A PRELIMINARY ESTIMATION OF LUNAR HEAT FLOW FROM CHANG'E-2 MICROWAVE RADIOMETER OBSERVATIONS. Shuoran Yu[1] and Wenzhe Fa[2], [1]Space Science Institute, Macau University of Science and Technology, Macao 999078, China (toniyu90@gmail.com). [2]Institute of Remote Sensing and Geographical Information System, Peking University, Beijing 100871, China (wzfa@pku.edu.cn).

Introduction: Lunar heat flow provides important information for constraining internal temperature profile of the Moon, estimating the bulk concentration of radioactive elements (Th, U and K) in lunar crust, and testing models for formation and thermal evolution of the Moon [1]. Based on long-term measurements of Apollo heat flow probes, heat flows at the Apollo 15 and 17 landing sites were estimated as 0.021 and 0.016 Wm^{-2}, respectively [2]. Given these two measurements were conducted at the boundary between highlands and maria, it is still in debate whether the estimated heat flow is representative at global scale or not.

Given the low dielectric loss of lunar regolith, microwave at proper frequency can penetrate several meters below lunar surface. Thermal emission from lunar surface layer correlates closely with subsurface temperature profile, from which internal heat flow of the Moon can be estimated. Therefore, spaceborne passive microwave remote sensing provide an effective tool for global studying of heat flow of the Moon.

In this study, Chang'E-2 (CE-2) microwave radiometer (MRM) Level 2C data were analyzed with the purpose to invert lunar heat flow at global scale. The observed brightness temperatures (TBs) were preprocessed by radiation correction, removal of sidelobe components in Level 2A and 2B procedures, and validation based on ground truth at Apollo landing sites. Then a radiative transfer model is used to simulate thermal emission from lunar regolith layer, with considering the dielectric and temperature profile of lunar subsurface. This model shows a linear relation between brightness temperature and internal heat flow. Using this relation, heat flow at mid-latitude region (60°S – 60°N) is inverted from TB at 3 GHz.

Thermal Emission Model and Heat Flow Inversion Approach: In this study, lunar surface layer is described by a two layer model, i.e., a regolith layer atop an underlying bedrock. The regolith layer is described by its physical temperature, dielectric constant and thickness, and the underlying bedrock is described by its dielectric constant. Using a similar radiative transfer approach as in [3], thermal emission from lunar surface layer can be calculated, with considering temperature and dielectric profiles within the regolith layer. Based on the relation among dielectric constant, bulk density and regolith composition [4], dielectric constant profile of regolith layer was introduced with an assumed porosity profile [5]. The model input physical temperature profile was obtained by resolving one-dimensional heat transfer equation [6] where temperature gradient at equilibrium depth is mostly dominated by internal heat flow [7].

Figure 1 shows the simulated TBs at 3.0, 7.8, 19.35 and 37 GHz as a function of heat flow for highland region at lunar midnight. It can be seen that TB at four channels increases linearly with internal heat flow. Among the four channels, 3.0 GHz is most sensitive to heat flow because of its larger penetration depth. Further analysis shows that this linear relation depends on frequency, FeO and TiO_2 abundances, lunar regolith thickness, and local time. Therefore, as this parameter dependent relation (represented by two coefficients) is obtained from thermal emission model, lunar internal heat flow can be estimated from TB at 3 GHz.

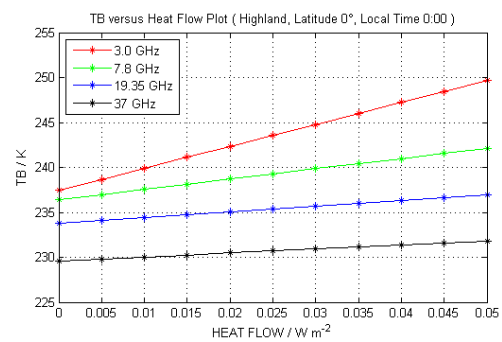

Figure 1. Simulated TB as a function of heat flow for lunar highlands at lunar midnight.

Data Validation and Normalization: In this study, CE-2 MRM level 2C data are analyzed for our heat flow inversion. Because cross-polarization leakage and spillover factor of antennas were not measured, TB at 2C level does not rigorously follow the properties of antenna system [8] and data validation is required before any quantitative analysis. Here the data were validated by using the simulated TBs at Apollo 15 and 17 landing sites where in situ measurements of heat flow and other geophysical parameters are available. We found that there is an obvious offset about 14 K between the observed TB and model simulations. Therefore, this offset was added directly to the observed TBs in the heat flow inversion.

For a given location, thermal emission correlates closely with dielectric properties of regolith as well as physical temperature that depends upon solar illumina-

tion [9]. In order to reduce the effect of time- and latitude-dependent influences on TB, the TBs used in heat flow inversion should be normalized for latitude and local time. Figure 3 shows the normalized TB map at 3.0 GHz with a spatial resolution of 2°, which represents thermal emission at midnight if each resolution cell were at lunar equator.

Results and Discussions: Using maps of FeO and TiO_2 abundances [10] and regolith thickness [11], the coefficients in linear relation between TB and heat flow can be obtained from TB simulation for each pixel. Then, heat flow can be estimated from TB at 3 GHz by using these coefficients.

Figure 3 shows the inverted heat flow map for mid-latitude region. It is prominent that heat flow of Oceanus Procellarum varies from 0.05 to 0.15 Wm^{-2}, which is much higher than other regions. Heat flow of Ferroan Highland Terrane is relatively uniform with a mean value about 0.03 Wm^{-2}, and that of South-Pole Aitken is about 0.04 Wm^{-2}. The inverted heat flows in Apollo 15 and 17 landing sites are 0.053 and 0.019 Wm^{-2}, respectively. Our inverted heat flow at Apollo 15 landing site deviates largely from the in situ measurement, which might be caused by the scale difference between the large resolution of CE-2 radiometer and the in situ geophysical measurement.

Spherical harmonic analysis of the inverted heat flow shows that the average heat flow of the Moon is 0.029 Wm^{-2} and the difference of heat flow between farside and nearside is about 0.001 Wm^{-2}.

Conclusions: In this study, lunar heat flow for mid-latitude region is inverted from 3.0 GHz TBs observed by CE-2 MRM. Our results show that: (1) Oceanus Procellarum has a very high heat flow. Ferroan Highland Terrane and South-Pole Aitken present a heat flow around 0.03 Wm^{-2} and 0.04 Wm^{-2}, respectively. (2) The mean heat flow of the Moon is 0.029 Wm^{-2} and heat flow difference between farside and nearside is about 0.001 Wm^{-2}. The inversion error depends mainly on TB uncertainty and dielectric constant of regolith (relative with FeO and TiO_2 abundances). The in site measurements of heat flow were only conducted at two points, whereas a 3.0 GHz observation represents thermal emission from a resolution cell with a diameter of 28 km. If thermal conditions of these two points cannot represent their surrounding areas within a resolution cell, the estimated offset could be large.

References: [1] Wieczorek M. A. et. al. (2006) *Rev. Mineral. Geoch*em., *60*, 221-364. [2] Langseth M. G. et. al. (1976) *Proc. LPS VII*, 3143-3171. [3] Jin Y. Q. and Fa W. (2010) *IEEE Geosci. Remote Sens. Lett.*, *7*, 530-534. [4] Huang Q. and Wieczorek M. A. (2011) *LPS XLII*, Abstract#1879. [5] Heiken G. H. et. al. (1991) New York: Cambridge Univ. Press. [6] Vasavada A. R. et. al. (1999) *Icarus*, *141*, 179-193. [7] Mitchell D. L. and De Pater I. (1994) *Icarus*, *110*, 2-32. [8] Wang Z. Z. et. al. (2010) *Sci. China Earth Sci.*, *55*, 1392-1406. [9] Zheng Y. C. (2012) *Icarus*, *219*, 194-210. [10] Prettyman H. T. et. al. (2006) *JGR*, *111*. [11] Fa W. and Jin Y. (2010) *Icarus*, *207*, 605-615.

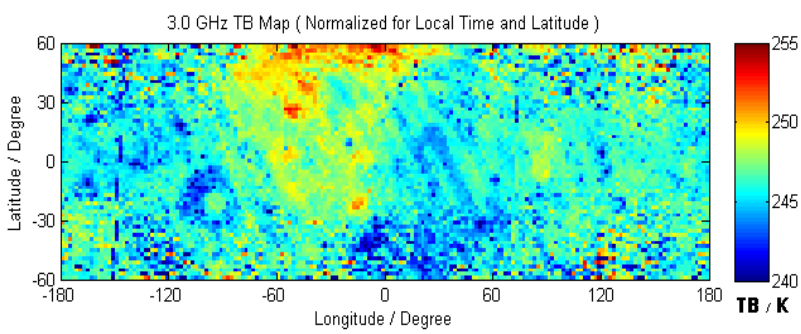

Figure 2. Normalized 3.0 GHz TB at lunar midnight for mid-latitude region.

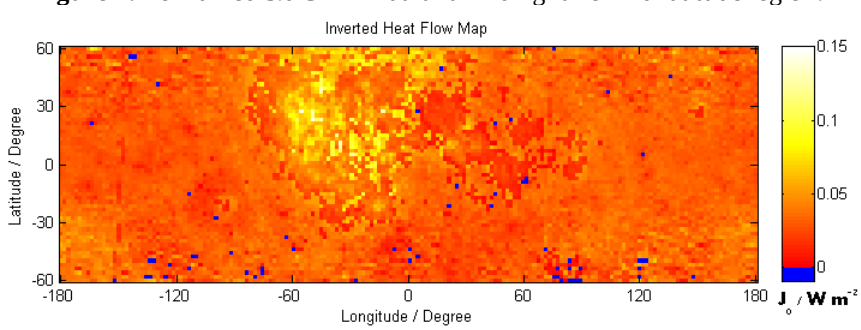

Figure 3. Inverted heat flow map for mid-latitude region.