PhD Offer at Observatoire de Paris and Université de Cergy Pontoise

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PhD subject

Title : Chemical origin of N_2 and CO differential depletion in prestellar cores: observations and laboratory investigations.

Summary :
Star formation occurs in dense cores of very cold interstellar clouds where most of gaseous species disappear. They stick on the surface of dust grains to form icy mantles. However the freeze-out process is far from being understood. For example, some species, which should be present (like O_2) are not detected, while some (like CH_3OCH_3) seem to be present in excess with respect to theoretical predictions (Bacmann et al. 2012), and others (like H_2O) are detected, but in excited states which are not understood (Lis et al. 2013).

Even more strangely, CO molecules are heavily depleted from the gas phase toward the centre of prestellar cores, whereas N_2 molecules still maintain a high gas phase abundance. CO and N_2 have identical masses, and similar sticking and binding energies (at least for thick ice mixtures), and therefore these two molecules should have the same depletion behaviour, from the physical point of view. The observed presence of species like ammonia (NH_3) and diazenylium (N_2H^+) is in contradiction with this simple idea, letting this problem unsolved for years, despite the fact that the balance between the solid and gas phases is a crucial point in the understanding of star formation. One consequence of this poor understanding may lie in the possible error of the estimation of the chemical composition, since the solid-state is more difficult to observe. Another indirect consequence of the freeze-out mechanism is its possible role in the triggering of the final collapse phase, required to form and ignite the new star. A better understanding of these mechanisms would also help to constrain the age of the prestellar cores.

Very recently two noteworthy progresses have been made by the applicants. On their side, Laurent Pagani and co-workers have developed a new observational method to derive with a minimum of observational bias the N_2/CO ratio across prestellar cores. In the centre of the L183 dense cloud they measured that the CO depletion reaches 3 orders of magnitude with respect to undepleted CO, while the N_2 abundance drops only by a factor 20 (Pagani et al. 2012). Experimentally, Francois Dulieu and co-workers have shown that the desorption energy of N_2 and CO can be different in the case of sub-layer regime. Even more promising, the solid-state chemistry of CO and N_2 appears to be very different. CO oxydation and hydrogenation leading to saturation (CH_3OH) have been demonstrated, whereas NH_3 formation seems to be a minor product in the N+H system: exit channels N_2 and H_2 are preferred.

The scientific purpose of our project is to try to understand if the observed differential depletion of these species has a chemical origin.

The project is two-folds. A first aspect concerns the observational evidences, and their chemical modelling. Beyond the L183 case, a new set of clouds is currently being observed. Following the method developed by Pagani et al. (2012), we will analyse the different prestellar cores, trace their physical structure (density, temperature, kinematics), derive the abundances of the different observed species and finally produce the CO/N_2 ratio profile across all the cores. The goal of this study will be to understand if the core L183 is unique in terms of depletion or if the depletion is chemically selective everywhere, and to separate the common features of the process from the particularities linked to each cloud. This part of the work will be done under the supervision of Laurent Pagani, Directeur de Recherche at LERMA/Obs Paris.

The second aspect consists in laboratory astrochemistry. New sets of experiments will be made on the experimental set-up named FORMOLISM (Formation of Molecules in the Interstellar Medium), and a new one named VENUS (Vers de NoUvelles Synthèses). These set-ups are localized in Cergy-Pontoise, are made with an ultra-high vacuum (UHV) chamber coupled to two (or more) triply differentially pumped atomic (H, O or N) or molecular beams (CO, H_2O...) aimed at the temperature-controlled (6K-300K) sample. Three analysing tools are commonly used: laser spectroscopy, mass spectroscopy and Reflection-Absorption Infrared Spectroscopy. The study will start with the desorption of species and we will investigate the differences in the chemical desorption processes (Dulieu et al 2013), and if the segregation process (Dulieu et al 2005) could play a role. The second experimental part will be a systematic study of reactivity of CO, NO, H_2CO, HCN and HNCO exposed to N, H, and O atoms.

In the end, the mechanisms which will have been identified as major in the differentiation process of N_2 and CO in the laboratory will be injected in the dynamico-chemical model of P. Lesaffre to test its ability to reproduce the observed profiles. This would both confirm our understanding of the physico-chemistry inside clouds and give us their age. At the end of the thesis, the PhD student should be able to conclude if the chemically biased depletion of gas in dense cores is a frequent state of star forming regions and if it can be used to assert the age of prestellar cores. She/he will be skilled in most of the basic techniques of surface science and atomic and molecular beams and will be able to argue if solid-state chemistry is one of the clues of the astrophysical problem of gaseous depletion. She/he will also know how to run astronomical observations, data reduction, radiative transfer and chemical modellings.

The candidate should be interested by laboratory experiments and studies of the interstellar medium. A solid background in physics and some interest in chemistry is required.

The Candidate should submit a CV, an application letter, 2 letters of recommendation and the names and contact emails of 2 referees to laurent.pagani@obspm.fr and francois.dulieu@obspm.fr