The ISM & Plasmas group

Andrea Ciardi & Emeric Bron

LUX Inaugural Day - 14/03/2025

Many astrophysical themes :











Supernovae & remnants











Prestellar cores



Giant Molecular Clouds









Accretion disks











Multiple scientific themes, one common axis : bridging the gap from laboratory astrophysics to astrophysical observations



Part 1 - The Atomic and Molecular Physics and ISM teams
 (Meudon and Paris)

Atomic and Molecular Physics: Vacuum UltraViolet (VUV) Spectrograph

Christian Balança, Norbert Champion, Christophe Blaess, Lydia Tchang-Brillet

 10m High resolution VUV spectrograph in Meudon: a unique instrument in Europe
 → moderately charged atomic ions (2+ - 5+) (transition metals and rare earths) and small molecules (H₂, D₂, HD, CO...)



Focal distance : 10.7 m
High resolution ~ 150 000 (8mÅ, slit 30μm)
Wavelength range (300Å -3000Å)
Sources: vacuum sparks, hollow cathode lamp, Penning discharge lamp

Astrophysical applications:

- Stellar abundances (CP, supernovae, Sun)
- Variation of fine structure constant with gravity (Fe V in white dwarfs)





 $\Delta \alpha / \alpha_0$ = (6.36±0.35_{stat}±1.84_{sys}) x10⁻⁵

Laboratory spectra + Analysis/parametric interpretation

Atomic data: λ , $\Delta\lambda/\lambda \sim 1 - 5 \times 10^{-6}$ Energy diagram E, transition probabilities gA, log(gf), Landé factors g_L

Opacity of kilonovae: ionised lanthanides, ex: Nd³⁺ (1740 lines & 357 levels, previously unknown)





Atomic and Molecular Physics : collision rate calculations

Ch. Balança, F. Dayou, N. Feautrier , S. Sahal-Bréchot

Theoretical calculations of collision cross sections: (quantum chemistry, potential energy surfaces, collision dynamics)

- Ro-vibrational excitation of molecules via collisions with He, H₂ (ISM) N₂H+, C₂H-, C₄H-, C₈H-, HC₅N (long carbon chain study)
 - → Needed to deduce physical conditions from molecular emission in the ISM
- Stark broadening coefficient of atomic and ionic lines
 - → Needed e.g. to deduce the density in plasmas such as stellar atmospheres

Cross sections for reactive collisions:

- Gas-phase reactions involving neutral and/or ionic species
- Perspective for solid phase interactions (e.g. ice mantles interstellar dust grains)
- → Needed to study ISM chemistry

Diffusion of atomic and molecular data:

VAMDC (service d'observation)

C. M. Zwolf



The Meudon PDR code

F. Le Petit, J. Le Bourlot, E. Roueff, E. Bron, A. Piluso, D. Languignon, A. Doussot

HII region

Photo-

evaporation

A state-of-the art model of photodissociation regions (PDRs)

Probing radiative feedback of young massive stars



 applications in wide range of environments: PDRs, diffuse clouds, protoplanetary disks, high redshift DLA, ...

Also a "service d'observation":

- Plateforme MIS et Jets (ANO5): making model results accessible to the community
- The Meudon PDR Code is now an ANO CC



Compressed layer

Hot chemistry

Inferrence of maps of physical conditions:

- Bayesian inference + spatial smoothness prior
- new MCMC sampler: efficient local
 (P-MALA) and global (MTM) exploration
- neural network emulator of the Meudon PDR code to speed up sampling

Palud et al. 2023a, 2023b, & 2025 (subm.)



80 70 $T_{01}(H_2)$ 60 50 $\mathbf{\Sigma}$ 40 $T_{12}(H_{3}^{+})$ Ŧ 30 20 10 4024534 173882 HD 73882 HD 110432 4041117 HD 210389 4043384 HD 154368 41027778 "HD 24398 ...

Puzzle of H₃⁺ excitation temperature in diffuse interstellar clouds:

- ➡ introducing a sufficient number of H₃⁺ levels
- role of chemical pumping
- role of molecular fraction

Le Bourlot et al., Mol. Phys. e2182612 (2023) Felix-Gonzalez et al, A&A 693, 181 (2025)

ORION-B IRAM-30m Large Program & ANR DAOISM

M. Gerin, H. Mazurek, I. Beslic, F. Le Petit, E. Bron



PI: M. Gerin & J. Pety

- Detailed study of a star forming GMC
- ~10⁶ pixels, tens of molecular lines
- Template for GMCs in galaxies
- Collaboration with data science & Machine learning



First study of ionization fraction across a full GMC:

- finding most informative line ratios from large model grids, a Machine Learning approach (Bron+2021)
- application on Orion B observations (Beslic+2025)

Beslic+2025, *Pety*+2017, *Gaudel*+2022

Ionization fraction in the diffuse ISM

M. Gerin



High sensitivity of $H_2CO \ 1_{10}-1_{11}$ line to excitation conditions including x(e) Absorption more prominent in regions where x(e) << 3x10⁻⁵ and C+ has recombined to C and CO

Chemistry and 3D structure of prestellar cores

L. Pagani

- complex task (no information along line of sight)
- taking advantage of chemical stratification



Jets and outflows: models and observations

S. Cabrit



Disks, jets and outflows

- Interstellar heritage
- Mechanical, radiative and CR feedback

Tabone+2020, Rabenanahary+2022



