Hayabusa's Adventure around a Tiny Asteroid Itokawa

COSPAR

Capacity Building Workshop on Planetary Science

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Montevideo, Uruguay

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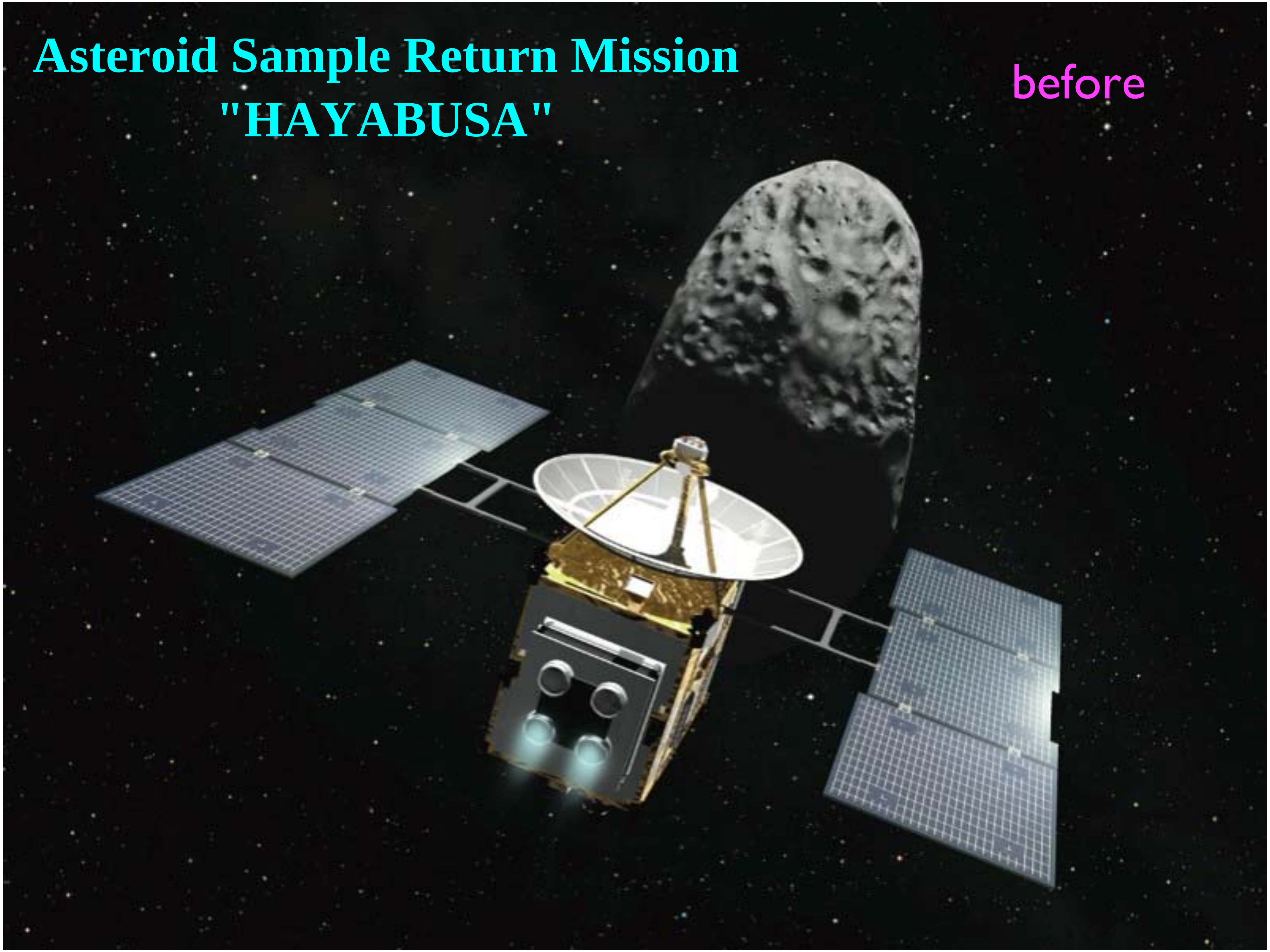
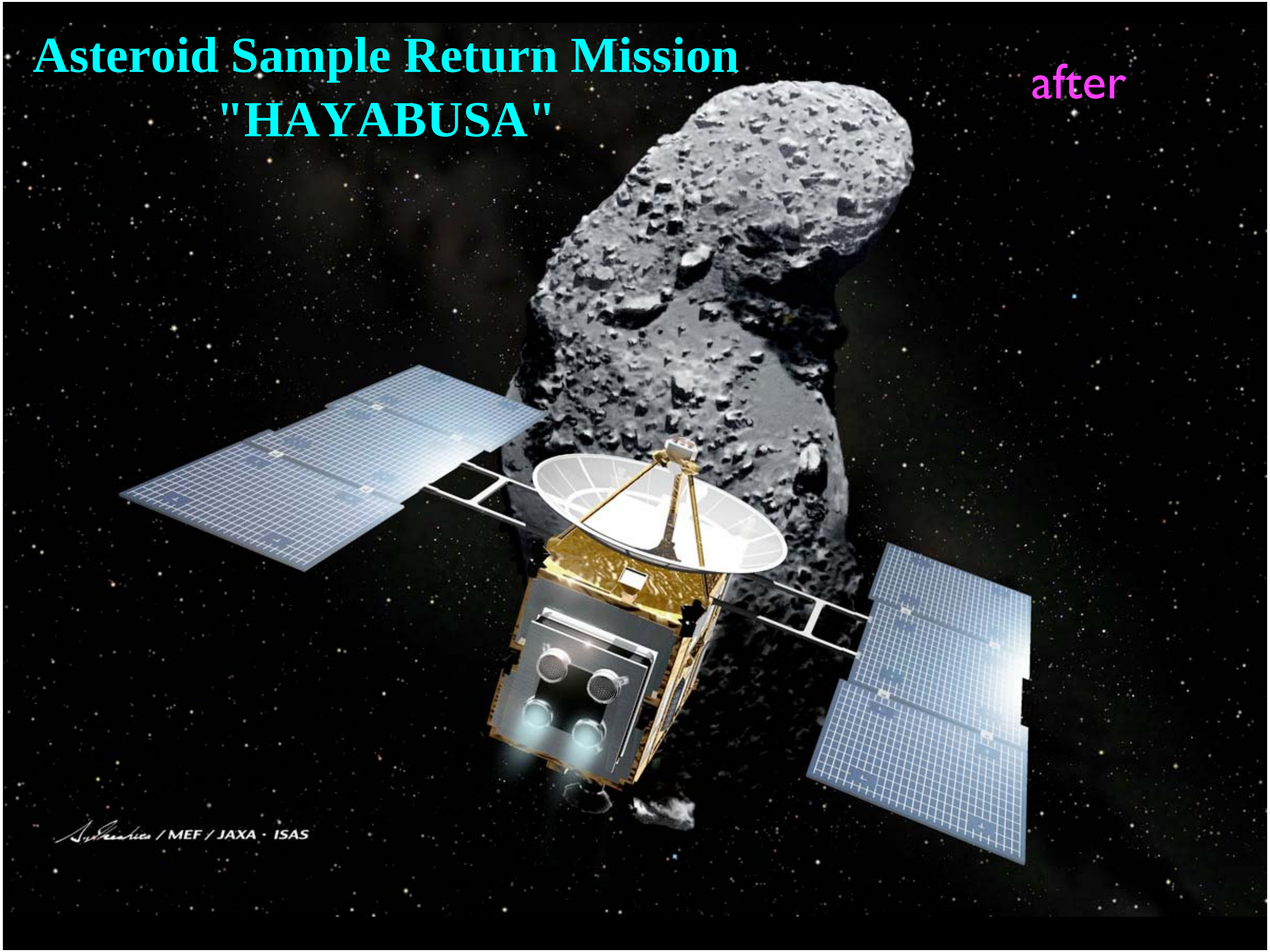
(JAXA)

Hayabusa Mission & Science Team


Asteroid Sample Return Mission
"HAYABUSA"
before

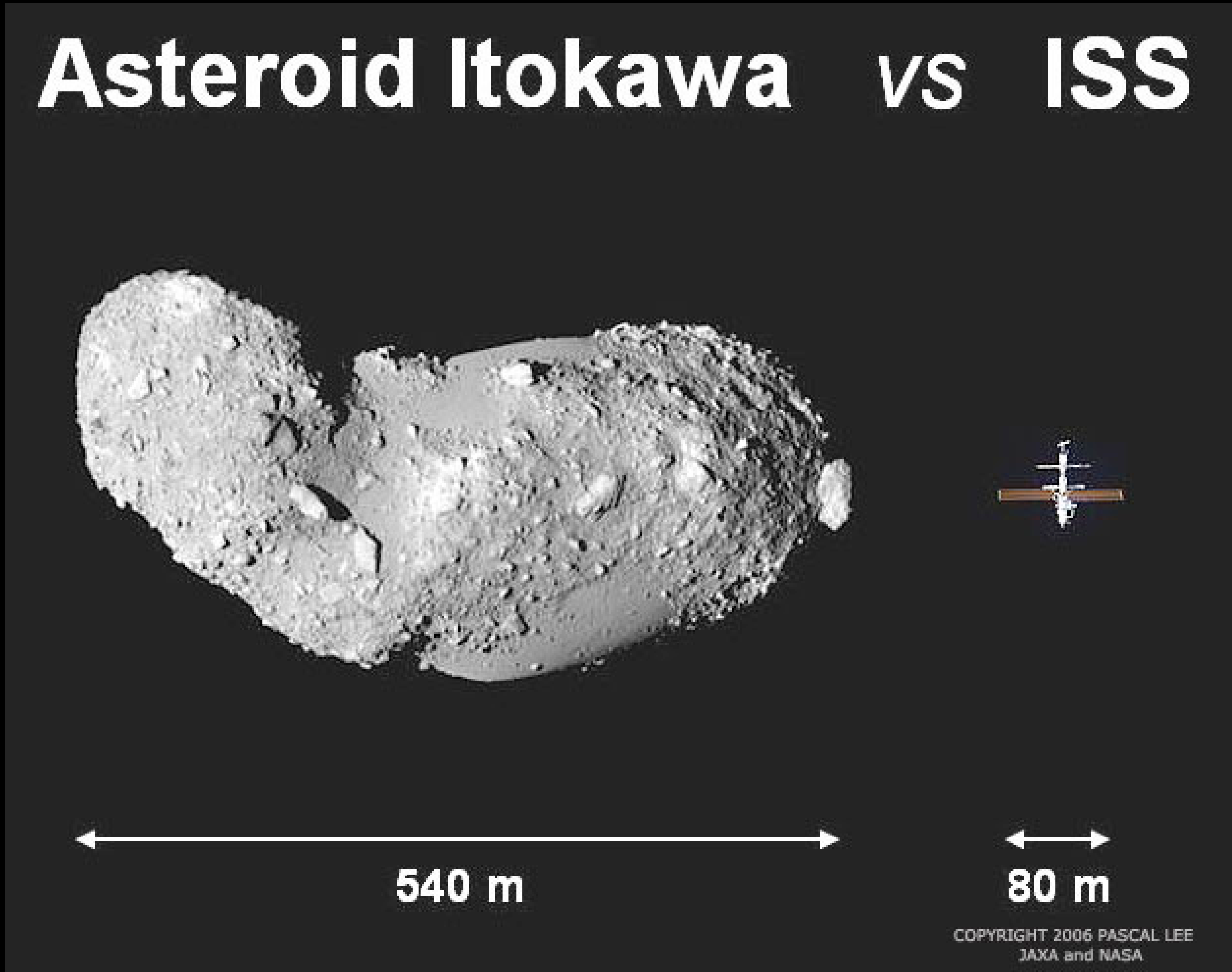
Asteroid Sample Return Mission "HAYABUSA"

after




/ MEF / JAXA · ISAS

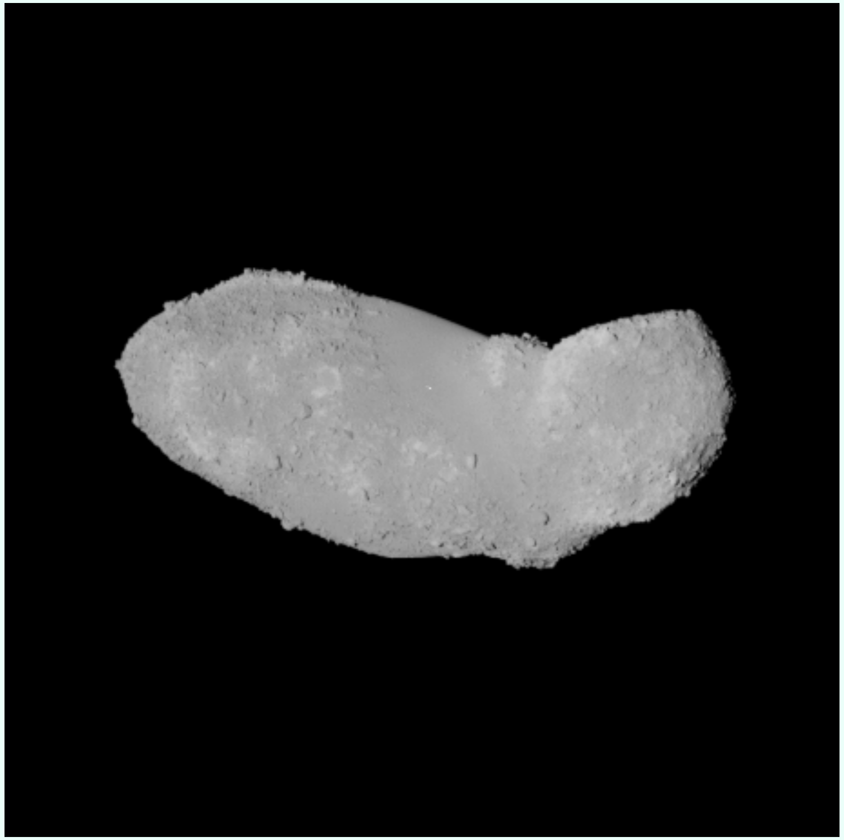
It's a Small World !



It's a Small World ! (Part-2)

It's a World of "Little Prince"

(25143) Itokawa



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Contents

- Brief summary of Hayabusa mission
- Mission : as time sequence
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- Scentific Results
- Post Hayabusa Mission

Brief Summary
of
Hayabusa Mission

MUSES-C

- MUSES = Mu Space Engineering Spacecraft

  = Technological demonstrator by MU rocket

- C = third spacecraft (A: HITEN, B: HALCA)
- After the successful launch, it was named "Hayabusa," which mean falcon in Japanese.

  "halcón"

New Technology in Hayabusa

Five Key Technology to be demonstrated :

1. **Interplanetary Cruise via Ion Engines as Primary Propulsion**
   Microwave driven & CC Grid Ion Engine
2. **Autonomous Navigation and Guidance using Optical Measurement**
3. **Sample Collection from Asteroid Surface under Micro Gravity**
4. **Direct Reentry for Sample Recovery from Interplanetary Orbit**
5. **Combination of Low Thrust and Gravity Assist**

Other New Technology introduced :

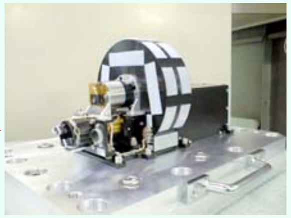
Bi-Propellant Small Thrust Reaction Control System (20N),
X-band Up/Down Communication, Complete CCSDS Packet Telemetry,
Duty Guaranteed Heater Control Electronics,
Wheel Unloading via Ion Engines, PN-Code Ranging,
Lithium Ion Re-chargeable Battery, Multi-Junction Solar Cell, etc.

Scientific Objectives

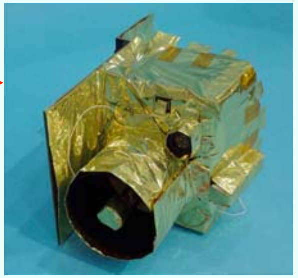
- To know the nature of sub-km sized S-type asteroid
- To investigate the relationship between asteroids and meteors
- To have key information for the origin and evolution of asteroids

Remote Sensing Instruments onboard Hayabusa

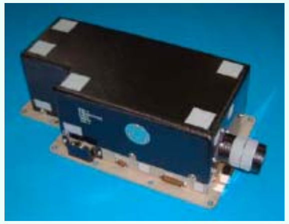
- **Multi-Spectral Telescopic Imager (AMICA)**
  - > CCD viewing angle 5.7°with 8 band-pass filters
  - > About 1500 still images obtained



- **Laser Altimeter (LIDAR)**
  - > Measurement accuracy of 1 m at 50m altitude
  - > 1,670,000 hits obtained



- **Near-Infrared Spectrometer (NIRS)**
  - > 64-channel InGaAs detector at wavelengths of 0.8~2.1 micron
  - > Viewing angle 0.1° (6-90 m per pixel spatial resolution)
  - > More than 80,000 spectra obtained

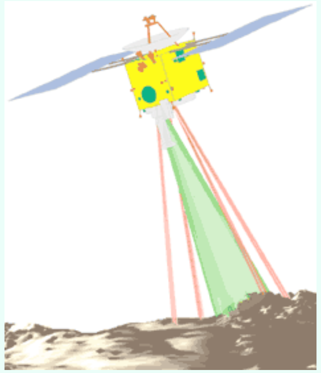


- **X-ray Fluorescence Spectrometer (XRS)**
  - > CCD viewing angle: 3.5°, 160 eV resolution at 5.9 keV
  - > 6,000 spectra from the asteroid surface obtained

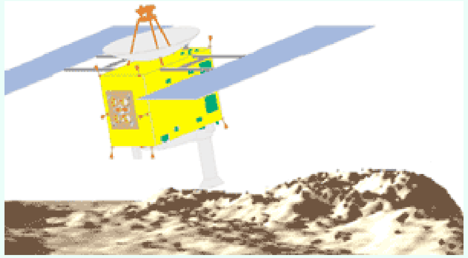
Mission Scenario

Launch
9 May 2003

Earth Swingby
19 May 2004



Asteroid Arrival
12 Sept. 2005



Observations, sampling

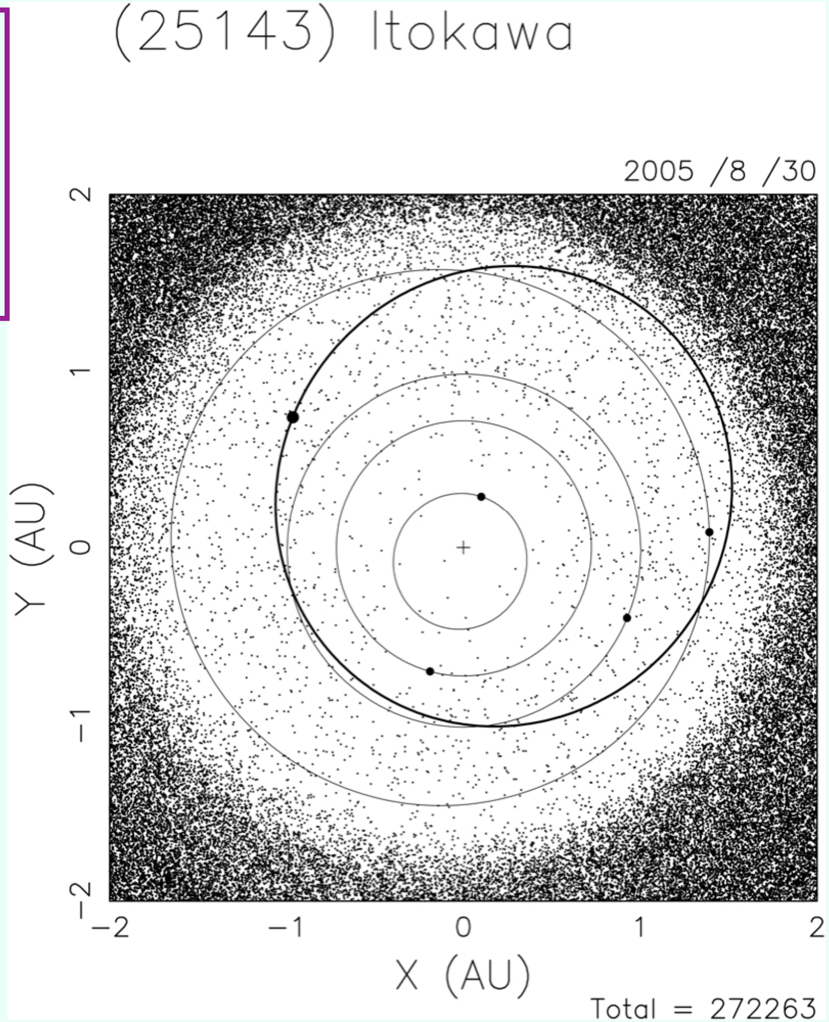
Earth Return
~~June 2007~~
→ June 2010

Hayabusa Mission by CG

Asteroid (25143) Itokawa

26 Sept. 1998 : Discovered by LINEAR
1998 SF36
June 2001 : Numbered (25143)
August 2003 : (25143) Itokawa

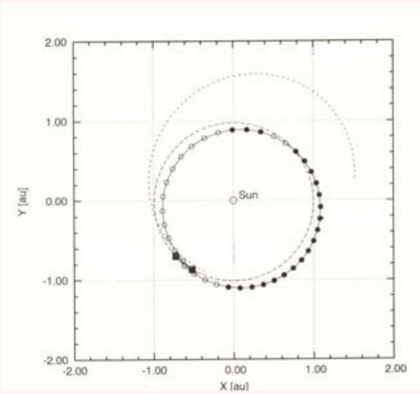
Asteroid Itokawa was named after the late Prof. Hideo. Itokawa, the Father of Modern Japanese Rocketry

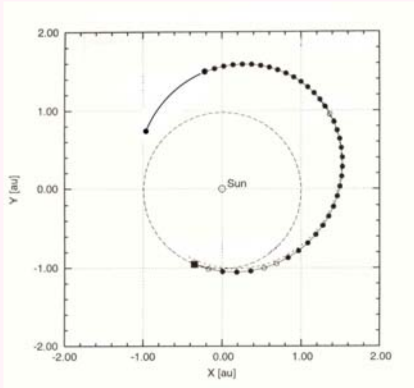


Mission

- Cruising Phase -

Orbit History until Asteroid Arrival





9 May 2003 | 19 May 2004 | 12 Sept. 2005

Launch | Swingby | Arrival

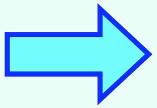
IES | IES

Conjunction

Launch

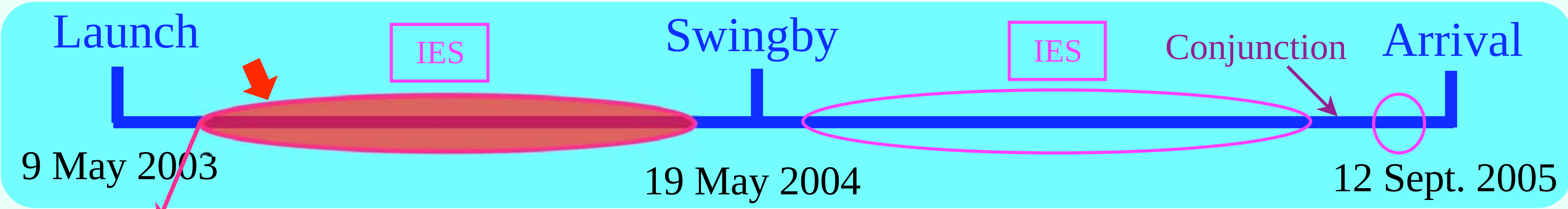
04:29:25 UTC
(13:29:25 JST)

MUSES-C

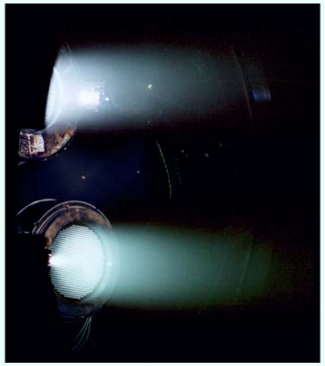


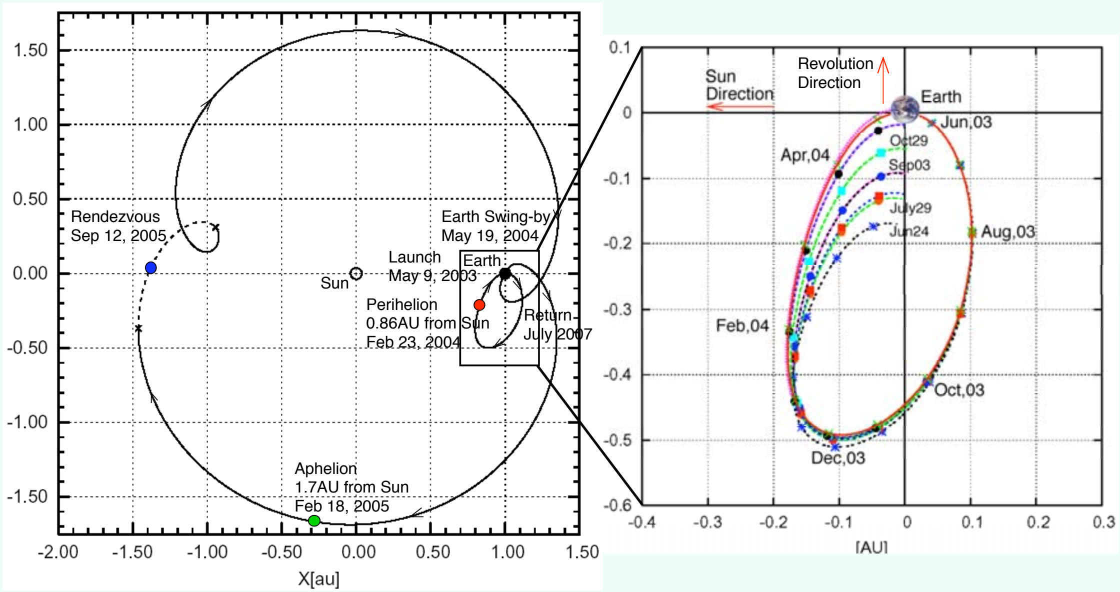
Hayabusa = 'falcon'

Ion Engine Operation 1



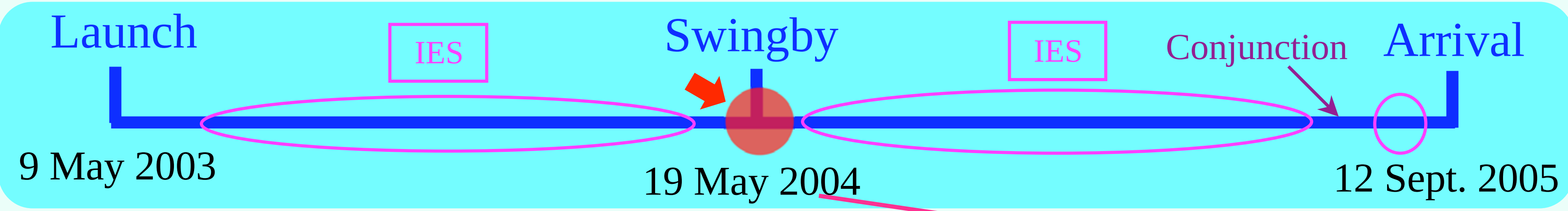
The ion engine system (IES) was started from the end of May 2003.

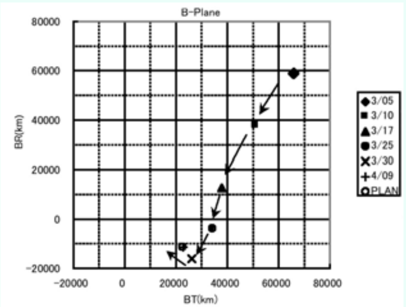




The Orbit determination under the thrust of the ion engine is difficult, so we made "ballistic period" (=ion engine is stopped) of about three days once in a month, and performed the orbit determination.

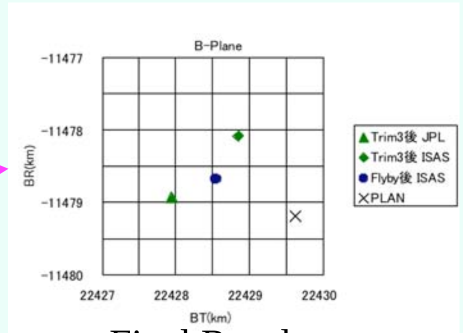
Earth Swingby





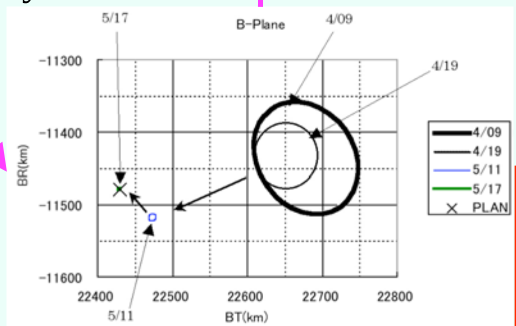
Targeting by IES

position on B-plane



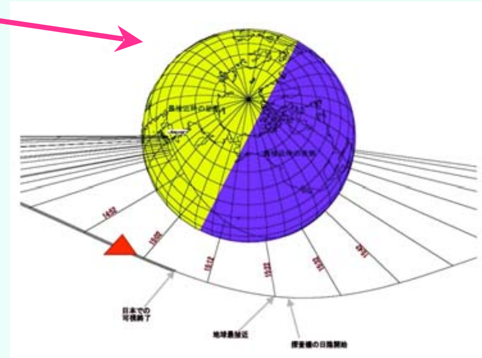
Final Result

Maneuver
20 April 2004
12 May 2004



Targeting by Chemical Thruster

Error of the swingby point on B-plane is about 1 km.



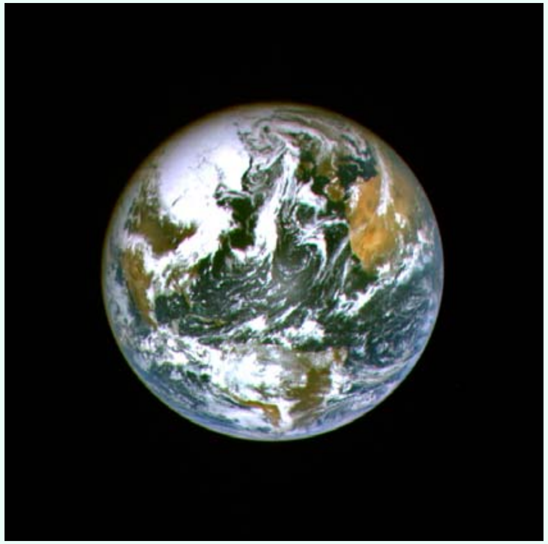
May 19, 2004, 06:21:42 UTC
Altitude : about 3700 km

Images Obtained at Earth Swingby

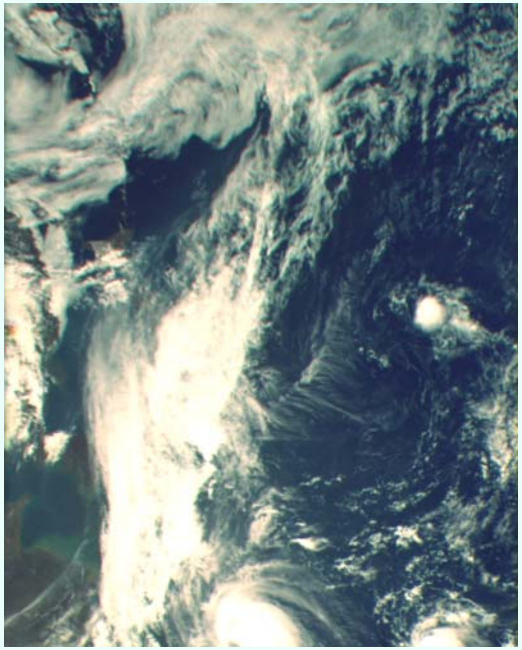
Moon at 340,000km

Earth at 60,000km

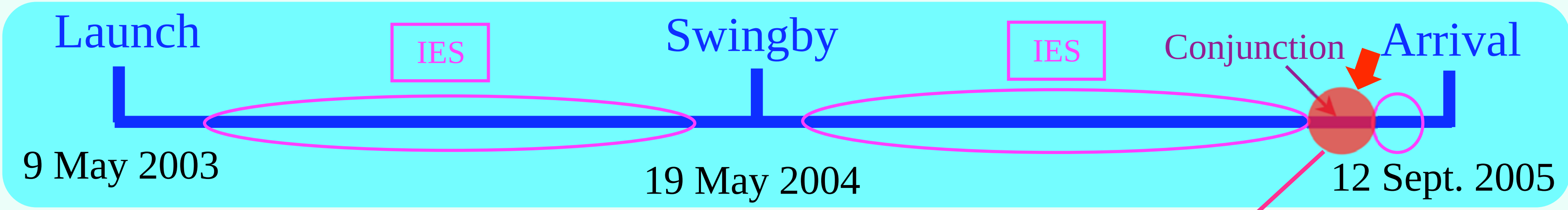
Earth after swingby

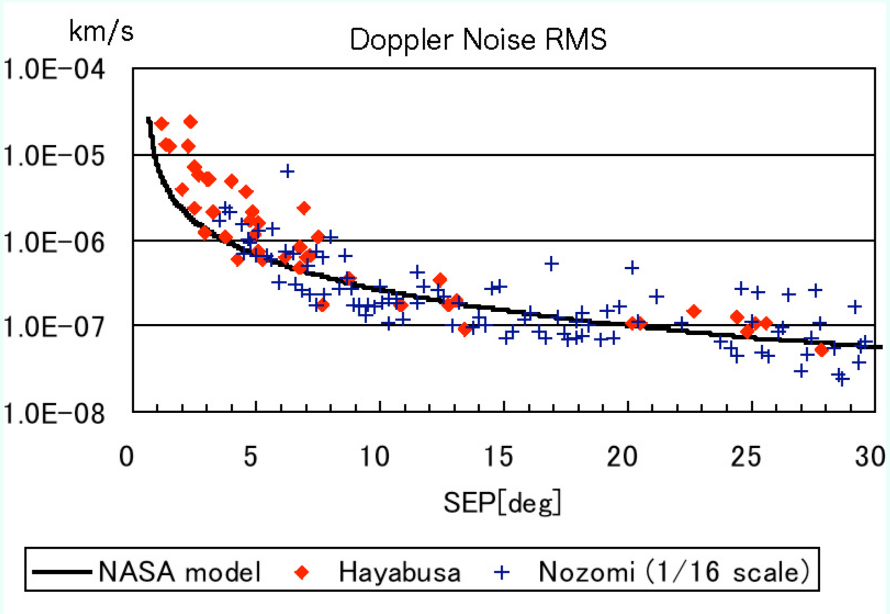


Earth at 295,000km



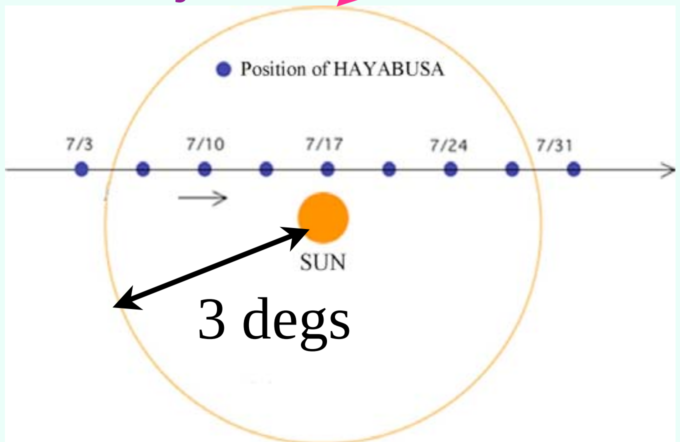
Solar Conjunction





Noise of Doppler

July 2005

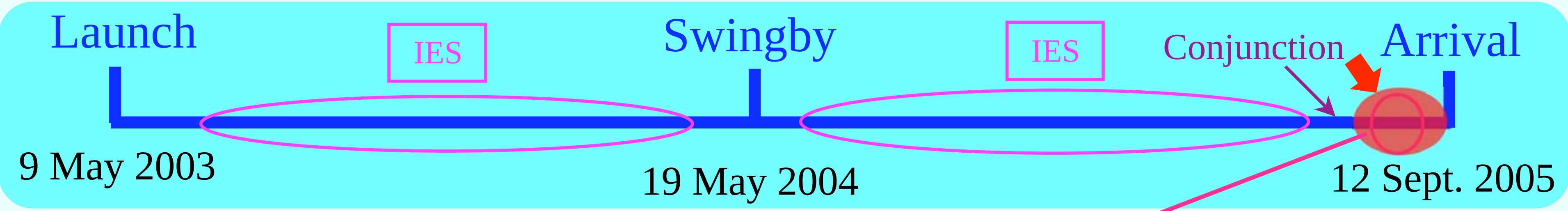


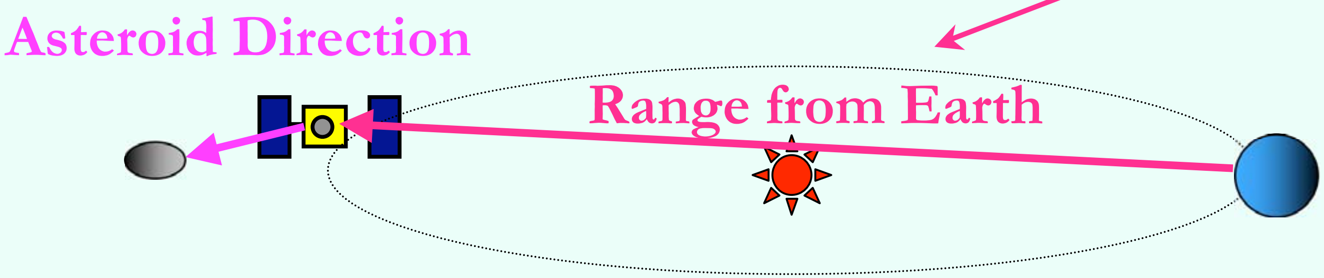
OD Error (1σ)

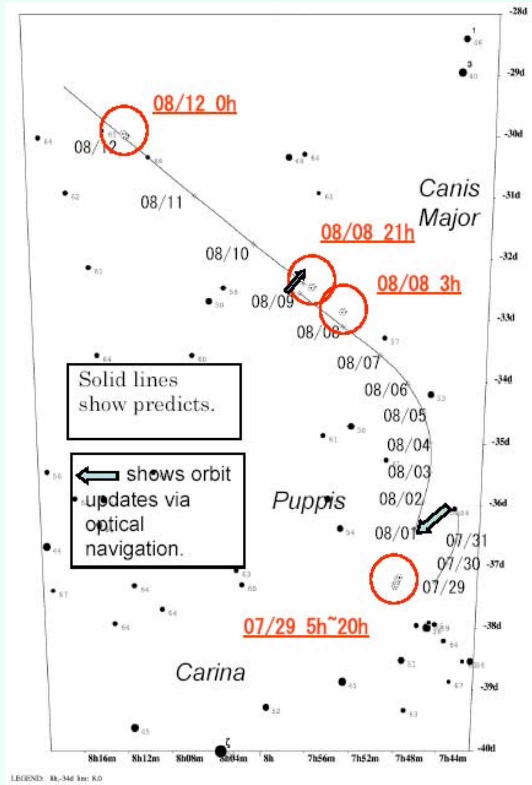
28 June 2005: 200km, 75cm/s

29 July 2005: 1800km, 72cm/s

Optical Navigation







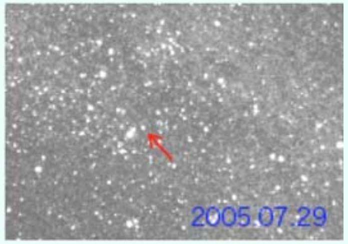
OD Error (1σ) :

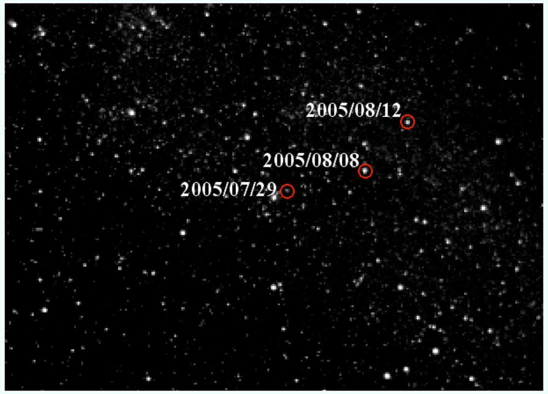
Just after the solar conjunction (29 July 2005)
45 km, 6 cm/s (← 1800 km, 72 cm/s)

At the end of August (29 Aug. 2005)
1 km, 2 cm/s

Images of Itokawa

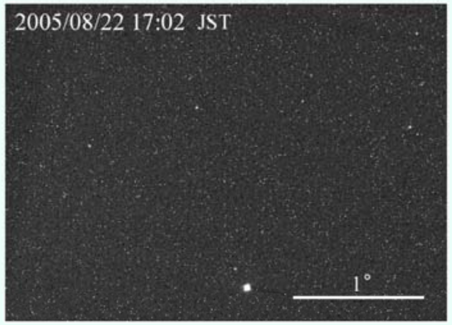
July 29 - Aug. 12, 2005



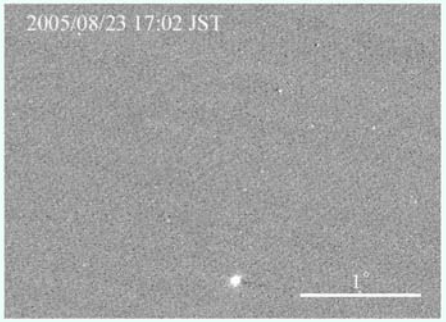


Fist images taken by Star Tracker

Aug. 22-23, 2005

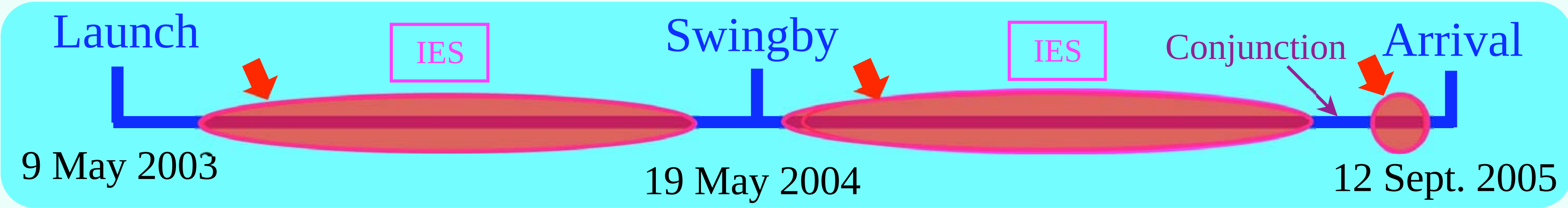


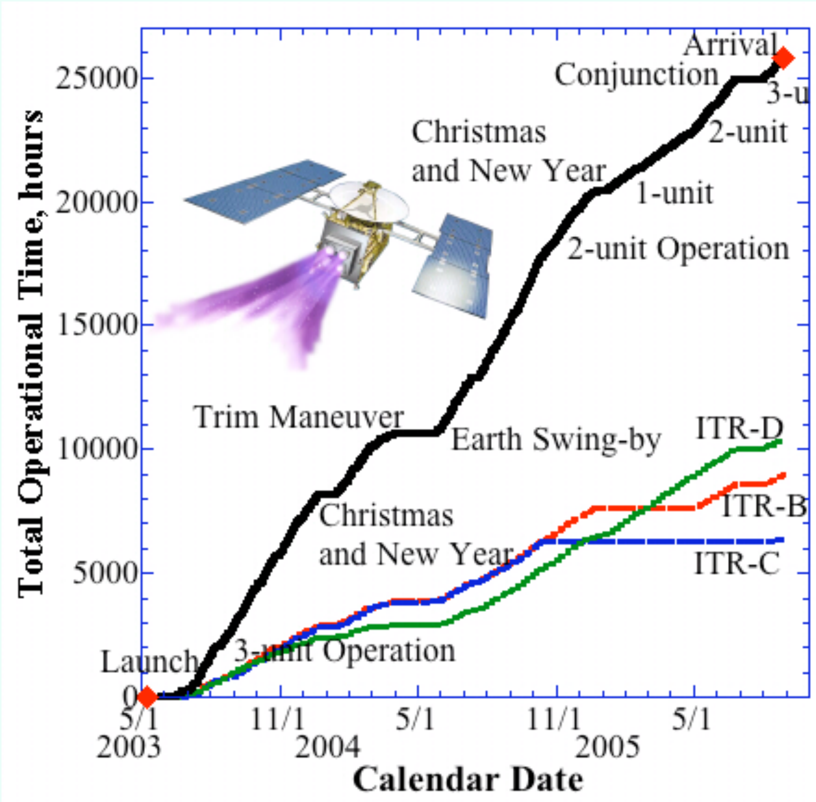
Aug. 23-24, 2005



Images by Optical Navigation Camera

Ion Engine Operation 2





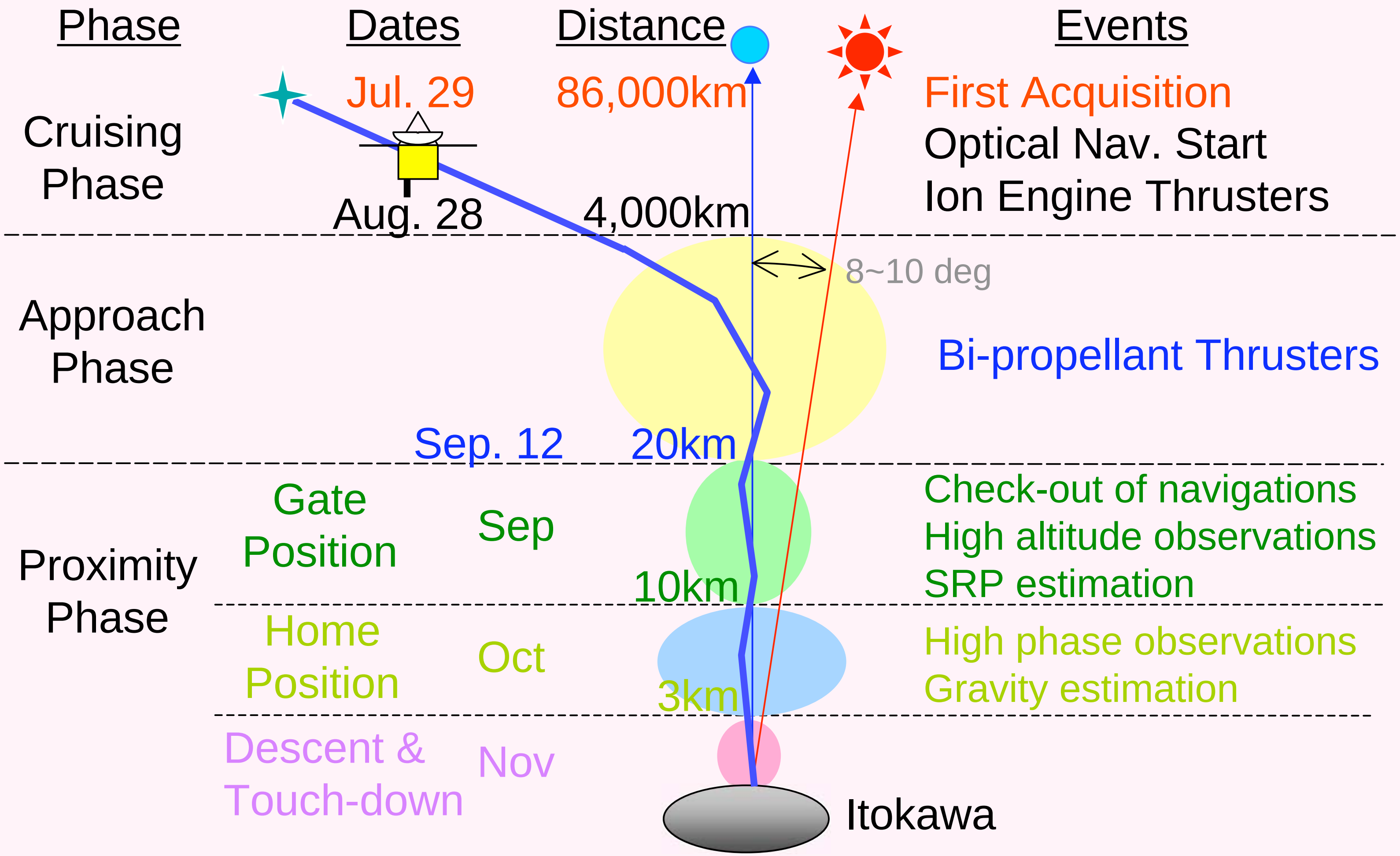
Aug 28, 2005:
The IES finished its role on the way to the asteroid.

Operation : 25,800hour&unit
Single Unit :10,400hour
Delta-V :1,400m/s
Prop. Consumption: 22kg

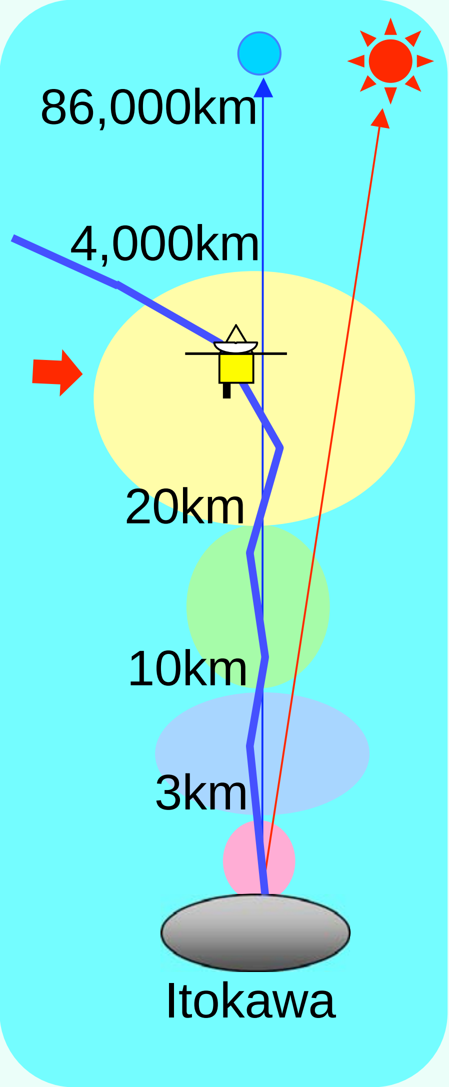
Mission

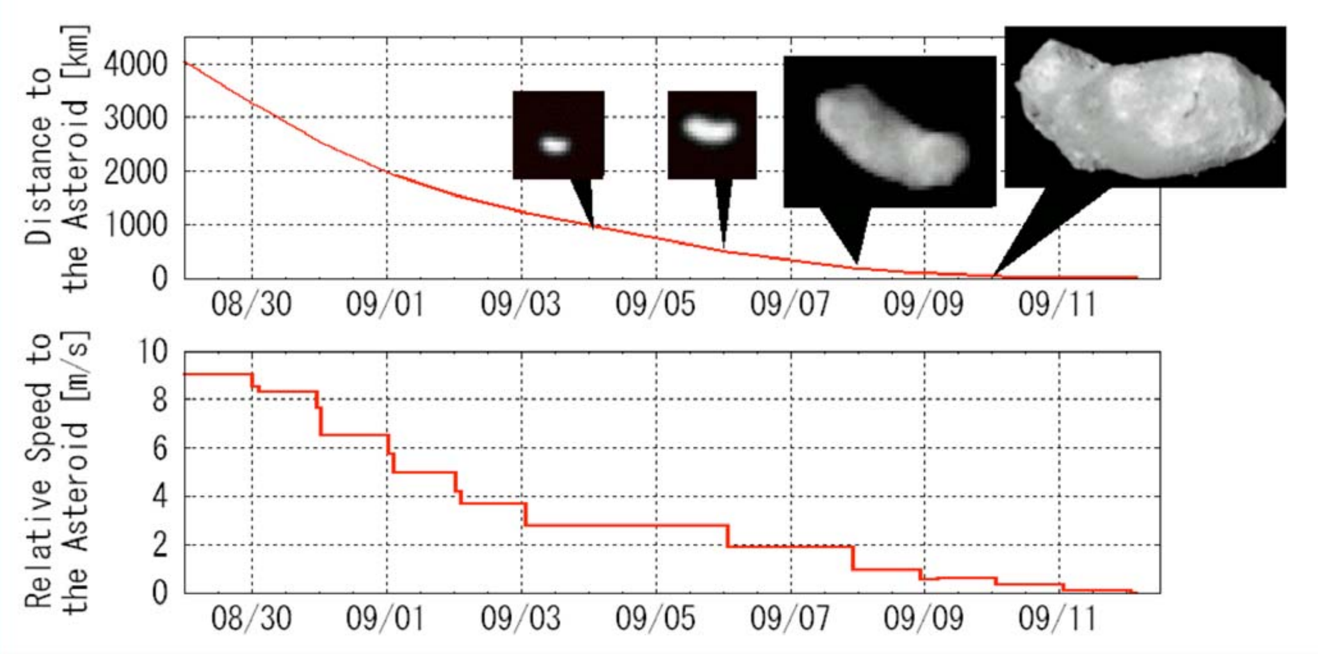
- Near & Around Itokawa -

Orbit at Proximity Phase

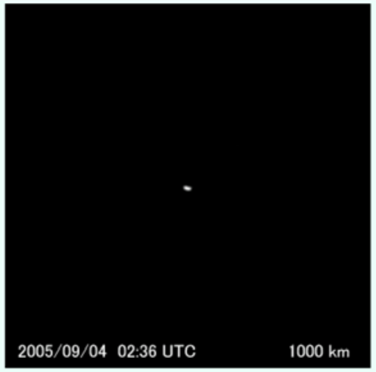


Final Approach
= Optical Navigation



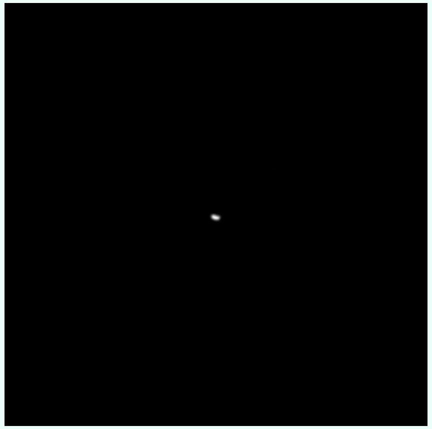


Rotation! (Sep. 5, 2005)

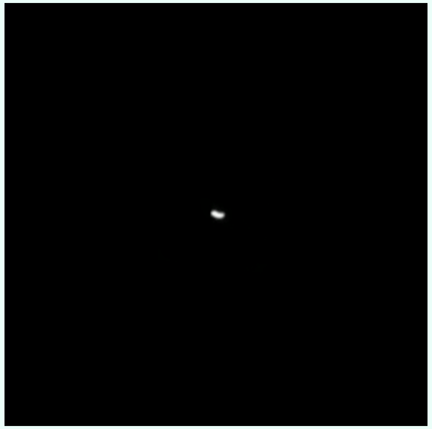


Images of Itokawa at Approach Phase

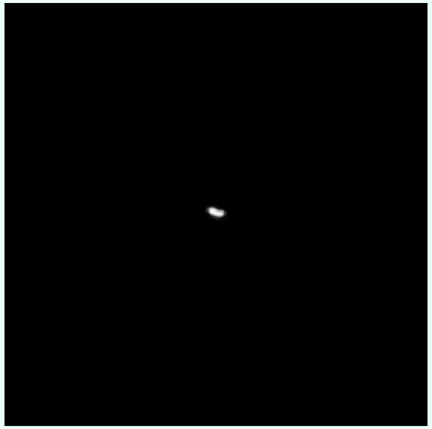
2005



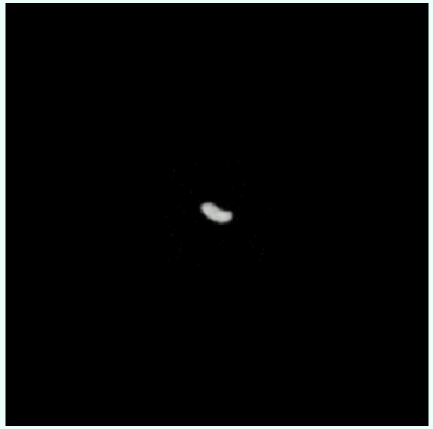
9/4 02:36 UTC, 1000km



9/5 15:30 UTC, 700km



9/6 03:32 UTC, 450km



9/7 16:00 UTC, 220km

1deg

9/8 16:15 UTC, 125km

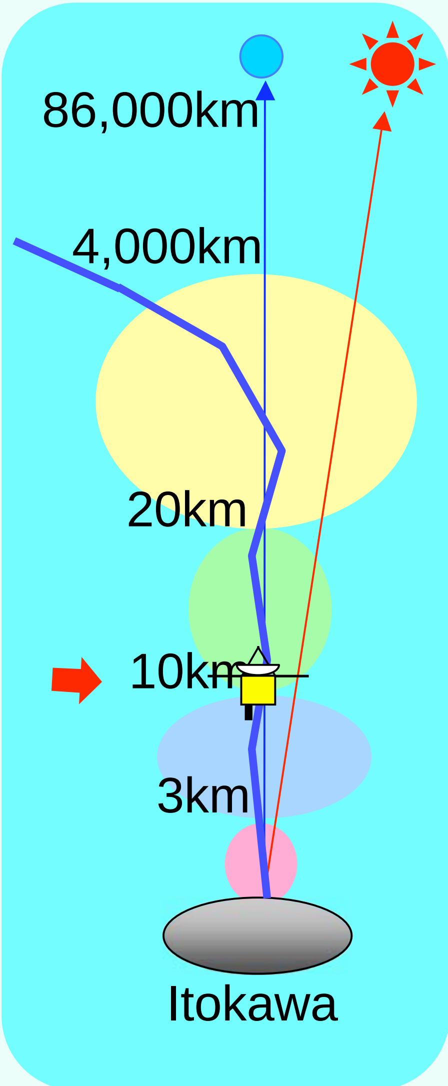
9/9 16:28 UTC, 70km

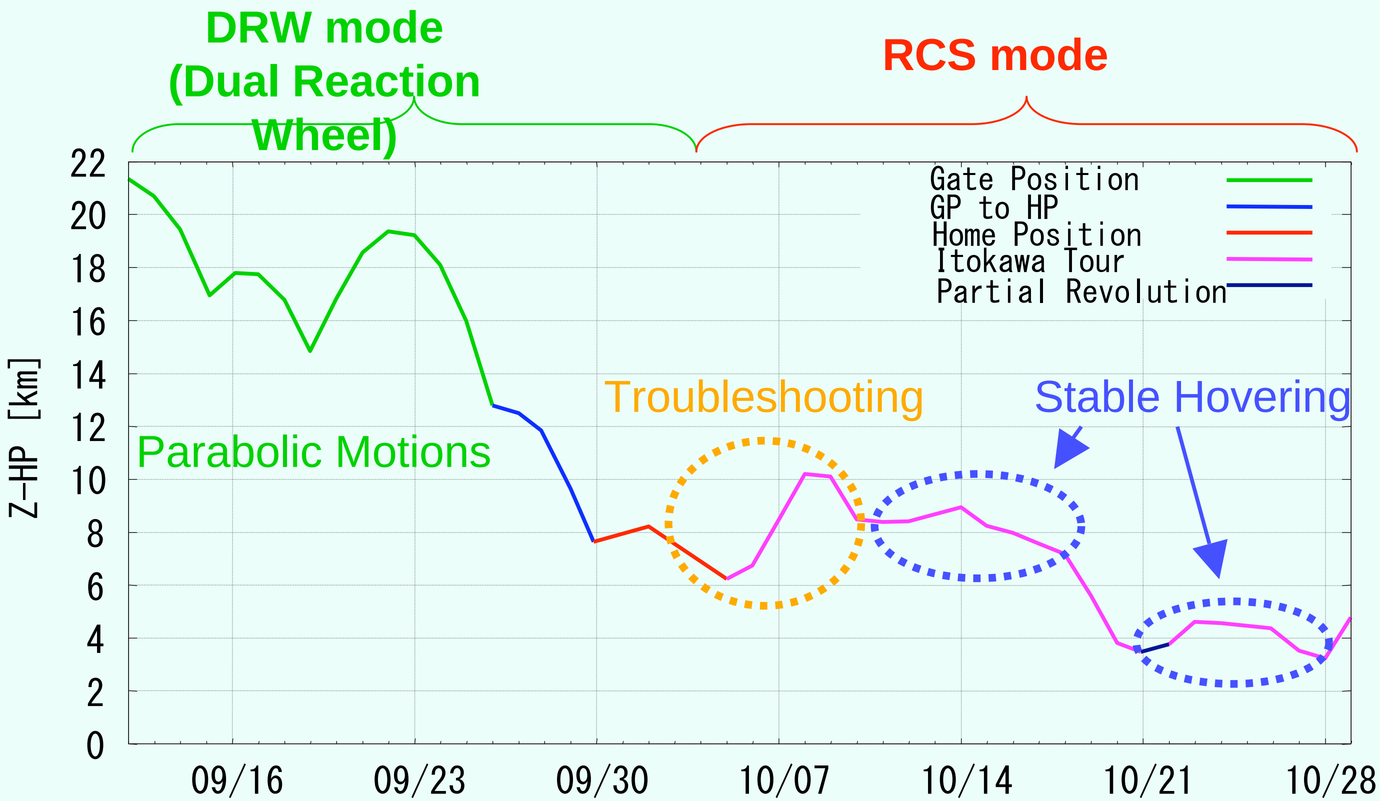
9/10 16:42 UTC, 30km

Arrival at Itokawa

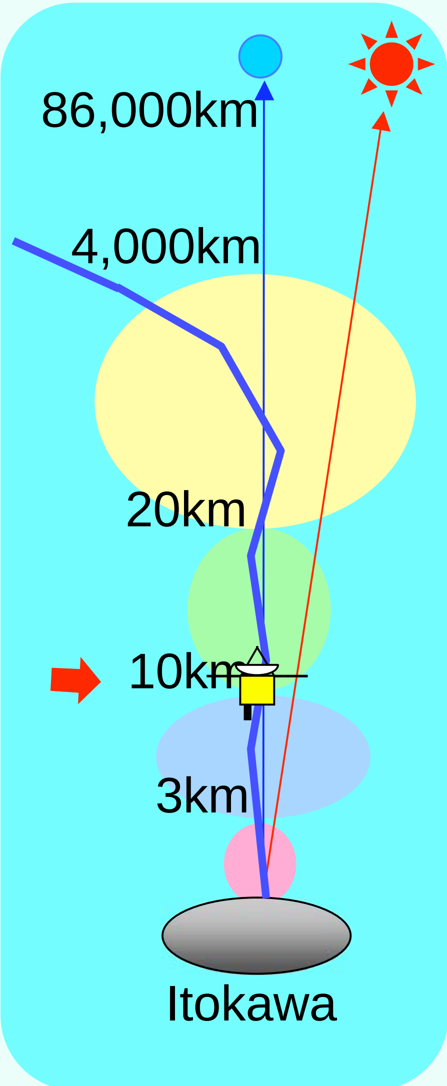
Sept. 12, 2005, at the distance of 20km

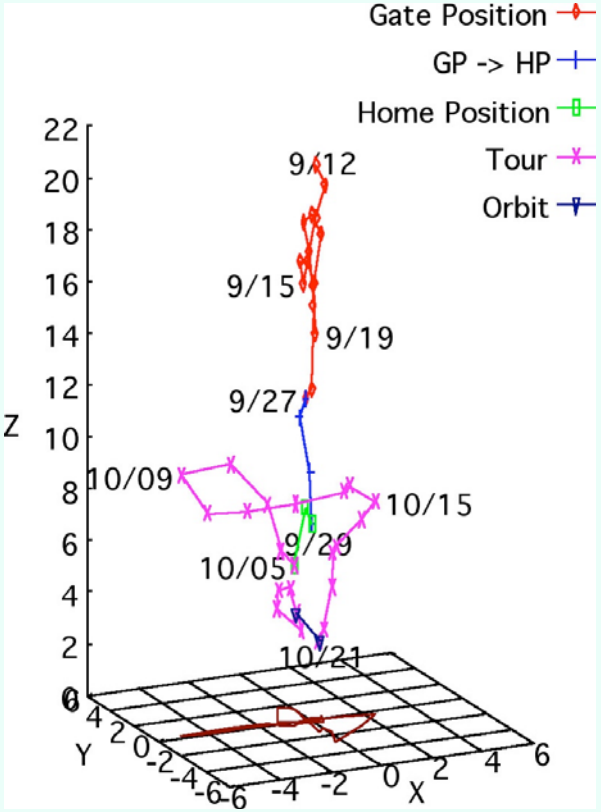
Gate Position to Home Position

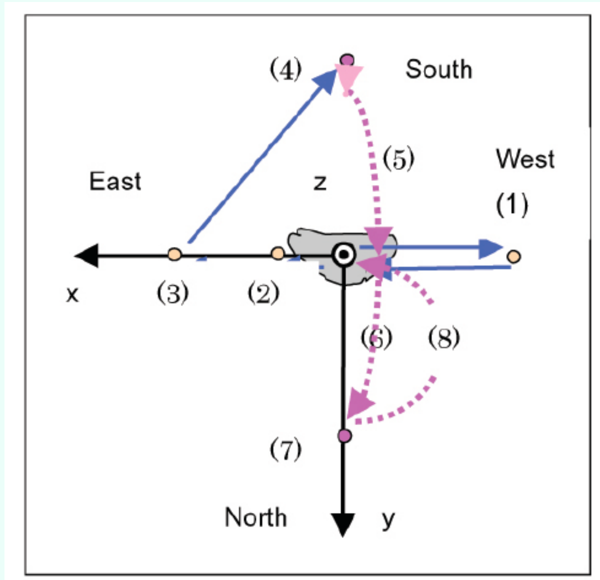




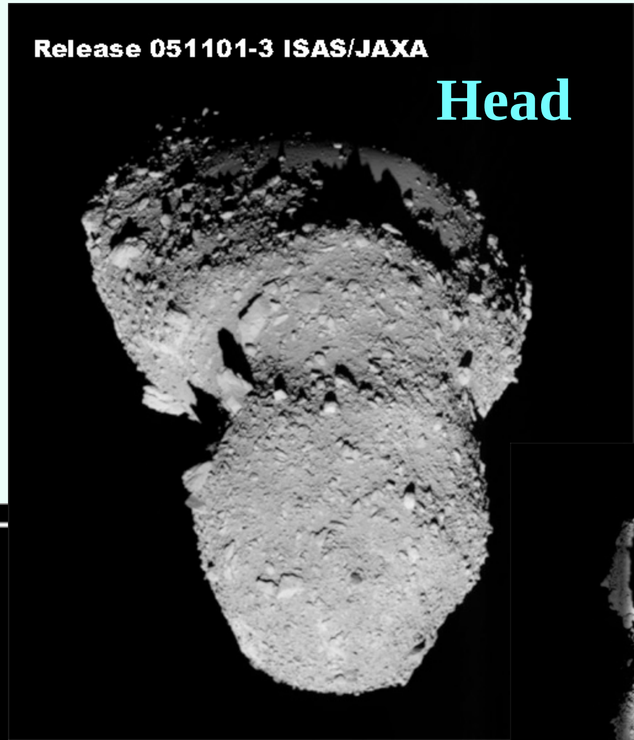
Gate Position to Home Position







Images of Itokawa : whole

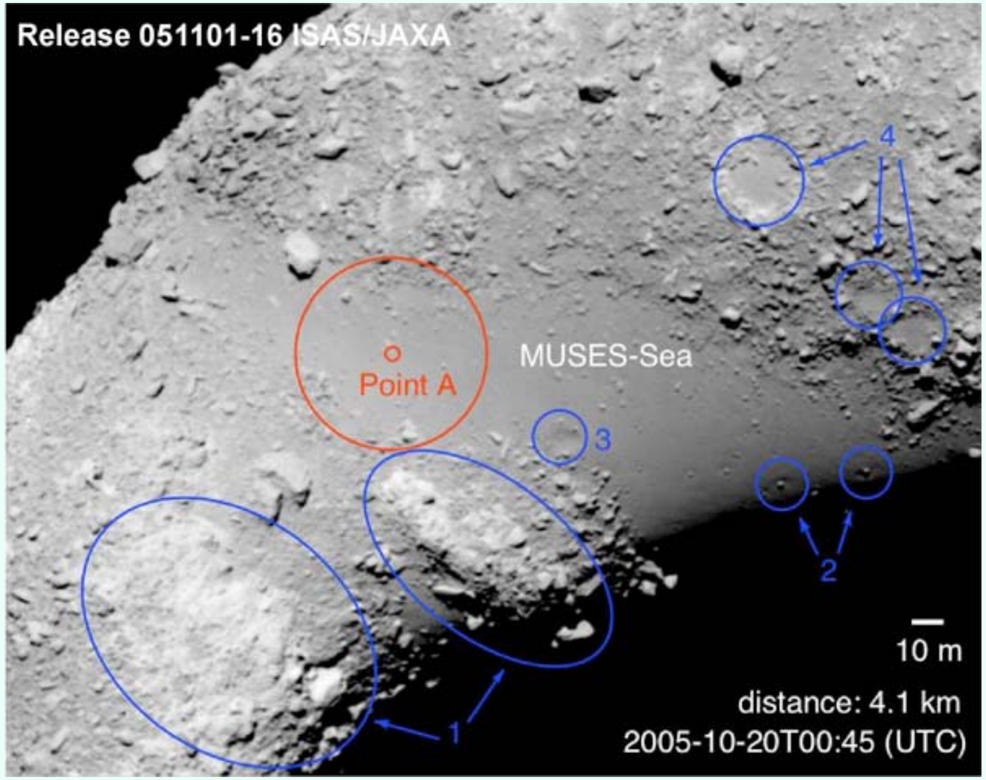


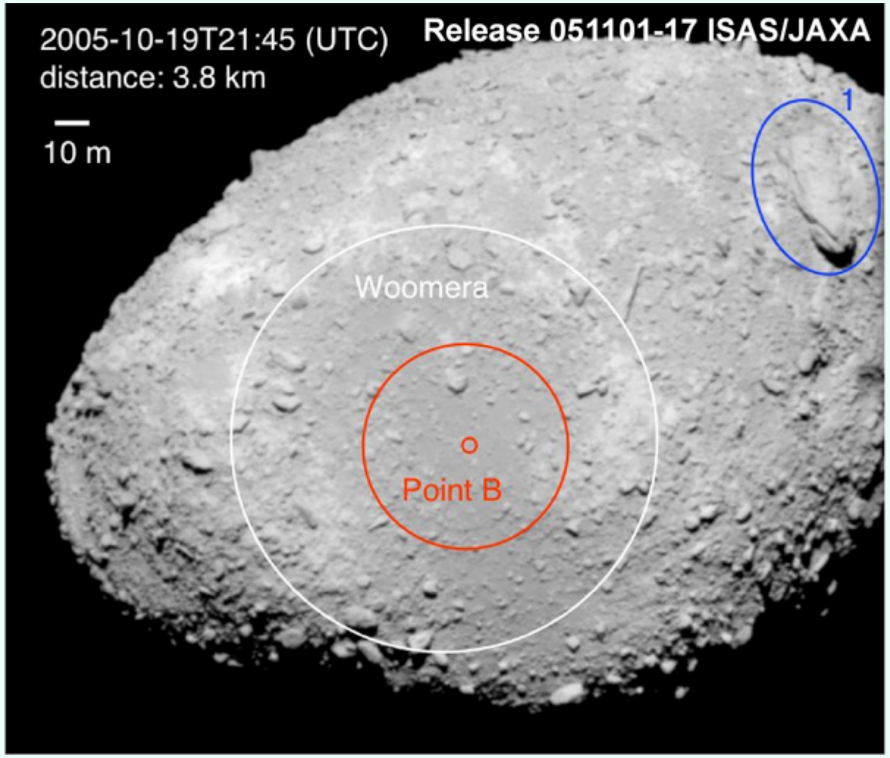
Global Shape of Itokawa: Sea Otter in Space?

Ecliptic plane of our solar system and this asteroid are considered to resemble a sea-otter on sea. This asteroid is divided into the head and body parts with constricted neck circular region. Ventral saddle-like parts and dorsal one are covered with smooth surface. Right is an ascii art which had been distributed in operators during the Rendezvous.

Images of Itokawa

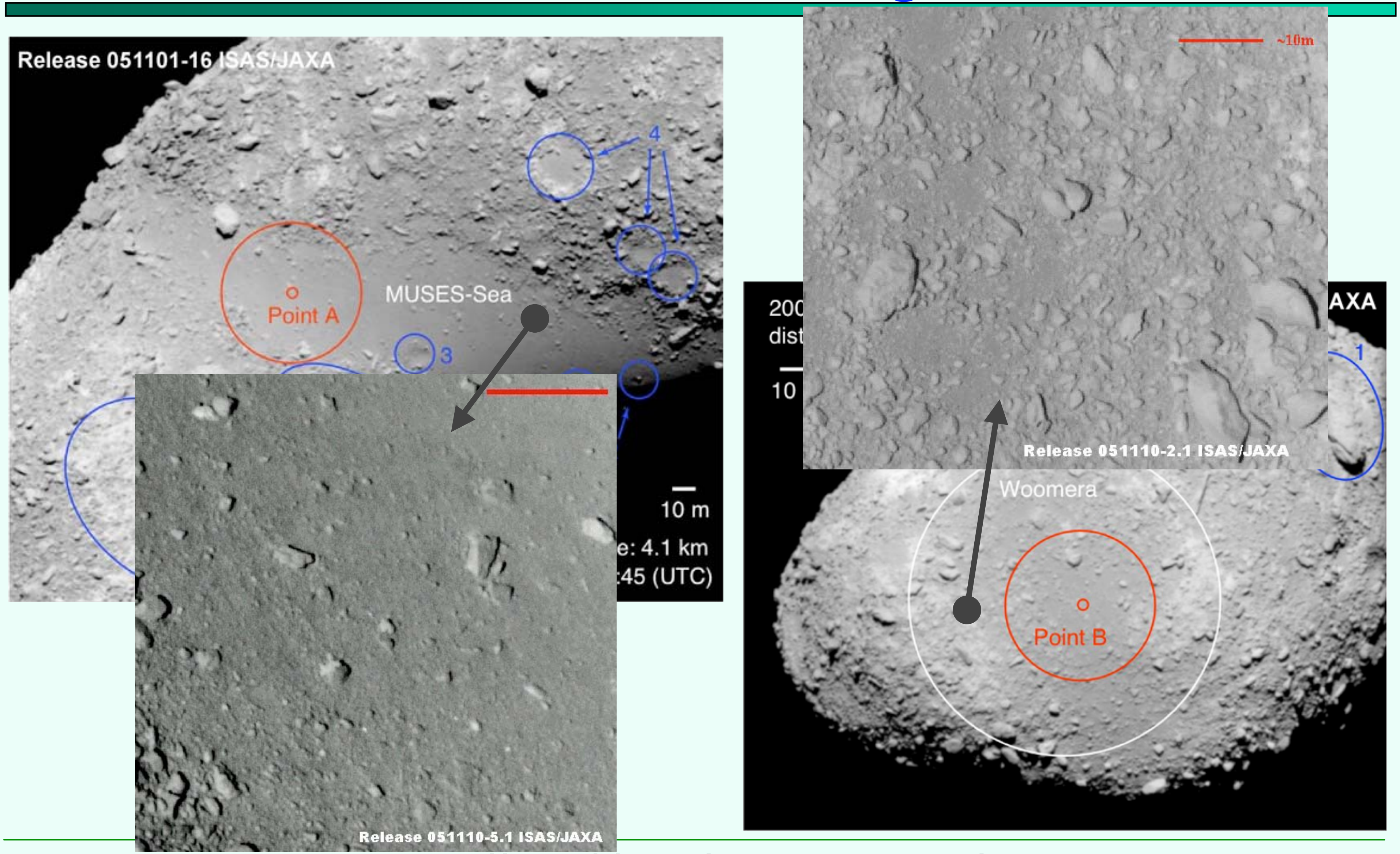
Smooth and Rough





Images of Itokawa

Smooth and Rough

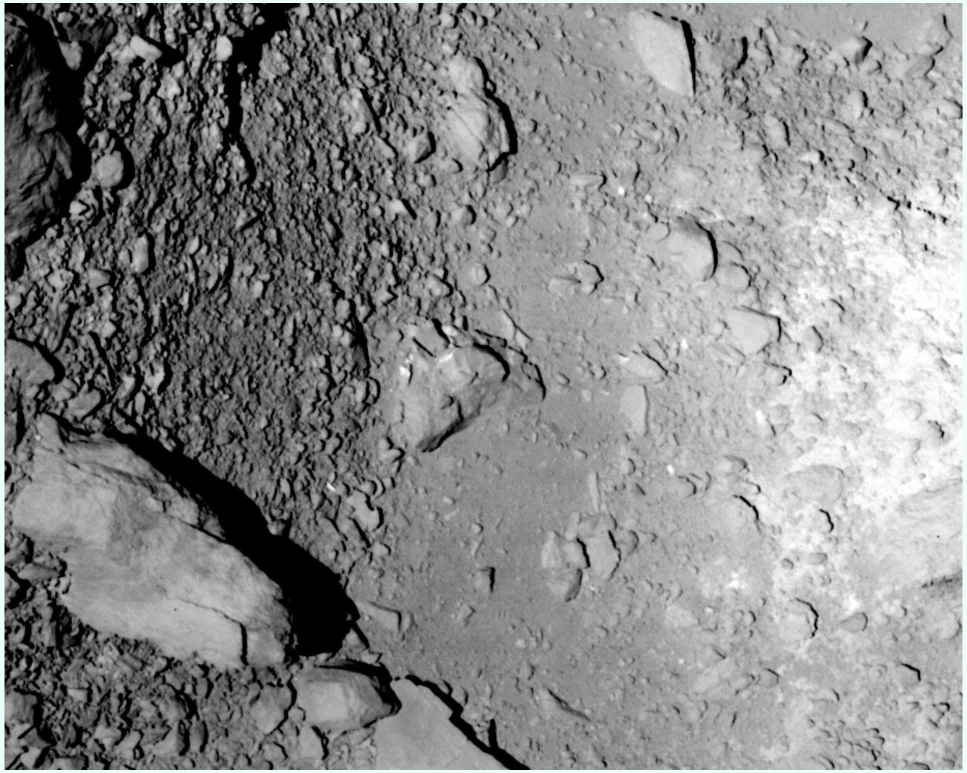


Images of Itokawa

Rough surface

Images of Itokawa

Large Boulders

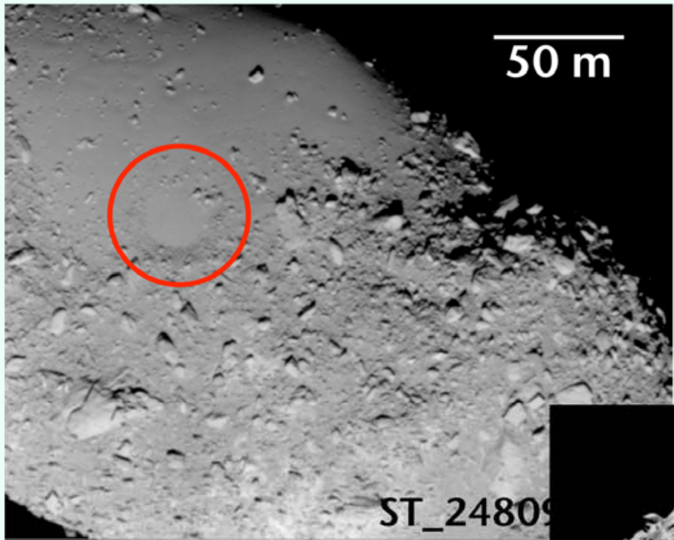


"Pencil"

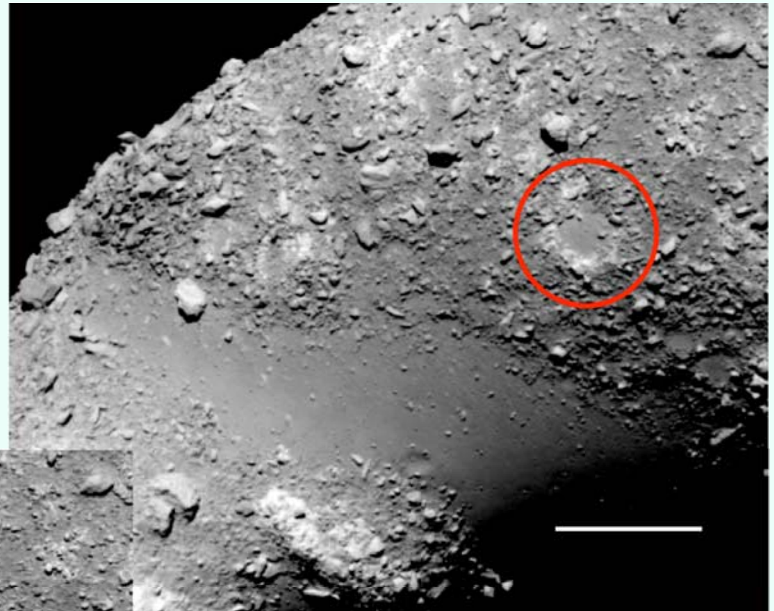
"Yoshinodai"

Images of Itokawa

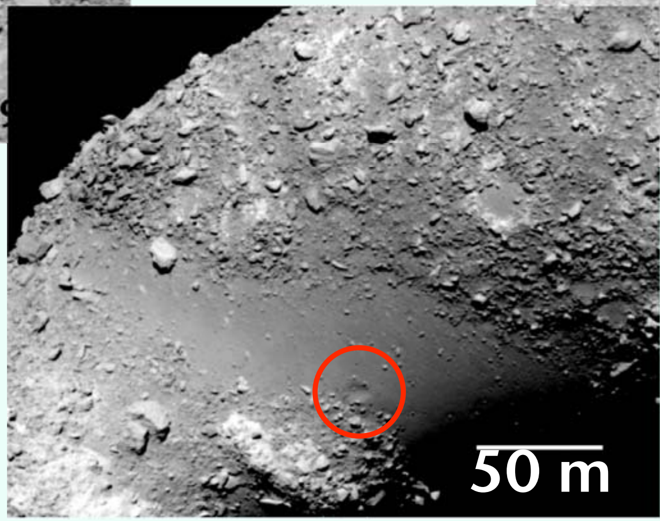
Craters



Fuchinobe (D=36m)



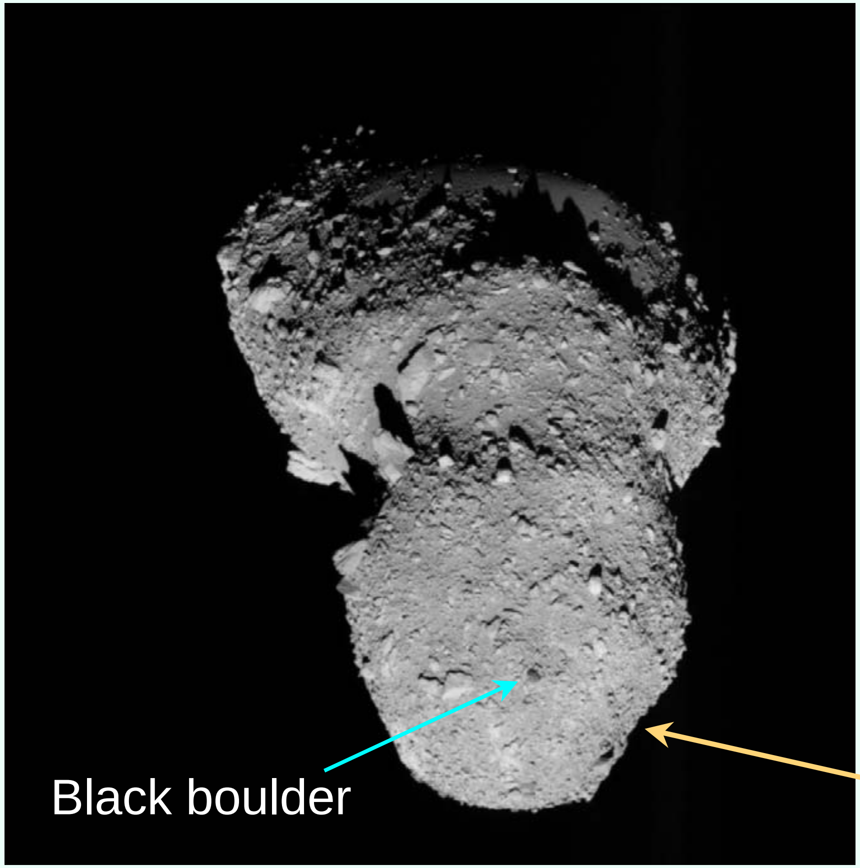
Komaba (D=27m)

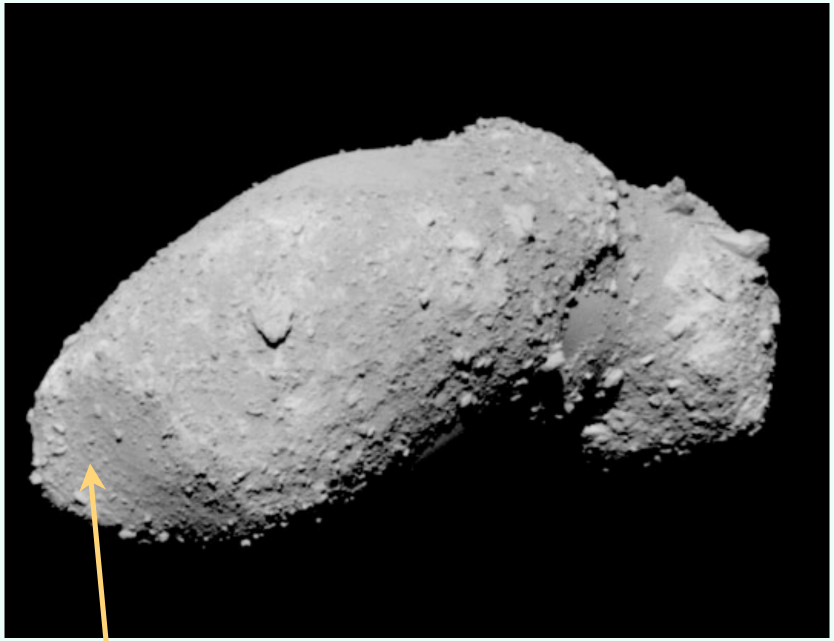


Kamisunagawa (D=10m)

Images of Itokawa

Other features

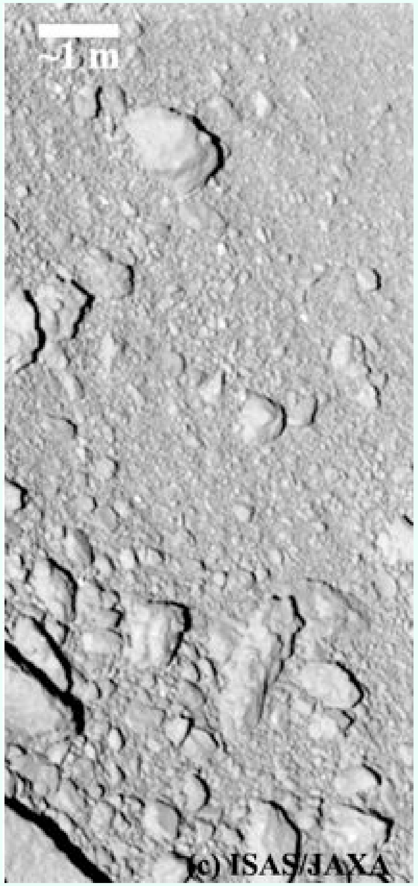




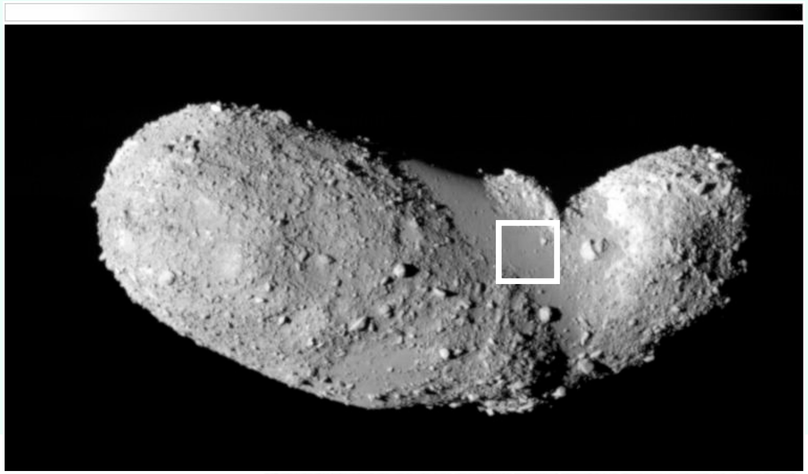
Facet

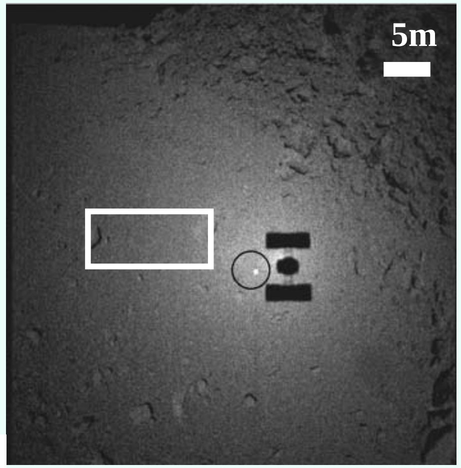
Images of Itokawa

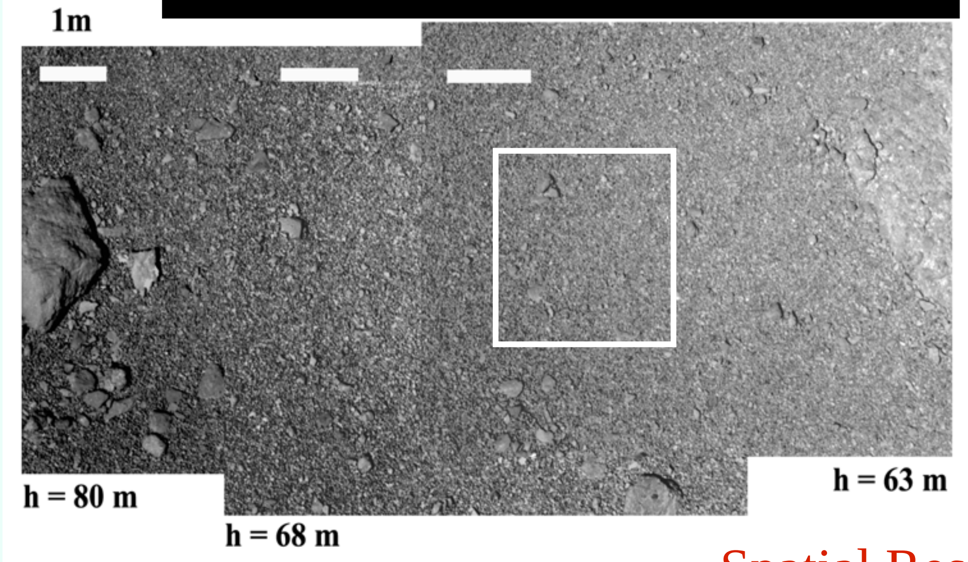
Close-up



boundary





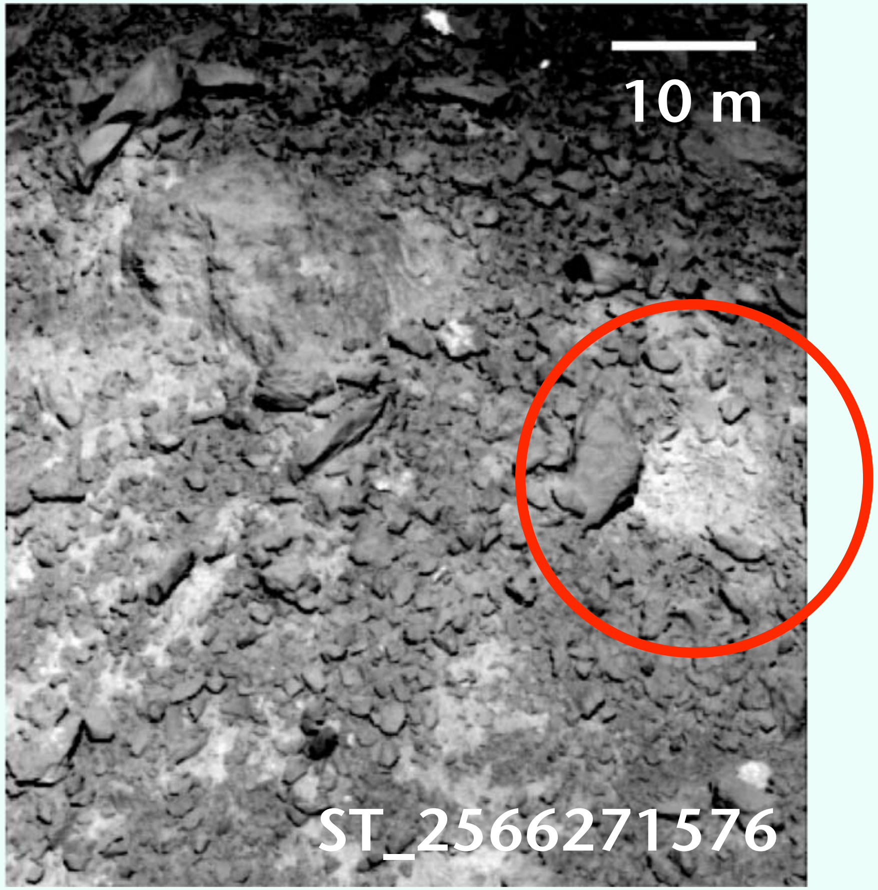


Spatial Resolution : 6-8 mm

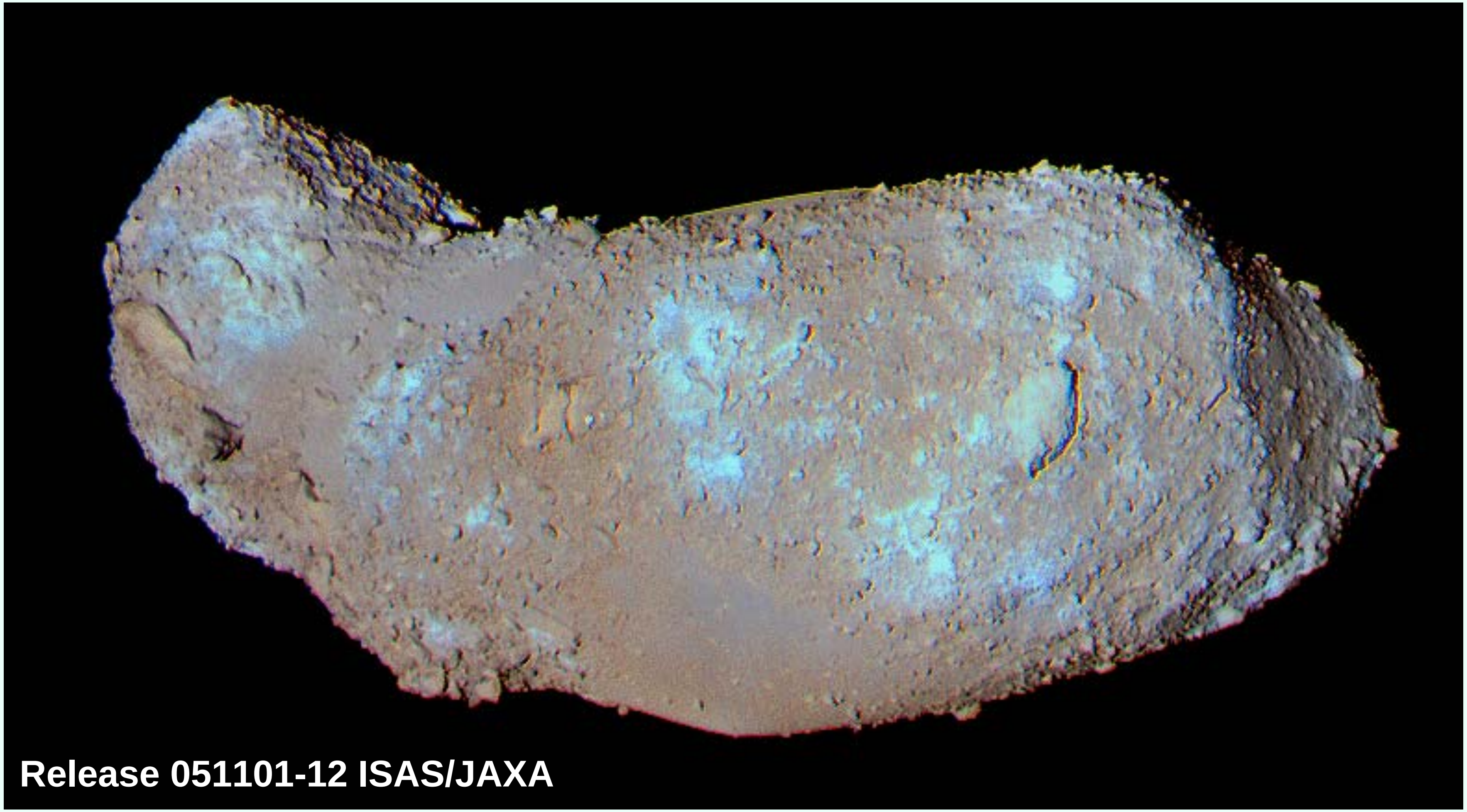
Images of Itokawa

Close-up

At 59m
6mm/pixel

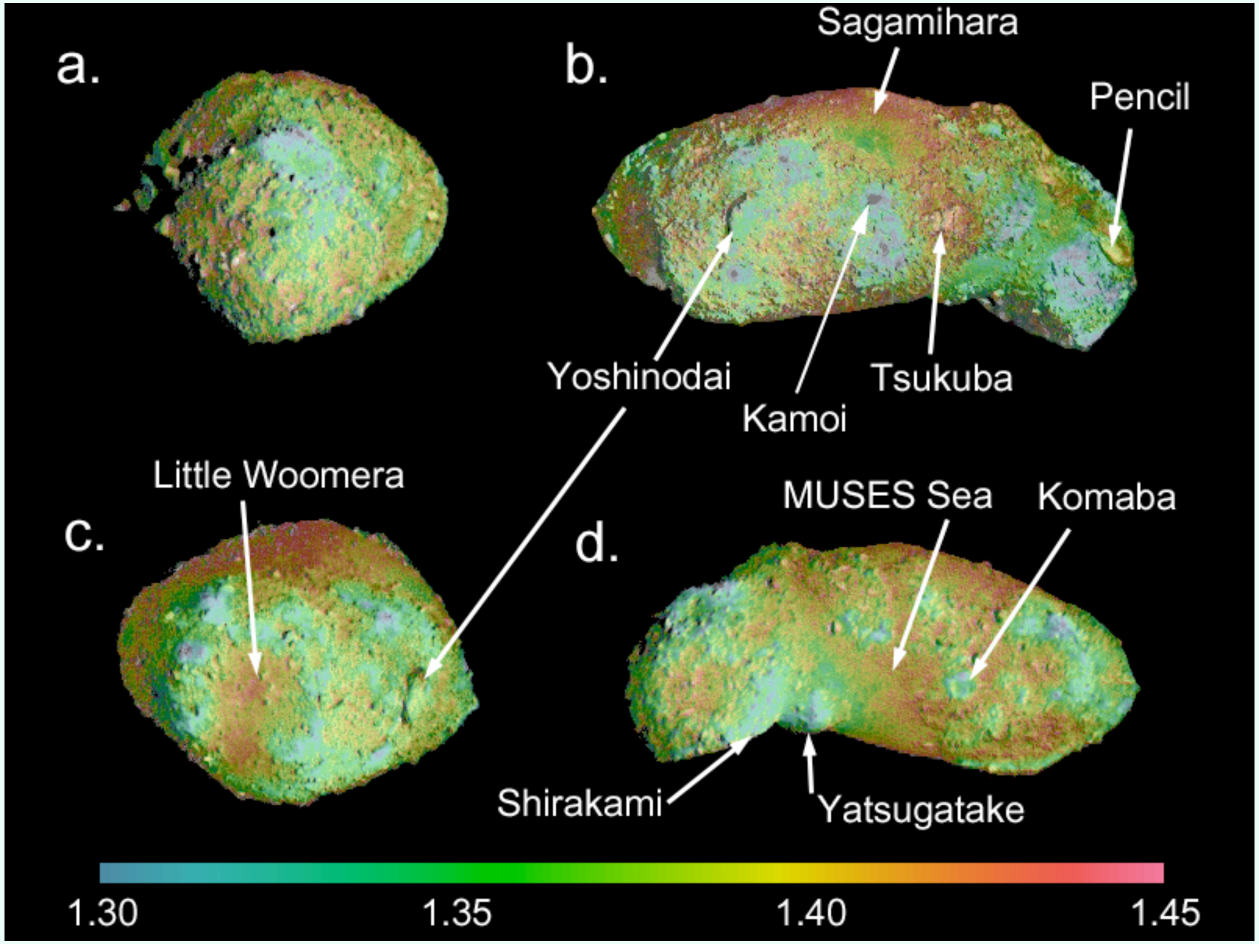


Images of Itokawa
color variation



Images of Itokawa

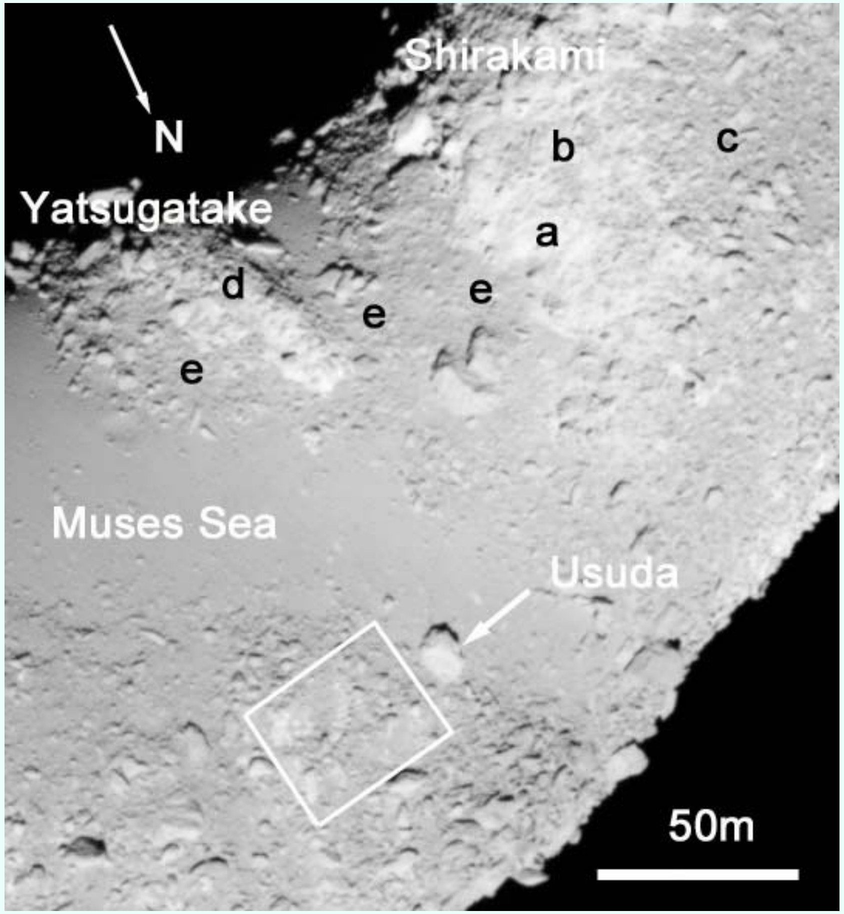
color variation

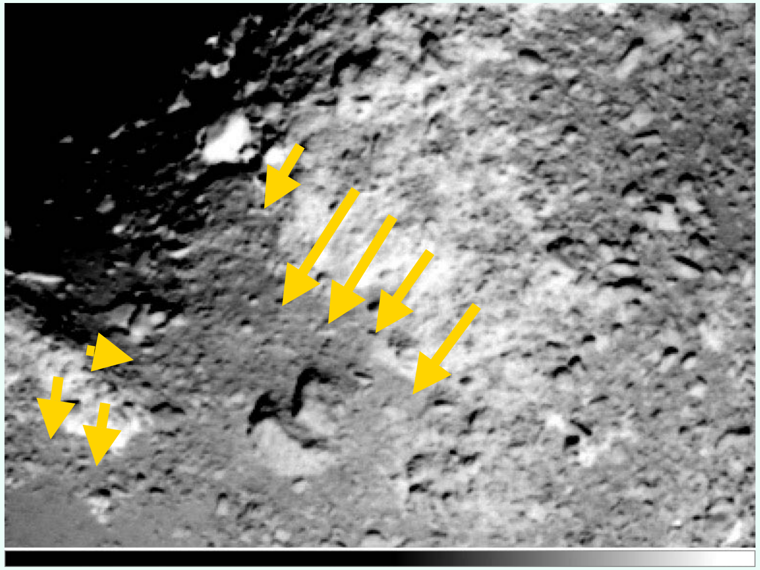


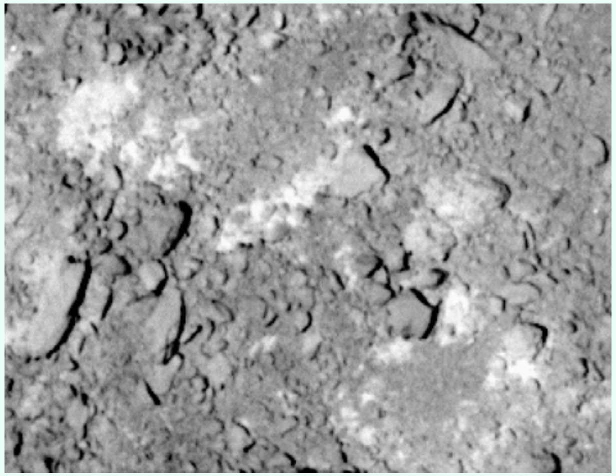
R(w-band) / R(b-band)   Ishiguro et al. (2006)

Images of Itokawa

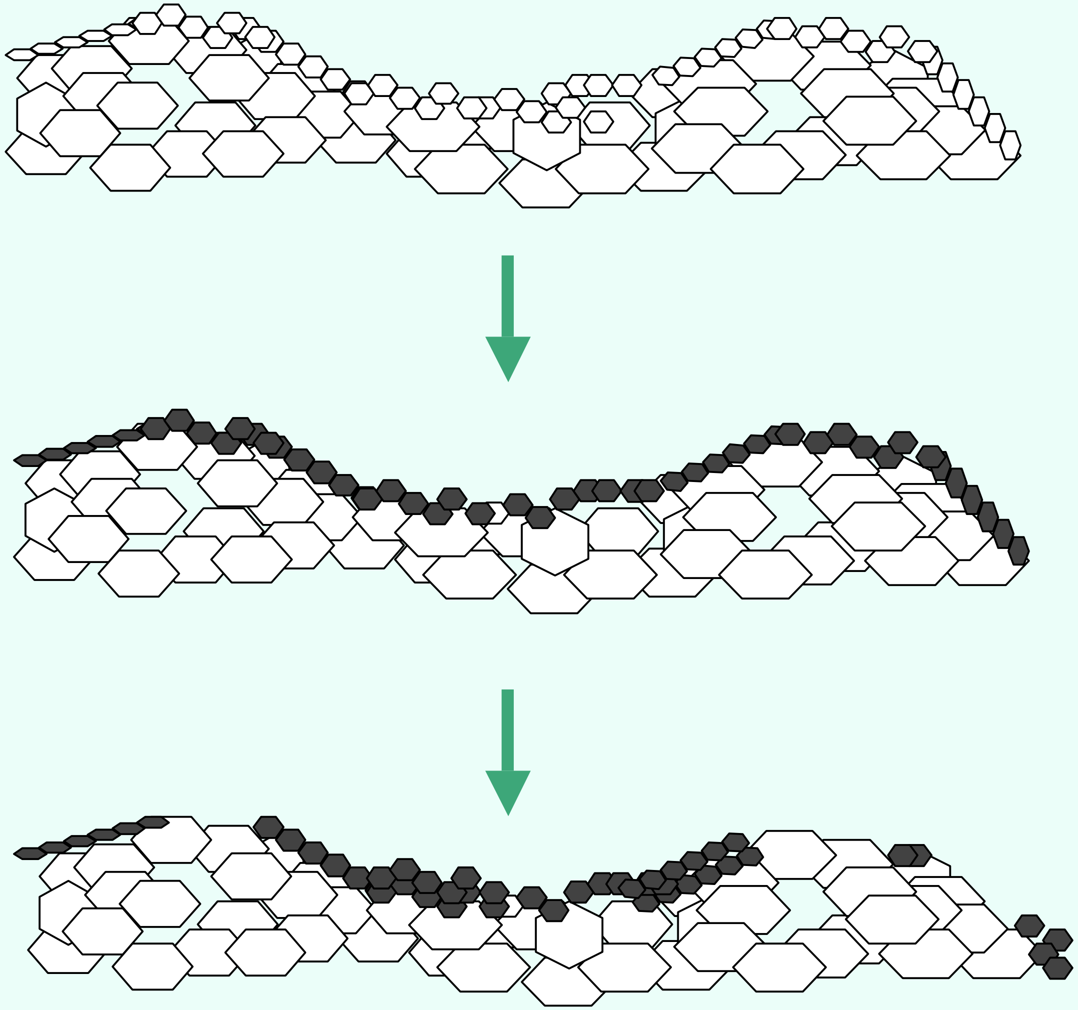
Bright Region







Explanation of Color Variation

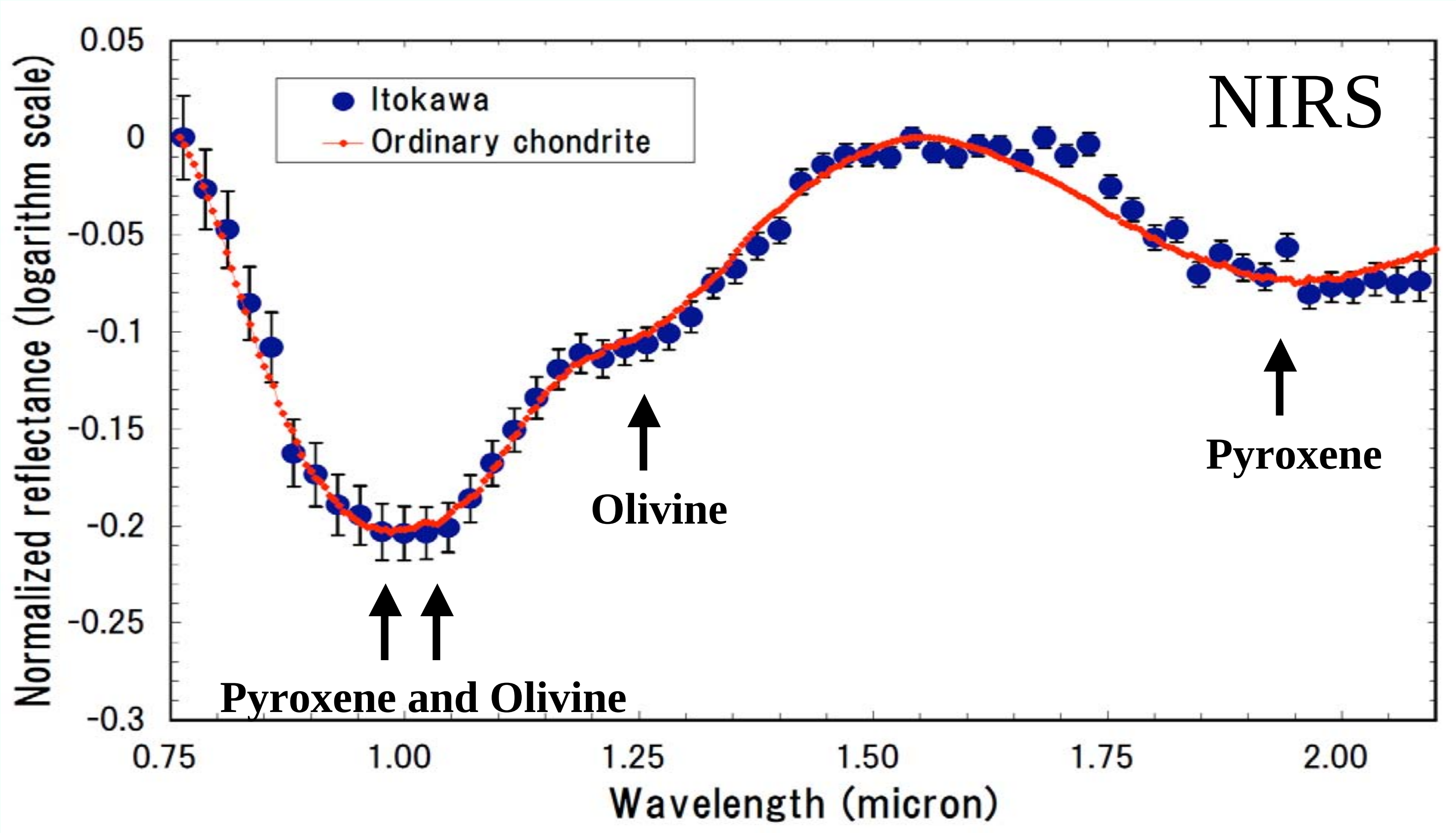


Rubble pile + collisions

Space Weathering

Shaking ➔
Surface movement
exposes underlying
brighter zone.

Near Infrared Observation

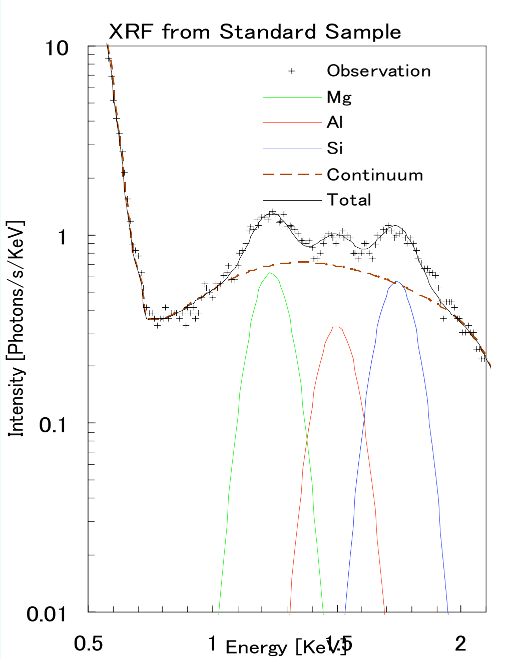


* Surface of Itokawa indicates olivine and pyroxene mineral assemblage.
* Reflectance spectrum of Itokawa is similar to that of ordinary chondrites.

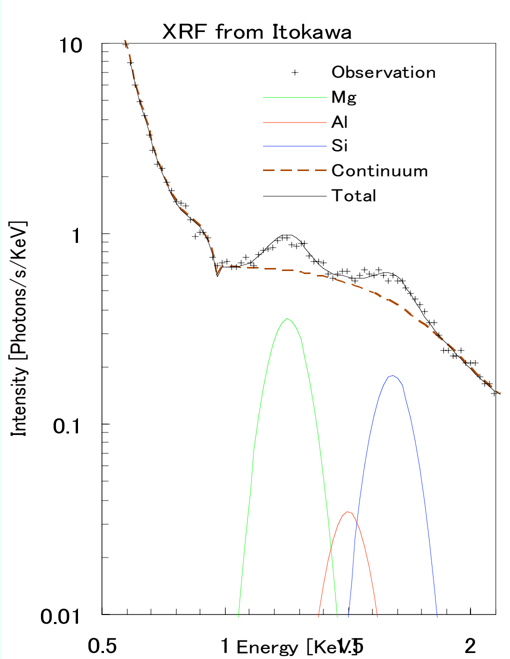
X-ray Observation

XRS

from standard sample

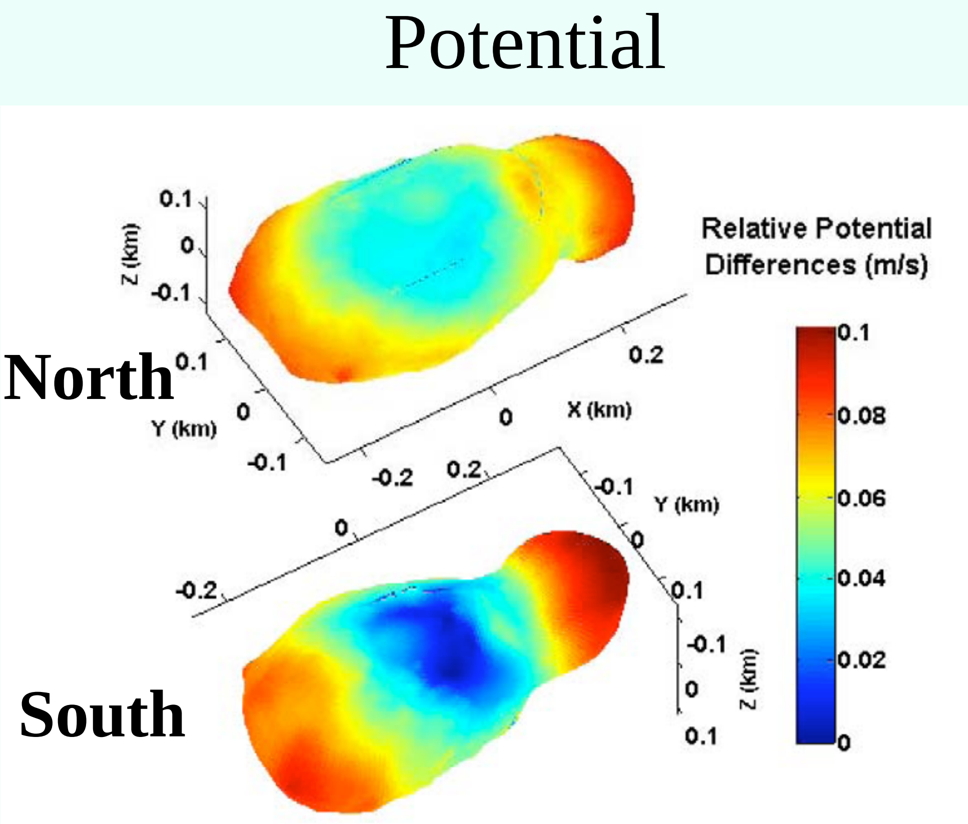


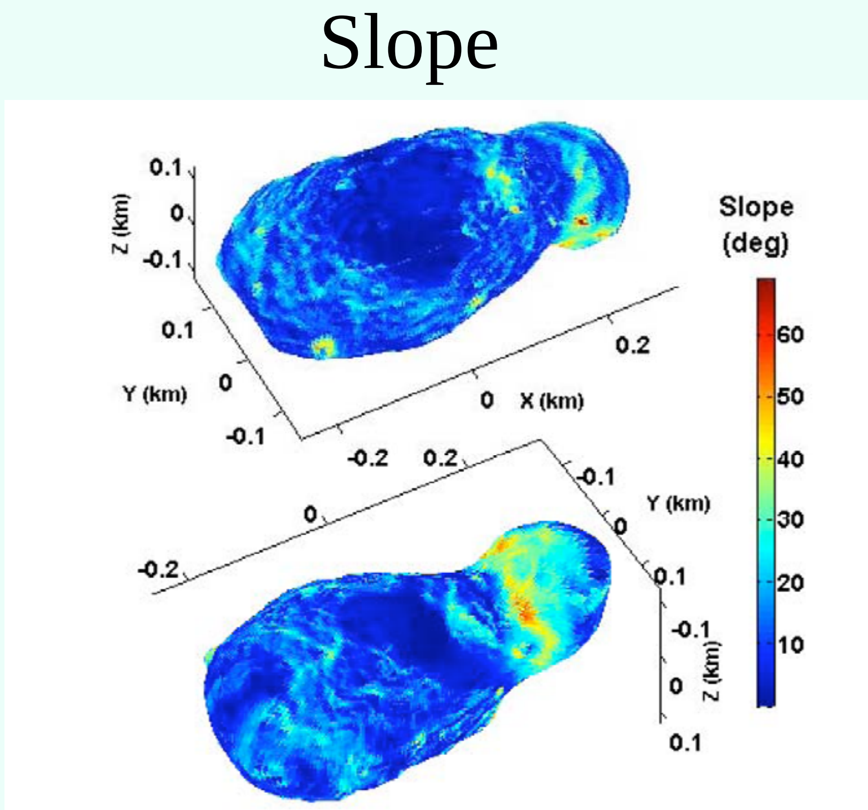
from Itokawa



*X-rays from Itokawa (right) has larger Mg/Si and smaller Al/Si than those of X-rays from the standard sample (left).
*Itokawa is similar to ordinary chondrites in composition.

Potential and Slope Maps



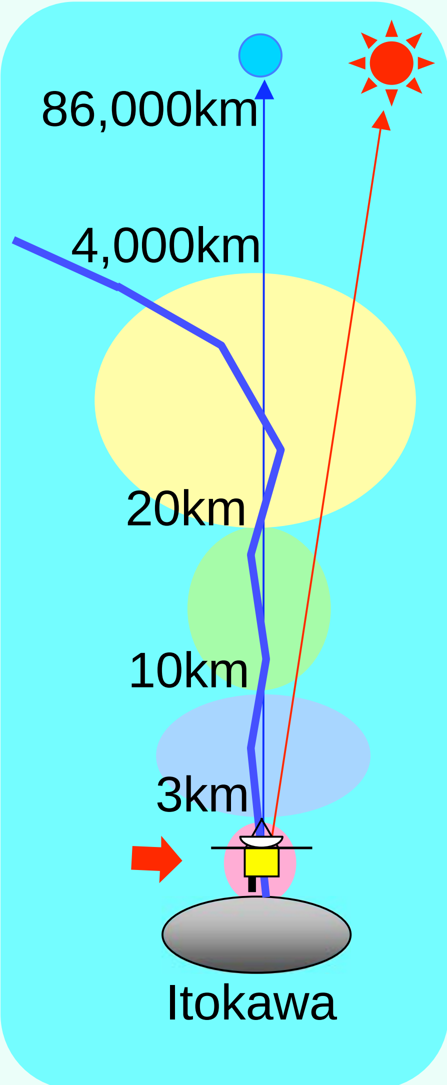


(Fujiwara, *et al.*, *Science* (2006))

Mission

- Descent & Touchdown -

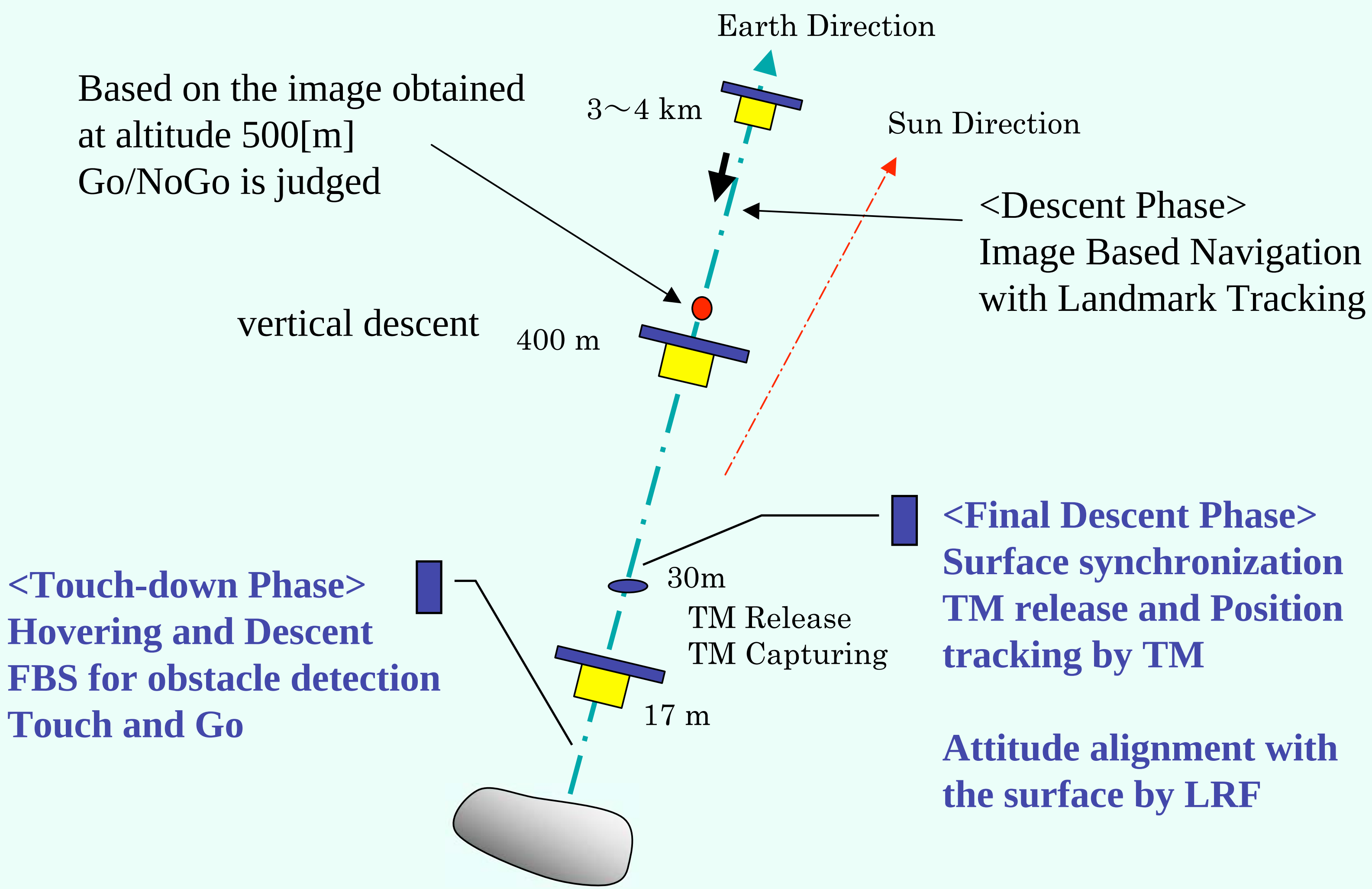
Descent Rehearsal and Touch-down



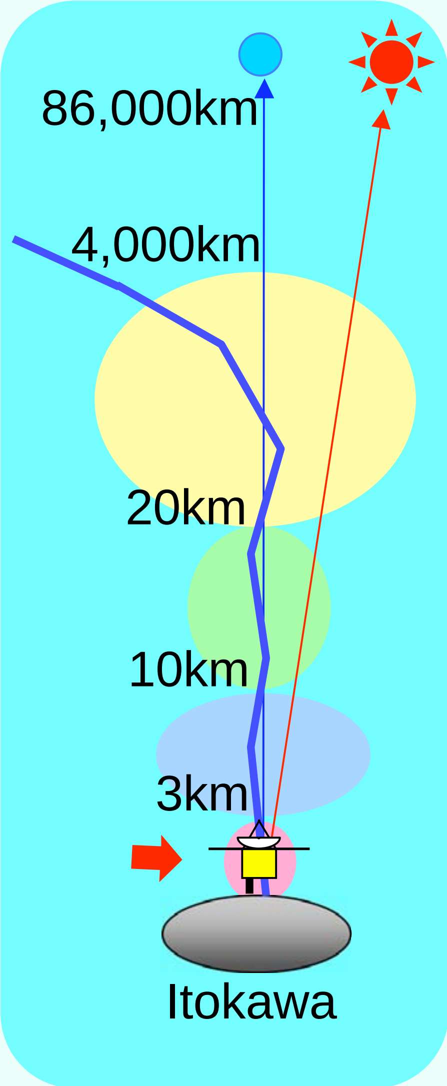
2005

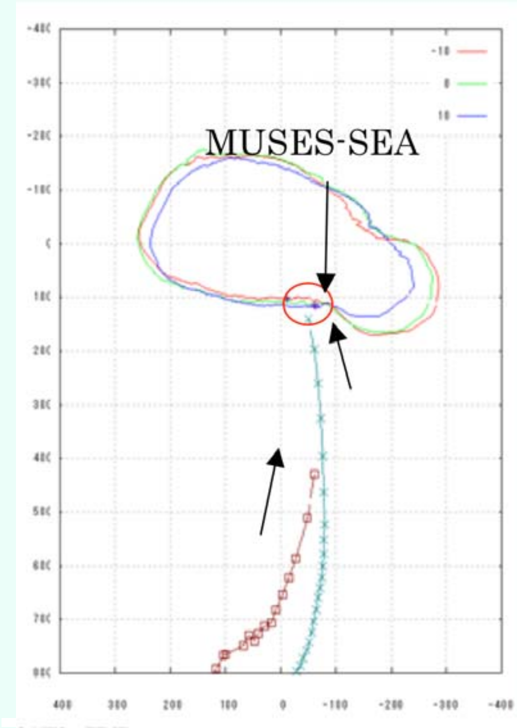
1. Rehearsal #1 .... Nov. 4th
2. Nav & Guide Practice .... Nov. 9th
   (Target Marker Release#1)
3. Rehearsal #2 .... Nov. 12th
   (MINERVA Lander Release)
4. Touch-down for Sampling#1 .... Nov. 20th
   (Target Marker Release#2)
   (Two Touch-downs + One Landing)
5. Touch-down for Sampling#2 .... Nov. 26th
   (One Touch-down + One Sampling CMD Issued)

Touch-down sequence

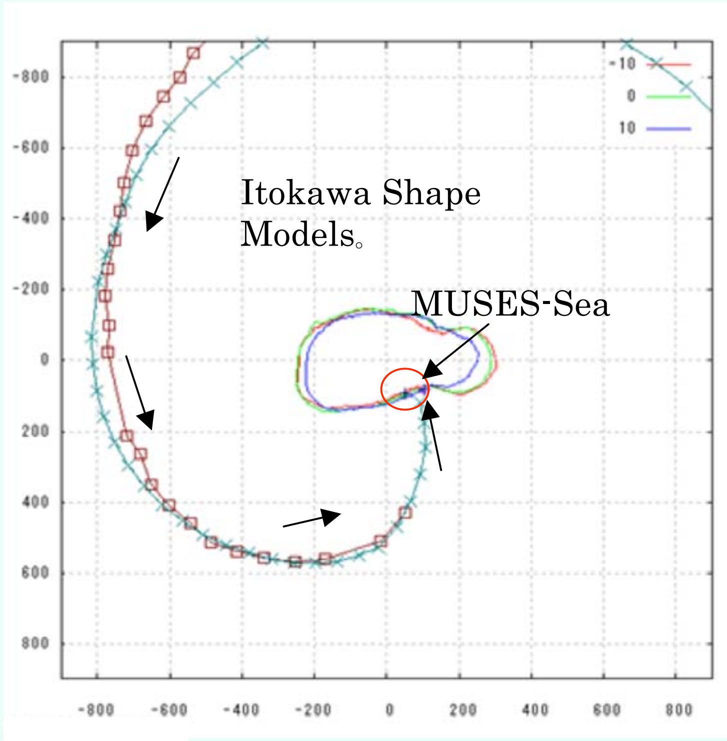


Approach and Descent Path #2



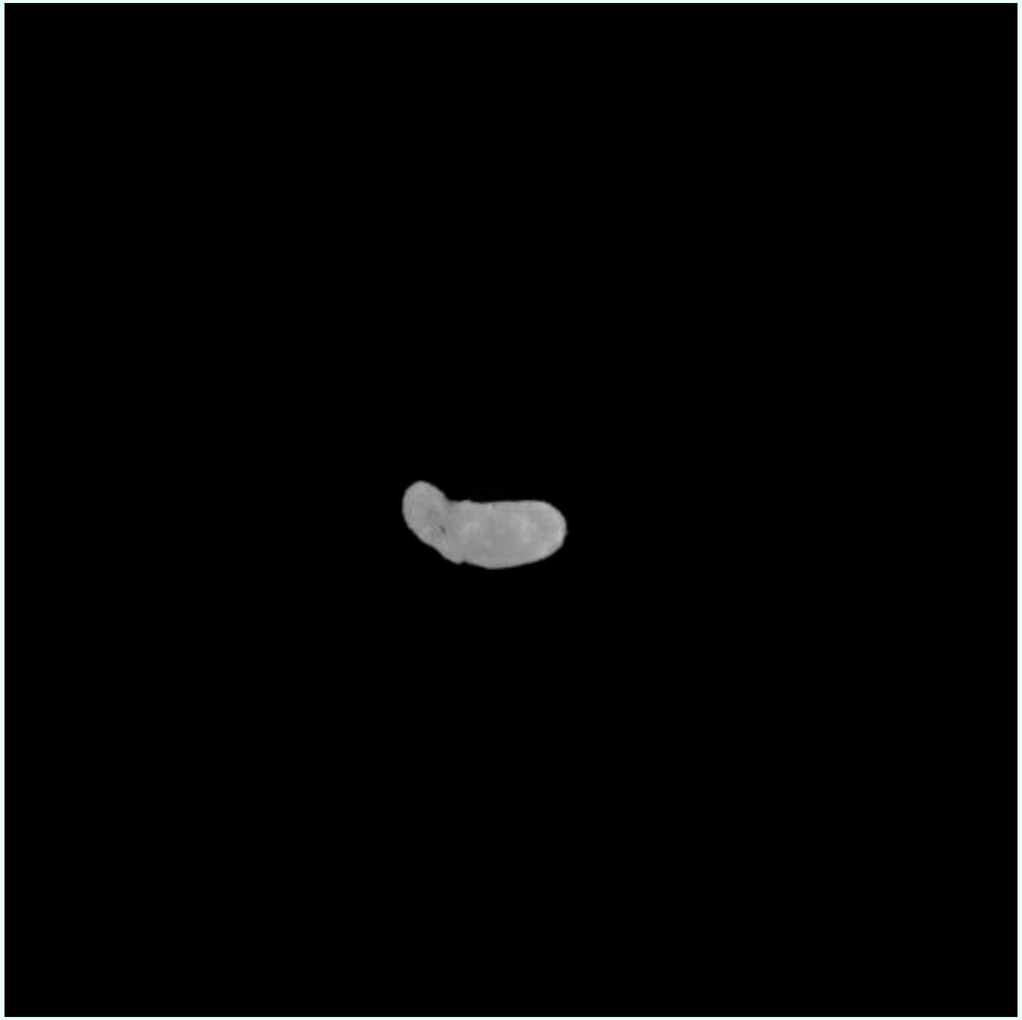


Planned and Actual Path
(Semi-Inertial)

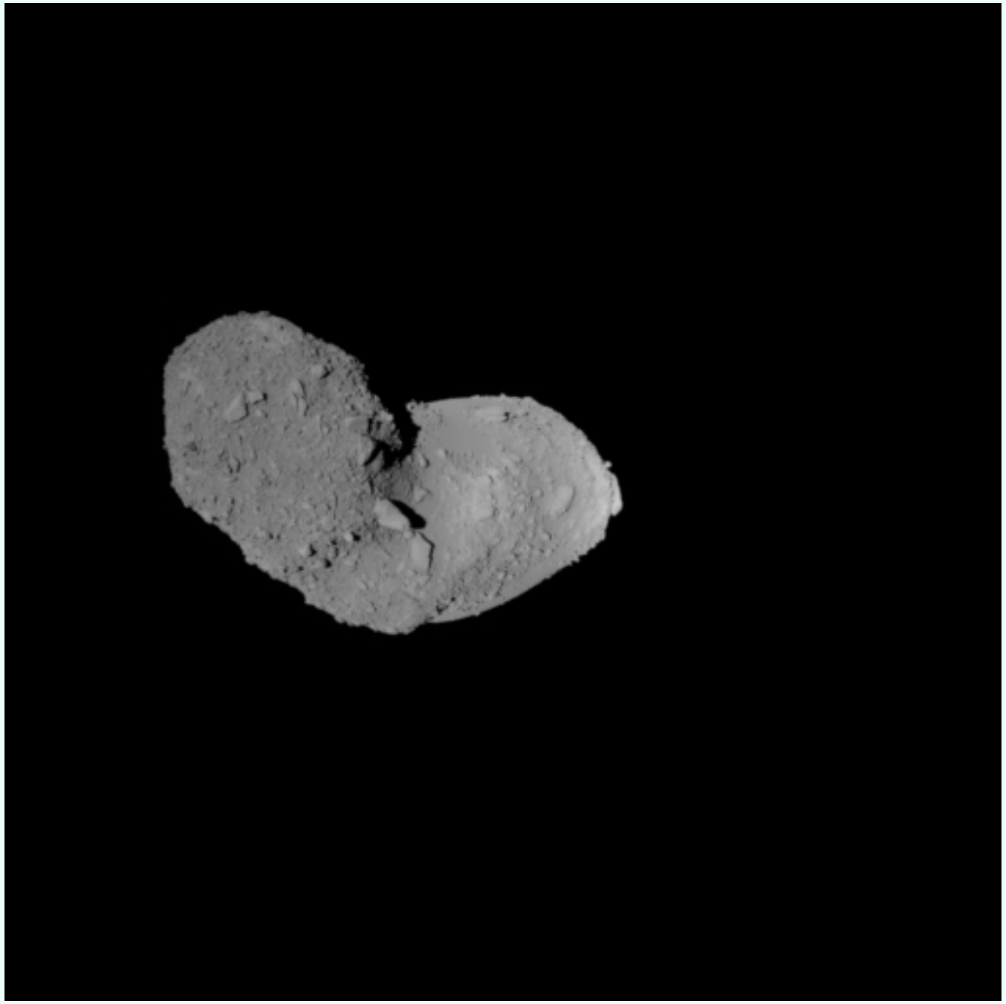


Planned and Actual Path
(Itokawa-Fixed)

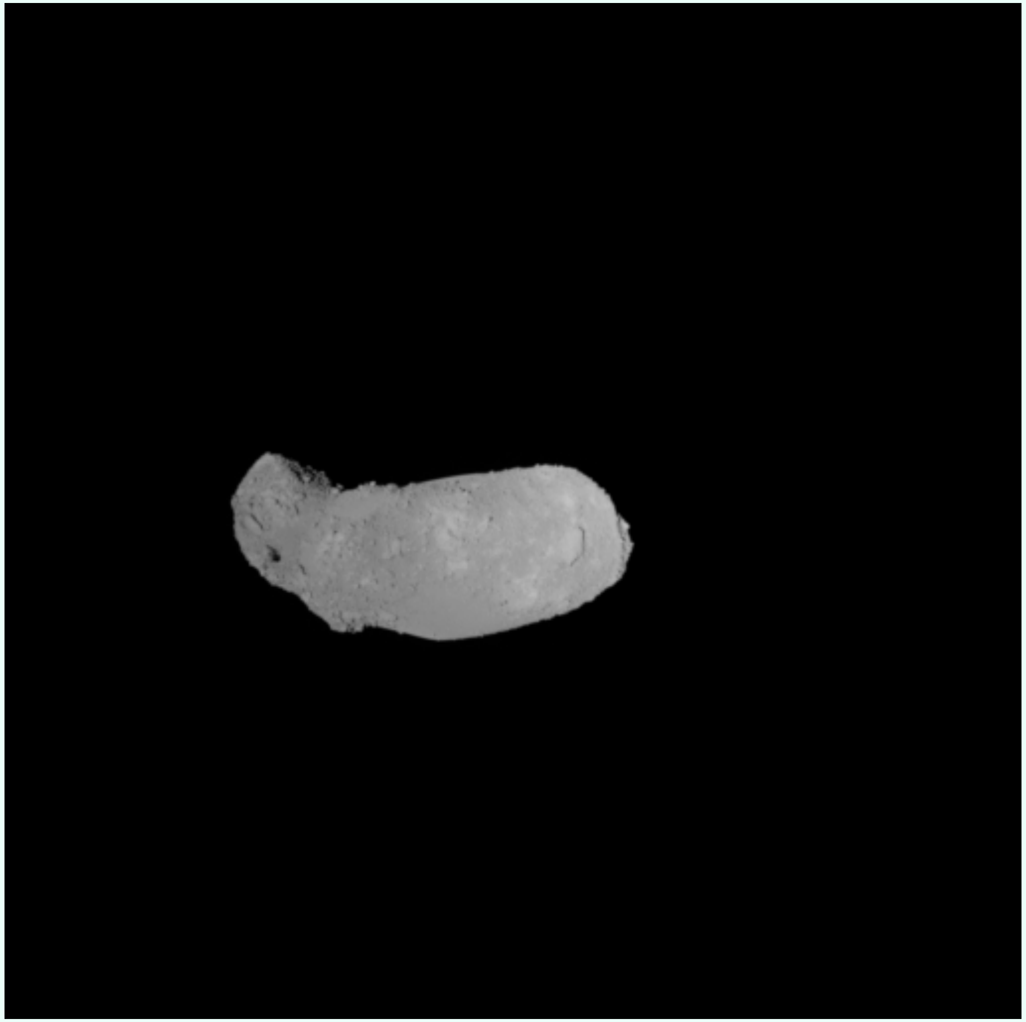
Rehearsal No.1 (Nov. 4, 2005)



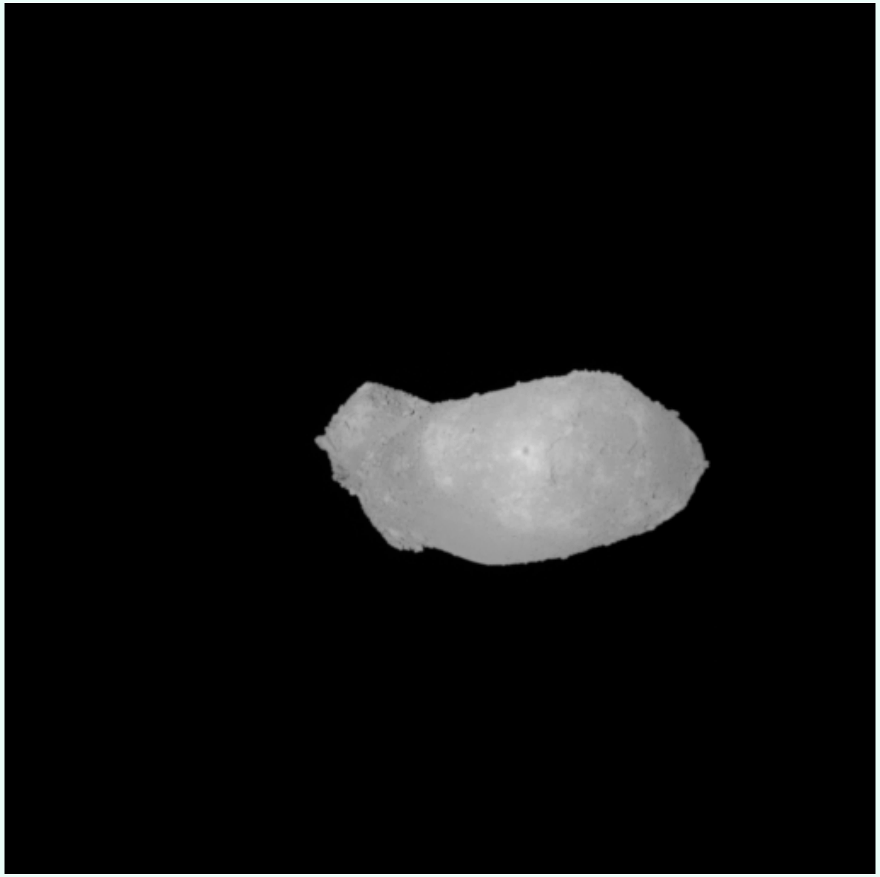
Navigation & Guidance Practice (Nov. 9, 2005)



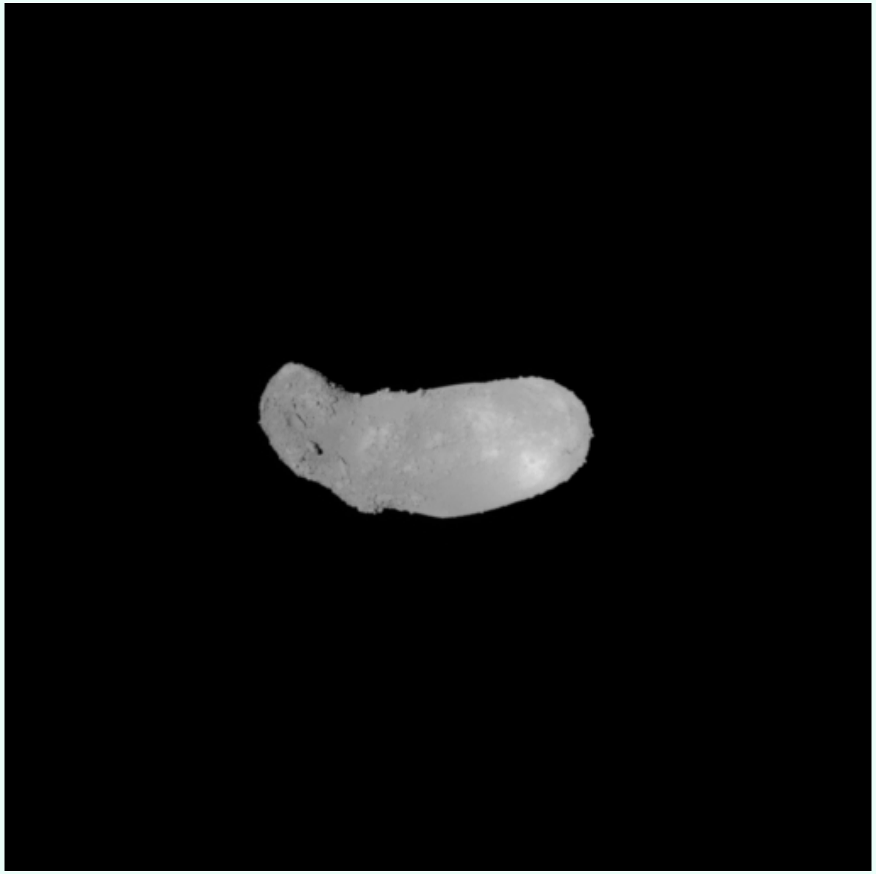
Rehearsal No.2 (Nov. 12, 2005)



Touch-down for Sampling

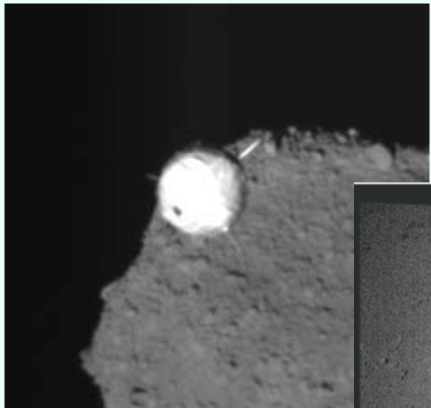


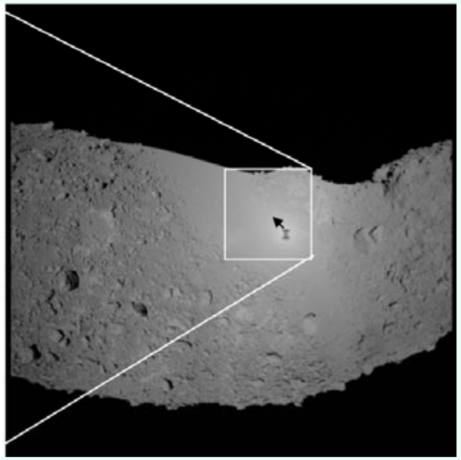
Touch-down for Sampling#1



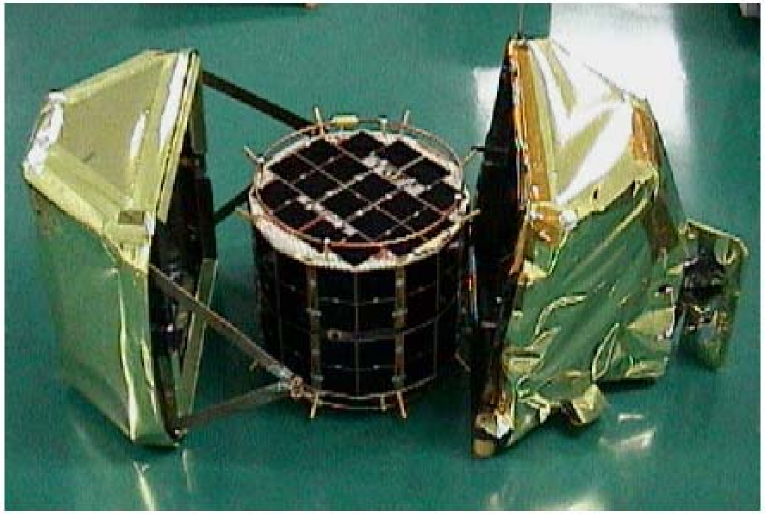
Touch-down for Sampling#2

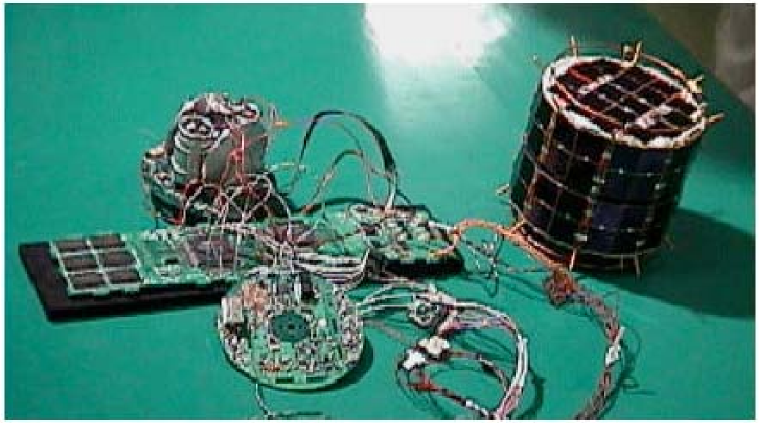
Target Marker

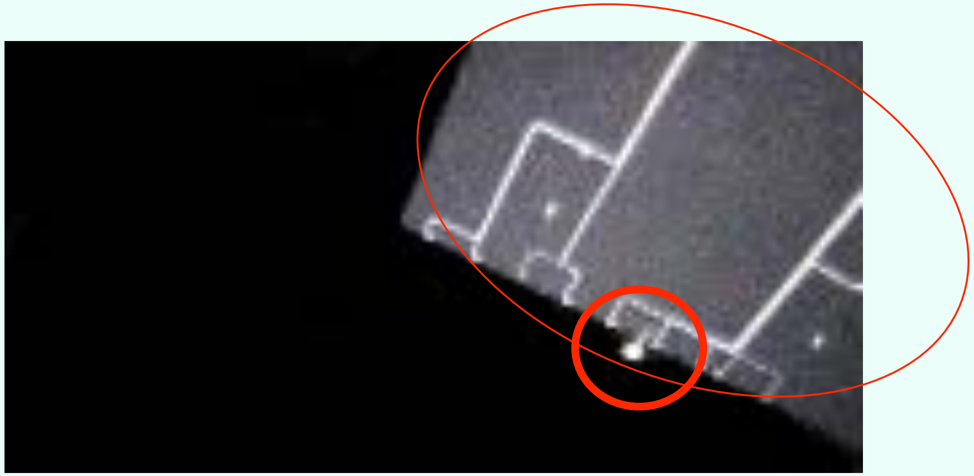




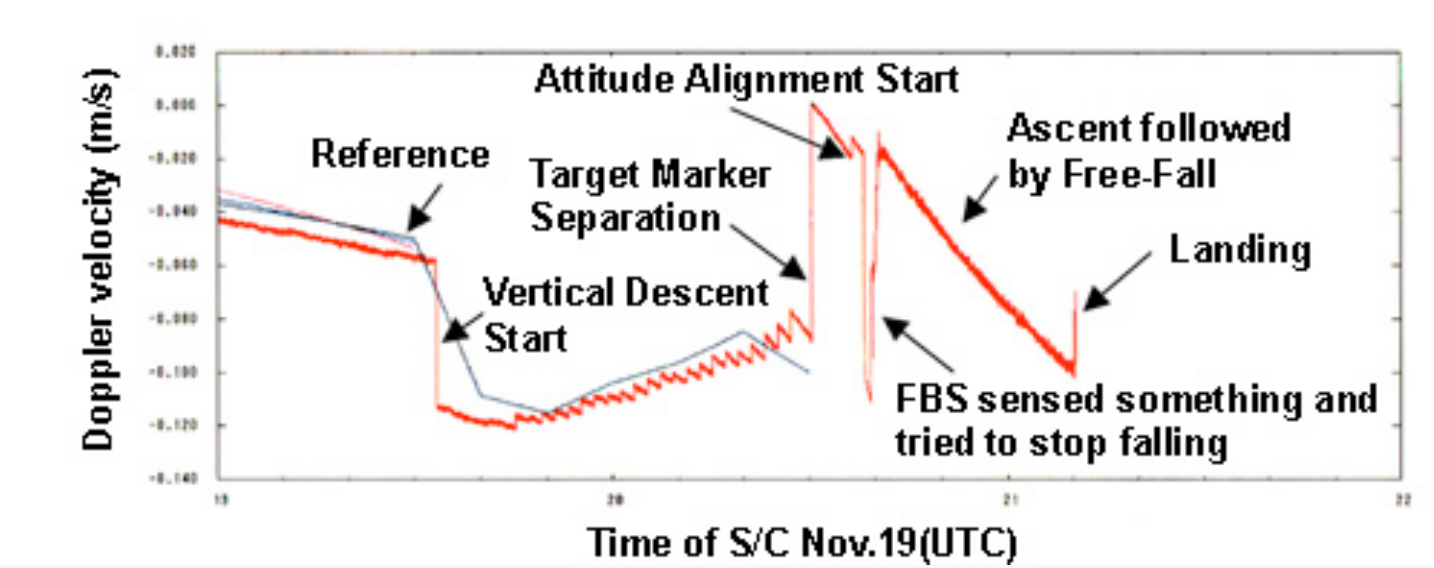
MINERVA





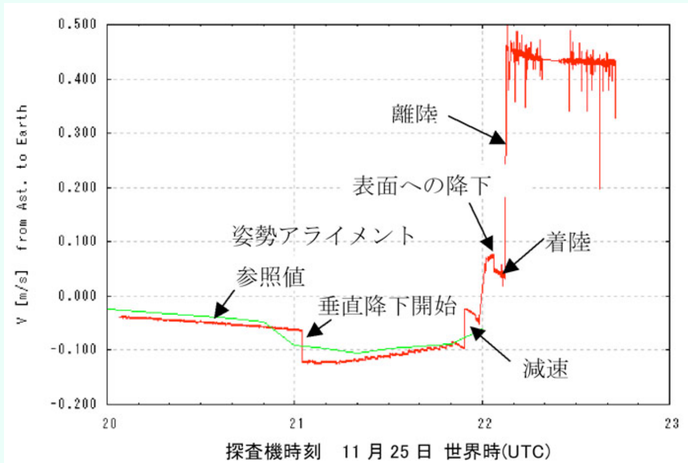


What happened at 1st touch-down ?

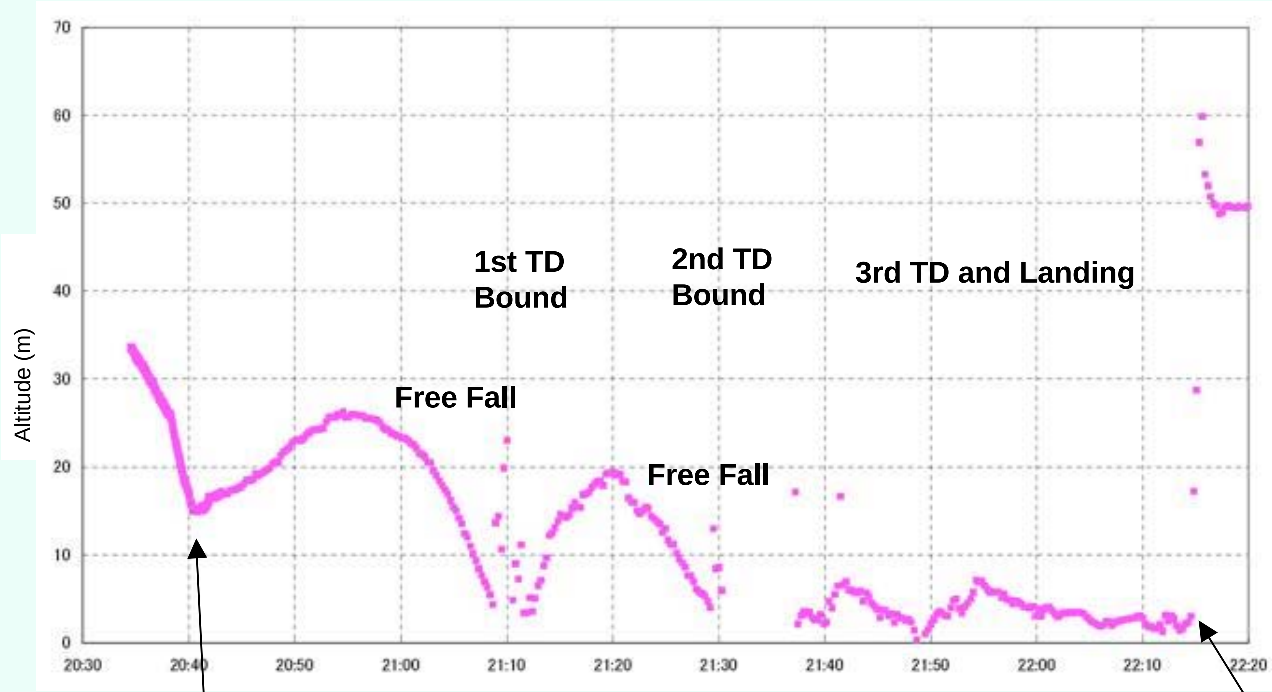


1st touch-down

2nd touch-down



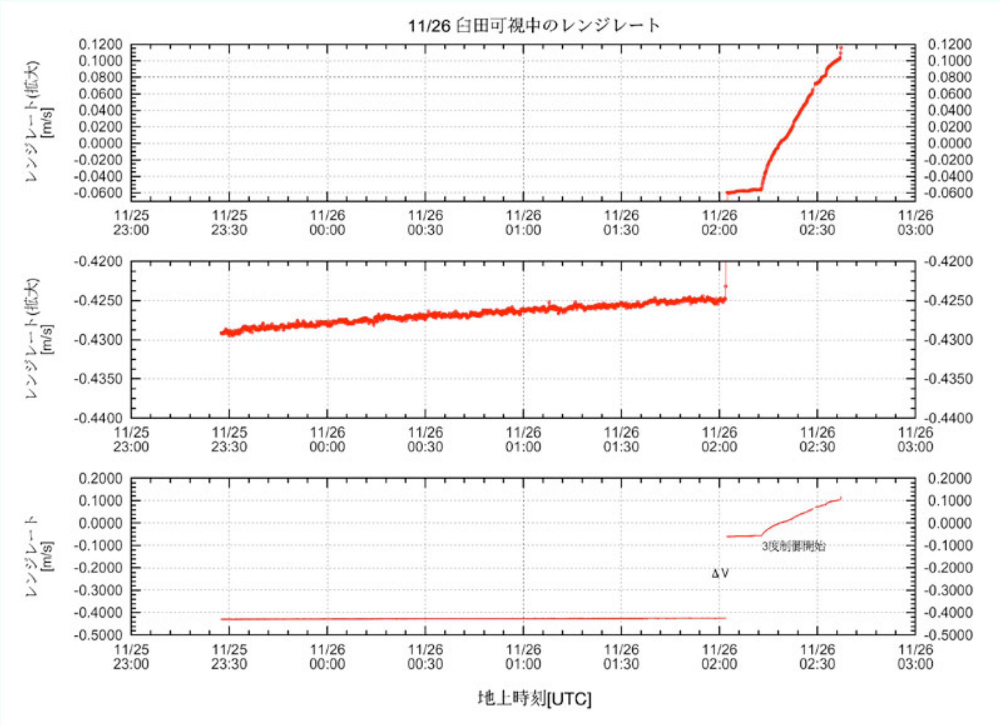
What happened at 1st touch-down ? -> answer



Escape dV
by ground command

Obstacle was detected by FBS
TD sequence was terminated
S/C maneuvered at the initial velocity and free-fall was performed
There are high possibilities for Hayabusa to collect any sample by natural touchdowns

After 2nd Touching Down



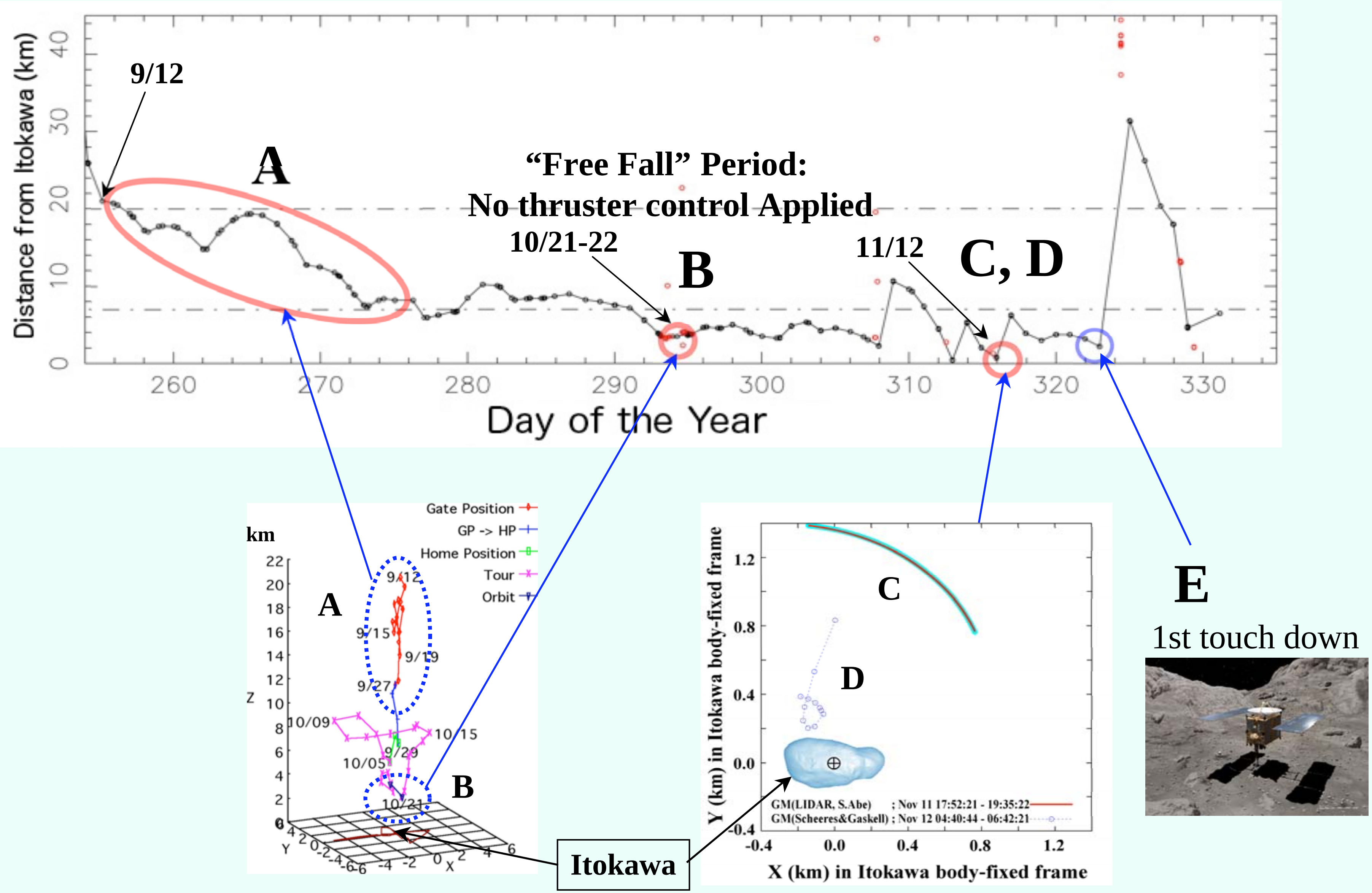
- Hayabusa had lost contact due to fuel gas eruption for 45 days since December 8th.

- A beacon, un-modulated signal from the spacecraft was acquired on January 23rd, 2006.

- Since then, Haybusa is operated without losing its contact.

Mass Determination

Mass Estimation



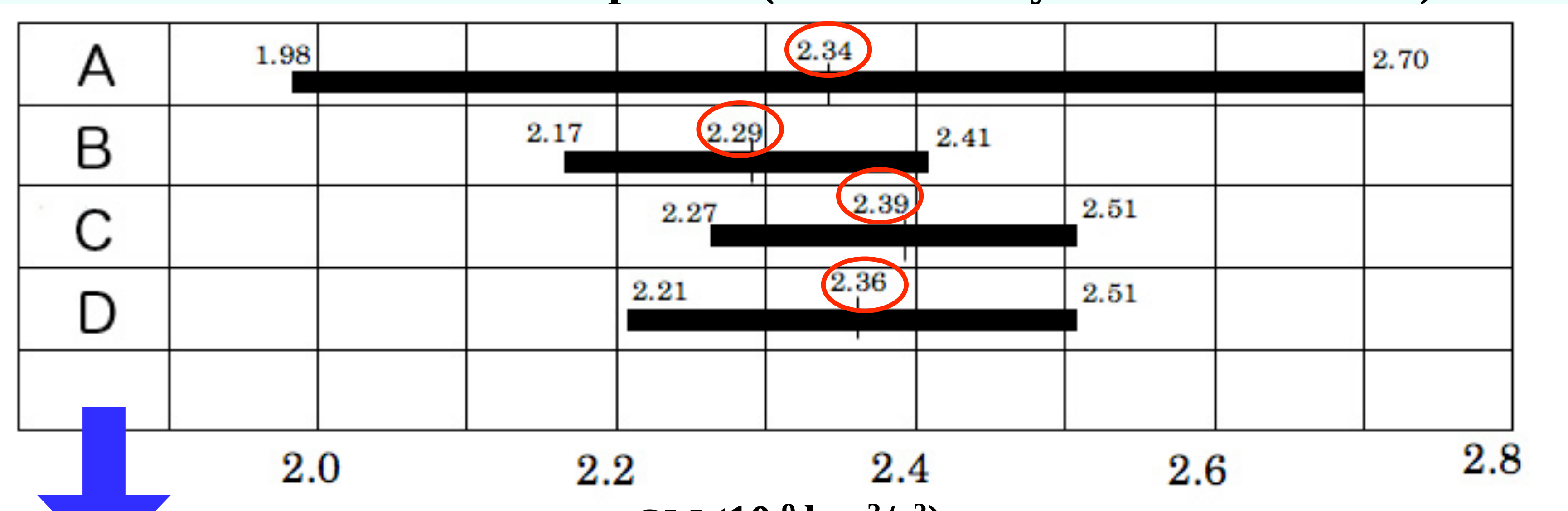
Results of Mass Estimation

1st result

Groups	Period / Data type	Distance from Itokawa	Model of Itokawa	**GM** **10^{-9} km^3/s^2**	Error
A	9/12～10/2 R&RR	20 - 7 km	point mass	**2.34**	15%
B	10/21-22 R&RR, Opt., LIDAR	3 km	point mass	**2.29**	5%
C	11/12 LIDAR, Opt.	1427 - 825 m	polyhedron	**2.39**	5%
D	11/12 Opt., LIDAR	800 - 100 m	polyhedron	**2.36**	6%
E	11/19 LRF	20 - 10 m	-	-	-

Mass and Bulk Density of Itokawa

Estimated GM in each period (GM=Gravity Constant x Mass)



GM (10^{-9} km^3/s^2)

GM：(2.34± 0.07) x 10^{-9} km^3/s^2

Mass：(3.51 ± 0.105) x 10^{10} kg

Volume = (1.84 ± 0.092) x 10^{7} m^3

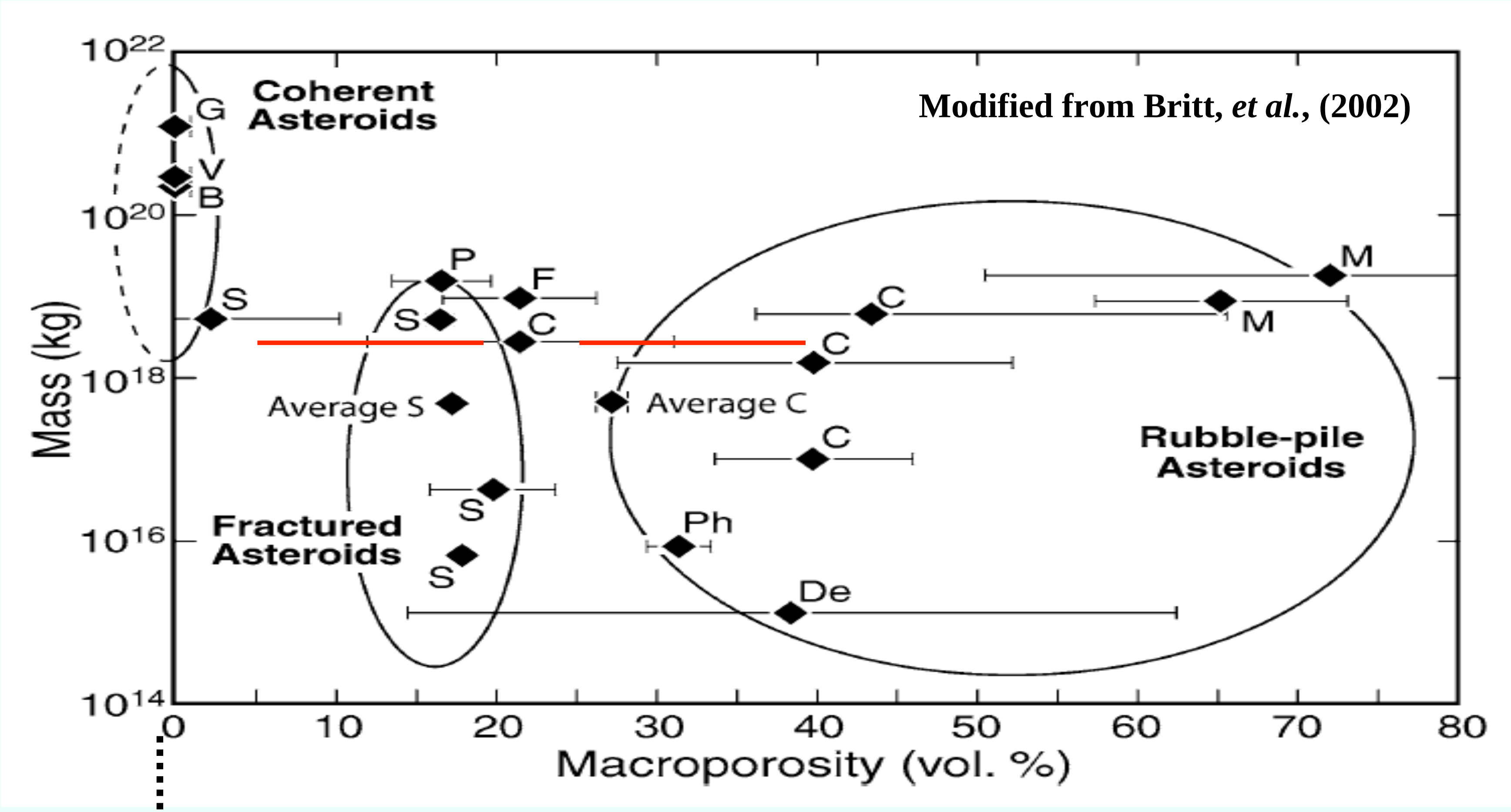
Bulk Density：1.9 ± 0.13 g/cm^3

Macro-porosity = 40%

Ordinary chondrite

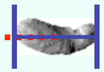
Density ~ 3.2 g/cm^3

Macroporosity of Itokawa



3.51 x 10^{10} (kg)

Itokawa (S)



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

Mission

- From now on -

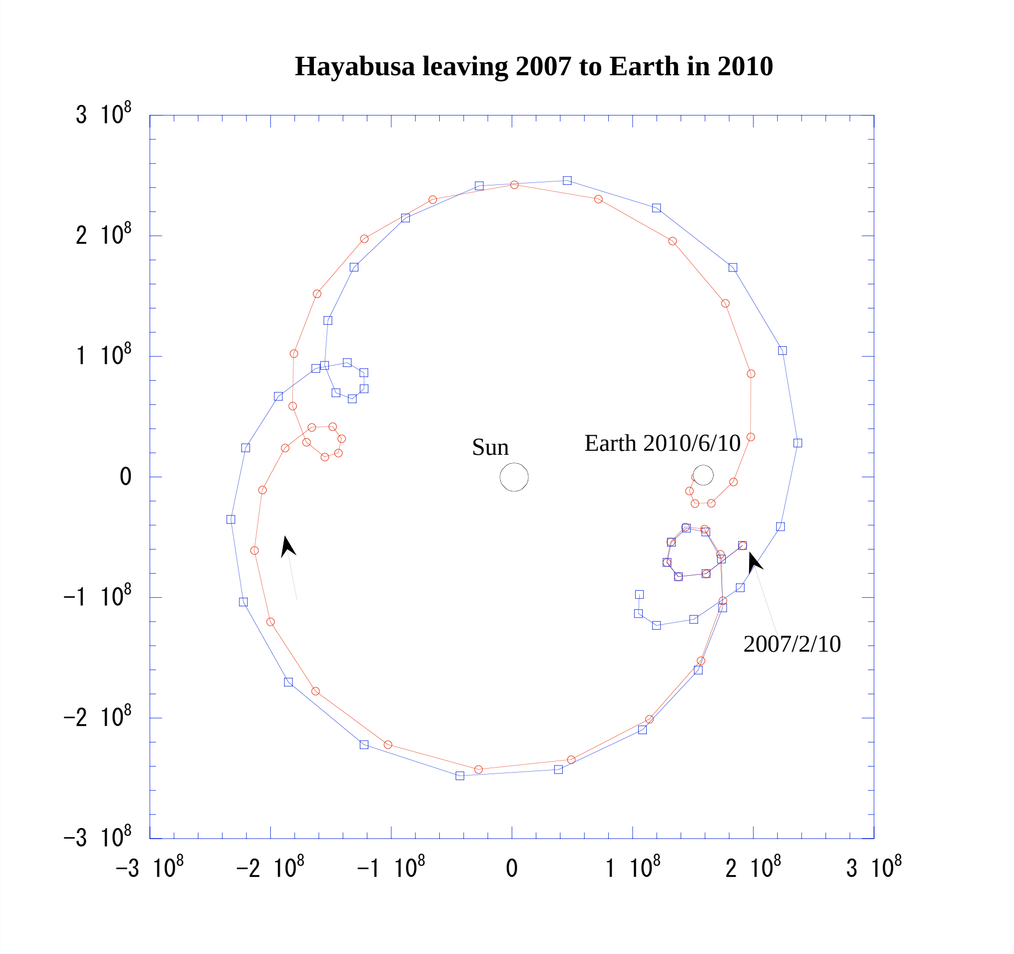
Current Status

Current (July 2007) status is as follows:

- The chemical thrusters cannot be used.
- Two out of three reaction wheels are broken.
- The ion engines are OK.

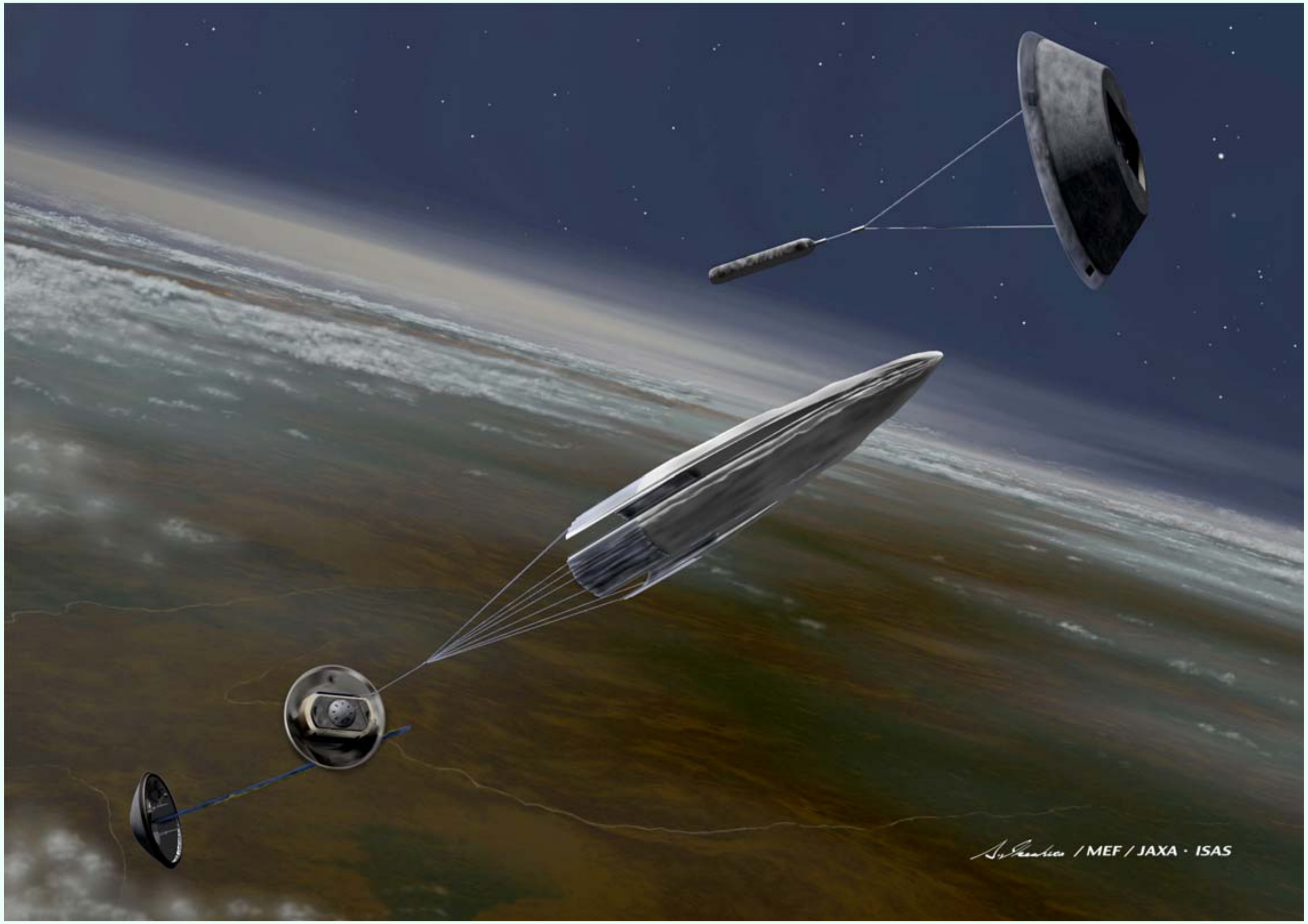
- Orbit control : by the ion engines
- Attitude control : by one reaction wheel, the ion engines, and the solar radiation pressure

Return to the Earth



- New trajectory (red line) leaving Itokawa vicinity in April 2007, returning to Earth in June of 2010 is shown here.
- The Xenon gas consumption meets the current amount that remains.

We hope ...



Scientific Results

- short summary -

Fundamental Parameters of (25143) Itokawa

Ground-based observation

Rotational Period: P = 12.1324 hours

Spin Axis : almost perpendicular to the ecliptic plane, retrograde

Size, shape : by Kaasalainen, by Ostro

Observation by Hayabusa

Size: Principal Axis: X=535 m, Y=294 m, Z=209 m (±1 m)

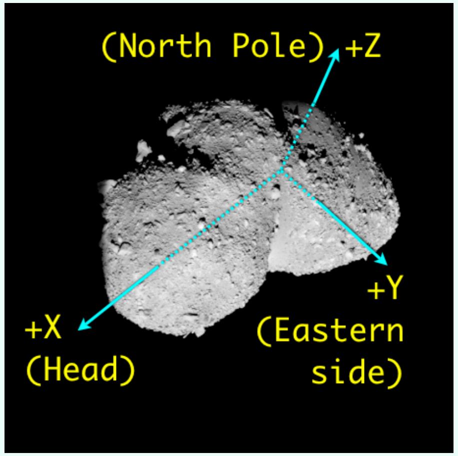
Spin Axis: Orientation in space [β,λ]=[128.5, -89.66]

Nutation is within error range.

Mass: $(3.510 \pm 0.105) \times 10^{10}$ kg

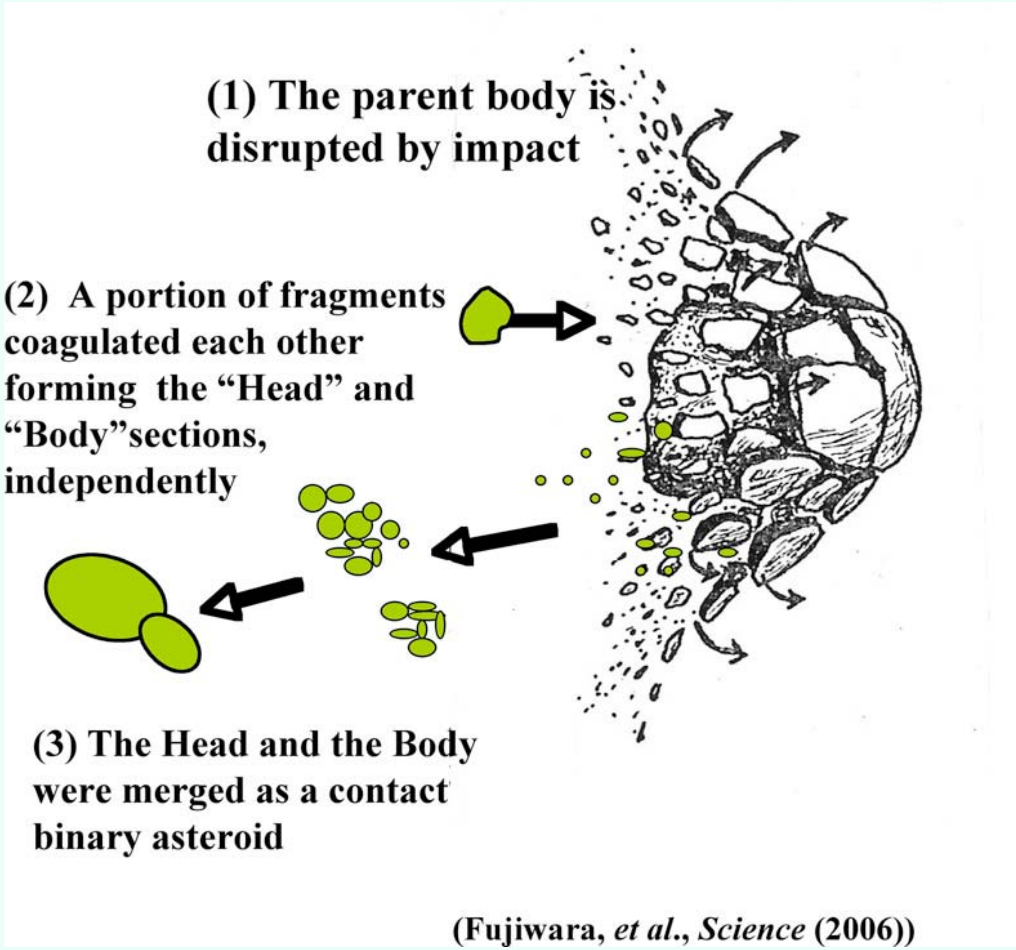
Volume: $(1.84 \pm 0.092) \times 10^{7}$ m^3

Bulk Density: 1.90 ± 0.13 g/cm^3



Formation Scenario of Itokawa

“Rubble Pile” Hypothesis



- **Extremely low bulk density for an S-type asteroid and high macro-porosity of ~40 %**
- **Global shape is round rather than blocky**
- **Surface is covered with many boulders**
- **No large structures extending to the entire body (e.g., long linear ridge found on Eros and Phobos) found**
- **Parts of some facets are exposed on the surface (?)**
- **Slope is generally low (relaxed in many areas)**
- **Large boulders cannot be formed during impacts to result the craters existing now on Itokawa. They must be associated with much larger impact events.**

What Hayabusa found on Itokawa

- Itokawa is the first very small asteroid with clear indications of "rubble-pile" structure.
- Itokawa maybe formed by gravitational coagulation of ejected fragments from a catastrophic disruption of its large parent body by an impact.
- Itokawa is the smallest body of the solar system that spacecraft ever explored, but it has a lot of features on the surface.
- Itokawa, which is S-type asteroid, is mother body of ordinary chondrite meteorites.
- We saw the actual view of a potentially hazardous asteroid for the first time.

Post Hayabusa Mission

Hayabusa-next

Itokawa

S-type : stone

1999 JU3

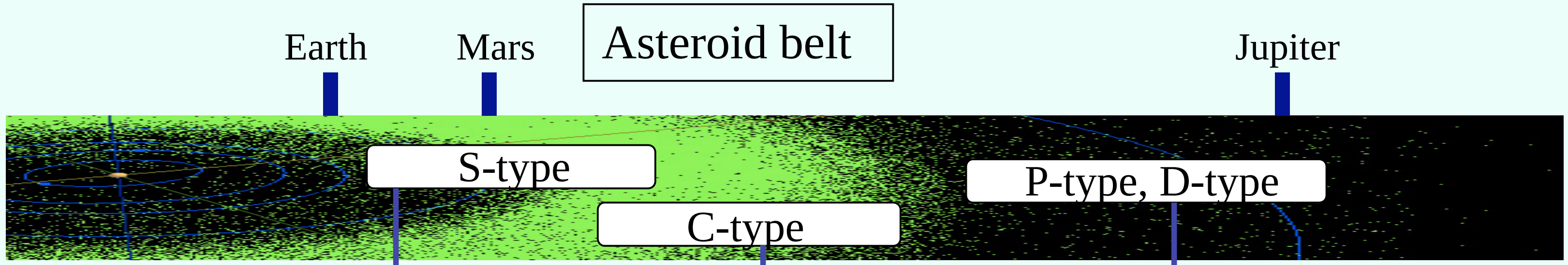
C-type : organic, water-content mineral

Wilson-Harrington

Proposed to
Cosmic Vision of ESA

dormant comet nucleus

Future Plans



S-type Asteroid

- Abundant in the inner part of the asteroid belt
- Relation between the ordinary chondrites
- Origin of planets

C-type asteroid

- Abundant in the outer part of the asteroid belt
- Contains organic matters
- Important information about the origin of life

P, D-type or dormant comet

- more primitive body and no (rare) meteorite related to these objects
- Origin of the solar system

Comet nucleus, trans-Neptunian objects

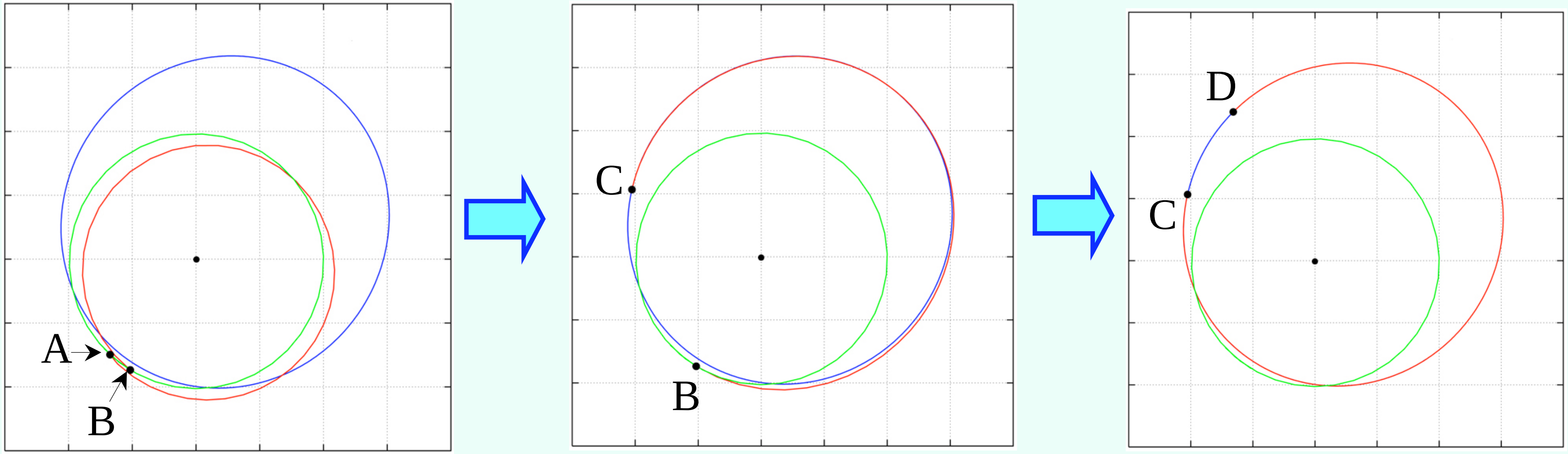
(rather difficult)

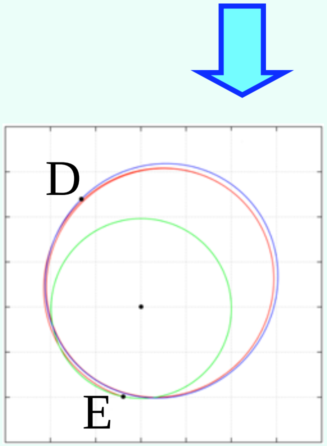
Small World

Gracias!

Information

Orbit of Hayabusa





A: Launch .... May 9, 2003
B: Earth Swingby .... May 19, 2004
C: Asteroid Arrival .... Sept. 12, 2005
D: Asteroid Departure ... Feb. 2007
E: Earth Return .... June 2010

(Hayabusa:Red, Itokawa:Blue, Earth:Green)

Orbital Evolution of Itokawa

Past

Inner edge of the asteroid belt

Secular resonance ν6, or Mars encounter

Present

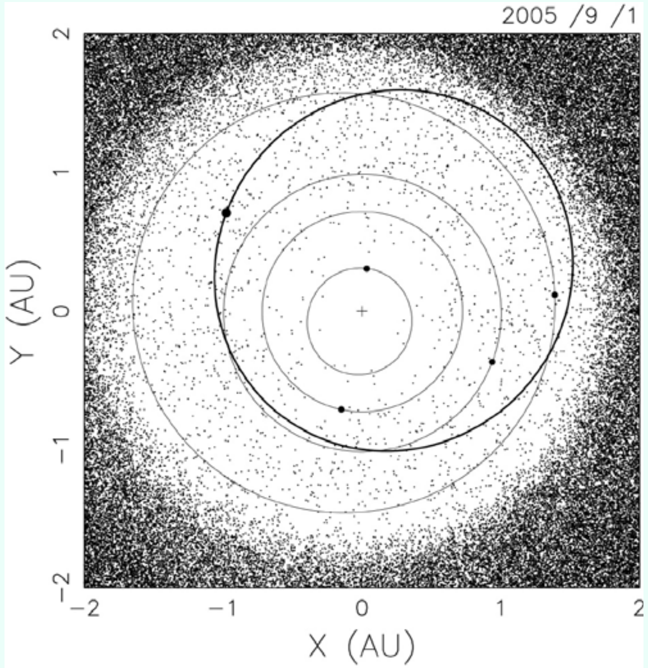
Apollo type orbit

Chaotic motion

Future

Collide with the sun or inner planets

Collision probability with the Earth is about once in one million years.



by P. Michel and M. Yoshikawa

Chaotic Motion of Itokawa