

SURFACE COMPOSITION OF THE GALILEAN SATELLITES FROM GALILEO NEAR-INFRARED MAPPING SPECTROSCOPY

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Abstract. The Galileo Near Infrared Mapping Spectrometer (NIMS) is currently obtaining spectral maps of Jupiter's moons to determine the composition and spatial distribution of minerals on the satellite surfaces. Sulfur dioxide, as a frost or ice, covers much of Io's surface, except in hot volcanic areas. A weak spectral feature at 3.15 μm suggests the presence of an OH containing surface compound (hydroxide, hydrate, or water) and a broad absorption above 1 μm is reasonably attributed to iron-containing minerals, such as feldspars and pyrite. Water is the dominant molecule covering Europa's surface, occurring as ice but also as a hydrate. The trailing side shows high concentrations of these hydrous minerals, whose identifications are not yet established. Ganymede's surface exhibits water absorption bands, largely due to ice but hydrates are also present. A dark component is present, but with a smaller proportion compared to Callisto. Some of the non-ice features seen on Ganymede are similar to those found in Callisto's spectra (see below). Among the icy Galilean satellites, Callisto shows the least amount of water ice, covering about 10% of the surface in patchy concentrations. Most of the surface is covered with unidentified (as yet) dark minerals. The exposed ice is often associated with impact craters, implying that the darker material exists as a blanket over more pure ice. Non-ice spectral features at 3.88, 4.03, 4.25, and 4.57 μm are present in Callisto's spectra (and some of these appear in Ganymede's spectra), each with different spatial distributions. Laboratory spectra suggest that the 4.25- μm feature is due to carbon dioxide which is trapped in the surface grains. The band at 4.03 μm may be due to sulfur dioxide, which probably originated from Io. Molecules containing CN, SH, SiH, and perhaps deuterated constituents are candidates for the other features, some of which could be derived from shock-heated and modified material from impacts, perhaps of carbonaceous composition. There is evidence for the presence of hydrated minerals on Callisto, based on water band shifts and shapes.

1. Introduction

Infrared reflectance spectra are diagnostic of surface materials because molecular vibrational excitations produce identifiable spectral features in this energy region. The Galileo Near Infrared Mapping Spectrometer (NIMS, Carlson et al., 1992) measures reflected solar radiation in the near-infrared range of 0.7 to 5.2 μm . We have used this spectral imaging capability to detect and map minerals on the surfaces of the Galilean satellites; here we provide a summary of these findings.

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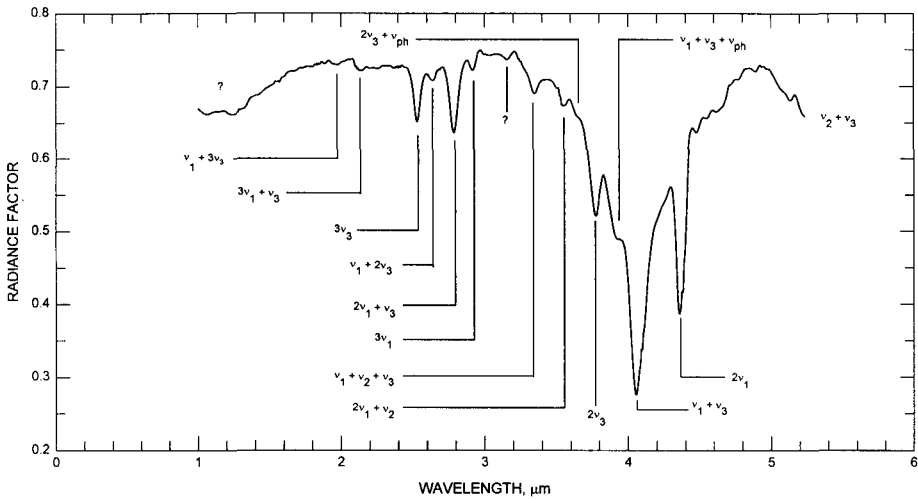


Figure 1. Representative spectrum of Io. Most of the features are due to SO_2 , for which identifications are given. Other absorbers give the $3.15\text{-}\mu\text{m}$ band and the broad absorption at $1 - 1.5\text{ }\mu\text{m}$ (see text).

(See Carlson et al., 1997b, this issue, for a summary of Jupiter atmosphere measurements and Lopes-Gautier et al., 1997, for measurements of Io's volcanic thermal emission.)

2. Io

Widespread active volcanism rapidly resurfaces Io through lava flows and plumes. The latter are thought to contain gaseous sulfur and sulfur dioxide, which subsequently condense on the surface. NIMS spectra have been used to map the distribution of sulfur dioxide and two other materials, using spectral features as shown in Fig. 1 (Carlson et al., 1997a). Most of the absorptions in this spectrum are due to SO_2 , for which band identifications are shown, but the weak feature at $3.15\text{ }\mu\text{m}$ and the broad absorption in the 1 to $\sim 1.5\text{ }\mu\text{m}$ region are not due to sulfur dioxide.

The $3.15\text{-}\mu\text{m}$ band was first reported by Salama et al. (1990) and confirmed by NIMS and ISO measurements (Carlson et al., 1997a; Schmitt et al., 1997). The proximity of this band position to that of the fundamental stretch transition of O-H prompts us to suggest that a hydroxide, a hydrate, or even water is the absorber, present in low concentration. This material appears to be equatorially distributed on Io's surface, and may be associated with the optically thick equatorial deposits of SO_2 .

The shorter wavelength feature, the broad absorption seen from $\leq 1\text{ }\mu\text{m}$ to $\sim 1.5\text{ }\mu\text{m}$ was observed previously by Pollack et al. (1978), who suggested iron salts or feldspars as the origin of this feature. Another possibility is iron pyrite, FeS_2 (Kargell, 1997). Ferrous iron absorptions are common in this wavelength region, appearing in many minerals, so it may not be possible to obtain a definitive identification. Whatever its identification, it appears to be more concentrated in the southern polar regions and associated with dark material (Carlson et al., 1997a).

3. Europa

The outer three Galilean satellites, Europa, Ganymede, and Callisto, are often referred to as the icy satellites of Jupiter, and of these, Europa exhibits the most water ice on its surface. Water occurs in another form on this satellite, specifically as hydrated minerals. Figure 2 illustrates two examples of Europa spectra, one from the bright plains and the second from the dark region on the trailing side. The plains spectrum is quite similar to spectra of pure water ice, notably in the $2\text{-}\mu\text{m}$ band, which is centered at $2.0\text{ }\mu\text{m}$ and is symmetric in spectra of pure water ice and in the plains spectrum.

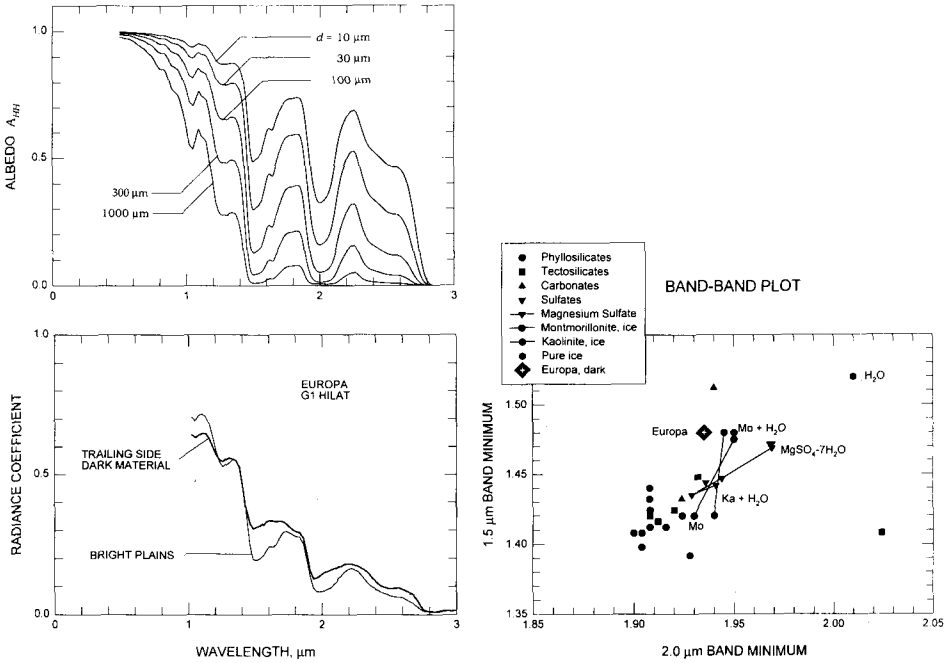


Figure 2. Europa and water ice spectra. A (top, left): calculated spectra of pure water ice for various grain sizes. B (bottom, left): Europa spectra; the thin, solid line is a bright plains spectrum; the thicker line spectrum is for trailing-side dark material. Note the shift and asymmetry in the 2- μm band caused by hydration. C (right): band-band plot, showing the position of the 1.5- and 2- μm bands for Europa's dark material, pure ice, hydrated minerals, and hydrate-ice mixtures.

The spectrum of the dark material on the trailing side is quite different from pure ice or the plains material in the shape and position of the water bands, particularly the 2- μm band. These changes in shape and position occur when the water molecule is in a force field different than ice, as when physically or chemically bonded on surfaces (adsorbed), within layered minerals such as clays, within channels as in zeolites, or incorporated within the crystal structure (water-of-crystallization or coordinated water). Figure 2c compares the band positions of various mineral classes, pure water, ice, and Europa's dark material. With additional laboratory data, especially for hydrate-ice mixtures, and detailed NIMS spectra we can better identify the mineral classes present on Europa and investigate their formation.

4. Ganymede and Callisto

Spectral images of Ganymede and Callisto indicate a surface with ice and a blanket of darker material. The ice is evident as a frost coating, particularly in the polar regions, and as exposures on ridges and craters. Hydrates are also present, based upon band shifts and shapes, but the amount of hydrated material is less on these two satellites than on Europa.

Several new absorption features have been found in spectra of Callisto and Ganymede (Carlson, et al., 1996; McCord et al., 1997) and are illustrated in Fig. 3. The feature at 4.25 μm is thought to be due to carbon dioxide, although this identification is not firm as other mineralic absorptions could mimic this feature. The 4.57- μm feature is perhaps from a compound containing the CN group. A possibly related carbon-containing mineral is indicated by weak absorption at 3.4 μm , tentatively interpreted as some material containing CH or CH₂ groups. Sulfur compounds may be present. A band at 4.03 μm could be due to SO₂ (c.f. Fig. 1) and SH-containing compounds may produce a feature at 3.88 μm .

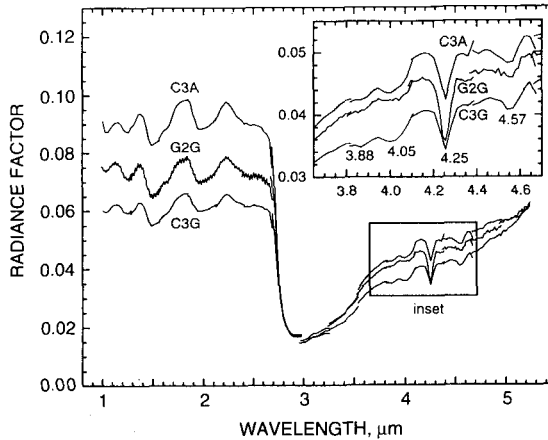


Figure 3. Spectra of Ganymede and Callisto showing ice and non-ice features. Carbon and sulfur compounds are candidates for these new absorptions (see text). These compounds may arise from impact material which has been shock-heated and modified. An Iogenic source of sulfur is also probable.

The spatial distributions of the materials causing these absorptions are non-uniform and different for the different spectral features. The 4.25- μm feature is correlated with many surface features, being prominent in the Tornarsuk crater and the Asgard region (see Fig. 4, color plates). Interestingly though, the Osiris crater on Ganymede shows the opposite, i.e., very little absorption from the crater material. Such spatial behavior may be clues to the origin of these minerals.

While the origin, exogenic or endogenic, is not yet established for the material, it is interesting to consider some possibilities. Some of the compounds and radicals noted above (CO_2 , CN, CH_3) fit nicely with those predicted by Zahnle et al. (1992), who investigated the volatile elements formed from impacts. While much of the volatiles escape, a fraction may be incorporated into surface layers and would consist of CO_2 , C_2H_2 , HCN, and other C- and N-bearing molecules. Sulfur compounds could be introduced by this process as well as originating from Io.

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