MOON SURFACE EXPLORATION IN JAPAN Tatsuaki.Hashimoto[1], Takeshi.Hoshino[1], Satoshi.Tanaka[1], Hisashi Otake[1], Hitoshi Morimoto[1], Masatsugu Otsuki[1], Sachiko Wakabayashi[1], and Koich Masuda[1], [1]Space Exploration Center, Japan Aerospace Exploration Agency (3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan)

Introduction: JAXA launched Kaguya (SELENE) moon orbiter in September, 2007 and the spacecraft was successfully put into moon orbit in October[1]. It observed moon surface and gravity field with 13 instruments and a couple of small satellites till the hard landing in June, 2009. As the next step of moon exploration, a lunar lander SELENE-2 has been considered[2]. It lands on the moon surface and performs in-situ scientific observation, environment investigation, and research for future lunar utilization including human activity. At the same time, it demonstrates some key technologies for lunar and planetary exploration such as precise and safe landing, surface mobility (rover) and overnight staying. Landing site candidates of SELENE-2 are in near side, low or middle latitude area. They are selected from the view point of lunar science. That is, solving mysteries on the origin and evolution of moon-earth system. The lander carries laser altimeters, image sensors, landing radars for precise and safe landing. Landing legs and precisely-controlled propulsion system are also developed. The rover is designed so as to travel in wide area and observe featured terrain with scientific instruments. Some instruments require long term observation on the moon surface. We are developing survival technologies for two weeks night without radio-isotope energy. As scientific instruments, multi-band cameras, a microscopic camera with a grinding tool, and a very broad-band seismometer, etc. are considered. For future lunar exploration, measurement of radiation, regolith dust, and soil mechanics are also planned.

Status of SELENE-2 Study: The mission definition of SELENE-2 has completed in 2007 and Phase-A study has been continuing from then. The Strategic Headquarters for Space Policy of Japanese government established "Basic Plan for Space Policy" in June, 2009[3]. Following the plan, a concrete strategy of Japanese lunar exploration had been discussed in "Study group for lunar exploration" of Japanese government which was organized from August, 2009 to July, 2010. The final report of the group says that a spacecraft should land on moon surface in around 2015 to prepare for a larger scale lunar exploration using advanced robot technology in 2020. The lander in 2015 in the report corresponds to SELENE-2. Delta Mission Definition Review (delta-MDR) of SELENE-2 was held in September, 2010 to modify the mission definition decided in June, 2007 to meet the report of the group.

Because of the severe budgetary situation of Japanese government, however, development plan of SELENE-2 is delayed. On the other hand, NASA plans Resource Prospector (RP) Mission to explore lunar volatile in the polar region and is looking for international partners to realize the mission[4]. Though original SELENE-2 plans to land on the middle or low latitude region from the scientific view points, the joint feasibility study of the collaboration mission between JAXA and NASA is now conducted.

Mission Objectives of SELENE-2: Considering scientific interest in the moon and present world's situation, the missions of SELENE-2 are defined as follows,

1. Development and demonstration of technologies.
   Safe and accurate landing
   Surface mobility: rover
   Night survival technologies without radio isotope
2. In-situ observation and investigation for science and future lunar utilization.
   Detailed and sub-surface geological observation
   Geophysics to know interior structure of the moon
   Measure lunar environment for future utilization
3. Contribution to international space exploration activity and meet public interest.

To accomplish the mission, following exploration scenario is considered. After launching with a H-2A class rocket, the spacecraft is put into GTO (Geostationary Transfer Orbit) or LTO (Lunar Transfer Orbit). In case of GTO insertion, the spacecraft conducts some orbit maneuvers to reach the moon. After arriving to a lunar orbit, the orbiter is separated and it is used for communication relay between instruments on the moon surface and earth stations. The selection of a landing site is under discussion, considering scientific interest and technological feasibility.

One of the mission objectives is the geological observation. Therefore, accurate and safe landing to a scientifically interested area is required. Considering the rover mobility, a hundred meter accuracy of navigation and guidance is essential. For the successful landing, descent propulsion system, a laser altimeter, a landing radar, image-based landmark navigation, hazard avoidance technologies, landing legs, etc are studied.

For the exploration rover, mobile gears to climb about 25 degree slopes or about 20 cm rocks are developed. The rover must be light weight and low power consumption to meet system requirements. It has to stand lunar surface environment such as high temperature in the day time, low temperature in the night time, and regolith dust. It has a manipulator arm and a grinding tool for geological observation.

To survive in two-week night on the moon surface without radio-isotope energy is another technological challenge. We have developed a night survival unit with sophisticated thermal isolation and high performance Lithium Ion batteries.

On the surface, the rover and other instruments such as a seismometer are deployed and start observation while about ten days, that is lunar day time. Some instruments such as a seismometer, an electromagnetic measurement, or a feat flow meter, however, require a few months observation. Therefore, night survival system is essential. From the results of some numerical simulations and thermal-vacuum experiments, instruments that require a few watts power can survive two-week night with sophisticated thermal isolation and high-efficiency Lithium Ion batteries.

An artist image of SELENE-2 configuration is shown in Fig.1. Spacecraft dry mass is about one ton and mission payload on the lander including 100kg rover will be about 300 kg

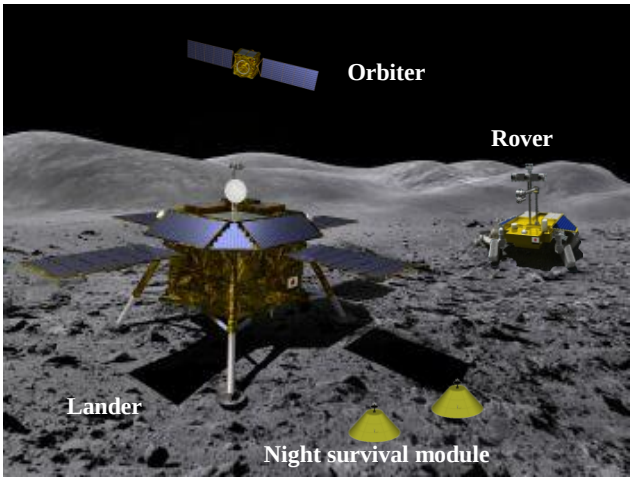

Fig.1 An artist drawing of SELENE-2 configuration

Detailed geological observation at some representative geological units such as PKT (Procellarum KREEP Terrane), or FHT (Feldspathic Highlands Terrane) may enable us to clarify the formation process of magma oceans. Moreover, it would be preferable to locate and select sites with “fresh outcrops” (i.e. intact lunar rock formations) since most parts of the moon surface have been altered since their original formation by meteor impacts crushing rocks and regolith.

Geophysical observations are also indispensable. Seismic observations are the most important in order to clearly understand the internal structure of the moon. The existence and size of core, and the velocity profile of the mantle will enable us to estimate the bulk abundance and thermal state of the moon. Since seismic observations require global "network", the possibility of establishing an international coordinated multi-point observations should be discussed.

Research on lunar surface environment and investigation of possible in-situ resource utilization for human activity or construction of observatories are also important for enabling future lunar exploration schemes as well as for increasing our scientific knowledge. Some instruments for measuring lunar surface environment are also used for planetary science.

The third kind of mission objectives of SELENE-2 is political, educational, cultural, or diplomatic purposes. However, those issues are difficult and need high-level discussion. Therefore, so far, the study is limited to discussions on high definition TV (HDTV). International corporation and coordination are discussed in the frame of International Space Exploration Coordination Group (ISECG), bilateral agency to agency discussion, or bottom up collaborations of researcher level. HDTV on Kaguya spacecraft provided clear and wonderful movies of the moon and the Earth, including famous “Earth rise”. SELENE-2 plans to show similar moon surface movies for public outreach.

Conclusion: Present status of Japanese moon surface exploration study is presented. Considering the situation in the world, mission and landing site of SELENE-2 might be changed. Anyway, however, JAXA is expecting to perform a moon surface mission around 2020.

References: [1] Y. Takizawa, et al.(2008), 26th ISTS, 2008-k-20, [2] T. Hashimoto, et al (2011), Acta Astronautica 68, pp1386-1391, [3] http://www.kantei.go.jp/jp/singi/utyuu/basic_plan.pdf, [4] http://sservi.nasa.gov/articles/nasa-looking-to-mine-water-on-the-moon-and-mars/