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Radioresistance of adenine to cosmic rays

Objective

Adenine (Fig 1) is a purine nucleobase and an integral part of the composition of biomolecules like DNA, RNA and ATP. Adenine or its precursors may possibly have reached the early Earth via comets and meteorites. Comets and meteorites carry organic molecules including amino acids and nucleobases or their precursors. The aim of this work is to study the effect of heavy ions at high energies in order to simulate the role of galactic cosmic ray irradiation in adenine.

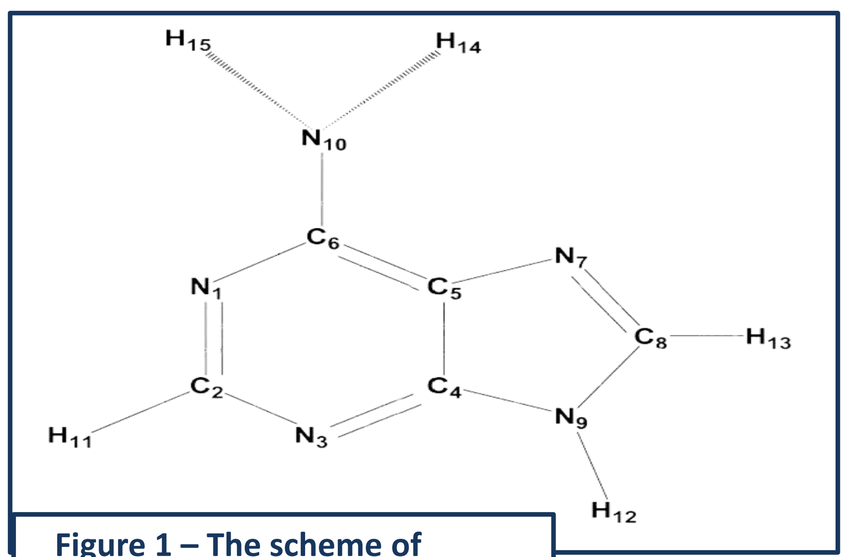

Figure 1 – The scheme of adenine molecule.

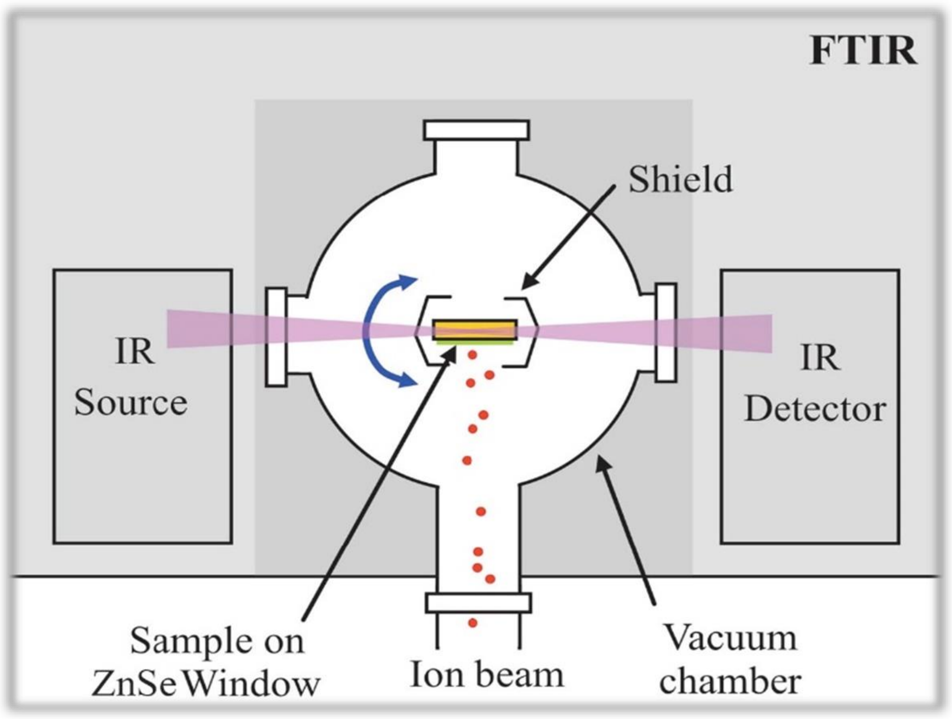

***Figure 2** : Schematic experimental set-up employed for bombardment of soli adenine by heavy ions. t al, 2010) [2].*

Ionic Beam	Energy (MeV)	Electronic stopping Power (10^3 keV.μm^{-1})	Nuclear Stopping Power (keV.μm^{-1})	Sample thickness (μm)	Water ice Thickness (μm)	Penetration depth (μm)
Xe^{23+}	92	11,2	71	0.29	0	16
Kr^{33+}	820	5,8	3,6	0.45	0	120
Ca^{10+}	190	3,1	2,2	0,22	0	51
Ca^{10+}	190	3,1	2,2	0,22	0,20	51
C^{4+}	12	1,0	0,9	0,28	0	12

Table 1. – Irradiation of samples of adenine for different ion beams at different energies.

Results

Figure 3 shows the evolution of adenine IR spectrum under irradiation (Xe^{23+} - 92 MeV). IR absorption peak area decreases and of new bands appear between 2300 cm^{-1} - 2000 cm^{-1}. In order to evaluate the resistance of adenine to heavy ion irradiation, we focus on the evolution of the IR absorption band at 914 cm^{-1} (Fig. 4). This band correspond to the vibration of NCN at imidazole ring. Figure 5 shows adenine destruction cross section as a function of the electronic stopping power.

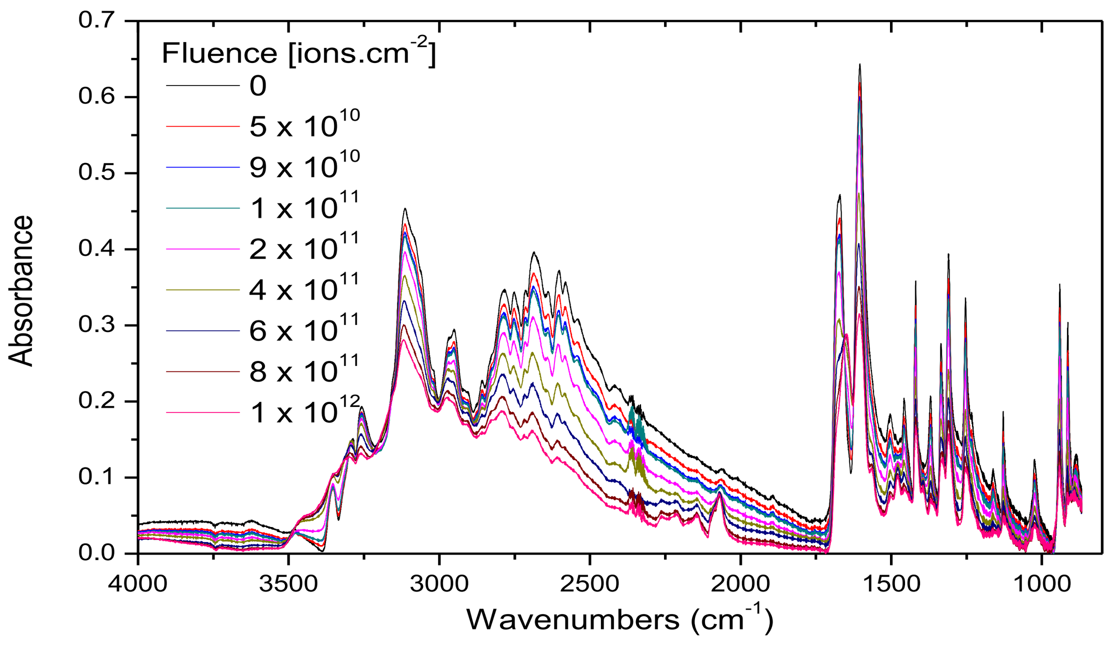

Figure 3 : Adenine Infrared spectra during irradiation with Xe^{23+} (92 MeV).

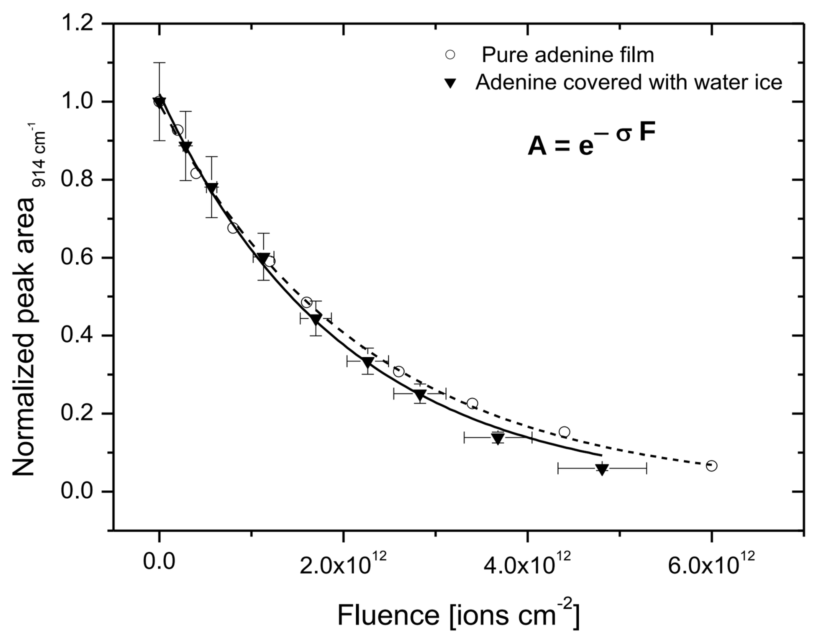

Figure 4 : Evolution of the IR absorption peak area at 914 cm^{-1} of adenine film and adenine covered with water ice as a function of 190 MeV Ca^{10+} fluence.

Projectile	Apparent destruction cross section [×10^{-13} cm^2]
Xe^{23+}	22.2 ± 0.3
Kr^{33+}	10.9 ± 0.2
Ca^{10+}	4.5 ± 0.4
C^{4+}	1.24 ± 0.06

Table 2. – Adenine apparent destruction cross section for different projectiles.

Adenine fragmentation –New molecules

Figure 6 shows this absorption band and its deconvolution. The peaks founds at: 2074 cm^{-1}, 2090 cm^{-1} (CN^-), 2100 cm^{-1} (HCN), 2154 (H_3N), 2174 cm^{-1} ($C_2N_2H_4$), 2212 cm^{-1} ($C_2N_2H_4$), 2235 cm^{-1} (vCN) and 2260 cm^{-1} (vCN). The absorption band at 2139 cm^{-1} is attributed to CO. The formation of molecules with oxygen is due to residual gas pollution in the chamber, mainly H_2O and CO_2.

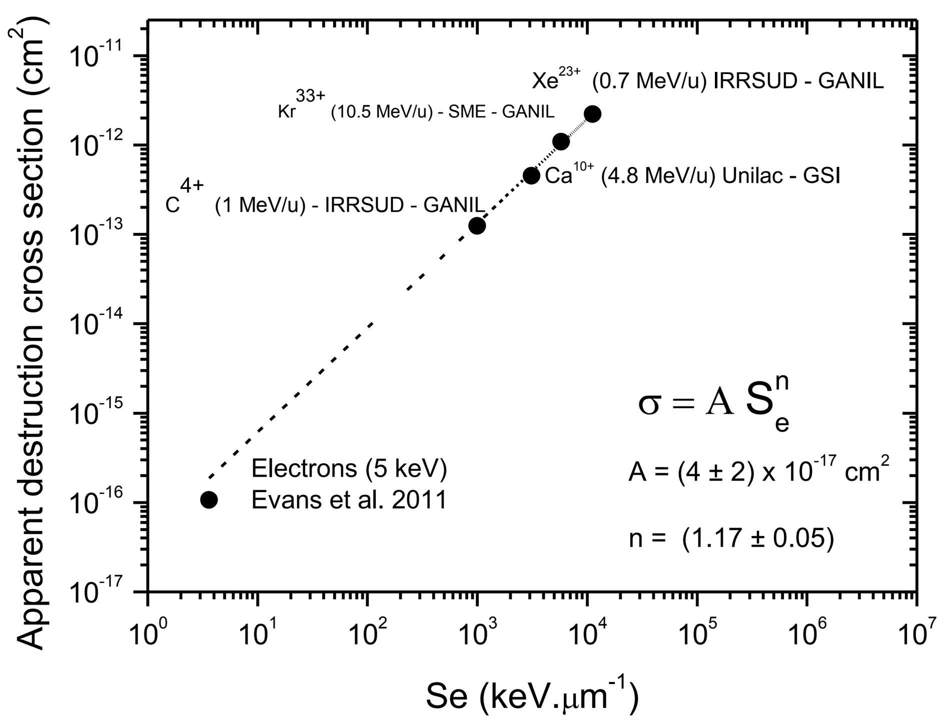

Figure 5 : Adenine apparent destruction cross section as a function of the electronic stopping power.

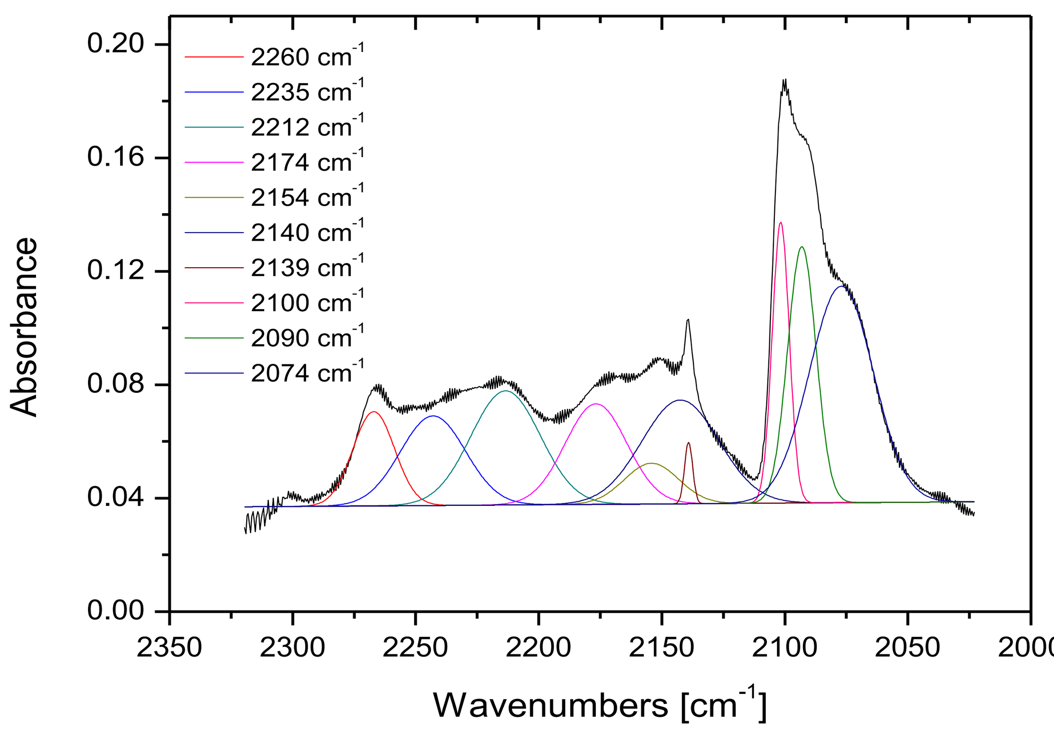

Figure 6 – Deconvolution the IR absorption band at 2300-2000 cm-1 of adenine irradiated by Xe^{23+} at fluence of 4 × 10^{12} ions cm^{-2}.

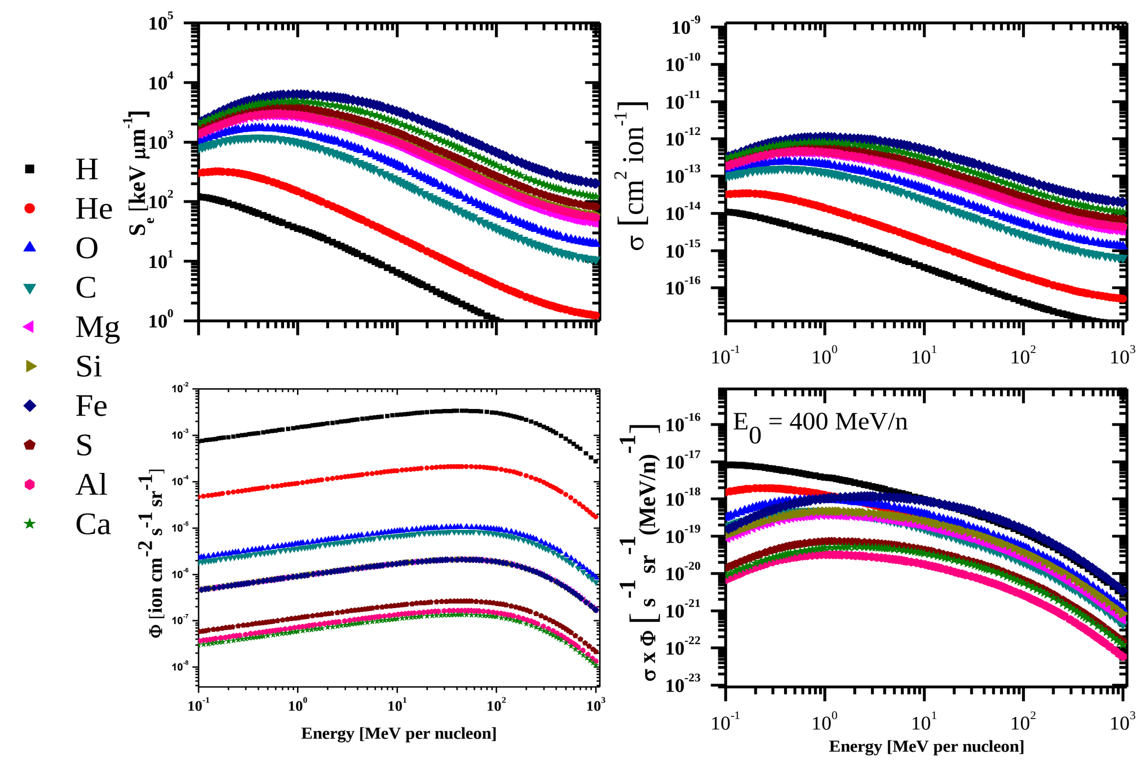

Figure 7 - Energy dependence of main galactic cosmic rays relative to (a) the electronic stopping power, (b) the apparent destruction cross section,(c) the differential flux in ISM, (d) the destruction rate.

Astrophysical implications

Using the code SRIM was possible to generate the electronic stopping power for the ten most abundant ions in the cosmic rays(Fig 7-a). Applying the power law was possible to determine the adenine destruction cross section (Fig 7-b). In order to study the survival of adenine exposed to cosmic ray irradiation, we reproduced here (Fig 7-c) the figure from Shen et al. [3]. The destruction rate (Fig 7-d), e. g. the product between the destruction cross section and the ion flux (σ(E)×ϕ(E)), is the physical quantity which will determine adenine half lifetime according the equation : $\tau_{1/2} = \ln 2\,(4\pi \sum_Z \int \sigma(Z,E)\,\Phi(Z,E)\,dE)^{-1}$

The half lifetime of adenine under irradiation was evaluated equals to (10.± 8) Myears. The average time of survival of a DC is around 10 Myears . Consequently, if adenine was formed in those regions, it is still possible that adenine molecules remain today.

Conclusion

The destruction of pure adenine by heavy ions in the electronic stopping power domain was studied. The destruction cross section was determined as a function of electronic stopping power under the form: A S_e^n. With n = 1.17

Our results show that the destruction of adenine exposed to cosmic rays is dominate by iron and protons. Although heavy ions are far less abundant than protons the results show that it is important to take them in consideration to understand the evolution of adenine under the bombardment of cosmic rays.

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