CONSTRAINTS ON THE COMPOSITION OF METHANOL-BEARING TRANS-NEPTUNIAN OBJECTS AND CENTAURS FROM NIR SPECTROSCOPY OF IRRADIATED ICES Elsa Hénault[1], Donia Baklouti[1], Rosario Brunetto[1], Zahia Djouadi[1], Obadias Mivumbi[1], Philippe Benoit-Lamaitrie[2], Silvin Hervé[2], Jerôme Bourçois[2], Cyril Bachelet[2] and Riccardo G. Urso[3] [1]Université Paris-Saclay, CNRS, Institut d'Astrophysique Spatiale, 91405 Orsay, France (elsa.henault@universite-paris-saclay.fr), [2]ICJLab, Université Paris-Saclay, CNRS/IN2P3, Institut de Physique des 2 Infinis Irène Joliot-Curie, Orsay 91405, France, [3]INAF–Osservatorio Astrofisico di Catania, via Santa Sofia 78, 95123, Catania, Italy.

Introduction: Methanol has been detected at the surface of the Centaur Pholus [1], the Trans-Neptunian Object (TNO) 2002 VE_{95} [2] and the cold classical Kuiper Belt Object Arrokoth [3]. Methanol is found alongside water, the most widespread ice of the outer solar system [4]. Thermodynamical studies predict that water and methanol ices should be ubiquitous on small bodies like Arrokoth as they are the two most stable ices against sublimation [5]. Methanol is detected in the coma of comets where its relative abundance to water ranges from <0.2% to 4.8% [6]. Methanol is also omnipresent in interstellar ices where its abundance can be higher, in the <0.2% to 31 % range [7]. The methanol detected on TNOs could be directly inherited from the protostellar cloud as these objects are thought to be remnants of the building blocks of the outer solar system. But even if they stayed dynamically stable, like Arrokoth over 4.6 Gyrs [8], their surfaces have undergone physico-chemical changes as they were subjected to different weathering events, particularly solar wind and cosmic ion irradiation [9].

The surfaces of Pholus, 2002 VE_{95} and Arrokoth also present red slopes in the visible and near-infrared (Vis-NIR) range. This effect is commonly associated to "complex organic molecules" similar to laboratory produced "tholins" [1,2,3]. Such red slopes can be reproduced in the laboratory upon irradiation of methanol [10]. The ratio of the NIR bands of methanol used for its detection depends on the irradiation dose and the original composition of the ice [11]. Methanol can then be used as a proxy to constrain the origin and history of the objects that bear it.

Until now, TNOs surfaces were observed in the Vis-NIR, while laboratory experiments of complex ices were mostly probed in the mid infrared (MIR) range where chemical information is easier to derive [12,13,14]. We aim at measuring and providing Vis-NIR spectra of irradiated methanol ices, pure and mixed with water, which were previously well characterized in the MIR, in support of past New Horizons and future JWST observations.

Methods: We use the INGMAR experimental setup to simulate the effects of solar wind at the surface of icy bodies [11]. INGMAR is a high-vacuum chamber connected to the SIDONIE ion accelerator, separator and implanter (part of the JANNuS-SCALP platform of IJCLab) [15]. The ices are formed by condensation of a gaseous mixture on a substrate cooled down to 60 K by a He-cryocooler. We use 30 keV H^+ ions to irradiate the ices, H^+ being the most abundant component of the solar wind and producing physico-chemical modifications mainly via inelastic energy loss. We monitor the physico-chemical changes upon irradiation of the ices by Vis-NIR-MIR spectroscopy. Transmittance spectra cover the 0.4 to 5 µm range while the reflectance spectra cover the 0.6 to 2.5 µm range. We investigate pure methanol ice and water-methanol ice mixtures of different proportions.

Results: The major irradiation products of CH_3OH are CO_2, CO, CH_4, H_2CO and H_2O, whose production yields depend on the dose and the relative abundances of water and methanol in the initial mixture [12,13]. To characterize the evolution of the irradiated ices, we focus specifically on the two following parameters:

CO/CO_2 ratio. The overlap between our transmittance spectra and MIR spectra from the literature, which display the fundamental bands of CO_2 and CO, allows us to establish a trend in their production rate upon irradiation [14]. The CO/CO_2 ratio varies as a function of irradiation dose and initial composition of the ices.

Vis-NIR slopes. From reflectance spectra, we define the JR slope, the normalized reflectivity gradient [16] between the J and R bands, at 1.25 and 0.68 µm respectively, as a parameter to represent the overall behavior of Vis-NIR spectra upon irradiation. We detect an increase of the JR slope with increasing irradiation dose until reaching an asymptote which depends on the original ice composition. The JR slopes obtained in the laboratory are comparable with those of Pholus, 2002 VE_{95} and Arrokoth. In the hypothesis of methanol being the main source of carbon for the formation of "complex organic molecules" at the surface, then its irradiation can produce the observed slopes, but only for those initial ice mixtures where it was at least as abundant as water.

Conclusion: Since the originally co-condensed CO, CH_4 and to some extent CO_2 are expected to be depleted at the surface of small icy bodies [5], we suggest that if CO and CO_2 are observed on the surface of methanolrich bodies and if their ratio corresponds to those of methanol irradiation by-products, it could be possible to give an insight into the original composition of the ices and their subsequent irradiation history.

Finally, the ratio between NIR methanol bands and the JR slope, as a function of irradiation dose, are parameters which together act as a probe of the history of the surface and its original composition. We aim at combining these clues to achieve a better understanding of the chemical history of TNOs and Centaurs.

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