Numerical Simulations of Filament Formation and Fragmentation

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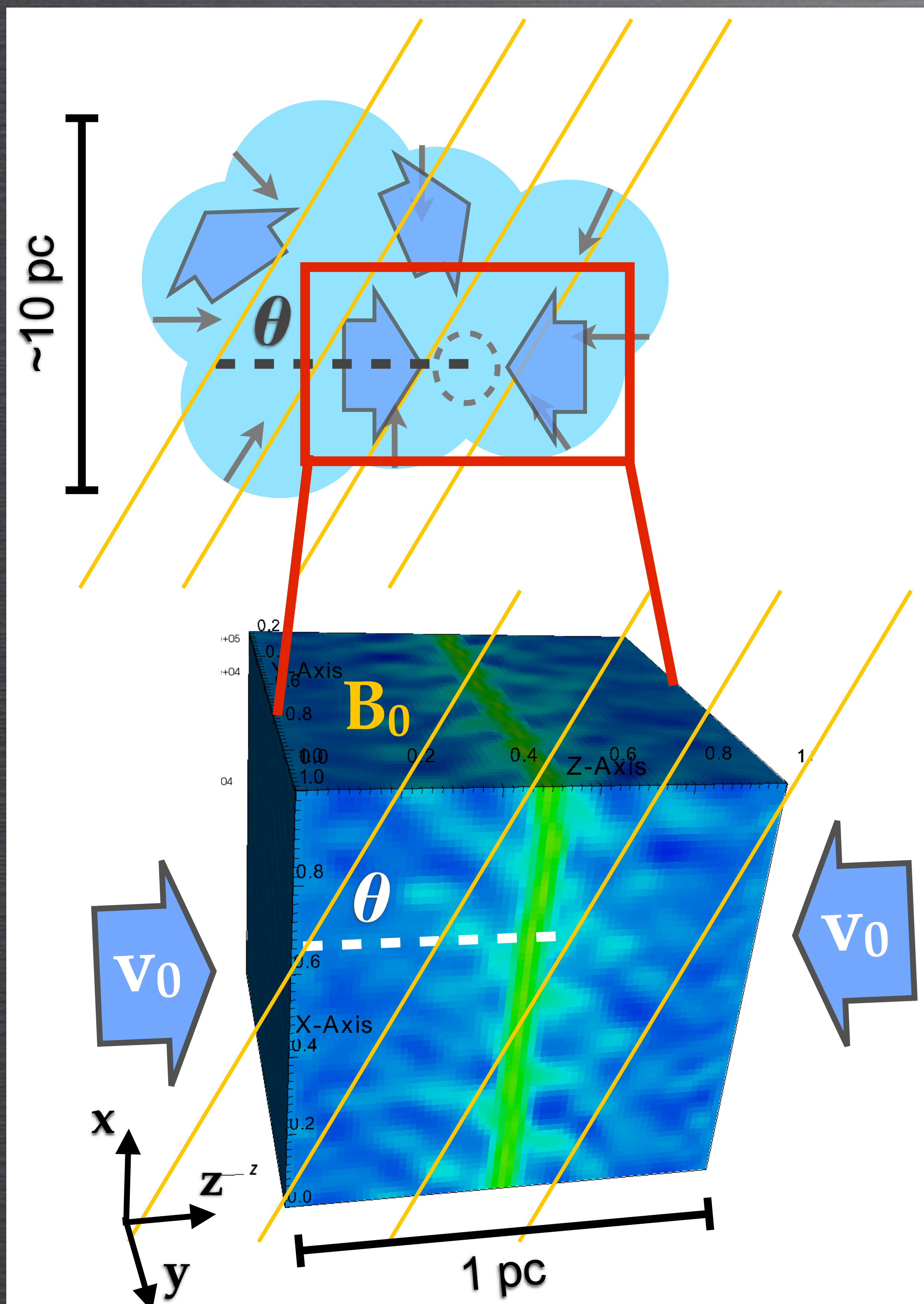
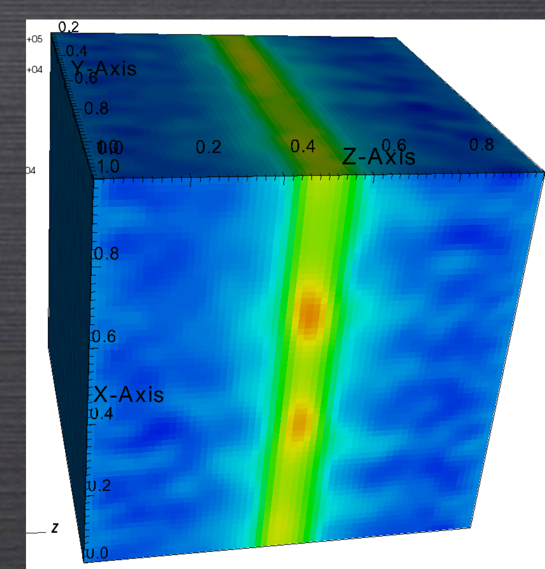
with Eve Ostriker
Lee Mundy
Shaye Storm
and The CLASSy Collaboration

Filaments 2014, NRAO

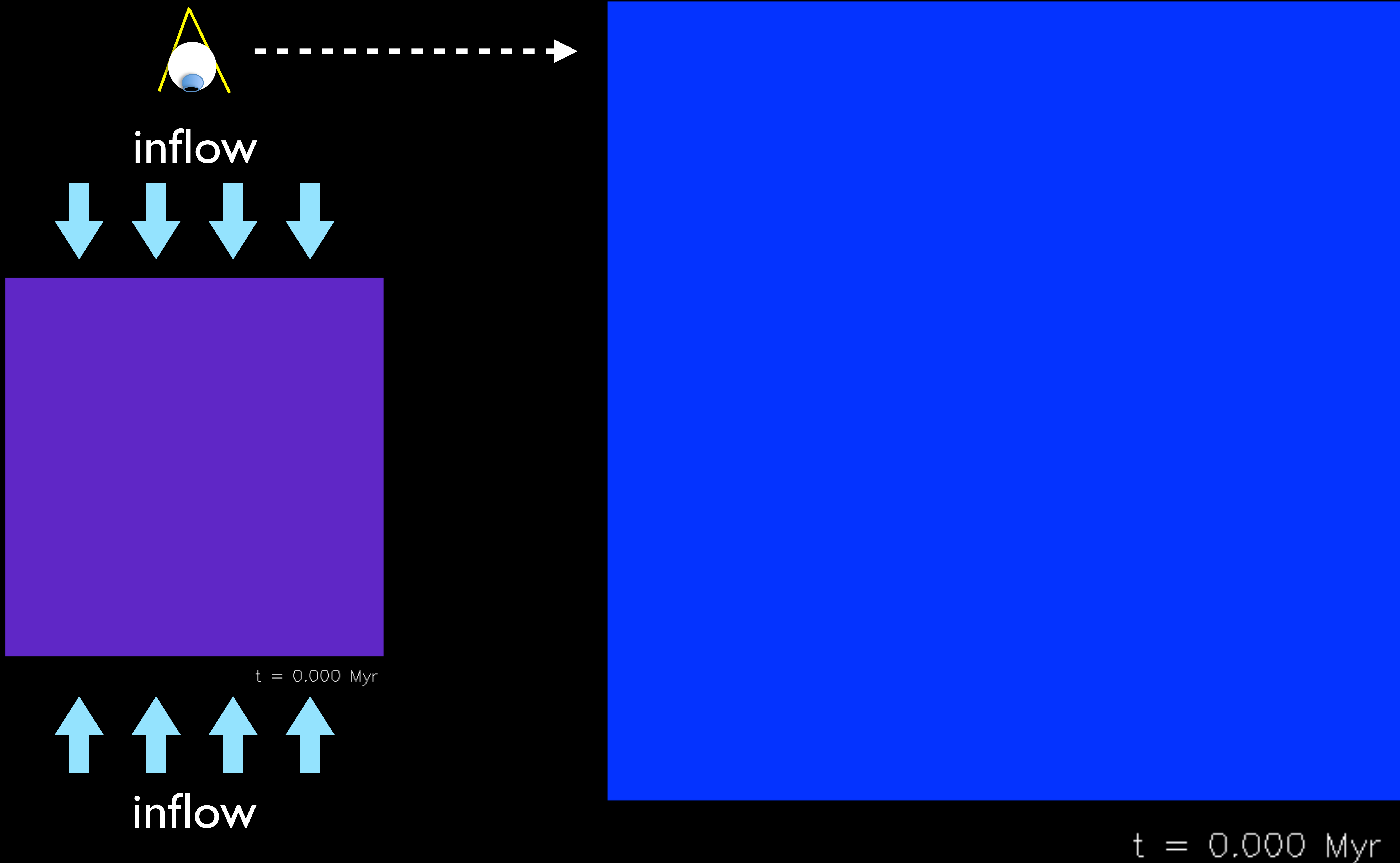
Simulation Setup



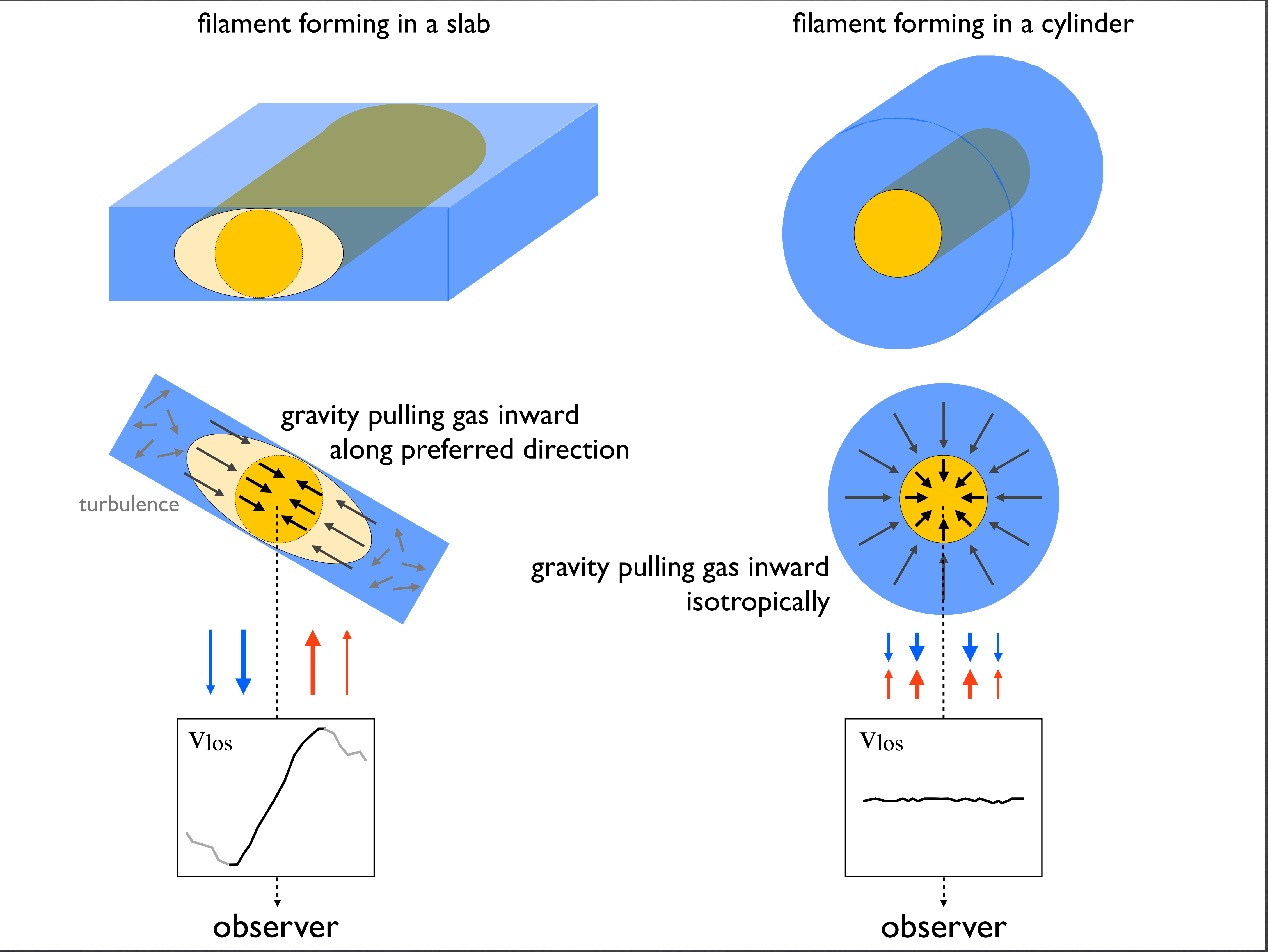
- Oblique MHD shocks
- Include:
  - self-gravity
  - perturbation field
  - ambipolar diffusion
- cloud density:
  - $n_0 = 1000\ cm^{-3}$



Structure Formation

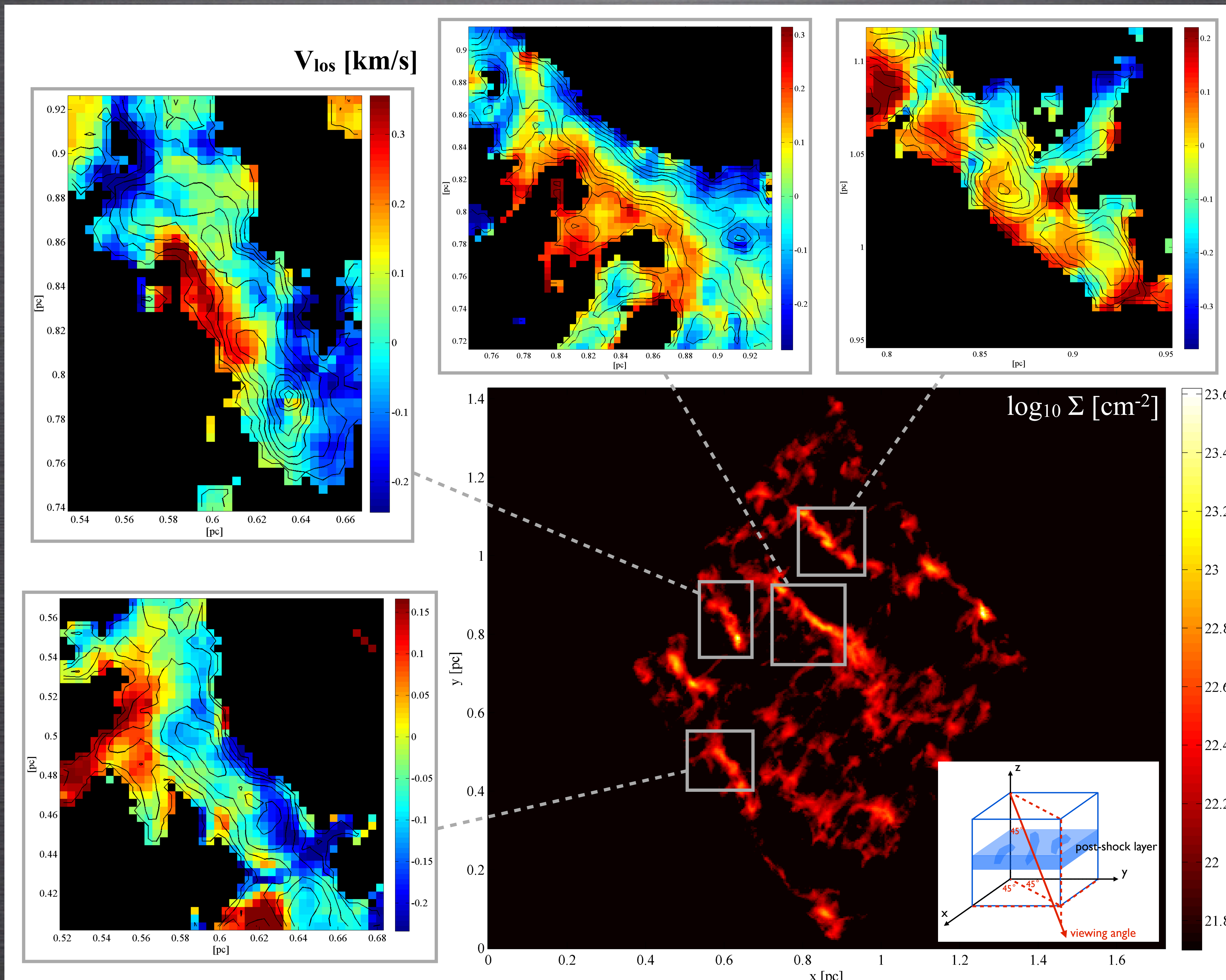


Kinematics



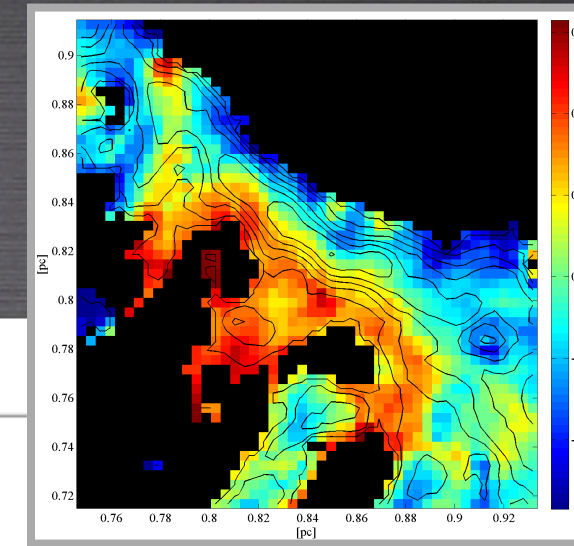
(Mundy et al. *in prep.*)

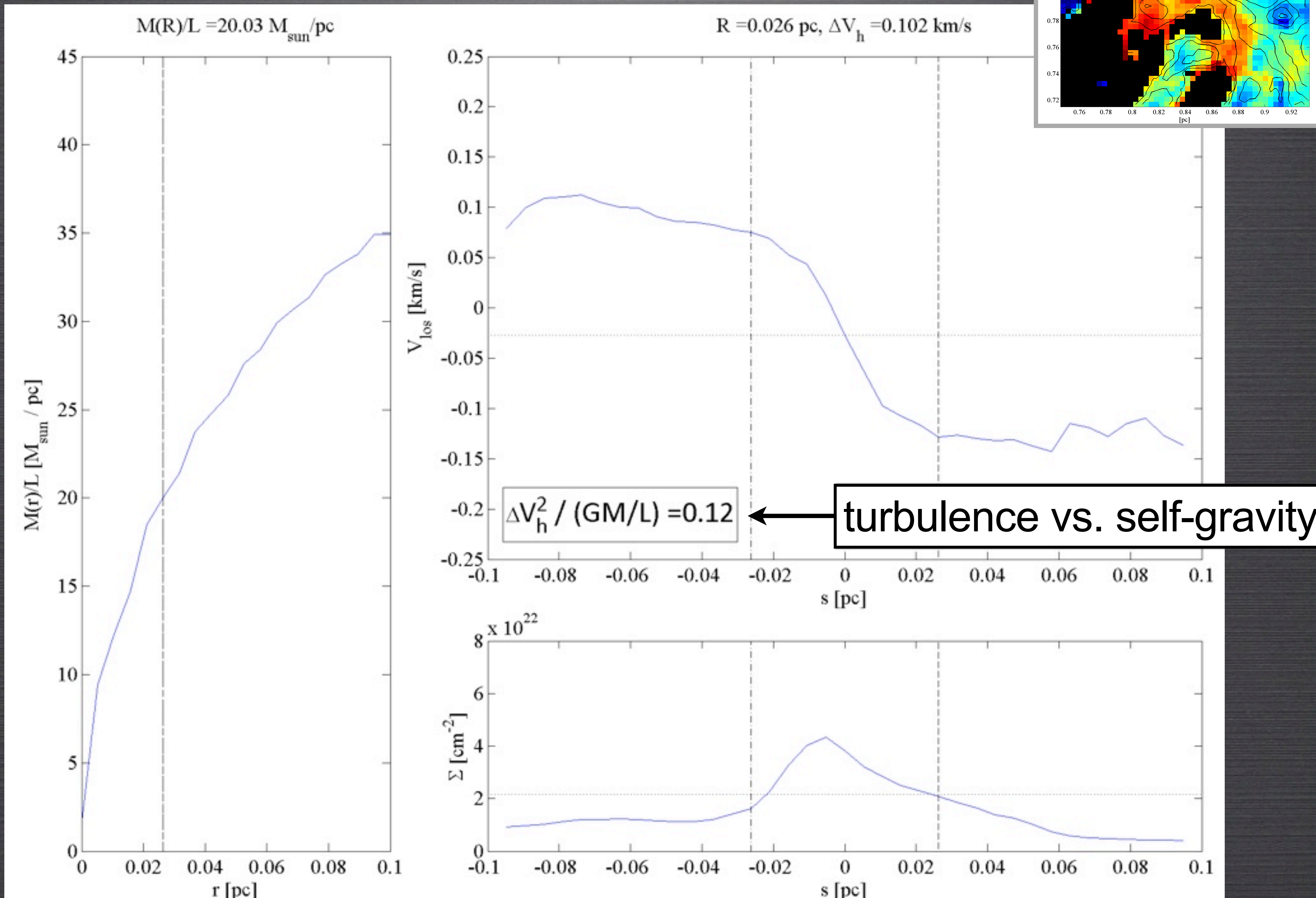
Line-of-sight Velocity



(Mundy et al. *in prep.*)

Filament Structure

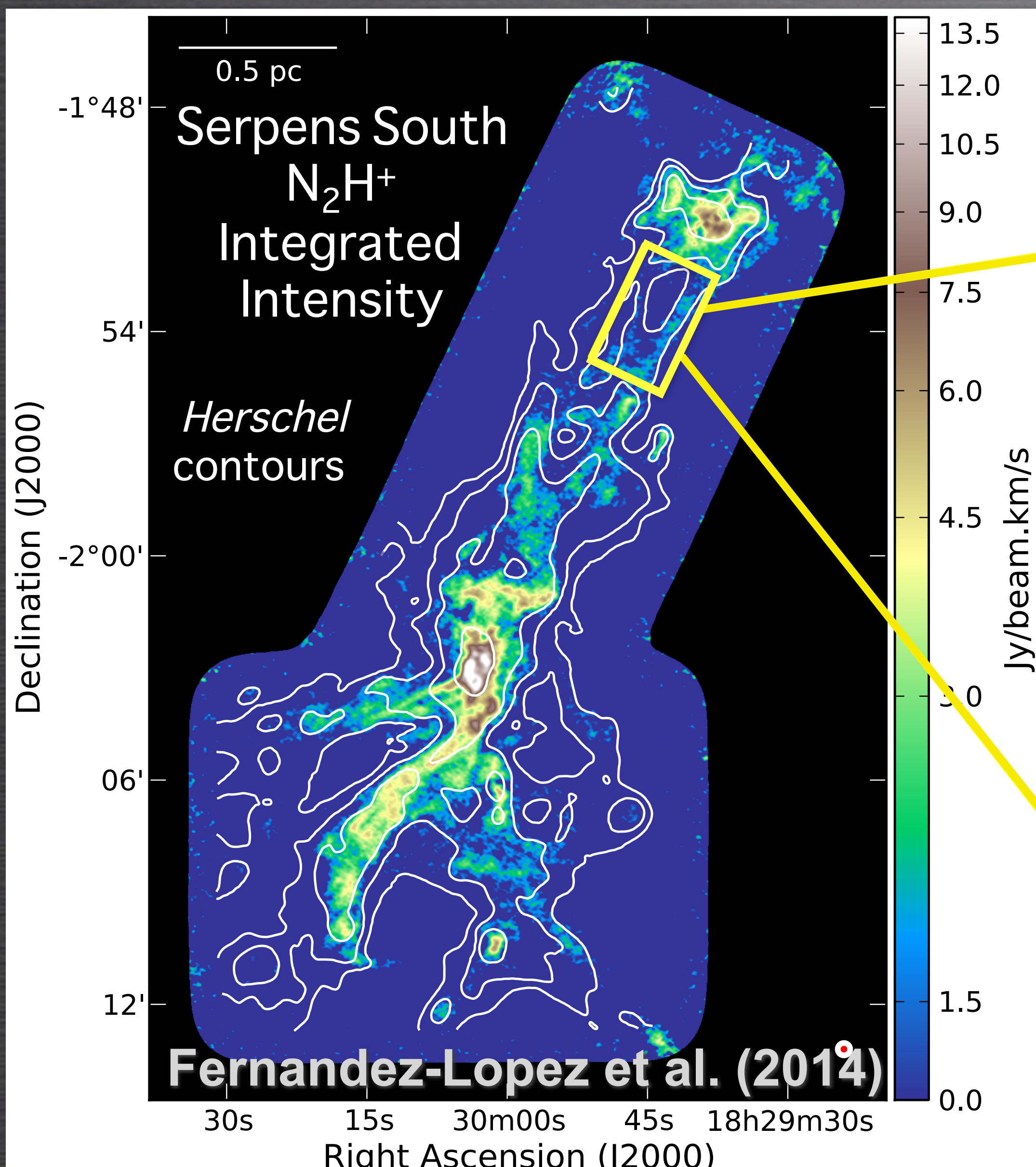




(Mundy et al. *in prep.*)

Observations

- CLASSy results



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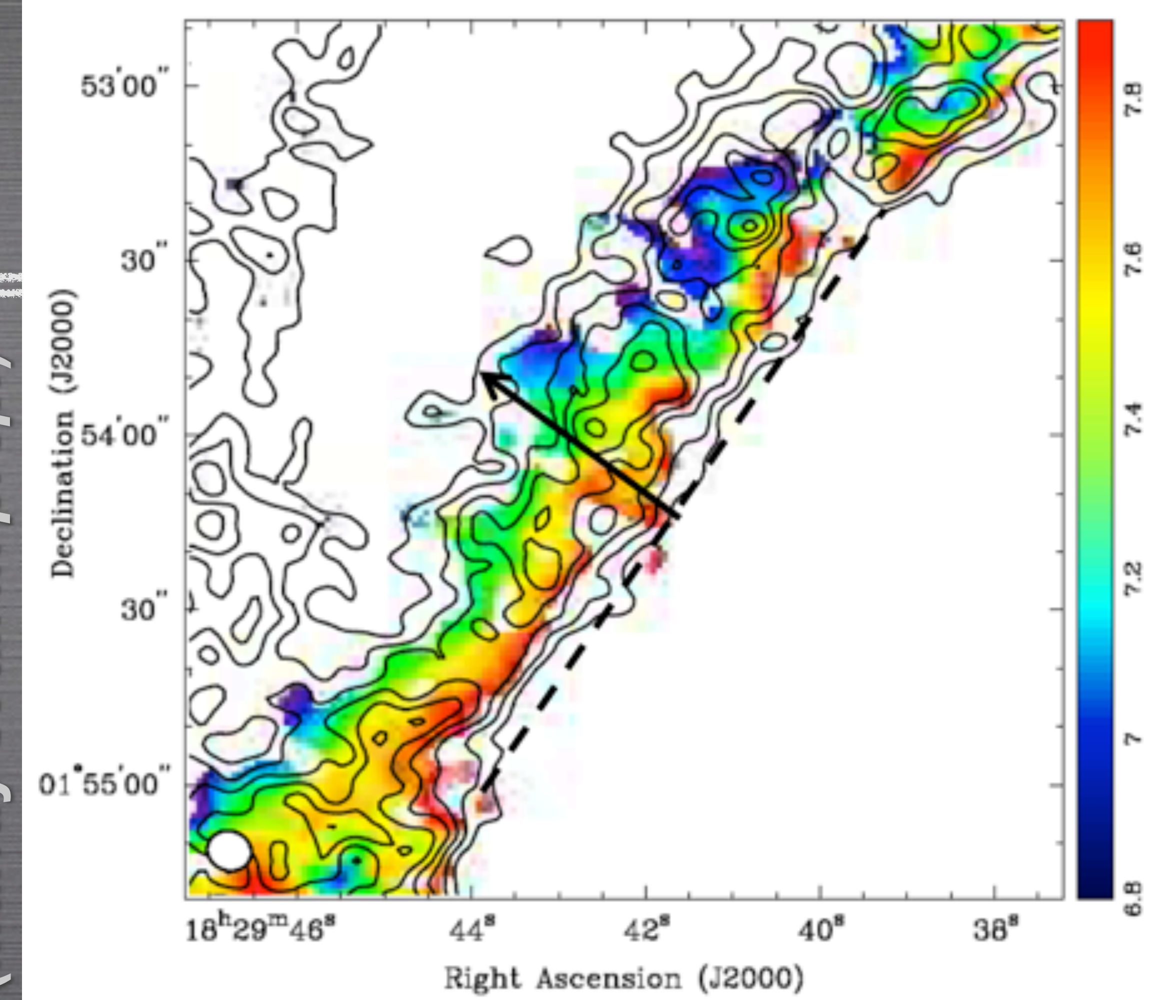
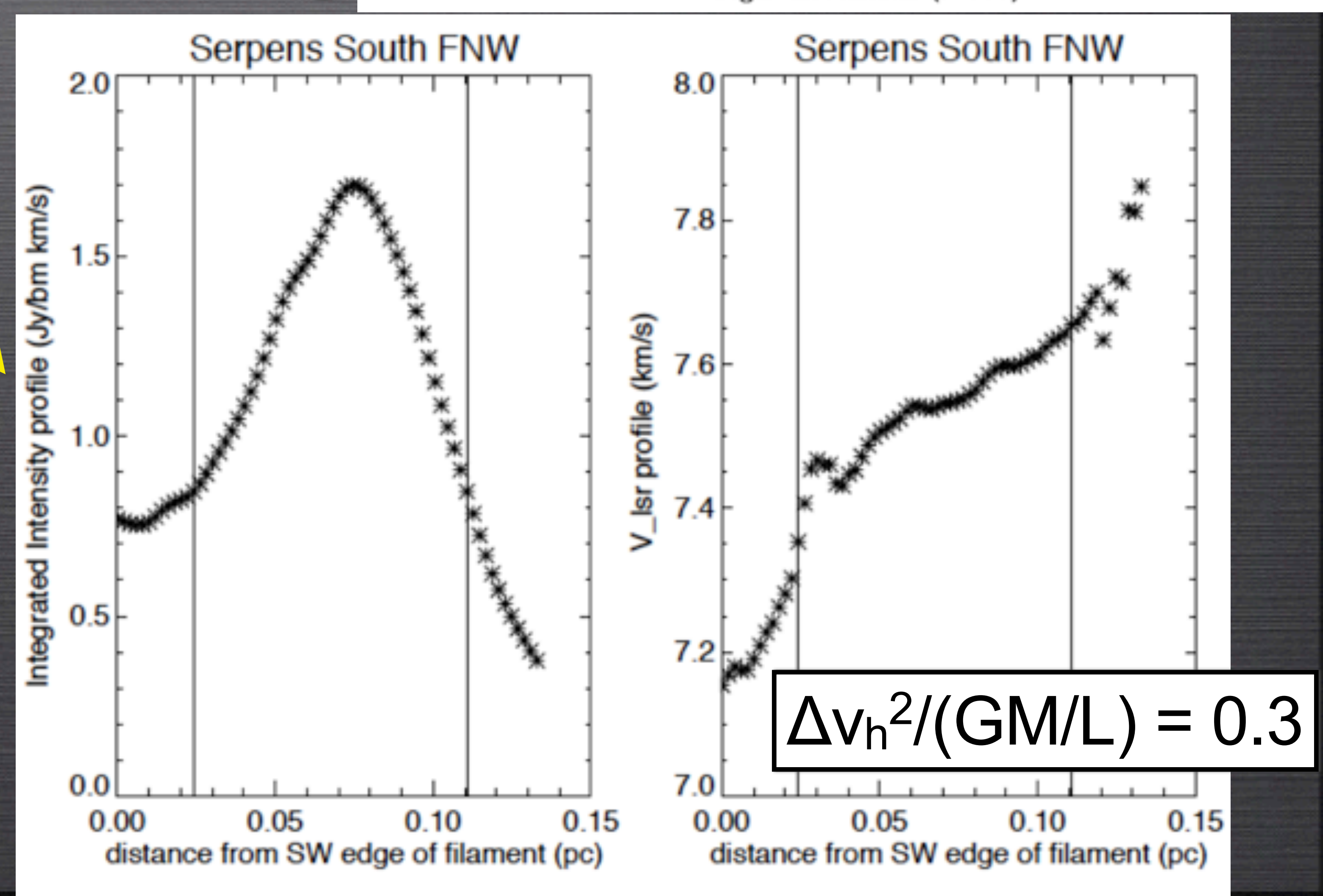


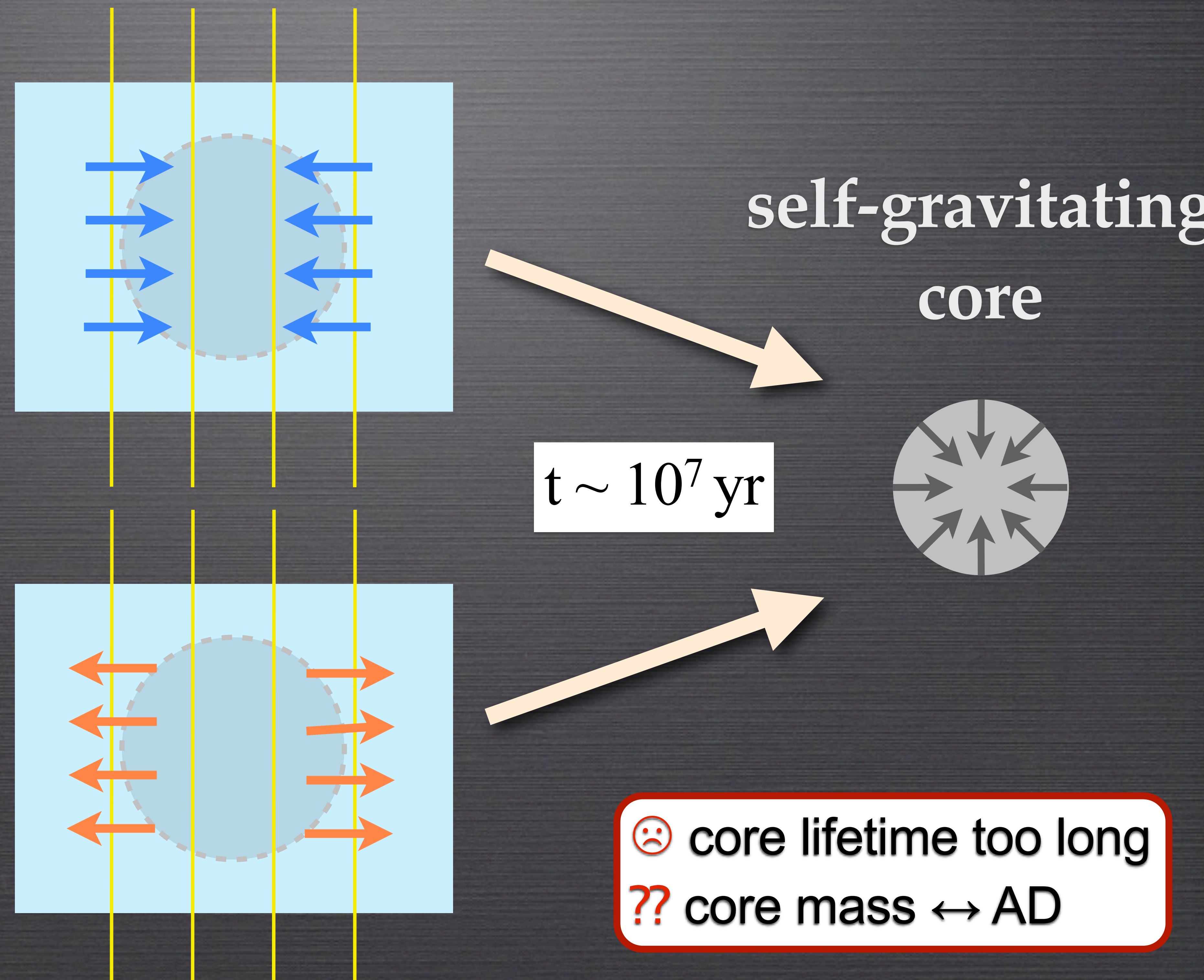


see also S. Storm's poster
K. Lee's poster

Core Formation

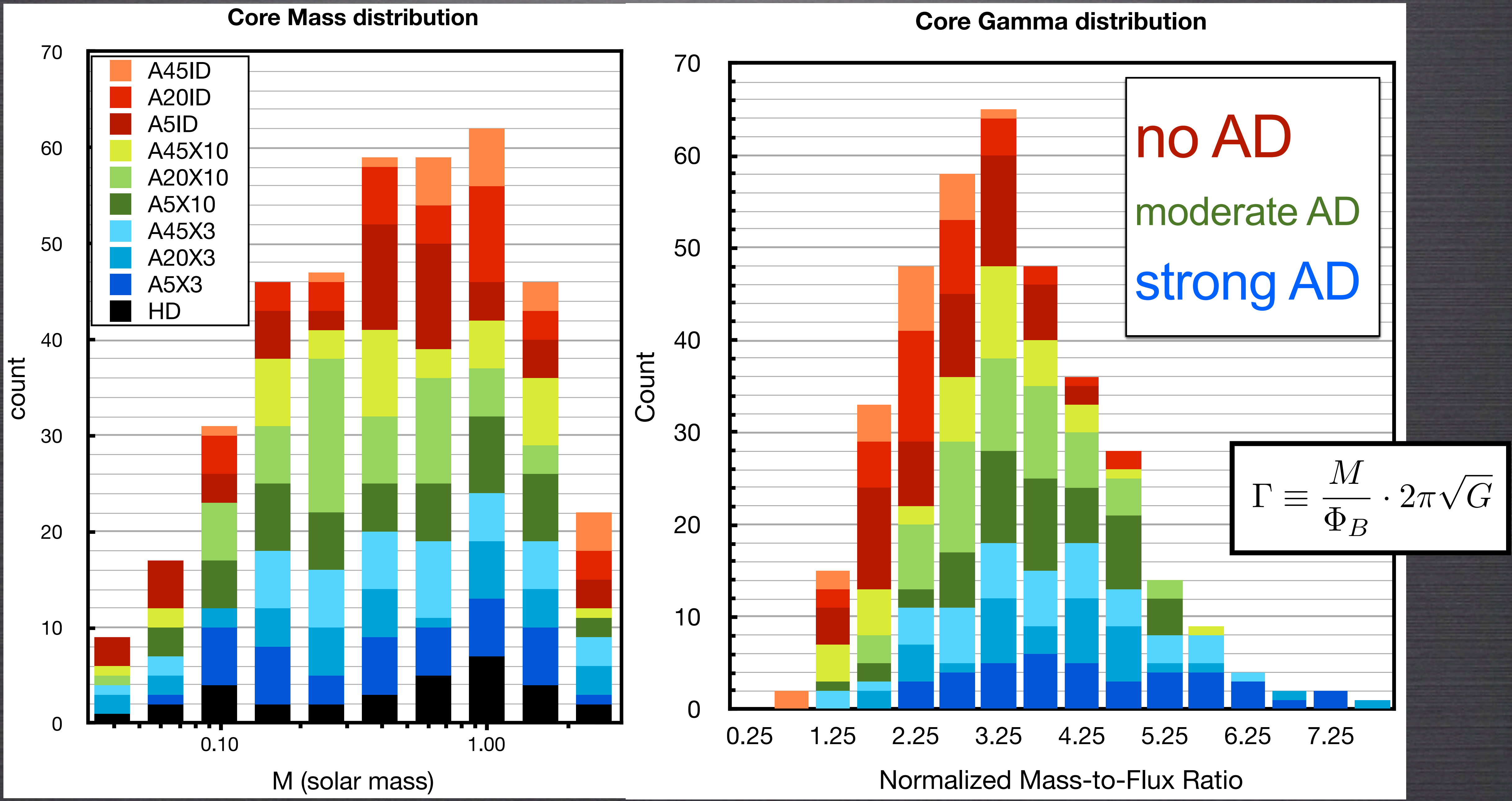
- Classical picture

quasi-static
fragmentation
through
ambipolar
diffusion



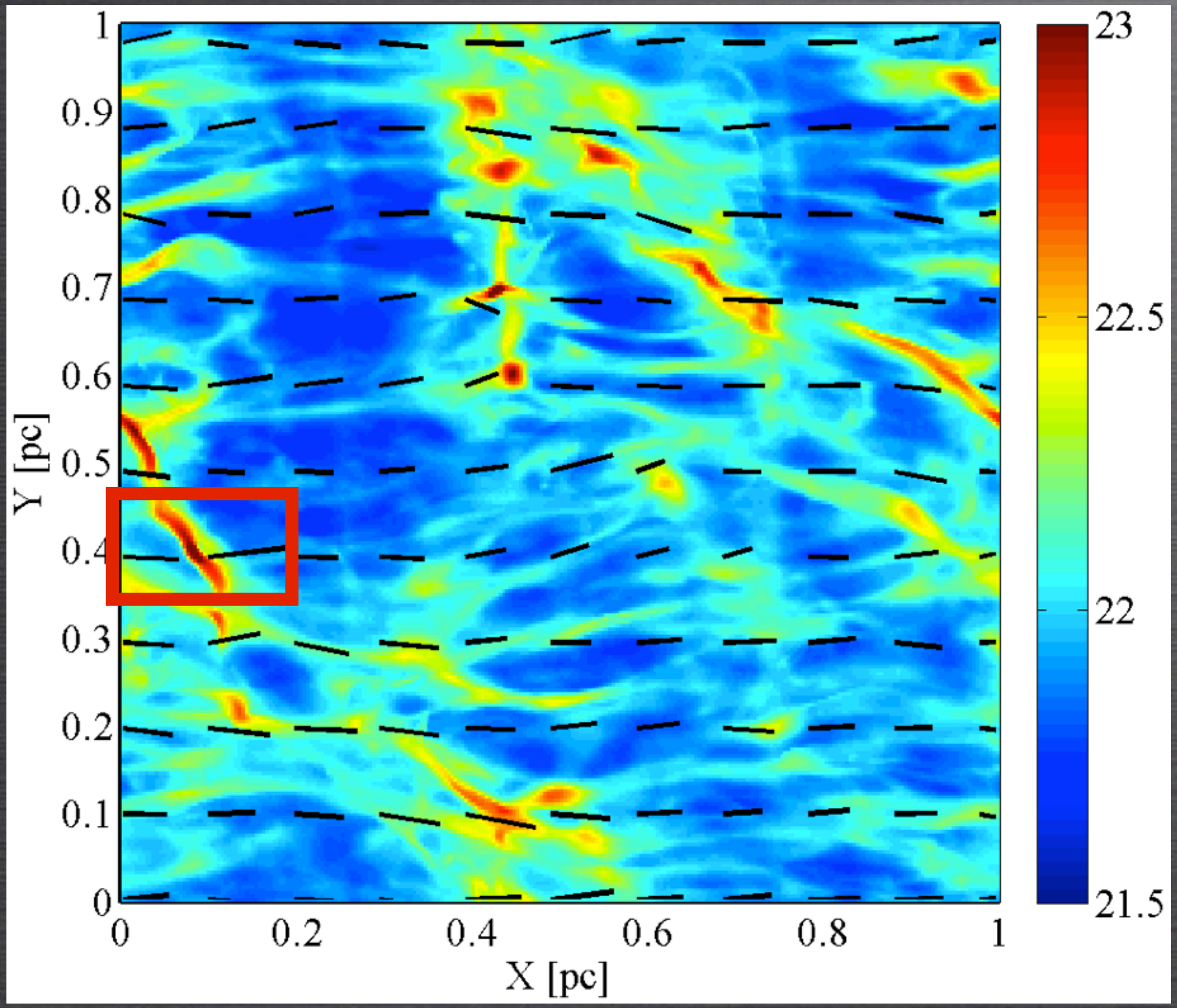
Simulation Results

- Models with same pre-shock pressure
  ⇒ similar core masses, with or without AD

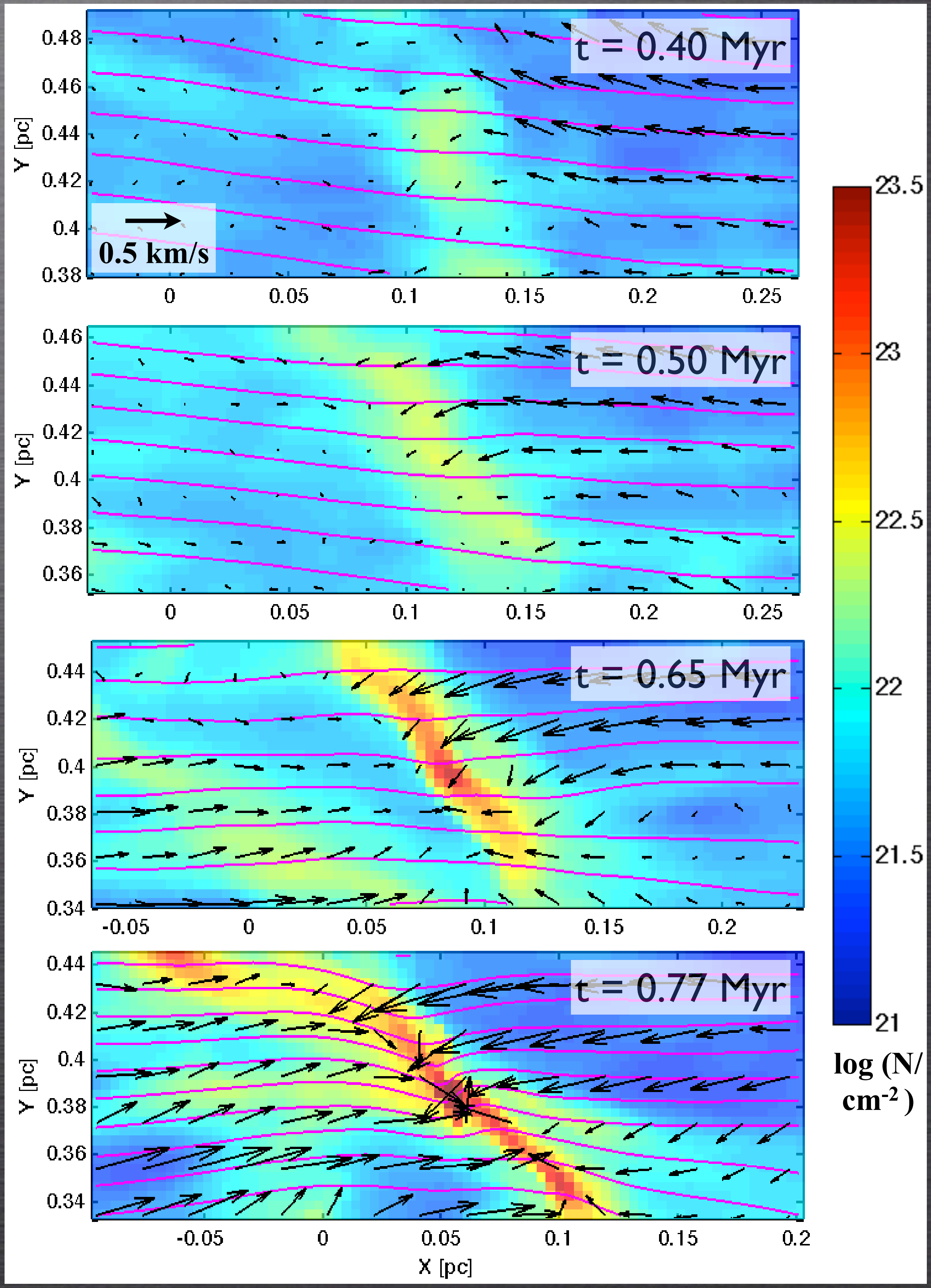


(Chen & Ostriker 2014)

Anisotropic Gas Flows

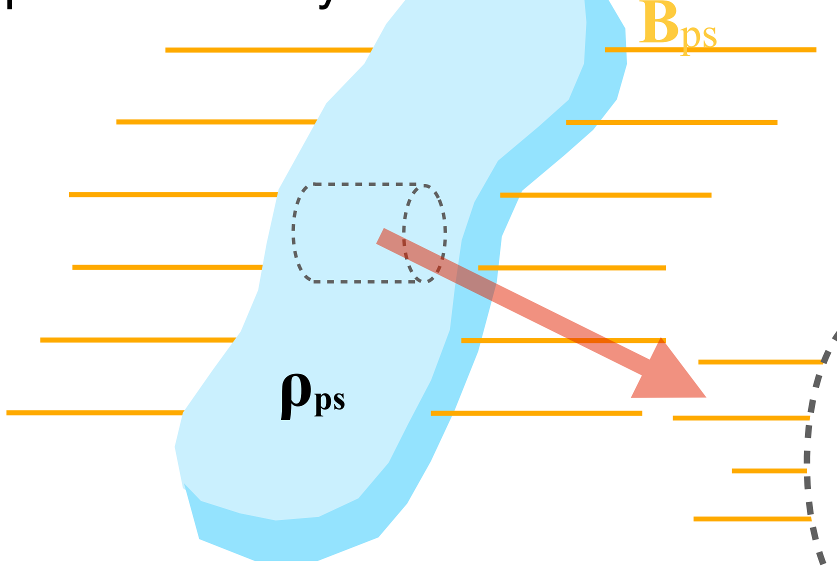


(Chen & Ostriker 2014)



Anisotropic Core Formation

filament formed in post-shock layer

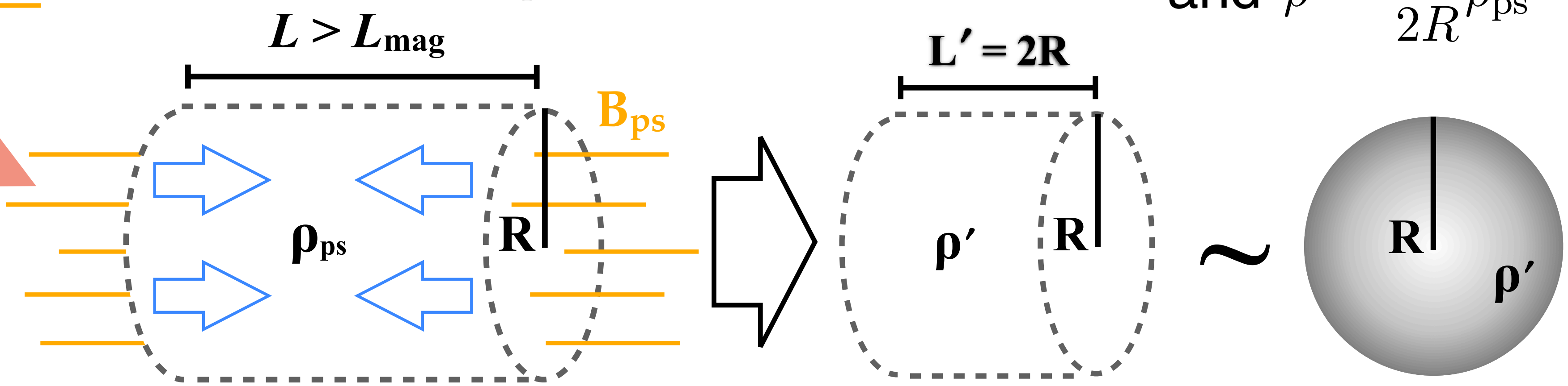


Magnetic critical length

$$L_{\rm mag} = \frac{B_{\rm ps}}{\rho_{\rm ps}} \frac{1}{2\pi\sqrt{G}}$$

contract longitudinally until $L' \sim 2R$

and $\rho' = \dfrac{L}{2R}\rho_{\rm ps}$



Thermally supercritical: $R \sim R_{\rm BE}\left(\rho'\right) = 0.65\dfrac{c_s}{\sqrt{G\rho'}}$ ➡ $R = 0.84\dfrac{{c_s}^2}{G\rho_{\rm ps}L}$,

$$M = \pi R^2 L \rho_{\rm ps} = 2.2\frac{{c_s}^4}{G^2\rho_{\rm ps}L}$$

Magnetically critical, Anisotropic

$L = L_{\rm mag}$ ➡ $\rho_{\rm ps}L = \dfrac{B_{\rm ps}}{2\pi\sqrt{G}}$

$$M_{\rm crit,cyl} = 14\frac{{c_s}^4}{\sqrt{G^3}B_{\rm ps}}$$

$$= 1.3\ {\rm M}_\odot \left(\frac{B_{\rm ps}}{50\ \mu{\rm G}}\right)^{-1}\left(\frac{T}{10\ {\rm K}}\right)^2$$

$$= 2.8\frac{c_s}{\sqrt{G^3\rho_0{v_0}^2}} \propto \mathcal{M}^{-1}$$

Magnetically critical, Isotropic

Spherical core with $R = \dfrac{L_{\rm mag}}{2} = \dfrac{B_{\rm ps}}{4\pi\sqrt{G}\rho_{\rm ps}}$

$$M_{\rm crit,sph} = \frac{4\pi R^3}{3}\rho_{\rm ps} = \frac{1}{48\pi^2 G^{3/2}}\frac{{B_{\rm ps}}^3}{{\rho_{\rm ps}}^2}$$

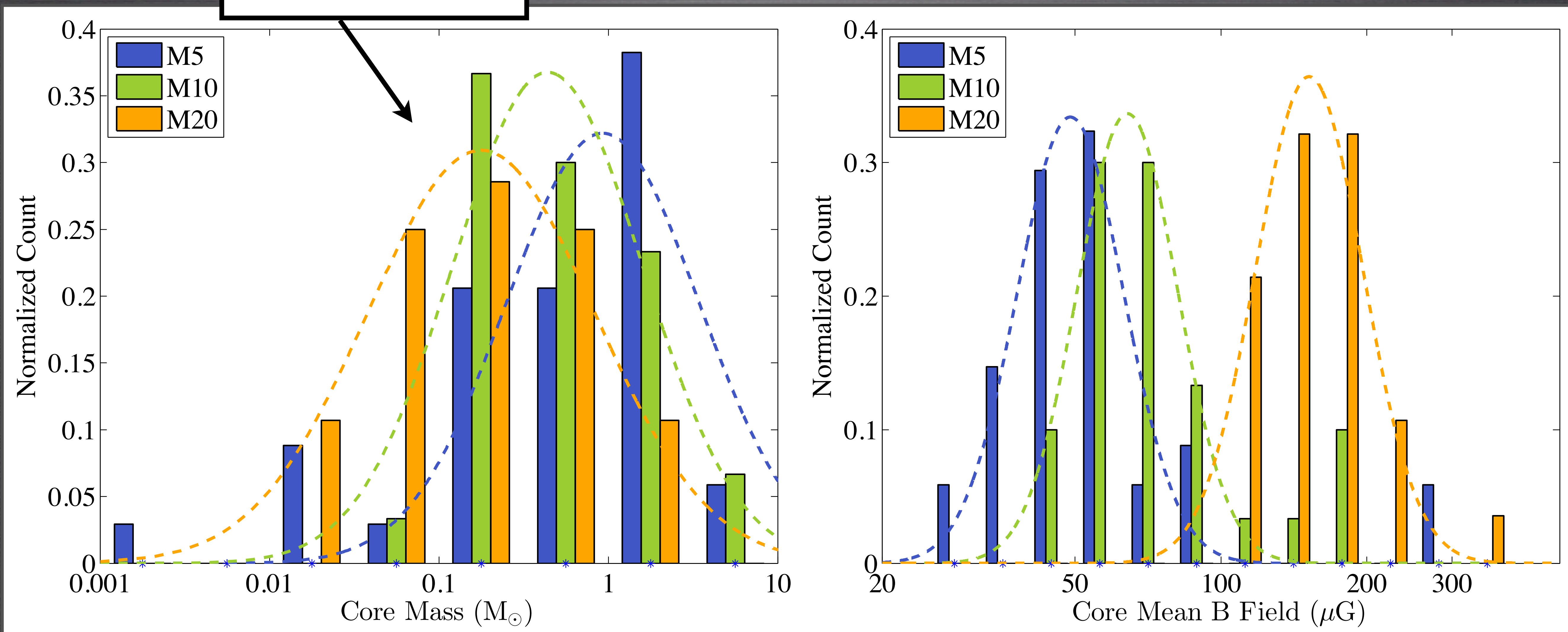
$$= 5.21\ {\rm M}_\odot\left(\frac{B_{\rm ps}}{50\ \mu{\rm G}}\right)^3\left(\frac{n_{\rm ps}}{10^4\ {\rm cm}^{-3}}\right)^{-2}$$

Core Properties

- Core mass varies with inflow Mach number

$$M_{\rm core} \propto \mathcal{M}^{-0.9}$$

(Chen & Ostriker *in prep.*)



- $B_{\rm core}$ is within a factor of 2 of $B_{\rm post\text{-}shock}$

Summary

- Filament network and core properties found in our simulations are comparable to observations

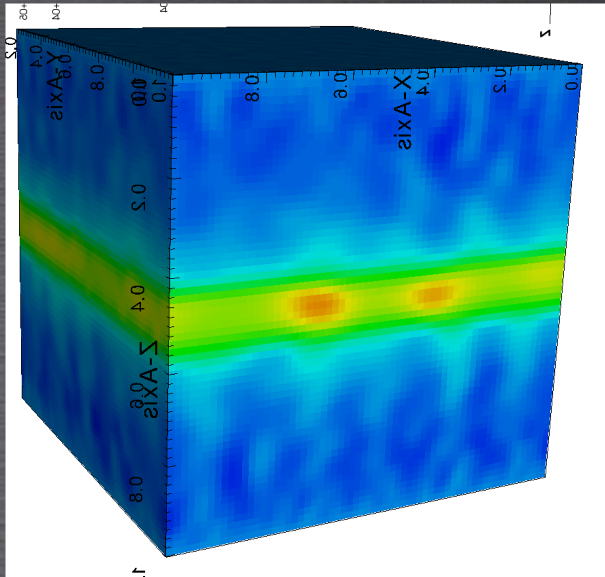
- Filament transverse velocity gradients provide evidence of condensation in flattened structures

- Magnetically-supercritical, low-mass cores form anisotropically via contraction along $\vec{B}$

- These cores have masses and magnetic fields that depend on pre-shock ρv^2 in cloud

Post-shock Layer

- B-field direction in the layer
  - ⇒ parallel to the shock front



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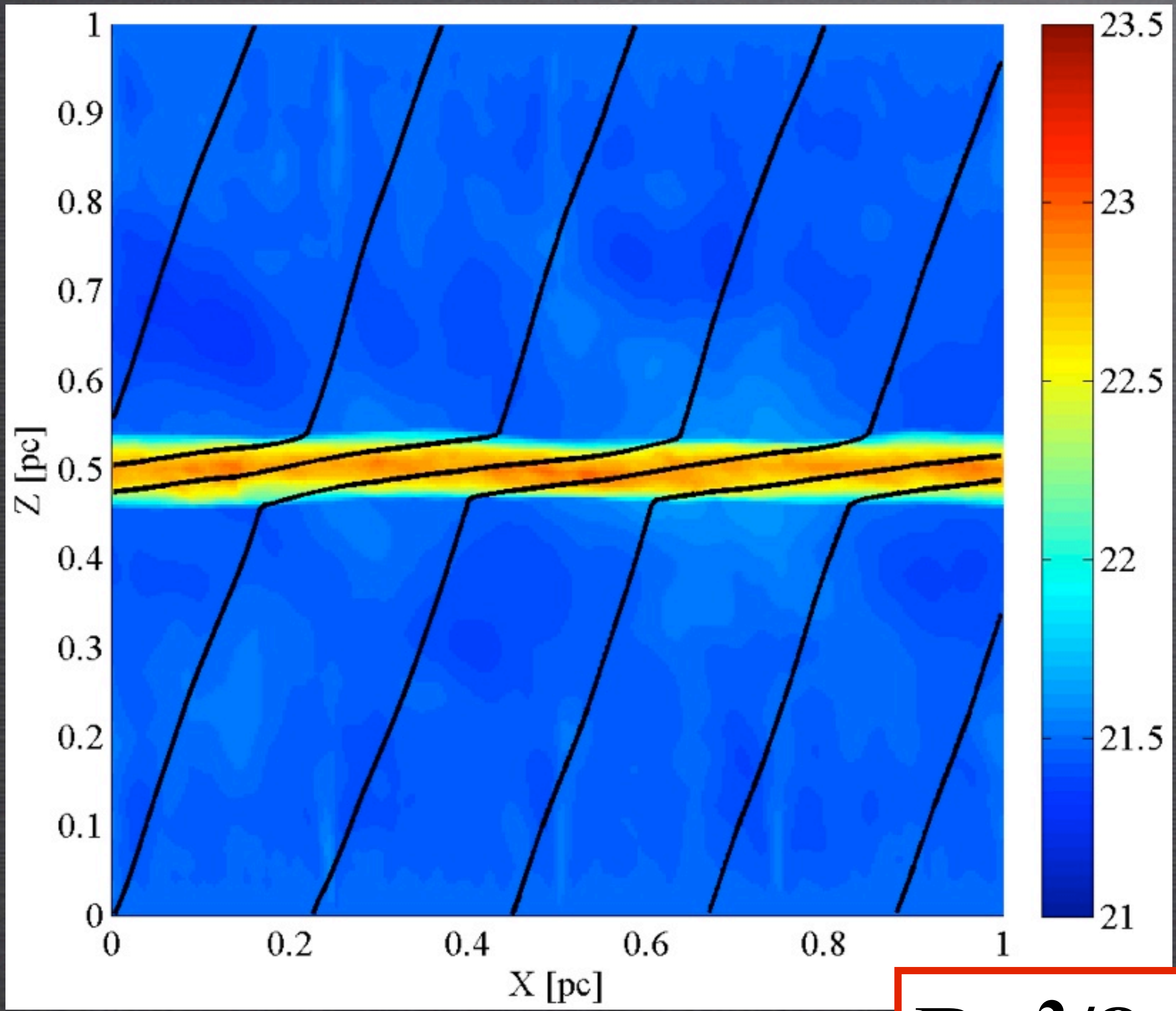
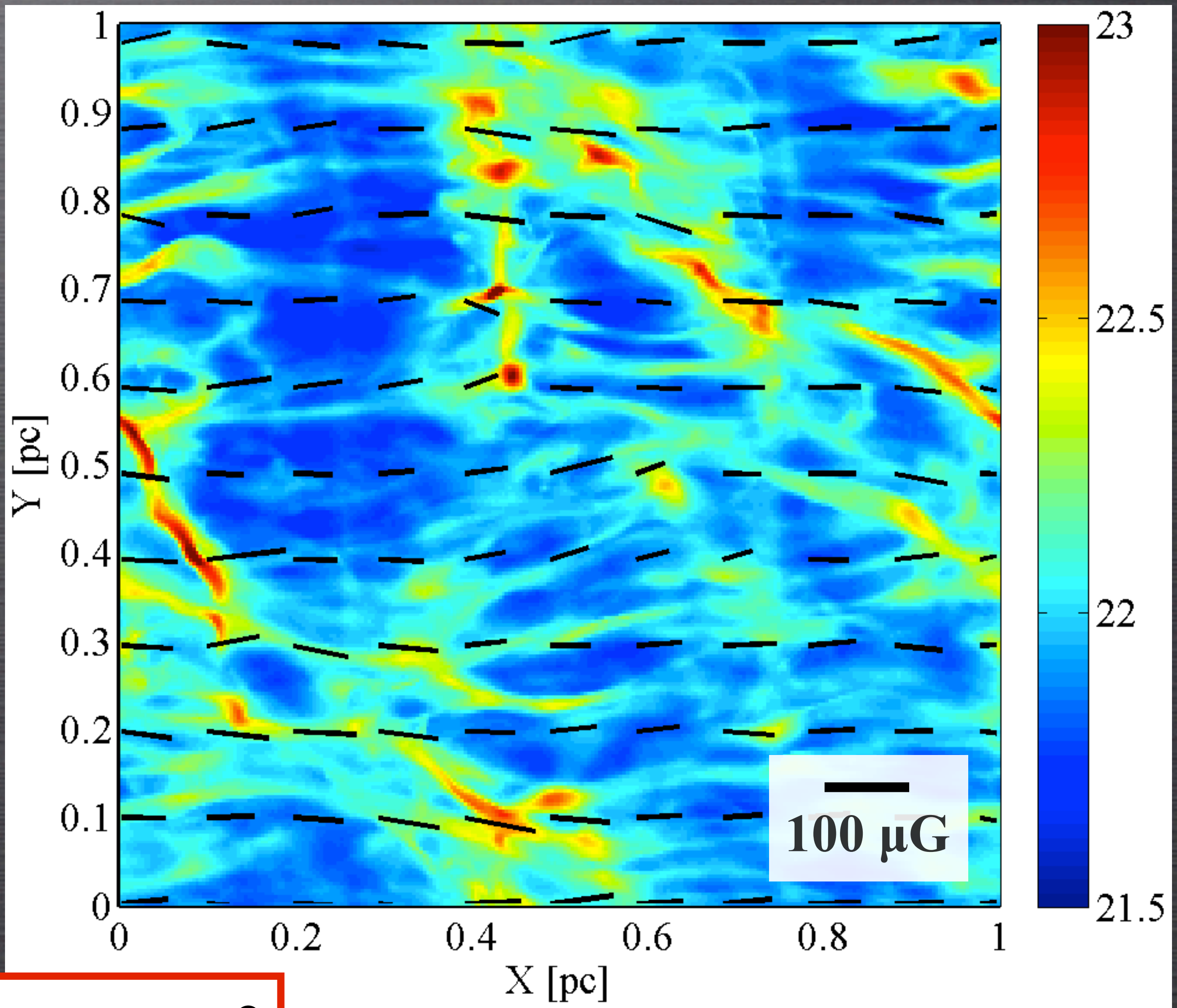


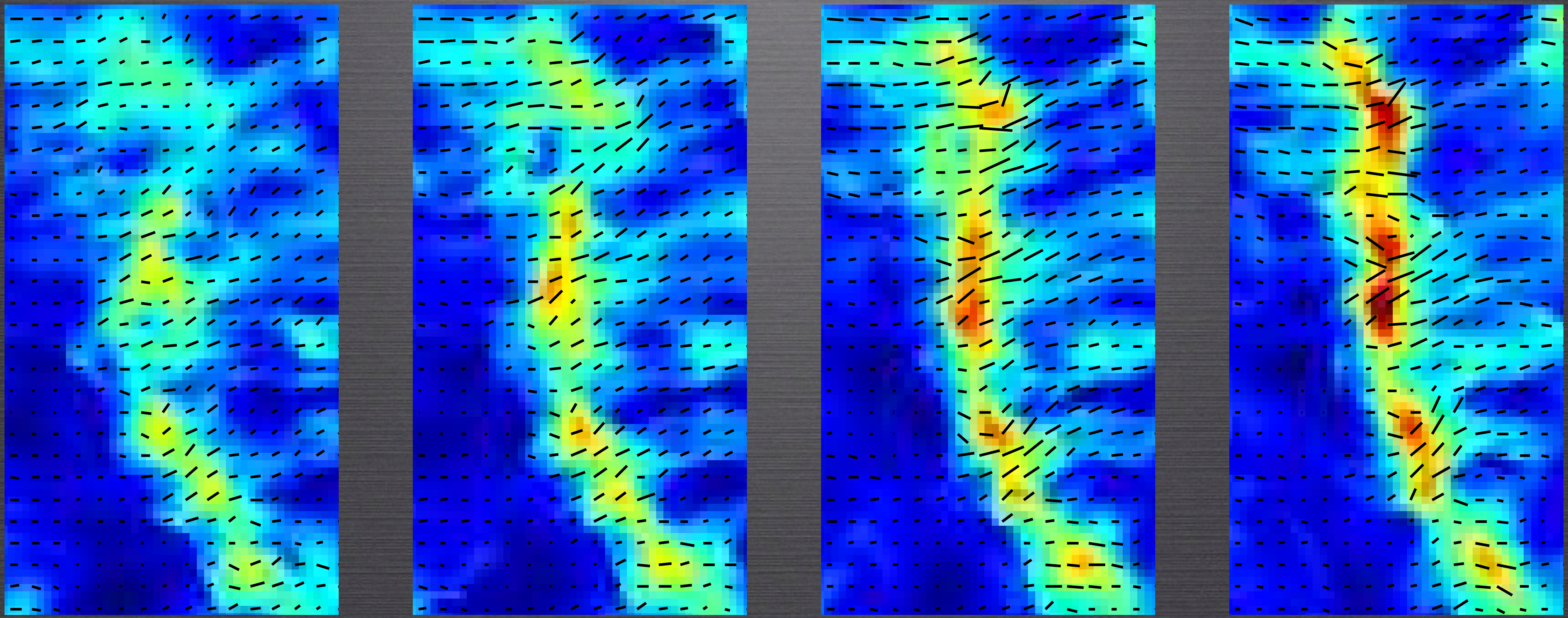


$$B_{ps}^2/8\pi \sim \rho_0 v_0^2$$

Filament Fragmentation

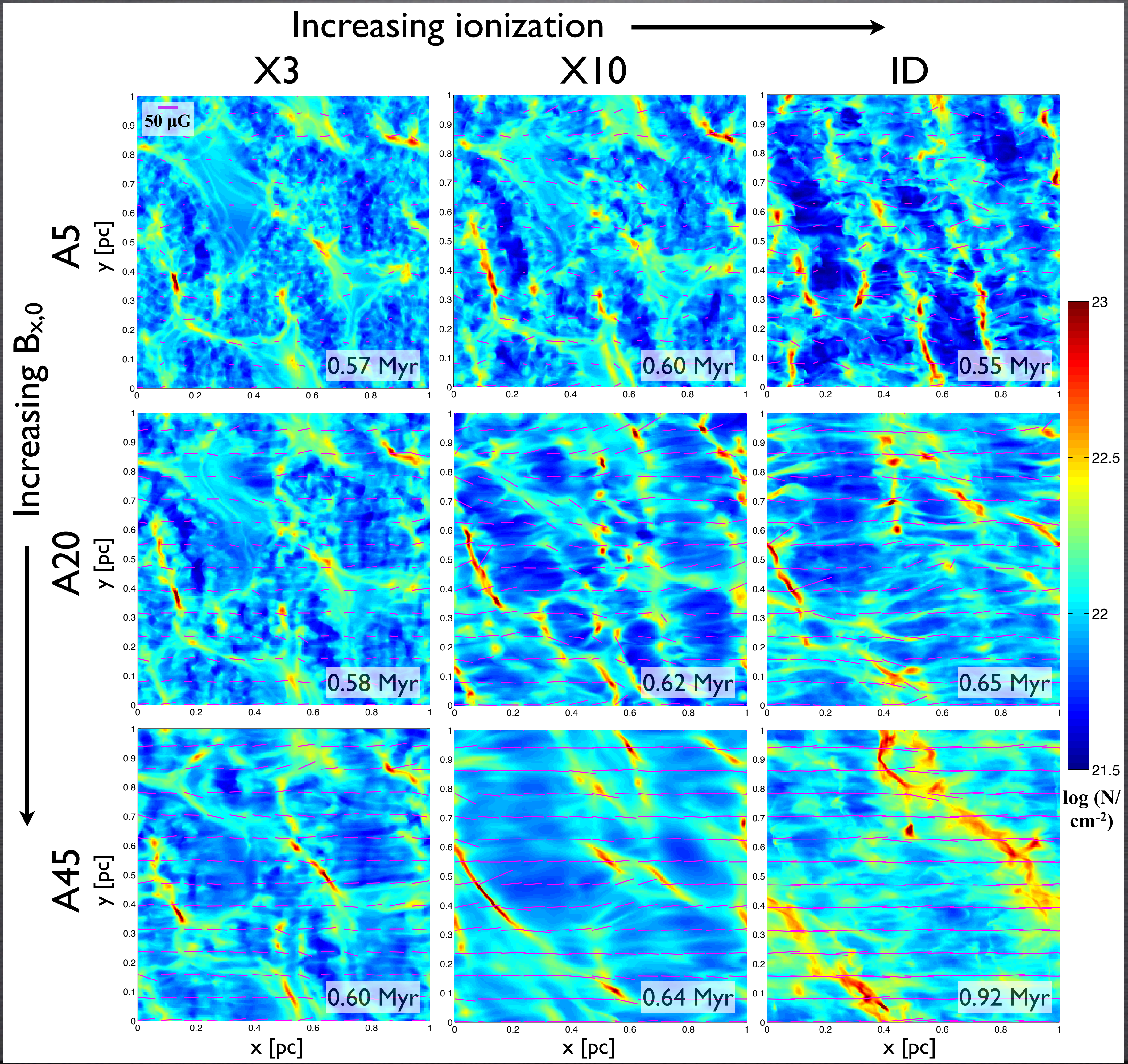
time →

(Δt = 0.05 Myr)



- How do magnetically supercritical cores form?

Structures



Increasing ionization
X3
X10
ID
Increasing $B_{x,0}$
A5
A20
A45
y [pc]
x [pc]
50 μG
0.57 Myr
0.60 Myr
0.55 Myr
0.58 Myr
0.62 Myr
0.65 Myr
0.60 Myr
0.64 Myr
0.92 Myr
23
22.5
22
21.5
log (N/cm^{-2})

Super BE-mass Cores

- Bonnor-Ebert Sphere

$$M_{\rm BE} = 1.18\frac{{c_s}^4}{\sqrt{G^3 P_{\rm edge}}} = 1.85\frac{{c_s}^4}{\sqrt{G^3 P_{\rm mean}}}$$
$$= 1.85\frac{{c_s}^3}{\sqrt{G^3 \rho_{\rm mean}}} = 3.8\frac{{c_s}^3}{G^{3/2}}\frac{R^{3/2}}{M^{1/2}}.$$