A GONIOMETER LIGHT SOURCE DESIGN FOR EVALUATING THREE-DIMENSIONAL THERMAL INFRARED EMISSION FROM LUNAR AND ASTEROID ANALOGUE REGOLITH SAMPLES.

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Introduction: The structure of the lunar surface is direct evidence of the impact and space weathering processes the Moon has been exposed to over extended periods of the Solar System's history. The analysis of the topmost layer, up to around 100 microns in depth, of the lunar surface, can therefore provide clues for understanding the history of the Moon and by extension other airless bodies in the Solar System.

Limited in situ measurements of the surface and the lunar regolith, have been performed at local scales through the Apollo, Luna and Chang'e landings. Alternative remote ways of obtaining a global data set are therefore required. One such way is via remote sensing techniques using Thermal Infrared (TIR) radiation emitted by the Moon and mapped by an orbiting satellite such as NASA's Lunar Reconnaissance Orbiter [1][2].

By comparing remote sensing TIR measurements from an airless body with three dimensional thermophysical models, several properties of the lunar surface and subsurface can be inferred, including composition, emissivity, albedo, surface roughness, porosity, thermal conductivity and density [3].

One of the most challenging aspects of creating a 3D thermophysical model is to accurately take into account the anisotropic emissions that are associated with different surface slope angles and roughness. Previous models for the lunar surface have assumed isotropic emissions and do not converge with experimental results taken both during the night and at low temperatures during the day [3]. Controlled laboratory measurements at different emission angles (e.g. via a goniometer) and under airless body conditions are thus necessary to create an accurate model.

Several goniometer systems have shown that the Apollo soils and lunar simulants do not scatter isotropically for visible wavelengths but instead re-emit radiation that falls with increasing angle of reflection [4] [5] [6]. A new instrument, the Oxford Space Environment Goniometer (OSEG), is able to make phase function measurements in the TIR and has recently shown that the surfaces do not radiate TIR in an isotropic fashion [7]. The OSEG setup heated samples to 100^{o}C from below and measured the directional re-radiation.

However, to include a full realistic treatment of scattering across visible to infrared wavelengths, the OSEG setup needed be updated to include a light source. This abstract reports on the improvements made to the OSEG [8][9] in order to measure the directional anisotropic re-radiation for airless body samples with varying illumination angles.

With these enhancements, the multi-angle TIR emission data from the OSEG will be more directly comparable with data from the Diviner Lunar Radiometer off-nadir measurements as part of NASA's Lunar Reconnaissance Orbiter (LRO) [2]. The Hyabusa2 and OSIRIS-REx missions also plan to perform multi-angle TIR measurements of asteroids 162173 Ryugu and 101955 Bennu respectively [9] [10]. The surface roughness, rock abundance, composition and thermal conductivity of these bodies could thus be more accurately inferred as well.

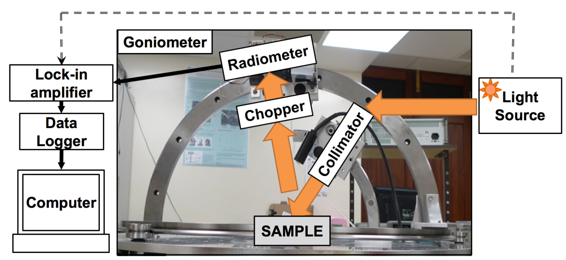

Figure 1: Annotated experimental setup where a sample is being illuminated the designed light source.

Goniometer design: The first OSEG design allowed phase function measurements of powdered airless bodies regolith simulant samples to be made across wavelengths from the visible to the thermal infrared. A radiometer carriage was designed to move around the sample to allow different emission/reflection angles to be measured. The wavelength selection between the visible and the thermal infrared could then be changed by swapping the detector inside the radiometer carriage.

The new setup uses a light source mounted on a second carriage that moves up and over the sample. The carriage can move to angles of up to 75° from the overhead position. For measurements in the visible a green laser is mounted onto the light source carriage and used to illuminate the sample. In the thermal infrared, a high powered, highly uniform, compact, wide beam (50 mm) light source is required to heat the sample. Figure 1 shows a photograph of the new setup.

Custom 2 Axis Automated Linear Translation Stage: Field of view and beam uniformity measurement were performed using a custom built 2 axis linear translation stage that was automated using stepper motors. A tailored electronic interface board was created to do this, allowing step sizes as small as 4.0±0.1µm to be achieved.

Infrared Radiometer carriage. The radiometer uses a thermal infrared pyroelectric detector (Infratec LIE-312F) with a reference chopper, an aluminium mirror and several baffles to remove off-axis rays. The field of view of the radiometer was measured using a constant heat source placed behind a heat shield with a pin hole. For these measurements, baffles in the optical setup could be adjusted or added to create the optimal field of view for measuring the emissivity of the samples as seen in Figure 2.

The shape of the field of view is important. At 0° a perfect circle is desired. The field of view will then become ellipsoidal with the semi major axis proportional to the cosine of the emission angle as the radiometer moves. This geometry allows the directional re-radiation to be directly measured by the OSEG setup without correction factors. This measurement also ensured the area of the field of view (even at maximum emission angle) did not go beyond that of the sample.

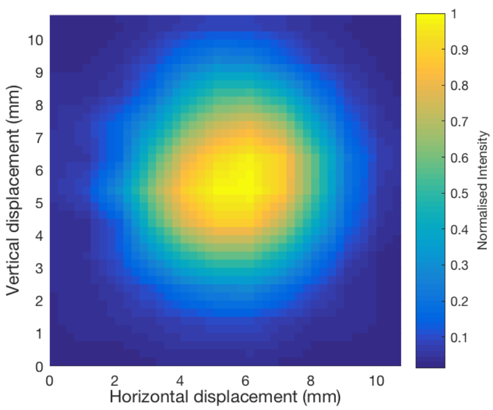

Figure 2: Radiometer field of view.

Light source. The method for creating the TIR radiation was changed from heating samples from below with a 50W sample cup heater controlled with a feedback loop, to illuminating the samples with a light source to simulate solar radiation. The light source therefore needed to be compact, high powered, highly collimated and uniform. This was performed with a standard 100W Quartz-Halogen incandescent bulb fixed to a semi-opaque convex lens (B270 Optical Crown Glass).

The light source's uniformity was tested directly (without a lock-in amplifier) using a SiPiN photodiode that was sensitive across wavelengths from 0.4 – 1.1 µm as seen in Figure 3.

Unfortunately, the measured lamp output did not meet the uniformity required to achieve a sensitivity of 0.01 emissivity. Further work on the lamp design is required to achieve a deviation of less than 1.5% or alternatively demonstrate sufficient stability to allow the non-uniformity of the light source to be removed as part of the instruments calibration scheme.

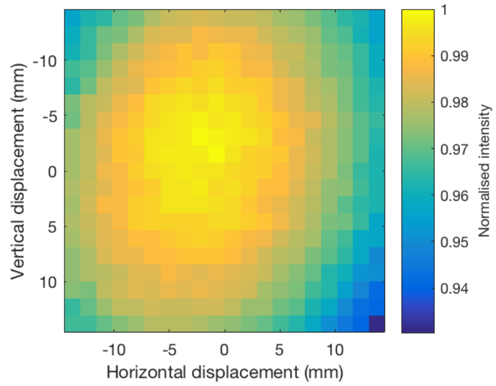

Figure 3: Light source field of incidence. The light is source is shown to be uniform within 5% over the region of interest (disc of radius 12mm).

Conclusion: The OSEG is now ready to measure the angular re-radiation of our powdered samples using the newly developed solar illumination light source. Measurements show this light source has good uniformity (5% across the beam) and has enough power to heat the sample to 100 K above the ambient temperature. These angular re-radiation measurements can then be fed back into 3D thermophysical models to improve their accuracy. They can also be compared to off-nadir measurements made by Diviner, Hyabusa-2 and OSIRIS-Rex to directly infer the surface roughness and composition of the surface regolith of airless bodies.

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