Exoplanets characterization

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

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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: \( R \propto M^{0.25 \text{-} 0.33} \) polytropic solution for incompressible material
Baraffe 2010, Fortney 2010

In (very) short: \( R \propto Cst \) in the range 0.2 – 10 \( M_{\text{jup}} \): 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
Rapid increase of small planets number since Corot-7b, thanks to space missions Corot and Kepler

Baraffe 2010

This work

D. Rouan - LESIA – Qui Nhon Avr 2014
• Consistent with the recent work of Marcy et al (2014) on small mass exoplanets

Marcy et al 2014

This work
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

- $Q_1 = d M^{-1} a^{0.18}$
- $Q_2 = M^{0.6} d$

Metallicity does not give any trend

Converted in physical quantities:

- $R \propto M^{0.53}$
- $R \propto a^{0.06}$: slow increase of radius with distance to star
Not a big surprise...
**Role of metallicity and orbital distance**

- No significant trend in each case

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**Graphs:**

- Left: 
  - $Z > 0$
  - $Z < 0$

- Right: 
  - $a > 0.06$ UA
  - $a < 0.045$ UA
Cluster analysis:

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

\[ \log(R/R_\odot) \text{ vs } \log(M/M_\odot) \]

- Z=2% Irr
- 50% H2O Irr
- 10% H2O
- 50% H2O
- 90% H2O
- 100% H2O
- 100% rock
- 100% Fe
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

PLATO 2.0
(PLAnetary Transits and Oscillations of stars)

Heike Rauer (Principal Investigator)
Don Pollacco (Science coordinator)
and the PLATO Team

+ TESS, CHEOPS, ESPRESSO, ...
We need more characterization
Further characterization of a Hot Super-Earth

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: $T > 2200 \text{ K}$ → ocean of melted lava
- strong wind and UV flux: primitive atmosphere should be totally blown, but there may be a vapour ($\text{CaO, Al}_2\text{O}_3$) in equilibrium with the lava

Kepler-10b, 55 Cnc: same conclusions

ARE THOSE PREDICTIONS CHECKABLE?
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
Radiative heating/cooling is very fast (\( t_{\text{cool}} \propto T^{-3} \))

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
Along the orbit: temperature lag → asymmetry in the detected thermal emission

The longer the wavelength, the more important the asymmetry
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 $\lambda$

2: Presence of an atmosphere?

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

2: Presence of an atmosphere?

- $\tau = 0.6$
- $\tau = 0.06$

Longitude

Relative flux

- atmosphere-free
- atmosphere

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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 (0.7 – 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
Characterization of Hot Super-Earth (lava ocean planets) on several physical parameters is within reach thanks 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 with $S/N > 5$. 
Thanks for your attention