Sampling Systems for Hayabusa and follow-on missions: Scientific Rationale, Operational Considerations, and Technological Challenges

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Scientific Rationale

What We Can Learn about Asteroids (1): "Chronology", "Environment", "Composition", & "Structure"

* Admit that there are many things we can learn from ground and remote observations

<From Ground Observation>

Orbital Elements
Spectral Type (Taxonomy)
Thermal Properties (Space-IR)
Geometric Albedo
Rotation Period (Light curves)
Spin State (Light curves)
Binary System, Associated Dust Bands
Global Shape (Radar < Fly-by < Rendezvous)
Local Geography, Roughness (Same as above)

<From Remote Measurements by Rendezvous>

Global Surface Composition (X-, Gamma- Rays)
Local Surface Mineralogy (NIR)
Local Surface Topography / Geology (LIDAR, Vis.)
Gravity-Mass, Bulk Density, Macro-Porosity

What We Can Learn about Asteroids (2): "Chronology", "Environment", "Composition", & "Structure"

- Carefully identify what ONLY returned sample analyses an answer
- Evaluate complementary outputs between landers and sample analyses

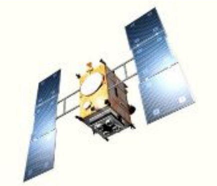
<From Direct Surface Investigations>

Size distribution of exposed materials on surface
Sub-surface structure
Internal (Macroscopic) structure by wave propagation
Microscopic porosity and structure / material strength
Space Weathering Effect
Surface thermal properties, etc.

<From Material Sample Return>

Absolute Dating
Meteorite/Cosmic Dust Connection
Mineralogy/Petrology
Isotopic Ratios
Major & Trace Elements
Carbonates & Organics
Noble Gas, etc.

➔ Seriously evaluate the minimum amount of sample mass required for each discipline in 2020's, more than decade later than Stardust and Hayabusa era; only such an evaluation can justify the nominal mission success criteria.

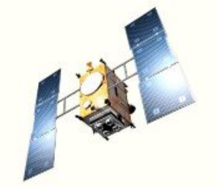


Sampling GOALS for Carbonaceous Asteroids from Meteoritic Scientists in Japan

- Acquire a total amount of up to 10-g samples mainly for organic and hydrated mineral analyses
- Characterize geological contexts at the sampling site
- If possible, acquire stratigraphic information of the samples
- If possible, acquire not only powdery samples but also chunks

➔Clearly distinguish between "goals" / "targets" (decision making drivers) and "requirements" (measurements of success and failure) for mission design

➔ We ALL "target" to acquire as much sample mass as we can but no one can "require" them unless the s/c goes back to Itokawa or Eros…



Success Criteria for Sample Return Science Discussed among Hayabusa Follow-on Mission Team Meteoritic Scientists in Japan

MINIMUM SUCCESS OF SAMPLE RETURN SCIENCE:

Bring some amount of surface samples of the target body back to ground laboratories enough to understand surface compositions and carbon isotopes for comparison with terrestrial samples

(The same level as the maximum success of Hayabusa-1)

NOMINAL SUCCESS OF SAMPLE RETURN SCIENCE:

Bring >1g* of sub-surface samples of the target body back to ground laboratories to test existence of organic compounds

(New addition to Hayabusa-1) [15% mass for initial analysis = 50mg x 3 time repeats]

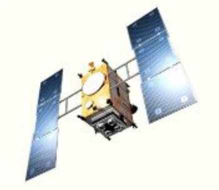
EXTRA SUCCESS OF SAMPLE RETURN SCIENCE:

Bring >10 g of sub-surface samples of the target body back to ground laboratories to study chirality of organic compounds

(New addition to Hayabusa-1) .

* Analytical technology assumed as of 2008

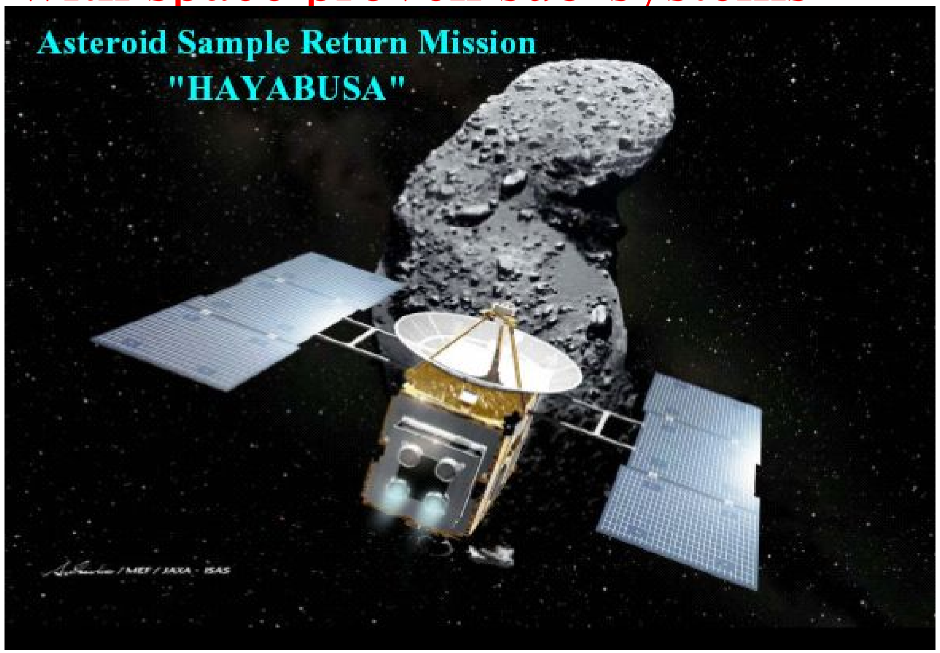
Operational Considerations



Lessons Learned from Hayabusa (1): Expect the Unexpected

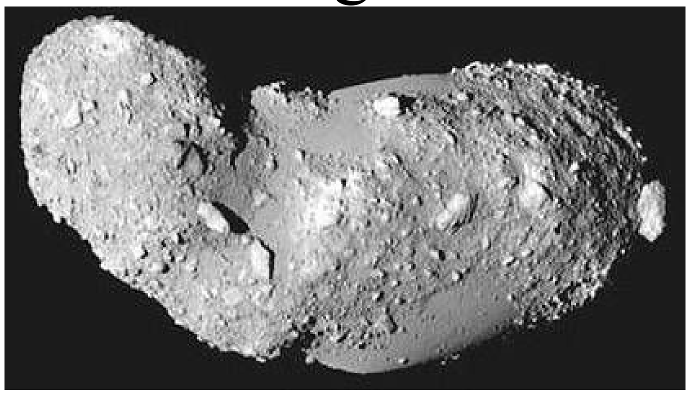
- Our destination is inevitably always the first visited target (unlike the Moon and Mars)
- Pre-arrival information of the target is limited in spite of the ground observation campaign effort prior to the spacecraft design; We'll never know what the sampling site actually is like until we get there and complete its global investigation

➔ Its sampling strategy and system must be robust and flexible for the surprise while retaining high TRL with space proven sub-systems

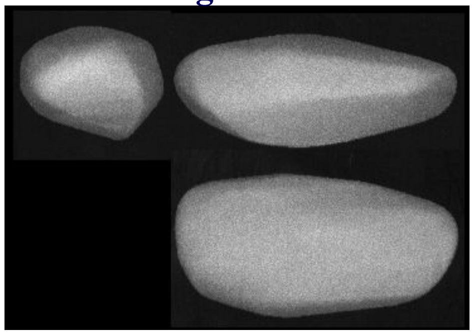


Lessons Learned from Hayabusa (2): Know Your Enemy and Never Underestimate Them

- Target selection criteria from telescopic info: Several key parameters suitable for surface sampling with appropriate TRL instruments, in addition to scientific rationale, (e.g.) rotational period, spin angle, etc.
- Completion of global mapping for creating 3-D shape model is the top priority during the observation period, prior to the sampling preparation and site selection
- Sample site characterization is vital for both mission safety and scientific gain

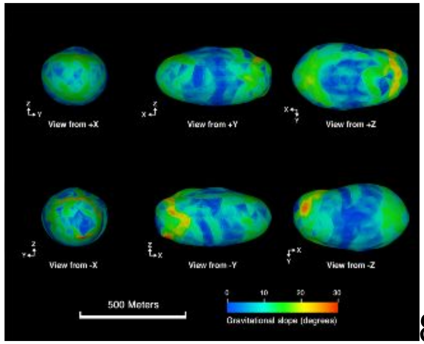


Ground Light Curve Model



Kaasalainen, et al (2002)

Ground Radar Model



Ostro et al.(2004)

Lessons Learned from Hayabusa (3): Design the Whole Spacecraft as a Sampling Device

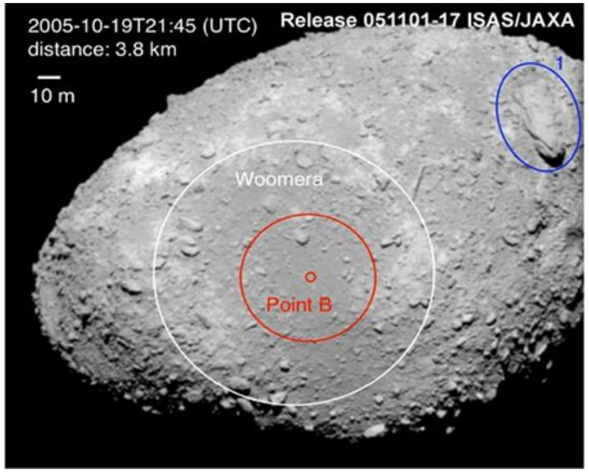
• We can target the maximum science output with ample sample mass for mission design goal; yet we must also define the minimum requirement that still justifies this mission in the worst scenario

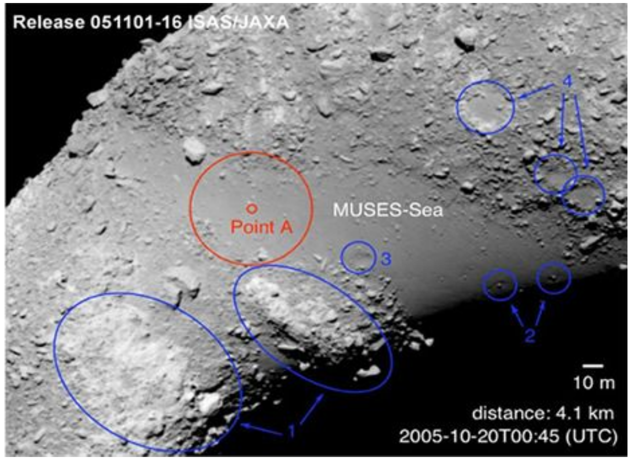
• DON'T BUY "100g or bust" policy. Mission safety is the top priority as we need to COME BACK

•Pin-point landing accuracy and autonomous maneuvering capability dictate the sampling sites over scientific arguments

• Sampling device must be suitable for ANY surface conditions unless the landing ellipse is less than the size of sampling device

• The sampler is NOT just one of sub-systems but the spacecraft itself; equivalent-sized obstacle with the spacecraft is a killer





Technological Challenges

Pros & Cons of Sampling System Options: Many tens of ideas emerged but few satisfies all the conditions

- Docking Robot/ Catch Ball
- Hummer*
- Mole
- Drilling / Coring
- Scoop
- Fish Net
- UFO Catcher
- ● Rotation Brush/Blade*
- Sticky Pad
- Gas Injection*
- Explosives*
- Shot Gun & Carpet*
- Impulsive Coring
- ● Bullet Projection*, etc…

Separated Operation

Stay Too Long

Electronic Wires Required

Phobos−Grunt

NG for Monolith

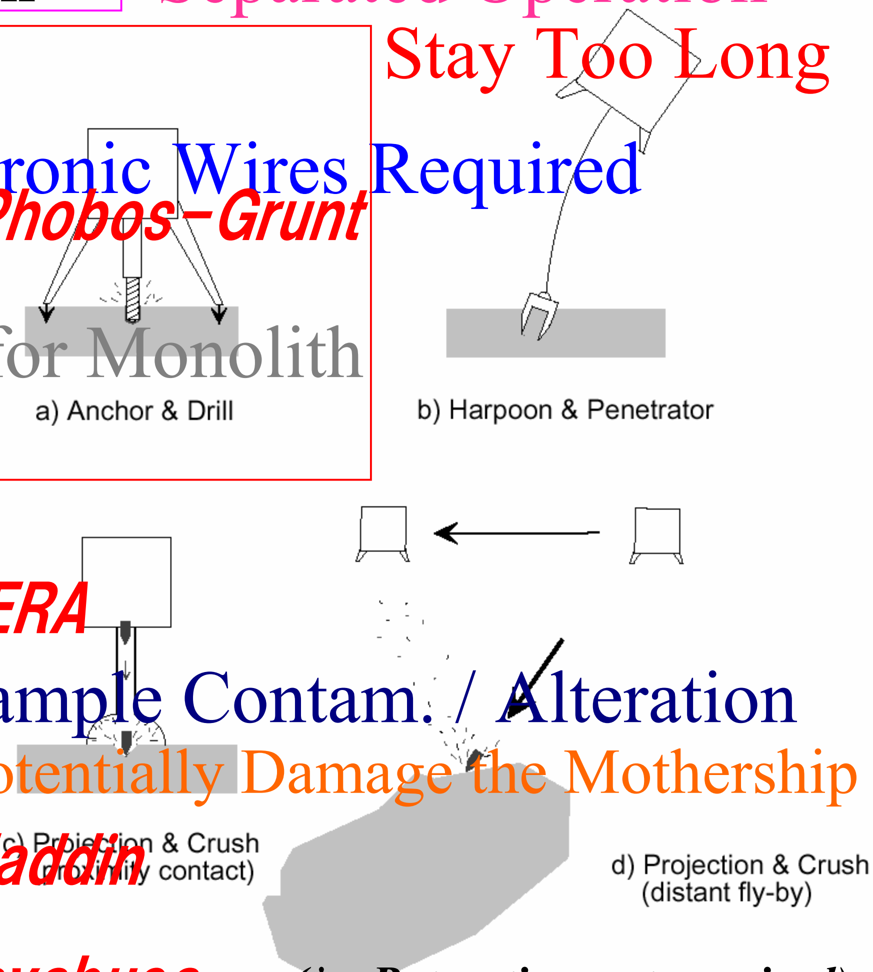
HERA

Sample Contam. / Alteration

Potentially Damage the Mothership

Aladdin

Hayabusa



(= Retraction not required)*

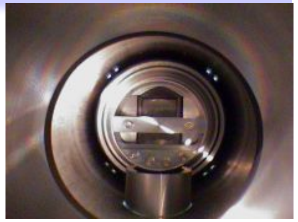
➔ Only two options with red dots were studied in detail for MUSES-C sampler in late 1990's

Hayabusa's Impact Sampling System

- Collect sufficient amount of samples (>several 100 mg) compliant with both monolithic bed rock and regolith targets
- Projectors designed to fire a 5-g metal projectile at 300 m/s
- Powder cartridge and sabot to conceal residual gas during sampling
- "Ta" projectile not to spoil sample analysis with enough material strength

Spacecraft

Return Capsule
(Sample Catcher & Container inside)



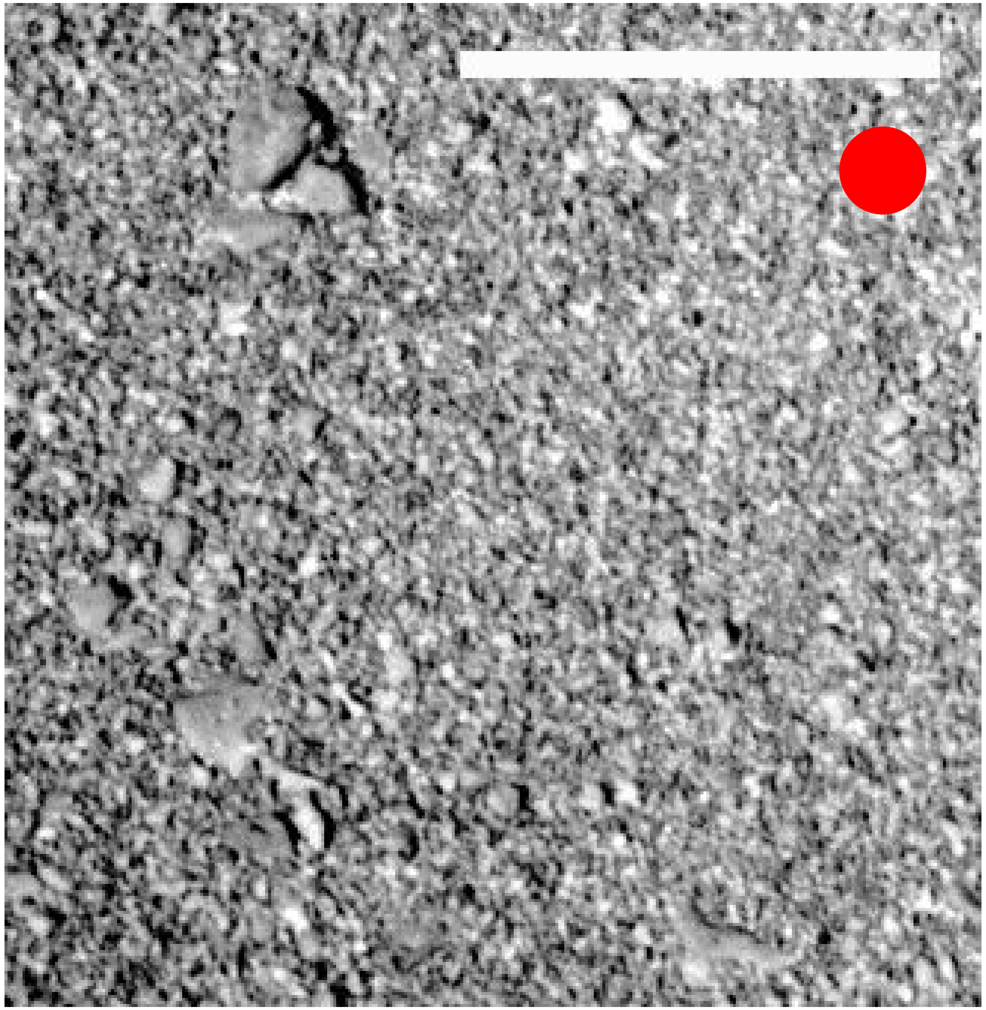
Projectors
(Up to three)

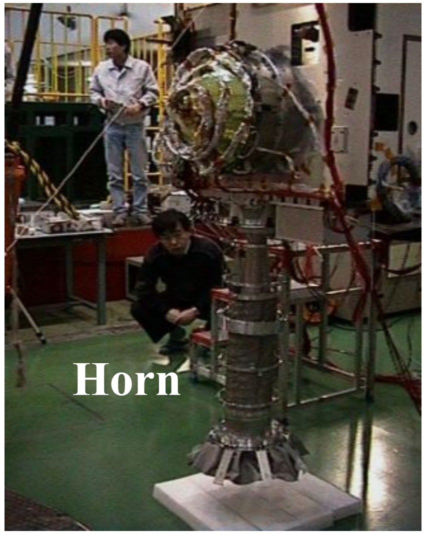
Conical Horn
(Concentrator)

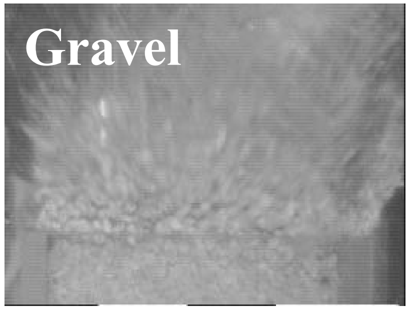
Extendable Fabric Horn

Metal (Al) Horn with Dust Protection Skirt and LRF Trigger Target

1G and Micro-G Impact Experiments on Powdery, Gravel and Monolithic Targets

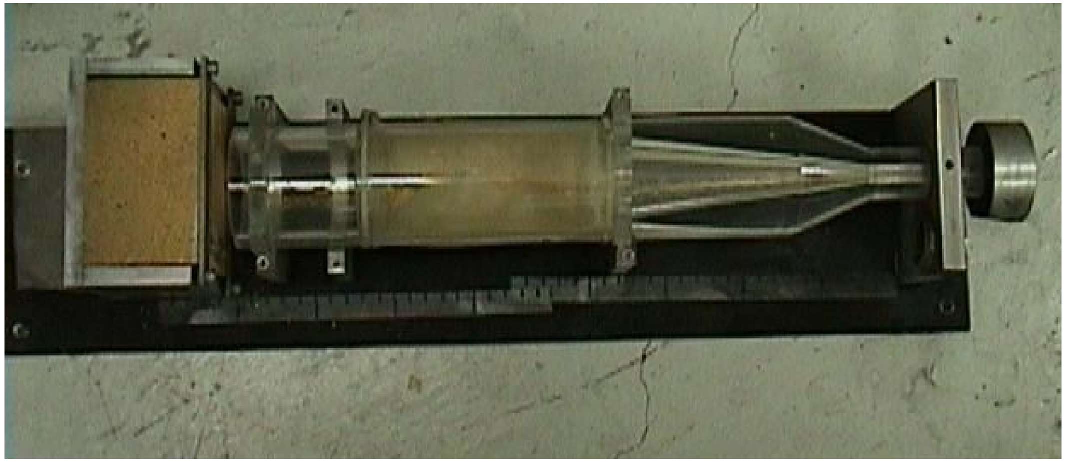


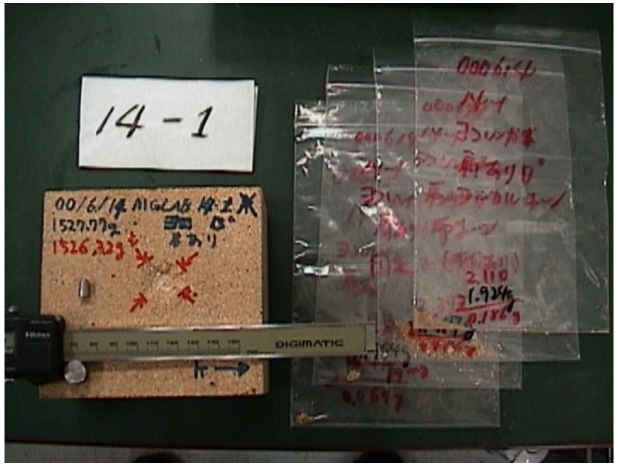




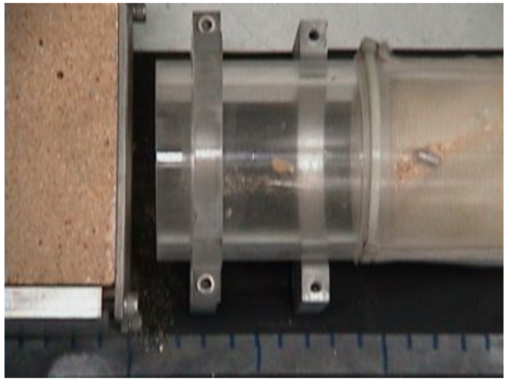
- Projectile: 10mm dia., 5-g Ta
- Horn diameter: 200 mm

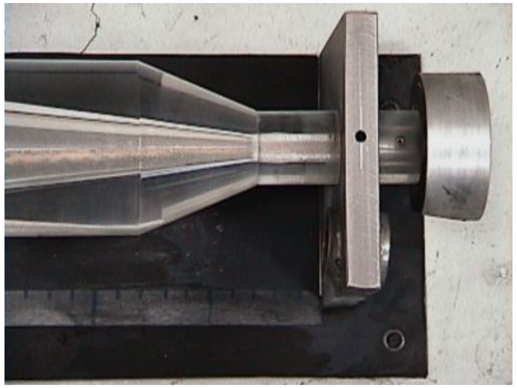
MUSES-C 40% Scaled Horn μG ($10^{-4\sim-5}$G) Impact Tests on Bricks at MGLAB



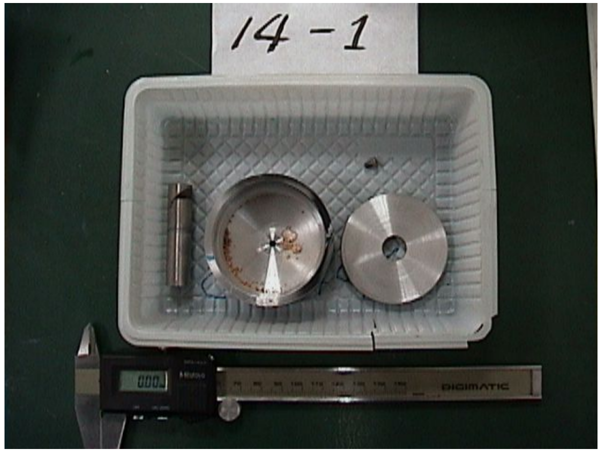


Target & All Ejecta



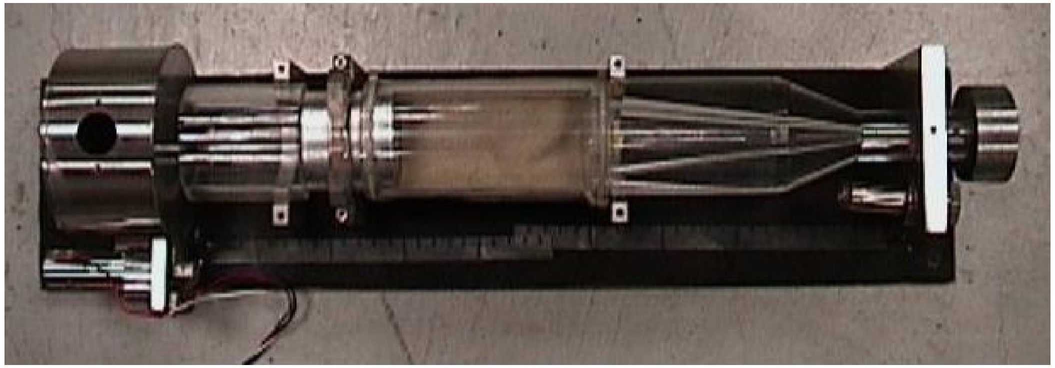


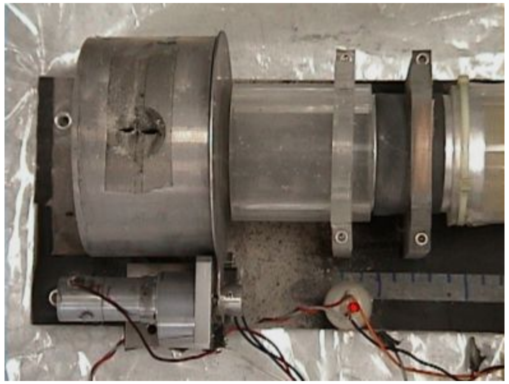
Target and Projectile (left) and Conical Horn and Catcher (right) after the Capsule Recovery

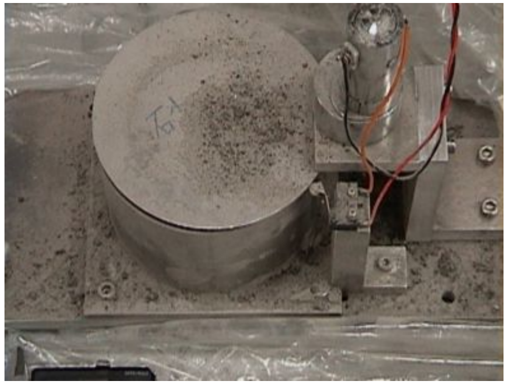


Collected Samples

MUSES-C 40% Scaled Horn μG ($10^{-4\sim-5}$G) Impact Tests on Lunar Regolith Simulants &Glass Beads (175-250 mm) at MGLAB





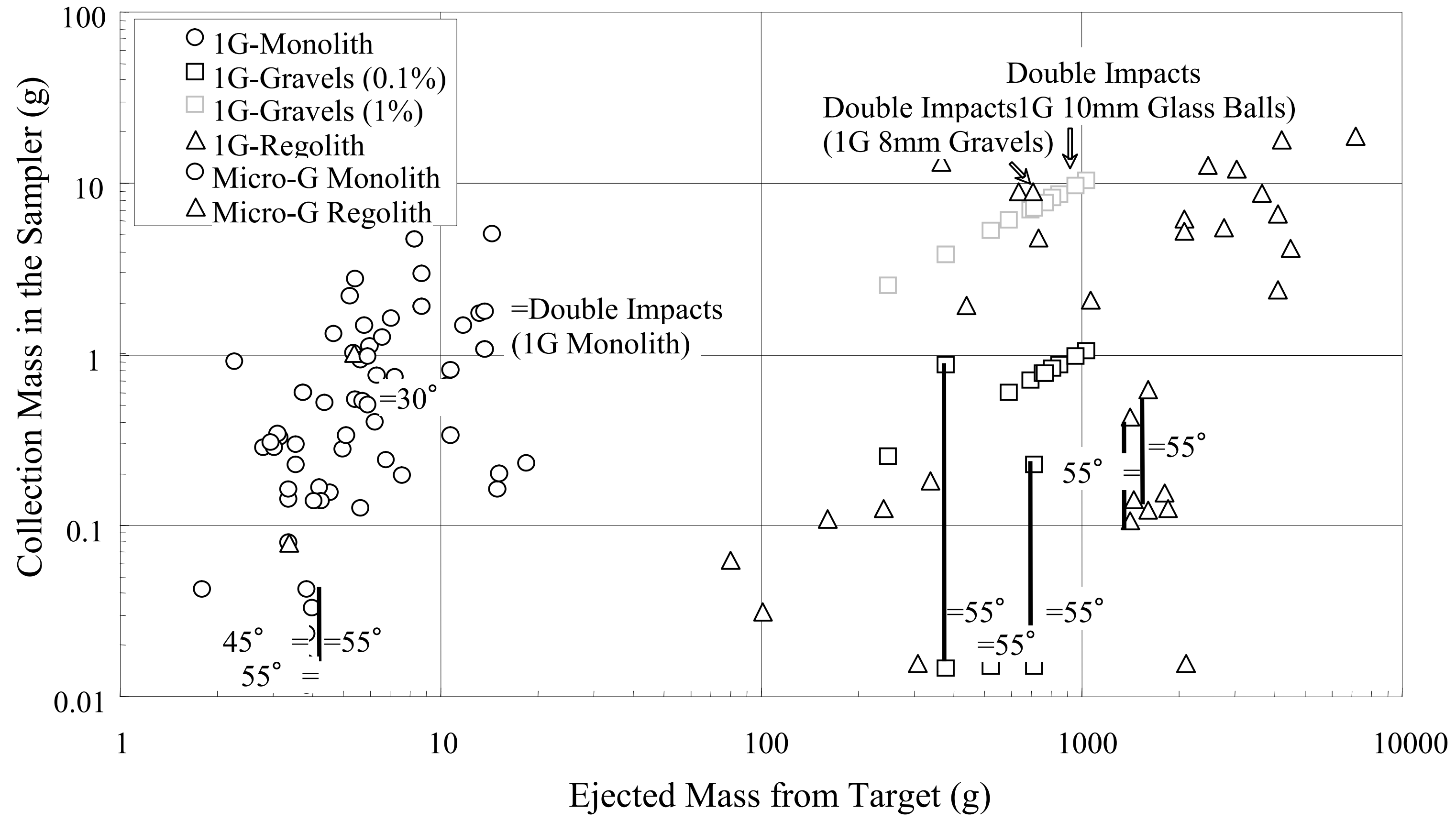


Horizontal (left) and Vertical (right) Regolith Container after the Capsule Recovery

Projectile deeply embedded in the regolith simulants

Sample Collection Performance

Yano, et al., Science (2006)



○ : Monolith（>>10 mm）

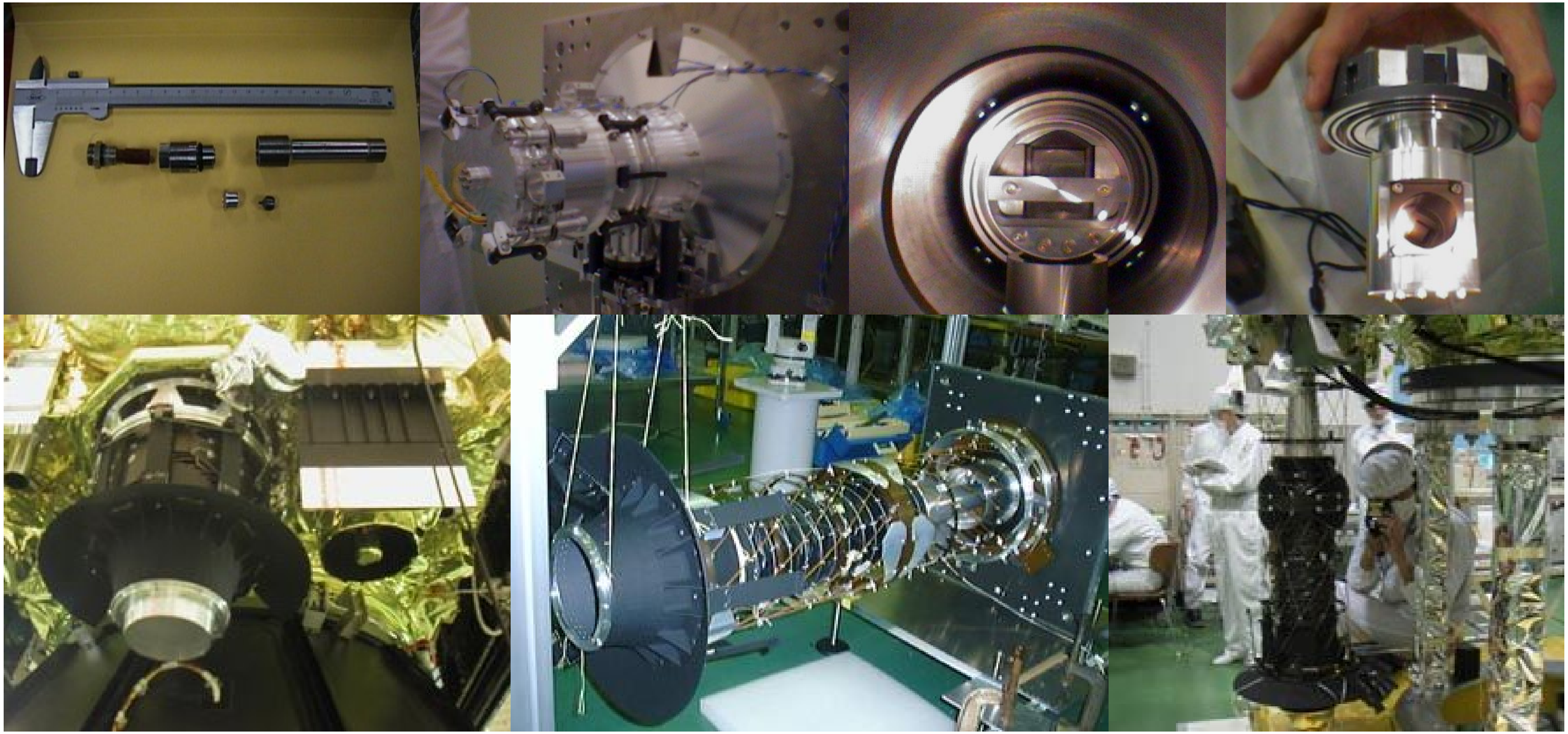
□ : Gravels（3~10mm）

△ : Regolith（<< 1mm）

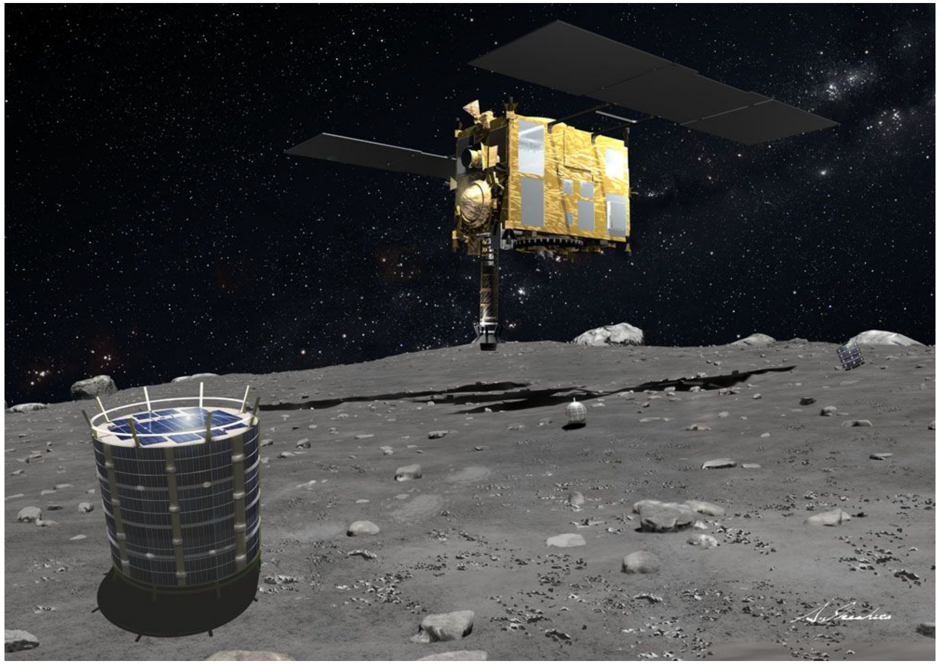
➔ Designed to collect sufficient amount of samples (>several 100 mg) compliant with both monolithic bed rock and regolith targets

Hayabusa Sampler Flight Model

- Projectors designed to fire a 5-g metal projectile at 300 m/s
- Powder cartridge and sabot to conceal residual gas during sampling
- “Ta” projectile not to spoil sample analysis with enough material strength



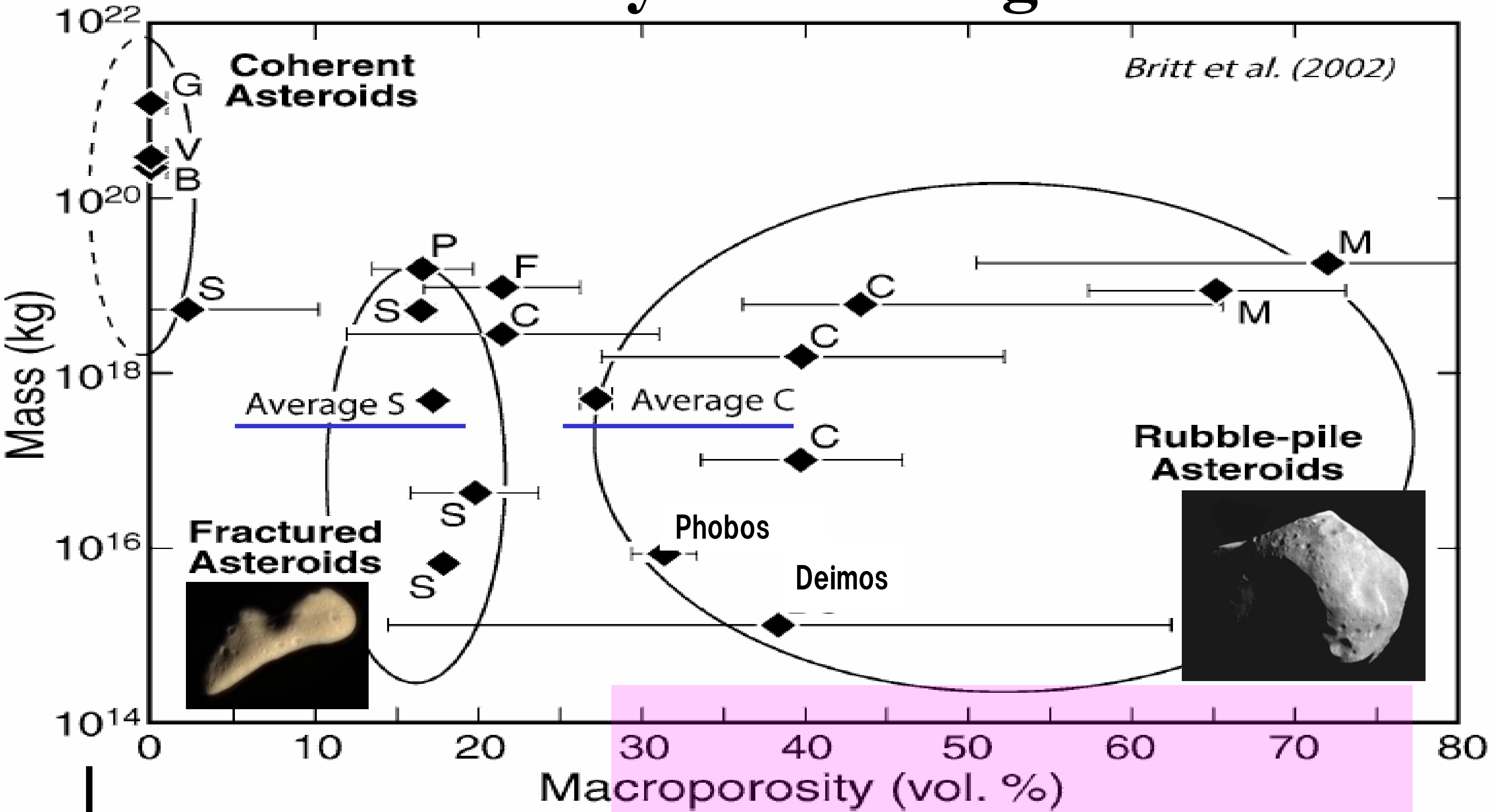
Sampler Upgrades for 1999 JU3-Class Mission



1) Strength Measurement of Carbonaceous Chondrite and Production of C-type Asteroid Surface Analogs
2) *<u>Shape and Angular Momentum of Projectiles</u>*
3) Direct Sampling Site Investigation by the Spacecraft

4) Contamination Control Protocol for Hydrated Minerals and Organics
5) Touch-and-Go Sequence Algorithm

Macro-Porosity: Expected Ranges for Post-Hayabusa Targets



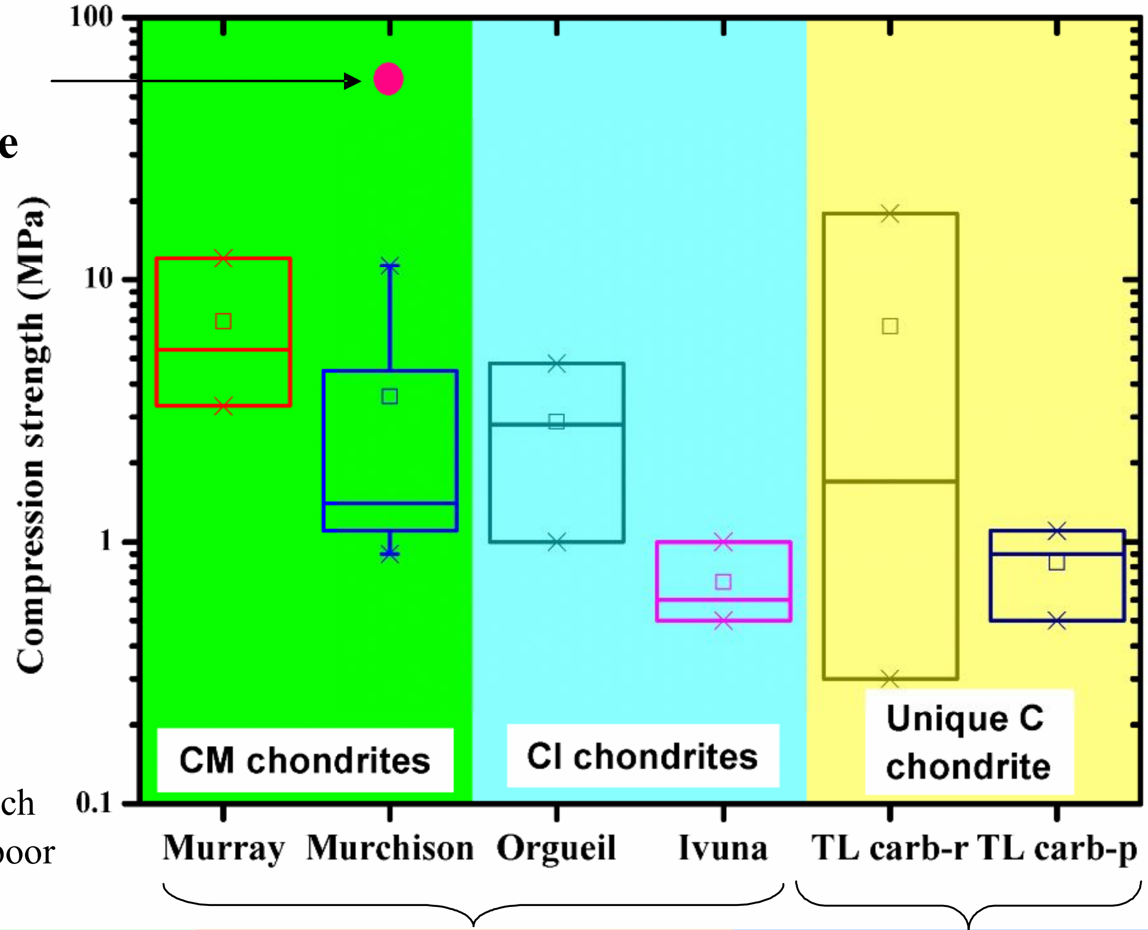
Expected Ranges
for carbonaceous NEO SRs

3.58 x 10^{10} (kg)

Itokawa (S)

How Strong Are Small Carbonaceous Asteroids?: Compressive Strength Measurement of Sub-mm Meteorite Powders

5x10 mm
Compressive
Strength

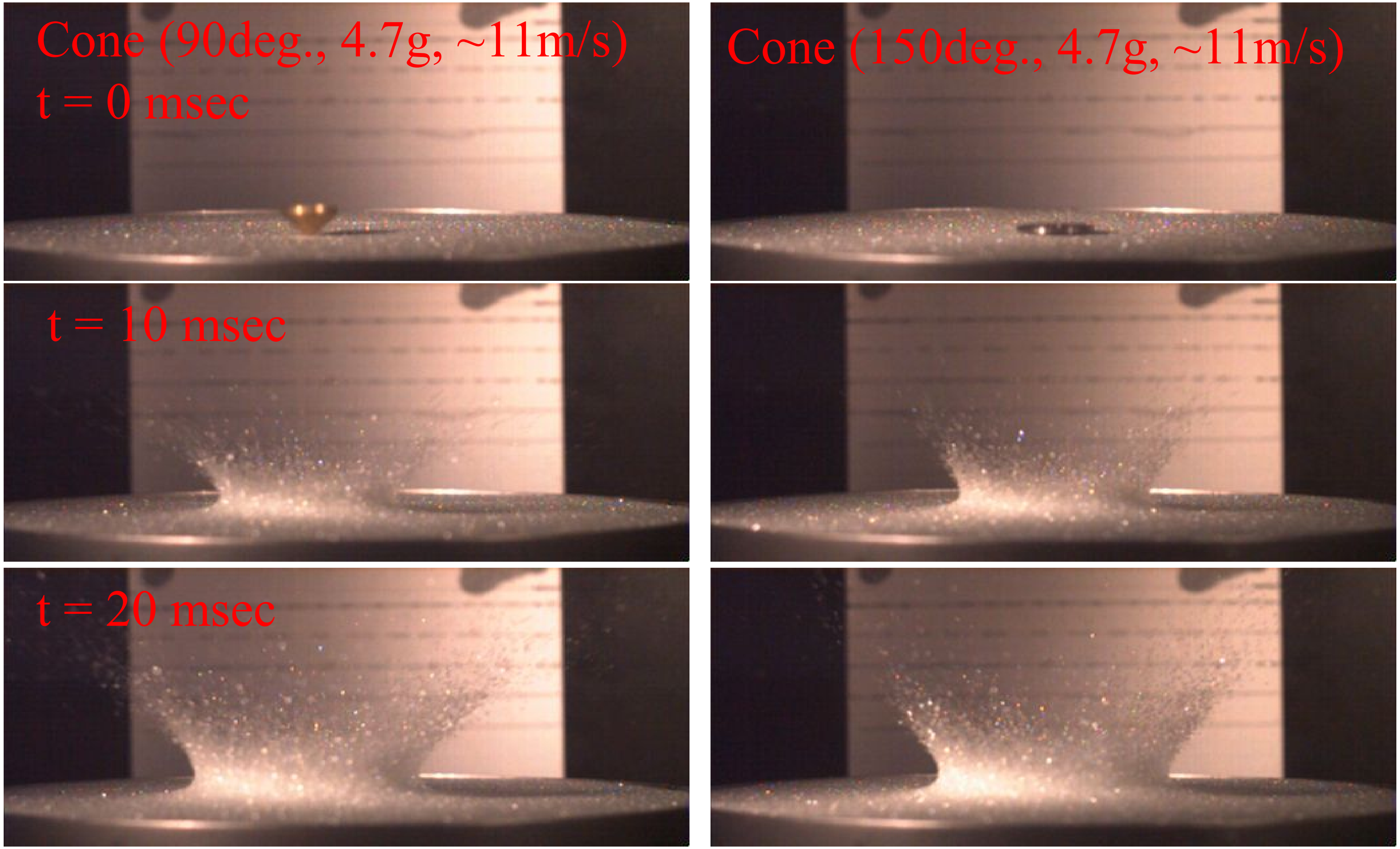


TL: Tagish Lake
carb -r: carbonate -rich
carb -p: carbonate -poor

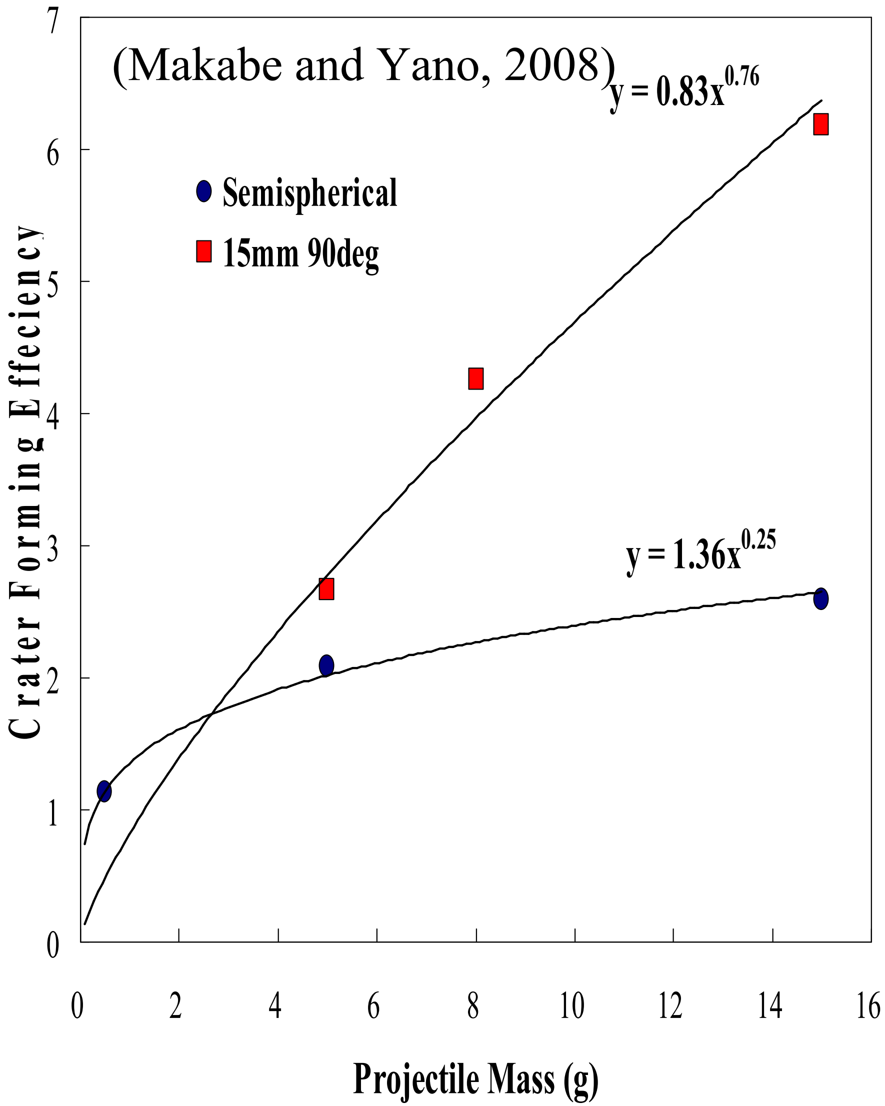
Probable parental asteroids	C-type asteroids	T- (or D-) type asteroid

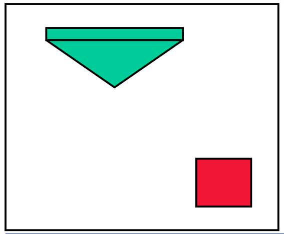
(Miura, Tsuchiyama, Noguchi and Yano, 2008)

How to Increase the Sample Mass WITHOUT Increasing System Resources of the Sampling Device?: Shape and Roll

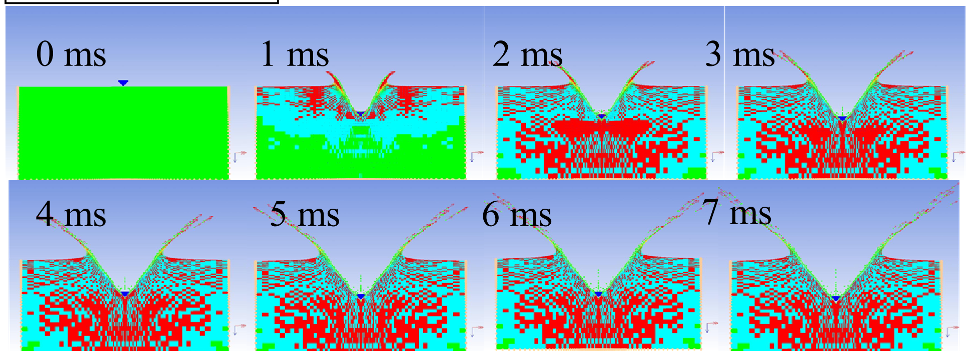


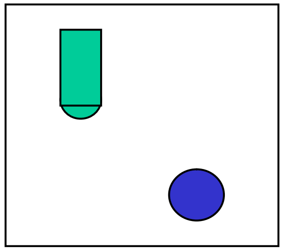
Projectile Shape Effects



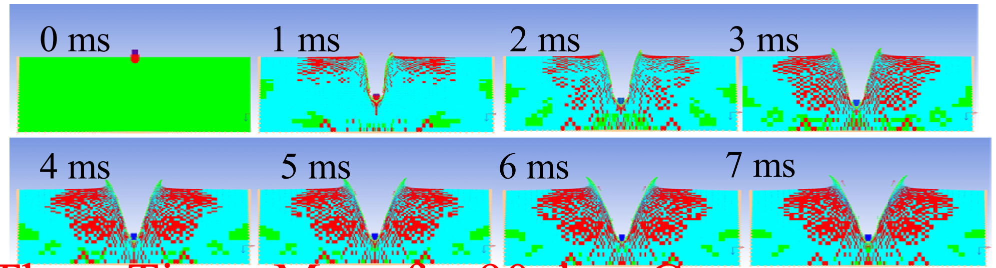


90 deg. Conical Projectile:
Hayabusa-2 Model
for Porous Asteroids



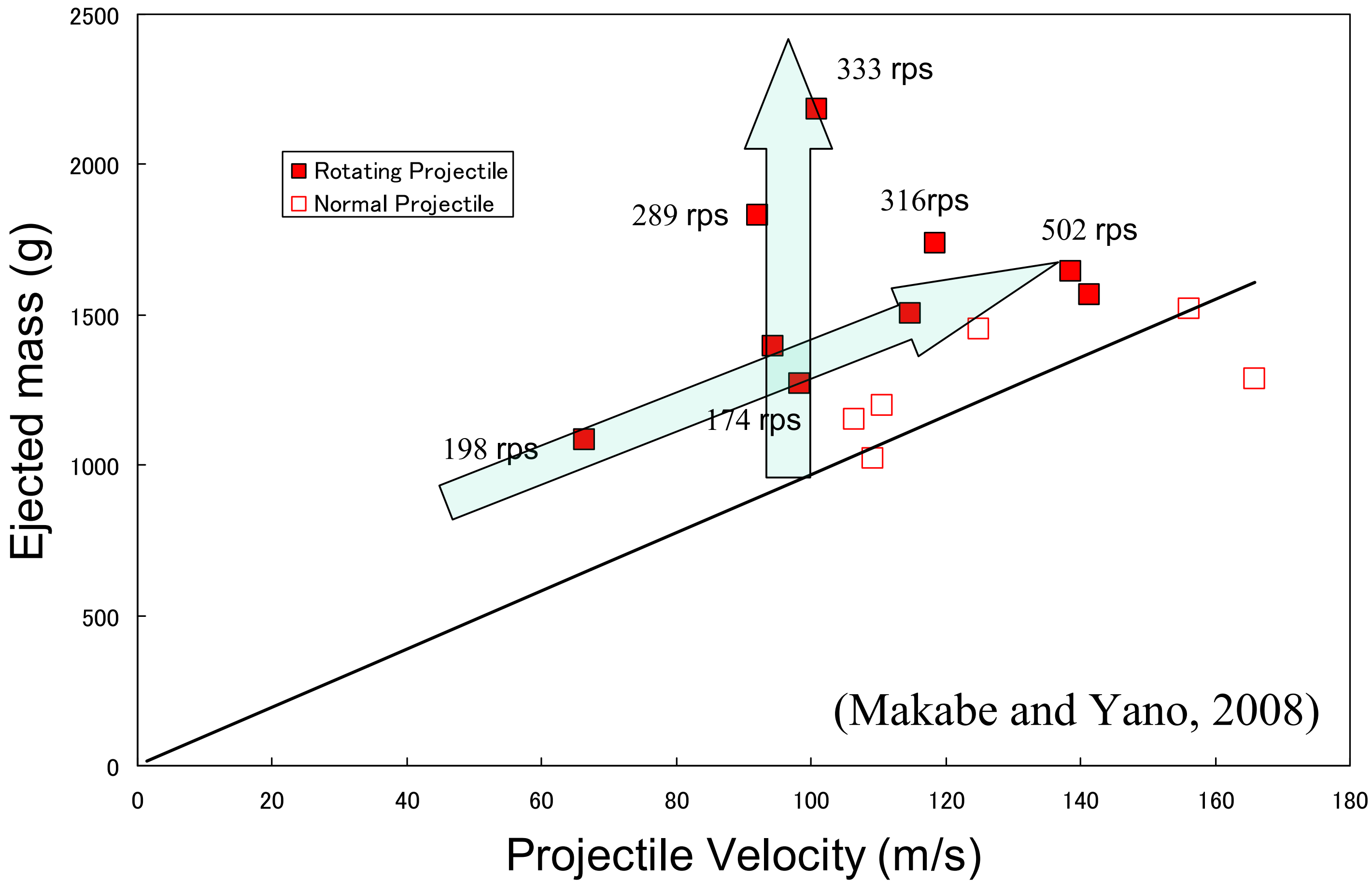


Hemispherical Projectile:
Hayabusa-1 Model
for Consolidated Asteroids



➔ Crater Forming Efficiency Increases Three Times More for 90 deg. Cone-type Than Hayabusa Projectiles

Projectile Angular Momentum



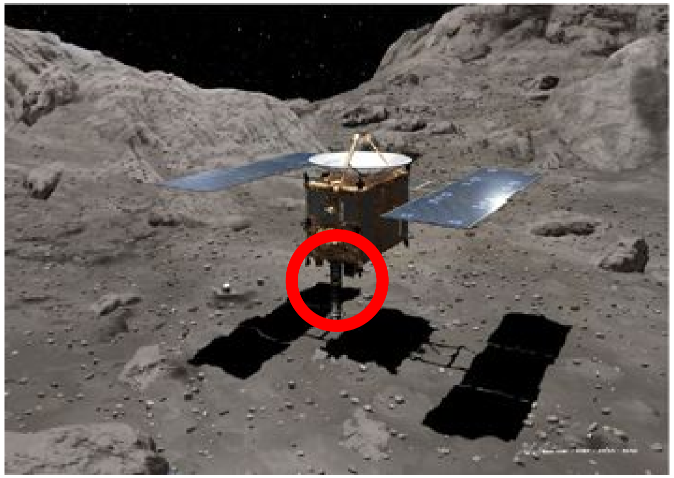
1.The higher projectile velocity is , the higher rps is.

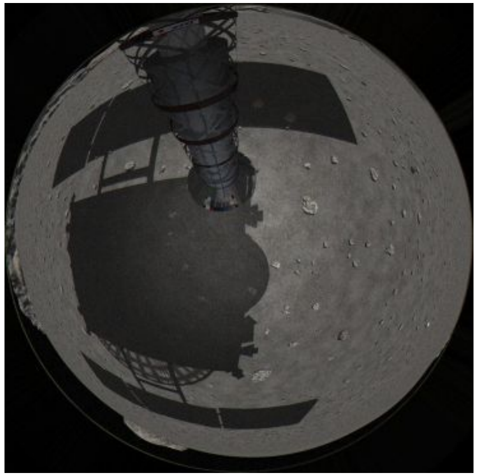
2.In the same velocity region, the higher rps is, the larger ejected mass becomes

3.The variation of rps depends on the ratio of projector inner diameter and sabot diameter

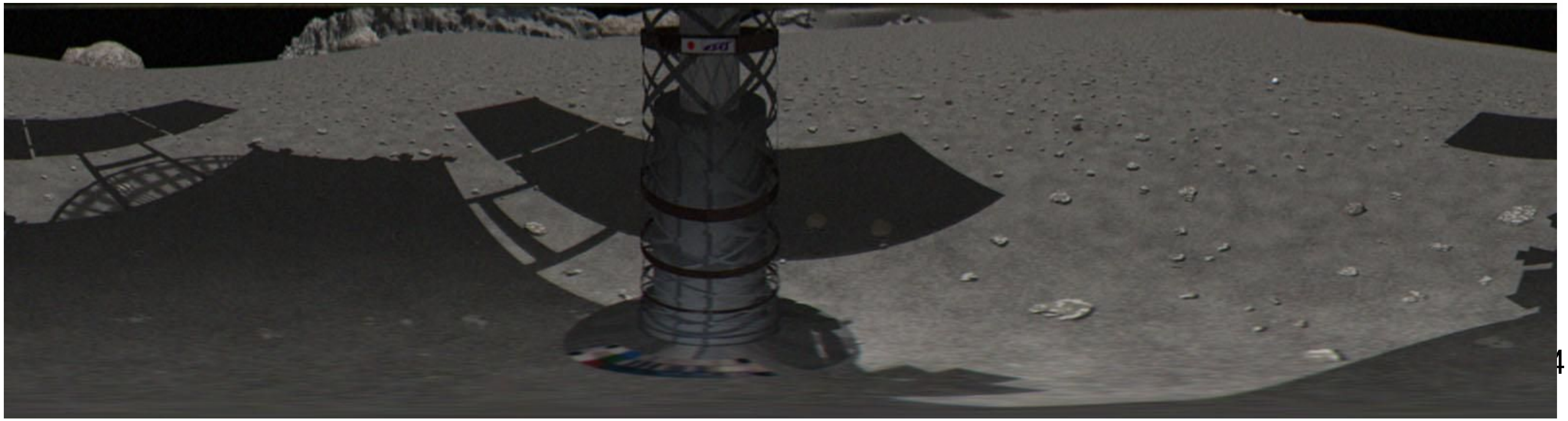
Sampling Site Investigation: Observing Impact Consequences & Operational Assurance

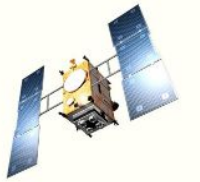
- Sampling Monitor Camera: Landing to horizon before and after the impact sampling
- Sample Detection System: To confirm uplifted ejecta by light curtain





(Yano, et al., 2008)





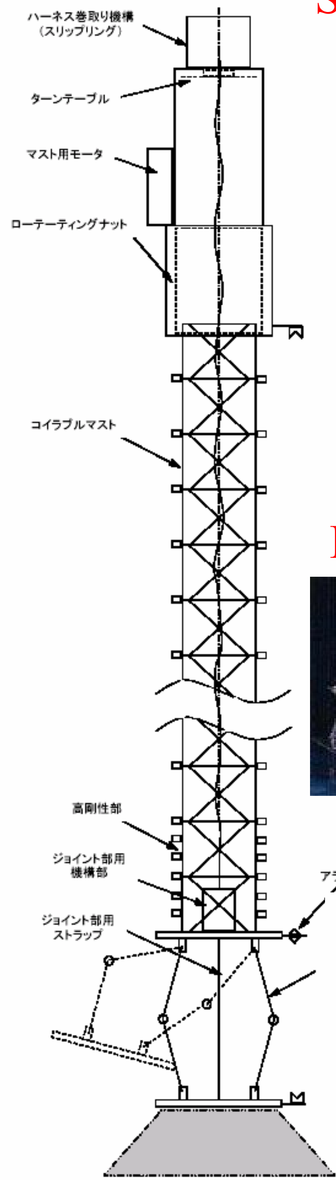
Further Development for Wilson-Harrington Class Mission: Extendible Mast Design

Requirements for Initial Design:

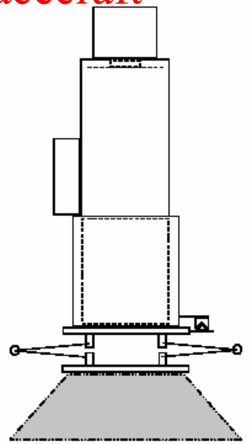
1) 5-m or longer extension
2) Multiple repetition of deployment &retraction
3) Precise alignment in retracted position for capsule insertion
4) Mainly composed of space-proven hardware

➔ Experiments conducted for touchdown consequences and conditions with the robotic 3D motion simulator at JAXA since 2008

➔ Reference model of the extendible mast has a space flown record by SFU and Tsubasa

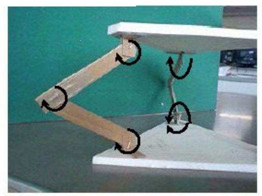


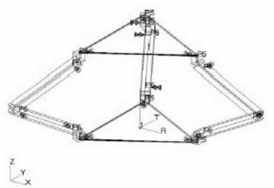
Spacecraft



Extendible Mast

Joint

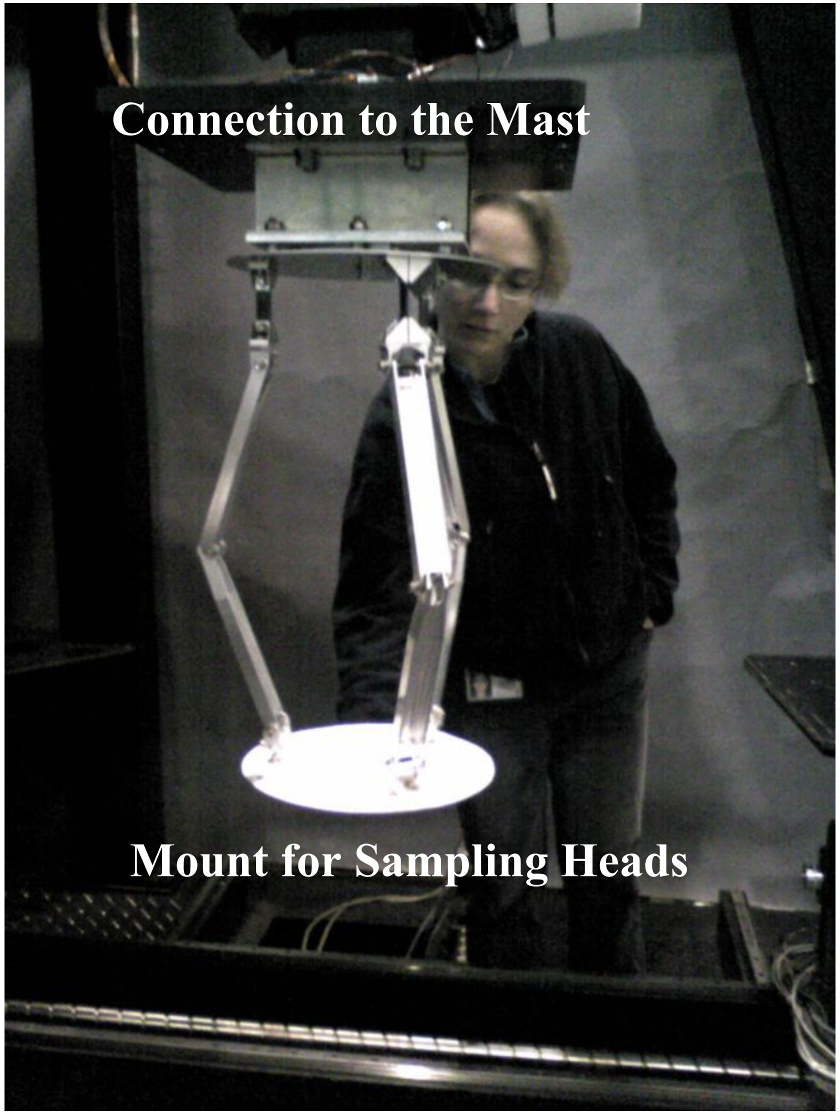


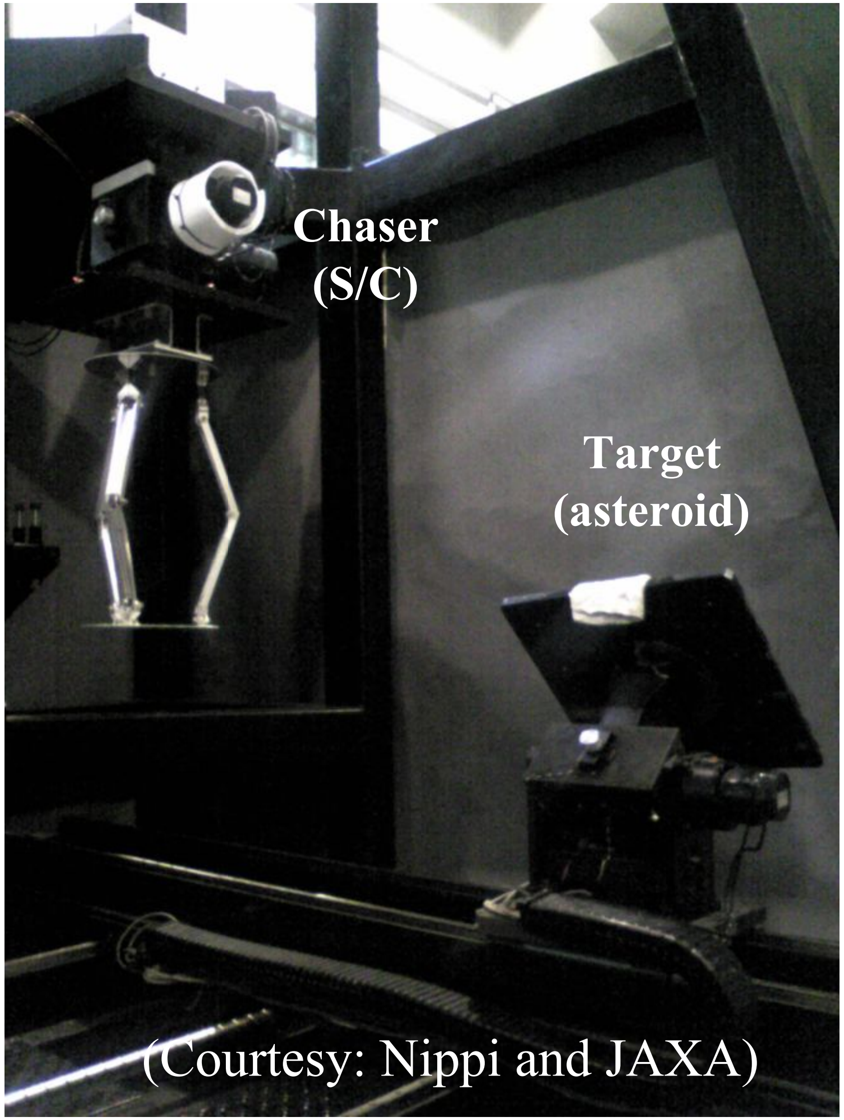


Two Sampling Heads

(Courtesy: Nippi and JAXA)

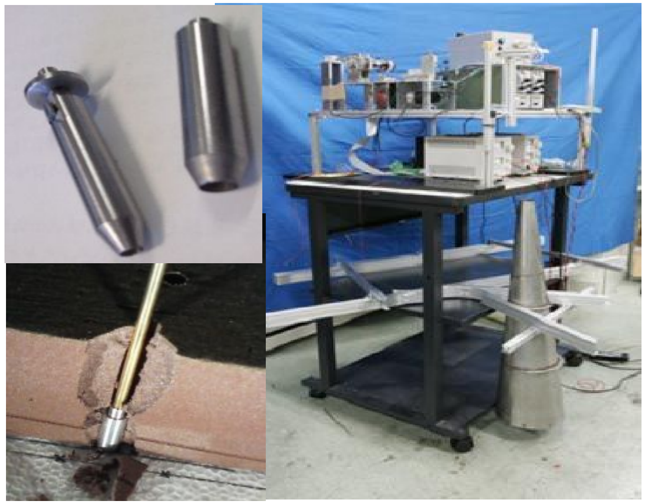
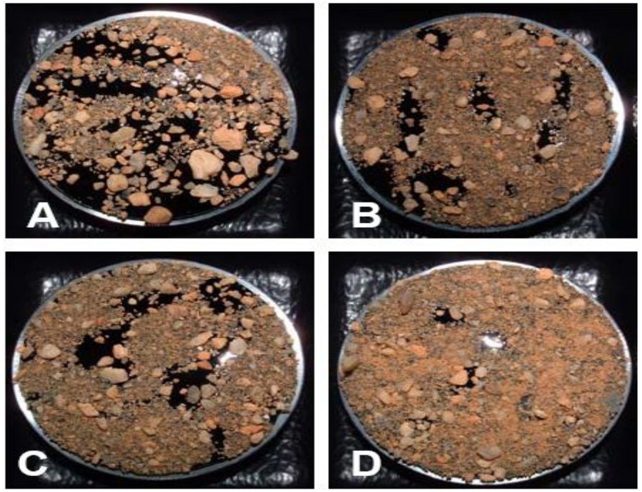
9-DOF Robotic Motion Simulation Test of the Link Joint at JAXA

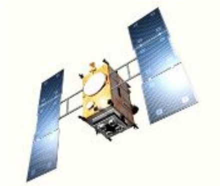




(Courtesy: Nippi and JAXA)

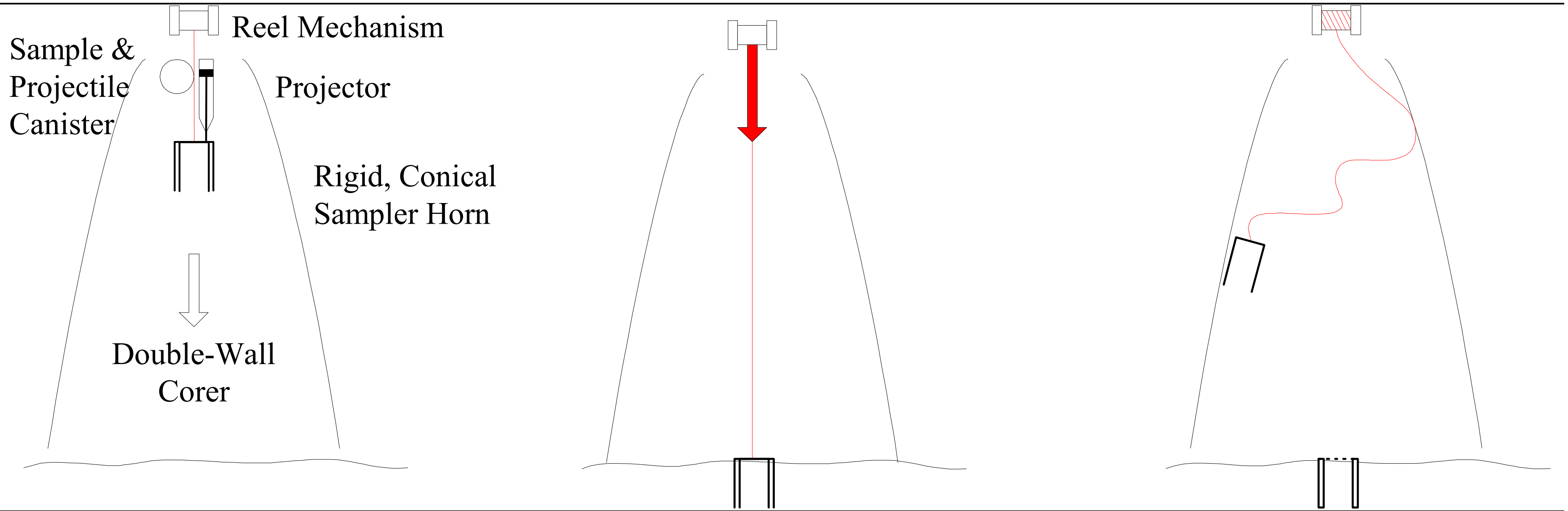
Complementary Sampling Head Options

Hayabusa	Corer Impacts (e.g., JAXA)	Sticky Pads (e.g., APL)
		
Monolithic Rock	▪Uplifted impact fragments	▪ **Only coated powders if any**
Gravel and Regolith	▪Impact ejecta as the minimum ▪Surface-sub-surface samples retaining stratigraphic info	. Top surface samples retaining size distribution
Heritage	**Hayabusa**	**HERA (Concept Study)**



The Sampling Head-1: Impact Corer with Horn

Firing & Impact of Corer, Fragment Collection → **Pull-Out or Wire Cutting** → **Tether-Corer Retrieval**



Same as HAYABYSA-1

Impact ejecta not captured inside the corer can also be collected by Hayabusa-like conical horn deflection as the minimum success

New Addition

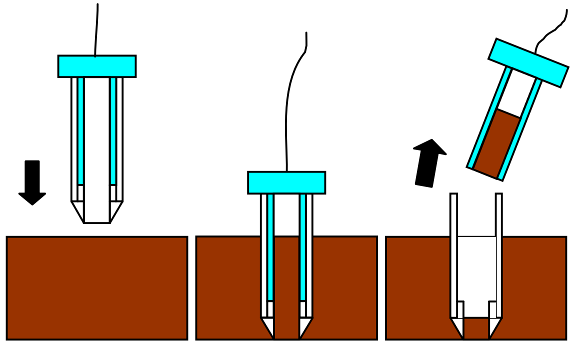
In case of the corer being stuck, the spacecraft can escape from the surface by cutting the tether

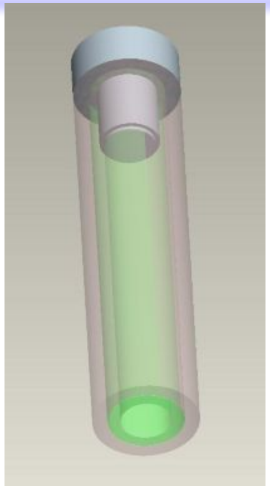
New Addition

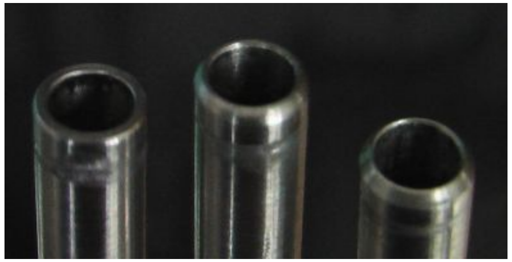
Protected and guided by the horn from entangling the tether and bouncing the corer

Double Corer Projectile Development

Dual Corer Concept

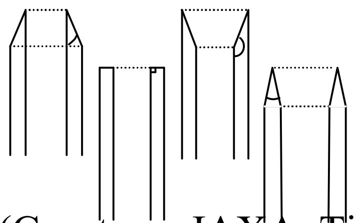






Vertical Round Blade

Optimization of penetratable shape



(Courtesy: JAXA, Titech, and TMU)

Porous Asteroid/ Comet Analogs

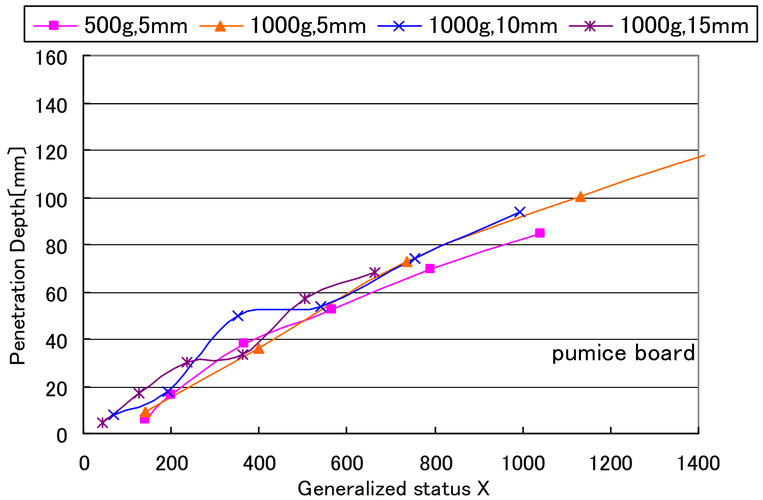
sand

pumice

Pumice board

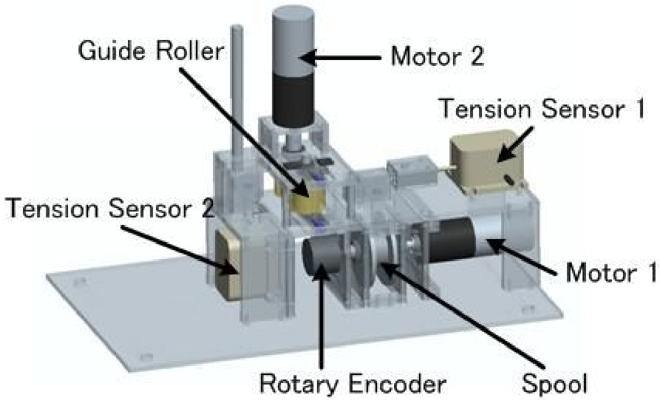
Collection of startigraphic samples is a new addition to Marco Polo impact sampling compared to Hayabusa.

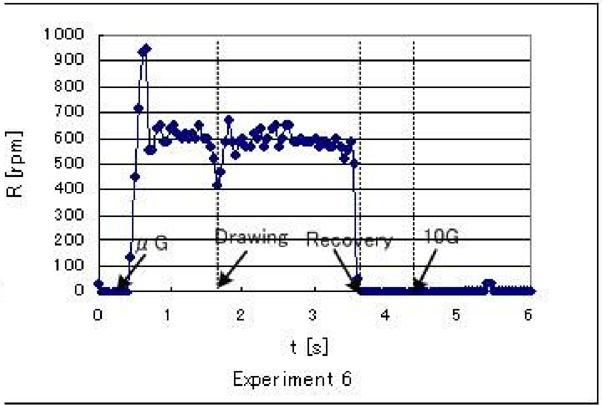
Penetration Experiment

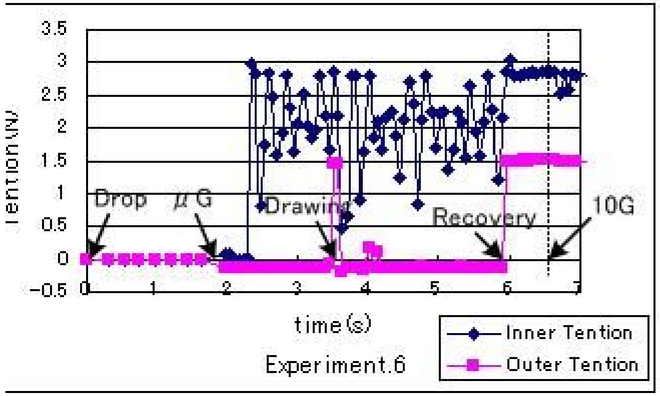


Short Tether Reel System Feasibility Tests

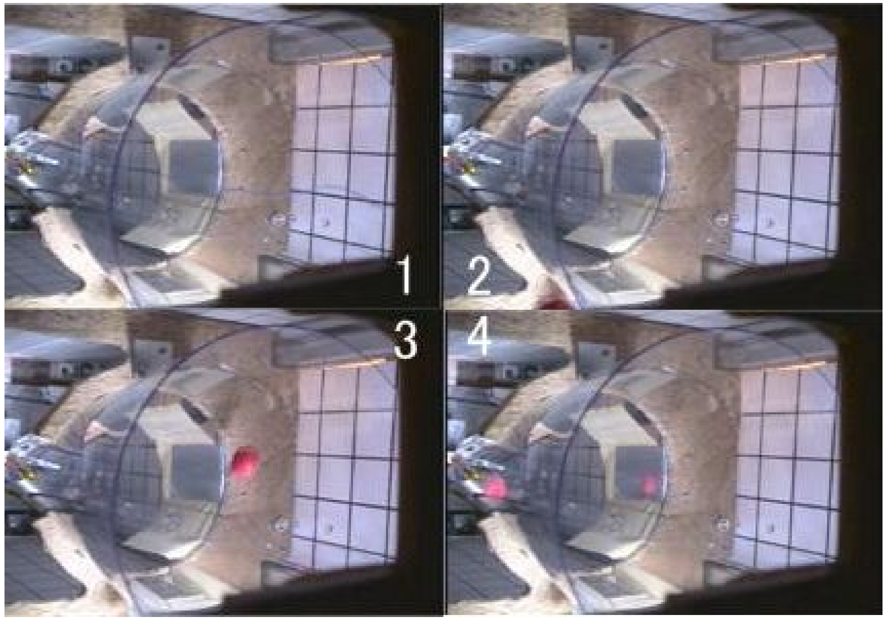
Drop tower and parabolic flight tests proved this system winds the tether without tangling





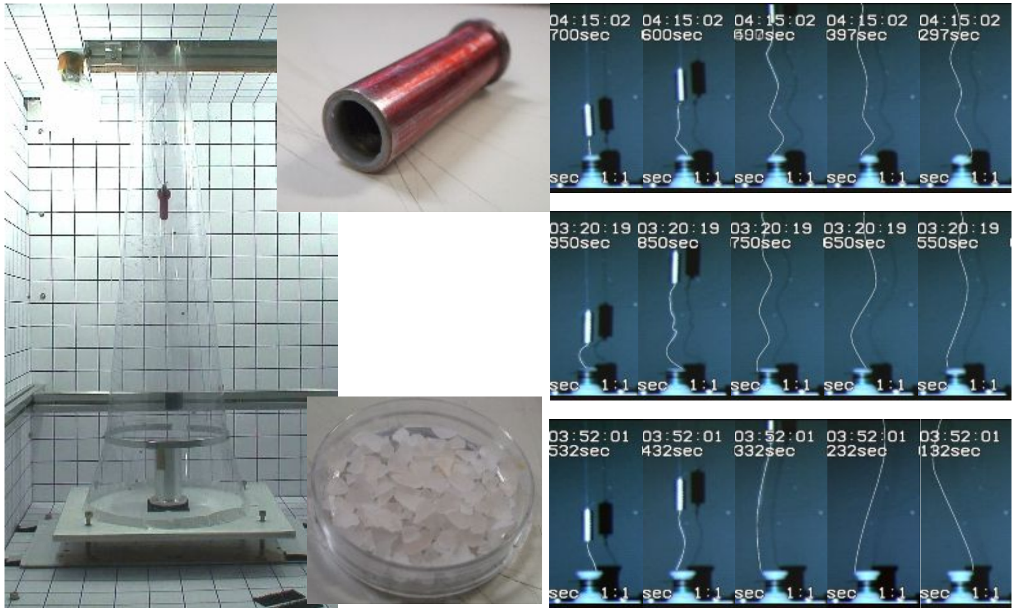


（constant speed：600rpm, constant internal tension：2N）



Drop Tower Test

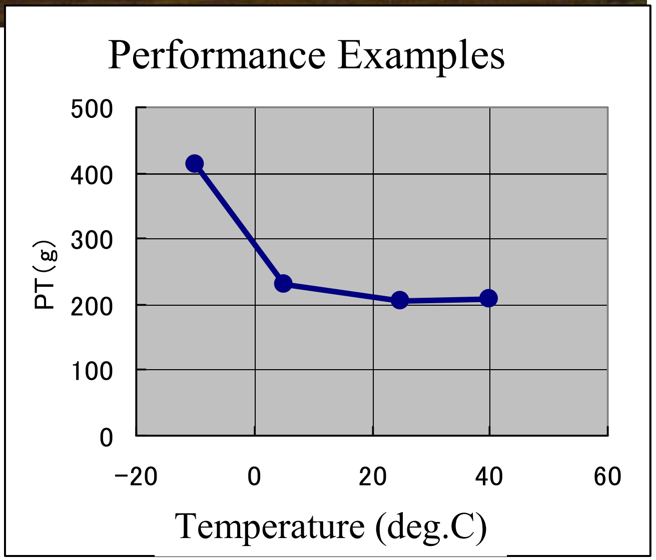
(Courtesy: Titech and JAXA)

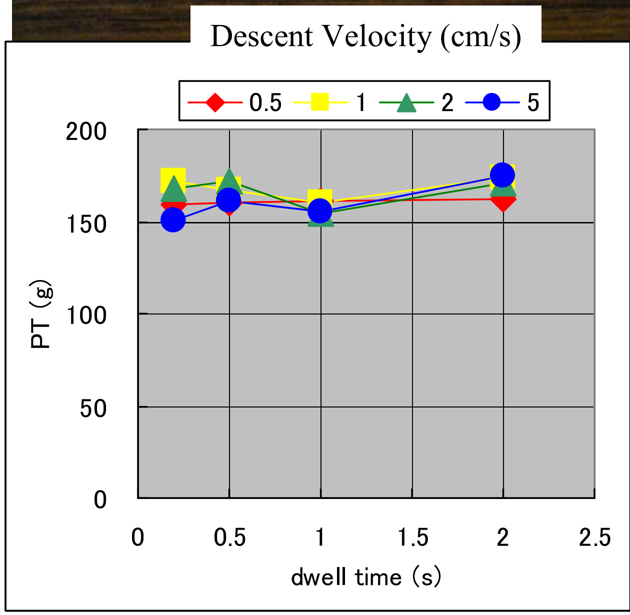


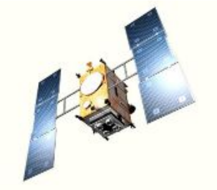
Parabolic Flight Test

The Sampling Head-2: Sticky Pad Silicone Gel Development

Probe Tuck Mass (g)







Summary: Key Developments of Hayabusa Follow-On Missions and Samplings:

	Hayabusa	1999 JU3-Class	Wilson-Harrington-Class
Ion Engines	Mu-10	Mu-10	Mu-20
Return Capsule	~12 km/s	~12 km/s	~14 km/s
Telecomm.	HGA with MGA and LGA	Phased Array	Phased Array + New DSN on Ground
Sampling Options	Impact sampling	Projectile shape & ang. momentum	Ejecta and stratigraphic samples, Sticky pad
Touch-and-Go	With landmark matching	Increased Autonomy	Increased Autonomy
Instruments suitable to	S-type	C-type	Dormant Comet, C-, D-types
Surface Science	Micro Rover	Sampler Horn Micro-Rover Small Lander	Sampler Mast, Micro-Rovers, Large Lander