Lunar heat flux measurements enabled by a microwave radiometer aboard the Deep Space Gateway. M. Siegler[1,2], Christopher Ruf[3],Nathaniel Putzig[1], Gareth Morgan[1], Paul Hayne[4], David Paige[5], Seiichi Nagihara[6], R. C. Weber[7]; [1]Planetary Science Institute, [2]Southern Methodist University, [3]University of Michigan, [4]University of Colorado, [5]University of California Los Angeles, [6]Texas Tech, [7]NASA Marshall Space Flight Center.

We would like to present a concept to use the Deep Space Gateway as a platform for constraining the geothermal heat production, surface and near-surface rocks, and dielectric properties of the Moon from orbit with passive microwave radiometery. This will compliment desired landed heat flux measurements from a reusable lunar lander as well as orbital thermal and radar data. We target and instrument with wavelengths between 300MHz and 3 Ghz (100cm-10cm). This should allow detailed mapping of the upper ~15m of the Moon to constrain **1) dielectric properties, 2) presence of bedrock, buried rocks and ground ice, and 3) subsurface temperatures that would constrain geothermal heat flux.** Despite this potential capability, no purposefully designed, passive microwave instrument has explored another body for geophysics measurements. With renewed interest in human and robotic site assessments enabled by the Deep Space Gateway, we believe the time for a microwave radiometer has come.

Any warm body will emit microwaves from a depth determined by the wavelength of the emitted microwave radiation and the properties of the material overlying it. Passive microwave instruments are traditionally used for atmospheric (e.g., JUNO MWR) and sea surface observations (e.g., Jason, Topex); however, microwave observations of a solid surface will reveal a wealth of information about subsurface temperatures and material properties. While instruments like the JUNO MWR can measure temperature profiles 100s of km into the Jovian atmosphere, similar wavelengths will see subsurface temperatures ~1-10m into lunar regolith. The depth which is measured depends on the dielectric properties of the surface.

Therefore, if we know the near-subsurface temperature profile (which is now well constrained by LRO Diviner), we can constrain near surface variations in dielectric properties. This is especially applicable to short wavelengths (~3Ghz, 10cm) which predominately sample the near surface layers constrained by infrared measurements. These measurements will be critical for interpreting microwave wavelength radar measurements of the subsurface from orbit. For the Moon, we know surface transparency in microwave wavelengths varies mainly due to changes in minerology (dominated by the dielectric properties of TiO_2 and ilmenite) and density (i.e., subsurface rocks). This allows a microwave radiometer to be used to map Ti-rich minerology as well as buried density anomalies.

Once shorter wavelengths have been used to constrain near dielectic properties, longer wavelengths can be used to find variations from expectations of standard a lunar regolith column. Decreases in microwave brightness temperature are indicative of buried rocks of bedrock, which prevent microwave radiation at depth from being seen. Increases in microwave brightness temperatures from expectation are indicative of high geothermal heat flux.

Passive microwave maps of the Moon have been produced by Earth-based radio observations and recently by a twice-flown Chinese Chang'E 1 and 2 lunar orbiting microwave radiometer (MRM). The Chinese lunar instrument was a copy of a terrestrial meteorology instrument, rather than specifically designed for the Moon, and it has known calibration issues. Despite these shortcomings, published work and even can extend our knowledge of the thermal and physical state of the subsurface beyond the infrared and yield information about electrical properties unobtainable from radar.

The longest Chang'E wavelength was 3GHz (10cm), which has should show a small variation due to geothermal heat flux, on the order of 1K per 10mW/m^2. When expected temperature differences due to latitude, slope, and albedo, this appears to be exactly what we see (Figure 1). Interestingly the areas where the largest increase in brightness temperature are seen are also rich in Th and other heat producing elements (Figure 2), suggesting that we are indeed seeing increased geothermal heat flux. As temperature differences due to variations in heat flux become larger with depth, we desire measurements to ~100cm, where temperature differences on the order of ~5-10K per 10mW/m^2 should be expected. Given a large platform like the Deep Space Gateway, we believe that such an instrument can revolutionize our understanding on the near surface and interior composition of the Moon.

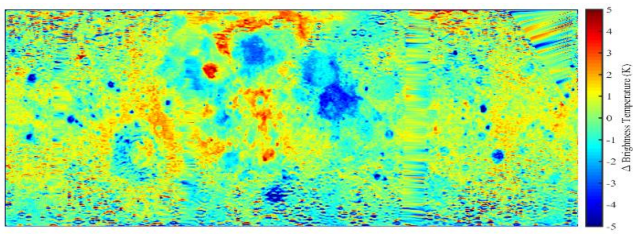

Figure 1: Chang'E-2 MRM 3GHz midnight data corrected for latitude, slope, and albedo variations. Note the prominent cooling from high-Ti mare and rocks (e.g. Orientale), but residual warming of low-Ti areas in the Procellarum region.

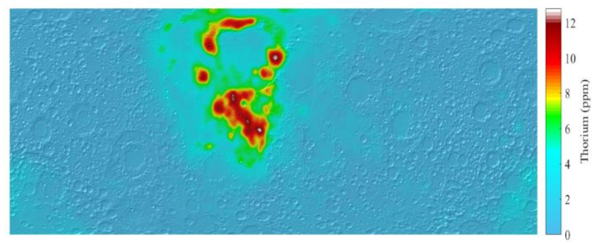

Figure 2: Thorium in the upper 1m of the lunar regolith as measured by Lunar Prospector. Note that areas with high crustal Th, and therefore expected higher crustal heat production, are also hotter than expected in the Chang'E data in Fig. 1.

We have designed a preliminary system with 300MHz to 3Ghz frequency range that should exceed the capability of the Chang'E MRM. The longer wavelengths will allow for heat flow constraint in even Titanium-rich regions and global mapping of regolith thickness. The basic instrument is simply electronic instrumentation that can be added to existing radar or communications antenna systems. In the case of communications or SAR instruments, nadir pointing would be required.

Table 1. Microwave Radiometer Specifications		
	Min	Max
Frequency Range (MHz)	300	3000
Gain (dB)	37	97
Dynamic Range (Hardware)	0	25
Noise Figure (dB)	2.5	3
Lo Synthesizer Lock Time (µs)		500
Switch Transition Time (µs)		90

- Mass: >2kg electronics added to existing communication or radar antenna system
- Power: ~4.6 and 8.6W depending on digital switching mode.
- Cost: ~$1-5M
- Volume: Minimal electronics, antenna pointed to nadir desired.
- Amount of crew interaction: None, if using communication antenna, nadir lunar pointing required.
- Desired deep space gateway orbit: Any, but favored greatest time of day/latitude/longitude coverage, minimum orbit height (LRO-like orbit)
- Other resource needs: None