Investigating Cold Gas Filaments in Cool-core Clusters

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Abstract

- **Aims.** Cold gas ($T\sim10^4$ K) nebular structures with optical emissions were found around central regions of some cool-core (CC) galaxy clusters. We wish to compare the results between the observation of CC clusters and our simulation in order to interpret the dynamics of cold gas in the clusters.
- **Methods.** We perform hydrodynamic simulations with two different configurations of gas properties, modeling cold gas as "Brick" or "Mist" to trace gas kinematics using the initial condition of the Perseus cluster.
- **Results.** The Mist simulation run, which assumes lighter cold gas, shows larger variations in both line-of-sight (LOS) velocity and velocity dispersion evolution, while the Brick simulation shows very quiescent gas velocities.
- **Conclusions.** The Mist model, which assumes that cold gas dynamics is coupled with the hot gas motions, is more consistent with the observational data.

Introduction

- Multi-phase gas lives in CC galaxy clusters:
  1) **Intracluster medium (ICM, hot gas)**: diffuse and ionized gas, emitting X-rays with a temperature around 10^7 to 10^8 K
  2) **Cold gas**: $T\sim10^4$ K, formed through ICM radiative cooling, emitting transition lines in optical wavelengths, e.g., $H\alpha$, [O II]
- Gas properties and interactions between different phases are not well understood yet. Therefore, we study the **velocity** and **velocity dispersion** of cold gas and compare the results with the latest observations.

Methods

- Our simulation used the FLASH code with adaptive mesh refinement (AMR) with 1 Mpc simulation box and the initial condition of the Perseus cluster. (Wang & Yang, 2022)
- Set up two simulations with different models of the cold gas:
  1) **Brick simulation**: gas motions and interactions follow hydrodynamic equations, representing heavier cold gas clouds that are dynamically coupled to hot gas.
  2) **Mist simulation**: cold gas clumps are removed from the grid and replaced by a tracer particle representing lighter, passively evolving cold gas mists that are unresolved in the simulations.

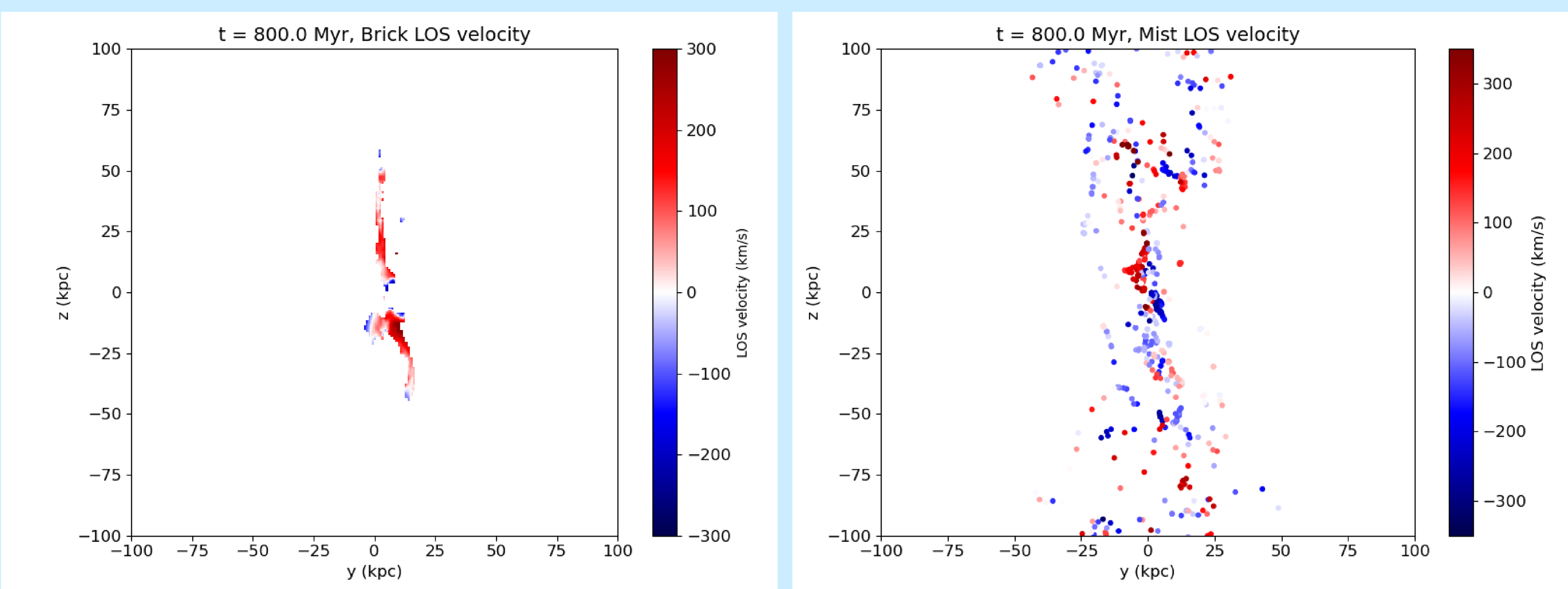

Figure 1. Cold gas LOS velocity at t = 800 Myr, Left panel: the Brick simulation; Right panel: the Mist simulation

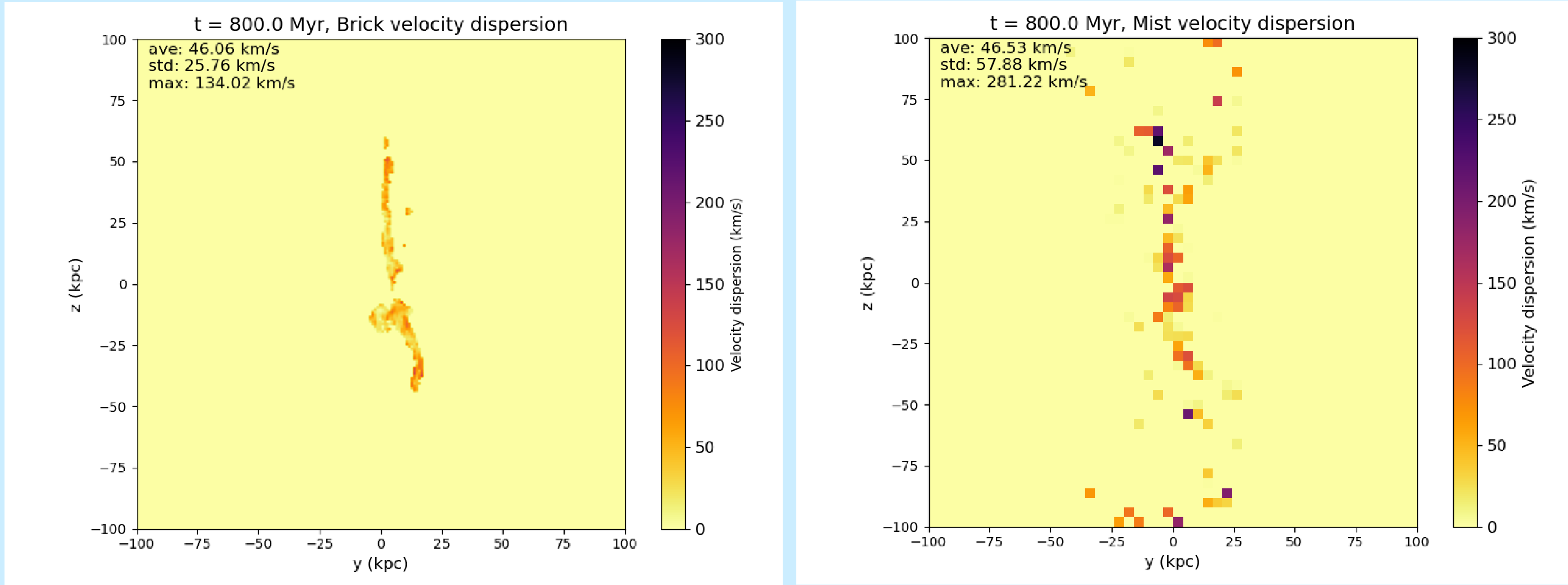

Figure 2. Cold gas velocity dispersion at t = 800 Myr, Left panel: the Brick simulation; Right panel: the Mist simulation

Results

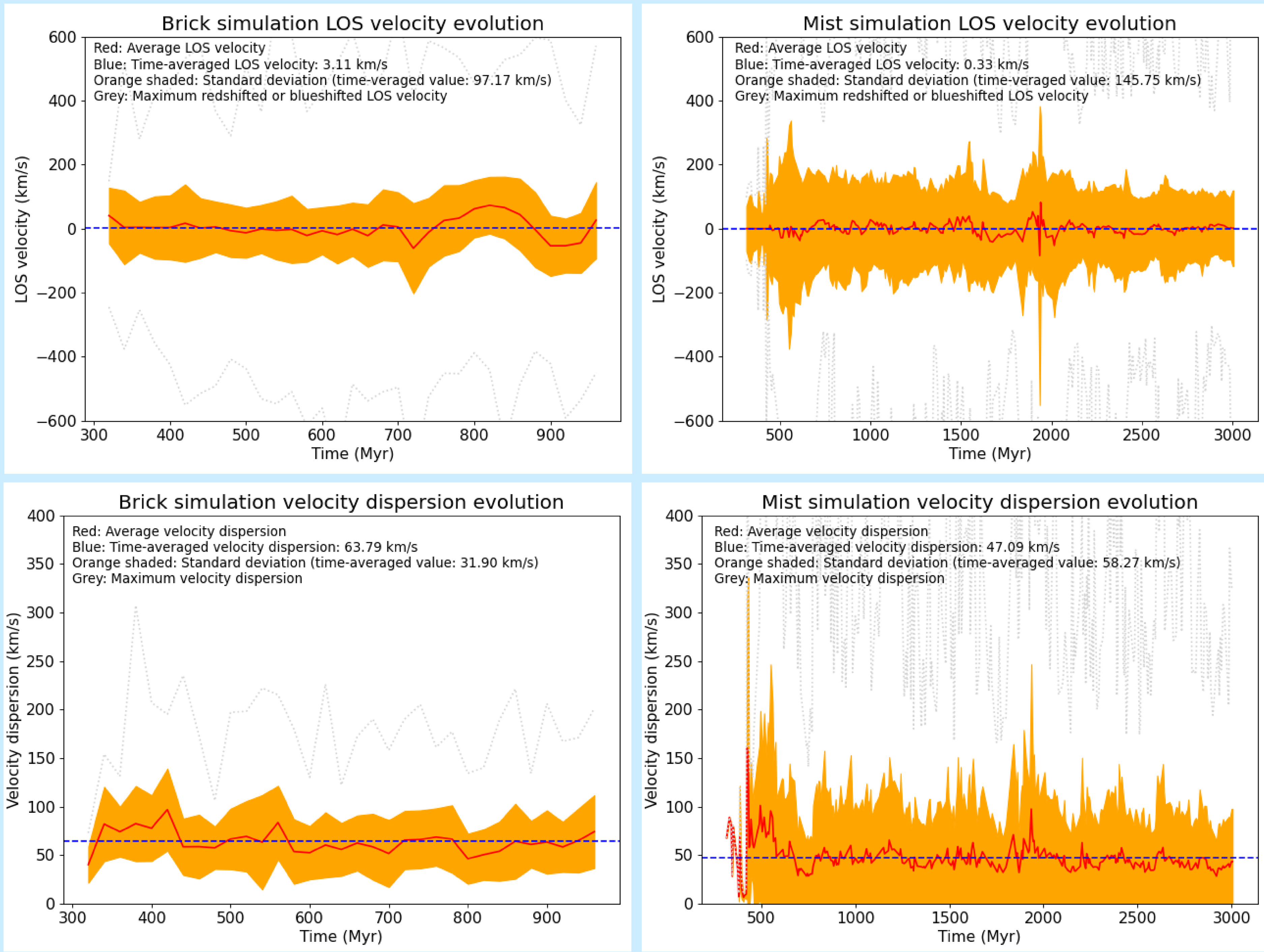

Figure 3. Evolution of LOS velocity (top) and velocity dispersion (bottom) for the Brick (left) and the Mist (right) simulations.

- In both runs, the time-averaged LOS velocity shows no difference, but the Mist simulation has a larger standard deviation and maximum LOS velocity, most consistent with the large LOS velocity (up to 600 km/s) in some observed CC clusters (Gingras et al, 2024).
- For velocity dispersion, the Mist simulation also holds a larger standard deviation and maximum values. While the low velocity dispersion in both runs is consistent with some quiescent clusters (e.g., the Perseus, Vigneron et al, 2024), the Mist simulation could explain larger observed values (~ 400 km/s) in other clusters (Gingras et al, 2024).

Conclusions

- The gas kinematics in the Mist simulation can better explain observations in CC clusters, implying that the cold gas should be modeled with "Mist", which passively follow the ICM motions.

References

[1] Wang & Yang, 2022, MNRAS, 512, 5100

[2] Gingras et al, 2024, ApJ, 977, 159

[3] Vigneron et al, 2024, ApJ, 962, 96