Magnetism & Turbulence: Theory

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Padoan+ 07

How compressible?

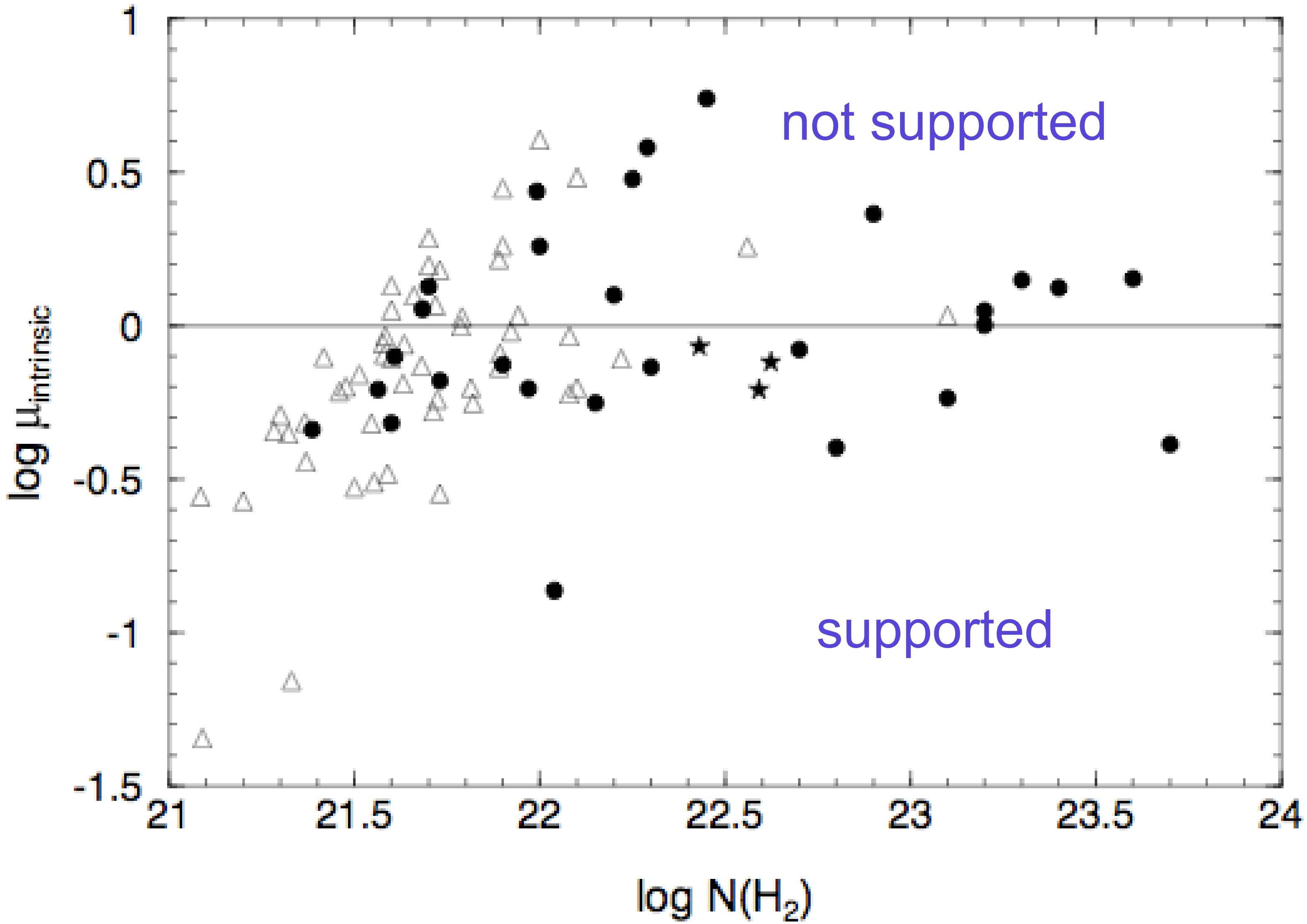
$$M_A = \frac{v}{v_A} = 1$$

subcritical envelopes
critical cores
Elmegreen 07

turbulent envelopes
shock compressed cores
Padoan+ 07

subcritical envelopes
subcritical cores
Mouschovias+ 06

turbulent envelopes
supercritical cores
Krumholz+ 06

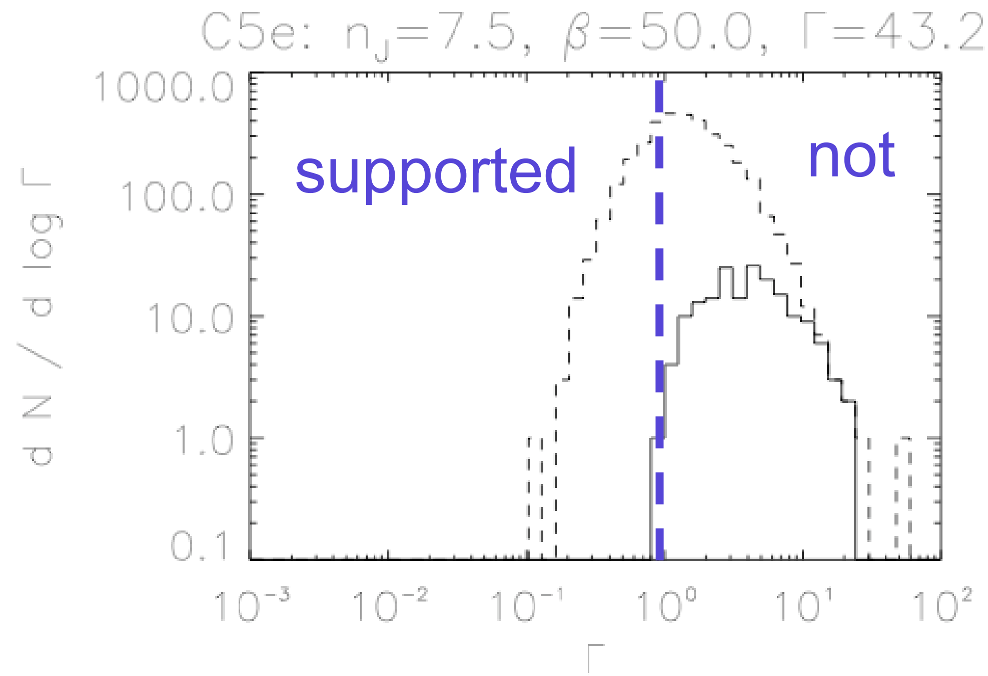


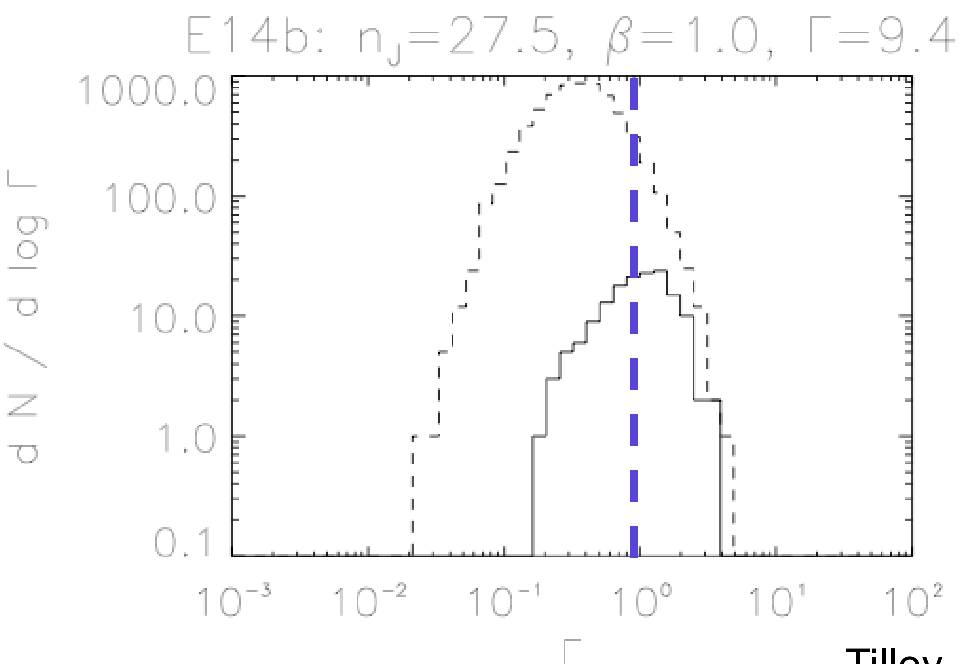
Crutcher 99, Heiles & Crutcher 06

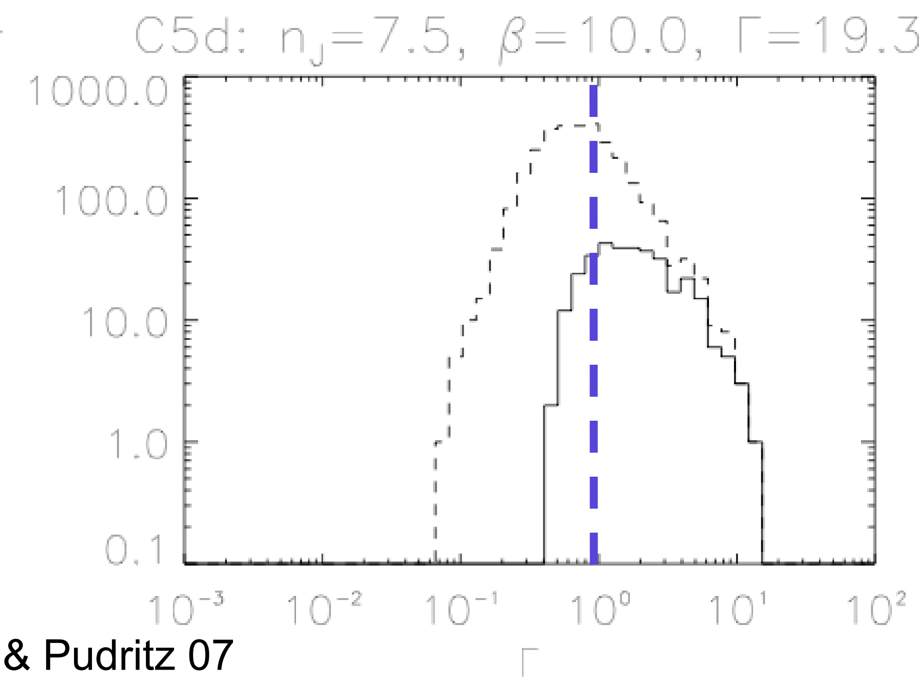
$$\Gamma = \frac{M/\Phi}{\left(M/\Phi\right)_{crit}}$$

so $\Gamma < 1$ implies magnetic support.

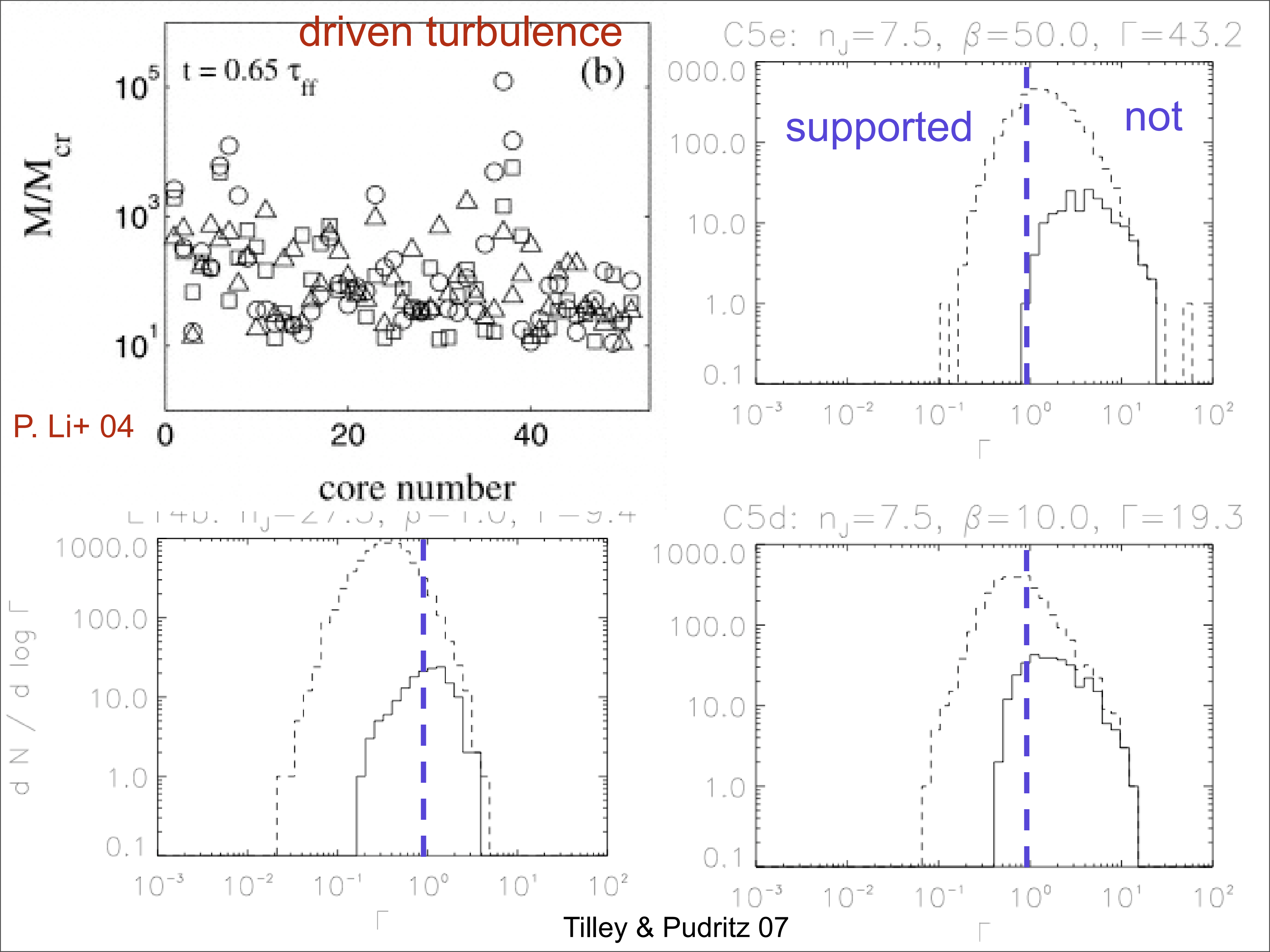
decaying turbulence







Tilley & Pudritz 07

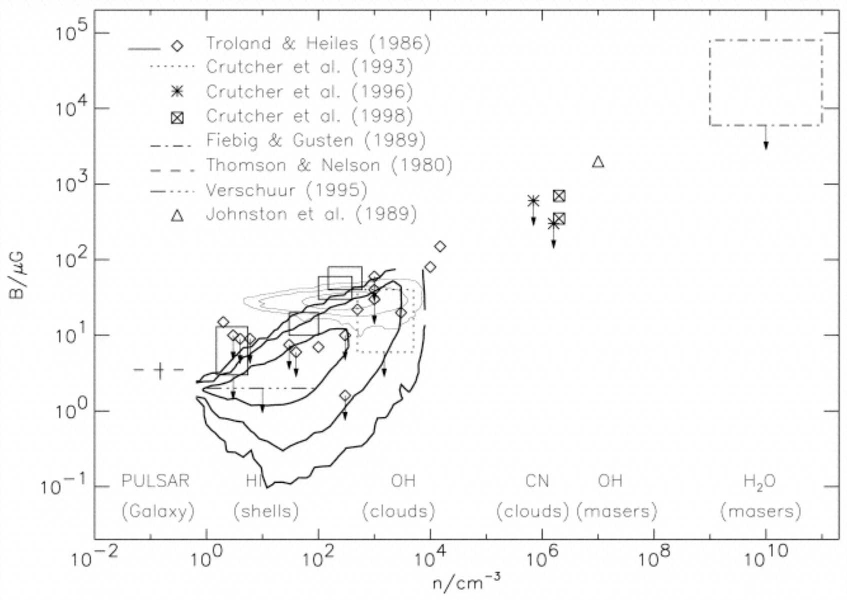


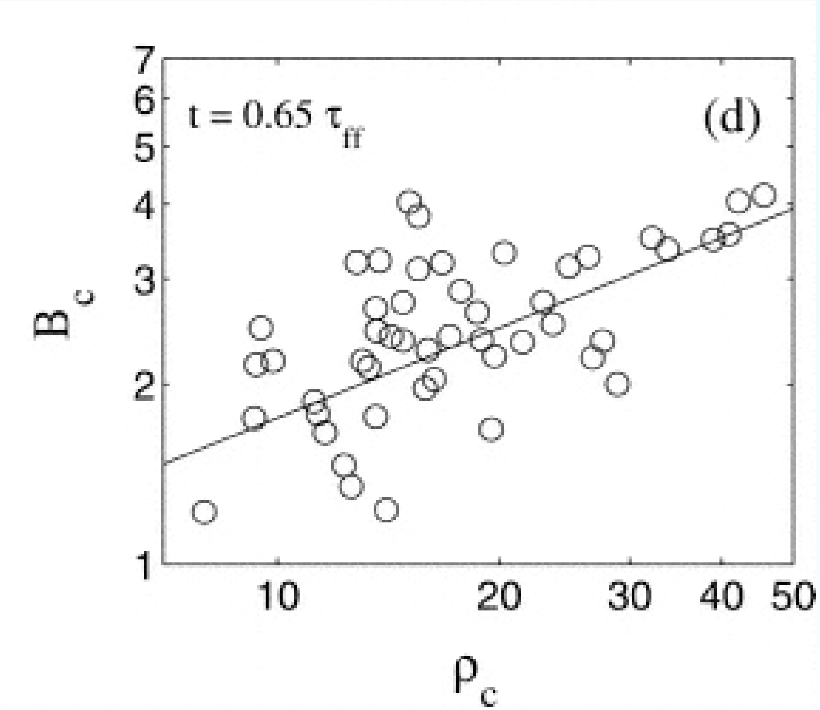
driven turbulence
t = 0.65 τ_ff
(b)
M/M_cr
10^5
10^3
10^1
0
20
40
core number
P. Li+ 04
C5e: n_J=7.5, β=50.0, Γ=43.2
supported
not
1000.0
100.0
10.0
1.0
0.1
10^-3
10^-2
10^-1
10^0
10^1
10^2
Γ
dN / d log Γ
C5d: n_J=7.5, β=10.0, Γ=19.3
Tilley & Pudritz 07

Other evidence for ambipolar diffusion

eg Mouschovias+ 06

- $B \propto \rho^{1/2}$ relation?
- Also seen in MHD turbulence



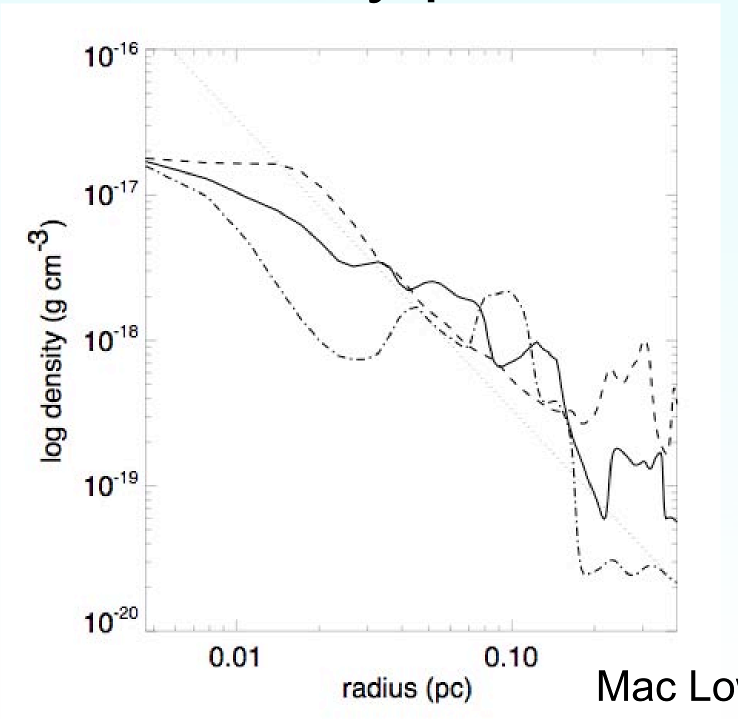


Padoan & Nordlund 99, P. Li+ 04

Other evidence for ambipolar diffusion

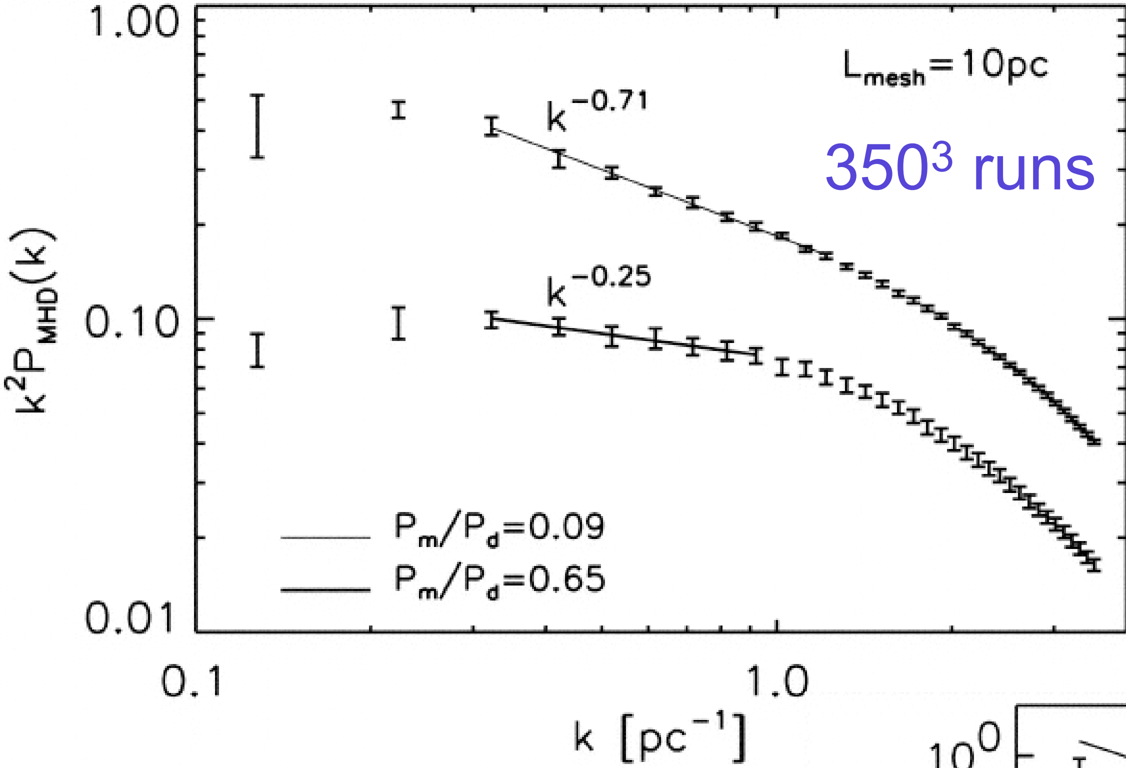
eg Mouschovias+ 06

- $B \propto \rho^{1/2}$ relation?
- r^{-2} density profile?



Mac Low+ 07

- Also seen in MHD turbulence
- general property of collapsing magnetized cores

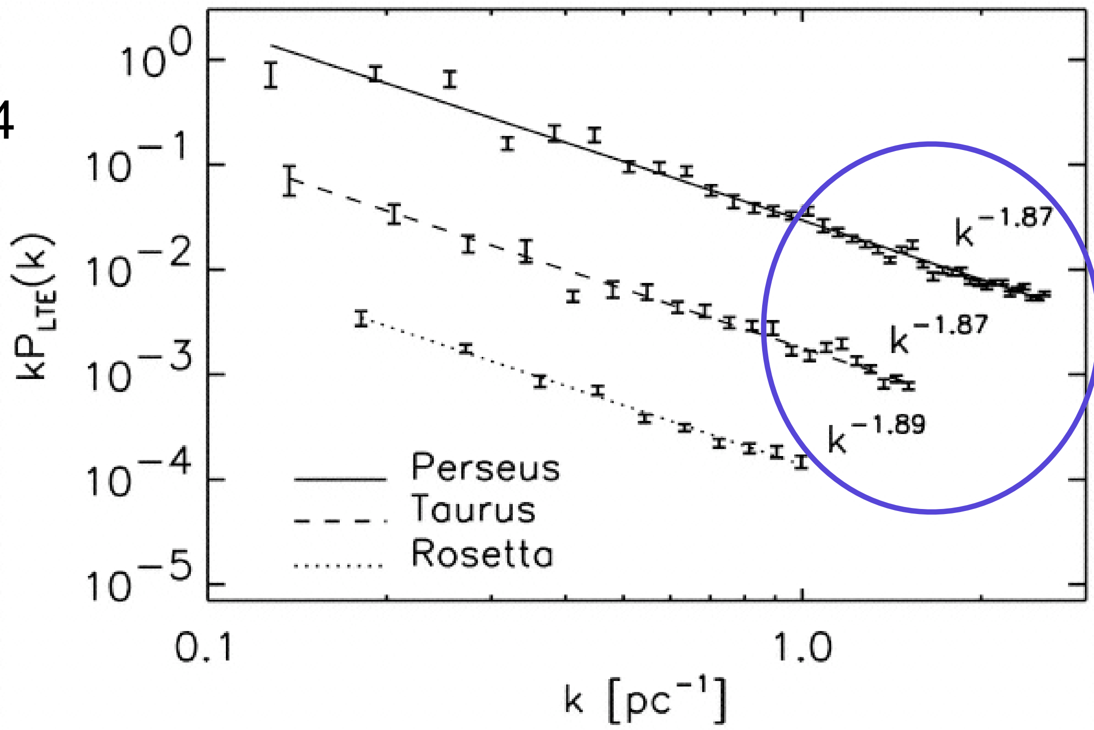


350^3 runs

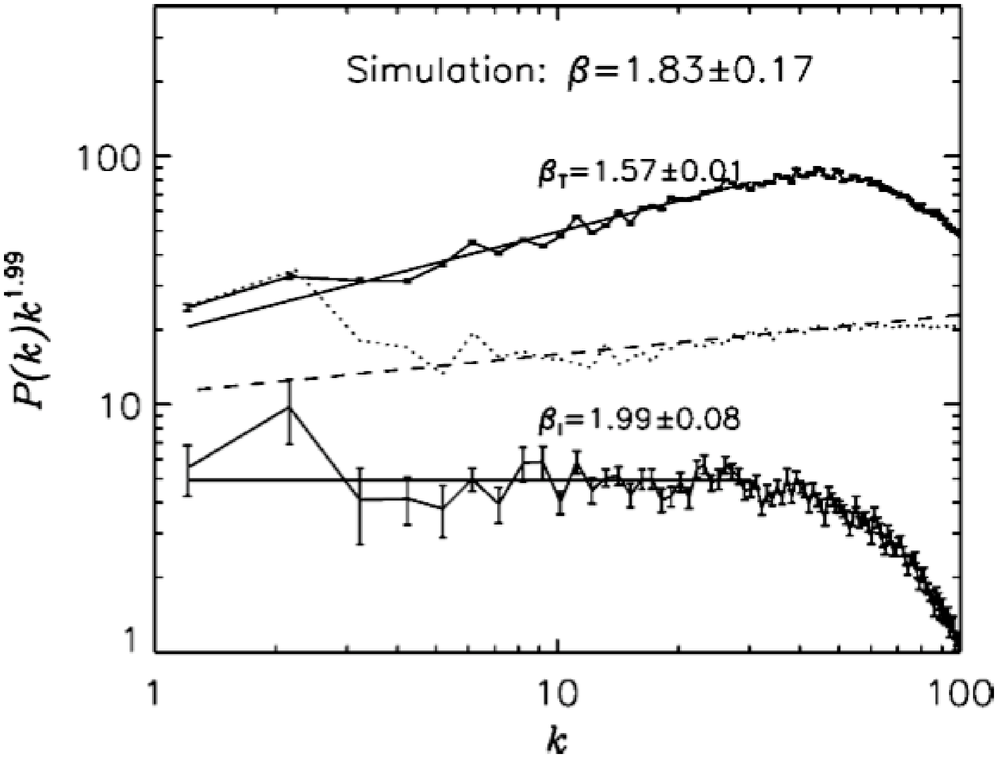
$M_A > 1 \qquad kP(k) \propto k^{-1.71}$

$M_A < 1 \qquad kP(k) \propto k^{-1.25}$

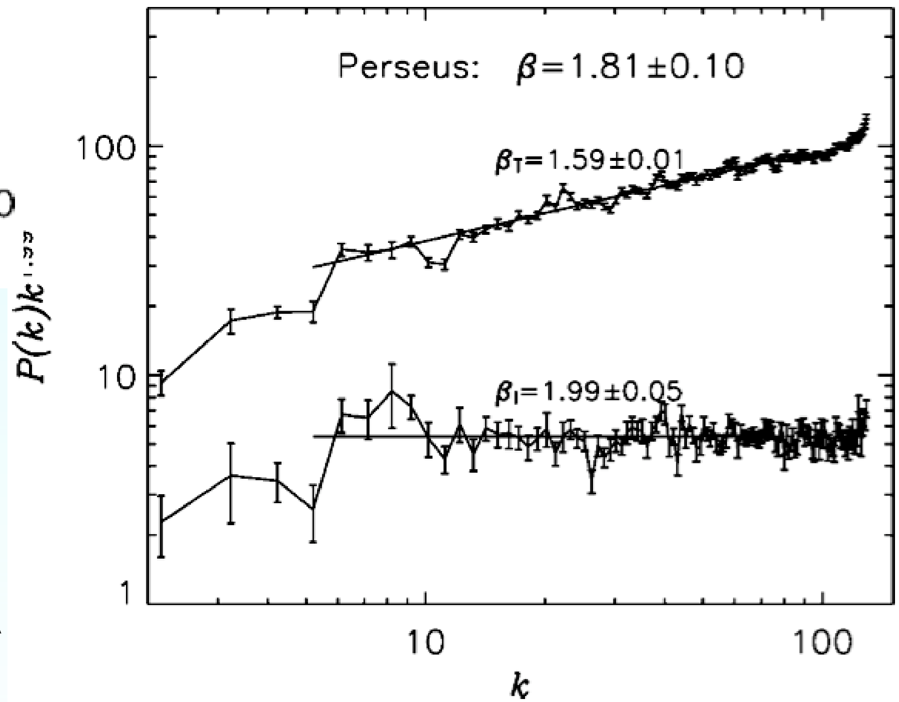
Padoan+ 04



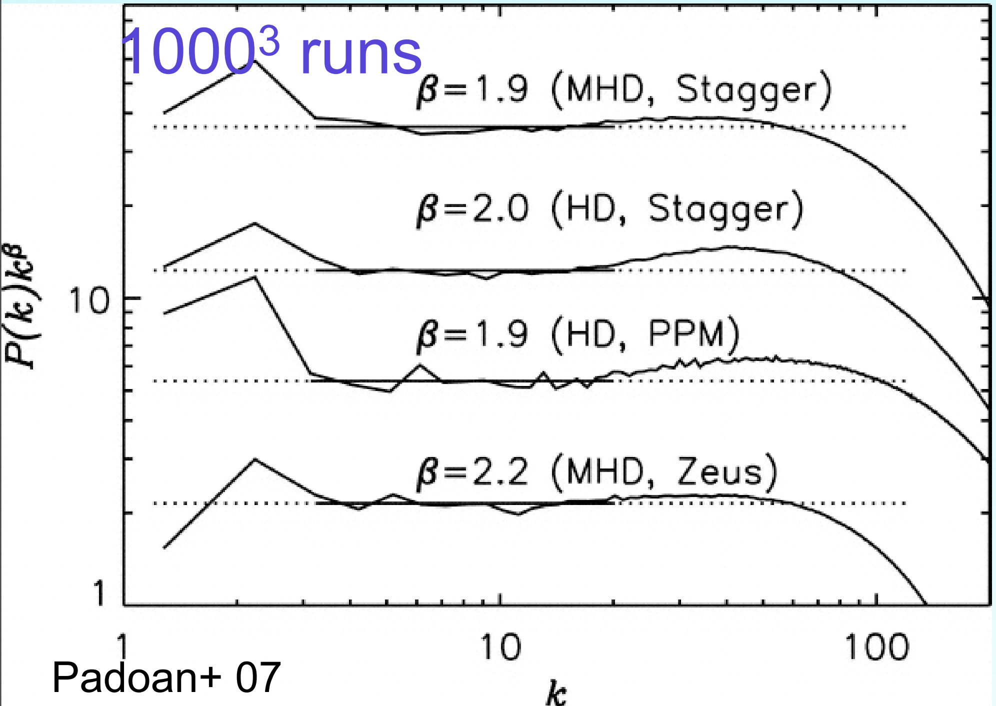
Ossenkopf & Mac Low 02 get similar values for Polaris Flare



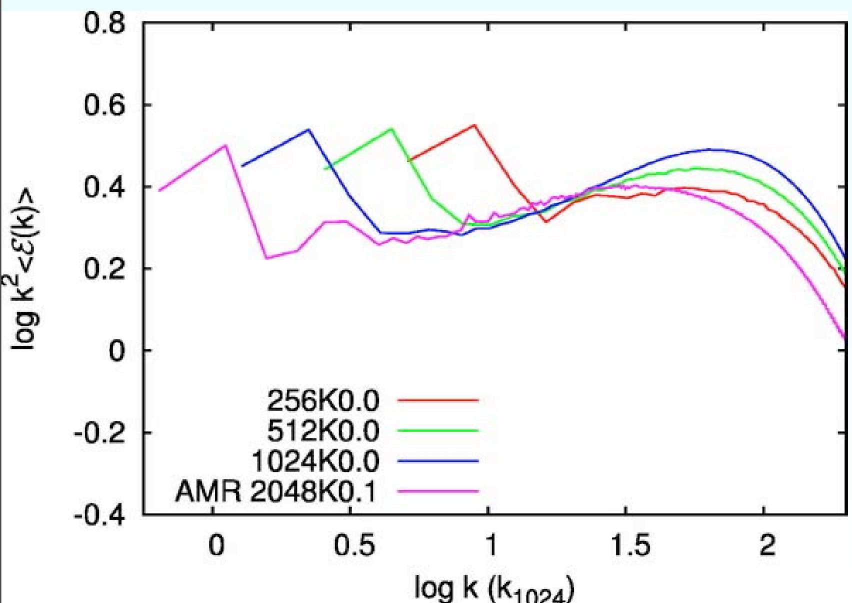
Padoan+ 06 use method of Lazarian & Pogosyan 00, by comparing integrated intensity and single power channel spectra to derive velocity power spectrum



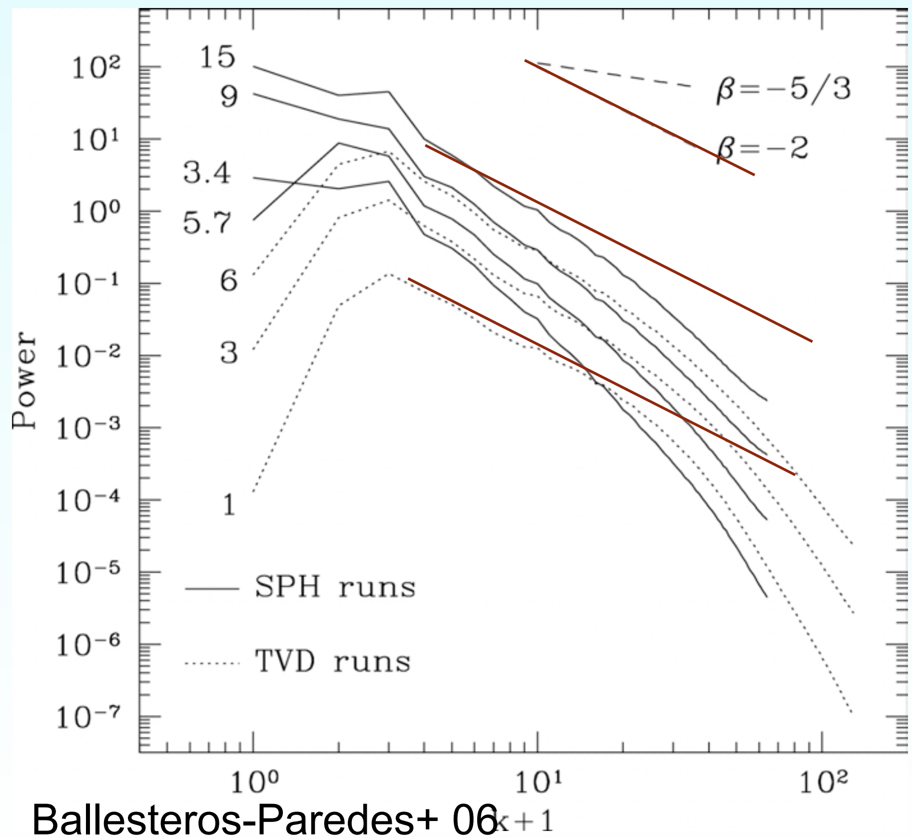
1000^3 runs



Padoan+ 07

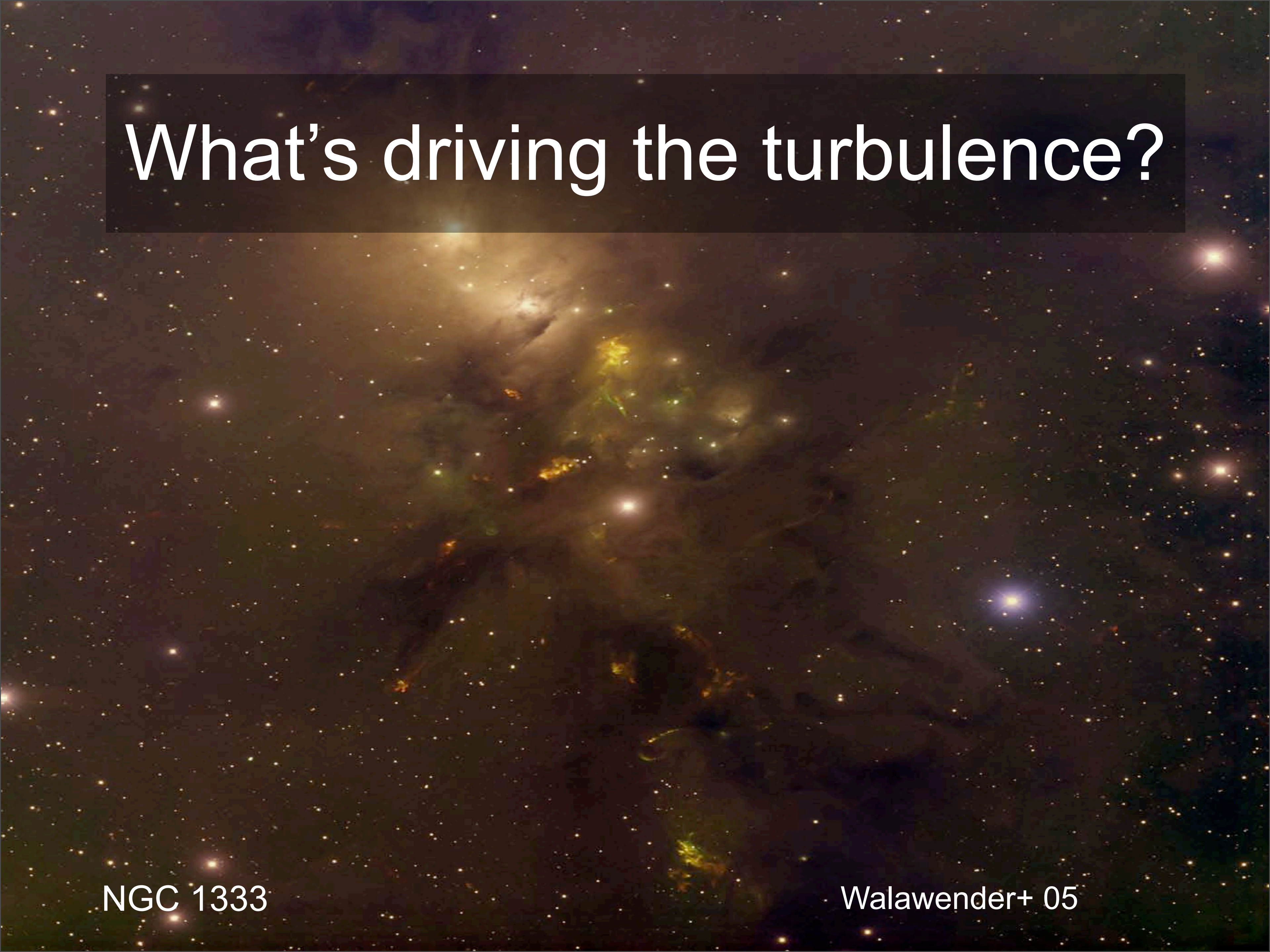


Kritsuk+ 07

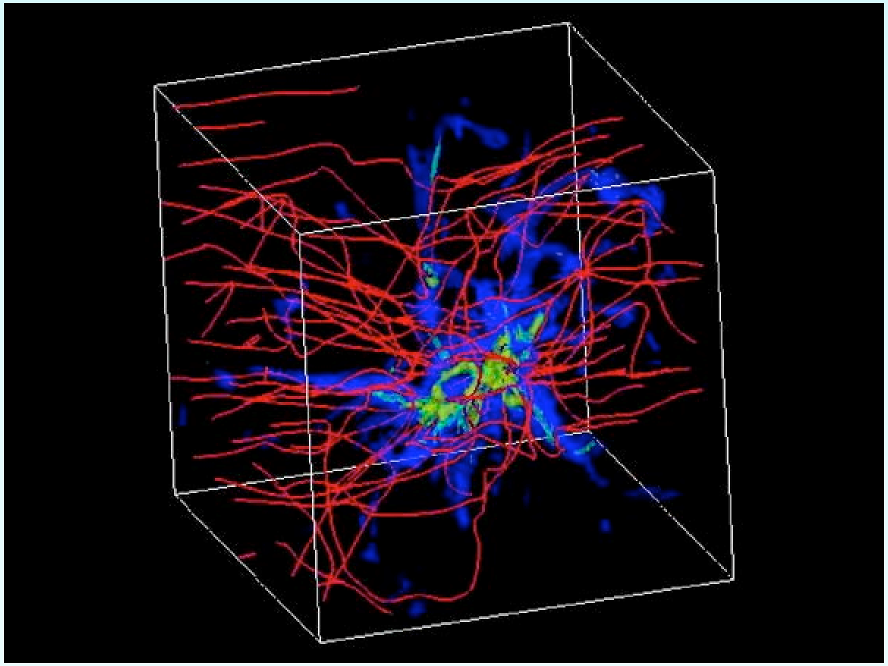


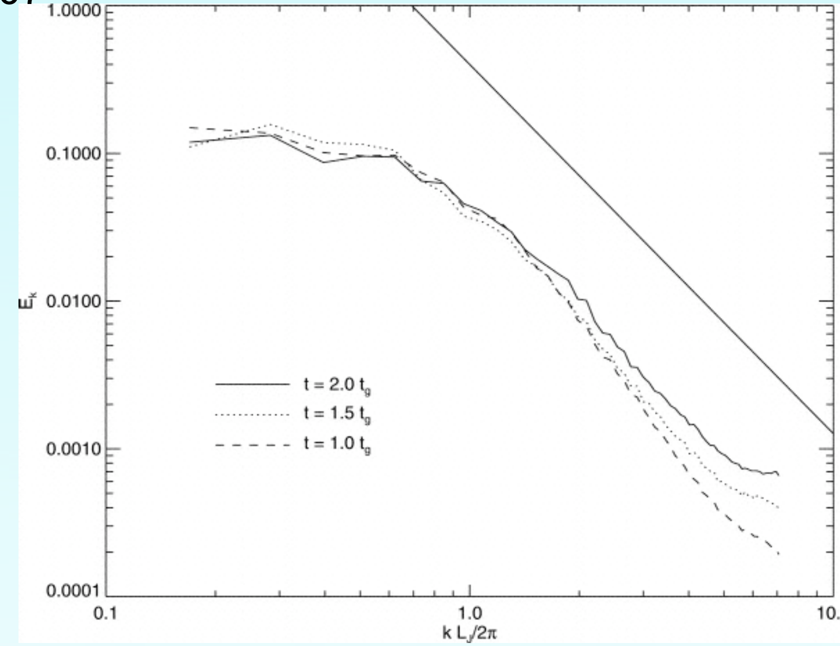
Ballesteros-Paredes+ 06

What’s driving the turbulence?

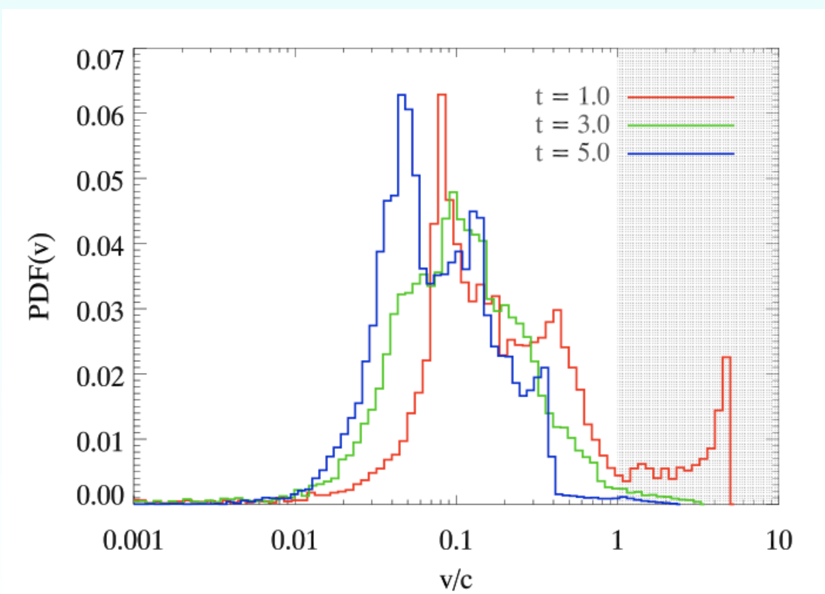


Z. Li & Nakamura 07



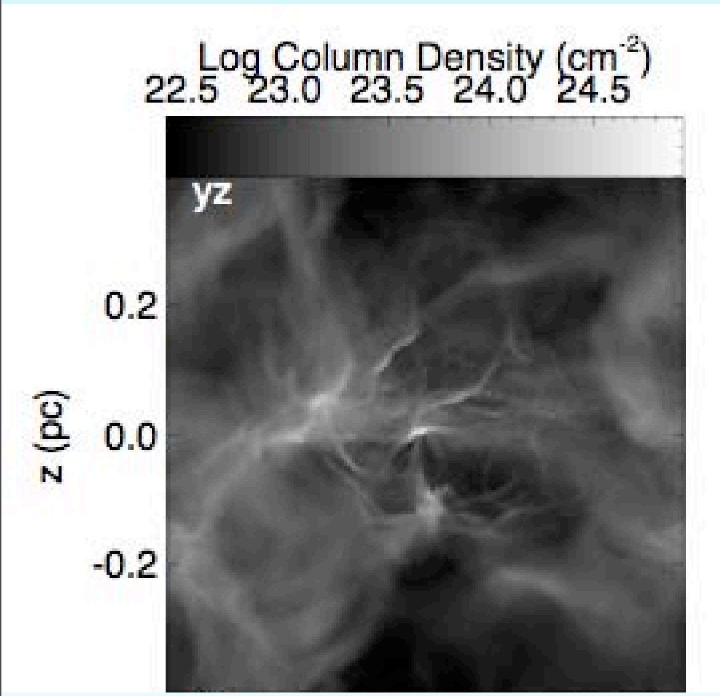


prominent break in power spectrum close to outflow length, not observed at least in Polaris Flare (Ossenkopf & Mac Low 02)

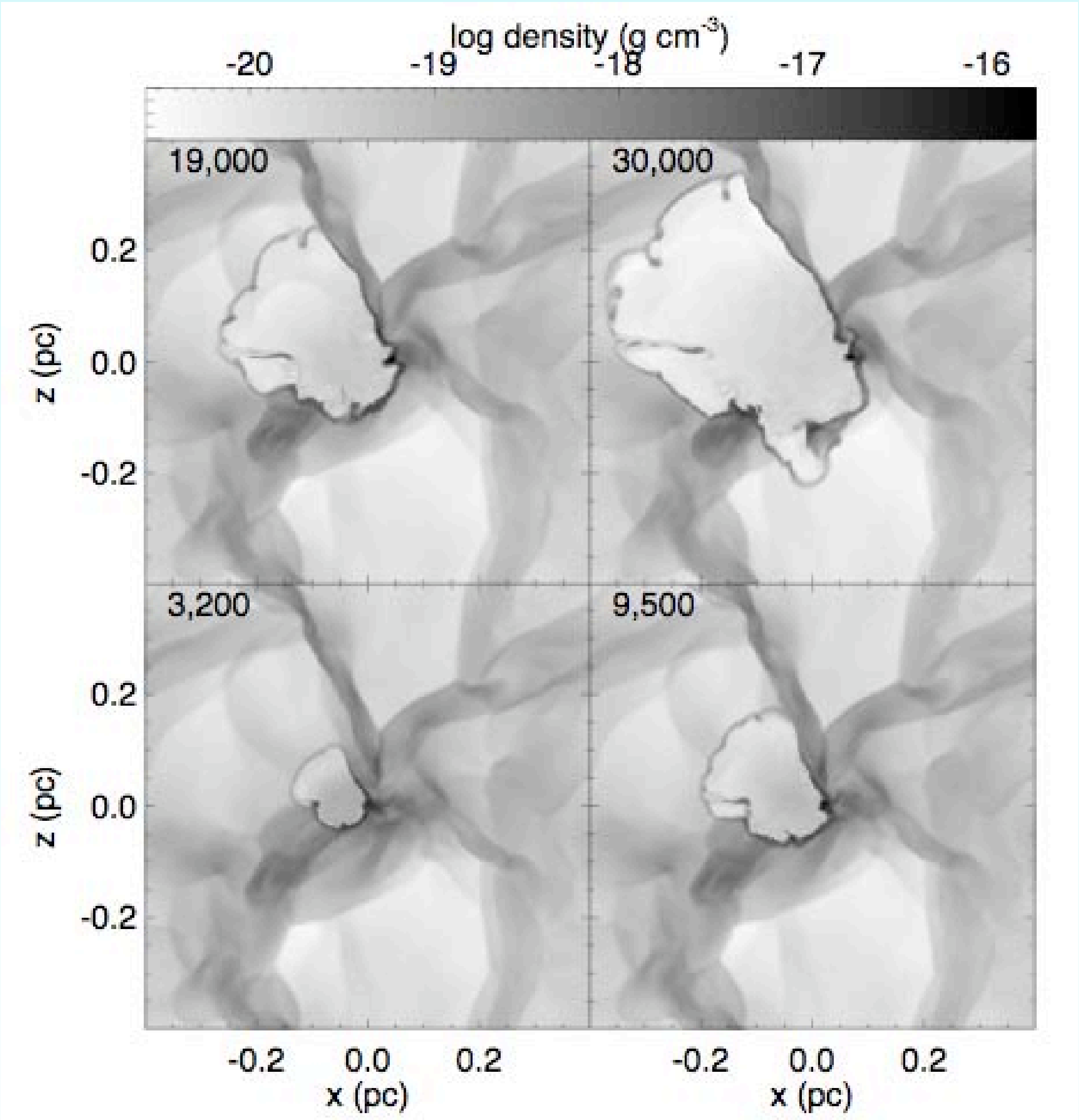


Banerjee+ 07

Mach 5 jet leaves little super-sonic material



Mac Low+ 07



H II regions?

3D models of colliding flows

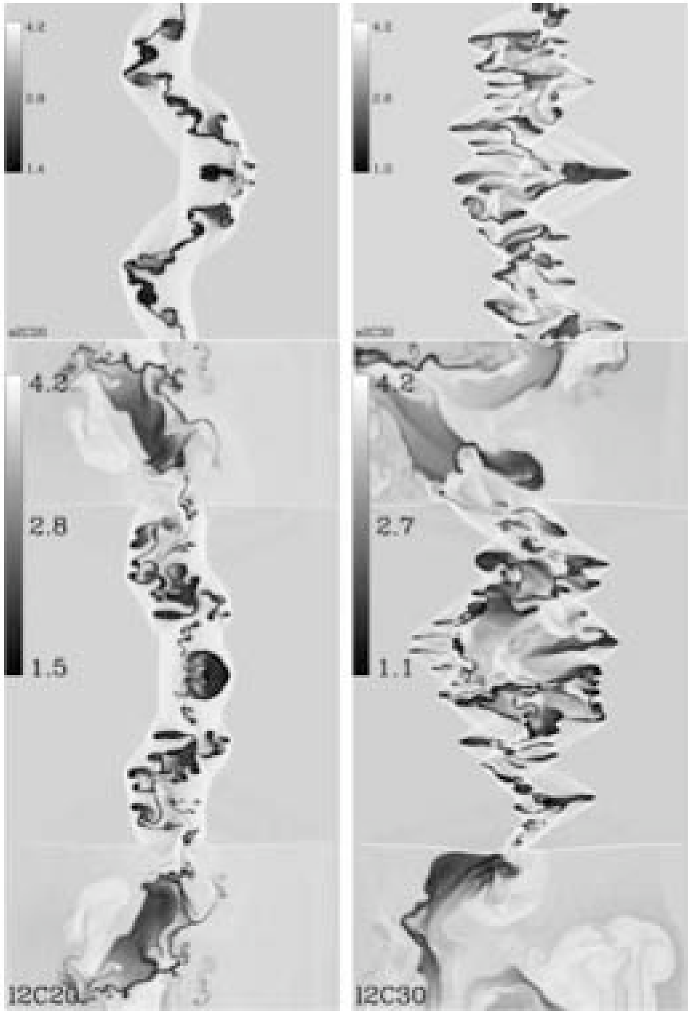
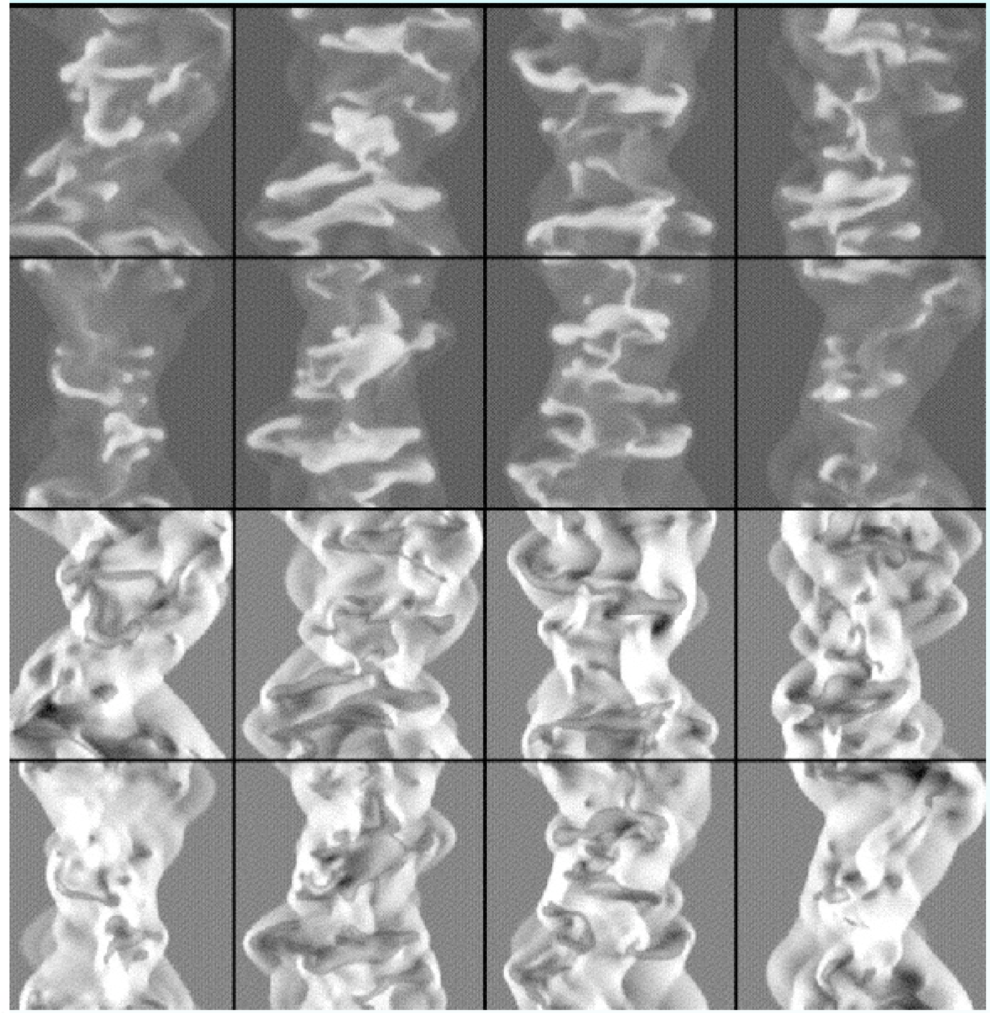


FIG. 19.— *Top:* Stills of models s2C20 and s2C30 with open boundary conditions in the transversal direction. The resolution is $N = 512$. *Bottom:* Stills of models l2C20 and l2C30 with open boundary conditions in the transversal direction and an "inactive" region above and below the inflow. The resolution is $N = 512 \times 1024$.

Heitsch+ 2006



Váquez-Semadeni+ 2006

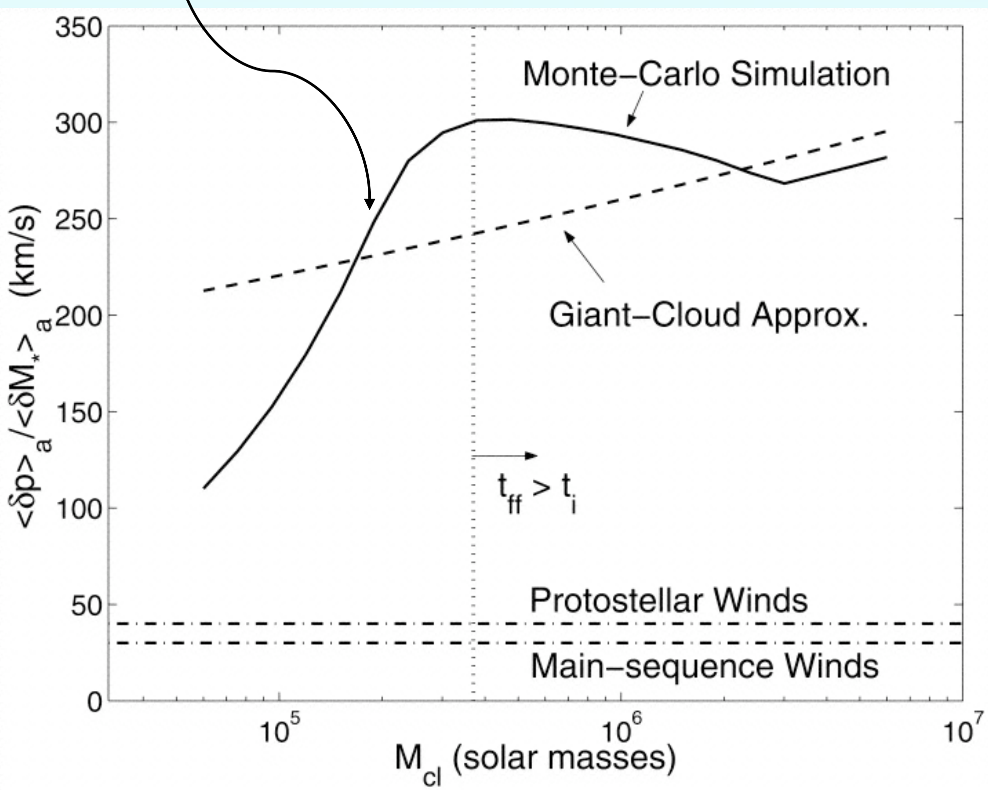
With self-gravity

Matzner argues small clouds supported by outflows, large ones by HII regions, so long as

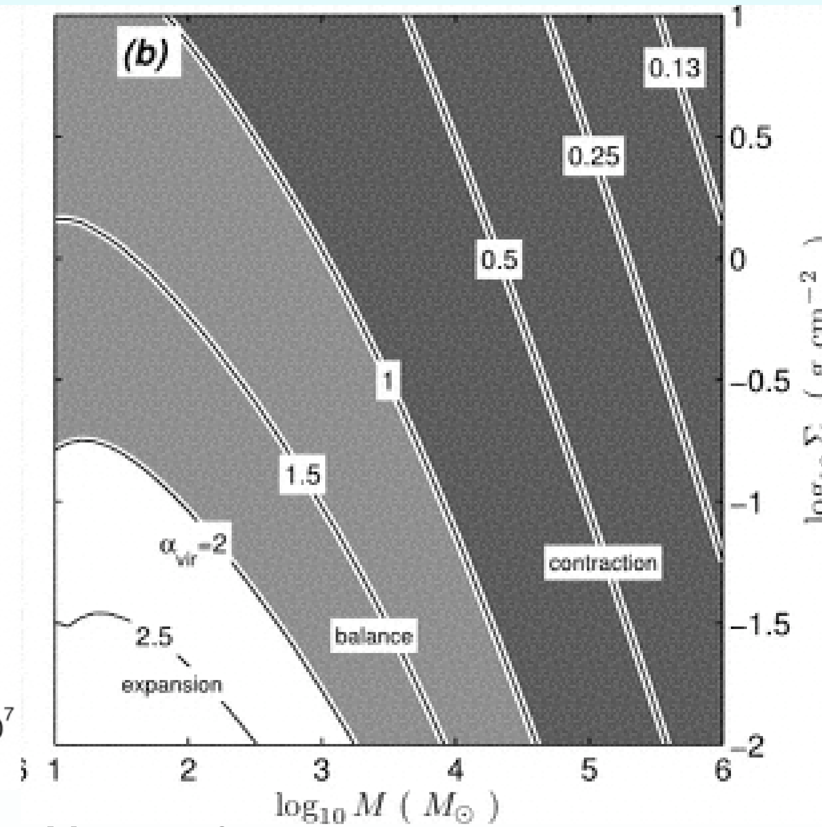
$$\mathrm{SFE}_{\mathrm{tot}} < \frac{1}{4\phi_w/\phi_{\mathrm{II}} + 1} \simeq 33\% \, .$$

HII regions

outflows

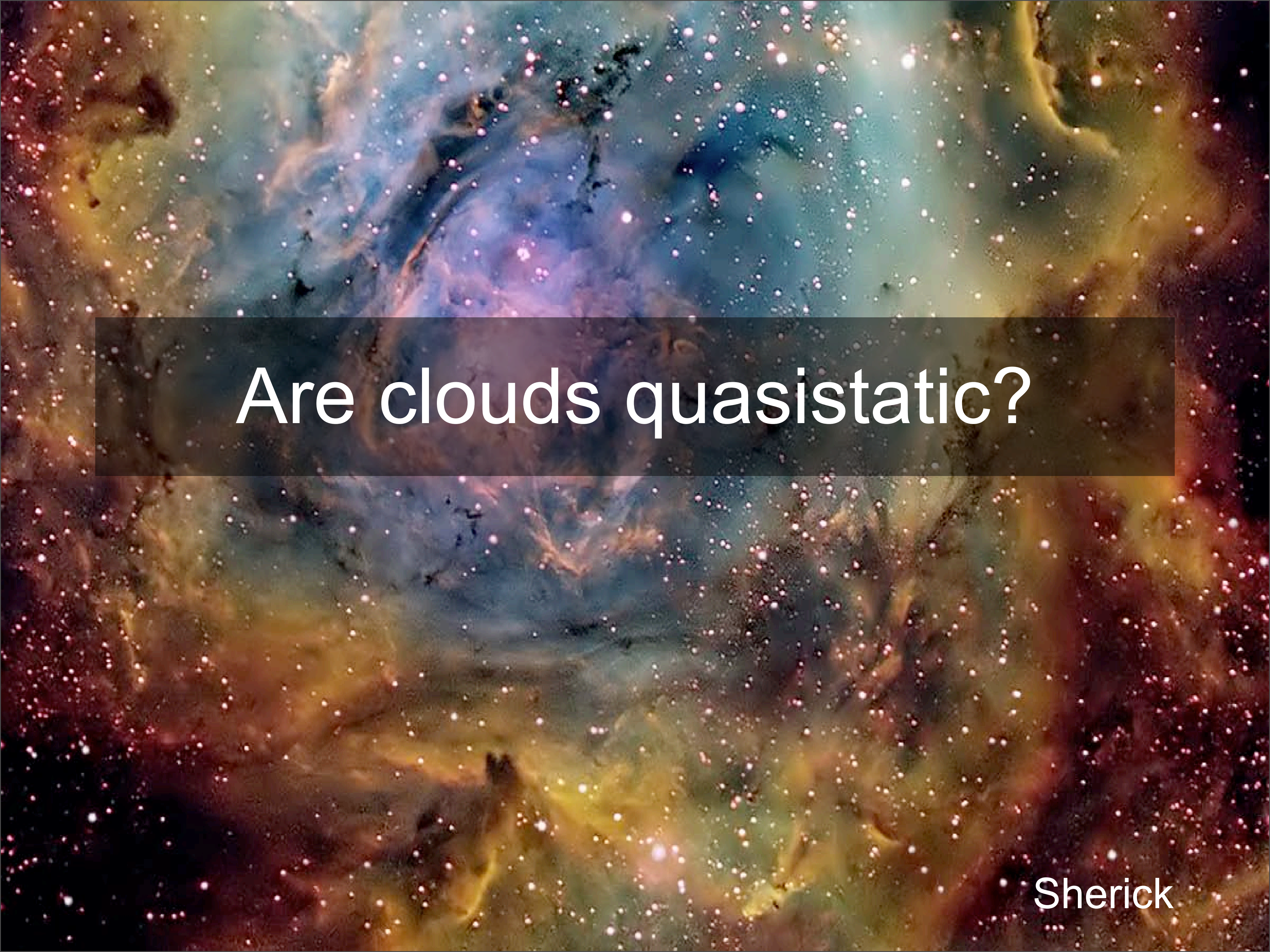


Matzner 02



Matzner 07

Are clouds quasistatic?



Sherick

Turbulence *Prevents* Collapse

- Classical theories suggest that turbulent motions can be treated as an additional pressure (Chandrasekhar 1951, von Weizsäcker 1951)

$$c_{s,eff}^2 = c_s^2 + \frac{\langle v^2 \rangle}{3}$$

- Supersonic turbulence increases the mass supported against collapse

$$M_J = \left(\frac{\pi}{G}\right)^{3/2} \rho^{-1/2} c_{s,eff}^3$$

Turbulence *Promotes* Collapse

- Supersonic turbulence drives shock waves that produce density enhancements.
- In isothermal gas, the postshock density increases with the Mach number M as

$$\rho_s = \rho \mathrm{M}^2$$

- Supersonic turbulence decreases the mass supported against collapse

$$M_J = \left(\frac{\pi}{G}\right)^{3/2} \rho_s^{-1/2} c_{s,eff}^3$$

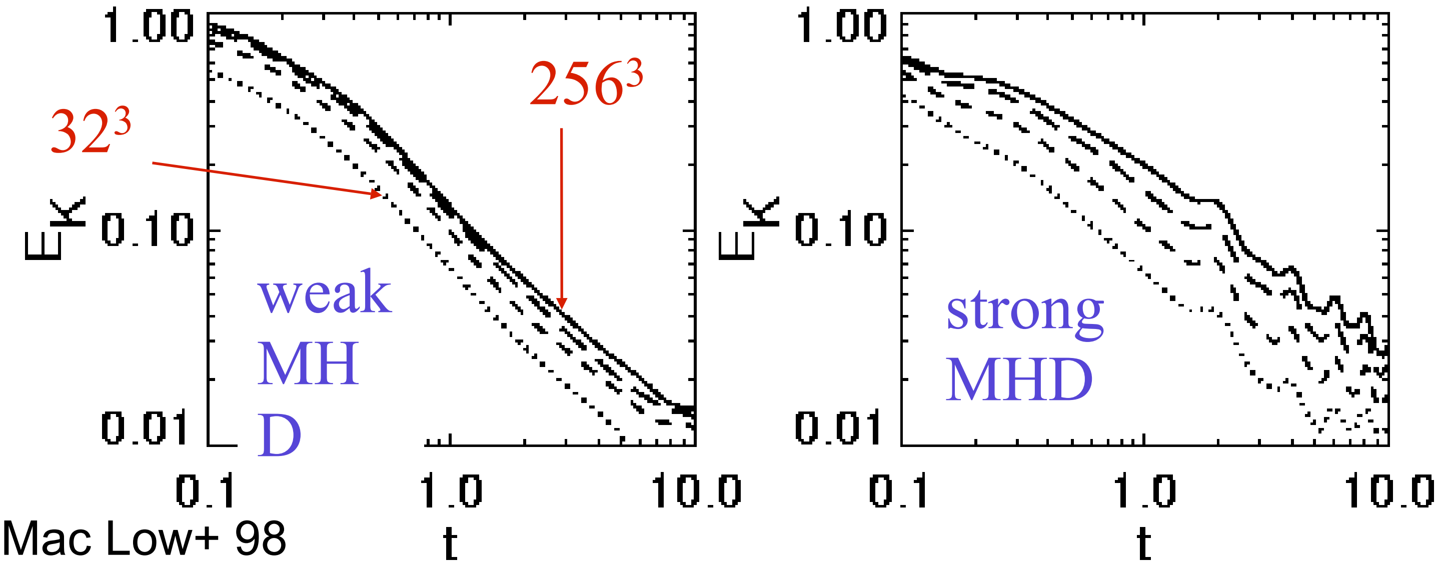
Turbulence *Inhibits* Collapse

$$M_J = \left(\frac{\pi}{G}\right)^{3/2} \rho_s^{-1/2} c_{s,eff}^3 \propto$$

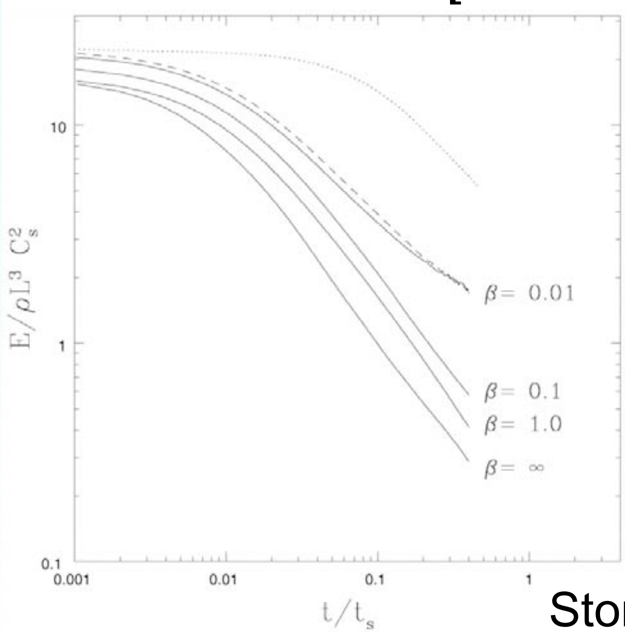
$$\propto \frac{c_s}{v}\left(c_s^2 + \frac{\langle v^2 \rangle}{3}\right)^{3/2} \square\ v^2$$

- Turbulence is intermittent, so uniform pressure does not represent it well.
- On average, increasing velocity increases Jeans mass, but locally, compressions can decrease it

Kinetic Energy Decays



Mac Low+ 98



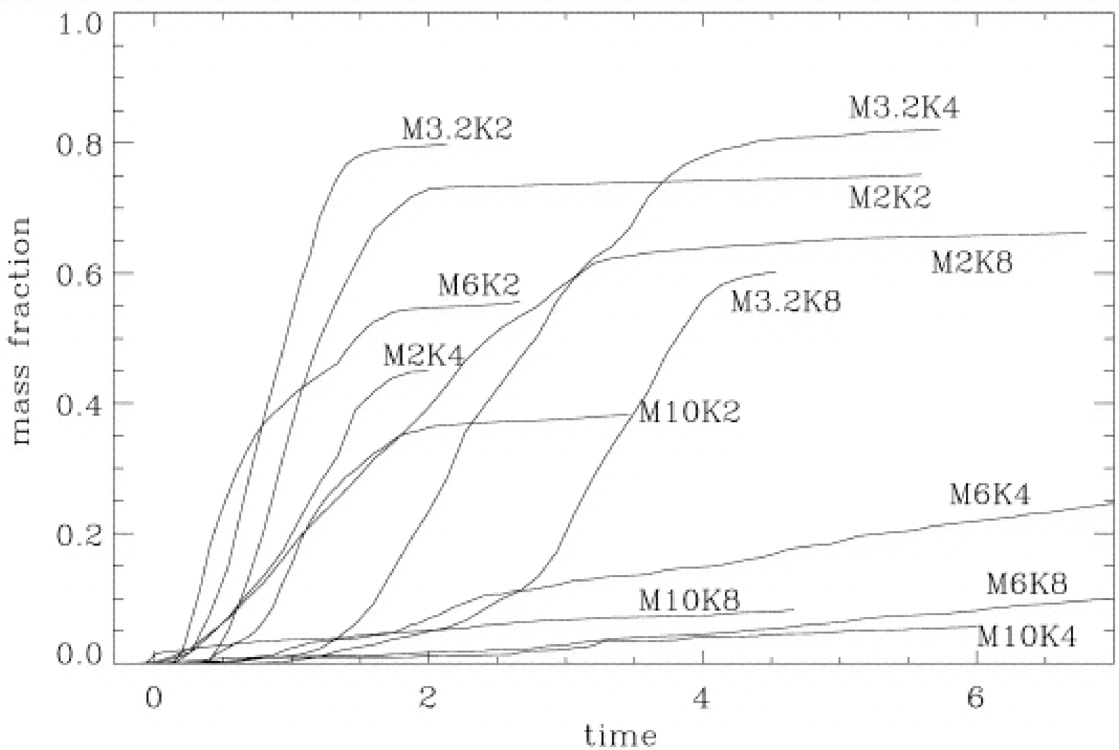
Stone+ 98

also see Padoan & Nordlund 99

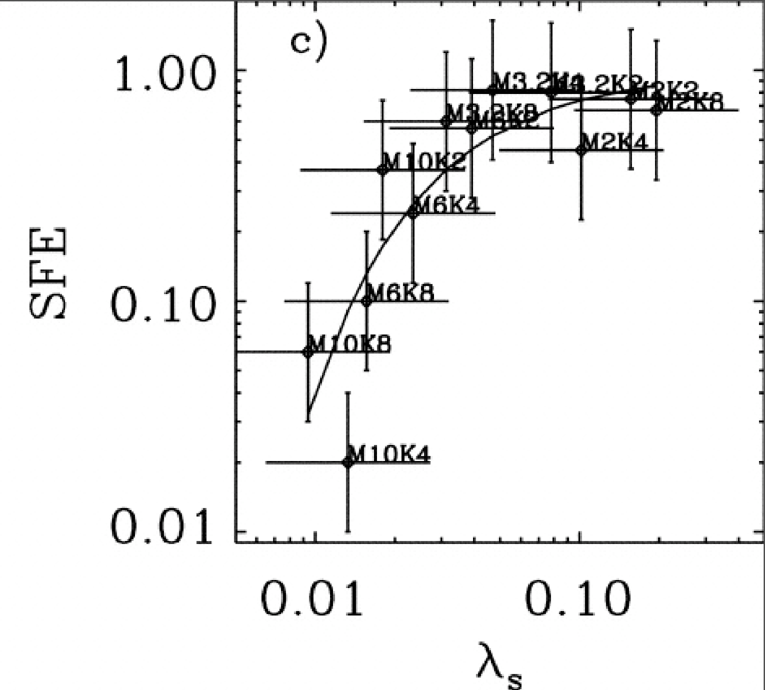
$$\dot{E}_{kin} \cong -\frac{0.21}{\pi} m k v_{rms}^3 \approx 0.42 \frac{m v_{rms}^3}{\lambda_D}$$

Mac Low 99, Mac Low & Klessen 04

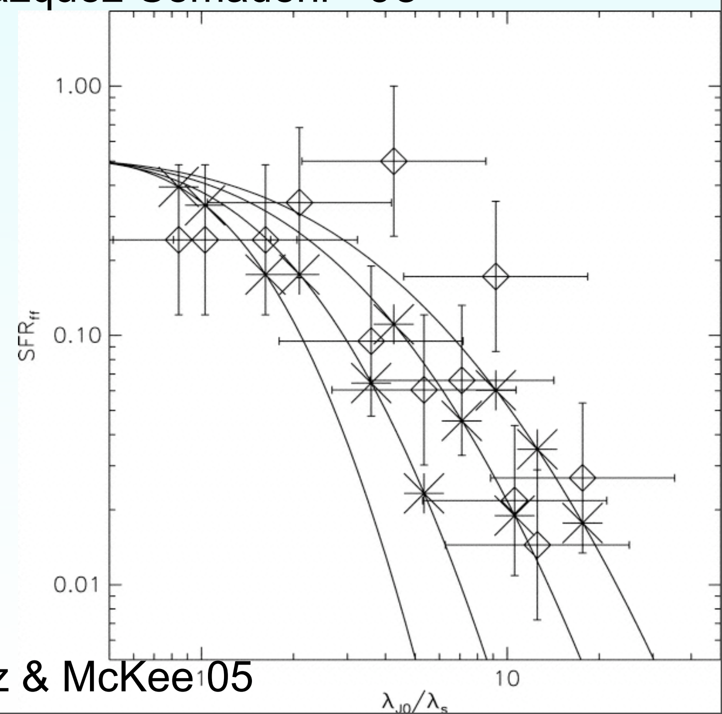
Star Formation Efficiency



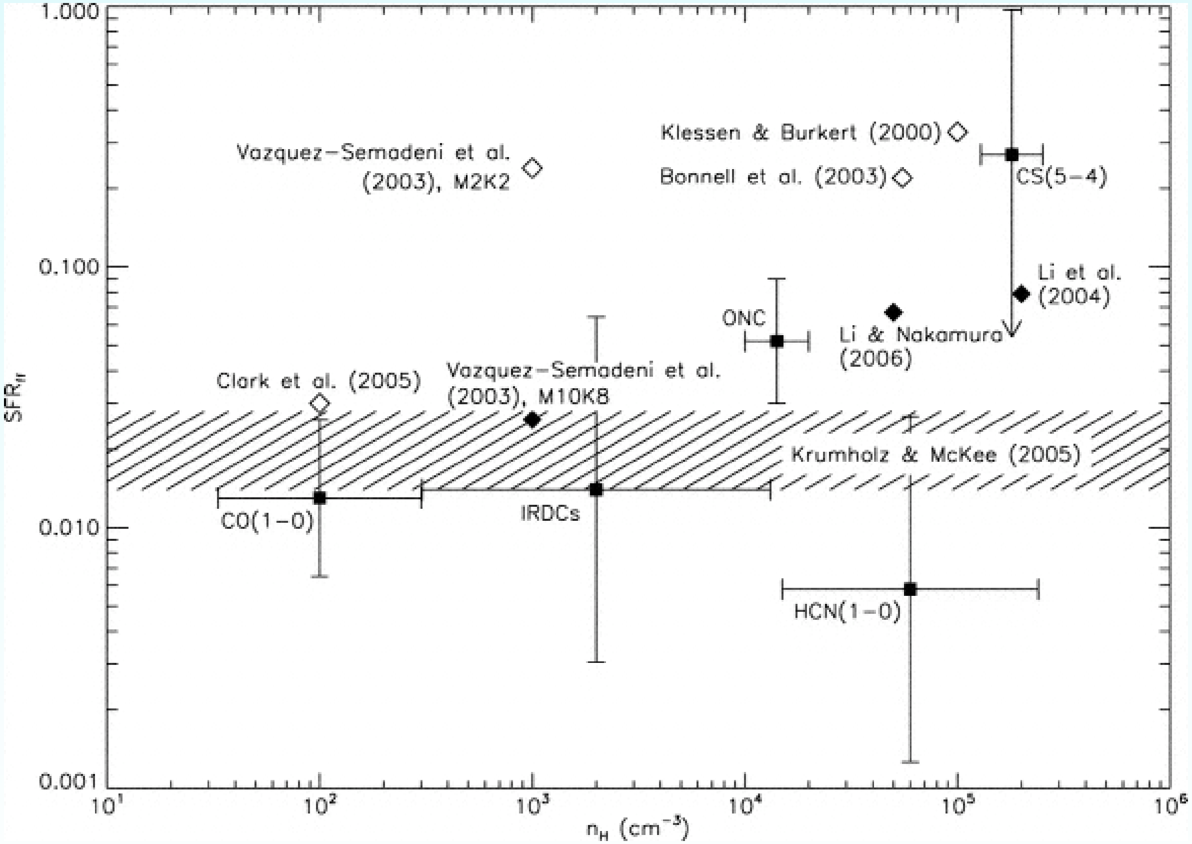
Vázquez-Semadeni+ 03; see also Klessen+ 00



Vázquez-Semadeni+ 03



Krumholz & McKee 05



Krumholz & Tan 07

density dependent SFR?

(CS may be close to actual value, argues Elmegreen 07)

How long-lived?

$t_{GMC} = 10 t_{ff}$

$t_{GMC} = t_{ff} = t_{cross}$

turbulent envelopes
supercritical cores
Krumholz+ 06

turbulent envelopes
shock compressed cores
Padoan+ 07

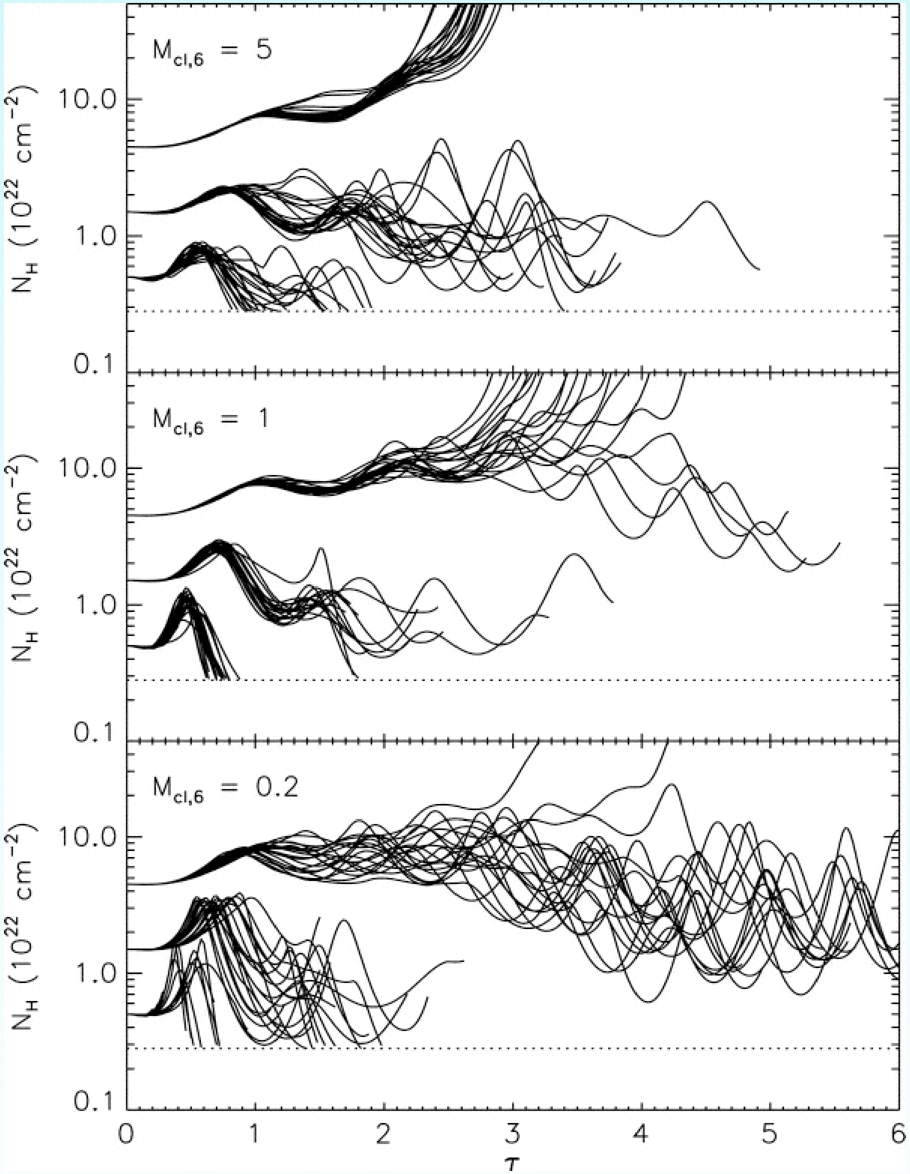
subcritical envelopes
subcritical cores
Mouschovias+ 06

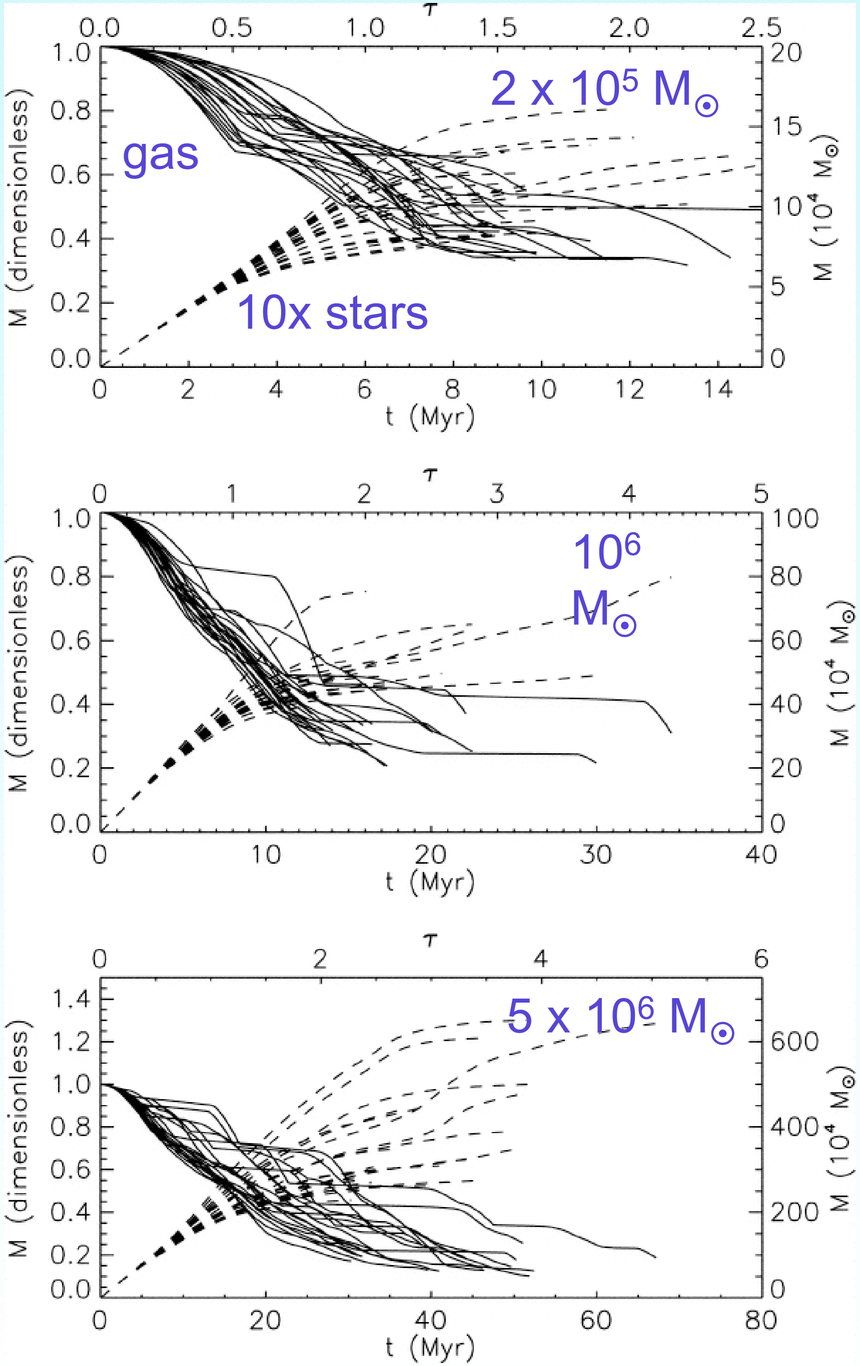
subcritical envelopes
critical cores
Elmegreen 07

Ballesteros-Paredes+ 99

Y. Li+ 06 - galactic scale

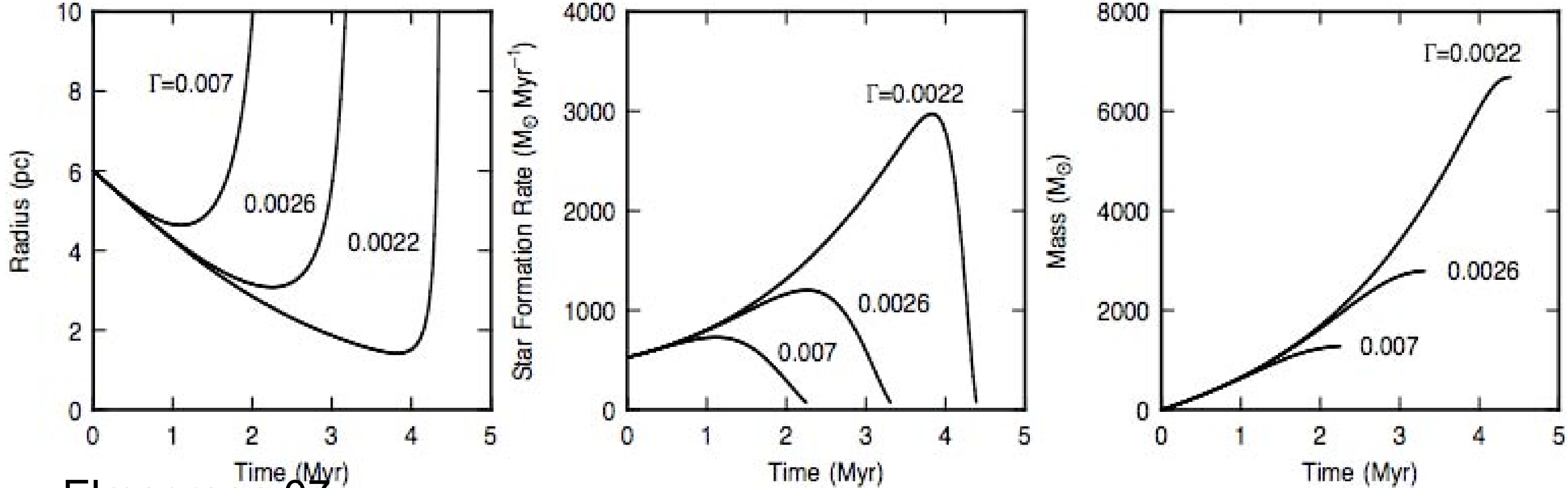
Krumholz+ 06





also see similar work by

Huff & Stahler 06



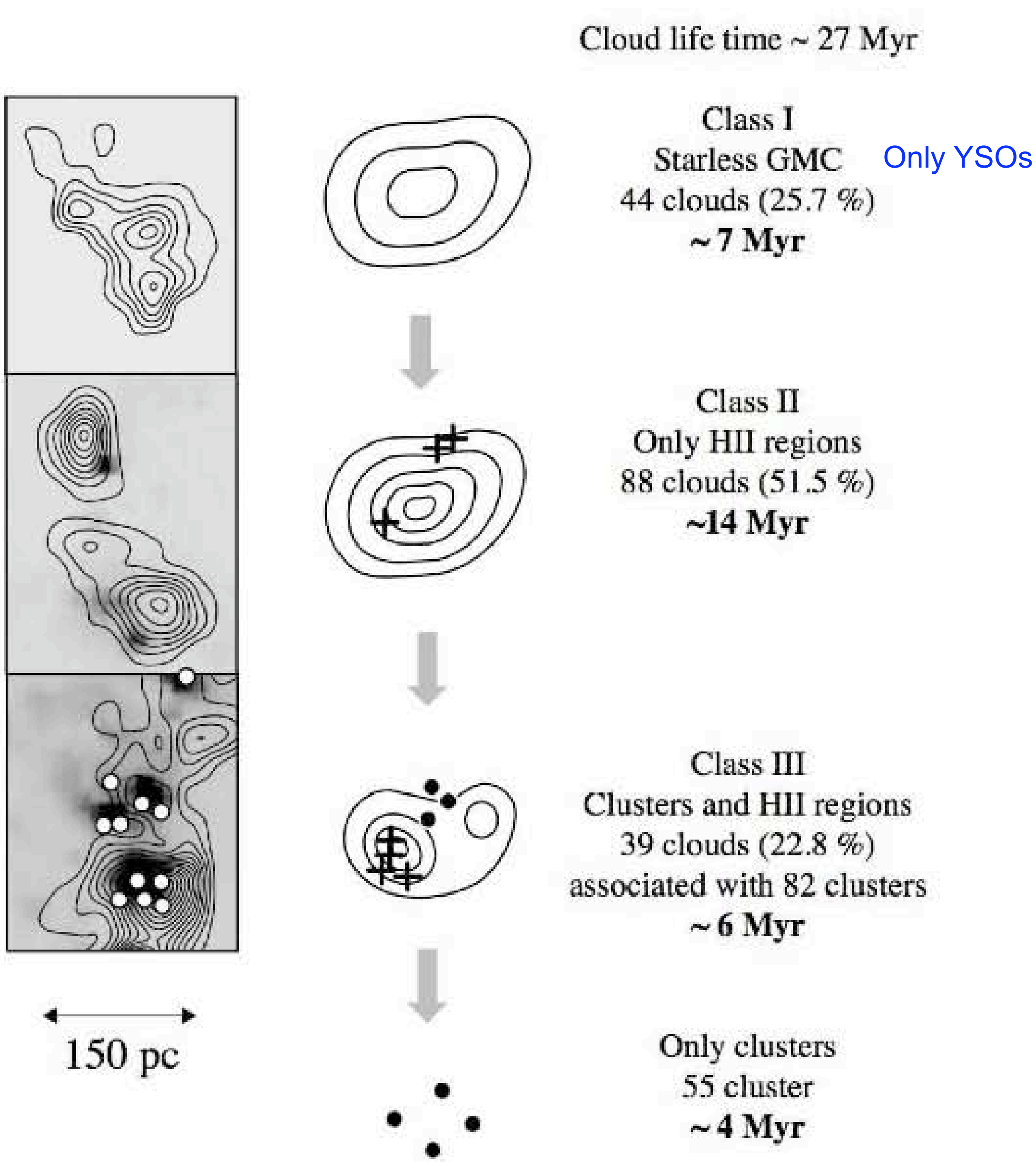
Elmegreen 07

10^4 $M_\odot$ cloud
"H II" feedback

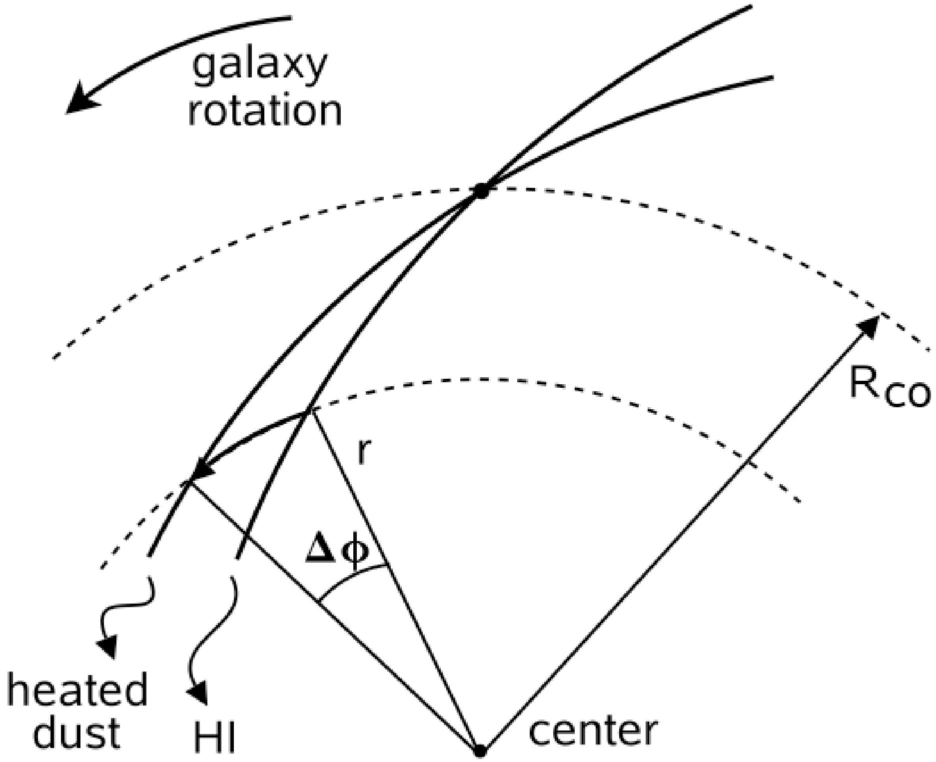
spherical cloud core rather than filamentary GMC

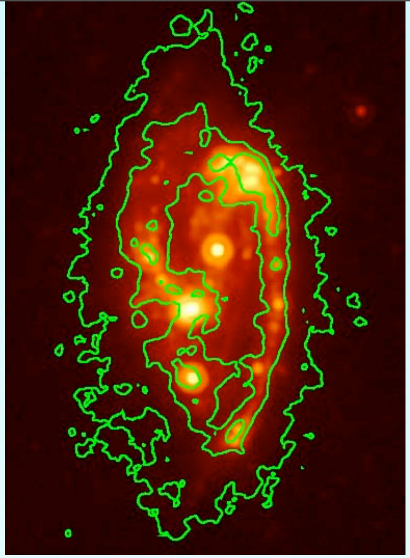
LMC cloud lifetimes

so-called starless GMCs actually have Spitzer YSOs within them (Gruendl+ 07)

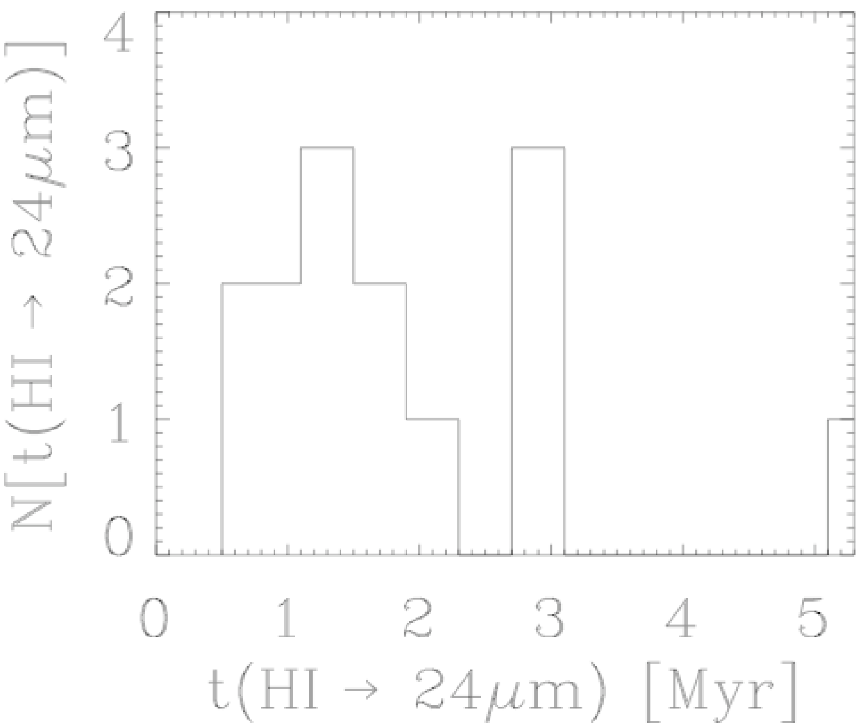


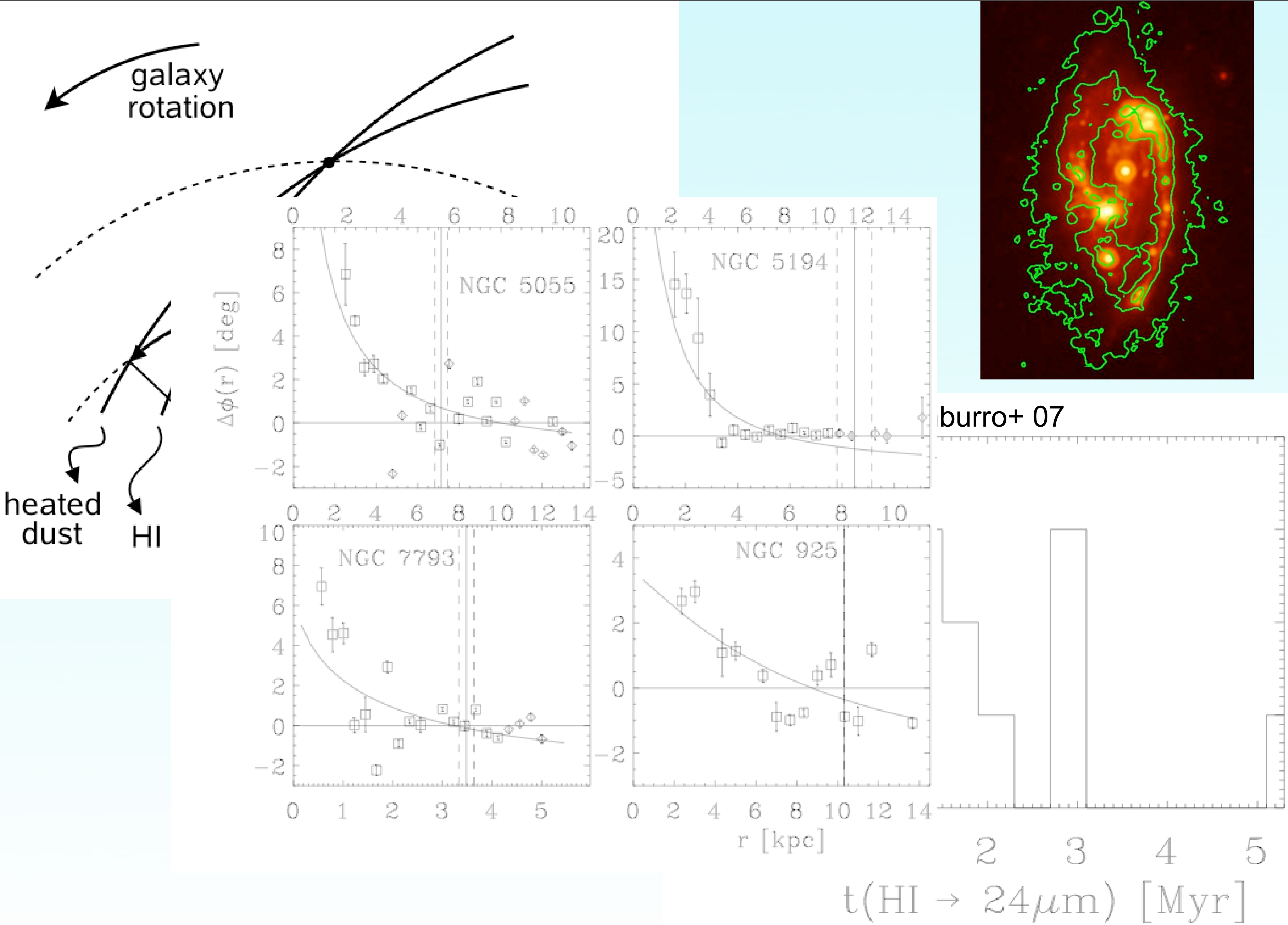
Blitz, Fukui+ 06


galaxy
rotation
R_{CO}
r
$\Delta\phi$
heated
dust
HI
center

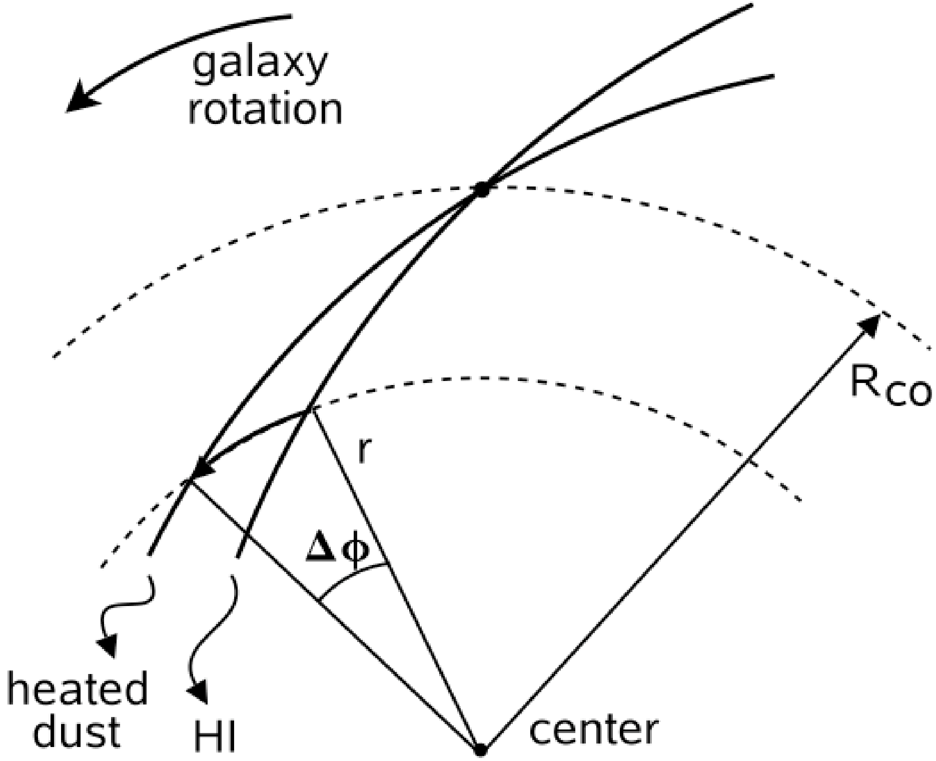


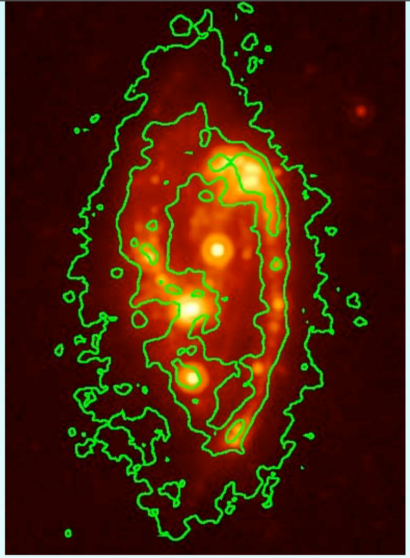
Tamburro+ 07


N[t(HI → 24μm)]
t(HI → 24μm) [Myr]
0
1
2
3
4
5

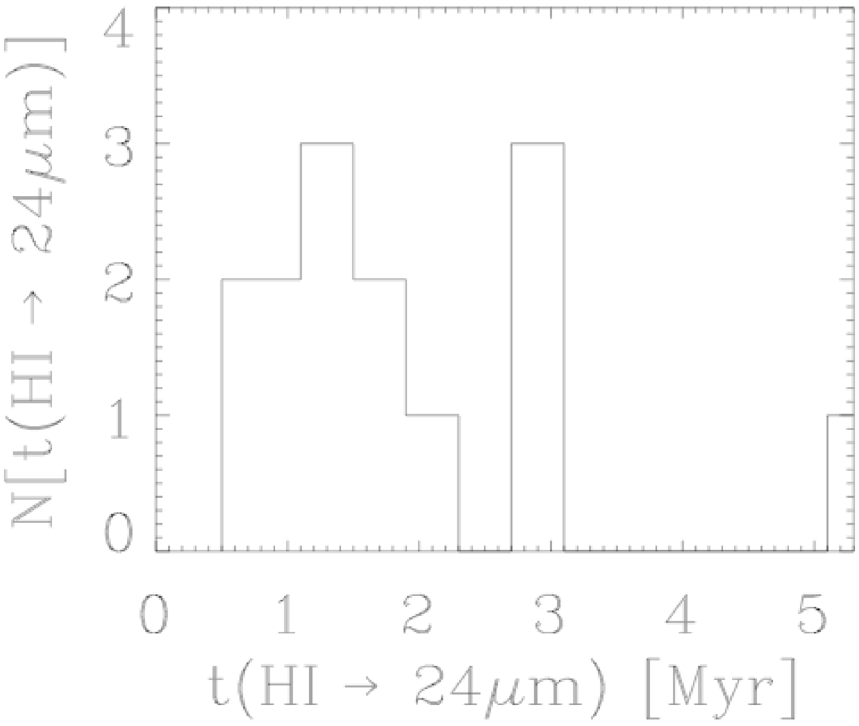


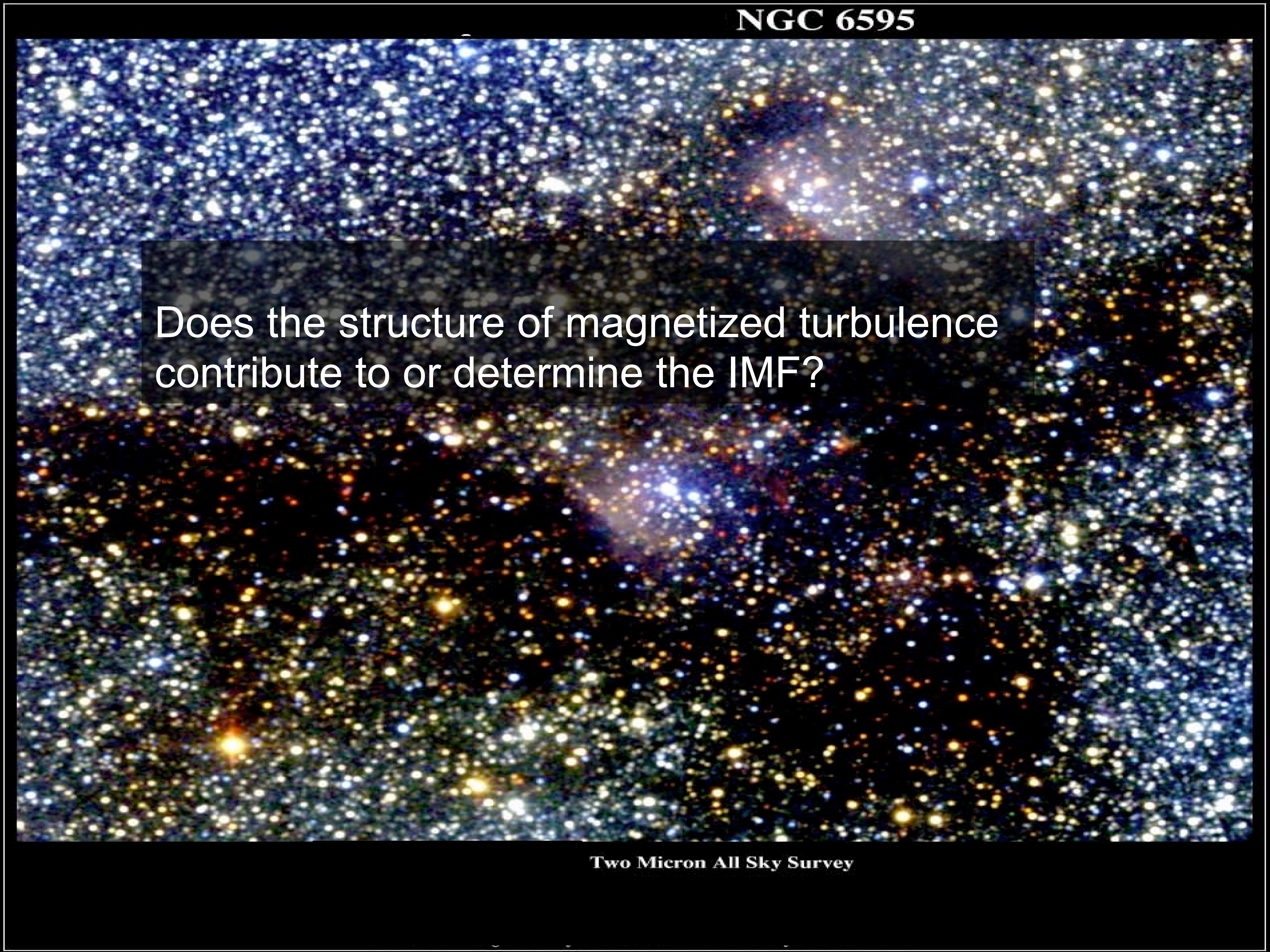
galaxy rotation
heated dust
HI
NGC 5055
NGC 5194
NGC 7793
NGC 925
Δφ(r) [deg]
r [kpc]
aburro+ 07
t(HI → 24μm) [Myr]


galaxy
rotation
R_{CO}
r
$\Delta\phi$
heated
dust
HI
center

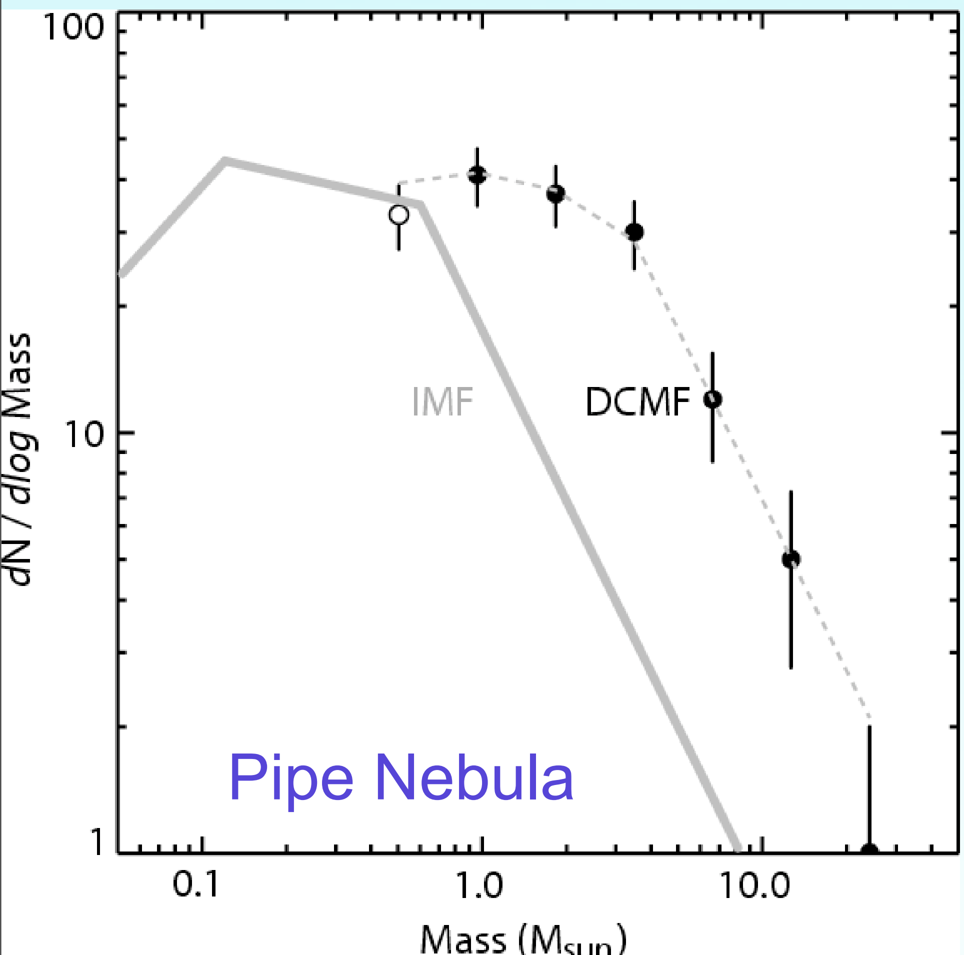


Tamburro+ 07

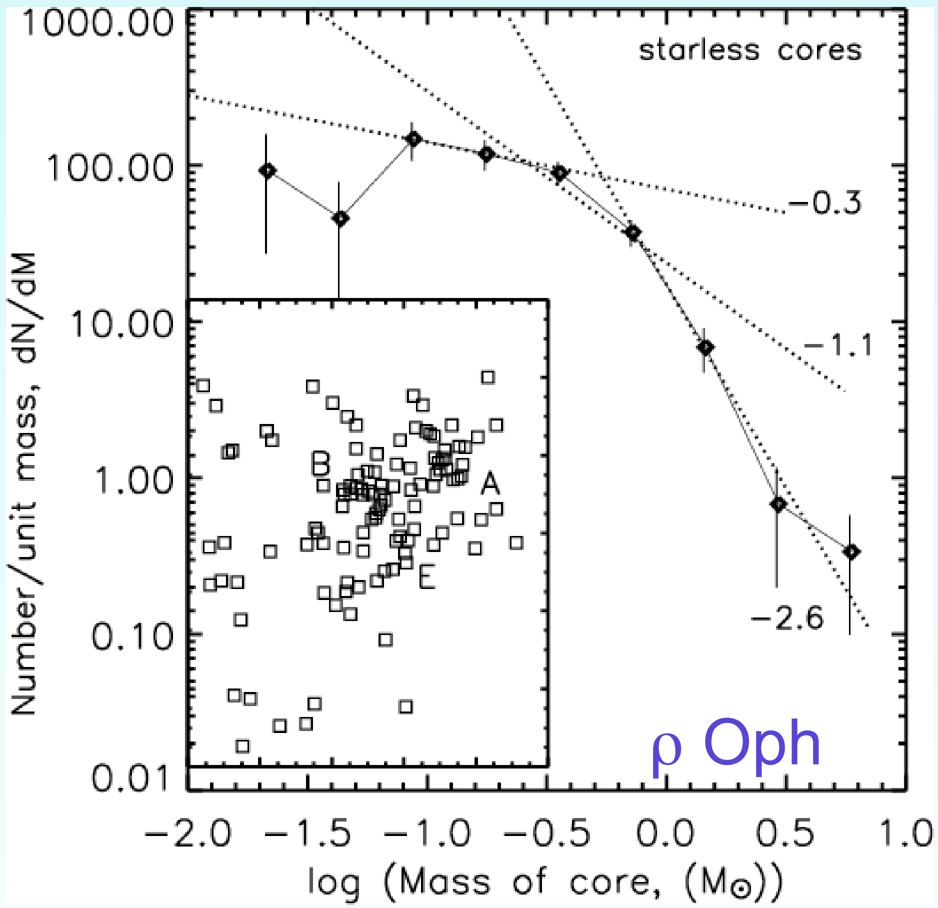

N[t(HI → 24μm)]
t(HI → 24μm) [Myr]
0
1
2
3
4
5


NGC 6595
Does the structure of magnetized turbulence contribute to or determine the IMF?
Two Micron All Sky Survey

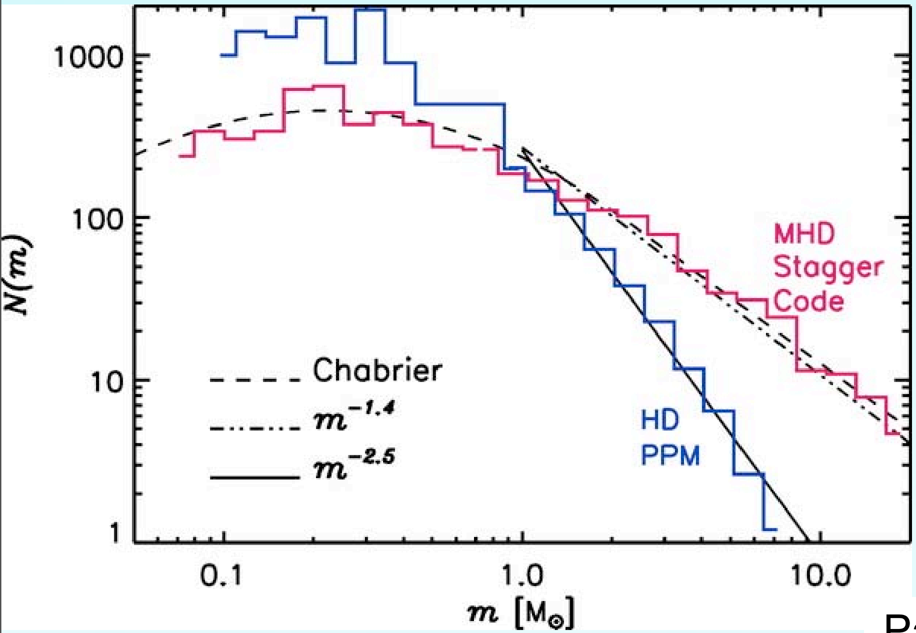
Alves+ 07

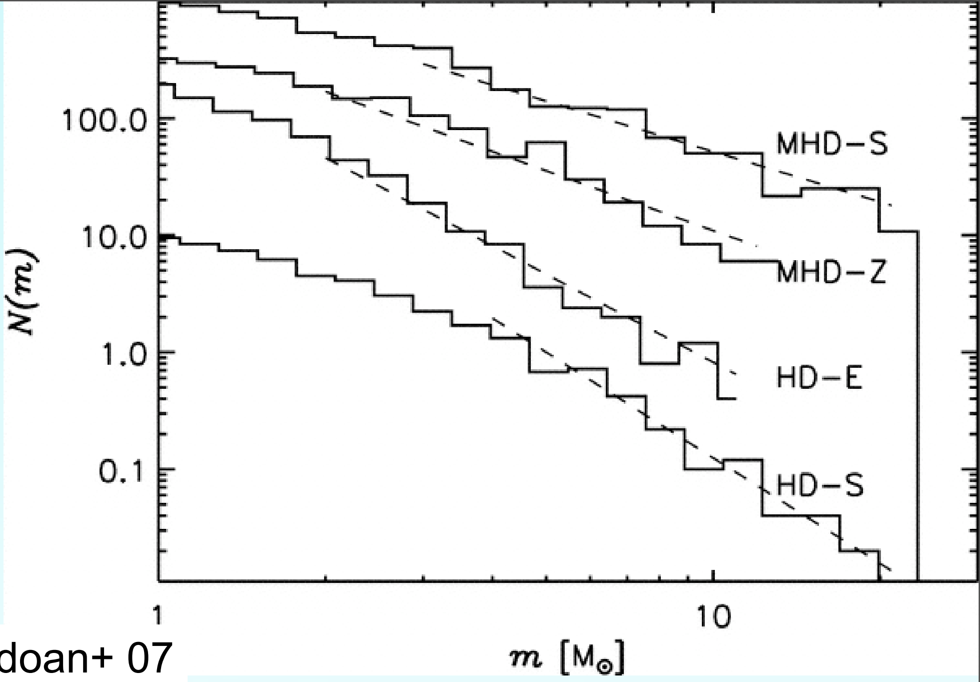


Stanke+ 06

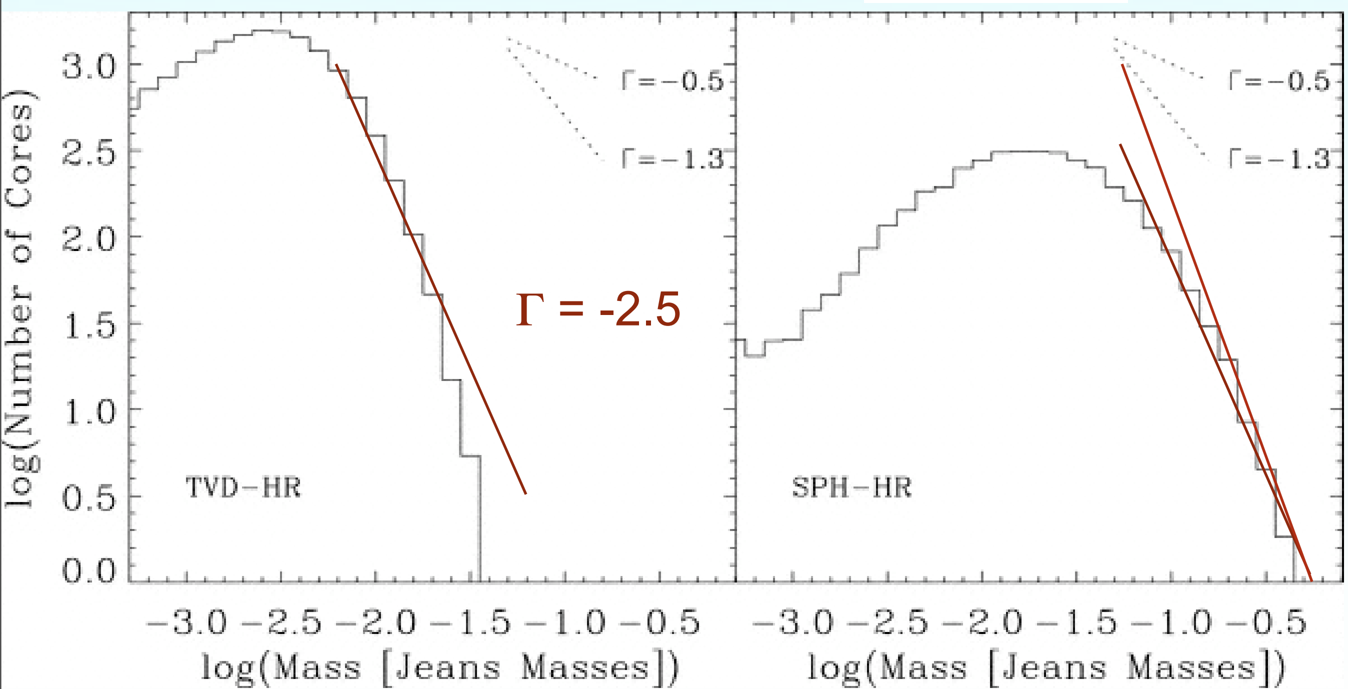


see also Motte+ 98; Testi & Sargent 98; Johnstone+ 00, 01; Motte+ 01; Beuther & Schilke 04





Padoan+ 07



Ballesteros-Paredes+ 06

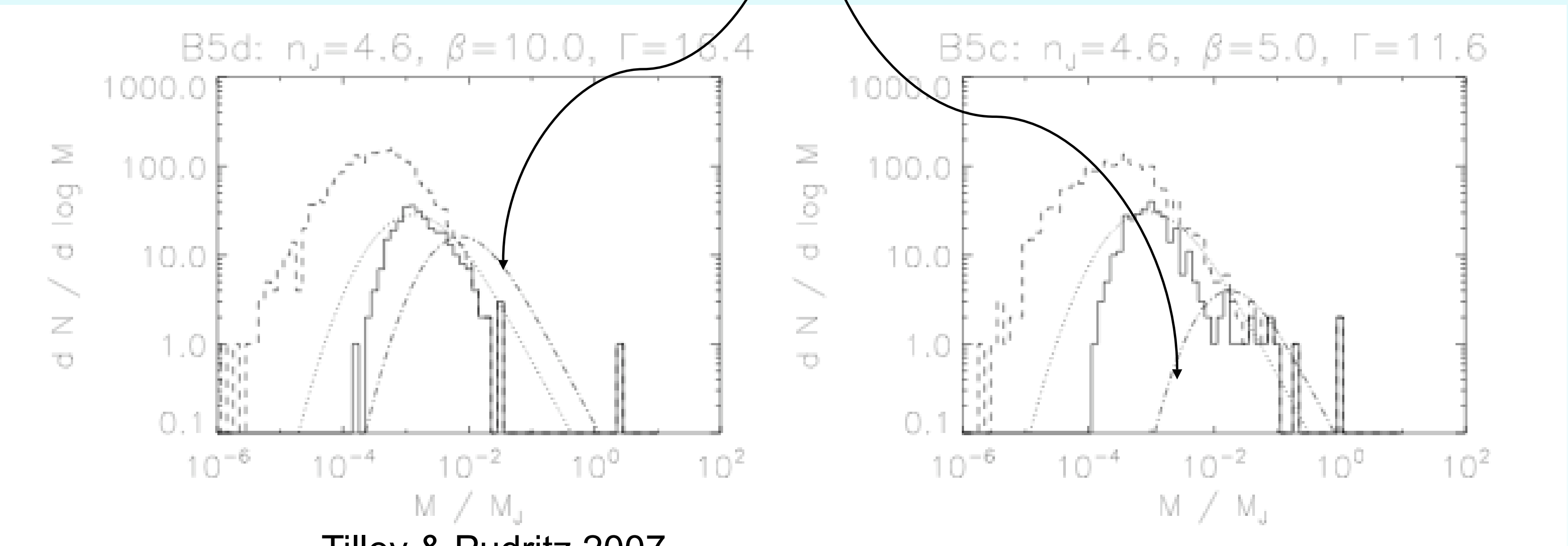
$$N(m)d\log m \propto m^{-x} d\log m$$

$$x = 3/(4-\beta) \quad \text{for MHD}$$

$$x = 3/(5-2\beta) \quad \text{for hydro}$$

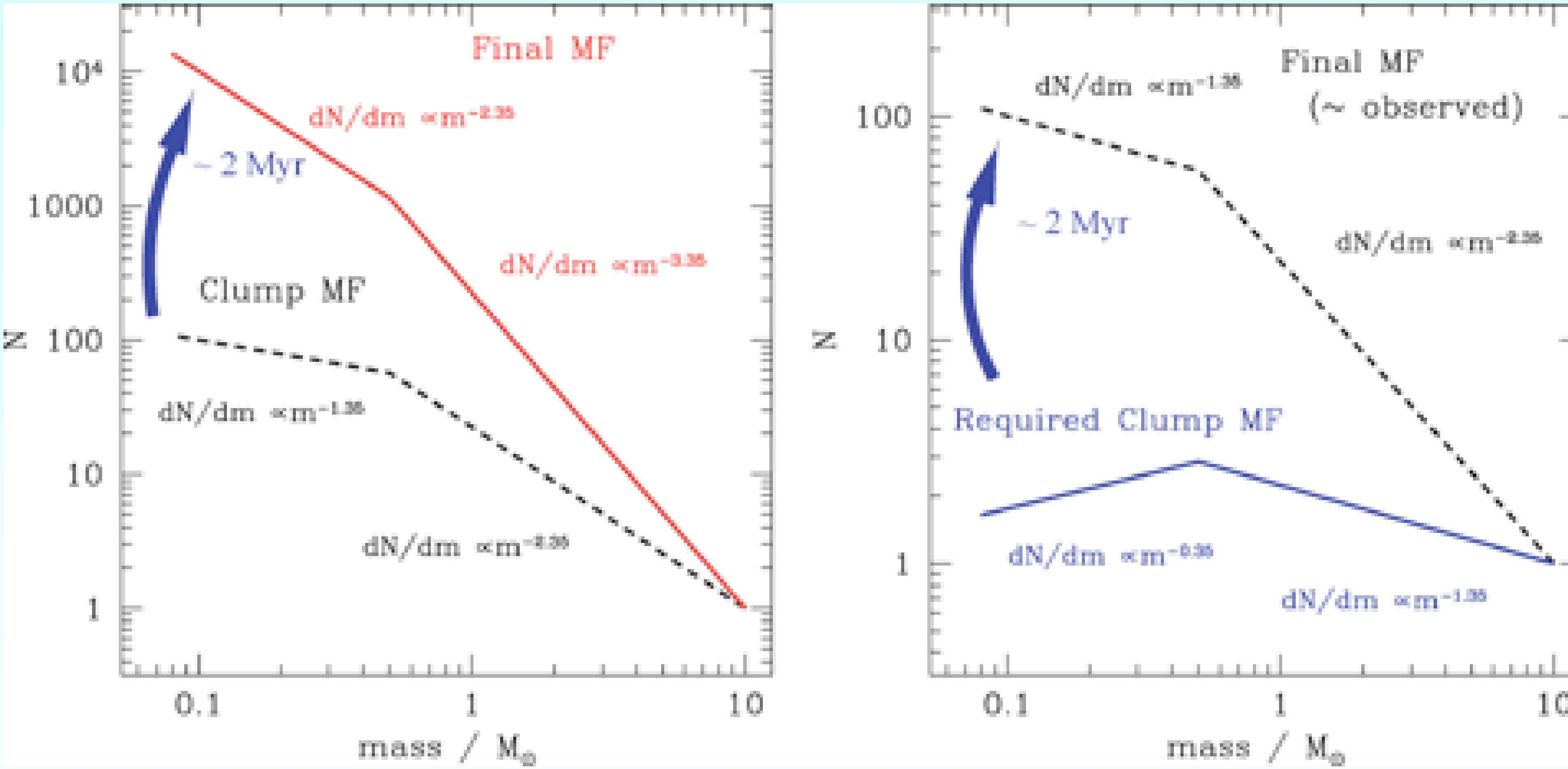
Padoan & Nordlund 02
Padoan+ 07

PN 02



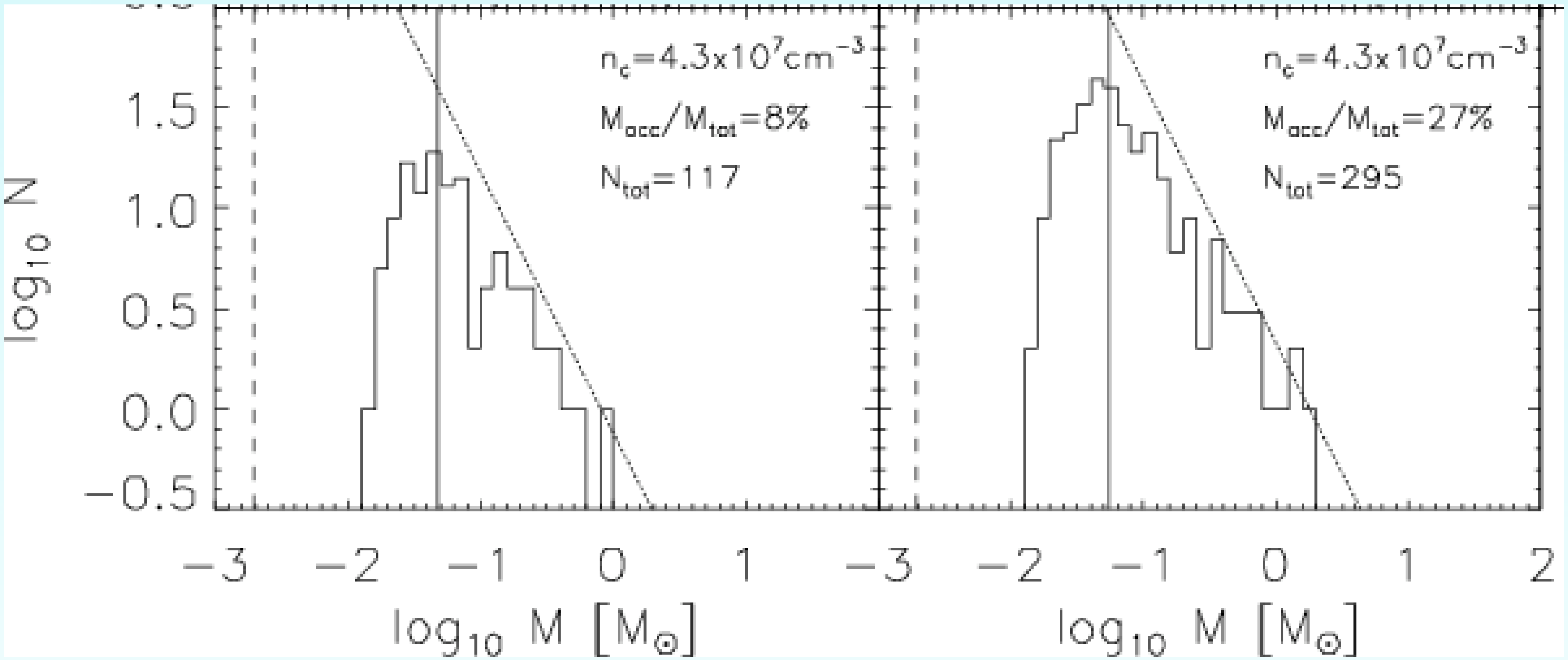
Tilley & Pudritz 2007

256^3 Zeus-MP


Final MF
~2 Myr
Clump MF
dN/dm ∝m
dN/dm ∝m
dN/dm ∝m
dN/dm ∝m
N
10⁴
1000
100
10
1
0.1
1
10
mass / M⊙
Final MF
(~ observed)
~2 Myr
Required Clump MF
dN/dm ∝m
dN/dm ∝m
dN/dm ∝m
dN/dm ∝m
N
100
10
1
0.1
1
10
mass / M⊙

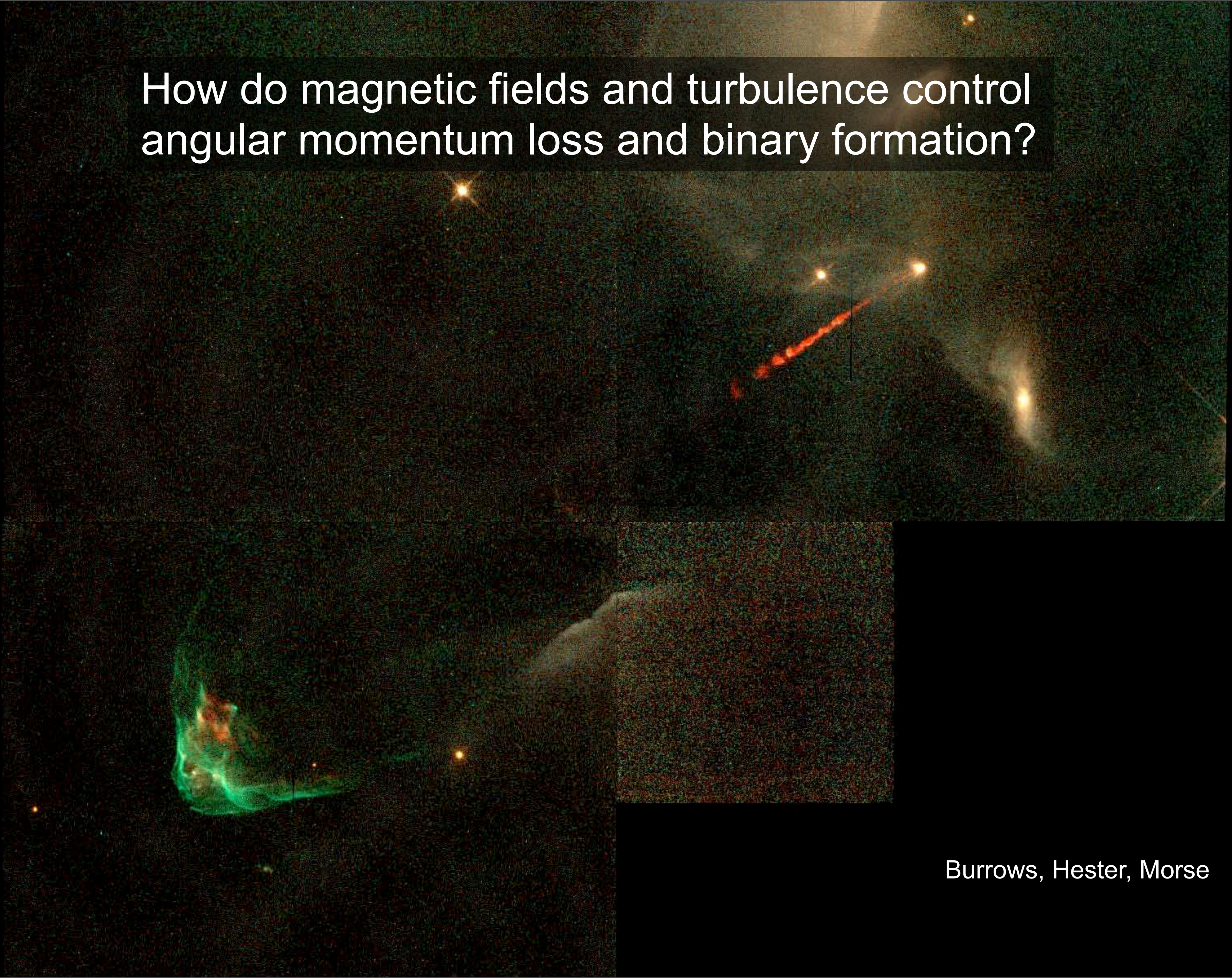
Clark+ 07

Another approach to turbulent fragmentation



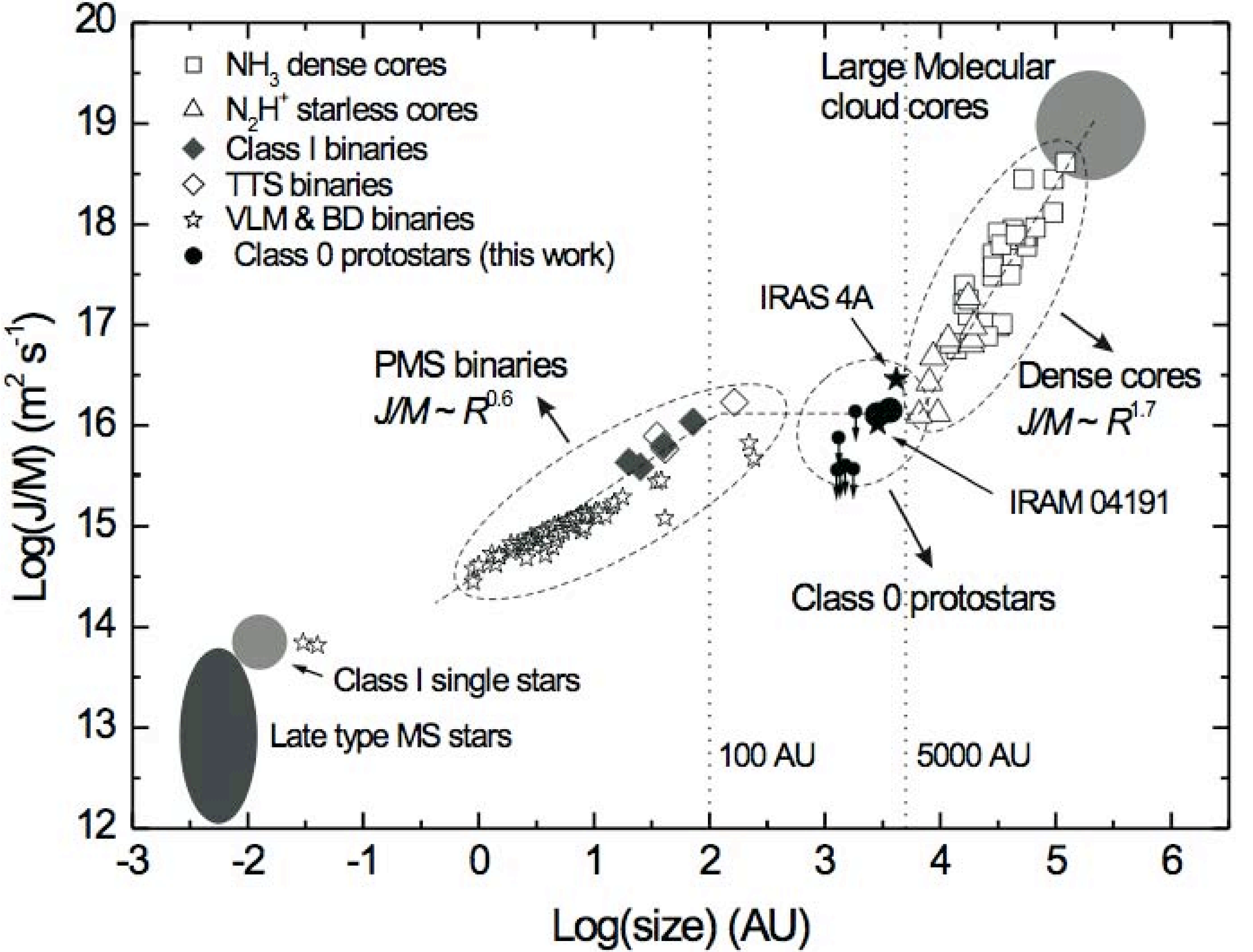
Jappsen+ 05, using Larson 05 EOS

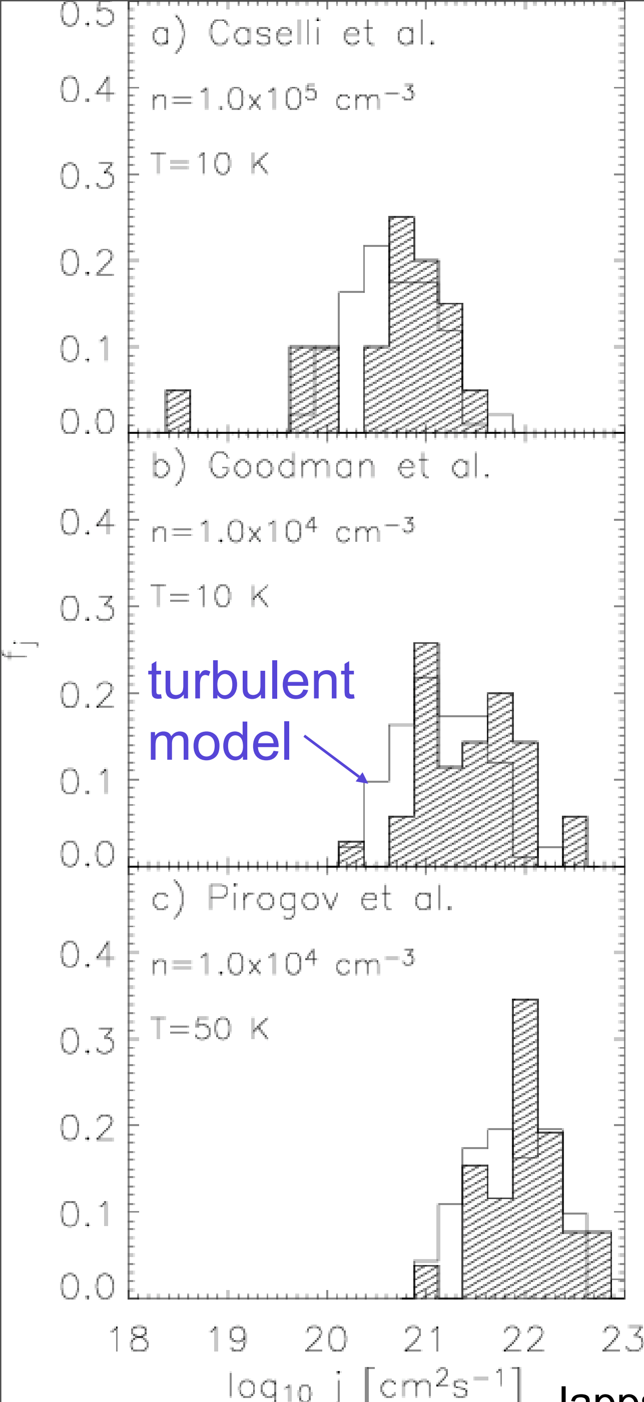
How do magnetic fields and turbulence control angular momentum loss and binary formation?



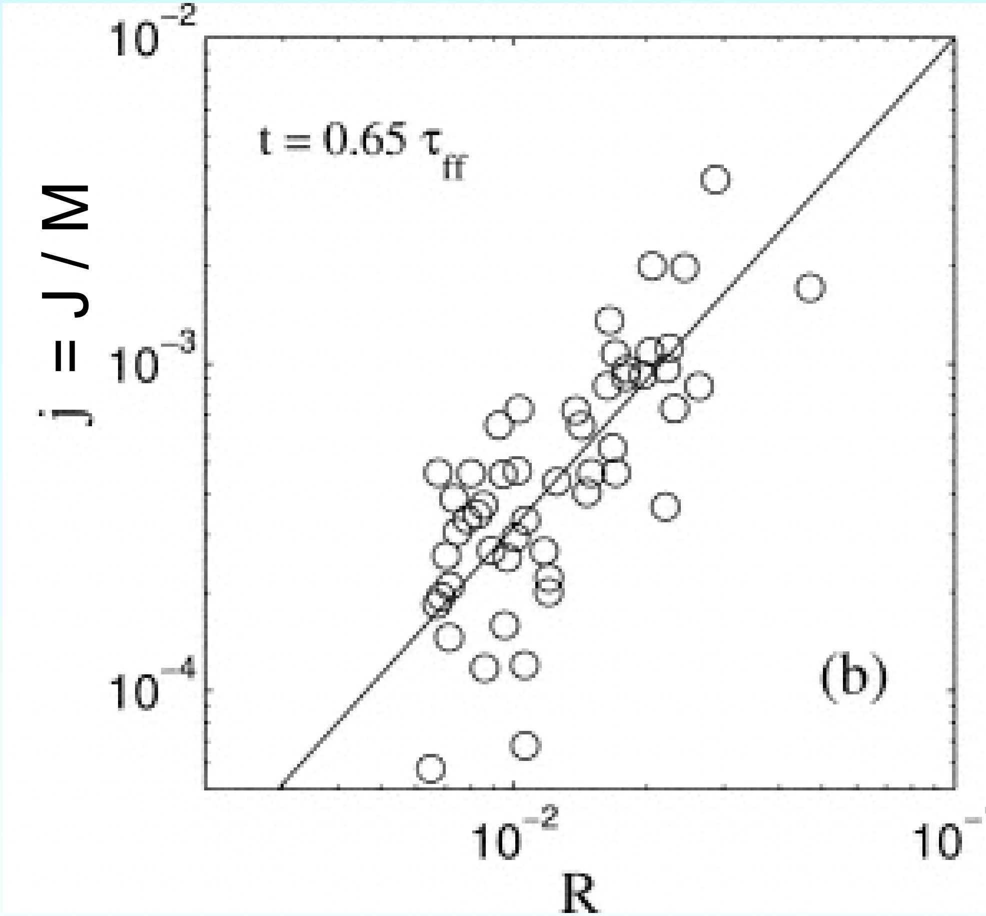
Burrows, Hester, Morse

Chen, Launhardt, Henning 07

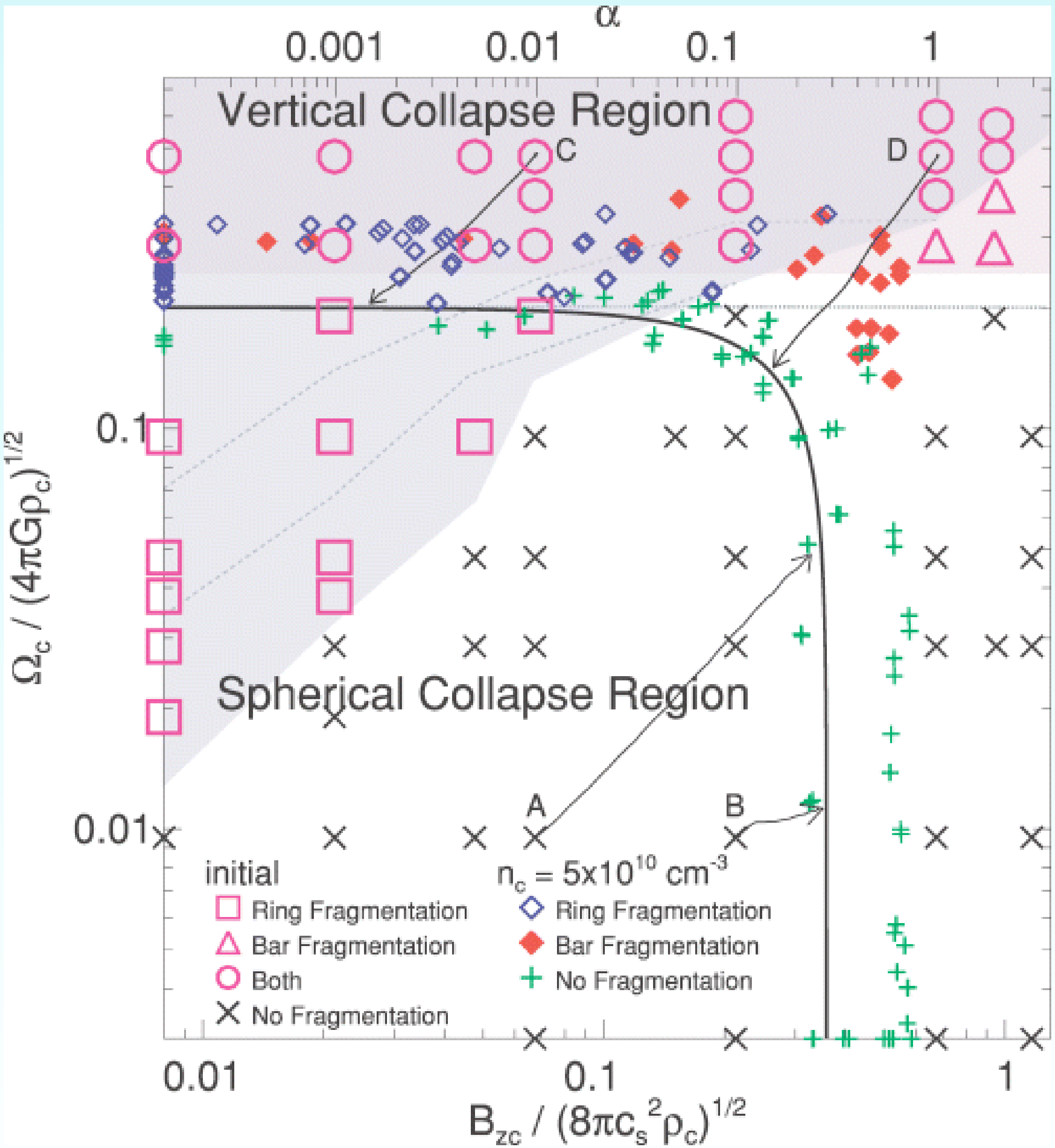




Jappsen & Klessen 04



P. Li+ 04



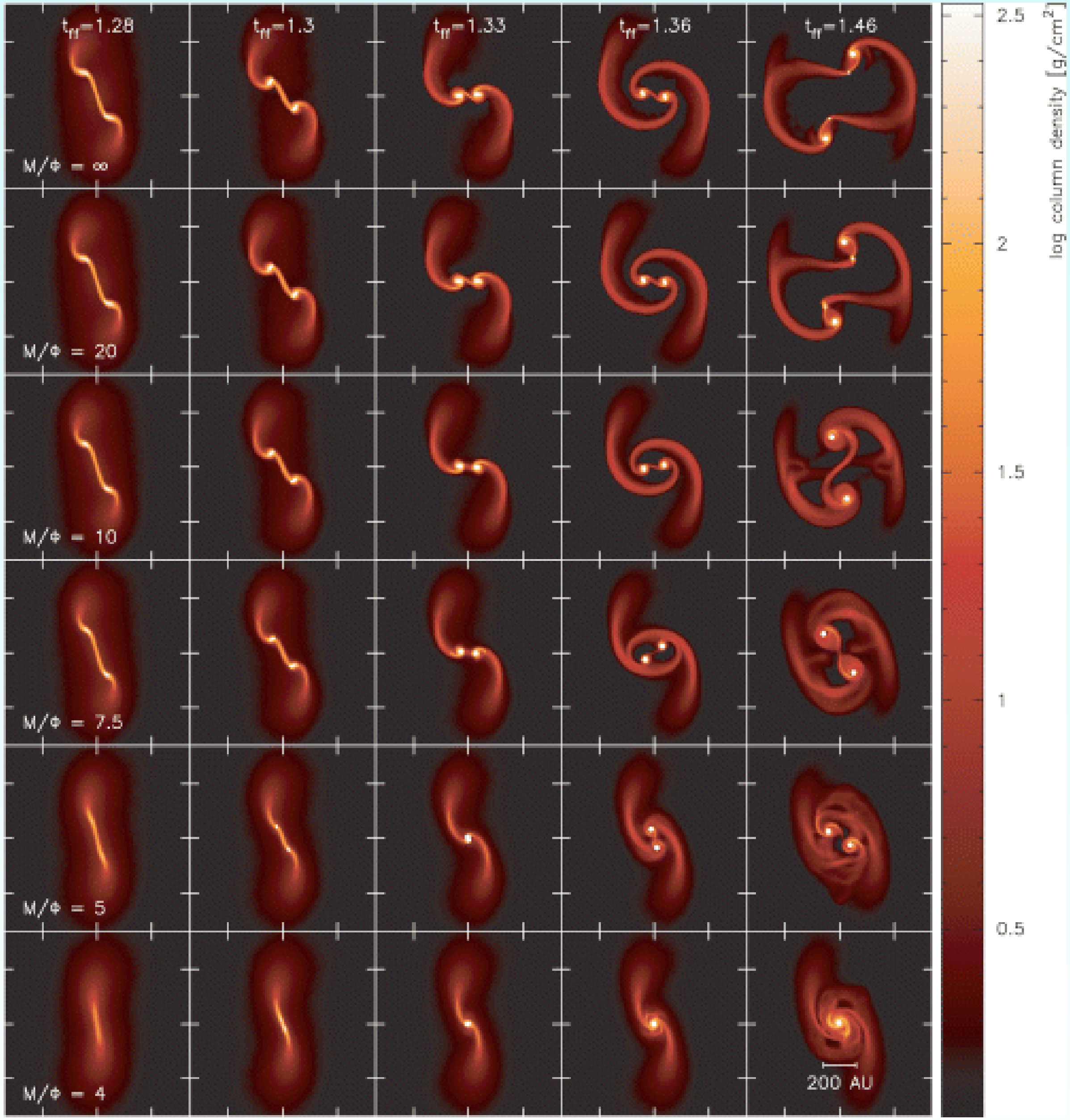
α
0.001
0.01
0.1
1
Vertical Collapse Region
C
D
0.1
0.01
Spherical Collapse Region
A
B
initial
Ring Fragmentation
Bar Fragmentation
Both
No Fragmentation
$n_c = 5 \times 10^{10}$ cm^{-3}
Ring Fragmentation
Bar Fragmentation
No Fragmentation
0.01
0.1
1
$B_{zc} / (8\pi c_s^2 \rho_c)^{1/2}$
$\Omega_c / (4\pi G \rho_c)^{1/2}$

Machida+ 05

hydro

M/Φ = 20

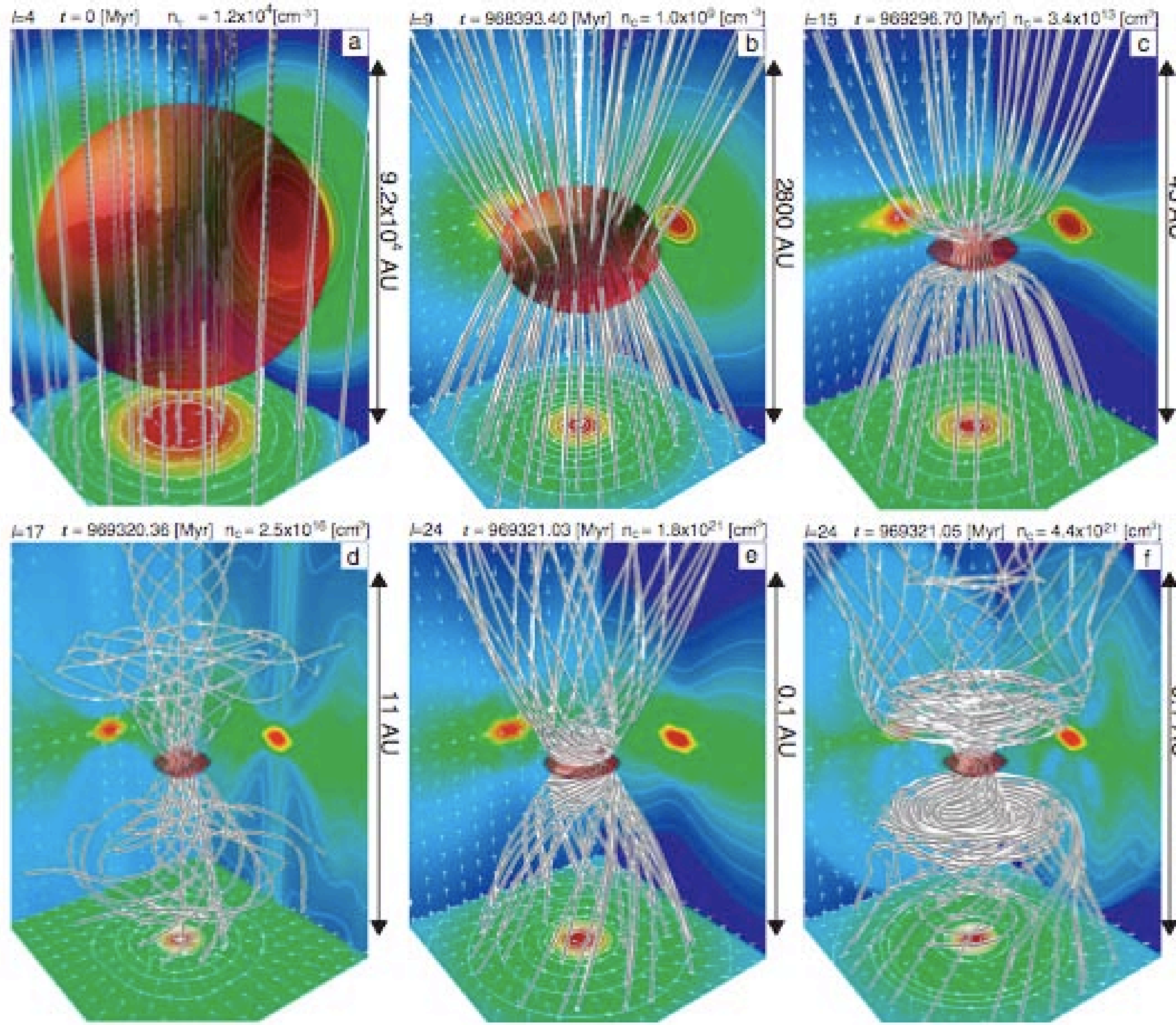
M/Φ = 4



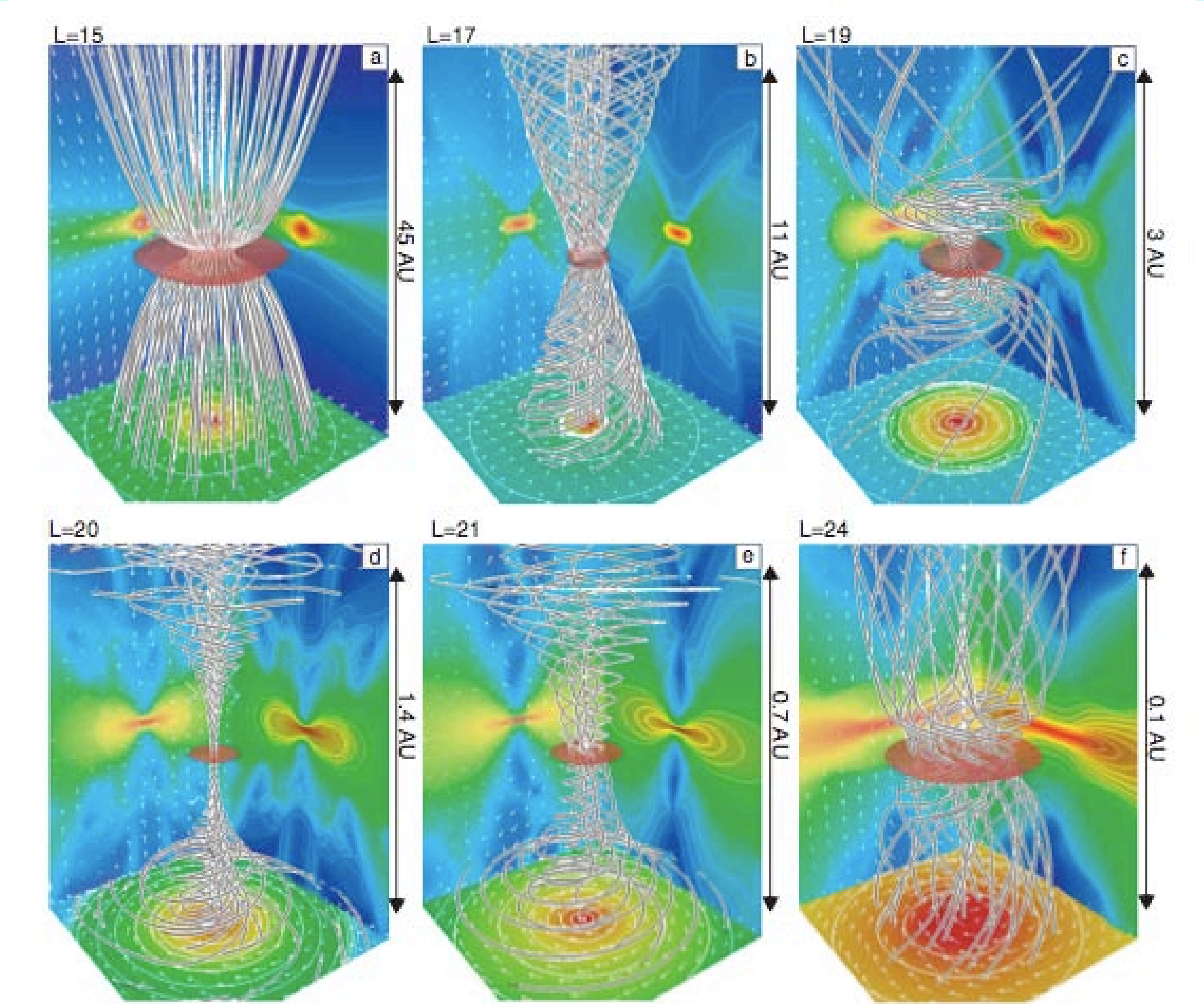
higher initial density perturbations make binaries more likely.

Price & Bate 07

300K MHD SPH


l=4 t = 0 [Myr] n_c = 1.2x10^4 [cm^-3]
a
9.2x10^4 AU
l=9 t = 968393.40 [Myr] n_c = 1.0x10^9 [cm^-3]
b
2800 AU
l=15 t = 969296.70 [Myr] n_c = 3.4x10^13 [cm^-3]
c
45 AU
l=17 t = 969320.36 [Myr] n_c = 2.5x10^16 [cm^-3]
d
11 AU
l=24 t = 969321.03 [Myr] n_c = 1.8x10^21 [cm^-3]
e
0.1 AU
l=24 t = 969321.05 [Myr] n_c = 4.4x10^21 [cm^-3]
f
0.1 AU

Machida+ 07



Machida+ 07