**Investigating Surface Roughness Effects on the Directional Emissivity of Surfaces Using the Oxford Space Environment Goniometer.** T. Warren[1], J, Arnold[1], I. Thomas[1], S. Lindsay[1], B. Greenhagen[2] and N. Bowles[1]. (1) Atmospheric, Oceanic and Planetary Physics, University of Oxford, Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom, (warren@atm.ox.ac.uk, jessica.a.arnold@physics.ox.ac.uk , thomas@atm.ox.ac.uk, lindsay@atm.ox.ac.uk, bowles@atm.ox.ac.uk). (2) Johns Hopkins University Applied Physics Laboratory, Laurel, MD USA, (benjamin.greenhagen@jhuapl.edu).

**Introduction:** Measurements of the light scattering behavior of the regoliths of airless bodies in the Solar System, across wavelengths from the visible to the far infrared are essential to understanding their physical properties and composition [1]. Phase function measurements from the visible to the far infrared are: (1) Critical to understanding remote sensing data acquired with a range of photometric angles. (2) Necessary inputs into three-dimensional thermal-physical models, which attempt to predict the surface temperatures of airless bodies. This presentation investigates how the regolith's surface roughness affects its phase function.

To measure the phase function we are using the newly developed 'Oxford Space Environment Goniometer' (OSEG). The OSEG allows phase function measurements of samples to be made under vacuum ($<10^{-6}$ mbar) whilst enclosed by a cooled (<150 K) radiation shield. The cooled radiation shield reduces the thermal background allowing phase function measurements from the visible to the thermal infrared (TIR) to be made.

**Infrared OSEG Design:** The OSEG was primarily designed to make Directional Emissivity (DE) measurements in the infrared. However, it is also able to make Bidirectional Reflectance Distribution Function (BRDF) measurements in the visible and near infrared, dependent on the type of illumination source installed in the instrument (Figure 1). To make DE measurements a 3mm deep, 50mm diameter sample is placed in the centre of the OSEG. The sample is heated from below and the radiometer carriage is moved to different emission (e, Figure 1) and phase angles ($\psi$, Figure 1). Traditionally the phase angle is defined as the angle between the illumination plane and the emission plane. However, as the OSEG does not currently illuminate the sample the phase angle is defined from an arbitrary plane.

*Radiometer.* For measurements in the infrared, the radiometer uses a high performance pyro-electric detector (Infratec LIE-332F-66) with a reference chopper. Currently, narrow band wavelength selection is provided by flight spare filters from the Diviner Lunar Radiometer instrument [2,3] and broadband wavelength selection is provided by a KBr window (0.23 – 20μm).

*Mechanical Implementation.* Stepper motors are used to control the position of the radiometer's phase and emission angles ($\psi$ and e, Figure 1). A stepper motor is also used to control the sample changer that can hold up to four samples. A PC is used to control all the stepper motors and to monitor temperatures within the instrument using certified reference 100Ω platinum resistance thermometers.

*Cold Shield and Vacuum Chamber.* For measurements in the TIR the level of background thermal radiation must be reduced. Therefore, the goniometer is surrounded by a cold shield (<150 K). To cool the cold shield to such low temperatures, the whole system must be enclosed in a ($<10^{-6}$ mbar) vacuum chamber (Figure 2). Critical components including the radiometer carriage have also been coated in high-emissivity Nextel black velvet paint to prevent stray light reflections from affecting the measurements.

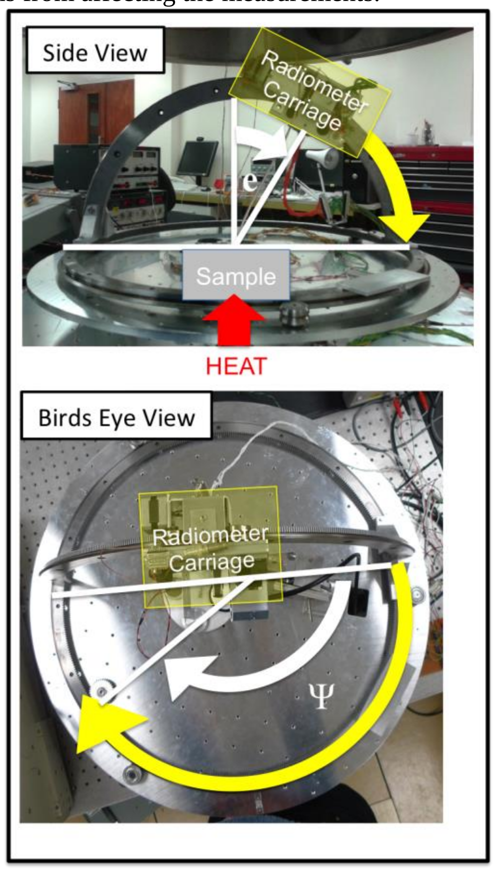


Figure 1: The side and birds eye view of the OSEG demonstrating its angular movement. Emission angle is e and the phase angle is $\psi$.

Figure 2: (left) Photograph of the goniometer setup inside the vacuum chamber and (right) the cold shield surrounded in MLI (multi-layer insulation) inside the vacuum chamber.

**Initial Broadband Directional Emissivity Measurements of Nextel Black Paint 811-21**

Broadband Directional Emissivity measurements of Nextel velvet black paint 811-21 have been made under ambient pressure in air (Figure 3). For this measurement a KBr (0.23 – 20µm) window on the front of the detector element case provided wavelength selection. The Nextel target was spray painted evenly with four layers of paint to provide smooth scale topography. Over the currently accessible angular range, measurements made by the OSEG are in agreement with previous measurements of the DE of Nextel made by other infrared goniometers [13 and there within]. Study 1 and 2 (Figure 3) were made by heating the sample from below to temperatures of 92.5, 123.5 and 148 °C over a wavelength range of 4 – 25µm.

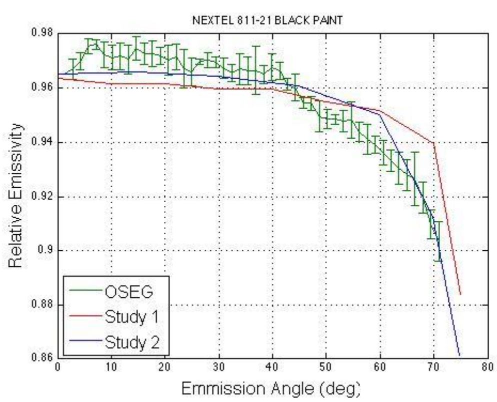


Figure 3: Measured DE values of Nextel 811-21 black paint by OSEG is shown in green. The error bars represent the standard deviation of all the measured DE values at a particular emission angle. Study 1 and 2 are previous DE measurements of Nextel from [13 and there within].

**Future work: Surface Roughness Modeling and Measurements**.

The DE of a surface is defined both by the scattering properties of the constituent materials [4,5] and the macroscopic (submillimeter to decimeter) scale topography [1,6,7]. We have been using the OSEG to investigate the DE of surfaces of varying roughness. To investigate the effect of macroscopic scale surface roughness on the DE, we are developing a range of targets to compare the DE of a flat surface against those with a defined slope distribution (e.g. sinusoidal, v-groove, craters).

Most phase function modeling work has previously focused on calculating the DE functions from a predefined surface height function assuming that the roughness scale is small compared to wavelength and therefore diffraction effects dominate [8]. For larger-scale topography, surface roughness properties are usually fitted to a model that includes a Gaussian slope distribution [6,9,10] that is not defined *a priori*. However, another slope distribution could be substituted into these models. Periodic surfaces have been considered for ocean bottom morphology [11], but this assumes that the: (1) BRDF of the material without any topography is isotropic. (2) Slopes are small enough that shadowing can be neglected. Although these conditions are not realistic for a natural surface, especially at high incidence angle, we could make a surface close to this for testing purposes. An alternative approach that uses isotropic facets, along with ray tracing [12] is also a possibility.

Surface targets that incorporate both periodic and random surface textures at multiple scales will be measured in the OSEG, allowing direct comparison between theory and measurement.

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**References:** [1] Hapke B. (1984), Icarus, 59, 41-59. [2] Paige, D. A. et al. (2009), Space Sci. Rev.150, 125-160. [3] Paige, D. A. et al. (2010), Science, 330, 479. [4] Foote, E. J. (2012) LPSC XXXXIII abstract #2357. [5] Pommerol, A. et al. (2011), Planetary and Space Science., 59, 1601-1612. [6] Helfenstein P. and Shepard M. K. (1999), Icarus, 141, 107-131. [7] Bandfield J. L. et al. (2015), Icarus, 248, 357-372. [8] Beckmann P. and Spizzichino A. (1987), Artech House, Inc. [9] Cook R. L. and Torrance K. E. (1981). [10] Smith B. G. (1967) JGR, 72, 16, 4059-4067. [11] Zaneveld J. R. and Boss E. (2003) Limnol. Oceanogr., 374–379. [12] Cooper K. D. and Smith J. A. (1985) IEEE, Ge 23, 5, 668-673. [13] PhD Thesis Lila Raj Koirala (2004), Univ of the FAF Hamburg, Germany.