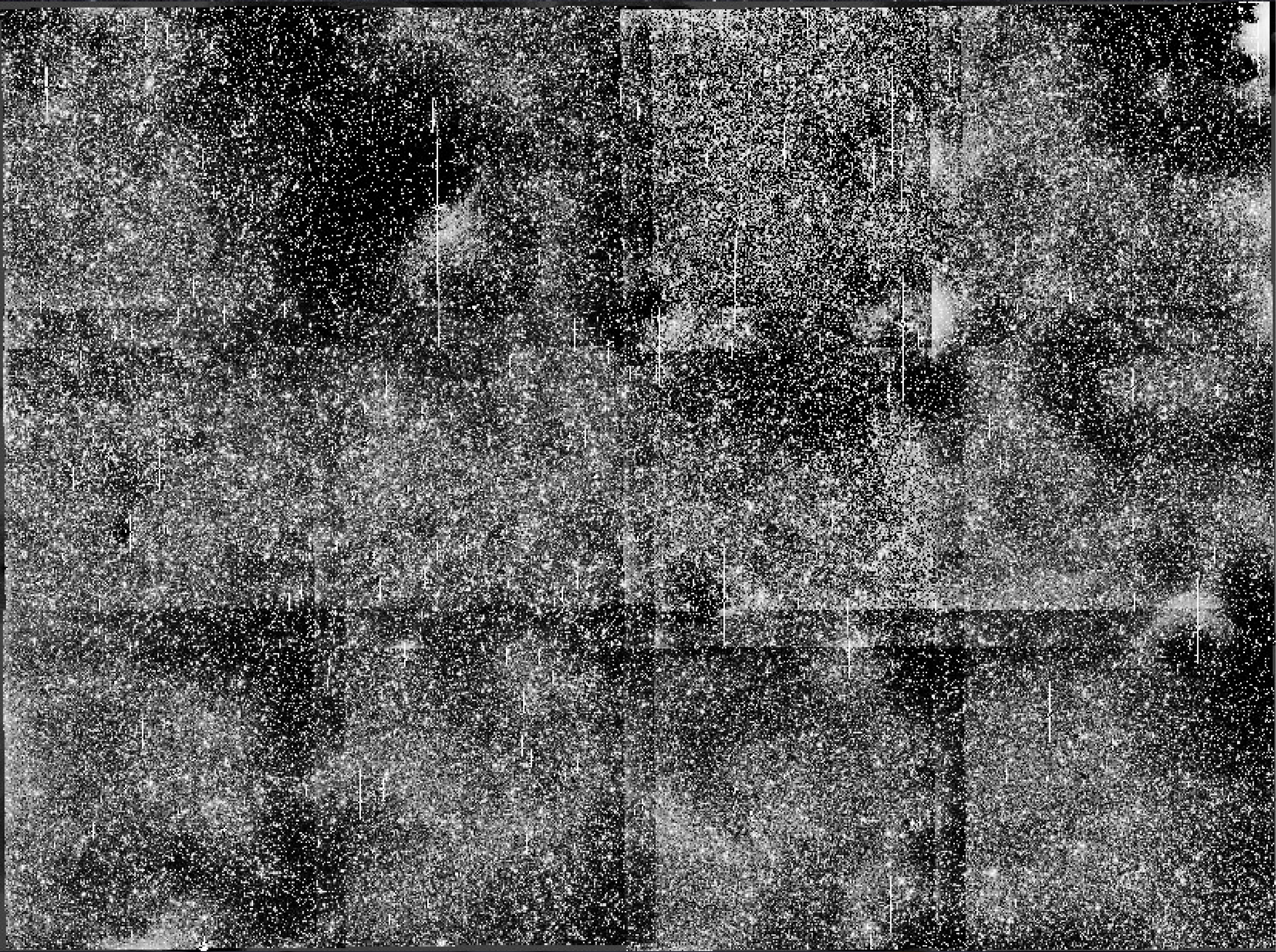


Planet Formation and the CoRoT planet census

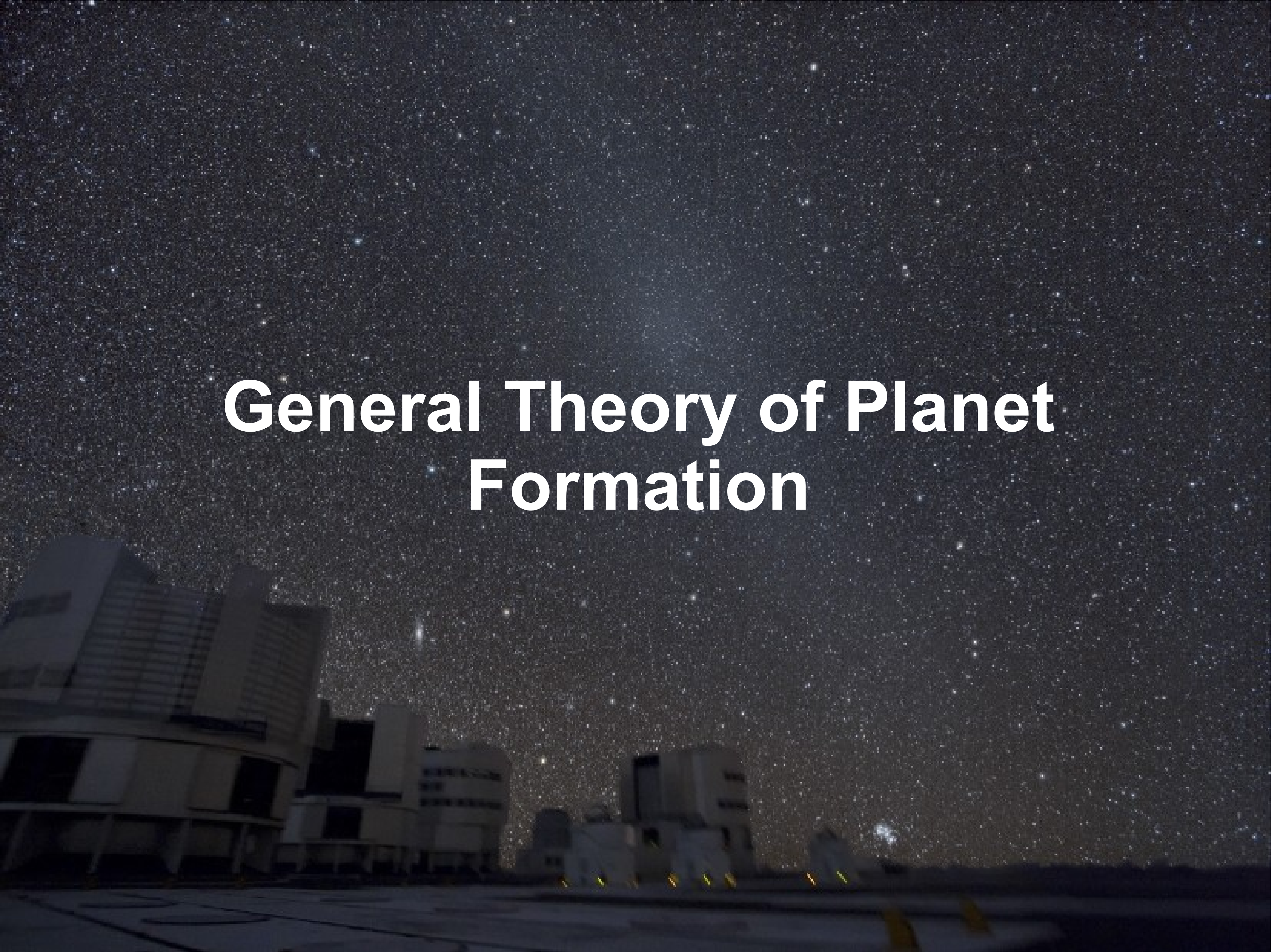
Günther Wuchterl
Thüringer Landessternwarte Tautenburg

Making good planets is hard!

- Understand star formation
- Understand nebula formation
- Understand planetesimal formation

- You heard that we do not know a lot of things
- You heard that theory is hankering behind observations.
- Can we change this,
- Can we build a new theory that is both fast and predictive for all stellar masses and periods?

General Theory of Planet Formation



Assumptions and Principles

- ***Diversity of nebulae***: study planet formation in any gravitationally stable nebula for all stellar masses,
- ***Strong planetesimal hypothesis***: there are always enough planetesimals,
- ***Study cores of all masses including zero*** - Do not separate into nucleated instability or disk instability;

Calculate and Count

- **Choose host star and orbital period**
- **Planetary equilibria with all core masses**
- **Hydrostatic equilibrium (P vs. core and gas)**
- **Thermal equilibrium (L vs. planetesimal accr.)**
- **Connected to the nebula:**
  - **mechanically: force balance with neb. pressure, and**
  - **thermally: radiate into equilibrium temperature nebula**

How to understand this?

- **Think of planet formation as analogy to the van der Waals gas with gravity as the long-range force,**
- **Take planets as analogy to the liquid phase in coexistence with the nebula as gas,**
- **Look at**
  - **Pečnik and Pečnik+W for the isothermal case**
  - **Schönke 2007 etc., for stability and analytics**
  - **Broeg and Broeg+W for realistic planets**
  - **Wuchterl et al. For the CoRoT-stellar-mixture**

Results

Planetary equilibria in stable nebulae

Radiative/Convective gas-spheres; SCVH + Ferguson

Stars: spectral types A,G,K,M; 0.4 to 2 $M_\odot$

Periods: 1 to 64 days.

Mark 1: Dec 2005

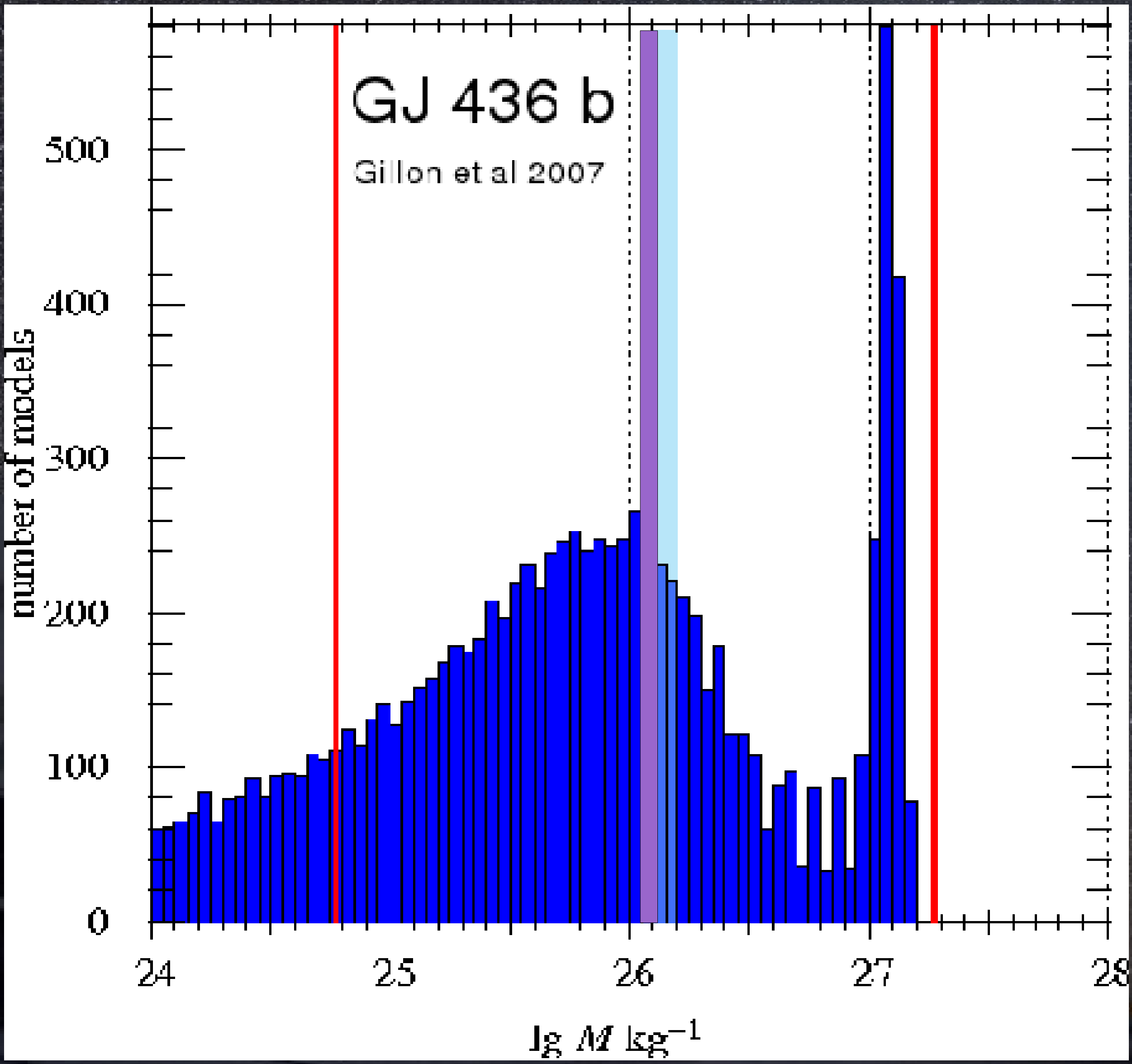
Mark 2: Sept 2007

Mark 3: June 2008

At Chris Broegs webpage

http://www.space.unibe.ch/~broeg/

GJ 436 b + HAT-P11b: Hot Super-Neptunes



Planetary masses

Blue: CoRoT Mark 1 theoretical mass spectrum for 0.4 M_{Sun} and 4 d period (Mark 1.1 Broeg '06);
Red: Earth and Jupiter;
Light-blue: GJ 436b.

HAT-P-11 bNeptune
25.7 M_E
4,9 d

Theoretical planet populations for CoRoT – Two Steps

1. ***Formation* at *short* periods ("launch prediction"): planetary IMFs for CoRoT stellar masses and CoRoT planet periods,**
2. ***Evolution* for these initial populations: radii and epoch of observation radius distributions;**

1: 2006 Dec. 26th: CoRoT Launch Prediction: Planetary Masses from Formation Theory

Wuchterl et al.; 2006+n, Lammer et al. 2006+n
Dec. 26th: **astro-ph/0701003 ;astro-ph/0701565**

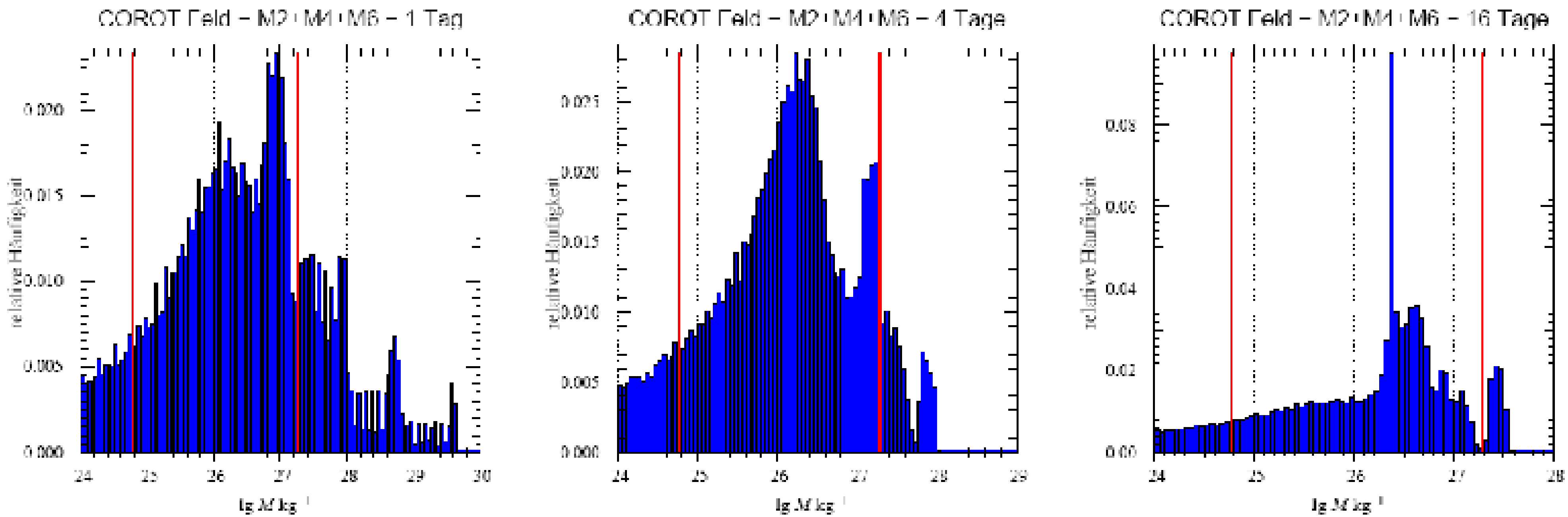


Fig. 1. Theoretical planetary initial mass functions calculated from planet formation theory for a typical CoRoT-field. Results are shown for planetary orbital periods of 1, 4, and 16 days, from left to right. The relative frequency is plotted as function of lg mass in kg. Vertical red lines mark the Earth and Jupiter masses. ~ 10^6 planetary models in total. Structures of width < 0.3 dex have to be taken with care, because of undersampling in spectral type due to the unexpected richness of the mass-spectra. ('M2+M4+M6' designates planetary core-accretion and is not related to the stellar population).

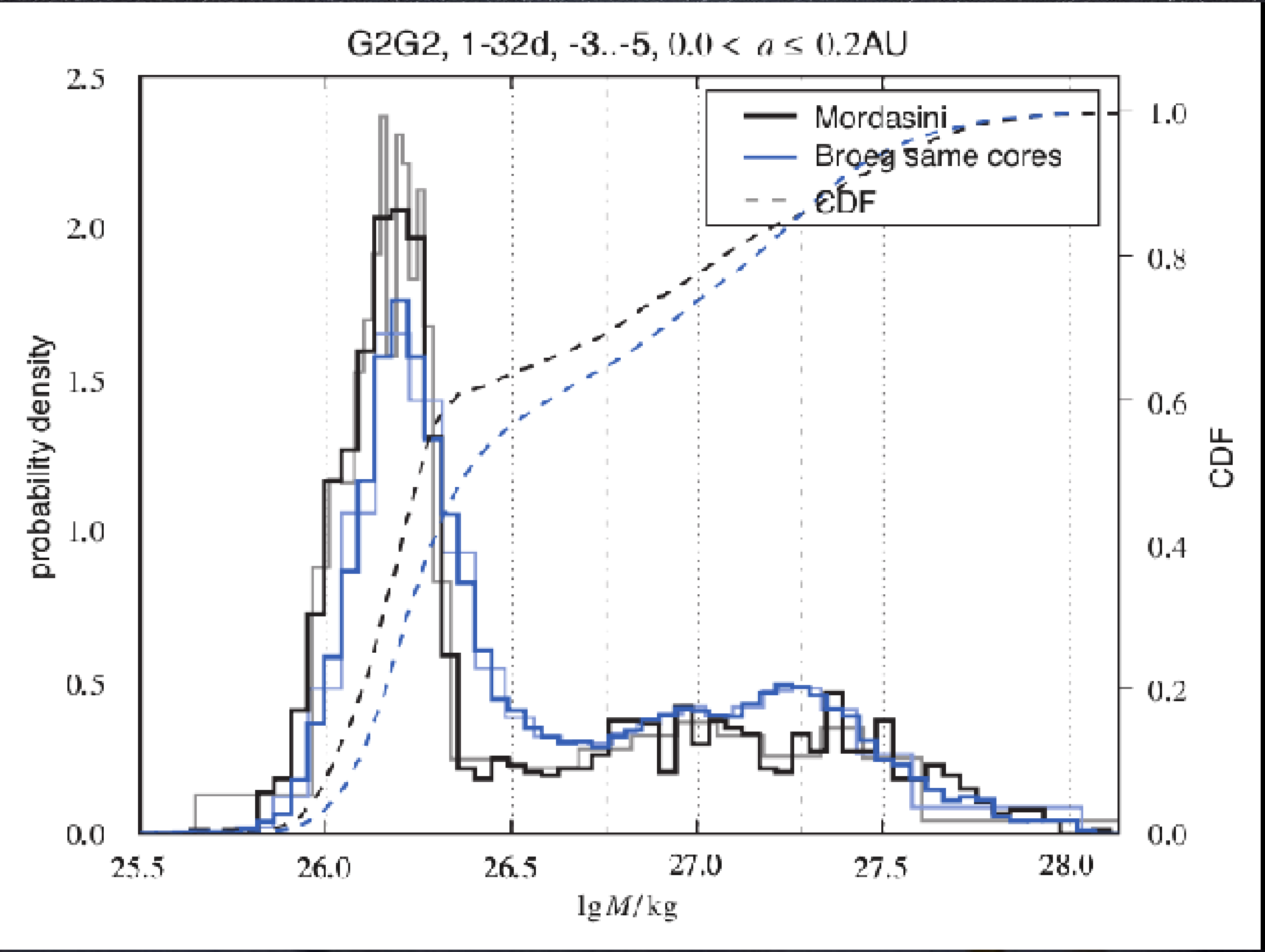
How is this theory doing?

Minimum Embedded Equilibrium Mass versus observations

by Christopher Broeg (Icarus submitted)

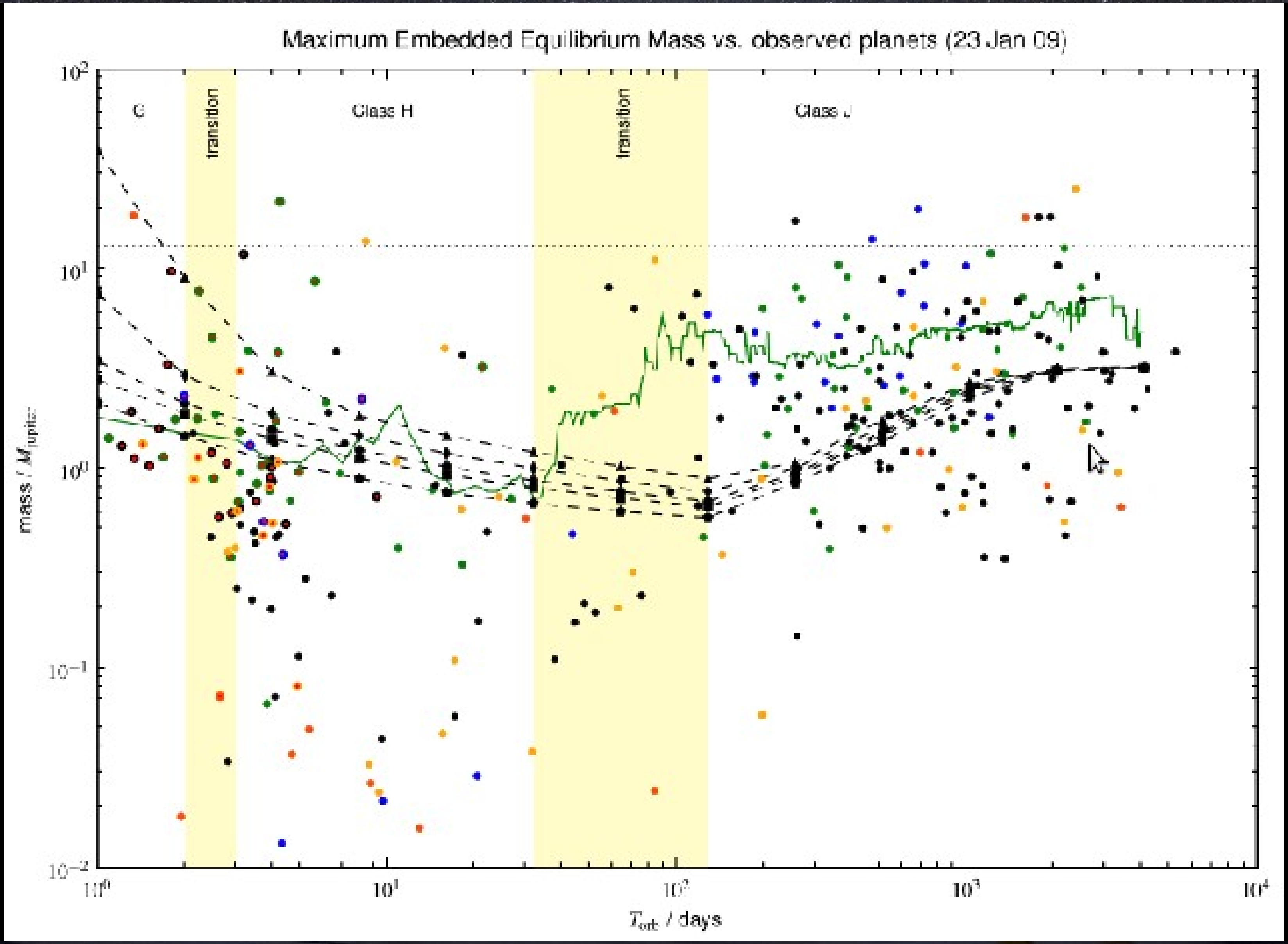
Is this queer? Comparison to conventional theory

see Broeg at Symp CoRoT



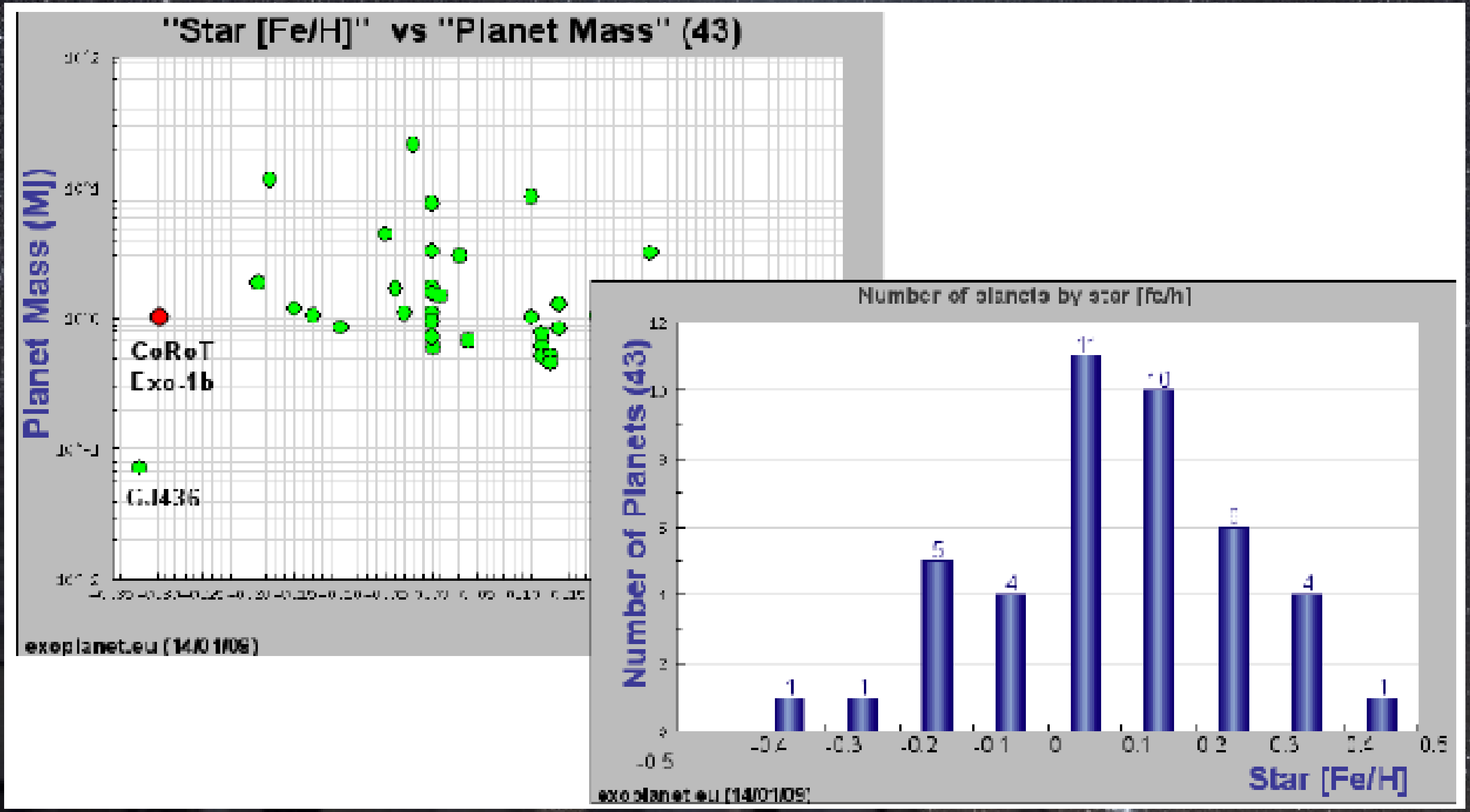
What about observations?

See Poster by Broeg

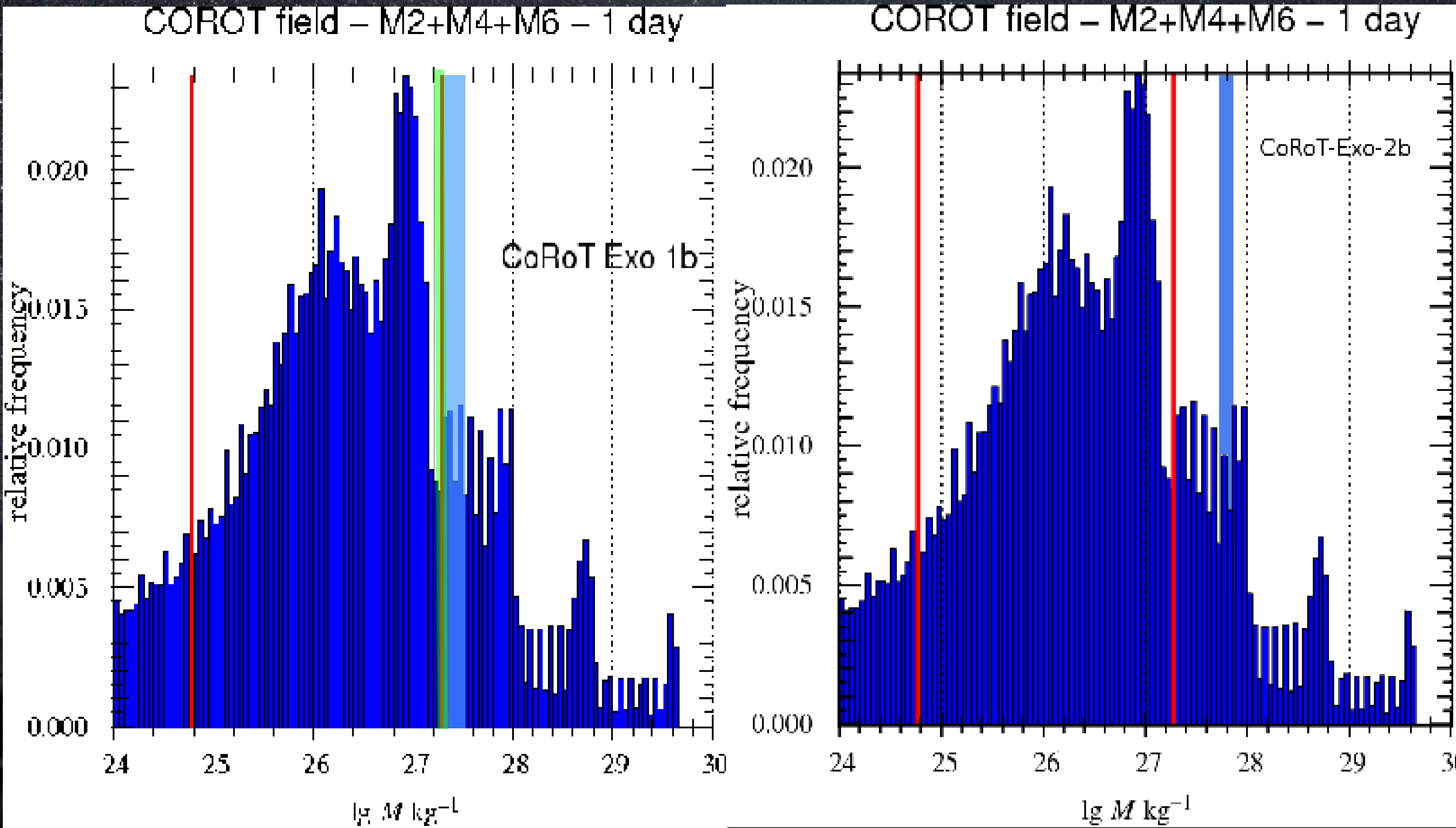



The CoRoT Seven

1: Planet around a metal poor star

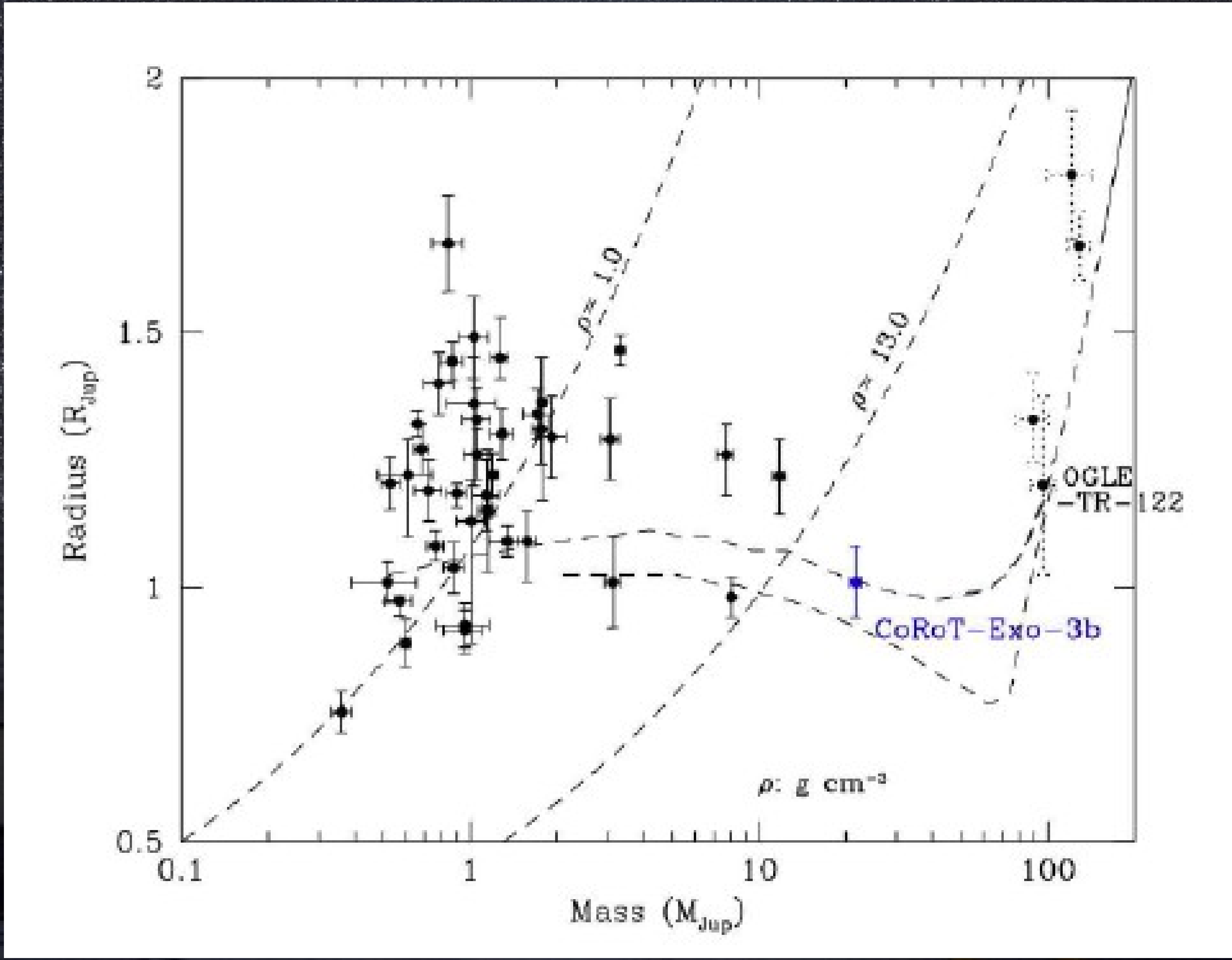


CoRoT-Exo-1b, -Exo-2b

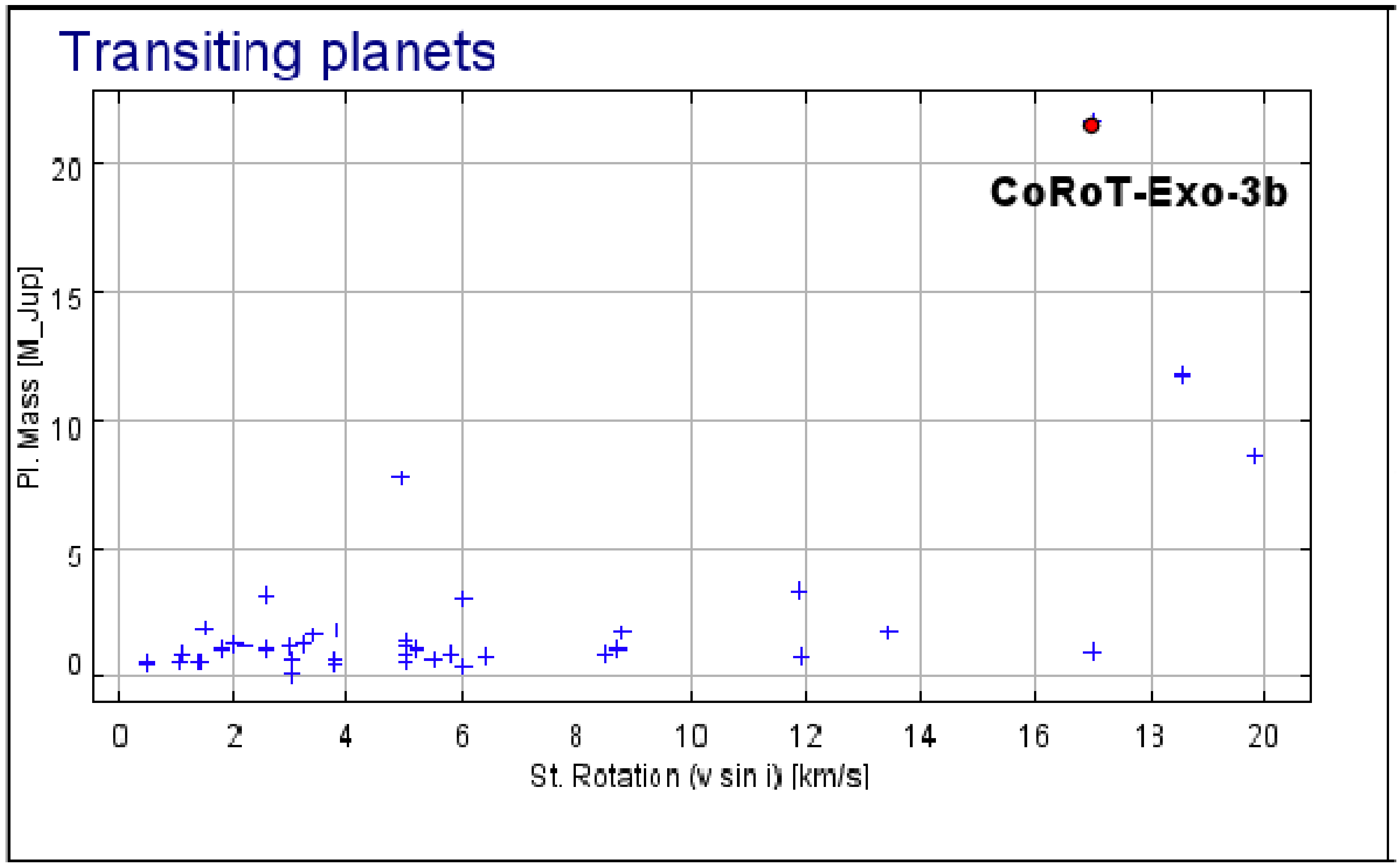


Theoretical predictions: Broeg 2006, 2007, Wuchterl et al. at CoRoT-launch, astro-ph/0701003

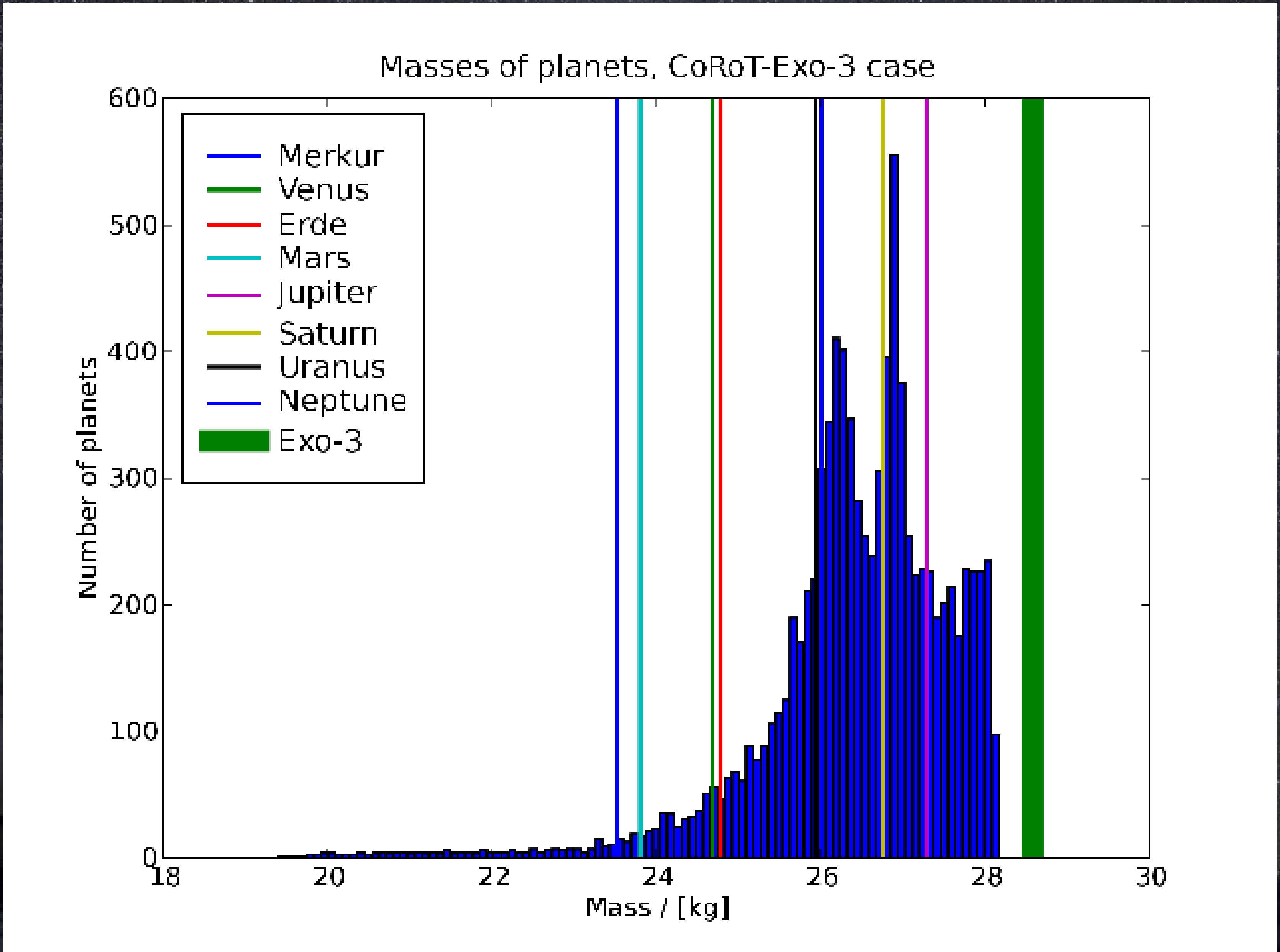
3: Planet or failed star !



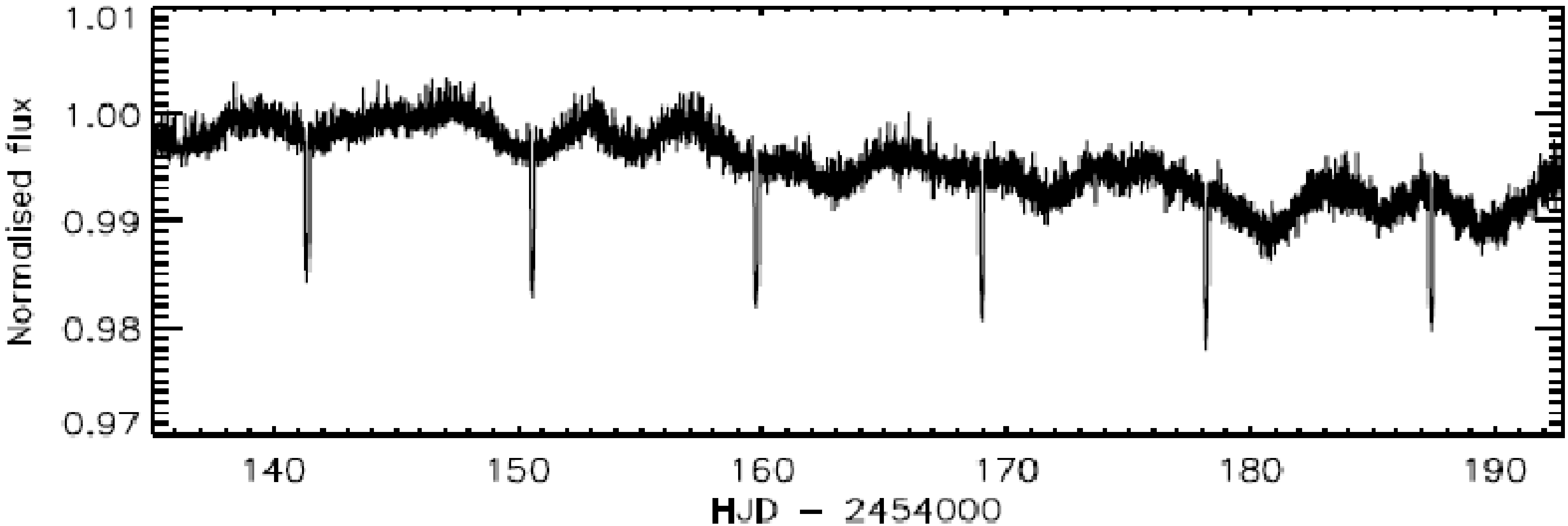
Planet around fast rotator



Planets at 1d/1M$_{\odot}$ vs CoRoT-Exo-3b



Loose synchronous 9d orbit

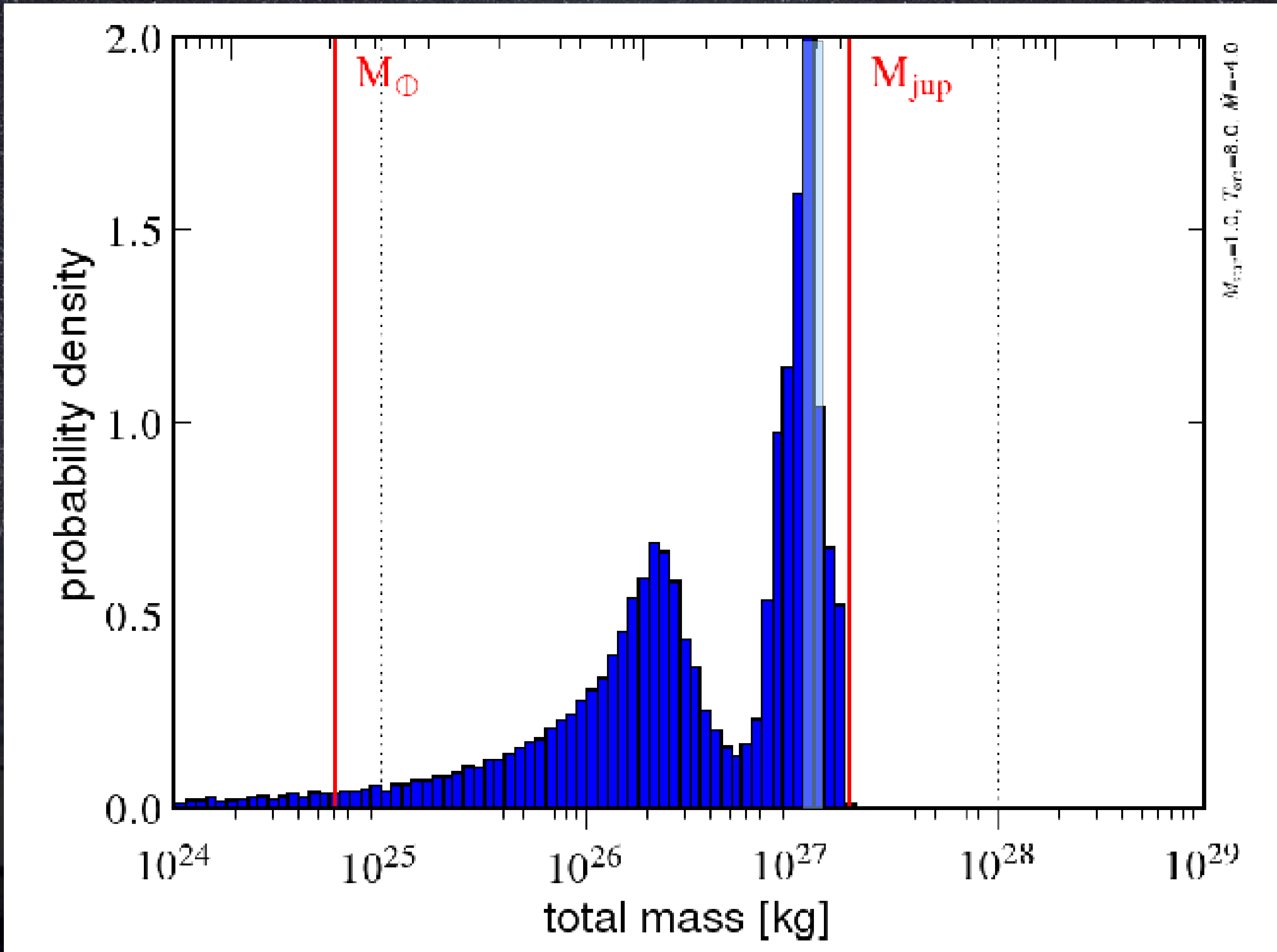


F0V

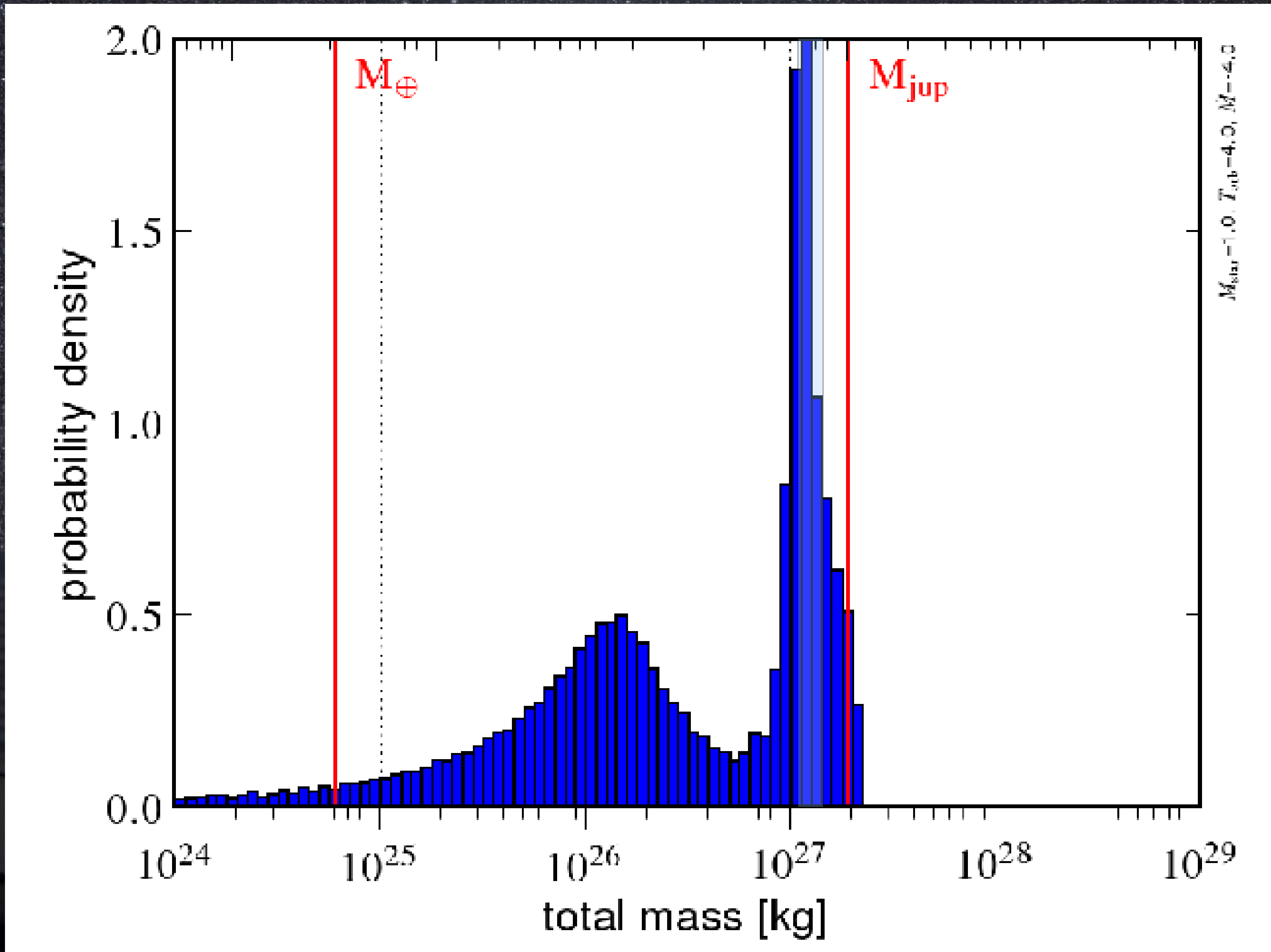
V=13.7 mag

P*=8.87+/-1.12

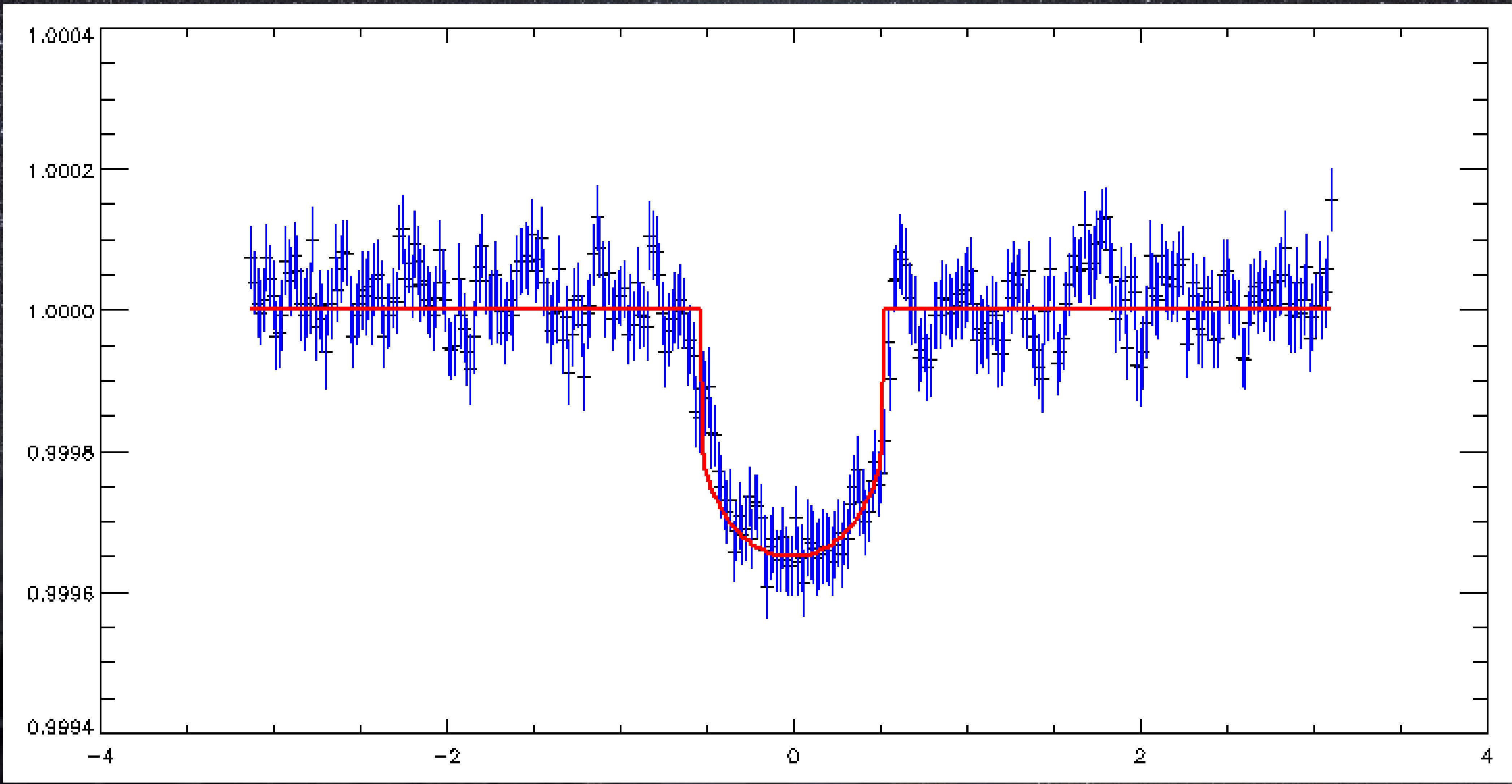
CoRoT-Exo-4b and theory for Exo-4

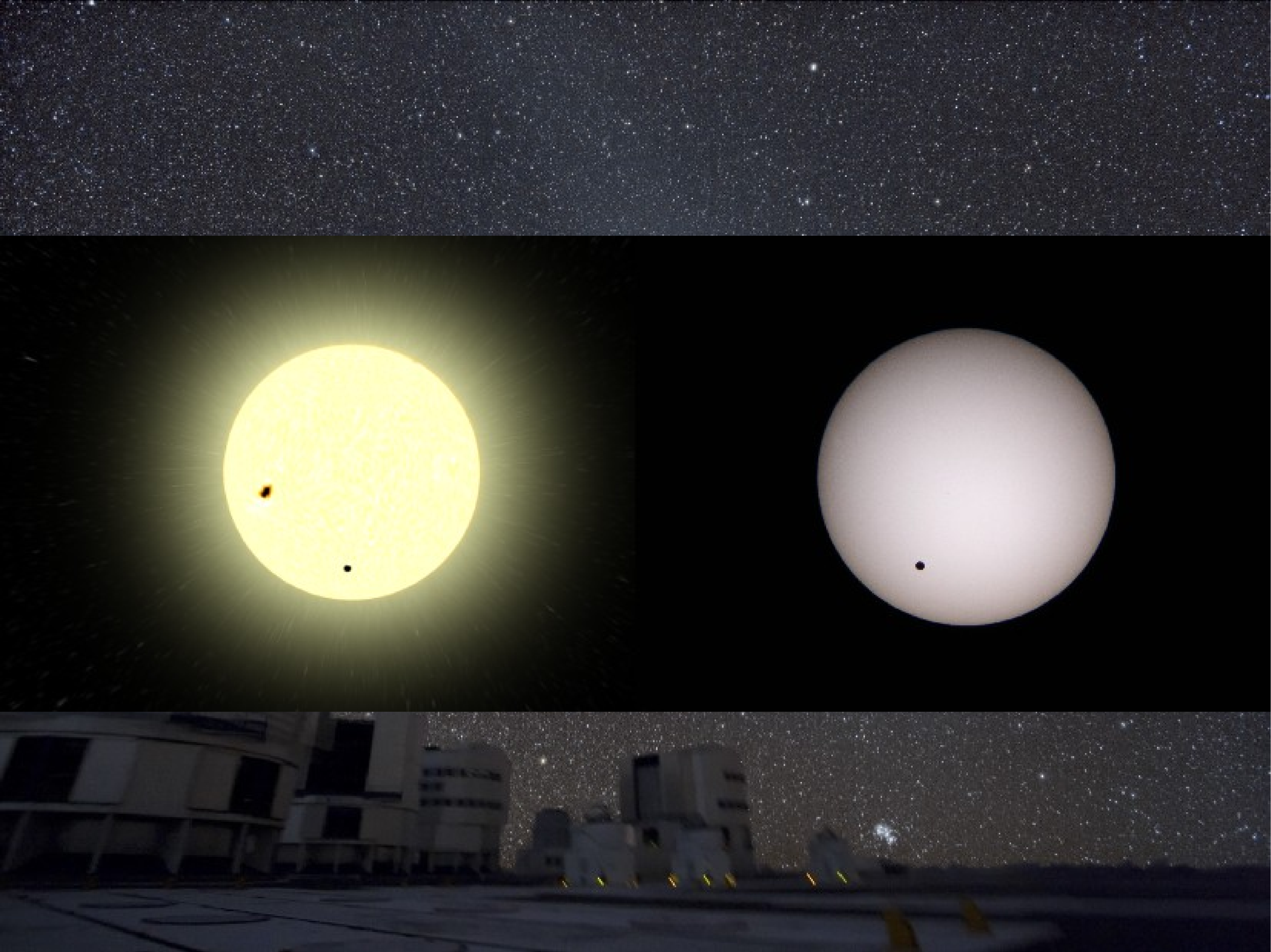


CoRoT-Exo-5b and theory for Exo-5



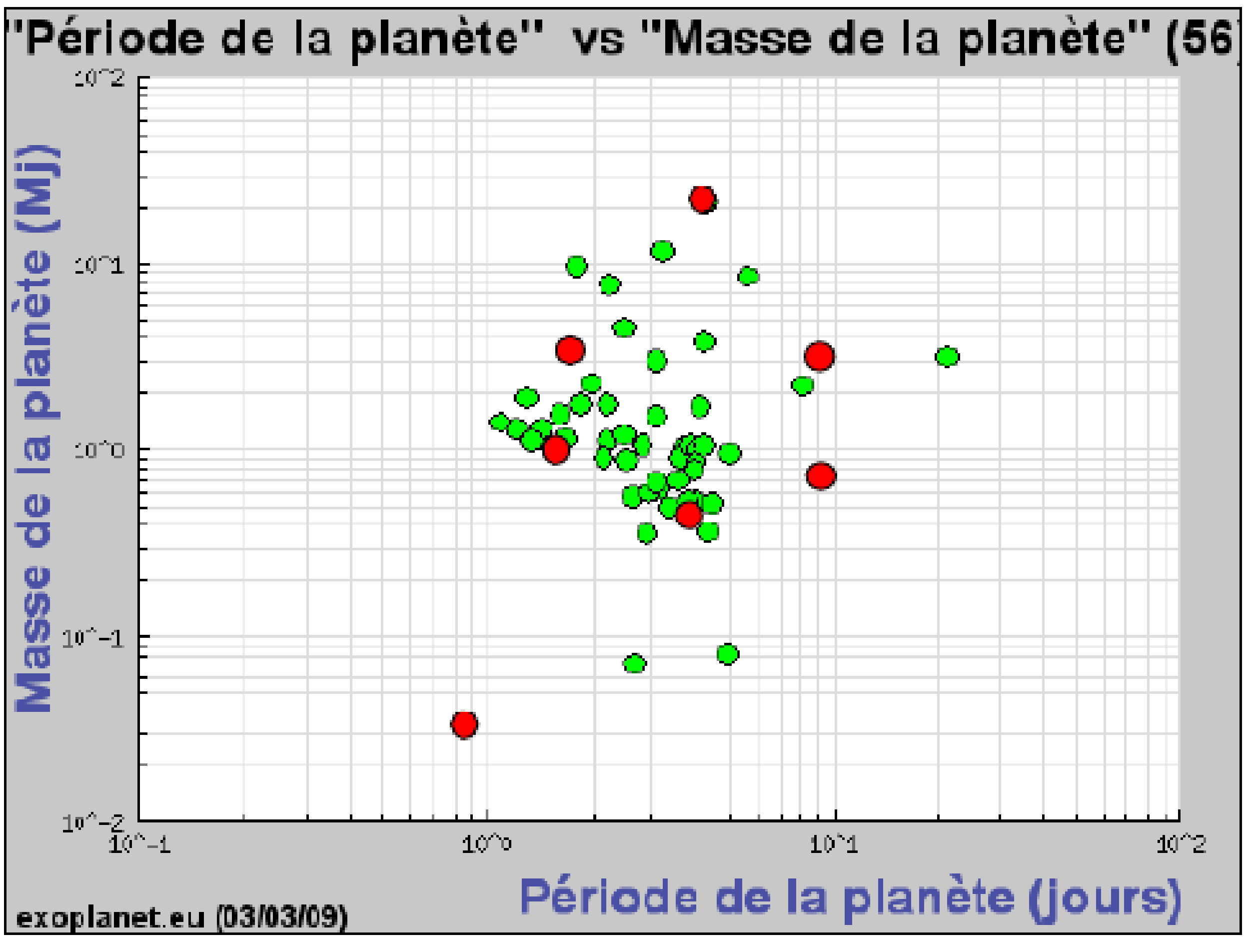
Transit signal: LRa01_E2_0165





CoRoT-Exo-7b
the movie

CoRoT planets in red



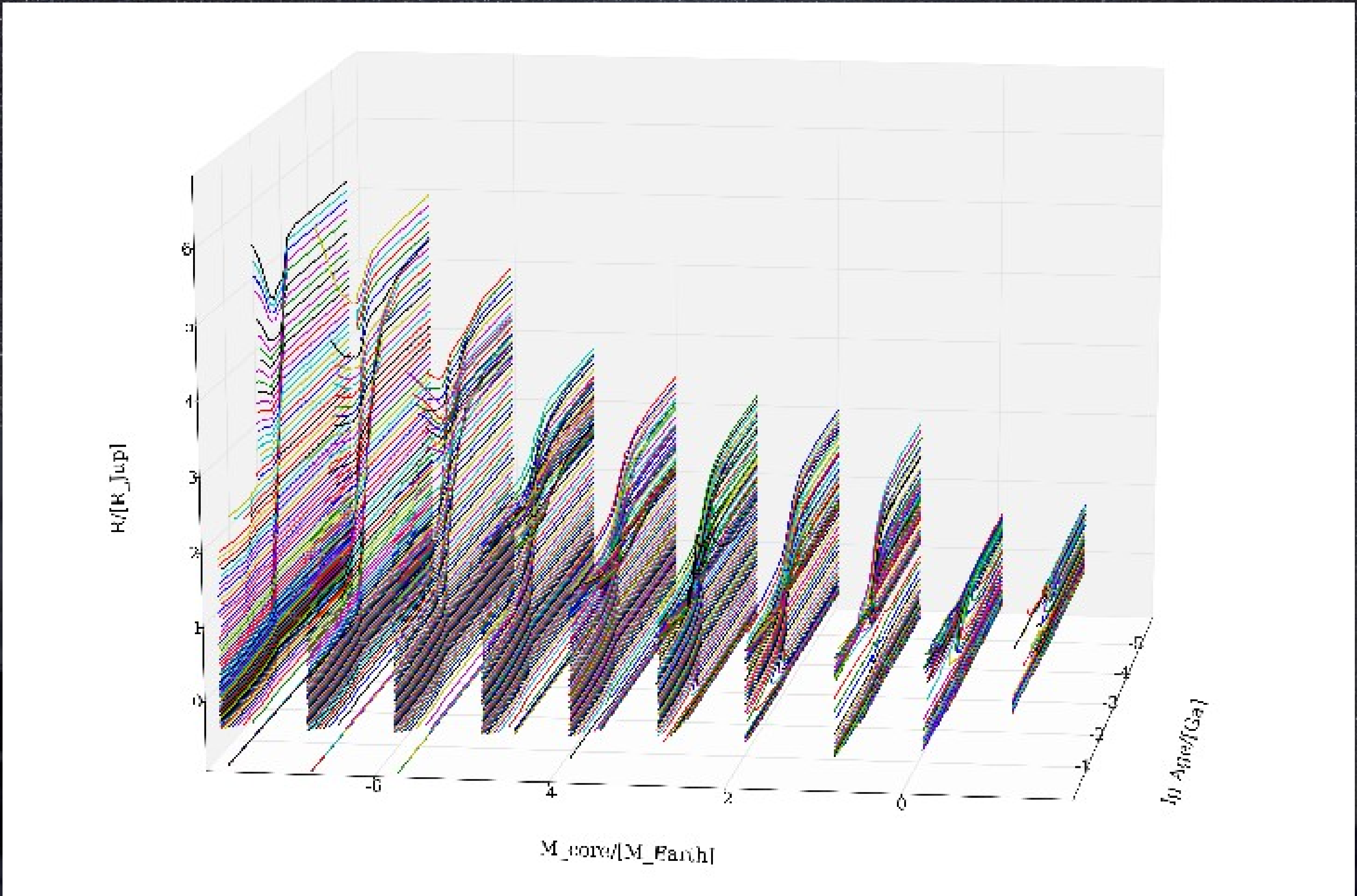
Planet
- around fast rotator
- around the most metal poor star
- on loose synchronous orbit (˜10 days)
- Super Earth at very short period (Rp=1.6REarth)

2: Evolution and Age
From initial to present radii

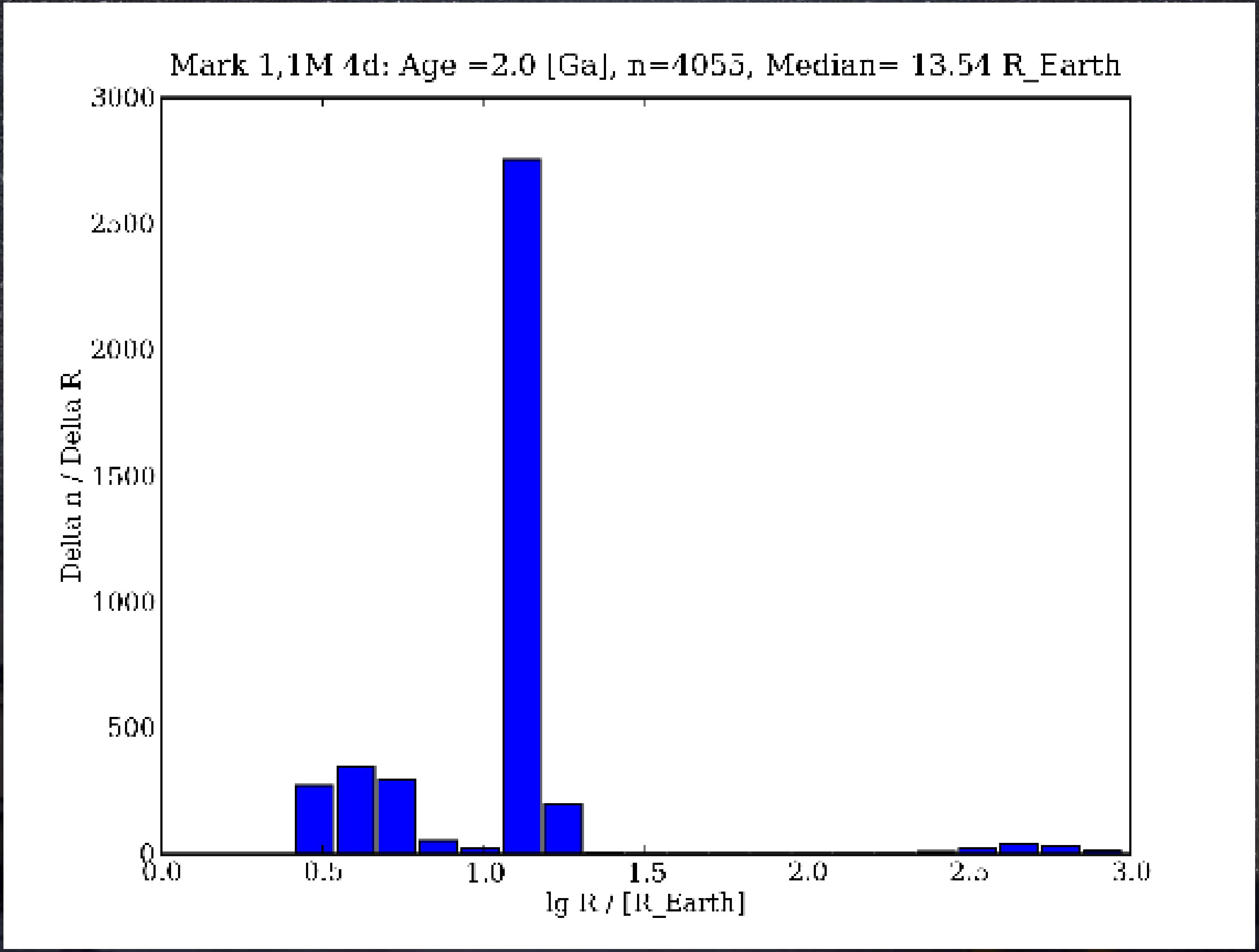
Initial masses and interior structure for the “IMF”-ensemble of planets

Evolution of planetary populations:
switch-off planetesimal accretion
nebula decompression (if any)

Radius versus time for population



Evolution with constant mass => radius function: M_Sun, 4 d, 2 Ga



Conclusion

- General Theory is faster than observation,
- ... is predictive for the entire discovery space, stellar masses 0.4 to 2 , 1 to 50 day online,
- CoRoT-planets at or near peaks in the mass spectra,
- Distribution of radii bimodal as masses,
- Transit searches need to “jump” from Jupiters to Neptunes with not much in between.


CoRoT-Exo-7b - goodies
http://corot.TLS-Tautenburg.de/Exo-7b

Src01 mosaic, Alfred Jensch 2m TLS Tautenburg, Bringfried Stecklum

Main sequence - requirements

- Force equilibrium
- Energy balance
- Main Sequence:
  - Force-equilibrium
  - Energy balance: source (planetesimals) = loss (radiation into exterior)

A planetary main sequence
To be or not to be

- Planet formation and evolution is near static most of the time: checked by non-linear rad-fluid-dynamics (Wuchterl 1993)
- Dynamical paths to multiple planetary equilibria (Wuchterl 1995, Wuchterl, Guillot + Liss 2000)
- ... is hydrostatic for HD 149 026 case (huge core) and short periods (< 16d) in general (Broeg and Wuchterl)