Methane stratification on Pluto inferred from New Horizons LEISA data

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Abstract

In this talk we demonstrate that the relative intensity of the CH_4 band depth reflect a stratification of CH_4, either in the CH_4 concentration in N_2-rich ice and/or in the relative abundance between the N_2-rich:CH_4:CO and CH_4-rich ices, depending on the area. The stratification of CH_4 is shown to result from the differential sublimation between N_2 and CH_4 which tends to concentrate CH_4 in N_2 ice grains and, produces a CH_4-rich phase that accumulates on the surface.

1. Introduction

The diurnal, seasonal and astronomical cycles on Pluto trigger sublimation-transport-condensation cycles of the volatile ices (N_2, CH_4, CO) with different amplitudes and time constants at the surface. Evidence of vertical stratification has been put forward by Douté, Schmitt et al. [1] using the spectral shift of the CH_4 bands. Their stratified model also better fitted their high spectral resolution disk integrated observations This was further confirmed by several authors from spectral analysis and modeling of new observations [2, 3]. In addition to differential sublimation of the surface CH_4:N_2 ices, other processes were proposed to explain such a vertical stratification. For example Grundy and Stansberry proposed a process of solar gardening in which sublimation preferentially remove N_2 from a little below the surface, not exactly at the surface and thus enrich that layer in CH_4 [4].

Following the Pluto flyby by the New Horizons spacecraft the qualitative distribution of the two major volatile ice phases identified on the surface of Pluto, N_2-rich:CH_4:CO ice and CH4-rich ice, has been mapped by Schmitt et al. (2017) [5] and the spatial transitions between the predominant zone of these phases have been highlighted. The first quantitative composition map has been derived by Protopapa et al. (2017) [6].

2. The CH4 maps

Different CH_4 qualitative abundance maps have been obtained from several CH_4 bands (Fig 1). These maps display relatively different spatial distributions, but with regular evolutions at a given location from the weakest to the strongest CH_4 bands (Fig. 2).

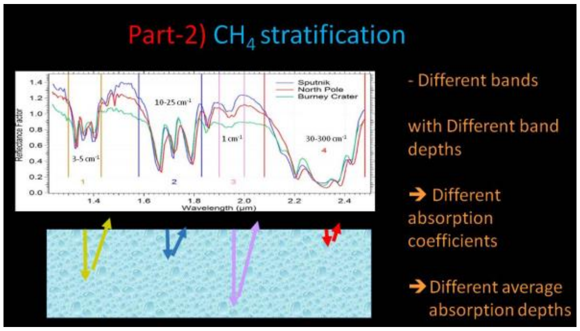

Figure 1: The four CH_4 band groups with different strengths and absorption depths

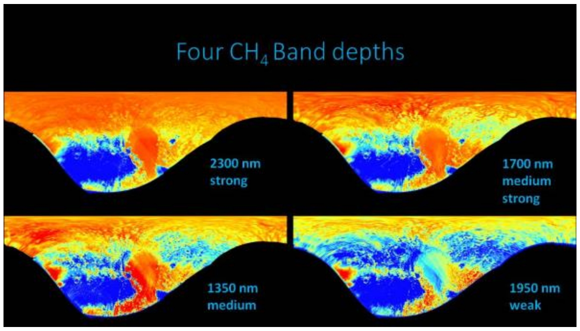

Figure 2: The maps of the four CH_4 band groups with different strengths. Increasing integrated band strengths from light blue to yellow to red. Dark blue area have no methane.

In this talk we demonstrate that these band depth changes reflect a stratification of CH_4, either in the CH_4 concentration in N_2-rich ice and/or in the relative abundance between the N_2-rich:CH_4:CO and CH_4-rich ices, depending on the area. For this we use in addition our 'CH_4 state index' that allow to separate between N_2-rich and CH_4-rich phases based on the spectral position of the CH_4 bands and a new N_2 ice distribution map including the area where the N_2 ice band is too weak to be observed directly. These various indicators help to decipher between stratification and grain size effects as large variations have been found across Pluto surface [6].

We will show that several different configurations appear to exist at the surface of Pluto according to the latitude, and that they may be the witness of different stages in the sublimation-condensation cycles or of different timescales. The CH_4 band ratio maps are particularly interesting to map these different configurations (Fig. 3). The stratification of CH_4 is shown to mostly result from the differential sublimation between N_2 and CH_4 which tends to concentrate CH_4 in N_2 ice grains and, according to the phase diagram, produces a CH_4-rich phase that accumulates on the surface. But other situations may exist where the stratification may be reversed due to CH_4-poor N_2-rich ice condensation. We will discuss the meaning of the different band depth variations seen across the CH_4 bands, for the different types of CH_4 configurations, in terms of relative effects of grain size, methane concentration and vertical stratification.

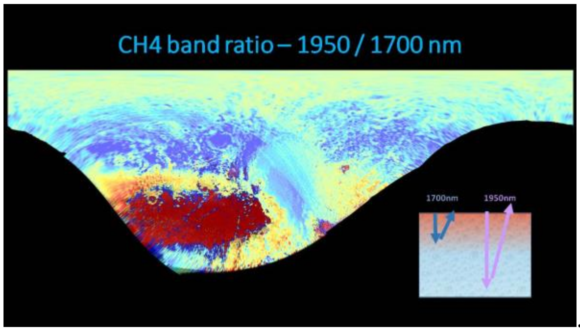

Figure 3: The map of the 1950 nm / 1700 nm CH_4 band groups evidencing at least 3 major types of CH_4 configurations (north polar regions (pale yellow), mid-northern latitudes (blue) and area surrounding Cthulhu Regio and East of Tombaugh Regio (red-yellow).

3. Summary and Conclusions

The occurrence of the different configurations of vertical CH_4 distribution on Pluto witness different thermal and sublimation history of the ices. The CH_4 concentration and the depth of these stratified terrains could be interesting quantitative indicators of the strength of the sublimation process, as they can be correlated with the nitrogen sublimation fluxes obtained by volatile transport models (Bertrand et al. 2018) [7]. A layered medium radiative transfer modeling of the LEISA spectra will be necessary to confirm these stratifications and to extract this information.

Acknowledgements

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