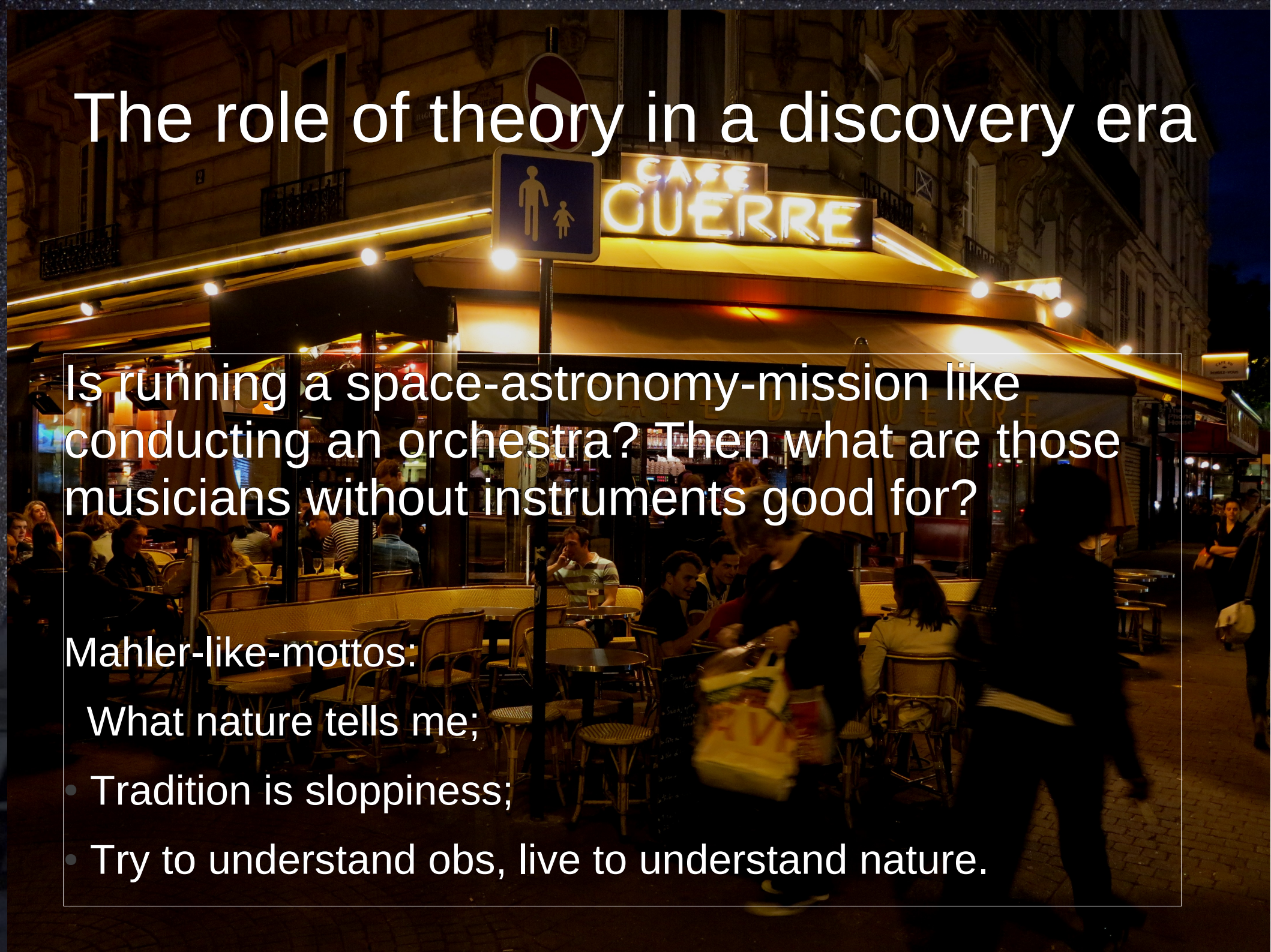
Planet Formation
What CoRoT tells us

Günther Wuchterl
Thüringer Landessternwarte
CoRoT/DLR
Tautenburg

Title partly following design title format of Mahler symphony no. 3

The role of theory in a discovery era



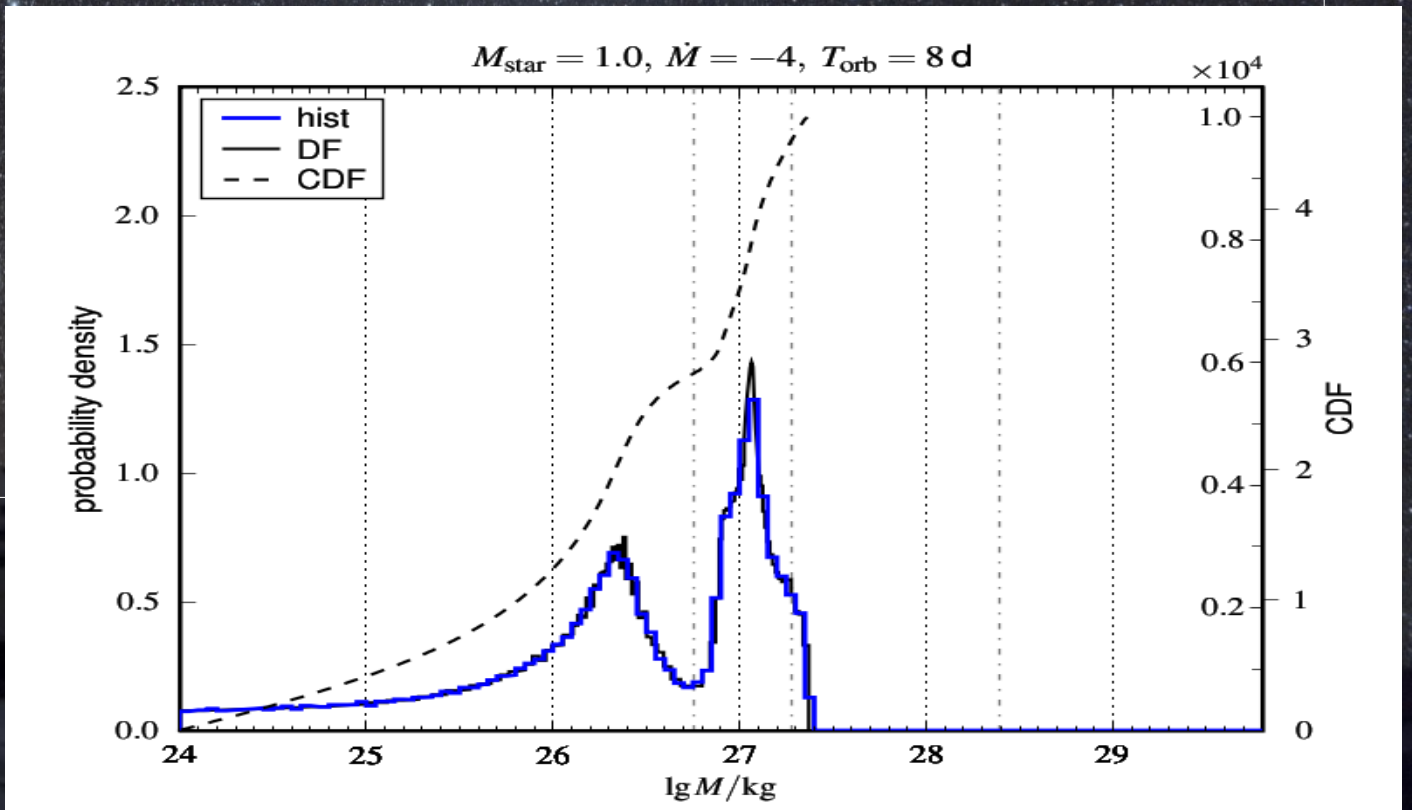
Is running a space-astronomy-mission like conducting an orchestra? Then what are those musicians without instruments good for?

Mahler-like-mottos:

- What nature tells me;
- Tradition is sloppiness;
- Try to understand obs, live to understand nature.

A new robust predictive theory ready at the CoRoT launch

- Physical foundations of planetary mass from formation theory – Pečnik, Broeg, Schönke
- Planetary Statistics – Neptunes rule, Broeg 2005, 2006, 2009 – CoRoT Mark 1,2,3



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**

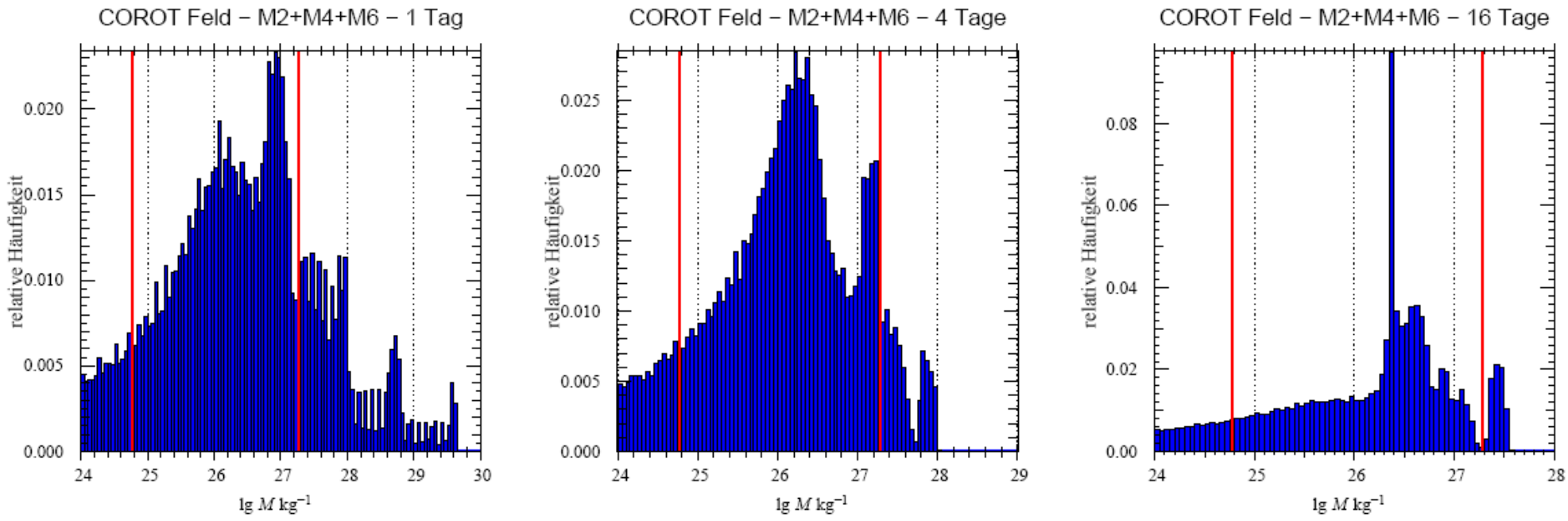


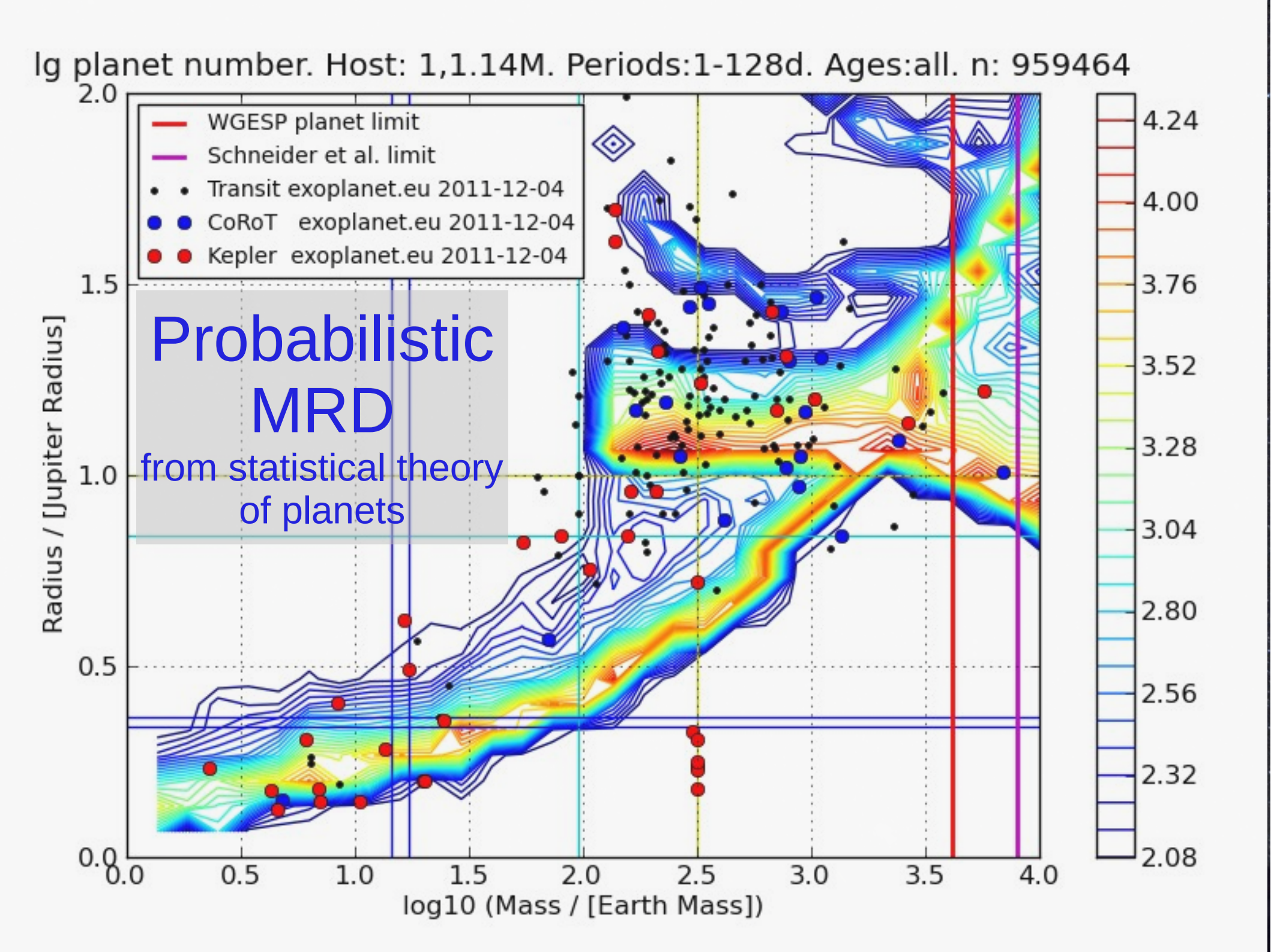
Fig. 1. Theoretical planetary initial mass functions calculated from planet formation theory for a typical CoRoT-field. Results are shown for planetary orbital periods of 1, 4, and 16 days, from left to right. The relative frequency is plotted as function of lg mass in kg. Vertical red lines mark the 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).

Planet formation theory

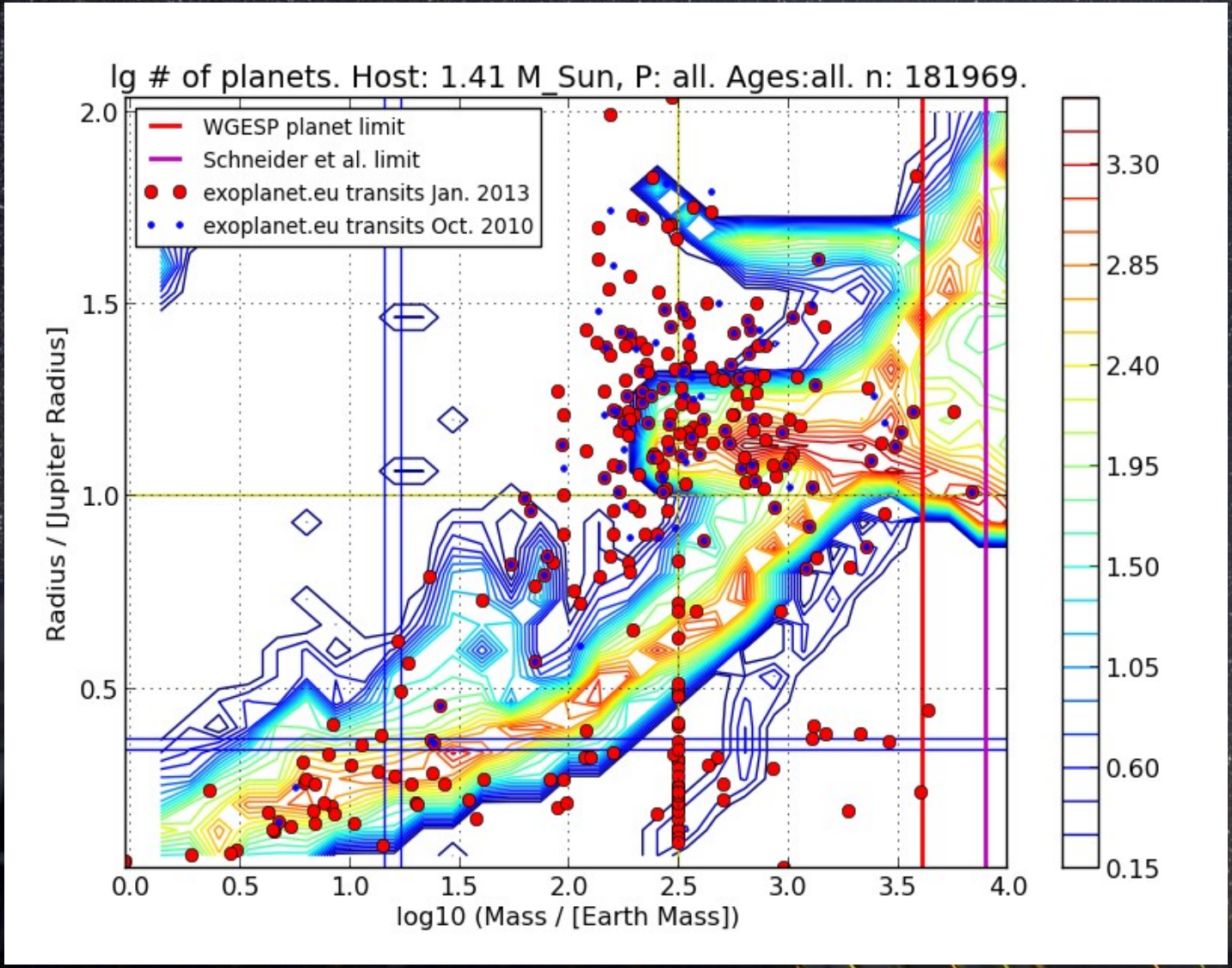
The unknown, randomness and chaos (week and strong) require a statistical approach: a general theory of planets that rest on simple, phyiscal assumptions and produces a probabilistic mass-radius-diagram (MRD) for sorting the main observables.

The CoRoT Mark-1R theoretical planet atlas

- 100 x 100 x 3 x 5 x 8 = 1.2 Mio (15 TB) of planets and planetary evolutions
- 200 Mio planetary structures + radii + lum.
- 0.8 – 2 solar mass hosts (A,F,G,K stars);
- 1 d – 128 d orbital periods;
- Complete: all „simple“ core – env. objects from stable nebulae – including zero core mass;
- Mass spectra;
- Radii-distributions for ages from 0 to > 14 Ga;

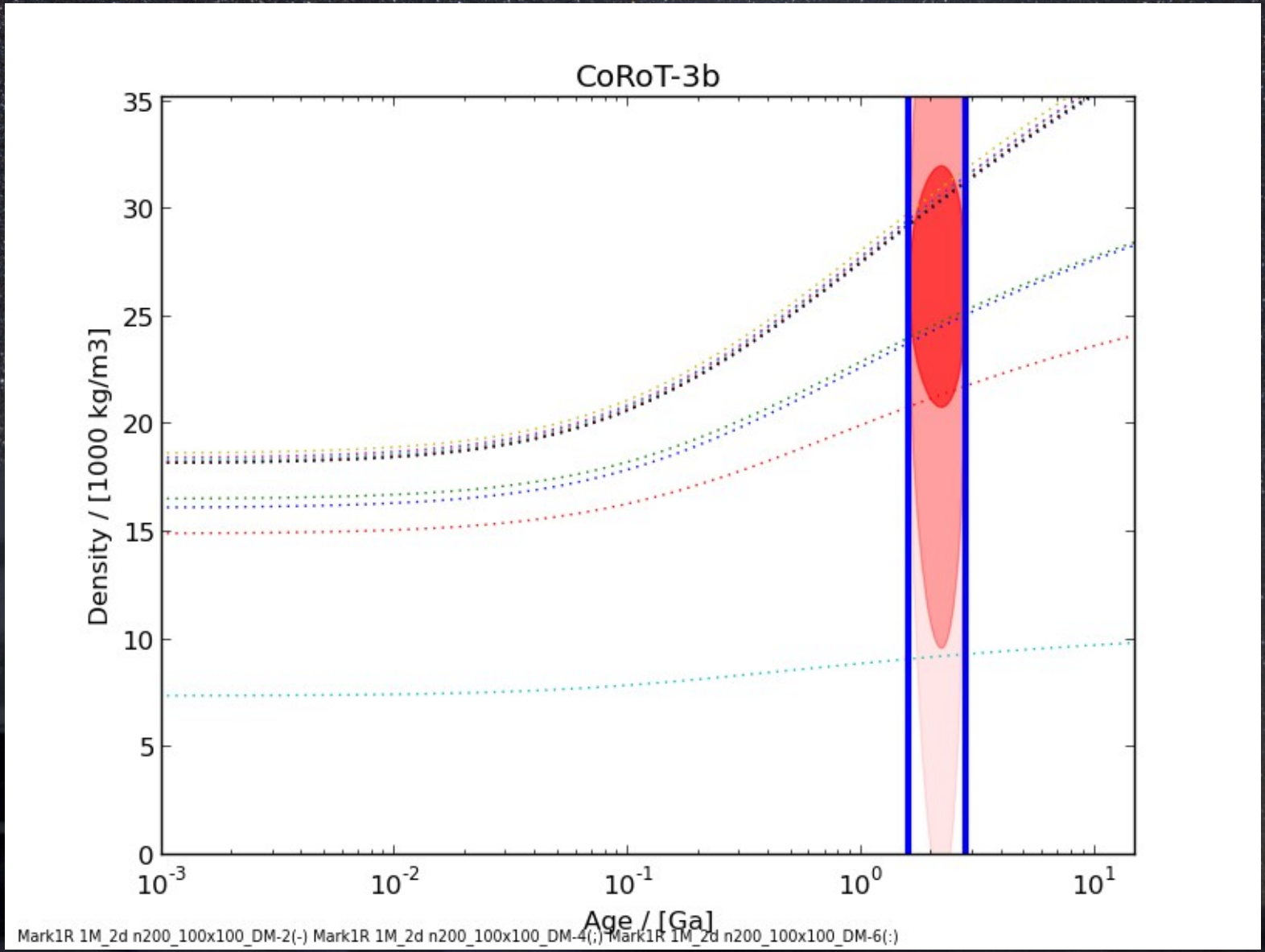

lg planet number. Host: 1,1.14M. Periods:1-128d. Ages:all. n: 959464
WGESP planet limit
Schneider et al. limit
Transit exoplanet.eu 2011-12-04
CoRoT exoplanet.eu 2011-12-04
Kepler exoplanet.eu 2011-12-04
Probabilistic MRD
from statistical theory of planets
Radius / [Jupiter Radius]
log10 (Mass / [Earth Mass])
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.24
4.00
3.76
3.52
3.28
3.04
2.80
2.56
2.32
2.08

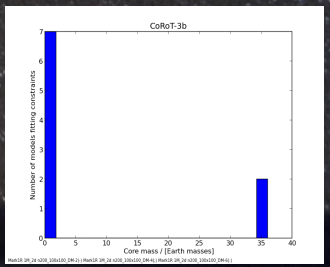
Low density giants – what anomaly? CoRoT-2, -18, the hot giant sample



CoRoT-2: tells about the properties of young planets, see M. Havel's talk

CoRoT-3: the nature of planethood





What CoRoT-7 tells us

remember V. S. Safronov

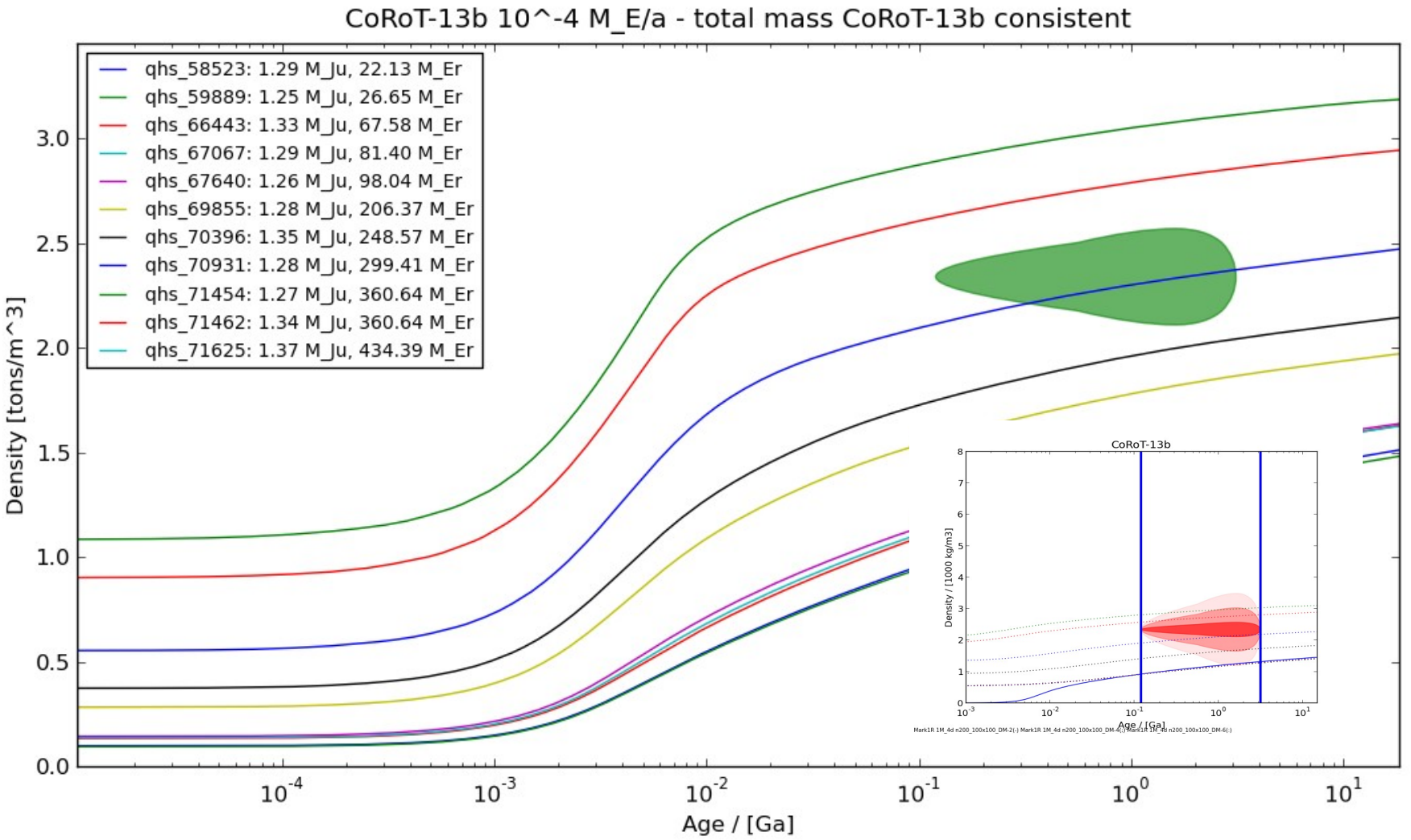
- 6 times the mass, 5 times the volume of earth → high density, condensible element planet;
- Planetesimal hypothesis holds *outside* the solar system and for stars unlike the Sun;
- Planetesimal accretion can be even more efficient than in the SoSy;
- Ultra-compact system b,c,d → dynamically full like SoSy;
- „terrestrial“ systems common in our neighbourhood

CoRoT-9b: A quantum of solace

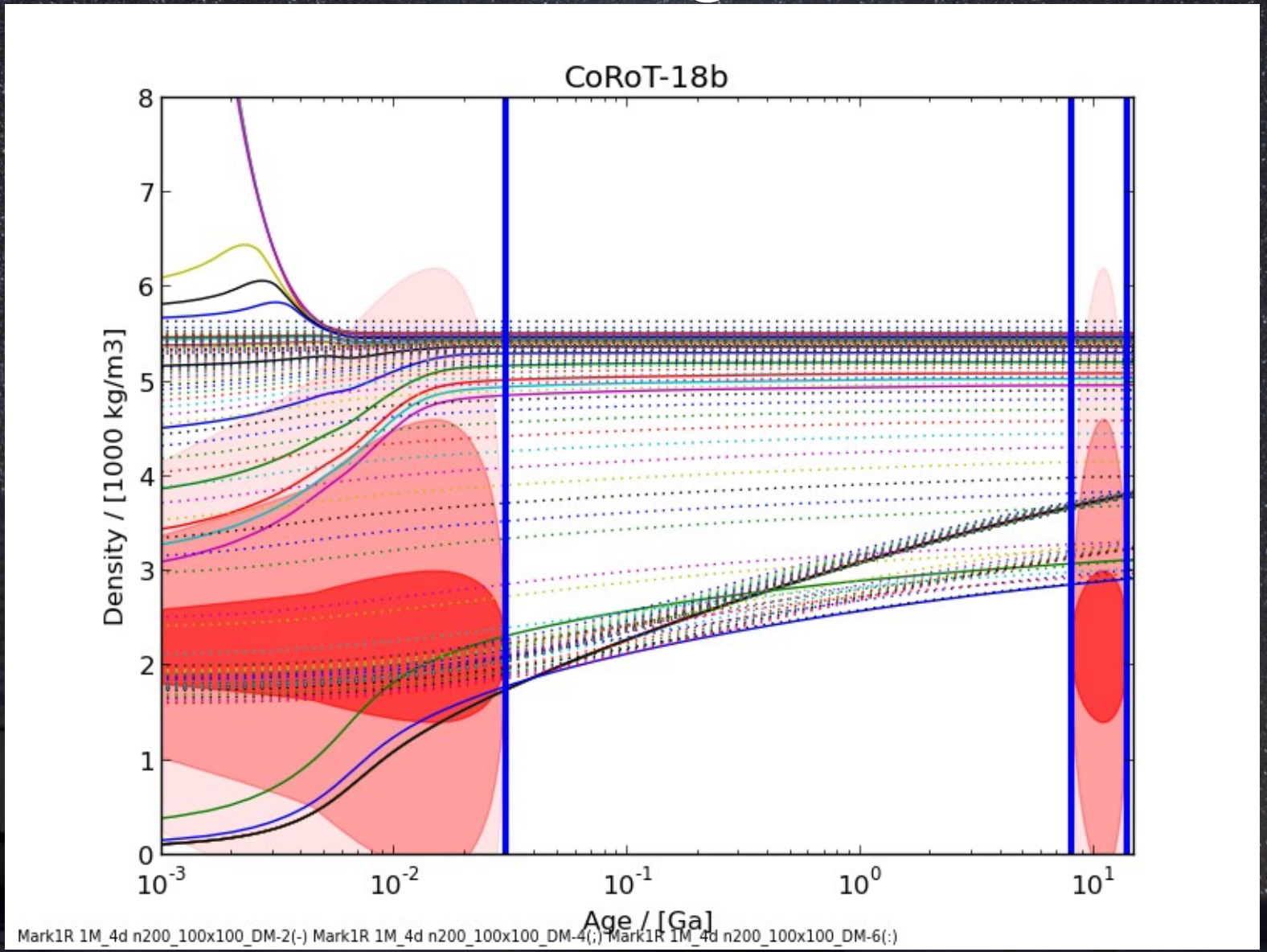
- 100 d – far enough away;
- Radii of remote Jupiters are consistent with standard theory;
- … as are the radii of planet-BD-transition mass objects (CoRoT-3b, -15b, -27b).

CoRoT-13 supercritical exo-cores

(like an extrem HIP 80 838 b aka HD 149 026 b)



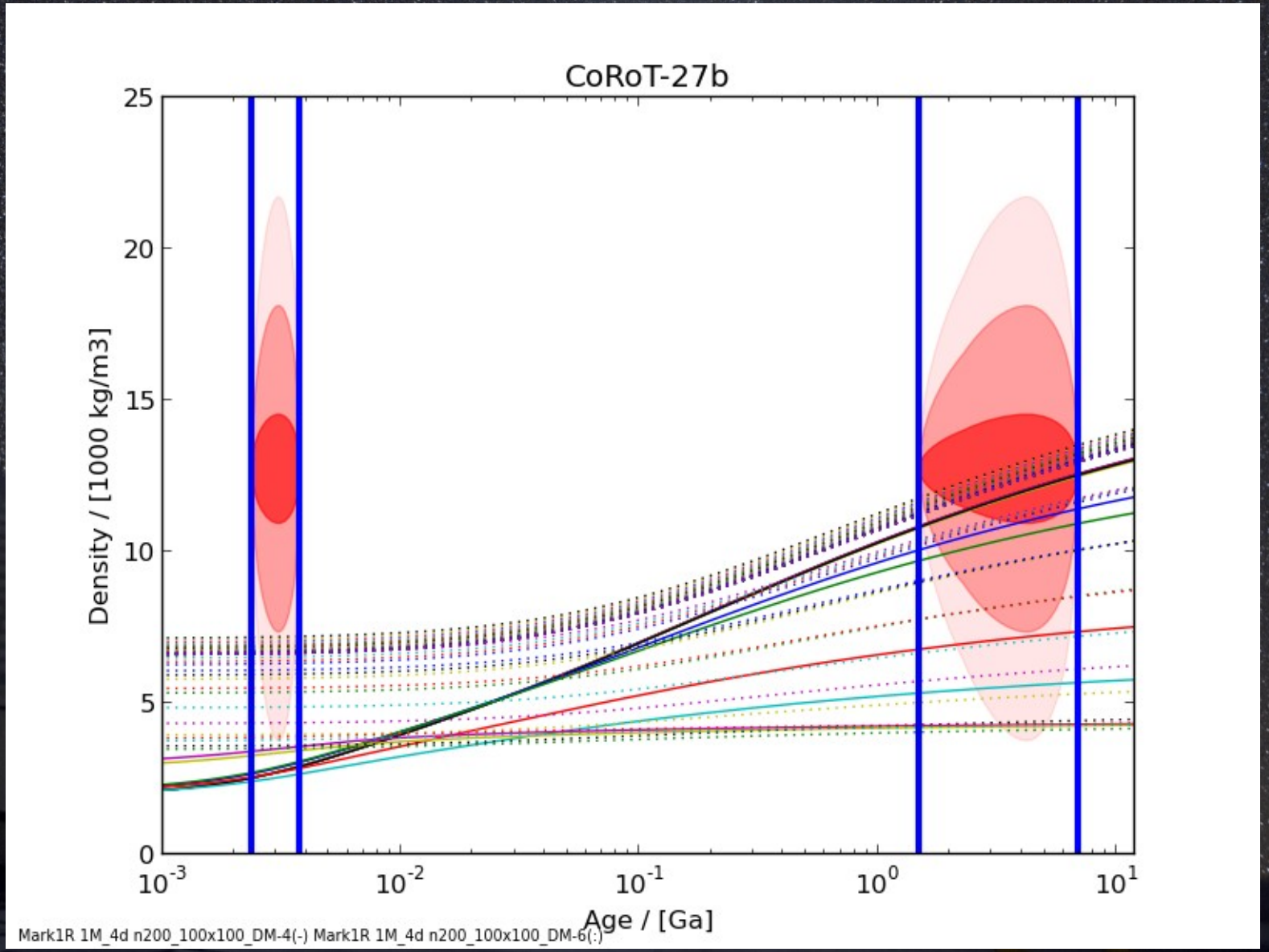
CoRoT-18b: fast clues to early evolution and origins of diversity



CoRoT-20: monster cores point to efficient planetesimal accretion

- Guillot/Havel: 400 to > 1000 M_earth core
- Jupiter mass(es) of condensibles!
- Maximum mass nebula:
  1.14 M_Sun * 0.1 (stable nebula) * 0.02 (Z) ~ 800 M_earth ~ 2.4 M_Jup of condensibles;
- Entire condensible inventory of a stable nebula in one planet;
- : Planetesimal mechanism extremely efficient in non-standard (low ang. momentum?) nebulae.

Practical theory – resolving the age CoRoT-27: planets as clocks



CoRoT on to migrate or not to migrate

- Test 1: Ultra compact systems are hard to migrate; CoRoT-7; no violent migration;
- Test 2: Hot Neptunes (supercritical close-in planets) grow when migrating; CoRoT-7c,d, -13b; no violent migration;
- Test 3: The binary snowplough – secondary star excluding snow-line origin; CoRoT: not yet – time to worry?
- Stellar spin – planetary orbit misalignment
- : Theorists return to in-situ or throttle migration (alternative: “dark angular momentum”?).


Farwell standard model.
Hello planet diversity!

Sum: CoRoT's cosmogonic fossils

- Impossible planets - Planets inconsistent with the standard model 2b, ...
- Extremely supercritical planets (low env./core) – in-situ vs. migration (CoRoT-13b, 18b)
- Supercores (20b) - extreme solid accretion (400 - > 1000 M_earth, 1 - >3 M_jup solids) – non-standard nebulae and theory
- super massive megaplanets (3b, 27b)
- ~~Missing~~ links to Brown Dwarfs (3b, 15b, 27b)
- The nature of planethood (3b, 15b, 27b)
- A quantum of solace for theory (9b) – remote giants are sosy-like
- The planetesimal mechanism works widely (7b, 13b)
- Ultra-compact systems – key to the migration dilemma (7b,c,d)
- The absence of circumprimary planets (needs more work)
- Hot Neptunes (planetary statistics, migration test) (7c,d, 24b,c)

CoRoT-25b about Saturn-mass