A retrieval of lunar surface rock abundance by LRO Diviner infrared observations

X.H. Gong[1], M.J. Xia[1], Y.F. Yao[1], H.Liu[1], H.Q. Xu[1] [1]Donghua University, Shanghai, 200000, China (Xhgong@dhu.edu.cn)

Introduction: The lunar surface rock abundance is a prior parameter for understanding the geological properties of the Moon. It was found that rocks would present an obvious thermophysical difference contrasting to the regolith at night from the Infrared (IR) observations[1]. And the LRO Diviner radiometer has obtained the global thermal mapping of the Moon in 9 spectral channels from the wavelength 0.3 to 400 microns[2]. By comparing the simulation temperature results solved from the one-dimensional thermal equation with topography and Adobe parameters concerned and the Diviner thermal mapping at night, the influence of the rocks of the lunar surface could be derived[3,4].

Data: The observations from Diviner radiometer Channel 8 obtained in a whole year of 2010 were collected to describe the global IR thermal properties of the lunar surface at night. The times of observation are restricted from 19:30 to 5:30 next morning by every hour, and the IR temperature between ±60° latitudes at midnight (0:30-1:30) is shown in Fig. 1 by 0.5×0.5 degree every grid. It can be noticed that some "hot spots" are distinguished from their surroundings, which might be caused by the thermophysical difference between the lunar rocks and regolith.

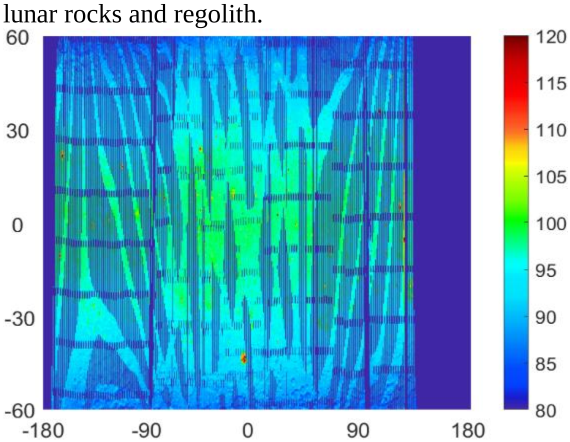

Fig.1 IR observations of Diviner Channel 8 from 0:30-1:30 at lunar local time

Model: The retrieval of the rock abundance depends on multiple temperatures presented by rocks and regolith, and the measurements of temperature are contributed from all the compositions by their own fractions. We try to simulate the temperature of rocks and regolith at night respectively from the one-dimensional thermal model. For the regolith temperature, it is mainly influenced by different factors such as the lunar surface albedo, the solar illumination and also the rocks. In the place where the slope is large, the topographical variance plays an important role in affecting the solar incidence angle and further the thermal property, as the solar incidence angle is a key parameter of the boundary condition when solving the one-dimensional thermal conduction equation. For the studied areas, the subsolar point is considered at the equator and the sun incidence angle θ_i depending on slope can be calculated as[4]:

$$\cos\theta_i = \hat{n}_l \times \hat{s} \quad (1)$$

where $\hat{n}_l$ is the unit normal vector in situ and $\hat{s}$ is the unit normal vector of the subsolar point.

To investigate the thermal conduction process of the regolith, the one-dimensional thermal equation is employed[4]:

$$pC\frac{\partial T}{\partial z} = \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) \quad (2)$$

And the thermal parameters are following the former studies[5]. The Albedo depending on solar illuminations can be calculated by an empirical formulation [4]:

$$A(\theta) = A_0 + a(\theta_i/45)^3 + b(\theta_i/90)^8 \quad (3)$$

The upper and lower boundary conditions are given as[3]:

$$K(z,T)\frac{\partial T}{\partial z}\bigg|_{z=0} = TSI(1-A)\cos^+\theta_i - e\sigma T_s^4 - J_0 \quad (4)$$

$$K(z,T)\frac{\partial T}{\partial z}\bigg|_{z=0} = -J_0 \quad (5)$$

Here, the value for TSI is 1414W/m^2 and J_0 can be neglected. $cos^+\theta_i$ is $\cos\theta_i$ if $\cos\theta_i > 0$, otherwise it is 0.

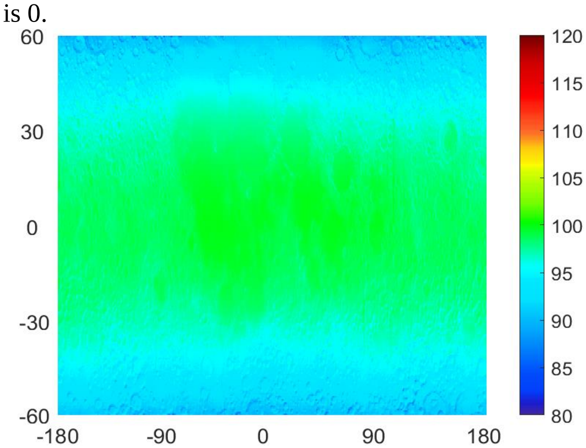

Fig.2 Simulated surface temperature at midnight (Local time 0:00) with topography

The global simulation results of the lunar regolith temperature at midnight is provided in Fig.2. An obvious difference between the simulation and measurement results is that the simulations lack of the "hot spots" existing in Fig.1. The rock's temperature at night is also simulated from the one-dimensional thermal model with rock thermal-physical parameters, and the method is following the study by Bandfield et.al[3]. By comparing these results together, it is possible to conclude the proportion of rocks.

Results: According to Plank's blackbody radiation theory, the measured temperature is corresponding to a specific radiance as[6]:

$$P(T) = \frac{8\pi v^3 h}{c^3} * \frac{1}{e^{hv/kT} - 1} \quad (6)$$

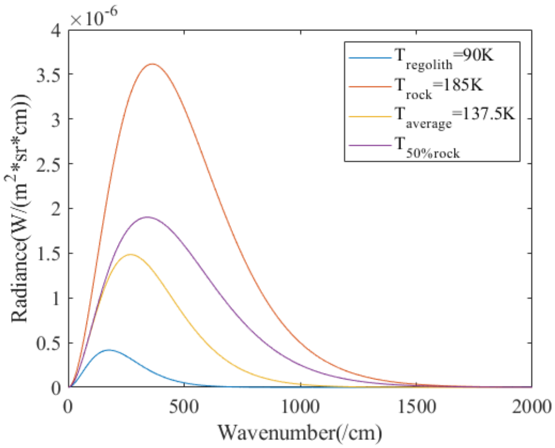

Fig.3 The radiance at different temperatures and wavelengths

The Plank radiance at different temperature and wavelengths is shown in Fig.3. For example, if the rock temperature is taken as 185K and the regolith temperature 90K, it can be concluded that the radiance average and radiance converted from the average temperature is not totally the same. To obtain the exact contributions of each part, we need to convert the rock and regolith temperatures to radiances first and then derive the rock fraction by a weighted formula:

$$f_{rock} = \frac{P_{IR} - P_{regolith}}{P_{rock} - P_{regolith}} \quad (7)$$

For each observation collected, we record the temperature, position, and local time, and then calculate a weighted radiance by rock fraction from the regolith and rock simulation results at the corresponding position and time, and the global lunar surface rock abundance is obtained in Fig.4.

To validate the reliability of the retrieval, the King Crater (120 °E, 5.5 °N) is chosen to present the result. With a retrieved ~10% rock abundance, the temperature at King Crater shows a better agreement with the measurements than only the rock or regolith.

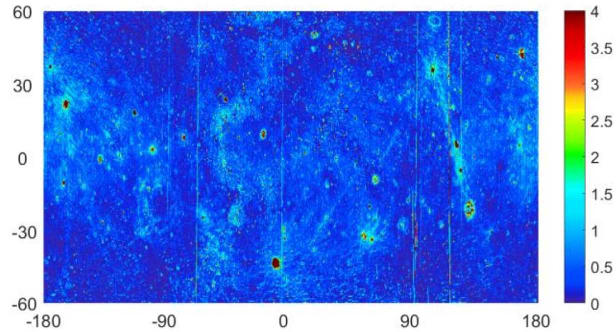

Fig.4 The global rock abundance (%) derived from Diviner IR measurements

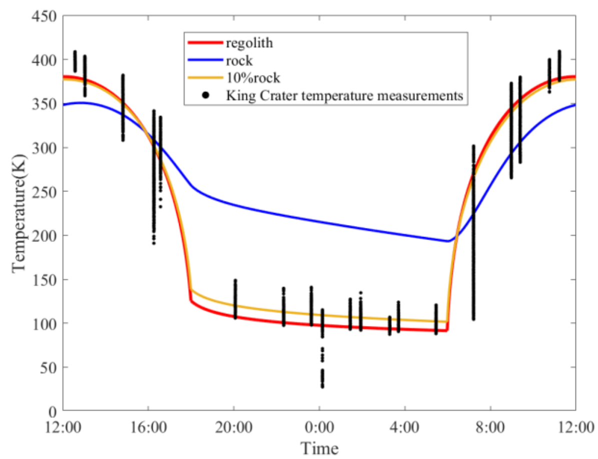

Fig. 5 The rock abundance and temperature with 10% rock at King Crater (120 °E, 5.5 °N)

Summary: We calculated the rock abundance directly from the modeled regolith and rock temperatures and the Diviner IR measurements. And for those craters with obvious rock characters, such as Tycho Crater, King Crater, our result also shows a high rock abundance, which is reasonable. Also, compared with the former studies by Bandfield et.al[3], our result shows a good agreement with the rock abundance variation tendency and the absolute value is a bit higher, which might be resulted from different calculation method.

References:

[1] D. Paige, et al. (2010)Space Sci. Rev. 150:125. [2] J.P.Williams and D. Paige, et al.(2011) *JGR*, 116, E12. [3] J. L. Bandfield et al. (2011)*JGR*, 116, E12. [4] N. Liu and Y. Jin(2020) *IEEE Trans Geosci Remote Sens*, 58,1892-1903. [5] A. R. Vasavada and D. Paige et al.(1999) *Icarus*, 141, 179–193 [6] H. M. Roeser.(1979) *J Franklin Inst*, 184(1):109.