ACTIVE GALACTIC NUCLEI THERMAL HEATING

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ABSTRACT

1. INTRODUCTION

•Cool-core problem and current resolution?
•Elaborate on Voit analytical work - the toy model - a heating curve balancing cooling that preserves the entropy profile
•Elaborate on Greg's work?
•AGN feedback in other simultions
•Paper outline

Galaxy clusters have predictable entropy profiles whose shape (although not necessarily normalization) are mass-independent. Cavagnolo et al. (2009) Although -ray observations of the intracluster medium (ICM) indicate that the central cooling times in some galaxy clusters are much shorter than the age of the universe, no cooling catastrophe is observed. This argues that there is a heating mechanism that offsets the cooling and acts on timescales comparable to the cooling time. Given a variety of physical considerations, the primary heating source is largely accepted to be active galactic nuclei (AGN). What is not well-understood, however, is the manner in which AGN deposit energy into the ICM. **The goal of this work** is to constrain the radial dependence of the AGN energy injection by comparing a simplified model of AGN heating with key X-ray observable quantities. This effort builds on work by Meece et. al. Meece Jr (2016); Meece et al. (2017) using an idealized model of thermal feedback over the cluster core following a power law, inspired by analytical work by Voit et. al. Voit et al. (2017).

2. METHODOLOGY

2.1. *AGN Feedback*

•Energy from the AGN is deposited as purely thermal energy in a sphere encompassing the cluster.

$$\dot{e}(r) = \left(\frac{r}{r_c}\right)^{-\alpha} \exp{-r/r_c} \tag{1}$$

•Details of feedback: smoothing length, cut off radius, scaling factor

Using a cutoff radius r_c = 1 Mpc. In order to avoid the asymptote at the origin, the radius r is smoothed to a minimum radius of 1 kpc The total AGN heat tracks the cooling rate, which is updated every 10Myr We use a different α for each run, sampling from 2.0 to 2.9 in 0.1 increments and 2.5 to 2.7 in 0.05 increments.

•Conic feedback

$$\dot{e}(\theta) \propto \cos^2\theta \tag{2}$$

where θ is the polar angle.

•Each simulation is run for 8Gyr, or appoximately 4 sound crossing times for the cluster.

Energy from AGN feedback is deposited thermally in a sphere encompassing the cluster. The deposited energy follows a power law:

$$\dot{e}(r) \propto \left(\frac{r}{r_c}\right)^{-\alpha} \text{ erg s}^{-1}\text{ cm}^{-3}. \tag{3}$$

The thermal energy deposited in the cluster is scaled to exactly offset the total cooling within the cluster, thus maintaining overall energy balance. Simulations were run with a range of radial heating distributions ranging from $\alpha = 2.0$ to 2.9. All simulations used the adaptive mesh code `Enzo` **?** using AGN feedback algorithms modified from Meece Jr (2016); Meece et al. (2017).

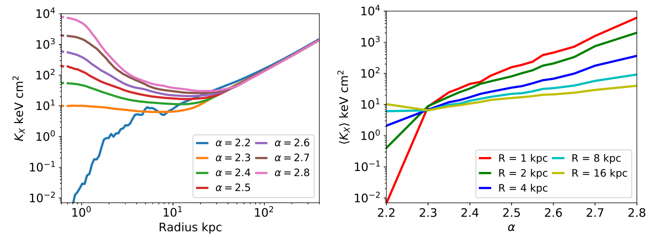

Figure 1. Left: Mean entropy as a function of spherical radius from several representative simulations. **Right:** Mean cluster core entropy calculated within impact parameters ranging from $R = 2^0 - 2^4$ proper kpc for the same set of simulations, as a function of α. In both panels, entropy is calculated by the mass-weighted temperature and the volume-weighted density, and all data is taken after 700 Myr of simulation evolution.

2.2. *Initial Conditions*

Simulations are initialized in a Perseus-like configuration, in the manner of Meece Meece et al. (2017) and Li et al. Li et al. (2015)

3. RESULTS

•Feedback failed to self regulate
•Core entropy increases with α
•Surface brightness decreases with α
•<More results from conic feedback>

4. DISCUSSION

•Higher energy input into core leads to slower collapse times, larger flat entropy cores.

•Formation of multiphase gas leads to collapse?

Higher α, corresponding to more energy input at the cluster core, predictably raised core entropy. Lower α left a flat entropy profiles closer to the initial conditions. The higher α simulations push out enough gas from the core to decrease x-ray brightness.

Although this is a very simplified model of cluster feedback, it can be used to constrain the broad properties of AGN feedback – in particular, the radial dependence of its heat deposition – using X-ray observations. In the near future, we

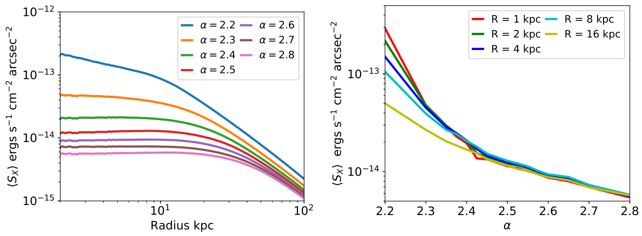

Figure 2. Left: Mean simulated X-ray surface brightness in the 0.5 − 2.0 keV band as a function of observing radius. **Right:** Mean surface brightness of cores of radii $R = 2^0 - 2^4$ proper kpc from the same simulations as a function of α. All data is taken after 700 Myr of simulation evolution.

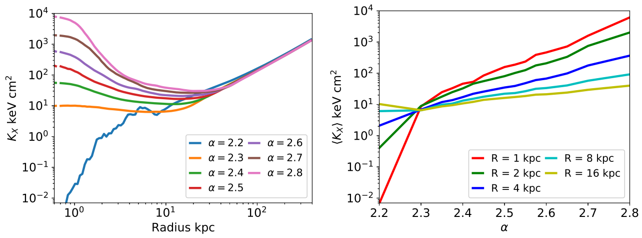

Figure 3. Left: Mean entropy as a function of spherical radius from several representative simulations. **Right:** Mean cluster core entropy calculated within impact parameters ranging from $R = 2^0 - 2^4$ proper kpc for the same set of simulations, as a function of α. In both panels, entropy is calculated by the mass-weighted temperature and the volume-weighted density, and all data is taken after 700 Myr of simulation evolution.

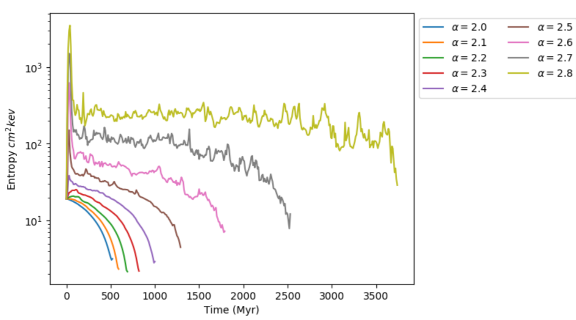

Figure 4. Mean core entropy on the inner 10 kpc as a function of time from several representative simulations. evolution.

Figure 5. Cold gas fraction as a function of time

will make direct comparisons to Chandra X-ray data of entropy and surface brightness profiles using the ACCEPT survey Cavagnolo et al. (2009) and its successors.

5. ACKNOWLEDGMENTS

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