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PPS25-P01 Room:Convention Hall Time:May 23 17:15-18:30

Advanced Lunar Imaging Spectrometer for the Next Japanese Lunar Mission SELENE-2: Present State and Science Objectives

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A future lunar landing mission SELENE-2 is being planned by Japan Aerospace Exploration Agency (JAXA). In the present design, SELENE-2 consists of a lander, a rover, and a communication relay orbiter, but detailed configuration - landing site(s), mission life etc. - is now under investigation. Advanced Lunar Imaging Spectrometer (ALIS) is an imaging spectrometer which we are developing for SELENE-2 lander.

Scientific objectives of ALIS are geological investigation around the landing site by VIS/NIR (Visible and Near Infra-red light) spectroscopy, making of the photometric model of the lunar surface by repeated observation with various photometric conditions, and production of an operation map for the rover to access sampling targets such as ejecta from central peaks. ALIS has been miniaturized in order to reduce weight and electricity consumption. It has a VIS-NIR imaging spectrometer (700-1700 nm with 5 - 10 nm resolution) . The spectrometer is composed of an imaging sensor (InGaAs) and a diffraction grating unit. The spectrometers take '1-line spatial resolution' x 'wavelength resolution' image as one shot. Line images are assembled by scanning image on a slit of the spectrometer with rotating ALIS body. We conducted a concept design of new ALIS and computed its thermal model and optical model to confirm its feasibility. The idea of scientific operation also will be presented.

Keywords: the Moon, remote sensing, hyper spectral sensor, lander

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PPS25-P02 Room:Convention Hall Time:May 23 17:15-18:30

Development of gamma-ray spectrometer for in-situ observations of elemental composition for SELENE-2

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For in-situ elemental analysis of lunar surface, we are developing gamma-ray spectrometer (GRS) for SELENE-2 mission. The GRS primarily measures K, Th and U abundances of the lunar surface and also can measure Fe and possibly other major elements.

To determine the elemental abundances with satisfactory accuracy, the energy resolution of the gamma-ray detector is an important factor. In view of operation on the lunar surface during lunar day, thermal feasibility of the instruments is important. Therefore we decided to use $LaBr_3$ scintillator, which has high energy resolution and can be used in high temperature environment.

Here we summarize science goals of the gamma-ray detector, expected sensitivity and current status of GRS development.

Keywords: SELENE-2, Lunar exploration, gamma-ray spectrometer

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PPS25-P03 Room:Convention Hall Time:May 23 17:15-18:30

Development status of thermal control unit for lunar surface scientific instruments in SELENE-2 mission

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We are developing the temperature control unit for long-term survival instruments in the SELENE-2 mission. In the SELENE-2 mission, several geophysical instruments are being considered to deploy on the lunar ground surface, including a seismometer, a magnetometer, a heat flow meter, and a VLBI radio source. These types of instruments require a long-term observation term beyond the lunar nights to obtain statistically sufficient amount of data. The lunar survival module was designed for temperature control of the instruments in the severe temperature environment (variable in -200 to 100 degC) on the lunar surface.

Conceptual examinations were conducted by numerical thermal modeling and thermal vacuum tests with a bread board model. Results of both thermal calculations and thermal vacuum tests showed a sufficient potential of the long-term survival on the Moon without high power consumption by heaters. We started designing an engineering model of the module based on the above mentioned results. The status and recent progresses of the lunar survival module developments are reported in this presentation.

Keywords: SELENE-2, thermal design, Moon

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PPS25-P04 Room:Convention Hall Time:May 23 17:15-18:30

Recent status of SELENE-2/VLBI instrument

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VLBI (very long baseline interferometry) technique is anticipated to be applied for precise positioning of an orbiter or a lander in lunar and planetary explorations. VLBI measures a difference in an arrival time of a signal transmitted from a radio source to two ground stations. The differential VLBI (DVLBI) measurement consists of the differenced delay between two radio sources (orbiter-orbiter or orbiter-quasar). The differential delays give plane-of-sky position differences of two radio sources in contrast to conventional 2-way Doppler measurements that give line-of-sight position information. The combination of VLBI with Doppler can be used for gravity field estimation of the Moon and planets, and for determining their rotations through the precise positioning of orbiters or landers.

VLBI observation is proposed for a lunar landing mission SELENE-2. The purpose is to investigate the internal structures through the estimation of the gravity field of the Moon. The VLBI technique is expected to contribute the understanding of the internal structure and leading the origin and thermal evolution of the Moon and planets. This presentation shows the recent status of SELENE-2 VLBI instruments.

Keywords: selene2, internal structure, VLBI

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PPS25-P05 Room:Convention Hall Time:May 23 17:15-18:30

Lunar electromagnetic response to be observed by Lunar ElectroMagnetic Sounder (LEMS) in the SELENE-2 mission

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The present status of lunar interior structure is a consequence of the thermal history of the Moon. Therefore information on its internal structure is a key issue to understand the lunar origin and evolution. The electrical conductivity structure, which is independent of the seismic velocity structure, is important to estimate the thermal structure in the lunar interior, since the electrical conductivity of silicates has a strong temperature dependence. Hence, we propose a lunar electromagnetic sounder (LEMS) to estimate the electrical conductivity structure of the Moon.

Temporal variations in the magnetic field of lunar external origin induce eddy currents in the lunar interior, which in turn generates the magnetic field of lunar internal origin. In the SELENE-2 mission, the inducing magnetic field is to be measured by two triaxial fluxgate magnetometers onboard a lunar orbiter, and the induced field as well as the inducing field is to be measured by two triaxial fluxgate magnetometers onboard a lunar lander. We plan to use dual magnetometer technique as mentioned above to avoid strict electromagnetic compatibility requirements like those for the Kaguya spacecraft.

Here we present a current status of the LEMS mission. We also show electromagnetic response of the Moon by assuming electrical conductivity structures of the lunar interior. It turns out that the magnetic field date as obtained in the Apollo mission are insufficient to estimate the electrical conductivity structure for the outermost few hundred kilometers of the Moon because of the low sampling frequency. Estimation of lunar electromagnetic response was attempted by using the magnetic field data obtained by the lunar magnetometer (LMAG) onboard the Kaguya spacecraft. Although the magnetic field data at higher frequencies are available, it is difficult to estimate electromagnetic response only by the lunar orbiter. Thus it is very significant to measure the magnetic field by both a lunar lander and a lunar orbiter in the SELENE-2 mission.

Keywords: electromagnetic sounding, lunar interior, SELENE-2

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PPS25-P06 Room:Convention Hall Time:May 23 17:15-18:30

On lunar broadband seismic observation in SELENE-2

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SELENE-2 is the first lunar landing mission of Japan. We are developing a broadband seismometer system as a powerful candidate for a payload instrument. In this presentation, we demonstrate the necessity of broadband seismometer observation, its scientific targets inspired by the results of the Apollo passive seismic experiment and current status of the development of the seismometer system. The Apollo projects in 1970's installed an equilateral triangle seismograph network at apexes where Apollo 12, 14, 15 and 16 landed, with a side of about 1,000 km long. The observation had lasted for over 7 years until September 1977 and it provided us with the first information on the lunar seismicity and the lunar structure down to a depth of 1,000 km. It, however, had two drawbacks: (1) the size of the network is limited within 1,000 km, and (2) the sensitivity of the seismometers with a limited narrow band of 0.17 Hz is marginal to detect the small deep moonquakes which occurred frequently. In addition, due to the strong scattering of seismic waves, P and S wave arrivals could not be picked up accurately, and the typical picking error is up to 10 sec. Because of these problems, the lunar velocity models obtained so far are less certain, in particular, at depths greater than 200 km. In the SELENE-2 project we plan to have only one landing site and so we cannot run a seismic network observation by the project alone. Thus, we need to obtain more information from the feeble seismic waveforms using a broadband (0.02-50 Hz) seismometer having 10 times higher sensitivity than that of the Apollo seismometers to overcome the drawback (2) as mentioned above. The characteristic frequency of the shal- low layer is about 0.12 Hz for the seismic velocity model of Nakamura (1981). Below that frequency, we expect clear detection of seismic phases reflected and converted at an internal discontinuity such as the core-mantle boundary. The long-period seismic waveforms may provide us not only information on the depth of an internal discontinuity but also seismic velocity contrast at the boundary. Long-period seismology will definitely open a new frontier of lunar science. Another scientific target of our project is to determine the corner frequency of deep moonquakes which can provide us information on the physical state in the source region. Although it was suggested that the corner frequency of deep moonquakes is much longer than that of earthquakes, the result is not conclusive because of the narrow band of the Apollo seismometers. To realize the highly sensitive broadband seismic observation in a timely manner, we make use of the heritage of a short-period seismometer (SP) developed in the past Lunar-A project and a long-period broadband seismometer VBB (LP) developed in the ExoMars project. We customize these seismic sensors to work properly under the severe conditions at the lunar surface. The thermal shield module is the key technology to realize high performance in the seismic observation on the moon.

Keywords: moon, moonquake, internal structure, broadband seismometer

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PPS25-P07 Room:Convention Hall Time:May 23 17:15-18:30

Development of separation mechanism of lunar penetrator module for installation in a three-axis stabilized satellite

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The lunar penetrator module (LPM) developed for the former LUNAR-A project consists of a hard landing probe "penetrator" itself, a de-orbit motor to cancel the orbital velocity and attitude control system for 90 deg re-orientation by so-called Rhumb Line Control during the free-fall phase. The total length of LPM is 1.5 meters, and the total weight is about 45 kilograms. Though the impact on the lunar surface nominally designed to be vertical with a velocity of 280~300 m/sec, there is a high possibility that the penetrator will hit on the surface with a finite attack angle, which is the offset angle between the longitudinal axis of LPM and the velocity vector. This will inevitably occur due to a possible misalignment of the separation mechanism w.r.t the carrier spacecraft, slight errors of the motor ignition, the attitude control of LPM, and other influences. In case of non-zero attack impact, rotational torque will be applied to the penetrator. And also, we concern that the large attack angle results in the deflection of penetration trajectory, and it provides the shock environment significantly different from the case of zero attack normal incidence. Therefore, the permissible range of initial attack angle at impact must be configured so that the lunar penetrator comes to rest with an adequate depth and a pitch angle. On the former LUNAR-A project, the maximum attack angle was set to 8 deg. We are conducting to design several types of separation mechanism for installation in a 3-axis stabilized satellite such as a series of Russian Luna-Glob and to make a trade-off study concerning assumed essential parameters and requirements with the carrier spacecraft. Furthermore, we should give careful consideration to allow us to make a full-size test on the ground facility. In this paper, we describe some formulas of newly designed separation mechanism and report a result of preliminary test using breadboard models.

Keywords: penetrator, separation mechanism, 3-axis stabilized satellite, lunar exploration, internal structure

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PPS25-P08 Room:Convention Hall Time:May 23 17:15-18:30

Development of a Small Digital Telescope for Observations of Lunar Rotation

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We have developed a BBM (Bread Board Model) of a digital telescope for ILOM (In-situ Lunar Orientation Measurement) and made some experiments in order to know the performance of the optical system and the driving mechanism under the lunar environment. It is a special small digital telescope like PZT (Photographic Zenith Tube) for study of lunar rotational dynamics with the target accuracy of 1 milli-second of arc (1 mas).

Effect of large temperature change is one of the most serious problem for such a precise observation. We propose two methods for reducing the effects of such a large temperature variation. One is to use a diffractive lens, and another is to correct the effects by making use of the characteristic patterns in the shifts of star images. Ray tracing simulations show that the tolerance for the temperature change becomes wider by about one order of magnitude by introducing the diffractive lens, and it suggests that the temperature change of up to 5 degrees is allowed for the observation change of 1 mas, which is more than one order of magnitude larger than that for conventional lenses. Regarding the another method, we succeeded in approximating the effects of uniform temperature change with better than 0.03nm on the CCD array or 10 micro-second of arc by using a linear function of temperature.

The attitude control system, on the other hand, can make the tube vertical within an error of 0.006 degrees (or about 20 arcseconds), which is within the tolerance for the measurement of 1 milli-arc-second accuracy by using PZT. Performance of the mechanical system on the Moon is evaluated by vacuum test, and there is no serious problem hitherto.

We also investigated possible optical effects upon the central position of star images such as the ghost, off focus, stray rays, scattered rays, diffractive rays of unnecessary degrees and vibration of mercury surface by using ray tracing simulations and experiments. The effects are proved to be far below the 1 mas level except the effect of vibration of the mercury surface which is under investigation.

Keywords: Lunar rotation, telescope, PZT, physical libration, internal structure

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PPS25-P09 Room:Convention Hall Time:May 23 17:15-18:30

A study of future lunar exploration system for sample return

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We report results of the design for the sample return system as a future lunar exploration which is planned to be launched after SELENE-2. Candidate missions for SELENE-3 are the sample return from the lunar surface, observations for inner structure, and lunar environment utilizations for astronomy and scientific experiment, therefore, the system is requested to realize these scientific missions. We studied the components of spacecraft, mass and power budgets, and mission profile and the sequence of events. We also investigated the bus equipments for the takeoff, rendezvous with an orbiter, and the navigation and control system to return to the earth. We displayed the restriction of systems under the assumption of landing sites; low latitude areas on the lunar near side, lunar far side, and polar areas.

Keywords: Moon, SELENE-3, sample return

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PPS25-P10 Room:Convention Hall Time:May 23 17:15-18:30

Evaluation of the lunar laser topographic data by KAGUYA-LALT - comparison with LRO-LOLA -

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The laser altimeter (LALT) on board Japanese lunar orbiter KAGUYA has obtained about 22.06 million lunar ranging data and 10.34 million of these data are selected for making the lunar topographic data. Further, global and polar (more than 79 degrees in both latitude) grid data whose resolution is 1/16 degree (1.895km in the equatorial region) and 1/32 degree (0.947km in longitude)*1/128 degree (0.237km in latitude) respectively, has been made and released from 1st November, 2009, followed by 2nd version of these data sets based on revised orbit data of the KAGUYA main orbiter from 19th January, 2012.

However, as pointed out by Korohkin et al. (2010), these grid data show several misfits comparing with the real topography, such that a small crater about 10km diameter is represented as a small dome by the false interpolation, probably caused by the sparse data distribution due to the small laser return rate on the rough terrain. In this poster presentation, we compare LALT grid data with Lunar Reconnaissance Orbiter (LRO)-LOLA for the evaluation of the global topographic accuracy of the LALT grid data, and also for the difference of the Mean Earth / Polar axis lunar reference system employed for both LALT and LOLA topography.

Korokhin et al., 2010, Removal of topographic effects from lunar images using Kaguya (LALT) and Earth-based observations, Planet. Space Sci., 58, 1298-1306.

Keywords: Lunar topography, Comparison, Laser altimeter, grid, LALT, LOLA

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PPS25-P11 Room:Convention Hall Time:May 23 17:15-18:30

On the range measurement error of LALT aboard KAGUYA

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The Laser Altimeter (LALT) aboard lunar explorer KAGUYA (SELENE), which was launched in September 2007 and operated until June 2009, measured the distance between the satellite and the lunar surface, and achieved the first accurate lunar topographic map including polar regions (Araki et al 2009). Originally it was designed so that range measurements could be done for slope terrain with 30 degrees from 100 km orbit with the laser energy of 100 mJ. However, decrease of the laser energy down to 70 mJ occurred in the beginning of the nominal mission phase. In addition, due to a sudden decrease in the laser energy on 14, April 2008, the observation was suspended for a while, and intermittent observation was carried out until the end of the nominal mission phase (October 2008) for the investigation. In the nominal mission period, range measurement sometimes failed in the slope regions because the light bounced on the surface was not detected with sufficient intensity. In this report we investigate such situation by using laser energy telemetry, distance between the satellite and the lunar surface, slope, and reflectance of the surface.

references: Araki et al. (2009) Science 323, 897-900.

Keywords: Kaguya, Laser altimeter, LALT

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PPS25-P12 Room:Convention Hall Time:May 23 17:15-18:30

Estimation of the permittivity of the lunar basalt layer based on the Kaguya observation data

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Lunar Radar Sounder (LRS) onboard the SELENE [Ono et al., 2009] discovered subsurface layers in lunar maria. The depth, T, of the subsurface reflector is a few hundred meters, and is given by $T=(c/E_r^{0.5})t/2$, where c is the speed of the light in the vacuum, E_r is the permittivity of basalt, and t is delay time of the subsurface echo from the surface echo. The permittivity of Apollo basalt samples returned from the lunar surface was in a permittivity range from 4 to 11 [e.g., Carrier et al., 1991]. These values are useful for the rough estimation of the thickness of the basalt layer. However, in order to obtain accurate thickness of the lava flow layers, we need to know the reliable permittivity of the lunar basalt layers. Using the LRS data applied Synthetic Aperture Radar (SAR) processing [Kobayashi et al., 2011], Terrain Camera (TC) data [Haruyama et al., 2008], and Multiband Imager (MI) data [Ohtake et al., 2008], we estimate the permittivity in each lunar lava flow units: Unit 85 of Mare Humorum [Hackwill et al., 2006], Unit Unit Sy1 of Mare Smythii [Hiesinger et al., 2010], and S13 of Mare Serenitatis [Hiesinger et al., 2000]. The permittivity E_r is calculated as $E_r=(ct/(2T))^2$ [Ono and Oya, 2000].

In order to determine T, we focus on the ejecta composition (TiO_2 and FeO). When the meteorite digs up different subsurface layers from the lunar surface layer, the formed ejecta composition would differ from that of lunar surface layer if subsurface layers have the different composition. Firstly, we compare the composition of the ejecta with that of the lunar surface by MI data and distinguish the haleod crater, around which ejecta composition is different from that of the lunar surface layer, from the non-haloed crater, around which ejecta composition is the same with that of the lunar surface layer. Secondly, using TC data, we investigate the depth of these craters, and determine the boundary-depth range around these craters by a pair of the haloed and non-haloed craters. For assumption of the heterogeneity of subsurface structure, the non-haloed crater must be close to the haloed crater. The distance between these craters is limited within 6 km, and the deepest non-haloed crater is selected. Thirdly, in order to determine ct/2, we use the LRS data applied SAR processing. The synthetic aperture is 5 km, and the spatial resolution is 600 m on the lunar surface in the along-track direction [Kobayashi et al., 2011]. We use the LRS data within 2.5 km from the center of these craters. If the ejecta contains the much more highland material, we assume that the deepest subsurface echo shows the boundary between highland and mare, and calculate the permittivity by depth of the deepest subsurface echo. On the other hand, if the ejecta does not contain the mush more highland material, we assume that the shallowest subsurface shows the boundary between the lunar lava flow units, and calculate the permittivity by the depth of the shallowest subsurface echo. The exsitence of the highland material in the ejecta is decided by the abundance of TiO_2 and FeO.

As the results, the ejecta composition in Unit 85 and Sy1 indicates the rough intermediate composition.The derived relative permittivity ranges of Unit 85, Sy1, and S13 are 3.3-6.0, 3.0-5.7, and 1.7-5.8, respectively.The estimated bulk density ranges in Unit 85, Sy1, and S13 are 1.8-2.7 g/cm^3, 1.7-2.6 g/cm^3, and 0.8-2.7 g/cm^3, respectively. The average density for Apollo basalt particle is $>$3.32 g/cm^3 [Carrier et al., 1991]. Thus, even the derived maximum bulk density is lower evidently than that of the lunar basalt. It is considered that the bulk density of the lunar lava flow layers can decrease by several reasons: composition, vesicles, cracks, tubes, and the existence of the paleoregolith layer. If the low permittivity results only from the porosity in the rock, the derived porosity is about 18-20% in each unit.

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The layered structure of lunar maria: Identification of the HF-radar reflector in Mare Serenitatis using optical images

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Comparison of the Lunar Radar Sounder (LRS) data to the Multiband Imager (MI) data is performed to identify the subsurface reflectors in Mare Serenitatis. The LRS is FM-CW radar (4-6 MHz) and the 2 MHz bandwidth leads to the range resolution of 75 m in a vacuum vacuum, whereas the sampling interval in the flight direction is about 75 m when an altitude of the spacecraft with polar orbit is nominal (100 km). Horizontally continuous reflectors were clearly detected by LRS in limited areas that consist of about 9% of the whole maria. The typical depth of the reflectors is estimated to be a few hundred meters. Layered structures of mare basalts are also discernible on some crater walls in the MI data of the visible bands (VIS). The VIS range has 9 wavelengths of 415, 750, 900, 950, and 1000 nm, and their spatial resolution is 20 m/pixel at a nominal altitude. The stratigraphies around Bessel and Bessel-H craters in Mare Serenitatis are examined in this paper. It was revealed that the subsurface reflectors lie on the boundaries between basalt units with different chemical compositions. In addition, model calculations using the simplified radar equation indicate that the subsurface reflectors are not compositional interfaces but layer boundaries with a high-porosity contrast. These results suggest that the detected reflectors in Mare Serenitatis are regolith accumulated during so long hiatus of mare volcanisms enough for chemical composition of magma to change, not instantaneously. Therefore combination of the LRS and MI data has a potential to reveal characteristics of a series of magmatism forming each lithostratigraphic unit in Mare Serenitatis and other maira.

Keywords: radar sounder, lunar maria, layered structure, crater wall

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PPS25-P14 Room:Convention Hall Time:May 23 17:15-18:30

Young Mare Volcanism in the Orientale Region Contemporary with 2 Ga PKT Peak Period

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The crater retention ages of the mare deposits within the Orientale multi-ring impact basin are investigated using 10 m resolution images obtained by Selenological and Engineering Explorer (SELENE, nicknamed Kaguya) spacecraft, in order to constrain the volcanic history of the Moon around the nearside-farside boundary. Precise crater-counting analyses reveal that mare deposits in the Orientale region are much younger than previously thought: ~2.8 Ga mare basalt in the eastern part of Mare Orientale and ~1.7-2.2 Ga mare deposits in Lacus Veris and Lacus Autumni, maria along the northeastern rings of the basin. These results indicate that the central and periph-eral regions of the Orientale basin experienced volcanic activities ~1 and ~1.8 billion years after the basin-formation impact, respectively. The dominance of uniform surface age across the mare deposits in the peripheral regions strongly suggests that these volcanic eruptions are contempo-rary with the elevated volcanic activity episode proposed for the Procellarum KREEP Terrane (PKT) region on the lunar nearside at around ~2 Ga and that this activity peak is much more widespread than previously estimated.

Keywords: Orientale Basin, Mare volcanism

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PPS25-P15 Room:Convention Hall Time:May 23 17:15-18:30

Numerical thermal erosion model of lava flow coupling with evolution of ground slope

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Schroter's Valley is one of the largest sinuous rilles on the Moon, a meandering negative-relief feature. The Schroter's Valley is located on the Aristarchus Plateau (305 ~ 313^{o}E, 22 ~ 30^{o}N), which is supposed to be an uplifted mare terrain. The rille appears as a singular sinuous rille as meandering primary rille including a more meandering inner rille. Typical sinuous rilles are 20 to 40 km in length and less than 1 km in width (Schubert et al., 1970), however, the primary rille of Schroter's Valley has been reported to be 125 km in length, up to 4.5 km in width, and 400 m in depth (Gornitz, 1973), and inner rille which is originated from the cobra-head of primary rille is reported to be ~170 km in length, 640 m of average width, and 95 m in depth (Garry et al., 2008).

The origin of sinuous rille is poorly understood. Previous researches have supposed that sinuous rilles are related to the basaltic lava flow. In past research, Honda and Fujimura (2005) developed numerical model of the sinuous rille formation of lunar lava flow. In this model, cooling rate of lava temperature as a function of distance from the lava source was calculated for estimation of thermal erosion velocity. The variation of chemistry of lava, physical properties such as density and viscosity during solidification of lava flow are incorporated in this model. They considered the effect of shifting from turbulent flow in initial phase to laminar flow in the last stage in their model. This model assumes that the ground slope maintain constant with time. However, the slope of floor of lava flow is changing with time, an erosion velocity of lava flow decreases along the downstream of lava flow following the lava temperature decreasing along the downstream.

In this study, we constructed the numerical thermal erosion model of lava flow coupling with evolution of ground slope. By using this numerical model, more large volume of lava flow is needed to originate the Schroter's Valley, because the slope of ground becomes shallower than initial one with time. If the maximum volume of eruptive volume on the Moon (Head et al., 2000) constrains the formation of Schroter's Valley, the eruptive temperature and thickness of lava flow which originate the rille are more than 1600 ^{o}C and 30 ~ 40 m, respectively.

Keywords: Sinuous rille, thermal erosion, numerical simulation

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Detection and Visualization of the Absorption Features of the Reflectance Spectra on the Moon based on Data from Spectra

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The Spectral Profile (SP) onboard Kaguya/SELENE is a visible and near-infrared spectrometer covering wavelengths of 0.5-2.6 micrometer and observed the Moon globally.Generally, the reflectance spectra contain mineral information. We can detect the lunar minerals by analyzing the SP spectra.

Modified Gaussian Model (MGM) developed by Sunshine et al. [1990] is one the methods of such analyses. MGM resolves the reflectance spectra and quantifies the features of the absorption bands. By comparing the results of MGM (detected features of the absorption bands) with those of the known samples, we can identify the observed minerals.

However, the original MGM tool has two problems, which are; (i) The tool is difficult to be applied to a large amount of spectral data, and (ii) The comprehension of the results of MGM tends to be complicated.

We focused on these two problems. A new produce was added to refer and access to the meta data of SP data. We also developed a visualization tool which helps to comprehend the detected features of the absorption bands easily on the lunar image. RGB color was allocated corresponding to the value of absorption features, such as central wavelength and strength of the absorption bands, and displayed on the observed spots in the lunar image.

We succeeded in customizing MGM tool and applied it to bunches of SP data.The visualization of the deconvolved absorption features was successful, too. The set of the two tools would enable us to analyze SP data efficiently, detect the minerals, and clarify their distribution on the surface of the Moon.

In the presentation, we show some examples. The target areas are the lunar swirls. We exhibit the results of our analyses of SP data using the set of developed tools and try to understand the spectral characteristics of the areas.

Keywords: Spectral Profiler/Kaguya, visible-near infrared spectrum, Moon, feature of absorption band, Modified Gaussian Model, Visualization

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PPS25-P17 Room:Convention Hall Time:May 23 17:15-18:30

Composition and Crystallinity of Dark Mantle Deposits on the Moon

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The lunar mantle makes up 90% of the lunar volume. Therefore, it is important to determine the mantle composition in order to understand the lunar bulk composition including information about origin and evolution of the Moon. However, the composition of the lunar mantle remains unclear.

Pyroclastic beads are a direct clue to lunar mantle composition. These very low-albedo beads on the lunar surface are Fe-bearing volcanic glass or partially crystallized spheres. The color variation of volcanic glass corresponds to its composition, in the order of higher TiO2 content (e.g., orange glass, yellow glass, green glass). It is believed that if the erupted magma is quenched slowly, the magma of intermediate to high TiO2 content can be small crystallized ilmenite grains and generate black beads, instead of generating orange and yellow glass. Thus, the TiO2 content of the beads and the quenching speed of the erupted magma correlate with the colors and crystallinities of the pyroclastic beads. Chemical studies of pyroclastic beads acquired by Apollo missions indicate that the beads were formed from erupted magma from deeper (300 to 400km) in the mantle than basaltic magma. It is also assumed that the beads retain the original composition of the magma.

Dark Mantle Deposits (DMDs) are one of the darkest and smoothest areas on the Moon and are believed to contain pyroclastic beads, as were found in the Taurus-Littrow region near Apollo 17 site. However, detailed spectral analysis of the DMDs is lacking because of the limited wavelength coverage and spatial resolution of the previous remote-sensing data.

This study focused on DMDs on the Aristarchus Plateau and used spectral data obtained by the Multiband Imager (MI) on the SELenological and ENgineering Explorer (SELENE). We chose this region because DMDs on the Aristarchus Plateau are the largest regional DMDs and because volcanic activity has lasted longer there than in other areas up to the Eratosthenian in this region. Previous studies reported that the crystallinity of this region is the lowest of all DMDs and that its composition is orange glass, indicating high TiO2 content.

This study re-evaluates composition and crystallinity of this region in more detail, using data with wider spectral coverage. The MI is a high-resolution (20m x 20m per pixel) spectral imager with both visible and near-infrared coverages at spectral 9 bands. Using MI spectral data, we can distinguish minerals and glass from the absorption features after removing the continuum.

In order to select locations representing DMDs suitable for checking their compositions, we mapped the Aristarchus Plateau area using the reflectance data at 750nm and then selected locations where reflectance is lower than 5.5%. We also produced an MI color-composite mosaic based on differences in absorption features, in order to distinguish pyroclastic beads from the surrounding mare. We then estimated the TiO2 content of pyroclastic beads by comparing the wavelength of the absorption center in the MI data with that of the laboratory-measured data of Apollo pyroclastic beads from the RELAB database. By comparing the spectra of different mixing ratios of glass (orange, yellow) and black beads from Apollo samples as endmembers, we estimated the crystallinity (estimated content of black beads) of the DMD.

The derived wavelength of the absorption center of the DMD spectra was 1050nm, which is similar to that of yellow glass. Thus, the pyroclastic beads of the DMD are assumed to be yellow glass, which has inter-mediate TiO2 content. Our results suggest that the crystallinity of the pyroclastic beads was 20%, and 40 to 50% of this region comprised materials ejected by the Aristarchus crater.

The result of low crystallinity of the beads possibly shows that only small volatile materials were contained in the magma source in this region because magma with higher volatile content cools more slowly and is likely to have higher crystal content.

Keywords: Dark Mantle Deposit, pyroclastic beads, Aristarchus plateau, Moon, composition, crystallinity

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Vertical trend of modal mineralogy and Mg# of the lunar highland crust estimated from Kaguya spectral data

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Mg# (Mg/[Mg+Fe] in mole percent in mafic minerals) is a key geochemical parameter of lunar highland rock for addressing the crustal formation process because it provides the degree of differentiation of the magma ocean at the time of its solidification. In a previous study, we reported the mafic mineral abundance and the Mg# distribution of the lunar highlands, which clearly indicates a dichotomic distribution, with a higher Mg# in the farside highlands than in the nearside [1]. A simple yet plausible model for interpreting the observation is dichotomic crustal growth from the magma ocean.

This study investigates the vertical trend of mafic mineral abundance and Mg# of the lunar highland crust using Kaguya spectral data. We utilize a new algorithm that derives Mg# from spectral reflectance data to develop a global map of mafic mineral abundance and Mg# at high spatial resolution [1]. From the generated global map, we checked 1) the correlation between the basin radius (excavation depth) and the averaged mafic abundances and Mg#s of the major highland basin ejecta (averages were derived for the region from one to two radii from the basin center), and 2) the correlation between distance from the basin center, and mafic abundances and Mg#s of the individual basin ejecta (ejecta deposited nearer the rim are assumed to be excavated from deeper within the crust).

The results indicate a vertical trend within the highland crust; the mafic mineral abundance decreases with depth while the Mg# increases with depth. These results are inconsistent with previous studies about trends of mafic mineral abundance [2][3] and with the simple crustal formation (Mg#) model explained by flotation of plagioclase crystal, suggesting a need for further study.

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Keywords: Moon, Kaguya, highland crust, Mg#, spectral data

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GEOLOGICAL STRUCTURE OF THE LUNAR SOUTH POLE-AITKEN BASIN BASED ON DATA DERIVED FROM SELENE MULTIBAND IMAGER

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The SPA is the biggest impact basin on the lunar far side. Previous studies have suggested that the mantle materials have been exposed. This excavation depth has estimated about 120 km. Crustal thickness of lunar farside is about 100 km, so most of the anorthosite composing the crust may have been excavated and ejected from the basin. However, the basin formation process and consequent mineralogy of this basin are still unclear because of the degradation after the supposedly ancient the SPA basin generated impact. For example, it is averaged of the lunar surface elevation by the rock collapse or space weathering. Therefore, crater scaling law in previous studies may not be applied to this basin, and it is possible that the impact melt size, transient cavity size and excavation depth of the SPA basin will not be estimated using crater scaling law in previous studies. On the other hands, previous observations are indicated that the crustal material remembered on the center of the SPA basin, and are apparently inconsistent with the theory of previous studies. And we study about the impact melt of the SPA basin to extrapolate the scale and the azimuth of the impact. In this study, we analyzed the distribution of the minerals and the topographic feature (such a peak ring) within the SPA basin, and compared these results. Finally, we supposed the geological structure, for example, impact melt pool size, transient cavity size and excavation depth, of this large impact crater.

We used the topographic data derived from SELENE LALT and the mineralogical data derived from MI. There are four rings investigated from previous data such as altimetry data of Clementine. However, they are not uncovered the full ring structure of the rings. We extended the previous identification by plotting the points with the same altitude. On the other hands, mineral phases have diagnostic absorption features depending on the minerals. Plagioclase, olivine and pyroxene have absorption bands at around 1250 nm, 1050 nm and 950 nm, rerespectively. These minerals are the three commonest minerals on the Moon. We identified these three minerals within the SPA basin using MI data. Especially, to select anorthosite (plagioclase$>$90%) spectra, we detected a peak shoulder at around 1250 nm.We made a color-composite image (RGB image) in which red, green and blue are assigned to a continuum removed absorption depth at 950nm,1050nm and 1250nm,respectively. We provided the geological structure of the SPA basin by comparing these topographic rings and the mineralogical distribution.

We identified four rings from the LALT data. The West- East example diameter of the second ring estimated 1,330 km. The fourth ring estimated 610 km. The topography inside the fourth ring is smooth compared to the outside areas. On the other hands, from the RGB map, we found out the lithofacies distribution. First, plagioclase located near the fringe region within the SPA basin. Second, on the middle area, where is red and yellow patches presented area, there are low and high-Ca pyroxene. And third, on the center of the basin, high-Ca pyroxene present. The mineral composition of this area is uniformity than other area.

The boundary derived from topographic data matched the presence of the anorthosite distribution derived from mineralogical data. This suggests that second ring corresponds to a transient cavity within which crustal material is excavated. On the other hand, it is possible that impact melt filled within only the fourth ring, because this ring is the innermost ring. If impact melt filled within the second ring or the third ring, it might not present peak ring inside these rings. And, the mineral composition within the fourth ring is uniformity than outside this ring. If the impact melt filled within this ring, the diameter of impact melt pool of the SPA basin is about 610km. This estimate is about the same diameter of calculation from previous studies.

Keywords: moon, South Pole-Aitken, basin, geological structure

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PPS25-P20 Room:Convention Hall Time:May 23 17:15-18:30

Lithological variations in the Nearside of the Moon

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Procellarum KREEP Terrane (PKT) that is characterized by high-Th concentration has been recognized to be one of important crustal constituents. However spatial distribution of the PKT materials has not been precisely understood since most of the PKT area is covered by maria. High-Th concentration area in the PKT shows complex irregular shape and apparently seen as main constituents of Imbrium basin rims. Therefore origin of the high-Th area in the PKT have been considered to result from Imbrium forming impact. However the highest Th concentration is observed in Fra Mauro area where includes the Apollo 14 landing site but not in the Imbrium basin rims and interior of the Imbrium basin though some high-Th spots in Imbrium basin are observed in some small craters (e.g., Aristillus). Mineralogical and petrological characteristics of some regions in the PKT are investigated to make sure distribution of the Th-rich PKT materials. In this presentation, variations of petrological characteristics in and around the PKT are compared and addressed issue on distribution of the PKT materials.

Keywords: The Moon, Crust, Magma ocean, Kaguya, Remote-sensing, Procellarum KREEP Terrane

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Evaluation of spatial distribution of craters on lunar surface for detection of secondary craters.

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Secondary craters are impact craters formed by ejecta that were thrown out of a primary crater. Secondary craters give a biased spatial distribution of craters. Researchers extract craters excluding a surface that contains secondary craters from lunar image based on his or her subjective views.

The purpose of this research is to develop an algorithm for evaluating spatial distribution of craters on lunar images. The algorithm applies to ideal spatial distribution of craters and real spatial distribution of craters, and evaluates whether a non-random portion in real area by comparing a single-linkage hierarchical clustering parameter.

We demonstrated for two regions on Mare Crisium. As a result of visual inspection, one region contains a lot of clustered secondary craters, and another region contains few clustered secondary craters. The clustered secondary craters could be evaluated non-random spatial distribution of craters quantitatively by our clustering analysis.

Keywords: moon, secondary crater, spatial distribution, clustering analysis

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PPS25-P22 Room:Convention Hall Time:May 23 17:15-18:30

Observation of surface locality on the Moon for production of lunar sodium exosphere with a 40cm telescope at Haleakala

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The Moon has a completely collision-free atmosphere with its surface pressure of about 10^{-17} times compared to that of the Earth. Previous studies showed that the lunar exosphere is consisted of He, Ar, Na, K, H, O. Among these constituents, Na and K have large resonant scattering cross sections, making ground-based observation of these atoms in the lunar exosphere relatively easy and a variety of observations has been made in the past.

Similar surface bounded exosphere does exist on Mercury. Production of the exosphere on Mercury looks to be dependent on its surface locality, and it is explained by local difference of the surface geology (e.g. Sprague et al., 1998). In addition, Kagitani et al. (2010) suggested local dependence on the lunar surface for production of lunar sodium tail based on the observation from Kaguya spacecraft. There is a surface geological difference between Lunar mare and mountain. There is more Na in Lunar mare than mountain, on the other hand, Lunar mountain were formed by meteoroid impacts, so Na particles are easy to be released. From this, we think that Lunar exosphere has local dependence for production.

We made observation of local dependence on the lunar surface for production of lunar sodium exosphere at 2 locations, one is Long. 90 deg. W Lat. 20 deg. N (mountain) and another is Long. 90 deg. W Lat. 20 deg. S (mare). The observation was continuously made at the summit of Mt. Haleakala with our 40cm Schmidt-Cassegrain telescope and a high dispersion Echelle spectrograph in the period of July 17-25, 2011. Results and the plan of next observations will be presented at the meeting.

Sprague et al., 1998, Icarus, 135, 60-68, Mercury: sodium atmospheric enhancements, radar bright spots, and visible surface features.

Kagitani et al., 2010, Planetary and Space Science, 58, 1660-1664, Variation in lunar sodium exosphere measured from lunar orbiter SELENE (Kaguya)

Keywords: Moon, Exosphere, Geological dependence, Sodium

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Angular dependence of the solar wind protons scattered at the lunar surface

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Since the Moon does not have neither global intrinsic magnetic field nor thick atmosphere, it is well known that the solar wind directly impacts the lunar surface. The behavior of low energy electrons around the moon has been investigated by the satellite observations such as Apollo Project and Luna Prospector. Previously there was almost no observation of the low energy ions around the Moon, and the solar wind ions after impacting the lunar surface was not understood. When arguing about the interaction of the lunar surface and the solar wind ions, the behavior of the solar wind ions after impacting the lunar surface has been regarded to be absorbed by the lunar surface from the knowledge obtained by laboratory experiments.

MAP-PACE on Kaguya (SELENE) observed scattering of the solar wind ions at the lunar surface. MAP-PACE on Kaguya (SELENE) completed observation of the low energy charged particles around the Moon from low altitude (less than 100km) polar orbit. MAP-PACE consists of 4 sensors: two electron sensors (ESA-S1, ESA-S2) and two ion sensors (IMA, IEA). Since each sensor has a hemispherical field of view, two electron sensors and two ion sensors that are installed on the spacecraft panels opposite to each other can make full 3-dimensional measurements of low energy electrons and ions. Initial analysis found that the scattered ions were almost protons and 0.1%~1% of the solar wind protons were scattered at the lunar surface. Although the feature of the scattered ions at the satellite altitude became clear by initial analysis, understanding the scattering characteristics at the lunar surface, such as a scattering angle, was not clear.

In order to understand the scattering characteristics at the lunar surface, we have investigated the relation between the incidence angle of the solar wind to the lunar surface and the output angle of the scattered protons from the lunar surface using the high angle resolution mode data of MAP-PACE-IMA. We also investigated the relation between the output angle and the energy. As a result, we have found that the protons are scattered back to the direction opposite to the incidence vector of the solar wind for all the incidence angles and they are scattered back inside a scattering cone with 40 degrees around the center axis. The energy loss of the scattered proton is largest along the axis of the scattering cone and it is smaller at the edge of the cone. In addition, we have succeeded in explaining these characteristics by a scattering model that considers the microscopic surface of the lunar regolith.

Keywords: solar wind, lunar surface, scattering

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Broadband whistler-mode waves detected by Kaguya near the lunar crustal magnetic anomalies

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Broadband magnetic waves with frequency range of 0.03-10 Hz in the spacecraft frame were observed by Kaguya near the Moon [Nakagawa et al., 2011]. The waves were not propagating parallel to the ambient magnetic ?eld direction and had a compressional component. There was neither peak frequency nor preferred polarization. Nakagawa et al. [2011] identified them as whistler-mode waves because of their large group velocity compared with the solar wind velocity as well as the observed frequency range. Although the generation mechanisms of the waves were suggested to be associated with ions reflected by the Moon, precise process has not been clarified yet.

Recently we have revealed the statistical properties of narrowband whistler-mode waves near the Moon [Tsugawa et al., 2011]. There would be a link in the generation mechanism of narrowband and broadband whistler-mode waves. In the present study, we perform statistical analyses to reveal the properties of the broadband whistler-mode waves near the Moon. The results reveal that the waves are mostly observed just near the lunar crustal magnetic anomalies in dayside. It suggests that most of the waves are generated by the solar wind interaction with the magnetic anomalies. Furthermore, we investigate the velocity distributions and fluxes of reflected ions by the magnetic anomalies and lunar surface. We also discuss other possible generation mechanisms of the waves based on the measured plasma parameters around the Moon.

Keywords: magnetic anomaly, reflected ions, upstream whistler waves

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Estimates of lunar crustal magnetic field distributions using plasma sheet electrons

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Lunar crustal magnetic anomalies have been observed by surface magnetometers at the Apollo landing sites, magnetometers onboard orbiting satellites, or the electron reflection method with the use of the electron's magnetic mirror effect. The spatial scale length of the lunar magnetic anomaly ranges from less than a few km up to several hundred kilometers. However, the measurement of lunar magnetic anomalies by satellite-borne magnetometer is limited by orbital altitudes, and further, the electron reflection method underestimates the strength of surface magnetic fields with wavelengths smaller than the electron gyrodiameter. Therefore, it is difficult to perform a precise measurement of weak and small-scale magnetic anomalies from the orbiting satellite. On the other hand, surface magnetometers can measure actual magnetic fields on the lunar surface but the observations were made at only a few points so far. The small-wavelength component may provide important information on the origins of lunar magnetic anomalies, which have been debated for a long time.

In this study, we estimate the lunar crustal magnetic field distributions using electrons observed by Kaguya when the Moon was located in the terrestrial plasma sheet. Electron velocity distribution functions obtained at low altitudes (~10-30 km) sometimes indicate relatively high-energy electrons ($>$ 1 keV) thought to strike the lunar surface within one gyromotion from our reversed particle trace calculations, which suggests that these electrons were nonadiabatically scattered by local surface magnetic fields. If we assume that these surface magnetic fields have vertical scale lengths much smaller than Kaguya's orbital altitude, we can infer their surface distributions from the observed electron velocity distribution functions. Electrons will be scattered upward from the lunar surface depending on the strength of the parallel magnetic field component with respect to the lunar surface. Therefore, a minimum value of the product of the strength and the horizontal scale length of the horizontal magnetic field component can be derived from the electron's scattered velocity obtained by the particle trace calculation. Thus, it is possible to infer small structures of the surface magnetic fields by using the high-angular resolution data of electrons obtained by Kaguya.

Keywords: Moon, magnetic anomaly, plasma, Kaguya