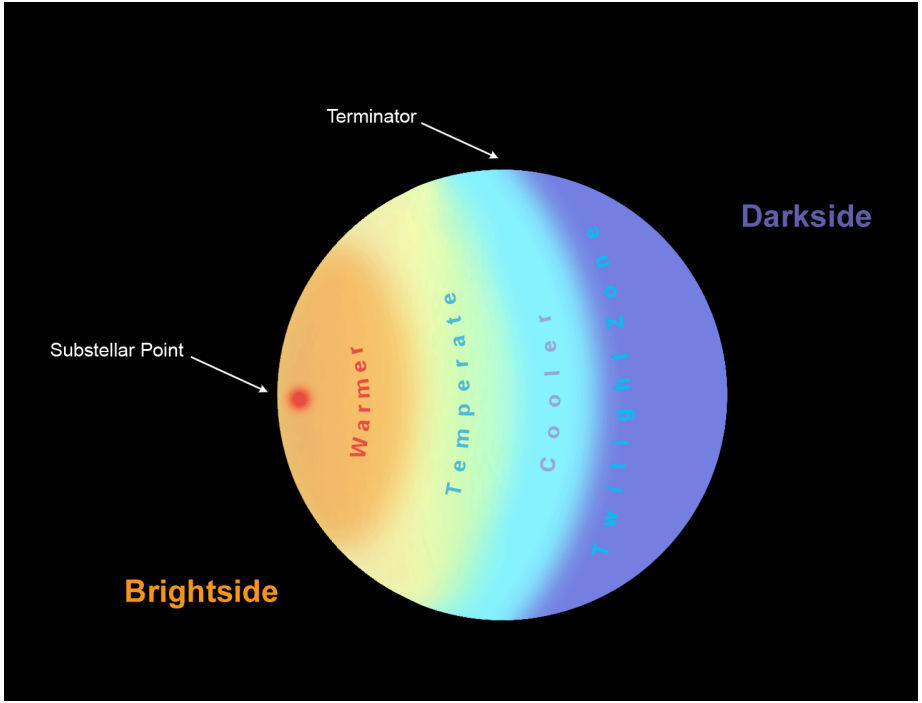
- ➔ Distance to the Sun: 5 AU.
- ➔ Orbital period: ~ 11 years.
- ➔ Composition: H2 and He, with NH3, H2O and NH4HS clouds, CH4.
- ➔ Banded large-scale atmospheric structure (jets).
- ➔ Spots indicative of storms and and eddies.
- ➔ Cold planet: **T ~ 160 K.**



Picture from JWST, and JUNO mission.

Exoplanets: Hot Jupiters

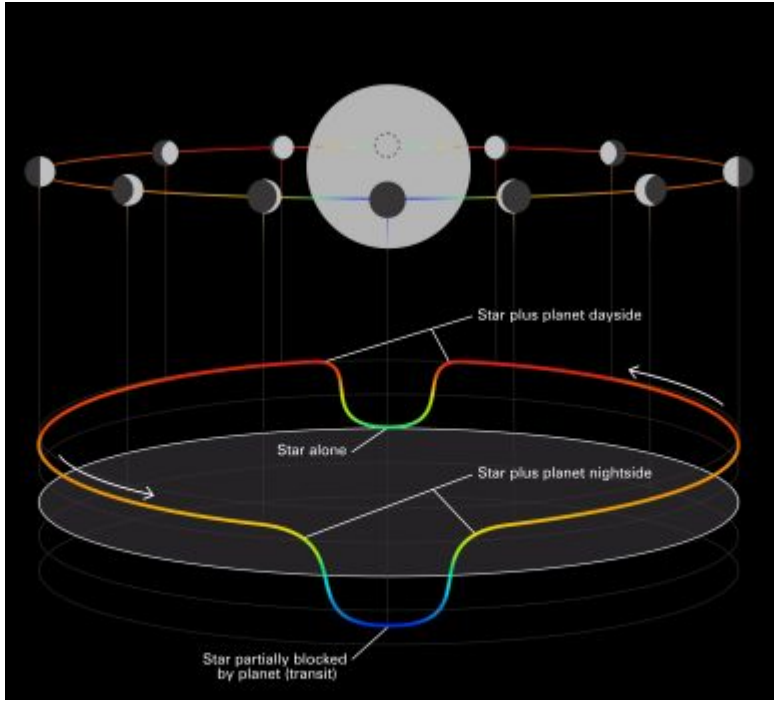
- ➔ Planet as massive and big as Jupiter, but **300x closer** to the host star.
- ➔ Hot planets: T ~ **1000-4500 K**
- ➔ Tidally locked on circular orbit,
- ➔ They don't exist on our Solar System.
- ➔ Very common in our galaxy: more than **1500 Hot Jupiter detected** !
- ➔ How does a planet that big got so close to its host(s) star(s) ?



Credits: http://backalleyastronomy.blogspot.com/2016/04/daydream-destinations-part-2.html

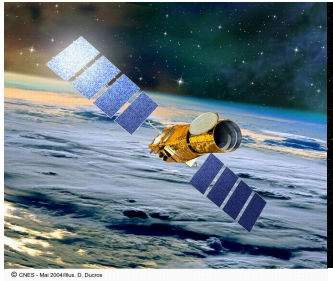
Observation: How and what do we see ?

- We need space-based telescope (but some ground-based can work.)
- We point the telescope at the star, and wait for the planet to pass in front of it.
- We measure a whole orbit.
- Allows to derive the radius of the planet, the dayside flux and some informations about temperature, chemistry, cloud formation etc..

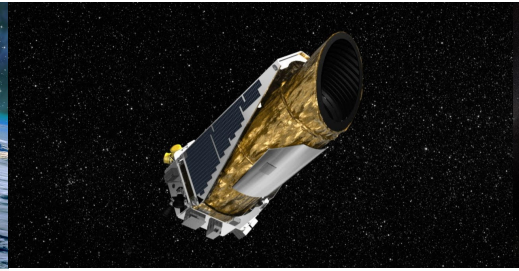


Credits: ESA website

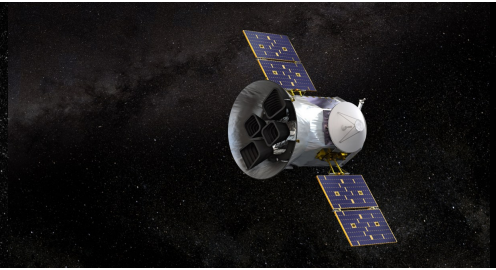
Observation: Few past and current missions



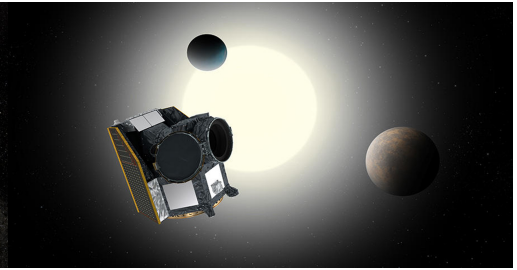
COROT (2007-2014)



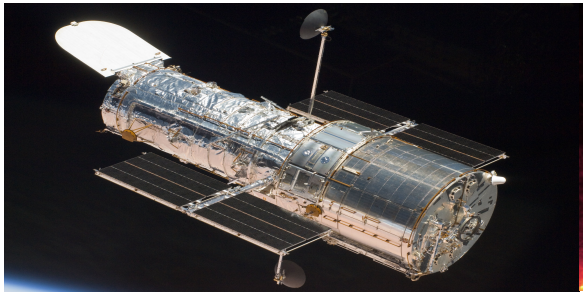
Kepler (2009-2018)



TESS (2018-)

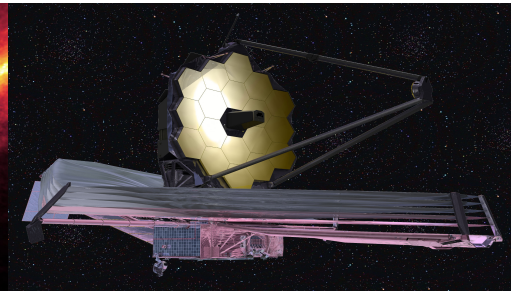


CHEOPS (2020-)



Hubble Space Telescope

Spitzer Space Telescope



James Webb Space Telescope

The Generic Planetary Climate Model (PCM)

- **Generic Planetary Climate Model:** 3D model aiming to simulate the atmosphere of planets. Originally developed for **Earth** and **IPCC reports**.
- Computes the temporal evolution of variables controlling the atmospheric evolution of planets.
- **Dynamical core:** solves the primitive hydrostatic equations of meteorology.
- **Physical package:** Physical model computing difference phenomenon, such as radiative transfer,...
- **My thesis:** Hot Jupiter-like exoplanets and Brown Dwarf 3D atmospheric modeling using the *Generic PCM.*

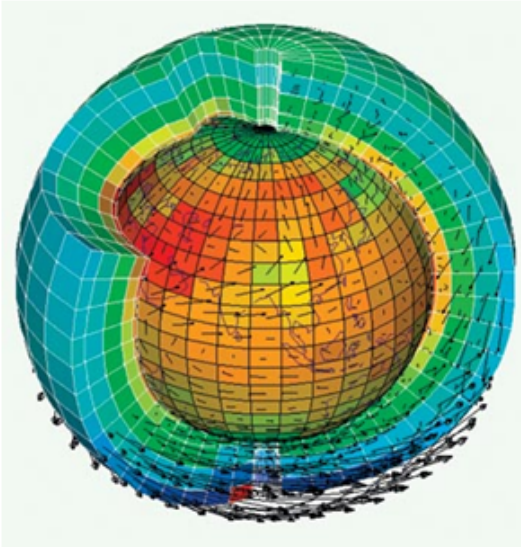
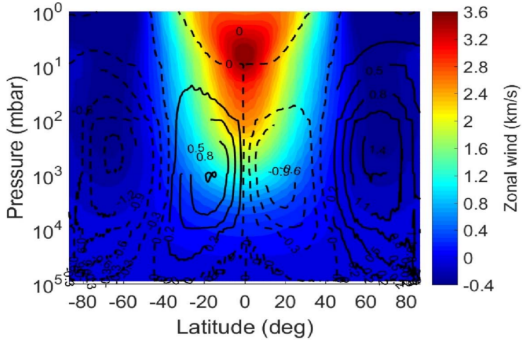
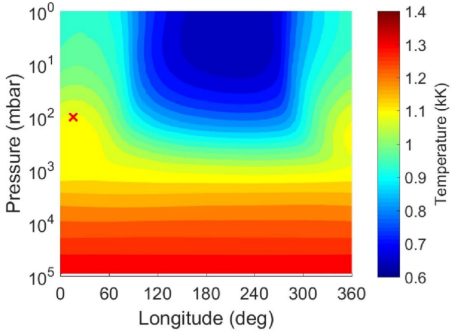


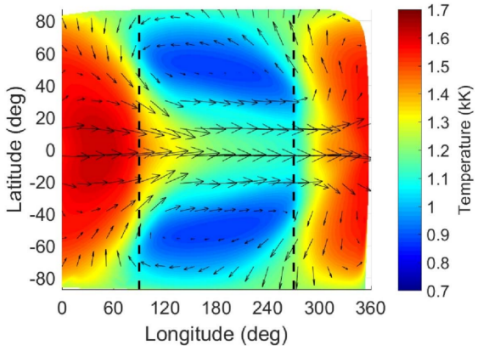
Illustration of the model's grid, showing the Dynamical and Physical grid.

Source: : https://orchidas.lsce.ipsl.fr/overview/lmdz.php

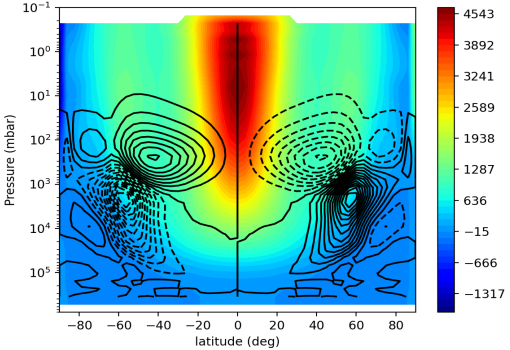
Results : Atmospheric Dynamics

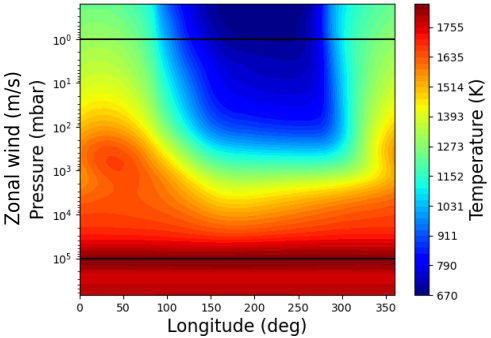


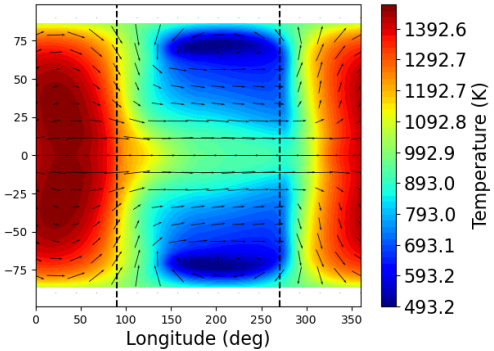




Mendonça et al, 2018







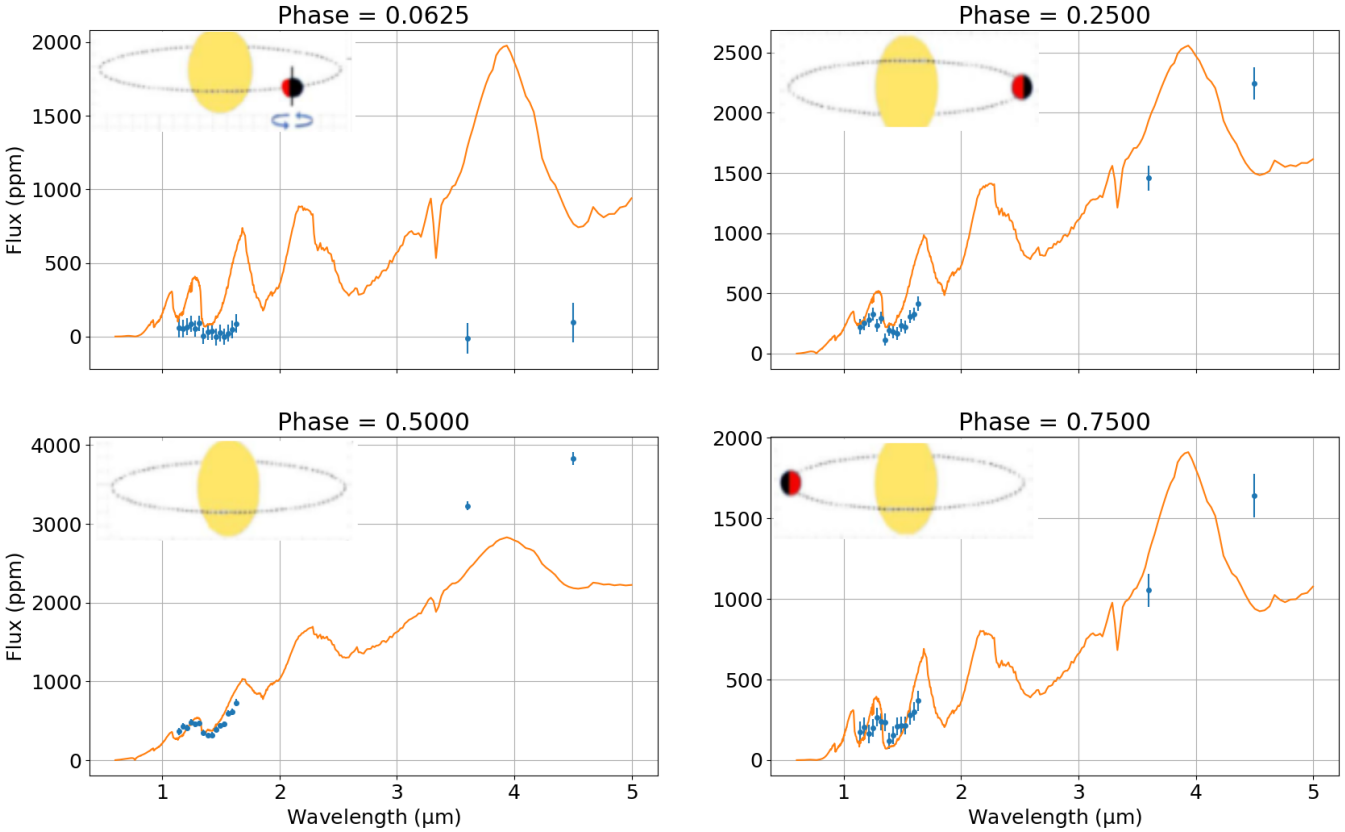
This work

Mean Zonal wind

Meridional mean of temperature

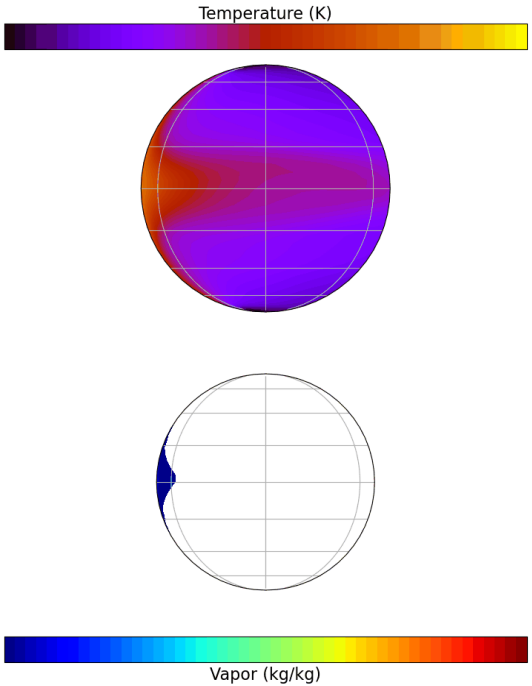
Temperature field at 10 mbars

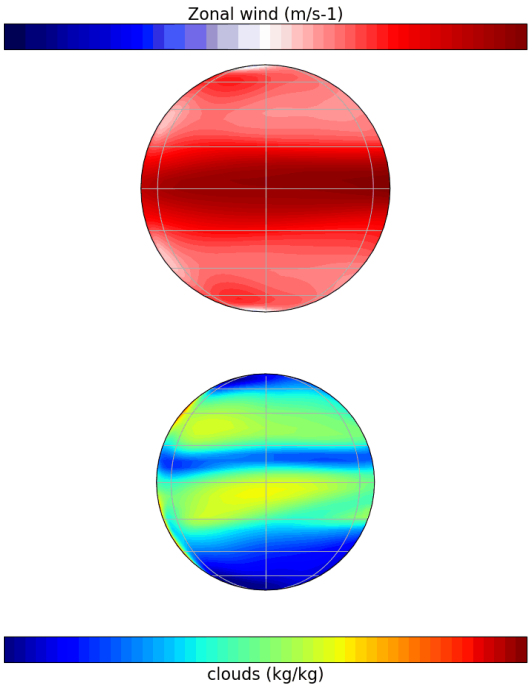
Results: Observables from space telescopes



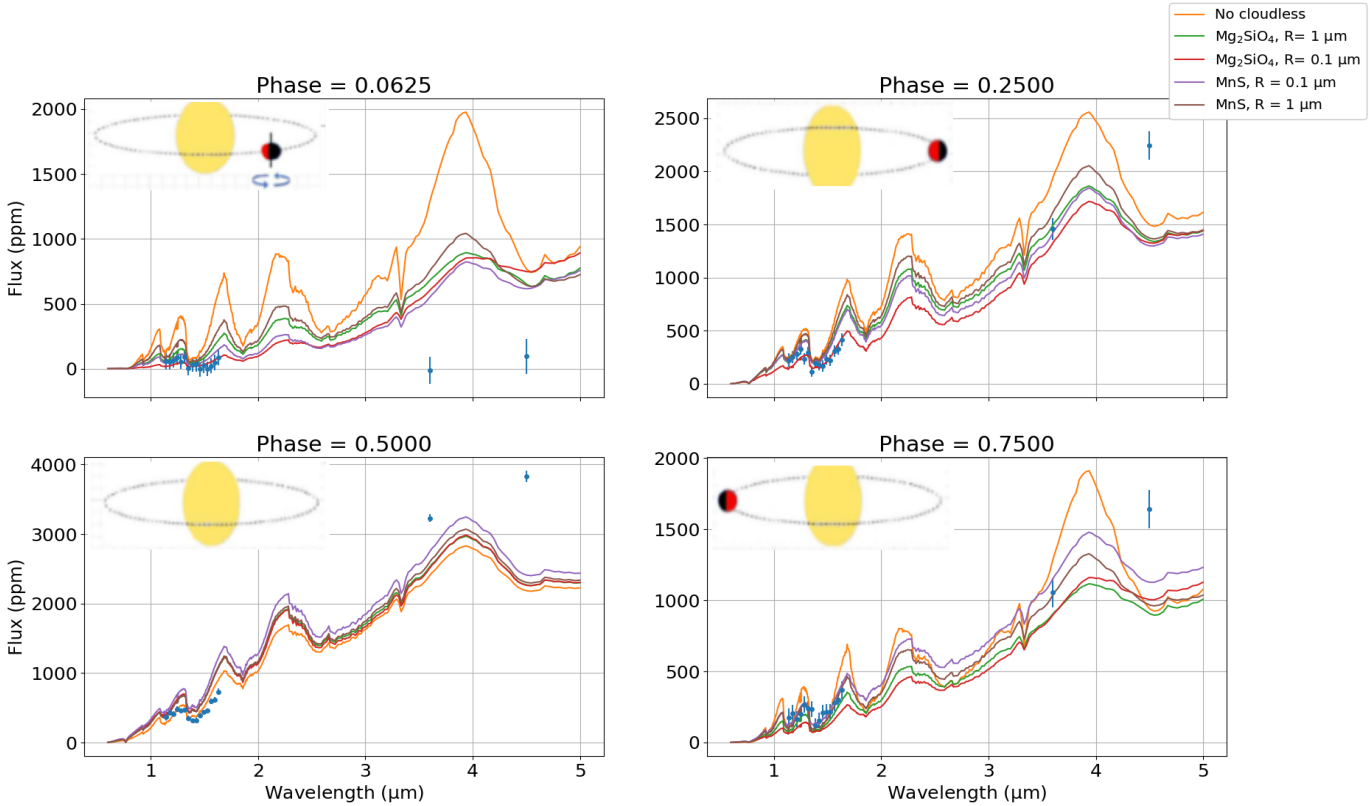
- → <u>1.1-1.7 microns:</u> HST WFC3 data.
- → <u>3.6 and 4.5 microns:</u> Spitzer Space Telescope.
- → Day-side (*lower left*) is well fitted but not night-side (*upper left*).
- → Quarter phase are intermediate (*right column*).
- → Seems like we're missing something here.

Results: Cloudy simulations





Results: Cloudy simulations



Clouds effects:

→ Only form on night-side (because colder temperature)

→ Suppress night-side emitted flux.

→ Create greenhouse effect that warms day-side.

→ More emitted flux on day-side.

Take home messages

- ➔ We have a model that allows **to accurately simulate the atmosphere of Hot Jupiter-like exoplanets.**
- ➔ We developed and coupled **a cloud model** to the *generic PCM.*
- ➔ Our cloudy simulations show better agreement with previous data.
- ➔ We're waiting for **JWST observations** (december 1st) to be able to confirm the cloudiness of these planets.