International Marco Polo Symposium and other Small Body Sample Return Missions

Microgravity Geology: In-situ Measurements and Laboratory Simulations

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Hajime YANO
(ISAS&JSPEC/JAXA, Japan)
yano.hajime@jaxa.jp

Microgravity Geology, a New Research Field of Solar System Science

• Current planetary system formation theory has a “black box” in the intermediate state between dust-to-dust aggregation (e.g., Mukai, et al., Blum, et al.,) and planetesimal growth/ disruption (e.g., Kokubo, et al., Michel, et al.) that are never able to learn from exploration of large, differentiated bodies.

• Yet, no one had witnessed geological evolution of small planetesimals or equivalent, until Hayabusa’s in-depth exploration of Itokawa, a sub-km rubble pile asteroid.

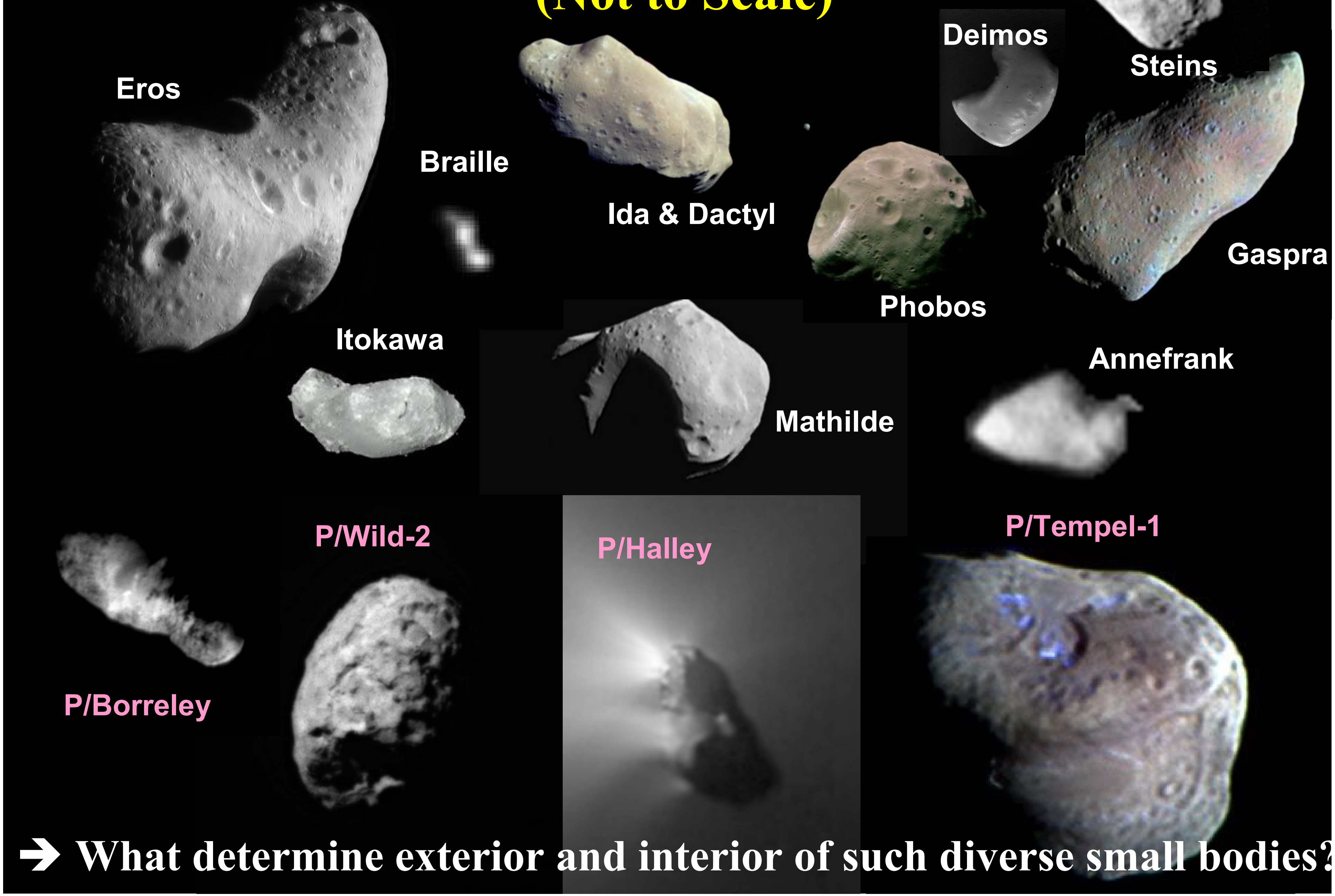
• Geological features of Itokawa surprised us about both similarities and differences from larger asteroids like Eros and much larger satellites/planets.

• Apparent similarities between Itokawa and the Earth (and Mars) are not necessarily due to the same geological processes as the terrestrial geology largely affected by the presence of water in atsmosphere, surface and underground, let alone five orders of magnitude difference of G-levels.

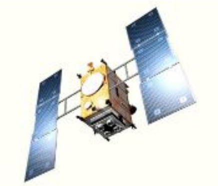
➔Thus, a need to create a new research field of “Microgravity Geology” is clear in order to understand the missing link of the planetary evolution processes, as well as better preparation for future robotic and human exploration of such microgravity bodies. Such knowledge can also be beneficial to natural disaster management on the Earth for better understanding of their triggering mechanisms

➔ The author has won the governmental grant in 2008-2011 to establish this new discipline at ISAS, with an emphasis on experimental approach

Diversity of Geological Features on Microgravity Bodies (Not to Scale)

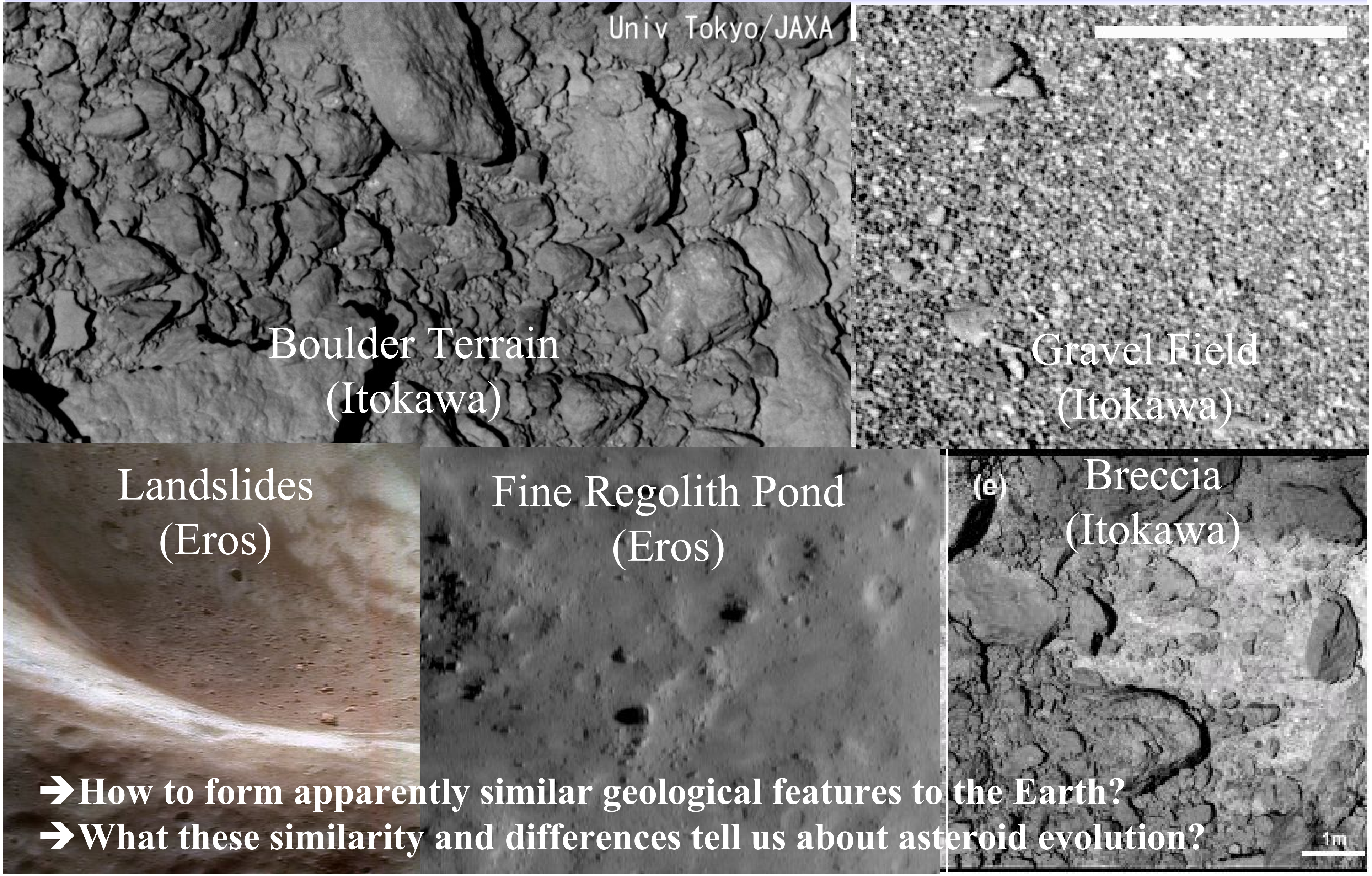


→ What determine exterior and interior of such diverse small bodies?



Terrestrial Geological Features: Governed by Gravity, Heat, Air and Water

Asteroidal Geological Features: Mainly due to Impacts and Vibrations in Vacuum and Microgravity



➔How to form apparently similar geological features to the Earth?

➔What these similarity and differences tell us about asteroid evolution?

Main Focuses of Microgravity Geology Research

<Understanding Physical Processes >

• Impacts (Gravity-strength regime scaling, Ejecta redistribution, Low density/weak strength monolithic targets vs. granular targets, etc.)

• Vibration (Wave propagation, seismic efficiency, diffusivity, quality factor, etc. in regolith and low density targets)

• Granular Mobility (Brazil Nuts effect, granular convection, dust levitation, surface mobility, non-gravitational activities such as cometary gas release, etc.)

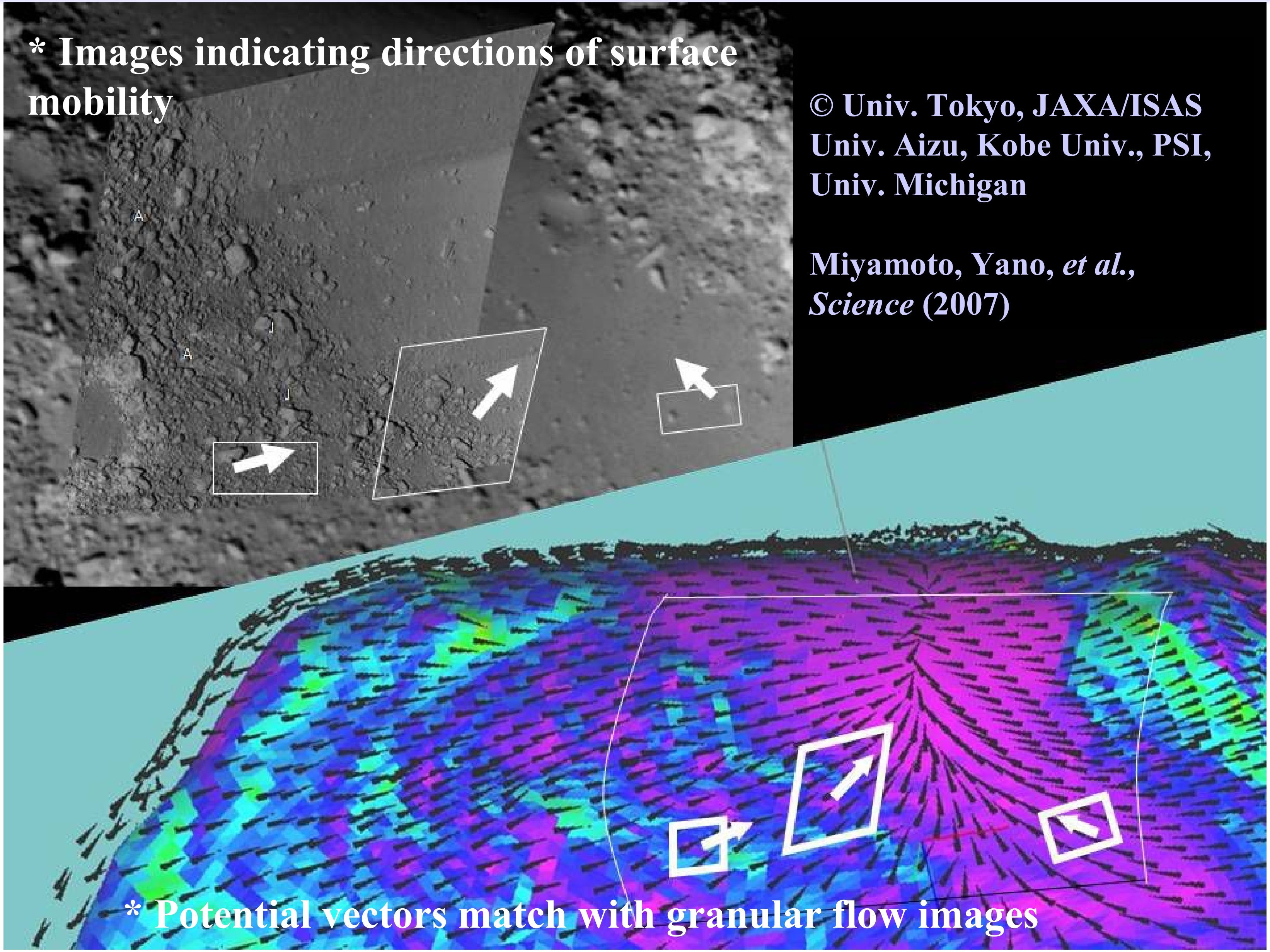
➔Also investigate other internal/external forces than impacts such as Centrifugal force, YORP, tides, etc.)

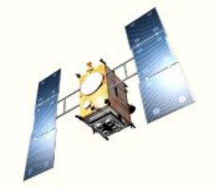
< Applications to Small Body Exploration >

• Development of sampling system and landers for Hayabusa follow-on missions

➔ Determine specifications of experimental apparatus and model calculations for duration, energy level of each event

An Example: Image-Model Comparison of Granular Flow and Surface Potential on Itokawa





How to Obtain Fundamental Data for Microgravity Geology?

< Spacecraft Data >

* *Sub-km Asteroids： Itokawa (Hayabusa)*
* Asteroids: Eros, Phobos, Jovian Retrograde Satellites, etc.
* Cometary Nuclei: Tempel-1, Wild-2, etc.

←→ *Comparative Data (High-G Bodies): Earth, Moon (Kaguya), Mars*

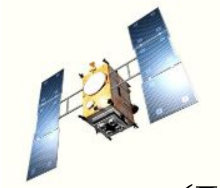
< Experimental Facilities in Japan >

* Drop Tower (MGLAB): 4.5 sec., 10^{-5} G *(cf. ISAS in 2 sec.)*
* Parabolic Airplane (DAS): 20 sec., 10^{-2} G
* High-Altitude Balloon (ISAS)： ~60sec., $10^{-3\sim-4}$ G

cf. Suborbital Flight (NASA Suborbital EX): ~180sec., 10^{-5} G

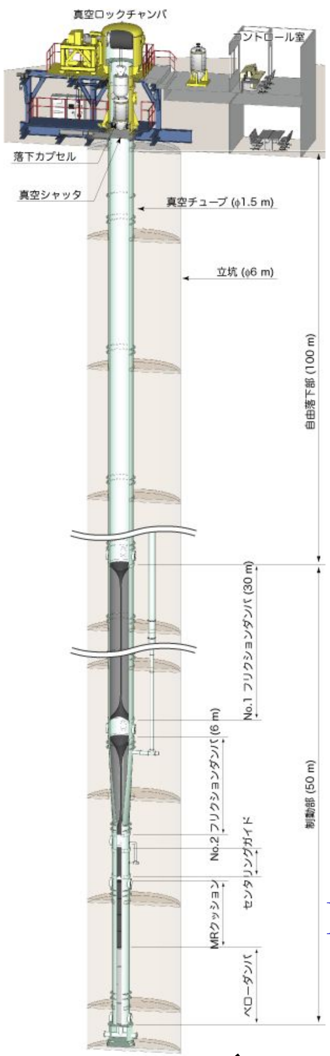
< Modeling >

* Shape Model←→Gravitational Potential Simulation
* Micro-G Impact Hydrocodes (Autodyn 3-D), etc.



Experimental Work Example (1): Granular Behaviors in Variable Gravity (Impact Cratering , Brazil Nuts, and Dust Levitation)

<Impact Cratering>

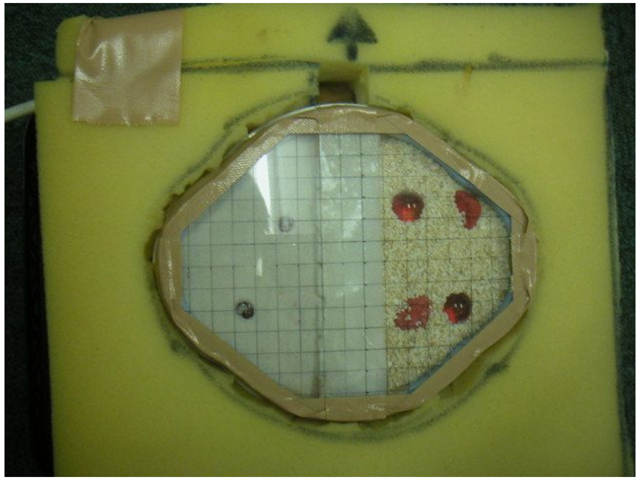


Drop Tower: MGLAB

- How to grow an impact crater in microgravity, presumably in strength regime?
- <u>Frictional force may play an important role to determine crater size in microgravity</u>

（MGLAB Tests by Takagi, Yano, et al. 2003~）

<Brazil Nuts Effect>



Parabolic: DAS

* Parabolic flight by GS-II (1G=> 2G=> micro-G=> 2G=>1G) proved that <u>granular convection speed greatly varied with gravity level</u>

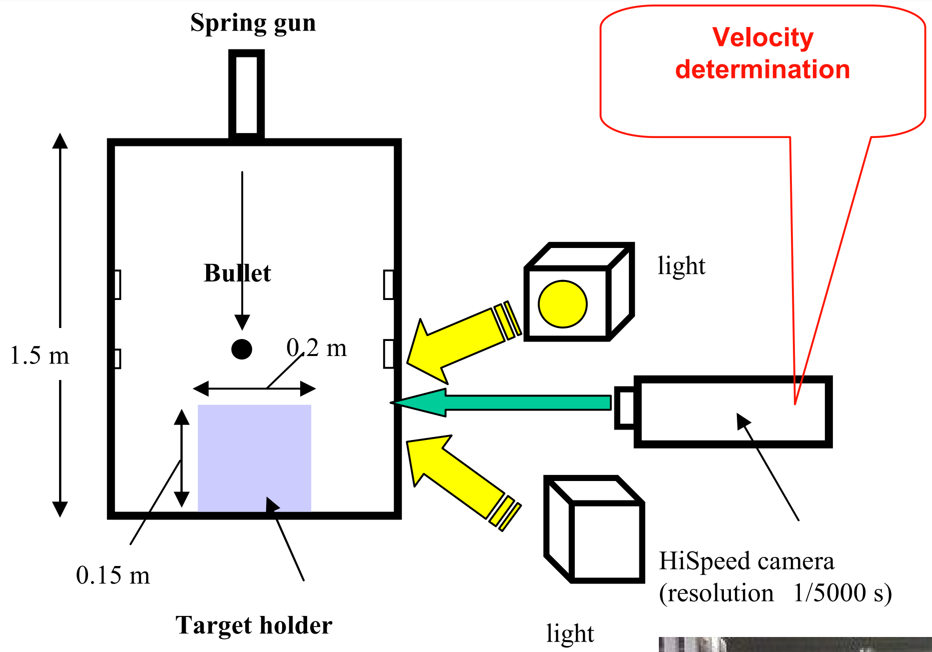
（Yano and Makabe, 2007, Miwa, 2009）

<Dust Levitation>

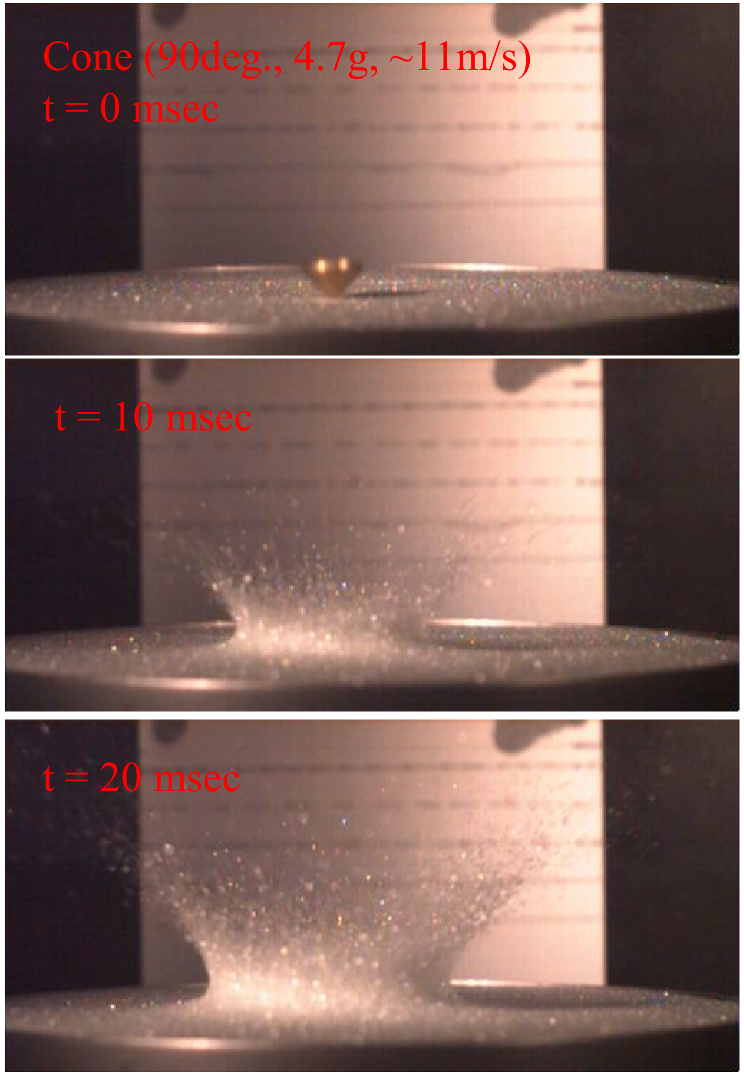
ISAS drop space tests will start soon

(Bellerose & Yano, 2009~)

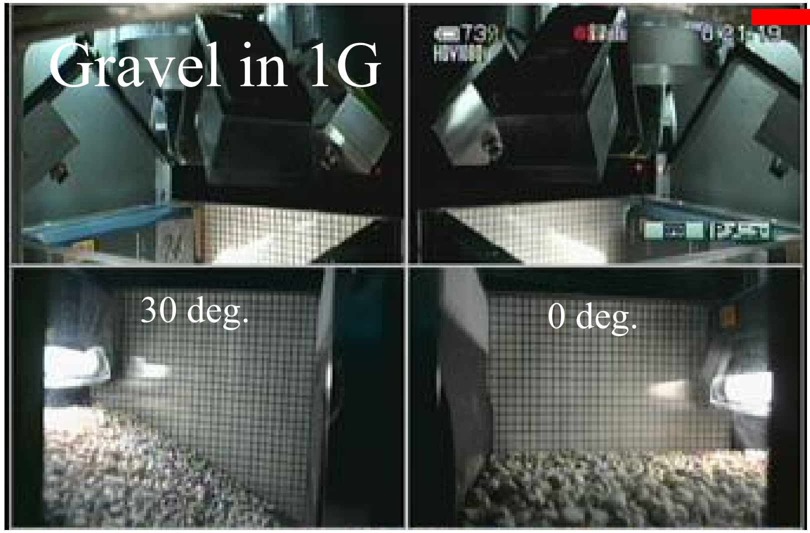
Apparatus: Coil Spring Gun for 10's m/s Speed Impact Tests in 1G

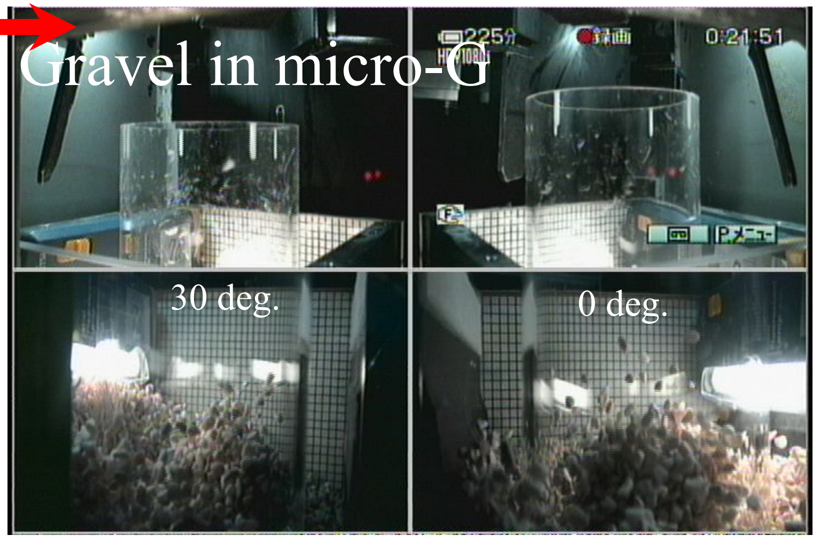


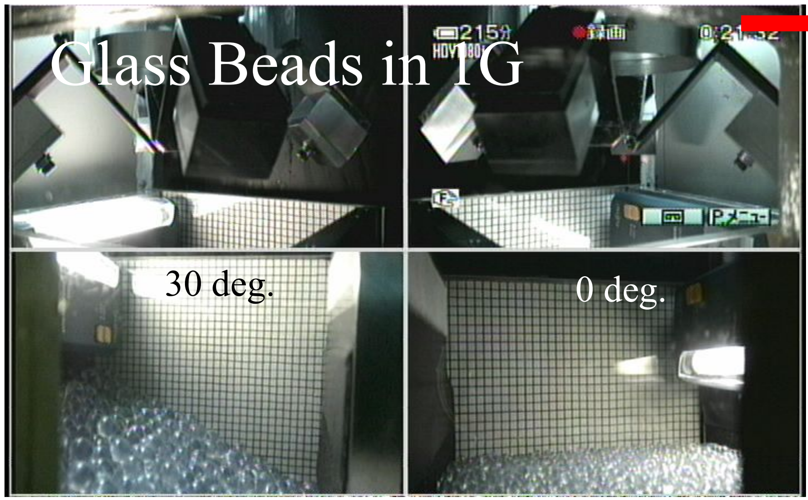
* We built an original coil spring gun for more safety, easer to operate without gun powders



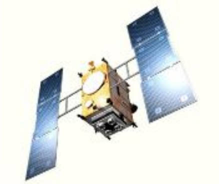
Experimental Work Example (2): Drop Tower Tests for Low Velocity Disruption of Gravels



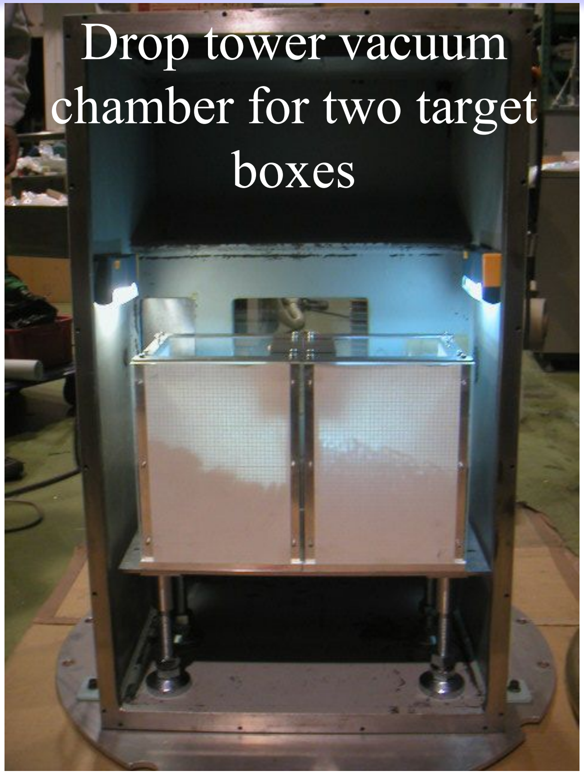




* Could simulate <u>disruption of gravel field by spacecraft touchdown</u> as well as ejection and re-distribution of these surface materials due to secondary impacts



Apparatus: Microgravity Low Velocity Deployment Device in Vacuum Chamber



Drop tower vacuum chamber for two target boxes

Arms to open only during the microgravity condition

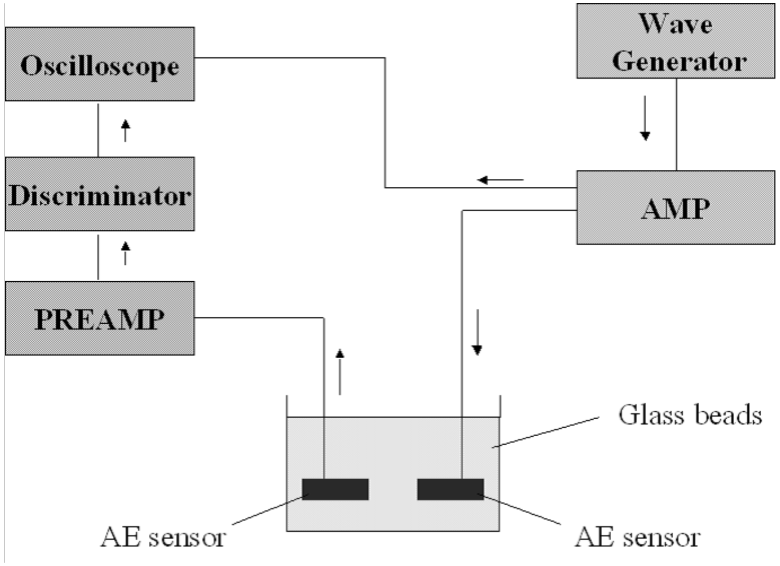
Target boxes to be observed by video cameras

Glass bead gravels

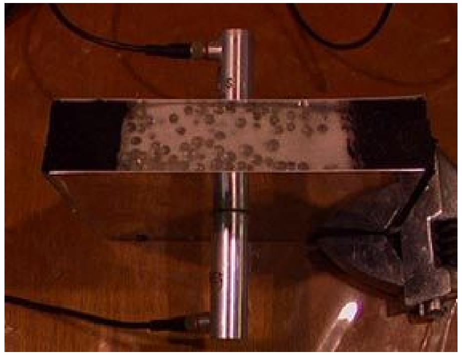
Pumice gravels

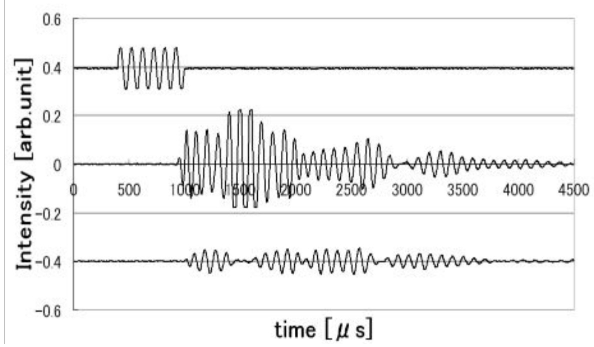
Experimental Work (3): Wave Attenuation inside Regolith and Porous Materials

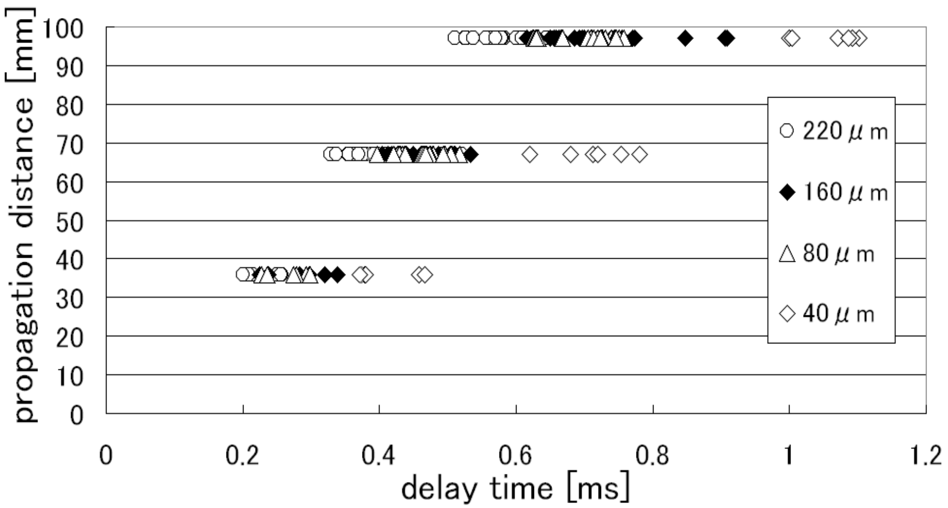
- How effectively can impact energy contribute to global and local mobility of surface materials?
- What can we learn about sub-surface, internal structure of rubble piles and regolith layers?

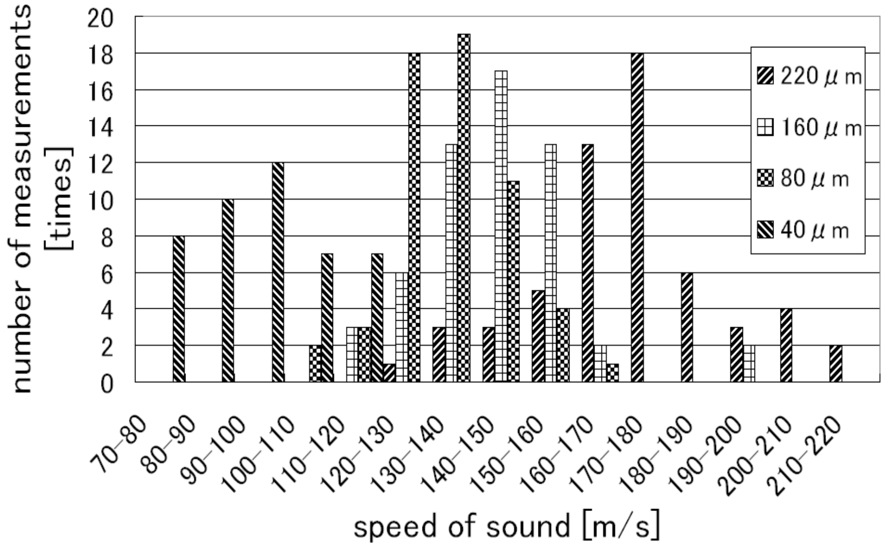


（Teramoto & Yano, 2005）









Summary (1): Microgravity Geology Experimental Apparatus in Use at JAXA So Far

<1G Experiments for Calibrations>

* (H2/N2/Air) Two-stage Light Gas Gun (V~km/s order)
* Single-stage Sabot Powder Gun（with Rifling Capability）(V~ 100m/s order)
* Coil Spring Gun (V~10m/s order)
* Wave Generator & Piezo-electric Sensors
* Single Axis Vibration Table
* Measurement Apparatus of Angle of Repose
* High-speed Digital Video Camera (>10,000 fps) & Portable Oscilloscopes
* High-definition Digital Video Camera

<Micro-G Experiments>

* Single-stage Sabot Powder Gun in Vacuum Chamber (with Rifling Capability)
* Low Velocity Deployment Device in Vacuum Chamber (V~ 10 cm/s order)
* Portable Vibration Container with a viewing cover
* High-speed Digital Video Camera (~1400 fps) & Portable Oscilloscopes
* High-definition Digital Video Camera

➔ *All suitable for Drop Tower, Parabolic, Balloon, and possibly Suborbital*

➔ *A dedicated 2-second-long drop space is under construction at ISAS*

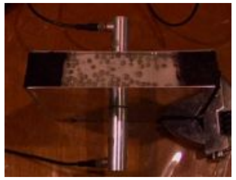
➔ Research collaborations with international scientists are most welcome.

Summary (2): Research Theme Flow of "Microgravity Geology"

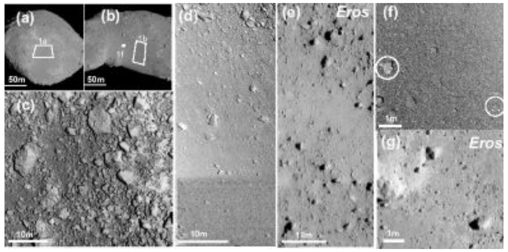
Theme-1: Geological Data Analysis on Microgravity Body

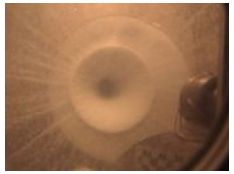
Terrestrial Geology Database

Planetary Exploration Database



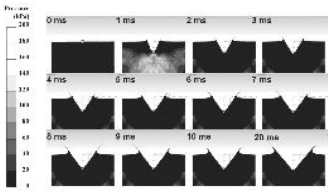
Theme-2: 1G Impact Tests/ Elastic Wave Measurements



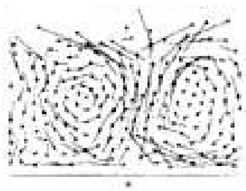


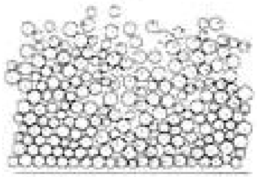
Theme-3: Micro-gravity Impact Tests

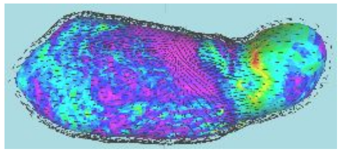
Theme-4: Microgravity Granular Convection



Theme-5: Microgravity Geological Activity Simulation







Theme-6: Physical Models of Microgravity Geology

Creation of Microgravity Geology (New Research Field of Solar System Science)

If you are interested, email: yano.hajime@jaxa.jp