Polarimetric observations of the NEA "2024 MK" during close approach within the Lunar Distance

Photometric observations of the Hayabusa2# targets NEA "Torifune"

EOU Seminar
24 July 2024 13:00-14:30
M2 Kazuya DOI

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1-1. Classification of Asteroids

【Classification by Orbit】

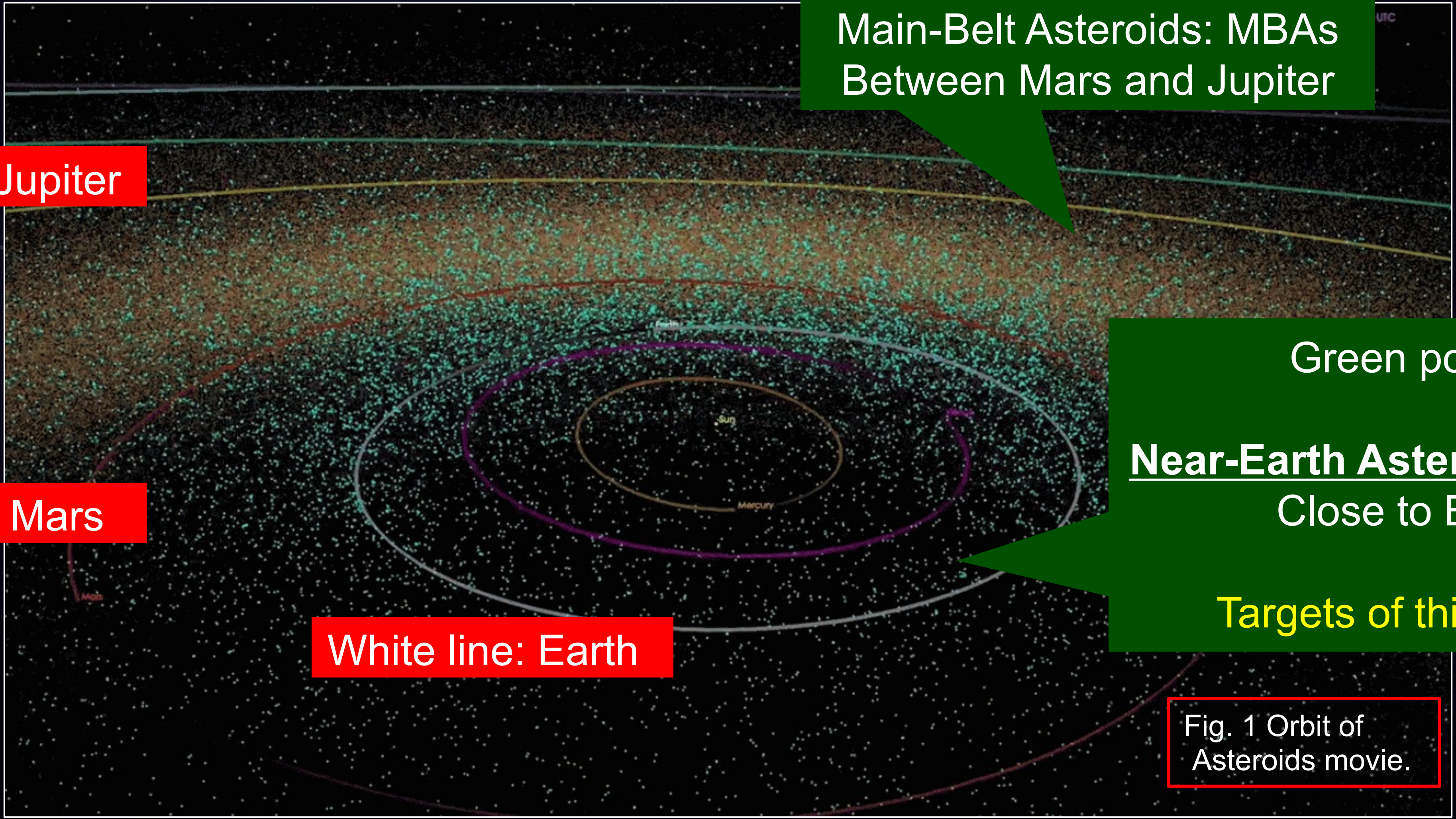


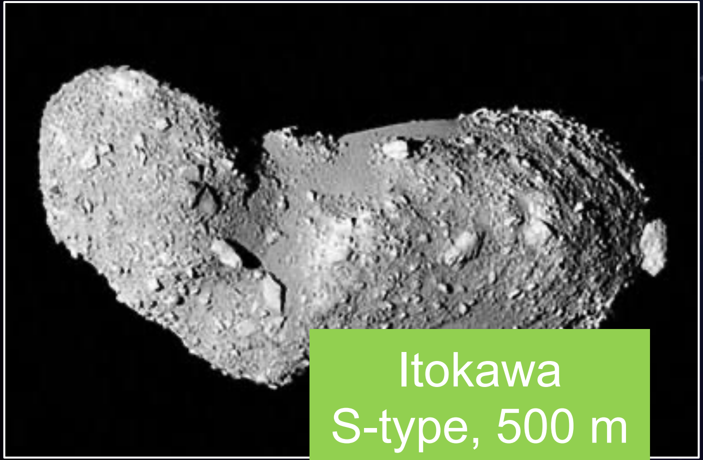
Fig. 1 Orbit of Asteroids movie.

1-1. Classification of Asteroids

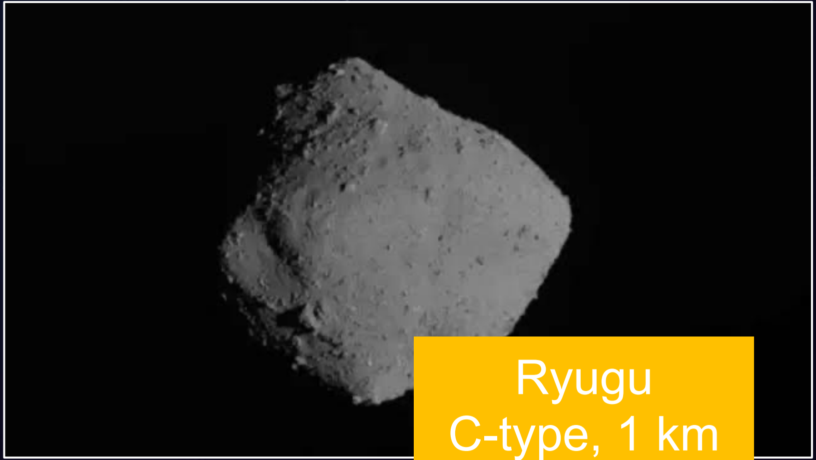
Near & Large

【Potentially-Hazardous Asteroids: PHAs】

- Specifically, minimum orbit intersection distance is within 0.05 au, and diameter >140 m NEAs.
- PHAs have a high probability of collision, and cause significant potential hazards. e. g., Itokawa, Ryugu, Apophis



Itokawa
S-type, 500 m
Albedo ~0.25



Ryugu
C-type, 1 km
Albedo ~0.05

Apophis
S (Sq)-type,
340 m

Fig. 2, 3, 4, 5 Image of asteroid impact, S-type PHA Itokawa, C-type PHA Ryugu, Orbit of PHA Apophis.

1-1. Classification of Asteroids

【Classification by Composition: Taxonomy】

5 major types,

1. **S-type**

   Stony, silicate and olivine-rich.

2. **C-type**

   Carbonaceous.

3. D-type

   Tagish Lake meteorites.

4. V-type

   Basaltic, fragments of Vesta.

5. X-type

   Various metallic meteorites.

Fig. 6, 7 S-type Asteroid Itokawa, C-type Asteroid Ryugu.

Tab. 1 Characteristics of the five major types.

Major Taxonomic Types	Reflectance Spectrum (0.4-0.9 um)	Spectral Features	Visible Albedo	Suspected Composition
D (D,T)	Blue → Red	Relatively featureless spectrum Steep red slope	0.02-0.06	Primitive carbonaceous Organic-rich compounds Hydrated minerals
C (C,B,F,G)	Blue → Red	Slight bluish to slight reddish slope Shallow to deep absorption blueward of 0.5 μm Hydrated asteroids with absorption at 0.7 and 3.0 μm	0.03-0.10	Hydrated minerals Silicates Organics
X (E,M,P)	Blue → Red	Slightly reddish spectrum E: absorption features at 0.5 and 0.6 μm	E: 0.18-0.4 M: 0.10-0.18 P: 0.03-0.10	
S (S,Q,A,K,L)	Blue → Red	Moderately steep red slope (λ < 0.7 μm) Shallow to deep absorption at 1.0 and 2.0 μm	0.10-0.22	Stony composition Magnesium Iron silicates
V	Blue → Red	Moderate to steep Very deep absorpt	0.60	Volcanic basalts Plutonic rocks

C-type
Low albedo

S-type
Moderate albedo

1-2. Origin of NEAs

【Asteroids as survivors of planetesimals】

- Asteroids retain primordial information from before the formation of planets.
- Origin of life (water) have been brought by Asteroids (and/or Comets)?

Study of NEAs is important!

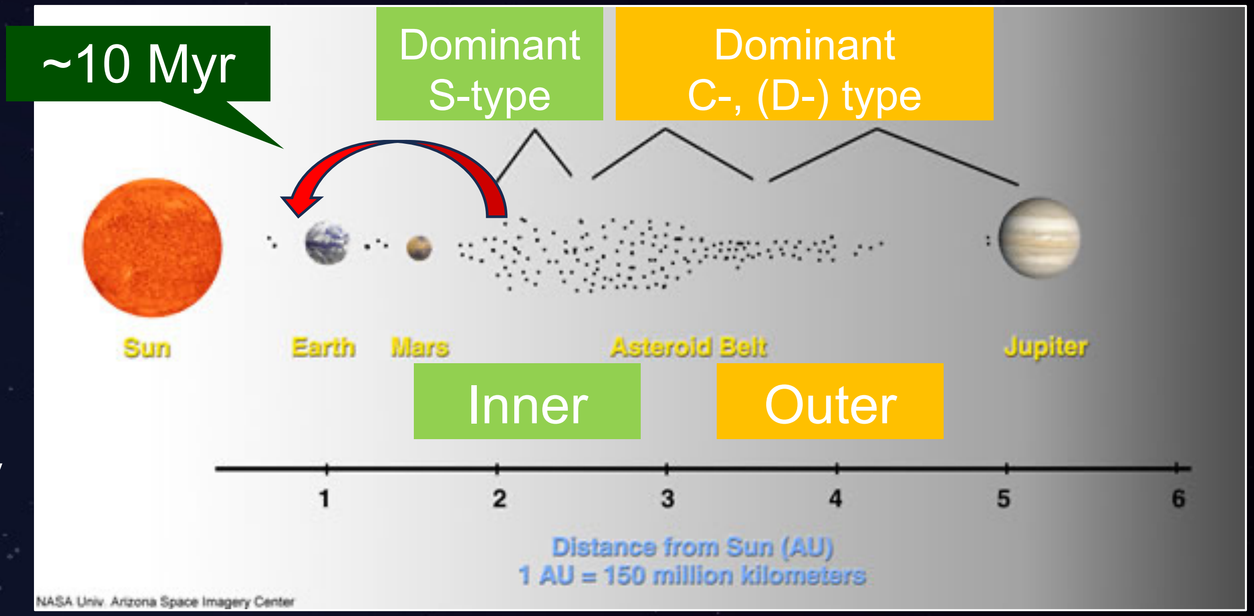


Fig. 8 Simple model of distribution of asteroids in the Solar System.

【Most NEAs originate from the Inner Main-belt】

- Scattered by Jupiter's gravity, many S-types (stony) come from the inner Main-belt.
- In contrast, C-types (carbonaceous) are primarily located in the outer Main-belt.

1-3. Number

【1.4 million discovered (as of 2025)】

- The number of discoveries is increasing steeply.
- Due to improvements of observational instruments and skills.

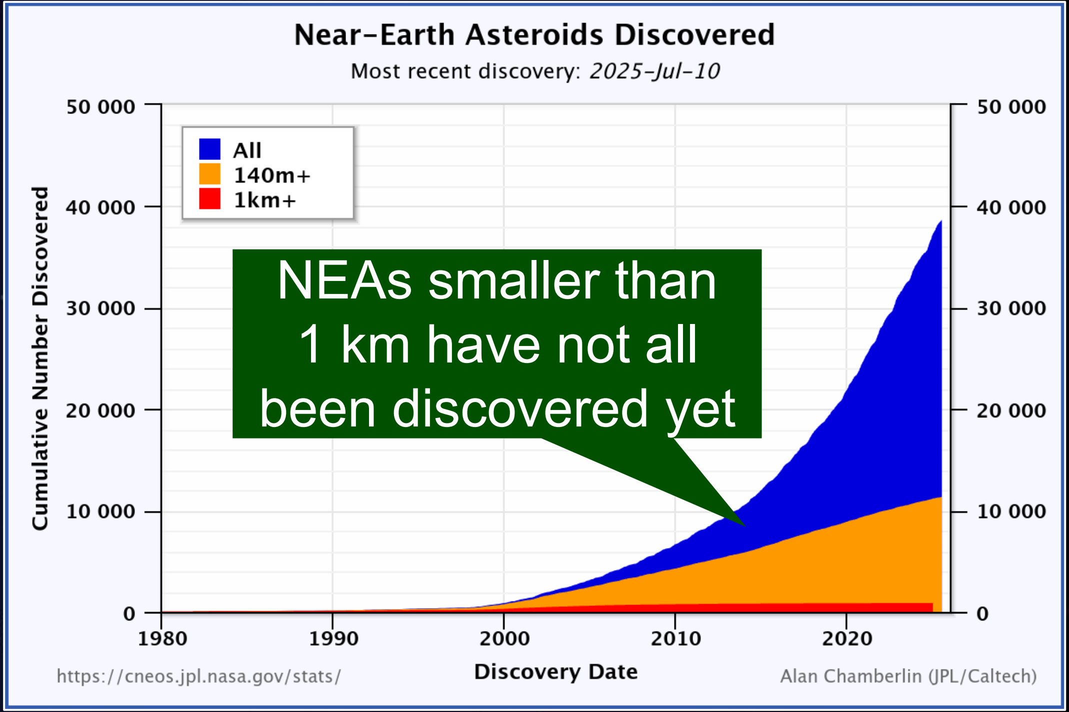


Fig. 9 Number of NEAs discovered as of 2025.

We can not respond to the unknown!

【Number of NEAs (as of 2025)】

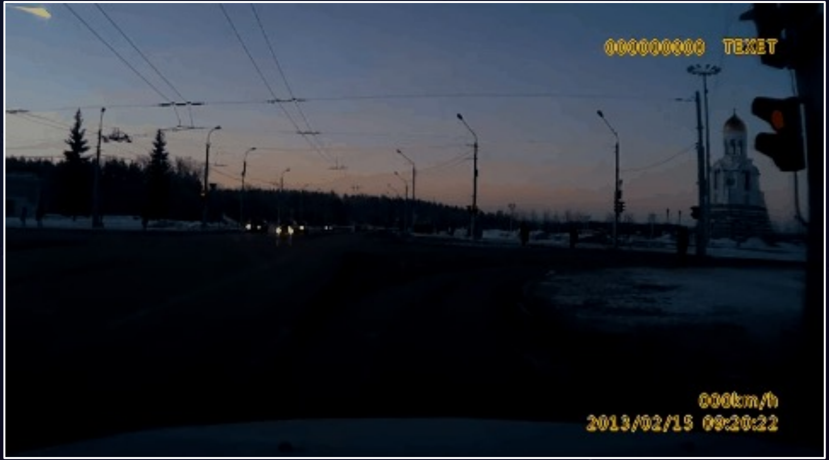
- ~39,000 have been discovered, but the **physical properties of many newly discovered NEAs are unknown**.
- Most NEAs larger than 1 km have been discovered because they are bright, but many NEAs smaller than 1 km remain undiscovered because they are dark.

1-4. Planetary Defense

Avoiding collisions
Predicting hazard

【Protecting the Earth from Asteroids (and Comets) collisions】

- 66 million years ago, Dinosaurs extinction was caused by collision of 10-20 km Asteroid (or Comet).
- In 2013, ~20 m Asteroid exploded over Chelyabinsk, injuring 1,500 people.
- In 1994, Comet Shoemaker-Levy 9 collided with Jupiter. etc.



- So now, multiple missions are being conducted to achieve and contribute Planetary Defense by NASA, ESA and JAXA etc.

Fig. 10, 11, 12 Chicxulub meteor, Chelyabinsk meteor explosion movie, The collision of Comet Shoemaker-Levy 9 with Jupiter.

1-4. Planetary Defense

【Recent impact event】

- December 4, 2024, 1:23 (JST)
- Size: ~0.7 m
- No human hazard
- Discovered only 3 hours before the impact!
- It is so important to understand the behavior of NEAs

Fig. 13 Impact of C0WEPC5 movie.

1-4. Planetary Defense

【Planetary Defense response process】

Step1: Discovery

Orbit determination through follow-up observations

Step2: Investigate of **physical properties**

(size, composition, porosity etc.)

To evaluate the possibility of changing the orbit and predicting hazards

This study contributes to this step!

Step3: Avoidance or Damage minimization

Alert to the public, Spacecraft impact etc.

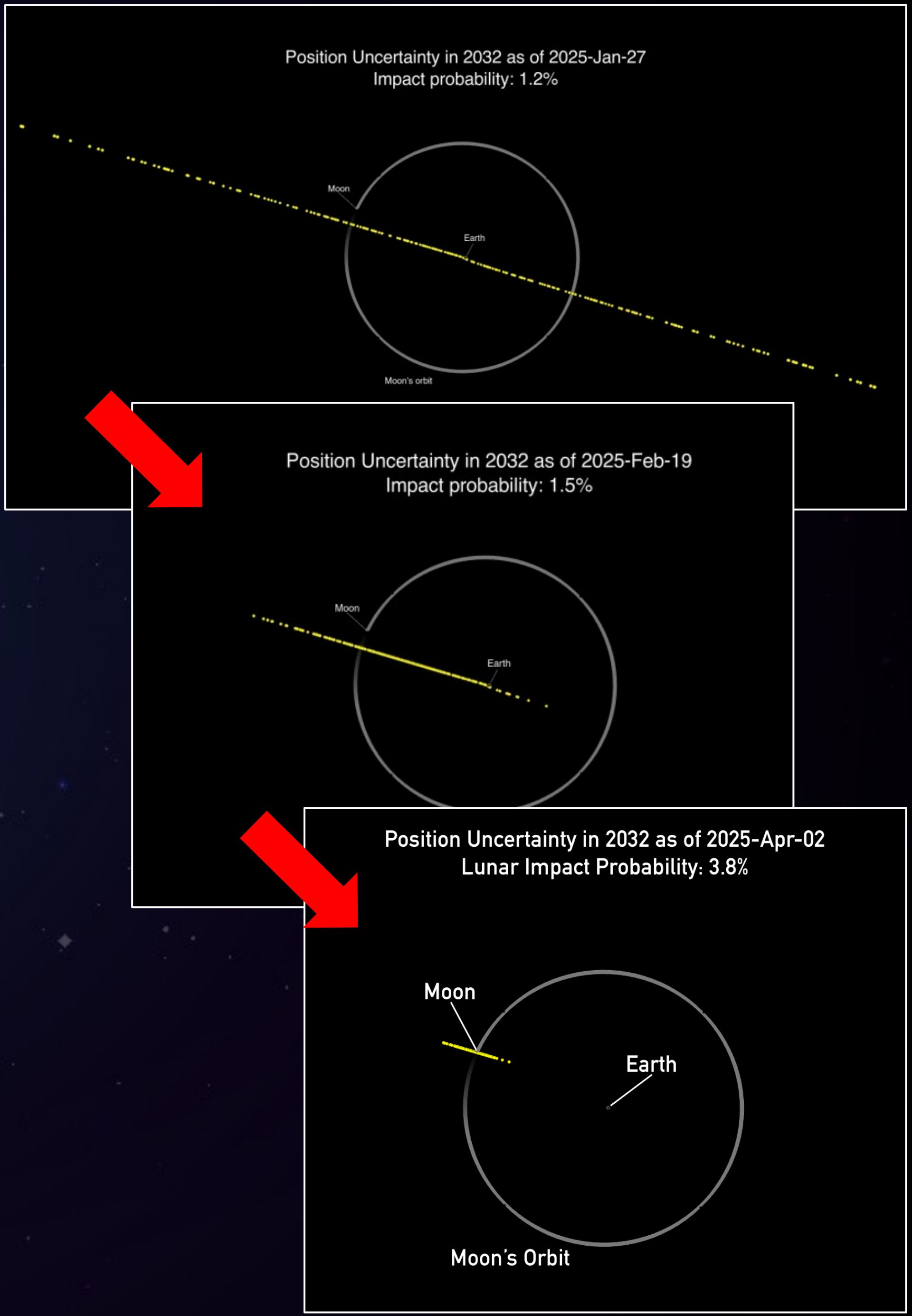


Fig. 14 Change in position uncertainty of NEA 2024 YR4.

1-5. Planetary Defense Missions

【NASA DART & ESA HERA Missions】

- Target: Binary NEAs, Didymos-Dimorphos
- Change the orbit of Dimorphos (satellite) by impacting it with a DART spacecraft.
- Investigate details (physical properties; crater size, mass, etc.) by HERA spacecraft.

More fragile than expected!
Need to know more about NEAs!

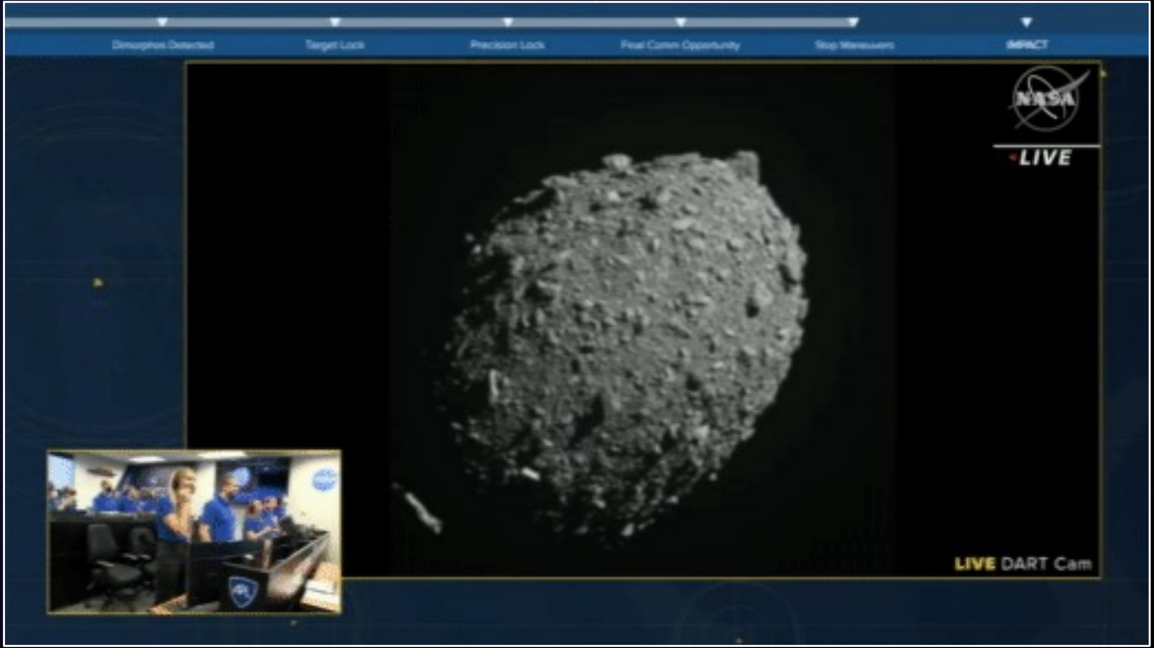
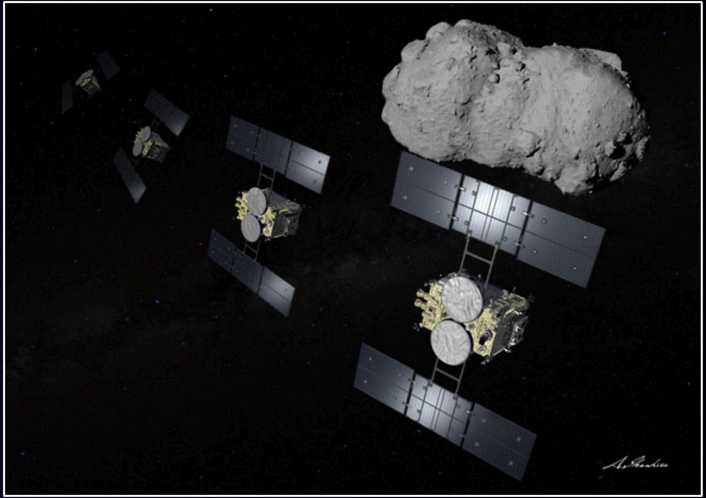


Fig. 15, 16 Image of DART impact, Impact of DART spacecraft movie.

1-6. JAXA Hayabusa2# Mission

【Hayabusa2# Mission objectives】

1. Advancement of long-term solar system navigation technology.
2. Realization of exploration of small and fast rotating Asteroids.
3. Acquisition of science and technology contributing to **Planetary Defense**.



This study observed Torifune

【Targets Asteroids】

1. **Torifune**
   Flyby in July 2026. PHA, Itokawa like?
2. 1998 KY26
   Rendezvous in July 2031.
   Size: <17 m, Rot. Period: 10 min (so fast). Monolith?

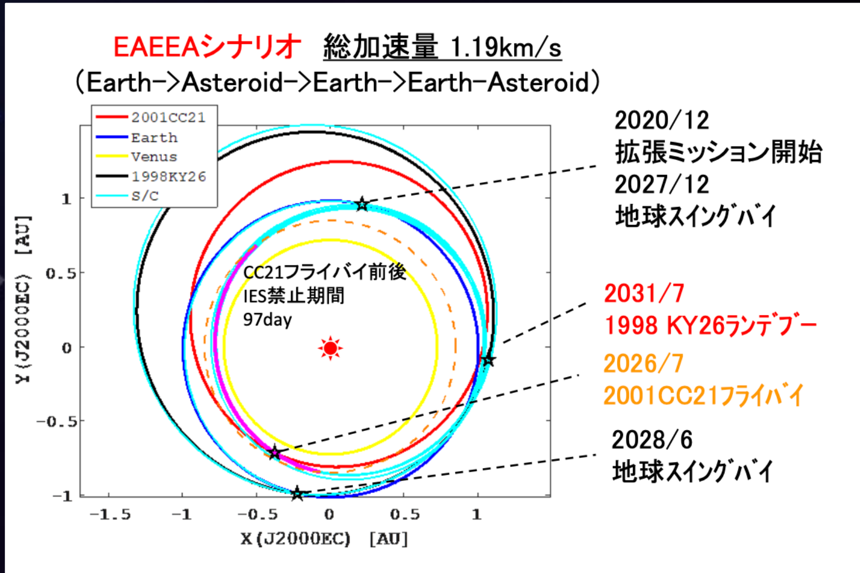


Fig. 17, 18 Hayabusa2 Flyby image, JAXA EAEEA scenario.

1-6. JAXA Hayabusa2# Mission

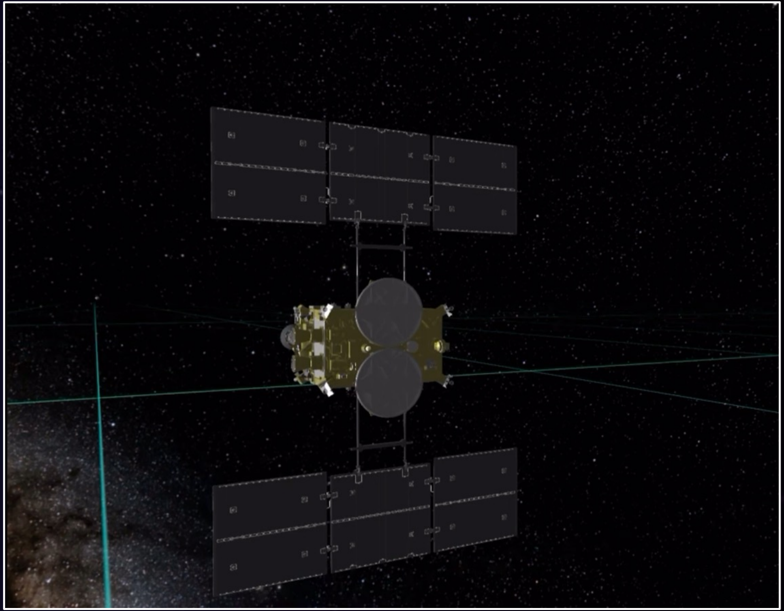
【Torifune Flyby】

- Flyby speed is ~5 km/s (so fast!)
- Planned closest distance ~1 km (“Kamihitoe method”)

【Hayabusa2 onboard camera】

- Designed for rendezvous, so it is not capable of telephoto imaging.
- At the Flyby, the exposure time and gain must be **pre-determined**.
- **Surface Color information** from **ground-based observations in advance** is essential.

This study



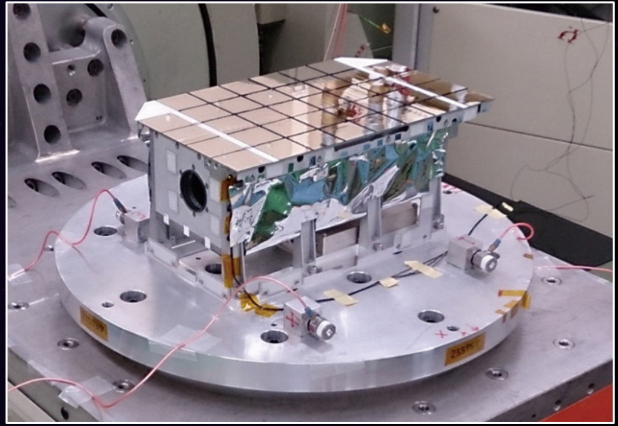


Fig. 19, 20 Simulation of the Torifune Flyby at ~1 km, Hayabusa2’s onboard NIRS3 spectroscopic camera.

1-6. JAXA Hayabusa2# Mission

【Surface Color homogeneity or heterogeneity】

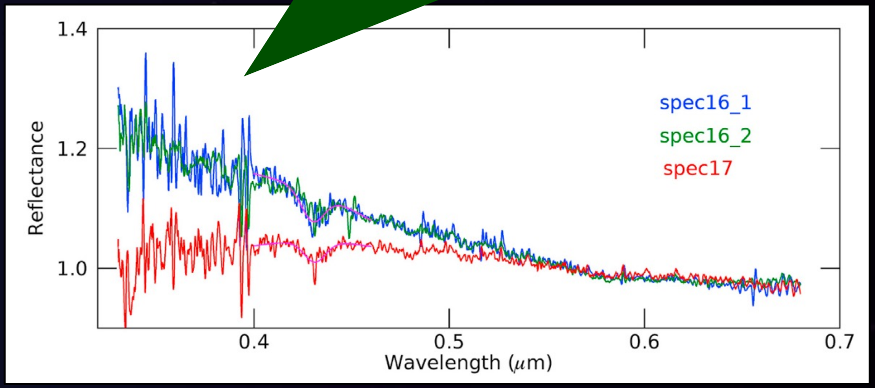
- Many asteroids have been confirmed to exhibit surface color homogeneity.

- Some asteroids have been reported to exhibit surface color heterogeneity (front-back side). e. g., NEA Phaethon etc.

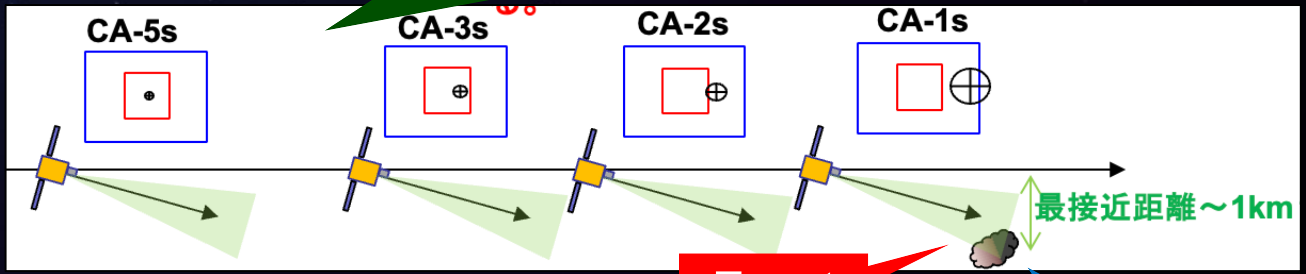
【Flyby can observe only one (front) side】

- Ground-based observations can provide color information on the most scientifically valuable side.

Surface Color heterogeneity of Phaethon



Spatially resolvable time is only 2-3 s!



Front

Back

Fig. 21, 22 Reflectance spectrum of Phaethon, Hayabusa2 Flyby plan.

2. Purpose and Goals

【Summary of Introduction】

- Clarifying NEAs is so important; Planetary Defense, Surface information etc.
- Ground-based observations before the “in-situ” observations are essential.

【Goals】

- Obtaining information (behavior) to understand NEAs.
- Contributing to Planetary Defense, especially Hayabusa2# mission.

【Purpose】

- Deriving the **<u>physical properties</u>** of unique NEAs through ground-based observations.
  Surface composition, albedo, grain size and porosity etc. (Representative NEA)

3-1. Observation methods

(A) Polarimetric observations
- Grain size
- Porosity
- Surface composition (rough)
- Albedo

Pirka

(B) Photometric observations
- (Local) Surface composition
- Size
- Rotation period
- Shape

Seimei

Spectroscopic observations
- Surface composition

Occultation observations
- Orbit
- Size
- Shape

Radar observations
- Size
- Shape

Other observations

(Thermal infrared, Survey, In situ, Astrometry etc.)

- Temperature
- Orbit
- Size
- Shape
- Albedo
- Rotation Period
- Albedo etc.

3-2. Identification of target Asteroids

【Identification method】

- 'Blink' 2 fits data (images taken 5-10 min apart), while tracking in Asteroid (no-sidereal) mode, so that the moving objects are stars (sidereal), and the stationary object is the target Asteroids.

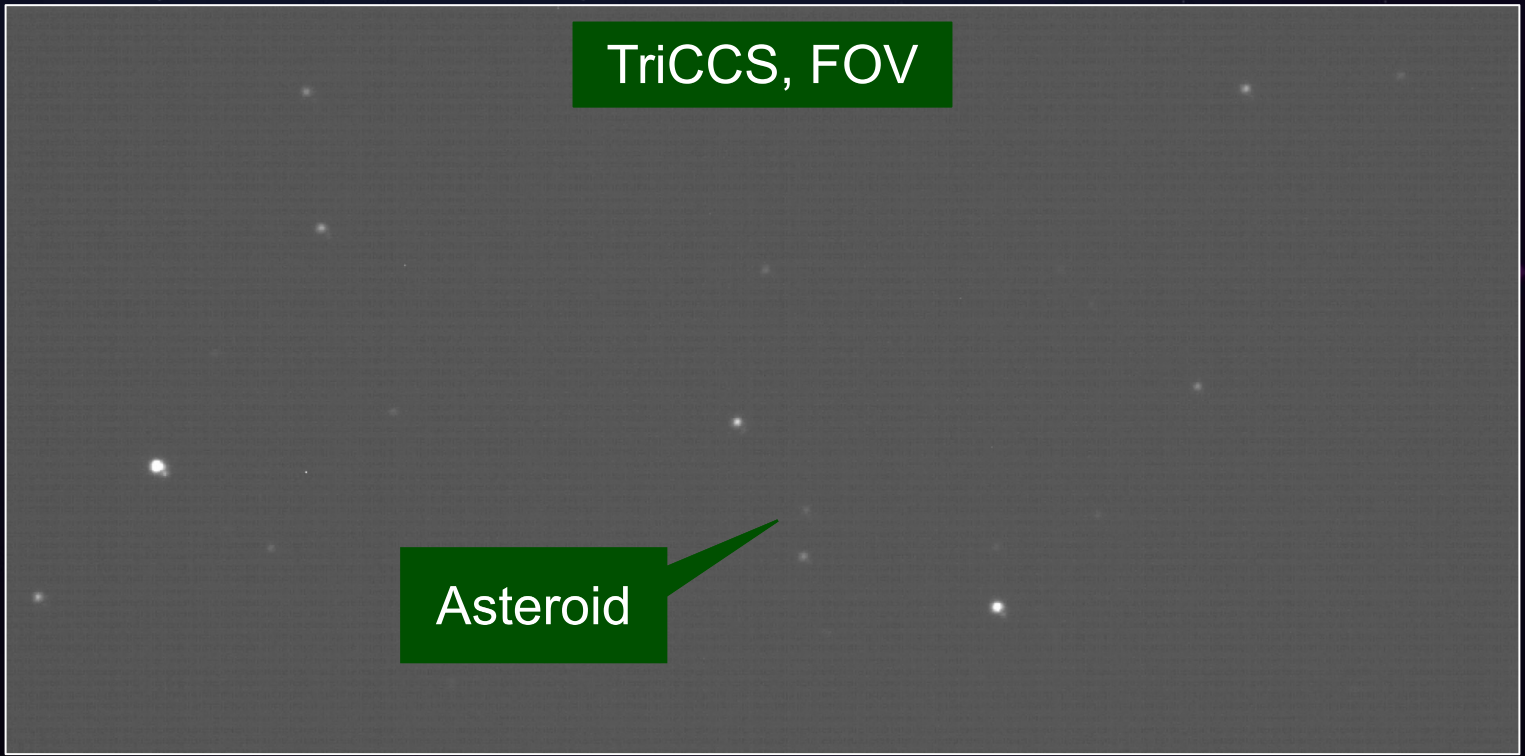


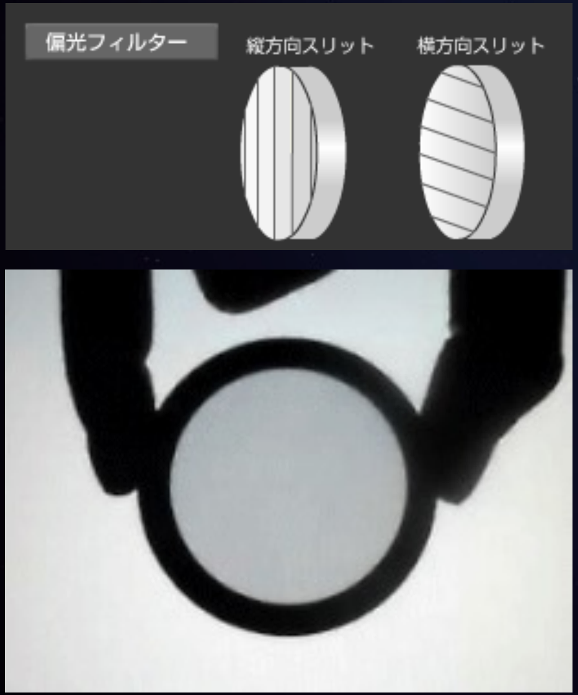
Fig. 23 2 fits data of target Asteroids blink movie.

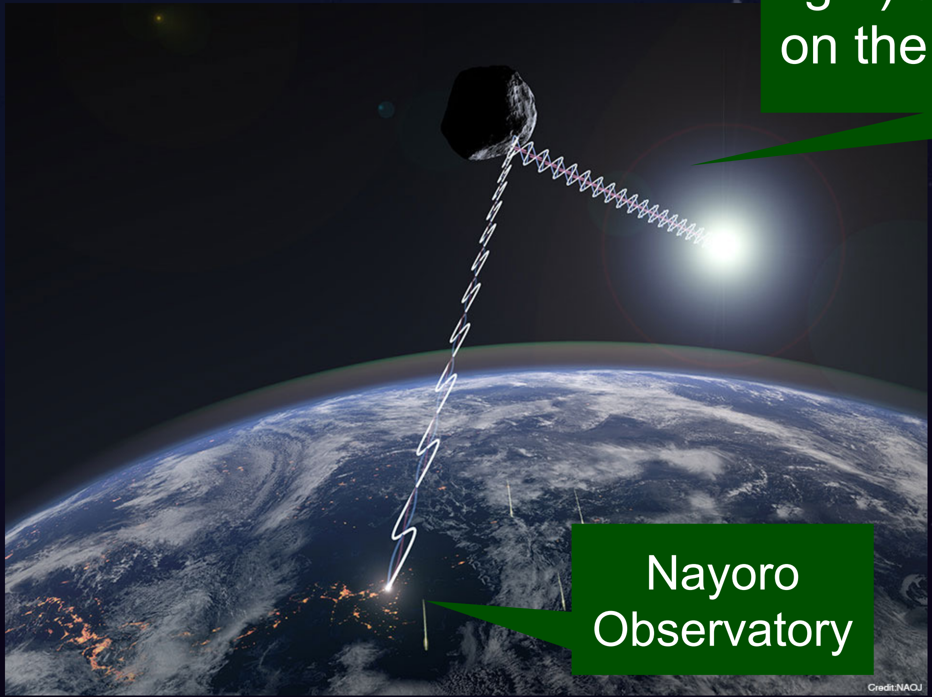
3-3. (A) Polarimetric observations

【Polarization】

- Light that vibrates in various directions, with only certain directions of vibration being selected.

Asteroids reflect sunlight (unpolarized light) and polarization occurs depending on the <u>surface scattering properties</u>.





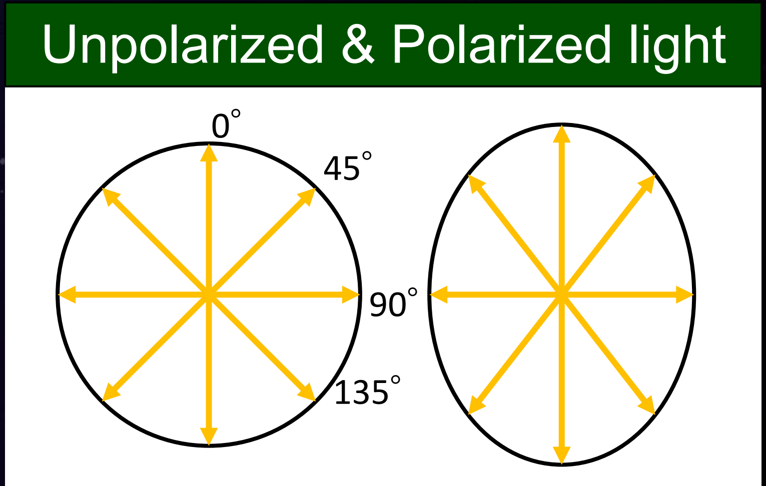


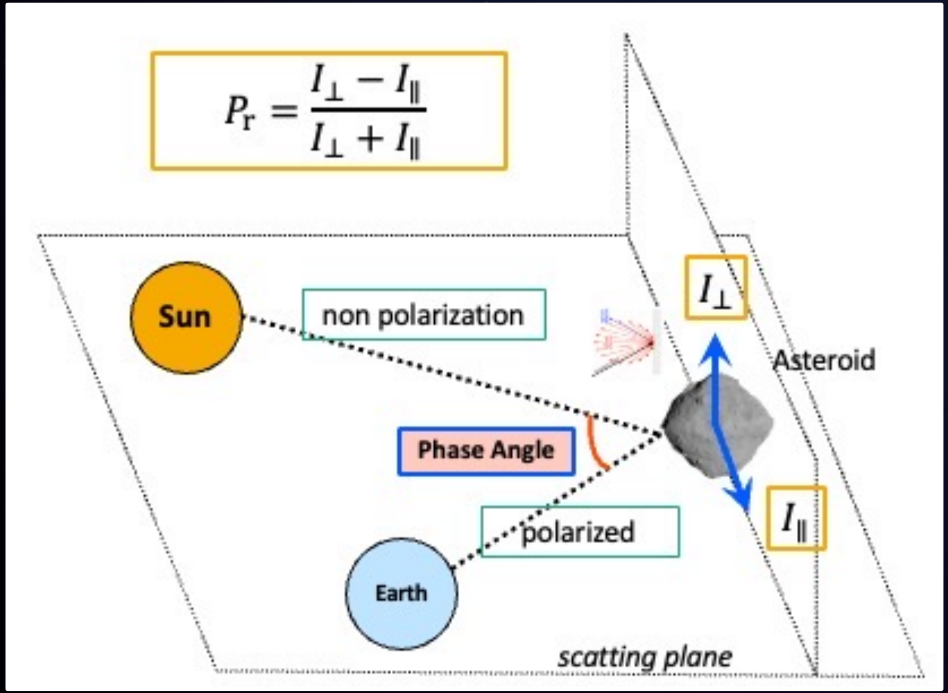
Fig. 24, 25, 26 Polarization filter movie, Polarization of Asteroid, Unpolarized and polarized light.

3-3. (A) Polarimetric observations

【Polarization degree】

- Linear Polarization degree: $\boldsymbol{P_r} = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}$ %
- Polarizer: Wollaston Prism

  separate into Ordinary-ray (O-ray: $I_\perp$) and Extraordinary-ray (E-ray: $I_\parallel$)



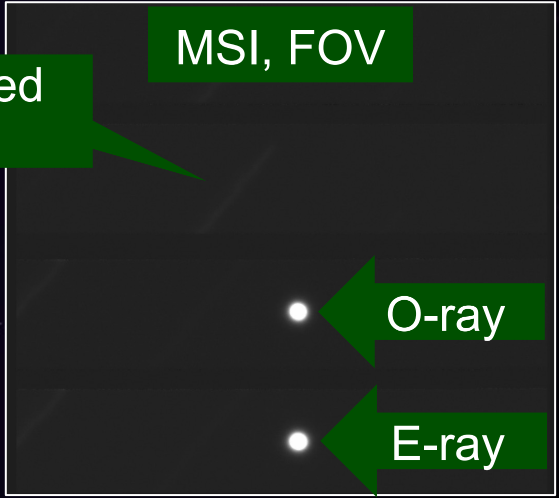


Fig. 27, 28, 29 Basic information of asteroid polarization, Wollaston Prism, MSI FOV.

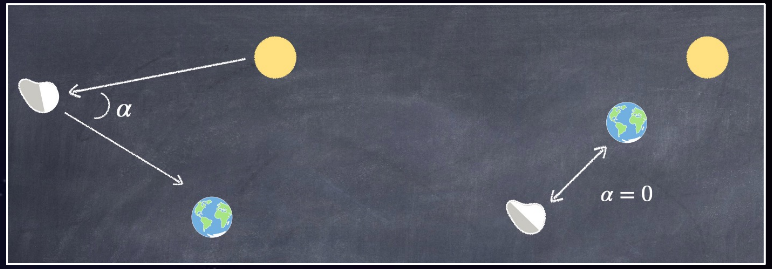
3-3. (A) Polarimetric observations

【Polarization degree】

- Linear Polarization degree: $\boldsymbol{P_r}$ depends on the phase angle: α
- Phase angle: Sun-Target-Observer (S-T-O) angle

Tab. 2 Comparison of MBAs and NEAs.

	MBAs	NEAs
Distance from the Earth	Far	Close
Change in phase angle over a few days	Small	Large (wide range) Obtain various data !



P_r vs α linear polarization curve

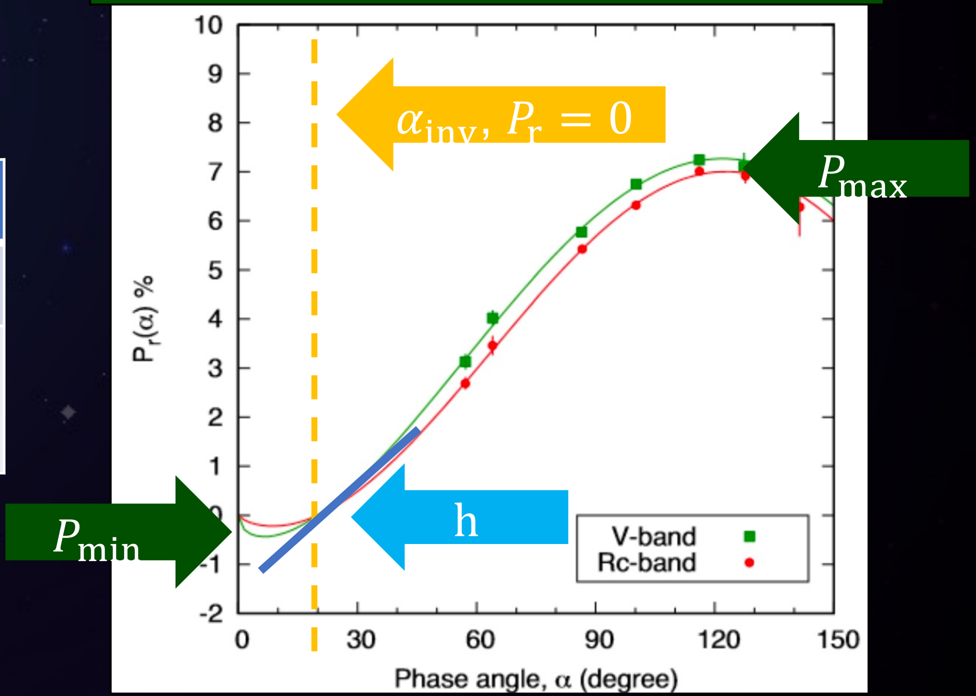


Fig. 30 NEA 1566 Icarus [Ishiguro et al., 2017].

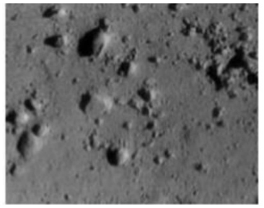
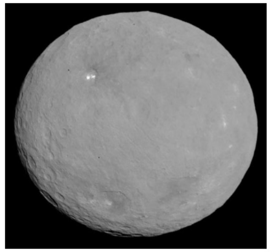
3-3. (A) Polarimetric observations

【Surface scattering property】

- **<u>Regolith grain size</u>**

  Laboratory experiments, the Liner Polarization degree tends to increase when the particle size is either much smaller or larger than the observed wavelength.

Grain size parameter: $X = \frac{\pi d}{\lambda}$
d: Grain diameter [μm]
λ: Wavelength of observational light [μm]

25143 Itokawa	433 Eros	The moon	1 Ceres
			

Rough   <u>Grain size</u>   Fine

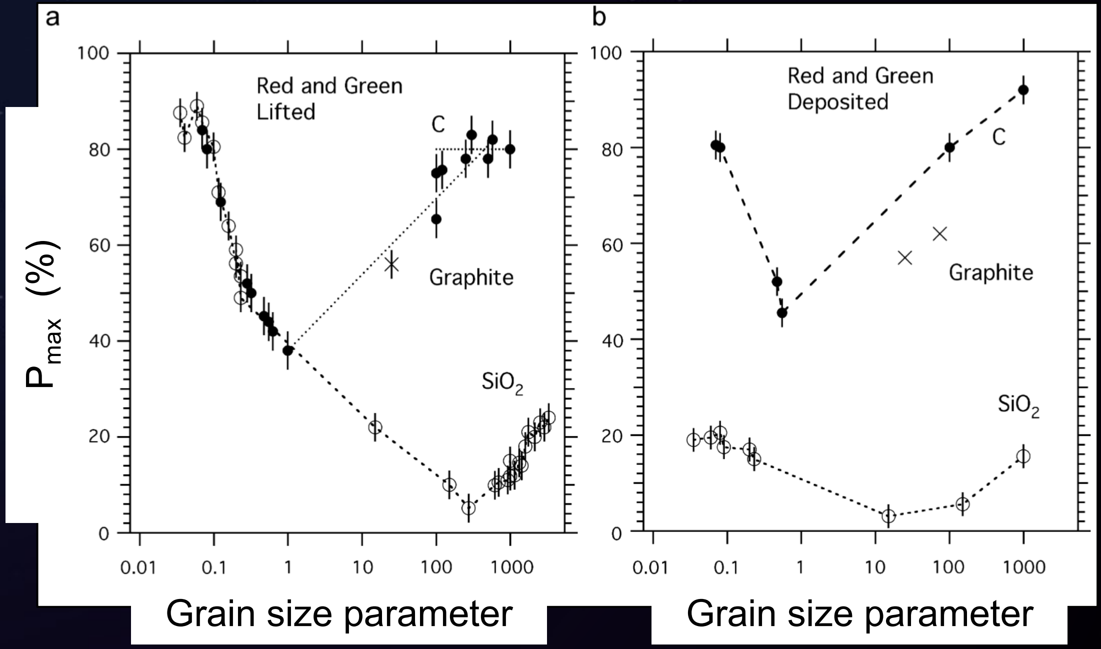


Fig. 31, 32 Regolith grain size of some asteroids and moon, Pmax vs Grain size parameter [Hadamcik et al., 2009].

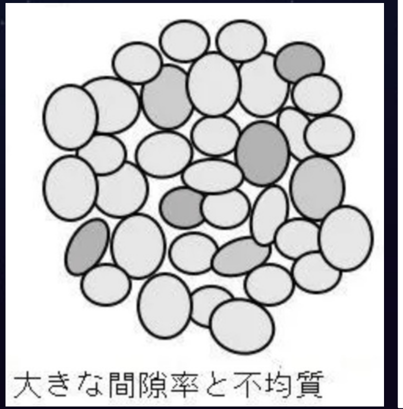
3-3. (A) Polarimetric observations

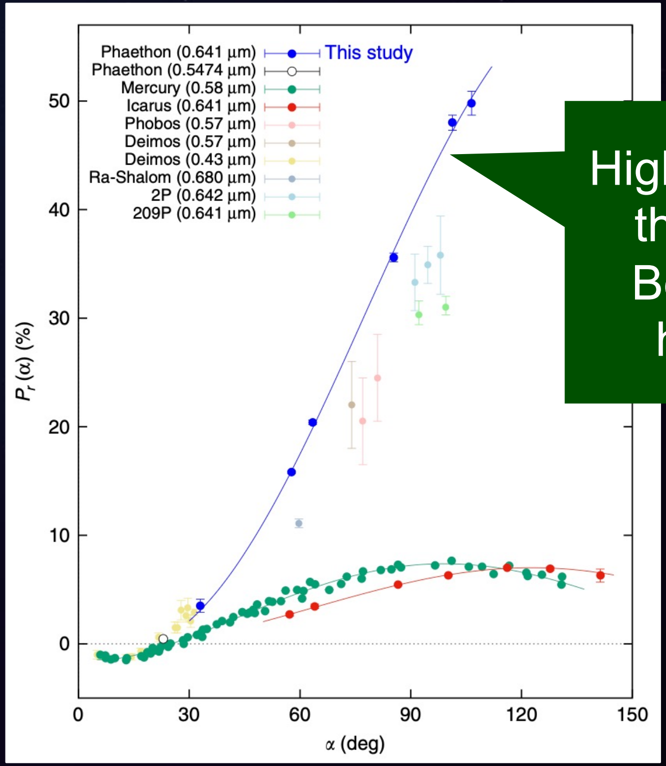
【Surface scattering property】

- **<u>Porosity</u>**

Regardless of grain size, the Liner Polarization degree tends to increase strongly due to high porosity arising from irregular grain shapes and heterogeneous surface structures.

NEA Phaethon has shown <u>higher than expected</u> polarization degrees and such behavior has been attributed to highly porous surface grains.





Higher Polarization than expected! Because of the high porosity

Fig. 33, 34 Image of high porous, Liner Polarization degree of NEA Phaethon [Ito et al., 2018].

3-3. (A) Polarimetric observations

【Surface scattering property】

- **Surface composition & Albedo**
  Polarization curve shape (visually)
  estimate Taxonomy Type (C or S or E(X))

Tab. 3 Polarization parameter characteristics of C-type and S-type.

Polarization parameters	α_{inv}	h	P_{max}	P_{min}
C-type	Small	Steep	High	Deep
S-type	Large	Mild	Low	Shallow

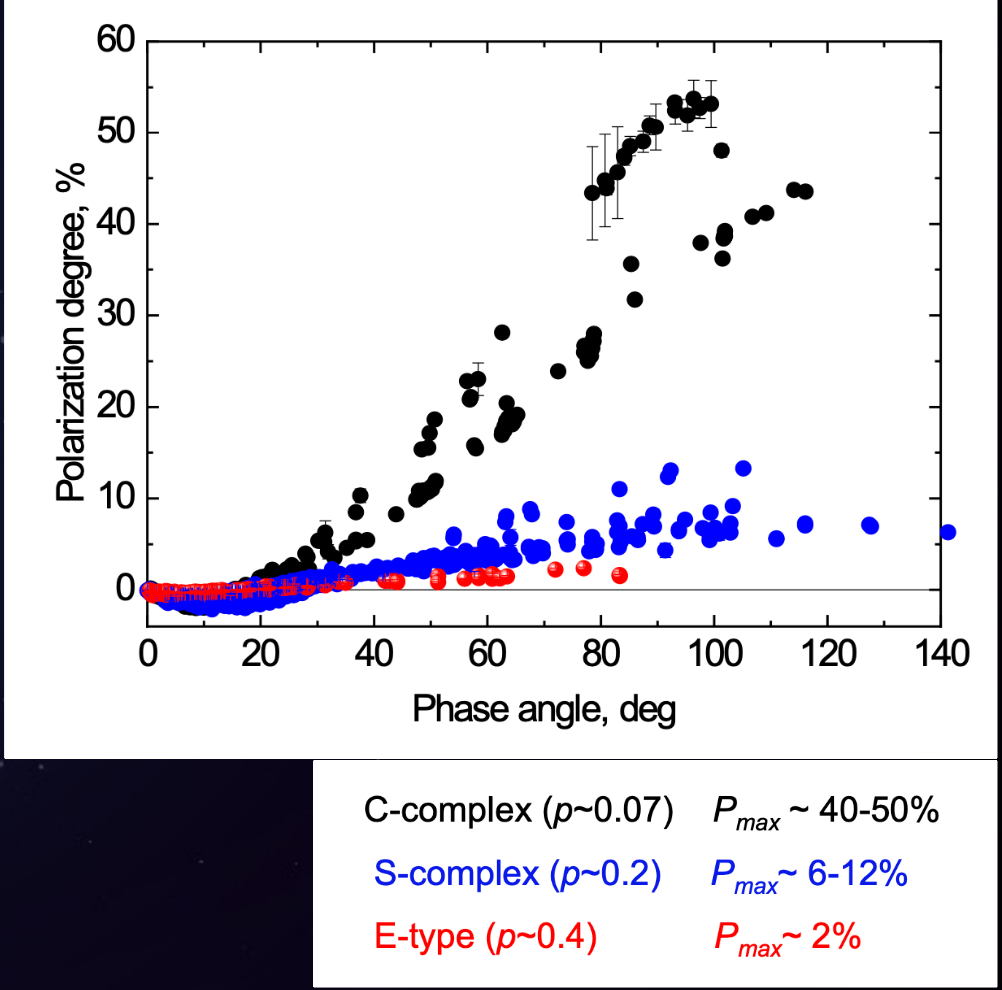


Fig. 35 Polarization of typical C-, S-, E-Type Asteroids include NEAs [Belskaya, 2024].

3-3. (A) Polarimetric observations

【Surface scattering property】

- **Regolith grain size**
- **Porosity**
- **Surface composition & Albedo**

⬇

- The surface scattering properties are not simple, as they involve several contributing factors.
- It is certain that the polarization degree of Asteroids depends on surface scattering properties, but the detail remain unclear.

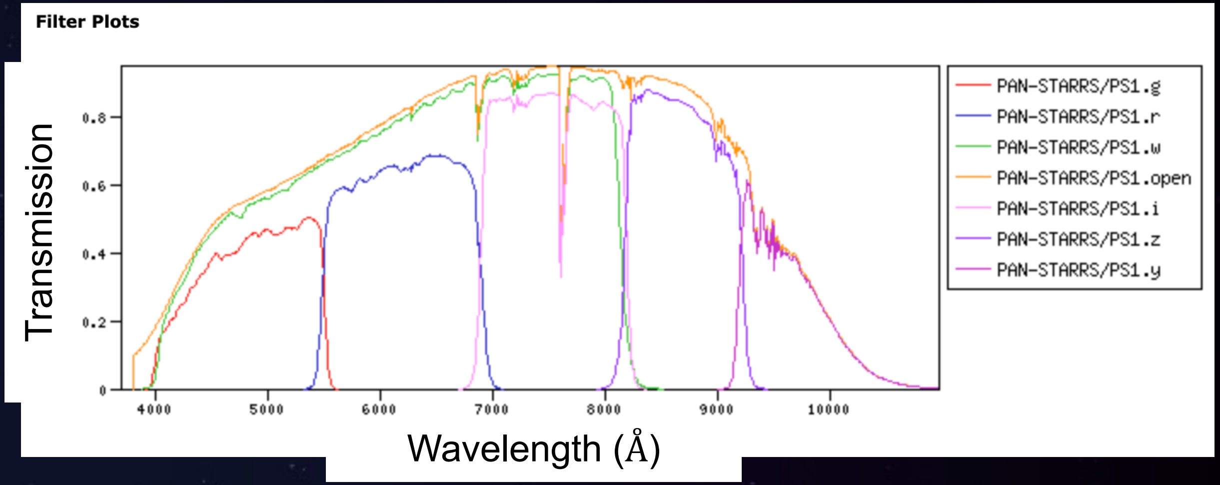
3-4. (B) Photometric observations

【Surface Color】

- Using broad band filter (e. g., SDSS, Pan-STARRS filter) derived <u>color index</u> estimate Taxonomy Type

Color index;
e. g., g-r, r-i

g: g-filter mag.
r: r-filter mag.
i: i-filter mag.



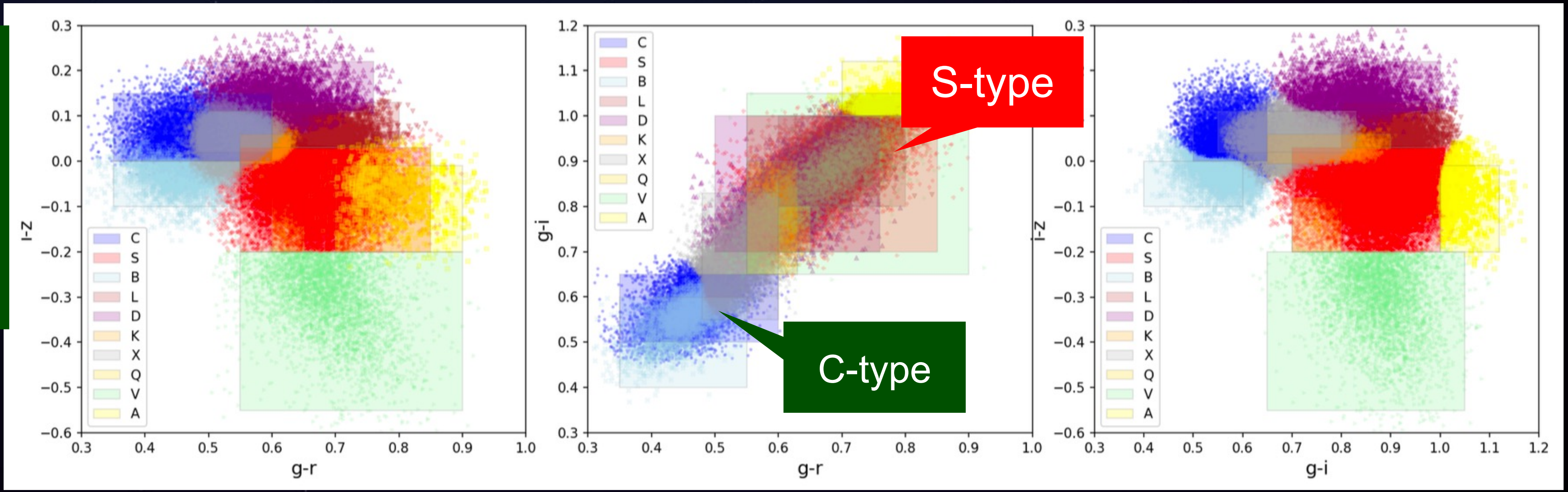
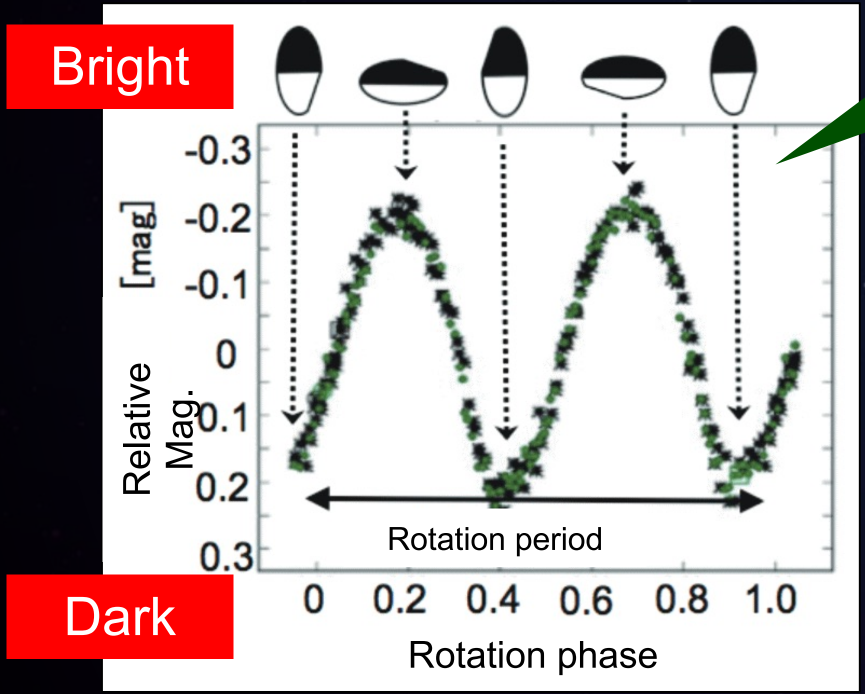


Fig. 36, 37 Filter transmission of Pan-STARRS filter, Asteroid color index of SDSS system.

3-4. (B) Photometric observations

【Local (Front + Back side) Surface Color】

- Color light-curve: Light-curve observations + broad band filter color photometry.



Normal light curve
(w/o filter)
Only Rotation period

Color light curve
(w/g-, r-, z-filter)
The local surface composition of each sides, corresponding to the rotation period can be understood

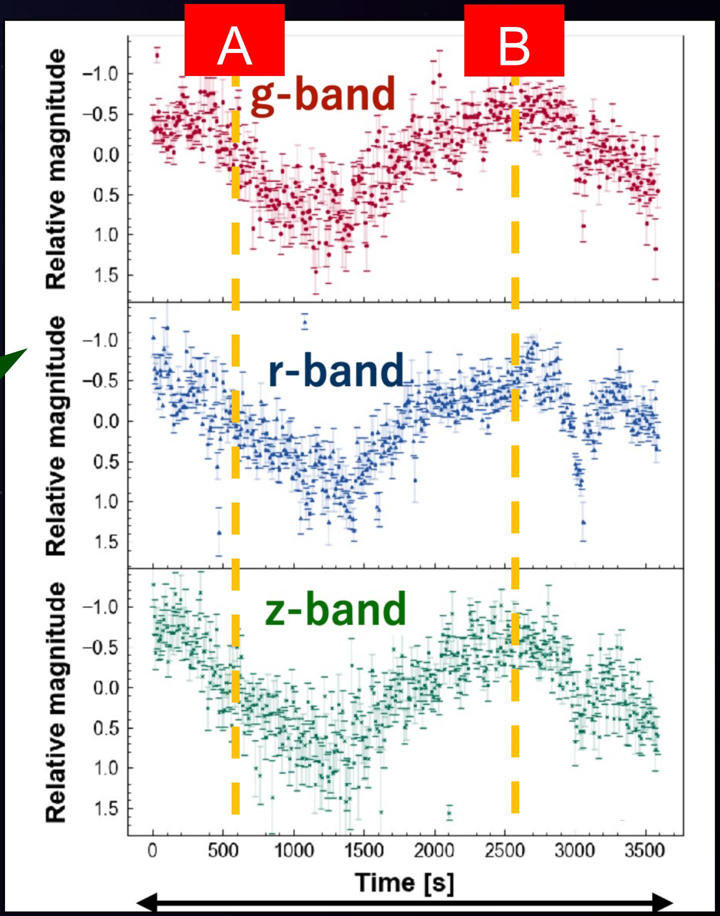


Fig. 38, 39 Rotation period of asteroid,
TriCCs color-light curve of tiny NEA [Beniyama et al., 2021].

3-5. 1.6 m Pirka Telescope & MSI

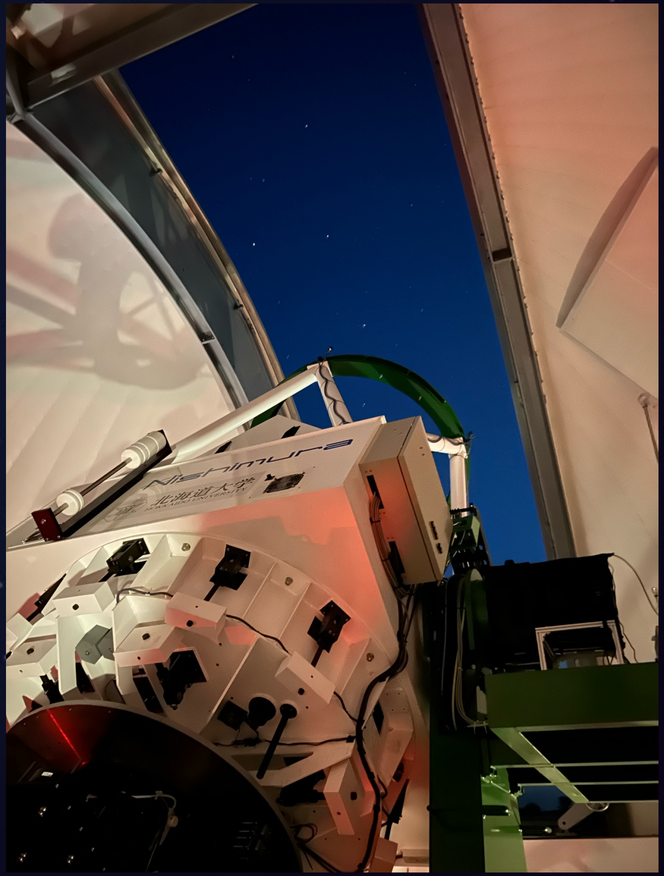
【Pirka Telescope】

- Location: Nayoro Observatory
- Own: Hokkaido Univ.

【MSI (Multi-Spectral Imager; Watanabe et al., 2012)】

- Wavelength: 0.36-1.05 μm
- Field of view (FOV): 3.3 ’ × 3.3 ’
- Array format: 512 × 512 pixels
- Filter: Johnson-Cousins U, B, V, Rc, Ic
- Polarizer: Wollaston Prism

Can conduct polarimetry



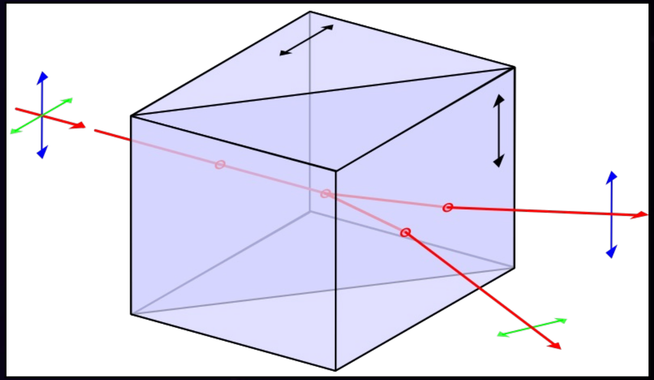


Fig. 40, 41, 42 Pirka Telescope, MSI [Watanabe et al., 2012], Wollaston prism.

3-6. 3.8 m Seimei Telescope & TriCCS

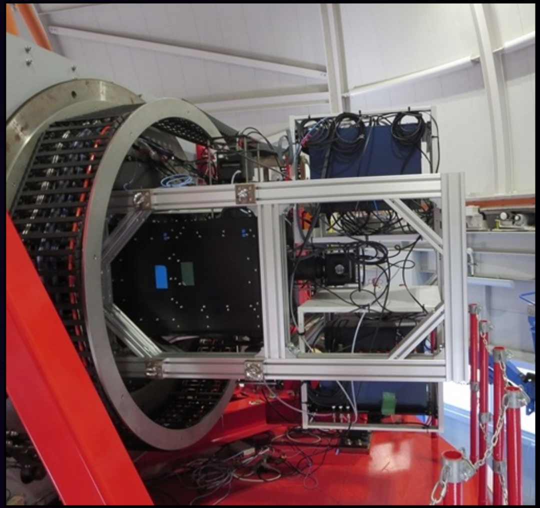
【Pirka Telescope】

- Location: Okayama Observatory
- Own: Kyoto Univ., and open use by NAOJ
  The largest optical telescope in East Asia

【TriCCs (Tricolor CMOS Cameras) 】

- Imaging mode:
  Tri-colors simultaneous photometry
- FOV: 12.6’ × 7.5’
- Array format: 2,220 × 1,360 pixels
- Filter: Pan-STARRS g2, r2, i2, z

Can conduct Color
Light-curve photometry



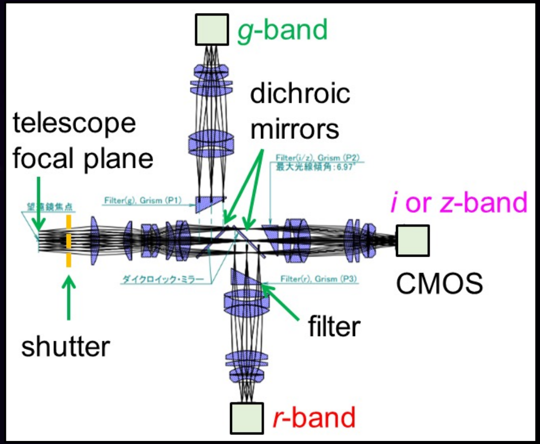


Fig. 43, 44, 45 Seimei Telescope, TriCCs, Imaging mode details of TriCCs.

4-1. 2024 MK Information

【Information】

- Discovered at 16 June 2024, Closest approach within the ~76 % Lunar Distance (LD) at 29 June 2024 (only once in several decades event).
- Minimum V-mag. over the next ~200 years: 17.8 mag., so that only opportunity for ground-based observations (mid-size telescope).

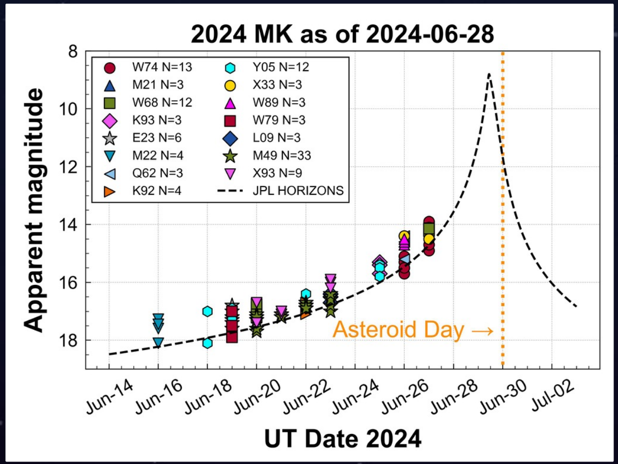


Fig. 46, 47 Orbit of 2024 MK, Apparent magnitude of 2024 MK.

Tab. 4 2024 MK; 6th closest approach among known PHAs.

Year	Name	Geocentric distance		Estimate size [m]
		[km]	[LD]	
1957	2019 CD2	75300	0.20	260-590
2001	2017 VW13	120200	0.31	200-440
1914	1998 KJ9	233200	0.61	280-900
1971	2002 JE9	263600	0.69	140-310
1923	2021 MK1	273500	0.71	140-320
2024	**2024 MK**	**295400**	**0.76**	**100-230**
2018	2018 AH	297000	0.77	80-170

4-1. 2024 MK Information

【Other studies】

- NASA Goldstone Radar observations derived shape (meter-scale topography including hills, ridges, concavities and boulders) and size ~140 m (Naidu et al., 2024).

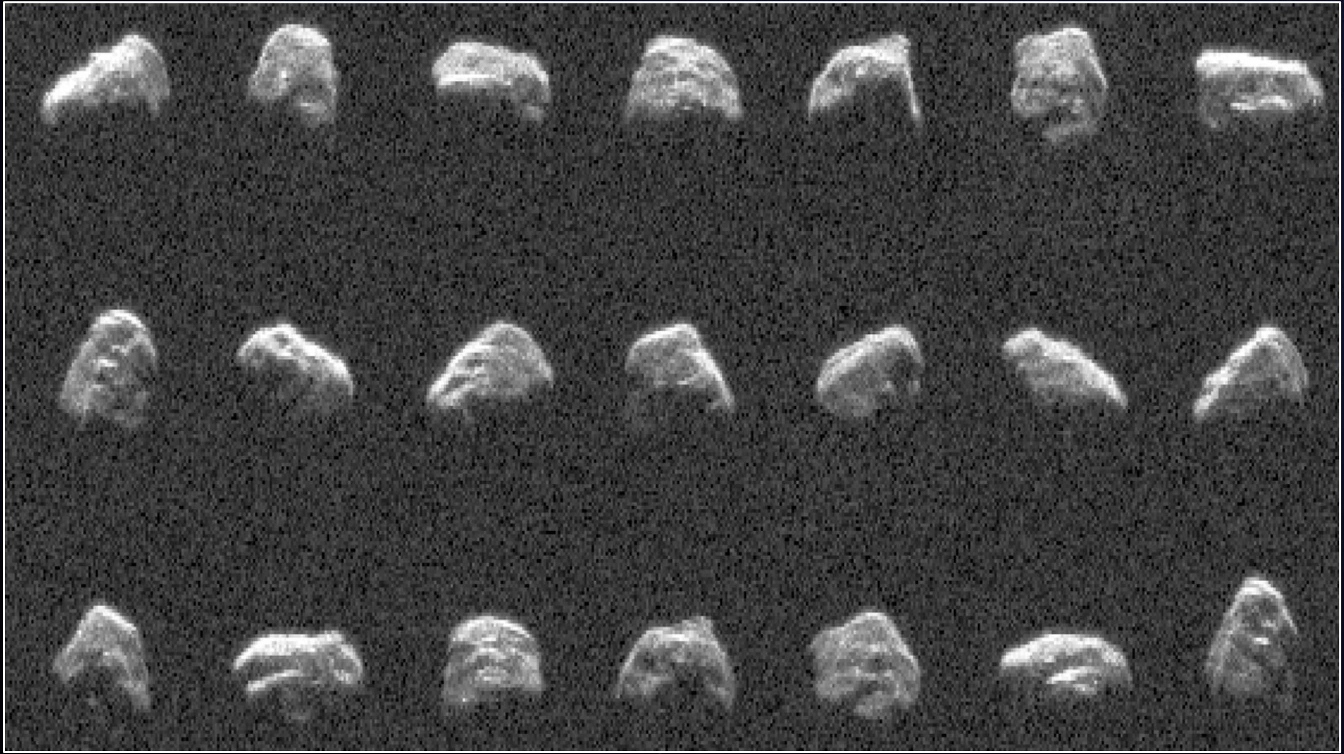
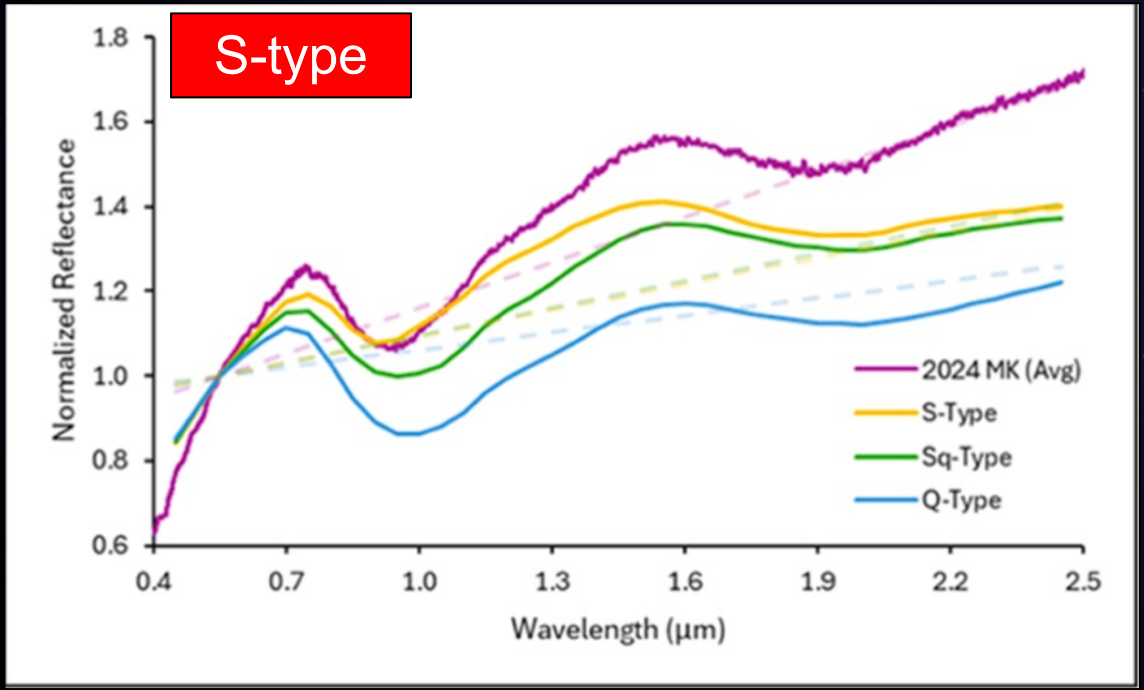


Fig. 48, 49 NASA Goldstone radar images and movie of 2024 MK [Naidu et al., 2024].

4-1. 2024 MK Information

【Other studies】

- NASA IRTF/SpeX Spectroscopic observations derived reflectance spectrum most likely **S-type** (McGraw et al., 2024).
- Light-curve observations derived rotation period 0.66 and/or 0.73 hours (Sioulas, 2024).



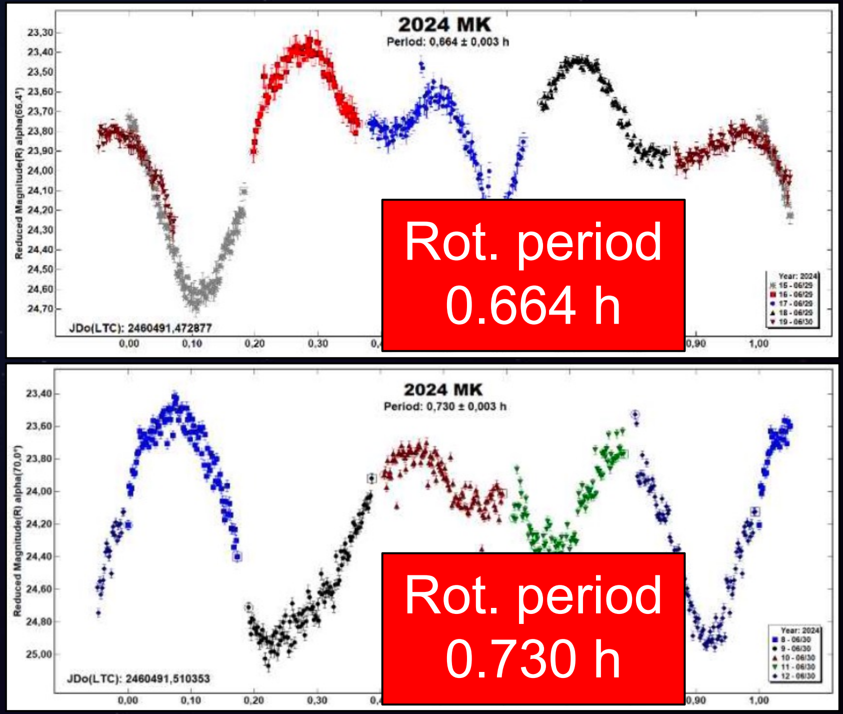


Fig. 50, 51 Vis-NIR reflectance spectral of 2024 MK [McGraw et al., 2024], Light-curve and rotation period of 2024 MK [Sioulas, 2024].

4-2. 2024 MK Observations & Results

Aimed to derive
surface scattering properties

【Observations】

- Polarimetric observations with the Pirka telescope.

Tab. 5 Observation data condition of 2024 MK.

Date	α	Filter	Notes
29 Jun. 2024	26-28°	*V, Rc*	Closest approach night, S/N ~1500
2 jul. 2024	101°	*V*	Max *α*, S/N ~50, can not be observable after (dark)

Tab. 6 Weather condition around the closest approach.

	6/26	6/27	6/28	6/29	6/30	7/1	7/2
Weather							
V-mag.	15	14	13	9	12	15	17
α	60	58	50-48	15-27	89-90	98-99	100-101
Obs.	×	×	×	○	×	×	○

Over the next 200 years, we can not observe "ichigo-ichie"

4-2. 2024 MK Observations & Results

【Results】

Importance

Tab. 7 Observational conditions of 2024 MK.

Date	UT	Filter	Exp. [s]	*V*-mag. [mag.]	r [au]	Δ [au]	α [°]	ϕ [°]
29 Jun. 2024	14:46:23-14:48:51	*V*	30	9.71	1.01840	0.00196	26.351	232.798
29 Jun. 2024	14:50:18-14:52:47	*V*	30	9.73	1.01840	0.00196	26.765	232.639
29 Jun. 2024	14:55:36-14:58:05	*V*	30	9.74	1.01839	0.00196	27.386	232.335
29 Jun. 2024	14:58:36-15:01:05	*V*	30	9.76	1.01839	0.00196	27.696	232.188
29 Jun. 2024	15:06:06-15:08:35	*Rc*	30	9.78	1.01838	0.00197	28.418	231.816
29 Jun. 2024	15:08:50-15:11:20	*Rc*	30	9.79	1.01837	0.00197	28.727	231.683
2 Jul. 2024	16:56:48-17:17:19	*V*	300	16.85	1.01337	0.01683	100.984	249.566

4-2. 2024 MK Observations & Results

【Results】

- Plot of P_r vs α
  (Re-calculate from previous seminar)

Tab. 8 Polarization degree of 2024 MK.

Date	Filter	α [°]	$P_r \pm \sigma P_r$ [°]	$\theta_P \pm \sigma\theta_P$ [°]
29 Jun. 2024	*V*	26.351	1.23 ±0.12	-26.30 ±0.51
29 Jun. 2024	*V*	26.765	1.55 ±0.20	-15.33 ±0.67
29 Jun. 2024	*V*	27.386	1.47 ±0.15	-24.22 ±0.51
29 Jun. 2024	*V*	27.696	1.67 ±0.16	-22.55 ±0.49
29 Jun. 2024	*Rc*	28.418	1.51 ±0.17	-20.72 ±0.56
29 Jun. 2024	*Rc*	28.727	1.43 ±0.14	-21.44 ±0.51
2 Jul. 2024	*V*	100.984	35.15 ±5.70	-2.48 ±0.77

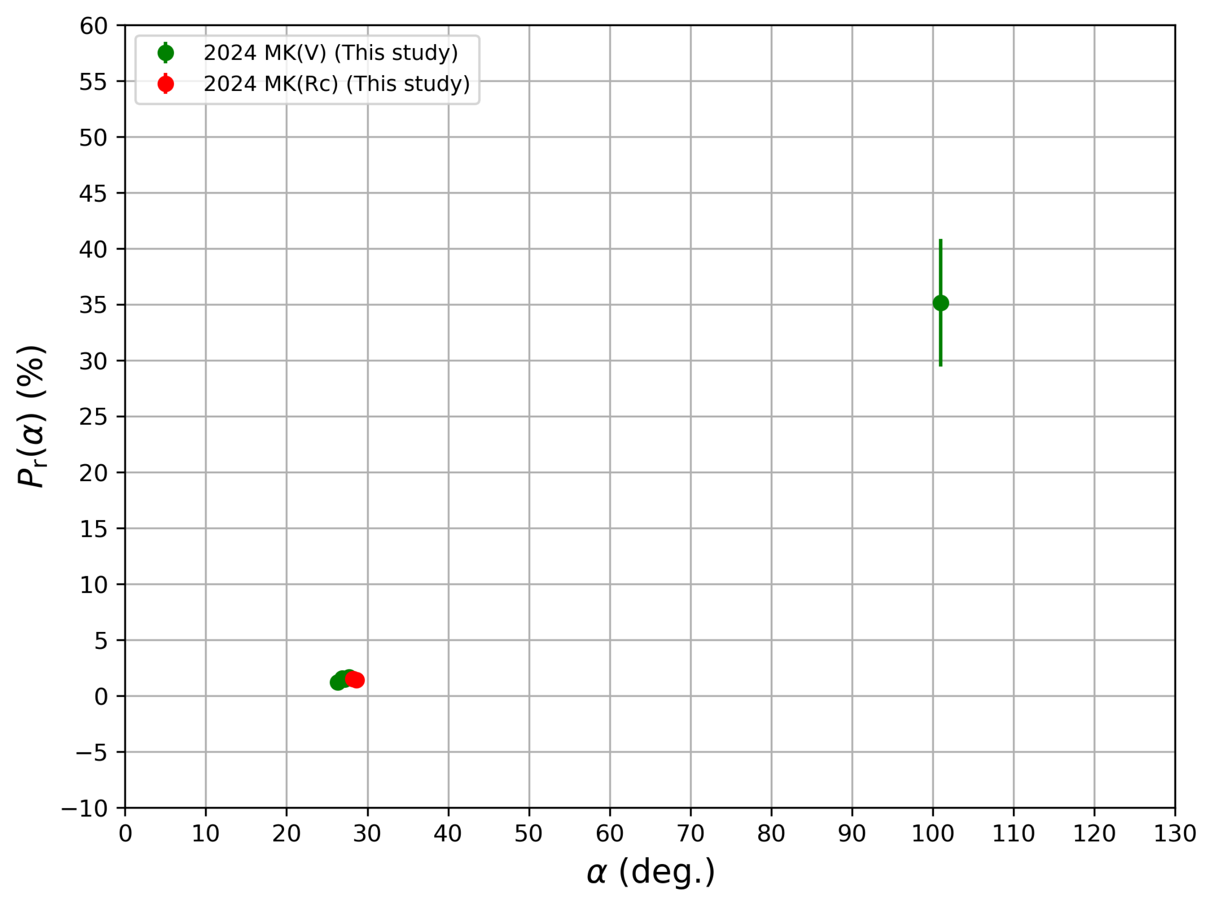
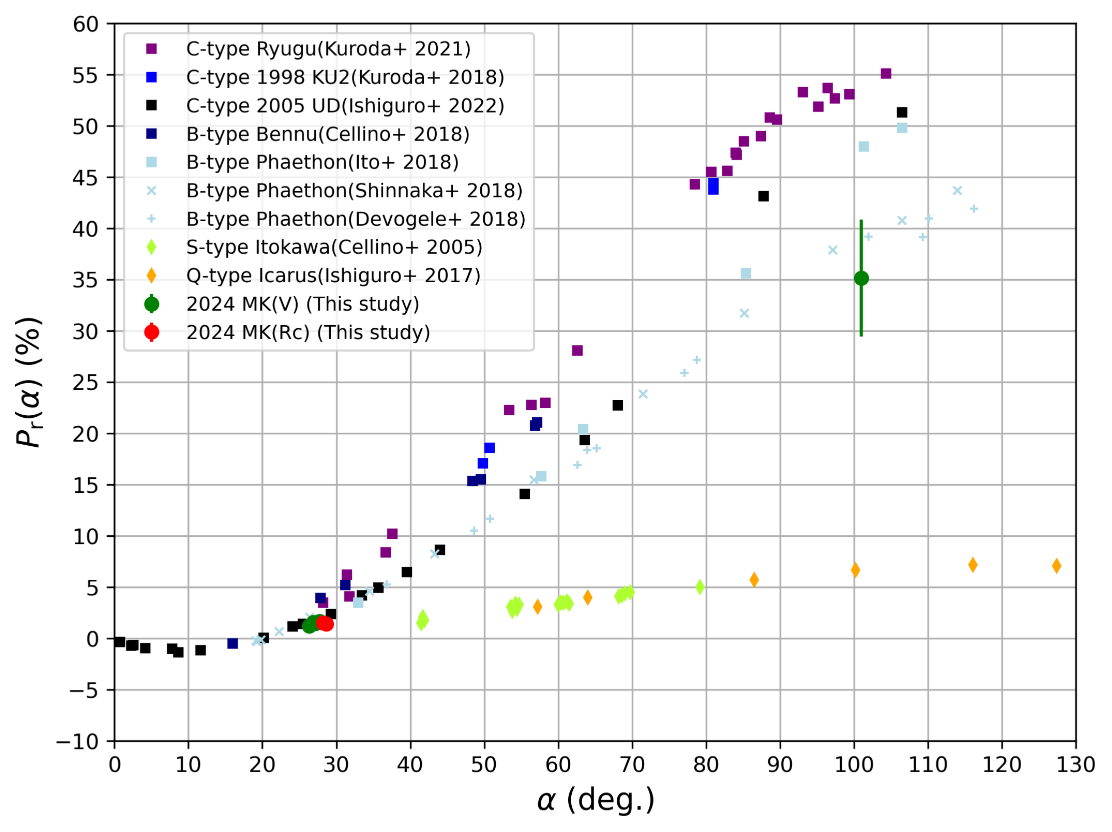


Fig. 52 Polarization degree of 2024 MK.

4-2. 2024 MK Observations & Results

【Results】

- Compared with Liner Polarization degree of NEAs.



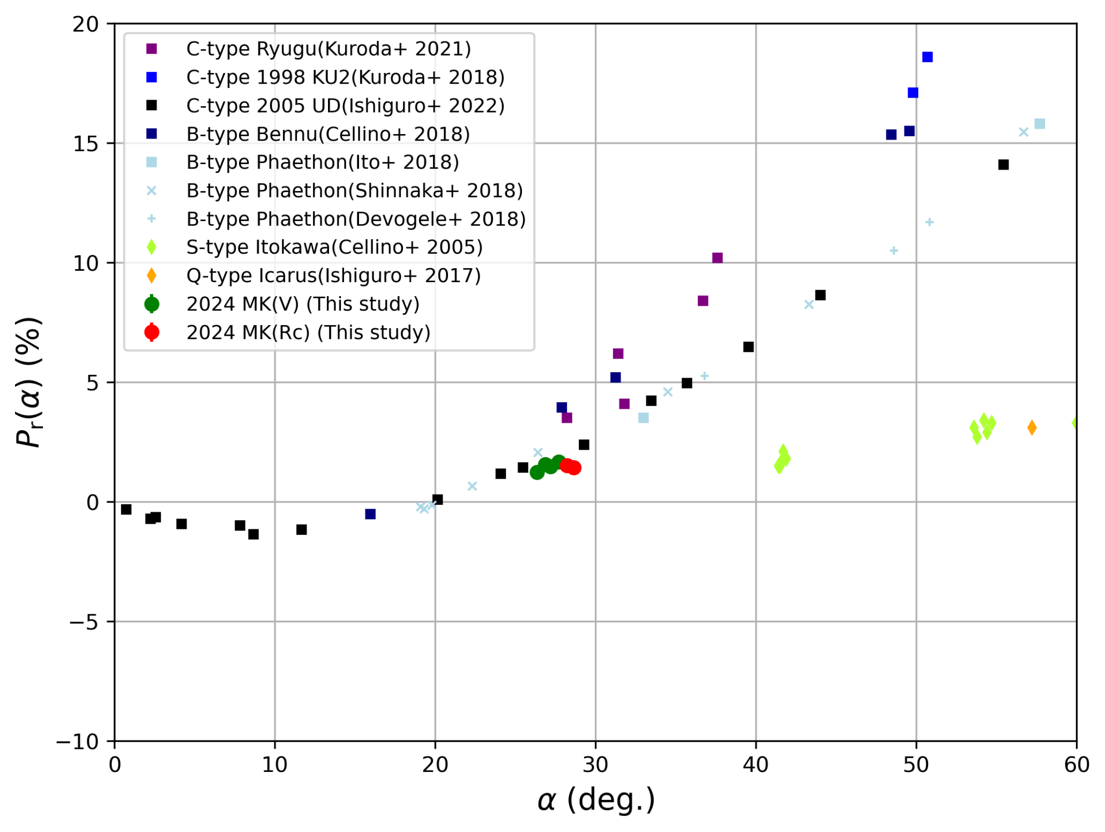


Fig. 53, 54 Polarization degree of 2024 MK and Several previous polarimetric results of NEAs.

4-2. 2024 MK Observations & Results

【Results】

- 2024 MK exhibit high polarization degree.
- It seems **C-type**.

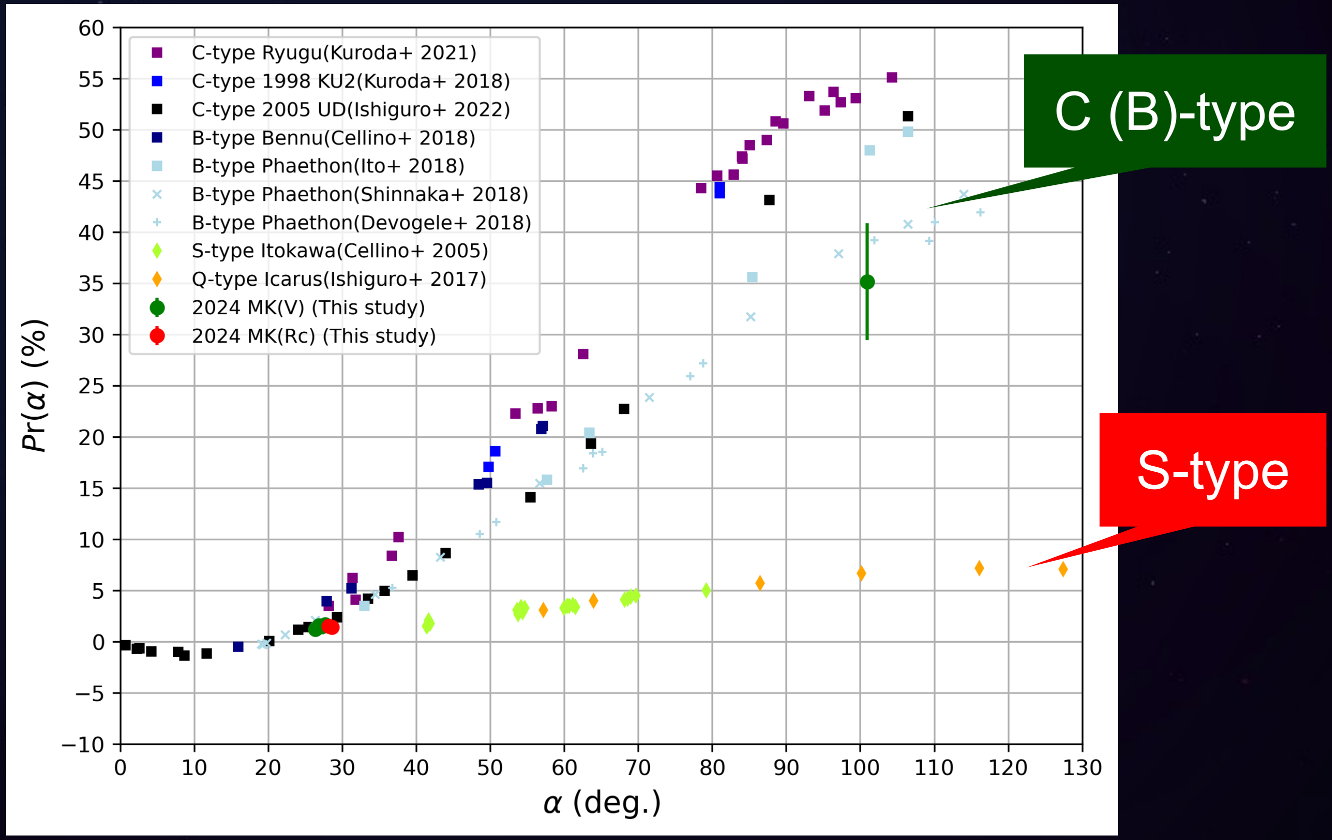
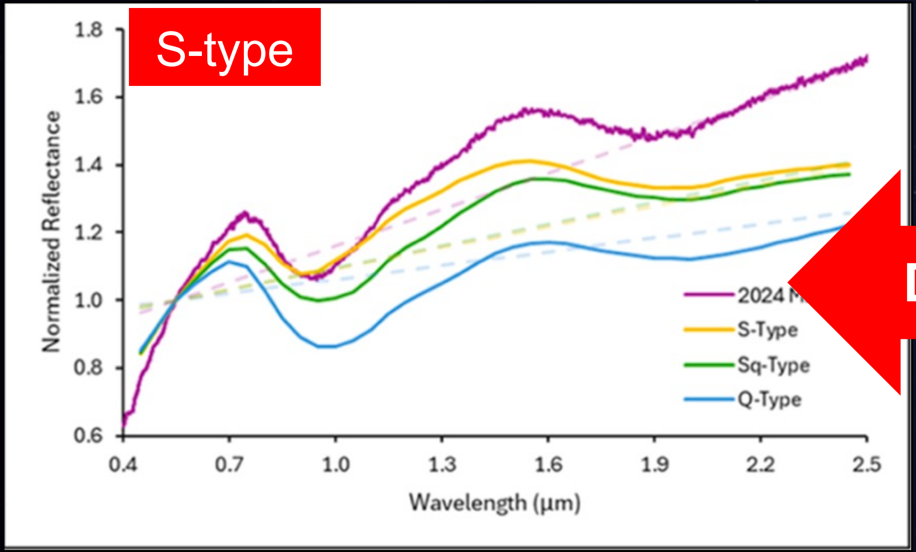


Fig. 53 Polarization degree of 2024 MK and Several previous polarimetric results of NEAs.

4-3. 2024 MK Discussion

【Discussion】

- Spectroscopy derived characteristics of **S-type reflectance spectrum**.
- Polarimetry derived characteristics of **C-type scattering properties**.



Discrepancy!

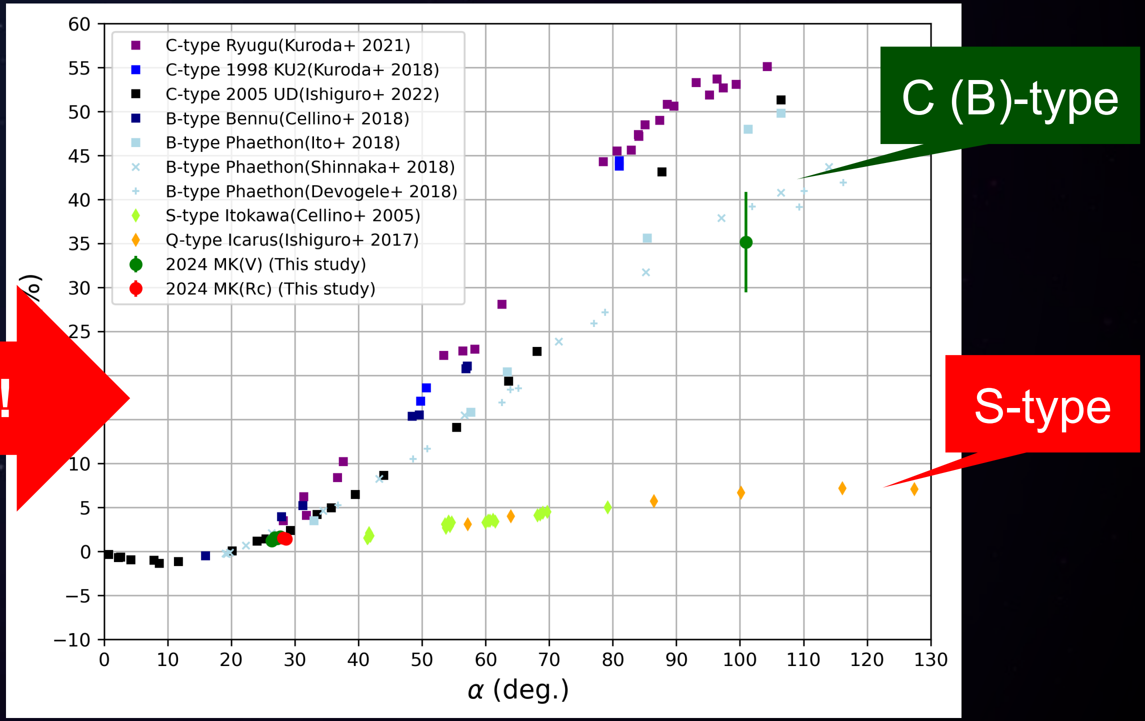
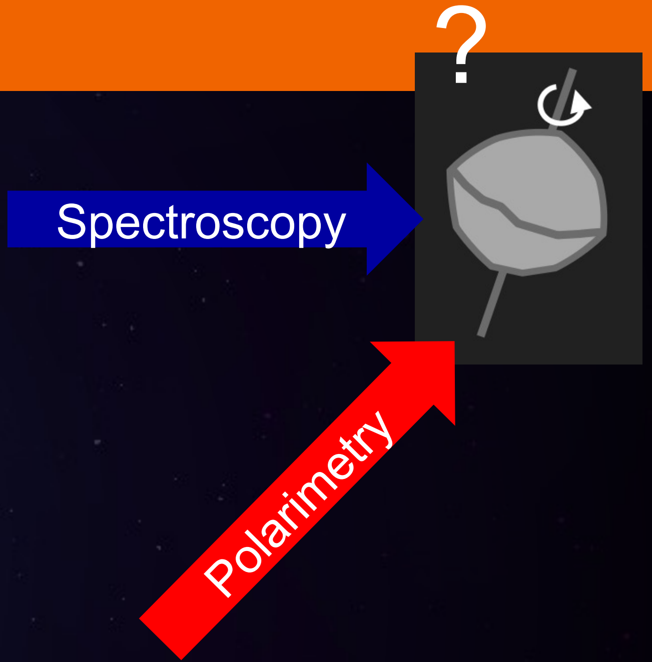


Fig. 50 Vis-NIR reflectance spectral of 2024 MK [McGraw et al., 2024].

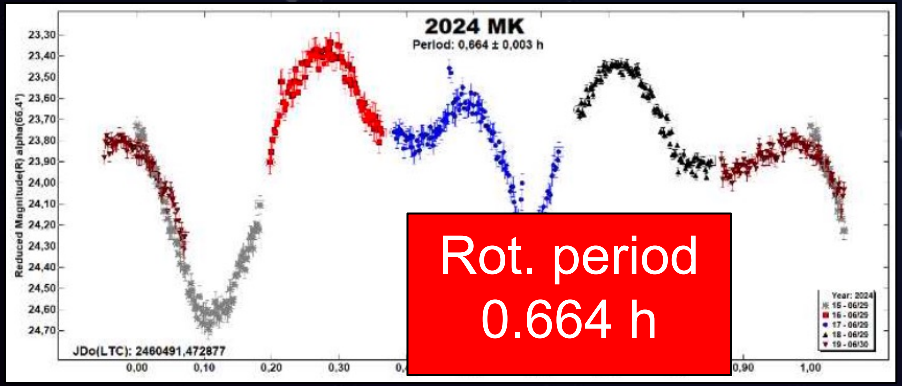
Fig. 53 Polarization degree of 2024 MK and Several previous polarimetric results of NEAs [This study].

4-3. 2024 MK Discussion



【Discussion】

1. Rotation phase (observed different surfaces?)
   -> Differences in the observed surface (front-back) based on rotation period (0.66 or 0.73 hours) and observation timing.
   -> We and McGraw et al. (2024) observed the same surface, so <u>compositional heterogeneity could not be detected.</u>



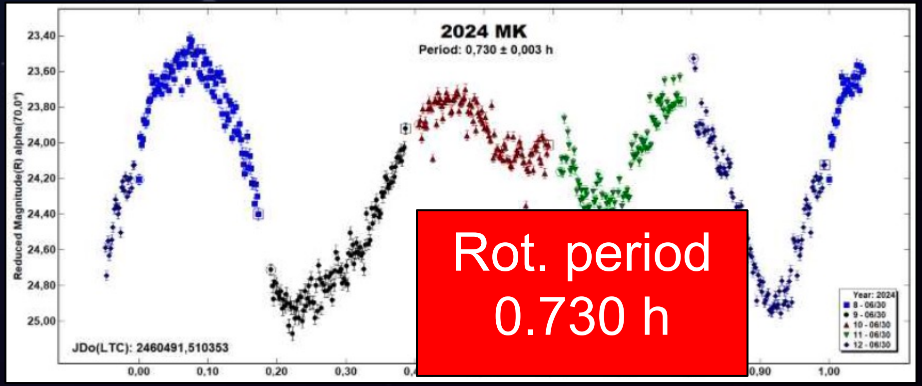


Fig. 51 Light-curve and rotation period of 2024 MK [Sioulas, 2024].

4-3. 2024 MK Discussion

【Discussion】

2. Regolith grain size

-> May be more space-weathered and/or possess finer regolith grains than typical S-type.

-> Presence of fluffy aggregates on the surface increases the Polarization Degree.

e. g., NEA 1998 KU2 (Kuroda et al., 2018)

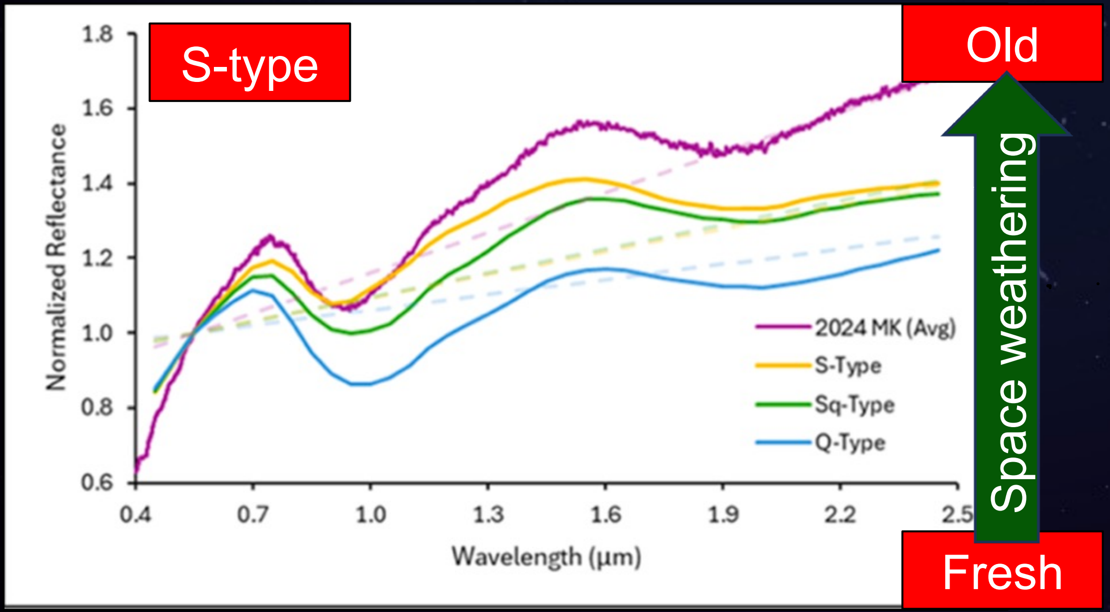


Fig. 50 Vis-NIR reflectance spectral of 2024 MK [McGraw et al., 2024].

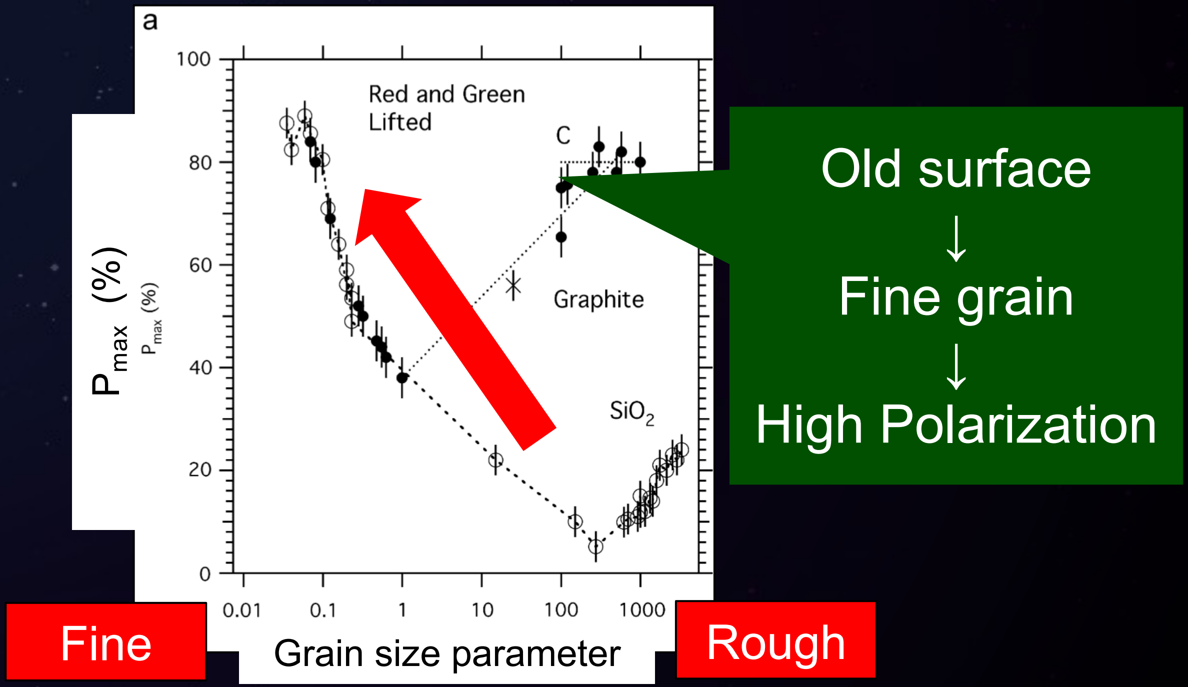
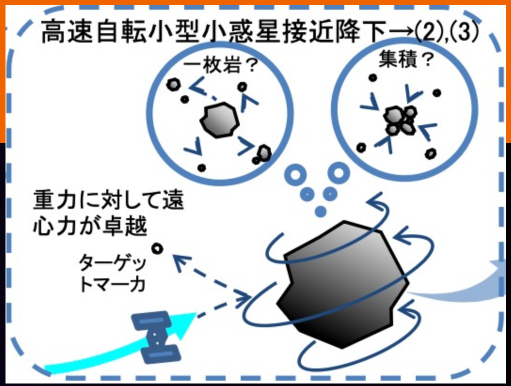


Fig. 32 Pmax vs Grain size parameter [Hadamcik et al., 2009].

4-3. 2024 MK Discussion



【Discussion】

2. Regolith grain size

-> Assuming $P_{\max}$ ~35.15 ± 5.70 %, estimated grain size: **sub-micron – micron** size.

-> Likely a **Monolith** and lacks surface grains? (not simple? **Rubble-pile**?)

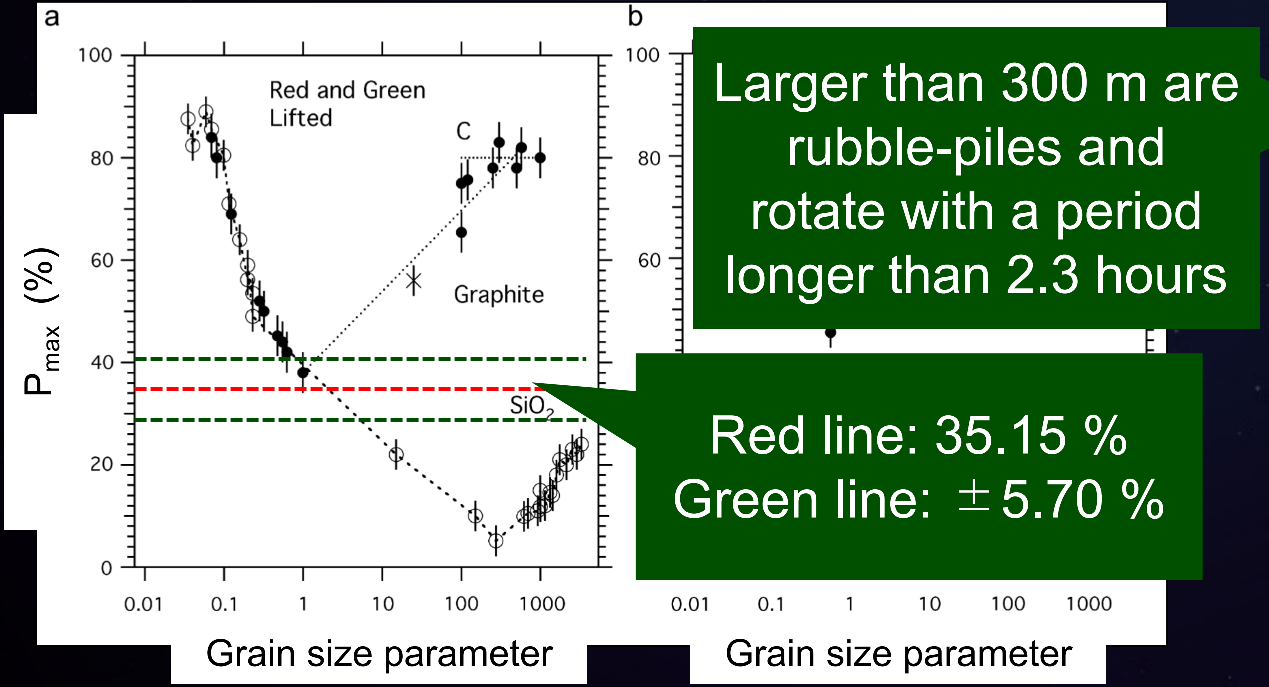


Fig. 32 Pmax vs Grain size parameter [Hadamcik et al., 2009].

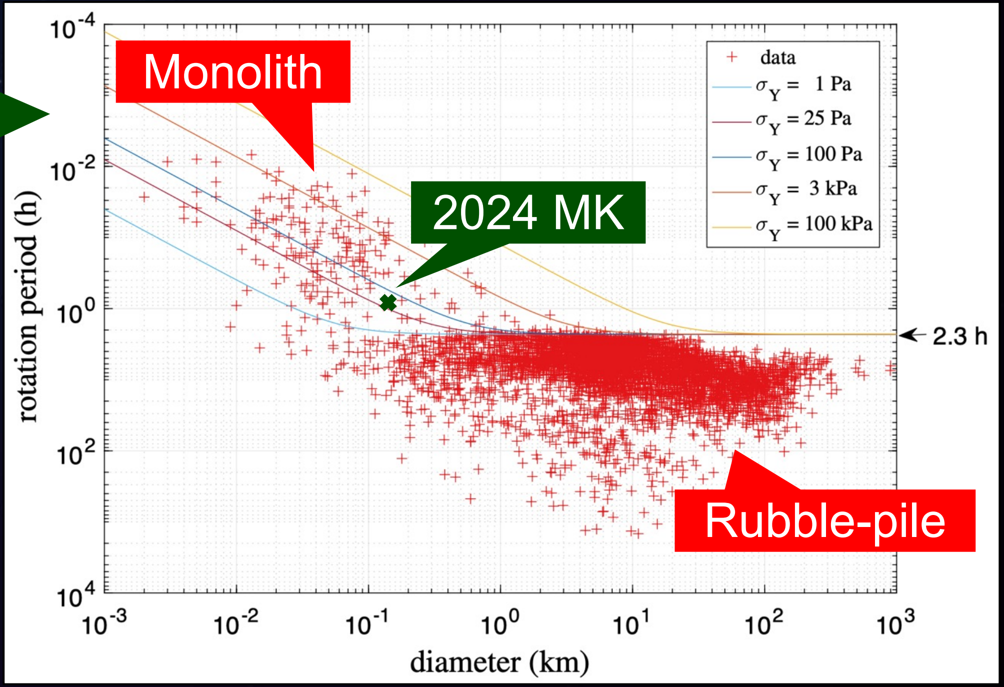


Fig. 54 Spin barrier of asteroids [Persson and Biele, 2022].

4-3. 2024 MK Discussion

【Discussion】

3. Porosity

-> **High porosity** increases the Polarization degree, regardless of grain size.

e. g., NEA Phaethon (Ito et al., 2018)

~~1. Rotation phase~~

2. Regolith grain size

3. Porosity

-> Although 2024 MK is classified **S-type**, we conjected that its **C-type** like polarization characteristics may be attributed to the grain size and/or porosity of its surface regolith.

-> We are planning to report this results and publish as a letter paper by PASJ.

5-1. Torifune Information

【Information】

- Hayabusa2# next targets NEA (PHA), named last year by JAXA, previous 2001 CC21.
- Flyby in July 2026; next year!
- Similar to (Hayabusa targets Asteroid) Itokawa?

Tab. 9 Comparison of Itokawa and Torifune.

	Itokawa	Torifune
Taxonomy	S-type	S (Sq-) type
Size, Shape	535 × 294 × 209 m	~500 m
Surface	Rubble pile	?

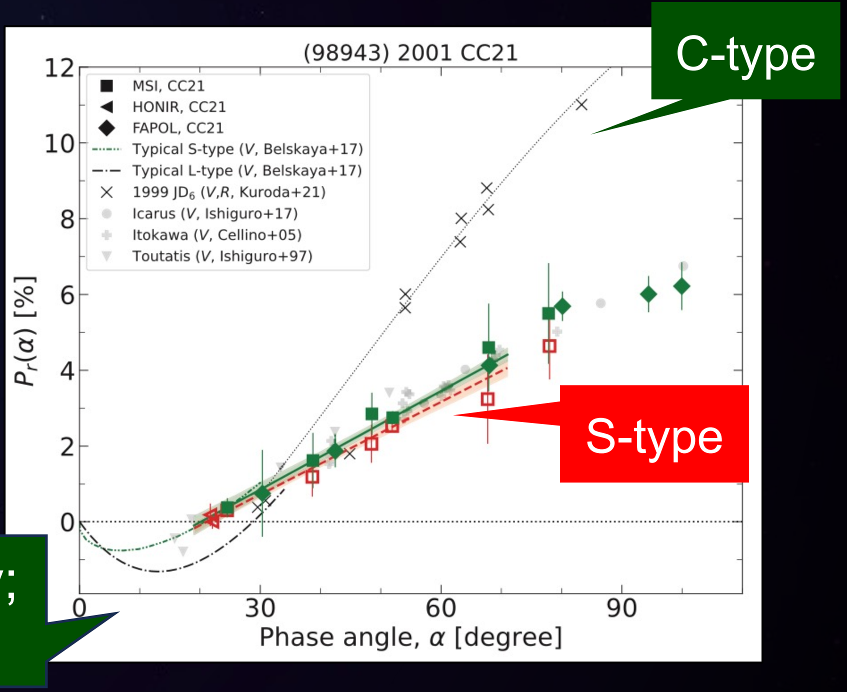


Fig. 55 Polarization curve of Torifune [Geem et al., 2023].

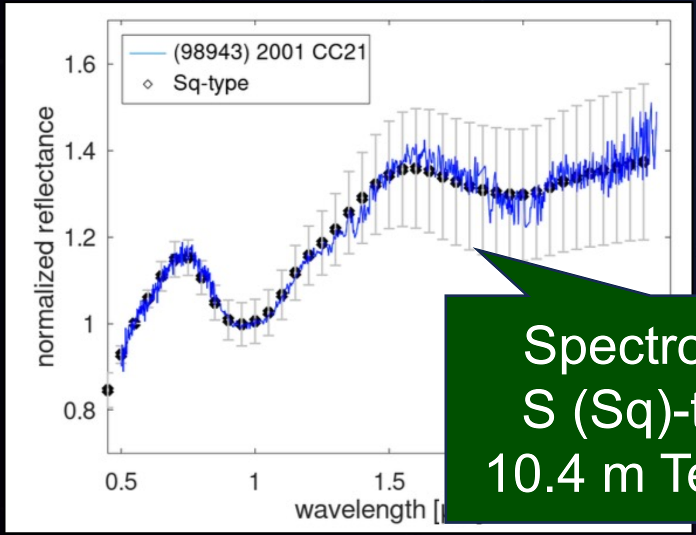
【Other studies】

- Polarimetric observations derived **S-type** Liner Polarization degree (Geem et al., 2023).

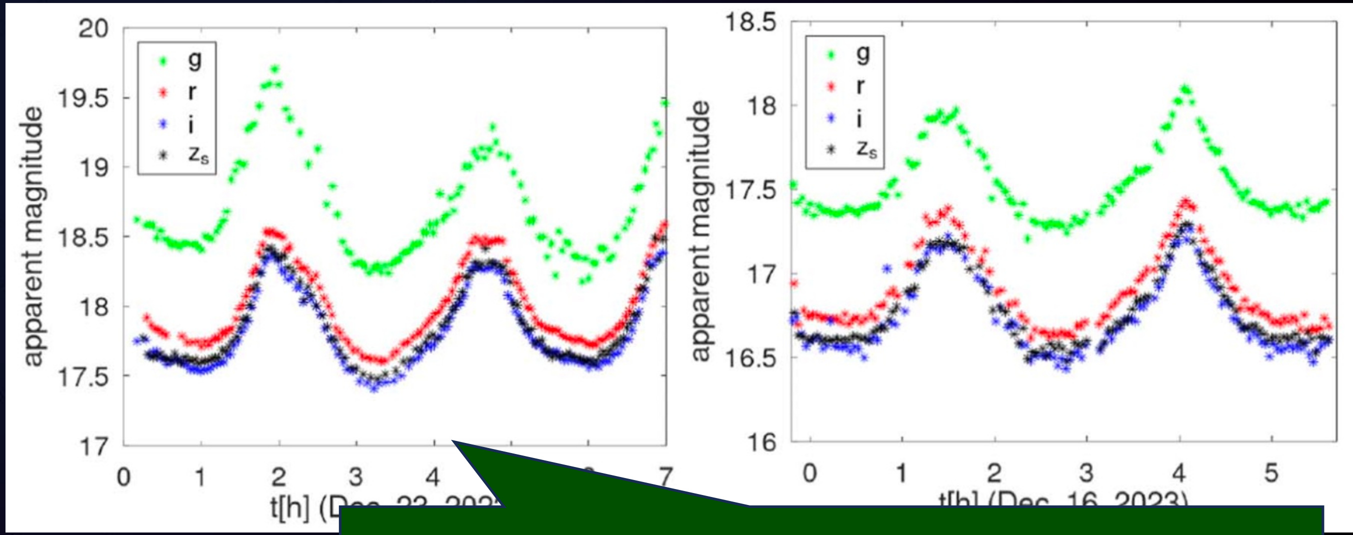
5-1. Torifune Information

【Other studies】

- Spectroscopic observations derived **S (Sq)-type** reflectance spectrum (Popescu et al., 2025).
- Photometric observations derived **S-type** local color (g-r = 0.563 ± 0.019, r-i = 0.178 ± 0.012) and large-scale surface **homogeneity** (Popescu et al., 2025).



Spectroscopy;
S (Sq)-type by
10.4 m Telescope



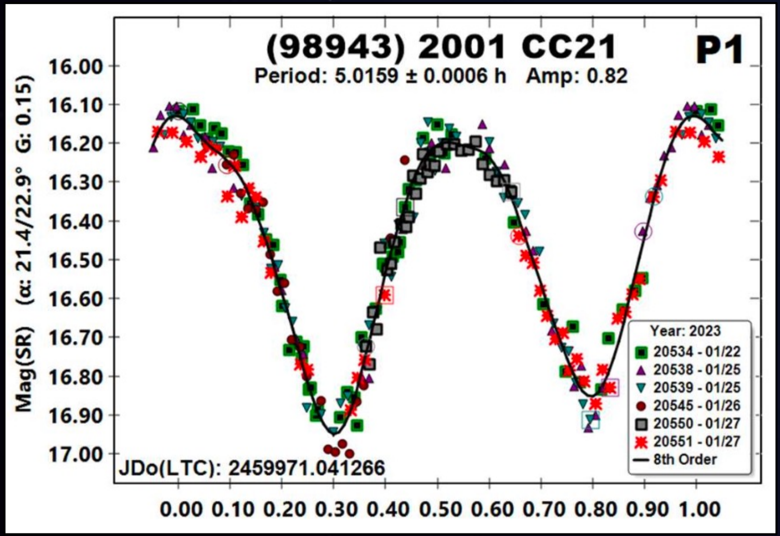
Photometry; S-type and homogeneity
by 1.5 m Telescope, S/N >50

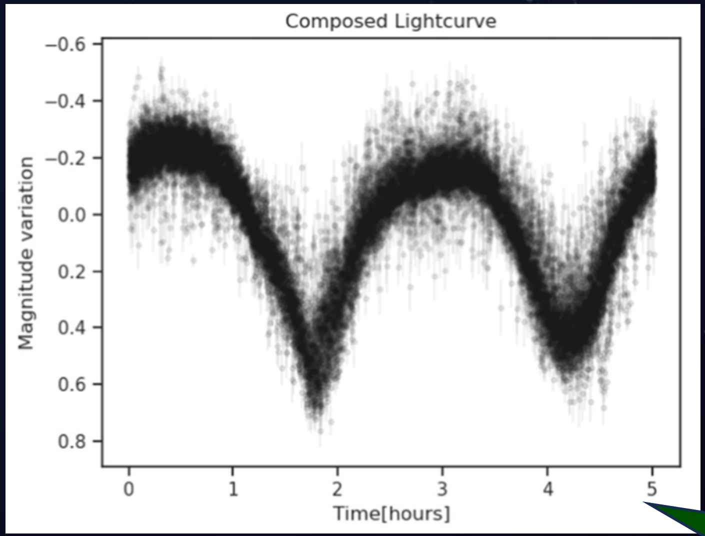
Fig. 56, 57 Reflectance spectrum of Torifune, color light-curve of Torifune [Popescu et al., 2025].

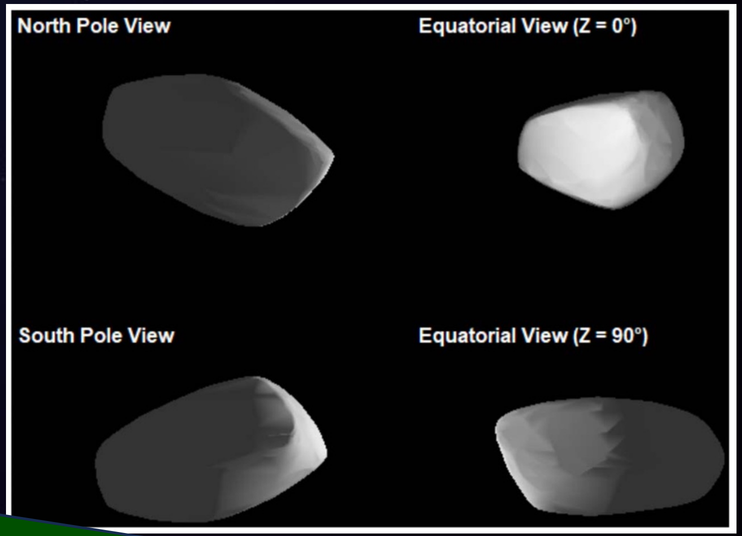
5-1. Torifune Information

【Other studies】

- Light-curve observations derived rotation period 5.02 hours (Popescu et al., 2025, Fatka et al., 2025, Fornasier et al., 2024b) and 3D model (Popescu et al., 2025).







Photometry (Light-curve); 5.02 hours

Fig. 58, 59, 60 Light-curve of Torifune [Popescu et al., 2025, Fatka et al., 2025, Fornasier et al., 2024b], 3D model of Torifune [Popescu et al., 2025].

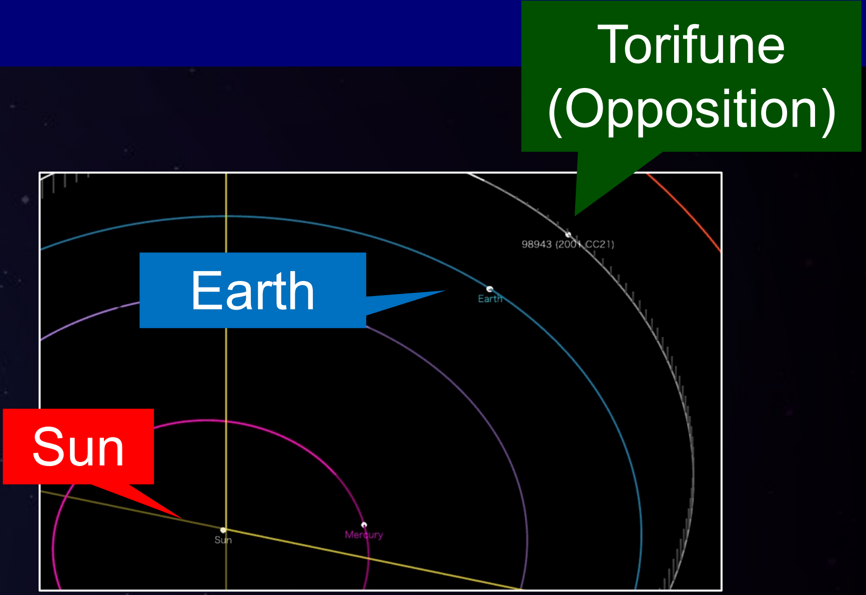
5-2. Torifune Observations & Results

【Observations】

- We submitted a proposal and accepted by NAOJ.
- Photometric observations with the Seimei telescope, aimed opposition surge.
- We allocated 2 nights by NAOJ each night ~5hours.

Tab. 10 Observation data condition of Torifune.

Date	α	Filter	Exp. [s]	Notes
27 Nov. 2024	5-6°	*g2, r2, i2*	120	~20 min.
28 Nov. 2024	6-7°	*g2, r2, i2*	120	~3 hours



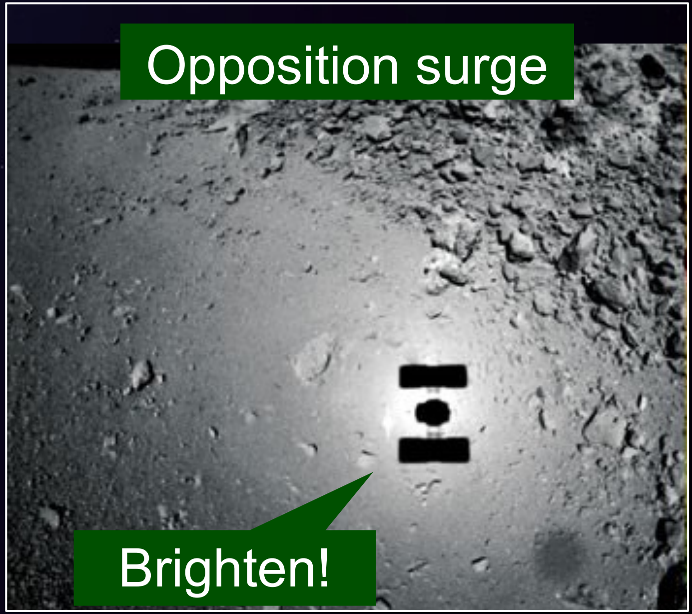


Fig. 61, 62 Torifune’s position at 11/27-28, Opposition surge of Itokawa and Hayabusa.

5-2. Torifune Observations & Results

【Results】

- Great Color light-curve!
- g-r = 0.518 ± 0.006,
  r-i = 0.149 ± 0.007
  (Pan-STARRS filter mag.)
  -> **S-type**, S/N ~150!

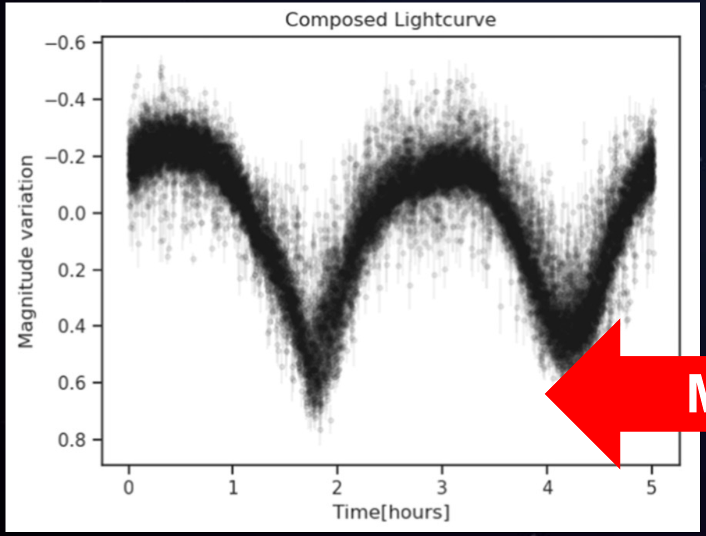


Fig. 59 Light-curve of Torifune [Popescu et al., 2025].

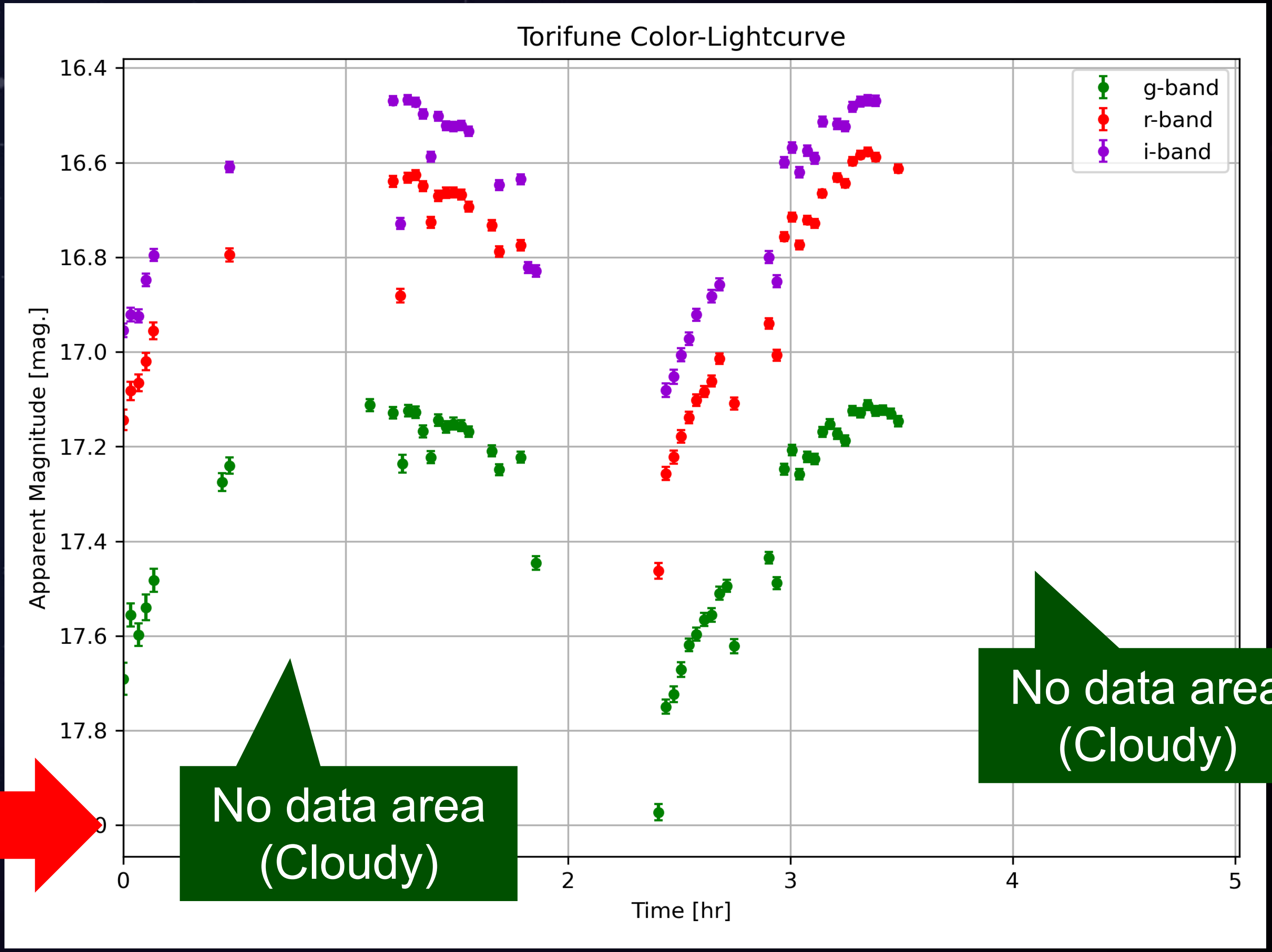


Fig. 63 Color light-curve of Torifune [This study].

5-2. Torifune Observations & Results

【Results】

- We could not detect large-scale color heterogeneity from color index variation.

  -> **surface homogeneity**

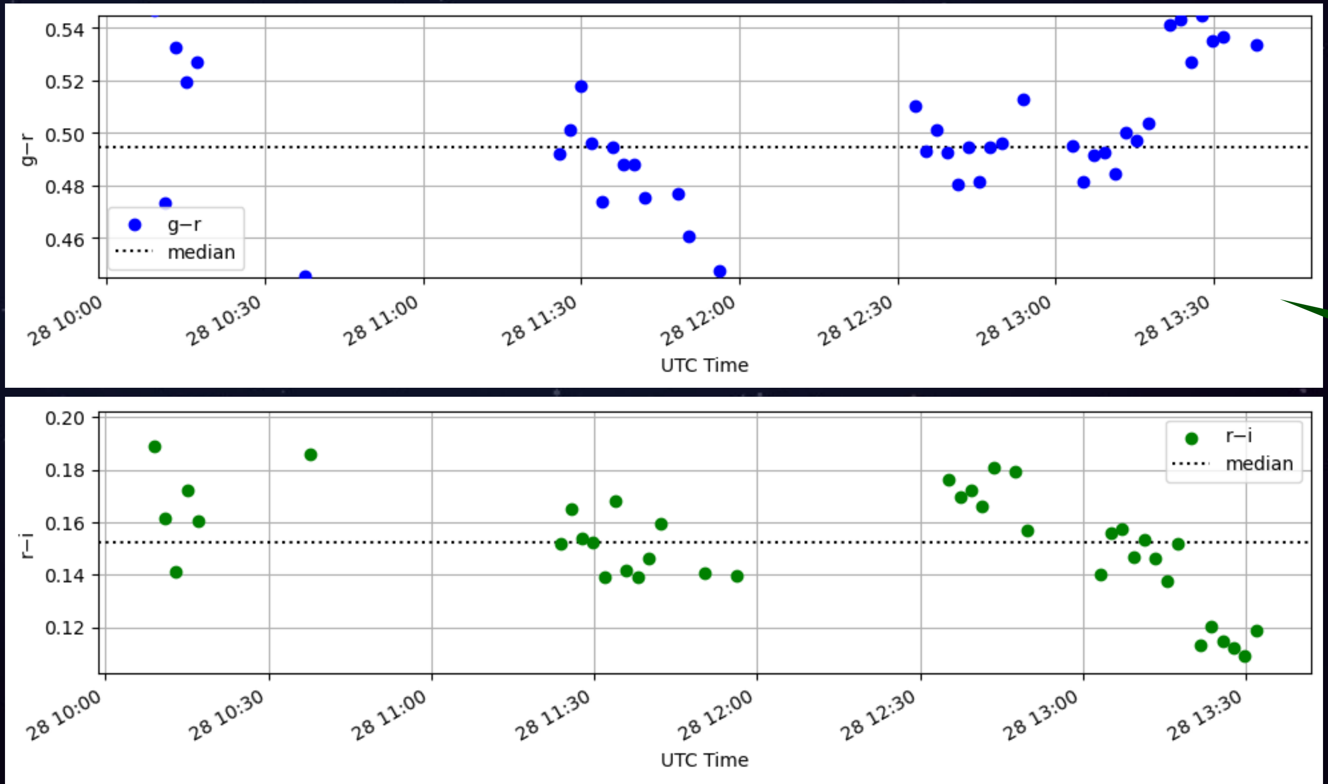


Fig. 64 g-r and r-i color index variation of Torifune [This study].

Small color variation

↓

Surface homogeneity

5-3. Torifune Discussion

【Discussion】

- **S-type**
- **Surface homogeneity**

- Similar results to previous studies
- Higher accuracy
- Not enough, we need to observe again!

- We can provide valuable results of surface color information for the Hayabusa2# mission

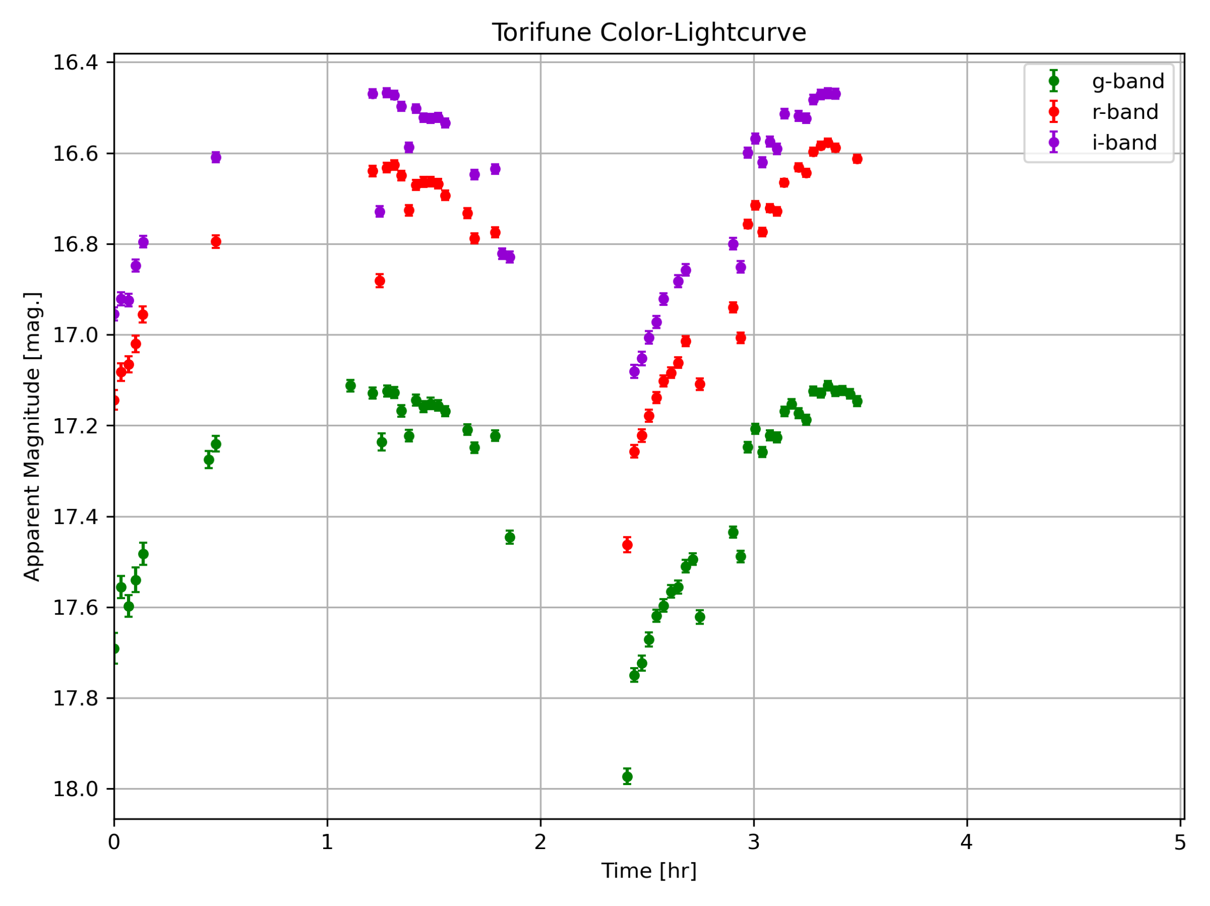


Fig. 63 Color light-curve of Torifune.

5-4. Torifune Future works

【Future works】

- We will observe again using Seimei telescope at 22 Oct. 2025.
- We aimed bright timing. It is last chance.

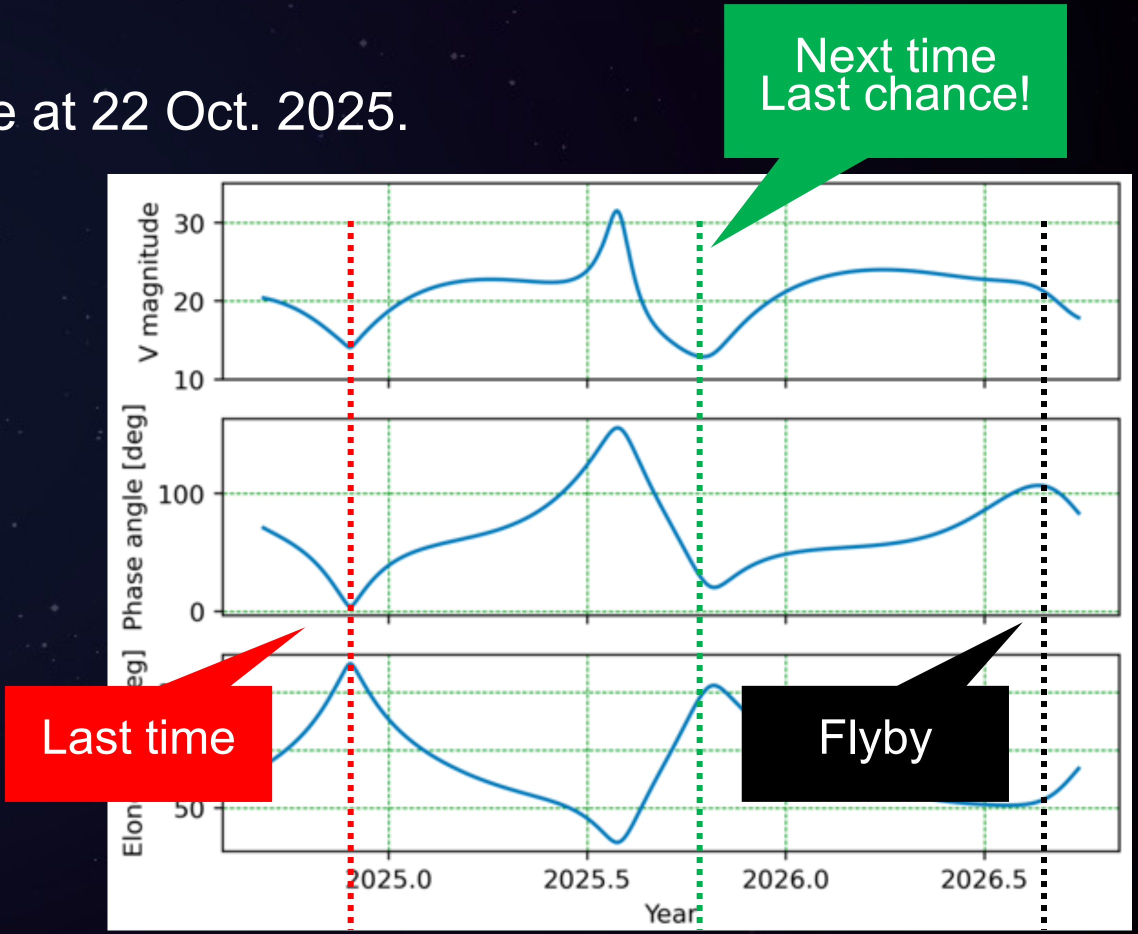


Fig. 65 Observational conditions of Torifune.

- We will be presenting at JAXA Hayabusa2# meeting in October.
- If we can derive new results, we will publish as a paper and 'Hayabusa2# special issue' in Space Science Reviews by PSJ.

6. Summary

【2024 MK】

- S-type NEA, however C-type like polarimetric characteristics.
- We are writing and planning to be published as a letter paper by PASJ.

【Torifune】

- S-type NEA, surface homogeneity.
- We will observe with Seimei telescope again at October 22.
- We reported observational results and next plan to JAXA Hayabusa2# team.
- We will be presenting at JAXA Hayabusa2# meeting in October.
- If we can derive new results, we will publish as a paper and ‘Hayabusa2# special issue’ in Space Science Reviews by PSJ.

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