Hydrodynamic Models of AGN Feedback on Cooling Core Clusters

2007 Spotlight on Graduate Research Competition in Physics and Astronomy

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Outline

Cooling Galaxy Clusters and AGN jets

- Background
  - Galaxy Clusters and AGN
  - Cooling Flows and Galaxy Formation
  - AGN jets and Feedback
- 3D Hydro Models
- Precessing Jet Models
- Conduction and other physics

Background – Clusters and AGN

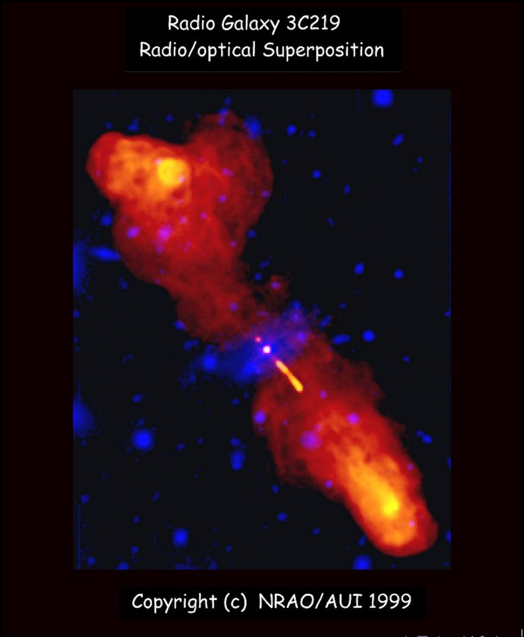
Galaxy Clusters

- Largest gravitationally bound structures in the Universe.
- Dark matter, hot gas, and (contributing the least) galaxies.

Active Galactic Nuclei (AGN)

- Bright (in many wavelengths) galaxy centers, often with jets that can extend far past the actual galaxy.
- Powered by accretion onto central supermassive black hole.

Jets


Radio Galaxy 3C219
Radio/optical Superposition
Copyright (c) NRAO/AUI 1999

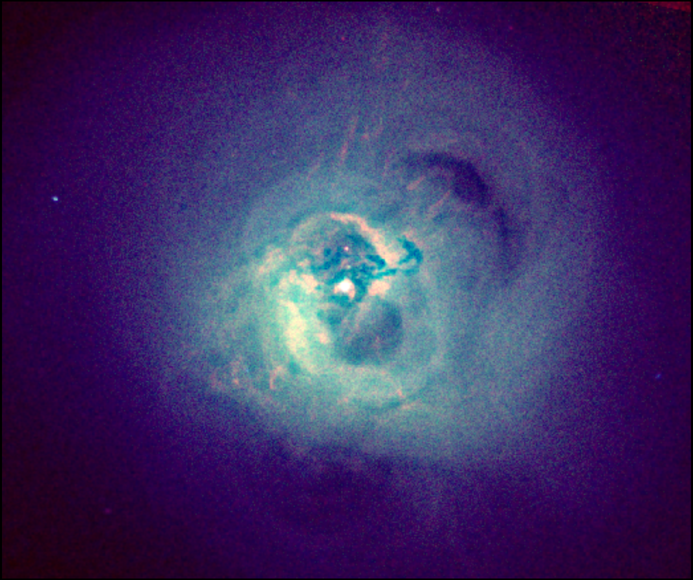
Background – Cooling

- The Intracluster Medium (ICM) in rich relaxed clusters is cooling, primarily in X-ray.
- Central cooling times shorter than the age of the cluster, but strong observational limits on the amount of cool gas.
- Nothing below $\sim \frac{1}{3} T_{virial}$ (from XMM-Newton observations).
- This is the classic Cooling Flow Problem.
- This is also same as the cutoff in the high end galaxy luminosity function.

Background – AGN jets

- Powerful, with right energy to balance cooling (but see Bîrzan et al. 2004 for possible problems with this idea).
- Often in cluster centers, just where heating is needed.
- But how exactly does this heating work?
- Is the efficiency enough and is the heating spatially distributed properly?

Evidence for Interaction



Perseus A, Fabian et al. 2005

Our Work

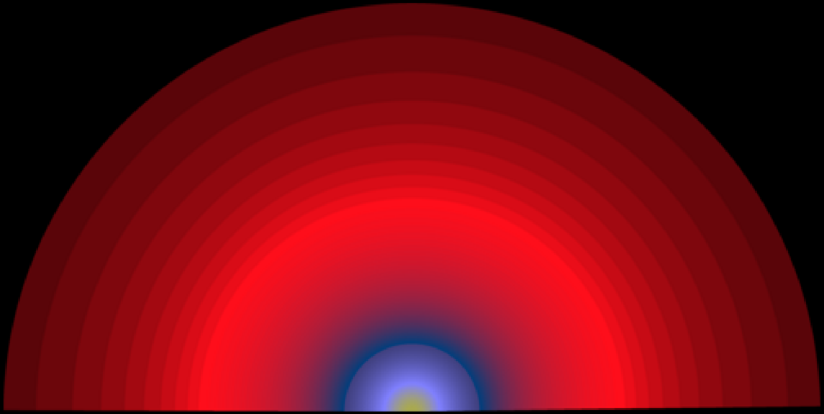
Use models to assess the efficiency and spatial distribution of heating from AGN jets under the assumption of ideal hydrodynamics.

- Initially cluster is spherically symmetric, hydrostatic, ball of gas.
- β-model atmosphere with static potential.
- Supersonic, underdense jet injected on the inner boundary.
- Radiative Cooling.

Modified Public Hydro Code

- Modified and updated version of FORTRAN 77 NCSA release.
- ZEUS-MP v1.5.13
- `http://www.astro.umd.edu/~vernaleo/zeusmp.html`

3D Models: Single Jet Burst – Density



Feedback Scenarios

Can we close the feedback loop by coupling the jets to the cooling ICM?

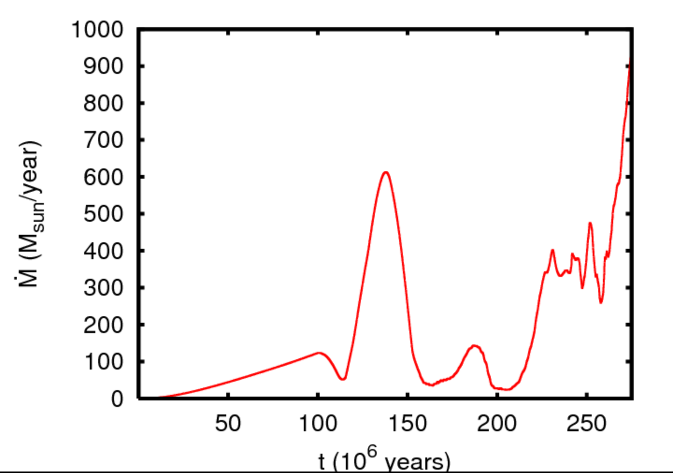
- Single Jet.
- Inject a jet with $L_{kin} \propto \dot{M}$.
- Delayed Feedback.
- This is getting close to feedback with (almost) no limiting assumptions.
- See Vernaleo & Reynolds 2006.

Delayed Feedback

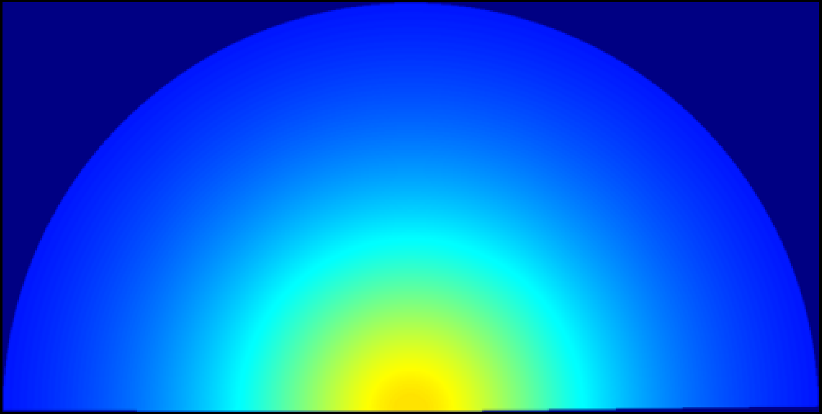
$$v_{jet} = \left(\frac{2\eta \dot{M} c^2}{A\rho} \right)^{\frac{1}{3}}$$

We introduce a delay (100 Myrs which is the dynamical time of the cluster center) between v_{jet} and $\dot{M}$.

Delayed Feedback – Mass accretion on inner boundary



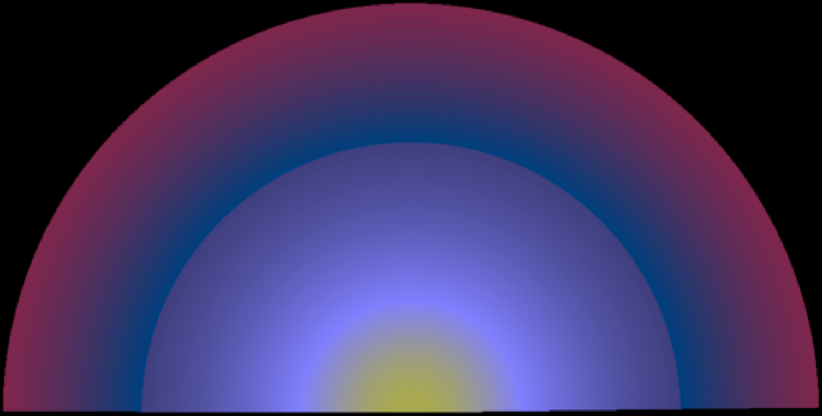
Channel Formation and the Failure Mode of Feedback Models



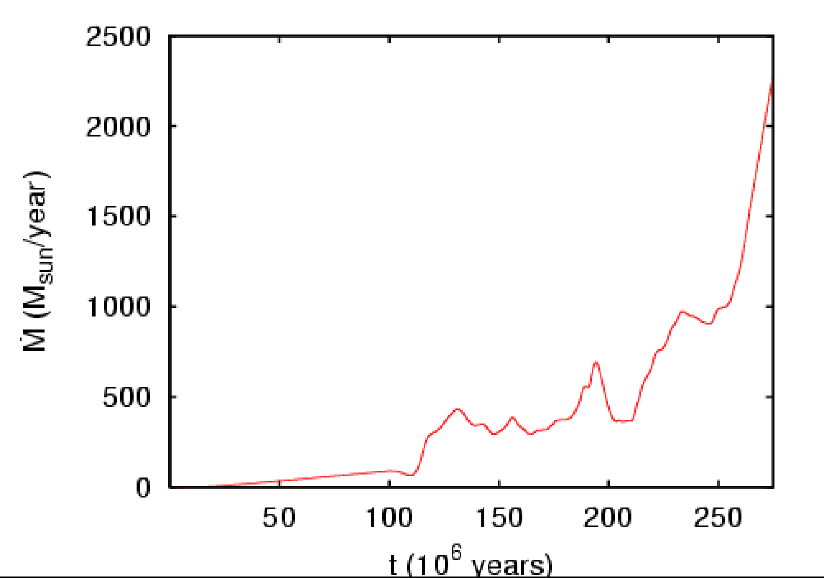
Precessing jets

- Vary the jet axis.
- This will break the symmetry that caused the channels in our previous work.
- Some evidence for this in Perseus (Dunn et al. 2006).

Precessing Jet – Density slice



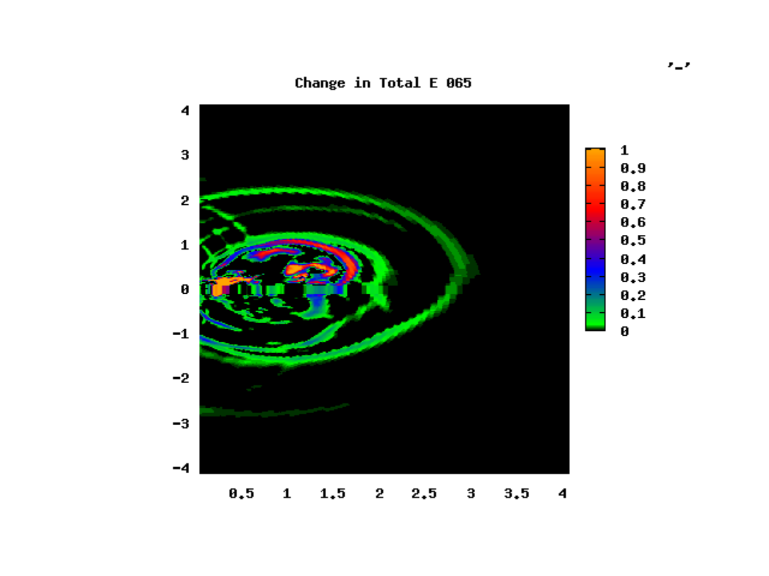
Precessing Jet – Mass accretion on inner boundary



Still no stable solution.

- Basically get the same result for all $\dot{M}$ based feedback cases.
- Even without channel formation, cooling proceeds.
- Jet would need to cover entire range of angles in less than cooling time for central gas.
    - Seems unlikely.
- Hard to couple (powerful) jets to ICM core gas in ideal hydro.
- Jet does excite lots of sound waves and weak shocks, seemingly more than a fixed-axis jet.

Waves and weak shocks



Possible Solutions

- Need something to capture sound wave energy.
- In ideal hydro, too much of the AGN power is lost in these waves that cannot dissipate.
- We need other plasma processes in the gas to do this.

ICM Physics

- Viscosity:
  - Intact bubbles in Perseus show some evidence for this.
  - Reynolds et al., 2005 did some simulations of this.
- Magnetic Fields?
- Thermal Conduction
  - Conduction at some fraction of Spitzer value.
  - Bring heat from outer regions in.
  - Dissipate wave energy.
  - If conduction can help us tap the wave energy before it leaves the core, a stable balance should be possible (See Fabian et al. 2005).

Conclusions

- In 3D hydro models, we are unable to balance cooling by coupling jet power to cooling gas.
- It is hard to see how jets can heat gas isotropically, even though they have enough power to do so.
- Jets excite lots of sound waves and weak shocks, but that energy is lost.
- Possible solution in thermal conduction.