Cold fronts in cool core clusters

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Summary. Cold fronts have been detected both in merging and in cool core clusters, where little or no sign of a merging event is present. A systematic search of sharp surface brightness discontinuities performed on a sample of 62 galaxy clusters observed with XMM-Newton shows that cold fronts are a common feature in galaxy clusters. Indeed most (if not all) of the nearby clusters ($z < 0.04$) host a cold front. Understanding the origin and the nature of such frequent phenomenon is clearly important. To gain insight on the nature of cold fronts in cool core clusters we have undertaken a systematic study of all contact discontinuities detected in our sample, measuring surface brightness, temperature and when possible abundance profiles across the fronts. We measure the Mach numbers for the cold fronts finding values which range from 0.2 to 0.9; we also detect a discontinuities in the metal profile of some clusters.

1 Introduction

Chandra and XMM-Newton observations have shown that many clusters host very sharp surface brightness discontinuities. The drop in the X-ray surface brightness is accompanied by a rise of similar magnitude in the gas temperature. These discontinuities, dubbed cold fronts [1], have been detected both in merging and in cool core clusters. While the first ones have been immediately related to the merging event [2], the origin of the latter is still not fully understood. As we will show, cold fronts are quite common in cool core clusters. Thus, understanding the nature of such a widespread phenomenon is mandatory to characterize the dynamics of galaxy clusters and of their cores.

The most popular scenarios to solve the cooling flow problem concern AGN and the interaction between the radio lobes inflated by the AGN and the ambient gas itself. The mechanical energy transferred from the lobes to the thermal plasma is in many, but not all cases, sufficient to quench the cooling (see [4]).

Another class of heating sources includes mechanisms which provide heat from outside the cool core region. In this context considerable effort has gone into exploring the role of conduction (i.e. [5], [6]). As it turns out there are various difficulties: firstly the conductivity of the ICM is unknown; secondly in some systems the temperature profiles are rather flat (i.e. M87, Ghizzardi
et al. 2004 [6]), and thirdly, while heating from conduction scales like $T^{5/2}$, cooling is more efficient at lower temperatures.

Another possible way of heating the flow from outside has to do with the ubiquitous presence of cold fronts in cluster cores. Although the kinetic energy in these cold fronts, a fraction of the thermal energy, is in itself insufficient to offset the cooling, cold fronts could act as an energy reservoir. Hydrodynamical simulations ([7] and [8]) show that cold fronts in cores could be set off by minor, frequent, mergers that would provide a constant supply of energy. Clearly a detailed observational characterization of cold fronts is of primary importance to explore this scenario in greater detail. We study cold fronts in a large sample of galaxy clusters observed with XMM-Newton to provide a precise description of this phenomenon and to better understand the dynamics of cluster cores.

2 Hunting for cold fronts in a large XMM-Newton cluster sample.

We have performed a systematic characterization of cold fronts in a sample of 62 clusters observed with XMM-Newton. The large collecting area of the EPIC telescope onboard the XMM-Newton satellite allows a detailed inspection of the spectral properties of the galaxy clusters, which are important to study the dynamics of the core. The sample includes two different subsamples. The first comprises roughly 20 nearby bright clusters with redshifts in the range $[0.01 - 0.1]$. The second subsample comprises all the clusters available in the XMM-Newton public archive up to March 2005, having redshifts in the range $[0.1 - 0.3]$ (see [9]).

The systematic search for surface brightness and temperature discontinuities in the clusters of our sample resulted in the detection of cold fronts in 21 objects corresponding to a percentage of 34%. It is interesting to study the frequency of cold fronts in different redshift ranges. If we progressively reduce the sample, excluding gradually the more distant clusters, the fraction of clusters having a cold front increases. The occurrence of cold fronts is 41.8% for clusters with redshift $0.01 < z < 0.2$, 50% for clusters with $0.01 < z < 0.1$ and 72.2% for clusters with $0.01 < z < 0.07$. A large fraction (87.5%) of the nearest clusters ($z < 0.04$) host one or more cold front. This is in agreement with results derived analyzing a sample of 37 relaxed nearby clusters observed with Chandra [10]. Since projection effects and the XMM-Newton resolution can hide a non-negligible fraction of cold fronts, our result implies that probably all the nearby clusters host one (or more) cold fronts.
3 Characterizing cold fronts

The results reported in the previous section show that cold fronts are indeed a common feature in cluster cores. The precise characterization of this phenomenon is a preliminary and necessary step in assessing whether they can play a significant role in the cooling-heating balance within the cluster cores. First, we consider some general features of cold fronts in galaxy clusters (Sec. 3.1); we then characterize the discontinuities by measuring the surface brightness and temperature jump (Sec. 3.2) and finally we derive abundance profiles across cold fronts (Sec. 3.3).

3.1 General aspects of cold fronts in cool core clusters

We have derived surface brightness, temperature and pseudo-pressure (hereafter SB, T and P) maps for some cool core clusters using the *adaptive binning + broad band fitting* method (see [11] for a detailed description of this procedure). Two relevant features have been detected: a surface brightness peak displacement and a spiraling pattern in the temperature maps. As an example we consider 2A0335+096, which hosts a cold front in the southern direction ∼70″ from the SB peak. As already outlined in [6], the position of the BCG of this cluster matches the P peak, while the SB and the T peaks are shifted in the south direction by 16 arcsec. Similar shifts have been observed in others (i.e. A1795) but not in all (i.e. A496) clusters.

![Fig. 1. Temperature maps for (a) 2A0335+096, (b) Perseus and (c) Centaurus. All of them show a spiral pattern.](image)

Another interesting feature is visible in the T maps. In Fig. 1 we show the T maps for 2A0335+096, Perseus and Centaurus: all of them show a spiral structure. Both phenomena have a natural explanation within the scenario proposed by [10] and [8]. According to their model, cold fronts are formed when the central cold gas is subsonically sloshing in the dark matter gravitational potential. Frequent minor mergers can induce gas oscillations in
the cluster core displacing the thermal gas from the bottom of the potential well. Under these circumstances, the P peak and the BCG which trace the gravitational potential, and the SB and T peaks which trace the thermal gas, decouple. Simulations by Ascasibar and Markevitch [8] also show that the gas can acquire some angular momentum while oscillating. In this case, some spiraling structure in the T map is induced.

3.2 Measuring discontinuities and velocities of cold fronts

![Graphs showing surface brightness and temperature profiles](image)

**Fig. 2.** Surface brightness and temperature profiles for 2A0335+096 (upper panels) and Perseus (lower panels) with the best fits.

To quantify the dynamics of cold fronts in cool cores we derive the SB and T profiles for each cluster in 15 degrees wide sectors. The sectors have been chosen following the SB contour levels in order to properly characterize the jump. Classic deprojection procedures cannot be applied because of the lack of spherical symmetry. We describe the cold front discontinuity by modeling the electronic density and the gas temperature with power laws inside and outside the cold front edge. We then project these quantities assuming that the cold front has a width of $\Delta \varphi$ and an inclination angle $\Delta \vartheta$ with respect to the line of sight. A detailed description of this procedure will be given in
In Fig. 2 we plot as dots the SB and the projected T for the southern sector in 2A0335+096 (top panels) and for the southwestern sector in Perseus (bottom panels); the solid lines are the best fits. For 2A0335+096, we find a density jump $n_{in}/n_{out} = 1.97$ and a temperature jump $T_{in}/T_{out} = 0.88$. This corresponds to a Mach number of $M = 0.86$. For Perseus we find a density jump $n_{in}/n_{out} = 2.1$ and a temperature jump $T_{in}/T_{out} = 0.79$ corresponding to a Mach number $M = 0.8$. A more complete and detailed analysis of the discontinuities for all the clusters of our sample will be presented in [12].

### 3.3 Metal profiles across the cold fronts

We derive the iron abundance profiles across the cold front for some clusters. Fig. 3 shows the profiles for Perseus (northern and southwestern sectors) and for 2A0335+096 (southern sector). The dashed lines mark the position of the cold fronts. The iron abundance has a discontinuity across the cold fronts for the Perseus cluster. Even if the data quality for 2A0335+096 is not as high as for Perseus, an indication for a discontinuity seems to be present also for this cluster. This behavior is expected in a sloshing scenario as the cold metal rich gas is shifted towards more external regions where the iron abundance is lower.

![Metal profiles across the cold fronts](image)

**Fig. 3.** Metal profiles in some sectors of Perseus (a-b) and 2A0335+096 (c). The dashed lines mark the cold fronts positions. A discontinuity is clearly visible in the Perseus cluster. Some indication of discontinuity can be seen for 2A0335+096.

### 4 Conclusions

Cold fronts could play an important role in providing heating from the outer regions of the core giving a contribution to quenching the cooling flow in cool cores. The main advantage in considering such phenomenon as a possible heat source is twofold: cold fronts are a common feature in the galaxy cluster...
population; they could have a purely "gravitational origin". Ascasibar and Markevitch [8] show that frequent minor mergers can induce a disturbance to the gravitational potential well and cause gas sloshing and cold fronts. Each cluster during its formation undergoes several minor merger events. Among the possible heating processes, this mechanism has the advantage of being common to all the clusters and of being unrelated to any particular feature of the cluster (i.e. the presence of an active AGN.)

An analysis of a large sample of clusters observed with XMM-Newton shows that 87.5% of the nearby (z < 0.04) clusters host a cold front. The analysis of the surface brightness, temperature and pressure maps for some clusters shows that in some cases the SB and T peaks are decoupled with respect to the P peak. In some clusters, we also observe a spiraling pattern in the temperature map; both these features are expected in a sloshing scenario [8].

We have measured the Mach numbers of cold fronts, finding values that range from 0.2 to 0.9. The analysis of the metal profiles shows that the iron abundance has a sharp discontinuity across the cold front edge in Perseus and some indications of that are present also for 2A0335+096. A detailed characterization of the discontinuities can help to understand the dynamics of the innermost regions of the cluster and to quantify the amount of heating that the cold front can provide to cluster cores.

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