Dawn of the Age of Solar System Exploration

- HAYABUSA, Ikaros, and Future -

JAXA

Contents of the Presentation

Ikaros

- Solar-powered Small Sail-craft

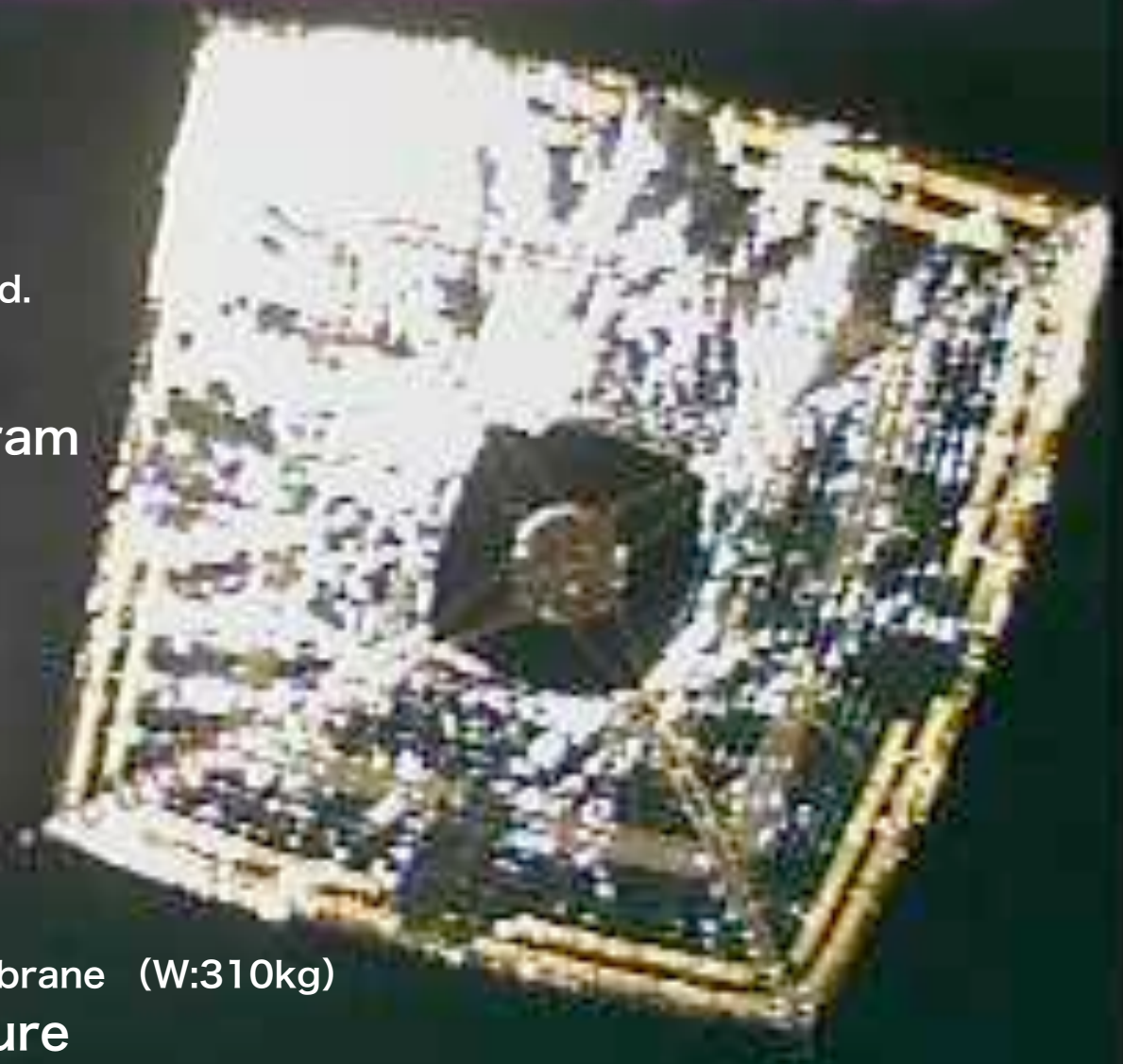
Return of Asteroid Explorer Hayabusa

- Asteroid Itokawa and Mission Objective
- Hayabusa's Engineering Challenges
- Recovery of SRC

Hayabusa 2
and Future Solar System Exploration

IKAROS : Solar-powered Small Sail Craft

(Interplanetary Kite-craft Accelerated by Radiation Of the Sun)

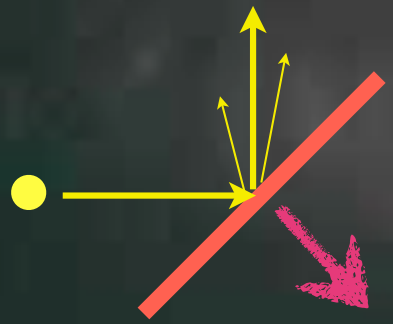


May 21, 2010 6:58 am JST
Launched by H-IIa-17

Acceleration by Solar Radiation confirmed.
6/9 Sail-Membrane Full-deployment
12/8 Venus Swing-by
Accelerated at Thrust = 0.1 gram

Technology Demonstration

for next Hybrid Solar-power Propulsion



1.12 mN Thrust on 14m x 14m Sail Membrane (W:310kg)

※ Solar Wind (Proton) Pressure
less than 1 % of Photon Momentum Pressure (4.57×10^{-6} N/m^2 @Earth)

Mission Objectives of Ikaros

1)**Expand the solar power sail that diameter is 20 meter class, and obtain the characteristic of a sail dynamics.**
2)Generate electric power using the very thin flexible solar arrays attached on the sail, and evaluate their performance.
3)Demonstrate the navigation technology utilizing acceleration generated by photon pressure on the sail.
4)Estimate a length and direction of acceleration vector of photon pressure.

Alfred Gilbert(1854-1934) 1884

Ikaros in the Greek Myth

Ikaros :

- A Young Artist/Carpenter
  confined at the top of a high Tower.
- Tried to escape/fly by constructing Wings
  made from Feathers and Wax.
- Wax meld down due to excessive high flight
  near to the sun.
- Ikaros fell down on the ground
  : Tragic Episode

In Respect for
His Pioneer-Spirit

Ikaros is the world-first
Interplanetary Solar-powered
Sail Spacecraft.

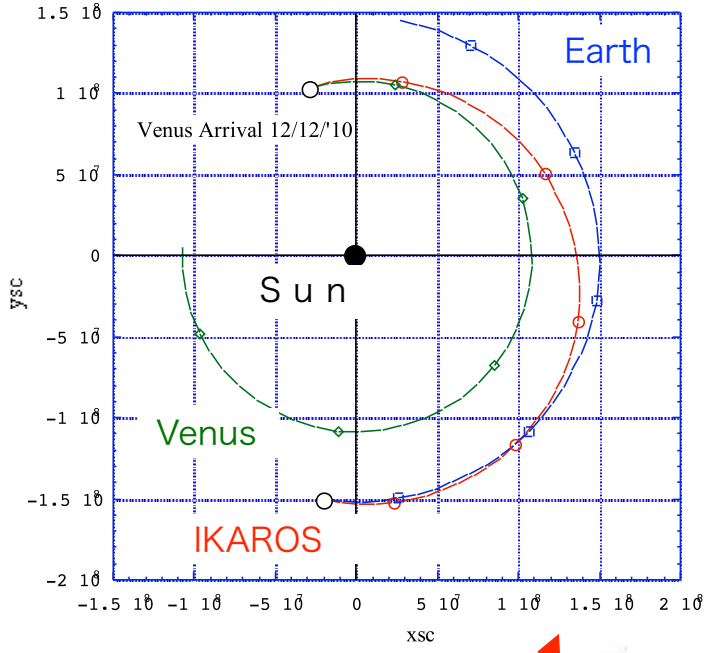
Alfred Gilbert(1854-1934) 1884

About IKAROS

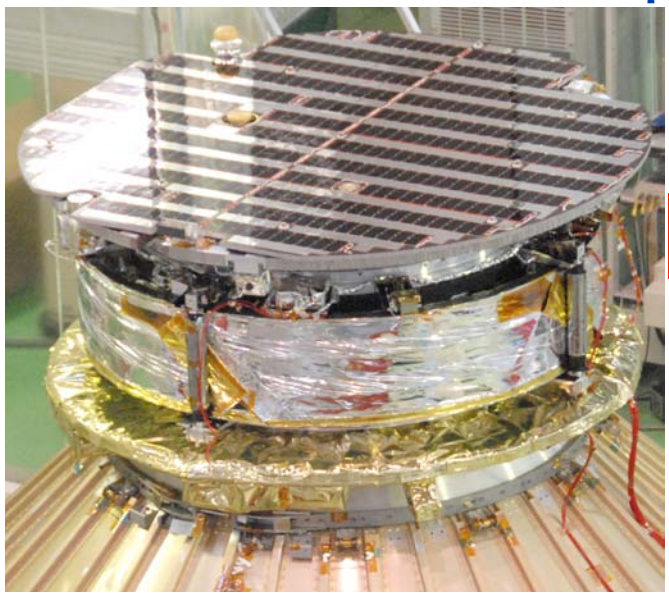
<Major Characteristics>

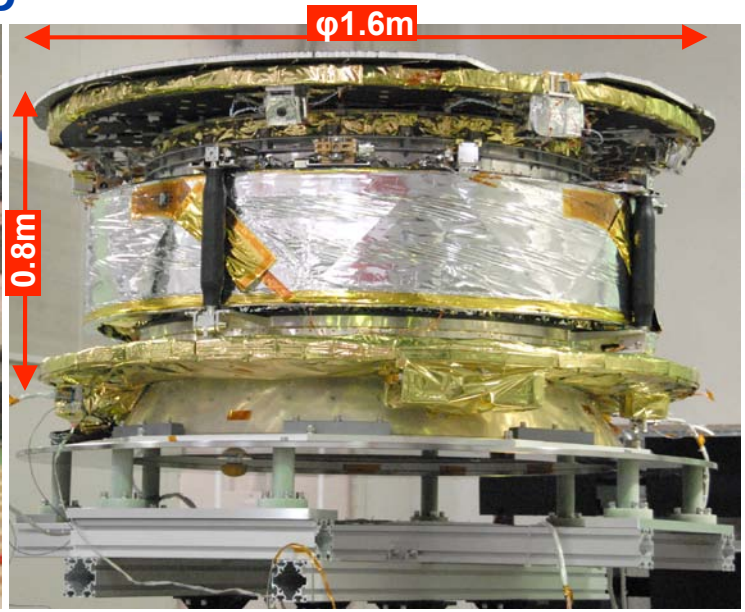
Scheduled launch day:		May 18, 2010 from the Tanegashima Space Center
Launch Vehicle:		H-IIA
Configu-ration	Body:	Diam. 1.6 m x Height 0.8 m (Cylinder shape)
	Membrane:	Square of side 14 m and cross section 20 m (after deployment)
Mass	Launch time mass:	310 kg *Including membrane mass
	Dry mass:	290 kg
	Membrane mass:	15 kg *Including 2 kg of 4 tip masses
Orbit:		Venus transfer orbit
Attitude control system:		Spin

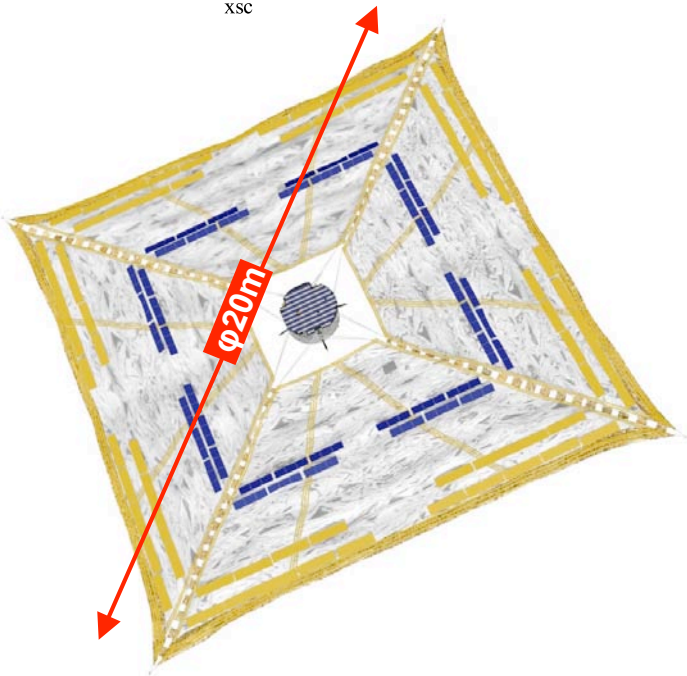
Trajectory Plan



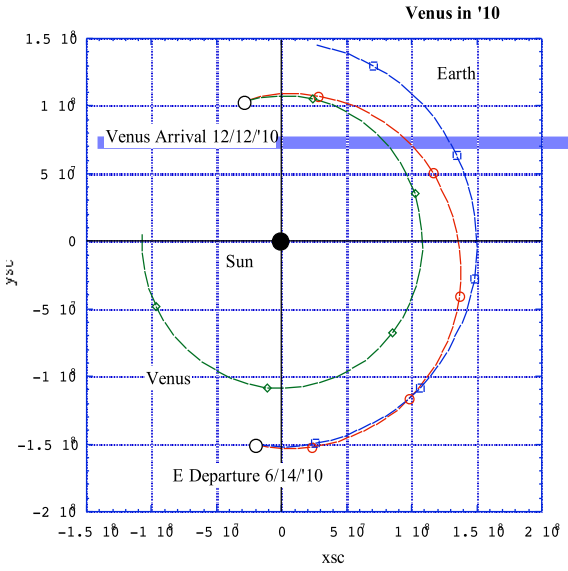
Sail Membrane Rolled up



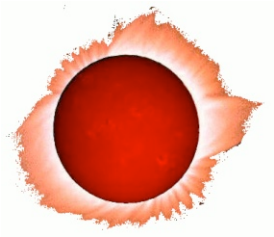




IKAROS Operation Scenario



Trajectory Plan

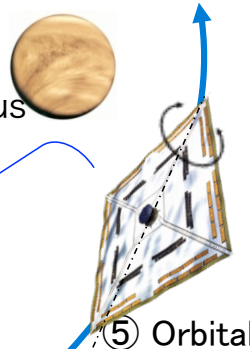


Full Success
(Half a Year)

Minimum Success
(several weeks)

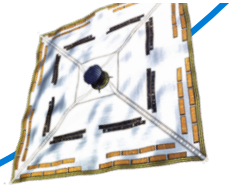
Earth

Venus

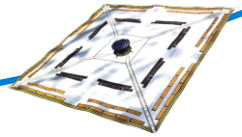


⑤ Orbital Maneuver
Solar Sail (Dec)

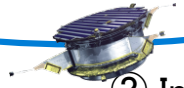
IKAROS



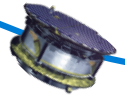
④ Demonstration of
Solar Sail Acceleration
(July 9)



③ Sail Deployment (2.5rpm) (June 2 – 9)
Power Generation
by Thin-film Solar Array (June 10)
Spin Rate (1-2.5rpm)

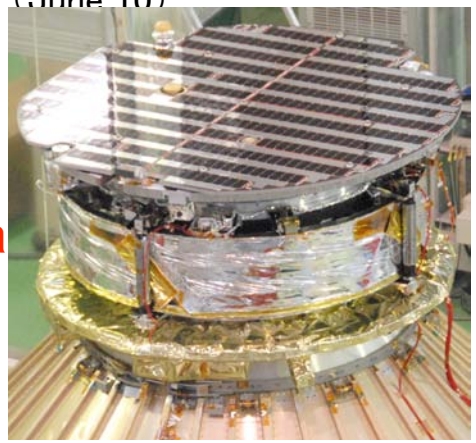


② Initial Check
Spin-up (25rpm)



① Launch (May 21st)
Sun-directed Spin SEP (5rpm※)

Earth

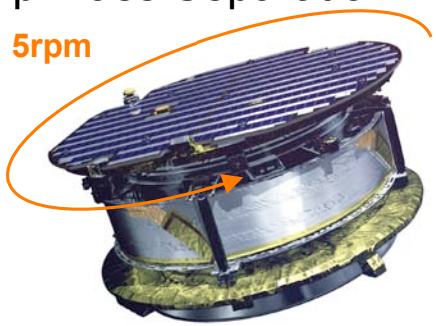


Minimum Success : Solar Sail Deployment and Electric power Genera
Full Success : Acceleration by Solar Sail, Navigation and Control

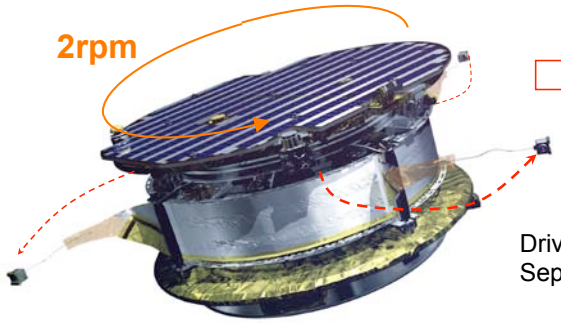
Sail Expanding Method of IKAROS

Tip Mass Separation

Separation from launch vehicle

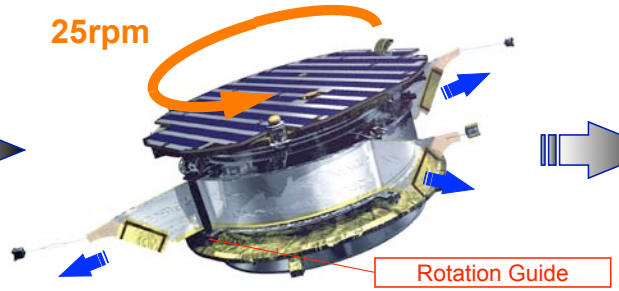


Spin-down

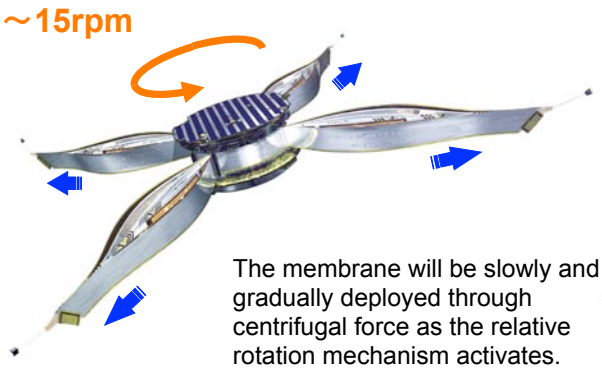


Drive tip mass separation mechanism
Separated all four masses at the same time

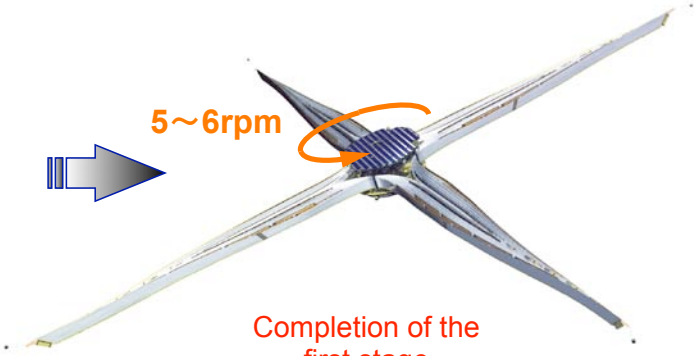
First Stage Deployment (Quasi-Static)



To spin up to 25 rpm, and start the first stage deployment by activating the stopper (rotation guide) that holds the membrane through the relative rotation mechanism

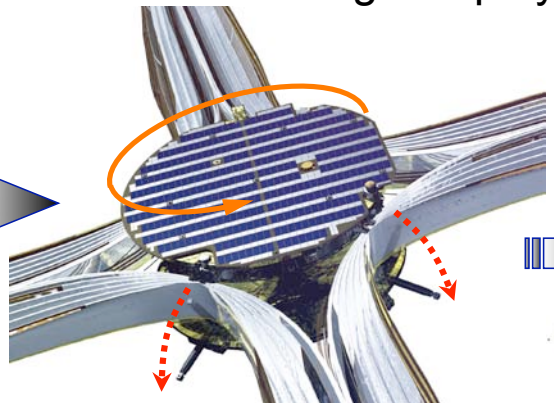


The membrane will be slowly and gradually deployed through centrifugal force as the relative rotation mechanism activates.



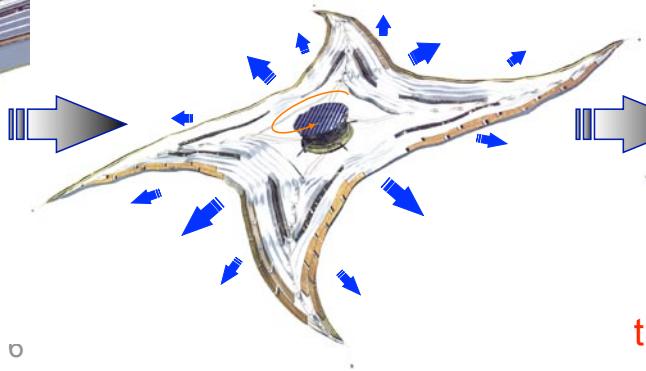
Completion of the first stage deployment.

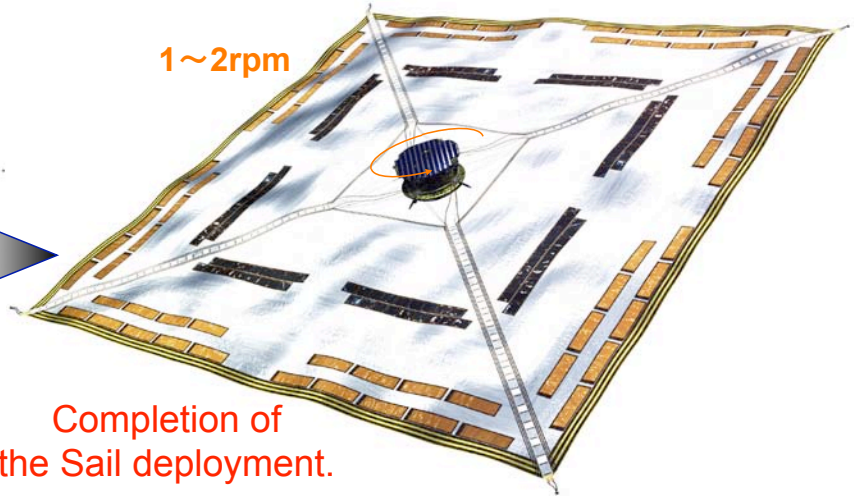
Second Stage Deployment (Dynamic)



Activate the stopper (rotation guide) and release the hold of the membrane to start the second stage deployment.

As the membrane is released, it will deploy dynamically.

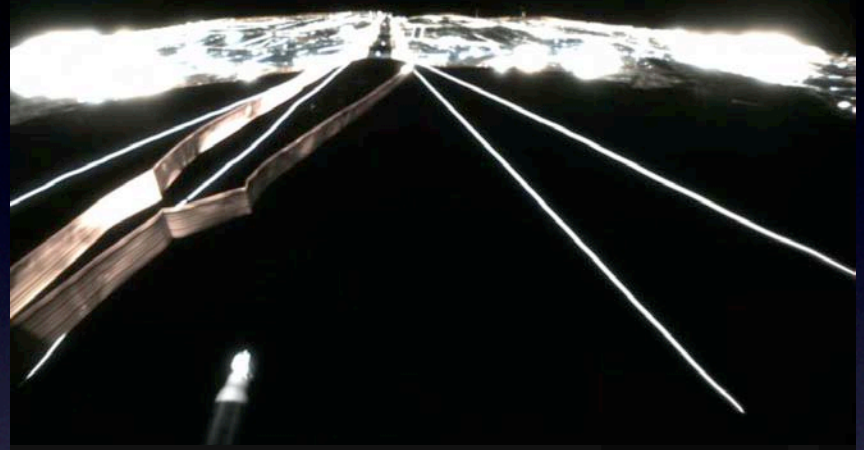




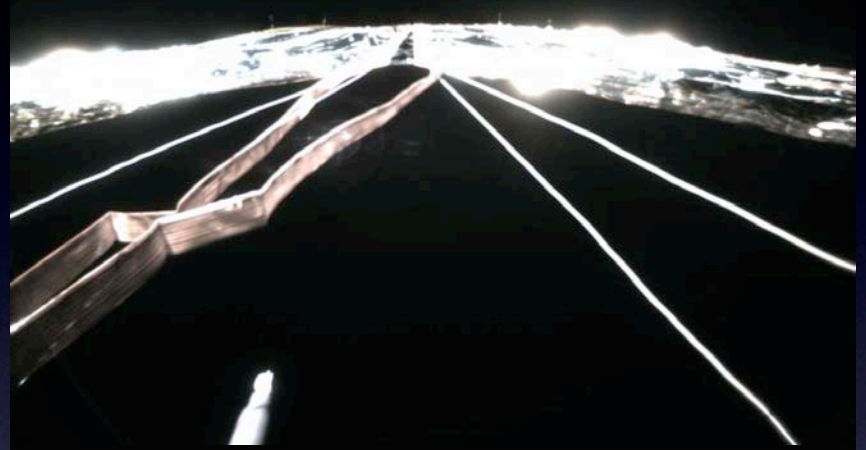
Completion of the Sail deployment.

Monitor Camera Image @2nd-Stage Deployment

After Second Stage Expanding (CAM-H1)

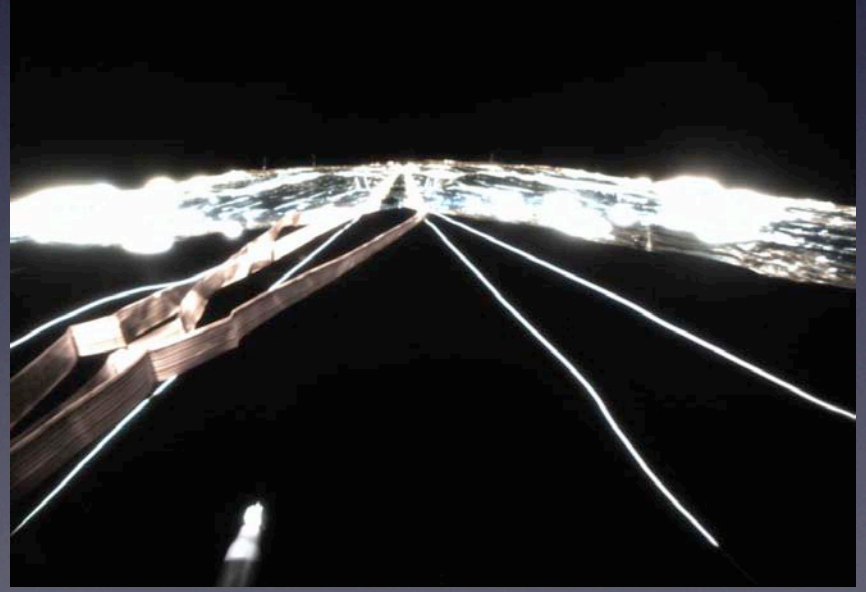


After Second Stage Expanding (CAM-H2)



After Second Stage Expanding (CAM-H3)

After Second Stage Expanding (CAM-H4)



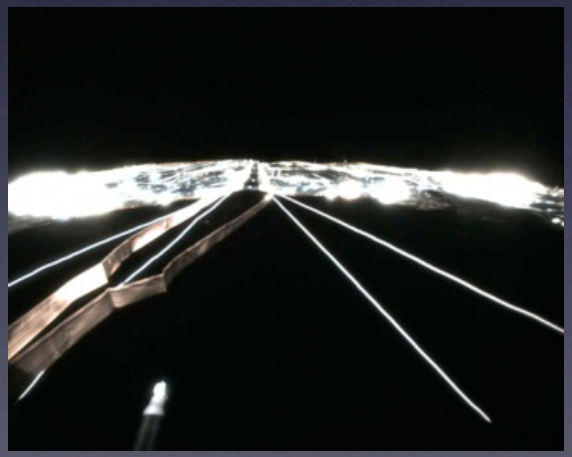
Sail Membrane Deployment (CAMC-Image)

Monitor Camera Image

Tip Mass Separation

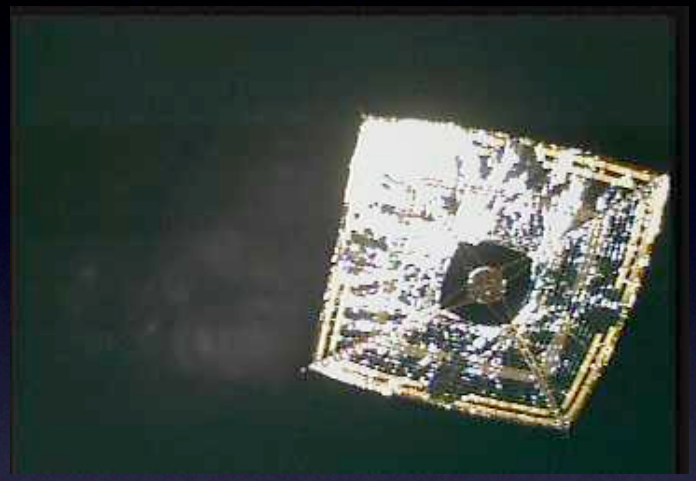
1st-stage Deployment

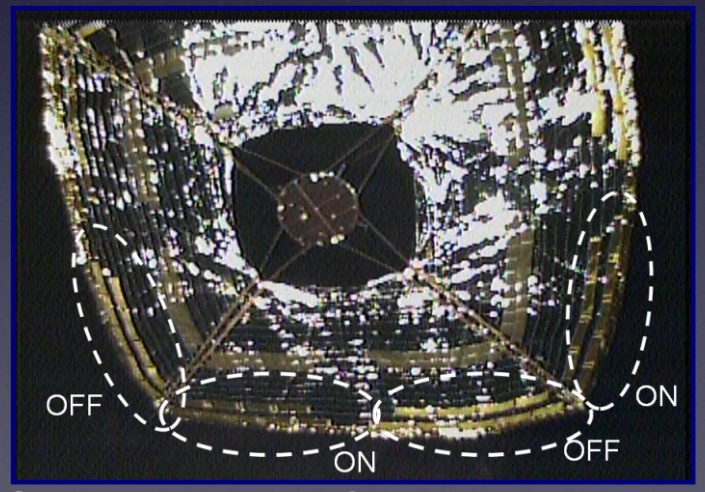
1st-stage
Deployment to 2nd



2nd-stage Deployment

Separated Camera Image





ON: Mirror Ref. Mode
OFF: Diffusion Mode
Operation of LCD

Return of Asteroid Explorer Hayabusa

HAYABUSA Traveled 6 billion km for 7 years

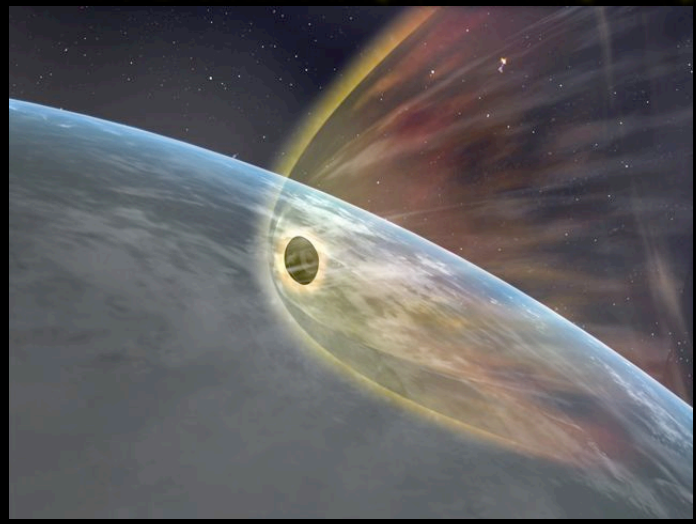
Launch: May 9, 2003

In Search of
Clue to the Origin of Solar Sys.
by Asteroid Sample Return

Touch Down

(2005 10-12)

Return (2010 6/13)



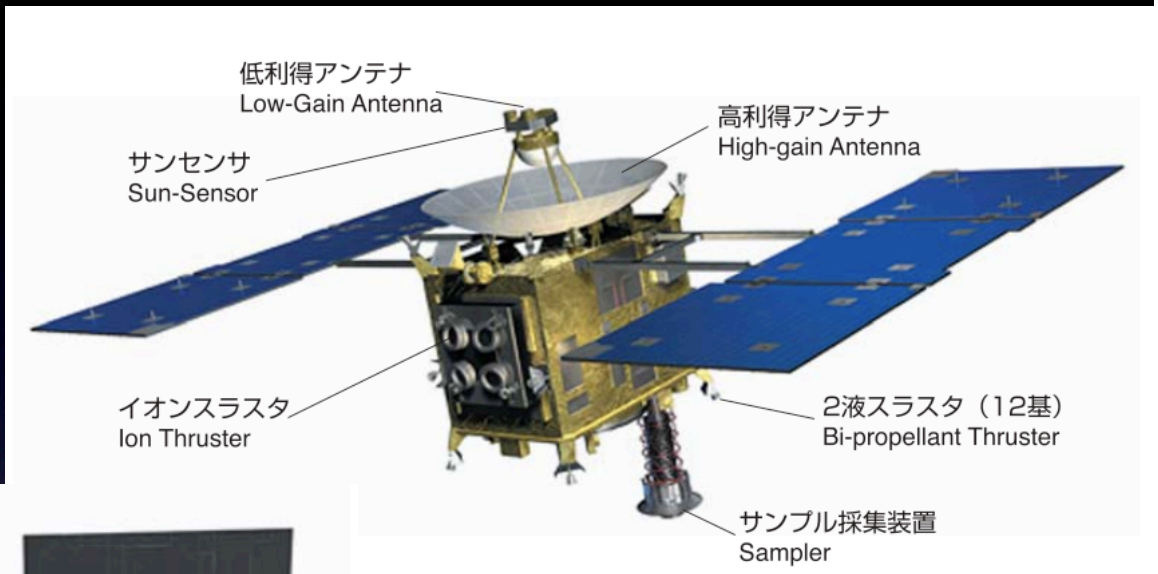
Asteroid Explorer Hayabusa

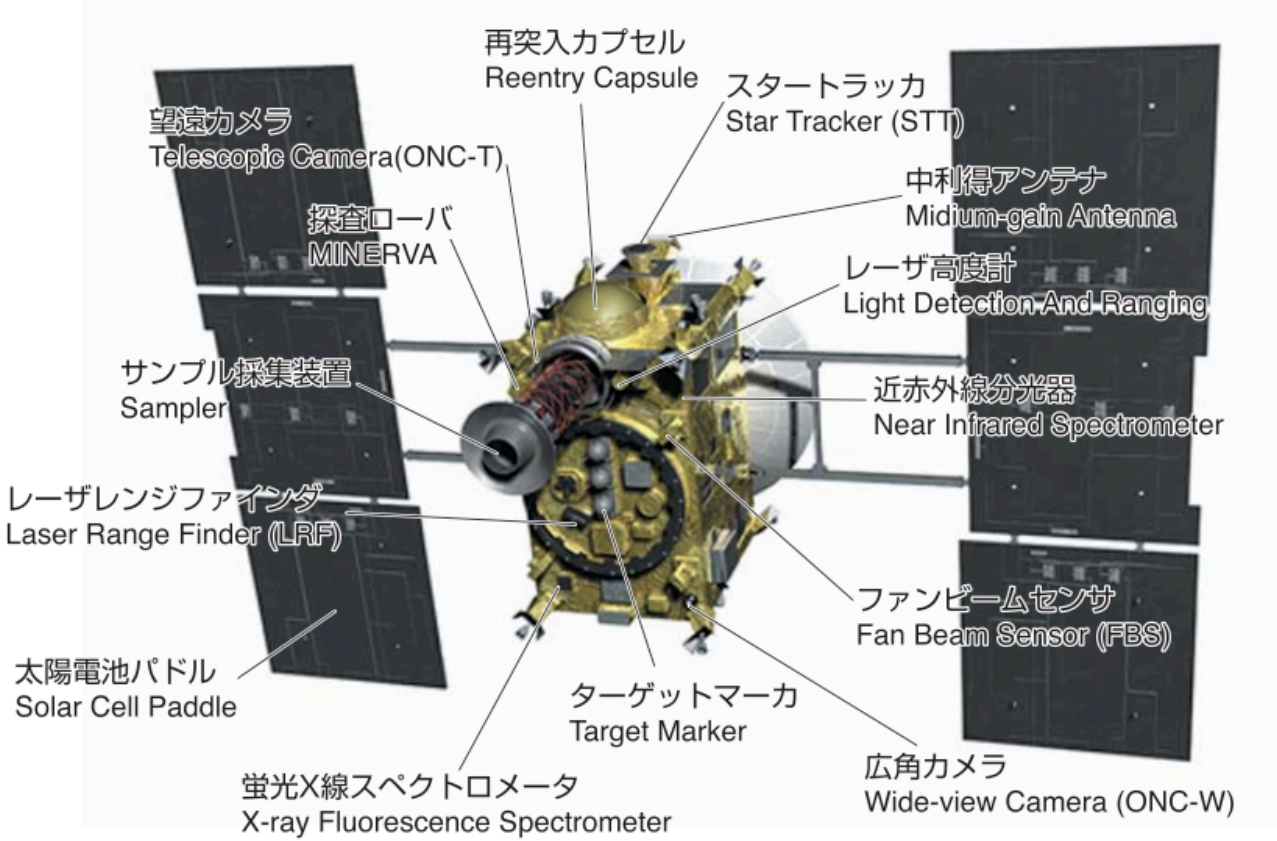
Weight

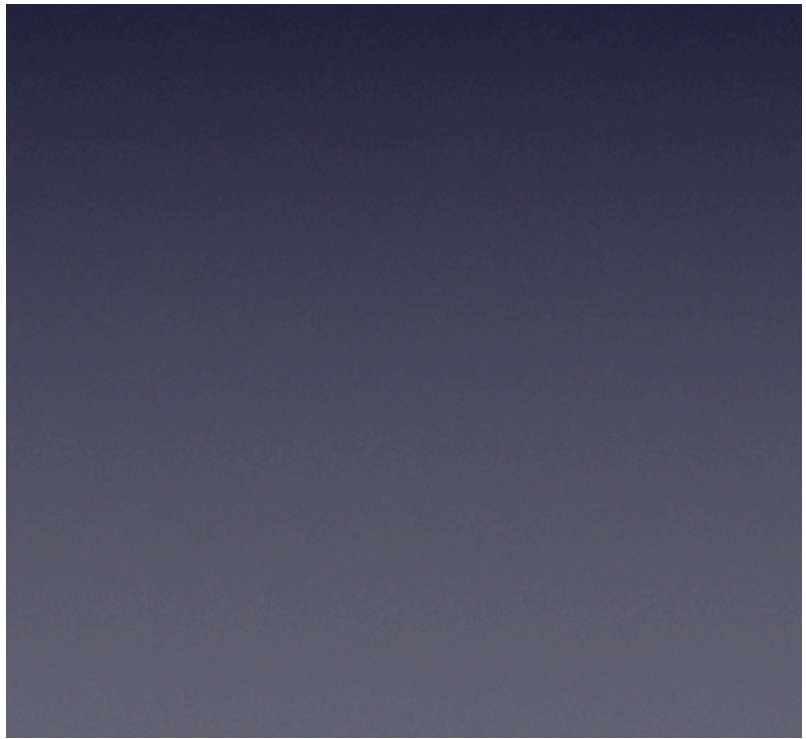
Dry Weight 380 kg
Chemical Fuel 70kg
Xe Propellant 60kg

Total 510 kg

Size：1m× 1.6m× 2m





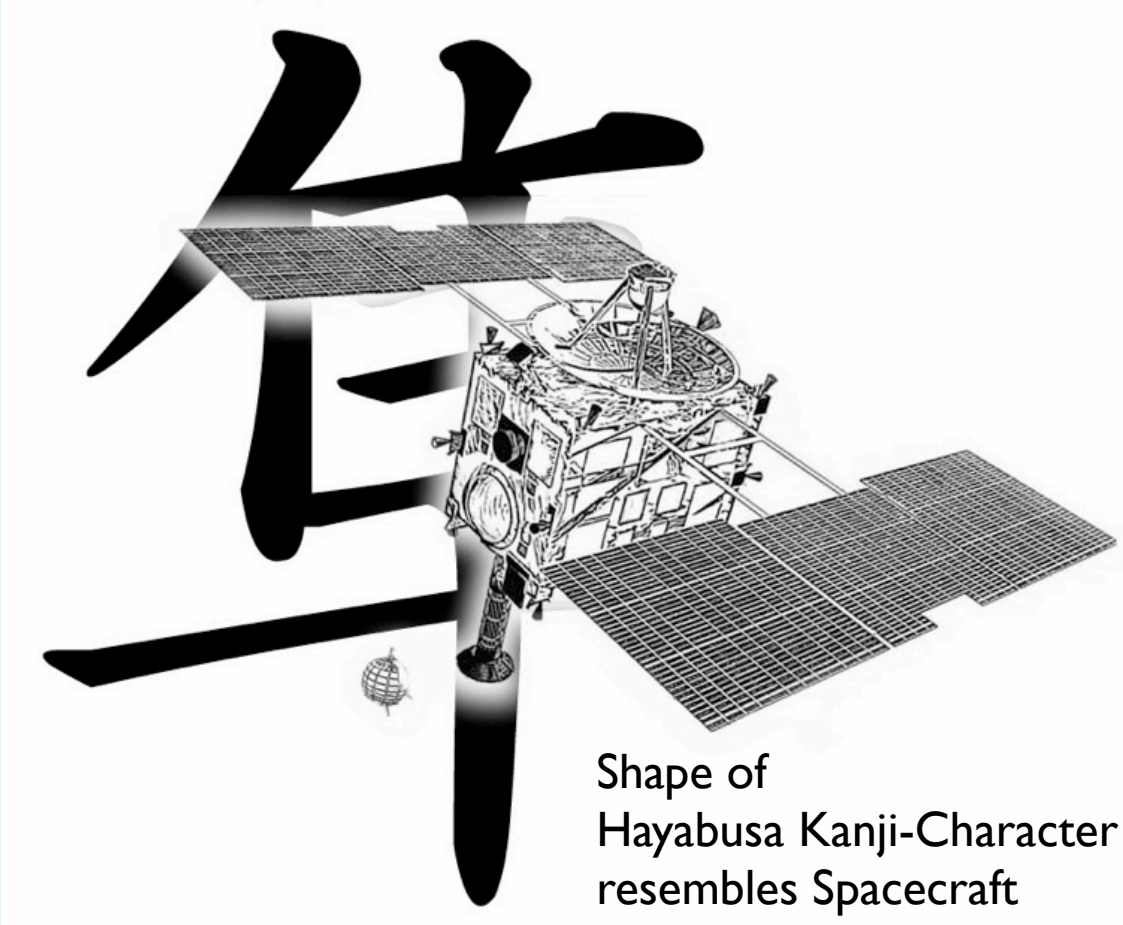


Hayabusa : Falcon

Hayabusa = Falcon

prey upon mice (small animals)

by instantaneous "catch-and-go" from the Sky.



Shape of
Hayabusa Kanji-Character
resembles Spacecraft

Asteroid Itokawa

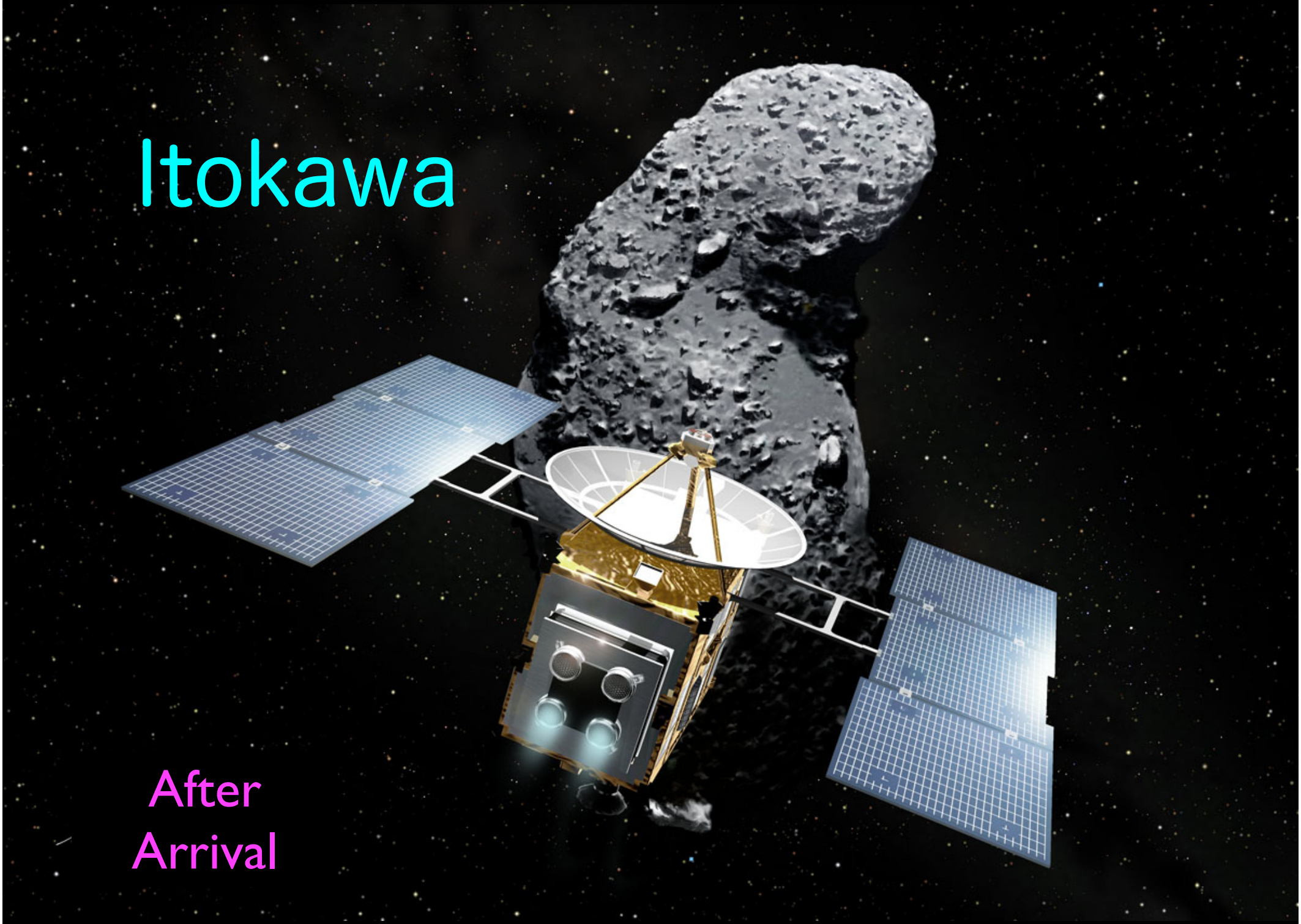
Itokawa

Japanese

Father of Rocket

Prof. Itokawa

before
Arrival


Itokawa
After
Arrival

Small Asteroid

A Clue / Fossil
for the Origin of Solar System

At the beginning
Large Solid Planets formed by
Asteroid's Collision and Combination

Chem. Elements melt-down and
Shuffled inside the large Solid Planets.
=> different fro the original composition.

Small Asteroid still maintain
the original composition at the birth of S.S.

Size of Itokawa

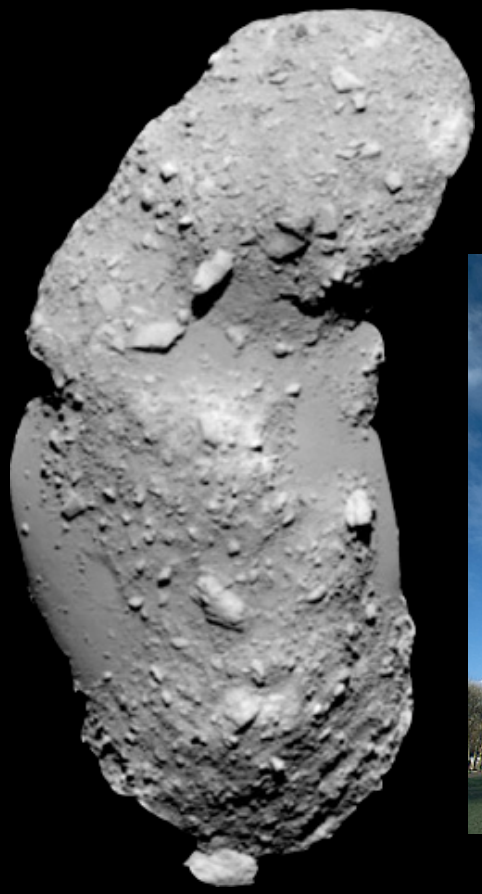
オスタンキノ・タワー

Останкинская телебашня

540 m

Russia, Moscow

535m



La tour Eiffel

324m

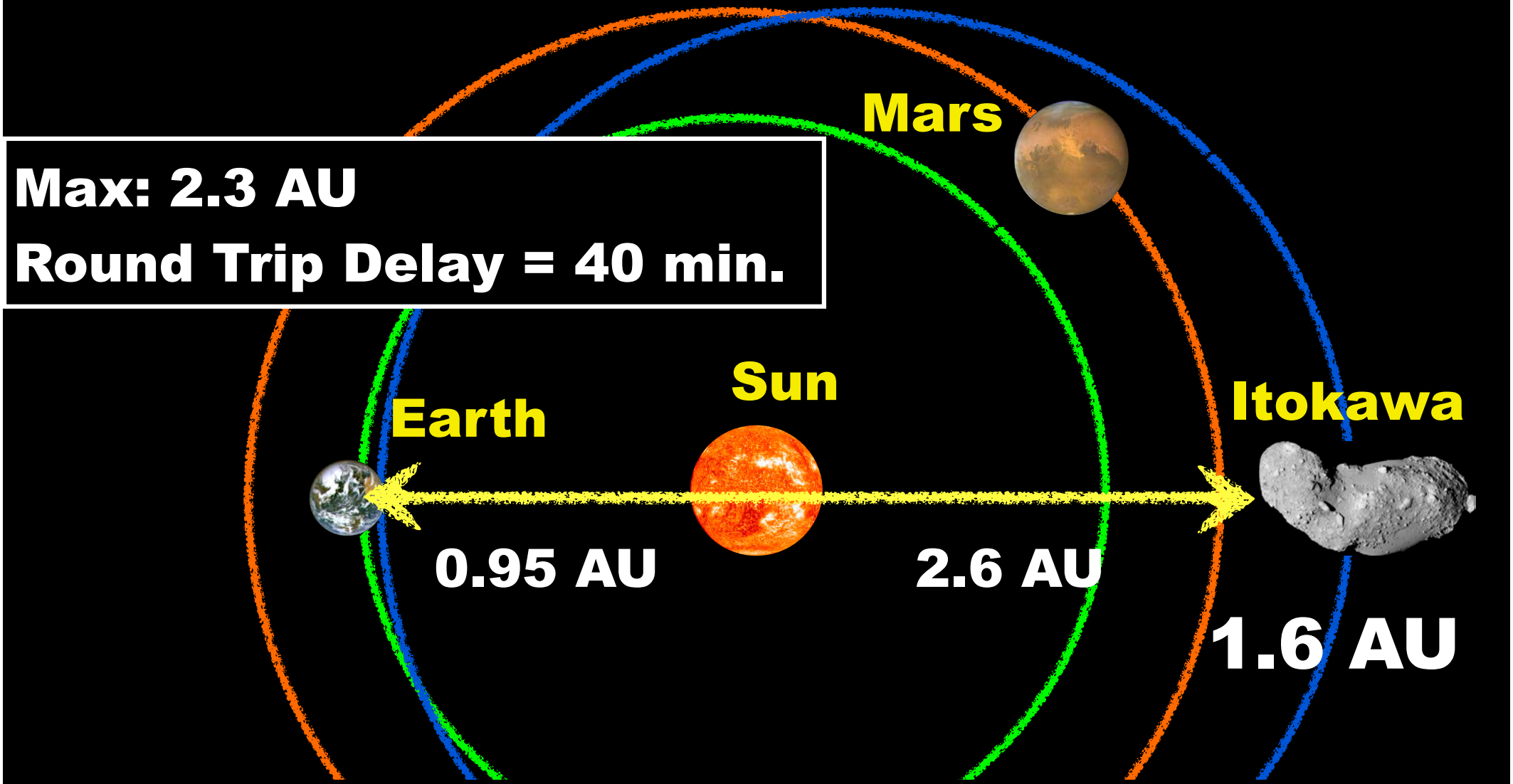
Tokyo Tower

333 m

Le Petit Prince's Star

Gravity is
1/10,000 of
Earth's Gravity

Distance to Itokawa



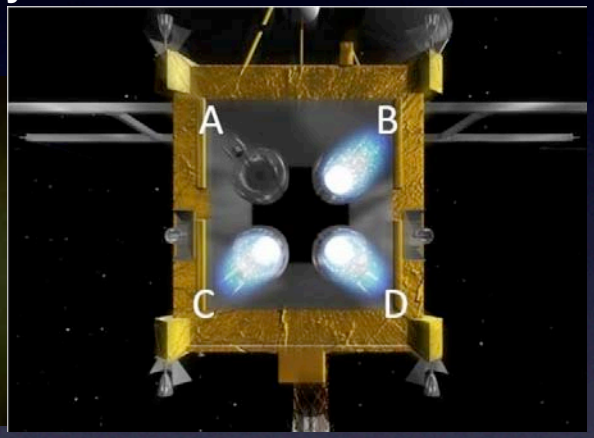
1 AU=149,598,000km = 8_m20_s by light

Hayabusa's Engineering Challenges

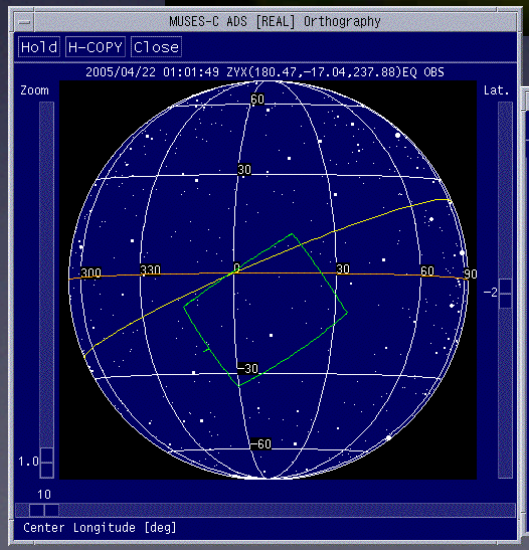
Hayabusa Engineering Challenges

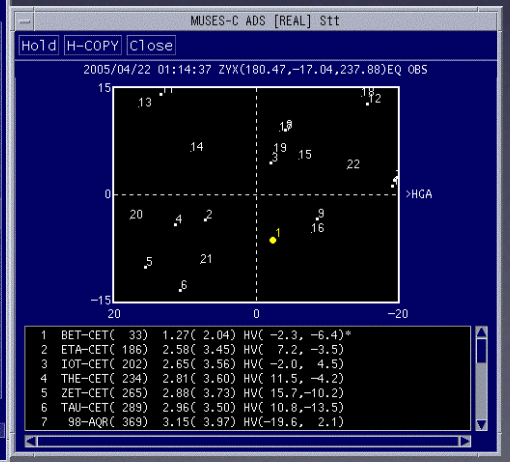
demonstrated :

1. **Interplanetary Cruise via Ion Engines as Primary Propulsion comprising Microwave driven & CC Grid Ion Engines,**
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.**

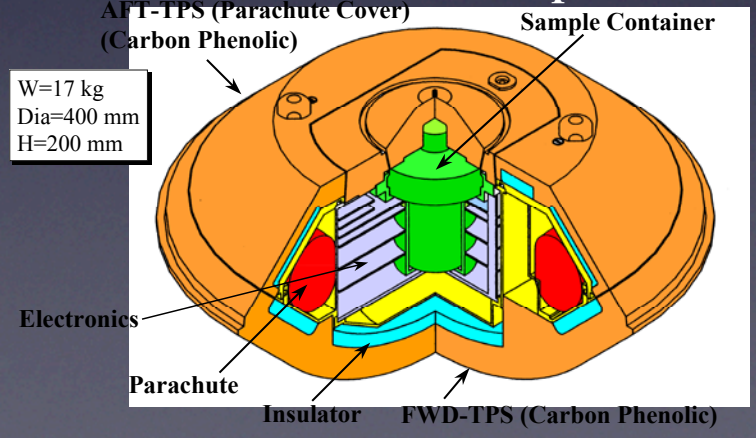


Sampler





Autonomous Navi and Guidance

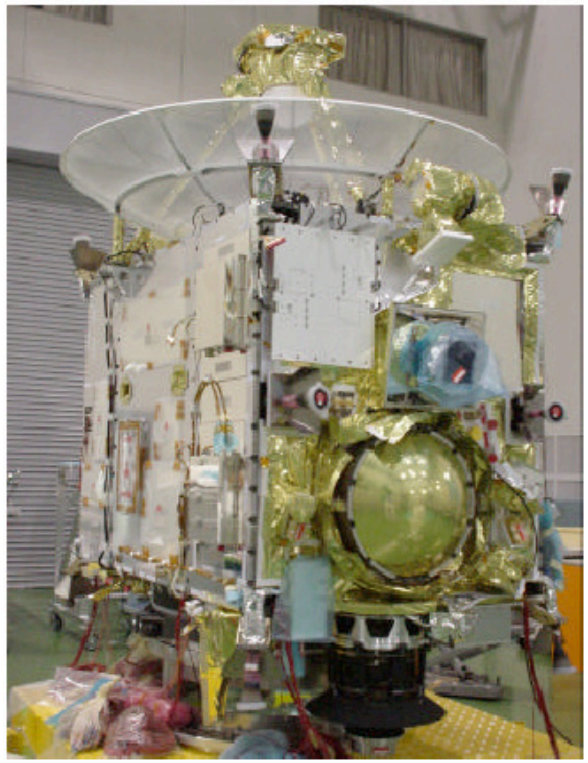


Reentry Capsule

Hayabusa Ready to Launch

Like a Good Shelf (things are put in order !)

+X Axis Panel



-X Axis Panel

Top View

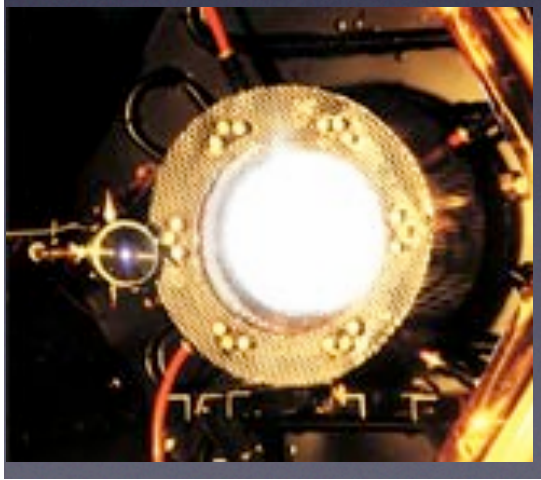
Ion Engine Thruster「μ10」

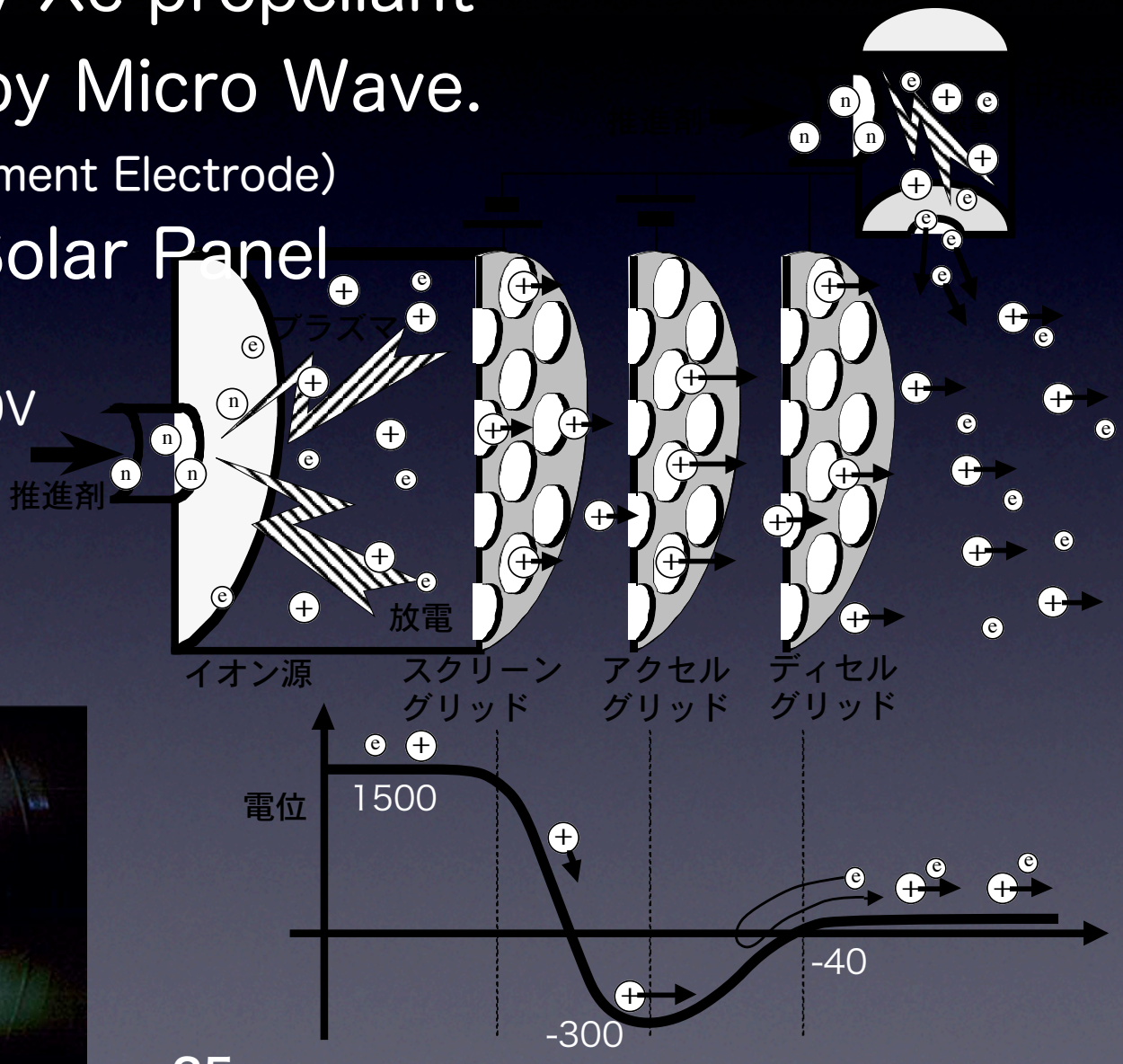
- Electrostatic Acc. by Xe propellant
- Plasma Generation by Micro Wave.

(Long-life expected without Filament Electrode)

- Power supplied by Solar Panel

4.25 GHz　　Acc. Beam : 1500V
8 mN /engin　　30mN/kW
Isp = 2000-3000s
m = 2.5sccm (0.25mg/s)





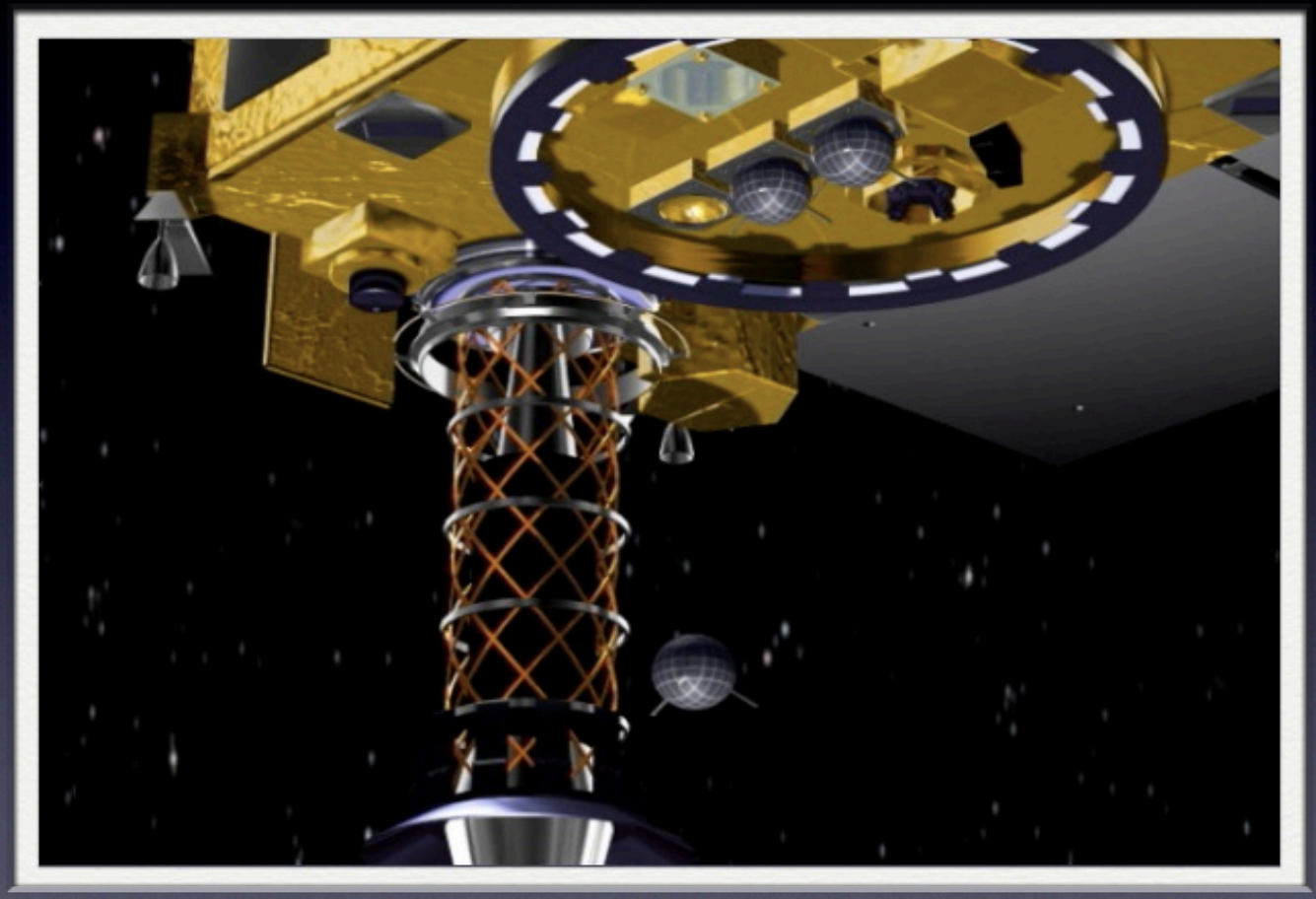
Autonomous Approach and Landing

- Autonmous Descending by means of Laser Altimeters

- Drop a Target Maker (TM) @H=30m
- Slow Descending Checking the TM

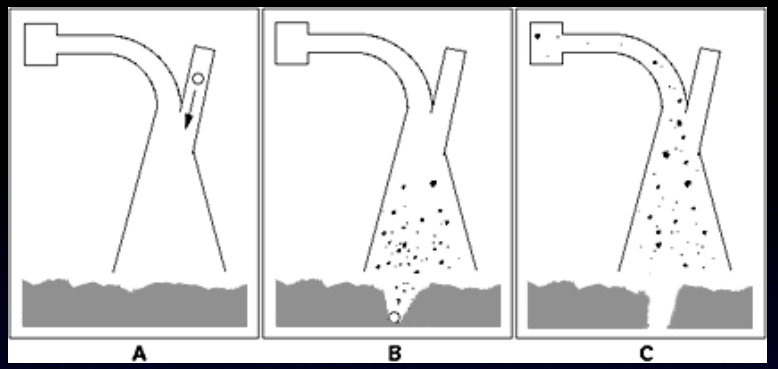
- FBS (Fan-beam Sensors) for measuring Distance and Surface Inclination

- Finally stopping Engines and Fall freely at Slowest Speed.



Sampling

Projectile (several grams)
shot at 300 m/s
(Actually NOT shot)

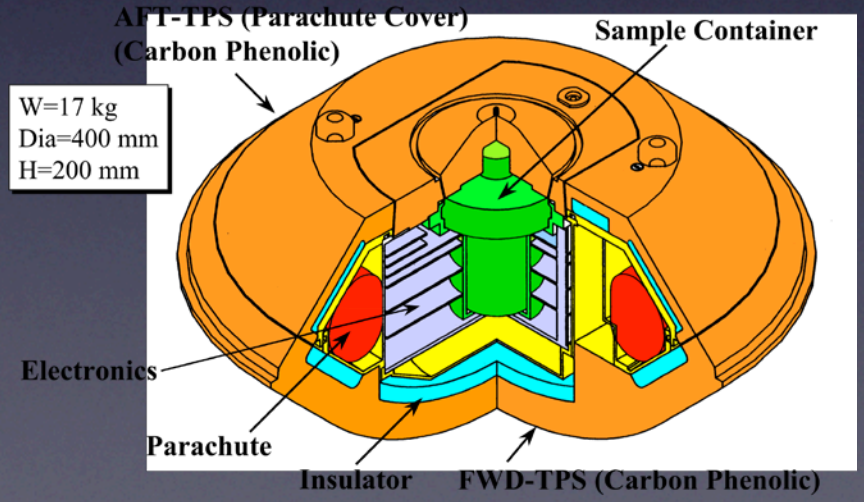


Sample Return Capsule

Tot. W : 510 kg
(Dry: 3580 kg) :
Size 1m× 1.6m× 2m

Diam. : 40cm
Weight : 16.3 kg

Main Body



Major Difficulties occurred since launch

- 2004 Fall: Largest solar flare ever of X25.
- 2005 August: 1st Reaction Wheel was lost.

-- Arrival at Itokawa --

- 2005 October: 2nd Reaction Wheel was lost.
- 2005 November: Fuel leak after completion of 2nd touch down.
- 2005 December: Gas eruption tumbled the spacecraft
  7 weeks of loss of contacts.

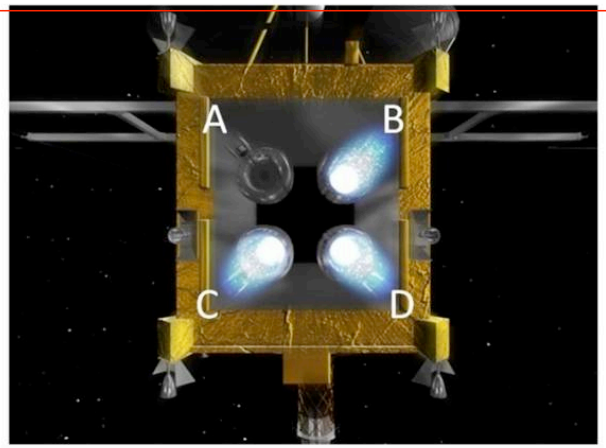
-- Chemical engines function lost, Battery got dead. --

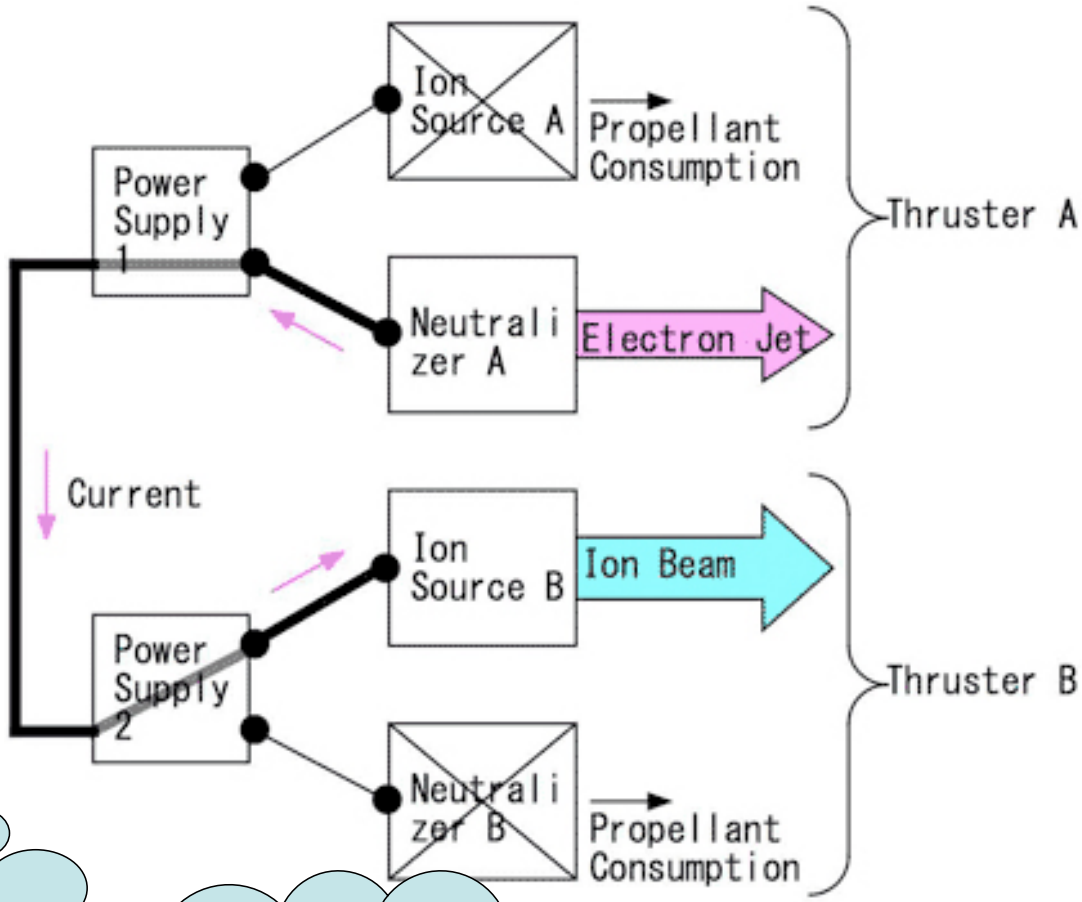
- 2006 January: Restoration, Attitude Control via Xe cold gas jet.
- 2006: Refurbish Operation.
  New Attitude Control via Solar Radiation Torque, Charging Battery
- 2007 January: Closing lid of capsule worked.
- 2007: 1st half ion Engine Delta-V Completed.
- 2009 March-April: 2nd half ion Engine Delta-V started.

Reconfigured Ion Engines Operation Overcoming the Engines End of Life

Thruster D was shut off on November 4, 2009, only half a year before return. All Engines reached the end of life.

Measures :
Neutralizer of the engine-A is combined with the ion source of the engine-B, taking the advantage of Bypass Diode Embedded at Fabrication Process.

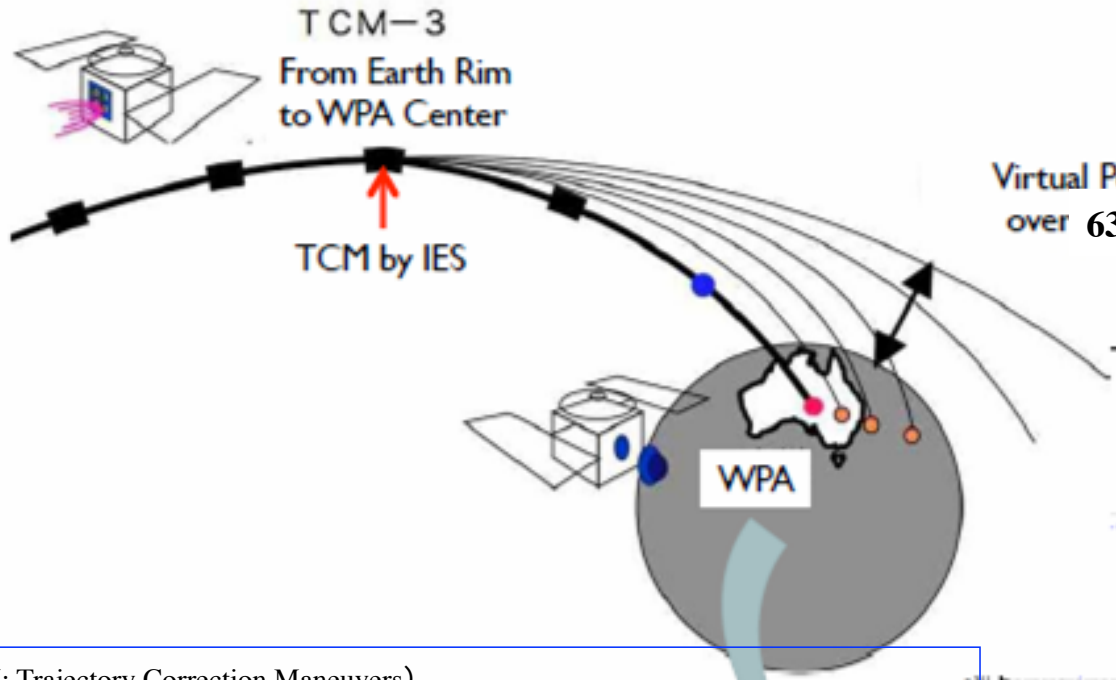




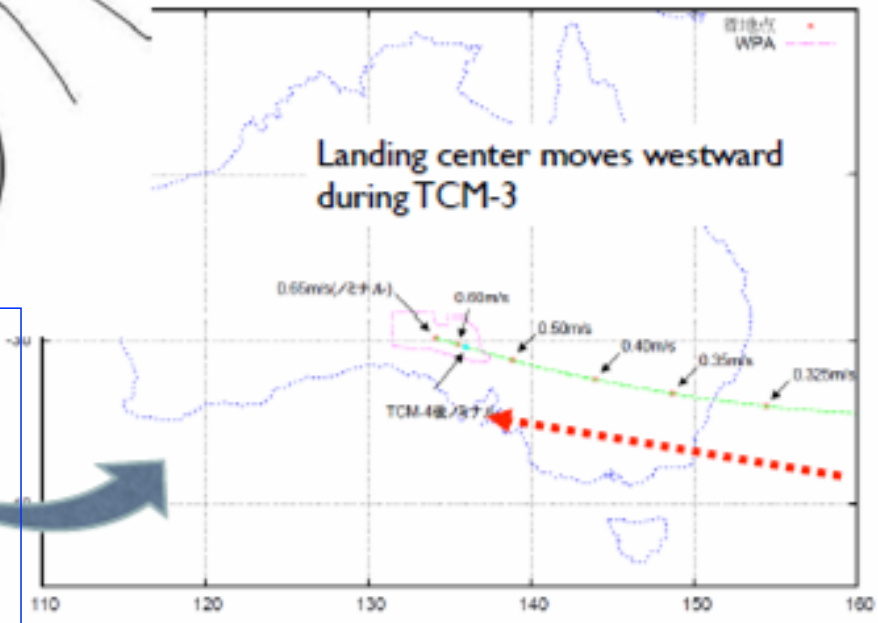
This restoration was achieved by the Ion-Engine Team lead by Kuninaka-san.

TCM－3　(June 3 - 5)

TCM－3：
Combination Operation of Ion Thruster



Virtual Perigee
over **630 km**



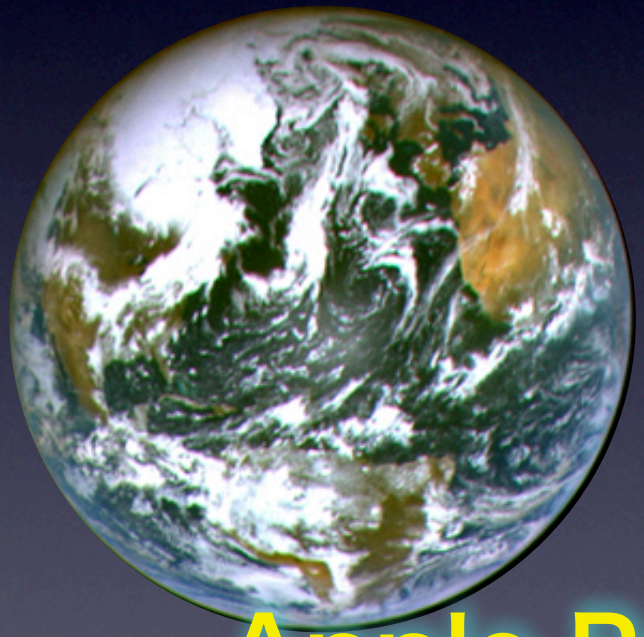
(TCM: Trajectory Correction Maneuvers)

- ❑ TCM-0: 2.1 m/s (41h) Rim Targeting　　4/4 12:00 - 4/6 05:00 (UTC)
- ❑ TCM-1: 3.4 m/s (64h) Rim Targeting　　5/1 11:00 - 5/4 02:56 (UTC)
- ❑ TCM-2: 5.1 m/s (93h) Fine Rim Targeting 630 km　5/22 22:00 - 5/26 18:38 (UTC)
- ❑ TCM-3: 2.8 m/s (50h) WPA Targeting　　6/3 03:00 - 6/5 04:44 (UTC)
- ❑ TCM-4: 0.1 m/s (0.5h) Woomera Targeting 6/9 03:30 - 06:004(UTC)

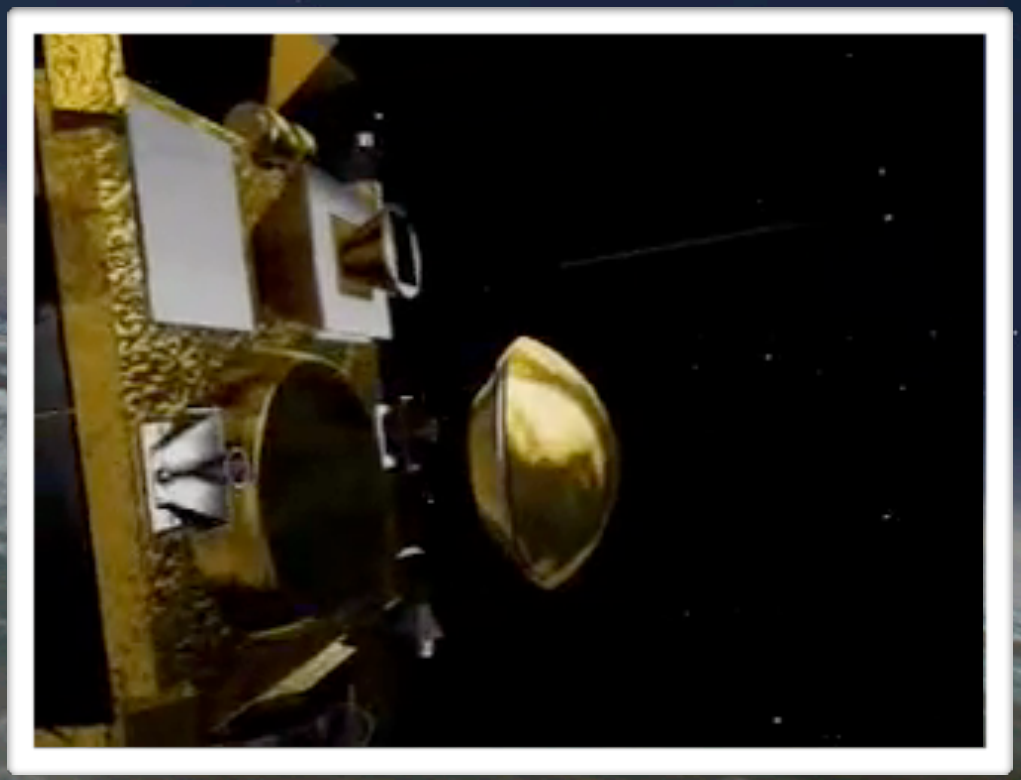
Total 251h.

Earth and Atmosphere vs. Apple and Peel

$$\frac{100\text{km}}{12{,}000\text{ km}} = \frac{1\text{ mm}}{12\text{ cm}}$$



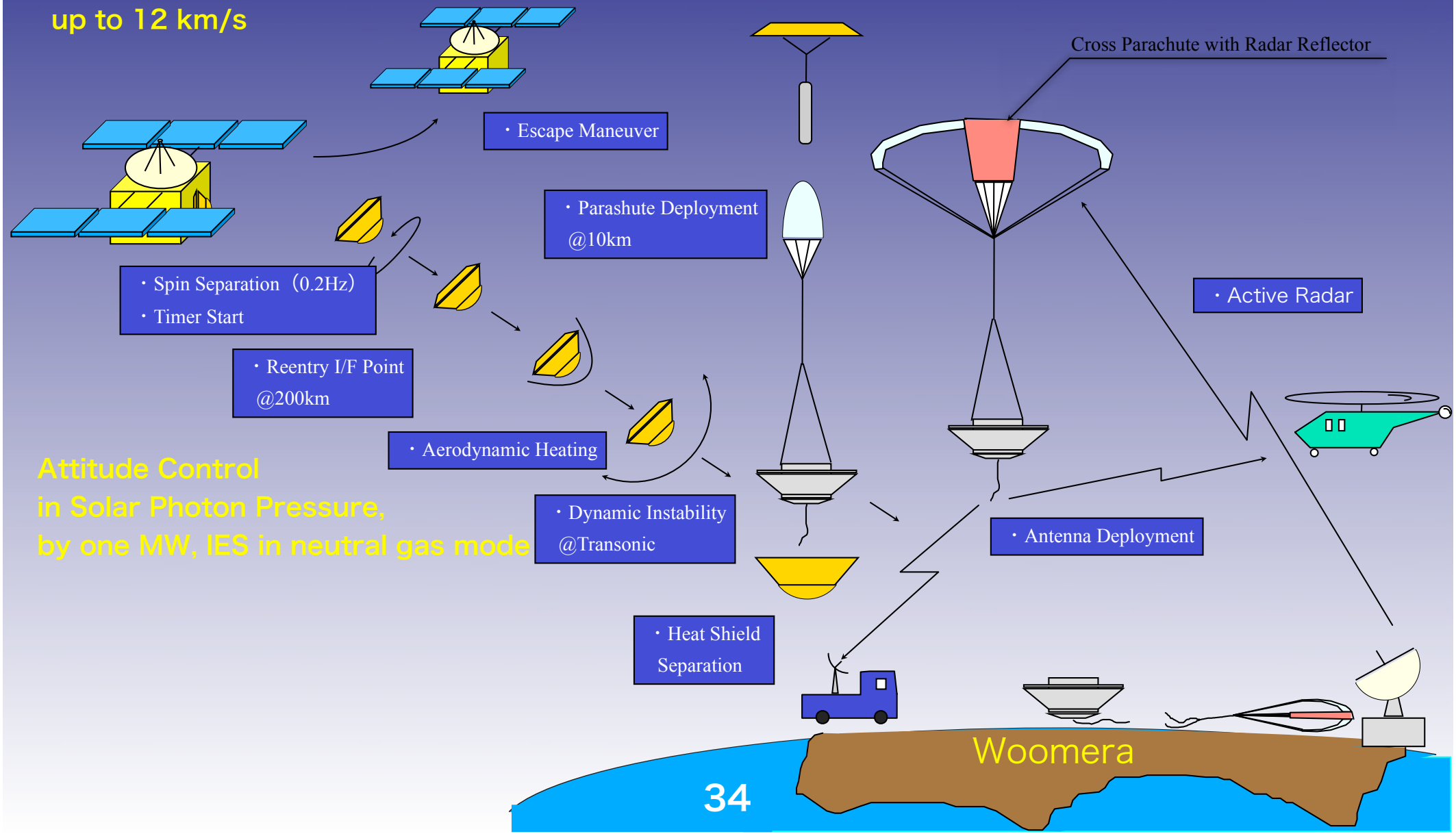
Apple Peel at Saltzburg
shot from Vienna



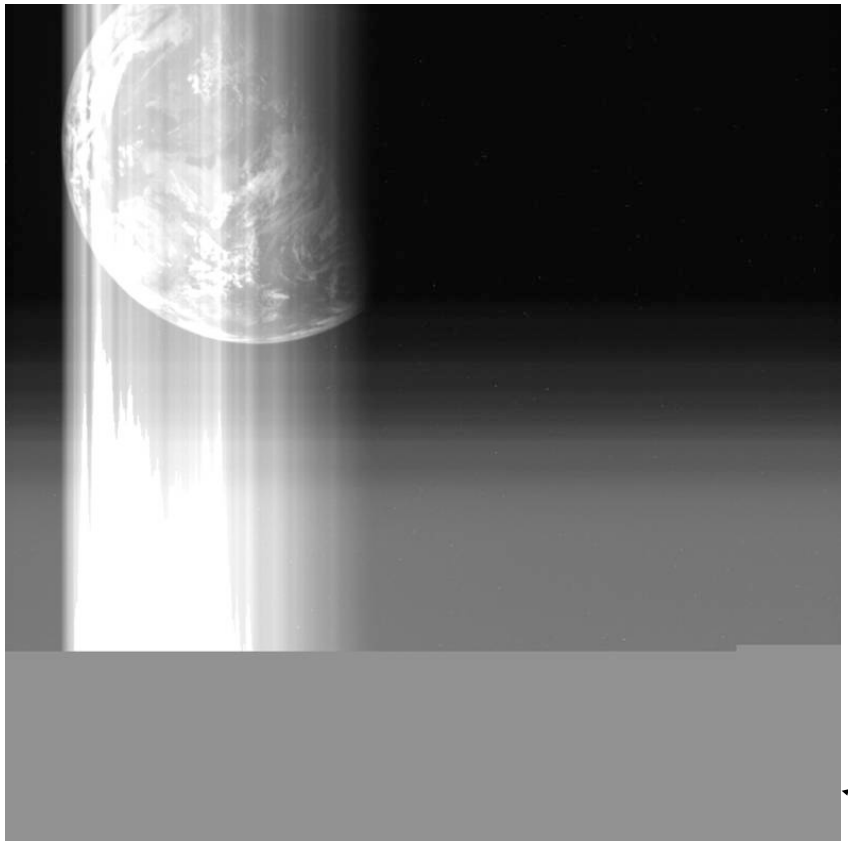
At Midnight June 13, Reentry of SRC on Woomera, SA

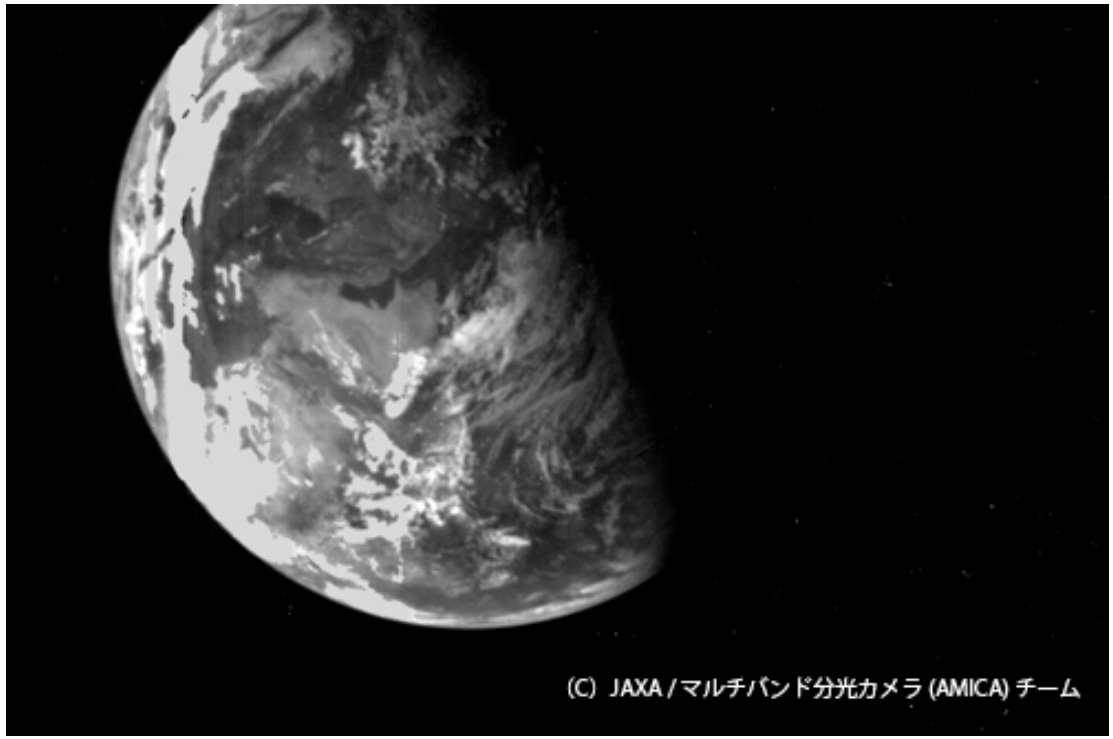
/ MEF / JAXA · ISAS

SRC Reentry Sequence



Last Shot: Wanted to make Hayabusa see its Home.





Could not transmit whole data.

- Capsule was separated 3 hours prior to Reentry.
- Whole team agreed to have this last operation, while the operation is not required once the capsule was separated.
- The photo really made us feel sympathy with Hayabusa.

Reentry of Hayabusa SRC

Hayabusa separated the capsule at 7:51 p.m. and reentered the atmosphere at 10:51 p.m. on June 13th, 2010 (JST)

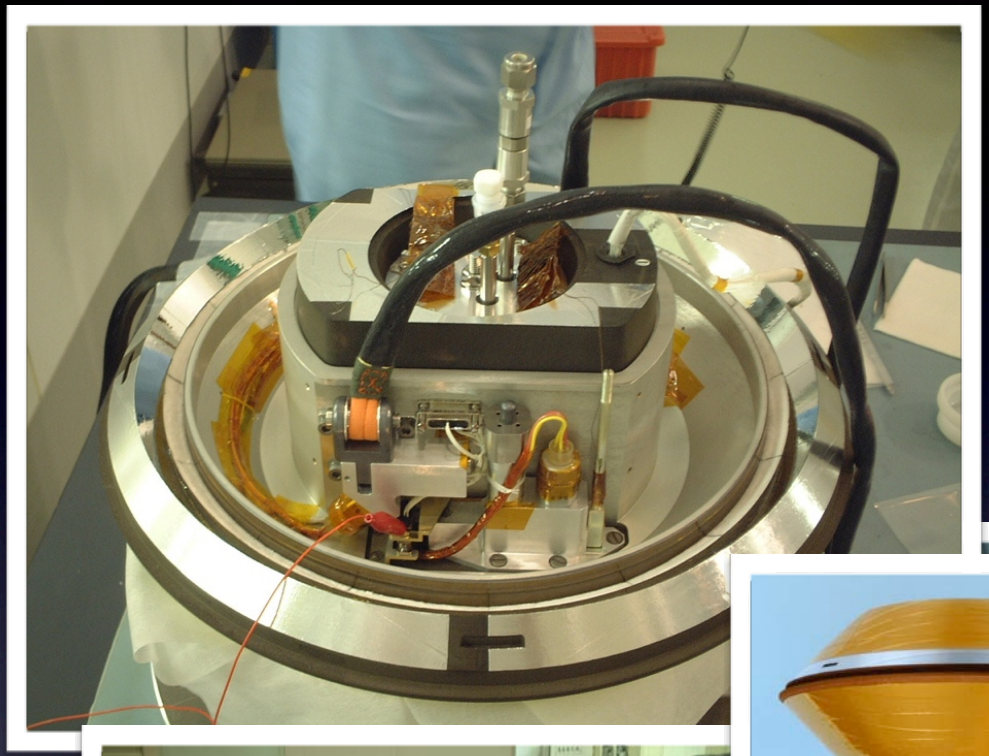
Illustration by 高荷 義之

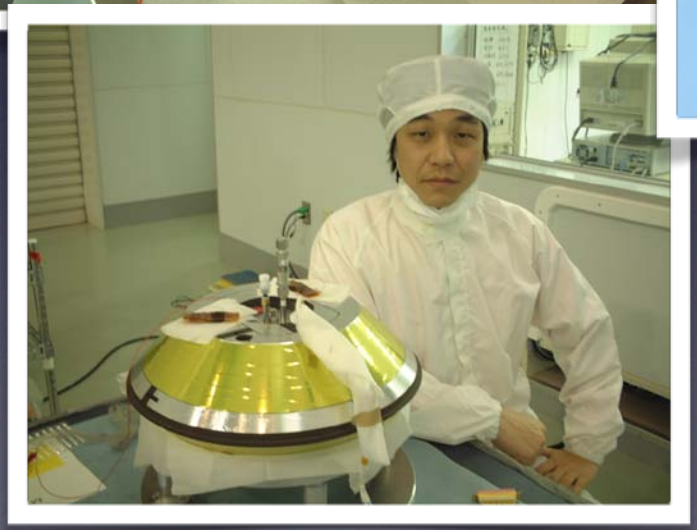
Asteroid Explorer HAYABUSA (MUSES-C) "Reentry"


Discovered and Localized
just within 1 hour !

Recovery of the Hayabusa SRC

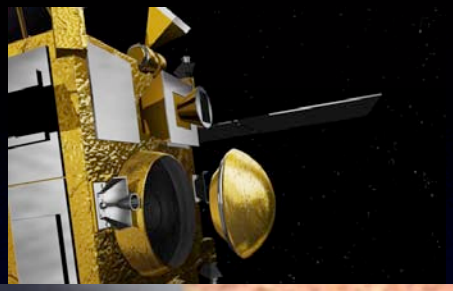
SRC in March/2003

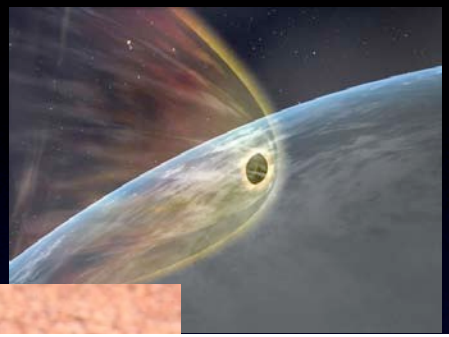




SRC Recovery (1/2) , 2010

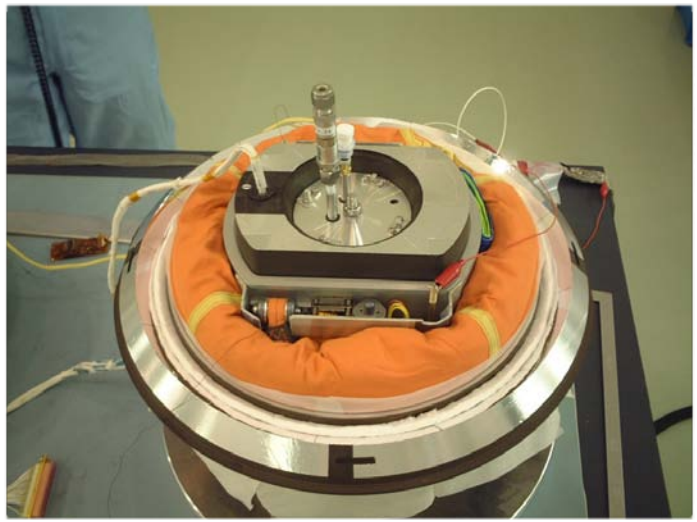
SRC Recovery (2/2), 2010





Aft-body Heatshield

Forebody Heatshield



Chute Anchor Separated Safely

Main Body

Sterilization of SRC

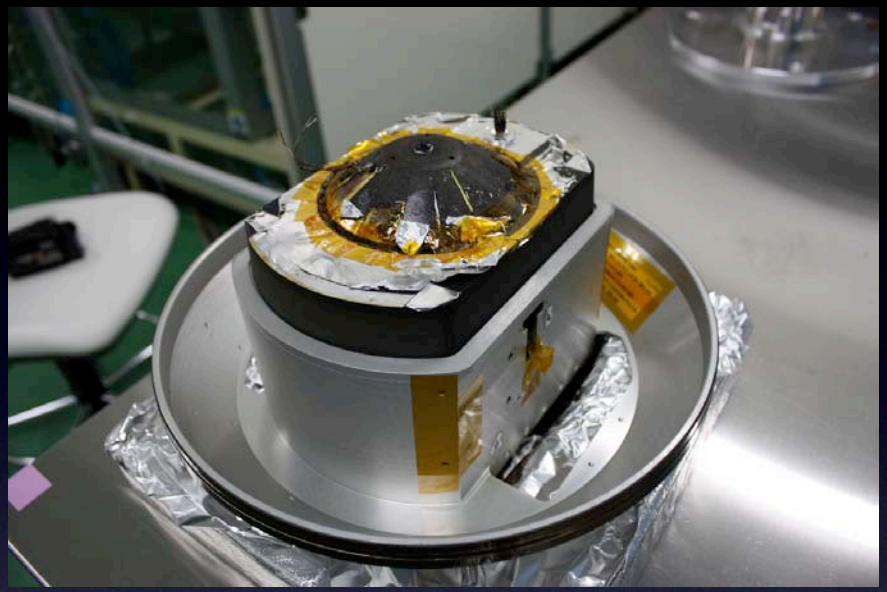
Non Explosive

Not Activated

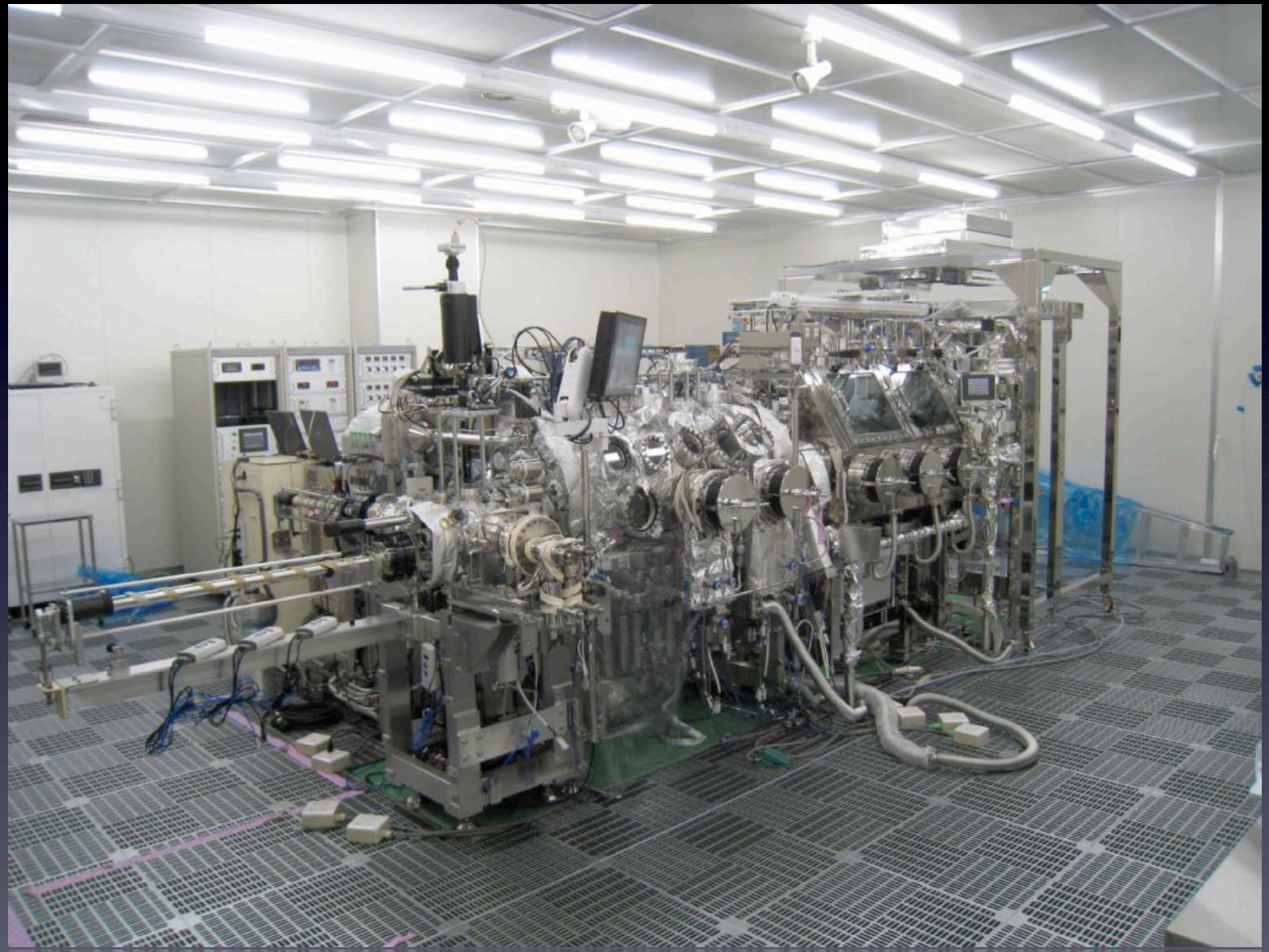
No Space Contamination

Hayabusa Curation Activity

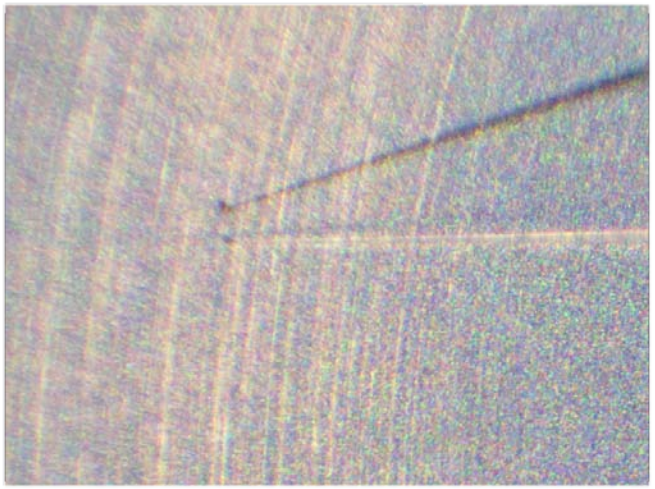
SRC transported to Japan June 18

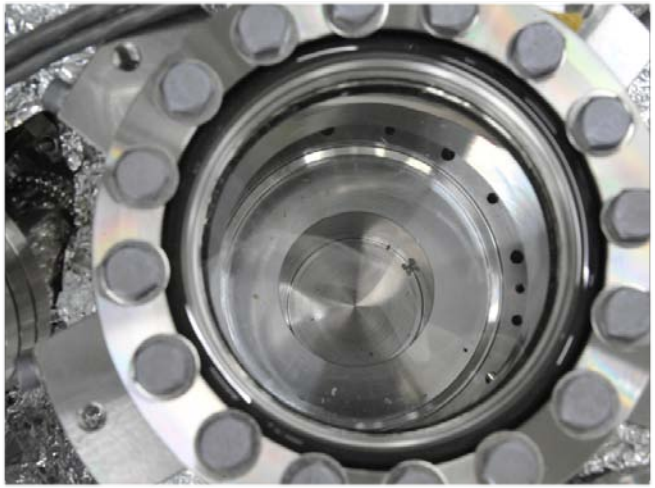


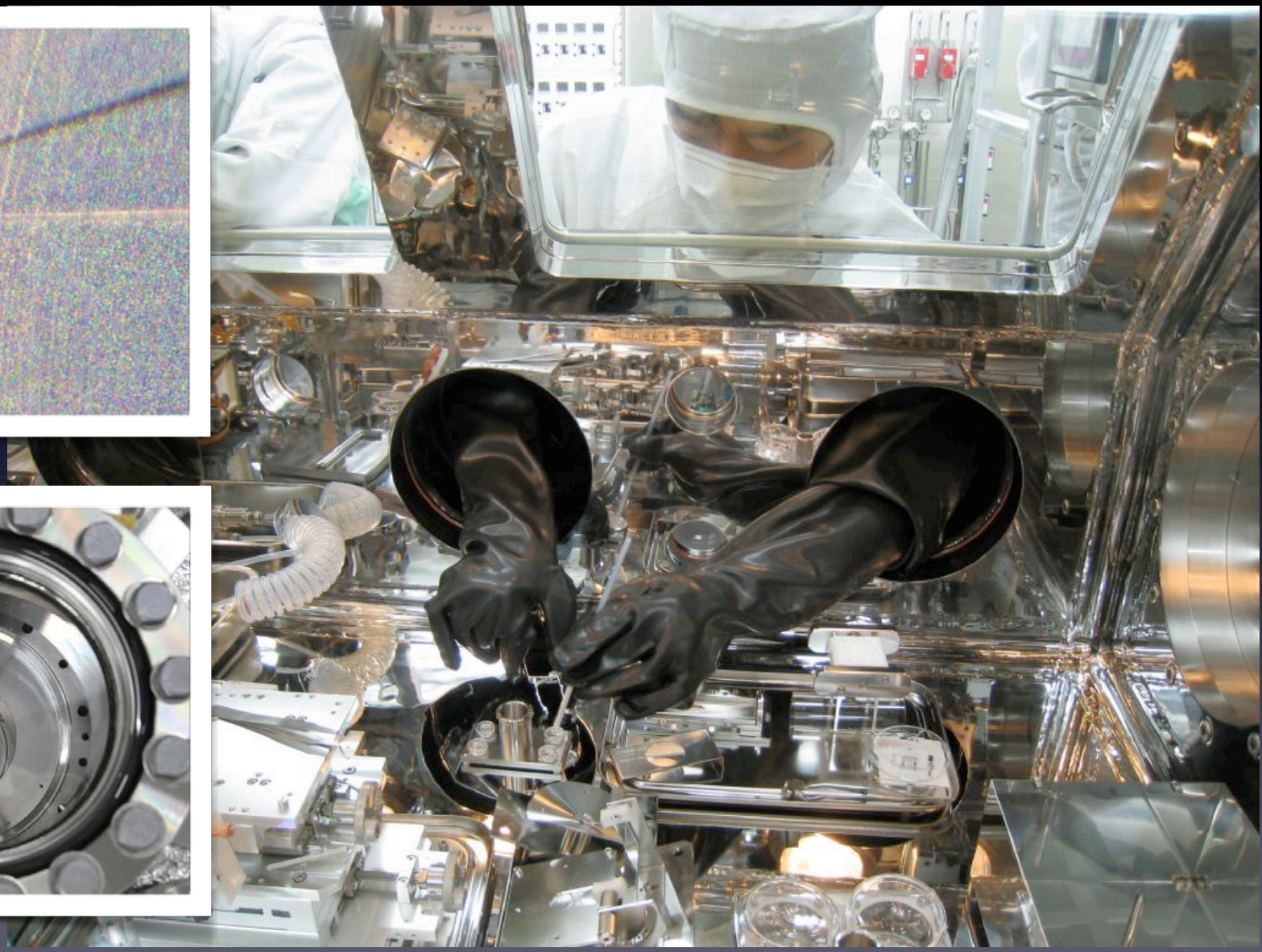
Curation Facility at JAXA



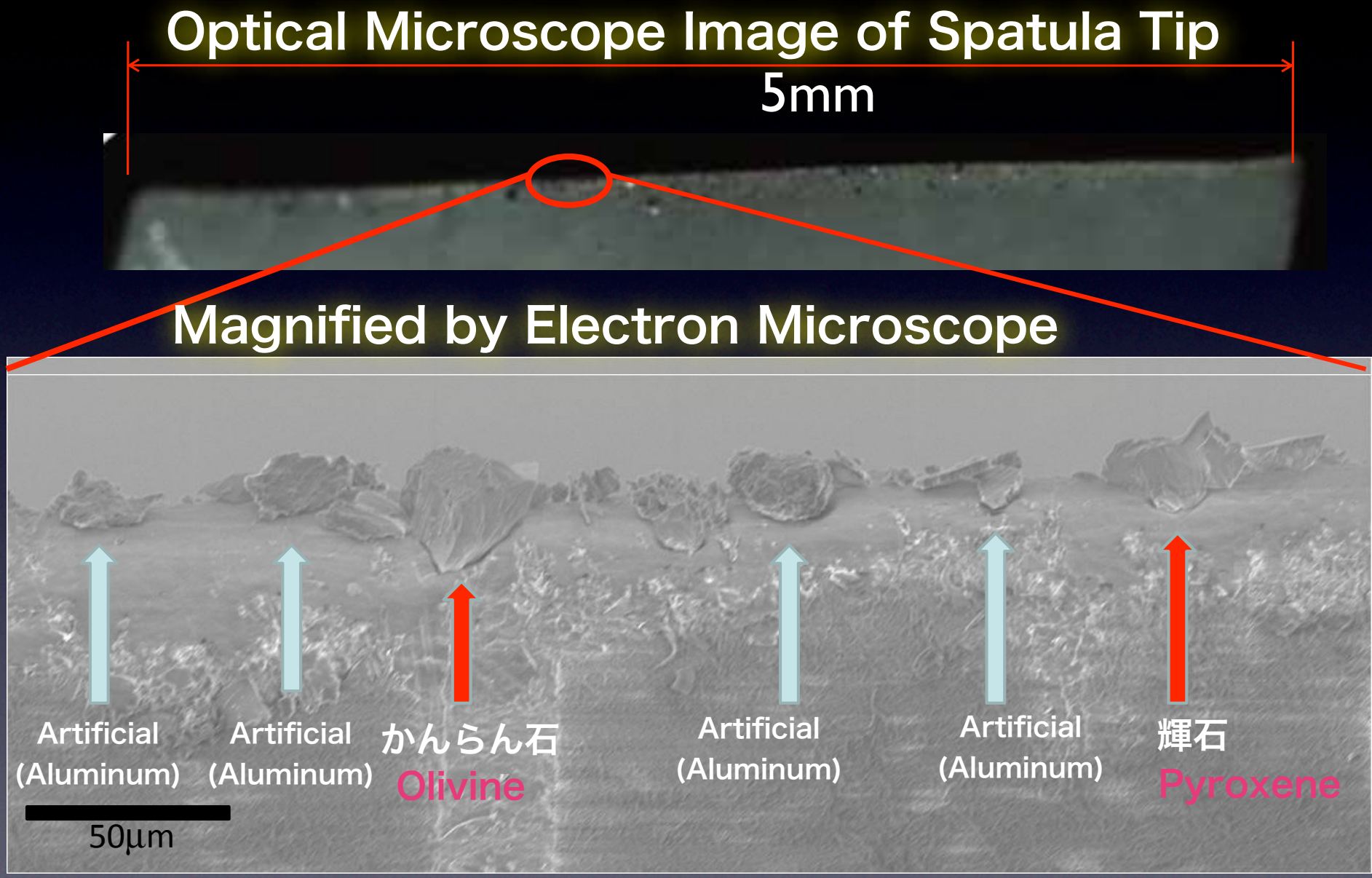
Collecting Minute Particles







over 1,500 Particles from Itokawa



What comes out from Hayabusa ?

Great Advance in Solar System Exploration.

The method of round-trip exploration including surface activity was demonstrated in real, for the first time.

New scientific return regarding small bodies was obtained even from in-situ observation.

Possibly asteroid-origin minute particle samples may be obtained from the catcher recovered.

Any scientific update will be reported whenever obtained.

Japan will put a successor mission, Hayabusa-2, for more primitive bodies.

And More .....

Future Solar System Exploration

Hayabua 2 ～Crater Obs & Sampling

A Travel in search of Origin of Life
Target : C-type Asteroid

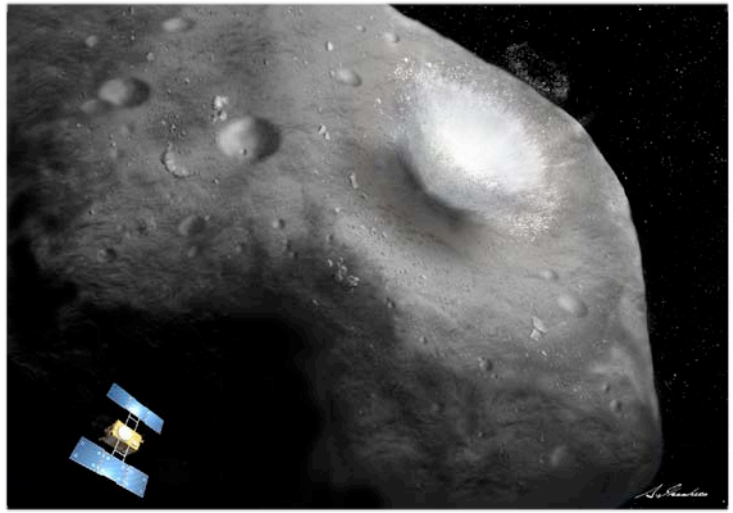
Launch : 2014/ July or Dec.

Arrival : 2018/Aug －2019/Dec.

Return : 2020/ Dec.

The impactor collides to the surface of the asteroid.

2019



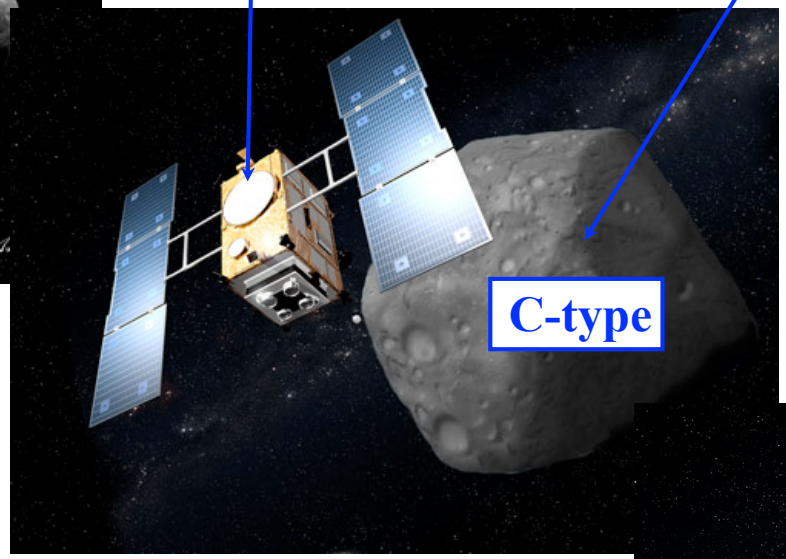
Hayabusa-2 Spacecraft

Launch window:
2014 – 2015

HGA: Planar Antenna

Target asteroid
1999 JU3 (C-type)

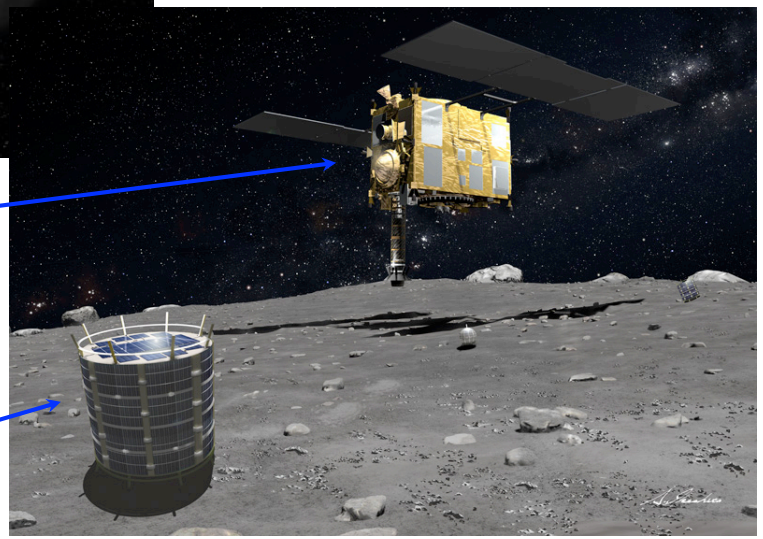
Optical camera
Near IR spectorometer
IR camera
Laser altimeter
etc.



C-type

Changes form Hayabusa

Reaction Wheels
Chemical Thrusters
Ion engines
Software
etc.



MINERVA2

Lander

Impactor

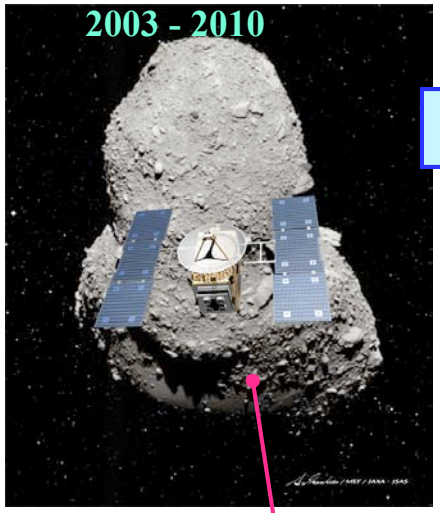
Primitive Body Exploration Program investigated in Japan

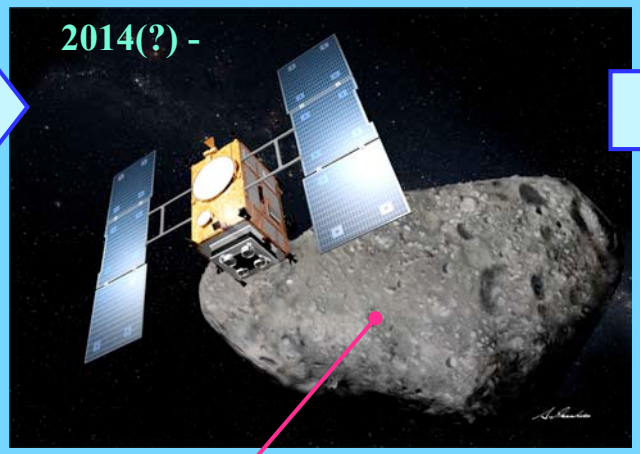
Post Hayabusa

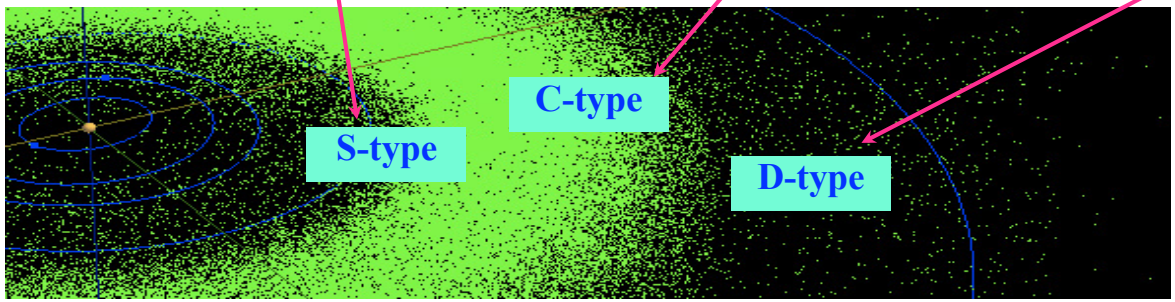
Hayabusa

Hayabusa2

HayabusaMk2







Asteroid Belt

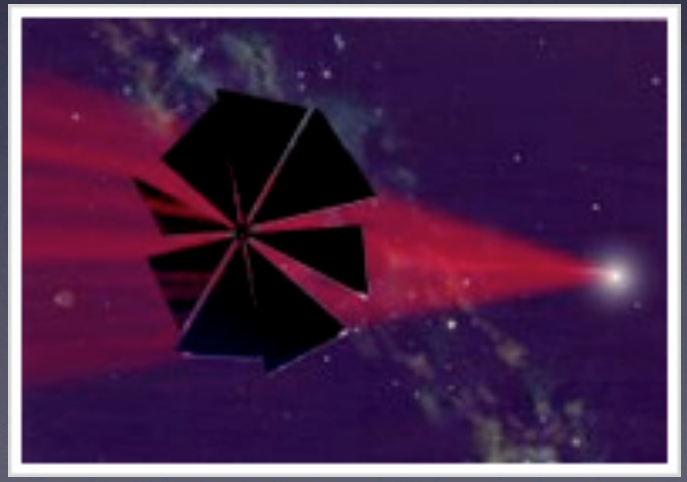
Solar Sail in the Future

Hybrid Propulsion (Solar Photon Pressure + Solar Electric Power) is flexible Tool for the Further Solar System Exploration.

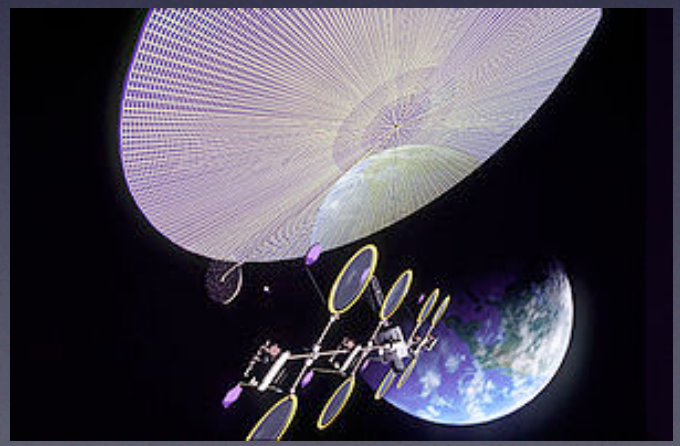
Thin-film Solar Array realizes sufficient Power Generation even in Jupiter Orbit, which will lead to Satellite Power System and contribute to the Earth Environmental Issues

Technology Development for Interplanetary Exploration beyond Jupiter

World's Solar Sail



Satellite Power System



Future Solar System Exploration

- Jupiter and Trojan Asteroid Exploration Mission (WG)
- MELOS (Mars Exploration Mission) (WG)

木星・トロヤ群小惑星探査計画
Jupiter and Trojan asteroids exploration mission