Revisiting the effects of rings on the reflected light curves of exoplanets

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Direct imaging of exoplanets provides us with unique information complementary to other observation methods. Current direct imaging observations mainly detect thermal emission from young Jupiter-like planets and have enabled us to constrain their atmospheric structures and evolution models. Future facilities will aim to directly detect the reflected light from exoplanets, enhancing our ability to characterize mature planets. Specifically, the Roman Space Telescope, scheduled for 2027, will install coronagraphic instruments and demonstrate unprecedentedly high-contrast imaging of exoplanetary systems at the wavelengths of 570-830 nm. This will enable, for the first time, the characterization of the reflected light of Jovian planets in distant orbits.

Among the properties that potentially have first-order effects on the reflected light curves is the presence of planetary rings. Indeed, the presence of rings appears to be ubiquitous based on the fact that all large planets in the solar system have rings, with the most prominent one being the Saturn's ring. While the signature of the rings of transiting planets has been proposed (e.g., Barnes & Fortney 2004, Ohta, Taruya, Suto 2009; Ohno and Fortney 2022), the observational evidence remains elusive. The future data of reflected light will be a complementary approach. A limited number of previous works examined the anomaly in the reflected light curves as a clue to the presence of planetary rings (e.g., Arnold & Schneider 2004, Dyudina, Sackett, Bayliss et. Al 2004, Zuluaga, Sucerquia, Alvarado-Montes 2022). However, previous models adopted simplistic and mutually inconsistent assumptions for the scattering properties of rings, and the dependence of the ring parameters remain to be studied further.

In this study we developed a simple but realistic light-curve model of a ring composed of macroscopic particles with isotropically scattering (i.e., Lambertian) surface. After validating our model against the Monte Carlo model of the previous work, we simulated how the reflected light from a planet with such a ring would vary over its orbital period, and examined the parameter sets that would facilitate detection of the ring.

The results show that the peak of the light curve of a planet with a ring shifts from that without a ring, and the offset is primarily controlled by the position of the vernal/autumn equinox relative to the orbital ascending node of the orbit (the largest offset correspond to the situation where the equinox coincides with the ascending node). We also find that the minor anomalies in light curves due to the shadow of the ring on the planetary surface contain the information of the planetary obliquity. With the Roman telescope in mind, we discuss the precision and time resolution of data necessary to constrain these ring properties . The light-curve characteristics of a planet with a ring will be a unique clue to the ubiquity of planetary rings and provide insights into the formation and evolution process of rings.

Keywords: exoplanets, direct imaging, Jovian planets, planetary ring, Roman Space Telescope