

**CONSTRAINTS ON TITAN'S SURFACE COMPOSITION USING VIMS SOLAR OCCULTATION MEASUREMENTS.** T.B. McCord<sup>1</sup>, P. O. Hayne<sup>1,2</sup>, C. Sotin<sup>2</sup>. <sup>1</sup>Bear Fight Institute, 22, Fiddler's Road, P.O. Box 667, Winthrop, WA, 98862, USA. <sup>2</sup>NASA/Jet Propulsion Laboratory and California Institute of Technology, Pasadena, USA.

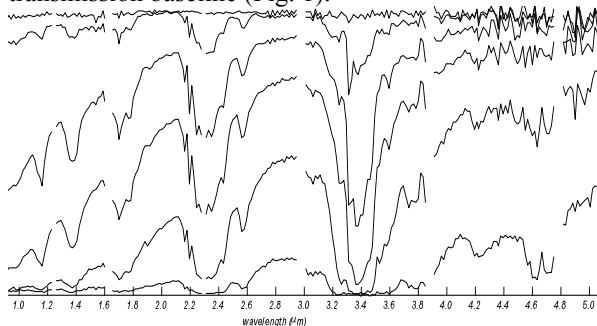
**Introduction:** Titan's surface is obscured by a thick absorbing and scattering atmosphere, allowing direct observation of the surface within only a few spectral windows in the near-infrared, complicating efforts to identify and map geologically important materials using remote sensing IR spectroscopy. The atmosphere is approximately 1.5 bars pressure at the surface and contains approximately 5% methane, which absorbs heavily in the near infrared. Scattering increases slowly and monotonically toward shorter infrared wavelengths. These effects vary in space and time. Radiative transfer models attempt to account for the effects of known atmospheric constituents on Titan's reflectance, yet many spectral features remain partly or wholly unexplained [1,2]. Thus, and despite the measurements returned by the Cassini mission, present knowledge of Titan's surface composition is inadequate, e.g., for guiding and testing models of the satellite's interior evolution [3,4] and the geologic and atmospheric processes shaping its surface [5].

Interior evolution models of Titan suggest it has differentiated, with an outer water layer composing ~50% of the satellite by mass, overlying a deeper silicate mantle [3]. A range of hydrocarbons and nitriles is present in the atmosphere, and methane is removed from the atmosphere by chemical reactions on geologically short time scales and must be replenished possibly by outgassing from the interior [6,7]. Numerous river channels dissect Titan's surface, some of which feed into polar lakes and seas, likely composed of methane and ethane, confirming the exchange of volatile hydrocarbons between the atmosphere, surface, and possibly the interior [8,9]. Based on the above considerations, previous investigations of Titan's surface composition have therefore focused on evidence for exposures of water ice "bedrock" and hydrocarbons derived from the atmosphere or interior [1,10]. Given both the inherent complexity of rigorous radiative transfer models and the lack of data on individual line profiles for the array of molecules present in Titan's atmosphere under realistic thermodynamic conditions, it has proved challenging to properly account for atmospheric effects in deriving Titan's surface reflectivity in the near-infrared [11].

**Data and Methods:** We therefore investigate the atmosphere's infrared transmission with direct measurements using Titan's occultation of the Sun as well as Titan's reflectance measured at differing illumination and observation angles observed by Cassini's Visual and Infrared Mapping Spectrometer (VIMS). We focus on two important spectral windows: the 2.7-2.8- $\mu$ m "double window" and the broad 5- $\mu$ m window. By

estimating atmospheric attenuation within these windows, we seek an empirical correction factor that can be applied to VIMS measurements to estimate the true surface reflectance and map compositional variations.

The solar occultation data are 12x12 cubes with an integration time of 40 ms. Vertical resolution depends on integration time and the geometry of the observation (on the order of 20 km). Data are usable down to ~40 km altitude, where line of sight opacities become large. Transmission spectra are calculated by dividing each calibrated radiance spectrum by an average of ~5 spectra acquired before the Sun is obscured by Titan, which are therefore assumed to represent the 100% transmission baseline (Fig. 1).

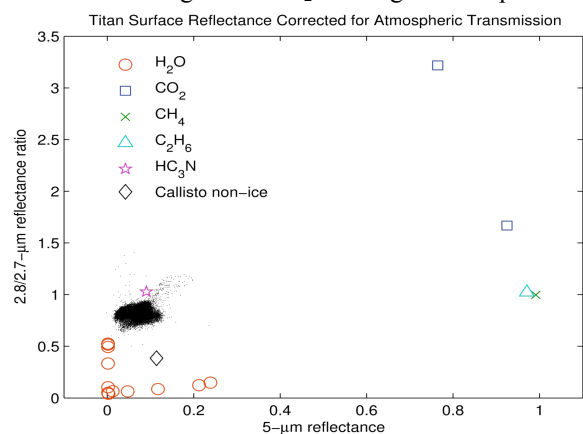


**Figure 1.** Example VIMS relative transmission (0 to 1) spectra for the S17 solar occultation. The approximate altitudes are (top to bottom): 1000, 500, 250, 200, 150, 80 km.

We restricted the on-planet observations to those with sequence numbers up to S38, which provides a sufficiently large yet manageable dataset. We calculated the airmass (path length traversed by the reflected beam) for every pixel intersecting Titan's surface:  $\mu' = (1/\mu_0 + 1/\mu)$ , where  $\mu_0$  and  $\mu$  are the cosines of the solar incidence and emergence angles, respectively. Our radiative transfer model is intentionally simple, and assumes single-scattering within the optically-thin methane windows, but accounts for multiple reflections between surface and atmosphere [12].

**Results:** Using the atmospheric opacities derived from the occultation measurements, we correct the VIMS data for Titan's viewing geometry-dependent atmospheric effects for both the 5- $\mu$ m reflectance and 2.8/2.7- $\mu$ m reflectance ratio. We then compare the corrected reflectance data to that of compounds proposed to exist on Titan's surface (Fig. 2). We will present the known uncertainties in the approach and their implications for interpreting the compositional information, and discuss the broader implications for Titan's surface composition and geologic history.

Uncorrected reflectance 2.7/2.8- $\mu\text{m}$  ratios are almost always  $> 1$  and therefore not consistent with water ice, as noted previously [11,13]. Hydrocarbons expected on Titan's surface tend to have ratios near unity, although this is not always the case [14], and any amount of hydration will tend to drive this ratio below unity. Applying the atmospheric correction, we see that the 2.8/2.7- $\mu\text{m}$  ratio shifts toward smaller values and broadens somewhat; a slight shoulder near 0.9 is also apparent. In this case, water ice is still off-scale toward lower ratios for the great majority of Titan's surface, although most of the surface has a ratio below unity, consistent with various hydrated forms of tholins and simple organics. The hydrocarbons considered fall near somewhat higher ratios than the Titan data, and carbon dioxide is off-scale toward higher ratios ( $\sim 1.6$  for fine-grained  $\text{CO}_2$  frost). However, Titan's corrected reflectance may be consistent with mixtures of hydrocarbons or fine-grained  $\text{CO}_2$  existing at some places.



**Figure 2.** Scatter plot showing the atmosphere-corrected Titan points (black dots) compared to laboratory spectra of various ices and organics, as well as a Galileo-NIMS spectrum of Callisto "non-ice" material. Most Titan points fall somewhat between pure water ice and pure hydrocarbons with a branch of points directed toward fine-grained (2–20  $\mu\text{m}$ )  $\text{CO}_2$  ice. None of the pure substances considered fall within the cloud of Titan points, suggesting mixtures among these or other components may dominate the surface. Liquid droplets or solid frosts of methane or ethane will tend to draw both the 5- $\mu\text{m}$  reflectance and 2.8/2.7- $\mu\text{m}$  ratio toward unity.

### Conclusions:

- We propose a simple correction to VIMS Titan data to account for atmospheric attenuation and diffuse scattering in the 5- $\mu\text{m}$  and 2.7–2.8  $\mu\text{m}$  windows, generally applicable for airmass  $< 3.0$ .
- The narrow 2.75- $\mu\text{m}$  absorption feature, dividing the window into two sub-windows, present in all on-planet measurements is not present in the occultation data, and its strength is reduced at the cloud tops, suggesting the responsible molecule is concentrated in the lower troposphere or on the surface.
- Our empirical correction to Titan's surface reflectance yields properties shifted closer to water ice for

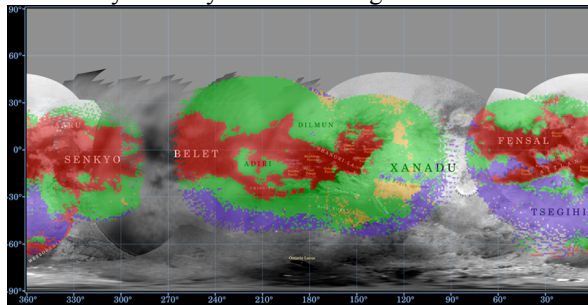
the majority of the low-to-mid latitude area covered by VIMS measurements.

- Four compositional units are defined and mapped on Titan's surface (Fig. 3) based on the positions of data clusters in 5- $\mu\text{m}$  vs. 2.8/2.7- $\mu\text{m}$  scatter plots; a simple ternary mixture of  $\text{H}_2\text{O}$ , hydrocarbons and  $\text{CO}_2$  might explain the reflectance properties of these surface units.

- The vast equatorial "dune seas" are compositionally very homogeneous, perhaps suggesting transport and mixing of particles over very large distances and/or and very consistent formation process and source material.

- The compositional branch characterizing Tui Regio and Hotei Regio is consistent with a mixture of typical Titan hydrocarbons and  $\text{CO}_2$ , or possibly methane/ethane; the concentration mechanism proposed is something similar to a terrestrial playa lake evaporate deposit [15], based on the fact that river channels are known to feed into at least Hotei Regio.

- Future work will focus on extending the simple atmospheric correction to larger airmass values, which will expand the corrected data to higher latitudes; full radiative transfer modeling and retrieval of surface reflectivity is always the ultimate goal.



**Figure 3.** Map of compositional units.

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