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Scattering functions fits for Arecibo Observatory planetary radar data

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Abstract

We continue the work of testing scattering models on near-Earth asteroids using dual-polarization radar observations to elucidate their near-surface physical properties [1]. We study the effectiveness of four traditionally used model scattering functions: Hagfors (Eq. 1), exponential (Eq. 2), Gaussian (Eq. 3), and the Cosine law (Eq. 4) and propose a formulation of the Bragg approximation (Eq. 5). We test the suitability of these functions in modeling the near-surface backscattering process.

1. Introduction

Radar studies of planetary bodies are a cost-effective, ground-based, accurate, and consistent method for studying decimeter-scale structures on the near-surface of asteroids. Previous work [1] included: 3200 Phaethon, 3122 Florence, 285263 (1998 QE_2), 481532 (2007 LE), 441987 (2010 NY_{65}) and 2014 JO_{25}.

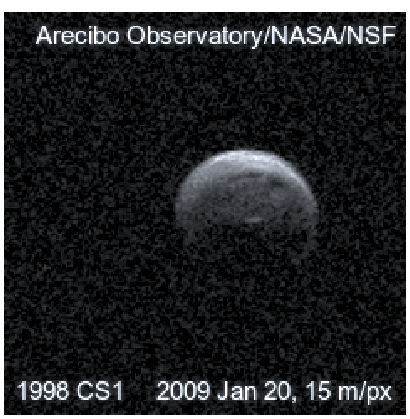

Figure 1: Delay-Doppler image of 1998 CS_1, with a resolution of 15 m/px taken on Jan 20, 2009.

We now add to our study: 385186 (1994 AW_1), 136617 (1994 CC), 58707 Kyoshi (1998 CS_1), 185851 (2000 DP_{107}) and 153591 (2001 SN_{263}). Radar experiments were done using S-band radar (2380 MHz, 12.6 cm) in Continuous Wave (frequency only-CW) and delay-Doppler images using the Arecibo Planetary Radar System.

Hagfors:

$$\hat{\sigma}_H(\theta) = (RC/2)(\cos^4\theta + C\sin^2\theta)^{-3/2} \quad (1)$$

Exponential:

$$\hat{\sigma}_E(\theta) = (3RC/\cos^4\theta)(\exp(-\sqrt{6C}\tan\theta)) \quad (2)$$

Gaussian:

$$\hat{\sigma}_G(\theta) = (RC/\cos^4\theta)(\exp(-C\tan^2\theta) \quad (3)$$

Cosine:

$$\hat{\sigma}_C(\theta) = R(C+1)\cos^{2C}\theta \quad (4)$$

Bragg Approximation:

$$\sigma_B(\theta) = [\frac{4k^4 h_{rms}^2 L^2}{(1+(2kL\sin\theta)^2)^{1.5}}][R_{P_\epsilon}^2\cos^2\theta + \frac{(\epsilon-1)(1+R_{V\epsilon})^2}{2\epsilon}\sin^2\theta]^2 \quad (5)$$

Where:

$$R_{P\epsilon}(OC) = R_{V\epsilon} - R_{H\epsilon}$$
$$R_{P\epsilon}(SC) = R_{V\epsilon} + R_{H\epsilon}$$
$$R_{V\epsilon} = (\epsilon\cos\theta - \sqrt{\epsilon-\sin^2\theta})/(\epsilon\cos\theta + \sqrt{\epsilon-\sin^2\theta})$$
$$R_{H\epsilon} = (\cos\theta - \sqrt{\epsilon-\sin^2\theta})/(\cos\theta + \sqrt{\epsilon-\sin^2\theta})$$

2. Methods

Targets in this study have both CW spectra as well as radar images with enough range-resolution received as a function of a span of backscattering angles.Resolution can range from 7.5 m/px to 600 m/px depending on targets distance and observing conditions. Reconstruction of the scattering function provides constraints [2] on the near surface composition, placing limits on the values for the real and imaginary parts of dielectric properties such as permittivity (ϵ), the density (ρ), the radar cross section (σ) and the radar albedo ($\hat{\sigma}$). Analysis of the backscattering function is done by plotting the backscattered power as a function of the backscattered angle [3] (θ_i) in both the same-circular (SC) & opposite circular (OC) polarization, primarily selecting targets where a roughly spheroidal shape could be assumed based on said delay-doppler images. We fit the studied functions (Eqs. 1-5) to the back-scattered signal from asteroids of varied sizes and taxonomical classes. We then explore the usefulness of each model, and a combination of models, to constrain near-surface characteristics.

Table 1: Sample values for: Circular Polarization ratio (μ), radar cross section (σ) and total radar albedo ($\hat{\sigma_T}$) for all analyzed targets.

Target	Tax Class	μ	σ	$\hat{\sigma_T}$
1994 AW_1	Sa	0.303	0.046	0.354
1994 CC	Sq	0.372	0.070	0.210
1998 CS_1	Sa	0.237	0.192	0.374
2000 DP_{107}	M,C	0.315	0.176	0.301
2001 SN_{263}	C,B	0.165	0.544	0.251

From CW we obtain the circular polarization ratio (μ), the radar cross section (σ) and the radar albedo ($\hat{\sigma}$), a sample of measured values are shown in Table 1. We fit the scattering functions onto the data (Eqs.1-5) to obtain solutions for R (parameter relating to Fresnel reflection coefficient [4]) and C (parameter relating to surface structure [5]). Traditionally, C has been considered to depend only on the surface undulations so that the rms slope of an average surface facet is $s_0 = 1/\sqrt{C}$. We find solutions for L (surface correlation function), hrms (surface height distribution), and ϵ from the fit to our composite Bragg equation.

3. Results and Conclusions

Here, we use 1998 CS_1 to display an example of the radar images used (Fig. 1) and set of scattering models fitted to the observed radar cross section at a specific incidence angle, normalized with an estimate of the contributing area. For this target the Hagfors law provides the best fit to the data, red solid line seen in Fig. 2. The preferred fit is determined by selecting the least χ^2 value from all functions applied to each target.

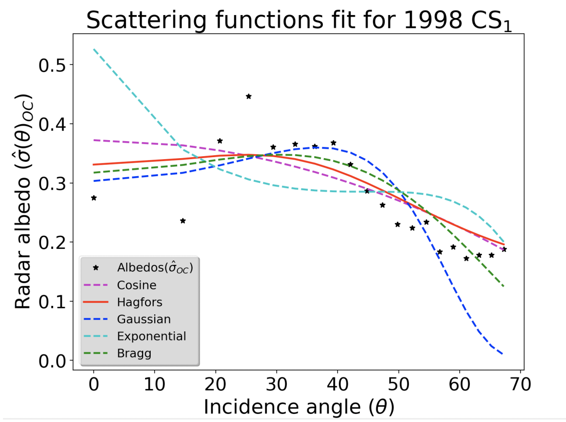

Figure 2: Fit of all scattering functions to the delay-Doppler image of 1998 CS_1 (Fig. 1).

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