Chemical enrichment in the hot intra-cluster medium seen with XMM-Newton

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Introduction

The hot intra-cluster medium (**ICM**) is rich in heavy elements (mostly from O to Ni), which are synthesized in Type Ia (**SNIa**) and core-collapse (**SNcc**) supernovae explosions. These **metals** accumulate over time into the deep gravitational potential well of galaxy clusters and groups since the major cosmic epoch of star formation (z≈2-3).

However, the **SNIa** explosion mechanisms (each predicting different yields) are not well constrained, while the **SNcc** yields depend on the initial mass function (IMF) and initial metallicity of their stellar progenitors.

Therefore, measuring the abundances in the ICM may provide valuable **constraints** on theoretical models for SNIa and SNcc.

Methods & Materials

Using the XMM-Newton EPIC and RGS instruments, we measure the abundances of 9 key elements (**O**, **Ne**, **Mg**, **Si**, **S**, **Ar**, **Ca**, **Fe** and **Ni**) in a sample of 44 nearby cool-core galaxy clusters/groups (the **CHEERS*** catalog, ~**4.5 Ms** net exposure; de Plaa et al., to be submitted).

The RGS spectra are used to derive the O/Fe and Ne/Fe ratios. The EPIC spectra are used to derive the other abundance ratios, after a careful and complete modelling of the background components.

The spectral fitting was performed with SPEX v2 (Kaastra et al. 1996).

*CHEmical Enrichment Rgs Sample

Results

While the absolute Fe abundance is found to vary typically within ~0.3-1.5, all the objects of our sample are consistent with having **uniform** X/Fe abundance ratios, suggesting that the enrichment process must be similar at all scales.
This also allows us to derive an average X/Fe abundance pattern, representative of the nearby ICM as a whole. We address a careful attention to all the possible systematics, which we keep under control.

Moreover, our large dataset allowed us to derive average **Cr/Fe** and **Mn/Fe** abundances (**Fig. 1**). In particular, this is the first time that Mn is detected and robustly measured in the ICM.

~4.5 Ms

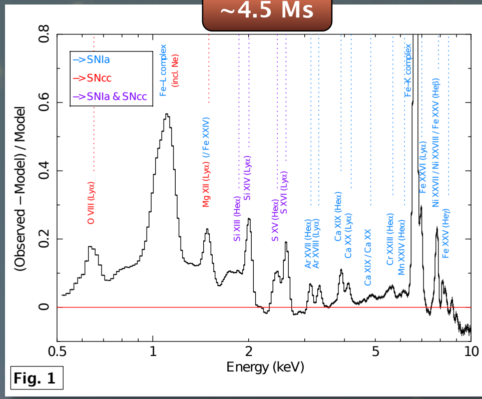

Fig. 1

We then compare our average X/Fe abundance pattern with theoretical predictions of SNIa (Iwamoto et al. 1999) and SNcc (Nomoto et al. 2013) yields. We find that these classical yields models **fail** to reproduce our abundance ratios (**Fig. 2**), regardless of the assumptions made for the SNIa explosion mechanism (deflagration vs. delayed-detonation) and for the SNcc IMF and initial metallicity. In particular, the **Ca/Fe** and **Ni/Fe** ratios are clearly underestimated (see also de Plaa et al. 2007).

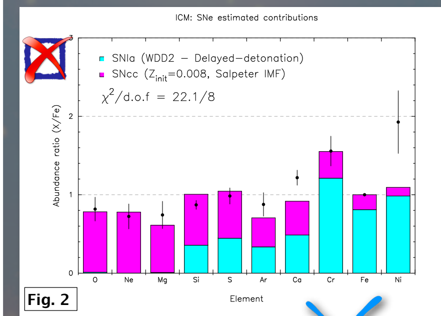

Fig. 2

- A significantly better agreement for **Ca/Fe** can be achieved, by invoking either an alternative delayed-detonation model describing well the Tycho remnant (Badenes et al. 2006), or an additional contribution of **Ca-rich gap transients** (Waldman et al. 2011), a recently discovered sub-class of supernovae, exploding preferentially in galaxy outskirts (**Fig. 3**).

- On the other hand, a better agreement for **Ni/Fe** can be achieved only if we assume a **bi-modality** in SNIa explosions, where about half of SNIa explode as deflagration - the remaining part exploding as delayed-detonation (**Fig. 3**).

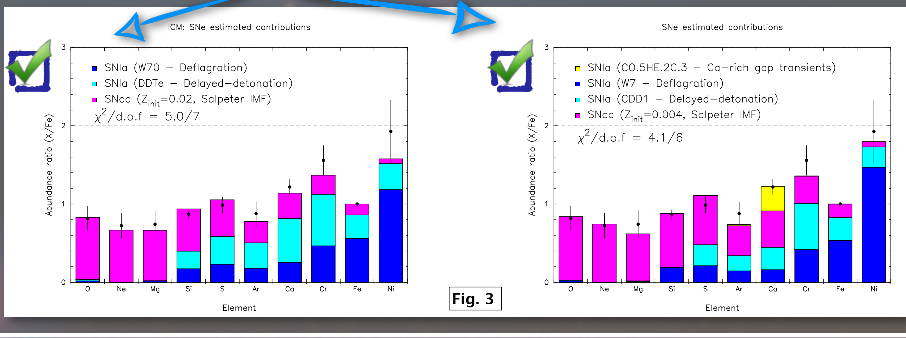

Fig. 3

Current limitations & Future prospects

Because the systematic uncertainties largely dominate over the statistical uncertainties, stacking more observations will not help further to improve the accuracy of our results. Therefore, our sample constitutes the **most accurate** abundance estimates ever performed in the nearby cool-core ICM so far, and should be a **legacy** for any related future work.

A significant improvement to this study will be achieved by:

1) improving the predicted yields **models** for both SNIa and SNcc, as well as their uncertainties,

2) reducing the uncertainties in measuring the abundances, in particular thanks to the micro-calorimeter technology onboard the next-generation X-ray missions (e.g. **Athena**, **Fig. 4**),

3) in parallel, keeping efforts on improving the atomic databases and **plasma codes**,

4) carry out new independent observations on **SNIa** and **SNcc** (including Ca-rich gap transients), in order to constrain their rates and their underlying physics.

Fig. 4

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See talk by Jelle de Plaa!
(Wednesday, 11:25)

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