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Interior structure of super-Earths and mini-Neptunes

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Abstract

The discoveries of several hundreds of exoplanets greatly enhance the probability of finding low-mass planets (~10 $M_\oplus$, where $M_\oplus$ is one Earth mass), similar to Earth. But in the few cases already identified, it appears that to determine the exact nature of the planet is a difficult affair. Low mass planet can be either Earth-like, icy-rich bodies, or even primitive planets which still possess primitive atmospheres. In order to be more accurate in our characterization of the nature of low-mass planets, we need: 1) to increase the amount of candidates by appropriate followup of transiting planets already detected; 2) to refine the modeling of low-mass planetary interior with and without primitive atmospheres. These two complementary approaches are needed for searching habitable worlds in other stellar systems.

1. Introduction

The discovery of 1200 exoplanet candidates by the Kepler mission opens a new era in the research of Earth-like planets. Ground and space observations provide information on the mass, radius, period, orbital radius, and albedo of exoplanets. Determining both mass and radius is critical to distinguishing between an iron-rich, a silicate, an icy planets, or a mini-Neptune[1]. The mass can be determined by radial velocity measurements, while the radius is measured from transits. Unfortunately, this information is still limited to a very small number of exoplanets, especially for low-mass planets (Figure 1). The present study focuses on the interior structure of rocky and icy planets for various amounts of primordial atmosphere and different distances to the star. It allows us to propose interior structure models for exoplanets with known radius and mass..

2. Planetary population

The first task of this study is to determine the key characteristics of the exoplanet candidates. These characteristics include the mass, the radius, the albedo, the orbital parameters, and the characteristics of the star. There are only a few exoplanets for which mass and radius are available (Fig. 1). But even with this small sampling, the diversity requires a better understanding of the parameters that drive the formation and evolution of the different layers (atmosphere, H_2O layer, rocky interior, core)..

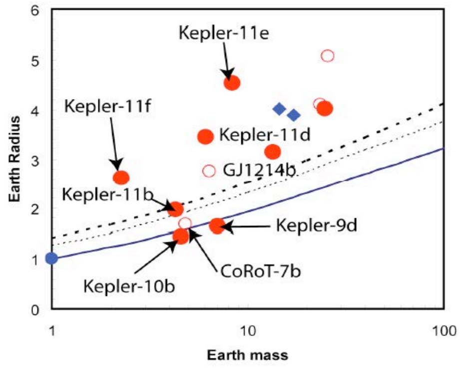

Figure 1: Diagram Radius-Mass for transiting exoplanets. The plain, dotted and dashed curves represent the relationship for silicate, 50% ice and 99% ice exoplanets, respectively. Blue diamonds: Uranus and Neptune. Blue disk: Earth. Red circles: transiting exoplanets.

3. Super-Earths and Mini-Neptunes

Two classes of planets are of special interest for habitability: the silicate planets (SP), and the icy planets (IP). Both classes correspond to planets that don't have a primitive atmosphere made of He and H_2. As shown in Figure 1, the (mass, radius) location of these planets is confined in a narrow band. Only four exoplanets fall within that band at the time of writing (Kepler-9d, Kepler-10b, Kepler-11b, and CoRoT-7b). However, we cannot make the difference between a silicate planet with a primitive atmosphere (class SPPA) and an icy-rich planet (class IP) (Adams et al., 2008). The fourth class of planet we are interested in is the class of Neptune-like planets that can be considered as icy planets with primitive atmosphere (IPPA). Such planets may turn into icy planets (IP) if their primitive atmosphere is eroded during migration.

Our objective is to provide models of planets for a given (mass, radius) and then to discriminate between these planets based on other arguments such as the distance to the star and the albedo. For the Earth-like (SP) and icy (IP) planets, we use models already developed by the team[1,3]. One key step is now to better understand the interior structure of the IPPA, which have characteristics different from both the gas giants (Jupiter and Saturn) and the terrestrial planets (Mercury, Venus, Earth, Mars). The mass, radius, and gravity fields of the IPPA Uranus and Neptune are such that a nominal interior model includes a liquid iron core, a silicate mantle, an H_2O layer and an H_2 and He rich atmosphere[4]. The mass percentage of the atmospheres of Uranus and Neptune (about 10%) is relatively small compared to that of the large gaseous planets (about 90%). Very little is known about the H_2O layer, and nothing is known about the silicate layer which is several times the mass of the Earth. But the main concern is that there is no way to reconcile models of accretion and observations for these two planets[4].

This study describes simulations of the interior structure that include the high pressures silicate phases (postperovskite and a layer of MgO and SiO_2 above ~10.5 Mbar). It also investigates the density profile in the so-called ice layer. Finally, it computes the values of the periodic Love number that can be constrained by the orbital properties of the exoplanets.

4. Conclusions and future work

The mass is a key parameter that can be determined by high resolution spectroscopic measurements. Radial velocity measurements of some Kepler exoplanet candidates will be obtained to 1) ascertain the planetary nature of the companion, 2) characterize the central star, 3) measure the true mass of the planet, and 4) determine the sky-projected angle between the stellar spin and the planetary orbital axis. The first task is to improve the radial velocity precision of the SOPHIE spectrograph which is 5 m/s at present time, with a goal of 1 m/s level of radial velocity accuracy. At least 10 new low-mass planets could be characterized in 2011 in the Kepler field of view. The statistics will be used to determine the likelihood of Earth-like and icy planets around other stars. One important question that this study can help to answer is the minimum mass for a planet to retain its primitive atmosphere. The result may have important implications for the definition of a habitable planet and the likelihood of such planets.

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