Interstellar Medium and Plasmas
(IMP; pole 2)

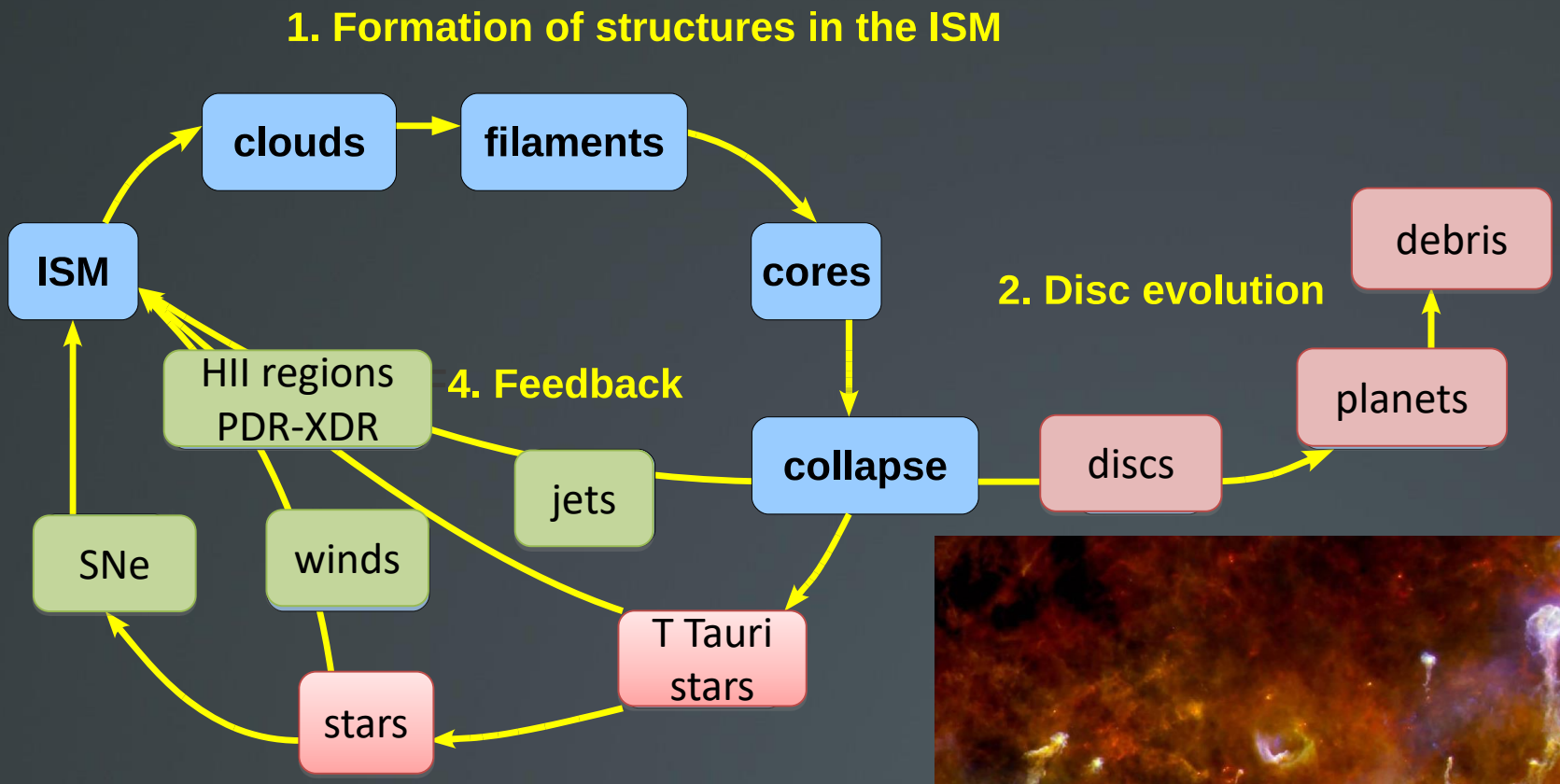
December 1, 2017: 40 members; 4 sites (Denfert, Meudon, ENS, Jussieu)

Permanent members (26):
19 staff scientists, 5 emeriti, 2 engineers

Non permanent members (14):
8 PhD students, 2 postdocs, 4 CDDs

Journée des entrants; Dec. 8, 2017

Outline : galactic matter cycle



Scientific drivers

1. **Mechanisms regulating the condensation of diffuse interstellar medium (ISM) into stars and protoplanetary discs ? (and back)**

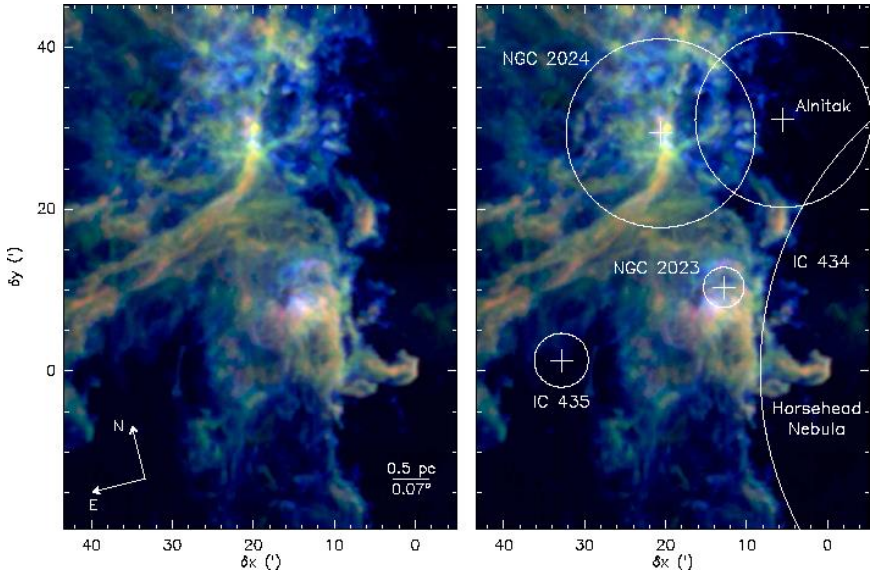
2. **Photodissociation regions (PDRs) : how can we interpret their signatures ?**

3. **Chemical complexity : characterization, origin, impact on ISM physics and star formation**

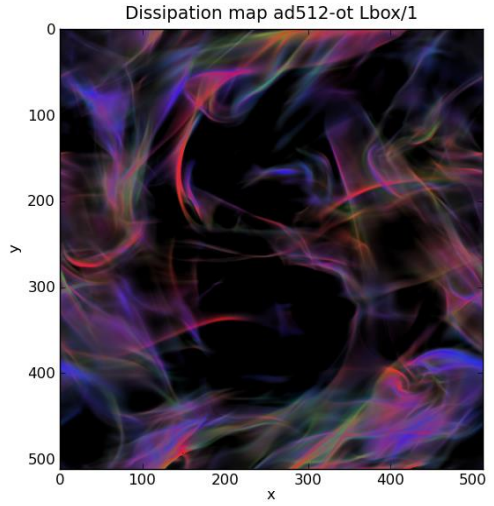
4. **Turbulent cascade: dissipative processes, magnetic field**

5. **Accretion/ejection: stellar radiative and mechanical feedback**

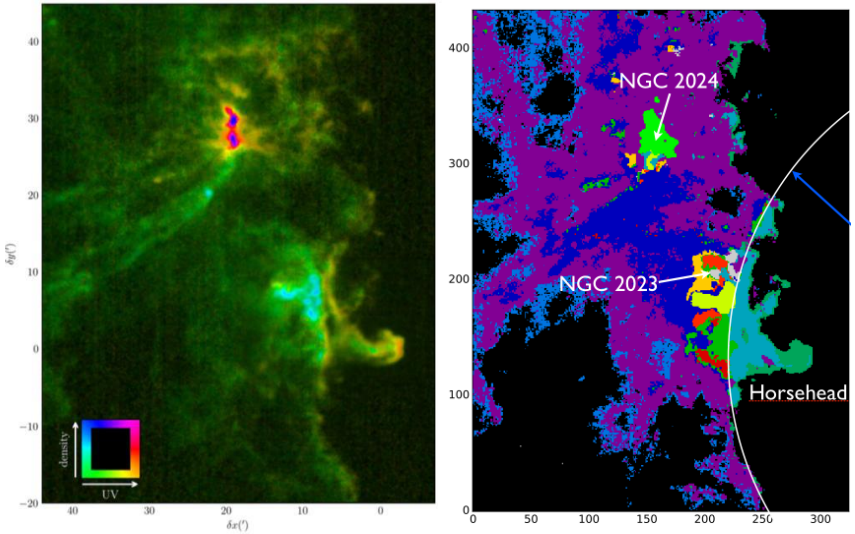
Complementary approaches



Observations



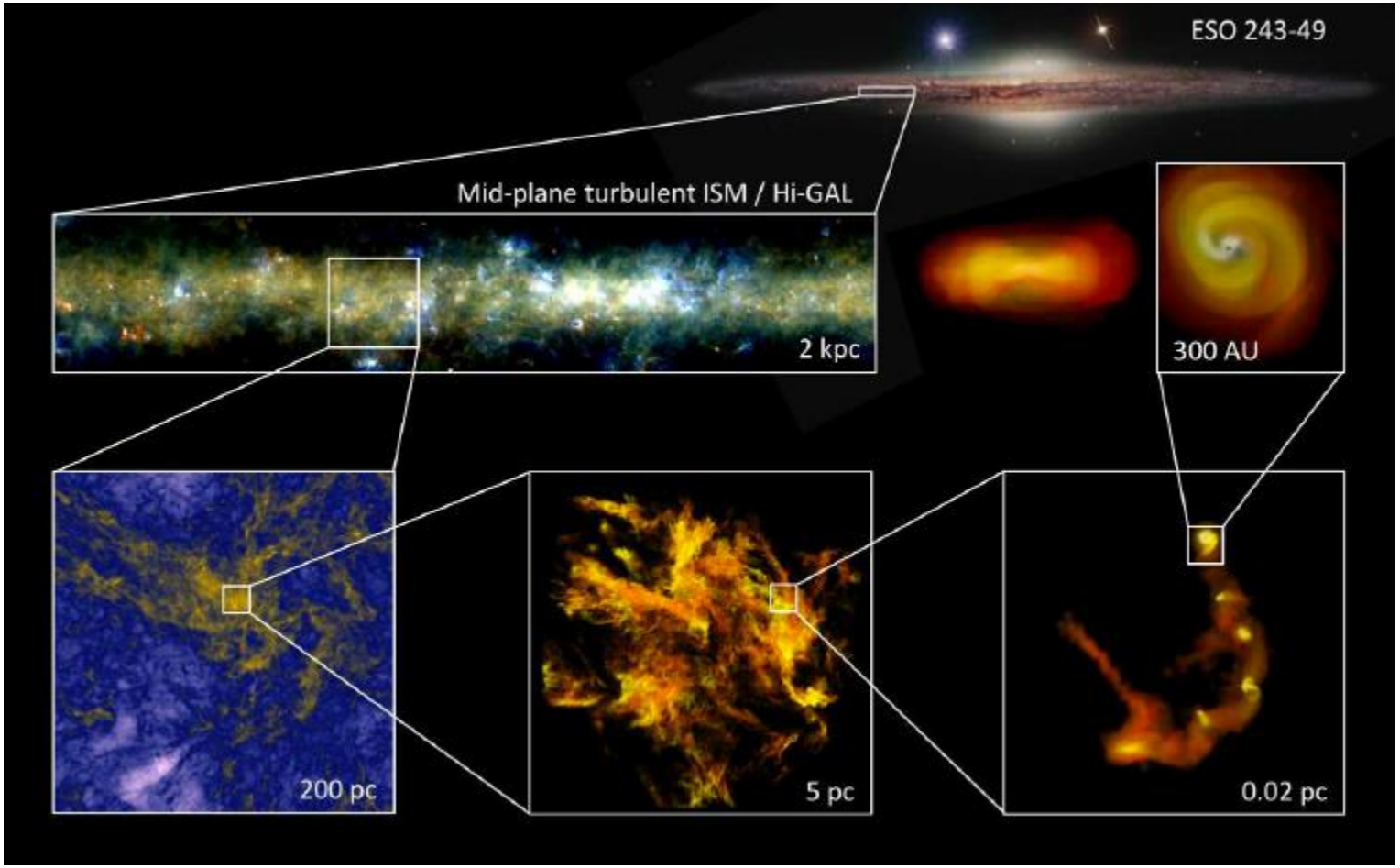
Theory and numerical simulations



Analysis, modeling and interpretation

Laboratory experiments

Structuration of the ISM



Magnetic fields are significant on all scales

Origin, role, and characterization of magnetic fields

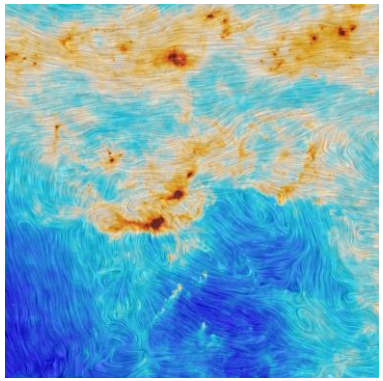
Different new approaches to a 3-D cartography of galactic magnetic fields are now available:

→ **foreground in CMB experiments (Planck)**

→ **ALMA and NOEMA**

→ **Stellar polarization surveys & GAIA**

→ **LOFAR, SKA (+ precursors)**

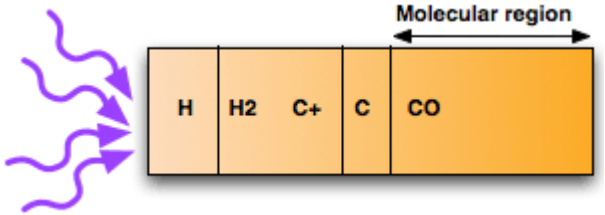


Polarization map at 353 GHz
(Planck Collaboration Int. XX 2015)

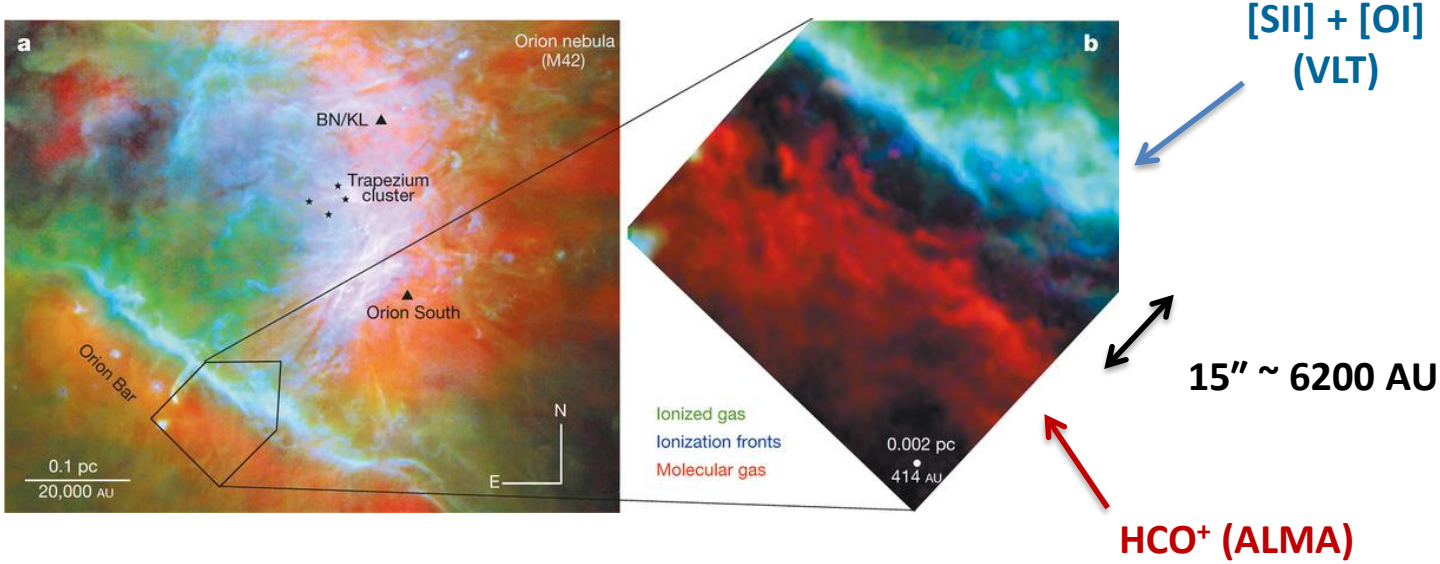
→ ANR programme BxB
(Boulanger, Lévrier, Falgarone, et al.)

- **3D mapping of the magnetic field in the Solar neighborhood, by combining data from GAIA, Planck, LOFAR + theoretical modeling**
- **Statistical analysis and description on the turbulent magnetized ISM**
- **Tying CMB polarization studies to the astrophysics of the galactic foregrounds**

PhotoDissociation Region (PDR) models



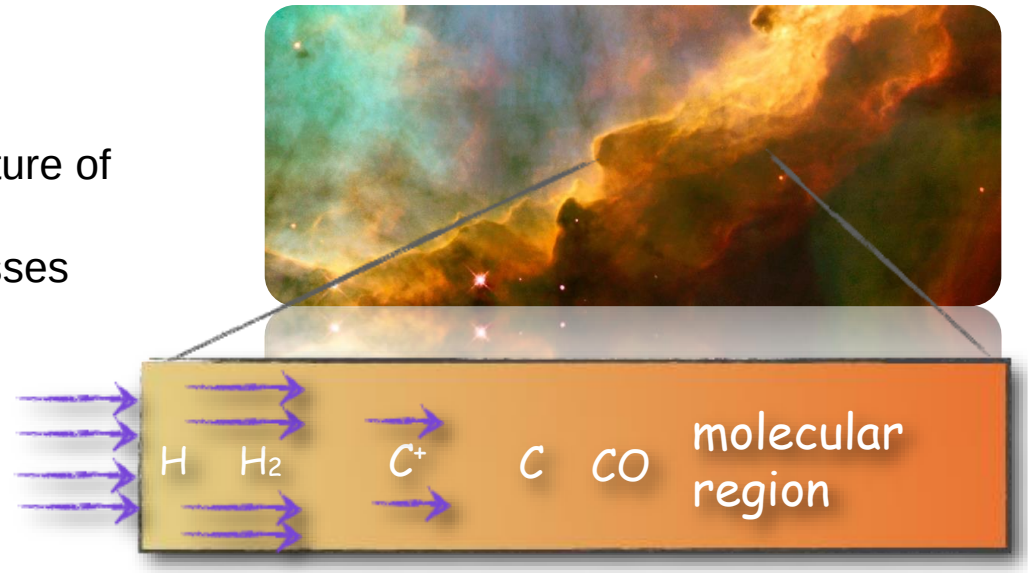
- **Compute the atomic and molecular structure of interstellar clouds**
- **Require an analysis of (gas & dust) physical and chemical processes**



essential for interpreting observations

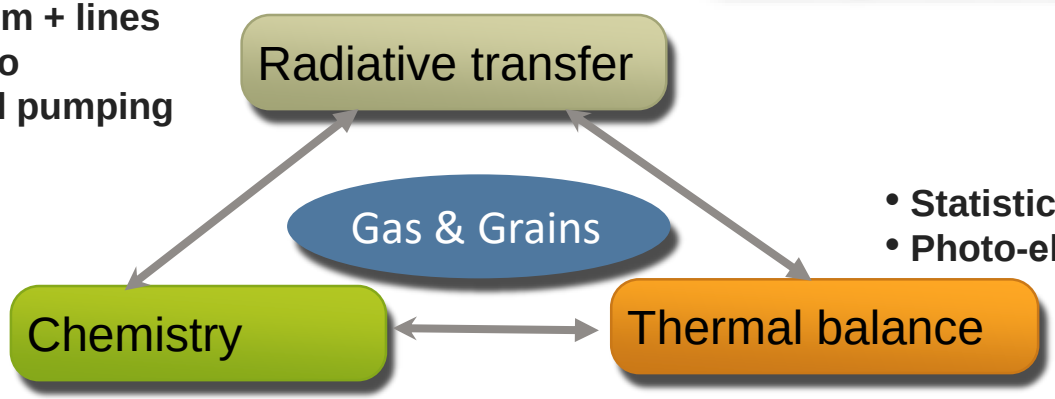
Meudon PDR code (Le Petit et al.):

- compute the atomic and molecular structure of interstellar clouds.
- analysis of physical and chemical processes



Coupled physics:

- **continuum + lines**
- **UV - radio**
- **non local pumping**



- **Statistical equilibrium**
- **Photo-electric effect, cosmic rays, …**

- **several hundred species**
- **thousands reactions**
- **gas & grains**

Downloadable at: http://pdr.obspm.fr

MIS & Jets (ANO5)

(150 visits/month)

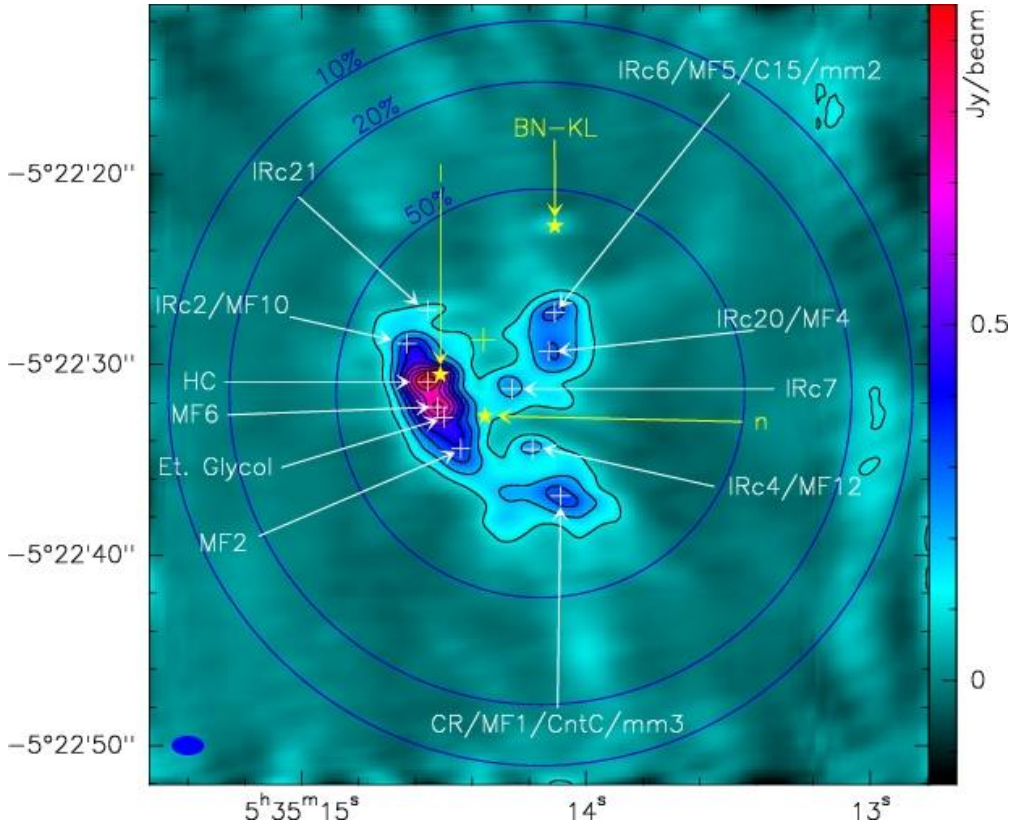
→ ERS program proposal on the JWST

→ Involvement on GUSTO (NASA balloon-borne sub-mm experiment, for [CII], [OI], [NII] mapping of the Galaxy)

Anatomy of interstellar clouds

Orion; ALMA (215-252 GHz),
1” (400 au)
thousands of lines,
70 species (HC_3N, CH_3OH, HCOOH, etc.)

Pagani et al. (2017)

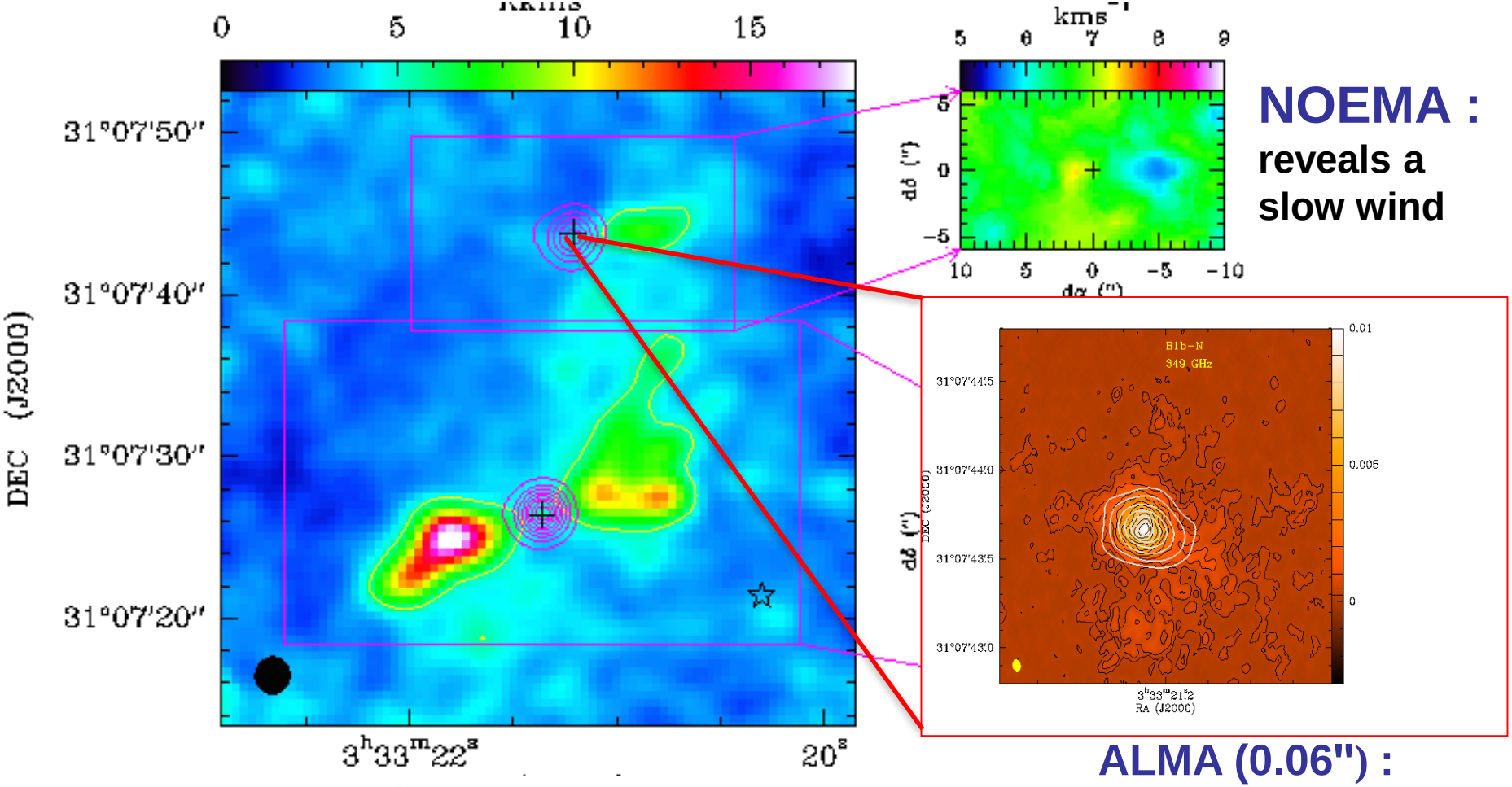


→ **grasp on the chemical complexity of the ISM**

→ **new techniques for exploiting the data (Machine Learning)**

access to the initial phases of stellar formation

B1b-N: first hydrostatic core? (before class 0)

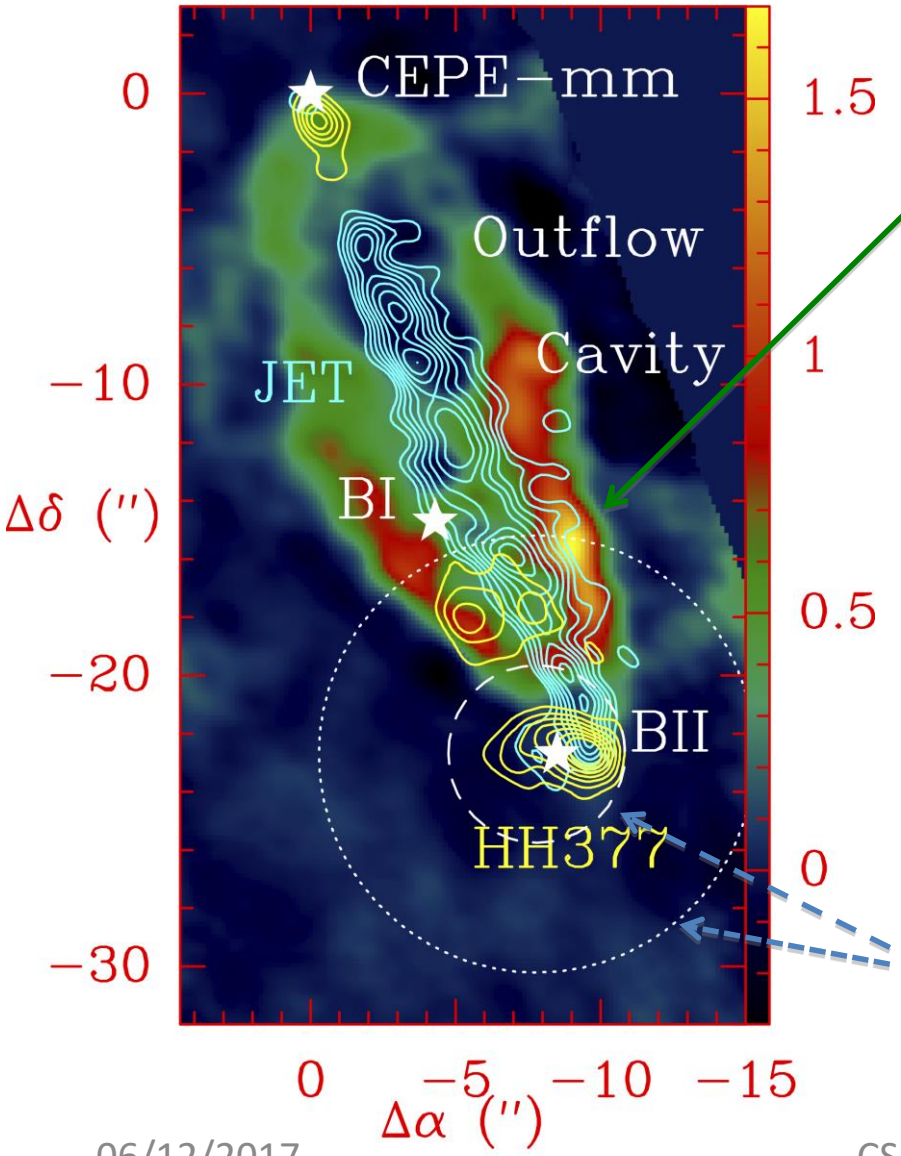


NOEMA :
reveals a slow wind

ALMA (0.06") :
reveals a young disk

Gerin et al. 2015, 2017

Jets and outflows in young stellar objects



Dynamics and origin of ejection ?

NOEMA maps in CO2-1 (1″):
Cavity (colors), terminal shock (cont.), jet (cont.)
Lefloch, Gusdorf et al. 2015

→ Observations in the submm/IR range
- Herschel (legacy): H_2O, CO, [OI]
- *Spitzer* (JWST) : H_2, Si^+, Fe^+, S…
- ALMA and NOEMA : shock chemical tracers (SiO, CH_3OH, SO, SO_2)

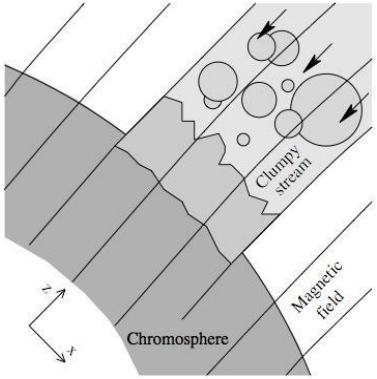
New: SOFIA: high-J CO, [OI] 63µm
→time-dependent self-irradiated shock models

SOFIA beams : [OI] detected in all kinematical components of CO (16-15)
Gusdorf et al. 2017

Accretion on Young Stars and its feedback on the environment

ANR Starshock (PI)
PICS Palerme

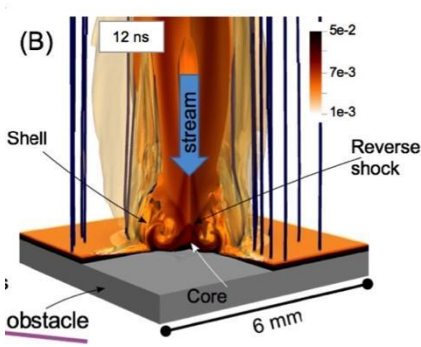
How to reconcile X ray observations with the models ?



Schematic of a clumpy stream Matsakos et al. A&A 2013

Different scenarios already proposed (RHD & MHD simulations with PLUTO)

- Effect of B strength/inclination & of clumpiness
- Effect of radiation trapping
- Experiments on the structure & stability of the base of the accretion column
- as well as on radiative shocks



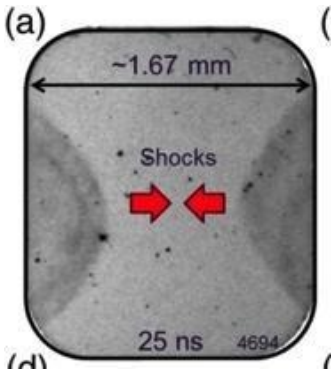
3D simulation of the ELFIE laser experiment with GORGON (Revet & al. Science Adv. 2017)

However, no clear explanation yet

(Bonito & al ApJL 2014, Orlando & al AA 2018, Matsakos & al EPJ Web 2013, Ibgui & al EPJ Web 2013, Revet & al S. Adv. 2017, Suzuki & al. PRL 2017, Chaulagain & al. HEDP 2015, Singh et al. HEDP 2017, etc.)

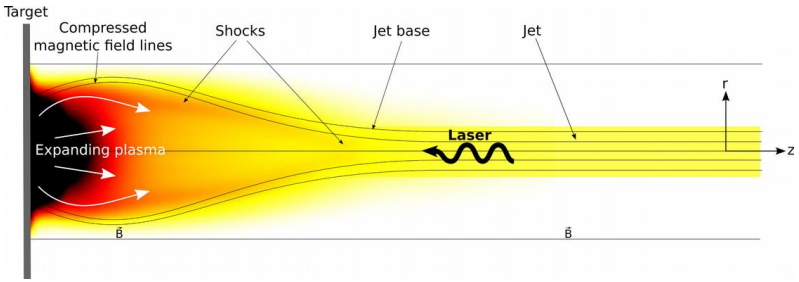
PROJECT

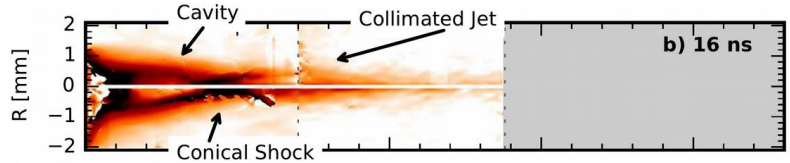
- **Extension of this work**
- **Heating of the chromosphere** *(Co-tutelle Obs Palerme)*
- **Feedback on the inner circumstellar disk** *(**ERC SPIDI, PI Bouvier, IPAG**)*

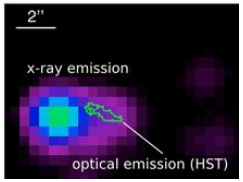


Suzuki et al, PRL 2017: collision between 2 radiative shocks in Xe at ORION laser facility / UK,

Plasma laboratory experiments and modeling







First magnetically confined laboratory jet (LULI, Ciardi et al.)

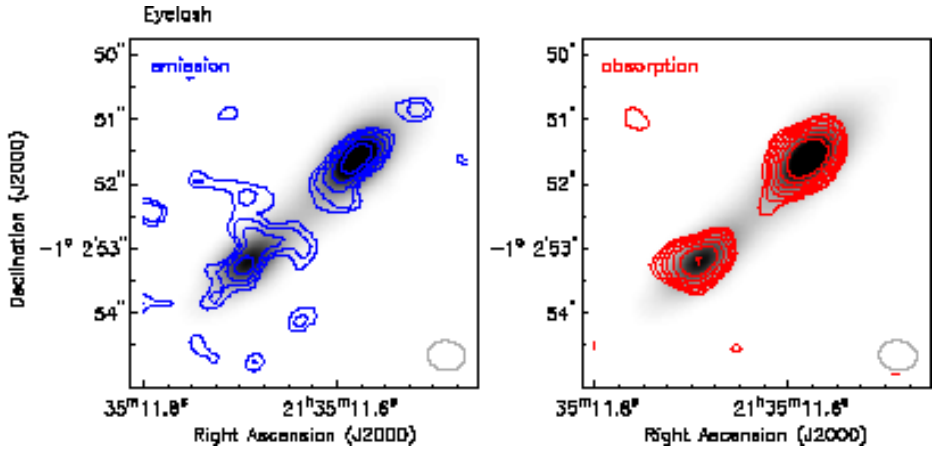
Chandra observations (X-ray)

- **Development of numerical codes**
- **Validation through laboratory experiments**

from our Galaxy to external galaxies (Lyrics, MIST)

- **ISM lines discovered by Herschel at high frequencies can be detected in the sub-mm/mm range by ALMA/NOEMA in redshifted galaxies**

ISM in external galaxies (redshift + grav. amplif.-x35-)



CH^+ (J=1-0) at z = 2.5 (835 GHz)
ALMA in band 6
(Falgarone et al. 2017, Nature, 548, 430)

→ dynamics and chemistry at high z/earlier stages of the evolution

Molecules, magnetic fields and Intermittency in coSmic Turbulence (ERC-MIST, PI: Falgarone)

"Following the energy trail"

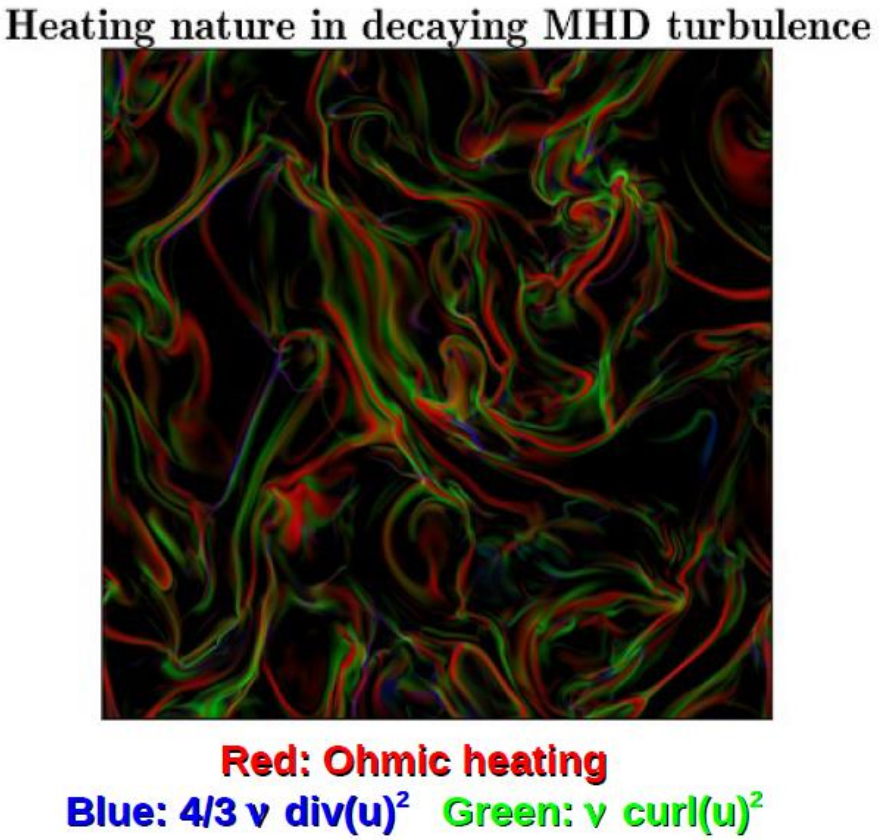
Molecules in the early universe:

- **probe truly cold universe ($T<<10^4$ K)**
- **provide unique diagnostics of gas dissipative physics**

(1) observations: chemical and thermal markers of turbulent dissipation

(2) statistical analyses of magnetic and velocity field: search for non-Gaussian signatures of intermittency

(3) numerical experiments: (a) formation of molecules, (b) split of the energy trail



3D simulations of turbulent dissipation regions
Momferratos et al. (shocks; vortices; currents)

Pole 3

Molecules in the Universe

gas-grain physico-chemistry

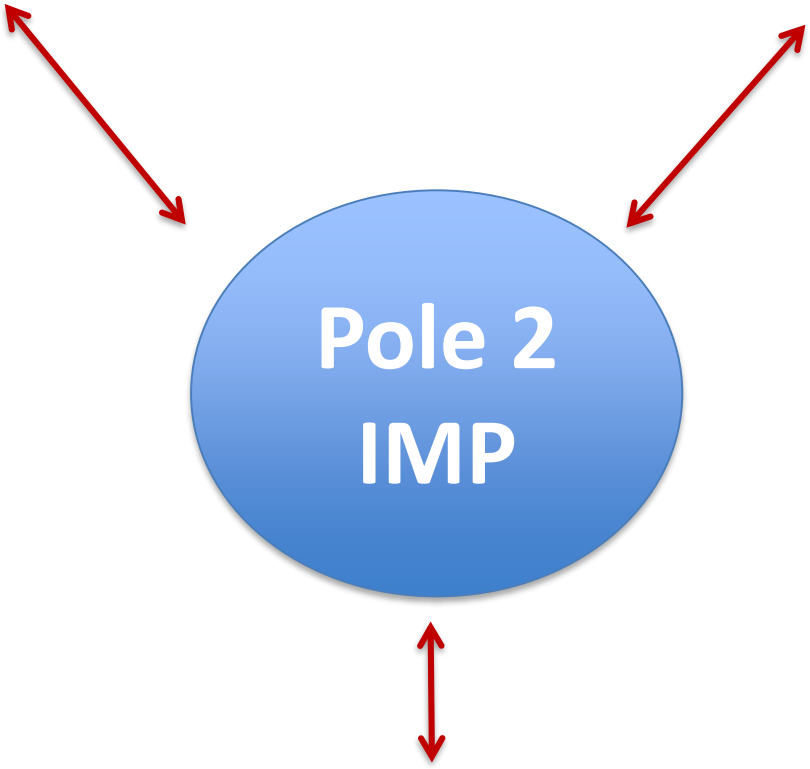
VAMDC (ANO5)

Pole 1

Galaxies & Cosmology

mm/sub-mm/IR observations

ISM in external galaxies; Lyrics foregrounds



Pole 4

Instrumentation & Remote sensing

Herschel, SOFIA, (OST)

Distributed in 4 sites:

ENS – LRA
ISM : dynamics, chemistry, turbulence and B-field
Stellar plasmas: dynamo and convective transport

UPMC Plas@Par - **Jussieu**
Stellar plasmas: accretion-ejection, diffusion theory.

OP-**Meudon**
Stellar feedback: UV irradiation, PDRs
Stellar Plasmas: atomic data, stellar models

OP-**Denfert**
Prestellar cores, star / planet formation,
stellar feedback : AGB winds, protostellar jets

IMP; pole 2

coordination: Thibaut Le Bertre (thibaut.lebertre@obspm.fr)
+ 1 representative per site :
Sylvie Cabrit; Chantal Stehlé; Franck Le Petit; Michel Perault
[with support of the administrative team]

- **Joint Astrophysics Meeting (JAM) organised by Antoine Gusdorf**
- **Web pages: maintained by Benjamin Godard**
- **General IMP meetings : twice a year (april & october)**
- **e-mail distribution list (quinquennal.lerma-pole2@sympa.obspm.fr)**