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Composition and thermal evolution of planetesimals in the primordial nebula: a key to understand the nitrogen deficiency in comets?

O. Mousis (1), J. I. Lunine (2), A. Guilbert-Lepoutre (3), A. L. Cochran (4), J.-M. Petit (1) and D. Cordier (5,6)
(1) Université de Franche-Comté, Institut UTINAM, CNRS/INSU, UMR 6213, Observatoire des Sciences de l'Univers de Besancon, France (olivier.mousis@obs-besancon.fr / Fax: +33-381-666944), (2) Dipartimento di Fisica, Università degli Studi di Roma "Tor Vergata", Rome, Italy, (3) UCLA, Department of Earth and Space Sciences, 595 Charles E. Young Drive East, Los Angeles, CA, 90095, USA, (4) McDonald Observatory, University of Texas, 1 University Station, C1402, Austin, TX 78712, USA, (5) Université de Rennes 1, Institut de Physique de Rennes, CNRS, UMR 6251, France, (6) Ecole Nationale Supérieure de Chimie de Rennes, France

Abstract

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 hydrates (dominated by H_2S, Xe, CH_4 or CO) 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, most of which being fitted on experimental equilibrium data [1]. Based on the use of recent Kihara potential parameters [2, 3], our model allows us to find that argon and molecular nitrogen cannot be efficiently encaged in clathrate hydrates formed in the primitive nebula (see Fig. 1). 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 [4, 5] and is also found 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.

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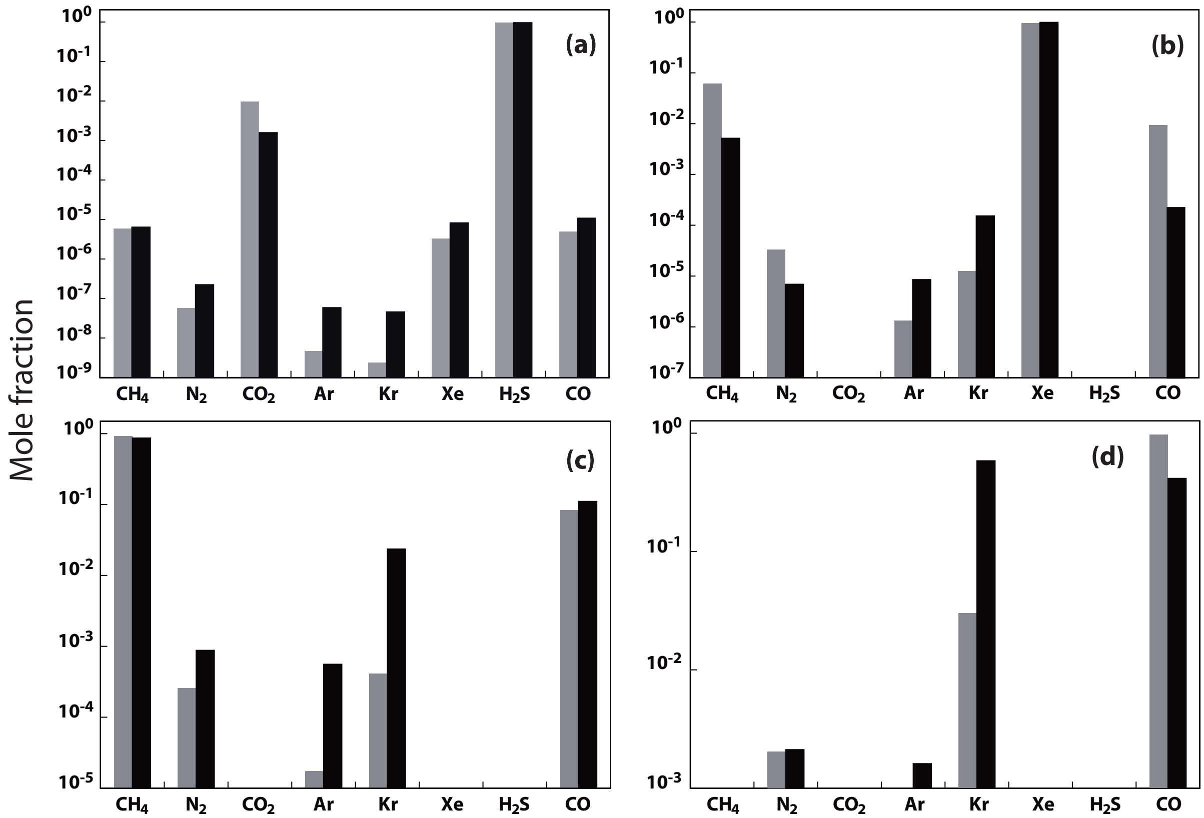

Figure 1: Mole fraction of volatiles encaged in H_2S- (a), Xe- (b), CH_4- (c) and CO- (d) dominated clathrates formed in the nebular conditions. Structure I is the clathrate structure expected to be formed from these molecules in the primordial nebula. Grey and dark bars correspond to structure I and structure II clathrates, respectively.