

## FRONTIERS AND CHALLENGES IN LABORATORY ASTROCHEMISTRY

# Space chemistry research at ATOMKI

Experimental Molecular Physics Research Group

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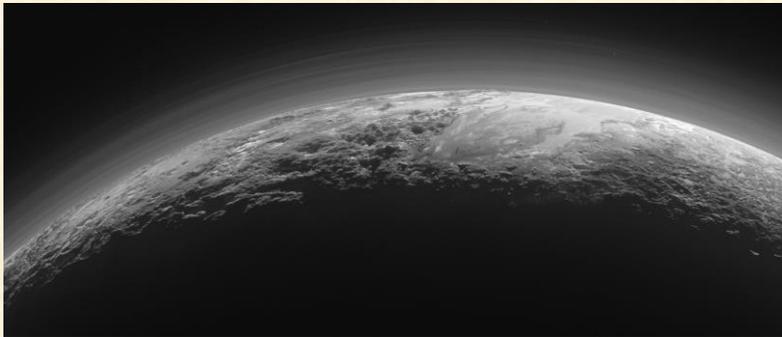
# Radiation is one of the main drivers for astrochemistry

cosmic rays, solar wind, magnetospheric ions, electrons, UV photons ...

focal point: **ion impact** - modelled by the **Atomki accelerators**

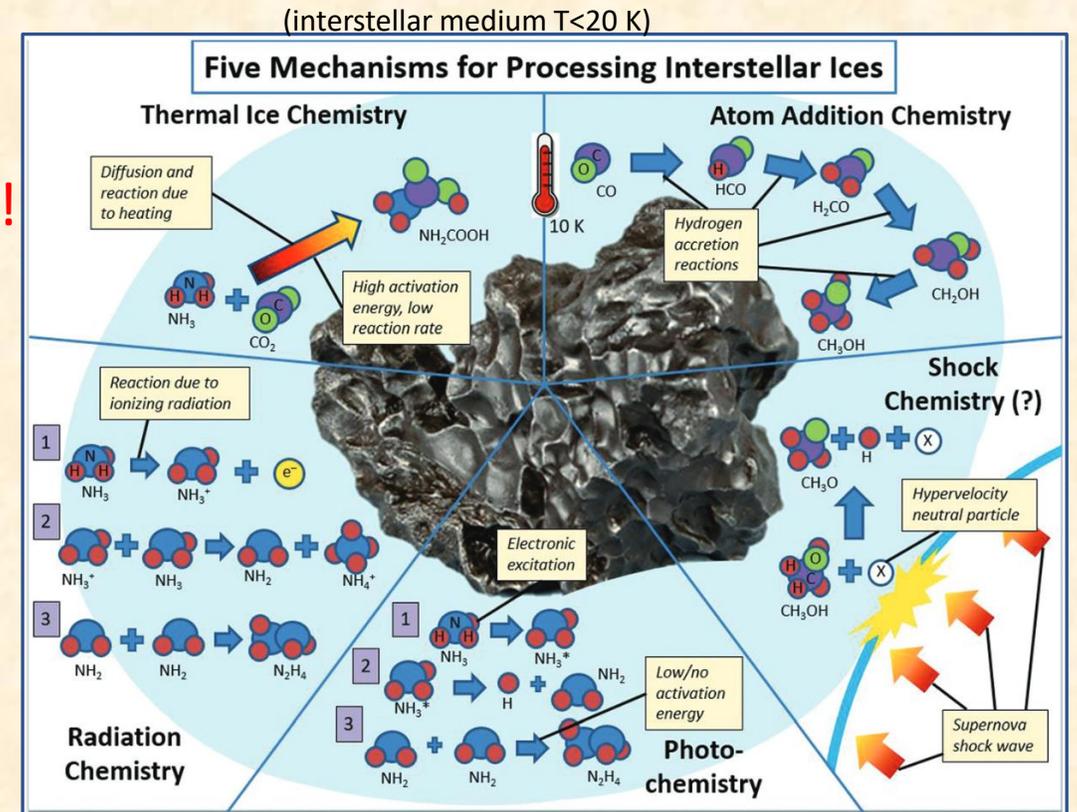
Molecular processes - fragmentation  $\text{CO}_2$  and synthesis  $\text{O}_2$  in planetary atmospheres

in the icy cover of dust particles in ISM  
(interstellar medium  $T < 20 \text{ K}$ )



Molecules are formed in space!

on the surfaces of icy moons



# What is our current standing in space chemistry?

- We established **two accelerator based astrochemical experimental stations** at Atomki in the period **2019-2022** in collaboration with our partners



## ATOMKI – AQUILA

The Atomki Queen's University Ice chamber for Laboratory Astrochemistry

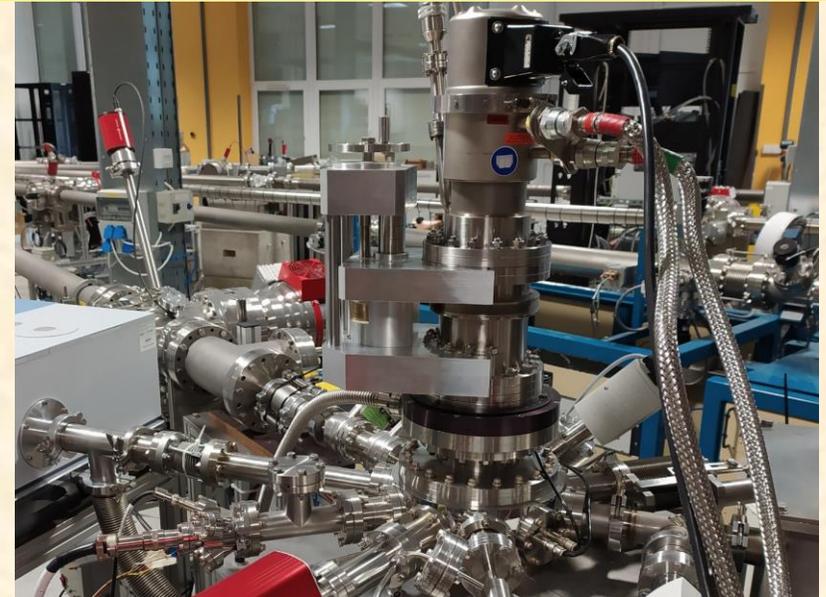


## ATOMKI – ICA

The Ice Chamber for Astrophysics/Astrochemistry



At Electron Cyclotron Resonance (ECR) Ion Source, 0.5 – 20 keV



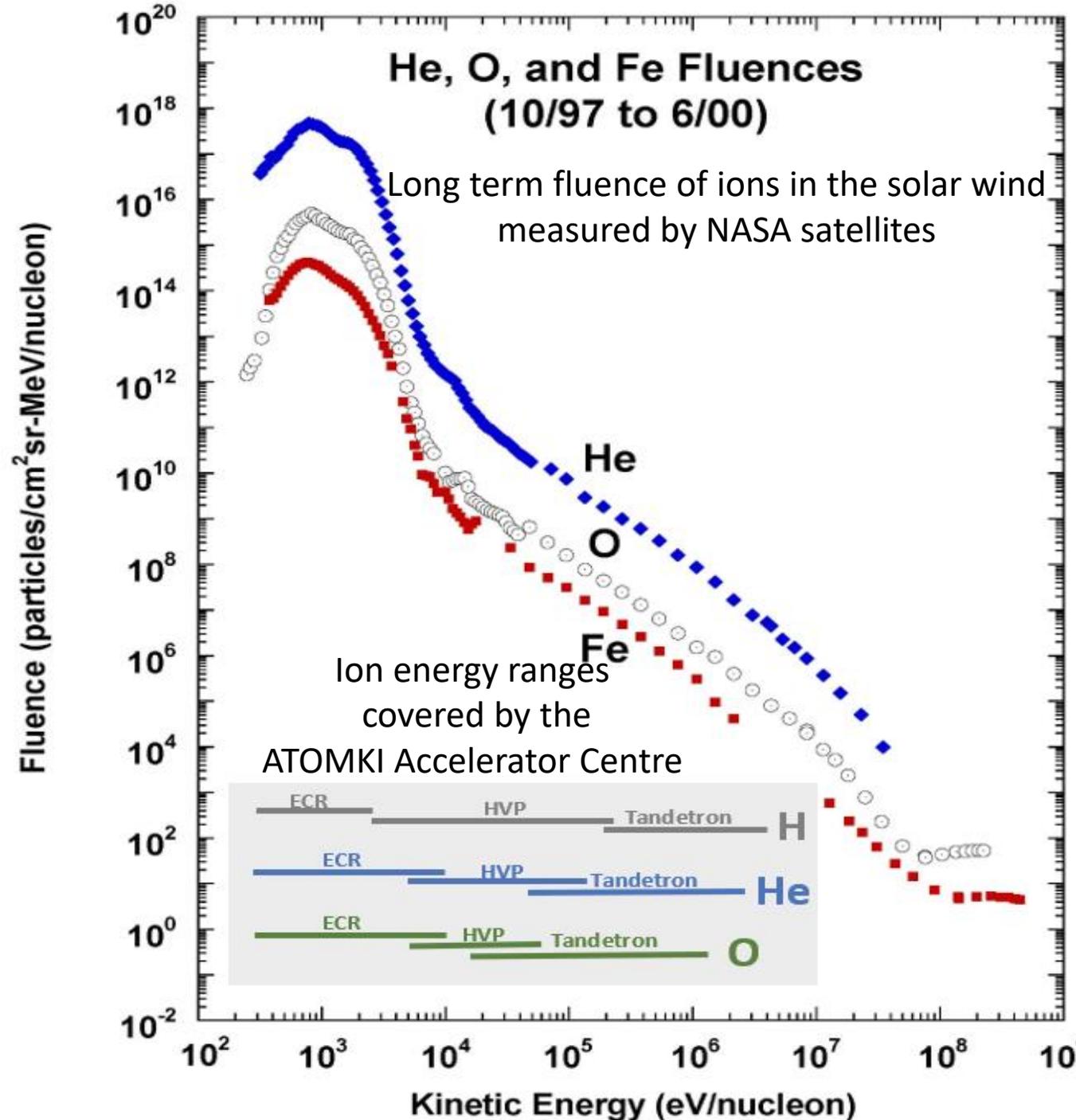
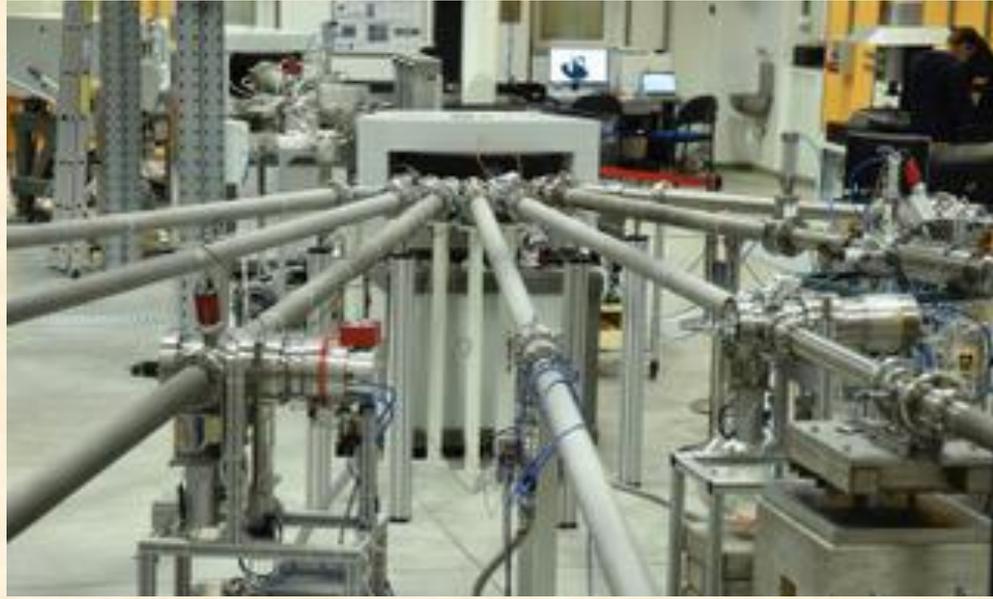
At Tandetron Accelerator 0.2– 6 MeV

**Most popular – and most active - Transnational Access (TA) providers within the Europlanet 2024 RI project**

# Ion selection at ATOMKI – Solar wind ions

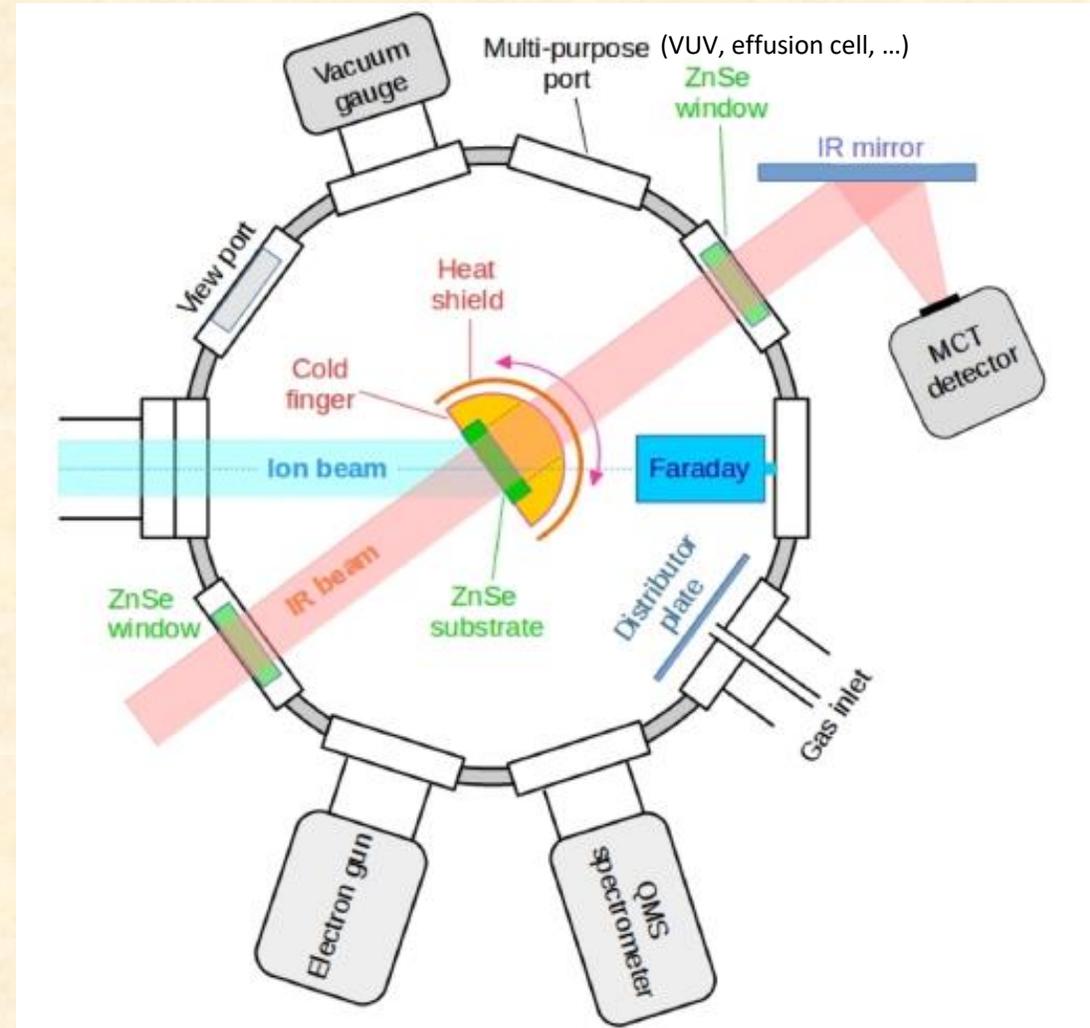
ECR ion source :  $H^+$ ,  $C^{1+, \dots, 5+}$ ,  $N^{1+, \dots, 6+}$ ,  $O^{1+, \dots, 7+}$   
 $Xe^{1+, \dots, 23+}$ , + molecular and negative ions  
 0.5-20 keV

Tandetron accelerator:  
 $H^+$ ,  $He^{1-2+}$ ,  $C^{1-2+}$ ,  $O^{1-2+}$ ,  $S^{1-2+}$  0.2-6 MeV



# The ICA chamber at the Tandetron beamline

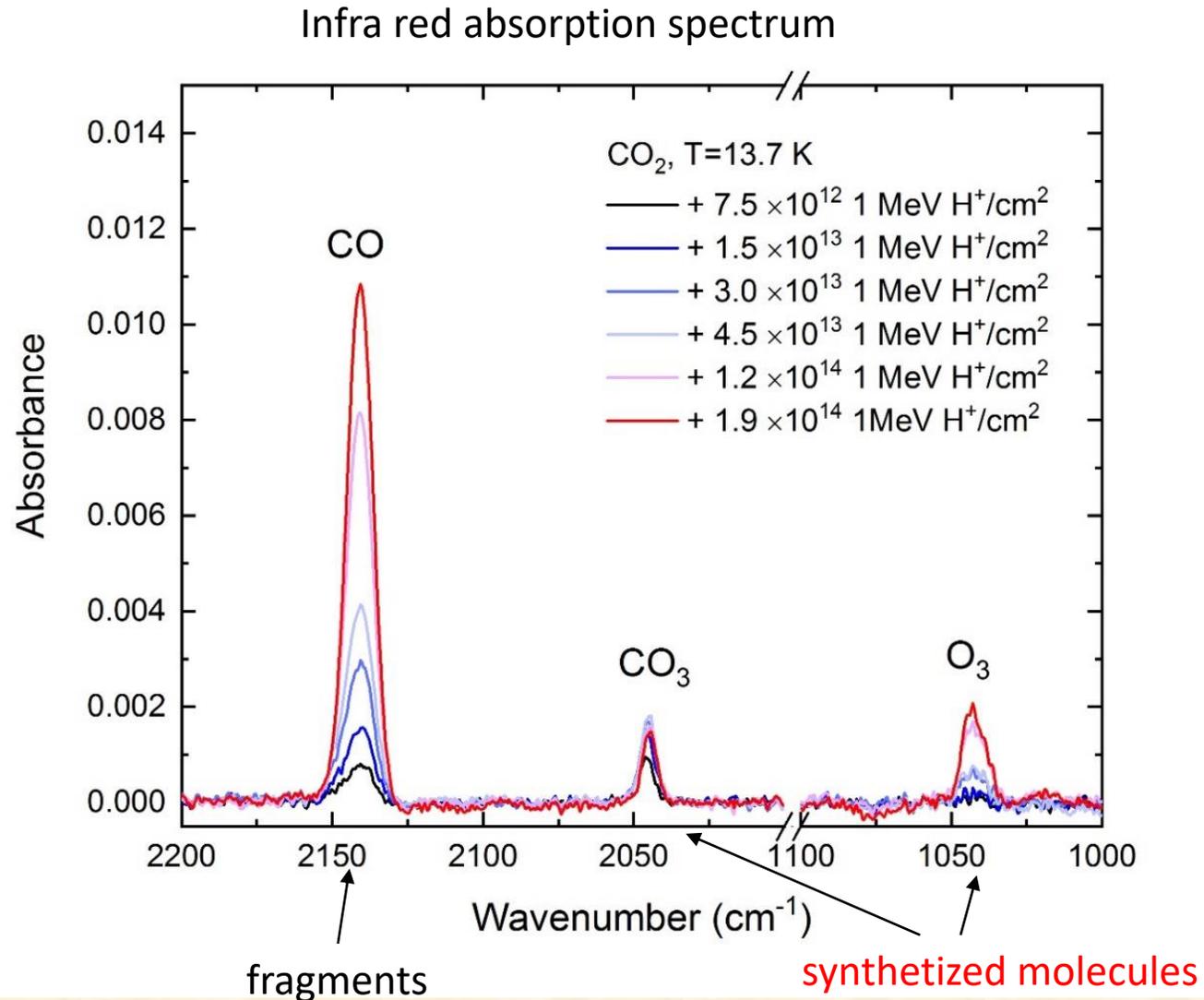
- Ices deposited onto four substrates by background deposition of gases.
- Refractories (e.g., elemental sulphur) deposited onto one substrate by effusive evaporation.
- Ices processed thermally, by electron beams, or by ion beams.
- *In situ* analysis: FTIR spectroscopy and quadrupole mass spectrometer
- *Ex situ* analysis: Raman spectroscopy, scanning electron microscope, electrospray ionization mass spectrometry ...



Investigation of astrophysical ice analogues:

## CO<sub>2</sub> ice processing

*Chemistry starts working in the irradiated ice and produce synthetized molecules*

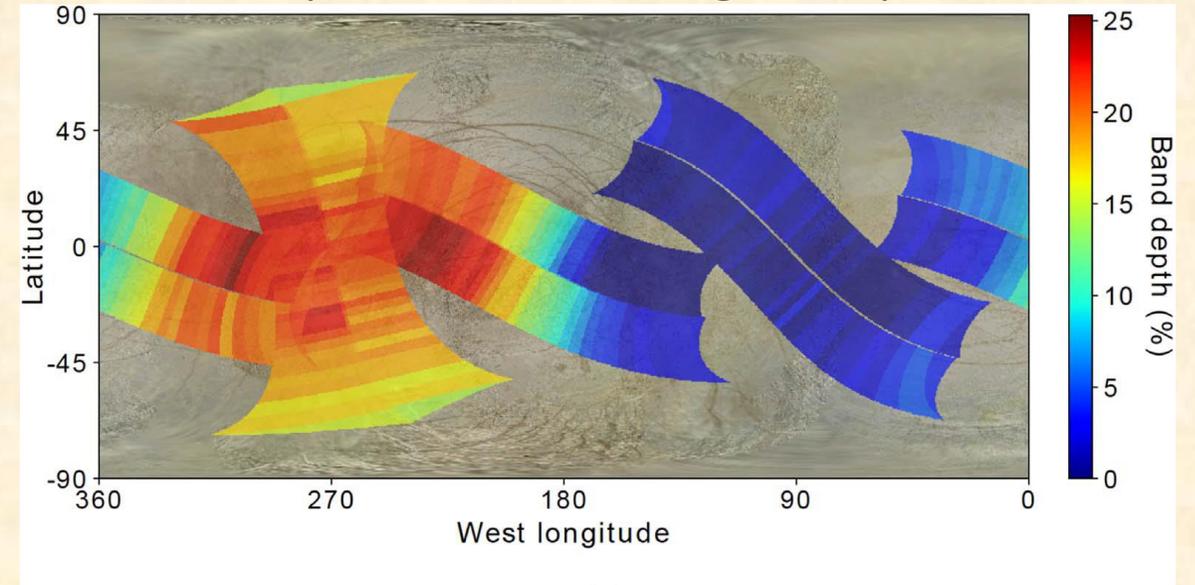


*Investigation of astrophysical ice analogues:*

## SO<sub>2</sub> found on the icy surface of Europa



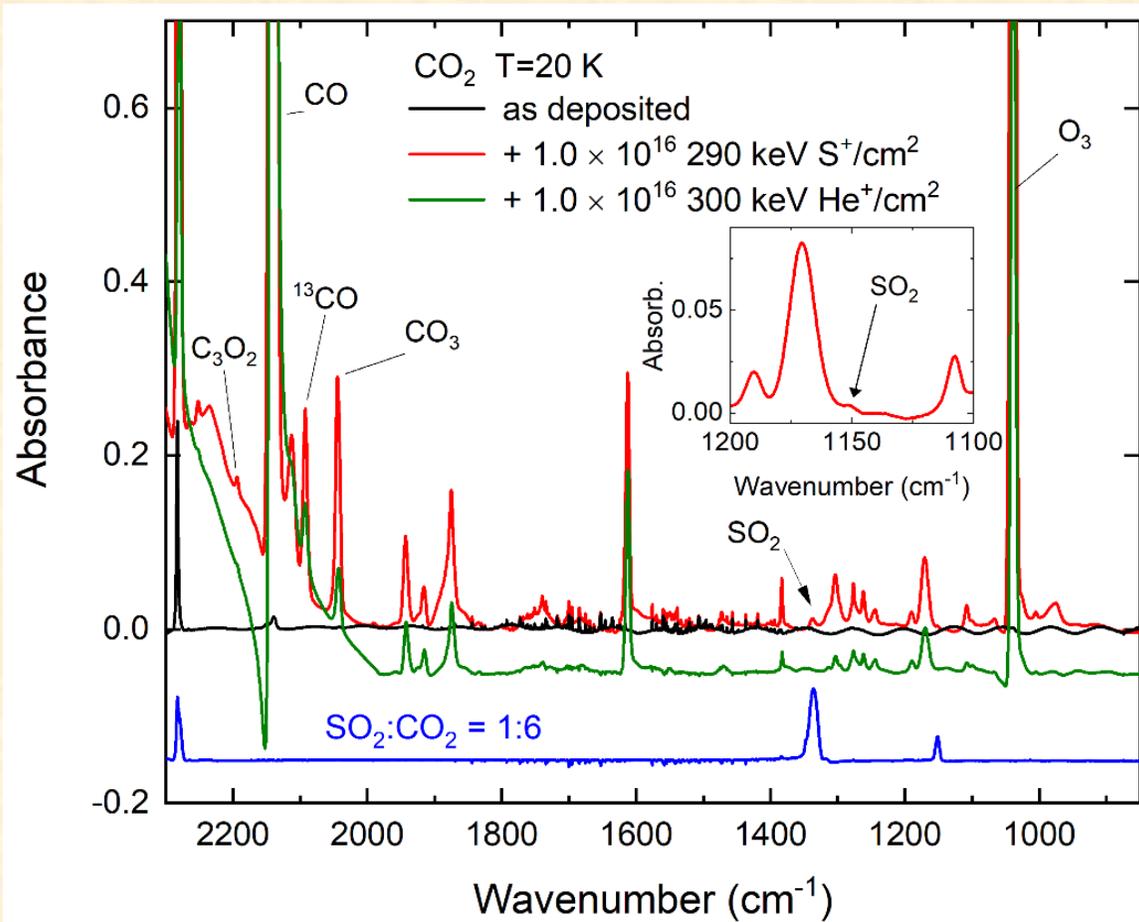
Hubble Space Telescope: SO<sub>2</sub> found by UV absorption on the Trailing hemisphere



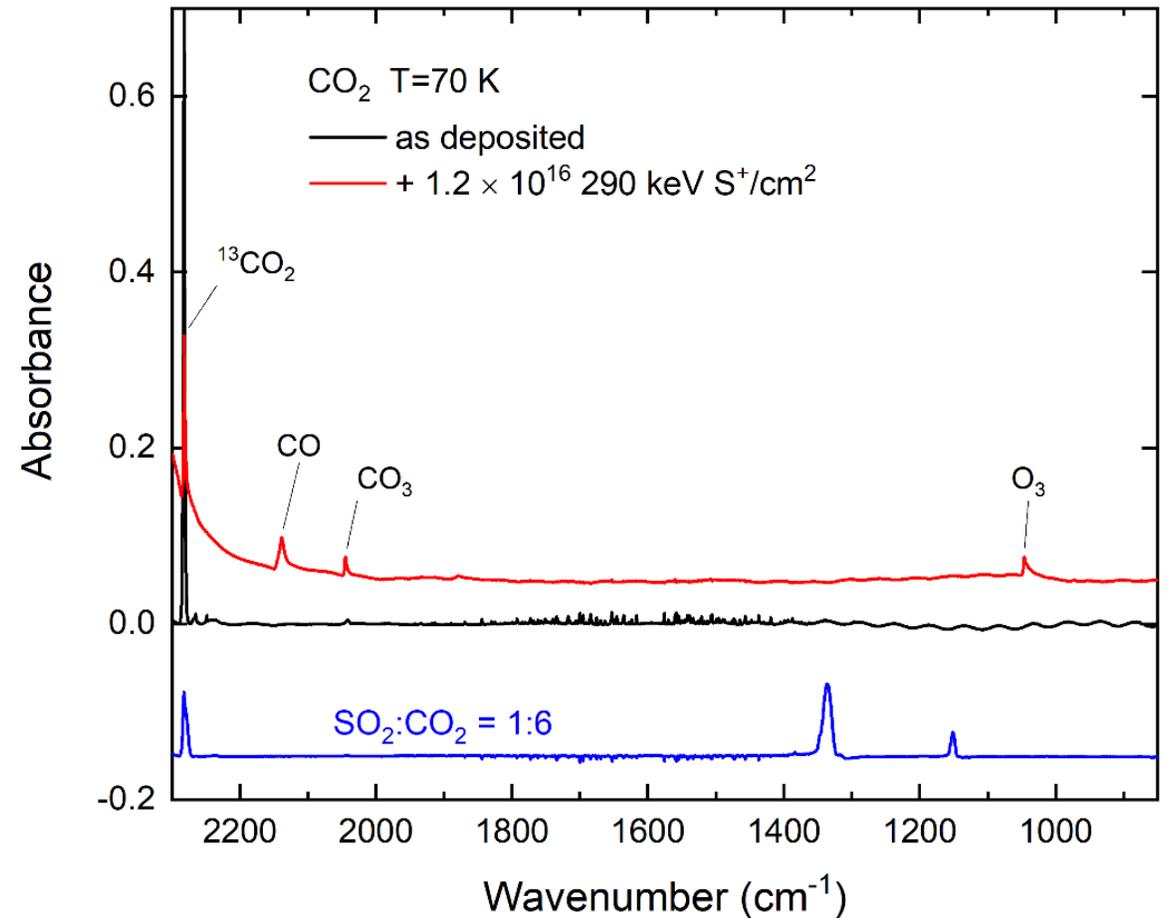
Becker et al., The Planetary Science Journal, 3:129 (10pp), 2022 June

Sulphur ion implantation sourced from Io?

# Implantation of 290 keV S<sup>+</sup> Ions into CO<sub>2</sub>



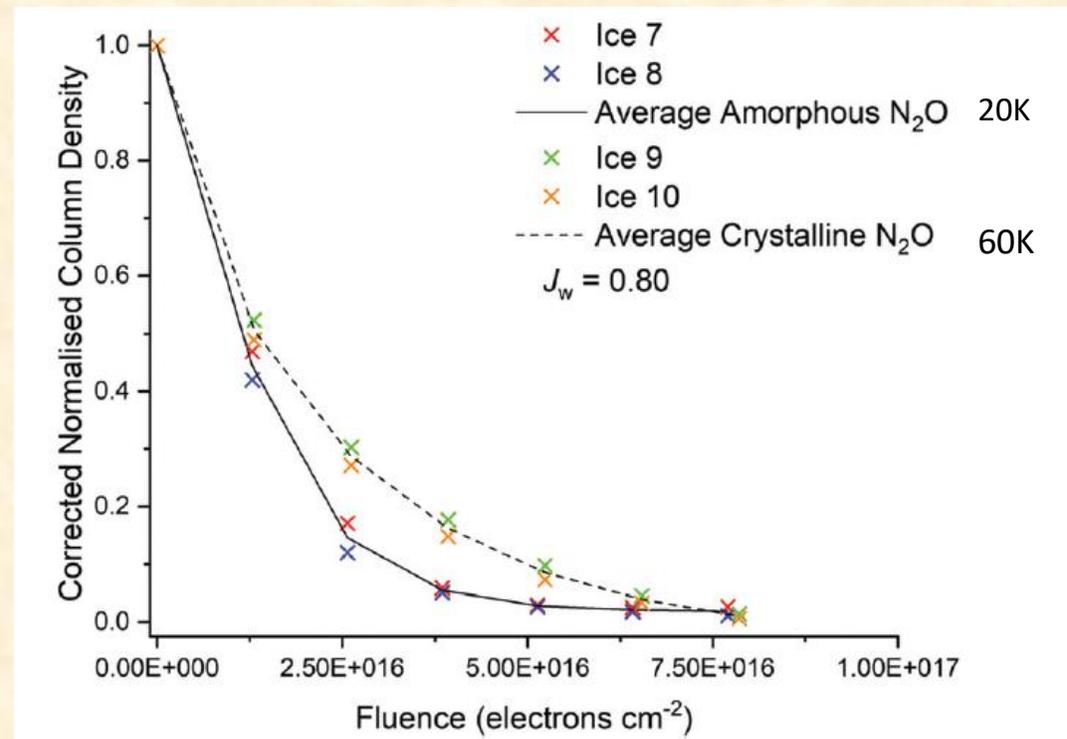
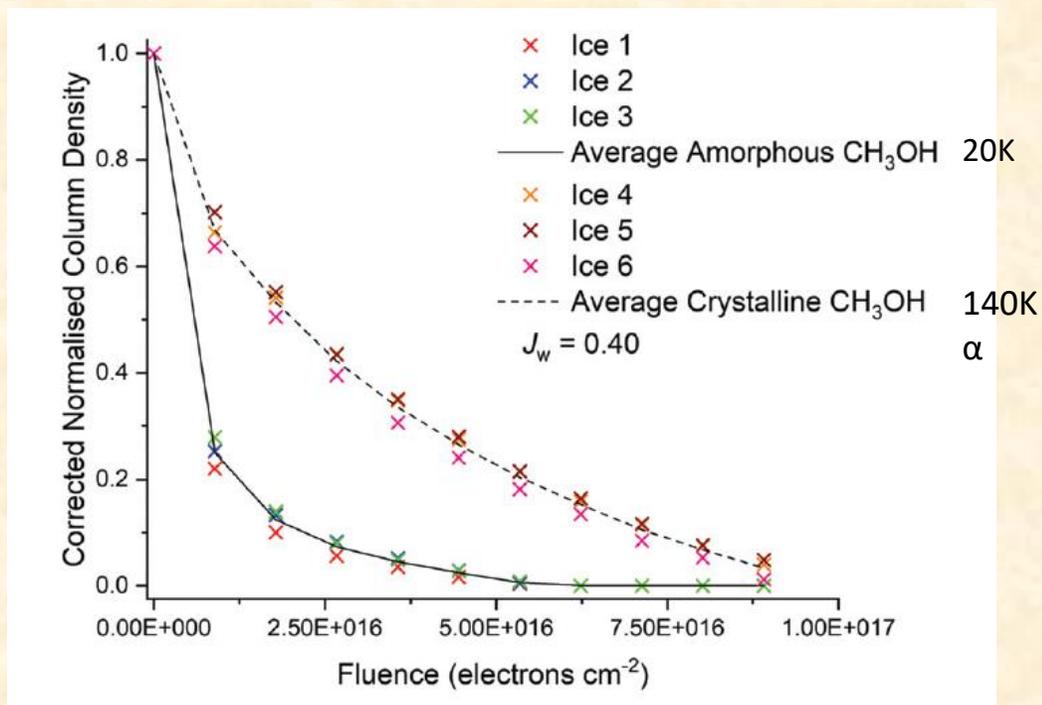
implanted ions forms new molecules



# Comparative electron irradiations of amorphous and crystalline astrophysical ice analogues

irradiation by 2 keV electrons

*Destruction of the molecules depends on the phase of the ice*

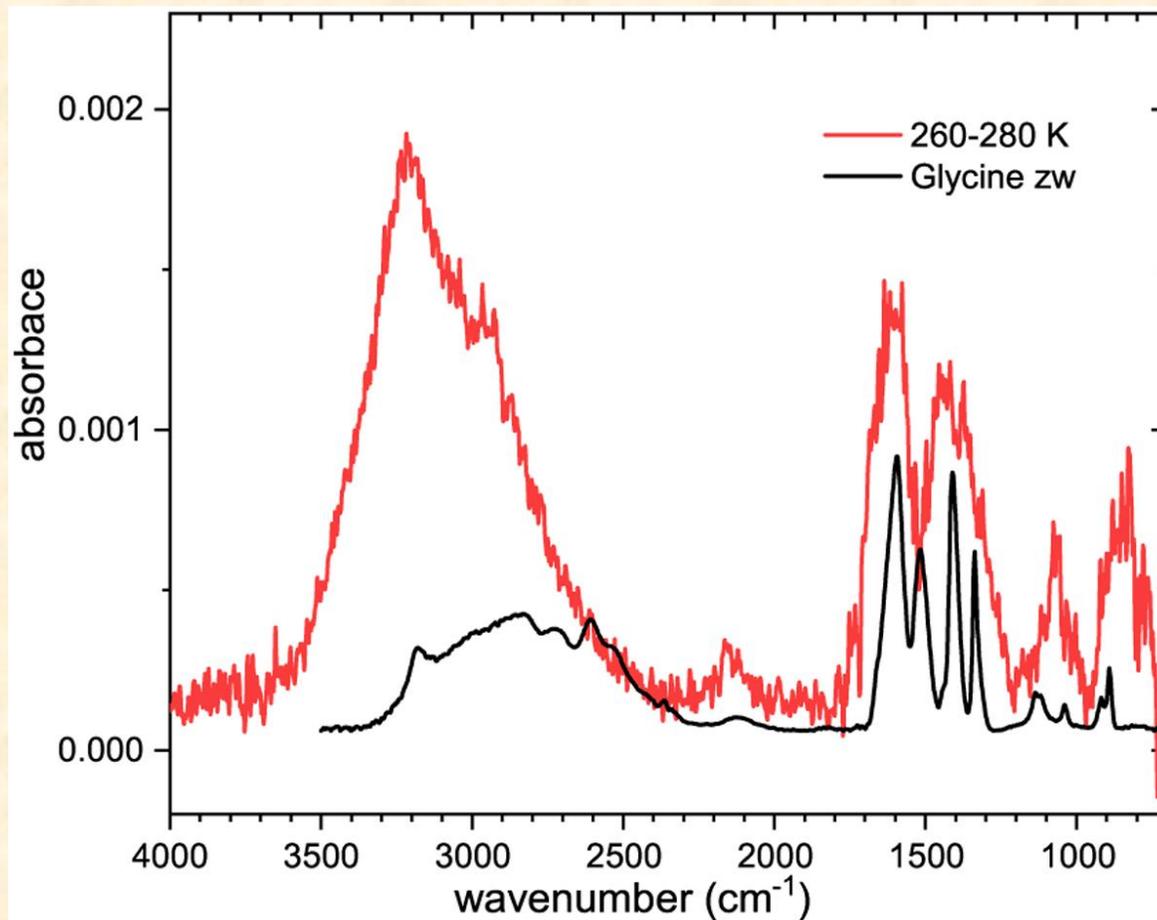


These observations have been rationalised in terms of the strength and extent of the intermolecular forces present in each ice. The strong and extensive hydrogen-bonding network that exists in crystalline CH<sub>3</sub>OH (but not in the amorphous phase) is suggested to significantly stabilise this phase against radiation-induced decay. Conversely, although alignment of the dipole moment of N<sub>2</sub>O is anticipated to be more extensive in the crystalline structure, its weak attractive potential does not significantly stabilise the crystalline phase against radiation-induced decay, hence explaining the smaller difference in decay rates between the amorphous and crystalline phases of N<sub>2</sub>O compared to those of CH<sub>3</sub>OH.

Can bigger molecules formed in the ices?

## Hydroxylamine in astrophysical ices: Infrared spectra and cosmic-ray-induced radiolytic chemistry

Residue of NH<sub>2</sub>OH:H<sub>2</sub>O:CO ice mixture irradiated by ECR ions (15-keV H<sup>+</sup>)

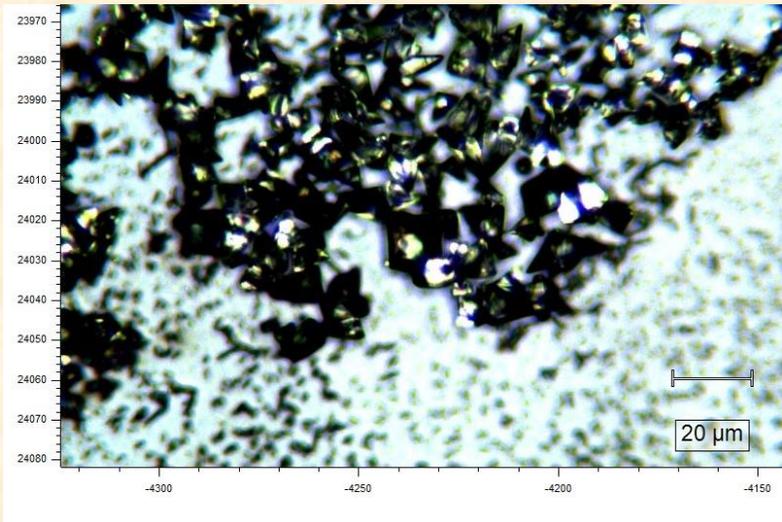


Glycine may have formed!

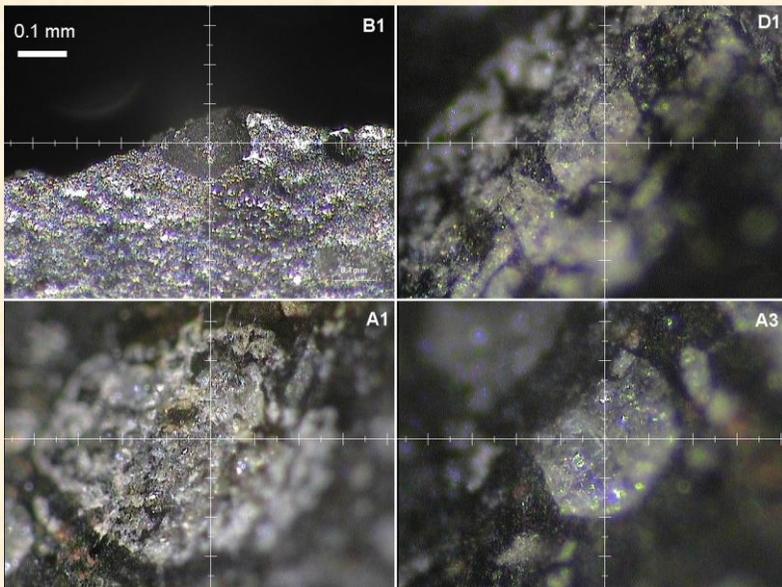
Maté Belén, et al.,  
*ASTRONOMY &  
ASTROPHYSICS* 695 Paper:  
A102, 16 p. (2025)

# *Not only ice analogues are studied in our labs:*

Cosmic ray processing of minerals



Space weathering of meteorites

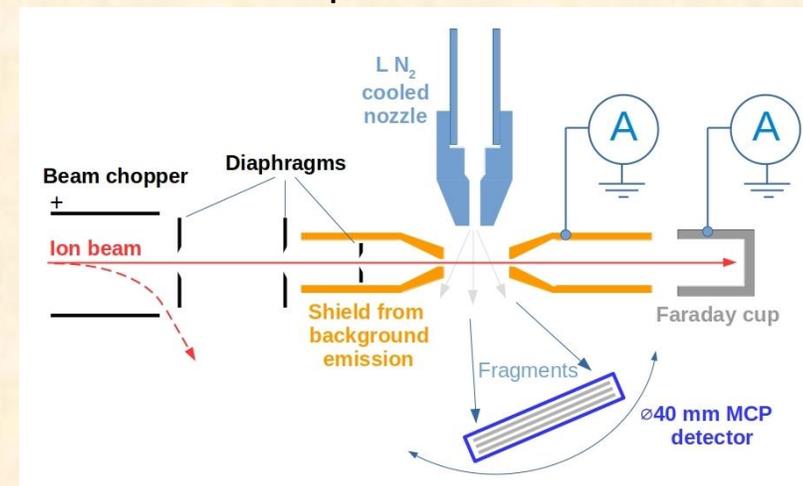


Technological applications: Space building materials

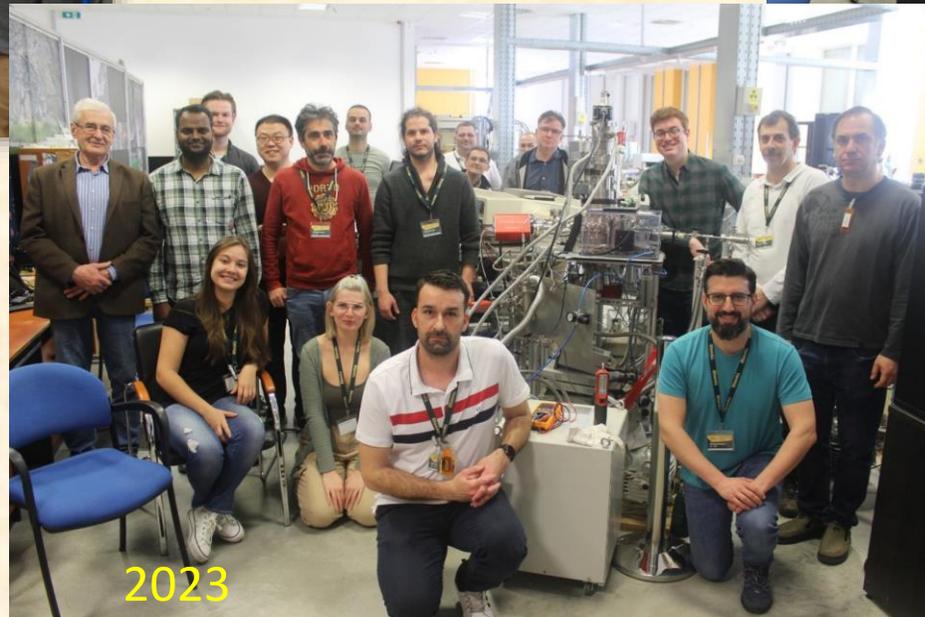
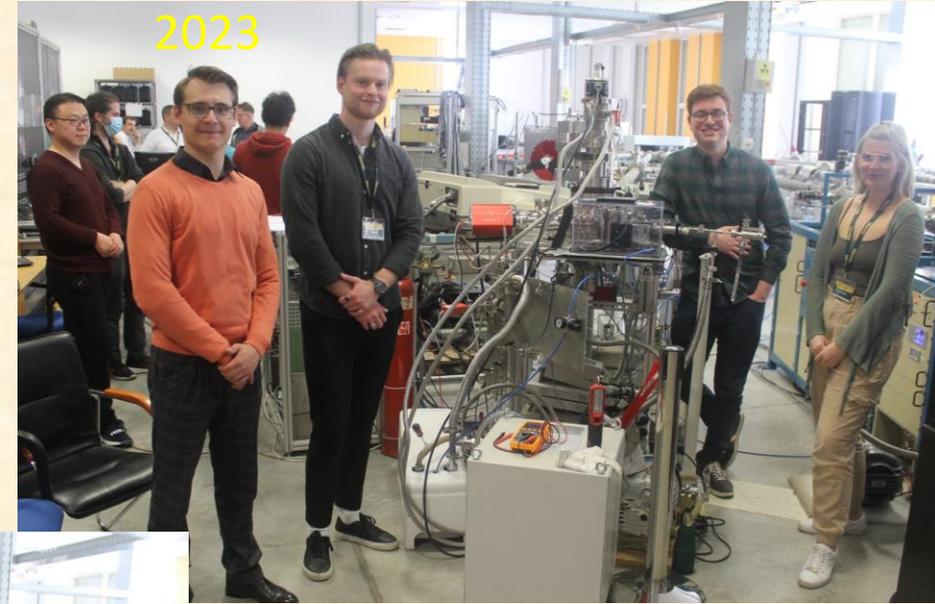


Plans: study fusion reactions in ice, widening our analytical arsenal - vertical beamline for powders, liquids and biological samples

Gas phase collisions



# The research group and its collaborators



# ATOMKI's Experimental Molecular Physics Research Group



Nigel Mason



Béla Sulik



Duncan V. Mifsud



Péter Herczku



Richárd Rác



Sándor Biri



Nandalal Mahapatra

PhD studs:



Gergő Lakatos

Adrija Bhowmick



Rodrigo Zamudio

Ex members:



Sándor Kovács

Rahul K. Kushwaha