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Titan's Atmosphere Observed by Cassini/VIMS Solar Occultations

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Abstract

VIMS solar occultations provide a unique opportunity to extract information on the vertical characteristics of Titan's atmosphere between 50-700 km with a vertical resolution of 10 km on average. We will present here the analysis of the full VIMS solar occultation dataset, which includes 10 occultations. Due to various observational problems, we could retain only 4 of them, which span different seasons and latitudes. We extracte the vertical profiles of methane and CO. CH_4 profiles show a significantly lower stratospheric abundance with respect to the GCMS value (1.28% vs. 1.48%). We also detect and identify several absorption bands that are not included in our atmospheric model. Most of them can be attributed to gaseous ethane, whose near-IR spectrum has been measured in laboratory but not modeled. Other additional absorptions are instead attributed to the C-H stretching bands associated with aerosols, generated by aliphatic and possibly aromatic hydrocarbons.

1. The VIMS solar occultations

The VIMS solar occultations retrieve Titan's atmospheric transmittance with a 10 km vertical resolution (on average) between 0.88-5 µm at a spectral resolution of ~13 nm (Fig. 1). The transmission spectra are dominated by 5 strong methane bands, but several other gases exhibit spectral features and must be taken into account. In our atmospheric model we include nine molecules: CH_4, CH_3D, CO, CO_2, HCN, C_2H_2, C_2H_4, C_2H_6 and N_2, as well as the N_2-N_2 Collision Induced Absorptions, using the updated spectroscopic coefficients from the most recent studies (as for example [1,2] for methane).

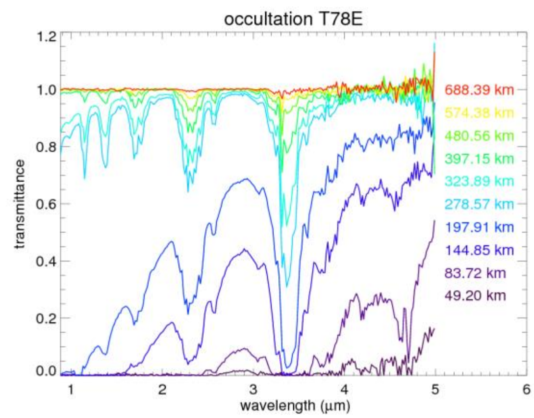

Figure 1: Example of 10 transmission spectra for the T78 egress occultation, at different altitudes. The strong bands that appear are mostly due to methane. The CO band at 4.7 µm appears below 150 km.

We use CIRS results to get climatological information: pressure, temperature, molecules' vertical distribution [3]. The effect of transmittance extinction due to aerosol, which is wavelength-dependent, sets in at the lowest VIMS wavelengths around 350-400 km, varying with season. The aerosol extinction is taken into account as continuum.

1.1 The Inversion Procedure

We employ a Levenberg-Marquardt inversion method, extensively used for nonlinear inversions of planetary atmospheres [4,5], to extract the CH_4 vertical profile between 100 and 700 km and the CO profile between 50 and 170 km. We could not invert the whole dataset: several of the 10 solar occultations acquired up to now exhibited significant problems due to pointing accuracy and unexpected parasitic light. We restrict thus our analysis to four occultations, spanning different moments of Titan's year between 2006 and 2011 and different latitudes, from the south polar region to 40°N (Table 1).

Table 1: latitudinal and temporal coordinates of the four analyzed solar occultations.

Flyby	Month	Latitude (N)
T10 ingress	Jan 2006	-70°
T53 egress	Apr 2009	+1°
T78 ingress	Sept 2011	+40°
T78 egress	Sept 2011	+27°

2. Results

2.1 Methane, CO and aerosols

All four occultations find significantly lower methane abundance in the stratosphere, on average 1.28±0.06 % with no significant differences between the occultations, with respect to the 1.48±0.09 % from the GCMS instrument on Huygens [6]. This result is in agreement with a recent analysis of CIRS data [7]. A lower stratospheric methane abundance would have significant consequences for the modeling of methane photochemistry on Titan's atmosphere, but the discrepancy between the various instruments is still to be explained and requires further studies. CO values are in agreement with CIRS results representative of higher altitudes [8], confirming that CO is well-mixed throughout the atmosphere. In addition, the spectral behavior of the aerosol extinction gives some hints at the behavior of the haze and its evolution with the season; only the two occultations obtained in September 2011 detect the presence of the detached layer, at 310 km (Fig. 2).

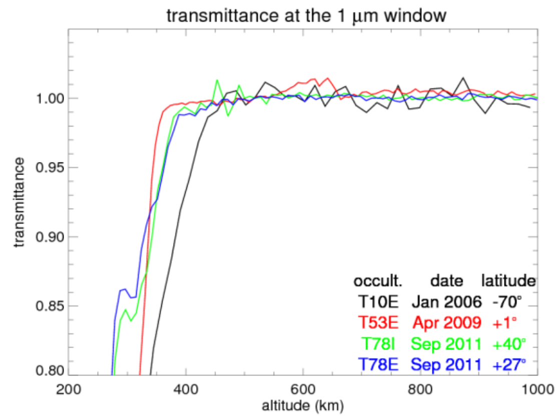

Figure 2: Transmittance as a function of altitude for the four analyzed occultations at the 1 µm continuum. The two T78 occultations exhibit the presence of the detached layer, at ~310 km.

2.2 Discovery of additional absorptions

Direct spectral computation using the retrieved methane values show the presence of additional absorption bands throughout the VIMS wavelength range, not included in our atmospheric model and detected here for the first time for the most part. These bands have the same structure and altitude evolution in all occultations. We have found that most of these bands belong to gaseous ethane (C_2H_6). Ethane is the second most abundant hydrocarbons on Titan (after methane), but its near-IR spectrum is only very partially modeled (our model includes all the modeled ethane lines, which are evidently not enough to reproduce its spectrum). However, we could compare our residual spectra with measurements from the PNNL laboratory [10] and the agreement is excellent (Fig. 3).

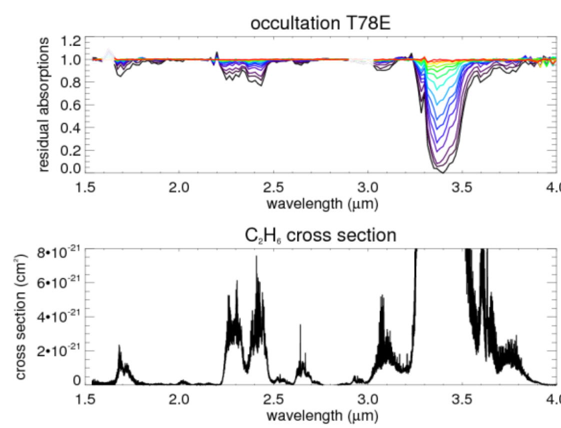

Figure 3: Comparison between the additional absorptions found by VIMS occultations (top) with the PNNL laboratory measurements of ethane spectrum (bottom). The match is very good. This is the example of the T78 egress occultations. The other occultations exhibit similar behavior.

This study leads to the reevaluation of the importance of ethane (and more generally of trace gases) on Titan's atmospheric spectra, which could have a consequence also on surface studies, some ethane bands affecting partially the surface windows especially at 2.7 µm. Propane (C_3H_8) also could have an influence, but it is difficult to disentangle it from ethane (and methane) due to the similarity of their spectra.

Not all additional absorption bands are attributed to ethane. A strong absorption at 3.4 µm, already identified by [9] in an analysis of the first VIMS solar occultation, is generated by the C-H stretching bands from aerosols. We tentatively attribute another newly discovered and narrow band at 3.28 µm to atomatics. If confirmed, this would be the first evidence of the presence of PAHs in the stratosphere, whereas the current chemical models suggest a depletion of PAHs much higher in the atmosphere, at ~600-700 km. Other residual bands in the 4.2-4.5 µm range can be attributed to the stretching modes of C-H, C-C and C-N bonds.

Acknowledgements

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