ARE NITROGEN-BEARING SPECIES PRESENT ON URANUS' MOON UMBRIEL? Richard J. Cartwright[1], David R. DeColibus[2], Julie Castillo-Rogez[3], Chloe B. Beddingfield[1,4], William M. Grundy[5,6], and Tom A. Nordheim[3]. [1]SETI Institute (rcartwright@seti.org), [2]New Mexico State University, [3]Jet Propulsion Laboratory, California Institute of Technology, [4]NASA Ames Research Center, [5]Lowell Observatory, [6]Northern Arizona University.

Background and Motivation: The classical Uranian moons Miranda, Ariel, Umbriel, Titania, and Oberon have surface compositions dominated by H_2O ice mixed with a spectrally neutral component [e.g., 1-3]. CO_2 ice is present on the surfaces of Ariel, Umbriel, Titania, and Oberon, primarily on their trailing hemispheres [4-5]. Spectrally red material (~0.4 – 1.3 µm) is also present on these moons, primarily on their leading hemispheres [e.g., 6,7]. The composition of the red material and the spectrally neutral material is not known, but organics and/or silicate minerals are assumed to dominate these components [e.g., 7,8].

Subtle absorption bands centered near 2.2 µm have also been detected on the five moons, tentatively attributed to ammonia (NH_3) bearing species [e.g., 7,9,10]. Charged particle bombardment should remove NH_3 from the surfaces of these moons on short timescales, perhaps in as little as 10^6 years at Miranda [11]. Consequently, NH_3 could be a tracer of geologic activity in the recent past, which may have exposed or emplaced NH_3-rich deposits. The youngest regions of Miranda (< 0.5 Ga) and Ariel (0.5 – 1.8 Ga) [12] display clear evidence for tectonic and possible cryovolcanic activity, supporting an association between 2.2-µm bands and recent geology [9].

In contrast, the surface of Umbriel is ancient (4.3 – 4.5 Ga) [12] with minimal evidence for endogenic activity [e.g., 13]. The detection of 2.2-µm bands on Umbriel therefore raises important questions about the longevity of NH_3 on the Uranian moons and the possibility that alternative and more radiation resistant species could be contributing to this spectral feature. To investigate the species contributing to Umbriel's spectral signature, we measured the area and depth of 2.20-µm bands in 33 spectra, as well as measuring other bands centered near 2.14, 2.22, and 2.24 µm. We assessed the distribution of these four bands, and compared them to laboratory spectra of various candidate species [14].

Observations: We analyzed 27 spectra of Umbriel collected with the SpeX spectrograph on NASA's Infrared Telescope Facility [15] between 2000 and 2021, and six more spectra collected with the TripleSpec spectrograph on the Astrophysical Research Consortium 3.5-m telescope at the Apache Point Observatory [16] between 2019 and 2021. All spectra were calibrated using the Spextool and Triplespectool data reduction suites [17], along with custom programs.

Results and Analyses: We measured the band areas and depths of Umbriel's 2.14-µm, 2.20-µm, 2.22-µm, and 2.24-µm bands, identifying 19 spectra with >2σ measurements for one or more of the four bands (***Figure 1***). We assessed the sub-observer longitudinal distribution of the four bands, finding no obvious spatial trends. We then calculated mean band area and depth measurements for Umbriel's leading and trailing hemispheres, finding no spatial trends (<2σ, ***Table 1***).

After assessing the distribution of the four bands, we compared their spectral signatures to a wide range of laboratory spectra (***Figure 2***). We found that a variety of N-bearing species including NH_3-H_2O mixtures, NH_3 ice, and CN-bearing organics provide good matches to Umbriel's 2.14-µm, 2.20-µm, 2.22-µm, and 2.24-µm bands, supporting the possible presence of nitrogenous components on Umbriel. Furthermore, the only constituent we investigated that matched Umbriel's 2.24-µm band is NH_3 ice. Our analysis also determined that carbonates like thermonatrite ($NaCO_3*H_2O$) and Al-bearing phyllosilicates like kaolinite ($Al_2Si_4O_5(OH)_4$) provide good matches to Umbriel's 2.20-µm band, CH-bearing organics (hydrocarbons) can match its 2.22-µm band, and mixtures of H_2O and CO_2 ices might explain the presence of its 2.14-µm band.

Table 1: *Mean band measurements*

Hemisphere	Spectral Feature	Mean Band Area (10^{-4} µm)	Mean Band Depth (µm)
Leading	2.14-µm Band	1.51 ± 0.624	0.9 ± 0.39
Trailing		1.72 ± 0.269	1.2 ± 0.22
Leading	2.2-µm Band	2.91 ± 0.857	1.8 ± 0.48
Trailing		2.04 ± 0.500	1.4 ± 0.33
Leading	2.22-µm Band	2.09 ± 0.614	1.3 ± 0.47
Trailing		2.15 ± 0.457	1.4 ± 0.34
Leading	2.24-µm Band	2.44 ± 0.874	1.2 ± 0.54
Trailing		2.25 ± 0.812	1.2 ± 0.50

Discussion: Our results and analyses indicate that NH_3 ice and other volatile N-bearing species could be present on Umbriel's ancient surface. Radiolysis of mixed H_2O, CO_2, and NH_3 deposits could form a variety of more refractory species that exhibit spectral features between 2.12 and 2.27 µm [e.g., 18], possibly explaining the persistence of these four bands on Umbriel. Additionally, volatile components could have

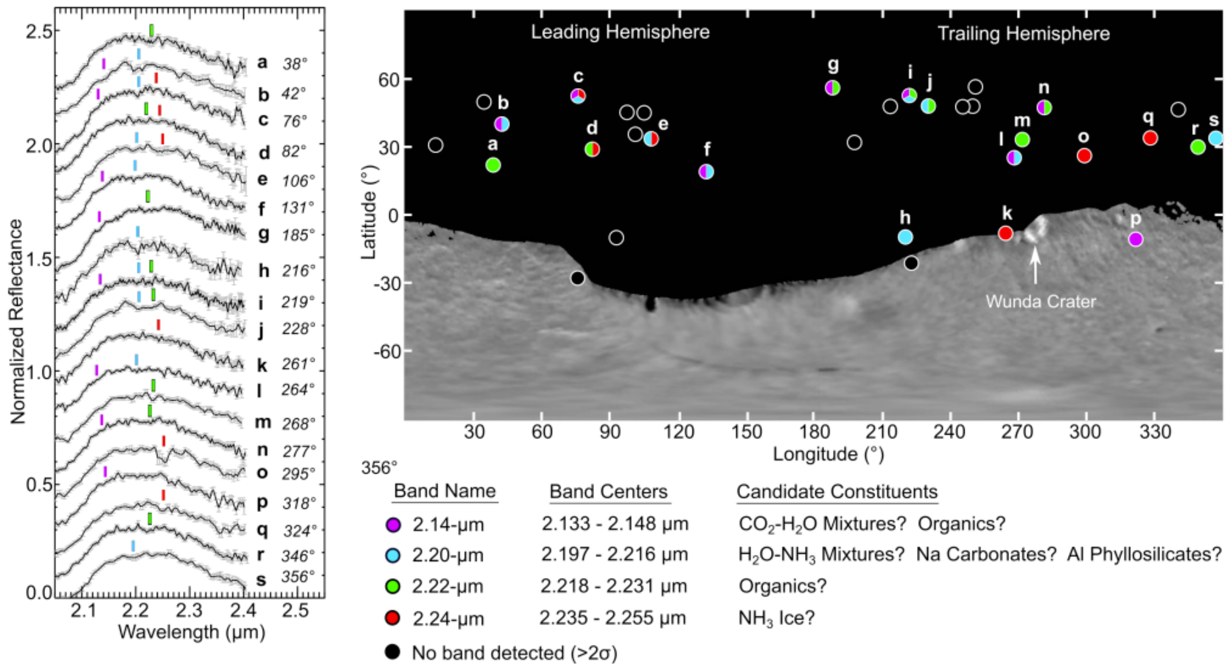

Figure 1. *Left: The 19 Umbriel spectra (a – s) displaying 2.14-µm, 2.20-µm, 2.22-µm, and 2.24-µm bands (purple, blue, green, and red markers, respectively) with band area and depths >2σ (sub-observer longitudes listed to the right of each spectrum). Right: Voyager 2 image mosaic that shows the mid-observation, sub-observer longitudes and latitudes for all 33 spectra, where color-filled circles represent spectra with band measurements >2σ and black circles represent spectra with no measurements >2σ (see legend). These disk integrated observations are not spatially resolved. The white arrow points to the bright annulus of material mantling the floor of Wunda crater.*

been delivered more recently in dust grains and other impactors. Although Umbriel's surface is old, it does have a few complex craters with bright floors, including Wunda crater (***Figure 1***). Perhaps these bright spots are emplaced and/or exposed deposits that are rich in NH_3 ice and other volatiles. In this scenario, N-bearing species and other volatiles may have originally formed in a relict ocean in Umbriel's early history or were retained in an undifferentiated crust.

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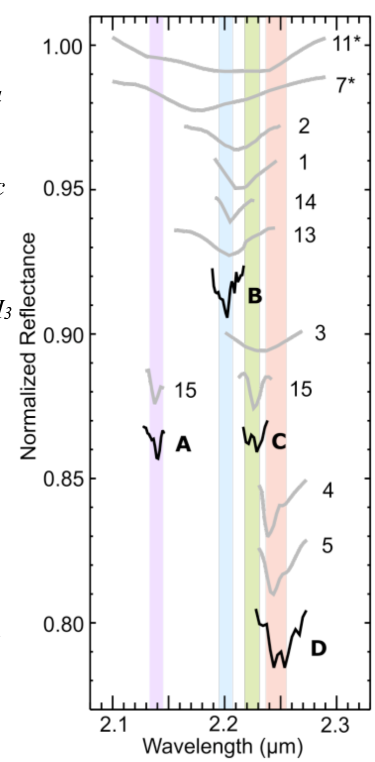

Figure 2. *Grand average, continuum-divided Umbriel spectra (A-D) compared to continuum-divided laboratory and synthetic spectra of (1) H_2O-NH_3 mixture, (2) flash frozen H_2O-NH_3, (3) amorphous NH_3, (4) NH_3 ice (88 K), (5) NH_3 ice (100 K), (7) $(NH_4)_2CO_3$, (11) NH_4Cl, (13) thermonatrite, (14) kaolinite, and (15) CH_3NH_2. Wavelength ranges of the 2.14-µm, 2.2-µm, 2.22-µm, and 2.24-µm bands are highlighted by the purple, blue, green, and red colored zones, respectively.*