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Irradiation effects in CO and CO_2 ices induced by swift heavy Ni ions at 46 MeV and 537 MeV

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Abstract. In order to simulate the effects of the heavy ion component of cosmic rays on ices in astrophysical environments, the CO and CO_2 ices were irradiated with swift nickel ions in the electronic energy loss regime. The ices were prepared by condensing gas onto a CsI substrate at a temperature of 14 K and analyzed by means of infrared (FTIR) spectroscopy. The physical process of deposition by Ni ions is similar to more important and abundant heavy cosmic rays such as Fe ions. Dissociation of the ice molecules, and formation of new molecules were observed. Also, sputtering (leading to desorption of molecules from the solid surface to the gas phase) was observed. It was found that the sputtering yield due to heavy ions cannot be neglected with respect to desorption induced by weakly ionizing particles such as UV photons and protons.

Keywords. astrochemistry, methods: laboratory, ISM: clouds, cosmic rays

1. Introduction

Ices such as H_2O, CO, CO_2, NH_3 can be found in a variety of astrophysical environments (e.g. icy grain mantles, the satellites and rings of giant planets, comets, dense clouds, protoplanetary disks). These ices are exposed to irradiation by energetic particles: proton and UV radiation are the dominant component in most cases, but also heavy ions are present in galactic cosmic rays and also in solar (and stellar) wind. Irradiation effects induced by electrons, UV photons, protons, and low energy heavy ions have been studied since some decades. Nevertheless, few experimental studies using swift heavy ions in order to simulate the heavy ion component of cosmic rays do exist. Therefore, we performed irradiations of ices with Ni ions in the electronic energy loss regime, where energy deposition in inelastic collisions with target electrons dominates, and ion penetration depths are rather high.

2. Experimental method and results

The heavy ion irradiation was performed at the IRRSUD and SME beam lines of GANIL (Grand Accélérateur National d'Ions Lourds) in Caen, France, with 46 MeV $^{58}Ni^{11+}$ and 537 MeV $^{64}Ni^{24+}$ projectiles, in a high vacuum chamber equipped with a closed-cycle helium cryostat. Ice films were grown at 14 K by exposing a CsI substrate to a steady flow of gas (purity approx. 99%). A Nicolet FTIR spectrometer covering the 5000-600 cm^{-1} wavelength region was used to observe the evolution of ice films (destruction/sputtering of ice parent molecules, formation of new species). The ion flux was typically about 1×10^9 ions $cm^{-2}s^{-1}$ (with 10% accuracy) and minimum and maximum fluences were 1×10^{10} ions cm^{-2} and 1×10^{13} ions cm^{-2}, respectively. For more details see Seperuelo Duarte *et al.* (2009).

The CO ices were irradiated with 46 MeV $^{58}Ni^{11+}$ and 537 MeV $^{64}Ni^{24+}$ ions. For both projectile energies, the same molecular species (CO_2, C_3O_2, C_5O, C_3, C_2O, C_4, O_3) were produced. It is important to note that the observed molecules are the same as obtained by irradiation with protons [Palumbo *et al.* (2008)], photons [Cottin *et al.* (2003)] and electrons [Jamieson *et al.* (2006)]. The CO_2 ice was irradiated with 46 MeV $^{58}Ni^{11+}$ ions. We observed the formation of CO, CO_3, O_3 and C_3. Again, the observed molecules are the same as obtained by proton, photon and electron irradiation. The destruction cross sections were found to be: 1.7×10^{-13} cm^2 (46 MeV) for CO_2 ice, and 1.4×10^{-13} cm^2 (46 MeV) and 3.5×10^{-14} cm^2 (537 MeV) for CO ices.

Another interesting result concerns the ion induced erosion (sputtering). The total sputtering yield of 46 MeV Ni on CO_2 ice is $Y = 4 \times 10^4$ molecules/impact, and $Y = 9 \times 10^4$ molecules/impact for CO ice. In good agreement with results obtained by Brown *et al.* (1982) for light ions (H, He), a quadratic dependence on the electronic stopping power ($Y\sim S_e^2$) is observed. Thus, the sputtering yield of 46 MeV Ni ions (0.8 MeV/u) is four orders of magnitude higher than that of 0.8 MeV protons (3 molecules/impact [Brown *et al.* (1982)]).

3. Conclusion

We have irradiated CO and CO_2 ices with swift nickel ions in the electronic energy loss regime. The destruction of the ice molecules and formation of new species were observed. An interesting result is the important role of heavy ion induced sputtering, because of the quadratic dependence on the electronic energy loss of the projectile. We estimated the specific sputtering flux (SSF) by multiplying the ion flux in cosmic rays by the corresponding sputtering yield, which was estimated as a function of velocity by calculating the energy loss with the widely used SRIM code (www.srim.org) and assuming $Y\sim S_e^2$. In the case of cosmic rays in dense clouds, the heavy ion SSF is dominant over that of protons, even if the abundance of heavy ions is at least three orders of magnitude lower than the proton one [Seperuelo Duarte *et al.* (2009)].

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