Recent observations of the composition of Pluto's and Triton's atmospheres and implications for surface-atmosphere interactions

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The surfaces of Pluto and Triton are covered by a variety of ices, the most volatile of which being N_2, CO and CH_4. Sublimation equilibrium of these ices at surface temperatures of ~40 K produces a predominantly N_2 atmosphere, in which CO and CH_4 must be present as well. However, the respective gas mixing ratios depend on the details of the surface-atmosphere interactions. For a long time, information of the gas abundances has been restricted to the single detection of CH_4 in Triton's atmosphere by Voyager [Herbert, F., and Sandel, B.R., 1991, JGR, 96, 19241] and in Pluto's from ground-based observations [Young, L.A., et al. 1997, Icarus, 127, 258]. A further complication is that the atmospheres of Triton and Pluto, monitored by stellar occultation observations, are known to vary temporally.

We observed Pluto and Triton in 2008, 2009, and 2010 respectively, using the CRIRES spectrometer installed on ESO VLT UT1 telescope, using AO mode and a spectral resolution of ~60,000. These observations, published in Lellouch et al. (A & A, 495, L17, 2009; A & A, 512, L8, 2010; A & A 530, L4, 2011) permitted us to (i) re-observe CH_4 in Pluto's atmosphere with high S/N in the 1.64-1.68 µm range and obtain its first detection in K band at 2.33-2.36 µm (ii) achieve the first observation of CH_4 in Triton's atmosphere since Voyager (iii) obtain the first detection of CO in Triton's atmosphere (at 2.35 µm) and evidence for its presence in Pluto's as well. The observations provide the molecule column densities, but using reasonable estimates of the surface pressures for the observation period (40 µbar for Triton and 15 µbar for Pluto), the estimated atmospheric mixing ratios are as follows:

	Triton	Pluto
CH_4 / N_2	$(2.4 +/- 1) \times 10^{-4}$	$(5 +/- 1) \times 10^{-3}$
CO / N_2	$(6^{+12}_{-4}) \times 10^{-4}$	$(5^{+10}_{-2.5}) \times 10^{-4}$

In Triton's case, the CH_4 column density is ~4 times larger than measured by Voyager.

Three scenarios can be a priori envisaged for the nature of surface-atmosphere interactions (i) the "ideal mixture" (solid solution): in this case, the expected partial pressure of each species is the product of its solid mole fraction and its pure vapour pressure. Given the "bulk" abundances of CO and CH_4 ices on Pluto and Triton's surfaces (Quirico, E., et al. 1999, Icarus 139, 159, Douté, S. et al. 1999, Icarus, 142, 421) this scenario would imply atmospheric abundances of CO and CH_4 much lower than observed (ii) the "pure ice" scenario. This case is relevant if segregated patches or grains of the different volatiles are present on the surface. In this case the atmospheric mixing ratios are in simple proportion of the pure vapour pressures at the relevant ice temperatures, and of the fractional area covered by each ice (iii) the "detailed balancing model" [Trafton, L.M, Matson, D.L. & Stansberry J.A. 1998, in Solar System Ices, eds. B. Schmitt, C. de Bergh, and M. Festou (Kluwer Academic Publishers), 773]. In this case, seasonal evolution of a N_2-dominated solid solution, with preferential sublimation of N_2 creates a thin surface layer enriched in the less volatile species (CO and CH_4). This "detailed balancing layer" controls the surface-atmosphere exchanges, and the atmospheric mixing ratios may be identical to those in the volatile reservoir below the surface veneer.

Based on the observed abundances and the thermodynamic properties of N_2 – CO – CH_4 mixtures, we suggest that the detailed balancing model is adequate to explain CO on both planets. In contrast, the atmospheric CH_4 abundances probably result from the sublimation of isolated and warmer CH_4 patches on Pluto and of pure CH_4 grains on Triton, where seasonal evolution would explain the enhanced CH_4 abundance compared to Voyager.

Finally, we will discuss the reported detection of CO in Pluto's atmosphere at millimetre wavelengths by Greaves et al. (MNRAS, 414, L36, 2011).