TITAN'S SURFACE COMPOSITION: CONSTRAINTS FROM LABORATORY EXPERIMENTS AND CASSINI/VIMS OBSERVATIONS.

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Introduction: Observations of Titan's surface are severely hindered by the presence of an optically thick, scattering and absorbing atmosphere. For this reason, very little was known of Titan's surface composition prior to Cassini. Observations from this mission have revealed a surface rich in geologic diversity, but its composition remains elusive [1, 2]. Surface composition has important consequences for models of Titan's interior, surface, and atmosphere, especially in the search for an endogenic methane source. Recent analysis of data from the Cassini Visual and Infrared Mapping Spectrometer (VIMS) [1, 3] confirms the presence of "dirty" water ice deduced from earlier ground-based studies [4, 5]. However, many regions of Titan are not spectrally consistent with water ice as the dominant component, and the identity of the other constituents remains ambiguous.

Evidence from VIMS spectra suggests CO_2 frost is consistent with the bright terrain [1], especially concentrated on two features suggested to be cryovolcanoes (Fig. 1) [6, 7]. CO_2 is not a likely cryomagma component [8], but instead is probably condensed from the atmosphere, as predicted by photochemical models [9]. On the other hand, some ice mixtures predicted by atmosphere and interior models to be on Titan's surface have unknown reflectance properties in the near-IR. Here we describe a series of infrared reflectance experiments on Titan-analogue ices, which are being planned at the Jet Propulsion Laboratory. An ongoing complementary effort to classify and map Titan's compositional units with the VIMS data will be constrained by the laboratory results.

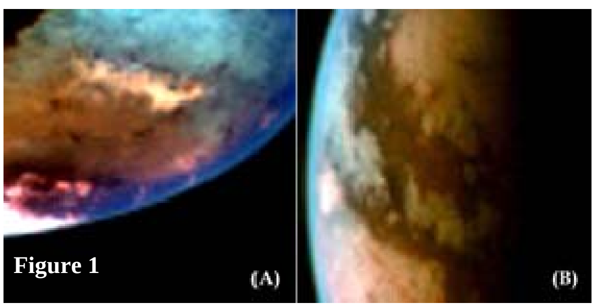

Figure 1

Spectral Information from VIMS: We use two methods to infer surface composition from VIMS reflectance data.

(1) *Spectral Mixture Analysis (SMA)*: Titan spectra are modeled as a linear combination of endmember spectra, using only reflectance values within the methane "windows" [1]. Dark material can be modeled well by H_2O ice and a spectrally neutral contaminant, plus CO_2. Bright terrain, particularly Tui Regio (Fig. 1A) and Hotei Regio (Fig. 1B), are modeled well by CO_2 ice and an unknown component, which is bright at 2.0 μm.

(2) *Absorption band search*: A custom band-fitting algorithm was developed to search for molecular absorptions within Titan's methane windows [1]. Only one absorption has been detected so far, near 4.92 μm and perhaps corresponding to the 4.90 (2042 cm^{-1}) triphonon band of CO_2 [11]. This absorption feature is again concentrated at Tui Regio and Hotei Regio. If CO_2 were present, we would expect the spectral contrast 2.8-2.7 μm to be positive and correlated with the strength of the 4.9-μm feature. This is indeed observed. The three correlated spectral traits are shown in Figure 2 for Tui Regio (the bright elongated feature): (a) 4.9-μm band depth, (b) 2.8/2.7-μm ratio, and (c) SMA CO_2 endmember. Whether or not the material is CO_2, we infer that all three spectral traits are due to the same compound or mixture.

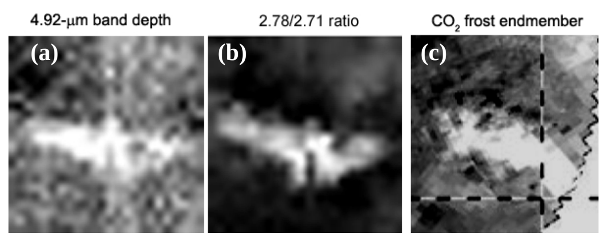

Figure 2

Laboratory Experiments: Discriminating among possible surface constituents with VIMS is only possible with the benefit of laboratory reflectance data for each candidate material. While spectra of pure compounds such as CO_2, CH_4 (liquid), NH_3, CH_3OH, hydrocarbons, and nitriles are generally well characterized in the region 1–5 μm, the reflectance properties of mixtures are poorly constrained. For instance, the 4.9-μm band of CO_2 may be shifted by bonding with H_2O ice, which could account for the ~20 nm shift observed in the VIMS spectra. Frequency shifts this large (and in the same direction) have been observed in the laboratory for $H_2O \cdot CO_2$ mixtures, but this particular band was not examined [12]. The spectral properties of liquid methane pooled on an H_2O-ice substrate are also unknown, and will be a starting point for a series of reflectance measurements to be carried out at the Jet Propulsion Laboratory (JPL). Such measurements will inform VIMS observations of Titan's North Polar lakes, which are gradually becoming illuminated by the rising springtime sun. Other compounds and mixtures, especially CO_2 and CH_4 clathrate hydrates, will be considered for study at high spectral resolution under Titan conditions. Components important for models of cryovolcanism on Titan also may be considered, including NH_3 hydrate and possibly ammonium sulfate [13].

Our experimental setup, which is presently in the construction phase, includes a monochromator capable of ~1 nm spectral resolution, and an imaging mid-wavelength infrared camera with nominal spectral range ~1–14 μm. Gas- or liquid-phase samples will be introduced and allowed to condense in the optical dewar, which will contain a water-ice substrate at ~90 K and 1.5 bar N_2. Reflectance spectra will be measured for all regions of the sample, including both transition regions and pure phases. Preliminary tests resulted in the successful delivery of liquid CH_4 to the substrate (Fig. 3).

Figure 3

Discussion and Future Work: Initial results from VIMS indicate Titan's surface is dominated by H_2O-ice mixtures, but the remaining components are poorly constrained. The surface is diverse in morphology and spectral shape, indicating a commensurate level of diversity in composition. Some interpretations suggest the IR-dark dune material is depleted in water ice, and possibly enriched in hydrocarbon and nitrile grains, while the bright terrain is covered by a patina of tholin-like haze particles [14]. However, the presence of CO_2 is perhaps quantitatively a better fit, especially for the bright terrain [1]. Our goal is to use new laboratory data to discriminate between proposed materials and map their distribution on Titan's surface. Of particular interest is the suggested CO_2 absorption feature, but we will also attempt to provide constraints on CH_4 liquid and clathrate hydrate, and possibly NH_3 hydrate and methanol – all of which are important cryomagma candidates [8].

Application of a full radiative transfer model to the VIMS data will allow modeling of atmospheric scattering and absorption, improving estimates of *I*/*F* for the surface. With improved reflectance spectra, results from the SMA will more realistically represent materials studied in the laboratory. An improved version of the band-fitting algorithm will be used to search for additional molecular absorptions due to surface materials.

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