Assessing Exomoon Detectability in TESS Light Curves: A Case Study of WASP-19

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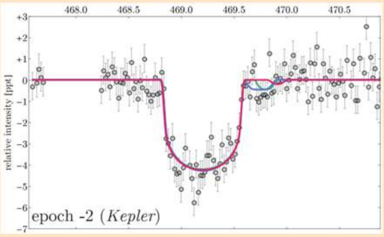
Abstract

Over the past decades, photometric methods have led to the discoveries of thousands of exoplanets. While similar techniques have been used to search for exomoons, none have been confirmed. We aim to survey potential exomoons using Transiting Exoplanet Survey Satellite (TESS) data and present a case study to illustrate our methodology. Considering reasonable sizes of exomoons on stable orbits, we generate synthetic light curves of one planet plus one moon cases. The synthetic light curves adopt the properties and noises of TESS light curves. We then employ a standard procedure to examine exomoon detectabilities from synthetic light curves. With huge amount of synthetic light curves derived from various exomoons, the detectability of exomoons from TESS data could be determined quantitatively.

Introduction

Exomoons are proposed to exist in exoplanetary systems, and their signals can be detected in photometric transit light curves.



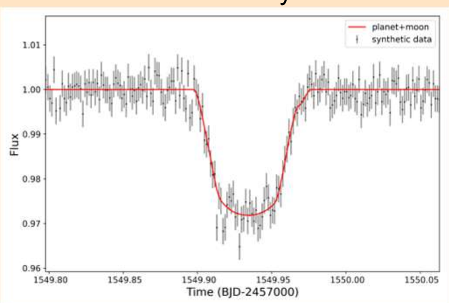
- Transit light curve of Kepler-1625 b and its exomoon candidate (*Teachey & Kipping* 2018).
- The small dip on the right-hand side indicates an exomoon in this system.

What we want to know:

What types of exomoons and how many of them can be detected in TESS light curves?

Method

- Fit the TESS data with the *Pylightcurve* package and update the planetary parameters for each system.
- Use the updated planetary parameters to generate the planetary orbit, and calculate the total flux based on flux calculation code by *Pál (2012)*.
- Generate the synthetic data using the planet+moon model. We injected 100 different mass of moons.
- Fit the synthetic data again and see if the moon's signal can be found correctly.



- The synthetic data of WASP-19 b plotted with the model. The injected moon's mass in this plot is 0.1 times the planetary mass (M_p).
- 100 different moons were injected into the modeling light curves.

- Define $\Delta\chi^2$ to be $\chi_p^2 - \chi_m^2$, where χ_p^2 is the reduced chi-square of the data fitted with planet-only model, and χ_m^2 is the one of the data fitted with planet+moon model.
- If the value is positive, it means the plane+moon model fit the data better.

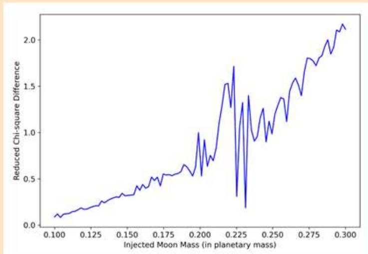
Result

- Here, we present the fitting results for WASP-19 b, a hot Jupiter with a planetary mass of 366.8 M_E and an orbital period of 0.79 days.
- All transit events of the synthetic light curves are fitted simultaneously.
- The following table shows the $\Delta\chi^2$ of different fittings.

	Inject an 0.1 M_p(~36 M_E) moon	Inject an 0.3 M_p(~110 M_E) moon
Error	0.079	2.158
Half Error	0.318	8.633

- When the uncertainties are reduced to half of their original values, the differences become more significant.

- We inject the moon having mass between 0.1~0.3 M_p. In this range, the moon can maintain a stable orbit.
- The plot shows $\Delta\chi^2$ for 100 different injected moon mass.



- The $\Delta\chi^2$ increases when the injected mass increases. It's hard to distinguish small exomoons' signal in WASP-19 system with TESS uncertainties.

Discussion

- To ensure the moon's dynamical stability, we set moon's semi-major axis to lie between the Roche limit and the Hill radius.
- We can detect an exomoon having mass of 0.3 M_p for systems like WASP-19 using TESS data. However, future telescopes with significantly smaller uncertainties may be able to detect and confirm smaller exomoons using our proposed methodology.
- A comprehensive future sky survey will identify systems with potential exomoons.
- Cases with multiple moons shall be considered.

Conclusion

- We explore the detectability of exomoon in TESS data using photometric method.
- Synthetic data were generated with various exomoons injected into the system.
- For a hot Jupiter like WASP-19 b, small exomoons (~0.1 M_p) cannot be clearly distinguished in the photometric light curves. However, for a larger moon (~0.3 M_p), the photometric method may efficiently detect it.

Reference

- Teachey A., Kipping D., 2018, Sci. Adv., 4, 1784
- Pál A., 2012, MNRAS, 420, 1630
- Tsiaras A. et al., 2016, ApJ, 832, 202