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What Titan's phase curves can teach us about exoplanet atmospheres

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Abstract

The recent years have seen rapid progress in the characterization of exoplanet atmospheres, a progress that will soon accelerate as new facilities in space and on the ground become available. Because the detection and interpretation of atmospheric features is challenging, it is natural to turn our view towards solar system objects for training our remote sensing techniques but also for inspiration on what to look for. In this context, and using imagery collected by the Cassini Imaging Science Subsystem camera, we have investigated how Titan's disk-integrated brightness varies with the Sun-Titan-observer phase angle at 15 colors covering the spectrum from 300 to 940 nm [1]. Interestingly, Titan's brightness increases very rapidly as the moon approaches back-illumination, and Titan's twilight often outshines the dayside at the largest available angles (166 deg). Closer to back-illumination, it is predicted that the twilight-to-daylight contrast will be in the range of 10-200. This brightness surge is unique to Titan in the solar system, and is caused by the combined effects of an extended atmosphere and abundant haze that scatters efficiently in the forward direction. Hazy and extended atmospheres may be common at exoplanets [2], and thus it is worth asking whether some of them might experience similar brightness surges. The question is relevant because a positive detection will give us insight into the scale height and the optical properties of the prevailing aerosols, and this information is difficult to extract by other means. The presentation will summarize the recent findings on the Titan phase curves, will explore how feasible it is to detect this optical phenomenon with space-based photometry of exoplanets, and will comment on other implications for exoplanet characterization.

1. Titan phase curves

The phase curves were prepared with photometrically calibrated images of Titan obtained with the Cassini Imaging Science Subsystem Narrow Angle Camera. About 6,000 images obtained between 2004 and 2015 were used. The effective wavelengths of the filters range from 300 to 940 nm. Some of the images were captured at phase angles as large as 166 deg, which expands on previous phase angle coverage by the Pioneer 11 and Voyager 2 spacecraft (see Fig. 1).

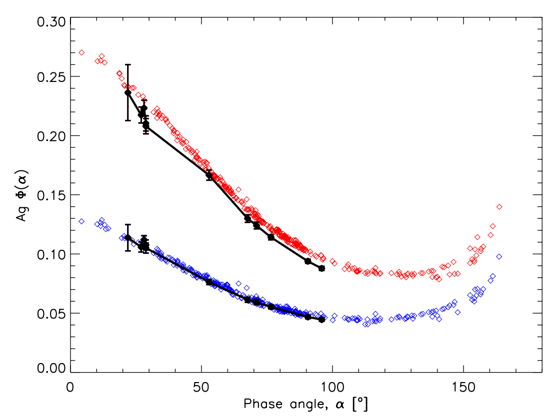

Figure 1. Cassini/ISS (color symbols) and Pioneer 11 (black symbols; [3]) phase curves at comparable blue and red wavelengths.

The brightness surge is attributed to forward scattering by Titan's haze from a ring around the moon's terminator (Fig. 2). The vertical extent of the ring, and thus the strength of the brightness surge, are enhanced by the extended nature of Titan's atmosphere.

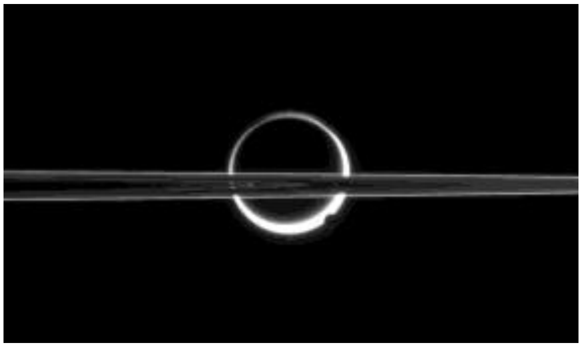

Figure 2. The brightness surge arises from the atmospheric ring that surrounds Titan when it is being back-illuminated.

2. Exoplanet phase curves

The key conditions for such an optical phenomenon to occur at an exoplanet are: 1) it must have an extended atmosphere, 2) abundant aerosols must occur at the optical radius level, 3) the aerosol particles must be efficient at forward scattering. Regarding conditions 1) and 2), it is known that there are numerous exoplanets with inflated atmospheres (Fig. 3, *paper under preparation*), and that haze is a common finding in atmospheric characterization efforts [2]. Assessing condition 3) requires detailed modeling of the aerosol microphysics [4].

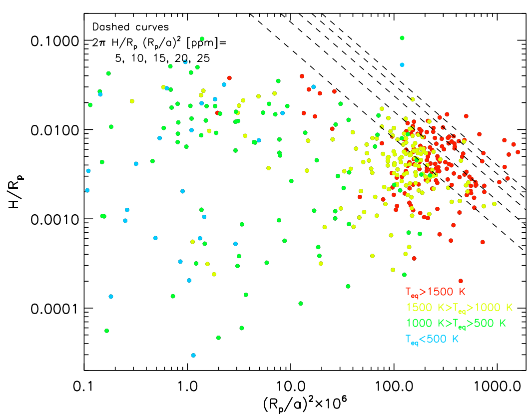

Figure 3. Known exoplanets arranged according to ratio of scale height and planetary radius (H/Rp), and planetary radius and orbital distance (Rp/a). Best conditions for a brightness surge occur towards the right/top of the diagram.

Photometric observations at large phase angles may therefore provide insight into the above conditions. For a few select planets, the brightness surge might reach up to a few tens of ppms (Fig. 3), which is within reach for a few past and future space telescopes such as Kepler, CHEOPS and PLATO. This information is complementary to the information that can be extracted from transits and occultations.

Summary and Conclusions

Motivated by recent findings on Titan, it is proposed that brightness measurements at large phase angles encode key insight into the optical properties and stratification of aerosols in exoplanet atmospheres. Future observational efforts should therefore try to constrain the occurrence of a brightness surge at the larger phase angles of the best exoplanet candidates.

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