Traces of exomoons in flux and polarization signals of starlight reflected by exoplanets

Berzosa Molina, Javier; Stam, Daphne; Rossi, Loic

Publication date
2017

Document Version
Final published version

Citation (APA)
Berzosa Molina, J., Stam, D., & Rossi, L. (2017). *Traces of exomoons in flux and polarization signals of starlight reflected by exoplanets*. Abstract from European Planetary Science Congress 2017, Riga, Latvia.

EPSC Abstracts
Vol. 11, EPSC2017-663, 2017
European Planetary Science Congress 2017

Traces of exomoons in flux and polarization signals of starlight reflected by exoplanets

J. Berzosa-Molina, D. M. Stam, and L. Rossi
Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands (j.berzosamolina@gmail.com)

Abstract

The detection of moons around extrasolar planets is one of the main focuses of current and future observatories. These silent companions contribute to the planets' observed signals but are barely detectable with current methods. Numerous gaseous exoplanets are known to orbit in the habitable zones of stars, and the expected abundance of natural satellites and their diversity in composition make them ideal targets when looking for habitable celestial bodies. And moons are suspected to play key roles in stabilizing a planet's rotational axis and hence its climate. We show that an exomoon orbiting an Earth-like exoplanet could be identified by measuring the flux and polarization of starlight reflected by the planet-moon system, allowing the characterization of their orbital motions and physical properties.

1. Introduction

Current instruments such as Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) on the Very Large Telescope (VLT) and Gemini Planet Imager (GPI) on the Gemini North telescope, together with the Exoplanet Imaging Camera and Spectrograph (EPICS) on the future European Extremely Large Telescope (E-ELT), have capabilities to perform high-contrast, direct imaging and characterization of exoplanets, both through spectroscopy and polarimetry.

Previous modelling of light curves and polarization signals [3, 9, 10, 8] shows that polarimetry not only increases the contrast between the exoplanet and its star, but can also unveil the structure and composition of the atmosphere and surface. Here, we take one step further by analysing how the presence of an exomoon influences the flux and polarization signals of an Earth-like exoplanet. The influence is two-fold: 1. the flux reflected by the planet-moon system increases according to the moon's reflection properties, and 2. the transits and eclipses between the moon, planet, and star modulate the observable signal (see Fig. 1).

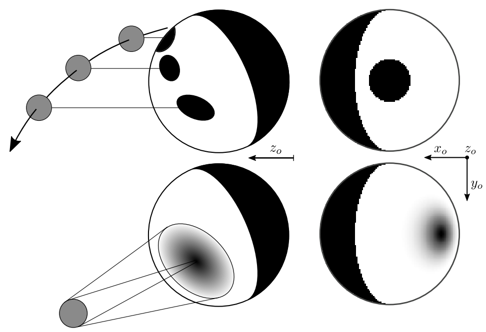

Figure 1: Sketches of a lunar transit of the planet (top left), an eclipse (bottom left), the discretization during a lunar transit (top right), and during a planetary eclipse (bottom-right). The z_o–axis points towards the observer.

2. Numerical model and results

We describe the flux and polarization of starlight that is reflected by a spatially unresolved planet–moon system by a Stokes vector [2] computed using and adding-doubling radiative transfer model [1], assuming the starlight is unpolarized [5]. Our model planet has a Lambertian surfaces with horizontally homogeneous atmospheric layers filled with gas and/or aerosol particles on top, and our model moon has a Lambertian surface without atmosphere.

The observable Stokes vectors at a certain epoch are a function of the illumination and viewing geometries of each body, which depend on the bodies' phase angle α (the angle between the direction to the star and the observer measured from the centre of the body), and on the orbital geometry of the bodies involved, as that can lead to situations in which they interfere with each other. In particular, we have modelled the following interferences (see Fig. 1):

- A transit: the interposition of a body between the observed target and the observer, partially (or to-

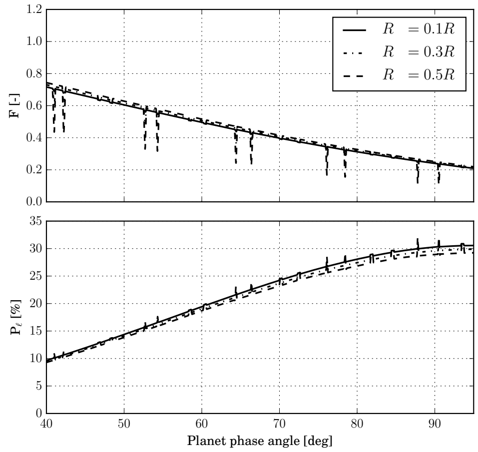

Figure 2: Flux (top) and degree of linear polarization (bottom) of an edge-on system consisting of an Earth-like planet and an exomoon with surface albedo 0.1, for different moon radii R_m expressed in the planet radius R_p.

tally) blocking the light that is reflected by the target while adding reflected light from the body.

- An eclipse: the interposition of a body between the star and the observed target, casting a shadow on (part of) the reflecting target.

We compute the orbital dynamics and geometries using the 'nested two–body' model introduced in [7, 6], that is based on the assumption that the motion of the planet and moon around the planet–moon system barycentre, as well as the motion of this barycentre around the star, can be described by Keplerian orbits.

Fig. 2 shows the flux and degree of linear polarization obtained as the exoplanet and moon transit and eclipse each other in a zero-eccentricity, system that is viewed edge-on, for different moon radii R_m.

3. Discussion

The traces of exomoons that we find in our numerical simulations (see Fig. 2), show up as remarkable signatures in the signal of the spatially unresolved planetary system. The flux and polarization variations due to eclipses and transits are of the same order of magnitude as the overall signal and can span several hours (depending on the moon radius with respect to the planet and the orbital periods). The observable signals appear similar to those obtainable with the well-known transit photometry technique applied on stars except for delivering enhanced contrast between bodies and a greater frequency of observation, although with much less photons and thus requiring much larger telescopes.

4. Conclusion

We aim to investigate the correlation between the flux and degree of polarization of the reflected starlight and the orbital characteristics of the planet-moon system. The results obtained for an Earth-like planet will be compared to those for a giant Jupiter-like planet, analysing the impact of using varying atmospheric models. We also aim at estimating the required instrument radiometric and polarimetric accuracy, assessing the feasibility of exomoon discoveries through polarimetry with current and future technology [4].

References

[1] 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.

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

[3] 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.

[4] Keller, C. U., Schmid, H. M., Venema, L. B., et al.: EPOL: the exoplanet polarimeter for EPICS at the E-ELT, Proc. SPIE, 2010.

[5] 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.

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

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

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

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

[10] 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.