JAXA Report on Hayabusa-2, Procyon, and International Collaboration Sample Return Working Group

May 21st, 2014

NASA-HQ (Rm 3D42) via Teleconference from JAXA/ISAS

Hajime YANO
(JAXA/ISAS, Japan)

About the Presenter

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Institute of Space and Astronautical Science (ISAS),
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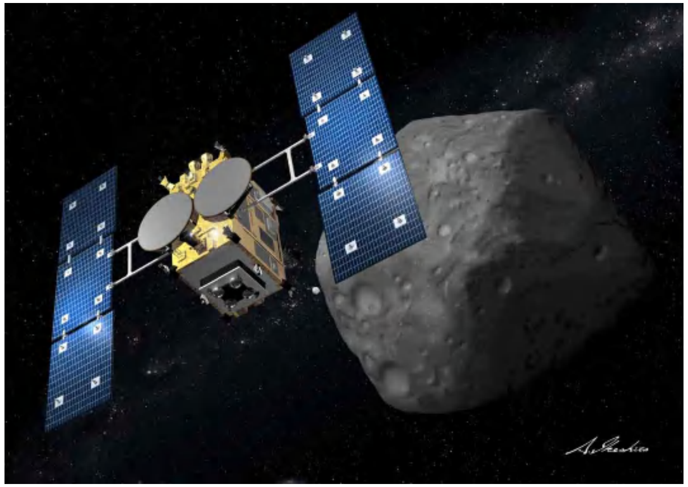
<Projects, WGs, Committee>

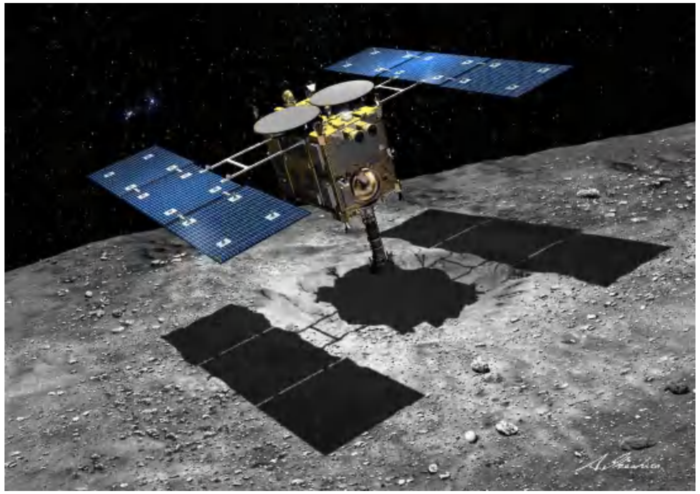
- *Hayabusa Project Team (1996-2013)*
- *IKAROS Project Team (2007-2013)*
- *Enceladus Sample Return Feasibility Research Team (2011-2013)*

- Tanpopo Project Team (2007~)
- Hayabusa-2 Project Team (2011~)
- Solar Power Sail Working Group (2002~)
- International Collaboration Sample Return Working Group (2013~)
- JAXA Planetary Protection Safety Review Board (2013~)

NASA Advisory Council
Planetary Protection Subcommittee May 2014

Hayabusa-2 Probability of Impact Analysis for Planetary Protection (Status Report)





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Presented by Hajime YANO (JAXA/ISAS, Japan)

On behalf of the Hayabusa-2 Project Team

(Contributed by Y. Tsuda, T. Chujo and H. Yano)

JAXA

Hayabusa-2 Mission Outline

Launch

2014

July 2018 : Arrival at 1999JU$_3$

Sample analysis

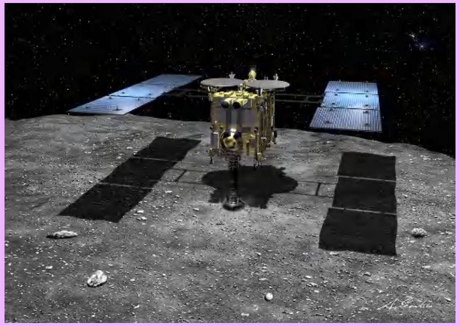
Earth Return

Dec. 2020

Dec. 2019 : Departure

Surface Rovers Deployment

Multiple Touch Downs & Samplings



Kinetic Impact

2018-2019

Hayabusa-2 Mission and Trajectory

◆Hayabusa2 is the 2nd Japanese sample return mission to small body. JAXA will launch Hayabusa2 in 2014, explore C-type asteroid 1999JU3, and return back to the Earth in 2020.

◆ Orbit of Asteroid 1999JU$_3$:
Perihelion 0.96AU
Aphelion 1.42AU
Eccentricity 0.19
Inclination 5.88deg (w.r.t. Ecliptic plane)

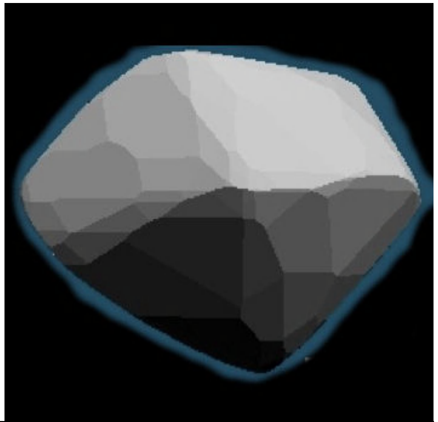
cf. Mars
r_a=0.093AU
r_p=1.67AU
inc=1.85deg

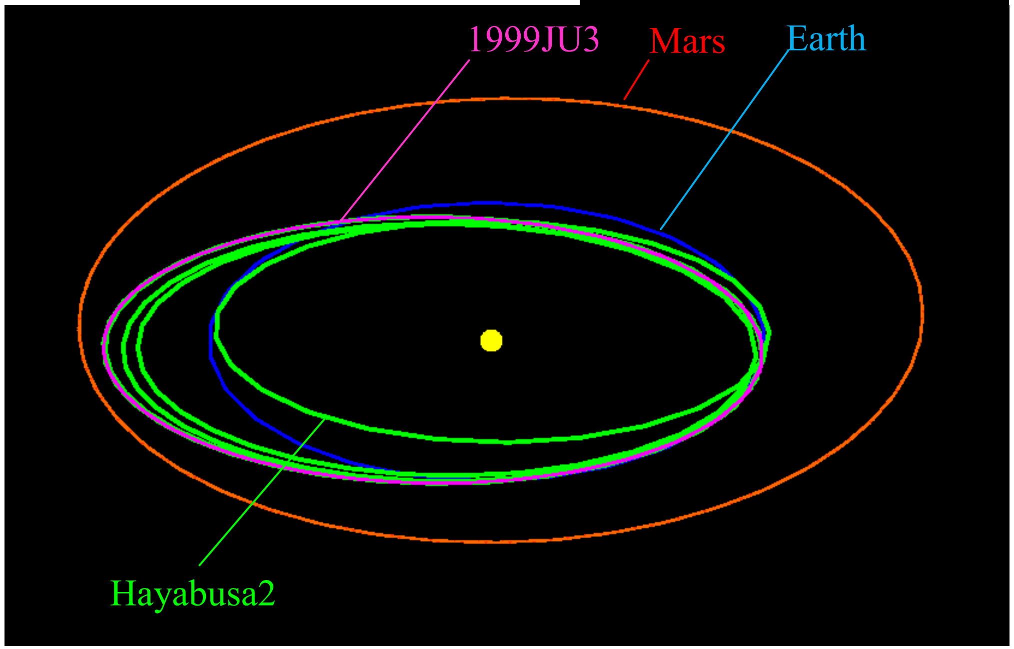
*1999JU$_3$ itself is far enough (i.e. has zero collision probability) both from the Earth & Mars.

◆ Mission Schedule

Earth Departure:	Nov-Dec, 2014
Earth Swing-by:	Dec, 2015
1999JU$_3$ Arrival:	Jul, 2018
1999JU$_3$ Dep.:	Dec, 2019
Earth Reentry:	Dec, 2020

*Two backup windows are planned (May-Jun 2015 and Nov-Dec 2015), for which PP analyses are also conducted.





The entire mission trajectory

Planetary Protection Activity of Hayabusa-2

- ✓ In 2012, the Hayabusa-2 project requested the COSPAR Planetary Protection Panel to recommend both outbound and inbound planetary protection requirements to the 1999 JU3 sample return mission.

- ✓ After careful consideration with respect to the COSPAR Planetary Protection Policy at the Alpbach Colloquium in 2012 followed by the COSPAR2012 GA in India, the COSPAR PPP concluded that the Hayabusa-2 mission was considered the outbound Category-II, in condition of "avoiding impact with Mars under all mission scenarios", and the inbound Category-V(B) as "unrestricted Earth return" for the 1999 JU3 samples.

- ✓ The above agreement also concurred with the recommendation of the NASA Advisory Council's Planetary Protection Subcommittee in 2012.

- ✓ The objective of today's report is to explain the last outstanding condition for completing the COSPAR requirements to the Hayabusa-2 mission:

➔ ***To prove that its impact probability analysis to Mars in all the mission scenarios is less than 1% in 50 years since its launch.***

Probability Analysis –Methodology

- Challenges in analyzing the Mars impact probability for Hayabusa-2
  - **The trajectory is controlled mainly by low thrust propulsion (Ion Engine System: IES).**
    → Non ballistic trajectory makes the 50yr probability analysis difficult.
  - **The trajectory plan includes the Earth swing-by and Earth Return.**
    → Probability of the Mars impact after the Earth gravity assist may not be negligible.

- Analysis Methodology: **Piecewise Impulsive Approximation**
  - The IES continuous thrust history is partitioned to small nodes, and the thrust in each node is represented by the equivalent impulsive ΔV at the center of the nodes.
  - The each impulsive ΔV is then treated as "TCM" of the ordinary trajectory deviation analysis for impulsive ΔV trajectory.
  - The Mars impact after Earth swing-by case is evaluated independently of the direct Mars impact case. An upper bound of the probability is evaluated employing an analytical/numerical-combined method. *(Result not shown in this preliminary report)*

- Analysis Strategy: Three-Step Analysis to reduce the computational burden.

1) **Phase-Free Analysis** (Mars true anomaly is neglected)
2) **High Fidelity Monte-Carlo Simulation** (Validation of step-1 for typical case only)

(Steps 1 and 2 → $p_{drct}(t)$)

3) **Mars Impact via Earth Swing-by Evaluation** → $p_{swby}(t)$

$$P_I = \int (p_{drct} + p_{swby})\, q\, dt$$

P_I: Overall Mars impact probability (for 50yrs), $q(t)$: Spacecraft failure rate

Mars Impact Probability (Preliminary)

The result at present considers "Direct Impact" case only. The Earth-swingby case is to be added. However, it is expected that the final result well satisfies P_I<<1e-2.

Table [N]: Nominal Window (Launch: Nov-Dec. 2014)

Trajectory Leg	IES ΔV / RCS ΔV	Impact Probability (direct) $\int p^{drct}_i dt$	Impact Probability (Via Earth Swby) $\int p^{swby}_i dt$	Reliability Based qi+1*a	Reliability based $\int (p^{drct}_i + p^{swby}_i) q dt$
Injection	No / No	1.0e-14	To be calculated	1.0e-5	1.0e-19
Earth to Earth	Yes / Yes*c	4.0e-13	To be calculated	3.0e-2	1.2e-14
Earth to Asteroid	Yes / Yes*c	0*b	To be calculated	1.1e-1	0*b
Asteroid Proximity	No / No	0*b	To be calculated	4.1e-2	0*b
Asteroid to Earth	Yes / Yes*c	0*b	To be calculated	4.2e-2	0*b
TOTAL					**1.2e-14**

*a (Very conservative) upper bound
*b Negligible (<1e-10)
*c Very small RCS TCMs exist which are negligible compared with IES ΔV

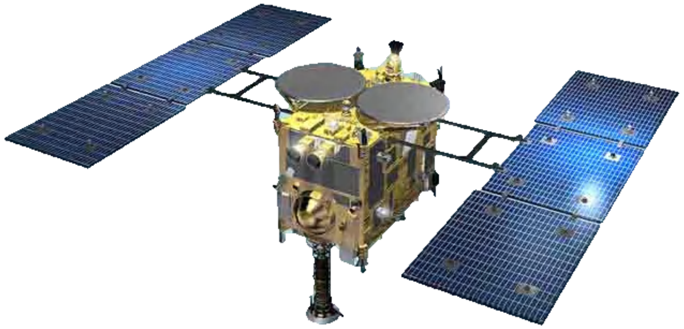
Table [BU1]: Backup Window1 (Launch: May-Jun. 2015) *TOTAL Only

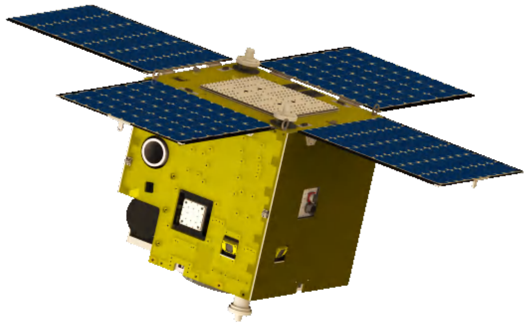
Trajectory Leg	IES ΔV / RCS ΔV	Impact Probability (direct) $\int p^{drct}_i dt$	Impact Probability (Via Earth Swby)*a $\int p^{swby}_i dt$	Reliability Based qi+1	Reliability based $\int (p^{drct}_i + p^{swby}_i) q dt$
TOTAL					**1.2e-14**

Table [BU2]: Nominal Window (Launch: Nov-Dec. 2015) *TOTAL Only

Trajectory Leg	IES ΔV / RCS ΔV	Impact Probability (direct) $\int p^{drct}_i dt$	Impact Probability (Via Earth Swby)*a $\int p^{swby}_i dt$	Reliability Based qi+1	Reliability based $\int (p^{drct}_i + p^{swby}_i) q dt$
TOTAL					**1.2e-14**

Probability Analysis for an Accidental Impact on Mars by PROCYON, Hayabusa-2's Piggy-back Micro-spacecraft (Status Report)





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NASA-HQ (Rm 3D42) via Teleconference from JAXA/ISAS

Presented by Hajime YANO (JAXA/ISAS, Japan)

On behalf of the PROCYON Project Team

(Contributed by R. Funase, Y. Kawakatsu, N. Ozaki, K. Ariu, S. Nakajima, Y. Shimizu, H. Yano)

Overview of the PROCYON Mission

Mission Scenario

[Nominal] 1-year Electric Delta-VEGA (EDVEGA)

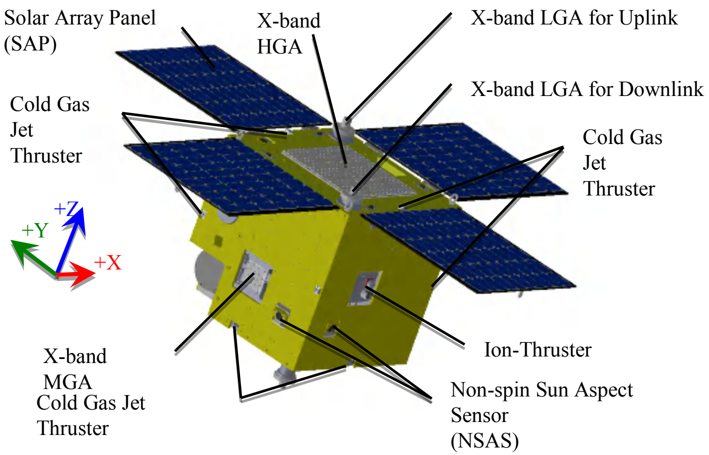
- Launch: 2014/12 → Earth Gravity Assist (EGA) : 2015/12
  → NEAs Flyby: 2016/TBD

[Backup 1] Direct Transfer

- Launch: 2014/12 → NEAs Flyby: 2015/TBD

[Backup 2] 2-year EDVEGA

- Launch: 2014/12 → EGA: 2016/12 → NEAs Flyby: 2017/TBD



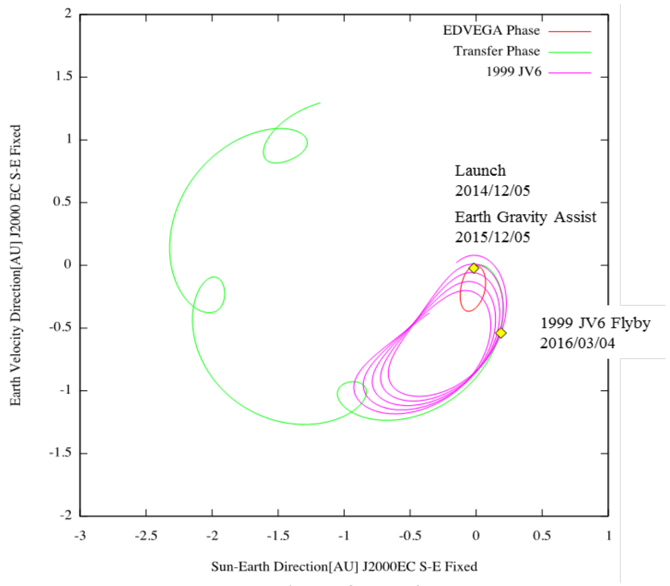
Specification of PROCYON

Mass	Initial Total Mass[kg]: 67.0 Fuel Mass(Xe)[kg]: 2.5
Ion Propulsion System (IPS) using Xe	Thrust[mN]: 0.25 Isp[s]: 1000.0
Reaction Control System (RCS) using Xe	Thrust[mN]: 19.0 Isp[s]: 24.2

IES maximum ΔV = 235[m/s] as 2-years (mission life time) continuous maneuver.

The phase-free minimum ΔV for Direct Impact on Mars is **250[m/s] as impulsive maneuver.**

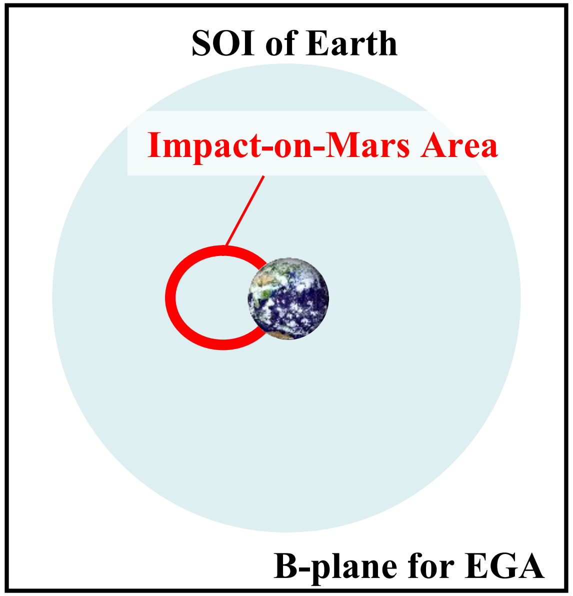
→ PROCYON does not have a capability to direct impact on Mars



Example of Trajectory
J2000EC Sun-Earth line fixed rotating coordinates

Probability Analysis for Impact on Mars via EGA — Phase-Free and Ballistic Analysis —

- Analysis Methodology
  - Evaluate B-plane position of EGA when the spacecraft crosses Mars SOI × 2,
    - **With** considering ballistic after EGA
    - **Without** considering the Mars position in the orbit (Phase-free)
- Initial Condition
  - Date-time of EGA: 2015-Dec-05 00:00:00
  - Position and velocity of the Earth is given by JPL ephemeris (DE405).
  - **V∞** = [1.16, 2.59. -3.59] [km/s] @ J2000 EC
  - ||**V∞**|| = 4.58[km/s]

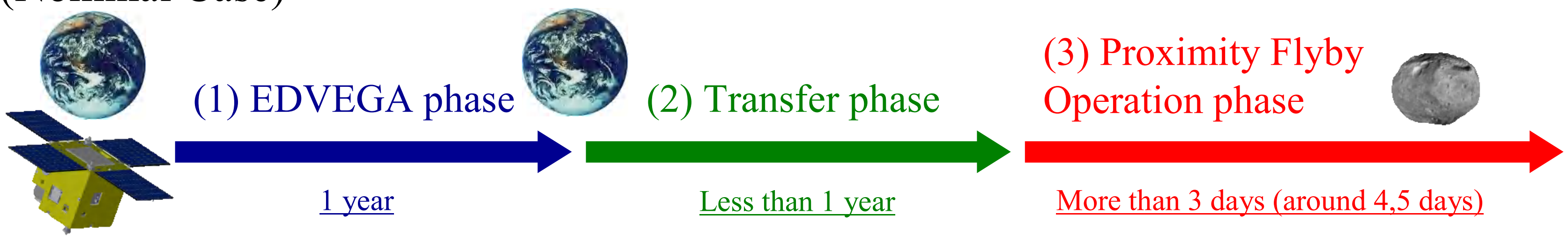


We assume that the probability of impact on Mars via EGA as follows:

$$\text{Probablity of Impact} = \frac{\text{Impact on Mars Area}}{\text{Area of Earth SOI}}$$

Analytical Results and Conclusion

(Nominal Case) **Earth Gravity Assist** **Asteroid Flyby**



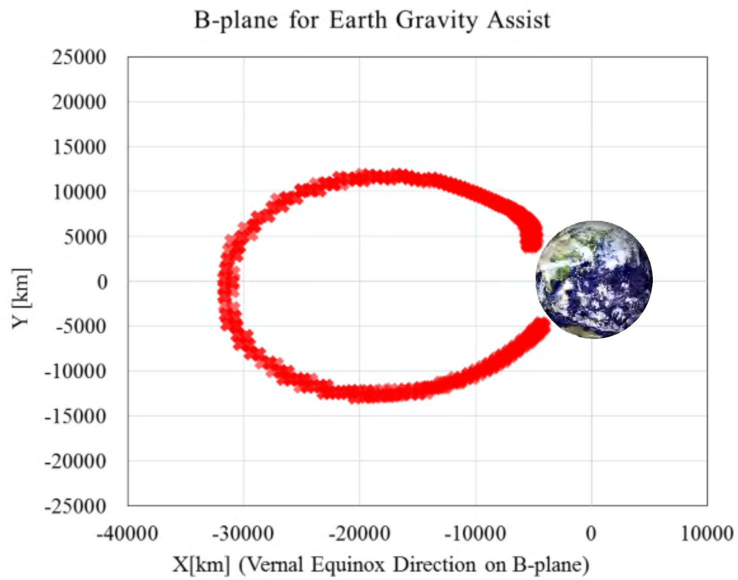
We select target asteroid after launch, depending on **launch date/ launch error**

Thruster: MIPS
Orbit Determination: R&RR

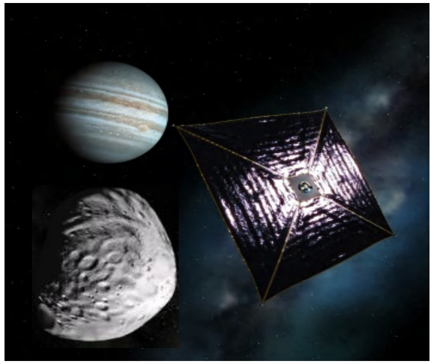
Thruster: MIPS (almost Ballistic)
Orbit Determination: R&RR

Thruster: CGJ
Orbit Determination: Optical Image

- Results
  - In the phase-free and ballistic analysis, the probability of impact on Mars via EGA is about 3.0×10^{-5}, which is by far less than 10^{-2}
- Conclusion
  - We conclude that the possibility of Mars impact is negligible within 50 year after its launch.
  - As a next step, we will analyze that the probability of impact **considering TCM guidance error** before EGA
  - Depending on the situation, **we will eliminate the candidate NEAs** if the spacecraft has too large probability of impact on Mar in the trajectory



JAXA/ISAS International Collaboration Sample Return Working Group for Astrobiology-Driven Explorations



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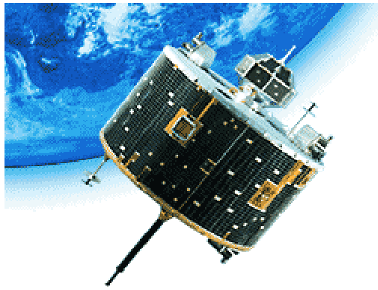
Presented by Hajime YANO (JAXA/ISAS, Japan)

On behalf of the JAXA/ISAS International Collaboration Sample Return WG

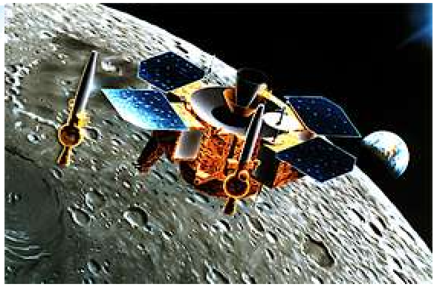
(Contributed by H. Kuninaka, H. Yano, Y. Shimizu, T. Yamada, K. Yamada, M. Ohtsuki, H. Sawada, K. Takai, Y. Takano, T. Shibuya, Y. Sekine, R. Funase, etc.)

Japan's Past Solar System Missions Sorted by Destinations

Moon



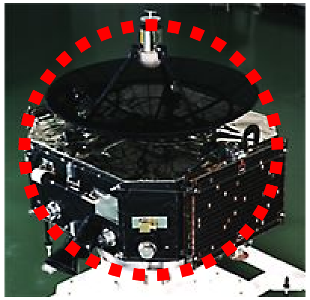
Hiten/Hagoromo



(LUNAR-A)

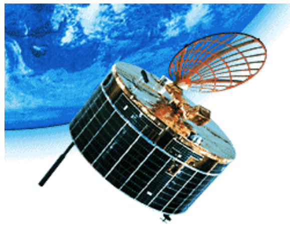
Kaguya

Planets

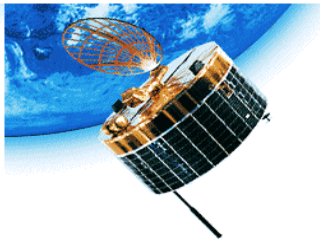


Nozomi

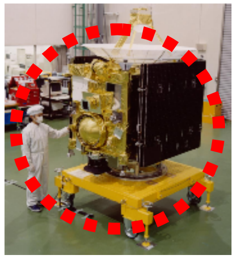
Small Bodies



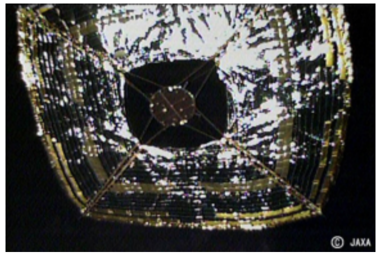
Sakigake



Suisei



Hayabusa



IKAROS

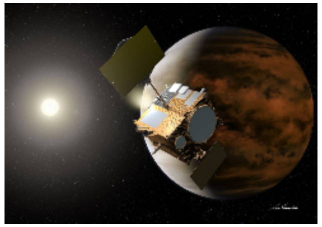
**** Technology verification missions in Italic.* International collaboration in red. PP activities in circle.**

JAXA

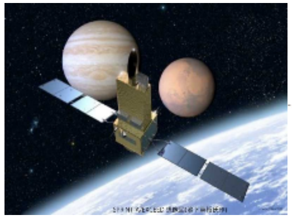
Japan’s Current and Approved Missions Sorted by Destinations

Moon

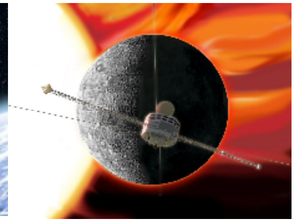
Planets



Akatsuki



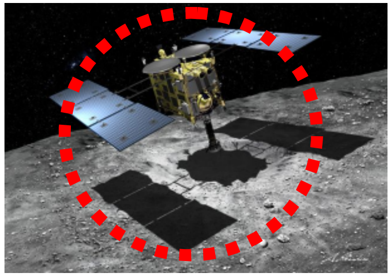
Hisaki



BepiColombo -MMO

JUICE

Small Bodies



Hayabusa-2

* *Technology verification missions in Italic.* **International collaboration in red. PP activities in circle.**

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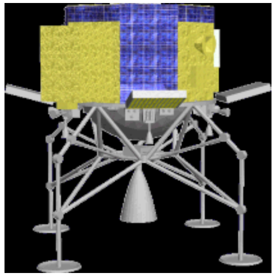
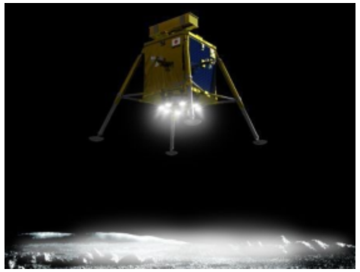
Japan's Proposed Future Plans
Sorted by Destinations

Moon

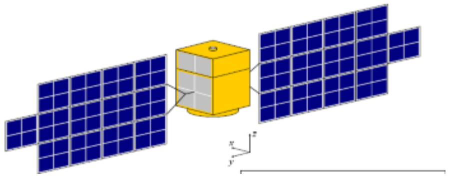


SLIM



SELENE-2

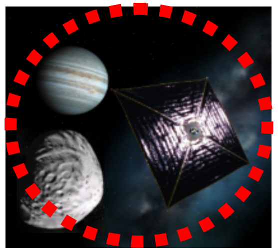
Planets



DESTINY

Mars2020 Rover, MELOS

Small Bodies



Solar Power Sail

* ***Technology verification missions in Italic.*** **International collaboration in red. PP activities in circle.**

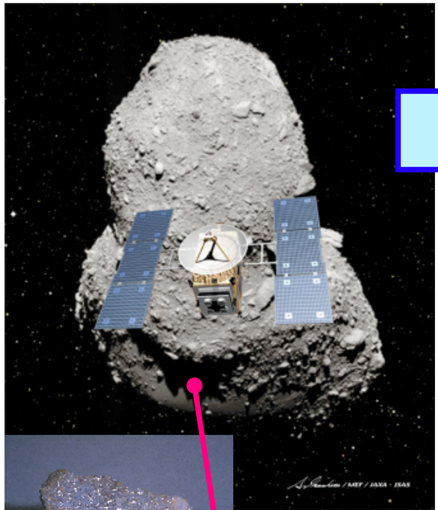
Future Direction-1: Deep Space Round Trips: Small Body Sample Returns by Hayabusa Heritage

Post Hayabusa Era

And Beyond

Hayabusa

Itokawa = S type
(2003-10)



Ordinary
Chondrites

Hayabusa-2

1999 JU3 = C type
Lessons Learned from Hayabusa
(2014-20)

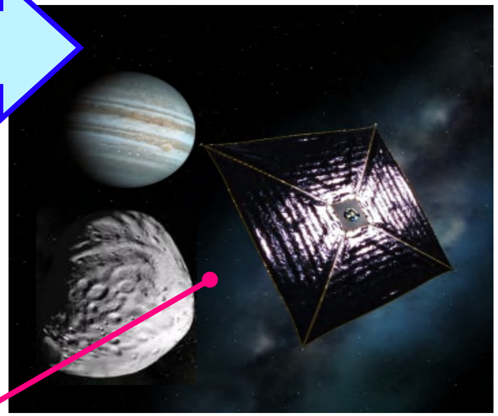
Carbonaceous
Chondrites

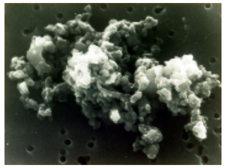
OSIRIS-REx

1999 RQ36 = B type
New Frontier Class
(2016-23)

Solar Power Sail

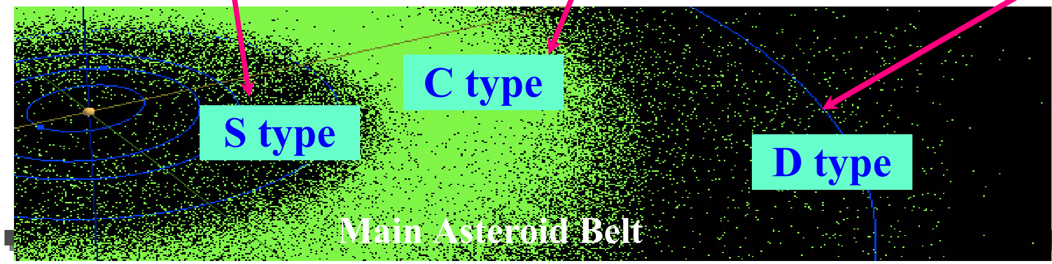
D type Jupiter Trojan
Hayabusa + IKAROS Technology (Early 2020's)





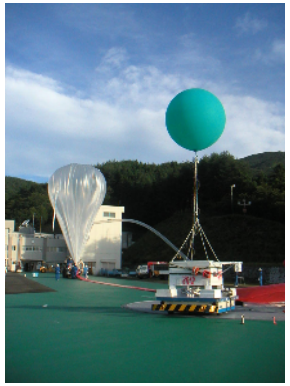
CP-IDP, Ultra-carbonaceous AMMs?

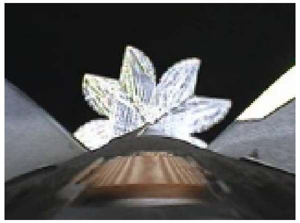
Future Targets:
Comet Nucleus, Icy Plumes



Future Direction-2: Going to Outer Planet Regions: Building up TRLs of Solar Sail Technology

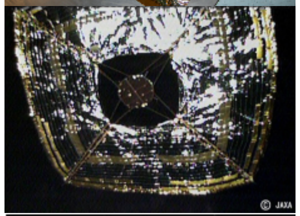
2003. August
Balloon Test(B30-71) at 36km alt.:
Active Deployment of Sail (4m)



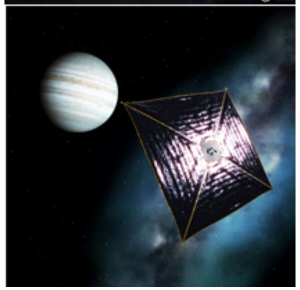


2004. August
Sounding Rocket(S310-34) at >100km alt.:
Active Deployment of Sail (10m)
Modeling of Sail Dynamics

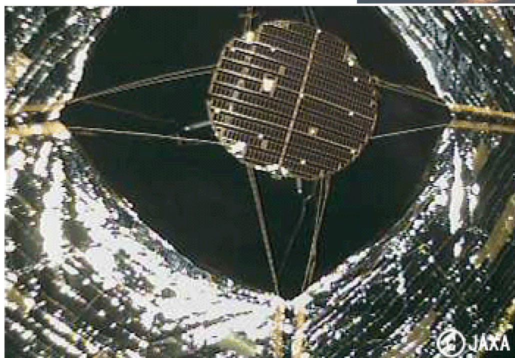
2006. September
M-V-7 Rocket Sub-payload (SSSAT) in LEO:
Deployment Demo of Small Power Sail (5m)



2010. May
H-IIA-17 Piggy-back (IKAROS) in deep space:
First Solar Sail in Interplanetary Space
Deployment of Sail Membrane (200 m^2)



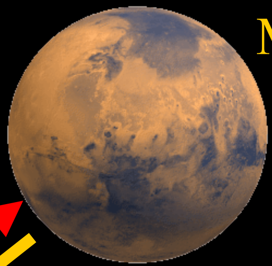
Early 2020's
Solar Power Sail (3000 m^2) with Ion Engines:
Cruising Science (IR astronomy, High energy astrophysics, Dust) and Jupiter and Trojan explorations



Future Direction-3: Astrobiology Driven Missions:

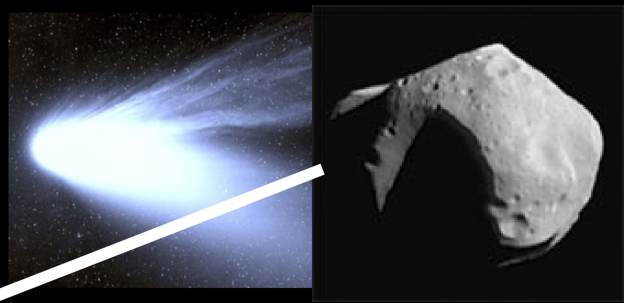
Tanpopo: Astrobiology Exposure & Meteoroid Capture onboard ISS

Litho-Panspermia Hypothesis:
ST1. Terrestrial Dust Capture
ST2. Survival of Terrestrial Microbes

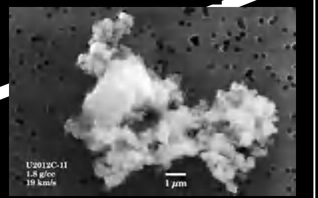


Mars

Martian Meteorites

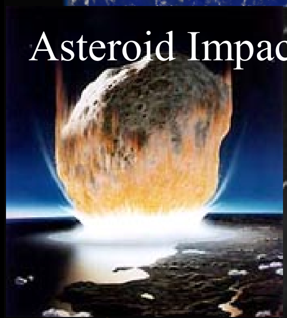


Volcano, Sprites,
Impact Ejecta, etc.



[Space Environment]
UV, Cosmic Rays, High Vacuum, Microgravity, etc.

Chemical Evolution Hypothesis:
ST3. Alteration of Astronomical Organic Analogs
ST4. Organic-Bearing Micrometeoroid Capture

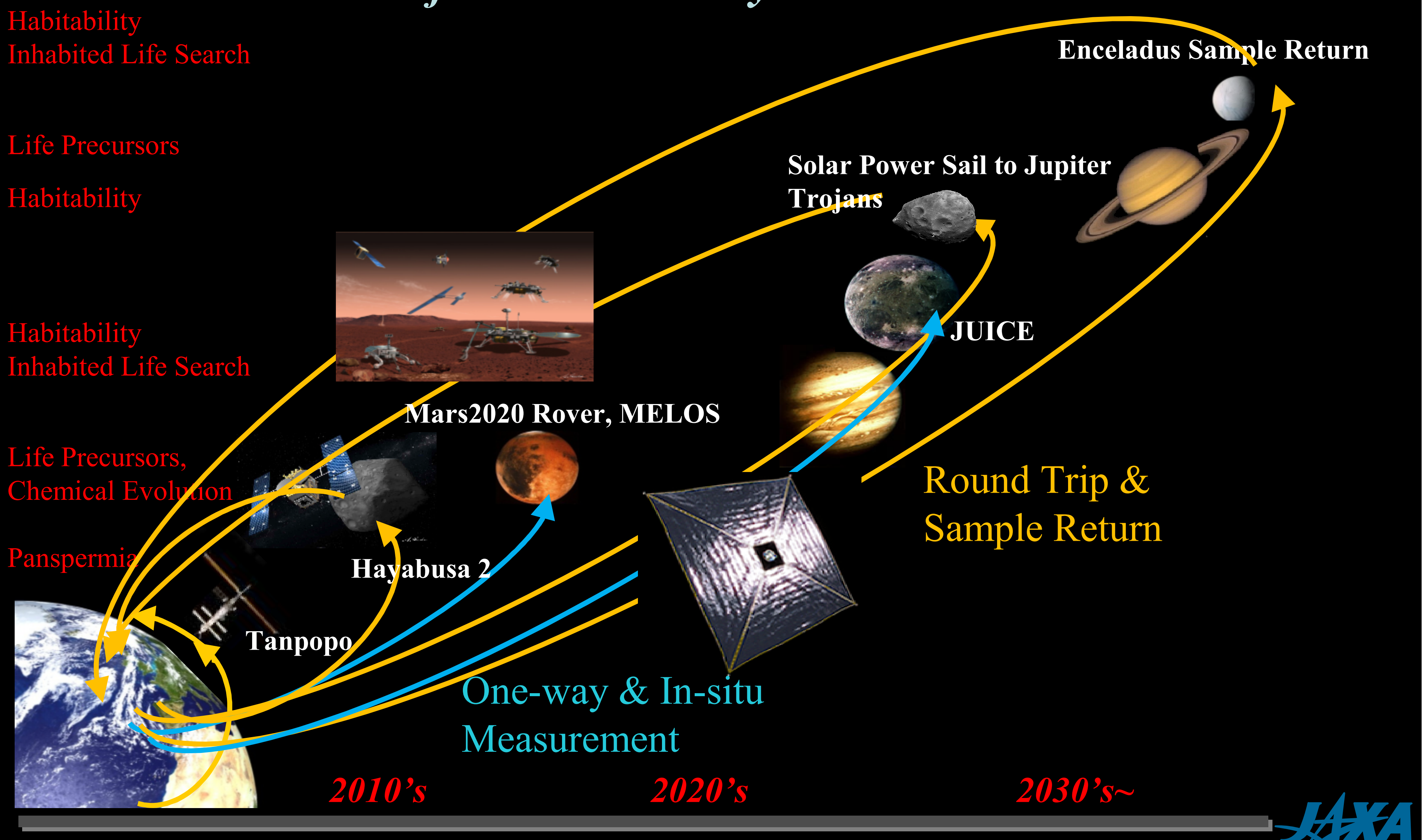


Contribution to Space Technology:
ST5. The Lowest Aerogel Validation
ST6. Small Orbital Debris Flux Measurement

JAXA

Solar System Exploration Vision in Japan:
Keywords: Round Trip, Outer Planets, Astrobiology and International

➔ All Subjects to Planetary Protection Considerations



JAXA Safety Review Board Structure: Planetary Protection Safety Review Board Established in 2013

JAXA Safety Panel

Chaired by Vice-president
Panel Member: Directors of JAXA Directorates

JAXA Safety Review Board

Chaired by Director of S&MA Department
Review Board Member: Safety specialists

JAXA System Safety (Rocket Payload Safety)Review Board

Chaired by Director of S&MA Department
Review Board Member: Safety specialists

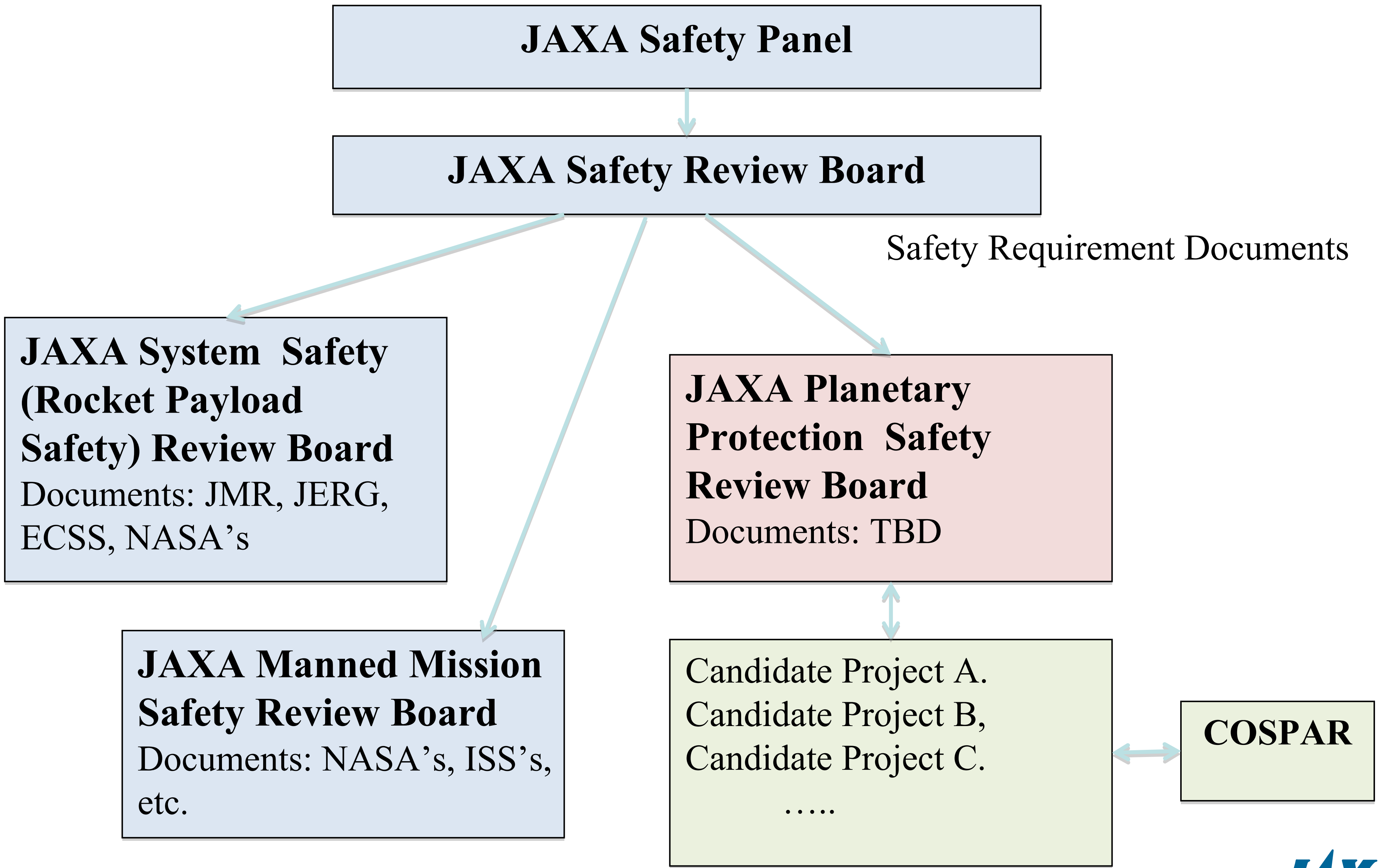
JAXA Manned Mission Safety Review Board

Chaired by Director of S&MA Department
Review Board Member: Safety specialists

JAXA Planetary Protection Safety Review Board

Chaired by ISAS S&MA manager
Review Board Member: Specialists

JAXA Planetary Protection Safety Review Process



ISAS International Collaboration Sample Return WG Established in 2013

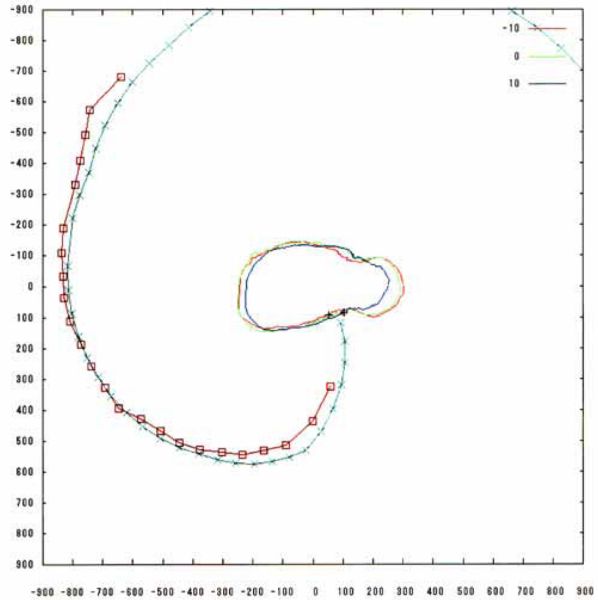
<Active partnership with international sample return missions by providing a <u>package of key enabling technologies</u>, rather than ad hoc instruments only>

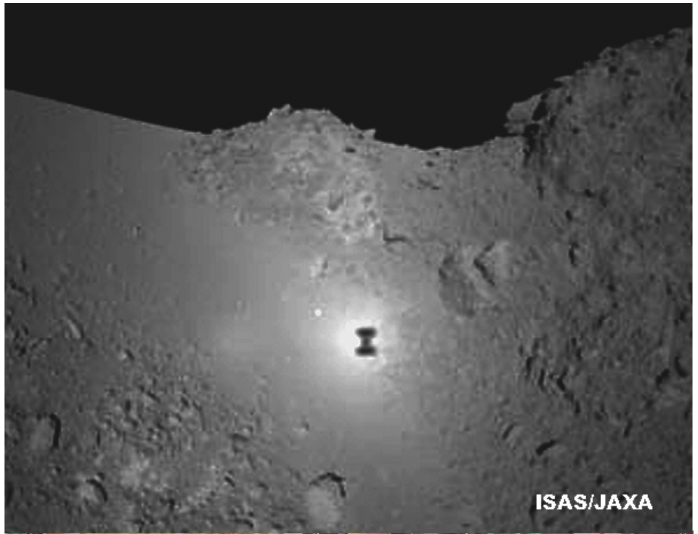
(1) Touchdown Sampling System
(2) Flyby Sampling System and Capture Media Development
(3) Ground Development and Calibration Experiment Facilities
(4) Containment System, Contamination Control and Sample Preservation
(5) Direct Earth Re-entry Capsule System
(6) Ground Operation of Returned Capsule Recovery
(7) Initial Sample Analysis and Curation Facility
(8) Biosafety Sample Handling Operation and Facility by JAMSTEC Partner

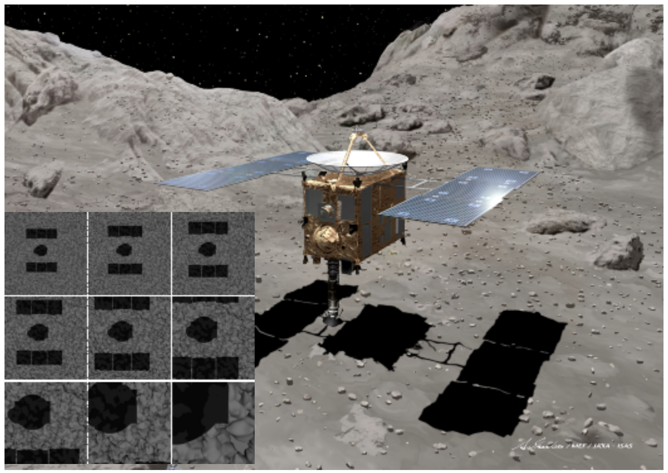
Mission Heritage	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Hayabusa-1 & 2	O		O	O	O	O	O	
Tanpopo		O	O				O	
Solar Power Sail	O			O	O	O	O	
JAMSTEC				O			O	O

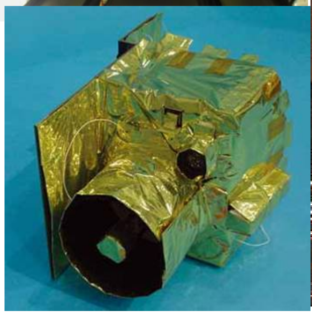
Key Technology-1: Touchdown Sampling System

Autonomous Touch& Go Operation on a Microgravity Body



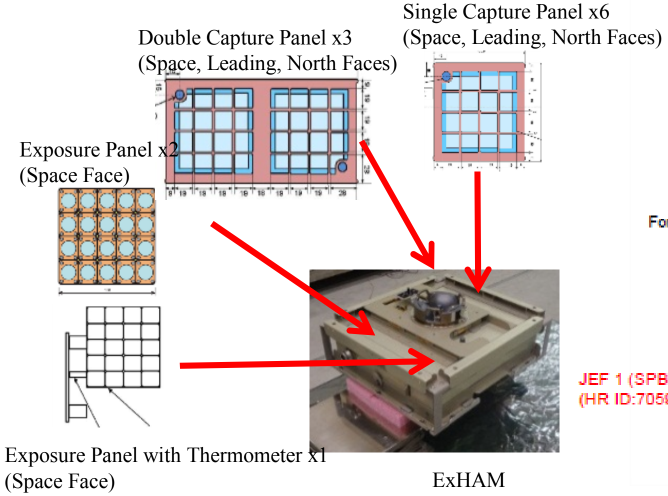


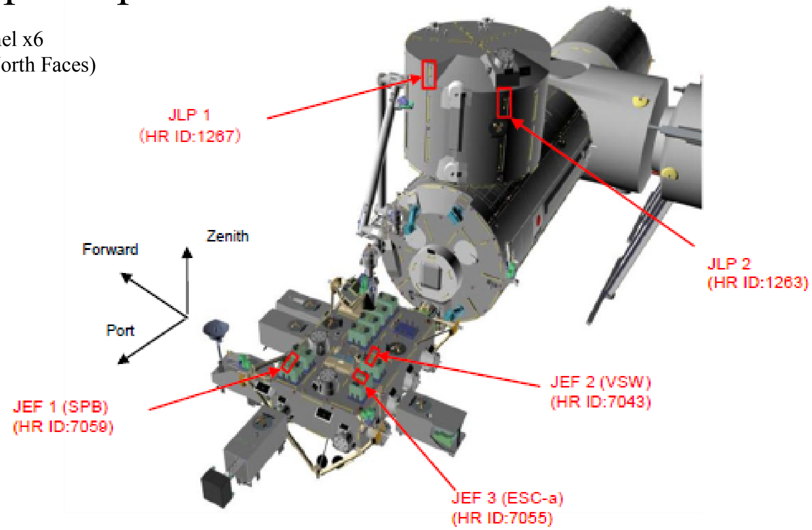




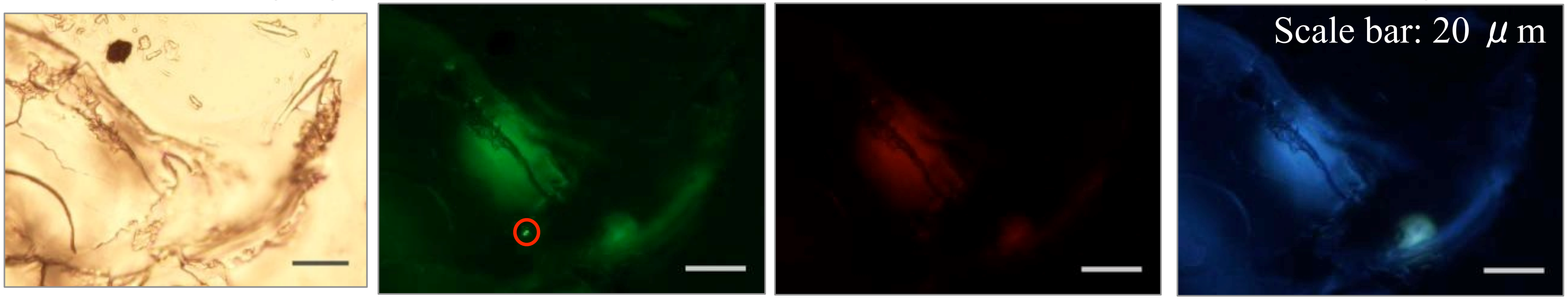
Key Technology-2: Flyby Sampling System and Capture Media Development

Japanese Double-Layered 0.01g/cc Aerogels in Tanpopo Capture Panel





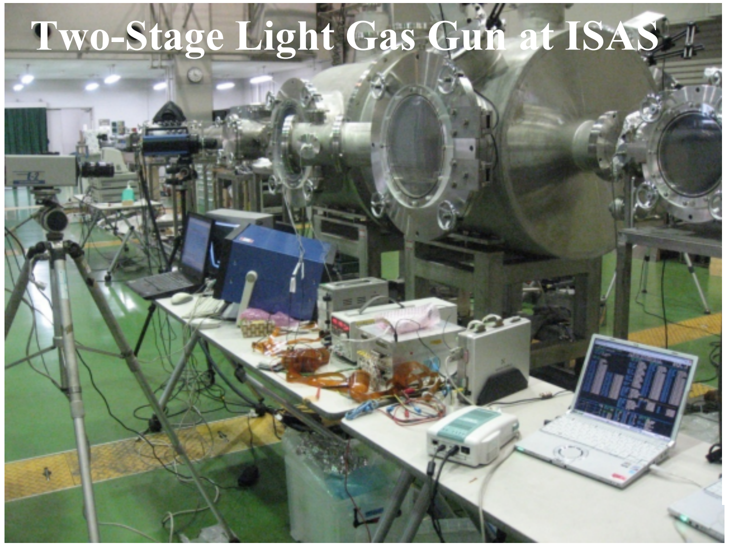
Captured microbe colony embedded in clay minerals, which were shot into the tanpopo aerogel at 6km/s:
Bleaching of green fluorescence from stained *D. radiodurans* R1 is faster than fluorescence from the glass

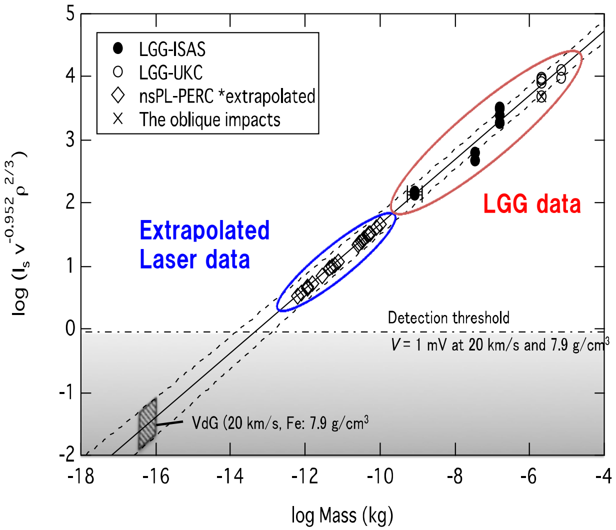


Green fluorescence Red fluorescence Blue fluorescence

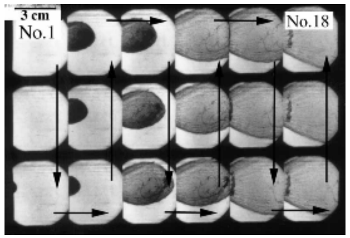
Key Technology-3: Ground Development and Calibration Experiment Facilities

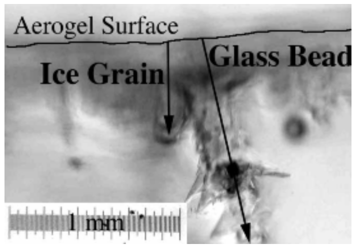
Hypervelocity Impact Facilities



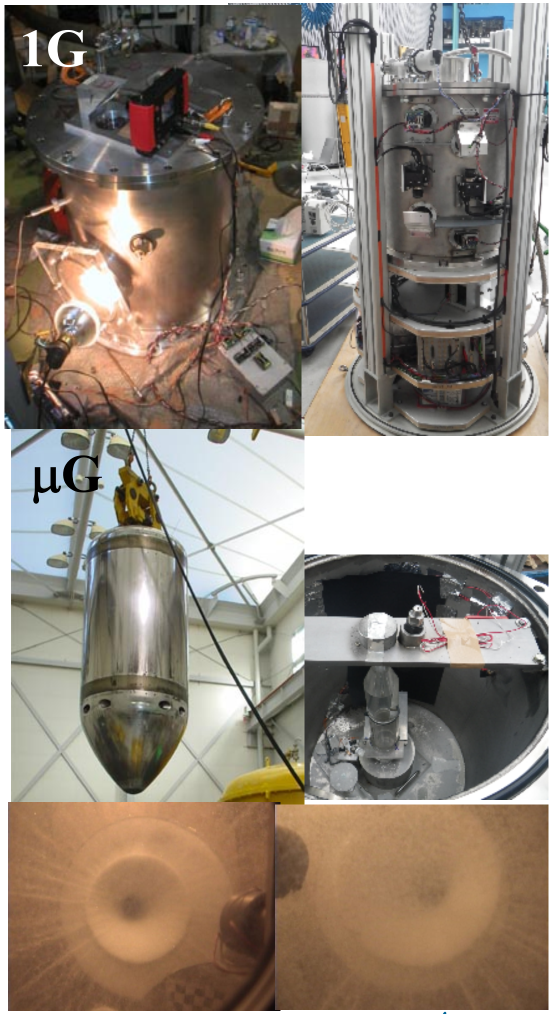


(ex) Hypervelocity Ice Impacts onto aerogels (Yano, et al.,1999)

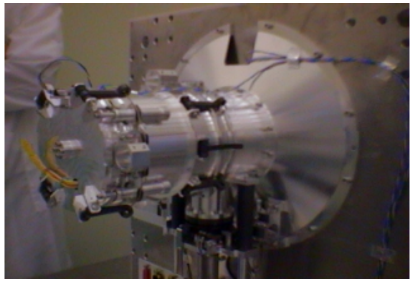
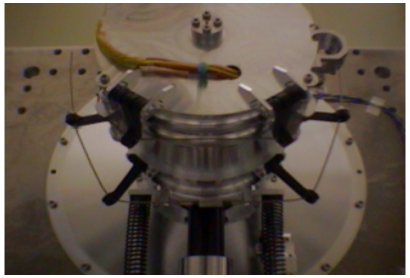
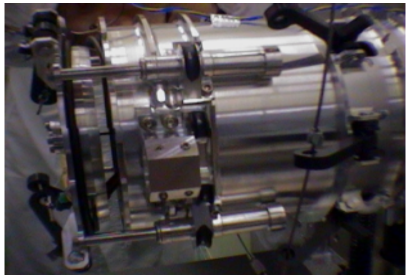
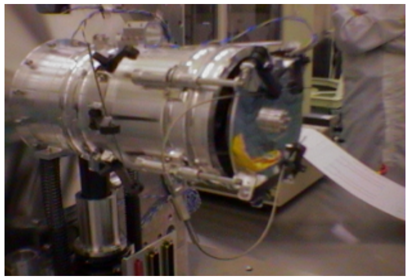




Microgravity Vacuum Chambers

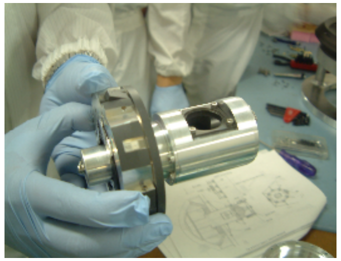
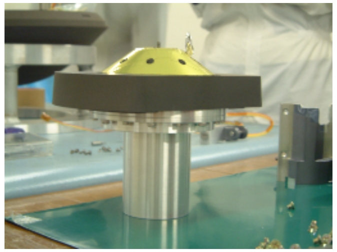
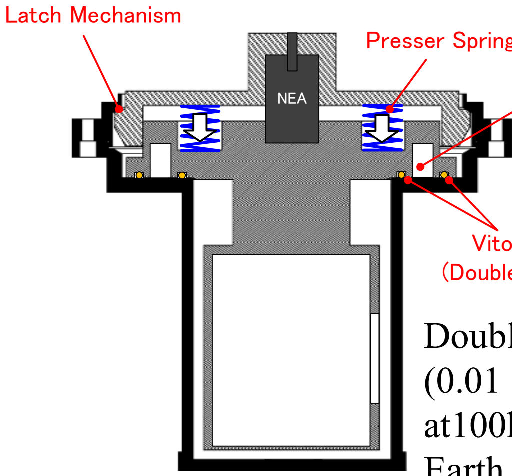


Key Technology-4: Containment System, Contamination Control and Sample Preservation

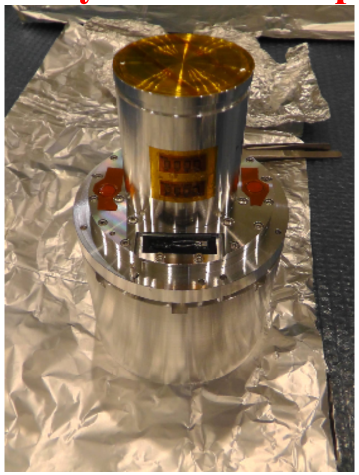
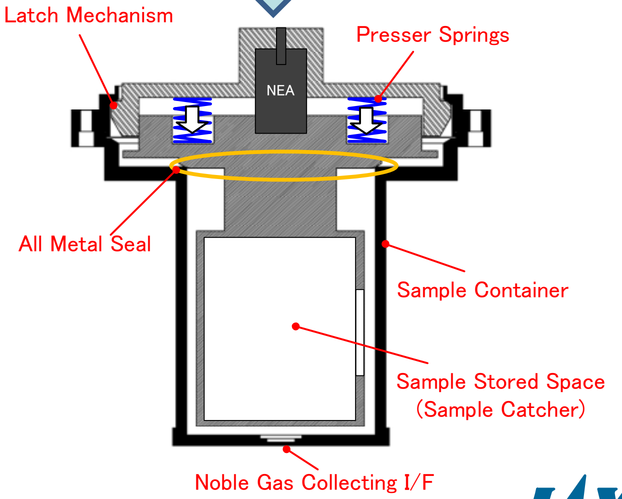
Hayabusa-2 (2014~2020)
* Al metallic vacuum sealing with mechanical latching mechanism by NEA and 12 presser springs * Noble gas ventilation interface located at the bottom of the canister * The Canister Interior Volume: 48mm(d)×57.5mm (l), ~70cm³
* ~50 g for the latching mechanism part (the total mass of the sample canister with this system is <500 g)

Hayabusa-1 Sample Container

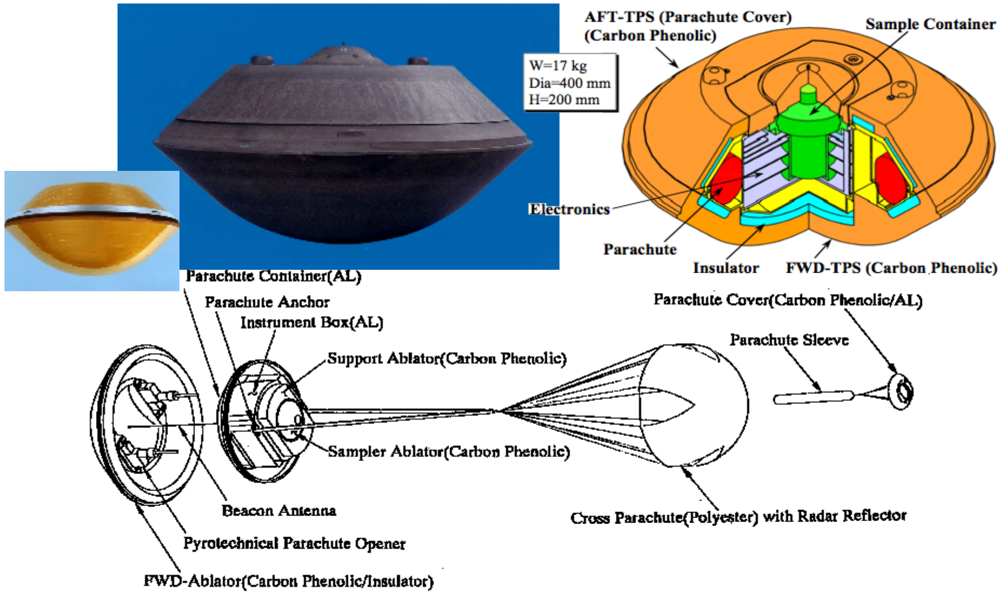




Double O-ring (0.01 Torr at100hr after the Earth return in 1 atm)

Hayabusa-2 Sample Container

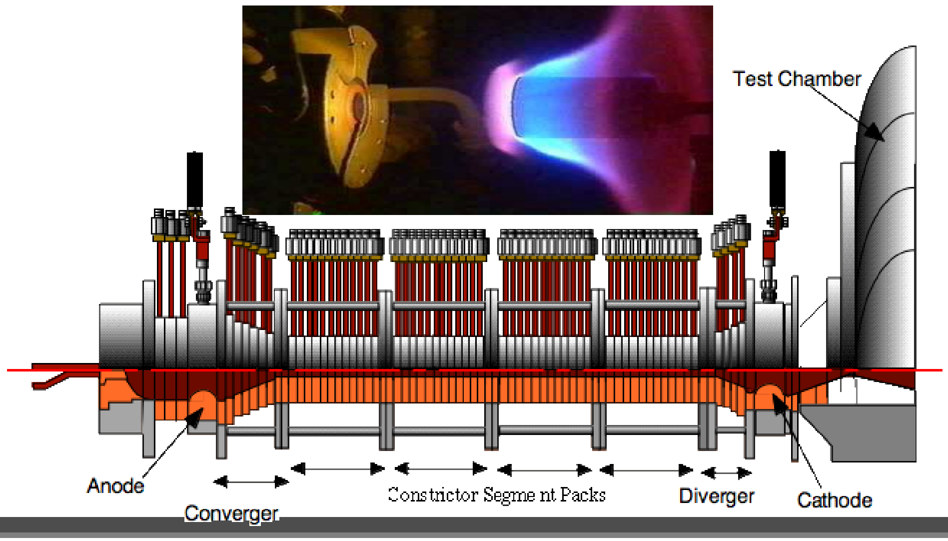



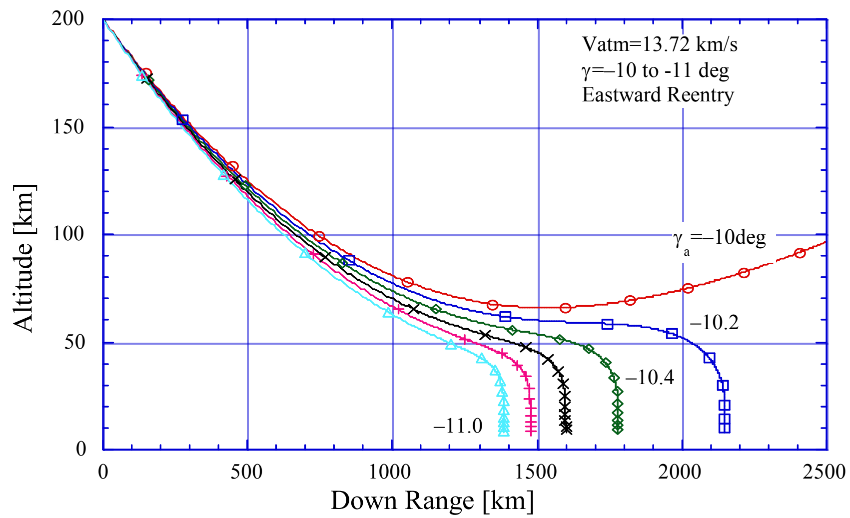
Key Technology-5: Direct Earth Re-entry Capsule System



	Hayabusa	Hayabusa-2
V0 (inertia)	12.06 km/s	11.88 km/s
Max. Heat Flux	15.7 MW/m^2	15.8 MW/m^2
Total Heat Input	256.7 MJ/m^2	235 MJ/m^2

➔ Solar Power Sail ERC needs higher heat resistance ablator materials than the Hayabusa series





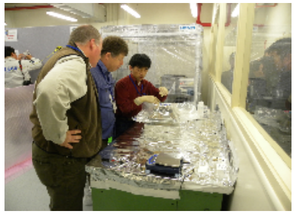
Key Technology-6: Ground Operation of Returned Capsule Recovery

Retrieval, Transport, Cleaning, Storing, Purging

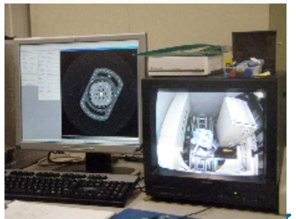
Contingency Sterilization

Soil Sampling

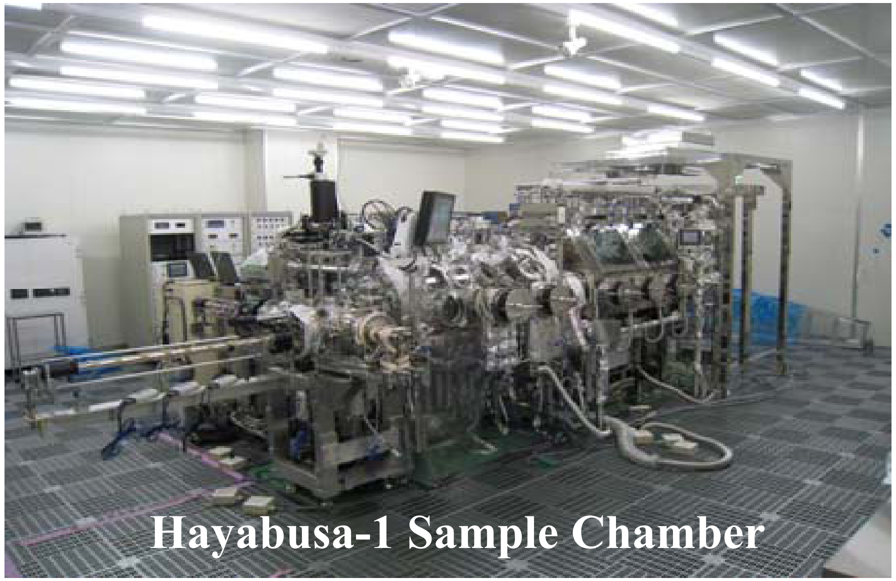
International Witness

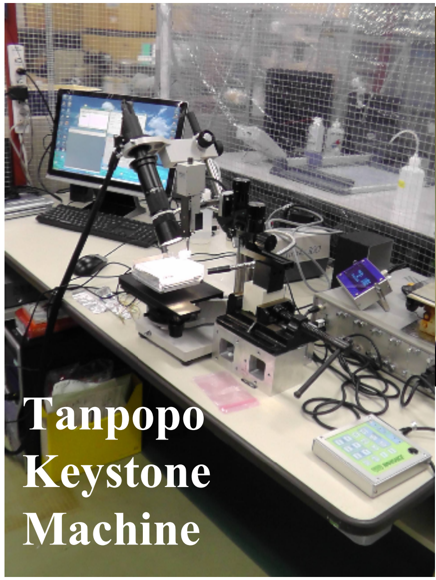


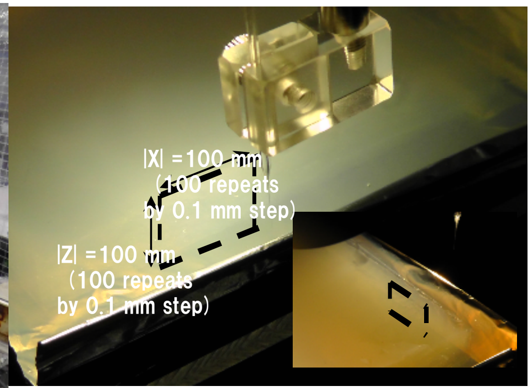
Pre-Open XCT Inspection

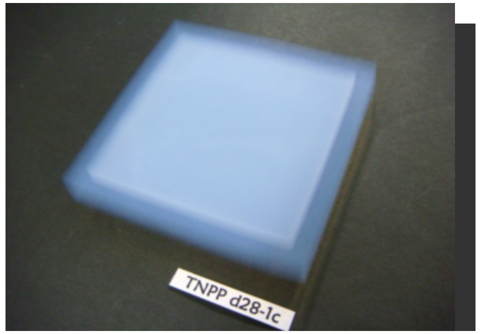


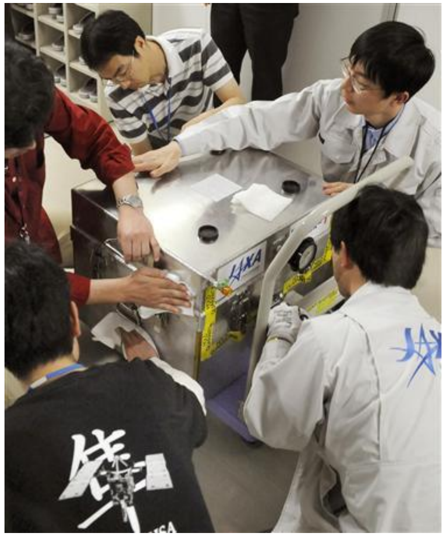
Key Technology-7: Initial Sample Analysis and Curation Facility

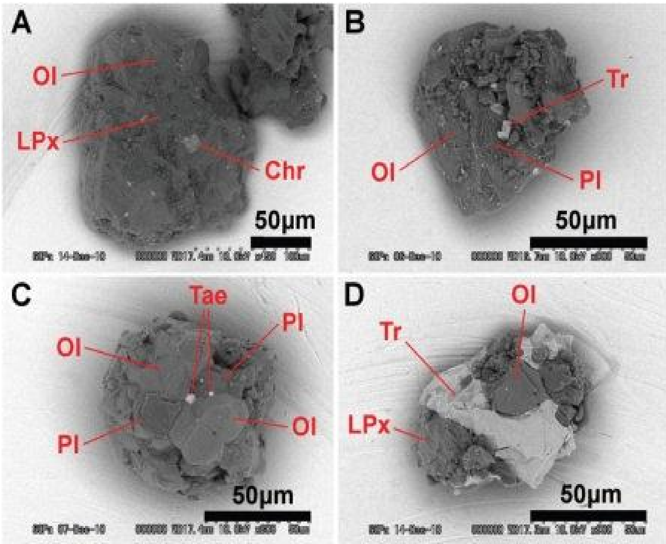


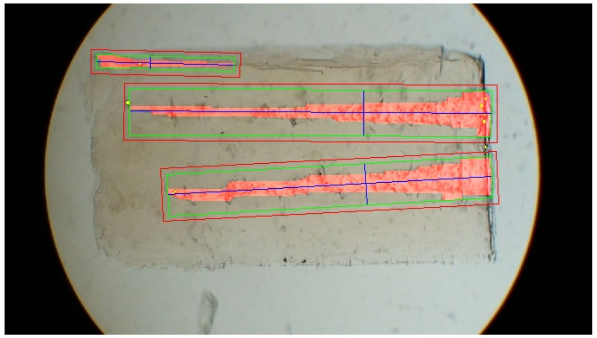








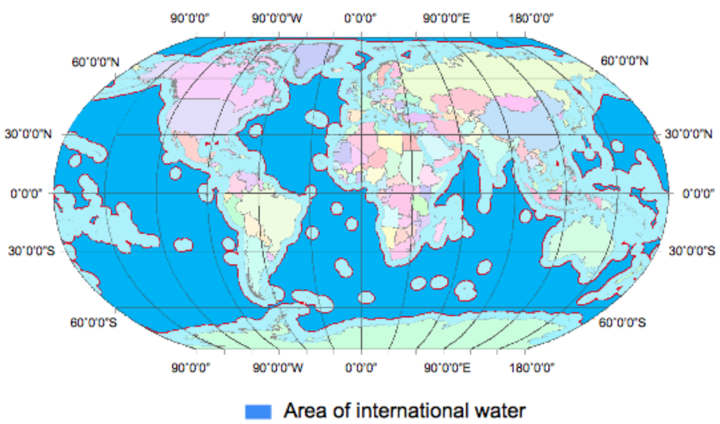




Key Technology-8: Biosafety Sample Handling Operation and Facility by JAMSTEC Partners

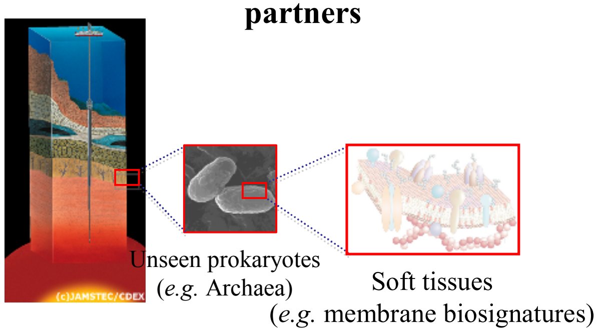
Subsurface hydrothermal microorganism sample return, contamination control and initial analysis on international waters of the Earth have been routinely and successfully conducted by the Research Vessel “Chikyu” of JAMSTEC Japan, as a part of the International Ocean Drilling Project (IODP) framework.

(A) International waters



(B) Onboard laboratory

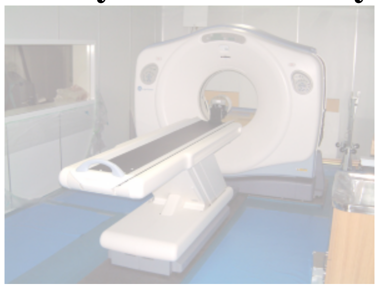
BSL4 laboratory installed on the “Chikyu” to be provided by JAMSTEC partners



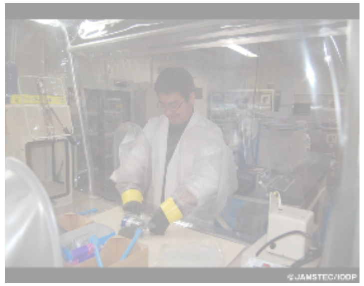
Present Routine Capability of the “Chikyu” Vessel

Helicopter Operation

Onboard Online Meeting Room



X-ray CT Scanner Prior to Opening



Anoxic Microbial Treatments

Microbial Culture Chamber

Stakeholders among Japanese Science and Engineering Community for New Sample Returns including Icy Plumes

NASA, COSPAR, etc.

*** International Collaboration WG for Sample Return Missions within JAXA/ISAS (Dec-2013)**
*** JAXA PP Committee (since 2013)**

JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

Cruising Operation
Integrated Sampling System
Impact Calibration Tests
Mission Design Support
Earth Return Capsule
Initial Sample Analysis,
etc.

JAMSTEC 独立行政法人 海洋研究開発機構
JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

Chikyu Vessel
Bio-safety Processing Facility,
Planetary Protection,
etc.

Scientists and engineers from University, Institutes with
Japan Astrobiology Network

Astrobiology	Geology
Extremophile Biology	Planetary Science
Marine Science	Astronautical
Geochemistry	Engineering, etc.

Science Council of Japan
(Large-scale Research Project: Deep Space Exploration including Enceladus SR)

JAXA

Summary and Hopes for NASA

• JAXA/ISAS has a three decade history of deep space exploration and has built unique expertise for sample returns

• Keywords in future Japanese exploration vision include: round trip, outer planet region, astrobiology and international collaboration, which all are associate3d with planetary protection activities in different levels.

• The new JAXA planetary protection review board and the ISAS international collaboration sample return WG have been established in 2013. Both astrobiology community and space exploration stakeholders in Japan are rapidly growing, too.

• Key enabling technologies that the new WG can provide as a package range from sampling system, earth return capsule, to curation and biosafety treatment facilities in collaboration with the marine microbiology community led by JAMSTEC scientists.

➔ The new WG hopes to have active collaboration with NASA through a comparable counterpart team with scientific background of astrobiology, engineering capability in deep space exploration and strong motivation to solve new planetary protection challenges such as backward contamination issues of icy plume returned samples from outer planet regions.