RADIOGENIC HEATING AS THE CAUSE OF THE NITROGEN DEFICIENCY IN COMETS. O. Mousis[1], A. Guilbert-Lepoutre[2], J. I. Lunine[3], A. L. Cochran[4] and J.-M. Petit[1], [1]Université de Franche-Comté, Institut UTINAM, CNRS/INSU, OSU THETA, Besançon, France (olivier.mousis@obs-besancon.fr), [2]UCLA, Department of Earth and Space Science, Los Angeles, CA, USA, [3]Department of Astronomy, Cornell University, Ithaca, USA, [4]McDonald Observatory, University of Texas, Austin, USA.

Introduction: We use a statistical thermodynamic model to investigate the composition of clathrate hydrates that may have formed in the primordial nebula. In our approach, we consider the formation sequence of the different ices occurring during the cooling of the nebula, a reasonable idealization of the process by which volatiles are trapped in planetesimals. We then determine the fractional occupancies of guests in the different clathrate hydrate formed at given temperature. The major ingredient of our model is the description of the guest-clathrate hydrate interaction by a spherically averaged Kihara potential with a nominal set of parameters. Our model allows us to find that argon and molecular nitrogen cannot be efficiently encaged in clathrate hydrates formed in the primitive nebula. Instead, these volatiles form pure condensates at temperatures below 30 K in the disk. Using a planetesimal composition based on these calculations, we find that it is possible to explain the loss of nitrogen, argon, and other pure condensates during the post-accretion evolution of planetesimals as a result of the internal heating engendered by the decay of radiogenic nuclides. This scenario provides a viable mechanism to account for the origin of the nitrogen deficiency observed in comets and is also found to be consistent with the presence of nitrogen-rich atmospheres around Pluto and Triton. Indeed, in the cases of such big bodies, gravity would have prevented the important losses of ultravolatiles during the planetesimals accretion.

Formation of cometesimals/planetesimals in the primordial nebula: The process by which volatiles are trapped in icy planetesimals, illustrated in Fig. 1, is calculated to first order using the equilibrium curves of stochiometric hydrates, clathrates and pure condensates, and the thermodynamic path (hereafter cooling curve) detailing the evolution of temperature and pressure between 5 and 20 AU roughly corresponding to the formation locations of the giant planets in the solar nebula.

Figure 2 represents the composition of these icy planetesimals expressed as a function of their formation temperature in the nebula. This figure corresponds to the condensation sequence depicted in Fig. 1 (single guest trapping approximation). The figure shows that CO is incorporated in planetesimals at higher temperature than N_2 (i.e. ~ 48 K vs. 22 K). In this case, the remaining water is used by CO to form a CO-dominated clathrate in the nebula, implying that N_2 is trapped in planetesimals in the form of pure ice only.

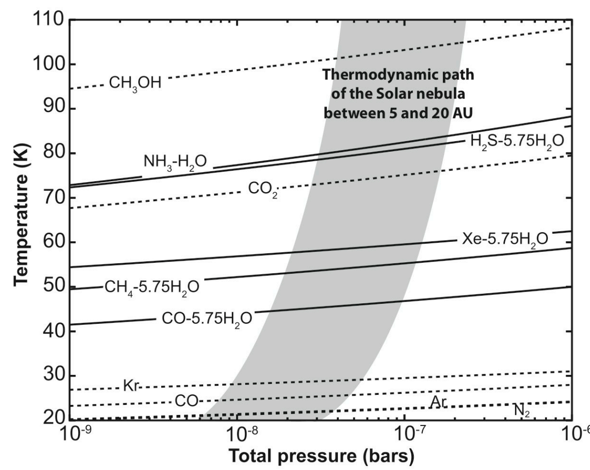

Figure 1: Formation sequence of the different ices in the primordial nebula (solid lines: clathrates, dashed lines: pure condensates). Species remain in the gas phase above the equilibrium curves. Below, they are trapped as clathrates or simply condense.

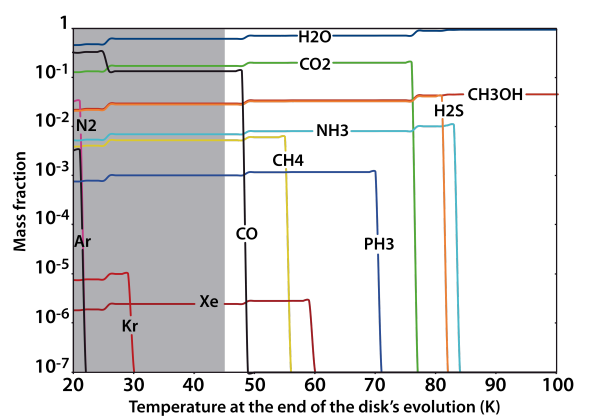

Figure 2: Composition of icy planetesimals calculated as a function of their formation temperature in the solar nebula. The gray area illustrates the implications of a radiogenic heating up to 45 K for the composition of planetesimals: Ar, Kr and N_2 initially trapped at low temperatures become devolatilized (see next column).

However, the clathration conditions of minor species (such as noble gases) must be investigated via the use of a thermodynamic statistical model describing the possibility of multiple guest trapping in clathrates formed in the nebula [1-3]. Figure 3 represents the mole fractions of various volatiles trapped in clathrates formed at temperature and pressure conditions depicted in Fig. 1 and calculated via our thermodynamic statistical model. The figure shows that Kr can be enclathrated at a temperature of ~55 K instead of condensing in the 20–30 K range in the solar nebula.

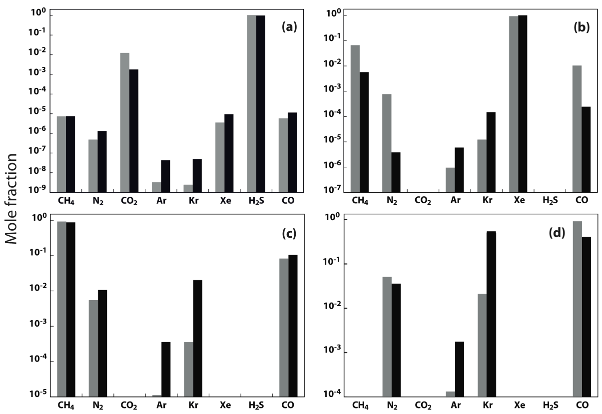

Figure 3: Mole fractions of volatiles encaged in H_2S- (a), Xe- (b), CH_4- (c) and CO- (d) dominated clathrates formed in the primordial nebula following the condensation sequence depicted in Fig. 1. Grey and dark bars correspond to structure I and structure II clathrates, respectively.

Thermal evolution of planetesimals: To investigate the influence of a planetesimal's thermal evolution on its composition, we used the fully three-dimensional model described in [4]. This model aims to evaluate the temperature distribution and evolution taking into account thermal and physical processes including the decay of radioactive nuclides. The model assumes that the object is a sphere made of a porous matrix of crystalline water ice. Dust is homogeneously distributed within this matrix. Neither sublimation nor condensation of volatiles, nor gas flow inside the matrix, are accounted for in the current version of the model. Figure 4 represents the thermal structure of a planetesimal having a size similar to that of Comet Hale-Bopp and as a function of time after its formation. It shows that, for « standard » parameters, it is possible to heat the planetesimal at temperatures high enough to simultaneously imply the loss of N_2 and the preservation of CO (between 22 and 48 K).

Conclusions and prospects:

- Our scenario provides a viable mechanism to account for the origin of the nitrogen deficiency observed in comets.
- It is also found consistent with the presence of nitrogen-rich atmospheres around Pluto and Triton. In the cases of such big bodies, gravity would have prevented the important losses of ultravolatiles during the planetesimals accretion.
- Reliable predictions can be made on the noble gas abundances in order to test this scenario. If radiogenic heating occurred within cometary nuclei, then Kr/Ar and Xe/Ar are predicted to be supersolar in comets.

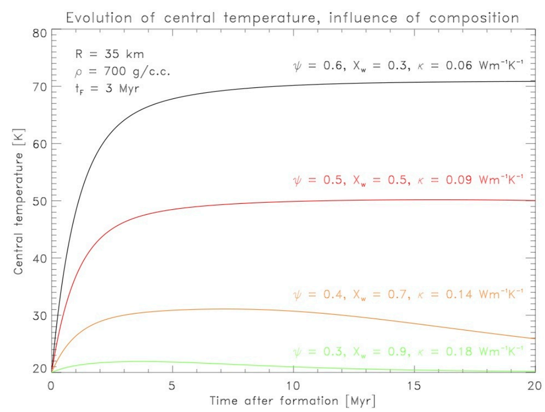

Figure 4: Evolution of central temperature of a planetesimal owning a size similar to that of Comet Hale-Bopp due to decay of radioactive nuclides.

References: [1] van der Waals, J. H. and Platteeuw J. C. (1959) In: *Advances in Chemical Physics*, vol. 2, Interscience, New York, pp. 1–57 (1959). [2] Lunine J. I. and Stevenson D. J. (1985) ApJS, 58, 493. Mousis O., Lunine J. I., Picaud S. and Cordier D. (2010) Faraday Discussions 147, 509. Guilbert Lepoutre A., Lasue J., Federico C., Coradini A., Orosei R., Rosenberg E. D. (2011) A&A 529, A71.