INVERSION OF DIELECTRIC CONSTANT AT LUNAR SOUTH POLE: BASED ON CHANG'E-2 MICROWAVE RADIOMETER DATA.

G. Wei[1], X. Li[1] and S. Wang[2], [1]Center for Lunar and Planetary Sciences, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China (weiguangfei@mail.gyig.ac.cn). [2]State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China (lixiongyao@skleg.ac.cn).

Introduction: Finding water on the Moon has always been one of most interesting and significant goals of lunar exploration, especial for the permanently shadowed regions (PSRs) on polar regions. Signals of water have been detected by radar observation[1], neutron spectrometer[2] and direct impact experiment by Lunar Crater Observation Sensing Satellite (LCROSS) [3]. In this work, we try to invert dielectric constant of regolith from microwave emission data at Cabeus crater, where it may harbor water ice as revealed by LCROSS ejecta plumes. Note that thermal environment at PSRs is quite complex because it is affected by scattered sunlight from surrounding terrains, earthshine and heat flows [4]. Therefore, we should take into account of a moderate thermal mode before retrieving.

Passive microwave remote sensing has been successfully applied in Chang'e-1 (CE-1) and Chang'e-2 (CE-2) of Chinese lunar exploration [5]. Microwave radiometer (MRM) onboard both CE-1 and CE-2 measured regolith thermal emission at four channels: 3, 7.8, 19.35 and 37 GHz. With increasing of wavelength (i.e. decreasing of frequency), MRM could see greater depth in the form of brightness temperature (Tb) which is related to regolith thermophysical properties, internal heat flux and plausible water ice.

Diviner onboard Lunar Reconnaissance Orbiter is a 9-channel push-broom radiometer that maps lunar surface thermal environment over a wavelength range of 0.3 to 400 μm [6]. With continued measurements over 8 years, it is possible to create a dataset that cover the Moon at any local time [7]. Bolometric brightness temperature (Tbol) calculated from channel 3 to 9 is more directly related to the heat balance of the surface [4] which is useful to represent surface temperature at PSRs. Thus, it is feasible to estimate subsurface temperature by thermal model.

Thermal model and inversion approach: In this study, we use MRM data at high frequencies (37, 19.35 GHz) obtained by CE-2. The average penetration depth of the Moon for the two channels are no more than 0.4 m [8] which are far less than the regolith thickness measured by Apollo in situ experiment and radar observations [9]. Thus, we assume that the regolith of polar regions is a half-space, and theoretical Tb can be calculated by Eq. 1 for the inhomogeneous materials [10].

$$Tb(\nu,t) = (1-r_\nu)\int_0^\infty \rho(z)\kappa_\nu T(z) e^{-\int_0^z \rho(z')\kappa_\nu dz'} dz \quad (1)$$

where r_ν is surface reflectivity at frequency ν, κ_ν is absorption coefficient. Here, κ_ν is given as a constant because the depth-dependent bulk density has been take into account [11]. $T(z)$ is temperature profile which can be calculated by heat diffusion equation (Eq. 2) and time-dependent upper boundary condition Tbol. The lower boundary condition is internal heat flux which was given as 18 $\mathrm{mW/m^2}$.

$$\rho(z)c(z)\frac{\partial T(z,t)}{\partial t} = \frac{\partial}{\partial z}\left(\kappa(z,T)\frac{\partial T(z,t)}{\partial z}\right) \quad (2)$$

Combining Eqs. (1) and (2), Tb of 37 and 19.35 GHz (Tb_{37}, Tb_{19}) at any local time can be calculated. Thus, we could find the best fit r_ν and κ_ν values by minimizing observed data (Tb_ν^o) and calculated ones.

$$r_\nu, \kappa_\nu = min\sum\sqrt{(Tb_\nu - Tb_\nu^o)^2} \quad (3)$$

As the r_ν and κ_ν are obtained, we can calculate dielectric constant of the material under CE-2's zero degree observation angle $r_\nu = |(1-\sqrt{\varepsilon'})/(1+\sqrt{\varepsilon'})|^2$. The specific loss tangent can also be obtained by $\tan\delta = \kappa_\nu \bar{\rho} c/(2\pi\nu\sqrt{\varepsilon'})$, where ε' is real part of dielectric constant, $\bar{\rho}$ is average bulk density and c is speed of light.

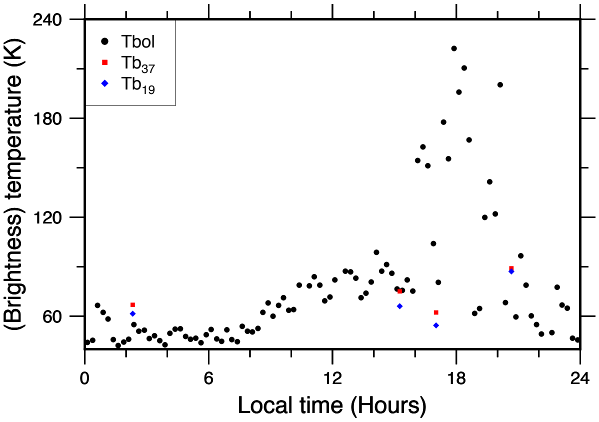

Fig. 1 (Brightness) temperature varies with local time at 84.25°S, 35.25°W which is located in Cabeus crater.

Results and Discussion: As shown in Fig. 1, Tbol (black points) at (84.25°S, 35.25°W) within Cabeus crater varies with local time in a diurnal day. Additionally, Tb_{37} (red square) and Tb_{19} (blue diamond) covering the same location were also selected. There are less repeat coverage data points because of CE-2's one year orbital observation. However, that does not influence our inversion results because the observed Tb_{37} and Tb_{19} at anytime can be used to retrieve dielectric constants.

Table 1 presents the inverted mean dielectric constant at 37 and 19.35 GHz. We also calculate the dielectric constant based on Carrier et al.'s [12] and Fa and Wieczorek's [13] models. The content of FeO and $\mathrm{TiO_2}$ are derived from Gamma-ray data as in the work of Prettyman et al. [14]. Note that the specific loss tangent ($\tan\delta$) was derived from the given density $\overline{\rho} = 1.7\mathrm{g/cm^3}$ [13].

Table 1 Inverted dielectric constant and comparison with other models.

Comparison	ε'	$\tan\delta$
this work (Tb_{37})	3.45	0.0049
this work (Tb_{19})	3.27	0.0056
based on Carrier et al. [12]	3.03	0.0029
based on Fa and Wieczorek [13]	2.84	0.0040

Obviously, the inverted dielectric constant (ε' and $\tan\delta$) from Tb_{37} and Tb_{19} are greater than that of Carrer et al.'s [12] and Fa and Wieczorek's [13] models. This may be caused by water ice in addition to topographic effect. Because 19.35 GHz has greater penetration depth than that of 37 GHz, the greater value of $\tan\delta$ inverted by Tb_{19} indicates vertical inhomogeneous of regolith or buried water ice in greater depths.

Conclusions: Water ice detection at PSRs is an important scientific goal in lunar exploration program. Here we tried to invert dielectric constant at Cabeus crater by combining the data sets from CE-2 MRM and LRO Diviner. The inverted ε' and $\tan\delta$ values are greater than those estimated from FeO and $\mathrm{TiO_2}$ content. It indicates buried water ice in addition to topographic effect. The greater value of $\tan\delta$ inverted from Tb_{19} also indicates vertical inhomogeneous of regolith and buried water ice in greater depths.

References: [1] Spudis P. D. et al. (1998) Science, 32(1):17. [2] Feldman W. C. et al. (1998) Science, 281(5382): 1496. [3] Colaprete A. et al. (2010) Science, 330(6003):463. [4] Paige D. A. et al. (2010) Science, 330(6003):479. [5] Zheng Y. et al. (2012) Icarus, 219:194-210. [6] Paige D. A. et al. (2009) SSR, 150:125-160. [7] Williams J. P. et al. (2016) Icarus, 283. [8] Fang T. and Fa W. (2014) Icarus, 232:34-53. [9] Shkuratov Y. G. and Bondarenko N. V. (2001) Icarus, 149(2):329-338. [10] Mitchell D. L. and Pater I. D. (1994) Icarus, 110:2-32. [11] Gong X. et al. (2013) LPS XLIV Abstract #2831. [12] Carrier W. D. et al. (1991) Lunar Sourcebook, pp.475-594. [13] Fa W. and Wieczorek M. A. (2012) Icarus, 218:771-787. [14] Prettyman T. H. et al. (2006) JGR, 111(E12)