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Mechanical feedback and backflows in early-type galaxies

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Abstract. The observed co-evolution between galaxies and upermassive black holes (SMBHs) is commonly explained via a self-regulating mechanism involving feedback from Active Galactic Nuclei (AGN). AGN feedback operates in basically two ways: mechanical feedback (via nuclear jets and winds, responsible for the observed relativistic outflows, and radiative feedback which explains the properties of the observed ionized gas. During the propagation of a relativistic jet, a backflow is also observed through the bow shock, which brings gas towards the central regions where the SMBH is located. Our main aim is to perform a series of numerical experiments aiming at modelling both the mechanical feedback and the backflow, and how the former affects the latter. We plan to focus on the smallest-scale properties of the previously studied backflow, and to understand its role on regulating the accretion onto the SMBH and how it modulates the power of the jet.

1. Introduction

We have performed a series of numerical simulations using a customised version of the AMR code FLASH (v. 2.4) to test the effects of reorienting jets from an active galactic nucleus (AGN) on the intracluster medium in a galaxy cluster environment with short central cooling time. We have investigated both the appearance and the properties of the resulting cavities, and the efficiency of the jets in providing near-isotropic heating to the cooling cluster core. We have kept the jet power and duration fixed across the models, varying only the jet re-orientation angle prescription.

We have tracked the total energy of the intracluster medium (ICM) in the cluster core over time, and the fraction of the jet energy transferred to the ICM. We have paid particular attention to where the energy is deposited. We hve also generated synthetic X-ray images of the simulated cluster and compared them qualitatively to actual observations.

Results: Jets whose re-orientation is minimal (<= 20^0) typically produce conical structures of interconnected cavities, with the opening angle of the cones being 15-20, extending to 300 kpc from the cluster centre. Such jets transfer about 60% of their energy to the ICM, yet they are not very efficient at heating the cluster core, and even less efficient at heating it isotropically, because the jet energy is deposited further out.

Jets that re-orientate by >= 20^0 generally produce multiple pairs of detached cavities. Although smaller, these cavities are inflated within the central 50 kpc and are more isotropically distributed, resulting in more effective heating of the core. Such jets, over hundreds of millions of years, can deposit up to 80% of their energy precisely where it is required.

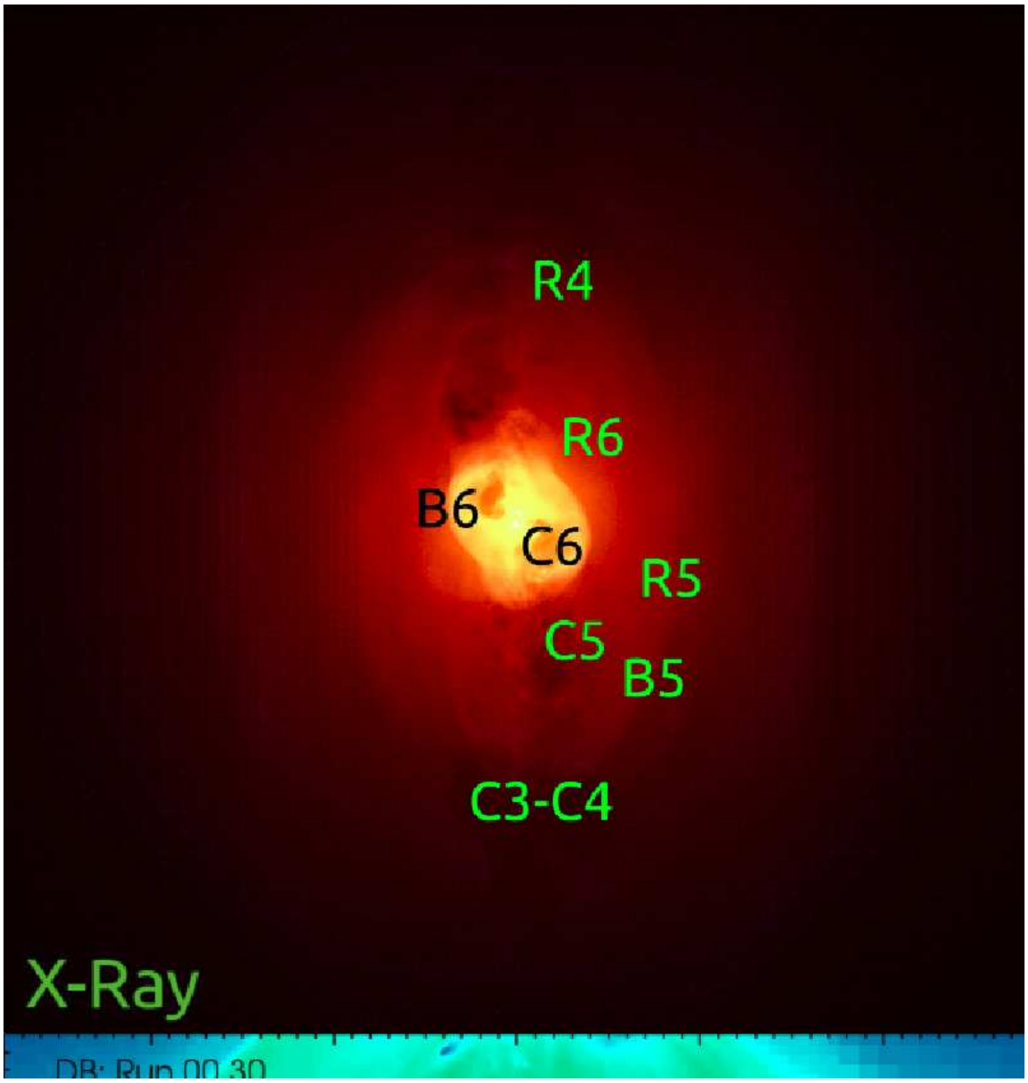

Fig. 1. X-ray (2-10KeV), projection along the x-axis (centre), pressure slice in the x = 0 plane (bottom). Size: 400 kpc, linear scale. Labels mark cavities (C), bow-shocks (B) and ripples (R), numbered from oldest to youngest.

Consequently, these models come the closest in terms of approaching a heating/cooling balance and mitigating runaway cooling of the cluster core even though all models have identical jet power/duration profiles. Additionally, the corresponding synthetic X-ray images exhibit structures and features closely resembling those seen in real cool-core clusters (see Fig. 1).

2. Evolution of backflows

Re-orienting jets heat the cluster gas core more efficiently. When a young jet inflates a detached cavity in a new direction, such a cavity forms within the cluster core. As a result, the core is subject to new shocks after every jet episode. Even at later times, when

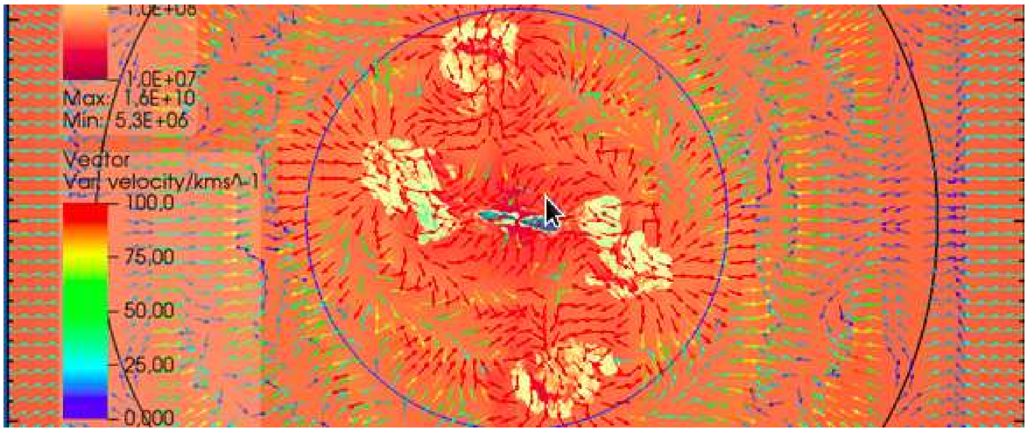

Fig. 2. Evolution of the backflow around the central accretion region. The large-scale backflow is now detached from the jet, and is mainly driven by thermal gradients thorugh th Crocco theorem mechanism.

bubbles start to rise, there are always many more bubbles within the innermost 100 kpc, whose distribution - in addition - spans a much larger solid angle, because the jet orientation is more isotropic. These combined effects hinder formation of cooling flows and also disrupt coherent backflows that could promote runaway thermal instability within the core. Reorienting jets are more effective at establishing a dynamical inflow-outflow balance. The interplay between jet-induced outflows and inward-directed backflow-augmented cooling flows creates an alternating inflow-outflow pattern with distance from the cluster centre. An example of late backflow is reproduced in Fig. 2, which demonstrated the persistence of this phenomenon over long temporal scales.

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