Ultraviolet Spectra of Ariel, Titania, and Oberon: Evidence for Trapped OH from Hubble Space Telescope Observations.

Ted L. Roush (NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, troush@mail.arc.nasa.gov), Keith S. Noll (STScI), Dale P. Cruikshank, and Yvonne Pendleton (NASA Ames).

Recognition of current satellite surface compositions provides information regarding the internal and external processes modifying icy surfaces, e.g. magnetospheric bombardment, meteoritic infall, or ultraviolet photolysis. Identification of SO_2 on Europa [1,2] and Callisto [3,4], and O_3 on Ganymede [5,6], Rhea, and Dione [7], has demonstrated that chemical modifications occur on icy bodies due to ion bombardment associated with the magnetospheric fields of Jupiter and Saturn. The icy satellites of Ariel, Oberon, and Titania similarly reside within the uranian magnetospheric environment, suggesting that their surfaces could also be modified by this mechanism. In order to investigate this issue, we have obtained ultraviolet spectra of Ariel, Titania, and Oberon.

Here we discuss our findings. Below we provide some background material by comparing the magnetospheric environments that the Uranian satellites experience relative to the satellites in the Jovian and Saturnian systems and review the satellites orbital motions relative to the respective magnetospheric fields. We next discuss details related to the instrumentation used, the observations and their subsequent reduction. This is followed by an analysis of the data that relates the position of the major absorption features observed to compositional interpretations and the relative strengths of the absorptions to the ion density within the Uranian system. Finally we provide a summary of our findings and discuss their implications for magnetospheric-surface interactions.

The Voyager spacecraft provided direct measurements of the magnetospheric environment at Jupiter, Saturn, and Uranus [e.g. 8-10], and can be summarized for several satellite surfaces that reside within these magnetospheric environments as follows. Ion densities and energies are greatest for the Jovian system and least for the Uranian system with values for the Saturnian system falling in between [11]. However, there is clearly some overlap in both parameters for the various satellites. For example, the energy of the ions encountering Oberon are equivalent to those encountering Io, but the densities are reduced by about 5 orders of magnitude. The ion densities are similar for Ariel and Callisto, but the ion energies are greater by about 3 orders of magnitude on Callisto. This large range of densities and ion energies present between these satellite systems may provide a mechanism for separating which of these two variables is most important in magnetospheric modification of icy surfaces. It is interesting that all the surfaces interpreted as providing evidence for magnetospheric modification (Europa, Ganymede, Dione, and Rhea) all have ion density and energy values that are within about one order of magnitude of each other.

All of these satellites have rotational periods that are synchonous with their revolution about the primary and, as a result the trailing hemispheres are preferentially bombarded by the planetary magnetospheres. It has long been recognized that leading versus trailing hemisphere albedo and spectral dichotomies exist for icy satellite surfaces in the Jovian, Saturnian, and Uranian systems, although not all of these have been attributed to magnetospheric sources [12-17].

Using the Hubble Space Telescope (HST) and now defunct Faint Object Spectrometer (FOS), we acquired spectra of Ariel, Titania, and Oberon. We used two grating positions of the FOS, G270 and G400, providing wavelength coverage from approximately 0.22- to 0.48 µm. Due to the faintness of these objects, the observations spanned three HST orbits and an acquire/peak sequence was used for at the beginning of each satellite observation. Integration times averaged 28 min. for G270 and 14 min. for G400. The data were reduced to flux using standard procedures maintained by the Space Telescope Science Institute. The solar spectrum was an average of two SOLSTICE observations [18] covering the 0.22- to 0.42-µm region and the solar spectrum of [19] covering the 0.42- to 0.48-µm region. Prior to ratioing the fluxes to the solar spectrum, narrow solar lines were used to fine-tune the wavelength positions. Geometric albedos (at the solar phase angle, α, of the observations ~0.8 degrees) were calculated by dividing the FOS flux by the solar spectrum for each grating position.

The derived geometric albedos agree with broad band albedos reported by [20], for $\alpha = 1$ degree, in the region of wavelength overlap between the two observations and to within the uncertainties of both data sets. Over the wavelength range of 0.34 to 0.47 µm the FOS data suggest a slightly redder slope than those reported by [20]. This red slope continues down to approximately 0.28 µm where the slope becomes blue, hence defining a broad albedo minimum near 0.28+/-0.01 µm. This strength of the albedo minimum is greatest for Ariel, intermediate for Titania, and weakest for Oberon. These features are similar in position to those associated with SO_2 on Europa and Callisto [1-4], although there is no apparent source of SO_2 molecules in the uranian system. Another material producing an absorption near 0.28 µm is trapped OH, which is a photolysis and radiolysis by-product from H_2O [21] and represents OH trying to absorb into an ice structure. Any trapped OH formed will be more likely to be retained at the lower temperatures of the uranian satellites compared to the warmer jovian satellites [22]. The total proton energy flux at Ariel is about two order of magnitude greater than that at Titania and nearly three orders of magnitude greater than that at Oberon [11]. This suggests the production rate of OH from radiolysis of water ice [23] would be greatest on Ariel and least for Oberon. The relative strengths of the 0.28 µm band observed for the satellites is consistent with the relative production rates of OH on these objects due to proton bombardment.

In order to undertake a more quantitative analysis of surface composition, we have selected the Ariel spectrum chiefly because it exhibits the strongest absorption. This analysis relies upon the development of Hapke [24] that describes the interaction of light with particulate surfaces. Using the values of the optical density of irradiated water ice [21] as an estimate for water ice optical constants and amorphous carbon optical constants [25], geometric albedos were calculated for mixtures of these materials. A model that reproduces the depth of the 0.28 µm feature of the Ariel data is dominated (92.7%) by large-grained water ice (~3.6 mm) with a small amount (6.9%) of finer-grained water ice (160 µm), and a trace (0.4%) of fine-grained amorphous carbon 34 (µm). Comparison of this model to the Ariel data suggests that some additional absorbing species is required for the 0.32-0.41 µm region.

Acknowledgements: This research supported by NASA's Planetary Geology and Geophysics program and the Space Telescope Science Institute.

References: [1] K.S. Noll et al. 1995, *J. Geophys. Res.*, **100**, 19057. [2] A.L. Lane et al. 1981, *Nature*, **292**, 38. [3] K.S. Noll et al. 1997, *GRL*, **24**, 1139. [4] A.L. Lane et al. 1997, *GRL*, **24**, 1143. [5] J.R. Spencer et al. 1995, *J. Geophys. Res.*, **100**, 19049. [6] K.S. Noll et al. 1996, *Science*, **273**, 341. [7] K.S. Noll et al. 1997, *Nature*, **388**, 45. [8] N.F. Ness et al. 1979, *Science*, **204**, 42. [9] N.F. Ness et al. 1981, *Science*, **212**, 211. [10] N.F. Ness et al. 1986, *Science*, **233**, 85. [11] R.E. Johnson 1990 *Energetic Charged-Particle Interactions with Atmospheres and Surfaces*, Springer-Verlag, New York. [12] R.N. Clark 1980, *Icarus*, **44**, 388. [13] T.V. Johnson et al. 1983, *J. Geophys. Res.*, **88**, 5789. [14] M.L. Nelson et al. 1986, *Icarus*, **65**, 129. [15] B.J. Burrati 1991 *Icarus*, **92**, 312. [16] B.J. Burrati et al. 1990, *Icarus*, **87**, 339. [17] B.J. Buratti & J.A. Mosher 1991, *Icarus*, **90**, 1. [18] T.N. Woods et al. 1993, *J. Geophys. Res.*, **98**, 10679. [19] L. Colina et al. 1996, *Astron. J.*, **112**, 307. [20] E. Karkoshka 1997, *Icarus*, **125**, 348. [21] I. Taub & K. Eiben 1968, *J. Chem. Phys.*, **49**, 2499. [22] J. Ghormley & C. Hochanadel 1971, *J. Chem. Phys.*, **75**, 40. [23]R.E. Johnson & T.I. Quickenden 1997 *J. Geophys. Res.*, **102**, 10985. [24] B. Hapke *1993 Theory of Reflectance and Emittance Spectroscopy*, Cambridge Univ. Press, NY. [25] F. Rouleau and P.G. Martin 1991, *Astrophys. J.*, **377**, 526.