WP 115 100 – the Mass-Radius relationship for gas giants

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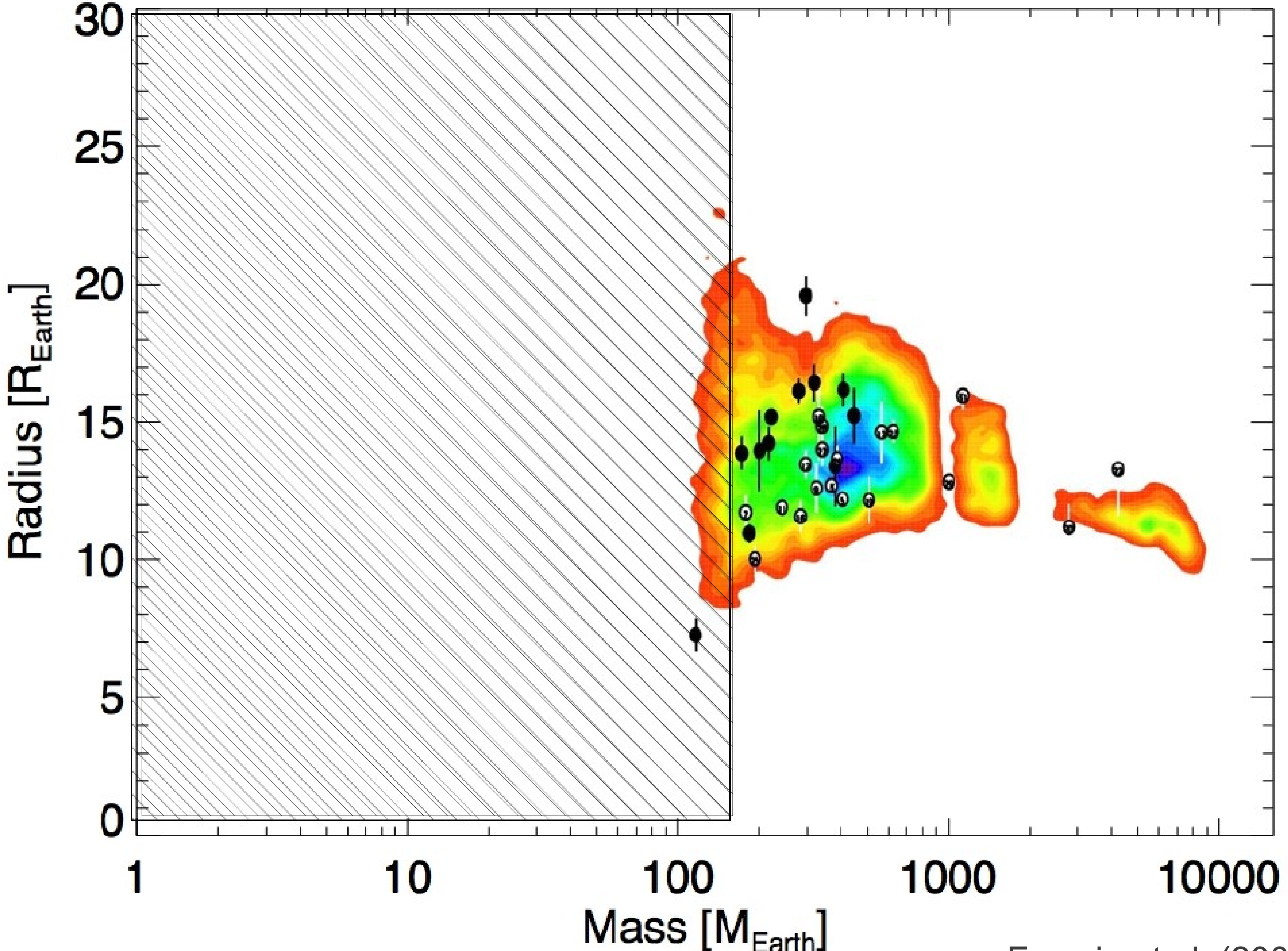
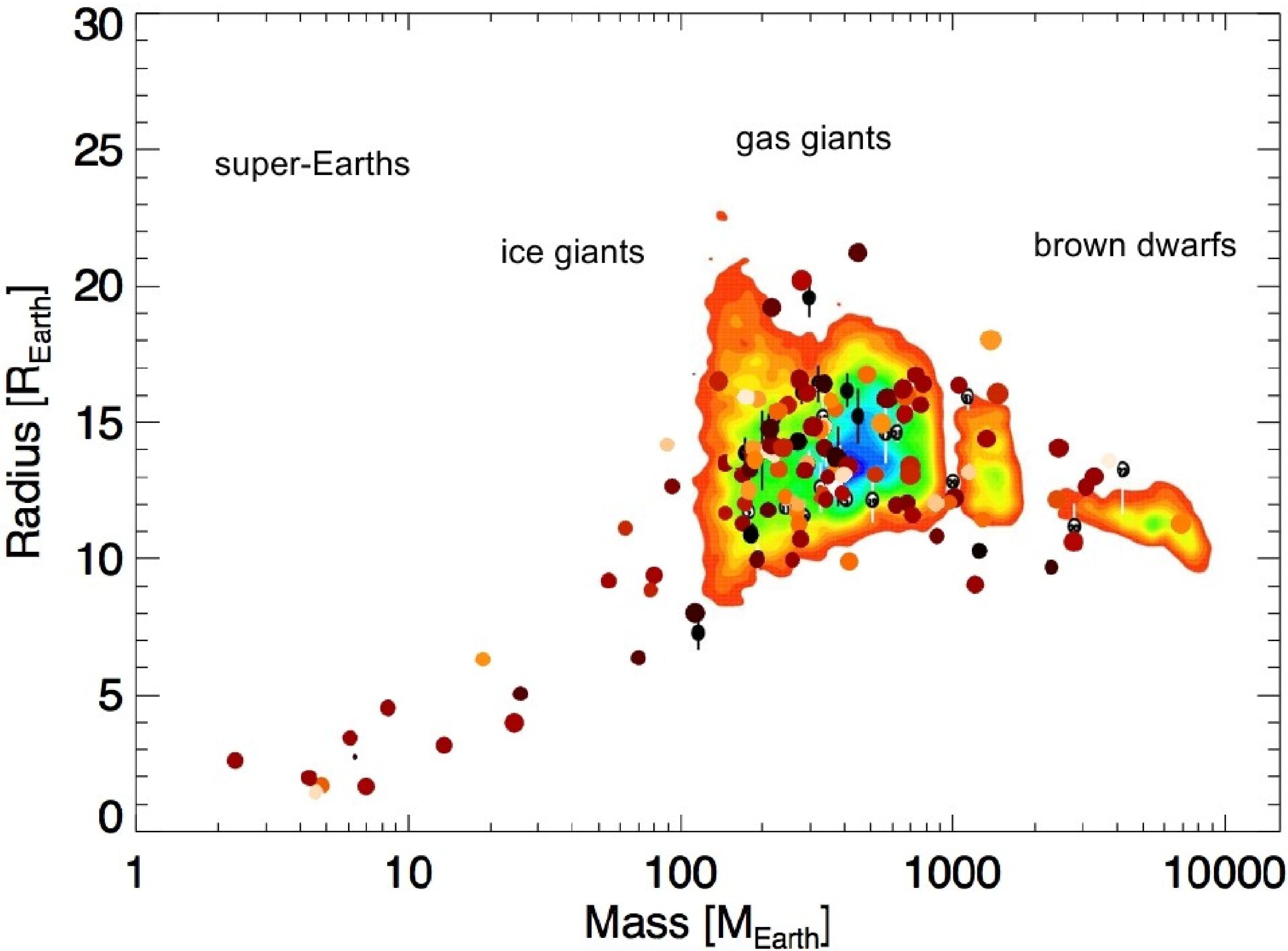
Objectives:
Understand the expected impact of PLATO photometry on the mass-radius relationship of gas giants and its implications for their structure.

M-R relation: predictions (~2008 data)



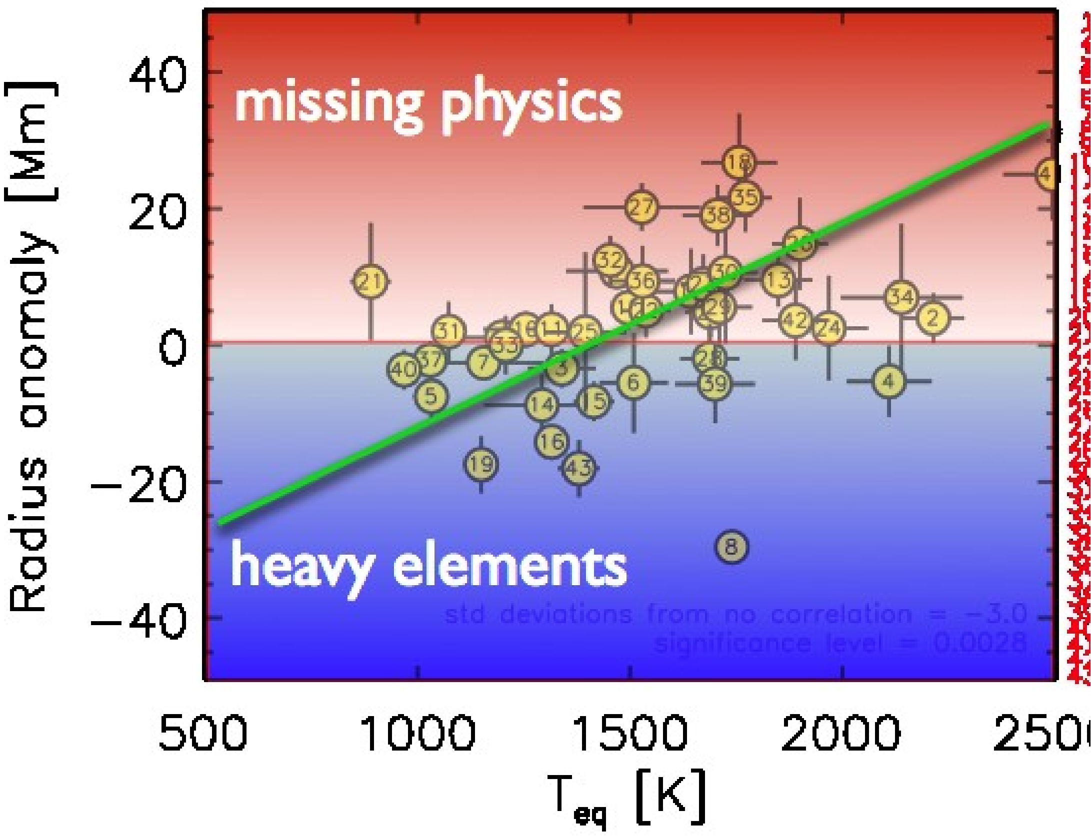
Fressin et al. (2009)

M-R relation: Feb 2011 data



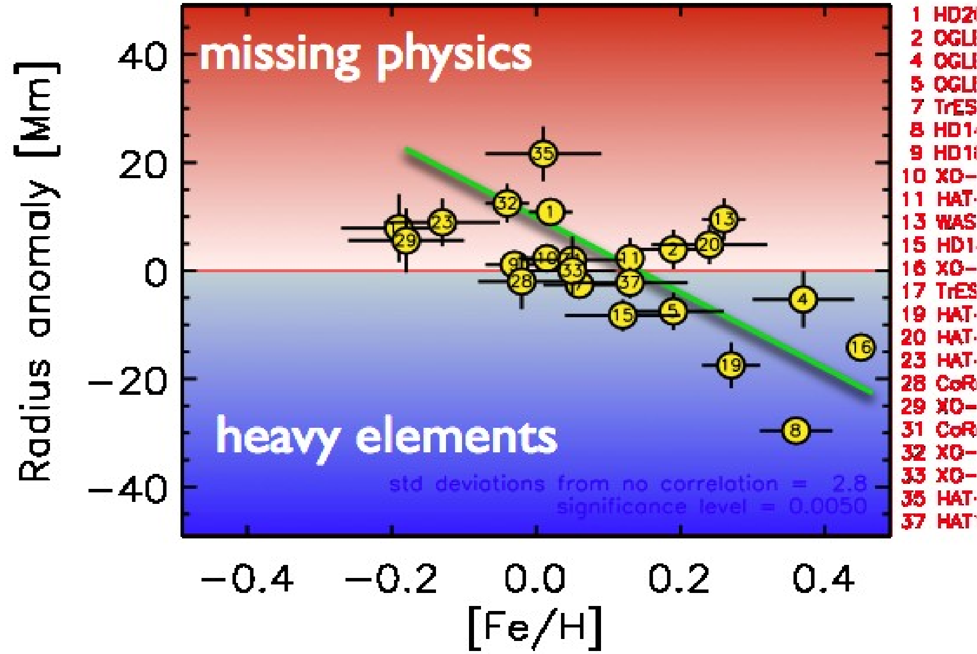
Inflated planets

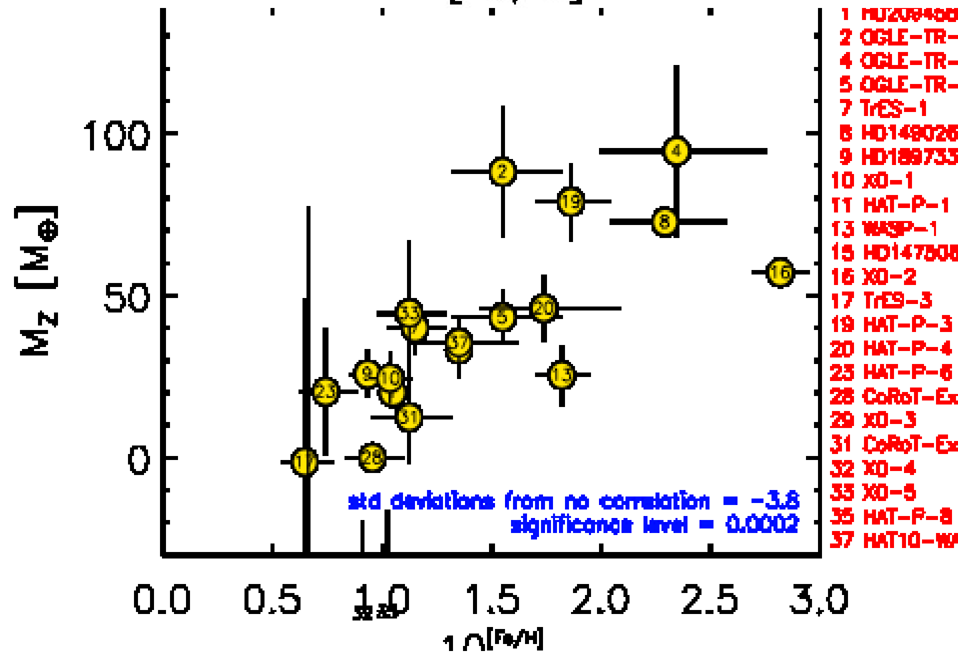
- Giant planets have been shown to be anomalously inflated (Bodenheimer et al. 2001, Guillot & Showman 2002, Baraffe et al. 2003, Guillot et al. 2006, Burrows et al. 2007, Miller et al. 2009...)
- The mechanism that leads to inflation is widespread, and the source of energy is most likely in the stellar heating (Guillot 2008)
- A very promising source is ohmic heating, due to the interplay between atmospheric winds and the planetary magnetic field (Batygin & Stevenson 2010, Perna et al. 2010, Batygin et al. 2011, Laughlin et al. 2011)



Inferring compositions

- Using a model for the « missing physics », the amount of heavy elements present in giant planets may be obtained from their size, mass, irradiation level and age.
- The mass of heavy elements thus derived is correlated with the stellar metallicity (Guillot et al. 2006, Burrows et al. 2007, Guillot 2008)





Statistics

Table 1. Minimal number of planets N_p required to sample a descriptive statistic with p parameters with b bins to a relative accuracy κ, and time T_{150} required to acquire such a sample for a planet detection rate of 150 per year.

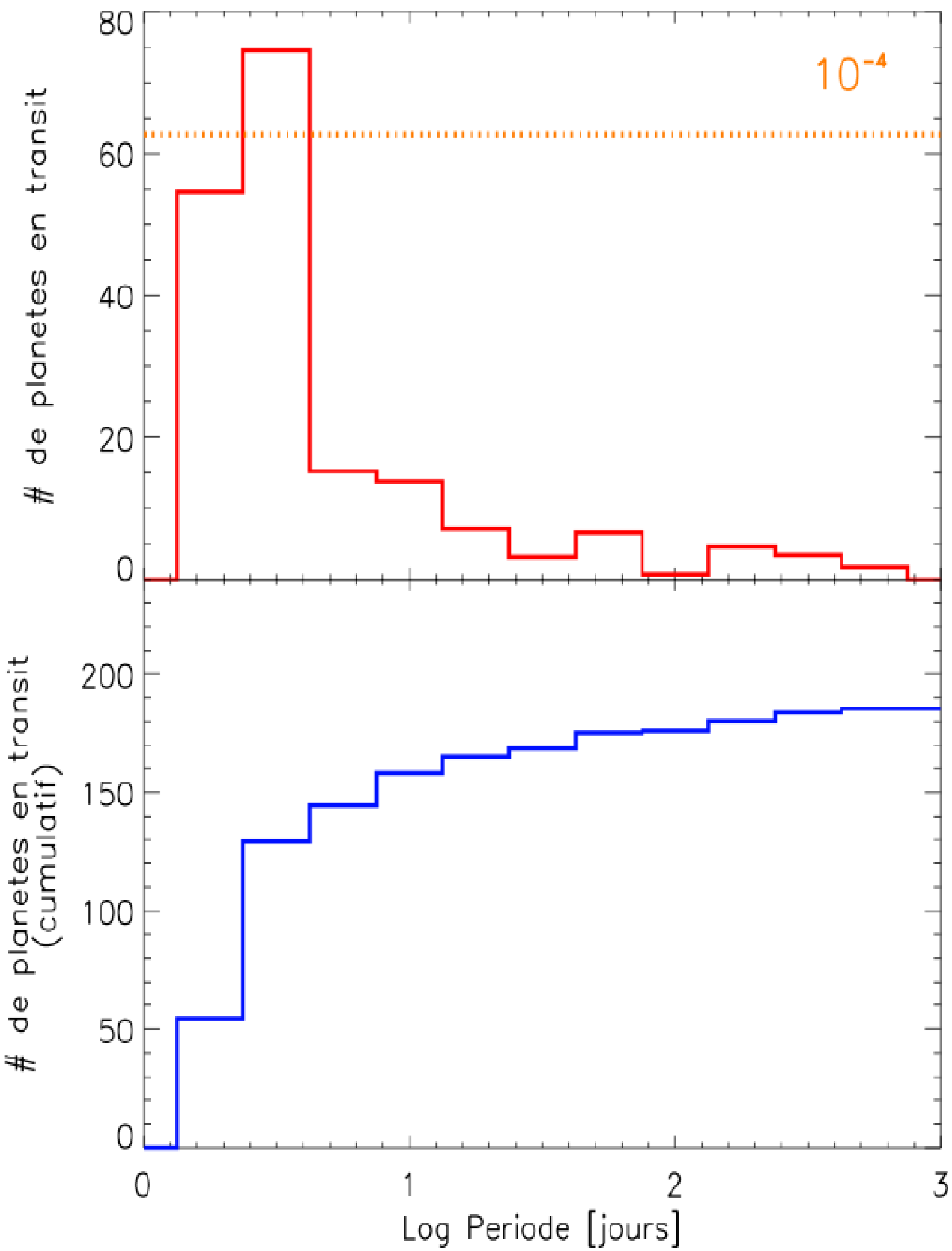
κ	p	b	N_p	T_{150}
0.5	2	2	$4 \times 2^2 = 16$	1.3 months
0.5	2	3	$4 \times 3^2 = 36$	2.9 months
0.5	2	5	$4 \times 5^2 = 100$	8 months
0.5	2	10	$4 \times 10^2 = 400$	3 years
0.5	4	2	$4 \times 2^4 = 64$	5 months
0.5	4	3	$4 \times 3^4 = 324$	2 years
0.5	4	5	$4 \times 5^4 = 2500$	17 years
0.5	4	10	$4 \times 10^4 = 40,000$	270 years
0.5	6	2	$4 \times 2^6 = 256$	1.7 years
0.5	6	3	$4 \times 3^6 = 2916$	19 years
0.5	6	5	$4 \times 5^6 = 62,500$	420 years
0.5	6	10	$4 \times 10^6 = 4,000,000$	27,000 years
0.2	2	2	$25 \times 2^2 = 100$	8 months
0.2	2	3	$25 \times 3^2 = 225$	1.5 years
0.2	2	5	$25 \times 5^2 = 625$	4 years
0.2	2	10	$25 \times 10^2 = 2500$	17 years
0.2	4	2	$25 \times 2^4 = 400$	2.7 years
0.2	4	3	$25 \times 3^4 = 2025$	13.5 years
0.2	4	5	$25 \times 5^4 = 15,625$	100 years
0.2	4	10	$25 \times 10^4 = 250,000$	1700 years
0.2	6	2	$25 \times 2^6 = 1600$	11 years
0.2	6	3	$25 \times 3^6 = 18,225$	120 years
0.2	6	5	$25 \times 5^6 = 390,625$	2600 years
0.2	6	10	$25 \times 10^6 = 25,000,000$	170,000 years

Dominik (2011)

- PLATO will allow to greatly improve the statistics of known transiting giant planets
    - More planets
    - Higher accuracy
- The important parameters describing the M-R relation are:
    - Planetary Mass
    - Planetary Radius
    - Orbital distance
    - Age
    - Stellar metallicity
    - Eccentricity
    - Stellar mass

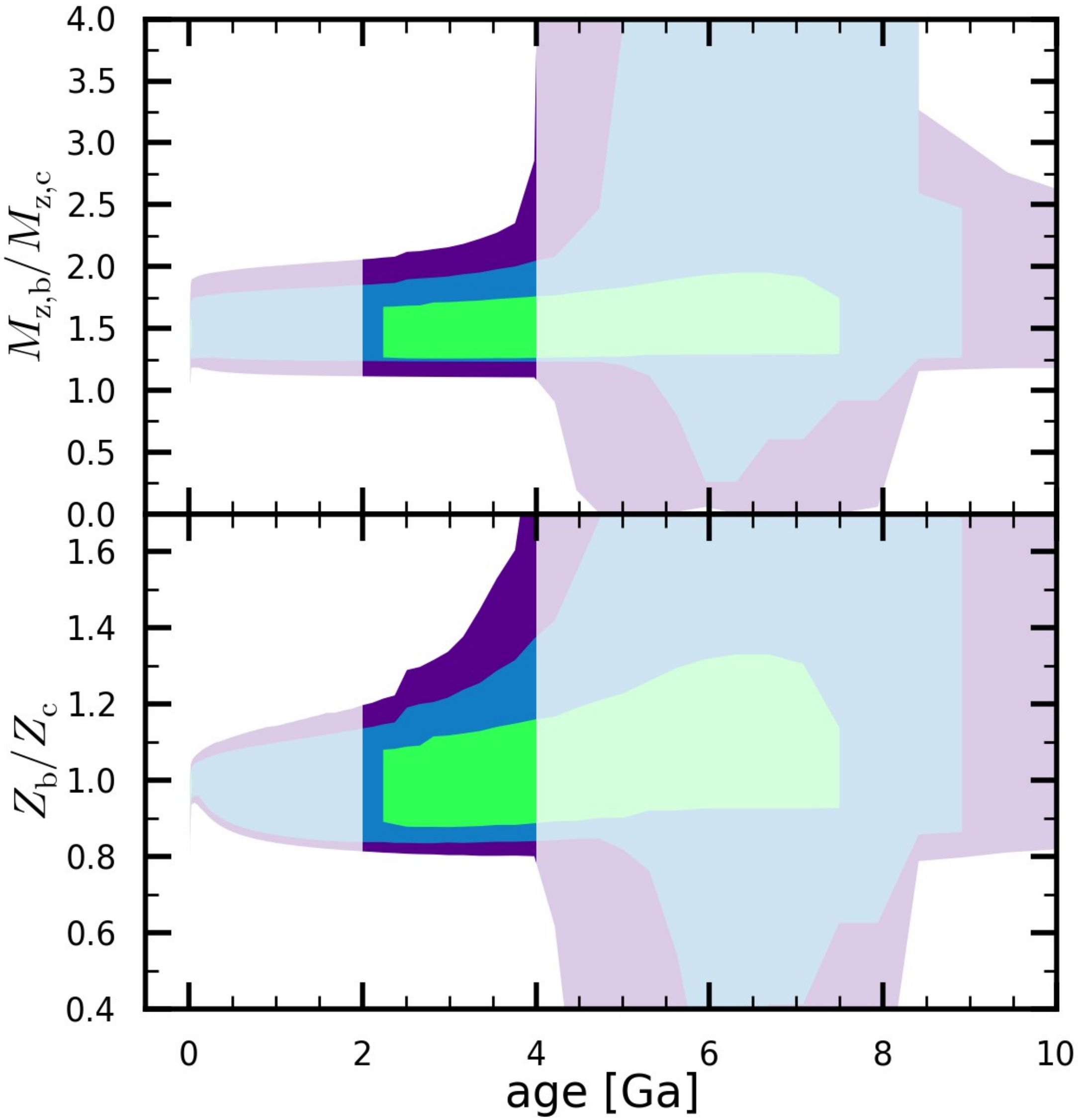
Statistics of far-out planets

- Given the radial velocity data, ~15% of all transiting giant planets have orbital periods P>10 days, ~3% have P>100 days.
- These are extremely hard to detect because of their relative rarity, the long time required, the long duration of the transits and the small probability of observing one at any given time.
- They are important for evolution models because less affected by irradiation, and for formation models, because it is a different population than close-in planets. Far-out planets are more likely to have moons, rings.
- PLATO can discover many more far-away transiting planets than possible with other instruments.



« Rosetta stone » planets

- CoRoT-2b: An extremely inflated planet (requires 25% of the irradiation energy to fit its radius!) (Guillot & Havel 2011)
- CoRoT-9b: A long period planet, for which tidal effects are suppressed and the mass of heavy elements may be obtained more accurately (Deeg et al. 2010)
- Kepler-9: the first multi-transiting system with 2 Saturn-like planets in a 2:1 resonance (Holman et al. 2010). The comparison between the two planets show that they have the same Z values, a surprising result for formation models (Havel et al., submitted)
- ...



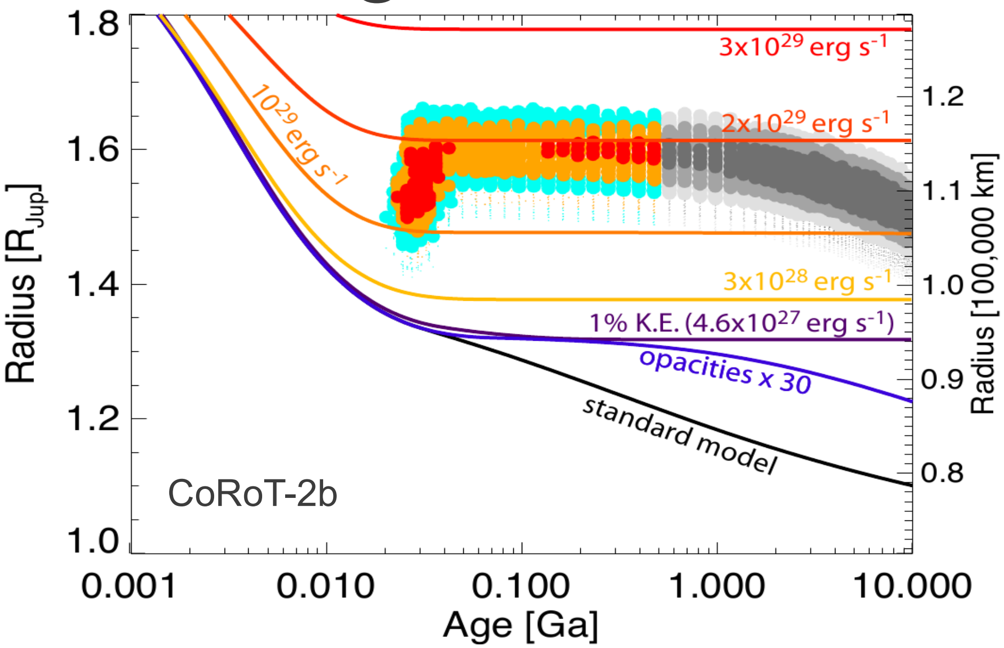
Havel et al. (submitted)

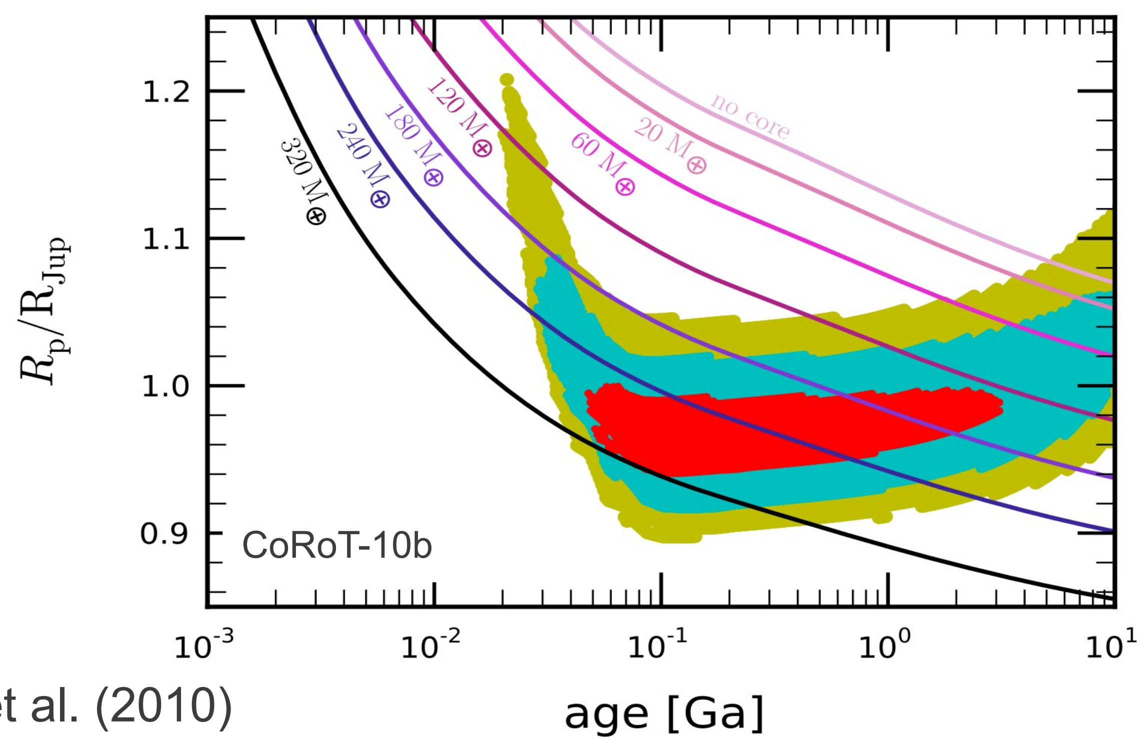
The importance of age

- With CoRoT, ages are weakly constrained (eg. via gyrochronology, Li content, star modelling...). PLATO will be able to provide more accurate ages using asterosismology data.

- CoRoT-2b : the planet has probably undergone a major event less than 50Ma ago (Guillot et Havel 2011). Is the star still in/close to the PMS phase ? Collisions ?

- CoRoT-10b : the planet may have a huge amount of heavy elements, but very poorly constrained (from ~ 120 to 320 Me) for an age estimate between ~ 50Ma to 4Ga. With only a relative precision of 30% on the age, we can restrict the mass of heavy elements within ~ 30Me (more than a factor 3 improvement) !

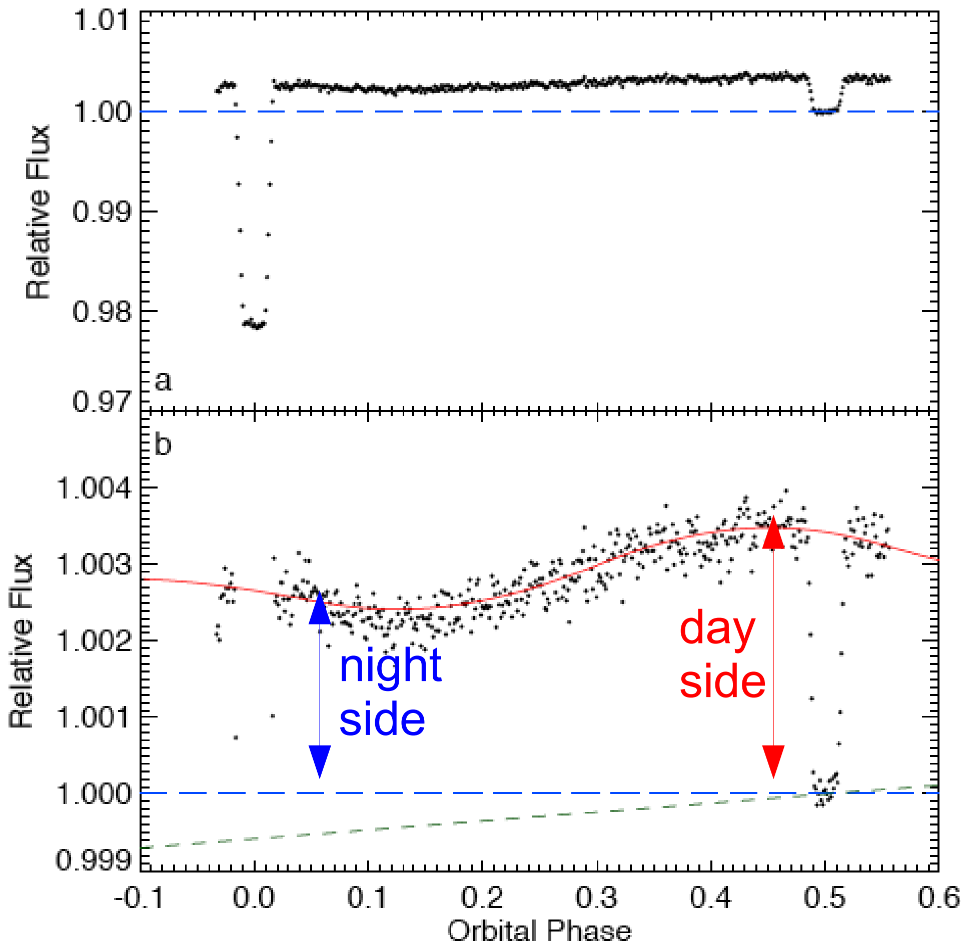




Bonomo et al. (2010)

Extremely accurate lightcurves: exoweather

- As currently possible in the infrared, the measurement of extremely accurate lightcurves allow a measurement of the night side & day side temperatures, and substellar offset.
- This informs us on atmospheric dynamics: strength of winds. This is crucial to understand planetary evolution of highly irradiated planets
- PLATO will discover planets around bright stars, allowing these measurements. With many such examples, we will be able to link sizes, atmospheric winds & compositions.

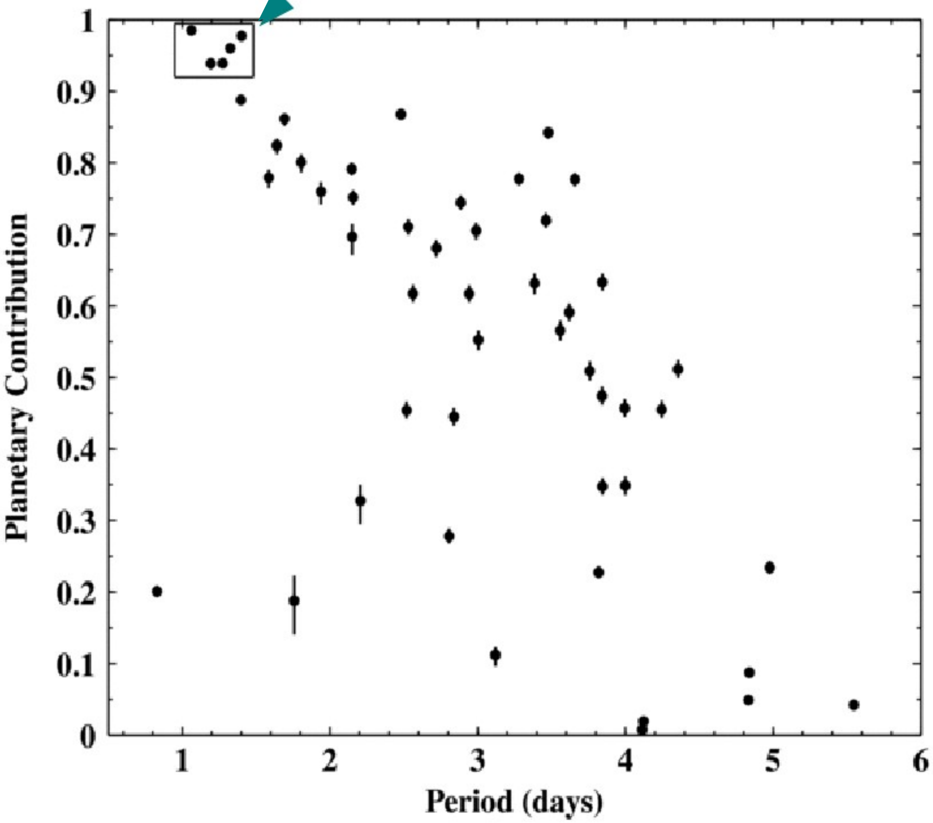


Knutson et al. (2007)

Probing the internal structure with k2

- The k2 love number may be thought as a measure of the level of the central condensation. Its measurement can inform us on the presence of a central core.
- Seager & Hui (2002) proposed to determine it from the planet shape during transit ingress & egress. This is probably too difficult (Barnes & Fortney 2003). However it can be measured from the planet's apsidal precession (Ragozzine & Wolf 2009).
- This requires the discovery of short period, (slightly) eccentric planets, the possibility to determine accurately primary & secondary transits and a long time-base. All of these are possible only with Kepler (with luck) and PLATO (much more extensively).

The k2 apsidal precession is dominant only for close-in (eccentric) planets



Ragozzine & Wolf (2009)

Summary

- Statistical information
  - In order to significantly increase the statistics of giant exoplanets over ground-based surveys, PLATO should discover ~300 to 700 giant exoplanets, i.e. survey 1,000,000 dwarf stars
  - PLATO will discover long-period transiting giant planets. To have 100 with P>100 days, ~5,000,000 dwarf stars are needed. (But already 10 would be great)
- PLATO will also provide accurate ages, and therefore much better constraints on the giant planet's heavy element content.
- Possible only with PLATO's very accurate lightcurves
  - Determination of « exoweather » and link with evolution models
  - Determining the internal structure of close-in slightly eccentric giant planets from apsidal precession due to the planet's flattening.