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Detection limit for the size of exomoons around *Kepler* planetary candidates and in simulated *CHEOPS* data

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Abstract

The increasing number of detected exoplanets has inspired a significant interest in the community as to whether these planets can host a detectable and habitable moon [4]. Here we show which are the most promising Kepler planetary candidates that are capable to host a detectable moon and what is the best way to increase our chance of discovering exomoons via the forthcoming $CHEOPS$ space telescope.

1. Introduction

Despite the efforts during the past 8 years that aimed on a discovery of an exomoon in the $Kepler$ data [9, 5, 6, 7, 2], there has no firm evidence for an exomoon found as of today [8, 3].

From the analysis of the data provided by the $Kepler$ spacecraft shows an apparent contradiction between the number of examined KOI systems by date and the lack of any firm detection. Two obvious arguments can resolve this paradox:

- Only few planetary candidates exhibit physical and photometrical parameters offering a STABLE AND DETECTABLE exomoon; or
- No moon larger than moons in our Solar Systems could exist in the Universe, which means they are far below the lowest detection limit and therefore remain undetected.

The latter argument mostly depends on precision and accuracy of the instruments, so there will be chances to push down this detection limit in the case of the next generation space telescope $CHEOPS$[1].

[1]http://cheops.unibe.ch/

2. (Un)detectable moon around Kepler candidates?

We calculated photometric transit timing variations (PTV: see TTV_p in [5]) from simulated observations with increasing moon size for all Kepler candidates[2] to determine the minimum radius of a theoretical moon that can be detected in the Kepler data.

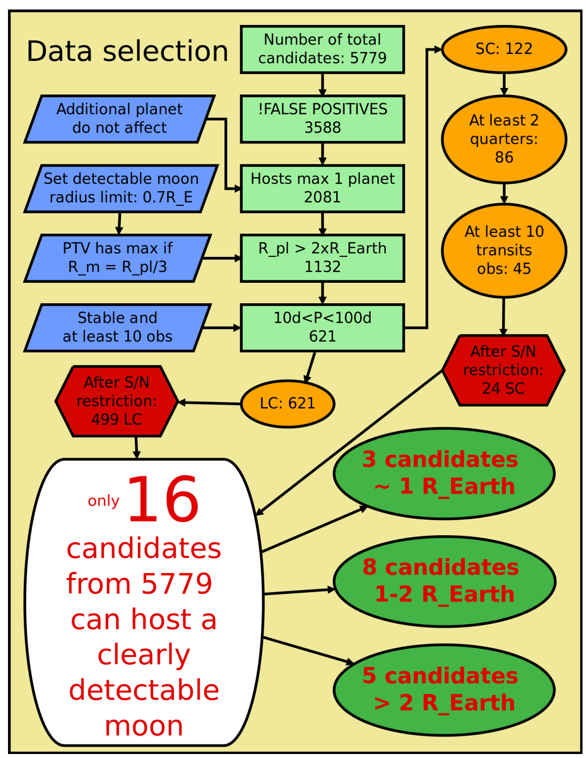

Figure 1: The flowchart of selection process and the result of our analysis which shows the decreasing number of candidates that can host a detectable moon.

[2]data taken from NASA Exoplanet Archive catalog

We made restrictions for size, orbital period, number of observed transit, etc. (see Fig. 1) to exclude non-stable and unobservable systems. For e.g. moons around planets can be stable on long timescale (a few billion years) if the host planets have orbital periods above 10 days [1]. During the analysis the maximum of PTV was calculated (similar to Fig. 2 red points), the 3σ detection limit was set by using a bootstrapping method (yellow lines). The minimum radius for a detectable moon can be found where the expected value of PTV exceeds the detection limit. If no such a point exists then there is no such a large moon in the system that can be detected by the Kepler space telescope. As in the Fig. 1 can be seen, there were only 16 planetary candidates (4 of them have SC data) that can host a theoretically detectable moon.

3. Observing strategy for CHEOPS

Efficient discovery of an exomoon requires multiple transit measurements to reduce the noise level without wasting time to systems that have no-signal or clearly detected. We tested a decision algorithm that trained by searching the most efficient detection index from simulated data, along a pre-set FAP levels and desired lower limits. It re-evaluates all the PTV signals data by date, and makes a decision that can be 1) firm detection, go to another object, 2) firm rejection, go to another object, 3) no decision, make more measurements. The detection statistics is a posteriori output. The initial result show that such an algorithm needs two or three times less time to reject systems or detect signals. By using this strategy in the case of CHEOPS spacecraft we can push the detection limit for an exomoon below the 0.5 Earth-sized (Fig. 2).

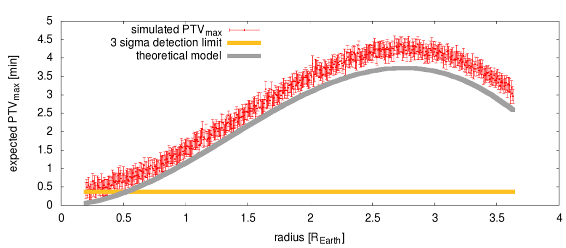

Figure 2: The expected amplitudes of PTV signal against the size of a probable moon in a case of simulated CHEOPS observation.

4. Summary and Conclusions

The analysis of Kepler planetary candidates has shown that the sixteen most promising systems among the 5779 (offering a stable and securely detectable moon) exhibit detection limits in the 0.8–4 R_E size range. In addition this detection limit can be pushed toward lower values until 0.4-0.5 Earth size in the best cases with the $CHEOPS$ spacecraft by using such an algorithm that can reject null event with high efficiency.

The analysis of Kepler candidates suggests that moons around two times the Ganymede's size do not exist in the Universe. This is an intriguing consequence of exomoon surveys with $Kepler$, and it is worth a deeper debate to contrast with current moon formation theories.

Acknowledgements

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