Science operation planning for Hayabusa2#'s flyby at Asteroid (98943) Torifune (#54)

T. Hirabayashi*, M. Yoshikawa, M. Hayakawa, Y. Mimasu, N. Hirata, T. Iwaki, S. Kamata, M. Kanamaru, K. Kitazato, T. Kouyama, N. Sakatani, H. Senshu, H. Takeuchi, S. Tanaka, E. Tatsumi, K. Yumoto, M. Abe, M. Fujiwara, M. Matsuoka, T. Morota, T. Saiki, Y. Shimaki, S. Shimomura, Y. Tsuda, M. Yamada, Y. Yokota, and Hayabusa2# Team

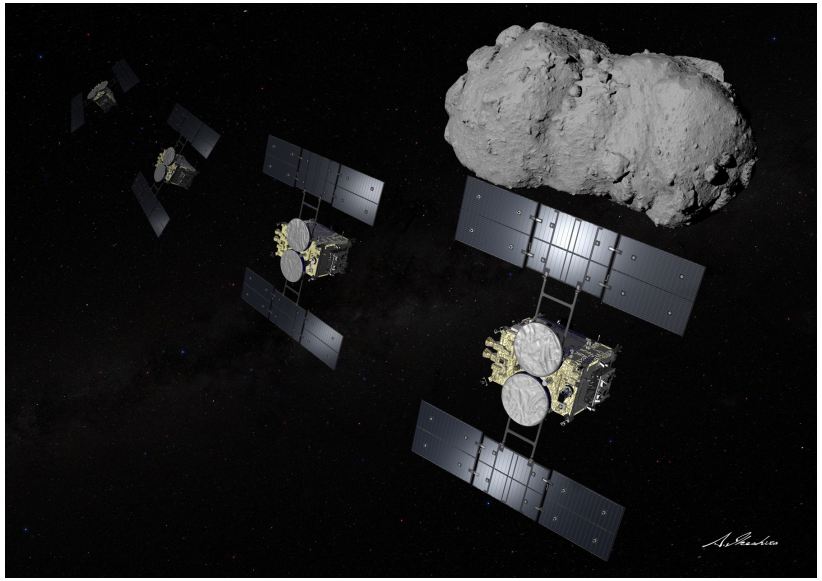
Planetary Defense Conference 2025

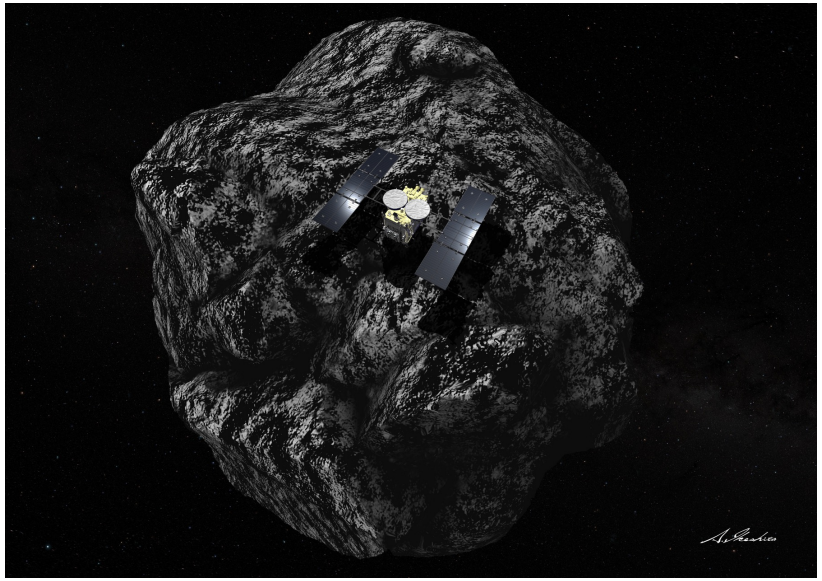
Session 2: Ongoing and Upcoming Space Mission Highlights

Day 2, Tuesday, May 6, 2025, 14:45 – 15:00, Stellenbosch, South Africa

Short summary of Hayabusa2 Extended Mission (Hayabusa2#)

- The Hayabusa2 Extended Mission (Hayabusa2#)'s objectives are:
  - Long-term spacecraft operations > 10 years
  - Exoplanets and zodiacal light monitoring
  - Torifune (2001 CC21) flyby in 2026
  - 1998 KY26 rendezvous in 2031
- The Torifune (2001 CC21) flyby mission objectives stem from technological innovations in Planetary Defense.
  - Engineering – GNC, critical decision making, key flight technologies for deflection and data acquisition.
  - Science – Rapid characterizations of the target properties under extremely limited conditions.
- The spacecraft encountered its safe mode recently.
  - The team has been investigating the issue and its resolutions.





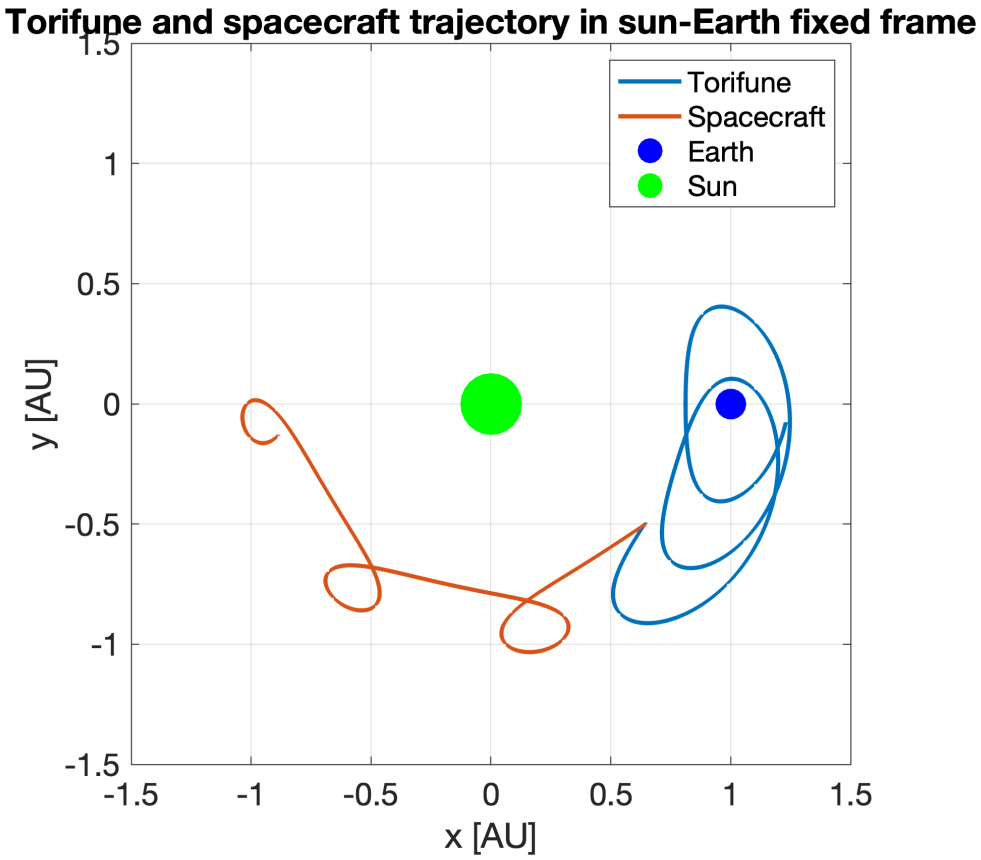
Torifune flyby and the asteroid's geophysical state

- Torifune flyby conditions:

Property	Value	Unit
Distance from sun	0.81	AU
Phase angle	~20	degree
Encounter speed	5.25	km/s
Date	July 2026	[-]

- Torifune geophysical conditions*:

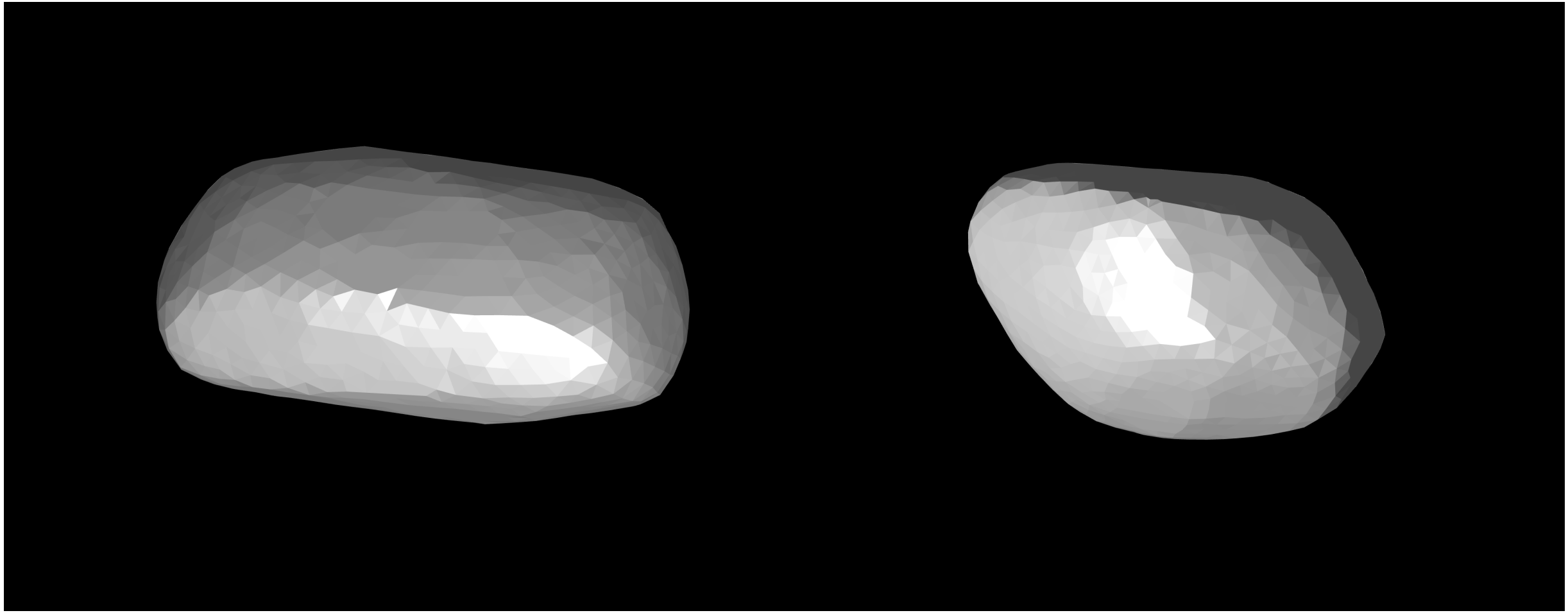
Property	Value	Unit
Size	0.25 – 0.5	km
Shape aspect (b/a)	< 0.6, 0.37	[-]
Taxonomy	S	[-]
Spin period	5.0121	hr
Spin axis	λ=260-280, β=+84	degree
Geometric albedo	0.2-0.23	[-]



*Bourdelle de Micas et al. (2024), Geem et al. (2023), Fornaiser et al. (2024), Wright et al. (2025), Fatka et al. (2024), and Popescu et al. (2025).

Torifune's shape is elongated but needs further observations.

- Multiple groups performed Earth-based photometric observations to reconstruct Torifune's shape, suggesting its elongated shape.



Fatka et al. (2024) on the left, and Popescu et al. (2025) on the right

Torifune flyby as demonstration of planetary defense technology

- **Fast reconnaissance (fast recon)** has been identified in the community as a remaining key technology to be developed.
- Key primary properties for fast recon identified by NEOWARP include **Composition**, **Mass**, **Orbit**, and **Strength** [NEOWARP WG, 2024].
- A flyby is the quickest proximity operation to gain measurements of these properties.
- One idea to make fast recon happen is to use **a "retired" spacecraft**.
- However, this case usually does not provide the best spacecraft for ideal investigations.
- Hayabusa2#'s flyby demonstrates this particular situation, addressing **how it can take advantage of its flyby opportunity to measure the primary properties.**
  - The spacecraft does not have a rotating platform.
  - The onboard cameras have wider field of views (FOVs), while narrower FOVs are favored when observing a target far from them.
  - Older instruments encounter higher noise than at the time of launch.

Overall flyby operation sequences

- Flyby operation planning summary

Phase	Time to CA	Activity
On-ground GNC phase	T-10 days – T-12 hours	TCM + Radar and optical navigation
Onboard GNC phase	T-12 hours – T-5 minutes	TCM + Optical relative navigation
Encounter phase	T-5 minutes – T-0 minutes	Final attitude maneuvering + science observations

- Primary science investigations start after T-5 minutes.
  - Instruments can use this window for science investigations.
  - Flight operations related to GNC are minimal in this duration.

Property characterization under limited conditions

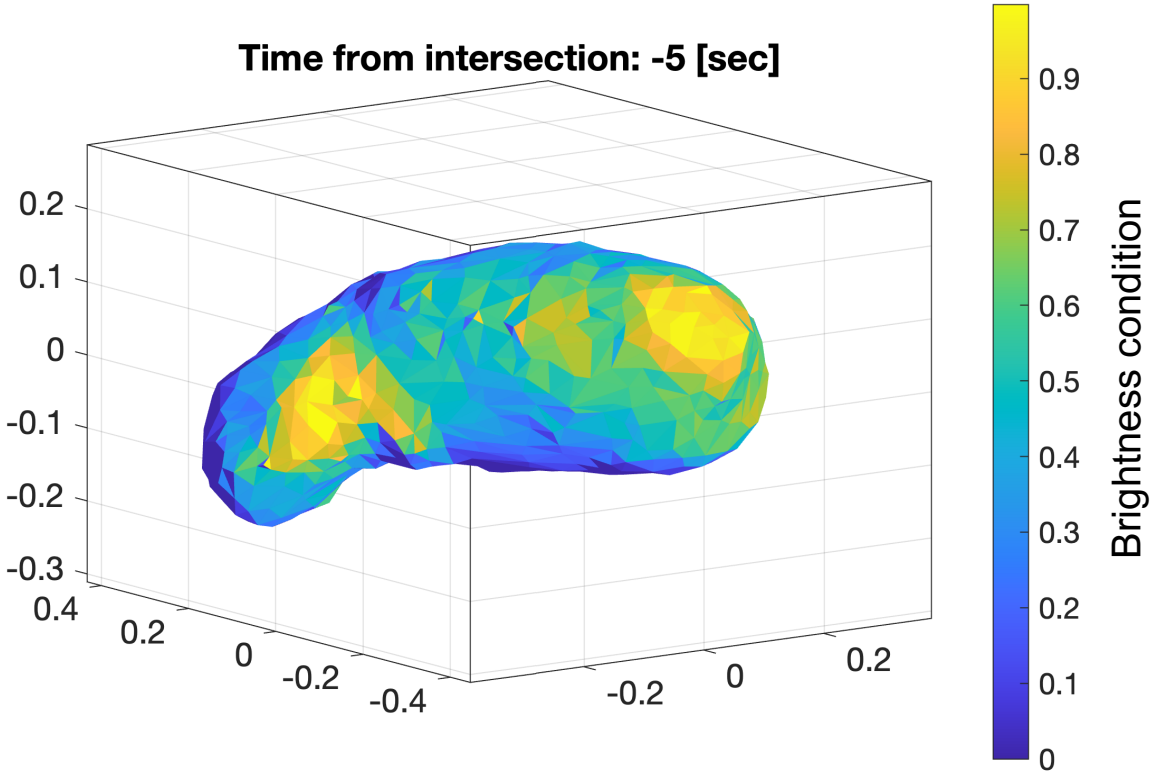
- Hayabusa2# plans to use the following instruments for investigations during the Torifune flyby .

Instrument	Description	Purposes
ONC-W1	Wide-angle camera (FOV = 69.7 deg)	Morphological properties
ONC-T	Narrow-angle camera (FOV = 6.3 deg)	Morphological properties
TIR	Thermal imager (FOV = 12.7 deg)	Thermal properties
NIRS3	Point spectrometer (FOV = 0.11 deg)	Composition
LIDAR	Laser altimeter (FOV = 4.3 x 10^{-2} deg)	Surface conditions, possibly navigation

- No major slewing and platform rotation at high speeds challenge us to make sure all instruments can sample useful data during the closest approach.
- Science operation planning needs to find the flyby orientation and timing that satisfy all instruments' constraints.
  - Tighter constraints than earlier stages of its nominal mission appear due to degradation.

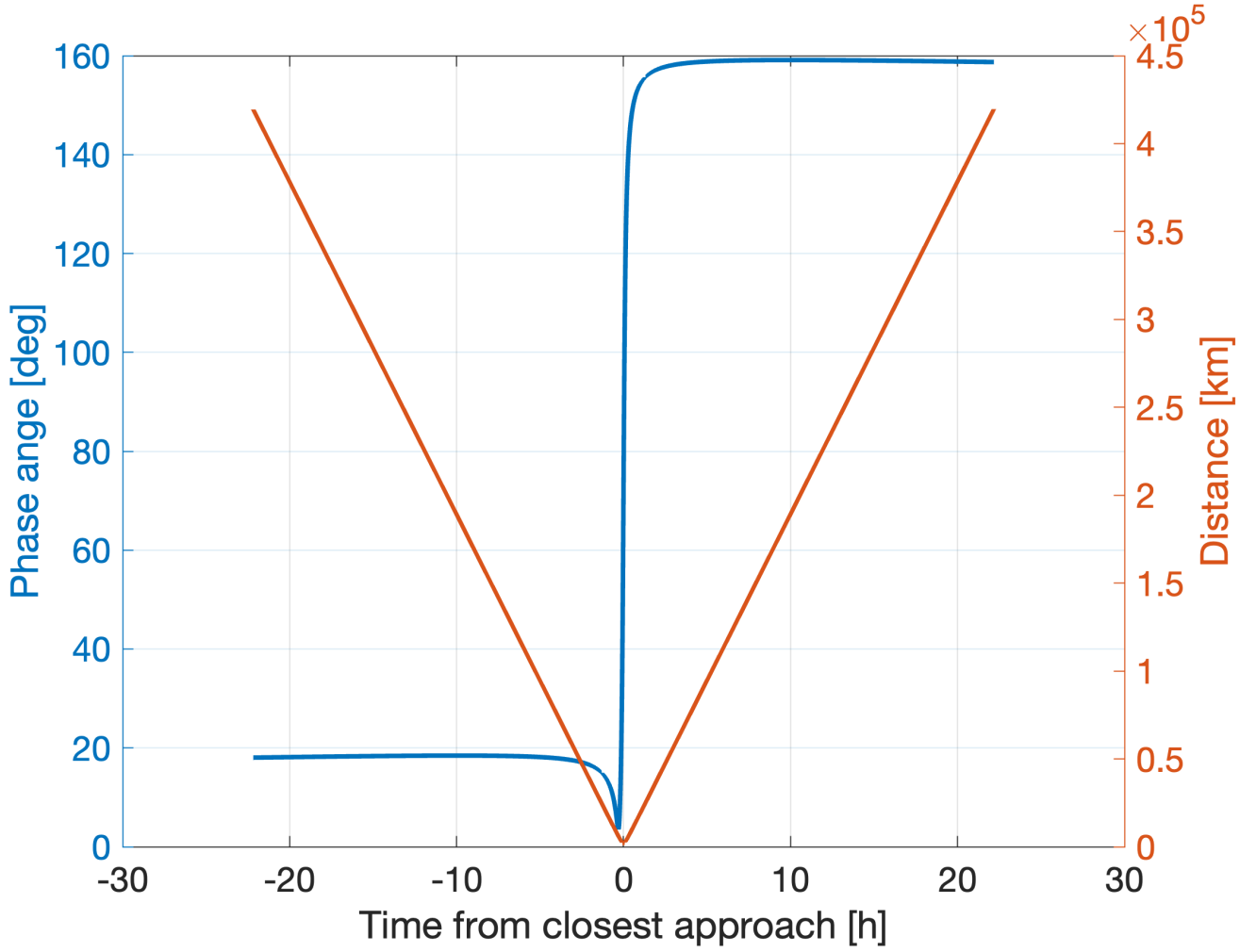
Planned flyby conditions that emphasize planetary defense

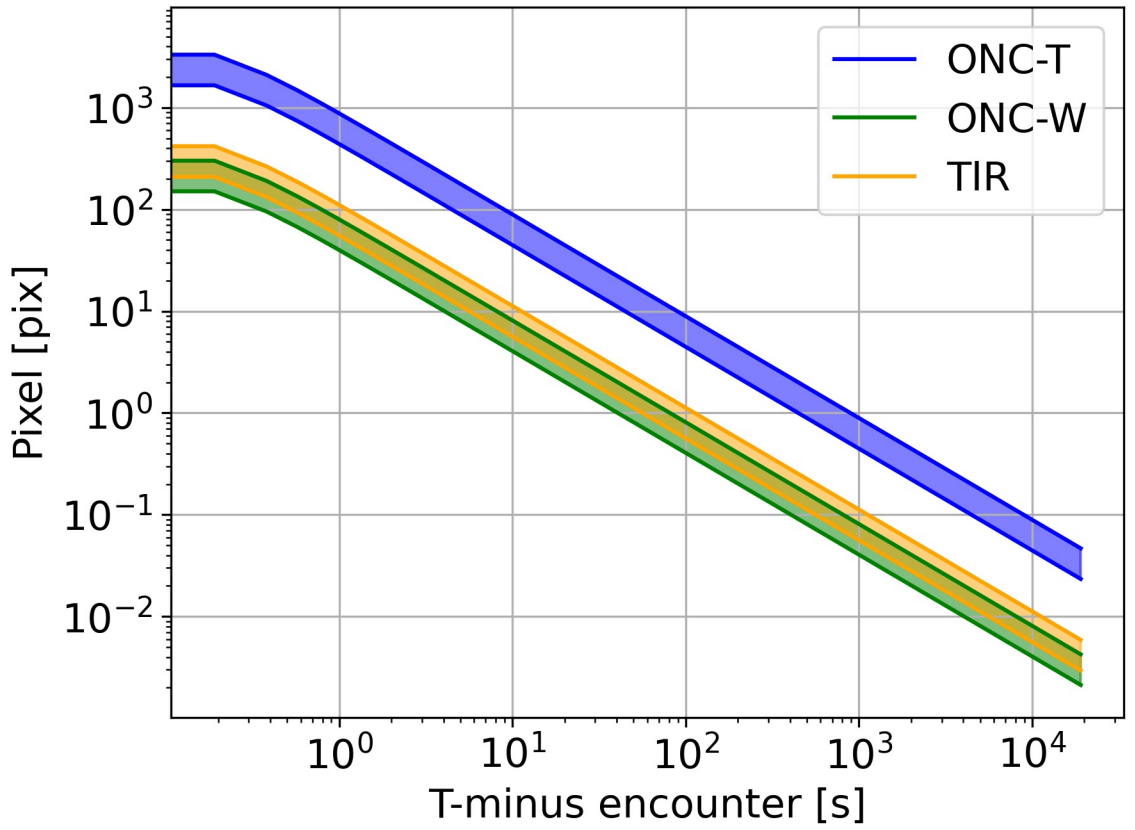
- The closest approach distance may be as close as possible, ~1-10 km from the target.
  - This is Hayabusa2#'s effort to push its limit to enhance high-accuracy GNC.
- This attempt also allows high-resolution observations without motion blur
  - Major slewing operations are not planned during its approach.
- The team established an integrated tool to offer the best viewing conditions to maximize the geophysical and geological characterizations using all instruments.



Geometry example maximizing characterizations for all instruments during flyby

Planned flyby conditions that emphasize planetary defense





The above figure (1-10 km) shows the pix number without motion blur. A closer approach enables higher resolutions without motion blur until closer to the closest approach.

Summary

- **The limited capability and timing test** how the Hayabusa2 spacecraft can maximize Torifune's property characterizations during the flyby.
  - **The spacecraft was not designed for flyby operations** and thus has critical disadvantages, but attempts to explore how to mitigate them.
  - Instruments are highly sensitive for rendezvous operations but not flyby operations, so they must be closer to the target to detail it.
  - Although all instruments are already 10 years old and have seen their degradation, they attempt to obtain critical data for characterization.
- Performing a ~km-distance flyby offers new opportunities for GNC innovations and observational chances.
  - Conducting a ~ km-distance flyby without a collision requires a higher GNC capability, offering a new demonstration of spaceflight operation.
  - A closer-distance flyby allows all instruments to achieve higher resolution. The view geometries can be almost fixed until seconds before the flyby.
- **Hayabusa2#'s Torifune flyby is an example of using a retired spacecraft that is already flying to demonstrate rapid reconnaissance operations.**
  - **This concept skips any steps before the launch, but it must be verified to meet fast recon requirements.**