Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS23-16 会場:201A 時間:5 月 23 日 15:15-15:30

かぐやで観測されたレーダエコー強度にもとづく月表面誘電率の決定
Determination of the permittivity of the lunar surface based on the radar echo intensity observed by the Kaguya

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The permittivity of the lunar surface is considered to depend on the compositions and porosity of the surface materials. Therefore the determination of the permittivity is important for discussion of the geological conditions of the lunar surface. If we are going to use echo power for determination of the permittivity, we should note that the radar echo intensity depends not only on the permittivity but also on the roughness of the surface. Therefore, we have determined the permittivity of the lunar surface with considering the surface roughness. In the analysis, the permittivity is determined by using the radar echo intensity obtained by Kaguya Lunar Radar Sounder (LRS) [Ono et al, 2000; 2008; 2010], and the surface roughness parameters derived from Digital Terrain Model (DTM) based on Kaguya Terrain Camera (TC) observation [Haruyama et al., 2008].

The global distributions of the echo powers in a frequency range of 4-6 MHz were derived from the Kaguya/LRS dataset. We have used the intensity of off-nadir echoes in an incident angle larger than 3 degree. The reason why nadir echoes are not used in the analysis is because the echo intensity changes drastically in small incident angle especially at the smooth surface. The echoes arrived after the arrival of the nadir surface echo were identified as off-nadir echoes in this study. In addition, we have also derived the global distribution of the surface roughness parameters. The RMS height sigma of the surface can be obtained by $sigma^2 = <(h(x+dx)-h(x))^2>$, where h(x) is height of the surface derived from the Kaguya TC/DTM, dx is baseline length, and <> denotes the average. If we assume the self-affine surface model, the roughness parameters H and s can be obtained by the least square fitting of the RMS heights to sigma = $s(dx)^H$. The off-nadir surface echo power can be calculated based on the radar equation. Assuming Kirchhoff Approximation (KA), the backscattering coefficient in the radar equation can be obtained from the roughness parameters H and s, and permittivity [cf. Bruzzone et al., 2011]. Using the roughness parameters H and s obtained by Kaguya TC/DTM and changing the assumed permittivity, we can calculate the expected off-nadir surface echo powers and compare them with observed off-nadir surface echo power. Based on the comparison, we can determine most plausible permittivity.

The obtained Hurst exponent H is less than 0.5 in the maria, and about 0.9 in the highlands. The parameter s is about 1 in the maria, and about 0.3 in the highlands. The global distribution of H is similar with that reported by Lunar Reconnaissance Orbiter (LRO) laser altimeter [Rosenburg et al., 2011]. By applying the analysis method mentioned above, we could obtain the observed and calculated surface echo powers in the regions where $0.25<H<0.35$, and $0.85<H<0.95$. Based on them, we could estimate the average permittivity in the maria (H˜0.3) to be 4-5, and that in the highlands (H˜0.9) to be 2.

It is inferred that the lunar basalt below the surface consists of grains and voids. The bulk permittivity of the lunar uppermost basalt layer depends on the permittivity of the grains and the ratio of the voids, or porosity. According to the previous studies based on the Apollo lunar samples [cf. Shkuratov et al., 2001], the grain permittivity can be estimated based on the ilmenite abundance. The ilmenite abundance can be derived from the Clementine multiband image data [Lucey et al., 2000].

Based on the bulk permittivity and grain permittivity determined in this study, we also estimated the porosity in the maria (H˜0.3) to be 30 % and that in the highland (H˜0.9) to be 60 %. It is considered that the surface of the highlands is older than that of the maria. Due to the longtime exposure to the impacts of the meteorites, the porosity of the lunar basalt in the highlands can be larger than that in the maria.

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Terrain Camera (TC), Electric permittivity, Porosity, Surface roughness