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Exoplanet's Figure and Its Interior[†] [⋆]

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Abstract Along with the development of the observing technology, the observation and study on the exoplanets' oblateness and apsidal precession have achieved significant progress. The oblateness of an exoplanet is determined by its interior density profile and rotation period. Between its Love number k_2 and core size exists obviously a negative correlation. So oblateness and k_2 can well constrain its interior structure. Starting from the Lane-Emden equation, the planet models based on different polytropic indices are built. Then the flattening factors are obtained by solving the Wavre's integro-differential equation. The result shows that the smaller the polytropic index, the faster the rotation, and the larger the oblateness. We have selected 469 exoplanets, which have simultaneously the observed or estimated values of radius, mass, and orbit period from the NASA (National Aeronautics and Space Administration) Exoplanet Archive, and calculated their flattening factors under the two assumptions: tidal locking and fixed rotation period of 10.55 hours. The result shows that the flattening factors are too small to be detected under the tidal locking assumption, and that 28% of exoplanets have the flattening factors larger than 0.1 under the fixed rotation period of 10.55 hours. The Love numbers under the different polytropic models are solved by the Zharkov's approach, and the relation between k_2 and core size is discussed.

Key words planets and satellites: interiors, planets and satellites: general, methods: numerical, methods: statistical

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1. INTRODUCTION

A large-scale exploration of exoplanets was started in the end of the last century. By the radial velocity method, the first exoplanet 51 Pegasi b was discovered and confirmed in 1995[1]. After the Kepler satellite was launched in 2009, a great number of exoplanets were successively discovered. In January 2015, NASA announced that the Kepler satellite had discovered 1000 exoplanets. Until 30th May 2016, about 3400 exoplanets have been discovered, and about 2000 exoplanets have been confirmed. Now, we have mainly the following methods for observing exoplanets: the radial velocity method, astrometric method, pulsar timing method, micro-gravitational lensing method, transit method, and directly imaging method[2,3]. Based on the transit method, Hui and Seager[4,5] proposed firstly a method to measure the aspheric figure of the exoplanet HD 209458b by using the data of its transit light curve. The aspheric deviation of a planet is generally caused by its rotation and gravitational tide[6]. The gravitational tide is caused by the gravitational force of the star in the exoplanetary system on its planet, thus to form a large bulge on the planet surface toward the star, which leads to the exchange between the rotational angular momentum of this planet and the orbital angular momentum, and makes it produce a long-term energy dissipation[7,8]. The rotation of a planet will make it become an ellipsoid, for example the earth oblateness is about 1/298.257, and a rapidly rotating gaseous planet will have an even larger oblateness, for example the Saturn and Jupiter have an oblateness of 0.065 and 0.098, respectively[9,10]. Besides, there is an other kind of aspheric deviation which is caused by the geological motion of the planet itself, such as the Olympus Mons of the Mars[11]. When taking account of only the effect of rotation on the exoplanet's figure, its figure of hydrostatic equilibrium may provide a lot of information about its rotation velocity and interior density structure. Barnes and Fortney[12] improved later the method proposed by Hui and Seager[4,5], for the relation between rotation velocity and oblateness, they used the Darwin-Radau relation. Their methods are all based on calculating the difference of light curve between the spheroidal and ellipsoidal planets, but since they all assumed that HD 209458b is of tidal locking, its rotation period equals the revolution period, about 3 d, so that the observing signal produced by their estimated oblateness is smaller than the observing accuracy. Based on the previous results, Joshua et al.[13] analyzed the transit light curves of HD 189733b observed by the Spitzer space telescope for 7 times, and concluded that its oblateness is less than that of the Saturn.

For studying the interior structure of exoplanets, we need an interior model for reference, this paper has introduced at first the polytropic model and its structure, taking the Saturn as example, displayed the density profiles when the polytropic indexes are 0.5, 1.0, 1.5, 2.0, and 2.1, respectively. Then, the oblateness of the model is derived by solving the Wavre's integro-differential equation, and taking HD 189733b as example, the variation of oblateness with the rotation period is displayed for the different polytropic models. From the catalog of about 2000 exoplanets confirmed by NASA, we have selected 469 exoplanets,

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