Polarimetric Observations of NEAs; (422699) 2000 PD3, 2012 TC4, and (3200) Phaethon, with the 1.6m Pirka Telescope

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Abstract

We carried out optical polarimetric observations of three Apollo type near-Earth asteroids, **(422699) 2000 PD3**, **2012 TC4** and **(3200) Phaethon**, and BVRI photometric observations of 2000 PD3 using the 1.6m Pirka telescope in August-December 2017. We derived the geometric albedo of P_V= 0.22 ± 0.06 and the color indices (B-V = 0.282 ± 0.072, V-R = 0.198 ± 0.035, V-I = 0.203 ± 0.022) of **2000 PD3**, which are consistent with those of S-type asteroids (including Q-types). The polarization of a possible monolithic asteroid, **2012 TC4** is compatible with that of C-type asteroid. We found that our polarimetric data of **Phaethon** in 2017 is slightly but significantly deviated from the polarimetric profile taken at different epoch of 2016 using the identical instruments (Ito et al., 2018). This result suggests that **Phaethon** would have a regional heterogeneity in grain size and/or albedo on the surface.

Introduction

Polarimetric observing technique have been applied to study physical properties on asteroid surfaces because it is a powerful method for investigating the light scattering properties such as the albedo and the regolith particle size. The liner polarization degree P_r is defined as

$$P_r = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}$$

where $I_\perp$ and $I_\parallel$ are the perpendicular and parallel components of the intensities of light beam with respect to the scattering, respectively. P_r exhibits a strong dependence on the phase angle α (Sun-Target-Observer's angle).

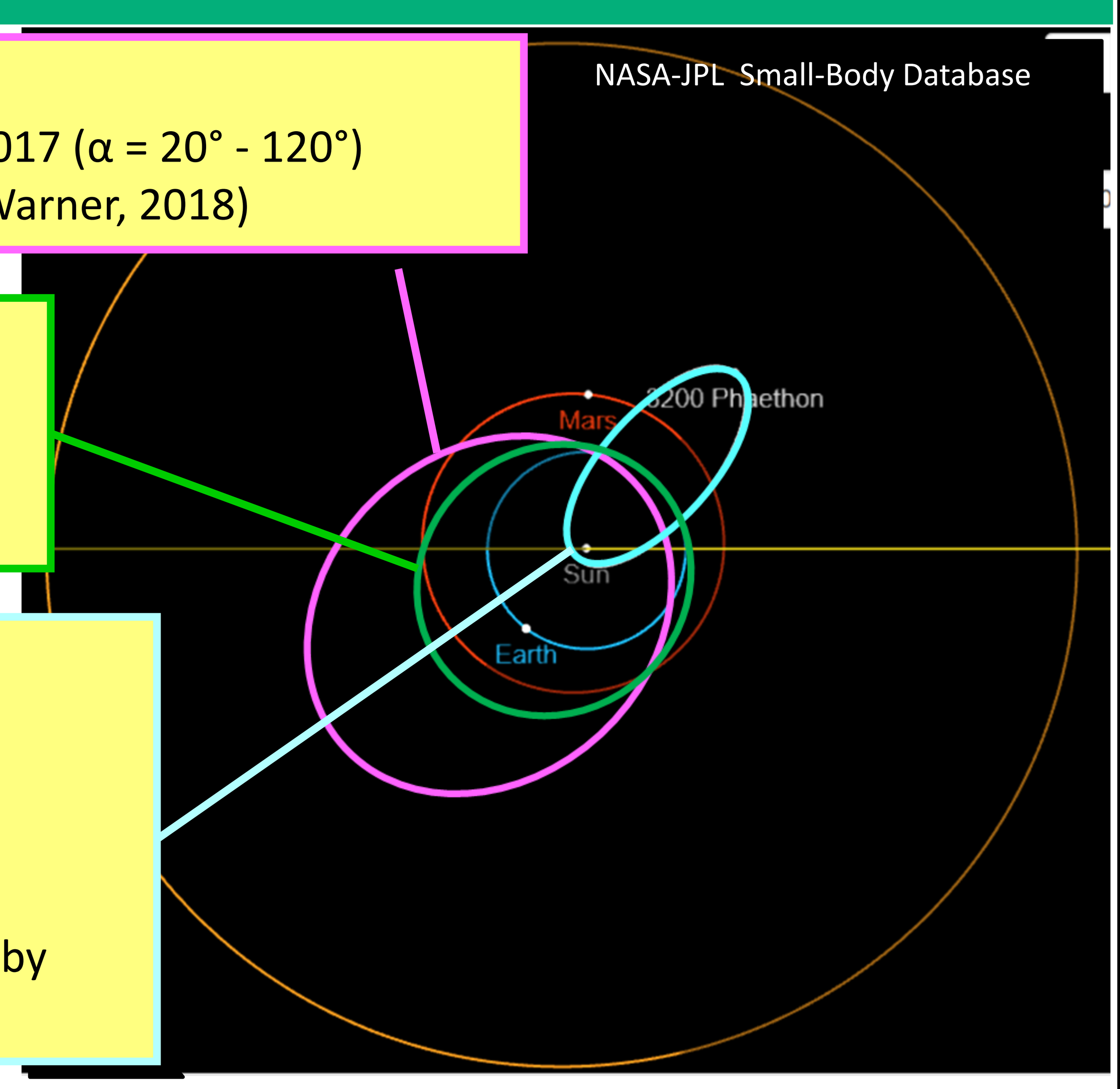
We carried out optical polarimetric observations of three Apollo type asteroids, 2000 PD3, 2012 TC4 and Phaethon, and photometric observations of 2000 PD3 at relatively large phase angles in order to understand the scattering properties of these NEAs.

Targets: Near-Earth Asteroids

(422699) 2000 PD3
- Wide phase angle range in 2017 (α = 20° - 120°)
- Rotation period ~ 42 hours (Warner, 2018)

2012 TC4
- A fast rotator (~ 0.2 hours; Warner, 2018) →a monolithic asteroid

(3200) Phaethon
- A parent body of the Geminid meteor stream
- F-type (Tholen, 1984) or B-type (Bus & Binzel, 2002)
- The target of the DESTINY+ flyby mission



NEAs are suitable for polarimetric observations which are made at large phase angles

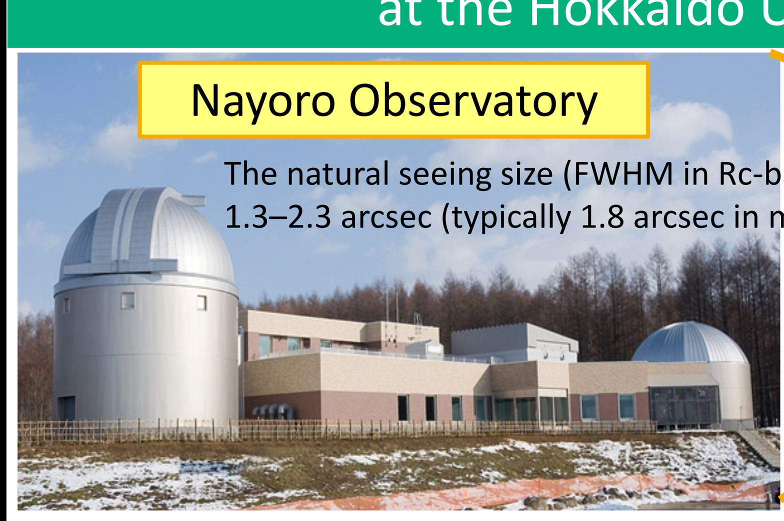
	2000 PD3	2012 TC4	Phaethon
a [au]	1.997	1.406	1.271
e	0.593	0.336	0.857
i [deg.]	7.689	0.857	22.221
ΔV [km/s]	6.9	9.3	15.2

Pirka Telescope

at the Hokkaido University's Nayoro Observatory

Nayoro Observatory

The natural seeing size (FWHM in Rc-band) 1.3–2.3 arcsec (typically 1.8 arcsec in median)

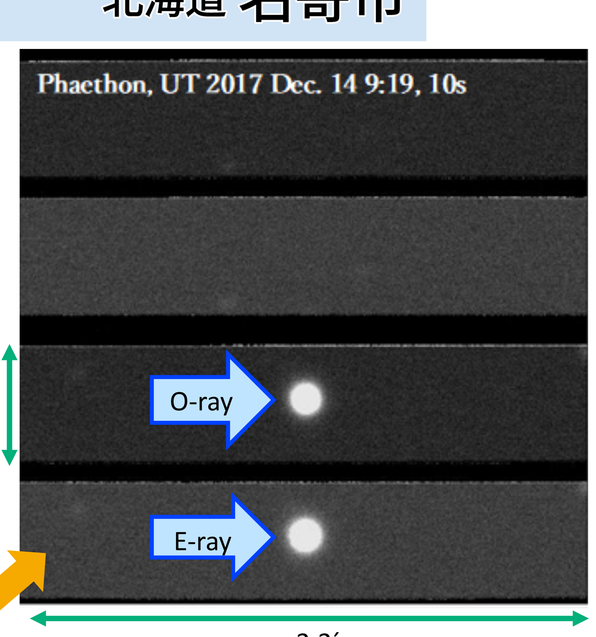


142.5◦ E longitude and latitude 44.4◦ N at 151 m above sea-level

Major Specifications

Optics	Ritchey–Chrétien
Foci	Cassegrain, Nasmyth x 2
Effective Diameter of Primary Mirror	1600 mm
Effective Focal length	19238 mm
Effective Focal Ratio	f/12.0
Unvignetted Field of View	20 arcmin in diameter (Cassegrain) 10 arcmin in diameter (Nasmyth A) 3 arcmin in diameter (Nasmyth B)
Material of Primary and Secondary Mirrors	Astro-sitall
Coating of Primary and Secondary Mirrors	Protected Aluminium
Mount	Alt-Azimuth Mount

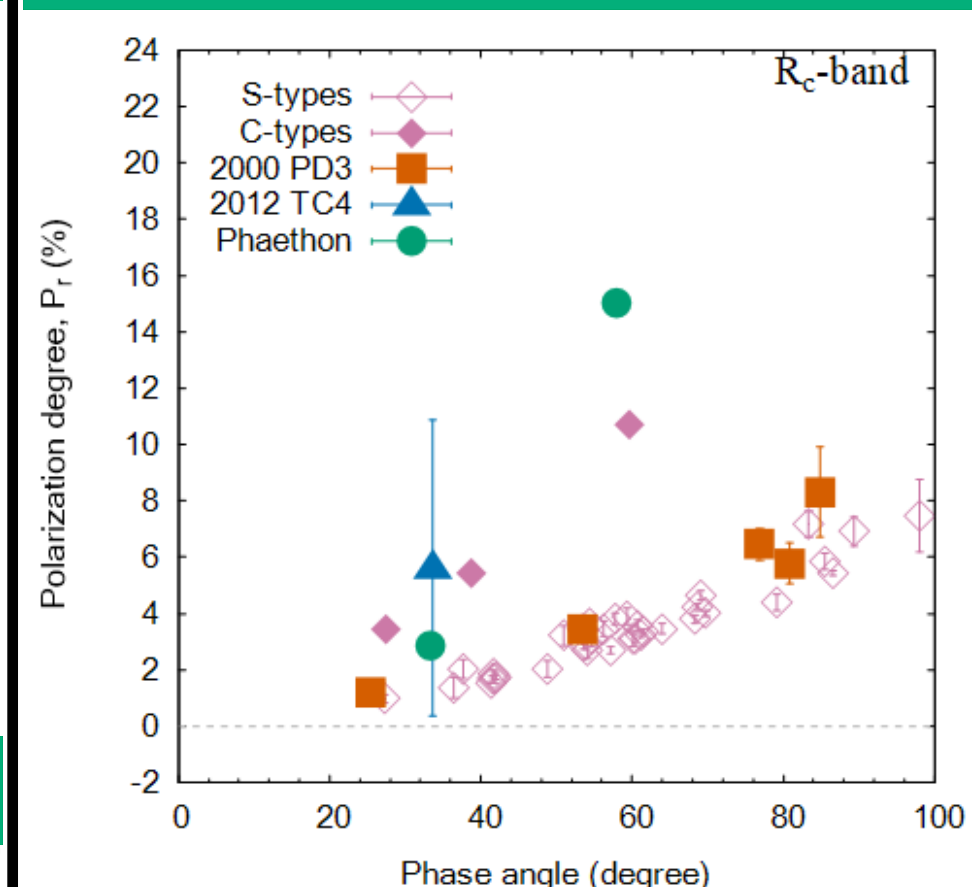
MSI: a visible multi-spectral imager
- Spectral coverage 0.36 – 1.05 μm
- FOV 3.3 × 3.3 arcmin. Pixel scale 0.389 arcsec. / pixel
- Filter Johnson-Cousins U, B, V, Rc, Ic



The polarimetric flame of Phaethon in the Rc-band

Pirka means clean and beautiful in the **Ainu** language

Phase angle vs. Polarization degree (P_r)

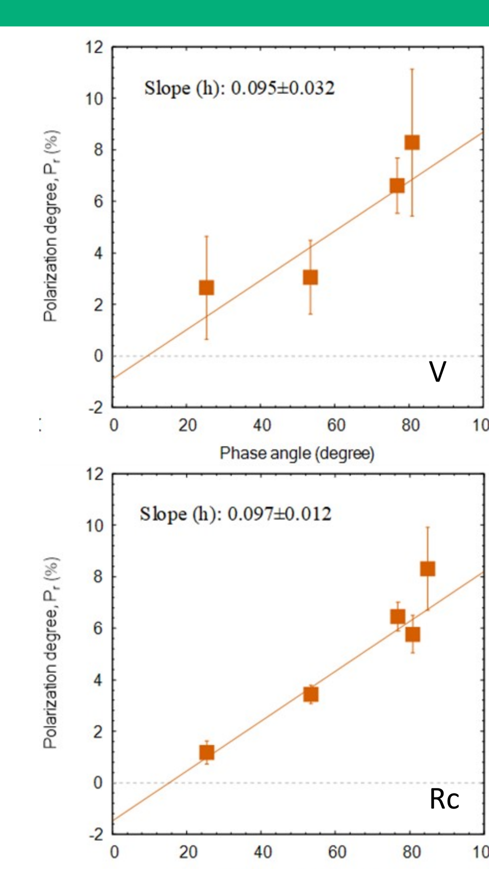


2000 PD3
- P_r are consistent with those of S-types

2012 TC4
- The middle value of 2012 TC4 trends to be higher than that of S-type asteroids

Phaethon
- P_r is much higher than those of S- and C-types

2000 PD3: Geometric albedo & Diameter



Empirical relationship so-called "the slope-albedo law"

$\log_{10}(p_V) = C_1 \log_{10}(h_{slp}) + C_2$ (Zellner and Gradie 1976)

C_1: −0.780 ± 0.037, C_2: −1.469 ± 0.036 (Cellino et al., 2015b)

Geometric albedo P_V = 0.22 ± 0.06

This albedo value is in good agreement with those of **S- or Q-type** (Belskaya et al., 2017)

Low inversion angle (α_{inv} ~ 10°& 15°)

α_{inv} ~ 20.7°(A typical value for S-type asteroids; Belskaya et al., 2017)

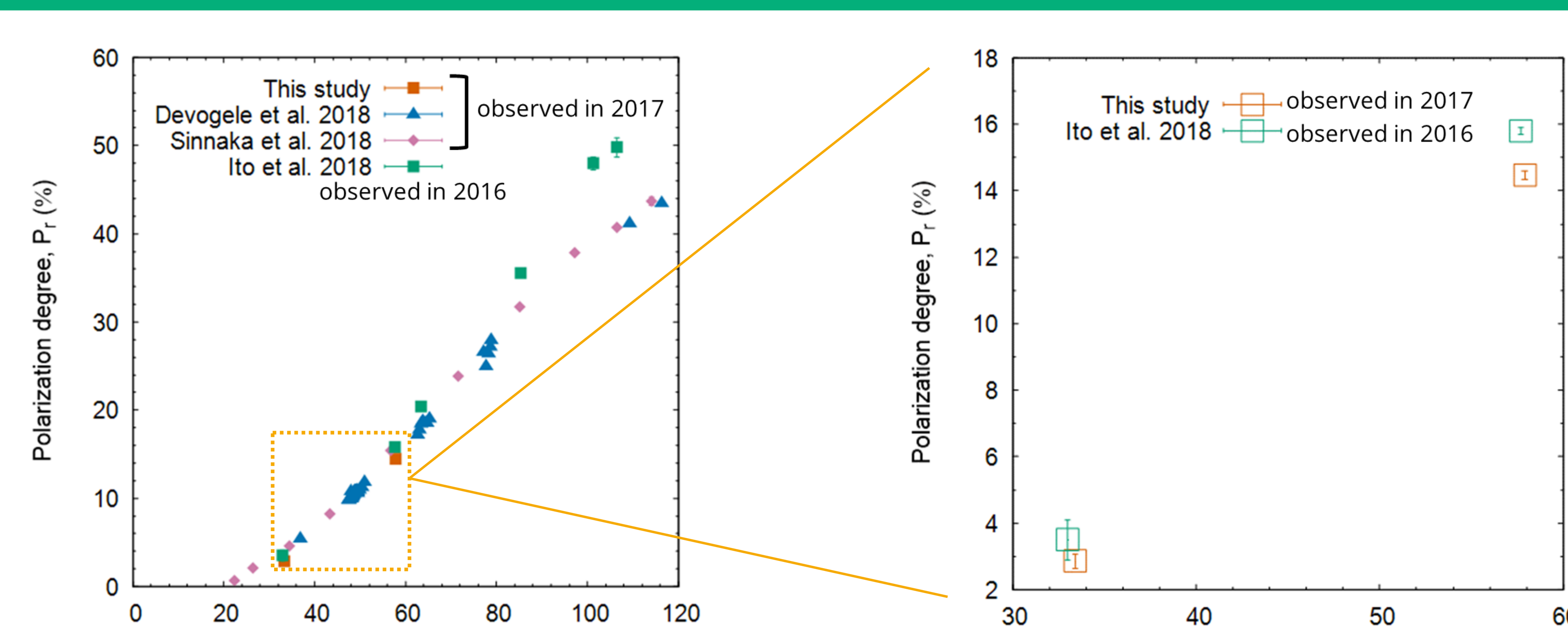
large grains ?

Effective diameter D = 0.69 ± 0.15 km from our derived values; P_V = 0.22 ± 0.06 and H = 18.10 ± 0.050

The small size may support that the small inversion angles are associated with large regolith such as the sub-km S-type asteroid Itokawa

2000 PD3 is a S- or Q-type asteroid and has large grains such as Itokawa

Phaethon: Reginal homogeneity on the surface

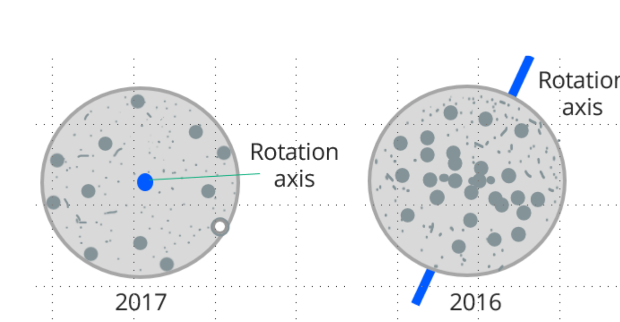


- The strong polarization of Phaethon is revealed by Ito et al. (2018), Devogèle et al. (2018) and Shinnaka et al. (2018)
- Significant discrepancies of P_r between 2016 (Ito et al., 2018) and 2017 (the others) were found

- In the identical instruments and analysis, we found the significant difference at the phase angle α ~ 58°

The polarimetric difference between 2016 and 2017 observations could be **real**

The significant difference of Phaethon's scattering property between 2016 and 2017 may be caused by the difference of apparent angle of the object from the Earth.
- Hanus et al. (2016) have shown ecliptic coordinates of the preferred pole orientation of (319°,-39°) with a 5° uncertainty.
- Phaethon exhibited the north-pole region in 2017 and the edge-on region in 2016 (e.g., Shinnaka et al., 2018)



A reginal inhomogeneity of effective **particle size and/or geometric albedo** on its surface