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Planet Formation - What CoRoT tells us

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Abstract

CoRoT provides a well-defined sample of radii, masses and densities of short period planets for a range of host star masses. That allows comparative studies of planet formation with respect to the solar system and host stars of different mass.

1. Introduction

We present a statistical theory of planet formation and evolution that allows to determine how frequent planetary masses and radii are. It is built on a small number of physical assumptions related to the planetary equilibria in arbitrary but gravitationally stable nebulae and the strong planetesimal hypothesis but does not a-priori assume a core and thus combines core-driven and disk-driven planet formation hypotheses. A new high resolution survey of all planetary equilibria and their subsequent evolutions in F- and G-star orbits with periods up to 128 days is presented. Results are compared to CoRoT discoveries in the age-density- and the probabilistic-mass-radius diagrams and effects of simple observational bias-models are explored.

Finally the following case studies and their planet formation perspectives are presented: (1) CoRoT-2b, "impossible" planets and planetary ages; (2) CoRoT-3b, -15b, -27b and the upper mass limit of planets; (3) CoRoT-20b and the super-core-problem; (4) extremely supercritical cores: CoRoT-13b. CoRoT-18b; (5) CoRoT-Jupiters and the radius anomaly; (6) CoRoT-7b,c,d, CoRoT-24b,c – ultra-compact systems, migration and Hot Neptune formation.

2. Statistics of planetary evolution

For every F- and G-type stellar host and all orbital radii corresponding to periods of 1-128 days we consider an ensemble of planets. To account for planetary diversity we construct *all* core-envelope protoplanets that are in hydrostatic and thermal equilibrium when embedded in protoplanetary nebulae. The result is a planetary ensemble with diverse masses and internal structures that covers the relevant parts of the planetary 'phase space'.

Every one of these ensembles is used as a set of initial conditions for planetary evolution calculations to Ga ages in order to determine distributions of planetary radii, densities and luminosities at any given time, see [1] for an overview.

3.Planetary density-evolution and CoRoT-planets

As an example, Fig. 1. shows that various evolutionary tracks of different theoretical planet-families that are consistent with the observational constraints for CoRoT-18b, given their present uncertainties. It also shows that an improved accuracy can help to distinguish between the different origins and age-options.

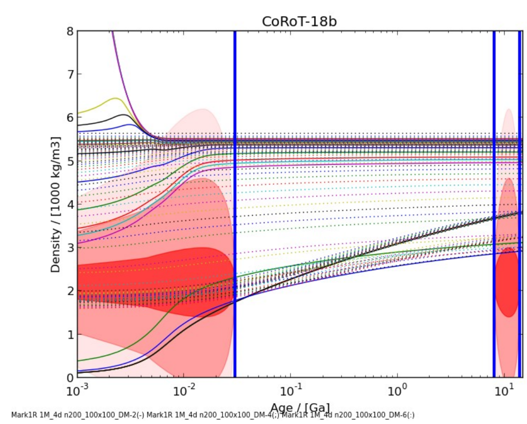

Figure 1 CoRoT-18b (age and radii constraints shaded red) and evolutionary density-tracks for all members of the theoretical ensemble that fit the mass constraint (full and dashed lines).

4.Theoretical mass-radius-diagram

If the theory described here produces planetary masses and radii with values and frequencies that are realistic and the properties of presently known exoplanets are not dominated by detection bias a comparison should lead to a roughly consistent view.

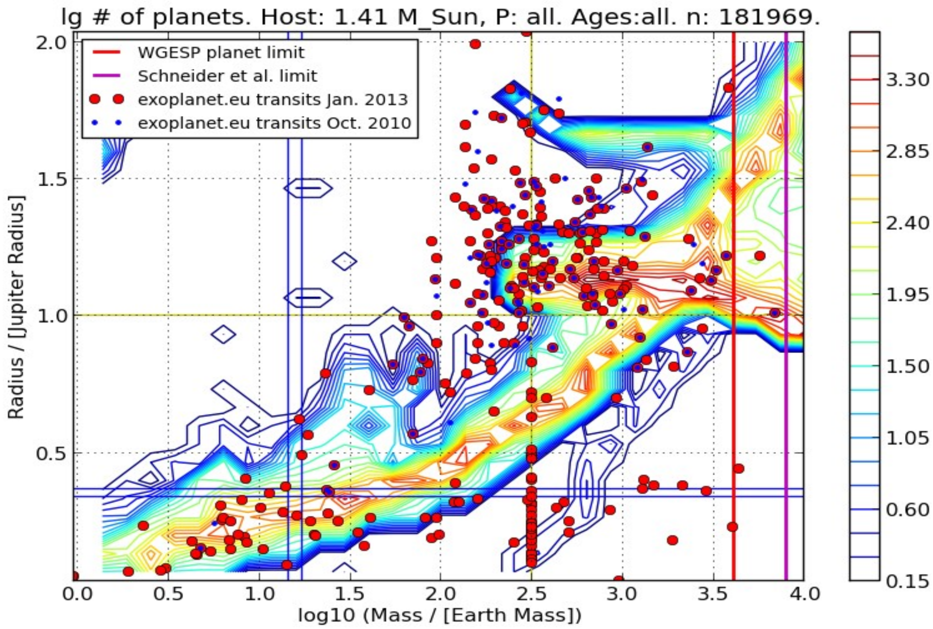

Figure 2 Probabilistic mass-radius-diagram. The number of planetary models (coloured contours corresponding to their decadic logarithms as indicated at the scale) for F-star hosts and planetary orbital periods of 1-128 d is shown as function of log10 planetary mass and planetary radius. Dots are planet detections and upper limits, straight blue lines give Uranus and Neptune values for reference.

We may thus cumulate the planetary models calculated for all periods and all ages relevant for a comparison with observations and thus determine a theoretical mass-radius-distribution for the age-mix in the sky. A sample result is shown in Fig. 2, where the distribution of the theoretical planetary models for stars with 1.14 solar masses is confronted to know properties of transiting planets.

Generally, detected planets cluster around regions in the mass-radius diagram with many theoretical models (red and yellow contours). Three differences between observed and theoretical distributions are apparent: (1) observations in the lower right corner scattered around Netpune-radii and with masses larger then 100 earth masses: these are due to upper mass-limits for Kepler-detections; (2) large numbers of theoretical models in the upper right corner with few corresponding detections: these may be attributed to a lack of very large cores; (3) theoretical masses exceeding the detected masses in the “Hot-Jupiter” clump – these will be discussed using the full sample of F and G stars at the conference.

Acknowledgements

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References

[1] Wuchterl, G.: Planet masses and radii from physical principles, IAU Symposium 276, eds. Sozzetti, A. and Lattanzi, M. G. and Boss, A. P., pp. 76-81, 2011.