LETTRES SCIENCES
ÉCOLE NORMALE SUPÉRIEURE

Irfu
cea
saclay
Institut de recherche sur les lois fondamentales de l'Univers

l'Observatoire de Paris

Influence du champ magnétique sur la formation stellaire

Patrick Hennebelle

Benoit Commerçon, Marc Joos, Jacques Masson, Andréa Ciardi
Sébastien Fromang, Romain Teyssier, Philippe André, Gilles Chabrier

Large Scale Structures

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Interstellar Cycle and Star Formation

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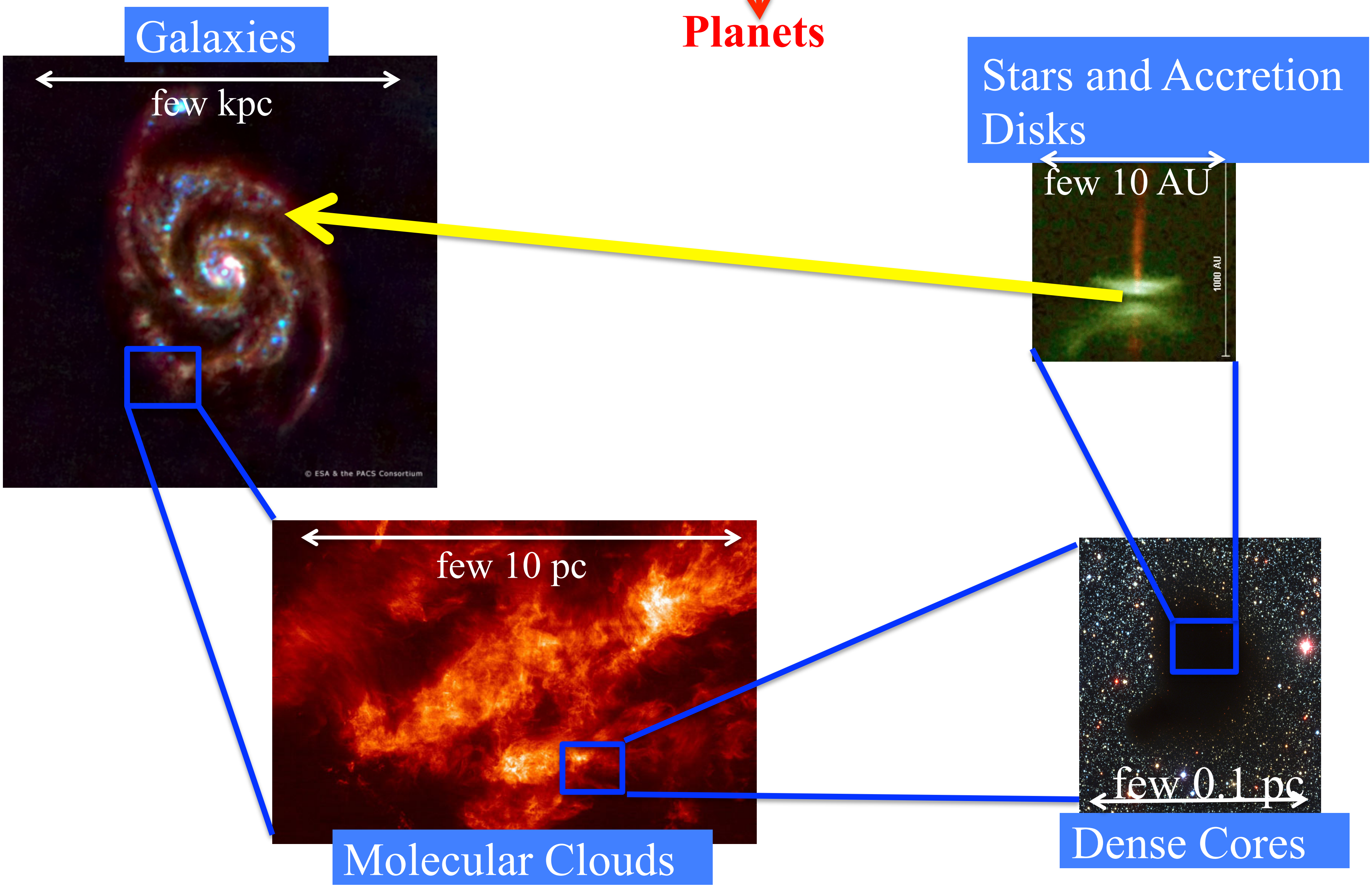
Planets



Why *must* we understand collapse ?

Major astrophysical questions

⇒**Determine the initial conditions of the protostars**:
-entropy
-angular momentum (*the angular momentum problem*)
-magnetic field (*the magnetic flux problem*)

⇒**Binary and multiple system formation**

⇒**Disk formation: Planet formation and migration**

1- Very early evolution: starless-class0 – 10^5-10^{10} cm^{-3}

2- Protostar formation: 10^{10}-10^{20} cm^{-3}

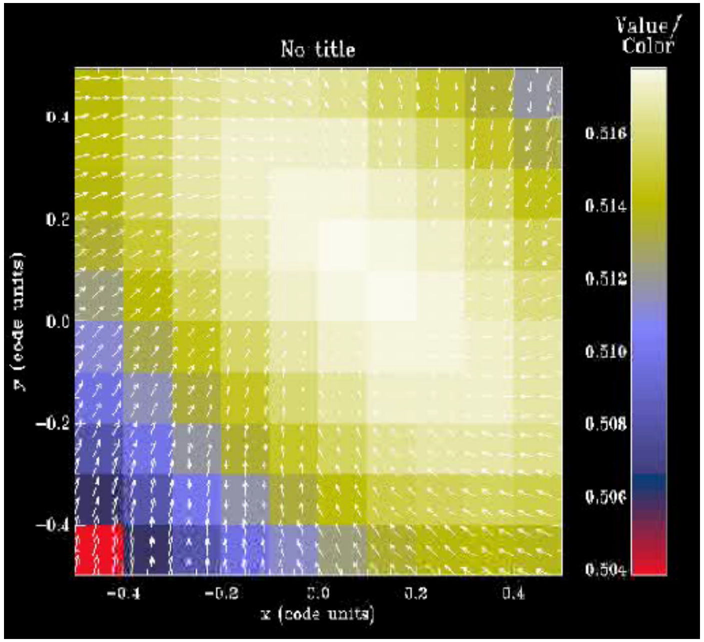
3- ClassI and later evolution

Zoom into the central part of a collapse calculation (1 solar mass slowly rotating core)

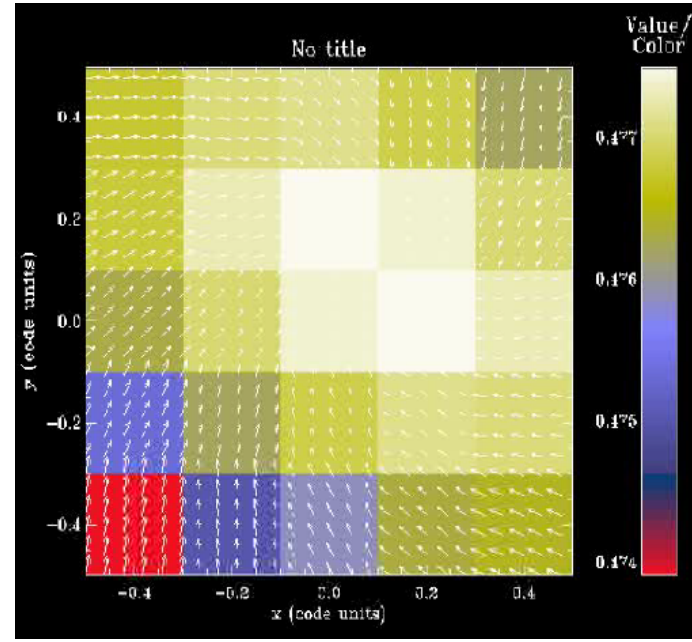
(Allen et al. 03, Machida et al. 05, Banerjee & Pudritz 06, Price & Bate 07, Hennebelle & Fromang 08)

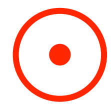
300 AU

XY
hydro



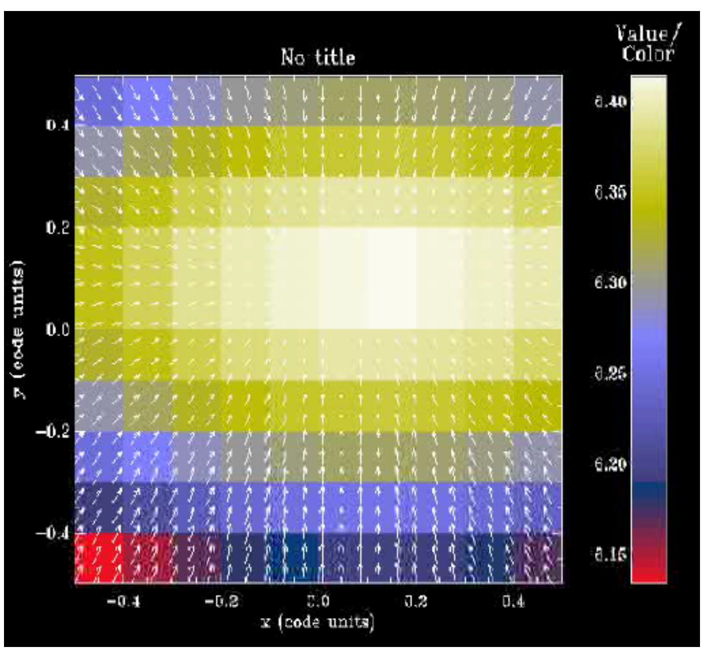
XY
MHD
μ=2





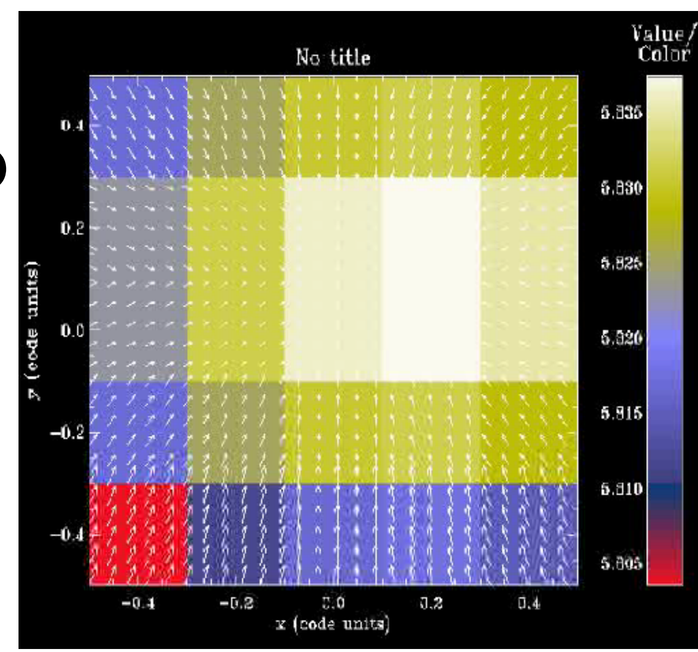
B, ω

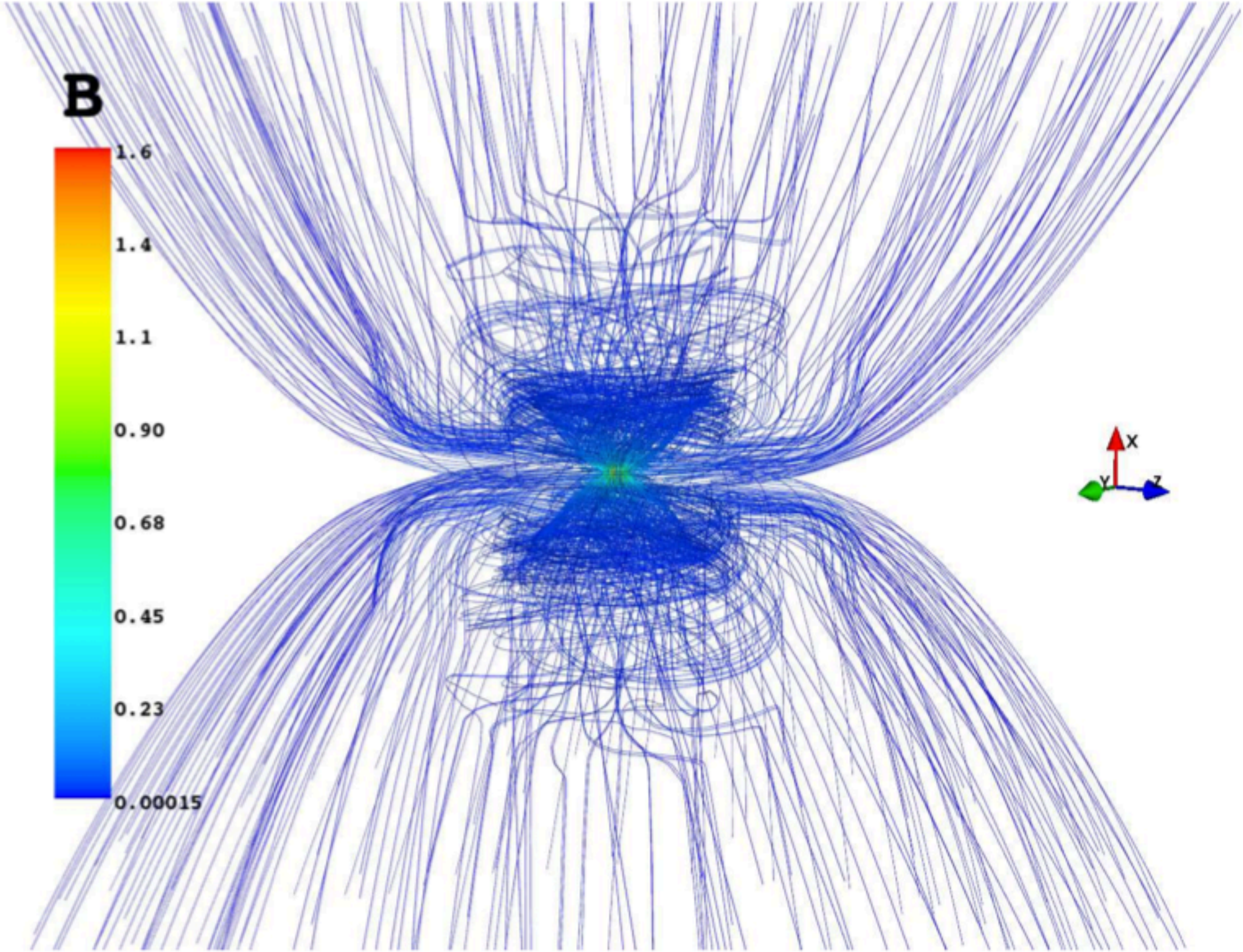
XZ
hydro



B, ω

XZ
MHD
μ=2



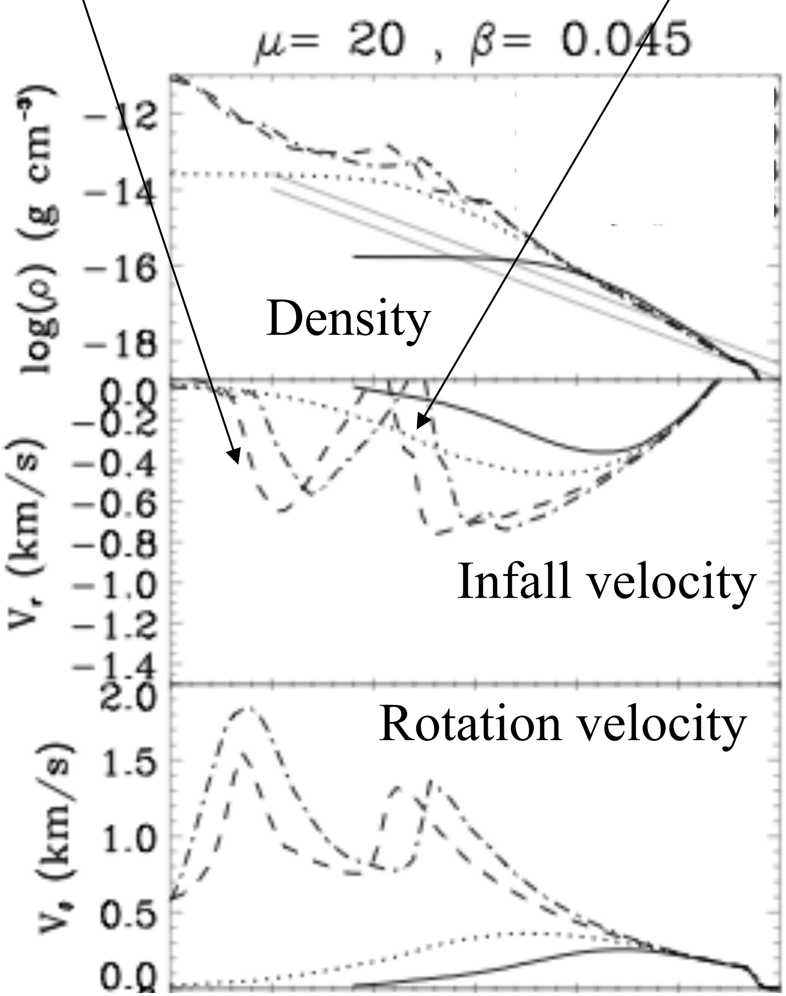


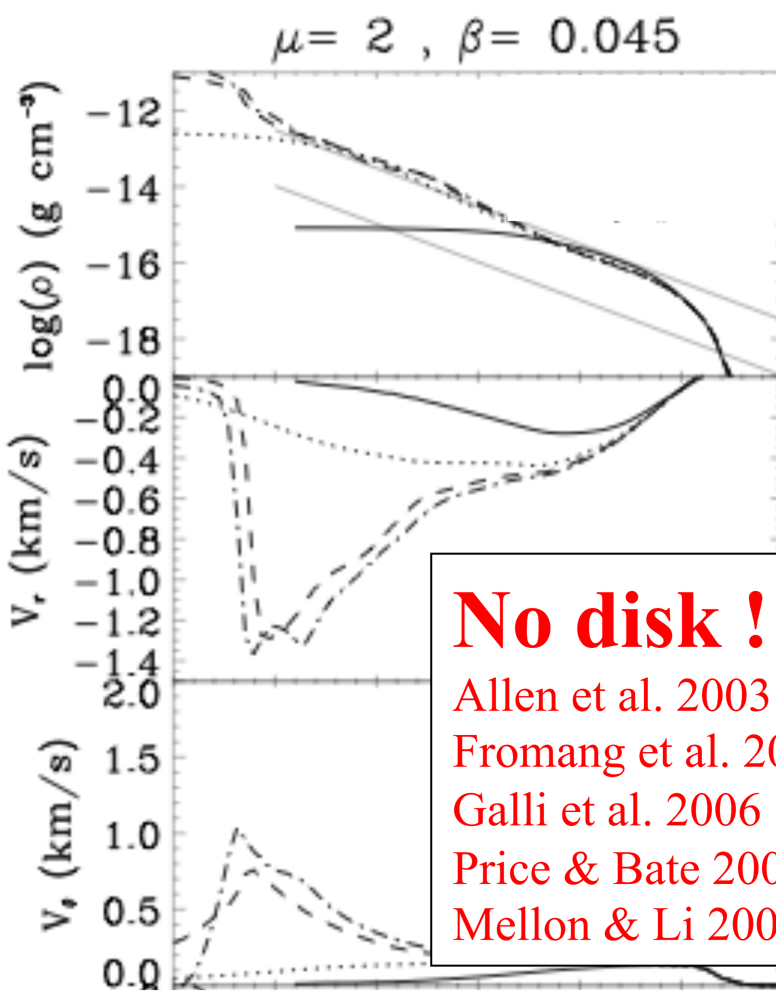
B
1.6
1.4
1.1
0.90
0.68
0.45
0.23
0.00015
x
y
z

Density, rotation and infall velocity profiles

Thermally supported core

Centrifugally supported disk

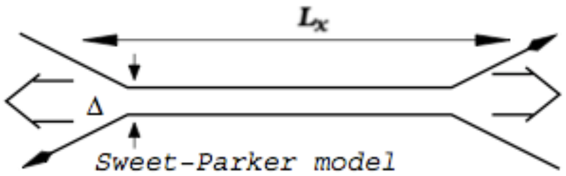


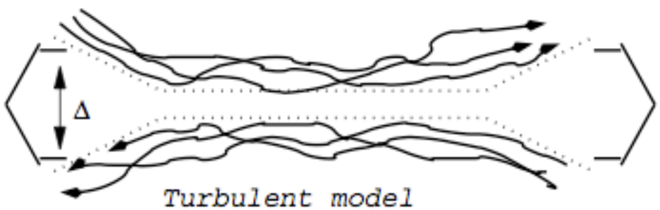


No disk !

Allen et al. 2003
Fromang et al. 2006
Galli et al. 2006
Price & Bate 2007
Mellon & Li 2008

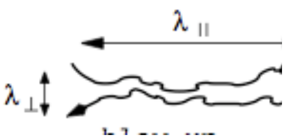
Hennebelle & Fromang 2008

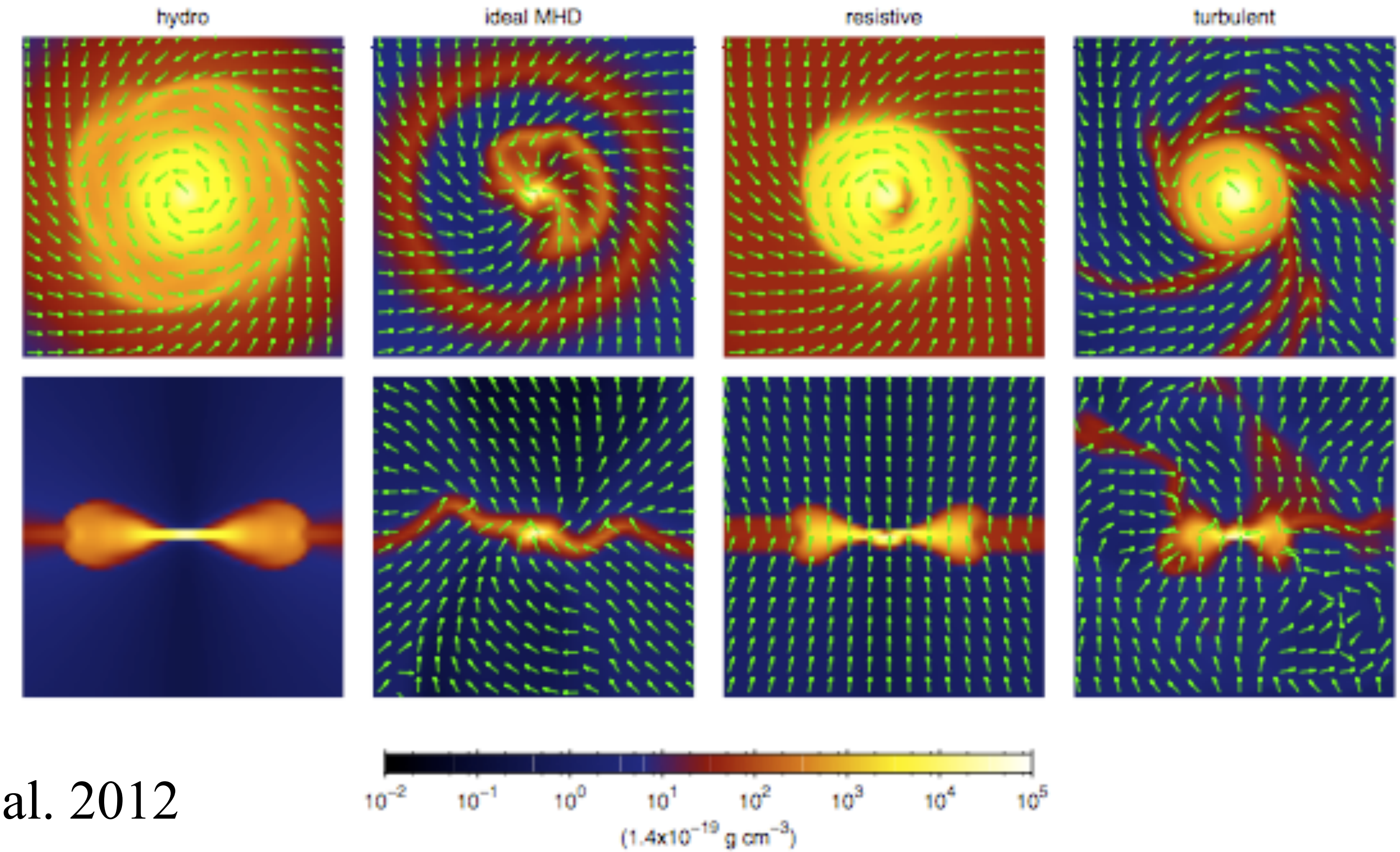




Another complication:
Impact of turbulence diffusion/reconnection

(Seifried et al. 2011, Santos-Lima et al. 2012,
Joos et al. 2013)





Santos-Lima et al. 2012

Comparison of the PdBI maps with MHD simulations

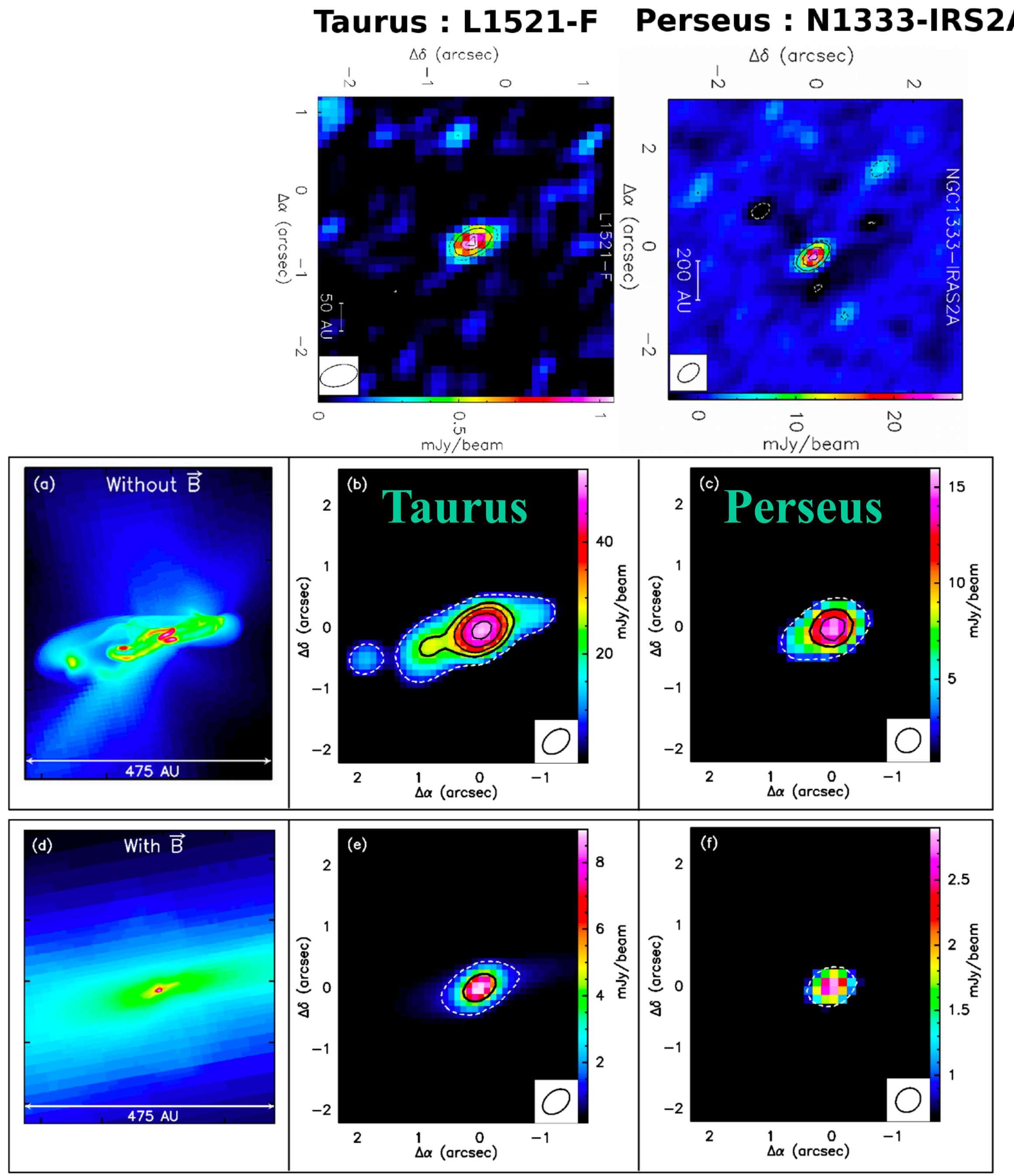
Hydrodynamical simulations produce too much extended (+ multiple) structures if compared to Maury et al. 2010 Observations.
→ MHD simulations ?

MHD simulations : produce PdB-A synthetic images with **typical FWHM ~ 0.2" - 0.6"**

Similar to Class 0 PdB-A sources observed !

↓

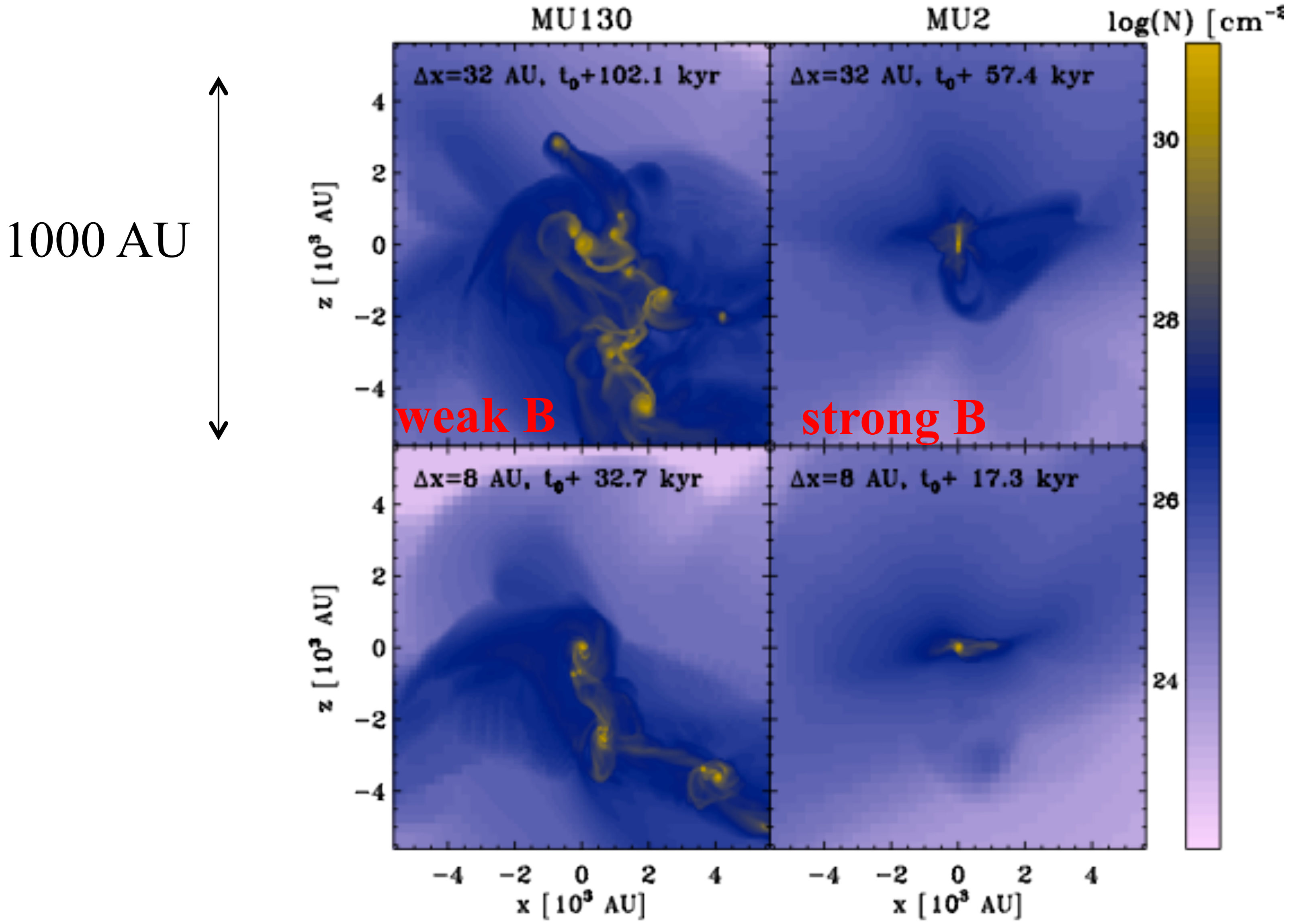
need B to produce compact, single PdB-A sources.



Maury et al. 2010

100 $M_\odot$ turbulent dense core collapse

Trend confirmed with lower resolution runs:



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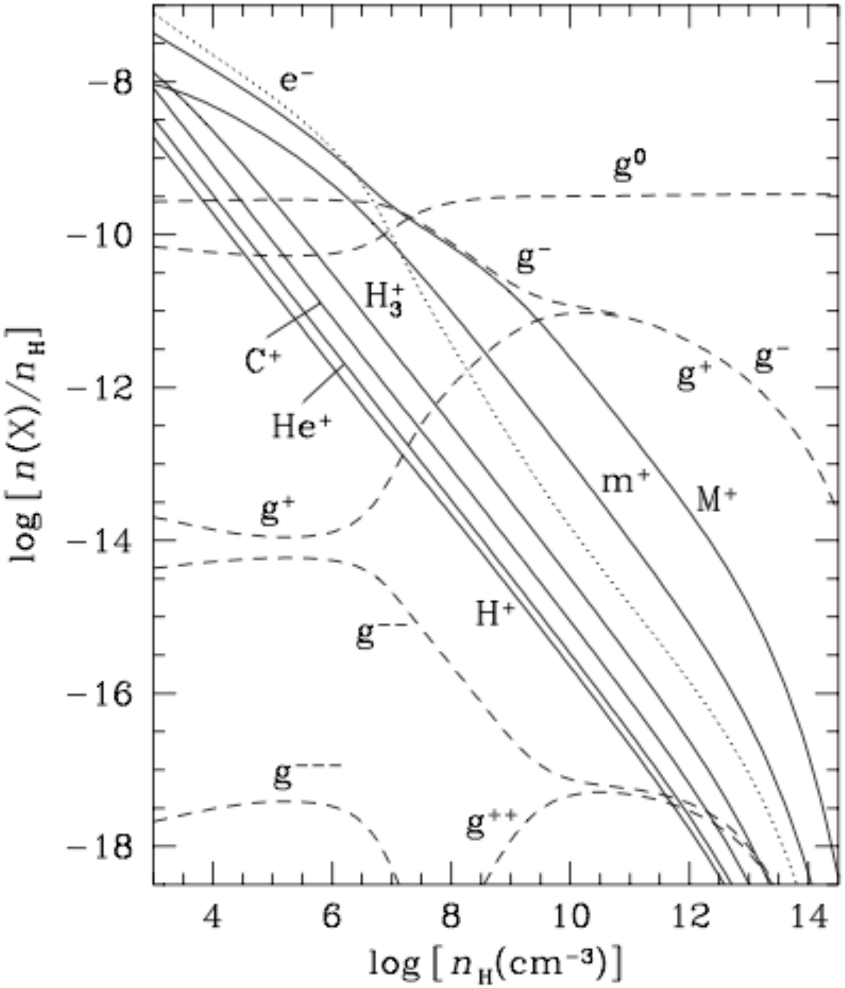
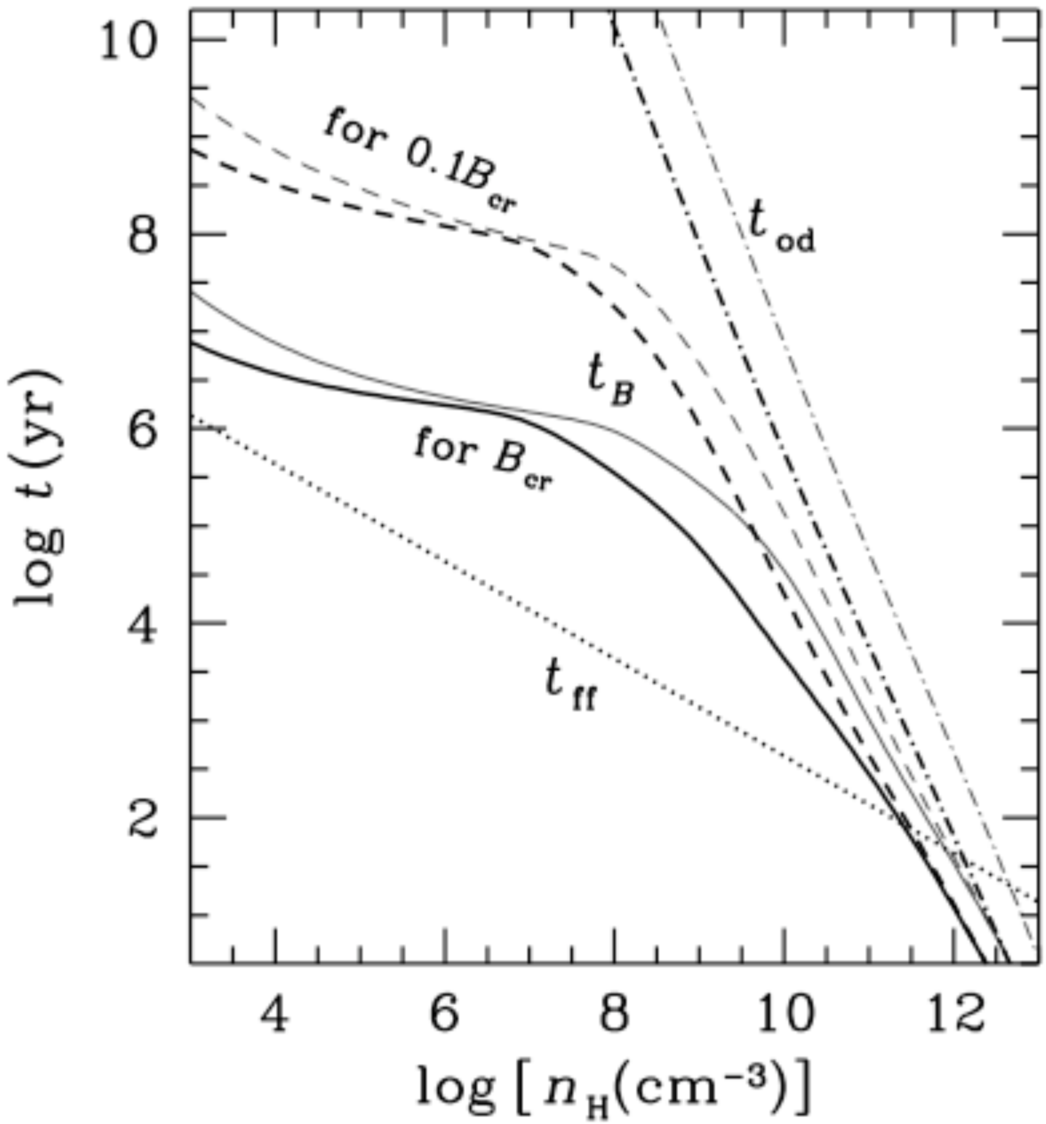
Detailed microphysics implying chemistry network

Abundances of species



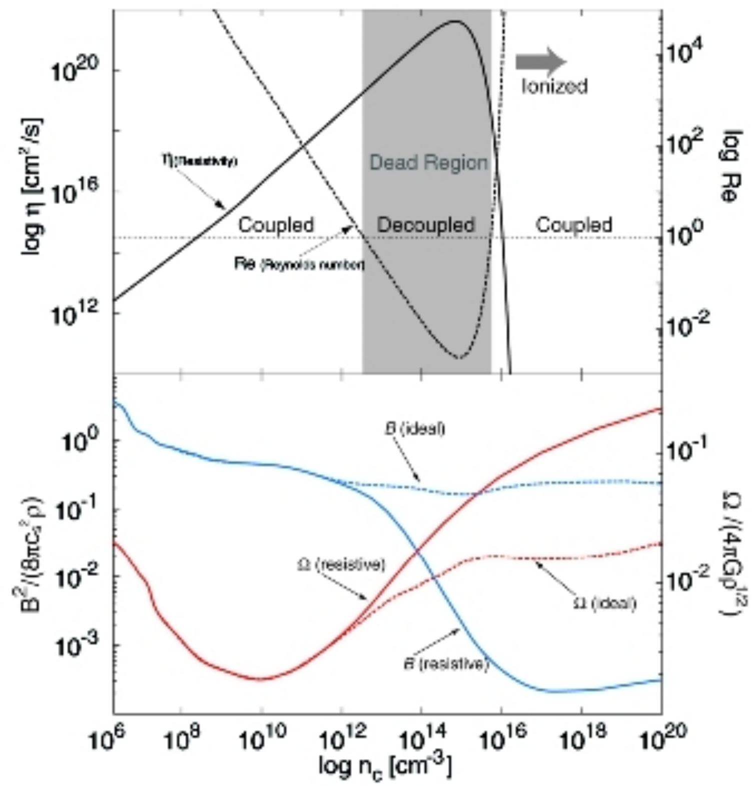
Nakano et al. 2002

Diffusion time vs density



Impact of ohmic dissipation (a solution to the flux problem ?)

Machida et al. 2007



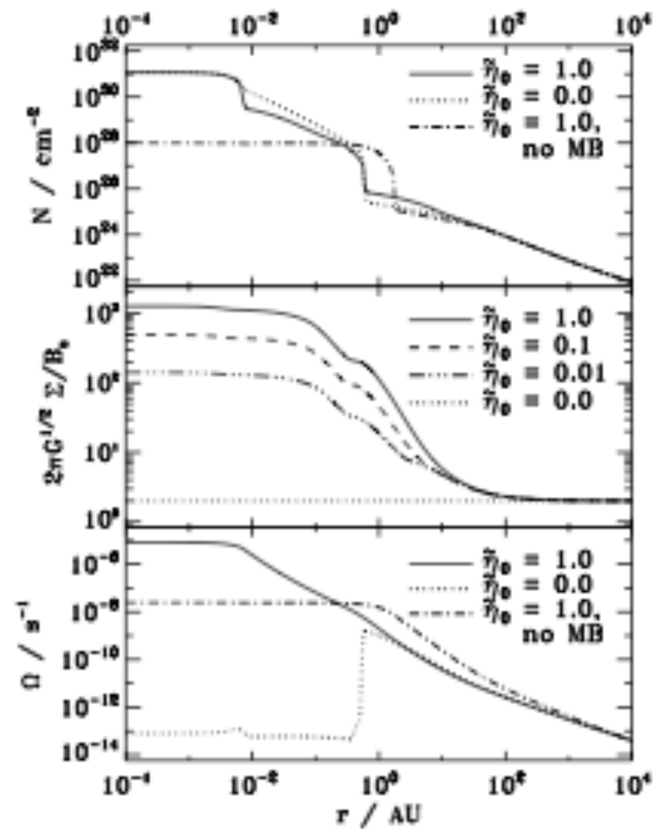
Interestingly: Desh and Mouschovias, Nakano et al. (2002) predicts that a lot of flux should be lost at densities larger than 10^{11} cm^{-3}(grains carry the charge).

First calculation with resistive MHD done by Machida et al. 2007

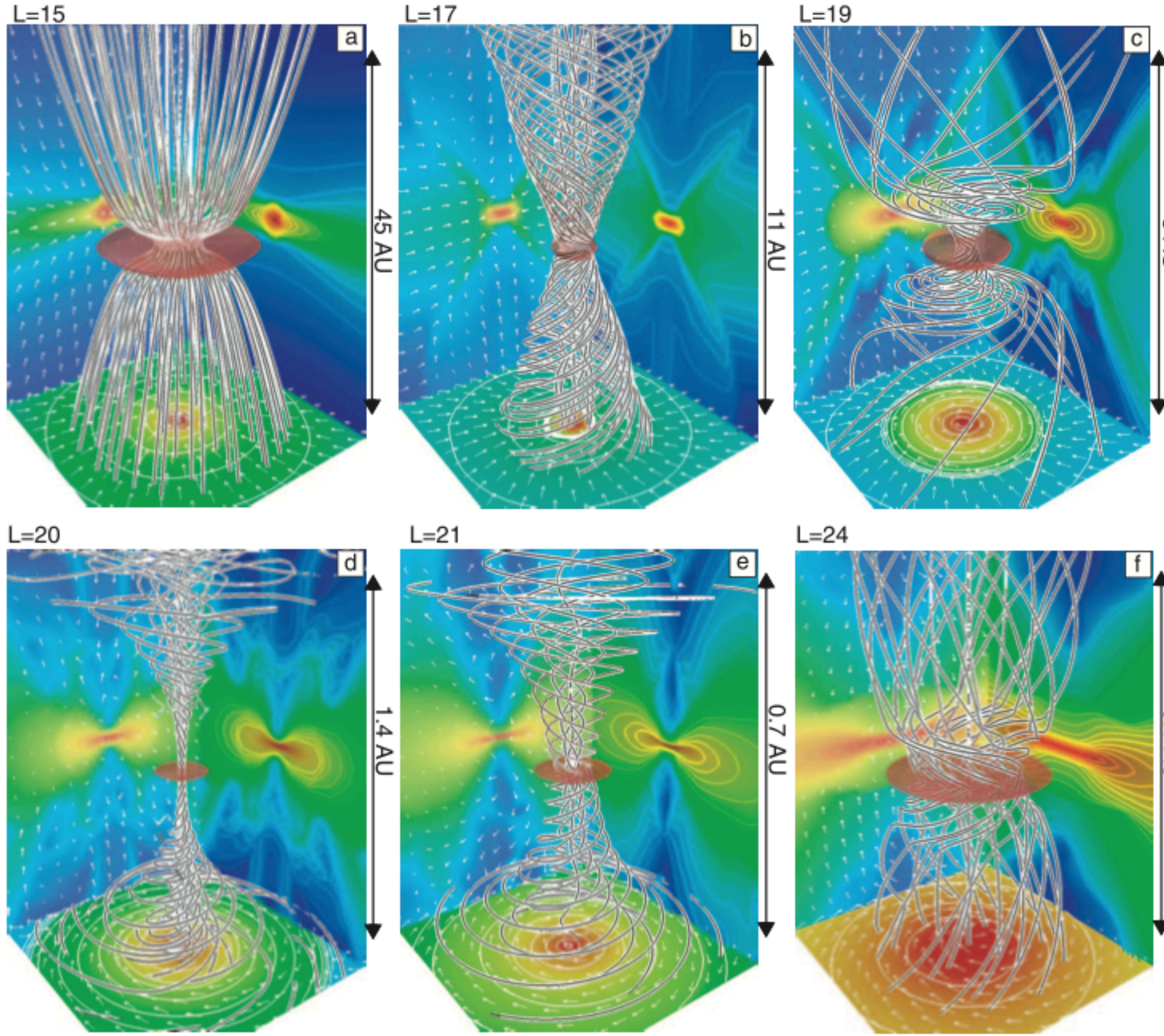
Characteristic scales of about 10-20 AU

⇒**Formation of compact disks**

Dapp & Basu recent work (1D calculation)



Structure of the magnetic field in protostars



Machida et al. 2007

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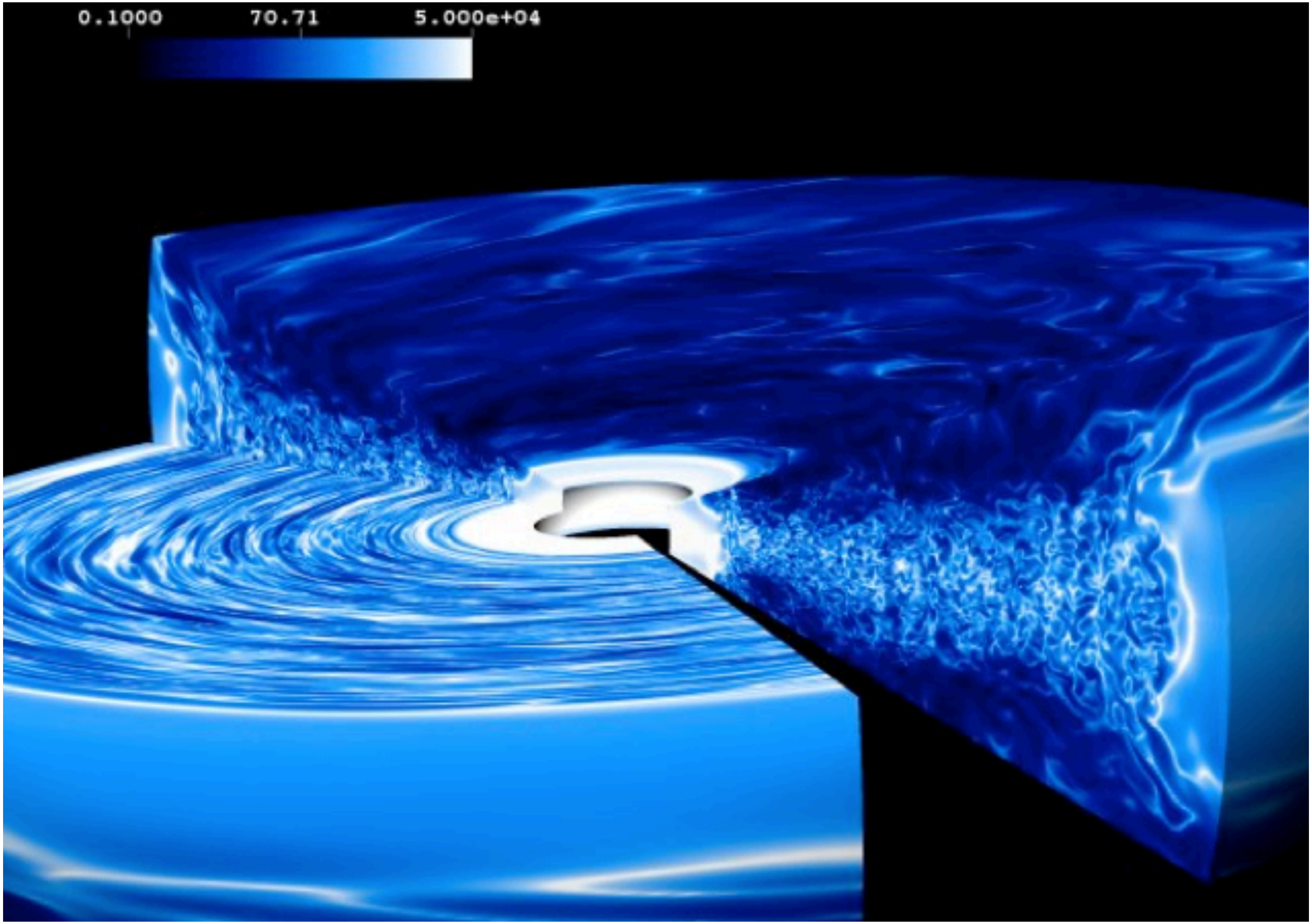
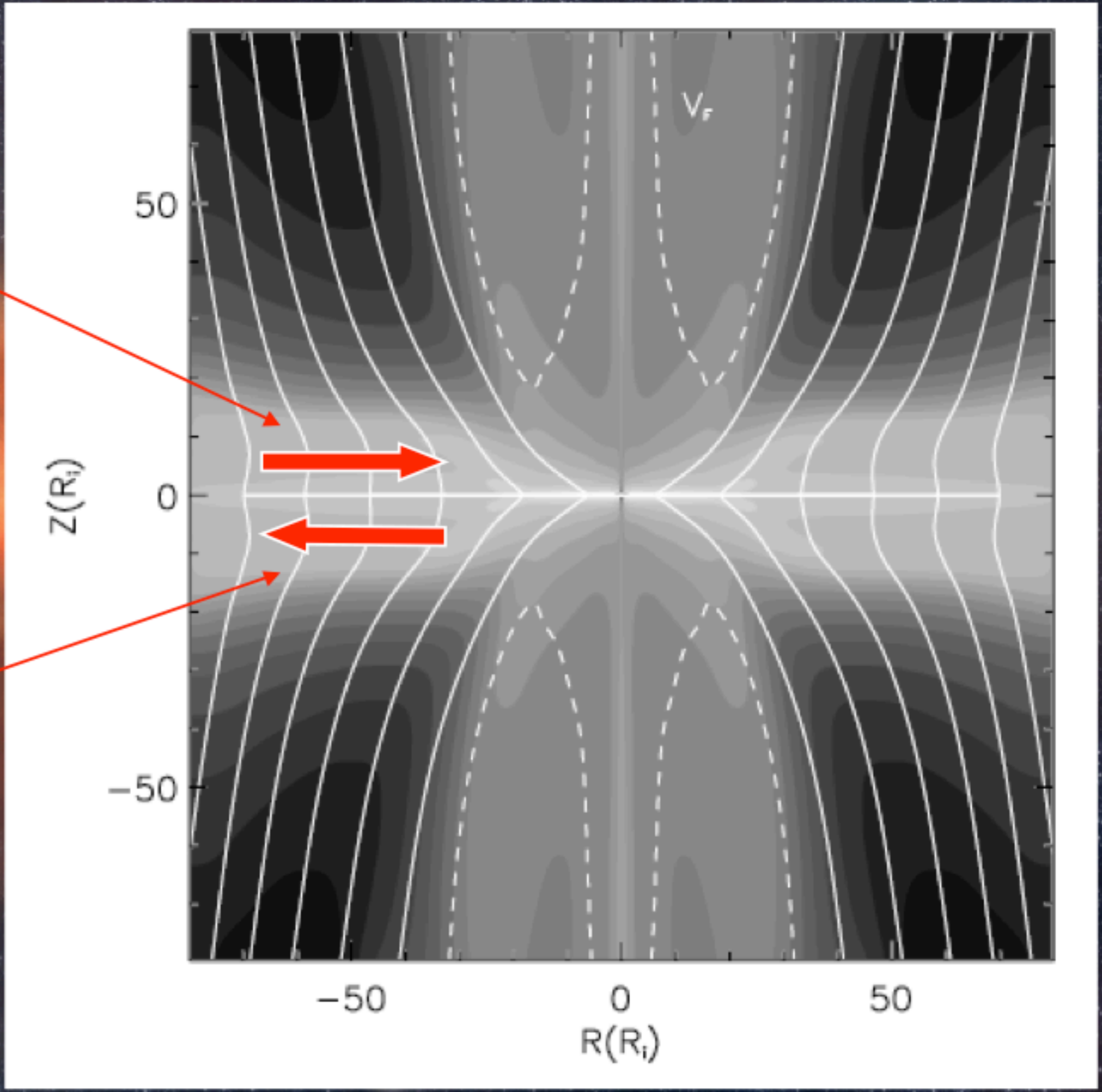


Fromang et al., Flock et al., Lesur et al.

Mass accretion takes matter and flux (in ideal MHD!)in

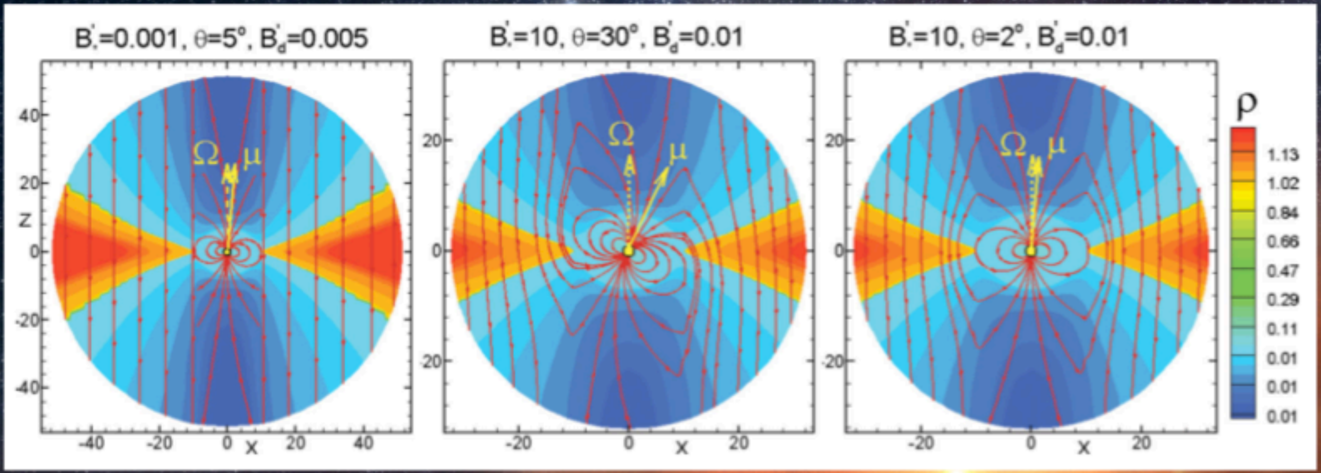


(turbulent) diffusion of field moves magnetic flux outward

How vertical magnetic flux is moved around is important for jet launching

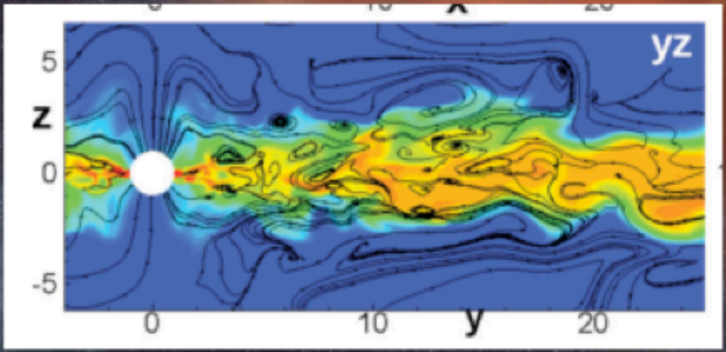
Ferreira et al.

Romanova et al. (2011,2012)

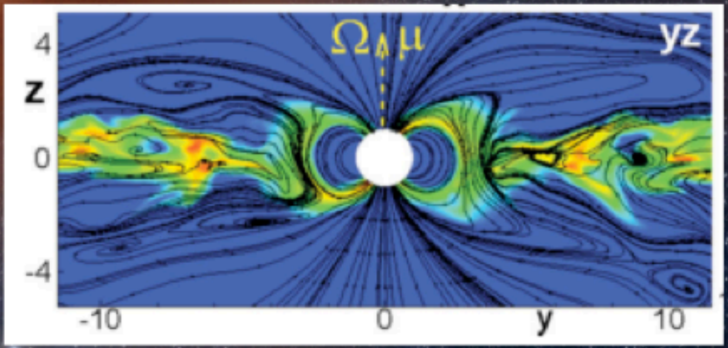


- Full 3D simulations
- ~80 cells accross the disk
- initial $\beta \sim 10^3$

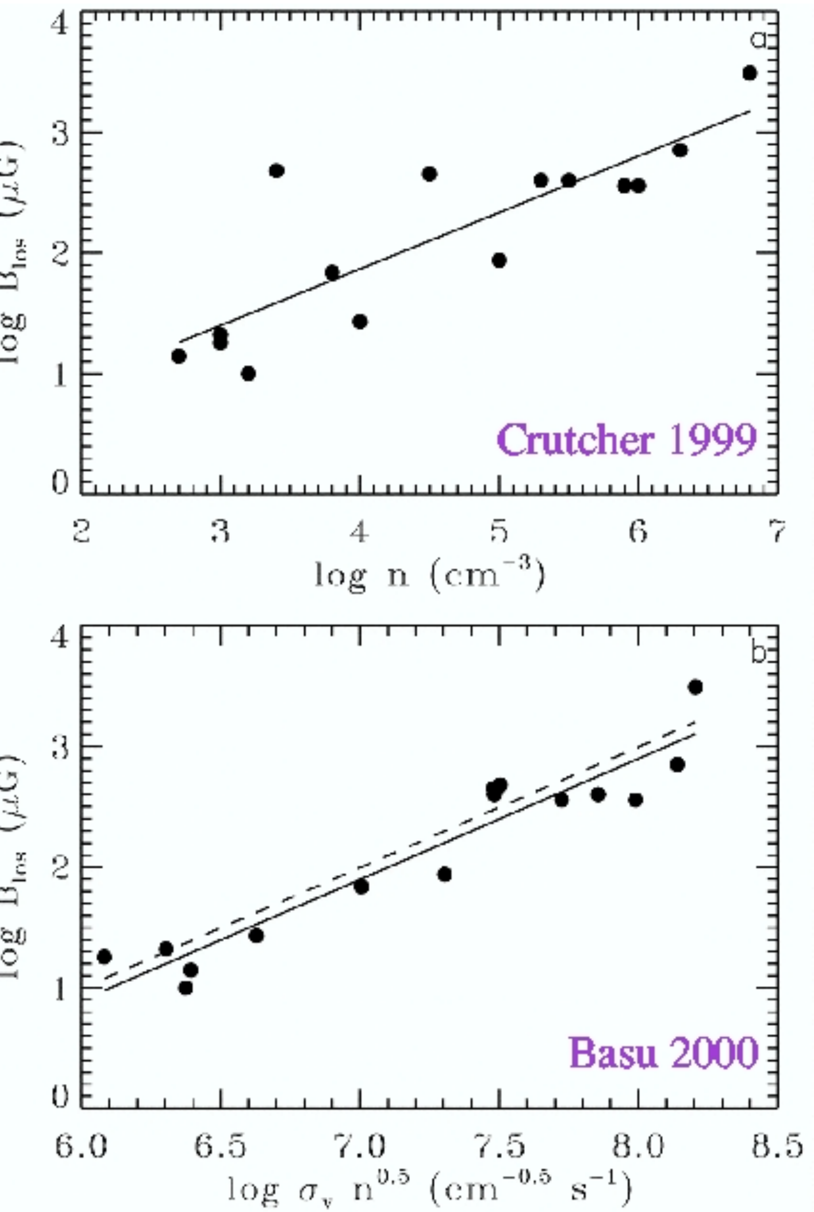
Star-disk boundary layer



Magnetospheric cavity



Magnetic Field Intensity
(based on Zeeman effect)



Flux conservation: $\phi \propto BR^2 = cst$

If the magnetic field is dynamically important, the gas flows along the field lines

$$\Sigma = \int \rho dl \approx \rho l$$

$$\Sigma R^2 = cst \Rightarrow B \propto \Sigma$$

Gravitational energy:

$$\phi \approx G\rho l^2 \approx G\Sigma^2/\rho \propto B^2/\rho$$

Mechanichal equilibrium:

$$\phi \approx \sigma^2$$

$$\Rightarrow B \approx \sigma\rho^{1/2}$$

Donati et al. (2005) measured with Espadon a magnetic field intensity at very high density (10^{17} cm^{-3} ?) a magnetic field of about 1kG in a class II (FU orionis). Typical scale about 0.05 AU.

This more or less fits with the $B / n^{1/2} = cst$ relation.

Does it mean that the magnetic field is conserved all the way, in contradiction with theoretical predictions ?

Is the field regenerated ? Or is it conserved ?

SPIROU will allow to
-test other cases (only one detection so far)
-go further away in the disk (may be 0.5 AU) and to lower densities.

It will also be possible to probe ~50 classI and ~100 classII