NEAR-INFRARED SPECTROSCOPY OF URANIAN SATELLITES: SEARCHING FOR CARBON DIOXIDE ICE ON UMBRIEL, TITANIA, AND OBERON. R. Cartwright[1], J. Emery[1], A. Rivkin[2], D. Trilling[3], [1]University of Tennessee, [2]JHU/APL, [3]Northern Arizona University.

Introduction: The five largest Uranian satellites are dominated by water ice and a dark, spectrally flat constituent that is possibly carbonaceous in origin [e.g., 1-3]. Carbon dioxide has been detected on Ariel, Umbriel, and Titania, but has not been detected on the furthest regular Uranian satellite, Oberon [4,5]. The detected CO_2 ice appears to be concentrated on the trailing hemispheres of these satellites, and it decreases in abundance with increasing semi-major axis [5].

While the origin of CO_2 in the Uranian system is unclear, destruction processes like sublimation, UV photolysis, and sputtering induced by charged particles should effectively remove primordial CO_2 from satellite surfaces over the age of the Solar System. Primordial CO_2 could plausibly exist beneath a protective regolith and become exposed by impact events. However, impact-exposed CO_2 ice would tend to concentrate on the leading sides of satellites [6], counter to the observed distribution on the Uranian satellites [5].

CO_2 might be produced by the bombardment of H_2O ice and carbon-rich materials by charged particles caught in Uranus' magnetic field, as demonstrated under lab conditions [7,8]. This production mechanism would lead to preferential accumulation of CO_2 on the satellites closest to Uranus due to higher magnetic field densities [9]. The rapid rotation rate of Uranus' magnetic field (~18 hours) should generate higher abundances of CO_2 on the satellites' trailing hemispheres.Therefore, radiolytic production of CO_2 from H_2O ice and carbon-rich materials can explain both the observed latitudinal and planetocentric distribution of this volatile in the Uranian system. Of note, the regular Uranian moon with the largest semi-major axis, Oberon, spends part of its orbit outside the confines of Uranus' magnetic field, which might explain why CO_2 has yet to be detected on its surface.

We gathered spectroscopic data of Umbriel, Titania, and Oberon to further investigate the distribution of CO_2 in the Uranian system. We timed our observations to coincide with unobserved longitudes that complement those investigated by a previous study [5]. We aim to match these near-infrared spectroscopic observations with photometric data gathered by the Infrared Array Camera (IRAC), onboard NASA's Spitzer Space Telescope (SST). These two data sets will allow us to investigate the surfaces of the Uranian satellites over a wide range of wavelengths.

Observations and Data Reduction: We gathered spectroscopic data using the SpeX spectrograph on NASA's Infrared Telescope Facility (IRTF) on four different nights (observational parameters for the spectra included here are summarized in Table 1). We gathered data over 5 orders (spanning 0.8 – 2.4 μm) in cross-dispersed mode (SXD), enabling us to search for several narrow CO_2 combinaton and overtone bands that occur between 1.5 – 2.2 μm. We used a 0.8 arcsecond slit, which we aligned with the parallactic angle in order to minimize slit losses due to atmospheric diffraction. SpeX operating in SXD mode has the necessary spectral resolution ($\Delta\lambda$ ~0.0016) to resolve these narrow CO_2 absorption features (FWHM ~0.0045). Along with local standard star observations, we also observed several well known solar analogs (SA 112-1333, SA 115-271, SA 93-101, and Hyades 64), which were used to ensure that our local standard stars were suitable choices for solar corrections. We used an IDL-based data reduction package (Spextool) designed for processing spectral data gathered by the SpeX spectrograph [10].

Table 1: Observational Parameters

	Umbriel	**Titana**	**Oberon**
Date	1-Nov-12	12-Oct-12	1-Nov-12
UT time	9:15	10:16	7:15
t_{int} (min)	60	60	68
S/N	~70	~90	~100
Long (°)	~125	~160	~235

Results: Example spectra for Umbriel, Titania, and Oberon are shown in Figure 1. Broad water ice bands centered near 1.55 and 2.05 μm are apparent in each of the spectra, as well as a crystalline water ice absorption band centered near 1.65 μm. These bands are much more subdued for Umbriel than the other Uranian moons. The water ice bands for all three of these Uranian satellites are relatively shallow compared to icy satellites in the Jovian and Saturnian systems, most likely due to the presence of a spectrally flat, carbon-rich substance. We do not detect strong evidence for CO_2 ice combination or overtone bands in the included spectra.

Discussion: Our results are consistent with previous spectroscopic studies of the Uranian satellites [e.g., 1-3] that detected surfaces dominated by water ice mixed with a spectrally neutral component. Our lack of CO_2 ice detection on Oberon (~235° longitude) is in agreement with previous work (~216° longitude) [5]. Given that Oberon spends a portion of its orbit outside the confines of Uranus' magnetic field, the absence of CO_2 on Oberon supports the hypothesis that CO_2 is generated via charged particle interactions with H_2O ice and carbon-rich materials on the trailing sides of the closest Uranian satellites.

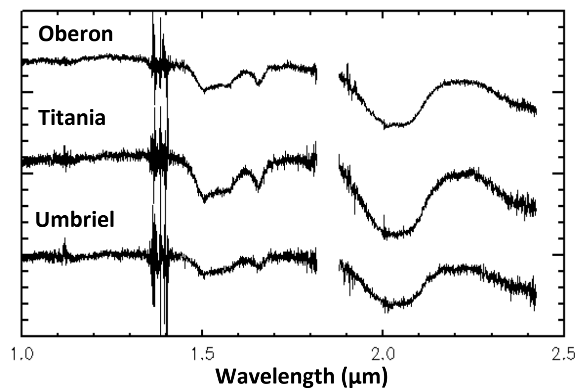

Figure 1: Near infrared spectra of Oberon, Titania, and Umbriel. Spectra offset by 0.6 units for clarity. Noisy region near 1.4 µm and gap near 1.9 µm coincide with wavelength ranges with low atmospheric transmission. The Oberon and Umbriel spectra are both from 2012/11/01 UT, and the Titania spectrum is from 2012/09/21 UT.

CO_2 ice has been detected on Umbriel and Titania [5] at longitudes relatively close to their antapexes of motion (~261° and ~300° for Umbriel and Titania, respectively), where magnetospherically-driven CO_2 production rates should be highest. Our observations of Umbriel and Titania were at longitudes on the Uranus-facing hemisphere, where magnetospherically-driven CO_2 production rates should be lower than at longitudes near their antapexes of motion. Thus, the absence of strong evidence for CO_2 ice in our Umbriel and Titania spectra might simply be due to lower abundances of this volatile at the observed longitudes.

There is a large difference in latitude between our observations (~17 N) and the previous study [5] where CO_2 detection was reported (~20 S). It is unclear whether CO_2 ice is concentrated on the southern hemispheres of the Uranian satellites. If CO_2 is confined to southern latitudes, then it is most likely produced by localized geologic processes and not magnetic field interactions with materials on Uranian satellite trailing hemispheres.

Of note, our data reduction process is ongoing, and the subtle signature of CO_2 ice combination and overtone bands might become more apparent after the application of more sophicated reduction techniques.

Summary and Future Work: Here we present spectroscopy of three of the largest Uranian satellites: Umbriel, Titania, and Oberon. We timed our observations to complement those of a previous study [5], and we plan to combine our near-infrared spectroscopic data with longer wavelength photometry gathered at similar longitudes. Multiple water ice bands are apparent in our data; however, narrow combination and overtone CO_2 ice bands are less certain and might be absent. Spectra presented here could be used to calculate upper limits for CO_2 ice abundances at the satellite longitdues we observed.

Future work will focus on refining our spectroscopic data reduction procedure and matching the resulting spectroscopy to longer wavelength photometric data gathered by IRAC onboard SST. Detailed compositional modeling using both datasets (0.8 – 2.4 µm spectroscopy, ~3.1 – 9.0 µm photometry) will enable us to characterize the distribution of materials, notably CO_2 ice, on the surfaces of the largest Uranian satellites.

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