A critical assessment of the metal content of the ICM

S. Molendi\textsuperscript{1}, D. Eckert\textsuperscript{2,1}, S. De Grandi\textsuperscript{3}, S. Ettori\textsuperscript{4}, F. Gastaldello\textsuperscript{1,5}, S. Ghizzardi\textsuperscript{1}, G. W. Pratt\textsuperscript{6} and M. Rossetti\textsuperscript{7,1}

\textsuperscript{1} INAF - IASF Milano, via E. Bassini 15 I-20133 Milano, Italy
\textsuperscript{2} Department of Astronomy, University of Geneva, Ch.d’Ecogia 16, 1290 Versoix, Switzerland
\textsuperscript{3} INAF - Osservatorio Astronomico di Brera, via E. Bianchi 46, 23807 Merate, Italy
\textsuperscript{4} INAF, Osservatorio Astronomico di Bologna, via Ranzani 1, 40127 Bologna, Italy
\textsuperscript{5} Department of Physics and Astronomy, University of California at Irvine, 4129 Frederick Reines Hall, Irvine, CA 92697-4575, USA
\textsuperscript{6} Laboratoire AIM, IRFU/Service d’Astrophysique - CEA/DSM - CNRS - Université Paris Diderot, Bât. 709, CEA-Saclay, F-91191 Gif-sur-Yvette Cedex, France
\textsuperscript{7} Dipartimento di Fisica dell’Università degli Studi di Milano, via Celoria 16, I-20133, Milan, Italy

\textbf{ABSTRACT}

\textbf{Aims.} Our goal is to provide a robust estimate of the metal content of the ICM in massive clusters.

\textbf{Methods.} We make use of published abundance profiles for a sample of \textasciitilde 60 nearby systems, we include in our estimate uncertainties associated to the measurement process and to the almost total lack of measures in cluster outskirts.

\textbf{Results.} We perform a first, albeit rough, census of metals finding that the mean abundance of the ICM within \(r_{500}\) is very poorly constrained, \(0.06Z_\odot \lesssim Z \lesssim 0.26Z_\odot\), and presents no tension with expectations. Similarly, the question of if and how the bulk of the metal content in clusters varies with cosmic time, is very much an open one.

\textbf{Conclusions.} A solid estimate of abundances in cluster outskirts could be achieved by combining observations of the two experiments which will operate on board Athena, the XIFU and the WFI, provided they do not fall victim to the de-scoping process that has afflicted several space observatories over the last decade.

\textbf{Key words.} galaxies: clusters: cool cores – X-ray: galaxies: clusters– intergalactic medium

1. Introduction

Over the last decade and a half, analysis of spectra from the latest generation of X-ray experiments, has allowed the measure of density, temperature, pressure and entropy of the Intra-Cluster Medium (hereafter ICM) for several hundreds of systems. For a more limited number of objects, long dedicated observations have permitted detailed studies of cores and of other regions of particular interest. More recently, the coming of age of SZ experiments has allowed to construct cluster samples significantly less biased and extending to greater cosmological distances than X-rays ones (e.g. Planck Collaboration XXIX 2013). All in all, the wealth of thermodynamic measures collected out to redshifts of \textasciitilde 1 has afforded an impressive improvement in our understanding of the physics of these systems and made clusters one of the major tools to estimate cosmological parameters.

X-ray data can also be used to derive another quantity, one that cannot be measured with SZ experiments, and that has been used to a lesser extent than others, namely the metal abundance. Spectra of high statistical quality can be used to derive the abundance of several elements: i.e. O, Mg, Si, S, Ar, Ca, Fe and Ni (see Tamura et al. 2004, Mernier et al. 2015), however, for the majority of systems, measures are restricted to the most prominent line, i.e. the Fe Kα line at 7 keV. These measures have been used by several workers (see de Plaa 2013 for a recent review) to infer several properties of the ICM. For example some have attempted to use metals as tracers of gas motions in the ICM (e.g. Ghizzardi et al. 2013, Rossetti & Molendi 2011). A few (e.g. Tamura et al. 2011) have audaciously attempted to use the limited spectral resolution of X-ray CCD to directly measure shifts in the lines. However most of the effort thus far has gone into trying to characterise the metal content of the ICM. Radial distributions of the metal abundance are available for several tens of systems while 2D distributions have been published for a more limited number of objects. Several authors have compared abundances of different elements to point out that the enrichment of the ICM requires contributions from both SNIa and SNcc (de Plaa et al. 2007, De Grandi & Molendi 2009). There have been a few attempts to connect the abundance distribution with the cluster formation and evolution history (e.g. Fabian et al. 2010), indeed the amount of metals that end up in the ICM is expected to depend critically upon the interplay between star formation and AGN activity and can be used to provide constraints on feedback processes that are complementary to the ones based on the entropy distribution (e.g. Voit et al. 2005, Pratt et al. 2010). Some have attempted to gauge the enrichment process of the ICM (Tornatore et al. 2007, Cora et al. 2008) and to relate it to the nucleo-synthesis and ultimately the star formation processes in cluster galaxies. More specifically, attempts to relate the observed Fe content of the ICM with that expected from the stellar population, have come to the conclusion that, for the most massive clusters, the former exceeds the

\textsuperscript{1} Things should be changing dramatically within a year from now with the launch of the first X-ray micro-calorimeter, the Soft X-ray Spectrometer (SXSI) on board the ASTRO-H mission. With a spectral resolution of 6 eV, measurements of line shifts and broadenings associated to subsonic motions are well within the reach of the SXSI.
latter by a factor of several (e.g. Loewenstein 2013). This is recognized as a problem because, unlike for less massive systems, where the potential well is sufficiently shallow to allow the escape of at least part of the metals injected into the ICM, for massive clusters all metals are expected to remain within the system. In this paper we provide a critical assessment of the metal content of the ICM. In §2 we briefly review the methodology and systematics involved in measuring abundances in the ICM. In §3 we perform our estimate of the metal content of the ICM, while in §4 we discuss our finding and their implications. In §5 we consider future prospects for the measure of the Fe content of the ICM. Finally in §6 we summarize our results.

Abundances are reported relative to the solar photospheric values of Anders & Grevesse (1989), where Fe= 4.68×10⁻⁵ (by number relative to H). We make this choice despite the significant evolution of solar reference systems of the last 2 decades, (see Lodders 2010 for a review). Indeed, these changes have led to the introduction of new references which have been superseded in a matter of years. In this framework, the choice of an old but widely adopted and recognized abundance reference is not such a bad one. To ease comparison with other systems we old but widely adopted and recognized abundance reference is seeded in a matter of years. In this framework, the choice of an old but widely adopted and recognized abundance reference is not such a bad one. To ease comparison with other systems we

2. Measuring Abundances

Both continuum and line emission from the ICM are two body processes. The continuum emission is proportional to the product of the number of all ions by the number of electrons, while the line emission is proportional to the number of ions of a given species times the number of electrons. Under these conditions it is easy to show that the equivalent width of a given line is proportional to the ratio of the number density of the element producing the line over the number density of hydrogen. In other words the equivalent width of the line is proportional to the relative abundance of the element producing it (e.g. Sarazin 1988). Thus, even at the relatively modest resolution afforded by current CCD detectors, ~ 2% at 6 keV, intense and isolated lines, such as the FeKα line, typically feature equivalent widths comparable or in excess of the spectral resolution. Several authors (e.g. de Plaa 2013) have pointed out that the above conditions lead to direct and reliable estimates of the metal abundance in clusters. Some years ago we (De Grandi & Molendi 2009) carried out a study to verify this expectation. We performed a detailed spectral analysis of the spectra of the central regions of 26 cool core clusters. These systems are bright and the spectra are of high statistical quality allowing precise estimates of the equivalent width of a few ion species. We identified and investigated three possible causes of systematic uncertainties: 1) the calibration of the X-ray experiment; 2) the plasma code used to fit the X-ray data and 3) the thermal structure of the ICM. By comparing measures of the three detectors onboard XMM-Newton we found that systematic errors on the abundance to be below 3% for Si and Fe. By comparing the mekal (Mewe et al 1985, 1986 Kaast 1993, Liedahl et al 1995) and apec (Smith et al 2001) plasma codes, available within the X-ray spectral fitting package XSPEC (Arnaud 1996), we found differences of 10% for Si and 5% for Fe. Finally, by fitting spectra with different multi-temperature models, namely 2T and 4T, we found that systematic differences were always below 3% for Fe. So, in conclusion, focusing on Fe, which is the element that is typically used to measure the metal abundance of the ICM, we found that systematic errors were below 5%. Thus, we could confirm that, if data of sufficient statistical quality is available, robust and precise estimates of the metal (i.e. Fe) abundance can be made.

3. Metal content of the ICM

The first measurement of the Fe line in clusters dates back to 40 years ago (Mitchell 1976). Since that time much has been learned about the metal content of clusters. In the following subsection we review the relevant literature.

3.1. The state of the art

Amongst the first systematic studies of abundance profiles is a paper based on BeppoSAX data, which we wrote more than a decade ago (De Grandi & Molendi 2001). There we showed for the first time that while non cool-core (hereafter NCC) systems show relatively flat profiles, cool-core (hereafter CC) clusters feature an abundance excess in their center. An important aspect of this measurement is that the profiles could be extended out to about 0.4r₁₈₀. More recently, we performed a more extensive study based on a sample of 60 massive clusters observed with XMM-Newton (Leccardi et al 2010). From Fig.6 of that paper we found that the strength of the metal abundance excess correlates with the central entropy in the sense that, within roughly 0.1r₁₈₀, systems with lower central entropy feature a stronger central excess. In the intermediate region (i.e. between 0.1r₁₈₀ and 0.2r₁₈₀) the three groups of clusters we identified, namely low entropy core systems (LEC), medium entropy core systems (MEC) and high entropy core (HEC) systems all show an abundance excess with respect to the metallicity measured in the outer region. Beyond 0.2r₁₈₀ we found no evidence of any difference in abundance between clusters belonging to the three classes described above.

Another important point is that this external region extends out to 0.4r₁₈₀. In other words, while the XMM-Newton observations have achieved to show a significant improvement in our characterization of core and rim-core regions, they have not permitted us to extend our exploration of the metal abundance of outskirts beyond what was previously known. We have discussed the reasons for this failure elsewhere (Molendi 2004, Ettori & Molendi 2011) and we will not review them here. We do however wish to draw our readers attention to the fact that measurements of metal, i.e. Fe, abundance of clusters extend out to rather small radii. If we take as reference the mass of the ICM measured within r₁₈₀, as determined in Eckert et al. (2012), see their Fig.6, we find that the gas mass within 0.1r₁₈₀ ranges between 2% and 5% of the total gas mass, depending on how peaked the surface

² This may have improved over the last few years however, since there is no single fitting package containing updated versions of these codes, the comparison is somewhat complicated.
³ r₁₈₀ is defined as the radius within which the mean density is 180 times the critical density of the Universe. For massive clusters r₁₈₀ ≈ 1.65r₉₀, where r₉₀ is another reference radius often used in the literature, defined similarly to r₁₈₀.
⁴ In our works, we considered as 'massive’ systems with mean temperatures in excess of 3.5 keV (see Leccardi & Molendi 2008b) roughly corresponding to 3 × 10¹⁴M⊙.
Fig. 1. Simulated two temperature spectrum and best fitting one temperature model. The simulated spectrum and its components are plotted in red, the 1.8 keV and 3.6 keV components are shown as a dotted and dashed line respectively, while the total spectrum is reported as a solid line. The best fitting one temperature model is shown as a solid black line. Both the simulation and the fit were performed in a broad energy band, 0.5 keV - 10.0 keV, however, here we show only the 0.7 keV - 4.0 keV range. Note how the one temperature model does an adequate job of reproducing the shape of the L-shell blend arising from the two temperature spectrum, for a more detailed discussion see text and Gastaldello et al. (2010). Given the didactic nature of this simulation, background components have not been included, it should go almost without saying that contributions from the latter will make attempts to discriminate between different spectral models even more arduous.

In recent years there has been one attempt to measure the metal abundance at larger radii with the Suzaku satellite on the Perseus cluster. Werner et al. (2013) measure a flat abundance profile out to ~ 0.9r180 with a mean value consistent with the one we determined in Leccardi et al. (2010). This is certainly a very interesting measure, however it cannot be used to provide a robust estimate of the metal abundance in clusters at large radii for at least 4 good reasons. 1) The measure has been performed only on one system. 2) It does not provide a full azimuthal coverage of the cluster, indeed the coverage decreases as a function of radius. 3) The measure has been performed assuming a single temperature model, an assumption made in all the analysis of outer regions, including our own Leccardi et al. (2008a) but one that cannot be tested with the current data and which could lead to systematic errors on the abundance (see §3.2 for details). 4) Even under the unverified assumption of a single temperature medium, abundance measurements in cluster outskirts are extremely challenging (e.g. Ettori & Molendi, 2011) indeed, when the continuum from the cluster is only a few percent of the total signal that is measured, an exquisite characterization of the background is required to provide reliable estimates of thermodynamic parameters. For the metal abundance, which typically requires the characterization of equivalent widths of a few hundreds eVs at 6 keV, even more so. This is illustrated by the fact that while a few tens of measures of the temperature around r180 are available in the literature (e.g. Reiprich et al. 2013), there is only one for the abundance.

3.2. Abundance bias in the outskirts

In this subsection we provide an example to illustrate why metal abundances could be significantly overestimated in cluster outskirts. As pointed out in §3.1 spectra from outer regions are typically fit with one temperature models, however there is mounting evidence that the temperature structure is more complicated. Measurements of the surface brightness in outer regions indicate that inhomogeneities are certainly present on scales of several tens of kpc and beyond (Nagai & Lau, 2011; Roncarelli et al. 2013; Eckert et al. 2015), moreover, although not yet detected, they likely extend to significantly lower sizes (e.g. Gaspari et al. 2014). Since regions of different density will be kept in approximate pressure equilibrium by sound waves, the overdense regions will also be cooler and at a lower entropy than less dense regions. A key issue is how metals are distributed between the different phases: do all components share the same abundance or are some metal richer than others? We have shown that in relaxed (e.g. Ghizzardi et al. 2013) and intermediate systems (Rossetti & Molendi, 2010) entropy and metallicity tend to anticorrelate, i.e. regions of lower entropy are metal richer. If mixing and thermal equilibration processes are ineffective in homogenizing gas that is set into motion by the continuous accretion process in clusters, as suggested by some of our recent work (Eckert et al. 2014; De Grandi et al. 2015), it may well be that the lower entropy clumps have different, likely higher, metallicity than the surrounding medium.

Hereafter we model in a rudimental fashion a multi-temperature plasma, our purpose is not to reproduce in detail the thermodynamic structure of the ICM but more modestly provide an example of how inhomogeneities characterized by the entropy vs. metallicity anticorrelation could bias abundance measures. We consider a volume of ICM which is filled with gas at two different densities, the more rarefied component filling most of the volume and the denser only 5%. Since, as already pointed

5 There is also a measurement on the Virgo cluster (Simionescu et al. 2015), however this is a low mass system with a total mass of roughly 1.4 × 10^14 M⊙ and we will not consider it further.
out, sound waves will maintain gas of different densities in approximate pressure equilibrium, overdense region will also be cooler. We assume the hotter component to be at 3.6 keV, a relatively low temperature similar to that found in the outer regions of hot clusters and the cooler to be at half that temperature, i.e. 1.8 keV. We also assume the cooler component to have a high metal abundance of 0.4Z⊙, and the hotter one to have a lower metallicity of 0.05Z⊙, in agreement with the scenario described above. Since the cooler component, filling 5% of the volume, is twice as dense as the hotter one, its mass will be 10% of the total mass. We have simulated the spectrum from this two temperature plasma using the fakeit command in the XSPEC spectral fitting package (Arnaud 1996) using redistribution matrix and effective area files for the EPIC pn (we have also verified that, as expected, adopting response files from other CCD instrument does not change our results significantly). By fitting the simulated spectrum with a one temperature model we derive a metal abundance in the range 0.2Z⊙ - 0.25Z⊙. This is a factor of ∼ 3 larger than the mass weighted metal abundance that can be readily derived from the numbers provided above, i.e. 0.08Z⊙ and about a factor 2 larger than the emission weighted abundance, i.e. 0.11Z⊙. Note that both simulated and fit spectra are shown in Fig.1. As pointed out in §3.1 spectra from outer regions are typically fit with one temperature models mostly because the statistical quality of the data is insufficient to allow multi temperature fitting. Moreover, even if a multi temperature fit is attempted, some assumption on the relation between the metallicity of the different components needs to be made as the metal abundance of the different components are largely degenerate with respect to one another. Fitting our simulated spectrum with a two temperature model, with the two abundances free to vary independently of one another, confirms this. If we assume that the two components have the same abundance we find a metallicity of 0.13Z⊙, almost a factor of 2 larger than the input mass weighted abundance.

Despite some disagreement on the steepness of the temperature profiles, (e.g. Walker et al. 2012; Eckert et al. 2013), the shared view is that they decline with radius. This implies that, with the exception of the hottest systems, the Fe abundance in the outermost regions of many clusters will have to rely on L-shell measures alone. Under such circumstances, constraining the metal abundance is equally if not more arduous. In Eckert et al. (2014) we showed that the spectrum of a particular region could be fit comparably well with a single temperature model and a multi-temperature one differing by more than a factor of 3 in metal abundance. Before closing this subsection, it is worth reminding our readers that significant biases in the estimate of metal abundances in multi-temperature regions have been recognized and studied for some time (e.g. Buote 2000a, b; Molendi & Gastaldello 2001, Rasia et al. 2008, Gastaldello et al. 2010). In his seminal papers Buote identified an ”Fe-bias” which leads to an underestimation of the Fe abundance, while in Gastaldello et al. (2010) the authors describe an ”inverse Fe-bias”, working in the opposite direction, which also happens to be the one at work in our example. What is perhaps less well understood is that biases can be equally important in the outskirts as in the cores of clusters (see Reiprich et al. 2013, for a discussion of this issue).

3.3. A rough census

In this subsection we attempt a first census of metals out to r180. As previously discussed, we have good estimates of the metal abundance within 0.2r180 from Leccardi et al. (2010). For the region between 0.2r180 and 0.4r180 we also assume the abundance measured in Leccardi et al. (2010), but we complement it with a factor of 2 uncertainty, see §3.2. Since we do not have any reliable estimate of the metal abundance beyond 0.4r180, we assume it to be anywhere between 0.01Z⊙, i.e. almost no metal, and 0.24Z⊙, the value measured between 0.2r180 and 0.4r180. The upper bound is not based on any data but on the educated guess that metal abundance profiles do not increase with radius. By combining these estimates with measures of the gas mass within a given radius (Eckert et al. 2013) we derive a mean, cumulative, gas mass weighted, metal abundance profile, ZMW(< r), out to r180, see Fig.2. The mean abundance within r180, i.e. ZMW(< r180), is found to be anywhere between 0.06Z⊙ and 0.26Z⊙. We point out that the line has been detected shows that, however little, some Fe must be present. The upper bound is not based on any data but on the educated guess that metal abundance profiles do not increase with radius. By combining these estimates with measures of the gas mass within a given radius (Eckert et al. 2013) we derive a mean, cumulative, gas mass weighted, metal abundance profile, ZMW(< r), out to r180, see Fig.2. The mean abundance within r180, i.e. ZMW(< r180), is found to be anywhere between 0.06Z⊙ and 0.26Z⊙. We point out that the line has been detected shows that, however little, some Fe must be present.
out that, albeit weak, these are, to our knowledge, the first constraints on the metal content within $r_{180}$.

4. Discussion

We have shown that the mean Fe abundance in clusters is very poorly constrained, ranging from a minimum of 0.06$Z_{\odot}$ to a maximum of 0.26$Z_{\odot}$. Although the data used to perform the calculation has been published for some time, and from our own group we might add, this is the first estimate of the mean metal abundance within $r_{180}$. In this section we shall discuss, amongst other things, how, despite their weakness, the limits on the metallicity can provide useful insight.

Over the last decades several authors have discussed the relation between the Fe content of the ICM, as estimated from observations, and the one expected from the stellar population observed in clusters (e.g. Renzini 1997; Loewenstein 2013; Renzini & Andreon 2014). Under the assumption that the most massive systems in our Universe, i.e. rich clusters, are closed boxes, in the sense that material that falls into them can no longer escape, their total Fe content should be easily predicted if SNe Fe yields are known and cluster total stellar masses are measured (e.g. Loewenstein 2013). The authors that have performed this exercise have found that the expected metal content of the ICM falls short of the observed one, assumed to be roughly 0.3$Z_{\odot}$ by a factor of several (e.g. 2 in Loewenstein 2013). In the previous section we have shown that, while the observed abundance is indeed close to the one adopted by these authors, the mean cluster abundance could differ from it very significantly, for the simple reason that the metallicity of the bulk of the ICM has yet to be measured. For example in a recent paper, Renzini & Andreon (2014), derive a mean ICM metallicity of 0.3$Z_{\odot}$, by making use of metal abundances measured within 0.6 $r_{500}$, i.e. roughly 0.4 $r_{180}$ for rich clusters.

If taking an inventory of metals in local clusters is no easy task, trying to establish if and how abundances vary across cosmic time is even more arduous. There have been several attempts to characterize the redshift evolution of the metallicity (e.g. Balestra et al. 2007; Maughan et al. 2008; Baldi et al. 2012; Ettori et al. 2015). In the latest and most complete of these papers, Ettori et al. (2015), we found no significant evidence of evolution in metallicity in the outermost regions, roughly corresponding to the 0.2$r_{180}$-0.4 $r_{180}$ range. However, the question of if and how the bulk of the metal content in clusters, which lies beyond our current reach, varies, remains very much an open one.

It is worth noting that there are other useful information that could be gleaned from the distribution of metals in outskirts. As already discussed in §1 these measures can be used to gauge the formation and evolution process of cluster in a fashion that is complementary to the one involving the measurement of thermodynamic variables. For example, it could be used to test AGN feedback processes (since metals efficiently trace bulk motions) and pinpoint the metal injection epoch (e.g. Fabjan et al. 2010).

As an interesting aside, we note that in cluster cores the metal budget does not appear to be a problem. Under the assumption that the metal excess observed in cool cores is due to stars currently residing in the BCG invariably found at the center of these systems (De Grandi et al. 2004), we have found that the mea-
sured Fe mass in the ICM is comparable to the expected one (e.g. De Grandi et al. 2014).

5. Future Prospects

The characterization of metal abundances in cluster outskirts requires data from new experiments that are more sensitive to low surface brightness emission than existing ones. The Japanese satellite ASTRO-H (Takahashi et al. 2012) should be operational within the next year; it carries several experiments, the Soft X-ray Imager (SXI) is comparable to the CCDs on board Suzaku, with one notable exception, i.e. the significantly larger field of view, $35^\prime \times 35^\prime$, and may lead to some improvements with respect to the latter experiment. The Soft X-ray Spectrometer (SXS) provides unprecedented spectral resolution and will undoubtedly make very significant contributions in several fields (e.g. Kitayama et al. 2014). In the case at hand however, the relatively high instrumental background combined with the small field of view, $3^\prime \times 3^\prime$, and effective area, 300 cm$^2$ at 6 keV, will make exploration of cluster outer regions with the SXS challenging. Indeed no systematic study of cluster outskirts with SXS is foreseen at this time (Kitayama et al. 2014). The launch of Spekt-RG is currently scheduled for 2017; the eROSITA experiment (Merloni et al. 2012), on board Spekt-RG, has characteristics similar to previous CCD imagers and should have a sensitivity to low surface brightness emission comparable to that of the XMM-Newton EPIC cameras.

The ESA mission Athena, currently in its phase A study and with an expected launch in 2028, will carry a Wide Field X-ray Imager (WFI) and an X-ray Integral Field Unit (XIFU). The XIFU is a microcalorimeter array with large collecting area and a $3.5^\prime \times 3.5^\prime$ field of view. The design of XIFU on board Athena includes an anti-coincidence system as well as a passive shield, which are expected to reduce the instrumental background by more than an order of magnitude (Lotti et al. 2014). In the current design the WFI enjoys a combination of very large effective area, 2 m$^2$ at 1 keV, and good angular resolution, $\sim 5^\prime$, extending over a very large, $40^\prime \times 40^\prime$, field of view. Moreover, there are a number of current activities on the telescope and detector design that, if successful, will lead to an experiment with low, stable and extremely well characterized background.

While the limited field of view of the XIFU will likely not allow a full coverage of cluster outer regions, its high spectral resolution combined with the low background will afford a sampling of the temperature structure of cluster outskirts. This information can be subsequently fed into the WFI spectral modelling: as pointed out in 4.2 an adequate characterization of the temperature structure of the plasma is a key point to keep biases in the abundance measurements under control. In Fig. 6 we provide an example of an abundance profile measurements with the WFI on board Athena, details on the properties of the simulated cluster are provided in the figure caption. As shown by the figure, the profile can be measured out to about $r_{180}$. A key point is that the fitting of the WFI spectra has been performed with the same spectral model that has been used to simulate the data, in the case at hand a one temperature plasma. Another point worth bearing in mind is that these measurements depend upon a few critical parameters: a decrease in effective area or, alternatively, an increase in background intensity, will lead to larger errors, that, assuming no change in the level of systematics, cannot be recovered with longer exposure times. Similarly a loss of reproducibility of the background will lead to an increase of systematic errors, this is illustrated in Fig. 3 where we show how rapidly systematic uncertainties grow in the outskirts as background reproduction degrades. For instance at $r_{500}$, corresponding to $0.62r_{180}$ we expect a systematic uncertainty on the measure of the abundance of 2%, 4% and 10% for a background reproducibility good to 1%, 2% and 5% respectively, while at $r_{180}$ we expect a systematic uncertainty of 7%, 14% and 35% for the same levels of background reproducibility. Thus, a de-scoping of the mission entailing a loss in effective area, or in background reproducibility, or an increase in background intensity, could limit significantly measures of metal abundances in cluster outskirts.

6. Summary

Our results are summarized as follows.

– Robust estimates, characterized by systematic uncertainties of the order of a few percent, are available for cluster core and circum-cores. The mean metal abundance within these regions, i.e. $r < 0.2r_{180}$, is $\sim 0.3 Z_{\odot}$.

– Between $0.2r_{180}$ and $0.4r_{180}$ we have several tens of measurements, however the limited statistical quality of the data does not allow a detailed reconstruction of the thermodynamic structure of the gas in these regions. This leads to systematic uncertainties in metal abundance measures which could be as large as a factor of 2 or even more.

– Since almost nothing is known of the metal abundance beyond $0.4r_{180}$, where the bulk of the gas mass resides, any claim of tension between the measured and expected metal content of the ICM should be viewed with a good dose of skepticism. Using published data and assuming that between $0.4r_{180}$ and $r_{180}$ the abundance be constrained between 0.016$Z_{\odot}$ and 0.246$Z_{\odot}$, we have performed a first, albeit rough, census of metals within $r_{180}$. We find the mean, mass weighted, abundance within $r_{180}$, i.e. $Z_{MW}(< r_{180})$, to be between 0.06$Z_{\odot}$ and 0.26$Z_{\odot}$; this broad range does not conflict with expectations. Similarly, the question of if and how the bulk of the metal content in clusters varies with cosmic time, is very much an open one.

– A solid estimate of abundances in cluster outskirts could be achieved by combining observations of the two experiments which will operate on board Athena, the XIFU and the WFI, provided they do not fall victim to the de-scoping process that has afflicted several space observatories over the last decade.

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