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An introduction to the lunar and planetary science activities in Korea

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Abstract

Korea is planning a series of lunar space programs in 2020 starting with a lunar orbiter and a lander with a rover. Compared to other countries, Korea has a relatively brief history in space and planetary sciences. With the expected Korean missions on the near-term horizon and the relatively few Korean planetary scientists, Korea Institute of Geoscience and Mineral Resources (KIGAM) has established a new planetary research group focusing on development of prospective lunar instruments, analysis of the publicly available planetary data of the Moon, organizing nationwide planetary workshops, and initiating planetary educational programs with academic institutions. Korea has also initiated its own rocket development program, which could acquire a rocket-launch capability toward the Korean lunar mission. For the prospective Korea's lunar science program, feasibility studies for some candidate science payloads have been started since 2010 for an orbiter and a lander. The concept design of each candidate instrument has been accomplished in 2012. It is expected that the development of science payloads may start by 2014 as Phase A. Not only developing hardware required for the lunar mission but also educational activities for young students are high priorities for Korea. The new plan of the Korean lunar mission can be successfully accomplished with international cooperative outreach programs in conjunction with internationally accessible planetary data system (PDS). This paper introduces the KIGAM's international cooperative planetary research and educational programs and also summarizes other nationwide new developments for Korean lunar research projects at Kyung Hee University and Hanyang University.

Keywords: Korea; Future Korean lunar mission; Lunar exploration; KSLV; KIGAM; KARI

1. Introduction

With a relatively short history of Korean space program, now Korea is planning on its independent lunar exploration program for the coming ten years (Fig. 1). Still there are not enough resources and researchers in this area at present. Probably, there are many more space engineers available for the prospective lunar exploration than scientists who are associated with previously or presently in this field.

Some promotional activities in planetary geology for both science and education collaborating with international research groups especially of Japan, the United States, France, etc. could make Korea to accomplish its goals toward successful lunar missions much positively. New initiative of research and educational efforts coming together with space engineers and researchers would lead Korea to enter a new era toward space age even faster than expected. Recent Asian lunar orbital missions such as SELENE-1, Chandrayaan-1, and Change'-1 provided a new view of lunar surface and uncovered lunar geology and lunar environment. Currently, LRO, Chang'e-2, and GRAIL are orbiting the Moon and many more lunar explorations will continue in the 2010s, such as LADEE,

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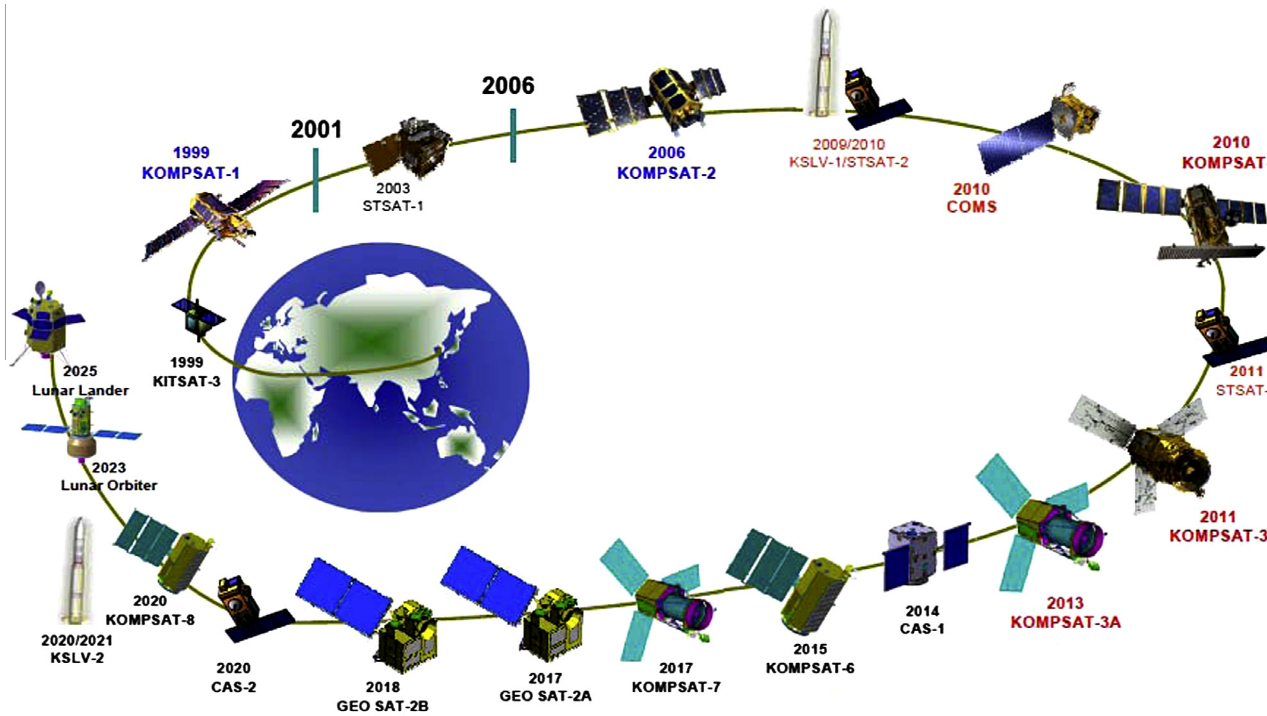


Fig. 1. A diagram of Korea's national space development plan provided by KARI.

Constellation Orion, Constellation Altair Lander, Chang'e-2, SELENE-2, Chandrayaan-2 (http://www.jspec.jaxa.jp/e/activity/selene2.html; http://www.isro.org/scripts/futureprogramme.aspx; http://lpi.usra.edu/lunar/missios/; http://www.china-defense-mashup.com/ http://lpi.usra.edu/lunar/missios/).

While Korea focuses on its science goals from the orbit of the Moon for the next 10 years, future missions of other nations will focus on the lunar surface investigations by landers and rovers. Furthermore, manned lunar mission will be planned. With respect to current status of other nations' lunar program, Korea's lunar program is fairly late; however, its role can be defined for Korea's scientific and engineering development as well as an internationally important role which may rise around that time. Korea's lunar exploration is one of the nation's goals and it will open a new era of Korean space and planetary exploration for the Moon and beyond.

2. Future Korean lunar exploration

Korea has started its space program by launching the first satellite, KITSAT-3, in 1999. Using other nation's rocket system, Korea focused on developing a better Earth observing satellite system by developing nearly ten satellites for the past 15 years. Korea launched its first carrier rocket, Naro-1 on January 2013 successfully and STSAT-2C was placed into low Earth orbit. The solid-fuel rocket second stage was built by KARI, and the first stage was purchased by KARI from NPO Energomash, Russia (Fig. 1) (http://en.wikipedia.org/wiki/Naro-1). Currently Korea is developing its own rocket system, Korea Space Launching Vehicle (KSLV). This is planned to be used for the Korean prospective lunar mission.

Korea Aerospace Research Institute (KARI) is heavily focused on research developments on aerospace engineering (Song et al., 2009; Kim et al., 2009). Therefore, for prospective planetary missions, scientific roles for future mission will be carried by relevant research organization. KARI and the Ministry of Education, Science and Technology of Korea (MEST) have set the launch schedule for an orbiter and a lander including a rover in 2020 (Fig. 1). A study accomplished by KARI indicated that the expected weight of the Korean orbiter would be about 550 kg (Song et al., 2009). This will limit the total weight of science payloads to be about 100 kg. This will bring us to have much more careful selection of scientific goals and careful development of selected instruments. At this stage, the first stage of science definition and investigation of possible candidate instruments are being accomplished by relevant researchers. As the second stage, prototypes of core scientific payloads will be developed. Then, engineering model and furthermore flight model of scientific payloads will be developed consequently.

3. Research and developments at KIGAM

3.1. Geological investigation in participating in Kaguya GRS program

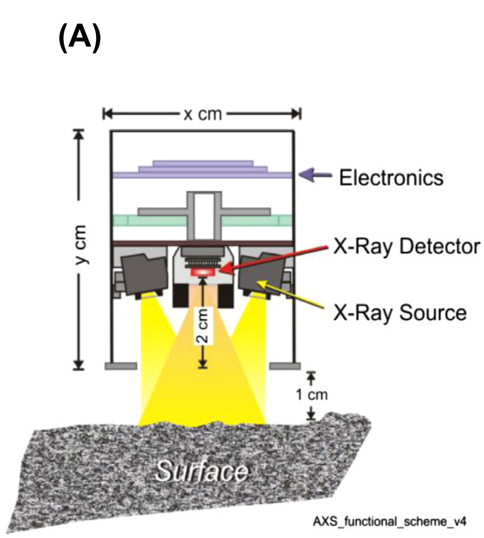
Since 2008, the KIGAM-based planetary science program has expanded by the bilateral international cooperative research program associated with the SELENE-1 (Kaguya) Gamma Ray Spectrometer group for the lunar geological research programs (Hasebe et al., 2009; Kobayashi et al., 2010; Kobayashi et al., 2012; Yamashita et al., 2010, Yamashita et al., 2012). For effective utilization of Kaguya data as well as other lunar data obtained from the previous and recent lunar missions, KIGAM's planetary research group is developing a Geographic Information System (GIS)-based lunar planetary mapping system for both research and public outreach. Also, teaching courses of lunar and planetary science at tertiary level are under development through the university networks.

An efficient way of instructing researchers how to investigate planetary surfaces and geologic evolution of a planetary body such as the Moon is through a GIS planetary data system of layered map information for comparative analysis including topographic, gravity, mineralogic, UV, geologic, and elemental data depending on the planetary body (Lawrence et al., 1998; Lucey et al., 1995; Lucey, 2004; Wilhelms, 1987). Layered information gives the researcher a greater perspective of the processes that shaped the surface of the planetary body including both endogenic and exogenic. Therefore, in 2009, KIGAM-SPS (Space and Planetary Science) introduced a new "planetary GIS-based mapping system" referred to as PGMSK for both research and education (Kim, 2009). The PGMSK (Planetary Geology and Mapping System of Korea) mapping system forms the basis for robust interpretations of the geologic evolution of planetary bodies such as in the Moon case.

For example, we compared the Kaguya GRS data with the Apollo-based geologic information in order to assess the geologic evolution using categorized age Stages 1 through 3 based on the time before and after the imbrium impact event of the large impact basins on the Moon, South Pole Aitken and hypothesized Procellarum Basins (Kim et al., 2012). The investigation shows that the geologic evolution of the two basin regions is very distinct from one another and the rest of the Moon (Kim et al., 2012). The opportunity of the participation in Kaguya GRS program for KIGAM's researchers was beneficial in not only expanding geological applications using the Kaguya data but also understanding required scientific knowledge and techniques for prospective Korean missions using a GRS instrument for the surface investigation of the Moon and other planetary bodies. In addition to being useful in understanding geologic evolution of the Moon (including South Pole Aitken and Procellarum basins) through the coupling of various geologic, elemental, mineralogic, and geophysical information, and thus a greater perspective, PGMSK will optimize the identification of prime targets for future missions.

3.2. Development of an active X-ray spectrometer for SELENE-2 rover

The planetary research group at KIGAM has proposed to develop an Active X-ray Spectrometer (AXS) for the SELENE-2 rover. An AXS using radioactive sources have been frequently used to chemically characterize planetary surfaces (Brückner et al., 2003; Gellert et al., 2006; Gellert et al., 2009). Especially, using an Alpha Particle X-Ray Spectrometer (APXS), Mars missions of the Mars Pathfinder and the two Mars Exploration Rovers (MER) missions have successfully determined the chemical composition of rocks and soils along their traverses. A modified AXS instrument is envisaged to be on board of the Japanese SELENE-2 rover with a launch date in 2018. The new AXS instrument will consist of an X-ray generator using a pyroelectric crystal and a large-area X-ray silicon drift detector (SDD) with an integrated field effect transistor similar to the detector of the MER APXS (Ida and Kawai, 2005; Gellert et al., 2006) (Fig. 2). To develop an AXS for the SELENE-2 Rover, KIGAM is collaborating with multiple international organizations: Waseda University, Lunar and Planetary Laboratory at



(B)

	Lunar Mare Basalts		Lunar Highland Rocks		
Type	High-Ti	Low-Ti	Ferroan Anorthosite	Mg-Rich	KREEP
Mission	A-11	A-12	A-15	A-17	
Sample	10049	12064	15363	72415	Mean
Na	0.38	0.21	0.22	0.10	0.64
Mg	4.2	3.9	2.32	27.0	6.39
Al	5.0	5.7	14.8	0.69	8.79
Si	19.2	21.6	21.2	18.8	22.4
K	0.30	0.06	0.011	0.002	0.69
Ca	7.9	8.4	12.0	0.79	6.80
Ti	6.8	2.4	0.070	0.02	1.00
Cr	0.22	0.25	0.065	0.23	0.13
Mn	0.19	0.21	0.052	0.09	0.11
Fe	14.5	15.5	3.70	9.09	8.24

Fig. 2. Preliminary 3-dimensional and cross-sectional view (A) of the AXS sensor head. Table (B) shows chemical data (in weight percent) for different major lunar rock types. It should be noted that in many cases the concentrations of the elements are similar between different rock types.

the University of Arizona, Johannes Gutenberg University, Max Planck Institute for Chemistry, NASA Goddard Space Flight Center, and KARI.

The AXS is designed to make X-ray measurements on the hostile lunar surface. It is to be mounted on the arm of the lunar rover of the SELENE-2 mission. The AXS data will be used to determine concentrations of elements in various samples: rocks, regolith samples, and breccias encountered at the landing site and along the traverse of the rover. The AXS can measure the major elements of Mg, Al, Si, Ca, Ti, and Fe and the minor elements of Na, K, P, S, Cl, Cr, and Mn as well as the trace elements of Ni depending on their concentrations. The total uncertainty of the AXS measurements are estimated to be within 10%, and the uncertainty of the major elements could be within a few percent. The precisions of AXS for high-abundance elements (i.e. Fe) and low-abundance elements (i.e. Ca) are found to be few percent to about 5% for a basalt sample. The total measurement error targeted for the AXS would provide successful rock identification and classification for AXS on the Moon. JAXA has been announced the six priority landing sites as Tycho, Copernicus, and Apollo 14 landing site, Zucchius, Marius Hills, and Mare Humorum.

3.3. Academic activities and outreach program provided by KIGAM

Not like some other countries, there has not been established a single department which is named as "planetary science" at any of Korean universities up to now. Recent developments in the field of Korean planetary sciences focus on cosmochemistry using planetary materials (i.e. meteorites). The department of astronomy and space science at Chungnam National University has started a graduate course for planetary physics since 2010. Also, the University of Science and Technology at KIGAM campus has opened a new major on planetary remote sensing recently. In order to promote planetary sciences for Korea, establishment of teaching courses at university levels are essential. In addition to above efforts, an initiation of professional activity such as planetary special session on a national conference has been started through International Symposium on Remote Sensing since 2009. This effort will expand to other national conferences relevant to the field of space and planetary sciences.

Since 2007, KIGAM—SPS has organized planetary workshops as international scientific collaborative activities participated in science teachers' educational camps from K-1 to K-12. KIGAM—SPS has constructed lunar and Mars paper globes to distribute them to teachers for educational purposes since such map products are essential for teaching students about new worlds. Map translation and production of both global maps of the both Moon and Mars in Korean have been completed in part based on the collaboration with the U.S. Geological Survey, Flagstaff.

It is obviously true that KIGAM-SPS has received invaluable support and benefits by collaborating with well established planetary research groups at Waseda University (Institute for Science and Engineering), University of Arizona (Lunar and Planetary Laboratory), United States Geological Survey, and Centre d'Etude Spatiale des Rayonnements in France. While its conducting collaborative research program, KIGAM-SPS was able to promote nationwide planetary science and educational activities. Since a space mission based planetary science research program gives opportunities for researchers and students to learn multidisciplinary knowledge and technology, Korean researcher and students eventually obtain the essential scientific knowledge and experience quickly toward successful Korea's prospective planetary science programs. While preparing the Korea's lunar mission, we frequently see that Japanese students, who have been involved in space missions, get a job very effectively in either space industry or other advanced technological institute. Students who expand their learning capabilities and experiences in the advanced space technology can adapt their learnt skills for relevant advanced job tasks. This opportunity is likely to occur for Korean students while working on Korea's planetary program and collaborating with other international planetary science groups. Developments of human resources and advanced technology are required for a sustainable system of planetary exploration. Because of this reason, it is important for Korea to educate students and heavers of the next age.

4. Other academic organizations for lunar exploration

4.1. Research and development of lunar engineering and space constructions at the ISERI

Hanyang University has established the International Space Exploration Research Institute (ISERI) in 2012. The institute has a primary goal to promote space exploration technology. Also the institute is to design and build a small, light multitasking robot system (Extra-Terrestrial Demonstration System: ETDS) to perform *in-situ* experiments which can be compared with the terrestrial analog testing results to build simulation models for corresponding systems. ISERI collaborates with America's space exploration R&D company Honeybee Robotics and operates industry-university-institute collaboration team, R&D team, and an international cooperation team based on international research work. The ISERI focuses on the *in-situ* Resources and Utilization project. The research group at the university has developed Korean lunar stimulant, KOHLS-1(Korea Hanyang Lunar **S**imulant-**1**), made of volcanic ash from Kyungju (Fig. 3) and is conducting research projects associated with planetary drilling, anchoring, lunar concrete, and exploration rover. Fig. 4 shows the description of lunar simulant concrete which is used a non-liquid polymer instead of water–cement hydration. This is known to improve tensile strength for the

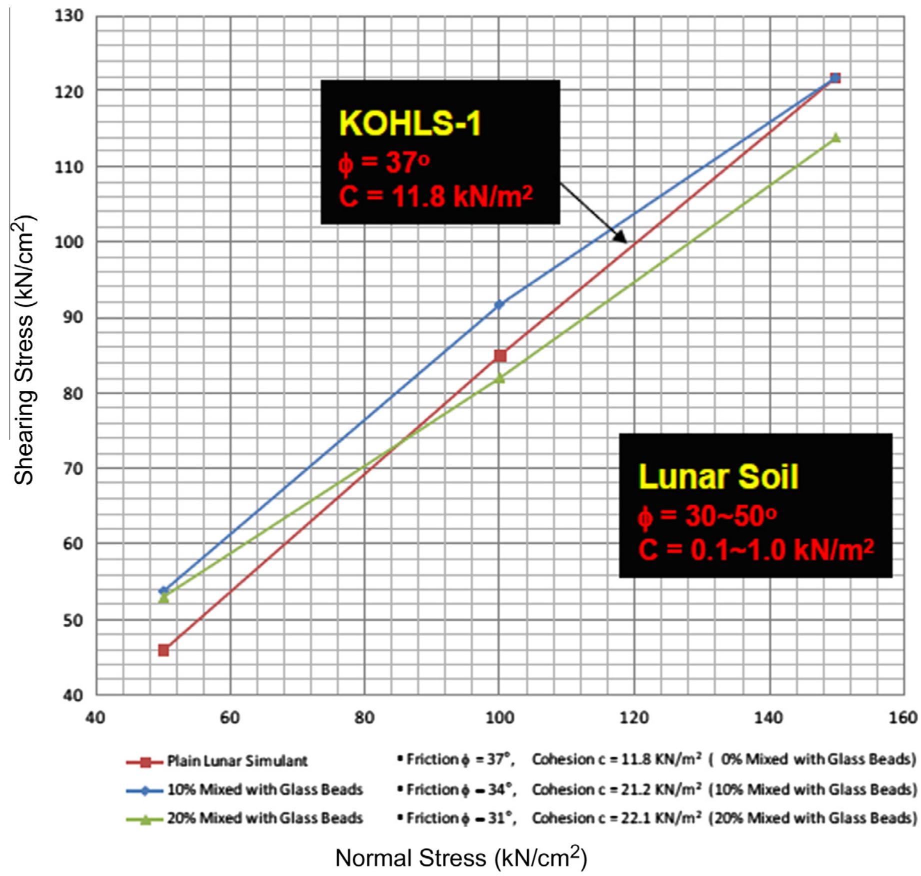


Fig. 3. Comparison of shearing stress as a function of normal stress for a lunar simulant (KOHLS-1) with lunar soil sample data. The density of KOHLS-1 is known to be 1.9 g/cm^3 compare to the calculated bulk density of lunar soil at any depth is 1.68 g/cm^3 (Heiken et al., 1991).

Sieve Number (#)	Percentage (%)
10	5
20	3
40	10
60	7
100	7.5
200	17.5
	50
Total	100

Fig. 4. Description of the production for lunar concrete by ISERI. This figure shows the steps to make lunar concrete. The steps are following to be quarry–grinding–sieving–mixing–production–completion. (After quarry, grinding, sieving, mixing–production to make concrete). There are six kinds of particle fractions from 10 to 200. The fractions of the sieving size are listed as the table in this figure.

Fig. 5. A photo of a cubesat for lunar exploration at Kyung Hee University collaboration with U. C., Berkeley (Bang, 2012).

concrete simulant. The ISERI specialized in automation and robotics in construction, engineering and management, project management. This lab has led numerous international conferences since 2004, focuses primarily on lunar exploration and construction, and has established as a gateway into the world of space exploration for Korea.

4.2. Development of Cubesat for earth and lunar missions at Kyung Hee University

The Space Science Department at the Kyung Hee University (KHU) is developing the CINEMA (Cubesat for Ion, Neutral, Electron, Magnetic Fields) cubesats collaborating with U.C., Berkeley to develop three cubesats for future lunar exploration. Each cubesat contains magnetometers. The main scientific objectives for the CENEMA are the multi-observation of ionspheric ENA (Eenergetic Neutral Atom) imaging, ionospheric signature of suprathermal electrons and ions, and complementary measurements of magnetic fields for particle data. The CINEMA cubesat consists of a suprathermal electron, ion, neutral (STEIN) instrument and a 3-axis magnetometer of magnetoresistive sensors. Each cubesat has a volume of 10 cm × 10 cm × 30 cm with 3.1 kg in mass (Fig. 5). The cubesat has an altitude control system (ACS) which uses torque coils, a sun sensor, and the magnetometers and spin at 4 rpm. The spin axis is set to be perpendicular to the ecliptic plane. The CINEMA is planned to be placed in low earth orbit that crosses the aural zone and cusp at the end of 2012 and also to be used for future lunar mission (Bang, 2012).

5. Summary

With an international collaborative program, Korean institutes centered by KIGAM and KARI proposed an Active X-ray Spectrometer for the SELENE-2 Rover. The proposal is accepted as a pre-project at present. The launch date of SELENE-2 mission is set to be 2018. Participation of SELENE-2 program will promote space and planetary sciences and as well as space technology of Korea very effectively. The required activities in the participation for the SELENE-2 mission will provide invaluable resources and technology for future Korean lunar mission planed in 2020. Since the establishment of KIGAM—SPS in late 2008, our efforts include investigations of geologic evolution of the Moon, as well as continued support toward the national needs for a successful participation of Korea's prospective planetary missions. At present, KIGAM—SPS is not only focusing on essential research programs including planetary data analysis and the development of space instruments for the surface exploration, but also utilizing the PGMSK for teaching Korean scientists and students to increase research activities in planetary sciences of Korea. Coming together by both Korean space engineers and planetary scientists to promote their prospective research activities in space and planetary science programs of Korea, a prosperous space age of Korea would be promised much more quickly than we anticipate.

Acknowledgements

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