hamburger sternwarte

Disc Formation and Feedback from YSOs

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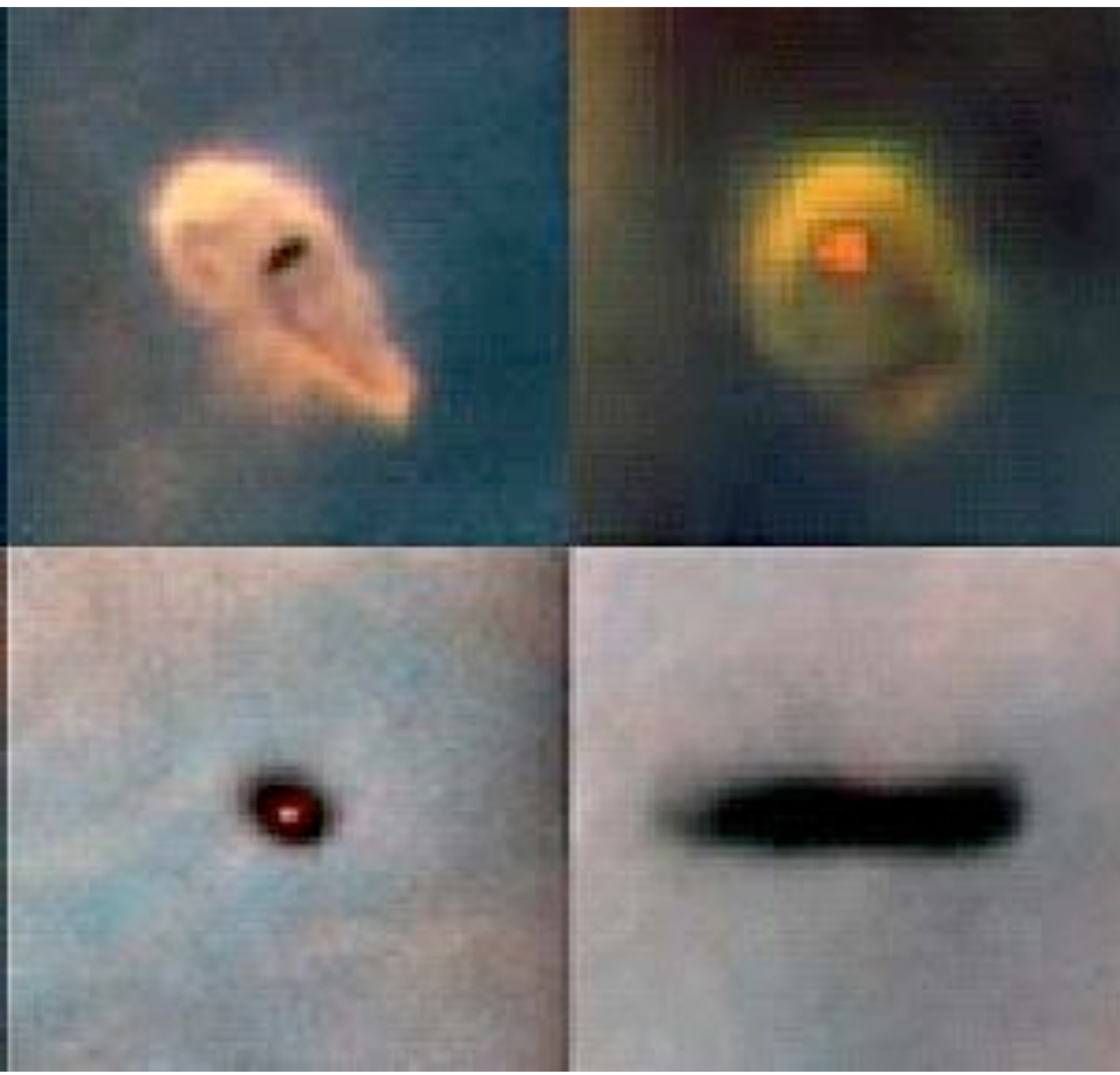
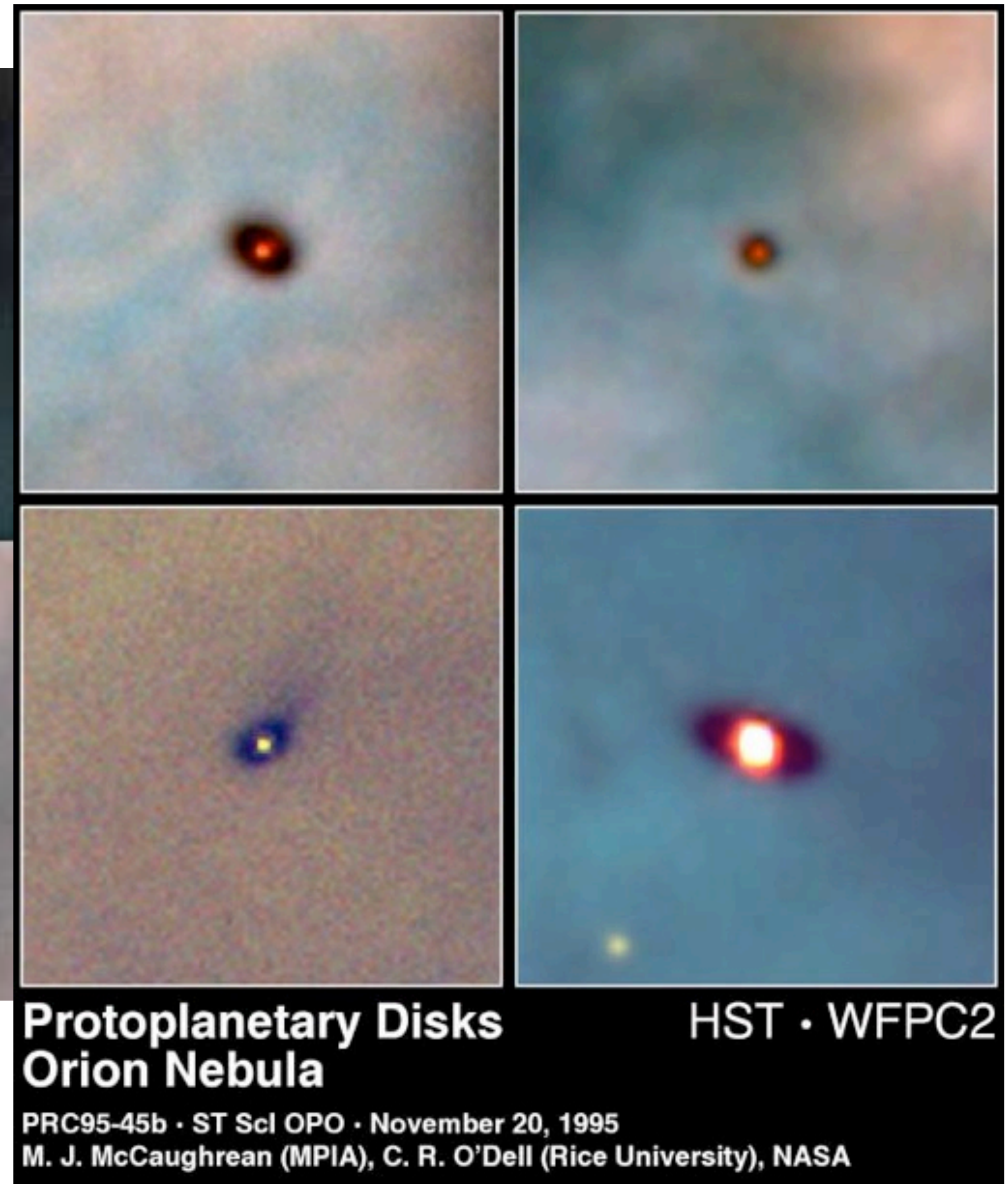
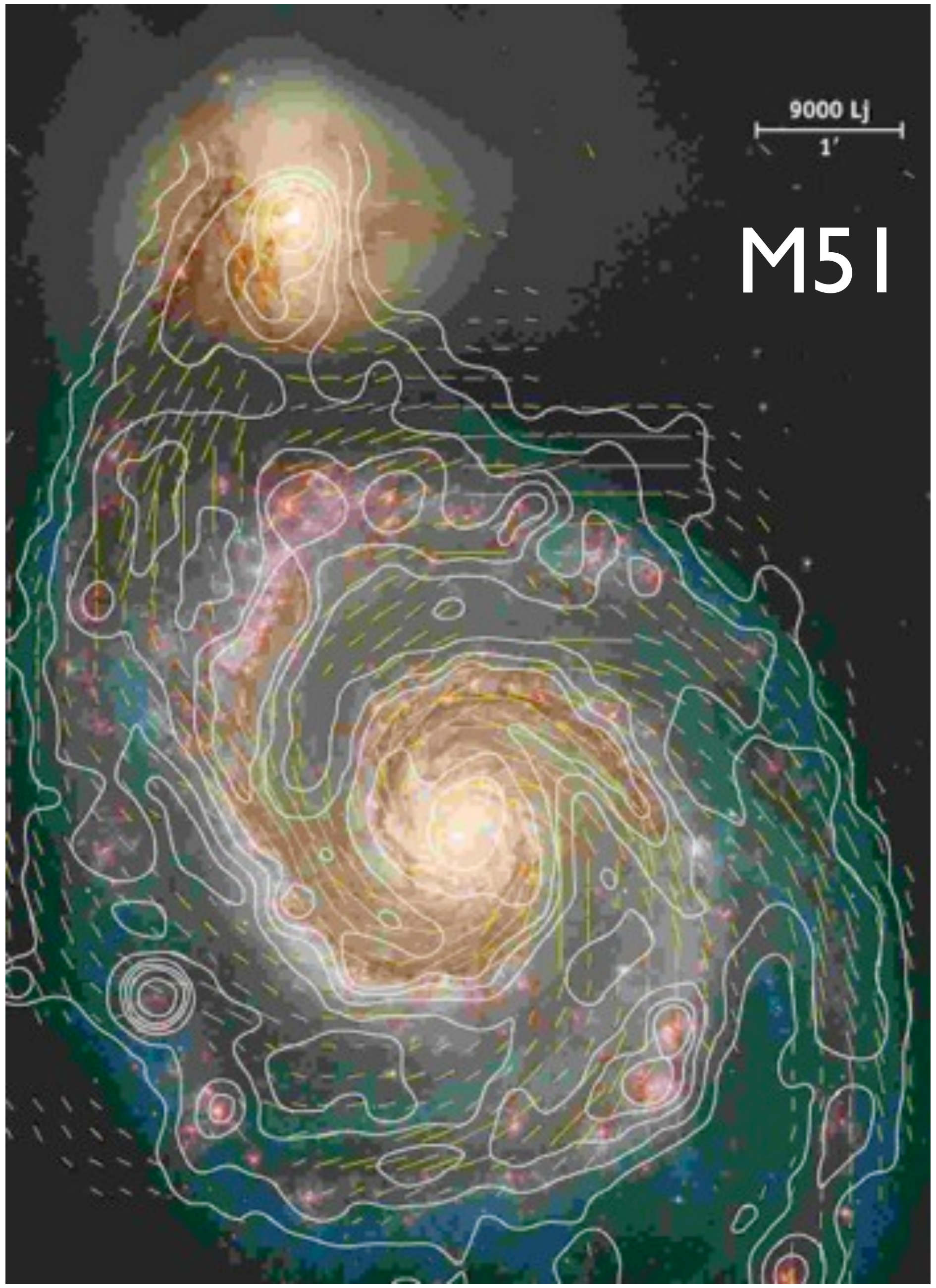
Star Formation: Early-type discs

Observations of protostellar discs



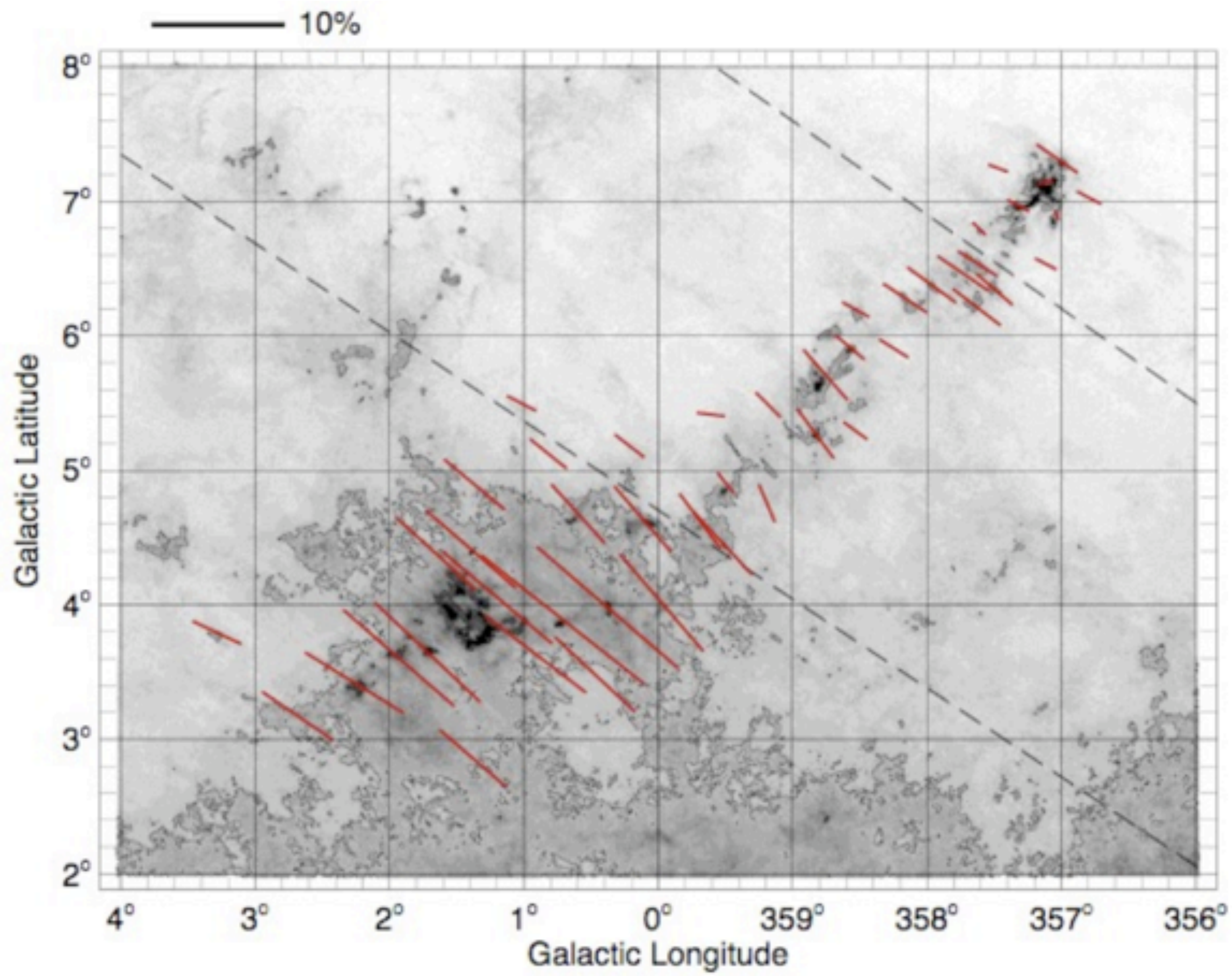


Magnetic Fields



galactic B-fields (e.g. *R.Beck 2001*)
large scale component: $\sim 4\mu G$
total field strength: $\sim 10\mu G$

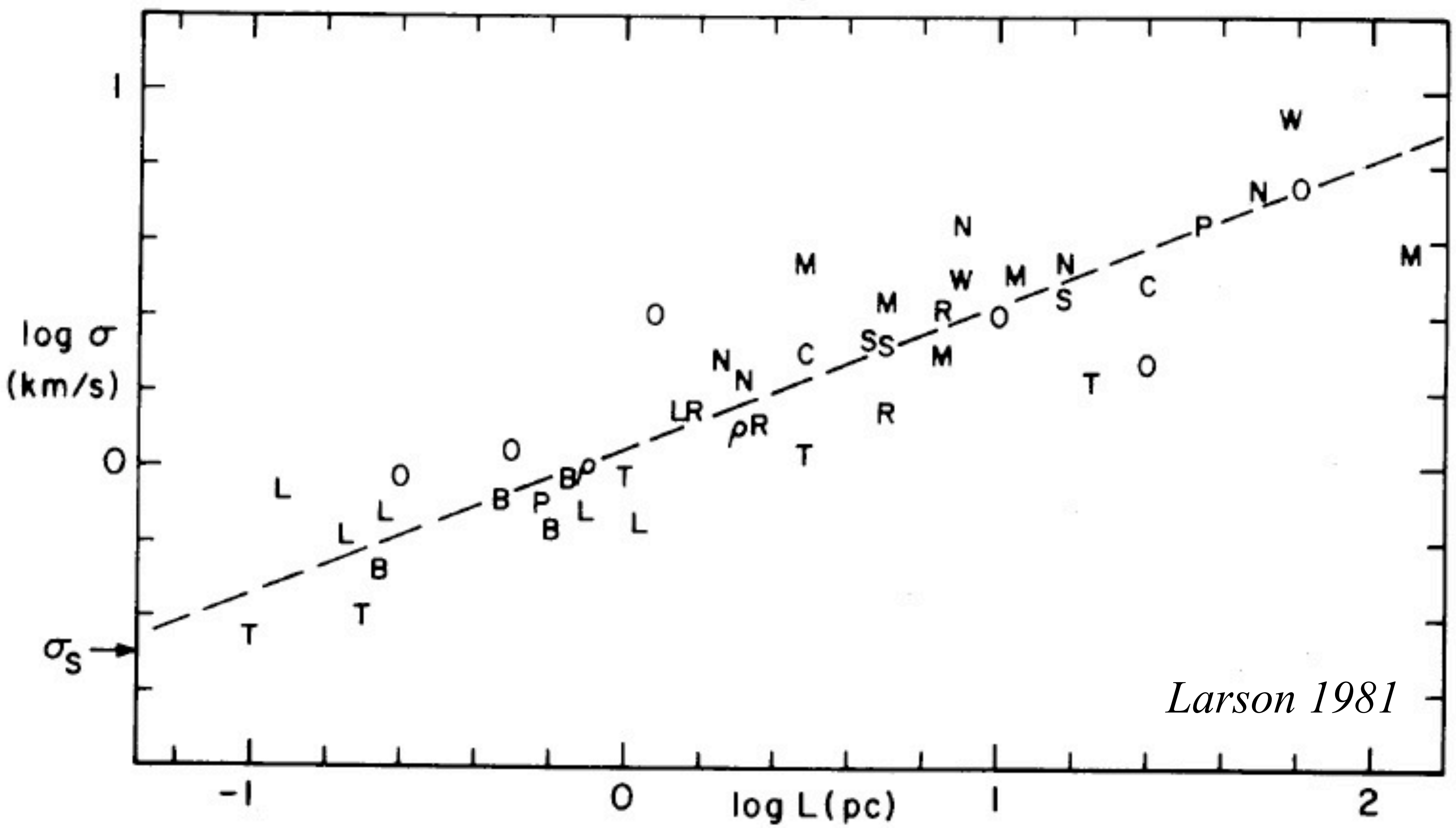
The ISM is permeated with magnetic fields



magnetic polarization measurements in the Pipe nebula
F.O.Alves, Franco, Girart 2008

Turbulence

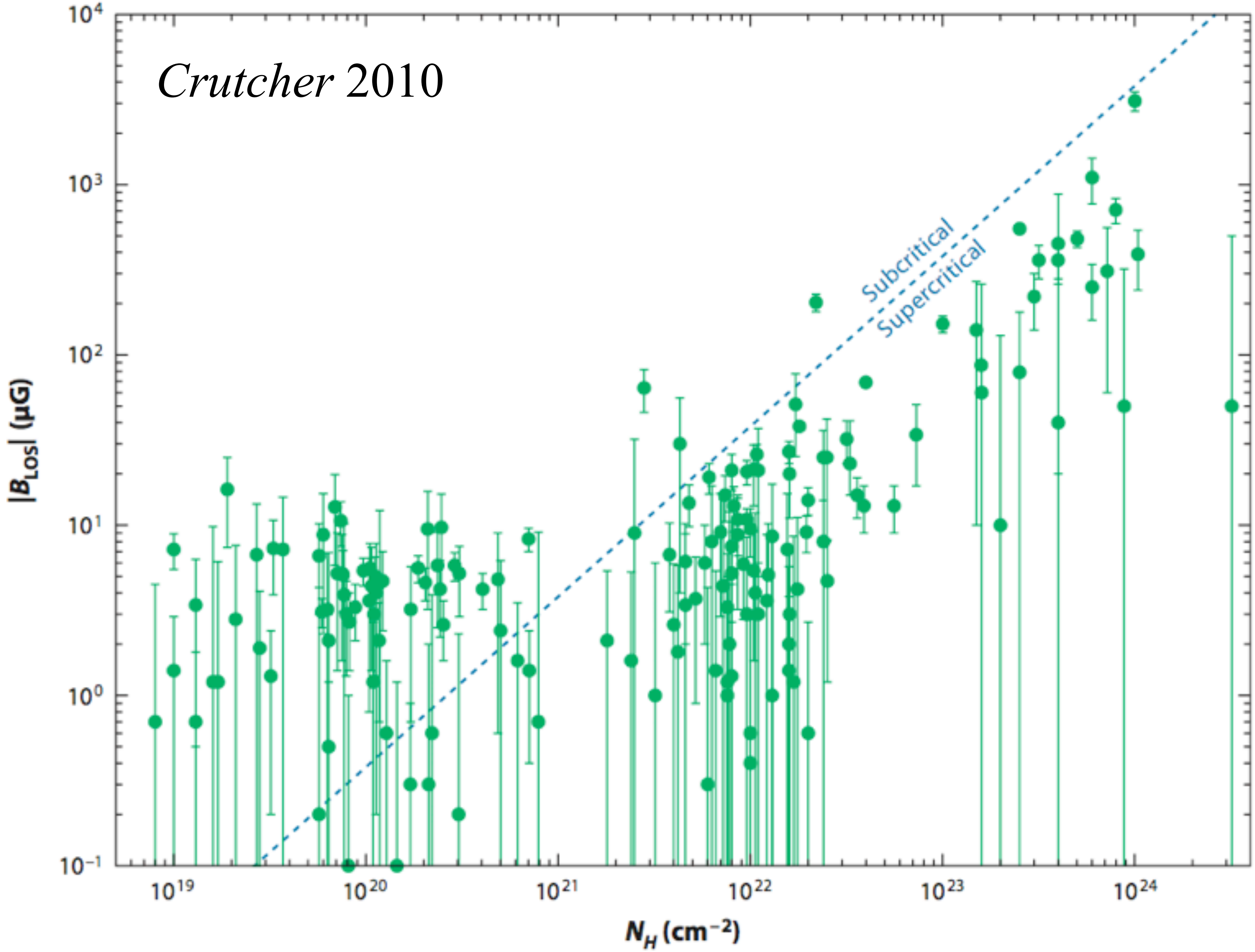
Larson relation: Turbulence in Molecular Clouds



⇒ supersonic high mass cores

⇒ sub-sonic low mass cores (R < 0.1 pc)

Magnetic Fields



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

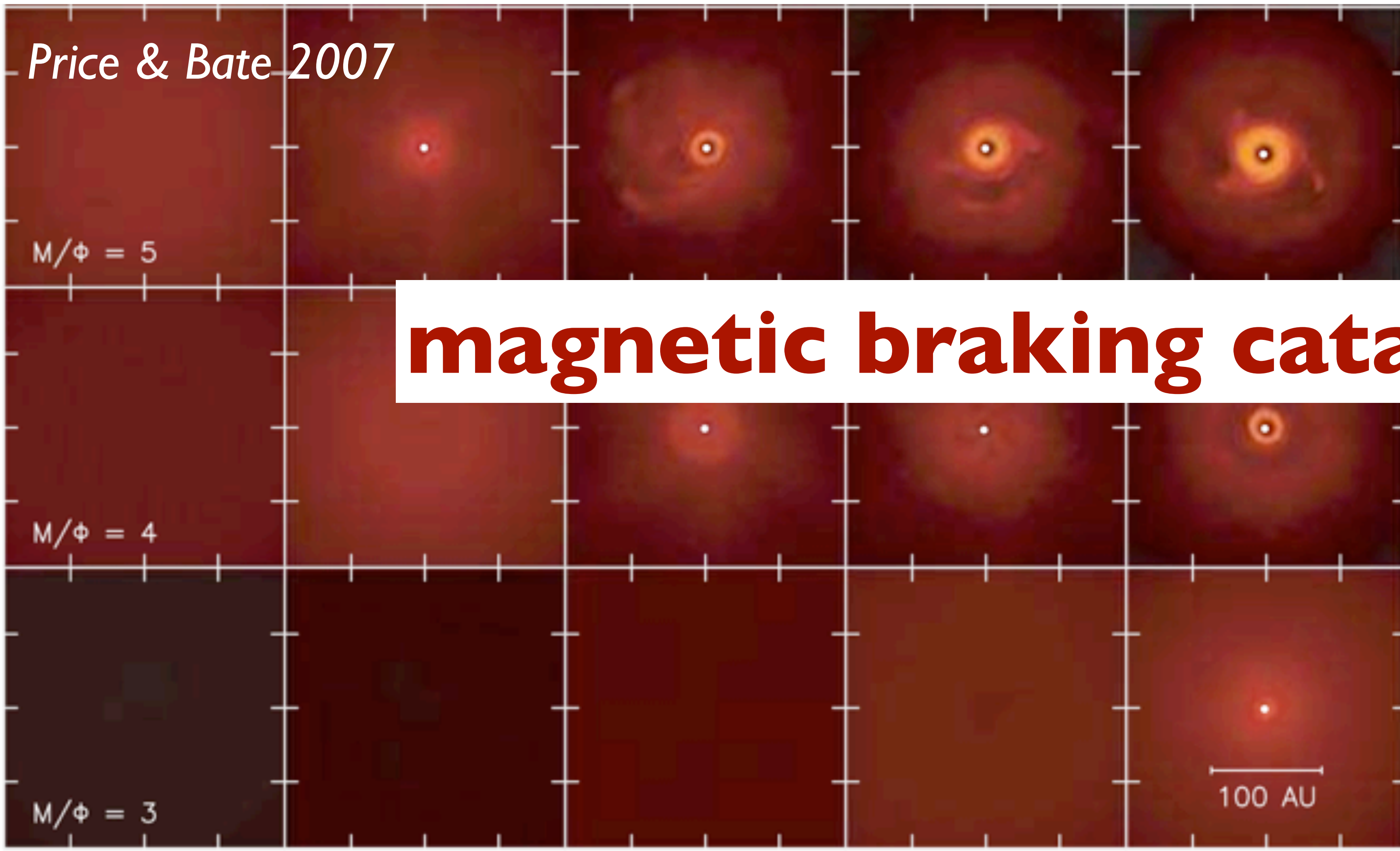
$$\mu = 2 \ldots 5$$

Star Formation: Early-type discs

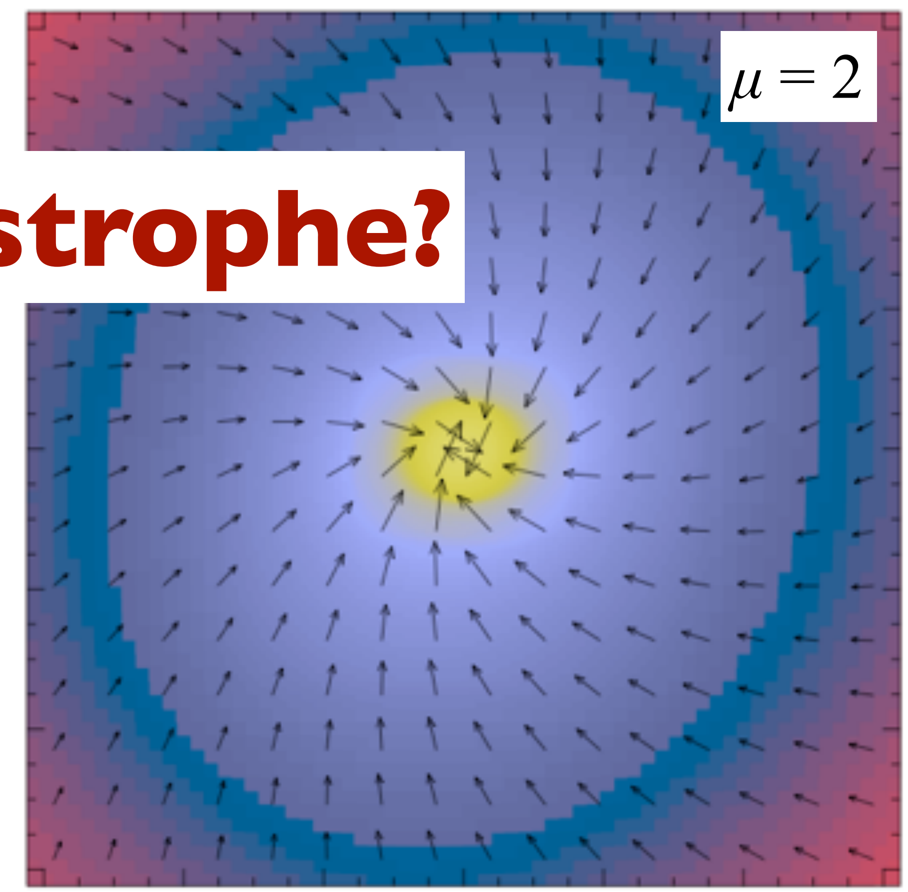
Collapse of magnetised, rotating cloud cores

- **stronger** magnetic fields: $\mu < 5$ in agreement with observations

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



magnetic braking catastrophe?



Hennebelle & Teyssier 2008, ...

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

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

Magnetic Braking Catastrophe

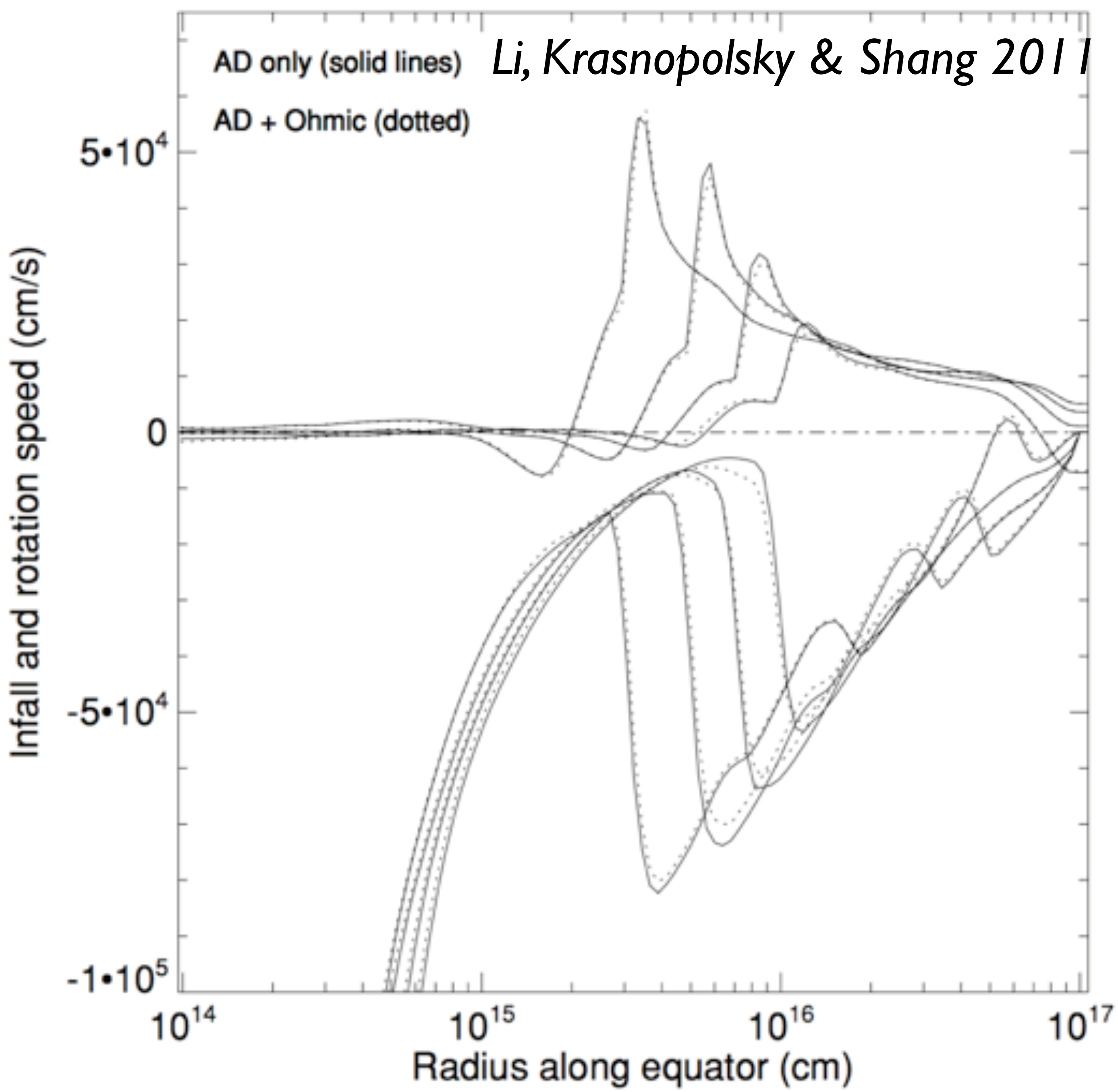
Solutions?

- 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*)

Magnetic Braking Catastrophe

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

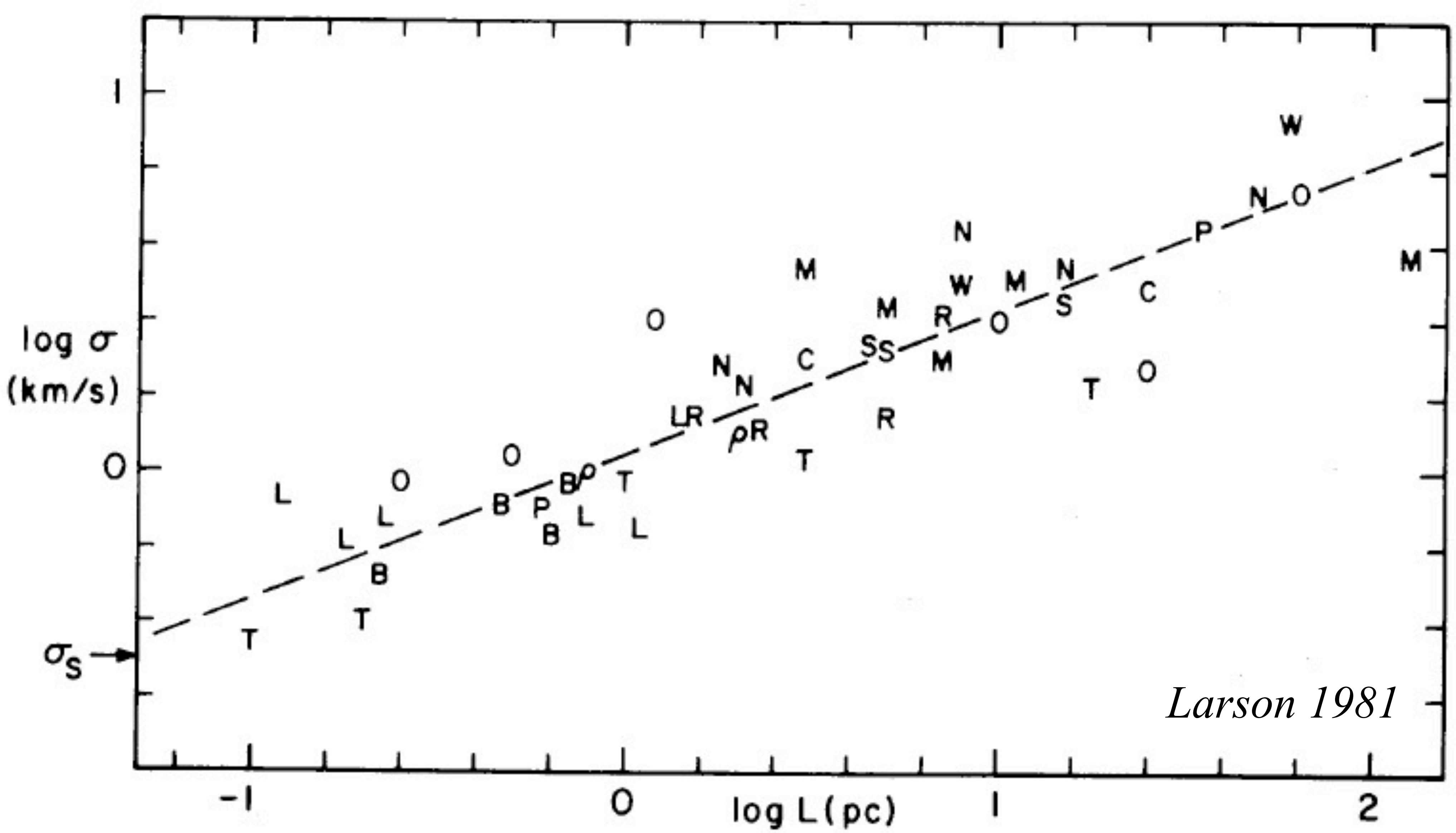
⟹ not effective enough to reduce magnetic braking



⟹ *Li, Krasnopolsky & Shang* 2011*:*

"The problem of catastrophic magnetic braking that prevents disk formation in dense cores magnetized to realistic levels remains unresolved"

Magnetic Braking Catastrophe



$\Longrightarrow$ what about turbulence?

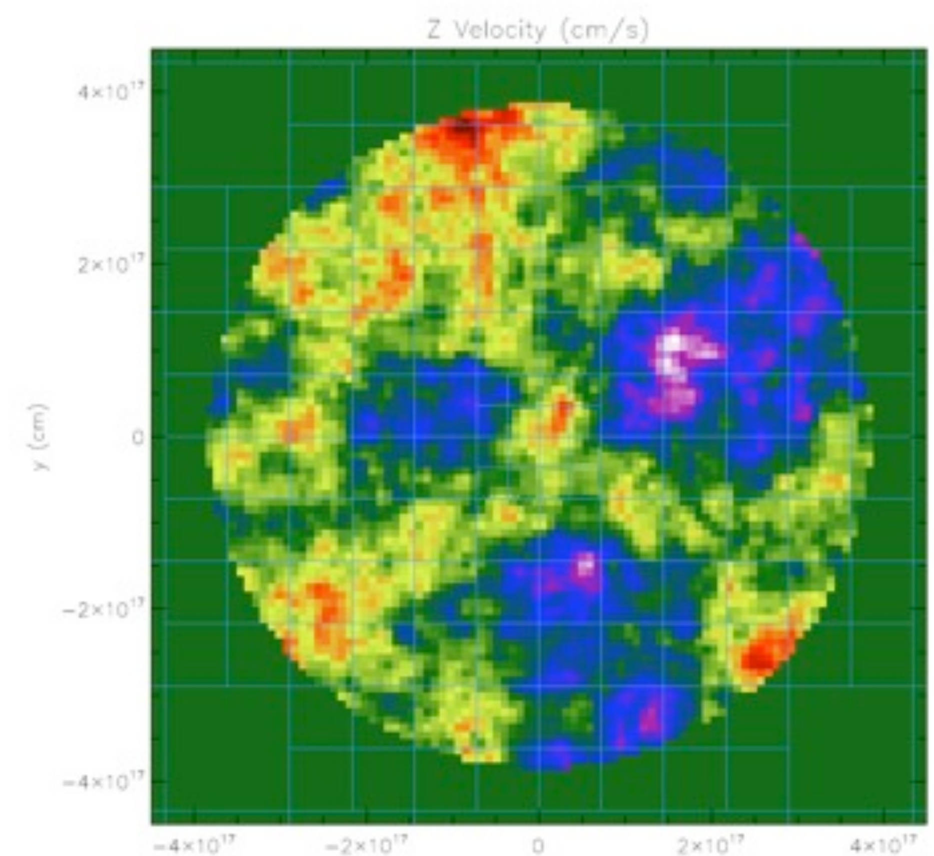
Collapse of Turbulent Cloud Cores

Seifried, et al. 2013

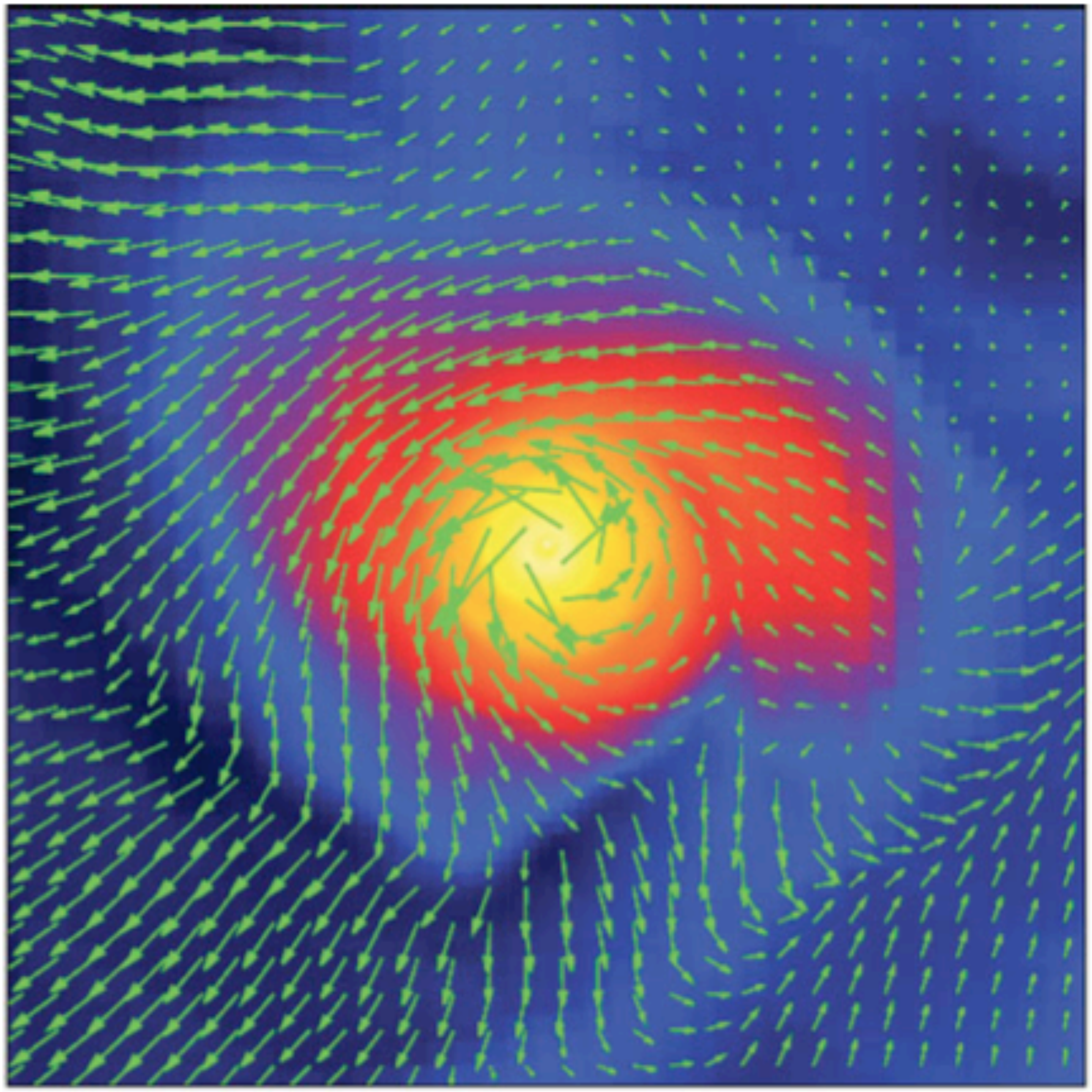
Run	m_{core} ($M_\odot$)	r_{core} (pc)	μ	Rotation	Ω (10^{-13} s^{-1})	β_{turb}	Turbulence seed	p	M_{rms}	t_{sim} (kyr)
2.6-NoRot-M2	2.6	0.0485	2.6	No	0	0.087	A	5/3	0.74	15
2.6-Rot-M2	2.6	0.0485	2.6	Yes	2.20	0.087	A	5/3	0.74	15
2.6-NoRot-M100	100	0.125	2.6	No	0	0.084	A	5/3	2.5	15
2.6-Rot-M100	100	0.125	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

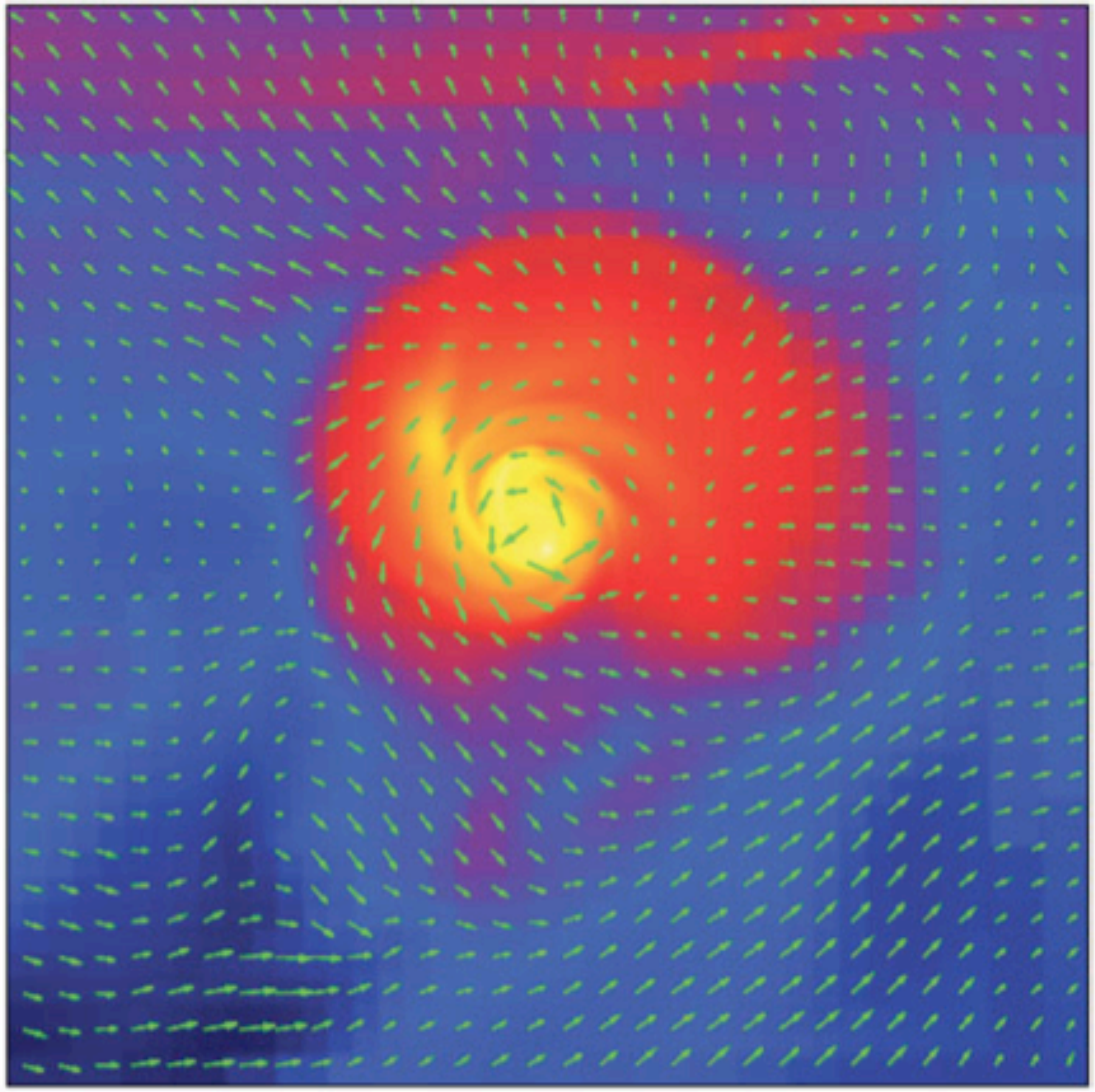
- low + high mass cores
- strong magnetic field
- with/without global rotation
- sub-/supersonic **turbulence**

- resolution: 1.2 AU



Collapse of Turbulent Cores

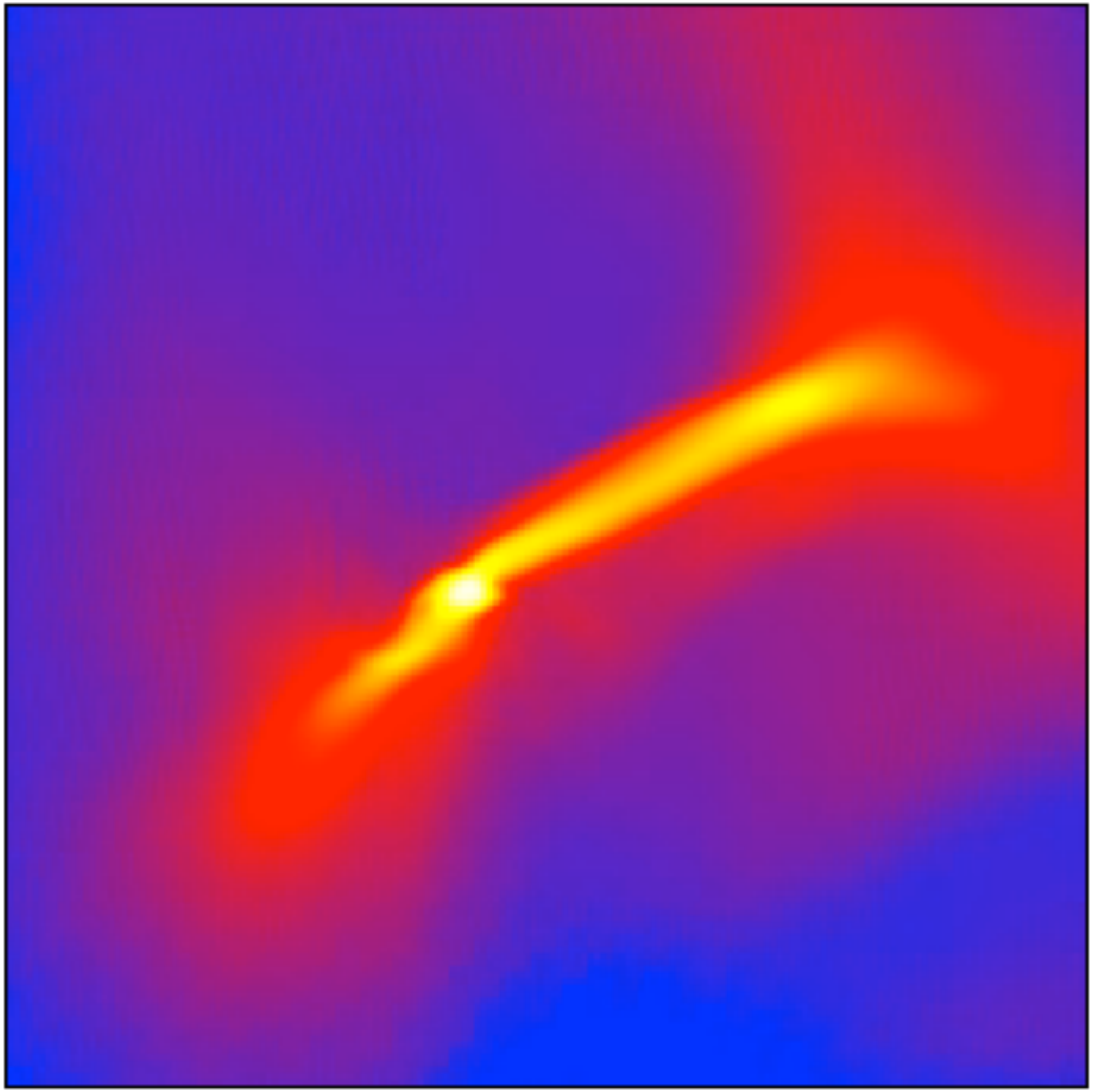




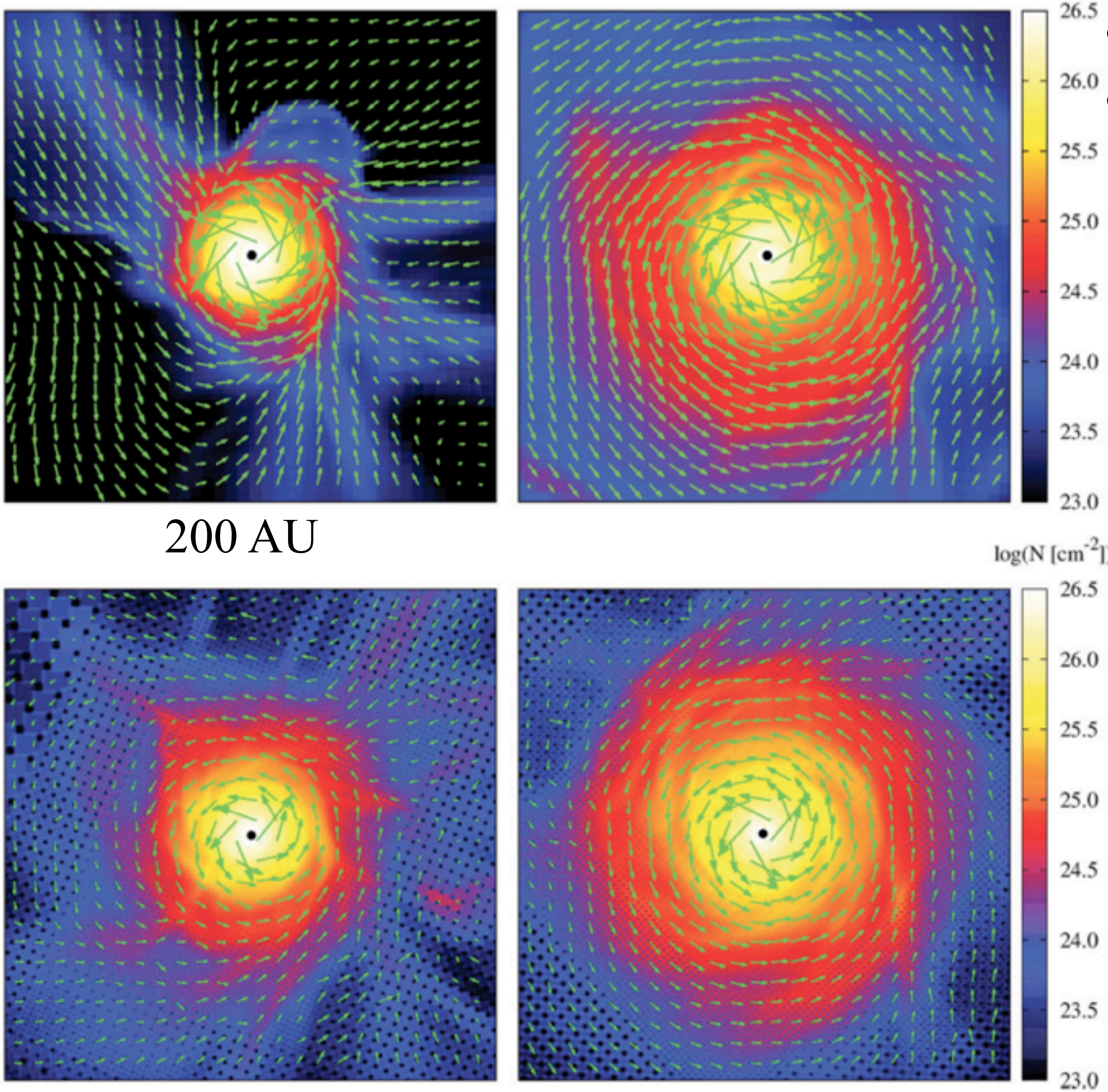
Seifried, RB, Pudritz, Klessen 2012

$\Longrightarrow$ discs "reappear"

Collapse of Turbulent Cores



Collapse of Turbulent Cores



- low mass cores
- strong magnetic field: $\mu = 2.6\ \mu_{crit}$
- transonic turbulence $\mathcal{M}a = 0.74$

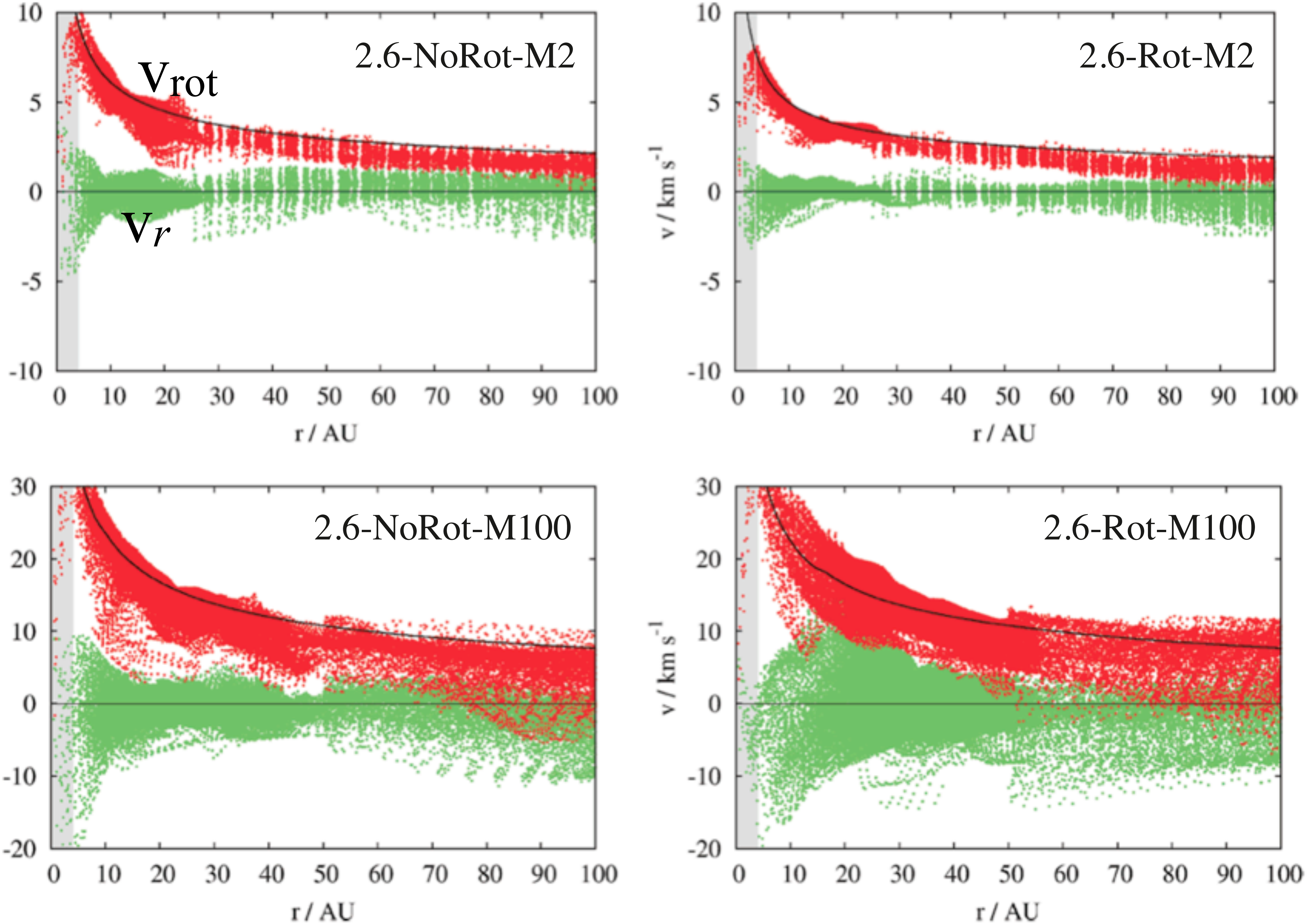
- **no** global rotation

- with global rotation

Seifried, et al. 2013

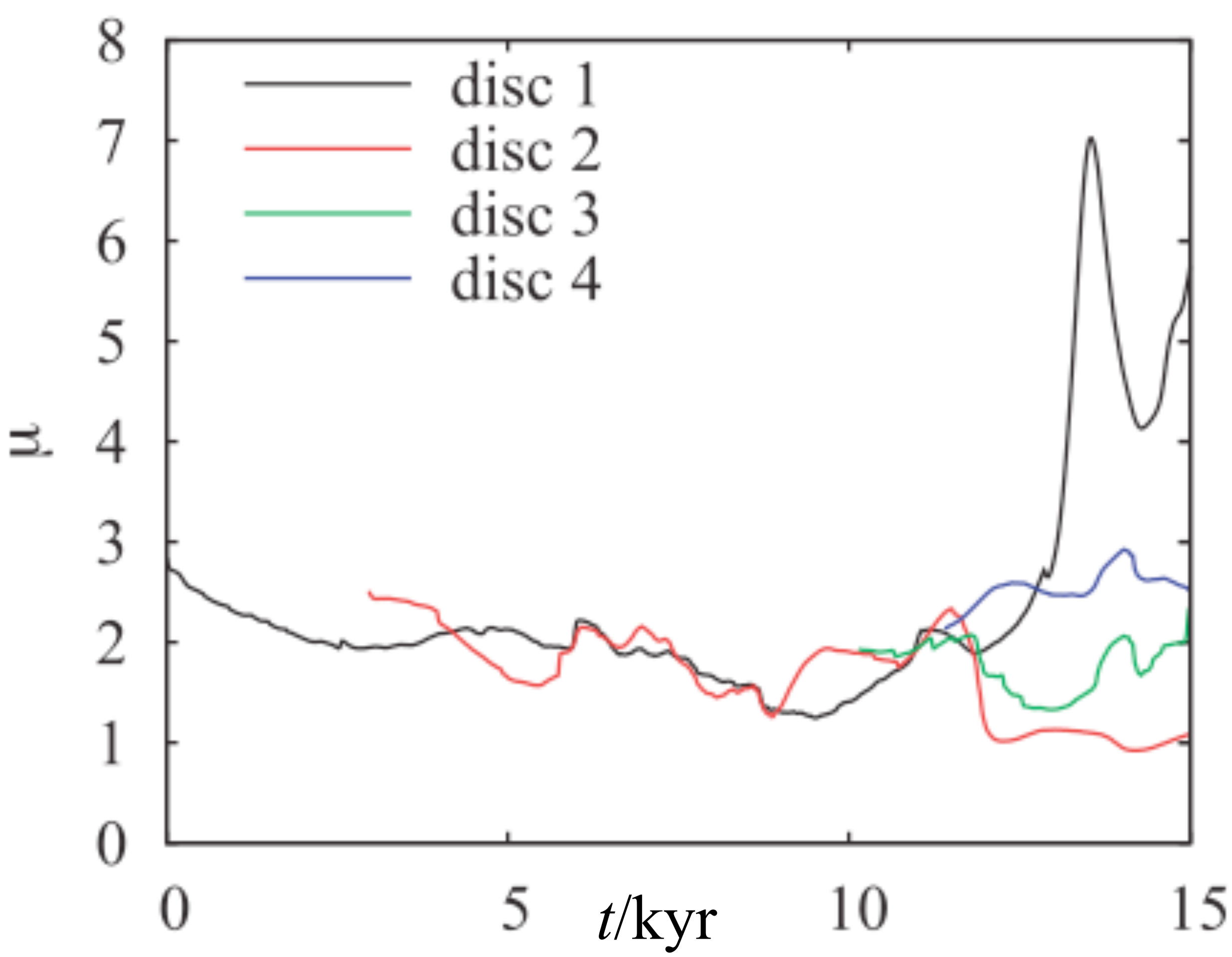
Collapse of Turbulent Cores

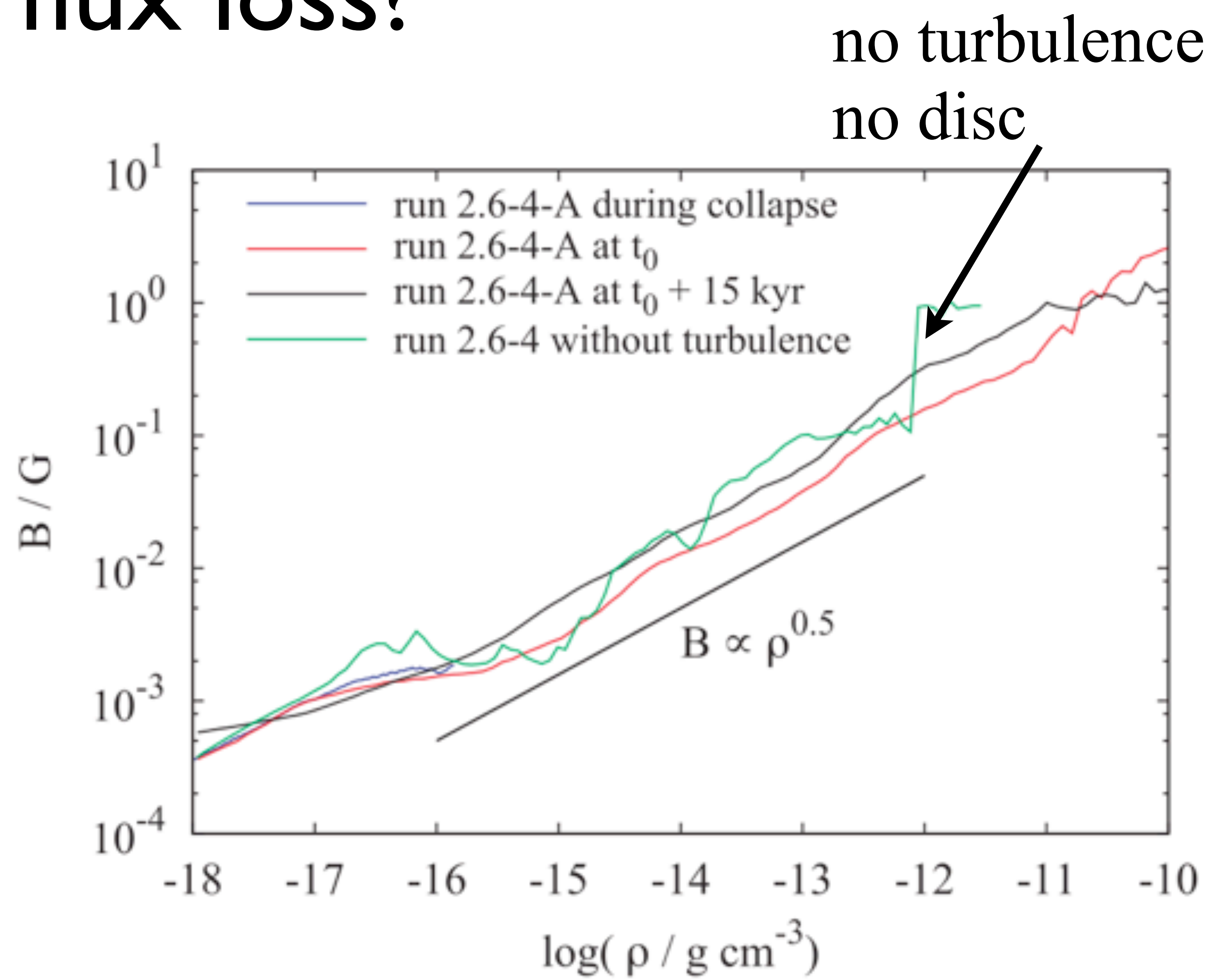
velocity structure



Collapse of Turbulent Cores

due to flux loss?

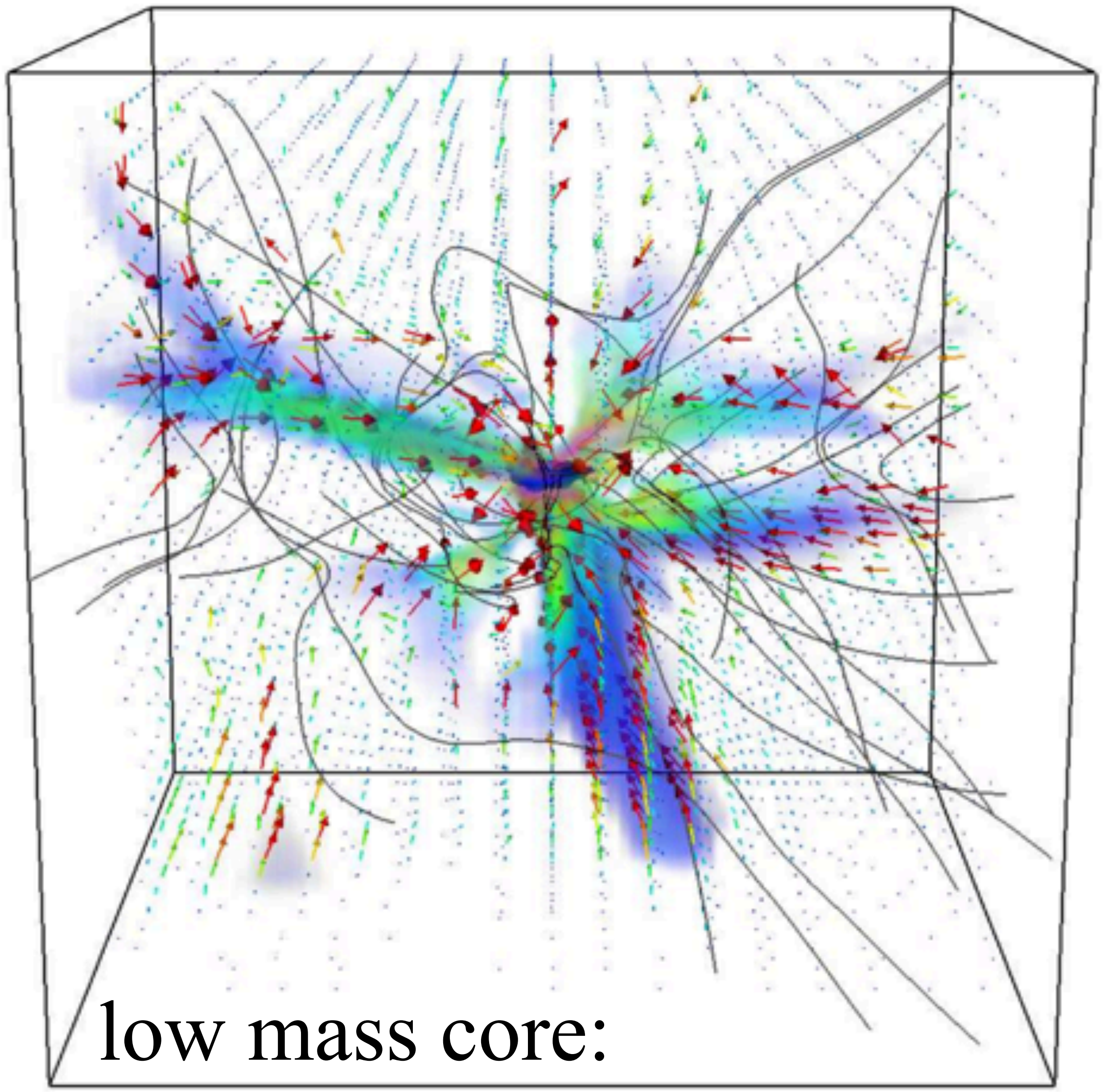




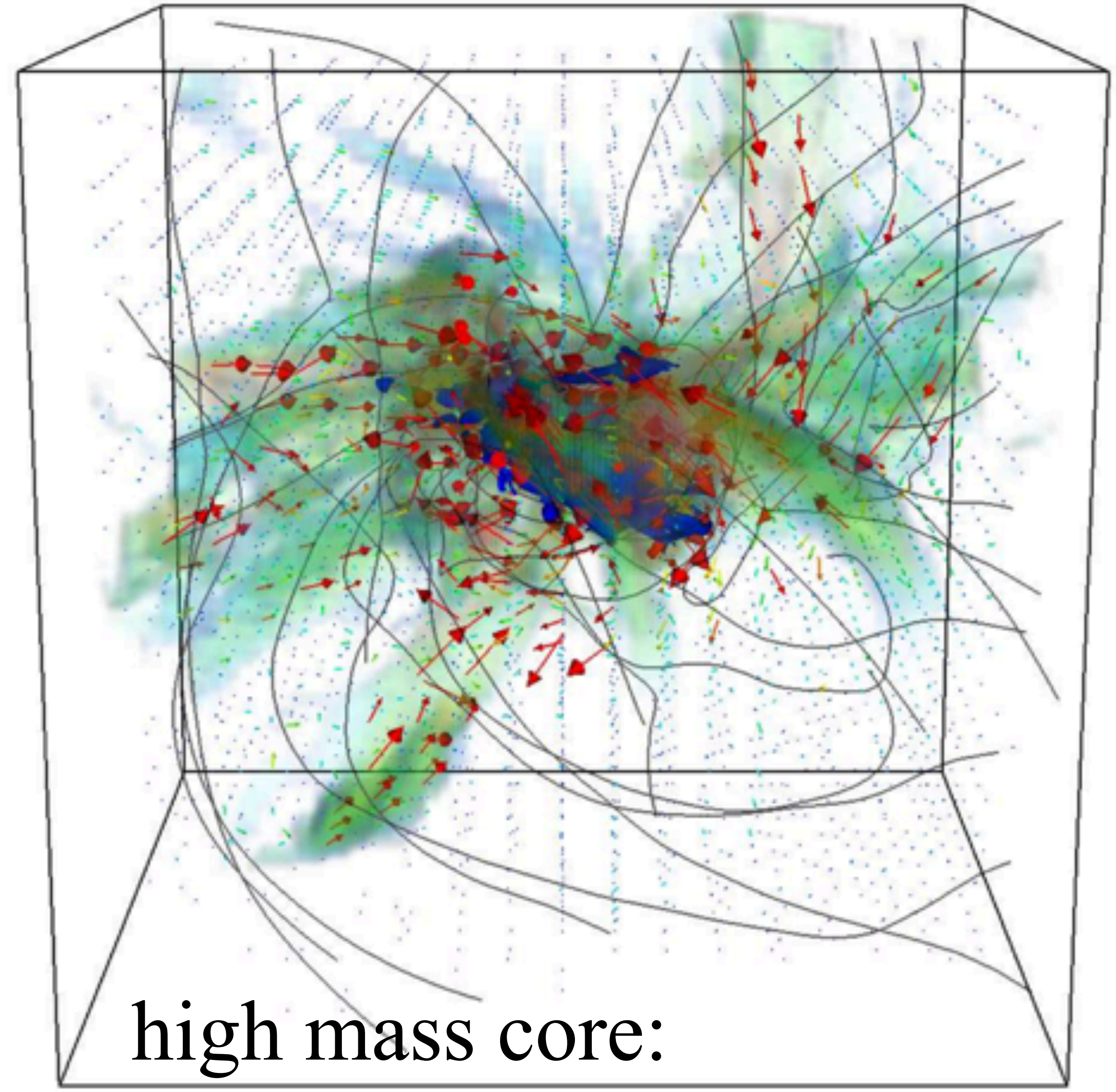
$\Longrightarrow$ no flux loss

Collapse of Turbulent Cores

accretion flow



low mass core:
$M_{\rm core} = 2.6\ \mathrm{M}_\odot$

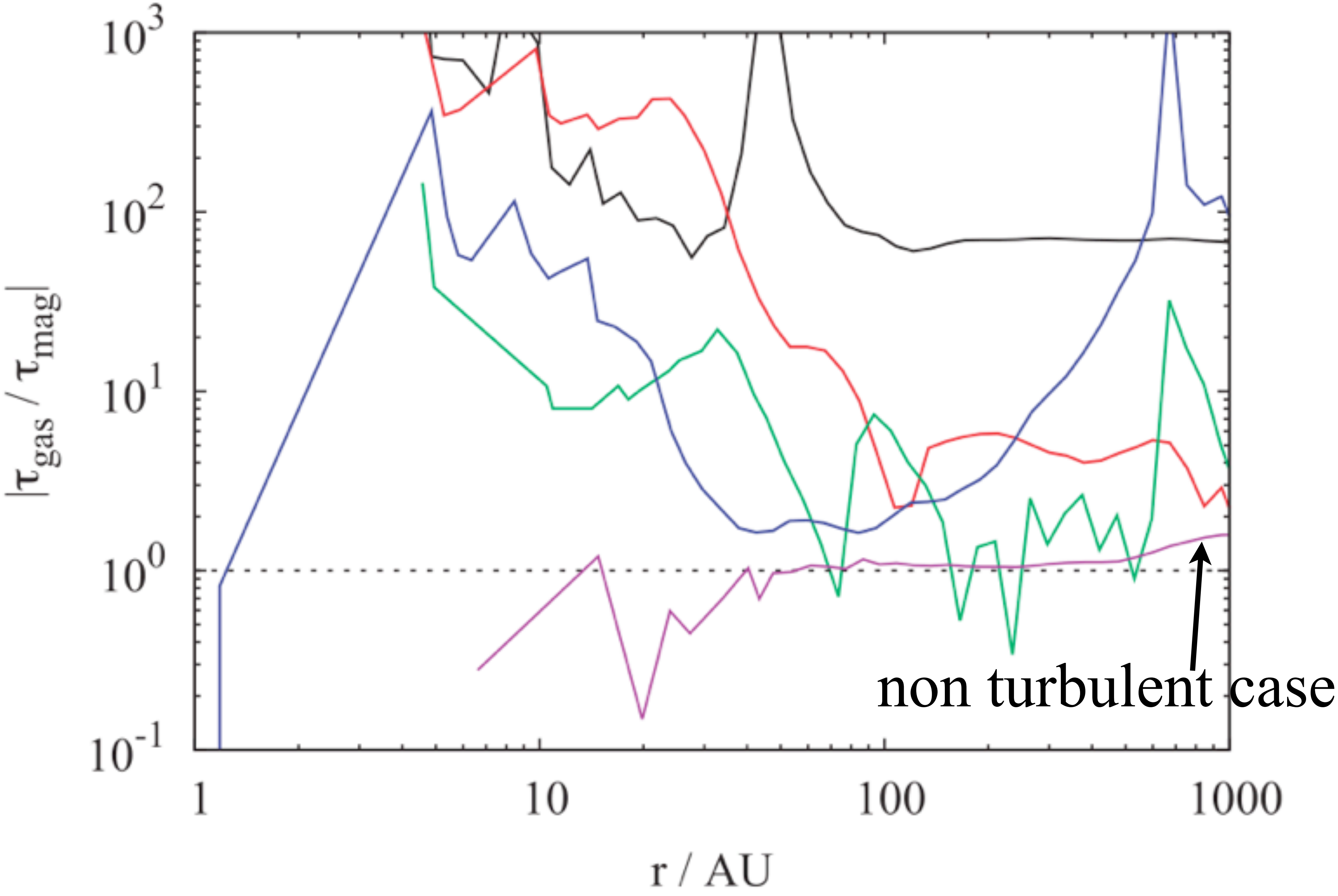


high mass core:
$M_{\rm core} = 100\ \mathrm{M}_\odot$

Seifried, et al. 2014

Collapse of Turbulent Cores

Torques

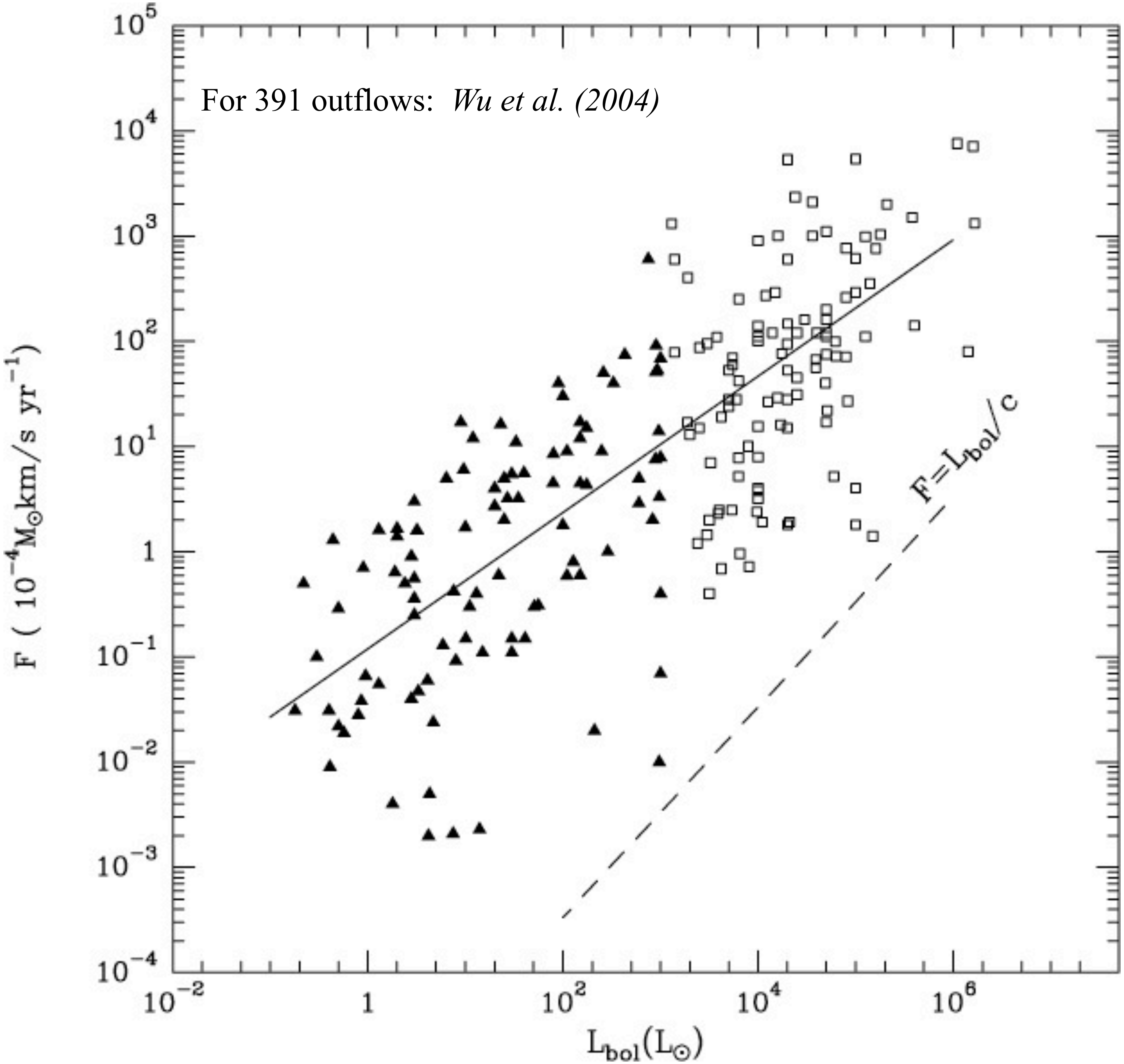


Outflows & Jets

- Outflows & Jets are ultimately linked to the formation of stars

⇒ what's their impact on star formation?

What drives Outflows & Jets?



outflows launched by magnetic fields

Jet Launching

Lorentz force:

(assume axi-symmetry, i.e. $\partial_\Phi \mathbf{B} = 0$)

$$\mathbf{j} \times \mathbf{B} \quad = \quad -\frac{1}{2}\nabla \mathbf{B}^2 + (\mathbf{B}_\mathrm{p} \cdot \nabla)\left(\mathbf{B}_\mathrm{p} + B_\phi \mathbf{e}_\phi\right) \underbrace{-\frac{B_\phi^2}{R}\mathbf{e}_R}$$

hoop stress
(jet collimation)

different force types:

- **magnetic pressure**: force along gradient
- **tension**: force along magnetic field lines
- **hoop stress**: force towards axis

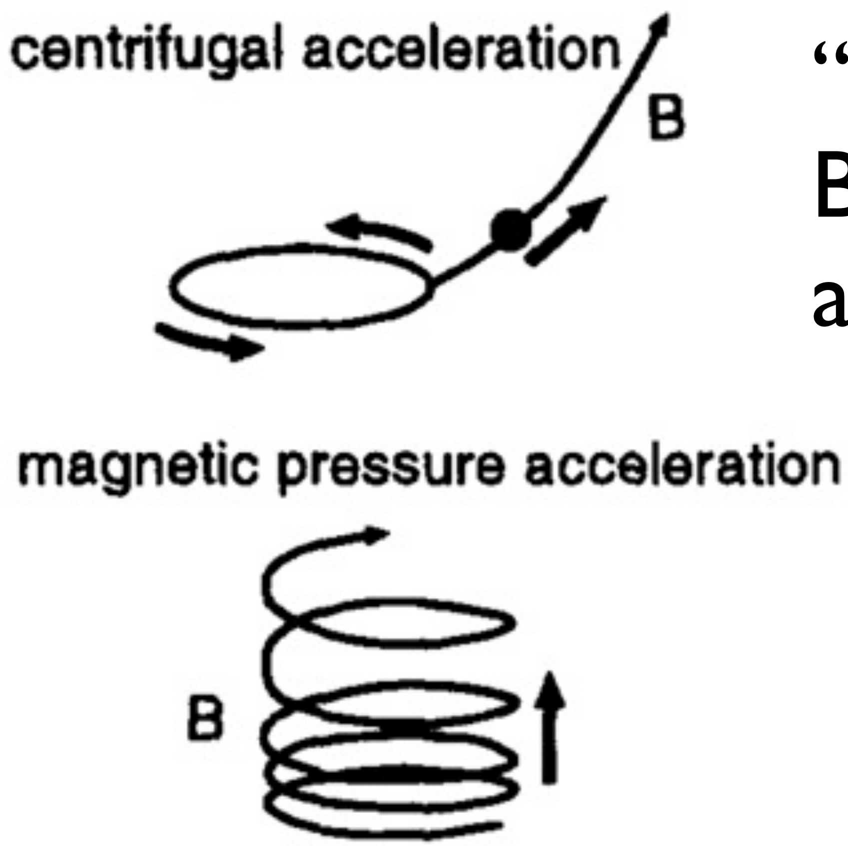
Jet Launching

Lorentz force:

(assume axi-symmetry, i.e. $\partial_\Phi \mathbf{B} = 0$)

$$\mathbf{j} \times \mathbf{B} \quad = \quad -\frac{1}{2}\nabla \mathbf{B}^2 + (\mathbf{B}_\mathrm{p} \cdot \nabla)\left(\mathbf{B}_\mathrm{p} + B_\phi \mathbf{e}_\phi\right) \underbrace{- \frac{B_\phi^2}{R}\mathbf{e}_R}$$

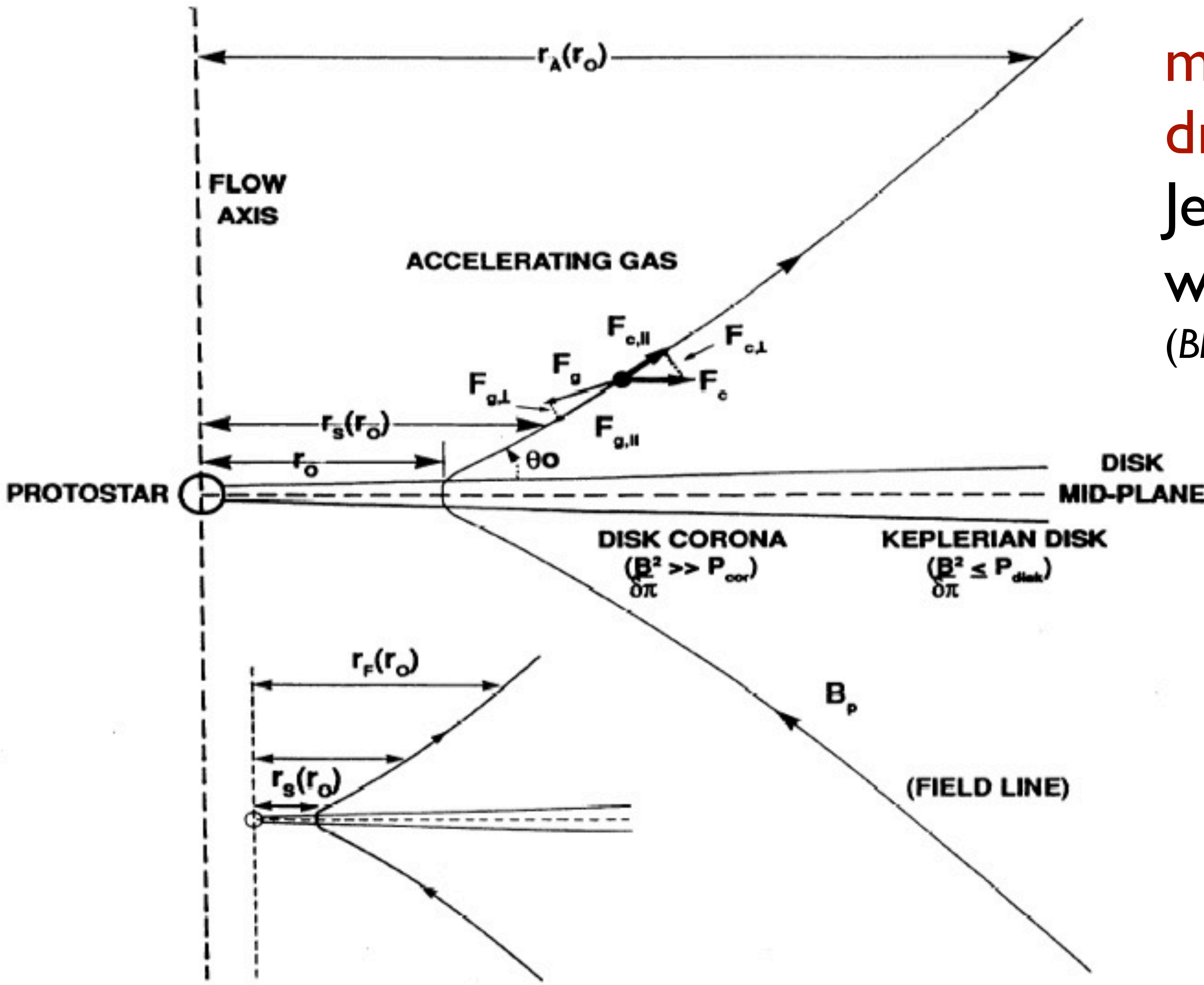
hoop stress
(jet collimation)



"beads on a wire"
Blandford-Payne type
acceleration

courtesy *Matsumoto & Shibata, 1999*

Jet Launching



Pelletier & Pudritz, 1992

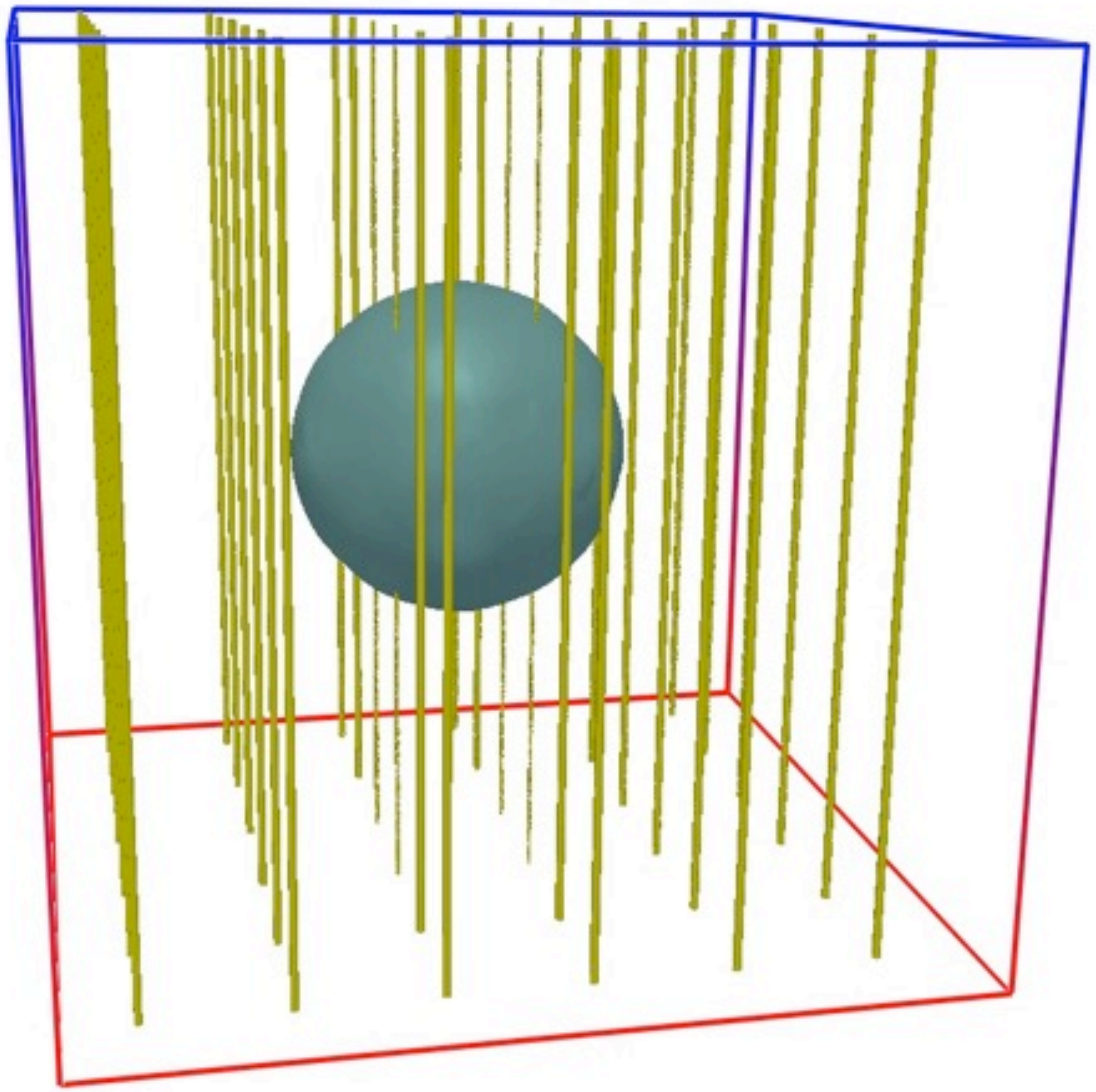
magneto-centrifugally driven wind

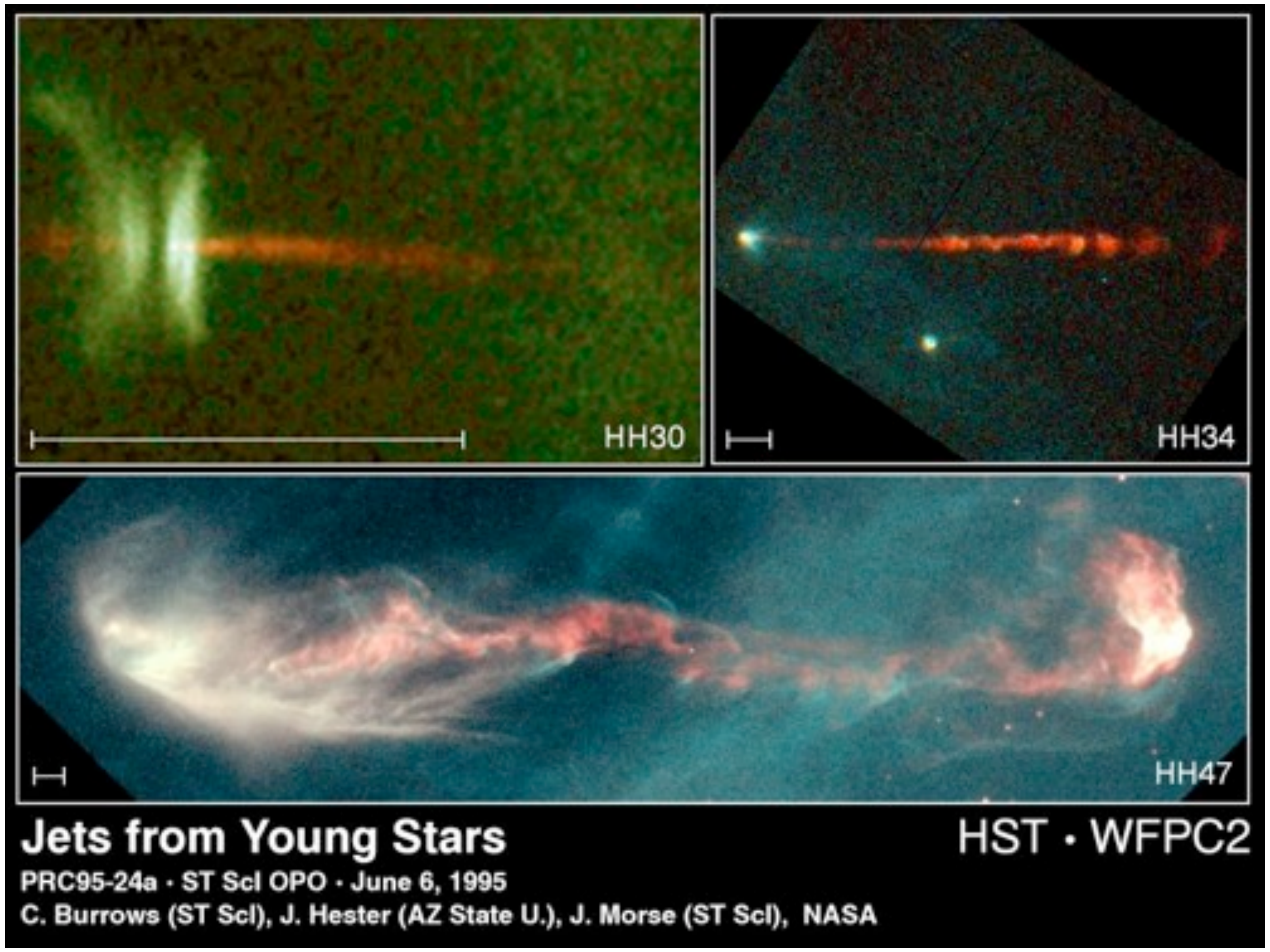
Jet launch if angle of B_p with disk plane $< 60^\circ$

(Blandford & Payne 1982)

$\Longrightarrow$ discs are necessary to drive jets & outflows!

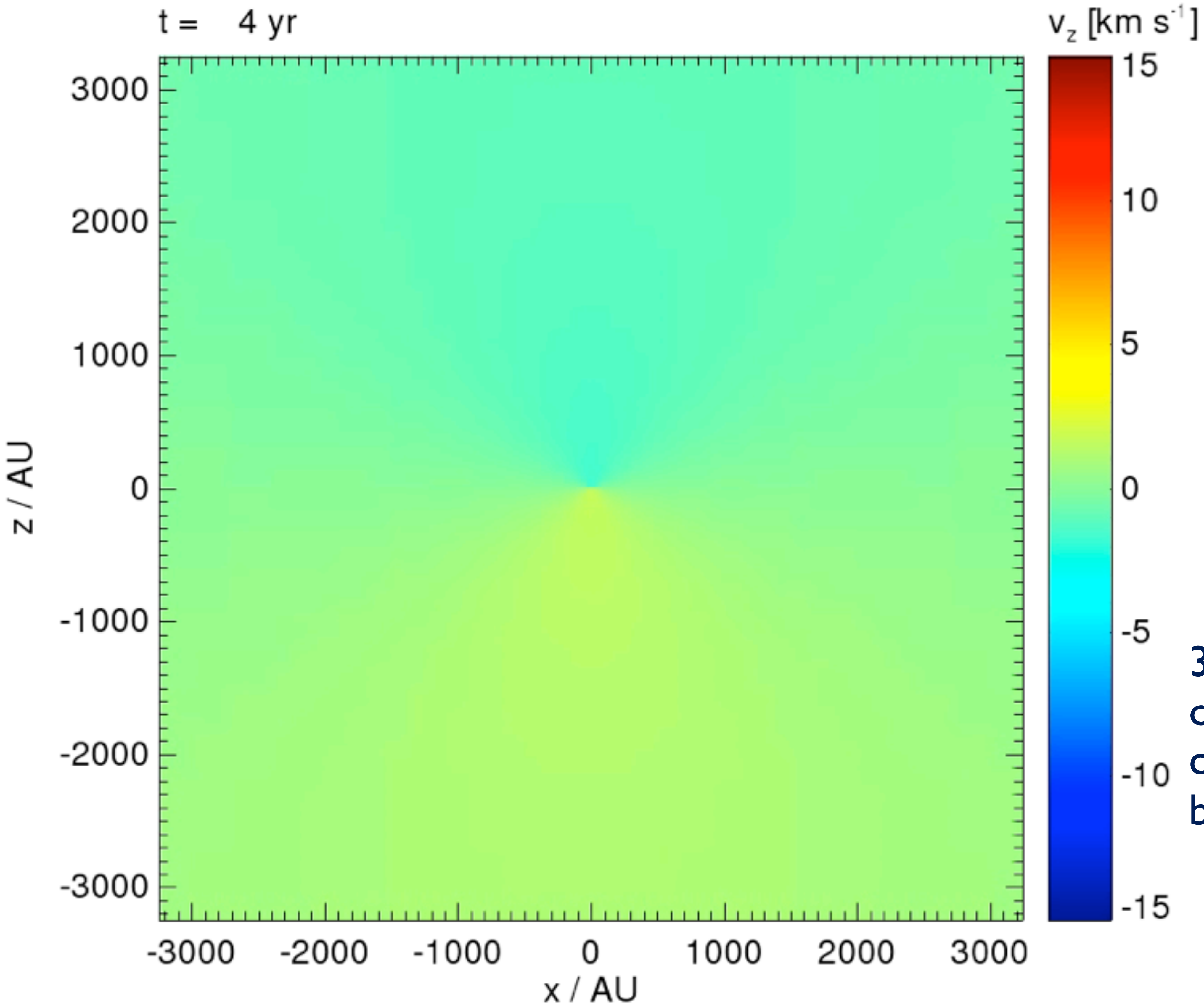
Collapse of Magnetised Cloud Cores





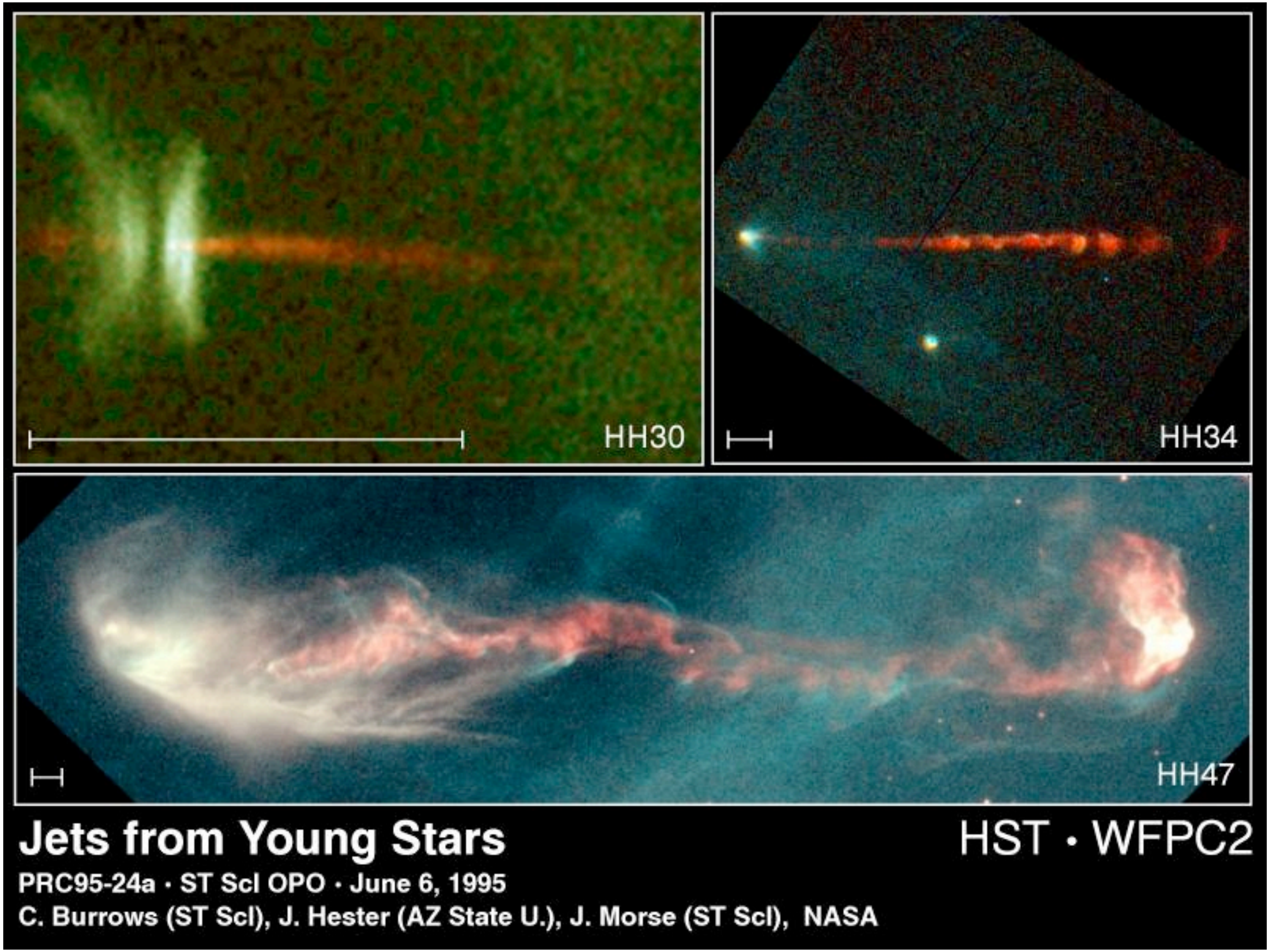
- magnetically driven Jets / Outflow from YSOs

Outflows from Collapse of Magnetised Cores



3D MHD simulation of a massive collapsing cloud core by Daniel Seifried

Feedback: Impact of Jets & Outflows



Feedback: Impact of Jets & Outflows

- Jets are powerful:

$$L_{\rm jet} = \frac{\dot{M}_{\rm jet} v_{\rm jet}^2}{2} \approx 2.9 \times 10^{32} \left(\frac{\dot{M}_{\rm jet}}{10^{-8}\ M_\odot\ {\rm yr}^{-1}} \right) \times \left(\frac{v_{\rm jet}}{300\ {\rm km\ s}^{-1}} \right)^2 {\rm ergs\ s}^{-1}$$

$\sim 8\%\ L_\odot$

$$E_{\rm jet} = L_{\rm jet} \tau_{\rm jet} \approx 10^{44}\ {\rm ergs}$$

with $\tau_{\rm jet} = 10^4$ yrs

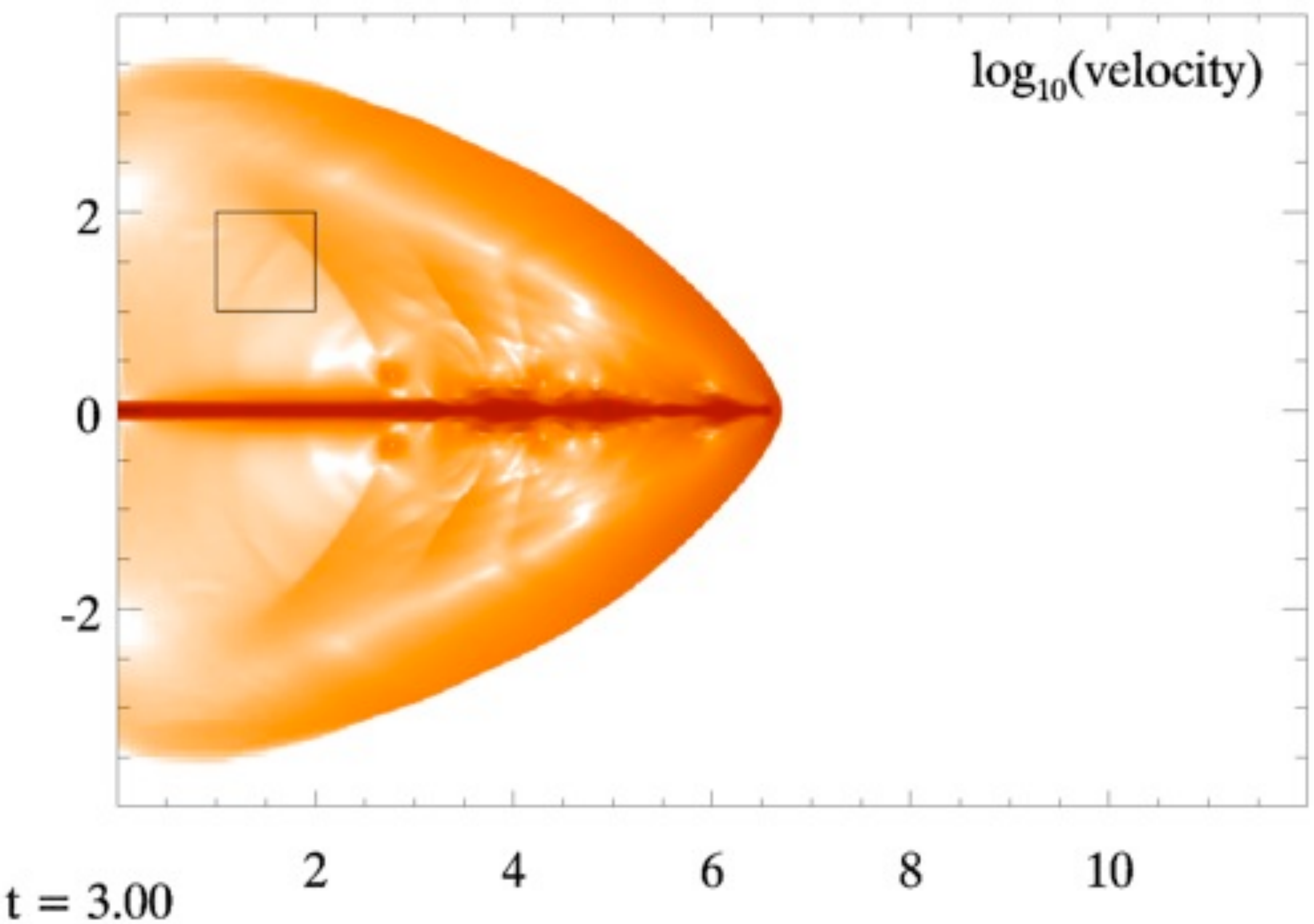
$\Longrightarrow$ cf. $E_{\rm turb} \sim 10^{46}$ ergs

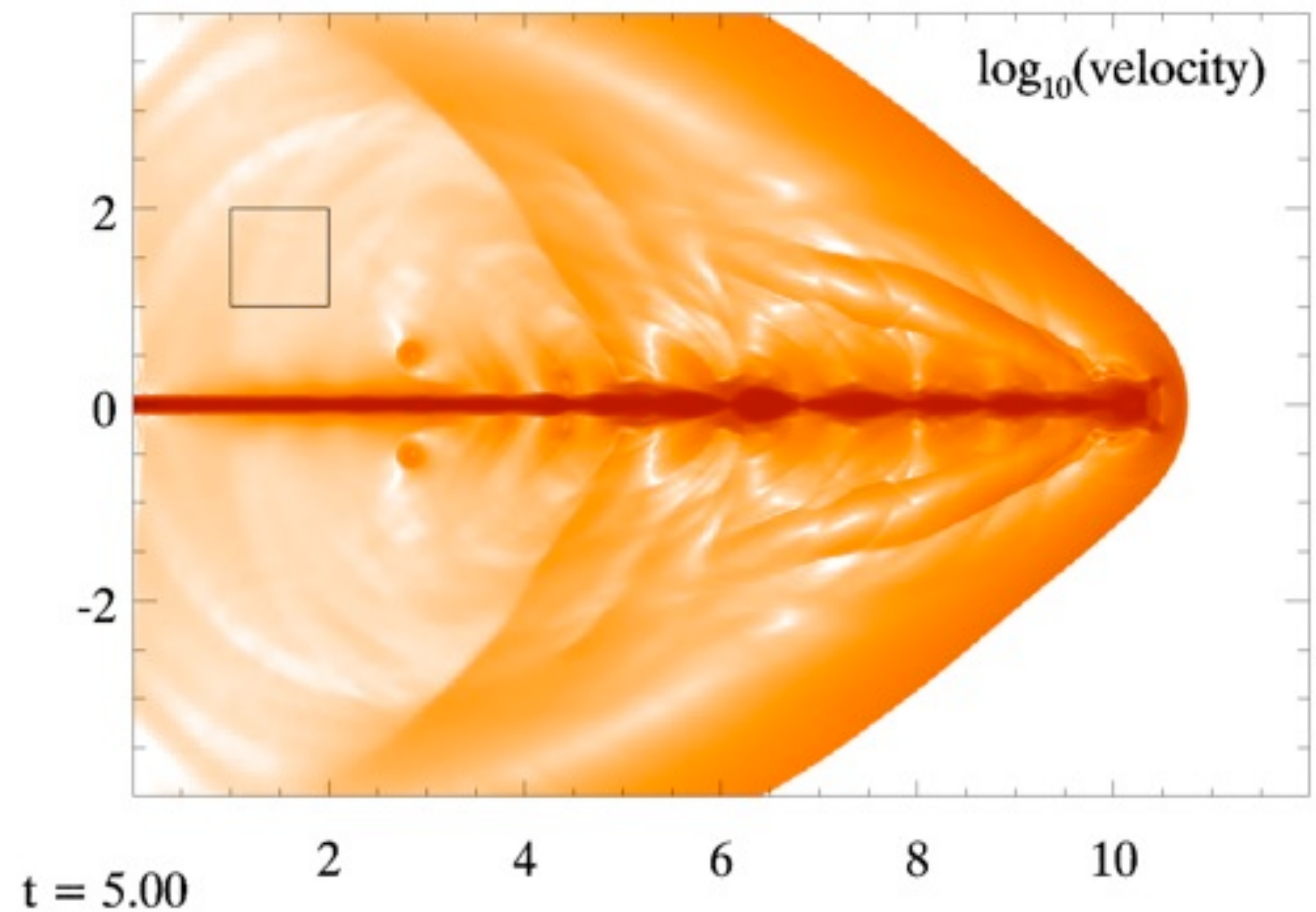
$\Longrightarrow$ Jets from a little stellar cluster ***could*** maintain the turbulence

$\Longrightarrow$ But how **efficient** do they couple to the ISM?

Feedback: Impact of Jets & Outflows

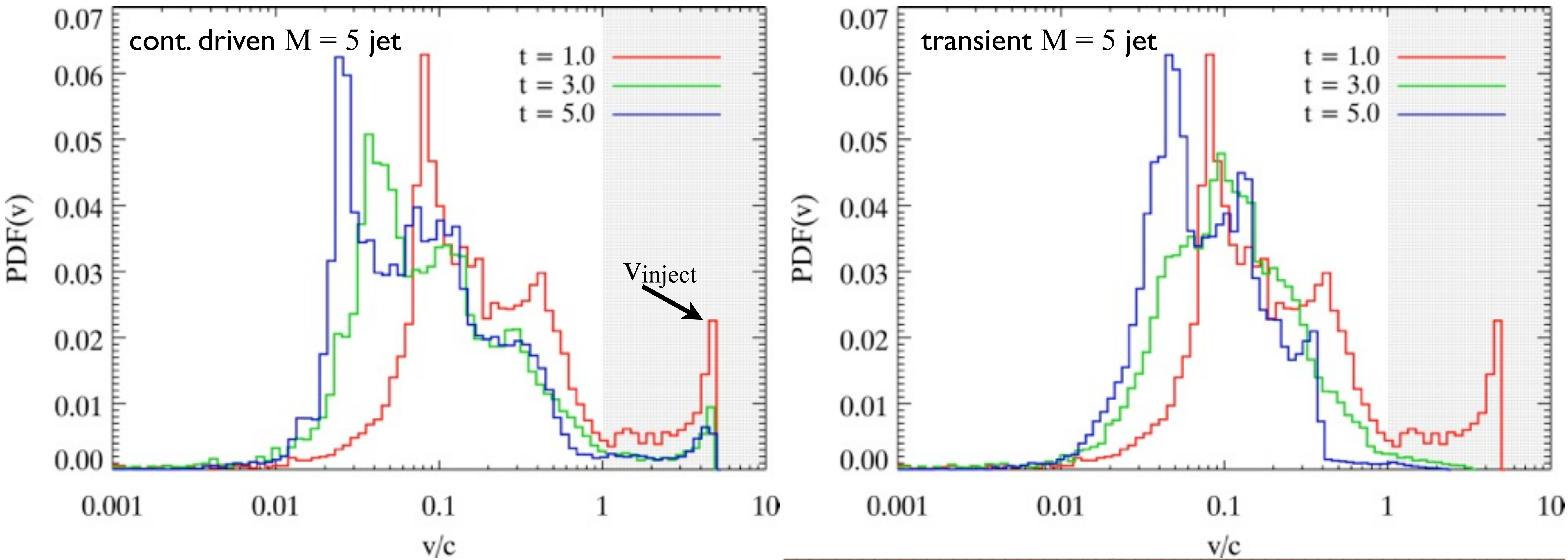
- numerical experiments with **single**, high Mach number jets (momentum injection)
- detailed analysis with velocity PDFs





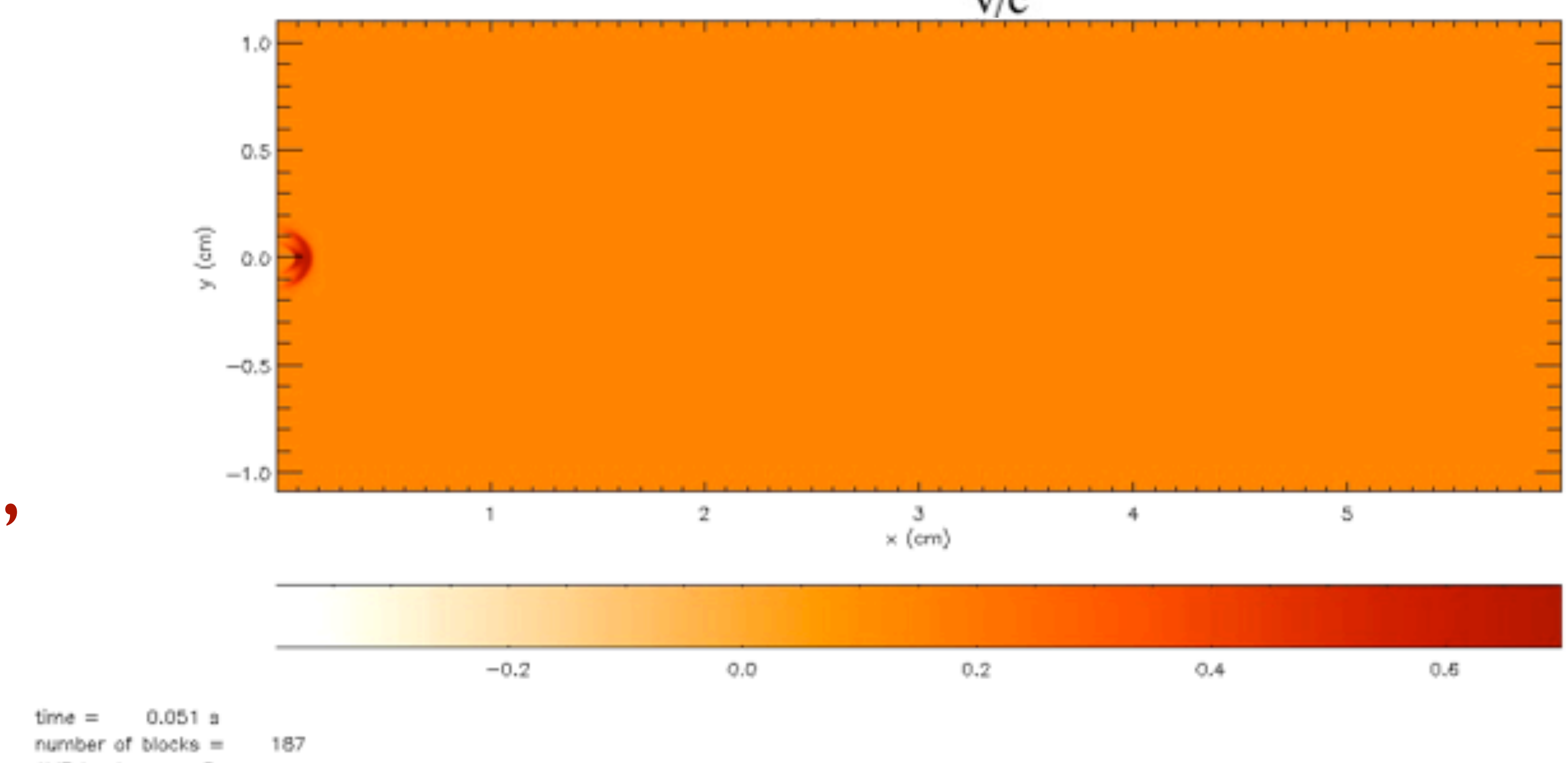
RB, Klessen & Fendt 2007

Feedback: Impact of Jets & Outflows

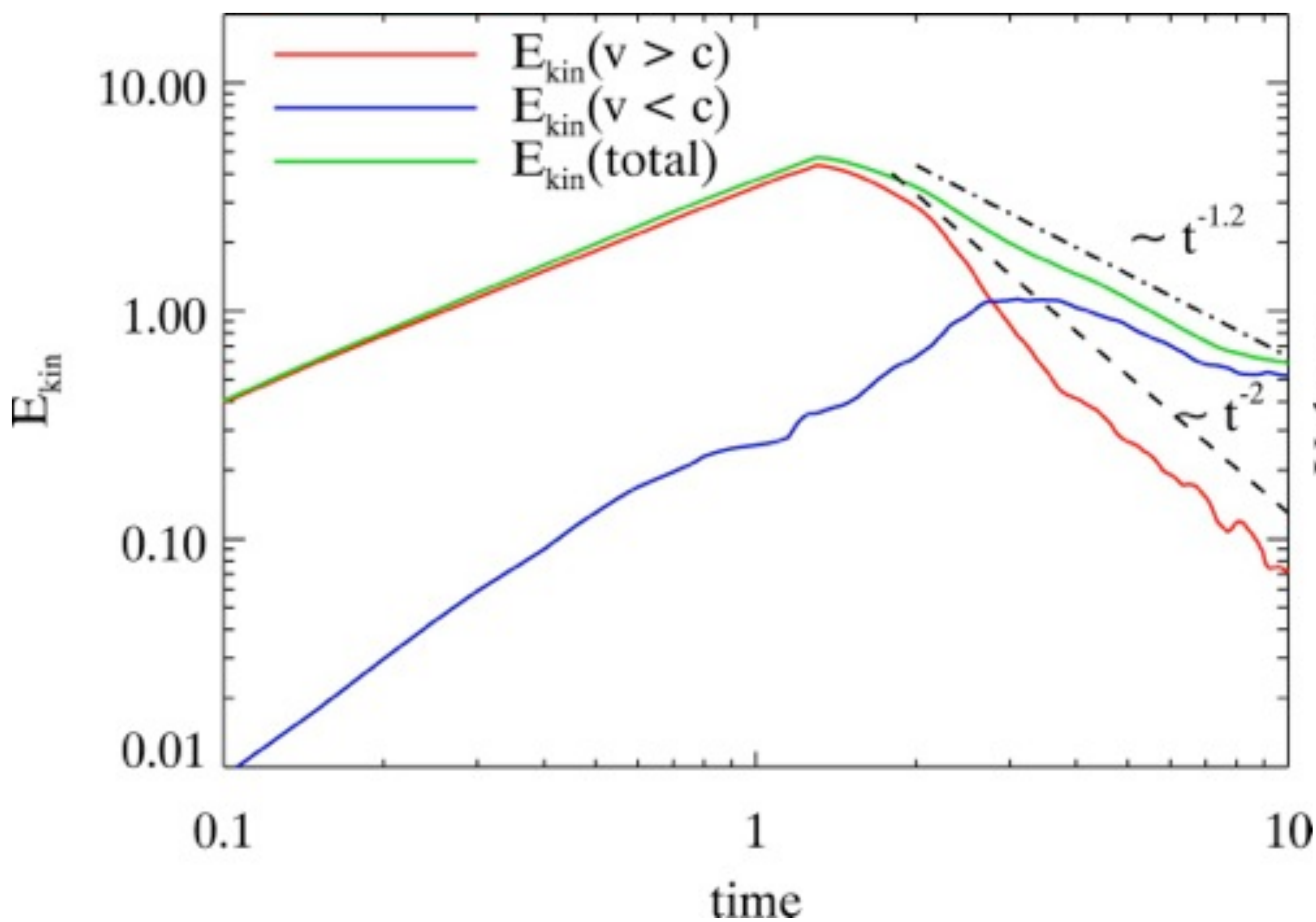


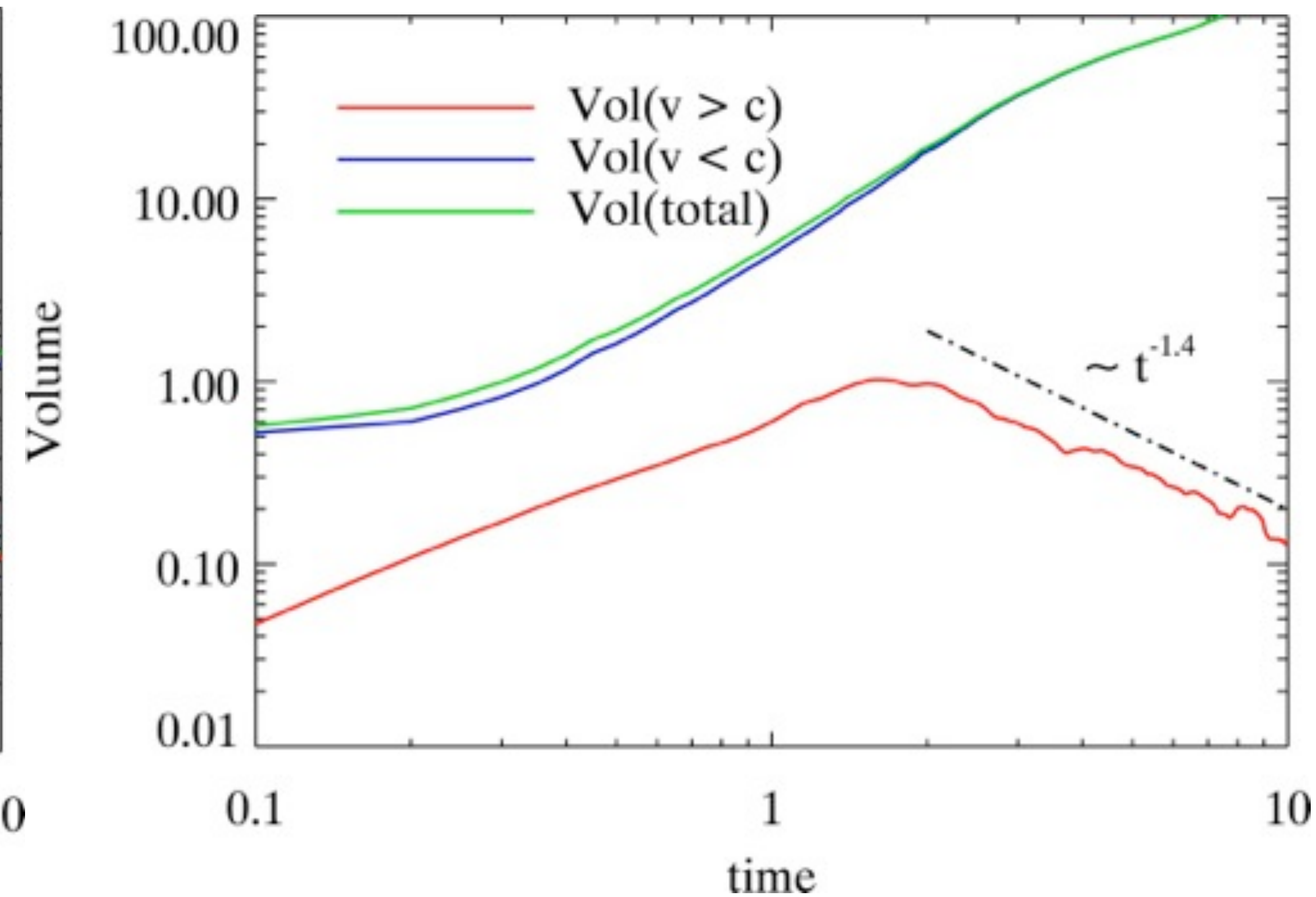
- turbulent motions are sub-sonic
- very **little** supersonic fluctuations

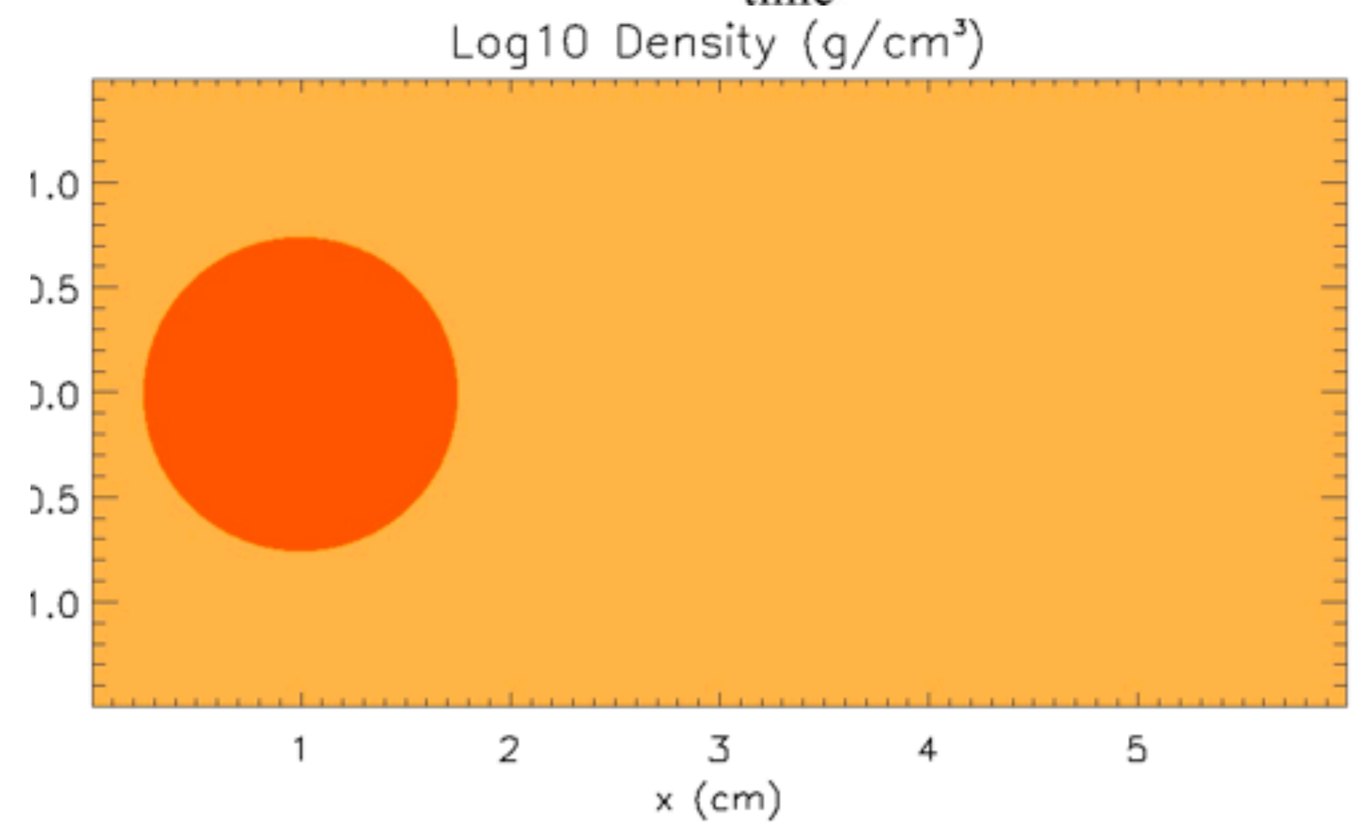
  $\Longrightarrow$ "supersonic desert"



Feedback: Impact of Jets & Outflows



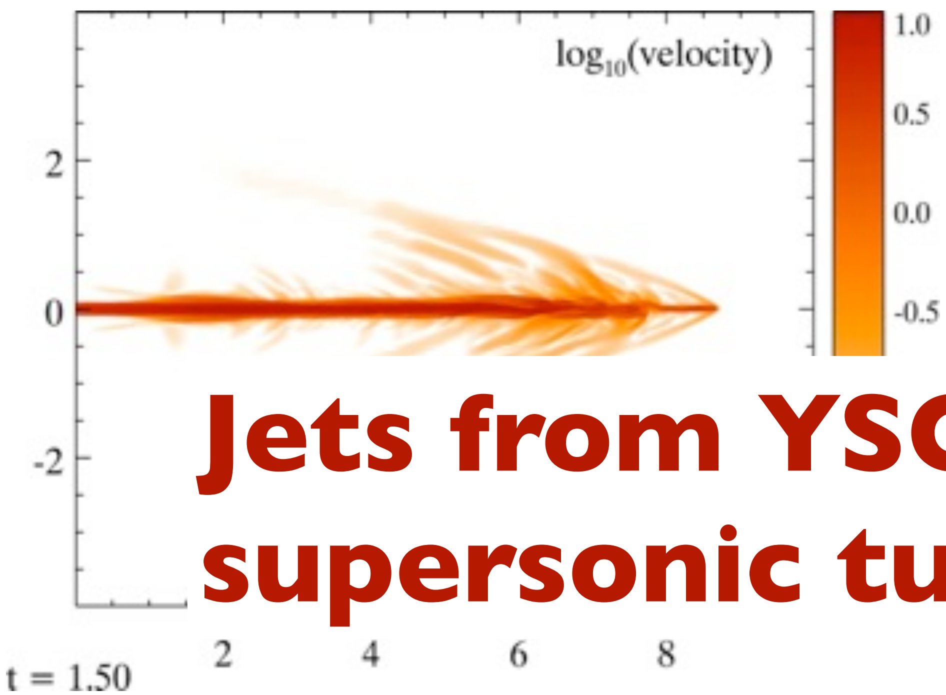


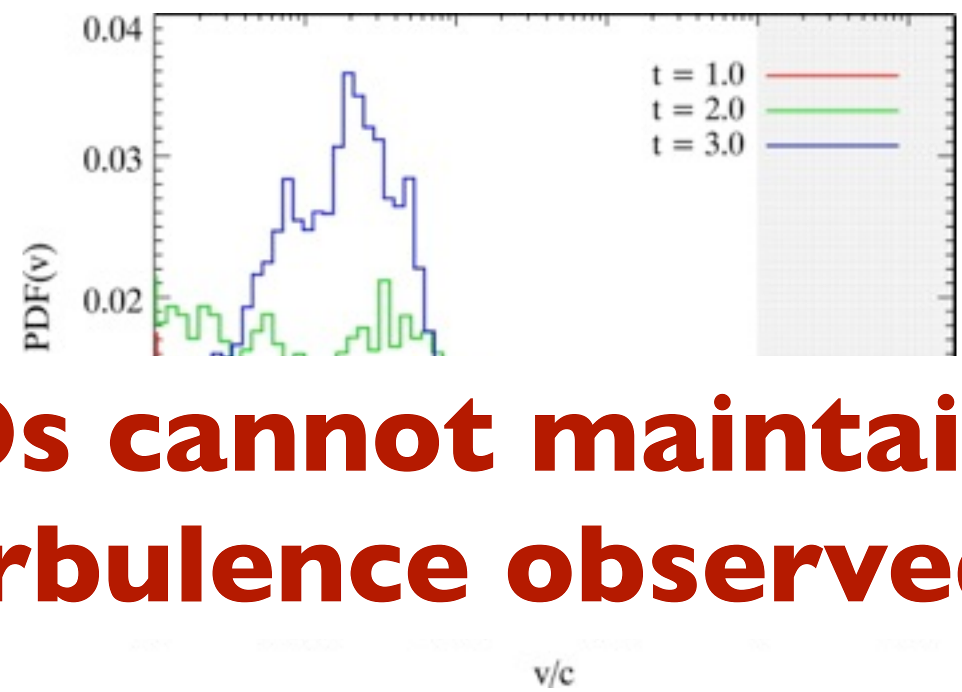


- supersonic fluctuations decay **quickly**: $E \propto t^{-2}$ (*Mac Low et al. '98*)
- supersonic fluctuations occupy only a **small** fraction of all fluctuations

Feedback: Impact of Jets & Outflows

Influence of Magnetic Fields





magnetic fields **suppress** the
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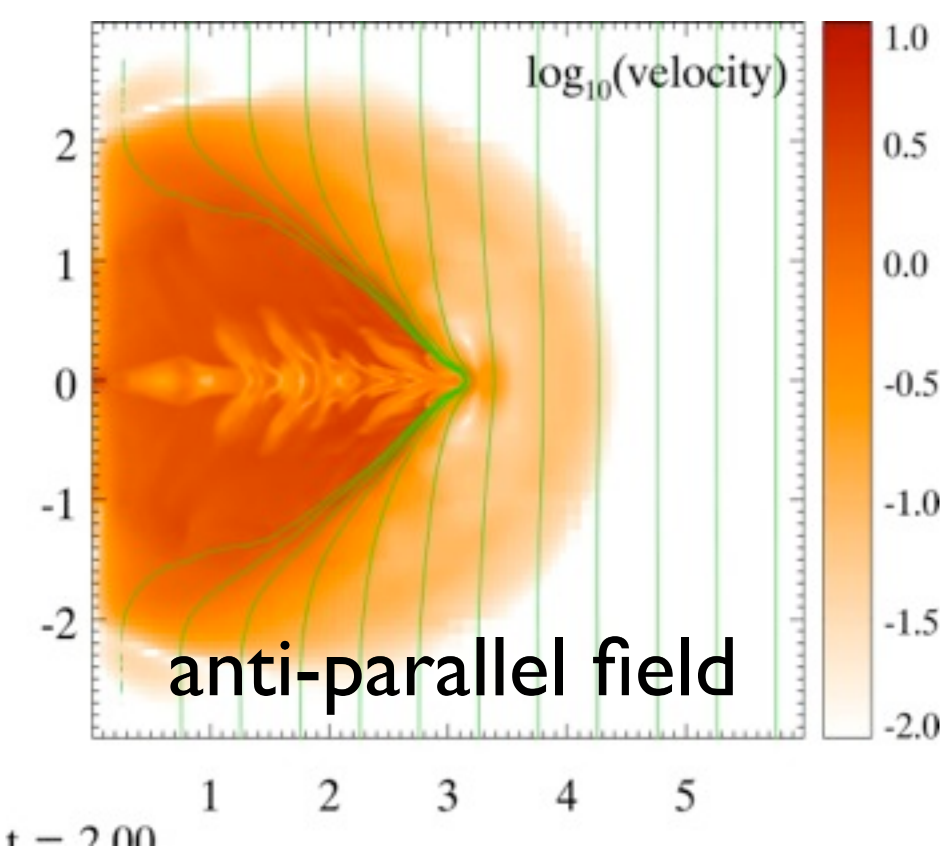
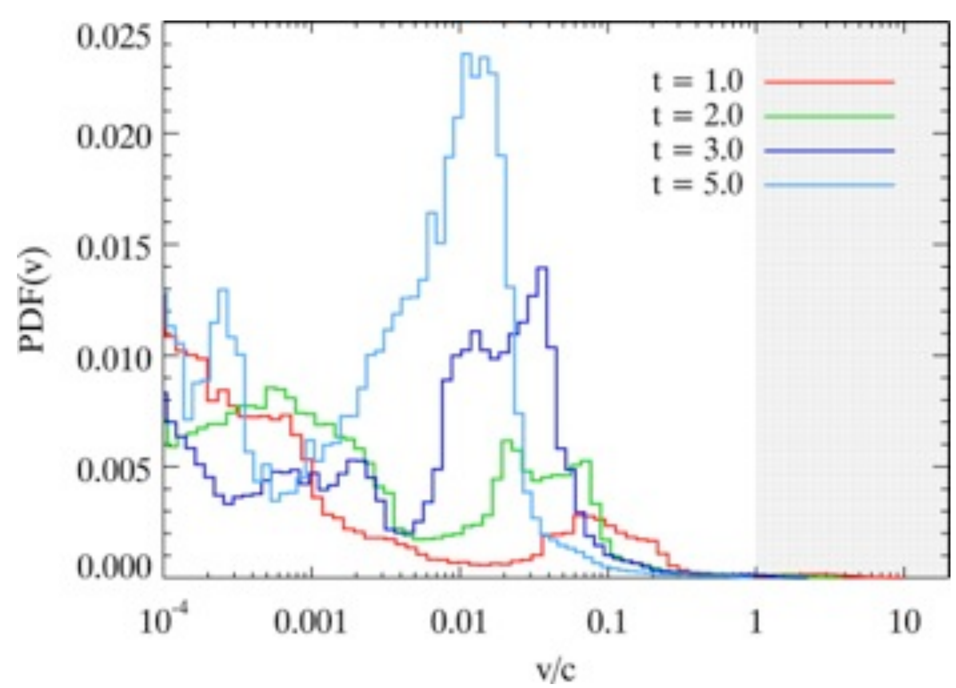
velocity
fluctuations

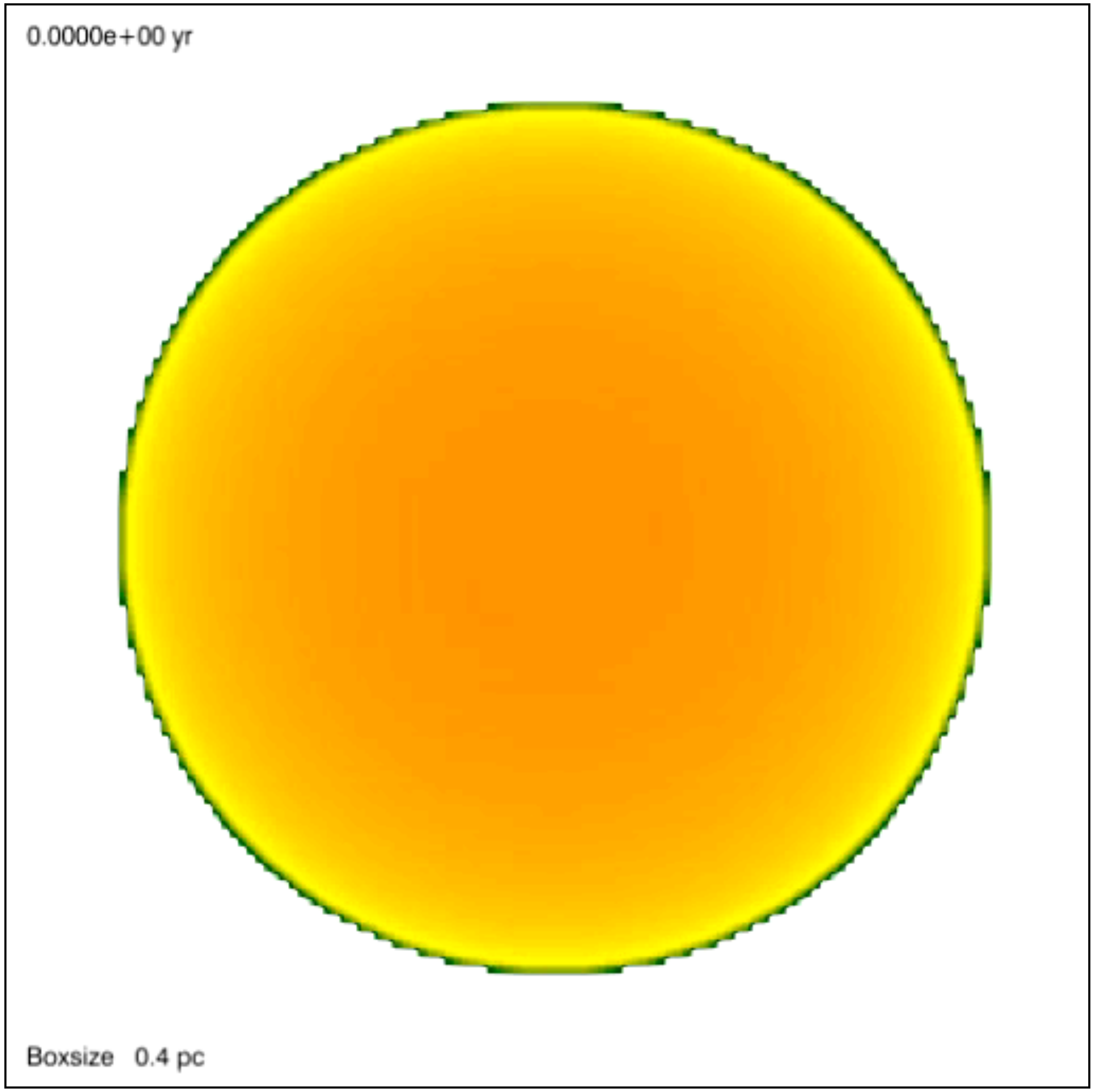
Jets from YSOs cannot maintain the supersonic turbulence observed in MCs





stabilize jet (aligned field)

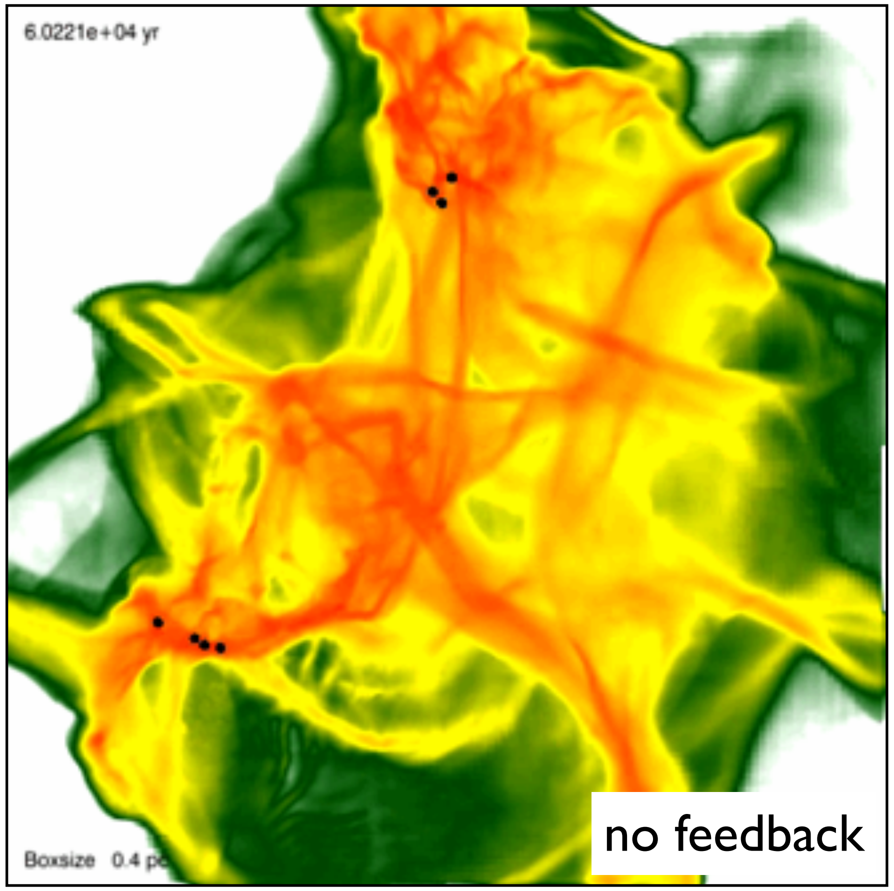
Feedback: Impact of Jets & Outflows

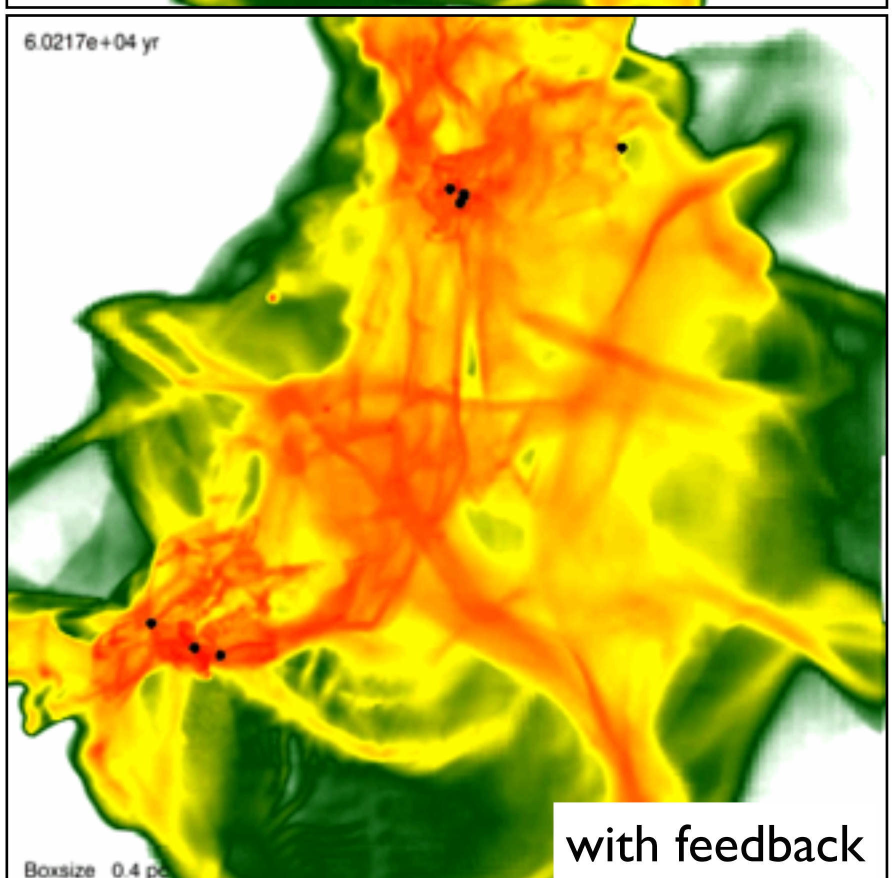


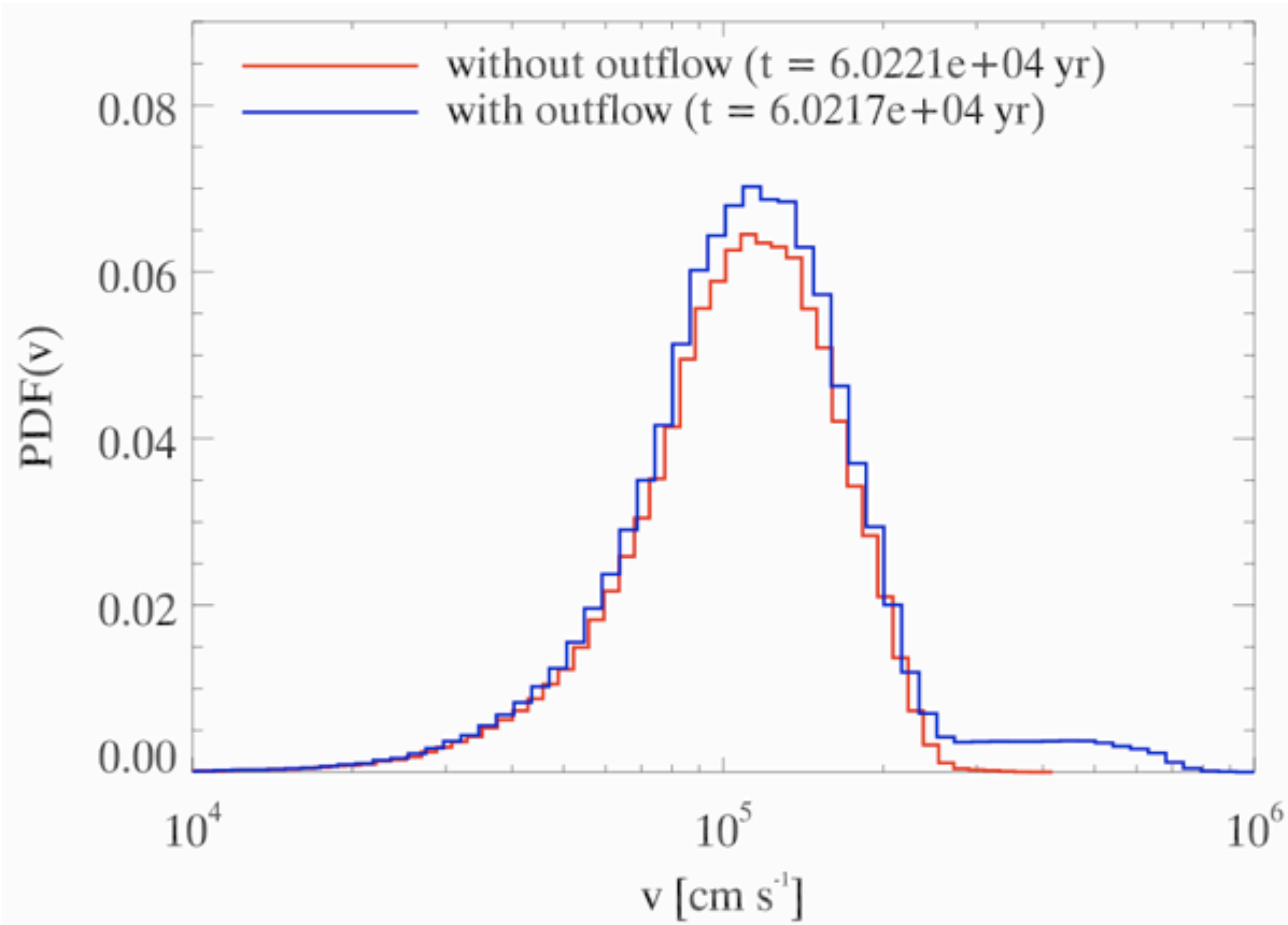
Global simulation

- collapse of a turbulent cloud core (*Li&Nakamura* 2006; *Carroll et al.* 2008, *Dale & Bonnell 2008*, *Wang et al.* 2010, *Federrath et al.* 2014)

Feedback: Impact of Jets & Outflows



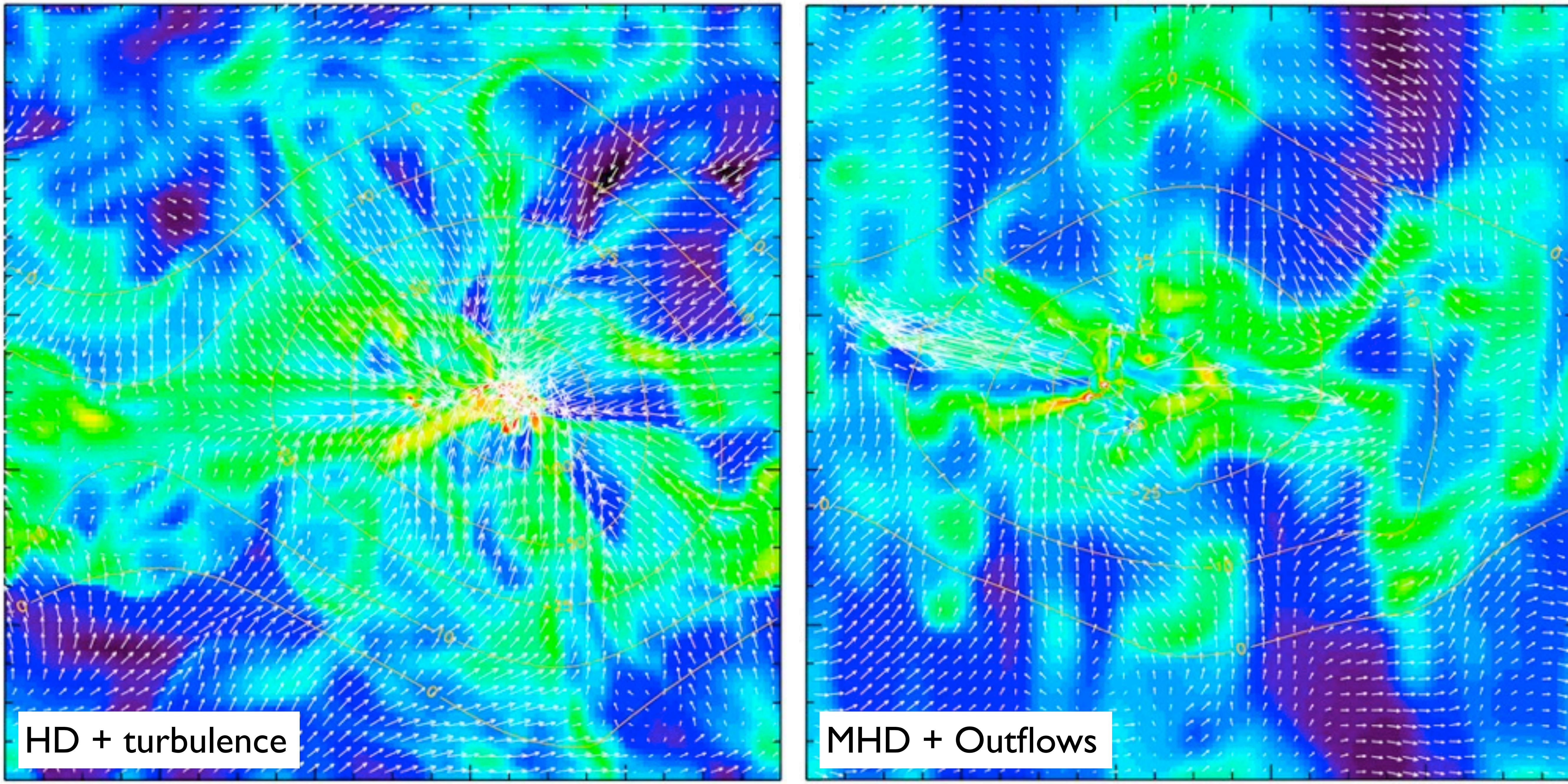




- influence on small scales
- self-regulated SF?
- large scale turbulence?

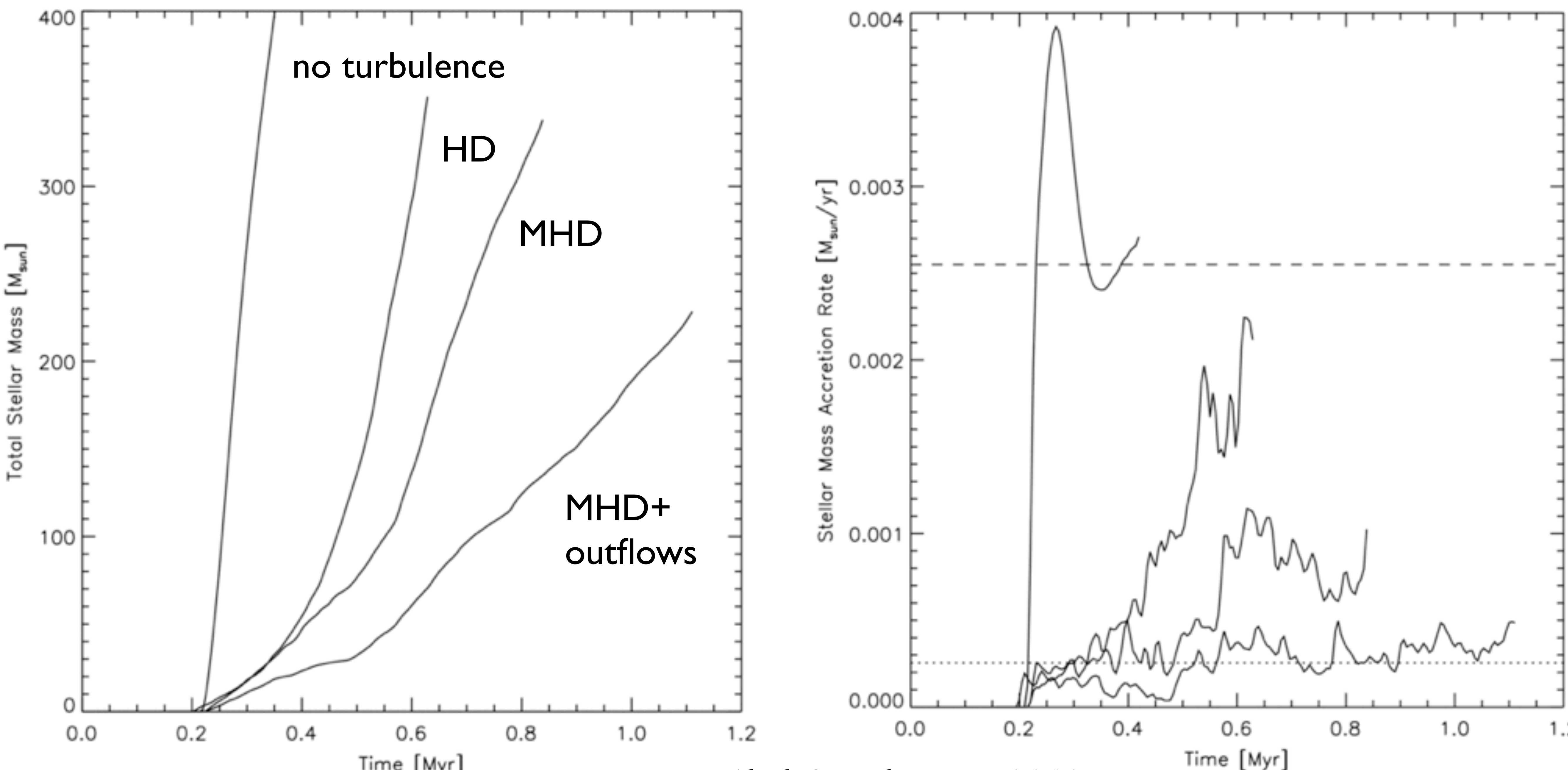
Feedback: Impact of Jets & Outflows

Wang et al. (2010): Collapse of a massive, turbulent cloud core (M_{core} = 1600 M_{sol}) + feedback from jets & outflows



Wang, Li, Abel & Nakamura 2010

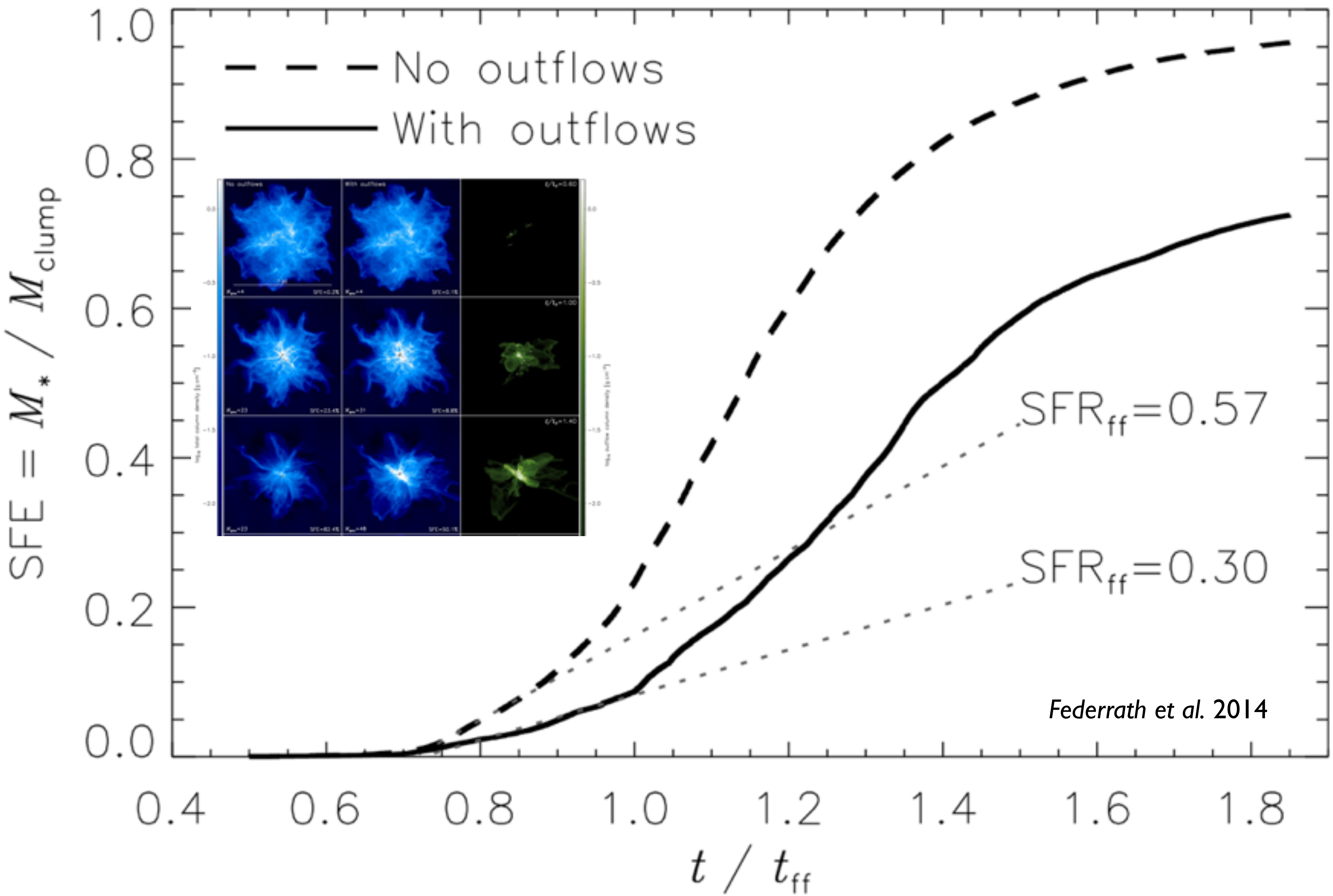
Feedback: Impact of Jets & Outflows



Wang, Li, Abel & Nakamura 2010

$\Longrightarrow$ Outflows & Jets do not stop star formation

Outflows during Cluster Formation



$\Longrightarrow$ Outflows & Jets do not stop star formation

Summary

- It is easy to form discs

- Angular momentum is efficiently transported during disc formation by gravitational torques
  $\Longrightarrow$ protostellar discs allow efficient accretion

- Magnetic braking catastrophe only for unrealistic ICs

- Influence of Outflow feedback?

$\Longrightarrow$ not conclusive:

$\Longrightarrow$ might not be too important on cloud scales