Modeling AGN Jet Feedback in Galaxy Cluster Simulations

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Introduction

- The cold gas formation rate at the centers of 'cool core' galaxy clusters is much smaller than expected based on X-ray luminosity. Some type of distributed heating is required
- Feedback from Active Galactic Nuclei (AGNs) is considered the main mechanism
- The wide range of length and time scales involved makes it a challenging problem
- Sub-grid physics is needed in simulations of AGN feedback
- Key Questions:
  - How can energy be deposited in a distributed manner?
  - How can the observed structures be explained?
  - Why is there cool-core/non cool-core dichotomy?
  - How is feedback regulated?

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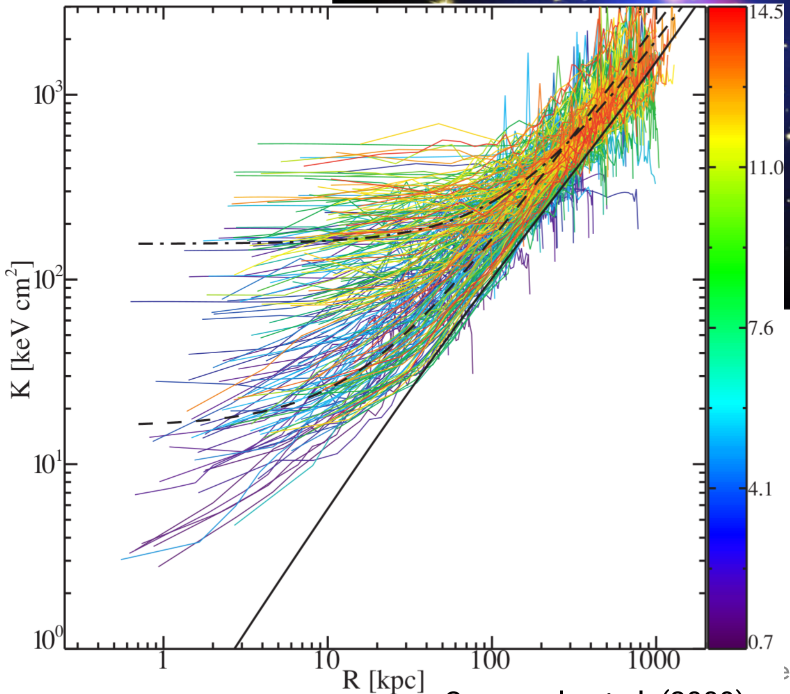

Cavagnolo et al. (2009)

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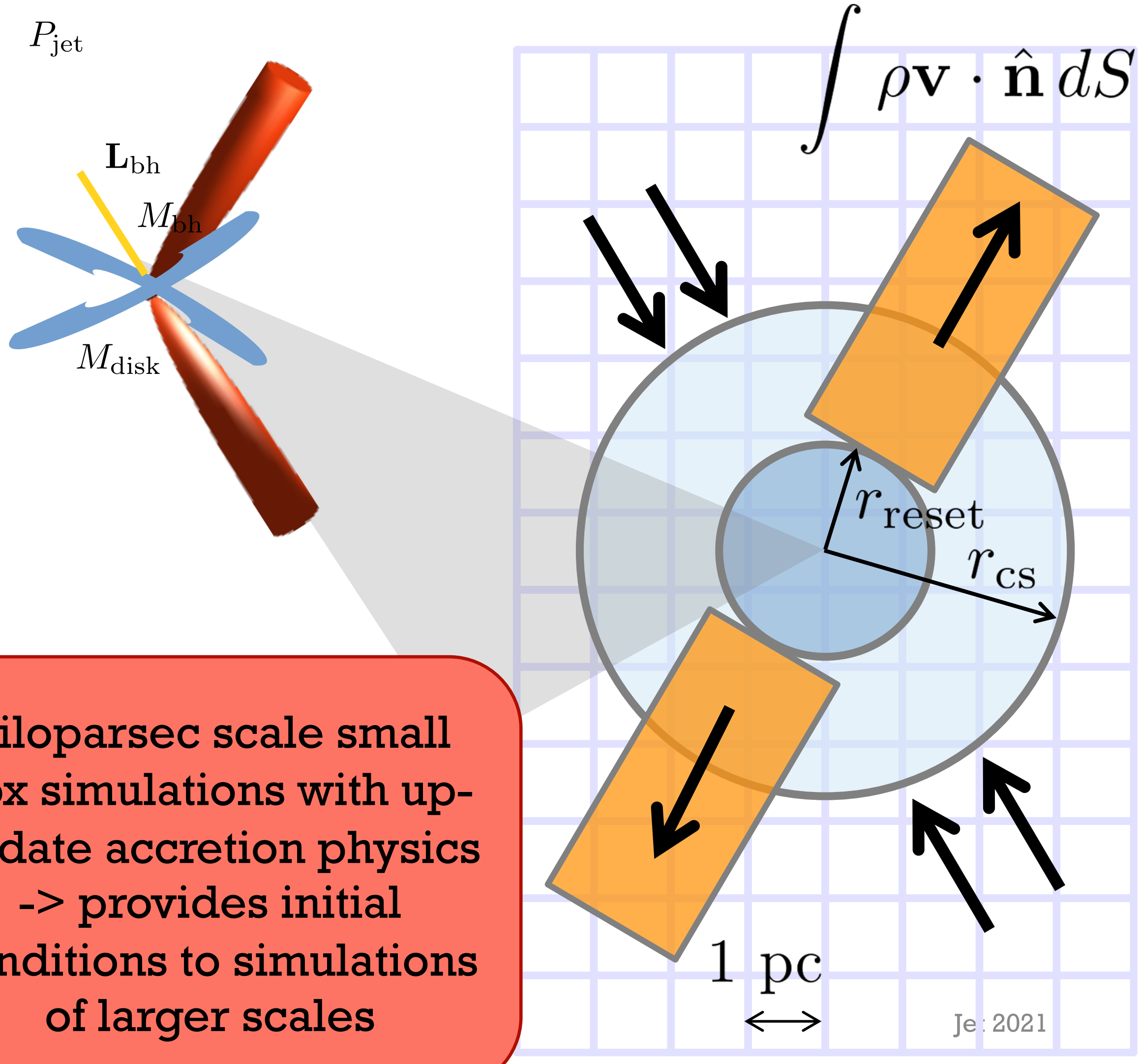
Physical Picture: Chaotic Cold Accretion

- Thermal instability drives accretion
- Accretion produces feedback in forms of jets/winds
- Feedback entrains gas that becomes thermally unstable
- Thermodynamic regulation of gas in cluster simulations requires phenomena operating on milliparsec scales

Novel Modeling Approach

- Measure accretion rate through a control surface
- Update associated 1D BH+disk model
- Kernel reset to remove accreted gas (sink particle approach)
- Impose feedback via injection cone/cylinder
- Allow the jet to precess with precession angle and period as input parameters



Kiloparsec scale small box simulations with up-to-date accretion physics -> provides initial conditions to simulations of larger scales

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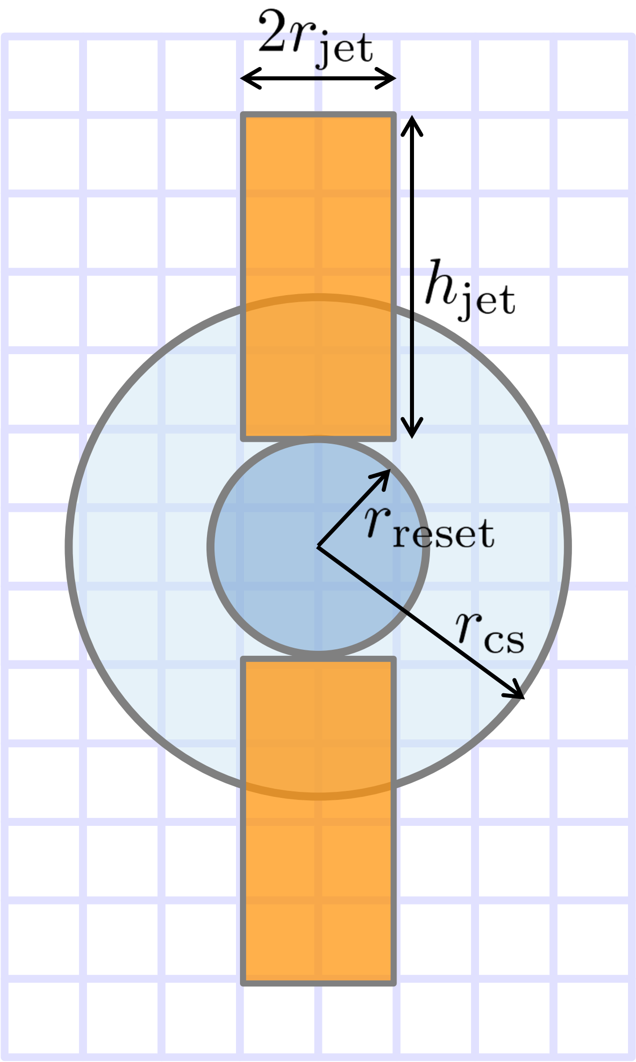
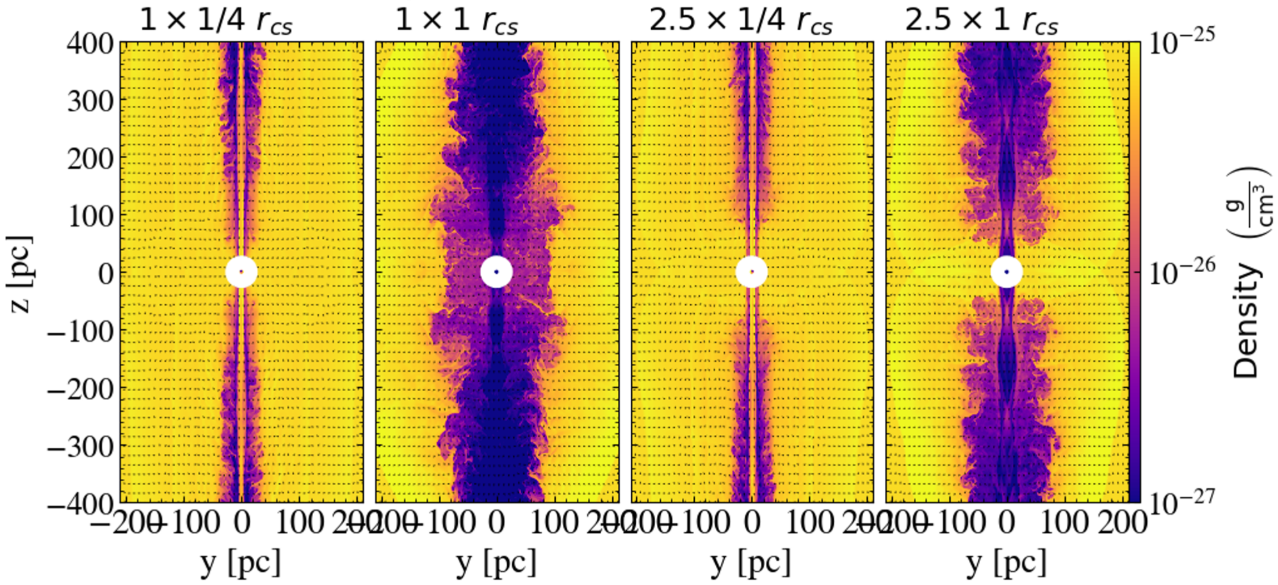


- Test model with different resolutions and jet sizes
- Properties including accretion rates, feedback energy, shocked volume, and amount of entrained mass show good convergence behavior with resolution
- To reproduce some of the shock structures and fluid instabilities, a short, fat jet injection region is favored

Implementation in FLASH



Lü & Ricker (2021)

Jet 2021

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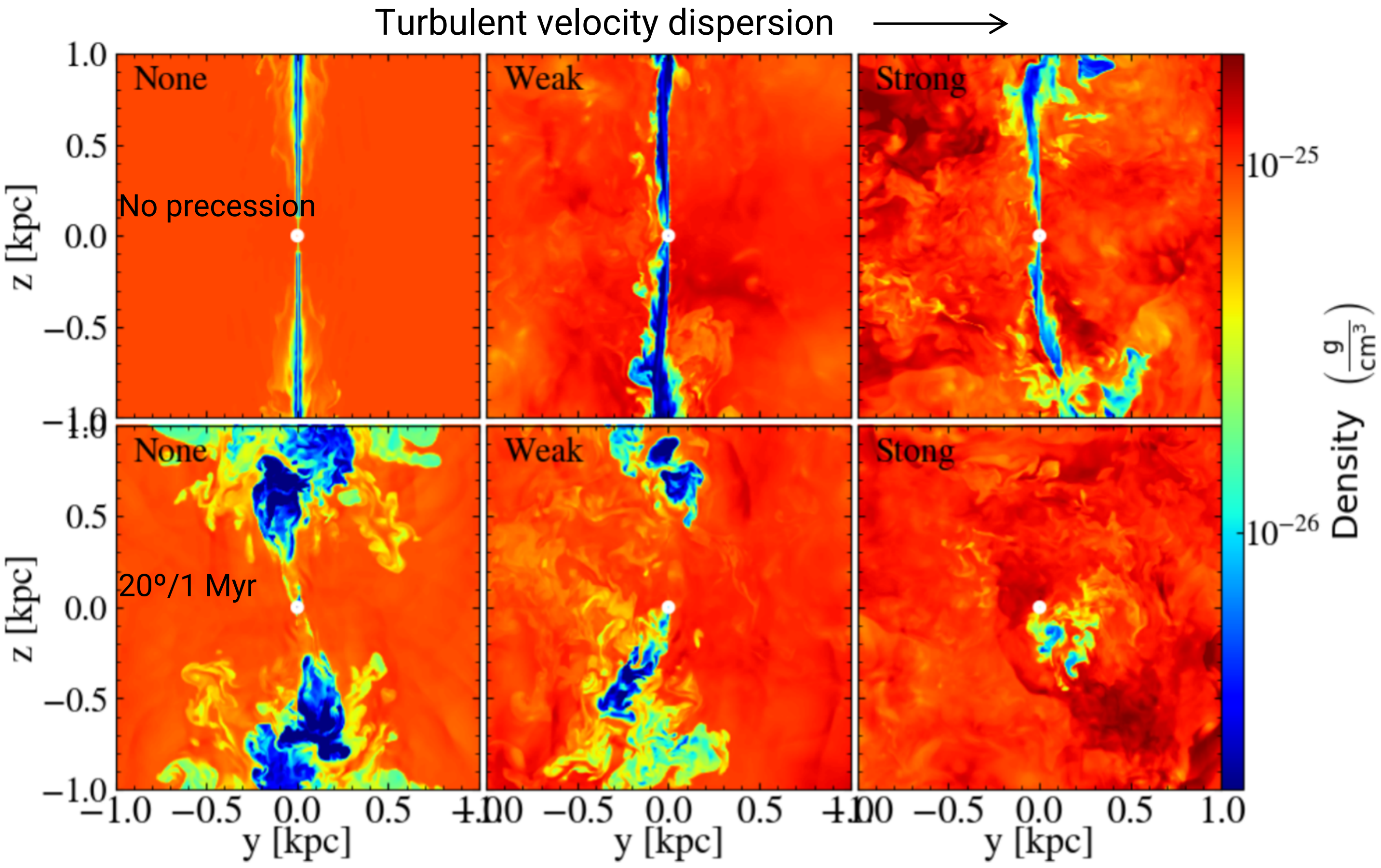

Lü & Ricker (2021)

Included physics	FLASH AMR code: Gas dynamics, sink particle, accretion + jet feedback, turbulent stirring and radiative cooling
Simulation volume	1 kpc on a side in 3D
Resolution	~7.8 pc (max 6 levels refinement)
Key Parameters	Jet precession P=1, 2, 5Myr, θ = 10, 20 and 30^O Feedback efficiency ε = 0.15 Turbulent stirring energy from Hitomi Decay timescale $\tau_d = 3.15 \times 10^{12}$ s

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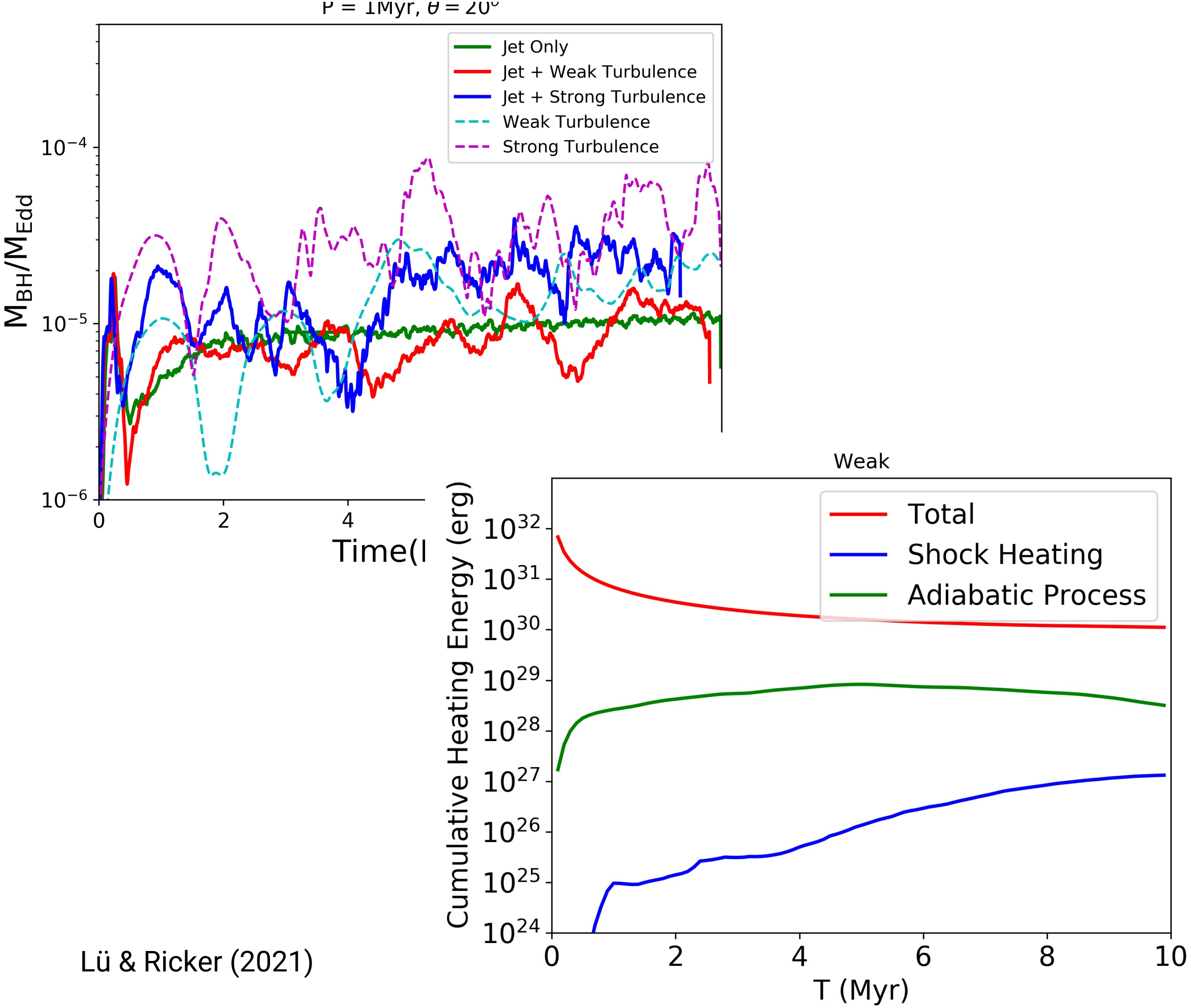

Lü & Ricker (2021)

Jet precession and turbulence

1. Jet precession helps the bipolar jets deposit energy in a more isotropic manner. Larger precession angles and more rapid precession leads to more distributed energy deposition

2. Jet feedback + external driving turbulence enhances kinetic energy of the ICM over a range of scales. Precession from the jet enhances the quenching effect of turbulence

3. Precession changes the dynamical properties of the gas due to the balance between jet-driven turbulence and external-driven turbulence