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Near-surface bulk densities of asteroids derived from dual-polarization radar observations

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Abstract

We present a new method to constrain the near-surface bulk density and surface roughness of regolith on asteroid surfaces using planetary radar measurements. The number of radar observations has increased radically during the last five years, allowing us to compare and contrast the radar scattering properties of different small-body populations and compositional types. This provides us with new opportunities to investigate their near-surface physical properties such as the chemical composition, bulk density, porosity, or the structural roughness in the scale of centimeters to meters.

1. Introduction

The dual-polarization radar observations are a powerful, cost-effective tool to characterize both the dynamical and the physical properties of the terrestrial planets, moons, and the small bodies of the Solar System. The number of radar-observed asteroids and comets has increased rapidly over the last five years enabling improvements in statistical analysis. Also, the laboratory studies of the materials that are relevant to asteroids and comets have improved during the last decade (e.g., [2, 3]).

Our goal is to improve the theoretical methodology for deriving the near-surface densities of asteroids, which has been formerly challenging due to a small number of radar-observed targets.

2. Methods

In a typical planetary radar measurement a circularly polarized signal is transmitted using either a frequency of 2380 MHz (wavelength of 12.6 cm) or 8560 MHz (3.5 cm). The echo is received simultaneously in the same circular (SC) handedness and the opposite circular (OC) handedness as compared to the transmitted signal. The delay and doppler frequency of the signal give highly accurate astrometric information, and the intensity and the polarization are suggestive of the physical properties of the target's near-surface.

The penetration depth of the signal is typically a few wavelengths depending on the absorption of the material. If the surface is smooth and the effective near-surface is homogeneous in the wavelength-scale, the echo is received fully in the OC polarization. Wavelength-scale surface roughness or boulders within the effective near-surface volume increase the fraction of echo power received in the SC polarization [4, 7].

The radar reflectivity of the target can be described using the radar albedo, $\hat{\sigma}$. For an ideal metallic sphere, $\hat{\sigma} = 1$.

The OC-polarized part of the echo is composed of a quasi-specular component and a diffuse component. Traditionally, the OC radar albedo has been treated as a product of the Fresnel reflection coefficient (at normal incidence), R_F, and the backscatter gain factor, g: $\hat{\sigma}_{OC} = gR_F$ [5]. For an ideal sphere, $g = 1$. However, there has been a lack of methods to determine R_F or g independently. Instead, g is often simply guessed to be in the range of 1.1-1.5.

To resolve this problem, we utilize the information that the diffuse components of the OC and SC parts are correlated (Fig. 1). A linear least-squares fit to the detected values of $\hat{\sigma}_{OC}$ and $\hat{\sigma}_{SC}$ allows us to separate the diffuse-scattering part from the quasi-specular part of $\hat{\sigma}_{OC}$. Thus we are able to evaluate the surface roughness of a specific target compared to other similar objects and also approximate the bulk electric permittivity (or the refractive index, m) of only the regolith that is composed of grains much smaller than the wavelength. For the latter part, we can use the following relation [1]:

$$\hat{\sigma} = R_F = \left|\frac{m-1}{m+1}\right|^2 \quad (1)$$

Combined with the spectro-photometric informa-

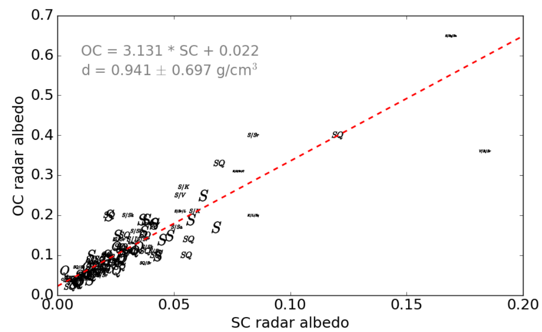

Figure 1: The diffuse parts of the OC and SC polarized echoes are correlated so that for asteroids that have a similar chemical composition, such as the S- and Q-type asteroids, the SC and OC radar albedos can be found to follow a certain trend. When $\hat{\sigma}_{SC} = 0$, $\hat{\sigma}_{OC} \approx R_F$. The $\hat{\sigma}_{OC}$-axis intercept point as well as the gradient of the line depend on the electric permittivity of the targets.

tion of the target and laboratory studies of the permittivity-density dependence provides us a way to set strong constraints on the density or porosity of the target's near-surface.

Sources of errors for the method are caused by the size estimation of the target, which is required for assessing the radar albedos. In addition, part of the echo is scattered by an inclined surface, which sets a requirement for a correcting factor. The radar reflectivity as a function of the scattering angle has been shown for the lunar surface by, e.g., Thompson et al. [6].

3. Summary and Conclusions

We improve the methods to interpret the physical properties of planetary surfaces using radar observations. In this paper, we concentrate on asteroids. The new method allows us to obtain strong evidence on the electric permittivity of small bodies of similar chemical compositions. Furthermore, we can estimate the density or the porosity of the material by utilizing laboratory measurements of the relation of the electric permittivity to these parameters. This provides us an access to information on the near-surface physical properties such as the abundance of metal, bulk density, or the structural roughness in the wavelength scale. A major part of this information, which is essential for landing space probes and understanding how these bodies were formed, is not accessible with other ground-based methods.

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