Radial distribution of metals in the hot intra-cluster medium as observed by XMM-Newton

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Introduction & Motivations
The intra-cluster medium (ICM) contains metals!

Mitchell et al. (1976)
The intra-cluster medium (ICM) contains metals!

NGC 5846

Abell 4059: core

Counts s$^{-1}$ Å$^{-1}$

Counts s/keV

0 0.01 0.02 0.03

0 0.01 0.1 1 10

Mg XII Mg XI Ne X Fe XIX – XX Na X Fe XVIII Fe XVII O VIII / Fe XVIII O VIII N VII

→ SN Ia → SN cc → AGB

de Plaa et al. (submitted)

RGS

EPIC

Mernier et al. (2015)

CIE

GDEM

1 CIE

2 CIE

O Fe L/Ne Mg Si S Ar Ca Fe Ni

MOS

pn

0.5 1 2 5 10

Energy (keV)
The origin of (heavy) chemical elements

**Core collapse supernovae (SNcc)**

- Produce: $\rightarrow$ O, Ne, Mg, Si, S
- Explode (and enrich) quite fast after star formation

**Type Ia supernovae (SNIa)**

- Produce: $\rightarrow$ Si, S, Ar, Ca, Fe, Ni
- Time delay between star formation and SNIa explosions (?)
The *spatial distribution* of metals through the ICM provides valuable information on the *chemical enrichment history* of galaxy clusters!
Introduction

This project

Previous works

Results

Astro-H

Conclusions

Enrichment history in clusters: abundance profiles

1) Early enrichment

- **Uniform** abundance distribution in the **outskirts** (SNIIa and SNcc)
- Metals already in place (and well mixed) at \( z > 2-3 \)

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Werner et al. (2013)

Simionescu et al. (2015)

See next talk

(Esra Bulbul, on behalf of Cemile Ezer)
How about enrichment by SNcc in the core?

2) Later enrichment

- **Peaked** abundance distribution in the core (Fe \(\Rightarrow\) SNIa)

- Enrichment by SNIa from the central brightest cluster galaxy (BCG) at \(z > 1\)

(see also: De Grandi et al. 2014)
2) Later enrichment

- **Peaked** abundance distribution in the core ($\text{Fe} \rightarrow \text{SNIa}$)
- Enrichment by SNIa from the central brightest cluster galaxy (BCG) at $z > 1$

(see also: De Grandi et al. 2014)
Observations
• **Cool-core** galaxy clusters, groups & ellipticals

• O VIII line in RGS: $> 5\sigma$

• **Nearby** ($z < 0.1$)

• New deep observations of 11 objects (1.6 Ms)

• + archival (public) data

**CHEERS** stands for: **CHEmical Enrichment Rgs Sample**

(PI: Jelle de Plaa)

⇒ 44 objects

⇒ ~4.5 Ms of XMM-Newton total net exposure

XMM-Newton
• Every pointing → 8 concentric annuli (fixed angular sizes)

• **Point sources** are removed from the analysis

• **MOS** and **pn** spectra fitted independently (cross-calibration uncertainties are taken into account)

• **SPEX** (v2): Multi-temperature model (**GDEM**)

• Careful **background** modelling (five components)

• **Stacking** all the measurements (in units of $r_{500}$, ~20 measurements per reference radial bin)

Mernier et al. (2015)
Results
The (average) Fe profile

Mernier et al. (2017)
The (average) Fe profile

Previous measurements

Simulations

Comparison observations vs. simulations should be addressed very carefully!
Abundance profile of other metals

Systematic uncertainties under control:

✓ Projection effects
✓ Thermal modelling
✓ Background uncertainties
✓ Weight of individual observations
✓ Atomic code uncertainties

Mernier et al. (2017)
Radial distribution of the SNIa fraction

- Uniform SNIa/(SNIa+SNcc) fraction all across the ICM (at least up to ~0.5r_{500})!
  (see also: Ezer et al. 2017)

- If the BCG (now red and dead) is indeed responsible for the central Fe peak, it may have also produced SNcc

- More generally, within ~0.5r_{500}, SNIa and SNcc enrichment may share the same origin

- The time delay between the bulk of SNIa and SNcc enrichment is short: less than the time scale necessary to diffuse out the metals

Mernier et al. (2017)
Conclusion
**Conclusions**

**Take home message**

*Type Ia and core-collapse supernovae enrich the ICM at the same proportion (up to \( \sim 0.5r_{500} \))*

- Fe (produced by SNIa) centrally peaked, sometimes with an inner drop
- SNcc products (O, Mg, Si) are also centrally peaked
- Fe profile: very good agreement with previous measurements & simulations
- SNIa and SNcc contributions to the ICM enrichment may share the same origin, and occur at similar epochs
- Need for better measurements in the outskirts (Hitomi 2, Athena) and improved simulations in the very core