## NAOJ 50-cm Telescope for Public Outreach discovered inhomogeneous scattering properties on the surface of asteroid (3200) Phaethon


### Summary

In December 2017, an international team of astronomers, led by post-doc researcher Yoshiharu Shinnaka from Koyama Astronomical Observatory of Kyoto Sangyo University, successfully observed the asteroid (3200) Phaethon (hereafter, Phaethon). This small asteroid is thought to be the parent body of the Geminid meteor shower, which can be seen in middle of December every year). We confirm Phaethon shows an extremely strong polarization compared with other asteroids (already reported from limited data points from NAOJ news release* entitled as "New Mystery Discovered Regarding Active Asteroid Phaethon" [*1]) and find inhomogeneous scattering properties on its surface.


Photo: Optical Polarimetric imager PICO attached to the 50-cm telescope for public outreach at NAOJ, Mitaka, Tokyo (credit: NAOJ/Reiko Furusho)

### Description of asteroid Phaethon

Asteroid Phaethon is an Apollo-type, near-Earth asteroid with a diameter of ~5 km, a rotational period of ~3.604 hours, the geometric albedo of ~0.122 (moderate value among asteroids), and peculiar orbital properties (which is a large orbital inclination of 22.2 degrees and small perihelion distance of 0.14 au). Phaethon is also likely the parent body of the Geminid meteor shower, which can be seen in middle of December every year due to small distances between the orbits of the Earth and Phaethon. Although a small brightening and faint comet-like tails were observed around its perihelion passage, these observed mass-loss

events are not sufficient to explain the activity of the Geminids meteor showers. Phaethon probably released a large amount of dust particles in the past, but mechanisms of this mass-loss from Phaethon are still in debate. Some mechanisms are proposed such as a comet-like activity driven by water ice sublimation, collisional collapse in the past. From these kinds of reasons, this asteroid is the target of flyby mission in the JAXA's DESTINY+ mission (scheduled to launch in 2022). Any information about Phaethon (such as shape model, rotational period and axis, properties of surface materials) is helpful to the DESTINY+ mission.

**Description of our polarimetry of Phaethon and polarization**

In the case of asteroids, when the light that we received from asteroids at visible wavelength is the scattered sunlight by their surfaces, we expect the observed light to be in a state of partial linear polarization. The degree of linear polarization depends on scattering properties (such as size, texture, components) of the surface and the solar phase angle at observation. Moreover, in the case of asteroids, the linear polarization degree of an asteroid as a function of the solar phase angle, α, have been used for the polarimetric classification for asteroids and for the estimates of the geometric albedo via an empirical slope-albedo relation.

In order to better understanding properties of surface materials of Phaethon, the team carried out the polarimetric observations using the imaging polarimeter PICO attached to the 50-cm telescope for the public outreach at the Mitaka Campus of the National Astronomical Observatory of Japan, Tokyo, Japan(NAOJ), every day from 2017 December 9 through December 21. Thanks to the clear skies in Tokyo during our observation, we could acquire the high-quality polarimetric data set of Phaethon over a wide range of the solar phase angle, α, from 19°.1 to 114°.3, especially, the data points at the lower α region (α<30 deg) are newly reported.

**Description of the 50-cm Telescope and PICO**

The 50-cm telescope for public outreach locates at the Mitaka Campus of NAOJ. Since April in 1996, this telescope have been used to the regular stargazing parties of public. The parties are held twice a month, at the night of Friday before the second Saturday and the fourth Saturday.

The optical imaging polarimeter, Polarimetric Imager for COmets (PICO), was developed in 2004 and had been used for the optical polarimetric imaging observations of comet 9P/Tempel 1 at the NASA/Deep Impact mission in 2005 at the Lulin observatory, Taiwan[*2]. Since then the PICO was attached to the 50-cm telescope at Mitaka station and was used for polarimetric observations of the solar system small bodies like comets and asteroids.

**Brief description of our results**

The derived phase-polarization curve shows that the maximum of linear polarization degree, Pmax, is more than 42% at α>114°. This value is significantly larger than those of the moderate

albedo asteroids (Pmax ~9%), implying peculiar surface properties of Phaethon. This trend is consistent with other polarimetric observations of Phaethon. In the previous studies, some interpretations were pointed out (e.g., relatively large grains, high surface porosity, and lower the geometric albedo than the current estimation) to explain Phaethon's large linear polarization degree. The curve also shows a normal inversion angle, at which the linear polarization degree changes its sign, indicating that Phaethon has not peculiar geometric albedo. Moreover, we found significant differences between our linear polarization degree during the 2017 December and that in 2016 (orange plus symbols), suggesting that Phaethon has a region with different properties for light scattering near its rotational pole. It is expected that not only determination of pole orientation but also the variation of scattering properties of materials with location on Phaethon's surface will be elucidated by detailed observations of the close flyby of Phaethon by the DESTINY+ mission. These results becomes important basics data to be planning the flyby mission.

*1: New Mystery Discovered Regarding Active Asteroid Phaethon
https://www.nao.ac.jp/en/news/science/2018/20180629-cfca.html (NAOJ website)

*2: Ikeda et al., Publi. Astron. Soc. Japan, 59, 1017 (2007)
http://adsabs.harvard.edu/abs/2007PASJ...59.1017I
Furusho et. al., Icarus, 190, 454 (2007)
http://adsabs.harvard.edu/abs/2007Icar..190..454F

## Information of our paper

These results of asteroid Phaethon were published as Shinnaka et al. "Inversion angle of phase-polarization curve of near-Earth asteroid (3200) Phaethon" in *The Astrophysical Journal Letters* on 2018 September 10 (online).

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**Related links** (Kyoto Sangyo University)

* https://www.kyoto-su.ac.jp/news/20180903_859_comet.html (Japanese)

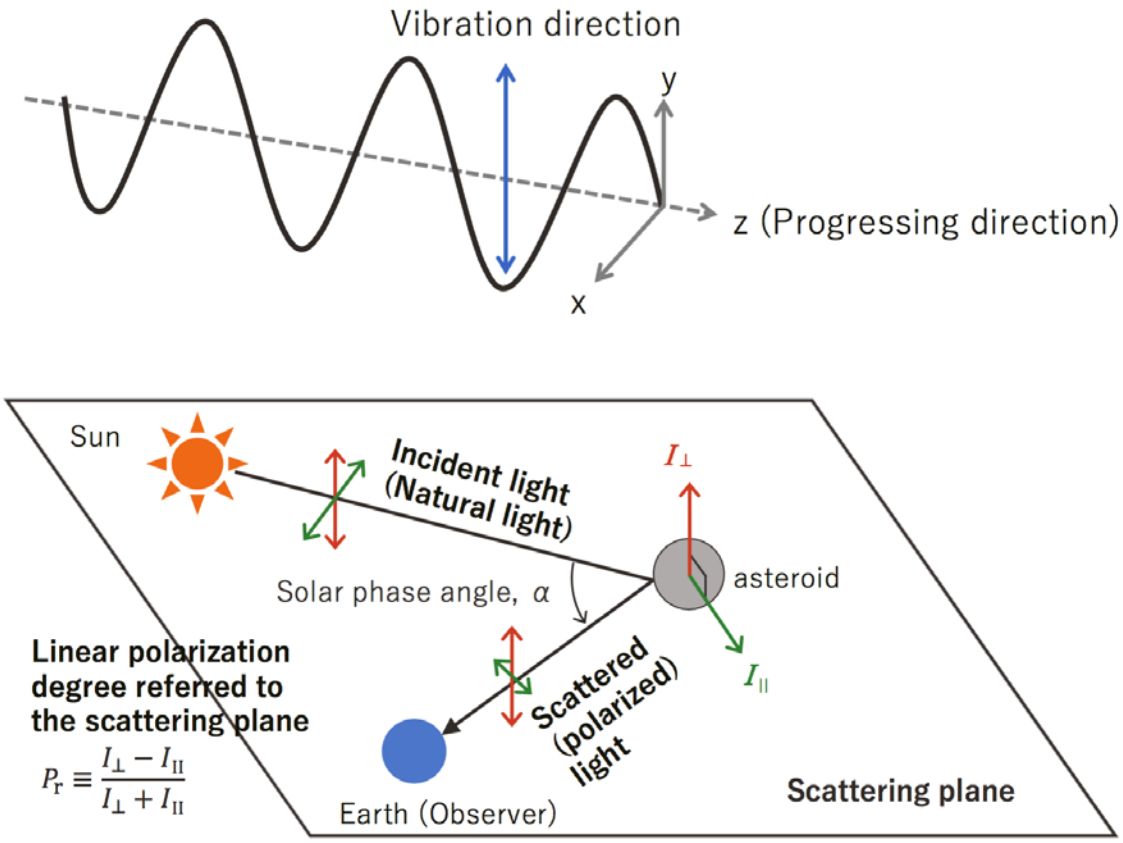


Figure 1: polarization (exactly, linear polarization) in an asteroid. When the light that we received from asteroids at visible wavelength is sunlight (natural light) scattered by their rocky surface, we expect it to be in a state of partial linear polarization. The degree of linear polarization depends on scattering properties (such as size, texture, components) and the solar phase angle at observation.

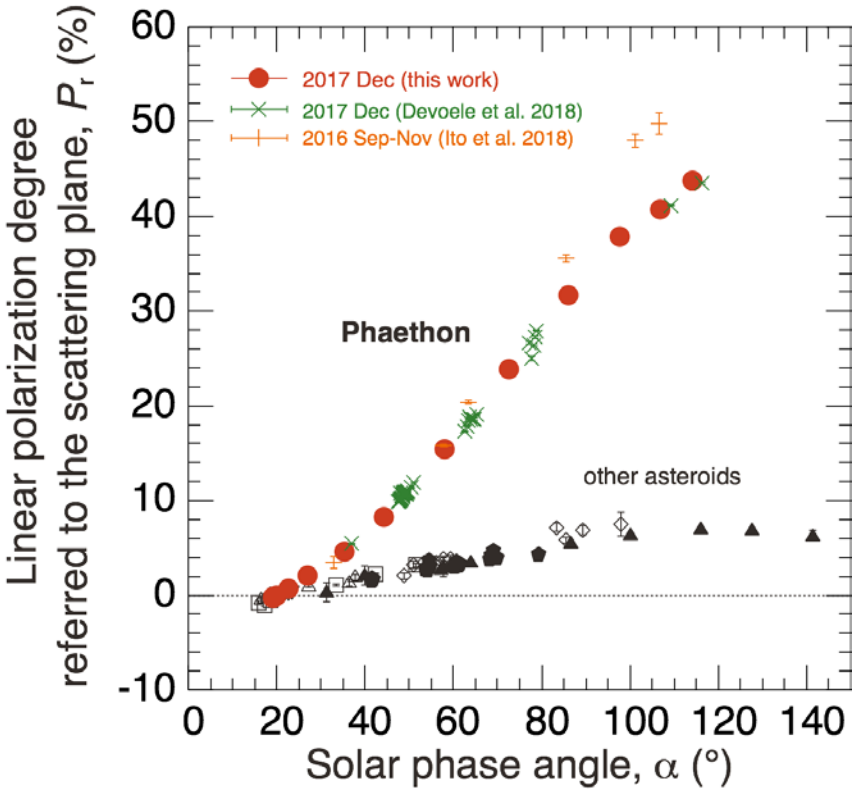


Figure 2: Observational results of Phaethon. A most important thing of this research is that we derived linear polarization degree over wide range of the solar phase range, α, from 19.3 to 114.degrees, especially, the data points at the lower α region (α<30 deg) are newly reported. The linear polarization degree of an asteroid as a function of the solar phase angle, α, have been used for the polarimetric classification for asteroids and estimation of the geometric albedo via an empirical slope albedo relation. Moreover, we found significant differences between our Pr during the 2017 December and that in 2016 (orange plus symbols), suggesting that Phaethon has a region with different properties for light scattering near its rotational pole.