



PEPR Origins



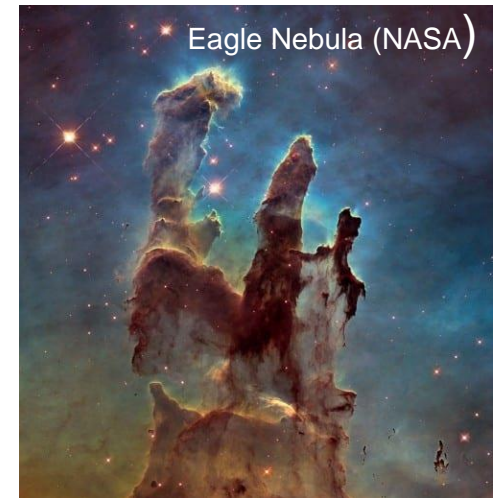
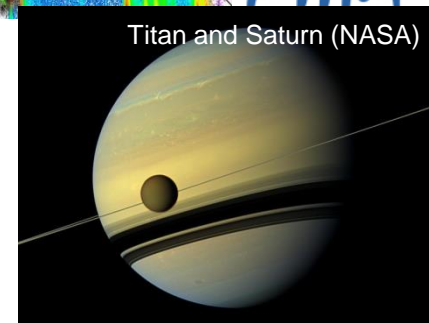
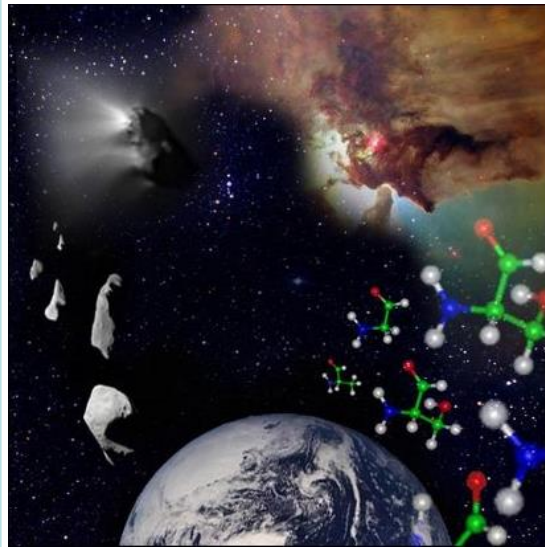
Multiple-beam irradiation platform to investigate the origin and evolution of organic matter of the Solar System (MIRRPLA)

Alicja Domaracka, Philippe Boduch, Hermann Rothard (Caen, CIMAP)
Grégoire Danger (Marseille, PIIM)



Outline

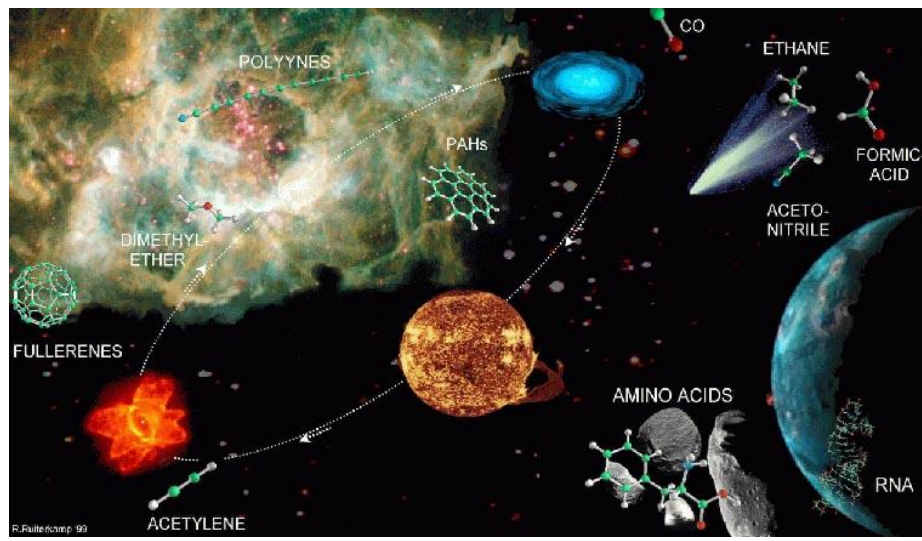
- General context and motivation
- PEPR Origins
- Ions in space
- MIRRPLA platform
(scientific and technical challenges)
- Summary and perspectives



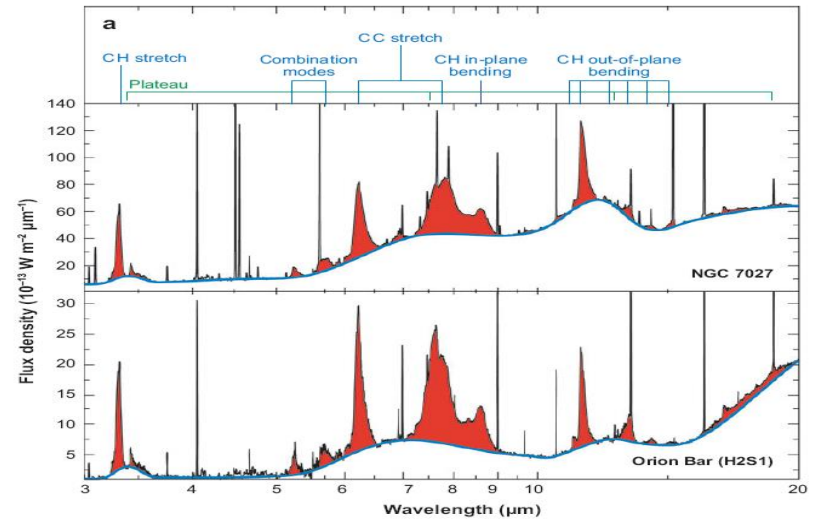


Motivation: molecular diversity in space

In interstellar medium, more than 250 molecules have been indentified, e. g. large carbonaceous molecules like PAHs and fullerenes, COMs...



<http://www.eana-net.eu>

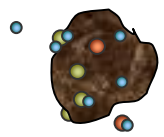


E. Peeters et al. *Astron. Astrophys.* 390 (2002) 1089

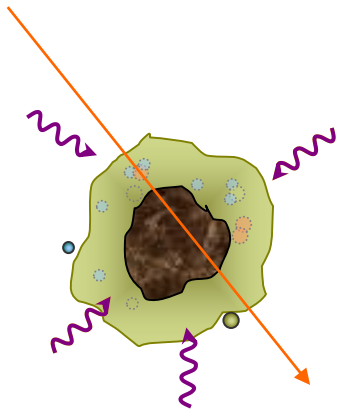
Laboratory studies (quantum chemistry, experiments...) are needed in order to understand the physical and chemical processes leading to such rich chemical inventory.



Astrophysical ices

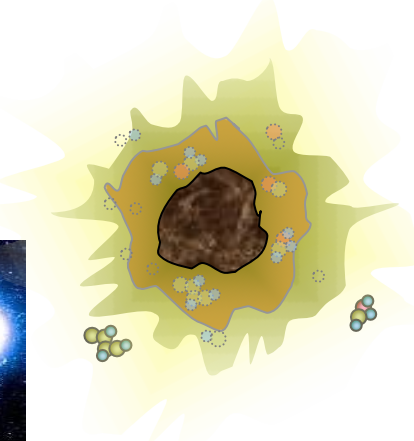


Icy mantles are formed from simple molecules (H_2O , CO , CO_2 , NH_3 , CH_4 , etc).



Energetic processing by:

- photons (including UV and X-rays),
- electrons (high and low-energy),
- ions (cosmic rays, solar wind, magnetosphere).



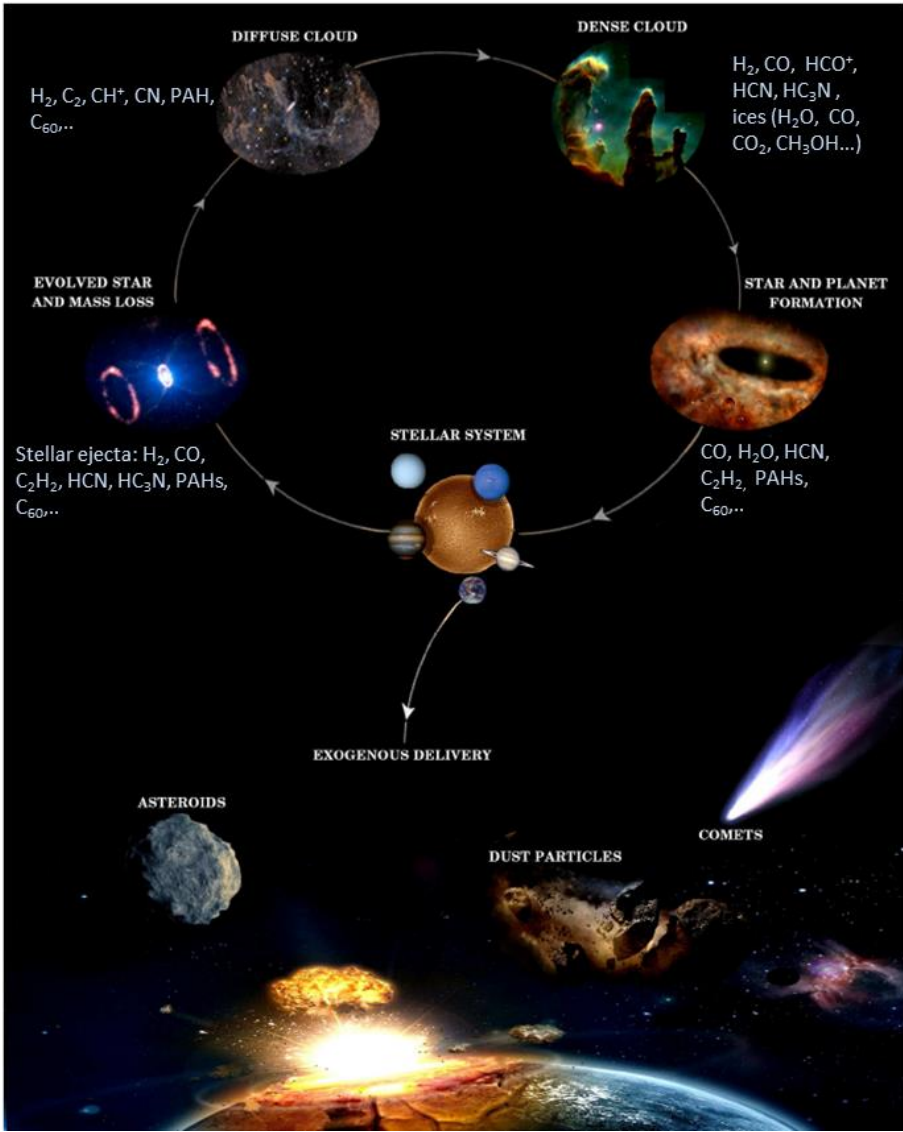
Irradiation leads to:

- ice structural changes,
- desorption/sputtering,
- radiolysis (fragmentation) and formation of new molecular species.



The life cycle of the interstellar matter

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Complex organic molecules (COMs) and prebiotic molecules

- Formation mechanisms?
- Stability under ionizing radiation?
- Origin of life?

astrochemistry/astrobiology



PEPR Origins

PI: Alessandro Morbidelli, Laboratoire Lagrange

Origins, from planets to life - technological, societal and epistemic breakthroughs

Objectives: Understanding the origin of life, discovering and characterizing other Earths

Unveiling our origins: scientific approach, technological challenges and applications

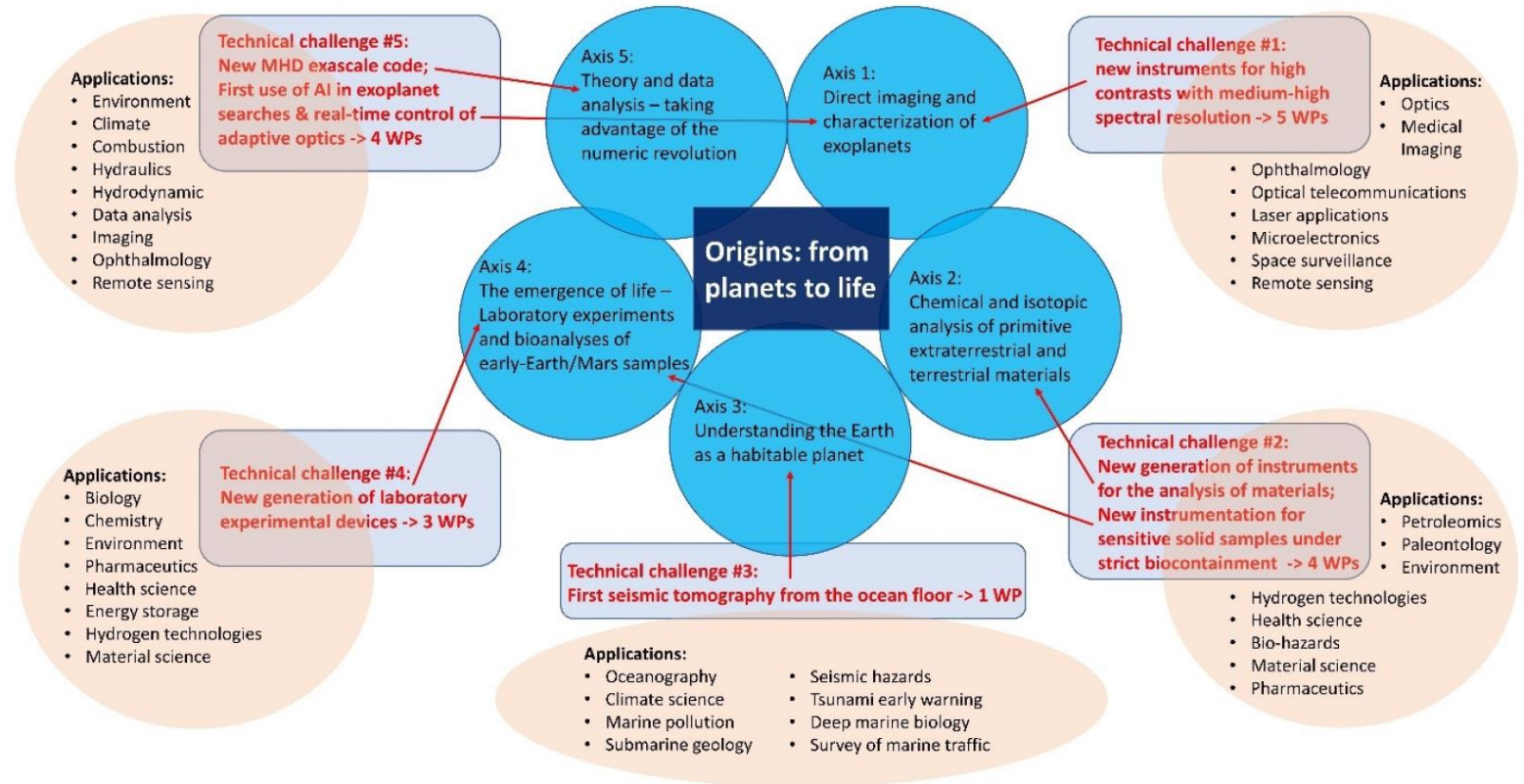


Fig. 1: Structure of our project (technological part): main research axes, technological challenges and potential applications

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PEPR Origins in numbers

Origins, from planets to life - technological, societal and epistemic breakthroughs

Objectives: Understanding the origin of life, discovering and characterizing other Earths

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- 28 national organizations
- development of 17 instruments (e.g. Platform MIRRPLA: axis 4)
- 45,5 M€ for 7 years

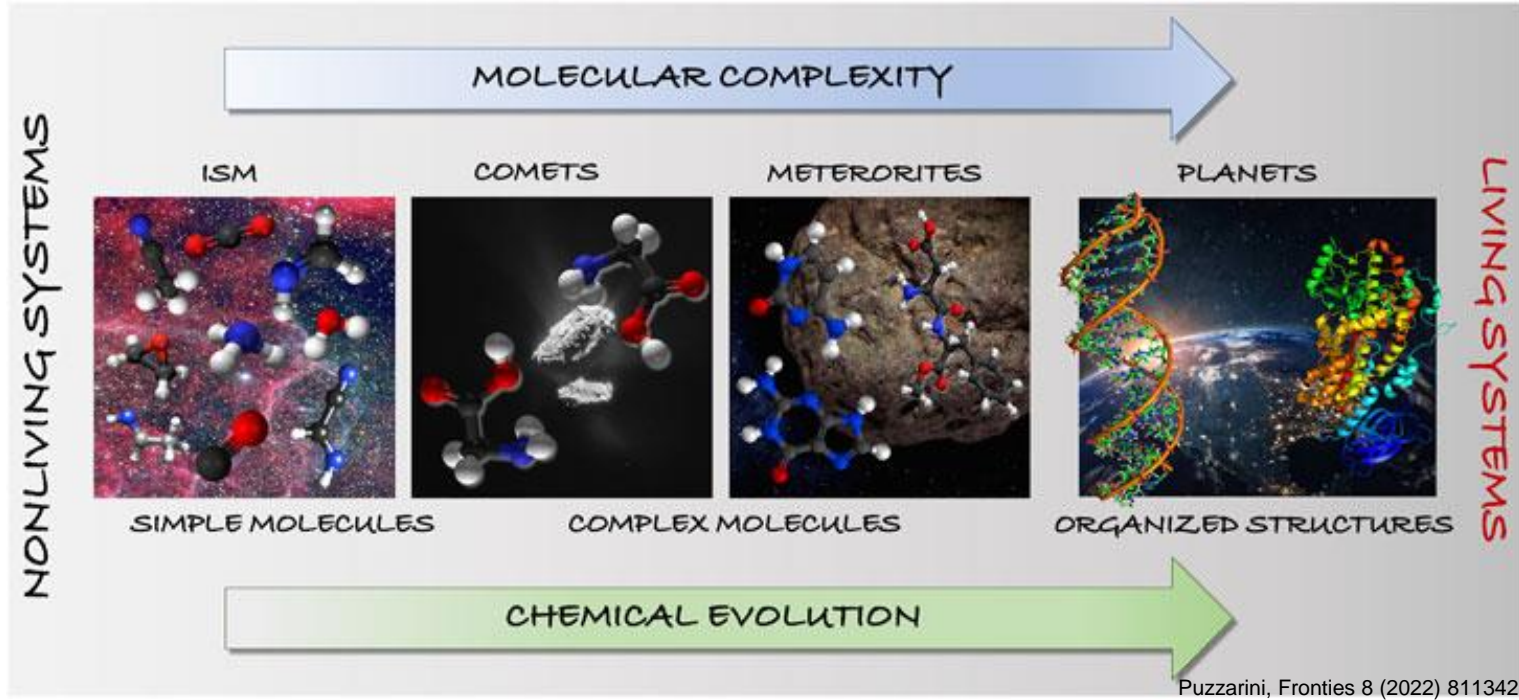
The location of the institutions participating to this project (pins). In blue, those involved in focused projects (WPs). The colored lines highlight collaborations in each of the research axes.





MIRRPLA: Multiple-beam irradiation platform

to investigate the origin and evolution of organic matter of the Solar System



Molecular systems in space are processed by several sources of radiation:

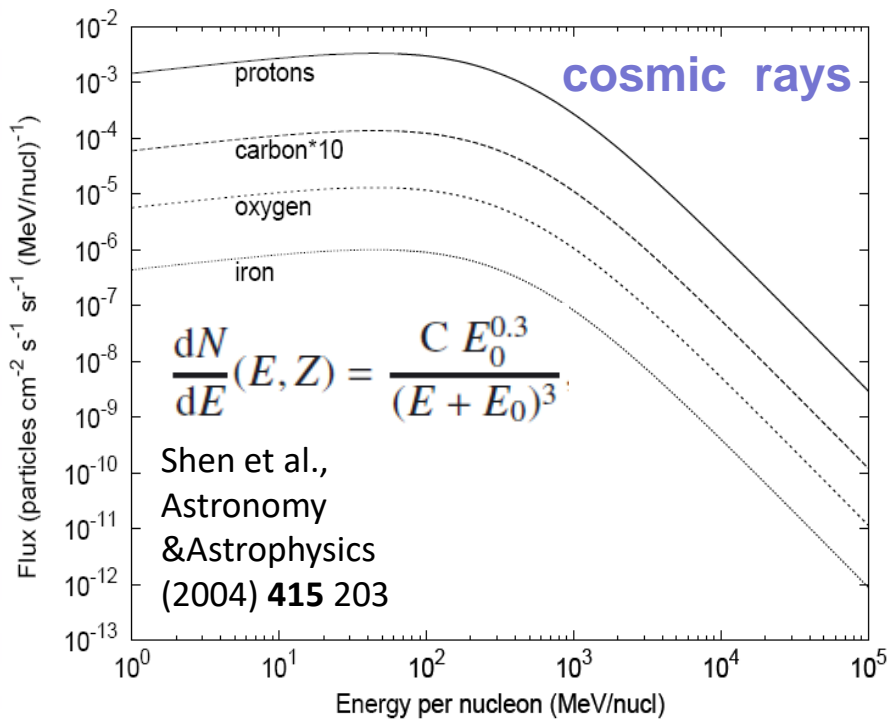
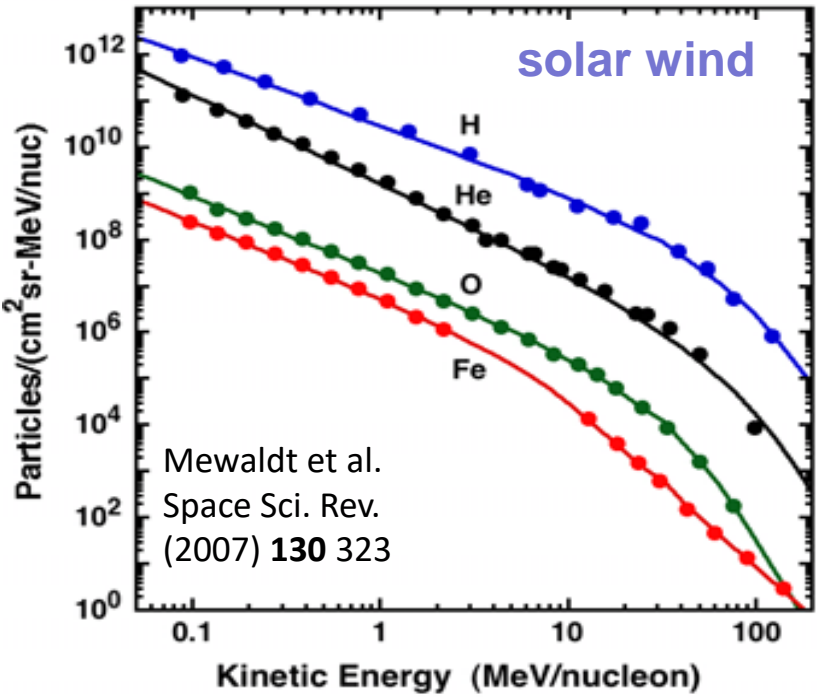
- photons (including UV and X-rays);
- electrons;
- ions.

→ ionisation, fragmentation, desorption/sputtering, reactivity,...



Ions in space

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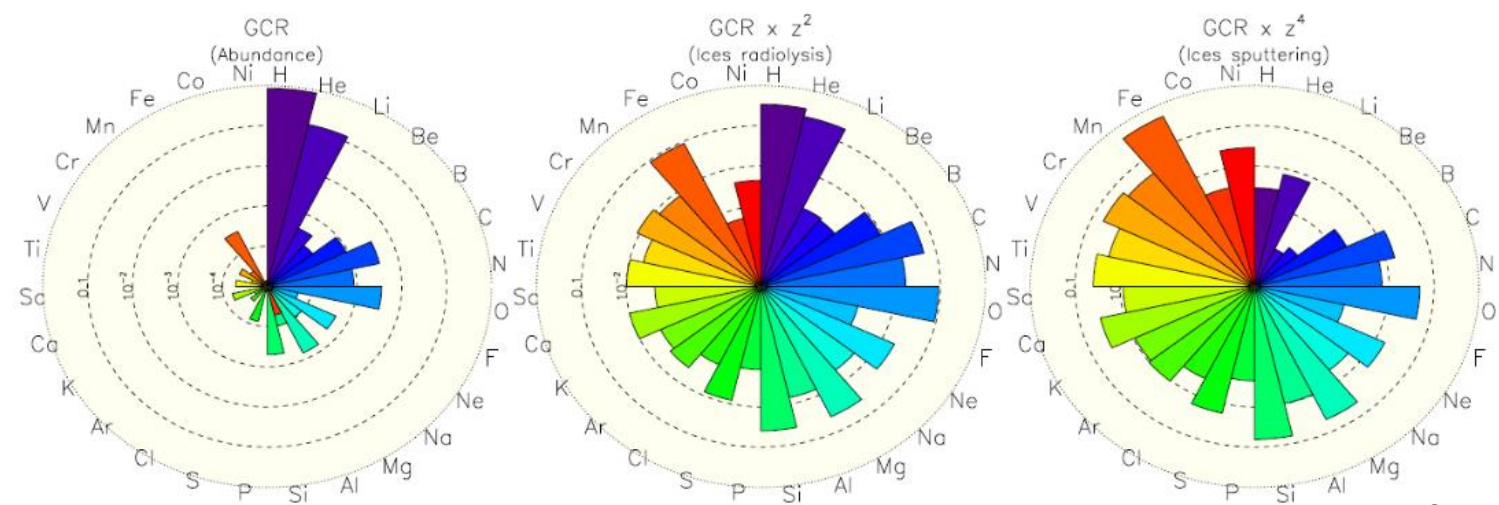


H/Fe ~ 10⁴
H/Ni ~ 10⁵



Heavy ions: why ?

- large electronic energy loss S_e
- scaling laws: S_e^n with $n \approx 1/2, 1, 3/2, 2, \dots 4$



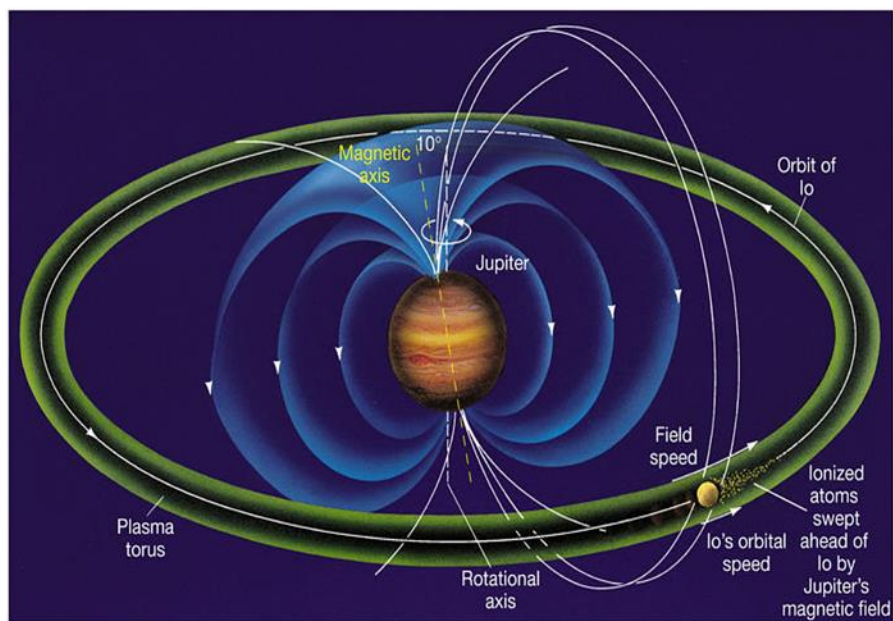
Courtesy of E. Dartois

- *Unexplained findings (gas phase molecules in dense clouds...e.g. CO...)*

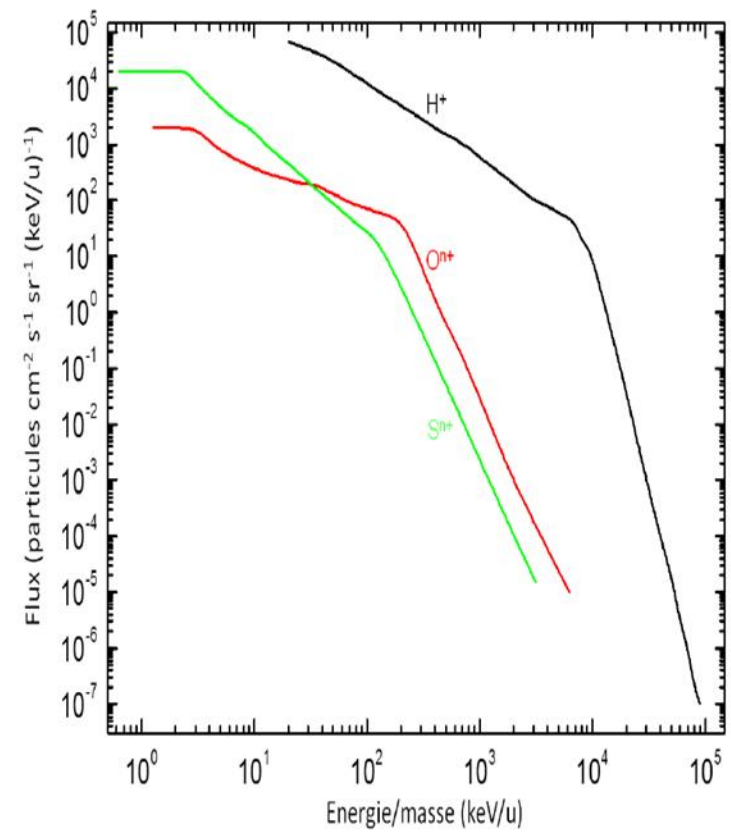


Jupiter's magnetosphere

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- Astrochemistry: origin of CO₂ and H₂SO₄ on Europe, organic molecules



Basic processes in ion collisions

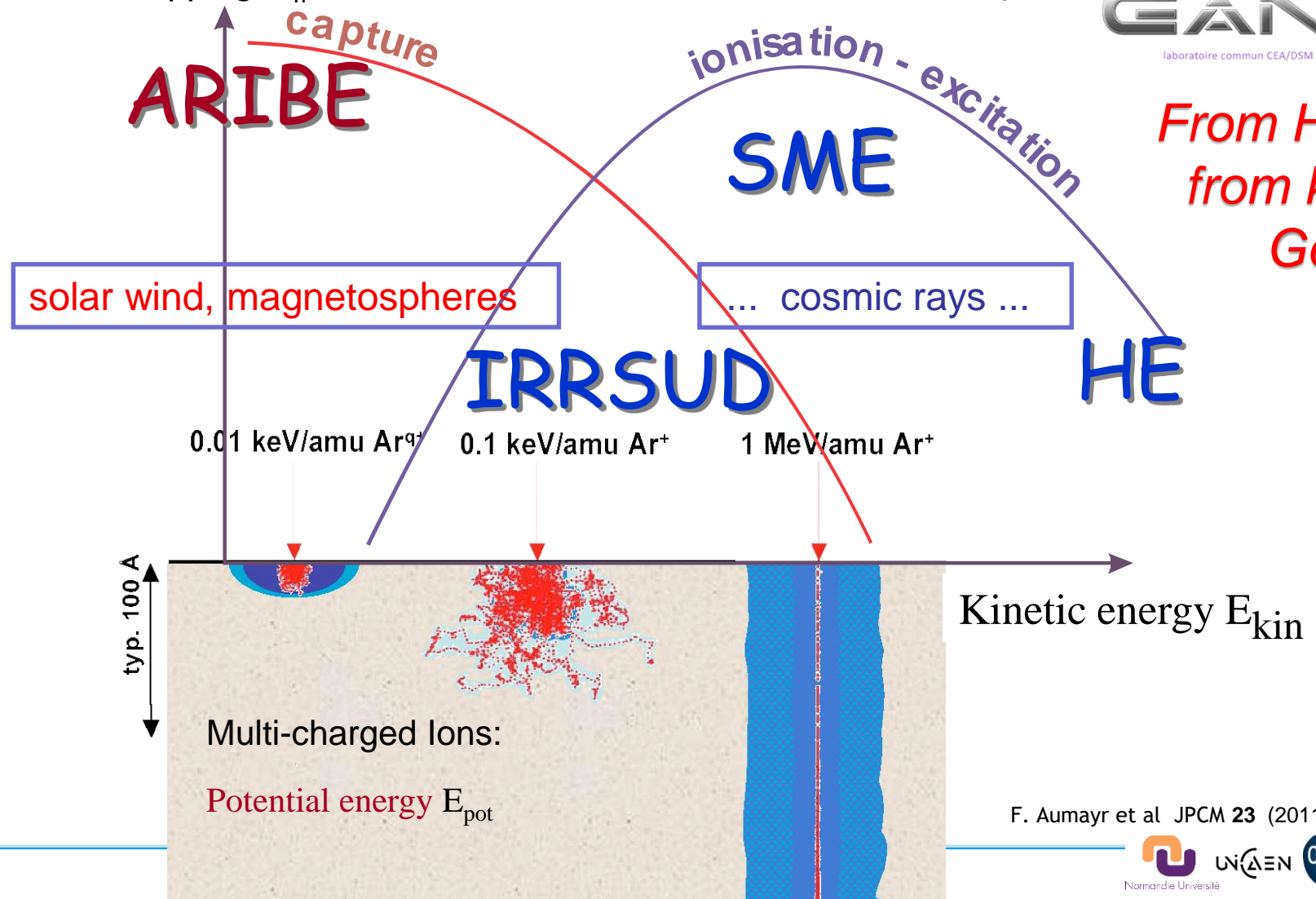
Elastic collisions: ion - nucleus
"nuclear stopping" S_n

Inelastic collisions: ion - target electron
"electronic stopping" S_e



*From He to U,
from keV to
GeV*

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F. Aumayr et al JPCM 23 (2011) 393001

Astrophysics + chemistry @CIMAP

Targets:

Pure ices of small molecules (H_2O , CO , CO_2 , NH_3 , CH_4 etc.),
mixed ices, COMs

Structure: amorphous vs. cristalline, porous vs. compact (H_2O)

Radiolysis: radiation resistance and survival times of molecules

Formation of **new molecular species** (irradiation / implantation)

Increasing chemical complexity: **emergence of life?**

Sputtering: origin of gas phase molecules

Solid materials (silicates, nepheline etc): sputtering

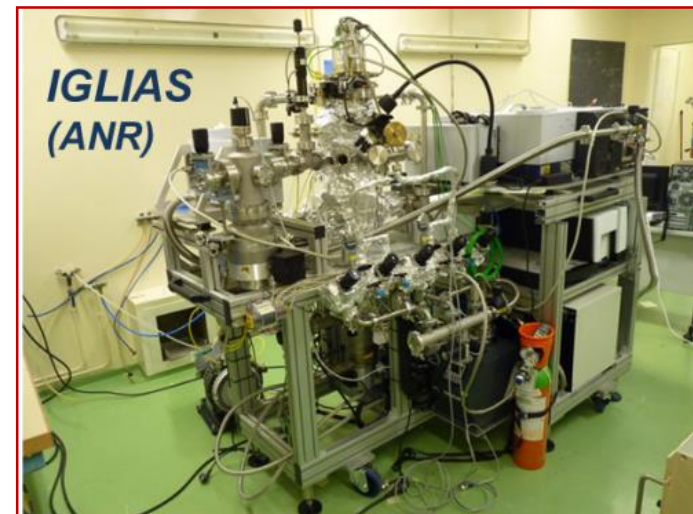
Methods:

infrared absorption spectroscopy (FTIR),
UV-vis, QMS

Aim:

- input to astrochemical models
(cross sections, yields: scaling laws)
- comparison to space observations

about 40% i-PAC beam time is allocated to astrophysics;
since 2009: >80 publications; > 40 invited talks

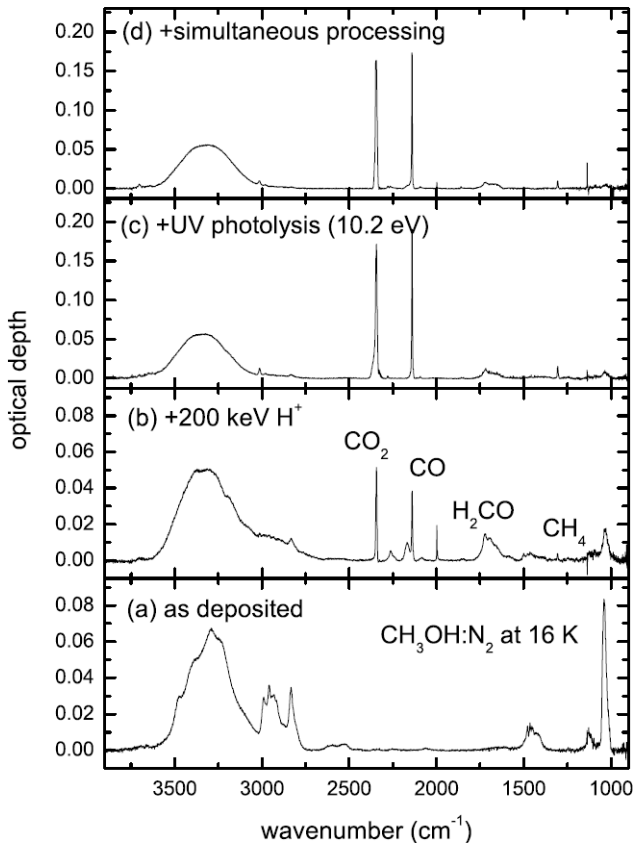




Radiation field in space: complex!

“real” conditions: simultaneous irradiation with ions, photons and electrons
 -> radiation synergies effects?

Simultaneous UV- and ion processing of astrophysically relevant ices
 The case of CH₃OH:N₂ solid mixtures
 F. Islam, G. A. Baratta, and M. E. Palumbo
 AA 561, A73 (2014)



“...from a quantitative point of view the behavior of newly formed molecules can in some instances significantly depend on the UV/ions dose ratio. Hence the effects of simultaneous processing on other astrophysically relevant mixtures should be experimentally investigated to better understand the chemical evolution of solid phase molecules in space.”

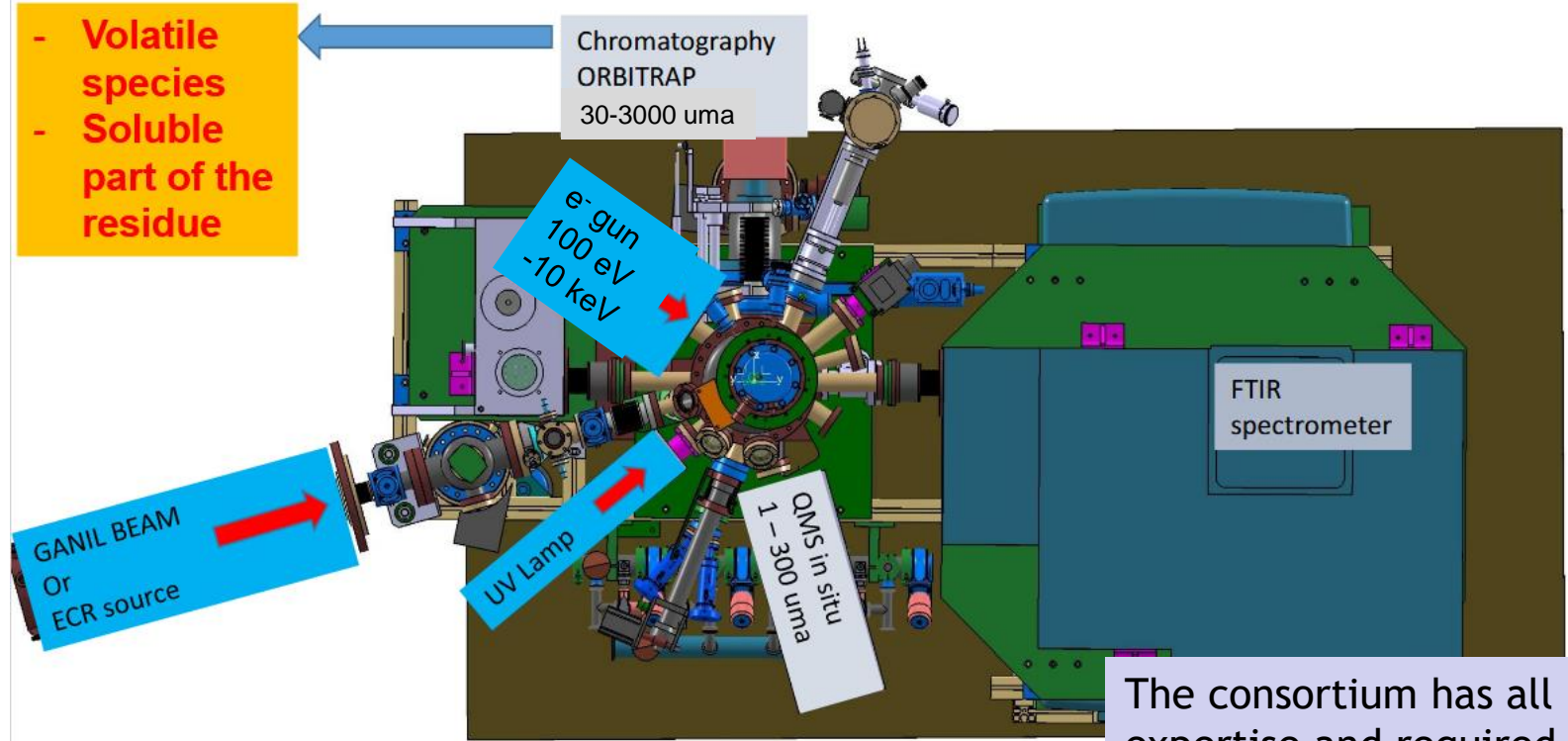
Investigations on synergy effects on simultaneous energetic processing of ices are needed.
(no data in astrobiology context yet!)



MIRRPLA: a new platform

1st objective: to design and build an ultrahigh vacuum chamber equipped with a cold head for sample preparation and multiple-beam irradiation with UV photons, electrons and ions

- Volatile species
- Soluble part of the residue



The consortium has all expertise and required skills to carry out the project.

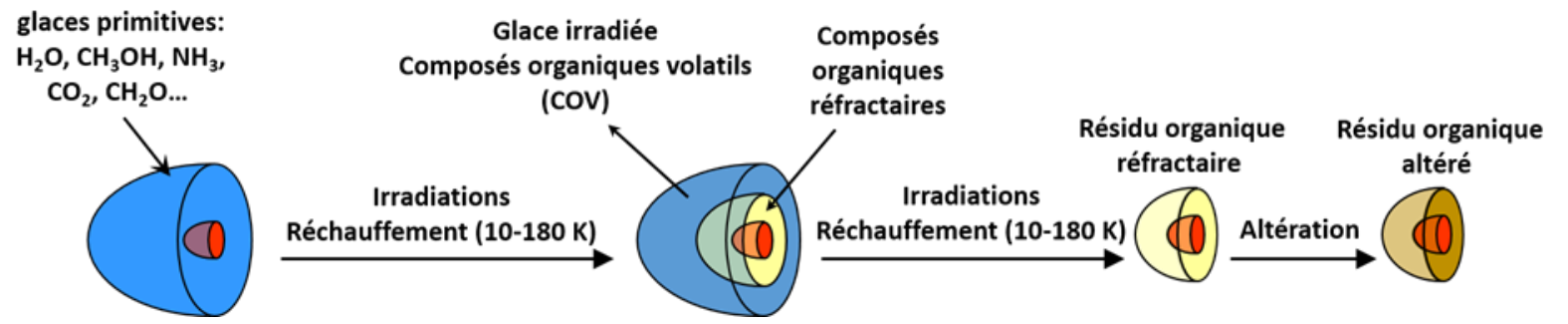
Competences:
 CIMAP: ion irradiation, FTIR, QMS
 PIIM: photon and electron irradiation, FTIR, GC-Orbitrap

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MIRRPLA: investigation synergy effects

2nd objective: to use the novel multiple-beam irradiation platform to investigate irradiation synergy effects on formation and destruction of complex organic matter/prebiotic species in a wide range of kinetic energies of the projectile (from keV to GeV) in combination with UV photon (~10eV) and electron irradiation (100 eV-10keV).



Courtesy G. Danger

Analysis: in-situ FTIR, QMS, GC-orbitrap, ex-situ SIMS, HRMS

First samples: CH₃OH, H₂O:NH₃:CH₃OH

Organic residues: " **primary material**" to investigate its further chemical evaluation/complexification under different environmental conditions
PEPR Origins WP2.4 *Microfluidic platforms for investigating matter complexification towards the origins of life*



Timeline: key dates

Start: March 2023

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Work package	1st year	2nd year	3rd year	4th year	5th year
WP1 Management	M1	M4	M6		
T.1.1 Scientific coordination of the MIRRPLA project					
T1.2 Set-up of the file server					
T1.3 Global coordination of the involved manpower and partners					
T1.4 Administrative and financial follow-up of the project					
T1.5 Organization of periodic meetings of the project team					
T1.6 Preparation of reports, organisation of collaboration meetings					
WP2 Experimental development	M2	M3	M5	M7	
T2.1 Design of the MIRRPLA platform design (CAD)					
T2.2 Design of a control unit and acquisition system for the platform					
T2.3 Adaptation of existing low energy ion sources					
T2.5 Ordering of vacuum equipment					
T2.6 Ordering of FTIR spectrometer, QMS, GC-(MS/orbitrap), UV lamp					
T2.7 Ordering of equipment and consumables					
T2.8 Mounting of the equipped vacuum chamber					
T2.9 Vacuum test and commissioning of the platform					
T2.10 Tests of precise sample preparation					
T2.11 Mounting and testing of low-energy ion beam line					
T2.12 Mounting and testing of GC-MS/orbitrap					
T2.13 Final commissioning of UHV system and validation					
T2.14 Mounting MIRRPLA at GANIL ...					
WP3 Scientific exploitation					
T3.1 Tests of low-energy ion, photon and electron irradiation of methanol ice separately (FITR, QMS and GC analysis)					
T3.2 Tests of low-energy ion, photon and electron irradiation of methanol ice simultaneously (FITR, QMS and GC analysis)					
T3.3 Tests of low-energy ion, photon and electron irradiation of water mix ices (FITR, QMS and GC analysis)					
T3.4 Ice irradiation with GANIL beam lines					
T3.5 Irradiation of mixed ices containing simple molecules					
T3.6 Irradiation of complex systems					
WP4 Training					M12
T4.1 Knowledge transfer to master students and PhD students about handling of vacuum equipment, collision physics, data analysis					
T4.2 Knowledge transfer to PhD students and post-docs how to prepare successful beam time application at the large scale facilities					
T4.3 Short training for young scientist how to use the MIRRPLA platform					
WP5 Dissemination and valorization of the results			M8	M9	M11
T5.1 Creation and maintenance of the project website					
T5.2 Scientific publications in science journals					
T5.3 Short communications in form of scientific highlights					
T5.4 Organization of scientific kick of meeting					
T5.5 Outreach activities					

July 2024: start of commissioning

September 2025: methanol ice - full investigation

2026: opening platform to external users



MIRRPLA: budget

Equipment: ~800 k€

- UHV chambers, turbo-and cryo-pumps, cold head, QMS
- FTIR spectrometer under vacuum
- GC-Orbitrap contacted to UHV chamber
- UV lamp with differential pumping stage, dosimetry system
- electron gun (100eV-10 keV), optics:
- adaptation of low-energy ion source to cover low-energy solar wind ions, sweeping device

Personnel: ~270 k€

- 1 PhD student (3 years)
- Post-doc- 24 months

**100% funded
in the frame of PEPR Origins**

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Summary

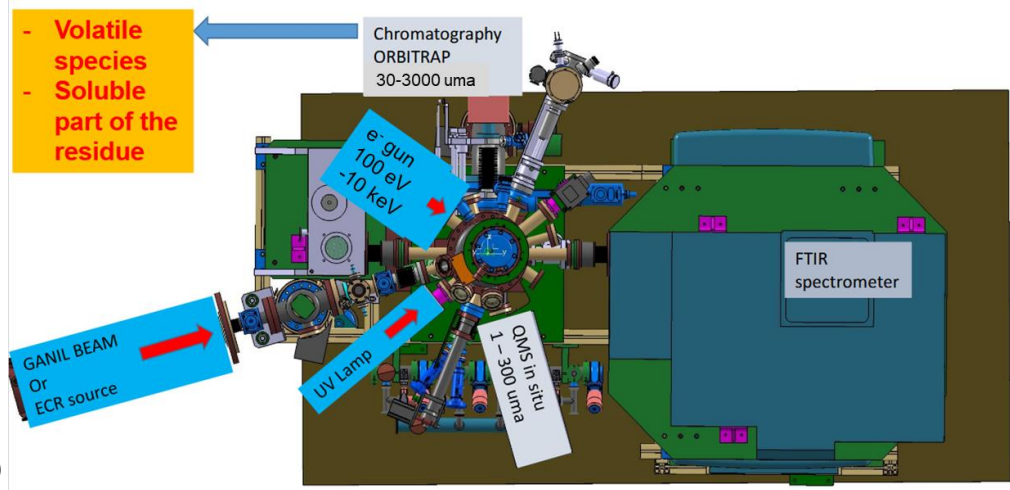
MIRRPLA: an unique worldwide multi-beam platform

Irradiation: UV photons, 100eV-10keV electrons, keV-GeV ions

Samples: 10-300K (ices/films)

Analysis: in-situ FTIR, QMS, CG-orbitrap

Location: GANIL room D2 (new layout is needed!)



Impact beyond the origins of life

The platform will be open to the whole scientific community via GANIL-CIMAP-CIRIL user's facility.

- **Health:** unique opportunity to investigate fundamental processes at the molecular level by mixed irradiation of biomolecules and DNA fragments to develop new cancer treatment models. Another connected field the exposure of living beings to the complex radiation field in space (space missions).
- **Environmental science:** evolution under ionizing radiation of air pollutants like polycyclic aromatic hydrocarbons (PAHs), soot particles
- **Material science:** to develop, characterize and optimize design a new generation of polymer materials; radiation effects on materials used in spacecraft