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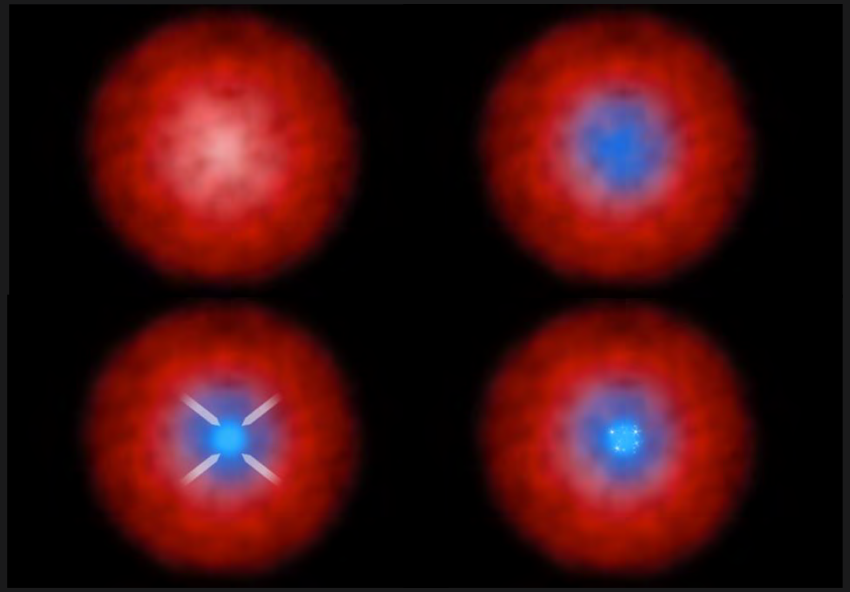
Simulating feedback from active galactic nuclei in galaxy clusters with pre-existing turbulence

Jia-Lun Li, Hsiang-Yi Karen Yang
National Tsing Hua University (NTHU)

arXiv

Cooling Flow Problem

- Radiative cooling rate: $L_x \propto n^2$
- Cool-core clusters: $t_{cool} << t_{Hubble}$
- Massive gas inflows and high SFR
  → absent in the observation

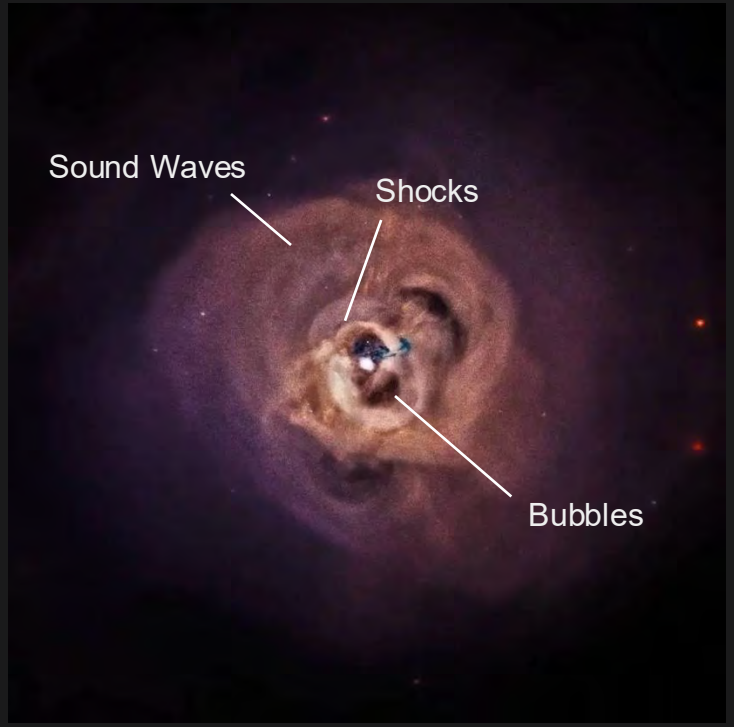


NASA/CXC/M.Weiss

AGN Feedback

Feedback from AGNs is believed to prevent catastrophic cooling in galaxy clusters.

- Mixing of ambient and bubble gas
- Weak shocks
- Sound waves
- Turbulence dissipation



X-ray: NASA/CXC/SAO/E.Bulbul, et al.

Motivation

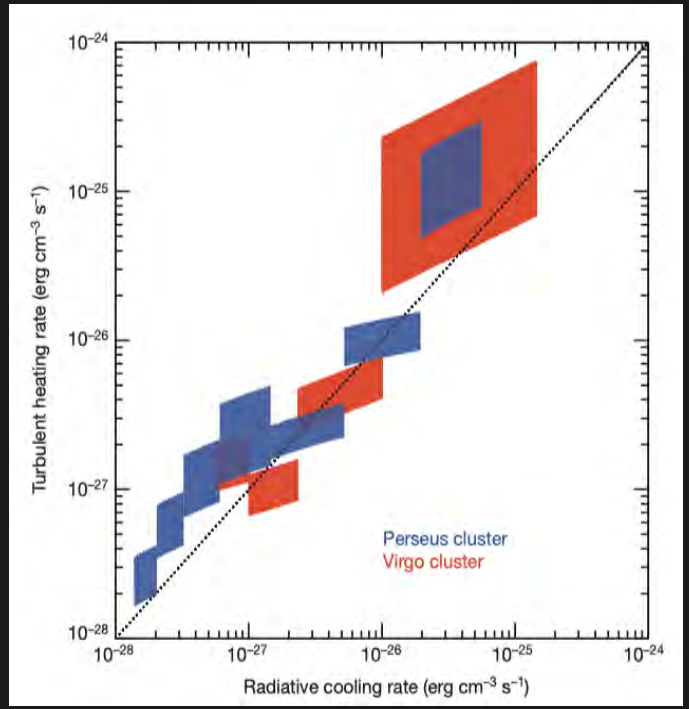
A long-standing debate: Whether turbulent heating alone can balance radiative cooling

Turbulent Heating - Observation

Zhuravleva et al. (2014)

- Chandra X-ray surface brightness fluctuations
- Assuming all density fluctuations are due to turbulence

⟶ Turbulent dissipation can balance radiative cooling

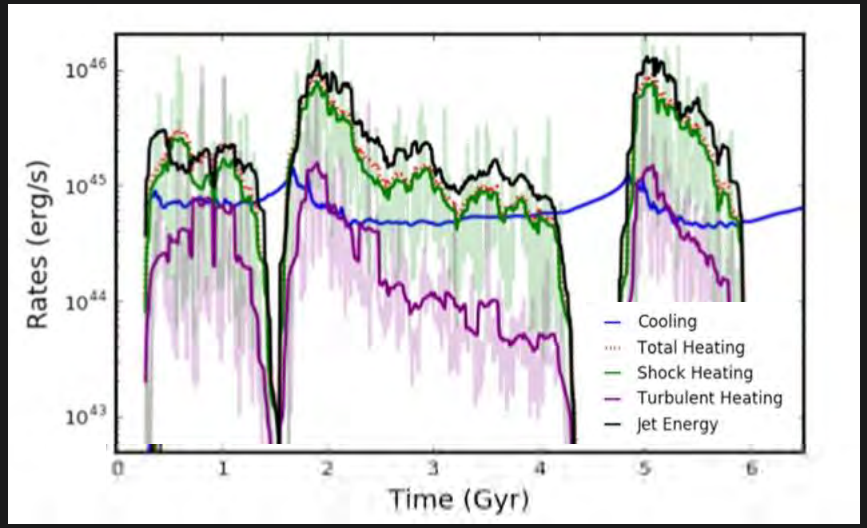


Zhuravleva et al. (2014)

Turbulent Heating - Simulation

- By simulating self-regulated AGN feedback, turbulent heating alone is insufficient to balance the radiative cooling is demonstrated

(Li et al., 2017; Yang & Reynolds, 2016; Mohapatra & Sharma, 2019 etc.)



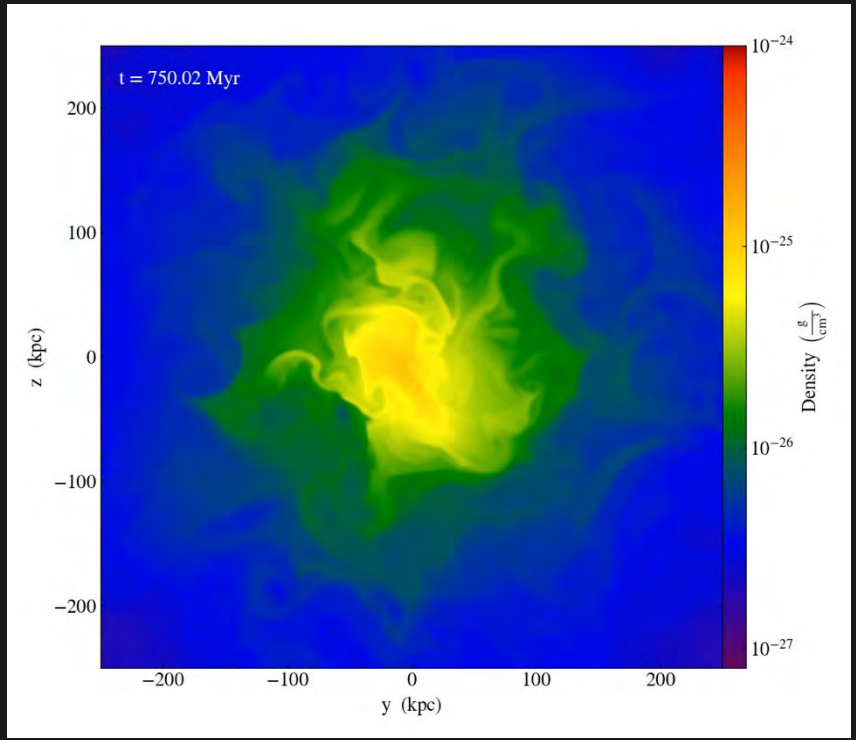
Li et al. (2017)

Why there is the discrepancy between the observation and simulations?

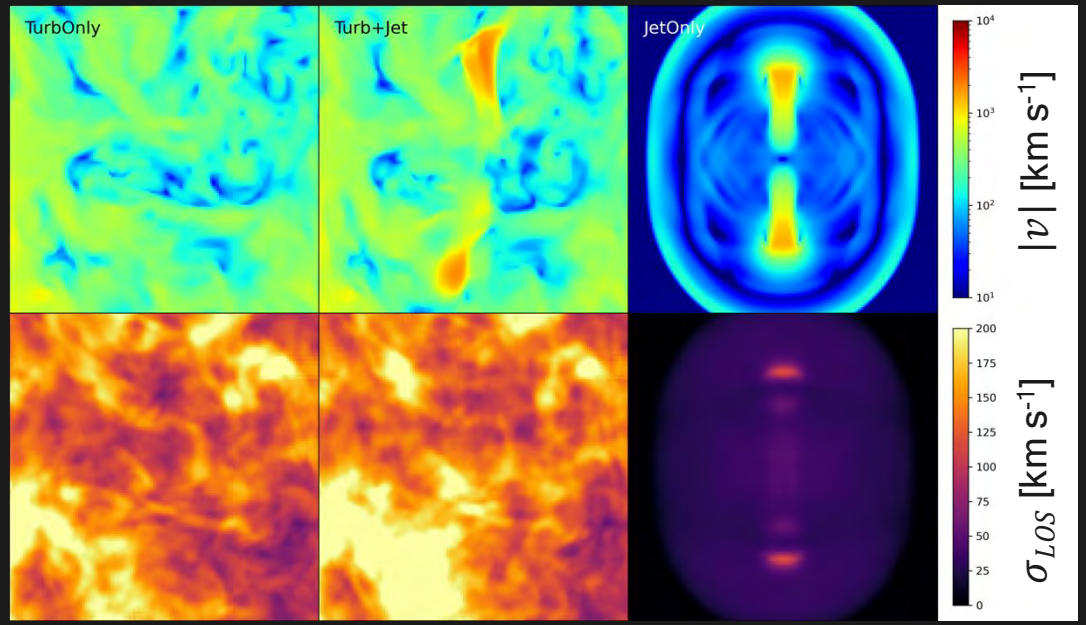
- Observation: the assumption may not be fully justified, as the density perturbation could be caused by multiple sources
- Simulation: previous studies didn’t consider turbulence arising from processes other than AGN activity

Methodology

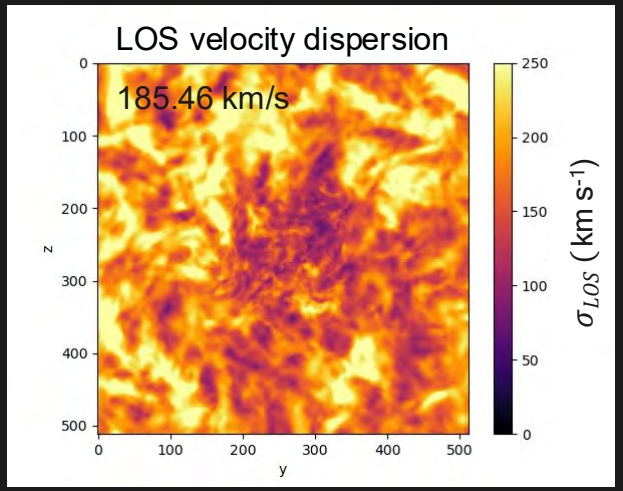
- 3D hydro simulation of Perseus-like cluster using the FLASH code
- Pre-existing turbulence: Ornstein-Uhlenbeck (OU) process
- Jet injected after pre-existing turbulence reaches steady state (t~1255 Myr)
- Single jet activity: bipolar, purely kinetic, duration time is 10Myr, jet power is 5×10^{45}erg/s



Three Sets of Simulations



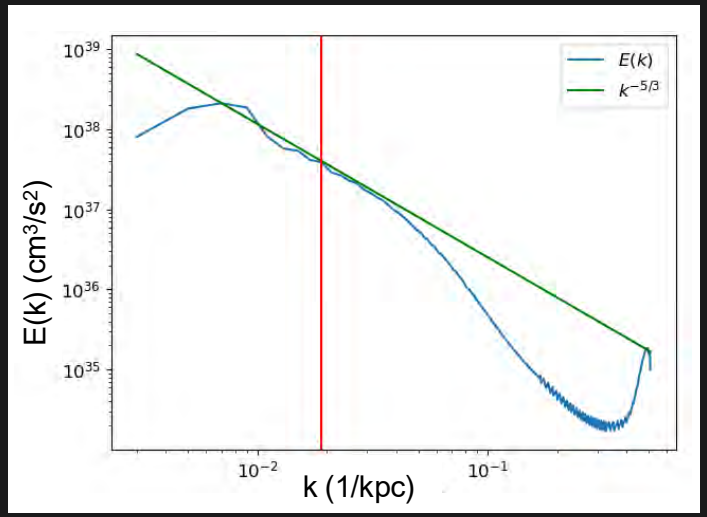
~1305Myr



- $\sigma_{LOS} = \sqrt{\langle {v_{LOS}}^2 \rangle - \langle v_{LOS} \rangle^2}$
- We chose the setting where σ_{LOS} is comparable to the Hitomi observed level (Hitomi Collaboration, 2016)

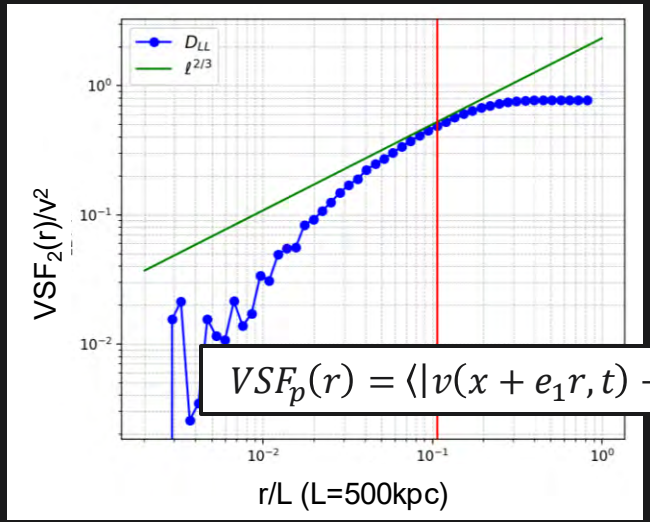
Computing Turbulent Heating Rate

Kolmogorov energy spectrum



$$E(k) \propto \varepsilon^{2/3} k^{-5/3}$$

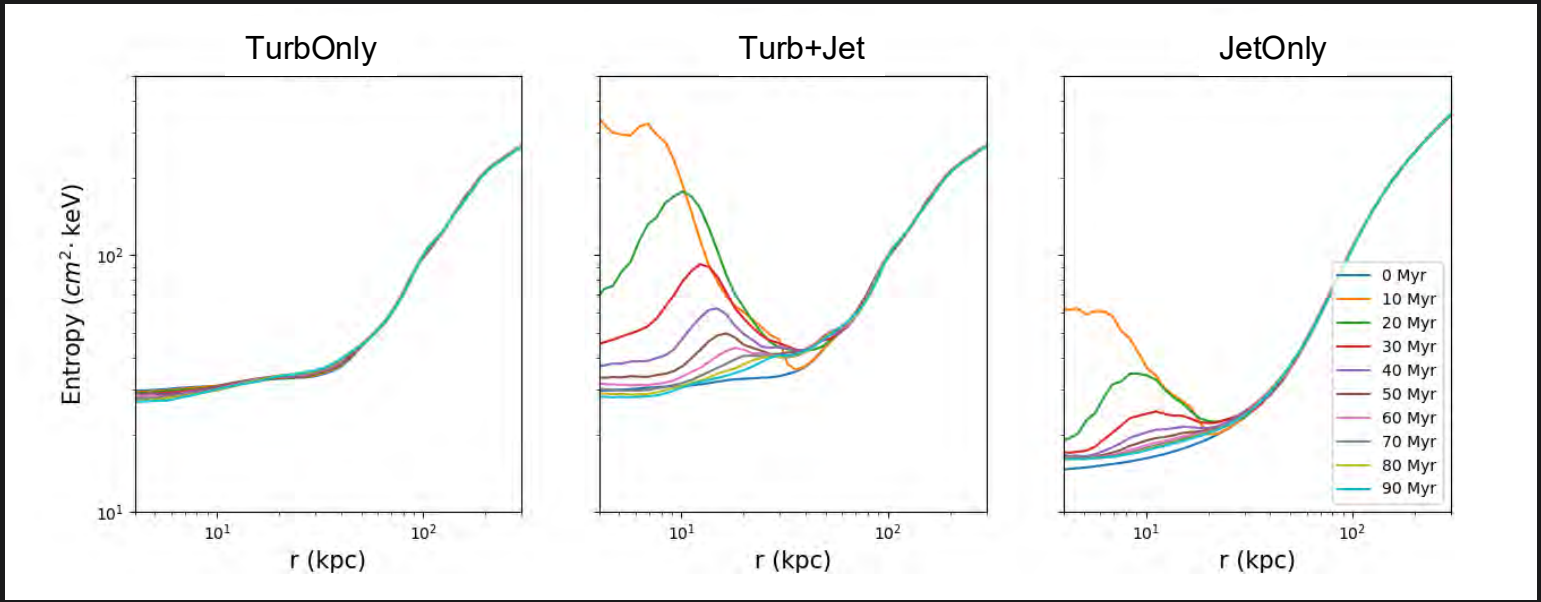
Velocity Structure Function



$$VSF_p(r) = \langle |v(x + e_1 r, t) - v(x, t)|^p \rangle$$

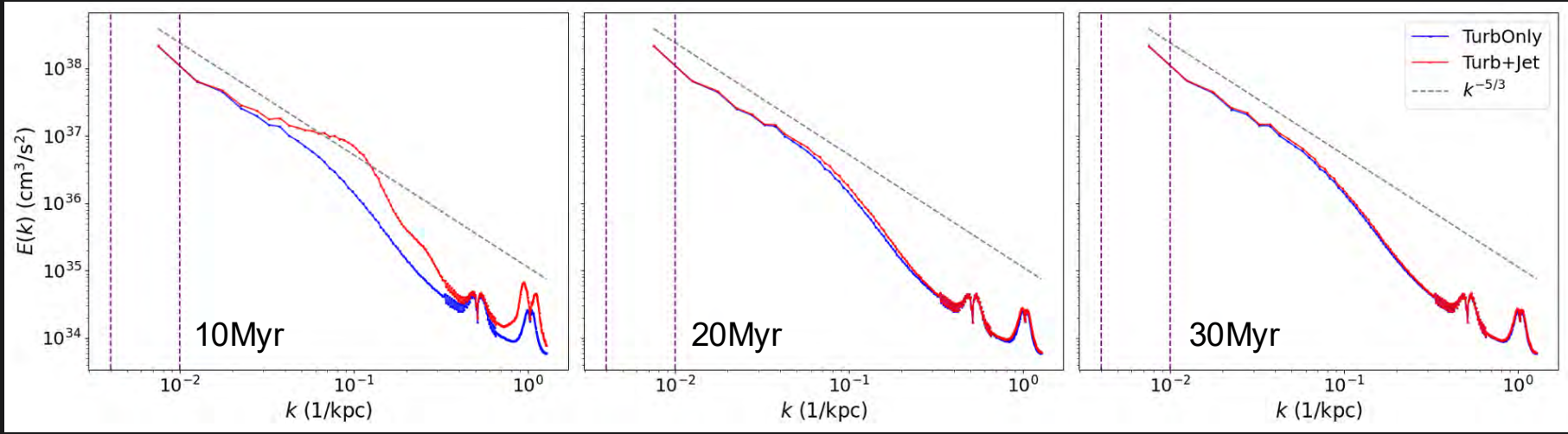
$$VSF_2 \propto \varepsilon^{2/3} l^{2/3}$$

Entropy Profile



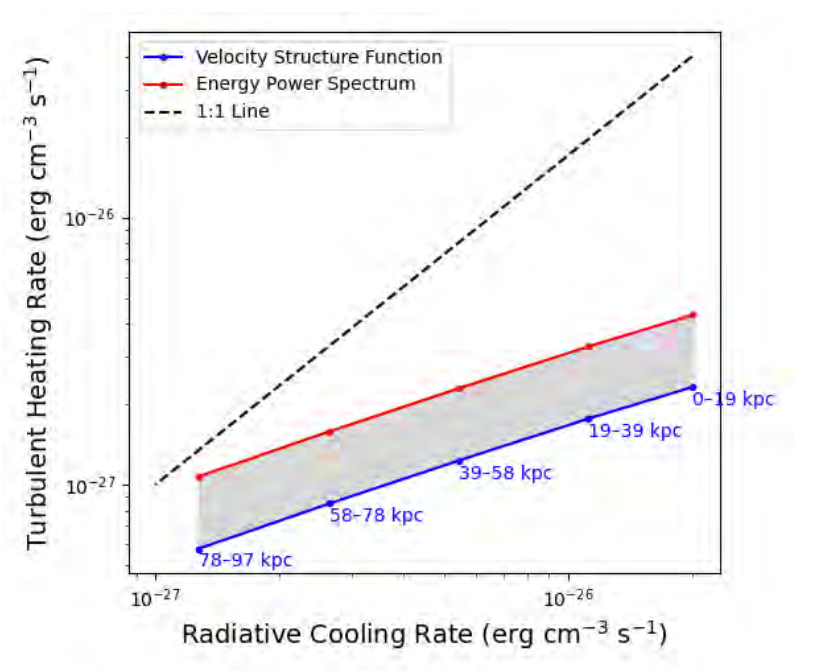
- Entropy $K = k_B T / {n_e}^{2/3}$
- The entropy profiles of the Turb+Jet run and JetOnly run are almost the same, which means that the turbulence does not affect heating significantly

Assessing the Jet's Contribution to Turbulence



- The rapid disappearance indicates that the impact of the jet on the power spectrum is short-lived → Not real turbulence
- In our simulation, the AGN jet is an inefficient driver of sustained turbulence

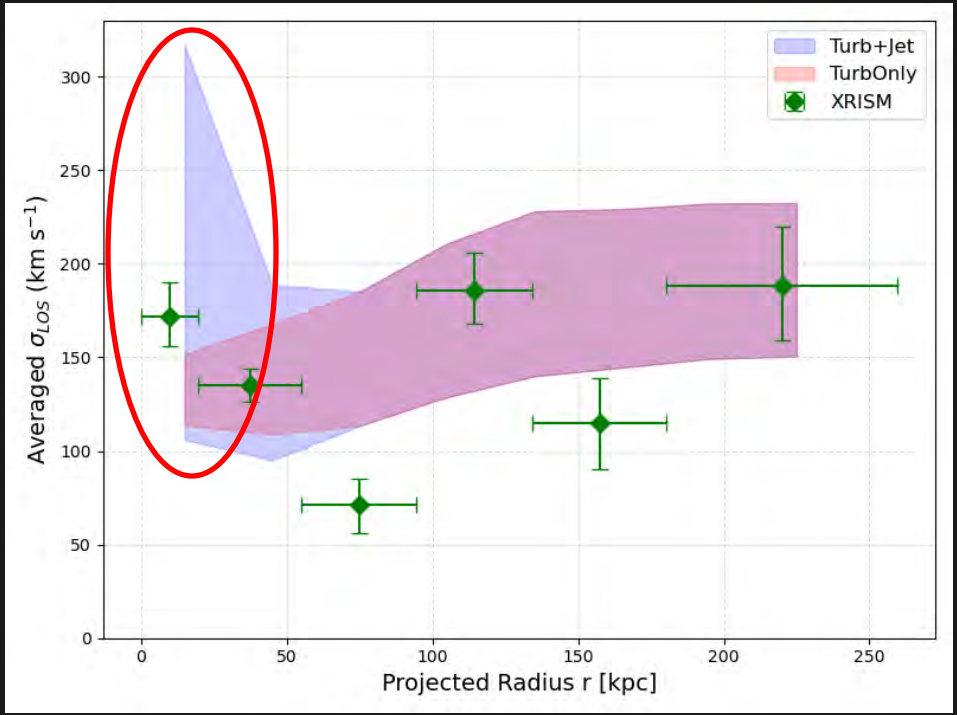
Turbulent Heating Rate - TurbOnly



$$Q_{turb} = \rho_0 C_Q V^3 / l$$

- Our result suggests that turbulent heating in the cluster center is not sufficient to balance cooling

Compare with XRISM



- Interpreting the enhanced σ_{LOS} as turbulence would overestimate the true turbulent heating rate

Conclusion

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- The velocity field is mainly governed by pre-existing turbulence
- However, our results show that jet heating remains dominant
- Our results suggest that turbulent heating may be subdominant in the central region, which is consistent with previous simulation studies
- The enhanced σ_{LOS} near the cluster center is due to a transient, unresolved coherent bulk motion driven by the jets, not sustained turbulence