Interaction between Shocks and Clumps With Self-Contained Magnetic Fields

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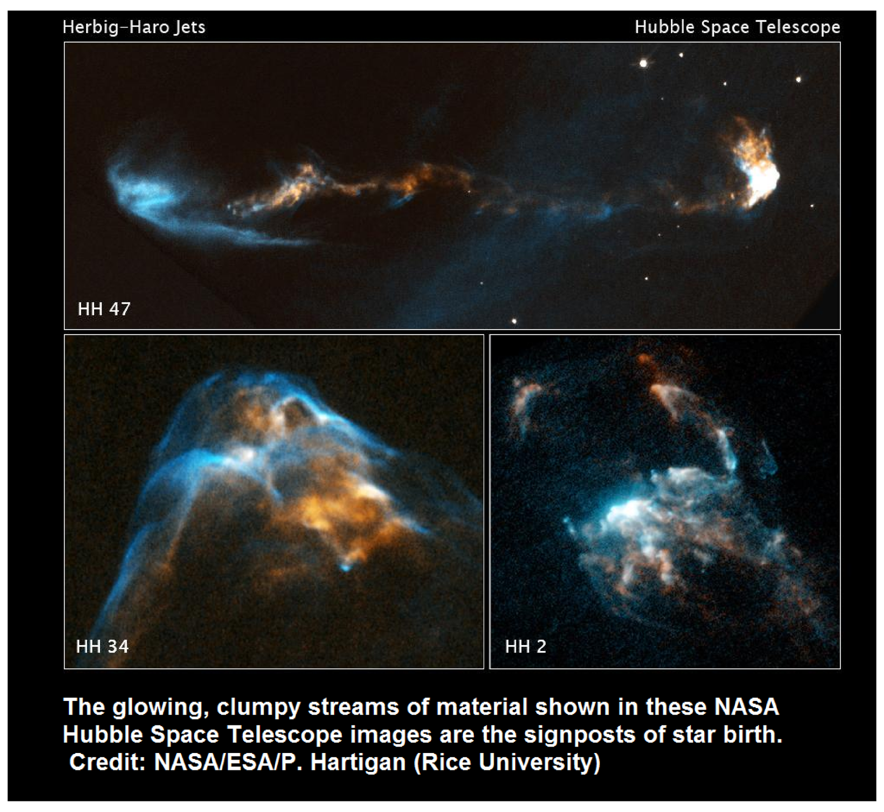
Introduction

Problems involving magnetized clouds and clumps, especially their interaction with shocks are common in astrophysical environments (e.g. YSO and HH objects). Realistic clumps may have tangled magnetic field self contained within them. This magnetic field will be compressed by the shock and its energy spectrum and spatial structure may affect the evolution of the clump during the shock encounter. Using our parallel MHD code AstroBEAR, we set up an initial state with magnetized clumps of different contained magnetic field configurations. We then drive strong shocks through these clumps (including the effects of radiative cooling) and compare our results to previous studies of global uniform field scenarios.



The glowing, clumpy streams of material shown in these NASA Hubble Space Telescope images are the signposts of star birth. Credit: NASA/ESA/P. Hartigan (Rice University)

We explore:

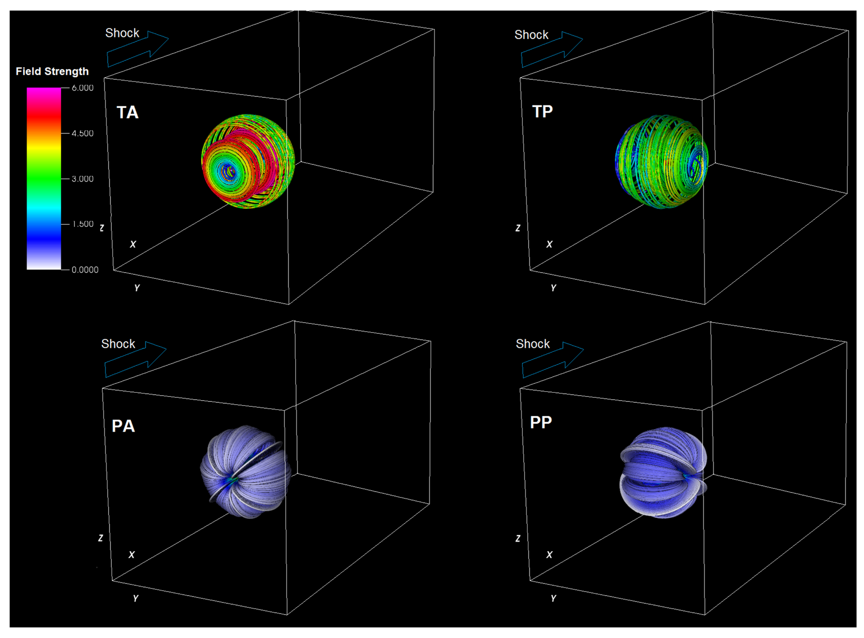
- evolution of clump morphology when there is a tangled magnetic field contained.
- energy transfer and mixing ratio between the shock and the clump
- mathematical model that can explain the evolution of physical quantities (such as kinetic energy)

Model

We use the Adaptive Mesh Refinement (AMR) code *AstroBEAR2.0*[6] to solve the equations of radiative-MHD in 3D. The domain: $|x| \leq 2400$ AU and $0 \leq |y|, |z| \leq 60$ AU, $1296\times324\times324$ cells; a resolution of 50 zones per clump radius.

Initial conditions:

- Static molecular gas with $\mu = 1.3$
- Ideal gas eqn. of state ($\gamma = 5/3$)
- ambient density $= 1\,cm^{-3}$
- ambient temperature $= 5000\,K$
- density contrast $= 100\,cm^{-3}$
- shock mach=10
- average Magnetic $\beta = 0.25$ 1
- clump radius $r_c = 15 a.u.$
- effective radius $r_e = \sqrt{(r_c^2 - z^2)}$



- field configurations:

$$A_{tor,z} = \begin{cases} B_0 \frac{fr_e^2 - r^2}{2fr_c}, r \leq fr_e \\ B_0 \frac{(r_e - r)^2}{2(1-f)r_c}, r > fr_e \end{cases}$$

$$A_{pol,\theta} = -\frac{B_0 (r_c - r)^2 r sin\theta}{2r_c^2}$$

Parameter Space:

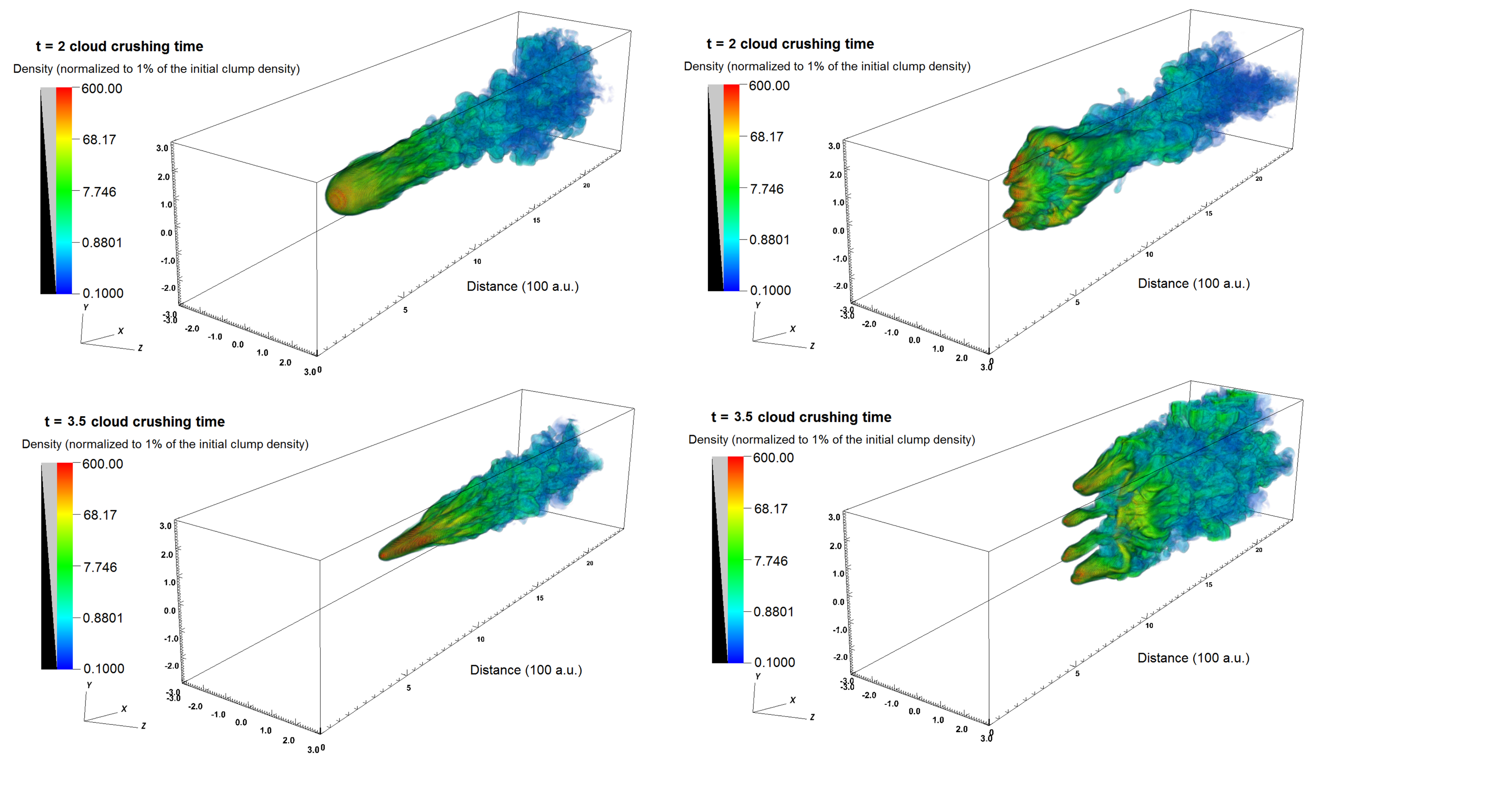
cloud deformation time scale: $\tau_{mag} = \frac{r_c}{u_A} \approx 436yrs$

cloud crushing time scale: $\tau_{cc} = \frac{\sqrt{\chi} r_c}{u_{wind}} \approx 95yrs \ll \tau_{mag}$

transmitted shock cooling time scale: $\tau_{trans} \approx 48yrs \ll \tau_{cc}$

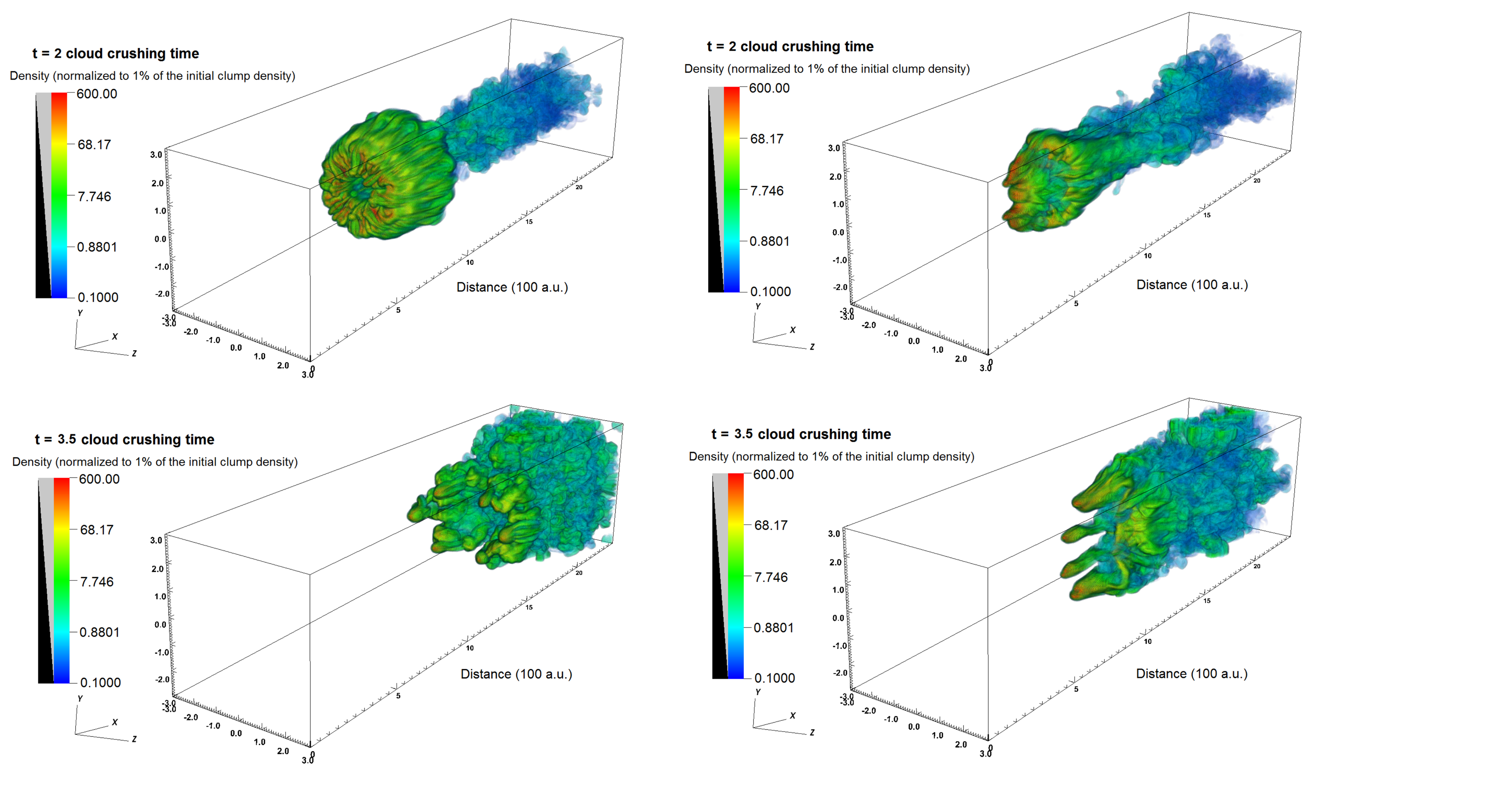
Morphological evolution: toroidal cases

Contained magnetic field exhibits obvious effect on the post shock morphological evolution at 2 and 3.5 crushing time. The toroidal aligned case resembles the "nose cone" shape observed in the MHD jet simulations. The toroidal perpendicular case the field pinches the clump onto z axis, but the shock compresses the clump onto the x axis. As a result, the clump eventually deforms into a set of "clumplets".

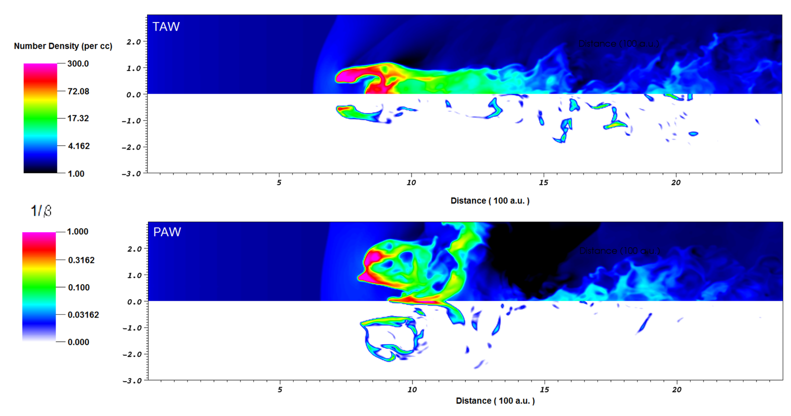


Morphological evolution: poloidal cases

The poloidal aligned case develops a hollow core at $2\tau_{cc}$. The "shaft" shaped feature surrounded by the hollow core has a relatively low β. Eventually, the "shaft" disappears and the clump is fragmented into radially distributed cold, magnetized "clumplets". In the poloidal perpendicular case, a "ring" feature is formed due to field pinch. It then gets destroyed from sideways by the shock, leaving an extended **U**-shape. As a result, two large "clumplets" located on the y-z plane form at $3.5\tau_{cc}$.



Instabilities



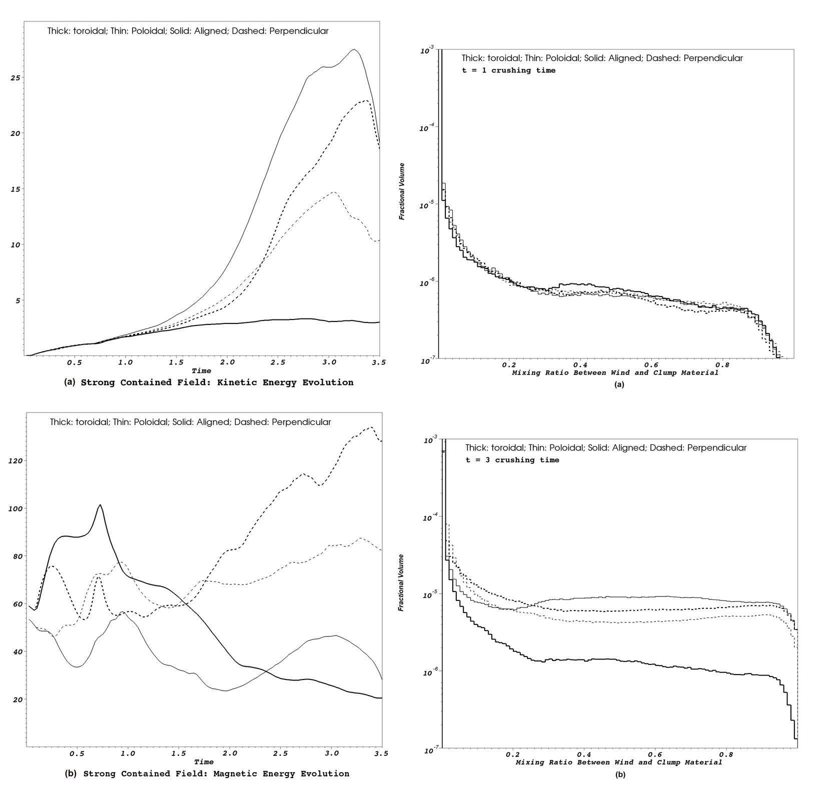
- magnetic field suppress the Kelvin-Helmholtz instability when: $\beta < 1$
- magnetic field suppress the

Rayleigh-Taylor instability when: $\beta < \xi/M = 10$.

Magnetic fields can be important in suppressing the instabilities associated with shocked clumps. By mapping the density and β (presented by $1/\beta$) for the two aligned cases. We observe that the shocked clump material develops a streamlined shape in both cases. The region where density is concentrated has $1/\beta > 0.1$.

Kinetic energy transfer, magnetic energy and mixing

We can identify the downstream turbulence of the TA and PA cases as the least and most volume filling respectively. The mixing ratio comparison also agrees with our intuition that the more the aerodynamic resistance provided by the field configuration, the less the mixing. This is borne out by the 4 cases: the toroidal aligned case has its field lines entirely aligned with the incoming shock plane; the two perpendicular cases have most of the field lines aligned with the shock plane, but there are also components that are along the shock direction; the PA case has most of its field aligned with the shock normal. The time evolution of kinetic energy contained in the clump material has similar behavior as in the mixing ratio plot: the more the initial field lines are perpendicular to the shock normal, the less energy transferred from wind to clump.



References

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