Rethinking Ram Pressure Stripping of Elliptical Galaxies in Galaxy Clusters

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1. Introduction

We investigate how turbulent structures of interstellar medium (ISM) change ram pressure stripping of elliptical galaxies in galaxy clusters. First, we simulate ram pressure stripping with several different strengths of random acceleration to ISM. Second, we include weak magnetic fields in ISM and intracluster medium (ICM), and study the effects of magnetic fields on ram pressure stripping. In these simulations, we focus on changes with different strengths of ram pressure impacted by ICM.

Most previous simulations of ram pressure stripping assumed that the structure of ISM is smooth even though real structure of ISM must be turbulent and weakly magnetized. Our new simulations present different views of ram pressure stripping with more realistic turbulent structure of ISM.

2. Method

We use FLASH3 code with its unsplit staggered mesh hydro and magneto-hydro solver. The simulations include a stationary gravitational field produced by spherical distributions of stellar mass $10^{11} \mathrm{M}_{\odot}$ with the same amount of dark matter halo mass inside a stellar effective radius 3 kpc. Simulations are described in the rest frame of a galaxy. We assume that the gravitational field is truncated at 100 kpc where the distribution of ISM is also initially truncated.

For a constant density $\sim 3 \times 10^{-28}\ \mathrm{g\ cm^{-3}}$ and temperature $\sim 2 \times 10^{7}\ \mathrm{K}$ of ICM, we setup the initial distribution of ISM to be a hydrostatic configuration. But this initial configuration is stirred for 0.5 Gyr before inflow of ICM starts to enter a simulation domain. We test three different inflow velocities with Mach $\sim$ 0.5 (M0p5), 1 (M1), and 2 (M2). We also varies the energy randomly isotropically injected by the stirring process from 2.5×10^{-7} (E1) to 2×10^{-6} (E4) $\mathrm{g\ cm^{2}\ s^{-2}}$ on a scale around 8 kpc.

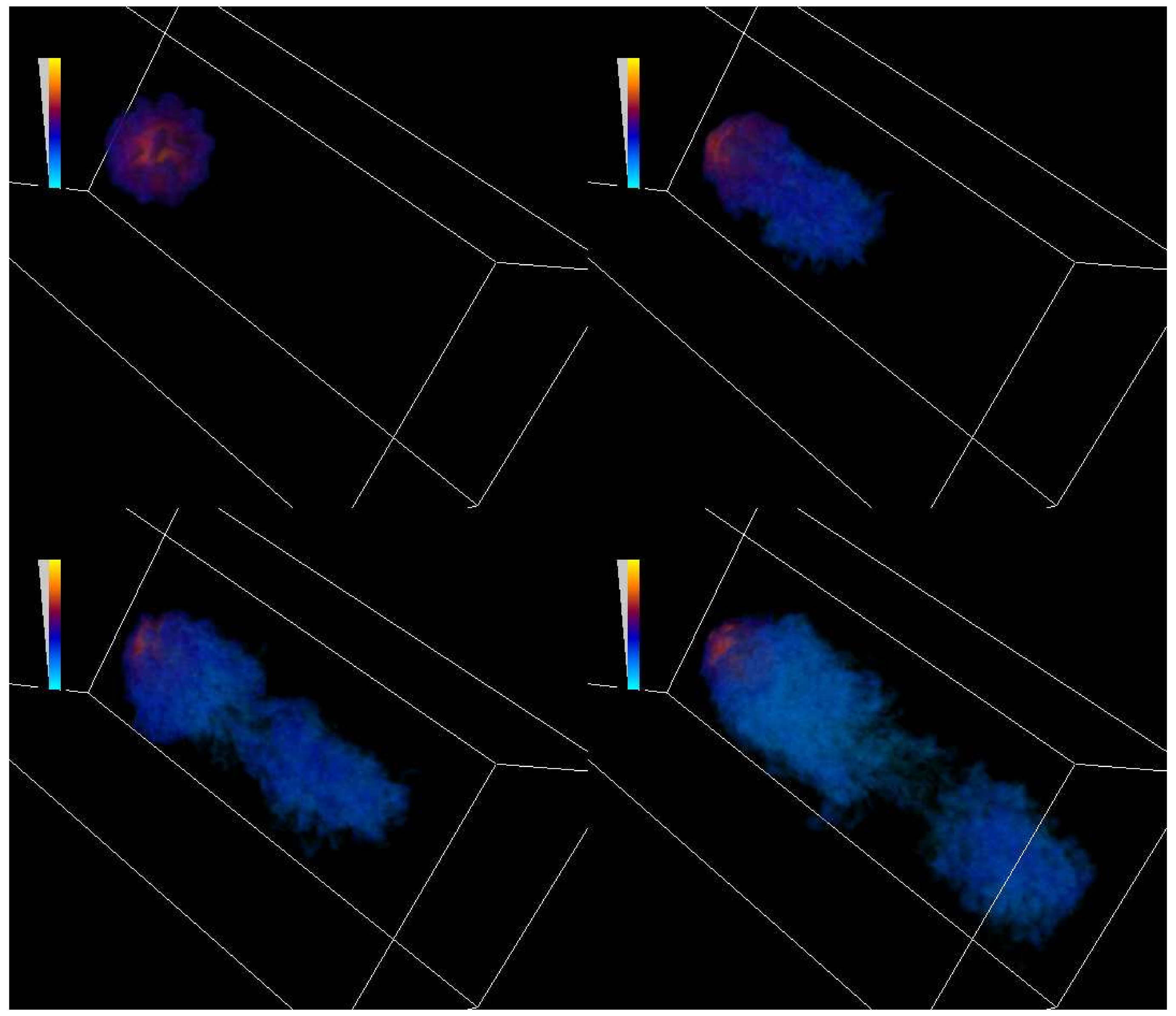

Figure 1. Distribution of ISM density in the simulation with M0p5 and E3 conditions. Clockwise, from top left, each panel corresponds to t $\sim$0.75, 2.5, 4, and 6 Gyr. Here, the ram pressure of ICM starts to affect the galaxy at t $\sim$0.8 Gyr.

3. Results

Stripping efficiency and shape for different turbulence strengths

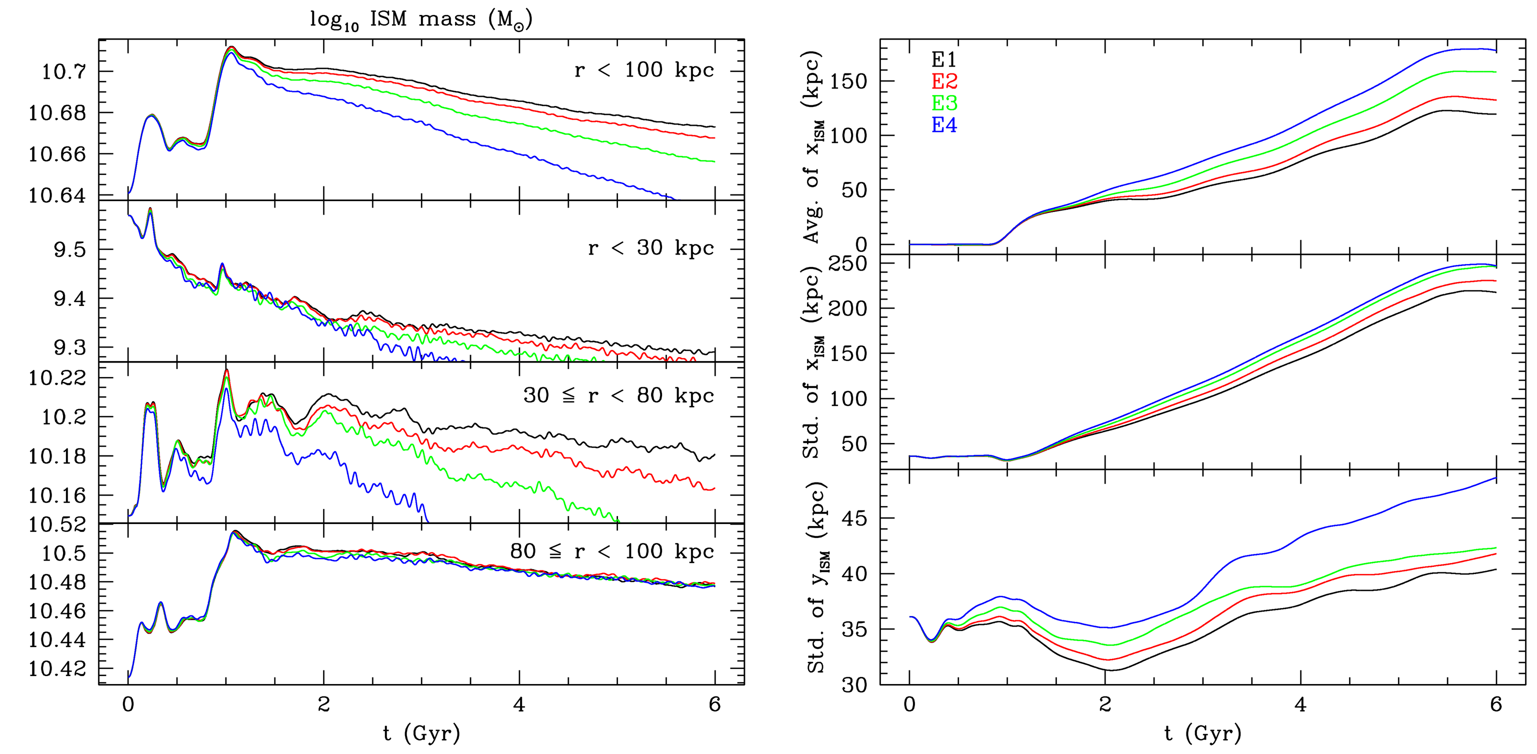

Figure 2. In the left panel, the changes of ISM mass are presented for the entire region, i.e. r $<$ 100 kpc, and for other three ranges. Different colors correspond to simulations with different injection energy from E1, i.e. less turbulent run, to E4, i.e. more turbulent run. The right panel shows the average position of ISM along x-axis and its standard deviation as well as standard deviation along y-axis. Here, the velocity of the inflow is Mach $\sim$ 0.5 in all cases.

Figure 2 shows that ISM with a weak turbulent structure can survive longer against ram pressure stripping than that with a strong turbulent structure. It is also found that the tail structure produced in simulations with a strong turbulent structure is wider than that with a weak turbulent structure. Figure 3 further shows this difference.

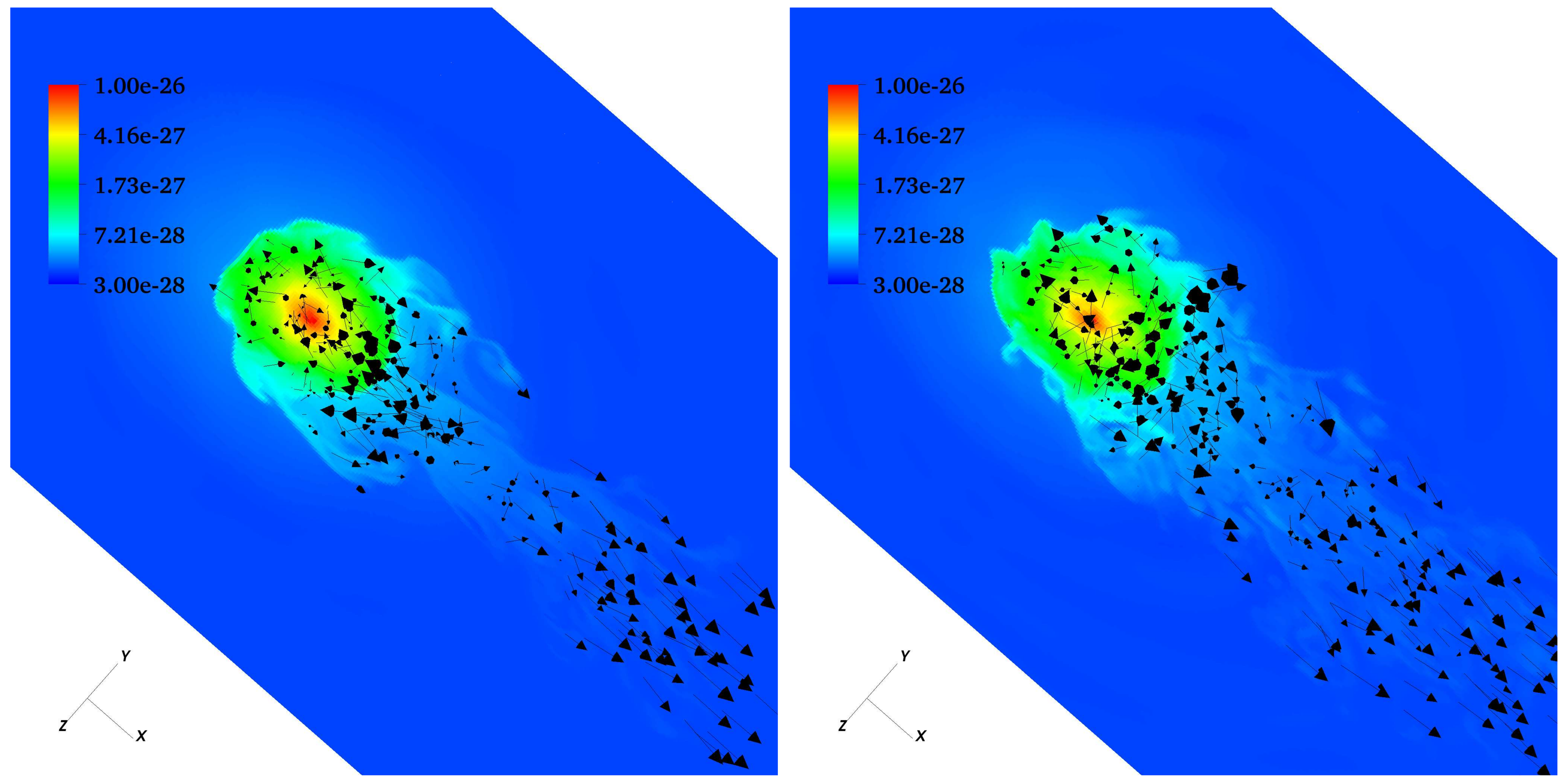

Figure 3. Distribution of density and ISM velocity field at $t \sim 2.5$ Gyr. In the run with the condition E1 (left), the high density tail is more narrow than that found in the run with the condition E4 (right). Black arrows represent velocity field of ISM.

Stripping for different strengths of ram pressure

In all simulations, turbulence is sub-sonic with Mach numbers ranging from about 0.07 (E1) to about 0.16 (E4). The inflow velocities of ICM are much higher than the strength of turbulence with Mach $\sim$ 0.5, 1, and 1.5, dominating the resistance of turbulent pressure against ram pressure.

We find that the change of stripping efficiency and shape is more significantly changed by the inflow velocities of ICM than varying the strength of turbulence.

Effects of turbulent magnetic fields

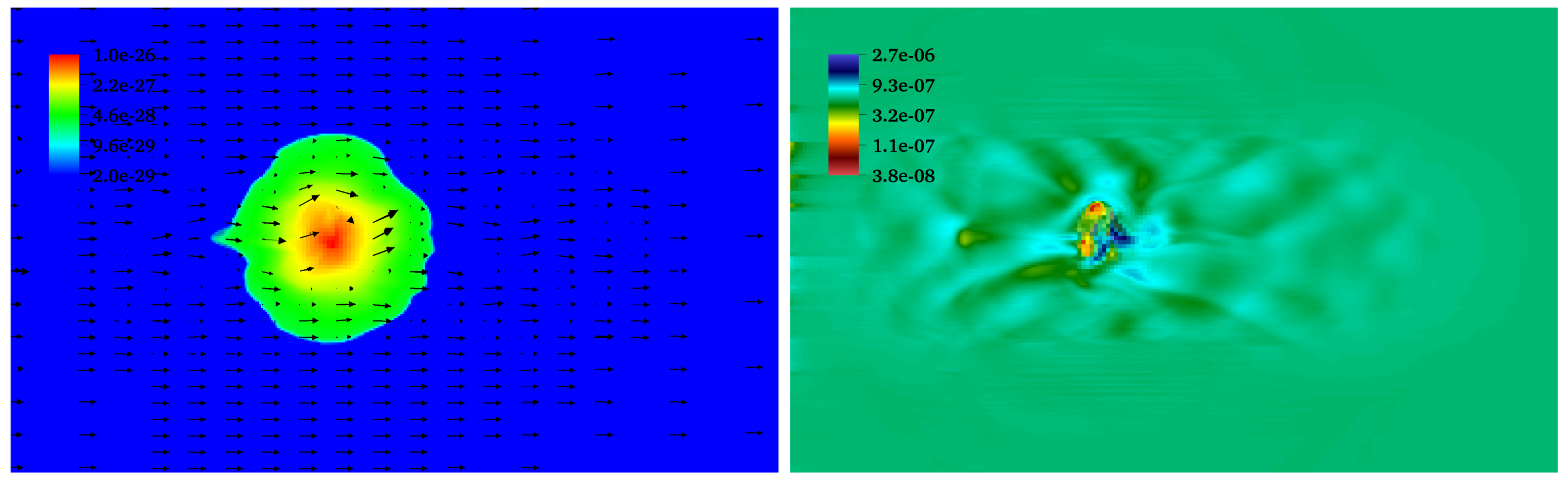

Figure 4. Magnetic field (arrow) and ISM density distribution (left) and the magnitude distribution of the magnetic field (right) at $t \sim$ 0.7 Gyr in the run with E4 and M1 conditions. We initialize magnetic field uniformly in a simulation box. But because we produce turbulent motion inside the galaxy, plasma beta is around 10^{-4} in ISM and is lower in ICM.

A main difference of including magnetic field effects in ram pressure stripping is the shape of the tail structure behind the galaxy as shown in Figure 5.

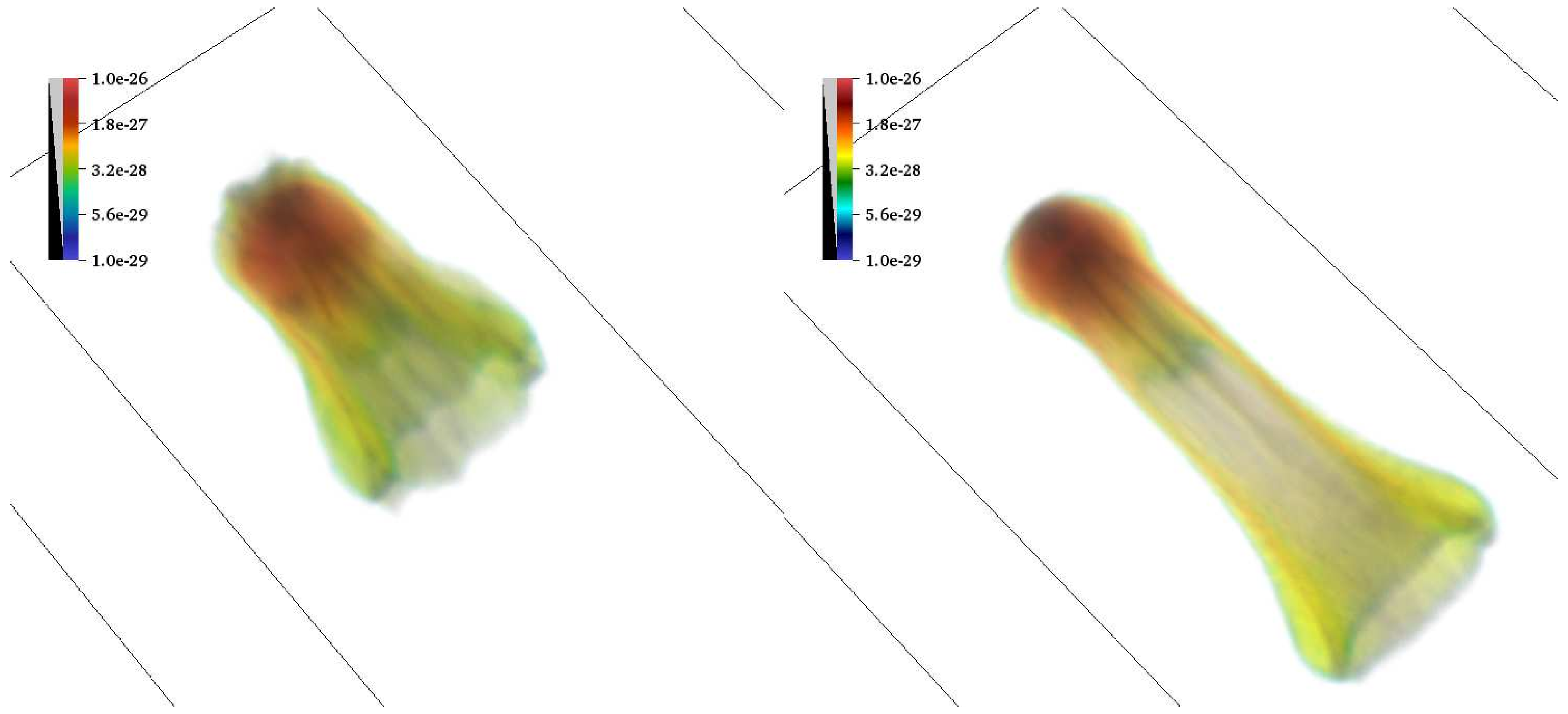

Figure 5. Distribution of ISM density at $t \sim$ 1.95 Gyr for E4-M0p5 run (left) and E1-M1 run (right). The spatial distribution of ISM stripped from the galaxy is highly aligned with the direction of the ambient magnetic field and the inflow.

The tail structure is also more regular with the effects of magnetic fields. We also find that the tail structure is longer with magnetic fields compared to the results without magnetic fields. However, the galaxy can keep more ISM inside it with magnetic fields although runs with magnetic fields loose more ISM than that without magnetic fields in the early phase of ram pressure stripping.

4. Conclusion

Our simulations explore how turbulent structures of ISM affect ram pressure stripping. Sub-sonic turbulent structures of ISM produce more fragile structure, resulting in the increasing loss of ISM by stripping. But turbulent magnetic fields of ISM suppress stripping, and produce the smooth shape of tails.

We will present simulation results with different configurations of magnetic fields in separate papers. Combining both ICM and ISM turbulences together will be investigated too.