Robotic Lunar Exploration Scenario
— JAXA Plan —

Tatsuaki HASHIMOTO
JAXA
Question:
What is Space Exploration?

Answers:
There are as many answers as the number of the people who answer the question.

Examples:
- To extend human being’s knowledge including the origin of Earth-Moon, Solar system, universe, and life.
- To explore the solar system as far as Pluto.
- To send astronauts to Mars.
- To build a man tended lunar base.
- To use space as commercial targets.
<<SCIENTIFIC EXPLORATION>>
Elucidation of Origin and Evolution of the Solar System

- Empirical study on the origin of Solar System
- Unraveling the diversity of the evolution of planets
- Understanding the environment necessary for life to emerge and to evolve
- Unified understanding of the physical steps of the solar system plasma phenomenon and planetary magnetospheres

<<EXPANSION OF HUMAN FRONTIERS>>
Expansion of human activities

- Intellectual surprise
- Satisfaction of intellectual curiosity
- Contribution to the world
- National pride
- Development of advanced technology

- Robotic exploration of planets
- Human exploration of planets
- Manned lunar base

BASIC PHILOSOPHY
Question: What is precursor missions?

Answers: There are many answers depending on the purpose of “Exploration”

Examples:
- Technology demonstration for future missions.
- Establish infrastructure for future missions.
- Investigation for surface environment including resource utilization for future missions.
- First step science for future top-science missions.
TECHNOLOGIES TO BE ESTABLISHED

Smart Landing
navigation sensors, autonomous obstacle avoidance, image-based navigation, landing legs.

Rover
locomotion for the unstructured terrain, navigation, autonomous path planning.

Survival Technologies on Lunar Surface
thermal control, power generation, communication.

Investigation
science observation, in-situ resource utilization.

Robotics
manipulator, tele-science, autonomy.

Return to the Earth
lift from the lunar surface, (docking with an orbiter), re-entry into the earth atmosphere.
INFLASTRUCURE TO BE CONSTRUCTED

Navigation
  landing beacon, Lunar GPS?.

Communication
  relay orbiter, surface-to-surface.

Power supply
  power-generation plant, solar power satellite, power transmission.

Common-use facilities
  human accommodation, observatory.

Transportation
  Earth to Lunar orbit, orbit to surface, surface to surface.
SCIENCE OF MOON and …

Interior structure of moon
   seismometer network (penetrater)

Interior material of moon
   investigation of particular interesting area

Sample return
   In-situ sample selection, detailed investigation in the
ground facility.

<Mars and beyond>
   Sample return from planets
      Mars, moons of planets, asteroid, comets
   Solar plasma and planetary atmosphere
      Earth&Moon, Mars, Venus, Mercury, …..
   Searching “Life”
      Mars, moons of planets, comets
JAXA Technology development and science observation scenario

COMMON TECHNOLOGIES
- Pin Point Landing
- Return to Earth
- Surface Mobility
- Surface Activities
- Robotics

TECHNOLOGIES DEDICATED TO HUMAN EXPLORATION
- ISS
  - Life Support System

~2015

SCIENCE

EXPANSION OF HUMAN FRONTIERS
Roadmap for Solar System Exploration Under Discussion

Moon
- SELENE
- ORBITERS
- SELENE follow-on series
- ORBITER
- LANDER
- ROVER
- PENETRATORS
- SAMPLE & RETURN
- MANNED MISSIONS?
- Studies of JAXA’s approach to the manned missions

Mars
- ORBITER
- LANDER
- ROVER
- SAMPLE & RETURN

Smaller, More Flexible Exploration Missions
- Hayabusa
- Planet-C
- BepiColombo
- Venus Balloons?
- Lander?
- Solar Power Sail?

Small Bodies

▲ ▲: On-going projects
▲ ▲: Proposed missions
International collaboration candidates
from the view point of JAXA precursor missions

• Fundamental technologies such as landing or surface investigation instruments should be developed by each nation.
  – Some onboard instruments can be shared.
  – JAXA heritage and development plan are shown later.

• Candidates of international collaboration are:
  – Science (different landing area, different investigation target, different observation method)
  – Infrastructure (Navigation, Power, Communication)
  – Manned technologies
  – Ground test facilities
  – Ground tracking stations
HITEN (MUSES-A)

Technology demonstration
- Lunar gravity assist
- Lunar orbit insertion
- Optical navigation
- Aero braking with earth atmosphere

1990.1 Launch
1990.3 1st Lunar gravity-assist and HAGOROMO (small sat) Lunar orbit insertion.
1991.3 1st aero-braking
1992.2 Lunar orbit insertion
1993.4 Hard-landing to the lunar surface
HITEN landing on 1993/4/10

Impact image taken from Australian observatory

Onboard camera images while descending
HAYABUSA (MUSES-C)

Technology demonstration
- Electric propulsion
- Autonomous approaching and landing to asteroid
- Sampling mechanism
- Re-entry capsule

2003.5 Launch
2004.5 Earth gravity-assist
2005.9 Arrived at asteroid Itokawa
2005.11 Land to Itokawa
2010.6 Earth return
HAYABUSA landing on 2005/11/25
Demonstrated technologies by HAYABUSA

Laser altimeter (50km to 50m)

Short-range laser sensor (120m to 3m)

Navigation camera and onboard image-processing

Landmark navigation (ground-base)
SELENE

- Mission: Lunar remote-sensing
- Lunar Orbiter Satellite + two Sub Satellites
- Launch: 2007
- Mass: 2885 kg

- 14 science instruments for measurements:
  - elemental abundance, mineral composition, topography, geological structure, gravity field, magnetic field, plasma environment, and terrestrial atmosphere
SELENE Mission

- The largest and the most comprehensive Lunar mission after Apollo
- Mission: Global observation of the Moon
  - Study on the origin and evolution of the Moon
  - Research on the future lunar utilization and activities on the moon
  - Technology development for future planetary exploration
## SELENE Mission Instruments

<table>
<thead>
<tr>
<th>Observation</th>
<th>Instrument and Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Orbiter</strong></td>
<td></td>
</tr>
<tr>
<td>Chemical elements distribution</td>
<td>X-ray Spectrometer (Al, Si, Mg, Fe distribution, spatial resolution 20 [km])</td>
</tr>
<tr>
<td></td>
<td>Gamma-ray Spectrometer (U, Th, K distribution, resolution 160 [km])</td>
</tr>
<tr>
<td>Mineralogical distribution</td>
<td>Spectral Profiler (Continuous spectral profile $\lambda = 0.4$ to 2.6 [$\mu$m], spatial resolution 500 [m])</td>
</tr>
<tr>
<td></td>
<td>Multi-band Imager (UV-VIS-IR imager, $\lambda = 0.4$ to 1.6 [$\mu$m], 9 bands, spatial resolution 20 [m])</td>
</tr>
<tr>
<td>Surface structure</td>
<td>Terrain Camera (High resolution stereo camera, spatial resolution 10 [m])</td>
</tr>
<tr>
<td></td>
<td>Lunar Radar Sounder (apparent depth 5 [km], resolution 100 [m])</td>
</tr>
<tr>
<td></td>
<td>Laser Altimeter (height resolution 5 [m], spatial resolution 800 [m])</td>
</tr>
<tr>
<td>Surface environment</td>
<td>Lunar Magnetometer (Magnetic field measurement, accuracy 0.5 [nT])</td>
</tr>
<tr>
<td></td>
<td>Plasma Imager (Observation of plasmasphere of the earth, XUV to VIS)</td>
</tr>
<tr>
<td></td>
<td>Charged Particle Spectrometer (Measurement of high-energy particles)</td>
</tr>
<tr>
<td></td>
<td>Plasma Analyzer (Charged particle energy and composition measurement)</td>
</tr>
<tr>
<td></td>
<td>Radio Science (Detection of the tenuous lunar ionosphere)</td>
</tr>
<tr>
<td>Imaging</td>
<td>High Definition Television camera (Images of the earth and the lunar surface, for public outreach)</td>
</tr>
<tr>
<td><strong>VRAD satellite</strong></td>
<td></td>
</tr>
<tr>
<td>Gravitational field distribution</td>
<td>VLBI Radio-source on the VRAD satellite (Near-side gravity field)</td>
</tr>
<tr>
<td></td>
<td>(VRAD = VLBI RADio source)</td>
</tr>
<tr>
<td><strong>Relay satellite</strong></td>
<td></td>
</tr>
<tr>
<td>Gravitational field distribution</td>
<td>VLBI Radio-source on the Relay satellite (Near-side gravity field)</td>
</tr>
<tr>
<td></td>
<td>Relay Sat. transponder (Far-side gravity field using 4-way range rate from ground station to Orbiter via Relay Satellite)</td>
</tr>
</tbody>
</table>
LUNAR-A

- Lunar orbiter with communication relay capability and a visible camera.
- Deploy two of penetrators with seismometers and heat-flow probes.
- Using moonquake, interior structure of moon will be investigated.
- Launch date is TBD.
- Mass: 540 kg
**Penetrator**

- Presently, modification of electronic circuits and improvement of communication performance are tried.
- Penetration test of full configuration will be done on May 31st, 2006.
- Final penetration test for improved model will be planned in July, 2007.

![Seismometer](image)

![Photo after high-G impact test](image)

42 kg
Small Orbiter with a Penetrator  
(A candidate of SELENE series payload)

Overview:
- A penetrator is released from orbiter at the altitude of 100 km.
- The penetrator is de-orbited and free-falls to be injected onto the lunar surface.
- Small orbiter is used for communication relay.

Spacecraft:
- Weight: 300 kg including penetrator
SELENE series candidate #1

Mission:
- Technology validation
- Understanding the moon and its environment

Configuration:
- lander and rover
  [option]
  relay orbiter, penetrator

Landing site:
- Sun light portion of the Polar region

Launch: early 1910’s

Launcher: H2A or H2B
SELENE series
candidate #2

Mission:
- Validation of technologies for sample & return
- In-situ analysis and returned sample analysis

Configuration:
lander, rover and re-entry capsule

Landing site: TBD
1) far-side: SPA (South Pole-Aitken)
2) nea-side: PKT (Procellarum KREEP Terrane)

Launch: mid-2010s
Launcher: H2A or H2B
Sample return option

Direct re-entry capsule developed by HAYABUSA

Rendezvous and docking was demonstrated by ETS-VII (1997-1999)

Re-entry was demonstrated by OREX (1995) and USERS (2002)

Direct return option

Using HTV option
Technologies to be validated by SELENE series

- Integrated landing system

- Navigation system for pin-point landing & autonomous obstacle avoidance

- Power generation system for an extended period of time

- Surface mobility to support material sampling/analysis and instrument setting

- In-situ resource utilization

- (Penetrator and seismometer)

- (Data relay from lunar surface)

- (Sample and return)
JAXA heritage and plan toward Mars

1. Landing and surface exploration technologies
   ✓ Applying Hayabusa and SELENE follow-on series technologies
   ✓ Lander & Rover missions, Sample Return missions, or Seismometer Network can be considered.

2. Small body science
   ✓ From asteroids to Martian satellites (Phobos, Deimos).
   ✓ Micro-rover, miniature instruments.

3. Solar plasma and planetary atmosphere science
   ✓ Total study of solar system compared with Earth (GEOTAIL, etc.), Moon (SELENE), Venus (Planet-C), Mercury (BepiColombo)
   ✓ Nozomi was launched in 1998, but failed to put into Martian orbit in 2003 at 1000 km from the Mars.
   ✓ Revenge mission of Nozomi is considered.