An extension of planetary geodesy side by side with Solar System small body explorations: MMX and Hayabusa2#

RISE Project, NAOJ

MMX/Hayabusa2#

Koji Matsumoto

2. Science goals

- One of the major goals of modern astronomy:

  Studying the origin of life in the universe

  → “Hoshi to Seimei”（星と生命）is being proposed in White paper of Japanese Astronomy by the Astronomical Society of Japan.

- Observing the solar system by planetary exploration is essential to complement astronomical observations.

- The keys to understand habitability:

  Not only　the atmosphere and the surface environment

  but also　internal vigor of planetary bodies (volcanic activity)

  and　material transport in the solar system.

- Participate in planetary missions to investigate the solar system bodies

  → contribute to understanding the habitable environments in the universe

3. Scientific objectives

- Participate in MMX (Martian Moons eXploaration) and Hayabusa2#, to contribute to a better understanding of the formation processes of habitable environments in the solar system.

- MMX

➢ To determine the origin of Phobos and Deimos, to elucidate the early Solar System evolution in terms of volatile delivery across the snow line to the terrestrial planets having habitable surface environments

➢ To explore the evolutionary processes of both moons and Mars surface environment

- Hayabusa2#

➢ To constrain the origin and evolution mechanism of small asteroids

➢ To establish knowledge about planetary defense

3. Scientific objectives

- In the context of planetary geodesy:

- MMX

➢ To put new constraints on the internal structure of Phobos from geodetic observation.

➢ To contribute to investigating origin of Phobos and Deimos.

- Hayabusa2#

➢ To support spacecraft operation and develop associated technical development.

(Note: Hayabusa2# is an extended mission with a risk of sudden termination)

3. Scientific objectives

- Geodetic products include precise orbit of spacecraft / gravity field, shape, rotation parameters, ephemeris of the target body.
- Multifaceted observations from a suite of instruments (cameras, altimeter, etc.) are to be integrated for scientific studies.
- Planetary geodesy is also an essential element of this integration.

  e.g., image registration, observation condition, Landing Site Selection (LSS)

  → Providing geodetic products is an indirect but crucial contribution to planetary explorations to maximize the scientific return.

- MMX Geodesy Science Strategy Team (G-SST) has been established in this context.

Geodesy supports planetary missions

9. Project Organization

MMX

- Geodesy Science Strategy Team (G-SST) consists of 25 members (13 domestic, 12 international)
- Leader: Koji Matsumoto
- Other 5 staffs of RISE project (N. Namiki, H. Araki, H. Noda, S. Kikuchi, K. Yamamoto) play an important role as the core of G-SST.
- Three RISE members (H. Noda, H. Araki, K. Matsumoto) also belong to LIDAR team.

Hayabusa2#

- S. Kikuchi contributes to Hayabusa2# as a member of the astrodynamics team to establish the methodology of spacecraft operation in the microgravity conditions.
- LIDAR PI changed from N. Namiki to S. Kamata (Hokkaido U.)
- N. Namiki, H. Noda, K. Matsumoto continue to support the LIDAR team of the extended mission.
- H. Noda participates in the ground occultation observation of small asteroids to constrain their orbits and sizes.

4. Scientific investigations

MMX

- MO1.1.3: Obtain information such as molecular release rates and mass distribution related to the presence of ice in Phobos, investigate the presence or absence of density contrasts on Phobos' surface, and constrain Phobos' origin independently of MO1.1.1 and MO1.1.2

Direct

- MO1.1.1: Spectroscopically reveal the surface-layer distribution of the materials that make up Phobos with the spatial resolution required for the scientific evaluation of sampling points and geological structures, thereby constraining Phobos' origin
- MO2.1.1: Identify weathering and evolutionary processes (impact frequency, degree of gardening, and space weathering processes) in surface-layer regolith specific to the Martian moons as compared to asteroids

Partly related through topography & S/C orbit

- MO1.1.2: Identify the major components of constituent materials from samples collected on Phobos' surface as Phobos indigenous materials that retain records of their formation, strongly constraining their origins from isotopic ratios, etc.
- MO1.2a.1: By constraining the formation of primitive materials in the Solar System and primitive bodies in the vicinity of the snow line from a material science perspective, and by estimating the Phobos capture process, constrain the initial conditions for the processes of planetary migration, material transport and evolution of the Martian surface in the early Solar System
- MO1.2b.1: For Phobos indigenous materials, identify primitive Martian components (Mars-originating components) ejected by a giant impact and components of the impactor body, clarify their features, estimate the scale and age of the impact, and constrain planetary migration, material transport, and planetary formation processes in the terrestrial planetary region

Indirect (sample analysis)

4. Scientific investigations

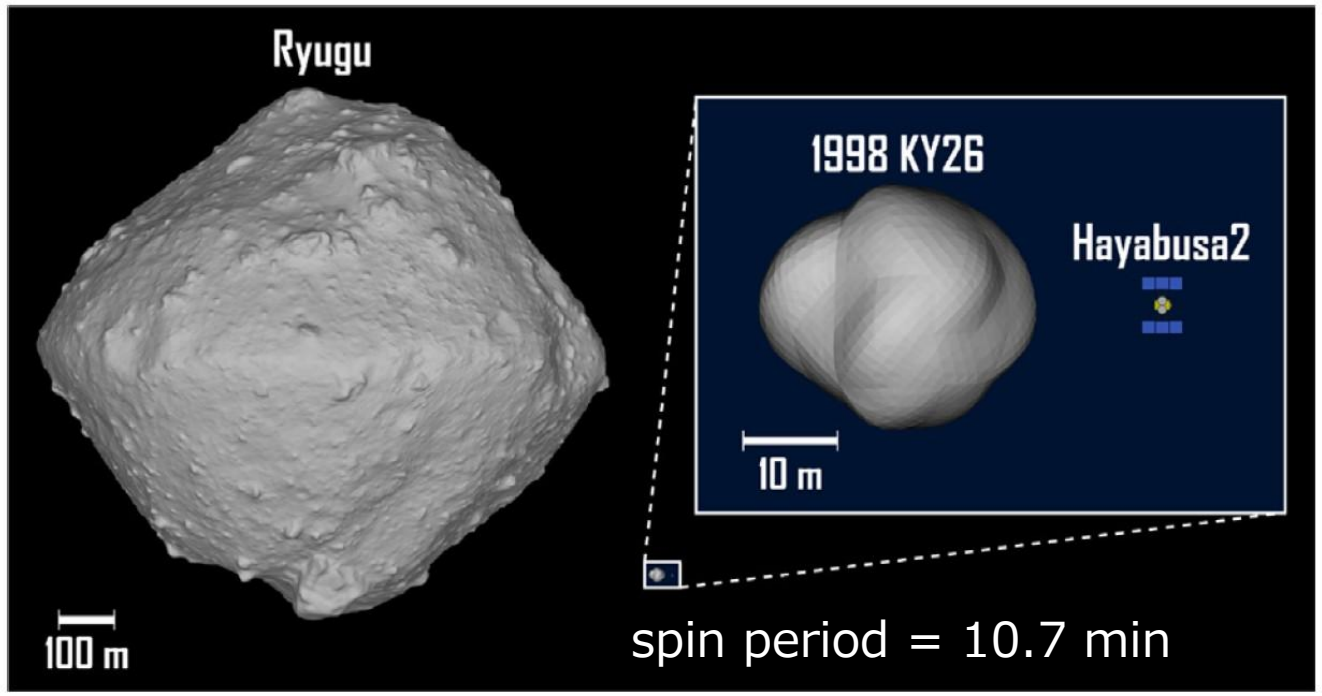
- Hayabusa2#

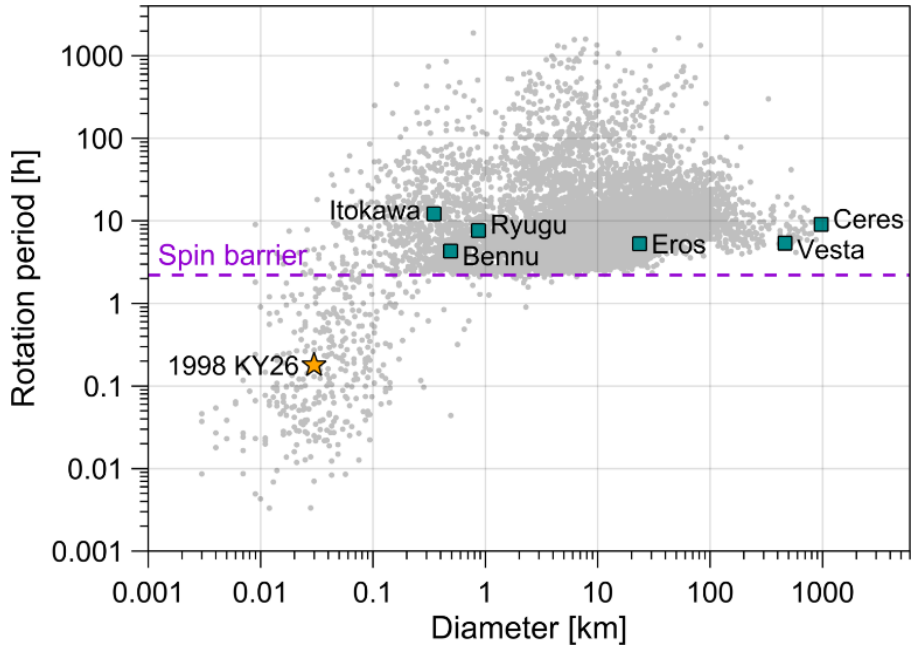
理学目標	ミッション要求（理学）
惑星間ダスト空間分布の把握	黄道光を観測し、惑星間ダストの空間分布を把握すること
系外惑星探索	恒星の前面を惑星が通過する際に起こる恒星の見かけの減光から系外惑星を探索すること
フライバイ観測による L 型小惑星の特性の制約	L 型小惑星にフライバイし、可能な限り近接から表面状態を観測すること
巡航中、および地球スイングバイ時の観測による搭載理学機器の長期性能評価	巡航時および天体通過時の観測により、搭載理学機器性能の経年変化を評価する
高速自転小惑星の形成・進化の解明	・天体の表面構造の詳細な観測を実施すること ・高速自転小型小惑星の運動と表面状態から内部構造に関する知見を得ること
Planetary Defense に資する科学の獲得	Planetary Defense に関する科学的知見を取得すること

- 2001 CC21
- Evaluate the aging of LIDAR
- 1998 KY26
- Planetary defense includes elucidating bulk characteristics of sub-100-m objects such as 1998 KY26.

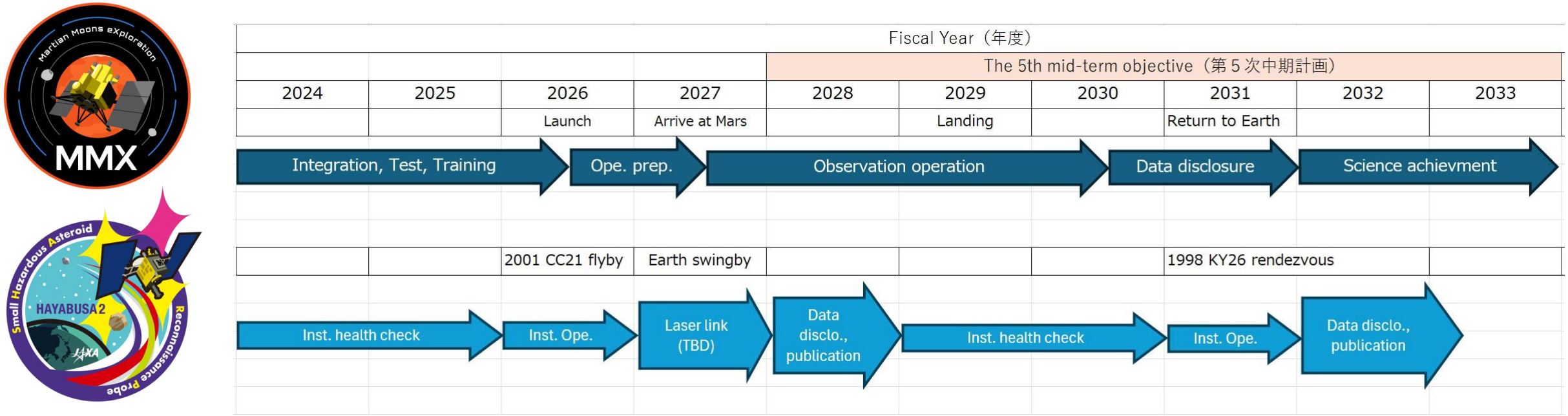
4. Scientific investigations

- Hayabusa2#
- 1998 KY26: a small fast rotator.
- Not even easy for the spacecraft to stay in the vicinity and make observations.
- Theoretical study to characterize a peculiar dynamical environment of such a small and fast rotator.





4.1. Science Investigations until 2033
7. Current Status



4.3. Threshold Science

- MMX

MO1.1.3 and the objectives regarding Phobos topography in MO1.1.1 and MO2.1.1.

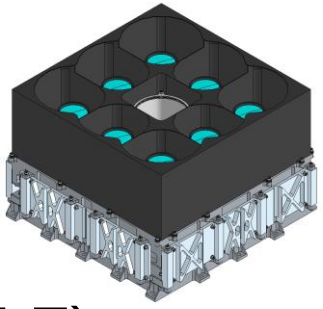
- Hayabusa2#

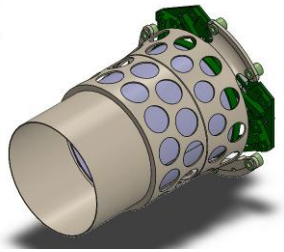
The spacecraft has exceeded its design life.

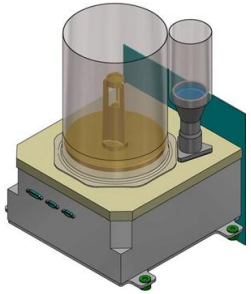
Considering potential unexpected termination, we set the minimum success to obtain new knowledge about observational techniques in the vicinity of a fast-rotating asteroid.

5. Instruments and data to be returned

MMX







Instruments

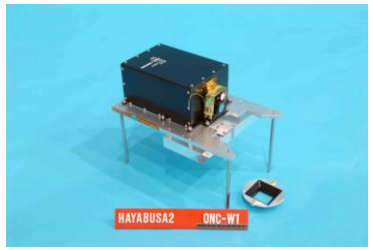
- Wide-angle camera (OROCHI)
- Narrow-angle camera (TENGOO/CAM-T)
- Altimeter (LIDAR)
- Ground tracking stations

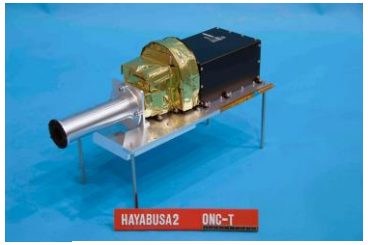
Data to be returned

- Spacecraft orbits with initial state vector as accurate as 10 m in position w.r.t Phobos center of mass and 10^{-3} m s^{-1} in velocity.
- Global Phobos topography with an average spatial resolution better than 4 m.
- Gravity potential model degrees and orders up to 5 in spherical harmonic expansion. Accuracy of C_{20} and C_{22} better than 2～3 %.
- Amplitude of libration in longitude better than 2～3%.

5. Instruments and data to be returned

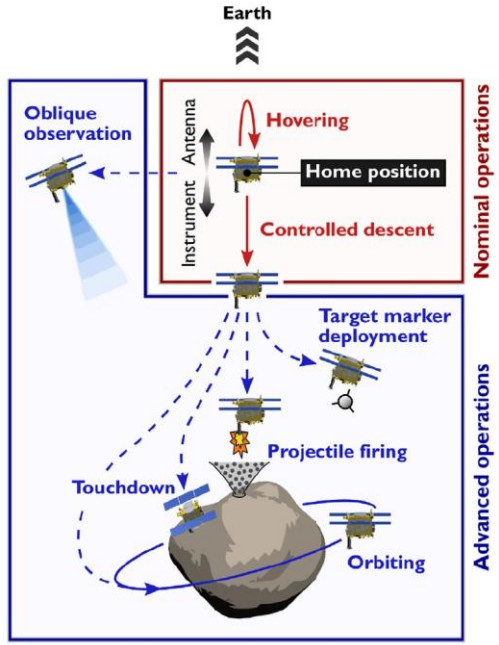
If Hayabusa2# successfully arrives and observes 1998 KY26





Instruments

- Wide-angle camera (ONC-W)
- Narrow-angle camera (ONC-T)
- Altimeter (LIDAR)
- Ground tracking stations
- Target marker/projectile



Data to be returned

- Spacecraft orbit
- Mass and average density of the asteroid
- Constraints on the surface and internal structures of the asteroid
- The quality of these products is subject to considerable uncertainty at present
  (it depends on the remaining resources at the time of arrival)

8. Cost assessments, budget line and status

- We expect an annual budget of roughly ¥15M (1,500万円) from the management expenses grant (運営費交付金).
- This estimate is based on the current budget of RISE project, including the salaries of a project researcher and administrative supporter.
- Additional personnel expenses during MMX Landing Site Selection activity and its preparation period (2027-2028) will be necessary.

10. Why NAOJ ?

- Activities at NAOJ

➢ MMX: Lead G-SST activities as the core

➢ Hayabusa2#: Development and application of new methods for the exploration of small bodies / support LIDAR operation

- Significance

➢ In-situ observations of solar-system objects are essential to one of the astronomical goals of 「星と生命」. It is significant that NAOJ, a leader in astronomy, takes part in planetary missions.

➢ In solar system exploration, providing geodetic products has a similar meaning to “open use”. NAOJ is a suitable place for our activity.

- Computer system is maintained by ADC.

1. Summary of the proposal

- Science goals and objectives

Participate in planetary missions to investigate the internal structures of the solar system bodies to contribute to understanding the habitable environments in the universe.

- Science investigations, instrumentation and data

MMX: Constraints on the internal structure of Phobos from geodetic observation. Provide geodetic products (spacecraft orbit, gravity/shape/rotation of Martian moons) by using cameras/altimeter/tracking data.

Hayabusa2#: Constraints on the internal structure of fast-rotating asteroid. Knowledge base for the spacecraft operation in the microgravity condition.

- Threshold science

MMX: Phobos global topography with spatial resolution better than 4 m. An accuracy of 2～3% for C_{20}/C_{22} and amplitude of libration in longitude.

Hayabusa2#: To obtain new knowledge about observational techniques in the vicinity of a fast-rotating asteroid.

- Cost estimation

¥15M from the management expenses grant (運営費交付金).

- Project Organization

RISE Project (one professor, one associate professor, three assistant professors, and one project researcher) and MMX G-SST members.

Backup slides

4.2. Science Investigations beyond 2034

Next Generation small body Sample Return mission (NGSR) is targeting a comet to bring back its subsurface materials and to unveil the origin of the solar system, namely, I) the origin of the solar-system "materials" in galactic evolution and II) the origin of the solar-system "bodies" to form planetesimals.

On the other hand, a rapid expansion of International Space Exploration (ISE) promotes lunar science and exploration. Studies of lunar astronomical observatory, network seismic stations, and sample return from the Moon are continuing. Certain progress will likely be made as long as the ISE continues.

Considering the above situations surrounding planetary geodesy, we cannot decide whether to choose small-body or lunar exploration in the late 2030s. Besides, the membership of RISE Project is changing during the 5th mid-term planning period. Therefore we would like to entrust the younger generation with that decision.

惑星科学コミュニティにおては、MMXの後継として次期戦略的中型候補の次世代小天体サンプルリターン（NGSR）ミッションの検討が進んでいる。NGSRミッションでは、木星軌道付近に遠日点を持ち水質変成を受けていない可能性の高い彗星核から試料を持ち帰り、太陽系物質/天体の起源を明らかにして銀河系における太陽系の起源に迫ることを目的としている。

一方で、国際宇宙探査の急激な進展により、月科学観測も進行している。月面天文台、月震ネットワーク観測、月サンプルリターンのミッション検討が行われている。国際宇宙探査が実施される限り、一定の進展は必ずあると期待される。

以上の状況を鑑みて、2030年代後半の惑星測地学の主対象が小天体となるか、月・火星・氷衛星などの大型天体となるかは、現段階では判別しがたい。また、現RISEプロジェクトメンバーの多くはそれまでに退職する。従って、国立天文台における惑星測地学の展望は将来のスタッフに委ねたい。

6. Originality and international competitiveness

- MMX will achieve the world's first sample return from the Martian sphere in 2031.

  (We need to monitor the development status of Chinese Mars sample return program Tianwen-3)
- No other spacecraft will make close, long-term observation of Phobos from QSO.
- MMX will first provide information on internal mass distribution of Phobos from geodetic observation.

- Hayabusa2# has a clear distinction from other small body missions (Hera, Psyche, etc.) by targeting the fast-rotating asteroid.