Processing of ices in space by energetic particles: synthesis and radiolysis of organics

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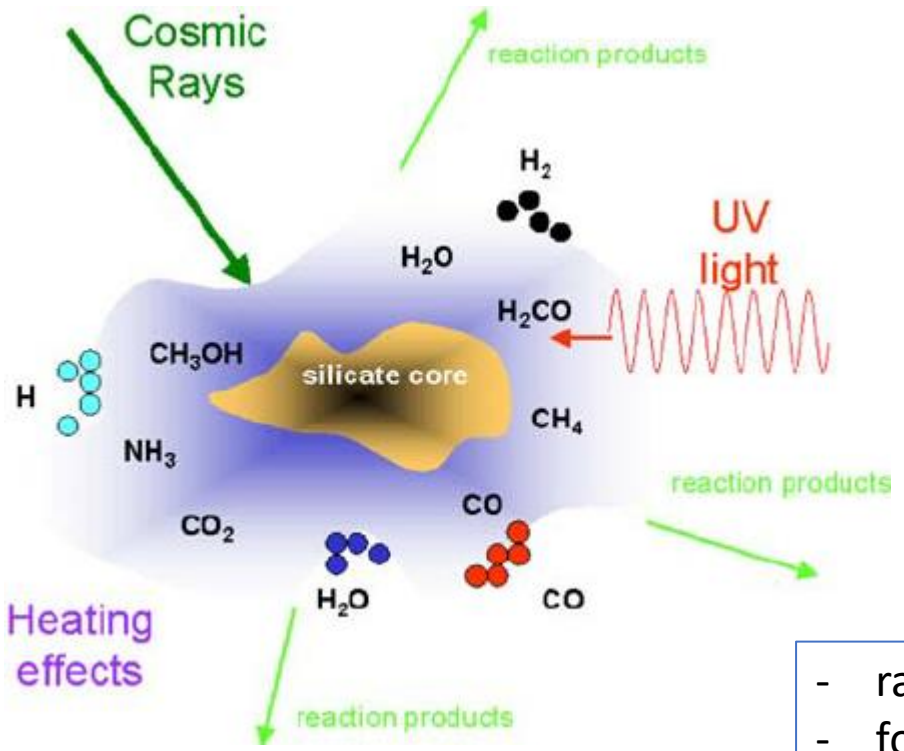
We thank the staff of CIMAP and GANIL and among them all in particular T. Been, C. Feierstein, T. Madi, J.M. Ramillon, F. Ropars, P. Rousseau, P. Voivenel, L. Maunoury and our collaborators B. Auge, C. Desfrancois, F. Lecomte, B. Manil, R. Martinez, Gabriel S.V. Muniz and N. Nieuwjaer. We gratefully acknowledge funding from INSERM-INCa (Grant BIORAD), Region Normandie Fonds Europeen de Developpement Regional - FEDER Programmation 2014-2020, and a Ph. D. grant from Region Normandie RIN 2018. The infrastructure of GANIL (Grand Accelerateur National d'Ions Lours, Caen, France) was used to do the research presented here. The research of Z.K. was supported by ENSAR2-Access-TNA GANIL and VEGA { the Slovak Grant Agency for Science (grant No. 2/0023/18)

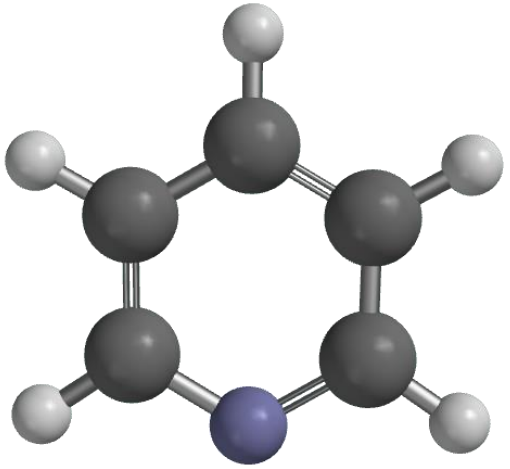
INTERSTELLAR DUST GRAINS IN DENSE MOLECULAR CLOUDS



Grains covered with thin layers of ice present in ISM clouds are exposed to:

- cosmic rays
- stellar winds
- electrons
- UV radiation

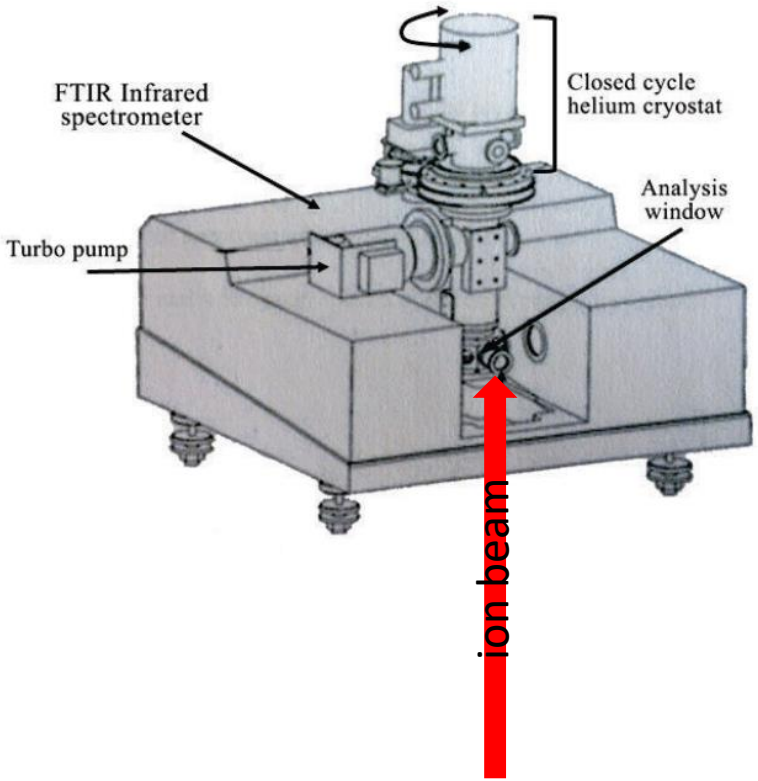
- radiolysis (fragmentation) of molecules
- formation of new molecules/radicals
- sputtering and desorption
- structural and phase changes



Pyridine C_5H_5N– complex organic molecule, liquid at room T

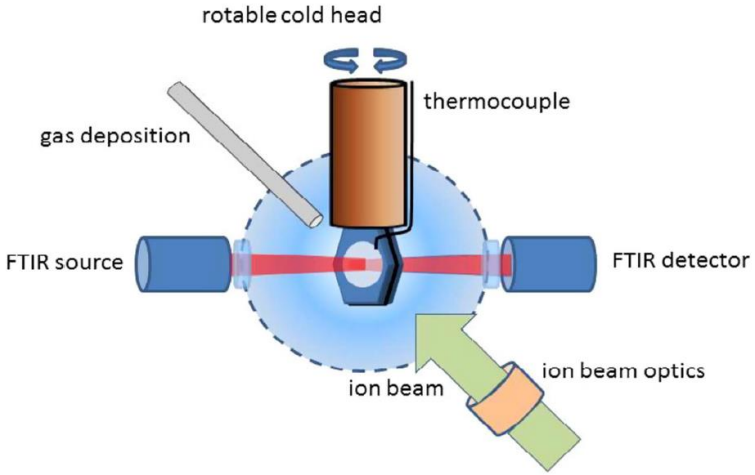
How long can COMs survive in space?

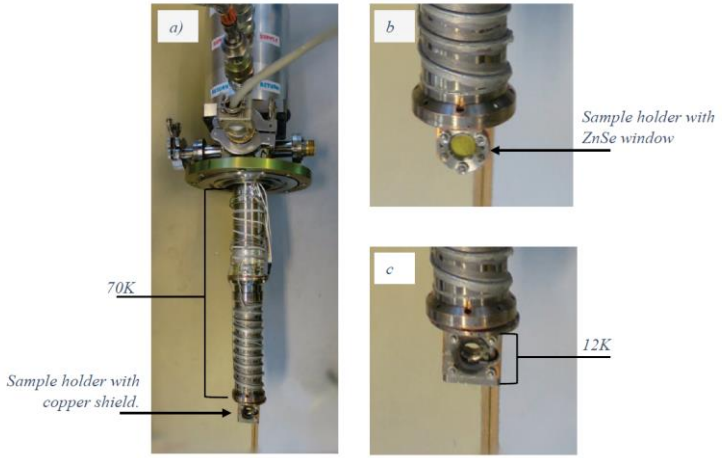
EXPERIMENTS

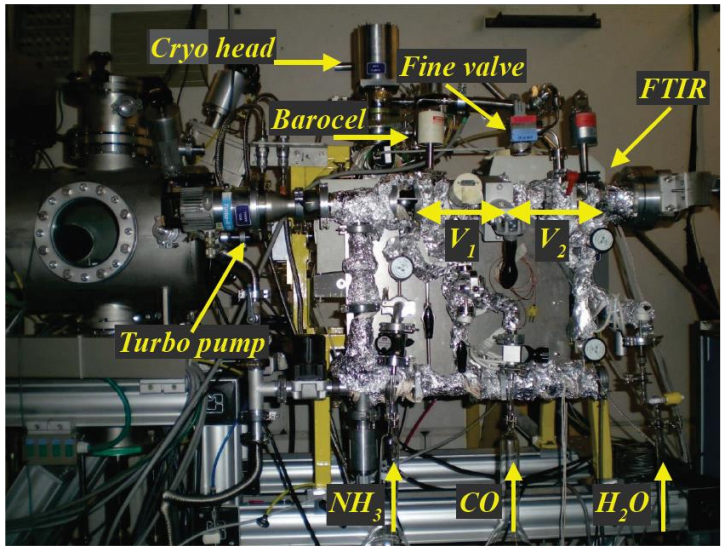


CASIMIR set-up

Chambre d'Analyse par Spectroscopy Infrarouge desMolécules IRradiées







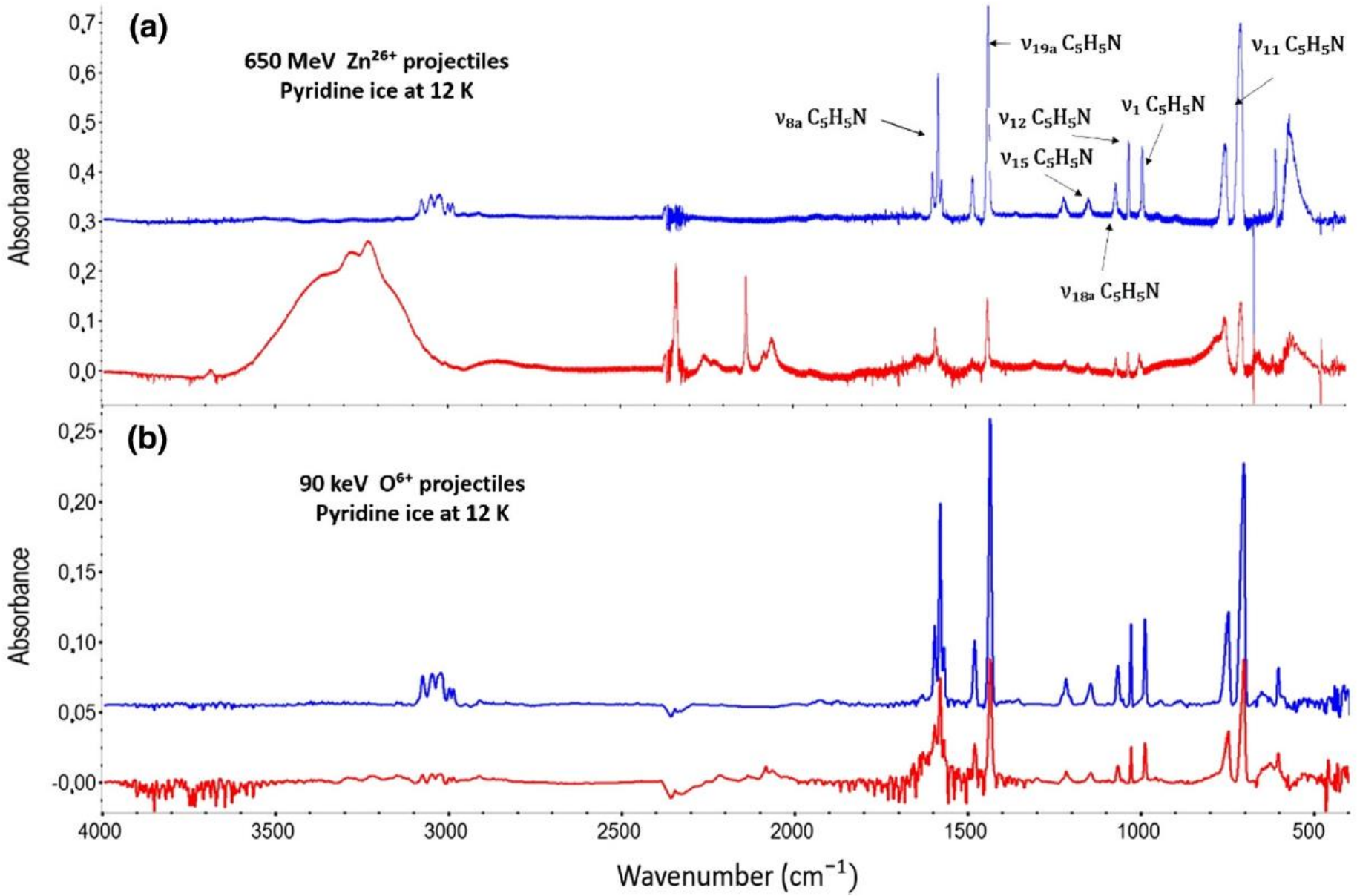
Two beamlines of GANIL:

ARIBE: 90 keV $^{16}O^{6+}$

SME: 650 MeV $^{70}Zn^{26+}$

Figures from Thesis of G. Vignoli Muniz and Rothard 2017

PURE PYRIDINE ICE T=12K



as deposited

after irradiation with
1.1×10^{13} 650 MeV Zn^{26+} ions

as deposited

after irradiation with
2.3×10^{15} 90 keV O^{6+} ions

initial column density

ion fluence [ions cm^{-2}]

number of not irradiated molecules

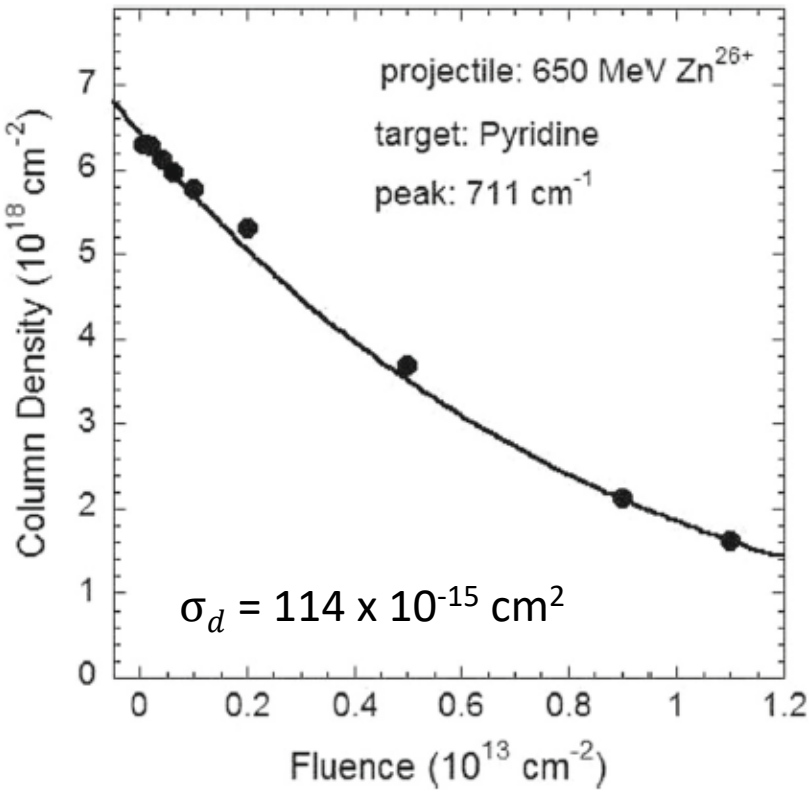
column density [molecules cm^{-2}]

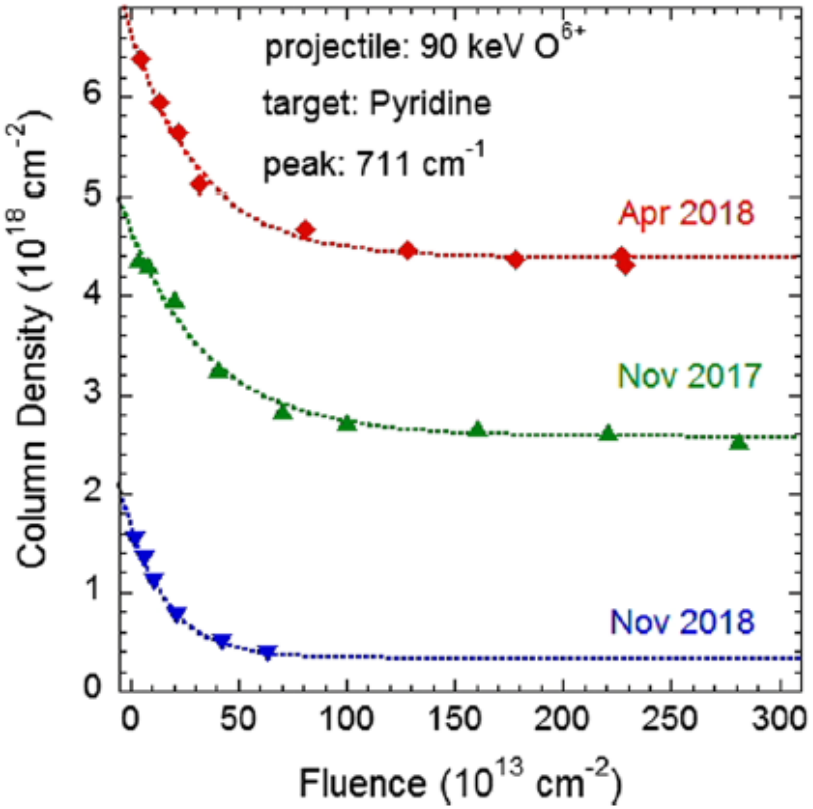
$$N(F) = N_0 e^{-\sigma_d F} + N_1 F + N_2$$

destruction cross section [cm^2]

sputtering yield [cm^2]

$$N = \frac{2.3}{A} \int \mathrm{Abs}_\nu \mathrm{d}\nu$$





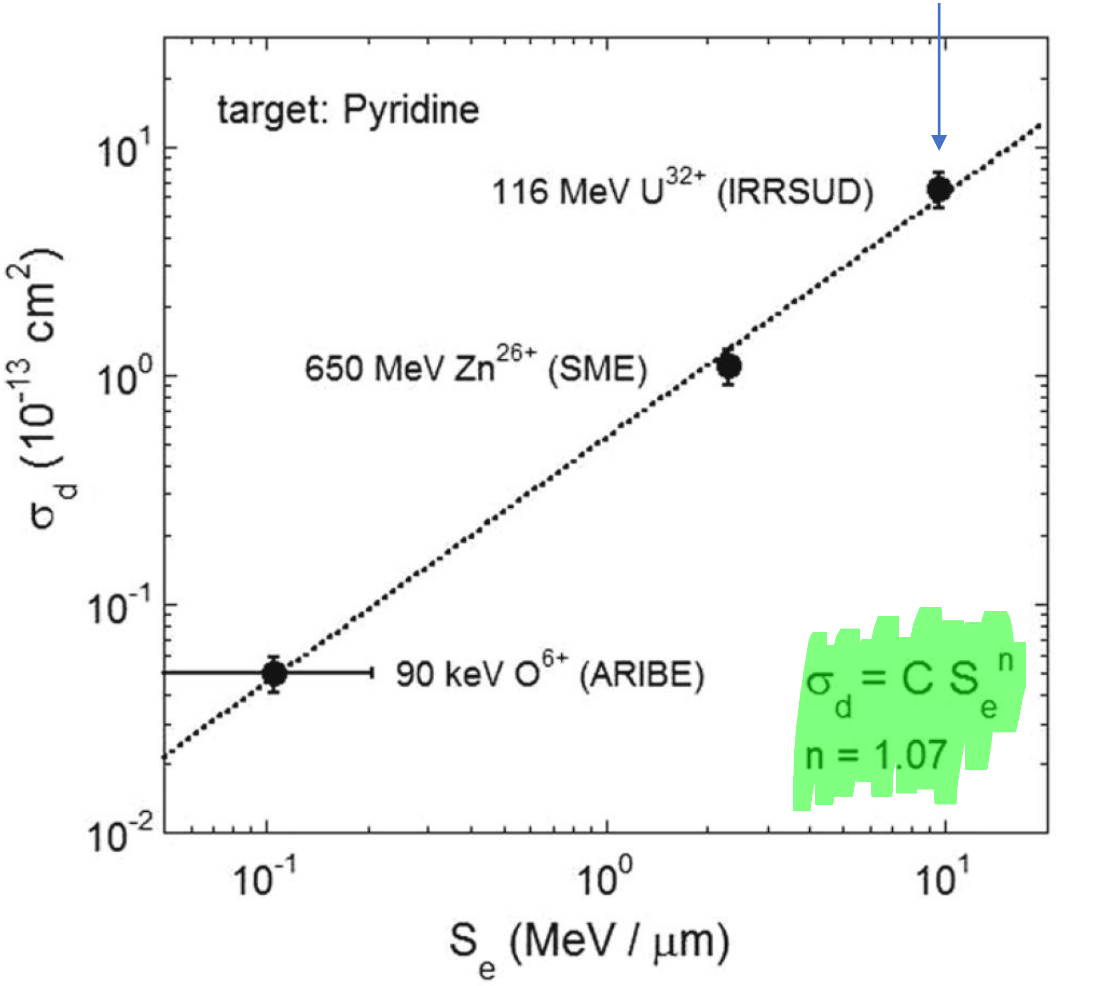
σ$_d$ [x 10^{-15} cm^2]

2.61

1.66

3.53

Vigoli Muniz 2017: Thesis



Electronic stopping power S_e

- corresponds to the energy loss via inelastic collisions (ionization, excitation of atoms) per unit of path length [MeV/µm]

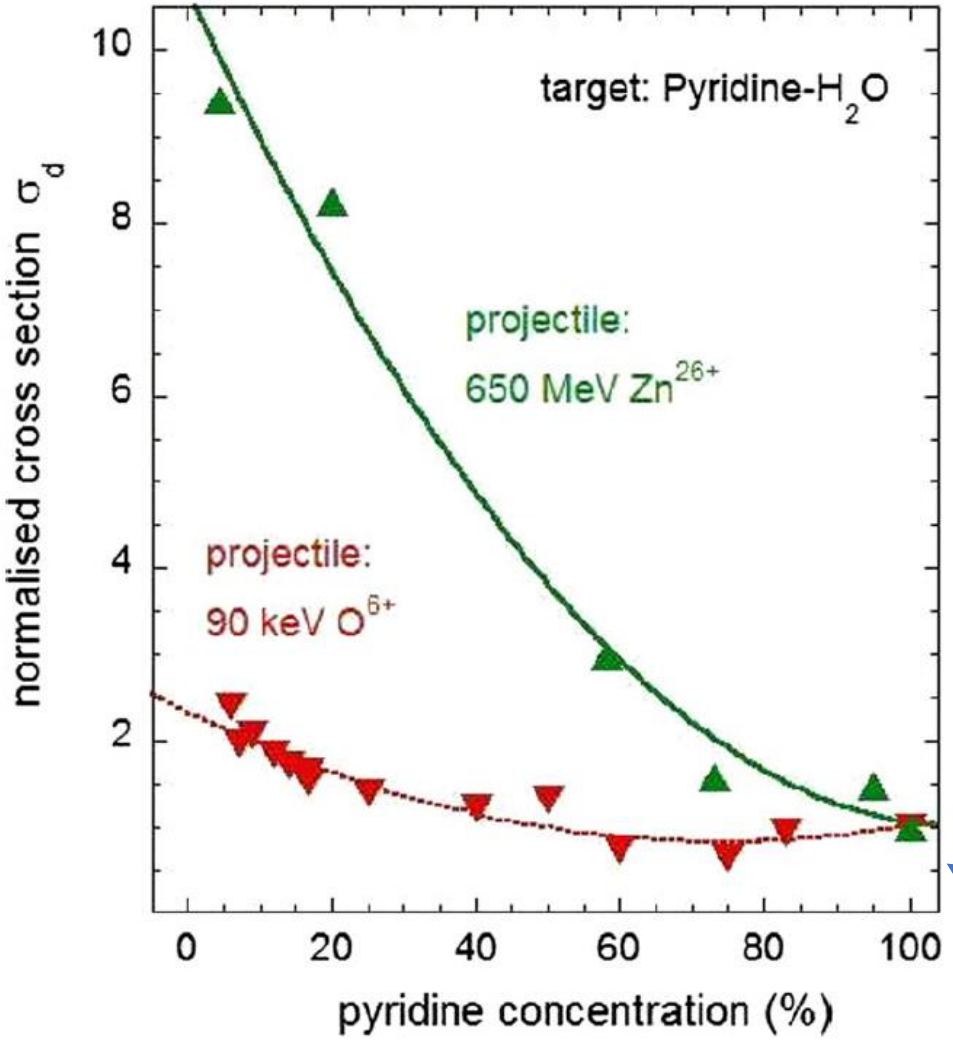
- calculated by SRIM software (Ziegler 2008)

$$\sigma_d = C\ Se^n$$

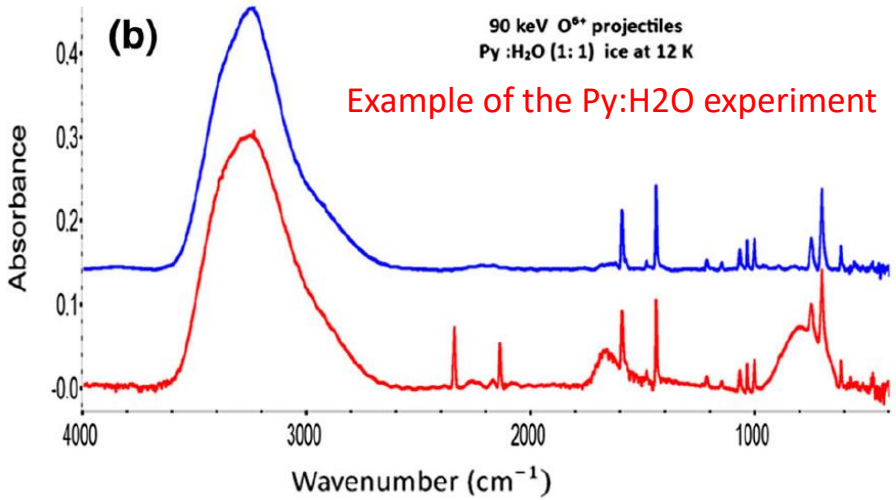
- observed for many simple and complex molecules (e.g. de Barros et al 2011, 2014; Andrade et al., 2013; Dartois et al., 2013 …)

PYRIDINE:WATER MIXTURES T=12K

- closer to real conditions in space
- amorphous and porous structure of ices
- at low concentration od Py - COMs embedded in water matrix



- **the destruction cross section decreases with increasing pyridine concentration**
- **presence of water makes pyridine less resistant to CR radiation**
- **The effect is stronger in the purely electronic stopping regime with higher S_e**



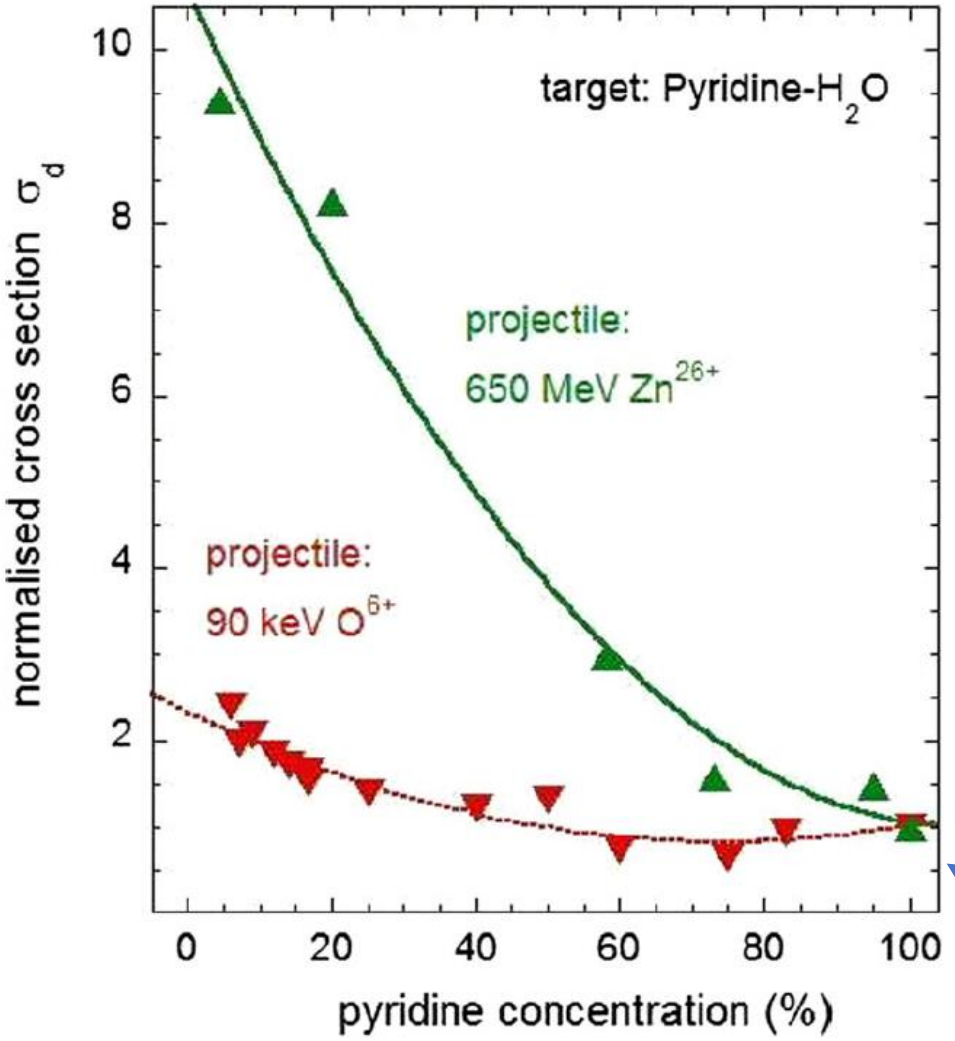
Example of the Py:H2O experiment

Average values of σ_d for 6 different vibrational bands

reminder:

$$N(F) = N_0 e^{-\sigma_d F} + N_1 F + N_2$$

PYRIDINE:WATER MIXTURES T=12K



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Average values of σ_d for 6 different vibrational bands

efficiency of protonation of Py molecule (PyH^+) depends on the number of H_2O molecules

reactive species from H_2O radiolysis contribute to the destruction of Py

less efficient ionization of COMS at higher concentration

related to the energy loss mechanisms

Summary

- Water environment significantly modifies the radiation resistance of pyridine
- In dense molecular clouds - pyridine can survive ~10 Myr (comparable cloud life time)
- Study of radio resistance of COMs is of significance for radiation biology

Eur. Phys. J. D (2021)75:57
https://doi.org/10.1140/epjd/s10053-021-00058-y

THE EUROPEAN PHYSICAL JOURNAL D

Regular Article - Topical Issue

Radiolysis of pyridine in solid water

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