Star formation (or not) in *magnetised* molecular clouds

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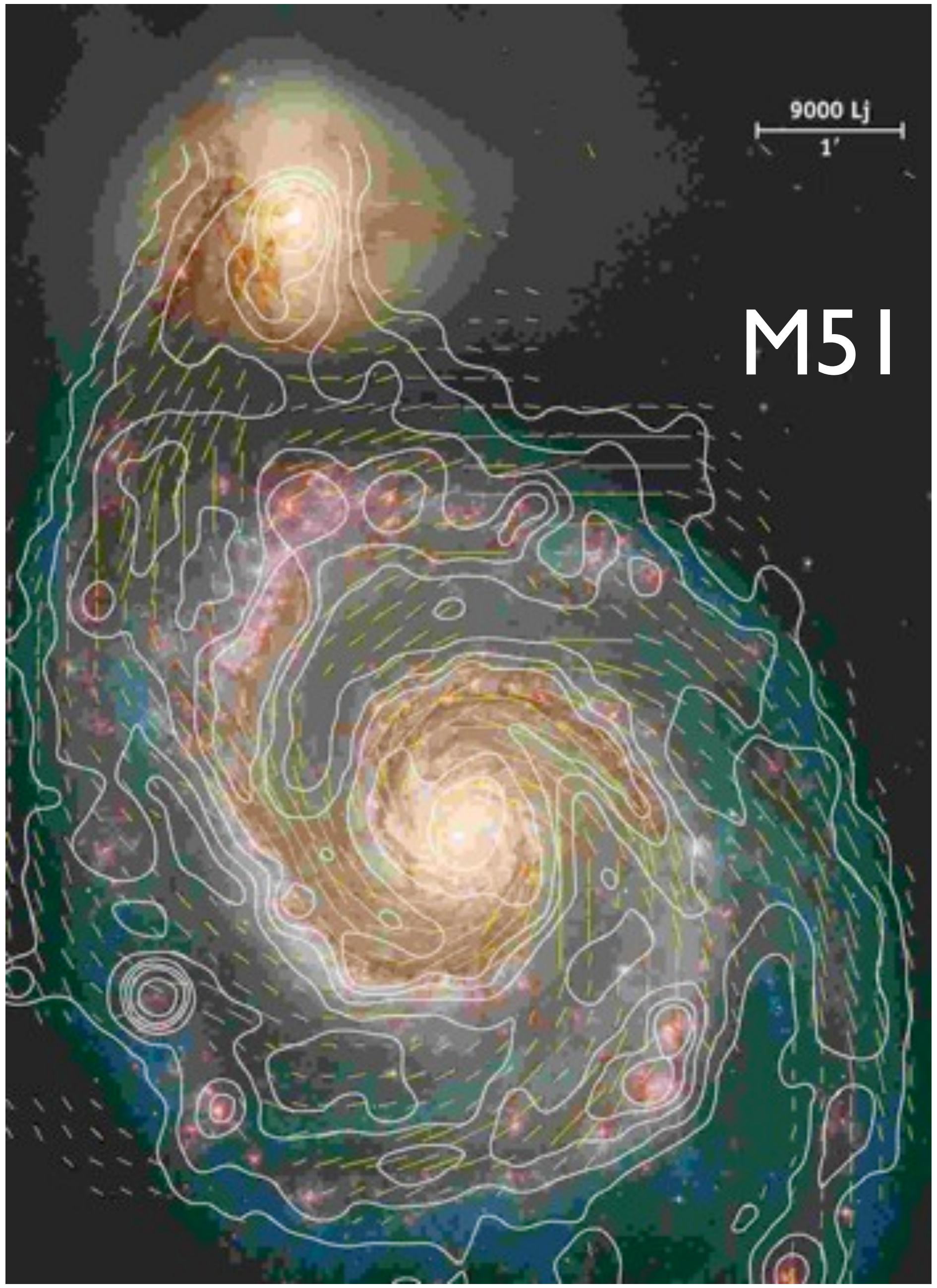
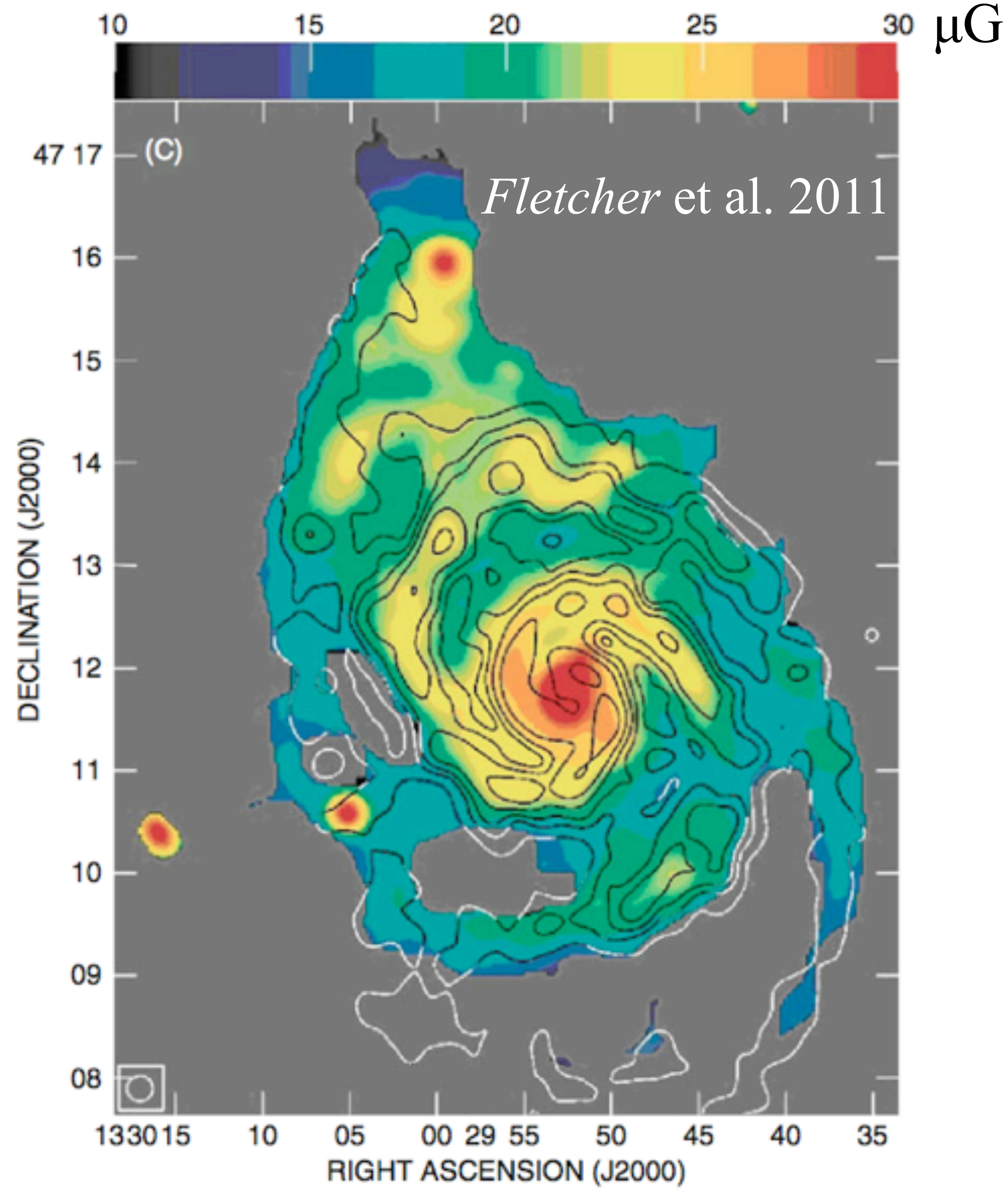
Based on work by: **Bastian Körtgen** (Hamburg)
co-workers: Daniel Seifried (Köln), Enrique Vazquez-Semadeni (UNAM)

Magnetic Fields in the ISM

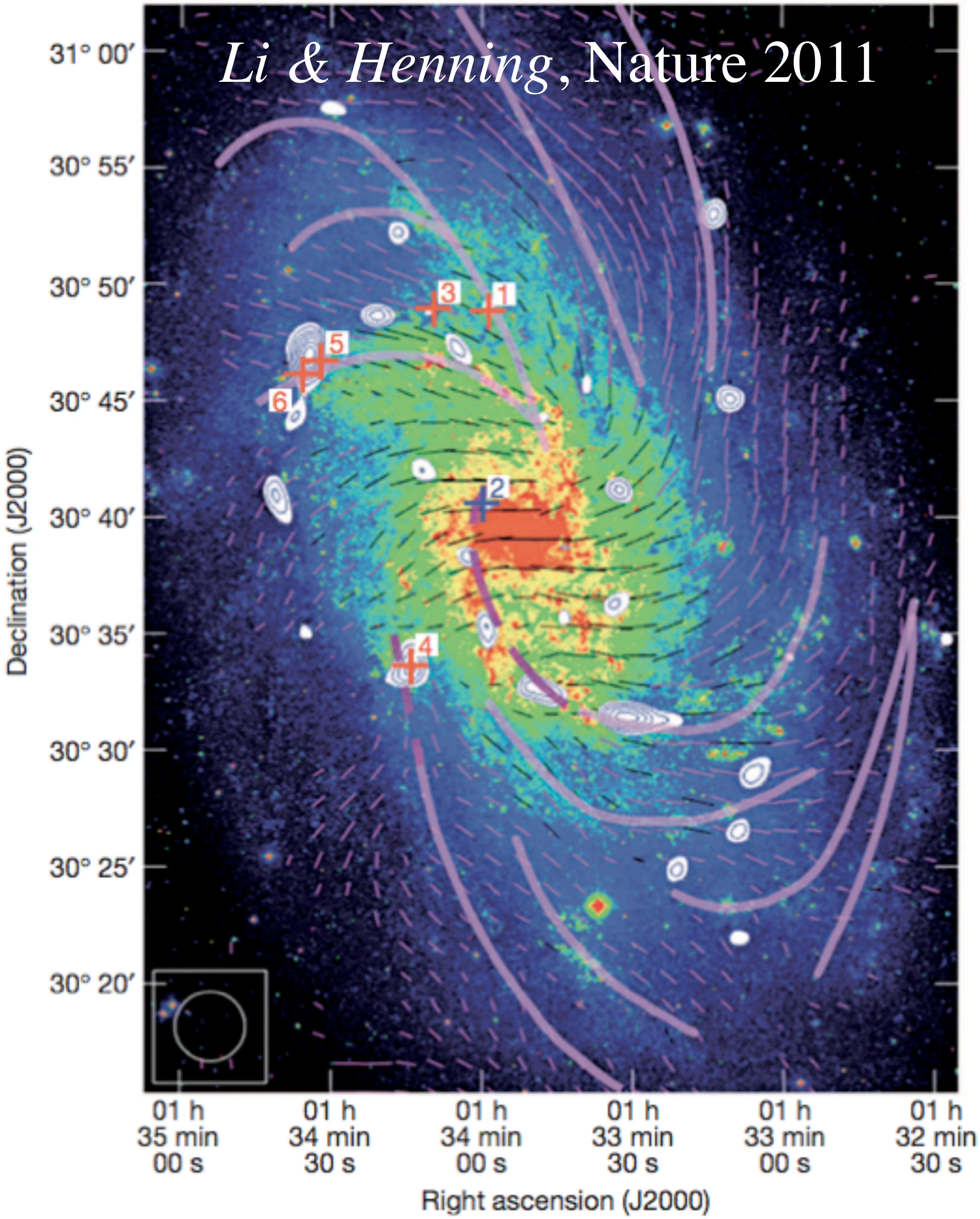


The ISM is *highly* magnetised



galactic B-fields (e.g. *R.Beck* 2001)
large scale component: $B \sim 6\mu G$
total field strength: $> 10\ \mu G$

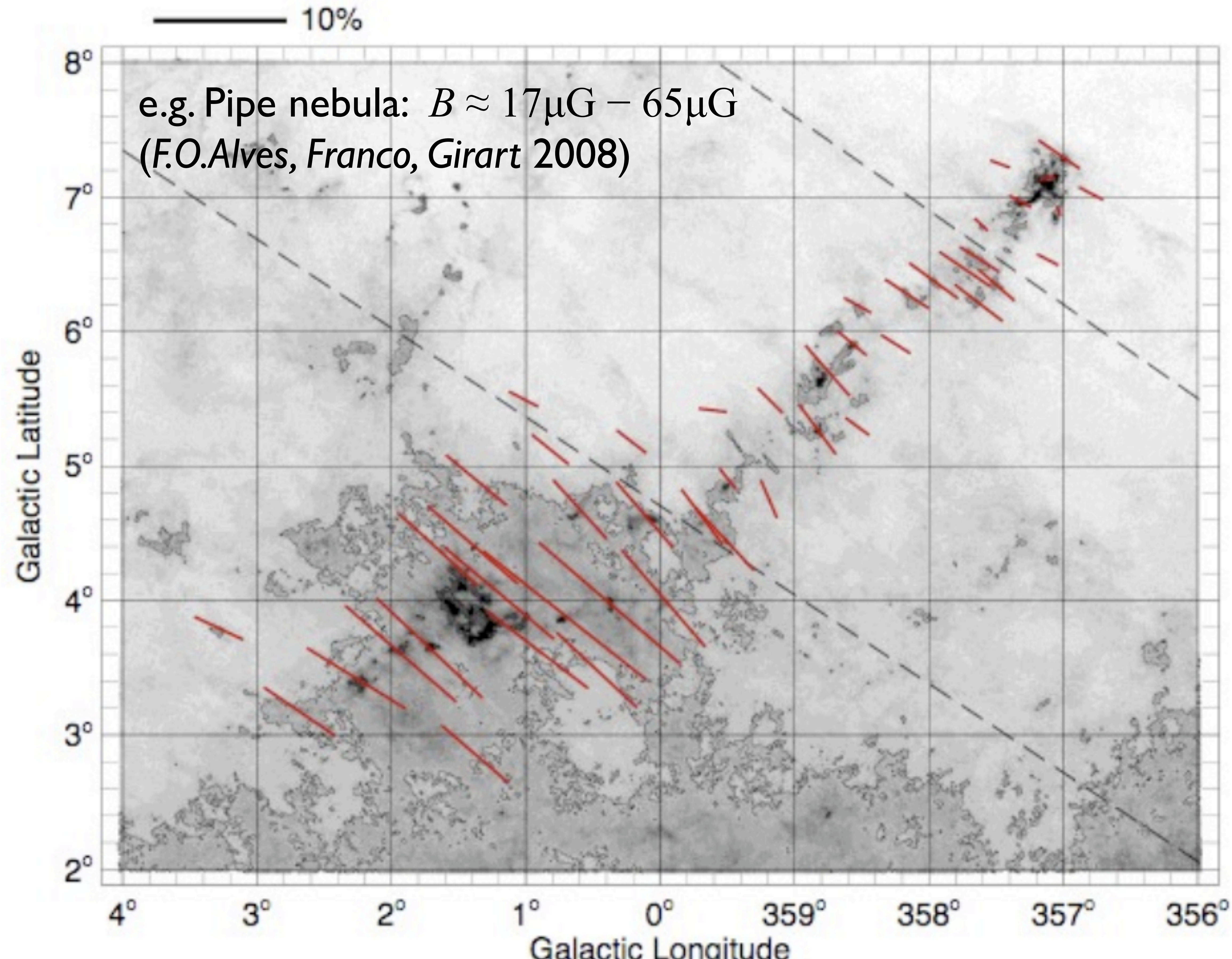
Magnetic Fields in the ISM



- M33: $B_{\mathrm{pos}} \sim 100 \ldots 500\ \mu\mathrm{G}$ in GMCs from polarised CO emission

$\Longrightarrow$ sub Alfvenic turbulence

Magnetic Fields in the ISM



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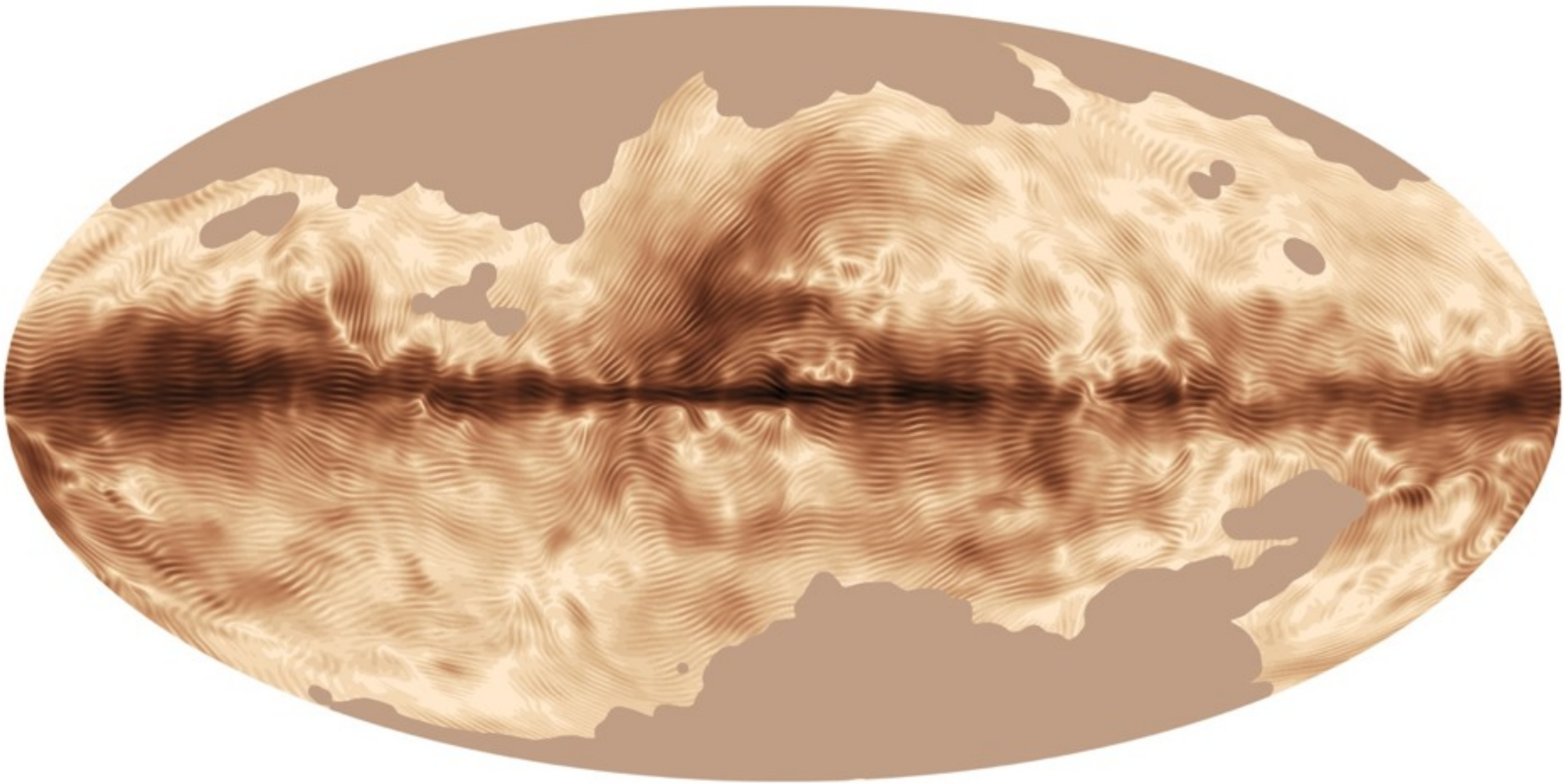
Magnetic Fields in the ISM

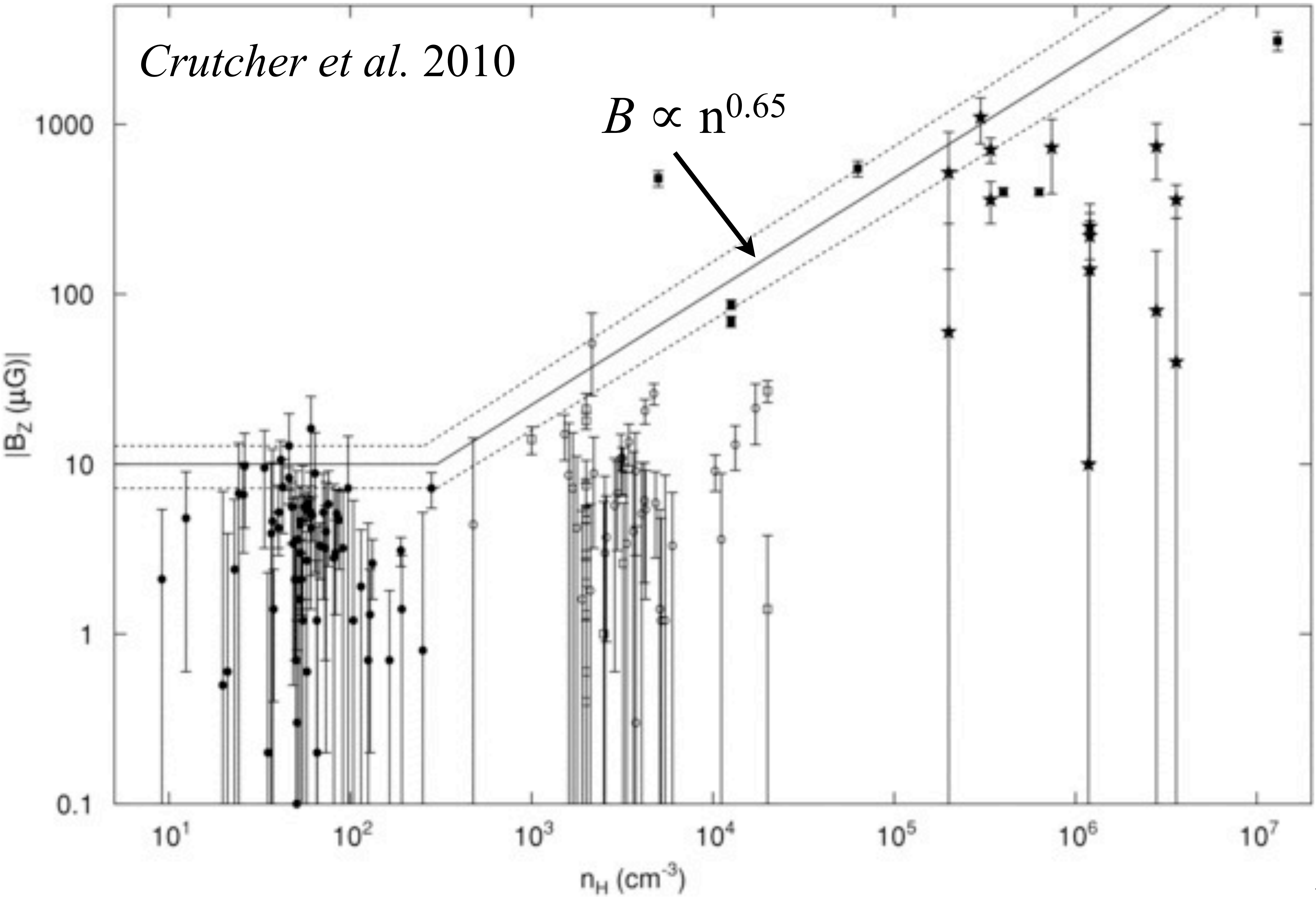
- PLANCK: magnetic field of the Milky Way



ESA PLANCK: *Milky Way's magnetic fingerprint*, May 2014

Magnetic Fields in the ISM

- Magnetisation of the ISM and cloud cores



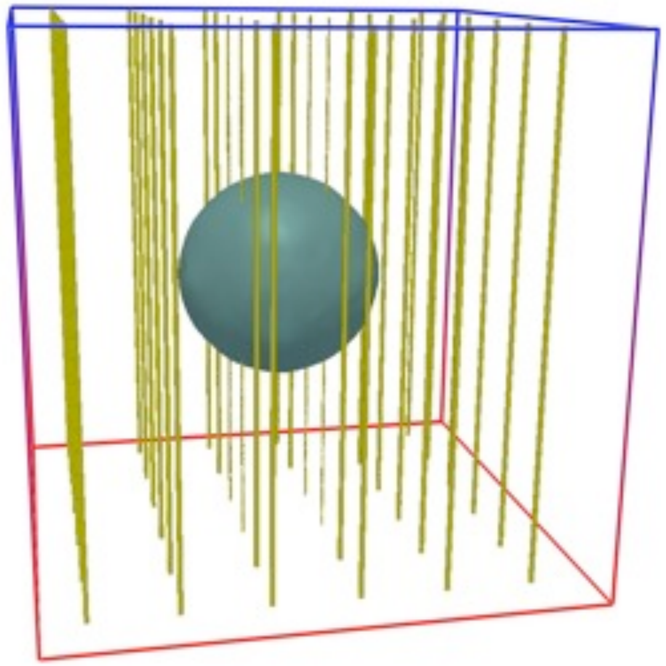
Impact of Magnetic Fields

magnetic flux is frozen into the plasma:

$\Longrightarrow$

mass-to-flux ratio:

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



$$\Longrightarrow \quad \mu = \frac{\Sigma}{B}$$

critical value for collapse:

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

spherical structure
Mouschovias & Spitzer 1976

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

uniform disc
Nakano & Nakamura 1978

Impact of Magnetic Fields

$\Longrightarrow$ minimal column density:

$$N_{\rm crit} \approx 2.4 \ \times 10^{21}\,{\rm cm}^{-2}\left(\frac{B}{10\,\mu{\rm G}}\right)$$

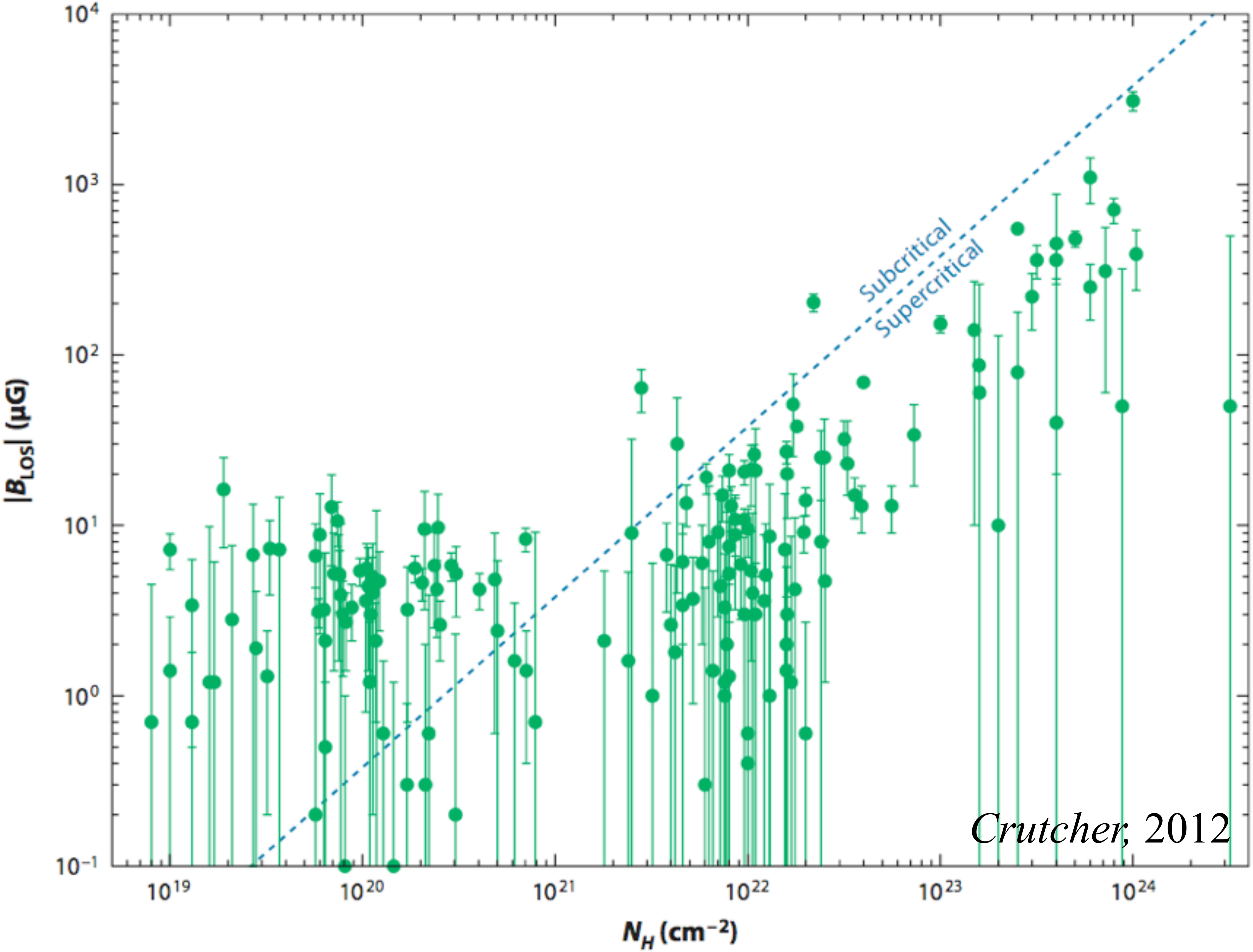
$\Longrightarrow$ minimal length scale:

$$L_{\rm crit} \approx 10^3\,{\rm pc}\left(\frac{B}{10\,\mu{\rm G}}\right)\left(\frac{n}{1\,{\rm cm}^{-3}}\right)^{-1}$$

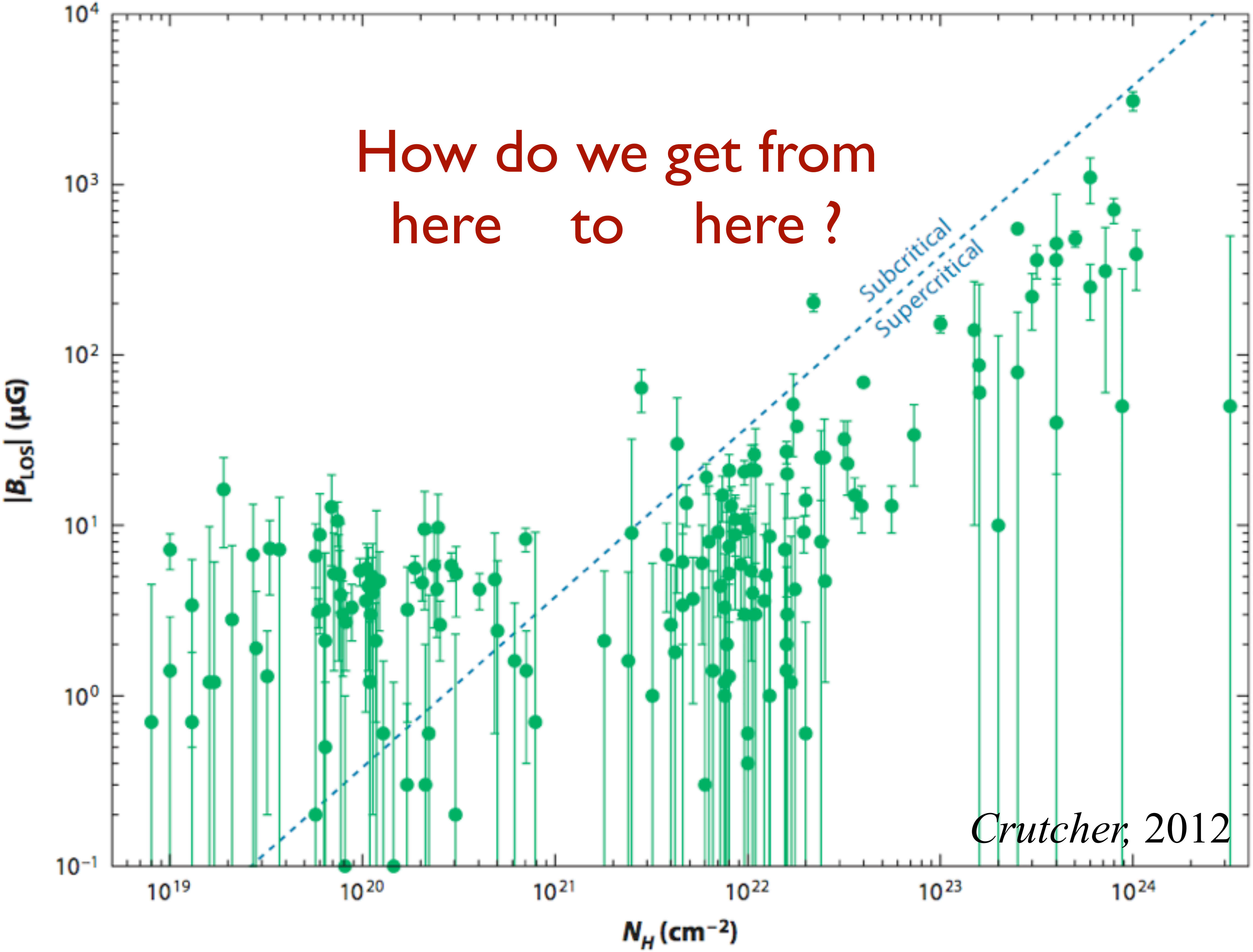
$\Longrightarrow$ time-scale for colliding flows:

$$t_{\rm crit} \approx 100\,{\rm Myr}\left(\frac{B}{10\,\mu{\rm G}}\right)\left(\frac{n}{1\,{\rm cm}^{-3}}\right)^{-1}\left(\frac{v_{\rm flow}}{10\,{\rm km\ sec}^{-1}}\right)^{-1}$$

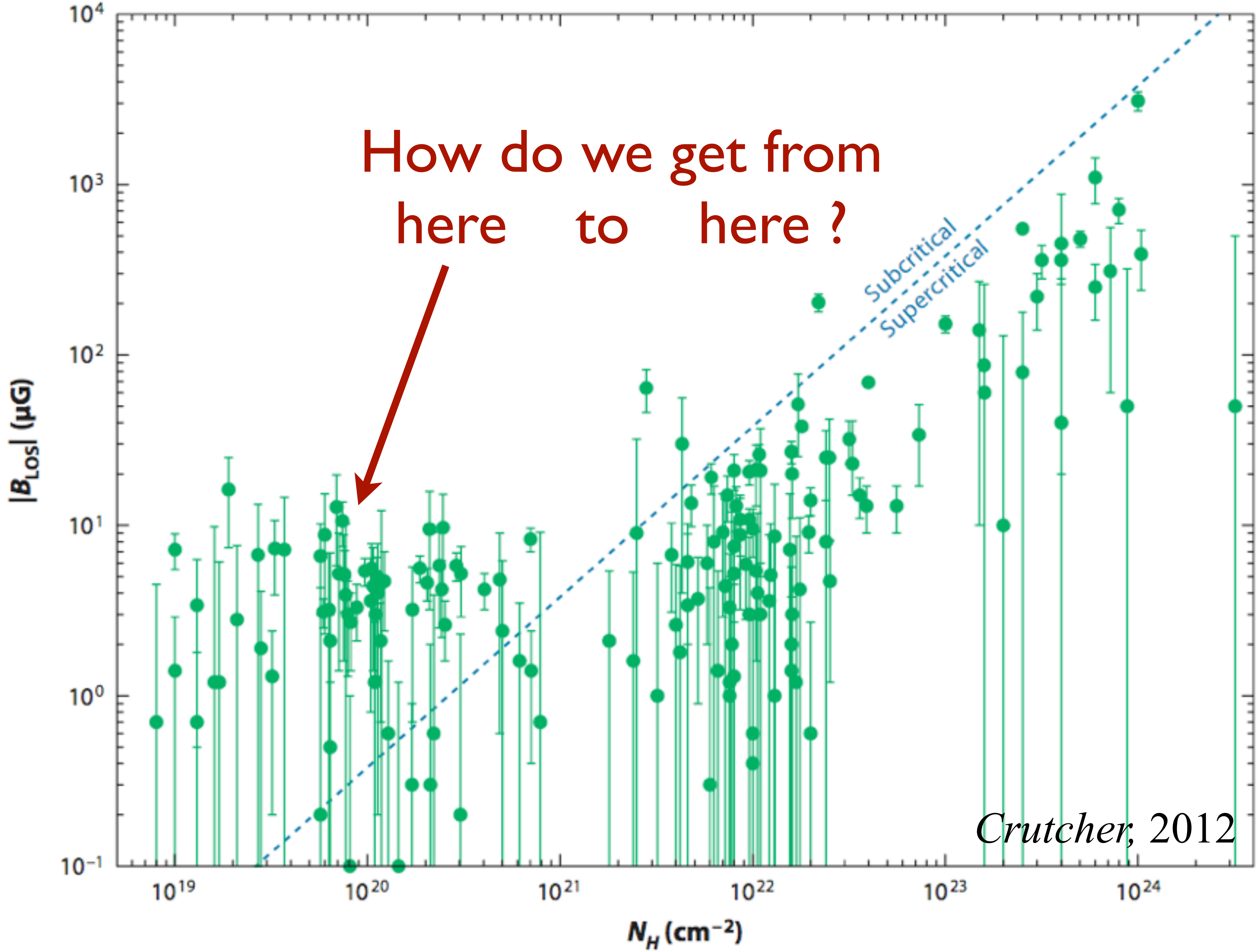
Magnetic Fields in the ISM



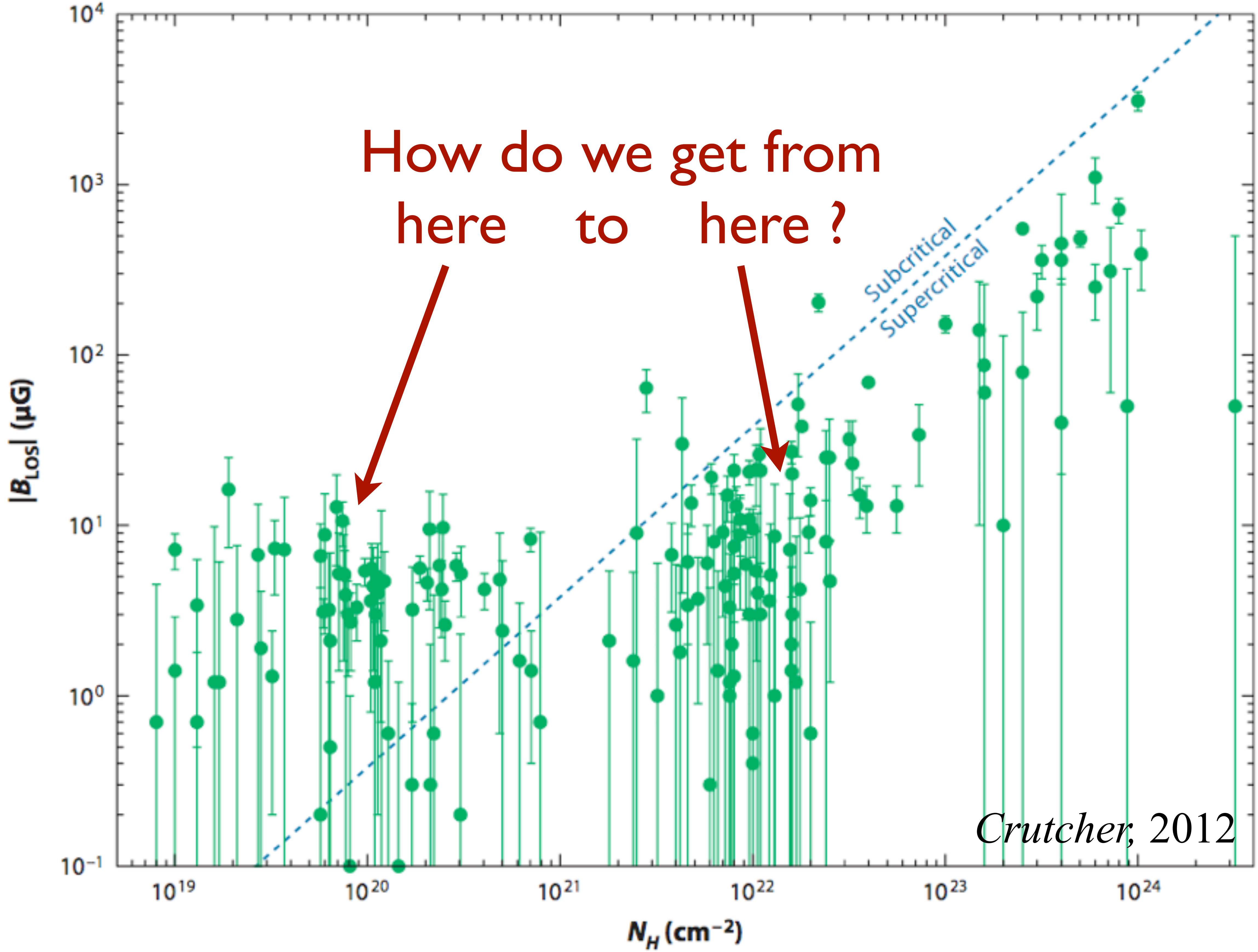
Magnetic Fields in the ISM



Magnetic Fields in the ISM



Magnetic Fields in the ISM



Dissipation processes

Solutions?

- flux loss by:
  - Ambipolar Diffusion (*Mestel & Spitzer* 1956, *Shu* 1987, *Mouschovias* 1987)
  - Turbulence + AD (e.g. *Heitsch et al.* 2004)
  - Turbulent reconnection (Lazarian & Vishniac 1999)
  - Ohmic resistivity (e.g. *Dapp & Basu* 2010, *Krasnopolsky et al.* 2010)
  - ...

AD in the WNM

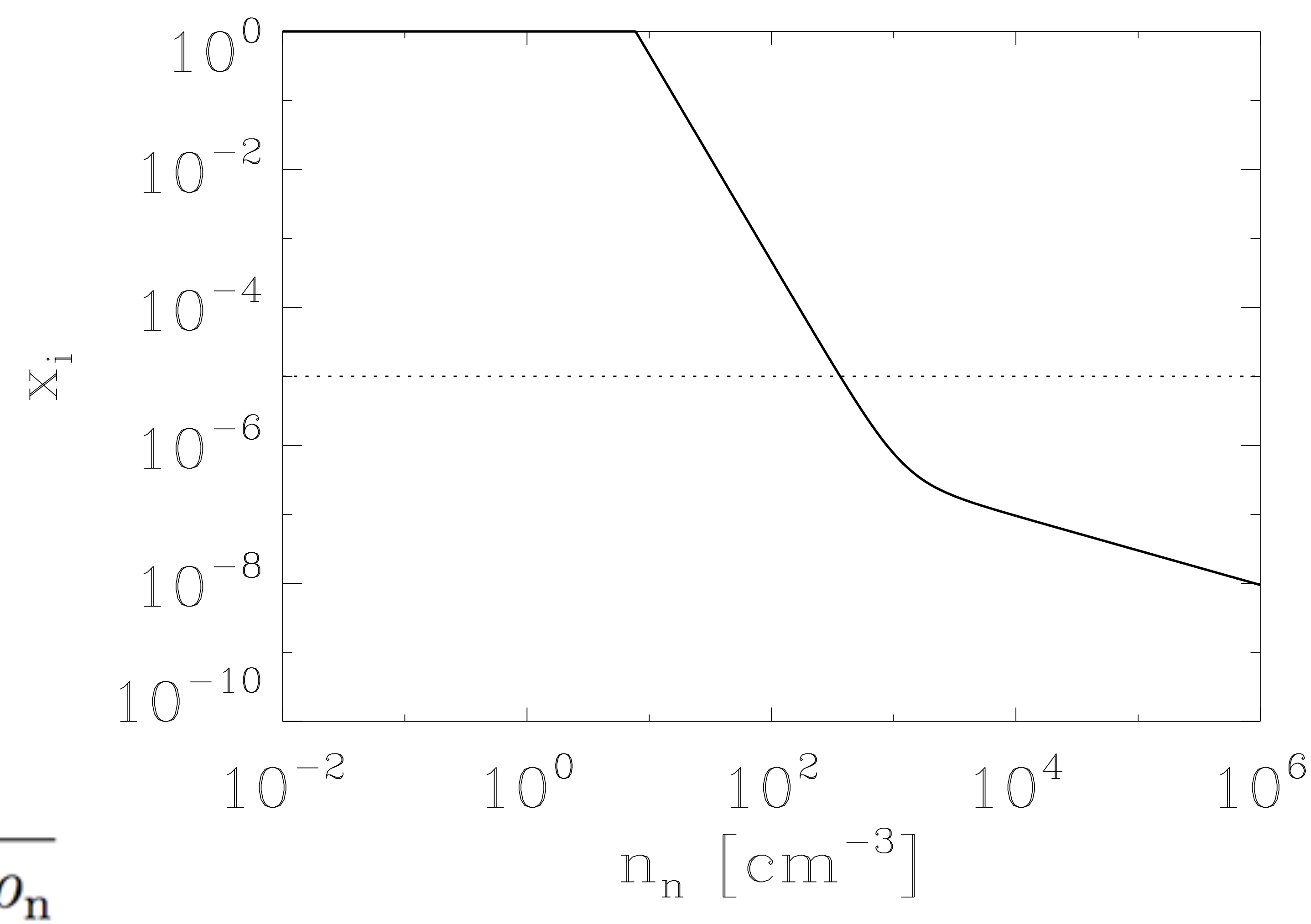
- Ionisation degree of the diffuse ISM:

$$n_i = K\left(\frac{n_n}{10^5\ \mathrm{cm}^{-3}}\right)^{1/2} + K'\left(\frac{n_n}{10^3\ \mathrm{cm}^{-3}}\right)^{-2}$$

$K=3\times10^{-3}\ \mathrm{cm}^{-3}$, $K'=4.6\times10^{-4}\ \mathrm{cm}^{-3}$

(e.g. Fiedler & Mouschovias 1993, Hosking & Whitworth 2004)

$\Longrightarrow \quad x_e \sim 10^{-5} \ldots 0.1$



$\Longrightarrow$ AD timescale:

$$t_{AD} \approx \frac{L}{v_d} \quad ; \quad v_d \approx \frac{1}{L}\frac{B^2}{4\pi}\frac{1}{\gamma\,\rho_i\,\rho_n}$$

$$\sim 10^3\ \mathrm{Myr}\left(\frac{L}{10\ \mathrm{pc}}\right)^2\left(\frac{B}{10\ \mu\mathrm{G}}\right)^{-2}\left(\frac{n_H}{100\ \mathrm{cm}^{-3}}\right)^{-1}$$

Cloud Cores

- Ionisation degree of cloud cores:

$x_e \sim 2.5\times10^{-8} \ldots 2.5\times10^{-7}$

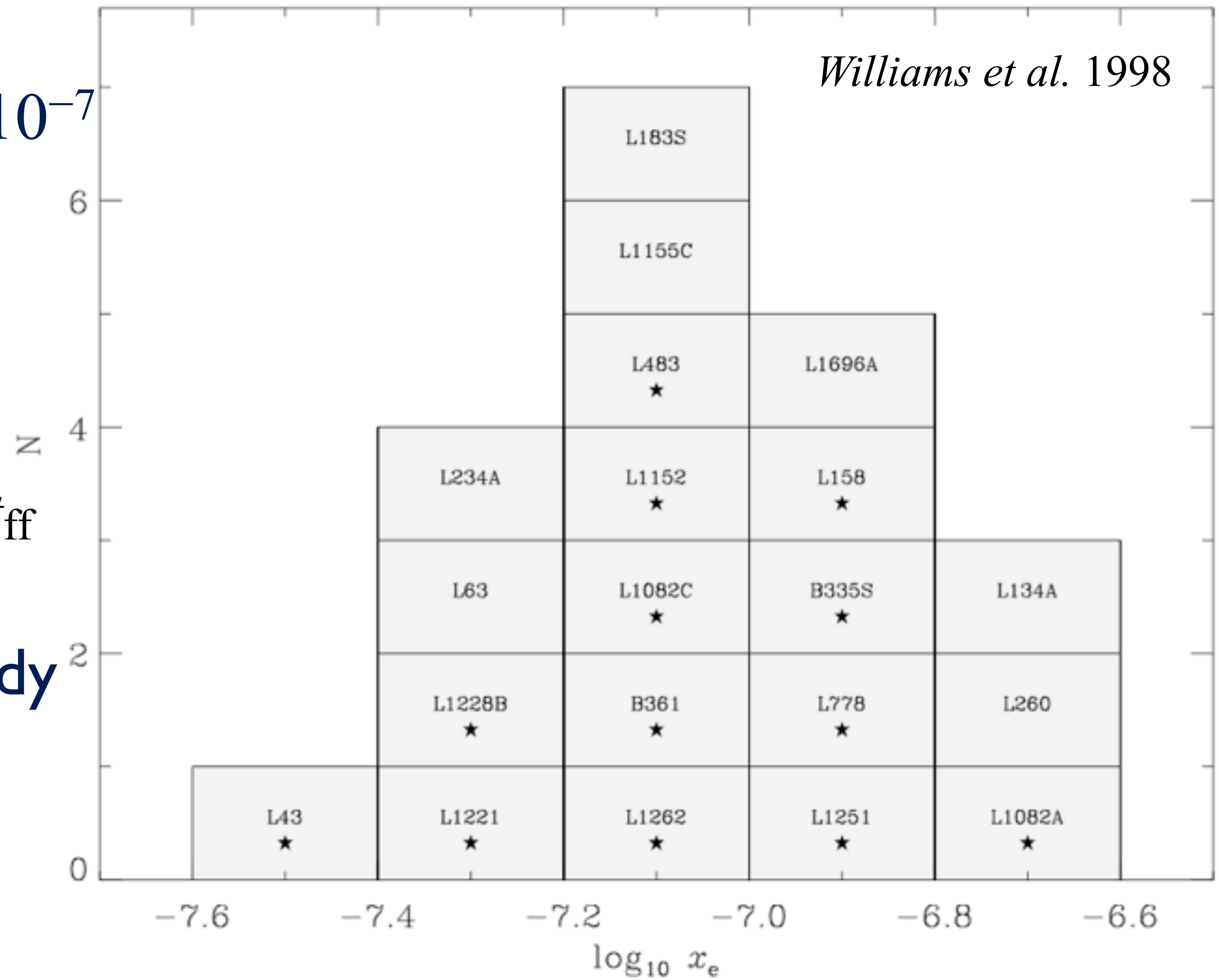
$\Longrightarrow$ ambipolar diffusion time scale:

$\tau_{AD} \sim 10\,(x_e/10^{-7})\,t_{ff}$

$\Longrightarrow$ but cores are already supercritical

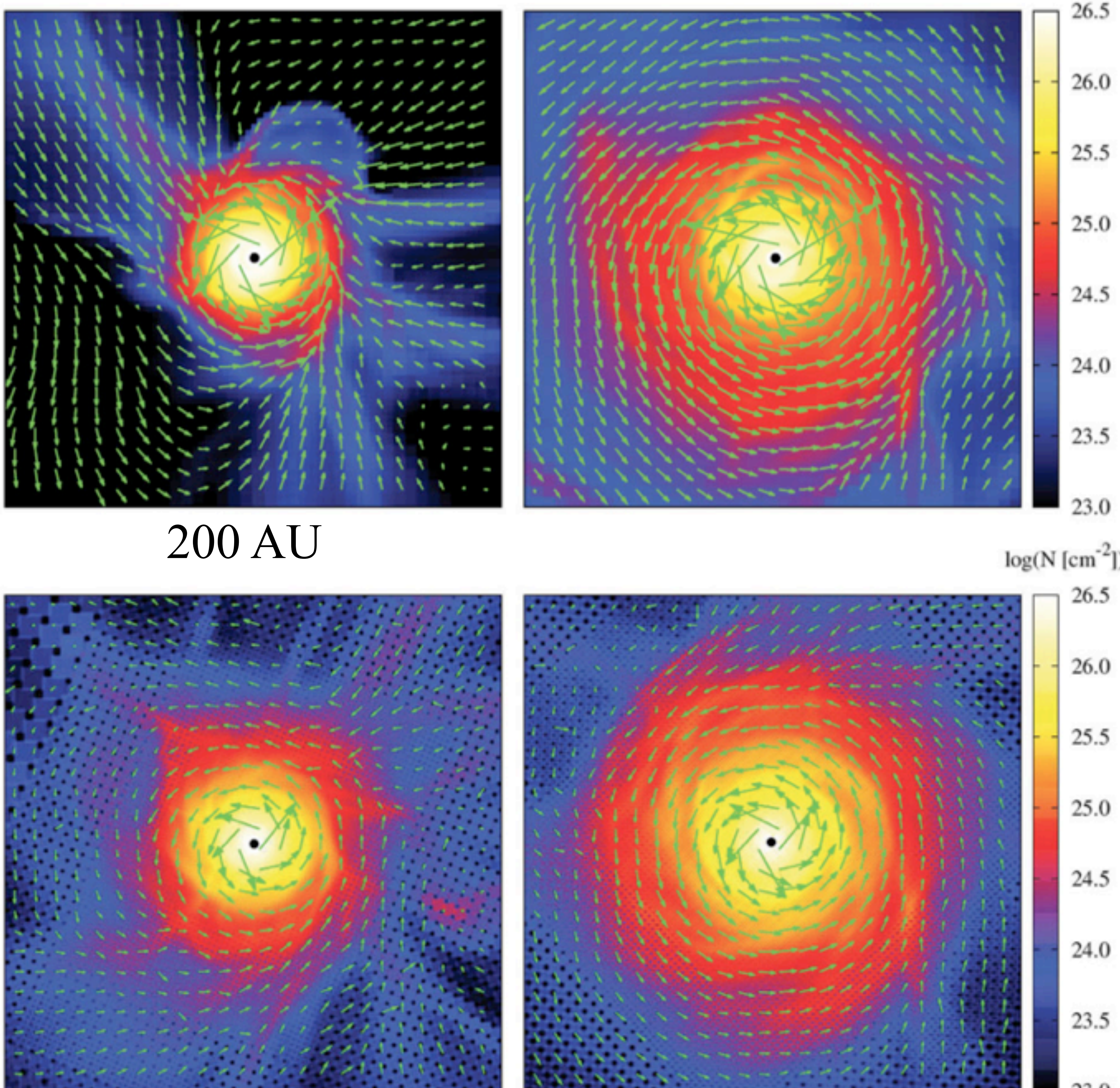
$n > 10^4\ \mathrm{cm}^{-3}$

$\Longrightarrow N_{cores} > N_{crit}$



$\Longrightarrow$ AD is not important for cores

Collapse of Turbulent Cores



collapse of slightly supercritical cores + turbulence

⟹ escapes "magnetic braking catastrophe"

(*Galli et al.* 2006, ...)

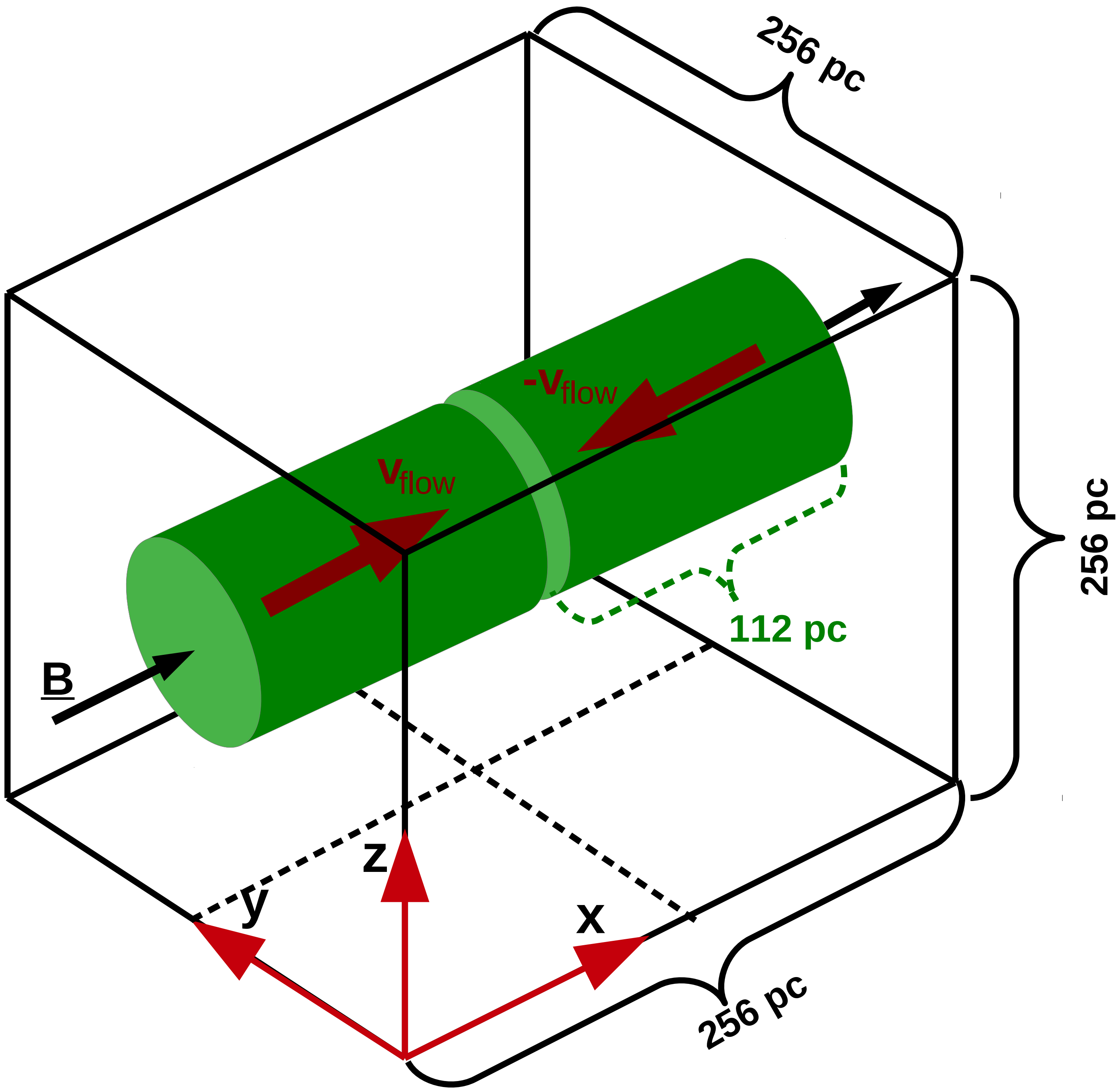
⟹ overcomes "fragmentation crisis"

(*Hennebelle & Teyssier* 2008,)

Seifried, et al. 2012, 2013
see Poster: **31**

Simulations of colliding flows

MC formation & star formation



see also *Vazquez-Semadeni et al.* 2007, 2010

Model parameter:

- $n = 1\ \mathrm{cm}^{-3}$
- $r = 32 \ldots 64$ pc

  $\Longrightarrow M_{\mathrm{inf}} = 2.3{\times}10^4\ \mathrm{M}_\odot$

  $\Longrightarrow N \approx 7{\times}10^{20}\ \mathrm{cm}^{-2}$
- $v_{\mathrm{inf}} = 14$ km/sec

\+ turbulence:

$v_{\mathrm{turb}} = 0.2 \ldots 12$ km/sec

\+ ambipolar diffusion

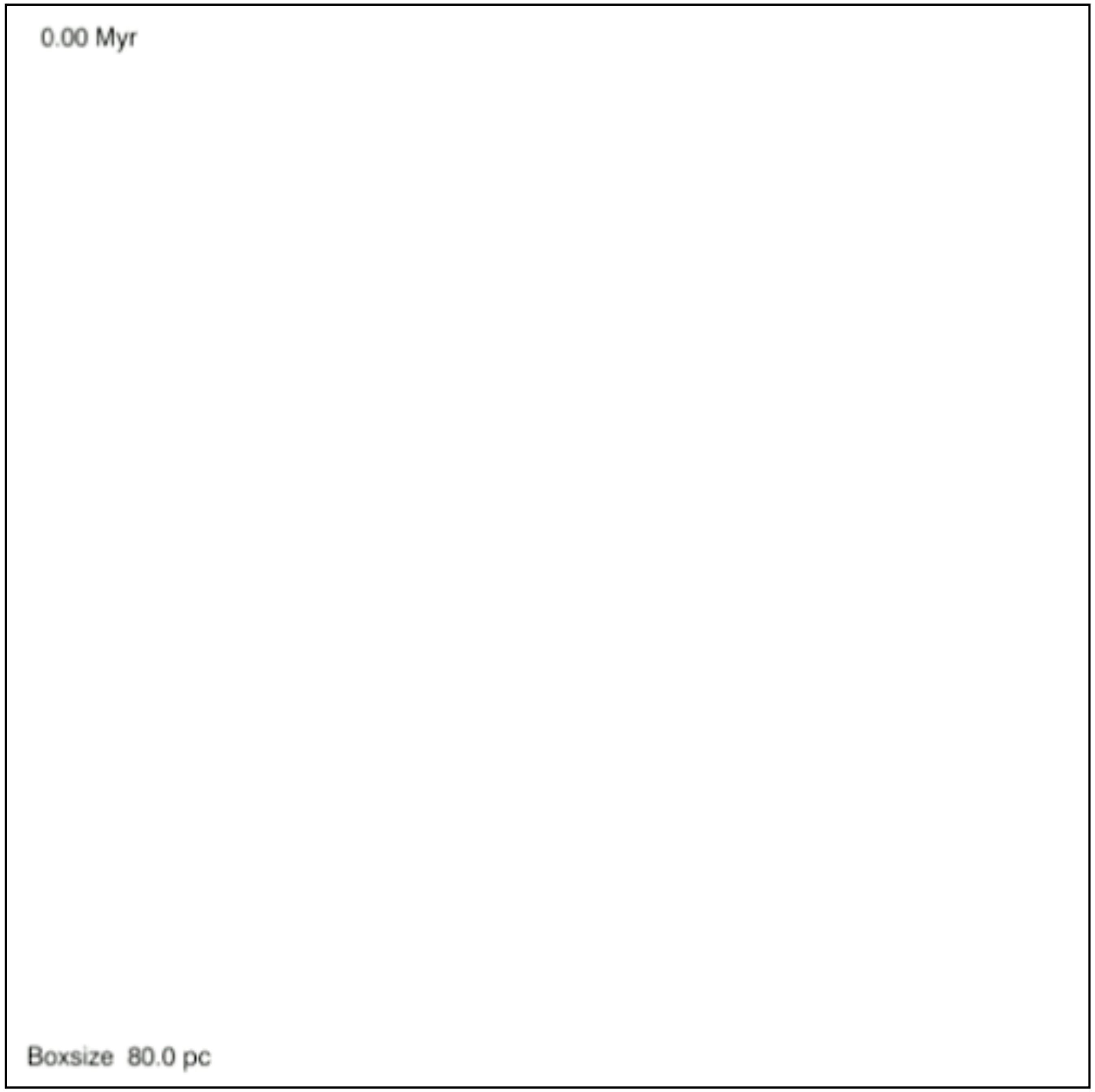
- $B_x = 1 \ldots 5\ \mu\mathrm{G}$

  $\Longrightarrow \mu/\mu_{\mathrm{crit}} = 1.1\ (B/3\mu\mathrm{G})^{-1}$

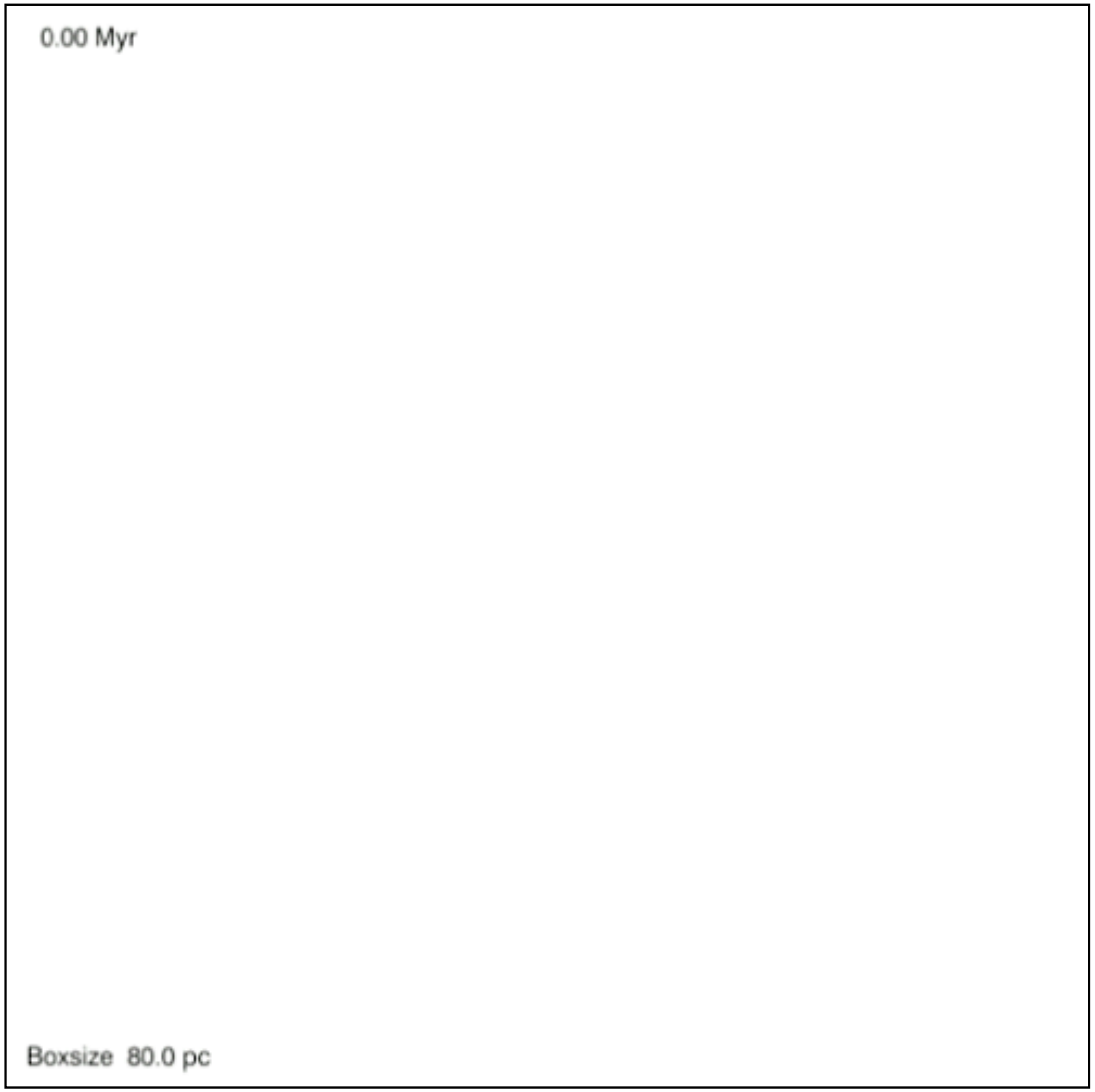
  $\Longrightarrow t_{\mathrm{crit}} \approx 15\ \mathrm{Myr}\ (\mathrm{B}/3\mu\mathrm{G})$

Simulations of colliding flows

influence of magnetic fields



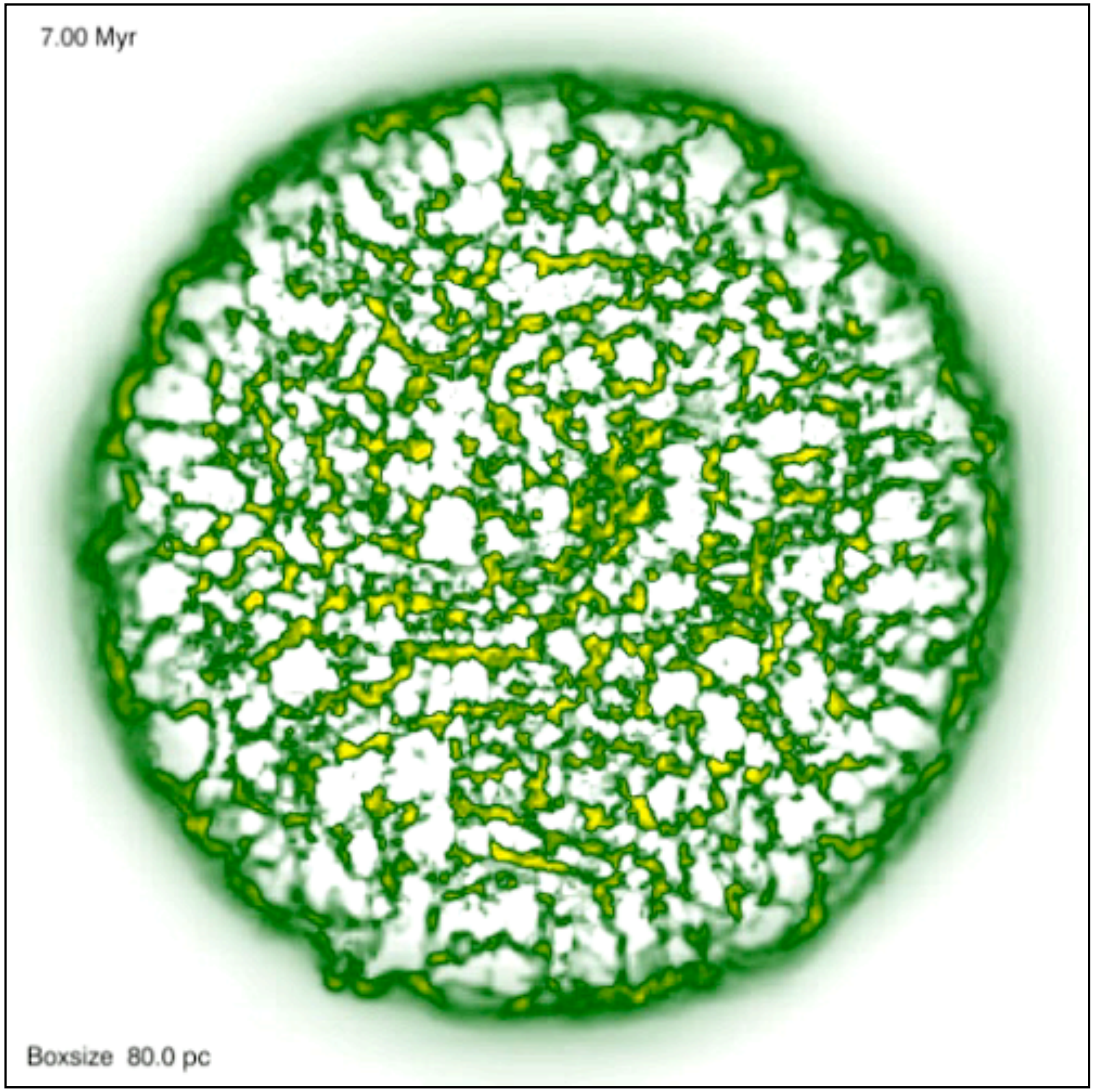
B = 3μG



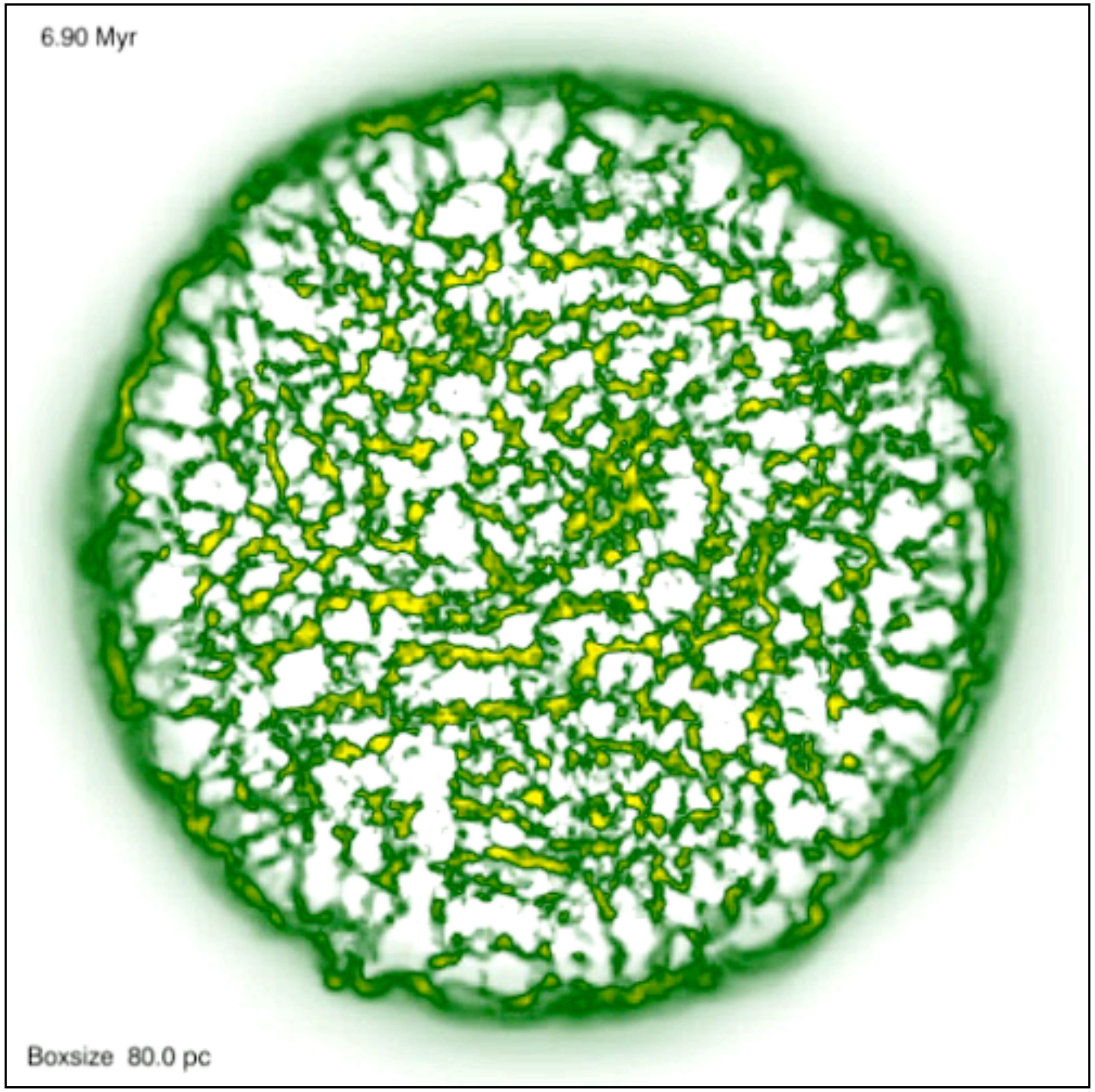
B = 4μG

Simulations of colliding flows

influence of ambipolar diffusion



ideal case

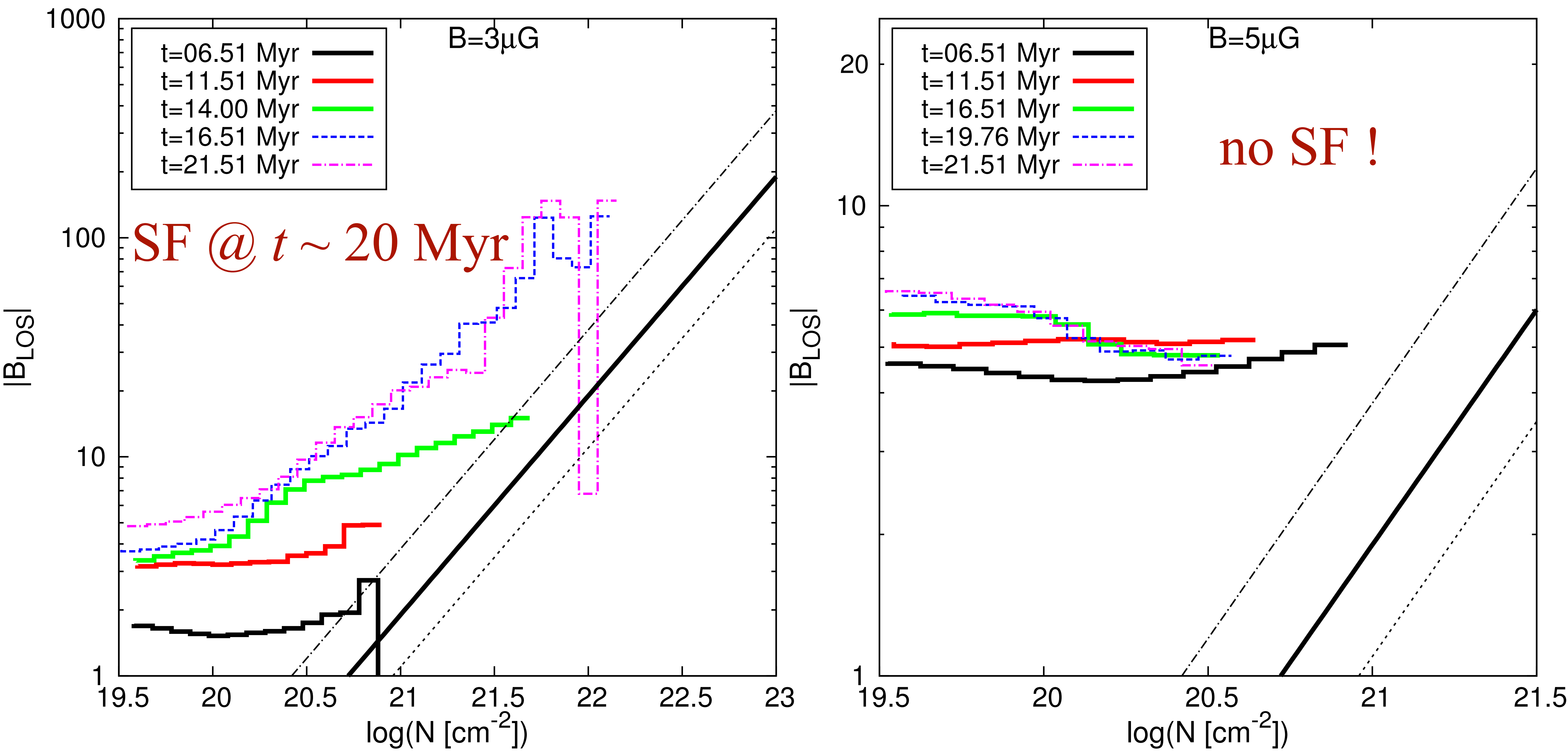


with ambipolar diffusion

$B = 4\mu G$

Simulations of colliding flows

results from head-on colliding flows with different field strengths



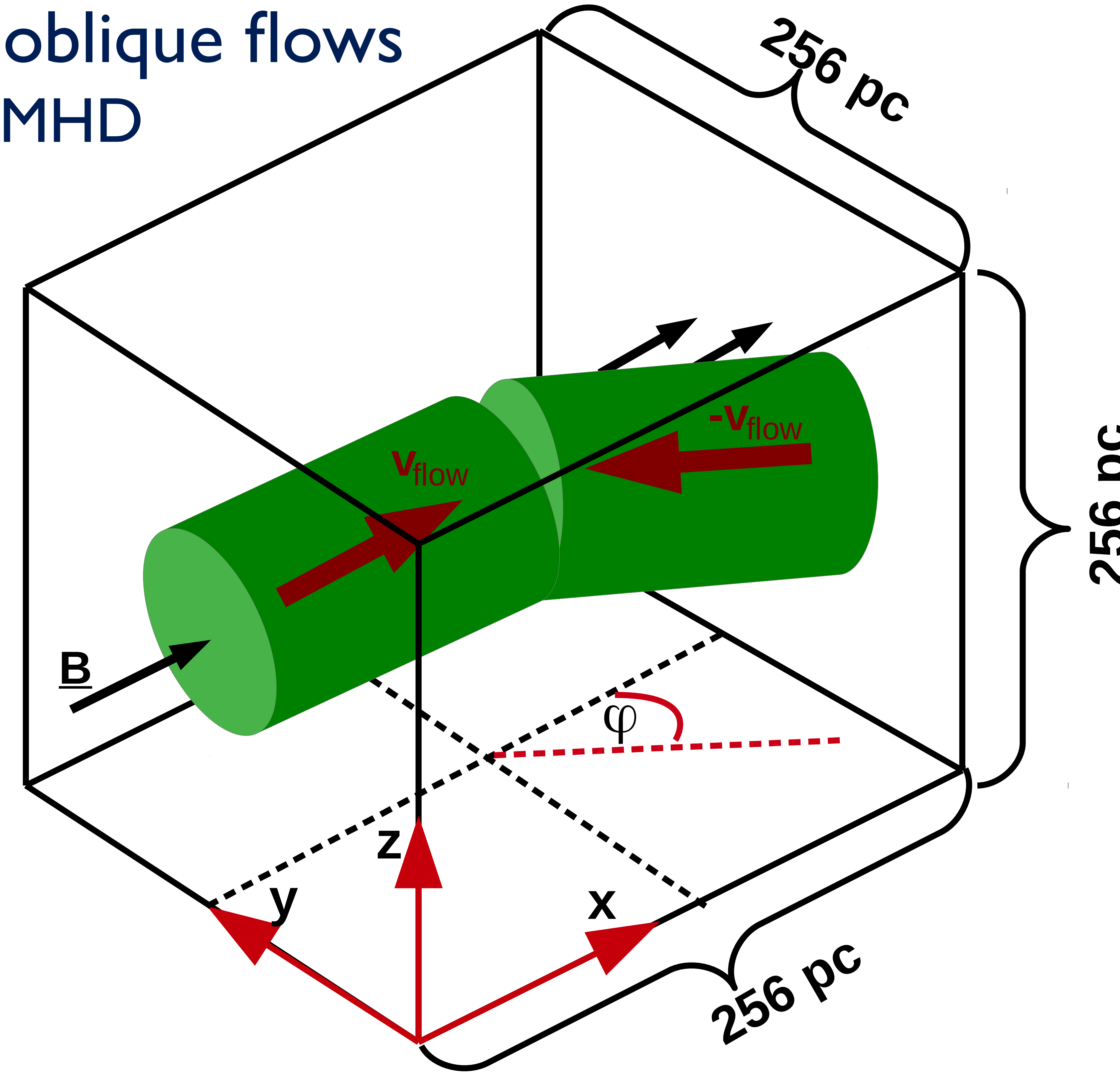
B. Körtgen, RB in prep.

Simulations of oblique flows

Simulations setup of oblique flows
$\Longrightarrow$ resemble non-ideal MHD

Model parameter:

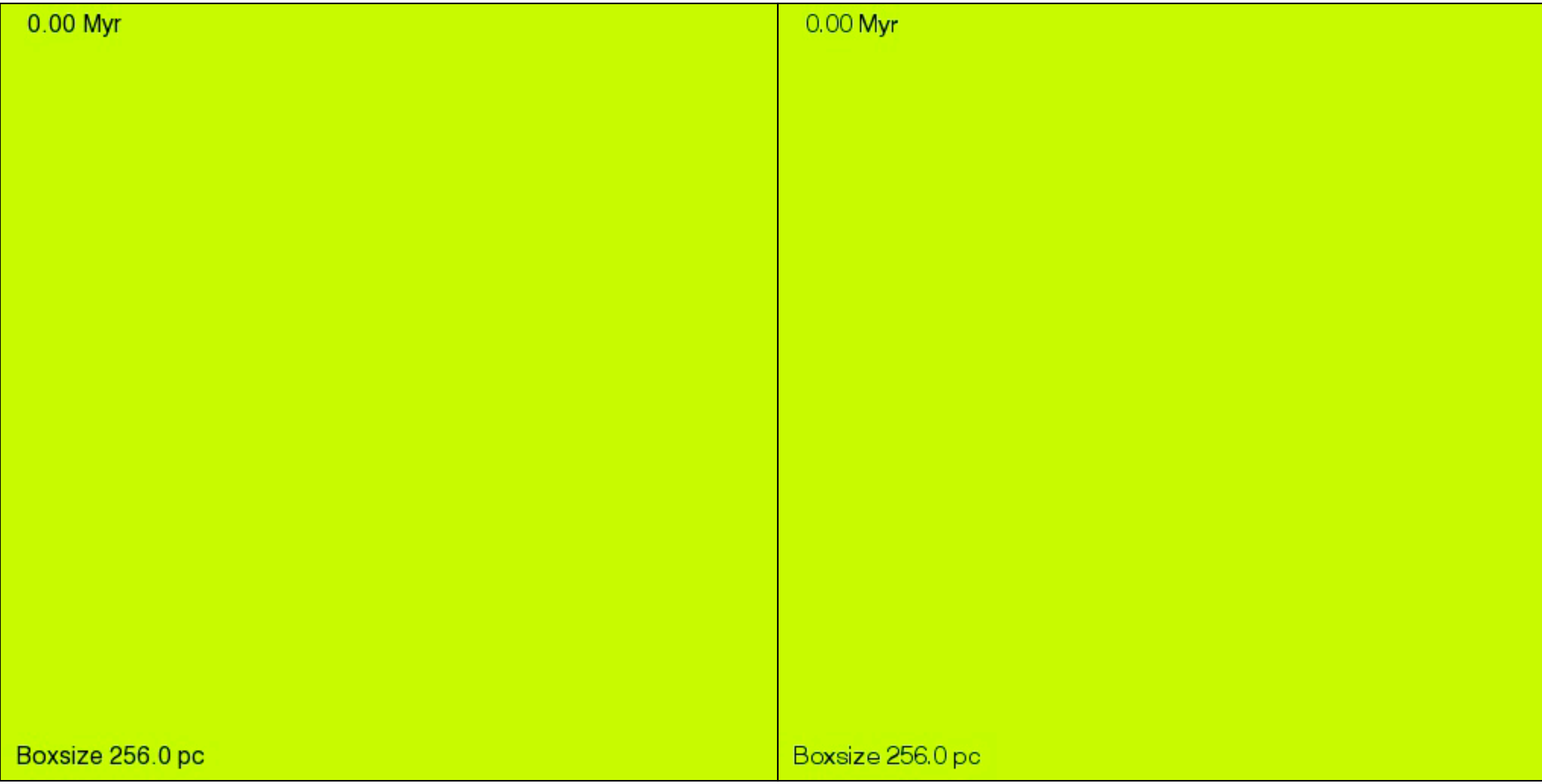
- $\varphi = 0, 30, 60$
- $n = 1 \ldots 10\ \mathrm{cm}^{-3}$
- $r = 32 \ldots 64$ pc
- $v_{\mathrm{inf}} = 14$ km/sec
- $v_{\mathrm{turb}} = 2..10$ km/sec
- $B_{\mathrm{x}} = 1 \ldots 5\ \mu$G



B. Körtgen, RB in prep.

Simulations of oblique flows

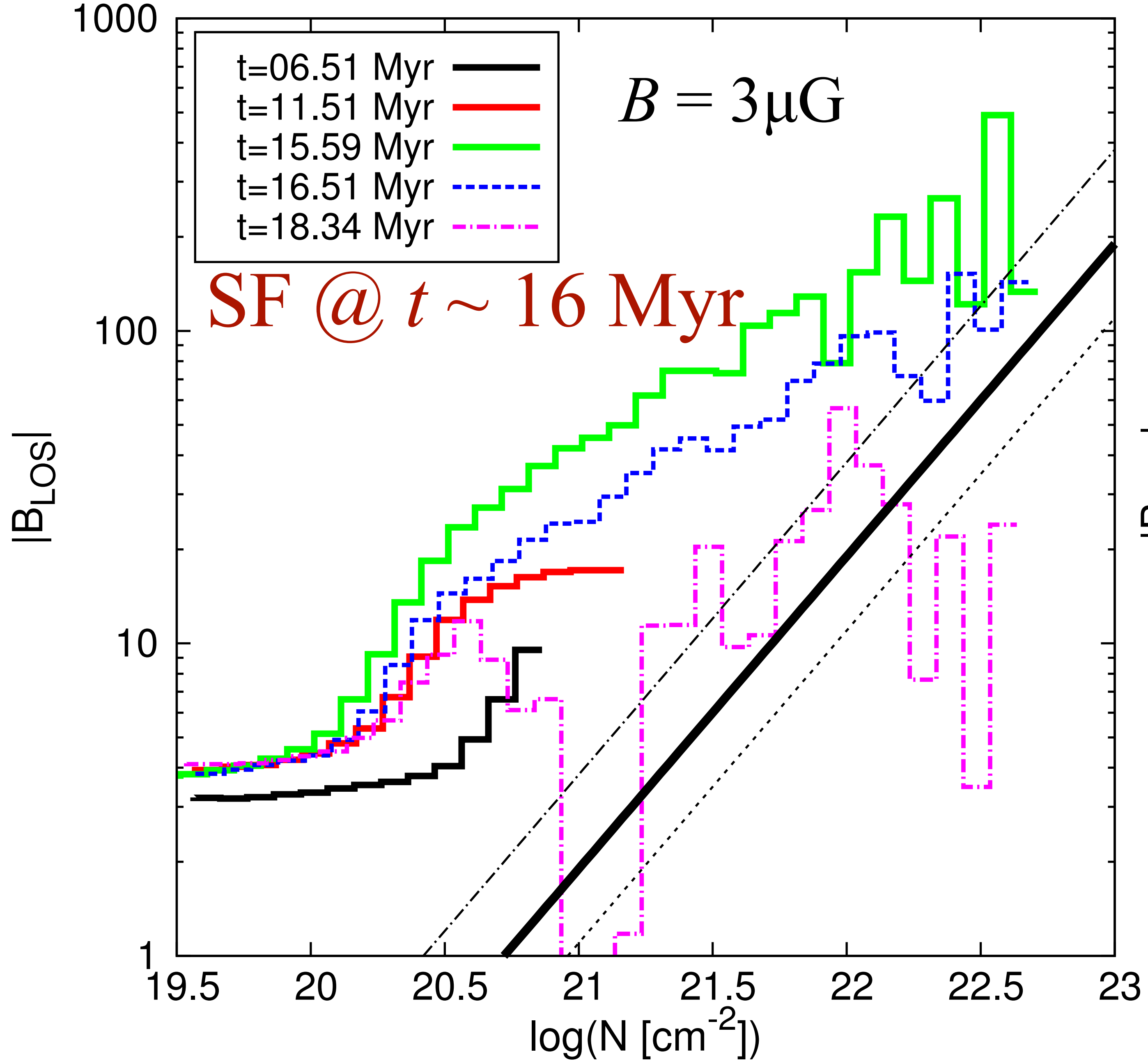
$\varphi = 30°$

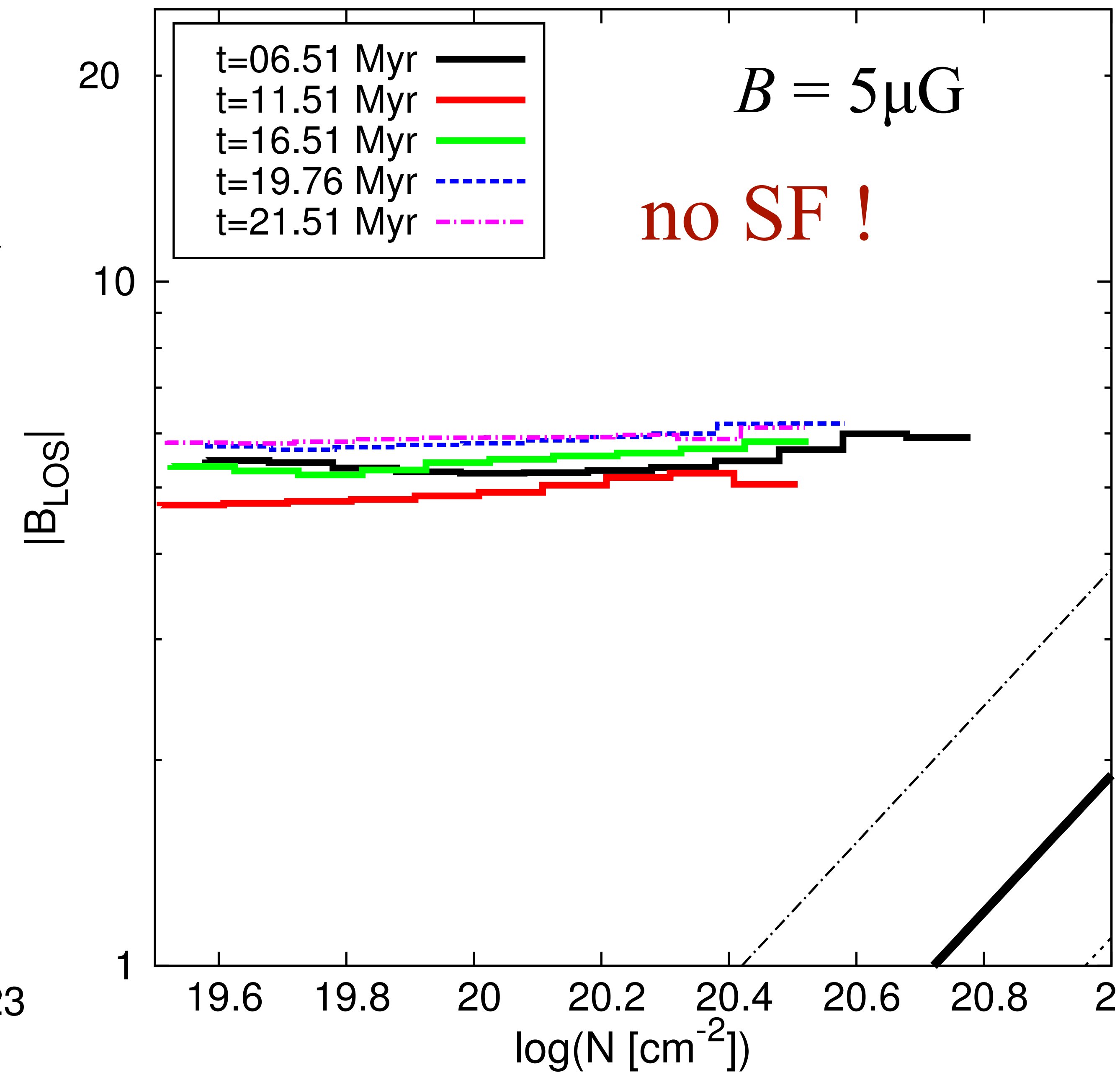


$B = 3\mu G$ $B = 5\mu G$

Simulations of oblique flows

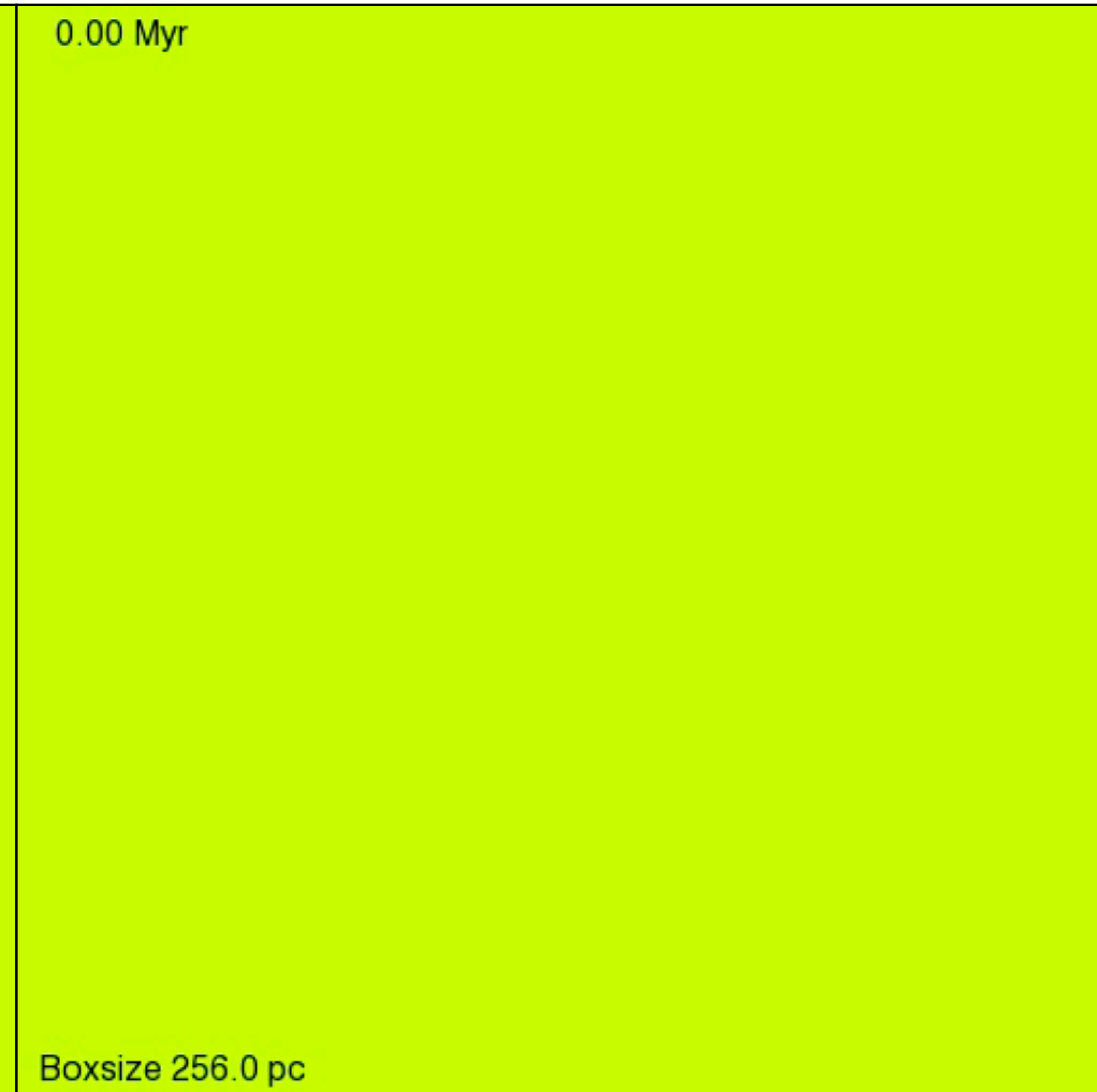
results from *oblique* flows with different field strengths at $\varphi = 30°$





Simulations of oblique flows

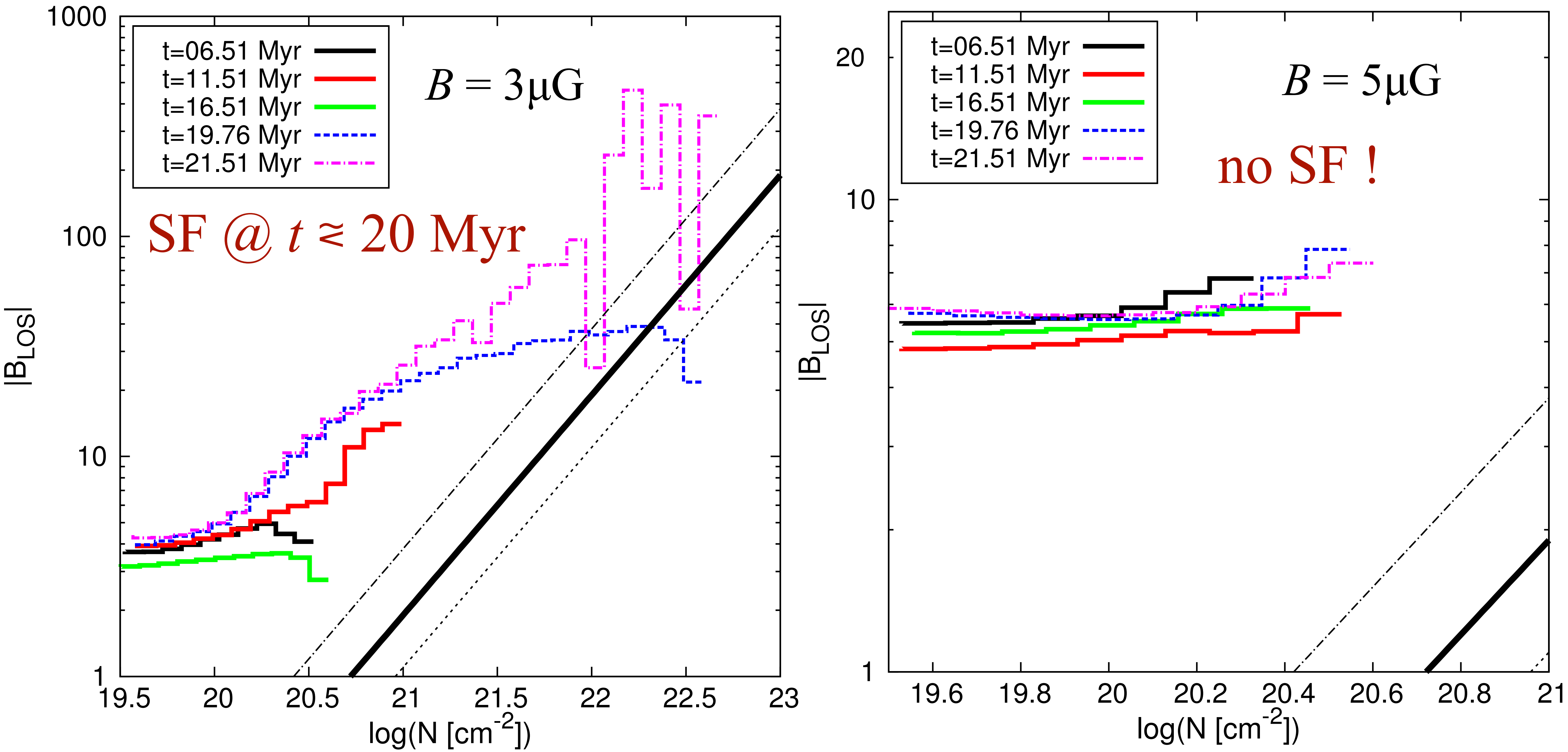
$\varphi = 60°$



$B = 3\mu G$ $B = 5\mu G$

Simulations of oblique flows

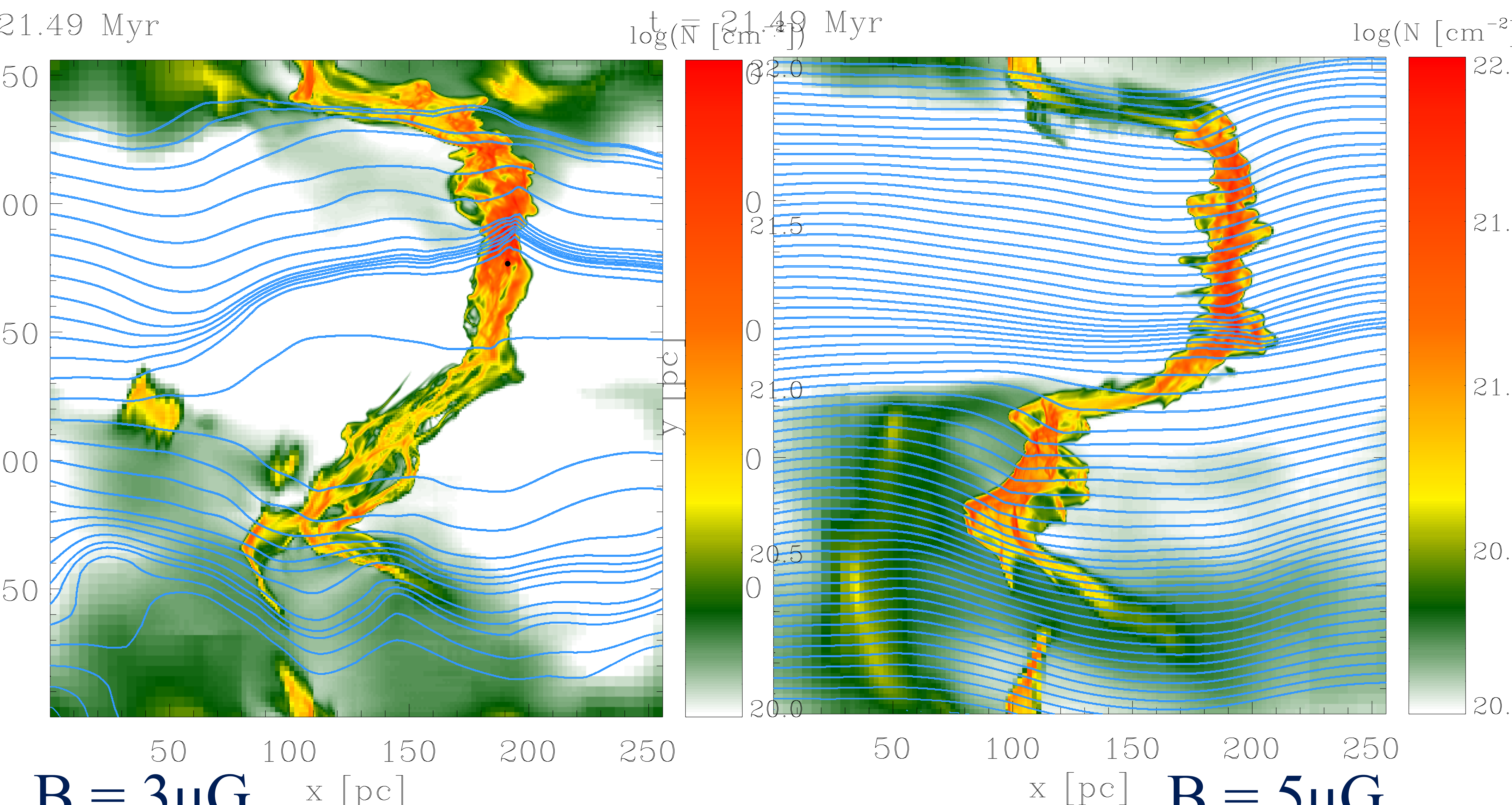
results from *oblique* flows with different field strengths at $\varphi = 60°$



B. Körtgen, RB in prep.

Simulations of oblique flows

results from *oblique* flows with different field strengths at $\varphi = 60°$



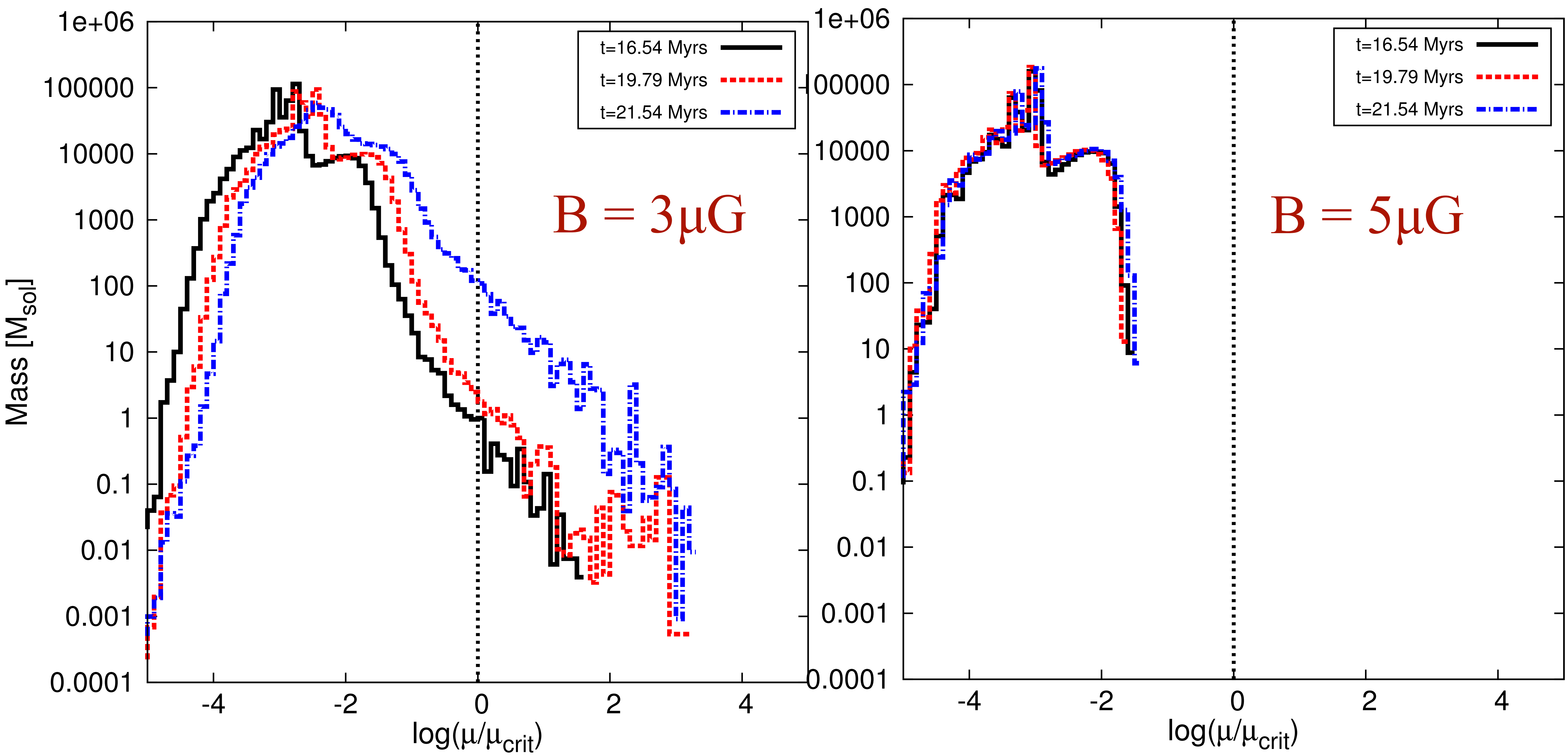
B = 3μG

B = 5μG

B. Körtgen, RB in prep.

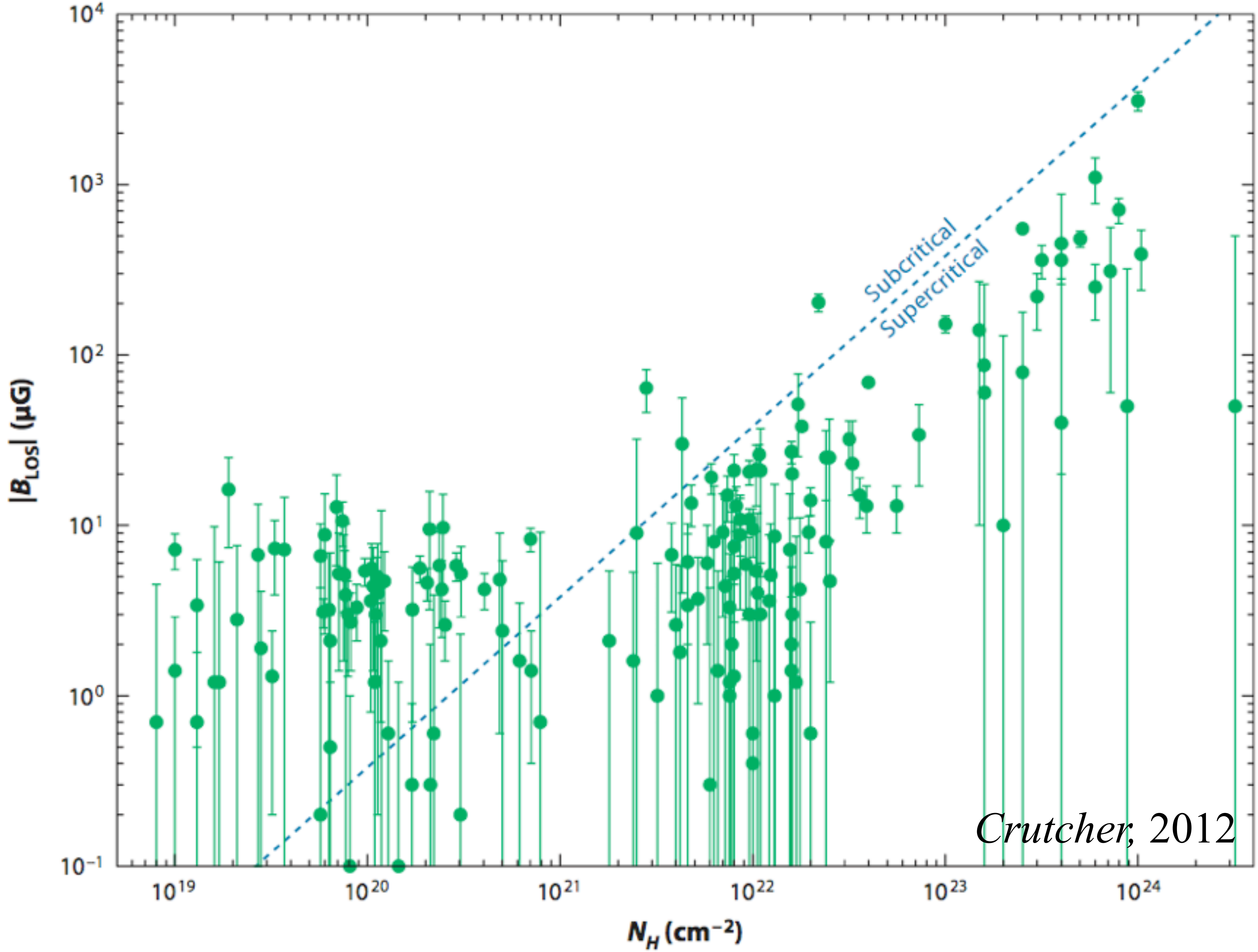
Simulations of oblique flows

results from *oblique* flows with different field strengths at $\varphi = 60°$



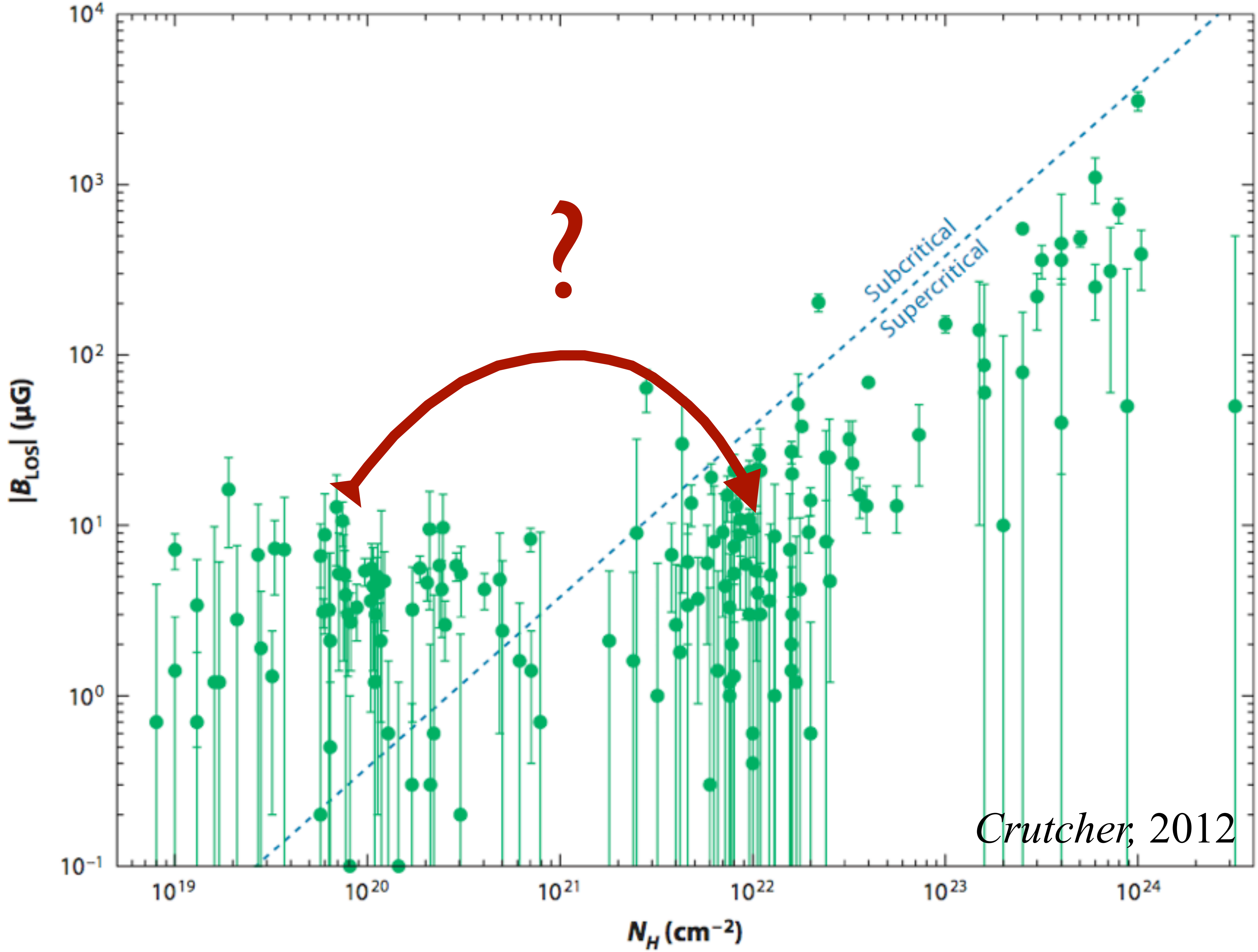
B. Körtgen, RB in prep.

Conclusion



10^4
10^3
10^2
10^1
10^0
10^{-1}
$|B_{LOS}|$ (μG)
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
10^{24}
N_H (cm^{-2})
Subcritical
Supercritical
Crutcher, 2012

Conclusion



?
Subcritical
Supercritical
$|B_{LOS}|$ (μG)
N_H (cm^{-2})
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
10^{24}
Crutcher, 2012