# Rapid Response Flyby Exploration using Deep Space Constellation deployed on Asteroid Flyby Cyclers

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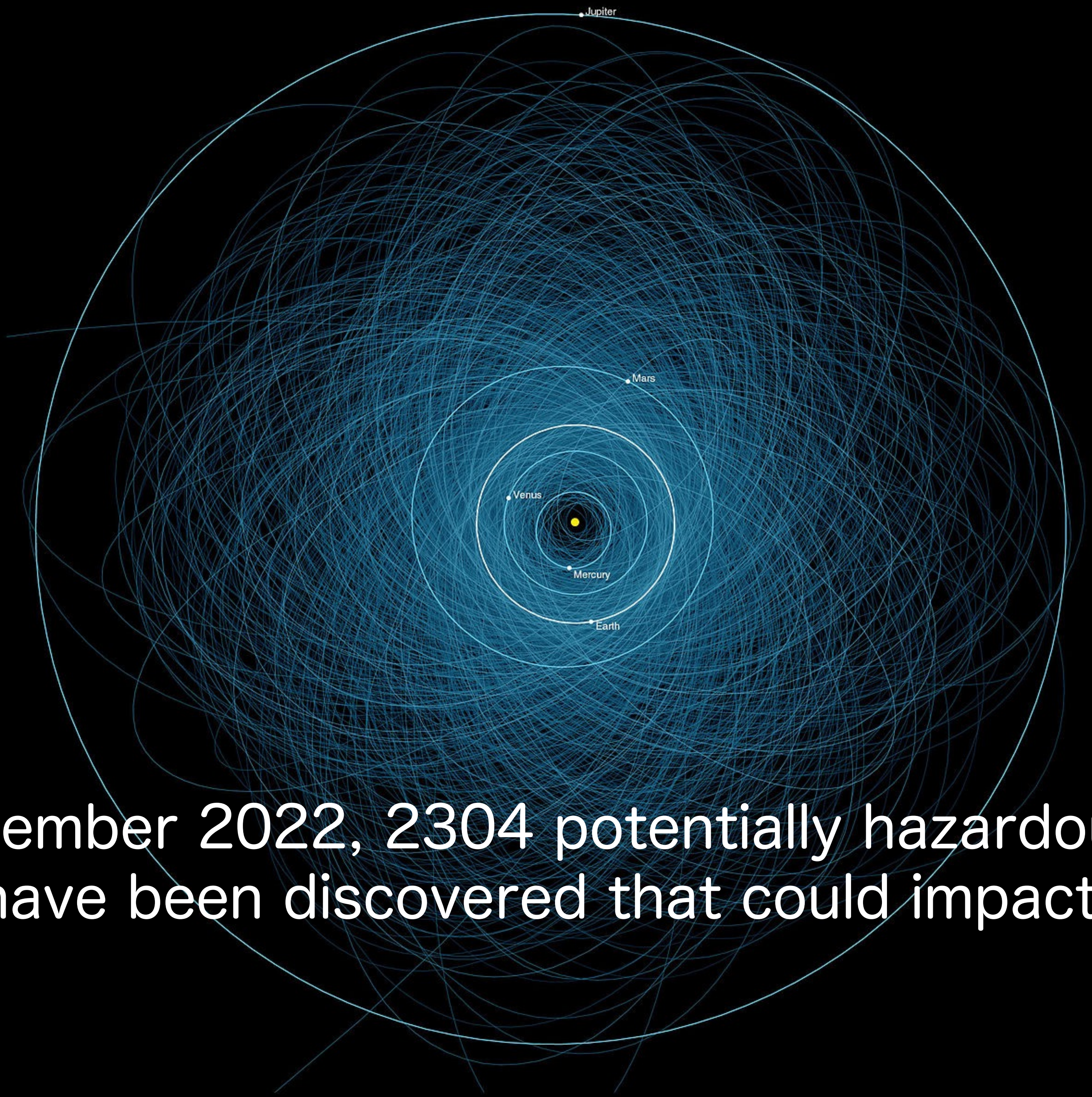
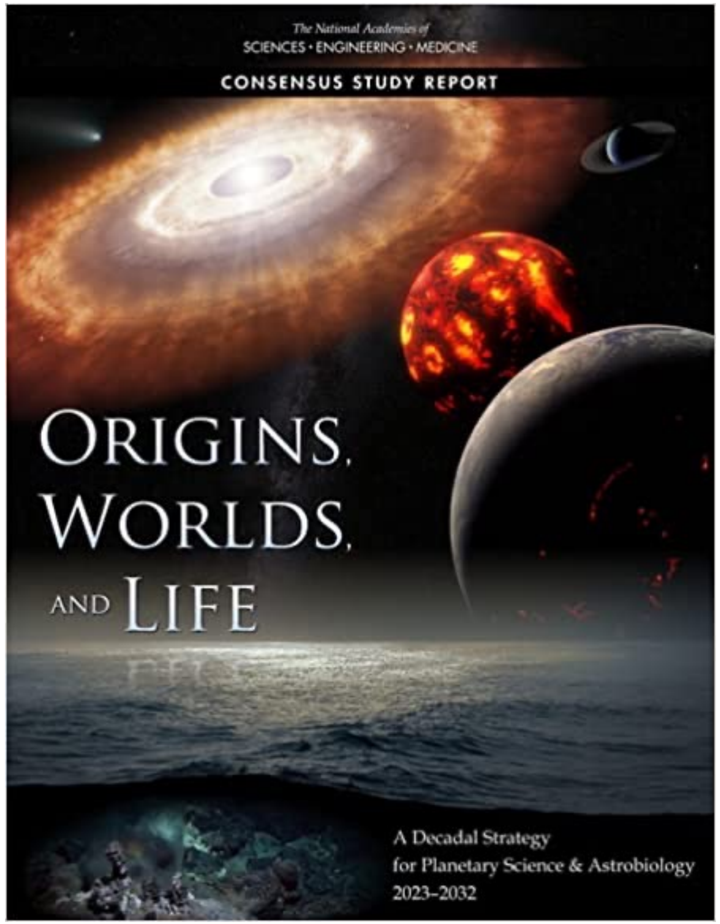



As of November 2022, 2304 potentially hazardous asteroids (PHAs) have been discovered that could impact the Earth.

# A Decadal Strategy for Planetary Science and Astrobiology 2023-2032

The U.S. Decadal Survey recommended completing the DART mission in 2023, launching the NEO Surveyor in 2026, and conducting a rapid response flyby mission by the end of 2032.

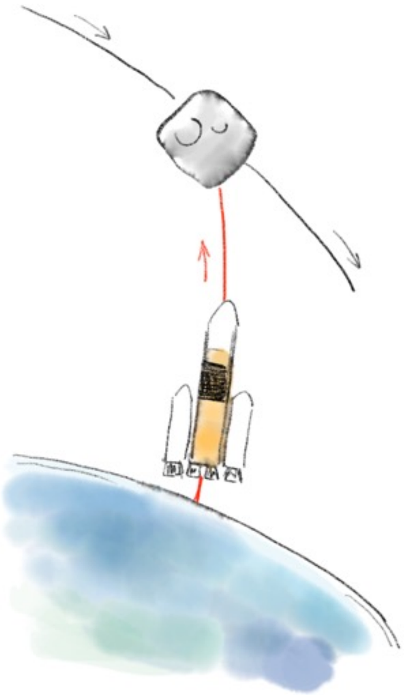
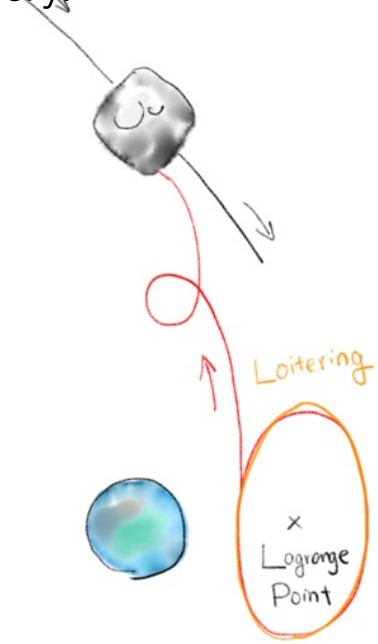
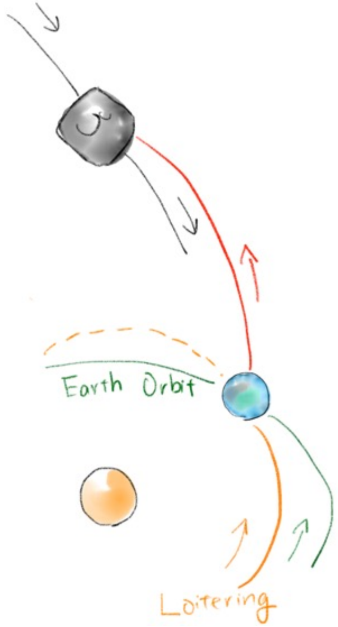



**Finding:** Prior characterization of a hazardous NEO via an in situ reconnaissance mission is advisable to determine its physical characteristics and to develop an appropriate mitigation response based on the available warning time. Although rendezvous missions are preferred, fast flyby missions may be required to obtain timely characterization data for short warning time scenarios.

**Recommendation: The highest priority planetary defense demonstration mission to follow DART and NEO Surveyor should be a rapid-response, flyby reconnaissance mission targeted to a challenging NEO, representative of the population (~50-to-100 m in diameter) of objects posing the highest probability of a destructive Earth impact. Such a mission should assess the capabilities and limitations of flyby characterization methods to better prepare for a short-warning-time NEO threat.**

*Next Steps for Planetary Defense Missions (p.18-21)*

# Rapid Response Exploration Scenarios

| Option | Direct Launch | Loitering at Lagrange Points | Loitering in Earth-resonant flyby orbit (Asteroid flyby cycler) |
|---|---|---|---|
| Overview | Launch a spacecraft just after the target object is found.<br> | Keep the spacecraft in halo orbit, and escape and aim for the target object just after discovery.<br><br> | Keep the spacecraft in an Earth-resonant flyby orbit and target the object with the Earth gravity assist just after discovery.<br><br> |

# Rapid Response Exploration Scenarios

| | Direct Launch | Loitering at Lagrange Points | Loitering in Earth-resonant flyby orbit (Asteroid flyby cycler) |
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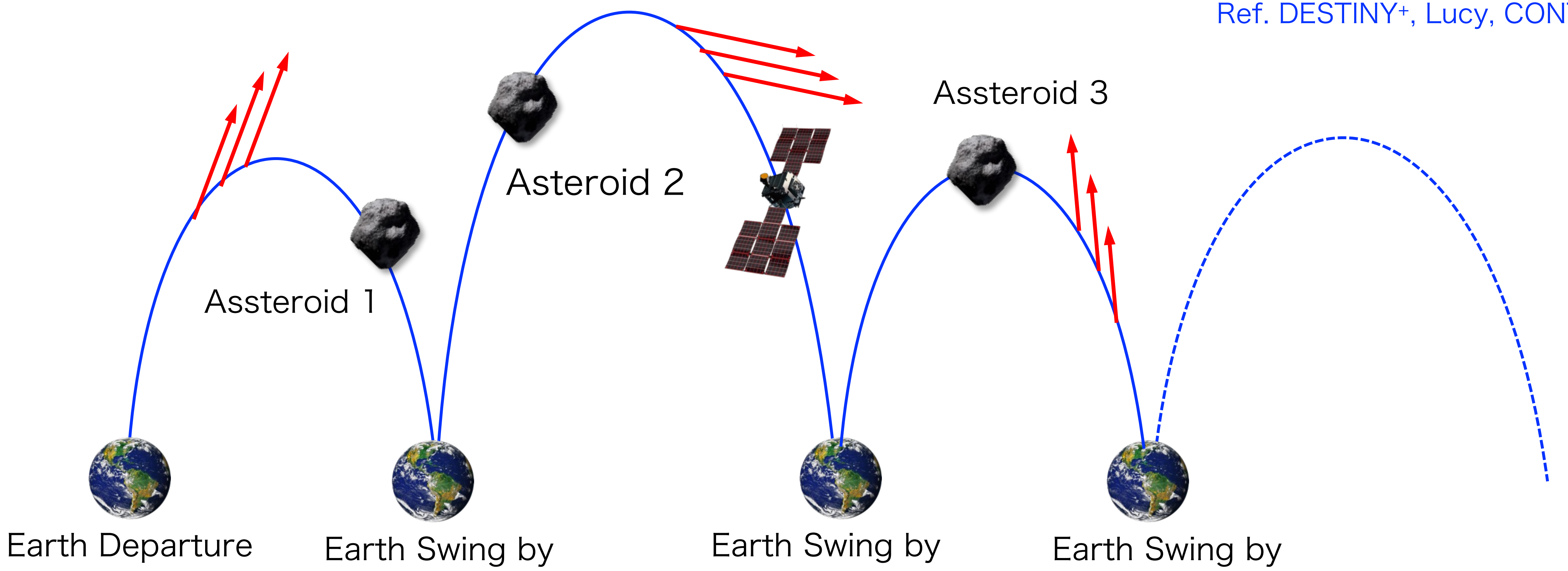
| Overview | Launch a spacecraft just after the target object is found. | Keep the spacecraft in halo orbit, and escape and aim for the target object just after discovery. | Keep the spacecraft in an Earth-resonant flyby orbit and target the object with the Earth gravity assist just after discovery. |
| Difficulties | The rocket must be ready for launch at any time, which is difficult to do when targeting hazardous asteroids, which occur only once every 10 years or so. | Since the escape energy from a halo orbit is low, a large acceleration is required from there by electric propulsion, etc. | It is necessary to be able to operate more than 10 probes simultaneously, and the challenge is to make them autonomous for this purpose. |
| Mission Class | Micro to small spacecraft (~50 kg) with large launch vehicle | Medium-size spacecraft (~500kg) | About 10 micro spacecraft (~50kg) |
| Note | A launch vehicle capable of immediate launch is essential. | ESA's Comet Interceptor | A cost-effective way to perform multiple asteroid flybys while waiting. |

**Proposed method**

# Asteroid Flyby Cycler Orbits

Naoya Ozaki, Kanta Yanagida, et al., " Asteroid Flyby Cycler Trajectory Design Using Deep Neural Networks," *Journal of Guidance, Control, and Dynamics*, 2022.

Ref. DESTINY+, Lucy, CONTOUR




By adopting an asteroid flyby cycler orbit (alternating asteroid flyby and Earth swing by) as shown above, it is possible to fly by one NEO (requiring $\Delta V$ consumption of about 10 m/s per year) per year.

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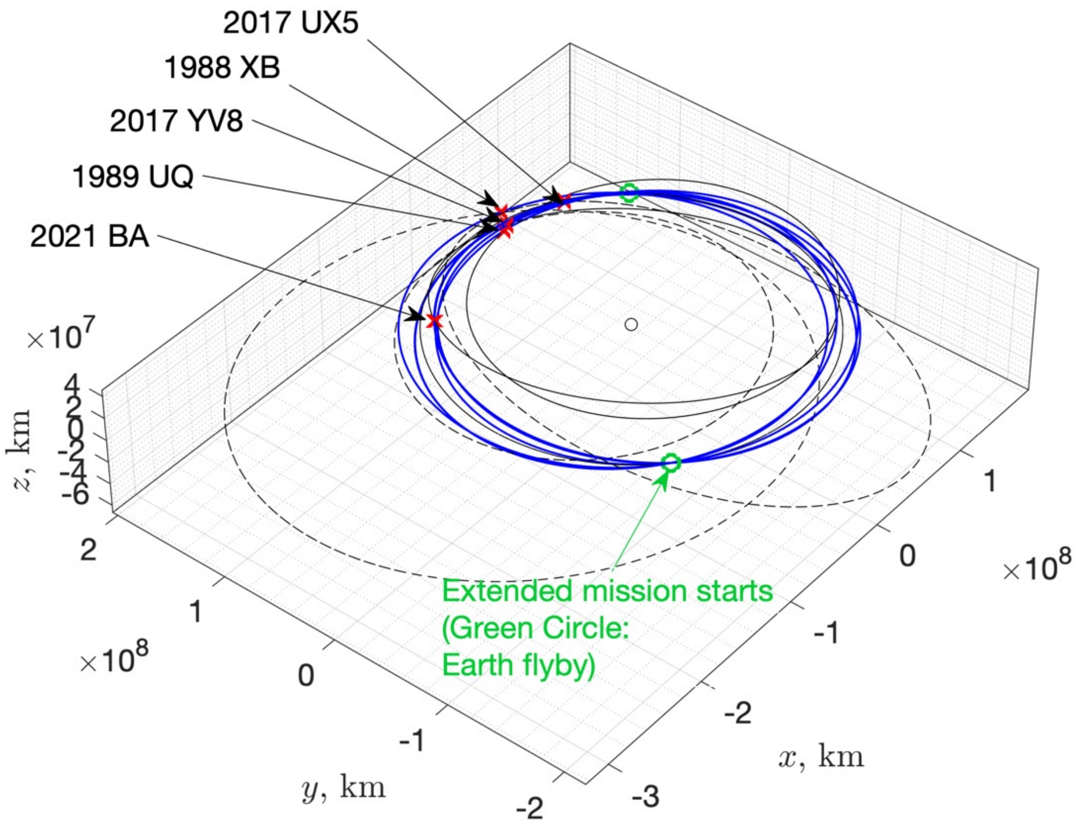


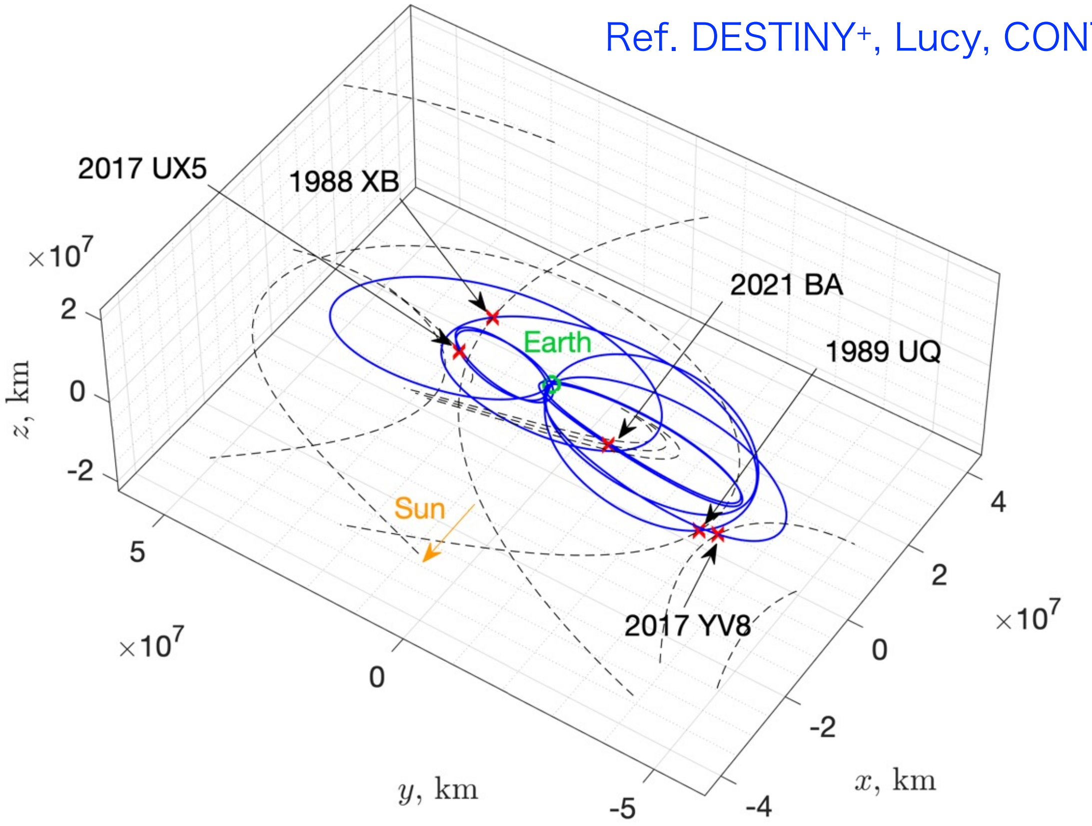


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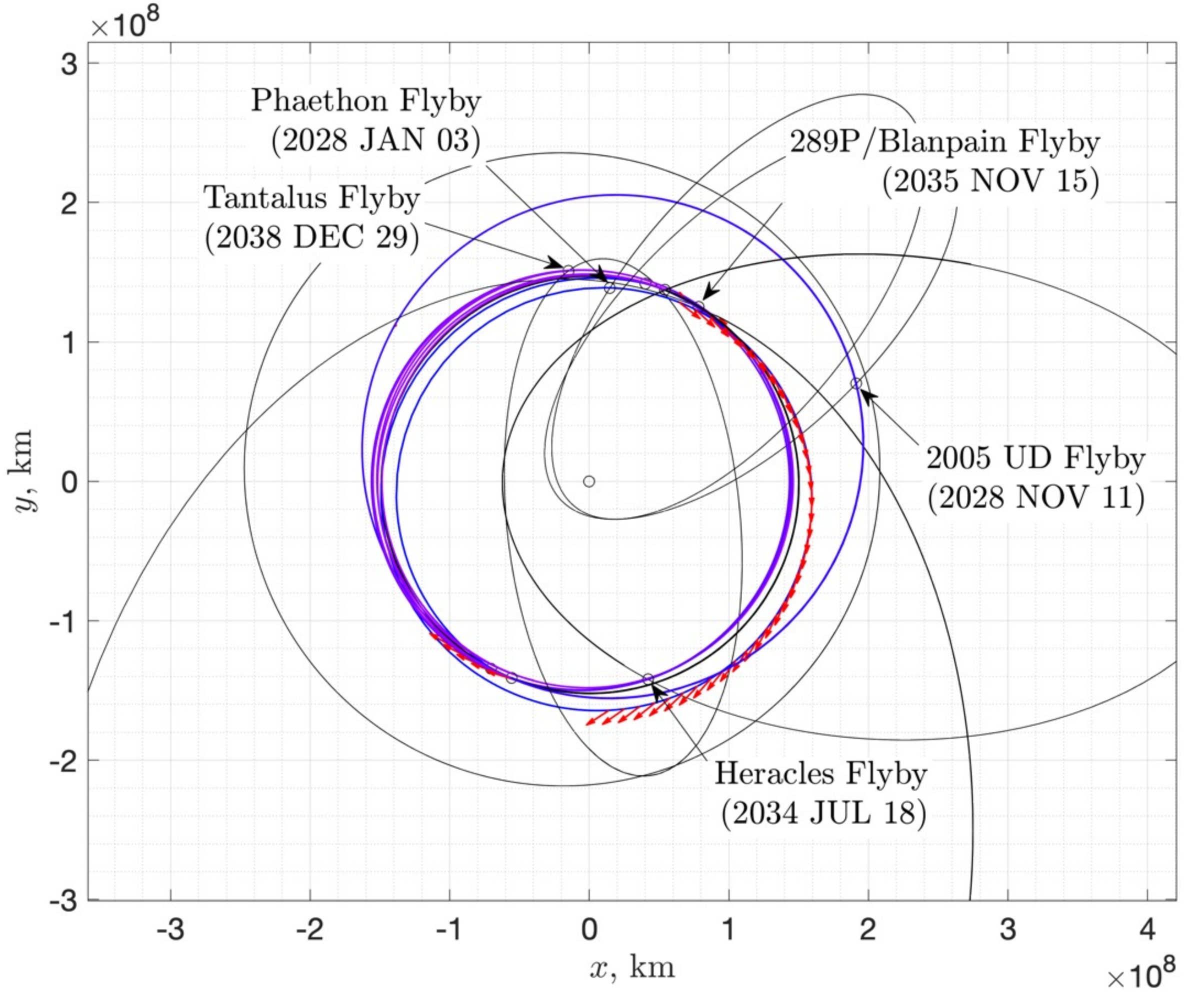
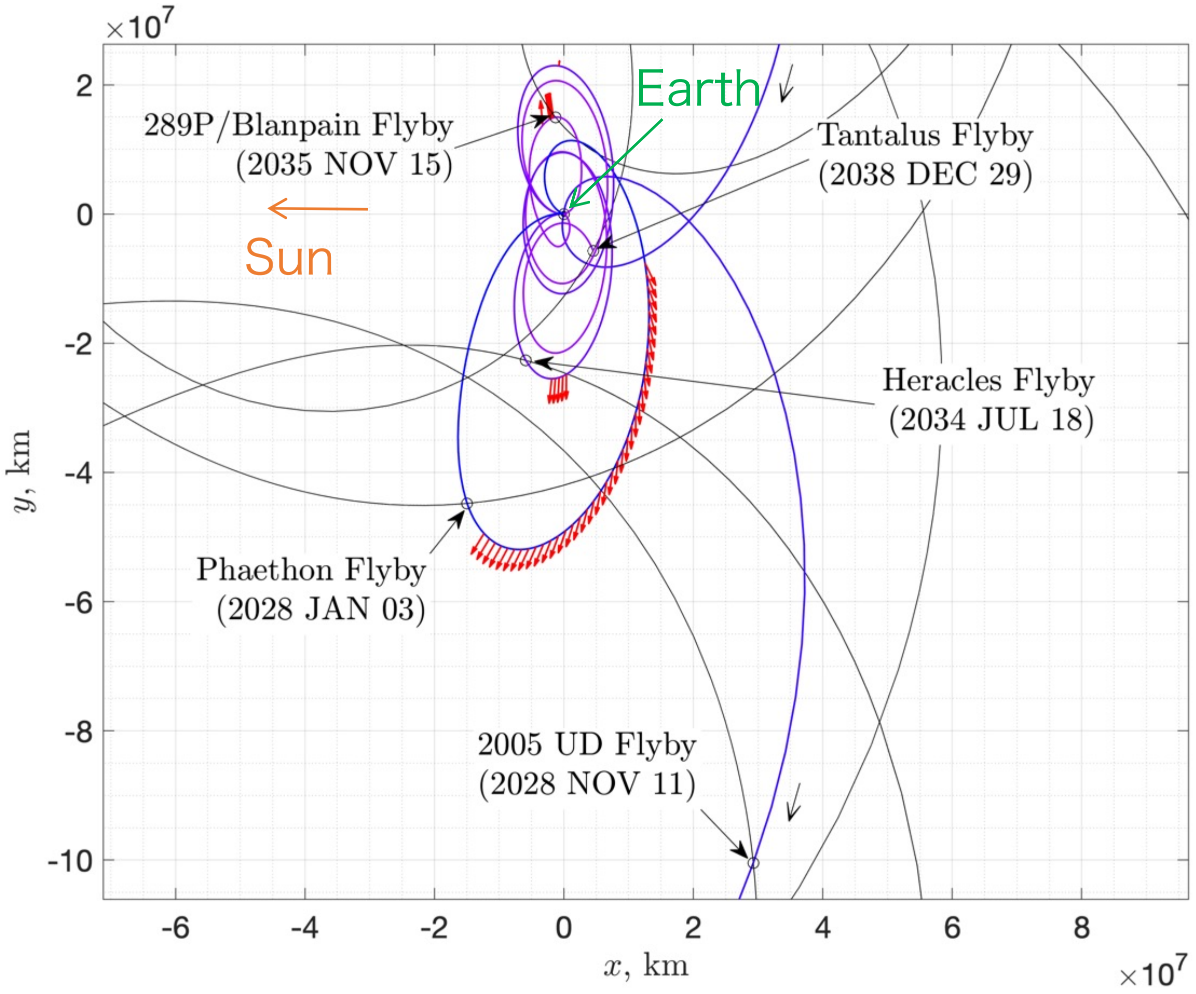
# Example Trajectory of DESTINY+ Extended Mission




Sun-centered, inertial frame

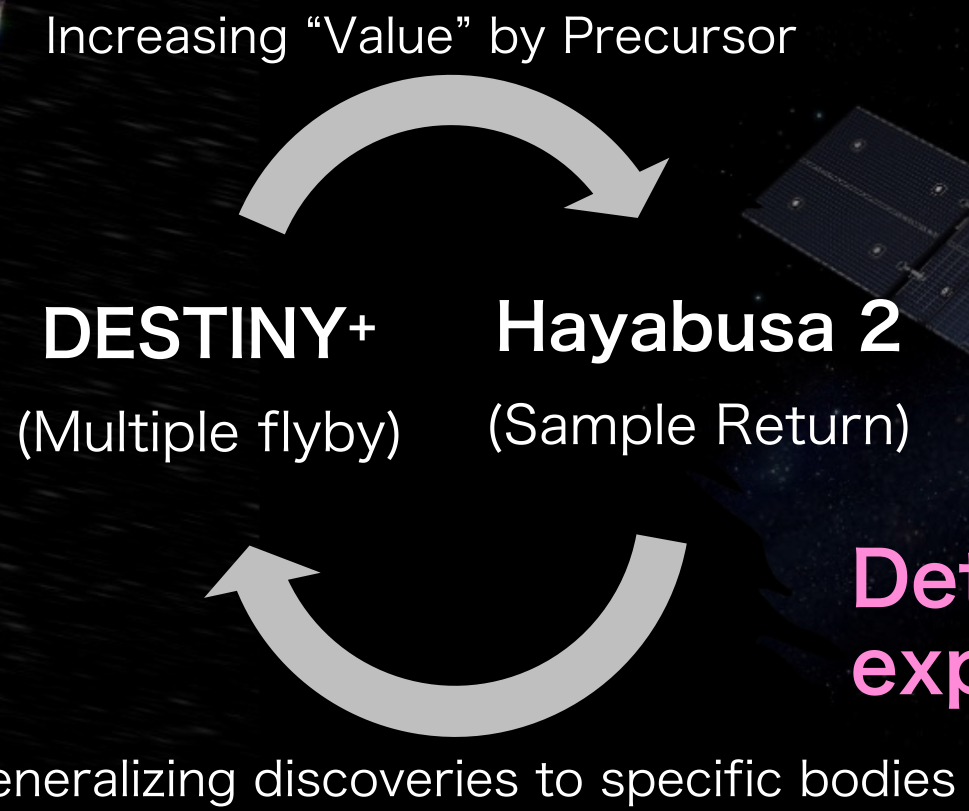



Earth-centered, Sun-Earth fixed rotating frame

# New Small Body Exploration Strategy of ISAS

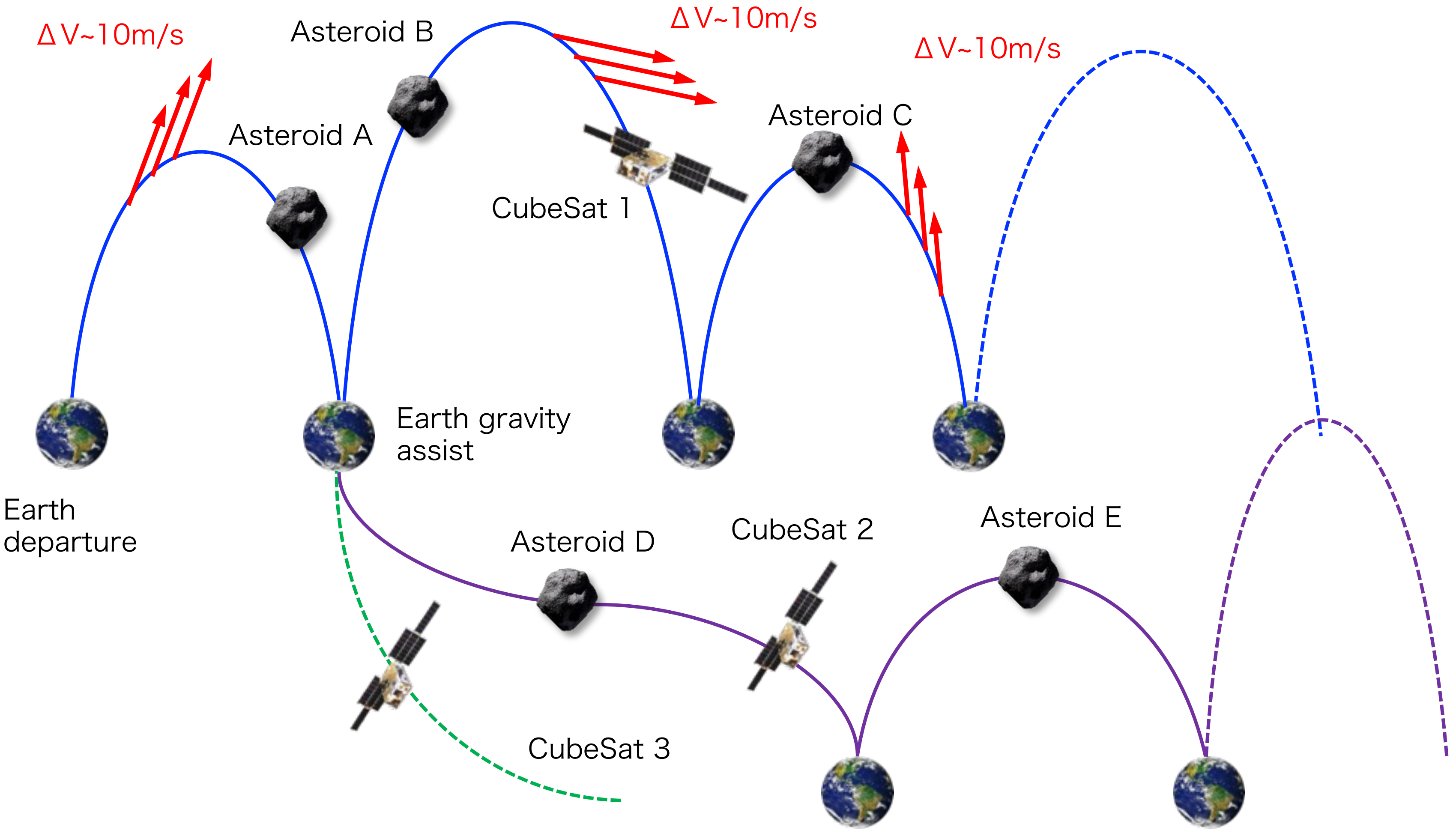
As of November 02, 2022, more than 1.23 million small bodies have been discovered. The combination of a time-consuming (rendezvous-type) sample return mission, which allows for **detailed exploration**, and a multi-flyby mission, which allows for **one-chance but easy access to multiple bodies**, makes small body exploration even more effective!

Extensive exploration



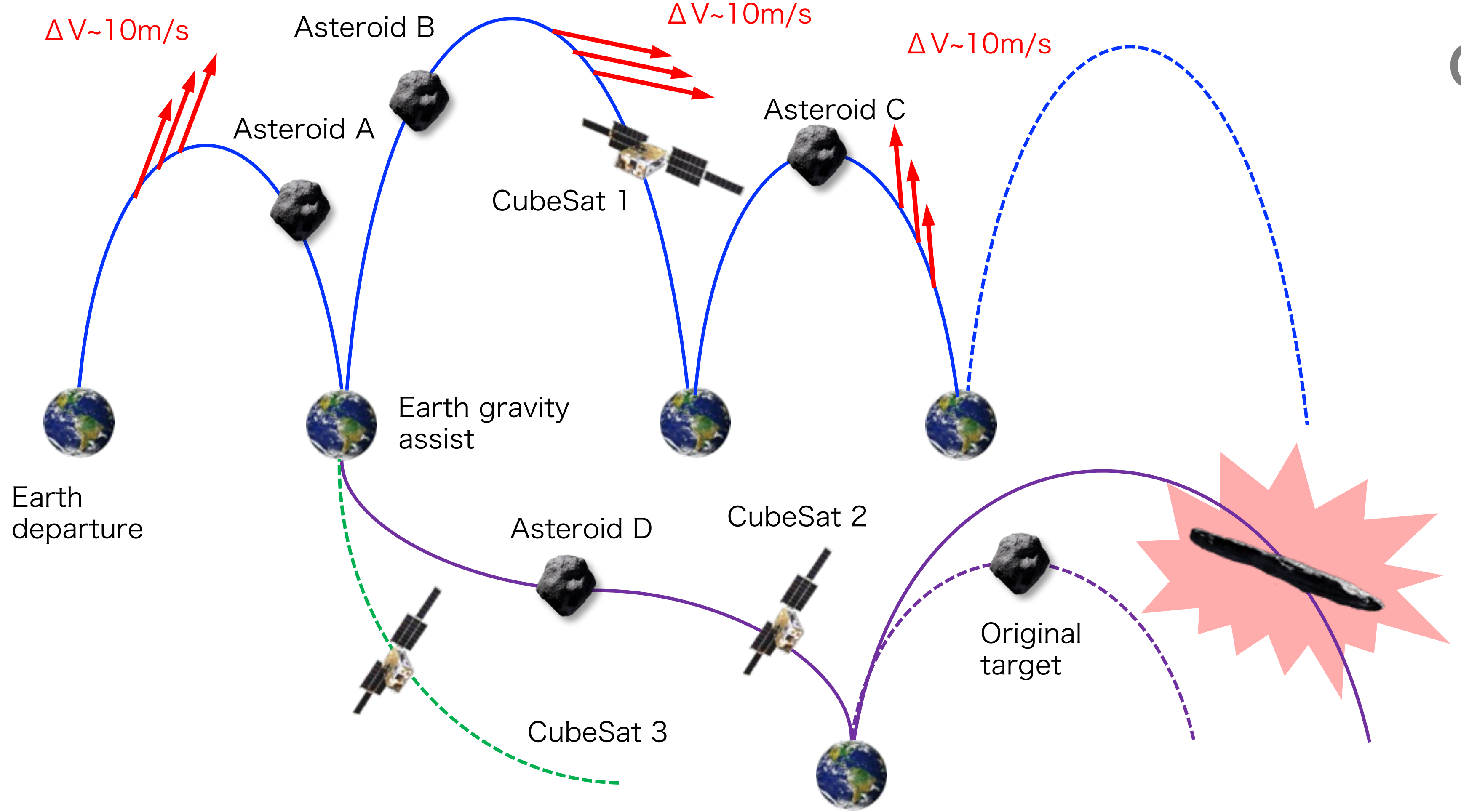

Detailed exploration

# Multiple Asteroid Flyby Exploration by Deep Space Constellation




**One asteroid flyby per month for a 12-spacecraft configuration**

# Multiple Asteroid Flyby Exploration by Deep Space Constellation




One asteroid flyby per month for a 12-spacecraft configuration

**Orbit correction by the Earth gravity assist can also realize rapid response exploration**

# Significance of the Deep Space Constellation Concept

## Planetary Defense

International cooperation through SmallSat-based deep space exploration missions to protect the Earth together in the world.

## Space Exploration Technologies

Improvement of technological capabilities and development of industry and human resources through continuous technology demonstration.

## Planetary Science

1) Statistical information on small bodies by super multiple asteroid flybys

2) the world's first direct exploration of interstellar objects and/or long-period comets.

# Conclusiton

- ✓In order to realize multiple asteroid flyby and rapid response flyby of small bodies, we proposed the concept of deep space constellations using asteroid flyby cycler orbits.
- ✓The significance of this concept is presented from the three viewpoints of "planetary defense," "planetary science," and "space exploration technology.

**Why don't we work together to realize the "world's first interstellar object exploration" and "protecting the earth from asteroid impact" mission?**