First Astronet Joint Call

STAR FORMAT

Star Formation: Models and Tools

French-German Project

4 teams

Paris Observatory/LERMA-ENS:

Patrick Hennebelle, Pierre Lesaffre, Edith Falgarone, Francois Levrier,
Marc Joos, Benjamin Ooghe, Jean-Francois Rabasse, Nicolas Moreau

Paris Observatory/LUTH:

Franck Le Petit, Jacques Lebourlot, **Cecilia Pinto**

University of Heidelberg and MPI:

Ralf Klessen, Robi Banerjee, Simon Glover, Cornelis Dullemond,
Paul Clark, Milica Milosavjevic, Christoph Federrath

University of Hamburg:

Peter Hauschildt

Financial overview:

-2 postdoctoral positions for 2 years

1 Heildelberg (coupling between AMR and radiative transfer codes)

1 Meudon/Luth (development of 1D PDR codes in spherical geometry)

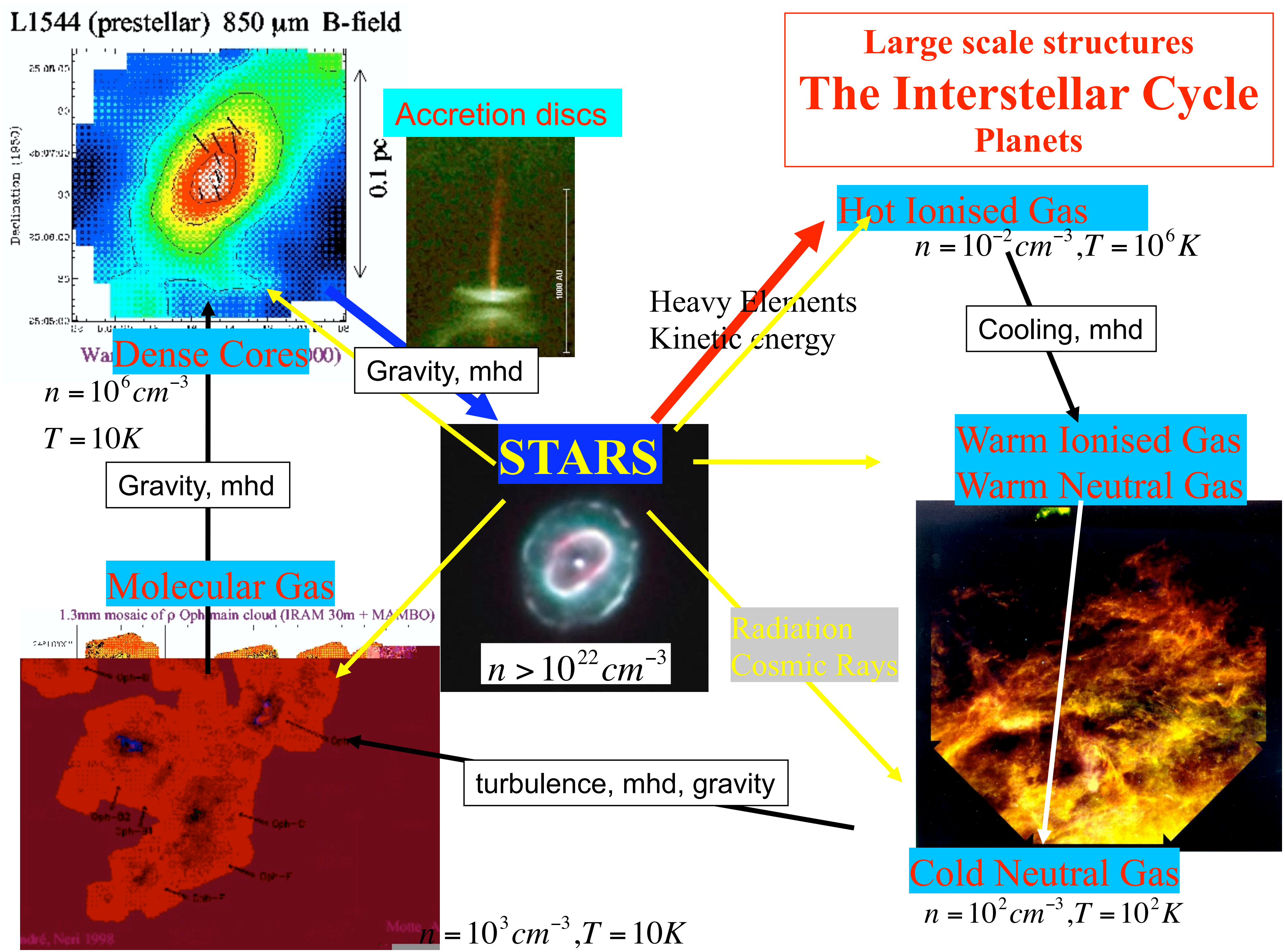
-2 PhD positions

1 Heidelberg: perform large scale MHD simulations

1 Lerma-ENS: study MHD collapse and fragmentation

-1 sofware engineer for 2 years

Lerma-ENS / Meudon: build the database



Large scale structures
The Interstellar Cycle
Planets
L1544 (prestellar) 850 μm B-field
Declination (1950)
0.1 pc
Accretion discs
1000 AU
Dense Cores
$n = 10^6 cm^{-3}$
$T = 10K$
Gravity, mhd
Gravity, mhd
Heavy Elements
Kinetic energy
Hot Ionised Gas
$n = 10^{-2} cm^{-3}, T = 10^6 K$
Cooling, mhd
STARS
$n > 10^{22} cm^{-3}$
Warm Ionised Gas
Warm Neutral Gas
Molecular Gas
1.3mm mosaic of ρ Oph main cloud (IRAM 30m + MAMBO)
Radiation
Cosmic Rays
turbulence, mhd, gravity
Cold Neutral Gas
$n = 10^2 cm^{-3}, T = 10^2 K$
$n = 10^3 cm^{-3}, T = 10K$

GOALS:

Leading scientific questions:

- **-what regulates star formation in galaxies ?**
- **-what determines the initial mass function ?**

-structure of molecular clouds ?

-how energy is injected ?

-magnetic versus turbulent support ?

-how the gravitational collapse proceeds ?

-Investigate the formation of molecular clouds, prestellar dense cores and circumstellar protoplanetary disks

-provide to the observers a well documented database of models necessary to interpret the future Alma and HSO data

Four realms of expertise:

-Compressible MHD simulations

Perform large scale MHD and self-gravitating simulations (10^9 cells) to study molecular cloud and dense core formations

Perform a series of smaller simulations extracted from the larger ones to study dense core collapse in great details

-Radiative transfer

Postprocess the 3D simulations, calculate simple chemistry and calculate continuum and simple lines radiative transfer

Compute "on the fly" simplified radiative transfer and simple chemistry

-Detailed chemistry

Extract profiles from the simulations and use PDR codes to make detailed predictions on abundances and spectral lines

-Database

Build a VO compatible database of clumps and cores extracted from the simulations including statistics, full clumps detailes and radiative transfer map

Link it to the Meudon-PDR codes

Expertise and Codes

LERMA-ENS:

MHD, out of equilibrium chemistry, observations of MC

RAMSES code

LUTH:

Detailed chemistry at equilibrium, radiative transfer, data base

Meudon PDR code

University of Heidelberg:

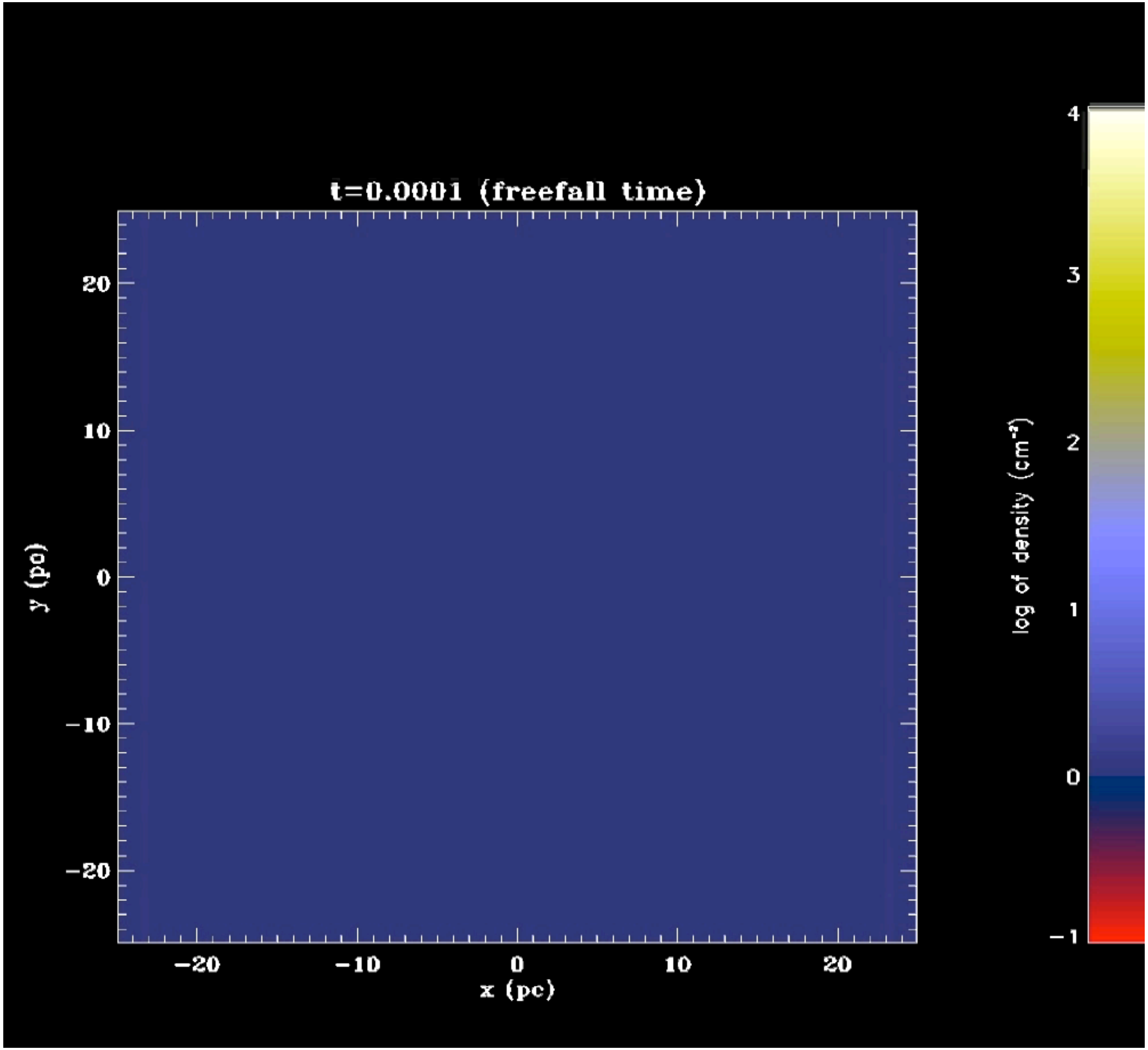
MHD, out of equilibrium chemistry radiative transfer

FLASH and GADGET codes, Dullemond's code (continuum)

University of Hamburg:

Radiative transfer

PHOENIX code



t=0.0001 (freefall time)
20
10
0
−10
−20
y (pc)
−20
−10
0
10
20
x (pc)
4
3
2
1
0
−1
log of density (cm⁻³)

ISM: transition HI to H_2

consistent models of ISM dynamics require to go beyond the simple models!

- magnetohydrodynamics

  (account for large-scale dynamics + turbulence)

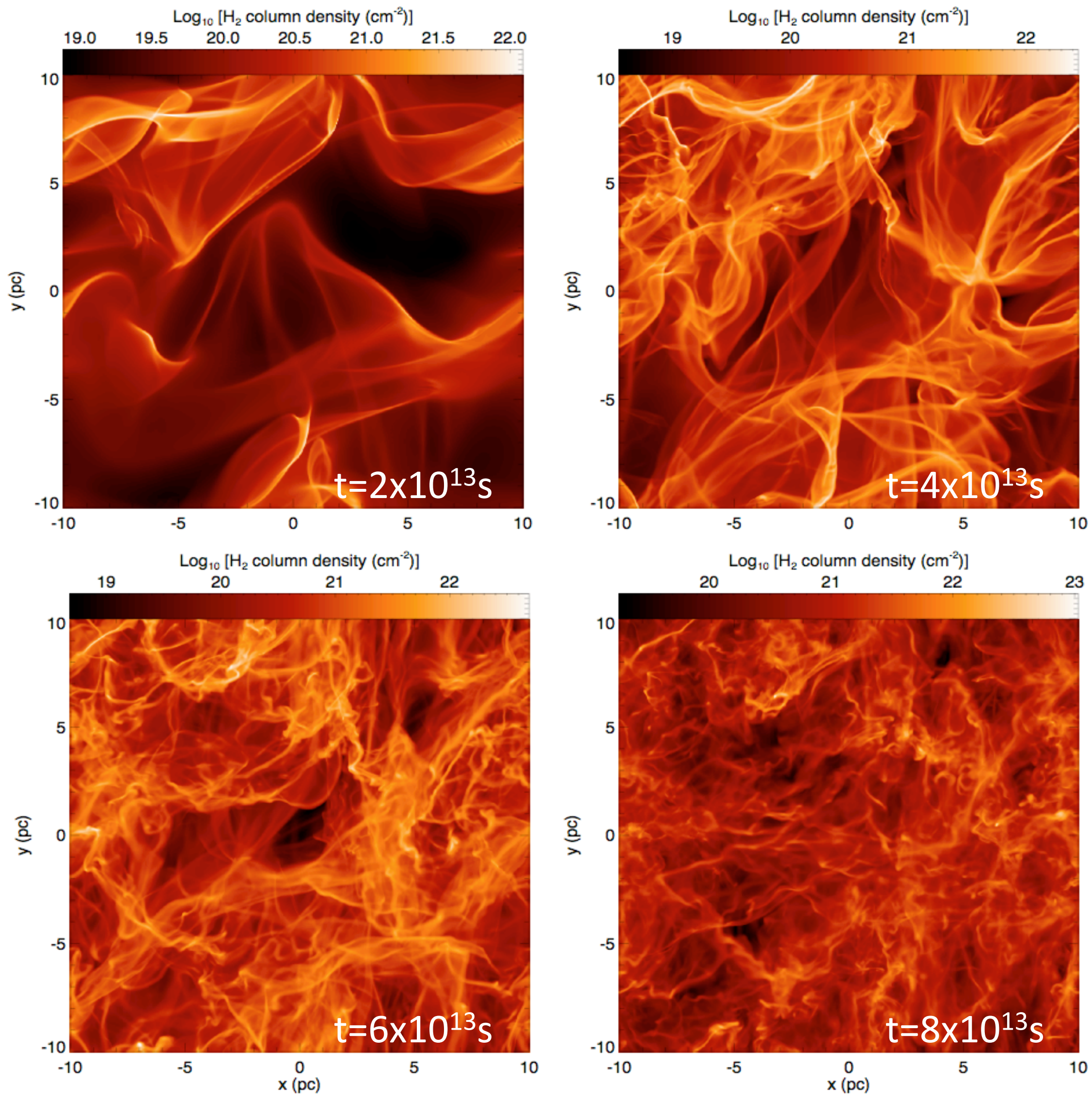
- time-dependent chemistry

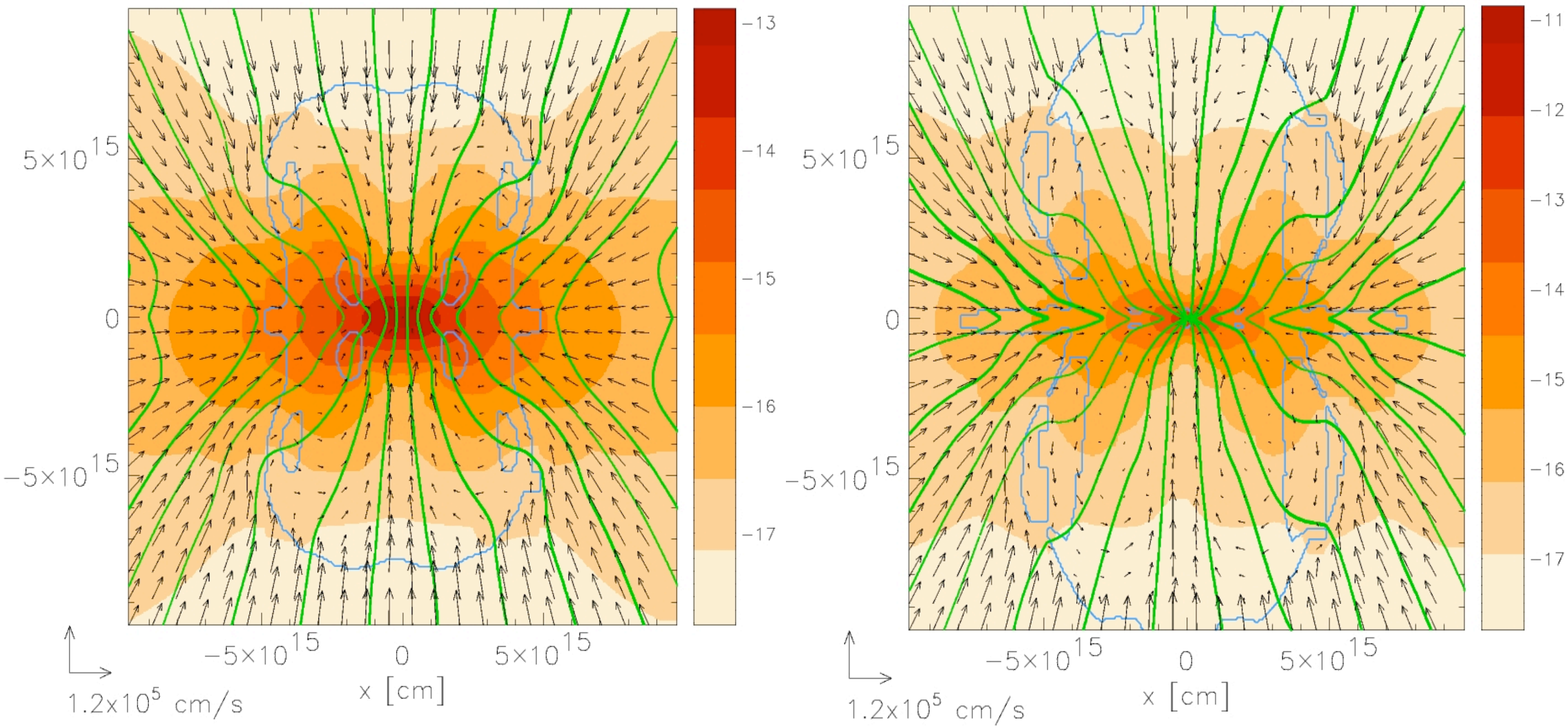
  (reduced network, focus on few dominant species, e.g. H_2)

- radiation (currently simple assumptions)

H2 forms rapidly in shocks / transient density fluctuations / H2 gets destroyed slowly in low density regions / result: turbulence greatly enhances H2-formation rate

(Glover & Mac Low 2006ab:)

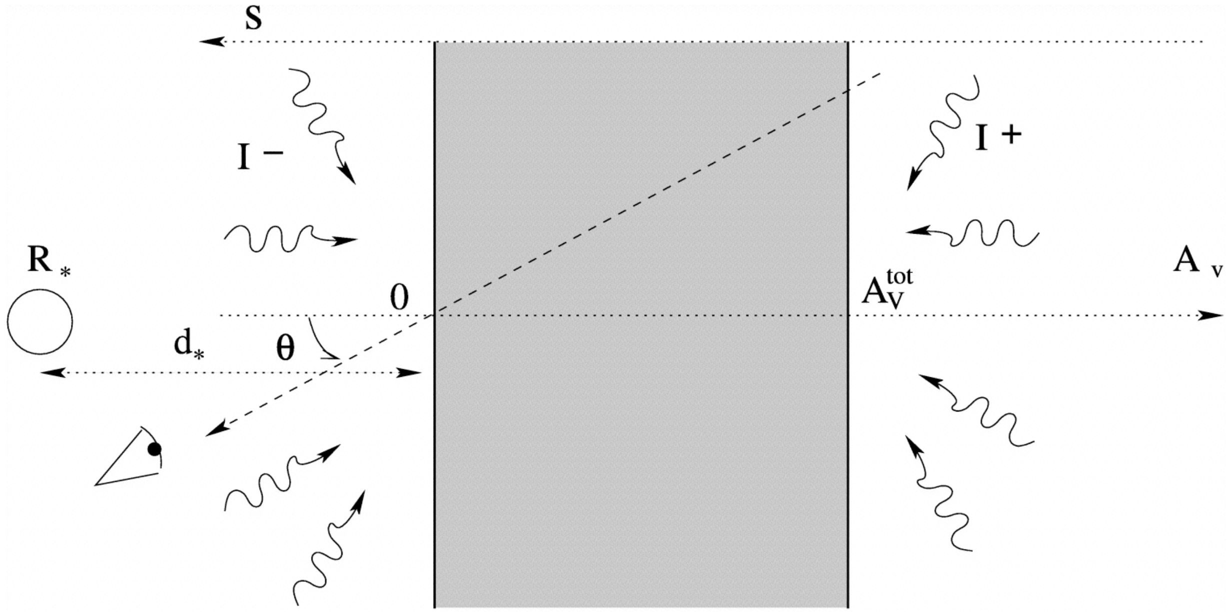


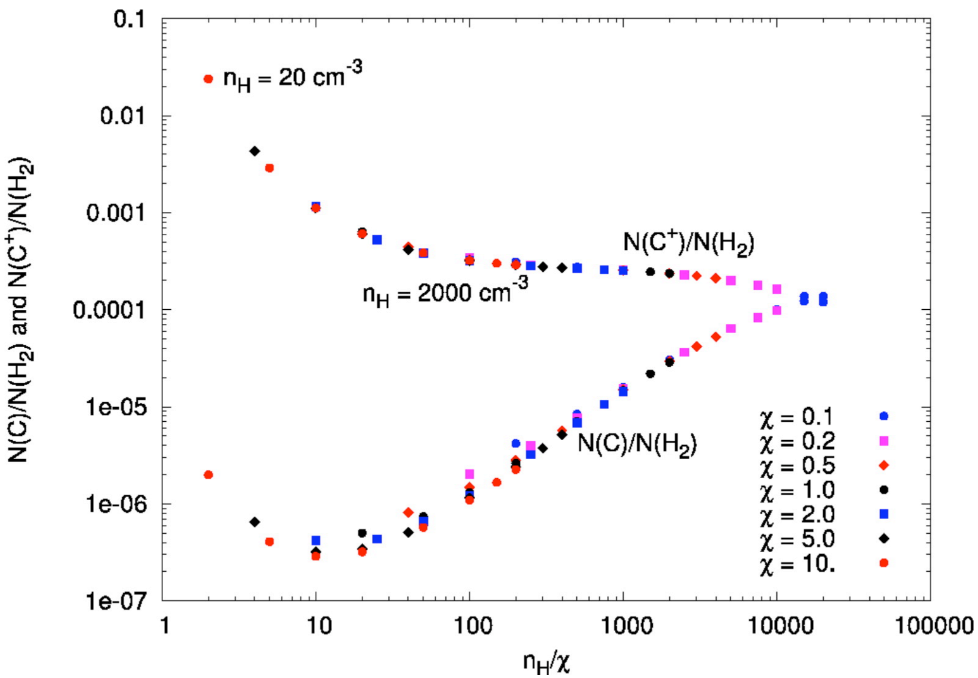


These 2D snapshots show the onset of the **large scale outflow**. After ca. 70.000 years into the collapse a strong toroidal magnetic field builds up whose magnetic pressure reverses the gas flow and drives an outflow (time difference between these snapshots: 1400 years).

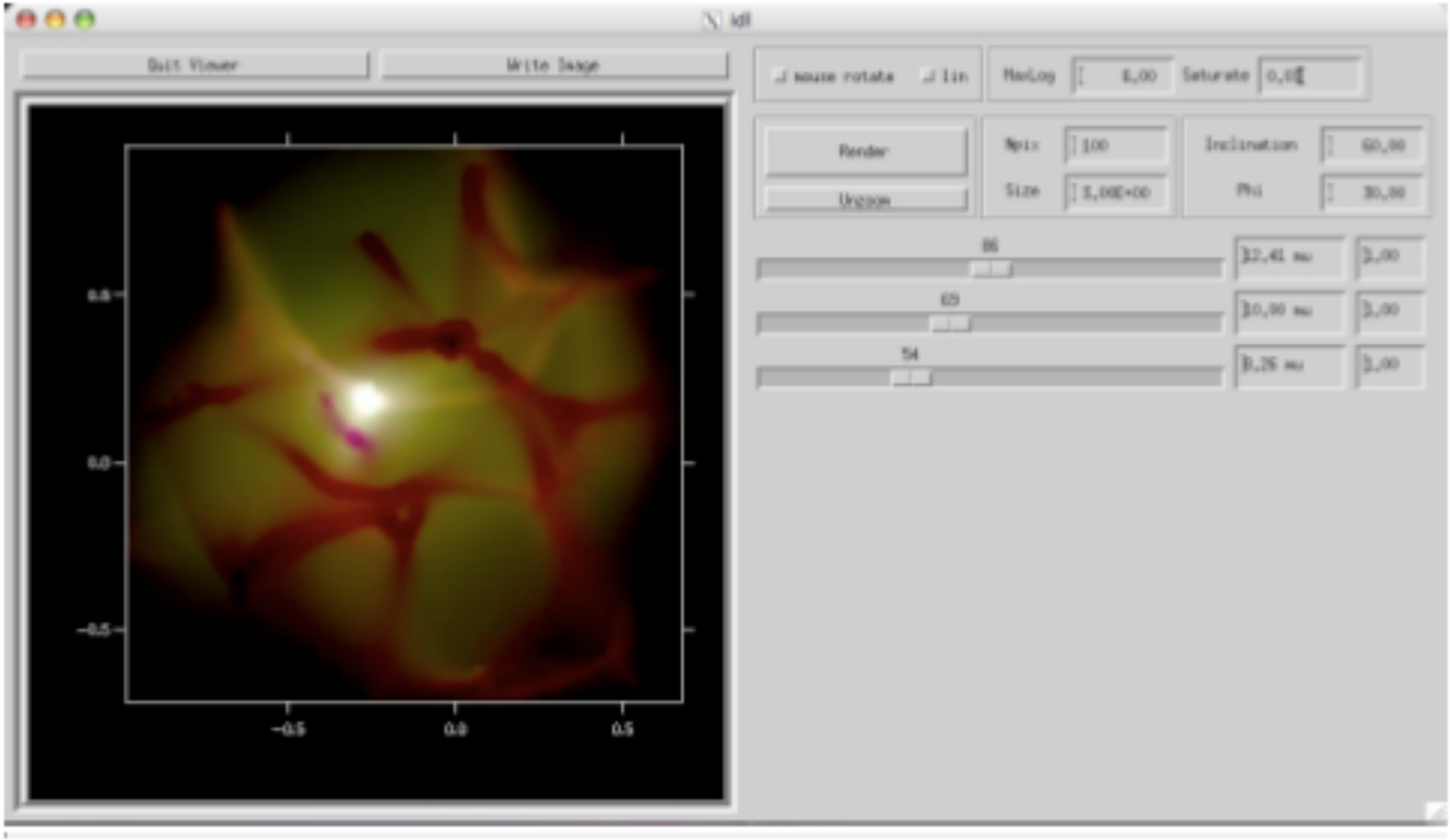
(Banerjee & Pudritz 2006)

Meudon PDR codes (Le Petit et al. 2006)





Kees Dullemond's radiative transfer code

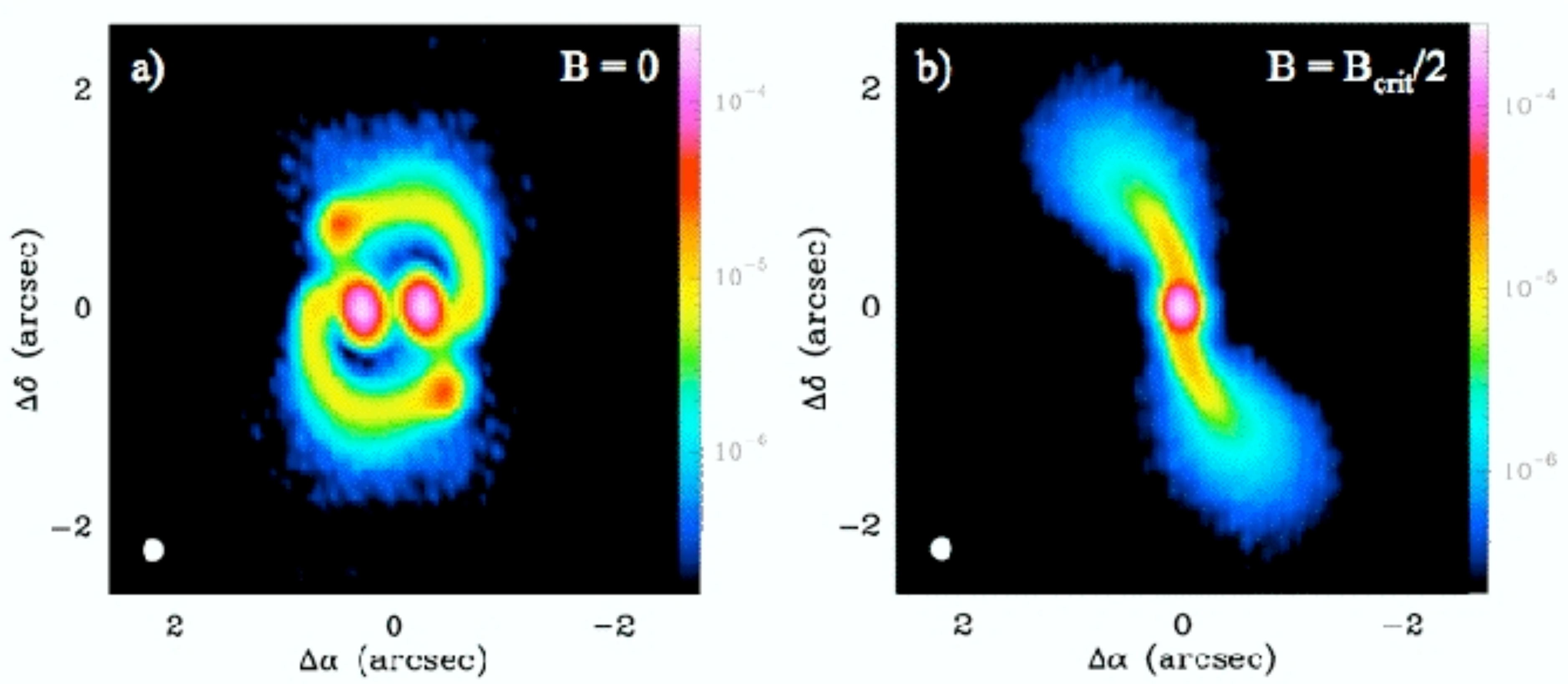


Prepare future observations

ALMA will give access to very good spatial resolution

Synthetic observations done with the ALMA simulator

Included in the Gildas software



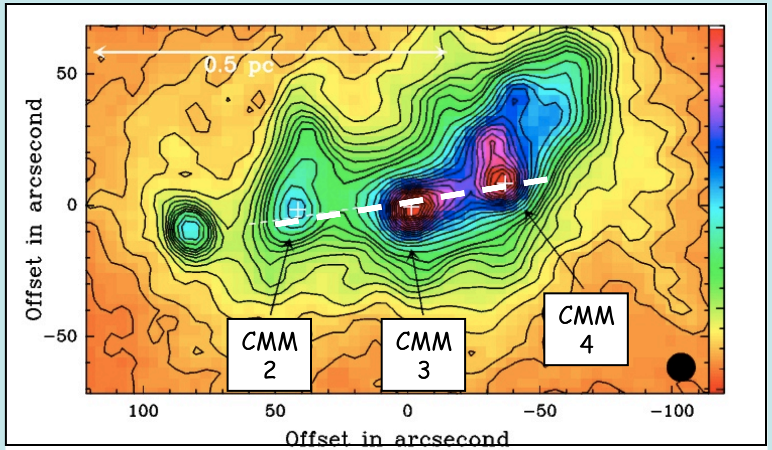
André, Hennebelle, Peretto 2008

Interpret observations

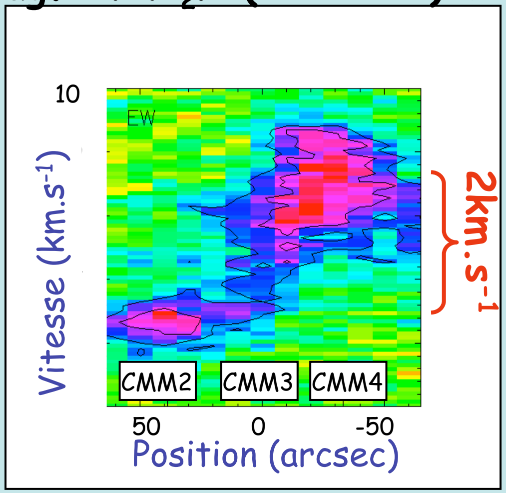
Modelling of a molecular clump
Observations 30m - SPH simulations 5,000,000 particles

(Peretto, André, Belloche A&A 2006, Peretto, Hennebelle, André A&A 2007)

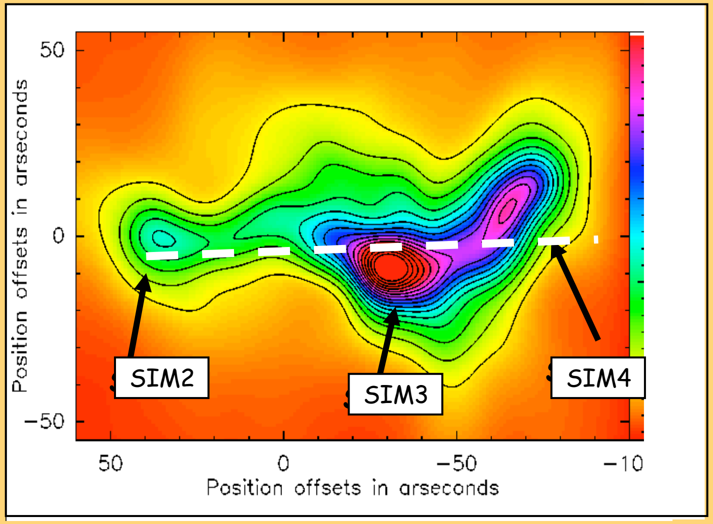
Continuum 1.2mm 30m



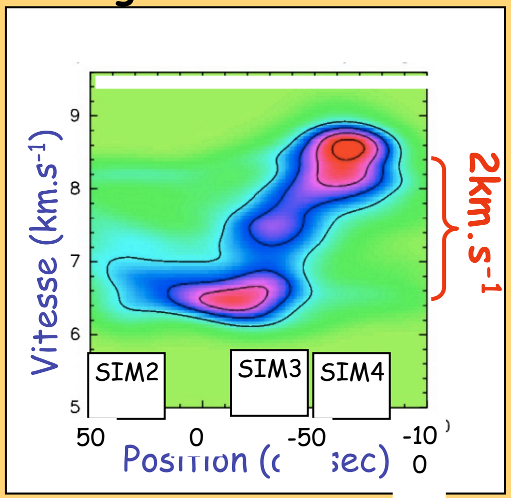
Diag. PV N_2H^+(101-012) 30m



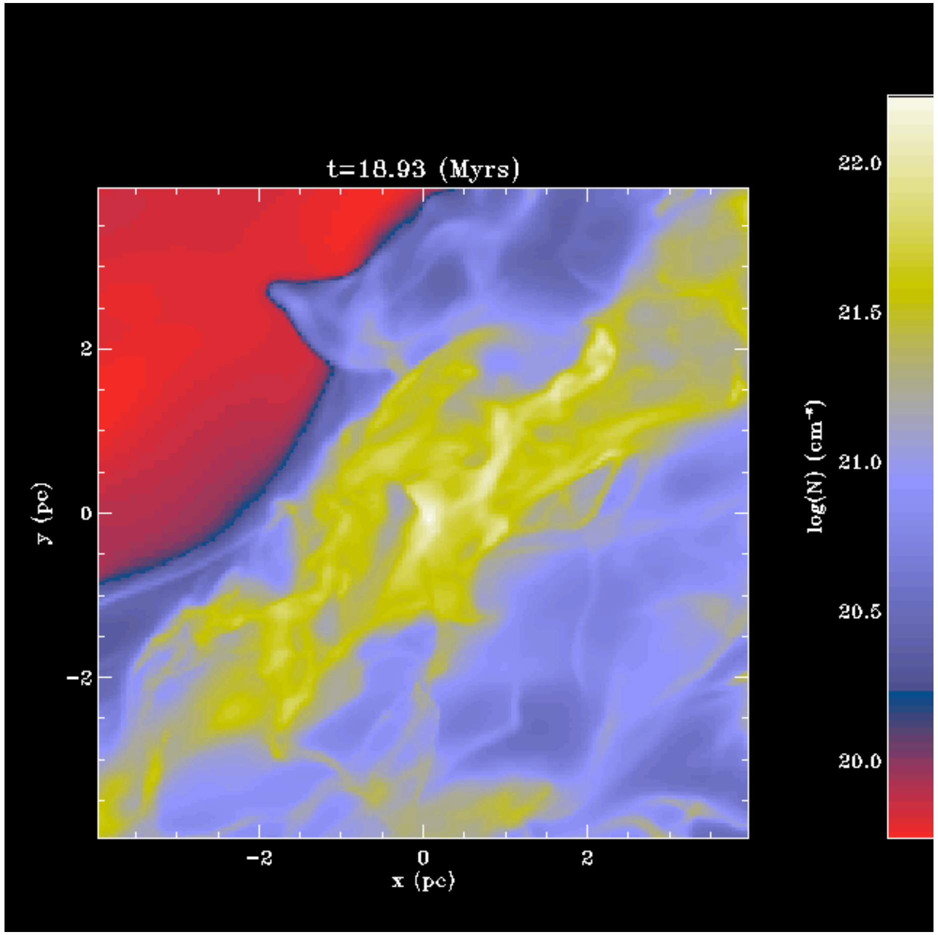
Carte colonne densité simulée 30m



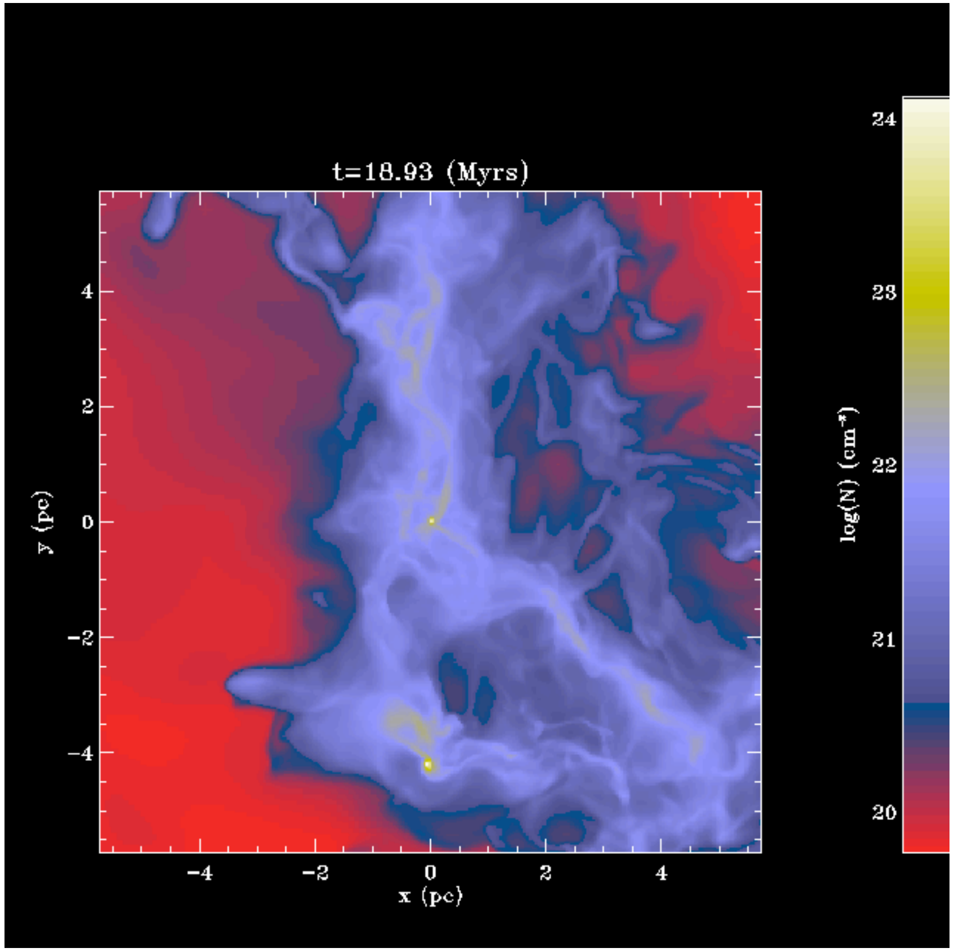
Diag. PV simulé 30m



Few examples of clumps in the database



Starless

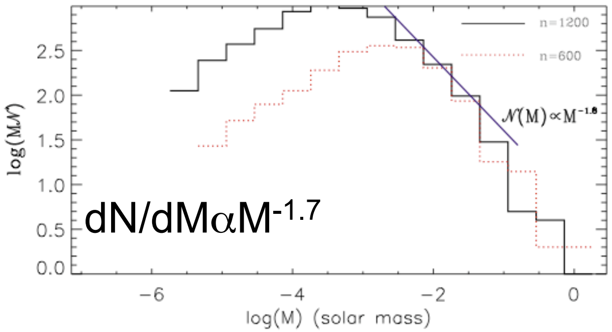


Star already formed

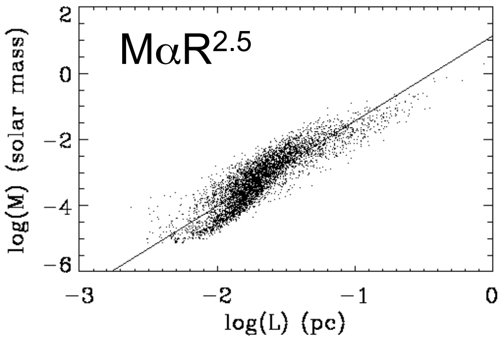
A set of clumps (few thousands) with their properties (mass, velocity dispersion)
Possibility to query on their properties.

Statistics of structures:

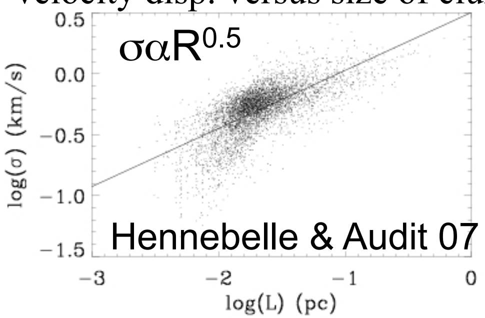
Mass spectrum of clumps



Mass versus size of clumps

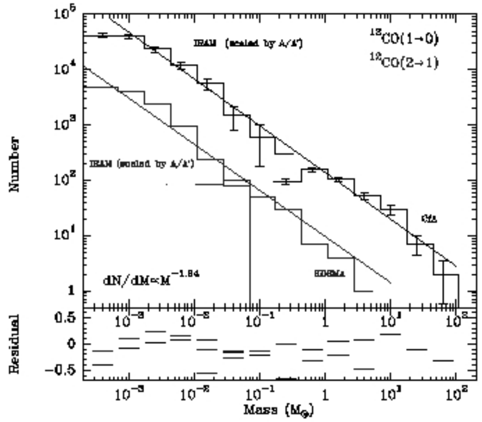


Velocity disp. versus size of clumps

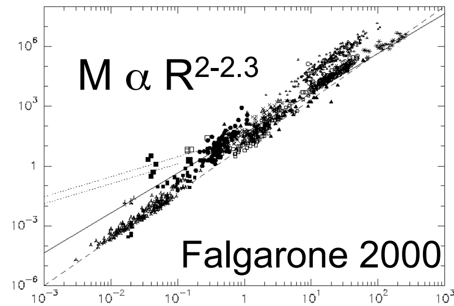


Universal Mass Spectrum

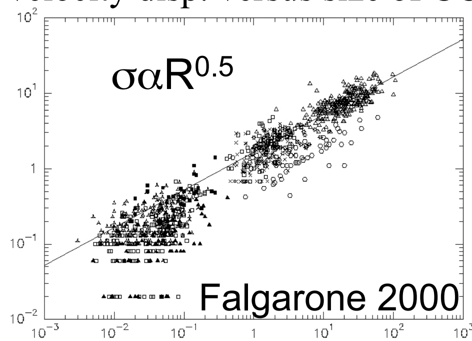
dN/dM α $M^{-1.6-1.8}$ (Heithausen et al .98)



Mass versus size of CO clumps



Velocity disp. versus size of CO clumps



The database will evolve….

This is the first time in Europe and one of the first time in the world that such effort is done in this context (running behind the cosmologists…)

-it will contain data from teams outside the observatory, at least from the german team

-new simulations will be continuously added

-the needs and the request will continuously change following discussions with observers and depending on the evolution of the numerical simulations

-Long ranging efforts

Merci à :

Laurent Bourges, Benjamin Ooghe et Nicolas Moreau