BD+20594B: A MEGA-EARTH DETECTED IN THE C4 FIELD OF THE KEPLER K2 MISSION.

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Introduction: The sub-Neptune sized transiting planet has been discovered in the field of Campaign 4 of the Kepler's spacecraft's K2 extended mission and the precise RV-measurements of HARPS are being used for determining its mass (16.3 $M_\oplus$) [1]. The field of C4 can be found in the direction of the Taurus Constellation and it was monitored by Kepler from 07 February to 23 April 2015. The Solar-like host star can be observed on the area of sky near the Pleiades star cluster and is located in the Constellation Aries at 152.1 pc from the Sun.

BD+20594b (K2-56b) with a radius of $2.23R_\oplus$ [1], having a relatively large average density of 8.10665 g $\mathrm{cm}^{3\ -1}$, is expected to be a predominantly rocky planet and thus it can be classified as a mega-Earth. In its main physical properties (mass, radius, average density) and in the orbital parameters this planet is similar to Kepler-10c.

Mega-Earths are giant terrestrial-like planets with masses over 10 $M_\oplus$ may appears to have a low-density thin/extended atmosphere above their rocky cores and they might be icy worlds with a spherical shell of high-pressure forms of ices surrounding a thick silicate mantle plus core. Their formation processes has not yet entirely been understood, however, it is likely that massive rocky planets could be formed in the massive protoplanetary disks. It is also likely that mega-Earths could accreted in systems in wich does not exist giant gaseous planet. However, if it has been kept on thinking about the theory of Batygin and Laughlin [2] large terrestrial planets could theoretically formed in protoplanetary disks even if the reverse direction of an inward migrating gas giant occur on time. Moreover, one part of giant terrestrial-like planets are thought to have been formed via stellar-induced photoevaporative mass loss of planets having solid cores, which had originally been surrounded by thick gaseous envelopes. The lowermost region of their mantle consists of ultra-high pressure phases of $MgSiO_3$ [3], which might be the characteristic compounds in the deep mantles of mega-Earths [4] and in cores of giant gaseous planets.

The main purpose of this study is to construct a plausible composition for BD+20594b, which can be categorized as a prototype of mega-Earths based on the measured parameters.

Model: Espinoza and his colleagues [1] proposed the 100% rocky composition for BD+20594b considering the theoretical calculations for massive planets with a 100% rock ($MgSiO_3$) composition, which is reported by Zeng et al. (2016) [5].

Here, I present a plausible composition based on the measured data and the surface gravity has also been calculated. It is expected that this planet has a metallic core and it has no significant water content in its interior.

Moreover, in this model, CsCl-type MgO and $P2_1/c$-type $MgSi_2O_5$ constitutes the deepest zone of the mantle by the further transition of $MgSiO_3$ ppv at the dissociation pressure of 900 GPa, which is in accordance with the results of Umemoto and Wentzowitch. This post-post perovskite (p-ppv) form are likely the dominant silicate (ultra-high pressure, UHP) mineral phase in the lowermost zone of the most of the massive terrestrial-like planets with masses ranging from 7-8 $M_\oplus$ to ~Neptune-mass planets. The mineral compositions for the regions of the silicate mantle are being modeled taking into account the relevant thermodynamic parameters of perovskite (pv), post-perovskite (ppv) and ultrahigh-pressure form of $MgSiO_3$ in the lower mantle and the olivine with its higher-pressure phases : wadsleyite (wdl) plus ringwoodite (rwd) in the upper mantle. The zero-pressure densities of Fe, UHP silicate phase, ppv, pv, wdl/rwd and olivine are 8.3 [6], 3.67727 (calculated for MgO by the data of Strachan et al. 1999)[7], 4.27 [8], 4.152[9] , 3.644 [9] and 3.347 [9] g $\mathrm{cm}^{3\ -1}$,which have been utilized to calculate local densities for planetary spheres.

Vinet EOS [10,11] has been used for computing the material properties in the upper mantle and in the pv belt in the lower mantle. Murnaghan equation of state [12] is suited at the calculation for pressure/density relation in the ppv and the UHP zones. Moreover, polytropic modified equation of state [6] is being used for the case of the core material.

A plausible composition for BD+20594 b: The mega-Earth BD+20594b has a larger total radius to a same mass planet with an Earth-like core mass fraction. Consequently, it has a relatively small metallic core which is being calculated to be 1.09156 $R_\oplus$ with a pure Fe composition for a 2.73 $M_\oplus$ CMF. The core radius is 0.489488 % of the total radius and the core mass it has been found as a relatively small mass fraction with a 16.75 % of the total planetary mass. The central pressure (P_c) and the surface gravitational acceleration (g_s) are obtained to be 3.8833 TPa and 32.1972 ms^{-2}.

If there is a relatively small difference in mass compared to the announced value (16.3 $M_\oplus$), the composition of BD+20594b is consistent with being a planet is layered in two main spherical shells: a small metallic core mass fraction overlaid by a thick silicate mantle plus crust. If it were an essentially less massive planet with a radius of $2.23R_{\oplus}$, it would have a composition of lighter compounds (ice-shell/gaseous envelope). For the case of an other scenario, the significantly less massive planet would have a pure silicate composition.

If BD+20594 had a Fe-Ni core with 20-30 % , the core radius would be less 1-2 % for it than in case of the pure Fe composition. For the case of this scenario, CsCl-type MgO and Fe_2P-type SiO_2 belt would constitute the lowermost mantle zone underneath the CsCl-type MgO and $P2_1/c$-type $MgSi_2O_5$ layer due to the transition pressure would exceed 2.1 TPa.

As shown in Figure 1, the wdl/rwd and pv layers are relatively thin compared to the ppv and UHP silicate belts. The UHP silicate layer has a largest volume fraction among the mineral phase belts of the mantle and thus in this model the zone of p-ppv is 27.7615 % of the MVF (mantle volume fraction). In terms of the geological timescale, BD+20594b is even a relatively young massive rocky world (3.34 Gyr), hence, it is thought to have a powerful geological activity. However, in the lowermost mantle region, the viscosity are might be extremely high to the convective motions and in this manner the heat transport occurs by means of heat conductivity in a non-convective system. For a given planetary mass range, mega-Earths are likely to sustain an active-lid tectonic system even though they are non-convective in their deep mantles. Tectonic processes could operate on massive solid planets due to the convectional flows in the upper regions of their mantles.

The planet could develop a relatively thin atmosphere with a thickness of several tens or hundreds of kilometers, containing carbon-dioxide and/or water vapour.

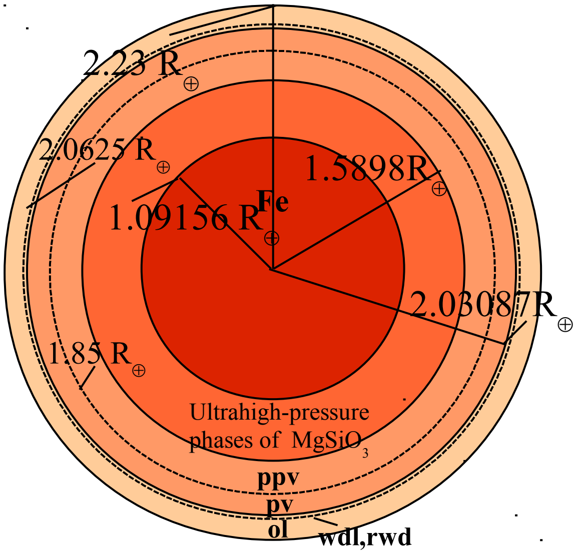

Figure 1. Schematic interior structure model for BD+20594b. The computed phase boundaries in the silicate mantle are plotted with dashed lines based on experimentally determined data . Conversely, the upper-mantle/lower mantle boundary, the theoretically calculated boundary of high-pressure silicate phase and the CMB are indicated with solid line.

Summary: Based on the physical parameters and the modeled composition, BD+20594b can be considered as a prototype of mega-Earths. It is to be hoped that more massive solid planets than 10 Earth-mass will be discovered in our galactic neighbourhood by space transit surveys such as K2 and TESS.

References:

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