Simulating AGN feedback in galaxy clusters with pre-existing turbulence

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Abstract

Active galactic nuclei (AGN) feedback's role in suppressing cooling flows in cool-core clusters is acknowledged, but the primary heating mechanism of AGN jets is debated. One potential heating mechanism is heating caused by turbulence induced by AGN jet-inflated bubbles. However, there has been disagreement between simulation and observational studies. Therefore, the goal of our study is to elucidate this discrepancy using 3D hydrodynamic simulations including both AGN feedback and pre-existing turbulence. Our results indicate that turbulence has a limited impact on entropy. We found that the observed line-of-sight velocity dispersion (σ_{LOS}) could overestimate the true velocity dispersion (σ_k), thus providing an explanation for the discrepancy between the simulated and observationally inferred turbulent heating rates. Leveraging new XRISM data, our research provides key insights into the long-standing problem of AGN heating in clusters.

Simulations

- We carry out 3D hydrodynamic simulations of AGN feedback using the FLASH code.
- To simulate the pre-existing turbulence, we follow the Ornstein-Uhlenbeck process which drives the time-correlated acceleration field.
- Since we want to know more about turbulent heating effects in the cluster, we compare three different runs:

Label	Jet active	Pre-existing turbulence
Fiducial	True	True
NoJet	False	True
NoTurb	True	False

Table 1. List of simulations parameter variations.

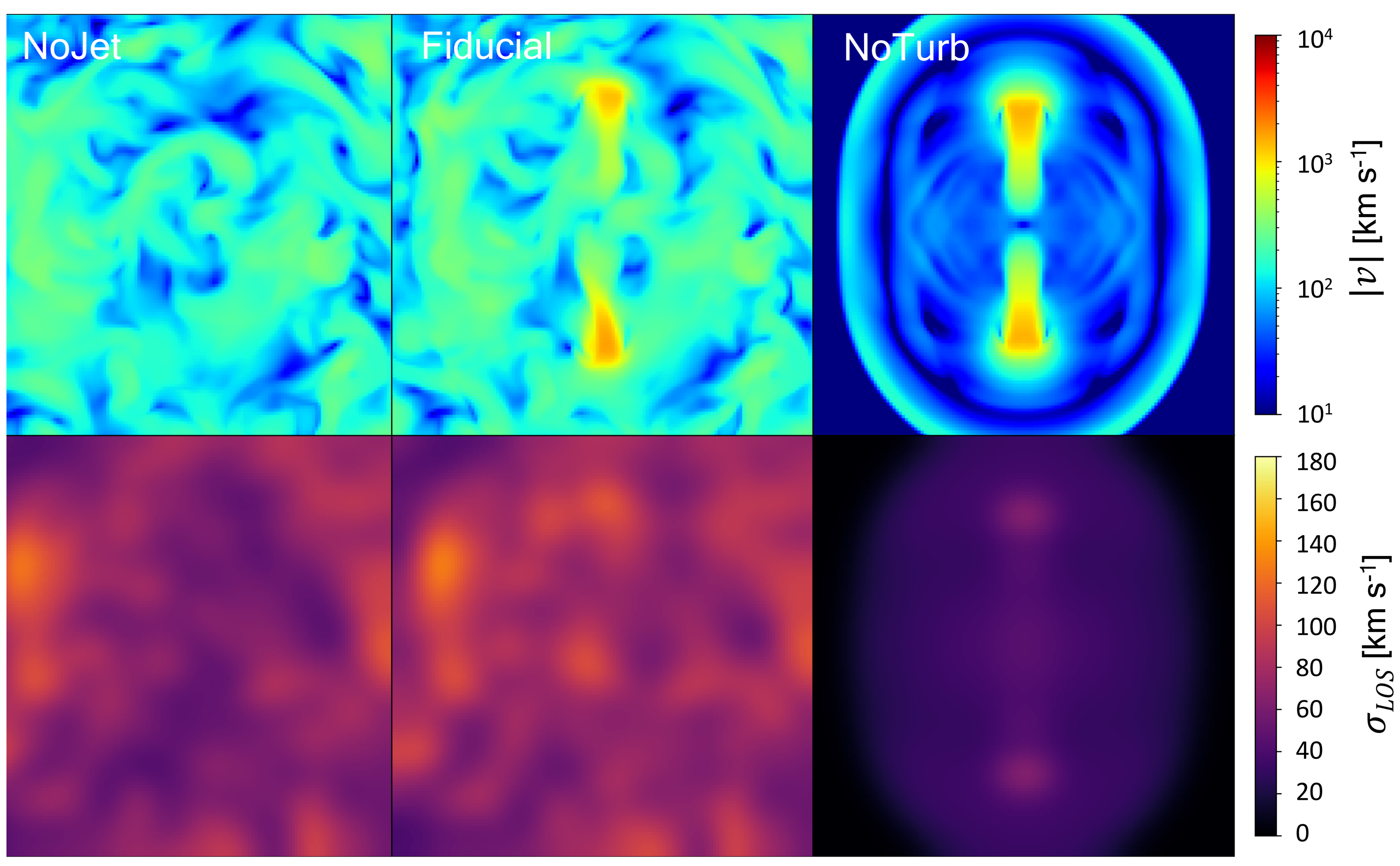

Fig 1. Columns from left to right are NoJet, Fiducial, and NoTurb. The first row shows thin projections (4 kpc) of the velocity magnitude $|v|$ weighted by density. The second row shows velocity dispersion weighted by X-ray emissivity along the line of sight (σ_{LOS}). Displayed images are 132 kpc on a side.

Results & Discussion

- From Figure 2, we found that the entropy profiles of the three runs are almost the same, which means that the turbulence does not affect heating significantly.

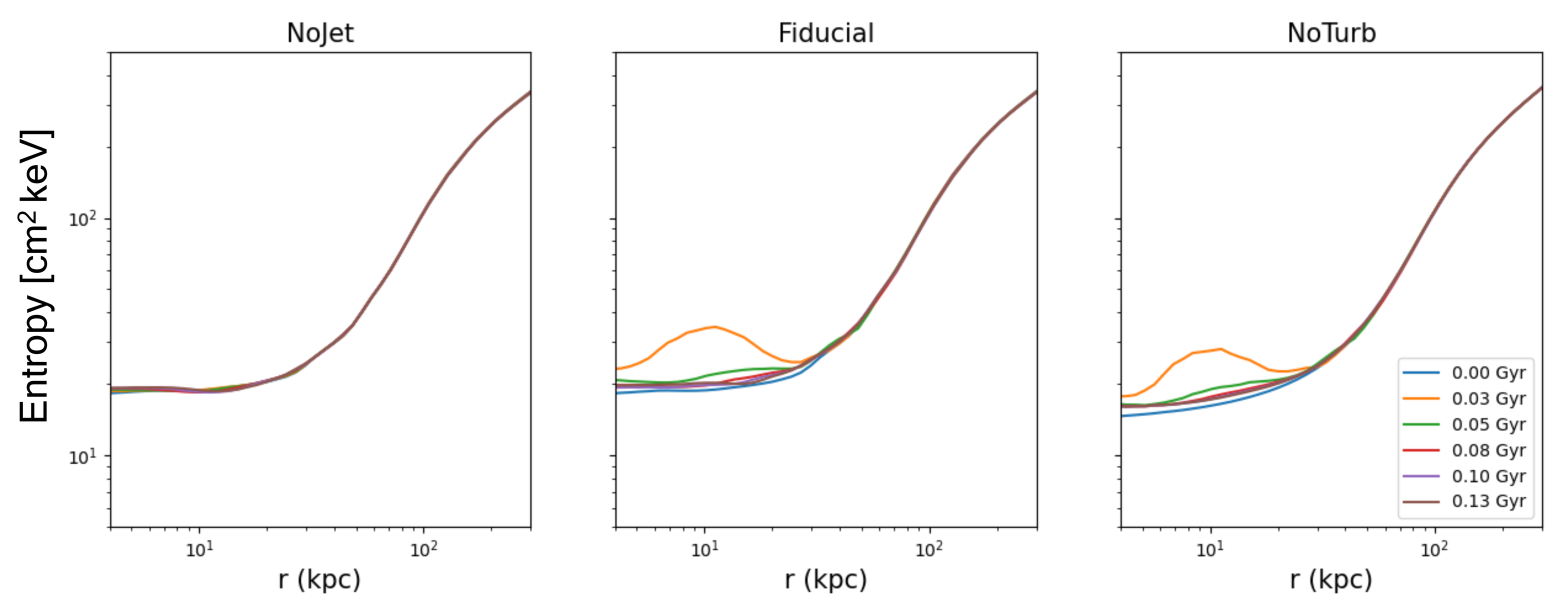

Fig 2. The evolution of the entropy profile after the jet ejection.

- Figure 3 shows that when σ_{LOS} is comparable to the Hitomi observed level, but σ_k is significantly lower than it.
- Since the turbulent heating rate $Q \sim \rho\sigma_l{}^3/l$ (where ρ is the density, l is the turbulence driving scale, and σ_l is the turbulence velocity dispersion at that driving scale) is highly sensitive to the velocity dispersion, this could be a potential explanation for the persistent inconsistency between observations and simulations.

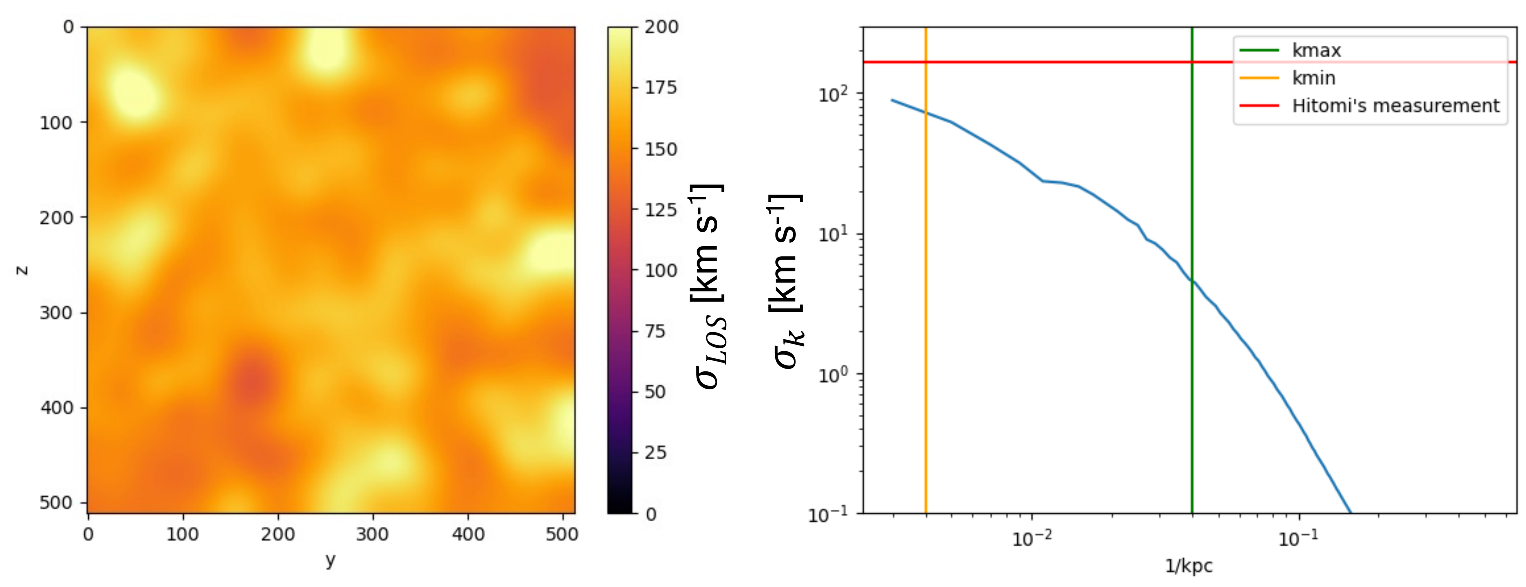

Fig 3. Left figure: LOS velocity dispersion σ_{LOS} in units of km/s. Right figure: velocity dispersion in k-space σ_k in km/s, which was obtained by using Fourier analyses.

Future Works

- Compute the velocity structure function in the simulation for comparison with observational data.
- Quantify the turbulent heating rate to assess its potential to counteract radiative cooling while attempting to constrain the turbulence driving scales.

Conclusions

- Although the velocity field is dominated by pre-existing turbulence (Fig. 1), the results we got from Figure 2 indicate that the heating from turbulence seems to be subdominant.
- The discrepancy between σ_{LOS} and σ_k is likely to be the reason for the long-standing inconsistency between simulations and observations.

Reference

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