Tracing the Evolution in the Iron content of the IntraCluster Medium
Diffuse hot baryons are the major baryonic components in clusters of galaxies. They contain the imprint of all the dynamical and thermodynamical processes that affected the cluster.
Clusters' baryonic pie

Ettori (2003)

- Hot: 70 (56–89) %
- Cold: 13 (8–19) %
- Other baryons (warm?): 17 (0–33) %
Detection of heavy elements in the hot phase of the baryons (Intra Cluster Medium) in groups and clusters of galaxies is a powerful mean to investigate the chemical enrichment and the thermodynamics of the ICM. Most of the K-shell and L-shell transitions of heavy elements lie in the 0.5-2 keV energy range, with many other important lines up to 8 keV. The X-ray spectral analysis of groups and clusters of galaxies is a powerful diagnostic to measure the abundance of heavy elements in the ICM.
In a low density, optically thin plasma in collisional equilibrium, the equivalent width of a given line is directly proportional to the number density of the corresponding ion.

The most prominent line is the Kα of the Iron (6.7-6.9 keV). This is will be the only line for most of the hot clusters and for the high redshift ones.

Peterson & Fabian 2005

The straightforward interpretation of X-ray spectra

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In high S/N objects, the richness of the X-ray lines diagnostics can be fully exploited (see the study of the cool cores and works by McNamara, Nulsen, Fabian, etc): spatial distribution of different metals, temperature structure in the central regions, etc.

The many implications of observation of heavy elements in the ICM

The production and diffusion of heavy elements into the ICM

The contribution of different types of SNae

The non gravitational heating of the ICM from star forming processes

The stirring of the ICM by nuclear activity in the BCG galaxy

The dynamical effect of clusters-groups merger events

The interaction of cluster galaxies and the ICM as a function of the cosmic epoch
If we want to study the abundance evolution, we need to analyze the spectra of distant clusters (the most distant around $z=1.3$, record is $z\sim1.6$).

In the low S/N regime, the main uncertainties are: the unknown temperature distribution of the ICM, the moderate spectral resolution that can be achieved in the X-ray imaging mode, the K-correction: the line rich energy range around 1 keV rest frame, is redshifted below 0.5 keV at $z\sim1$

Therefore our topic is based on a simple but hard observational task: measuring the emission $K\alpha$ line of H-like and He-like Iron in X-ray spectra of the ICM.
Several studies have been presented in the literature on the radial distribution of Fe in galaxy clusters. With BeppoSAX: De Grandi & Molendi (2001) on 17 nearby clusters (9 CC & 8 NCC at $z < 0.1$) found:

- a strong enhancement in the abundance in the central regions of the Cool Core clusters;
- a flatter Z profile in the NCC Clusters;
- the metallicity in CC clusters is higher than in NCC clusters at every

(see also Irwin & Bregman (2001) on 12 clusters at $0.03 \leq z \leq 0.2$)

De Grandi & Molendi (2001)
First results on the metals evolution

Mushotzky & Loewenstein (1997)

No evolution up to redshift 0.3 (with ASCA data)

See also Matsumoto et al. (2000) and Snowden et al. (2008)
Fe line is detected in most of the $z>1$ X-ray clusters

Rosati et al. (2004)
Chandra+XMM (MOS) combined fit of RXJ1252

Rosati et al. 2004
Iron abundance vs redshift

Analysis of the high-z clusters Chandra sample

We check that the effect of cooling cores is limited

Balestra et al. (2007)
Chandra data of 3 cluster samples

Santos et al. (2010)
Surface brightness concentration

KS-test distant + local samples: 16 %

Well developed cool cores are present at high-$z$
Not as prominent as in local clusters though

Santos et al. (2010)
This result has been confirmed by Maughan et al. (2008) on a sample of 116 Chandra clusters at $0.1 < z < 1.3$, where Z drop by 50% between $z=0.1$ and $z\approx1$

This evolution is not simply driven by the appearance or disappearance of the cool cores.

Maughan et al. (2008)
A sample of 40 galaxy clusters at 0.4 < z < 1.4 from the XMM-Newton archive, with sufficient S/N to perform a spatially resolved spectral analysis (2-3 bins).

Taking advantage of EPIC XMM-Newton high throughput and effective area, we performed a spatially resolved spectral analysis of the clusters in the sample.

The aim of this work is to determine if the decrease of Z with redshift observed by Balestra et al. & Maughan et al. is due entirely to physical processes associated with the production and release of Fe into the ICM, or partially associated with a redistribution of metals connected to the evolution of cool cores.

A. Baldi (2010) in prep; see also Anderson et al. (2009)
A spatially resolved spectral analysis of the clusters in the sample revealed hints of an evolution in abundance not limited to the cluster cores, but involving also regions farther than 0.4 $r_{500}$ from the center, extending the results of Balestra et al. (2007) and Maughan et al. (2008).

Baldi et al. (2010) in prep.
Metal accumulation in the ICM

Ettori (2005)
Fe abundance evolution and S0 fraction evolution

Calura Matteucci & Tozzi (2007)
Hydrodynamical simulations

see also Kapferer et al. (2009)
role of ram pressure stripping, etc
SPH simulations: strong dependence on the IMF

Borgani et al. (2009)
The WFXT mission: one high resolution, high collecting area and wide FOV X-ray telescope with low background, to image the 0.5-7 keV X-ray sky down to very low fluxes and characterize the spectra of millions of X-ray sources.

The scientific outcome will be a coverage of at least half of the 0.5-7 keV X-ray sky with a quality and a depth at the level of future wide area surveys, a product which is not delivered by any other existing or planned mission.
Murray et al. (2010)
Giacconi et al. (2010)
XMM COSMOS survey (2 deg$^2$) (Cappelluti et al. 2009)
Chandra COSMOS survey (1 deg$^2$) (Elvis et al. 2009)

Bands (keV)
- [0.5 - 2]
- [2 - 4.5]
- [4.5 - 7]

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WFXT simulation (one tile from the medium survey)

Bands (keV)
[0.5 - 1]
[1.0 - 2]
[2.0 - 7]

WFXT - 13 ksec
Detect detection: 50-100 counts
T measurements: 1500 counts
T profiles: 15,000 counts

Temperatures critical to cluster cosmology
Profiles, cluster physics
Large samples allow study of systematics
WFXT can reach into early groups
Detection of cool cores at high-z

Santos et al. (2010)
CLJ1415, z=1.0, the strongest cool core at z~1

280 ksec Chandra Cycle AO12
(PI J. Santos)
Observationally simple and well defined

The analysis of the data is straightforward (EQW = Abundance)

The Fe line is visible in the 0.5-7 keV range up to very high redshifts

Rich of implications for the physics of the baryonic components in Galaxy Clusters

However:

Plagued with small number statistics, few newly discovered high-z cluster expected in the next years.

Costly (deep Chandra exposure for each cluster)

The theoretical framework has a lots of variables
We already have evidence of evolution in the average Fe abundance, a factor of 2 from $z \sim 0.5$ to $z=0$. ICM was already substantially enriched at $z>1$. This evolution can be explained by the sink of low entropy, high-metallicity gas associated with small halos and/or galaxies, or enriched gas loss from disk galaxies, or by direct feedback from cluster galaxies.

To capitalize what we have learned so far with Chandra and XMM we must have a mission devoted to a wide area deep survey with a good spatial resolution of $\sim 5''$ like WFXT. Only a major leap in number statistics and source characterization (more than 20000 rich clusters with measured temperature, redshift and abundance) can provide a breakthrough in this field.

In the meanwhile, the use of Chandra to study in detail the heavy elements distribution in distant cool cores can provide significant insights on the feedback mechanism and the redistribution of heavy elements into the ICM.