Lunar Science Workshop
Kyung Hee University

An Overview of Korean Lunar Exploration Program

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Korea is planning to carry out lunar exploration, which is supported by National policy plan, # 13. The core concept of this lunar program called Korean Lunar Exploration Program (KLEP) is launching both an orbiter and a lander including a rover by 2020. We will explain the details of proposed KLEP as well as short introduction to Korea Aerospace Research Institute (KARI) who has lead so far the Korean space programs.

Space Science Activities in KASI

Young-Jun Choi
Korea Astronomy & Space Science Institute

Korea Astronomy & Space Science Institute (KASI) is a national-funded research institute at astronomy field in Korea. KASI has developed several space payloads from ultraviolet to infrared bands. Brief overview of space science activities and future plan in planetary science will be introduced.

Multi-Band Polarimetric Observations of the Lunar Regolith

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We carried out multi-band (U, B, V, R, and I passbands) polarimetric observations of the whole near side of the moon from the Lick observatory using a 15-cm reflecting telescope. Polarization of the light scattered by the lunar surface contains information on the mean particle size of the lunar regolith, which gradually decreases by continued micro-meteoroid impact over a long period and thus is an age indicator of the surface. We present a map of the mean particle size for the whole near side of the moon. We plan to compare our observations with computer simulations and laboratory experiments, which we recently began to conduct.

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Clues to Understandings Lunar Swirls from the Relation between Optical Properties and Regolith Structure

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Lunar swirls are some of the most beautiful yet mysterious features on the Moon. They are characterized by their unusual albedo markings, which are wispy or sinuous in form. Swirls are often associated with the invisible presence of notable magnetic anomalies. They are found without any topographic expression of their own and occur across mare or highland terrain. We have recently re-examined the spectroscopic properties of swirls using data from the Moon Mineralogy Mapper in order to determine whether there are compositional distinctions associated with their bright and dark markings. The data are consistent with the features being locally derived (rather than addition of a significant foreign component), but their albedo variations do not follow any common alteration or mixing pattern for lunar materials. Specifically, the spectral properties of swirls are not consistent with normal 'space weathering' of exposed lunar materials that results from the accumulation of nanophase metallic iron on soil grains when exposed to the harsh environment on the lunar surface. Instead, the observed characteristics of swirls argue for a difference in micro-scale texture of swirl regolith structure compared to that of nearby local soils. Some rearrangement of the fine components is also likely at swirls.

Key issues to explore in the lunar environment are the effects that a relatively strong local magnetic field may have on small electrostatic forces that control interaction between soil grains. The mobility of the finest fraction is another key question. In addition, all regolith evolution processes occur in the strong diurnal cycling involving solar radiation – exposure from visible to near-infrared electromagnetic radiation (heat) and solar wind energetic particles. If we could understand the direct cause and effect between the magnetic anomalies and the character and patterns in these enigmatic swirls, we would go a long way toward constraining the origin of the magnetic signatures themselves – which in turn would ultimately constrain the early history of the Moon.

The Core of the Moon

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A key unknown in lunar science is to what extent is the Moon is a melted, radially layered planet like Earth or a primordial relic of the early solar system, like many asteroids. A new era of lunar exploration is underway, offering major new insights into this decades-old question. Although the Moon today has no global magnetic field, new laboratory and spacecraft measurements strongly indicate that remanent magnetization in lunar rocks is the product of an ancient core dynamo. This confirms that the Moon is a highly differentiated object that formed an advecting, liquid metallic core. The dynamo field persisted from at least 4.25 to 3.56 billion years ago with an intensity reaching that of the present Earth. The field then declined by at least an order of magnitude by 3.3 Ga. The mechanisms for sustaining such an intense and long-lived dynamo are uncertain but may include exotic mechanisms like mechanical stirring by the precessing mantle.

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Plasma Interactions with Small-Scale Magnetic Anomalies: Current Understanding and Unsolved Problems

J.S. Halekas

U.C. Berkeley (soon to be U. Iowa)

The Moon is dotted by small-scale magnetic anomalies, which cover a substantial fraction of the lunar surface. Lunar magnetic field sources vary greatly in strength and extent, but all have coherence scales which are small compared to relevant plasma scales, especially in altitudinal extent. Nonetheless, as we have gradually learned over the last 40+ years, lunar magnetic fields strongly perturb the incoming plasma, with commensurate effects on the ion bombardment of the surface in and around magnetized areas, potentially altering space weathering of the surface in these select regions.

Early in the Apollo era, it became apparent that lunar magnetic fields significantly perturbed the solar wind flow, resulting in strong compressions of the interplanetary magnetic field carried in the flowing plasma, which then convected downstream, forming structures often termed "limb shocks" or "limb compressions" surrounding the downstream wake. These large-scale structures seemingly indicated a macroscopic plasma interaction, yet the limited availability of high-fidelity ion data limited the degree to which this could be shown conclusively. At the same time, it became apparent that lunar magnetic fields efficiently reflected solar wind electrons - indeed, the electron reflectance method serendipitously became a primary technique for mapping the distribution of lunar magnetism. This culminated in the Electron Reflectometer instrument on Lunar Prospector, which provided data that formed the basis of my doctoral thesis.

With the advent of high-quality ion measurements, provided by an international fleet of spacecraft from India, China, and Japan, our community has achieved a new leap forward in its understanding of plasma interactions with small-scale magnetic anomalies. We now know that lunar magnetic fields, despite their small scale, efficiently reflect ions as well as electrons. The evidence, from a combination of ion and energetic neutral atom observations, convincingly shows that the strongest anomalies reflect a significant portion (up to ~50% or greater) of the incoming solar wind flux. A number of observations implicate the role of an electric field in slowing and/or reflecting the incoming ions. This field is most likely set up by the differential motion of the electrons and ions in regions of strong magnetic gradients, resulting in both charge separation and currents, with the relative roles of these related electric field terms not yet understood. Kaguya observations also suggest a role for a dissipative process. However, we do not yet understand the relative roles of magnetic field, electric field, and dissipation, nor do we know the altitude distribution of these phenomena.

I will present a summary of the study of the lunar magnetic fields and the plasma interaction with them, summarize our current understanding, and present new results from the ARTEMIS mission. Though ARTEMIS does not have orbits tailored for the study of magnetic anomaly interactions, we do have a few orbits below ~50 km in altitude, providing a view of the region in which ions start to slow, as well as observations of ions reflected below the spacecraft. Given the two-point measurement capability of the ARTEMIS mission, together with a complete suite of plasma and waves instrumentation, the ARTEMIS data provide a new window on the microphysics of the plasma interaction with lunar magnetic fields. Nonetheless, unsolved problems remain!

Space weathering at lunar swirls and high lunar latitudes

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Space weathering processes, which gradually alter the optical properties of surfaces exposed directly to the space environment, have important consequences for the interpretation of remote sensing data and thus the characterization of bodies throughout the solar system. Direct exposure to solar wind and micrometeoroid bombardment are thought to be the dominant sources of space weathering, however, their relative effects and efficiencies are not yet well understood. We investigate how space weathering effects differ at high lunar latitudes, where both solar wind and micrometeoroid flux are reduced, and at lunar swirls, where micrometeoroid flux is unaffected, but where solar wind flux is likely reduced. In both cases, we observe similar spectral trends that may have important implications for how space weathering operates.

Characteristics of Small-Scale Magnetic Anomalies outside of Mare Crisium.

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Small structures of magnetic anomalies near Crisium are examined by using data acquired with the magnetometer (MAG) on Lunar Prospector (LP). Near the inner northern and southern edges in the Crisium basin, there are magnetic anomalies showing a bipolar perturbation in north-south magnetic field component (B_z) and monopolar perturbation in the radial component (B_x). From inspection of the data in the range of 40° ~ 100° E in longitude and 20° ~ 40° N in latitude covering Crisium, many small-scale magnetic anomalies were also found. They are distributed in a wide range of distances from Crisium. Although most of them have amplitudes smaller than the two main Crisium anomalies, their magnetic polarities (in B_x and B_z) are similar to those at Crisium. This suggests that the origin of the small structures of magnetic anomalies near Crisium is not different from that of the Crisium anomalies. In this study, we are discussing what causes these small anomalies.

The Principle of Scientific Mission Definition for the Korean Lunar Exploration

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Korean government set up the new plan, '1st National Space Development Promotion Plan', in 2007 to promote Korean space programs. According to the plan and its execution, Korean lunar exploration program was initially announced for a plan of lunar orbiter and lander. For a preparation of the missions, the Korea Aerospace Research Institute has carried out several projects on preliminary and conceptual designs of lunar scientific missions as precursor studies. The Korean lunar exploration planning committee also has performed on the planning research for the Korean Lunar Exploration in 2013.

We suggest the principle of scientific mission definition (priorities and selection criteria) for the Korean Lunar Exploration based upon case studies of lunar explorations.

Scientific Aspects for Korean Lunar Exploration

Young-Jun Choi, Yeo-Myeong Lim, Sung-Joon Park, Hong-Kyu Moon
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Korea is going to launch the first orbiter in 2017 and both orbiter and lander around 2020 for lunar exploration. Since the surface of the Moon has been a witness of the Solar System history, currently lunar whole surface map in visible spectral range was completed through a camera of the latest lunar missions. However, because lunar surface continuously changes by impacts of meteorites, the surface should be observed again. In addition, it would be useful to use multi-wavelength polarimetry in visible range or to measure surface reflectance in ultraviolet spectral range. Polarization of lunar surface depends on both albedo and surface roughness, which is related to thermal properties results from infrared (IR) observation. Further IR observations are required for studying mineralogy and confirming the existence of water ice at permanent shadow region in both poles. IR spectral range for scientific study of lunar surface is classified as three regions according to recently results of the study. In the first range, 0.5-1.5㎛, absorption lines of Olivine, Pyroxene can be detected. Water, ice, OH absorption lines can be detected in 2.6-3.6 ㎛range. Christian Feature (CF), in 7-9 ㎛ range, shows silicate mineralogy. We will briefly discuss about current Korean lunar exploration status and its scientific aspects.

Preliminary Study of a Lunar CubeSat Impactor mission

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In previous Lunar Orbiter missions, most payload instruments have been based on remote sensing techniques for scientific observations. For the case of lunar magnetic anomaly regions, data have been taken directly by 3-axis magnetometer measurements and indirectly by electron reflectometry. However, constructing source models for lunar magnetic anomalies remains difficult due to the high altitudes of existing data sets.

The main purpose of this study is direct near-surface measurements at magnetic anomalies with a CubeSat Impactor which is separated from a Lunar Orbiter. This method is very cost effective and is a simple way to take valuable data. These measurements would also provide key insights into a variety of unique phenomena associated with magnetic anomalies.

For this mission, we carried out a preliminary study of a CubeSat Lunar Impactor. We assumed that the volume and mass follow the Cubesat Standard. In this case the mass and volume are 3 kg and 3U, respectively. The power is estimated to be about 6 watts. The impact angle requirement is below 10 degrees and the Impactor will fall on the night side to avoid solar wind interference with the magnetic field. The mission duration takes around 30 minutes in the case of a simple separation method. We will perform more detailed studies for a variety of cases.

Are There Swirls at the Mare Crisium Magnetic Anomaly?

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There are no global magnetic fields the moon, but some localized magnetic fields exist on both the near and far sides. However, we don't understand how those magnetized regions emerged. Many lunar magnetic anomalies are correlated with bright markings and dark lanes on the surface, most commonly known as swirls. Mare Crisium (17.18˚N, 59.1˚E) is a 555 km diameter basin on the near side of the Moon. It contains two distinct crustal magnetic anomalies and a number of small regions of high albedo with uncertain origins, but no obvious swirls like at the type example Reiner Gamma. In contrast, Reiner Gamma exhibits sinuous high albedo regions and dark lanes. These high albedo regions and dark lanes might be related to the near surface magnetic field structure. If this is correct, the magnetic anomaly makes a mini-magnetosphere to reflect solar wind. To determine if there is a subtle signature of swirl-like feature at Mare Crisium, we use Lunar Prospector (LP) magnetometer (MAG) data to characterize magnetic fields. The data we use here include 12 orbit segments, 744 measurements, and an average altitude of 22.3 km. All data were collected from magnetically quiet times when LP was in the lunar wake (lunar night). Clementine UV/VIS data are used to characterize the surface optical properties (OMAT). OMAT is defined by the properties of the reflectance at 750 nm compared with the ratio of reflectance at 950 nm to reflectance at 750 nm. OMAT has been shown to provide a good estimate of the spectral effects of space weathering due to solar wind and micrometeoroid bombardment.

In Mare Crisium's northern anomaly, we find that the magnetic field lines point into the middle of anomaly region on vertical components. This location also has some high albedo anomalies that may be correlated with magnetic field features. However, a ray from the crater Proclus containing bright highlands material extends into the same areas, complicating our interpretation of the origin of the high albedo features. In the southern anomaly, the magnetic field points mainly point to the north and we find no obvious correlation between the magnetic field and any albedo anomalies. Therefore, there is no clear evidence yet that the Mare Crisium magnetic anomalies from swirls. Low altitude measurements of magnetic fields at Mare Crisium, and comparisons with observations at Reiner Gamma, could help us test our model of swirl formation and the mechanics of space weathering. Such measurements could be obtained with a Cubesat impactor mission.

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The lunar dust environment: experiments in space and the laboratory

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The lunar surface is exposed to a variety of plasma conditions as a function of local time, solar activity, and orbital position. The variable exposure to solar wind, UV radiation, magnetospheric plasmas, and meteoroid impacts result in a complex, time-dependent environment, which creates a natural dusty plasma laboratory. The charging, possible subsequent mobilization, and transport of fine lunar dust have remained a controversial issue since the Apollo era, and have been suggested to lead to the formation of a 'dusty exosphere', extending tens to hundreds of kilometers above the surface. A series of laboratory experiments, supplemented by theory and modeling, are used to improve our understanding of: (1) The properties of the near-surface plasma environment, and the generation of possible intense localized electric fields due to differential charging near the terminator regions and in shadows cast by topographic features. (2) The charging of grains resting on dusty surfaces and stirred by activities, their possible mobilization, lift-off, and transport. 3) The physics of impact phenomena of hypervelocity micrometeoroids and their interaction with the lunar environment. In addition to laboratory experiments, these issues are also addressed by in situ measurements on satellites orbiting the Moon. The Lunar Dust Experiment (LDEX) onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission successfully mapped the spatial and temporal variability of the dust size and density distributions in the

lunar environment. LDEX detected and measured the mass of submicron and micron sized dust grains, while in lunar orbit from 10/6/2013 - 4/17/2014. LDEX also measured the current from low-energy ions and collective charges from dust impacts that are below the detection threshold for individual dust detection, enabling the search for the putative population of grains with radii ~ 0.1 micron lofted over the terminator regions by plasma effects. LDEX has identified and characterized the dust ejecta cloud that is maintained by the sporadic micrometeoroid bombardment of the lunar surface. The density of the dust ejecta cloud increases with decreasing altitude, and shows significant enhancements during meteor showers. LDEX found no evidence of the plasma-lofted particles, and put strict new upper limits on the density of the high-altitude small grains.

The discovery and detailed understanding of the lunar ejecta cloud opens new pathways to learn about the dust populations comprising the sporadic background and the meteor showers, as well as the response of the lunar regolith as function of the mass and speed of the bombarding particles. The collected data will be further used to improve dust hazard models for the near-Earth environment. Ejecta clouds, similar to that observed around the Moon are likely to be present at other objects that are possible targets for future human exploration: asteroids, and the Martian Moons Phobos and Deimos. An LDEX-type instrument on precursor missions will greatly contribute to the safety of the crew and the mission to these targets.

The combination of laboratory experiments, computer simulations, and in situ space experiments will possibly close many of these open issues. Ultimately, a more complete understanding of the behavior of dust, and dusty plasmas on the Moon will eventually require in situ measurements on the lunar surface.

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Lunar swirls: A Union of Space Weathering, Magnetism, Surface Water and Plasma Physics

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1. University of California, Santa Cruz
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Since the Apollo era, lunar swirls have remained one of the most enigmatic features on the Moon. Lunar swirls are magnetized regions of the crust with bright, sinuous color markings on the surface. The brightest parts of these features are also low in surface water and hydroxyl molecules. The origin of the magnetization, color markings, and low water/hydroxyl content is uncertain. Most theories for the magnetization require an ancient magnetic dynamo on the Moon, but the details are not well understood. The dominant theory for the color markings is that the magnetic field is blocking the solar wind (a darkening agent) from the surface, but a more recent theory suggests bright, fine dust is being moved into the area by weak electric fields. We will present a new analysis that supports the solar wind blocking model, but also reveals there is much uncertainty in the details of the process. Ultimately, in situ measurements of these features are required to explain their formation. In turn, these measurements would provide great insight into how the spectral properties of airless solar system bodies change in response to the space environment. They would also help us constrain the origin of the underlying magnetization, and how surface water is formed on the Moon. We will present several mission architectures that use CubeSats to obtain these first-of-a-kind measurements.