The Importance of the Magnetic Field from an SMA-CSO-Combined Sample of Star-Forming Regions

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with

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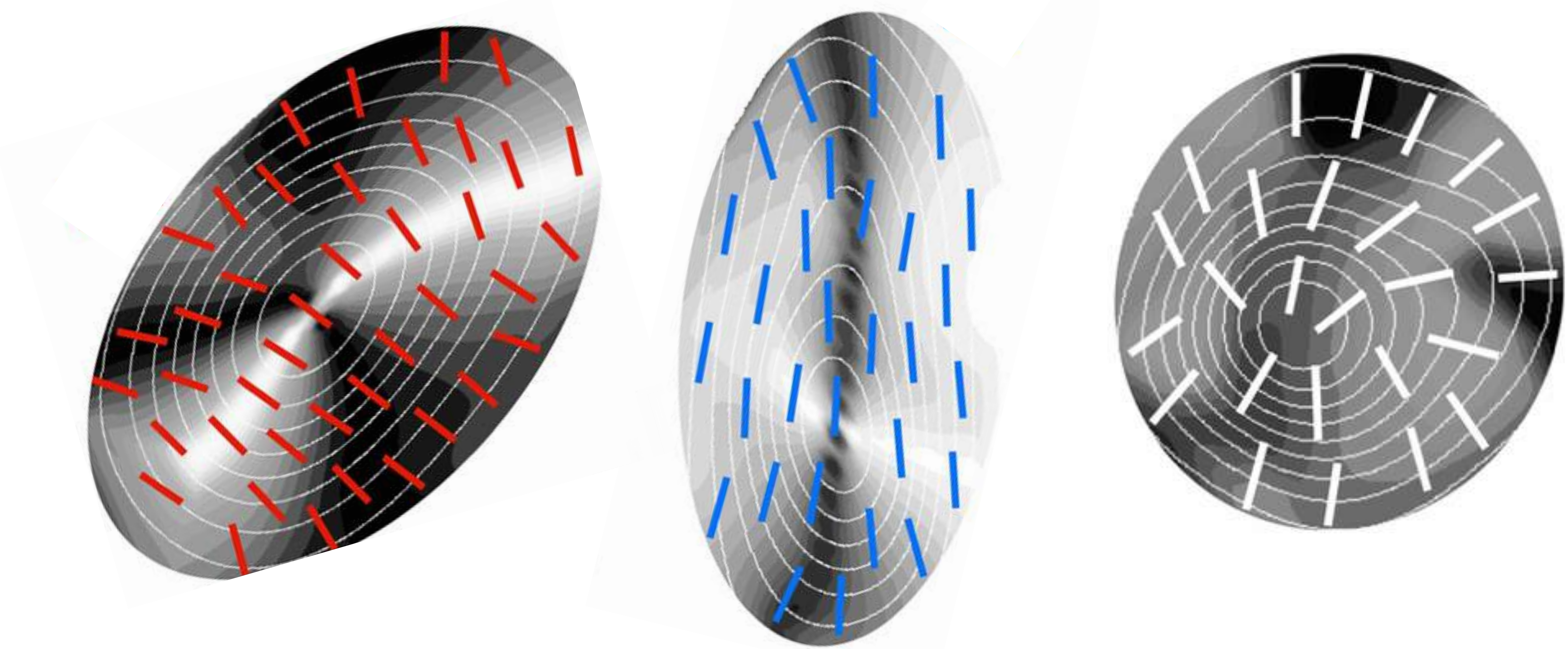
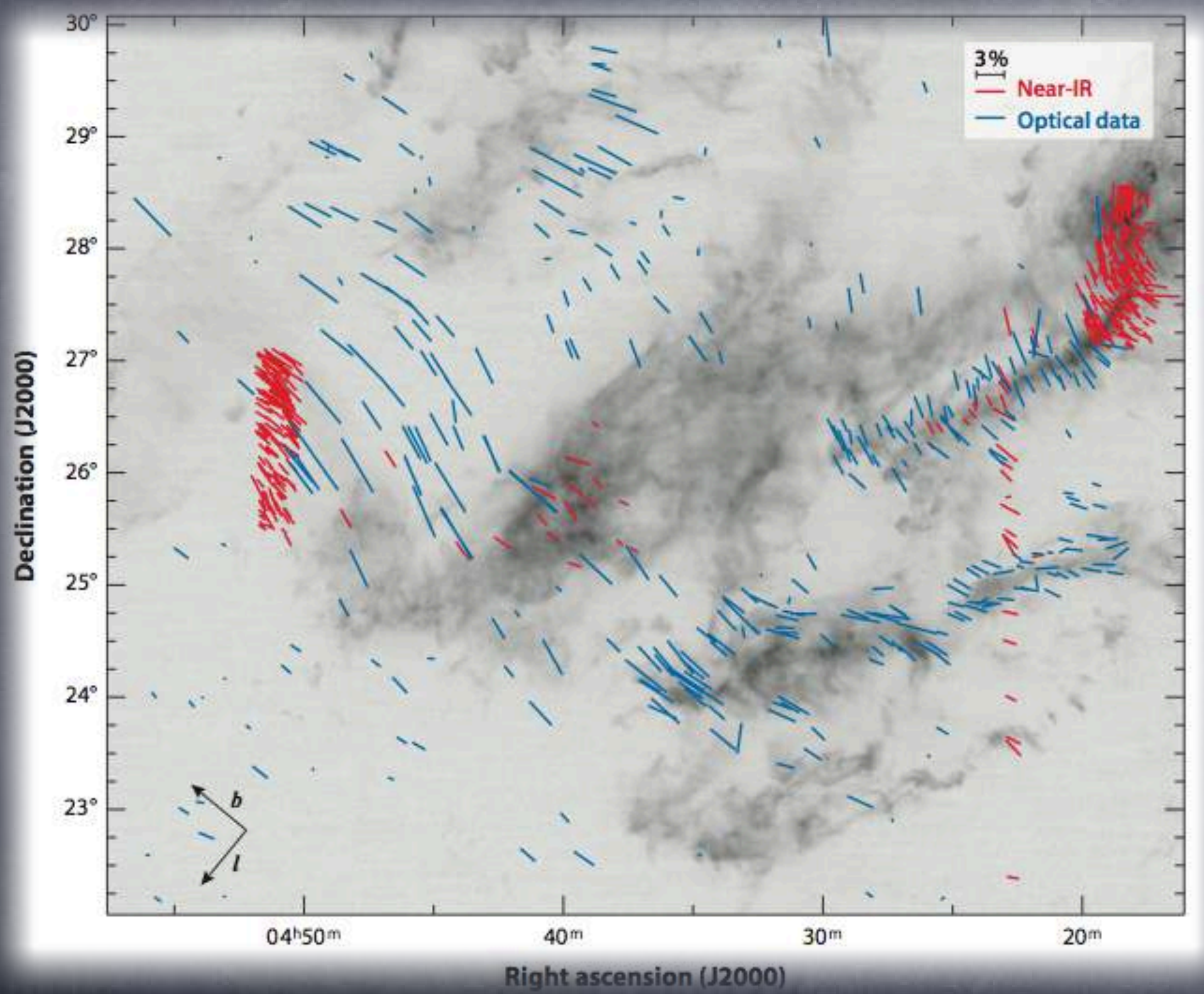
+ SMA pol legacy team: Qizhou Zhang, Josep Miquel Girart, Hua-bai Li, Ram Rao



Magnetic Fields in the Universe V, Cargèse; October 7, 2015

Magnetic Field Observational Techniques

main difficulty: weak signal,
~ few % of Stokes I



(Chapman et al. 2011)

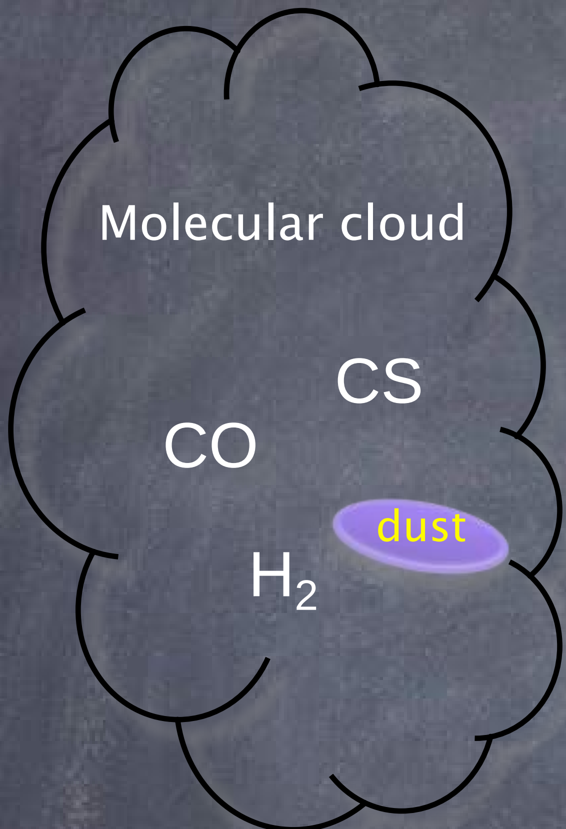
* Zeeman splitting:
  needs strong enough line emission,
  can get field strength, typically
  isolated and local (e.g., Crutcher 2012,
  Crutcher+ 2009)

* synchrotron radiation:
  needs relativistic electrons,
  typically not observed (but: HH80-81
  jet, Carrasco-Gonzalez+ 2010)

* absorption of background
  star light by dust
  (polarization in optical / NIR)
  only morphology, no field strength

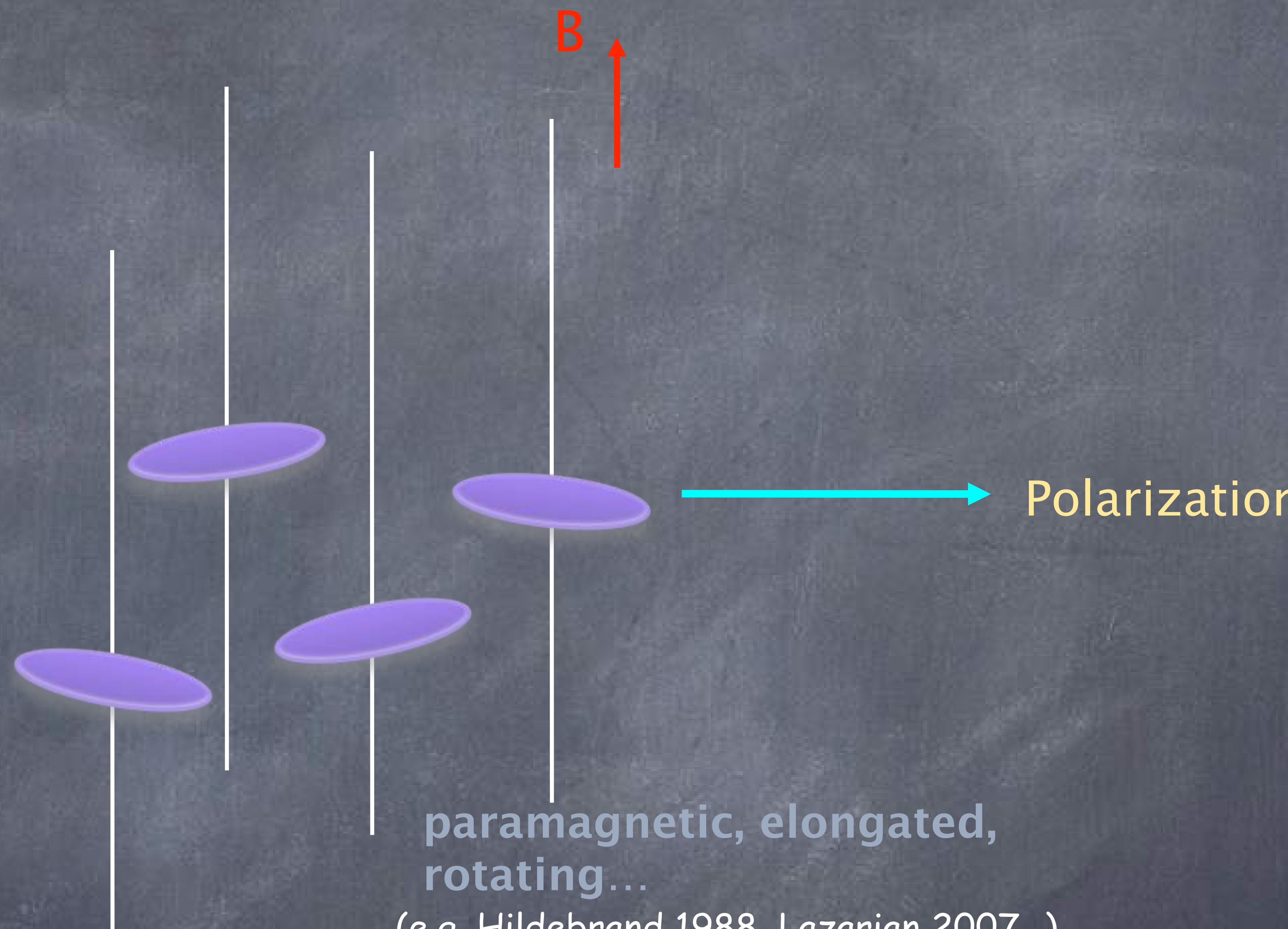
* thermal dust emission
  (polarization in mm / submm bands)
  only morphology, no field strength

Dust Polarization Mechanism



$n_{H_2} \sim 10^{4\text{-}7}$ (cm $^{-3}$)

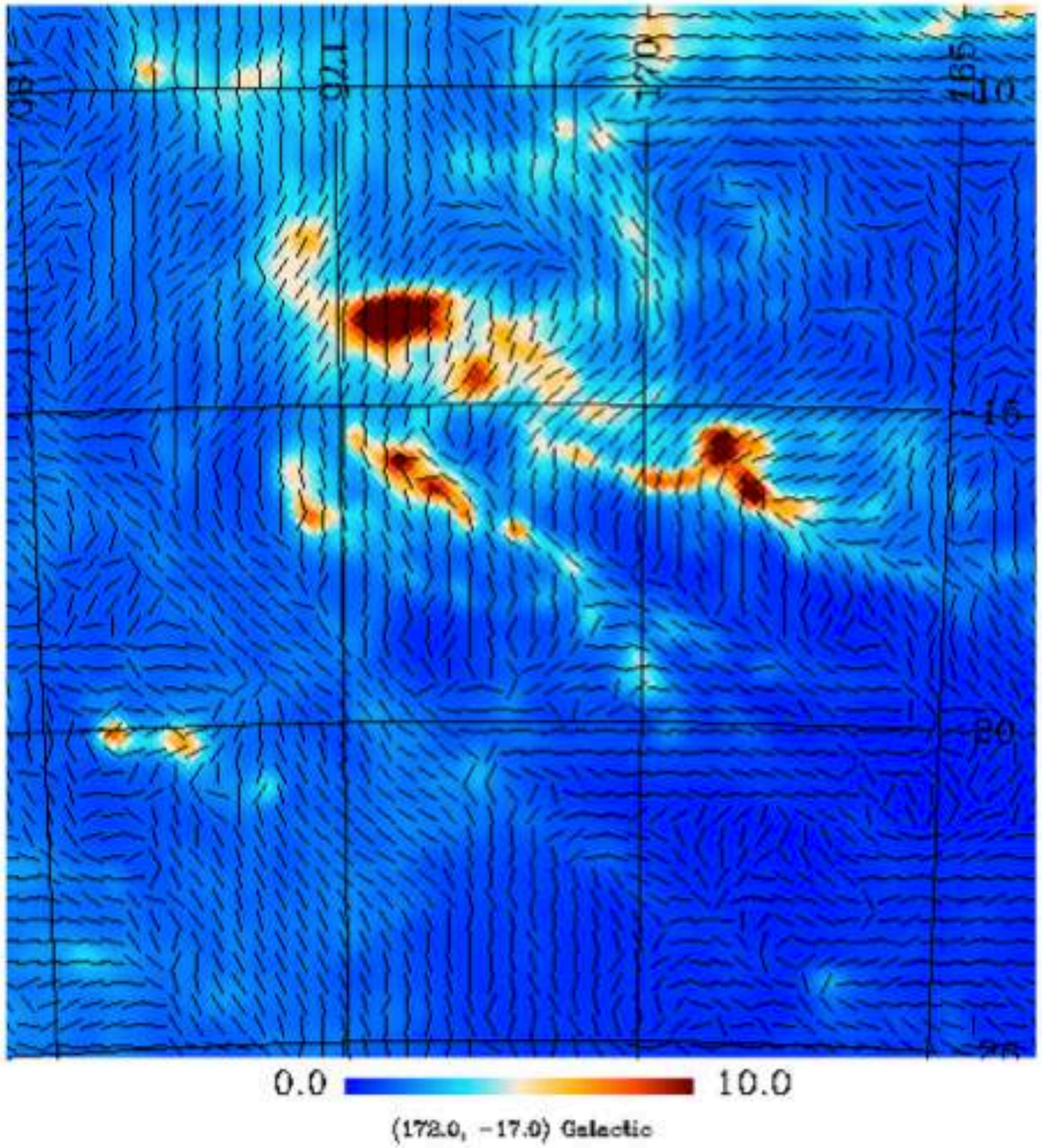
T ~ 10 (K)

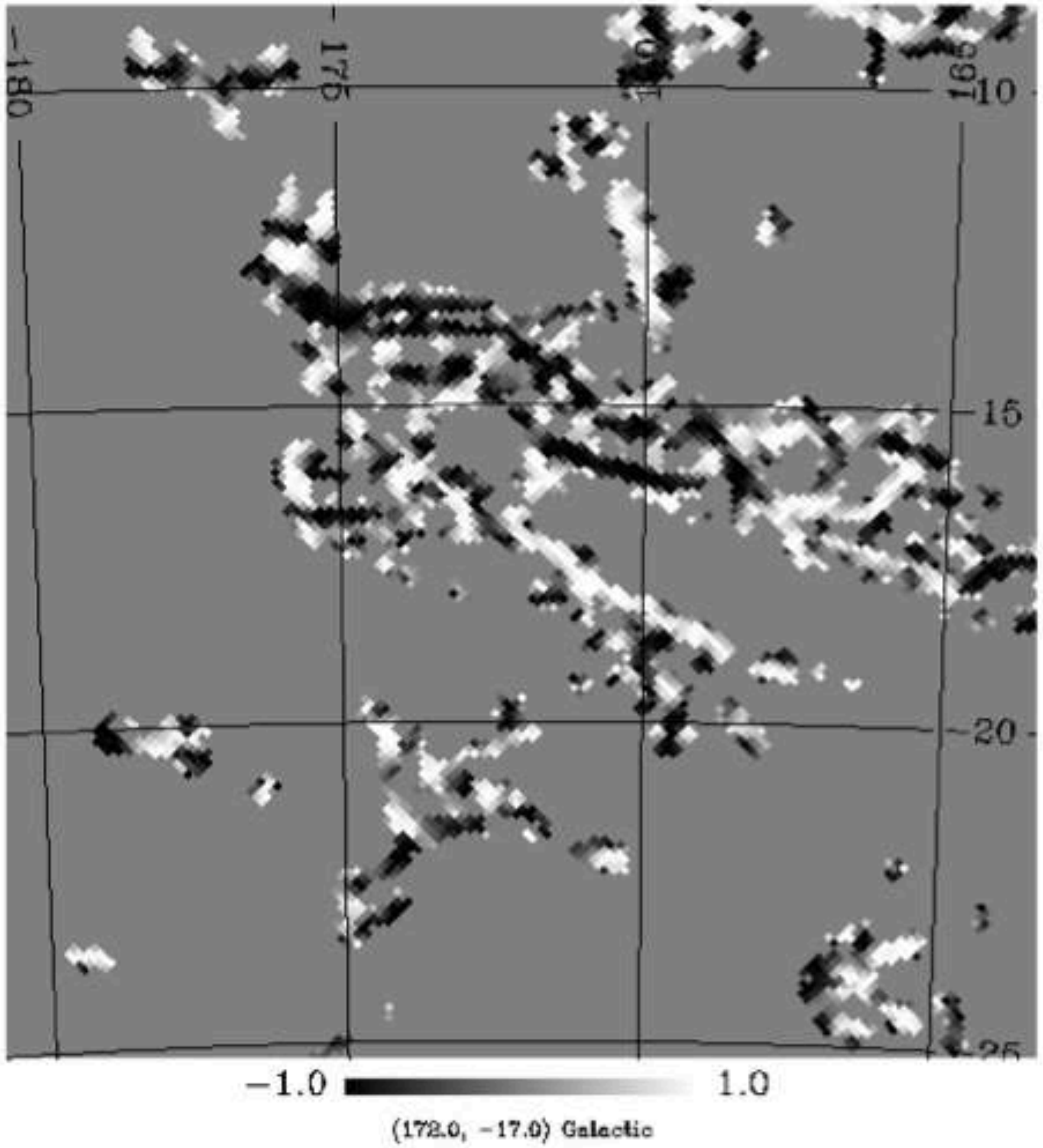


(e.g. Hildebrand 1988, Lazarian 2007…)

- individual dust particle: dipole
- in submm: linear polarization from thermal dust emission
- coherent alignment mechanism: B field is one possibility
- mechanism provides only projected field orientation/morphology
- need something more to derive field strength

to start with:
Larger Scale Interstellar Medium by Planck

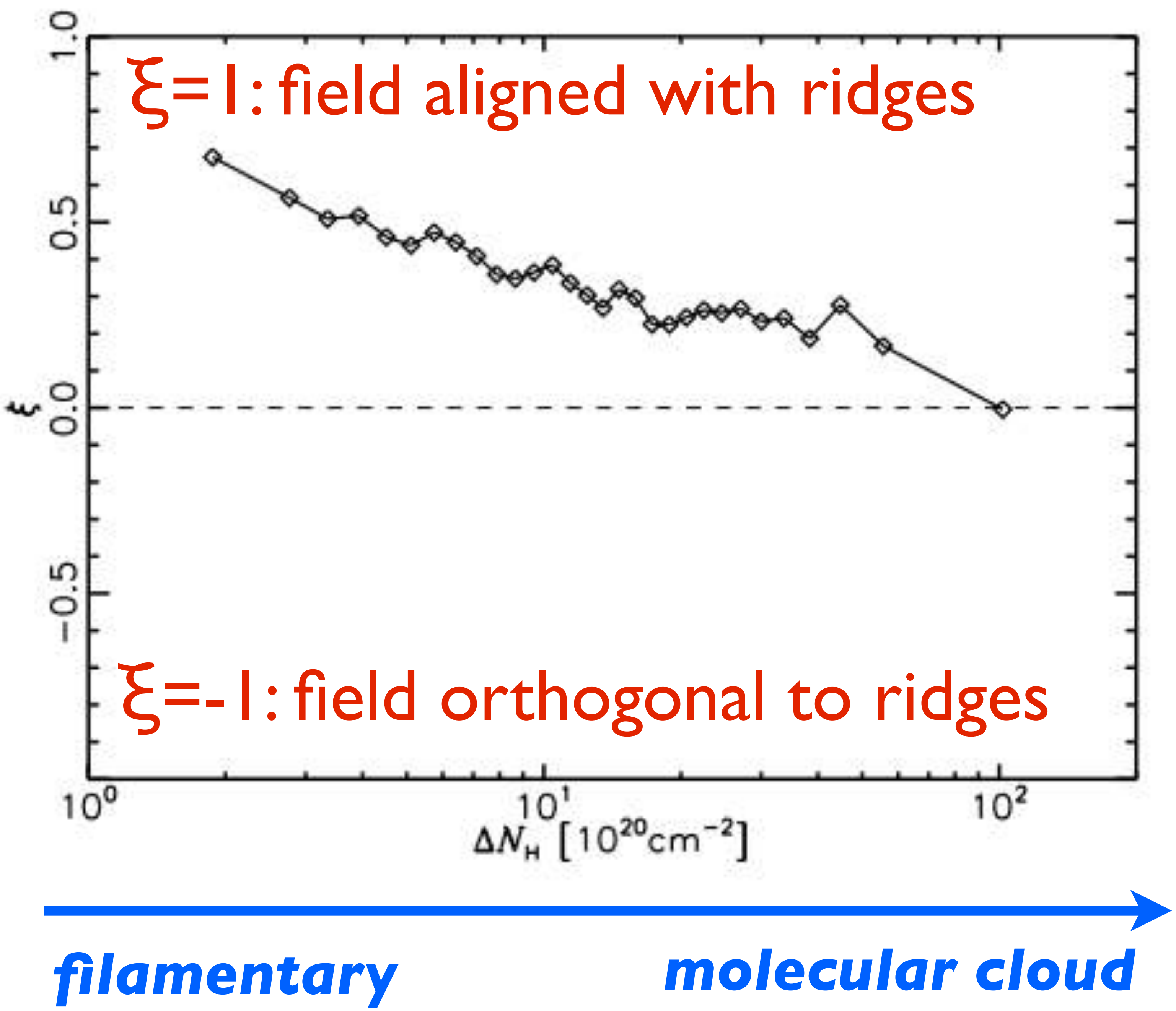




Taurus molecular cloud complex;
dust continuum at 350 GHz
15′ resolution

(Planck XXXII, 2014;
poster by Andrea Bracco)

Planck: Interstellar Medium



(Planck XXXII, 2014)

magnetic field vs structure:

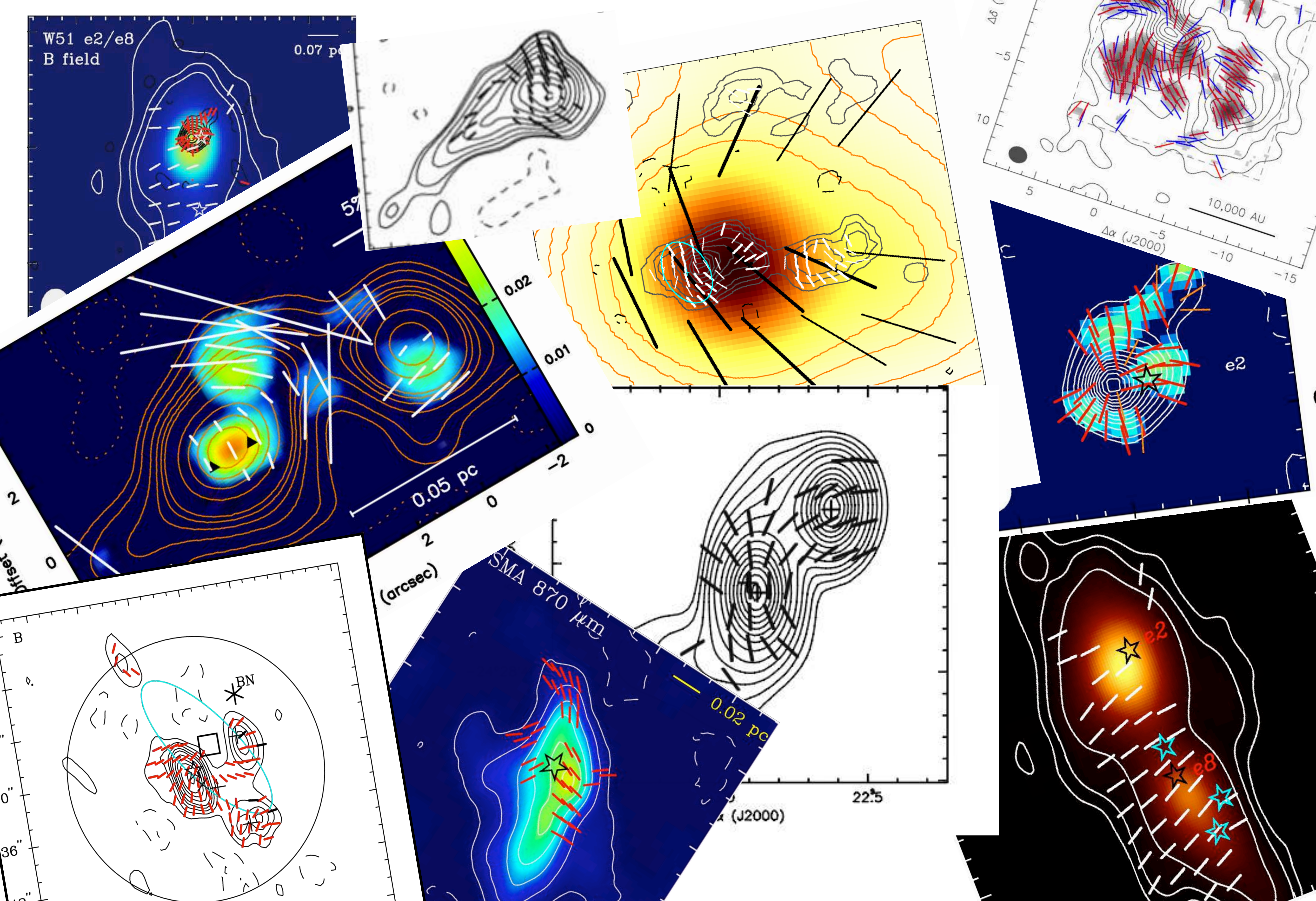
- field tends to be aligned with ridges in diffuse ISM
- alignment progressively changes as column density increases

- ***interpretation:*** magnetic field is guiding material, possibly significant level of turbulence organizing material parallel to magnetic field

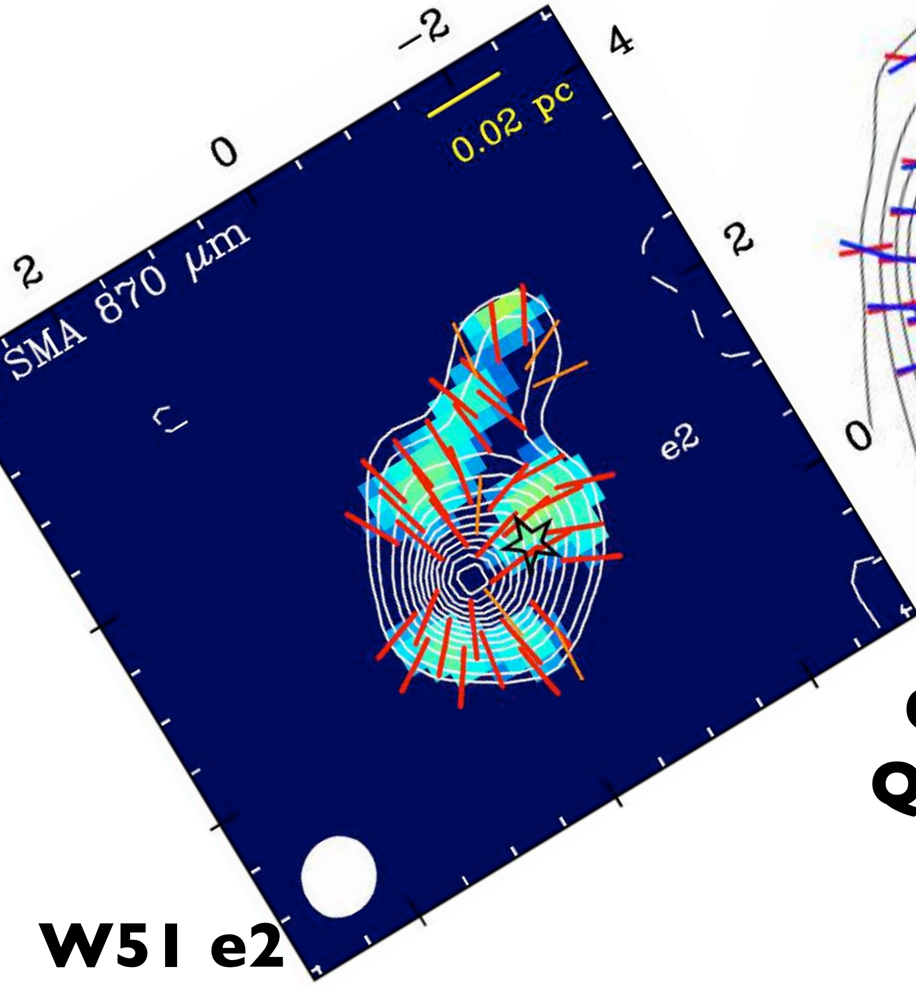
- ***question:*** how does the role of the magnetic field evolve towards smaller scales?

- utilize dust polarization observations on smaller scales with the SMA, CSO, JCMT, (ALMA)

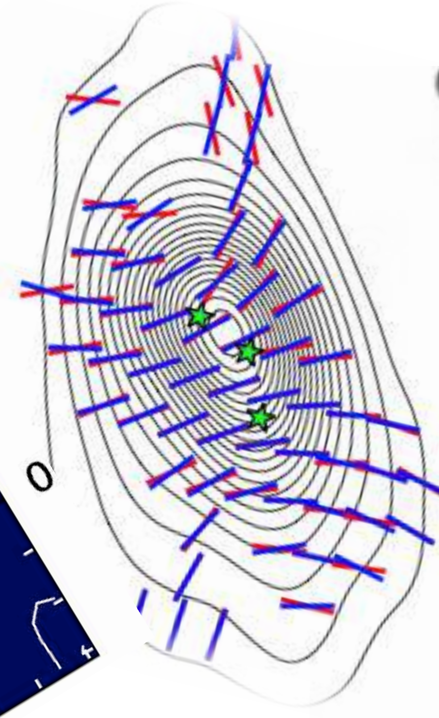
Magnetic Field Observations on Smaller Scales



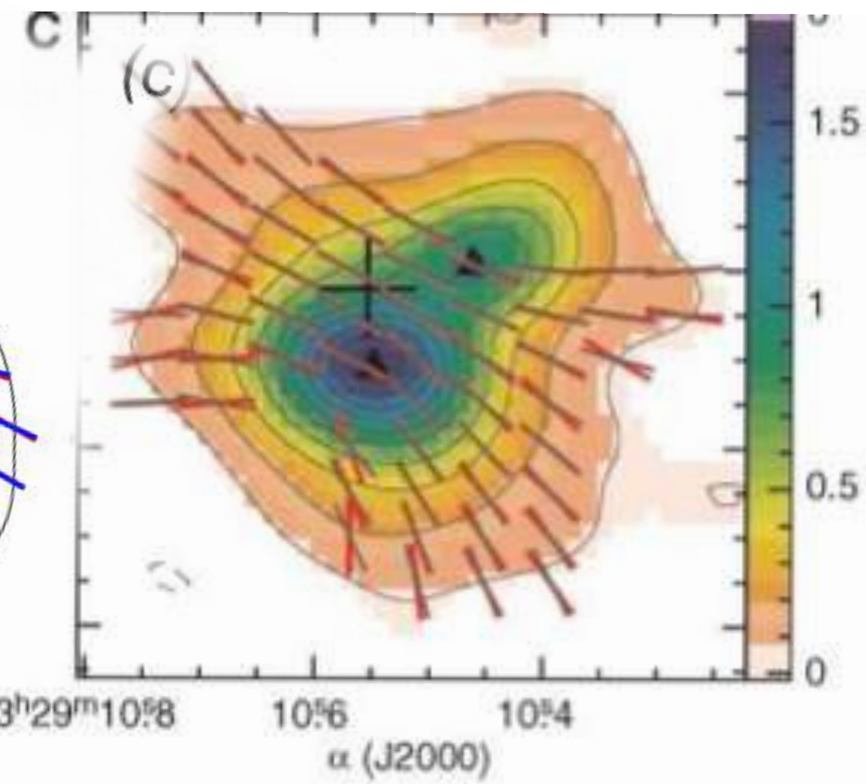
SMA: High-Resolution Cores in Star-Forming Regions



W51 e2
Tang+09

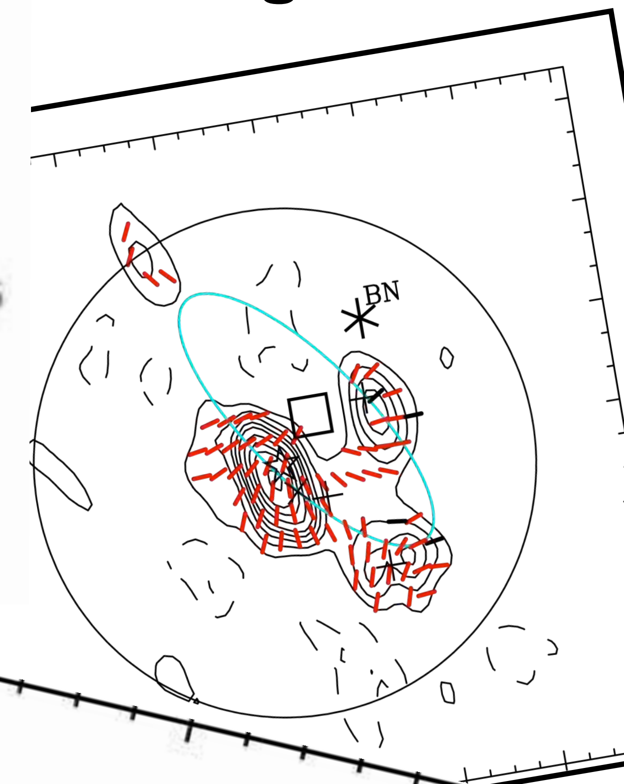


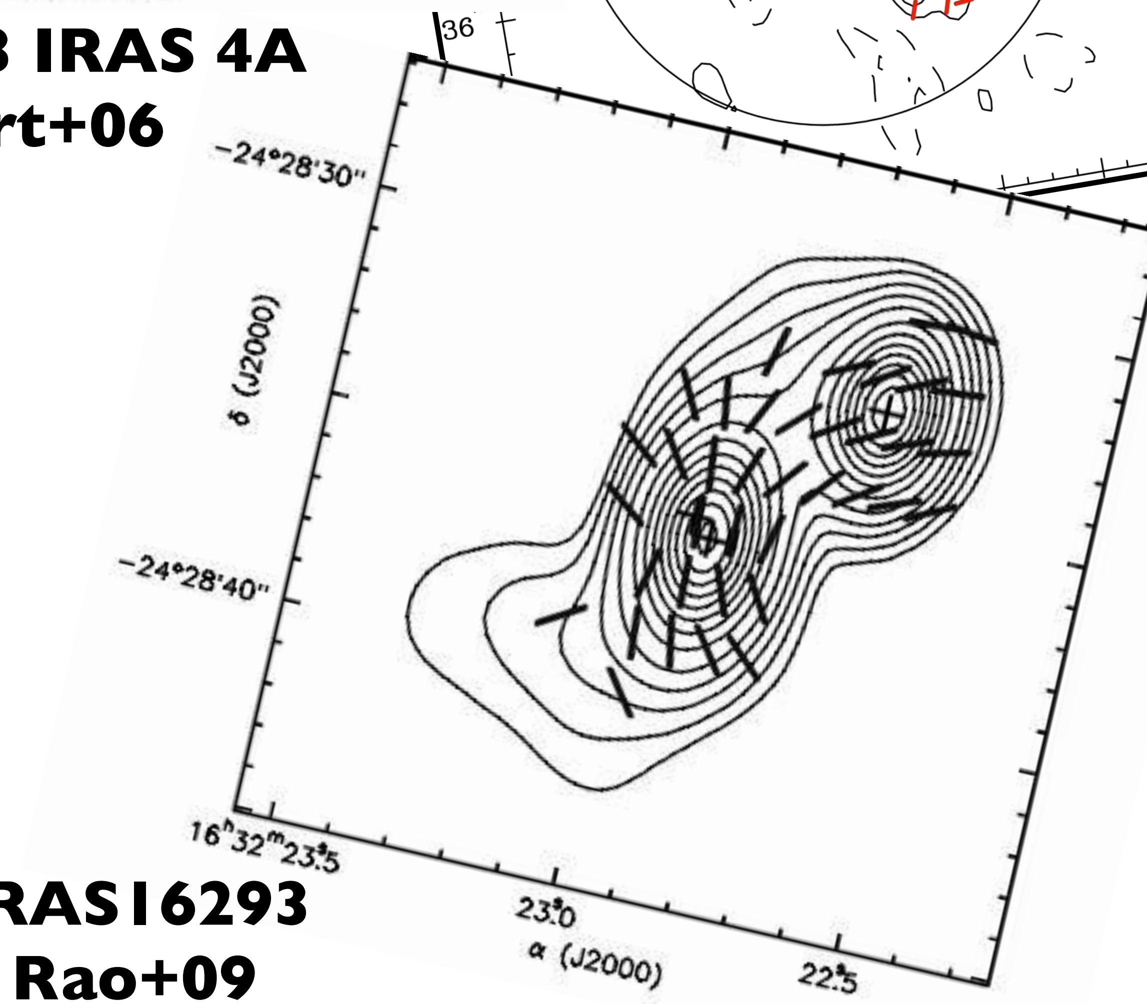
G240
Qiu+14



NGC1333 IRAS 4A
Girart+06

Orion BN/KL
Tang+10

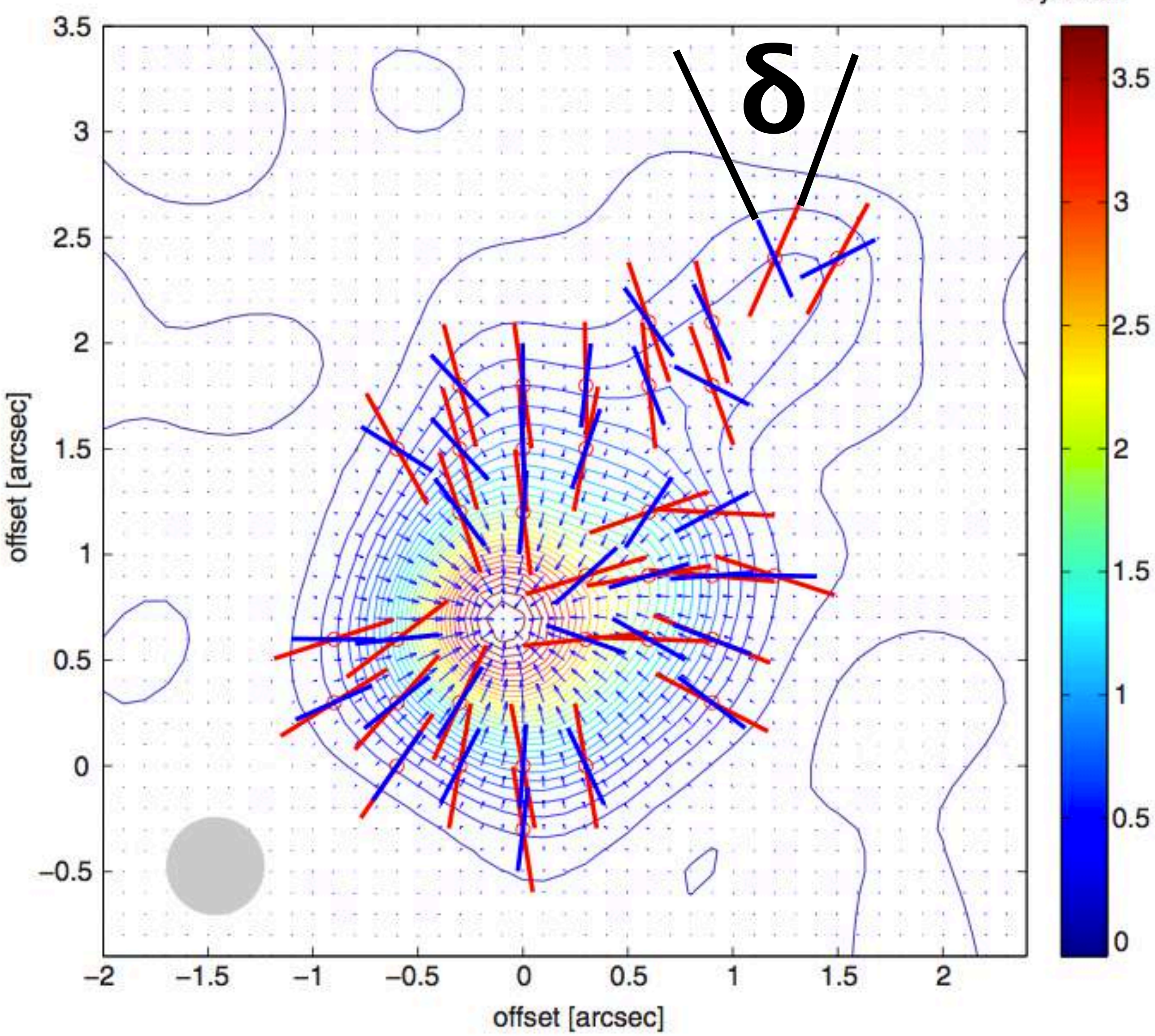


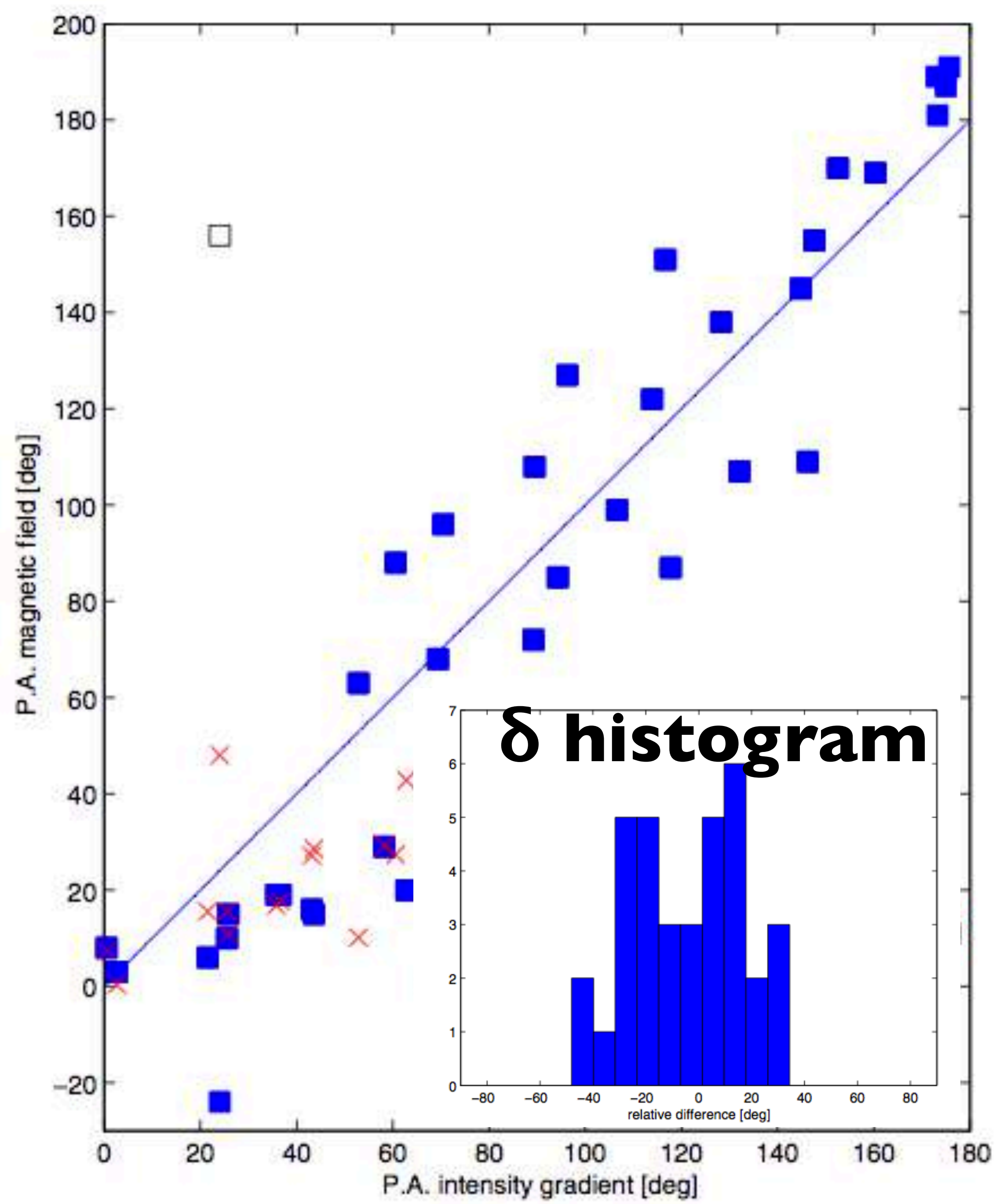


IRAS16293
Rao+09

- among the currently highest-resolution polarization observations, ~ 0.7"
- clearly resolved, shaped and pinched field structures:
  often field closely aligned with gradients

Key Observable: angle δ





motivation:

clear correlation in orientations between intensity gradient and field orientations !

(Koch, Tang & Ho, 2012a,b)

Increasing Sample Size: SMA Polarization Legacy Program and CSO archival data

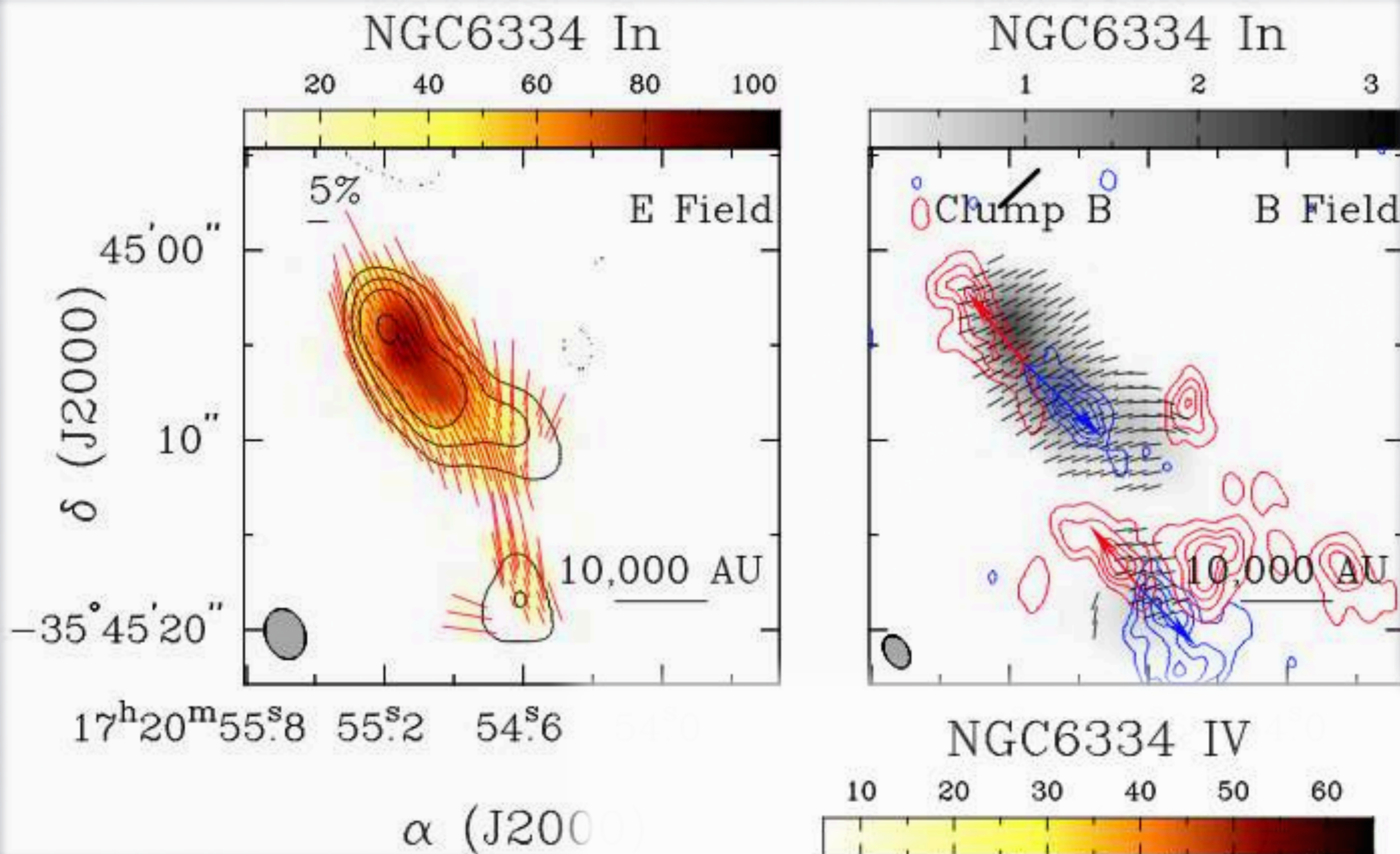
* about 20 additional sources (new or deeper integration, dedicated SMA legacy program, Zhang + SMA pol legacy team, 2014)

  total: about 30 sources in polarization with the SMA

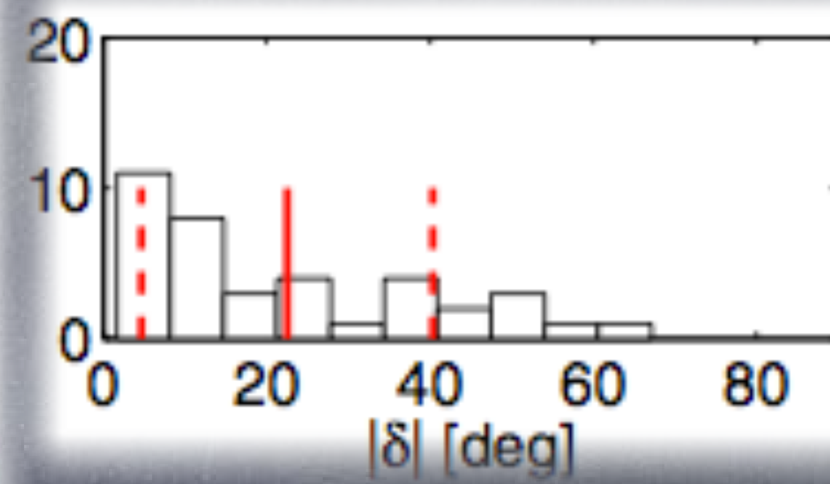
* high-mass sites with density > 10^5 cm^{-3} on scales 0.1 to 0.01 pc, resolutions around 1″ - 3″

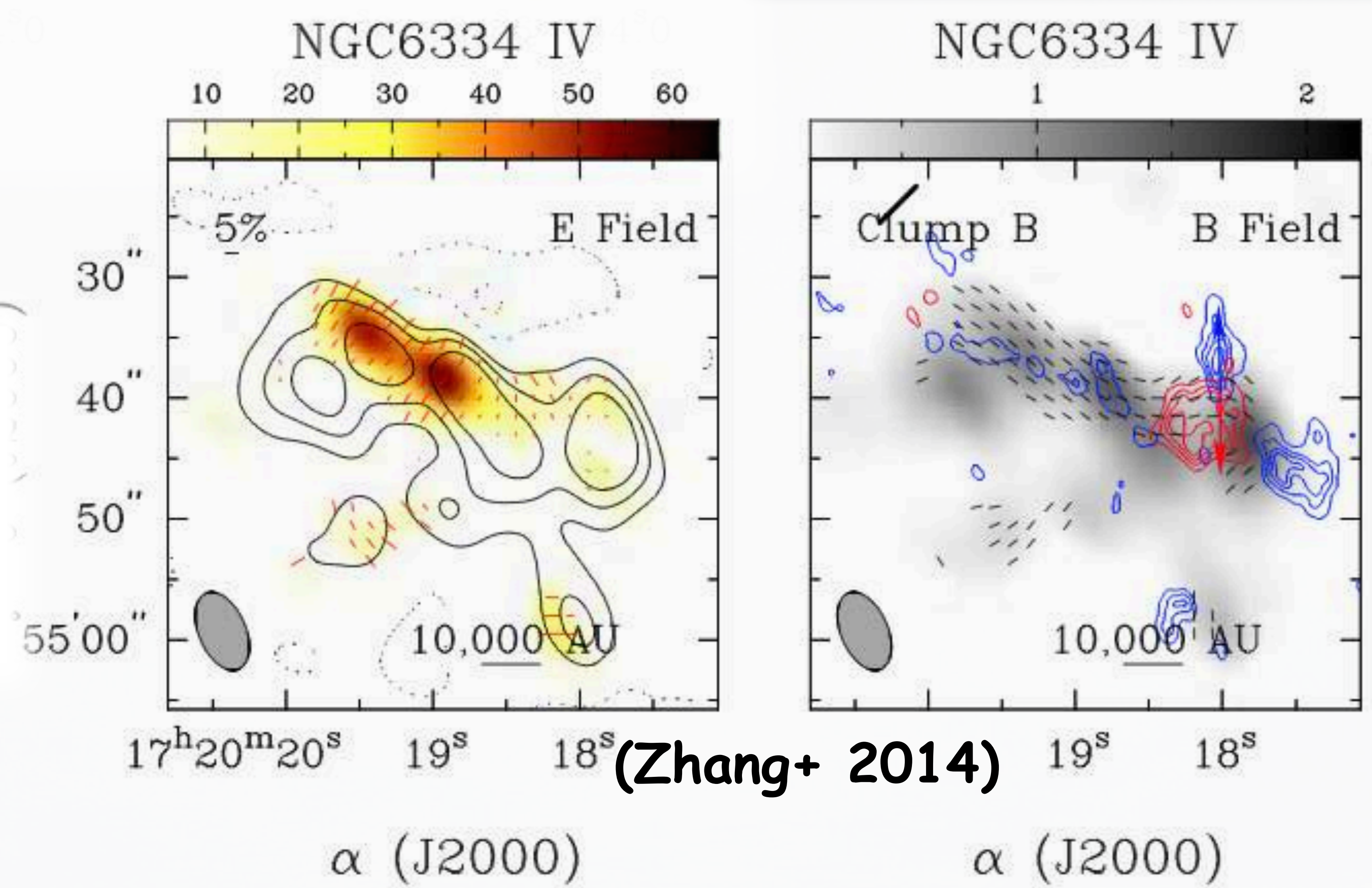
* additionally: CSO archival data (about 20 sources), covering scales of ~ 1 pc

* total sample: 50 sources (low- and high-mass star forming regions)

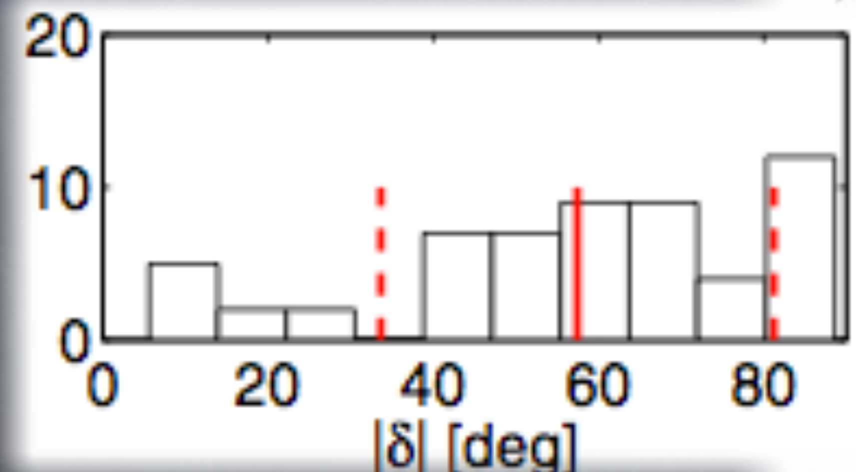


B ⊥ major axis





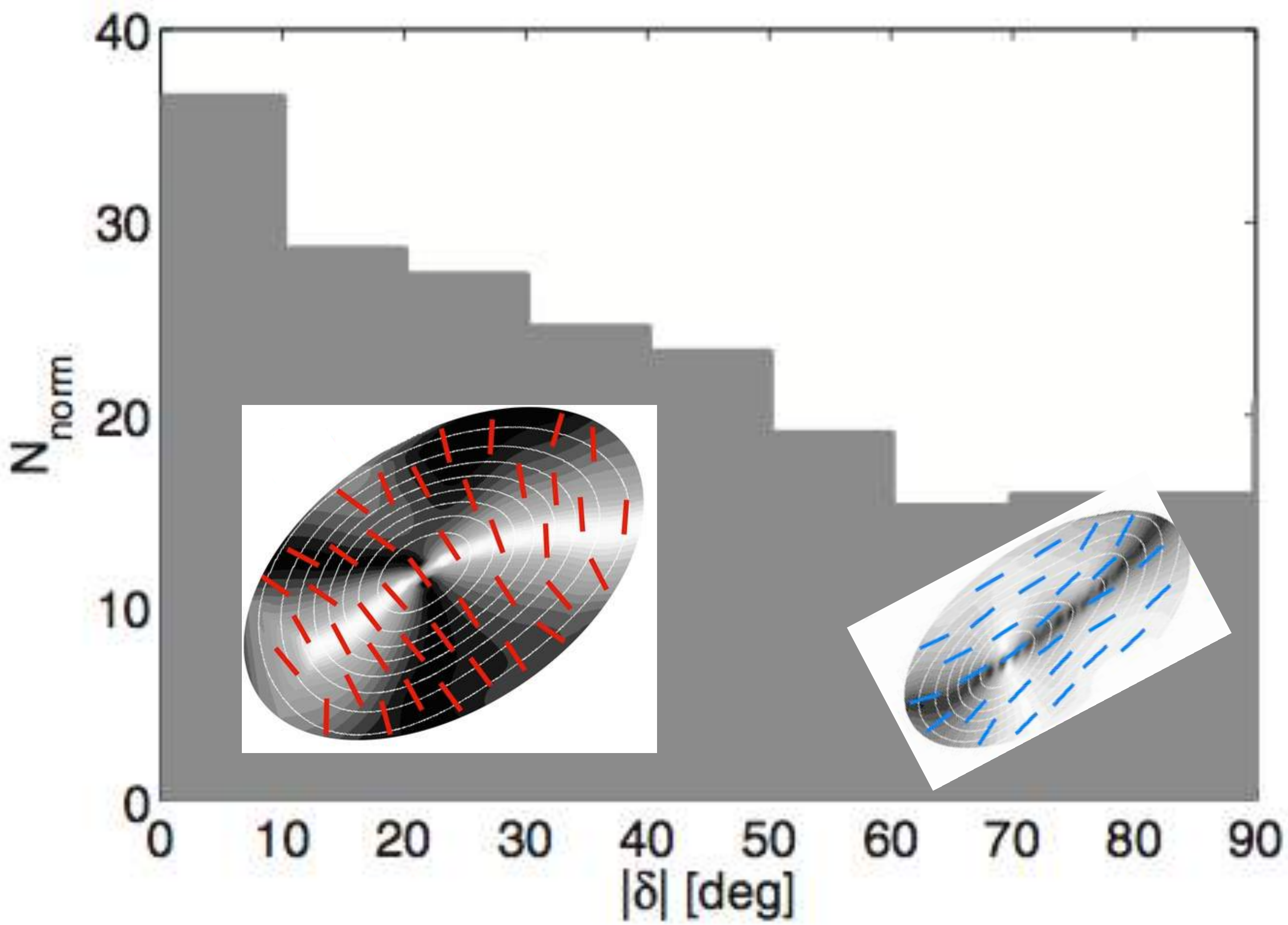
dominating in Planck data



(Zhang+ 2014)

B ∥ major axis

SMA Polarization Legacy Program + CSO Archival data: Magnetic Field vs Dust Continuum Structure



50 sources,
~ 4000 independent measurements

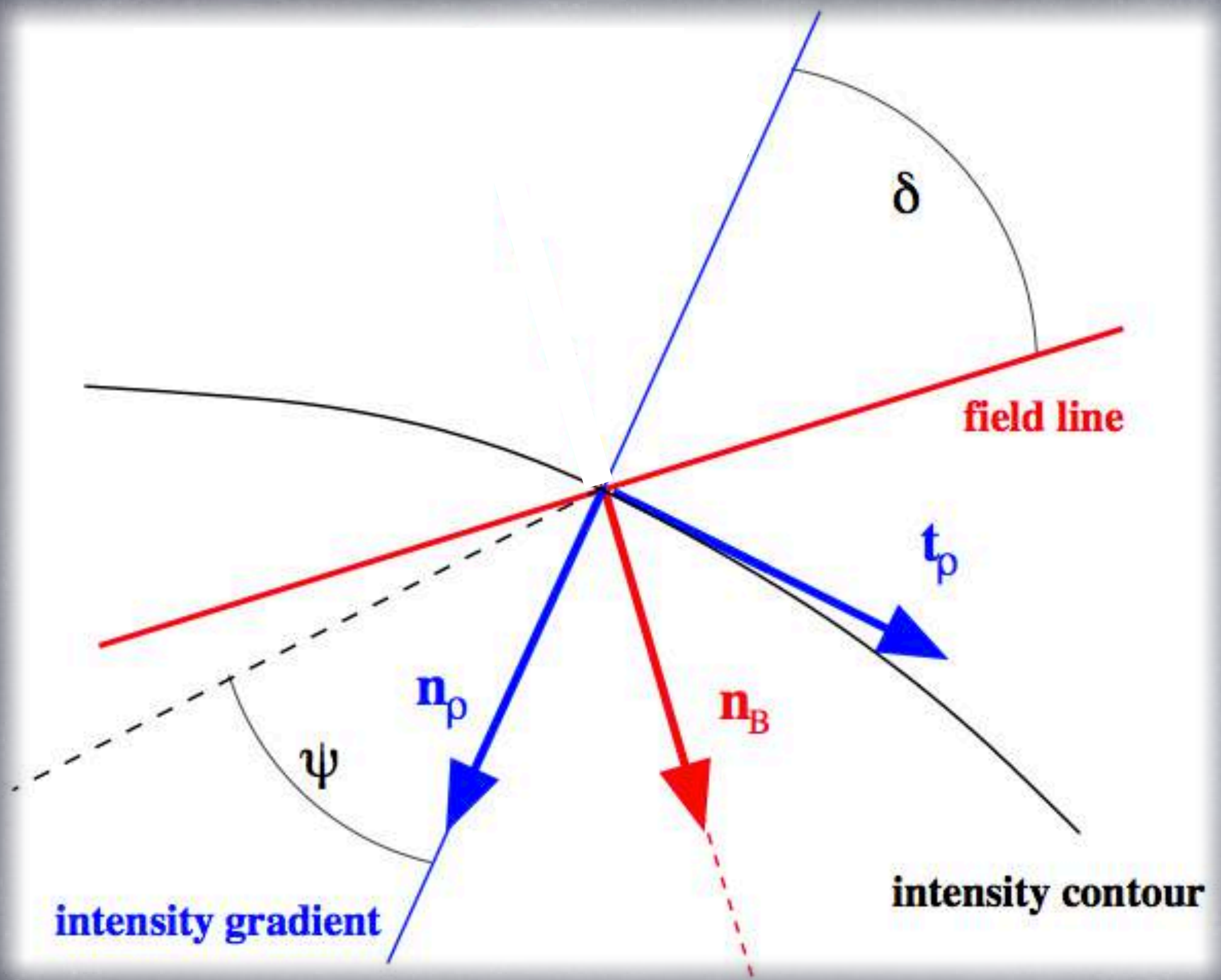
(Koch + SMA pol legacy, 2014)

- ***prevailing field orientation: roughly parallel to source minor axis (not bimodal)***

- ***opposite to Planck result:***
  field tends to be aligned with ridges in diffuse ISM
- intermediate scales: expect results from BLASTpol (poster by Laura Fissel)
- magnetic field very likely plays different roles as a function of scales

What is δ ?

(Koch, Tang & Ho, 2013)



project n_B into orthonormal system (normal, tangential to contour)

$$\rho\left(\frac{\partial}{\partial t}+\mathbf{v}\cdot\nabla\right)\mathbf{v}=-\nabla P-\rho\nabla\phi+\frac{1}{4\pi}\frac{1}{R}B^2\,\mathbf{n}_B$$

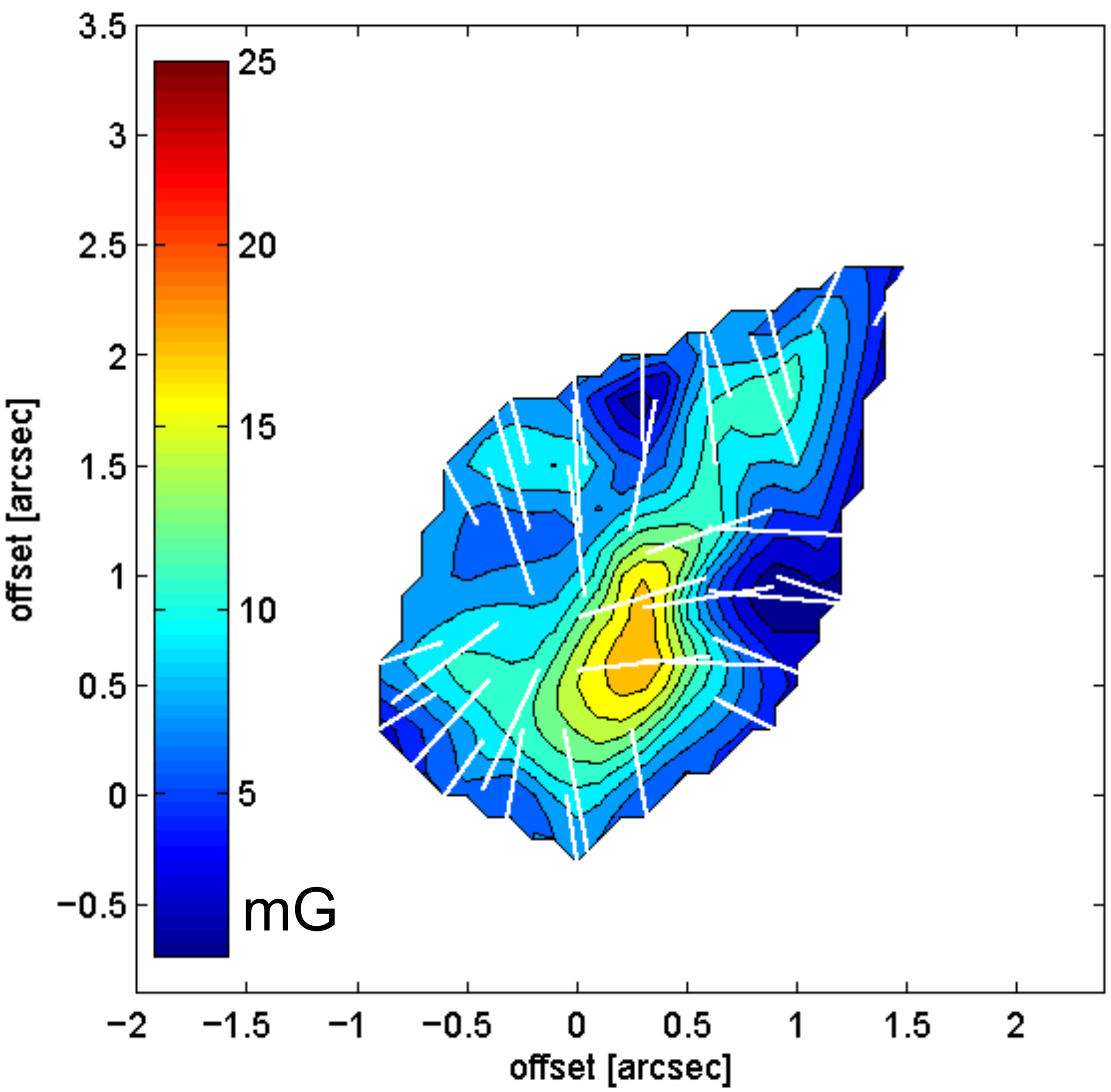
$$\rho\left(\frac{\partial}{\partial t}+\mathbf{v}\cdot\nabla\right)\mathbf{v}=-\nabla P-\rho\nabla\phi+\boxed{\sin|\delta|\,\frac{1}{4\pi}\frac{1}{R}B^2\,\mathbf{n}_\rho}+\sin|\alpha|\,\frac{1}{4\pi}\frac{1}{R}B^2\,\mathbf{t}_\rho$$

- δ measures alignment
- fraction of field tension force oriented along gradient

What can we learn from δ ?

Magnetic Field Strength Map

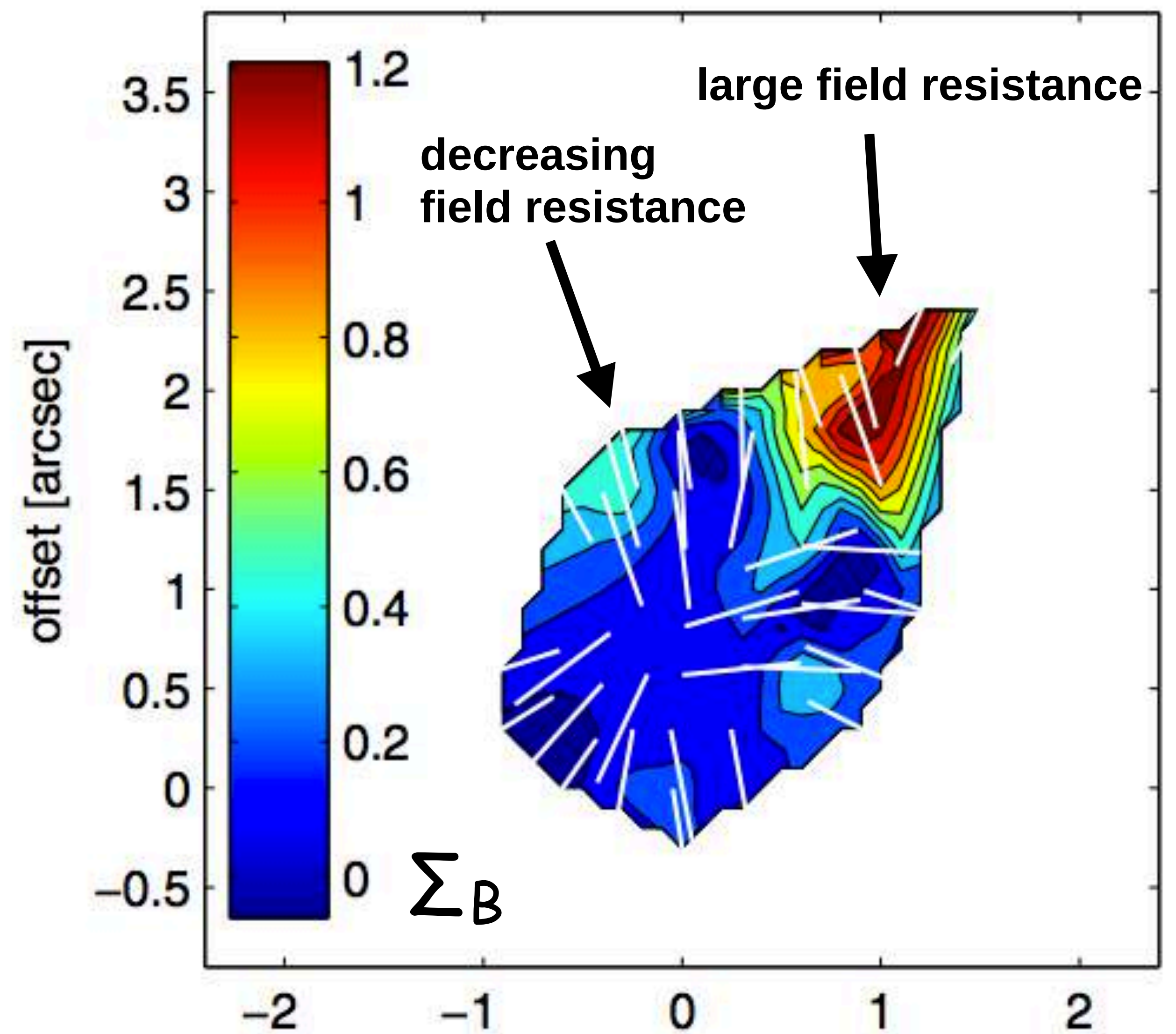
$$B = \sqrt{\frac{\sin\psi}{\sin\left(\frac{\pi}{2} - |\delta|\right)}(\nabla P + \rho\nabla\phi)4\pi\ R}$$



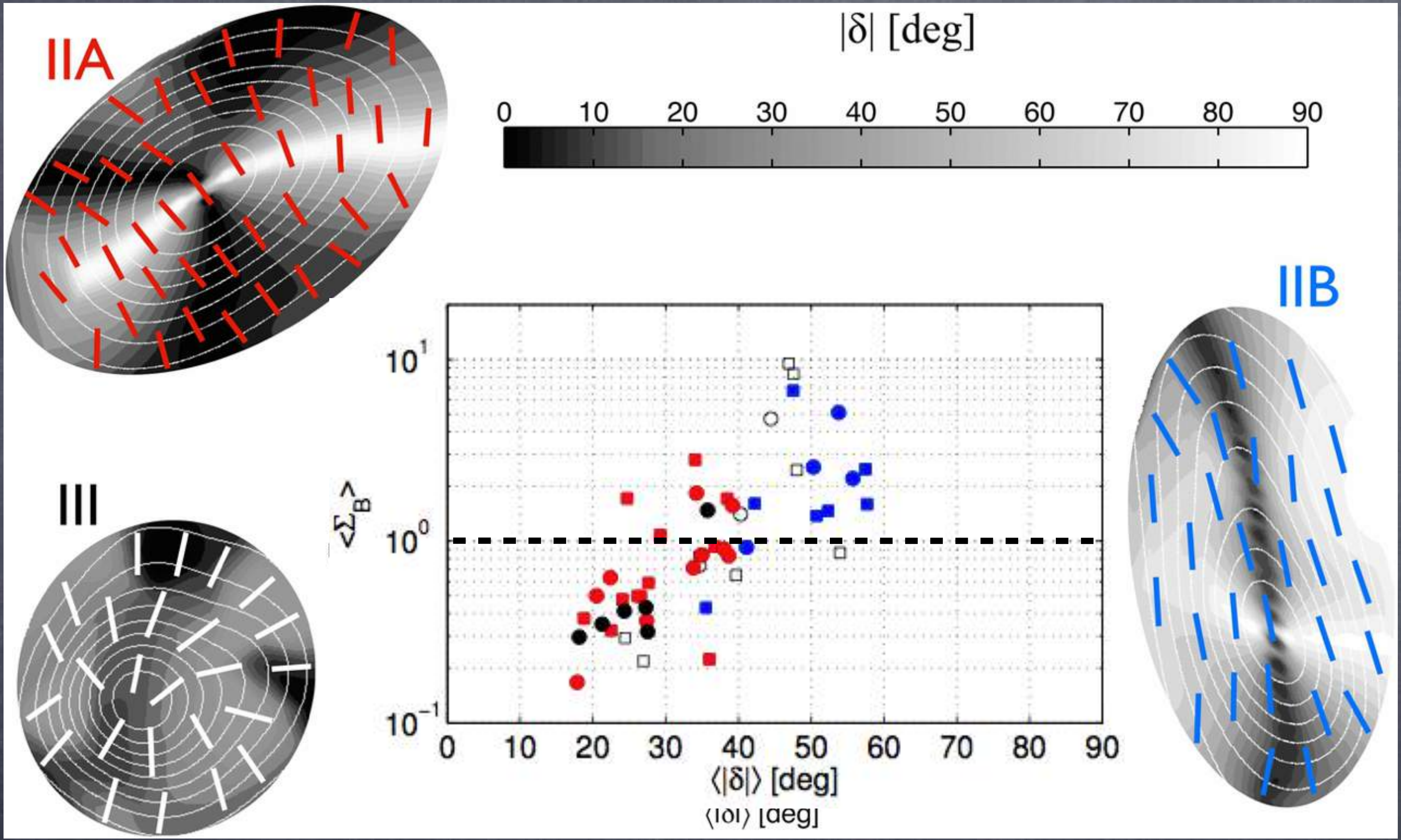
(Koch, Tang & Ho, 2012a,b;2013)

Field-to-Gravity Force Ratio Σ_B

$$\Sigma_B \equiv \frac{\sin\psi}{\sin\left(\frac{\pi}{2} - |\delta|\right)} = \frac{F_B}{|F_G + F_P|}$$



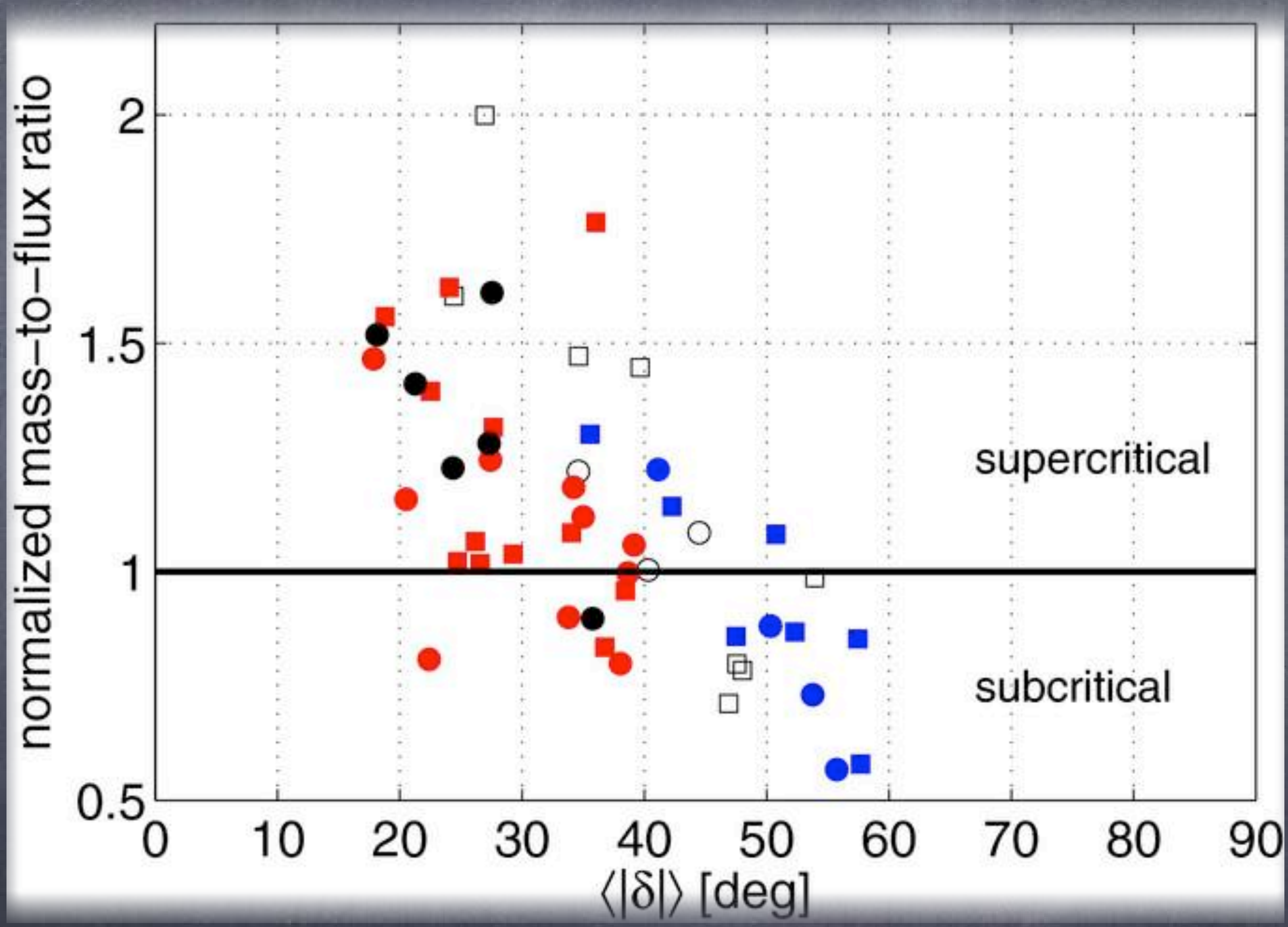
δ across a Sample of 50 sources (SMA+CSO): Σ_B



(Koch+ SMA pol legacy, 2014)

- average <|δ|> is systematically different across sample
- <|δ|> is typically small for sources with magnetic field parallel to source minor axis, <|δ|> grows for sources with field parallel to major axis
- $<\Sigma_B>$ grows systematically with <|δ|> with a transition across 1

δ across a Sample of 50 sources (SMA+CSO): mass-to-flux ratio



(Koch+ SMA pol legacy, 2014)

Conclusions

- ***observations:*** * δ is a key observable, discriminating between different types of source - magnetic field configurations; seen in SMA, CSO, JCMT (and BIMA / CARMA) data

  * prevailing field orientation is parallel to source minor axes; Planck observations of larger-scale ISM: opposite trend

  * δ is a tracer of the role of the magnetic field (sub-, supercritical; star formation efficiency)

  * sample of 50 sources: δ and Σ_B show clear correlation; i.e., the larger δ, the more the field dominates gravity

- ***methodology:***

basic idea: observed morphology reflects geometrical imprint of combined forces. This leads to:

* force ratio Σ_B (depends on angles only)
* local magnetic field strength B