Radioresistance of adenine to cosmic rays

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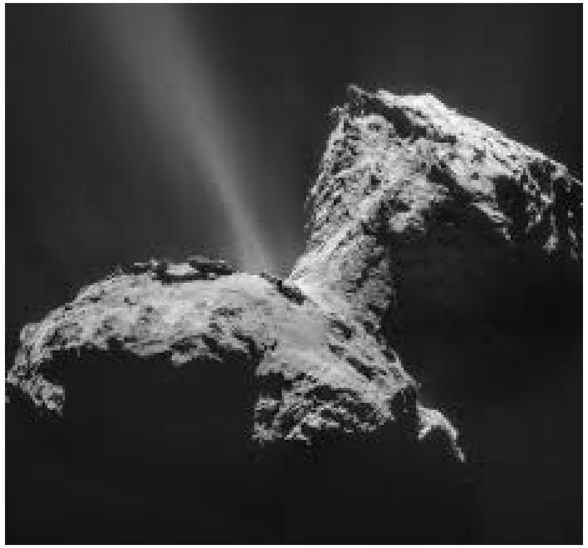
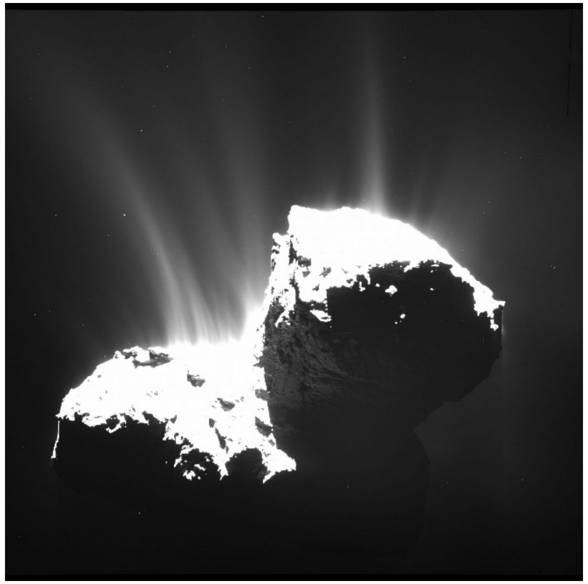
Introduction

- The presence of complex organic molecules (COM) such as nucleobases and amino acids in carbonaceous meteorites on Earth is a strong indication of its existence in outer space. †.
- Detection of glycine (amino acid) in the coma of comet 67P/Churyumov-Gerasimenko by the Rosetta space mission▪.
- Some groups have reported formation of COM under simulated astrophysical environments° .
- Stability of COM under irradiation of galactic cosmic rays and solar wind is not yet well understood.



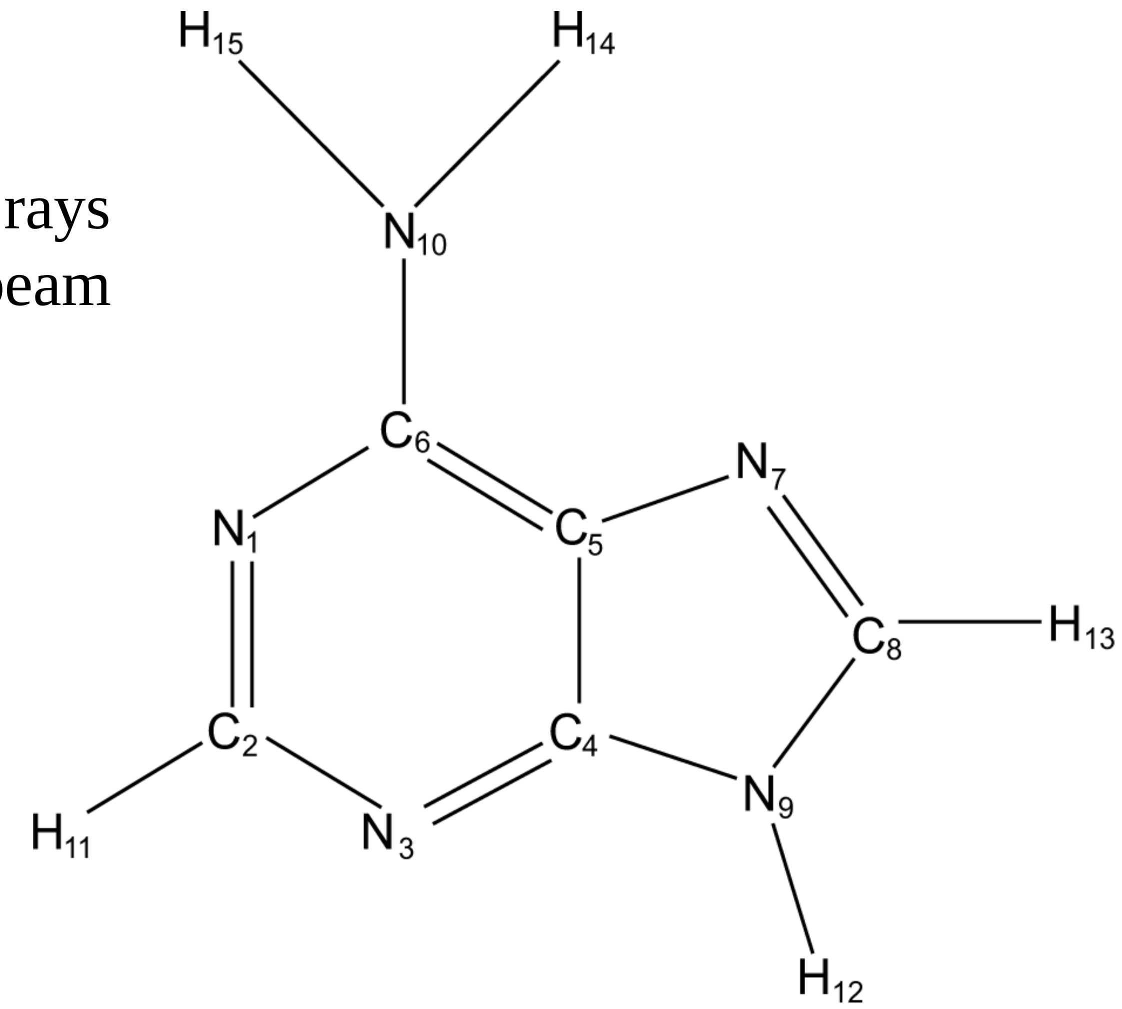


†Martins Z, Botta O, Fogel ML *et al. Earth Planet Sci Lett* 2008; **270.**
▪ Altwegg *et al. Sci. Adv.* 2016; **2**.
*Chyba C. & Sagan C. *Nature* 1992;**355.**
°Nuevo *et al. Astrobiology* 2014; **14.**

Objective

- To simulate and study effects of cosmic rays (swift heavy ions) of COM by using the beam line at GANIL and GSI.

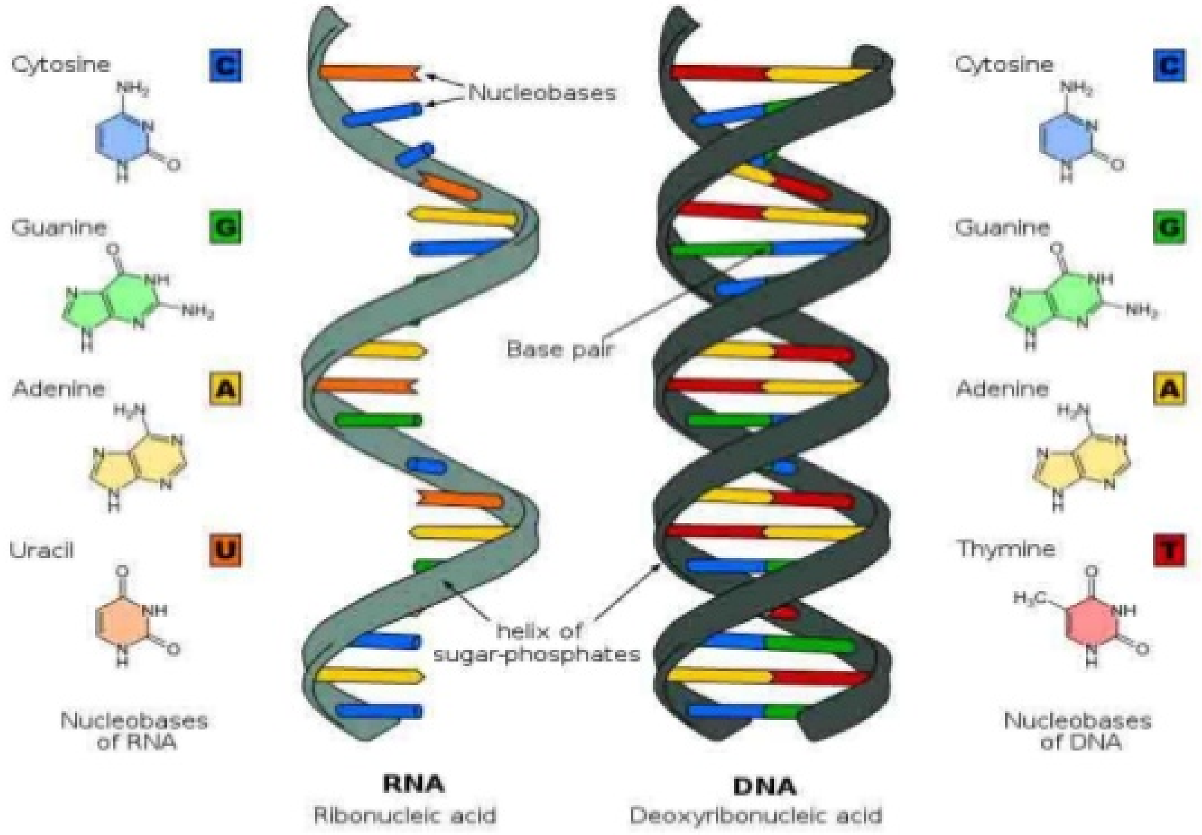
First results: irradiation of adenine.



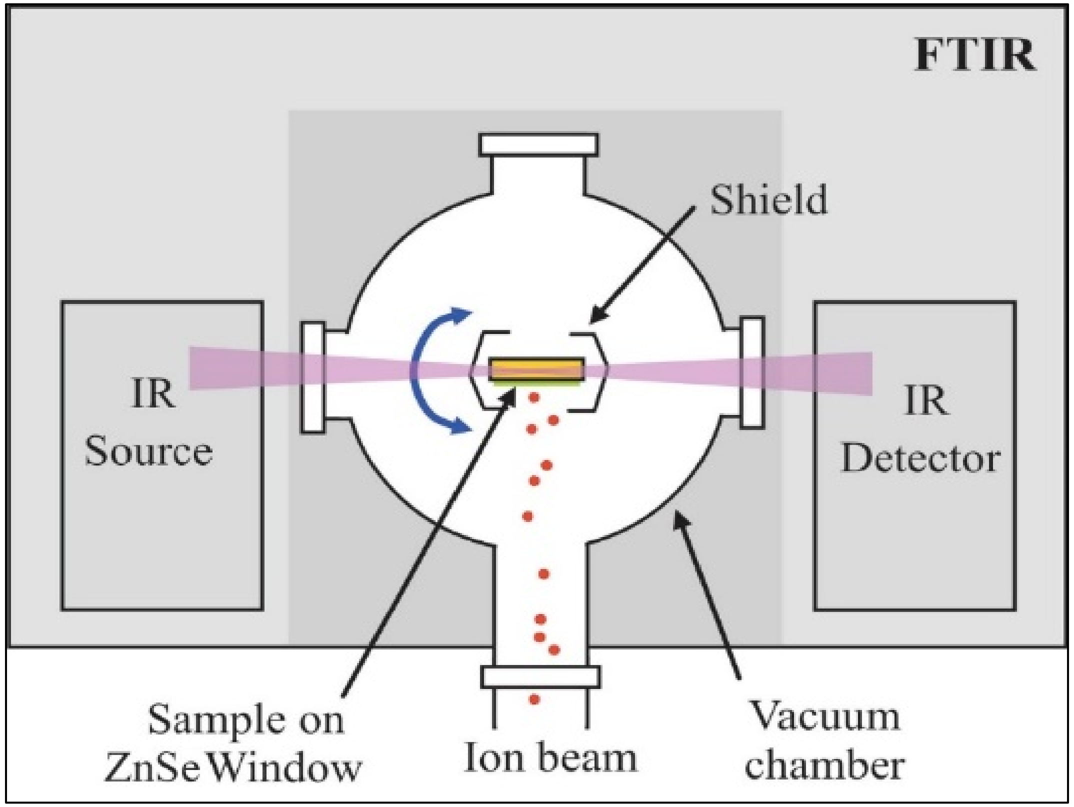
Adenine

- $C_5H_5N_5$
- A purine nucleobase
- An integral part of the composition of biomolecules of unique importance such as DNA and RNA
- A molecule that is evolutionarily preserved in all living beings, including viruses.

DNA, RNA and the nucleobases



Experimental methodology

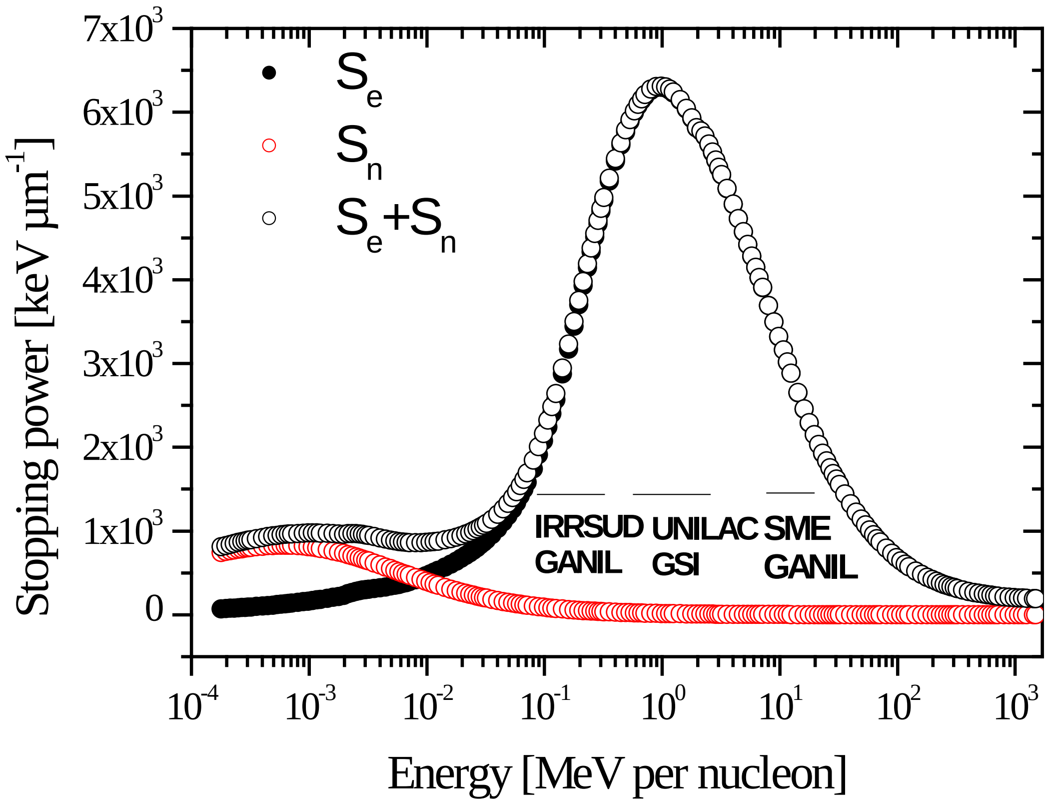


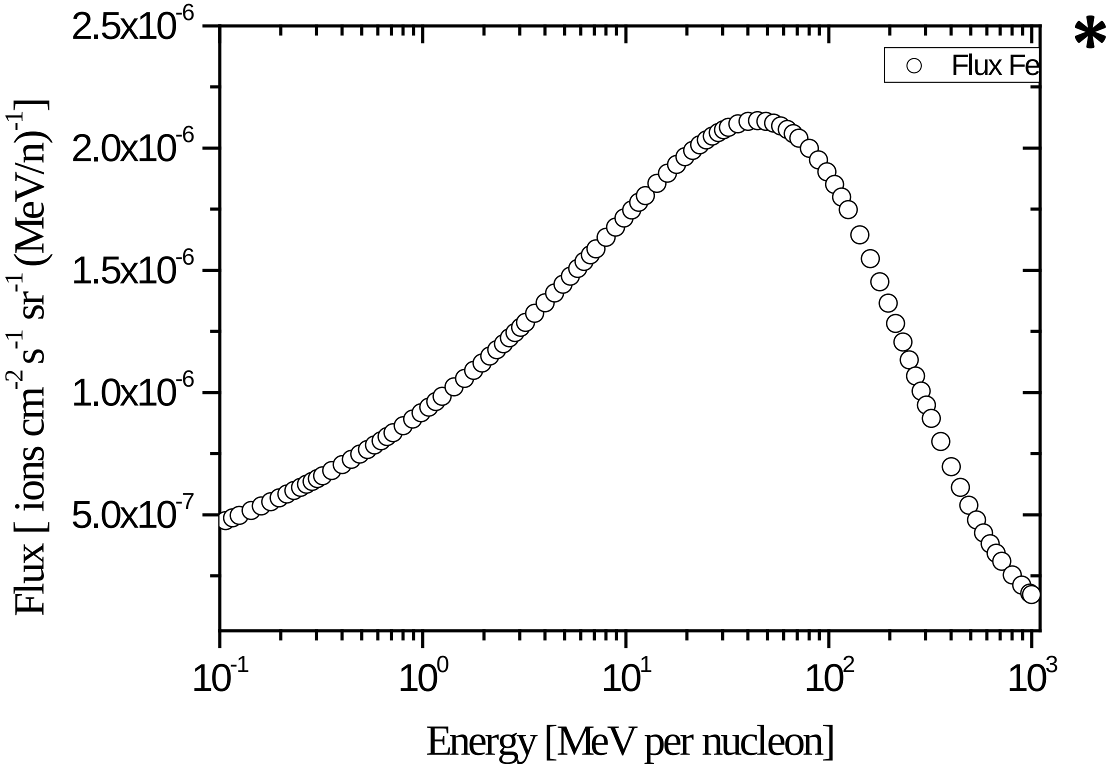
Low temperature (~ 12 K).
10^{-8} mbar.

Adenine sample
prepared for irradiation.

Swift Heavy Ions – Cosmic rays analogues

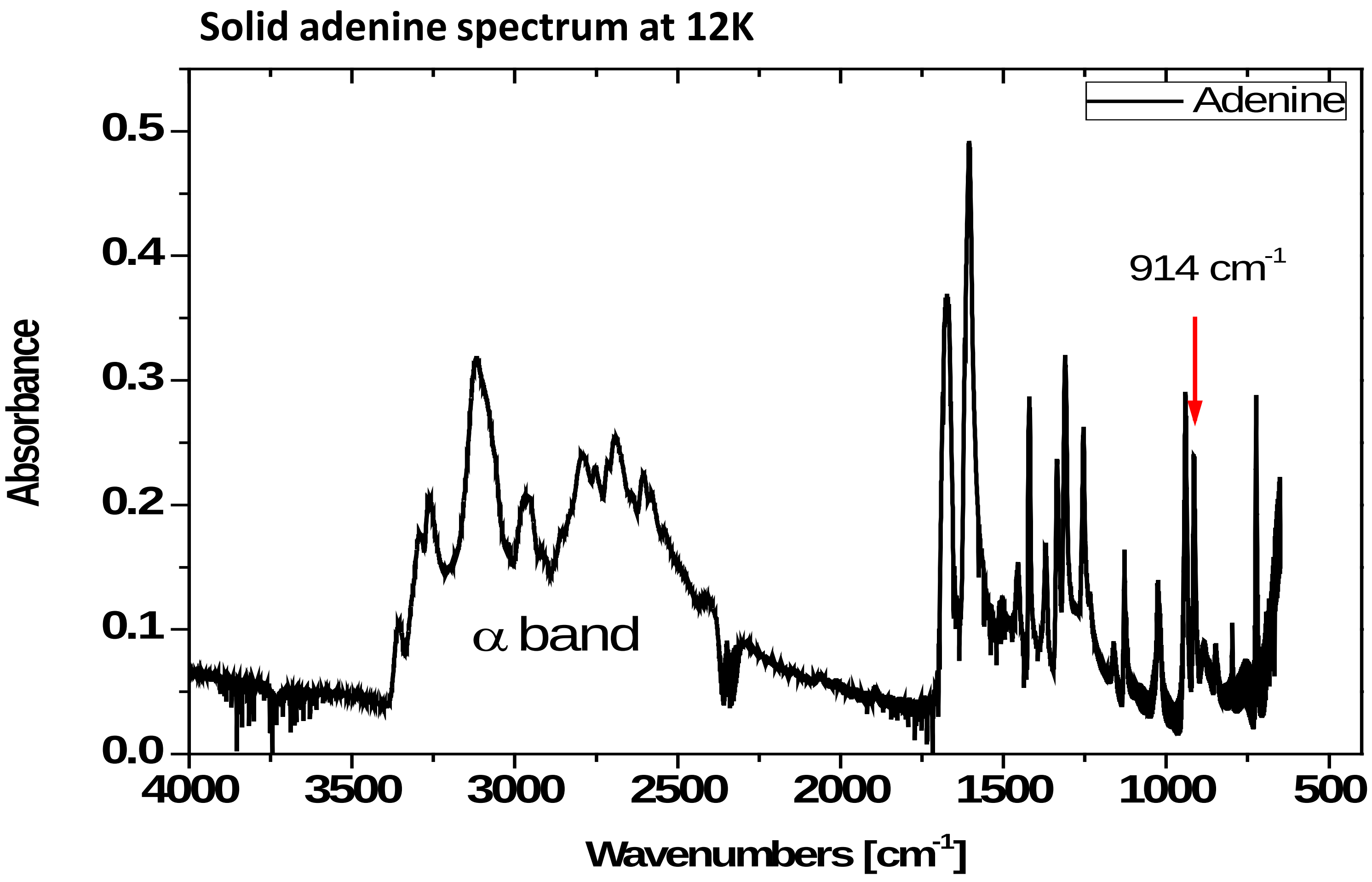
Cosmic rays are ions with a broad energy range from few MeV/n to TeV/n.

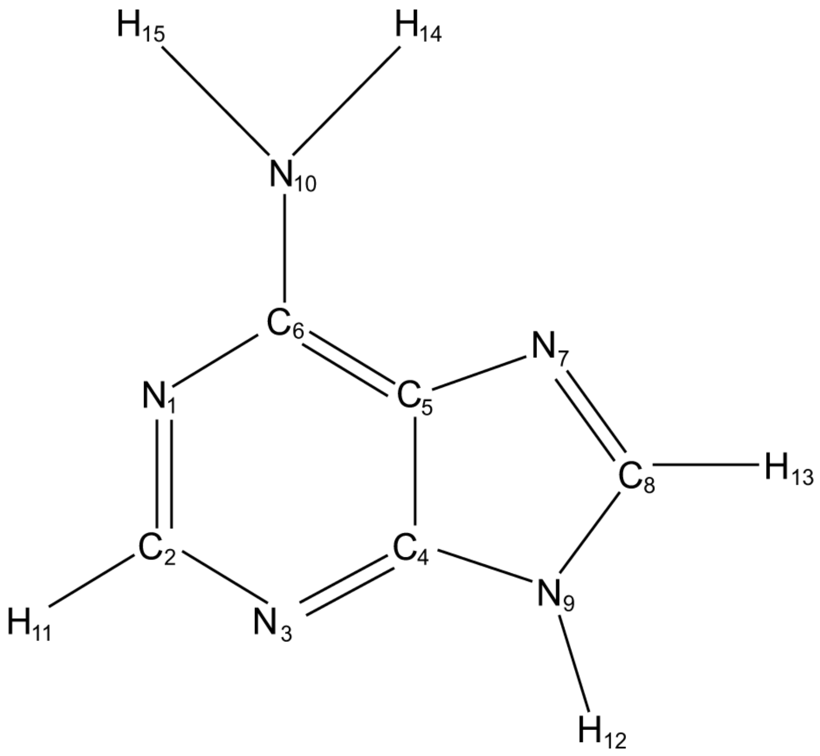




* Simulated flux of iron in the **interstellar medium (ISM)** from Shen *et al Astron. Astrophys. 2004;* **415**:203–215.

Complex molecules have complex IR spectra.



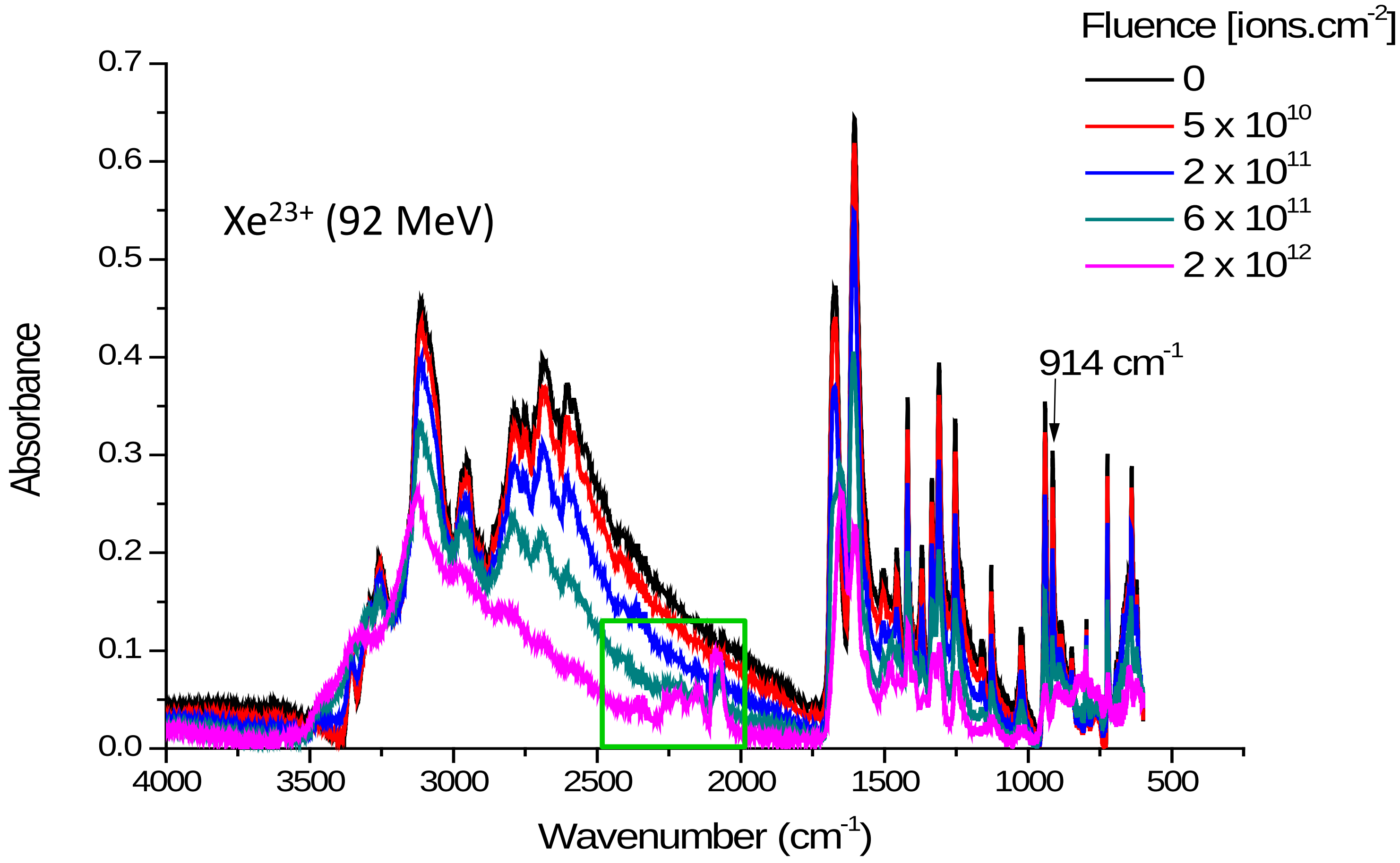


$$N = \frac{2.3}{A}\int Abs(\nu)\,\mathrm{d}\nu$$

Summary of performed experiments

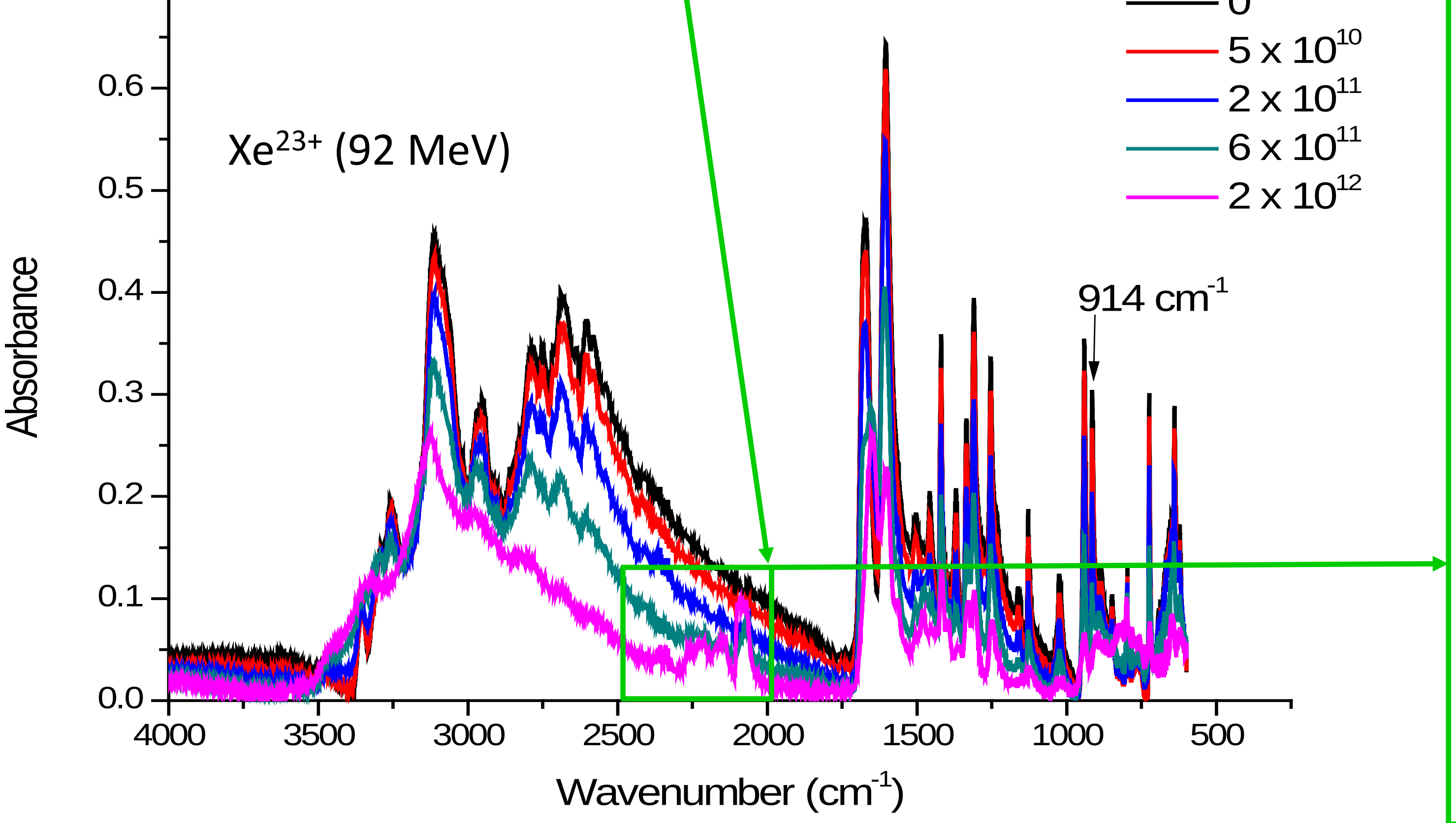
Ion Beam	Energy (MeV/u)	Electronic stopping power (keV.µm^{-1})	Nuclear stopping power (keV.µm^{-1})	Thickness (µm)	Penetration depth (µm)
Xe^{+23}	0.7	1.12×10^4	6.95×10^1	0.29	16
Kr^{33+}	10.5	5.80×10^3	3.6	0.50	120
Ca^{10+}	4.8	3.3×10^3	2.22	0.35	50
C^{4+}	0.98	$1{,}00 \times 10^3$	0.9	0.25	12

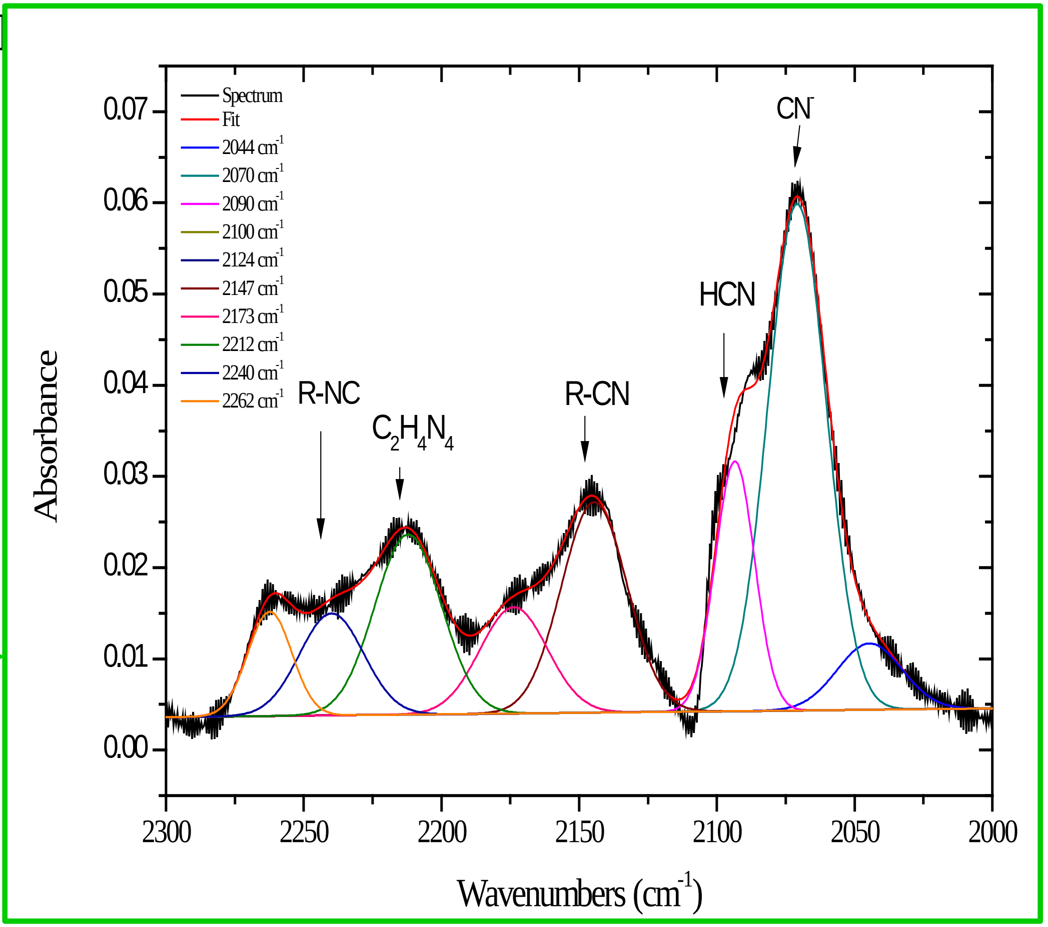
Results – IR spectra evolution



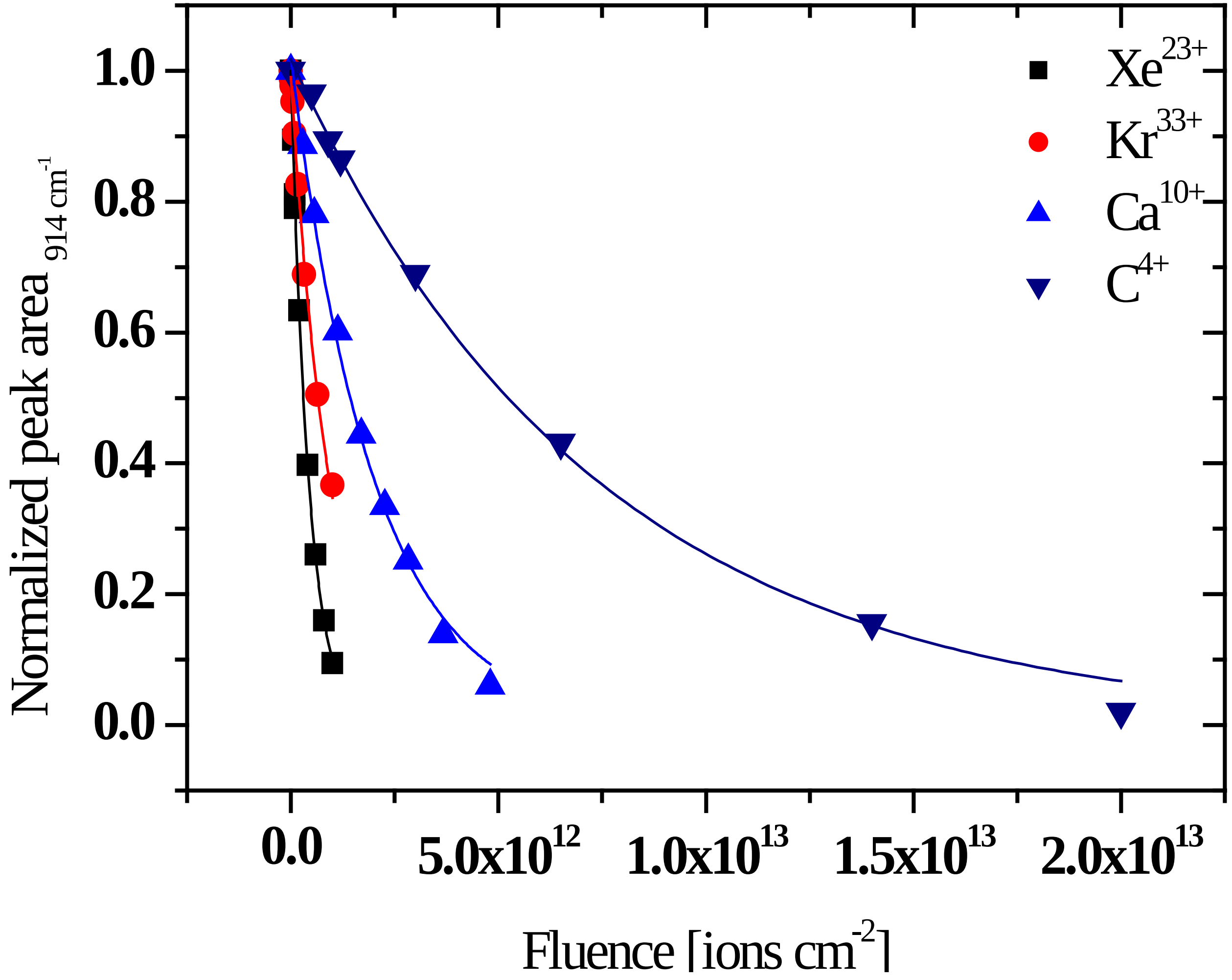
Results – IR spectra evolution

New molecules produced by fragmention of adenine.





Results - IR spectra evolution

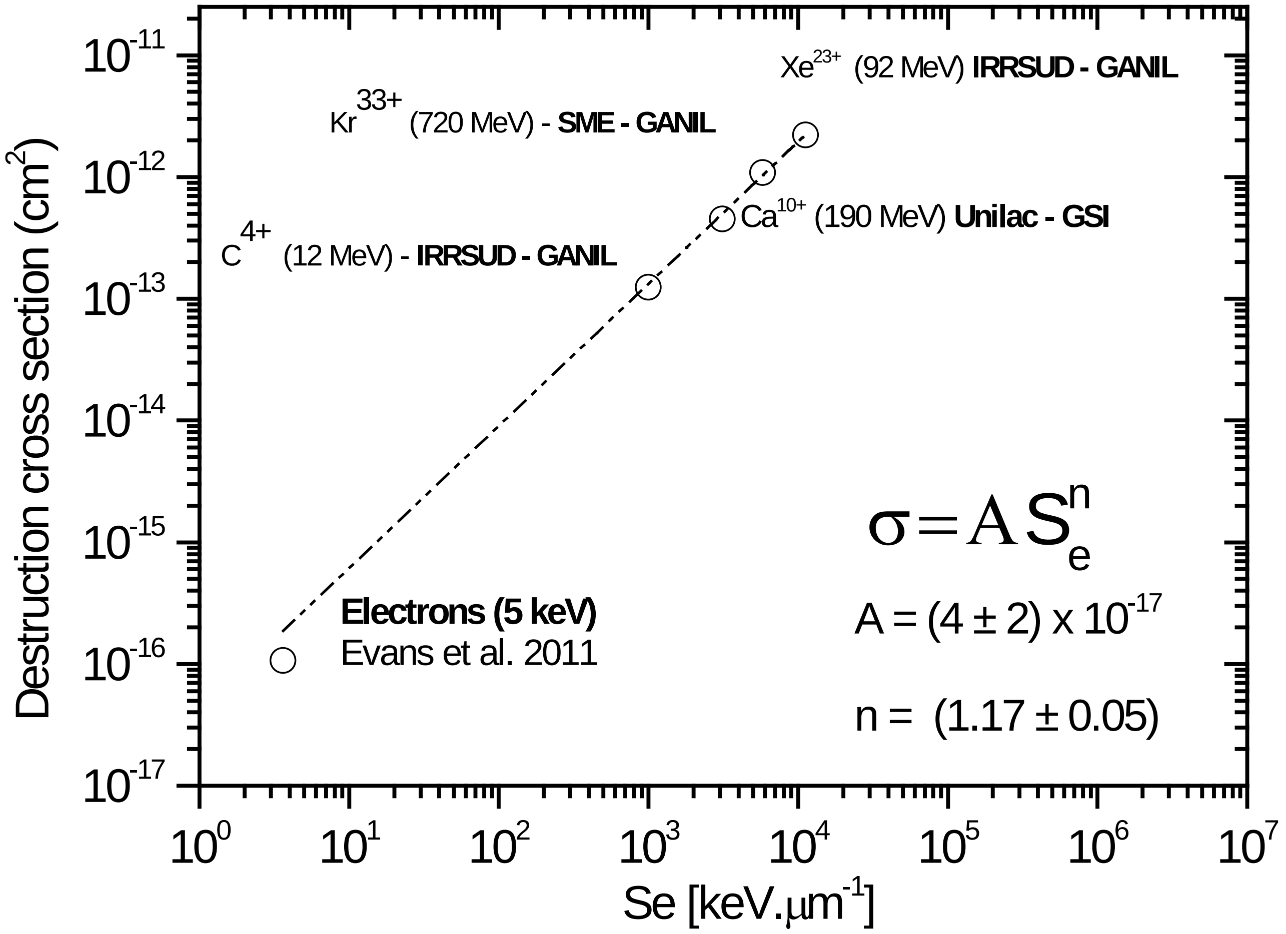


$$A = A_0 e^{-\sigma_d F}$$

Sample	Destruction cross section ($\times 10^{-13}$ cm^2)	S_e [$\times 10^3$ keV μm^{-1}]
Xe^{23+}	22.1 ± 0.1	11.2
Kr^{33+}	11.4 ± 0.3	5.8
Ca^{10+}	4.5 ± 0.2	3.3
C^{4+}	1.24 ± 0.06	1.0

Results

Cross section as a function of stopping power.



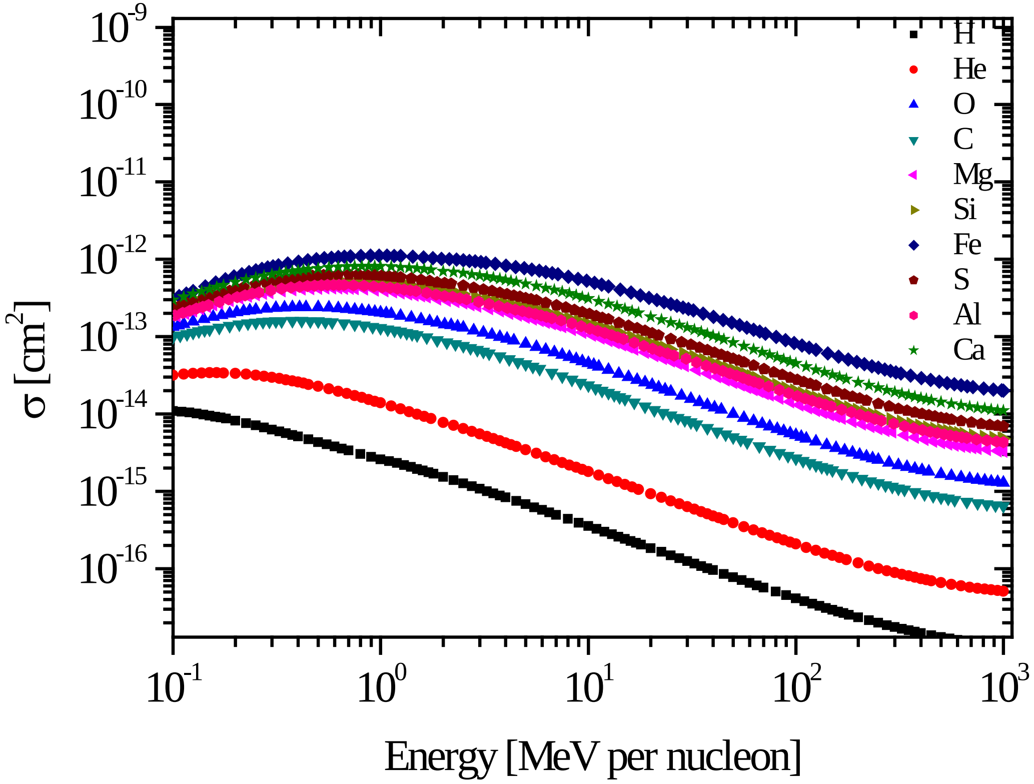
$$\sigma = 4 \times 10^{-17}\, S_e^{1.17}$$

Results obtained by our group show that the destruction cross section obeys a electronic stopping power law with:

$$1 \leq n \leq 1.5$$

Results

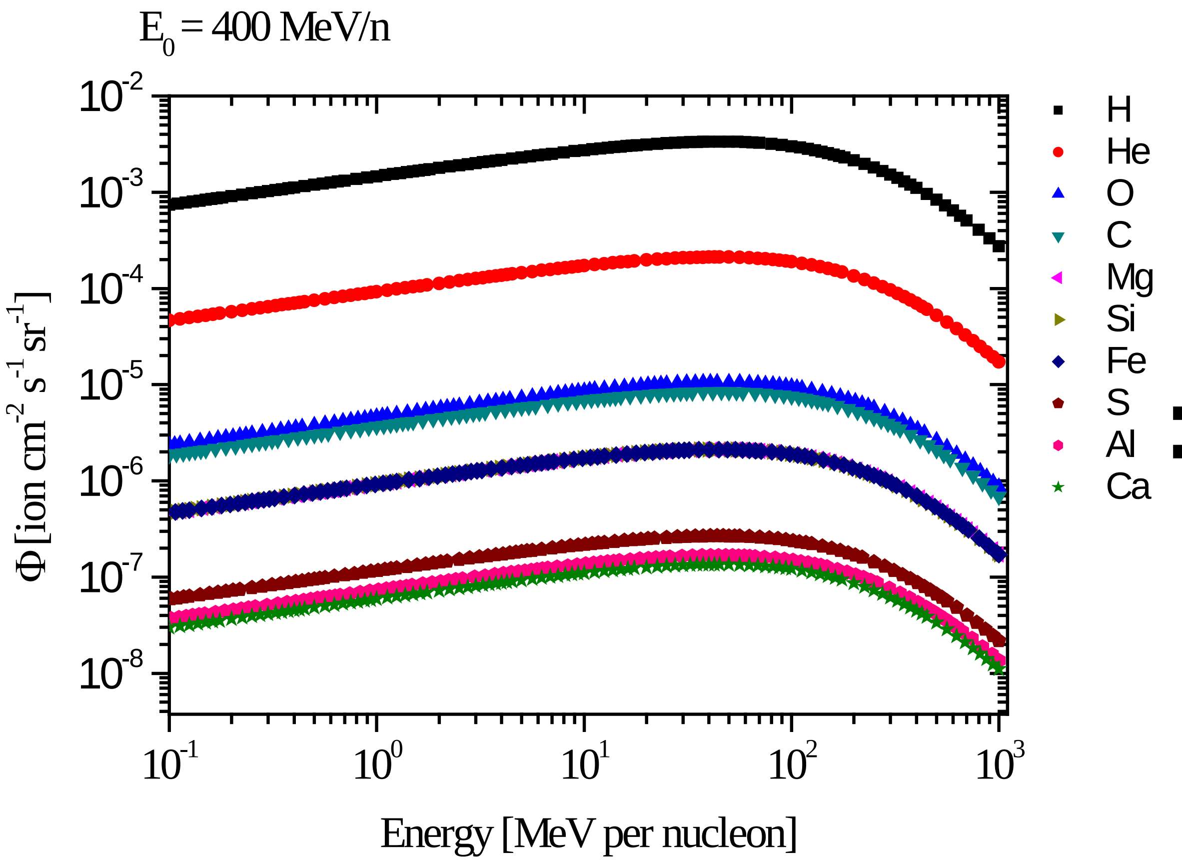
Destruction cross section



X

Flux : *

$$\phi(Z,E) = \frac{C\ (Z)\ E^{0.3}}{(E+\ E_0)^3}$$



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* Shen *et al* *Astron. Astrophys. 2004;* **415**:203–215.

Results

Destruction rate

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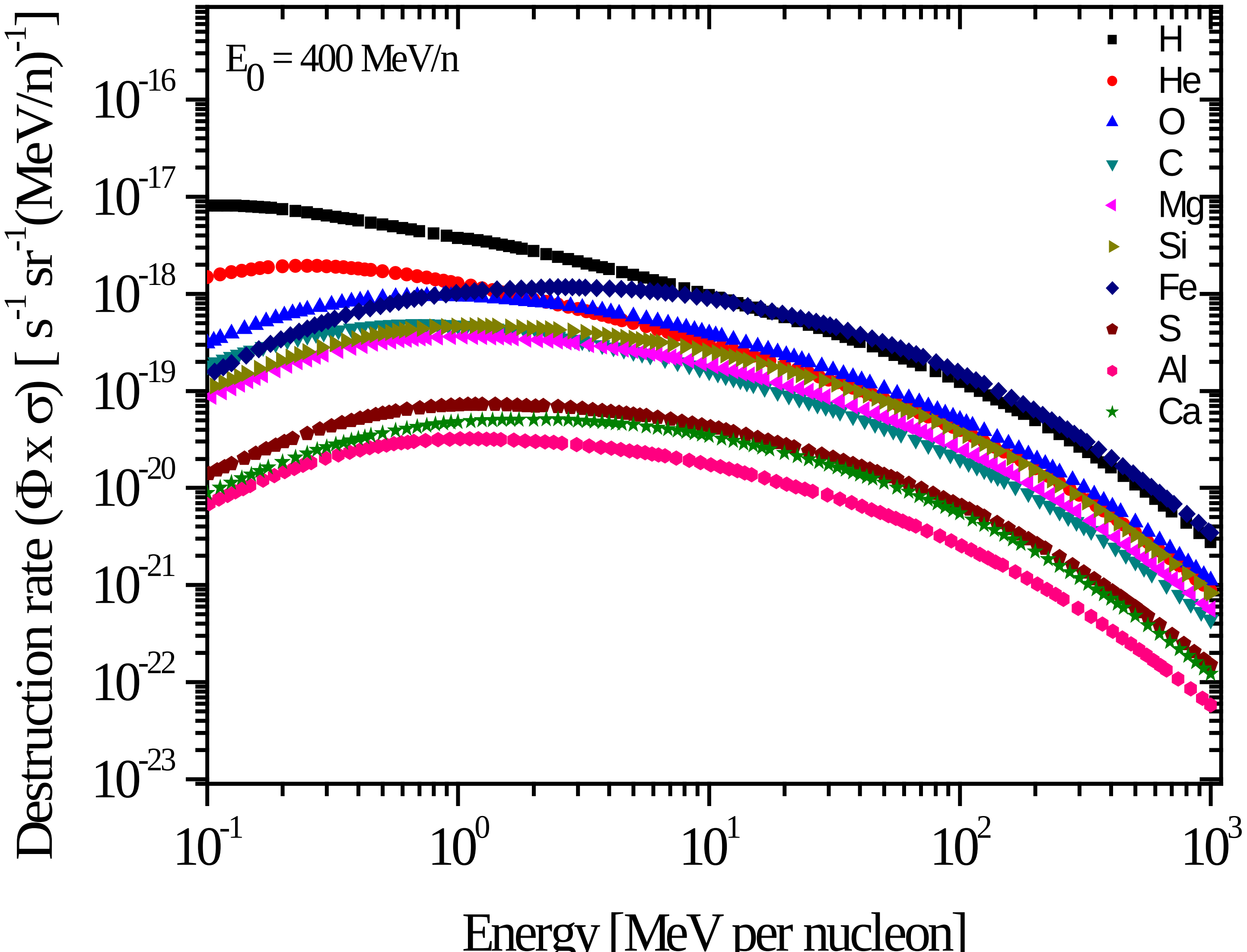


Results

Half-life of solid adenine exposed to cosmic rays in the ISM.

$$\tau_{1/2} = \ln 2 \left(4\,\pi \sum_{Z} \int \sigma(Z,E)\,\Phi(Z,E)\,dE\right)^{-1}$$

$$\tau_{1/2} = (10 \pm 8)\ x\ 10^{6}\ \boldsymbol{years}$$

The average time of survival of a DC is around 10 Myears. This is indeed close to the order magnitude of the half-life of adenine evaluated in this work.

Results

Comparision between different sources of radiation

The radiation G yield is defined as the number of adenine molecule destroyed per 100 eV absorbed.

Projectile	Radiation yield G (eV^{-1})	Reference
Xe^{23+} (92 MeV)	13.13	This work
Kr^{33+} (820 MeV)	12.56	This work
Ca^{10+} (192 MeV)	9.70	This work
C^{4+} (12 MeV)	8.29	This work
Electrons (5 keV)	1.98	(Evans et al., 2011)
UV photons (10.2 eV)	4.9×10^{-5}	(Guan et al., 2010; Saïagh et al., 2014)

Results

Half-life of solid adenine exposed to different source of radiation in distinct regions.

UV photons		
Region	Half-life (Myears)	UV flux ($cm^{-2}\ s^{-1}$)
ISM	4.5×10^{-1}	1.0×10^{8}
Dense Clouds (DC)	4.5×10^{4}	1.0×10^{3}

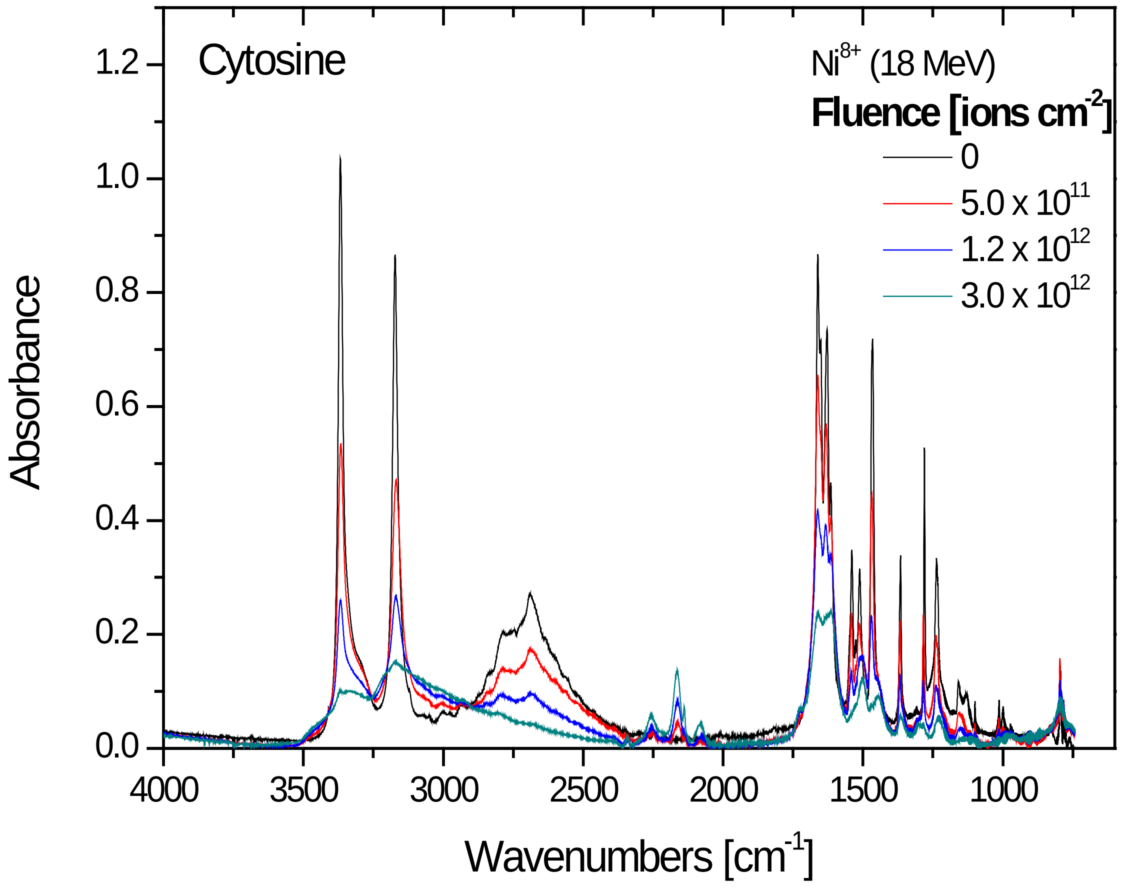
Cosmic Rays	
Region	Half-life (Myears)
ISM	10
Dense Clouds (DC)	≈10

Conclusions

- The adenine molecule destruction cross sections as a function of the deposited energy follow a power law: A S_e^n with n = 1.17
- The destruction of solid adenine by cosmic rays are dominated by iron and protons.
- The half-life of adenine was estimated in different region of space: ISM (0.45 Myears) and DCs (10 Myears).

Outlooks

- Irradiation of the all nucleobases that composes DNA and RNA. (Thymine, Uracil, Guanine and Cytosine).
- Improvement of the methodology of preparation of solid nucleobases : films more uniform.
- Irradiation of Pyridine, a important heterocyclic biomolecule using complementary techniques: IR spectroscopy and time of flight.
- Data under analysis.



Thank You for your attention!
Q&A

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