Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS024-01 Room:103 Time:May 22 16:30-16:45

Solar wind-regolith interaction: High reflection of the solar wind

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In this talk we will review new findings of the solar wind interaction with Moon and with Phobos based on the recent observations by the SARA instrument on board Chandrayaan-1 and the ASPERA instrument on board Mars Express. We also discuss potential future contributions of the space plasma investigation to lunar sciences.

High backscattered proton flux of the solar wind from the lunar surface was first reported by Saito et al. (2008) from Kaguya's plasma observations. The flux of the backscattered protons was 0.1-1%. The high backscattering was a big surprise because the lunar surface had been believed a complete absorber of the solar wind. Energetic neutral atom (ENA) observations by the CENA (Chandrayaan-1 Energetic Neutral Analyzer) sensor on board Chandrayaan-1 spacecraft consistently provided data of extremely high (~20%) neutral atom flux of the solar wind origin. The observed reflection efficiencies of backscattered particles both in forms of neutral atoms and ions are too high to be explained by theoretical predictions developed in laboratory experiences. On the other hand, the ratio of the backscattered fluxes between the backscattered neutrals and the ions are in the range of the expectation (10-100).

Not only from the Moon's surface, we also have tried to search for the backscattered protons in the Martian moon Phobos for comparison. We found significant proton flux during a flyby of the Mars Express spacecraft close to Phobos (Futaana et al. 2010). After careful removal of noise counts and comparing with the calculated ray tracing of the observed signals, we concluded that the detected signal can be explained by 0.6-10% reflection of the solar wind at the surface of Phobos. This result indicates that the solar wind backscattering is a general feature of the solar wind-regolith interaction in space.

Even though the interaction mechanism is not yet fully known, such high backscattering fluxes of the ENAs and plasma can be used to monitor solar wind proton access to the lunar surface remotely. We also analyzed the CENA data when the spacecraft flew over magnetic structures of crustal origin (called magnetic anomalies). By inverting the ENA flux obtained by CENA in orbit, we obtained a map of the backscattered ENAs (Wieser et al. 2010). The backscattered ENA flux shows a depletion inside the magnetic anomaly with an enhancement around the anomaly. This observation indicates that the magnetic anomaly deflectes the solar wind protons, and that the lunar surface inside the lunar magnetic anomaly is partially shielded from the solar wind. Consistently, we found clear correlation between the map of magnetic anomalies and the flux of charged protons, which are deflected by the magnetic anomaly (Lue et al. 2011). More than 50% of the solar wind flux are deflected by the strongest magnetic anomalies. The map also showed that even weak and distinct small magnetic anomaly could deflect the solar wind. The deflection of solar wind by the magnetic anomalies indicates a strong reduction of the solar wind access to the surface in the magnetic anomalies, reducing the space weathering effect at the upper crust of the magnetized regions.

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Keywords: Moon, Phobos, solar wind, regolith, energetic neutral atoms, magnetic anomaly

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PPS024-02 Room:103 Time:May 22 16:45-17:00

Interaction between the Moon and the Earth's magnetosphere observed by MAP-PACE on Kaguya

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The Moon stays in the Earth's magnetosphere for 3 - 4 days every month. The hot plasma-sheet plasmas in the Earth's magnetosphere can directly impact the lunar surface since the Moon has neither global intrinsic magnetic field nor thick atmosphere. On the other hand, plasmas originating from the Moon surface / exosphere sometimes reach the Moon orbiting spacecraft. MAgnetic field and Plasma experiment - Plasma energy Angle and Composition Experiment (MAP-PACE) on Kaguya (SELENE) measured lunar plasmas in a polar orbit with altitude of 100km, 50km, and in an elliptical orbit with perilune altitude as low as 10km. Although the plasma density in the Earth's magnetosphere around the Moon orbit (at about 60Re) was quite tenuous, MAP-PACE sensors succeeded in measuring characteristic ion / electron distributions in the Earth's magnetosphere including lobe cold ions, fast flowing ions associated with plasmoids, and cold ion acceleration in the plasma sheet / lobe boundaries. According to MAP-PACE observations, several characteristic phenomena caused by the interaction between Earth's magnetosphere and the lunar surface were so far found: 1) Ions originating from the Moon surface / exosphere [Tanaka et al., GRL 36, L22106, 2009], 2) Gyro-loss effect of electrons in the lobe / plasma sheet [Harada et al., GRL, 37, L19202, 2010], 3) Lunar surface charging to negative potential in the plasma sheet (even on the dayside of the Moon) and 4) Velocity dispersive structure of the plasma sheet ions reflected / scattered at the lunar surface. The ions originating from the Moon surface / exosphere are observed both in the solar wind and in the Earth's magnetosphere. The mass profile of these ions show heavy-ion peaks including C+, O+, Na+, K+, and Ar+ which indicates that these ions are the Moon origin. In the Earth's magnetosphere, these ions are clearly observed on the dayside of the Moon when the Moon is in the lobe. Since the convection electric field in the lobe region is much weaker than in the solar wind, the ions originating from the Moon surface / exosphere are possibly accelerated by the potential difference between the lunar surface and Kaguya. These ions often show characteristic energy / time variation. If these ions are accelerated by the potential difference between the lunar surface and Kaguya, the energy / time variation reflects the surface potential distribution on the lunar surface. Velocity dispersive structure of the plasma sheet ions reflected / scattered at the lunar surface is another example of the interaction between the lunar surface and the Earth's magnetosphere. When the hot plasma sheet ions impact the lunar surface some of them are reflected / scattered. Sometimes the reflected / scattered ions show velocity dispersive structure where higher energy ions are observed earlier. This velocity dispersion possibly reflects the non-uniform reflection / scattering of the plasma-sheet ions at the lunar surface. The plasmas observed around the Moon when the Moon is in the Earth's magnetosphere is gradually unveiling their characteristics. Understanding these phenomena will contribute to our understanding of the interaction between magnetosphere and non-magnetized airless bodies in general.

Keywords: moon, plasma, exosphere, magnetosphere

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PPS024-03 Room:103 Time:May 22 17:00-17:15

Properties of monochromatic whistler waves near the Moon detected by Kaguya

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We study monochromatic whistler waves near the Moon observed by LMAG aboard the Kaguya spacecraft. The waves were mostly left-hand polarized in the spacecraft frame and observed as narrowband magnetic fluctuations with frequencies close to 1 Hz. Although the monochromatic whistler waves near the Moon were also observed by Lunar Prospector [Halekas et al., 2006], the spectral formation mechanism and the generation process of the waves have not been fully understood.

In the present study, we perform statistical analyses to reveal the properties of the monochromatic whistler waves near the Moon. The results indicate that the intense waves are generated by the solar wind interaction with lunar magnetic anomalies. High occurrence rates of the waves are found in the range of the solar zenith angle (SZA) from 40 to 90 degrees with remarkable north-south and dawn-dusk asymmetries in the SSE coordinate. Similar asymmetries are found in the selenographical distributions as well. We explain these asymmetries by the localization of magnetic anomalies and the effects of SZA dependencies. Plasma wave theory predicts that the occurrence, intensity, and frequency of the waves are determined by the wave vector direction, magnetic field direction, and solar wind parameters. From the investigation of these parameter spaces we reveal that the properties of the waves can be explained by the Doppler shifted whistler-mode waves propagating against the solar wind.

Moreover, based on the results of the statistical analyses, we compare the properties of the observed waves quantitatively with those of upstream whistler waves from planetary bow shocks reported in previous studies. While we find different properties possibly caused by the differences of the distance from the source region, we discuss the similarities among them suggesting important clues in understanding the generation process of the monochromatic whistler waves near the Moon.

Keywords: whistler-mode, narrowband, magnetic anomaly, reflected ion

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PPS024-04 Room:103 Time:May 22 17:15-17:30

Study on the plasma waves around the Moon in the Earth's magnetosphere via KAGUYA spacecraft observations

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The moon is essentially unmagnetized. However, recent spacecraft observation revealed the existence of the localized magnetic field which is the so-called magnetic anomaly. Furthermore, the body of the moon is the dielectric. The charging of its surface strongly depends on the surrounding space plasma and the sunlit conditions. KAGUYA spacecraft has investigated the electromagnetic environment around the moon since its launch in 2007. In the present paper, we focused on plasma wave phenomena around the moon during its stay inside the geomagnetic tail region based on plasma wave data observed by the KAGUYA spacecraft.

We surveyed plasma wave activities and examined the difference of plasma wave features in the different plasma regimes in the geomagnetic tail regions considering the sunlit condition for the moon. The KAGUYA plasma wave data showed the generation of the Electric Cyclotron Harmonics (ECH) over the magnetic anomaly in the nightside, as well as that of the Langmuir waves in the earthside of the moon. We also analyzed the particle data obtained by PACE (Particle Angle and Composition Experiment). The PACE data showed the existence of the electron loss cone distribution with the low energy electron beam. By comparing the plasma wave data with the electron data, we found the good correlation of the ECH waves with the electron loss cone velocity distribution. In order to understand the generation mechanism of ECH waves, we calculate the linear growth rate by solving the kinetic plasma dispersion relation. Our linear analyses showed that the electron loss cone distribution with the low energy electron beam destabilize the ECH waves. Based on the spacecraft observations and linear analyses, we succeeded in establishing the generation model of the ECH waves in the view point of the moon-magnetosphere interaction.

Keywords: Space electromagnetic environment, Space plasma, Plasma wave, Geomagnetic tail region, KAGUYA spacecraft (SELENE)

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PPS024-05 Room:103 Time:May 22 17:30-17:45

Observations of the lunar subsurface structures and Jovian hectometric radiation by the Kaguya Lunar Radar Sounder

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The Lunar Radar Sounder (LRS) onboard the Kaguya (SELENE) spacecraft [Ono et al., 2000; 2008; Kasahara et al., 2008; Ono et al., 2010] successfully obtained 2363-hours worth of radar sounder data and 6570-hours worth of natural plasma wave data in the nominal operation period from October 29, 2007 to September 10, 2008 and 2390-hours worth of natural plasma wave data in the extended operation period until June 10, 2009.

It was found by the LRS observation that there are distinct subsurface reflectors with a depth of several hundred meters below the surface of the nearside maria. The reflectors are inferred to be paleoregolith layers covered by the basalt layers [Ono et al., 2009]. In several maria, the lava flow units have been identified based on the Clementine multispectral data [Heather et al., 2002; Hiesinger et al., 2003]. By analyzing Clementine multispectral image around the impact crater, Weider et al.[2010] estimated the thickness of lava flow units, and pointed out that the estimated thickness coincided with that reported by LRS. Kaguya multi-band imager (MI) [Ohtake et al., 2008] obtained multispectral images around the impact crater with higher resolution. The comparison between MI and LRS data will be important to determine the electric permittivity of the surface material, which is needed to derive the actual depth of the paleoregolith layers, and the evolution of the lave flow flux from LRS data.

Based on the analyses of LRS data, Oshigami et al [2009] reported that the subsurface echoes are found only in 10% of the western nearside maria such as Mare Humorum, Mare Imbrium, and Oceanus Procellarum. Pommerol et al. [2010] also suggested that detectability of the subsurface echoes depend on abundance of TiO_2 and FeO in the surface material, which was obtained based on Clementine multispectral image data. Kobayashi et al. [2009] proposed the estimation method of the thickness of the surface regolith layer by the apparent difference of altitudes measured by laser altimeter (LALT) [Araki et al., 2008] and LRS. It enables us to obtain the thickness of the surface regolith with several m, which is much less than the range resolution of LRS, or 75m.

In order to take advantage of lunar global subsurface radar soundings performed by the Kaguya spacecraft, we have to establish the analysis methods of radar sounder data obtained not only in nearside maria but also in farside highland regions and polar regions. We have two ideas of analysis methods: (a) Echo simulation based on the surface topographic data obtained by LALT and Terrain Camera (TC) [Haruyama et al., 2008], and (b) synthetic aperture radar (SAR) analyses [Kobayashi and Ono, 2002a; 2002b; 2006; 2007].

LRS was operated not only for the subsurface radar sounding but also for the passive radio wave observation. Through the operation period from October 2007 to September 2008, we could detect numerous events of auroral kilometric radiation (AKR), 39 events of type III solar radio bursts, and 7 events of Jovian hectometric (HOM) radiation with resolution of 2 sec or 0.1 sec. Fine structures were found in the spectrogram of Jovian HOM. The drift rate of the emissions was about 20 kHz/sec, which suggests the source motion with a velocity of 300 km/s. It is known that planetary radio emissions often shows narrow-band with a frequency drift, e. g. Jovian S-burst, and striated auroral kilometric radiation (AKR). Some previous studies explained that they are caused by kinetic Alfven waves and ion holes with ion acoustic velocity, which can modify the electron velocity distribution at the radio emission source. The velocity of 300 kHz derived from HOM observed by the Kaguya was however a little smaller than Alfven velocity (3000 km/s) and much less than ion acoustic velocity (15 km/s).

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Paleoregolith, Synthetic aperture radar (SAR), Jovian hectometric radiation (HOM)

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PPS024-06 Room:103 Time:May 22 17:45-18:00

Regional and global mapping of surface vector fields of the lunar magnetic anomalies

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The lunar magnetic anomalies give key information about the evolution of the lunar interior, in particular, a possible dynamo of the early Moon. There are two main problems of the origin of the lunar magnetic anomalies, the ambient field and the magnetization acquisition process. Based on the Apollo and Lunar Prospector observations, the basin-forming impact model was proposed to explain that several strong anomalies are located near antipodes of large impact basins [1]. However recent study of the Kaguya observations indicates that there are relatively weak magnetic anomalies almost over the Moon, suggesting an ancient global magnetic field such as an early lunar dynamo [2]. This possibility is supported by a numerical dynamo simulation assuming a dichotomy of the thermal condition at the lunar core-mantle boundary [3] and by the results from reanalysis of the previous dataset [4]. Thus the origin of the magnetic field recorded by the lunar magnetic anomalies should be reexamined although the basin-forming impact model has been believed so far.

For the study of the magnetization acquisition process, more detailed maps of the lunar magnetic anomalies are needed when compared with the geological and topographical data. Therefore we have developed a new method for mapping surface vector fields of the lunar magnetic anomaly field using the magnetic field observations by a satellite magnetometer (see Poster by Tsunakawa et al. at JpGU Meeting 2011). The surface vector mapping method has been applied to the Kaguya and Lunar Prospector datasets of low altitudes. We will report the results of regional and global mapping of the surface vector fields and discuss possible processes of the lunar magnetic anomalies.

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Keywords: Moon, Magnetic field, Magnetic anomaly, Kaguya

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PPS024-07 Room:103 Time:May 22 18:00-18:15

ORIGIN OF LUNAR WATER AND EVIDENCE FOR A WET MOON FROM D/H AND WATER IN LUNAR APATITES.

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Introduction: We have recently reported the first D/H measurements of lunar water from ion microprobe measurements of D/H in apatite from Apollo rock samples. A recent study of Cl isotopes in lunar materials has cast doubt on the estimates of lunar mantle water derived from apatite OH contents, and has called for a dry Moon during lunar petrogenesis. Here we report new measurements of water and D/H in lunar apatite from 12039,43 measured using the Hokudai ion microscope. Results: In this study, we have measured D/H and 1H/18O in eight apatite grains from 12039,43, bringing our total to thirteen apatite grains in 12039. The combination of plentiful and large apatite grains in coarse-grained pigeonite basalt 12039 have allowed us to make multiple measurements of D/H and H2O (presumably OH) in individual apatite grains from multiple thin-sections. We find that the water contents of individual apatite grains are homogeneous, but vary among different grains. Only one grain in 12039,43 was large enough for multiple spots, and dD values for those two spots were identical (dD=+765 +-42permil and +765 +-34permil). Discussion: D/H of the Moon. The mean and standard deviation of dD analyses of mare basalts 10044, 12039, and 75055 are +681 +-132permil (n=27). The mean and standard deviation of dD of 12039,43 are +698 +-61permil (n=9). This is almost identical to the mean dD of 12039,42 (mean dD=+689 +-180permil (n=13)), but with much less variability. Clearly the data are dominated by 12039, but the mean dD of 10044 is similarly elevated relative to Earth (10044: mean dD=+606 +-30permil (n=4)), as is the lone analysis of 75055 (dD=+735 +-36permil). That the D/H of these 3 mare basalts from different landing sites should be so similar argues that the mare source region is also similarly elevated in D/H. Other possibilities to explain the similarity in D/H of these 3 samples are likely untenable, but are considered below. The dD of two analyses of an intrusive highlands alkali anorthosite clast (14305,303) are also elevated relative to Earth (dD=+238 +-72permil; +341 +-53permil), but less so than those of mare basalts 10044, 12039, and 75055. An important point of an elevated D/H for this intrusive sample is that it would seem to argue against late-stage assimilation of regolith material (derived from comets or asteroids) by the extrusive mare lavas to explain the elevated D/H of the Moon. Origin of lunar water. If the D/H of water in lunar apatite is not formed by the processes of degassing, diffusion, or dehydration, then the D/H of lunar apatite may serve as a constraint for the nature of the late-accretionary population of material. If so, the only solar-system materials with D/H similar to that of mare basalt apatite would be bulk carbonaceous chondrites or comets. D/H of water from carbonaceous chondrites is similar to the D/H of water in the Earth mantle, suggesting cometary material as a source of water to the Moon.

Keywords: lunar, apollo, water, SIMS

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PPS024-08 Room:103 Time:May 22 18:15-18:30

Lunar carbon-bearing materials applied to magnetic changes

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The present study can be summarized as follows:

1) Light carbon-bearing materials formed in a high temperature can be explained to unsolved affairs of lunar magnetism and volcanic gases.

2) New light carbon-bearing materials which are applied to the Moon and Mars, many affairs are settled down; for example, the extinction of magnetic minerals on the moon and Mars, new dynamic processes of any dynamic formation process with carbon, and lifted volcanic gas on the Moon or Mars.

3) By containing of light carbon, magnetic Fe and Ni-bearing minerals can be changed to non-magnetic properties by new idea, which are checked by weak magnetic properties of the Apollo samples reported by previous scientists, and by iron meteorite solidified at core magnetic core coexisted with Fe-bearing carbon, carbides and carbonates.

4) By comparing with the magnetic intensity and light element content of the Apollo lunar samples, weak magnetism and irregular magnetism on the front and rear sides of the Moon can be explained by changing process of the magnetic properties by formation of Fe-carbonate of siderite as non-magnetic properties and magnetite formation at high pressure as magnetic properties in the Moon.

5) Lunar volcanic gases are generated from lifted volatile elements by reaction of iron metal and carbon, and triggered to lunar magnetic changes and lunar volcanic gases of non-volcanic pipes and/or mud-volcanoes. This new idea can be used to Martian phenomena, though the Earth phenomena are over-mixed to find real origin.

Keywords: The Moon, carbon-bearing materials, magnetic change, magnetic minerals, siderite, magnetite

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PPS024-09 Room:103 Time:May 23 08:30-08:45

High Pressure Polymorphs of Silica in shocked lunar meteorites and impact events in lunar surface

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Microcrystals of coesite and stishovite were discovered as inclusions in amorphous silica grains in shocked melt pockets of a lunar meteorite Asuka-881757 by micro-Raman spectrometry, scanning electron microscopy (SEM), electron back-scatter diffraction (EBSD), and transmission electron microscopy (TEM). These high pressure polymorphs of SiO2 in amorphous silica indicate that the meteorite experienced an equilibrium shock-pressure of at least 8-30 GPa. Secondary quartz grains are also observed in separate amorphous silica grains in the meteorite. The estimated age reported by the 39Ar/40Ar chronology indicates that the source basalt of this meteorite was impacted at 3800 Ma ago, time of Lunar Cataclysm, i.e., the heavy bombardment in the lunar surface. Observation of coesite and stishovite formed in the lunar breccias suggests that high pressure impact metamorphism and formation of high pressure minerals are common phenomena in brecciated lunar surface altered by the heavy meteoritic bombardment. We also confirmed existence of a post-stishovite polymorph, seifertite alpha-PbO2 type structure, in a different lunar meteorite, NWA4734, by X-ray diffraction using synchrotron radiation at BL10XU of SPring-8. Although this phase was previously suggested in the same meteorite only based on the cathode luminescence (CL) spectrum, it was never confirmed since there is no reference of seiferite in CL spectra. The present X-ray diffraction measurements confirmed existence of seifertite in this meteorite. The lattice parameter of this phase was consistent with that reported from a Martian meteorite (ElGoresy et al., 2008). The condition of the shock event in this lunar meteorite was more intense compared to Asuka-881757 lunar meteorite.

Keywords: High pressure, Polymorph, Silica, Lunar meteorite, Lunar Cataclysm, Asuka-881757

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PPS024-10 Room:103 Time:May 23 08:45-09:00

Ages of impact basins and early impact history of the Moon

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Dating of lunar impact basins is necessary to place constraints on the cratering history on the early Moon. In this study, we performed new crater size-frequency measurements in order to investigate ages and the stratigraphy of lunar impact basins. On the basis of the results, we will discuss the early impact history of the Moon.

Keywords: Moon, Kaguya, impact basin, cratering chronology, late heavy bombardment, lunar cataclysm

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PPS024-11 Room:103 Time:May 23 09:00-09:15

Optical maturity of crater ray materials on the Moon

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Fresh lunar impact craters have rays which are bright features radially expanding from host craters. It has been suggested that the rays are erased by space weathering that modify surface materials by exposure to solar wind and micrometeorite bombardments, and by impact gardening that mixes surface materials and subsurface materials by meteorite bombardments (Wilhelms, 1987). Werner and Medvedev (2010) surveyed lunar rayed craters with Clementine UVVIS images and showed that retention time of the rays of craters larger than 5 km in diameter is 750 Myr.

The purpose of this research is to investigate the retention time of rays around smaller lunar craters with high-resolution multiband images from Kaguya/MI (Multiband Imager). In our research, we surveyed rayed craters using OMAT (Optical Maturity) parameter developed by Lucey et al. (2000). The OMAT parameter is the optical index representing the degree of space weathering, which is derived from multiband images. Crater rays are not only bright, but also have larger OMAT value than the background. We surveyed craters from 300 m to 10 km in diameter in lunar highland with MI and TC images, and measured the OMAT profiles each crater. The craters the OMAT value at the crater rim is clearly higher than background OMAT value are detected as rayed craters. We described the size-frequency distribution of the detected craters. The craters larger than 1 km in diameter are plotted above the 1 Ga isochron. However, the distribution cannot be fitted by a single isochron. This suggests that the ray retention time is significantly longer than 1 Ga.

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PPS024-12 Room:103 Time:May 23 09:15-09:30

Combining the LP and SP Apollo Seismic Data to Explore "Broad" Band Seismology on the Moon

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Seismic data from Apollo missions is still one of the most important data set to investigate the structure and the state inside the Moon. On the other hand the data set suffer from constraints such as the number of seismic stations and their network location, and the sensitivity of the instruments. Our understanding of spectral feature of the lunar seismic events is limited to narrow frequency range because of the limitation of the instrument. Apollo missions had short period(SP) and long period(LP) seismometer and each seismometer covered about 1-10 Hz and 0.1-1 Hz respectively. In most of the previous studies, these data were treated independently and spectral features are discussed in limited band width. In this study we try to identify the spectral features from both LP and SP seismometer. From the two observations, we estimate the continuous spectrum that cover both of the LP and SP frequency range. By studying the spectral feature with broader frequency range, we can identify their characteristics more in detail compared to using just one observation.

Keywords: Moon, Earthquake, Moonquake

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PPS024-13 Room:103 Time:May 23 09:30-09:45

Lunar internal structure estimated from local admittance between gravity and topography

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A new spherical harmonic model of the lunar gravity field, complete to degree and order 100, has been developed from four-way Doppler measurements of Kaguya (SGM100h). On nearside, a comparison of SGM100h with a previous lunar gravity models reveals a general agreement. On farside, in contrast, the new gravity field model shows several circular signatures that correspond to topographic structures such as Moscoviense, Freundlich-Sharonov, Mendeleev, Hertzsprung, Korolev and Apollo basins. Those basins used to be identified as linear signatures in previous models. On the basis of new global gravity model, we classify lunar basins into Type I, Type II, and primary mascon basins.

For study of internal structure of those basins, we adopt spectral filter of wavelet. Wavelet analysis localizes the gravity and topography without a loss of spectral information. This advantage is particularly important for distinguishing compensation mechanisms of different types of lunar basins. We adopt a method with application of B-spline function of order 3 for isotropic window function. In addition, a scaling factor, f_S, that controls sizes of window in spatial and spectral domains varies from 2 to 5 in this study while the original method uses fixed value of 2.

We first calculate admittances of lunar highland where a good correlation between gravity disturbance and uncompensated topography is expected in short wavelengths. In order to estimate an appropriate f_S, admittances between gravity and topography in north polar area centered at 90 deg N and 0 deg E are calculated for f_S between 2 and 5. While the calculated admittances decrease in almost all degrees as f_S increases from 5 to 10, a difference between those for f_S of 10 and 15 is negligible. Therefore we use fS of 10 as a nominal value for the study of lunar highlands.

Admittances for highlands in the north polar area, nearside (45 deg S, 15 deg E), and farside (35 deg N, 145 deg W) increase with increasing degree up to 40 suggesting compensation of long-wavelength topography by lithospheric elasticity. Between degree of 40 and 65, admittance curves reach plateau corresponding to a ratio between gravity and uncompensated topography. The plateau values are between 110 and 130 mGal km^{-1} possibly suggesting a variation of crustal density between 2600 and 3000 kg m^{-3}.

We adopt f_S of 2 for lunar basins because major topographic and gravity signatures of basin are spatially compact.The Type I basins include Korolev, Dirichlet-Jackson, and Mendeleev basins on the farside. Admittance curves of these basins show similar trend that is characterized by one broad peak. A center of the admittance curve appears corresponding to central gravity high of Type I basin.

The Type II basins include Freundlich-Sharonov, Hertzsprung, and Orientale basins on the farside and limb. the Type II basins are distinguished from those for the Type I basins in that their admittance curves show two peaks; narrow peak around degree of 35 and broad peak at degree higher than 50. Magnitude of the narrow peak is equal to or higher than that of the broad peak. Degree of the narrow peak appears corresponding to wide central gravity high and volcanism associated with the Type II basins. In contrast to the Type I basins, the admittance curves of the Type II basins show a wide variation likely suggesting that the Type II basins are transitional between the Type I basins and primary mascon basins on the nearside.

Admittance curves of primary mascon basins are similar to those of the Type II basins and show two peaks. Unlike the Type II basins, however, magnitude of first peak at low degree is smaller than that of second peak at high degree. Besides, the second peak is as narrow as the first peak. An average of the admittances is nearly zero suggesting that the topography is isostatically compensated.

Keywords: lunar gravity, Kaguya

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PPS024-14 Room:103 Time:May 23 09:45-10:00

A determination of characteristics of impact basins from data of the Japanese lunar explorer "Kaguya"

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Impact cratering, especially large impacts such as basin-forming impacts, is one of the most important driving forces for surficial and interior structure (~ upper mantle) evolutions of the Moon. The formation process of impact basins has, however, remained unsolved. It is, therefore, important to determine accurate characteristics of the impact basins, such as the location of the center, the size and the height of a ring, and to understand the structure of the impact basins.

Visual inspection of photographs and/or topographic data has been a main tool to estimate the location of the center and the size of the impact basins, lacking quantitative capability and objectivity on those estimations. We propose here a new quantitative and objective procedure to estimate the characteristics based on a spherical function model. Furthermore, we apply the procedure to the latest lunar data, a topographic and a gravity models, obtained by the lunar explorer "Kaguya" and try to determine the characteristics of lunar impact basins.

Impact basins are expected to show an axisymmetric depression or a ring structure except of the case of extreme oblique impact. If the center of an impact basin is located at the North Pole, a broader structure of the impact basin can be represented by the sum of zonal terms of the spherical function over degrees that correspond to the size of the impact basin and smaller. This feature enables us to determine the center of the impact basin quantitatively and objectively as the location with the highest zonal component through the following procedure of 3 steps to virtual centers,

(1) a rotation to shift a virtual center of the impact basin at the North Pole,

(2) a localization to remove the effect of the structure far outside the impact basin,

(3) a calculation of the contribution of the zonal components.

In this study, we apply the new procedure mentioned above to lunar impact basins, determine the location of the center of the impact basins and estimate the size and the height of the rings. The data we use here is the spherical function model of lunar topography and the 1/16-degree gridded lunar topographic data.

We set virtual centers with an interval of 0.1 degree for latitude and longitude for an impact basin and estimate the location of the center as the location with the highest zonal component. Some impact basins with multi-rings show dominant zonal components at several degrees. In this case, we determine the location of the center for each degree. For the determination of the size of rings, we reproduce a topography map using lower terms of the lunar topographic coefficients, pick out points with the slope of topography of zero using cross-sections of the topography of the impact basins, and choose points that correspond to ring structures comparing to the topography map of the 1/16-degree gridded lunar topographic data. We estimate the size of a ring from the average of the distance from the center to each point on the ring. We also estimate the height of the ring from the difference between the average altitude of the points and the altitude of the center.

The procedure we apply here is powerful to estimate the characteristics of 25 impact basins. On the other hand, we cannot determine the location of the center of elliptical and polygonal impact basins. Some impact basins with multi-rings show offsets, up to 92 km, of the location of the center of each ring. We find a power-law relationship among the diameters of neighboring rings. A power-law relationship is recognized also between the diameter and the height of the rings identified in this study. These relationships suggest a regularity of the formation mechanism of the rings of impact basins.

Keywords: Impact Basin, the Moon, Spherical Harmonics, SELENE (Kaguya)

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PPS024-15 Room:103 Time:May 23 10:00-10:15

Structure of South-Pole Aitken Basin of the Moon from KAGUYA (SELENE) Selenodesy

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Figure Overprinted impact basins in SPA investigated here.

KAGUYA(SELENE) obtained the first precise gravity field of the lunar farside (Namiki et al., 2009) using 4-way Doppler tracking with relay satellite. Multi-frequency differential VLBI observation of two subsatel-lites improved the accuracy of gravity. A gravity field model SGM100h was obtained from one-year tracking data (Matsumoto et al., 2010) and the model was refined into SGM100i using VLBI data (Goossens et al., 2011). With topography data (Araki et al., 2009), Bouguer grav-ity anomaly, Moho depth, and crustal thickness are es-timted (Ishihara et al., 2009).

The South Pole-Aitken basin (hereafter SPA) is the largest and deepest impact basin in the solar system. It has abundant superimposed craters. Garrick-Bethell and Zuber (2009) (GZ09) showed that SPA is characterized by an ellipse with axes 2400 by 2050 km with the center at 53S - 191E. Here, we analyze the structure of SPA using KAGUYA selenodesy data. The direction of an ellipse denoting the depression is similar to that of GZ09. The region with the thinnest crust is offset southward from the center of SPA. Moho depth at the central region of SPA is around 30km (25km in crustal thickness) and shallower to the southward. This may be explained by the oblique impact hypothesis.

Our crustal thickness is affected by the assumed anor-thosite crustal density 2800 kg/m3. KAGUYA MI show-ed evidence of anorthosite in SPA (Ohtake et al., 2009). But spectral data of central peaks of craters inside SPA suggested the presence of px-rich impact melt sheet (Na-kamura et al., 2009). Then, higher crustal density would result in larger crustal thickness.

Since Bouguer anomaly is relatively flat in SPA, sur-face morphologies could be elastically supported. How-ever, there are overprinted small impact basins with gravity anomaly. We analyzed interior structure of small basins in and around SPA (Figure). We interpret that a positive gravity anomaly at the basin corresponds to a Moho uplift. There is a distinct mantle plug beneath Apollo. Just around the rim of SPA, obscure circular structure Amundsen-Ganswindt has a distinct Moho up-lift, suggesting a buried impact structure. A distinct Mo-ho uplift beneath Schrodinger corresponds to the presence of olivine at the central peak rings there (Ya-mamoto et al., 2010). In comparison between adjacent Poincare and Planck, older, less distinct Poincare shows stronger gravity anomaly. The observed anomaly corre-sponds to Type 2 like anomaly (Namiki et al., 2009), where a significant uplift at the center is probably due to overcompensation just after the impact. Basin structures in the central SPA show little gravity anomaly. Although it might be due to lower spatial resolution, there are sev-eral possibilities such as less density difference between crust and mantle and rapid relaxation of the uplift.

We use localized representation of gravity potential according to the Han (2008) where Slepian functions were used to estimate the gravity field over certain areas of the Moon. Then, we express the gravitational potential with localized spherical harmonics functions. We include data in a spherical cap area with a radius of 40 degree from the SPA center. This area is fully covered by 4-way Doppler tracking of KAGUYA. We obtained gravity adjustment about -70 to 50mGal in preliminary analysis (Goossens et al., in prep.). The revised gravity field would improve crustal thickness with slightly higher resolutions.

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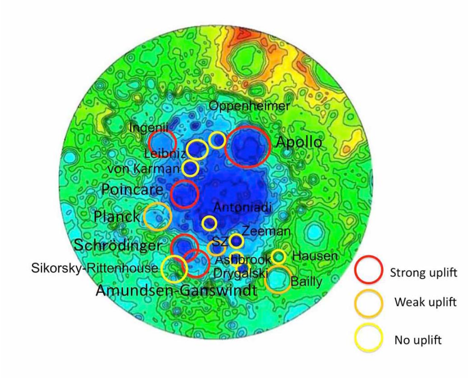

Keywords: Moon, gravity, crust, South Pole Aitken Basin, crater, impact

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PPS024-16 Room:103 Time:May 23 10:15-10:30

Concentrations of radioactive elements in the lunar crust constrained from relaxation of impact basins

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Concentrations of long-lived radioactive elements (Th, K, and U) are among the most important heat sources for the long-term thermal evolution of the Moon. These elements also tend to be concentrated in melt because these elements are incompatible elements. Thus, their distribution may reflect the solidification process of the lunar magma ocean (LMO). In order to understand such an early, pre-mare thermal evolution of the Moon, a detailed study of the lunar farside is necessary.

The lunar farside is geologically classified into the Farside Highland Terrane (FHT) and the South Pole-Aitken Terrane (SPAT), and the FHT is depleted in radioactive elements compared to the SPAT [e.g., 1]. Lunar topography and gravity field data indicate that crustal thickness at the FHT is ~70 km while that at the SPAT is ~30 km [2]. Based on these results, hypotheses have been proposed for spatial variation in concentrations of radioactive elements. One is that their concentrations in the FHT crust are much smaller than the SPAT crust. The other is that the SPAT crust is similar to lower part of the FHT crust [3]. Since the column density of radioactive elements are significantly different between two hypotheses, constraining concentrations of radioactive elements deep in the FHT crust is necessary to understand the lunar farside thermal history.

Rheology of the lunar crust and mantle strongly depends on temperature. Thus, long-term viscous relaxation of lunar major impact basins would reflect the upper part of the early Moon [4]. A Japanese lunar explorer KAGUYA revealed that no significant isostatic compensation occurred for many farside impact basins [5]. This result indicates that, at the timing of basin formation, the lunar Moho had been cold [5]. In this study, we constrain concentrations of radioactive elements, which are consistent with topography and gravity field data obtained by KAGUYA from thermal evolution calculation and viscoelastic deformation calculation.

We calculate thermal evolution and viscoelastic deformation independently. For the former calculation, we solve the thermal conduction equation, using the solidus of peridotite for the initial condition at 4.5 Ga. Here we only consider radiogenic heat for heat production. For the latter calculation, we use a time-integration scheme we developed recently in order to use time-dependent temperature profile calculated in thermal evolution calculation [6]. Parameters are concentrations of radioactive elements in the crust, crustal thickness, harmonic degree, and basin formation age. For each parameter setup, we calculate the time evolutions of surface and Moho topographies induced by a surface load and by a Moho load.

We compare our calculation results with KAGUYA topography data and a latest crustal thickness model [2], and estimate initial surface and Moho topographies of farside basins. We estimated the upper limit of the initial surface heat flux based on the requirement that crustal thickness should be non-negative. We found that the initial heat flux < 33 mW/m^2 is required for Freundlich-Sharonov (Crustal thickness ~67 km). The absolute age of Nectaris, which is fresher than Freundlich-Sharonov, is estimated to be 4.14-3.84 Ga. We found that Th < 0.5 ppm is necessary to satisfy the heat flux constrained from the non-negative crustal thickness requirement for formation age older than 3.84 Ga. This upper limit is much smaller than Th on the SPAT. Thus, the SPAT crust may be significantly different from the lower part of the FHT crust, suggesting regional variation in solidification processes of the LMO.

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Keywords: KAGUYA, Viscoelasticity, Impact basin

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PPS024-17 Room:103 Time:May 23 10:45-11:00

Study of the distribution of thorium on the lunar farside

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The abundance and the distribution of thorium on the lunar farside are important to investigate the lunar magma ocean and the influence of the Imbrium thorium-rich ejecta on the farside. The low thorium abundance on the lunar farside, typically less than 1 ppm, resulted in weak gamma-ray fluxes and thus it becomes relatively difficult to obtain the thorium map on the lunar farside by gamma-ray remote sensing method. We have analyzed the thorium distribution on the lunar farside by using Kaguya gamma-ray spectrometer (KGRS) that has the highest sensitivity among lunar gamma-ray spectrometers to date. In the presentation, we will mention the characteristics of thorium distribution on the lunar farside.

Keywords: gamma-ray spectrometer, Kaguya, SELENE, Thorium, lunar farside

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PPS024-18 Room:103 Time:May 23 11:00-11:15

Examination for Iron and Titanium Distributions on the Moon Observed by Kaguya Gamma-Ray Spectrometer

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The Kaguya Gamma-Ray Spectrometer (KGRS) was designed with a high-energy resolution to determine the lunar subsurface composition by observing gamma rays emitted from the Moon [1]. The absolute concentration maps of radioactive elements such as potassium, thorium and uranium were reported by successive KGRS data analysis [2, 3]. Preliminary results of iron and titanium maps have already been reported [e.g. 4]. Here, we report the progress made along the last year.

The iron and titanium maps were made by procedures similar to those in Lawrence et al. [5]. These maps are in good agreement with the Lunar Prospector maps reported by Prettyman et al. [6]. The relative concentration of iron in maria becomes lower in the order corresponding to Procellarum, Imbrium, Serenitatis, Fecunditatis, Nubium, Tranquillitatis, Crisium, South Pole-Aitken Terrane, Australe and Smythii. The titanium distribution is slightly different from that of iron. The titanium signature of Mare Tranquillitatis is higher than that of Procellarum and Imbrium. And, the relative concentrations of titanium in maria Fecunditatis, Crisium, South Pole-Aitken Terrane, Australe and Smythii are as low as that of highland regions.

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Keywords: Kaguya, GRS, Moon, Elemental map, Iron, Titanium

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PPS024-19 Room:103 Time:May 23 11:15-11:30

Validation of method for estimating abundance of FeO and TiO2 using kaguya (SELENE) Multi-band Imager data

arashi shirai[1*], Shoko Oshigami[1], Yasushi Yamaguchi[1], Makiko Ohtake[2], Noriyuki Namiki[3], Yuzuru Karouji[4]

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Understanding of elemental concentrations and its ratio on the Moon surface plays an important role to reveal a formation process of the Moon. Each mineral constituting a rock absorbs specific range of wavelengths and reflects light the rest. Especially, the colored mineral such as olivine, clinopyroxene and orthopyroxene absorbs visible and near-infraved band by Fe^{2+} containing in those minerals. Pevious studies aim to identify minerals from the feature of its reflectance spectrum observed by remote-senshing.

However, slope of the reflectance spectrum, absorption depth, and reflectivity change with progress of the space weathering generated by the cosmic ray radiations on the lunar surface. The degree of the space weathering is called "maturity". Several methods to eliminate influence of space weathering and estimate abundance of FeO and TiO_2 were developed from detailed studies of using a meteorite or the sample of the moon [e.g., Lucey et al. 1998., 2000]. These method are based on the following experiments with respect to FeO content : The ration of reflectance at 950nm (R_{950}) to that at 750nm (R_{750}), that is R_{950}/R_{750}, decrease as iron abundance in a mineral increases, while R_{950}/R_{750} increases and R_{750} decreases as maturity increases. As for the abundance of TiO_2, the algorithm is derived from the, relation between the ration of reflectance at 415nm (R_{415}) to R_{750} and R_{750}. However, various problems are pointed out. One of the problems is the possibility that effect of the space weathering is not completely isolated from FeO content in this method. Lucey et al. [1998] assume that a plot of R_{950}/R_{750} vs R_{750} concentrated into the optimized origin as space weathering advances for most minerals, but it is suggested that trends of constant iron but varying maturity are parallel than radial in the mare [Staid and Pieters et al., 2000]. Wilcox et al. [2005] provided a plot of R_{950}/R_{750} versus R_{750} through the study of about 10,000 craters in six mare regions using spectroscopic data of the Clementine. Their algorithm, derived from trends on the plot, better compensates for maturity and provides less uncertainties due to maturity variations than previous studies. However they did not consider the method for estimating TiO_2 content. In this study, kaguya Multi-band imager (MI) data of Humorum are used to review the method presented by Lucey et al. [1998] geological analysis as well as Wilcox et al. [2005].

Keywords: Multi band Imager, Mare Humorum

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PPS024-20 Room:103 Time:May 23 11:30-11:45

Compositional estimation of the lunar highland crust derived by the SELENE spectral data

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Global distribution of rocks of extremely high plagioclase abundance (approaching 100 vol%; called purest anorthosite (PAN)) was reported using an unambiguous plagioclase absorption band around 1250 nm found by the SELENE Multiband Imager (MI). The estimated plagioclase abundance is significantly higher than previous estimates of 82 to 92 vol%, providing a valuable constraint on models for lunar magma ocean evolution. Further study using continuous reflectance spectra derived by the SELENE Spectral Profiler (SP) revealed a global and common distribution of the PAN over the entire lunar surface, supporting the high abundance of PAN rocks within the upper crust.

In this study, we investigated a vertical compositional (modal abundance and/or mineral composition) trend of the PAN rocks within the crust using their reflectance spectra derived from SP and MI. Knowing the compositional trend of the lunar upper crust may enable us to understand the mechanism of the lunar crustal growth.

All of the SP data observed throughout SELENE mission periods were used in this study. The absorption depth at each wavelength was calculated after a linear continuum was removed. Spectra with the deepest absorption depth, around 1250 nm, which is caused by a minor amount of ferric Fe (in the order of 0.1 wt% FeO) contained in the plagioclase, were selected to detect the PAN rocks. To estimate modal abundance of each spectrum we used correlation of the absorption depth ratio of mafic minerals to plagioclase (900nm/1250 nm) to the crater diameter. Original burial depth of each outcrop was estimated from a crater scaling law using the crater diameter of each outcrop observed in MI data.

Results indicate that the majority of the derived absorption depth (strength) ratios (900/1250 nm) of the detected high plagioclase abundance anorthosite rock spectra appear to form a trend which increases as their estimated original burial depths increase within the crust (the trend is observed up to 30 km of the original burial depth).

Although understanding the actual cause of this trend requires further studies, such a trend may indicate a decrease in the mafic mineral abundance within the already very mafic-poor rock and/or an increase in the ferric Fe content of plagioclase with depth.

Keywords: SELENE, lunar exploration, highland crust, magma ocean

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PPS024-21 Room:103 Time:May 23 11:45-12:00

Modes of convective flow through deformable porous media,implication for lunar crust formation

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Modes of convective flow through deformable porous media,implication for lunar crust formation Existence of pure anorthite crust on the Moon as revealed by KAGUYA mission(0htake et al, Science 2010) indicates not only intensive floatation of plagioclase in the lunar magma ocean but further completion of compaction from the state of crystal mush. The time scale of this compaction process should control chemical composition of the anorthositic crust. The initial state of floating anorthosite aggregates is expected to be a kind of random close packing of crystals, which means melt phase should be included at about 30% vol. in the case of homogeneous grain size. During this stage fluid migration through crystal aggregate occurs extensively. Although this process has been conventionally modeled as fluid flow through porous media and convection in permeable flow and the time scale of fluid migration is estimated based on porous flow model, an important difference exists between rigid frame model and the lunar protocrust. In the lunar case porous frame which is constructed of plagioclase crystals should be deformable and it is slowly compacting so that the interstitial melt is finally squeezed out. Motivated by this difference we focus on the significance of deformability of porous frame in the convective flow through porous media. In this presentation we report on laboratory experiments which compare style of convective fluid flow in porous media between deformable frame and rigid one. As the rigid case glass beads are used for the porous frame whose grain size is 0.4mm to 3mm. To check density difference between solid and liquid(aqueous solutions) styrene beads(0.5-2 mm in diameter) are also used. As the deformable case soft gel such as agar and hydrogel is used. To see the difference in flow style we have conducted thermal convection experiments by using localized heat source at the base of experimental tank. Since the porous media is not transparent enough to allow optical inspection of fluid flow such as PIV we measured temperature at several points around the heater in vertical and horizontal directions. We observed localization of high temperature above the heater,which reflects convective flow induced by localized heat source. In the case of deformable frame not only the fluid but solid grains also exhibit slow migration in consistent with the convective flow. This induces rearrangement of particles, which should enhance effective compaction and efficient squeeze-out of melt phase.

Keywords: Convective flow in a fluid in a porous medium

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PPS024-22 Room:103 Time:May 23 12:00-12:15

Crustal materials in Procerallum KREEP Terrain

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Aristillus crater is located in Mare Imbrium, and is considered to probably show essential nature of Procerallum KREEP Terrain (PKT) (Jolliff et al., 2000). In this presentation, geological and petrological analysis for interior of the Aristillus crater were conducted, and crustal materials and its spatial structure of the PKT are discussed as compared with other craters in the PKT.

Keywords: Moon, Kaguya, crust, early differentiation, PKT, differentiation

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PPS024-23 Room:103 Time:May 23 12:15-12:30

Occurrence and origin of lunar troctolitic crust

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Lunar feldspathic crust is considered to be a product of a primordial magma ocean crystallization. Mineral distribution in the lunar crust provides us with keys to understand the chemical composition and the mode of crystallization of a lunar magma ocean. Mineralogical studies of feldspathic lunar meteorites show that low-Ca pyroxenes are likely the secondary product after olivine and plagioclase crystallized from a magma. The fact suggests that plagioclase and olivine are the two dominant minerals in the initial crust which formed by a magma ocean crystallization, but low-Ca pyroxene is not a direct product from a magma ocean. If that is a case, a magma ocean composition needs to be more aluminous than that previously estimated by a factor of two or three. Replacement of the primary olivines by low-Ca pyroxenes during the secondary heating events after the magma ocean solidification may have altered an initial abundance of olivine in the primary crust. Lower detectability of olivine than low-Ca pyroxene in the reflectance spectra observation may further bias the real abundance of olivine in the present lunar crust. Here, we discuss an occurrence and origin of the troctolitic crust of the Moon, on the basis of analyses of the Kaguya MI/SP data and mineralogical and spectroscopic analyses of troctolite clasts in the lunar meteorites.

Keywords: Moon, Crust, Troctolite, Magma Ocean

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(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS024-24 Room:103 Time:May 23 12:30-12:45

Constraints on FeO and refractory element contents of lunar Magma Ocean from conditions of crust formation

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The lunar highland crust is composed of purely anorthosite with tens of kilometers thick, and would be formed by the crystallization and flotation of anorthite from a global lunar magma ocean (LMO). The chemical composition, depth, and the actual differentiation mechanisms of LMO are still debated, although there are many previous studies. The FeO and refractory element (Al_2O_3 and CaO) contents of LMO are especially important due to the strong influence on the composition and the physical properties of the melt, and the amount of anorthite and other minerals crystallized in the cooling LMO. The purpose of this study is to constrain on the FeO and refractory element contents of the initial LMO consistent with the conditions of lunar crust formation.

At first, we assumed the bulk composition of the initial LMO varying FeO and refractory element contents and the differentiation mode varying the efficiency of crystal separation. Then we determined the composition of the LMO at the anorthite appearance by thermo dynamical calculations with MELTS/pMELTS. Finally, it is evaluated whether these results satisfy the following conditions: (1) the amount of crystallized anorthite enough to form the crust with the average thickness (~45 km), (2) the observed pyroxene composition of lunar highland crust, and (3) anorthite flotation in turbulent LMO at time of the anorthite appearance.

In present study, the compositional range considered was the FeO content by 0.5-2.5 times of BSE and the refractory element (Al2O3 and CaO) contents by 1.0-2.5 times of BSE. The mass balance evaluation of the amount of crystallized anorthite concluded that the crust with current thickness of the Moon could be formed from the FeO-enrichment of <2.3x and refractory element-enrichment of <2.0x composition. The mineralogical evaluation on pyroxene concluded that, if the refractory element contents are low (~1.0x), the extremely FeO-rich (>1.5x) initial composition does not reproduce pyroxene of which composition is consistent with that of lunar crustal samples. The fluid dynamic evaluation of anorthite flotation in turbulent LMO concluded that an anorthite crystal could float and separate in the initial composition with FeO-enrichment (>1.5x) due to the high density and the low viscosity of melt, regardless of the refractory element contents and the differentiation mode.

The present study shows the important conclusion that the FeO content of the initial LMO was comparable or higher than the BSE. This conclusion suggested the several possibilities: (1) the impactor object for the giant impact event of the Earth and Moon system originally had higher FeO content than BSE and/or (2) the oxygen fugacity of the LMO was higher than BSE for some reasons. More rigorous model with the detailed consideration on physics and chemistry of magma ocean processes of the cooling LMO based on the present study may give implication for the origin and evolution of the Moon.

Keywords: bulk composition of Moon, lunar magma ocean, anorthosite crust, differentiation, physical properties of magma, piston-cylinder experiments

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PPS024-25 Room:103 Time:May 23 14:15-14:30

A new analysis method for the reflectance spectra of silicates using Bayesian estimation

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Introduction: Visible and near infrared (VNIR) reflectance spectroscopy is a very powerful tool to observe planetary surfaces remotely and has revealed a wide variety of information on planetary surfaces [e.g., 1]. Because silicates often exhibit overlapped absorption bands in the VNIR range, they are often deconvolved into multiple simple bands for quantitative analyses.

Conventional MGM Algorithm: One simple approach would be to search for the optimum combination of simple bands that minimize the difference between observed and synthetic spectra by trying every possible parameter set. However, a direct search is usually impractical because it requires an astronomical number of trials. Thus, a more efficient mathematical method is necessary. In previous studies, the steepest descent method has been used frequently to resolve this problem, but this method is not necessarily good at finding the global minimum of a complex function with many local minima. Depending on the initial choice of parameters, an obtained result may be just a local minimum. Furthermore, this mathematical procedure needs to know how many model parameters (e.g., the number of Gaussians for MGM) should be used before the analysis. Generally, a fitting with more Gaussians will lead to a smaller error, but the complexity of the synthetics may become too large (e.g., over fitting).

New MGM Algorithm: In order to resolve these problems, we derived a new MGM algorithm using a Bayesian estimation approach, the exchange Monte Carlo (EMC) method, and the annealing method in this study. The mathematical details and numerical validation of the algorithm used in this study are given by [2,3].

Validation Analyses: In order to examine the validity and applicability of the new MGM algorithm proposed in this study, we conducted actual spectral deconvolution analyses using a series of reflectance spectra, olivine powder samples with different Mg/(Mg+Fe) ratios (mg#) and olivine-pyroxene mixtures with different mixing ratios

The results of our new MGM method indicate that the optimum number of Gaussian bands to reproduce the complex absorption band around 1 micron predicted is three for the reflectance spectra of all the olivine samples. This optimum number is the same as the number estimated empirically by [4]. Furthermore, the trends of the central wavelengths of individual bands band widths and the relative intensities of the three individual bands as functions of mg# are very similar to the results by a conventional MGM [4]. These agreements support that the results of these MGM analyses are not specific to particular datasets or analytical methods but reflect the intrinsic optical properties of olivine.

Though not all Gaussians are detected, most of the deconvolved Gaussians are close to one of the Gaussians of the end-member samples. This will allow us to identify the mineral components within such mixtures. In particular, the bands around 1.2 and 1.03 micron in the mixtures of olivine can be detected when its mixing ratio is as low as 25%.

Conclusion: The above results along with the intrinsic properties of the new algorithm (e.g., little dependence on initial parameter value selection and the capability of finding the optimum number of Gaussians) suggest that method would be appropriate for automated analyses and greatly expand the applicability of MGM greatly, particularly for large volume of spectral datasets obtained for Moon.

References: [1] Pieters, C.M. and P.A.J. Englert (1993) Remote geochemical analysis: Elemental and mineralogical composition; [2] Nagata, K. et al. (2011) Neural Networks, submitted. [3] Sugita, S. et al. (2011) JGR, to be submitted. [4] Sunshine, J.M. and C.M. Pieters (1998) JGR, 103, 13,675.

Keywords: Reflectance spectroscopy, Remote sensing, Bayesian estimation, Moon, Modified Gaussian method

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PPS024-26 Room:103 Time:May 23 14:30-14:45

Present status of next lunar landing mission SELENE-2

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SELENE-II lunar landing mission is one of the series of the Japanese lunar exploration program of the next two decades. A pre-project team has established in 2007(Phase-A) and the launch is scheduled in the mid-2010s. We report our up-dated status of the science aspects.

The main progress, so far, is significant advance of technological development of the candidate instruments. Especially, we obtained a clear vision of the thermal design of each instrument under sever temperature condition on the Moon. At present, six instruments out of 12 candidates were selected as "prior instruments" judging from both technical readiness and science significance. In addition, several instruments for future utilization and for outreach use have been also developed progressively.

Making an excellent science scenario (objectives) under restricted condition is also an important issue. In order to do this, the science review board by the ISAS space science committee members was established in September 2009, and the review board has been almost finished and highly valued to promote the lunar science.

The science achievement is obviously dependent on the landing site. The landing site selection has been aggressively discussed by the "Landing Site Selection Working Team", which was established in May 2010. The first draft of the result will be reported by the end of March 2011.

As of now, SELENE-II mission team is elaborating a "realistic" proposal from the viewpoints of both technological readiness and severe financial condition. We also introduce our strategy and perspectives to overcome these difficult problems to be solved.

Keywords: Moon, landing mission, lunar exploration, SELENE-2, science instruments

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PPS024-27 Room:103 Time:May 23 14:45-15:00

SELENE-2 Lunar BroadBand Seismometer: A key instrument to open a new window of lunar science

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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 and its scientific targets inspired by the results of the Apollo's passive seismic experiment. 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 shallow 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: moonquake, broadband seismometer, core, crust, lunar exploration, internal structure

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PPS024-28 Room:103 Time:May 23 15:00-15:15

SELENE-2/VLBI mission for study of lunar deep internal structure

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VLBI (Very Long Baseline Interferometry) radio sources were on board the SELENE two sub-satellites, Rstar and Vstar. The radio waves from the radio sources (called VRAD) were received at multiple ground stations which forms a type of tracking data, i.e. delay in arrival times of the wave of a radio source at two different stations forming a baseline carries information about the angular position of the radio source. Differential VLBI data between Rstar and Vstar, when both the radio sources were within the beam width of the ground antennas, were of particular importance because they are highly accurate with atmospheric and ionospheric disturbances almost cancelled out by the simultaneous observation. Such tracking data, i.e. "same-beam differential VLBI data" were used to develop an improved lunar gravity field model SGM100i [1].

The Japanese future lunar mission SELENE-2 will carry both a lander and an orbiter. We propose to put the VRAD-type radio sources to these spacecraft in order to accurately estimate lunar potential Love number k2 and low-degree gravity coefficients through precision orbit determination of the orbiter with respect to the lander by using the same-beam VLBI tracking technique. We also propose a new type of observation called inverse VLBI [2] in order to further improve the k2 estimate. The same-beam VLBI observation is only possible when the separation angle between the two radio sources is smaller than the beam width of the ground antennas. The relatively large shape of Rstar's orbit (100 km x 2400 km) did not allow the same-beam observation all the time, but the situation can be improved by adequately setting the orbit. For example, the Vstar-like orbit (100 km x 800 km) will almost always keep the separation angle smaller than the S-band beam width of domestic VERA stations since one of the radio sources is fixed on the near-side lunar surface.

A preliminary simulation study has been conducted under the condition of 2-week arc length, 12-week mission length, 6 hours/day 2-way Doppler observation plus S-band same-beam VLBI observation with the 4 VERA stations. The k2 uncertainty is evaluated as 10 times the formal error considering the errors in solar radiation pressure modeling and in lander position. The results show that, when combined with the historical tracking data including SELENE and when the orbiter inclination was 90 degrees, the k2 uncertainty is below 1 percent.

The potential Love number k2, together with displacement Love number h2, lunar mass, and lunar moment of inertia can constrain lunar interior properties such as radial profiles for density and shear modulus. The size and state of the core (liquid or solid) are of particular interest. The Love number h2 is obtained from lunar laser ranging (LLR) data, the mass is obtained from satellite tracking data, and moment of inertia is obtained from combination of LLR-based estimates of dynamical flattening and satellite-based 2nd degree gravity coefficients. Lunar Broad Band Seismometer (LBBS) will detect layer boundaries. We will discuss how well the internal properties can be inferred from the above-mentioned four parameters which will be improved by SELENE-2. We will also discuss the possible synergy of combining VLBI, LLR and LBBS data.

References: [1] Goossens et al., Journal of Geodesy, in press. [2] Kawano et al., Journal of Geodetic Society of Japan, 45, 181-203, 1999.

Keywords: Moon, SELENE-2, VLBI, artificial satellite tracking, gravity field, tidal Love number

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PPS024-29 Room:103 Time:May 23 15:15-15:30

Lunar Laser Ranging Experiment in SELENE2

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We present the development status of Lunar Laser Ranging experiment proposed to SELENE-2 landing mission. The Lunar Laser Ranging (hereafter referred to as LLR) measures the distance between laser link stations on the Earth and retroreflectors on the Moon, by detecting the time of flight of photons of high-powered laser from the ground laser stations. Since the Earth-Moon distance contains information of lunar orbit, lunar solid tides, and lunar rotation, we can estimate the inner structure of the Moon through rotation and tide. The ranges have been obtained since 1970's, when the Apollo and Luna mission put five retroreflectors on the Moon (Apollo 11, 14, 15, Lunakhod 1 and 2). The Lunakhod 1 had been lost for decades, but the LRO mission found it and the Apache Point Observatory in New Mexico, U.S.A., successfully ranged it on March 2010.

The retroreflector arrays of Apollo missions contain 100 (Apollo 11 and 14) or 300 (Apollo15) prism-type corner cube retroreflectors with diameter of 3.8 cm, mainly due to the thermal design. Because of the tilt of the retroreflector arrays from the Earth direction due to the optical libration, the returned laser pulse is broadened, causing the main range error of more than 1.5 cm per photon ([1]). Therefore the sub-cm accuracy is achieved only by the statistical manner, namely by accumulating photons within about less than 20 minutes to make one range (normal point). We propose a large single retroreflector of hollow-type so that a single shot accuracy could become sub-cm. Otsubo et al ([2]) showed that a retroreflector of 20cm diameter with appropriate dihedral angle reflects photons of 1.5 fold of Apollo 11. Moreover, optimization of three dihedral angles can result in more photons ([3]). Since the accuracy of 0.1 arcseconds is needed as the dihedral angle, the fabrication precision and the thermal stability is under study. Also, a new retroreflector in the southern hemisphere of the Moon will enlarge the retroreflector network on the Moon for better estimation of the lunar rotation and tides.

We plan to range the Moon from a Japanese ground station. Currently only two laser link stations in the United States and France range the Moon. However, because these telescopes are used as astronomical or satellite laser ranging facilities as well, the amount of LLR data are limited. Therefore new ground stations are needed to obtain more LLR range data for better estimation of the internal structure of the Moon. The 1.5 m telescope at NICT-Koganei, which is dedicated to satellite laser ranging, will be upgraded so that it can transmit high-powered laser with relatively longer pulse width (nanosecond) for the detection of returns from the Moon within several years. Within longer time span, we also plan to build a new laser station in a place like Okayama where the best seeing is available in Japan and to develop the adaptive optics for uplink laser ([4]).

[1] Murphy et al., 2008, PAPS, vol 120, pp. 20-37. [2] Otsubo et al., 2010, Adv. Space Res., vol 45, pp 733-740. [3] Otsubo, Geod. Soc, of Japan, 2010 Fall Meeting. [4] Kunimori, Geod. Soc, of Japan, 2010 Fall Meeting.

Keywords: Moon, selenodesy, lunar exploration, SELENE2, LLR

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PPS024-30 Room:103 Time:May 23 15:30-15:45

A current status of Lunar ElectroMagnetic Sounder (LEMS) proposed in the SELENE-2 mission

Masaki Matsushima[1*], Hisayoshi Shimizu[2], Hiroaki TOH[3], Ryokei Yoshimura[4], Futoshi Takahashi[1], Hideo Tsunakawa[1], Hidetoshi Shibuya[5], Ayako Matsuoka[6], Hirokuni Oda[7], Yuichi Iijima[6], Kazunori Ogawa[6], Satoshi Tanaka[6]

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Information of the internal structure of the Moon is a key issue to understand the lunar origin and evolution. Heat-flux, seismic, and magnetic field measurements made in the Apollo mission enabled us to estimate a thermal structure, an elastic structure, and an electric structure of the lunar interior, respectively. The electrical conductivity structure, which is independent of the elastic structure, is therefore important to give a crucial constraint on the lunar origin and evolution. Because of the low sampling frequency at which magnetic field data were obtained in the Apollo mission, estimates of the electrical conductivity contain significant ambiguity, larger than two orders of magnitude, for the outermost few hundred kilometers of the Moon. It is necessary to carry out electromagnetic sounding of the Moon at higher frequencies than before to accurately probe the shallow lunar interior.

In the SELENE-2 mission, 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. We measure the primary magnetic field by two triaxial fluxgate magnetometers onboard a lunar orbiter and the primary plus secondary fields by two triaxial fluxgate magnetometers onboard a lunar survival module, which is a thermal control system for long-time scientific measurements under a temperature condition being variable in a very wide range at the lunar surface. Dual magnetometer technique is to be utilized to avoid strict electromagnetic compatibility requirements like those for the Kaguya spacecraft. Here we present a current status of the LEMS mission, such as its design, its development, and some results of feasibility studies on the lunar electromagnetic sounding.

Keywords: SELENE-2, electromagnetic sounding, lunar interior

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PPS024-31 Room:103 Time:May 23 15:45-16:00

Lunar Surface Heat Flow Measurement in SELENE-2 Mission

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We are planning to operate a Heat Flow Probe system in the SELENE-2 mission. It measures temperature and thermal conductivities at several depths in the lunar subsurface layer to determine the heat flow with around 10% accuracy. The potential drilling/sensing instrument is the HP^3 (Heat flow and Physical Properties Package) developed by DLR, Germany. The HP^3 is an instrument originally designed for the Exo-Mars mission by ESA. We are planning to achieve long-term observations including lunar nighttime by loading the HP^3 into the Japanese survival system to be deployed on the Moon.

The heat flow measurement in planetary surface layer is a method to directly estimate an amount of the interior heat generation. In case of the Moon, the only internal heat source would be radioisotopes, whose bulk quantity and distribution are essential for determining lunar origin and its thermal history. In fact, pioneering in-situ measurements were conducted in the Apollo 15 and 17 missions. However, past studies have obtained the heat flow values only with large uncertainties due to the heterogeneous subsurface structure around the landing sites, regolith disruptions during the drilling process for inserting the probes, and possibly a secular drift of insolation durations. A high accuracy and reliable measurement of the heat flow is mandatory for precise discussions of the lunar geological issues.

The lunar subsurface layer has also recorded solar irradiance variation in past a few hundred years as temperature profile. History of solar irradiance is essential for constructing and validating climate models and future climate projections. For example, small temperature disturbances within several meters depth reveal the total solar flux during the low solar activity period in AD 1600-1700 when observational data are not available.

Keywords: heat flow, lunar exploration, SELENE-2

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PPS024-32 Room:103 Time:May 23 16:00-16:15

Lunar Dust Monitor for the orbiter of the next Japanese lunar mission SELENE2.

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Lunar Dust Monitor (LDM) is proposed to be onboard the orbiter of the next Japanese lunar mission SELENE2, which is planned to launch in mid 2010s. LDM has a large sensitive area for a quantitative study of the comic dusts observed in lunar orbit according to its concept design.

Dust particles around the Moon include interplanetary dusts, beta meteoroids, the interstellar dust, and possibly lunar dust that originated from the subsurface materials of the Moon. However there has been no quantitative observation data that shows their percentage. It has been said that tens of thousands of tons of the dust particles per a year flow into the Moon. Some of them have impact velocities enough to vaporize the lunar soil. The vaporization of ferrous surface silicate soils forms nanophase metallic iron particles glassy coat, which causes the space weathering of the lunar surface. Thus, the dust particle is an important component from the viewpoint of the Moon evolution.

LDM has performance following features: (1) LDM can observe the dust particle with quite the same orbital speed as the earth thanks to the observation on the lunar orbit, (2) LDM can prevent the solar wind plasma from inflowing to the detector inside owing to a reflector, and consequently, the generation of background noises and spurious signals can be suppressed, and (3) because the speeds of incident dust particles are measured with TOF using two grids inside the LDM sensor box, the speed can be measured with a high accuracy of 10% even for such low-speed particles as ones that is hardly detected by past impact ionization detectors. If the proposal is accepted, LDM will observe hundreds of dust particles in lunar orbit for nominsl mission life of one year. Using the observation data, the origin can be identified according to their trajectories (eccentricity and tilt angle), masses and so on.

In this paper, we summarize the significance of cosmic dust observation at 1 AU and report predicted results of the LDM.

Keywords: Cosmic dust, Lunar orbit, in-situ observation, SELENE2, Interplanetary dust, Impact ionization dust detector

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PPS024-33 Room:103 Time:May 23 16:30-16:45

Scientific goals and instrument specification of a proposed macro imager for the SELENE-2 mission

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SELENE-2, the next Japanese lunar mission, is being planned by the Japan Aerospace Exploration Agency (JAXA). SELENE-2 consists of an orbiter, a lander, and a rover, but mission details, such as landing sites and instruments, are still being discussed. Our team proposed a hyper-spectral macro camera, the Lunar Macro Imager (LUMI), for the SELENE-2 mission to investigate spectral characteristics and texture of polished rock samples on the Moon.

The objective of our observation is to measure the actual modal abundance and composition of each mineral species of purest anorthosite (PAN) rock, which has recently been detected from remote-sensing data acquired by the SELENE (Kaguya) Multi-band Imager. In addition to the modal abundance and composition, we are going to observe mineralogical texture (grain size and distribution of each mineral species) of the rock that reflects their thermal and pressure histories. The mineralogical texture is also enables us to estimate composition (Fe content) of the lunar magma ocean. We focus on PAN rocks because they are possibly crustal material crystallized directly from a magma ocean on the Moon.

To achieve these objectives, we designed our instrument to obtain hyper-spectral images in wavelengths ranging from 750 nm to 1700 nm. The spatial resolutions of our cameras are 20 micron /pixel with a SN exceeding 100 (we estimated the SN of our instrument under realistic temperature conditions).

Keywords: SELENE-2, macro imager, highland crust, magma ocean

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PPS024-34 Room:103 Time:May 23 16:45-17:00

Development and scientific objectives of Lunar Multiband Camera System (LMUCS)

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Lunar Multiband Camera System (LMUCS) has been designed for a future lunar landing mission, SELENE-2. The LMUCS is a filter-wheel type multiband camera mounted on a rover with gimbals for control of elevation and azimuth line-of-sight directions. In this presentation, scientific objectives and a result of conceptual design of the LMUCS are discussed.

Keywords: Moon, surface exploration, crust, rover, SELENE-2, Lander

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PPS024-35 Room:103 Time:May 23 17:00-17:15

Elemental analysis of the lunar surface rocks and regolith by Gamma-ray/Neutron Spectrometer (GNS) for SELENE-2

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We have proposed a gamma-ray/neutron spectrometer system (GNS) to analyze elemental abundance of the lunar surface rocks and regolith for SELENE-2 mission. The GNS primarily analyzes K, Th and U abundances of the lunar surface and also can measure Fe and possibly other major elements. In the presentation, we will summarize the scientific objectives and the design and the current status of GNS. The significance of the GNS mission is briefly mentioned here.

K, Th and U are distinctive elements in geochemistry because of their moderately volatility or refractory, incompatibility and radioactivity. Thus, the abundance of K, Th and U in the lunar crust and mantle is the key to address the important issues related to the origin and evolution of the Moon, such as bulk lunar chemistry, crystallization of lunar magma ocean, volcanic activity etc [J.J. Gillis et al. JGR 2004, S. Kobayashi et al., Abstract for 42th LPSC (2011) 1721]. In addition, K, Th and U are symbolic elements on the Moon because it represents the lunar dichotomy (See attached figure, Th map obtained by Kaguya gamma-ray spectrometer)?the western hemisphere of the nearside called Procellarum KREEP Terrain (PKT) is considerably enriched in Th, whereas the other region, Feldspathic Highland Terrain (FHT) is extremely depleted in it [B.L. Jolliff et al. JGR (2000)]. It is important to know where and how much K, Th and U are concentrated on the Moon

The gamma-ray remote sensing has the limitation of the spatial resolution, which seems to be currently at best 40 km by applying an image deconvolution analysis [e.g. D.J. Lawrence et al. GRL (2008)]. Thus, we still have not known the abundance and the distribution of K, Th and U within small, but geologically distinctive regions, such as crater floors (˜ dozens of km), central peaks (˜ several km) and domes (˜ dozens of km), even though we have lunar samples of Apollo and Luna mission, lunar meteorites and enormous remote sensing data. Further the local variation of K, Th and U abundances on FHT where we have never explored by landing mission is also unknown. The investigation of a local geology by the GNS would yield meaningful and new scientific data

The local geology is important now that we have the global K, Th and U map at our hands. Our scientific objectives, although they depend on the landing site of SELENE-2 that has not determined currently, are as follows:

(1) To investigate the elemental abundance of K, Th and U of the deep crust of PKT by exploring a crater with high/low Th feature within PKT to restrict the models of the lunar thermal history, the formation of PKT and the bulk chemistry of the Moon [S. Kobayashi et al., Abstract for 42th LPSC (2011) 1721, Y. Karouji, Proposal documents for SELENE2 landing site (2010) #21, #22].

(2) To know the lower limit of Th abundance and elemental abundance of major elements (e.g. Mg#) of rocks and regolith on the lunar surface within FHT to limit the model of the lunar magma ocean [H. Takeda et al. in this session].

(3) To understand comprehensively the variety of lunar volcanism by exploring silicic, nonmare, volcanic constructs, such as Hansteen Alpha, where K, Th and U are considered to be highly concentrated [T. Arai, Proposal documents for SELENE2 landing site (2010) #34].

Keywords: gamma-ray spectrometer, neutron spectrometer, SELENE2

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Landing site recommendation for SELENE-2

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SELENE-2 is the next Japanese lunar exploration project that is planned to be launched by the end of fiscal year 2015. In order to select landing site candidates which make the scientific return from the project plentiful, the SELENE-2 pre-project team call for members of "SELENE-2 Landing Site Research Board" and the board was organized in March, 2010 as one of the sub-teams of the JAXA SELENE-2 pre-project team. The board called for scientific proposals with landing site candidates from domestic researchers who are interested in lunar science and the members of the Japanese Society for Planetary Sciences, Japan Association of Mineralogical Sciences, the Geochemical Society of Japan, Seismological Society of Japan, and the Geodetic Society of Japan, etc. Finally, we have 35 scientific proposals with over 70 landing site candidates submitted from 21 groups. We discussed what the scientific targets of SELENE-2 should be and evaluated the proposals based on the targets. In our presentation, we will propose several model missions with a landing site which can be the scientific exploration of the highest priority today and the grounds of the selection.

Keywords: moon, Moon exploration, lander, landing site, SELENE-2, rover

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PPS024-37 Room:103 Time:May 23 17:30-17:45

Diversity of anorthositic highland crusts and exploration of the northern region of the Bailly basin

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Mineralogical studies of lunar meteorites of the Dhofar 489 group (e.g., Dhofar 489, 908, and 307) and Yamato (Y-) 86032, all possibly from the farside highlands, and reexamination of the Apollo anorthositic samples (FAN), revealed that mafic silicates show diversity of Mg numbers and large plagioclase crystals with minor mafic silicates are common [1,2]. Ohtake et al. [3] observed by the Kaguya multiband imager and spectral profiler, anorthosites composed of nearly pure anorthite (PAN) at numerous locations in the farside highlands. More olivine fragments are found in the matrices of the Dhofar 489 group (e.g., Dhofar 307, 309, 489, 908 etc.). Anorthositic clasts are major clasts in both groups, but more magnesian anorthosites are present in the Dhofar 489 group [2]. In conjunction with their low-Th concentrations, we proposed that the Dhofar 489 group may have been originated form some farside basins with the lowest Th concentration of the eariest crust of the Moon.

Based on the Th map made by the GRS group, Kobayashi et al. [4] showed the lowest Th zone surrounding SPA, including regions distributed north of the farside equator. This region of the lower-Th FHT, which extends from north of Dirichlet-Jackson (D-J) basin, to Hertzsprung and to the West of the Orientale basin, may represent the earliest and thickest anorthositic crust of the Moon. This lowest Th region extend to the nearside, north of the Bailly basin. We examined possible landing sites of the future lunar mission based on these maps. Bidirectional UV-visible-NIR diffuse reflectance spectra of NWA 482, Dho 307, Dho 911 and 60015 were obtained using a reflectance spectrometer at Brown Universikty.

Nyquist et al. [5] performed Sm-Nd and Ar-Ar studies of pristine ferroan anorthosites (FANs) of the returned Apollo samples and of Dhofar 908 and 489, and discussed implications for lunar crustal history. The pyroxene composition diagrams for 60025 in the new database show that the compositional range of 60025 pyroxenes is rather large for a pristine rock. In contrast, the 60015 FAN shows only a single tie line, but the sample does not show pristine crystalline textures. One simple explanation for the wide range of pyroxene compositions is a genomict breccia model, but in the LMO model it is not easy to postulate simple differentiation processes [1].

Haruyama et al. [6] made a large scale mosaic map of the region north of the Bailly basin similar to the D-J basin. Based on the Th map and this TC map, we propose that the highland plain between Pingre crater and Zuccherius crater is a good place to land to examine the region similar to the farside highland. In conjunction with such new observation, we also have to speculate a model in which the old lunar magma ocean (LMO) model could not explain the origin of the earliest crust. In order to explain diversity of the anorthositc rocks, we may have to invoke a model, in which trapped liquid grains with different Mg numbers are distributed along the grain boundaries of large plagioclase crystals. If we pick up an aggregate of only such large plagioclase crystals without mafic silicates at grain boundaries, it may represent a PAN common for both near and farside. Addition of a minor magnesian olivine may produce the magnesian anothosites observed in the Dho 489 group. In order to explain the formation of both FANs and the farside anorthosites, we may have to also invoke a convection model for the LMO [7].

References: [1] Takeda H. et al. 2011, abstract of 5th Kaguya (SELENE) Science Working Team Meeting, Waseda, Tokyo. [2] Takeda H. et al. 2006. Earth & Planetary Science Letters 247:171-184. [3] Ohtake M. et al. 2009. Nature 461:236-240. [4] Kobayasi S. et al. (2009) LPS 41, this volume. [5] Nyquist L. E. et al. (2011) NLSI Workshop, submitted. [6] Haruyama J. et al. (2008) Earth Planets Space 60, 243-256. [7] Loper D. E. and Werner C. L., Journ. of Geophys. Res., 107 (2002) 13-1-7.

Keywords: Lunar farside, basin, lunar meteorites, Plagioclase, Anorthosite, Bailly Basin

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PPS024-38 Room:103 Time:May 23 17:45-18:00

Lunar hole-structures as candidates of future lunar landing projects

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SELENE Terrain Camera discovered three huge hole-structures exceeding several ten meter diameters and depths on the Moon, which may be associated with underlying lava tubes. These lunar hole-structures and lunar lava tubes are possible targets of future lunar landing missions.

Keywords: Moon, hole, lava tube, SELENE, Kaguya, exploration

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PPS024-39 Room:103 Time:May 23 18:00-18:15

Investigation of lunar crustal structure in future lunar seismic experiments

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The internal structure and the thickness of the lunar crust are important parameters to understand the lunar differentiation process and the material distribution in the Moon. The recent analysis of Kaguya gravity data have indicated that the lunar crust could have horizontal heterogeneity of its interior and thickness on global scale (e.g.,Namiki et al.,2009,Ishihara et al.,2009). On the other hand, the observation of the seismic phases which pass through the lunar crust and the crust-mantle boundary can give good information about material distribution in the lunar crust and calibration points of crustal thickness to estimate the global thickness from analysis of the gravity data. Currently, deployment of new high-performance broadband seismometers on the lunar surface is planned in Japan, USA, and Europa and so on. This broadband seismometer has sufficient performance to detect seismic phases more clearly compared with past Apollo lunar seismometers. Using this seismometer, we will be able to decide the lunar crustal structure with better accuracy and derive the better estimation of the global crustal thickness combined with Kaguya gravity data in the future lunar seismic missions.

In this study, I have evaluated number of detection of lunar seismic events using the broadband seismometer and compared accuracy of determination of the lunar crustal structure derived from analysis of the new events with those of Apollo seismic experiments. Among Apollo seismic data, waveforms of artificial impacts and meteoroid impacts occurred on the lunar surface have been main events to investigate the lunar crustal structure. I, therefore, evaluated the number of meteoroid impacts can be located by the broadband seismometer using a meteoroid impact list based on a meteoroid mass-flux. In addition, an investigation of the lunar crustal structure using the meteoroid impacts whose locations and origin times are decided from detection of impact flashes by the ground observation is supposed. In this case, we can obtain the information about the lunar crust from analysis of the seismic events detected at only one station. We have also calculated the number of the meteoroid impacts can be located from ground observation using an ephemeris and the number of the events can be detected by the broadband seismometer among the ground-observed impacts.

The number of detected meteoroid impacts and the accuracy of determination of the internal structure derived from analysis of the impact events depend on the geometry of the seismic network. For the reason, we searched the optimized seismic network composed from a few seismometers to locate the meteoroid impacts and determine the internal structure and the thickness of the lunar crust with best accuracy using the method developed by (Yamada et al., 2010). In this presentation, I will report the scientific gains related with the lunar crustal structure derived from seismic observation on the optimized network. Then, some appropriate locations for deployment of the seismometer to obtain the important knowledge of the lunar crust will be discussed based on our and previous results.

Keywords: Lunar exploration, Lunar crust, Seismic observation, Meteoroid impact, Detection of impact flash, Design of seismic network

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PPS024-40 Room:103 Time:May 23 18:15-18:30

Technical readiness of lunar penetrator and its application to future lunar exploration

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The scientific objective of the former LUNAR-A penetrator mission was to explore the lunar interior by seismic and heat-flow experiments. Two penetrators containing two-component seismometer and heat-flow probes would be deployed from a spacecraft onto the lunar surface, one on the nearside and the other on the farside of the moon. The data obtained by the penetrators would be transmitted to the ground station by way of the LUNAR-A mother spacecraft orbiting at an altitude of about 200 km. The seismic observations could be expected to provide key data on the size of the lunar core, as well as data on the deep mantle structure. The heat flow measurements at two different sites would also provide important data on the thermal structure and bulk concentrations of heat-generating elements in the Moon. The developed lunar penetrator is a missile-shaped instrument carrier and is about 75 cm in length, 14 cm in maximum diameter and about 14 kg in weight. The penetrator is of a cylindrical shape with an ogive-nose and it contains a two-component seismometer and a heat flow probe, together with electronics, primary batteries, a tiltmeter, an accelerometer, and radio communication system. To protect these onboard instruments from the impact shock, the inside of the penetrator case is potted by a mixture of high rigid epoxy-resin and glass micro-spheres.

The LUNAR-A mission was supposed to be launched in 2004, but it was postponed because there was not only a malfunction of subsystem of the orbiting spacecraft uncovered during testing but also technological problems occurred during the course of the qualification of the penetrator. The orbiter-related issues resulted in a replacement of the valves used in the Reaction Control System (RCS) of the spacecraft, following a recall issued by the manufacturer who found a malfunction of similar valves, and the latter is a fault found in the qualification level test of the penetrator in November 2003. During this impact test, we could not communicate with the penetrator at the proper timing, which was programmed before shot. On the other hand, the internal review board of ISAS/JAXA for launch readiness was made in 2004 and the review board recommended that the improvement of the communication link between the penetrator and the orbiting spacecraft should be made, based on lessons learned from the US Deep Space-2 and European Beagle-2 failure of their communication link. And then, the LUNAR-A project had been reviewed by both the internal and external review boards of JAXA from the viewpoint of technological assessment and project management. From recommendations of the review boards, we determined to focus our attention on the improvement of the penetrator system, following a suspension of development of the orbiting spacecraft. Finally, it was announced that the LUNAR-A mission was officially cancelled in February, 2007. The main reason is that the reliability would be questioned because of no more than two penetrators available, compared to the present JAXA's confidence level. Another reason of the cancellation lies in the deterioration in the quality of the instruments onboard the mother spacecraft due to the long-term storage since it has been manufactured. A revial program to solve the penetrator technology issues was initiated in 2005 for the validation of a high degree of redundancy and robustness, and then, four times impact load tests with low-temperature thermal stress were conducted using both mock-up and fully-integrated models. Finally, the program has been completed in 2010. The follow-on mission to utilize the penetrator technology is now under consideration for the future program of the Japanese lunar exploration and/or within the framework of international collaborations.

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PPS024-P01 Room:Convention Hall Time:May 22 14:00-16:30

Structure and dynamics of the lunar exosphere

Shoichiro Yokota[1*], Yoshifumi Saito[1], Kazushi Asamura[1], Masaki N Nishino[1], Hideo Tsunakawa[2]

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The Moon has no global intrinsic magnetic field and only has a very thin atmosphere called surface-bounded exosphere. Some ground-based measurements have revealed the structure of the lunar exosphere since the discovery. The alkali components such as Na or K have especially been observed to understand the generation process and the transport mechanisms. The ground-based measurements and laboratory experiments have proposed that the alkali exospheric components are produced by ion-induced desorption (sputtering), photon-stimulated desorption, meteorite-induced vaporization and/or thermal desorption from the surface. One of the loss processes of the exospheric particles is photoionization and ion-pickup process. The ionized exospheric particles are transported by the surrounding electric field. By using the SELENE(KAGUYA) ion measurement data, we have studied the lunar exosphere as well as interactions between the solar wind and the planetary surface. MAP-PACE IMA has detected low-energy ions at 100-km altitude. The MAP-PACE measurements have elucidated that the ions originate from the lunar surface and exosphere and that the ions are at least composed of He+, C+, O+, Na+, K+ and Ar+. The measurements of ions from the Moon enable us to continuously monitor the lunar exosphere. The 1.5-year observation of SELENE(KAGUYA) shows that the ions from the Moon have been detected both when the Moon is exposed to the solar wind and when it is in the Earth's lobe region. The observation suggests that the solar wind is not the dominant source mechanism for the lunar exospheres. Moreover, the MAP-PACE observation shows the dependence on the solar zenith angle and the dawn-dusk asymmetry of the lunar exosphere. We report the features of the lunar exospheres obtained by the SELENE(KAGUYA) observation and discuss the source mechanism of the lunar exospheres.

Keywords: Moon, exosphere, mass analysis

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PPS024-P02 Room:Convention Hall Time:May 22 14:00-16:30

Study of lunar plasma environment using gyro-loss effect on electron velocity distributions

Yuki Harada[1*], Shinobu Machida[1], Yoshifumi Saito[2], Shoichiro Yokota[2], Kazushi Asamura[2], Masaki N Nishino[2], Hideo Tsunakawa[3], Hidetoshi Shibuya[4], Futoshi Takahashi[3], Masaki Matsushima[3], Hisayoshi Shimizu[5]

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The Moon possesses neither a global magnetic field nor a thick atmosphere. Therefore, the Moon and its surrounding plasma are ideal for investigating the interaction between charged particles and a solid body. Analysis of the data obtained by Kaguya (SELENE) revealed a partial loss in the electron velocity distribution function due to ”gyro-loss” effect, namely gyrating electrons being absorbed by the lunar surface. The empty regions in the observed electron distribution functions are consistent with the patterns of forbidden regions obtained by particle trace calculations, taking into account magnetic anomalies, lunar surface charging and electric fields around the Moon. In this study, lunar surface charging and electric fields around the Moon are studied by analyzing electron ”gyro-loss” events observed where there are weak or no magnetic anomalies.

Keywords: Moon, plasma, Kaguya

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PPS024-P03 Room:Convention Hall Time:May 22 14:00-16:30

Solar wind proton scattering at lunar surface

Kota Uemura[1*], Yoshifumi Saito[2], Masaki N Nishino[2], Shoichiro Yokota[2], Kazushi Asamura[2], Takaaki Tanaka[1], Hideo Tsunakawa[3]

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Interaction between the solar wind and a solar system object varies largely according to the object's properties, such as the existence of a global intrinsic magnetic field and/or thick atmosphere. The Moon's case is characterized by the absence of both of them. Until recently, understanding of the lunar plasma environment has suffered from a lack of in situ measurements of low energy ions. The interaction between the solar wind and the lunar surface has not been understood well until Kaguya observed the plasma environment around of the Moon. Especially, the behavior of the solar wind ions after impacting the lunar surface has never been observationally clear.

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. IMA on Kaguya found scattering of the solar wind ions where the solar wind ions lose energy by the interaction with the lunar surface. Initial analysis found that most of the scattered ions was protons and 0.1% ~ 1% of solar wind protons were scattered at the lunar surface.

We have investigated the angular dependence of the scattering and energy spectra of the scattered protons by using high angular resolution IMA data that were obtained dividing the hemispherical field of view into 16x64 sectors. We have found that the scattered protons have two components : backscattering and specular reflection. Backscattered component distributes within +-40 deg. scattering cone whose axis is aligned with the direction opposite to the incident solar wind ion velocity. The energy loss of the backscattered component is largest along the scattering cone axis and it is smaller at the edge of the cone. We have also found that the energy loss of the specular reflection component is less than that of the back scattered component. We have succeeded in explaining the characteristics of the angular dependence of the backscattered component by making a simple numerical model.

Keywords: solar wind, lunar surface, scattering

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Theoretical study of the spectral formation of monochromatic whistler waves near the Moon detected by Kaguya

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We study the spectral formation mechanism of monochromatic whistler waves observed by the Lunar Magnetometer aboard the Kaguya spacecraft orbiting at 100 km altitude above the Moon. The waves are observed as narrowband magnetic fluctuations with frequencies close to 1 Hz and are mostly left-hand polarized in the spacecraft frame.

Assuming whistler-mode waves in the solar wind frame propagating in the sunward direction with the group velocity comparable to the solar wind velocity, we find that, in the spacecraft frame, the Doppler-shifted frequency spectra of the waves are considerably modified making a peak at a certain frequency. The similar discussions have been made on the characteristics of upstream whistler waves observed near planetary bow shocks [e.g., Russell, 2007]. We suggest that the characteristics of the spectra of monochromatic whistler waves are determined by the relation between the group velocity vector of the waves and the solar wind velocity vector. By using the dispersion relation of whistler-mode waves in a cold plasma, we show that the factors controlling the solution are the wave vector, the magnetic field directions, and the solar wind parameters. We investigate these parameter spaces and find that the wave vector angles with respect to the sunward and to the magnetic field directions change the solution considerably than the solar wind parameters do.

To confirm the theory described above, we compare the peak frequency distribution predicted by the theory with the observed wave distribution. The consistency between the theoretical and observed wave distributions indicates that the frequency shift of the waves is well explained by the theory and that the most important controlling factor is the angle between the group velocity and solar wind velocity vectors.

Keywords: whistler-mode, Moon, monochromatic, group velocity, upstream, bow shock

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PPS024-P05 Room:Convention Hall Time:May 22 14:00-16:30

Data analysis of the causes of electrostatic solitary waves near the moon

Hajime Sugiyama[1*], Yoshiharu Omura[1], Hirotsugu Kojima[1], Kozo Hashimoto[2], Yoshifumi Saito[3], Masaki N Nishino[3], Shoichiro Yokota[3], Yoshiya Kasahara[4], Hideo Tsunakawa[5]

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Bi-polar pulses called ESW (Electrostatic Solitary Wave) were observed near the Earth's magnetosphere such as bow-shock and magnetopause by GEOTAIL, WIND and other satellites. However, it is reported for the first time that ESWs were observed in the region on which the Earth's magnetosphere made influence by the Kaguya satellite.

Kaguya is the satellite, which was launched on September 14, 2007 by JAXA to explore the moon. Various observation equipments were loaded on Kaguya. PACE(Particle Angle and Composition Experiment), WFC-L(WaveForm Capture-L) and LMAG(Lunar MAGnetomter) measured flux of charged particles, electric waveform and magnetic field respectively.

In this study, we transform data of plasma particles by PACE into reduced distribution functions and analyze them with electric waveform data and magnetic field data. In the presentation, we report the relation between charged particles and the causes of the ESWs in the vicinity of the moon.

Keywords: Kaguya, plasma, ESW

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PPS024-P06 Room:Convention Hall Time:May 22 14:00-16:30

Electric wave absorptions in Reiner Gamma by lunar radar sounder (LRS) on Kaguya orbiter

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Reiner Gamma is a sinuous higher reflectance features than the surrounding mare basalt area near the Oceanus Procellarum on the moon, and appears to associate with regions of significantly high crustal magnetic field. This association of crustal magnetic field with the high reflectance has been explained by several hypotheses: 1) less susceptibility to undergo optical maturation (e.g., space weathering) by magnetic field-induced deflection of solar wind (constant flow of charged particles coming from the Sun) (Hood and Schubert, 1980; Kurata et al. 2005), 2) electrostatic levitation of fine particles by magnetic field (Garrick-Bethell et al. in press). Therefore, it was suggested that the Reiner Gamma corresponds to magnetized materials in the crust or magnetic iron-rich ejecta materials, being able to deflect the solar wind and to deposit new fine particles. This would prevent surface materials to suffer space weathering, and so produce the higher reflectance.

Neish et al. (2010) have only focused on surface nature of Renner Gamma by Mini-RF (radio frequency) synthetic aperture radar. Here we show a first trial to determine surface electric properties on Reiner Gamma by Lunar Rader Sounder (LRS) on board Kaguya with numerical simulation of surface reflection echo. We found no subsurface echo underneath the Reiner Gamma, but found surface absorption characteristics of electric wave in Reiner Gamma. The surface reflection echo simulation inside and outside Reiner Gamma discriminated this absorption with the effect of surface reflection from topographic roughness, suggesting the presence of radar absorbent materials on the surface in Reiner Gamma.

Keywords: Kaguya(SELENE), Lunar Radar Sounder, Reiner Gamma

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PPS024-P07 Room:Convention Hall Time:May 22 14:00-16:30

Lunar space weathering dominantly induced by solar wind

Yoshiko Ogawa[1*], Junichi Haruyama[2], Tsuneo Matsunaga[3], Ryosuke Nakamura[4], Tomokatsu Morota[2], Takahiro Hiroi[5], Yasuhiro Yokota[3], Satoru Yamamoto[3], Sho Sasaki[6], Makiko Ohtake[2], Chikatoshi Honda[1], Hirohide Demura[1], Junya Terazono[1]

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Space weathering causes the change in optical properties, such as darkening and reddening of the planetary surface. Two competing processes have been proposed so far as the main mechanism of such space weathering; hydrogen irradiation by solar wind and bombardment of micrometeorites. We use the new data set obtained by Spectral Profiler (SP) combined with Terrain Camera (TC) onboard SELENE/Kaguya which observed the Moon, and approach the actual process of space weathering. We investigated the optical characteristics of the so-called lunar swirls, which consist of bright/white parts and dark/black parts making enigmatic 'swirl' patterns. We found such albedo markings of lunar swirls correspond to the extent of weathering and not composition, which means some factors to induce space weathering is inhomogeneous connecting with the swirl patterns of the albedo contrast. We conclude space weathering on the Moon would be induced by hydrogen from solar winds dominantly and the effect of the bombardment of micrometeorites may be minor.

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An estimate of the shallow lunar electrical conductivity using SELENE magnetometer data

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The electrical conductivity of the moon can be determined by electromagnetic response. From the simultaneous Apollo and Explorer 35 magnetometer observation, the electrical conductivity structure of the lunar interior was estimated. However, it so far contains significant ambiguity larger than two orders of magnitude especially for the shallow part. The ambiguity principally comes from low sampling rate of Explorer 35, which is 6.14 sec. So we thought that it is possible to improve the estimate of the shallow lunar electrical conductivity by using SELENE magnetometer data, which is averaged every 1 sec.

Because we use only the magnetic field observation of SELENE as the output, we suppose that the external input is randomly oriented uniform field. Under the condition that the electrical conductivity is uniform inside the moon, we compute Pr/P, when Pr and P represent the power of the vertical component and sum of three components, respectively. Then, we obtain the apparent electrical conductivity by comparing Pr/P$|_{theory}$ with Pr/P$|_{obs}$.

At $6{*}10^{-3}$ Hz, the apparent electrical conductivity is $2{*}10^{-4}$ S/m (skin depth is 400 km), which is consistent with Hood et al.(1982). On the other hand, at high frequency data, it is no more than $3{*}10^{-6}$ S/m. This value is much smaller than that of the previous estimates. We could give constraints on the shallow lunar electrical conductivity to some extent.

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The Lunar Electrical Conductivity Structure using Magnetic Data Set of KAGUYA

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The lunar electrical conductivity structure is important to understand the origin and evolution of the Moon. However, the conductivity estimated from simultaneous Apollo 12 surface and Explorer 35 orbital magnetometer records contains the uncertainty up to two orders of magnitude at shallow and deep parts of the Moon (Dyal et al., 1976; Hood et al., 1982). The object of this study is to remove this uncertainty to some extent and to improve the precision of the lunar conductivity estimation.

The external magnetic field fluctuations induce the electrical eddy currents in the Moon. The amplitude of the magnetic field resulting from these currents depends on the lunar electrical conductivity structure. Thus, the lunar electrical conductivity estimation can be achieved by analyzing the electromagnetic response of the Moon. But it is difficult to separate inducing magnetic field and induced magnetic field from data set observed by the magnetometer onboard KAGUYA, LMAG, because simultaneous magnetic observation at different point was not done. We analyze the time variation of the magnetic field when the Moon is in the geomagnetic tail lobe and goes into/out it, and then decide the lunar electrical conductivity.

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Modeling of lunar magnetic anomaly and paleomagnetic pole: Lunar dynamo in the past?

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Since findings in the Apollo era, the origin of magnetic anomaly is one of the biggest problems of the Moon. Whether or not the anomalies are records of an ancient magnetic field of lunar core origin puts strong constraints on the thermal evolution, internal structure and origin of the Moon. Magnetic field observations around the Moon by lunar-orbiting spacecrafts such as Lunar Prospector and Kaguya provide us with data to examine if the Moon once had a dynamo-generated magnetic field. For this purpose, we have conducted a study of modeling the lunar magnetic anomaly. A small-scale, relatively isolated anomaly can be modeled using point dipole sources, while more thorough modeling efforts are required for magnetic anomalies with complex structure. In this study, we have modeled lunar magnetic anomalies, taking effects of magnetization source with finite spatial scale into account. A rectangular prism is distributed in a bin of variable size as a magnetization source body. Depth of the bottom plane of the prism is fixed, while height of the prism can vary. Thus, for each prism, the magnetization vector and the height of prism are unknowns to be solved. Here, we report a preliminary modeling result using vector magnetic field data by Kaguya and Lunar Prospector low altitude observation. This technique will be applied to somewhat complicated anomalies, which are difficult to be modeled using a dipole source, such as Crisium-Antipode, Hartwig, Keeler-Heaviside, Kolorev, Krasovsky, Mendel-Rydberg, Moscoviense and Rima-Sirsalis anomalies. After modeling them, the obtained magnetization directions are mapped into distribution of paleomagnetic poles to discuss the ancient lunar dynamo hypothesis.

Keywords: Moon, magnetic anomaly, dynamo, paleomagnetic pole

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Geology of Th and K enriched Aristillus on the moon

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Global Th and K abundance map of the moon derived by the Lunar Prospector and SELENE gamma-ray spectrometer indicate that there are several highly enriched spots (hot spots) in these elements within the Procellarum KREEP Terrane. To understand the origin and distribution of the KREEP material, information of geologic characteristics and occurrence of these hot spots is important.

In this study we selected Aristillus crater among the hot spot and investigated geologic structure of this area by using SELENE Multiband Imager data.

Results indicate that relatively Fe-poor ejecta are observed in the northern area of the crater which is apparently corresponding to the Th rich material as previously suggested by [1] although reflectance spectra of this Fe-poor and surrounded relatively Fe-rich ejecta suggest basically similar mineralogy of these ejecta. Central peak of the crater has distinctively different Fe content compare to the Fe-poor ejecta and this may suggest the crater excavated Th rich material.

[1] Gillis et al. (1999) in Workshop on New Views of the Moon II, LPI.

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Estimation of the lunar surface permittivity based on Kaguya radar sounder and imager observations

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For the discussions on the lunar volcanic history, it is important to understand the composition, age, spatial extent, and the amounts of accumulation of the lava flow. Previous studies based on the spectral observation and the crater chronology suggested that the basalt of the lunar mare surface was formed by the deposition of the lava erupted several times (Heather et al., 2002; Hiesinger et al., 2003). Lunar Radar Sounder (LRS) aboard the Kaguya spacecraft succeeded in identifying echoes reflected from the paleoregolith which is at the interface of lava layers (Ono et al., 2009). By assuming the depth of subsurface layers as the thickness of the basalt at the lunar surface, we can obtain the amount of the accumulated basalt in the wide spatial region covered by the LRS observations. However, for the purpose of the estimation of the thickness of basalt from LRS observations, we need to know the electric permittivity of the basalt. In the previous studies, the typical permittivity was estimated to be in the range from 4 to 11 based on lunar rock samples [e.g., Olhoeft 1975]. Although this assumption is acceptable for the rough estimation, we need the accurate value of the permittivity of the basalt in each area on the lunar surface for the accurate estimation of the thickness of the basalt.

In this study, we estimated the accurate permittivity of upper basalt from observations of LRS, Multi-band Imager (MI; Ohtake et al., 2008), and Terrain Camera (TC; Haruyama et al., 2006). We focused on the craters (Bessel A, Bessel D) in Mare Serenitatis. We defined the permittivity of basalt around the crater as eps_1. The analysis method was as follows. First, we identified the boundary of the layers exposed on the inside wall of the crater based on the spectral images observed by MI. Next, we obtained the thickness T of the basalt exposed on the inner crater wall from the depth of the identified boundary by using the digital elevation model (DEM) based on TC. Finally, we calculated the permittivity eps_1 from the identified thickness T, the apparent depth D measured by LRS, and the permittivity of vacuum eps_0. However, we need to use assumptions of the crater formation model to calculate the thickness T. Because craters were created by the impact of meteors on the lunar surface, it should be considered that the boundaries between the subsurface layers were not simply exposed on the crater wall and are deformed by the shock wave generated when the meteor impacts. In this study, we assume some deformation models of the layers in order to estimate the permittivity eps_1 of the upper basalt layers.

We also compared the estimated dielectric constant with that of the rock samples collected by Apollo.

Acknowledgements: This study is based on TC / MI data provided by the Kaguya/LISM team through the SELENE Data Archive. We would like to express our deepest gratitude to the Kaguya/LISM team.

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Diverse crystallization trends in NWA 773 basalts

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At least three distinct crystallization trends in mafic rocks from the Moon can be extracted based on textural distinctions and pyroxene analyses from the Northwest Africa 773 (NWA 773) clan of lunar meteorites. The NWA 773 clan consists of brecciated and unbrecciated meteorites with a characteristic olivine gabbro cumulate lithology and other mafic rocks [1-5]. This study focuses on zoning trends in pyroxene within the olivine cumulate, in more evolved co-magmatic rocks that occur as breccia clasts, and a distinct mafic lithology characterized by fine-grained pyroxene+feldspar-rich groundmass [6,7]. Electron microprobe analyses for this study are from NWA 773 and NWA 2727.

Three trends can be distinguished based on Ti# (Ti/[Ti+Cr]) and Fe# (Fe/[Fe+Mg]) in pyroxene. (1) The main olivine gabbro cumulate clast (OGC) of NWA 773 [see 6,7]; smaller clasts of OGC in the breccia; co-magmatic, later-stage, coarse-grained, zoned pyroxene+feldspar-rich clasts, symplectite and extremely ferroan clasts with fayalitic olivine and silica and/or feldspathic glass form common trend with Ti# and Fe# both increasing in pyroxene. We refer to this as the ”main trend” of NWA 773 breccia. The large clast of OGC in NWA 773 was originally considered the most magnesian (most primitive) endmember of the main trend [6,7], but we have identified a slightly more magnesian clast with abundanct Cr-rich spinel.

(2) Within the olivine cumulate, pyroxene shows a wide range of Ti# but little variation in Fe# [6]. In this study, we collected pyroxene analyses along transects toward intercumulate K,Ba-feldspar-bearing pockets. These pockets are rich in incompatible elements and are considered products of residual liquids trapped between cumulate crystals (see Fig. 2B of [6]). We analyzed pyroxene adjacent to five pockets in NWA 773. In 7 of 9 transects in pyroxene, Ti# increases with minimal change in Fe# (”pocket trend”). Plagioclase feldspar adjacent to four of the five pockets showed a decrease in An-content (increase in Ab) approaching the pocket. These results are consistent with the interpretation of the pockets as residual liquids trapped in the cumulate.

(3) One group of texturally distinct clasts in the breccias of NWA 773 and NWA 2727 has a groundmass of fine, elongate, parallel crystals of feldpsar and pyroxene (straw-texture, see Fig. 6D of [6]). Pyroxene phenocrysts in the straw-textured clasts show complex zoning patterns. Fe-rich groundmass pyroxene analyses are similar to the main trend, but several analyses from the pyroxene phenocrysts have higher Ti# at a given Fe# than the main trend (straw-textured trend).

We infer that: (1) the main trend formed from fractional crystallization in the main body of NWA773 liquid; (2) the pocket trend formed from fractional crystallization as pyroxene grew toward trapped liquids in the cumulate; (3) the straw-textured trend formed from a separate mafic liquid with higher Ti#.

References: [1] Bunch et al., 2006, LPSC 37, #1375; [2] Jolliff et al., 2007, LPSC 38, #1489; [3] Zeigler et al., 2007, LPSC 38, #2109; [4] Zhang et al., 2010, MaPS 45, p. 1929-1947; [5] Nagaoka et al., 2011, LPSC 42, #1864; [6] Fagan et al., 2003, MaPS 38, p. 529-554; [7] Jolliff et al., 2003, GCA 67, p. 4857-4879.

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Geological structure of lunar SPA basin

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SPA is one of the biggest basins (2500 km in diameter) on the lunar far side. Previous studies have suggested that most of the crustal material of this basin was excavated and that the mantle materials have been exposed [1]. Therefore, 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 SPA basin-generated impact. For example, Pieters et al. (2001) and Ohtake et al. (2009) reported that the central part of the SPA basin contains anorthosite which is crustal material[2][3]. Additionally, Ishihara et al. (2009) estimated the anorthositic crust in the SPA basin to be 20 to 30 km thick based on data derived from the SELENE Relay satellite, its Main Orbiter transponder, and the Laser Altimeter [4]. These observations are apparently inconsistent with the theory of previous studies. In this study, we estimated the cause of this disagreement by investigating the distribution of anorthosite within the SPA basin and compared the results with topographic data. And we speculated the geological structure of this large impact basin.

We used the SELENE Multiband Imager (MI) to estimate the lunar mineralogy of SPA basin. MI is a high-resolution spectral imager with both visible and near infrared coverages at spectral bands of 415, 750, 900, 950, 1000, 1050, 1250 and 1550 nm. In all MI images, spatial resolution is adjusted to 20 m x 20 m per pixel. Mineral phases have diagnostic absorption features depending on the minerals. Plagioclase has an absorption band at around 1250 nm; olivine, at around 1050 nm; and pyroxene, at around 1000 nm. These minerals are the three commonest minerals on the Moon. We detected a peak shoulder at around 1250 nm compared to the line between 1050 nm to 1550 nm to select anorthosite spectra. Locations without this peak shoulder are categorized as other rocks.

We made a color-composite image in which red is assigned to a continuum-removed absorption depth at 950 nm; green, to that at 1050 nm; and blue, to that at 1250 nm to display the distribution of these minerals. We also used topographic data derived from the SELENE Laser Altimeter (LALT) to compare the mineralogy with topography. Its spatial resolution is finer than 0.5 degrees. We identified rings within the SPA basin based on the topographic features.

In the result of this study, we found anorthosite in 20 locations within the SPA basin. Particularly, 16 locations of them located near the fringe region within the SPA basin. Other four locations located near the center of this basin and recognized in the northwest area of this region.

The second topographic ring counted from the outside was matched the boundary of the anorthosite distribution derived from mineralogical data. In other words, few anorthosites present inside of the second topographic ring. This result suggests that the crustal material is excavated within the SPA basin, and that the second ring corresponds to a transient cavity of this basin.

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Keywords: Moon, South Pole-Aitken basin, Multiband Imager, Anorthosite

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Development of the Deferential Image Motion Monitor (DIMM) for Lunar Laser Ranging station

Seiichi Tazawa[1*], Hirotomo Noda[1], Hiroshi Araki[1], Hiroo Kunimori[2]

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We propose the Lunar Laser Ranging (LLR) experiment for SELENE-2 moon landing mission. We will upgrade the current SLR station (Koganei) for the first step and aim to find ranges from the LLR ground station to retroreflectors on the lunar surface. Because the influence of the atmosphere fluctuation is significant in LLR, it is necessary to improve the reliability of observed data by measuring the seeing during the observation. The seeing observation is generally conducted by using Deferential Image Motion Monitor (DIMM). We report the status of the DIMM to be developed newly for the LLR ground station.

Keywords: LLR, SELENE-2, DIMM

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Ground station for Lunar Laser Raging : condition and upgrade using present SLR station

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The paper presents a study of the ground station for the LLR (Lunar Laser Ranging) experiment in Selene2. The science goal of the LLR is to get better understanding of inner structure of the Moon and other principal physics through lunar orbit, lunar solid tides, and lunar rotation.

The current SLR (Satellite Laser Ranging) network on the Earth has about 30 operational stations and they track regularly about 30 earth orbiting satellite in which the most distant target is up to geosynchronous satellite(GEO) or about 40,000 km. A few stations can track retro-reflector arrays on the Moon which has distance of 380,000 km from the Earth. The signal strength from moon is as -40 dB weak as one from GEO because of space loss if all other conditions including the target cross section are same.

We plan to range the Moon from a Japanese ground station in two major steps. The first step is to acquire returned photons from the lunar retro-reflectors by upgrade of the existing SLR station to assess technology used and figure out necessary requirement for each subsystem and software. In the second step, full-scale development and installation in an ideal location will be planned. As the first demonstration site, the SLR station in Koganei is selected which has 1.5 m diameter telescope but does not have good atmospheric seeing.

The pointing stability of the telescope and the atmospheric seeing are the most important factors for LLR. We will monitor the seeing during ranging, and the adaptive optics approach will be taken for basic development by using tip-tilt mirrors, wavefront sensors and control software.

A tracking laser for long-distance target is to be introduced in a transmitting pass, which has 532nm wavelength, nominal repetition rate of 2 kHz, energy per pulse of 5 mJ and pulse width of about 20 nanoseconds. The kHz ranging engine (KRE), composed of a range gate generator and epoch timer (A033-ET) with newly developed control software, is capable of 2 kHz operation to control the tracking laser and data I/O. It can also control the present 20 Hz picoseconds laser by triggering using 1/100 divider. The requirements of LLR stations are investigated in terms of technology and site condition, and the upgrade of the present SLR station will be discussed.

Keywords: LLR, SLR

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Development of a Telescope for In-situ Lunar Orientation Measurements (ILOM) in the next Lunar Exploration - Evaluation

Hideo Hanada[1*], Seiichi Tazawa[1], Hiroshi Araki[1], Seiitsu Tsuruta[1], Hirotomo Noda[1], Kazuyoshi Asari[1], Sho Sasaki[1], Koji Matsumoto[1], Ken'ichi Funazaki[2], Atsushi Satoh[2], Hideo Taniguchi[2], Hiromasa Kato[2], Kikuchi Mamoru[2], Tomoe Takahashi[2], Atsumu Yamazaki[2], kohei Murata[2], Takahiro Iwata[3], Kosuke Heki[4]

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We are proposing a selenodetic observations by using an optical telescope on the Moon to study lunar rotational dynamics in post-SELENE mission. Main targets are direct observations of the lunar physical libration and the free librations of the Moon. A small telescope like PZT set near the lunar surface determines the orientation of the axis of rotation of the Moon by positioning of several tens of stars in the field of view at every moment for longer than one year [1]. An accuracy better than 1 mas is necessary in order to put a strong constraint upon the structure and property of the lunar deep interior, such as the existence of liquid core, since libration parameters related to property of the lunar core have amplitude of at most a few mas [2].

We have already developed a BBM (Bread Board Model) of the telescope and made some experiments in order to know the performance of the optical system and the driving mechanism under similar condition to lunar environment showing high vacuum, large temperature change and dusty condition.

The important problem which can affect the accuracy is effects of temperature change. We evaluated the effects of temperature change upon shifts of star images by simulations using a ray tracing method. The patterns of the shifts due to uniform temperature change are similar to divergent flows from the origin, and we can correct for the pattern of the shifts by using linear functions with the accuracy better than 1 mas. The other kind of effect such as horizontal or vertical temperature gradient causes shifts of star images in one direction as well as radial shifts, and we need more complicated model for correction.

After the performance test of the motor under the vacuum of 3 Pa for 8 to 29 hours, we found that the temperature near the motor increased. We need to establish the condition concerning the operation of the motor in order not to cause any damage in the driving mechanism.

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Keywords: lunar rotation, telescope, PZT, physical libration, lunar exploration

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Development of thermal control unit for scientific instruments on lunar surface

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We are developing the temperature control unit for long-term survival of scientific instruments. 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. Several devices for the module were actively considered in the recent progress.

Keywords: thermal control, lunar exploration, SELENE-2

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Development status and scientific objective of ALIS/LMUCS/LUMI for the SELENE-2 mission

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Conceptional design of SELENE-2 is on going. In this presentation, development status and science objective of ALIS/LMUCS/LUMI are discussed.

Keywords: Moon, SELENE-2, Geological survey, Spectroscopy, Crater