Metals in the intracluster medium


Metals in intracluster medium in clusters of galaxies


Metals in groups


Metals in hot ISM in E and S0 galaxies – present metal supply to ICM


Metals in spiral and starburst galaxies – past metal supply to ICM

Goals of observing metals in the ICM

- Metal mass in the ICM?
- Initial mass function (IMF) of stars and star formation history in clusters
Metals in the Intracluster medium

- **O, Mg**
  - From SN II
  - Formation history of high mass stars in clusters

- **Si, S, Fe, Ni**
  - From SN Ia and SN II
  - History of SN Ia and SN II

**Star formation and chemical evolution history in clusters**

Suzaku satellite provides better sensitivity to O and Mg lines
O and Mg with Suzaku and XMM

- Suzaku gives smaller error bars for O/Fe and Mg/Fe ratios
- XMM can spatially resolve the central region.

Sakuma+submitted Matsushita&Tamura
Fe abundances derived from Suzaku and XMM

Errors – Suzaku: 90%  XMM: 68%

Suzaku gives smaller error bars at > 0.1r_{180}
Systematic differences of ~10% in cluster temperature among Chandra, the PN, and the MOS were reported in relatively high-temperature clusters with Suzaku, temperatures of the Coma cluster derived from the continuum and Fe line ratio agree very well. This result supports accurate temperature measurements with Suzaku, which are important to abundance measurements.

The Coma cluster
T. Sato + submitted Poster 79
Metals mostly come from galaxies via past galactic wind at starburst and SN Ia. When and how metals ejected into ICM?

- O/Fe and Mg/Fe ratios are 1—1.5 solar ratio
- Extended distribution of Fe than stars
- Flatter Fe abundance profile at 0.1—0.5\(r_{180}\) than expected
- No evolution until \(z=0.6\) excluding the central region

- Metal synthesis in early phase in cluster formation
- O Mass to light ratio is sensitive to IMF of stars
Abundance Pattern outside cool cores observed with Suzaku

O, Mg, Si, S, Ar, Ca, and Fe ratios are close to the solar ratio within a few tens of %. -> contribution of both SN Ia and SN II
Abundance pattern at $r > 0.1r_{180}$

O, Mg, Si, S, Ar, and Fe ratios are close to the solar ratio. A significant fraction of Fe come from SN Ia.
Fe abundance profiles with XMM

28 nearby clusters observed with XMM (Matsushita 2011)

The observed flatter radial profile of the Fe abundance at 0.1-0.5r_{180} indicates early metal enrichment than numerical simulation


The Fe abundance derived from numerical simulations by Fabjan+08

weighted average of cD clusters with cool cores

error 68%
Integrated Iron mass to light ratios: $M_{Fe}(<r)/L_{K}(<r)$

Increases with radius at least up to 0.5$r_{180}$

Fe in ICM is more extended than stars

To derive total Fe mass to light ratio, we need to go beyond 0.5$r_{180}$
O Mass to light ratio – sensitive to IMF

OMLR within 0.5r180 is consistent with Salpeter IMF

Salpeter IMF (slope=2.35)
By Renzini (2005)

slope=3.35

Centaurus
Sakuma+ submitted)
A262 (Sato et al. 2009b)
NGC5044 (Komiyama et al. 2009)
NGC1550 (Sato et al. 2010)
Suzaku detection of Fe line up to the virial radius

Fujita et al. (2008) see also a flat Fe profile of the Perseus cluster

By Simionescu+11

High Fe abundance @ 0.5-1.0 $r_{180}$

Early metal enrichment

Suzaku field of view

circles: virial radius

Evolution of Fe abundance of ICM

Maughan et al. 2008 with Chandra

error 68%

Maughan et al. 2008 with Chandra

error 68%

consistent with no evolution at least up to z=0.6 excluding the central region
Metals outside cool cores ($0.1-0.5r_{180}$)

- Metals mostly come from galaxies via past galactic wind at starburst and SN Ia
- When and how metals ejected into ICM?

- Extended distribution of Fe than stars
- Flatter Fe abundance profile at $0.1-0.5r_{180}$ than expected
- No evolution until $z=0.6$ excluding the central region

- These results indicate that galaxies synthesized Fe in early phase in cluster formation and pollute the ICM before distributions of galaxies became more centrally peaked than ICM (at present ICM is more extended than stars)

- O Mass to light ratio is sensitive to IMF of stars
Metals within cool cores

- cD galaxies eject metals via SN Ia and stellar mass loss SN II?
- Abundance pattern of O/Mg/Fe within cool core
- Comparison with abundance pattern of elliptical galaxies – present supply of metals into ICM
- Cr and Mn abundances from the Perseus and the Centaurus cluster
- Differences between the Perseus and the Centaurus cluster
The cool core of the Centaurus cluster has a very high central Fe abundance and lower O/Fe and Mg/Fe ratios.

- Contribution of SN Ia is higher
- Not a simple accumulation of hot ISM in ellipticals

Matsushita & Tamura

Fe abundance of ISM in E galaxies

Fe abundances from SN Ia of ISM in elliptical galaxies observed with Suzaku are about 0.5-1.5 solar.

**upper limit of present SN Ia rate**

Fe abundance of ISM is

stellar Fe abundance + present SN Ia contribution

- Integrating the derived present SN Ia rate from the ISM abundances over the Hubble time gives an order of smaller value of Fe mass –to-light ratio than the observed values.

- The cool core of the Centaurus cluster has a higher Fe abundance, much higher Iron mass-to light ratios and smaller O/Fe and Mg/Fe ratios than hot ISM in E galaxies.

- The result indicates **higher SN Ia rate in the past**
Increase of O/Fe, Mg/Fe ratio at 0.1-0.3$r_{180}$

Metal supply from central galaxies by SN Ia and stellar mass loss is important at the central region.
Mn/Cr ratio vs. initial mass function of stars

- O/Fe, Mg/Fe ratios from SN II depend on IMF of stars
- SN II do not produce Mn very much
- SN Ia and SN II yield the same Cr/Fe ratio
- Mn/Cr ratio – another indicator of SN Ia
Cr and Mn detection from the Perseus cluster with Suzaku

Tamura et al. 2009

also XMM detection from 2A 0335+096 by Werner et al. (2006)

Mn is an indicator of SN Ia, since SN II do not produce Mn very much

Solar abundance pattern

- Perseus
Ti, Cr and Mn lines in the Centaurus cluster observed with XMM (Matsushita & Tamura)

\[ \frac{\text{Flux(He-like Mn)}}{\text{Flux(He-like Cr)}} \]

\[ \text{Mn/Cr(Centaurus)} > \text{Mn/Cr(Perseus)} \rightarrow \text{higher contribution of SN Ia in the Centaurus cluster} \]
Fe abundance profiles of the Centaurus cluster and the Perseus cluster

The Centaurus cluster has the highest Fe abundance in nearby cool core clusters. (Matsushita 2011)

In the Centaurus cluster, contribution of SN Ia is higher than the Perseus cluster.

Difference in mixing in the cool cores?

These abundance profiles are consistent with Sanders+06, Churazov+04, Tamura+09, Sanders+07, adopting the same model.
Enhancement of 7.8 keV line

- Excess Kβ emission?
  - Resonant line scattering?
  - Smaller turbulence in the Centaurus cluster than the Perseus?
- Excess Ni abundance?

Astro-H will resolve Kβ line and Ni lines and derive turbulent velocity
• In our Galaxy, $\text{Ni/Fe (SN Ia)} = \text{Ni/Fe (SN II)}$
• Without resonant scattering, the Centaurus cluster needs different type of SNe Ia which synthesize higher Ni/Fe ratio
Metals in the cool cores of the Centaurus cluster vs. The Perseus cluster

The higher Fe abundance and Mn/Cr ratio, and lower ratios of O/Fe and Mg/Fe of the center of the Centaurus cluster means very high contribution of SN Ia

Enhancement of 7.8 keV line resonant line scattering? or high Ni/Fe ratio?

Lower O/Fe and Mg/Fe ratios of the center of the Centaurus cluster than those of ISM in ellipticals

- Enrichment timescale of the SN Ia products in the Centaurus > several Gyr (Boehringer et al. 2004)
- Higher SN Ia rate in the past?
- Difference of mixing of SN Ia ejecta into hot gas?
Groups vs. clusters

- similar Fe abundance profiles up to $0.3r_{180}$
- SN II products tend to be more extended in clusters?
- The observed metal mass-to-ratio are smaller in groups and poor clusters reflecting that gas fraction is smaller in groups
  - difference in star formation history?
  - same star formation history but difference in the effect of feedback?
Suzaku observations of Fe abundance profiles of ICM in clusters and groups

similar Fe abundance profiles

Sato+07,08 09ab
Tokoi +08, Matsushita+07
Komiyama+08, Hayashi+09
O and Mg in ICM within $0.1r_{180}$ observed with Suzaku. Similar abundance pattern within $0.1r_{180}$

$\text{kT} \sim 2$-$4$ keV clusters

$\text{kT groups} \sim 1$ keV

Sato+07,08 09ab
Tokoi +08, Matsushita+07
Komiyama+08, Hayashi+09

errors 90%
In groups of galaxies, metals synthesized by SN II have similar radial profiles with SN Ia products within 0.3$r_{180}$.

Sato+07, 08 09, Tokoi +08, Komiyama+08
Metal mass to light ratio

Mainly low mass stars

Suzaku (<0.1r_{180})

O mass to light ratio \rightarrow SN II

Fe mass to light ratio \rightarrow SN Ia, SN II

NGC 4636, NGC 5044, NGC 1399, NGC 507, HCG 62, Abell 262, Abell 1060, AWM 7, Centaurus

Sato+07, 08 09ab, Tokoi +08, Matsushita+07, Komiyama+08, Hayashi+09

groups

clusters

Temperature (keV)
Integrated profiles of
Iron mass/K band luminosity

Sato+07, 08 09ab
Matsushita+07
Komiyama+08
Sakuma+submitted

Matsushita+07
Komiyama+08
Sakuma+submitted

clusters

groups

Abell 262
AWM 7

Fornax all
NGC 5044
NGC 1550

Murakami+
submitted
Groups vs. clusters

- similar Fe abundance profiles up to $0.3r_{180}$

- SN II products tend to be more extended in clusters?

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  - difference in star formation history?
  - same star formation history but difference in the effect of feedback?
SN II like abundance pattern of the cap region of a starburst galaxy, M 82

Metals synthesized from SN II escape from starburst galaxies?

Tsuru+2007
Metal abundances of hot ISM in spiral galaxies with Suzaku

Starburst winds and starburst region → SN II type
non-starburst galaxy (N 4258)
solar abundance

○ Halo1 (2T model)
△ Halo2 (2T model)
□ Halo3 (2T model)
◊ NGC 3079
× NGC 4258
Charge exchange in the disk of M82?
Konami et al. submitted

- Enhancement of Ly $\beta$ in the disk region

Poster 41
Summary

Origin of metals ICM
• Abundance pattern from O to Fe of the ICM within $0.1r_{180}$ is close to that of the new solar abundance by Loddars (2003)
• Differences between the Centaurus and the Perseus
• Early formation of metals in Intracluster Medium (ICM)

Metals in clusters of galaxies vs. groups
• similar abundance, but smaller metal mass to light ratios in groups, reflects history of ICM

Metals in hot interstellar medium (ISM)
• Fe abundance ISM in Elliptical and S0 galaxies gives present metal supply into ICM from these galaxies
• SN II like abundance pattern in galactic winds of starburst galaxies
• the solar abundance pattern of ISM in normal spiral galaxies

Astro-H
• rare metals, resonant line scattering, turbulence