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The importance of asteroseismology in exoplanetary science

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Abstract. While the number of discovered exoplanets continues to grow, the new challenge for the new space missions and ground-based observations has become to find a planet in the habitable zone. In such a context, the possibility to perform asteroseismology on parent stars becomes fundamental. The application of this technique will allow us to measure the mass and age of the stars in a more accurate way. In turn, we could obtain the physical parameters of the exoplanets and put the planetary systems in an evolutionary perspective.

Key words. planetary systems – stars: fundamental parameters

1. Introduction

The transit method for discovering extrasolar planets is the one that permits to have more information about the planet. Radius, mass (through the help of spectroscopy) and thus density can be evaluated. The number of planets discovered so far (552 as of June 2011[1]) suggests that planetary systems are not an exception, but the rule. The goal in the exoplanet search so is not anymore finding planets, but has become to find a planet in the habitable zone. To reach this goal, one of the most important things is giving always more constraints on the radius and mass of the planet. To improve the characterization of the planet, one of the possibilities is to study the transit at different wavelengths, as can be done by CoRoT (COnvection, ROtation and planetary Transits; Baglin et al. 2006). The Italian contribution to the scientific profile of the mission is presented, for instance, in Poretti et al. (2007, 2008). This information on the color variation of the transit is very useful to discriminate a lot of candidates, rapidly individuating false positives (due to the fact that planetary transit signal should be of the same magnitude in each color) and preventing the use of huge amount of telescope time for follow-up observations. Study of transits in different colors could also provide information about the planet's atmosphere (Borsa & Poretti 2011). Another way to improve the knowledge of a planet is the study of its parent star, and this can be done expecially through asteroseismology. Constraints given to the star are by consequence reported to the parameters of the planet.

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[1] See the continuously updated Encyclopaedia at http://exoplanet.eu

2. First results of Kepler

Kepler (Borucki et al. 2010) is a space mission devoted to the detection and characterization of exoplanets using the method of transits, with the objective of determining the frequency of Earth-size planets in the habitable zone. It uses a wide field-of-view (115 square degrees) photometer comprised of a 0.95 m effective aperture Schmidt telescope, feeding an array of 42 CCDs continuously and simultaneously monitoring the brightness of up to 170,000 stars.

Recently Borucki et al. (2011) reported a list of 1235 transiting candidates discovered by Kepler. Under standard physical and geometrical assumptions, the planetary candidates could be subdivided into 68 of Earth-size, 288 of super-Earth-size, 662 of Neptune-size, and 165 of Jupiter-size. Fifty-four planetary candidates are in the habitable zone of their host stars, and 170 stars show the presence of multiple transiting systems.

Another important milestone reached by Kepler is the discovery of a system composed of 6 planets, with all the planets transiting their parent star Kepler-11 (Lissauer et al. 2011). If placed in our solar system, Kepler-11g would orbit between Mercury and Venus, and the other five planets between Mercury and the Sun. At the moment, we do not know how and where these planets were formed and which kind of dynamical evolution put them in these close orbits.

2.1. The case of Kepler-10b

Kepler 10b (Batalha et al. 2011) is the smallest transiting planet discovered to date. With its radius of $1.416 \pm 0.033 R_{\rm E}$ and a density of 8.8 ± 2.5 g cm^{-3}, it is a dry, rocky planet with a high iron content. It has been found orbiting a Sun-like main sequence star of magnitude 10.96 in the Kepler bandpass, with a period $P = 0.837495 \pm 0.000005\ d$. Because of the relatively high brightness of the parent star, Kepler photometry was also collected with the 1-minute cadence for nearly 5 months (standard cadence for Kepler targets is of 29.4 minutes), so that it was possible to perform asteroseismic analysis on the data. This permitted to detect 19 distinct pulsation frequencies and the subsequent modeling resulted in precise determination of the fundamental stellar parameters.

The error bars on the radius and mass of the planet (Table 1) are very small with respect to other planets, even if the signal of the transit is only of 152 ppm. This is due to the fact that the physical properties of the transit signatures are derived by simultaneously fitting Kepler photometry and Keck Radial Velocities, adopting the mean stellar density of the host star as determined by asteroseismology.

Planetary Parameters	
Period [days]	0.837495 ± 0.000005
inclination [°]	84.4 ± 1.6
a [AU]	0.01684 ± 0.00033
Radius [$R_{\rm E}$]	1.416 ± 0.033
Mass [$M_{\rm E}$]	4.56 ± 1.29
density [gcm^{-3}]	8.8 ± 2.5
Stellar Parameters	
Mass [$M_\odot$]	0.895 ± 0.060
Radius [$R_\odot$]	1.056 ± 0.021
$T_{\rm eff}$ [K]	5627 ± 44

Table 1. Parameters of Kepler-10b and of its parent star (Batalha et al. 2011).

3. Other cases in literature

We briefly review here the application of the asteroseismic approach to other planetary systems.

3.1. HD 46375

Gaulme et al. (2010) presented the observation of the non-transiting extrasolar system HD 46375 in the asteroseismological field of CoRoT. Even for very low signal-to-noise data, in this work it is demonstrated that asteroseismology can constrain the stellar fundamental parameters and hence also the planetary ones. The comparison of the fundamental parameters

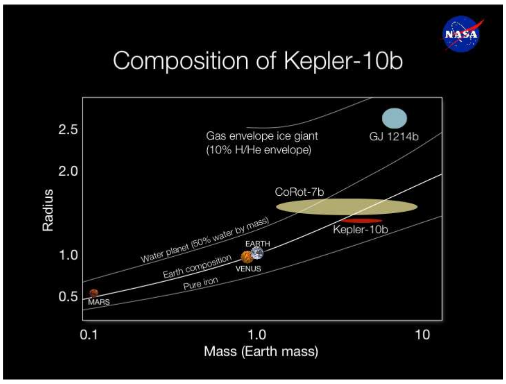

Fig. 1. Measurements on the Radius and Mass of Kepler-10b are extremely more accurate respect to other exoplanets like CoRoT-7b and GJ1214b, due to the use of asteroseismology in determining the stellar parameters. *Credits: NASA*.

before an after this work illustrates the potential of asteroseismology. The measured value of the stellar mass has increased by about 7% and the stellar radius by the same proportion, which correspond to a much denser star with a correspondingly higher large separation. The refined parameters are mass, effective temperature, radius, and age. The revision of the stellar mass allowed to re-estimate the projected mass of the known exoplanet to $M_P \sin i = 0.234 \pm 0.008 M_{Jup}$, instead of $0.226 \pm 0.019 M_{Jup}$ previously estimated in Butler et al. (2000).

3.2. HR 8799

High-contrast observations with the Keck and Gemini telescopes have revealed three planets orbiting the star HR 8799, with projected separations of 24, 38, and 68 astronomical units (Marois et al. 2008). HR 8799 is known since a long time to be a γ Dor variable (Zerbi et al. 1999), i.e., a star showing variability due to gravity modes on its surface. Moya et al. (2010) tried to find an age estimation for the star HR 8799, to determinate accurate mass of the planets and to study the dynamical stability of the system. They use the presence of the gravity modes for testing the internal structure, in particular its internal metallicity and age. They find that the age estimate for this star previously published in literature (30-160 Myr) is unlikely, and a more accurate value might be around 1 Gyr. This determination has significant implications for the value of the mass of the objects orbiting HR 8799. An age around 1 Gyr implies that the orbiting bodies would be brown dwarfs.

Another asteroseismologic study made on this star (Wright et al. 2011), permitted to give constraints on the inclination of the orbit of the objects.

3.3. HD 17156

HD 17156 is hosting a planet with a period of 21.2 d discovered by Fischer et al. (2007) in a Doppler survey, and shown to have transits by Barbieri et al. (2007). Gilliland et al. (2011) presented an accurate determination of the asteroseismic large separation, and hence accurate measurements of the stellar mean density, using HST observations.

This is the first star for which the density estimation has been possible using both asteroseismology and detailed analysis of a transiting planet lightcurve (Nutzman et al. 2011). The two measurements are mutually consistent. However, the same cannot be said for consistency with the spectroscopically determined log g where there is a nearly 3σ discrepancy, in the sense that the spectroscopic log g is too large.

3.4. HD 52265

This star was already known to host a planet (Butler et al. 2006; Naef et al. 2001), and was observed by CoRoT in the seismology field for 117 d. Ballot et al. (2011) made asteroseismic studies measuring solar-like oscillations, confirming that mode lifetimes decrease as the effective temperature increases. They identified this G0V star as a very promising object for stellar modelling and for studying the mixing processes in such stars. This seismic interferences will also improve the knowledge of the planet hosted by HD 52265.

4. PLATO

The project PLATO (PLAnetary Transits and Oscillations of stars; Catala et al. 2011) is one of the three medium-class missions selected in 2010 for definition study in the framework of the ESA Cosmic Vision 2015-2025 program. PLATO's objective is to characterize both exoplanets and their host stars, focusing on bright targets ($m_V \leq 11$) and including also a large number of very bright and nearby stars ($m_V \leq 8$). Its main science goals are the detection and characterization of planetary systems reaching small terrestrial planets in the habitable zone, and the identification of suitable targets for a more detailed characterization in the future, that will include the search for bio-markers in the nearby habitable exoplanets. PLATO's lightcurves will be long, ultra-precised (photometric precision of 2.7×10^{-5} in 1 hr on stars of $m_V = 11$) and continuous. They will be used to: *(i)* detect planetary transits and measure their characteristics; *(ii)* provide a seismic analysis of their host stars. The final goal is to have an evolutionary overview of extrasolar planetary systems.

5. Conclusions

The knowledge of an exoplanet is only as good as our knowledge of the star it orbits, and asteroseismology is the best way to determine stellar parameters such as mass, radius, density and age. The importance of the study of the parent star in giving very strict constraints on the physical parameters is well demonstrated by the case of Kepler-10b. Asteroseismology can also help giving information about the inclination of the orbit of planetary systems (Wright et al. 2011), if the planet is not transiting the star.

Future missions such as PLATO will have such precision allowing to do asteroseismology on all the target stars, and so to have the chance to really find and characterize Earth-size planets in the habitable zone.

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