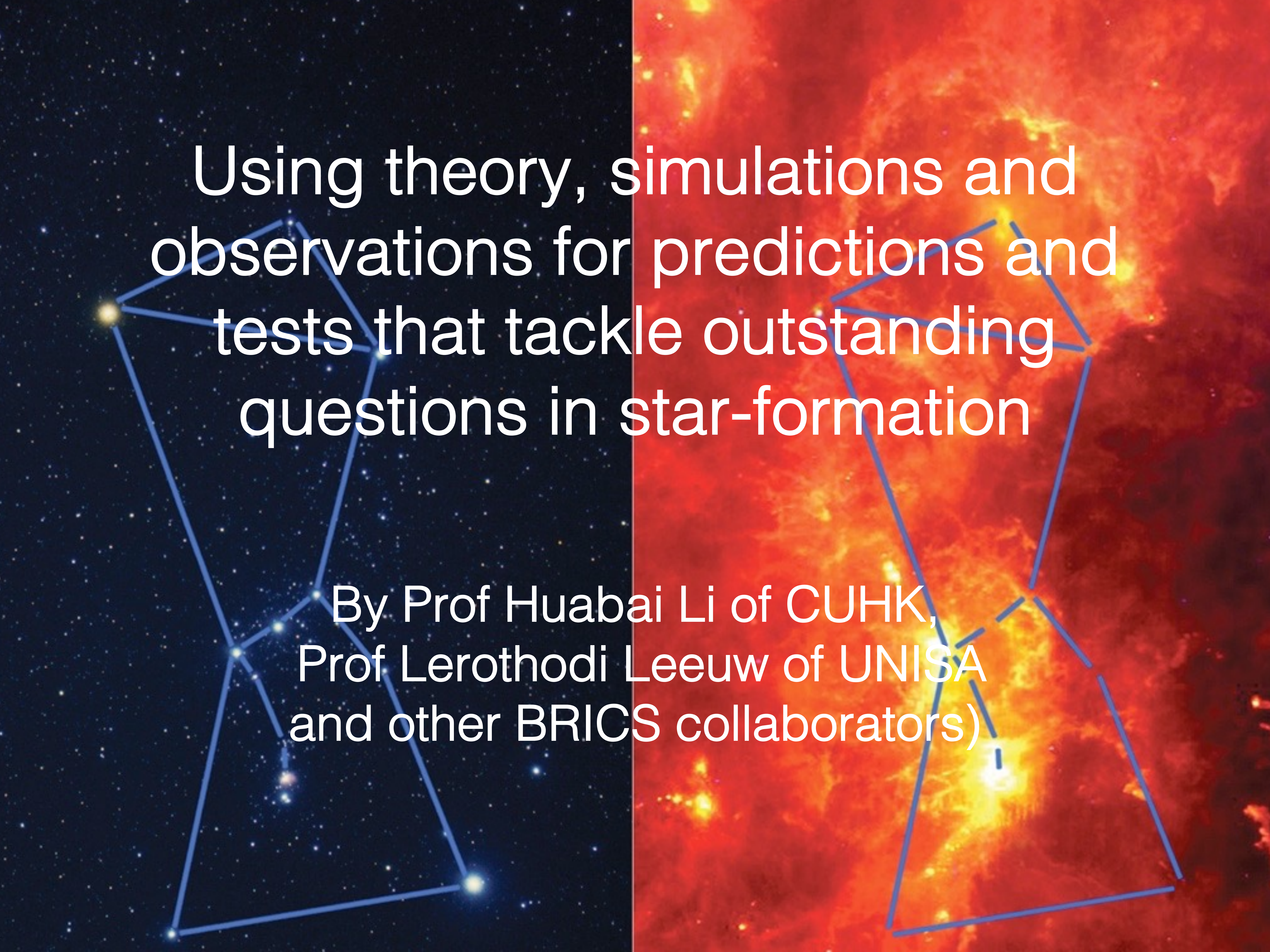
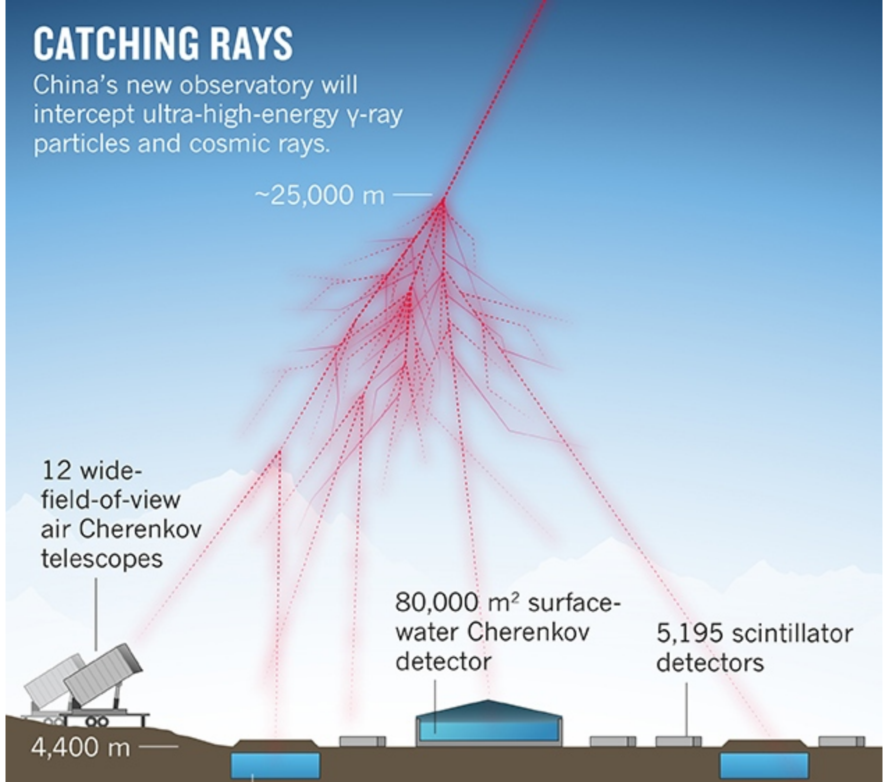


Using theory, simulations and observations for predictions and tests that tackle outstanding questions in star-formation

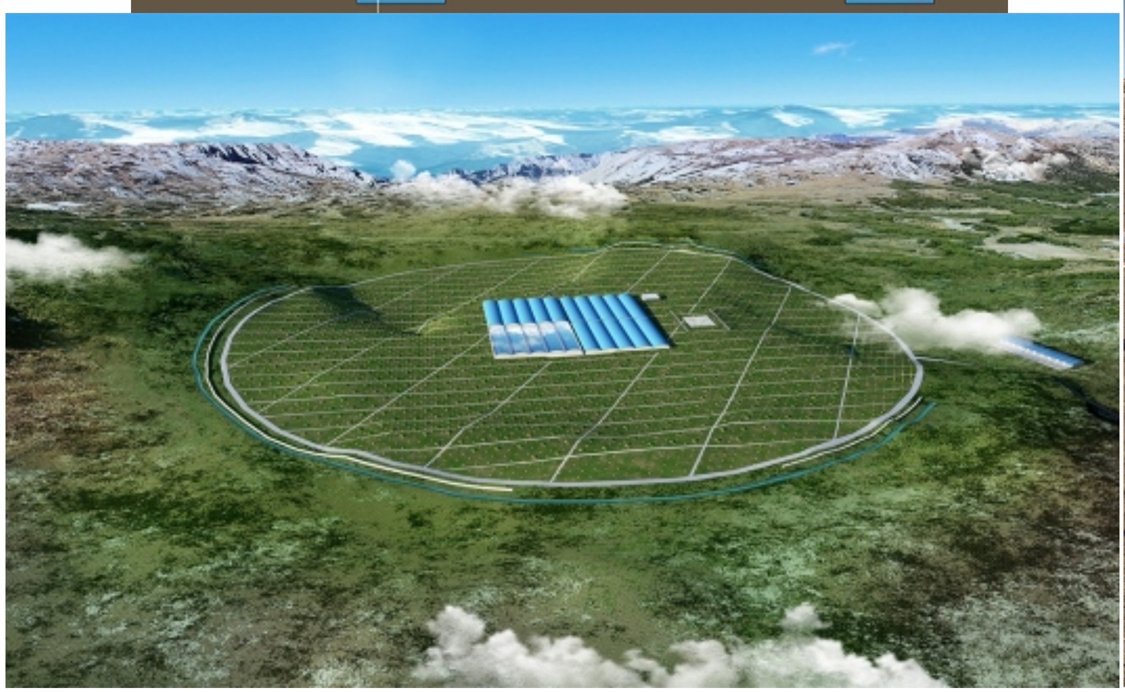
By Prof Huabai Li of CUHK,
Prof Lerothodi Leeuw of UNISA
and other BRICS collaborators)

Advanced MHD Simulations and High-resolution Observations for Tackling the Magnetic-Braking Catastrophe in Star-formation

By Prof Huabai Li of CUHK,
Prof Lerothodi Leeuw of UNISA
and other BRICS collaborators)



- Funding in most partner countries is being directed towards CTA, leading to shortage of funds for H.E.S.S.
- If H.E.S.S. operations continue beyond 2019, Namibia and South Africa will have to take a leading role.
- Namibia (NCRST) is willing to take over the site contract.
- There is great interest in the current H.E.S.S. collaboration to keep H.E.S.S. operating – but insufficient funding.

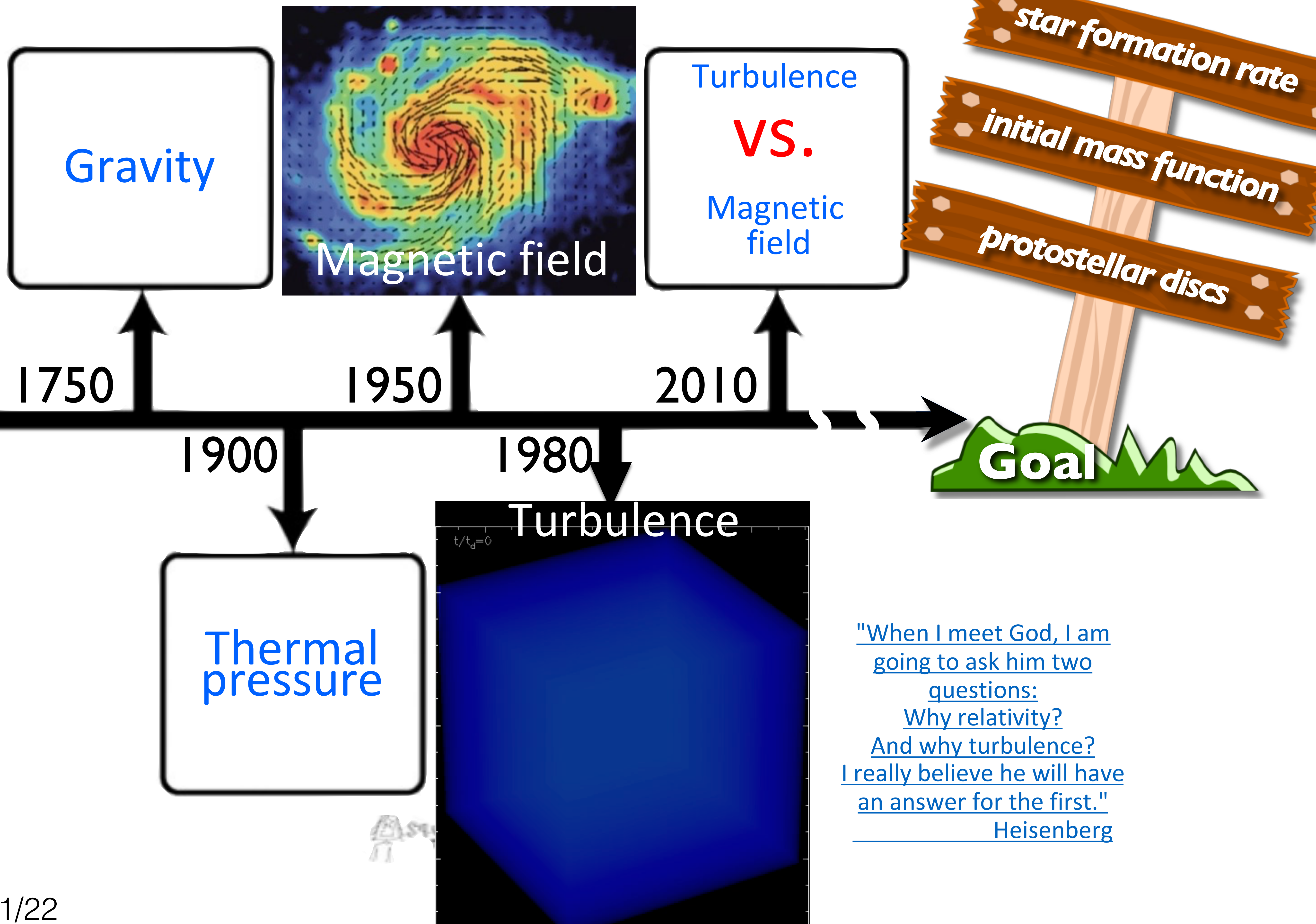


Astroparticle Physics Forum BRICS

by Astroparticle Physics Forum South Africa, and BRICS Partners

- A history of star formation theory
- Some goals: to explain star formation efficiency, IMF, disk and jets.

Star Formation Theory



"When I meet God, I am going to ask him two questions:
Why relativity?
And why turbulence?
I really believe he will have an answer for the first."
Heisenberg

- Star formation efficiency

Low star-formation efficiency

Some properties of MCs:

M ~ 10^5 solar mass

T ~ 10 K

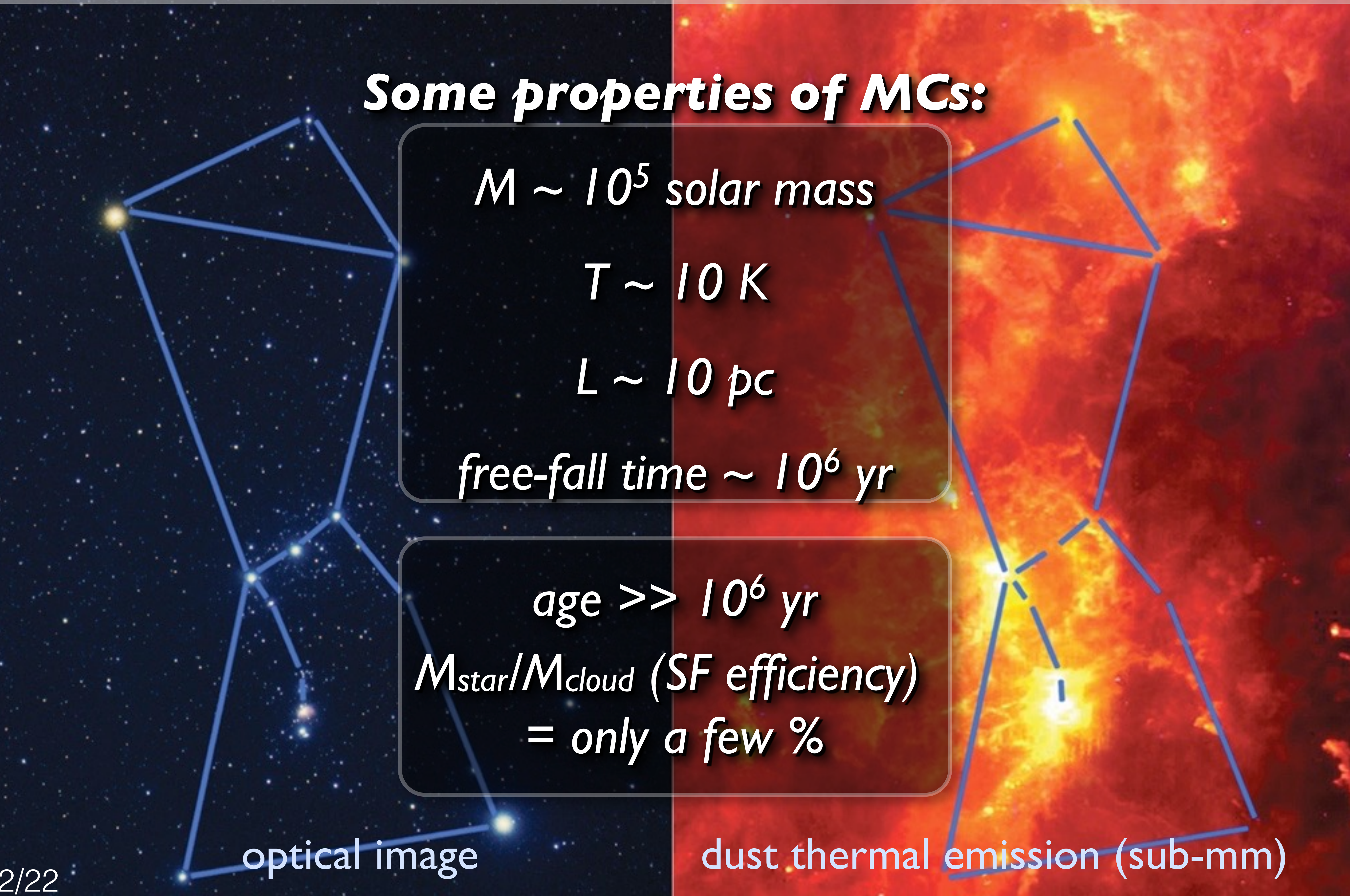
L ~ 10 pc

free-fall time ~ 10^6 yr

age >> 10^6 yr

M_{star}/M_{cloud} (SF efficiency)

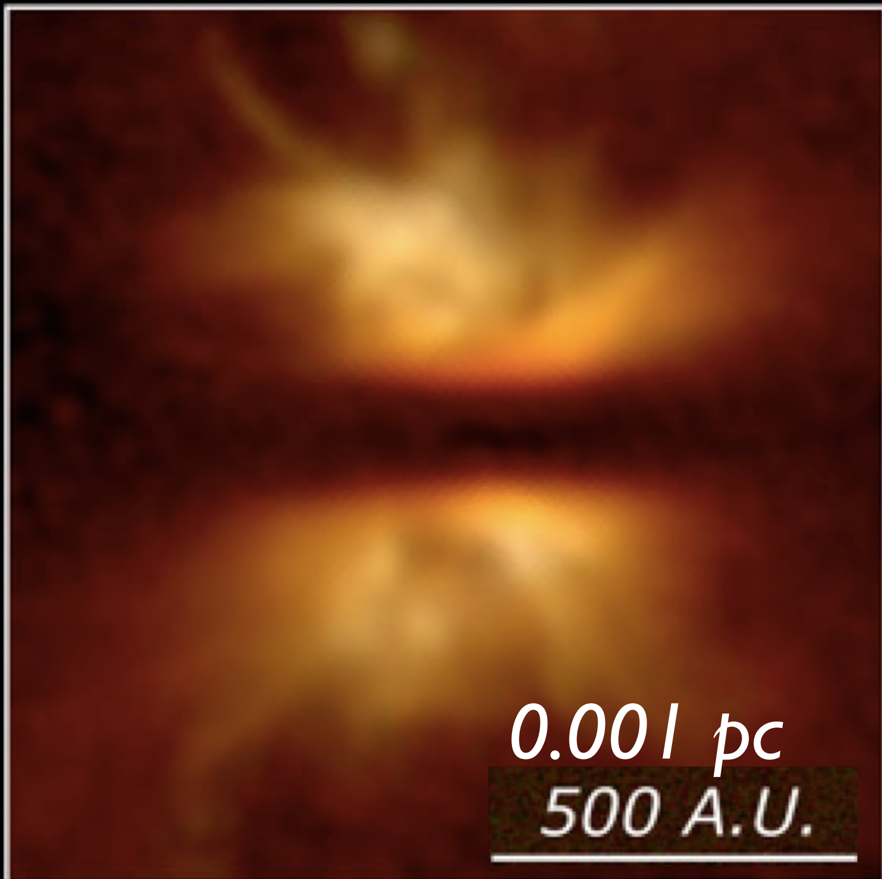
= only a few %

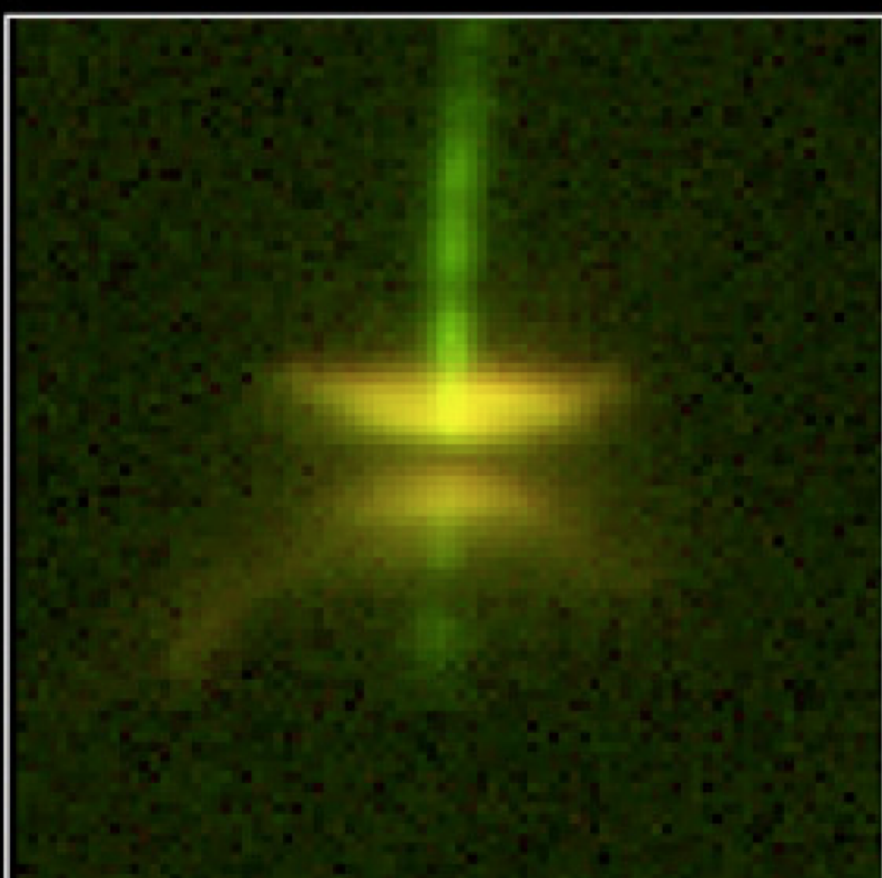


Disks and jets

Protostellar Discs & Jets

IRAS 04302+2247



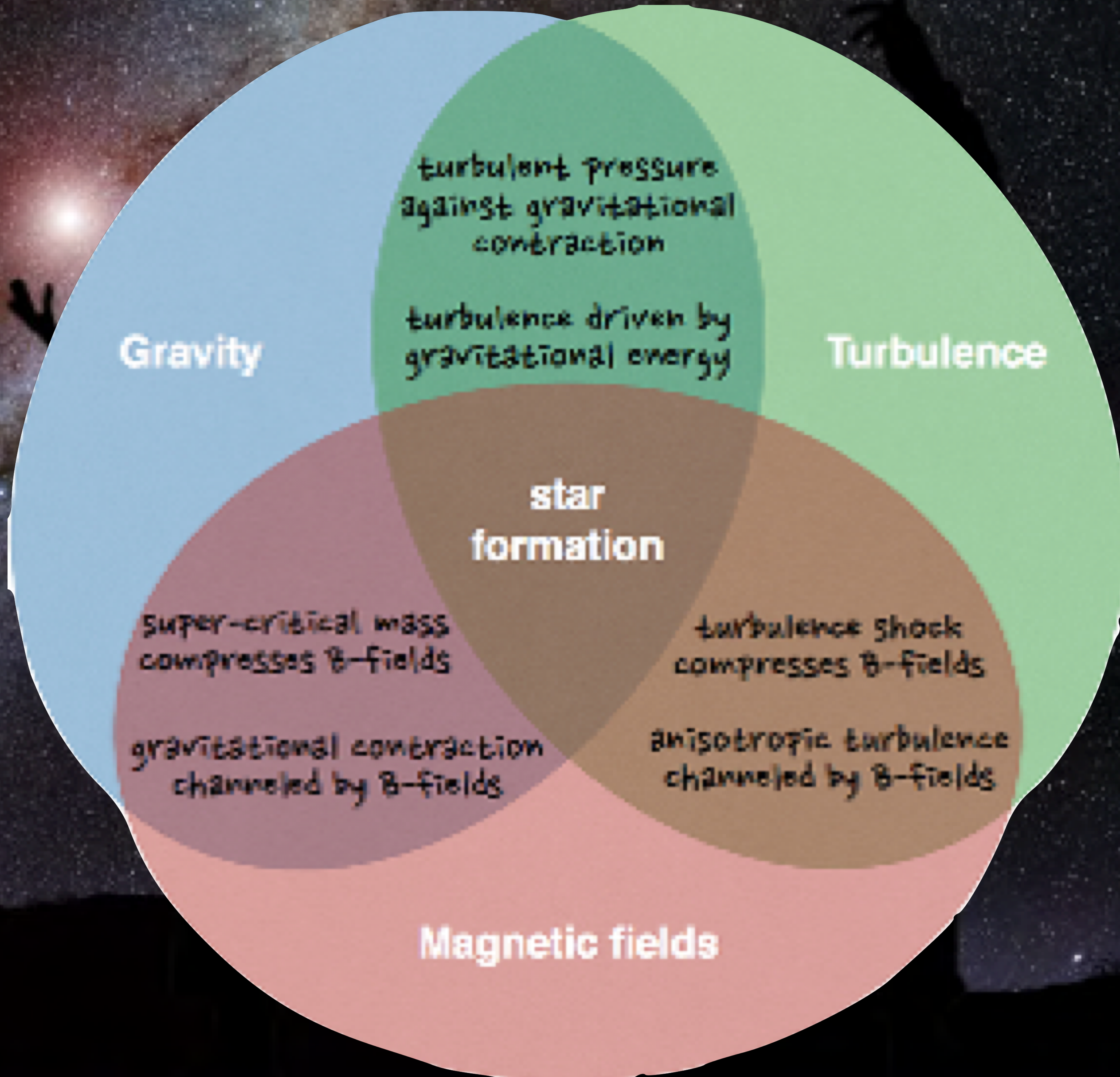


HH 30

HH47 (*1994-2008*)

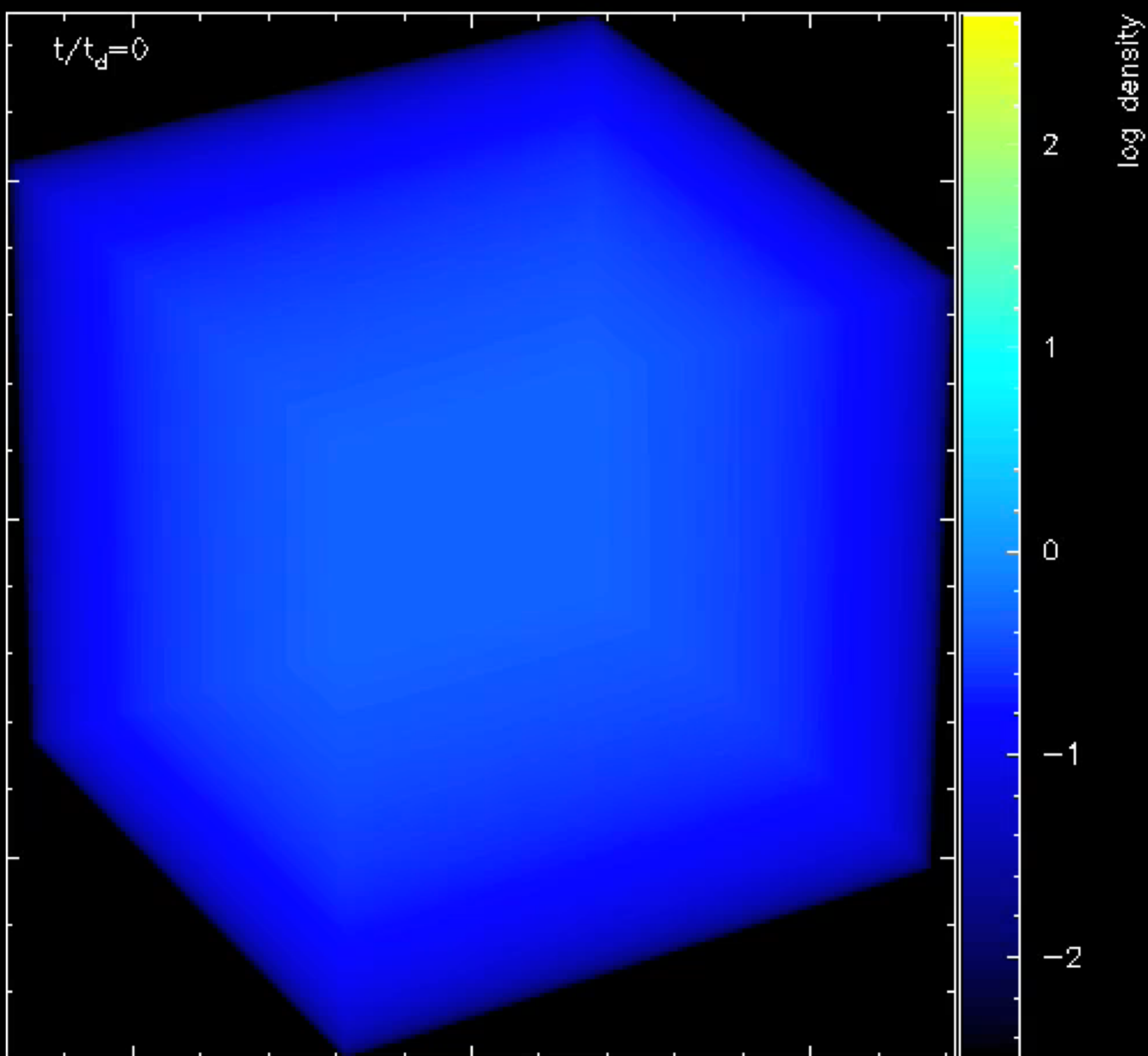
- Gravity vs turbulence vs B-field

"When the opponent is hard, I retreat.
When the opponent reaches the end of tether, I follow" — Taichi master Wang, Zhongyue (13th century)



- Simulation: supersonic turbulence prevent the global collapse of a cloud, but enhance density locally (lognormal density PDF) to result in small-scale contraction
- Observation: lognormal density PDF observed for Av < 2-5 mag; above which the PDF follows power laws (signature of contraction)

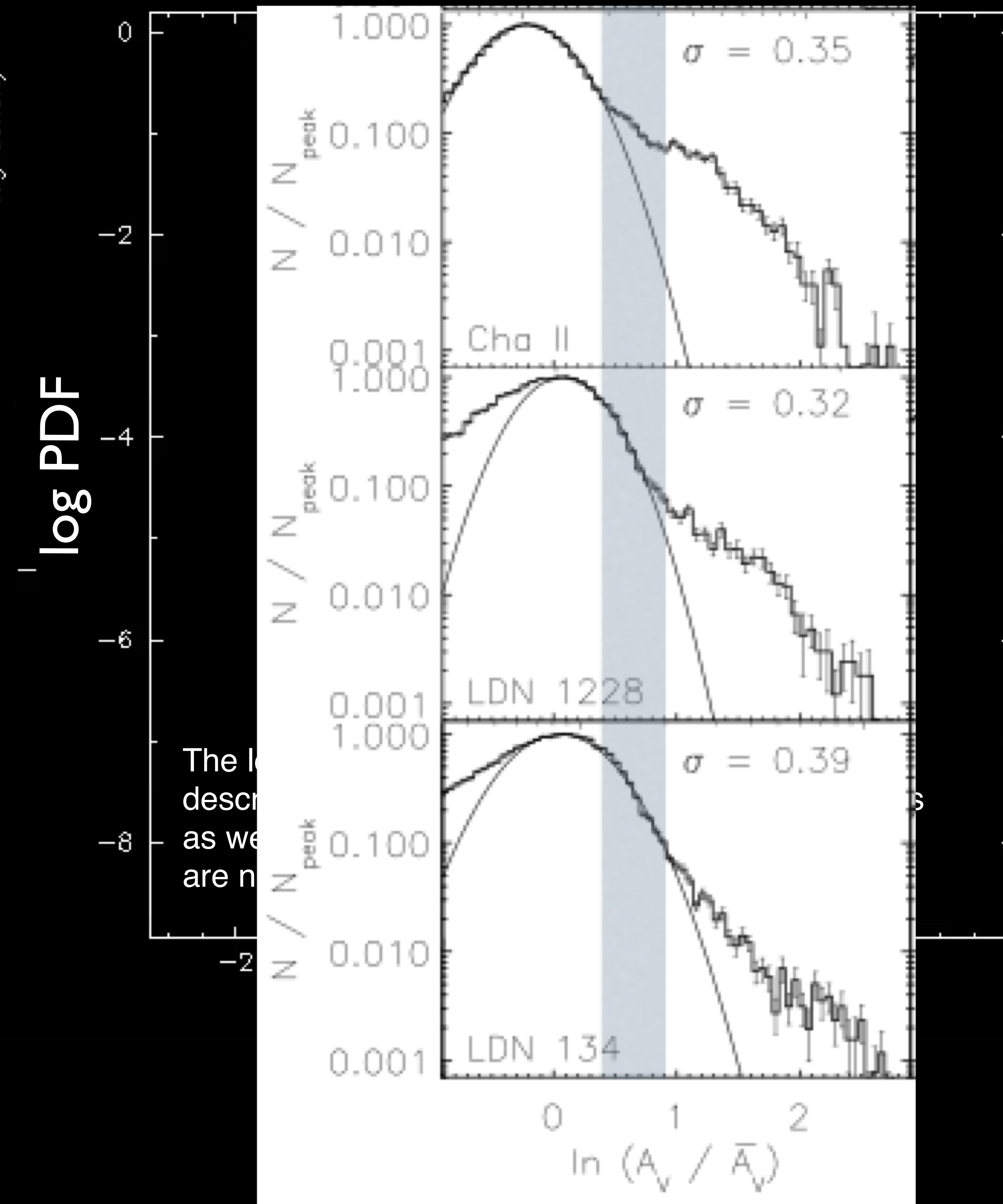
Turbulence vs. Gravity



Daniel Price and Christoph Federrath (2010)

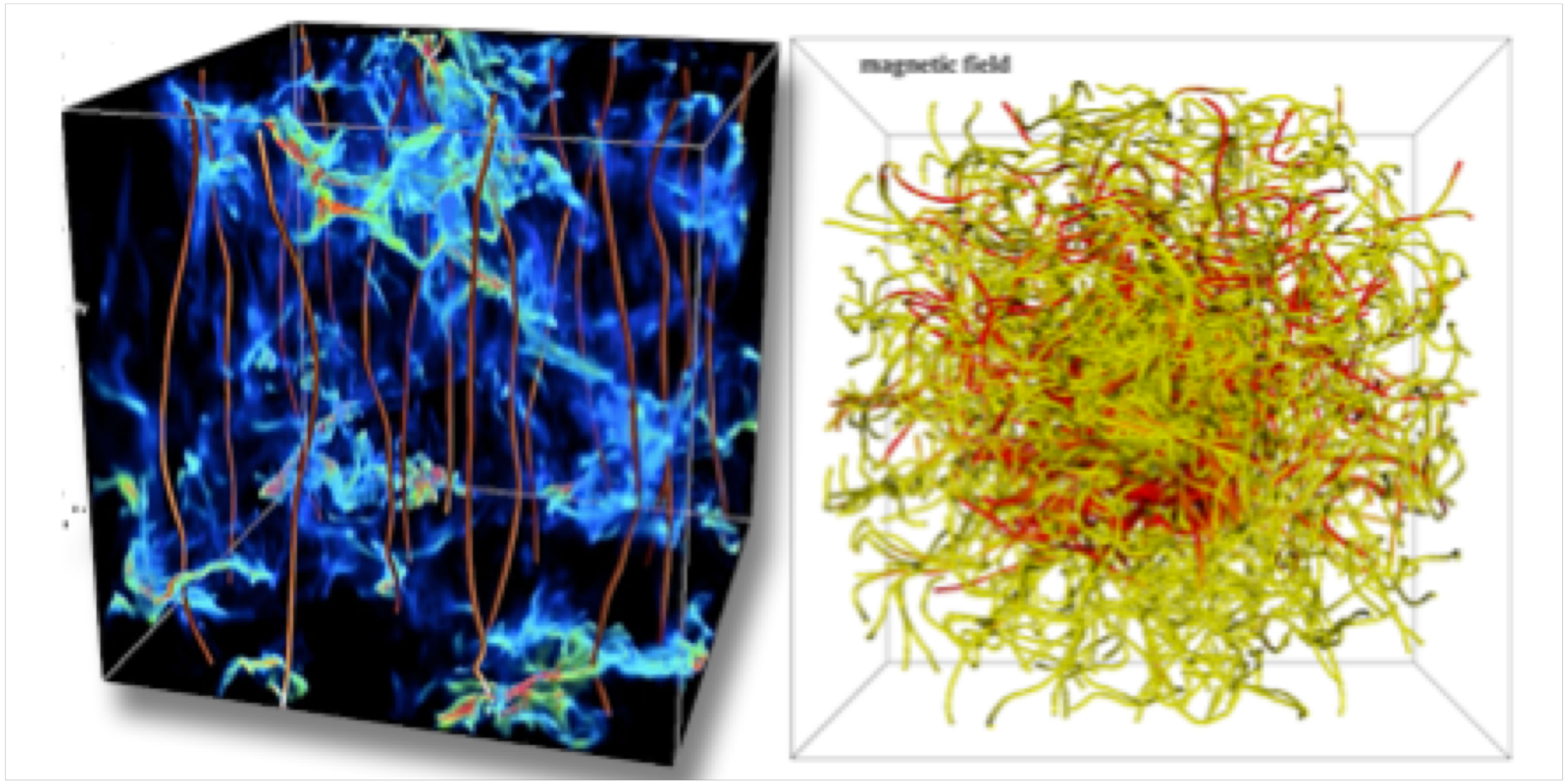
supersonic compression!

log-normal density PDF



sub-Alfvenic and super-Alfvenic turbulence simulations result in ordered and tangled B-field morphologies, respectively.

Turbulence vs. Magnetic field

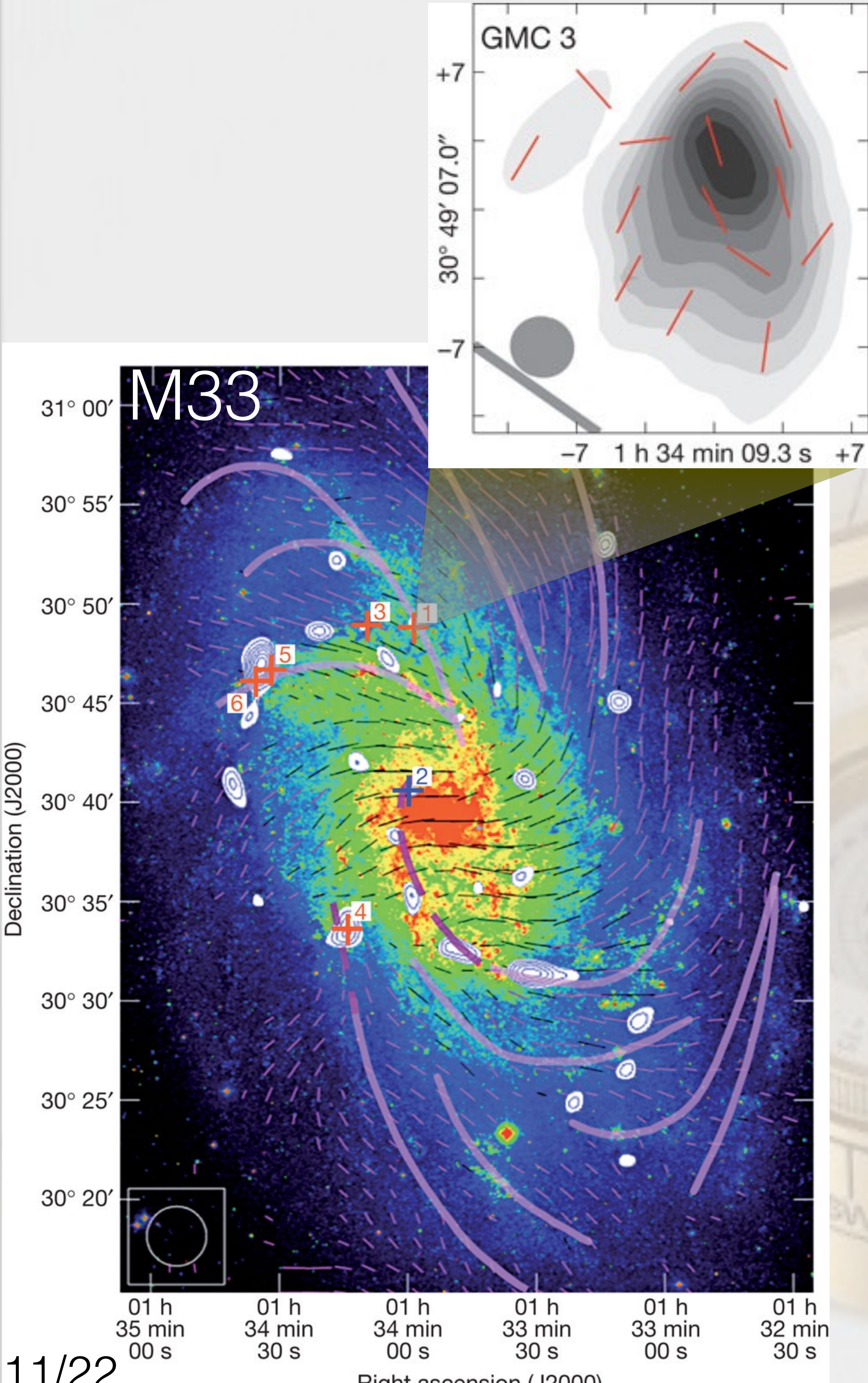


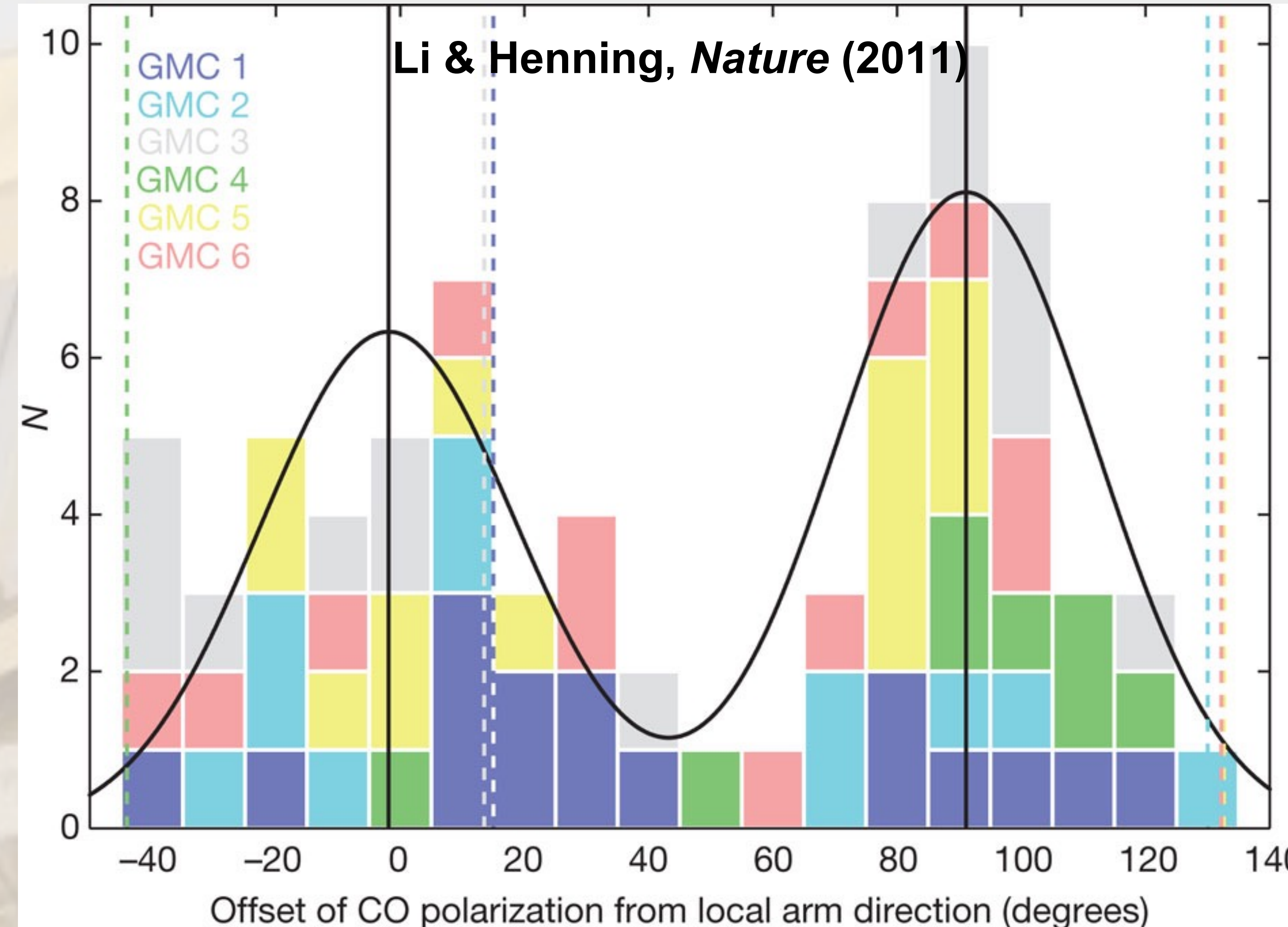
Otto, Ji & Li *ApJ* 2017

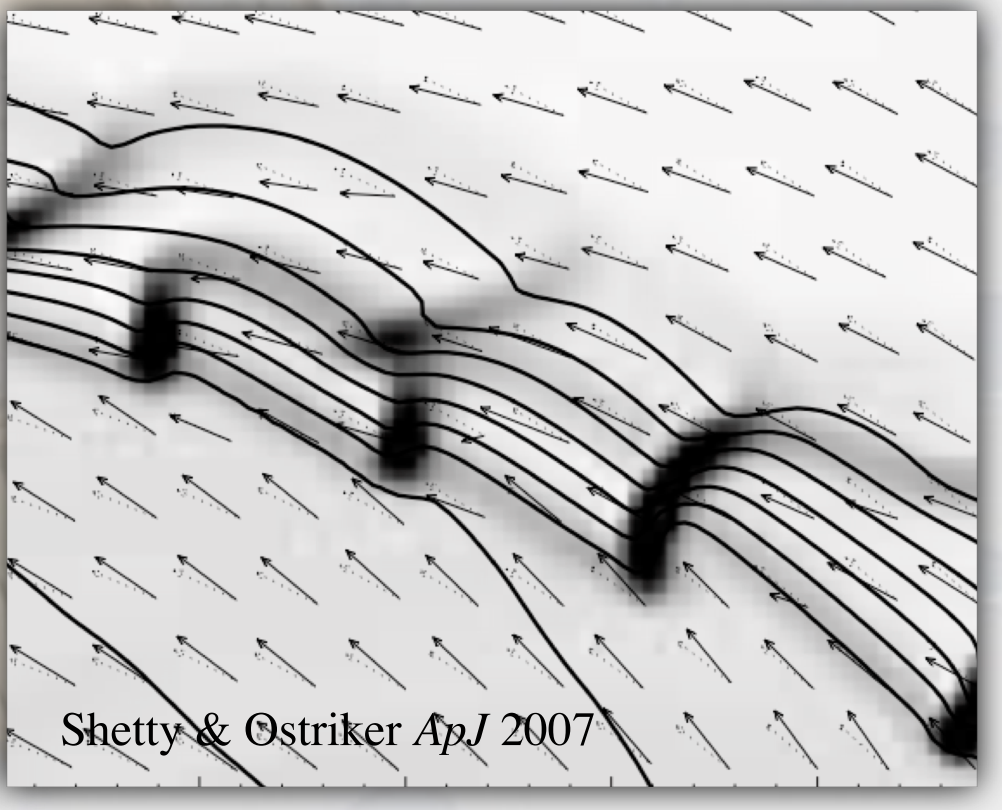
Federrath+ *ApJ* 2011

- Observation of M33 GMC B-fields favoured sub-Alfvenic turbulence

Turbulence vs. Magnetic field

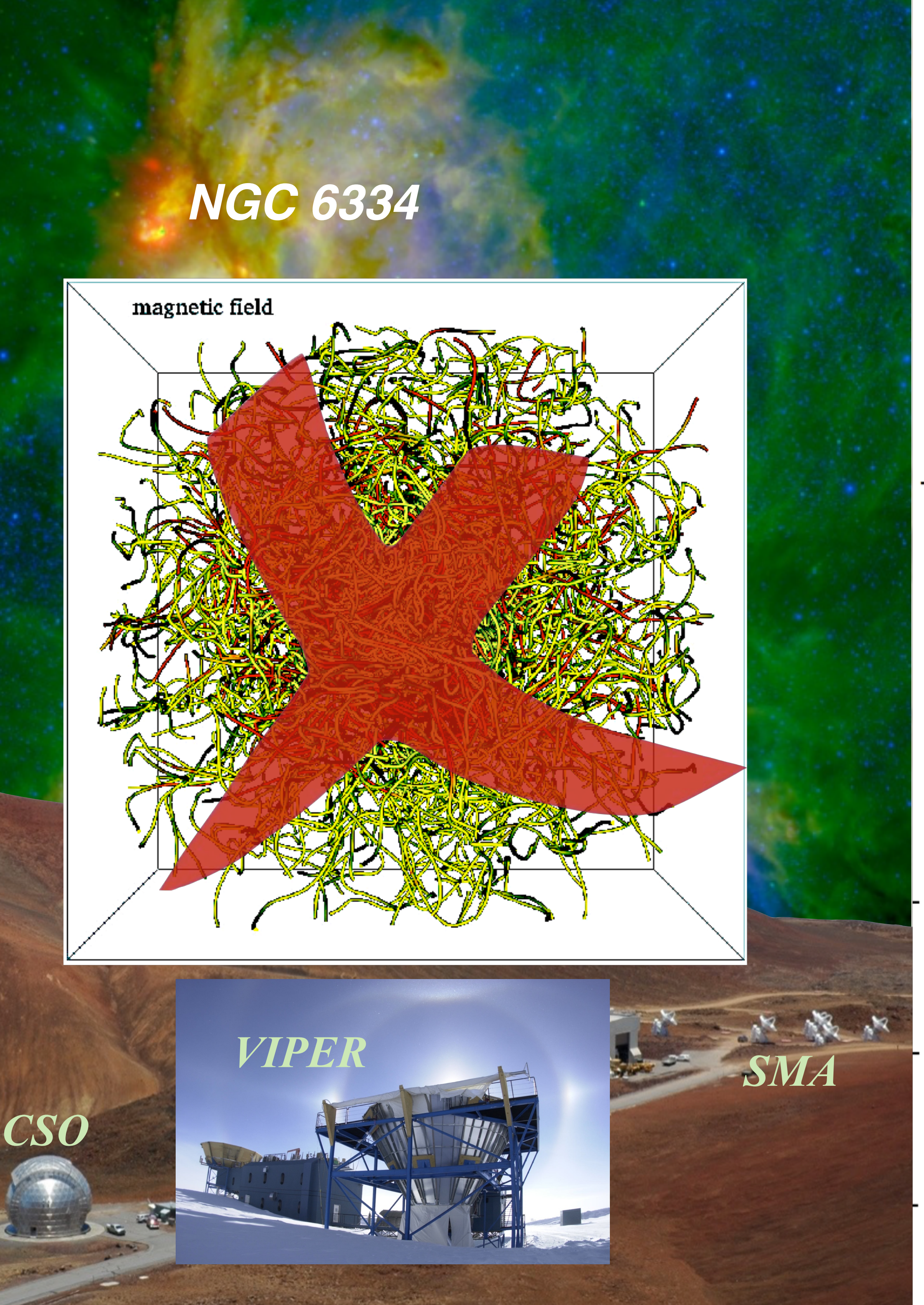


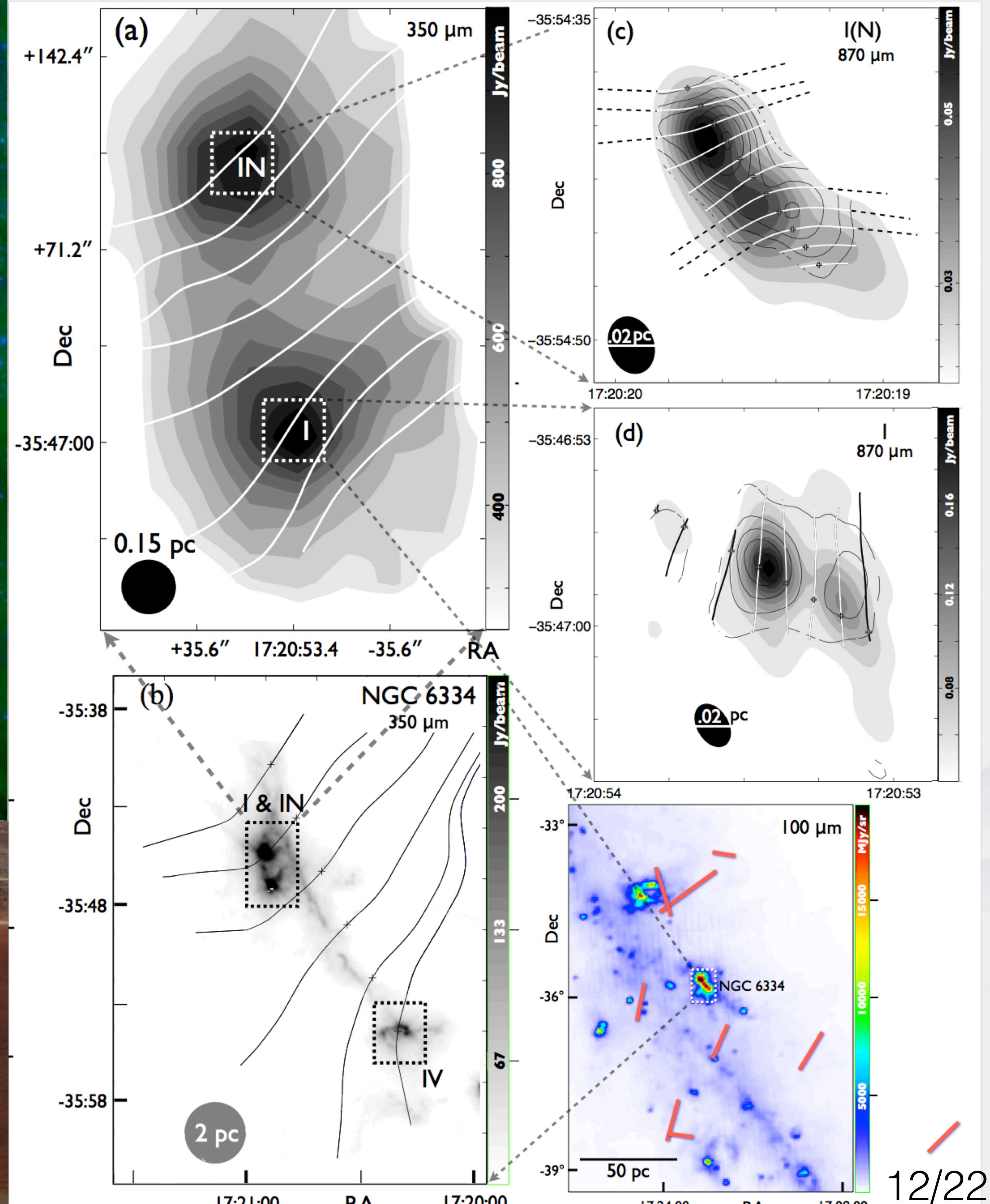




FIRST MULTISCALE STUDY of CLOUD MAGNETIC FIELDS from 10^2 to 10^{-2} pc

Turbulence vs. Magnetic field

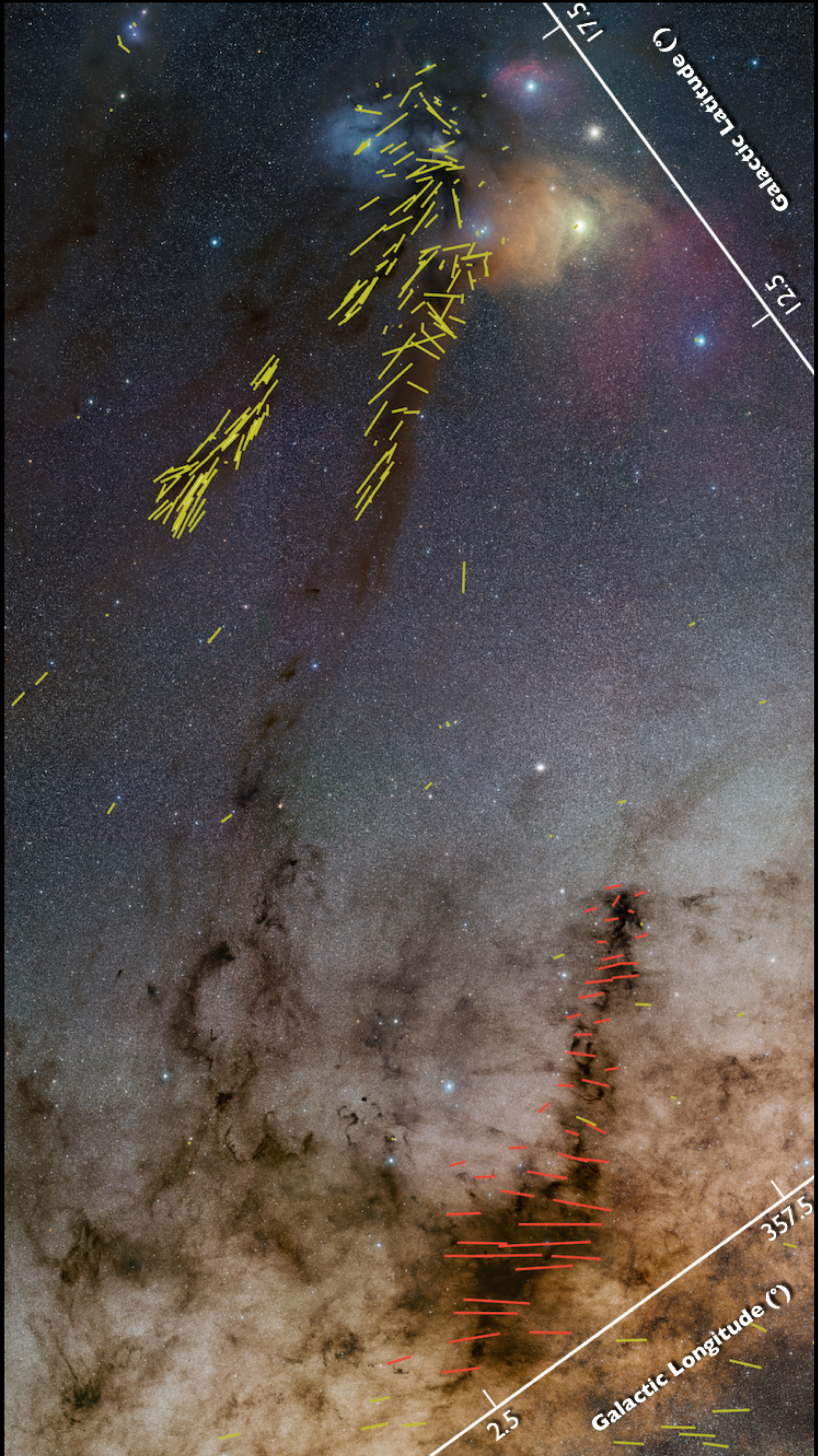




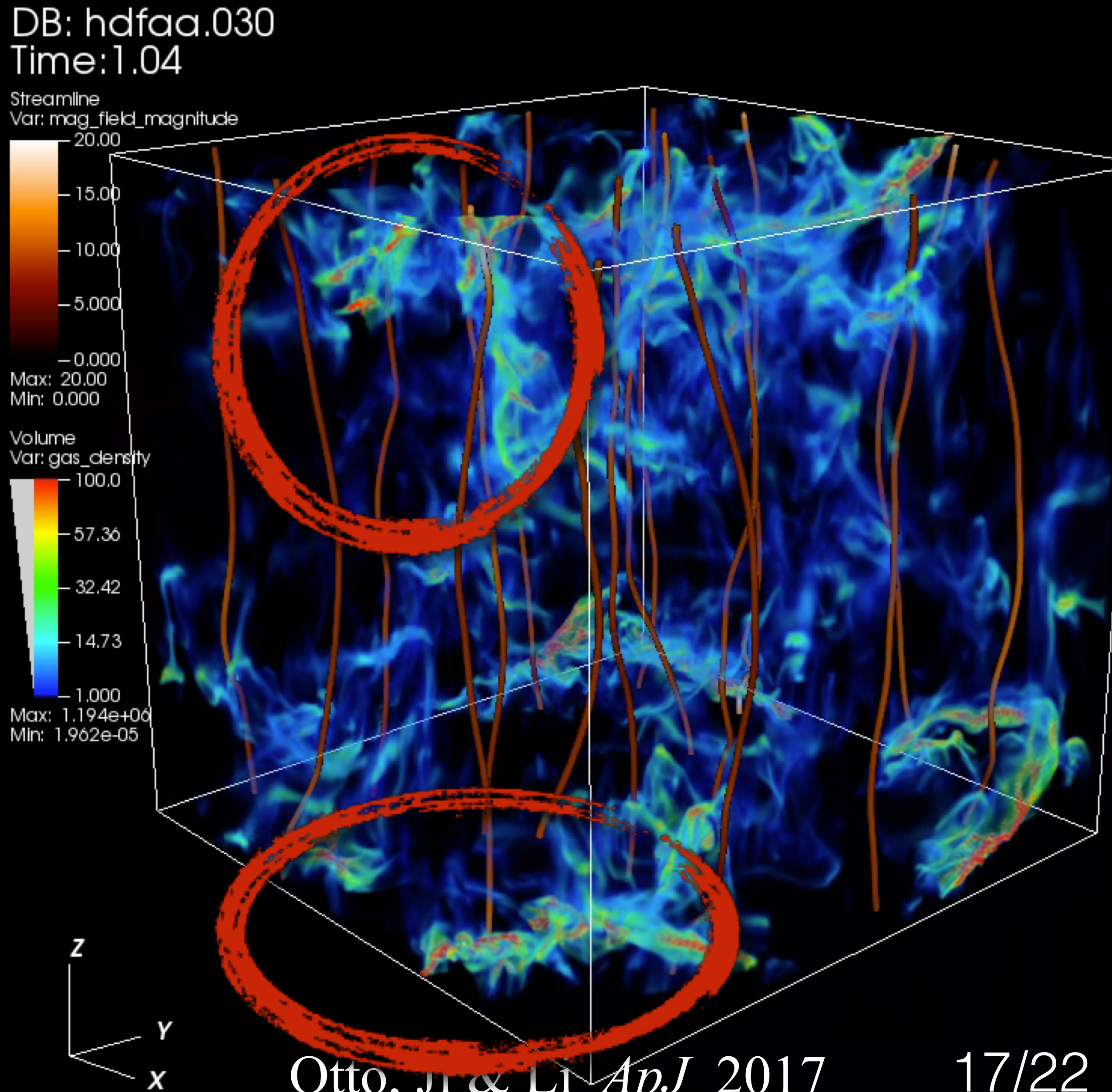
Li, Yuen, Otto, Leung+, ***Nature*** 2015

- Sub-alfvenic simulations with gravity result in bimodal (// or ⊥) field-cloud alignment

Gravity vs. Magnetic field



ordered B-field
+
sub-Alfvenic turbulence

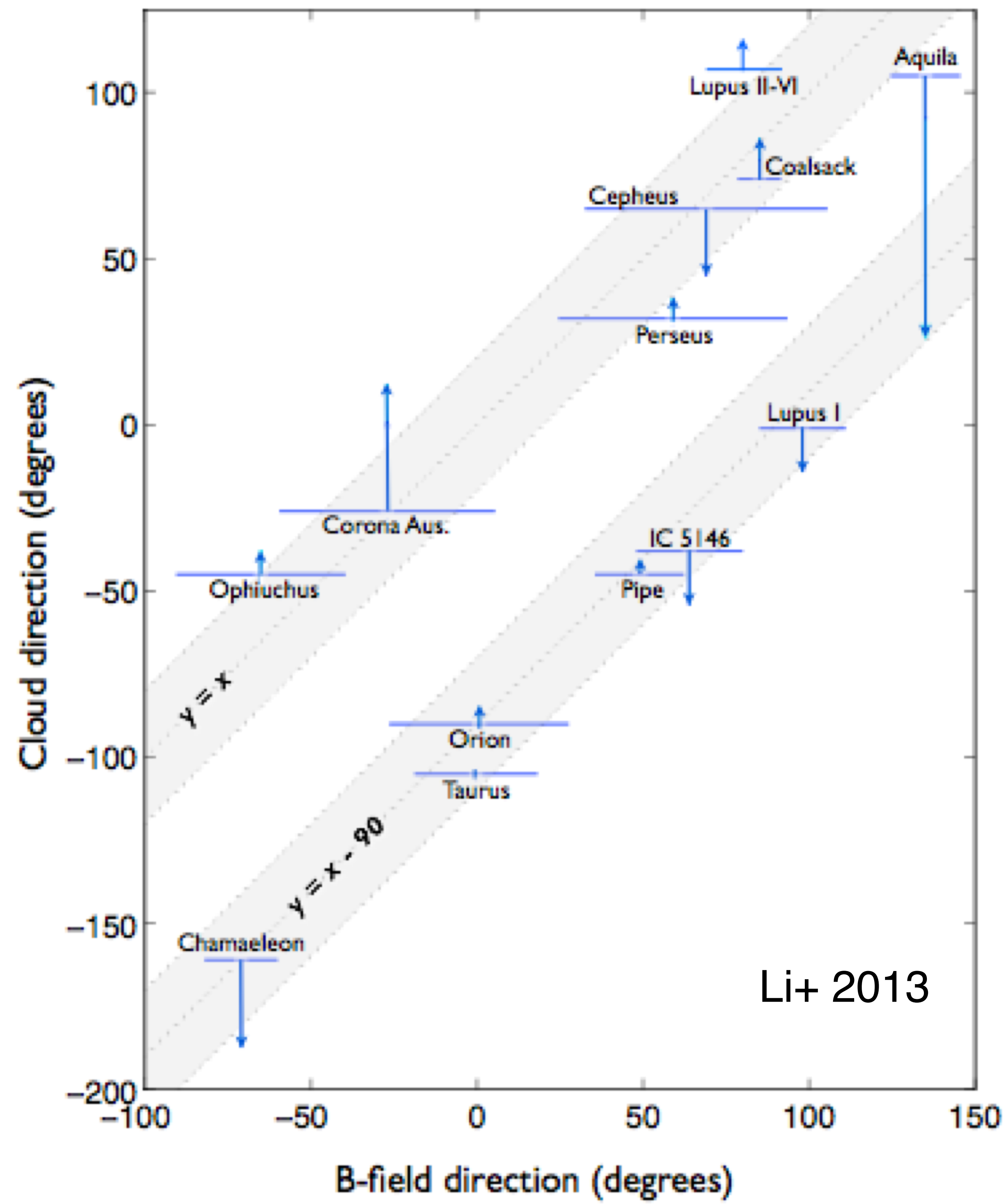


Otto, Ji & Li *ApJ* 2017

- Bimodal field-cloud alignment observed

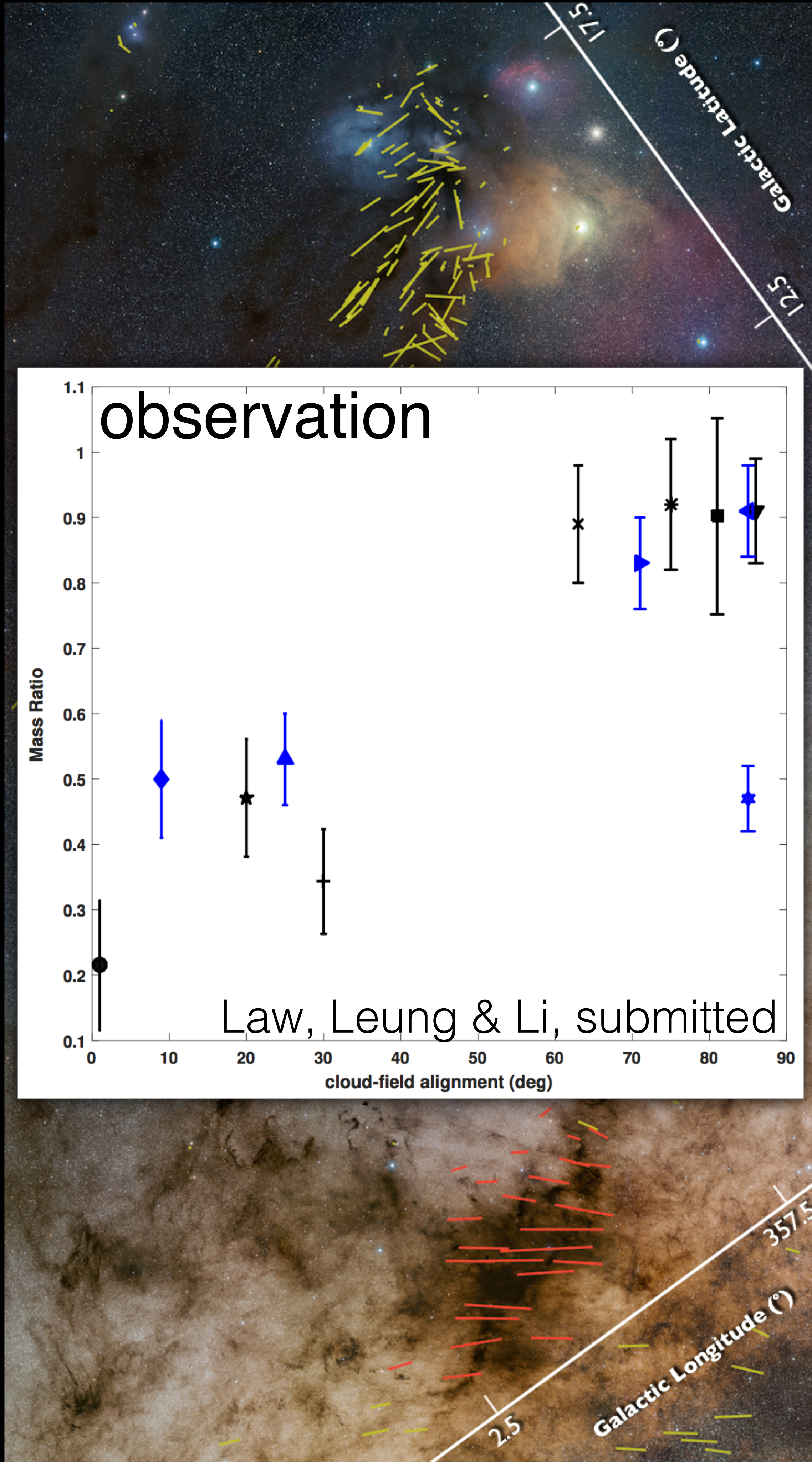
Gravity vs. Magnetic field

bimodal cloud-field alignment

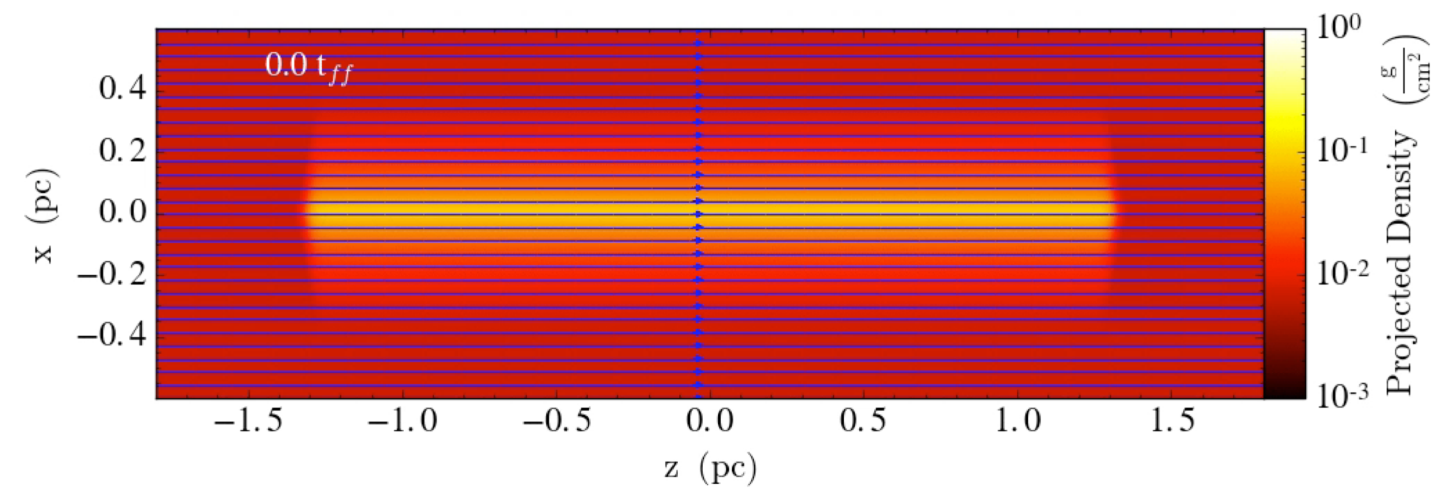


- Simulations and observations agree on that // alignment results in more concentrated, head-heavy filaments and ⊥ alignment results in filaments with more even mass distribution.

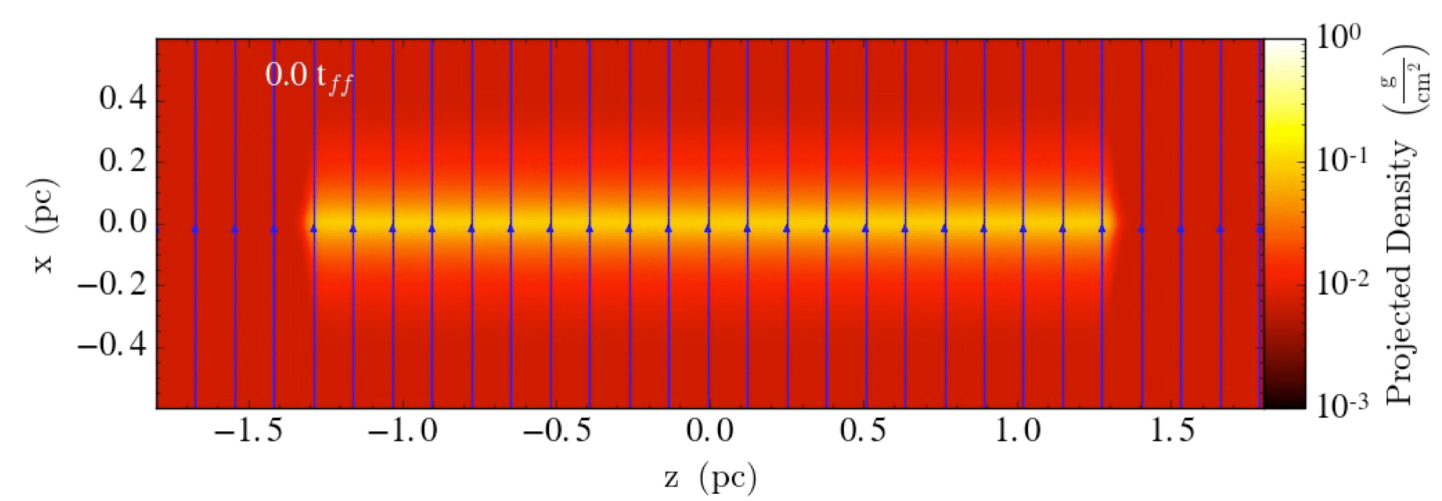
Gravity vs. Magnetic field



bimodal cloud-field alignment

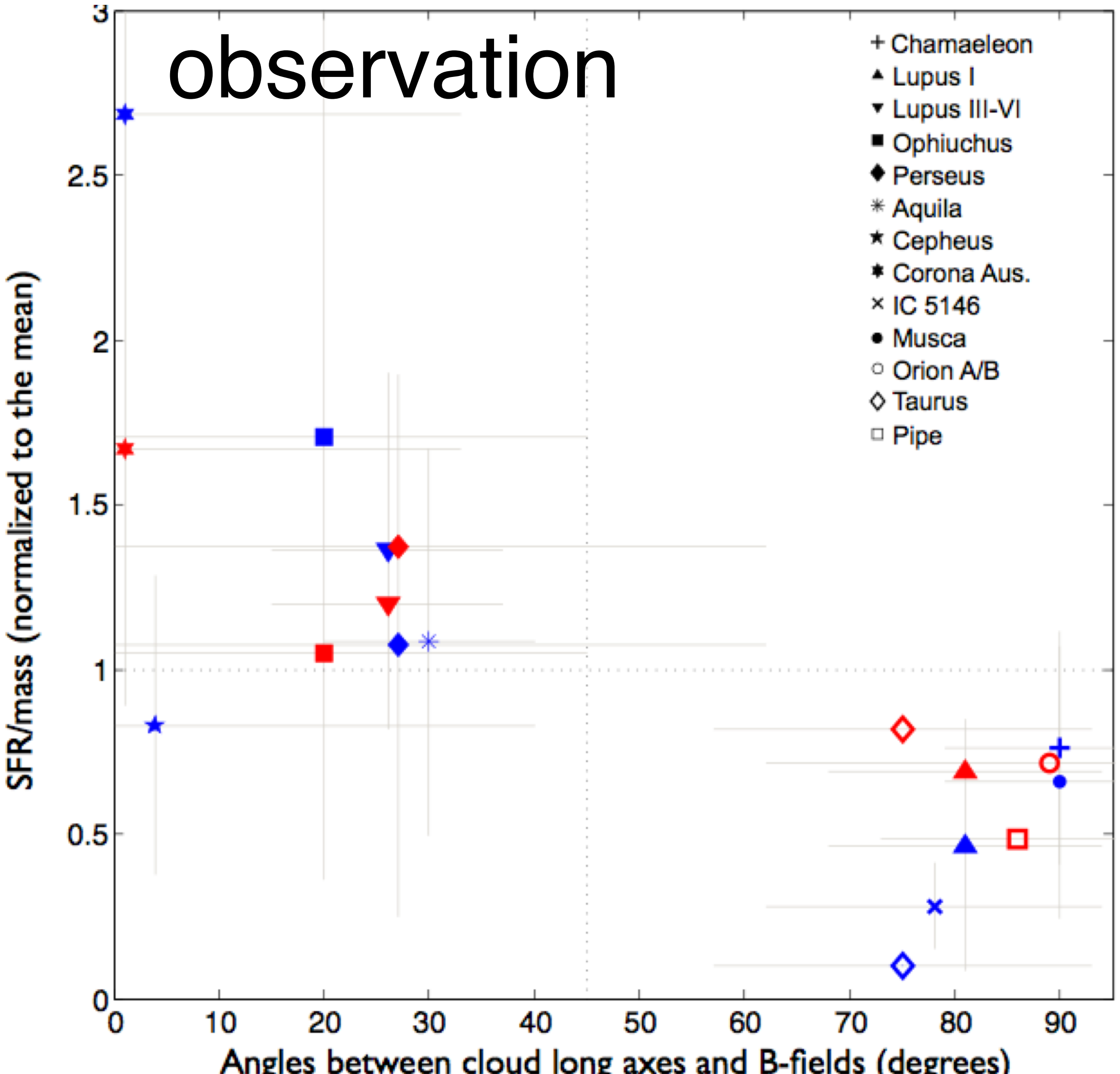


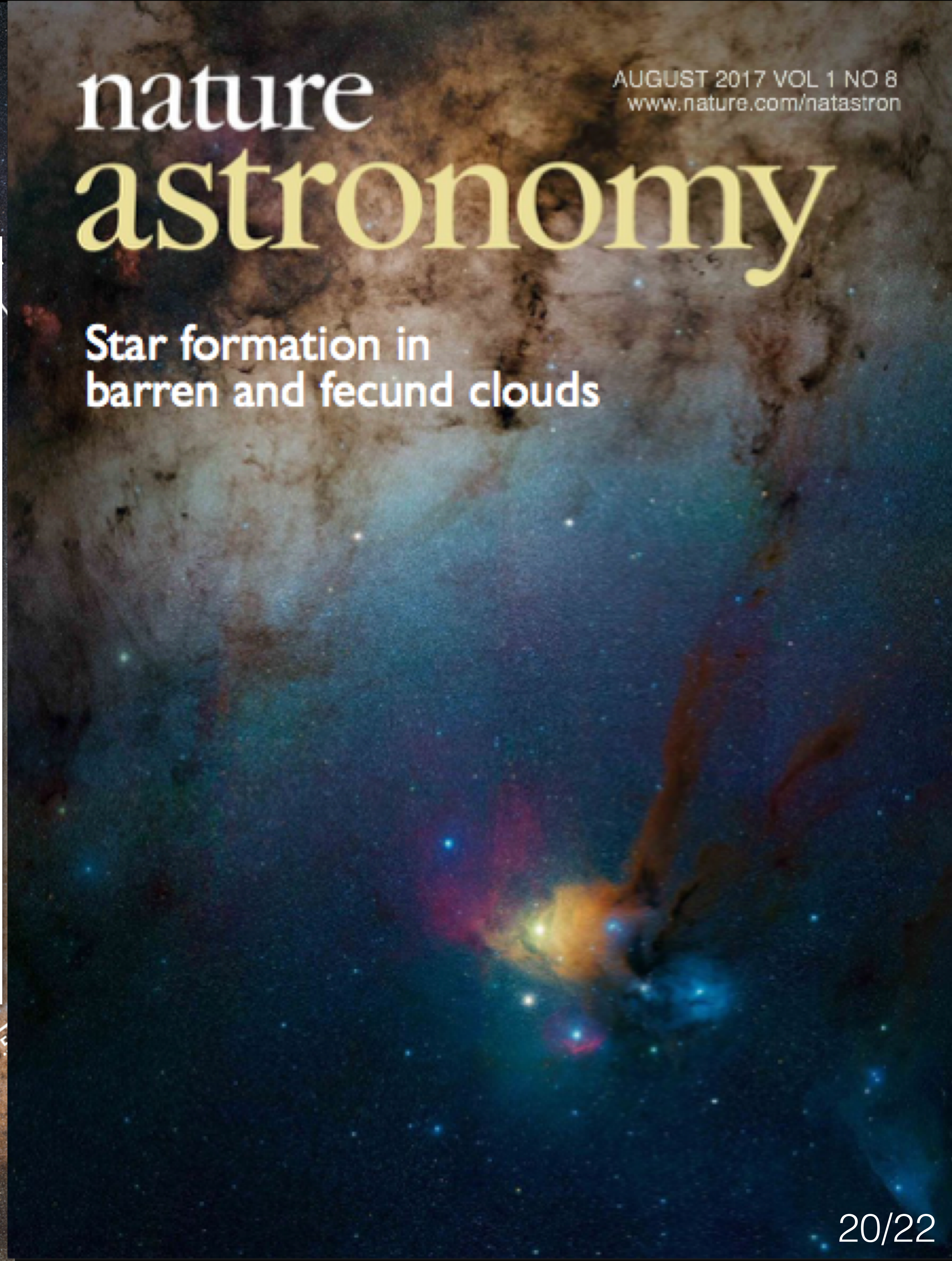
Guo, Wang & Li, submitted



- // alignment systematically shows higher star formation efficiency.

bimodal SF efficiency

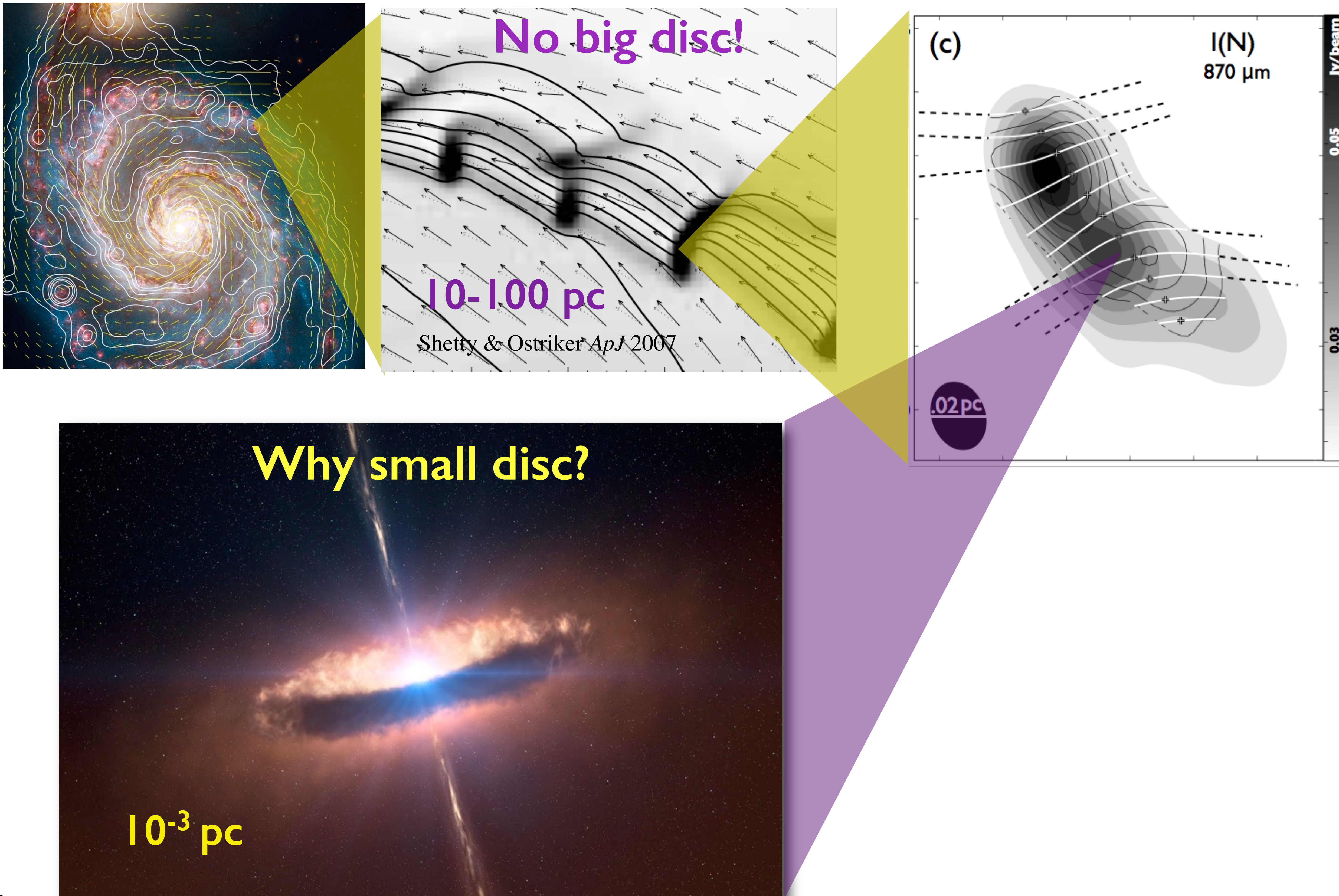




Li+ *Nature Ast.* 2017

The strong B-field scenario is considered to cause the "magnetic breaking catastrophe", i.e. if kinetic energy cannot tangle B-field at larger scale (from 100 to 0.01 pc, as we have shown), how can it be possible to form disks, which need to tangle B-fields < 0.001 pc scale! reminder: the smaller the scale the lower the kinetic (turbulent) energy

Problem: Disc formation — Magnetic braking catastrophe

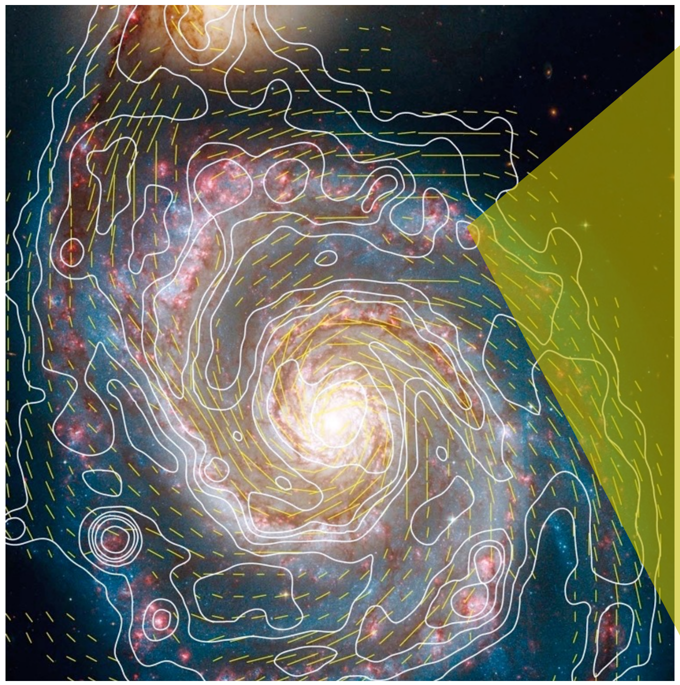


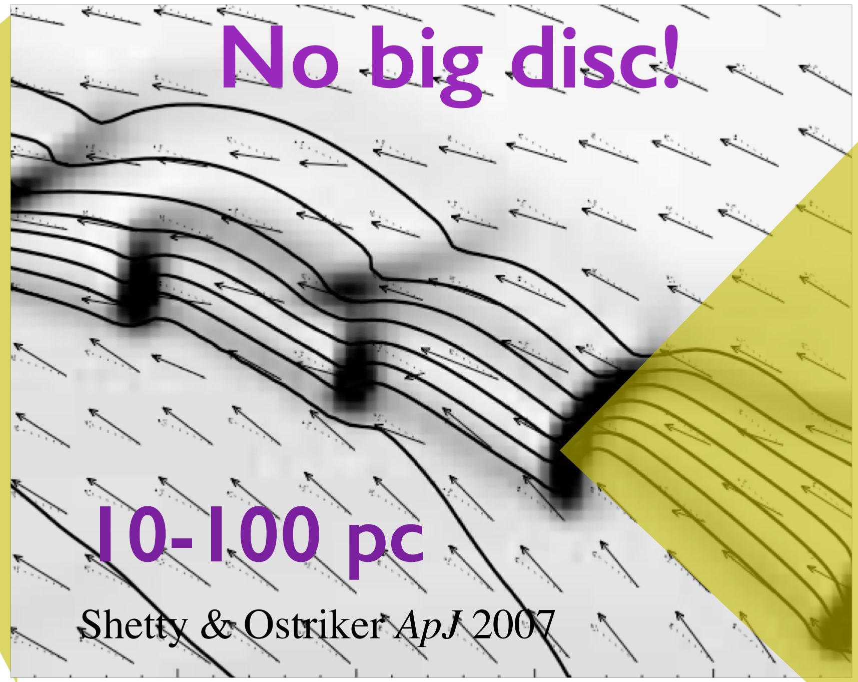
Tang, Li & Lee 2018

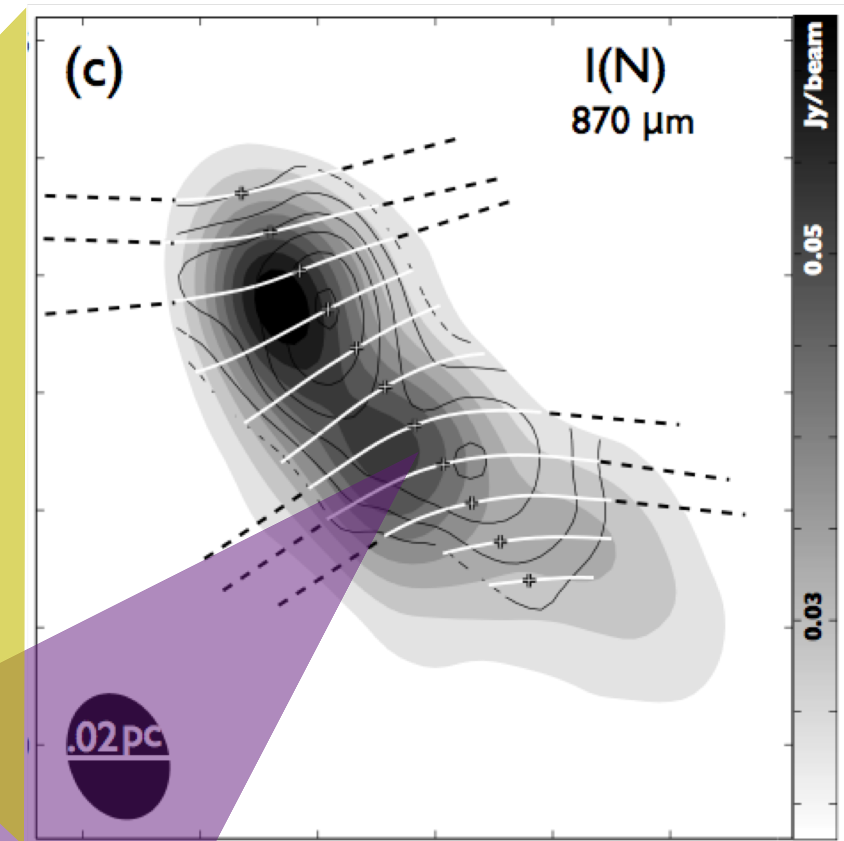
our proposed solution: turbulence induced ambipolar diffusion i.e., smaller eddies won’t be coupled with B-fields and thus won’t feel the “braking”.

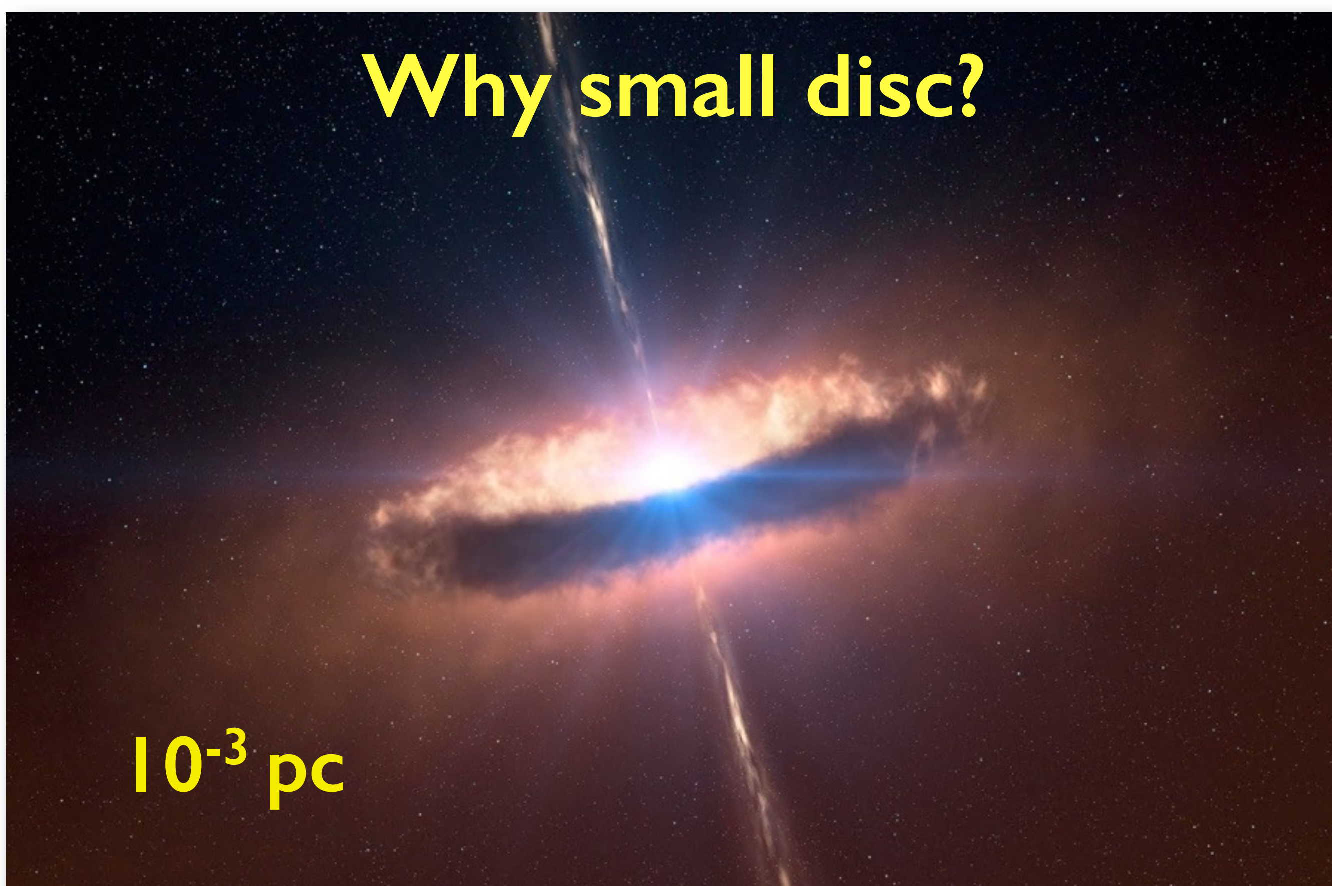
The decoupling of neutral turbulence and B-field is indeed observed recently (Tang, Li & Lee, ApJ, 2018), starting from < 0.5 pc!

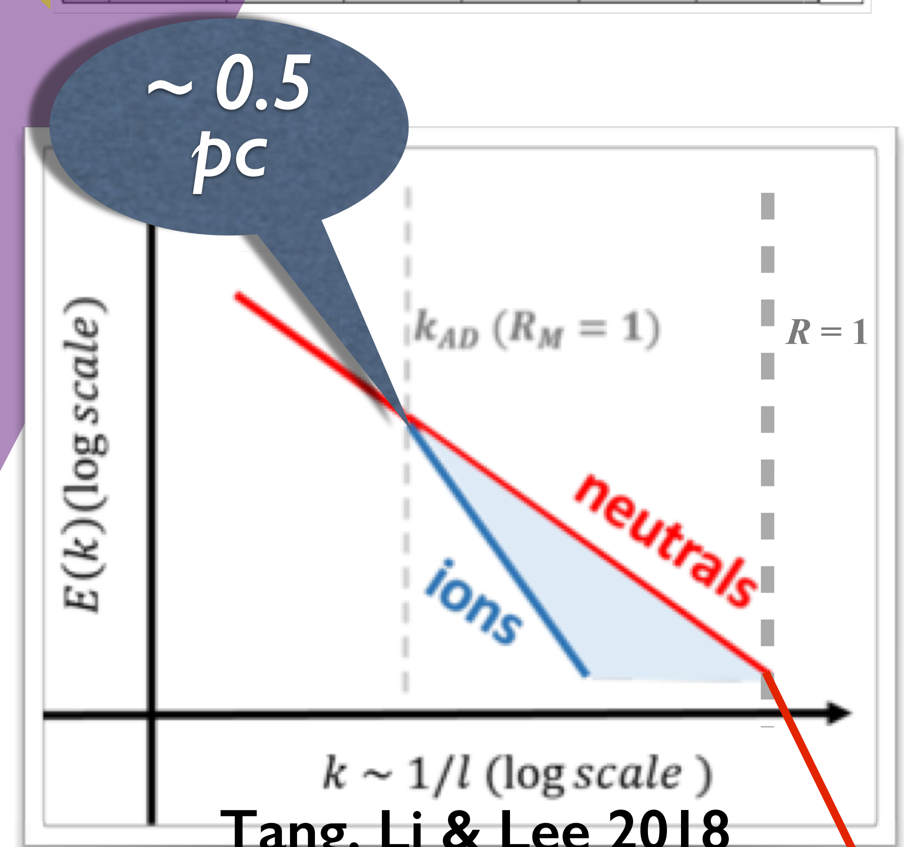
Problem: Disc formation — Magnetic braking catastrophe











So far, we **assumes flux-freezing** !!

Most of the cloud MHD simulations **assume flux-freezing** !!

But

$$\frac{\partial B}{\partial t} = \nabla\times(v\times B) + \eta\nabla^2 B$$ (induction equation)

$$R_M \equiv \frac{\nabla\times(v\times B)}{\eta\nabla^2 B} \sim VL/\eta$$

flux-freezing is true only when $R_M >> 1$

generalized Ohm's law: $E = -\mathbf{v}_i\times\mathbf{B} - \frac{\mathbf{J}\times\mathbf{B}}{n_e q_e} + \hat{\eta}\cdot\mathbf{J}$

$$= -\mathbf{v}_n\times\mathbf{B} - \frac{\mathbf{J}\times\mathbf{B}}{n_e q_e} + \hat{\eta}\cdot\mathbf{J} + B^2/(\rho_n \nu_{ni})\, J_\perp$$

Hall effect — Ohm diffusivity — magnetic diffusivity

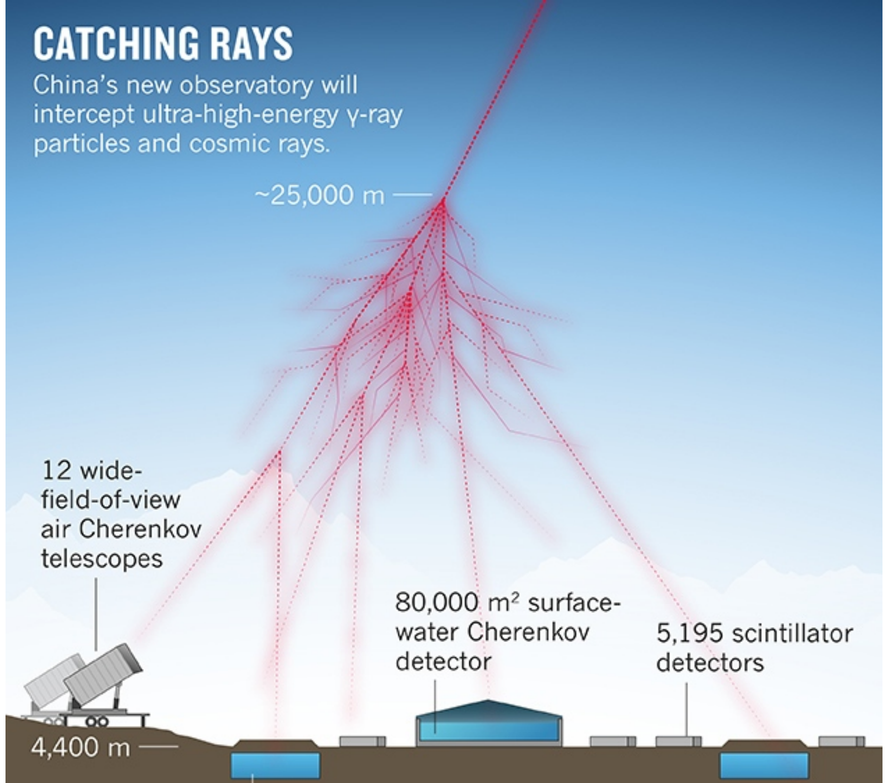
dominant in molecular clouds

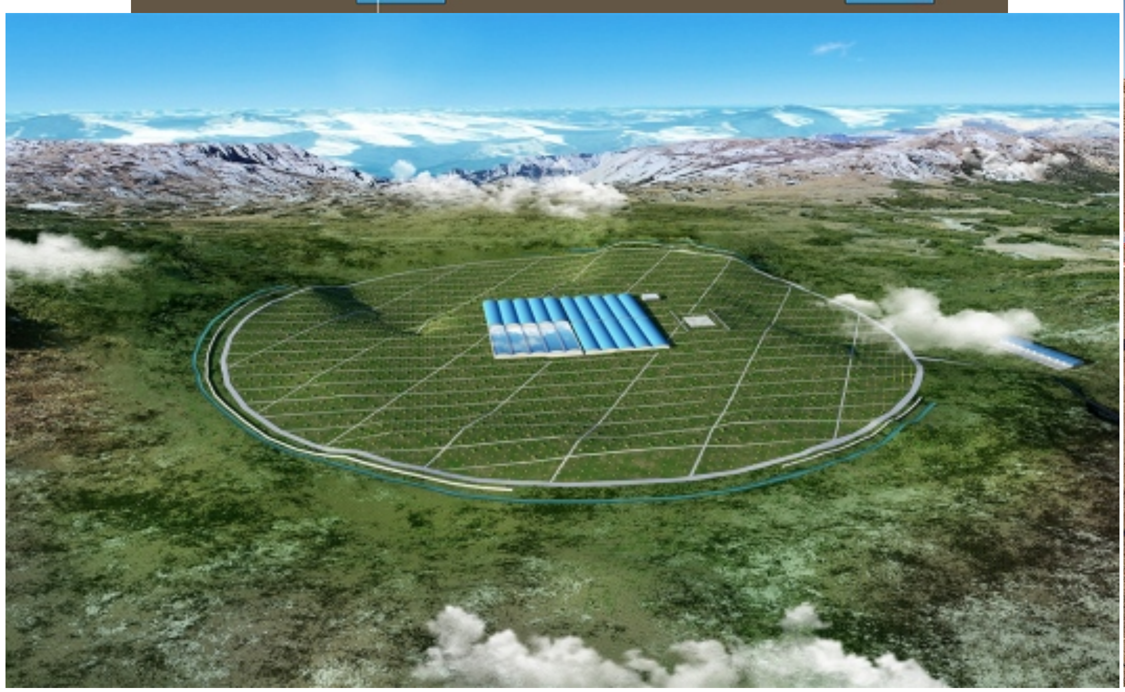
With typical cloud **turbulence**, B, density and ionisation fraction, Rm = 1 at scale ~ 0.5 pc! Below which, flux freezing fails — **turbulent** ambipolar diffusion

The observation seems to make sense: if we use the "effective magnetic diffusivity", instead of "ohmic diffusivity", the diffusion term in the induction equation is too large to be ignore.

However, in the state-of-the-art MHD simulations, the diffusion term is ignored and perfect flux freezing is assumed.
If the decoupling happens from 0.5 pc as we observed, these simulations need major improvement! And involving this diffusion term will tremendously increase the CPU time required to perform the simulation

This is one major reason for our Brics star-formation proposal.
From the observation side, the "0.5 pc" is only from one cloud, we need more tests.





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