UV SPECTRA OF THE ICY MOONS OF JUPITER AND SATURN. A. R. Hendrix[1], [1]Jet Propulsion Laboratory/California Institute of Technology, Mail Stop 230-250, Pasadena, CA 91109; arh@jpl.nasa.gov.

Introduction: Ultraviolet spectroscopy is a useful tool for surface composition studies: the short penetration depth means that weathering products are readily detected;. ultraviolet wavelengths sense the topmost layers of the surface, and are therefore very sensitive to exogenic effects. A thorough analysis of UV data can lead to a determination of the abundances and distribution of radiation products such as H_2O_2, O_3 and SO_2. Furthermore water ice has a distinctive absorption edge in the far-UV However, in order to more fully utilize the existing UV datasets of icy surfaces in the solar system, and to better prepare for future observations, ultraviolet laboratory measurements of a range of candidate materials are needed. Here we briefly review what has been learned from UV measurements of the surfaces of the icy moons of Jupiter and Saturn, within the context of needed laboratory measurements.

The Icy Galilean Satellites: The first in-depth ultraviolet studies of the icy Galilean satellites (Europa, Ganymede and Callisto) were accomplished with the use of the International Ultraviolet Explorer (IUE) satellite [1]. Subsequent disk-integrated observations with Hubble Space Telescope (HST) supported the initial findings of IUE, in addition to adding to our knowledge of the composition of the surfaces of these satellites. Galileo UVS observations contributed to disk-resolved studies of these bodies.

The ratio of IUE spectra of Europa's trailing hemisphere to its leading hemisphere led to the discovery of an absorption feature present primarily on the trailing hemisphere centered near 280 nm. The absorption feature, was attributed to an S-O bond and was suggested to be due to implantation of sulfur ions into the ice lattice on the trailing hemisphere [2]. HST measurements confirmed the absorption feature and it was suggested that the feature was similar to laboratory spectra of SO_2 frost on water ice [3]. Subsequent disk-resolved Galileo UVS measurements showed that the 280 nm absorption feature is strongest in regions associated with visibly-dark terrain [4]. These locations have also been found to have relatively high concentrations of non-ice material, interpreted to be hydrated sulfuric acid or hydrated salt minerals. An additional Galileo discovery was the presence of hydrogen peroxide (H_2O_2) on Europa, primarily in regions of lower non-ice concentrations, such as on the leading hemisphere [5].

IUE spectra of Ganymede's trailing hemisphere ratioed to the leading hemisphere revealed the presence of a possible absorption feature centered close to 260 nm [1], though the signal was approaching the IUE detection limits. It was suggested that ozone (O_3) in the ice could explain the apparent absorption feature. Subsequent HST measurements confirmed the presence of the O_3 absorption feature in the ice lattice on the trailing hemisphere [6]. Disk-resolved observations of Ganymede from Galileo showed that the O_3 feature was strongest in the polar regions, and at large solar zenith angles, suggesting a connection with the magnetic field lines, or with photolysis or ice temperatures [7].

New results from Callisto [8] show that at high southern latitudes, the NUV spectra tend to be spectrally blue (or "roll over") >280 nm – suggesting the shoulder of an absorption feature with a band center ~350 nm. The lower latitudes are generally darker and largely spectrally redder than the high southern latitude region. This suggests that an absorber is present at high latitudes, which is weathered away by charged particle or UV bombardment at low latitudes. We suggest that the high latitude absorption feature could be due to an organic species. A carbon cycle may be occurring on Callisto, with CO_2, carbonates and carbon sub-oxides are principal end-products. The overall dark grey visible appearance of Callisto is consistent with laboratory measurements of carbonization of organics through radiation.

The Icy Saturnian Moons: HST observations of Dione and Rhea [9] detected an absorption similar to the 260 nm absorption feature detected by HST on Ganymede and has been attributed to the presence of ozone on both satellites. Like Ganymede, Dione and Rhea orbit within the magnetosphere of their planet. Ozone on these satellites may be a product of radiolysis, though radiolysis is likely a much less important process in the Saturnian system than in the Jovian system.

More recently, with the arrival of the Cassini spacecraft at the Saturn system, far-UV measurements of the icy satellites have been made with the Ultraviolet Imaging Spectrograph (UVIS). The far-UV spectra of the icy satellites are dominated by the strong water absorption feature at ~165 nm (Fig. 1). At wavelengths shortward of ~165 nm, the icy satellites are extremely dark due to the presence of water ice. However, the spectra of the icy moons of Saturn do not exactly match the H_2O ice models, either in shape or in magnitude – and thus lab data of candidate non-water ice species are very much needed to address these data. We take for example Enceladus (Fig. 2). Notice that the albedo of Enceladus is ~0.3 at 180 nm, compared with ~0.65 at the same phase angle at 439 nm [11] – *so some species is present in the surface of Enceladus* *that is spectrally active in the 180-440 nm region, causing the reflectance to drop by a factor of ~2* [12].

The absorbing species on Enceladus must be spectrally active primarily in the NUV, since Enceladus is very bright (non-absorbing) in the visible and NIR. Candidate species are shown in Figs. 3 and 4. A tholin mixed with water ice may be the most appropriate choice to match the Enceladus spectrum, as the VNIR spectra of tholins are relatively bright and spectrally bland, with a strong drop-off in brightness in the NUV; mixture models are in progress. More laboratory data are needed to better understand Enceladus and the other icy Saturnian moons.

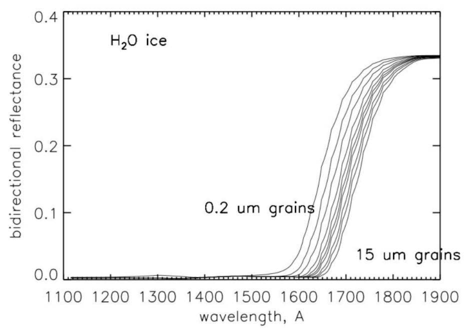

Fig. 1. Models of water ice reflectance spectra for several grain sizes, using optical constants [10].

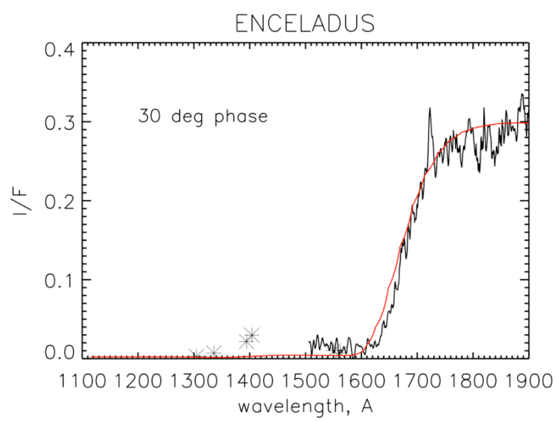

Fig. 2. Cassini UVIS spectrum of Enceladus with sample water ice model overplotted. The measured albedo, compared with the visible albedo at the same phase angle, suggests a strong absorption in the FUV-NUV-VIS region.

Laboratory Data Needs: Measurements of the optical constants of candidate ices and ice mixtures are needed in the ultraviolet (100-400 nm) to compare with spacecraft data of the icy moons of Jupiter and Saturn. The optical constants of non-ice species such as organics and different tholins are needed. In particular for the case of the Galilean satellites, laboratory studies of irradiated samples are needed.

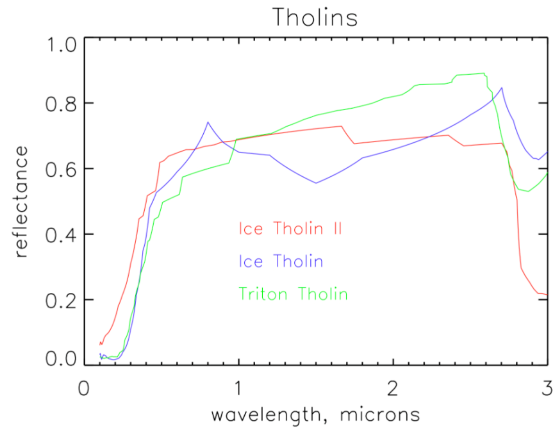

Fig. 3. Model reflectance spectra of tholins (after [13]). (The spectrum of ice tholin II is an extrapolation into the FUV.)

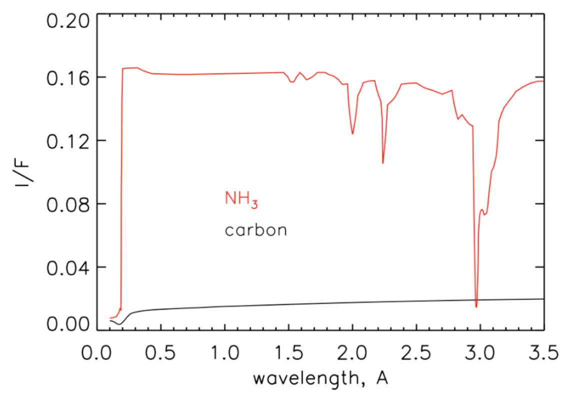

Fig 4. Model reflectance spectra of ammonia and carbon.

References: [1] Nelson R. M. et al. (1987) *Icarus, 72,* 358-380. [2] Lane A. L. et al. (1981) *Nature, 292,* 38-29. [3] Noll K. S. et al. (1995) *JGR, 100,* 19057-19059. [4] Hendrix A. R. et al. (1998) *Icarus, 135*, 79-94. [5] Carlson, R. W. et al. (1999) *Science, 283,* 2062-2064. [6] Noll, K. S. et al. (1996) *Science, 273,* 341-343. [7] Hendrix, A. R. et al. (1999) *JGR, 104,* 14169-14178. [8] Hendrix, A. R. and Johnson, R. E., *LPSC 2007.* [9] Noll, K. S. et al. (1997) *Nature, 388,* 45-48. [10] Warren, S. G. (1984) *Appl. Optics, 23,* 1206-1225. [11] Verbiscer, A. J. et al. (2005) *Icarus, 173,* 66-83. [12] Hendrix, A. R. and Hansen, C. J. (2007) *Fire & Ice Workshop abstract.* [13] Cruikshank, D. P. et al. (2005) *Icarus, 175,* 268-283.