The Interplay of Quasar and Radio-mode Feedback in Galaxy Clusters

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Motivation

AGN radio-mode feedback has been widely accepted as the dominant heating mechanism that counters the over-cooling of gas in cool-core clusters (CCCs; 1, 2, 3). Recent observations find substantial amounts of cold gas (> 10^{10} M☉) in a number of CCCs [4, 5, 6], as well as the evidence that some host quasars in their central dominant galaxies [7]. This raises questions about the importance of quasar-mode feedback in such systems. **Motivated by this, we explore the joint role of the radio-mode and quasar-mode feedback in CCCs.**

Radio- & Quasar-mode Feedback

We use 3D radiation hydrodynamic code Enzo [8] to simulate CCCs experiencing radio-mode and quasar-mode feedback. **Radio-mode feedback** is modeled by adding a pair of jets in which the gas is accelerated to high speeds in the vicinity of the central supermassive black hole (SMBH). **Quasar-mode feedback** is modeled using the ray-tracing radiative transfer package Moray implemented in Enzo [9], with a power-law SED from 13.6 eV to 100 keV.

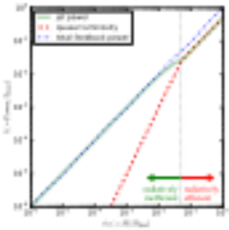

Figure 1. Power of the quasar-mode (red) and radio-mode (green) feedback as a function of accretion rate (adapted from Churazov et al. [10]). Feedback operates in the jet-dominated, radiatively inefficient state at accretion rates ṁ < 0.05. When ṁ ≥ 0.05, the AGN operates in the radiatively efficient state, with the power equally divided between quasar-mode and radio-mode feedback.

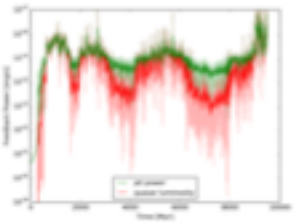

Figure 2. Evolution of quasar-mode (red) and radio-mode (green) feedback power. The AGN transitions between the radiatively efficient and inefficient states on time scales corresponding to a few Myr. Bands marked with lighter colors represent the instantaneous feedback power in each simulation time step, while solid lines show the average values over 20 Myr.

Comparison with Observations

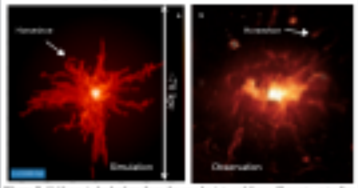

Figure 3. Cold gas is dredged up from the core by jets and forms filaments extending up to ~100 kpc. Images show Hα emission: (a) inferred from one of our simulations; (b) observed in the Perseus cluster [11]. Simulations reproduce the properties and geometry of the filaments seen in Perseus and other CCCs. After cold gas falls back to the center and settles into a rotating disk, the AGN enters radiatively inefficient state.

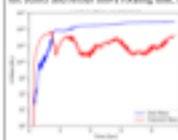

Figure 4. Evolution of cold, atomic gas in filaments (red) and the rotationally supported disk (blue). Note that the evolution of the filament mass exhibits positive correlation with the AGN duty cycle in **Figure 2.** The massive gas disk (~ 10^{11} M☉) forms from the infalling filaments, and possibly fuels star formation in the BCG [12].

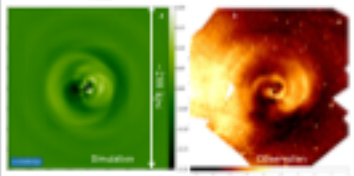

Figure 5. X-ray bremsstrahlung image of the simulated CCC shows cavities and ripples that resemble the Perseus cluster. The images show fractional variance from the axisymmetric X-ray surface brightness: (a) for kT > 0.5 keV ICM plasma in the simulation; (b) in the Perseus cluster, measured in the 0.5–7 keV band [13].

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Scan for a digital copy of the poster and simulation movies.

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