Laboratoire de Radioastronomie (LRA)

http://astro.ens.fr

F. Levrier - 21 septembre 2011

An overview

The team

- 10 permanent scientists : theoreticians and observers
- 10 students and post-docs
- 1 research engineer

Research areas

- Interstellar medium, accretion disks and star formation
- Magnetized fluid dynamics and astrophysical dynamos
- Opening towards cosmology

Methods and tools

- Observations with large international telescopes
- Analytical computations
- Numerical simulations with own 256-core machine and national computing centers

Astronomy's "Hilbert problems"

Do we understand the extremes of the Universe ?

- From the extreme vacua of the intergalactic medium to neutron stars
- Black hole gravitational fields that rip the fabric of space-time
- "Big Bang" physics beyond the standard model of particle physics

How do galaxies form and evolve ?

- Linear and non-linear growth of quantum fluctuations in the distribution of dark matter
- Acceleration of expansion : dark energy
- Dynamics and interaction of galaxies

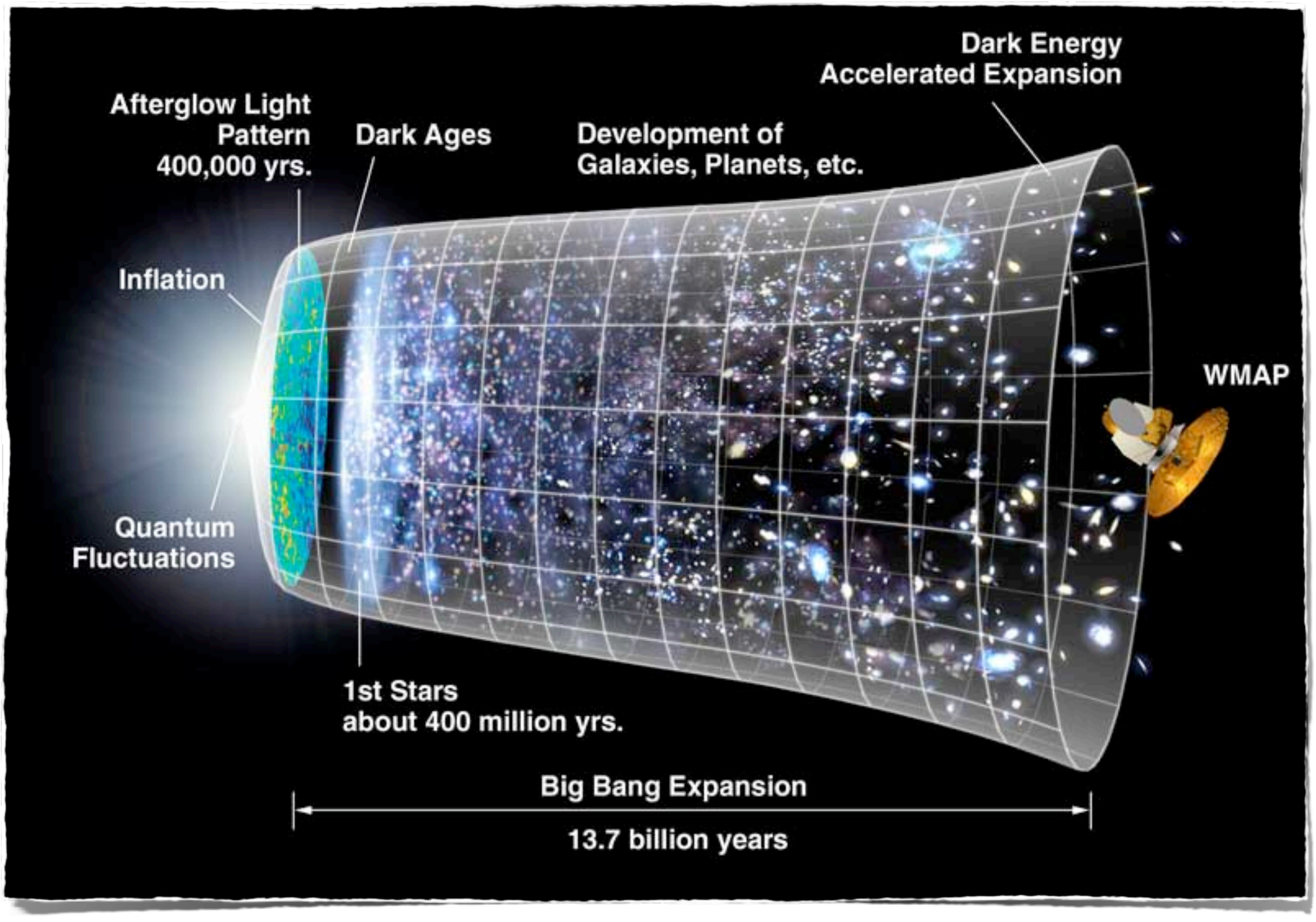
How do stars and planets form ?

- The cycle of interstellar material in galaxies
- Microphysics and macrophysics at work (turbulence, magnetic fields, chemistry,...)
- The Solar system as a giant laboratory

How do we fit in ?

- Complex molecules in space and exobiology
- Exoplanets : the search for another Earth
- SETI

A brief history of time...

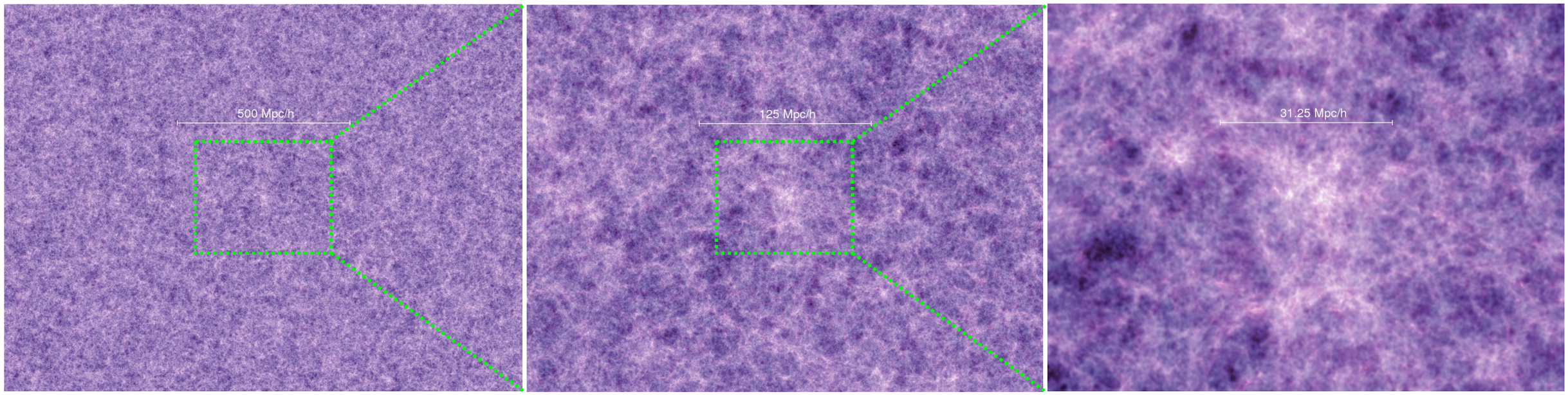


Formation of large-scale structures and galaxies

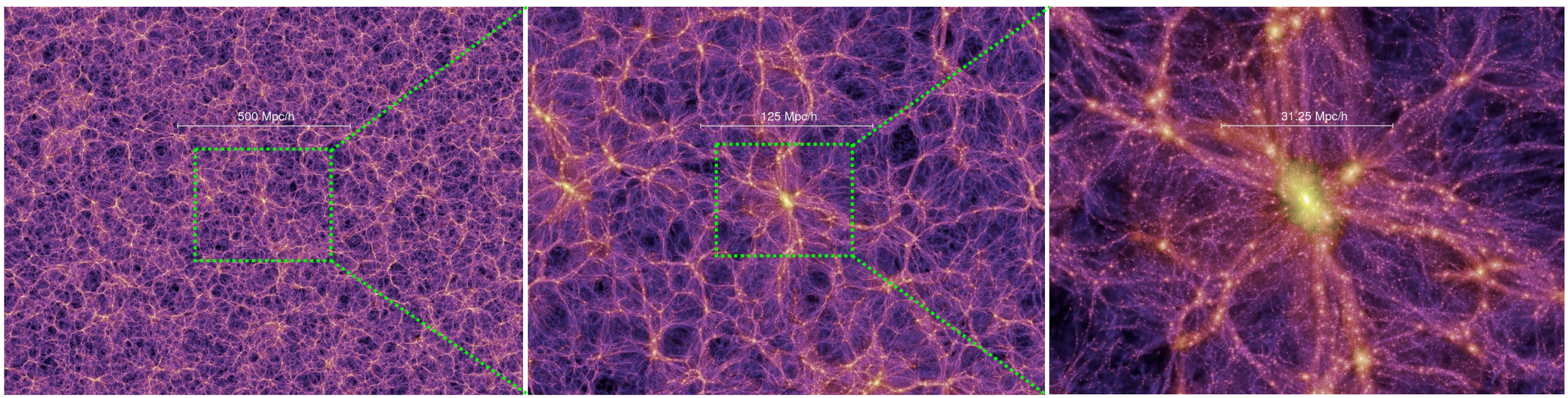
Millenium simulation (2005)

http://www.mpa-garching.mpg.de/galform/millennium/

Distant Universe (z=18)



Present Universe (z=0)

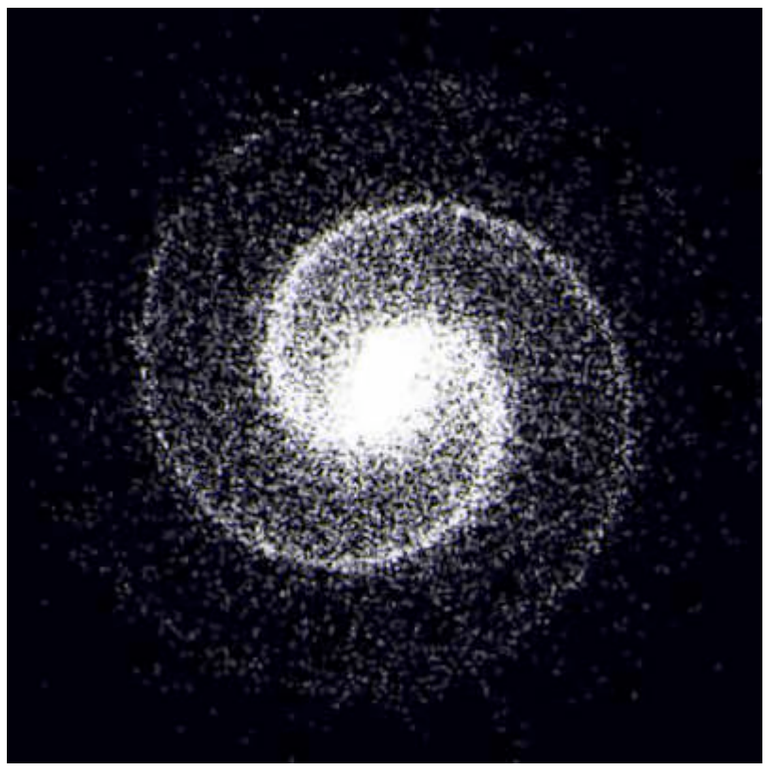


From galaxies to stars

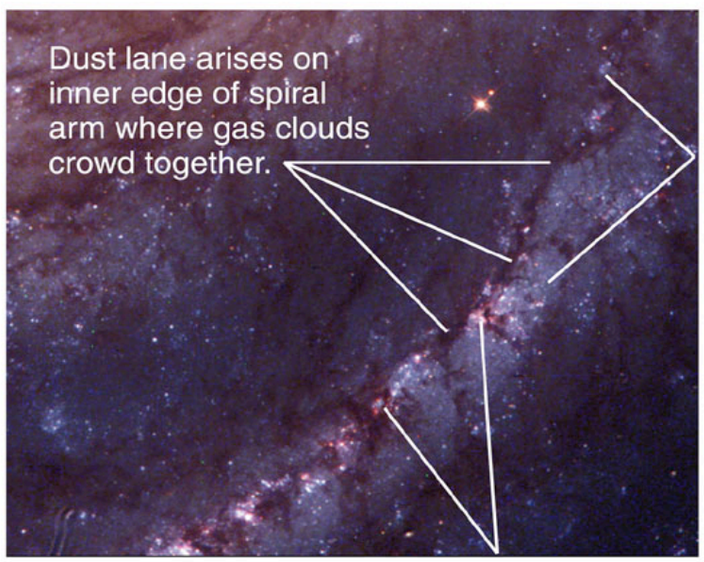
Hubble Deep Field

Tidal interactions

Density waves



Star formation in spiral arms



Star formation and the cycle of interstellar matter

Stars

$n > 10^{22}\ \mathrm{cm}^{-3}$

Stellar winds, Planetary Nebulæ, Supernova remnants, ...

NGC2440 with HST
(K. Noll / STScI)

Crab Nebula with HST
(A. Loll et al. / STScI)

Radiation

Heavy Elements
Kinetic energy

Cosmic rays

Large scale energy injection

Hot ionized gas (HIM)

$n \sim 10^{-2}\ \mathrm{cm}^{-3}, T \sim 10^{6}\ \mathrm{K}$

Warm ionized gas (WIM)

$n \sim 0.5\ \mathrm{cm}^{-3}, T \sim 8000\ \mathrm{K}$

Warm neutral gas (WNM)

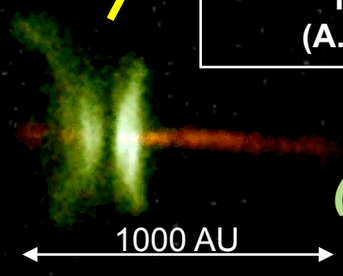
$n \sim 0.5\ \mathrm{cm}^{-3}, T \sim 8000\ \mathrm{K}$

Cold neutral gas (CNM)

$n \sim 10^{2}\ \mathrm{cm}^{-3}, T \sim 10^{2}\ \mathrm{K}$

... and dust grains

MHD, microphysics, gravity, turbulence, thermodynamics, particle physics...



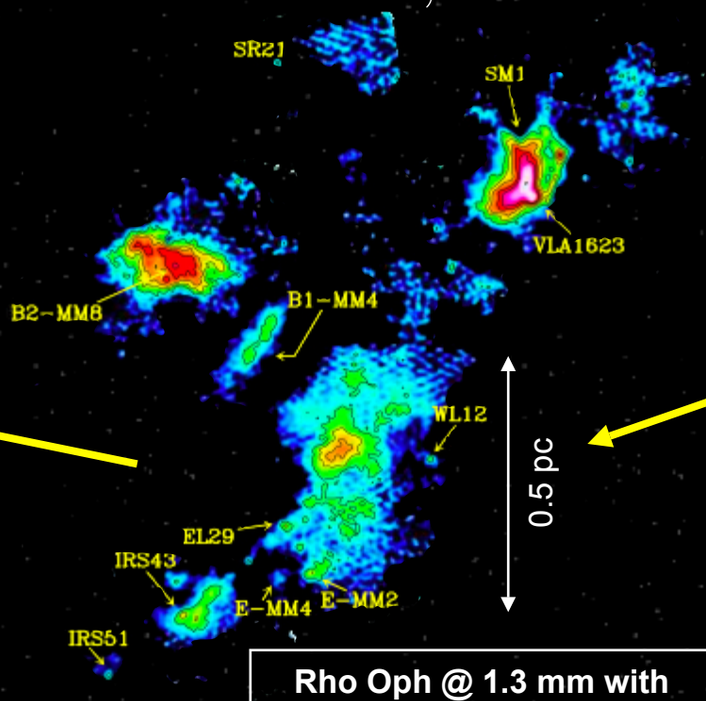
HH30 with HST
(A. Watson / STScI)

Protostellar objects (accretion disks, jets...)

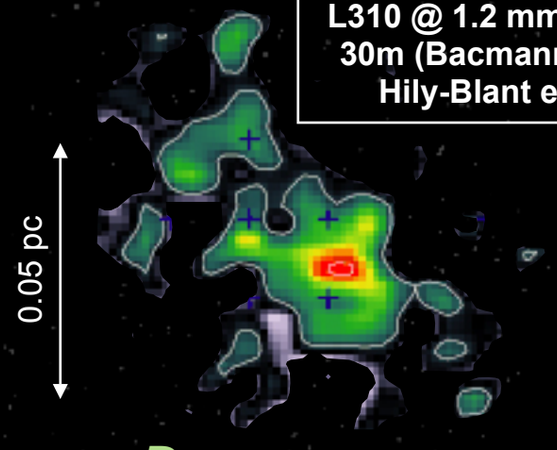
1000 AU

Molecular gas

$n \sim 10^{3}\ \mathrm{cm}^{-3}, T \sim 10\ \mathrm{K}$



Rho Oph @ 1.3 mm with
IRAM 30m (Motte et al. '98)



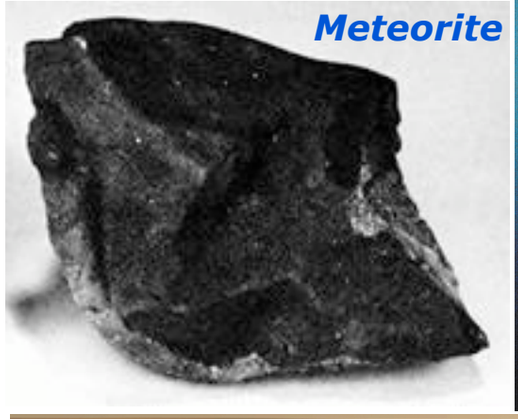
L310 @ 1.2 mm with IRAM
30m (Bacmann et al. '00,
Hily-Blant et al. '10)

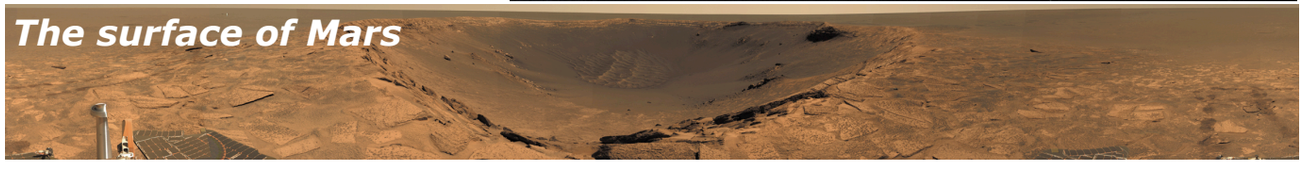
Dense cores

$n \sim 10^{6}\ \mathrm{cm}^{-3}, T \sim 10\ \mathrm{K}$

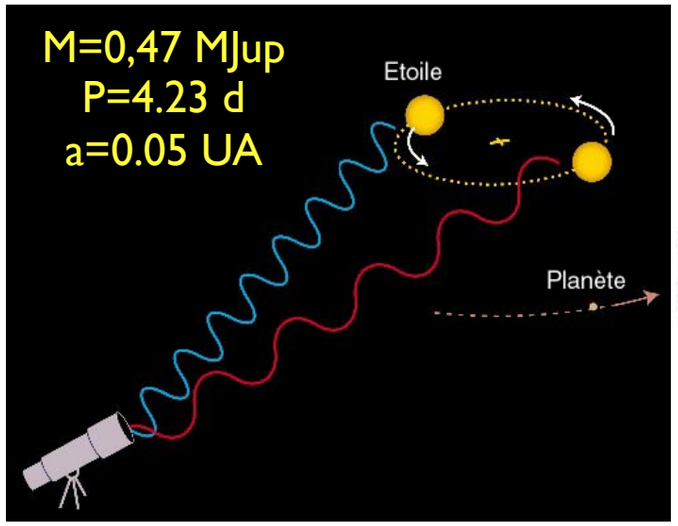
From stars to planets

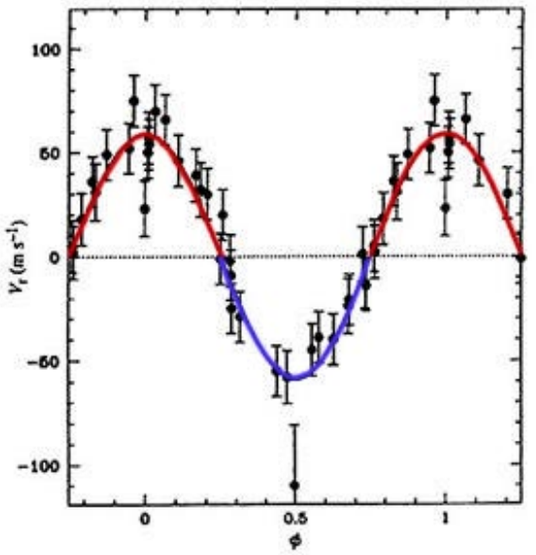
Our Solar system : a laboratory...



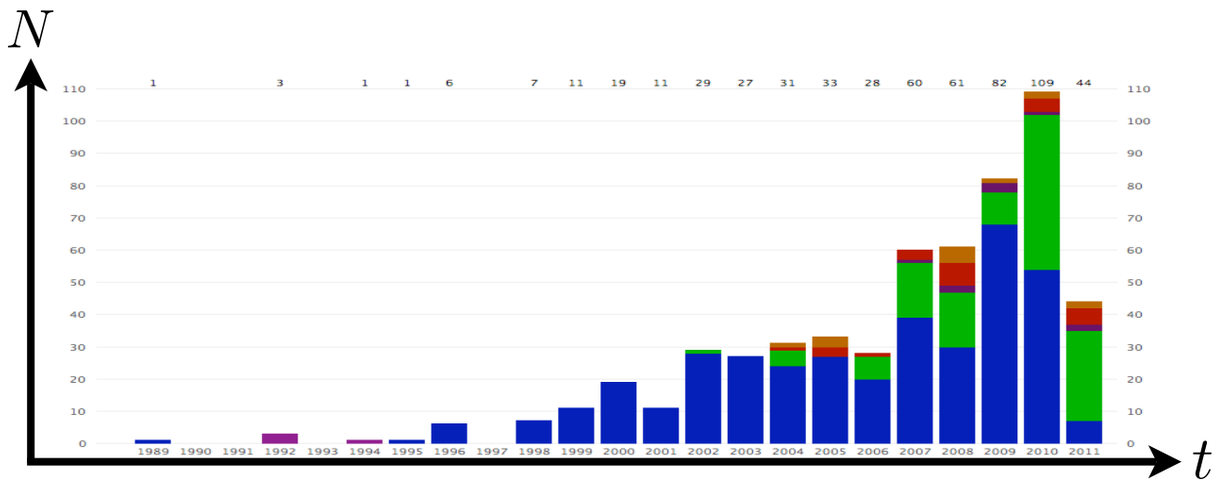


... but not a unique one.





Discovery of the first exoplanet 51 Peg B
(Mayor & Queloz 1995)



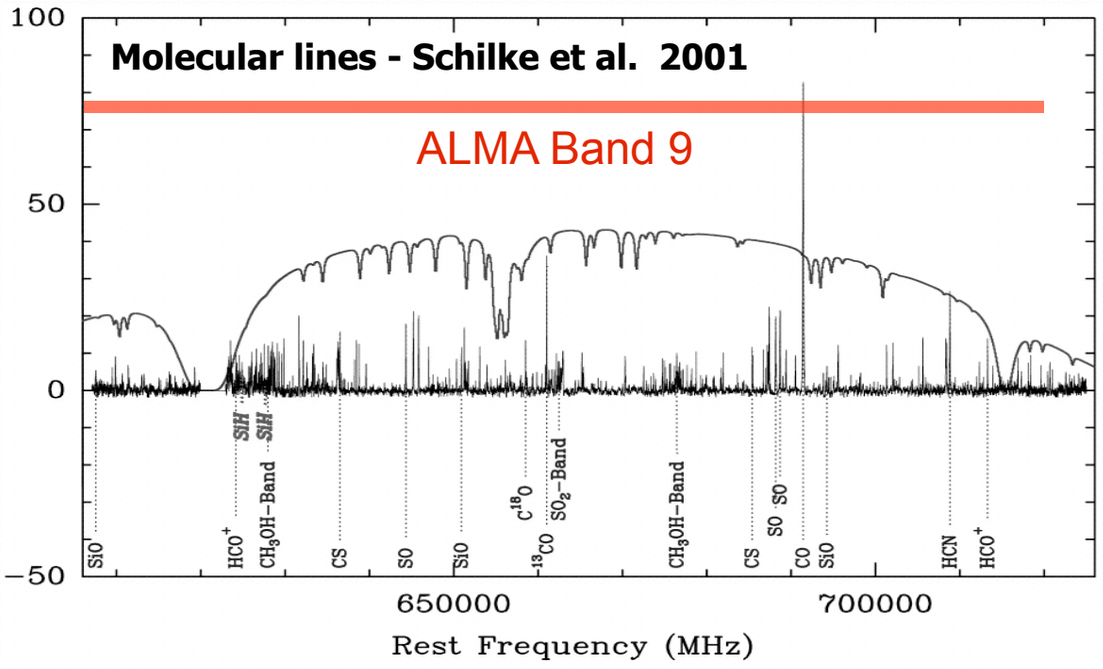
560 exoplanets known to date (09/2011)

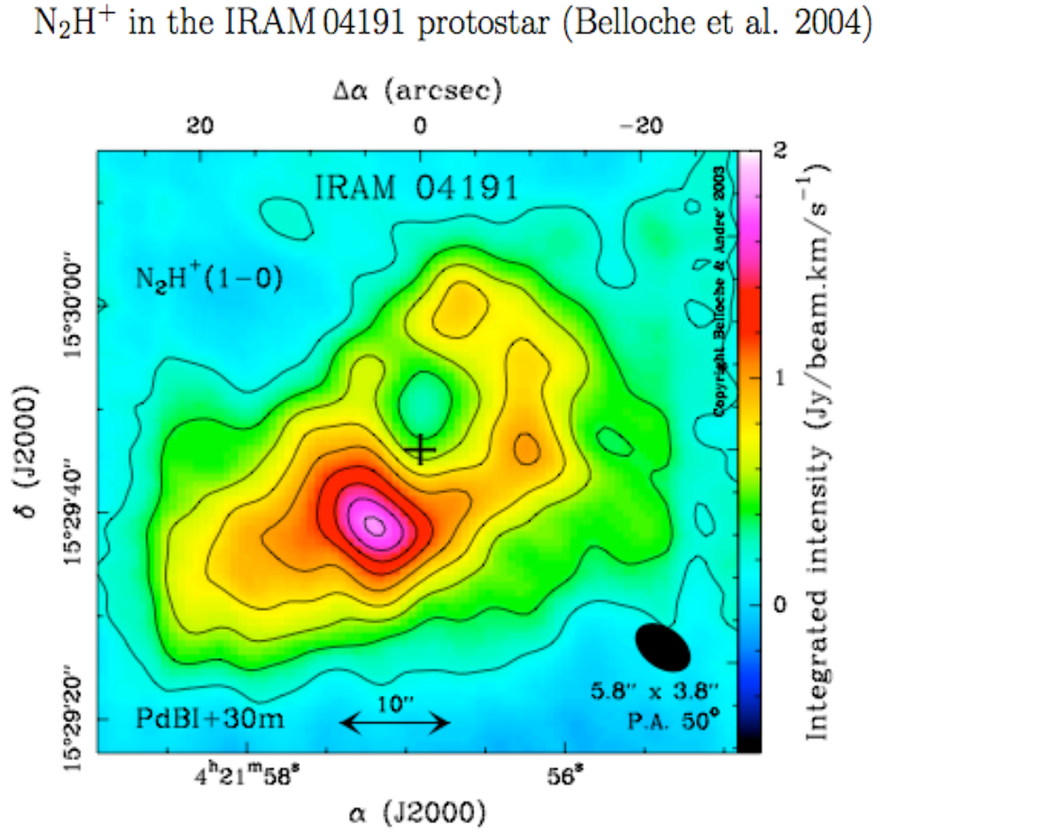
Solar system studies must be formulated in the context of protoplanetary disk and planet formation

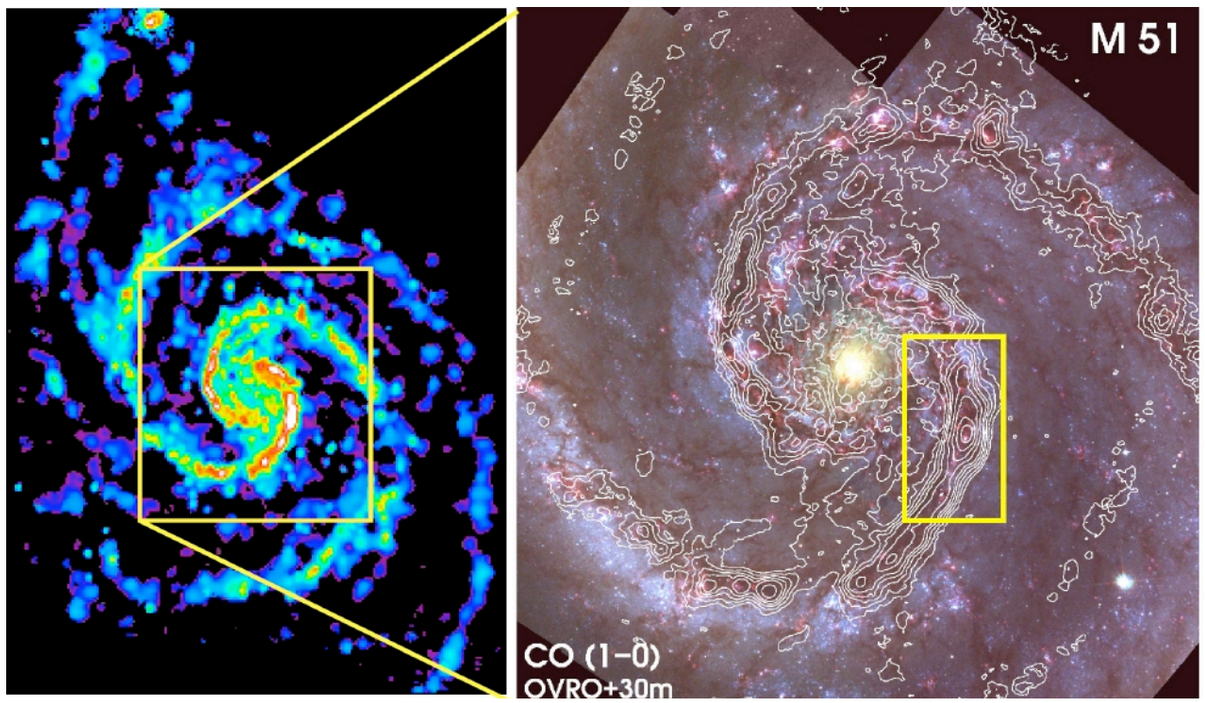
Chemistry in space

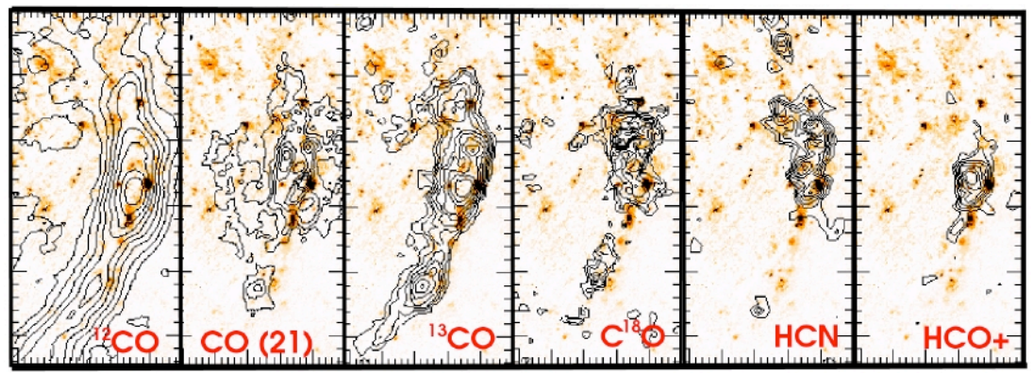
- **Rotational and vibrational modes of many molecules in the mm and sub-mm**
- **~150 molecules detected in the interstellar medium or circumstellar shells**
- **~35 in extragalactic sources**

CO, H_2O, OH, HCN, HCO^+, CS, NH_3, H_2CO, ...









The mother of all complex systems

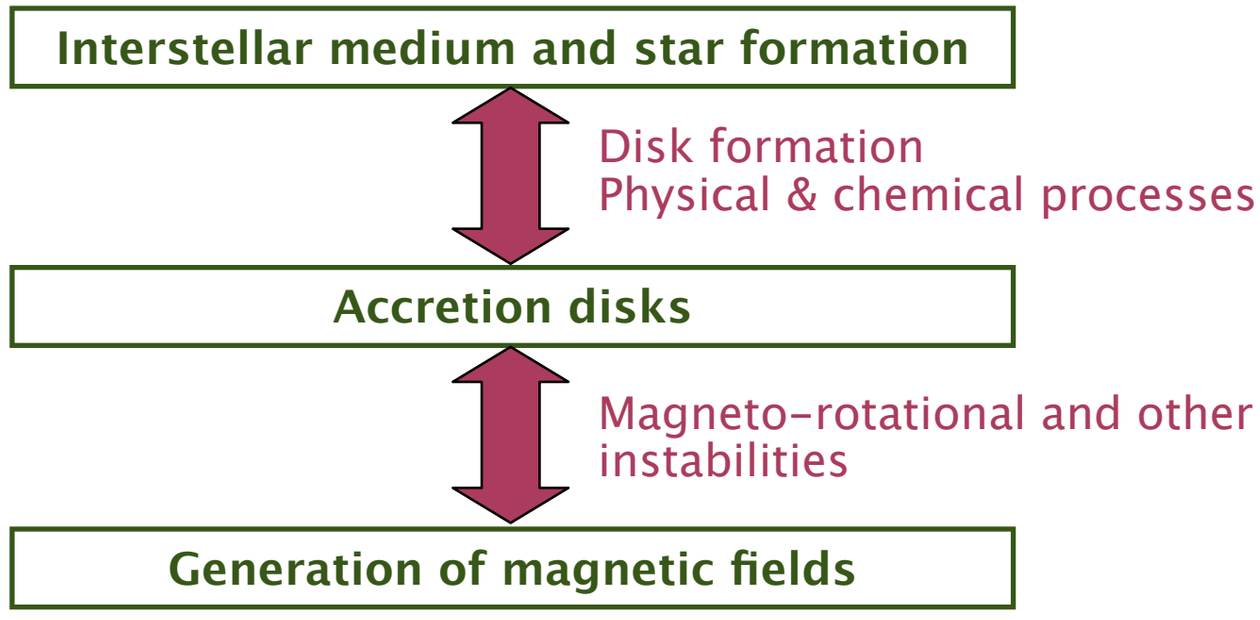
Observations ↔ Laboratory astrophysics ↔ In-situ exploration ↔ Analytical models ↔ Numerical simulations

Main research topics at LRA

Interstellar medium – Star and planet formation – Accretion disks – Magnetohydrodynamics – Dynamos

Methods

Observations (high resolution spectroscopy) – Numerical simulations (MHD turbulence)



Opening towards cosmology

- Initial conditions of Type Ia supernovae
- Molecular lines in extragalactic objects
- Foregrounds to the CMB (Planck)

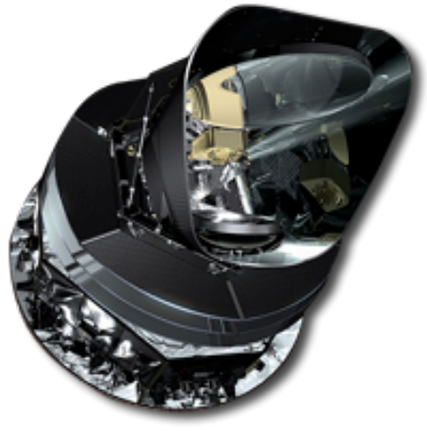
Tools of the trade

CEMAG 256-core machine : JxB

20000-core BlueGene machine @ IDRIS

Herschel

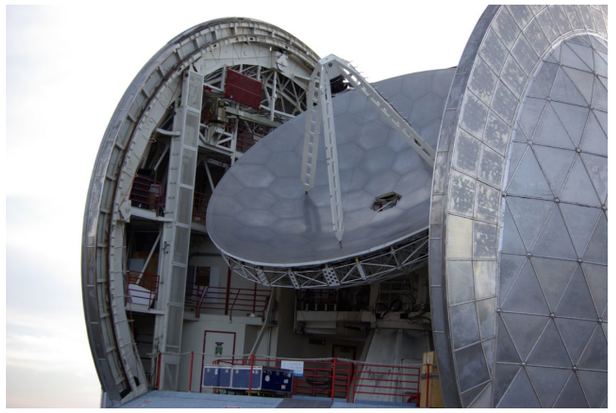
Planck



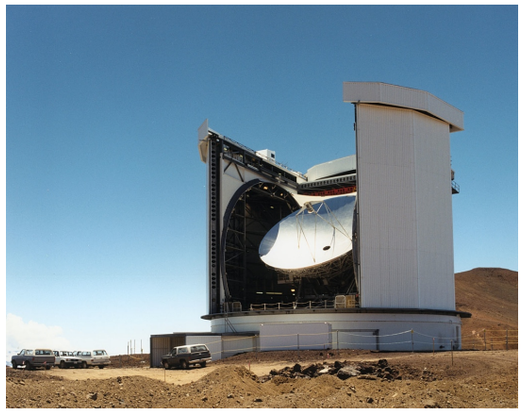
IRAM 30-meter (Spain)

IRAM Plateau de Bure (France)

CSO (Hawaii)

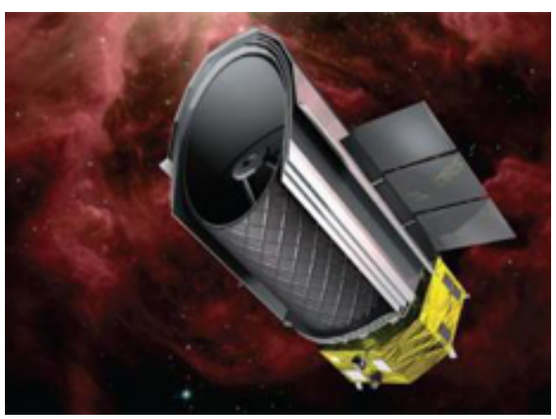


JCMT (Hawaii)

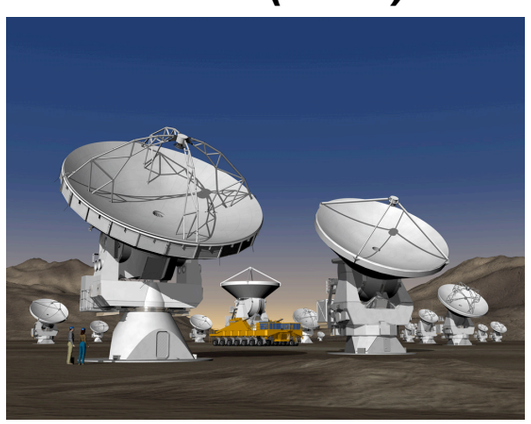


... and more to come !

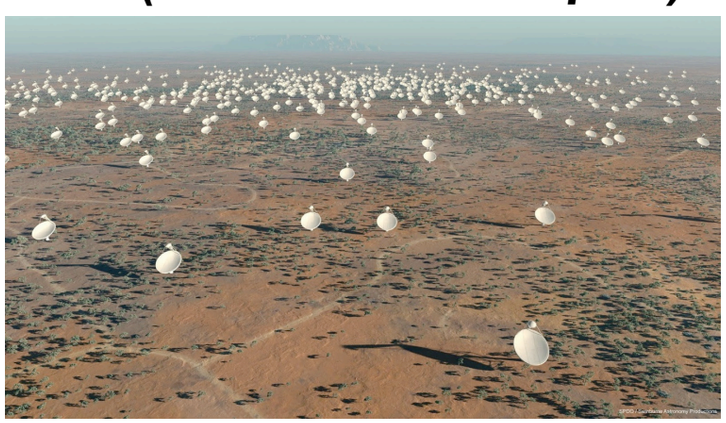
SPICA



ALMA (Chile)

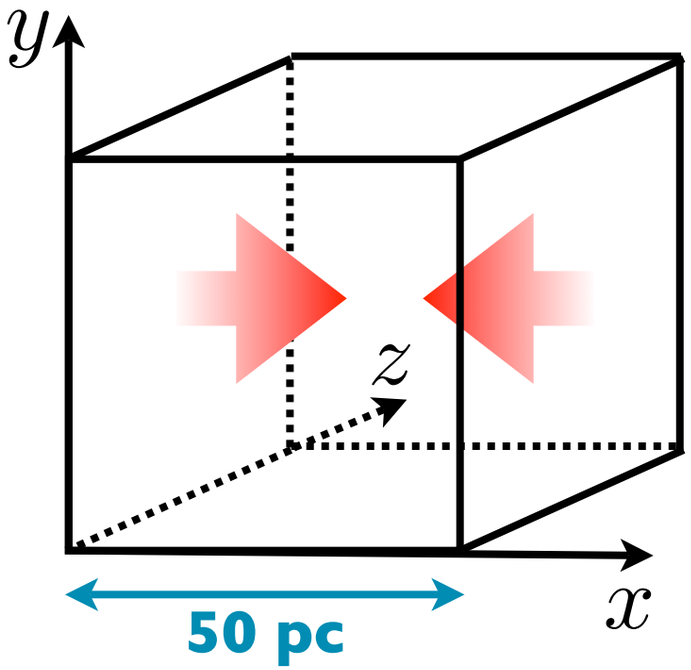


SKA (Australia / South Africa)



Formation of molecular clouds

Compressible MHD turbulence with gravity and cooling



- RAMSES code (Teysier 2002, Fromang et al. 2006)
- Adaptive Mesh Refinement with up to 14 levels
- Periodic boundary conditions
- Covers scales 0.05 pc - 50 pc
- ~30,000 CPU hours / 10 to 100 GB data sets

Converging flows of warm neutral gas

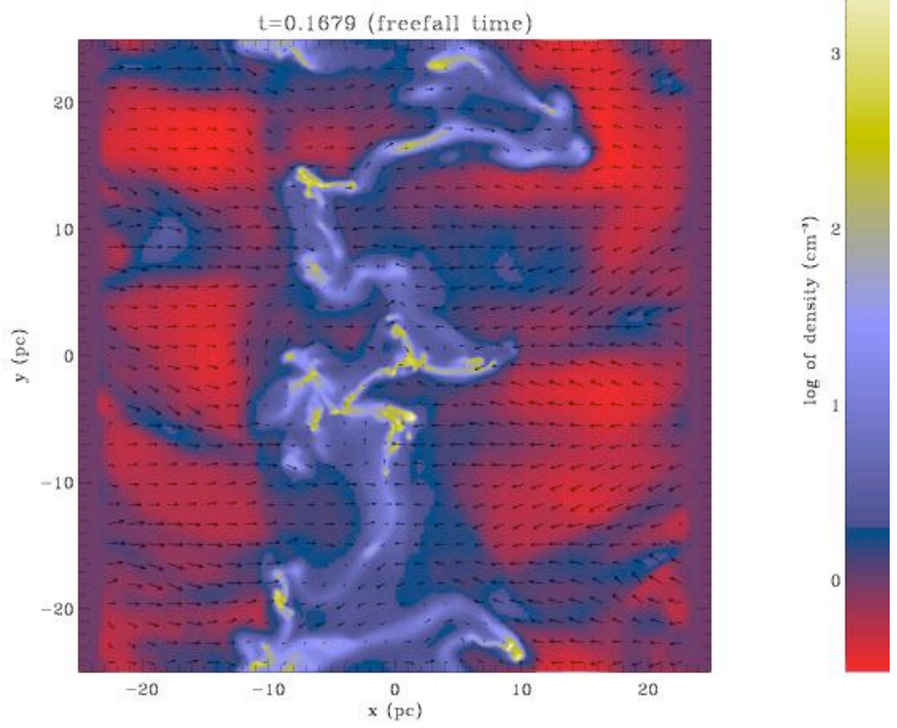
Hennebelle et al. (2008)

$n = 1\ \mathrm{cm}^{-3}$

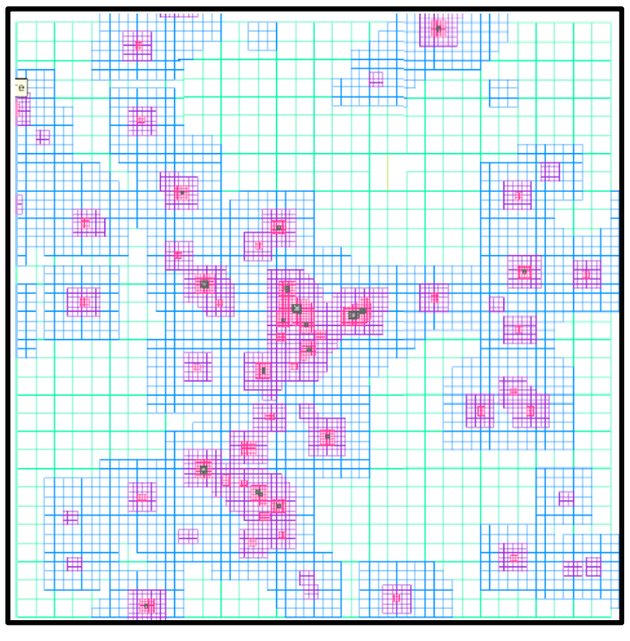
$B(t=0) = 5\ \mu\mathrm{G}$

$T = 10^4\ \mathrm{K}$

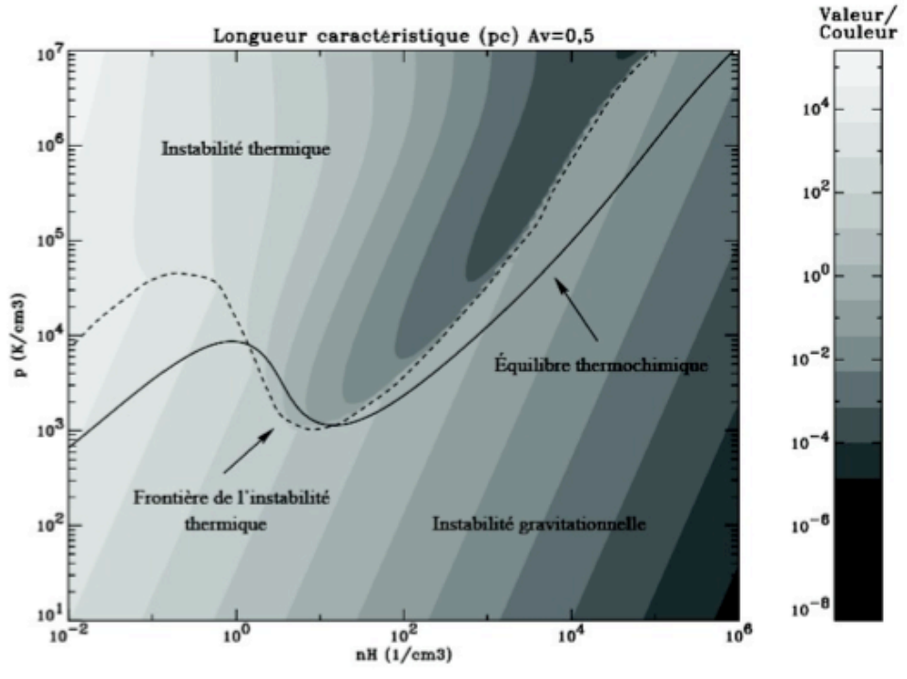
$v = 20\ \mathrm{km.s}^{-1}$



AMR scheme

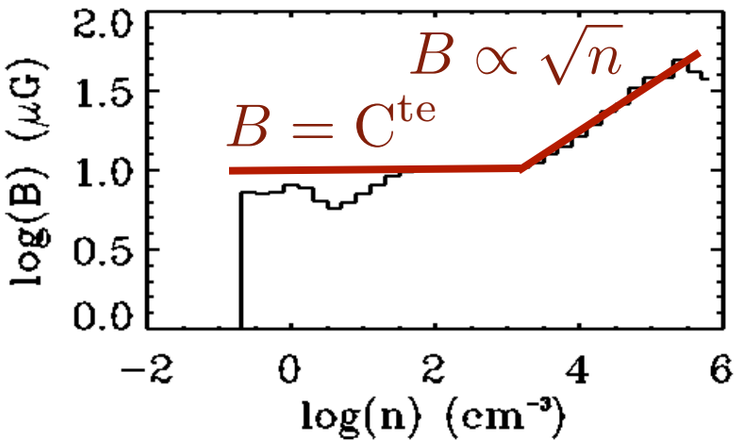


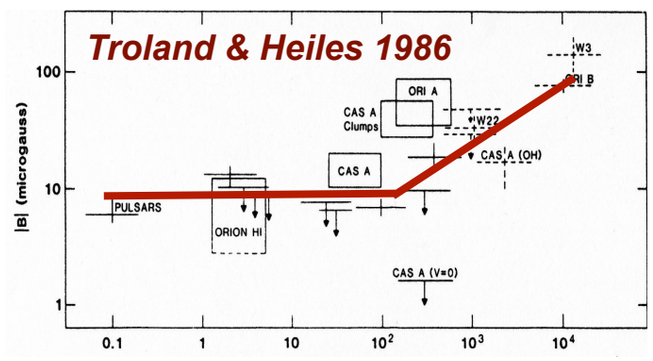
Thermal instability



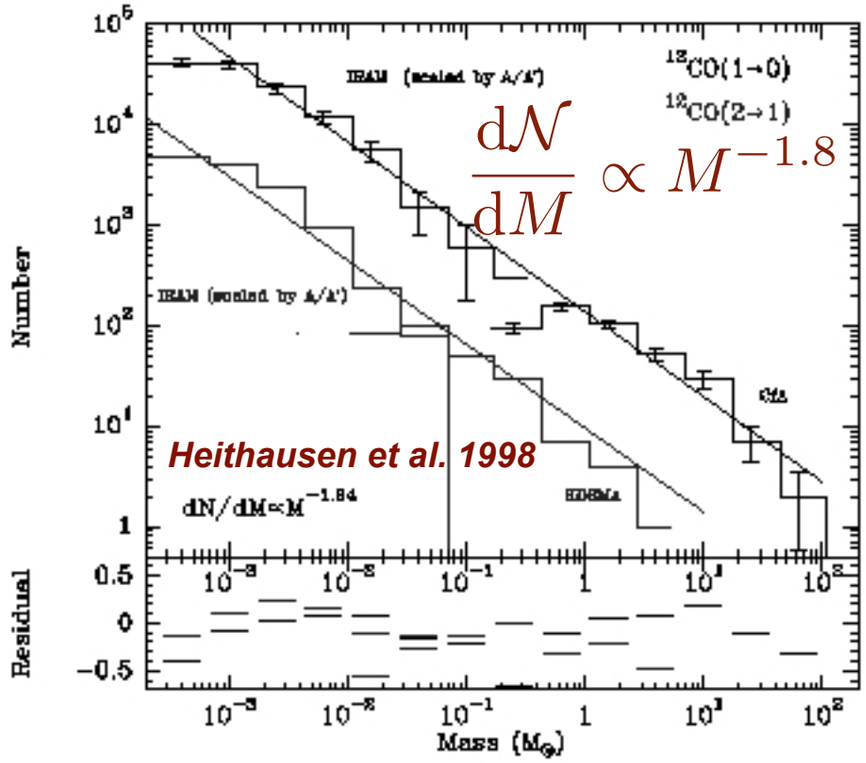
Comparison with observations

Magnetic field vs. density

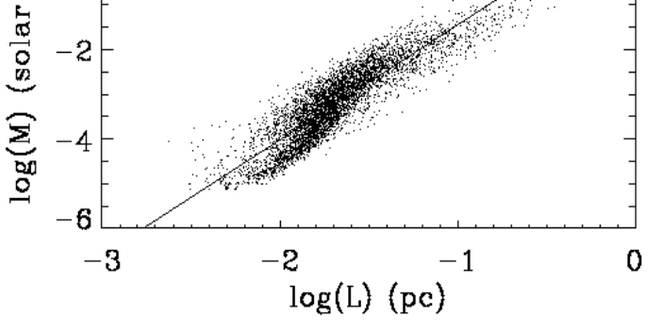


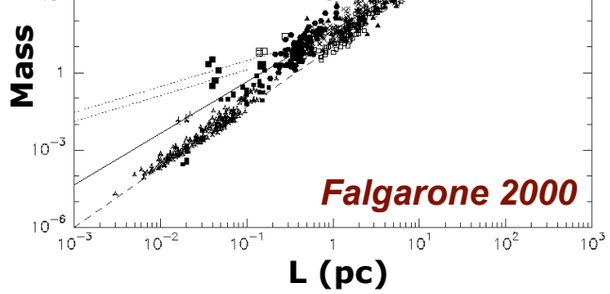


Mass spectrum

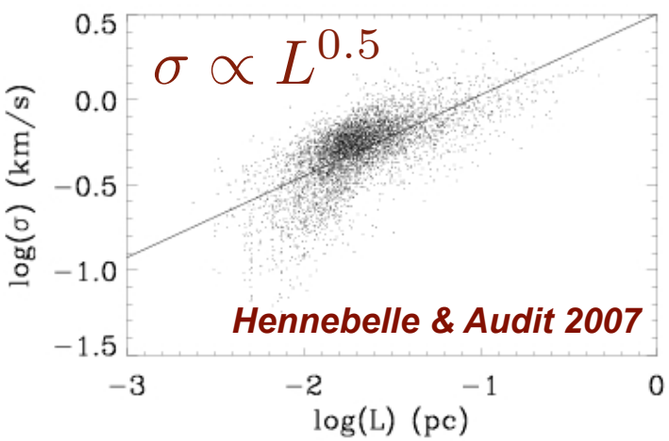


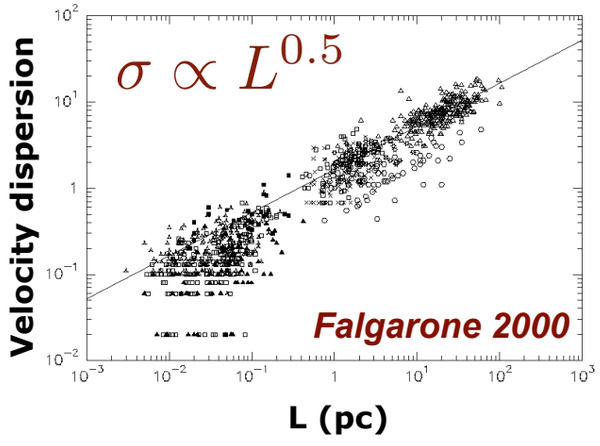
Mass vs. size

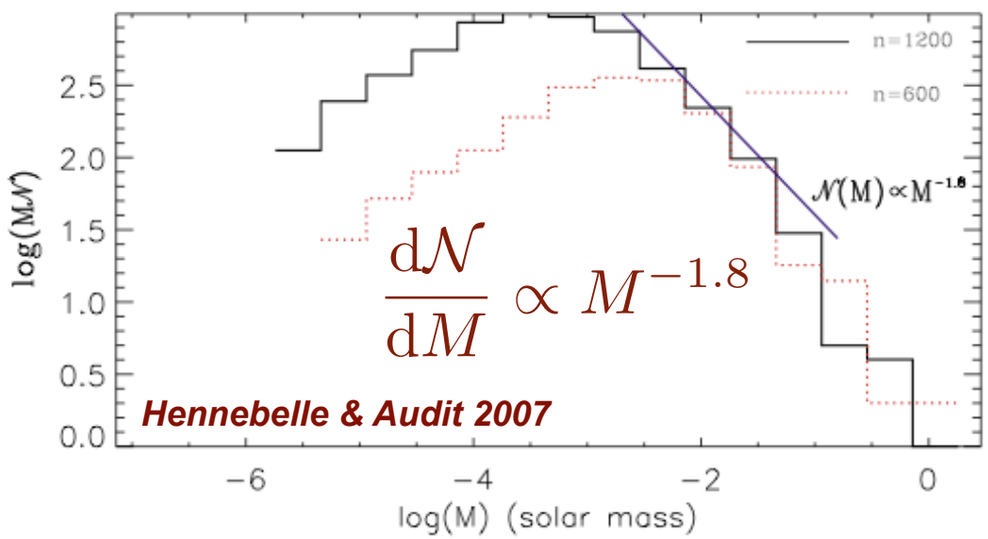




Velocity dispersion vs. size





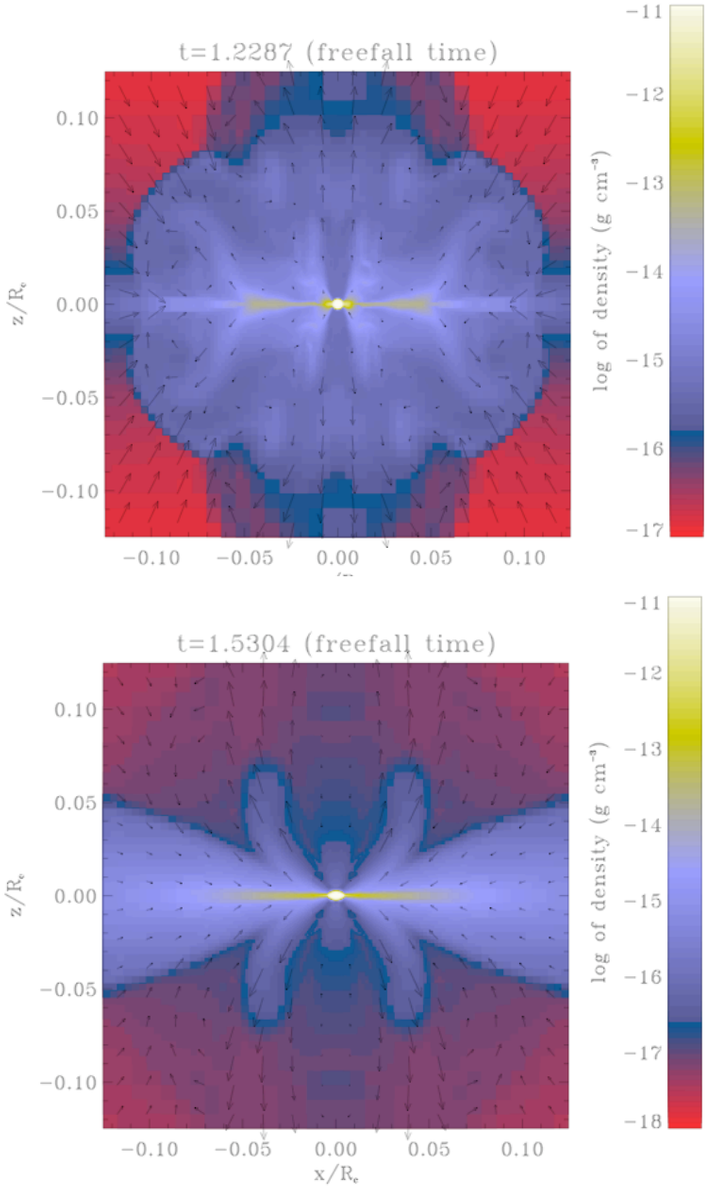


Collapse of prestellar dense cores

M. Joos, P. Hennebelle, B. Commerçon, F. Levrier

Scientific case for the simulations : The simulations describe the collapse of dense cores under their self-gravity, and aim to study the influence of turbulence and magnetic field in the process of fragmentation leading to the formation of several prestellar objects.

$$\mu = \frac{(M/\Phi)}{(M/\Phi)_{\rm crit}}$$



Weak magnetic field (μ=20)

Rotationally supported disk

Outflow

Reduced fragmentation

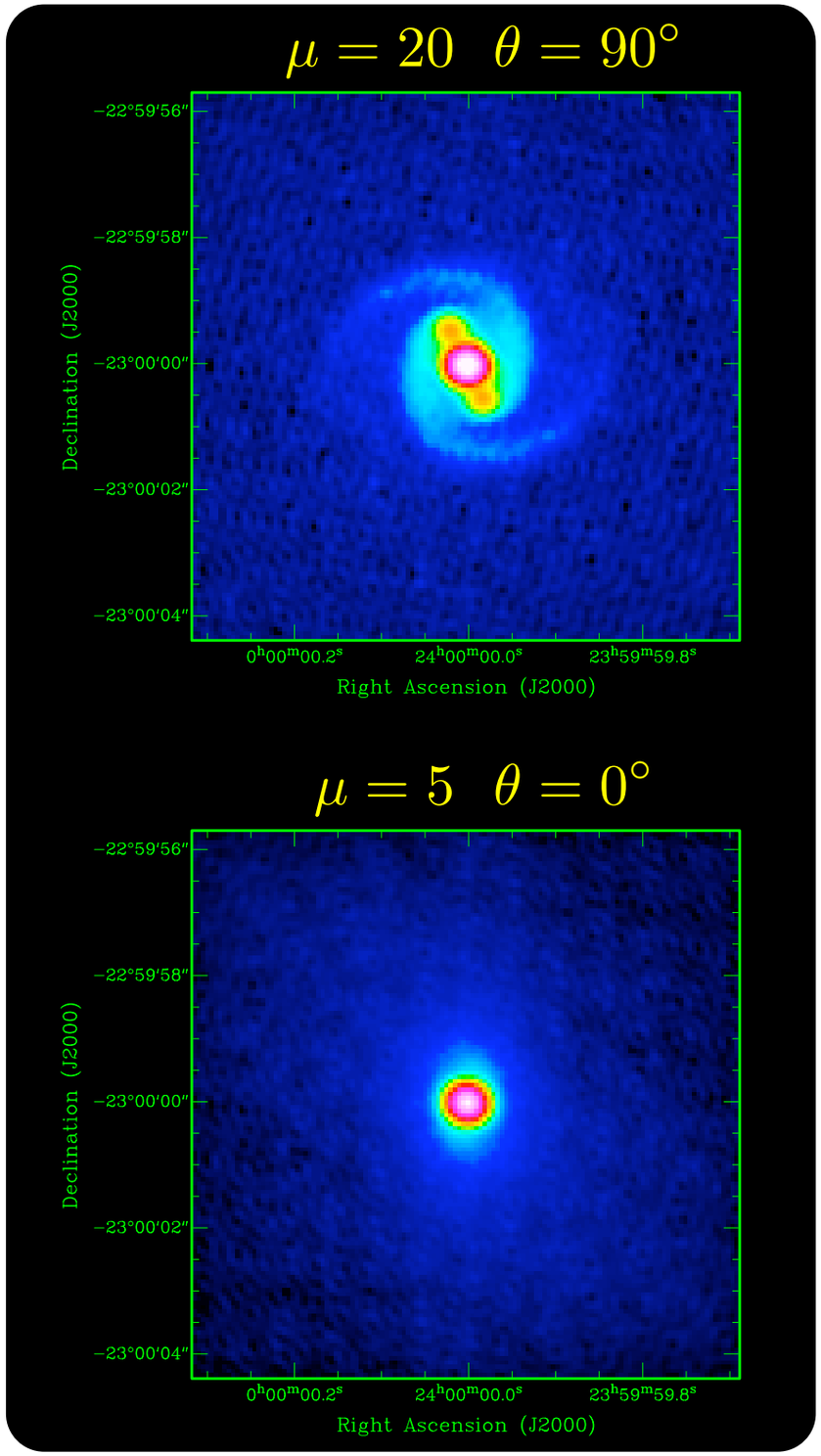
ALMA simulator

Strong magnetic field (μ=2)

Pseudo-disk

Outflow

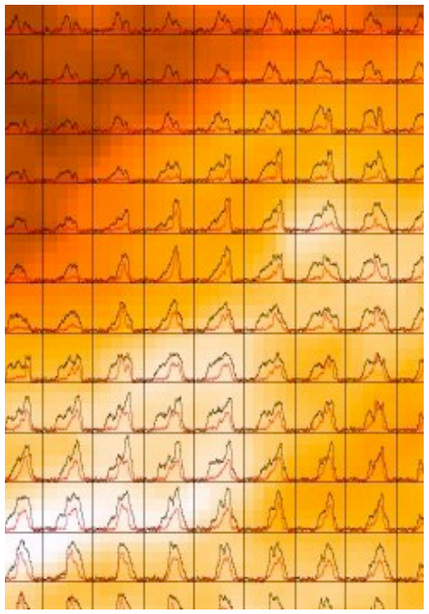
No fragmentation

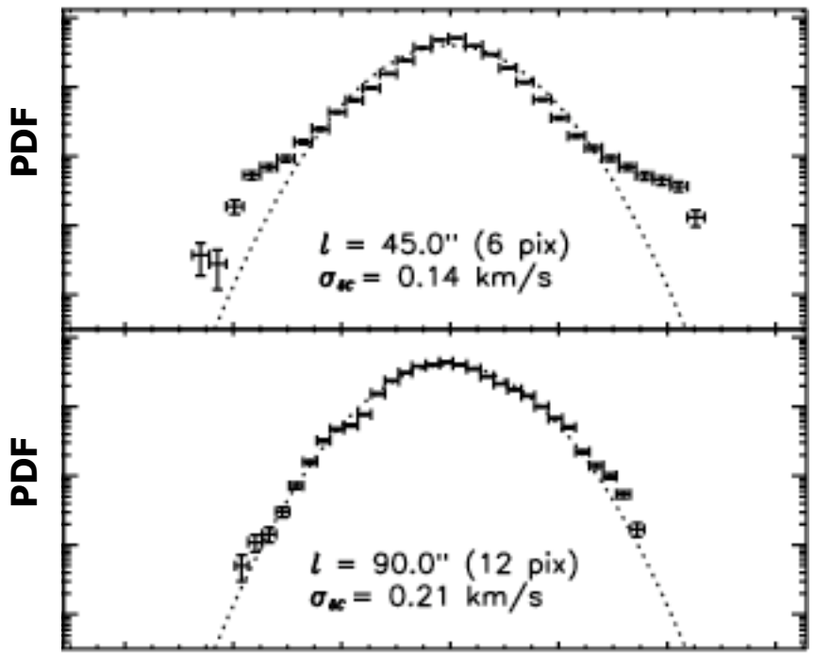


Turbulent energy dissipation

J. Pety, P. Hily-Blant, E. Falgarone, B. Godard

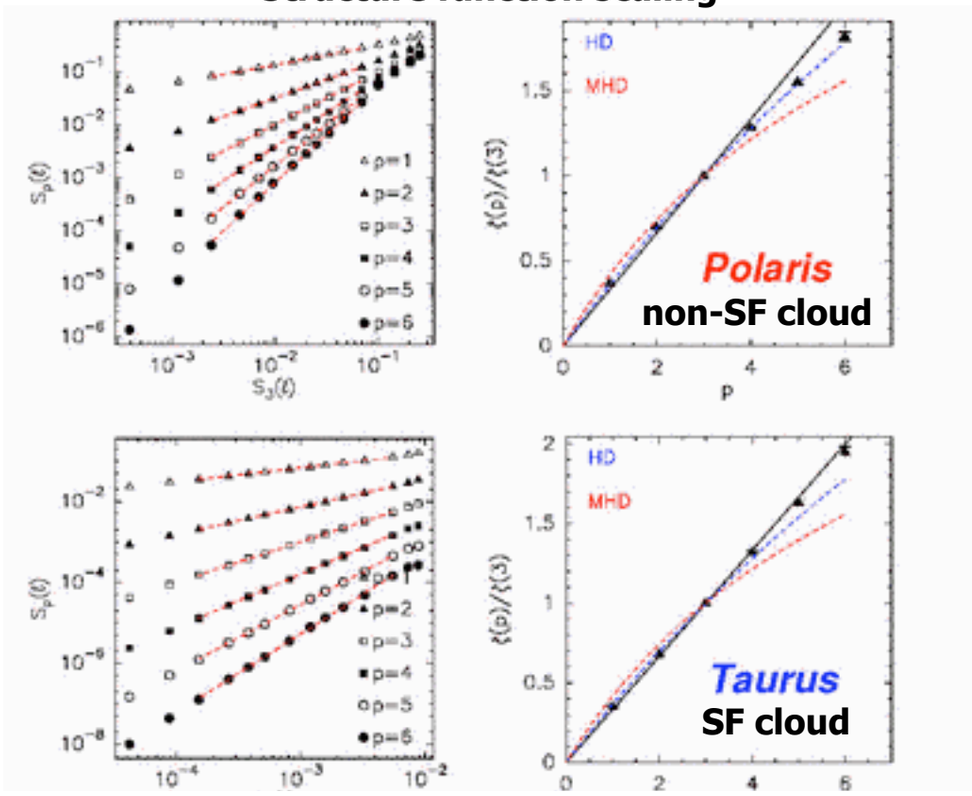
1.5 million spectra in 60 hours of telescope time





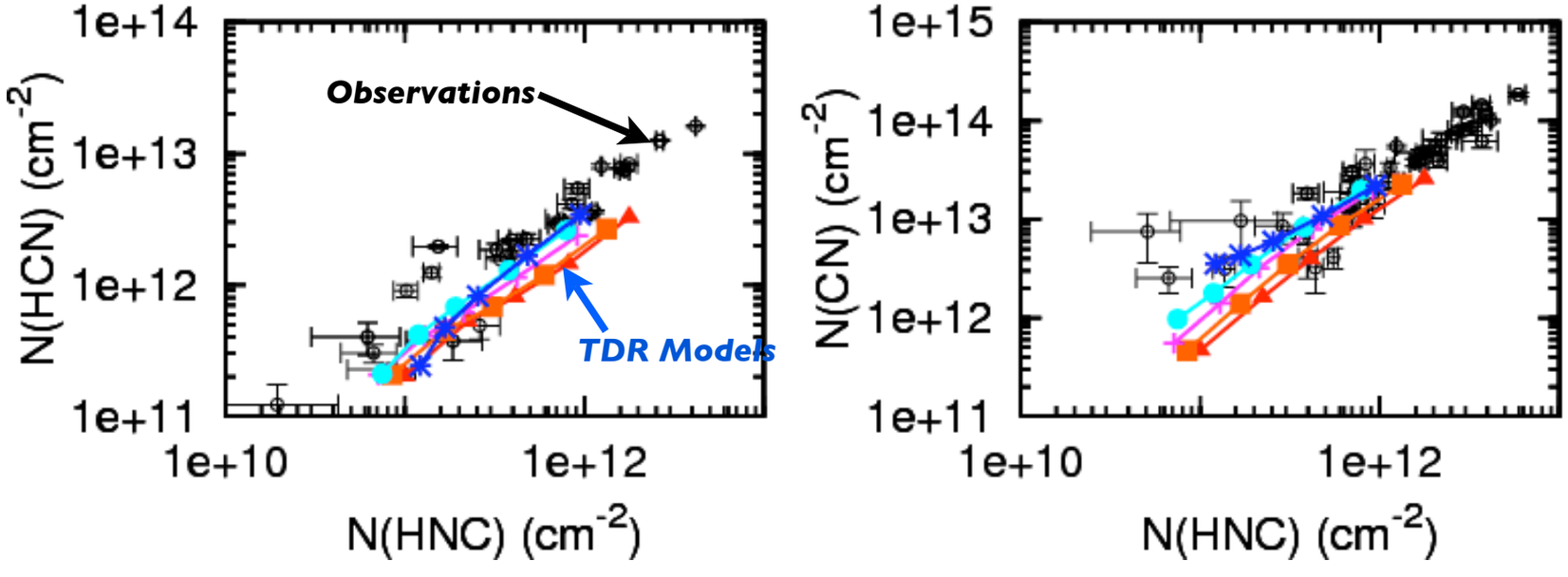
Normalized centroid increments

Structure function scaling



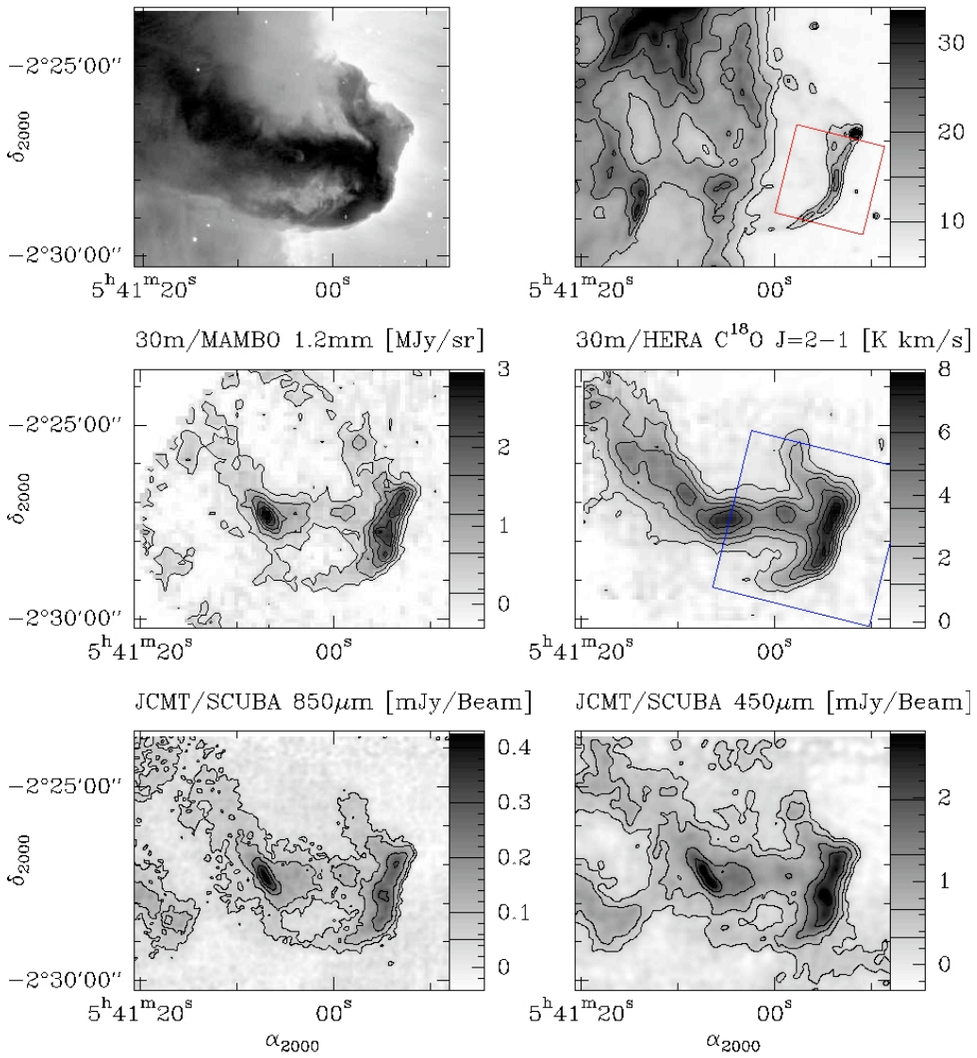
Non-Gaussian statistics of velocity field increments are signatures of **intermittent** dissipation of interstellar turbulence

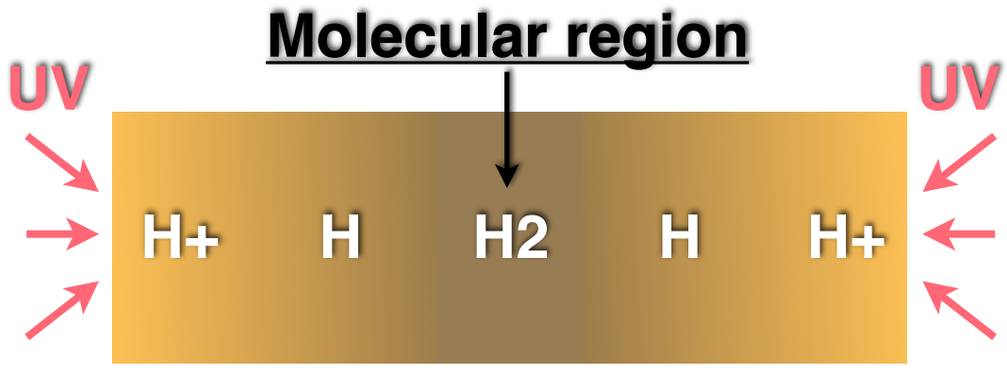
Hot chemistry in the cold diffuse ISM

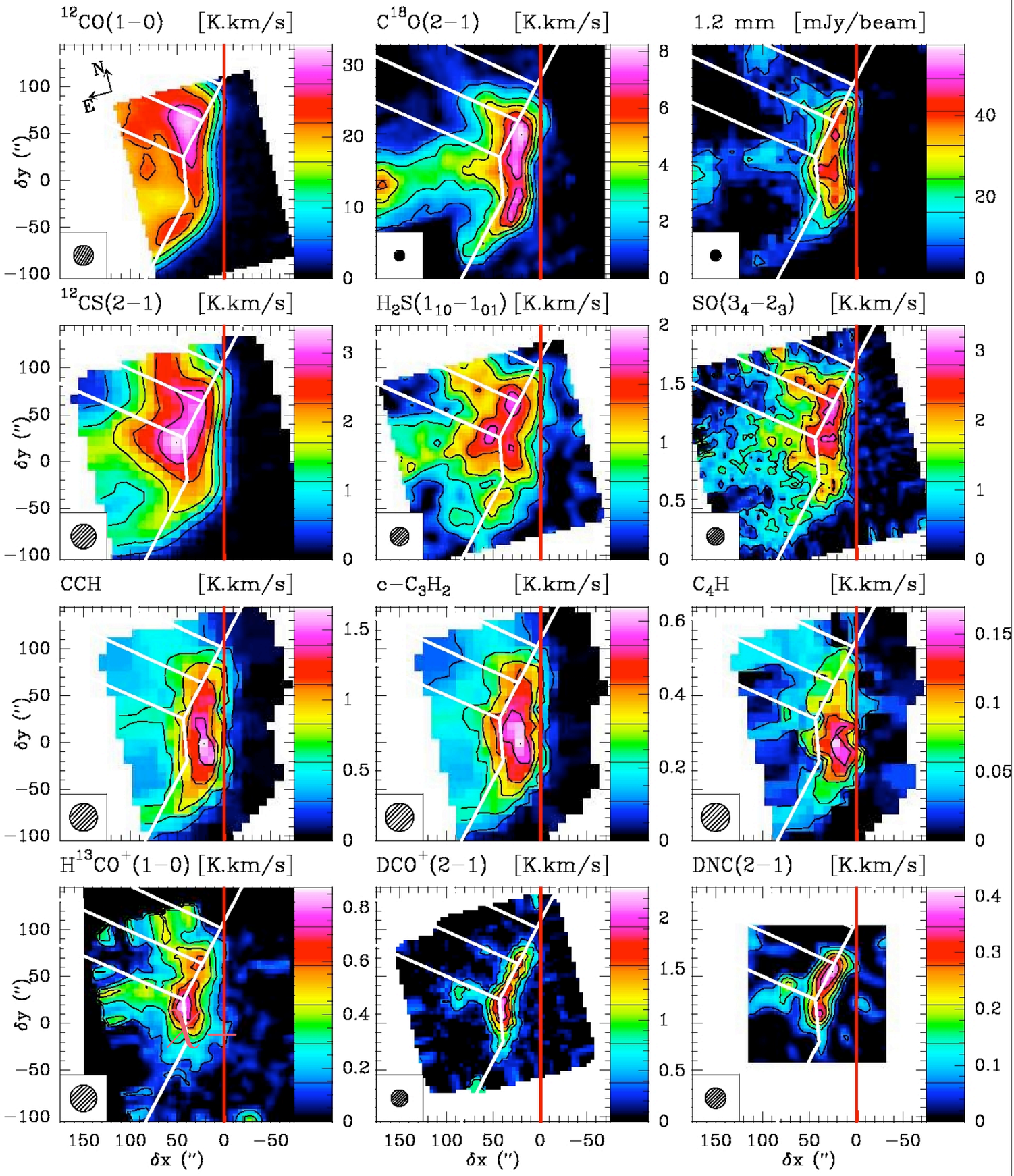


Chemistry in photon-dominated regions

M. Gerin, J. Pety, J. Goicoechea



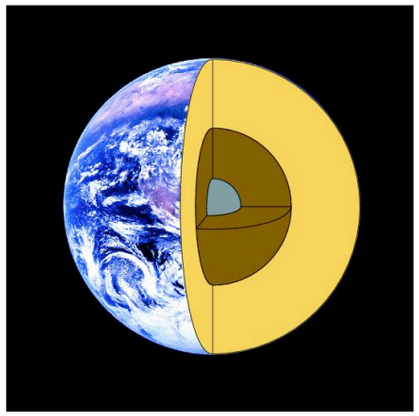


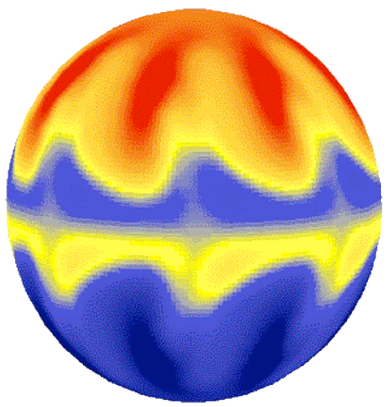


Dynamos in astrophysics : from the Earth to the Sun

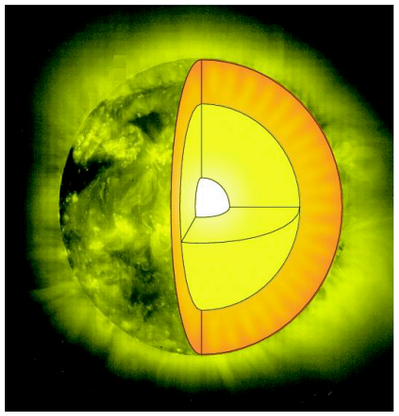
E. Dormy et al.

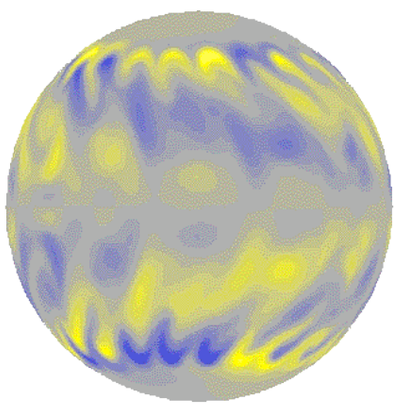
Earth



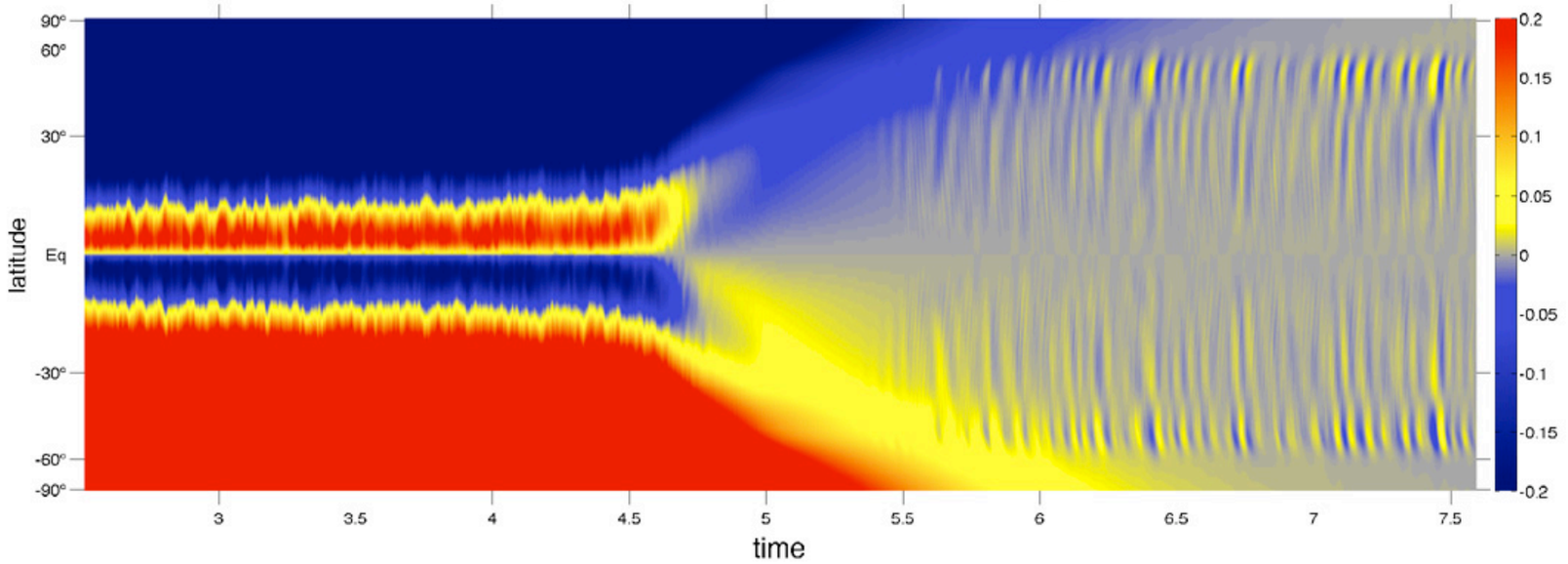


Sun





Radial field averaged over longitude

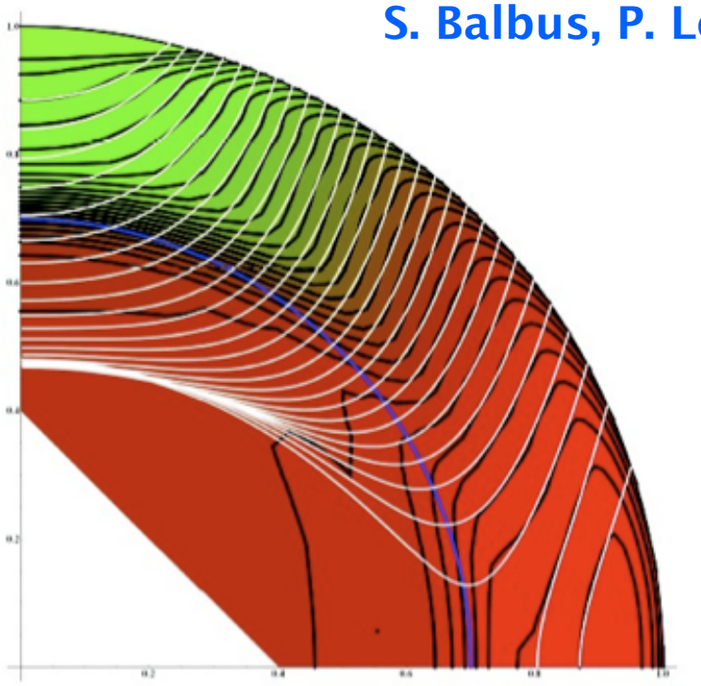


Transition from a steady dipolar dynamo mode (Earth-like) to a dynamo wave solution (Solar-like) for a critical value of the convective volume aspect ratio.

Some other topics...

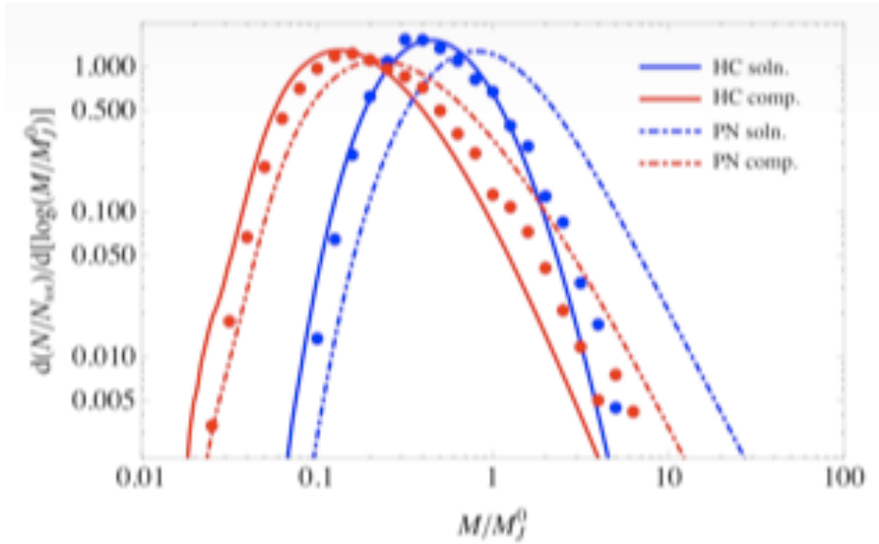
Isorotational curves in the solar interior

S. Balbus, P. Lesaffre



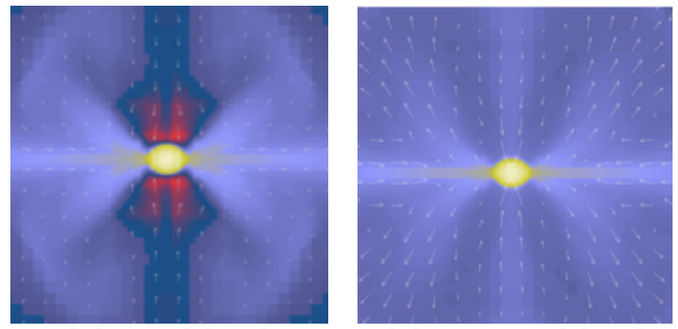
From the core mass function to the stellar initial mass function

P. Hennebelle



Non-ideal MHD effects on core collapse

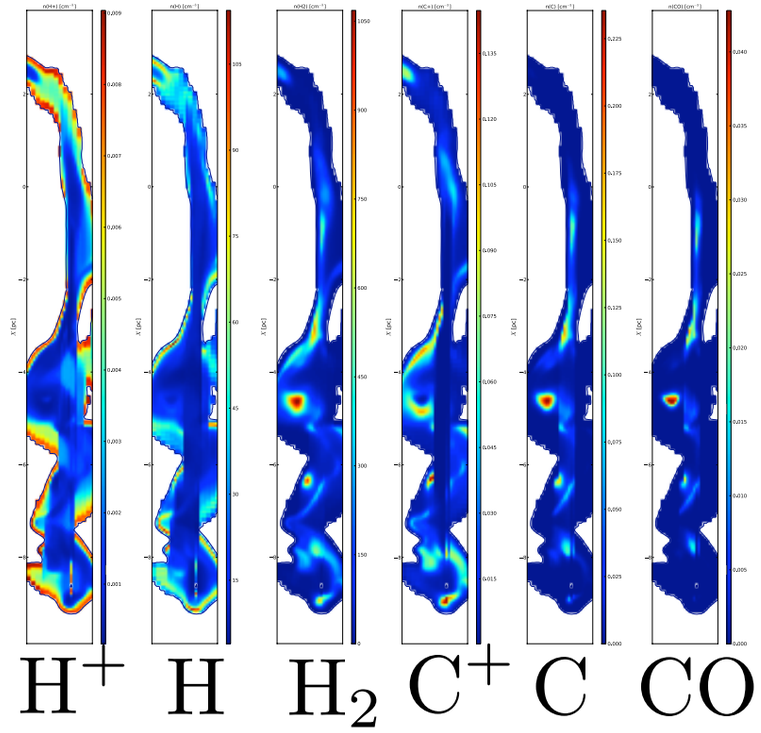
J. Masson, P. Hennebelle



With ambipolar diffusion | **Without ambipolar diffusion**

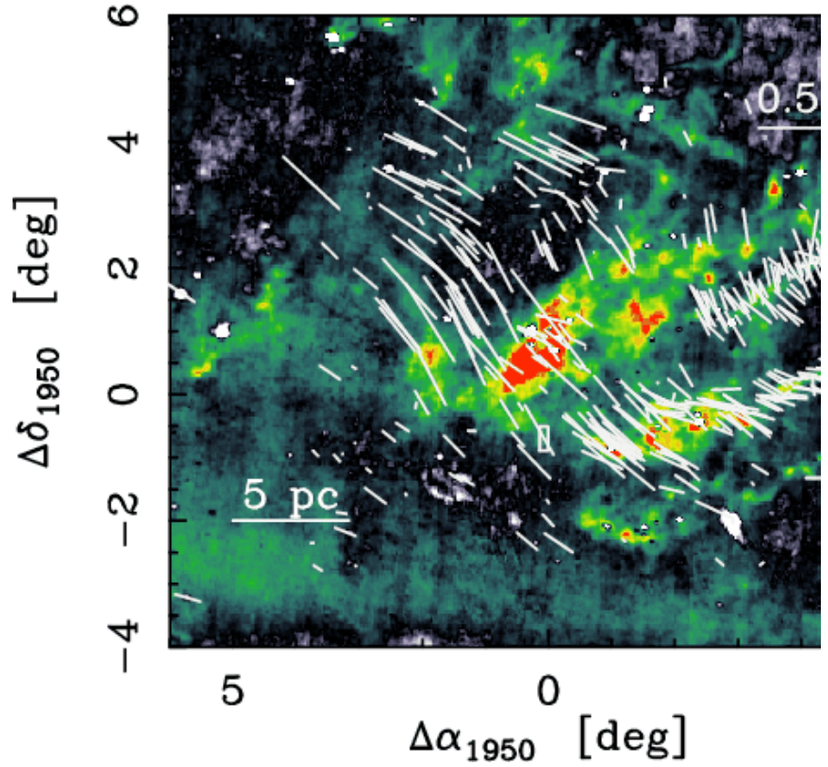
MHD simulations post-processed with UV photochemistry

F. Levrier



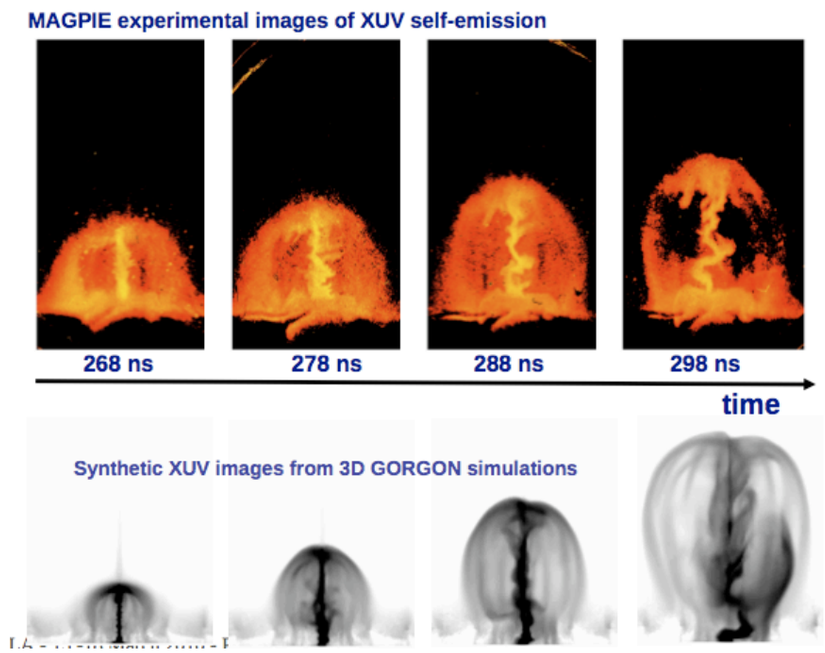
Filamentary structures in the ISM : threaded by the magnetic field ?

P. Hily-Blant, E. Falgarone



Simulations of laboratory experiments

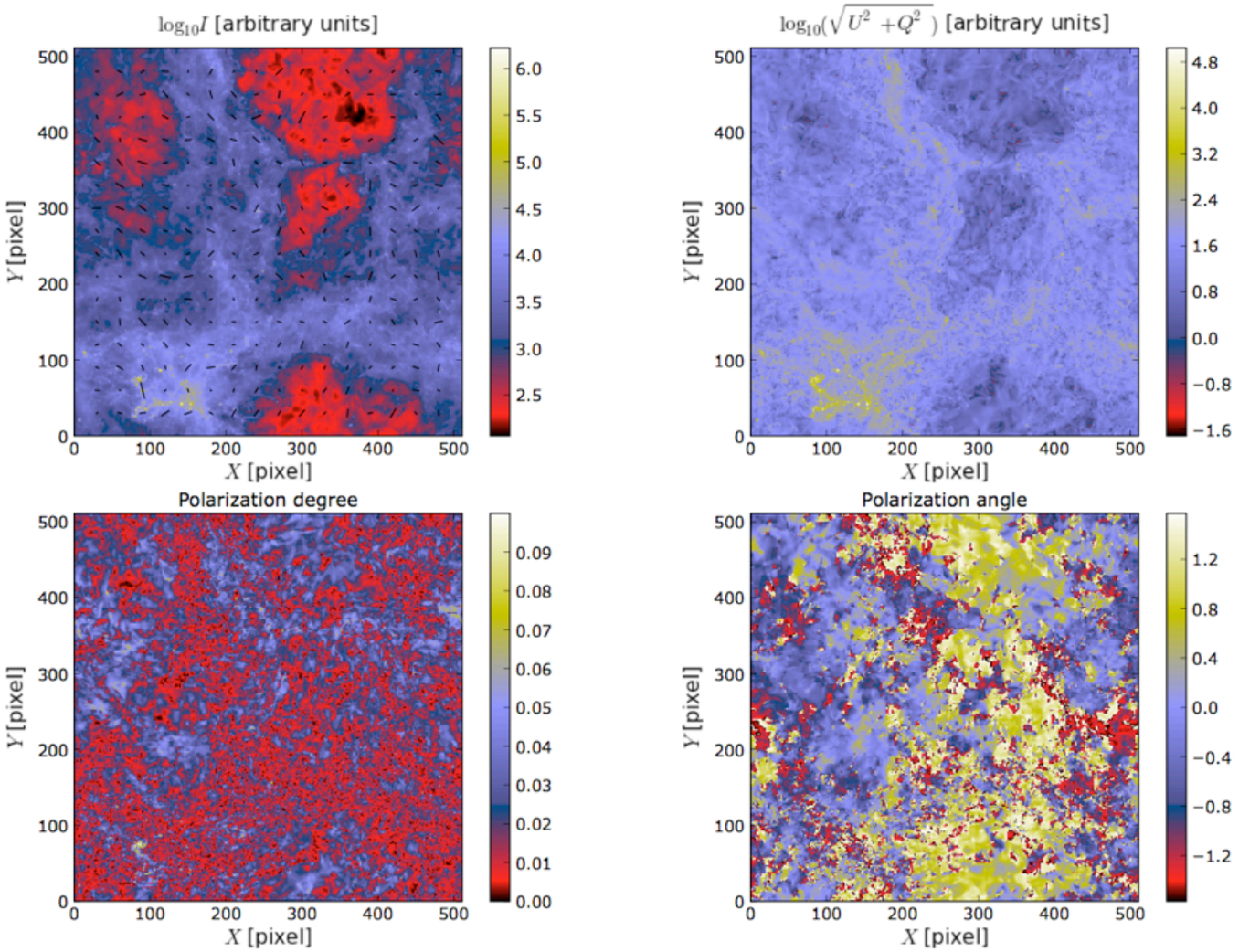
A. Ciardi



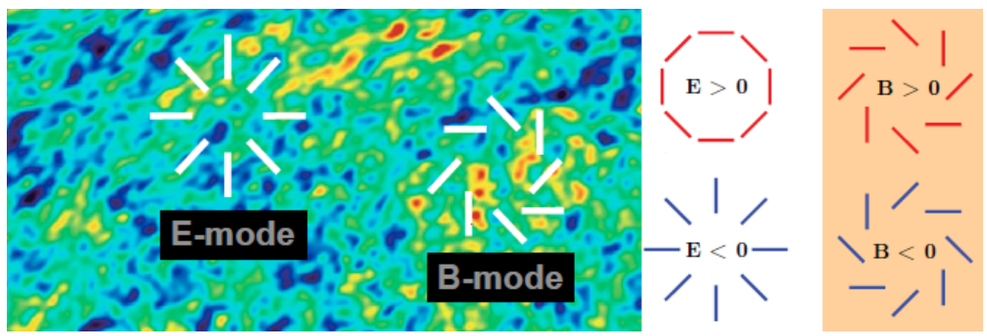
Opening towards cosmology

Statistics of polarized dust emission for the analysis of Planck data

F. Boulanger, F. Levrier, E. Falgarone



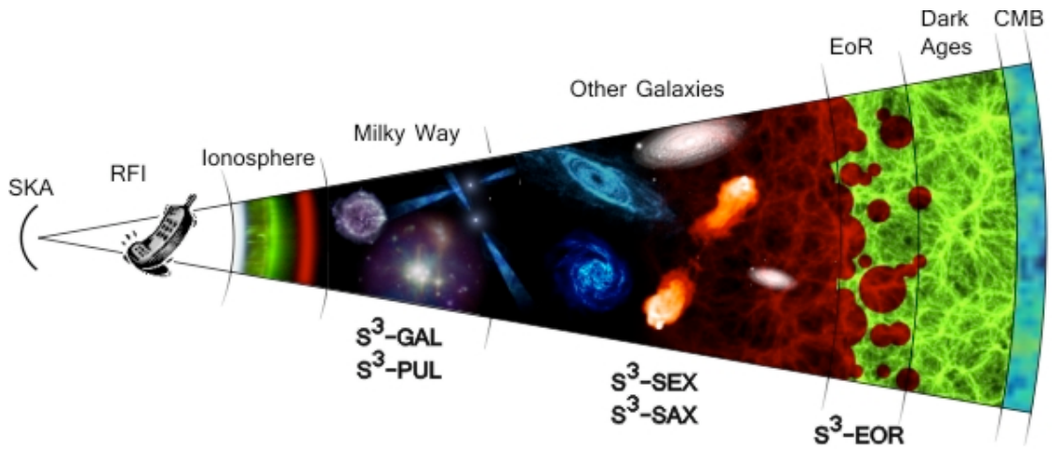
CMB polarization linked to primordial gravity waves

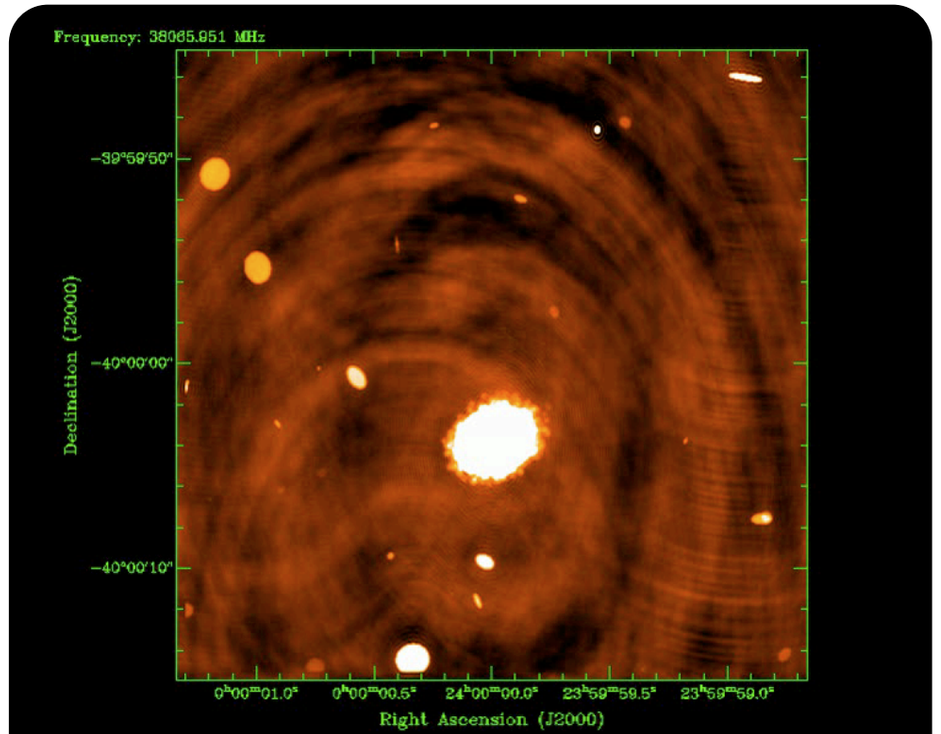


Simulated radio skies at high redshift for the SKA and ALMA

F. Levrier with Oxford astrophysics

SKA Simulated Skies (S^3)





30” x 30” x 64 channel simulation of an ALMA observation of a CO source at z~2 from S^3-SAX + continuum from S^3-SEX

Perspectives

Turbulence, magnetic fields and chemistry combined : observations and theory

MHD turbulence

- Towards non-ideal MHD
- Coupling to chemical network “on-the-fly”

Characterisation of ISM turbulence, magnetic fields and chemistry

High-resolution spectroscopy of the interstellar medium

- On-going Herschel and IRAM programs
- Participation in the SPICA mission project, ALMA proposals

Opening towards cosmology

- Characterization of foregrounds for the Planck mission
- Participation in the SKA project regarding extragalactic atomic and molecular gas

Within the Physics department

- Maintain close interactions within the Physics department (e.g. LPS for MHD)
- Maintain close interactions between observers & theorists
- Involvement in the teaching (introductory astrophysics, hydrodynamics,...)