CE-2'S MICROWAVE OBSERVATION OF THE MOON

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ABSTRACT

The microwave radiation of the moon has distinctive significance to research the surface and subsurface thermal properties and other physical properties. Benefited by their longer wavelength, microwave measurements own larger penetrating depth and could sense subsurface properties and structures in the regolith layers as long from several centimeters to tens of meters. Microwave measurements could be done under non-illuminated area. As a result, it is possible to get sensing data from permanent shadowed crater in the polar region, also the lunar nighttime scene of the surface.

Brightness temperature (TB) of the Moon have been measured by China's Chang'E-1 (CE-1) and Chang'E-2 (CE-2) lunar orbiter since 2007 and 2010. Here we show the results of CE-2's microwave observation of the Moon. (1) After sunset, 37GHz TB of the Moon drops down quickly, whileas 3.0GHzTB still rises up. It reveals the subsurface heating process in lunar regolith. (2) The heating and cooling of lunar surface in a lunation are presented. It answers when do the cold on the surface appear or disappear. (3) The complete catalog of thermal anomalies on the moon are proposed. (4) The basaltic units with different composition have different performance in microwave observation. Using the microwave map, we can classify basaltic units in maria to recover the history of magma flow.

A. CE-2 Lunar Orbiter and its Microwave Radiometer

CE-2 is the second lunar mission of China's Lunar Exploration Program. It was launched in 1st, Oct, 2010, after three years of CE-1's launch in 24th, Oct, 2007. CE-2 was an exact copy of CE-1. The plan was in case CE-1 failed to arrive at the Moon, CE-2 would be launched in the following months as a backup. Due to the successful performance of CE-1 in its 1.5 year's life span, CE-2 was modified and improved in ability, and serves as the precursor mission of the second stage of China's Lunar Exploration Program, aiming at the soft-landing and traveling on the Moon. CE-2 shoulders the responsibility to test some key technologies of CE-3, and to gain experience of soft-landing.

MRMs are the common scientific instruments onboard CE-1 and CE-2, which made the first two passive microwave remote sensing of the Moon. The science goal of CE-2's MRM is to measure the TB of the Moon, from which to retrieve the physical properties of lunar regolith.

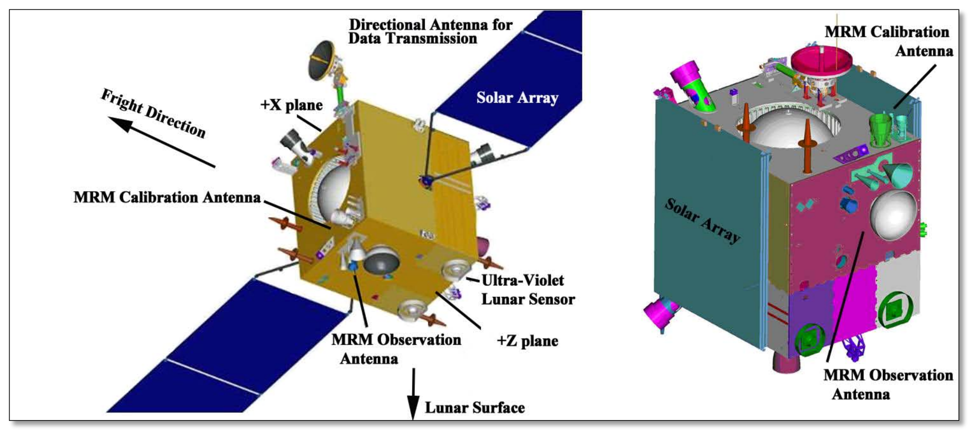
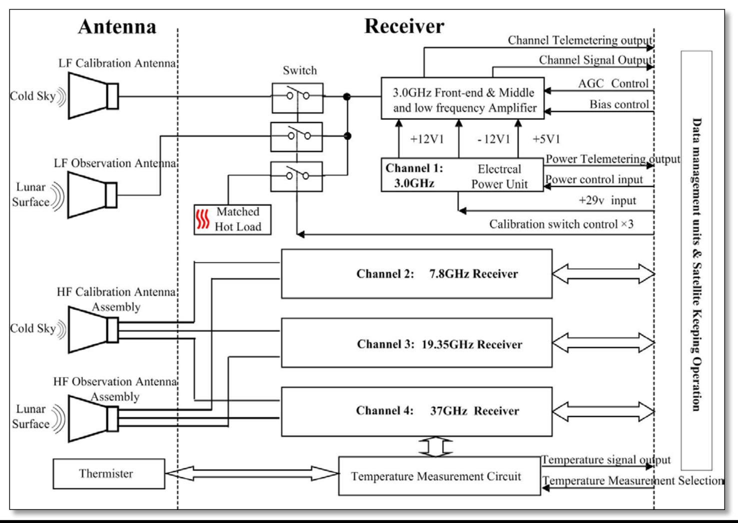


Fig.1. Configuration of CE-2's microwave radiometer

The MRM operated in four microwave frequency channels: 3.0, 7.8, 19.35 and 37.0 GHz (with wavelengths 10.0, 3.84, 1.55, and 0.81 cm, respectively). All four channels are estimated to have a sensitivity of 0.5 K in brightness temperature. Benefited from the lower altitude (about 100 km), the spatial resolution has been improved by two times than CE-1. The resolution on the lunar surface are in the range 17.5 km for 3.0 GHz channel and 25 km for 7.8, 19.35 and 37.0 GHz channels.



The observation antenna receive the microwave radiation from lunar surface, while as the calibration antenna observe the cold sky during every 11.6 s measuring period. The real-time calibration used two reference sources. The hot reference was an internal source of 300 K, and the cool reference was the 2.7 K space background. The space background however could be affected by astronomical bodies (e.g. the Sun, Earth, and bright stellar systems). During such incidence, the calibration was temporarily frozen.

B. Data analysis

In our previous work [*Chan et al.*, 2010; *Zheng et al.*, 2012], we have introduced the concept of *lunar local time* in terms of an "*hour angle*" (*h*). For the convenience of understanding, *hour angle* could be expressed as lunar 24-hour clock (h_{24}): $h_{24}= 12(\pi+h)/\pi$. Thus, a lunation period (29.5 days) is divided into 24 lunar hours.

The measurements of CE-1's MRM are carried during lunar local time h=-0.86–0.67 (h_{24}=8:43–14:34) in the day, and h=2.28– -2.48 (h_{24}=20:42–2:32) in the night. Fortunately, local time coverage of CE-2's measurements is over a complete lunation periods (h=-π–π, h_{24}=0:00–24:00) (Fig. 2). Therefore, CE-2's TB data set is much more useful for us to study the heating and cooling of lunar surface in a lunation period.

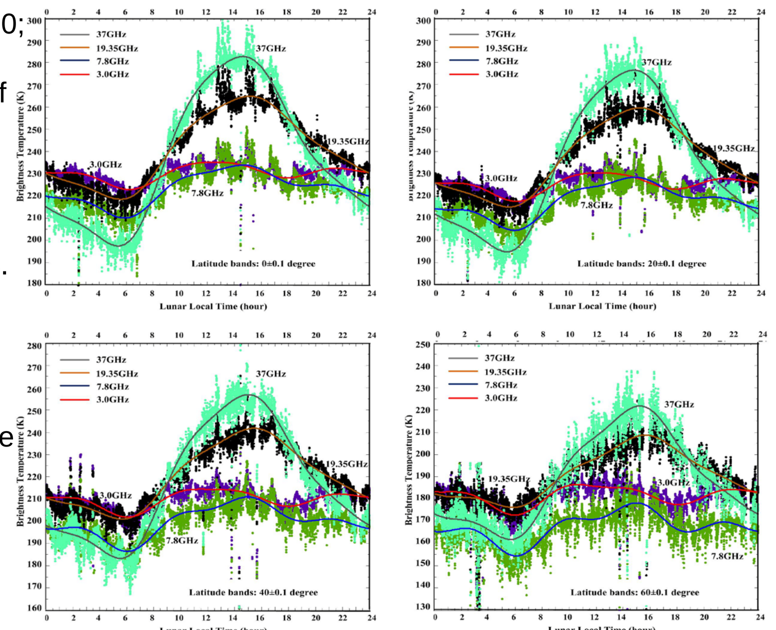


Fig.2. Diurnal variations of brightness temperature in latitude band, 0±0.1°, 20±0.1°, 40±0.1° and 60±0.1°.

Brightness temperature of the Moon is characterized by latitudinal variation and diurnal variation. The diurnal and latitudinal effects for the TB are combined to give rise to a model with spherical harmonics expansion (Fig. 3). An important result of this work is we found two strong peaks in TB around the equator in a diurnal period for 3.0GHz. One peak occurs near the lunar noon, and the other occurs near lunar midnight (Fig. 3a). At first sight, this is surprising and contrary to our intuition. However, since TB for the 3GHz channel represents a weighted mean of the physical temperature profile to deeper layers of the regolith, this double-peak in TB is consistent with a lunar surface model proposed by Keihm et al.(1973), consisting of a low density porous dust layer about 2 cm thick with low heat conductivity overlying a soil region with increasing density and conductivity. A careful investigation of 1D heat conduction model and the CE-2 TB data is underway and will be reported in the future.

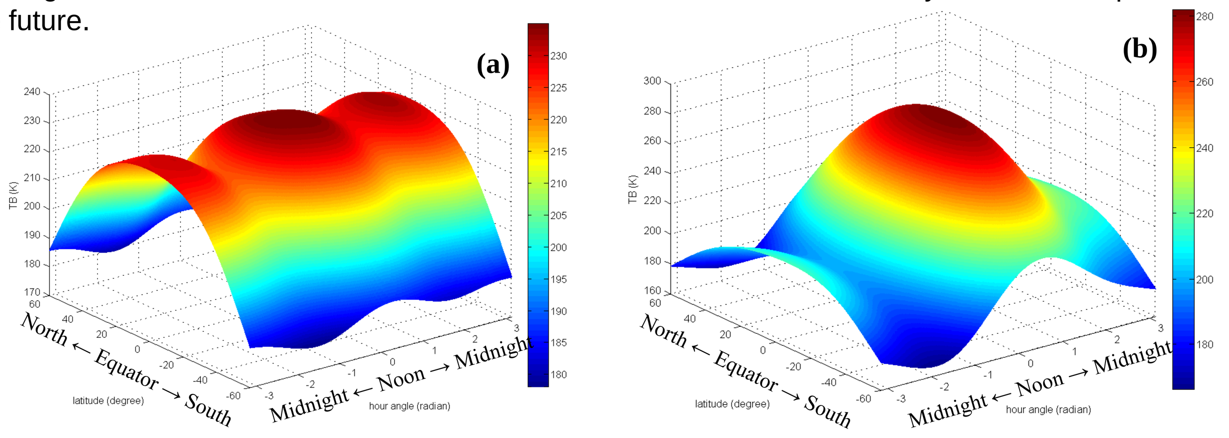
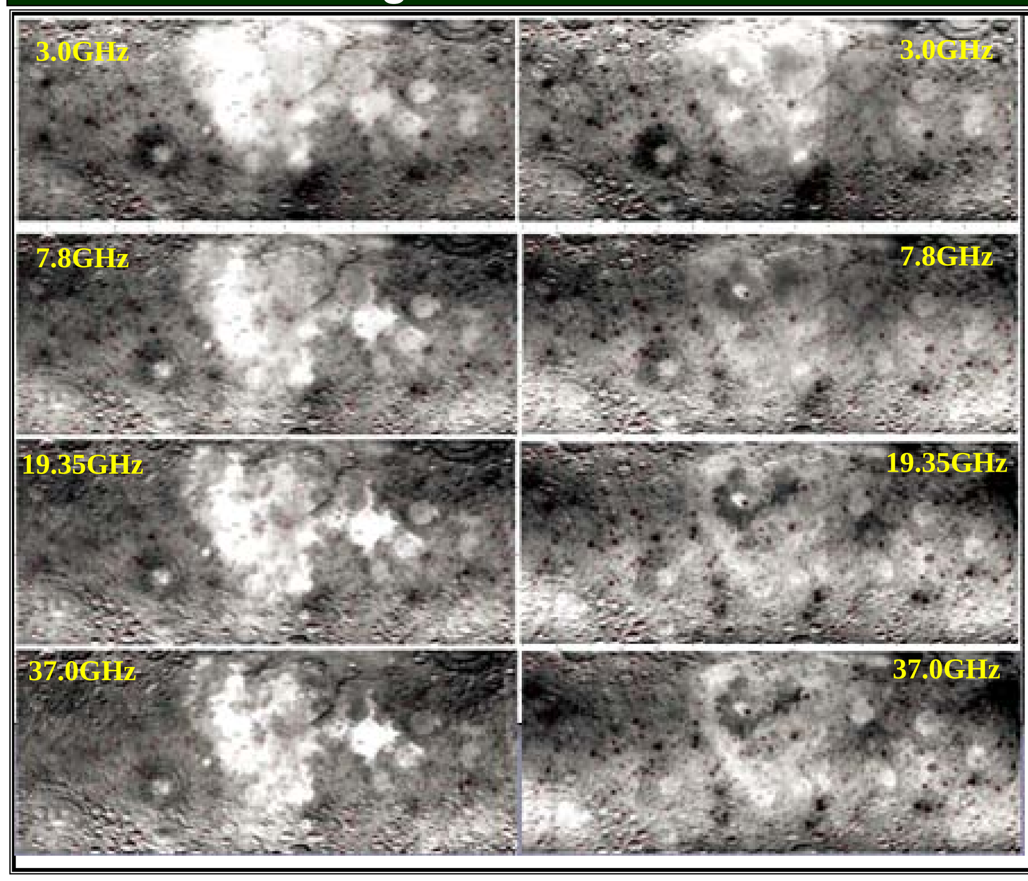


Fig.3. The 4th order spherical harmonics model (TB_{model}) fitted by CE-2's 3.0 GHz (left) and 37.0 GHz (right) TB data in the region with -60°< latitude < 60°.

C. Catalog of Thermal Anomalies on the Moon



In infrared observation from the earth, the entire disk during lunar total eclipse dotted by hundreds of "hot spots" [*D. Buhl et al.*, 1968; *Hunt et al.*, 1968].

However, those hot spots become into the cold spots in CE-2's microwave observation (Fig.4). A number of ray craters were shown to cool more quickly than their environs during lunar night.

Fig.4. τ- map of the Moon at lunar noon (left panels) and in lunar midnight (right pannels). τ = (TB-TB_{model})/TB_{model}).

D. Cooling and Heating of Lunar Surface in a Lunation

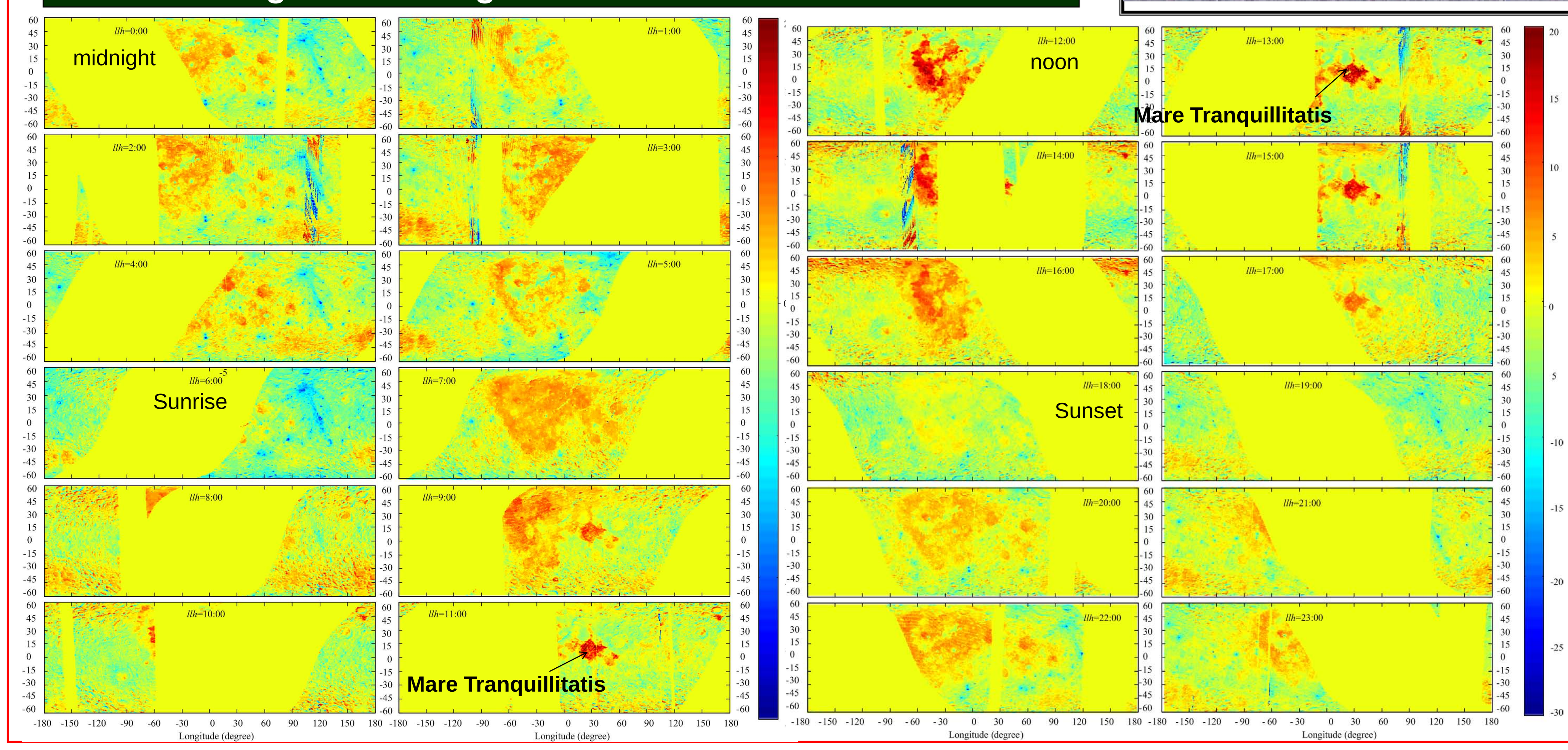


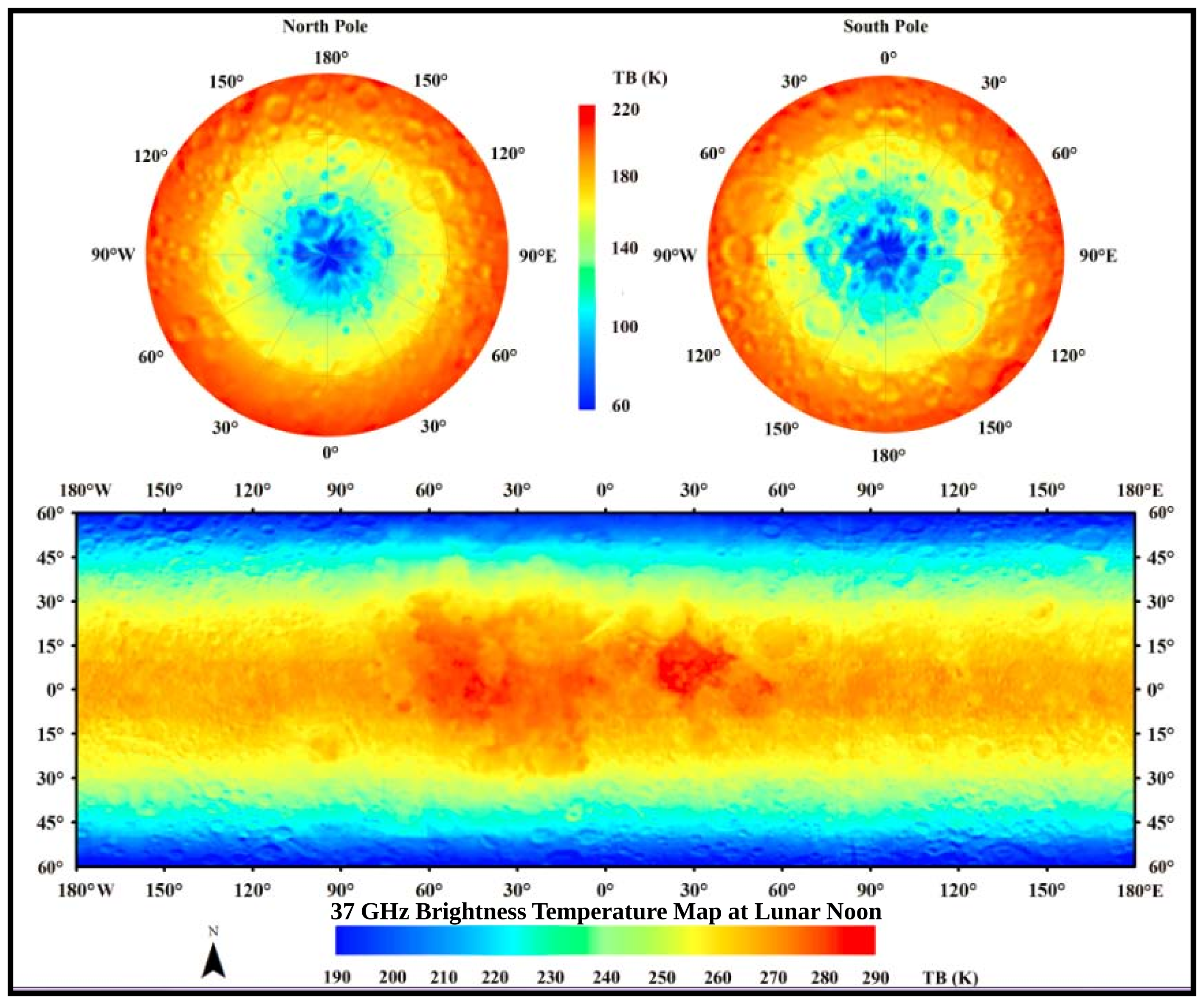
Fig. 5. Cooling and Heating of Lunar Surface in a Lunation from CE-2's microwave observation. *llh*: Lunar Local Hour. A lunation period was divided into 24 lunar hours. Similar as on the Earth, the sun will rise up at 6:00 and set down at 18:00 from lunar surface.

From Fig. 5, We can observed that:

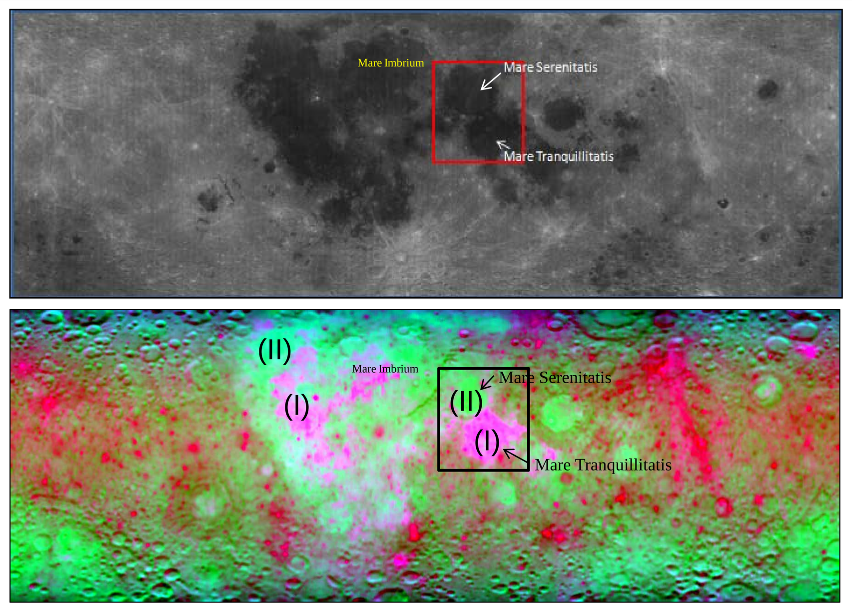
(1) Hundreds of cold spots are dotted on the surface in lunar night. They appeare on the surface after sunset, and disappeare after sunrise.

(2) The hottest areas during lunar daytime are located in Mare Tranquillitatis, the eastern part of Oceanus Procellarum, and the central section of Mare Imbrium. However, these hot areas become into the cold areas during lunar night. It suggests that these areas can be heated and be cooled more quickly than their environs.

E. Microwave Map of the Complete Moon



F. Basaltic Units Observed in Microwave Map



Different composition of basaltic unit leads to different thermal properties. In order to distinguish the maria basalts clearly, we constructed the RGB maps of CE-2's microwave observation (Fig.6).

Fig. 6 is composed by three color, red, green and blue, where R is (TB_{37GHz_day} - TB_{37GHz_znig})/ (TB_{37GHz_day} + TB_{37GHz_nig}), G is TB_{37GHz_day}, and B is TB_{37GHz_nig}. TB_{37GHz_day} and TB_{37GHz_nig} are the normalized 37GHz brightness temperature in the daytime and nighttime using TB model shown in Fig. 3. Three bands value of R, G, B were all normalized into the limitation of 0~1.

Fig. 6. Visible image (upper) of the moon and the RGB map of the CE-2's microwave observation (down)

From Fig. 6, we could observe that the maria basalts have different performance in CE-2's microwave observation. The maria materials could be distinguish into two types clearly: (I) represented in the *crab craw* region of the eastern parts of Oceanus Procellarum and the central section of Mare Imbrium, Mare Tranquillitatis and parts of Mare Foecunditatis, which are shown in purple. (II) represented in the northern and western parts of Oceanus Procellarum, Mare Serenitatis, Mare Crisium and other maria, which are shown in bottle-green.

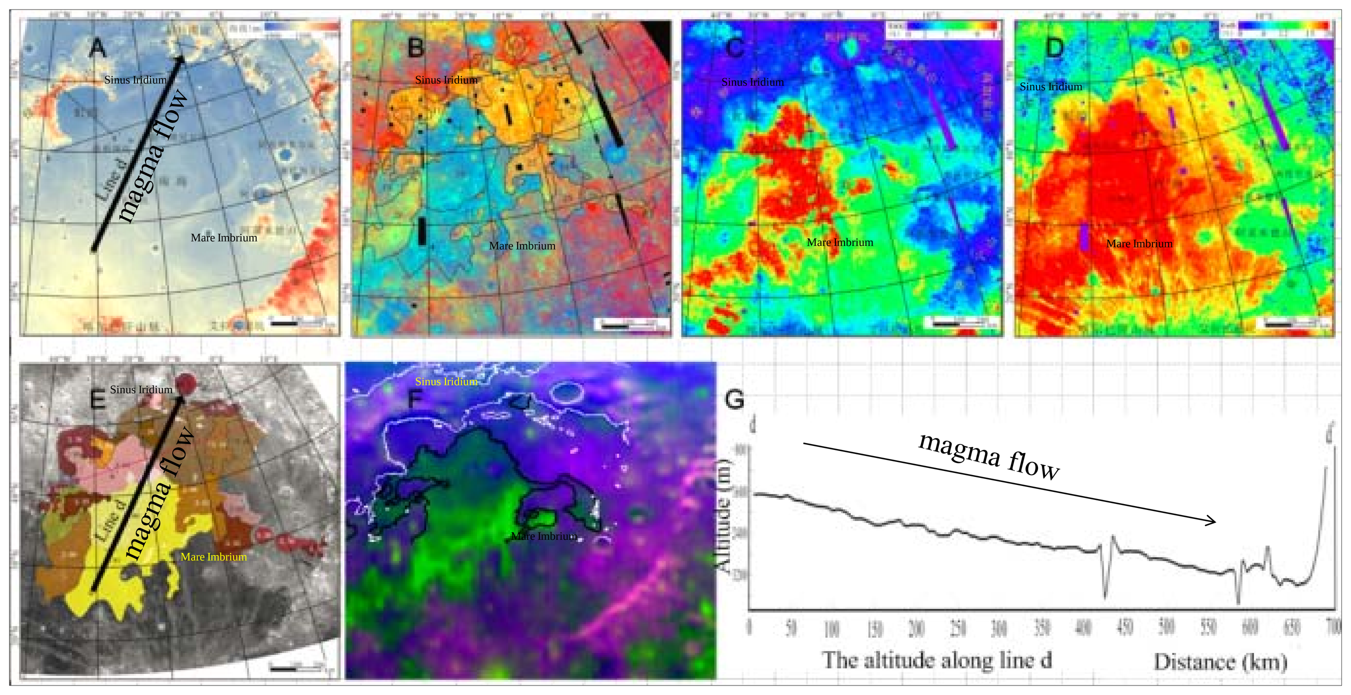


Fig. 7. The lava flow in Mare Imbrium. A. CE-1's topography data; B. False color image; C and D. TiO_2 and FeO abundance; E. Geologic ages; F. 37GHz RGB image. G. Altitude.

Acknowledgements and Correspondence

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