Clumps With External Magnetic Fields, Their Interaction With Shocks, and the Effect of Magnetic Thermal Conduction

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Introduction

Problems involving magnetized clouds and clumps, especially their interaction with shocks are common in astrophysical environments and have been a topic of research in the past decade. The magnetic field structure, whether aligned with the shock or perpendicular to the shock, can have profound influence on the shocked behavior and evolution of the clump. In this presentation we review some basic results of the shocked MHD clumps by past simulations, as well as movies of preliminary 3D simulations produced by our parallel MHD code AstroBEAR. We will also discuss future directions of numerical simulations on such topic.

Outline

1. Introduction
2. Previous work
3. Simulations of MHD clumps with external field
4. Future Directions

Meaningful Quantities

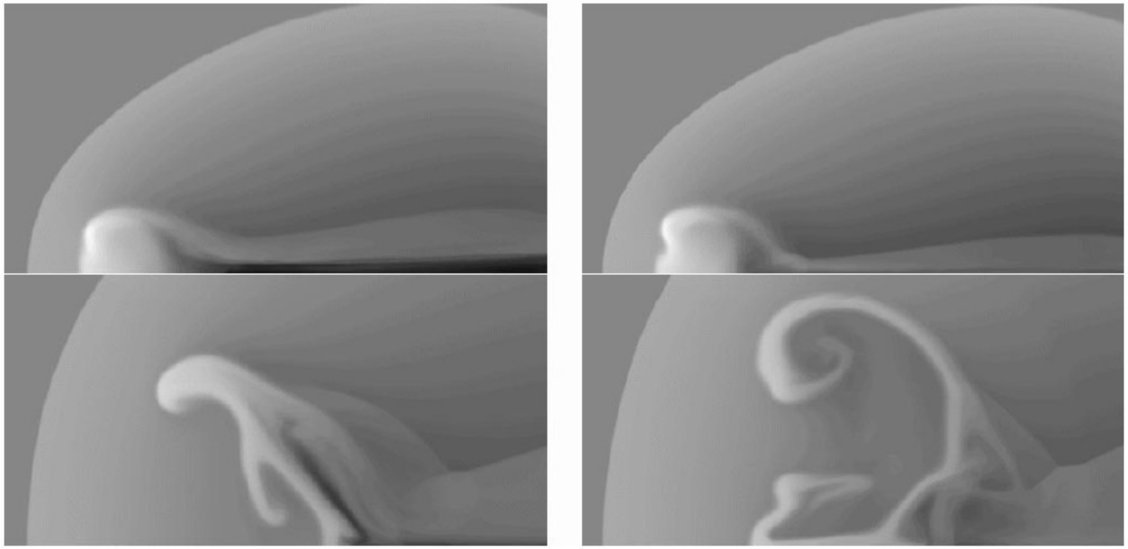
Density Contrast: $$\chi = \frac{\rho_{clump}}{\rho_{amb}}$$

Sonic Mach number: $$M = \frac{u_{wind}}{c_{s,amb}}$$

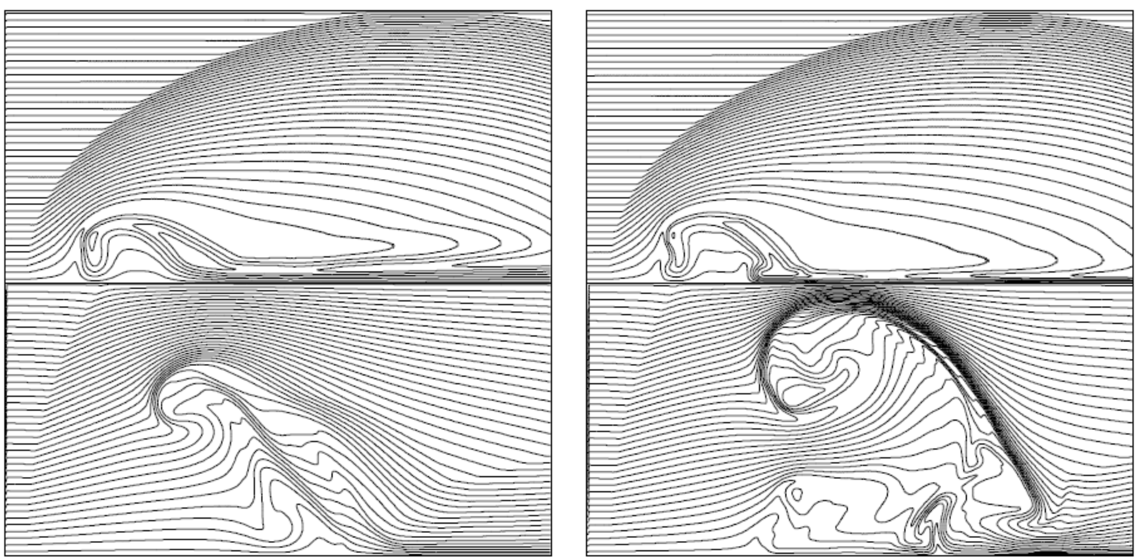
Alfvenic Mach number: $$M_A = \frac{u_{wind}}{v_a}$$

Magnetic Beta: $$\beta = \frac{2}{\gamma}\frac{c_{s,amb}^2}{v_a^2}$$

Clump crushing time: $$\tau_{cc} = \frac{\chi^{1/2} r_{clump}}{u_{wind}}$$



Density log plot at $2\tau_{cc}$ (top) and $6\tau_{cc}$ (bottom). Left: $\beta = 4$. Right: $\beta = 256$.



Field line plot at $2\tau_{cc}$ (top) and $6\tau_{cc}$ (bottom). Left: $\beta = 4$. Right: $\beta = 256$.

Jones, T.W., Ryu, Dongsu, Tregillis, I.L. 1996 ApJ, 473, 365

Aligned field evolution:

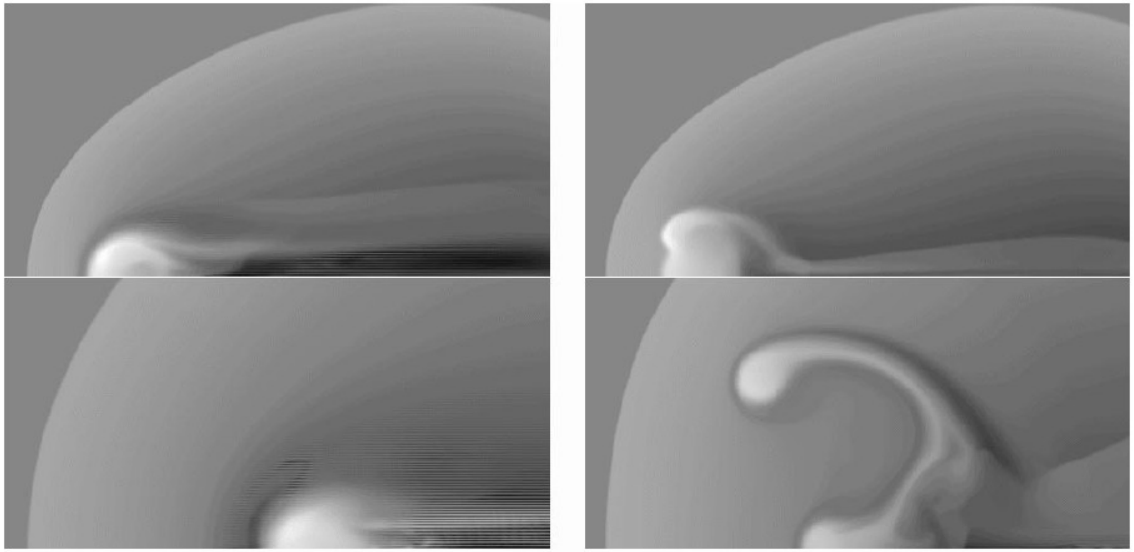
No significant difference in terms of density evolution even for $\beta = 1$.

The criterion for the magnetic field removing K-H instabilities at the clump boundaries is: $\beta < 1$ along the boundary. The criterion for the magnetic field to stabilize R-T instabilities is roughly: $\beta < \chi/M$.

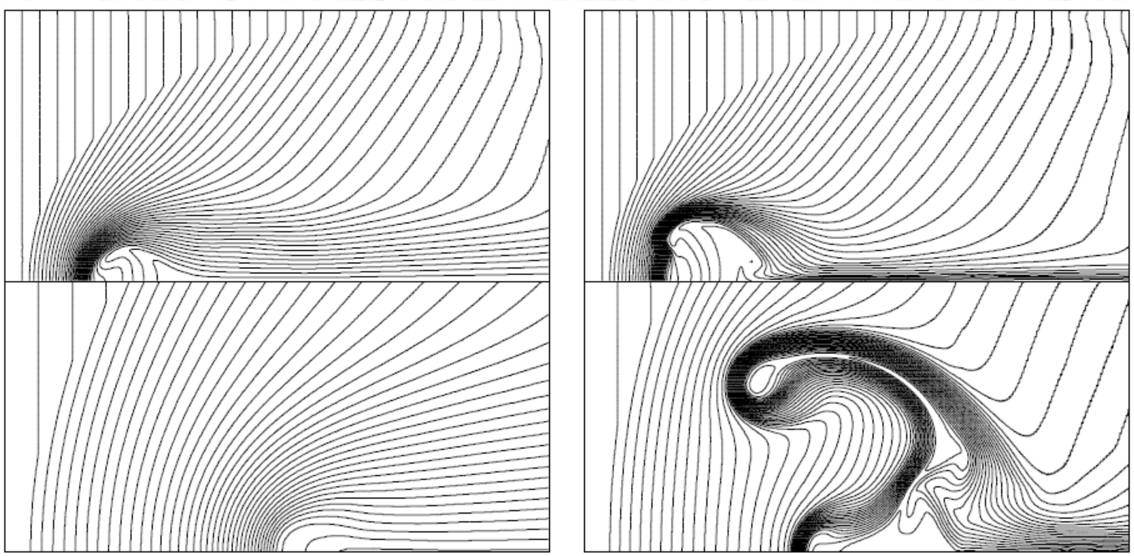
But there is no place that the magnetic field becomes energetically dominant; that is, almost everywhere $\beta >> 1$.

Magnetic fields stretched over the top of the clump can have a significant stabilizing influence that improves the flow coherence.

Jones, T.W., Ryu, Dongsu, Tregillis, I.L.
1996 ApJ, 473, 365



Density log plot at $2\tau_{cc}$ (top) and $6\tau_{cc}$ (bottom). Left: $\beta = 4$. Right: $\beta = 256$.



Field line plot at $2\tau_{cc}$ (top) and $6\tau_{cc}$ (bottom). Left: $\beta = 4$. Right: $\beta = 256$.

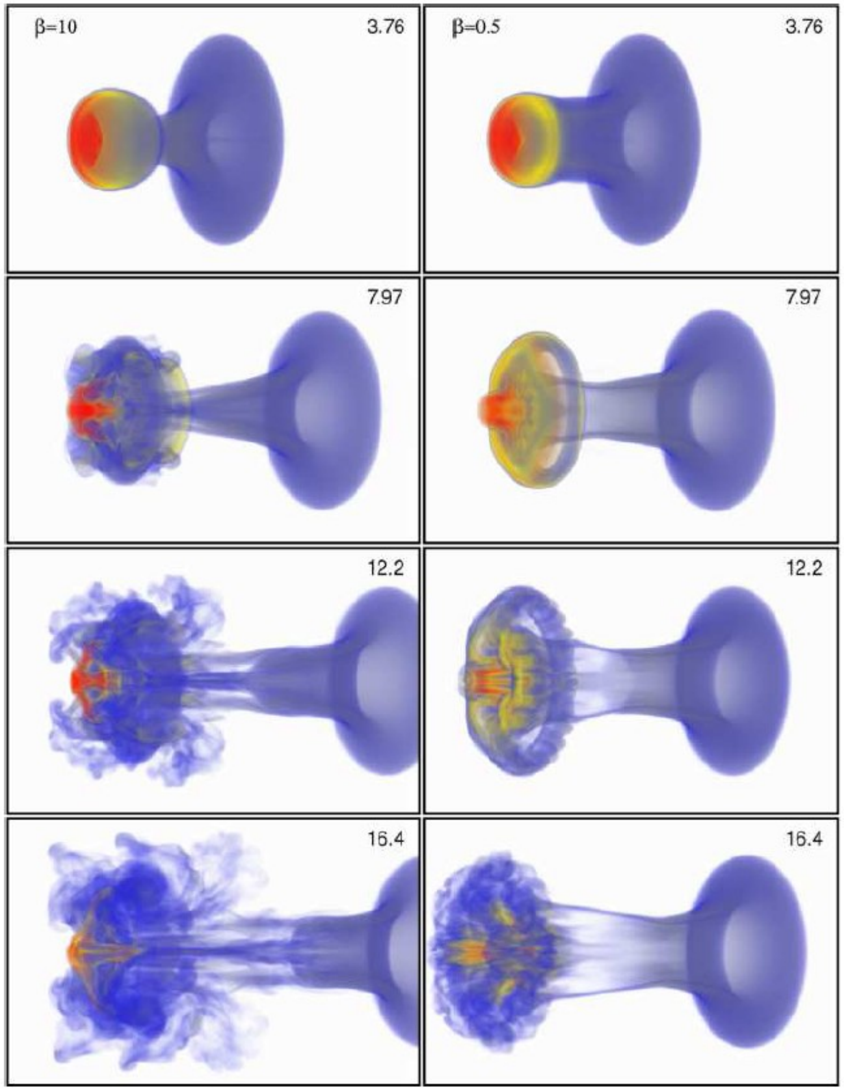
Perpendicular field evolution:

The magnetic field is stretched and wrapped around the clump, which effectively confines the clump and prevents its fragmentation, even for moderately strong field $\beta = 4$. The clump embedded in the stretched field is compressed, but then, because of the strong confining effect of the field develops a streamlined profile and is not strongly eroded.

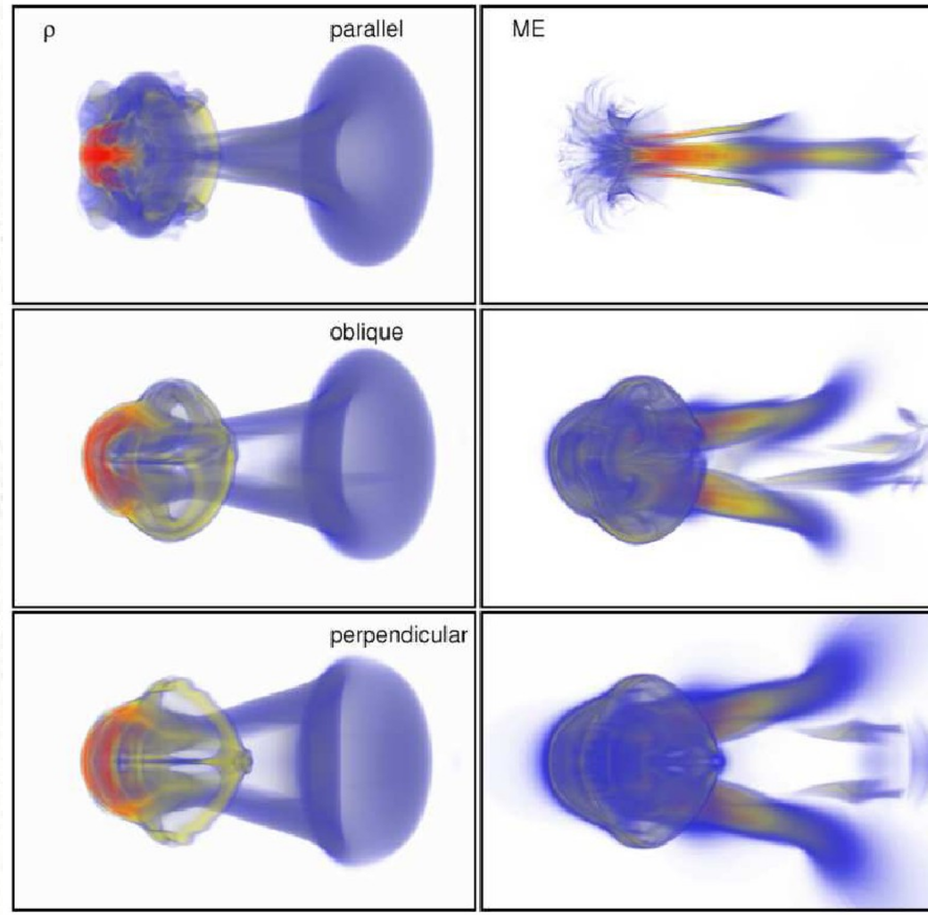
The magnetic pressure at the nose of the clump increases drastically, which acts as a shock absorber.

At later stage, the stretched field around the clump edge has $\beta < 1$ even for moderately strong initial field condition. This protects the clump from further disruption.

Min-Su Shin, James M. Stone, Gregory F. Snyder, 2008 ApJ, 680, 336



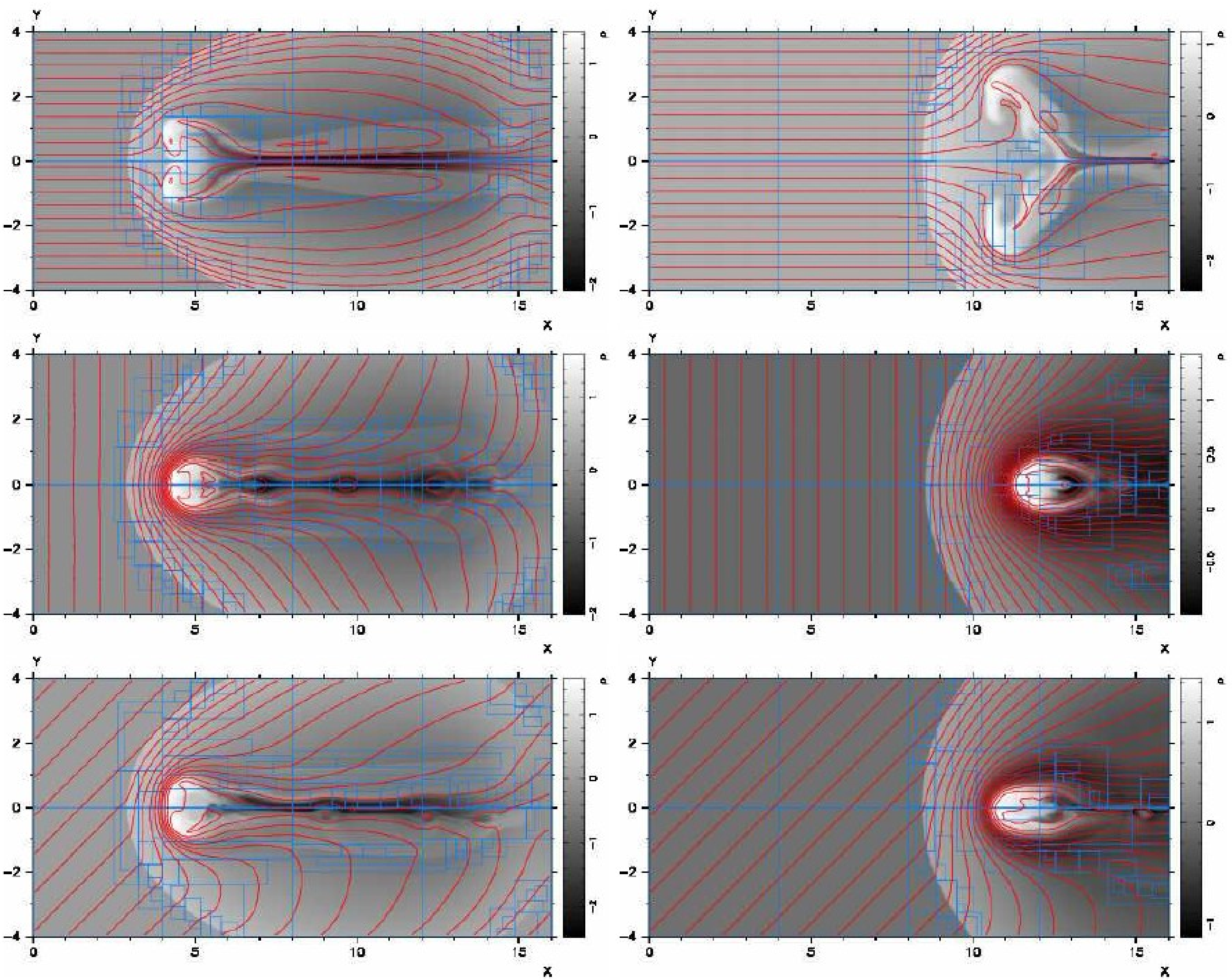
3D density contour at various clump crushing time for weak and strong aligned field.

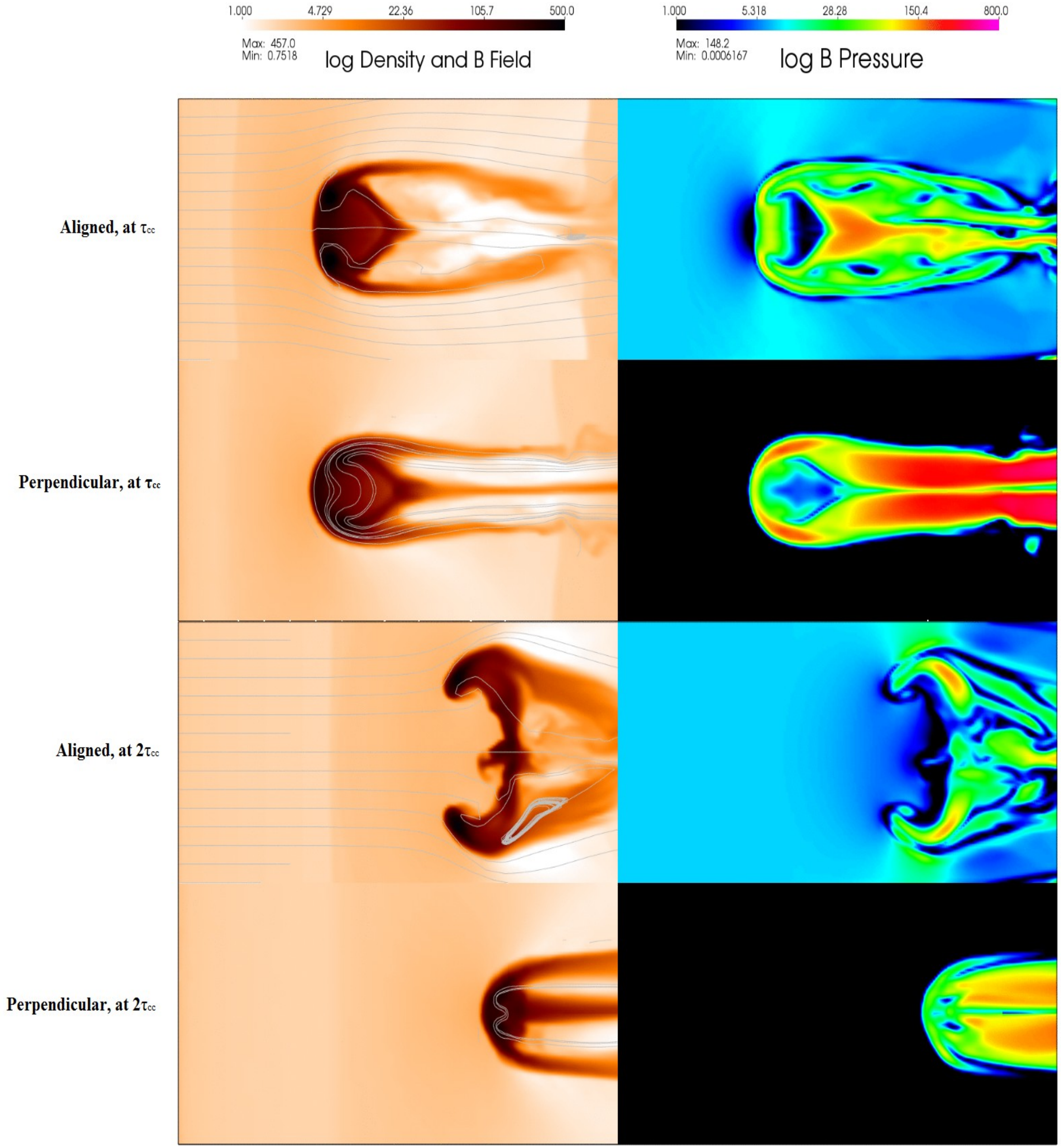


3D density contour (left) and magnetic pressure (right) for weak aligned field, perpendicular field, and oblique shock cases, at $4\tau_{cc}$.

Cunningham, Andrew J.; Frank, Adam; Varnière, Peggy; Mitran, Sorin; Jones, Thomas W. 2009 ApJS, 182, 519

2D simulations done by AstroBEAR 1.0. The logarithm of the density distribution is presented in gray-scale, red lines delineate the magnetic field lines and blue lines show regions of AMR-enhanced resolution.





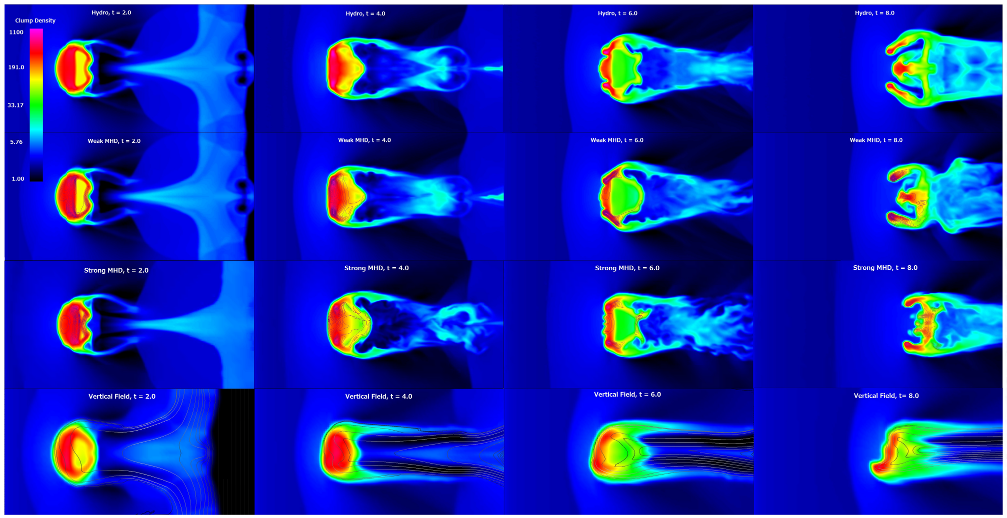
3D Contour of log Density

3D AstroBEAR simulation with $\chi = 100$, $M = 10$, $\beta = 0.5$. Initial ambient temperature is at 2000 K. The clump has a number density of 1 per cc, with a radius of 2.5 AU. DM cooling is present during the simulation.

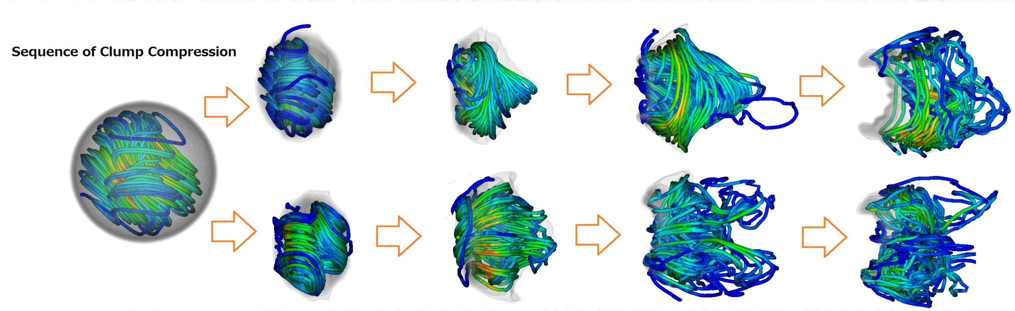
For the aligned field case, the field amplification occurs mainly along the axis behind the clump. In the perpendicular field case, the field is amplified in a cylindrical cavity next to the boundary flow. This amplified field prevents boundary flow to flow into the cavity, and pushes material towards the axis, forming a "tail" behind the clump. The field wrapping around the clump head also gets strongly amplified, which produces a streamlined profile.

http://www.pas.rochester.edu/~shuleli/clumpview/trial.gif

Future Work I: Contained field cases



The density evolution of contained field case remains similar to that of the hydro case in terms of morphology. The strong contained field does have a resistance that holds the clump material together at $t = 2\tau_{cc}$, the effect is weak comparing to the global field case of a greater β.

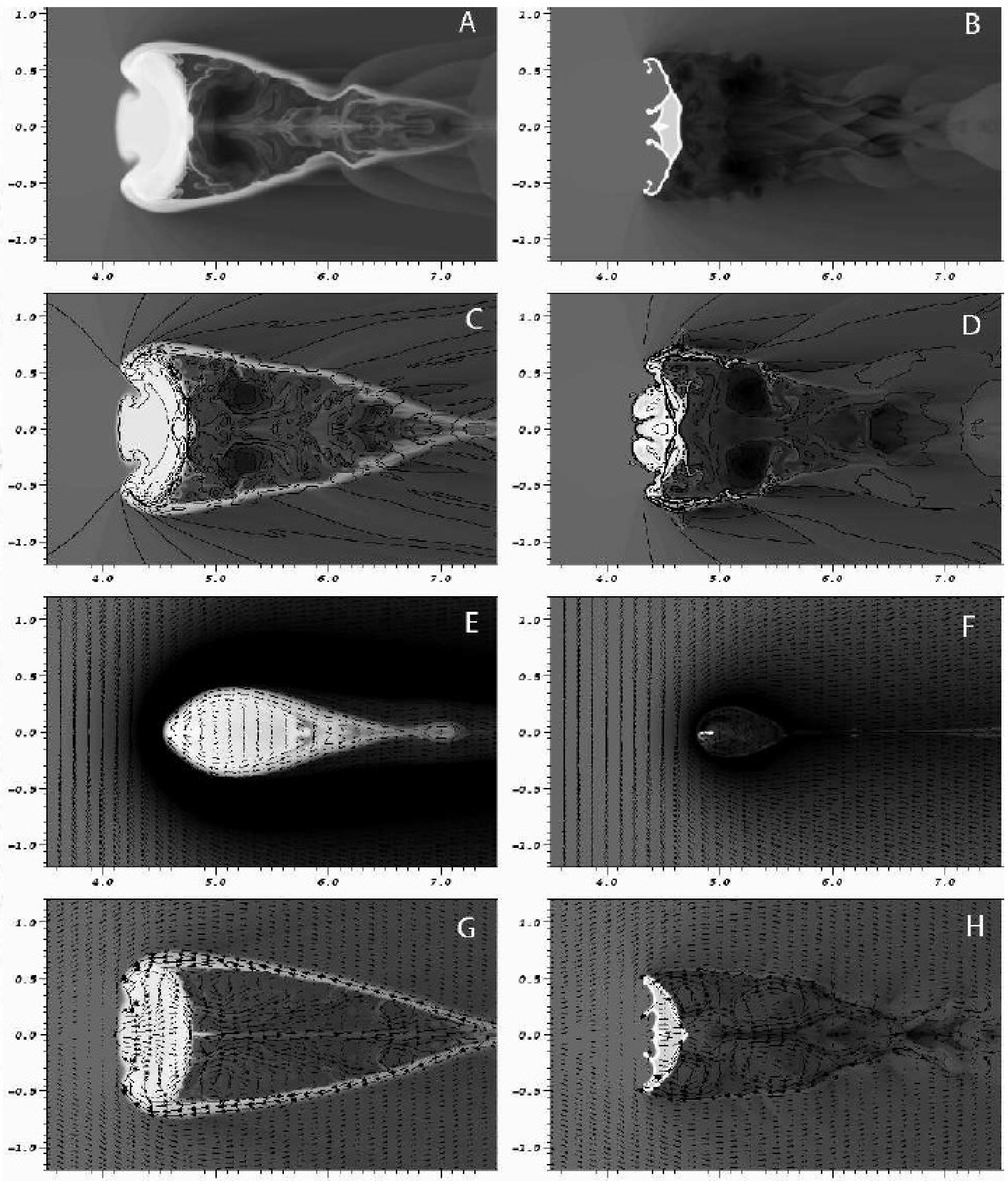


In the weak bounded field (top), field lines compressed and then unfold. The toroidal component becomes dominating. In the strong contained field case (bottom), the fields retain more of original configuration and provide some restriction of clump deformation.

Future Work II: Multiphysics processes

Cooling

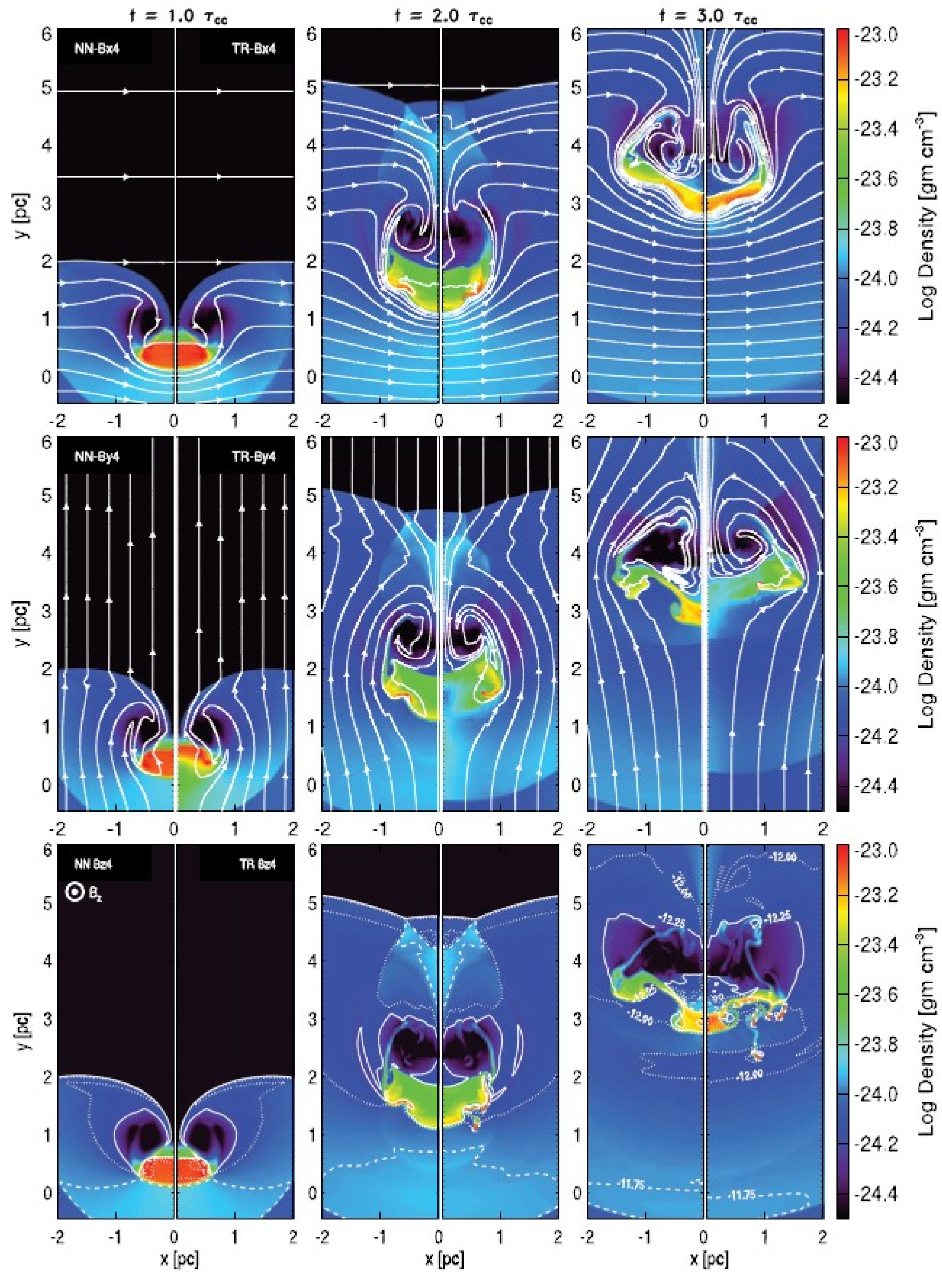
Fragile et al (2005 ApJ 619, 327)



Future Work II: Multiphysics processes

Anisotropic Thermal Conduction

Orlando et al (2008 ApJ 678, 274)



Future Work II: Multiphysics processes

Real Resistivity

The Current Sheet Reconnection Outflow Test

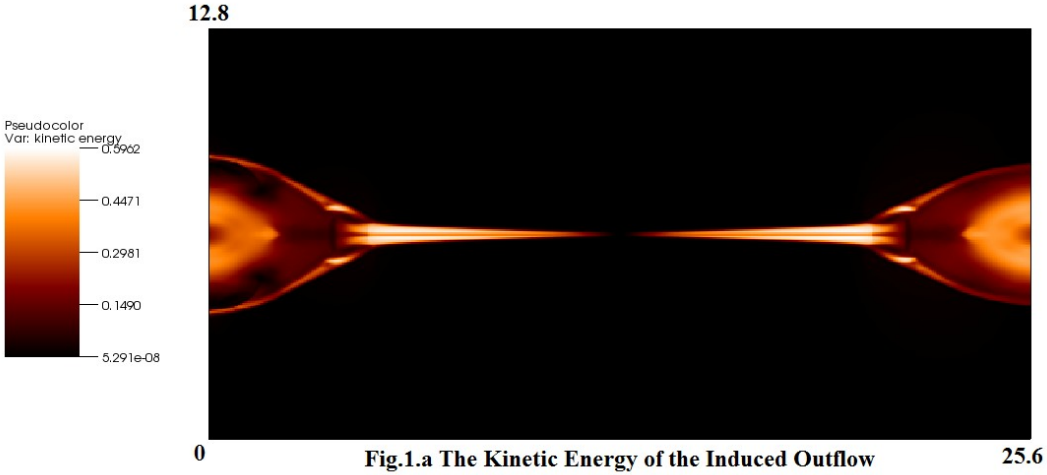


Fig.1.a The Kinetic Energy of the Induced Outflow

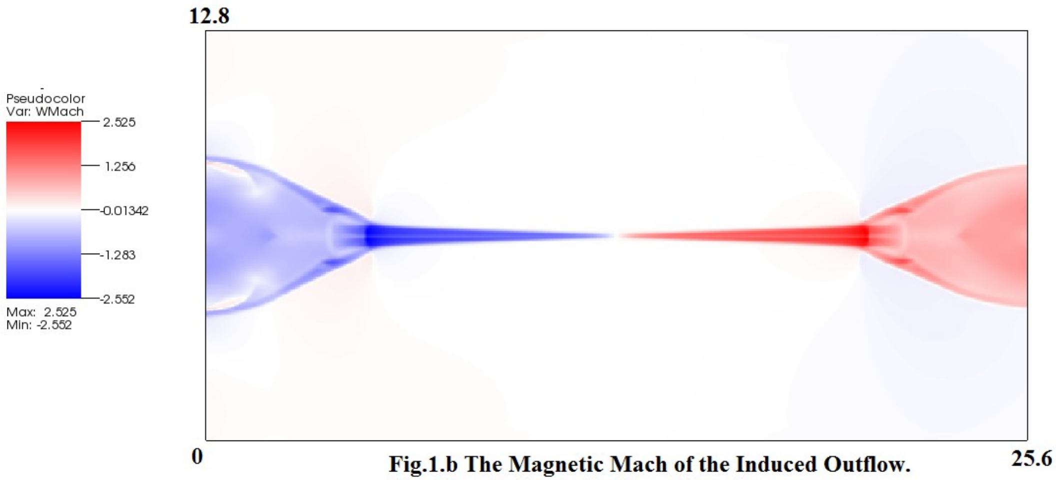


Fig.1.b The Magnetic Mach of the Induced Outflow. The Signs Indicate the Flow Directions.