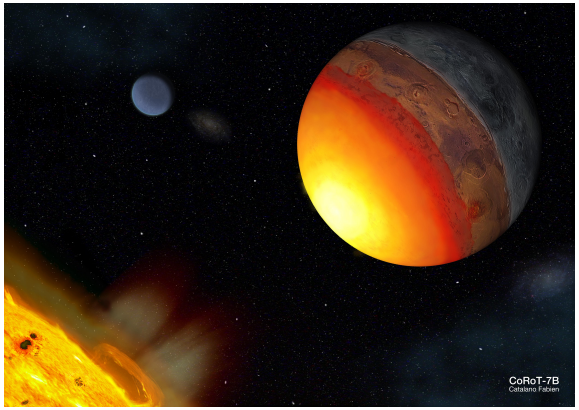
Exoplanets characterization

- *Radius vs Mass distribution*
  - *Spectroscopy w JWST of Hot Super-Earths*

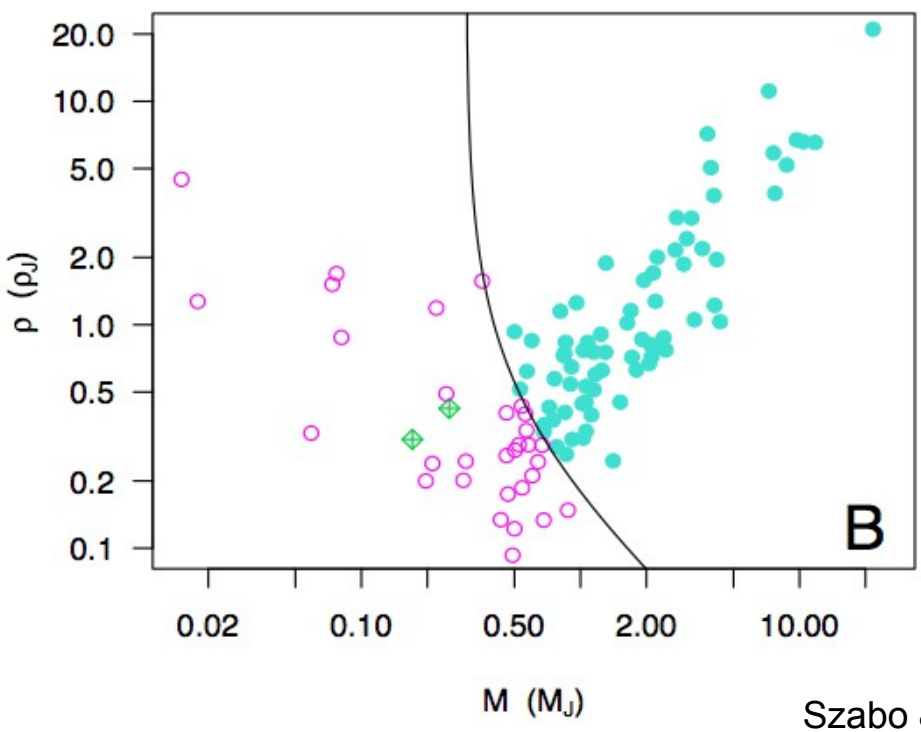
Daniel Rouan, LESIA Observatoire de Paris



Radius / Mass distribution

Density a key parameter

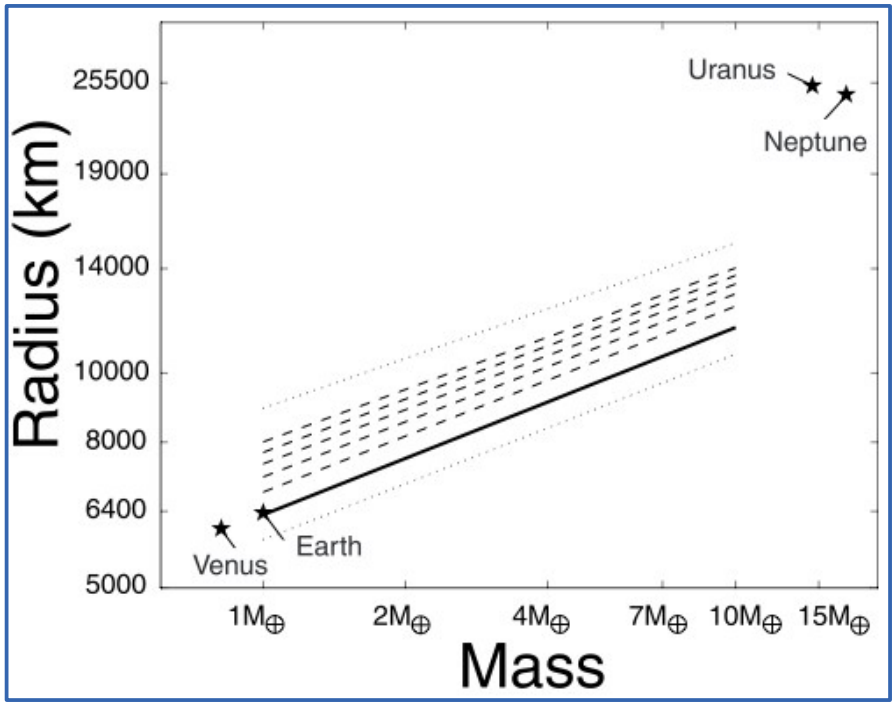
- The powerful coupling of transit detection and radial velocity measurement
  RV → MASS (without *sin* i ambiguity)
  Transit → RADIUS
  → DENSITY

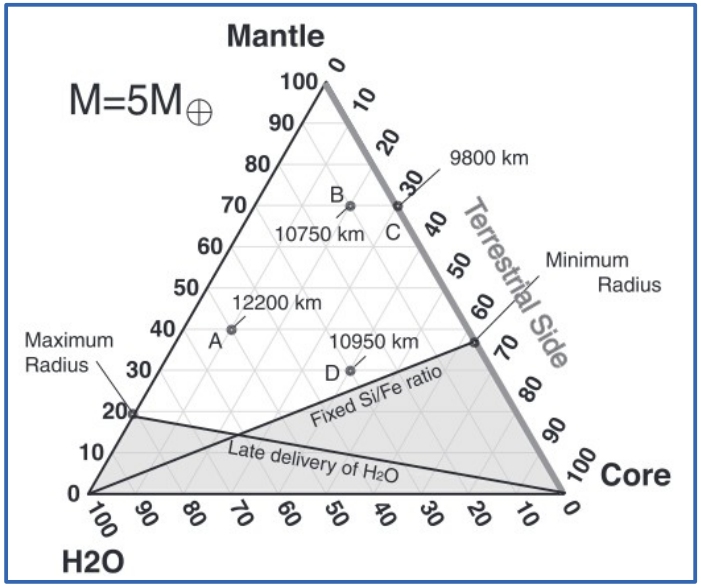


Szabo & Kiss 2013

Models of Super-Earths & Uranus

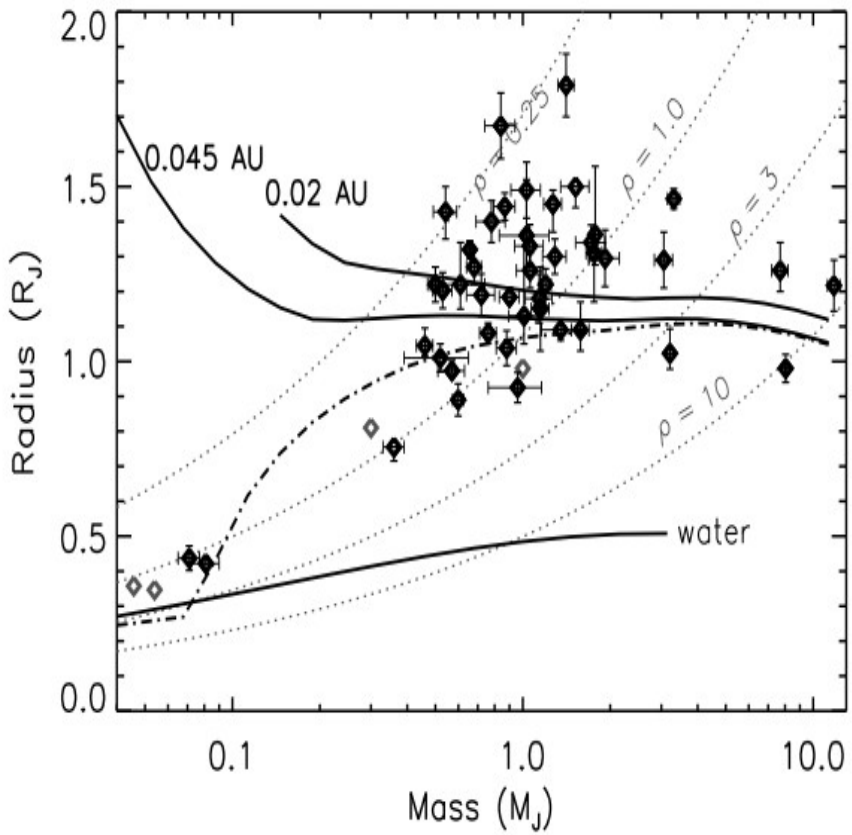
- Valencia 2007, 2010
  - Rocky super-earth : depends strongly on relative ratio between Core(Iron) - Mantle(Silicate) - Ice
  - In short : $R \propto M^{.25 - .33}$ polytropic solution for incompressible material

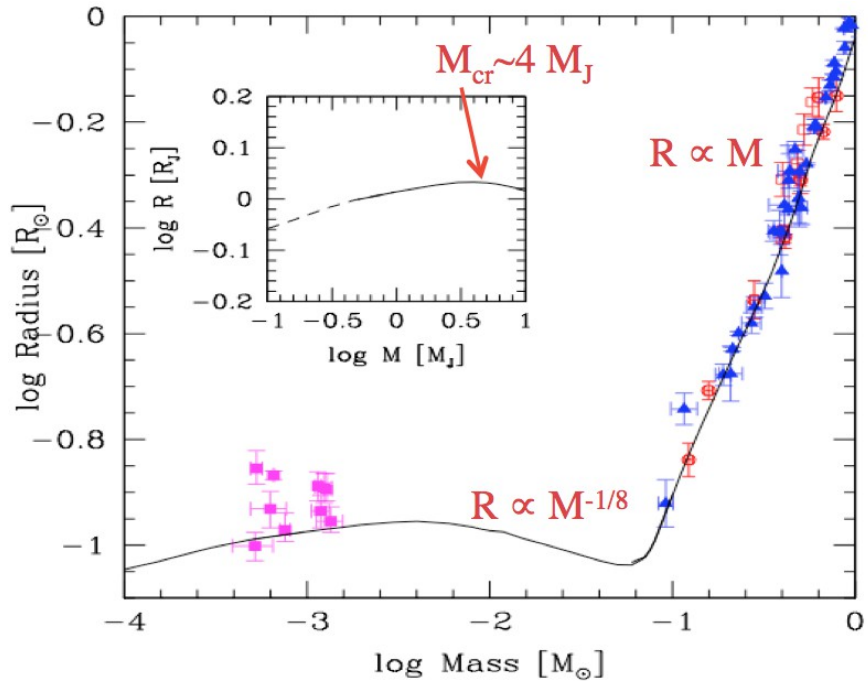




Models of Giant Planets structure

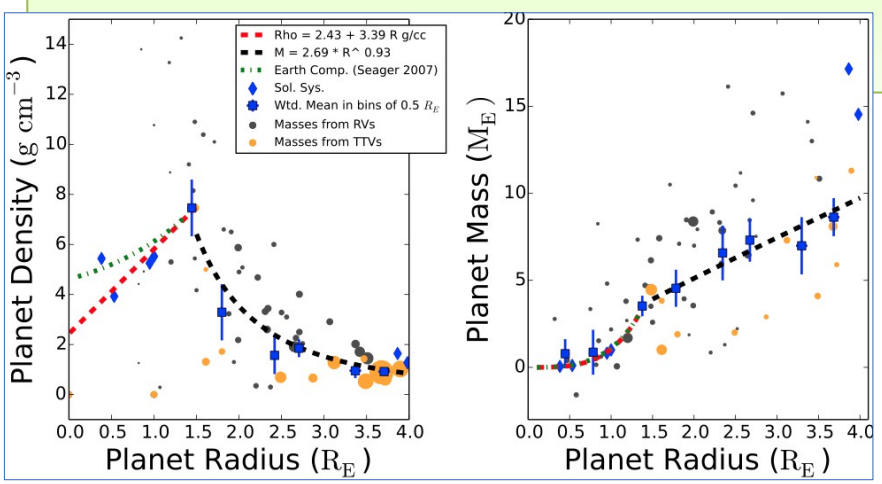
- Baraffe 2010, Fortney 2010
- In (very) short : R ∝ Cst in the range 0.2 – 10 M_{jup} : density is not a pertinent quantity
- Irradiation can change the radius by 10%



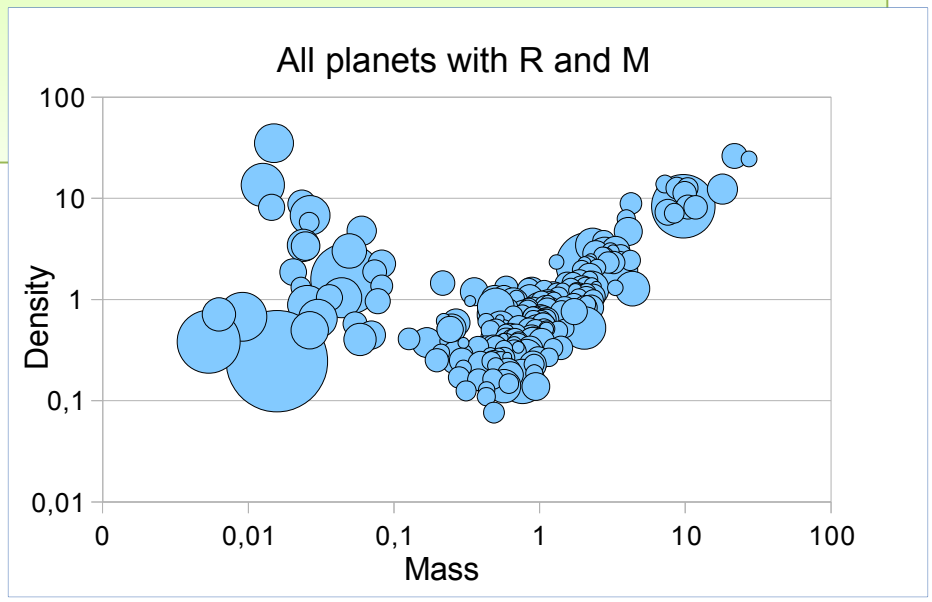


The selected sample

- Despite 1800 exoplanets, still a statistically modest population where density is rather well characterized
- Basis : Exoplanet.eu
- Selection :
  - Radius : only transit (no direct detection)
  - Mass : only radial velocity (TTV progressing but still large uncertainties and bias)
  - Acceptable uncertainties
- 220 planets at the end

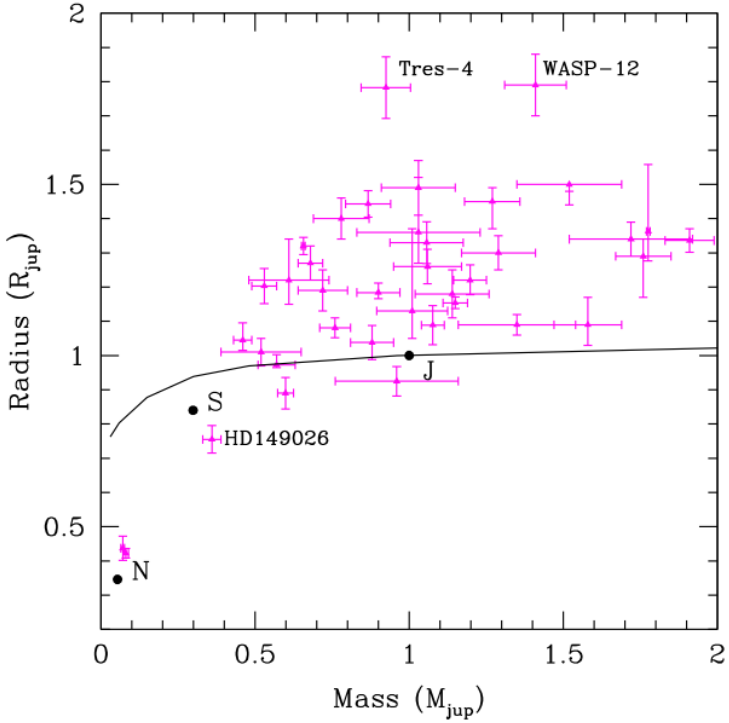


Weiss et al 2014

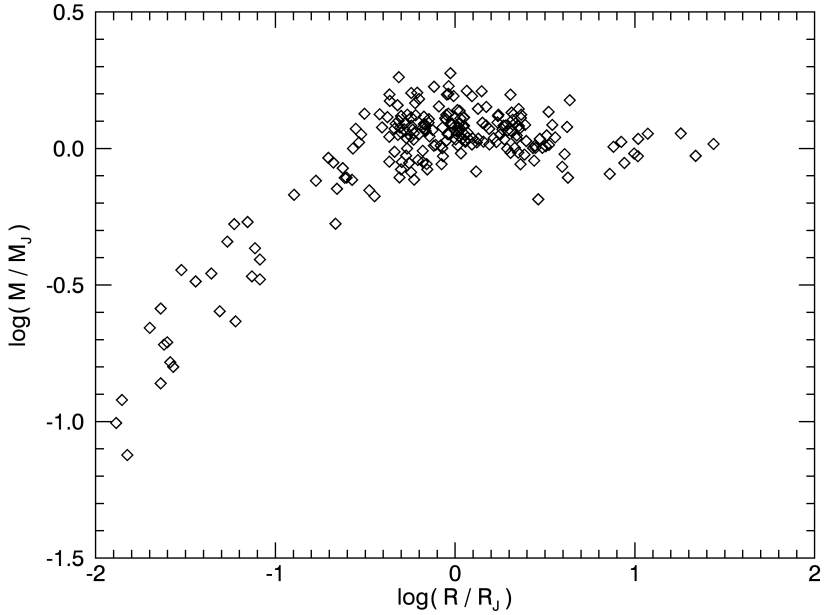


R vs M diagram

- Rapid increase of small planets number since Corot-7b, thanks to space missions Corot and Kepler



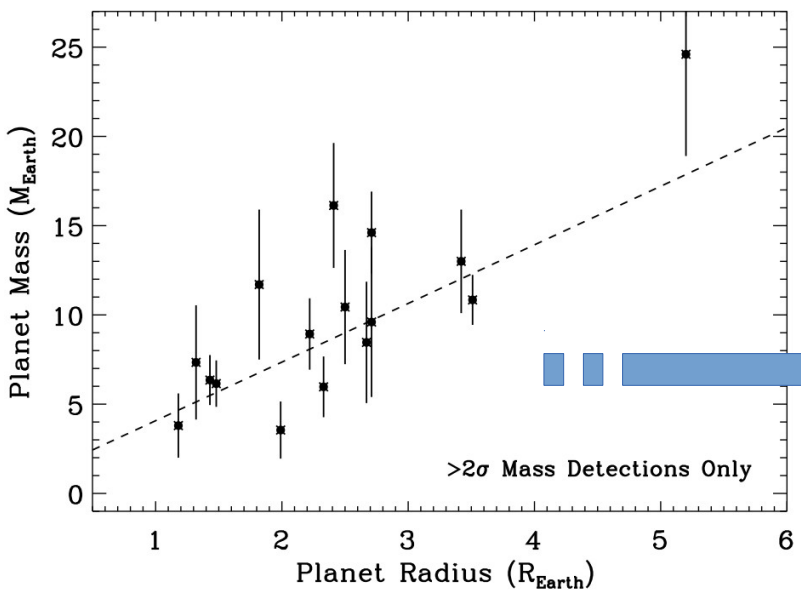
Baraffe 2010



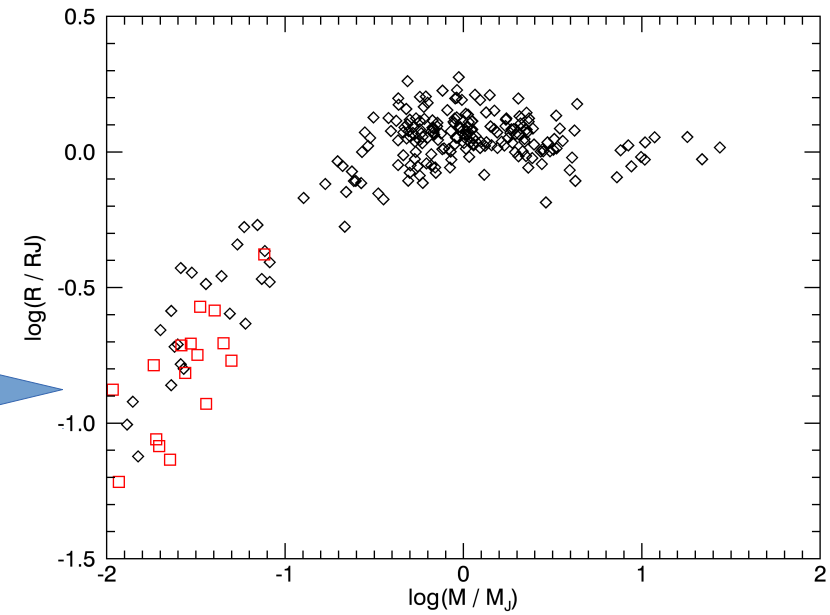
This work

R vs M diagram

- Consistent with the recent work of Marcy et al (2014) on small mass exoplanets



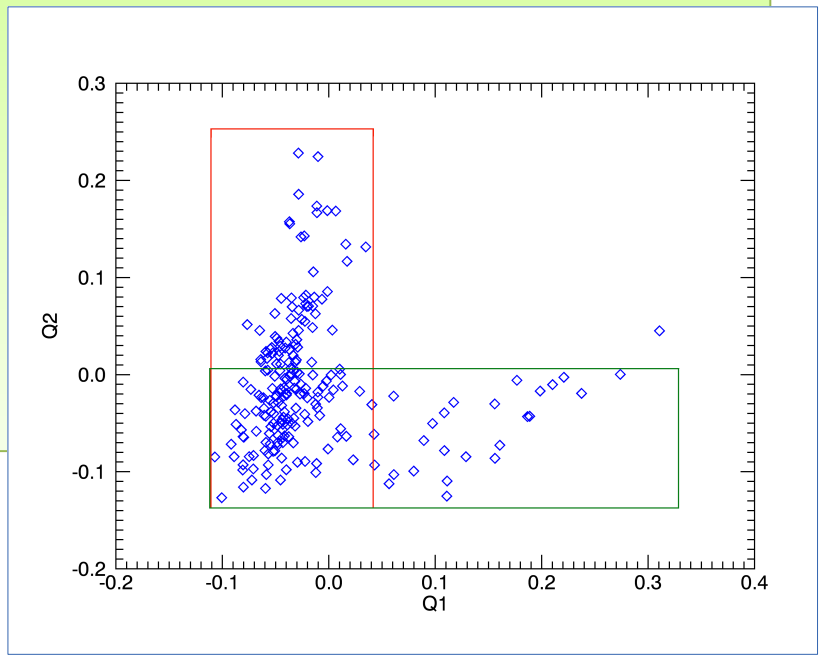
Marcy et al 2014



This work

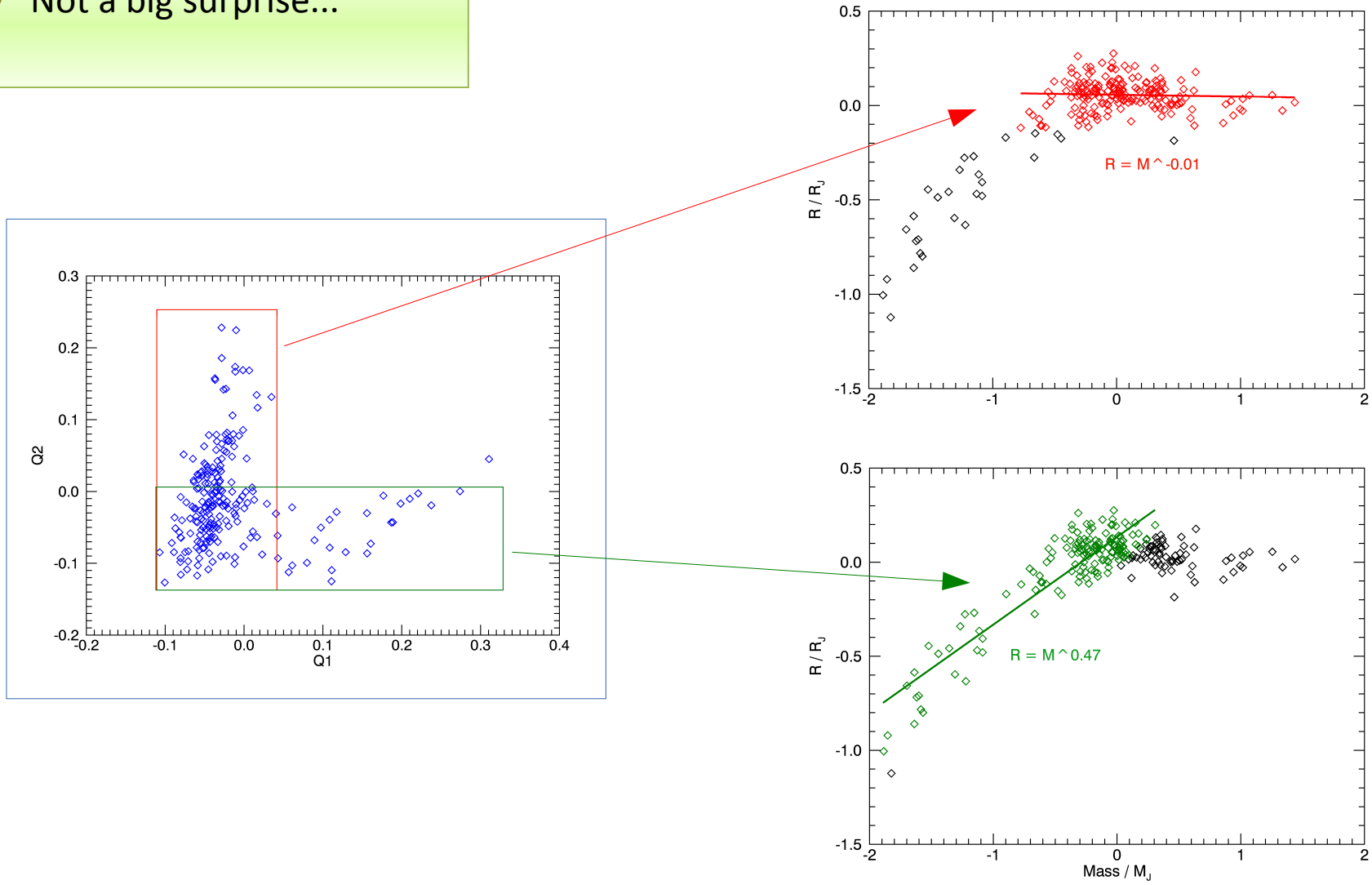
Analysis

- Attempt to use a statistical tool: ***Independent component analysis***
  - 4 parameters : Mass, Density, Metallicity, Semi-major axis
  - Looks for linear combination of parameters (here log[quantity]) that are the most *statistically independent*
- Results : if 2 vectors are looked for
  - $Q_1 = d\ M^{-1}\ a^{.18}$
  - $Q_2 = M^{.6}\ d$
  - Metallicity does not give any trend
- Converted in physical quantities :
  - $R \propto M^{.53}$
  - $R \propto a^{.06}$: slow increase of radius w distance to star



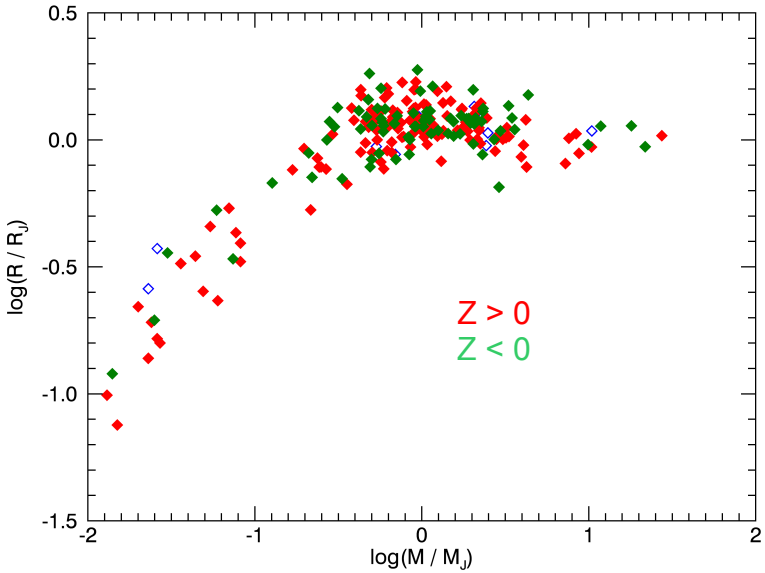
Analysis

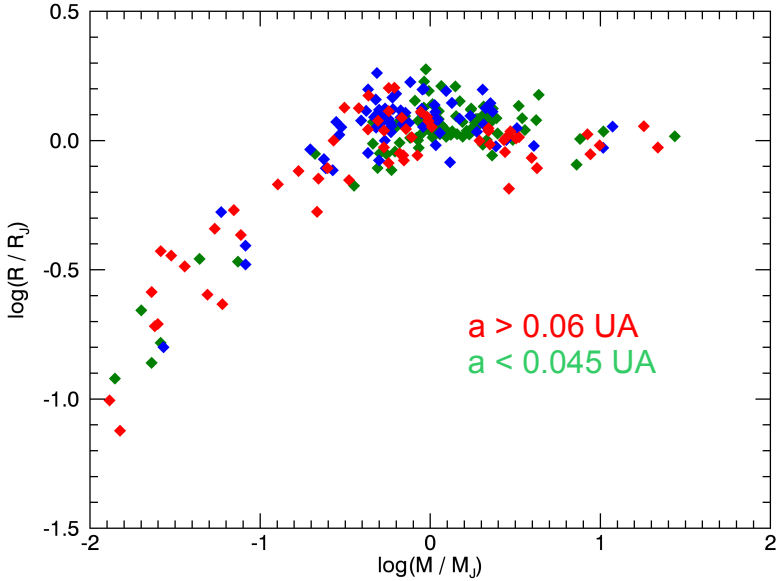
- Not a big surprise...



Role of metallicity and orbital distance

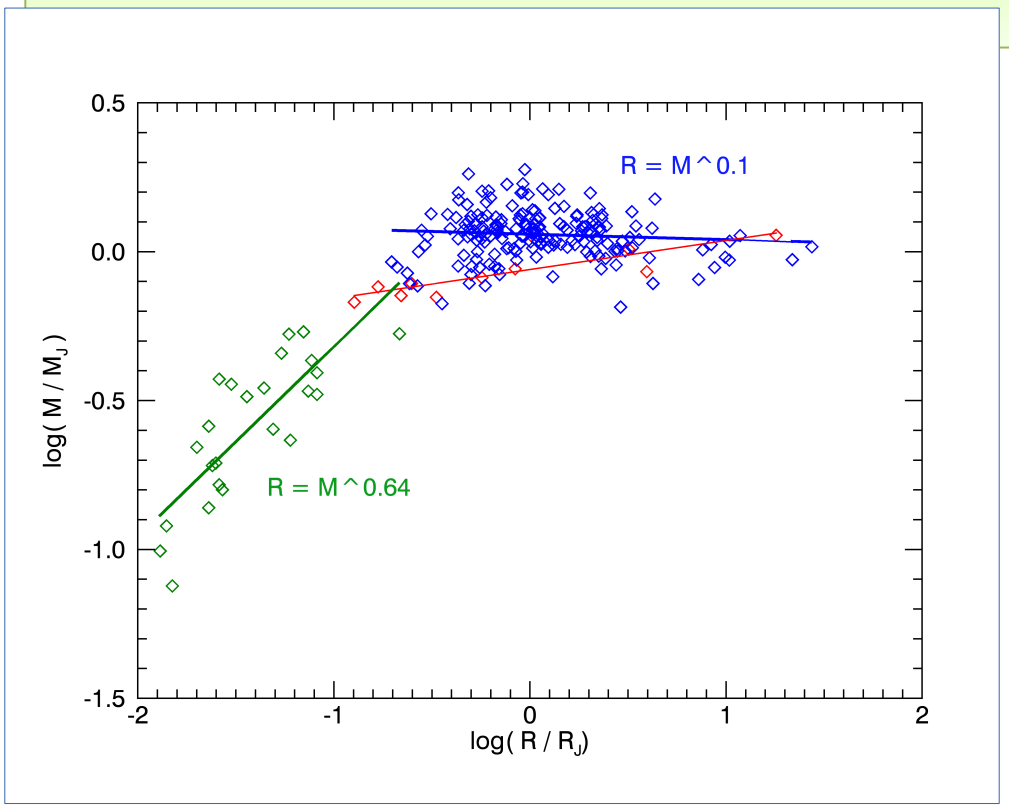
- No significant trend in each case

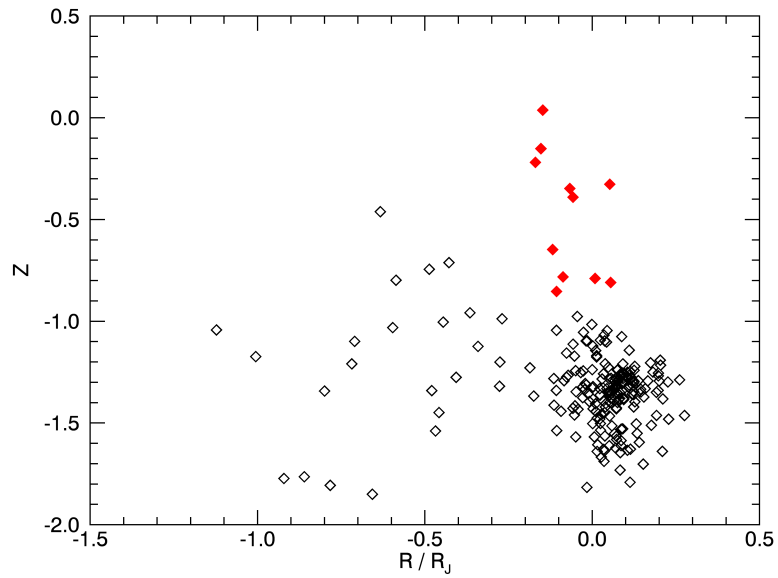




Analysis - II

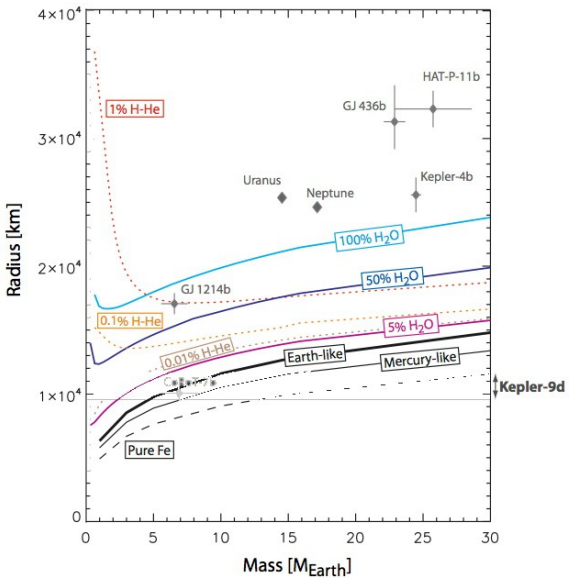
- *Cluster analysis :*
  - Isolates GP from S-Earths - Neptunes
  - Identifies a population of non- inflated GP with highest metallicity

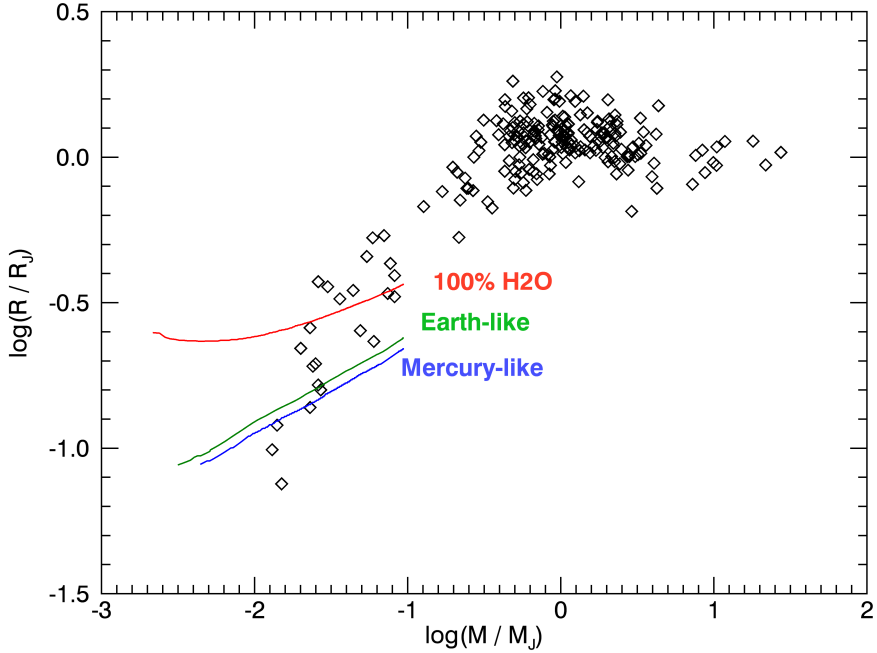




Comparison to theory - I

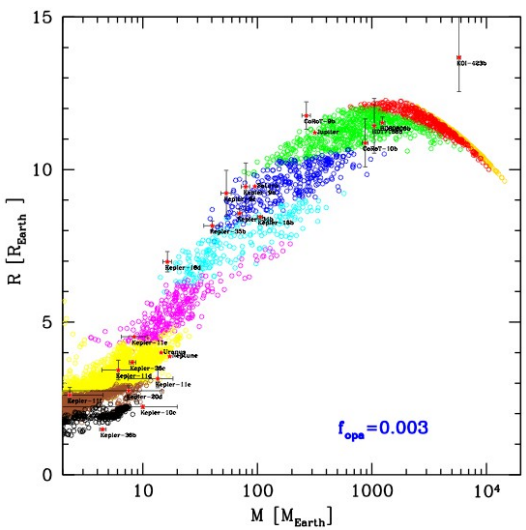
- Havel et al 2011 : Earth, super-Earth with different ice abundances
  - A consistent trend is hardly found

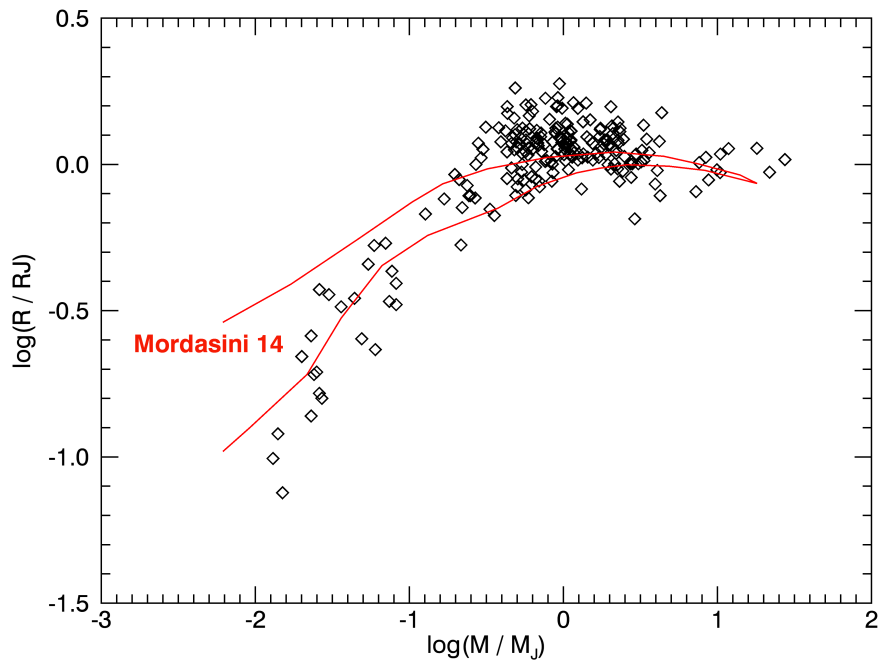




Comparison to theory - II

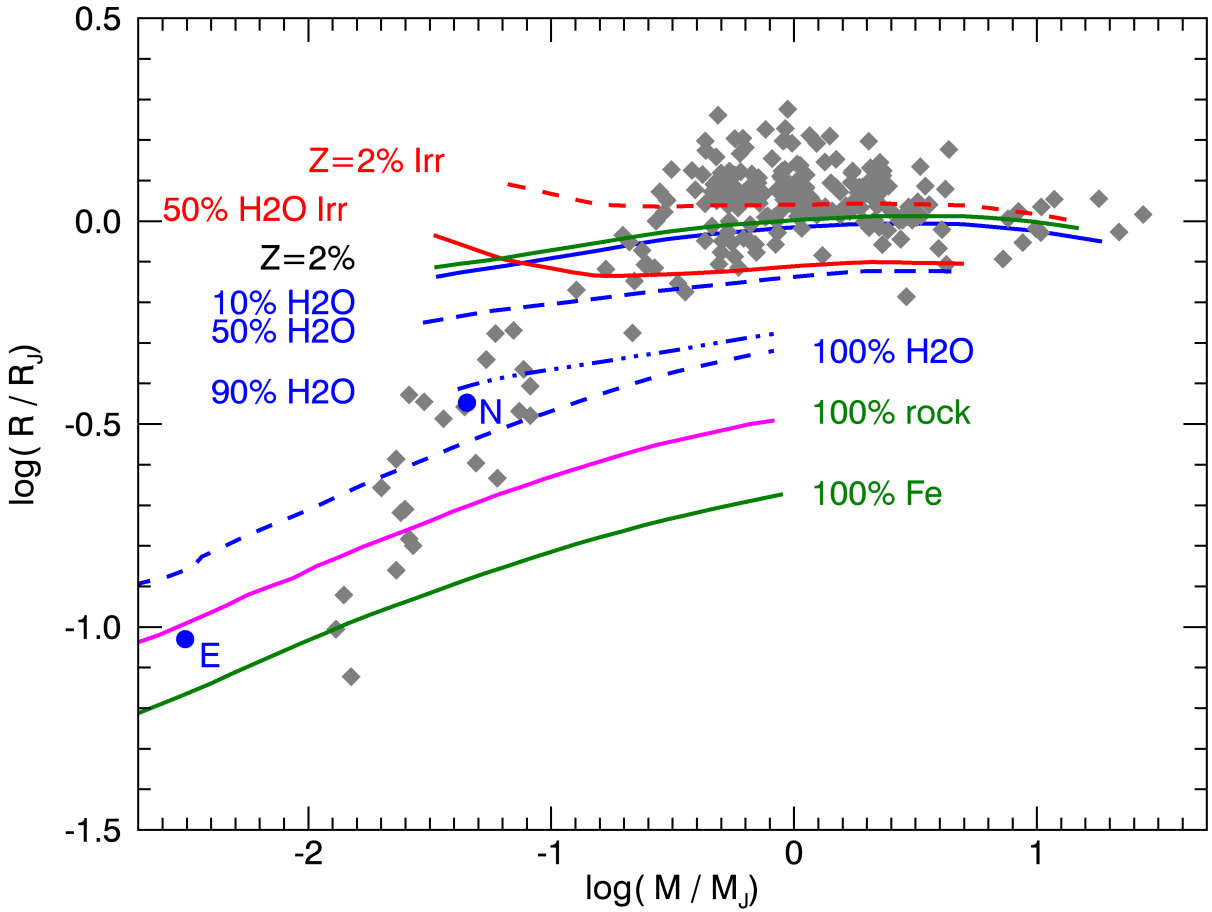
- Mordasini et al 2013 : population synthesis with a semi-empirical model of planet formation and evolution (including dust opacity)





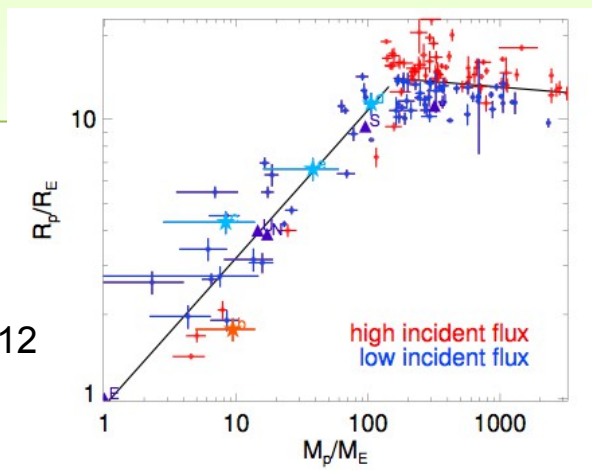
Comparison to theory - III

- Baraffe et al 2010 :

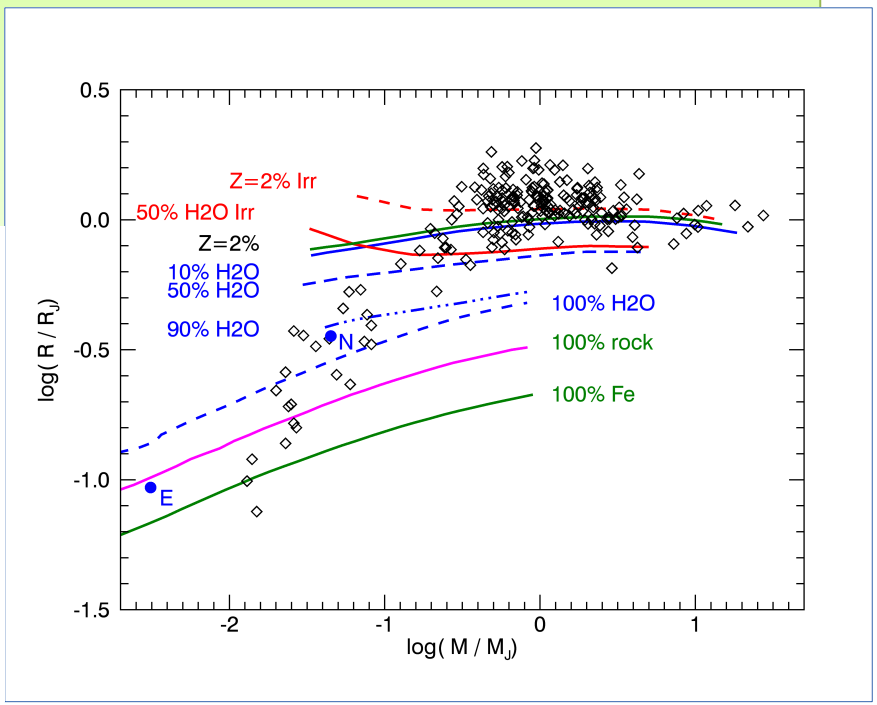


Questions

- Why this steeper power-law distribution for S-Earth to S-Neptune planets ?
  - Poor statistics + uncertainties ?
  - Observational bias ? Yes for the low-mass end
  - Equation of state to be refined ?
  - A *cosmic conspiracy* : describes a universal law of formation/composition/gas accretion or of evaporation during migration, depending only on mass ? Unlikely
- Why so many inflated Jupiters ?
  - Irradiation cannot explain all
- Link between metal-poor and swelling ?
  - Albedo of grains ?
  - Actual ?



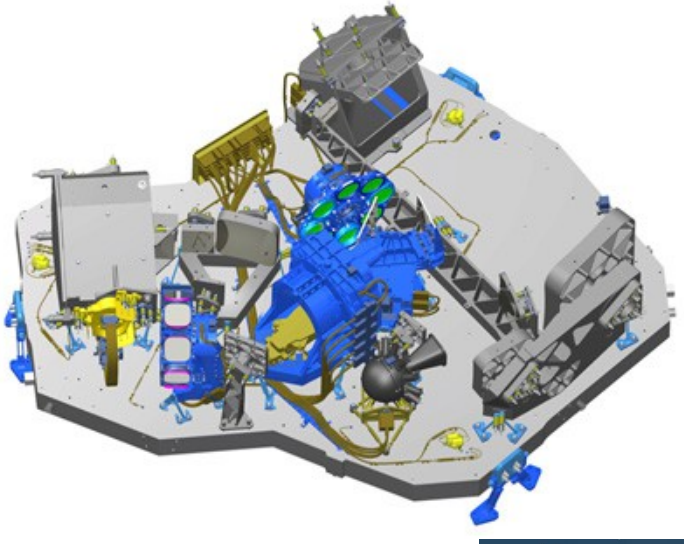
Weiss et al 2012

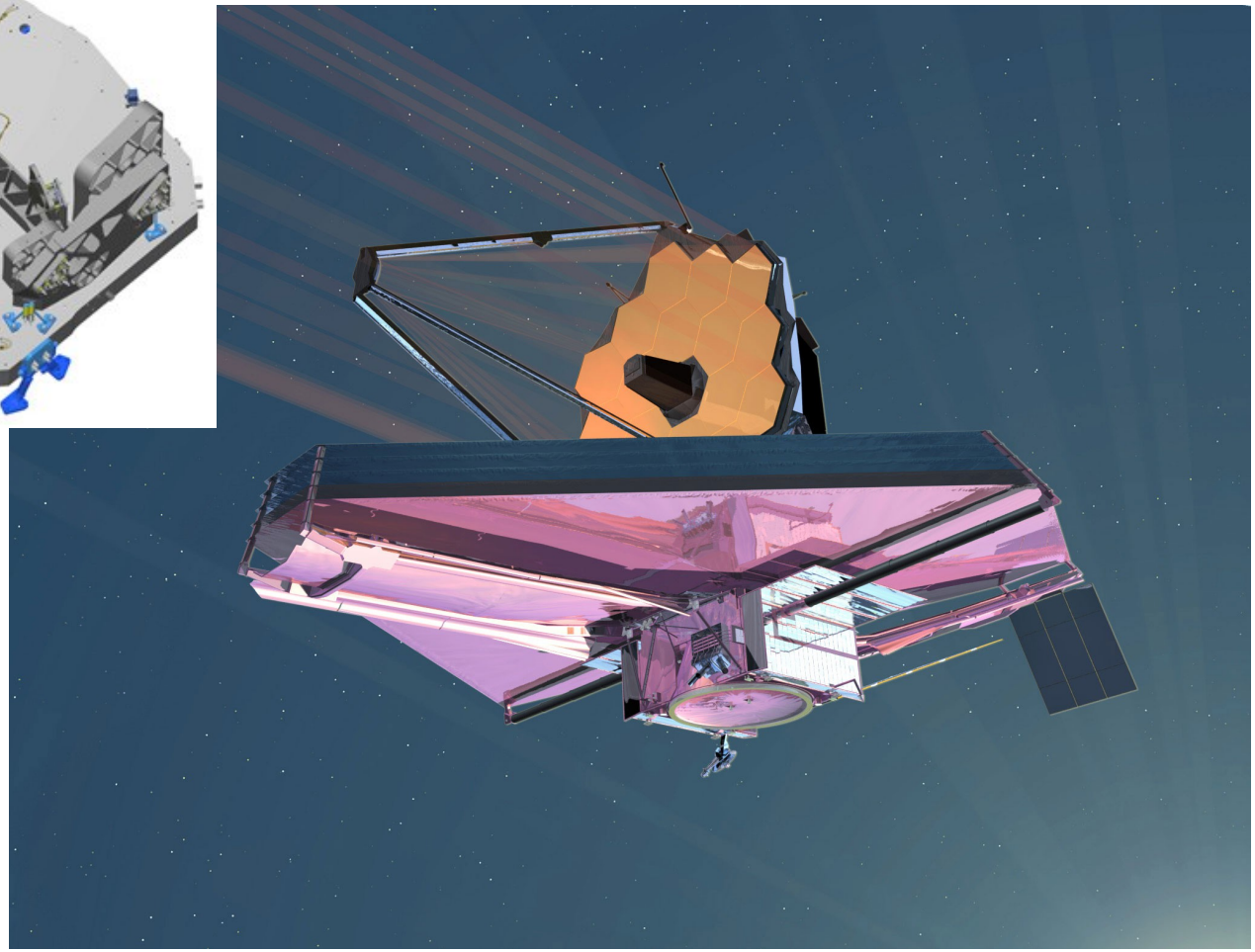


We need better statistics at better S/N

+ TESS, CHEOPS, ESPRESSO, ...

We need more characterization



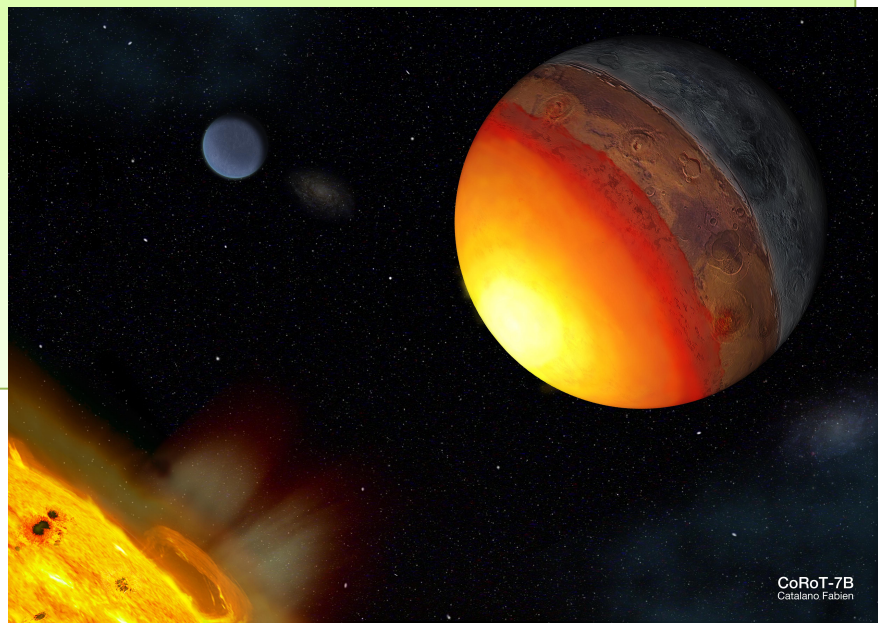


Further characterization of a Hot Super-Earth

B. Samuel, J. Leconte, F. Forget, A. Léger, J. Schneider, A&A 2014

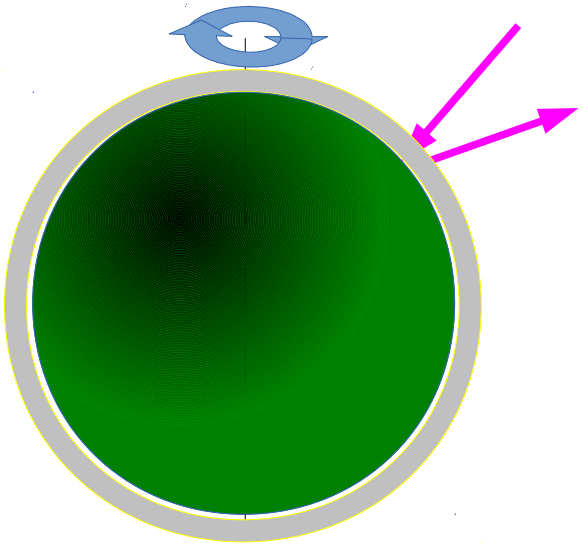
More on physics of Hot Super-Earths ?

- 2009 : the first small planet unambiguously characterized as a rocky one : **Corot-7b** (Léger et al 2011) : predicted characters
  - Very short period → planet extremely close from the star : 20 times closer than Mercury is from Sun
  - → should be phase locked because of strong tidal interaction with the star
  - → extremely hot irradiated side: T > 2200 K → ocean of melted lava
  - → strong wind and UV flux : primitive atmosphere should be totally blown, but there may be a vapour (Ca0, Al_2O_3) in equilibrium with the lava
- Kepler-10b, 55 Cnc : same conclusions
- ARE THOSE PREDICTIONS CHECKABLE ?



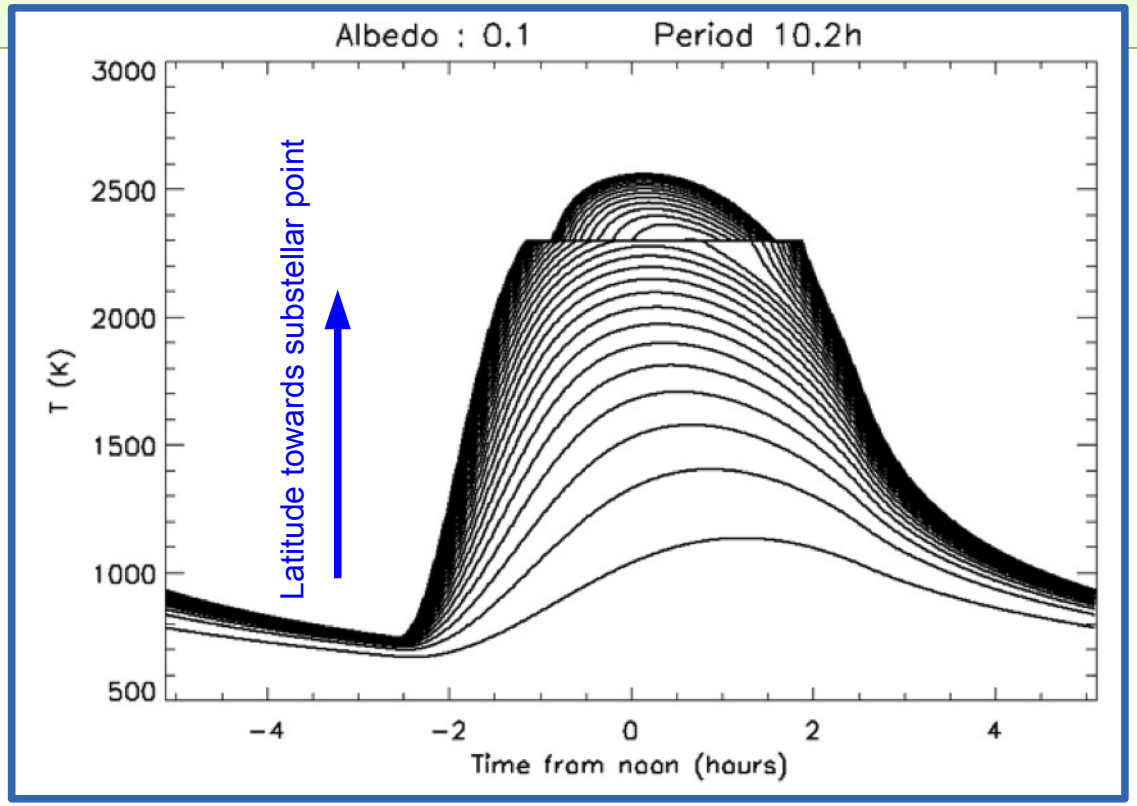
Can we test the paradigm ?

- Could the spectral signatures of those characters, *or departure from them*, be detected with NIRSPEC on JWST ?
- Physical characteristics which have been examined:
  - Rotation : phase-locked or not ?
  - Albedo ?
  - Presence of an atmosphere ?
  - Temperature distribution on the planet's surface



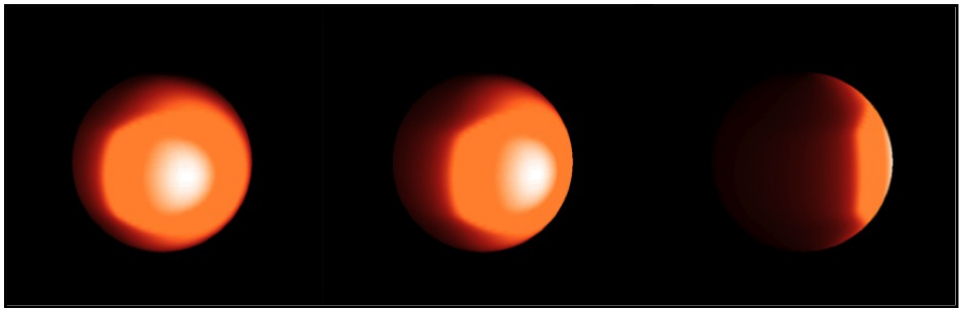
Simulation of rotation

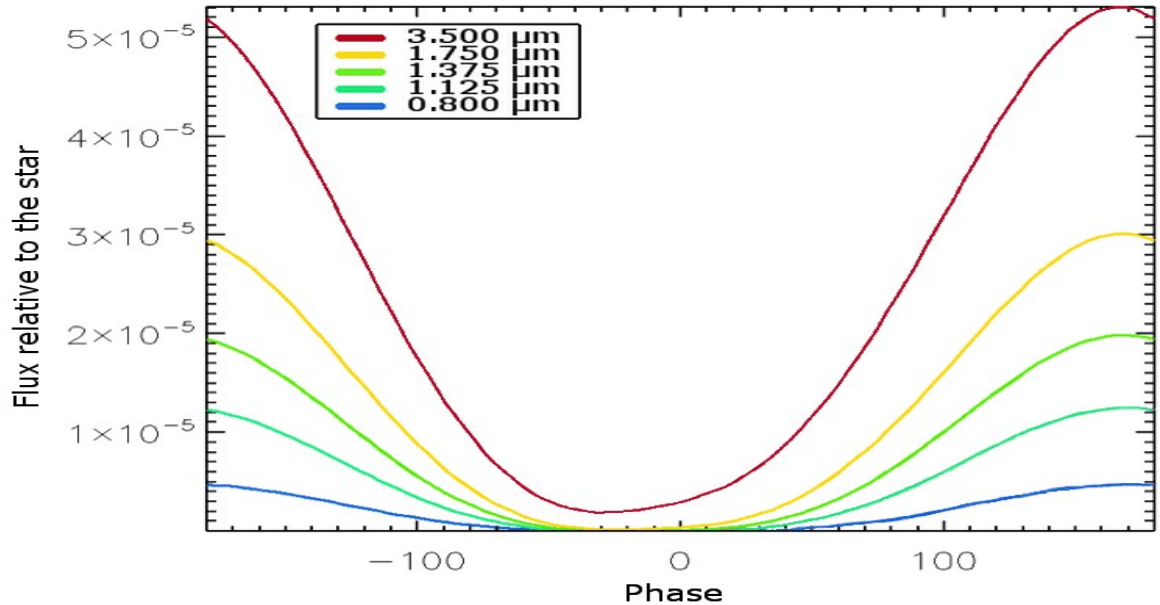
- Radiative heating/cooling is very fast ($t_{cool} \propto T^{-3}$)
- At latitude where melting occurs, the temperature stabilizes until the whole layer melts or become solid again
- There is an asymmetry in the temperature variation



Simulation of rotation

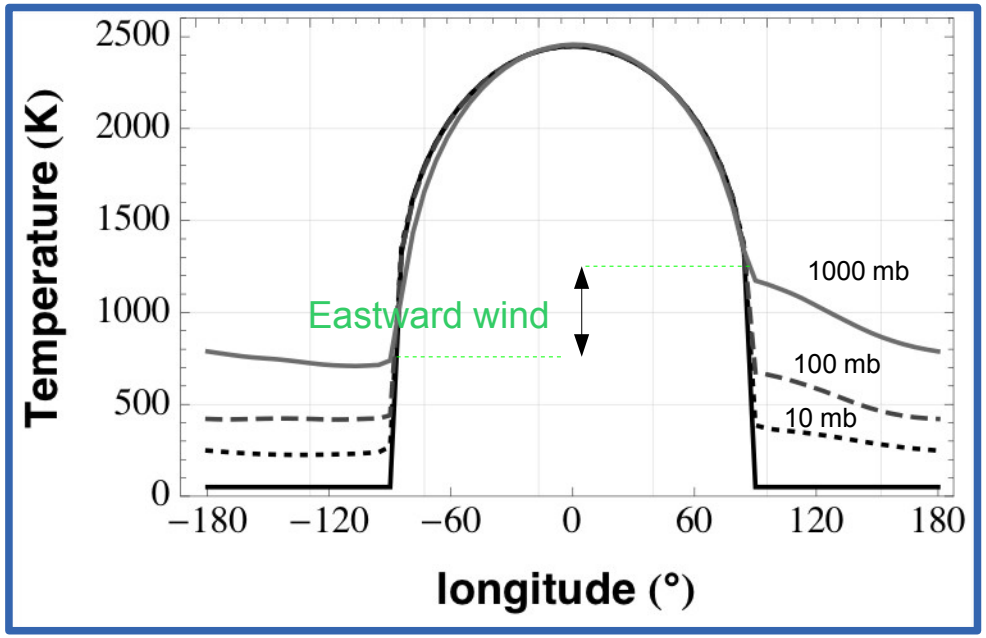
- Along the orbit: temperature lag → asymmetry in the detected thermal emission
  - The longer the wavelength, the more important the asymmetry

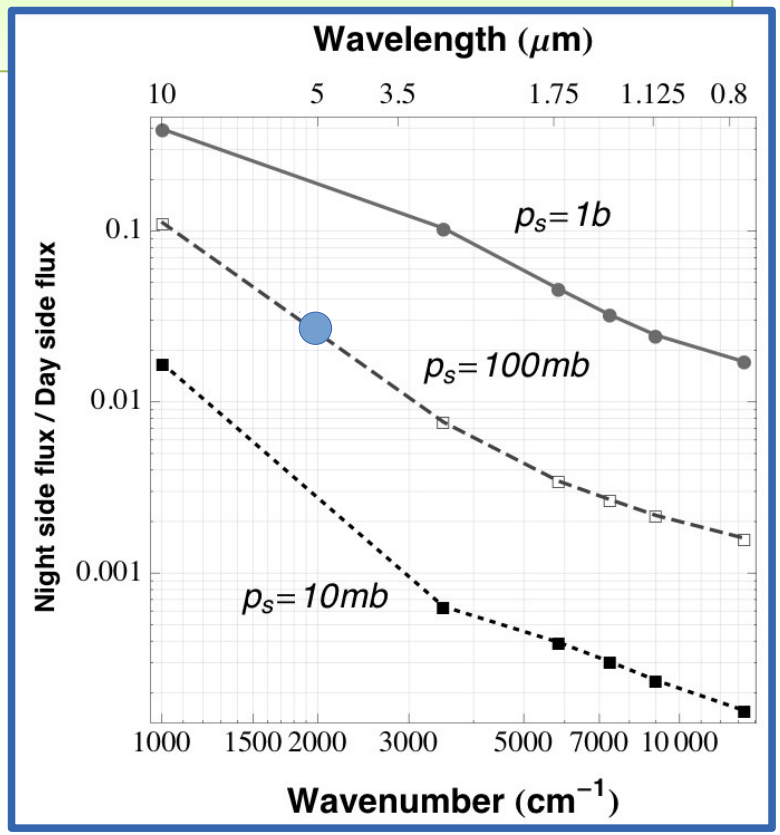




2: Presence of an atmosphere ?

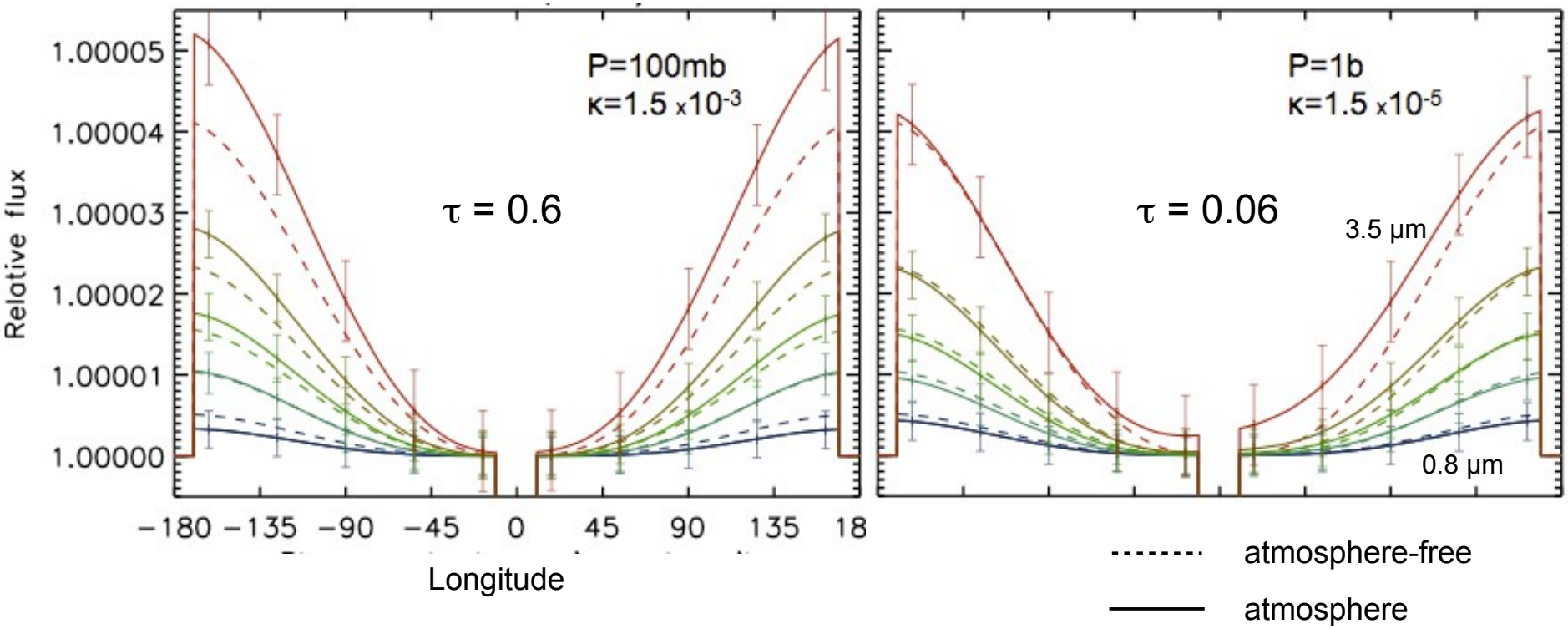
- The possibility of an atmosphere exists through vapour saturation(e.g. Na) in equilibrium with the very hot ground
  - → models (Schaefer, 2009) predict up to 100 mbars at the substellar point
- We ran a GCM model (LMD) with exchanges between a gray atmosphere and ground
  - → a clear effect on the night-side temperatures
  - Best seen at longest λ





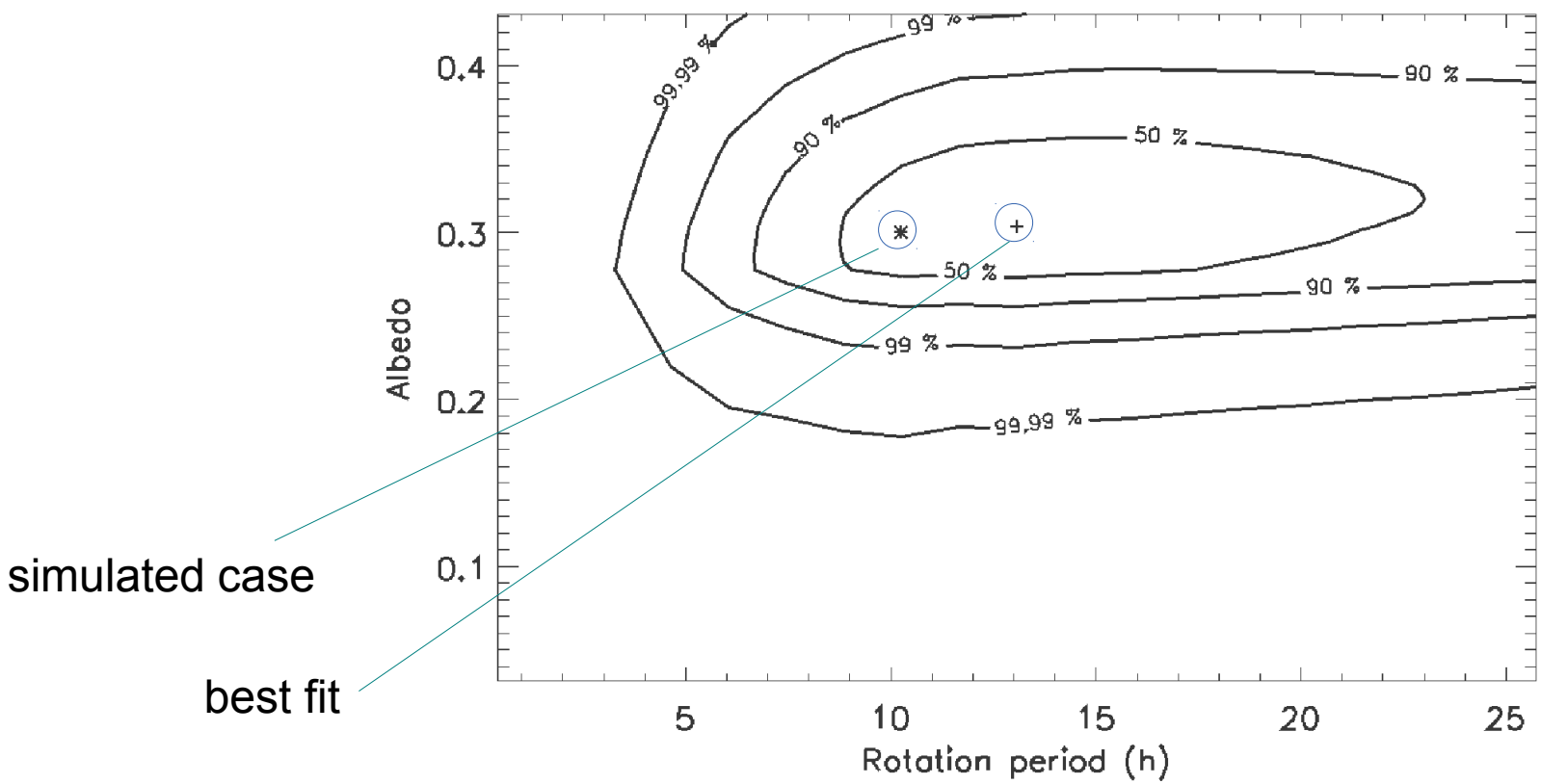
2: Presence of an atmosphere ?

- Modulation of the Light Curve detectable at 3.5 µm in case of a sufficiently thick (τ > 0.5) and/or dense (p > 100 mbar) atmosphere.



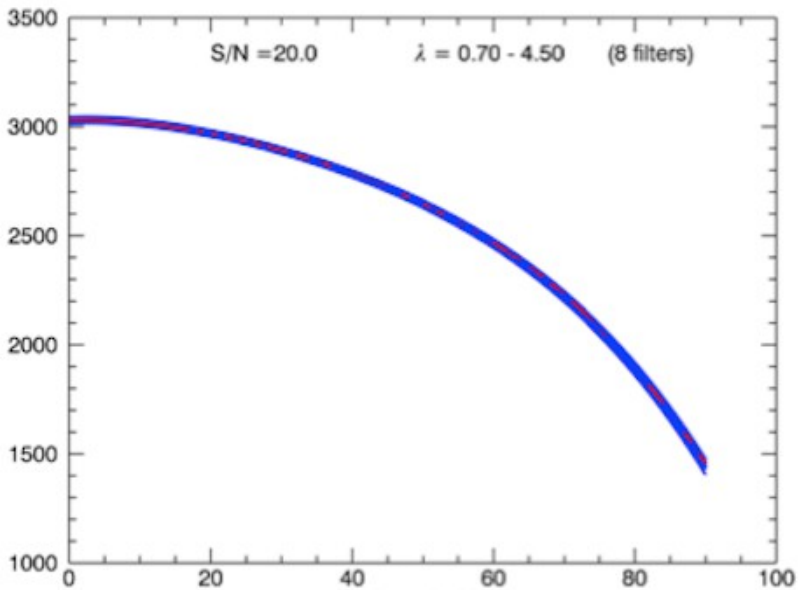
3: Albedo estimation

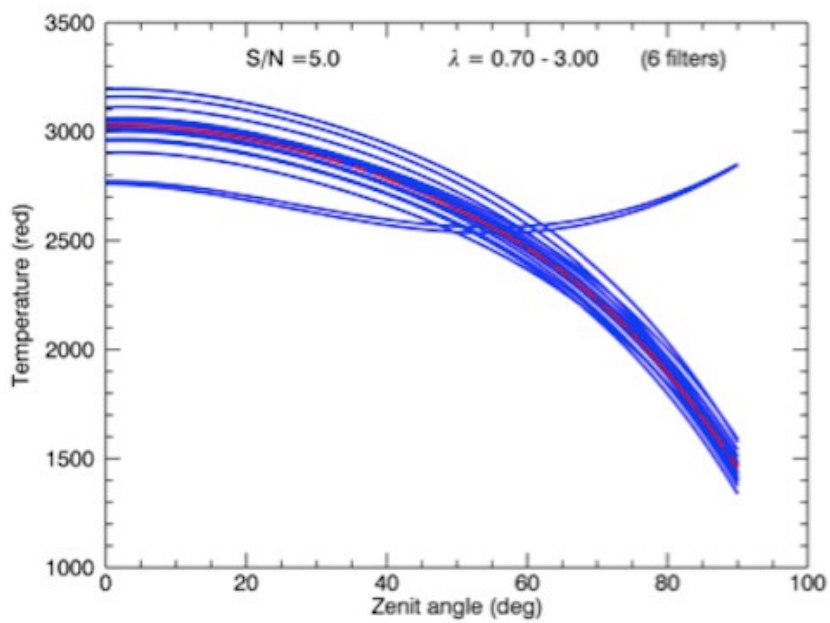
- Comparing a simulated LC to a family of cases → retrieval of the Bond albedo ± 0.03
- Rotation period is more degenerated but still retrieved to within few hours



4: Retrieval of temperature distribution

- For a S/N >5 and a broad wavelength range (.7 – 4.5 µm):
  - T(lat) retrieved to within 10K
- When S/N ≦5 and λ_{max} ≦ 3 µm :
  - few "catastrophic" solutions
- Required exposure time is between 70 h on Corot-7b and 3 h on a V=8 star





Conclusions

- Characterization of Hot Super-Earth (lava ocean planets) on several physical parameters is within reach thank to measurements with NIRSPEC-JWST
- Rotation vs phase-locked situation : detection of an asymmetry of the LC if rotation is comparable to or faster than the orbital period
- Bond albedo : retrieved to within ± 0.03
- The presence of an atmosphere with p > 100 mbar and/or t > 0.5 could be detected
- The latitudinal temperature profile can be retrieved from spectra w S/N > 5

Thanks for your attention