On the formation of disks during the collapse of magnetized prestellar cores

Patrick Hennebelle

(ENS-Observatoire de Paris)

Collaborators:

Benoît Commerçon, Andréa Ciardi, Sébastien Fromang,

Romain Teyssier, Philippe André, Anaelle Maury,

Edouard Audit, Cédric Mulet-Marquis, Gilles Chabrier, Marc Joos

Thermal Support

Consider a cloud of initial radius R and a constant temperature T

When R decreases, Etherm/Egrav decreases:

$$\frac{E_{therm}}{E_{grav}} = \frac{3}{2}\frac{M/m_p kT}{GM^2/R} \propto R$$

Centrifugal Support and Angular Momentum Conservation

When R decreases, Erot/Egrav increases:

$$j = R^2\omega(t) = R_0{}^2\omega_0$$

$$\frac{E_{rot}}{E_{grav}} = \frac{MR^2\omega^2}{GM^2/R} \propto \frac{1}{R}$$

Magnetic Support and Flux Conservation

When R decreases, Emag/Egrav is constant:

Typically one infers $\mu=(M/\phi)/(M/\phi)_c=1\text{-}4$

(Crutcher et al. 1999, 2004)

$$\phi \propto BR^2$$

$$\frac{E_{mag}}{E_{grav}} = \frac{B^2R^3}{M^2/R} \propto (\phi/M)^2$$

Consequences:

-centrifugal forces: non-isotropic and become dominant
⇒flattening of the envelope, formation of a *centrifugally supported disk*

-magnetic forces: non-isotropic and stay comparable to gravity
⇒flattening of the envelope BUT NOT the formation of a supported structure

This flattening which *looks like a disk* is sometimes called a pseudo disk (Galli & Shu 1993, Li & Shu 1996). *A pseudo-disk is simply a flattened envelope.*

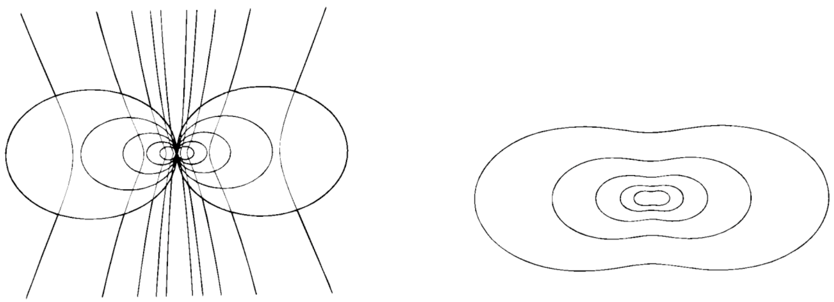


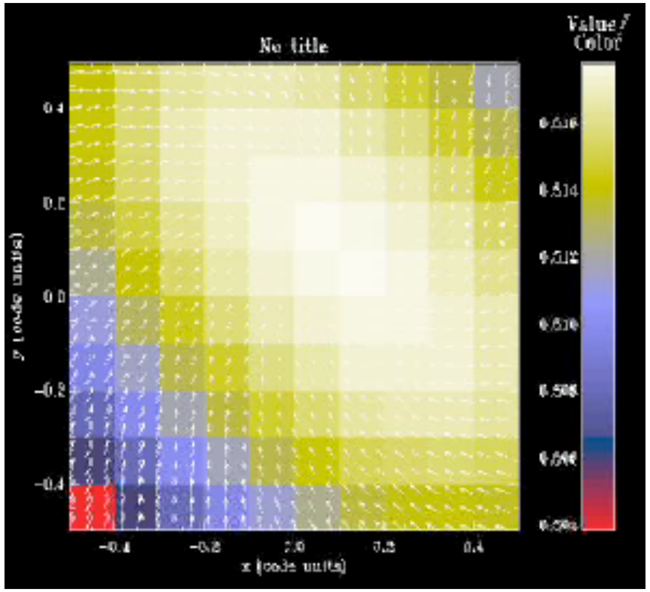
Fig. 2a Fig. 2b

Magnetic field brakes the cloud (twisting of the field lines)
⇒transfer angular momentum from the inner part towards the outer parts
⇒Angular momentum not conserved (locally)
=>rotation does not necessarily imply disk formation

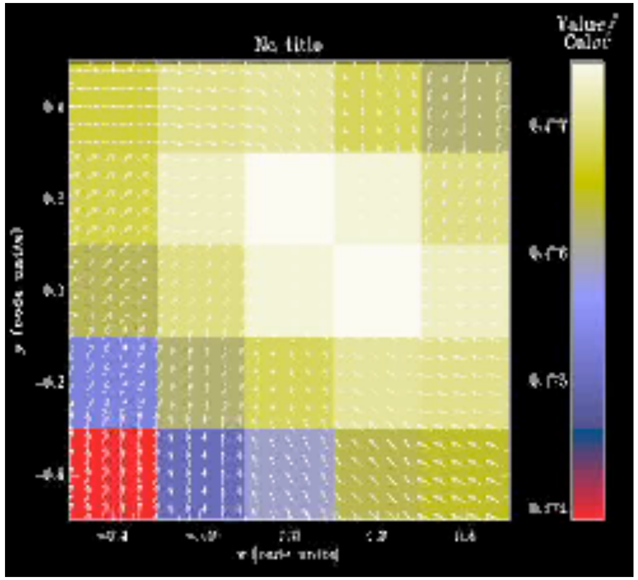
Zoom into the central part of a collapse calculation
(1 solar mass slowly rotating core)

300 AU

XY
hydro

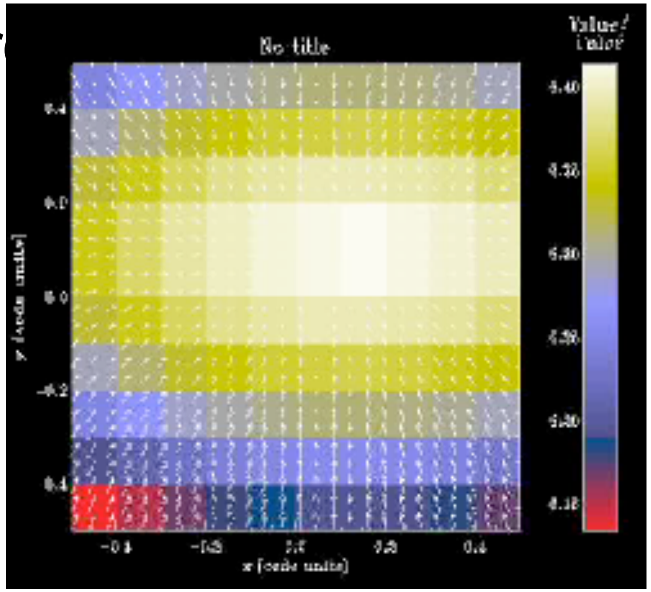


XY
MHD
μ=2

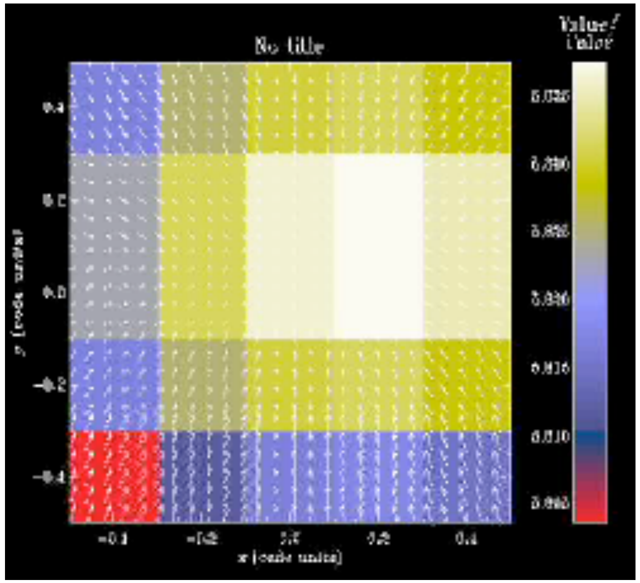


B, ω

XZhydr

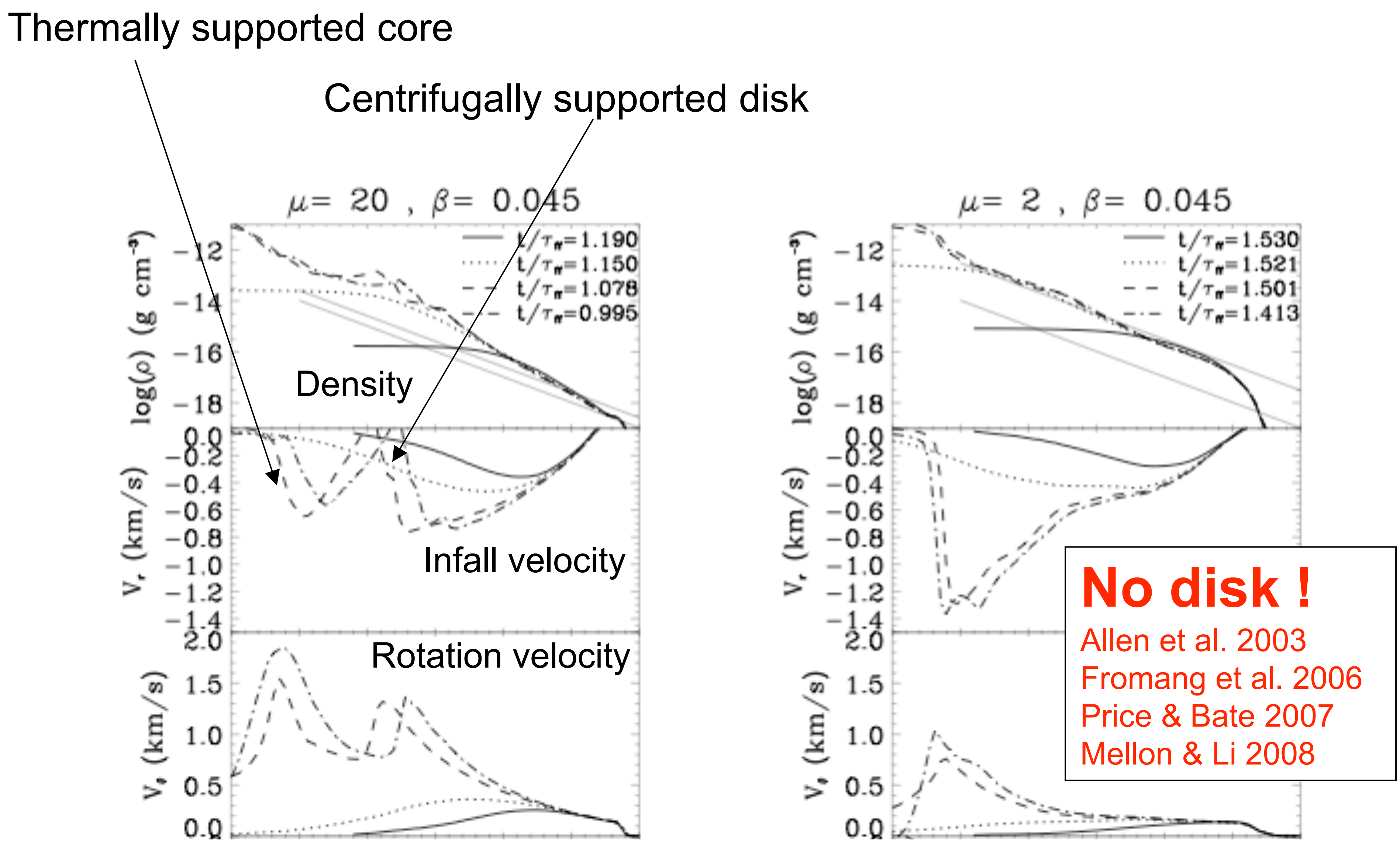


XZ
MHD
μ=2



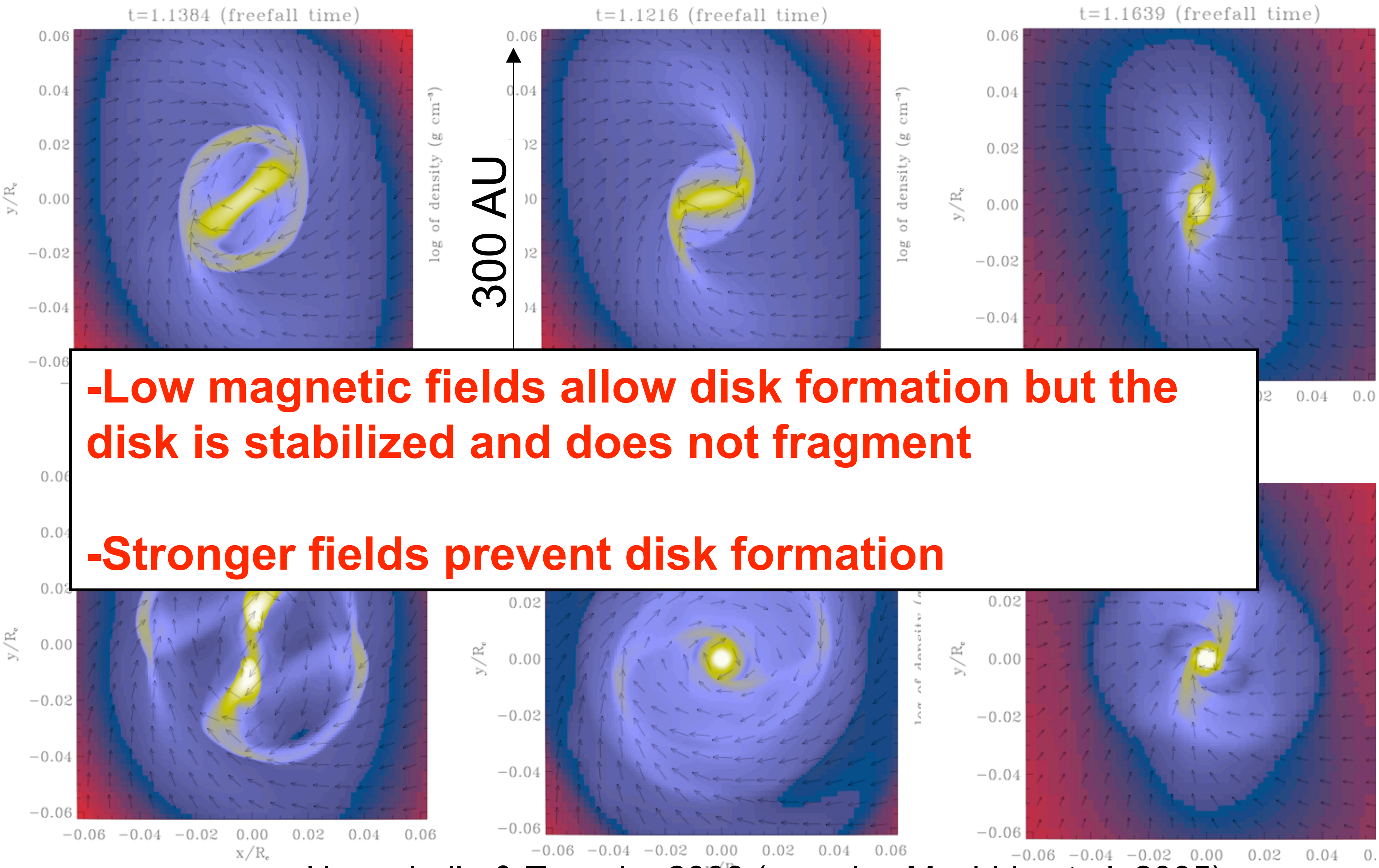
B, ω

Density, rotation and infall velocity profiles



Hennebelle & Fromang 2008

μ=1000 (hydro) μ=20 μ=5



-Low magnetic fields allow disk formation but the disk is stabilized and does not fragment

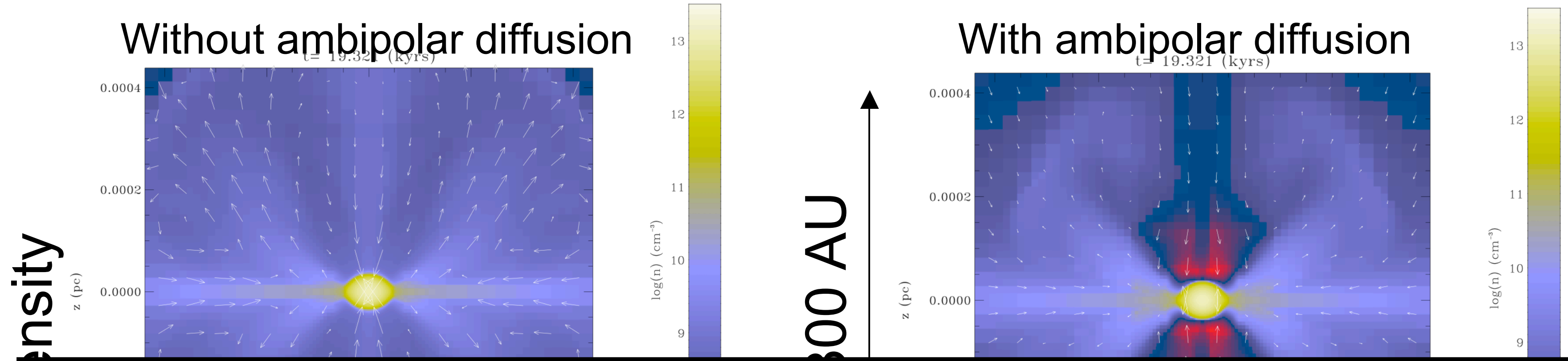
-Stronger fields prevent disk formation

Hennebelle & Teyssier 2008 (see also Machida et al. 2005)

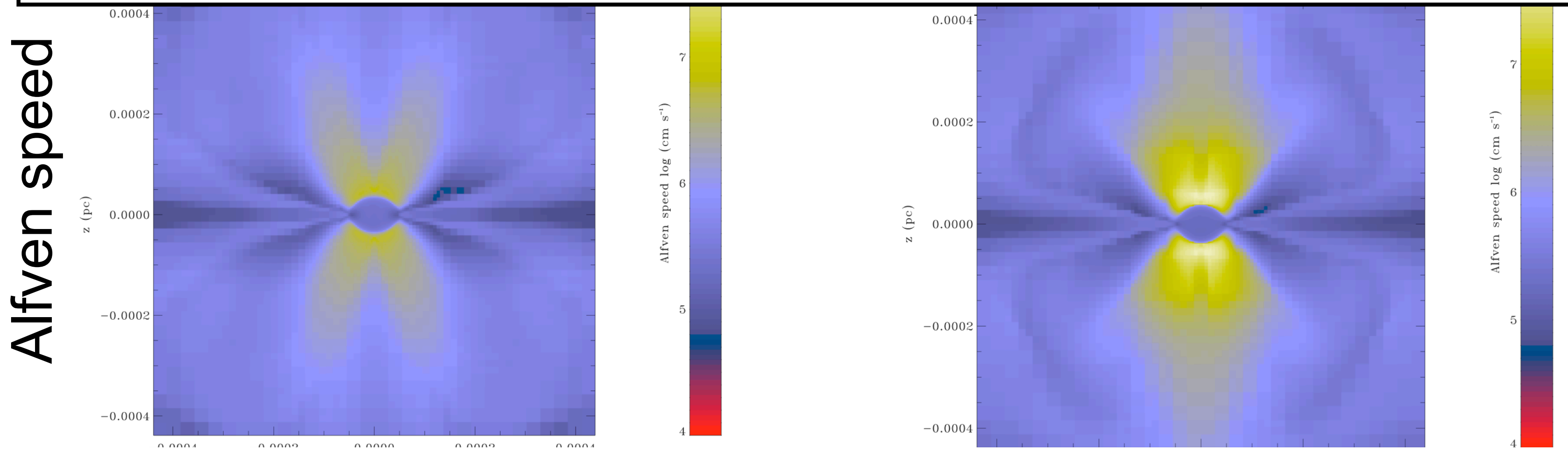
Can non ideal MHD modify this?
(Mellon & Li 2009, Duffin & Pudritz 2009)

τ_{amb}/τ_{ff} = 8 for critical cores
$\tau_{amb} \propto B^2$=>too slow!

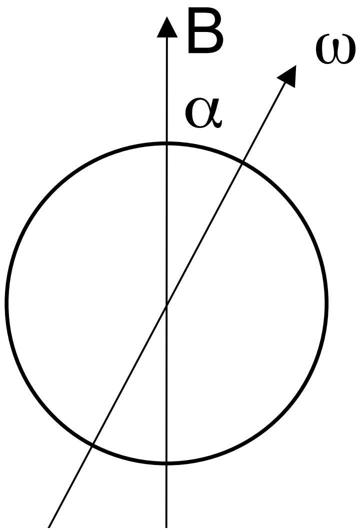
Mulet-Marquis et al. in prep



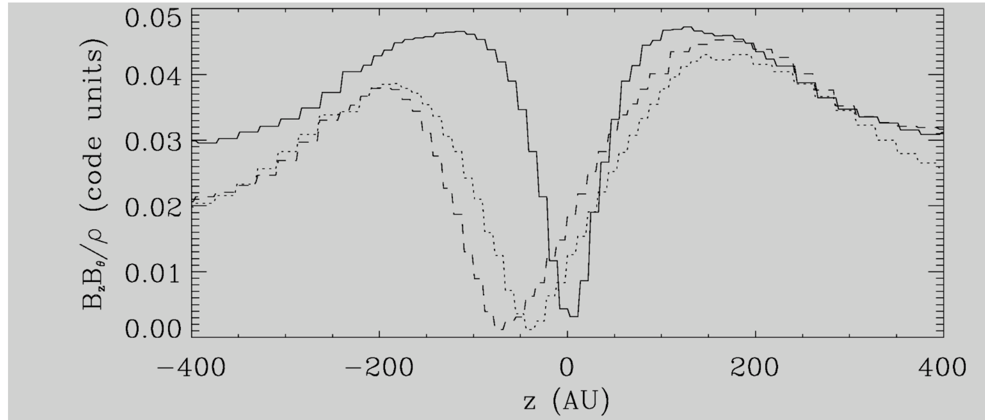
Non ideal MHD processes ambipolar diffusion and Ohmic dissipation (Shu et al. 06, Machida et al. 2008) can induce the formation of small 10 AU objects



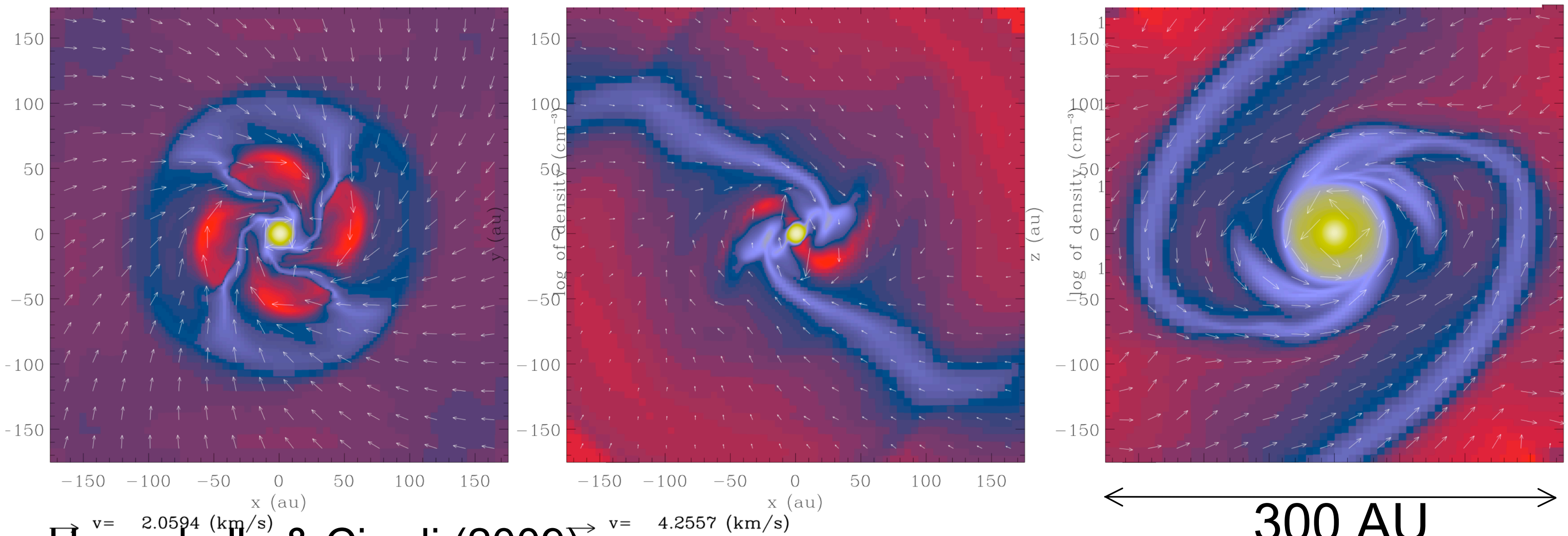
Can different magnetic configurations modify this ?



Magnetic braking less efficient when α increases

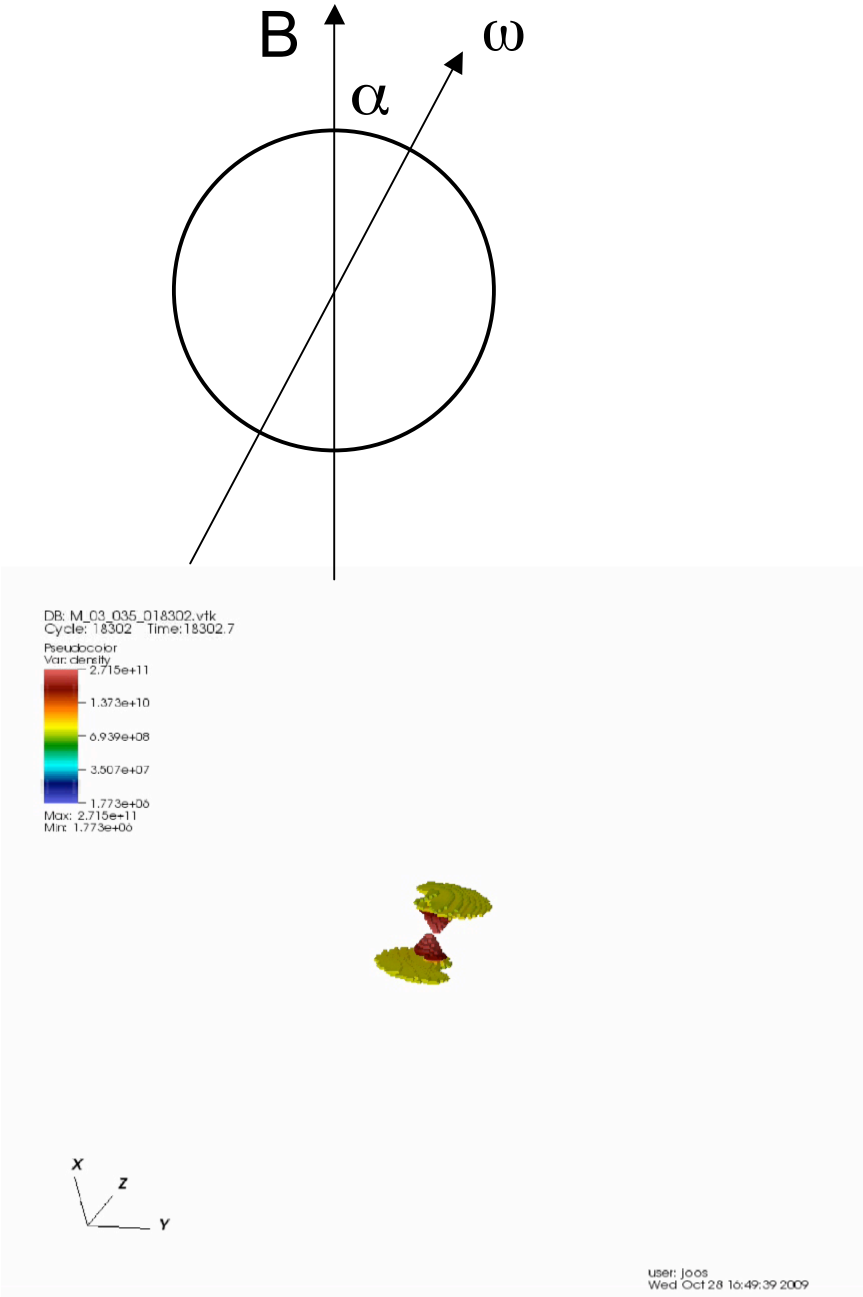


μ=5,α=0° μ=5,α=20° μ=5,α=90°

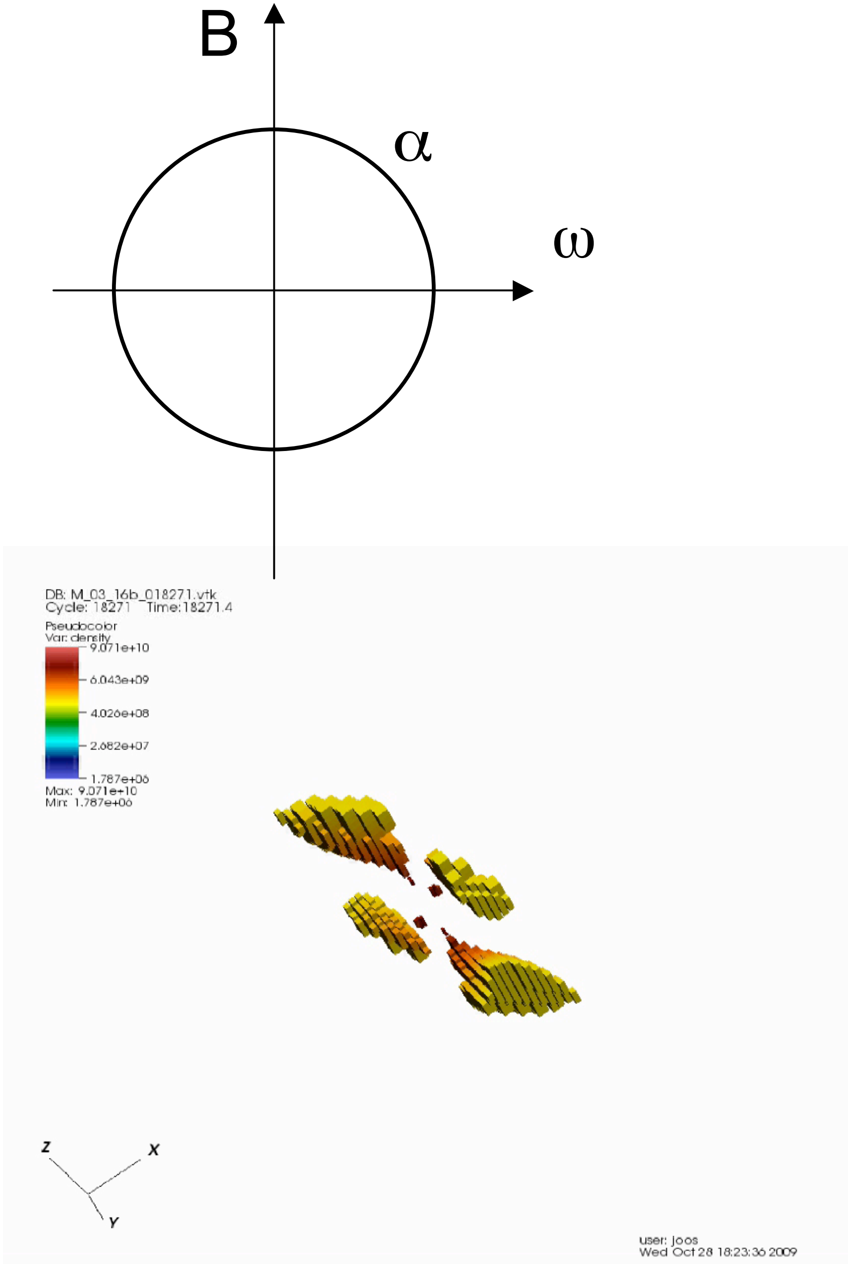


Hennebelle & Ciardi (2009)

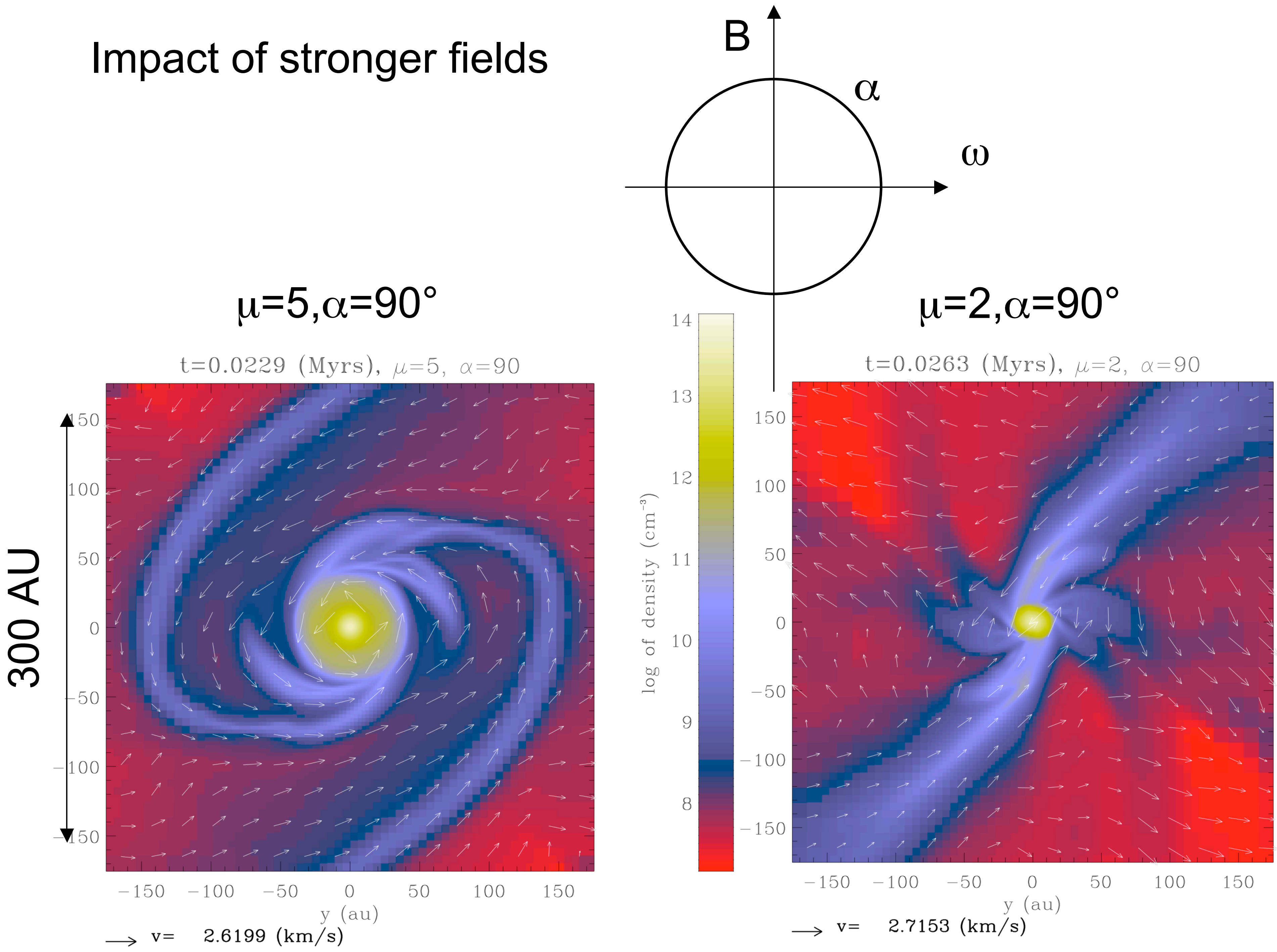
μ=5,α=20°



μ=5,α=90°

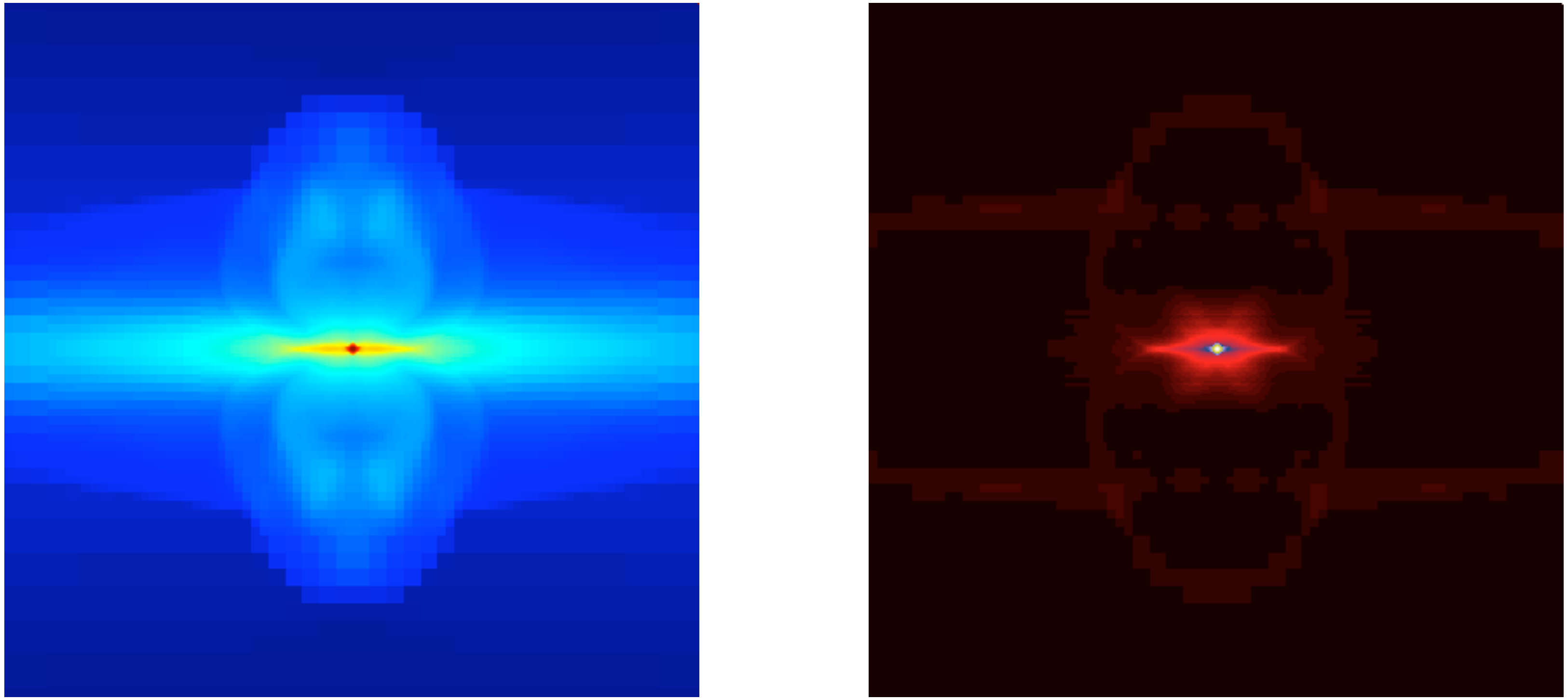


Impact of stronger fields



Radiative transfer + MHD calculation

density | temperature



Commercon et al. in prep

Conclusions

-A complicated problem => a complex answer
….and the field is fastly developing.

-In the aligned case, *centrifugally supported* disks do not form even for small values of the magnetic field (μ=5-10)

-*The aligned case is a little special*…
Disks form for larger values of B if the angle between the rotation and the magnetic field is large enough (but μ=2-3 seems to be the limit)

-Difficulty to bridge the gap between class-0/class-I phase yet
Magnetic field ***transfer*** momentum, if no envelope left, then nothing to brake. *Class-I disks should form !*