Magnetic Field Angles in Collapsing Molecular Clouds

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1 Abstract

Star formation holds many answers to how the universe has evolved and how we came into existence. A big question in star formation theory centers around the role of magnetic fields and how strong they must be in the cloud to coincide with the observed star formation rate. However, measuring the strength of magnetic fields is difficult due to molecular clouds being very optically thick in the optical band. Turbulence increases the difficulty by creating chaotic conditions within the clouds. One method of determining these characteristics is by simulating collapsing molecular gas clouds using the principles of self-gravitation, magnetic fields, and turbulence, the main components of star formation. Data analysis of Enzo simulation data was done to help determine what the relative strength and angular orientation of magnetic fields around pre-stellar cores were relative to the global cloud. The preliminary weak-field simulation trends are positively monotonic similarly to trends found in observations and strong-field simulations, an issue that needs to be addressed in the near future.

2 Introduction

Magnetic field strengths are difficult to measure in real observations of interstellar molecular clouds due optically thick dust densities and chaotic cloud turbulence. However, this dust emits light in the infrared spectrum that is polarized by the magnetic fields present in the molecular cloud. One can use this polarization to determine the angles of local magnetic field lines around identifiable pre-stellar cores relative to the global magnetic field along the line of sight. Stokes parameters can be used to accomplish this as they relate the observable effects of polarization due to magnetic fields in the plane of the sky (Soler 2013)

$$Q_{ij} = B^{i\,2}_{ijk} - B^{j\,2}_{ijk}, U_{ij} = 2B_{ijk}B_{ijk}$$

$$\theta = arctan(U/Q)/2, |\mathbf{B}_{POS}| = \sqrt{Q^2 + U^2}$$

The polarization angle relative to the line-of-sight magnetic field B_{los} is the primary focus of this research.

The results of an observational survey of the Orion cloud (Li 2009) yielded a positive, monotonic trend between the angles of dense cores and the intercloud medium. Simulations of collapsing clouds prior to the Orion polarimetry survey were used as a comparison (Ostriker 2001; Falceta-Goncalves 2008). The consensus was that simulations with relatively weak magnetic fields did not fit with observational data. The simulations considered in Li et al (2009) did not employ self-gravitation.

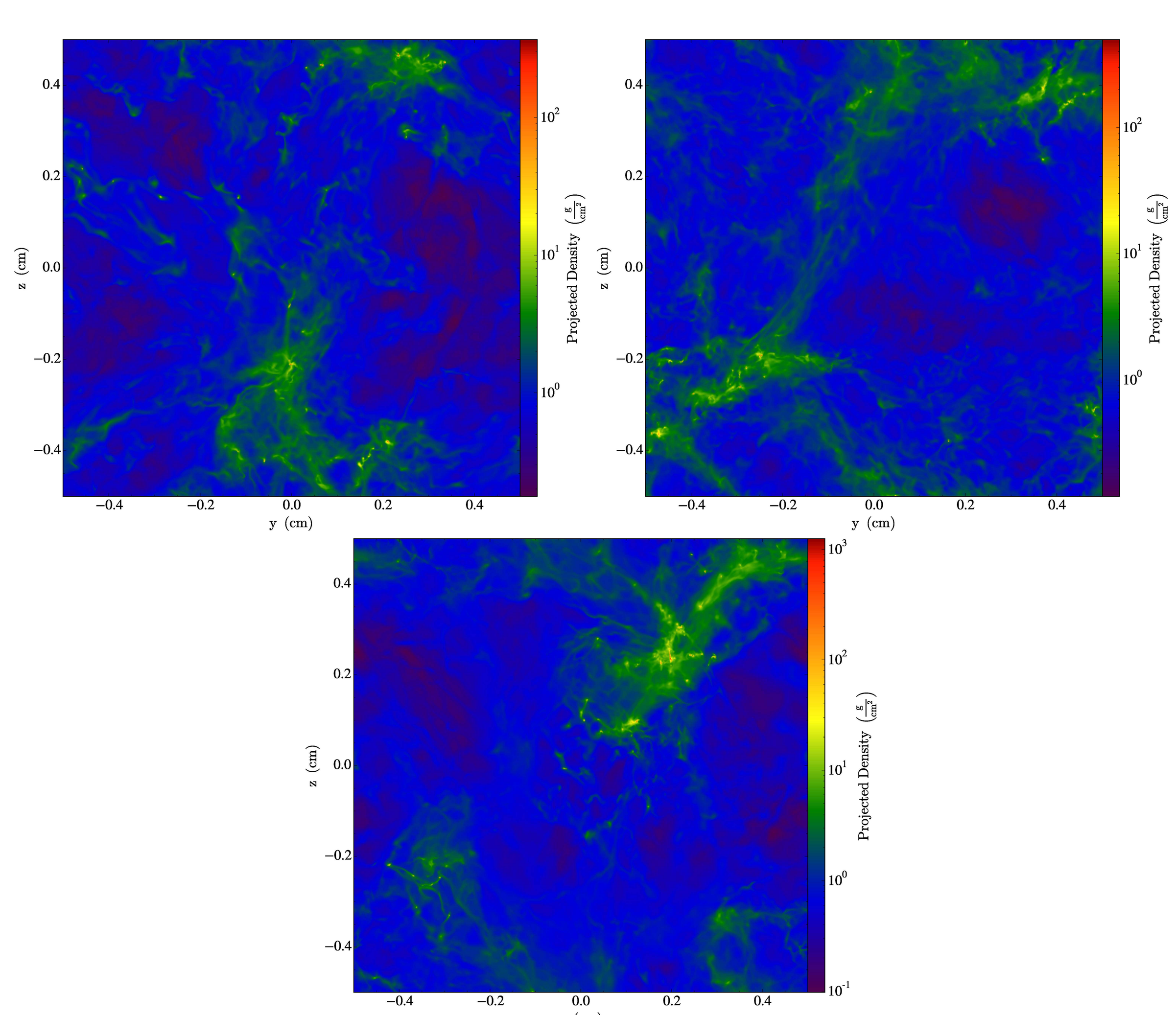

Figure 1: Projection of density along x-axis at snapshot RS0050, corresponding to a time $t = 0.5t_{ff}$ (free fall time), for simulations with trans-Alfvenic (upper left) and super Alfvenic (upper right; bottom) Mach numbers (all relatively weak magnetic fields)

Simulation data from Collins (2012), produced by the AMR software Enzo, was analyzed with the results compared to previous research (Li 2009; Ostriker 2001; Falceta-Goncalves 2008). These simulations are useful in that they include the three main components of star formation, self-gravitation, magnetic fields, and turbulence. The data is contained within cubes of volume $(512pixel)^3$ with 4 levels of resolution refinement and equivalent to a cube of volume $(5parsecs)^3$. To make an analogy to observational analysis, the data cubes were projected along the line of sight to simulate the plane of the sky. Three separate simulations, one trans- and two super-Alfvénic, were analyzed to identify the prestellar cores forming in the simulations and measure their magnetic field angles relative to B_{LOS}. The Alfvén Mach number can be a proxy for initial field strength, B_0

$$M_A = < v_{rms} > / < v_A >, v_A = B_0/\sqrt{4\pi\rho_0}$$

Where v_{rms} is the r.m.s. velocity and v_A is the Alfvén speed. An $M_A > 1$ represents weak magnetic fields, while $M_A < 1$ represents strong fields.

3 Magnetic Field Angles

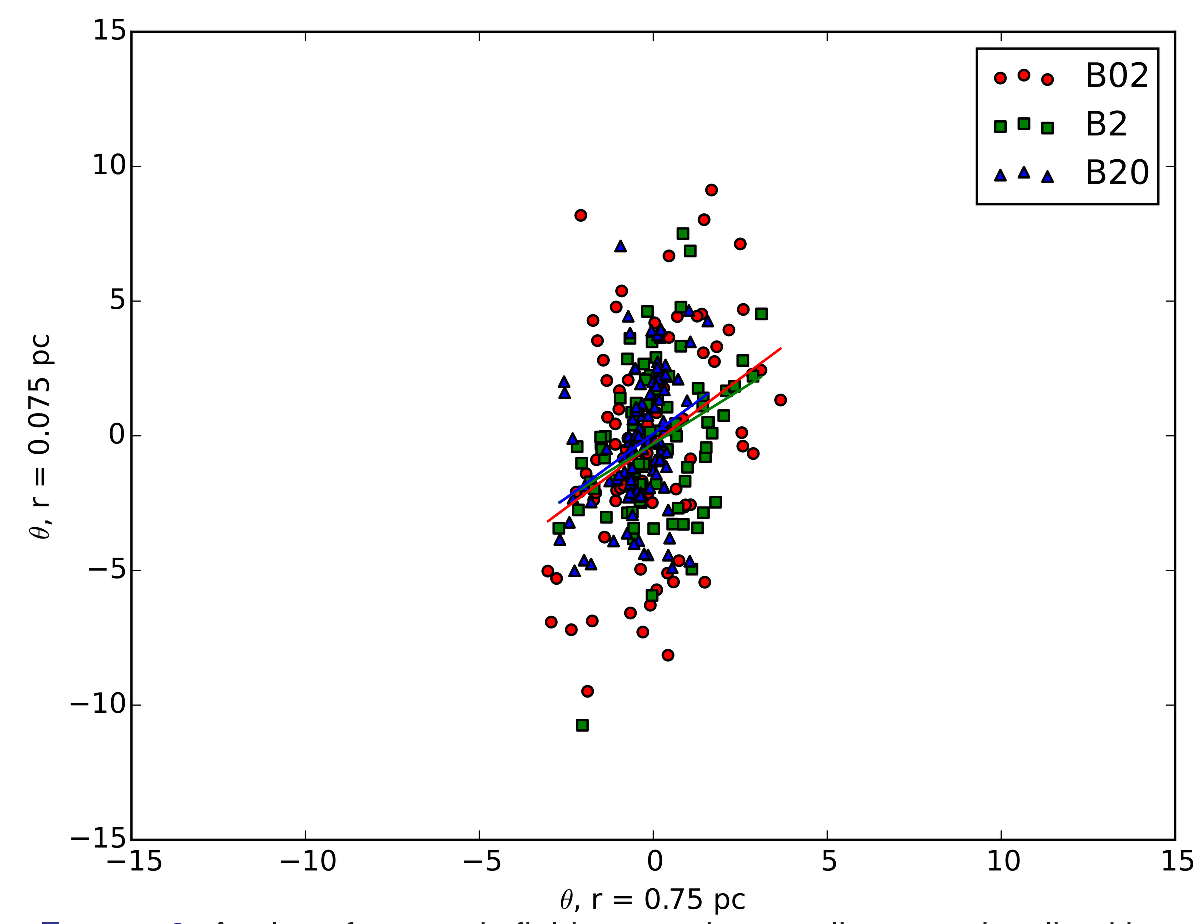

Figure 2: Angles of magnetic fields around pre-stellar cores localized in a circular radius of 0.75pc versus the same pre-stellar cores localized in a radius of 0.075pc, all three simulations at snapshot $t = 0.5t_{ff}$.

Using the Dendrogram function from the Python package AstroDendro, the prestellar cores were identified in the data and their pixels coordinates were used to isolate circular regions of the data around their centers. These circular regions were first taken at $0.75pc$ in radius and then an order of magnitude smaller. The average magnetic field angles in these circular regions were plotted as the larger scale versus the smaller scale angle. Figure 2 shows that projecting along the axis of the mean magnetic field of the cloud yields a steep scatter along the smaller scale size. Interestingly, a crude linear regression line plotted was similar in slope to trend lines from Li et al (2009). There was not a clear enough interpretation to be drawn from the measurements made in this way.

4 Dendrogram Trees

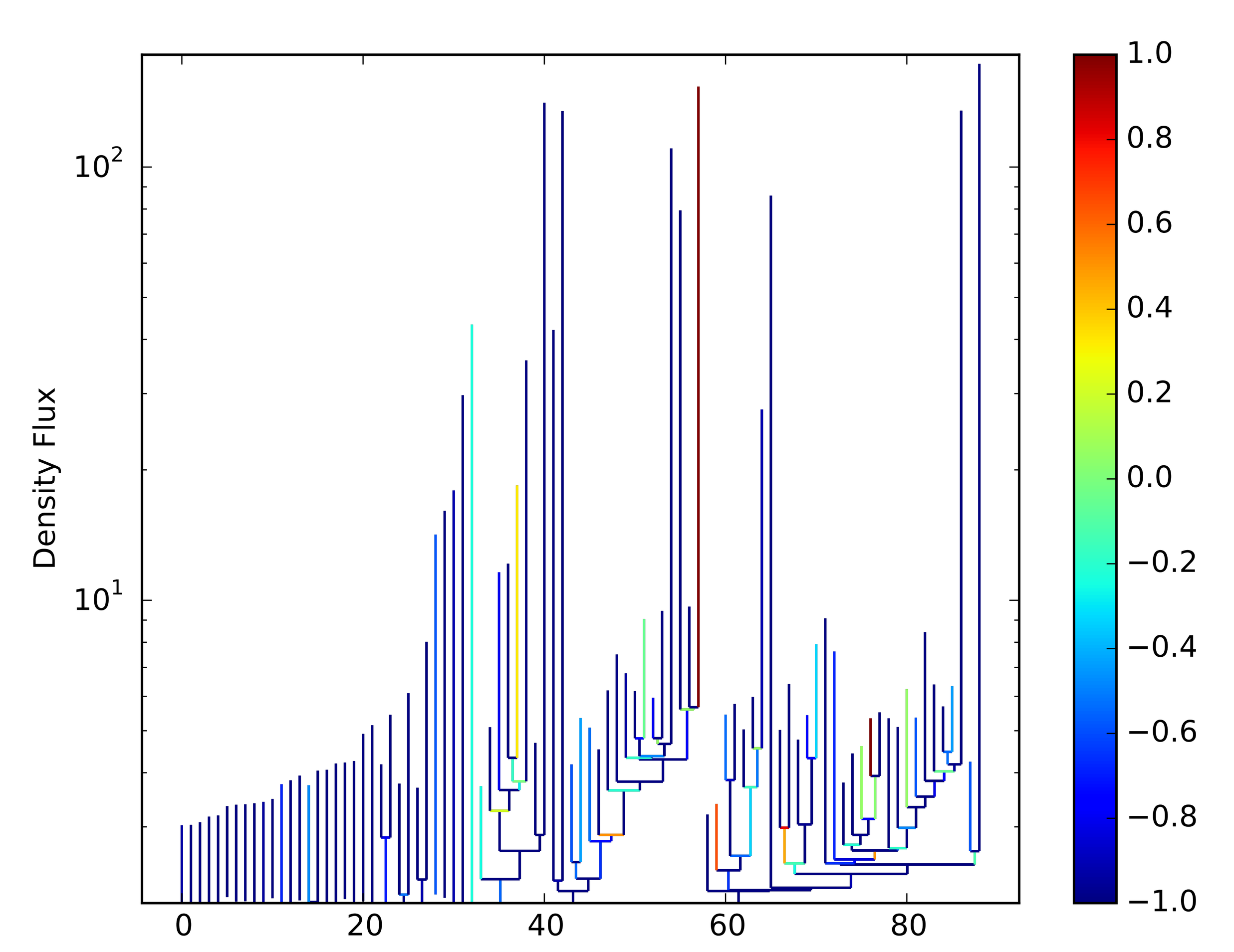

Figure 3: Dendrogram tree structure with the average angles of the structures, including the correpsonding substree for each structure, overlayed on the tree diagram lines. Trans-Alfvénic run at $t = 0.5t_{ff}$.

Using the hierarchical structure created by the Dendrogram, the structures were plotted by density flux as a function of structure ID number. Angle measurements were made using all of the data contained within the structures identified. These measurements were overlayed on the Dendrogram tree diagram in colormap. Figure 3 depicts the complexity of collapsing molecular clouds and how the field angles deviate from the mean magnetic field as a function of substructure. Again, a clear picture was not easily obtained from this method of plotting.

5 Size Scales

We proceeded to measure the field angles as a function of size scale, plotting the average magnetic field angle of each structure versus the size of the structure recorded by the Dendrogram. We were looking for any size scales in which the deviations from B_{LOS} changed in behavior.

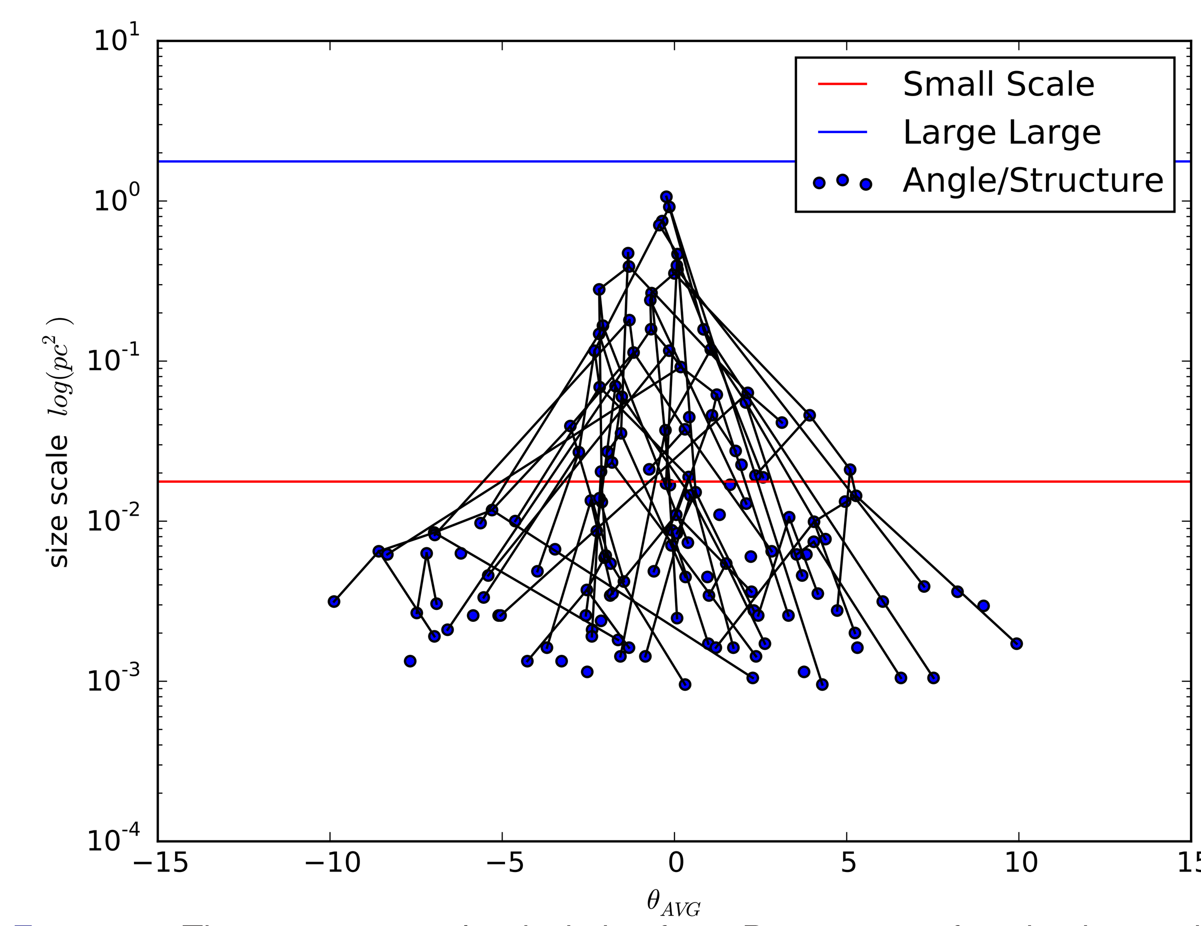

Figure 4: The average angular deviation from B_{LOS} as a function increasing size scale. Snapshot $t = 0.5t_{ff}$ of the trans-Alfvénic simulation. The two horizontal lines serve as a reference to the original plots made with isolated circular radii differing in size by an order of magnitude($r = 0.75pc, 0.075pc$).

Figure 4 is one of many plots made in this way. All the plots made this way displayed a similar monotonic trend from small scale to large scale, with the horizontal lines referring to the size scales used in Figure 2. The spread of angles among the smallest structures was now easily determinable, the greatest spread being 20 degrees. All angle spreads were well within the spreads found in observations and simulations (Li et al 2009). However, the simulations we used all had weak magnetic field parameters, whereas the simulation by Ostriker (2001) used strong field parameters, both of which fit well within obersvational angle spreads (Li et al 2009).

To reconcile this disagreement, more simulations will be run with improved parameters and stronger magnetic fields. The goal is to determine how valid the current simulation data is and how the trends persist and evolve with stronger magnetic fields.

6 References

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