Magnetic Field vs Density Relation in Star-Forming Clouds [2022]

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Keywords:
- Star Formation
- Molecular Clouds
- Magnetic Fields

Background

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We want to analyze how clouds transforms from subcritical (low mass/flus ratio) to supercritical (high mass/flux ratio) because of turbulent compression

- less-density regions tends to align with magnetic fields
- high-density regions tends to be perpendicular to magnetic field observed in polarized map of Galactic Dust

- B proportional to rho^0 (low densities)
- B proportional to rho^k (high densities) (k is uncertain)

There is a critical mass to flux ration under which magnetic pressure prevents fragmentation of the cloud.

Numerical Simulations

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Cloud was assumed layered in Z-direction

1. Initial Conditions:
   - Constant density in x-y plane
   - Constant magnetic field strength in z axis

2. Instigate perturbations to mimic turbulence (Gaussian random velocity perturbations in the x and y components with amplitude v)

(We fit the four free parameters using the Markov Chain Monte Carlo (MCMC) method (van Dyk 2003).

(We use the PYTHON package emcee (Foreman-Mackey et al. 2013) for this purpose)

3. Stop the simulation when maximum density has reached (100 times of the initial)

Observations

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Why B should increase when turbulence is increased or collapse starts?

Both neutral and the ionic elements moves really fast and randomly probably producing magnetic fields of higher strengths when the collapse initiates

1. The break density rho shifts to higher values with increasing Mach Number.

- probably because of the randomness caused by high mach number resulting in collapse delayed at mass would not collate at lower densities due to higher momentum?

2. With increasing initial Mach number the Magnetic field becomes more scattered.

- it should be as the initial high turbulence might have caused mass into chunks of high and low density regions with same magnetic fields (are these like vortices)

3. The transition happens at very similar magnetic field values for each different initial condition. (power law is narrow but flat part becomes more scattered)

- this implies mass-to-flux ratio values remains similar (less impact of ambipolar diffusion?)
- probably once the collapse starts the core for each initial condition behaves similarly in the supercritical regime as it would need a certain gravity value for same strengths of magnetic fields as observed near transition point.

Analytical Model

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When will the break density happen if we propose?

It shall happen when the magnetic pressure pushing mass out is equivalent of the ram pressure that initial turbulence possess. Post this ram pressure with help of ambipolar diffusion (neutral mass collapsing) will overpower and result in a collapse.

So (magnetic pressure B) increases due to compression until it counters the (ram pressure + the initial background magnetic field pressure B0)

1. Initial conditions:
   - equal pressure along z-direction for each layer (no z direction moment initially)
   - compression happens in x-y plane

2. Reaches quasi-equilibrium state: (equation 1)
   - when internal magnetic pressure equals the ram pressure + background magnetic pressure
   - compression ceases and oscillation starts? (what type of oscillations?)

3. Cloud half thickness: (equation 2)

4. Flux freezing (if ambipolar diffusion takes longer time than compression?) (equation 3)
   - because the ionic mass is the reason behind flux and if they only are compressed than the magnetic flux is preserved.

5. Simplifying equation 1 by using 2 and 3 to get the transition density relation

6. Results are close to the Simulation data with +- 0.1 deviation (outlier is the one with highest initial Mach Number)

Conclusions

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1. The transition density separates the region where turbulence dominates and cloud is relatively flat to the region where cloud collapses because of gravity dominance.

2. With increasing initial Mach number the initial spread of B-rho scaling is increasingly scattered

3. The transition density increases with increasing Mach number (as compression to increase magnetic pressure will need higher densities to counter increasing ram pressure)

Any Future Work

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- Explore around what happens due to high Mach numbers and why the scattering increases.