A CRYOGENIC REFLECTANCE SPECTROSCOPY FACILITY FOR CHARACTERIZATION OF CANDIDATE ICY SATELLITE SURFACE COMPOUNDS IN SUPPORT OF SPACECRAFT OBSERVATIONS. J. B. Dalton[1], [1]Jet Propulsion Laboratory, MS 183-301, 4800 Oak Grove Drive, Pasadena CA 91109. Email: dalton at jpl.nasa.gov.

Introduction: Interpretation of visible- to near-infrared spectral observations of icy satellite surfaces from spacecraft-based imaging spectrometers such as the Galileo Near Infrared Mapping Spectrometer (NIMS), Cassini Visual and Infrared Imaging Spectrometer (VIMS) and New Horizons Linear Etalon Imaging Spectral Array (LEISA) is critically dependent upon availability of laboratory spectra of candidate surface materials acquired under conditions relevant to these observations. Application of cryogenic laboratory reflectance spectroscopy to Galileo observations has demonstrated [1,2,3] the potential to differentiate mixtures of surface compounds on Europa, including sulfuric acid and sulfate salt hydrates, enabling the mapping of abundances and distributions of materials in discrete geologic units [4]. The Planetary Ice Characterization Laboratory (PICL) at JPL has been established in order to provide relevant measurements for studies of icy satellite surface compositions.

Background: Laboratory spectra are needed for a broad range of materials proposed to exist on icy satellite surfaces [5,6,7] including minerals, salts, volatile ices, and organics. Though the peer-reviewed literature abounds with published infrared spectra, only a few compounds have thus far been characterized in the manner required to facilitate quantitative interpretation of spacecraft observations of icy satellites. In order to be applied to such observations, laboratory measurements must satisfy the following four requirements:

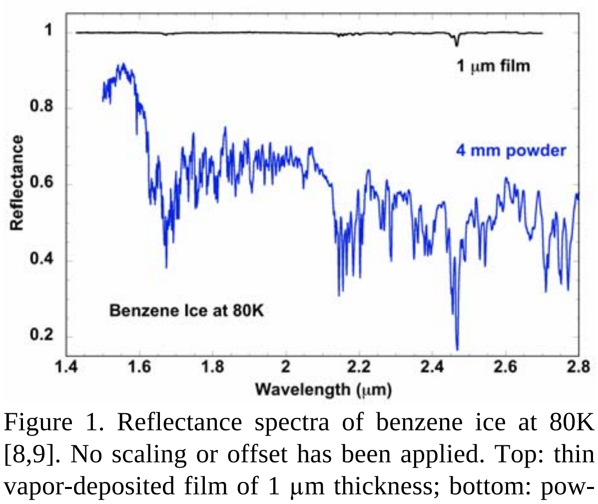

Figure 1. Reflectance spectra of benzene ice at 80K [8,9]. No scaling or offset has been applied. Top: thin vapor-deposited film of 1 μm thickness; bottom: powdered sample, 4 mm thick, ground and sieved under liquid nitrogen. Enhanced features in the macroscopic sample are relevant to IR observations of icy regoliths.

Wavelength range. Measurements are needed over the full wavelength range covered by the instruments making the observations. This is typically from ~0.35 to ~5 μm, but some instruments may make use of wavelengths as long as 25 μm. Published spectra often cover only a limited range, usually near a material's strongest absorption features, or, frequently, in the spectral range of the available laboratory equipment.

Temperature. Many spectral features of proposed icy satellite surface constituents display strong temperature dependence. Laboratory measurements acquired at the cryogenic temperatures relevant to the surfaces under study are urgently needed.

Sample thickness. Many of the highest quality published spectra of volatile ices relevant to icy satellites were measured using vapor-deposited thin (typ. ~1-3 μm) films. These are very useful for transmission studies in the mid-infrared, where ices and organic volatiles have fundamental absorption modes. Thin films avoid saturation of these strong bands. However, the near-infrared features measured by most imaging spectrometers are far weaker (up to two orders of magnitude) combinations and overtones of these fundamentals (Fig. 1), and are rarely strong enough to measure in samples of less than 10 μm thickness. Furthermore, the relative enhancements of some spectral features that arise from multiple scattering are not replicated in thin films, limiting their applicability to observations of icy satellite regoliths.

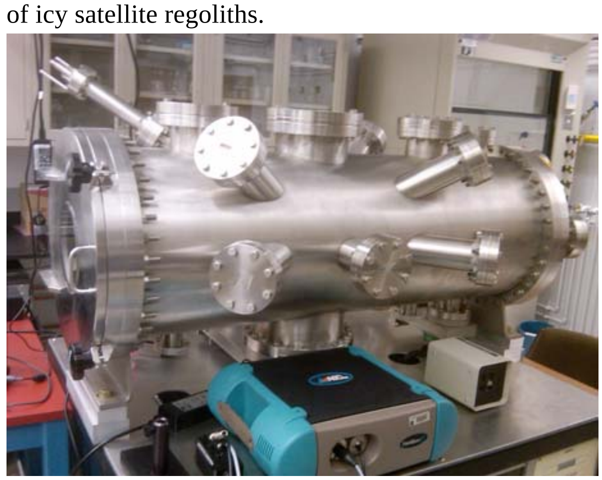

Figure 2. The Basic Extraterrestrial Environment Simulation Testbed (BEEST) at JPL is configured to acquire reflectance spectra of icy satellite surface compounds using relevant thicknesses, at relevant temperatures, in relevant wavelengths, with relevant geometry.

Reflectance viewing geometry. Spacecraft observations of icy satellites are acquired in a reflectance viewing geometry, and utilize reflected solar illumination. Due to scattering effects in icy regoliths, transmittance and absorbance spectra cannot be converted into units suitable for modeling these observations. While optical constants (real and imaginary indices of refraction) derived from transmittance measurements may be used to produce synthetic reflectance spectra via radiative transfer models, such optical constants must be derived from sufficiently thick (>~10 µm) samples to reproduce VNIR features.

Modeling. Identification of surface materials in remote sensing observations requires comparison to reference spectra of known materials. These do not need to be reflectance spectra; the identity of a material can be inferred visually from spectral features at corresponding locations. Determination of material abundance however requires more sophisticated approaches using models.

In linear mixture modeling, reflectance spectra are combined in weighted proportions to produce a composite spectrum. The weights applied to each constituent spectrum of this linear combination correspond to their abundances. If optical constants are available, synthetic reflectance spectra computed for various grain sizes may also be used.

Nonlinear mixture modeling explicitly treats the effects of reflection, refraction, scattering and absorption in surface grains and at grain boundaries. This requires knowledge of the optical constants and density of constituent materials, as well as estimates of grain sizes, porosity and roughness.

In both linear and nonlinear mixture modeling, spectra over a specific wavelength range are competed against each other to yield the best match to an observed spectrum. This requires that all materials of interest have their spectra measured across the same wavelength range.

Cryogenic Reflectance Facility: The Basic Extraterrestrial Environment Simulation Testbed (BEEST, Fig.2) at JPL is configured specifically to meet these needs. A programmable closed-loop liquid helium cryostat provides sample temperature control to within +/-0.5 K from 20 to 310 K. An oxygen-free copper sample holder provides a reflectance viewing geometry with normal incidence and phase angle of 10 degrees. A separate attachment may be used for transmission studies. A combination of dry-scroll and turbomolecular pumps provides oil-free vacuum down to 10^{-11} Torr. An Analytical Spectral Devices (ASD) FieldSpec Pro fiber-optic grating spectrometer covers visible to near-infrared (VNIR, 0.35 to 2.5 µm) wavelengths while a Thermo Nicolet Model 6700 FTIR spectrometer with two external liquid nitrogen cooled HgCdTe detectors provides longer infrared wavelength coverage (1.25-200 µm). Separate viewports allow the full wavelength range of both spectrometers to be utilized without disturbing the sample. Two Stanford Research Systems (SRS) RGA300 mass spectrometers monitor background and provide evolved gas analysis up to 300 amu at < 0.5 amu resolution. Samples are introduced as solids or liquids, or deposited from vapor phase using a custom gas mixing manifold. Grain sizes are verified *in situ* using a custom microscope and digital camera and subsequently via a Linkam LTS-420 Cryogenic Stage with an Olympus BX51 microscope.

Applications. The BEEST will be used to generate reflectance spectra for several compounds expected to occur on icy satellites, over the full wavelength range of current and planned VNIR imaging spectrometers (.35 – 200 µm), over the temperature range relevant to icy satellites (30 – 150 K), using a range of grain sizes (5 to 500 µm, depending on material properties). These reflectance spectra will enable linear mixture analysis for a number of satellites currently under investigation. Later efforts will focus on the derivation of optical constants from the reflectance measurements through a combination of radiative transfer modeling and subtractive Kramers-Kronig analysis [10,11]. This will enable more advanced radiative transfer modeling of intimately mixed grains in icy satellite regoliths.

Conclusion. While it is true that even higher quality optical constants may eventually be derived using transmission or a combination of transmission and reflectance measurements, given the present scarcity of reference spectra appropriate to abundance models for most materials of interest [6], even a single VNIR reflectance spectrum for many of these materials will represent a significant enhancement to the state of the art in the interpretation of icy satellite spectral observations. The facility described here will address this scarcity and enable retrieval of quantitative material abundances from spacecraft observations of icy satellites.

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