FLASH Code Tutorial

part V
special features

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FLASH code: special features

"Features" so far:

- gravity solvers
  - multi-pole
  - multi-grid
  - BHTree

- particles
  - sinks

- radiation module
  - MGD
  - ray-trace + ionising radiation

FLASH code: special features

- multi-species $\Longrightarrow$ with individual properties

Property Name	Description	Data type
A	Number of protons and neutrons in nucleus	real
Z	Atomic number	real
N	Number of neutrons	real
E	Number of electrons	real
BE	Binding Energy	real
GAMMA	Ratio of heat capacities	real
MS_ZMIN	Minimum allowed average ionization	real
MS_EOSTYPE	EOS type to use for MTMMMT EOS	integer
MS_EOSSUBTYPE	EOS subtype to use for MTMMMT EOS	integer
MS_EOSZFREEFILE	Name of file with ionization data	string
MS_EOSENERFILE	Name of file with internal energy data	string
MS_EOSPRESFILE	Name of file with pressure data	string
MS_NUMELEMS	Number of elements comprising this species	integer
MS_ZELEMS	Atomic number of each species element	array(integer)
MS_AELEMS	Mass number of each species element	array(real)
MS_FRACTIONS	Number fraction of each species element	array(real)
MS_OPLOWTEMP	Temperature at which cold opacities are used	real

FLASH code: special features

- `source/Multispecies/MultispeciesMain`
  ⟹ initialise properties: `Simulation_initSpecies.F90`

```
#include "Multispecies.h"
#include "Flash.h"

! These two variables are defined in the Config file as
! SPECIES SF6 and SPECIES AIR
  call Multispecies_setProperty(SF6_SPEC, A, 146.)
  call Multispecies_setProperty(SF6_SPEC, Z, 70.)
  call Multispecies_setProperty(SF6_SPEC, GAMMA, 1.09)

  call Multispecies_setProperty(AIR_SPEC, A, 28.66)
  call Multispecies_setProperty(AIR_SPEC, Z, 14.)
  call Multispecies_setProperty(AIR_SPEC, GAMMA, 1.4)
end subroutine Simulation_initSpecies
```

FLASH code: special features

- Material properties
  `physics/materialProperties`

  works with HD & MDH

  - `Viscosity/ViscosityMain`
    - `Constant`
    - `Spitzer` thermal viscosity
      $\Longrightarrow \nu \propto T^{5/2}$

  - `MagneticResistivity/MagneticResistivityMain`
    $\Longrightarrow$ so far: only `Constant` η

FLASH code: special features

- Material properties
  `physics/materialProperties`

  works with HD & MDH

  - thermal `Conductivity/ConductivityMain`
    - `Constant`
    - `SpitzerHighZ`
      $\Longrightarrow$ for electron conductivity (e.g. HEDP experiments)

$$K_{\text{ele}} = \left(\frac{8}{\pi}\right)^{3/2} \frac{k_B^{7/2}}{e^4 \sqrt{m_{\text{ele}}}} \left(\frac{1}{1 + 3.3/\bar{z}}\right) \frac{T_{\text{ele}}^{5/2}}{\bar{z} \ln \Lambda_{ei}}$$

FLASH code: special features

- **Relativistic** hydrodynamics:

$\Longrightarrow$ e.g. AGN jets: Lorentz-factor ~ 45

`physics/Hydro/HydroMain/split/RHD` *(A. Mignione)*

$$\frac{\partial}{\partial t}\begin{pmatrix} D \\ \boldsymbol{m} \\ E \end{pmatrix} + \nabla \cdot \begin{pmatrix} D\boldsymbol{v} \\ \boldsymbol{m}\boldsymbol{v} + p\boldsymbol{I} \\ \boldsymbol{m} \end{pmatrix} = 0$$

$$D = \gamma\rho\,, \quad \boldsymbol{m} = \rho h \gamma^2 \boldsymbol{v}\,, \quad E = \rho h \gamma^2 - p\,,\ h = 1 + \frac{\Gamma}{\Gamma - 1}\frac{p}{\rho}$$

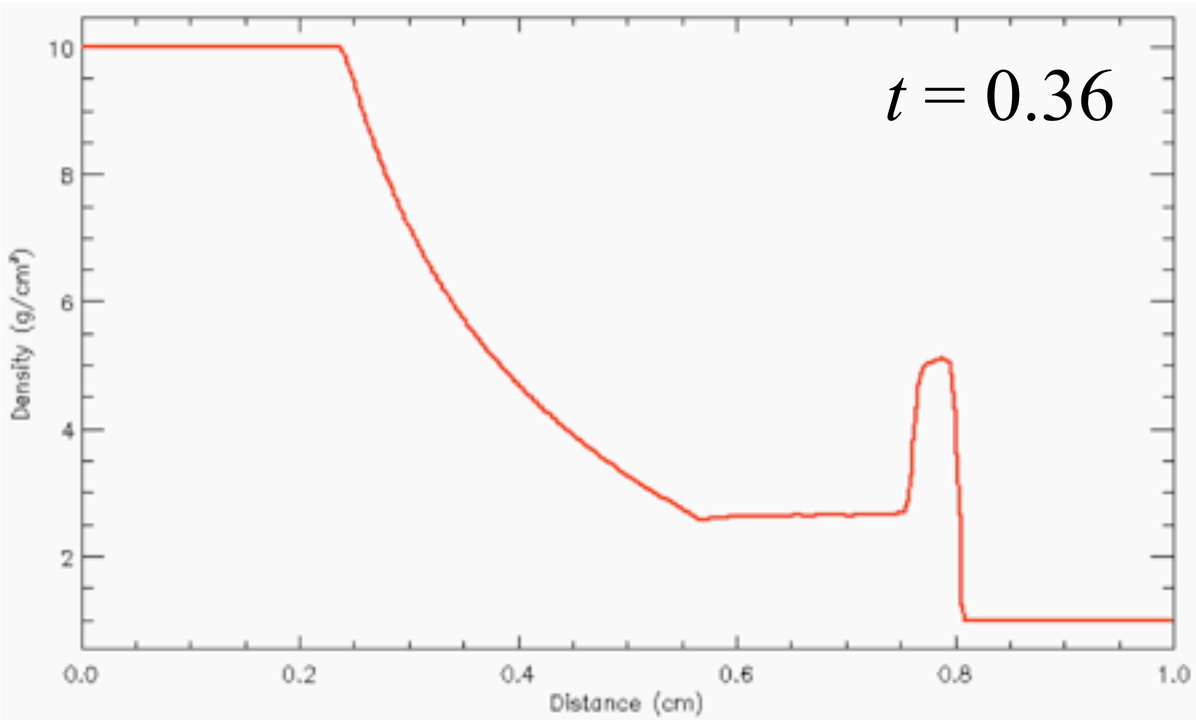
- h : enthalpy, Γ : specific heat ratio
- $\gamma = \left(1 - \boldsymbol{v}^2\right)^{-1/2}$

$\Longrightarrow$ use relativistic units: c = 1

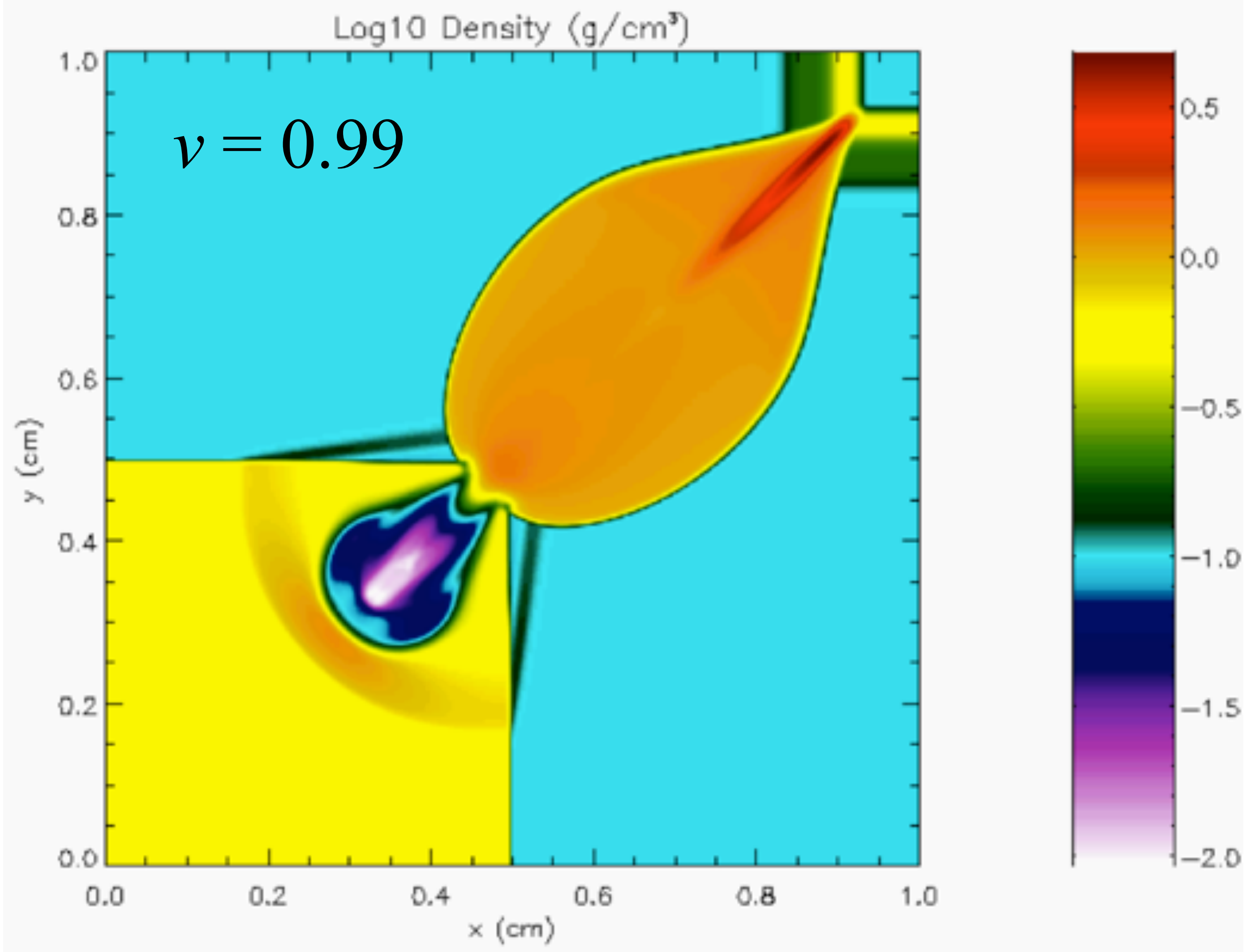
FLASH code: special features

- Relativistic hydrodynamics:
  `physics/Hydro/HydroMain/split/RHD`

$$\rho_L = 10 \qquad \rho_R = 1.0$$
$$p_L = 40/3 \qquad p_R = 2/3 \times 10^{-6}$$



`RHD_Sod`



`RHD_Riemann2D`

FLASH code: special features

- Relativistic hydrodynamics:
  `physics/Hydro/HydroMain/split/RHD`

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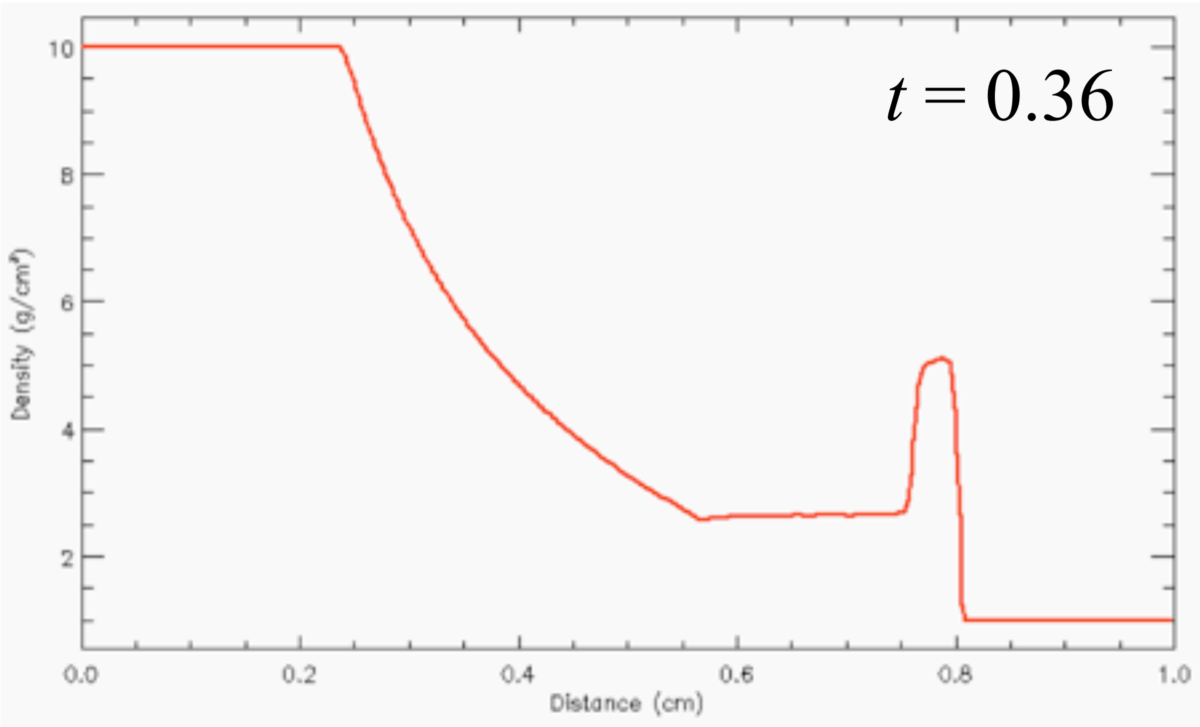

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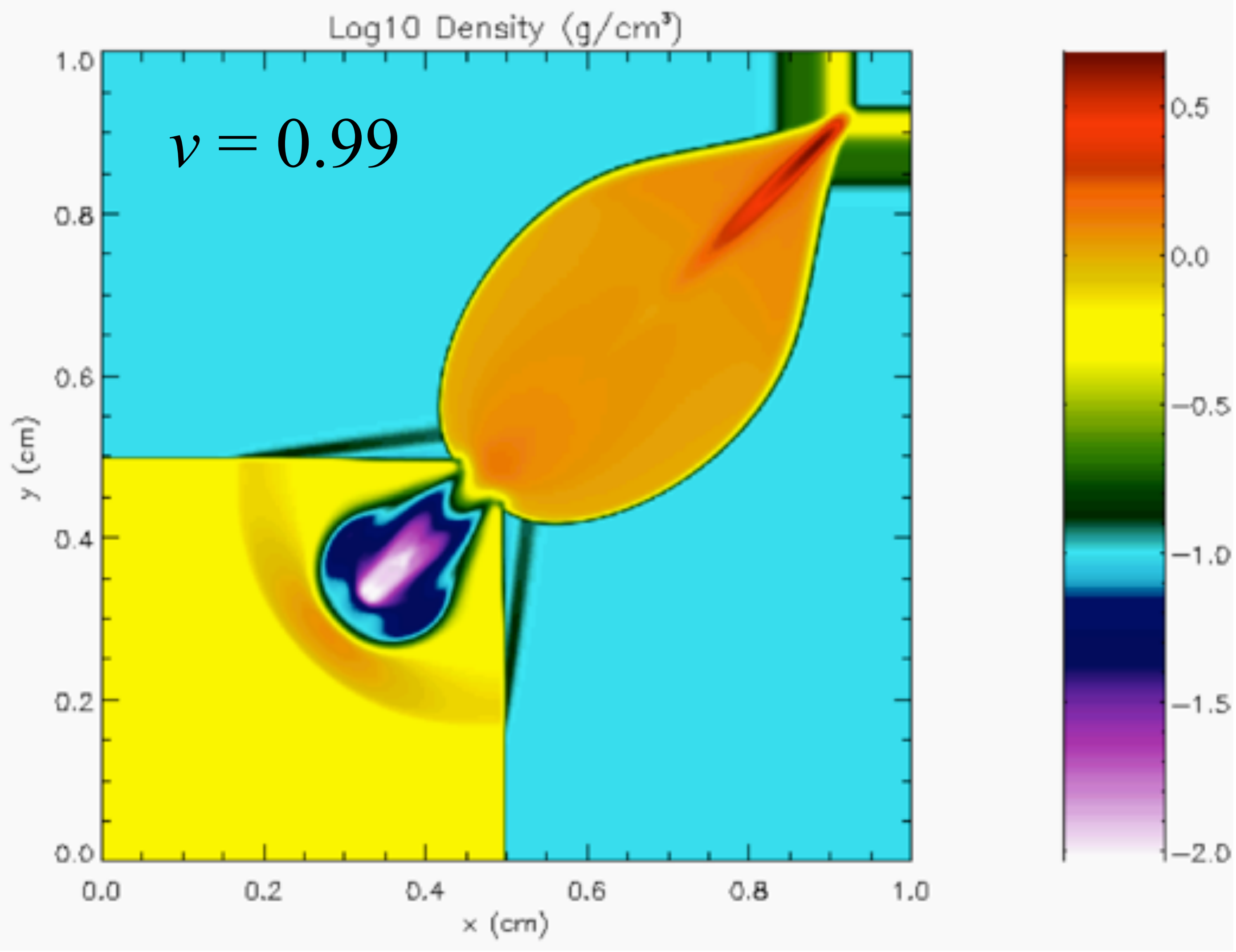

`RHD_Riemann2D`

$\Longrightarrow$ no RMHD yet

FLASH code: special features

- **Cosmology** unit:
  `physics/Cosmology/CosmologyMain`

use co-moving variables:

$$\rho \equiv a^3 \tilde{\rho}$$
$$p \equiv a \tilde{p}$$
$$T \equiv \frac{\tilde{T}}{a^2}$$
$$\rho\epsilon \equiv a \tilde{\rho} \tilde{\epsilon}$$

$\Longrightarrow$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v}\mathbf{v}) + \nabla p + 2\frac{\dot{a}}{a}\rho \mathbf{v} + \rho \nabla \phi = 0$$

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot [(\rho E + p)\mathbf{v}] + \frac{\dot{a}}{a}[(3\gamma - 1)\rho\epsilon + 2\rho v^2] + \rho \mathbf{v} \cdot \nabla \phi = 0$$

$$\frac{\partial \rho\epsilon}{\partial t} + \nabla \cdot [(\rho\epsilon + p)\mathbf{v}] - \mathbf{v} \cdot \nabla p + \frac{\dot{a}}{a}(3\gamma - 1)\rho\epsilon = 0\ .$$

$$\nabla^2 \phi = \frac{4\pi G}{a^3}(\rho - \bar{\rho})$$

$a(t)$: scale factor

~ variables: physical variables

$\Longrightarrow$ terms $\propto \frac{\dot{a}}{a}$ are source terms

FLASH code: special features

- Cosmology unit:

```
Cosmology_solveFriedmannEqn
```

$\Longrightarrow$ compute the scale factor ***a*****(t)**

$\Longrightarrow$ using a 4th order Runge-Kutta with

$$H^2(t) \equiv \left(\frac{\dot{a}}{a}\right)^2 = H_0^2 \left(\frac{\Omega_m}{a^3} + \frac{\Omega_r}{a^4} + \Omega_\Lambda - \frac{\Omega_c}{a^2}\right) \; ; \; \bar{\rho} \equiv \Omega_m \rho_{\mathrm{crit}}$$

H_0 : today's Hubble parameter $[1/\mathrm{sec}]$

curvature: $\Omega_c \equiv \Omega_m + \Omega_r + \Omega_\Lambda - 1$

FLASH code: special features

- Cosmology unit:

runtime parameters

Parameter	Type	Default	Description
useCosmology	BOOLEAN	.true.	True if cosmology is to be used in this simulation
OmegaMatter	REAL	0.3	Ratio of total mass density to critical density at the present epoch (Ω_m)
OmegaBaryon	REAL	0.05	Ratio of baryonic (gas) mass density to critical density at the present epoch; must be $\leq$ OmegaMatter (Ω_b)
CosmologicalConstant	REAL	0.7	Ratio of the mass density equivalent in the cosmological constant to the critical density at the present epoch (Ω_Λ)
OmegaRadiation	REAL	5×10^{-5}	Ratio of the mass density equivalent in radiation to the critical density at the present epoch (Ω_r)
HubbleConstant	REAL	2.1065×10^{-18}	Value of the Hubble constant H_0 in $\sec^{-1}$
MaxScaleChange	REAL	HUGE(1.)	Maximum permitted fractional change in the scale factor during each timestep

65 km/sec/Mpc

FLASH code: special features

- Cosmology unit:

one test setup: `Pancake`

$\Longrightarrow$ Zeldovich (1970) analytic solution
of a collapsing ellipsoid in an expanding background

$\Longrightarrow$ collapses first along the short axis $\Longrightarrow$ pancake structure

FLASH code: special features

- Collisionless plasma: charged particles **PIC** (particle in cell)

  $\Longrightarrow$ continuous MHD description breaks down
  for large ion gyroradius $r_{\mathrm{gyr}} \approx m_{\mathrm{ion}}\, v \,/\, q\, B$
  compared to the system size, e.g. solar magnetosphere

$\Longrightarrow$ in FLASH

`Particles/ParticlesMain/active/charged/HybridPIC`

  $\Longrightarrow$ charged ion particles within a continuous fluid

    $\Longrightarrow$ computational less expensive than pure
    multispecies particle simulations

FLASH code: special features

`Particles/ParticlesMain/active/charged/HybridPIC`

- coupling via Lorentz force:

$$\frac{d\mathbf{r}_i}{dt} = \mathbf{v}_i, \quad \frac{d\mathbf{v}_i}{dt} = \frac{q_i}{m_i}\left(\mathbf{E} + \mathbf{v}_i \times \mathbf{B}\right), \quad i = 1, \ldots, N_I$$

$$\mathbf{E} = \frac{1}{\rho_I}\left(-\mathbf{J}_I \times \mathbf{B} + \mu_0^{-1}\left(\nabla \times \mathbf{B}\right) \times \mathbf{B}\right) - \nabla p_e \quad ; \quad \frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

ρ_{I} : ion density, J_{I} : ion current, p_{e} : electron pressure

- `Grid_mapParticlesToMesh`
  $\Longrightarrow$ map particle mass and charge to mesh

- `Grid_mapToMeshParticles`
  $\Longrightarrow$ interpolate mesh fields to particle position

FLASH code: special features

`Particles/ParticlesMain/active/charged/HybridPIC`

- mapping schemes:
  - linear interpolation (Cloud-in-Cell):
    $\Longrightarrow$ `Particles/ParticlesMapping/CIC`
  - `Particles/ParticlesMapping/Quadratic`

- advancing:
  - Euler, RK, Midpoint, ...

- time scales:
  - due to velocity: $\Delta t \max_i(|\mathbf{v}_i|) < \Delta x$
  - due to plasma waves:

$$\Delta t < \frac{\Omega_i^{-1}}{\pi}\left(\frac{\Delta x}{\delta_i}\right)^2 \sim \frac{n}{B}(\Delta x)^2, \qquad \delta_i = \frac{1}{|q_i|}\sqrt{\frac{m_i}{\mu_0\, n}}$$

FLASH code: special features

- Collisionless plasma: charged particles PIC

⟹ particle properties:

Variable	Type	Default	Description
pt_picPname_1	STRING	"H+"	Specie 1 name
pt_picPmass_1	REAL	1.0	Specie 1 mass, m_i [amu]
pt_picPcharge_1	REAL	1.0	Specie 1 charge, q_i [e]
pt_picPdensity_1	REAL	1.0	Initial n_I specie 1 [m^{-3}]
pt_picPtemp_1	REAL	1.5e5	Initial T_I specie 1 [K]
pt_picPvelx_1	REAL	0.0	Initial $\mathbf{u}_I$ specie 1 [m/s]
pt_picPvely_1	REAL	0.0	
pt_picPvelz_1	REAL	0.0	
pt_picPweight_1	REAL	1.0	Real particles per macro-particle of specie 1

⟹ example: `Plasma`

FLASH code: developments

- FLASH: ongoing developments
  - chemistry: coupling with KROME (S. Bovino & D. Seifried)
  - radiation transfer
    $\Longrightarrow$ extend point source ray-trace
    using parallel rays for photon scattering (L. Buntemeyer)
  - implementation of TreeCol (Paul Clark & Simon Glover)
    $\Longrightarrow$ get column density for external radiation

Disc Formation in Turbulent Cloud Cores

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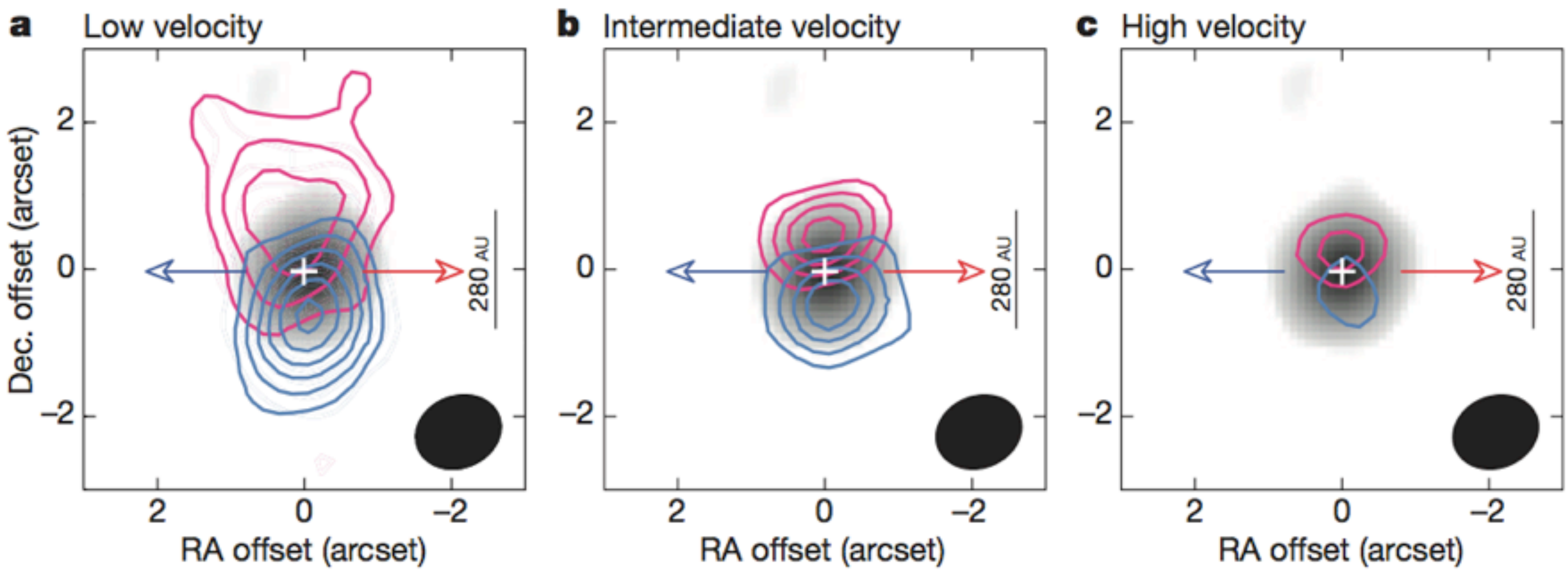
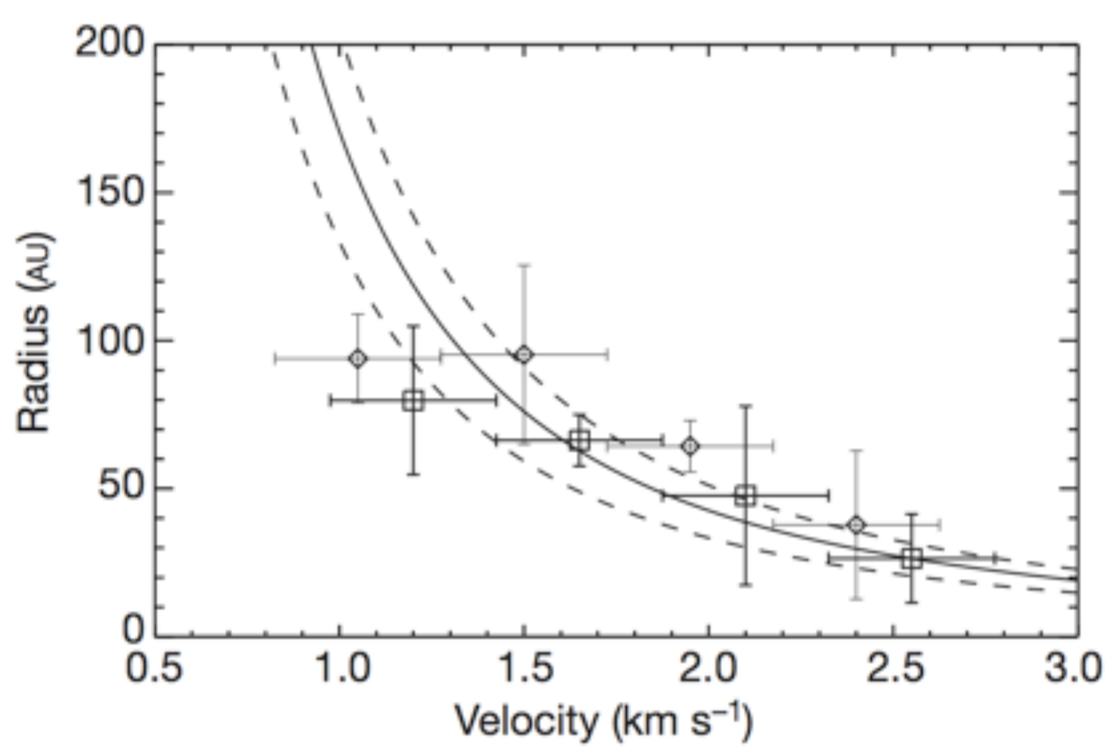
Co-Worker:
Daniel Seifried (Hamburg), Ralph Pudritz (McMaster), Ralf Klessen (ITA)

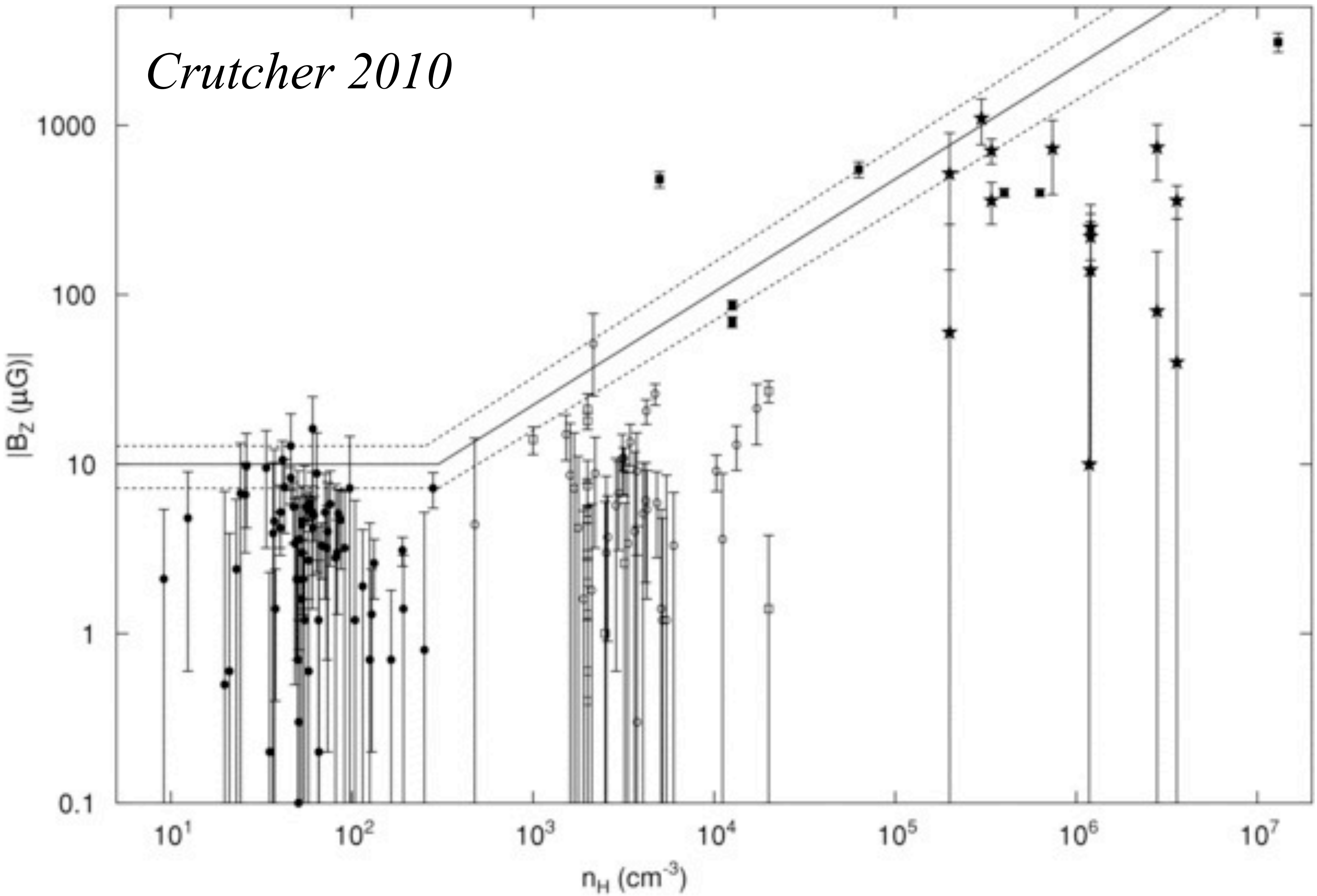
Star Formation: Early-type discs

Observations of Class 0 protostellar discs: *Tobin et al.* 2012





Magnetic Fields



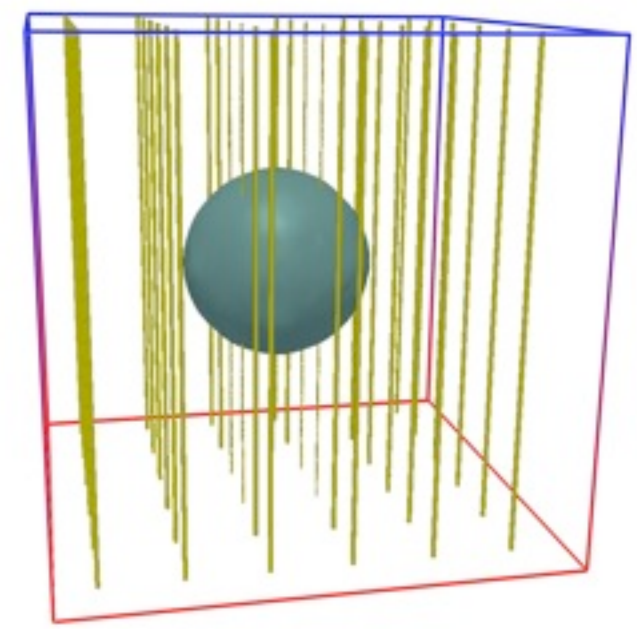
$\Longrightarrow$ mass-to-flux ratio for pre-stellar cores:

$\mu = 2 \dots 5$

Magnetic Fields

magnetic criticality

mass-to-flux ratio:



$$\mu \equiv \left(\frac{M}{\Phi}\right)$$ = self-gravity / magnetic support

critical value:

$$\mu_{\rm crit} = 0.13/\sqrt{G}$$

spherical collapsing structure
Mouschovias & Spitzer 1976

$$\mu_{\rm crit} = \frac{1}{2\pi\,\sqrt{G}} \approx 0.16/\sqrt{G}$$

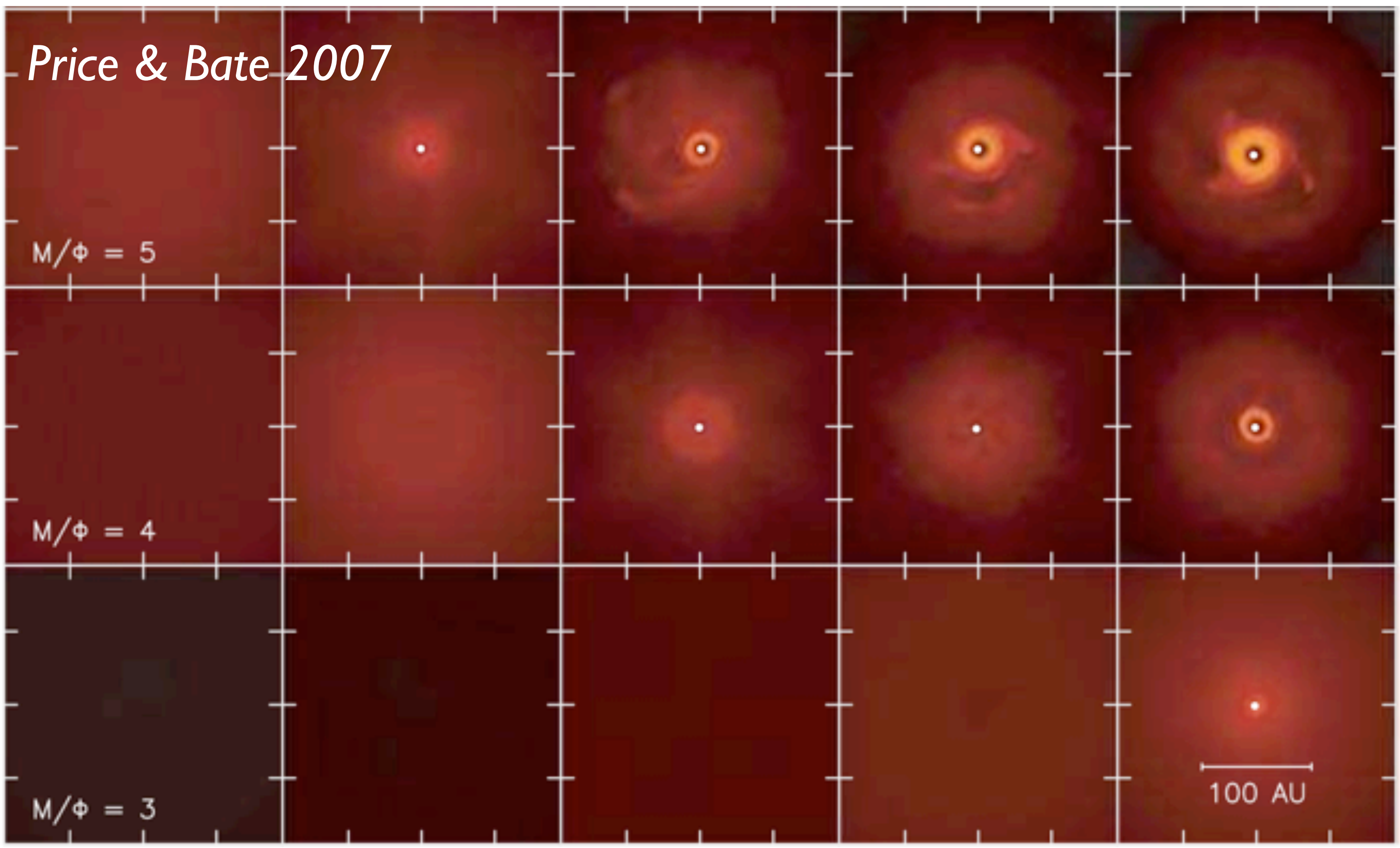
uniform disc
Nakano & Nakamura 1978

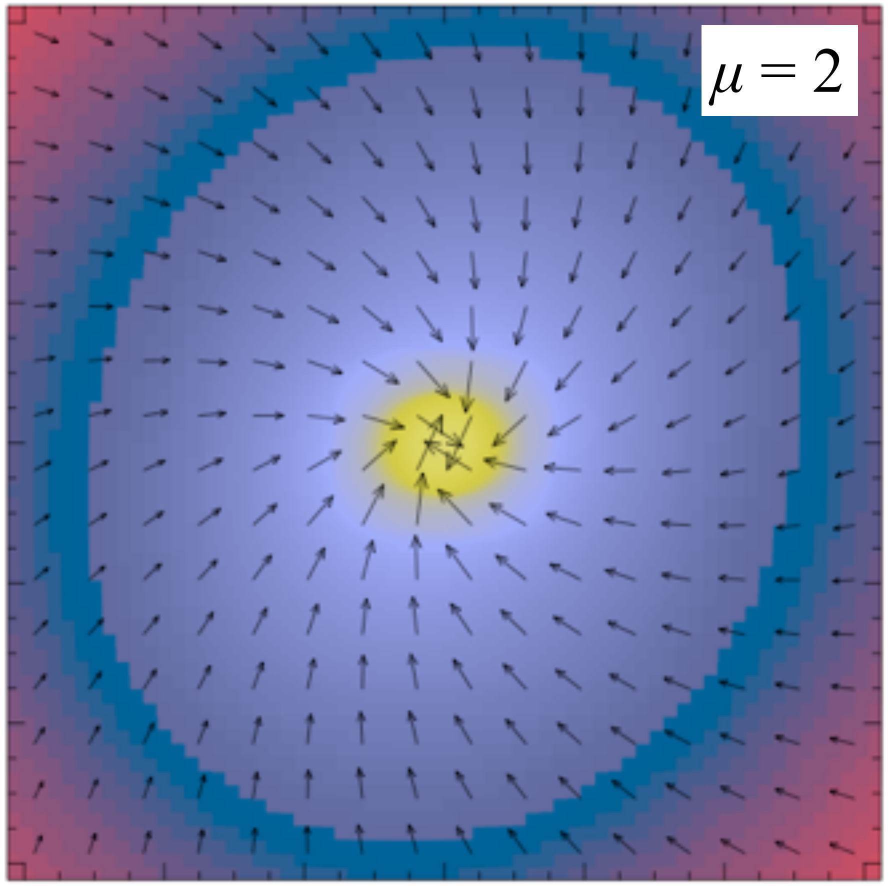
Star Formation: Early-type discs

Collapse of magnetised, rotating cloud cores

- **stronger** magnetic fields: μ < 5 in agreement with observations

(e.g. *Crutcher et al. 2010*)





Hennebelle & Teyssier 2008, ...

$\Longrightarrow$ ***too*** efficient magnetic braking

$\Longrightarrow$ ***no*** disc formation

Star Formation: Early-type discs

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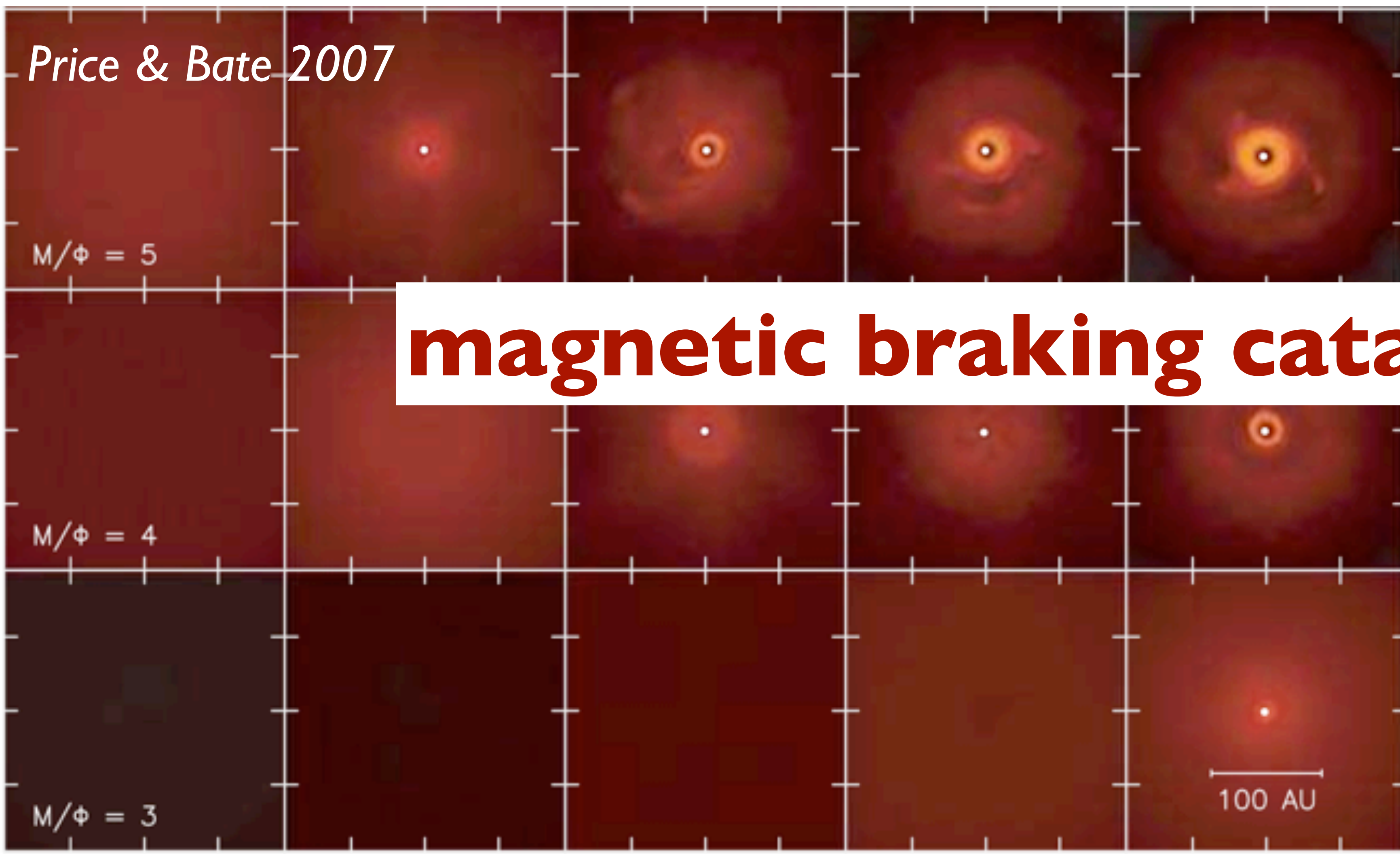
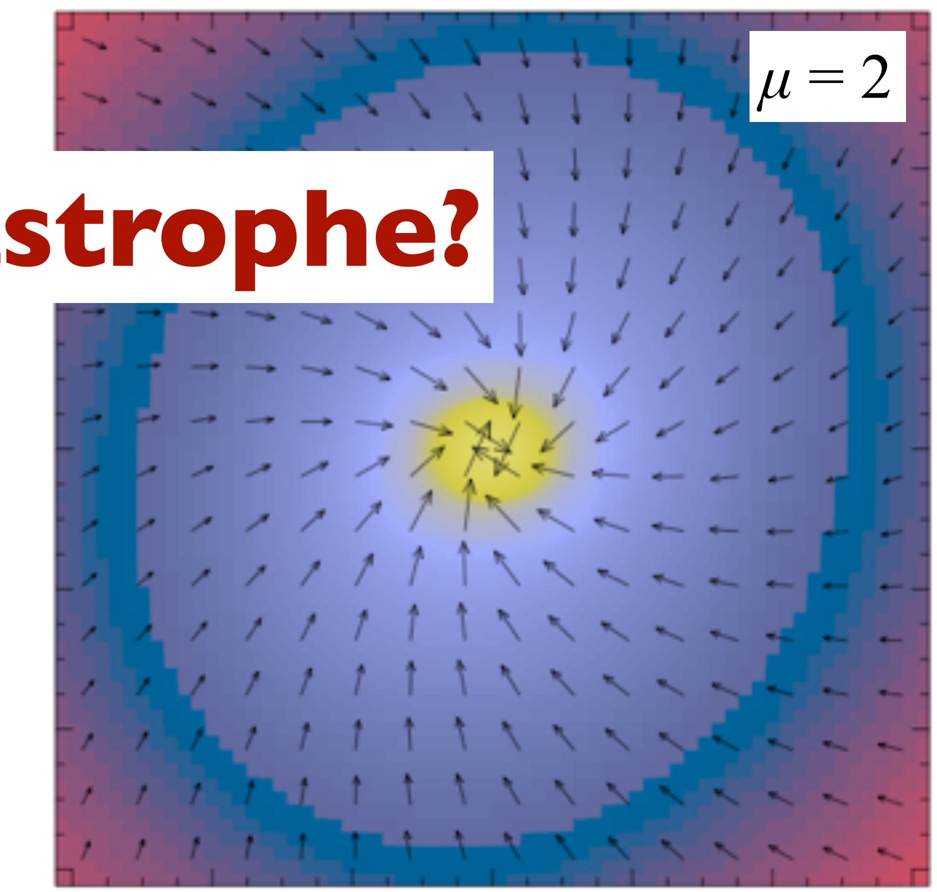


magnetic braking catastrophe?



Hennebelle & Teyssier 2008, ...

$\Longrightarrow$ ***too*** efficient magnetic braking

$\Longrightarrow$ ***no*** disc formation

Angular Momentum Problem II

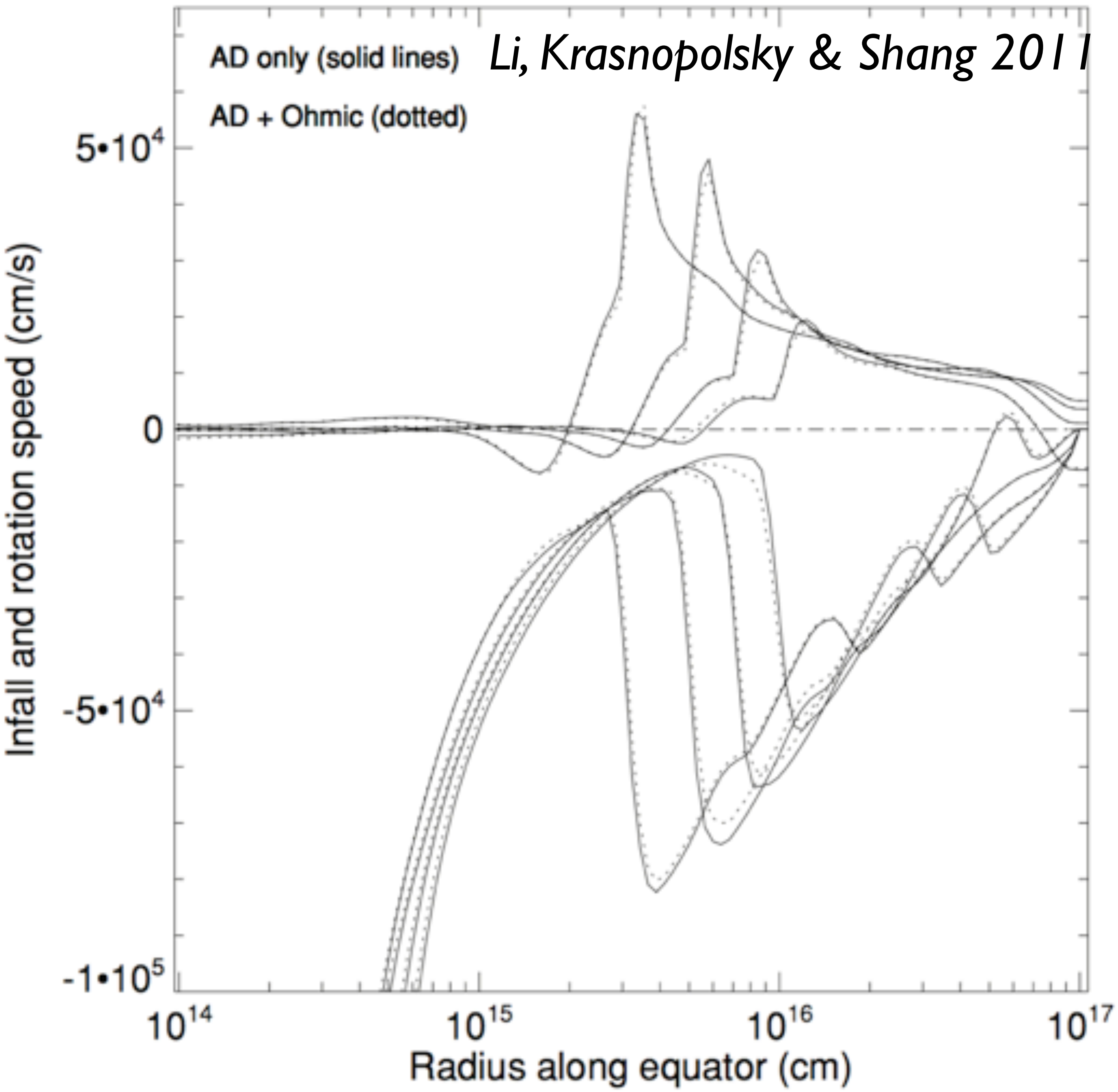
Solutions?

- flux loss by:
  - Ohmic resistivity (*Dapp & Basu 2011, Krasnopolsky et al. 2010*)
  - ambipolar Diffusion (*Duffin & Pudritz 2008, Li et al. 2011*)
  - turbulent reconnection (*Lazarian & Vishniac 1999, Santos-Lima et al. 2012*)
- Hall effect (*Krasnopolsky et al. 2011*)
- Outflows from small discs

Angular Momentum Problem II

$\Longrightarrow$ Non-ideal MHD and reconnection active only at small scales/high density

$\Longrightarrow$ not effective enough to reduce magnetic braking



$\Longrightarrow$ *Li, Krasnopolsky & Shang 2011:*
"The problem of catastrophic magnetic braking that prevents disk formation in dense cores magnetized to realistic levels remains unresolved"

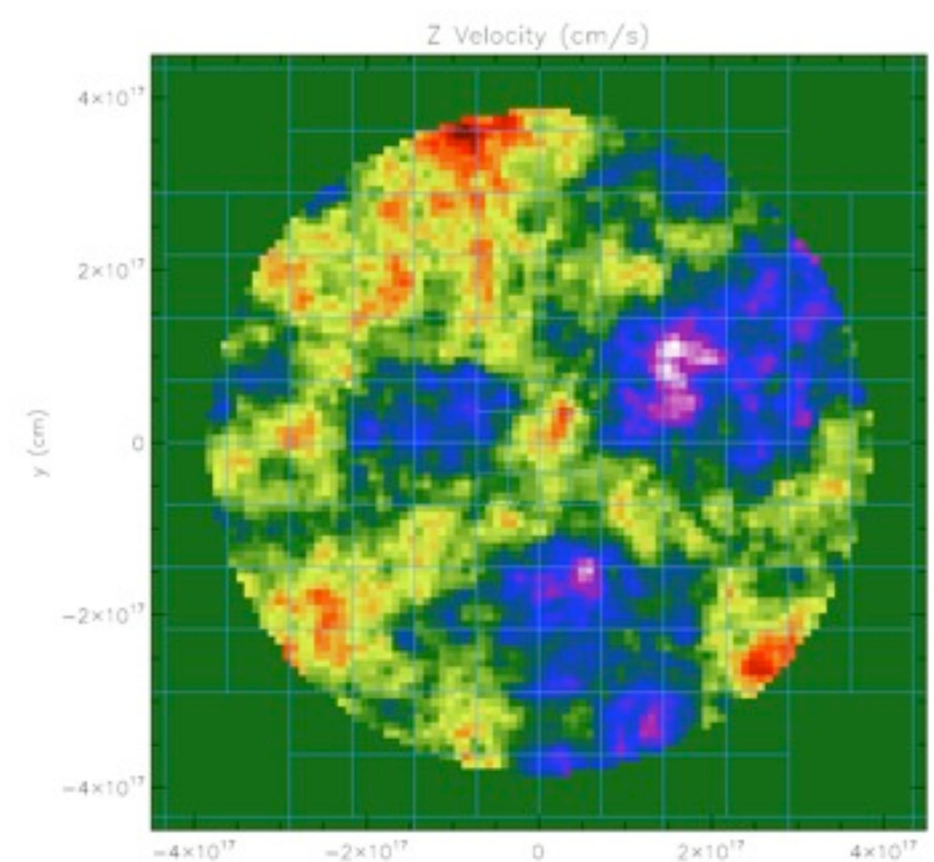
Parameter study of collapsing cores

Seifried, et al. 2013

Run	m_{core} ($M_\odot$)	r_{core} (pc)	μ	Rotation	Ω (10^{-13} s^{-1})	β_{turb}	Turbulence seed	p	M_{rms}	t_{sim} (kyr)
2.6-NoRot-M2	2.6	0.0485	2.6	No	0	0.087	A	5/3	0.74	15
2.6-Rot-M2	2.6	0.0485	2.6	Yes	2.20	0.087	A	5/3	0.74	15
2.6-NoRot-M100	100	0.125	2.6	No	0	0.084	A	5/3	2.5	15
2.6-Rot-M100	100	0.125	2.6	Yes	3.16	0.084	A	5/3	2.5	15
2.6-Rot-M100-B	100	0.125	2.6	Yes	3.16	0.084	B	5/3	2.5	15
2.6-Rot-M100-C	100	0.125	2.6	Yes	3.16	0.084	C	5/3	2.5	15
2.6-Rot-M100-p2	100	0.125	2.6	Yes	3.16	0.084	A	2	2.5	15
2.6-NoRot-M300	300	0.125	2.6	No	0	0.12	A	5/3	5.0	10
2.6-Rot-M1000	1000	0.375	2.6	Yes	1.90	0.081	A	5/3	5.4	10

- low + high mass cores
- strong magnetic field
- with/without global rotation
- sub-/supersonic **turbulence**

- resolution: 1.2 AU



Initial angular momentum of cores

- observational evidence for rotating cores ($R \sim 0.1$ pc)
  e.g. *Goodman et al., 1993*:

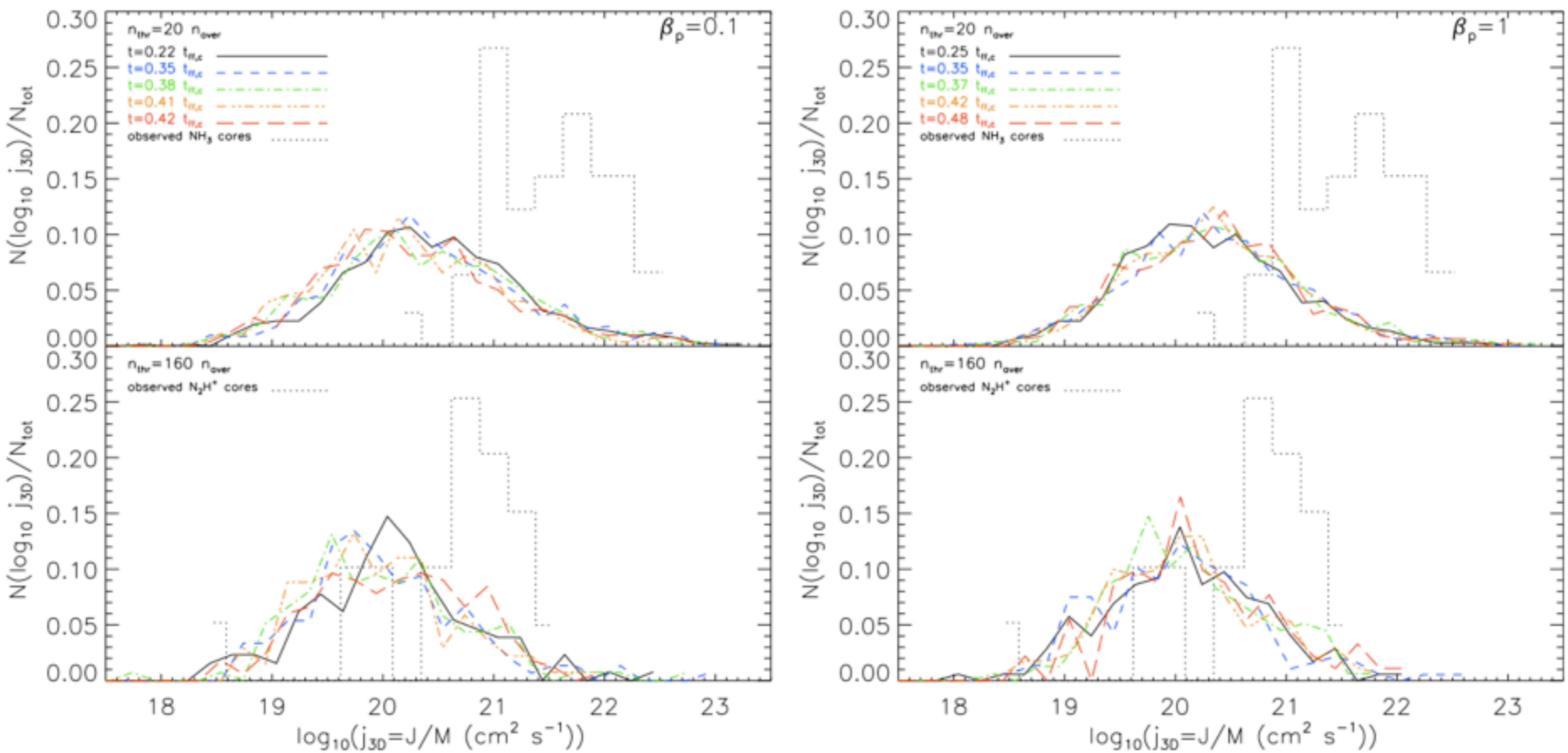
  $$\Omega \sim 10^{-14} - 10^{-13}\ \mathrm{s}^{-1}$$
  $$\Longrightarrow j \sim 10^{21}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$$
  $$\Longrightarrow \beta \sim 0.03 \propto (t_{\mathrm{ff}}\,\Omega)^2$$

  but: large scatter

- compare to galactic shear flow: $\Omega \sim 10^{-16} - 10^{-15}\ \mathrm{s}^{-1}$
  $\Longrightarrow$ generated by turbulence (*Barranco & Goodman, 1998*)?

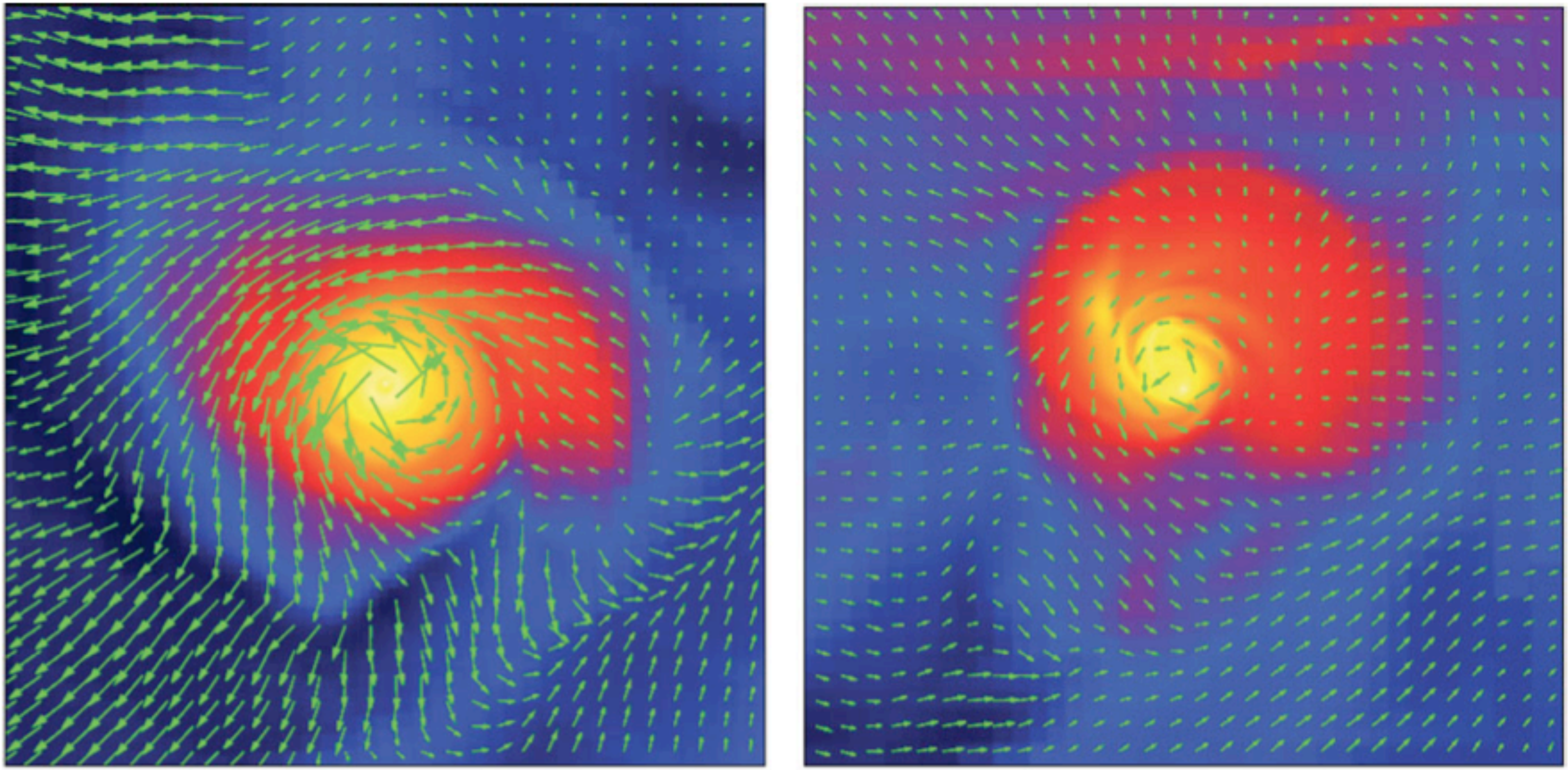
Initial angular momentum of cores?

- Dib et al. 2010:
  synthetic observations from simulations overestimate true values by a factor of **8−10**



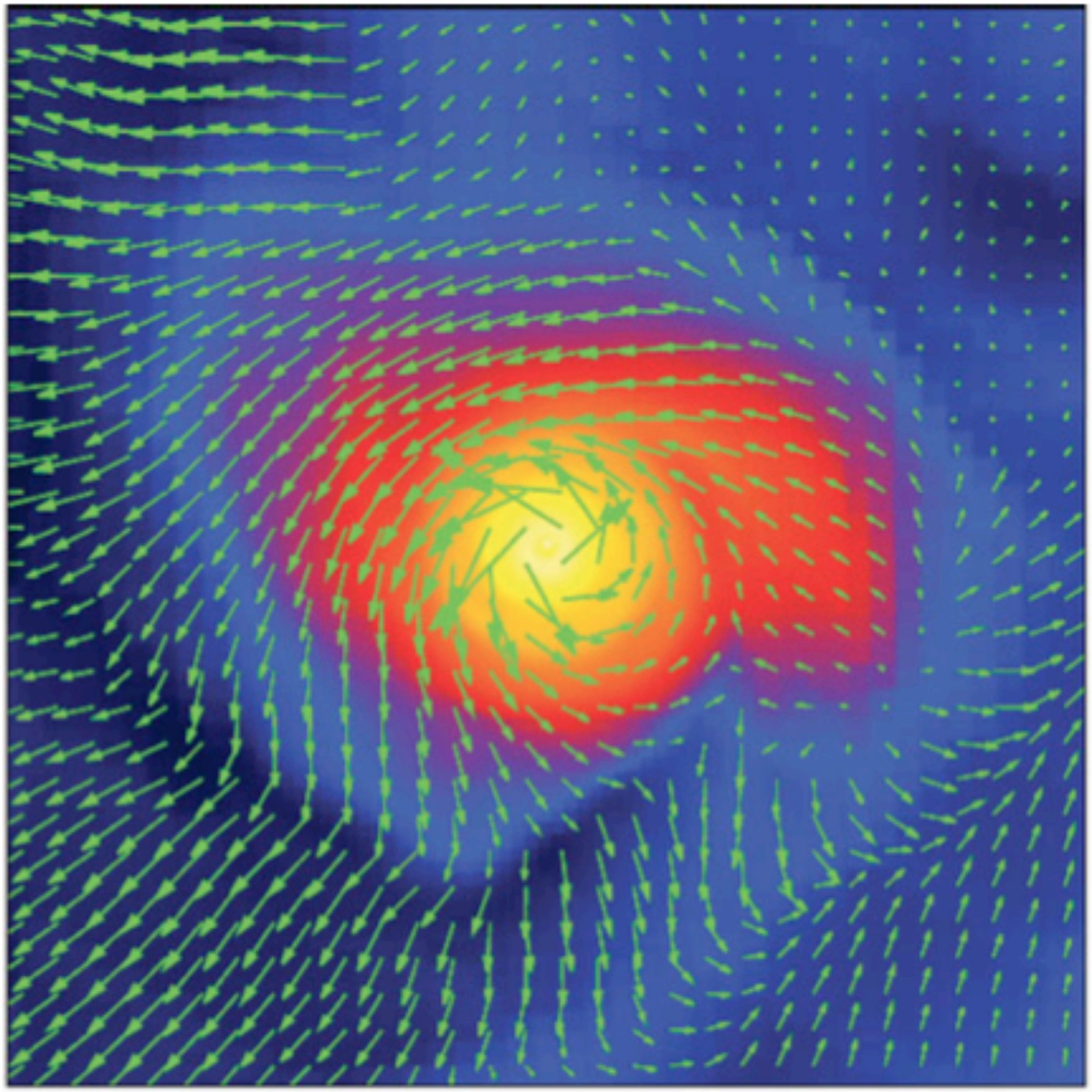
$\Longrightarrow$ also consistent with no global rotation on scales > 0.1 pc

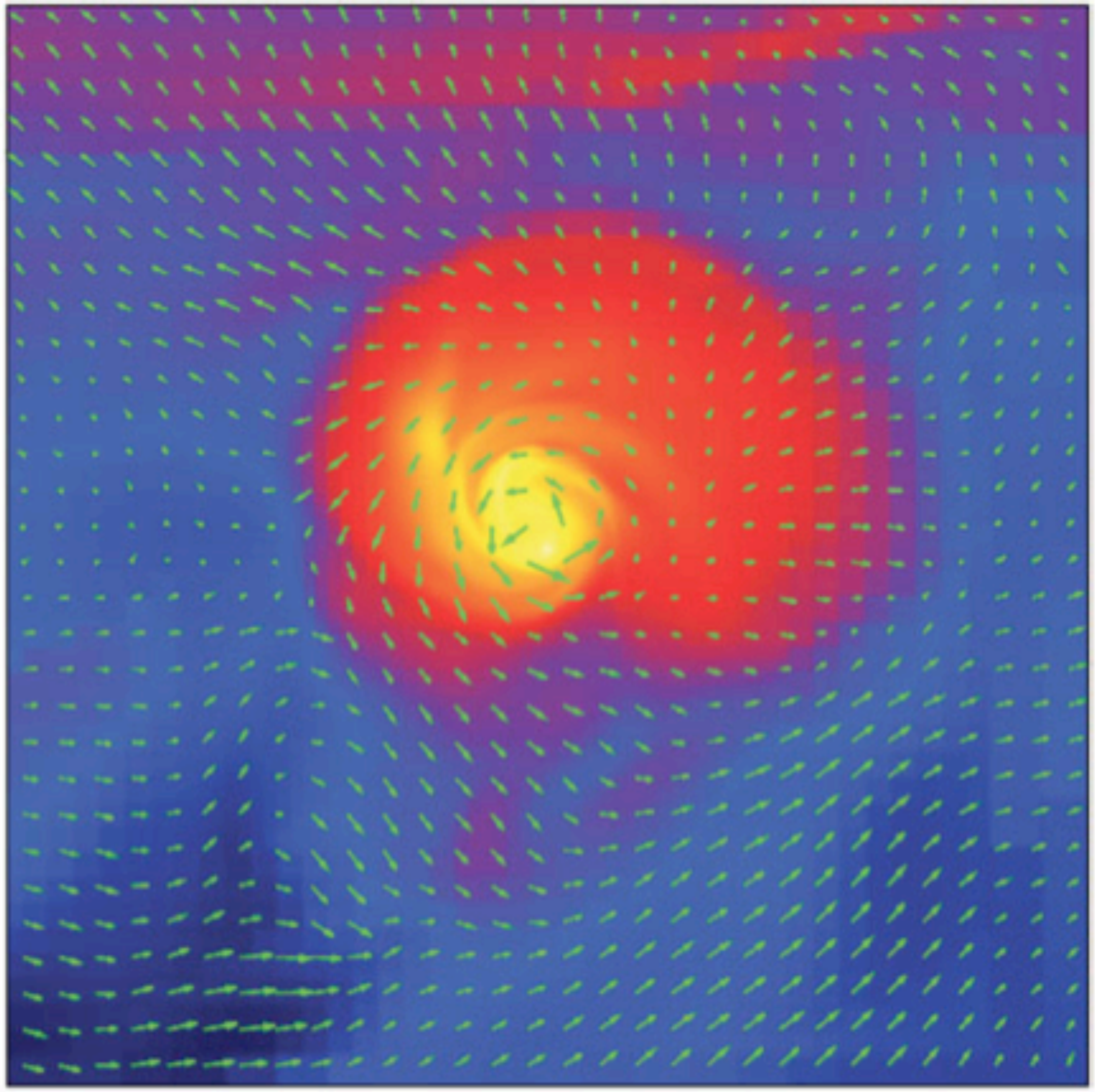
Collapse of Turbulent Cores



Seifried, RB, Pudritz, Klessen 2012

Collapse of Turbulent Cores

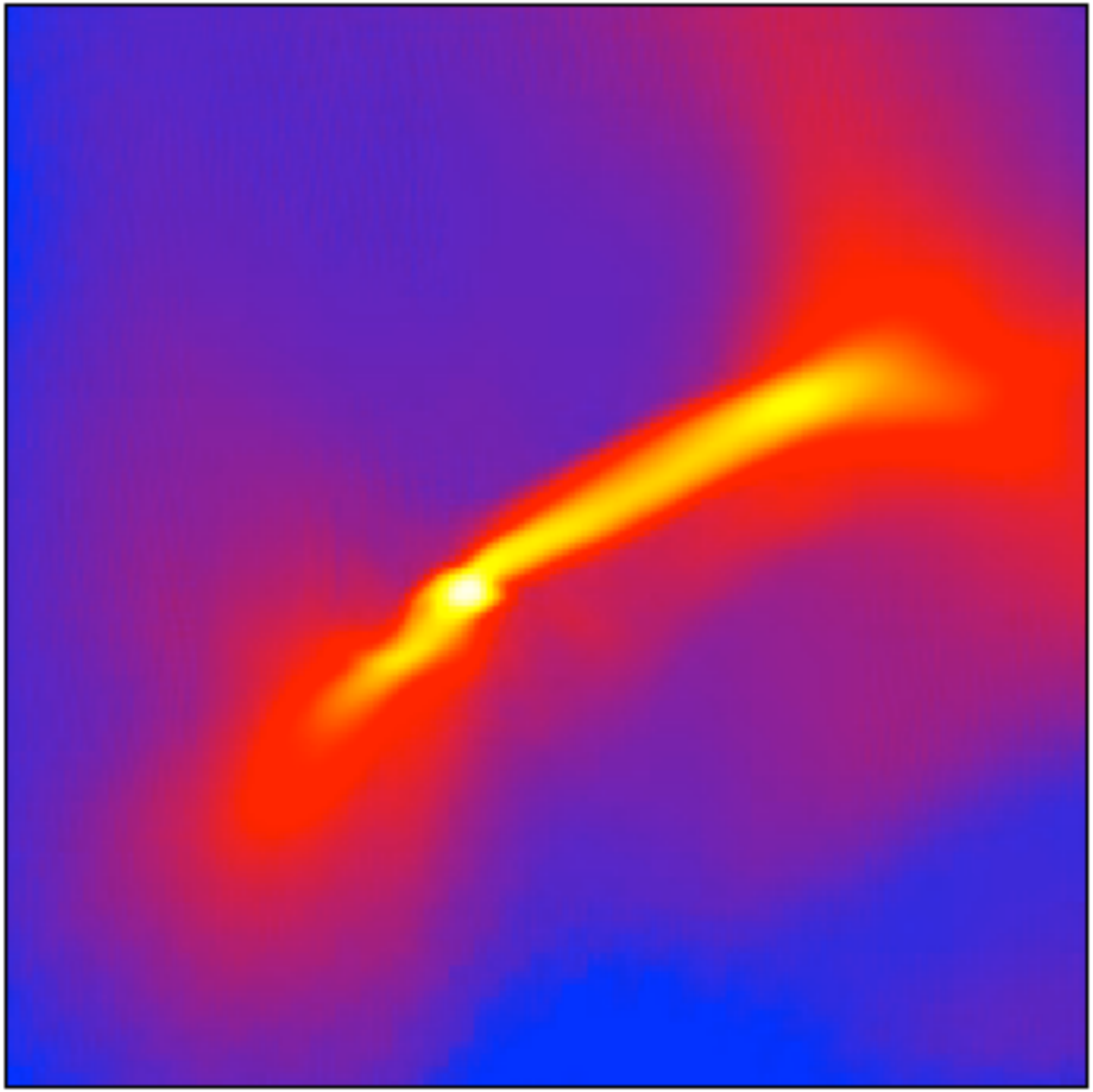




Seifried, RB, Pudritz, Klessen 2012

$\Longrightarrow$ discs “reappear”

Collapse of Turbulent Cores



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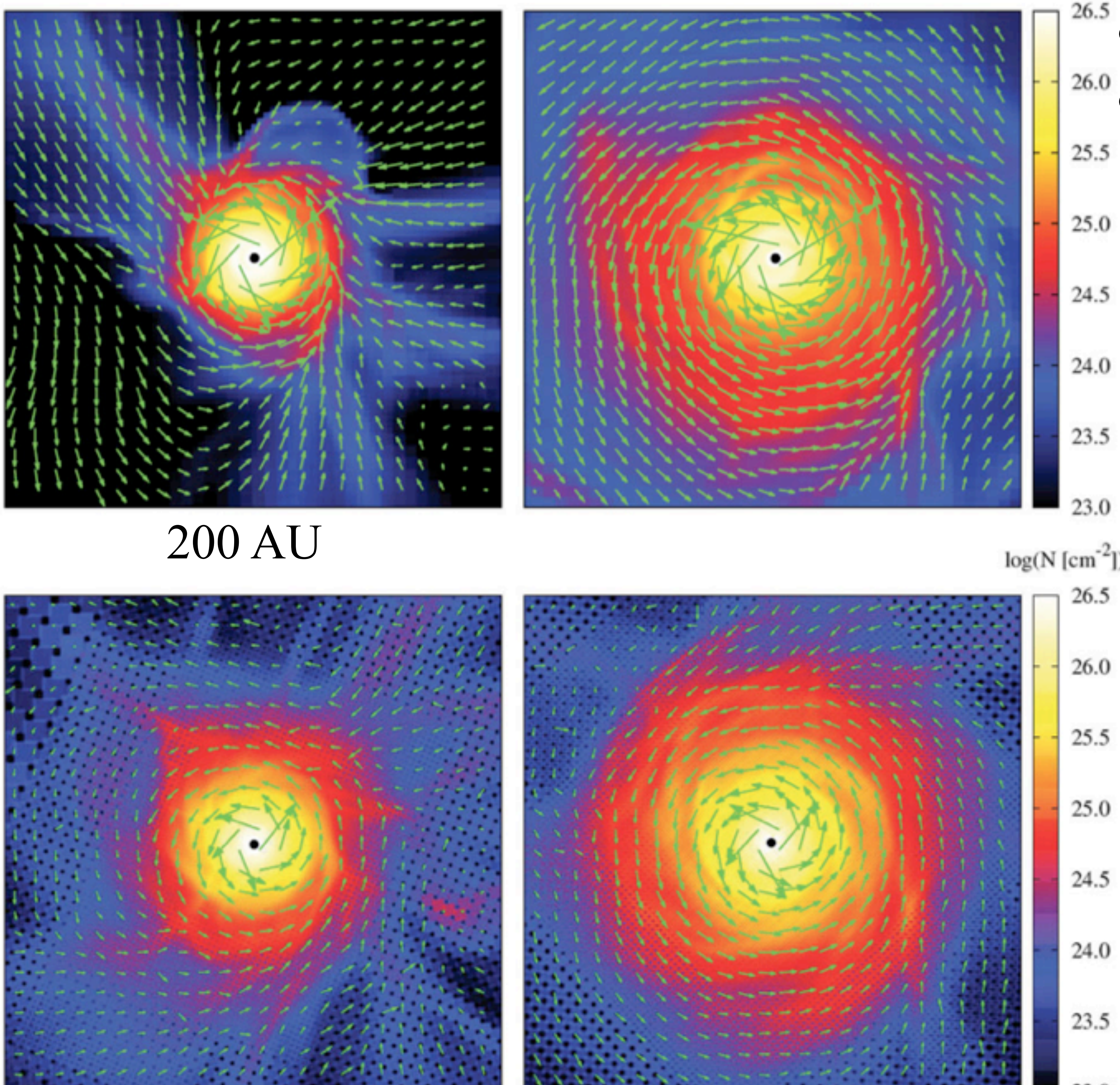
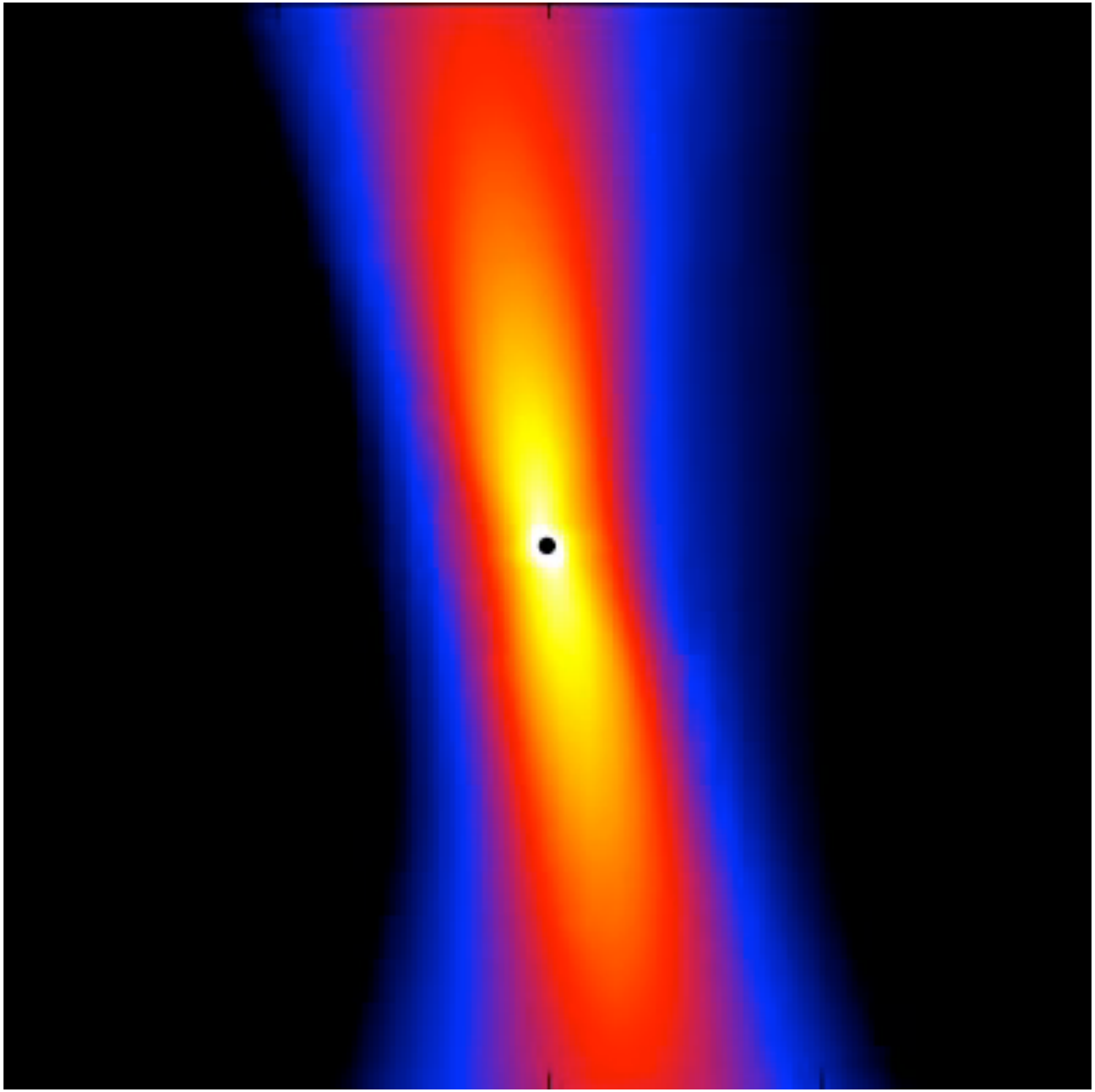


- low mass cores
- strong magnetic field: $\mu = 2.6\ \mu_{crit}$
- transonic turbulence $\mathcal{M}a = 0.74$
- **no** global rotation
- with global rotation

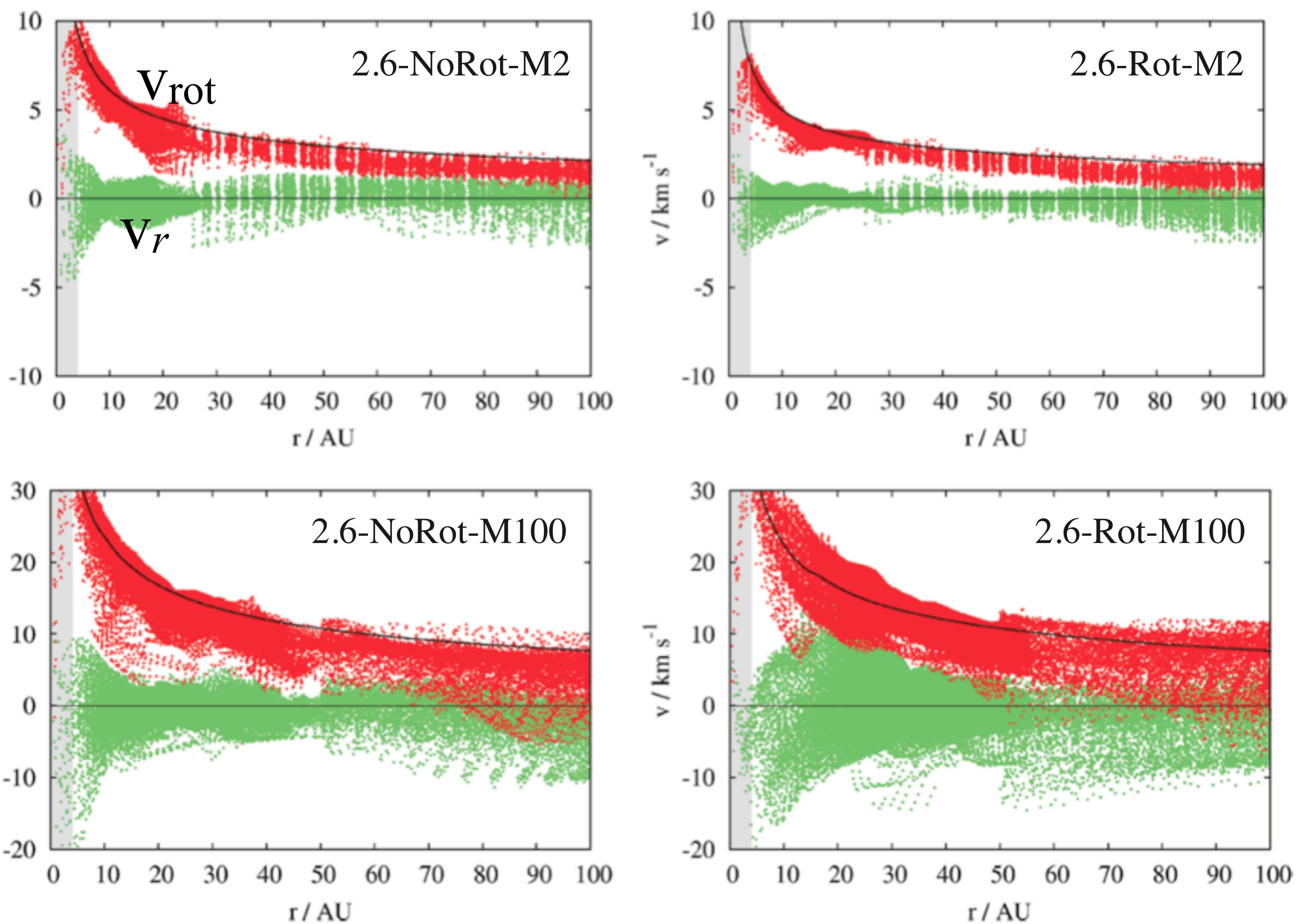
Seifried, et al. 2013

Collapse of Turbulent Cores



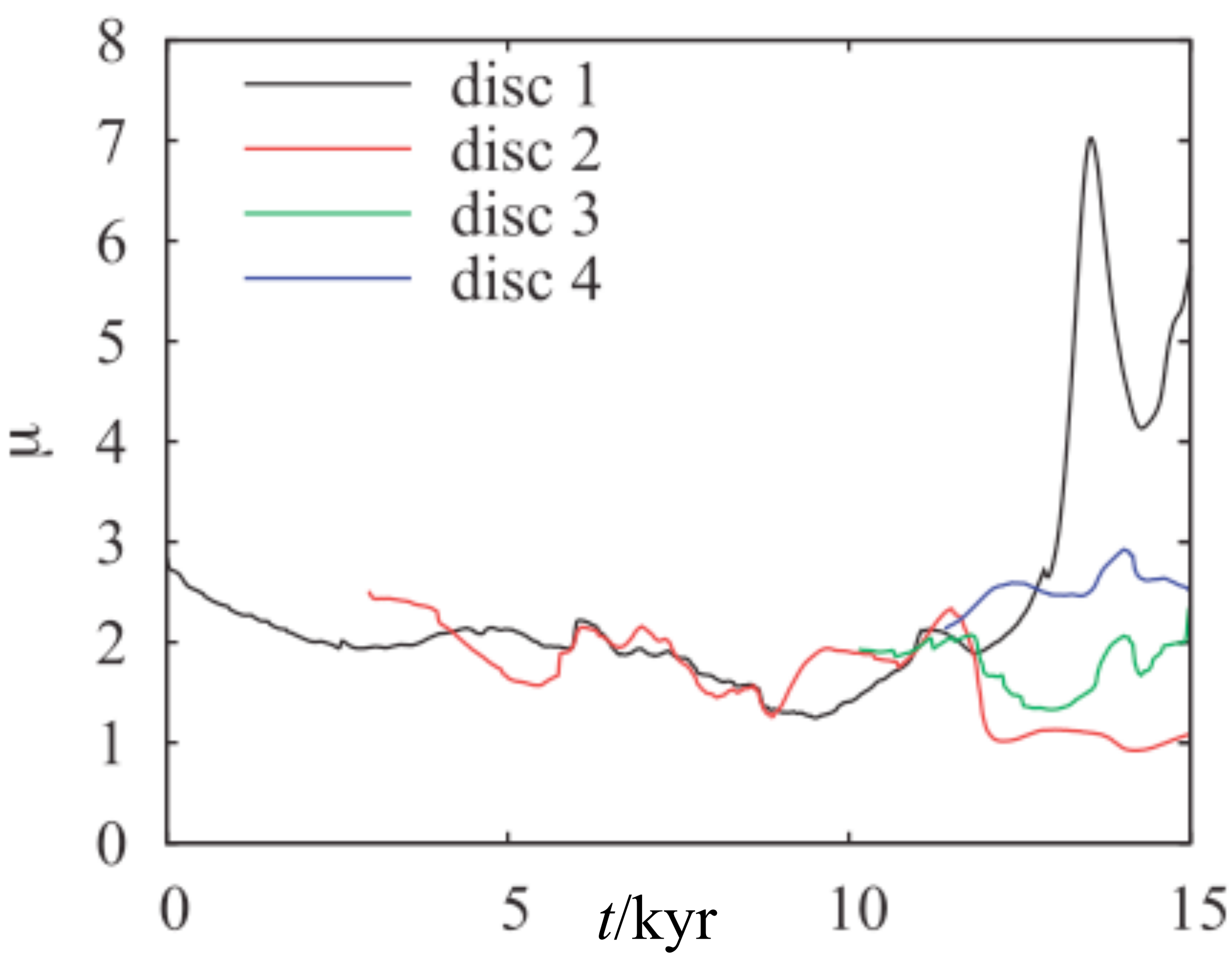
Collapse of Turbulent Cores

velocity structure

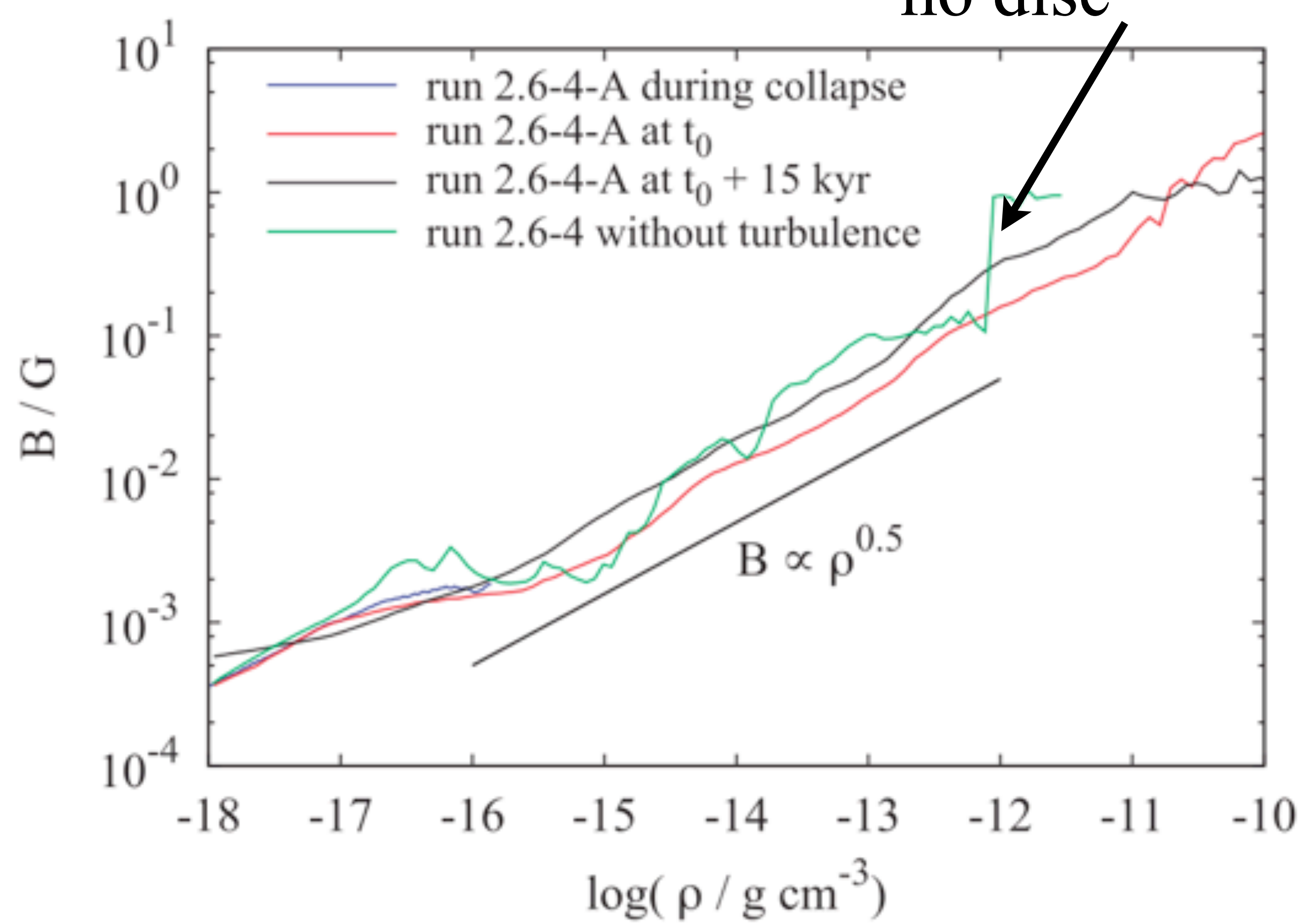


Collapse of Turbulent Cores

due to flux loss?



no turbulence
no disc



Collapse of Turbulent Cores

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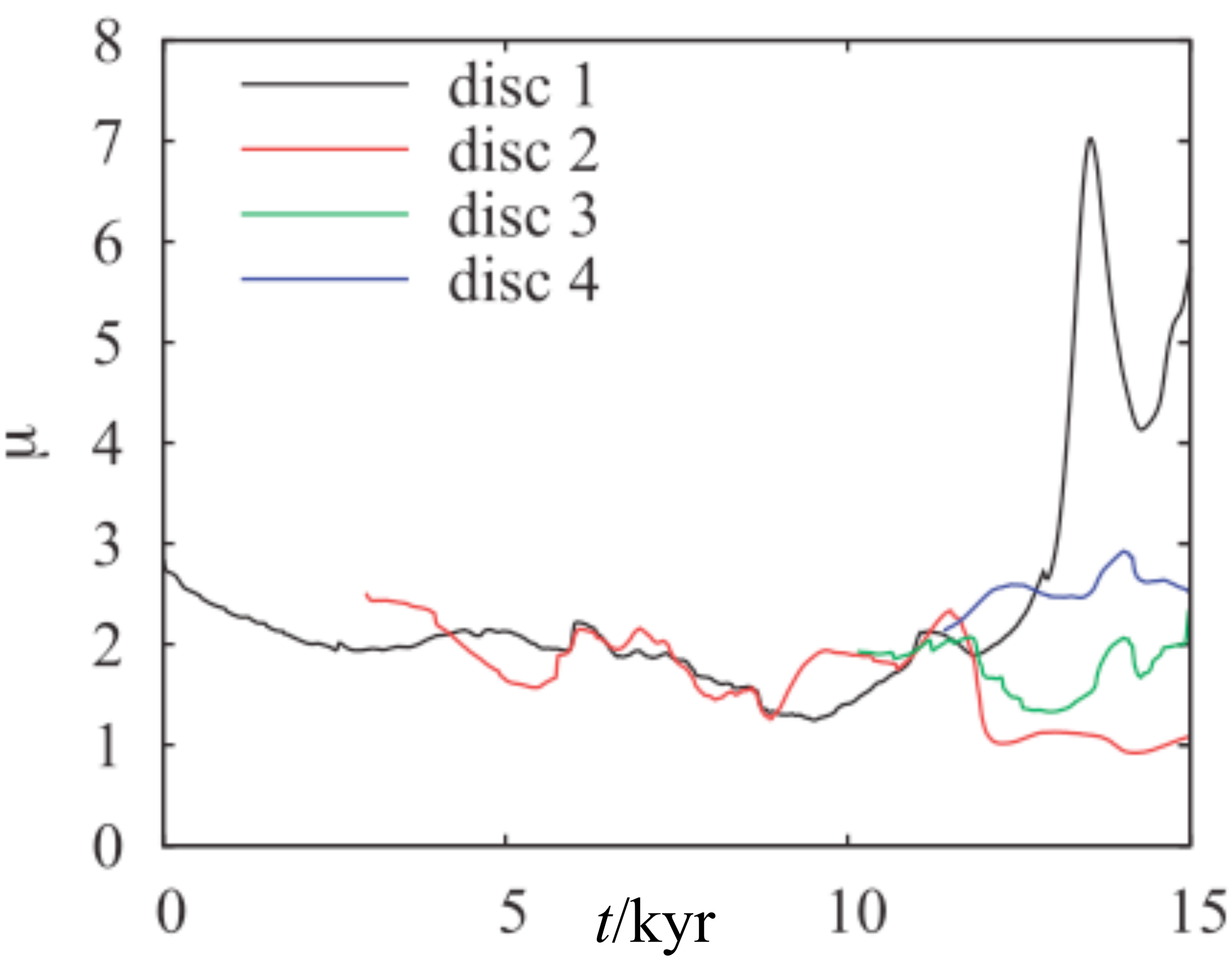
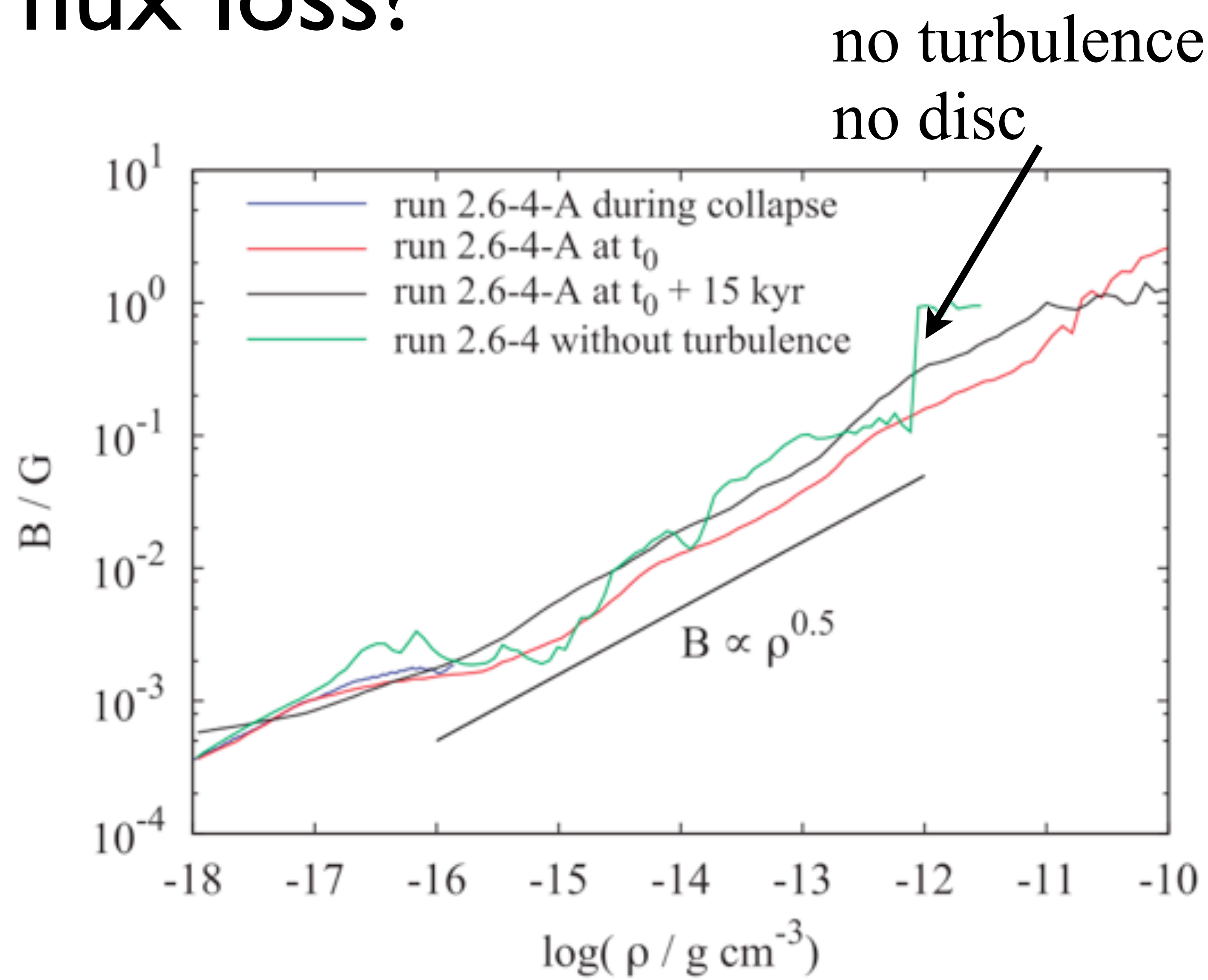
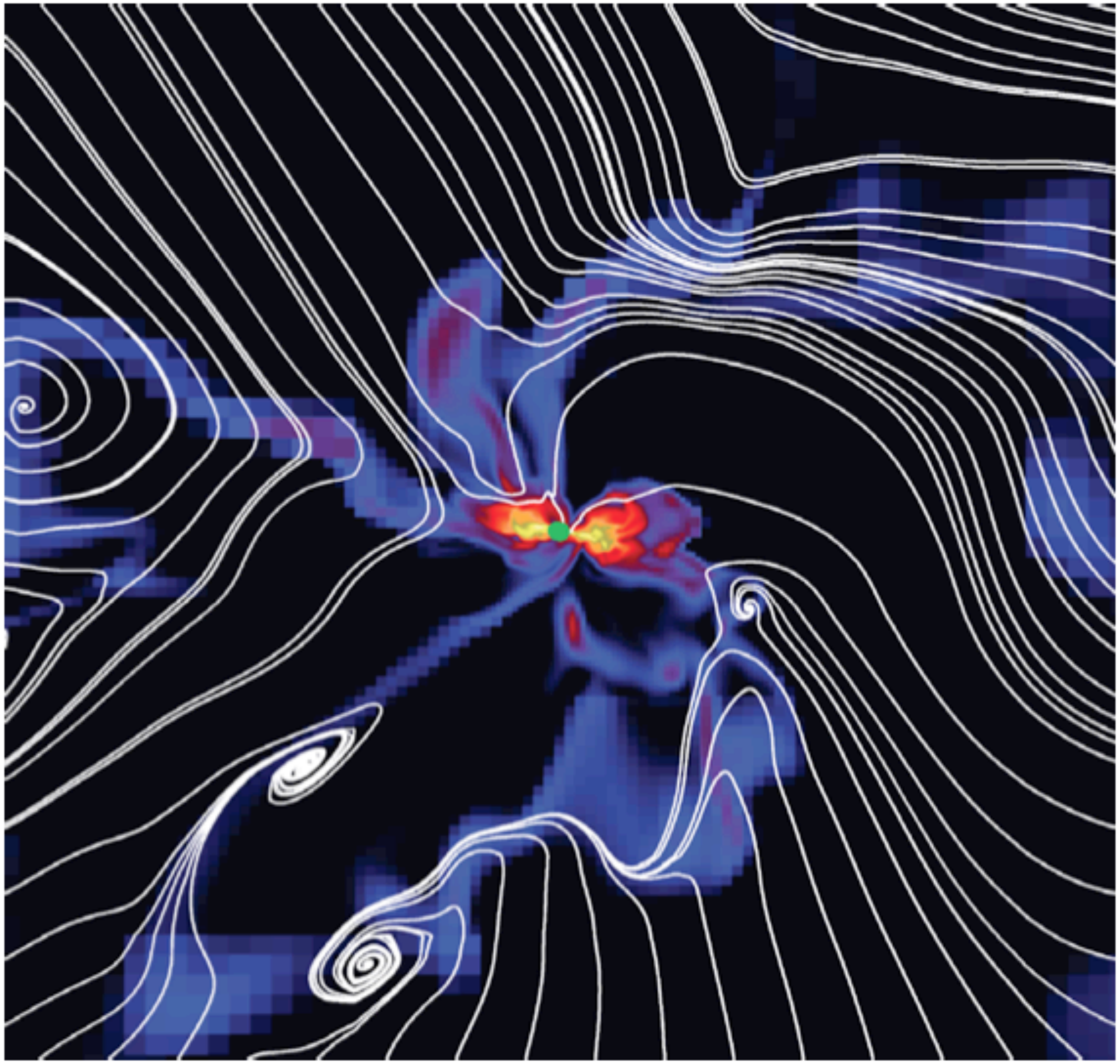




$\Longrightarrow$ only little flux loss

Collapse of Turbulent Cores

Magnetic field structure

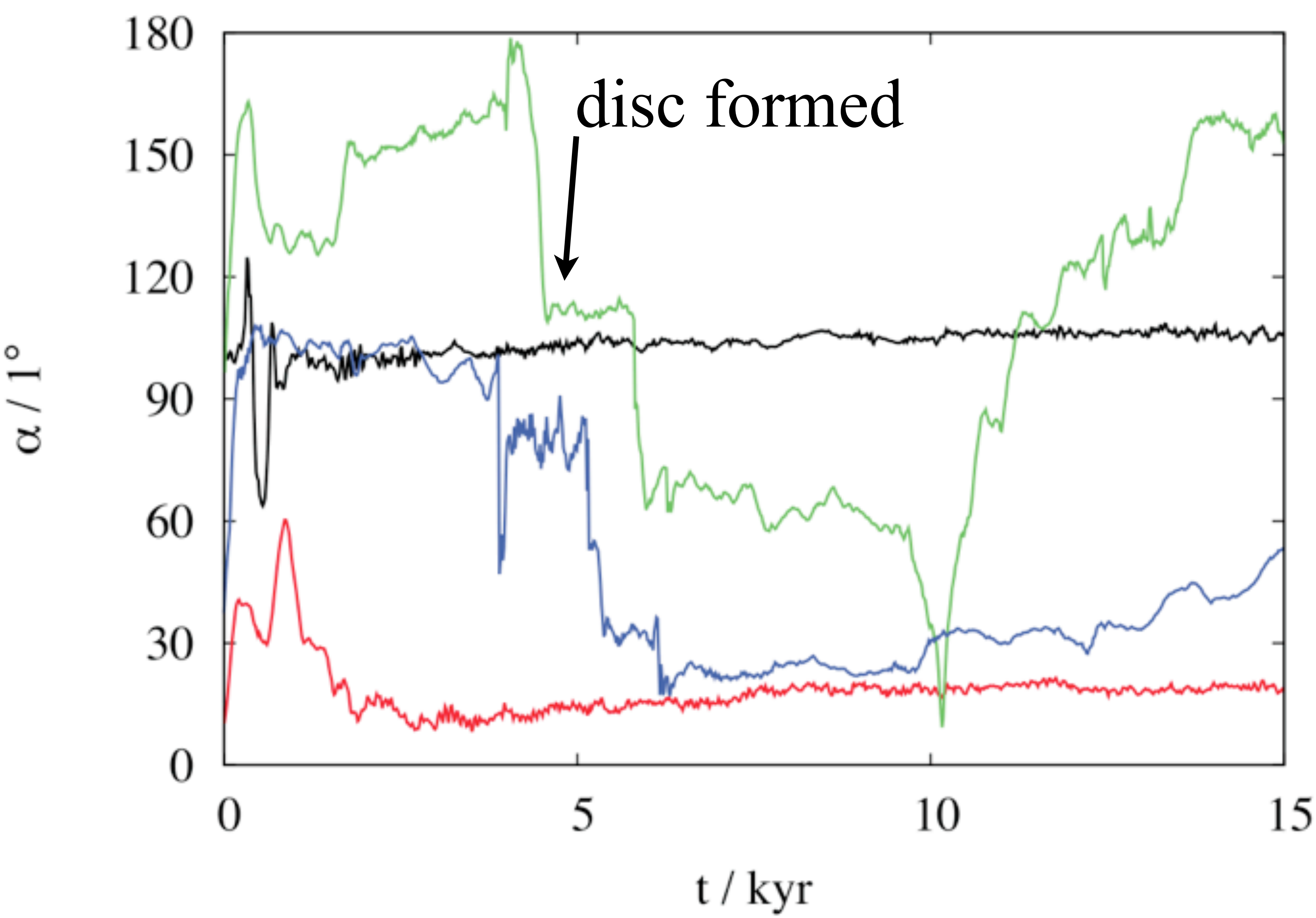


Collapse of Turbulent Cores

rotation vs. magnetic field orientation

$\Longrightarrow$ inclined rotation helps to form discs?

(*Hennbelle & Ciardi 2009, Joos et al. 2012*)



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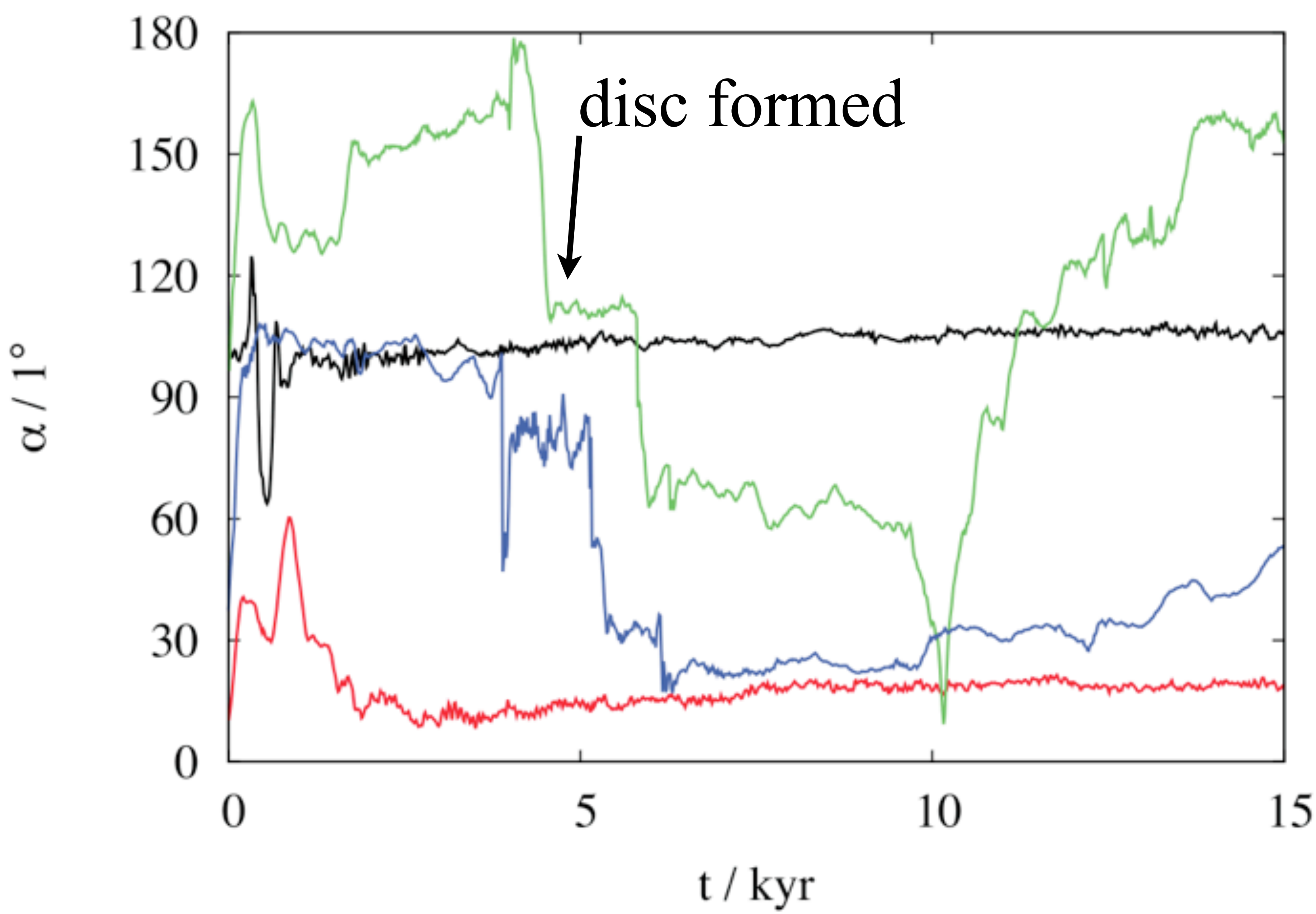


$\Longrightarrow$ but no large scale magnetic field component

Summary: Collapse of Turbulent Cores

- Magnetic braking catastrophe only for unrealistic ICs
- is easy to form discs in a turbulent environment

$\Longrightarrow$ see also:
Santos-Lima et al. 2012
Myers et al. 2013 (Chris' talk on Wednesday)

$\Longrightarrow$ flux loss by turbulent reconnection ?

(*Lazarian & Vishniac* 1999)

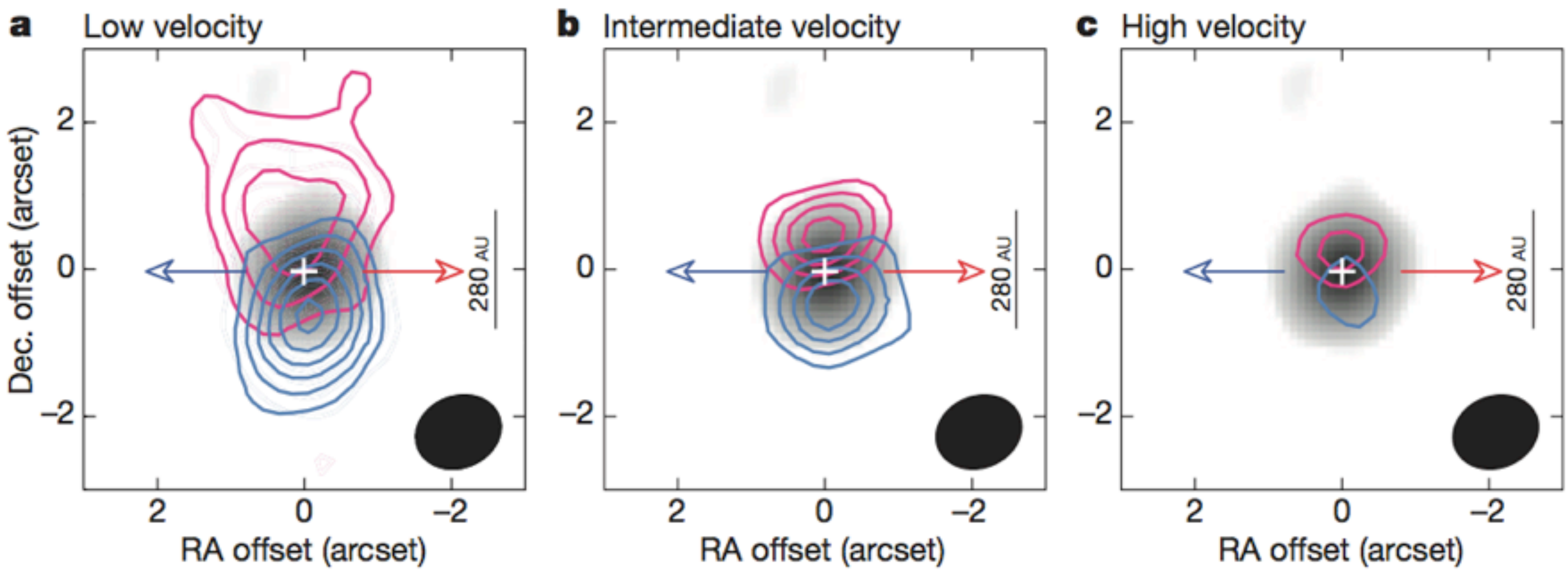
Disc Formation in Turbulent Cloud Cores

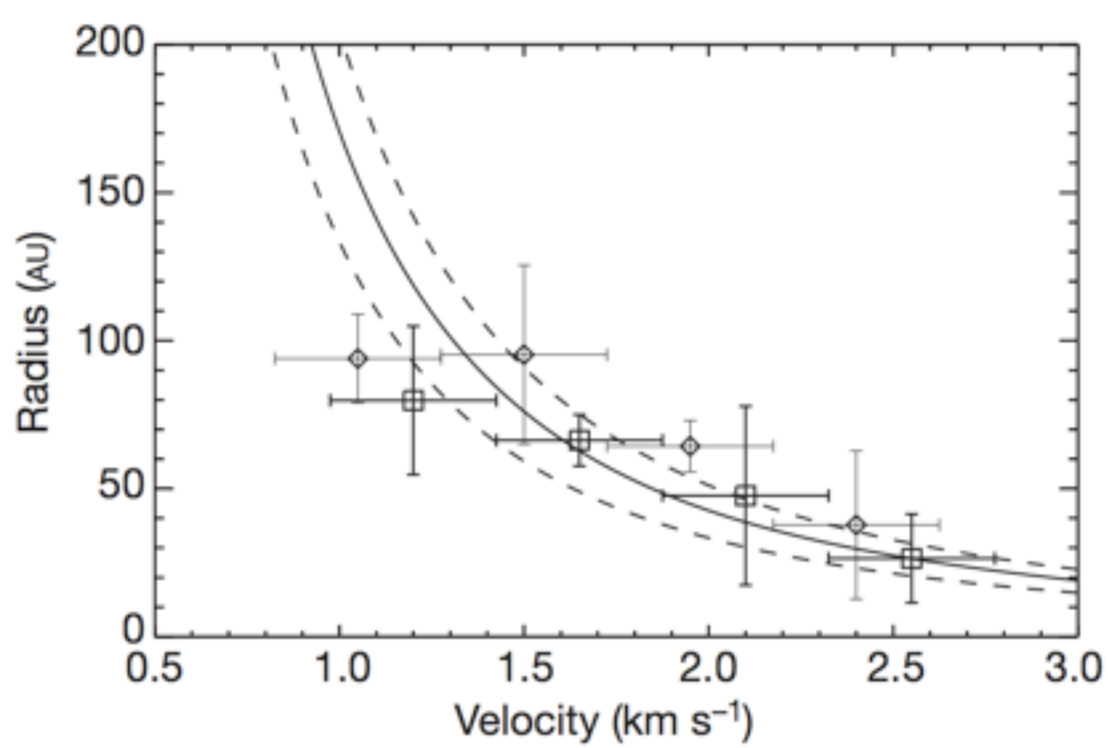
Robi Banerjee
University of Hamburg

Co-Worker:
Daniel Seifried (Hamburg), Ralph Pudritz (McMaster), Ralf Klessen (ITA)

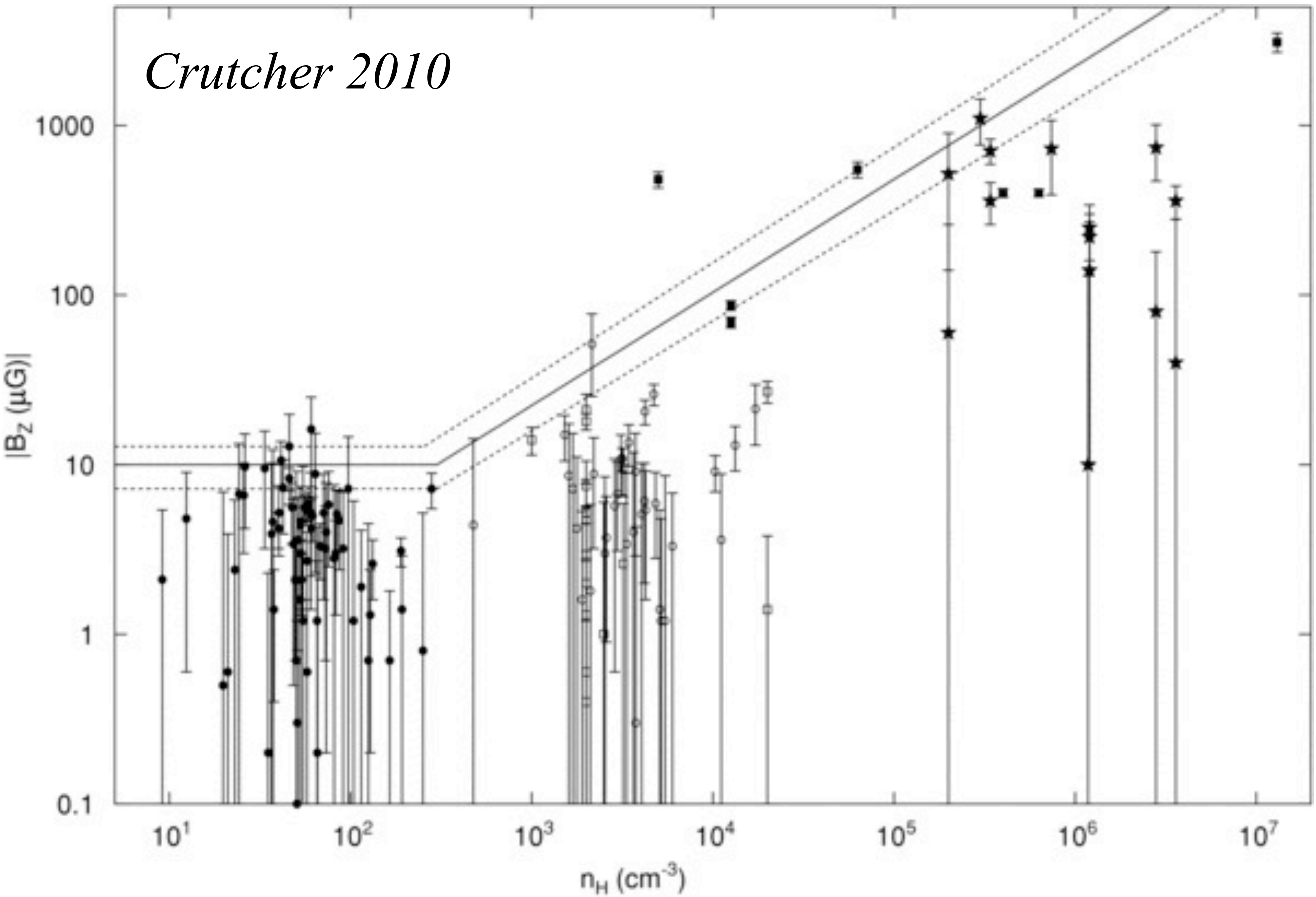
Star Formation: Early-type discs

Observations of Class 0 protostellar discs: *Tobin et al.* 2012





Magnetic Fields



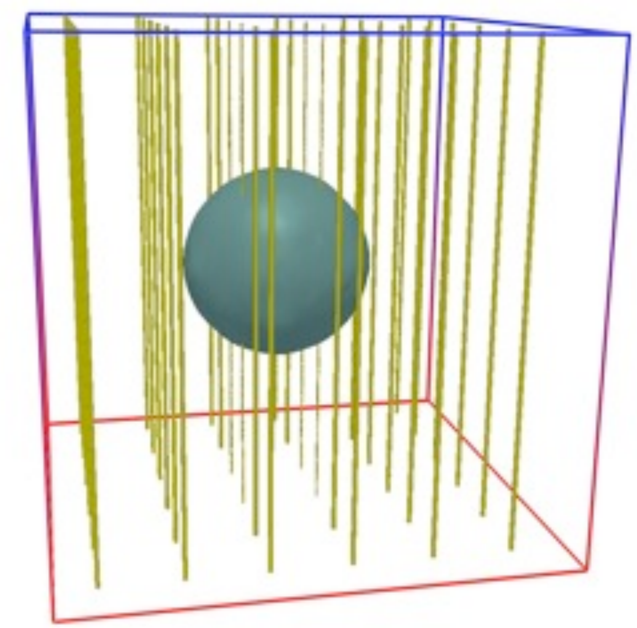
$\Longrightarrow$ mass-to-flux ratio for pre-stellar cores:

$$\mu = 2 \ldots 5$$

Magnetic Fields

magnetic criticality

mass-to-flux ratio:



$$\mu \equiv \left(\frac{M}{\Phi}\right)$$ = self-gravity / magnetic support

critical value:

$$\mu_{\rm crit} = 0.13/\sqrt{G}$$

spherical collapsing structure
Mouschovias & Spitzer 1976

$$\mu_{\rm crit} = \frac{1}{2\pi\sqrt{G}} \approx 0.16/\sqrt{G}$$

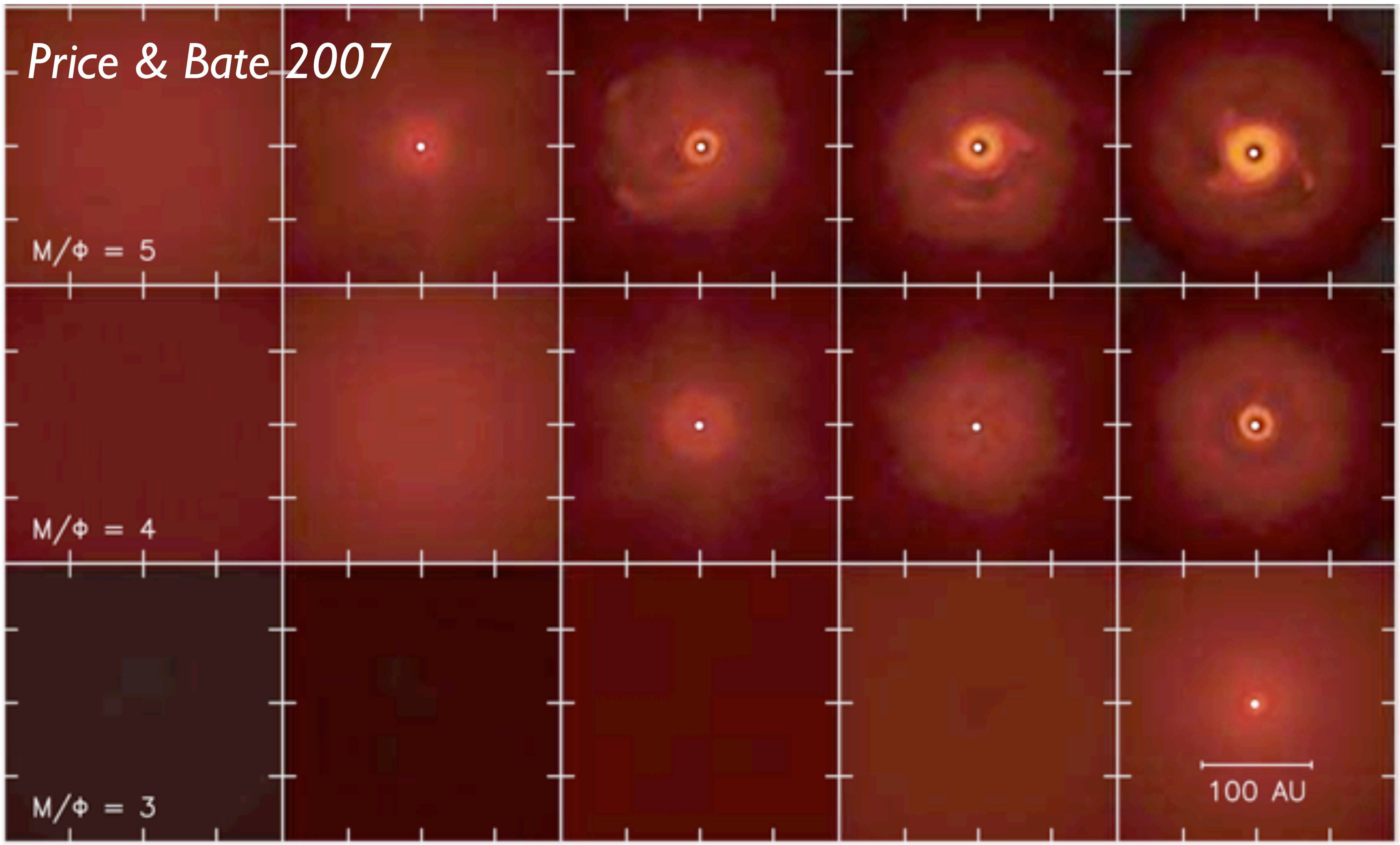
uniform disc
Nakano & Nakamura 1978

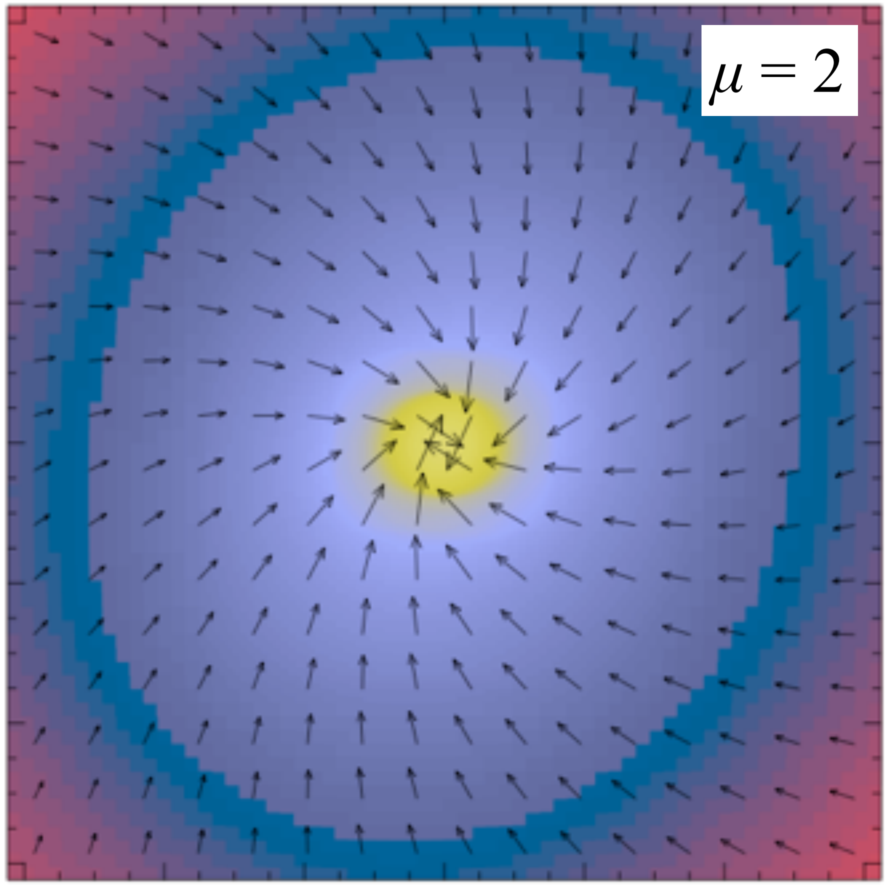
Star Formation: Early-type discs

Collapse of magnetised, rotating cloud cores

- **stronger** magnetic fields: μ < 5 in agreement with observations

(e.g. *Crutcher et al. 2010*)





Hennebelle & Teyssier 2008, ...

$\Longrightarrow$ ***too*** efficient magnetic braking

$\Longrightarrow$ ***no*** disc formation

Star Formation: Early-type discs

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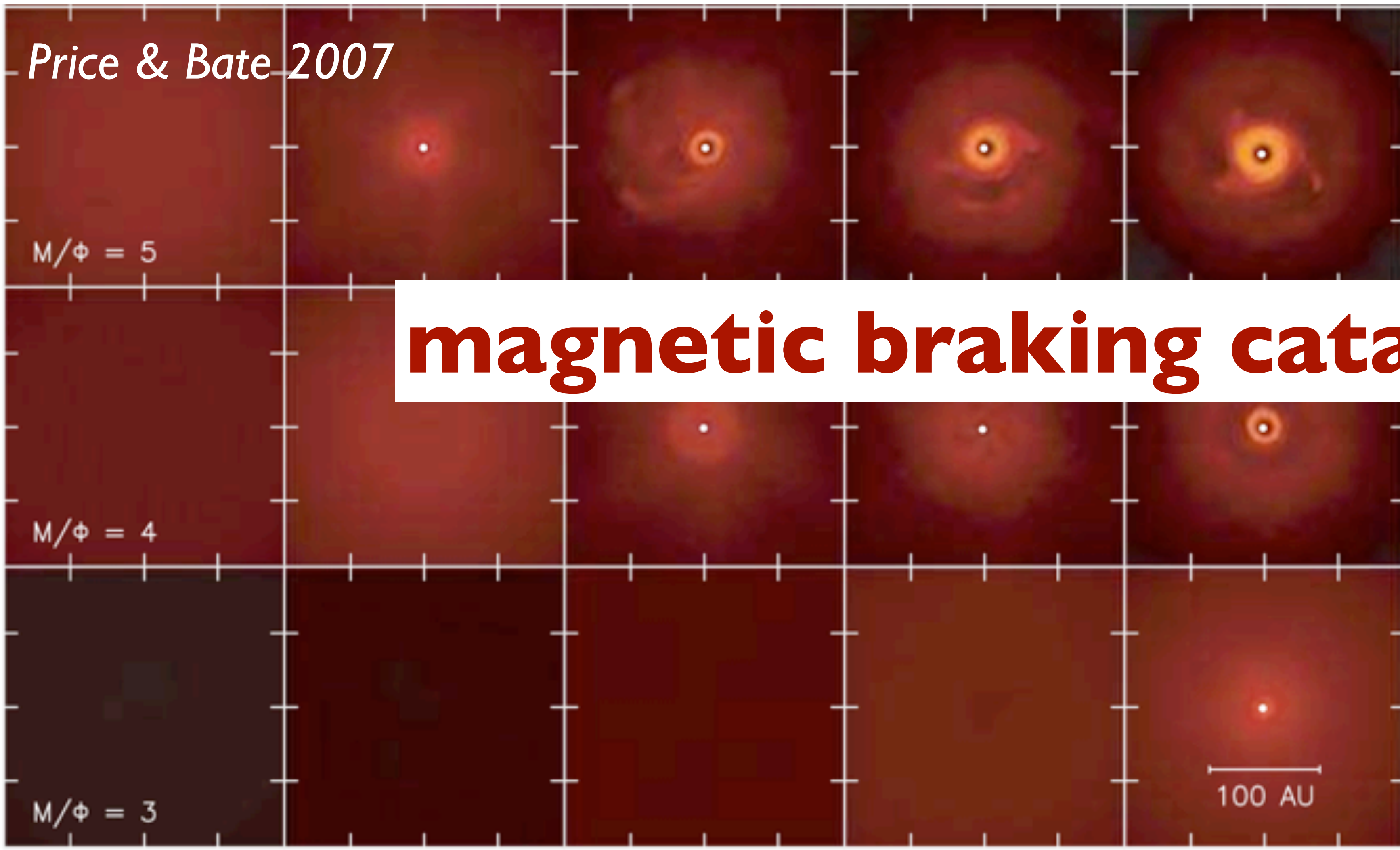
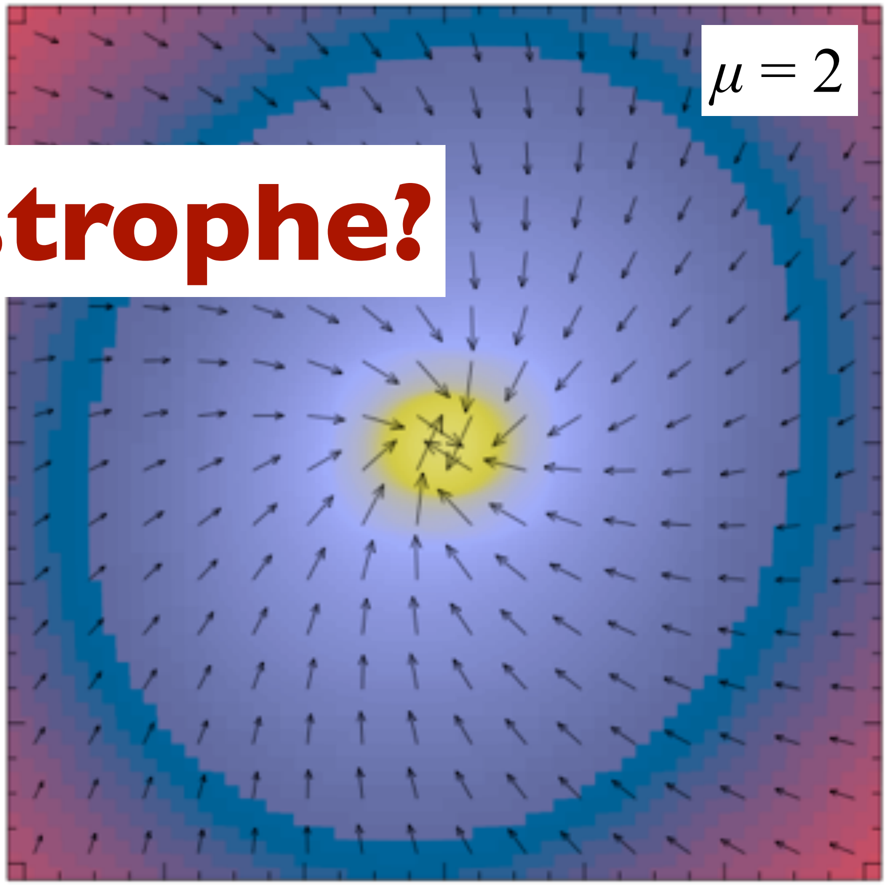


magnetic braking catastrophe?



Hennebelle & Teyssier 2008, ...

⟹ ***too*** efficient magnetic braking

⟹ ***no*** disc formation

Angular Momentum Problem II

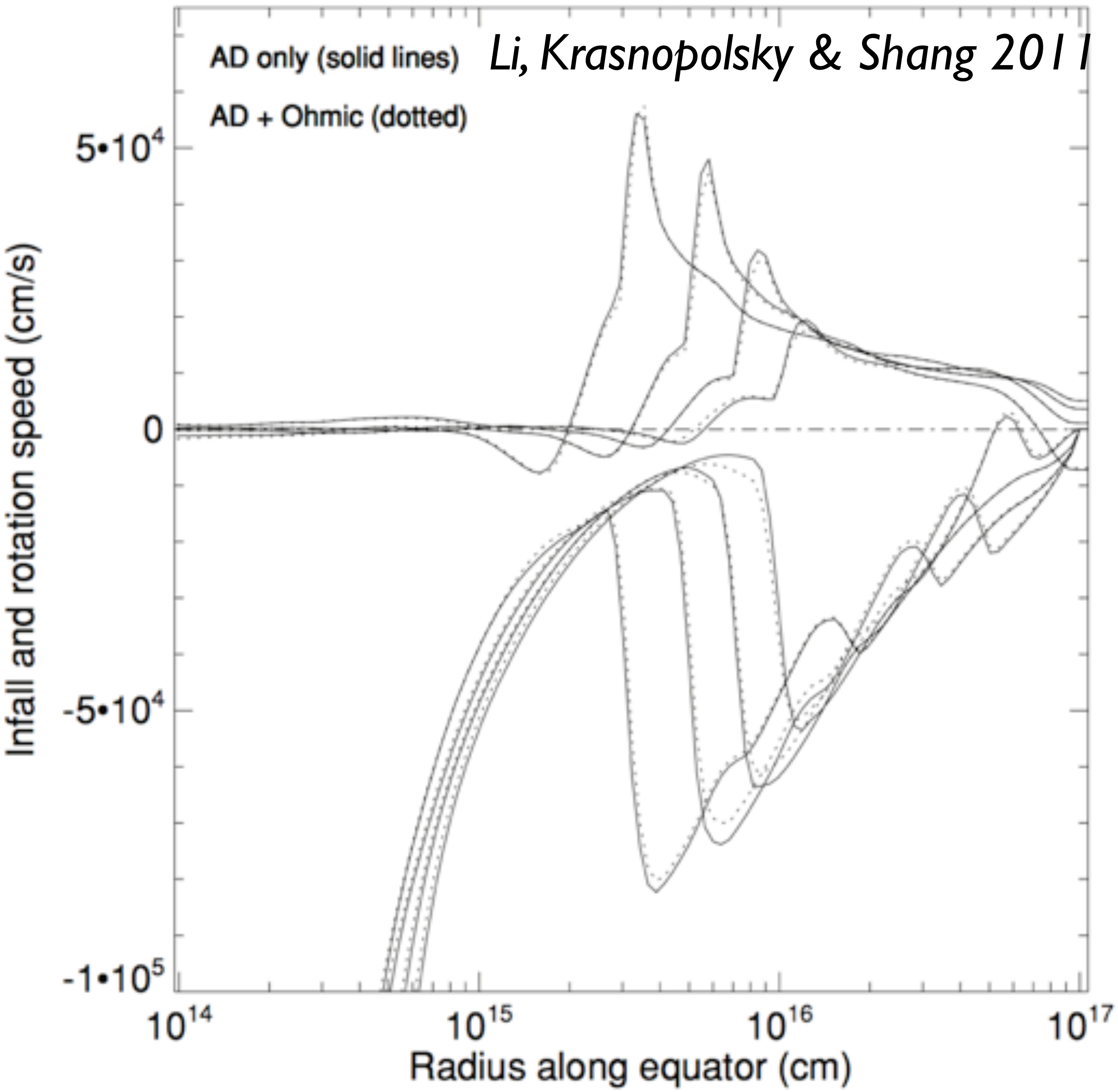
Solutions?

- flux loss by:
  - Ohmic resistivity (*Dapp & Basu 2011, Krasnopolsky et al. 2010*)
  - ambipolar Diffusion (*Duffin & Pudritz 2008, Li et al. 2011*)
  - turbulent reconnection (*Lazarian & Vishniac 1999, Santos-Lima et al. 2012*)
- Hall effect (*Krasnopolsky et al. 2011*)
- Outflows from small discs

Angular Momentum Problem II

⟹ Non-ideal MHD and reconnection active only at small scales/high density

⟹ not effective enough to reduce magnetic braking



⟹ *Li, Krasnopolsky & Shang 2011:*
"The problem of catastrophic magnetic braking that prevents disk formation in dense cores magnetized to realistic levels remains unresolved"

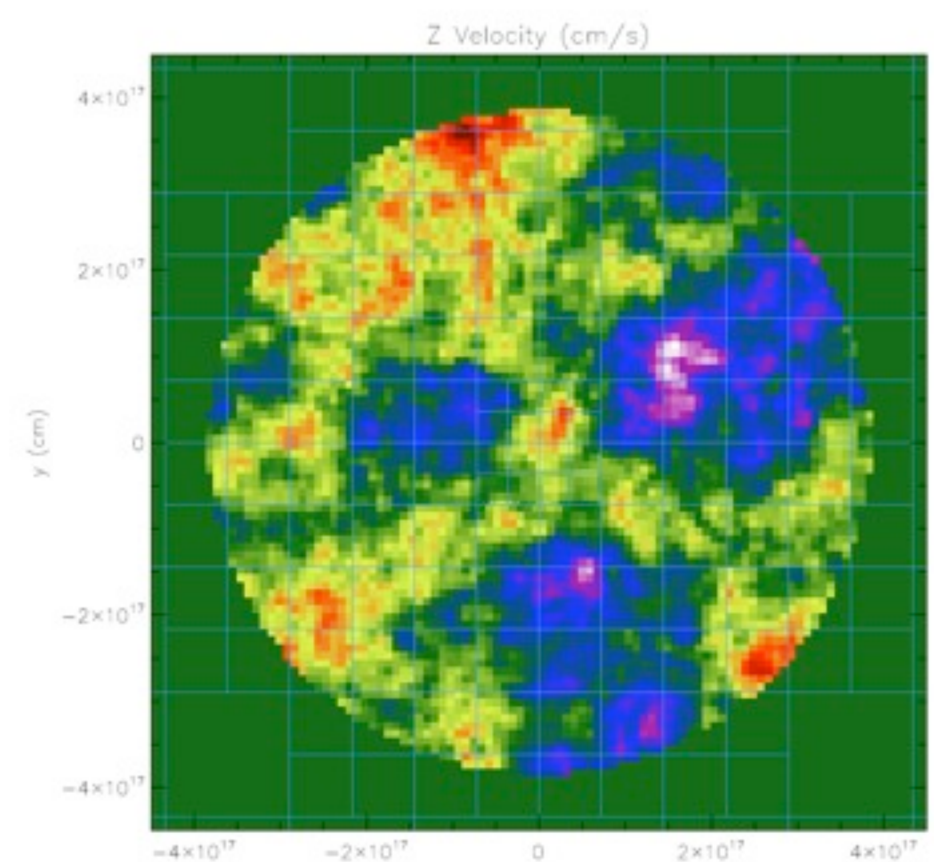
Parameter study of collapsing cores

Seifried, et al. 2013

Run	m_{core} ($M_{\odot}$)	r_{core} (pc)	μ	Rotation	Ω (10^{-13} s^{-1})	β_{turb}	Turbulence seed	p	M_{rms}	t_{sim} (kyr)
2.6-NoRot-M2	2.6	0.0485	2.6	No	0	0.087	A	5/3	0.74	15
2.6-Rot-M2	2.6	0.0485	2.6	Yes	2.20	0.087	A	5/3	0.74	15
2.6-NoRot-M100	100	0.125	2.6	No	0	0.084	A	5/3	2.5	15
2.6-Rot-M100	100	0.125	2.6	Yes	3.16	0.084	A	5/3	2.5	15
2.6-Rot-M100-B	100	0.125	2.6	Yes	3.16	0.084	B	5/3	2.5	15
2.6-Rot-M100-C	100	0.125	2.6	Yes	3.16	0.084	C	5/3	2.5	15
2.6-Rot-M100-p2	100	0.125	2.6	Yes	3.16	0.084	A	2	2.5	15
2.6-NoRot-M300	300	0.125	2.6	No	0	0.12	A	5/3	5.0	10
2.6-Rot-M1000	1000	0.375	2.6	Yes	1.90	0.081	A	5/3	5.4	10

- low + high mass cores
- strong magnetic field
- with/without global rotation
- sub-/supersonic **turbulence**

- resolution: 1.2 AU



Initial angular momentum of cores

- observational evidence for rotating cores $(\mathrm{R} \sim 0.1\ \mathrm{pc})$
  e.g. *Goodman et al., 1993*:

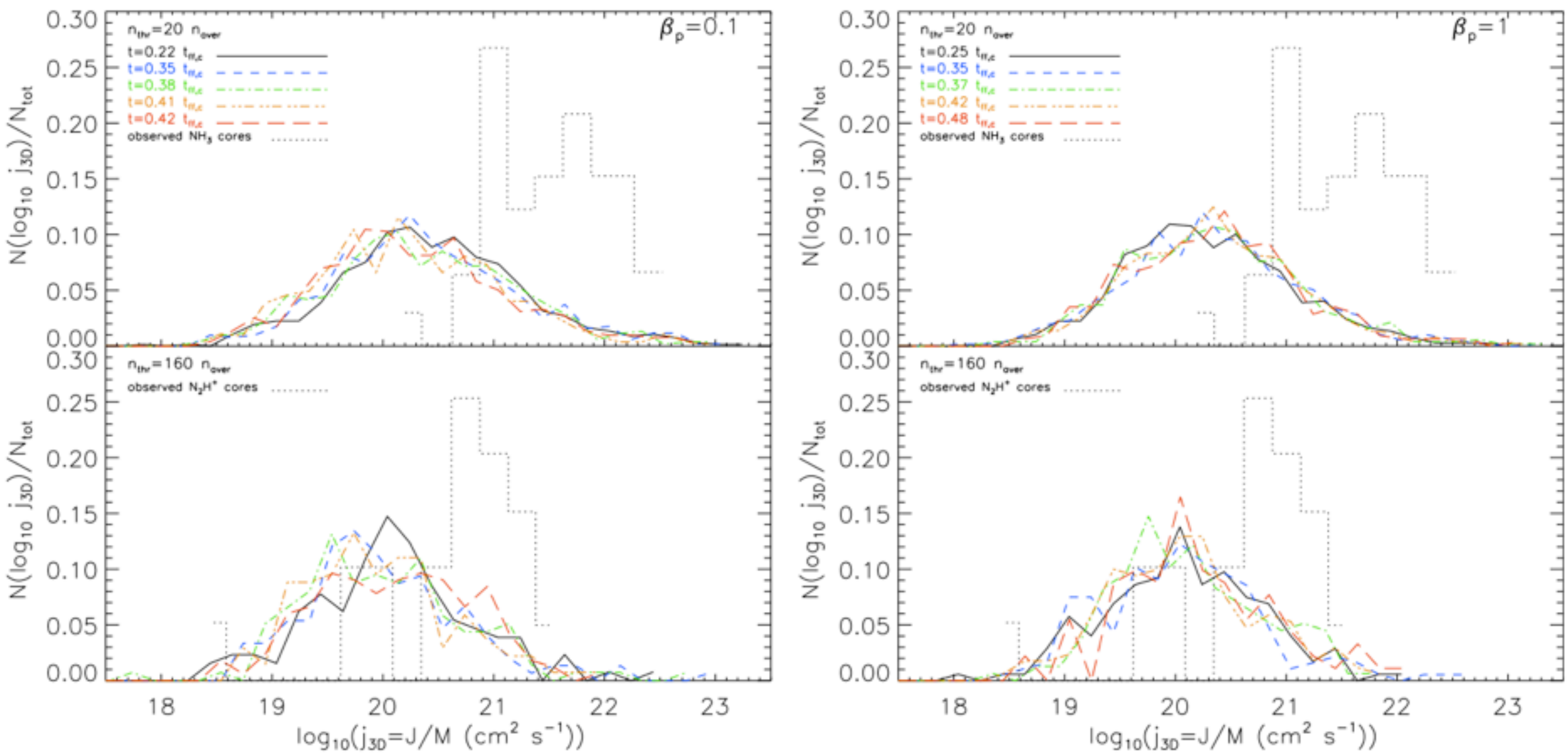
  $$\Omega \sim 10^{-14} - 10^{-13}\ \mathrm{s}^{-1}$$
  $$\Longrightarrow \mathrm{j} \sim 10^{21}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$$
  $$\Longrightarrow \beta \sim 0.03 \propto (t_{\mathrm{ff}}\, \Omega)^2$$

  but: large scatter

- compare to galactic shear flow: $\Omega \sim 10^{-16} - 10^{-15}\ \mathrm{s}^{-1}$
  $\Longrightarrow$ generated by turbulence (*Barranco & Goodman, 1998*)?

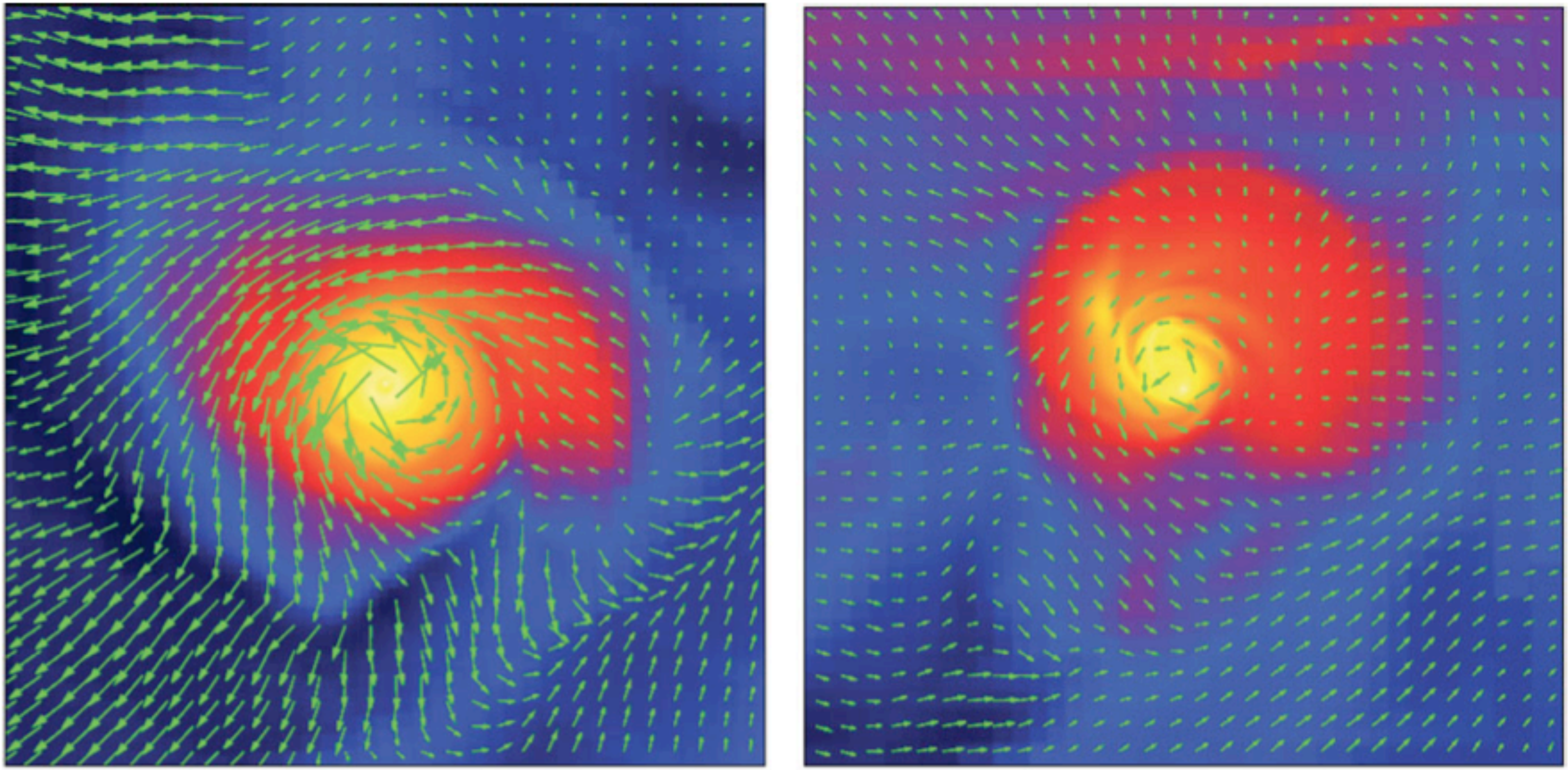
Initial angular momentum of cores?

- Dib et al. 2010:
  synthetic observations from simulations overestimate true values by a factor of **8−10**



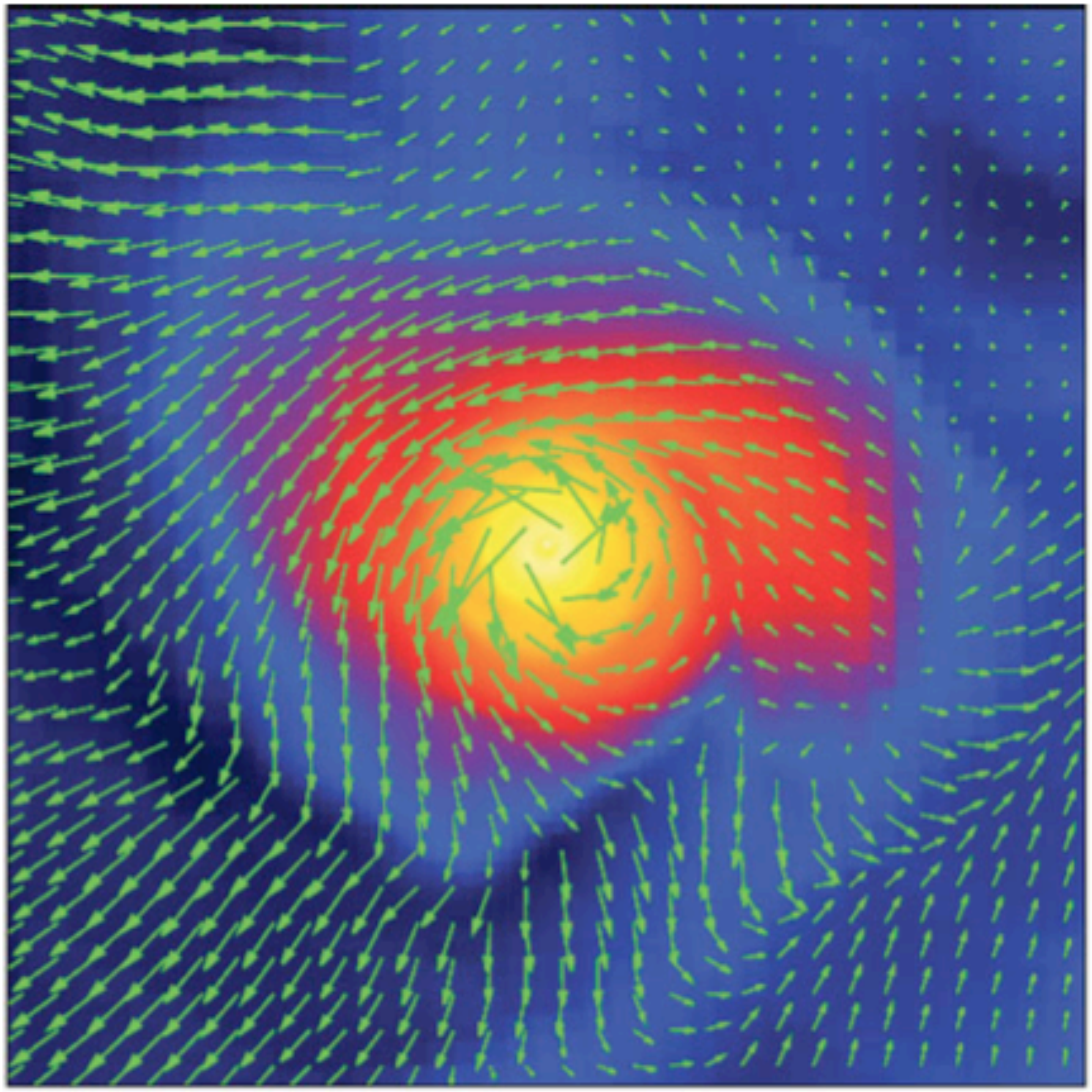
⟹ also consistent with no global rotation on scales > 0.1 pc

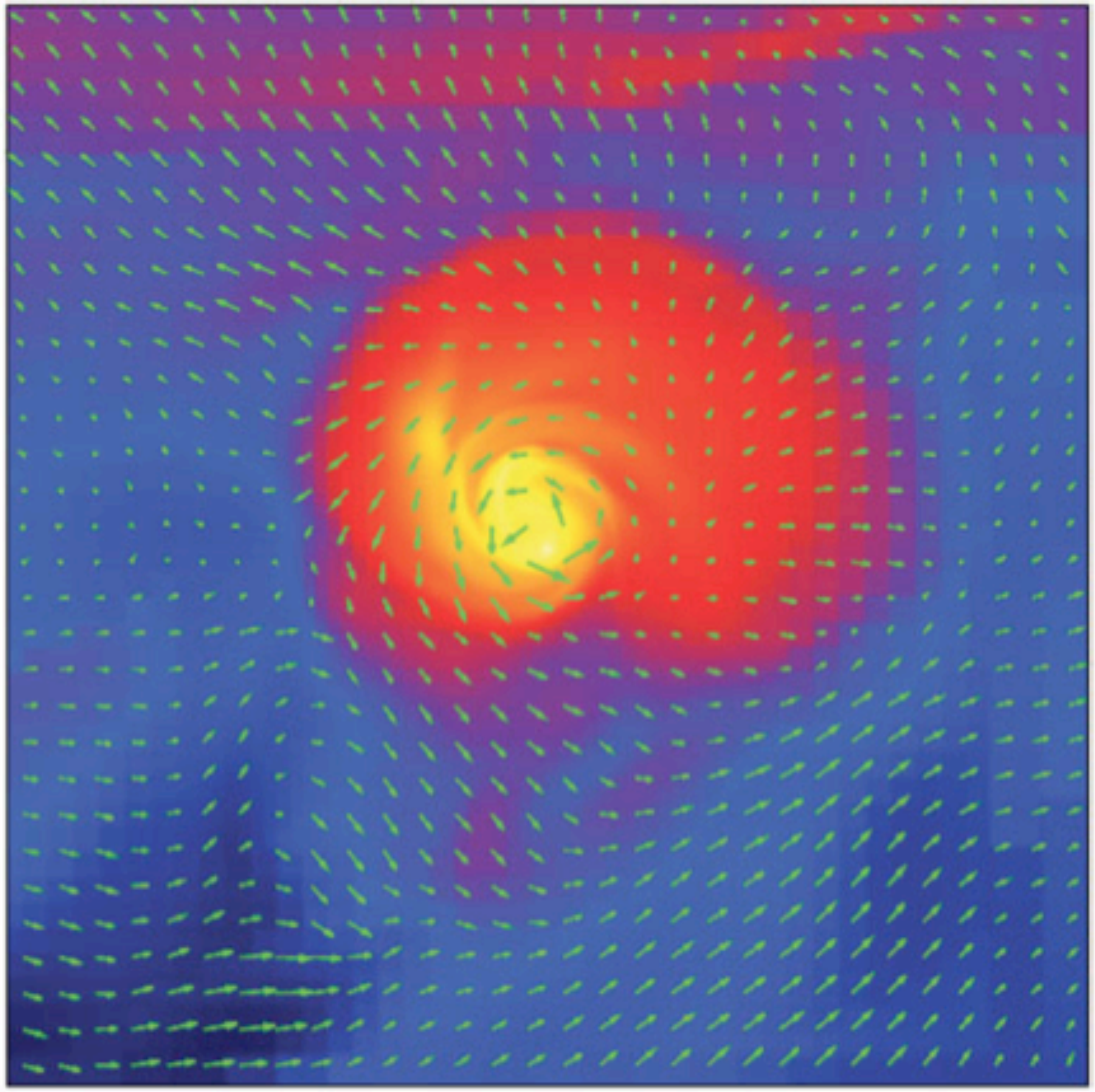
Collapse of Turbulent Cores



Seifried, RB, Pudritz, Klessen 2012

Collapse of Turbulent Cores

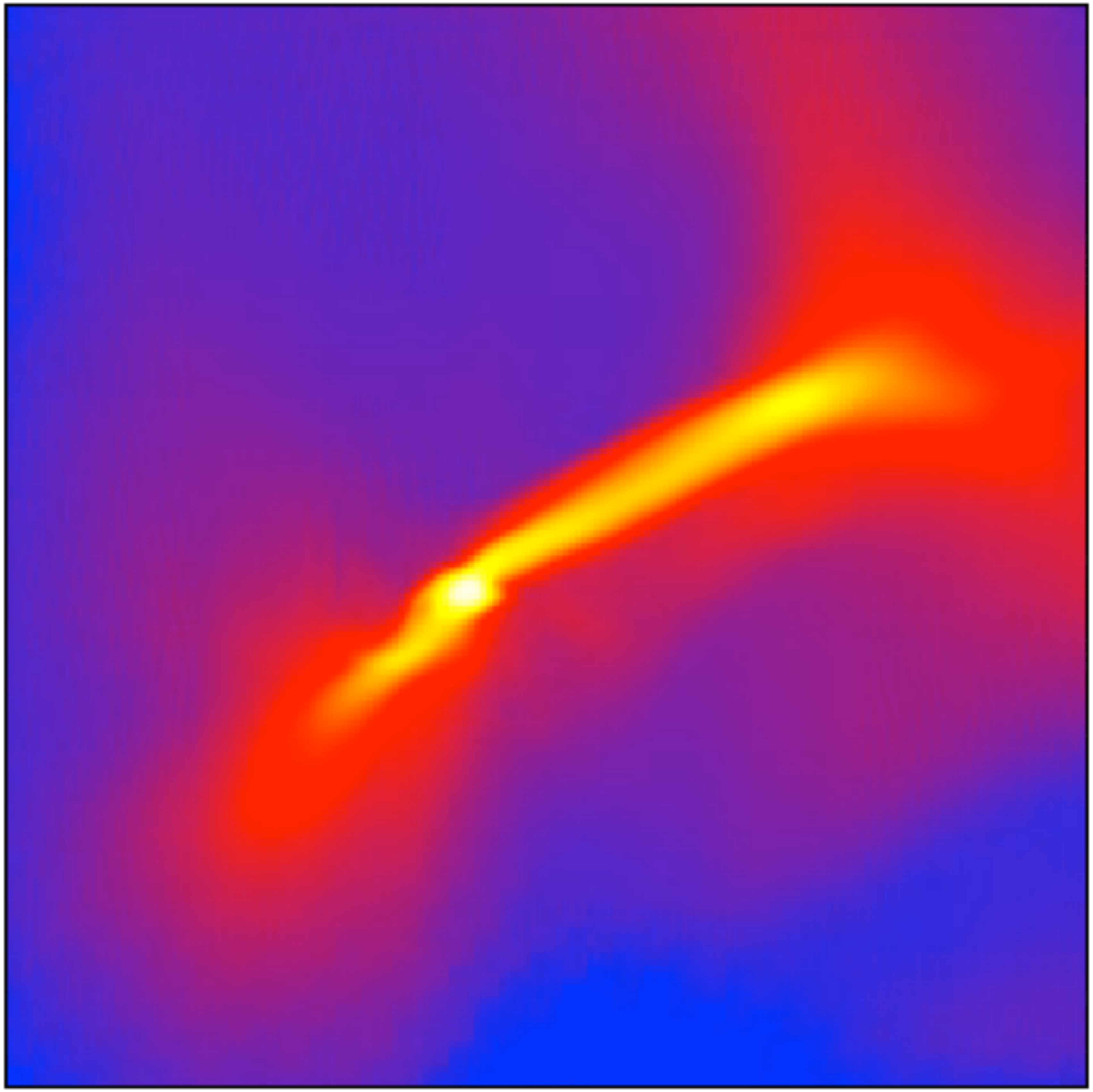




Seifried, RB, Pudritz, Klessen 2012

$\Longrightarrow$ discs “reappear”

Collapse of Turbulent Cores



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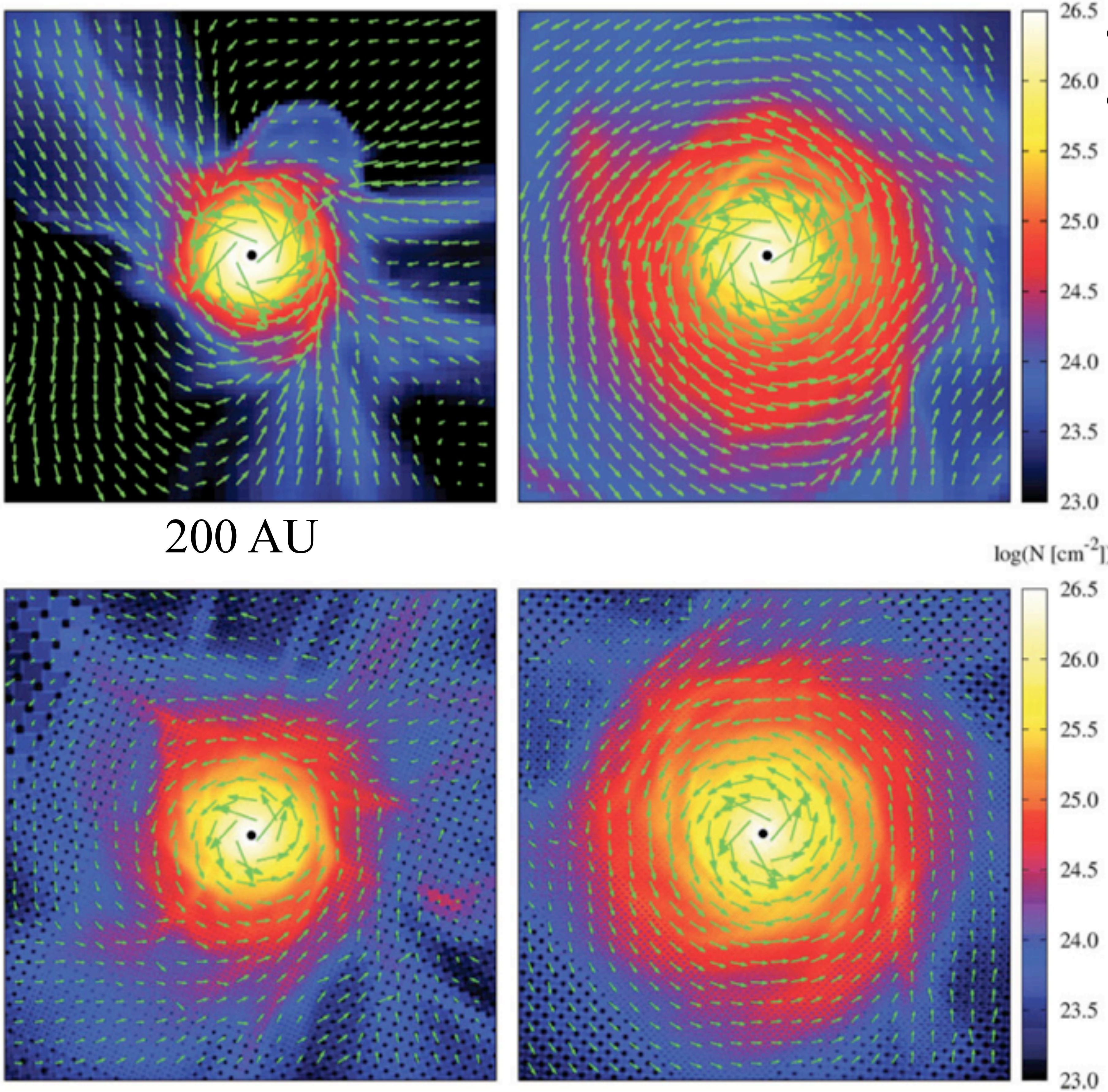
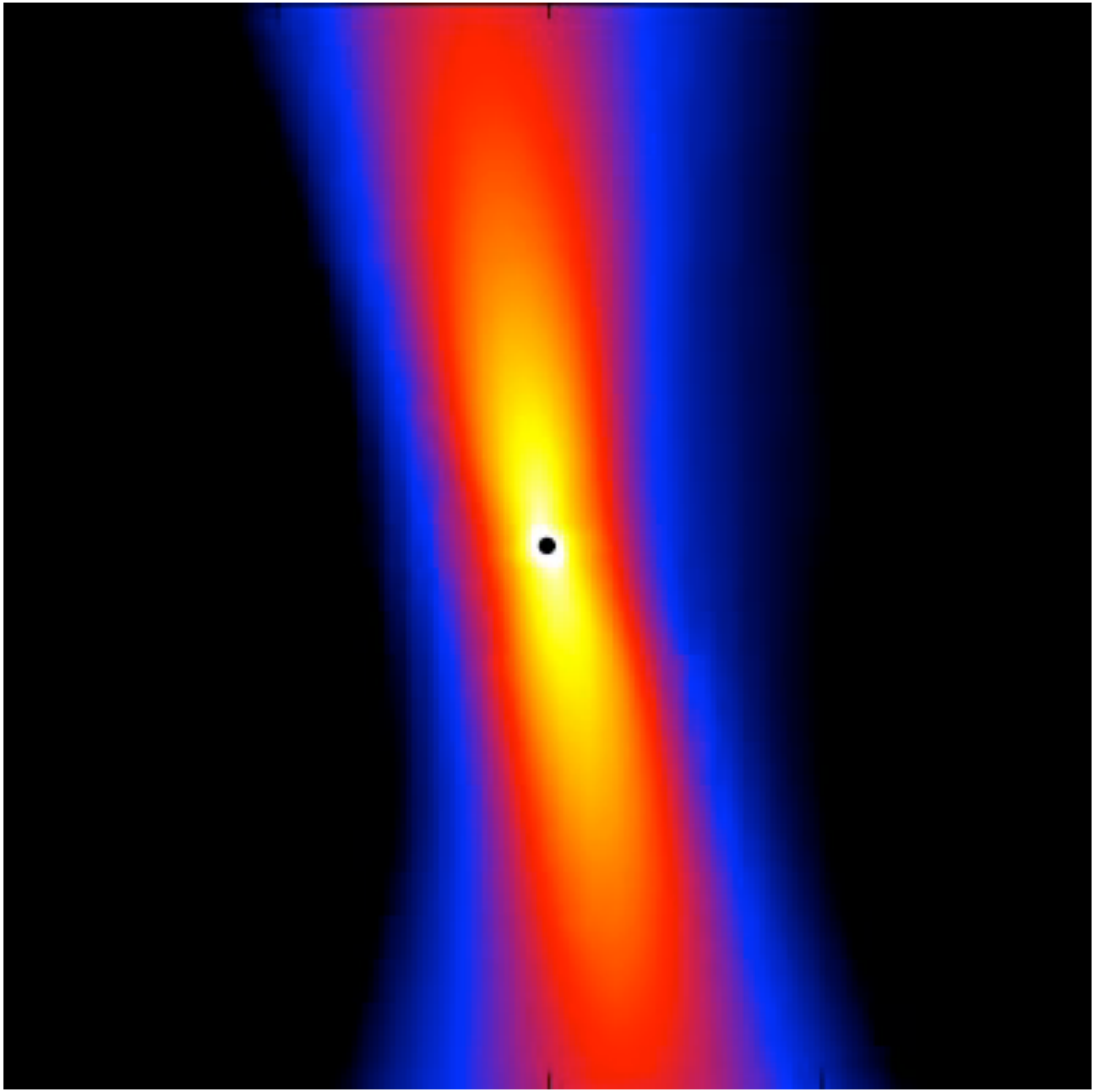


- low mass cores
- strong magnetic field: $\mu = 2.6\ \mu_{crit}$
- transonic turbulence $Ma = 0.74$
- **no** global rotation
- with global rotation

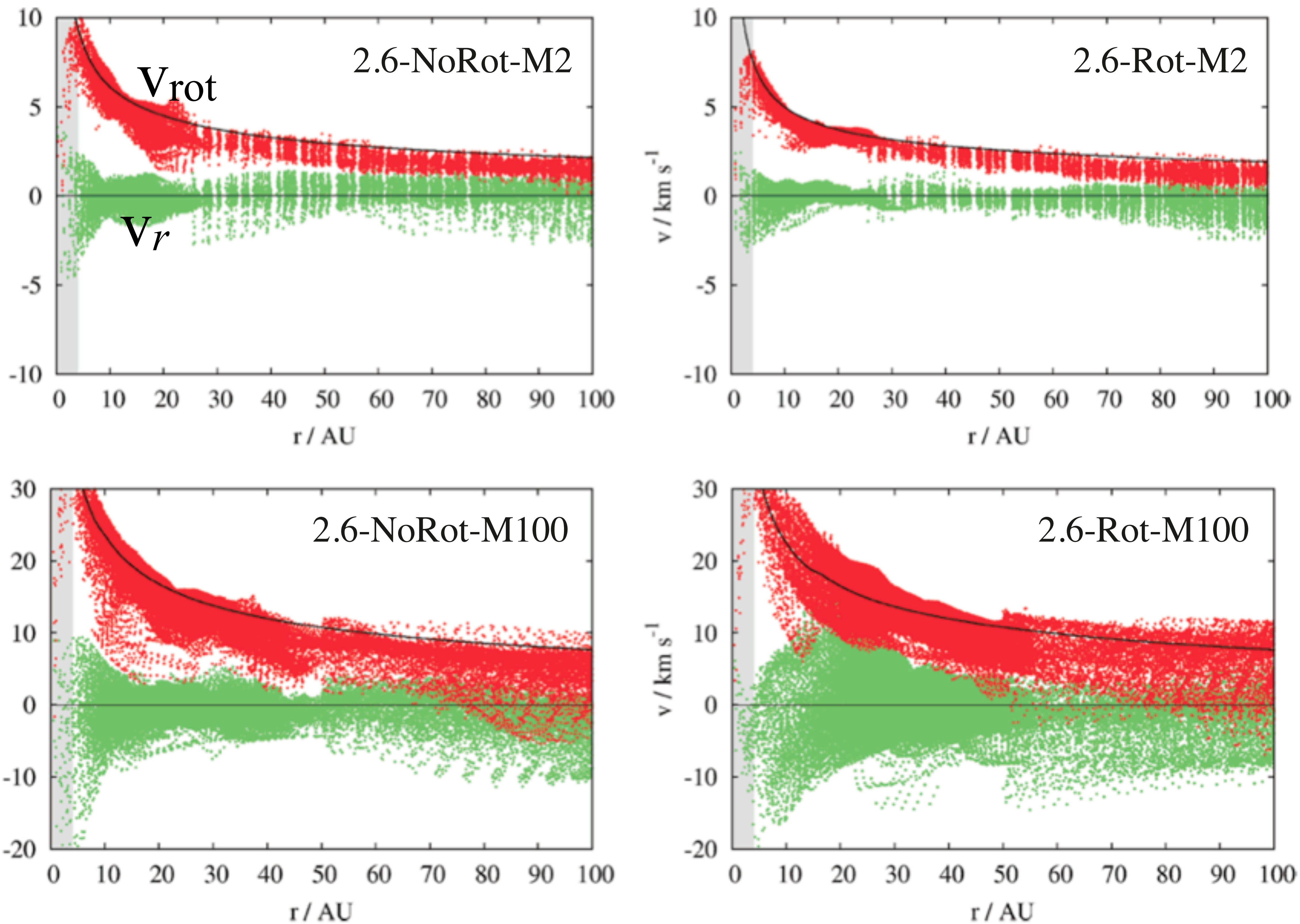
Seifried, et al. 2013

Collapse of Turbulent Cores



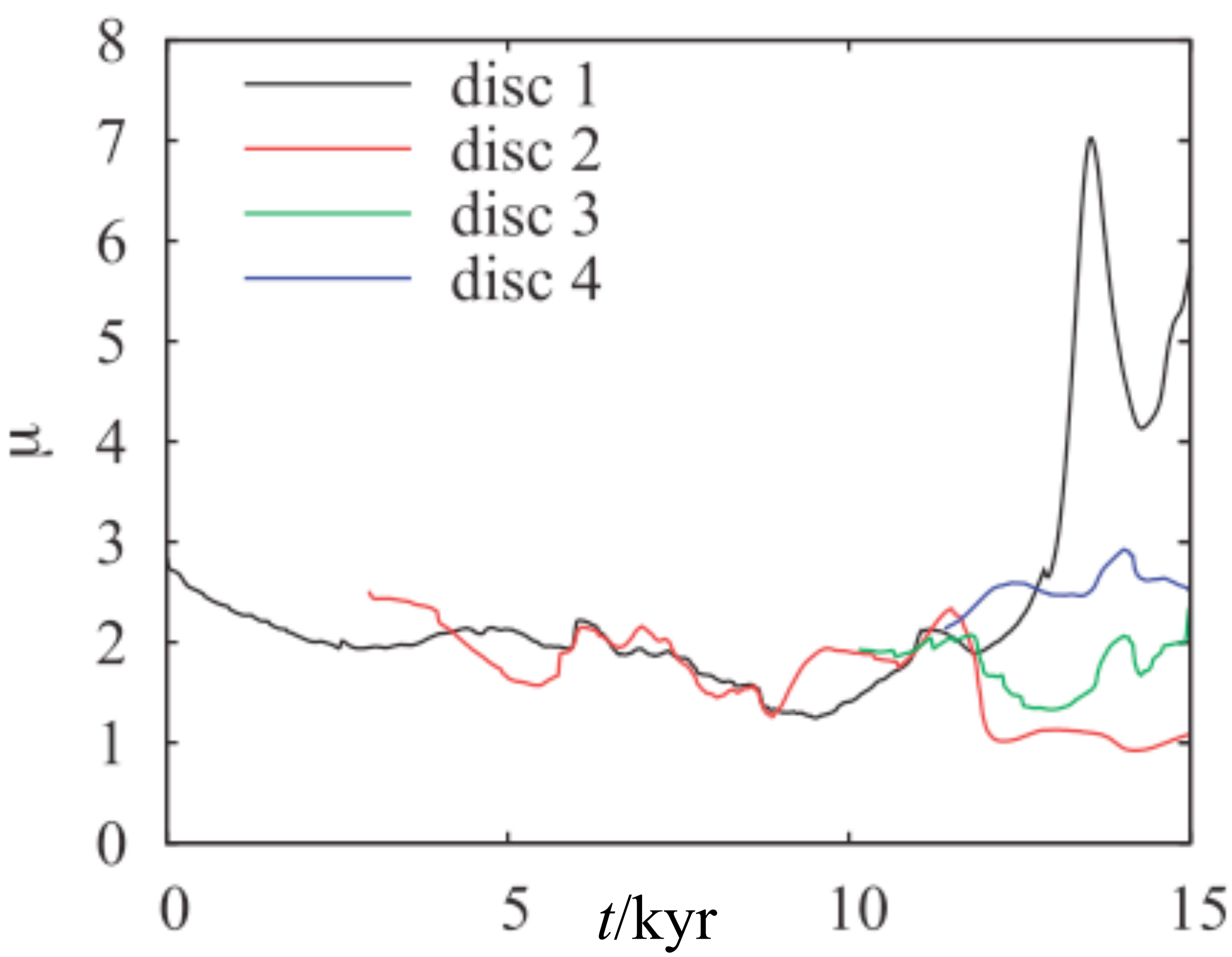
Collapse of Turbulent Cores

velocity structure

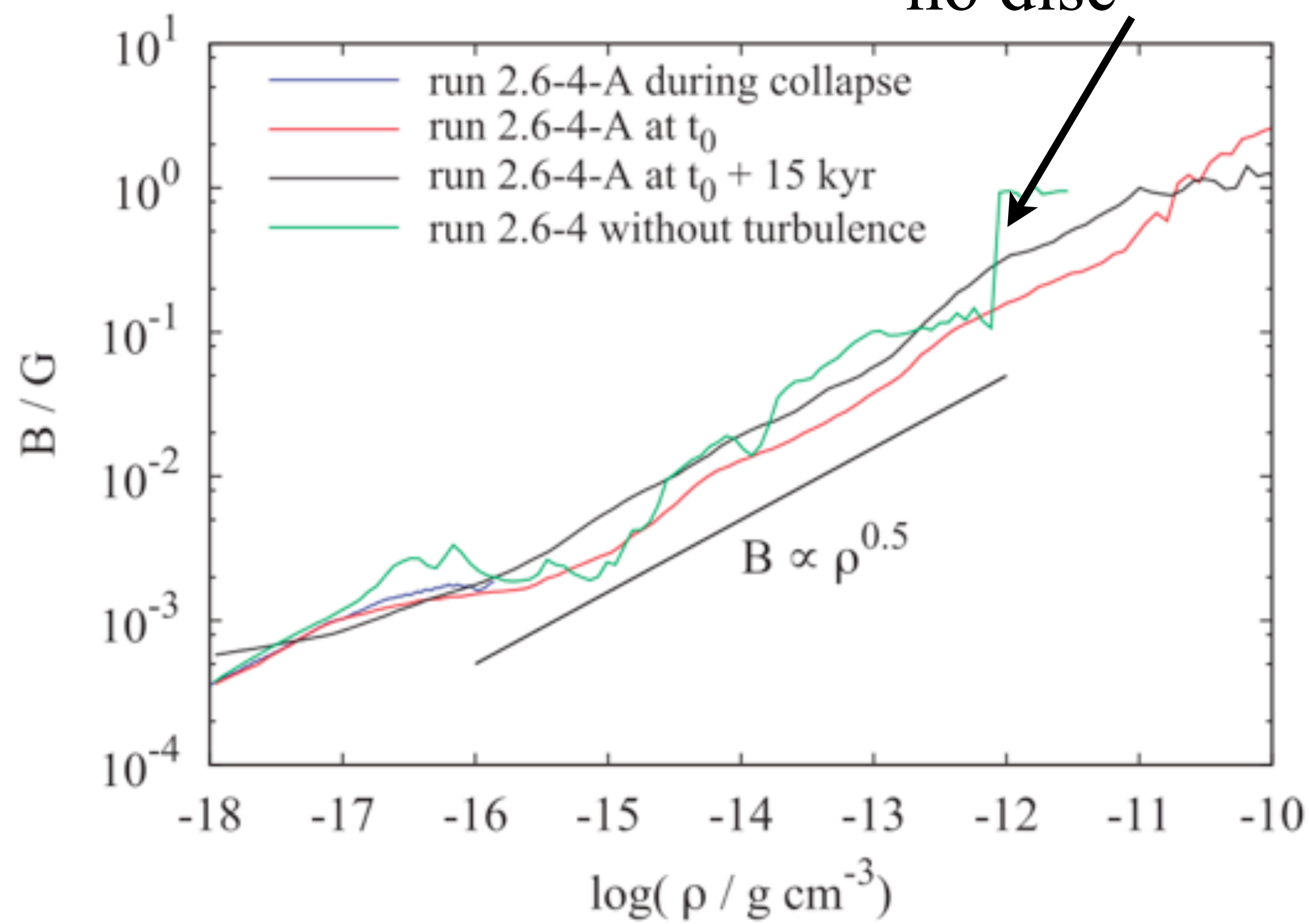


Collapse of Turbulent Cores

due to flux loss?



no turbulence
no disc



Collapse of Turbulent Cores

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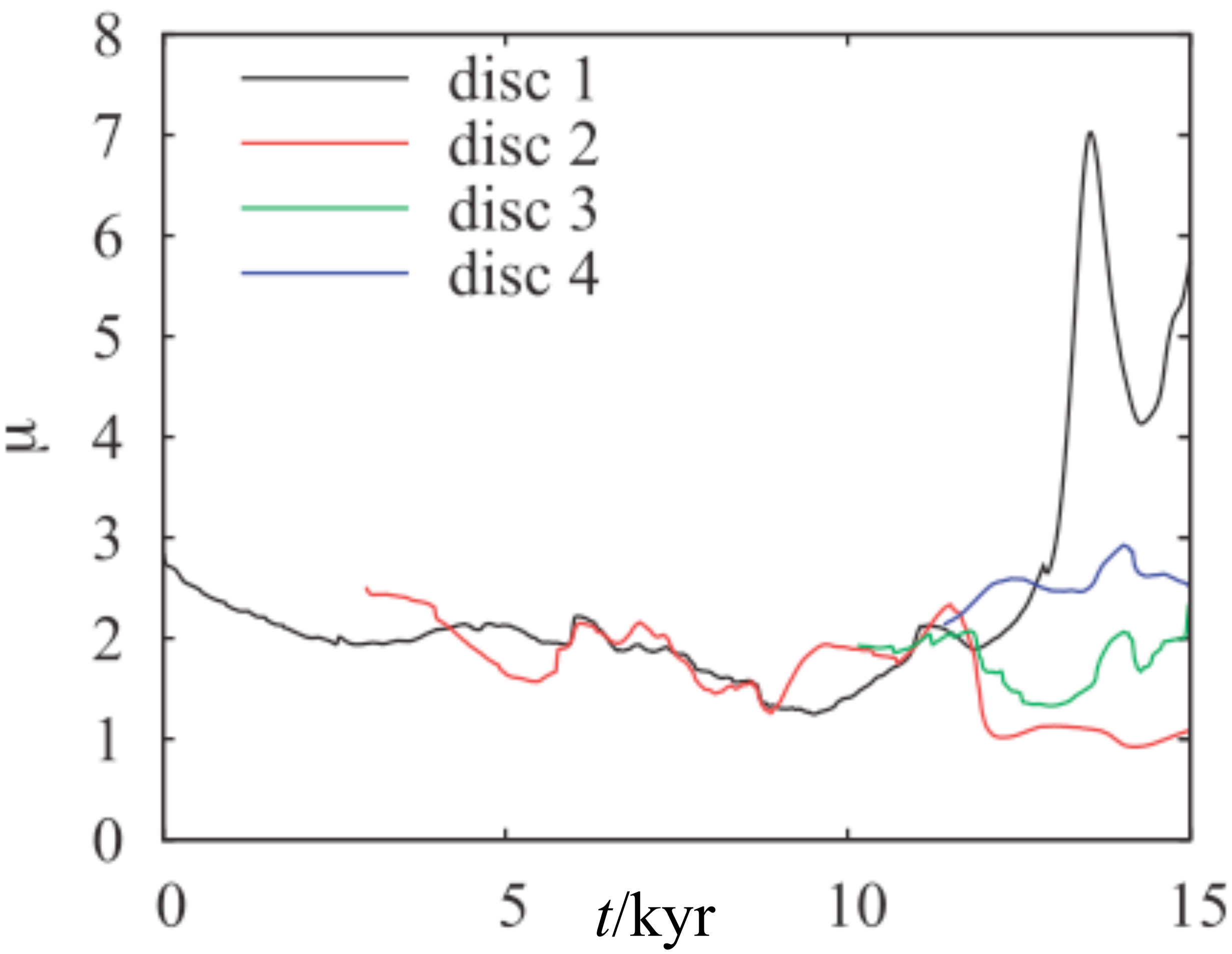
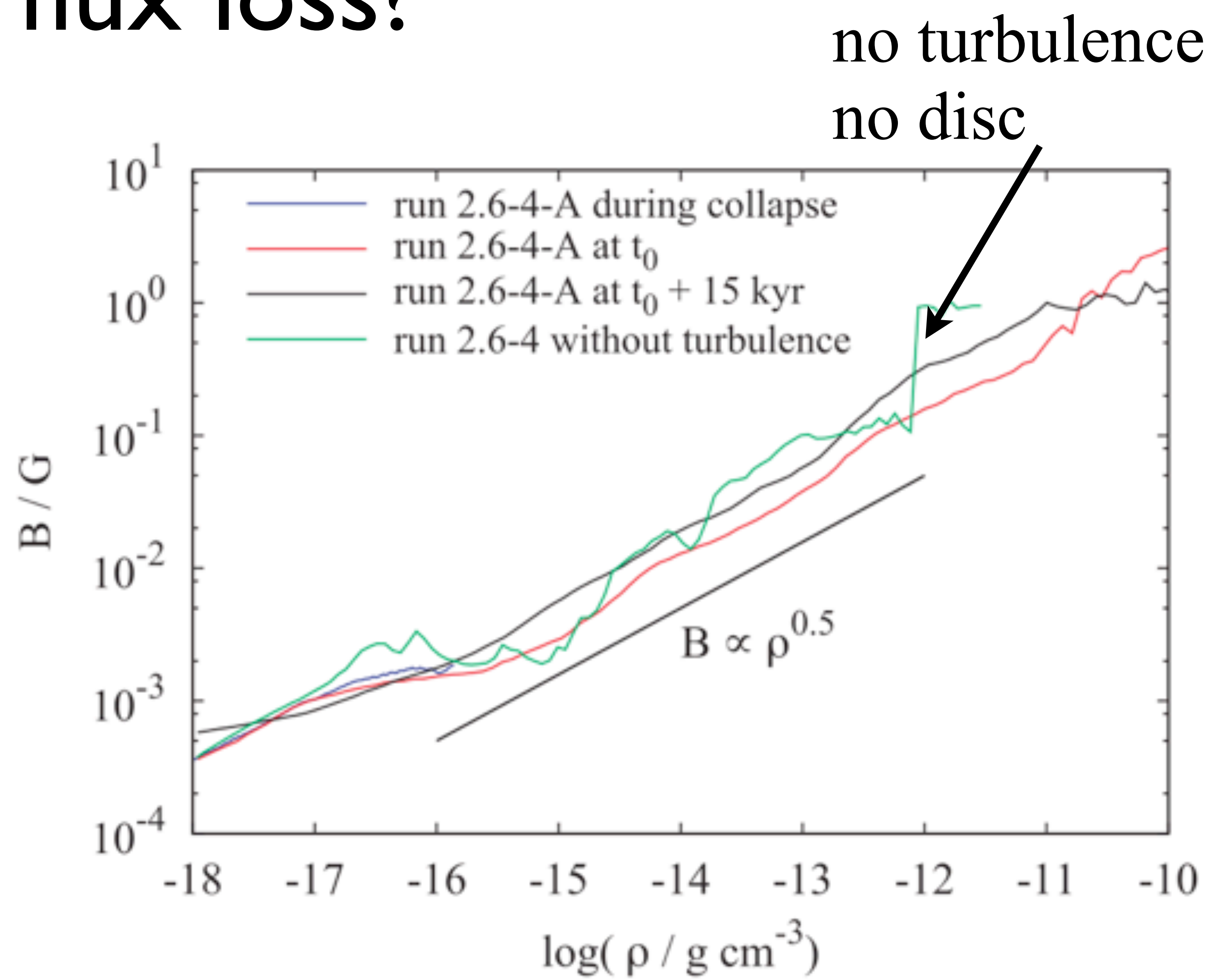
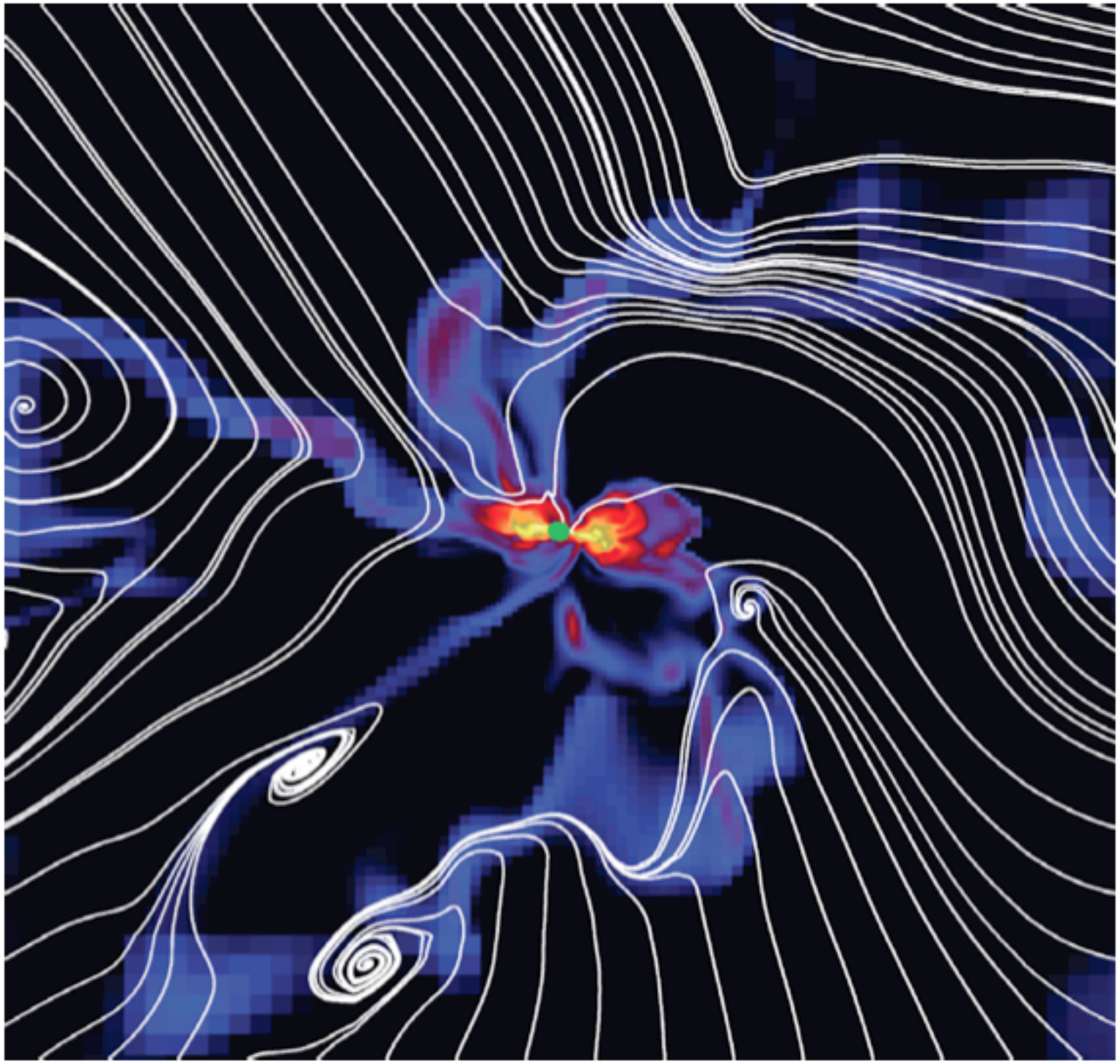




$\Longrightarrow$ only little flux loss

Collapse of Turbulent Cores

Magnetic field structure

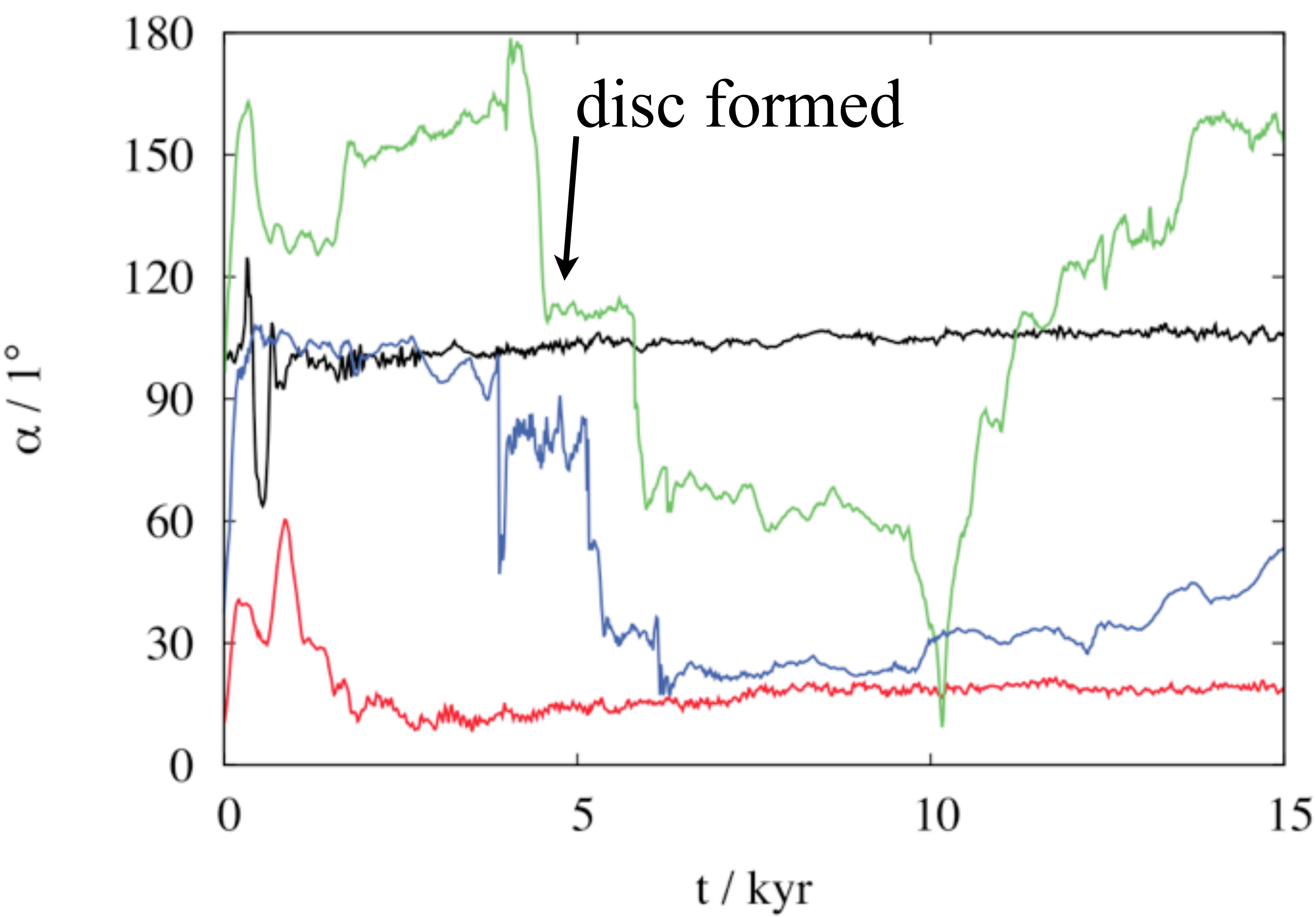


Collapse of Turbulent Cores

rotation vs. magnetic field orientation

$\Longrightarrow$ inclined rotation helps to form discs?

(*Hennbelle & Ciardi 2009, Joos et al. 2012*)



Collapse of Turbulent Cores

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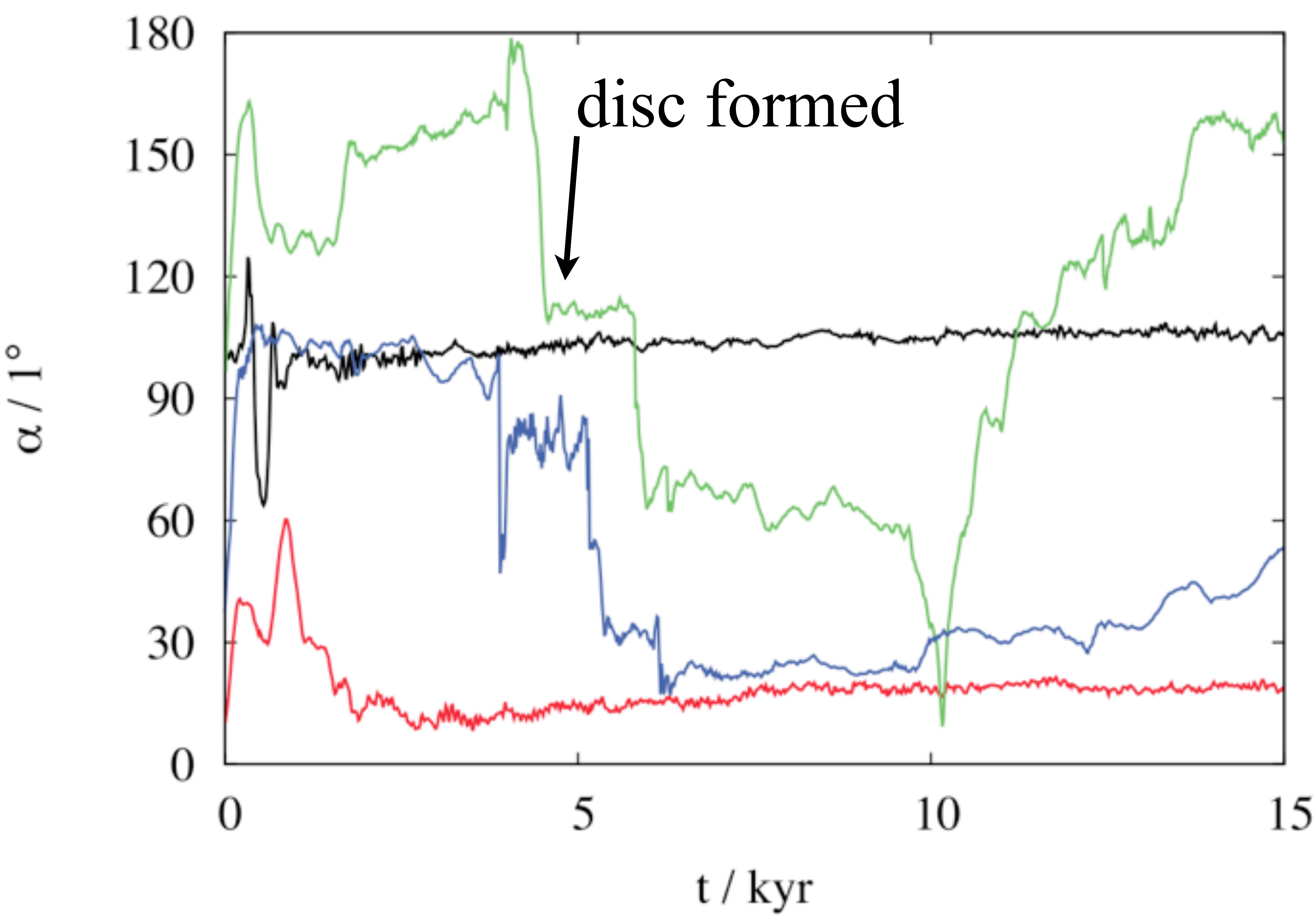

$\Longrightarrow$ but no large scale magnetic field component

Summary: Collapse of Turbulent Cores

- Magnetic braking catastrophe only for unrealistic ICs
- is easy to form discs in a turbulent environment

$\Longrightarrow$ see also:
Santos-Lima et al. 2012
Myers et al. 2013 (Chris' talk on Wednesday)

$\Longrightarrow$ flux loss by turbulent reconnection ?

(*Lazarian & Vishniac* 1999)