Light Field Cameras for Dust Grains on and near the Lunar Surface

Sungsoo S. Kim[1] (sungsoo.kim@khu.ac.kr), Young-Jun Choi[2] (yjchoi@kasi.re.kr), Minsup Jeong[2], Chae Kyung Sim[2], Dukhang Lee[2], Bongkon Moon[2], Seonghwan Choi[2], Dae-Hee Lee[2] Jakyung Nah[2], Minbae Kim[1], Mingyeong Lee[2], and Ian Garrick-Bethell[1,3]

[1]Kyung Hee University, Korea, [2]Korea Astronomy and Space Science Institute, [3]University of California at Santa Cruz

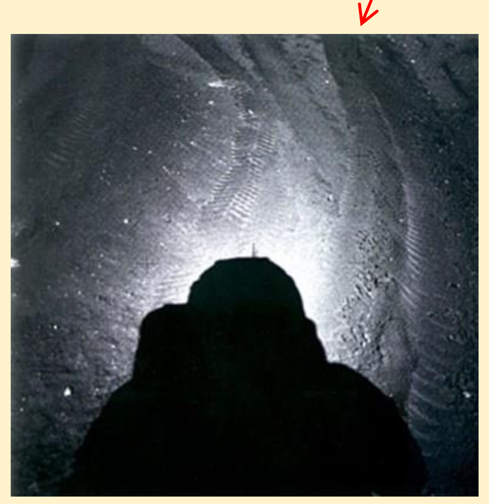
Introduction

We are currently designing and developing an instrument package, GrainCams, with consideration to be onboard one of the rovers provided by NASA's Commercial Lunar Payload Services (CLPS) program in the future. GrainCams will be composed of two light field cameras, SurfCam and LevCam. The SurfCam is being designed to capture 3-dimensional microscopic structures in the uppermost few mm layer of the lunar regolith, and the LevCam is being designed to detect dust particles levitating or lofting a few tens of cm above the lunar surface.

Fairy Castle Structure

A vast amount of information on physical and chemical (mineral) properties of the lunar surface is obtained from remotely sensed UV/VIS/IR data. Photometry, spectroscopy, and polarimetry are used to study compositions and physical, thermal, mechanical properties of the surface.

However, **reflectance and emissivity of the surface are highly sensitive to the porosity of the upper regolith** (several millimeters to centimeters thick), which has not been directly measured yet. Ohtake et al. (2010) and Hapke & Sato (2016), among others, estimated the degree of porosity to be 75–85% by comparing laboratory measurements of reflectance for returned lunar soil samples and actual remote measurements for the lunar surface. Such a high porosity is deemed responsible for the opposition surge, the directionality of thermal emissivity, and the thermophysical structure of the lunar regolith.

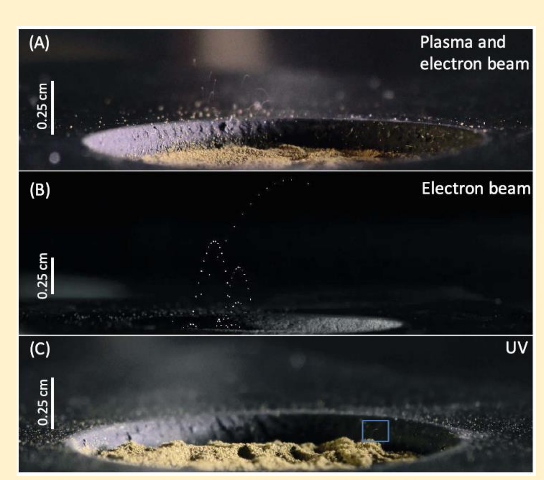


The lunar regolith is composed of irregularly shaped grains with a mass-weighted mean size of 50–200 microns. It is conjectured that **the very high porosity of the upper regolith is manifested by complex 3-dimensional structures often called "fairy castles"**, consisting of towers and branches leaning at extremely high angles and connected by lacy bridges and flying buttresses (Hapke & van Horn 1963). These exotic structures would be possible when likely charged small grains in weak gravity can be stably supported by one or two contacts rather than the three or more contacts required for low porosity soil. Mendell & Noble (2010) estimate that a fairy castle layer of 5–10 grains deep (<1 mm) would be enough to produce the photometric and emissivity phenomena mentioned above.

Lofted Dust Grains

Charging of the lunar surface is believed to be the main driver for the formation of fairy castle structures. The surface is positively charged due to the photoelectric ejection of electrons by solar illumination on the dayside, and negatively charged due to the plasma electrons near the surface on the nightside. Measurement of stationary (non-oscillatory) electric fields on the lunar surface, however, is highly challenging, and very few in-situ measurements (e.g., Apollo Suprathermal Ion Detector Experiment; Freeman & Ibrahim 1975) have been made so far.

The electrostatic charges on regolith grains collectively form static electric fields toward or out of the lunar surface, and the repulsive electric forces against the ground are constantly exerted on the grains. Based on the work by Stubbs et al. (2006, 2014), we find that **under average electric fields near the lunar surface, dust grains with sizes up to ~1 micron can experience repulsive electric forces larger than gravity**, and we anticipate that disturbances such as solar energetic particle events or nearby micrometeoroid impacts can boost the levitation of grains with sizes up to ~3 microns.



Images of dust transport and hopping trajectories in (a) plasma and electron beam, (b) electron beam, and (c) UV Experiments (Wang et al. 2016). Deposits of dust particles on the surface outside the crater also indicate their hopping motions in all three images. Large aggregates up to 140 μm in diameter are lofted in addition to individual particles (38–45 μm in diameter).

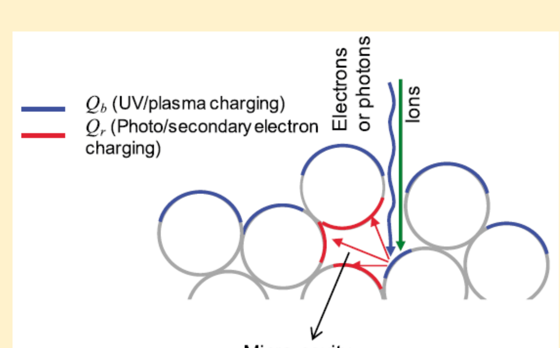


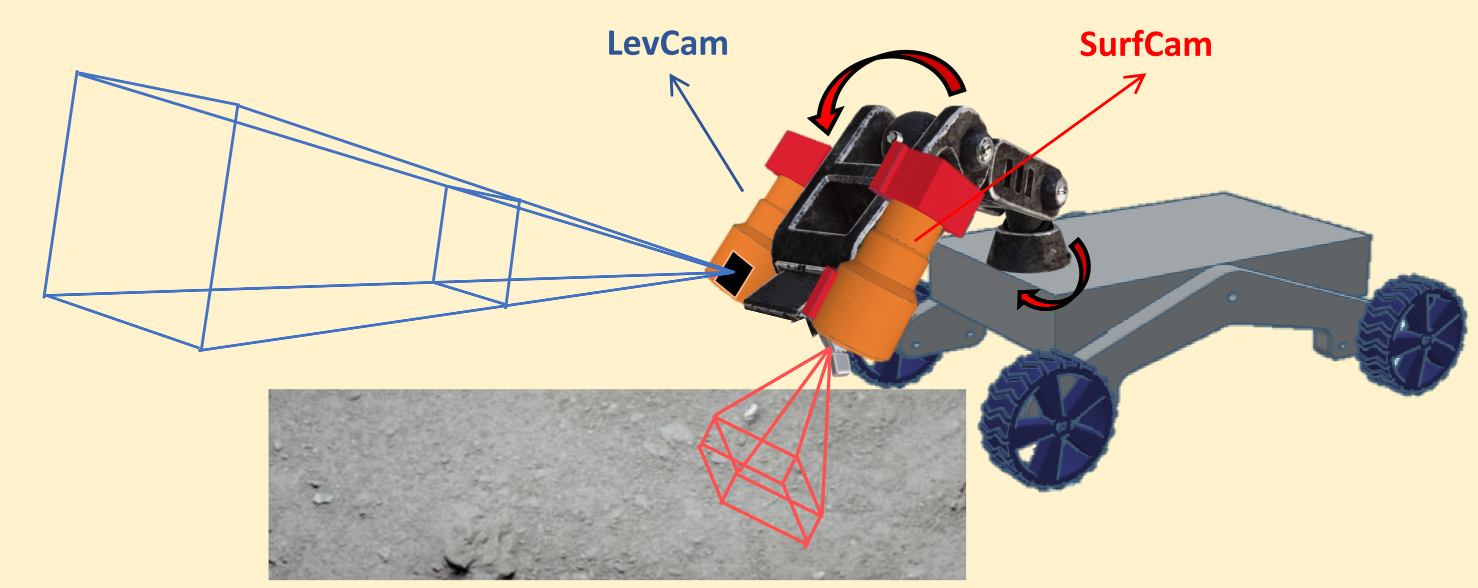
Illustration of charges and forces on dust particles for a patched charge model by Wang et al. (2016). Dust particles (gray circles) form a microcavity in the center. Photons and/or electrons and ions are incident on the blue surface patches of the dust particles, charging them to Q_b and simultaneously emitting photoelectron and/or secondary electron. A fraction of these emitted electrons are re-absorbed inside the microcavity and collected on the red surface patches of the neighboring dust particles, resulting in a negative charge Q_r.

Indeed, Rennilson & Criswell (1974) attribute the lunar "horizon glow" observed by Surveyor 5, 6, and 7 to the diffraction of sunlight by regolith grains of few micron sizes levitating few tens of centimeters above the lunar surface and estimate their number density to be a few per cm^3. Using the results of Zubko et al. (2020), we find that **a camera with a 5 cm aperture will collect enough photons to capture the motions of levitating grains with sizes of 0.3–3 microns within a 2-meter distance**.

Proposed Instruments

Our main scientific goal is to understand the electrostatic environment of the lunar surface by capturing two of its outcomes, the microstructures of the upper regolith and the levitating (or lofted) motions of regolith grains. For this, we propose an instrument package **"GrainCams"**, which is composed of the following two instruments

- **SurfCam**: A light field camera that will obtain 3-dimensional microscopic images of the upper few millimeters of the lunar regolith and reveal the enigmatic shape of the fairy castle structure. The obtained images will significantly improve our understanding of the photometric and emissivity characteristics of particulate surfaces on the airless bodies in the Solar system.
- **LevCam**: A light field camera that will measure 3-dimensional positions and velocities of levitating (or lofted) regolith grains near the lunar surface. The obtained measurements will be used for estimating the strength of static electric fields and will help us understand dust environment on and above the lunar surface.



Light Field Camera

Light Field Cameras (LFCs) capture not only the intensity of the light, but also the direction of the light reaching the camera, delivering high-fidelity **3-dimensional images** with much higher depth resolutions than conventional stereo cameras. A typical LFC has a **micro-lens array** placed in front of an image sensor. Focal distance and depth of field can be chosen after a photo is taken with an LFC.

These images demonstrates the capability of changing the focal distance after a photo is taken. Near focus (left) and far focus (right) processed with the Lytro Illum light field camera software. (Images from Wikipedia)

Science Enabled by Mobility

We propose to take lunar surface microscopies onboard the rover at several different distances (up to >150 meters) from the lander. Photometric properties of all previous landing sites have been altered (e.g., increase in brightness and suppression of opposition surge) by the lander's rocket exhaust, which is thought to disrupt the fairy castle structure of the adjacent (50–100 meters) lunar surface. Thus, **comparisons of surface images at different distances from the lander** will drastically highlight the unique structural characteristics of undisturbed upper lunar regolith.

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