The Formation of Molecular Clouds (Setting the SFE): Revisiting the Role of Turbulence & Fields

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The Cypress Cloud, Spitzer/GLIMPSE, FH et al. 10?

The Points to be Made:

(1) Molecular clouds are *finite*.
And gravity is a long-range force.
Thus, global gravity rules.
Filaments are a natural consequence.

(2) Molecular clouds are dynamic (= not in equilibrium).
They are collapsing and accreting mass (see Pipe/Ophiuchus).

(3) "Turbulence" in molecular clouds is driven by global gravity.
Turbulent support does not exist.

(4) Magnetic fields support diffuse envelope, but seem irrelevant in high-density filaments.

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(5) The SFE is set by rapid fragmentation during the cloud's formation (thermal/dynamical/gravitational).
The diffuse cloud "envelope" is not contributing to the SF budget (magnetic field, rotation).
Need for an exit strategy (feedback, dissociation, tidal disruption)?

Physical Constraints

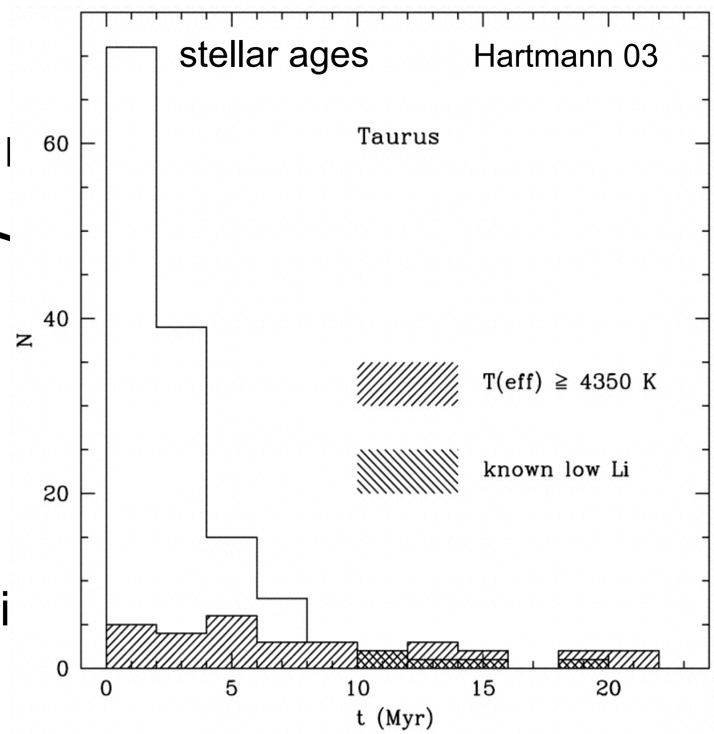
Most clouds form stars.
Stellar age spreads are small (1-3 Myr).
There is (nearly) no delay between cloud and star formation.

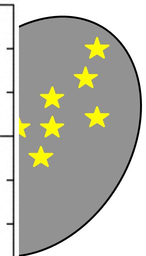
$$\tau_{ff} = \sqrt{\frac{3\pi}{32G\rho}}$$

3Myr @ 100 cm^{-3}

free-fall time independent of radius.

wi

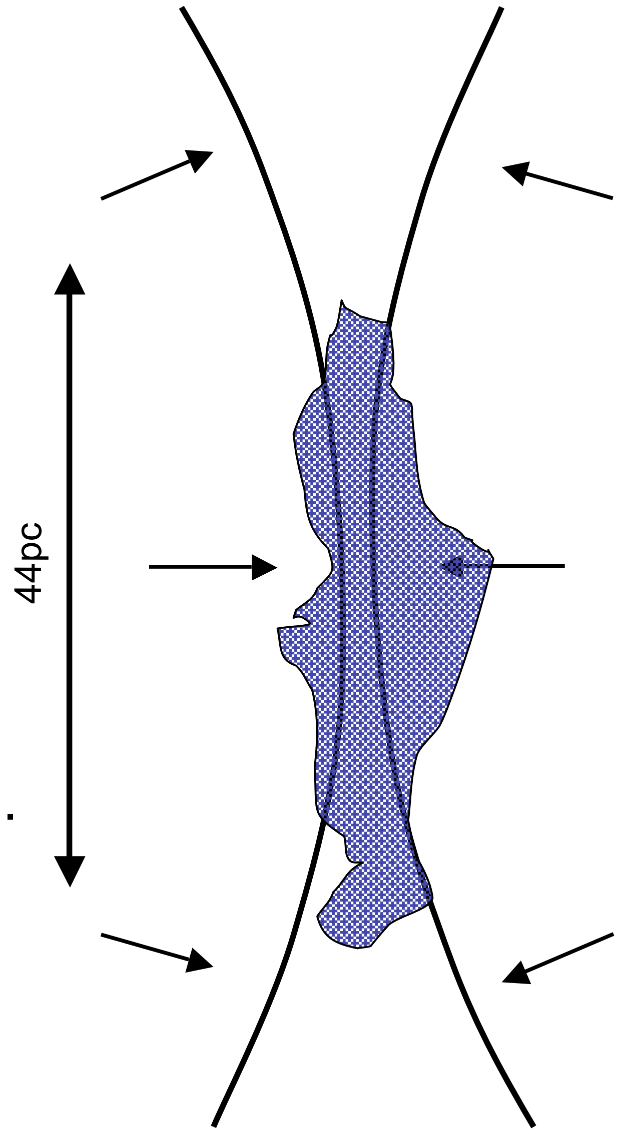




The rapid onset of star formation requires
***non-linear* density seeds during cloud formation.**

A Numerical Experiment of Cloud Formation:

Two uniform, identical flows
no assumption about turbulence
colliding head-on at interface
expanding shells, spiral arms
with large-scale geometric perturbation
mimicking unavoidable shear
in non-periodic domain.
allowing global gravitational modes
Burkert & Hartmann 04, Li 01



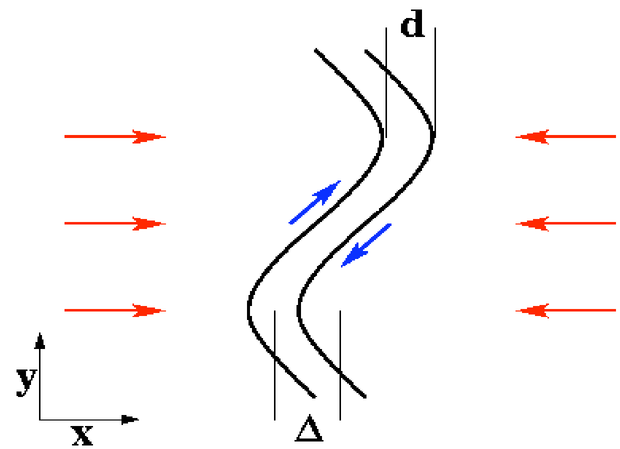
Heating and cooling to model WNM → CNM.
No stellar feedback.
Hydro and MHD models.
Fixed-grid simulations.

Methods: Proteus FH et al. 04, 07, 08
Athena Stone et al. 08

Fluid Dynamics of Cloud Formation

Large-scale flows assembling gas:

- spiral arms
- gravitational instability
- expanding/colliding shells
- galaxy mergers

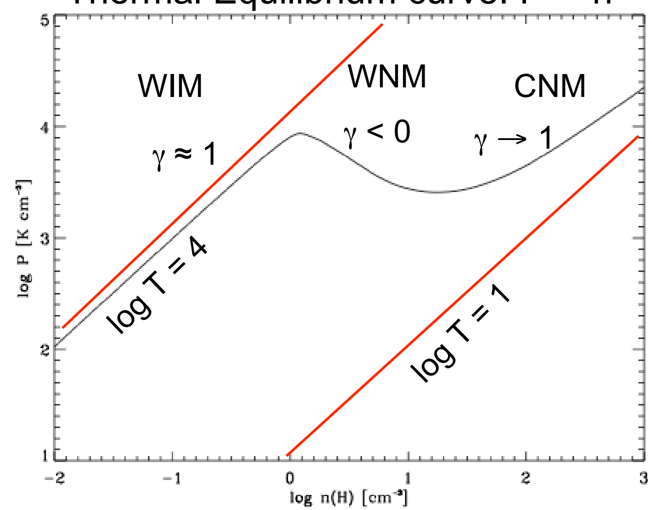


$$\mathcal{L}(n,T) \equiv n\Gamma - n^2\Lambda(T) \quad [\mathrm{erg\ s^{-1}\ cm^{-3}}]$$

Processes & Agents:

- shocks & shear flows
  fragmentation, turbulence
- radiative losses/thermal instability
  fragmentation, strong compression
- gravity
  fragmentation, collapse
- magnetic fields
  we'll get them later

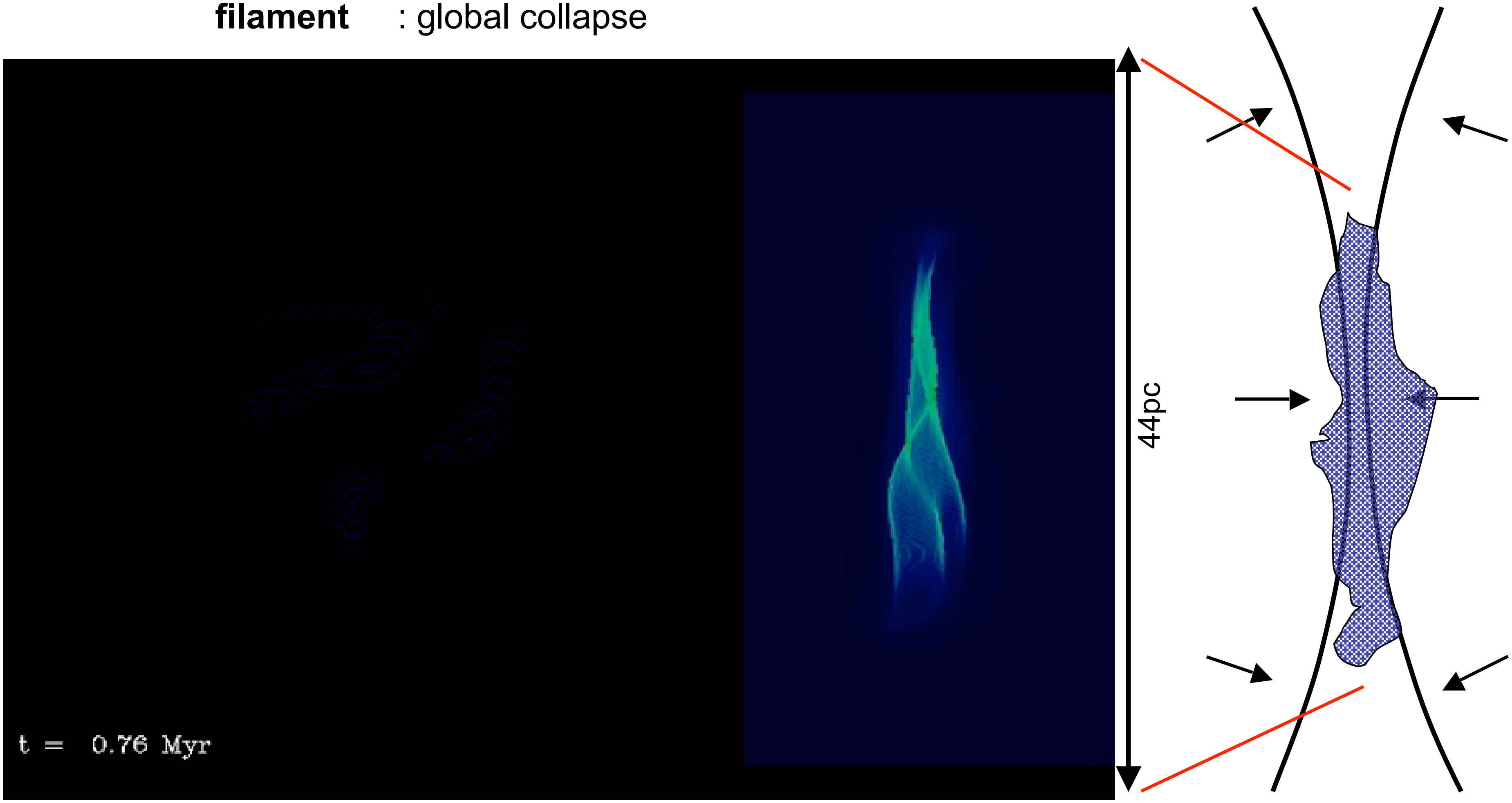
Thermal Equilibrium curve: $P \propto n^{\gamma}$



$$M_J \approx 5.0 \left(\frac{T}{10\ \mathrm{K}}\right)^2 \left(\frac{P}{10^4\ \mathrm{K\ cm^{-3}}}\right)^{-1/2} \mathrm{M}_\odot$$

Cooling, Gravity & Geometry

blue/**green** : thermal fragmentation;
red/**yellow** : local collapse;
filament : global collapse



3D at 256 x 512 x 512
$19 < \log N\ [cm^{-2}] < 23$

$n = 3\ cm^{-3}$
$v = 9\ km\ s^{-1}$

FH et al. 08a

The "rapid" formation of molecular clouds and stars

Global gravity increases CO formation.

without self-gravity | with self-gravity

[redacted]

$$\langle N_H \rangle = 2 \times 7.9 \text{ km s}^{-1} \times 3 \text{ cm}^{-3} t$$
$$= 1.5 \times 10^{20} \text{ cm}^{-2} (t/\text{Myr}) ,$$

but

N(filament) @ 10 Myr ~ $10^{22.5}$ cm^{-2}

Hf1, t=

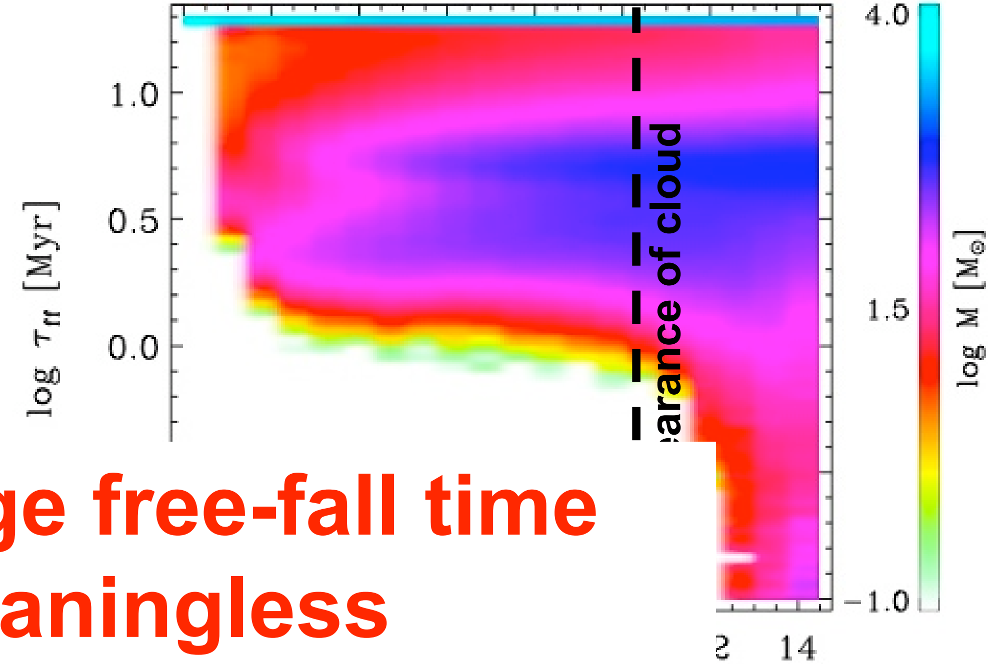
22 pc

[redacted]

FH & Hartmann 08

contours: HI
color : CO

Global vs local free-fall time

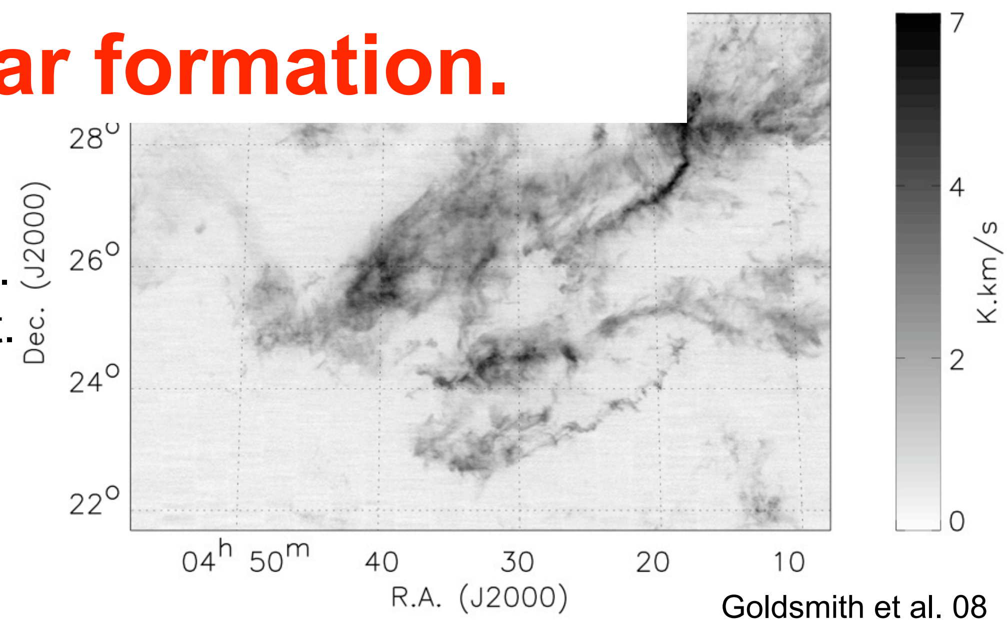


“Rapid” star formation: counting after appearance of cloud (CO).

Thermal frag
→ small
→ short
→ “prese

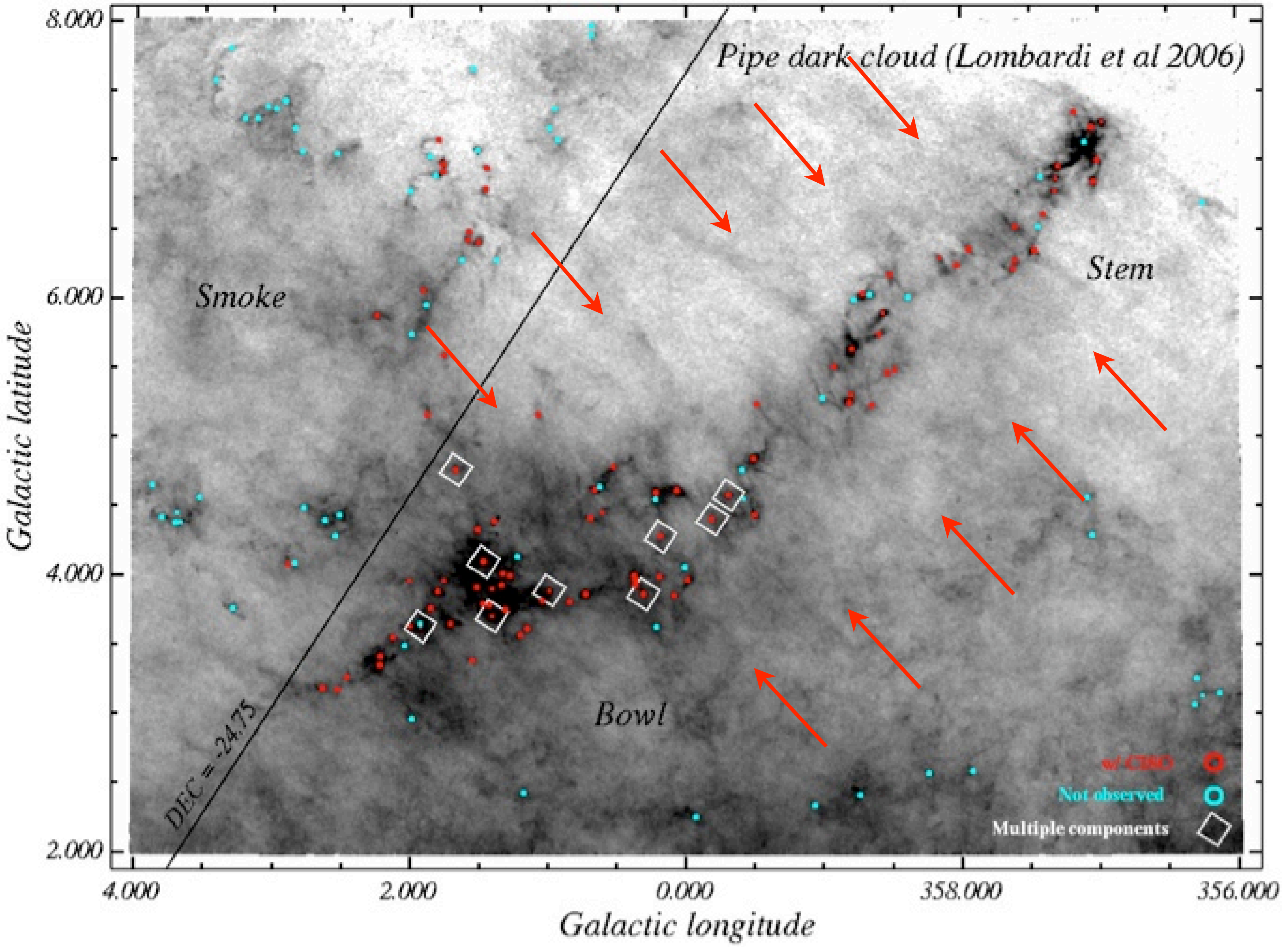
The average free-fall time is meaningless for the evolution of the cloud and for star formation.

Densest regions form stars, while the envelope (“blue”) is not participating.
The envelope gas need not be coherent.
see also talks by Vazquez-Semadeni & Banerjee



Goldsmith et al. 08

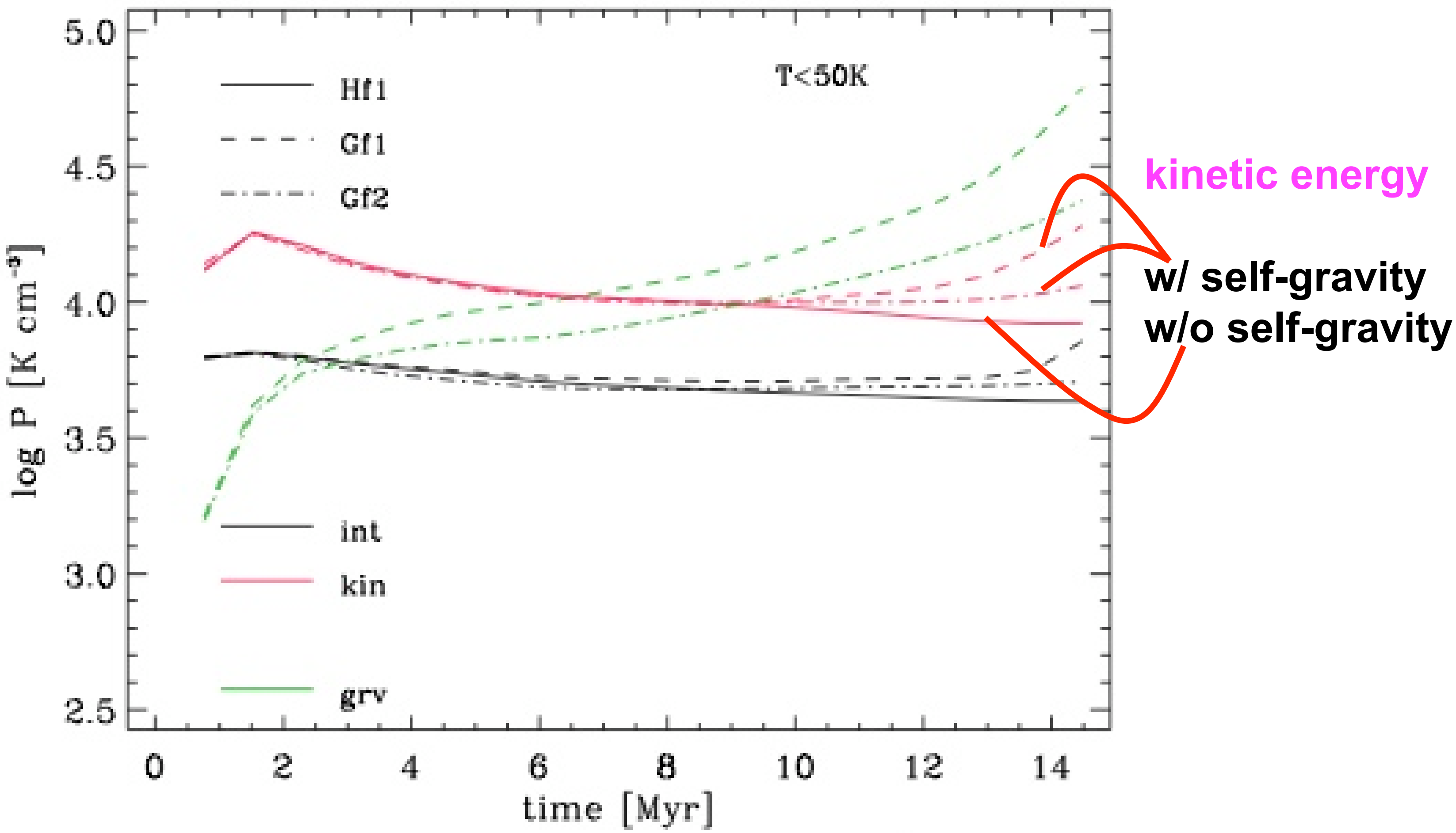
Clouds are not in ("virial") equilibrium:



The Role of Turbulence:

Turbulence is (at least partially) driven by gravity.
Field et al. 08, Vazquez-Semadeni et al. 07, FH et al. 08, 09

Turbulence in cold gas is *not supersonic hydrodynamically.*
Audit & Hennebelle 05, Vazquez-Semadeni et al. 07, FH et al. 06, 08



The Role of Turbulence:

Since turbulence is a **consequence of the cloud's formation and collapse,** it **can not** support the cloud.
The bulk of the energy is on the largest scales.
There is no scale-separation (no "micro-turbulence")

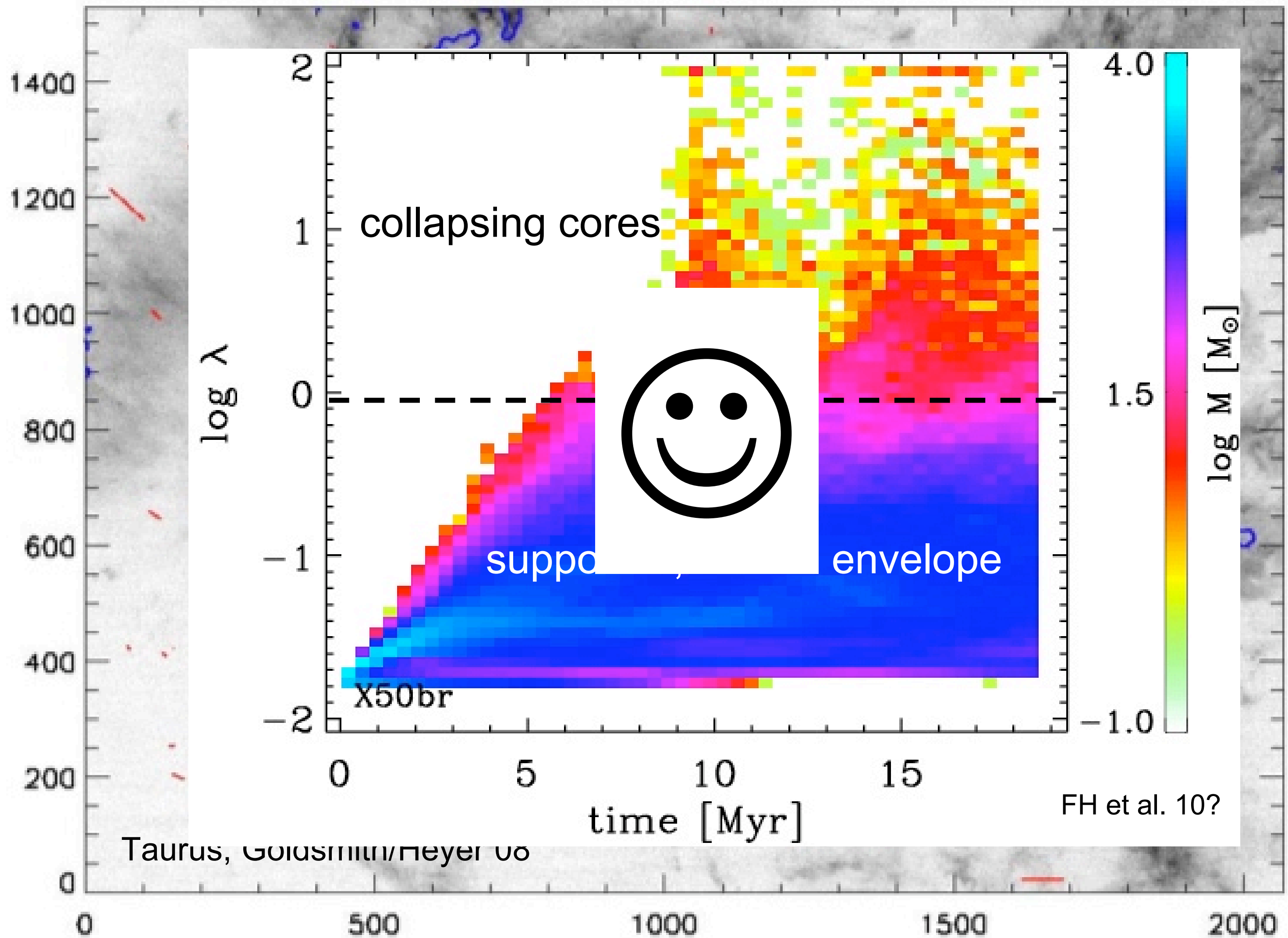
"Gravity makes things round." is only true if there is an isotropic pressure to counter it.

But: SNe, winds & HII regions can *fragment* the surrounding cloud.

("Turbulent fragmentation", PP et al., M-MML et al, RK et al, FH et al., VS et al. etcpp)

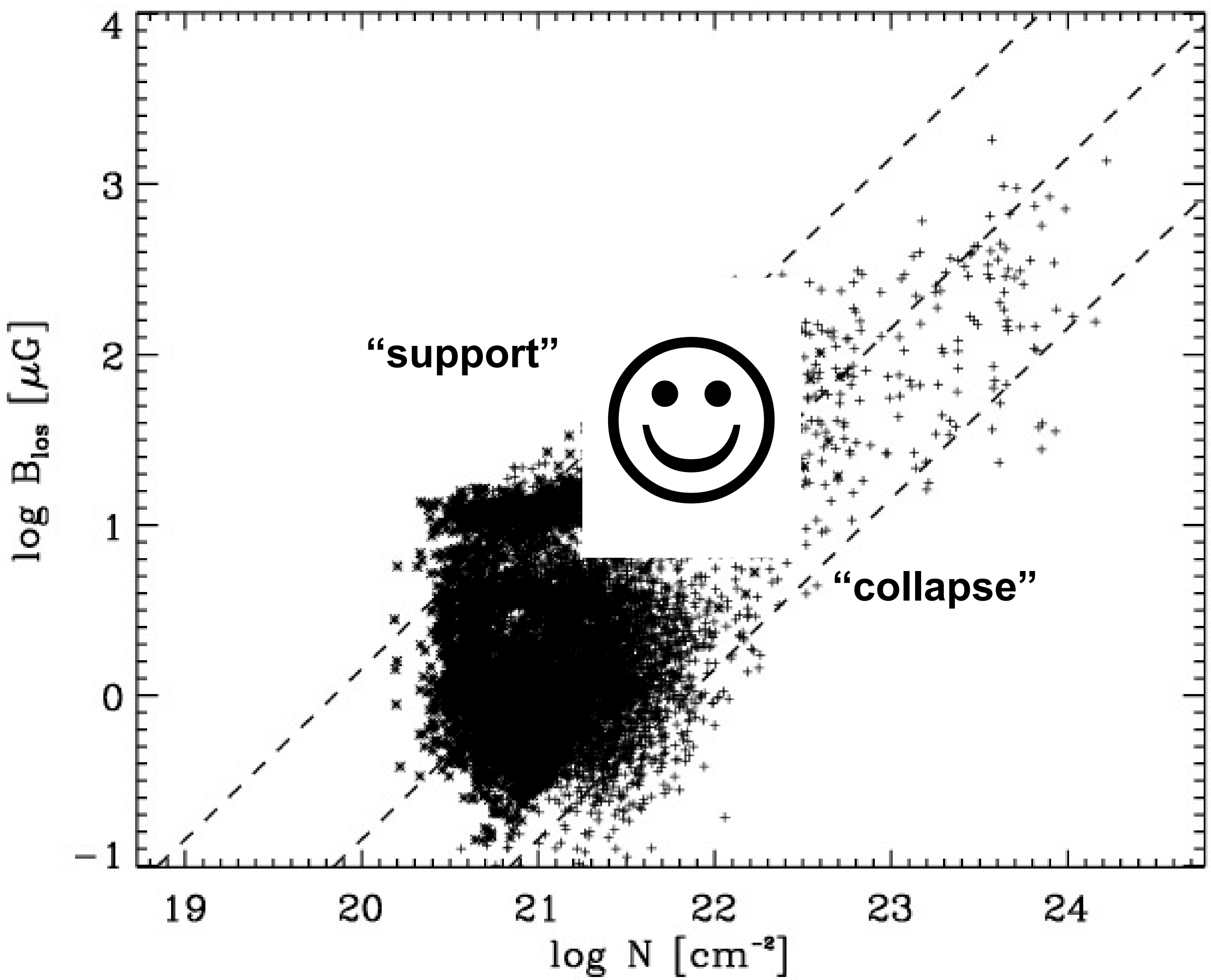
Magnetic Fields: Models

Collapse of dense regions, support of diffuse envelope.



Magnetic Fields: Observations

Field-Density Relation (from HI and OH Zeeman measurements// ~500 model cores):



Testing Star Formation Theories

Turbulence v

Mass-to-flux

$\mathcal{R}' \equiv$

Prediction:

R' > 1 for a

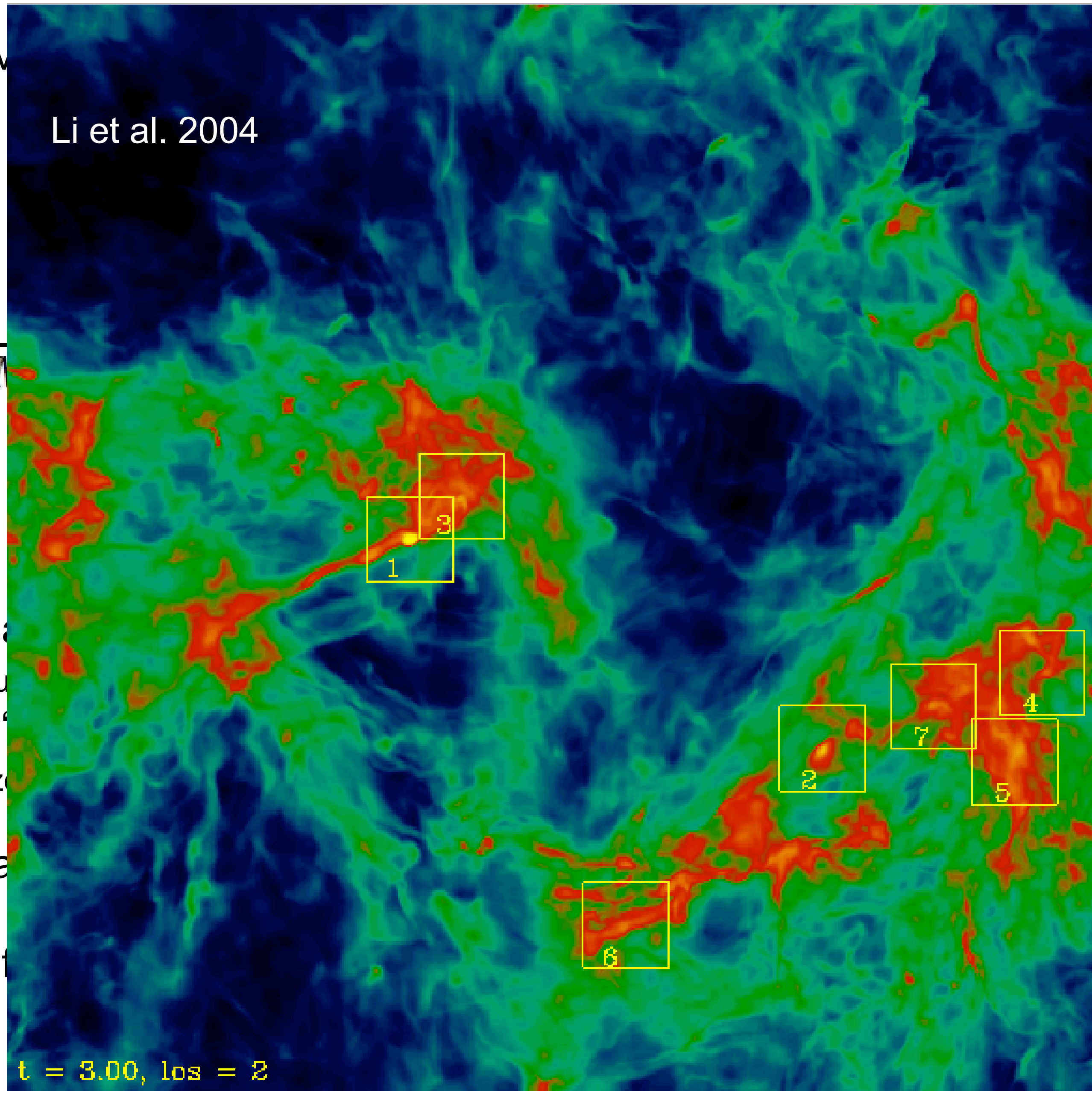
Mou

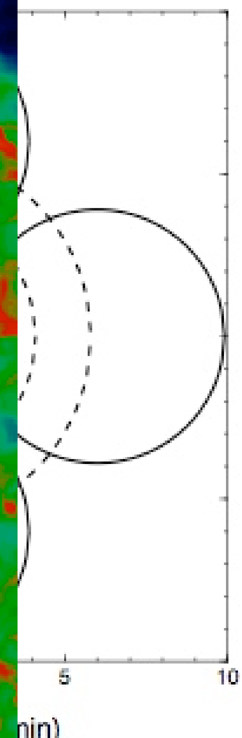
R' < 1 for '

Vaz

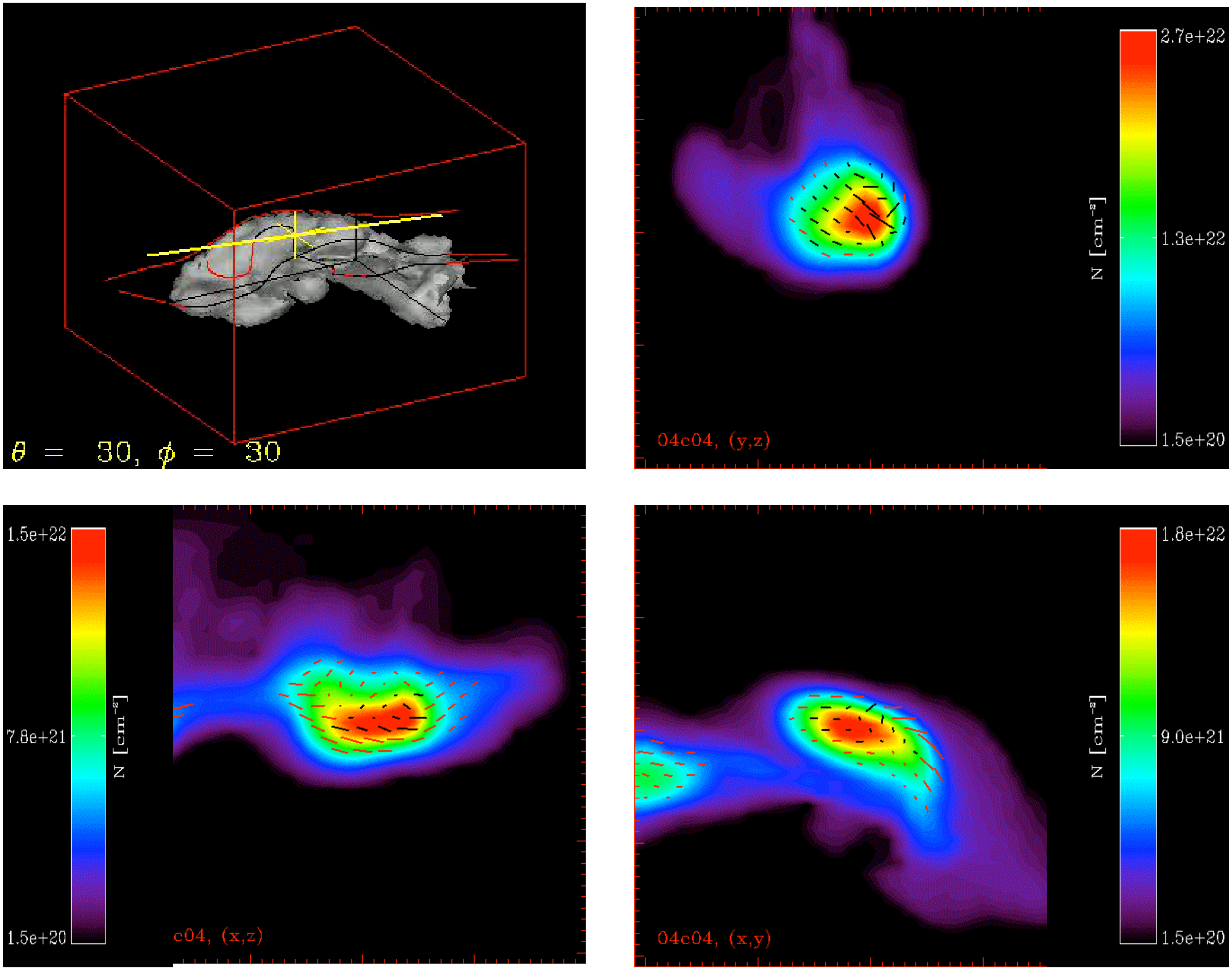
Crutcher et a

R' < 1 for t



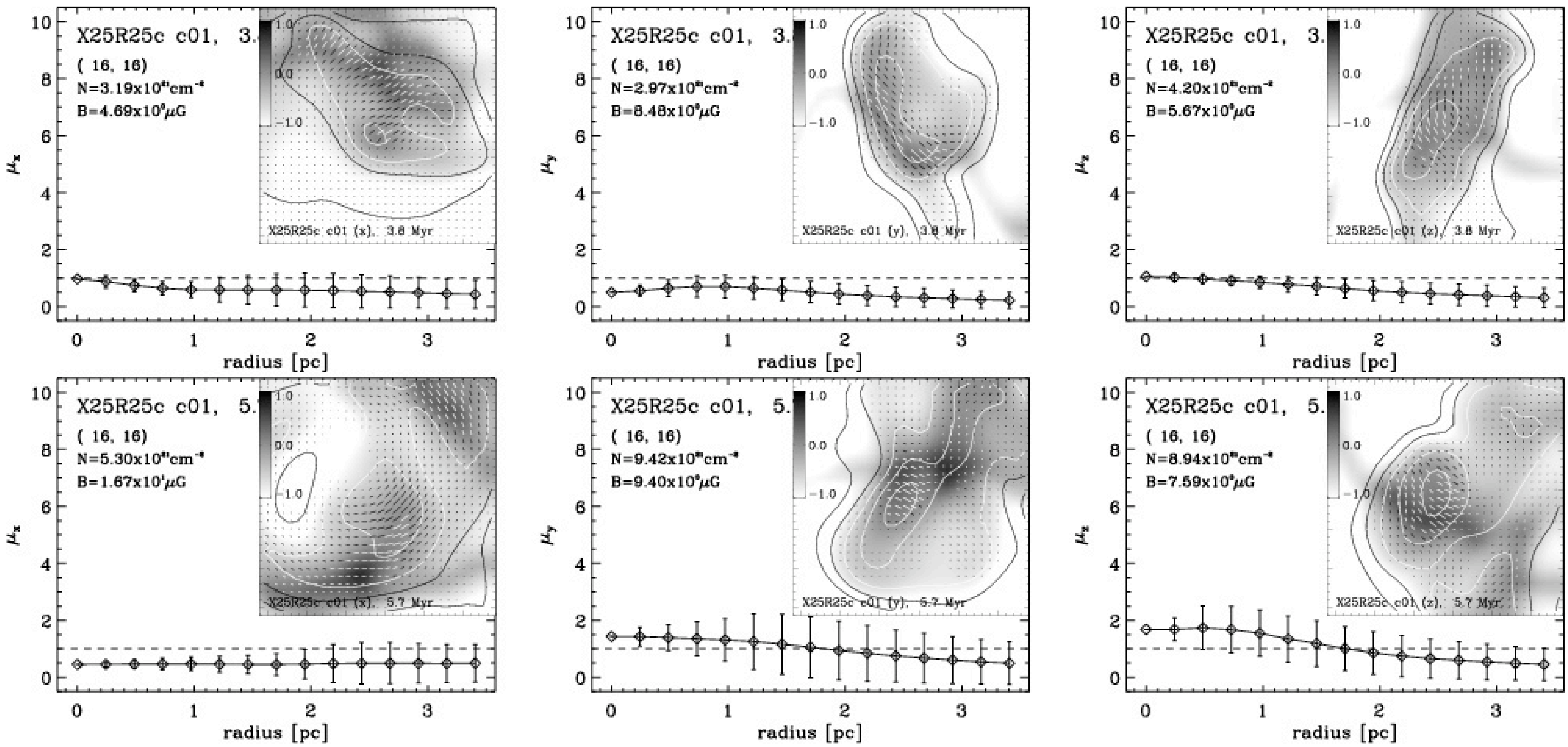


“typical” example



Testing Star Formation Theories

Core Profiles and Mass-to-Flux Ratios



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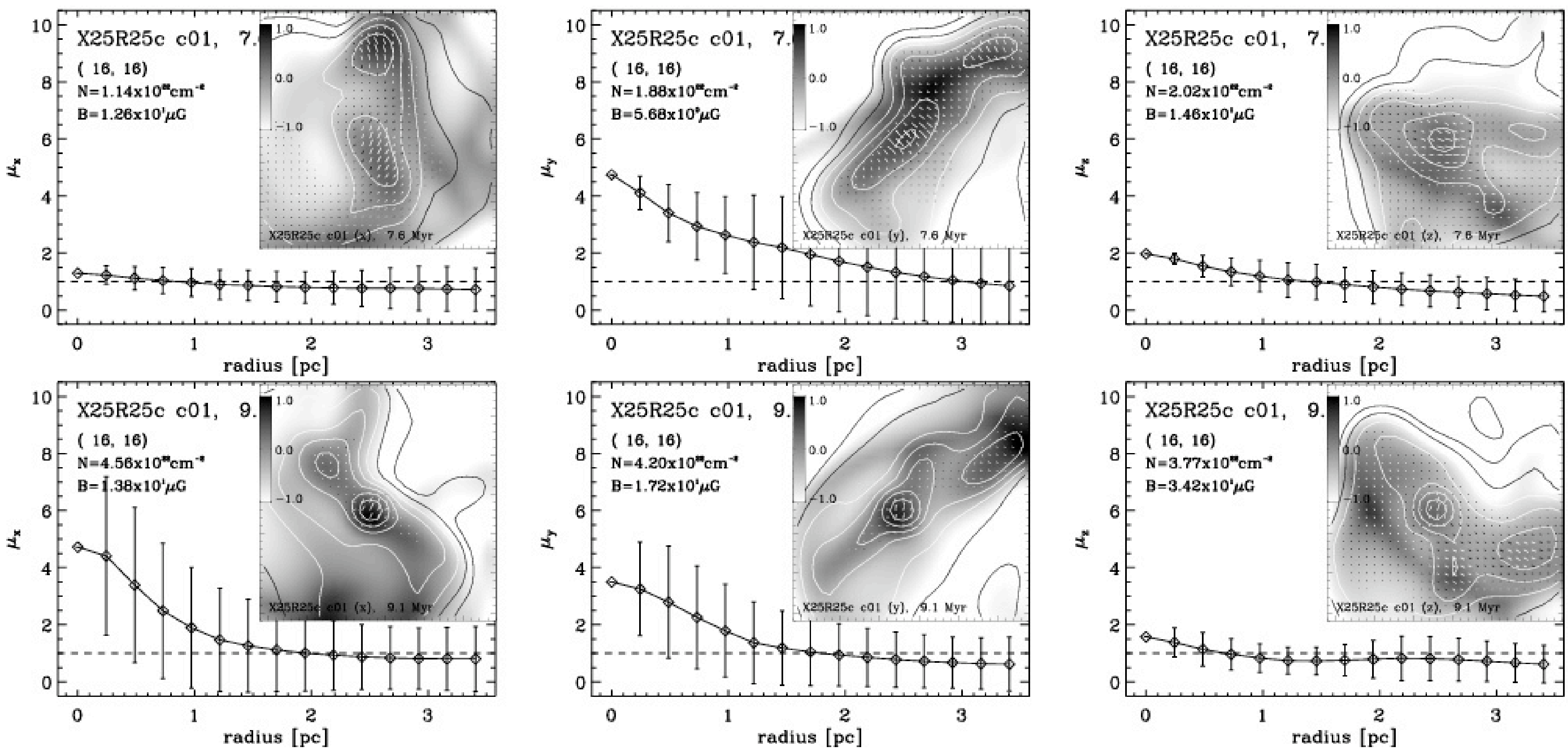

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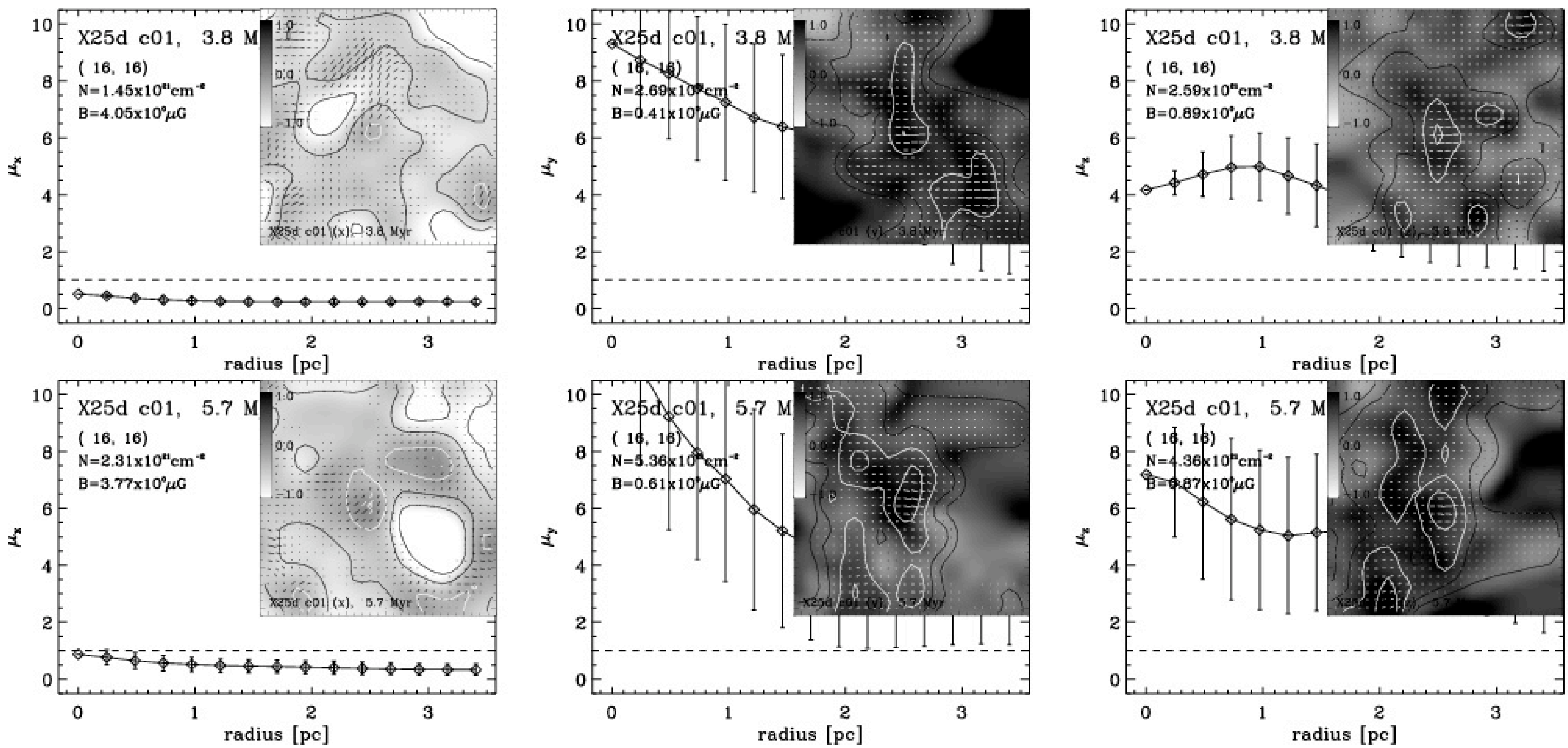

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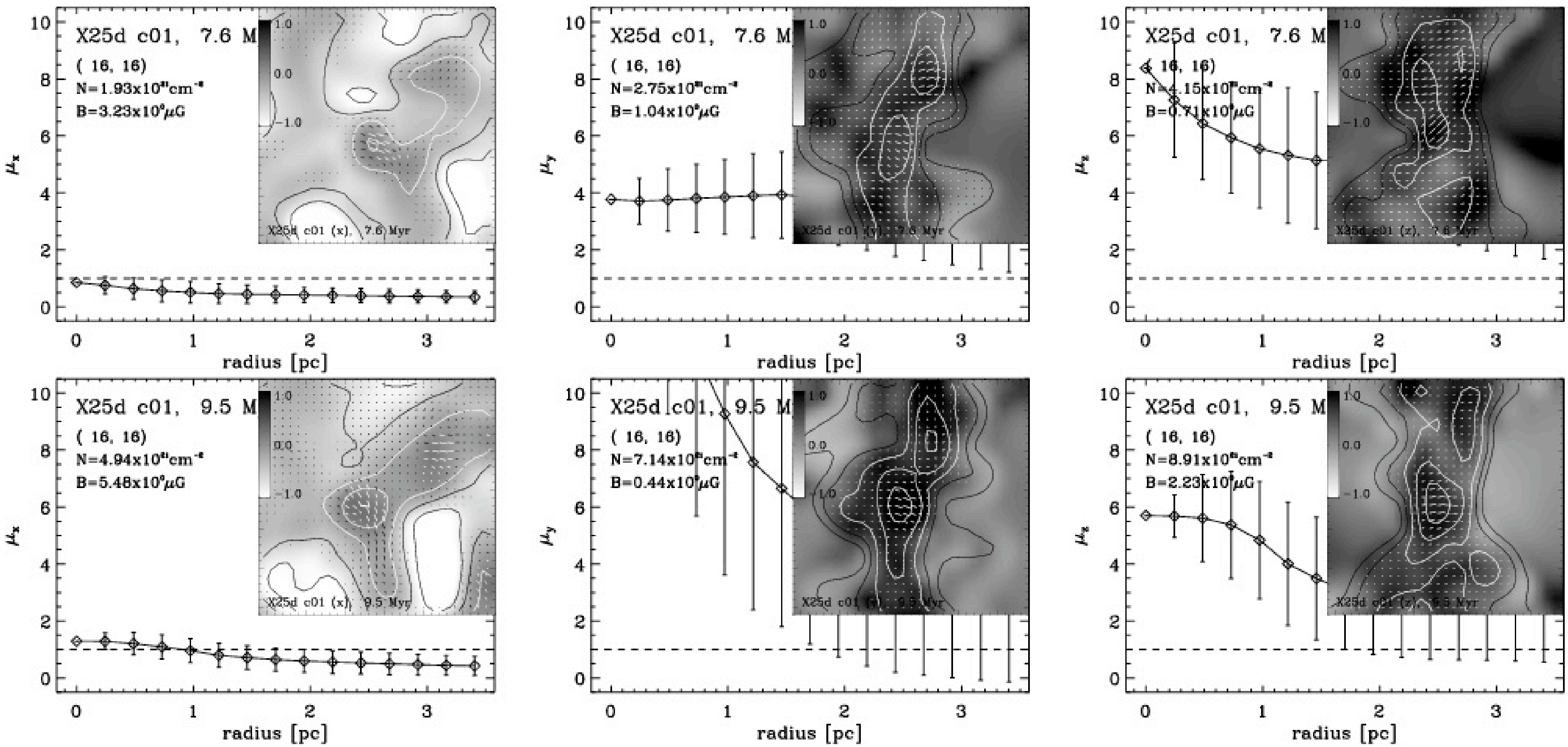

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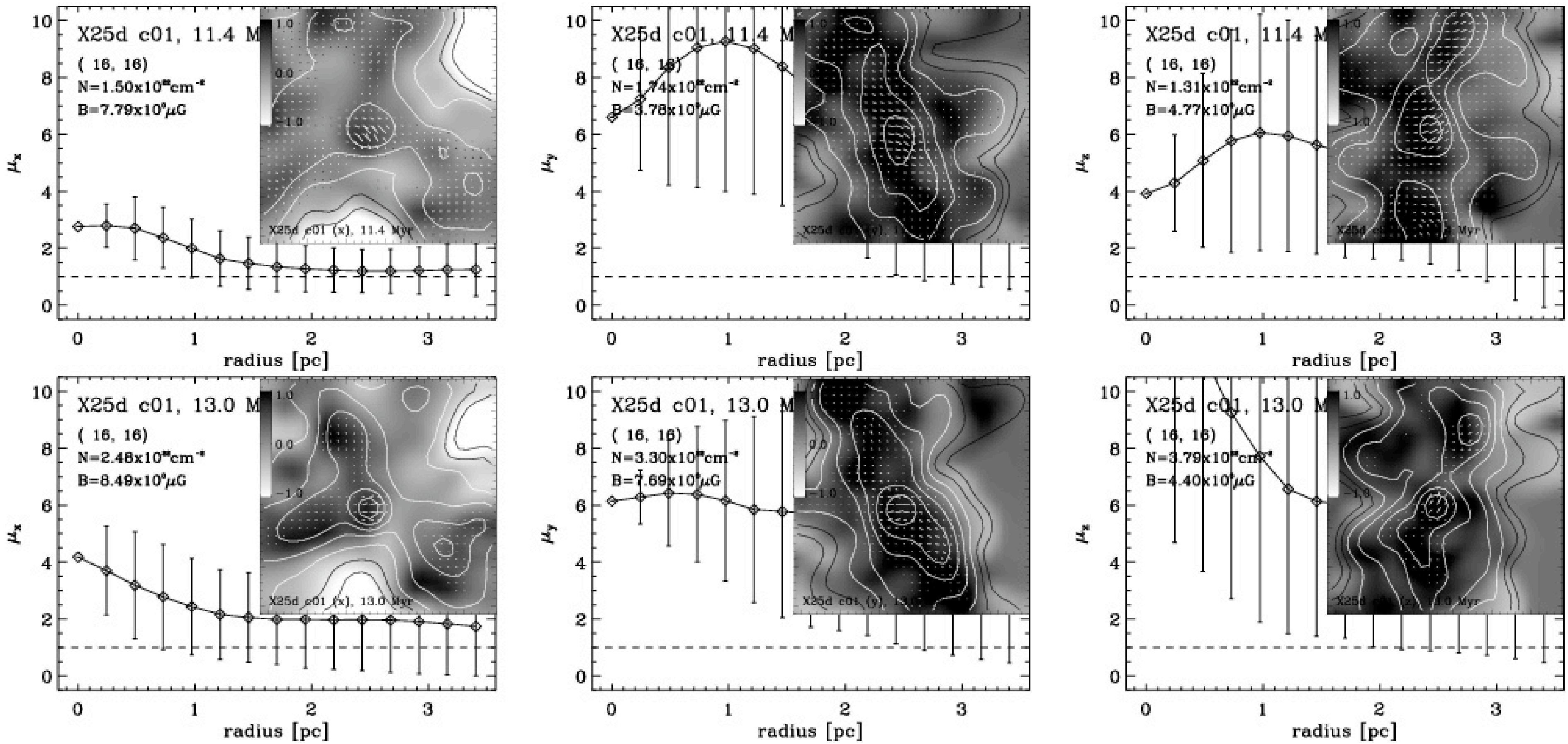
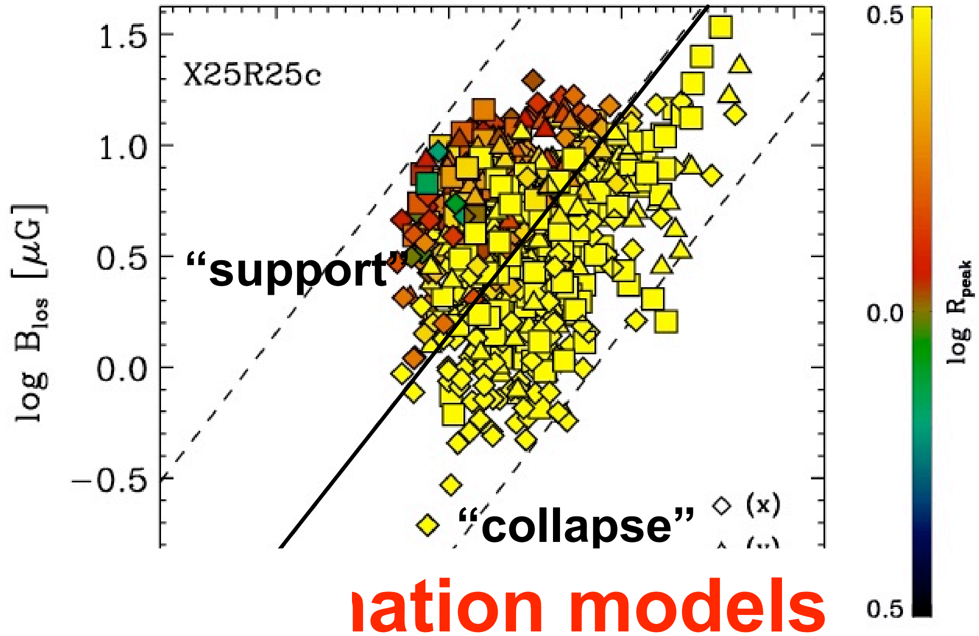


Testing Star Formation Theories

The Ratio of Mass-to-Flux Ratios:

Supercritical cores have R’ > 1.

Only a few cores have R’ < 1.



Mass-to-flux rat ... ation models
inconsister ... models”,
consistent with ... sion models”,
inconsistent wit... observations.

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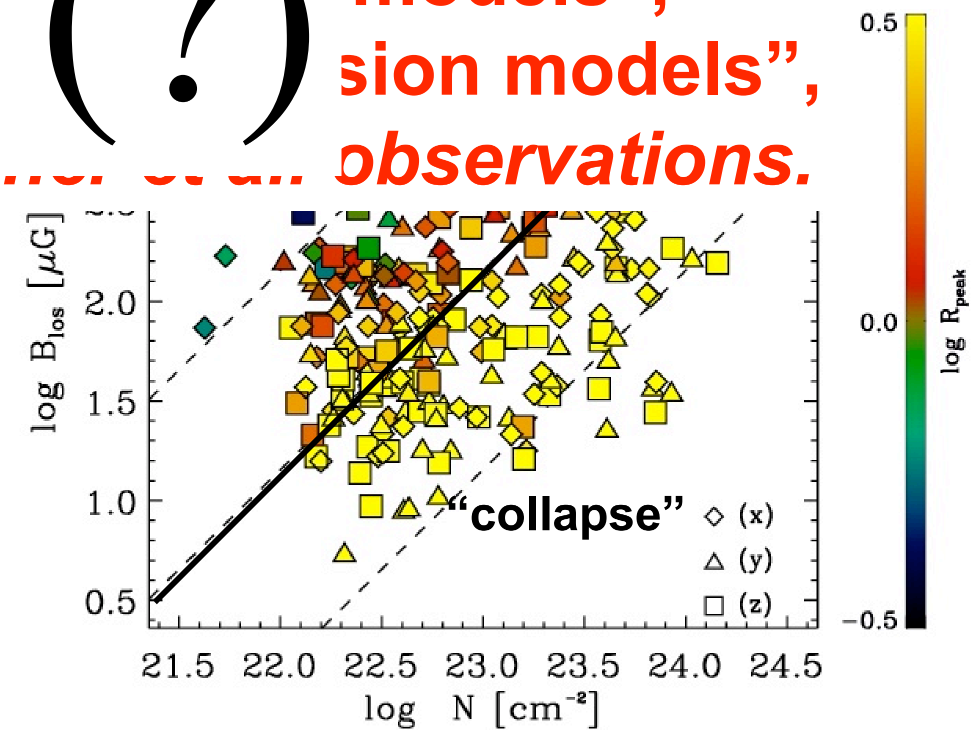

$$\mathcal{R}' \equiv \frac{M_{core}/\Phi_{core}}{M_{core+envelope}/\Phi_{core+envelope}}$$

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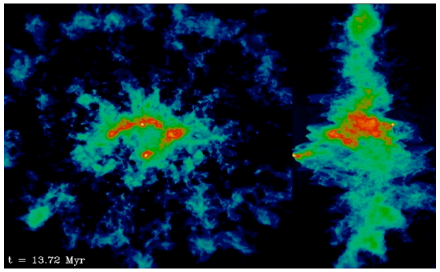

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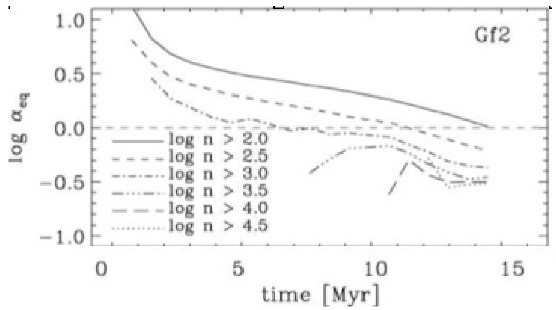
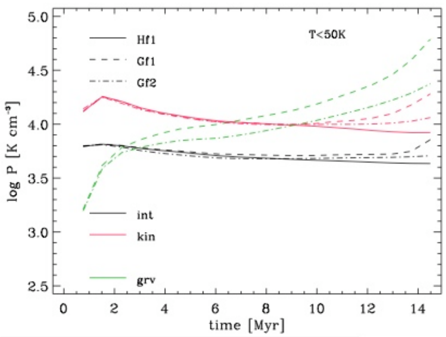


(3) Turbulence in molecular clouds is
driven by gravity.Turbulent support
does not exist.



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