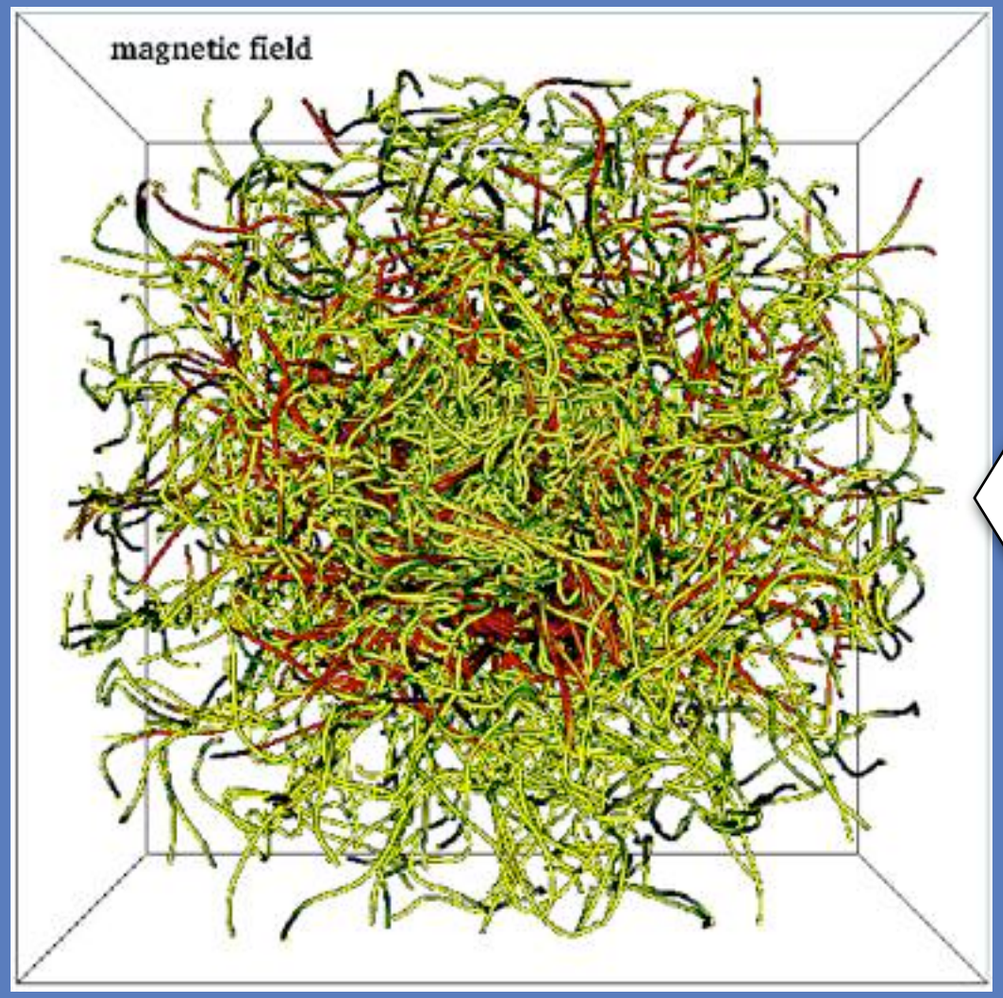
The link between magnetic fields and cloud/star formation

Hua-bai Li

香港中文大學
The Chinese University of Hong Kong

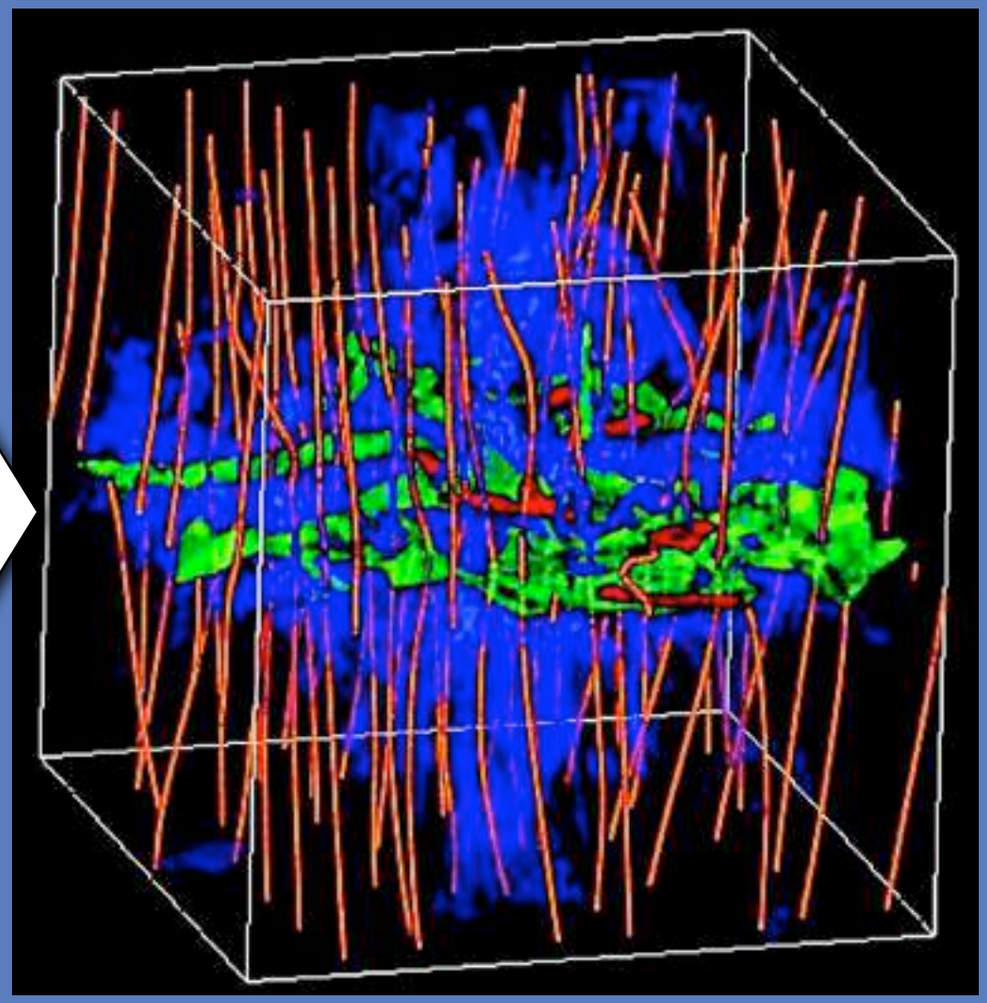
Cloud magnetic-field (B-field) morphologies

1. which morphology is closer to reality?



Federrath+, *ApJ* 2011

or

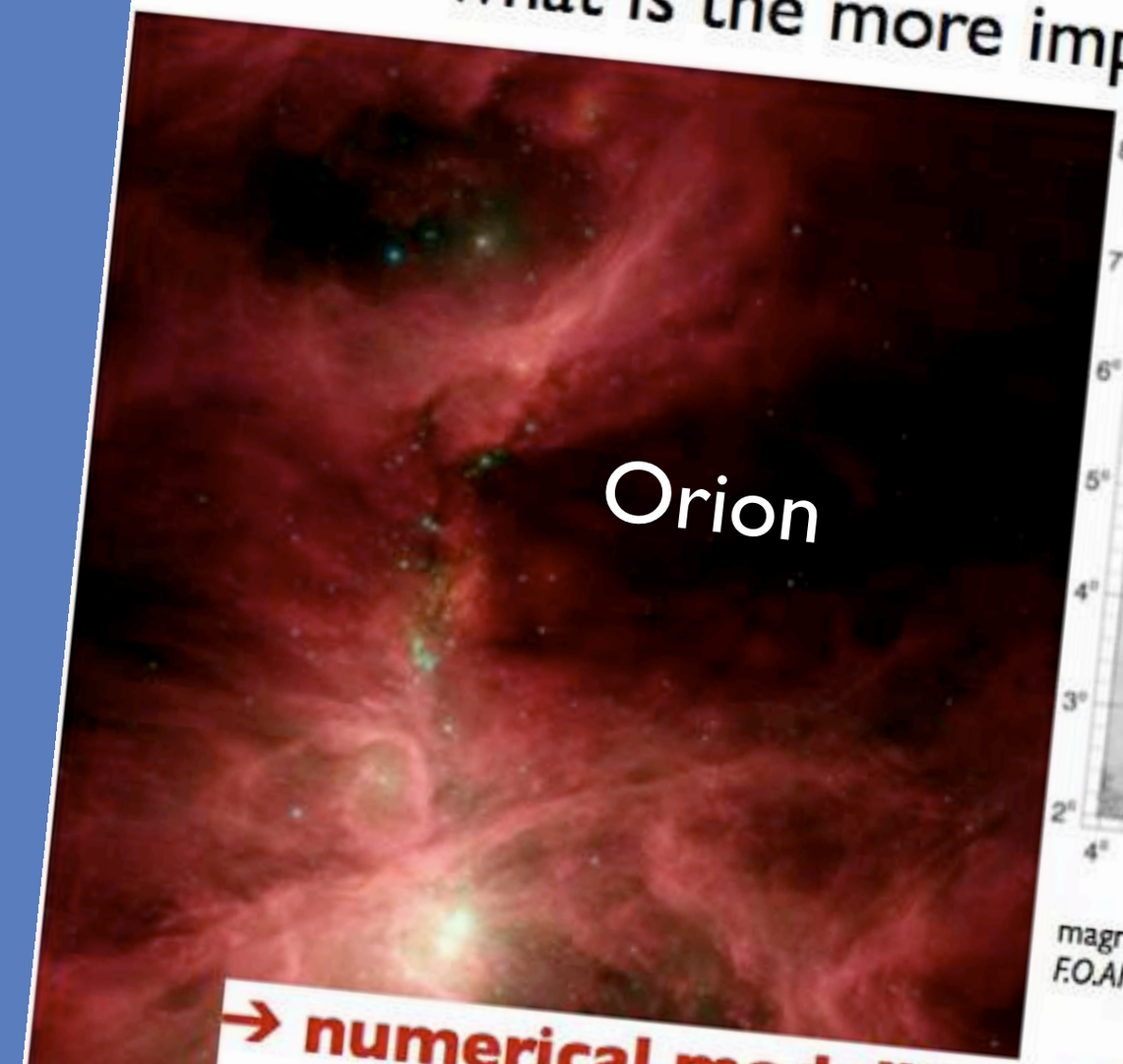


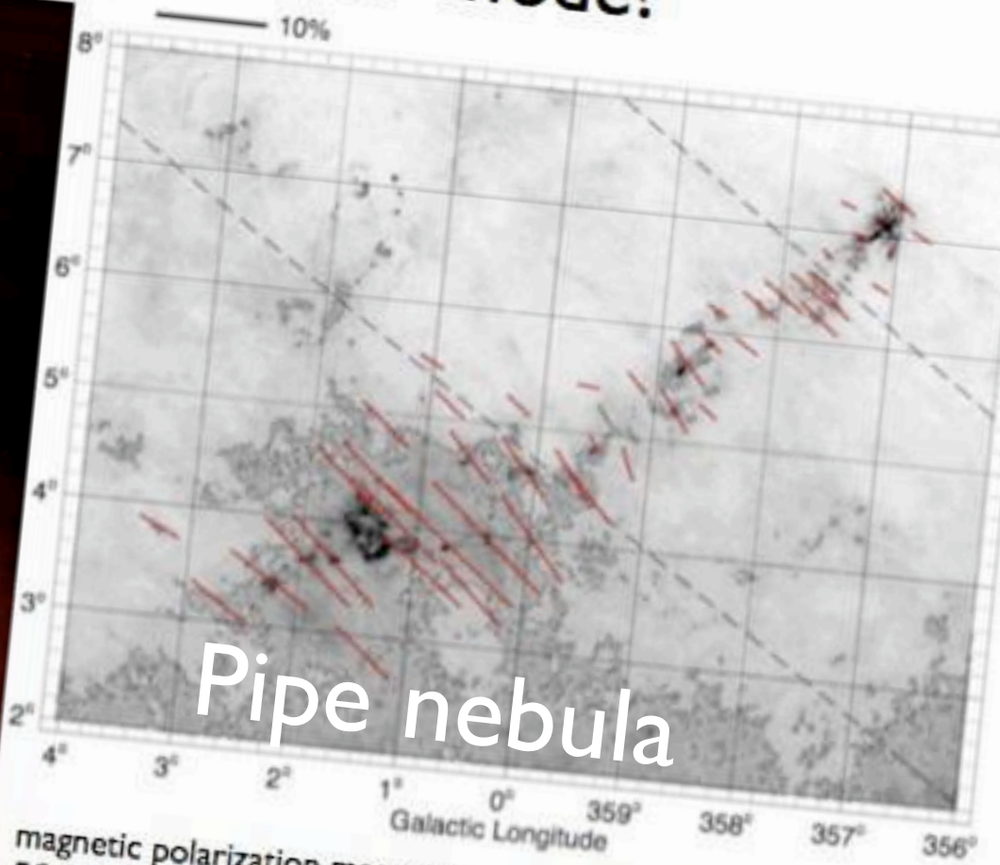
Nakamura & Li, *ApJ* 2008

2. consequences of the field morphology on:
   gas velocity, cloud shapes, fragmentation, etc

Motivation

what is the more important SF mode?

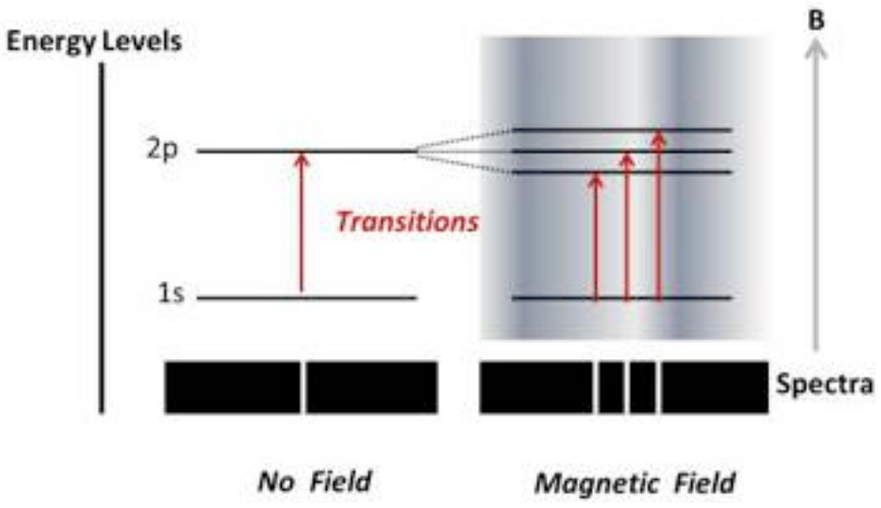




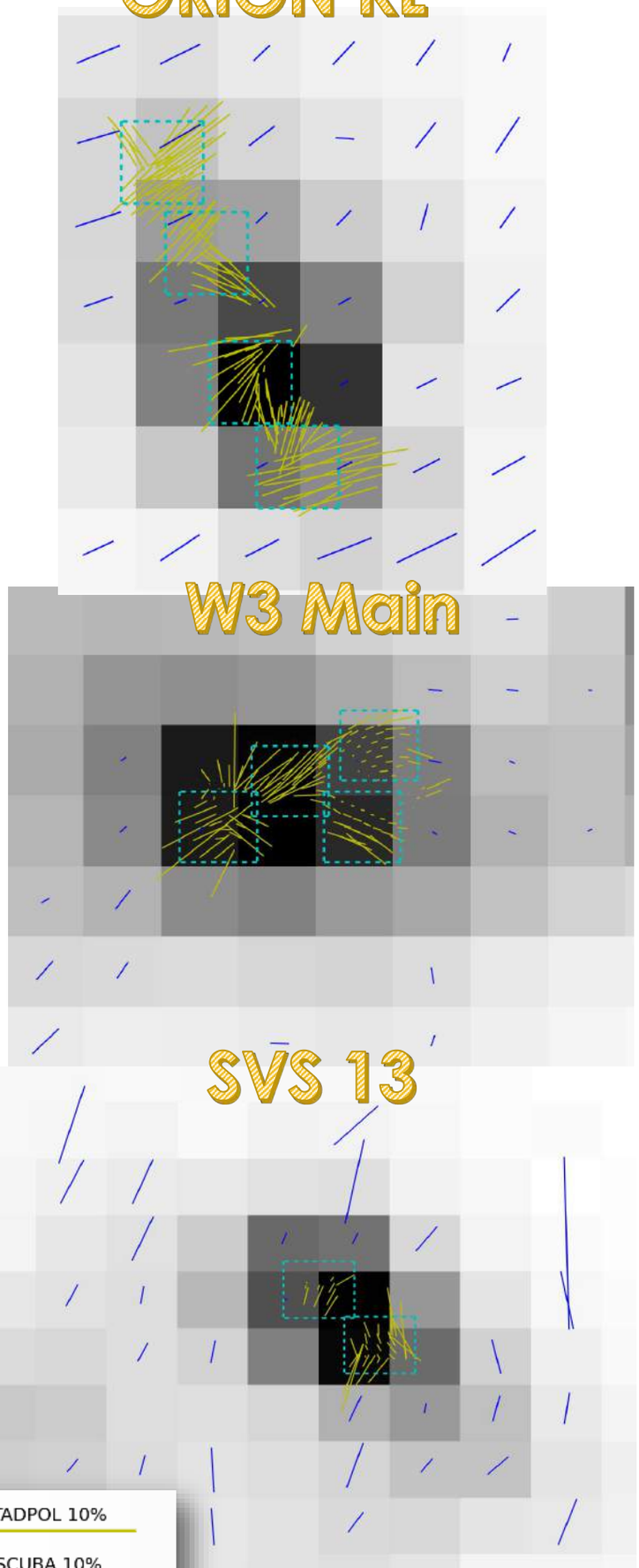
magnetic polarization measurements in the Pipe nebula
F.O.Alves, Franco, Girart 2008

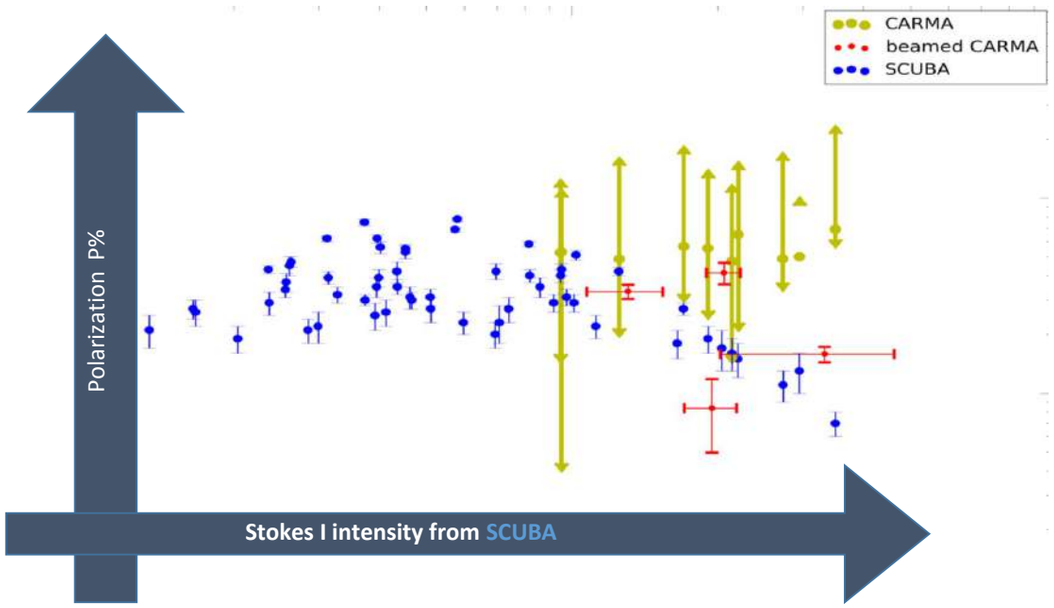
→ **numerical modelling of MC formation out of differently magnetized ISM**

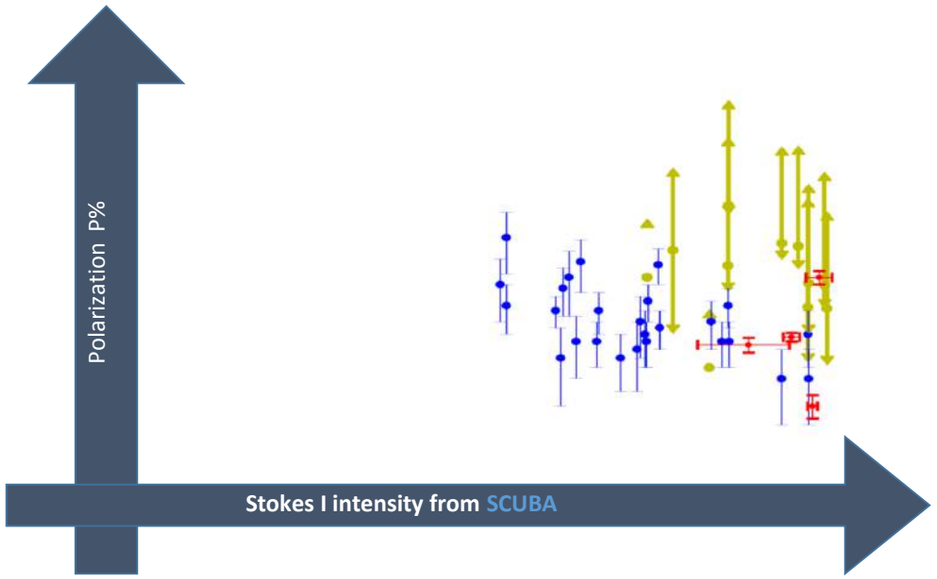
Orion Nebula, Spitzer obs. (*T. Megeath*)

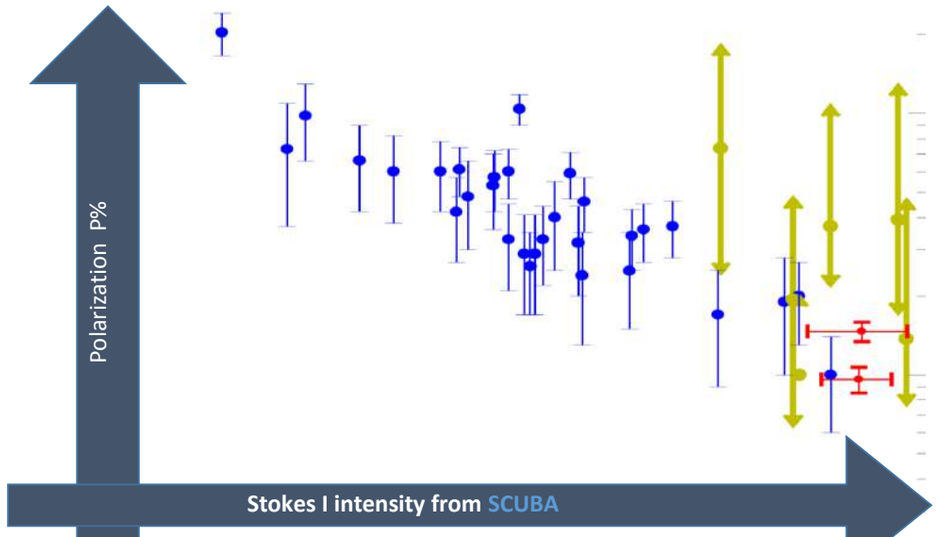
Observation tools	how to observe	results	note
 **Dust grain alignment**: a grain spins along the short axis, which precesses around B fields	***polarization*** of dust thermal emission	⊥ B	A_v > 100 mag
	polarization of background star light	// B	A_v < 5 mag
Zeeman effect 	freq. splitting of ***circular*** line polarization	B_{los}	difficult due to small B
	linear line polarization	⊥ or // B	Goldreich-Kylafis effect

Polarization Holes









Tang & Li in prep.

Polarization Holes

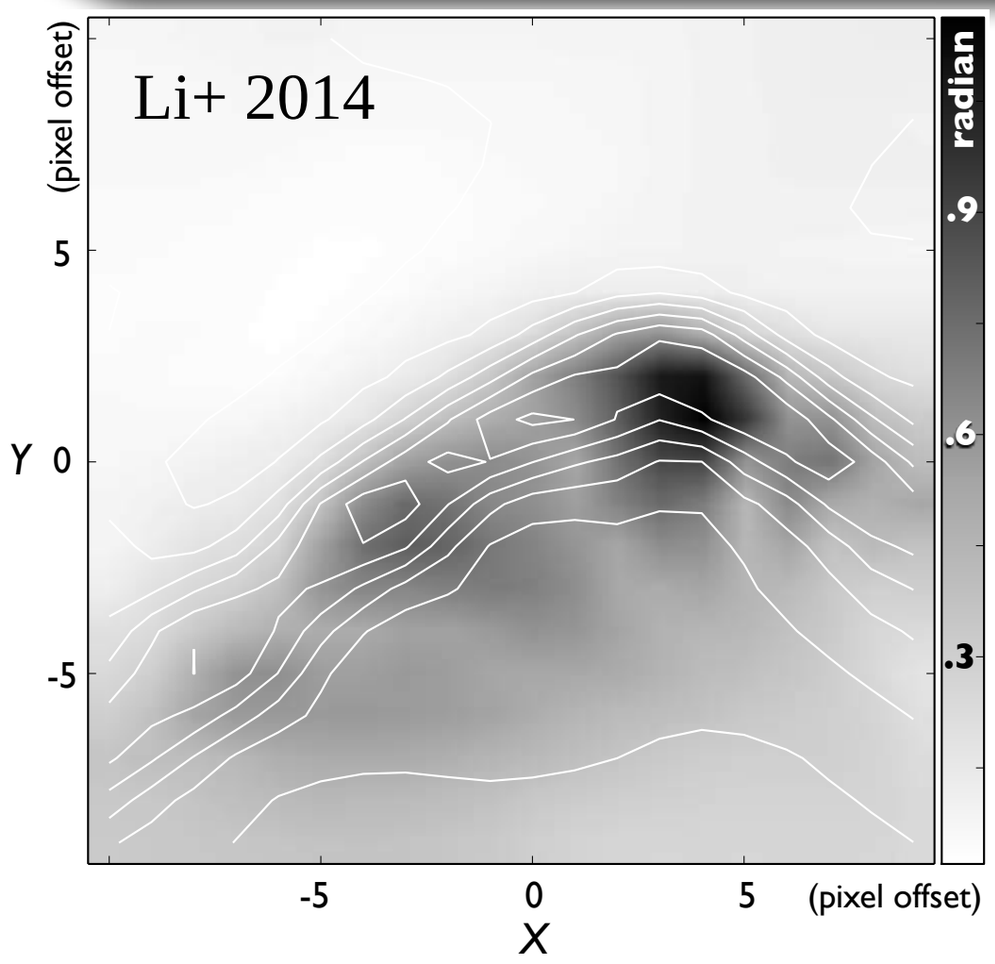
Tang & Li in prep.

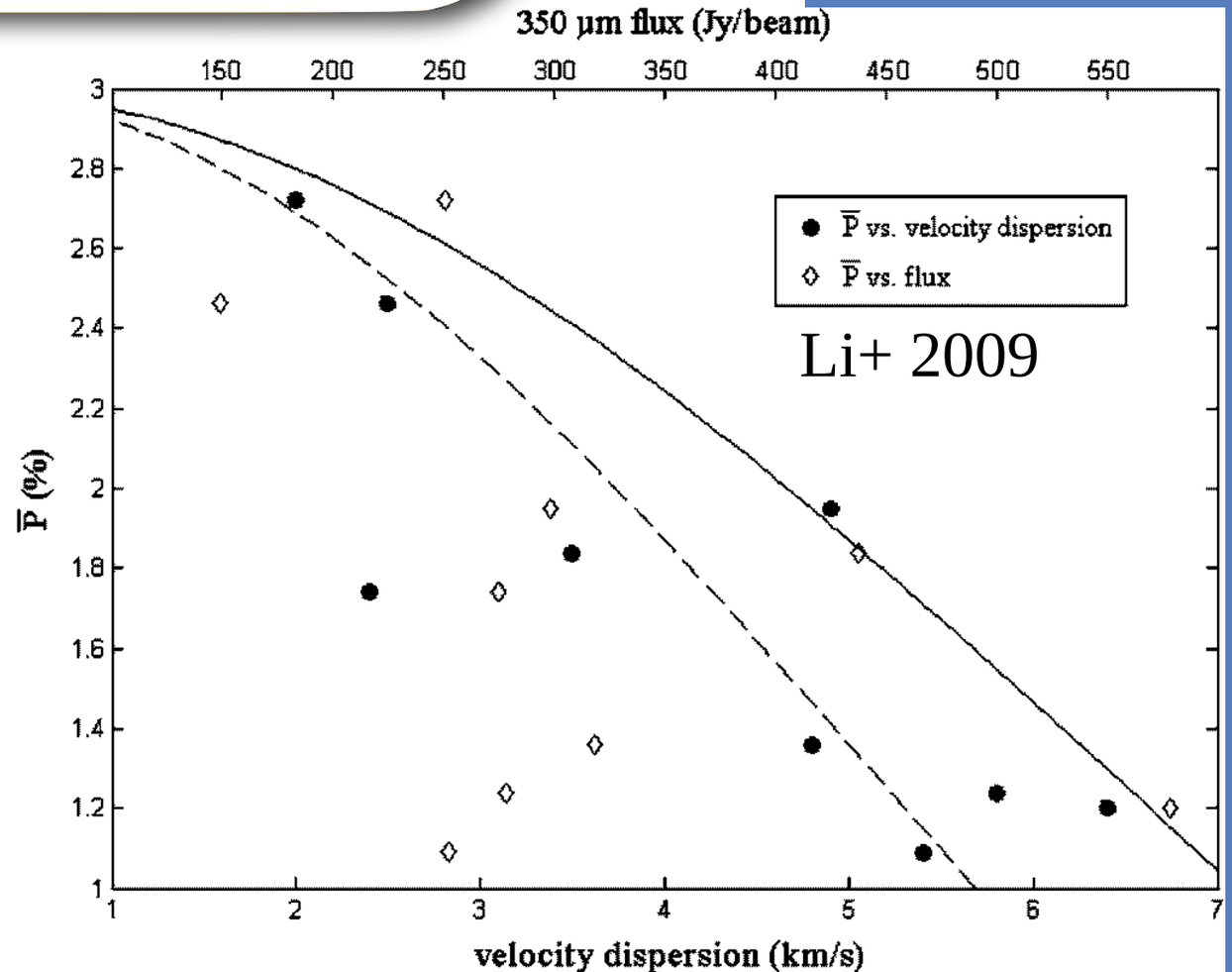
$\Sigma \propto l_{los}{}^{\beta}$ *Higher column density* Σ

$\sigma_v \propto l_{los}{}^{\alpha}$ → *more turbulent energy* σ_v

$\delta\phi = \sqrt{4\pi\rho}\,\frac{\sigma_v}{|B_{pos}|}$ → *more fluctuation of B-field* $\delta\phi$ *along line of sight!*

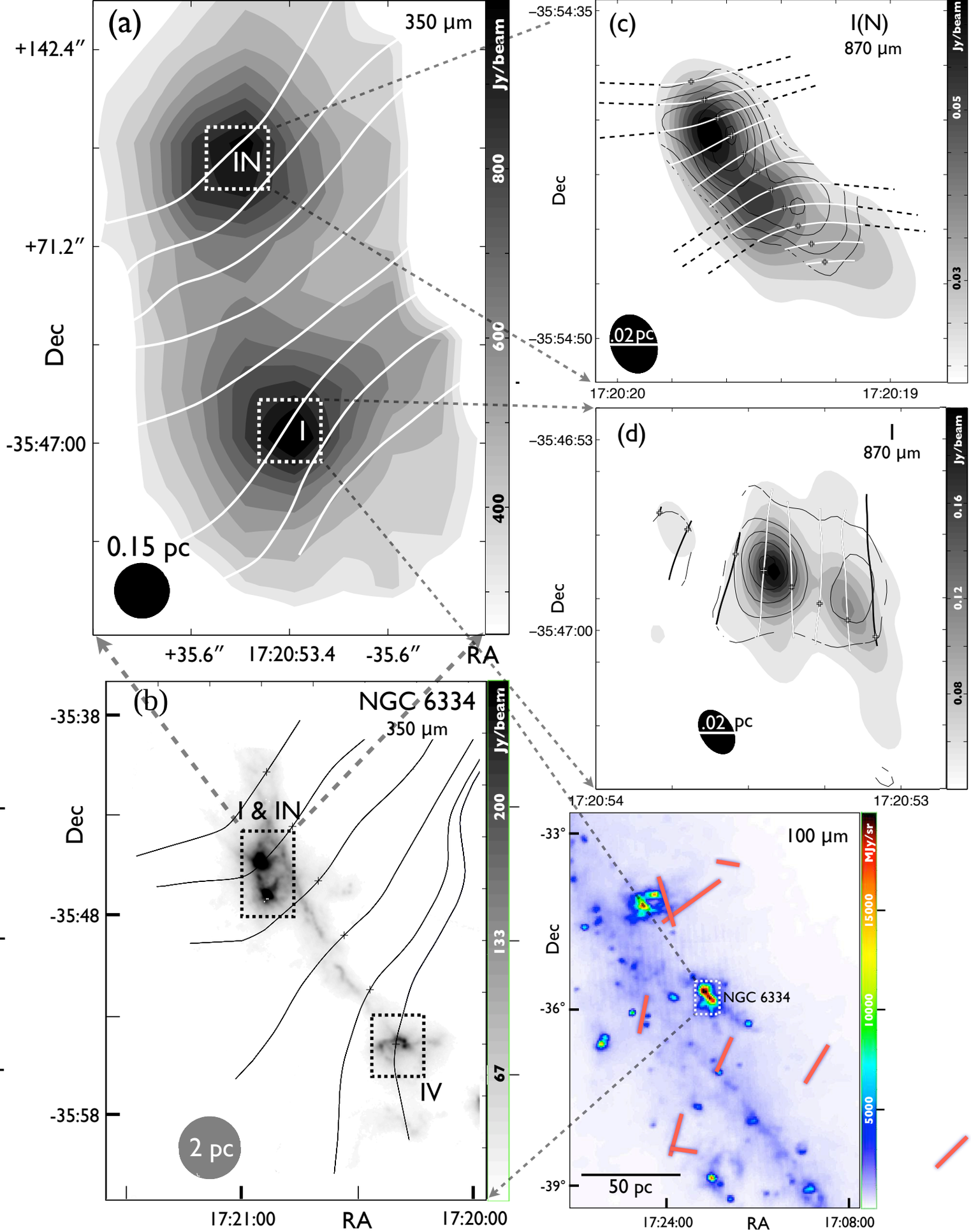
→ <u>LOWER</u> *degree of polarization*
→ *A simpler argument without involving alignment efficiency*





FIRST MULTISCALE STUDY of CLOUD MAGNETIC FIELDS from 10^2 to 10^{-2} pc

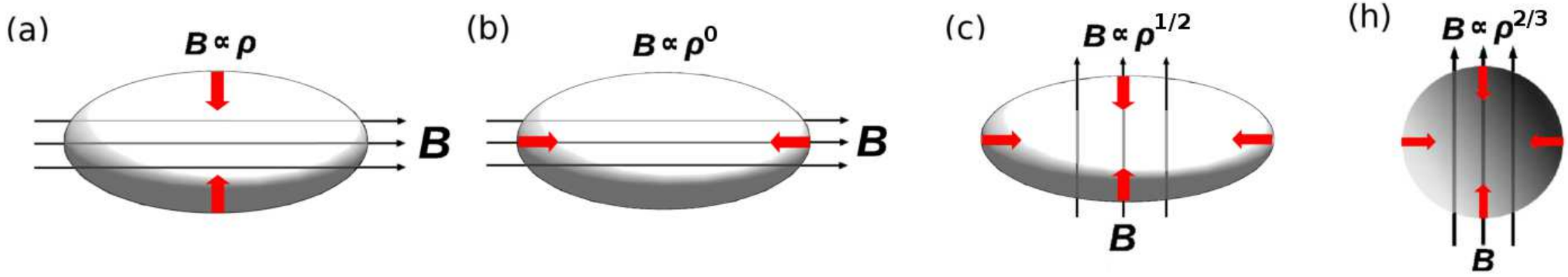
NGC 6334



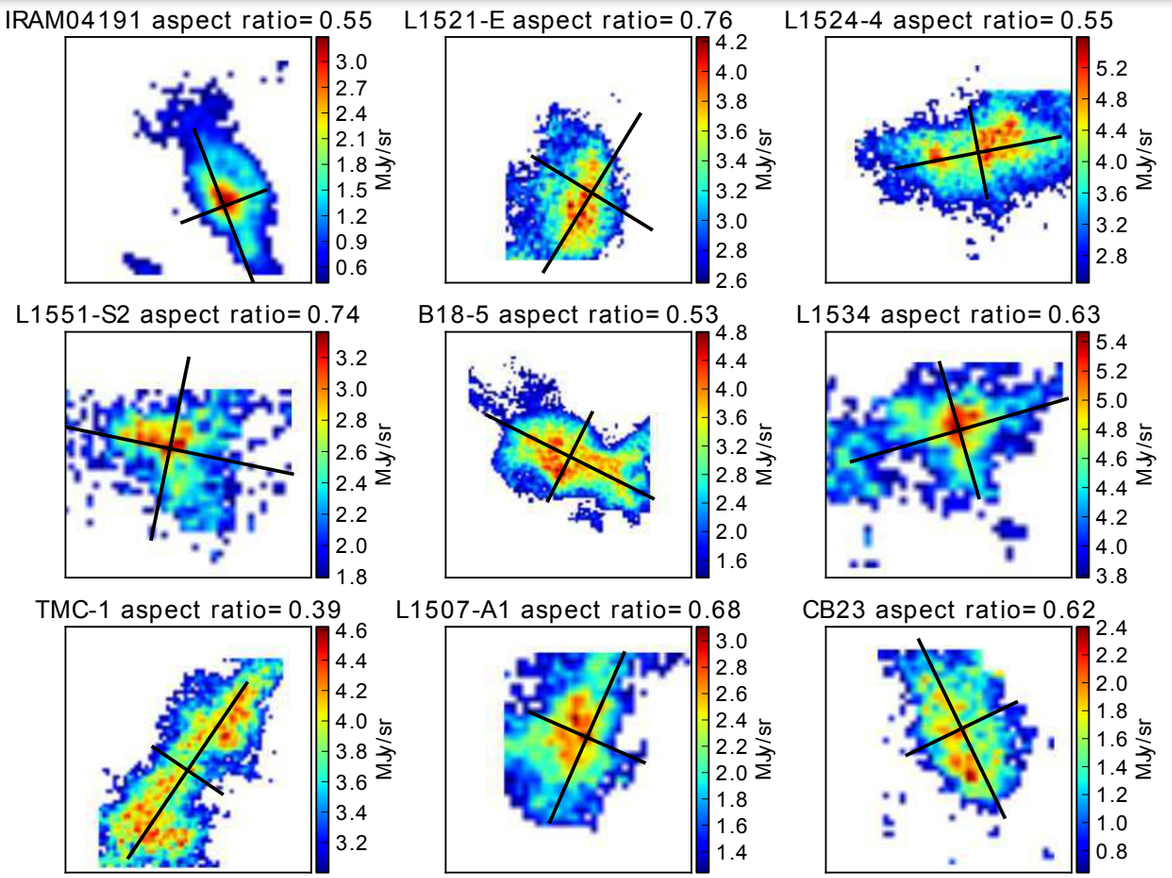
Li, Yuen, Otto, Leung, Tang, Zhang+ 2015

Clump shapes and B-ρ relations

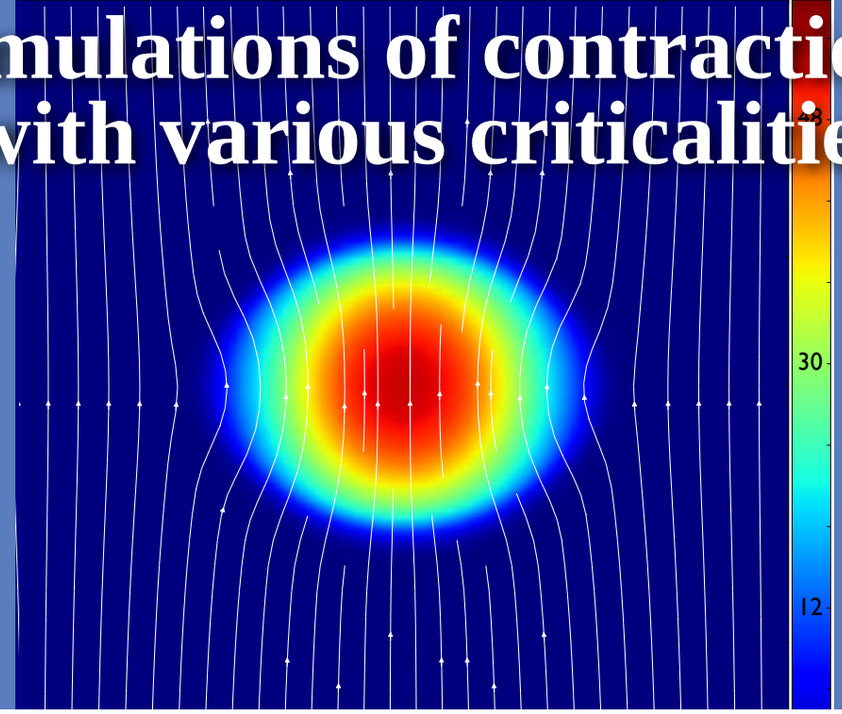
Tritsis et al. (2015)

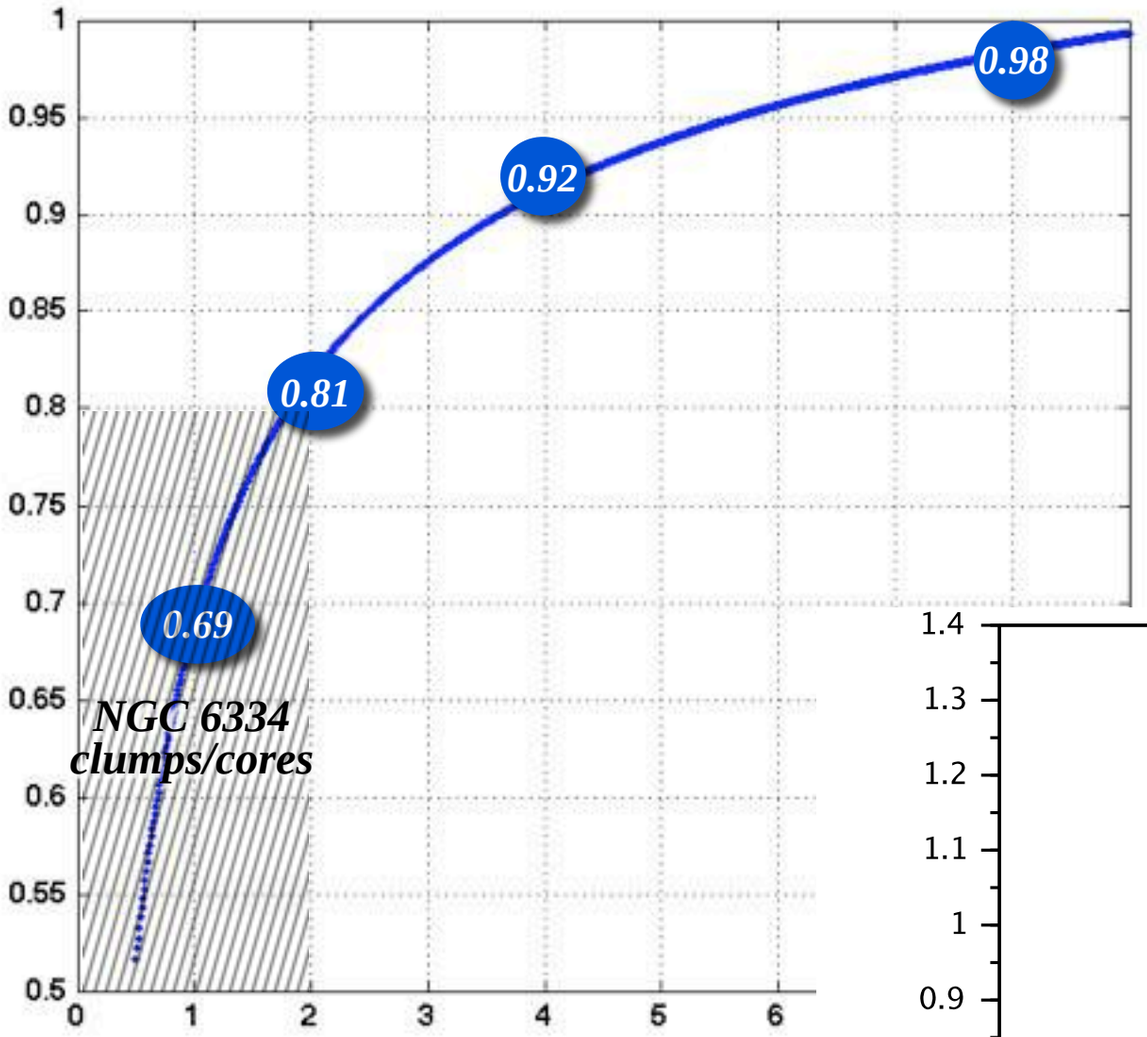


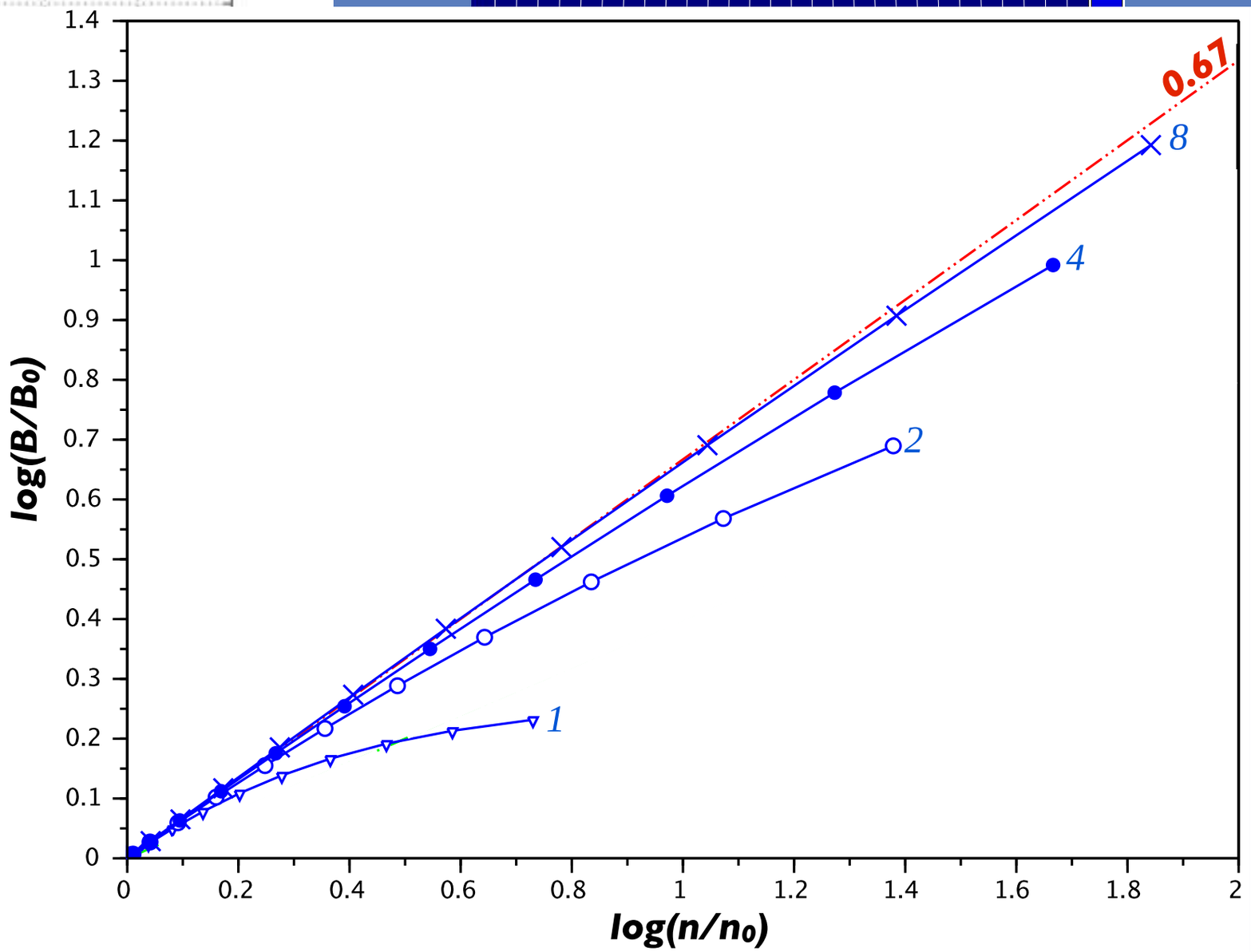
. Black arrows represent the direction of the magnetic field and bold red arrows the contraction. The $B \propto \rho^{2/3}$ relation is uniquely associated with spherical contraction



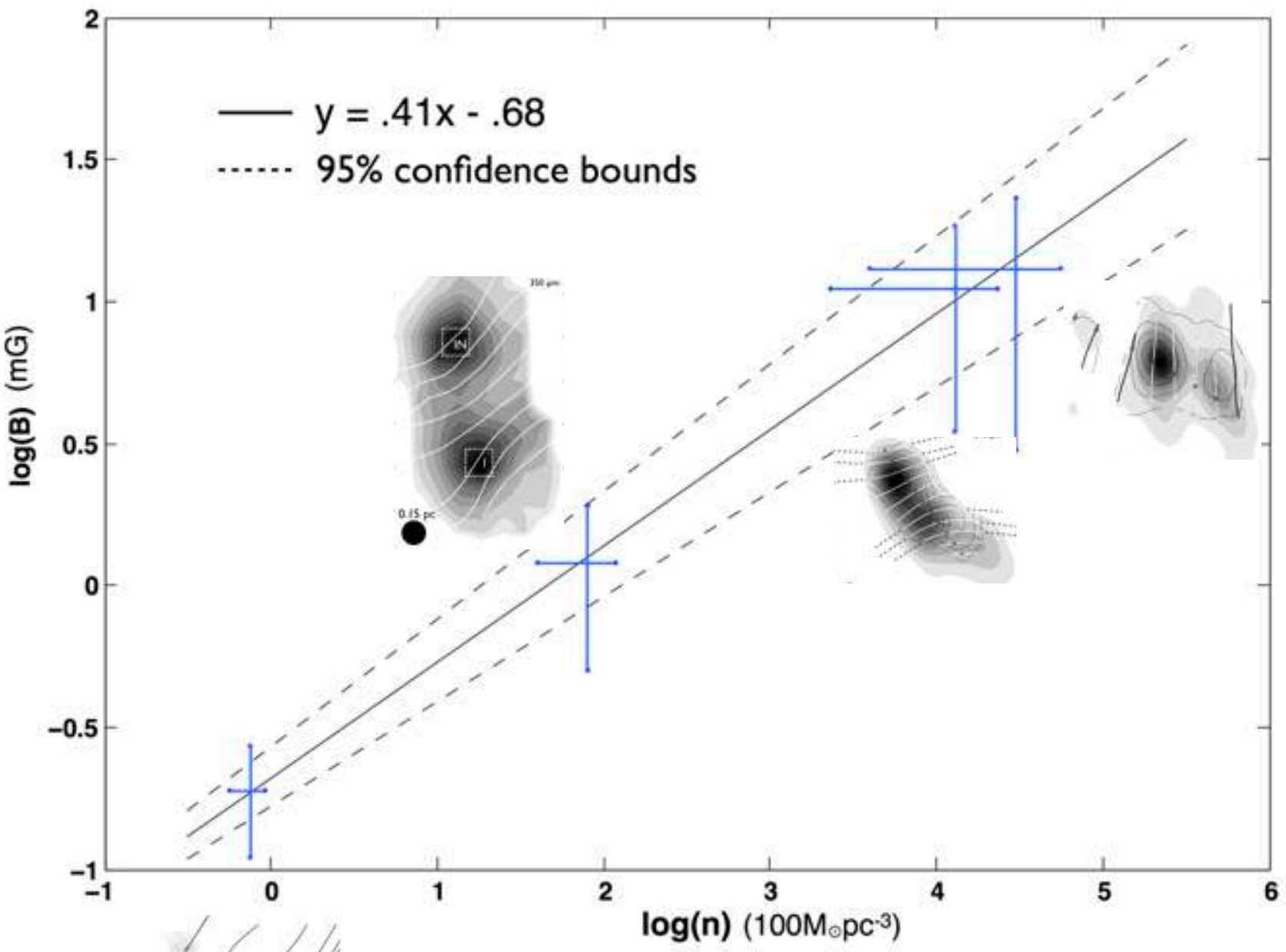
Simulations of contractions with various criticalities

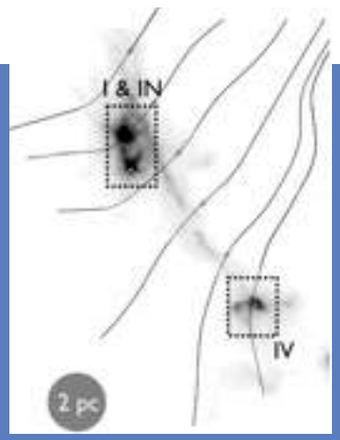




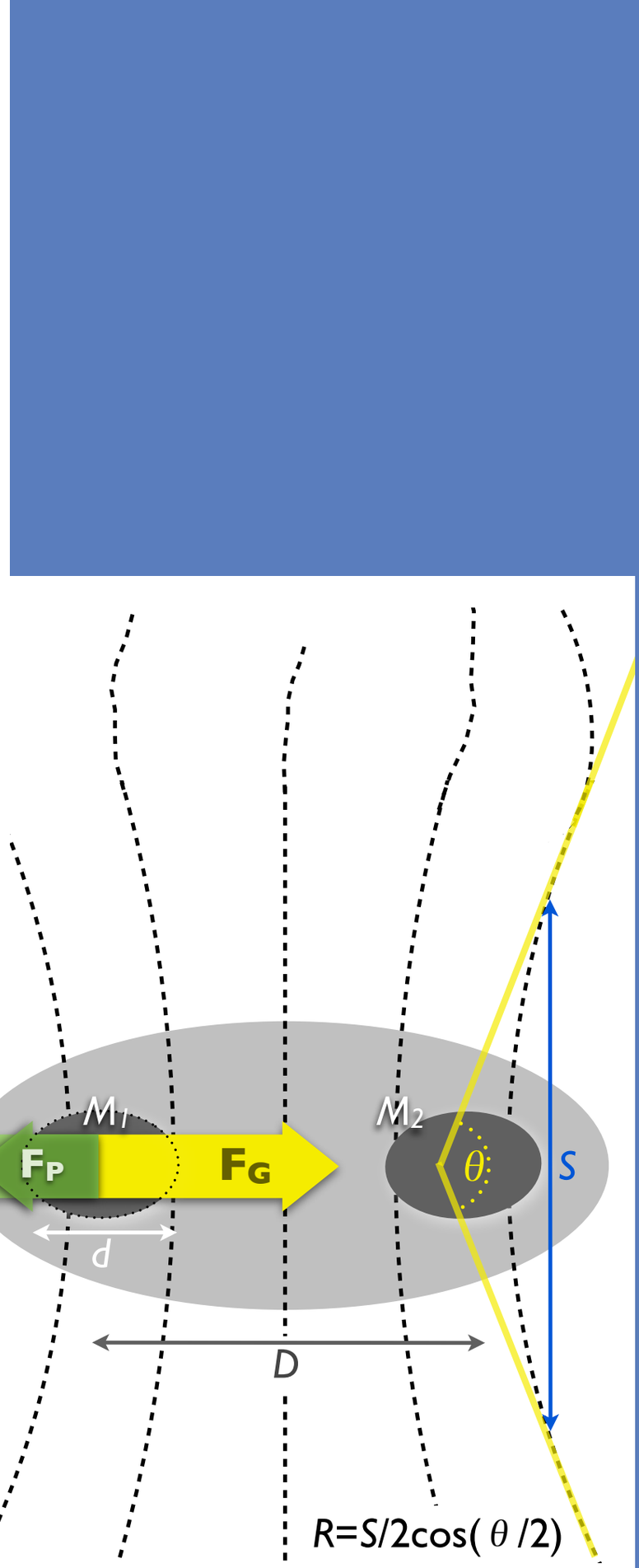


Li, Yuen, Otto, Leung, Tang, Zhang+ 2015





Li, Yuen, Otto, Leung, Tang, Zhang+ 2015



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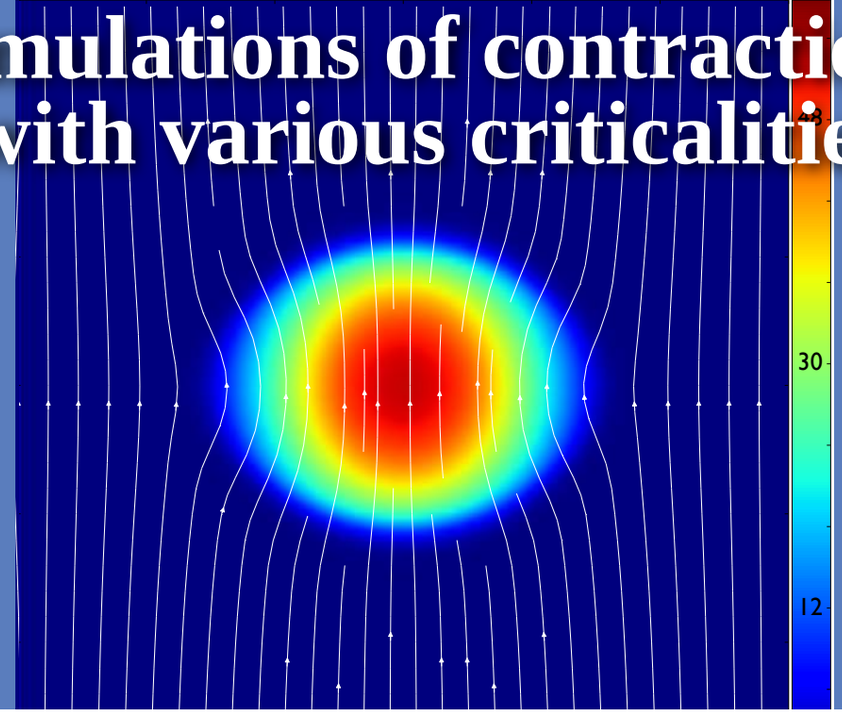
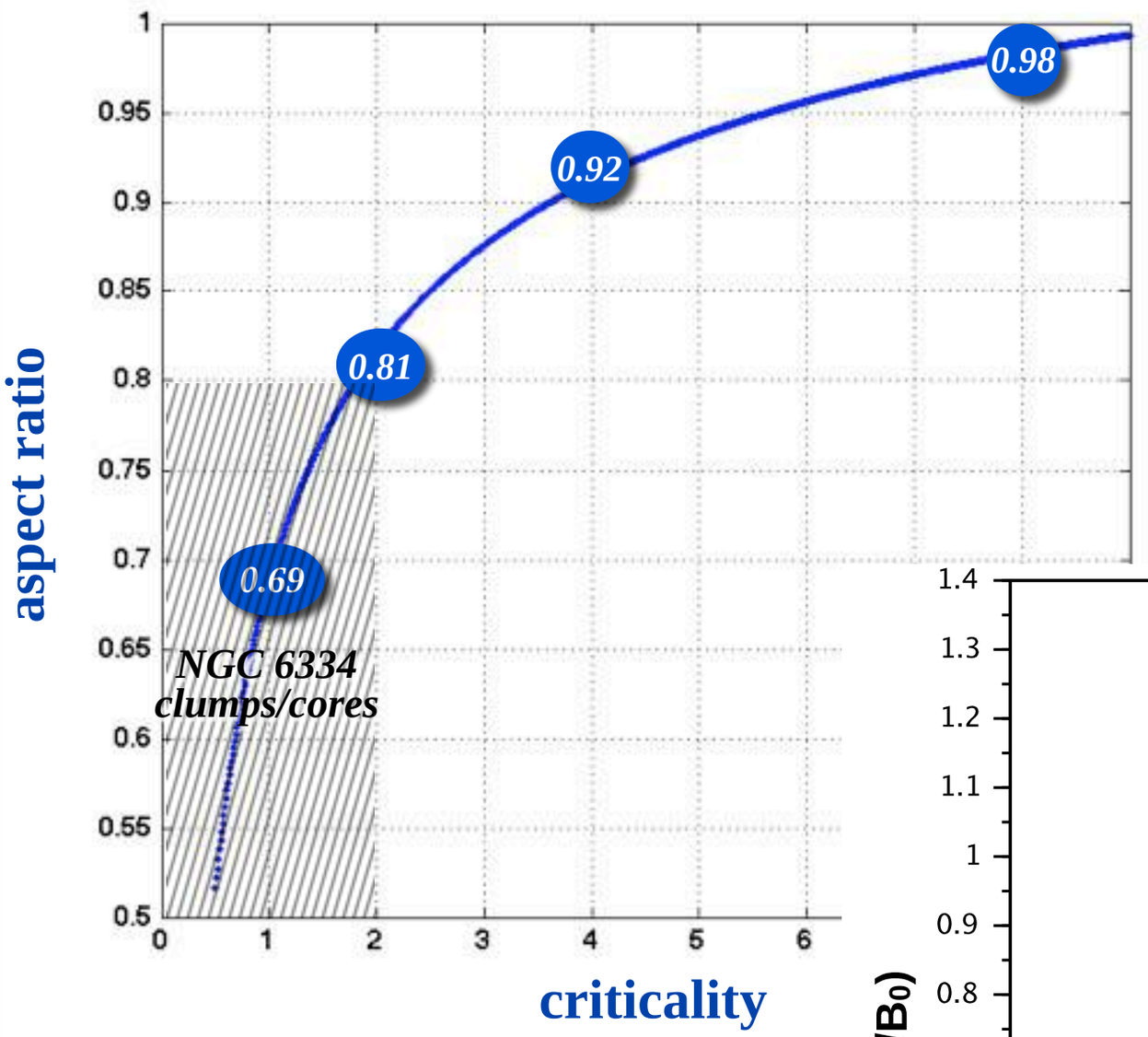
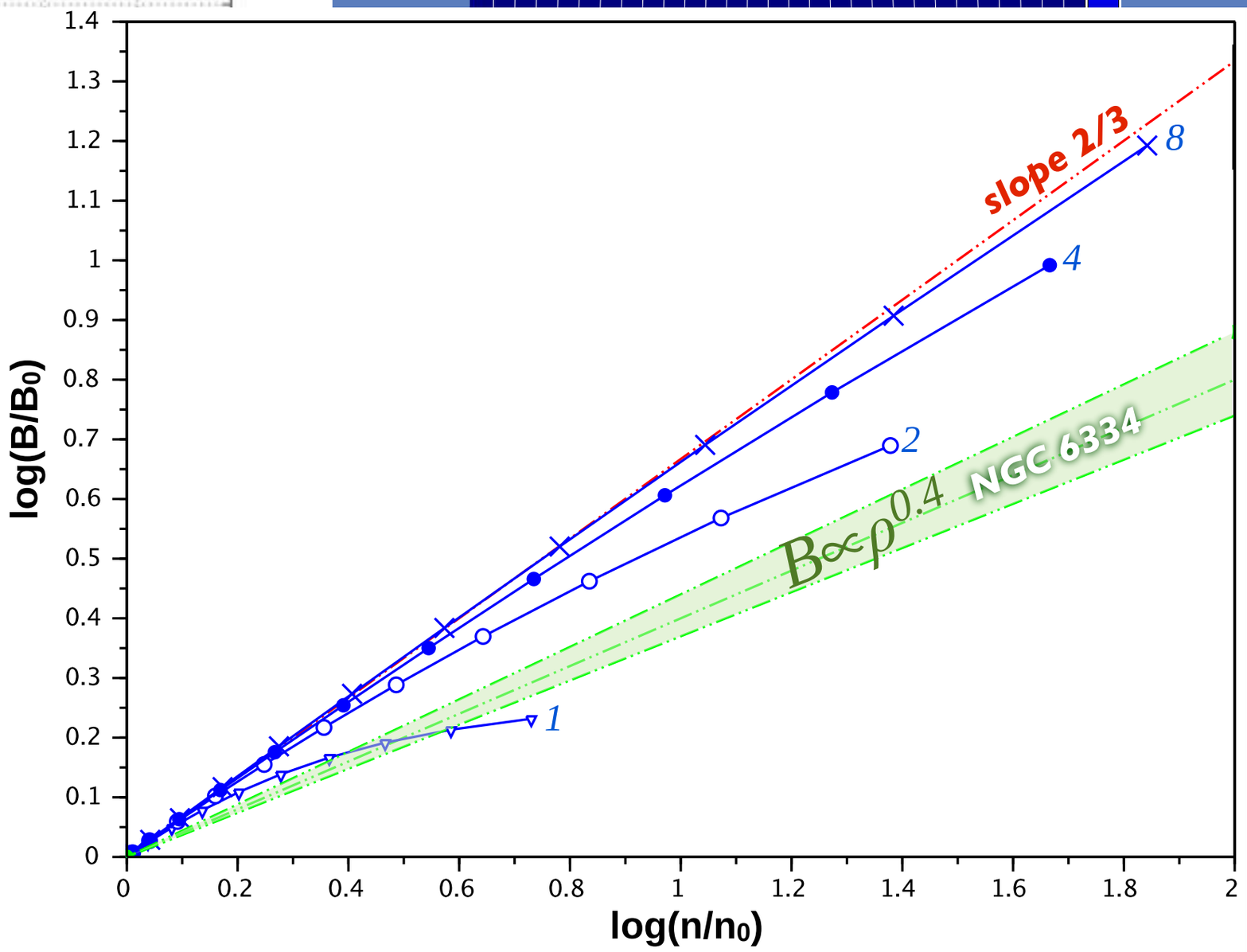
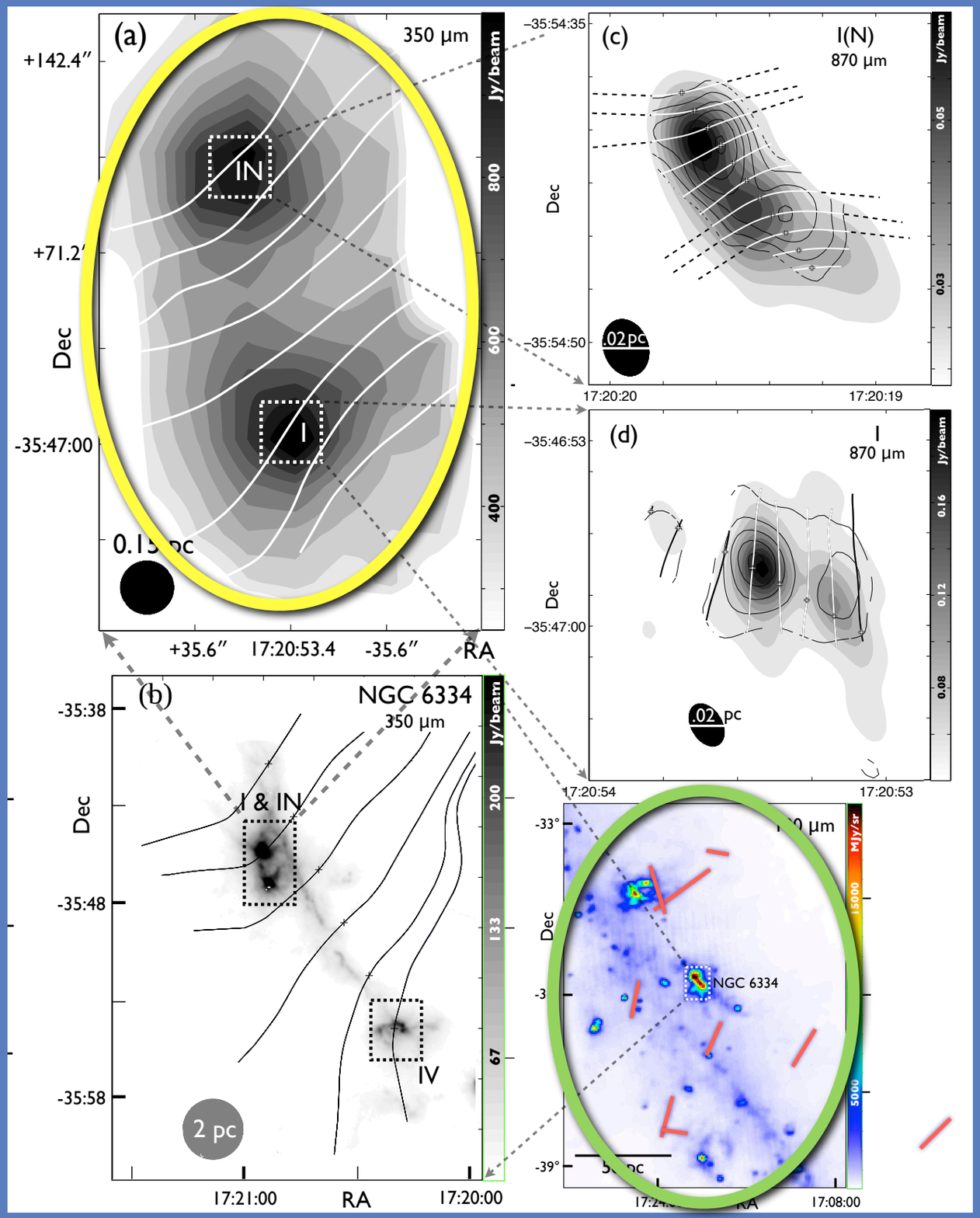




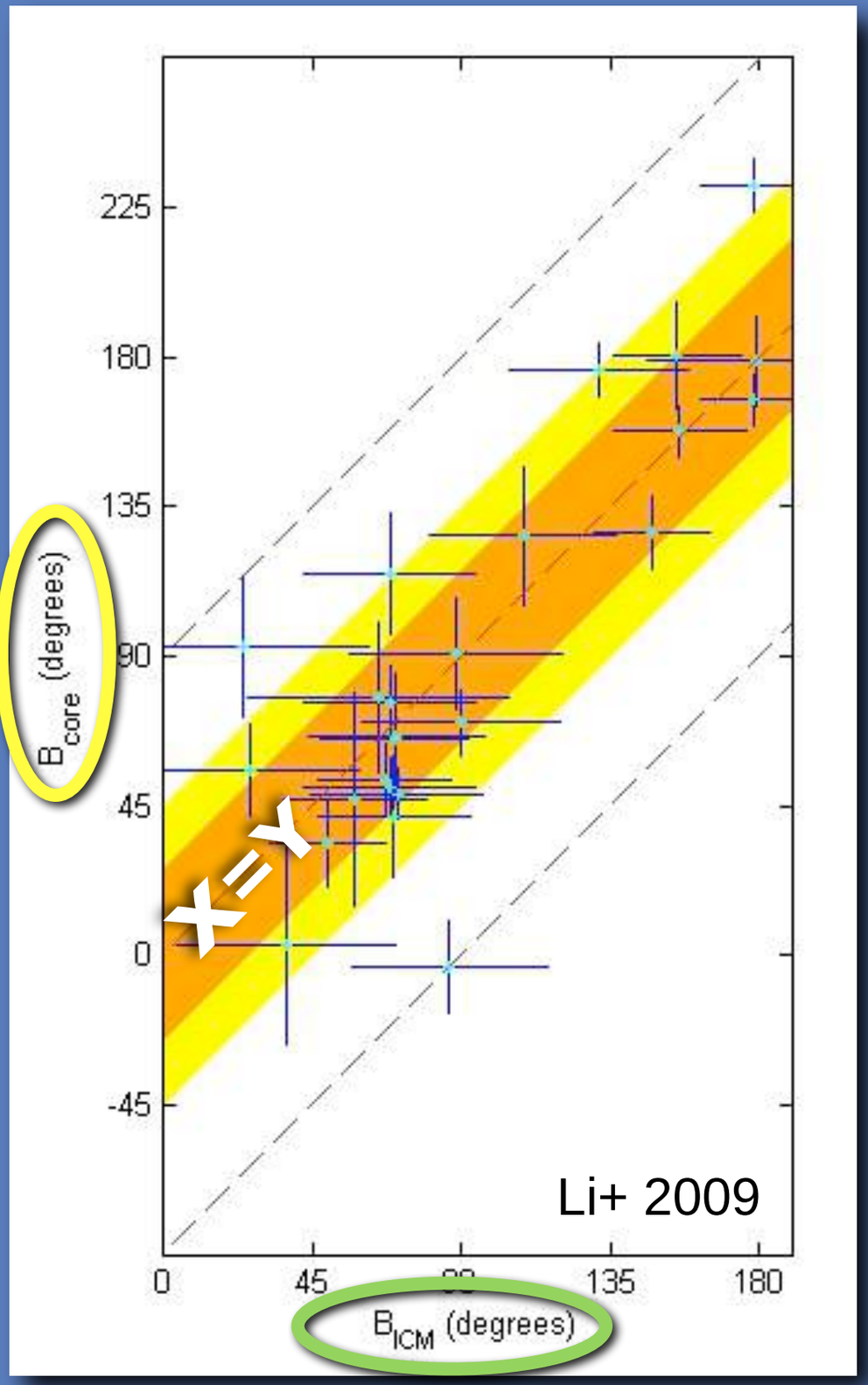


Li, Yuen, Otto, Leung, Tang, Zhang+ 2015

NGC 6334 is a special case?



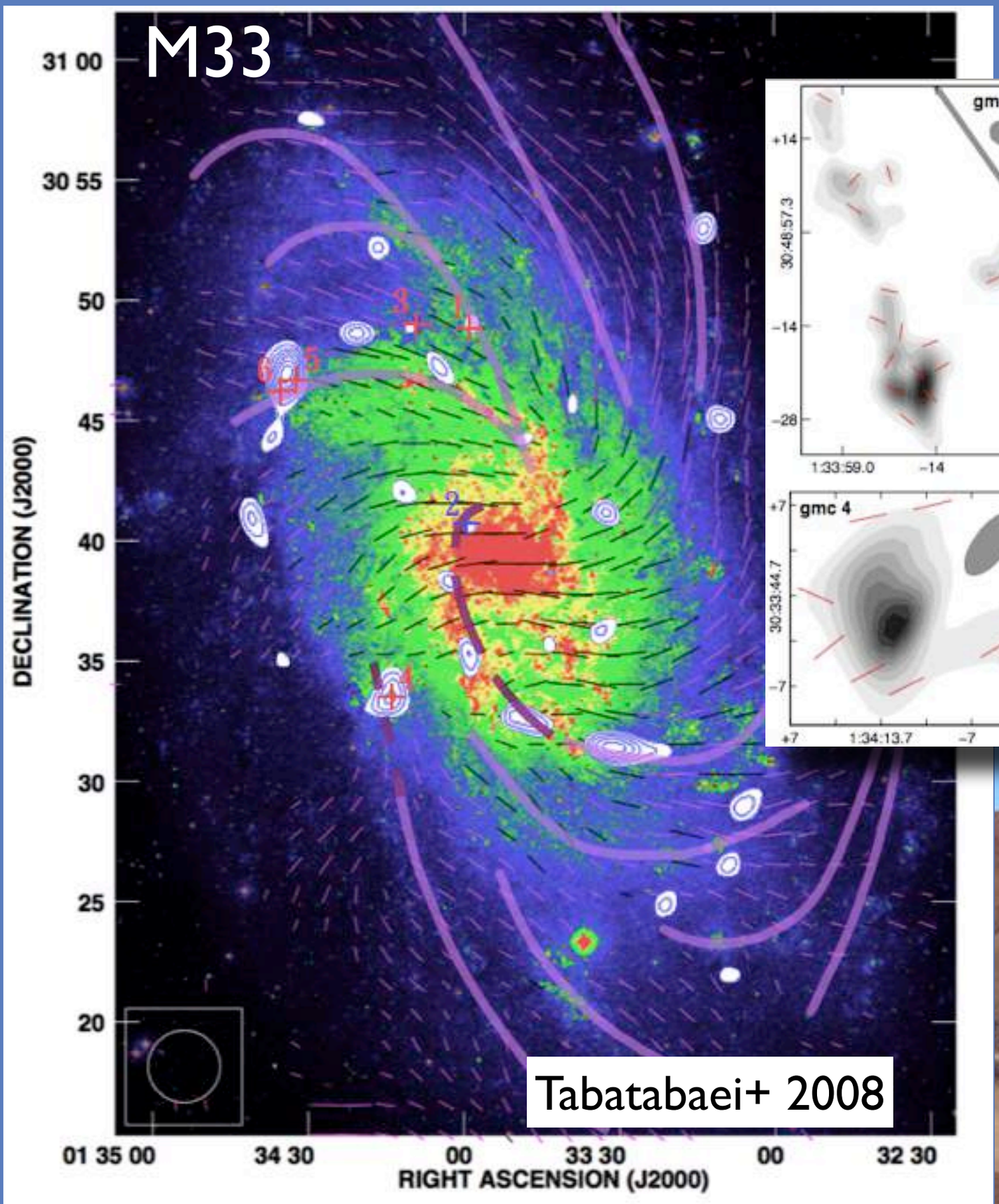
Probably not!



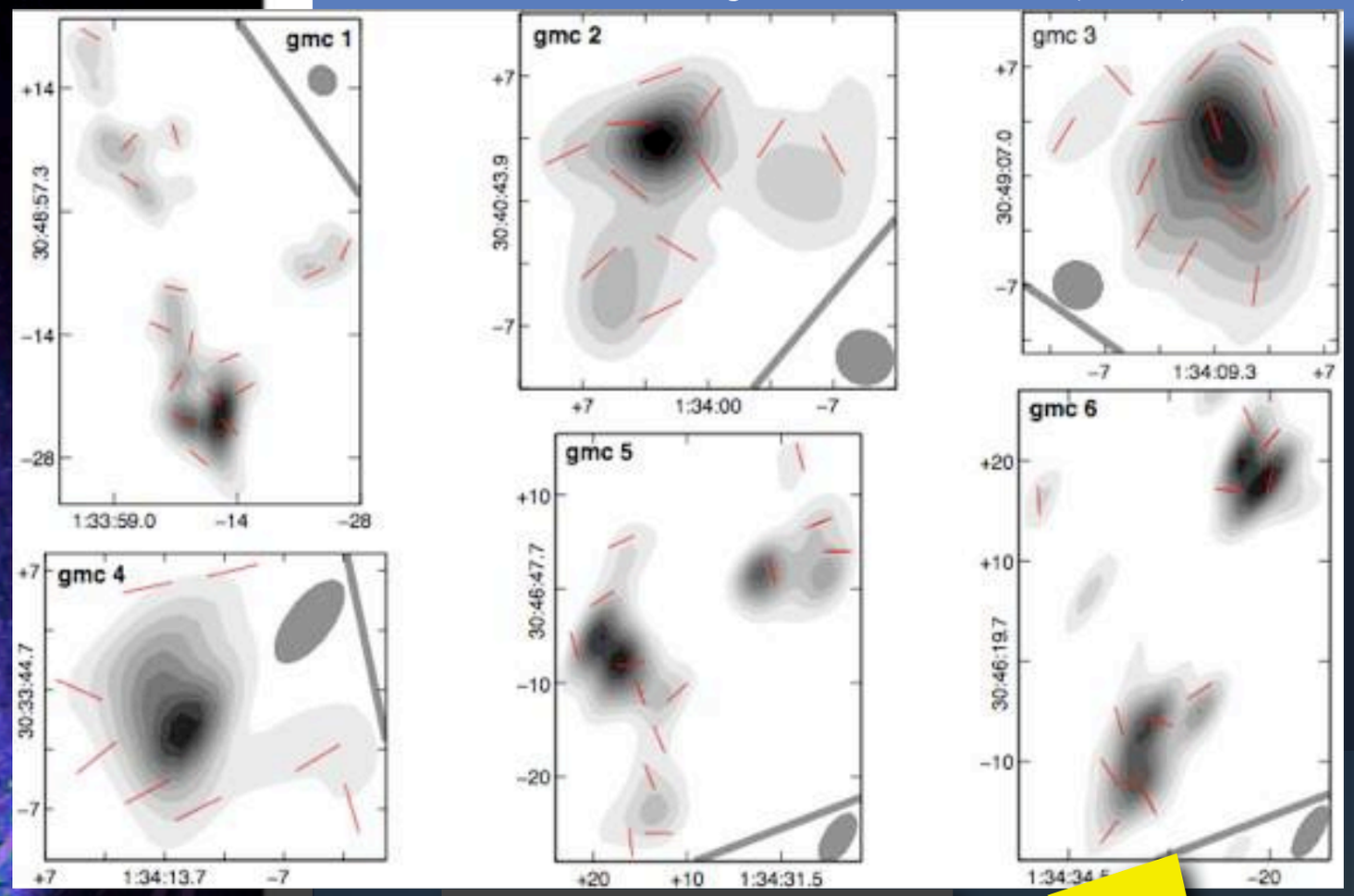
Milky Way is a special case?

The first Bird's-eye View of MC B-fields

Goldreich-Kylafis effect (CO):



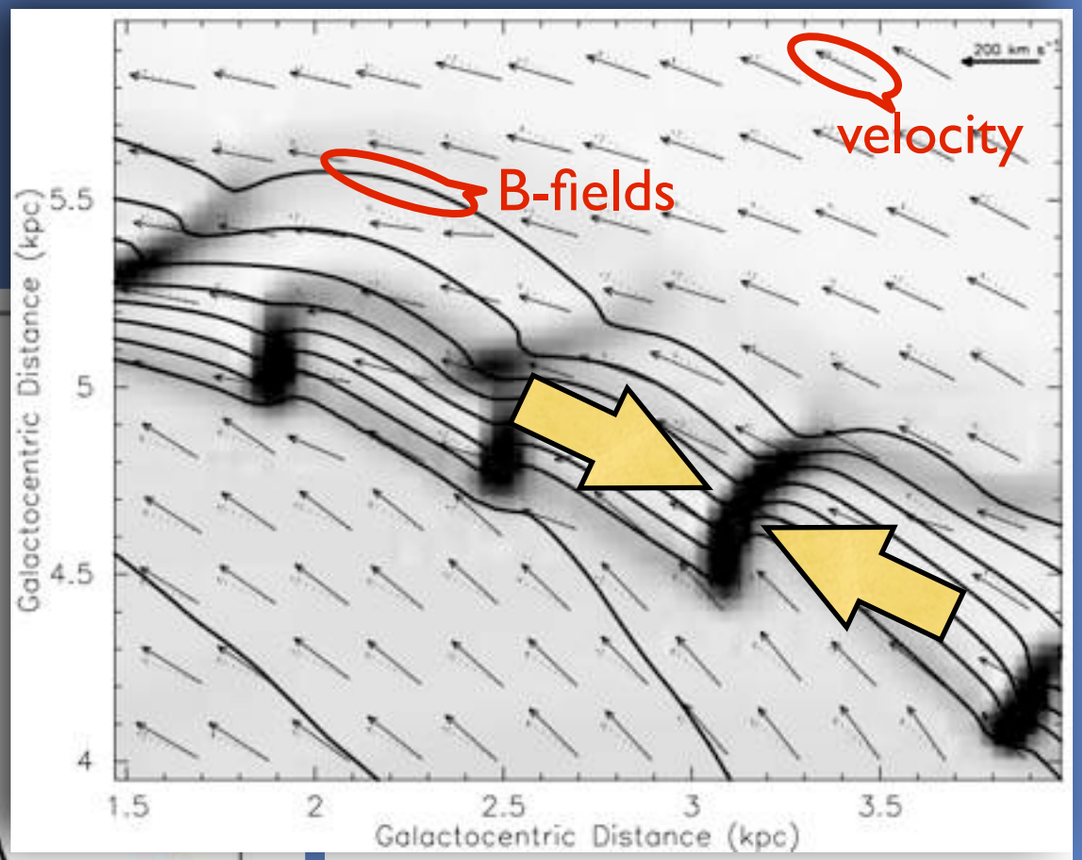
Tabatabaei+ 2008



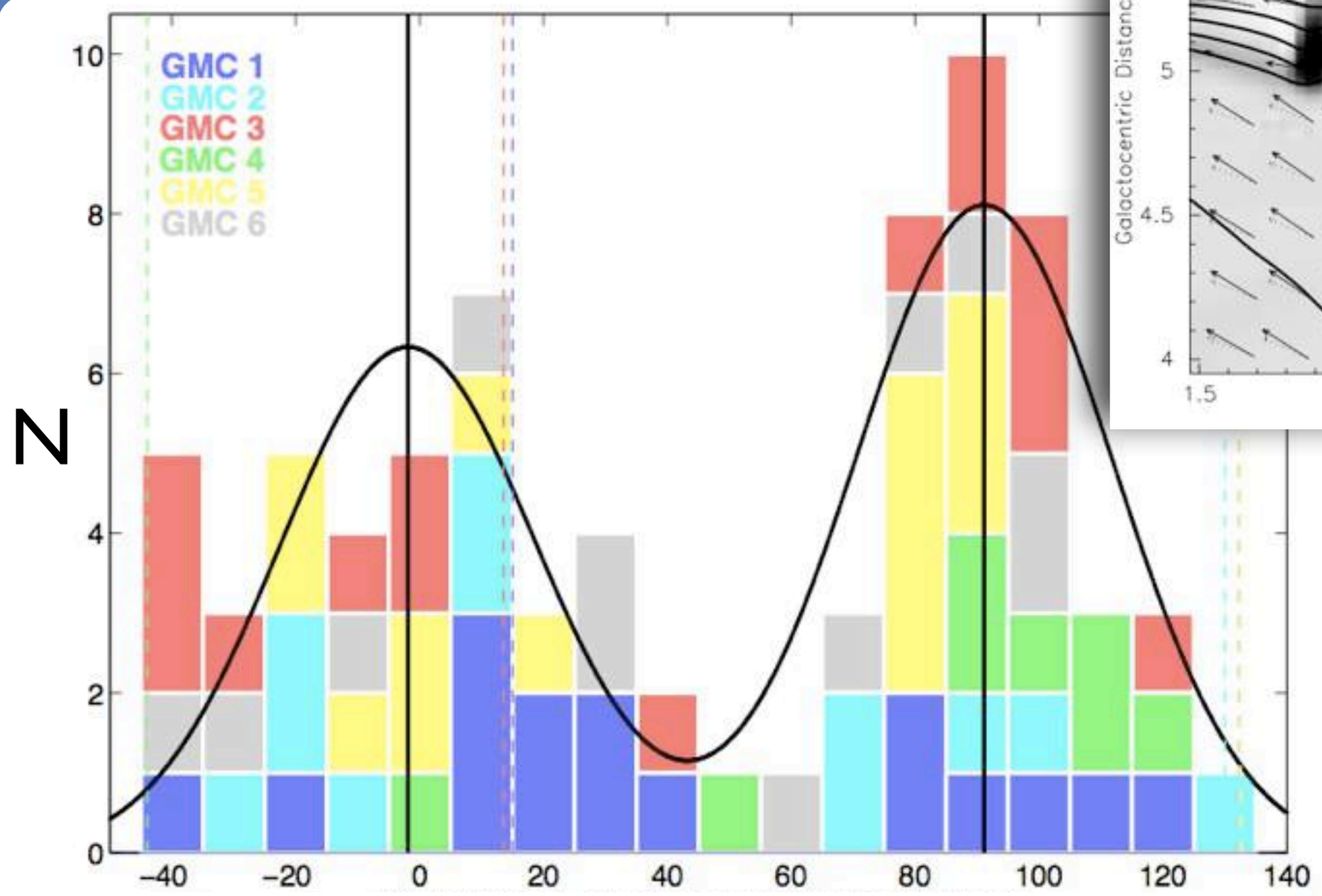
Li & Henning 2011

Probably not!

The first Bird's-eye View of MC B-fields



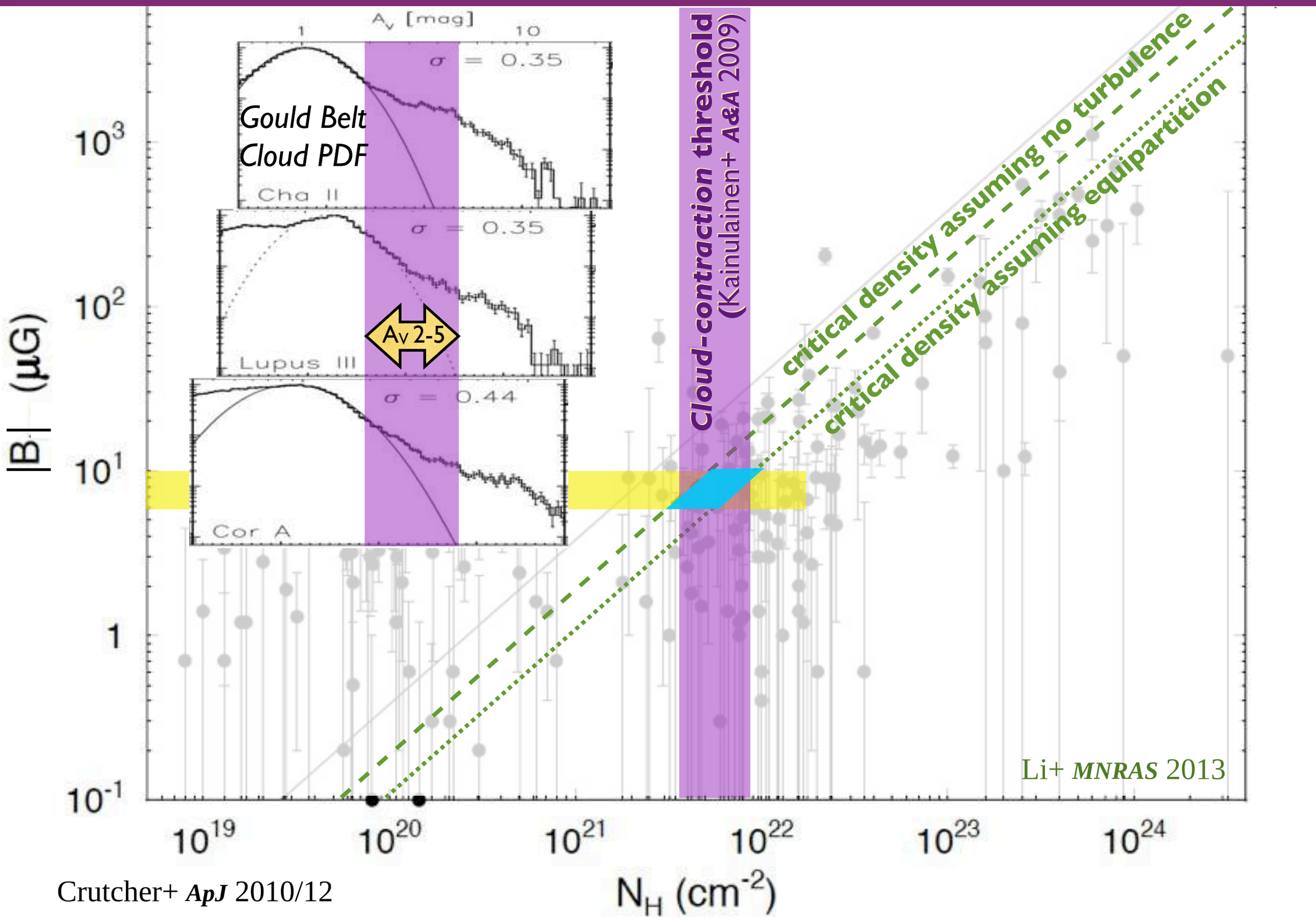
Shetty & Ostriker 2007



offset between CO pol. & spiral arms

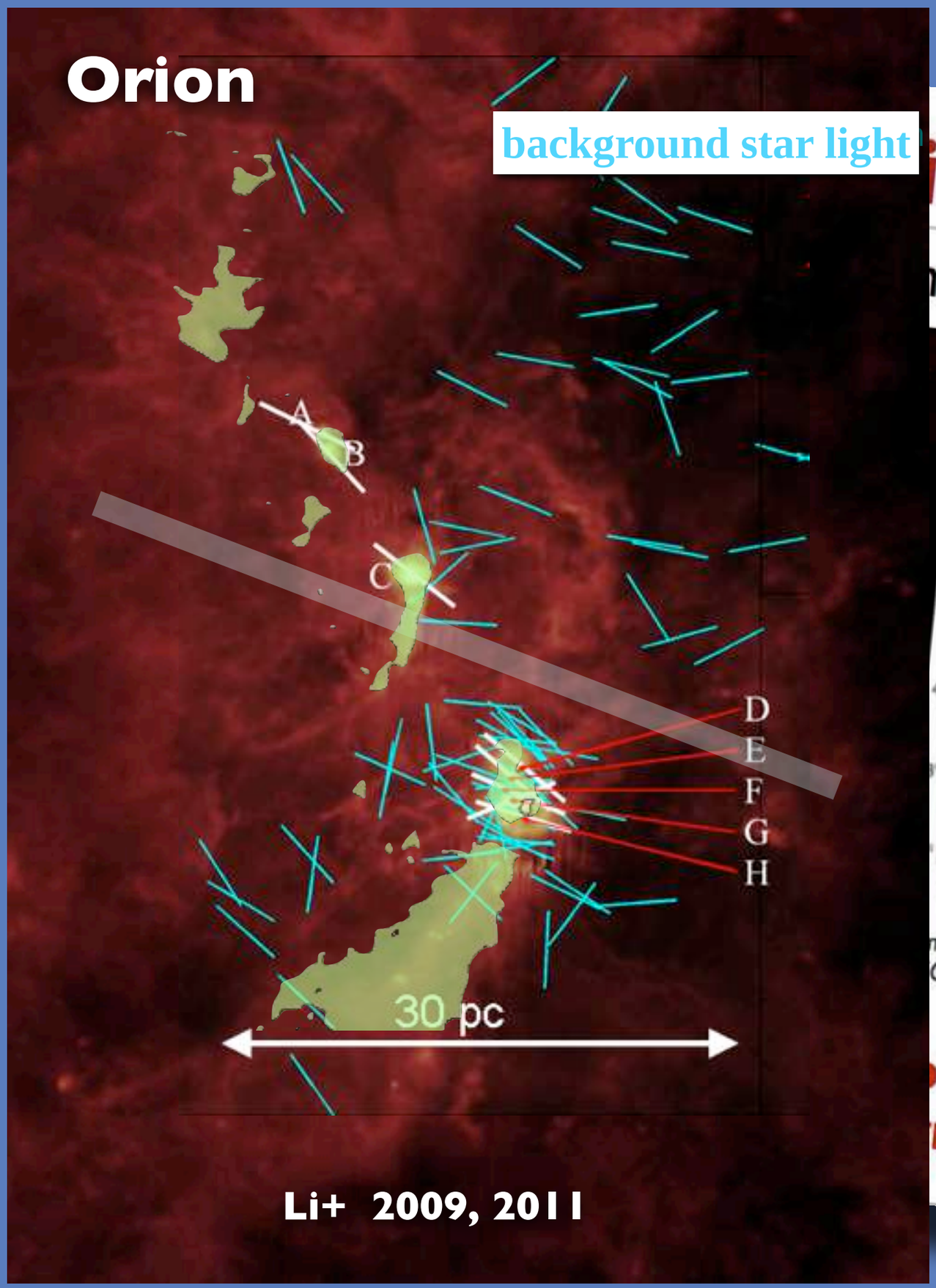
Li & Henning 2011

Galactic B fields define cloud contraction density threshold

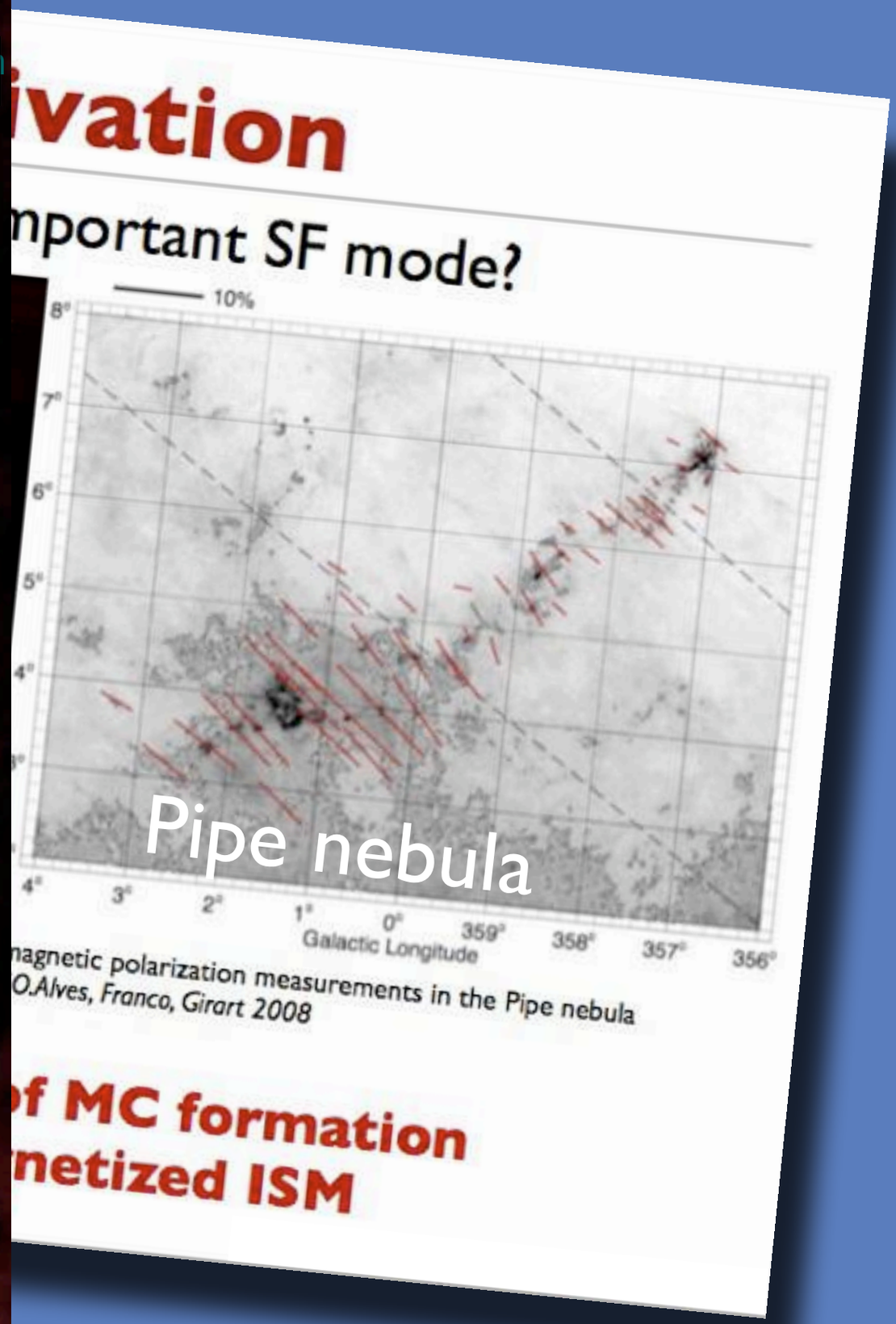


Crutcher+ *ApJ* 2010/12

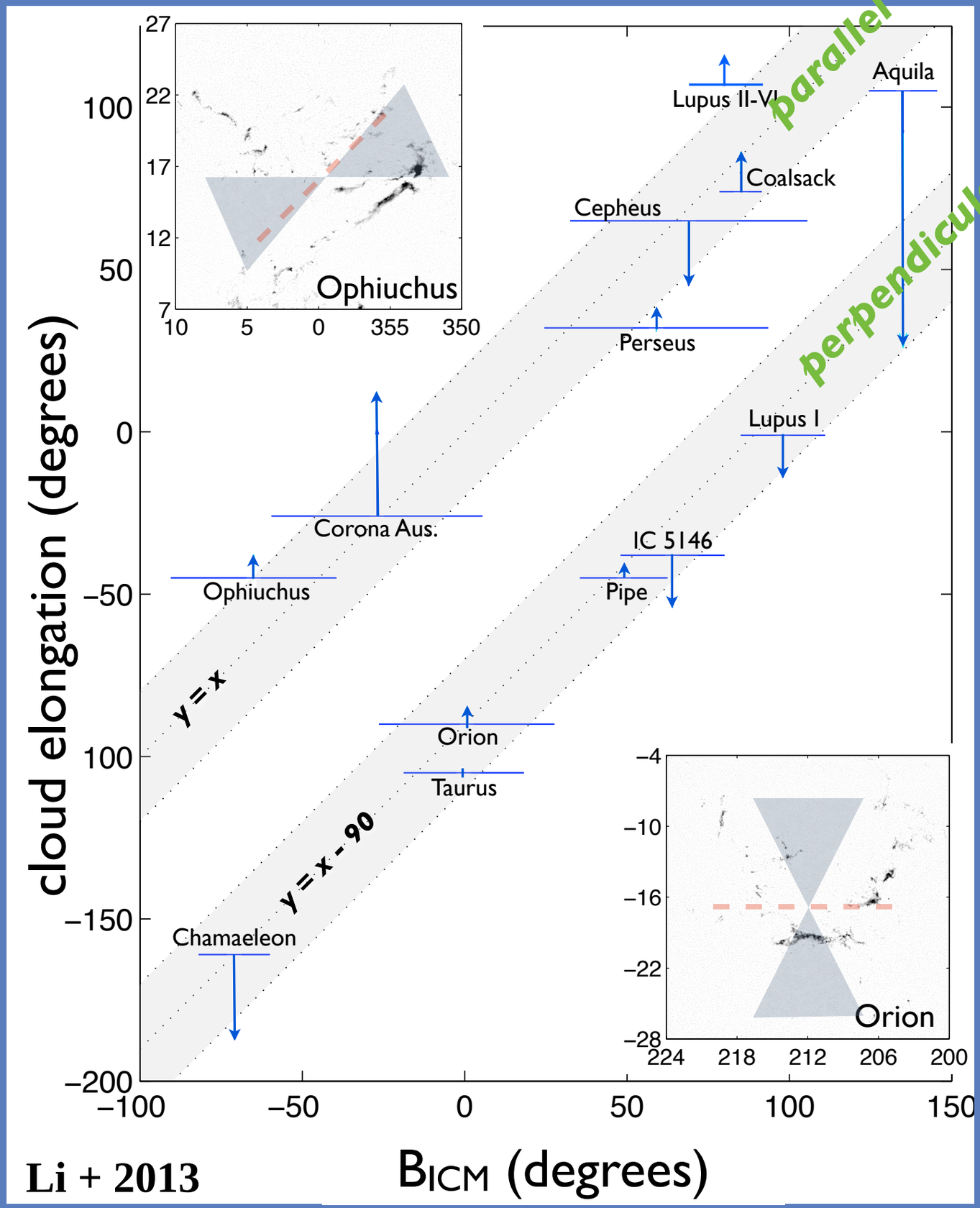
So clouds ⊥ B always?

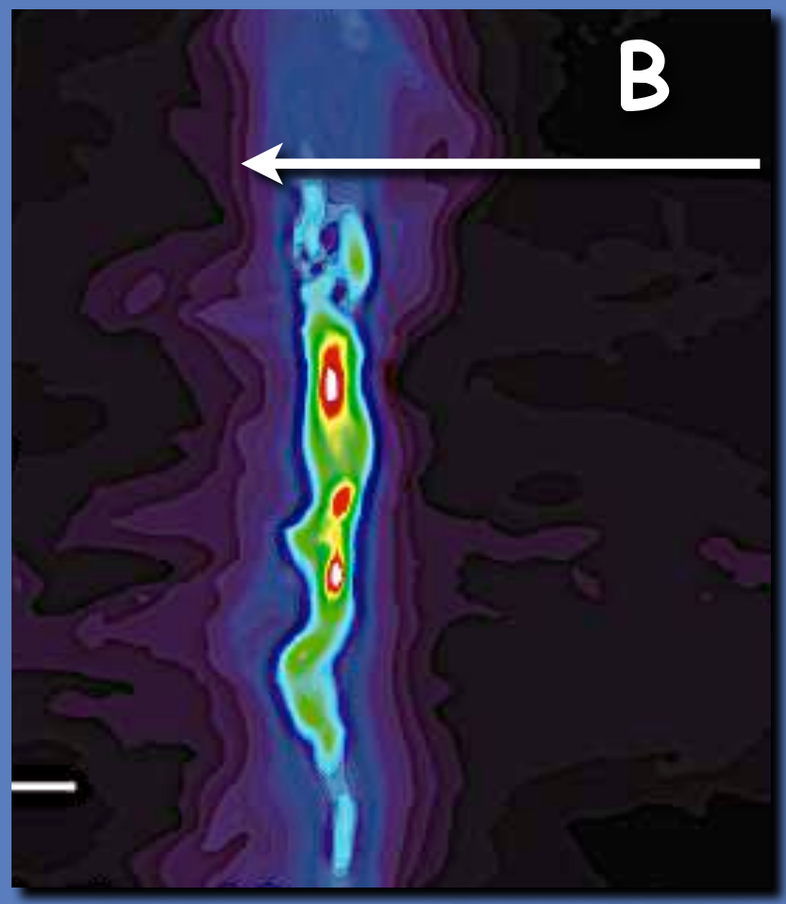


Li+ 2009, 2011

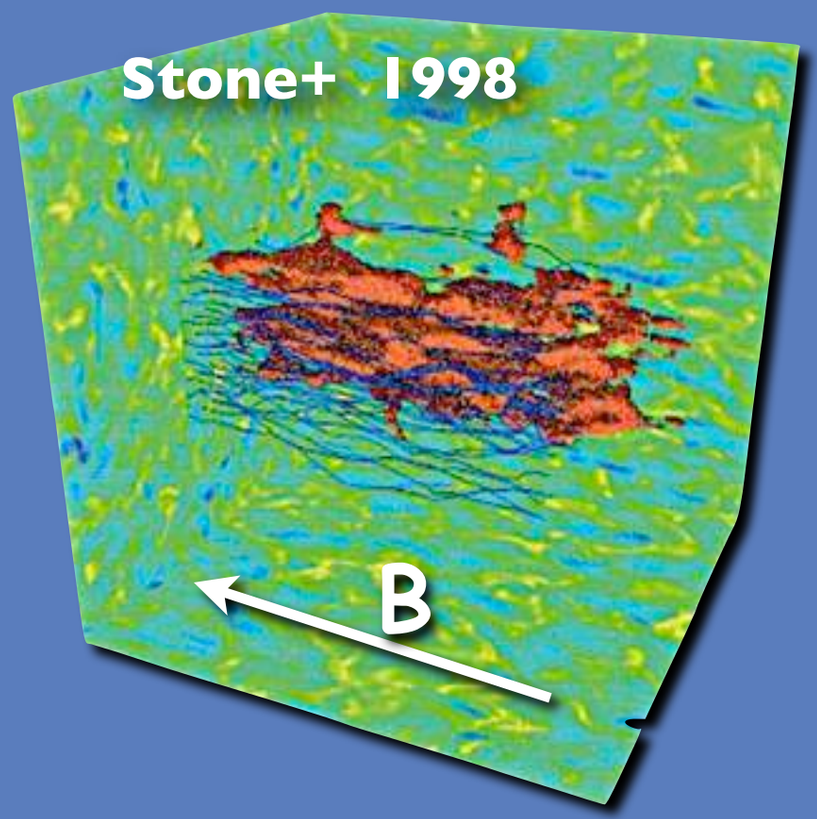


When Galactic B fields anchor deeply into molecular clouds ....

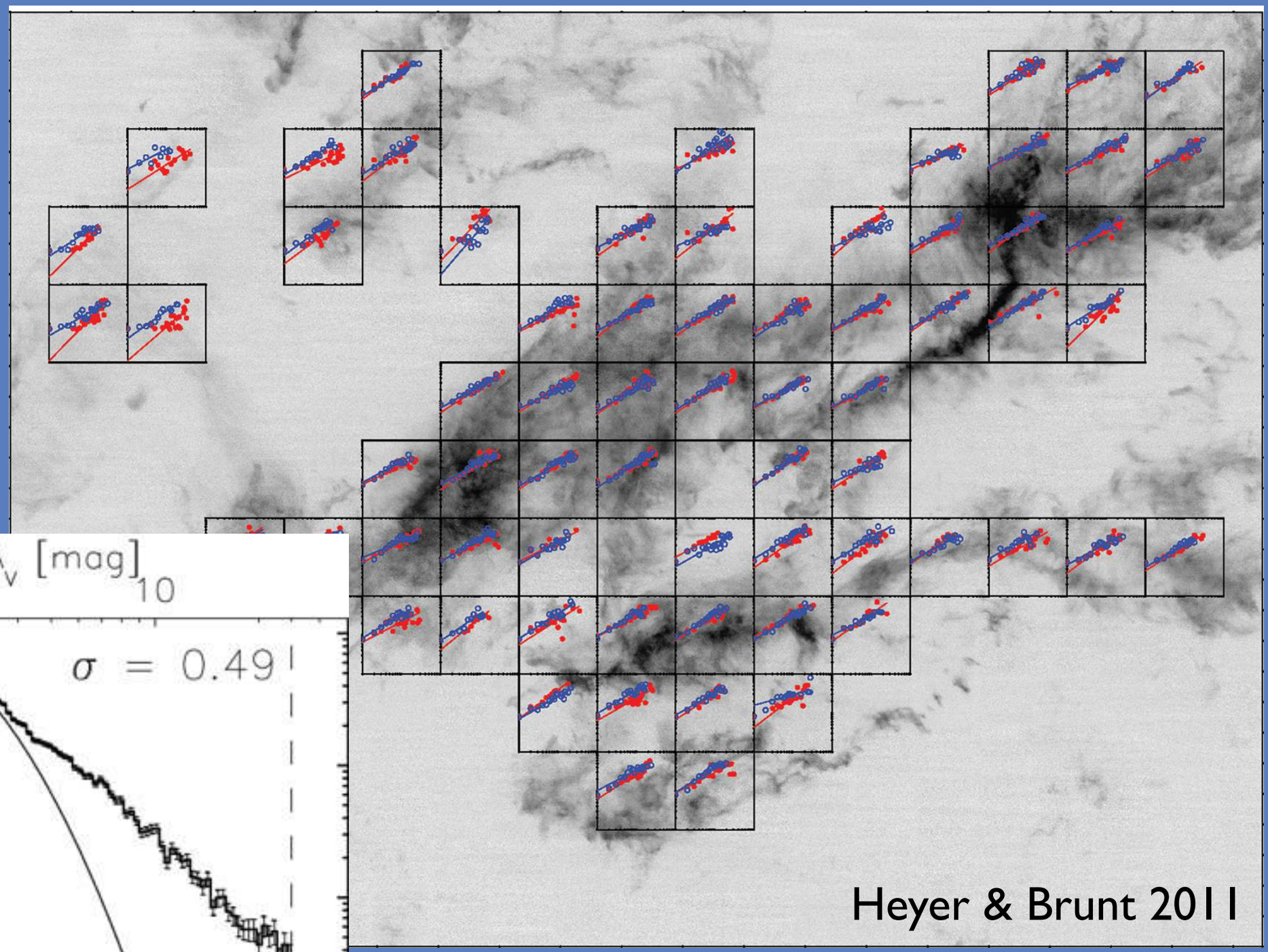


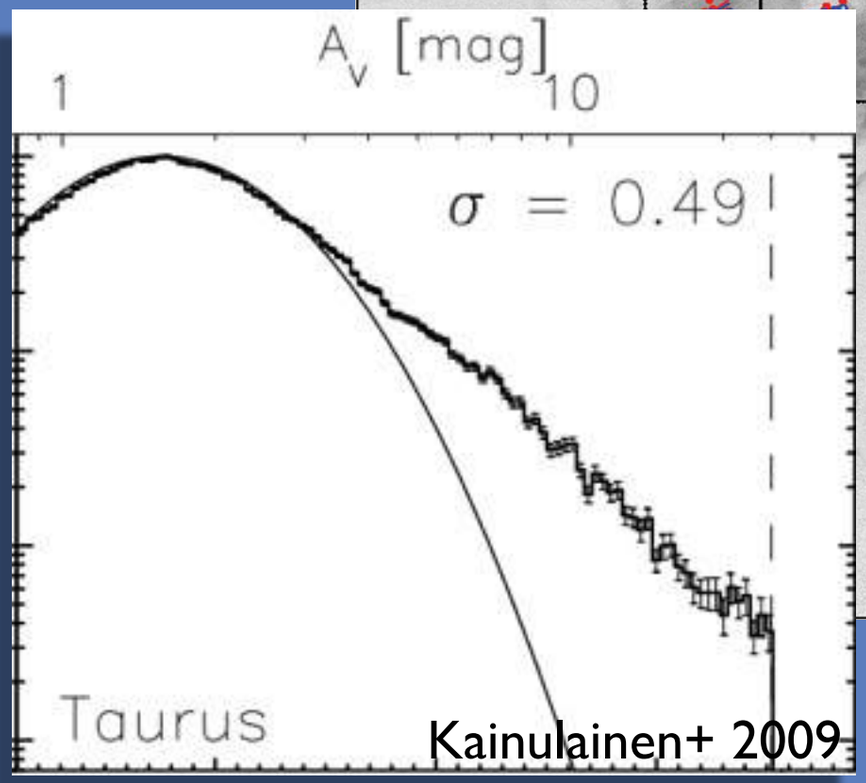


Nakamura & Li 2008



Turbulence anisotropy?
Only observed for $A_v < 3$ in Taurus





Kainulainen+ 2009

Av (mag)

2

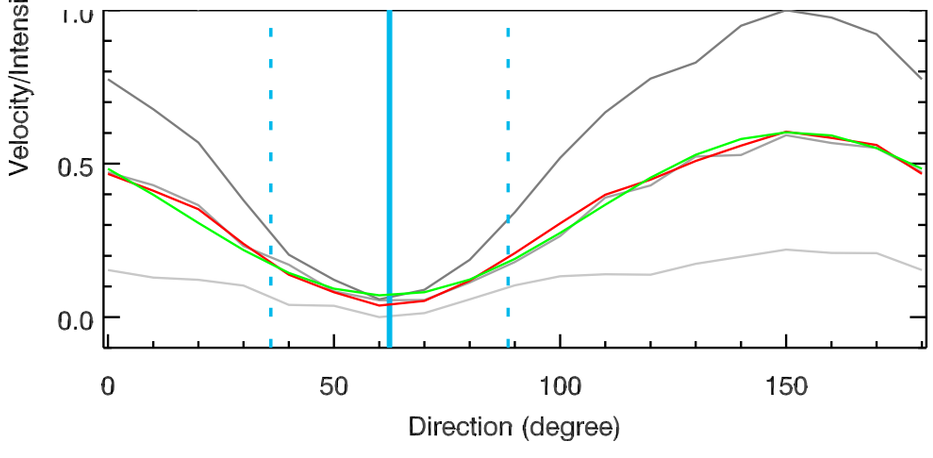
4

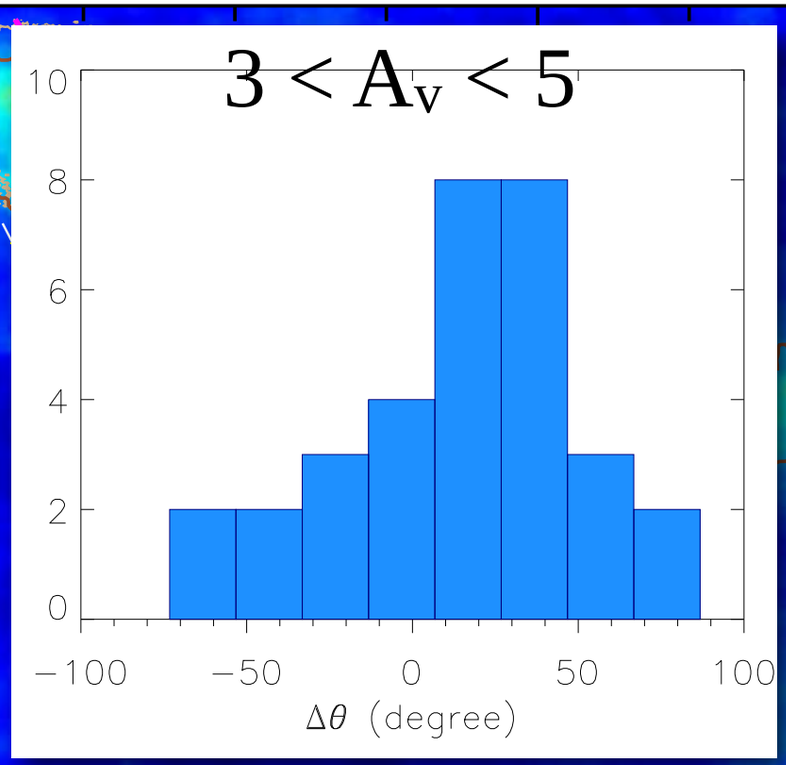
Velocity centroid map (along line-of-sight s):

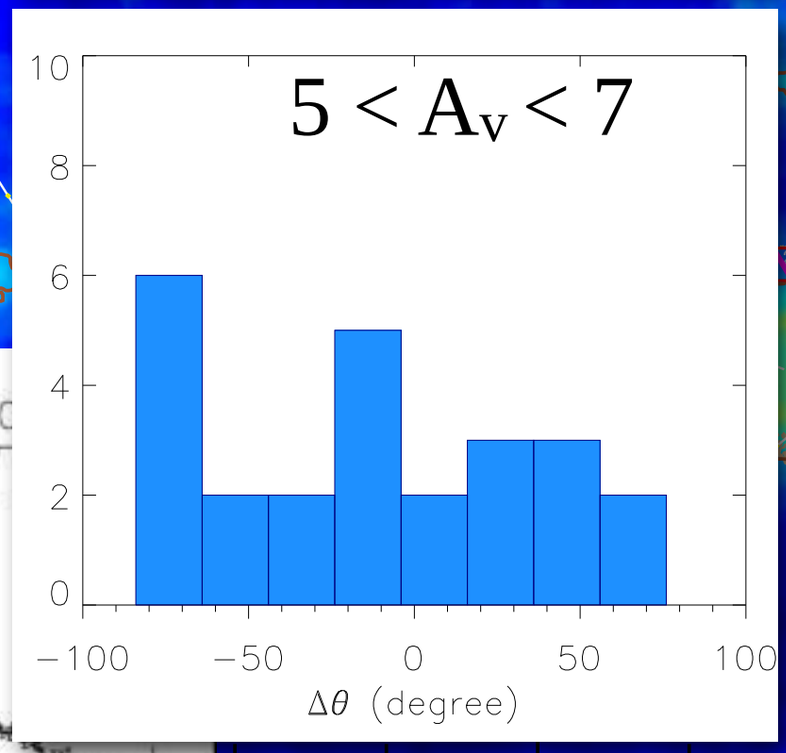
$$V(\vec{r}) = \frac{\int I(\vec{r},s)v(\vec{r},s)ds}{\int I(\vec{r},s)ds}$$

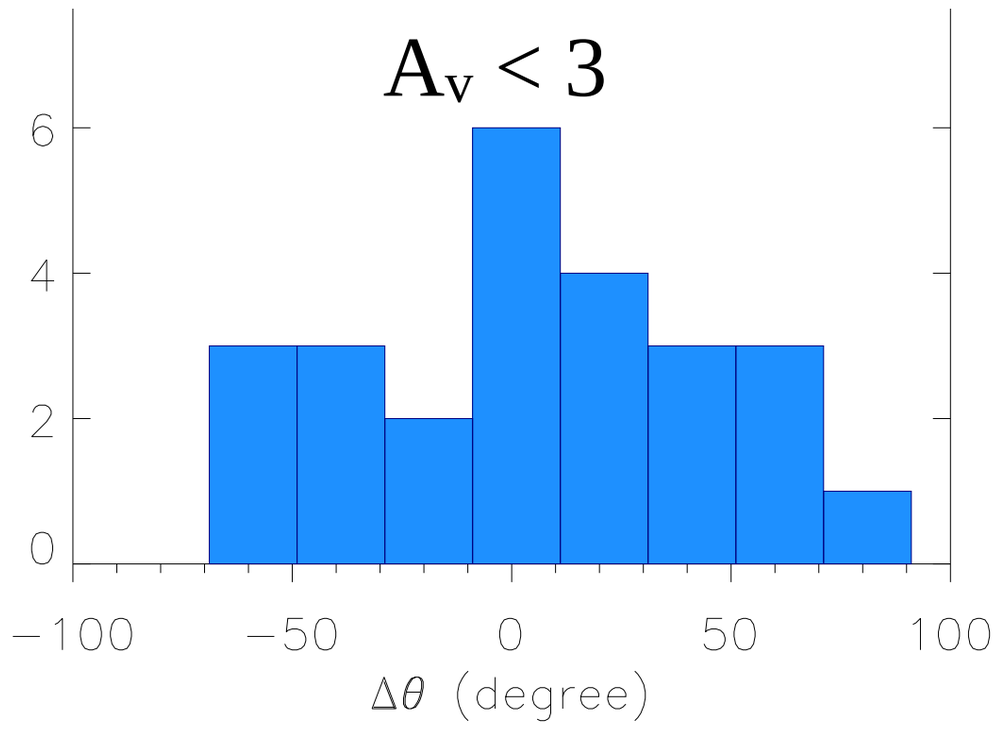
The two-point 2^{nd} order structure function:

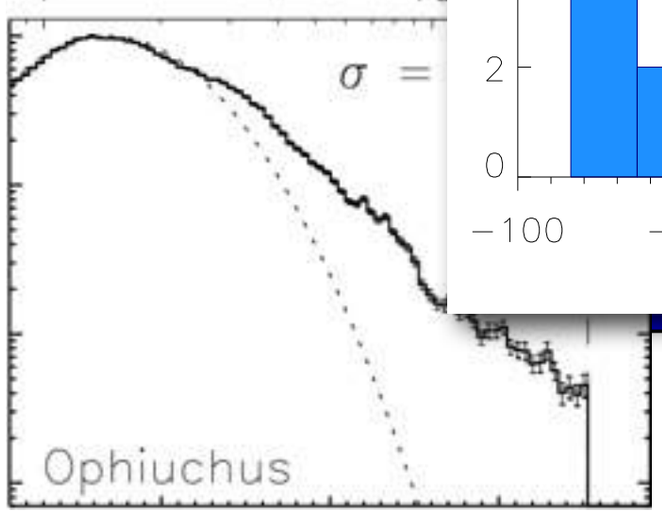
$$SF_V(l,\varphi) = median[V(\vec{r}) - V(\vec{r}+l\hat{e}_\varphi)]_{\vec{r}}$$

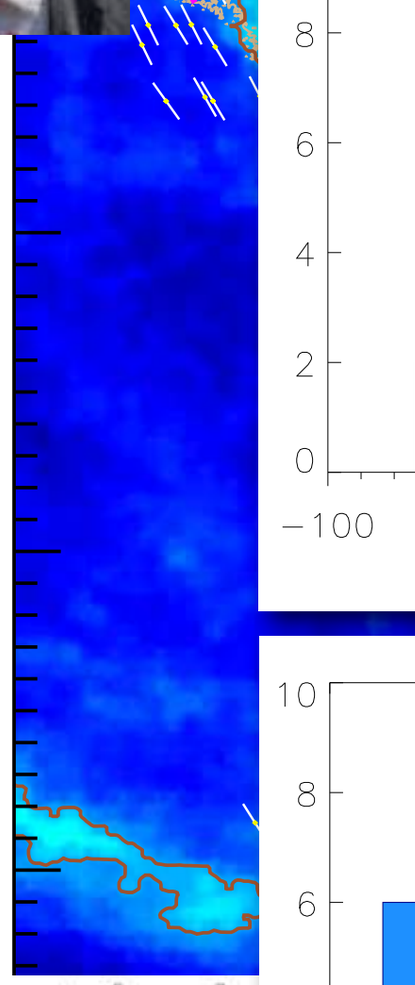












250

248

246

RA (J2000)

Ji, Li & Otto, in prep

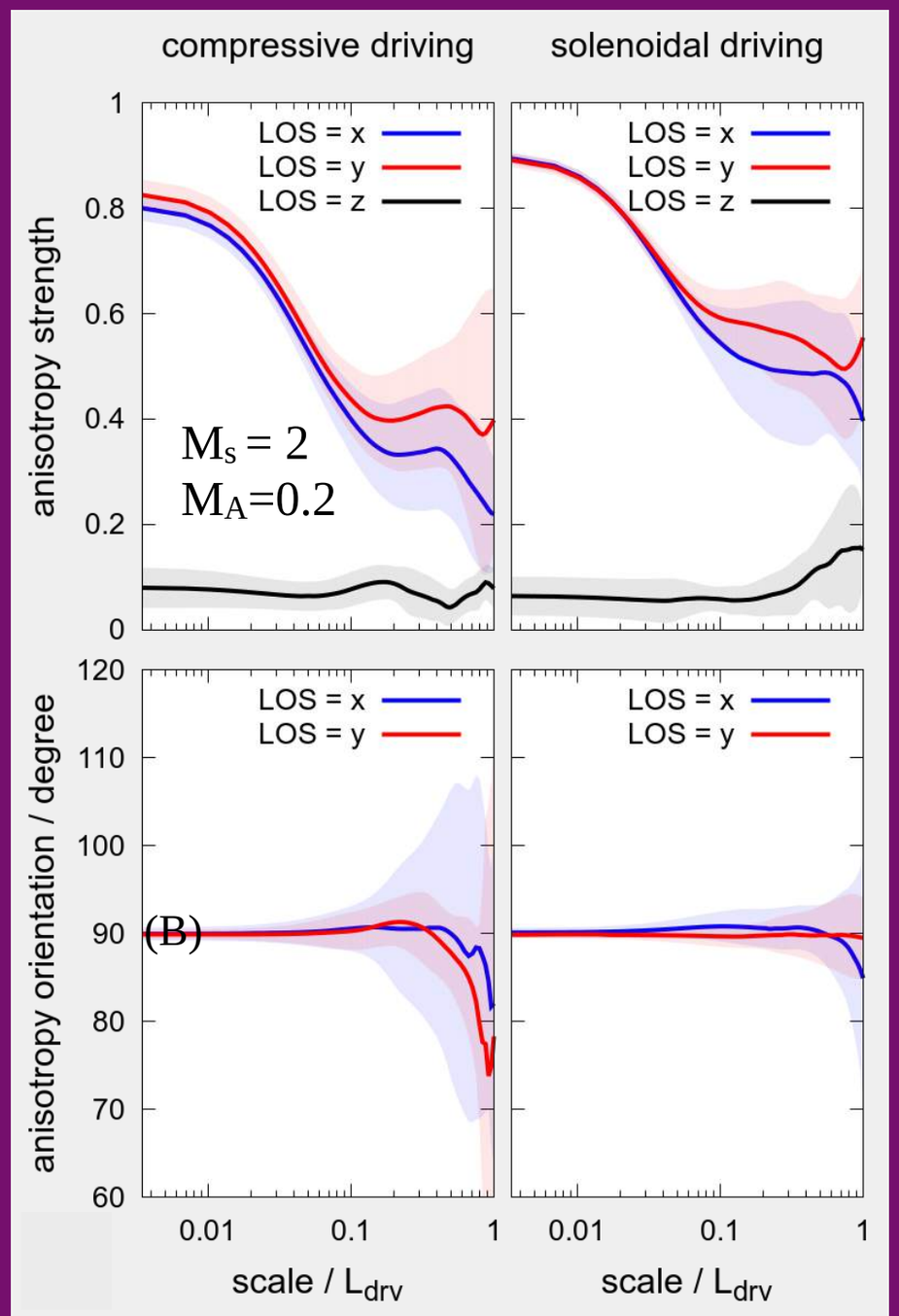
Do we see velocity anisotropy decreasing with N in ***sub-Alfvenic*** simulations?

2nd order structure function: (scale l, POS angle φ)

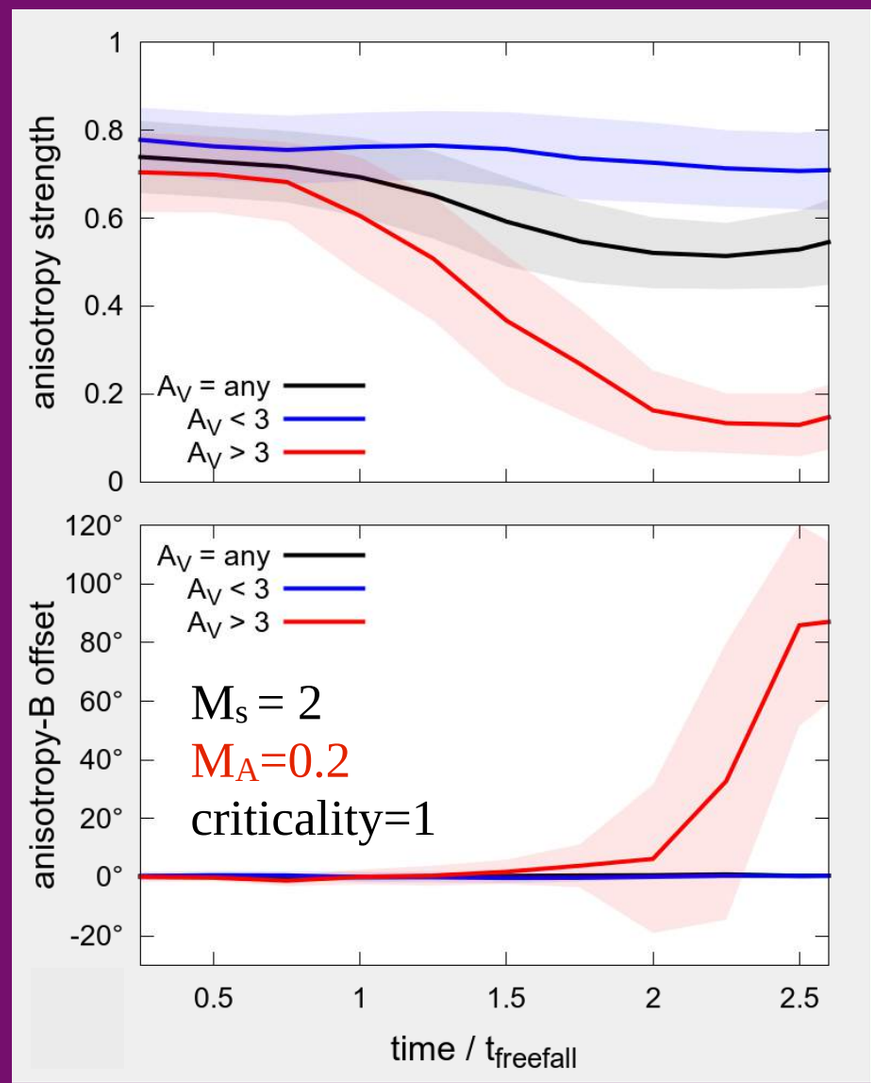
$$SF_V(l,\varphi) = \left\langle \left(V(\vec{r}) - V(\vec{r} + l\hat{e}_\varphi)\right)^2 \right\rangle_{\vec{r}}$$

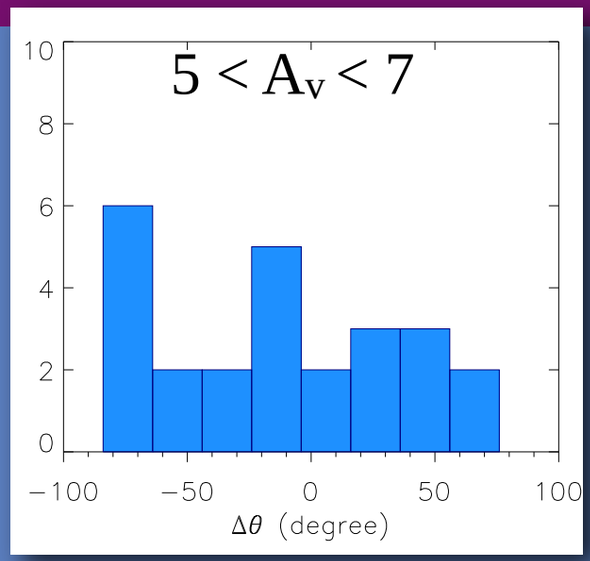
For each scale l, fit to:

$$SF_V(l,\varphi) \sim c_l \left(1 - b_l \cos[2(\varphi - \alpha_l)]\right)$$



Yes, when ***gravity*** is turned on!

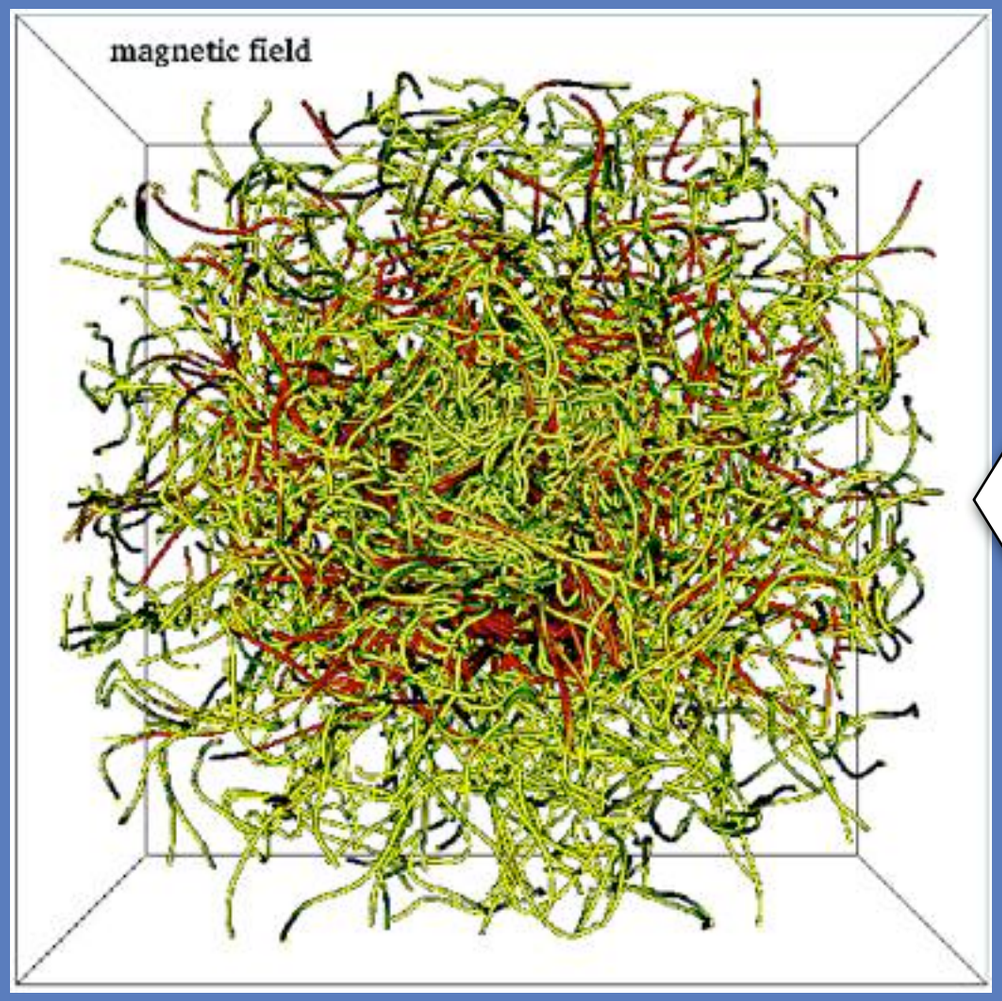




Otto, Ji & Li, in prep.

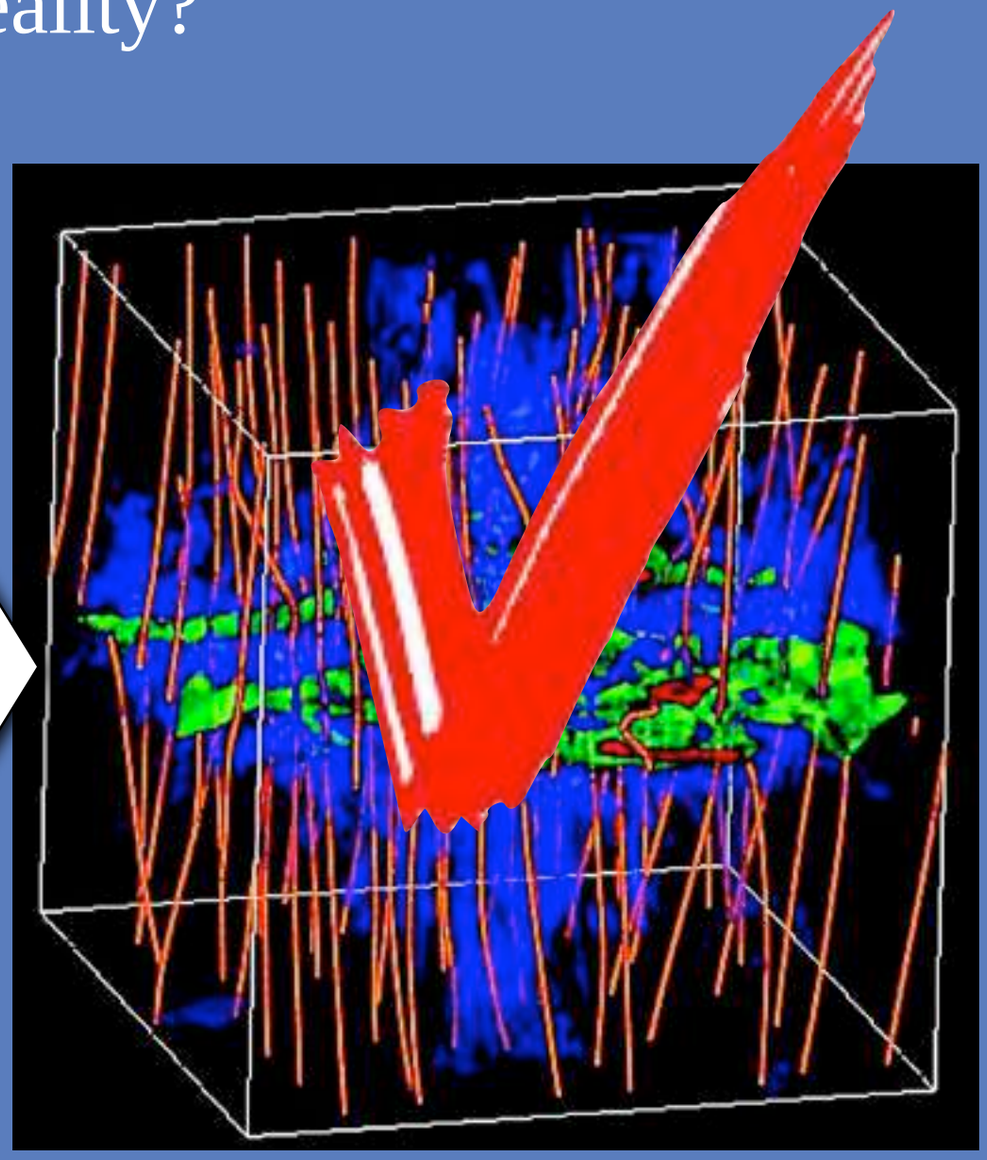
Summary

1. which morphology closer to reality?



Federrath+, *ApJ* 2011

or



Nakamura & Li, *ApJ* 2008

2. consequences of the field morphology:
   turbulence anisotropy observed for A_v < 3-5,
   cloud shapes tend to be // or ⊥ B (Gould belt) and
   $B \propto \rho^{0.4}$.(NGC 6334)