THE OXFORD SPACE ENVIONMENT GONIOMETER. T. J. Warren, I. R. Thomas and N. Bowles[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, thomas@atm.ox.ac.uk, bowles@atm.ox.ac.uk).

Introduction: Measurements of the light scattering properties of the regoliths of airless bodies in the Solar system, across wavelengths from the visible to the far infrared are essential to understanding their surface properties. This presentation describes work currently under way to develop a novel 'Space Environment Goniometer' (SEG). The SEG allows phase function measurements of regolith simulant samples to be made under vacuum ($<10^{-4}$ mbar) whilst enclosed by a cooled (<150 K) radiation shield. The cooled radiation shield reduces the thermal background allowing phase measurements from the visible to the thermal infrared to be made.

This work was originally motivated by the need for new emission phase function measurements to support analysis of data currently being returned by the Diviner Lunar Radiometer ('Diviner') instrument. Diviner is a nine-channel mapping radiometer on board NASA's Lunar Reconnaissance Orbiter. It has channels ranging from the visible to the far infrared (>400μm) [1], with three channels centered on the mid-infrared (8μm).

To fully interpret the brightness temperatures measured by a thermal-IR instrument requires a 3D thermophyscal model [e.g. 2,3]. These models typically assume that infrared radiation is scattered isotropically from the lunar surface. Although generally the models are in very good agreement with the measured brightness temperatures, there are some discrepancies [2]. One possible reason for these discrepancies is that the scattering properties of the regolith in the mid-infrared are incorrectly estimated by the models. Although significant progress is being made in determining the scattering properties of the lunar soil in the visible and near infrared [e.g. 4,5], there is still limited or no data available on the scattering properties in the thermal (TIR) infrared.

Therefore, we are developing an automated, vacuum compatible goniometer system capable of measuring both the bidirectional distribution reflectance function (BRDF) and directional emissivity in the TIR of samples under simulated lunar thermal conditions in the laboratory. The first use of the system will be to provide support for measurements made by the Diviner instrument in the mid-infrared.

Infrared Goniometer Design: The goniometer has been designed, constructed and tested (Figure 1).

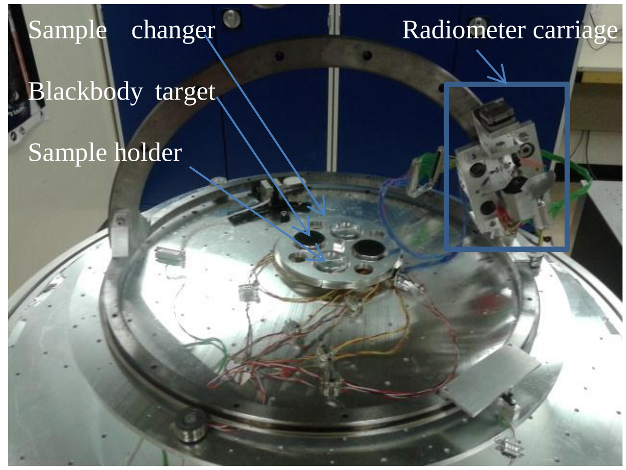

Figure 1: Photograph of the goniometer setup inside the vacuum chamber.

In the future, the SEG will make combined emission and reflectance measurements in the TIR surrounded by a cold shield (< 150 K) inside a vacuum chamber ($< 10^{-4}$ mbar) (Figure 3). The physical design of the goniometer is described below:

Light Source. For the initial test measurements (Figure 2) the goniometer used a green (532nm) laser to provide a collomated and geometrically well-controlled light source. The light source was chopped and coupled to an optical fibre light guide onto the sample. In the future for combined emission and reflectance measurements in the TIR the light source will be a 45W quartz halogen bulb and reflector providing a collimated beam directly onto the sample.

Radiometer. For testing and calibration in the visible the radiometer uses a visible Si PiN photodiode detector. For measurements in the infrared, the radiometer uses a high performance pyro-electric detector (Infratec LIE-312F) with a reference chopper for emission measurements and views of a calibrated blackbody target with a PRT to provide a traceable radiance calibration for thermal emission. Initial wavelength selection will be provided by spare Diviner filters [1].

Mechanical Implementation. Stepper motors are used to control the position of the radiometer's azimuthal and emission angles, and the position of the light source (i.e. incidence angle). A stepper motor is also used to control the sample changer, which can hold up to four samples, two of which are calibrated blackbody targets. A PC is used to control all the stepper motors and to monitor temperatures within the instrument.

Angle	Range
Incidence angle	0-74^o
Emission angle	0-84^o
Azimuth angle	0-180^o
Angular accuracy	0.1^o

Table 1: Angular range of the SEG, which is similar to other goniometers [5,6].

Cold Shield and Vacuum Chamber. For measurements in the TIR the level of background thermal radiation must be reduced. Therefore, the goniometer must be 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^{-4} mbar) vacuum chamber (Figure 2). The cold shield is made from 5mm aluminum alloy, and has a diameter of 0.8m and height of 0.5m. Critical components will also be coated in high-emissivity paint (e.g. NEXTEL Black velvet) to prevent stray light reflections from affecting the measurements. The cold shield has been tested and cools down to 150K with a ~3K temperature gradient between the top of the cold shield and the bottom.

As well as reducing the background TIR radiation, the cold shield and vacuum chamber will provide a lunar like environment around the sample. This simulated lunar environment induces a thermal gradient across the sample, which may affect the scattering properties of the lunar soil [7].

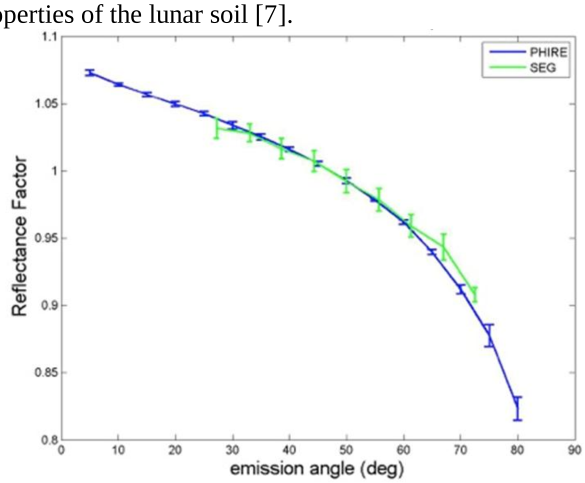

Figure 2: Comparison between measured Reflectance Factor (see [5] for definition) values of Spectralon in the visible by SEG and PHIRE (taken from [5], kindly supplied by Pommerol, A). The error bars represent the standard deviation of all the measured Reflectance Factor values at a particular emission angle, but at different phase angles.

Initial Results: The goniometer has been tested by comparing reflectance measurments of a certified spectralon target in the visible and near infrared to reflectance measurements made of a similar target by the PHIRE goniometer (Figure 2) [5]. Over the currently accessible angular range of the instrument there is good agreement (within 1 σ) between the two sets of measurements.

Summary and Conclusions: The goniometer is now ready to make directional emissivity measurements of lunar regolith analogue material inside heated sample cups. Once fully operational the goniometer will be able to measure full BRDF of lunar analogue minerals and Apollo samples heated both from abaove and from below. This will then allow photometric parameters [e.g. 8] to be fitted to the measurements, creating a new library of BDRF measurements directly comparable to the Diviner dataset.

Figure 3: (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.

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References: [1] Paige, D. A. et al. (2009), Space Sci. Rev.150, 125-160. [2] Paige, D. A. et al. (2010), Science, 330, 479. [3] Vasavada, A.R. et al., (1999), Icarus, 141, 179. [4] Foote, E. J. (2012) LPSC XXXXIII abstract #2357. [5] Pommerol, A. et al. (2011), Planetary and Space Science., 59, 1601-1612. [6] Shepard, M. K. (2001) LPSC XXXII abstract #1015. [7] Thomas, I. et al. (2012) LPSC XXXXIII abstract#2637. [8] Hapke, B. (1993), Cambridge Univ. Press.