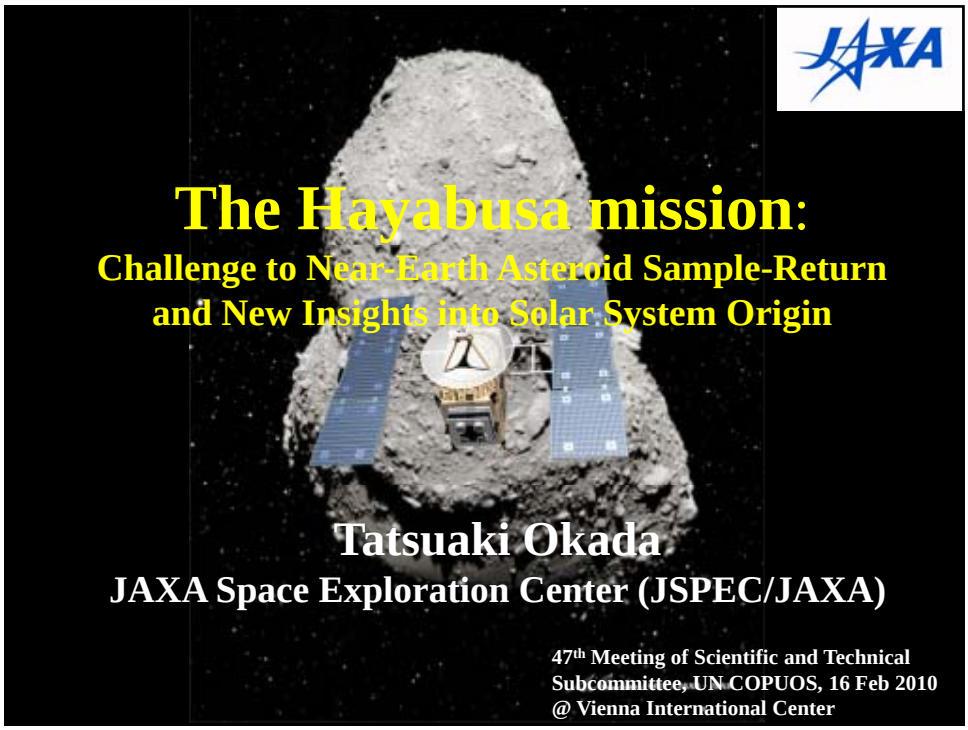


The Hayabusa mission:

Challenge to Near-Earth Asteroid Sample-Return and New Insights into Solar System Origin

Tatsuaki Okada
JAXA Space Exploration Center (JSPEC/JAXA)

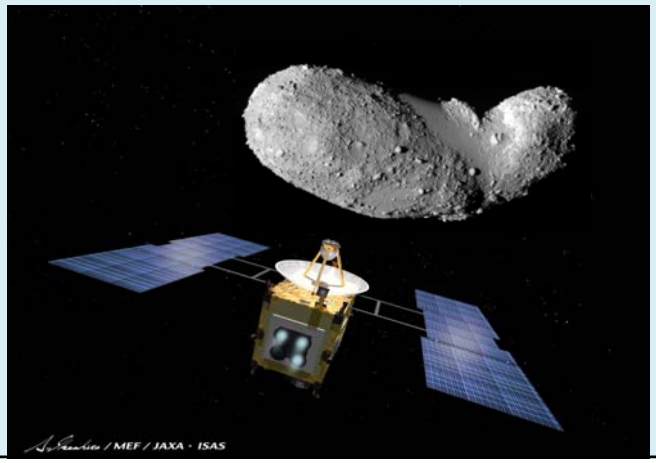
47th Meeting of Scientific and Technical Subcommittee, UN COPUOS, 16 Feb 2010
@ Vienna International Center

Hayabusa have changed the concept of small NEO!

- *"Seeing is believing"* -

The artist view shows asteroid Itokawa a cratered monolithic body

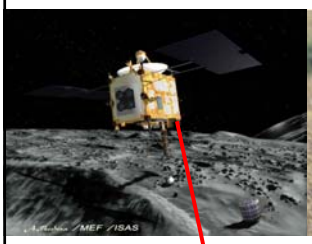
The real view shows the 1st sub-km sized asteroid ever explored is like a "Rubble-Pile" body covered with boulders!



CONTENTS

Introduction of Hayabusa

Why is it named “Hayabusa”?

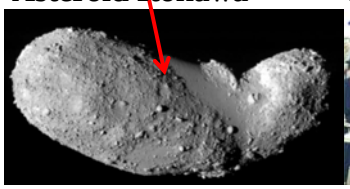


Yachoo! オンライン野鳥図鑑より

Hayabusa:
- “Advanced technology” in space flight
- “Touch and Away” for sampling

Falcon (=Hayabusa):
- “Fastest bird” in sky flight
- “Touch and Away” for hunting

Asteroid Itokawa



Prof. Itokawa

Hayabusa
-“Fastest fighter” designed by Itokawa

Named after the late Prof. Hideo Itokawa, the Father of Modern Japanese Rocketry

Objectives of NEO Sample-Return

SCIENCE:

NEO is a “relic” of the solar system since its origin.

- To understand the early stage of solar system evolution, formation process of the Earth, and the origin of life (water and organics).
- To investigate the asteroid-meteorite connection.

SPACE FRONTIER:

NEO is a “new frontier” for space exploration beyond the Moon orbit

- To demonstrate the key technologies for a round-trip with low cost

SPACE GUARD:

NEO is a “hazardous body” against human civilization

-To understand the nature of NEO and establish technology to reach there.

RESOURCES:

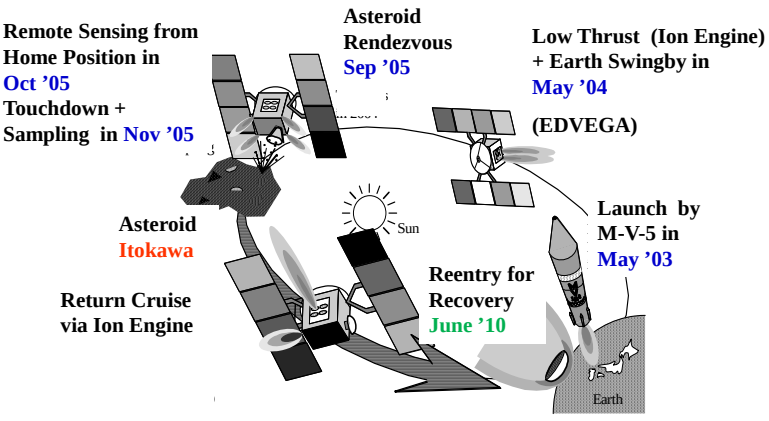
NEO is a possible body for supplying “natural resources” in space

- To develop the method to reach and collect materials for future utilization

Hayabusa Mission Profile

What is Hayabusa?

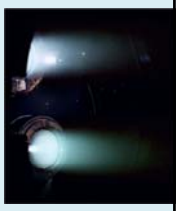
World's First Interplanetary Stop-Over Round-trip Flight
World's First Challenge to Asteroid Sample-Return



Key Technology of Hayabusa

to achieve those objectives

Key Technology to Be Demonstrated

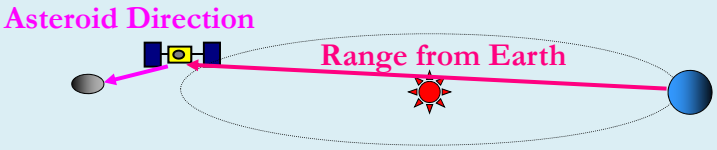


1. **Ion Engines** as primary propulsion for enabling 4 billion km interplanetary cruise: 10 times higher fuel efficiency than commonly used chemical propulsion system.
2. **Optical Navigation** and guidance autonomously: 1000 times better precision than usual radio tracking is needed for finding, approaching, keeping at, and descending to the sub-km class asteroid at 300 million km away from the Earth

3. **Impact Sampling** to collect materials under micro gravity:
   Collect a bit of samples from asteroid surface with unknown physical condition and strength.
   All the process finished in 1 sec before the attitude disturbed
4. **Direct Reentry** for sample recovery from interplanetary orbit: Thermal shielding of samples in capsule for 12km/s hyper-velocity earth reentry
5. **Low Thrust and Gravity Assist** combined cruise:
   No chemical gas jet used for reaction control.

Autonomous Optical Navigation System :

"Hole-In-One" operation needed at 300 million km away from Earth



Accuracy of Orbital Determination (OD) Error (1σ) :

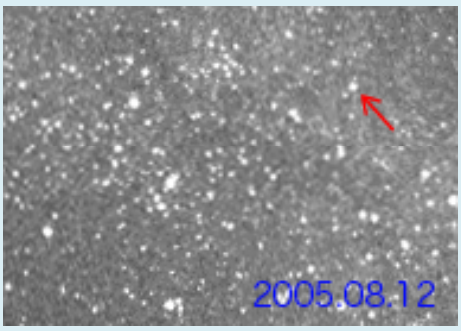
- Without **Optical Navigation** : **1800km, 72 cm/s**
  - → **impossible to find, approach, arrive at Itokawa**
  - → **impossible to keep at and descend to Itokawa**

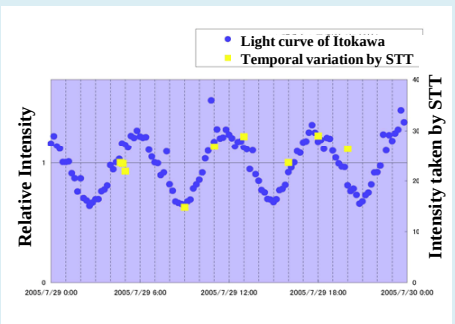
- With **Optical Navigation**:
  - Just after the solar conjunction (29 July 2005): **45 km, 6 cm/s**
  - At the end of August (29 Aug. 2005): **1 km, 2 cm/s**

Hayabusa finally "found" Itokawa - the 1st take! -

Optical Navigation for "Finding" Itokawa using STT (Late July〜Early August)

Itokawa is so small that it was difficult to find it!





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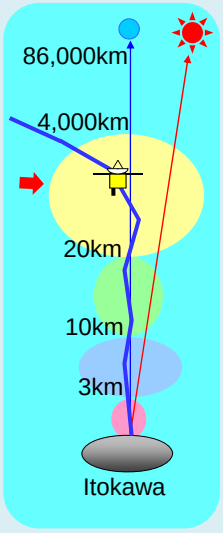
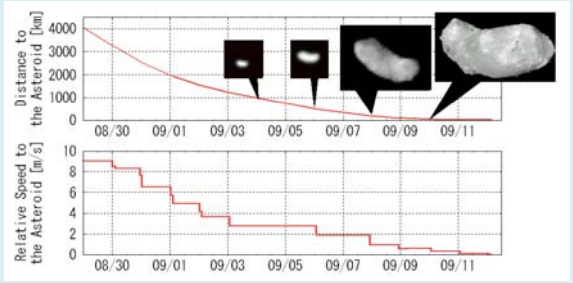
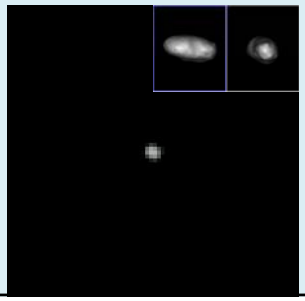
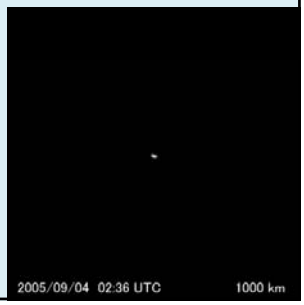
Final Approach

Precise optical navigation by ONC-T









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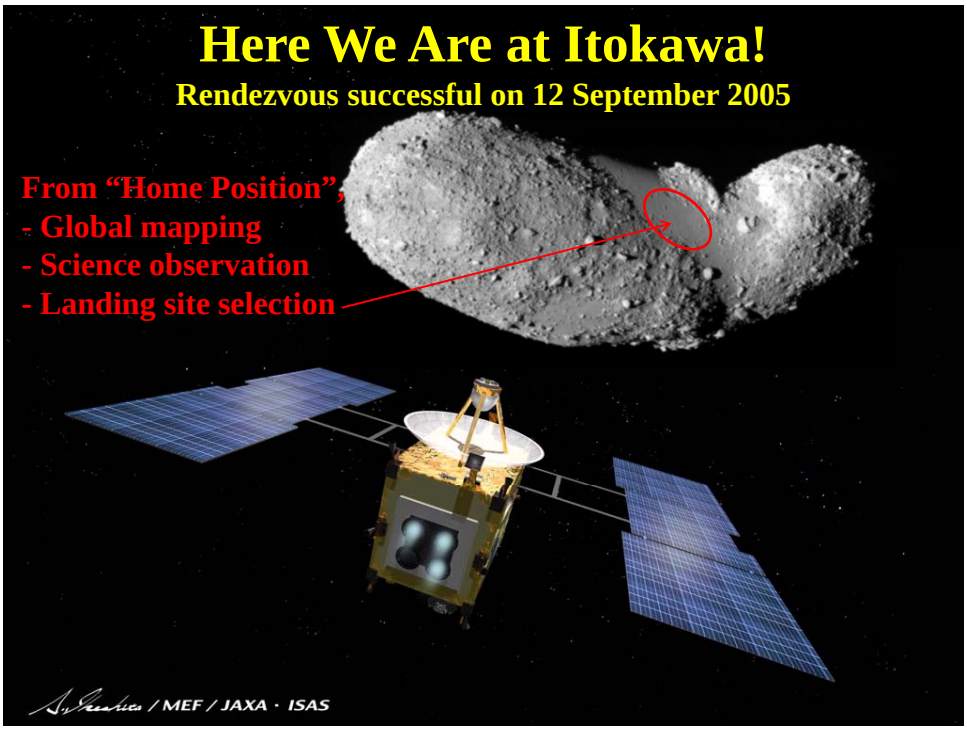
Here We Are at Itokawa!

Rendezvous successful on 12 September 2005

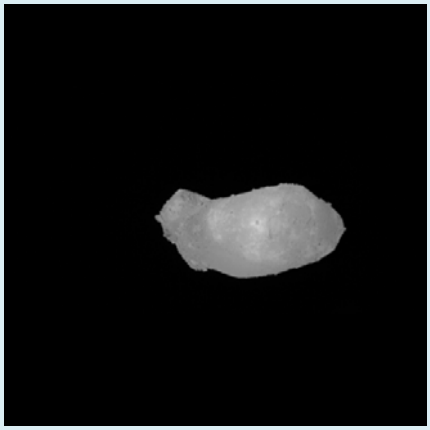
From "Home Position",
- Global mapping
- Science observation
- Landing site selection



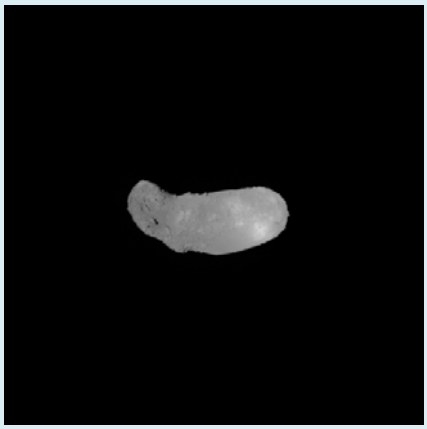
Challenge for Touchdown to Itokawa

Optical navigation for descent by ONC-W1

Touch-down for Sampling#1



Touch-down for Sampling#2



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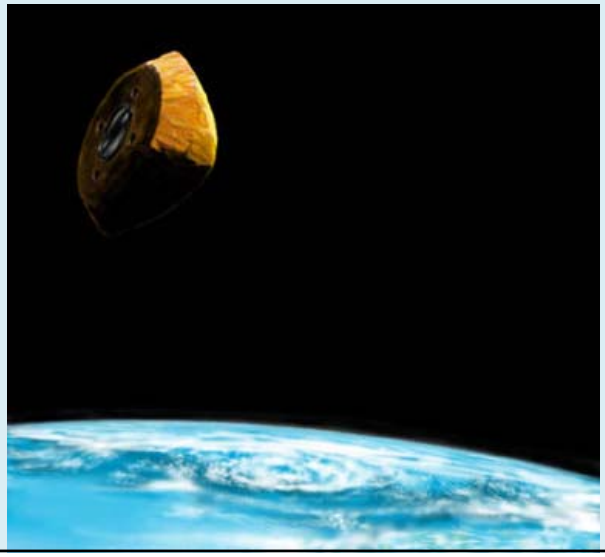
Sampling Successfully or not?!

Current Status and Earth Reentry



Current Status of Hayabusa

With much effort and fortune,
Hayabusa is still alive and on its final way to Earth Reentry!

- **2 of 3 reaction wheels (RW-X, Y) failed before Touchdowns.**

- **No fuels for RCS remained and Li-ion battery damaged after lost attitude control for 1.5 months after TD#2 in Dec 2005.**

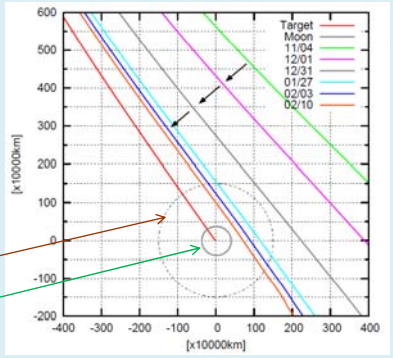
- **Attitude control of Hayabusa is now precisely conducted by using Xe gas thrust for IES neutralizer and the torques by solar radiation pressure, as well as the RW-Z.**

- **IES troubled in Oct 2009, but recovered with a combination of an Ion-thruster and a neutralizer at different position, showing a performance good enough for Earth return.**

Current Status of Hayabusa

Hayabusa is already coming back to Earth's Gravitation Area!
It is ready for the Final Goal!

- **Hayabusa is now in the orbit approaching the Earth within 600 thousand km on 10 Feb 2010!**
  within < 2 Earth-Moon distance.



Earth's Gravitation area

Moon Orbit

Hyper-Velocity Reentry:

Direct return to Earth from interplanetary orbit

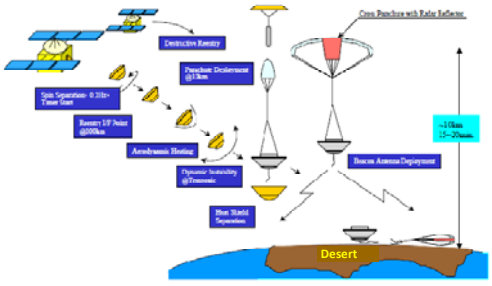


Figure 5.1-1 : Capsule re-entry and landing sequence

Velocity of reentry:12km/s

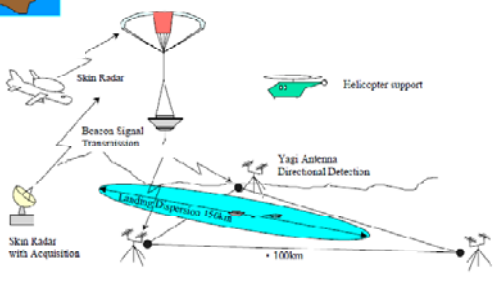


Figure 6.1-1 : Capsule localization concept

Planetary Protection Policy

"Is the sample safe enough for human?"

"YES, un-restricted sample-return is allowed from S-class NEO"

6 Check Points for "Sample-Return" (Category V in COSPAR PPP):

Does the preponderance of scientific evidence indicate:

Q#1: there was never liquid water in or on the target body?

- YES (sampling at shallow depth < 10cm, dry environment for billion years)

Q#2: metabolically useful energy sources were never present?

- Uncertain (little amount of carbon, but red-ox reaction plays a role?)

Q#3: there was never sufficient organic matter (or CO_2 or carbonates *and an appropriate source of reducing equivalents) in or on the target body to support life?*

- YES (little amount of organic matter)

Q#4: subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e. >160C)?

- Uncertain (Maybe thermally altered, but surface of NEO below 130C)

Q#5: there is or was sufficient radiation for biological sterilization of terrestrial life forms?

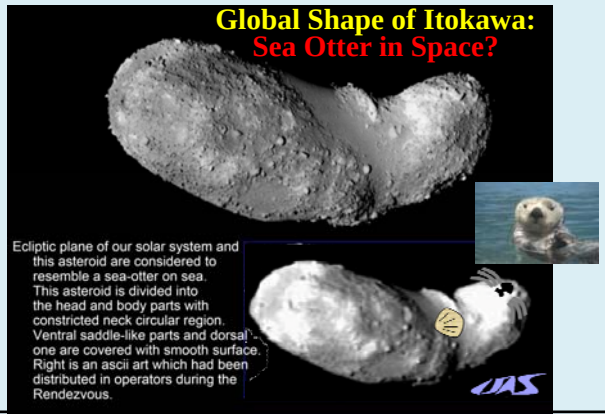
- YES (sampling at shallow depth < 10cm)

Q#6: there has been a natural influx to Earth e.g. via meteorites, of material equivalent to a sample returned from the target body?

- YES (for Ordinary chondrites or primitive achondrites)

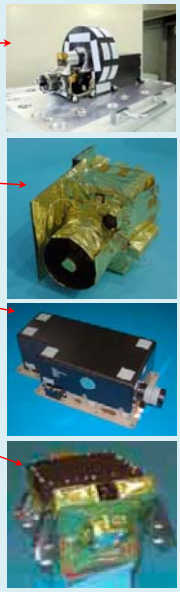
New Scientific Discovery in Hayabusa

Itokawa is a tiny asteroid, but we have learned a lot of interesting facts.



Remote Sensing Instruments onboard Hayabusa

- **Multi-band Imager (AMICA)**
  Imaging (geomorphology, 3D surface modelling)
  Collor, reflectance mapping
  Si-CCD, 1 million pix, FOV5.7°, 8-bands
- **Laser Altimeter (LIDAR)**
  Altitude, Roughness, Gravimetry
  H=50m ~ 50km, dH=1m
- **Near-Infrared Spectrometer (NIRS)**
  Mineral Mapping
  64ch linear InGaAs, wavelenth=0.8~2.1micron
  FOV=0.1 x 0.1°（6~90m footprint）
- **X-Ray fluorescent Spectrometer (XRS)**
  Elemental Mapping
  2D-CCD, FOV=3.5°, dE=160eV @5.9keV
- **Radio Science and Astro-dynamics**
  Gravimetry
  Doppler, Gravimetry by free falling
  at HP or during descent



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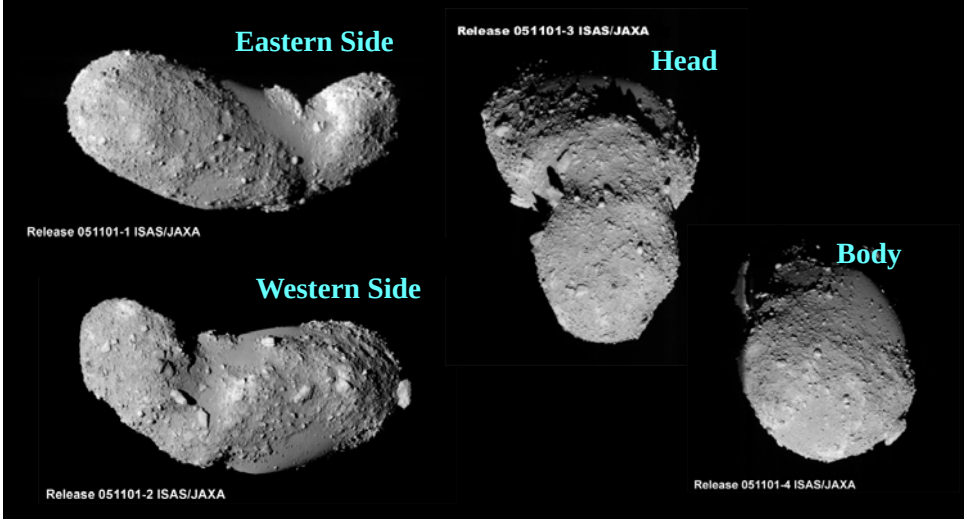
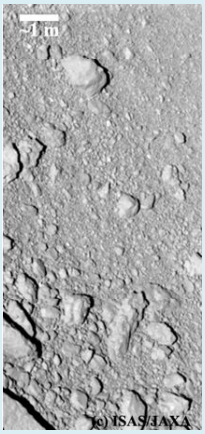
Global mapping of Itokawa

Sediments? : Less cratered, many boulders, and rounded shape
Dichotomy? : Hilly rough terrain vs. flat terrain
Contact binary? : "Head" and "Body" apparently contacted?

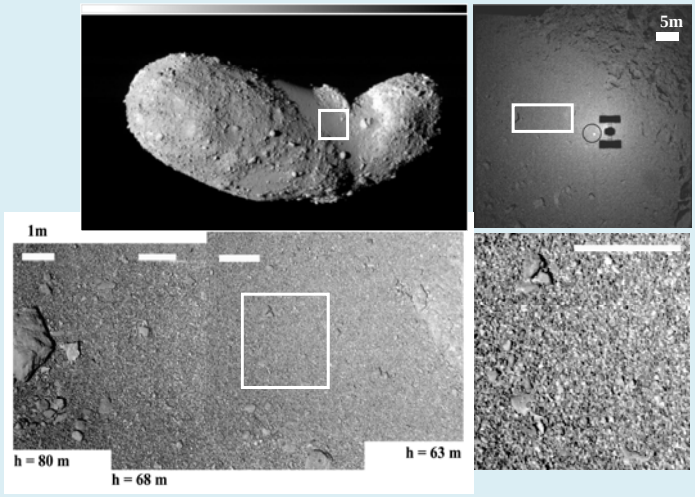


Close-up images:

- Almost geologist viewings from the orbiter (<1cm)
- No lunar-like sandy regolith but covered with pebbles to boulders



boundary



Spatial Resolution : 6-8 mm

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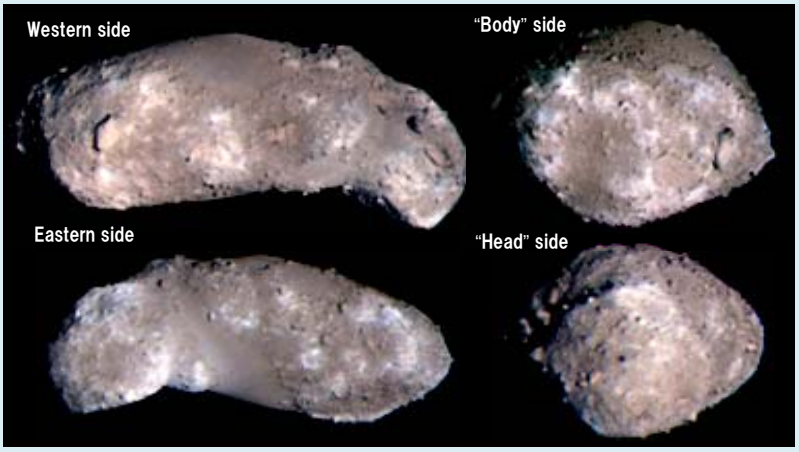
Color and Reflectance Map: Heterogeneity

Bluer at brighter, redder at darker

The 1st asteroid ever explored that show remarkable variation in both of color and reflectance.



Saito, et al., *Science* (2006)

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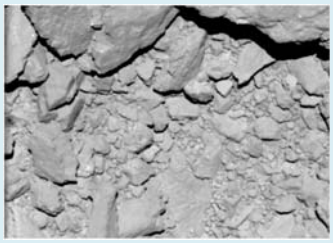
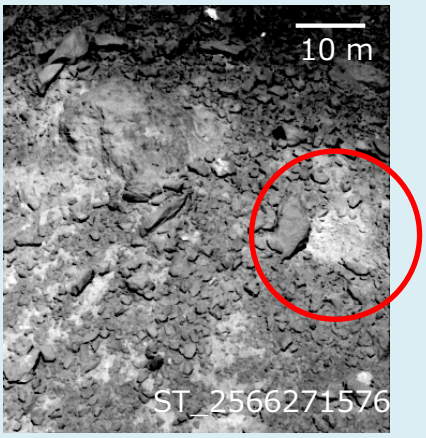
Close-up images:

Brighter surface is proven to be the "fresh" surface exposed where rocks moved, maybe the evidence of *Space-weathering*.



At 59m
6mm/pixel



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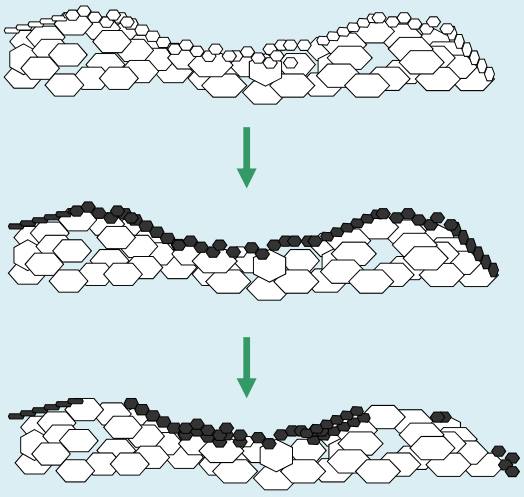
Explanation of Color Variation



Rubble pile + collisions

Space Weathering (darker, redder)

Shaking ➔
Surface movement exposes underlying brighter zone.

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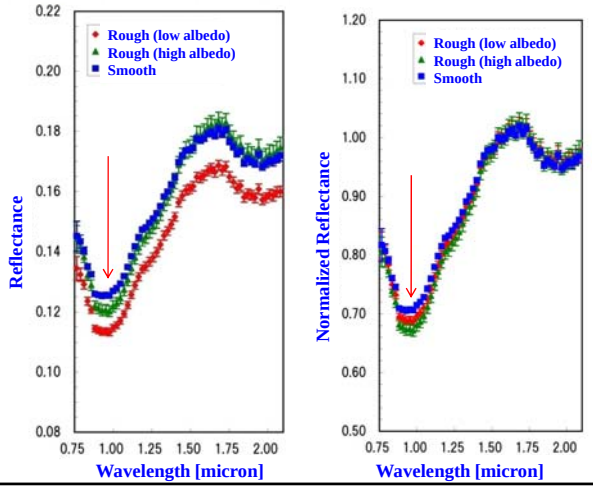
Composition: Mineral Assemblage

No regional variation in mineralogy found around the surface!

Same values of center wavelength for each absorption band

⇒ **Same mineralogy between rough-smooth surface, low-high albedo.**

⇒ **Itokawa formed from a single parent body?**



M.Abe, et al., *Science* (2006)

29

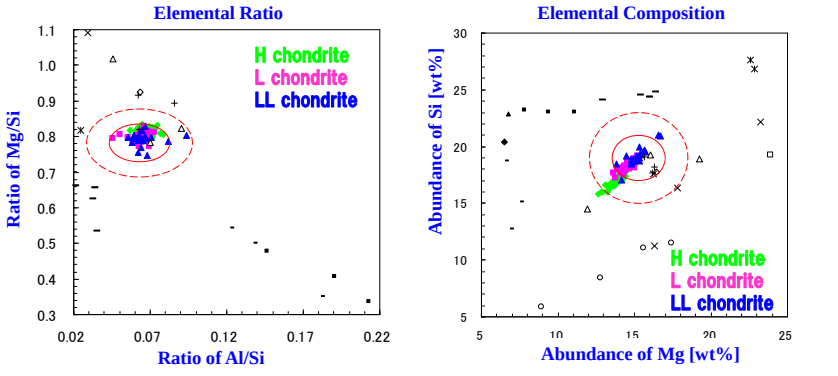
Composition: Major Elements

S-class asteroid is like an ordinary chondrite (LL or L)

= Most observed class of asteroid is like an most found type of meteorites on Earth

- Itokawa is like an Ordinary chondrite (especially LL or L), but some primitive achondrite is not ruled out.

- No remarkable difference in composition is detected around the surface



Okada, et al., *Science* (2006)

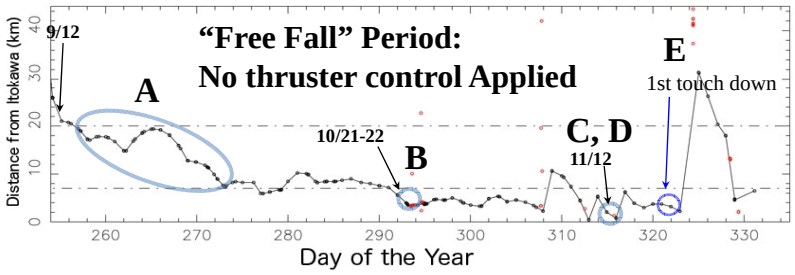
30

Gravity Measurements:

Itokawa has proven to be very low density (=high porosity), meaning the "Rubble-Pile"!

- **Bulk Density：1.9 ± 0.13 g/cm^3**

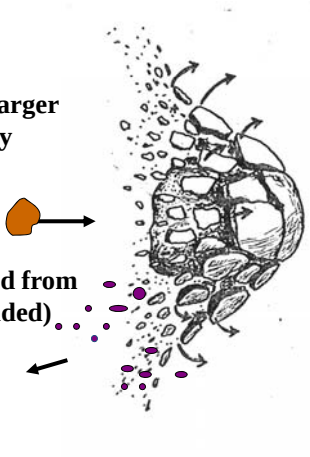
- **Macro-porosity = 40%**
  (3.2 g/cm^3 for O-chondrites)



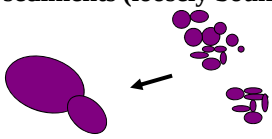
Scenario of Itokawa Formation

"Rubble-pile" sediments of fractured pieces from a parent body.
Contact binary of two sediments from the same origins.

(1) A parent asteroid much larger than Itokawa was crushed by another asteroid impact



(2) Head and Body parts are formed from coagulated sediments (loosely bounded)



(3) Head and Body are contacted afterwards

Fujiwara, et al., *Science* (2006)

Nature of Itokawa explored by Hayabusa

The only sub-km asteroid ever explored

1) **Low density body:** high porosity, not monolithic
   The 1st "Rubble-Pile" structure discovered
2) **Formed by Sedimentation:** many boulders, rounded shape
   Coagulation of pieces from a larger parent body
3) **Dichotomic Surface:** Hilly boulders vs. cm-order pebbles
   Particle flows by landslides under micro gravity
4) S(IV)-Itokawa is like an Ordinary chondrite (LL?)
   Solve the "Paradox" of an asteroid-meteorite connection
5) **Homogeneous** in composition
   No evidence of regional variation in composition. Formed from a parent body.
6) **Evidence of space weathering:**
   Fresh exposed surface shows brighter albedo, maybe by impact/tidal shaking.

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Future Plan for NEO missions

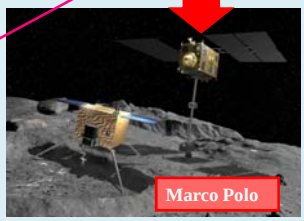
Missions after Hayabusa

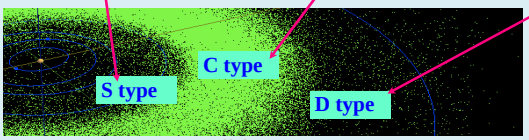
More pristine clues to origin of solar system, Earth , and life!
Longer distant journey for exploring the *New World* !

Hayabusa
Itokawa = S type

Hayabusa-2
1999 JU3 = C type
Successor of Hayabusa

Hayabusa-Mk2
D type, Dormant Comet
Advanced





Asteroid belt

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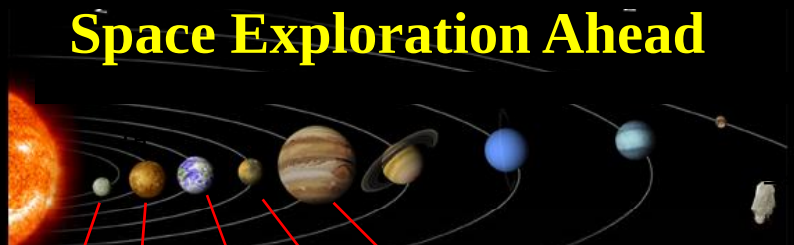
Space Exploration Ahead

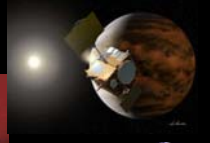


Sakigake, Suisei,
Hayabusa,Hayabusa-2,
Marco Polo

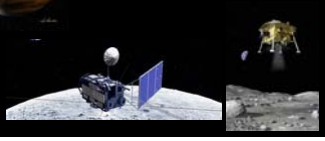
Nozomi

Membrane
Deployment

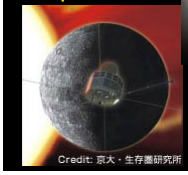
Akatsuki (Planet-C)
Launch this year



Hiten, Hagoromo,
Kaguya, SELENE-2,
SELENE-follow-on



Bepi-Colombo



Summary

- **Hayabusa is the first deep space round trip explorer to demonstrate key technology** that reach and touch the body beyond the Moon and return to the Earth.

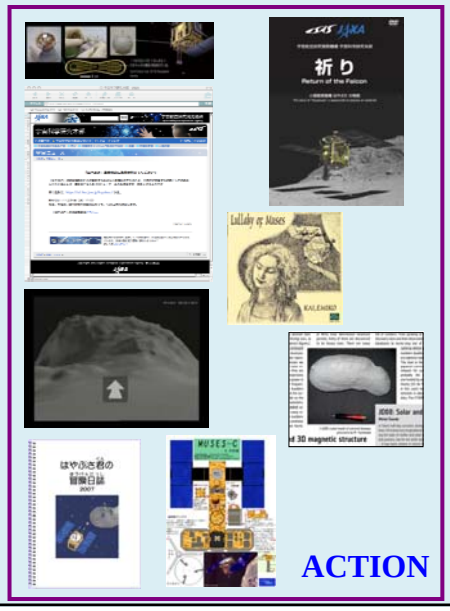
- **Hayabusa rendezvoused S-class, sub-km sized asteroid 25143 Itokawa and scientifically investigated the nature of the body;** contribution to the understandings of the origin and evolution of the solar system and the Earth

- In spite of many troubles, **Hayabusa** is now **in the final stage of round trip and will return the capsule to Earth in June**; it will be a great success if a little bit of samples are returned to Earth and they bring us some scientific break-through.

- We have only just begun with Hayabusa for NEO sample-return; **the follow-on missions should be done soon** for making further contribution to science research, human frontier, future utilization in space, and space guard.

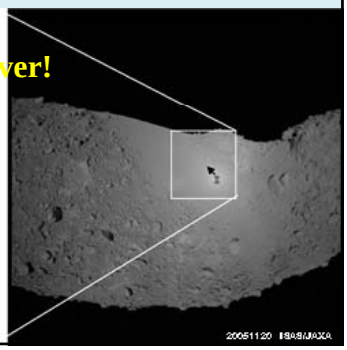
Public Outreach

Most loved mission in Japan and also around the world!



Target Marker

Landed light point markers for horizontal position control were deployed during rehearsal descent, one of which carried names and messages from 880 thousand people around the world!



Thank you!
&
Small World Again!