Workshop on Space Robotics, ICRA 2011

Advanced Probes for Planetary Surface and Subsurface Exploration

Takashi Kubota (JAXA/ISAS/JSPEC)

Hayato Omori, Taro Nakamura (Chuo Univ.)

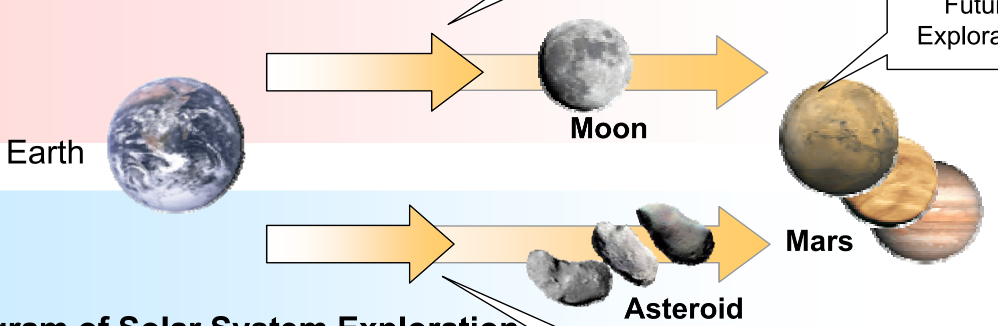
JAXA Space Exploration Program

Space Exploration Programs

- ■**Program of Lunar Exploration**
  - **Robotic Lunar Exploration**
    - **[Hiten, Kaguya, SELENE-2, SELENE-X, ･･･]**
  - **Human Lunar Exploration**

• Program of Robotic Explorer for Lunar Utilization
• Joint to International Lunar Activities

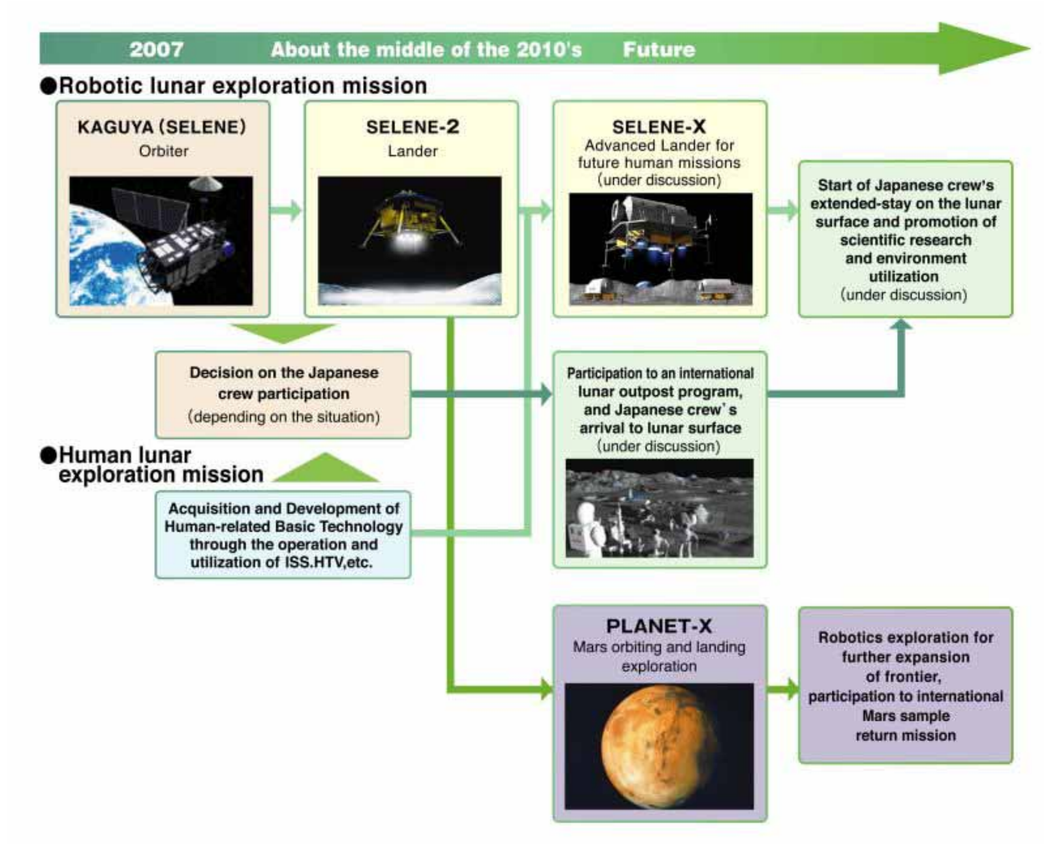
Future Exploration



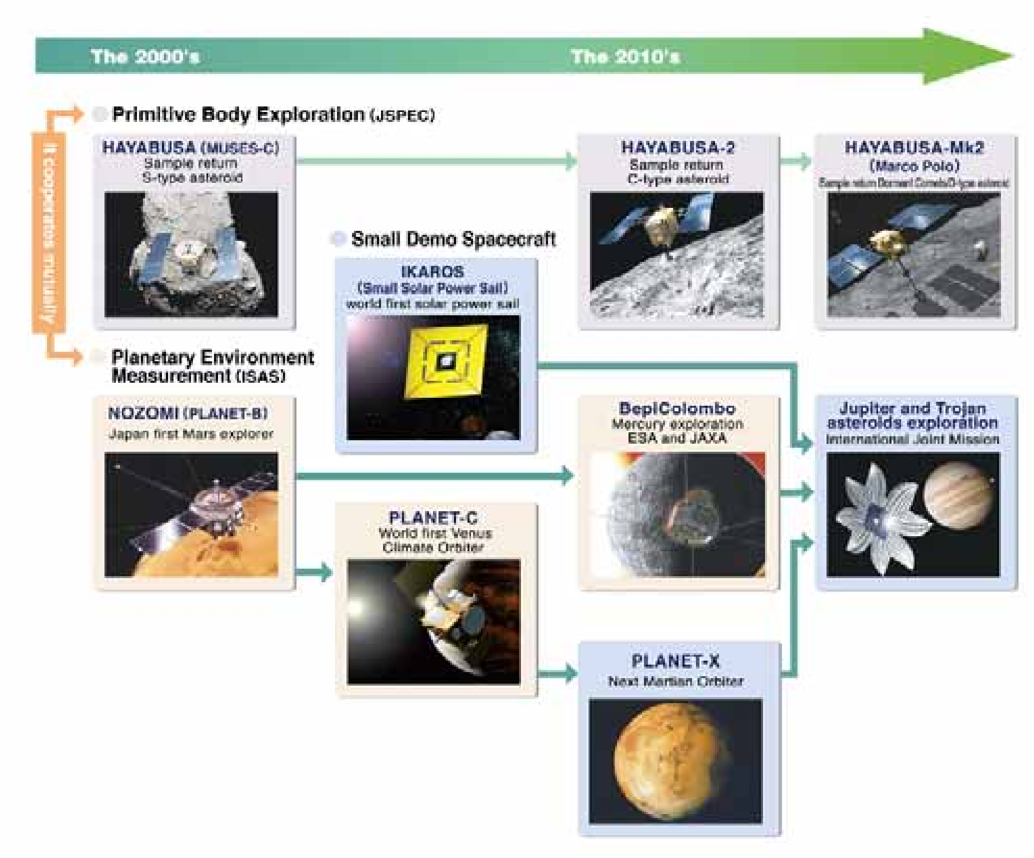
- ■**Program of Solar System Exploration**
  - **Primitive Body Exploration**
    - **[Hayabusa, Follow on Hayabusa, ….]**
  - **Planetary Exploration**
    - **[PLANET-C, BepiColombo, MELOS, …..]**

• Program for Origin and Evolution of Solar System

Lunar Exploration Road Map



Solar System Exploration Road Map



Surface Explorer Missions

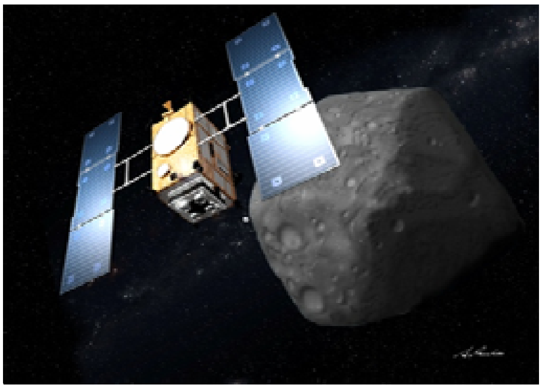
JAXA is planning direct exploration on lunar or planetary surface for

In-situ observation and Scientific investigation , and future planetary utilization.

- Detailed geological observation
- Geophysics to know interior structure
- Dust, radiation, climate, atomosphere environment

Surface and Subsurface Explorer is one of good means for direct, detailed, wide exploration.

Hayabusa-2 Mission



Hayabusa-2 :
- Asteroid Sample Return Mission
- Target Asteroid : C-type, rocky
- Rocks contain more organic matters
- Challenge very interesting objectives
  > what are original organic matters existed in the solar system ?
  > how they are related to life ?

- Primitive body exploration
  - Programmatic follow-on Mission of Hayabusa
- Sample return
  - from asteroid 1999 JU3
- Window
  - 2014-2015

Hayabusa-2 Mission

MINERVA-II :

- Asteroid Surface Explorer
- Revenge of MINERVA
- Same Functions
  - Hopping Mobility
  - Small, Light, Low Power Consumption
  - Autonomous Behavior
  - Wide Area Exploration
- Sampling Site Exploration
  - Position Estimation
  - Navigation and Guidance

Asteroid Exploration Rover

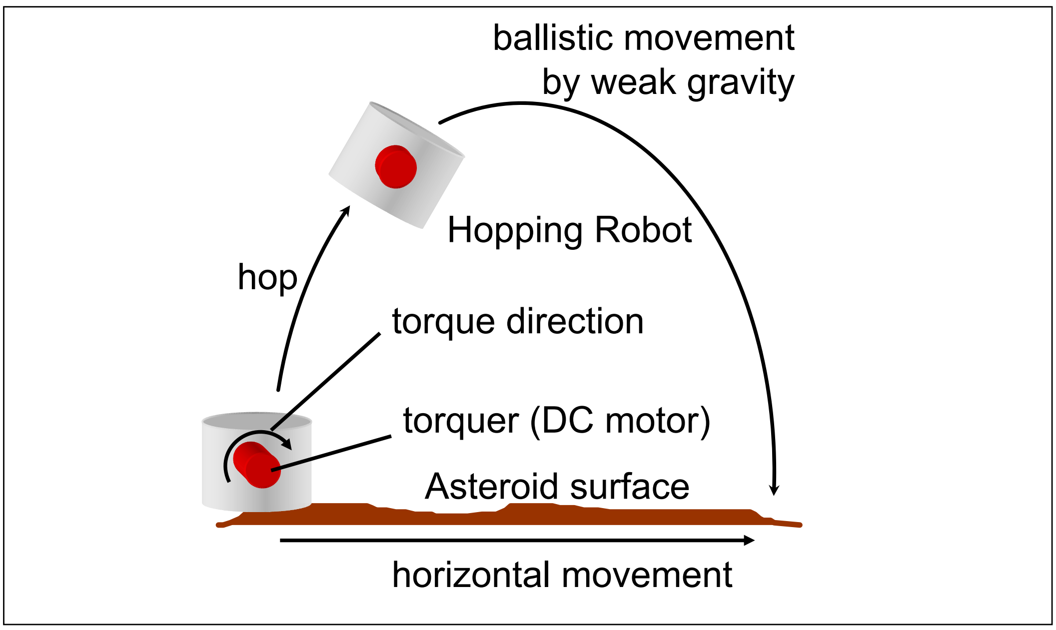
In-situ surface observation by intelligent robots would be a promising method to explore bodies.

Gravity acceleration on small body is so small.
Then hopping is one of good solutions.

Novel Hopping Mechanism

Hopping Mechanism by Torquers

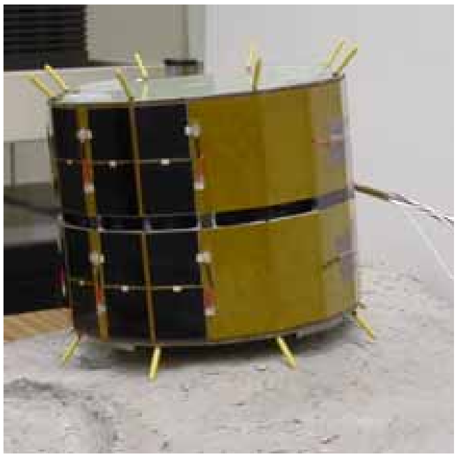
No actuator outside



Asteroid Explorer MINERVA-series

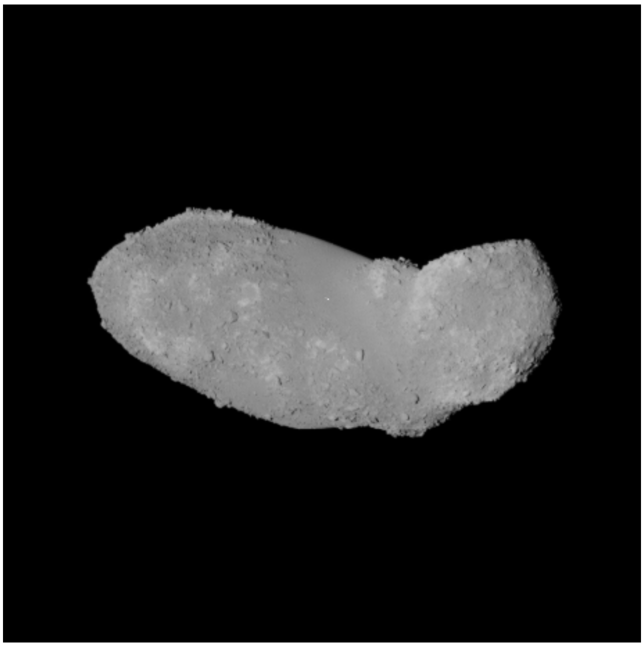
(MIcro Nano Experimetal Robot Vehicle for Asteroid)

- Asteroid Surface Explorer
- Novel Mobility
  by Hopping
- Surface Observation
  by Stereo Vision, etc.
- Temperature Measurement
- Surface Gravity Estimation
- Autonomous Behavior Functions



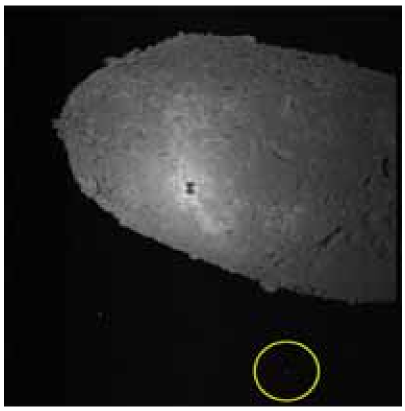
Flight Model of MINERVA and OME

Target Asteroid Itokawa



Hayabusa arrived at the target asteroid Itokawa on September 12th in 2005, and performed touchdown in November 2005, and returned back to Earth with samples on 13th June in 2010.

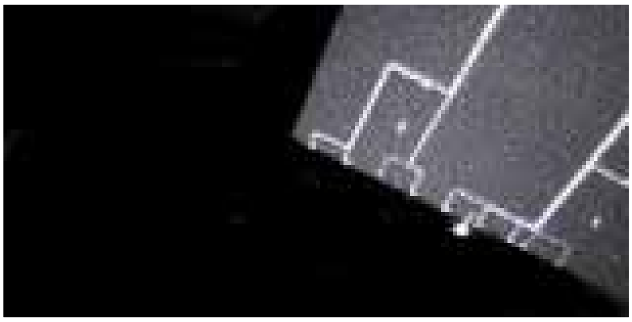
Overview of MINERVA Mission

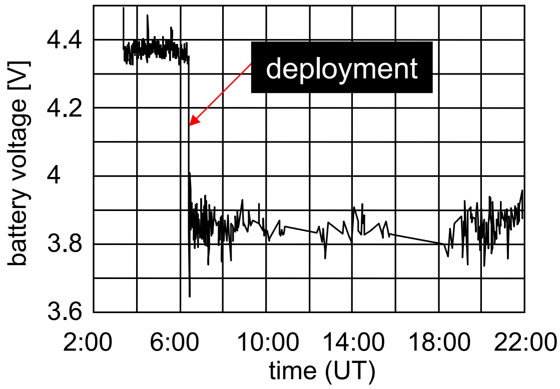


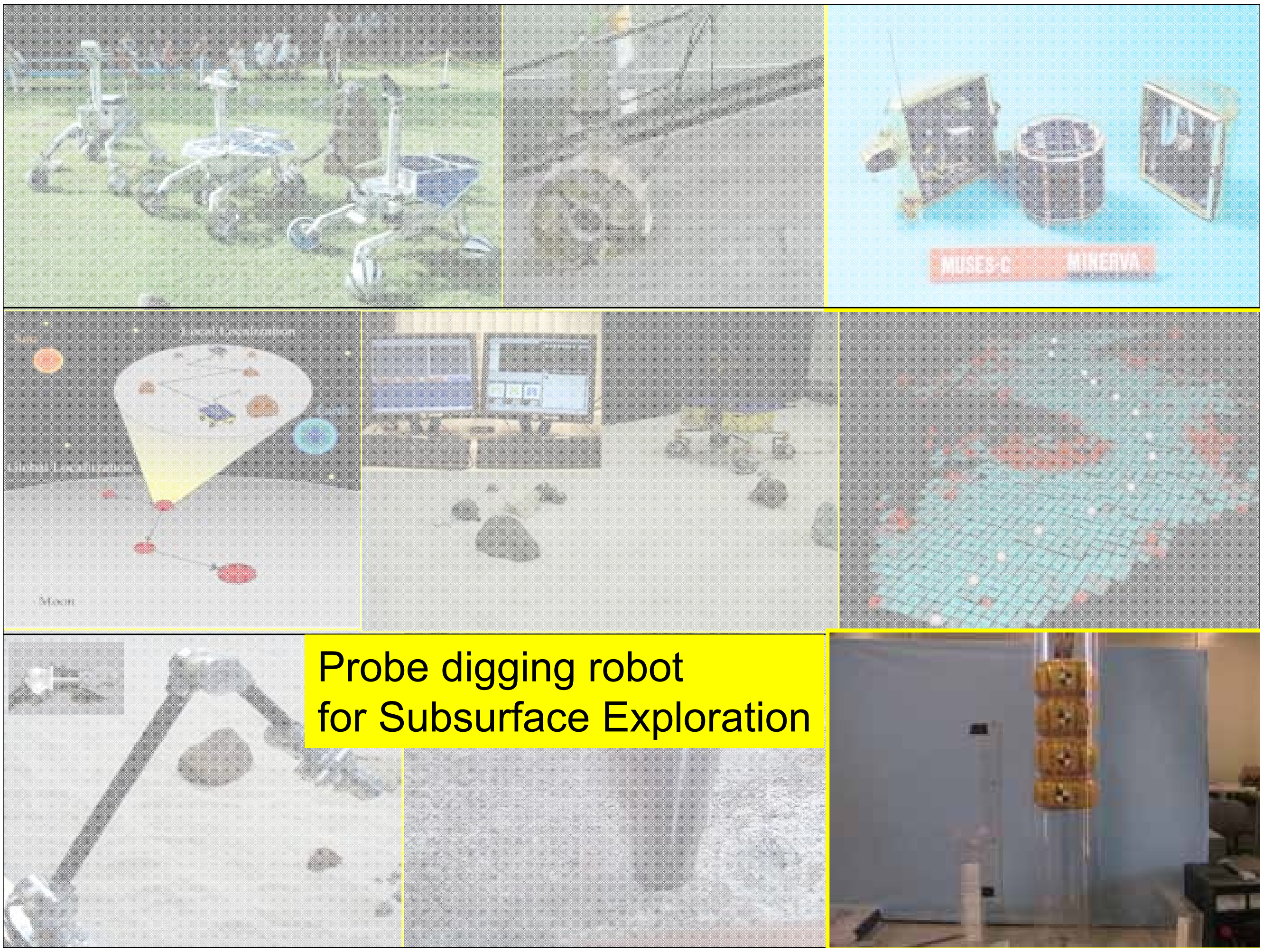
- The rover was deployed on Nov 12, 2005,
- Deployment was triggered by command from the Earth.
- Unfortunately Hayabusa failed in releasing MINERVA.
- The releasing velocity was bigger than the escape velocity.
- MINERVA could not land on the asteroid
- It rotates around the sun with Itokawa.
- MINERVA became an artificial planet.

Telemetry Data from rover

- The communication link between the rover and HAYABUSA was continuously established for 18[hour] after the deployment.
- The link was lost because the rover went out of the coverage of the antenna of HAYABUSA.
- The rover was also very healthy at the last telemetry.
- Only one image was transmitted to HAYABUSA just after the deployment







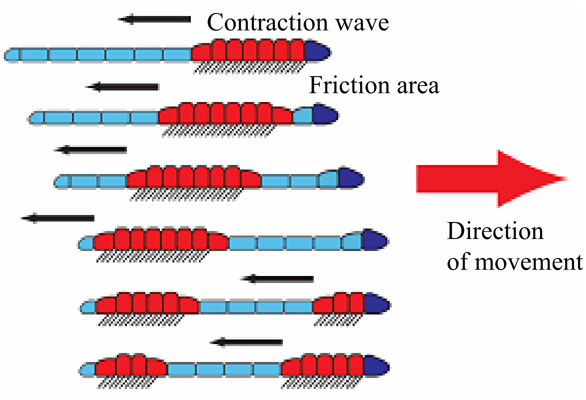
Excavation Technology

- Missions for lunar or Mars exploration by lander and rover in JAPAN
- Requirement by scientists is to excavate in depth of several meters to analyze geological samples or to deploy devices

Novel drilling technology by small, light-weight robot is required for lunar or planetary exploration

Earthworm typed Robot

Peristaltic Crawling of earthworm

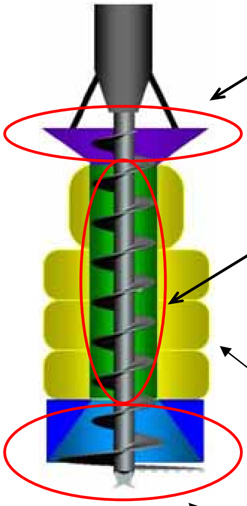


- Mobility can be performed by becoming shorter and thicker, then longer and thinner in each segment
- Contracted units can increase the friction between the segments and the surface

✓ Required **small space** for locomotion

✓ **Narrow object** such as a pipe and perforating soil

Proposed Robot



Propulsion unit

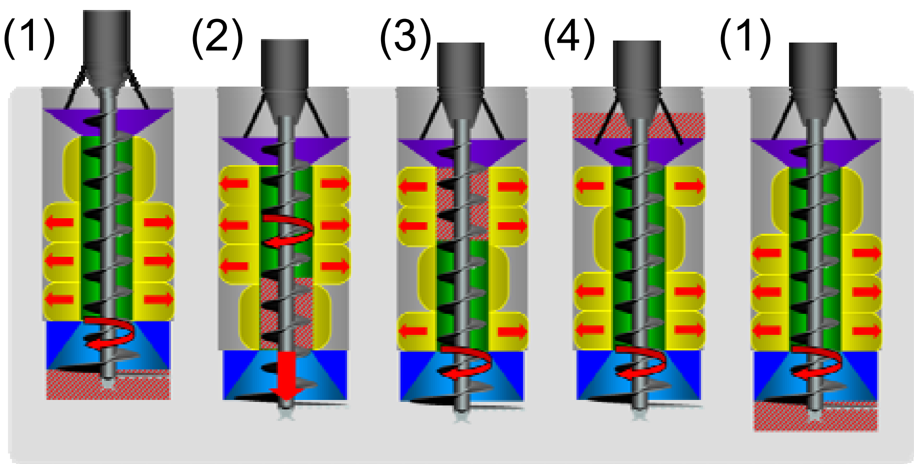
controls contact and noncontact of units with the surrounding wall, and maintains the rotation action of the excavation unit.

It assists the robot excavating underground

Excavation unit

Earth auger (EA) bores a hole and removes and transports the excavated regolith to the rear

Proposed Robot

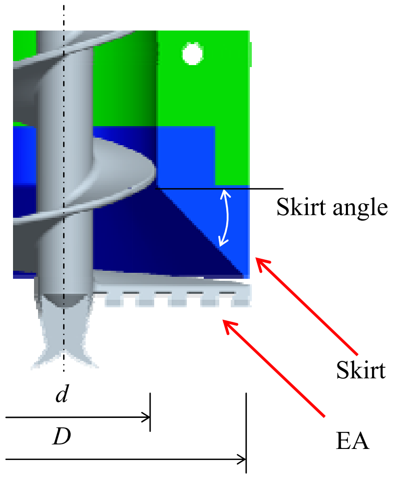


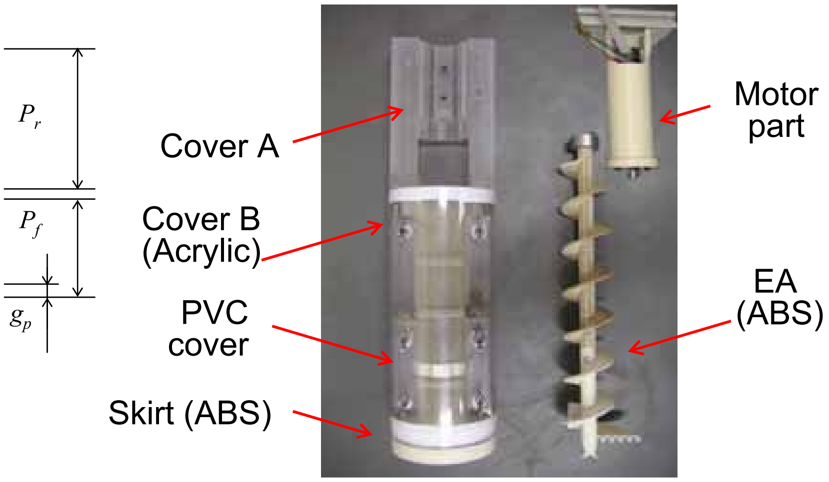
(1) Contracted units maintain contact with the wall of the hole and hold the body position and orientation against the rotation of the excavating EA.

(1)–(2) The second and third units from the front contract and hold their position while the front unit extends. At the same time, the EA excavates the regolith in front of the robot. The excavator can move downward.

(2)–(4) Contractions propagate toward the rear, and the spiral of the EA (transport part) carries excavated regolith to the rear. The regolith is then discharged from the rear.

Developed Excavation Unit

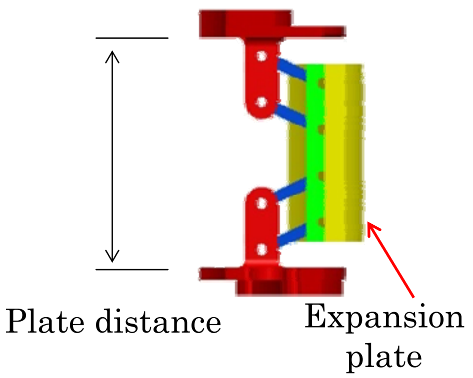


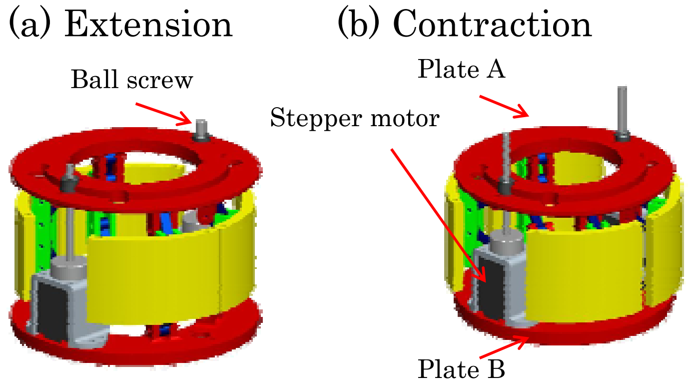


D [mm]	130	Skirt angle [deg]	45
d [mm]	65	L [mm]	425
P_f [mm]	20	g_p [mm]	7.3
P_r [mm]	55	Total mass [kg]	3.1

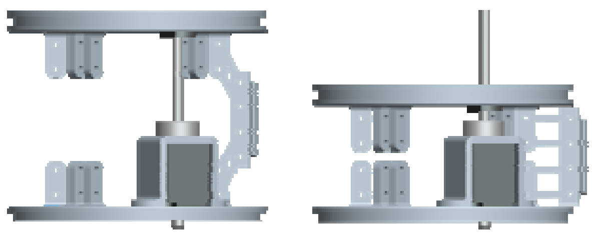
Pushing force [N]	Depth [mm]	Max. Motor torque [Nm]
60	342	12.4
52	288	11.0
22	137	6.4

Developed Propulsion Unit

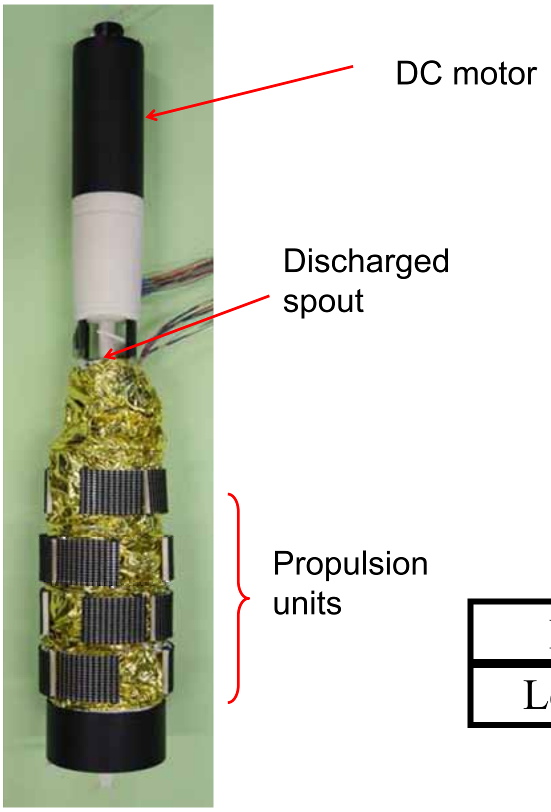


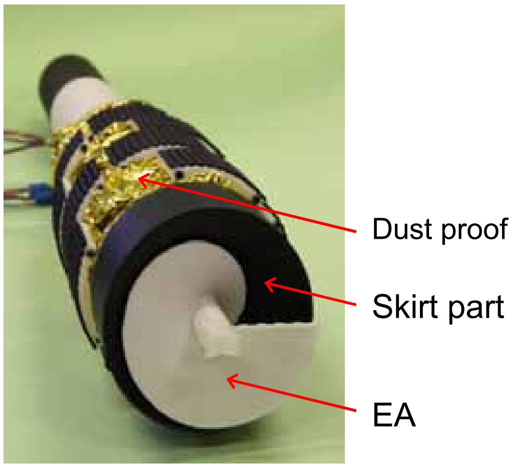


Max plate distance [mm]	84.0
Minimum plate distance [mm]	46.5
Max thickness [mm]	144
Minimum thickness [mm]	124
Diameter of space [mm]	65.0
Mass [kg]	0.51
Material	ABS



Developed Experimental Robot

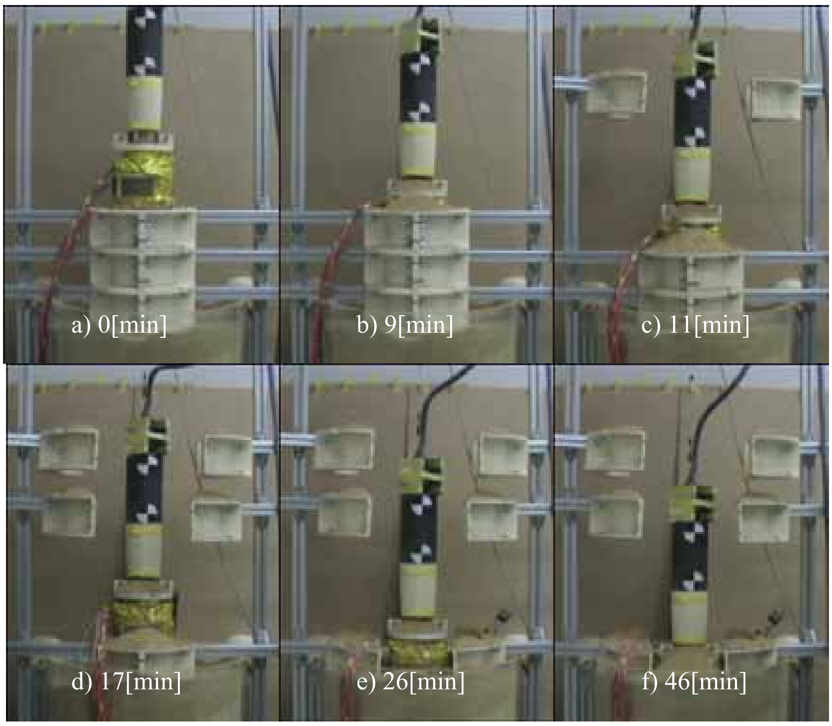




Mass [kg]	5.28
Length [mm]	800

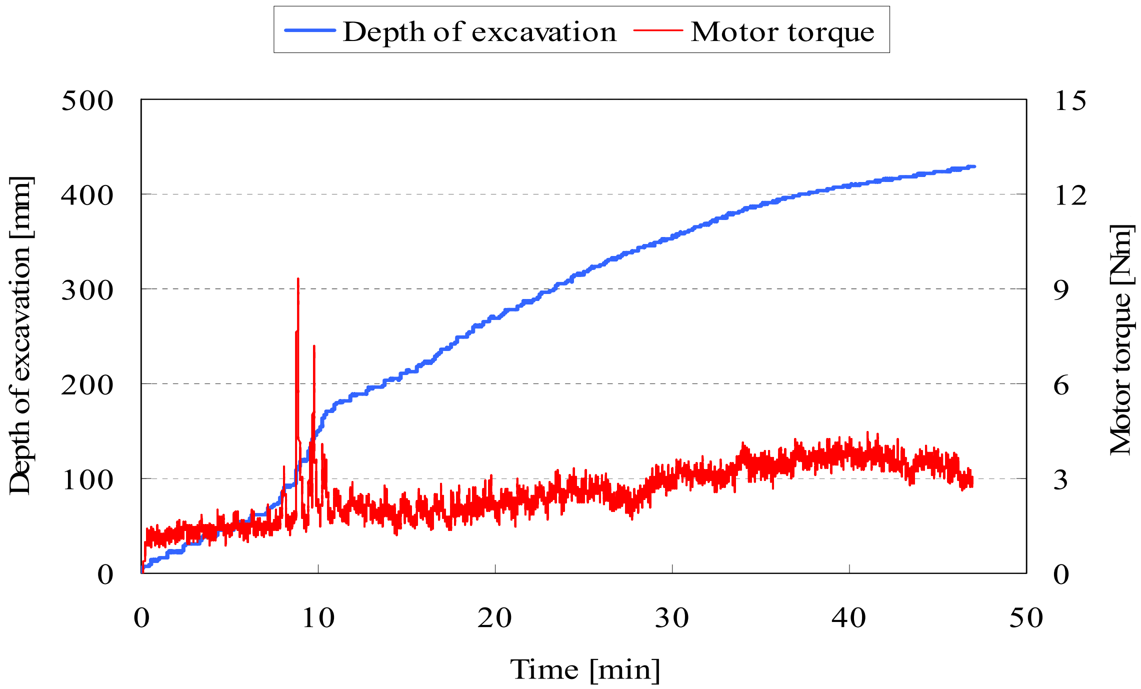
Experimental Results

Reddish soil
Launcher: ABS
EA:10 [rpm]



Experimental Results

Robot's velocity: 0.25 [mm/s]



Summary

- JAXA Roadmap of lunar or planetary exploration
- Robotics technology for planetary surface exploration
- Topics
    - Hopping robot for asteroid exploration
    - Drilling robot for subsurface exploration