INTERPRETATION OF PHASE CURVES OF IO AND GANYMEDE:
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Phase curves (whole-disk brightness vs. solar phase angle) of Io and Ganymede between 0° and 40° phase have been compiled from Voyager photopolarimeter and ground based observations (Figure 1), [1,2,3]. The V magnitudes are for mean opposition distance, with longitudinal brightness variations corrected for. The Ganymede data are restricted to the hemisphere where 90° ≤ orbital longitude ≤ 270°W, or, to the hemisphere facing away from Jupiter. The Io data are restricted to the longitudes 0°-121°W and 255°-360°W, or slightly more than the hemisphere facing Jupiter. Our data agree with photometry in smaller ranges of phase angles, made by Voyager television cameras [4], and other ground based observers [5].

A rigorous multiple scattering theory [6,7] is used to model the observations. Accurate photometric data over a large range of phase angle allow us to determine improved values of surface parameters: D the volume density, ρ the roughness, g the asymmetry factor of single particle scattering function, and Q the multiple scattering factor (or the proportion of multiply scattered light). The best-fit theoretical curves allow us to determine new zero-phase geometric albedos p for the satellites. Integration of the theoretical phase curve yields an accurate estimate of the satellite's phase integral q and Bond albedo A.

The phase curves are also compared with those of other atmosphereless solar system objects [5,7], and laboratory reflectance measurements of terrestrial analog samples [8]. Although the visual albedo of Io (p_V = 0.75) is as high as that of Europa, its phase curve is much steeper than that of Europa, which approximates that of a snow-covered sphere [9]. This implies that sulfur dioxide frost is not ubiquitously present as an optically thick layer over Io's surface [10]. Photometric properties of Io's surface also differ markedly from those of a Lambert reflector. Whereas sulfur flowers, colloidal sulfur, and frosts are good Lambert reflectors at phase angles between 5° and 40° [11,12,13], we conclude that such forms of sulfur by themselves, or in combination with SO_2 frost, do not represent well the surface of Io.

Ice crystals and orthorhombic sulfur S_8 are transparent at visible wavelengths [14], and multiple scattering of light among grains makes them good diffuse reflectors. Alteration of S_8 and SO_2 frost has occurred on Io to make them more backscattering. Possible mechanisms for suppressing multiple scattering are as follows: 1) Growth into thick crystals so that rays refracted into their interior are extinguished. 2) Transformation into allotropes that are opaque. 3) Contamination by impurities that increases the absorption index k of the grains. 4) Radiation damage by charged particle bombardment. Agglutination of ex-
tremely fine volcanic ash (0.001 < radius < 1 \(\mu m\)) [15] has to take place on Io in order to avoid invoking unreasonably large values of \(k\) to explain our data. Aggregation of small particles into large, highly irregularly-shaped "fluffy" particles can also increase backscattering (and produce a strong opposition effect) without the necessity of too large imaginary indices. Our conclusions are consistent with those derived from spectrophotometric studies [16,17], and models of Io [18].

The phase curve of Ganymede is indicative of a "dirty ice" surface, consistent with Voyager spectrophotometry of the satellite [19,20].

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