RADAR PROPERTIES OF THE ICY SATELLITES OF JUPITER AND SATURN.

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Introduction: The radar properties of the icy satellites of Jupiter and Saturn are extraordinary, with radar albedos and circular polarization ratios that dwarf values for non-icy solar system targets [1],[2],[3]. These properties are due to coherent backscattering [4], which is a highly efficient kind of multiple scattering from heterogeneities within a nearly transparent medium, in this case water ice, whose electrical loss at radar wavelengths is essentially negligible. The path length for exiting the medium in the backscatter direction is small compared to the absorption path length, the intensity of echoes in the backscatter direction is amplified by phase-coherent interference between waves on identical but time-reversed paths, and the incident sense of circular polarization is preserved [5].

The heterogeneities do not have to be discrete scatterers such as rocks or water-ice blocks; they can include any sort of variation in the dielectric tensor [6]. Because the satellite surfaces have constantly been subject to meteoroid bombardment, their regoliths naturally are structurally heterogeneous. Therefore a reasonably mature regolith of 100% pure water ice would be expected to return radar echoes with high albedos and that preserve the transmitted sense of circular polarization. These unusual signatures, first encountered with Arecibo (2380-MHz, 13-cm) observations of the icy Galilean satellites in 1975-76, had not been seen in any previous radar observations of solar system or terrestrial targets.

Contaminants: Ostro et al. [7] discussed the potential role of contaminants in icy satellite radar albedo variations as follows. "The correlation of our targets' radar and optical albedos [Fig. 1], also seen for groundbased radar observations of the icy Galilean satellites, is most easily understood as involving variations in the concentration of optically dark contaminants in near-surface water ice and the consequent variable attenuation of the high-order multiple scattering responsible for high radar albedos. Plausible candidates for contaminants causing variations in radar albedo include silicates, metal oxides, and polar organics such as nitriles like HCN and possibly acetylene polymers as well as complex tholins.... (In the case of the polar organics, lowering of the visual albedo would be furthered as UV photons or charged particle radiation act on the material.... Extremely small concentrations of impurities can dramatically reduce the microwave transparency of water ice (e.g., [8] and references therein)."

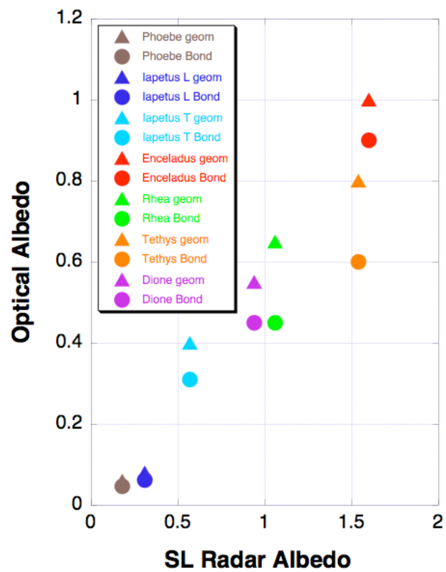

Fig. 1 Optical geometric albedo (triangles) and Bond albedo (circles) plotted vs. Cassini 2.2-cm radar albedos reported by Ostro et al. [7] in their Fig. 4 and Table 1.

The one-way 1/e absorption length in wavelengths of pure, homogeneous water ice at the temperatures of the satellite surfaces is more than 10,000. It can be orders of magnitude lower for water ice contaminated with small percentages of lunar soil, or nonmetallic meteoritic material, or metallic iron, or metallic iron oxides, or complex organics. Therefore any of these candidates might be responsible for the correlated optical and radar albedo variations.

Ammonia: Ammonia would reduce icy surfaces' radar albedos but not their visual albedos, whereas the other candidate contaminants could do both. Lorenz [9] and Lorenz and Shandera [10] explored the electrical properties of water ice containing ammonia along with their dependence on temperature and frequency, and concluded that NH3 concentrations much less than one weight percent can dramatically increase the radar absorption length. They caution that “these measurements are not entirely satisfactory, and absorption cell measurements with good temperature control would be most desirable."

Indeed, very accurate determination of the electrical properties of ammonia containing water ice as a function of concentration, chemical form [11], frequency, and temperature are sorely needed, because the increasing presence of ammonia with depth on Saturn's icy satellites offers an easy hypothetical explanation of the wavelength dependence of these objects' radar albedos: Black et al. [2,3] measured the 13-cm radar albedos of Enceladus, Tethys, Dione, Rhea, and Iapetus, and found that they mostly are lower than the 2.2-cm Cassini values measured by Ostro et al. [7].

However, for Europa, Ganymede, and Callisto, 4-cm and 13-cm albedos are essentially indistinguishable [1]. Ammonia is cosmogonically more likely in the Saturn system than in the Jupiter system, and the upper limits on NH3 from spectroscopic observations of the Saturn satellite system allow the presence of subsurface ammonia. Ostro et al. (2006) argue that "to simultaneously account for its role in affecting the radar properties while being absent from near-infrared spectra requires postulating that ammonia is depleted from the very outermost layer (centimeters or less) to which near-infrared spectra are sensitive, while being preserved at depths to which the radar sounds." "As argued by Lanzerotti et al. [12], a combination of ion erosion and micrometeoroid gardening may have depleted ammonia from the surfaces of Saturn's icy satellites.

"Given the hypersensitivity of water ice's absorption length to ammonia concentration, an increase in ammonia with depth could allow efficient 2.2-cm scattering from within the top one to several decimeters while attenuating 13-cm echoes, which would require a six-fold thicker scattering layer. If so, we would expect each of the icy satellites' average radar albedos to be higher at 2.2 cm than at 13 cm...."

Black et al. [3] agree that their 13-cm albedos "may further support the Ostro et al. [7] suggestion that the effective scattering layers on these moons are determined by an increasing amount of absorber with depth, such that relatively cleaner layers are seen by the 2.2 cm wavelength, while the 13 cm wavelength senses lower, more absorbing layers."

Thorough state-of-the-art measurements of the electrical properties of ammonia-containing water ice as function of concentration, chemical form, frequency, and temperature are needed to provide a firm foundation for realistic interpretation of the inter- and intra-object radar albedo variations in the Saturn system, with important implications for understanding the geologic nature and histories of these objects' surfaces.

References:

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