MID-INFRARED SPECTRA OF CONDENSED SO_2 PHASES: LAB DATA AND APPLICATIONS TO GALILEO MAPPING OF IO; D. Nash and B. Betts, San Juan Institute, 31872 Camino Capistrano, San Juan Capistrano, CA 92675.

Introduction

SO_2 in the form of frost or ice is present on Io's surface, as originally determined based on the identification of the $\nu_1 + \nu_3$ combination band of solid SO_2 near 4 μm in Io groundbased reflectance spectra [1, 2, 3]. Although numerous papers have addressed various aspects of SO_2 on Io [e.g., 4, 5, 6], there has been no comprehensive spectral study published that presents laboratory data covering the important mid-infrared signatures (~2-25 μm) of various SO_2 phases; this spectral range contains very diagnostic band features that can be used to constrain the composition and phase state of Io's surface materials. Key portions of this spectral range (2-5 μm) will be accessible to the Near Infrared Mapping Spectrometer (NIMS) on the Galileo spacecraft. The purpose of the lab work presented here is to provide reference spectra of candidate materials for comparison with observed infrared spectra of Io's surface; identification of compositional species present on Io; and mapping of their spatial distribution with NIMS.

Experiments

Using a miniature vacuum/environmental chamber fitted to a Fourier Transform infrared (FTIR) spectrometer [7], we produced detailed laboratory reflectance spectra in the mid-infrared range, covering 2.3-23 μm (4348-435 cm^{-1}), for a variety of phase states of SO_2 as follows:

SO_2 gas -- Has characteristic doublet absorption bands centered near the following wavelengths: 4.0, 7.4, and 8.6 μm. The band near 4.0 μm has a distinct and sharp minimum at 3.981 μm that we recognize as the most diagnostic feature of a gas phase in this spectral region.

SO_2 frost -- This is probably the most relevant reflectance spectrum for comparison to Io's surface; it is characterized by a high flat continuum with strong fundamental bands near the ~530, ~1140, and ~1300 cm^{-1} regions, and sharp combination and overtone bands in the range 1600 cm^{-1} (6.25 μm) to 4000 cm^{-1} (2.50 μm). The most important band, because it is strong and relatively easily observable in Io's spectrum, is the 4.07 μm (2459.4 cm^{-1}) $\nu_1 + \nu_3$ combination band. This is produced by normal isotope SO_2 consisting of $^{32}S^{16}O_2$ [8]. The band also has three identifiable Satellite bands on its redward flank due to fractions of SO_2 molecules containing isotopes ^{34}S, ^{35}S, and ^{18}O.

SO_2 slab ice -- Absorption bands for solid SO_2 ice are essentially the same as those in thick frost, except for an additional weak band at 3.92 μm.

SO_2 liquid -- The liquid SO_2 spectrum has major absorption bands at the following wavelengths: 2.72, 2.79, 3.85, 4.36, 5.38, and 6.2 μm. Note that the 2.72 and 6.2 μm bands are unique to the liquid phase.

Adsorbed SO_2 -- A monolayer adsorbate produces a band at 4.036 μm (2478.0 cm^{-1}); as it thickens and begins to form a crystal lattice, bands appear at 4.071 μm (2456.7 cm^{-1}) and at 4.37 μm (2288 cm^{-1}). As the lattice further thickens the 4.036 μm band blends into the deepening 4.066 μm band ($\nu_1 + \nu_3$ combination), and the 4.37 μm band ($2\nu_1$ overtone) gets stronger.

Surface textures -- We found it possible to produce a wide variety of surface textures for solid SO_2, ranging from frosts of many peculiar textures, to solid slab or glaze ice.

Applications to Io

Previously reported IR spectra of condensed SO_2 (e.g. in refs [6, 8, 9, 10, 11, 15]) have usually been produced as transmission spectra obtained on thin (or thick) films of ice, not as reflectance spectra of a free frost surface as reported here (or by [1, 2, 13, 14]). In comparing results of the two approaches, it appears that thin-film transmission spectra are not adequate to properly represent all the features present in reflectance spectra of macroscopic frosts or ices such as may exist on Io; this is because in thin lab samples there is insufficient optical pathlength to produce detectable absorption bands at certain wavelengths in reflectance spectra of thick deposits.

These systematic lab studies of band character and variation allow one to estimate what the phase state and concentration level is for condensed SO_2 on the surface of Io. Our lab results show that the $\nu_1 + \nu_3$ band minimum position is dependent on:

1. Phase state of the SO_2.
2. Frost/Ice thickness or density (g/cm^2).
3. Instrument resolution (because the band is asymmetric).

Relative thickness of a solid SO_2 (ice or frost) deposit, on a mm scale, can be assessed by strengths of bands for thickness as follows:

Thin -- 2.54, 2.79, and 3.75 μm bands absent, no 3.95 μm shoulder, 4.07 μm band present but narrow and unsaturated, 4.37 and 5.40 μm bands absent or weak;

Medium -- 3.75 band absent, 3.95 μm shoulder high, 4.07 μm band stronger, 4.37 and 5.40 μm bands present;

Thick -- 2.54, 2.79, and 3.75 μm bands strong, 3.95 μm shoulder low, 3.56 μm band distinct; 4.07 μm band broad and nearly saturated, 4.37 and 5.40 μm bands strong.

The Galileo infrared spectrometer (NIMS) is designed to measure spectra of Io's surface in the range 0.7-5.2 μm, with spectral resolution of 0.02 μm. Because our data show clearly that spectra of thin (~ 100 μm) SO_2 frosts are distinctly different than spectra for thick (> 1 mm) frost or ice, NIMS should be able to use the 4-μm band shape and depth (plus the presence or absence of the 2.54 and 2.79 μm bands) to map the relative thickness of solid SO_2 on Io's surface. Also, we estimate that NIMS should be able to detect a 0.2 cm-atm SO_2 atmospheric column over a spectrally neutral surface (such as sulfur) on Io.

References:

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