Hydrodynamical simulations of cluster formation with central AGN heating

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Summary. We analyse the effects of central AGN heating on the formation of galaxy clusters by means of hydrodynamical simulations. Besides self-gravity of dark matter and baryons, our approach includes radiative cooling and heating processes of the gas component and a multiphase model for a self-consistent treatment of star formation and SNe feedback [1]. Additionally, we incorporate a periodic feedback mechanism in the form of hot buoyant bubbles, injected into the ICM during the active phases of accreting central AGN. We find that AGN heating can substantially affect the properties of the stellar and gaseous components, in particular reducing the mass deposition rate on the central cD galaxy, thereby offering an energetically plausible solution to the cooling flow problem.

1 Method

Using the parallel TreeSPH-code GADGET-2 [2], we implemented a heating mechanism provided by an AGN, hosted in the central cluster galaxy. During the phases in which the AGN is "switched on", a certain amount of thermal energy is introduced into the ICM, generating centrally concentrated hot bubbles in regular time intervals. We parametrized our scheme in terms of the AGN duty cycle, the amount of feedback energy, the radius and the distance from the cluster centre of the buoyant bubbles. Initially, we implemented bubbles heating in isolated groups and clusters, spanning a wide range of mass, and in a second step, we considered full cosmological simulations that follow the assembly of galaxy clusters self-consistently.

2 AGN heating in isolated halos

In the left panel of Fig. 1, we analyse the bubble morphologies in terms of the projected mass-weighted temperature map of the centre of a $10^{15} M_\odot$ isolated galaxy cluster. The bubbles show well defined mushroom shaped structures and compress the surrounding gas above, which then forms characteristic cold rims. In the right panel of Fig. 1, we illustrate the unsharp masked X–ray emissivity map of the same cluster, where injection of bubbles into the ICM generates sound waves, which provide a source of ICM heating on larger

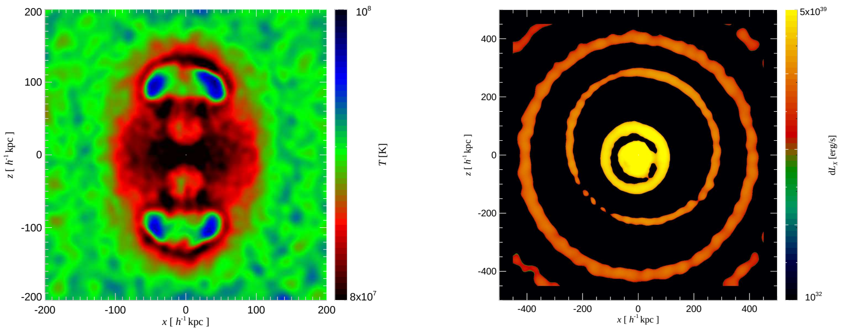

Fig. 1. The projected mass-weighted temperature map of a massive isolated cluster is shown in the left panel, while in the right panel the unsharp masked image of X-ray emissivity is represented.

scales. The gas entropy profile and the mean mass inflow rate as a function of time, are shown in Fig. 2. The intracluster gas is heated efficiently in the inner regions due to the AGN activity, and thus the entropy reaches a central floor, while the mass inflow rate stabilizes at a low level of $150M\odot/yr$.

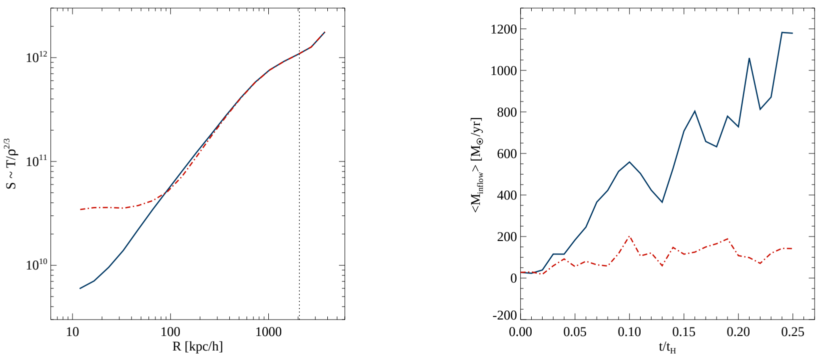

Fig. 2. The gas entropy profile (left panel) and the mean mass inflow rate as a function of time (right panel) are shown. Blue continuous line: cooling and star formation only; Red dot-dashed line: with additional AGN heating.

3 AGN feedback in cosmological simulations

In cosmological simulations of cluster formation AGN feedback provides a significant impact, as well as is the case for isolated halos. The estimated cooling time in a $10^{15}M\odot$ galaxy cluster at $z = 0$ is illustrated in the left panel of Fig. 3 (for a detailed description of the simulation characteristics and the models adopted see [3]). Bubble heating prevents the cooling time to drop substantially below the Hubble time, and thus the amount of central gas colder then 1keV is significantly reduced. Moreover, at lower redshifts the SFR of the central cluster galaxy decreases, and it appears older and redder, as shown in the right panel of Fig. 3. The white histogram is for the run without AGN heating, while the remaining two histograms show how SFR is suppressed at intermediate and low redshifts for the two different AGN feedback scenarios assumed.

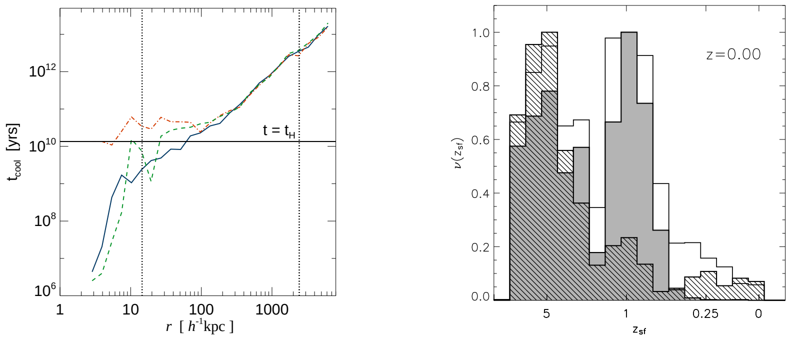

Fig. 3. The gas cooling time as a function of radius (left panel) and the histogram of stellar formation redshifts of the central cluster galaxy at z=0 (right panel). Blue continuous line: without AGN; Dashed and dot-dashed lines: different AGN feedback models.

4 Conclusions

The central heating mechanism provided by AGN activity, in the form of hot buoyant bubbles, appears to be a very important ingredient of galaxy cluster formation. AGN feedback affects both the gas and the stellar properties in the innermost regions, reducing the amount of cold IC gas and quenching recent star formation episodes, thus alleviating the cooling flow problem. Furthermore, the spreading of metals into the ICM is enhanced by AGN–driven bubbles, decreasing radial metallicity gradient and making the distribution less lumpy.

References

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