# A NEW MAP OF THERMAL VARIATIONS WITH DEPTH WITHIN OCEANUS PROCELLARUM AND MARE IMBRIUM USING CHANG'E-2 (CE-2) MICROWAVE RADIOMETERS (MRMS) DATA.

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**Introduction:** By virtue of its longer wavelength in comparison to UV-VIS-IR, microwave radiation carries information from deeper into the surface and can extend to several times the observation wavelength. Moreover, passive microwave measurements can be carried out during nighttime and in shadowed regions. Most observations of the lunar surface in these frequencies were Earth-based but they helped develop theoretical models to obtain the brightness temperature (TB) of the lunar surface and derive several of physical parameters including heat flow [1]. In this paper we preview the results from a new investigative approach that takes advantage of global lunar microwave data obtained from the Chang'E missions (CE-1 and CE-2). The multi-channel radiometers worked at four different frequencies (about 37, 19, 8, and 3 GHz), probing increasingly deeper into the surface.

The area under investigation is the most closely scrutinized surface of any extraterrestrial body, encompassing Mare Imbrium and Oceanus Procellarum in the west. Our work focuses on TB differences between the uppermost surface layer and several meters below, taken at (lunar) midnight (Fig. 1).

**Data and method:** The Level 2C Chang'E-2 (CE-2) Microwave RadioMeter (MRMs) data [2-3] was used in this study, following system calibration and geometric correction with Planetary Data System [4]. The MRM underwent onboard adjustments to ensure its reliability and accuracy using a two-point calibration method (for details see [2-5-6]). We used spherical harmonic fits for the Brightness Temperature (TB) variations with local time [6] to suppress the lunar phase effect. Normalized TBs at midnight were chosen to minimise the topographic effects on the emission [7].

We selected the widest range possible of data from the four frequencies available (3 and 37 GHz) to compare the average thermal emission at different depths within the lunar regolith (centimeters range for 37 GHz, 0.81 cm wavelength, to several meters at 3 GHz, 10 cm wavelength). Fig. 2 shows the derived microwave maps at the chosen frequencies. The penetration depth mainly depends on wavelength but also on the bulk density and loss tangent of the lunar regolith.

Cooler areas (Fig. 2) both in the 3 and 37 GHz bands are governed by the ilmenite ($FeTiO_3$) content in the regolith, which, due to the shallow penetration, blocks the deeper warmer contribution to the surface. The combination of the rocks and ilmenite appears as relative low-temperature regions (i.e., Aristarchus and north Imbrium's highlands). 'Hot' spots in the 3 GHz map are related to the ilmenite-poor composition and the rock distribution.

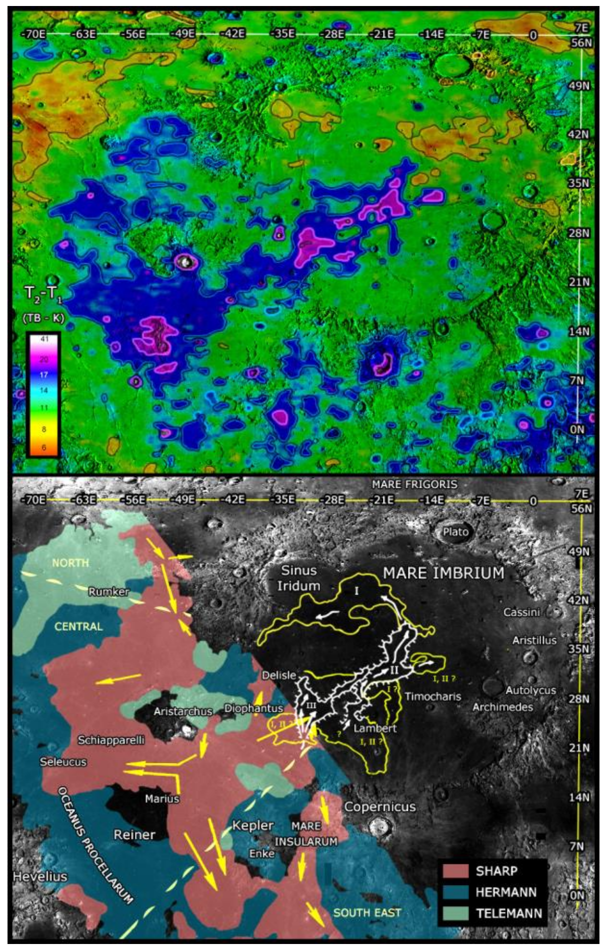


**Figure 1.** Upper. Map shows the temperature differences (K°) at midnight between the temperature average of the surface layer down to ~5 meters ($T_2$) and that of the uppermost ~1 m layer ($T_1$), [8] expressed as 'Brightness Temperature' (TB); below: 1] distribution of three formations in Mare Procellarum as described by [9] based on UV/VIS ratio, albedo, and other parameters. Arrows show proposed flow directions of units the for Sharp formation; Lower. Proposed areal distribution of the three most recent mare flows within the Imbrium basin (I-III), according to [10]. Background image is a lunar Clementine Global UVVIS 750 nm mosaic [11] overlaid on a shaded relief map [12].

In order to investigate further the thermal properties of the subsurface materials the 37 GHz thermal data were subtracted from the 3 GHz to produce a TB difference map (Fig. 1).

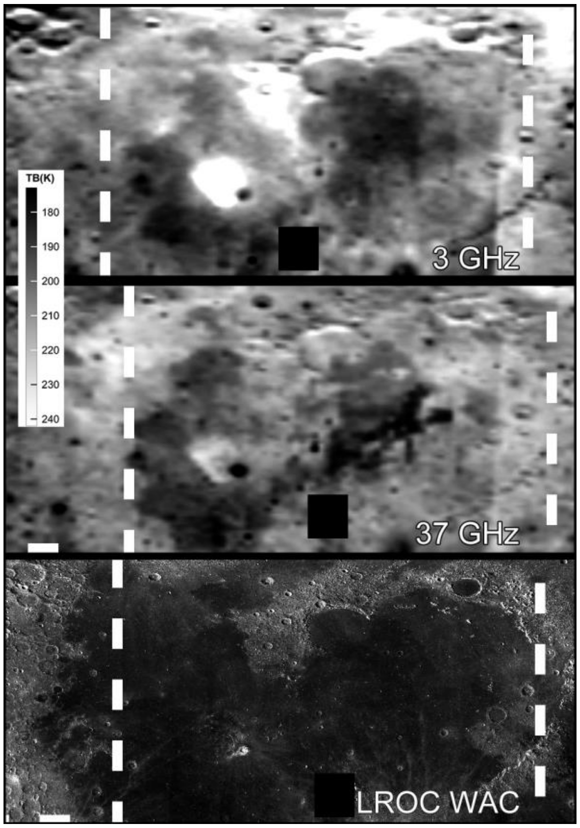


**Figure 2.** Microwave maps with latitude effect removed. Top two images were derived from lunar midnight data. LROC WAC reflectance image for reference.

**Results:** Mare flows within Mare Imbrium (MI) have been the focus of much research for over 40 years [e.g. 10] and still ongoing. Oceanus Procellarum (OP) does not share the same level of scrutiny but flows were mapped by [9] up to the inferred south-western rim of the Imbrium Basin (Fig. 1). The microwave map shows sharp temperature (differences) gradients that closely follow surficial and reflectance spectra recognized within MI by [10] and confirmed by several studies that followed. However, the TB map suggests that the high-Ti mare flow mapped as 'I' does not have an equivalent microwave signature. Likewise, we find no 'thermal lows' south of Lambert crater either. Instead, the relatively cooled subsurface can be traced as a single unit down to the Reiner crater. There is general agreement between the OP mare flow distribution marked as 'Sharp' by [9] and this work. Most available titanium maps [e.g. 13], which represent the $TiO_2$ wt% of the top millimeter of the lunar surface, show a low-Ti region radial to Aristarchus, including a large area separating the continuous 'blue' TB feature between OP with MI. It is likely that ejecta from the young crater might have scattered excavated low-Ti materials over this area.

The largest TB differences broadly correspond to the core of flow 'II' [10] and the Marius region in OP. The 'Telemann' (North) unit corresponds to an area that has reached thermal equilibrium between surface and sub-surface regolith.

The ('white') areas with the largest TB differences correspond to craters Aristarchus, Reiner and the south rim of Copernicus. These are covered with debris and impact melts from the relative recent impacts; the southern part of Copernicus differs from the northern section by having a much higher iron content [14], due probably to a larger presence of impact melt with similar composition to basalt.

**Conclusions:** This work represents just a preliminary look at the high-quality microwave data produced by the MRM instruments. Together with a qualitative analysis of spatial distribution of TB differences, progress is being made to extract quantitative data relating to several physical parameters, including ilmenite content, rocks distribution, and craters age estimation.

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