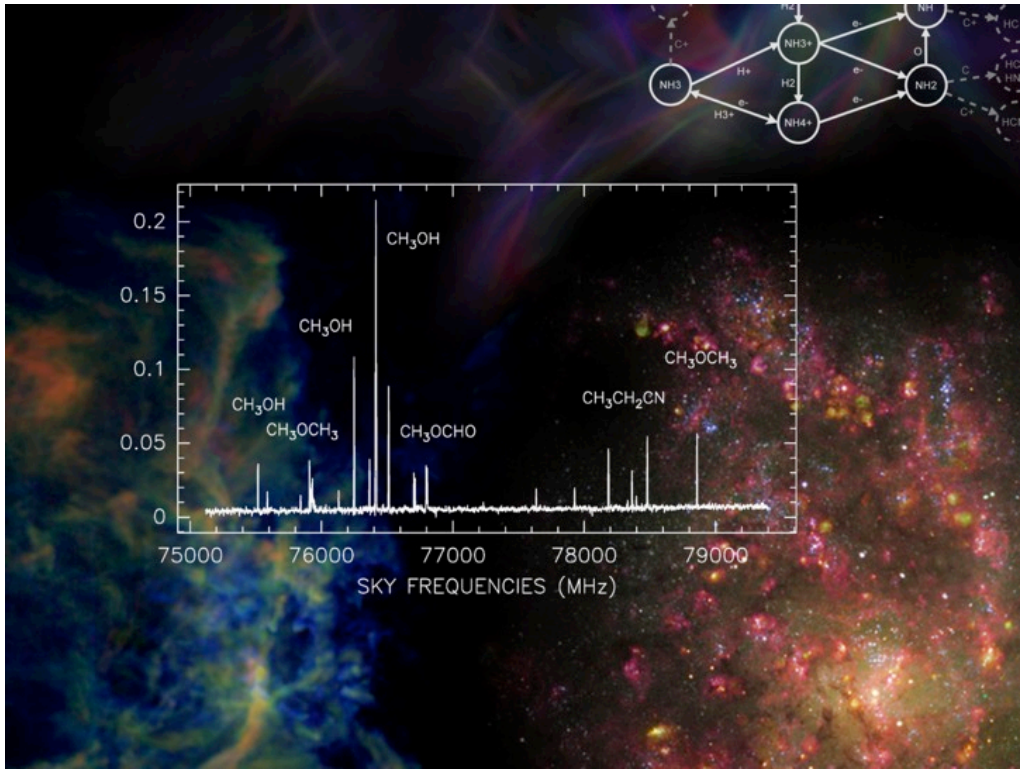
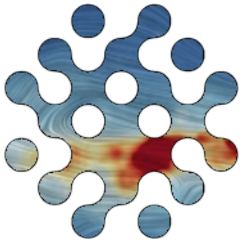
Towards understanding emerging phenomena in the interstellar medium: a multidisciplinary approach

K. Demyk, L. Biennier, J. Pety



PCMI in a nutshell



Organisation

Management team (J. Pety, K. Demyk, L. Biennier)
Scientific council: 20 researchers (from the 3 communities)
Support from INSU, INP, INC, CNES, CEA

Community

~350 researchers
55% Astrophysics – 25% Physics – 20% Chemistry

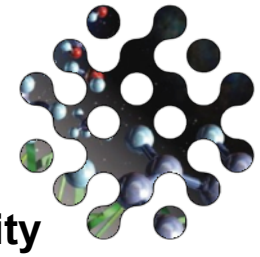
Project funding

1 call/ year (well focused science projects – individual teams/groups)
Reviewed by the scientific council

What is funded

Laboratory equipment and consumables
Observations/missions
Collaborative missions
Campaigns of measurements in large scale facilities
Organization of workshops, schools

Main scientific themes and their evolution



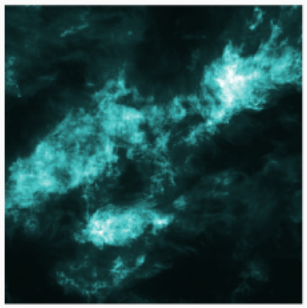
Based on the 5-year strategic planning of the PCMI council and community

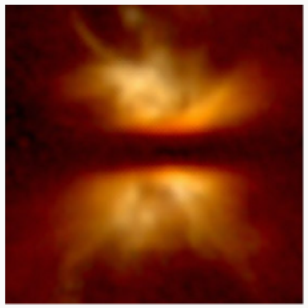
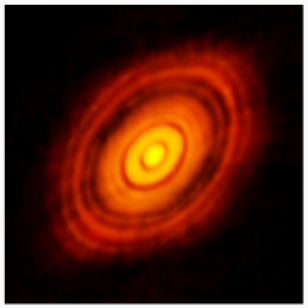
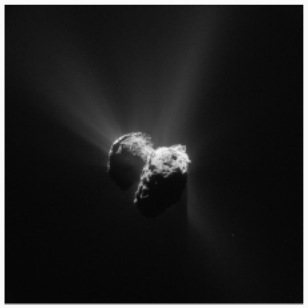
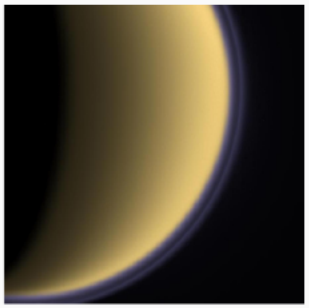
- **From interstellar clouds to protoplanetary systems**
  - Structuration of the ISM from the galactic scale to cold cores
  - Detailed understanding of star and planet formation
  - Role of dust and magnetic field
  - 3D structure of the ISM

- **ISM near and far**
  - Role of the galactic environment on the properties of the ISM and vice-versa
  - Metallicity and properties of dust
  - Molecules and atoms at high redshift

- **Astrochemistry and its link with exobiology**
  - Inventory of molecular complexity in the gas phase
  - Formation, evolution, destruction of nanograins
  - New challenges and opportunities in laboratory astrophysics
  - Golden age of ices
  - Link to exobiology

From the ISM to planetary systems: the astrochemistry point of view



PRESTELLAR PHASE: COLD & DENSE GAS, MOLECULAR FORMATION, ICES

PROTOSTELLAR PHASE: COLLAPSE, DENSE & HOT GAS, SHOCK CHEMISTRY, PARTIAL SUBLIMATION OF ICES

PROTOPLANETARY DISK GRAIN COAGULATION, GAS & ICES PROCESSING

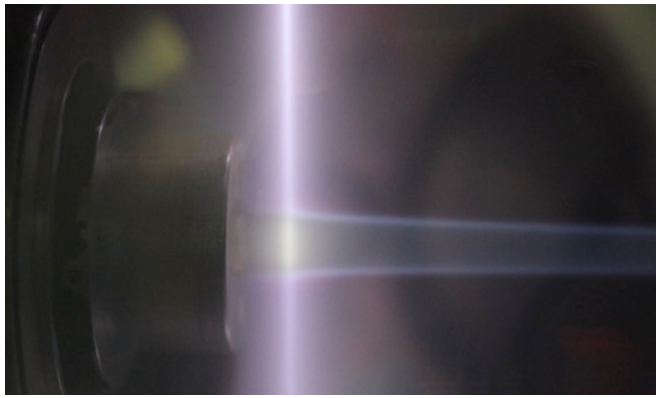
PLANETESIMAL FORMATION: GRAIN AGGREGATION

PLANET FORMATION INPUT OF ALTERED & PRIMITIVE MATERIALS

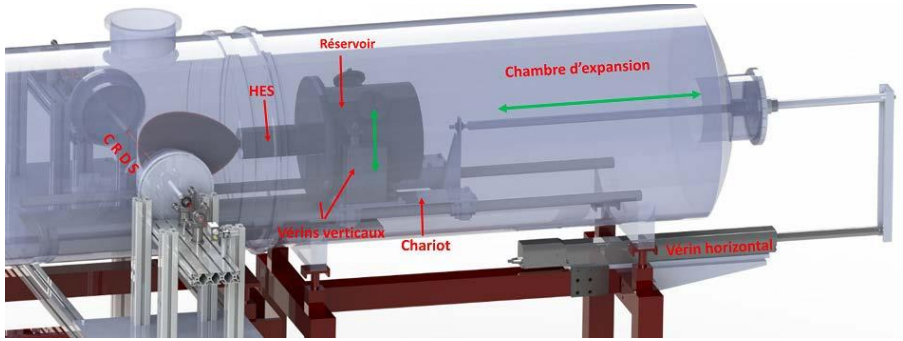
- What is the degree of complexity reached in the ISM? In the gas-phase? On the surface of grains?
- To what extend is this chemical heritage from ISM transmitted to solar system objects and to exoplanets?
- Requires deep knowledge of fundamental properties of the solid and gas phases under interstellar conditions.
- Necessary to combine observations /models /experiments /theory.

Finding the balance between PI setups & large-scale facilities

PI setups



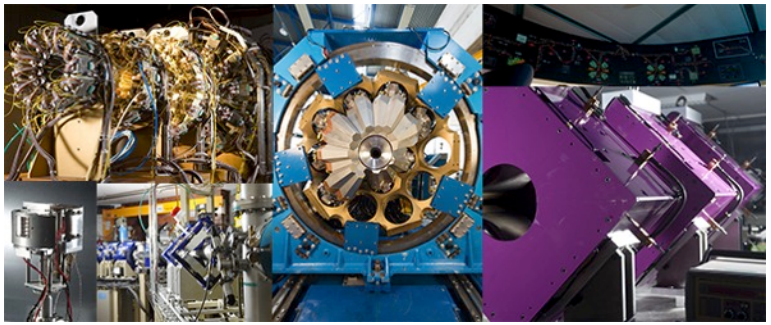
Cold gas flow reactors (20-300 K)[?] Ex: Reactivity of ions and neutrals (see. Talk of T. Hearne)



Ultrasensitive spectrometers [?] Ex: HT absorption spectra

Large scale instruments

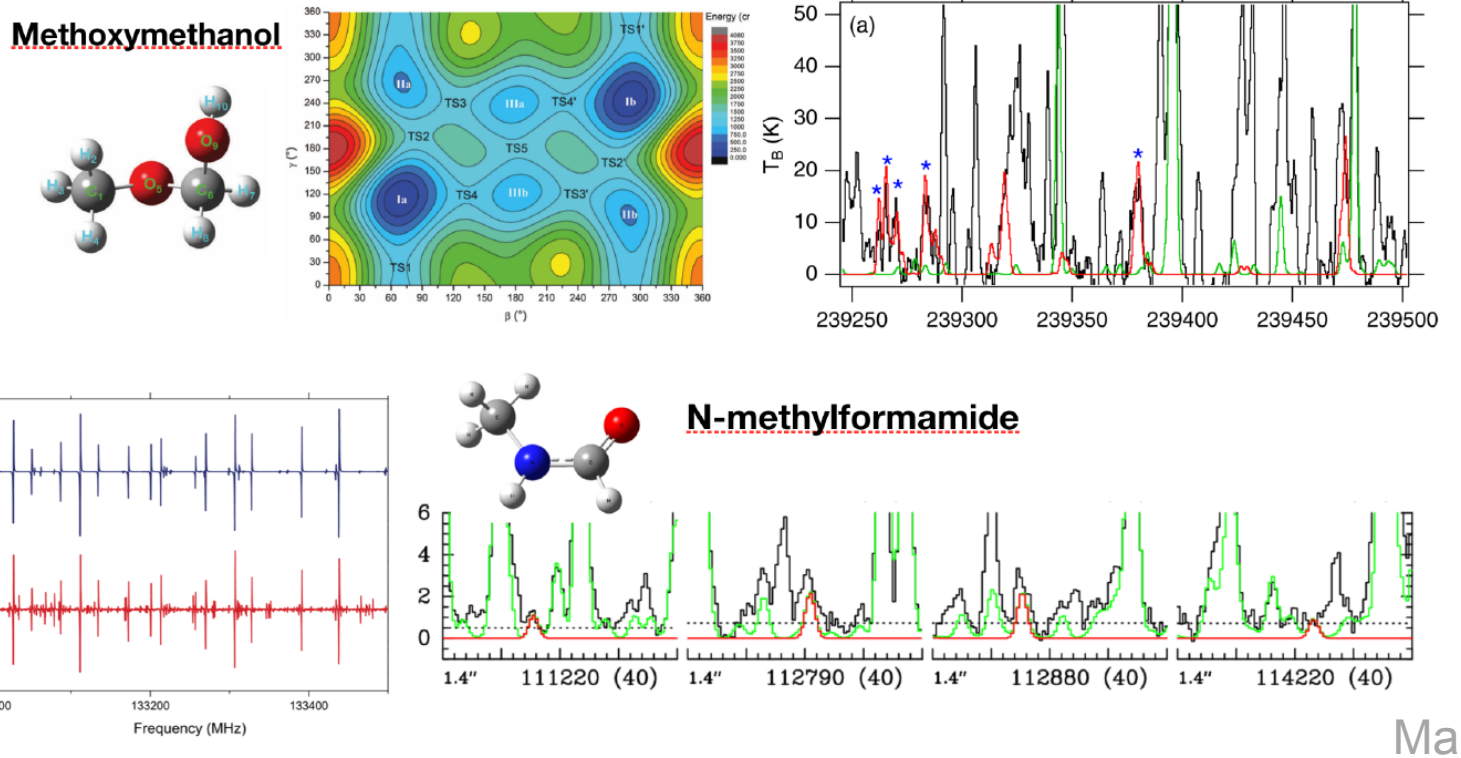
UV-VIS-FIR light sources: SOLEIL Synchrotron [?] Ex: VUV photodissociation branching ratios



Ion accelerators: GANIL [?] Ex: Ion bombardment of grain analogs

Identifying new molecules through rotational spectroscopy

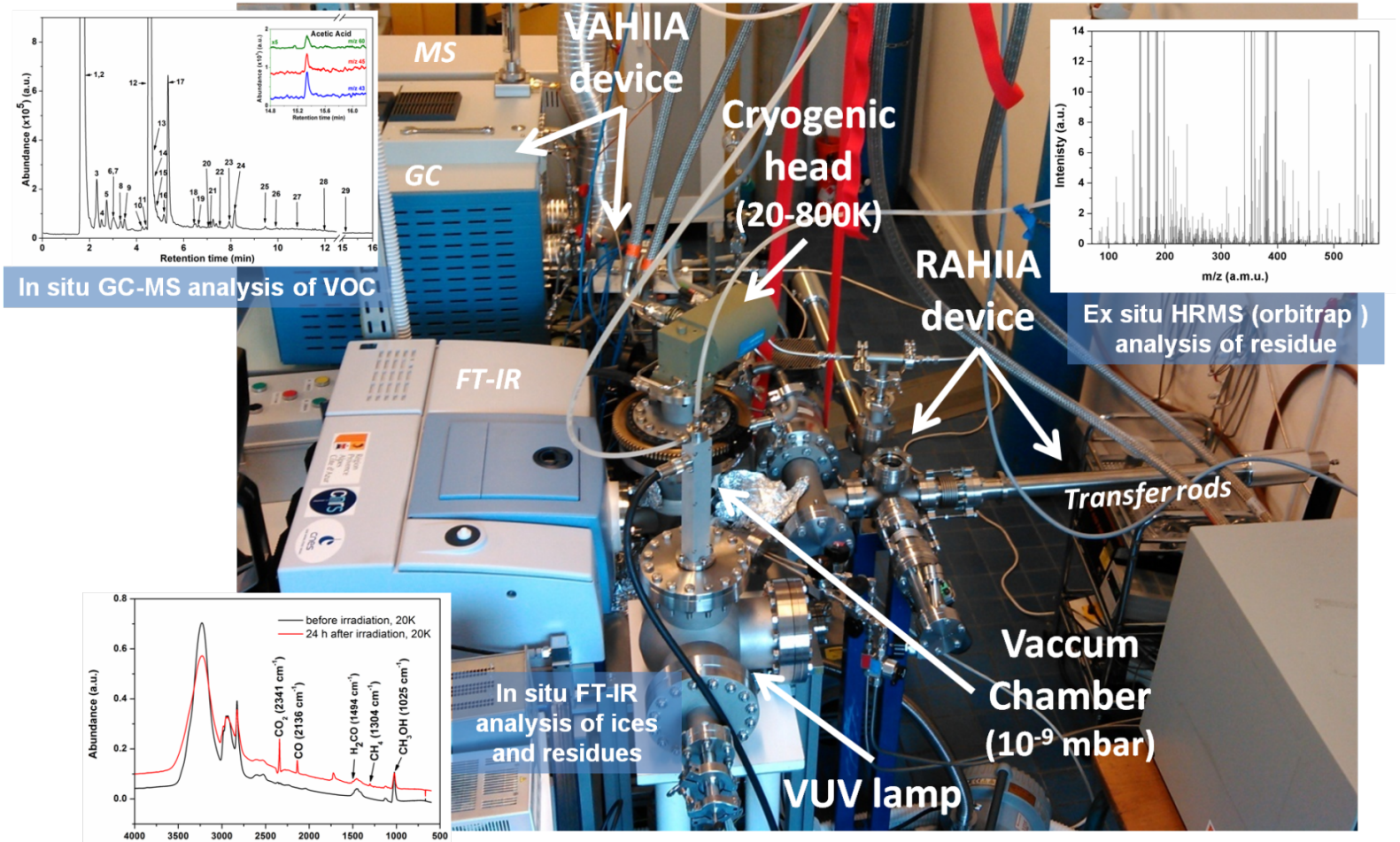
- What is the degree of complexity reached in the ISM?
  - First detection of N-methylformamide (CH_3NHCHO) methoxymethanol (CH_3OCH_2OH)
  - Requires high precision spectroscopic data to overcome spectral confusion



Margulès et al.
PhLAM

Laboratory experiments: unsuspected complexity on the surface of ices

- What are the physical and chemical processes which lead to emerging properties (ramification, chirality,…)?
  - 4000+ large species
  - Gas Chromatography (GC), high resolution mass spectroscopy (HRMS)



Danger et al.
PIIM

UV and X-ray photodesorption from interstellar ice mantles

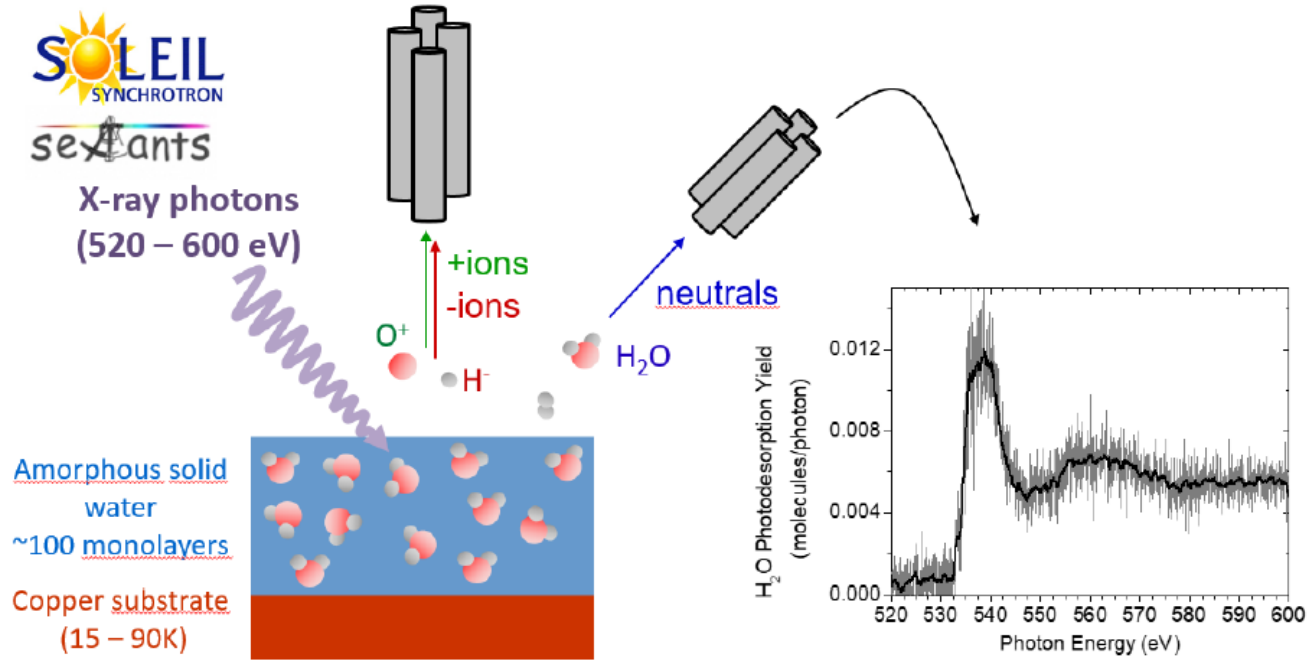
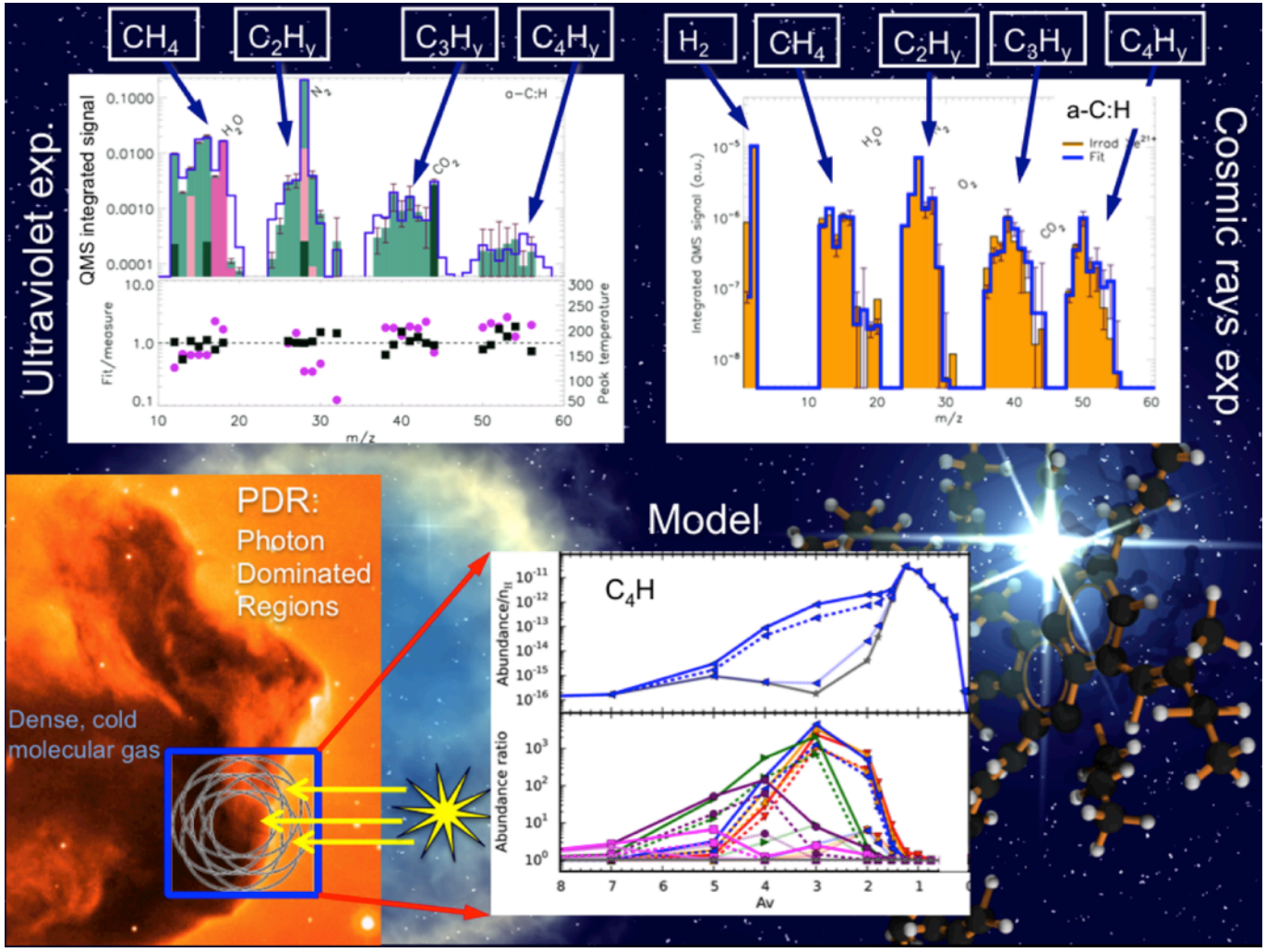


Photo-desorption is a complex mechanism that :

- Depends on the ice composition
- Induces chemistry within the ice
- Release molecules and radicals in the gas phase

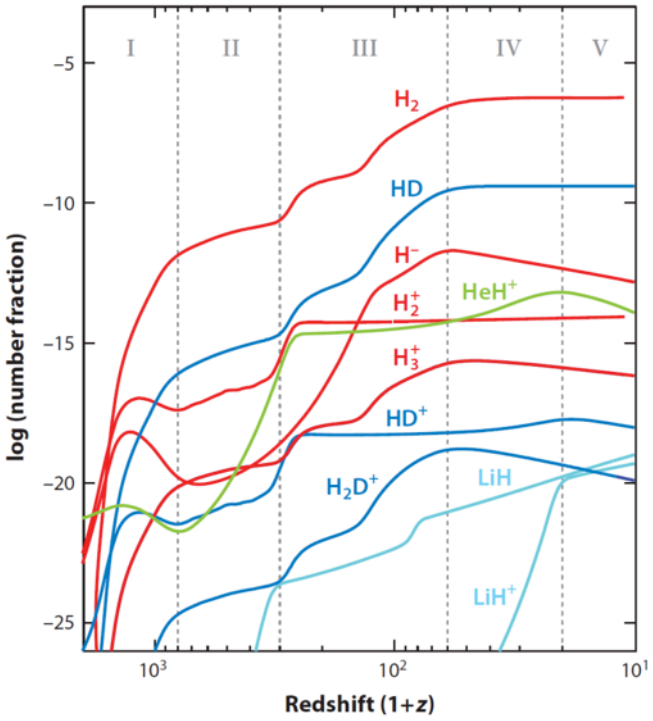
Fillion et al.
LERMA

UV & cosmic-ray irradiation of interstellar dust analogues: small carbonaceous species release

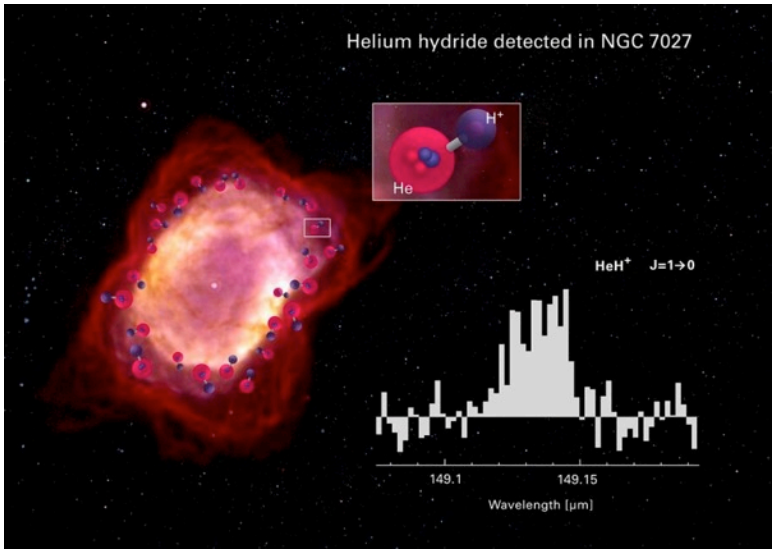


Dartois et al.
ISMO

Primordial chemistry



Galli et al. The Dawn of Chemistry, ARAA (2013)



Rolf Güsten et al. *Nature* (2019). → The detection of HeH^+ in a PNe constrains our knowledge of chemical networks leading to its formation

Challenges undertaken by PCMI community

- ➢ State-to-state chemistry - High temperatures data (QCT approaches)
- ➢ Ro-vibrational excitation of HD by H (including reactive channels)
- ➢ Lithium chemistry
- ➢ 3 body recombination

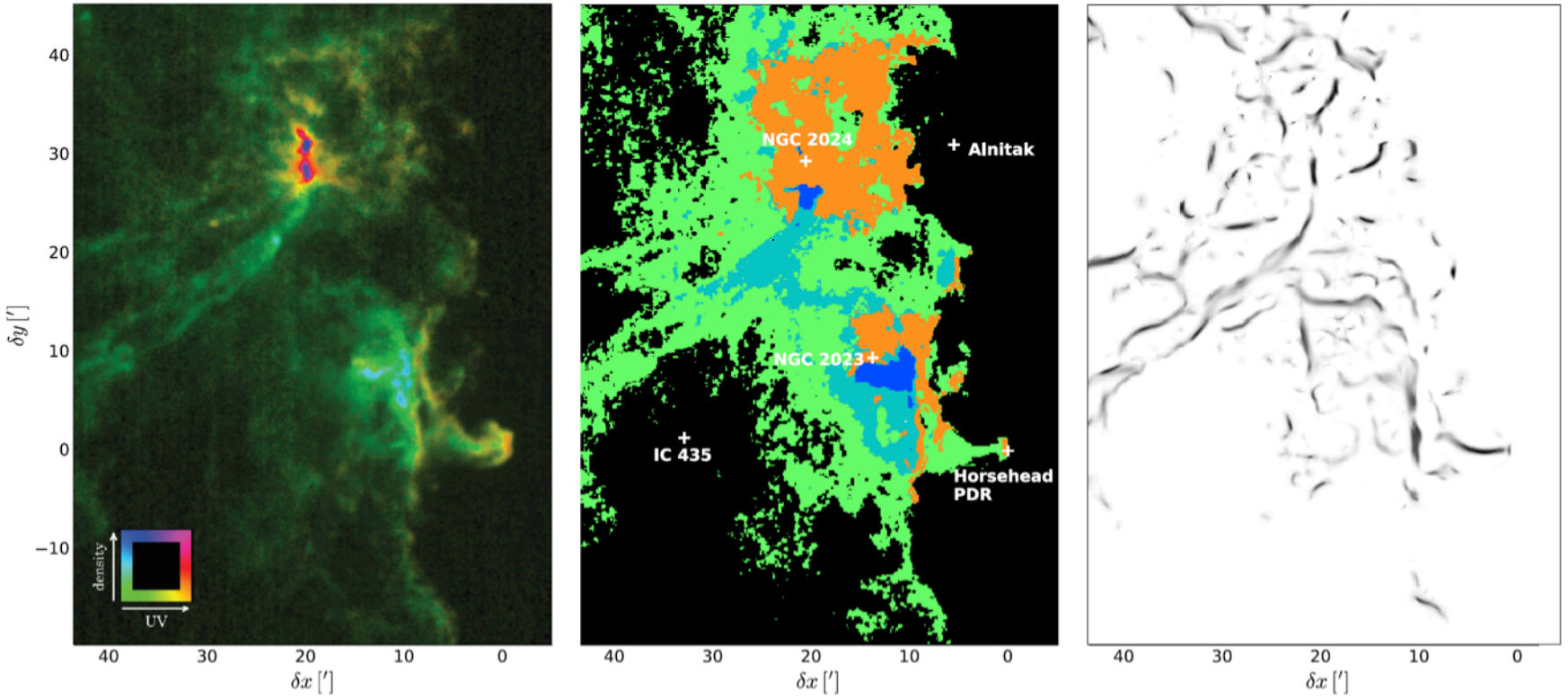
New insights from multi-tracer analysis over large fields of view

Multi-wavelength observations

MHD simulations

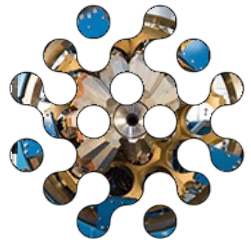
Theoretical chemistry simulations

Collisional rates calculations



- Requires state of the art expertise to answer the **exascale challenge**.
- Necessity to build bridges with the applied mathematics / statisticians communities

Summary



- Research themes require expertise well beyond astronomy (e.g., molecular spectroscopy, reactive collisions, dynamic, light-matter interaction, organic chemistry, ...).

- The studies are also based on a detailed knowledge of the physico-chemical and dynamical evolution of matter (gas, grains, and ices) at the molecular level. This requires state-of-the-art expertise in laboratory astrophysics (physics and chemistry).

- These researches combine theoretical calculations, original experimental devices, and large instruments (SOLEIL, GANIL, ...) to deal with the three main specificities of the interstellar matter (cold temperatures, very low volume densities, light-matter interaction).

- Within astronomy, PCMI shares many interfaces with other INSU actions, especially with the stellar physics program, the planetology program, the cosmology and galaxy program, and the high energy program.