MODELING THE BULK COMPOSITION FOR THE LARGE TERRESTRIAL PLANET: KEPLER-328 B.

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Introduction: The most stars in our Galaxy is likely to host a terrestrial planet [1]. More hundreds of confirmed transiting terrestrial planets have been found by Kepler and K2 Missions, up to date. A small fraction of them have been measured to have masses over 10 $M_\oplus$. The very massive rocky planets are moderately rare and they thought to be formed according to more scenarios.

Kepler-328 had been observed in the original observing field (K1) of the NASA's Kepler Space Telescope and is located in the Constellation Cygnus. The G-type star, having a mass of 1.15 M_{SUN} and a radius of 1.06 R_{SUN}, is being orbited by two known transiting planets. Kepler-328 b, having a mass of 28.6 $M_\oplus$ and a radius of 2.3 $R_\oplus$, orbits with a period of 34.921 days [2]. Its mean density 12.9 g/cm^3 has been consistent with a terrestrial composition. Based on its physical parameters, this planet is being categorized into the population of known very massive terrestrial planets: mega-Earths ($M > 10$ $M_\oplus$). The outer planet (Kepler-328 c) is a super-Neptune, which has been found to have a radius of 5.4 $R_\oplus$, a mass of 39.4 $M_\oplus$ and its orbital period is 71.3 days.

The main purpose of this study is to constitute a possible compositional and internal structure model for Kepler-328b in terms of the measured mass and radius. The relatively high bulk density of Kepler-328 b indicates that it needs to have a metal-rich interior. Consequently, a terrestrial composition with a relatively large metallic core is proposed to be modeled for this mega-Earth-class planet.

The radius of Kepler-328 b is smaller than expected for the mass, the relatively high average density indicates that the planet needs to have a relatively large sized metallic core, thus I focus on a composition with assuming an iron core and a silicate-mantle.

I compute an approximate interior structure model for K2-328b by modeling an Earth-like composition in its upper-mantle and in the upper zone of lower mantle, furthermore, ultrahigh- pressure (UHP) phases of $MgSiO_3$ have been predicted in the lowermost region of the lower mantle, respectively. In this manner, the upper mantle is suggested to build up from olivine (ol), wadsleyite/ringwoodite (wdl/rwd) and the lower mantle consists of silicate-perovskite (pv) and post-perovskite (ppv). The first-stage of the dissociation for $MgSiO_3$ over 750 GPa, formulated by $I\bar{4}2d$-type Mg_2SiO_4 + $P2_1/c$-type $MgSi_2O_5$, UHP1), constitutes the upper zone of the lowermost mantle layer. A metallic core is being supposed and it composed of hcp-phase of iron in the upper zone, while the iron composition in the innermost zone of the core is fcc-structured.

Modeling the internal structure and composition, the knowledge of the physical state of the constituent materials are required and equation of states (EOSs) have been applied utilizing the relevant thermodynamic parameters. The Vinet EOS [3, 4] has been used for calculating the material properties in the upper mantle (ol, wdl/rwd silicate phase belts) and in the silicate-perovskite belt in the uppermost layer of the lower mantle. Murnaghan equation of state [5] is being used for computing the pressure/density relation in the ppv-belt and in the deepest region of the mantle (UHP silicate mineral phases). The utilized zero-pressure densities for ol^1, wdl/rwd^2, pv^3, ppv^4, MgO^5, UHP silicate phases [6]^6, [7]^7, hcp-Fe^8 , fcc-Fe^9 are 3.347^1 [8], 3.644^2 [8], 4.152^3 [8], 4.27^4 [9], 3.677276^5 (calculated for MgO by the data of Strachan et al. 1999)[10], 8.255^8 [11] and 8.06^9 [12] g cm^3, respectively.

Plausible compositional model for Kepler-328b: The surface gravity is more than five times greater than on Earth: g_s = 52.9 m s^{-2} (5.388 g_{Earth}). The central pressure has been calculated to be 10.048386 TPa.

Considering the theoretical calculations for the planet, its internal structure is not consistent with a ~ 1/3 metal+2/3 rock (Earth-like) composition. The interior of Kepler-328b is more compressed as if it had an Earth-like structure. The radius of metallic core is computed to be 1.679 $R_\oplus$. The deepest mantle zone is composed of the first ultra-high pressure phase (UHP1) of $MgSiO_3$ to the core mantle boundary. The pv-layer has the second largest volume fraction in the mantle (25.57 % of the mantle volume fraction, MVF).

According to a likely scenario, the planet have formed with a relatively large CMF. However, it is also possible that Kepler-328 b had originally a thicker mantle. A small amount of its original mantle had been stripped by a giant collisional event with an other planetary body in the early stage of the evolution of the Kepler-328 system. At the same time, it is possible that Kepler-328 b is a remnant of a gas giants because its original gaseous envelope had been stripped by a given physical effect. In this case, the planet has a more compressed silicate interior and a smaller CMF as opposed to the modeled version.

A convective system for upper mantle may be expected in the interior of Kepler-328b. However, in the lower-

most region of the mantle, the viscosity might be too high to the convective motions and the heat transport take place by heat conductivity. For the case of a moderately compressed interior, one part of the mega-Earths are likely to have a stagnant-lid tectonic system owing to the high viscosity of their mantle materials.
In summary, Kepler-328 b has a relatively large metallic core, but its silicate mantle is in a greater fractional volume than that of the core (core volume fraction, CVF). The silicate interior in volume fraction is composed mostly of olivine.

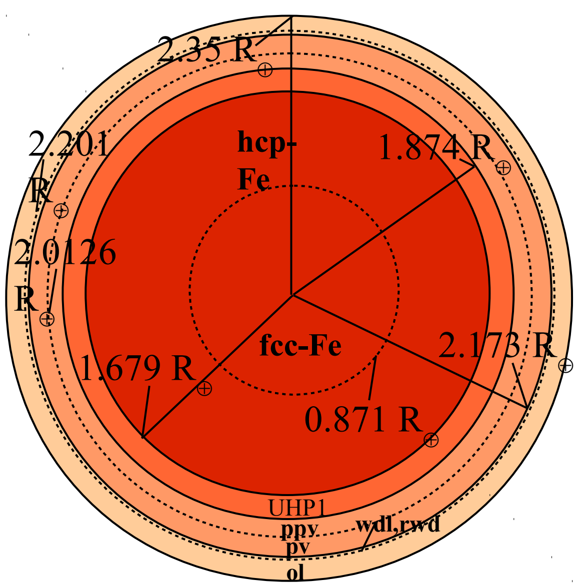

Figure 1. Schematic representation for the possible interior structure of the massive terrestrial planet: Kepler-328 b.

Summary: According to the modeling, Kepler-328 b has a relatively large core mass fraction. The better understanding of the details of the formation of very massive terrestrial-like planets may imply an excellent supplement to the general theories of planet formation. The discovery of them in the solar neighborhood due to the TESS and CHEOPS missions might provide a better opportunity for their examination.

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