Magnetic Field Angles in Collapsing Molecular Clouds

By Ezra S. Brooker

Synopsis

- What are molecular clouds?
- Why magnetic fields?
- What someone has done.
- What I’ve done.
- My answer…?
- Where to now?

What is a molecular cloud?

The basic characteristics

- Mass ~ 10^2-10^7 solar masses
- Radius ~ 10^1-10^2 parsecs
- Density ~ 10^4-10^6 particles/cm^3
- Temperature ~ 10-15 Kelvin
- Primarily H_2 and some plasma
    - Plasma → Magnetic Fields

Why care about magnetic fields?

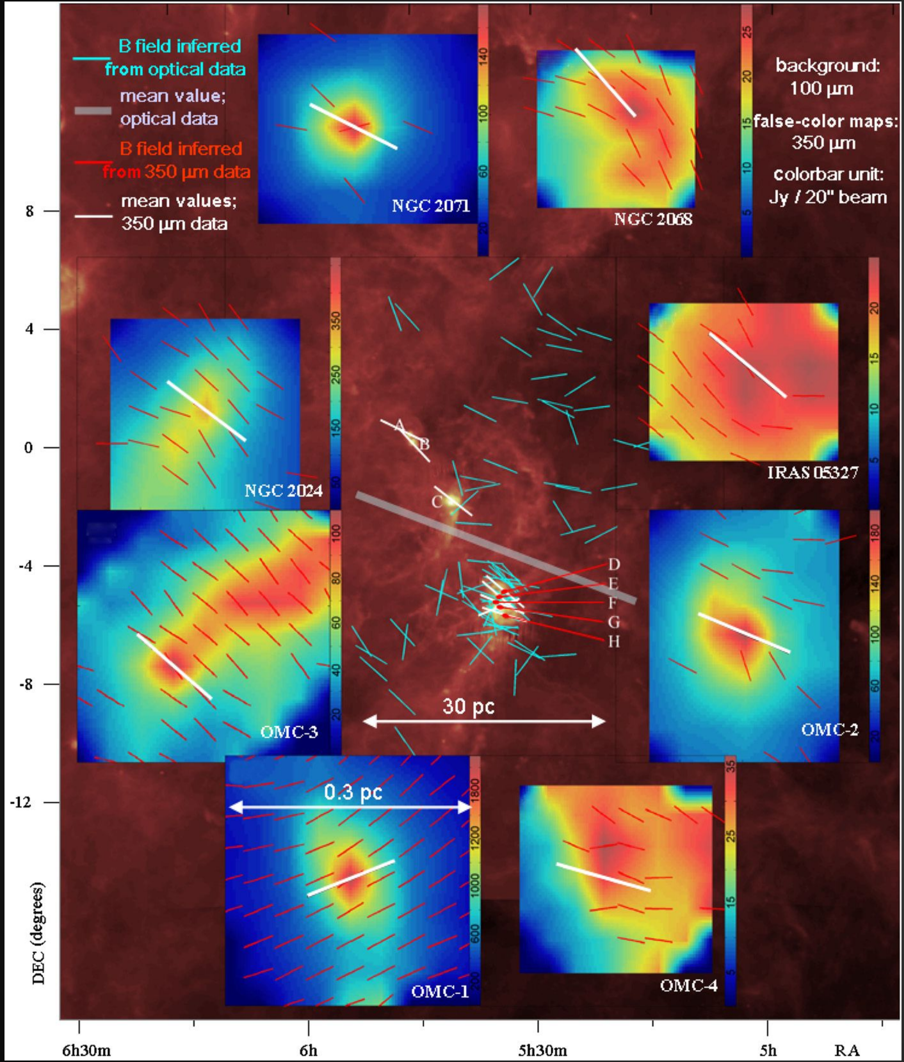
- Gravity pushes inward!
- Flux frozen **B** fields resist change, creating outward pressure. Important to cloud collapse calculations (Virial Theorem).
- Magnetic pressure, gas pressure, and kinetic pressure are main opponents of gravitational collapse. $\mathbf{P}_{kinetic}$ possibly dominant, though.

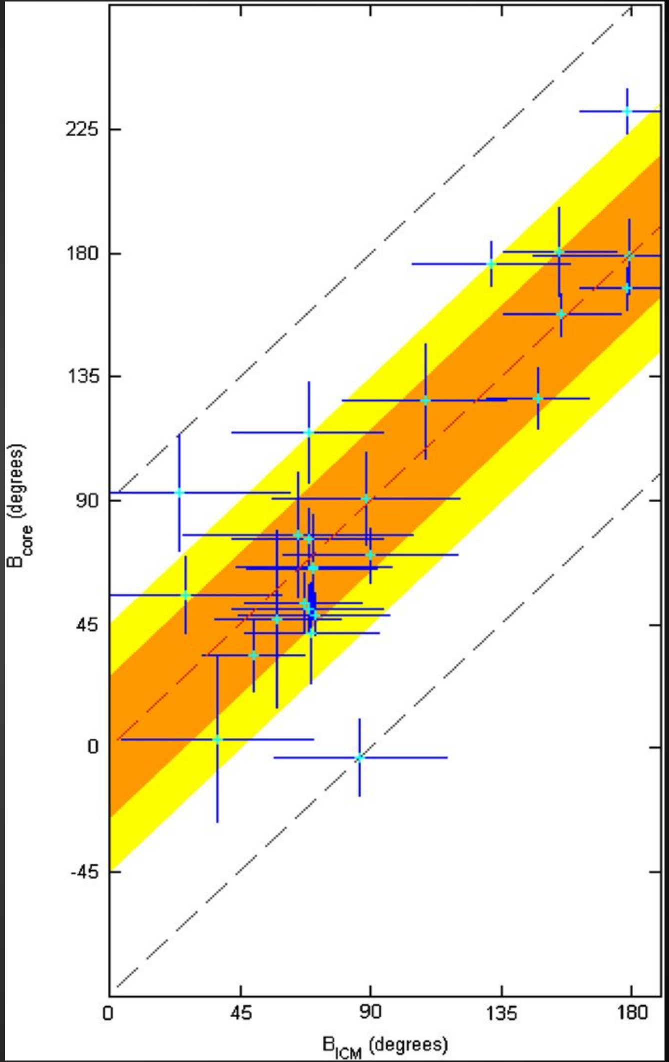
Magnetic fields and polarization

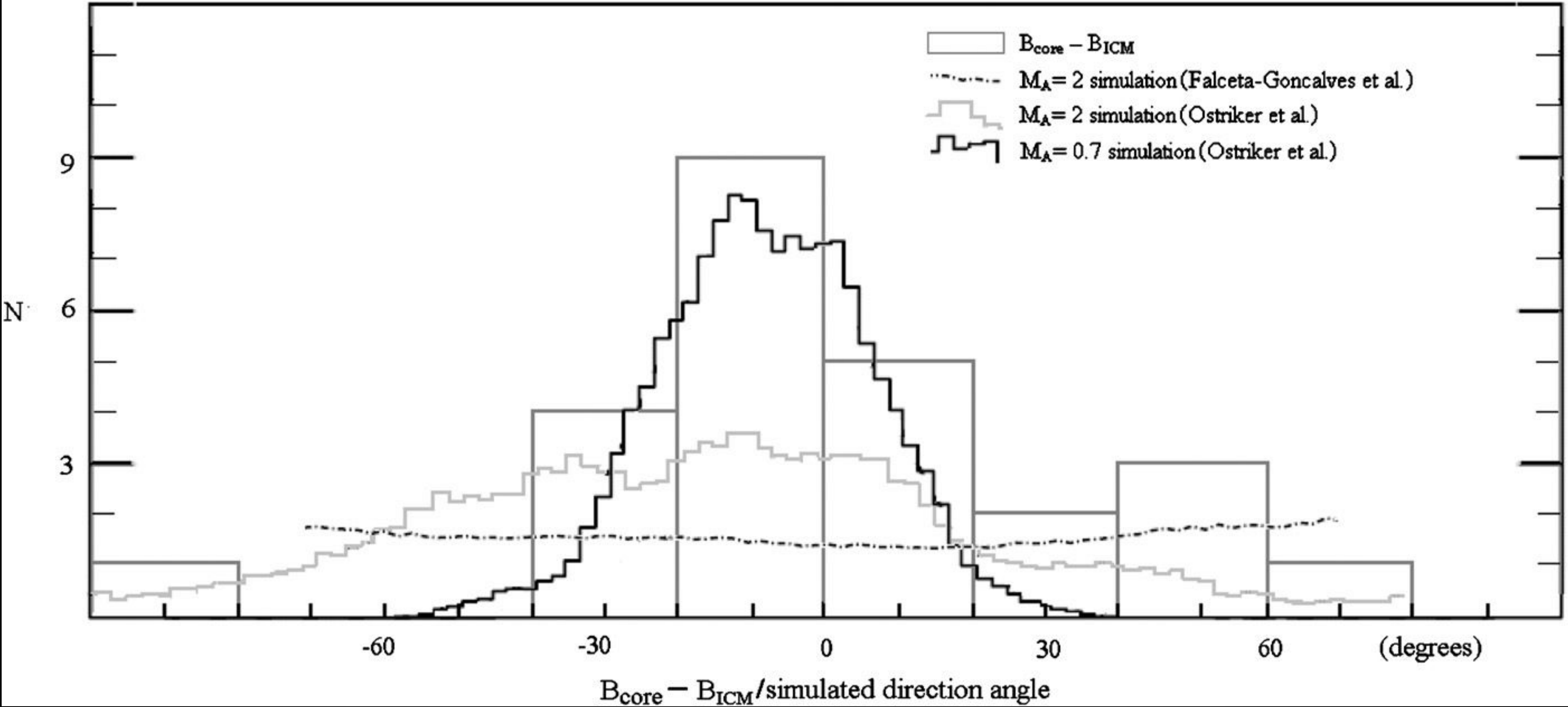
- We can’t directly measure **B** in clouds
- But MCs are very dusty and dust grains like aligning with $\mathbf{B}_{\text{cloud}}$ when they can.
- Background light is polarized by dust as well as the emission from the dust (infrared).
- We can observe this polarization and trace the magnetic field lines (usually).

What others have done (Li et al.)

- Optical and infrared polarimetry survey of Orion Molecular Cloud (OMC), ~30 pc wide.
- 8 dense cores, ~0.3 pc across.
- Traced the magnetic fields of the entire OMC and its mean field direction with optical data. Did the same for each core using infrared.


B field inferred from optical data
mean value; optical data
B field inferred from 350 µm data
mean values; 350 µm data
background: 100 µm
false-color maps: 350 µm
colorbar unit: Jy / 20" beam
NGC 2071
NGC 2068
NGC 2024
IRAS 05327
OMC-3
OMC-2
OMC-1
OMC-4
30 pc
0.3 pc
A
B
C
D
E
F
G
H
DEC (degrees)
RA
6h30m
6h
5h30m
5h


B_{core} (degrees)
B_{ICM} (degrees)



$B_{core} - B_{ICM}$
$M_A = 2$ simulation (Falceta-Goncalves et al.)
$M_A = 2$ simulation (Ostriker et al.)
$M_A = 0.7$ simulation (Ostriker et al.)
N
9
6
3
-60
-30
0
30
60
(degrees)
$B_{core} - B_{ICM}$/simulated direction angle

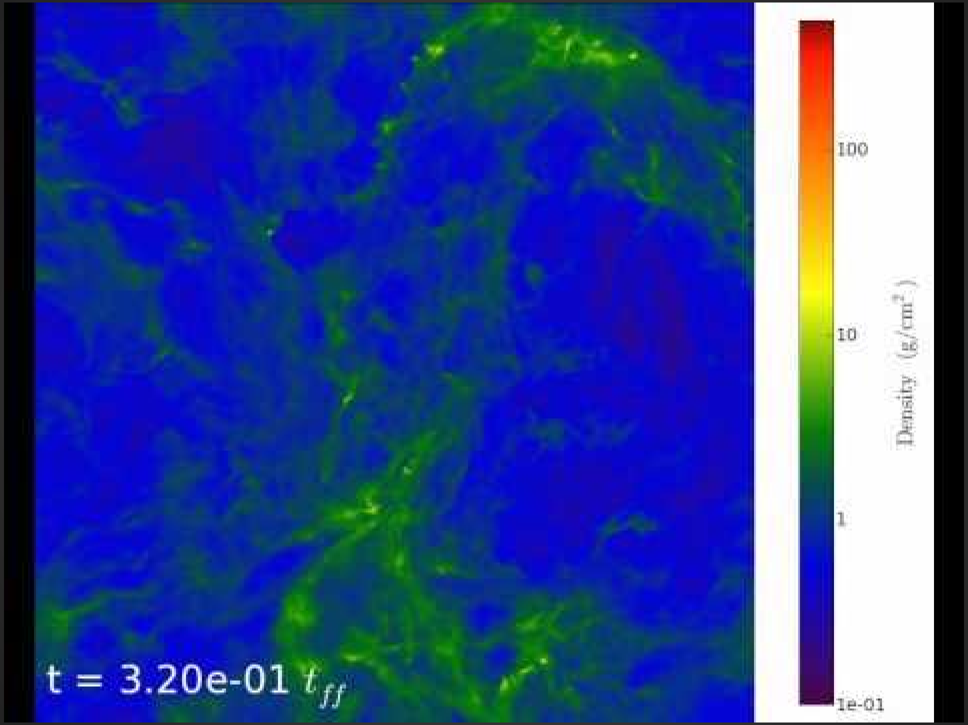
The significance of Li et al.

Made comparisons to Ostriker and Falçeta-Goncalves simulations. Ostriker’s strong-field simulation had similar corresponding field orientations for cores. Conclusion was drawn that weak-fields might not be prominent in MCs. BUT, simulations were not self-gravitating nor did they consider line-of-sight projections and de-polarization due to high densities (more on that later).

The simulations I used

- Simulation data courtesy of Dr. David Collins
- $(512\text{pixel})^3$ data cubes with 4 levels of AMR.
- Self-gravitating, magnetized, turbulent!
- Equivalent to $(\sim 5\text{pc})^3$ region.
- Three sets: β = 0.2, 2.0, 20.0 (weak fields)
- Evolution from 0.0-0.5 t_{ff}.

Evolution of the simulated collapsing molecular cloud for the run β = 0.2

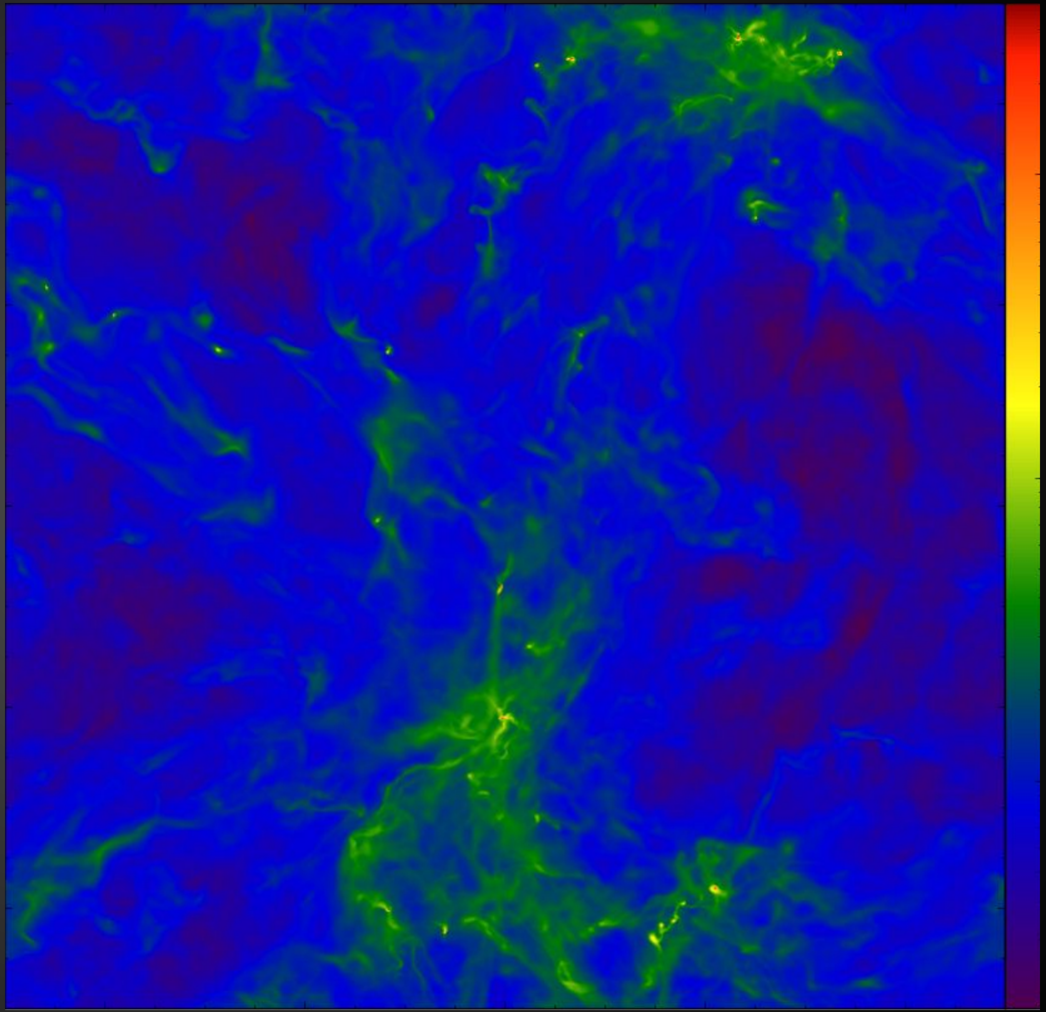


Stokes Parameters

- $Q_{ij} \propto \sum_k \varepsilon_{ijk}\, n_{ijk}\, (B_{ijk}^{i} B_{ijk}^{i} - B_{ijk}^{j} B_{ijk}^{j})$
- $U_{ij} \propto 2\sum_k \varepsilon_{ijk}\, n_{ijk}\, B_{ijk}^{i} B_{ijk}^{j}$
- $\theta_B = (½)\tan^{-1}(U/Q)$, polarization angle.
- $\varepsilon_{ijk} = (n_{ijk}/n_0)^p$ for $n_{ijk} \geq n_0$, = 1 otherwise.
  - Depolarization due to high densities.
    - Grain alignment issues: Collisions between grains, aspect ratio changes from grain growth, etc.
    - Randomly oriented magnetic fields also contribute.

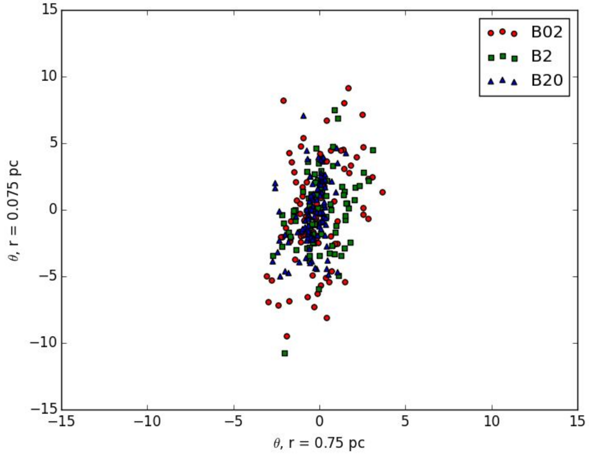
$\beta = 0.2$
$t = 0.5t_{ff}$
x-axis

Project data along the line of sight and make a dendrogram (hierarchical ID structure). Locate prestellar cores with data cube pixel coordinates stored in dendrogram.

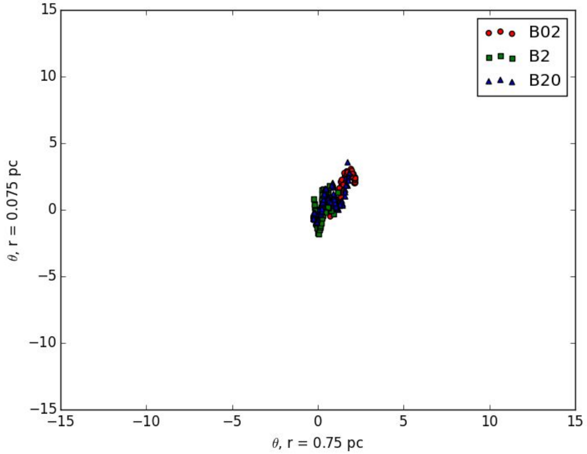


B_{core} versus B_{cloud}

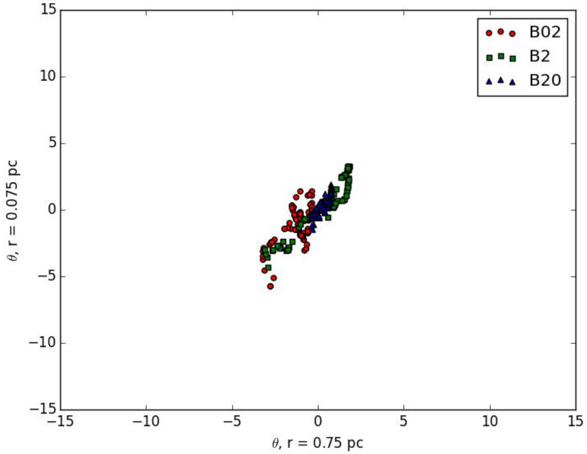
- Isolate each core within circular radii. R=0.75pc, 0.075pc were chosen.
- Calculate Stokes Parameters' and polarization angle (θ_B) for each radius. Compare θ_B for each set of radii (B_{core} vs B_{ICM} analogy).



x-axis



y-axis



z-axis

Which of these is the most interesting plot?

Dendrograms: It’s a tree

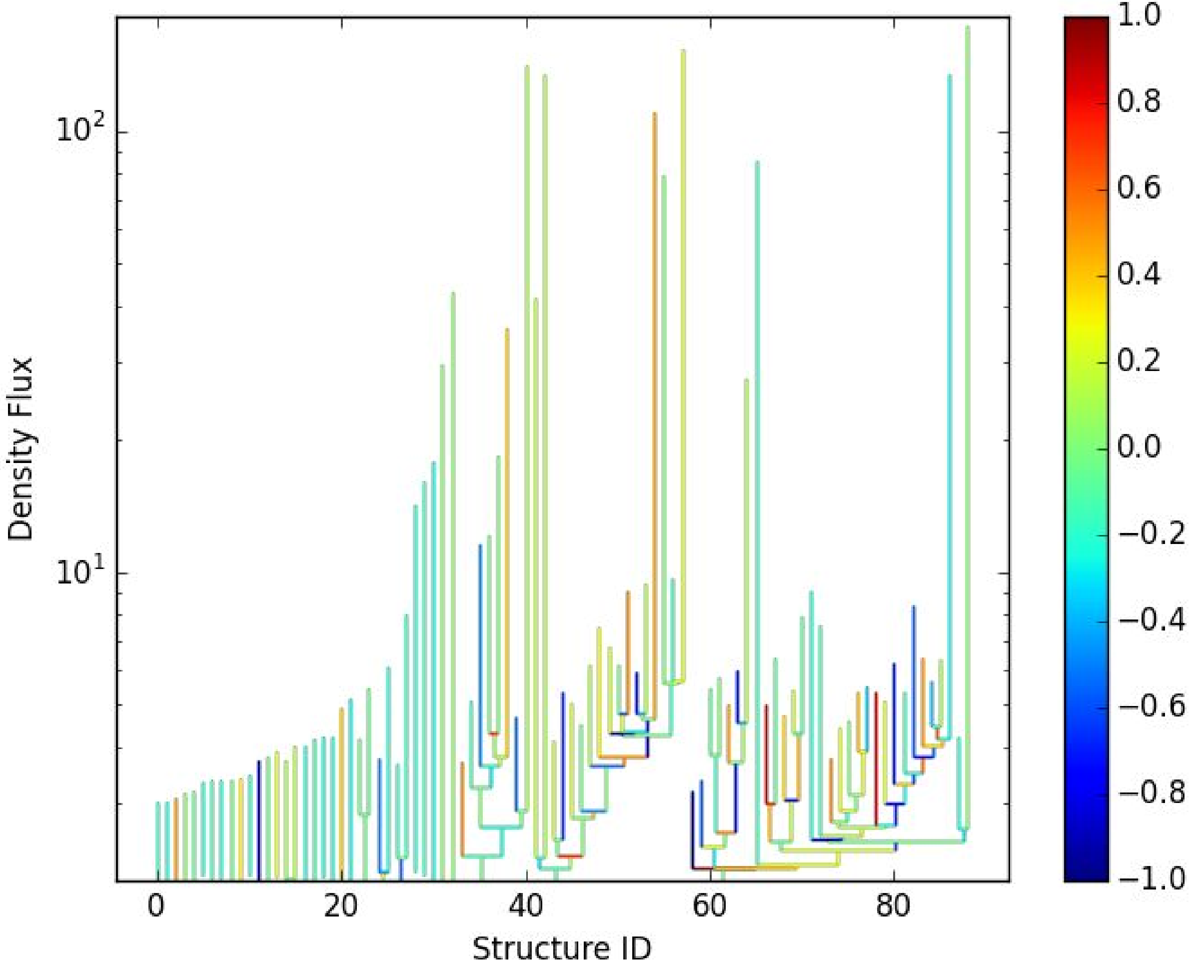
- Let’s go back to dendrograms. They’re essentially tree structures.
- Dendrogram function was given density flux measure criterion and located structures and their substructures (containing prestellar cores), marking the coord. of flux peak in each structure.
- Wanted to overlay θ_B measurements as a colormap on the plot of the dendrogram tree structure.

$\beta = 0.2$

$t = 0.5t_{ff}$

x-axis

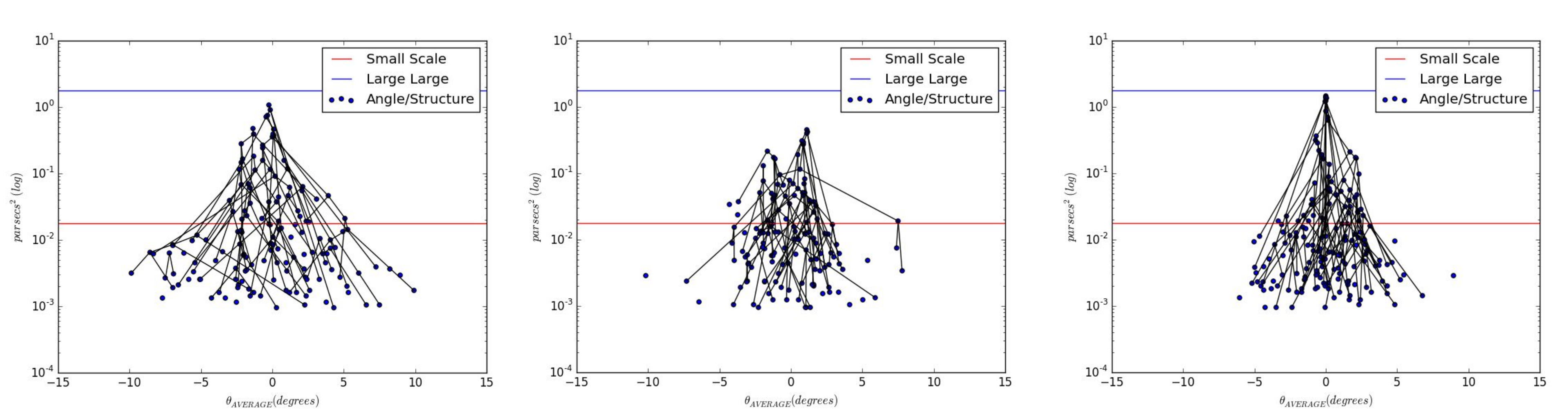
What does this mean?



Angles versus Size Scales

- New plan. Look at all the structures and θ_B for each. Plot from parent to final level of children structures.
- Plot the area of each structure versus θ_B for each structure.
- Should be able see how field direction evolves as a function of area around the prestellar cores.

$t = 0.5t_{ff}$



$\beta = 0.2$ $\beta = 2.0$ $\beta = 20.0$

We see that B_{core} becomes uncorrelated from B_{cloud} as we look further away from the cores.

Tentative Conclusions

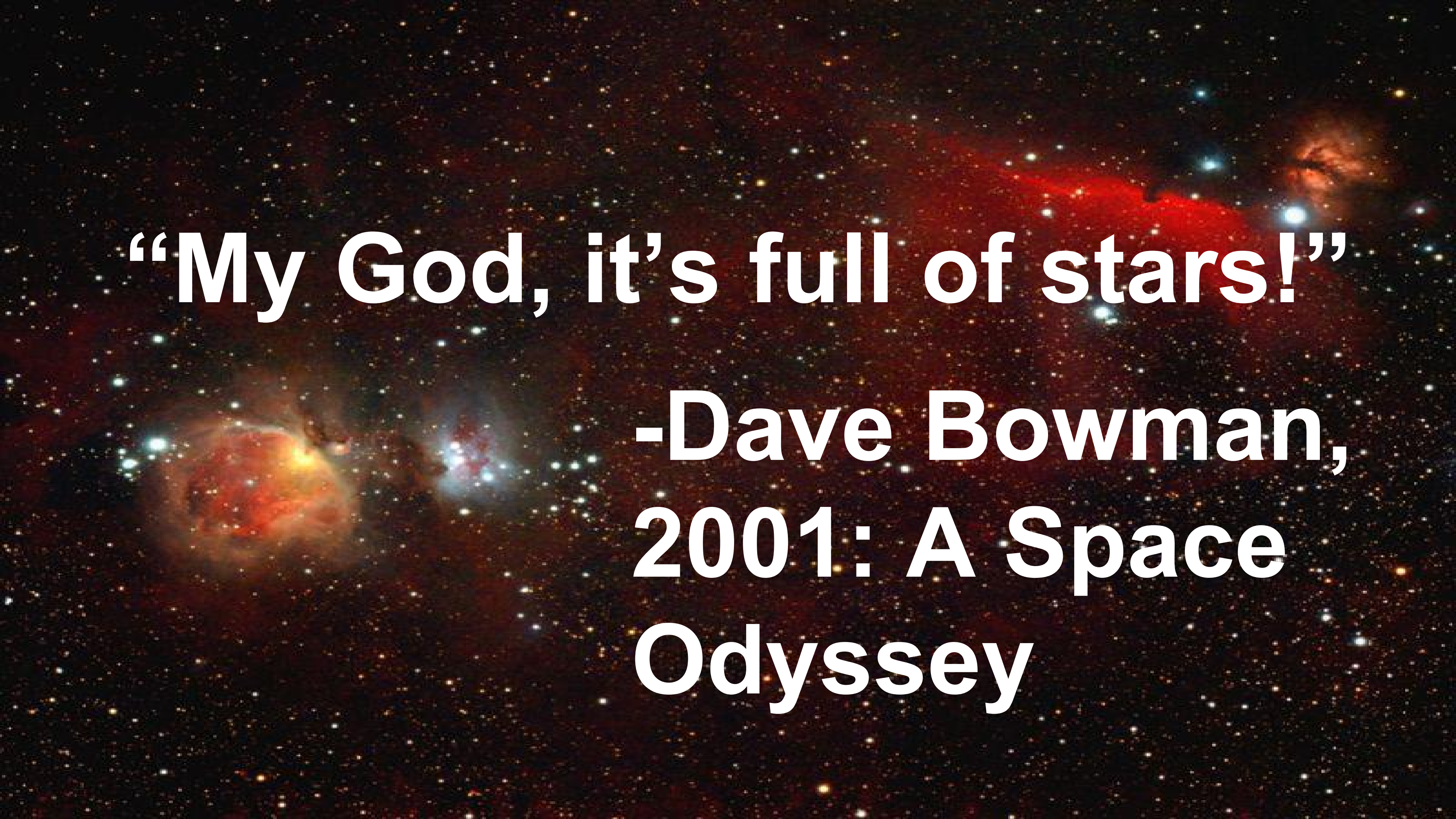
We have weak fields simulations with similar angular orientations to Li et al. (OMC polarimetry survey) and Ostriker et al. (strong field simulation). There is most likely more to this story than originally thought.

Some Issues

- My methods are lacking something important.
- Someone's simulation(s) might not be good.
- Unaccounted observational errors.
- Li et al. did not consider the effects of de-polarization at high densities. Neither did Ostriker and Falçeta-Goncalves.

The Future

- Scrutinize my calculations and code a few more times.
- Improve the (de)polarization parameter, make it more physical/realistic.
- Run more simulations, with strong fields included for a full spectrum of field strengths.
- Employ other observables (mass/flux, etc.)


"My God, it's full of stars!"
-Dave Bowman, 2001: A Space Odyssey