ALTITUDE-DEPENDENCE OF TITAN'S METHANE TRANSMISSION WINDOWS: INFORMING FUTURE MISSIONS.

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Summary: We examine near and mid-infrared methane transmission in a model Titan atmosphere, at altitudes anticipated for future aerial and surface missions.

Introduction: Titan's surface is inferred to be composed of a rich variety of components: hydrocarbons of varying complexity [1], CO_2, and water ice [2, 3] among others. Characterizing the constituents of Titan's surface is invaluable from a geological perspective for constraining the occurrence of volcanic and dissolution processes [4], from an atmospheric perspective in characterizing the products of photochemical reactions [5], and from an astrobiological perspective in examining the complexity of organics present on the surface [6].

The Visual and Infrared Mapping Spectrometer (VIMS) aboard the Cassini orbiter has provided valuable information about Titan's surface composition through detections of specific compounds, and characterization of spatial variations [1, 2]. Nevertheless, the number of compounds that can be detected by VIMS are severely limited by atmospheric extinction—through particle scattering at optical and very near-infrared wavelengths, and predominantly methane absorption in the near and mid-IR up to ~10 µm [7]. This atmospheric extinction permits only multispectral analysis, at wavelengths corresponding to specific methane transmission windows [2].

With absorption due to atmospheric methane resulting in zero transmission over many of the non-window wavelengths, improvements in the spectral resolution, spectral range, or signal-to-noise ratio (SNR) of spectrometers operating from orbit are unlikely to significantly increase the variety of compounds currently detectable by VIMS. Detection of additional compounds requires a mission operating at an altitude below orbit—effectively decreasing the methane content between the surface and the spectrometer. By decreasing the optical path, the absorption due to methane would be reduced compared to observations made from orbit—resulting in the widening of the methane transmission windows and potentially the creation of new windows.

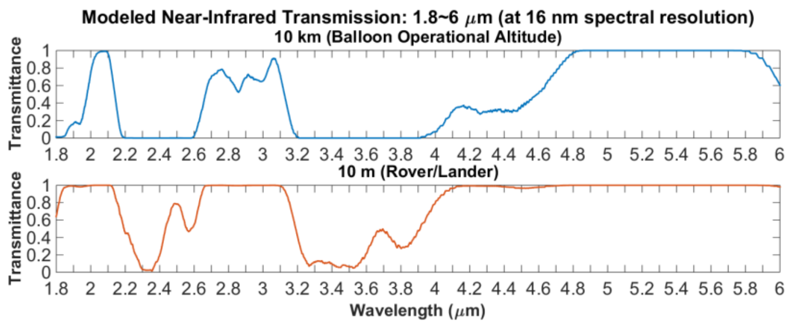

Fig. 1: Near-infrared transmission as a function of wavelength at two altitudes above Titan's surface in a model Titan atmosphere. The spectra are sampled to that of VIMS resolution (16 nm) [19]. All methane transmission windows widen considerably at balloon altitudes when compared to those from orbit, and widen even further for a rover/lander (see Fig. 2 for a direct comparison).

Here we quantify the transmission windows in the 1.8-10 µm range accessible to a spectrometer aboard a future aerial or surface mission, in the case that extinction is due solely to methane absorption. We also compare these methane transmission windows to those currently available to VIMS from orbit.

Methods: We construct a model atmosphere in which methane is the only absorber, using the altitudinal methane abundance profile measured by the Huygens Gas Chromatograph Mass Spectrometer (GCMS) [3], and temperature and pressure profiles as recorded by the Huygens Atmospheric Structure Instrument (HASI) (downloaded from the NASA Planetary Data System, and as reported in [8]).

To calculate the wavelength-dependent absorption of methane, we use the HITRAN 2012 line-by-line model [9] with line broadening modeled using a pseudo-Voigt profile [10] (to reduce computational intensity when compared with a Voigt profile), also accounting for the temperature-dependence of the line intensities. Four methane isotopologues are considered ($^{12}CH_4$, $^{13}CH_4$, $^{12}CH_3D$, $^{13}CH_3D$) with their abundances scaled to those inferred in Titan's atmosphere by the GCMS [3].

Absorption coefficients for all isotopologues, at wavelengths from 1.8-10 µm, are calculated in 30 m intervals above the surface. The HITRAN lines in this wavelength region are considered to be sufficiently complete [11]. The transmission observed at a given altitude is then calculated by integrating Beer's law over the distance to the surface. Thus, the reported transmission windows account for one-way transmission from the surface, and do not consider surface albedo effects.

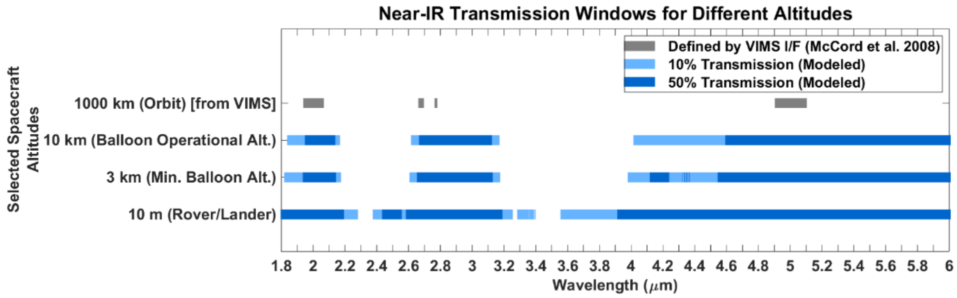

Fig. 2: A comparison of the transmission windows available to VIMS from orbit [2], with those modeled for a pure methane atmosphere at balloon and rover/lander altitudes. The modeled windows account for one-way transmission from the surface, in contrast with the two-way transmission as well as surface albedo effects recorded by VIMS. Wavelengths of 1.9-2.2, 2.7-3.1 µm, and redwards of 4 µm are regions to be considered for hyperspectral observations by a future aerial or surface mission.

Results and Discussion: We report near-IR one-way transmission as a function of wavelength through our model Titan atmosphere, for a suggested balloon, airplane or probe operational altitude of 10 km [12, 13, 14], and for an observational distance of 10 m for a sea-vessel, rover or lander **(Fig. 1)**. The synthetic transmission spectra indicate significant widening of all methane transmission windows (which we define as wavelengths where transmission is either greater than 10%, or 50%, as end members, the actual usable windows will depend on the SNR of a future instrument) when compared to the windows available from orbit [2]. In addition, a new window not accessible from orbit opens at ~3.1 µm. The windows are widest at the surface, where additional windows at 2.5 µm and 3.7 µm also become available.

Fig. 2 directly compares the spectral windows available to Cassini VIMS from orbit [2], with the windows at lower altitudes in our model atmosphere—now including the suggested 3 km minimum balloon altitude post atmospheric-insertion [12]. Our calculations suggest significant widening of the transmission windows when compared to orbit, particularly between 2.7 and 3.1 µm, and redwards of 4 µm. Qualitatively similar effects are observed at mid-IR wavelengths.

We note that the widths of the reported transmission windows are likely to be upper limits. Absorption in H_2 and N_2 collisional bands, along with CO absorption are expected to supplement methane absorptions between 2.1-2.6 and 2.8-4.8 µm [15]. N_2 and CH_4 scattering will also contribute to extinction at shorter wavelengths. We are in the process of adding these effects to our model. Furthermore, methane absorption is likely underestimated by HITRAN in the 1.8-2.1 µm window, and we are examining the effect of using the more comprehensive M5 line-by-line model [10], which would also allow extension of our findings to 1.2 µm. Lastly, the modeled one-way transmission is most relevant for thermal photons, which are scarce at near-IR wavelengths. The availability of thermal photons, and the utility of solar radiation (which must travel effectively one atmospheric length and undergo significant attenuation before use by any aerial or surface spectrometer) is being quantified. For evaluation of the windows available to a mission equipped with a uniform light source, the calculations are being extended to include two-way transmission, and account for surface albedo effects.

Nevertheless, the widening of the transmission windows, and the accompanying greater spectral range available for observation, suggest that a future aerial or surface mission could engage in true hyperspectral observations of the surface at select wavelengths, in contrast with the multispectral VIMS measurements. This would enable the detection of additional compounds and certain precise compositional distinctions. In particular, a ~5.3 µm band observed in pentane and higher order alkanes but not found in methane or ethane [16], the 4-5 µm overtone and combination bands of sulfates [17], and the 1.9 and ~3 µm H_2O absorptions of hydrated minerals (shifted relative to those of pure H_2O ice) [18], among others, all occur in the newly accessible or widened transmission windows.

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