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Impact of exomoons in flux and polarization phase curves of starlight reflected by exoplanets

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Abstract

While the search for exoplanets harvests an increasing interest, the times of exomoon detection and characterization are still to come. As those found in our Solar System, exomoons are potential candidates for hosting extraterrestrial life and/or granting their parent exoplanet with the required habitability conditions. Moreover, seizing and characterizing the orbit and properties of these companions is the keystone of a more exhaustive exoplanet characterization and a comprehensive understanding of planetary system formation mechanisms.

We show that measuring the flux and polarization of starlight reflected by a planet–moon system could potentially lead to the characterization of the lunar albedo, size and orbital parameters of its orbit around the planet.

1. Introduction

The capabilities of current and future instruments (e.g. SPHERE, GPI, EPICS) to perform high contrast direct imaging of exoplanets both through spectroscopy and polarimetry is about to open the prospect of extra–solar research by using an unexploited technique: measuring the state of polarization of starlight reflected by extra-solar bodies.

Previous studies have already modelled the phase light curves and polarization signals of exoplanets [12, 10] showing that polarimetry enhances the contrast between the exoplanet and its star. The spectral and temporal dependence of the polarization is also related to the properties of the planet and can be used to characterise the surface or atmosphere [5, 11].

We decided to investigate the effect of an exomoon on the reflected flux and polarization of a planet. In this line, we modeled phase curves of an unresolved Earth–Moon–like system including the transits and eclipses between the moon and the planet.

2. Numerical model

We describe the flux and polarization of starlight reflected by a spatially unresolved planet–moon system by a Stokes vector [4] computed using PyMieDAP [9], an adding-doubling radiative transfer algorithm [3], assuming the starlight is unpolarized [6]. Our model planet has a Lambertian depolarizing surface with horizontally homogeneous atmospheric layers filled with gas and/or aerosol particles on top, and our model moon has a Lambertian depolarizing surface without atmosphere.

The computed Stokes vectors at a certain epoch are a function of: (1) the atmosphere and surface properties of the bodies (e.g. radius and albedo), (2) the relative body–star–observer position, (3) the position of the moon around the planet. The latter is defined as a Keplerian orbit in the framework of a 'nested two-body' problem [8, 7] and will determine, in last instance, the duration, latency and shape of light curves during mutual events (see Fig. 1).

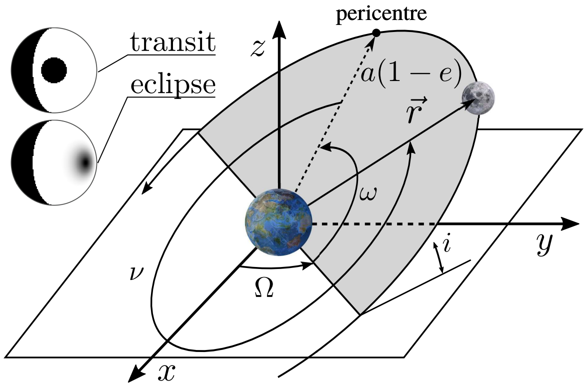
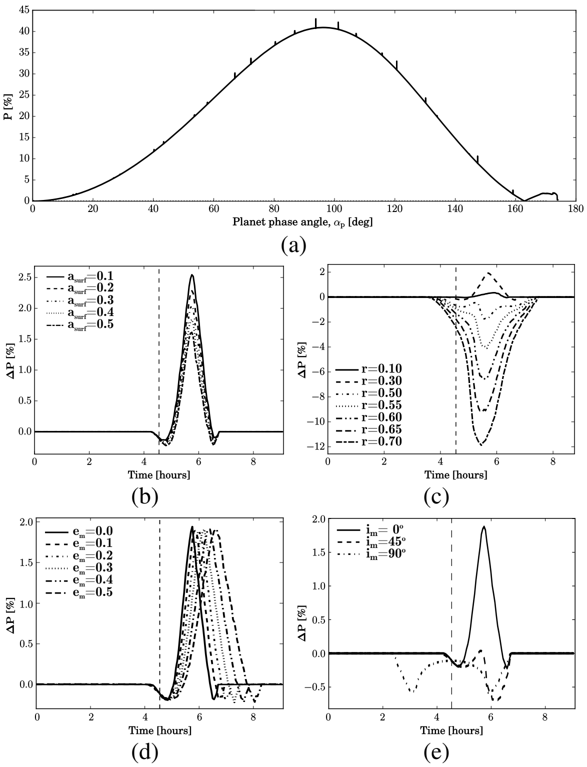


Figure 1: Geometry of the generic exomoon orbit around an exoplanet as a function of the lunar orbital parameters a, e, i, ν, Ω, ω. Top–left: example of modelled transit–eclipse events.



(a) (b) (c) (d) (e)

Figure 2: Degree of polarization phase curve (a), as well as change in degree of polarization, $\Delta \mathrm{P}$, during a lunar transit in front of the planet at $\alpha \approx 100°$ as a function of (a) lunar albedo $\mathrm{a_{surf}}$, (b) moon–to–planet ratio r, (c) moon orbit eccentricity $\mathrm{e_m}$, and (d) moon orbit inclination $\mathrm{i_m}$.

3. Discussion and results

Our results (submitted to A&A) show that the moon modulates the observed signal, both in flux and in polarization, revealing its presence [2, 1]. In particular, the variation of the degree of polarization is found to be maximum at phase angles close to 90° (see Fig. 2a). In fact, face–on coplanar systems will always display these events at a phase angle of 90°, making these moons easier to be detected.

We also analyzed whether exomoon characterization can be performed via the measurement of reflected starlight. We identify four different phenomena when varying the moon used in our simulations on the degree of polarization P (see Fig. 2): (1) change in duration of mutual events with i and e, (2) change in time interval between events with a and e, (3) change in curve's shape with i and R_m, (4) change in curve's amplitude with R_m and lunar albedo. These phenomena, and in particular the change in curve's shape, are strongly coupled with the surface and atmosphere properties of both the planet and moon along their disks, what might lead to batch fitting–like algorithms for exomoon characterization.

4. Conclusion

The outcome of our simulations reveal a strong correlation between the studied lunar properties (i.e. lunar radius and albedo) and moon orbit parameters (i.e. eccentricity, inclination and semi–major axis) and the shape, duration, and magnitude of the flux and degree of polarization variations of the reflected starlight of a extra–solar planet–moon system experiencing mutual transit and eclipse events at any phase angle.

With the foreseeable future arrival of very–high precision polarimeters, such correspondence could potentially lead to a detailed characterization of exomoons via polarimetry techniques.

References

[1] Berzosa Molina, J., Stam, D. M. and Rossi, L.: Traces of exomoons in flux and polarization signals of starlight reflected by exoplanets, in EPSC17, vol. 11, 2017.

[2] Berzosa Molina, J., Stam, D. M. and Rossi, L.: Traces of exomoons in flux and polarization phase curves of starlight reflected by exoplanets, (submitted) A&A, 2018.

[3] de Haan, J. F., Bosma, P. B. and Hovenier, J. W.: The adding method for multiple scattering calculations of polarized light, A&A 183, 371-391, 1987.

[4] Hansen, J. E. and Travis, L. D.: Light scattering in planetary atmospheres, Space Sci. Rev. 16, 527-610, 1974.

[5] Karalidi, T., Stam, D. M. and Hovenier, J. W.: Looking for the rainbow on exoplanets covered by liquid and icy water clouds, A&A 548, A90, 2012.

[6] Kemp, J. C., Henson, G. D., Steiner, C. T. and Powell, E. R.: The optical polarization of the Sun measured at a sensitivity of parts in ten million, Nature, 326, 270-273, 1987.

[7] Kipping, D. M.: How to weigh a star using a moon, MNRAS: Letters, Oxford University Press, 409, L119-L123, 2010.

[8] Kipping, D. M.: Transit Timing Effects Due to an Exomoon (in The Transits of Extrasolar Planets with Moons), Springer Berlin Heidelberg, 2011.

[9] Rossi, L., Berzosa Molina, J. and Stam, D. M.: PyMieDAP: a Python–Fortran tool to compute fluxes and polarization signals of (exo)planets, ArXiv 1804.08357, 2018.

[10] Seager, S., Whitney, B. A. and Sasselov, D. D.: Photometric Light Curves and Polarization of Close-in Extrasolar Giant Planets, ApJ 540, 504, 2000.

[11] Stam, D. M.: Spectropolarimetric signatures of Earth-like extrasolar planets, A&A, 482, 989-1007, 2008.

[12] Stam, D. M., Hovenier, J. W. and Waters, L. B. F. M.: Using polarimetry to detect and characterize Jupiter-like extrasolar planets, A&A, 428, 663-672, 2004.