Metals in hot intracluster medium and interstellar medium with Suzaku and XMM

Metals in intracluster medium in clusters of galaxies

- Sato+2007,2008,2009a, Matsushita submitted

Metals in groups

- Matsushita+2007, Sato+2009b,Komiyama+2009, Tokoi+2008, Hayashi +2009

Metals in elliptical and S0 galaxies

- Matsushita+2007, Tawara+2007, Hayashi+2009, Nagino&Matsushita 2010, Konami + submitted

Metals in spiral and starburst galaxies

- Tsuru+2007, Yamasaki+2008,Konami+2009, Konami+ in prep

Metal abundances in the Intracluster medium observed with XMM and Suzaku

Kyoko Matsushita,
K. Sato, M. Komiyama, K.Hayashi,
K. Tokoi, T. Ohashi, H. Murakami

Outline

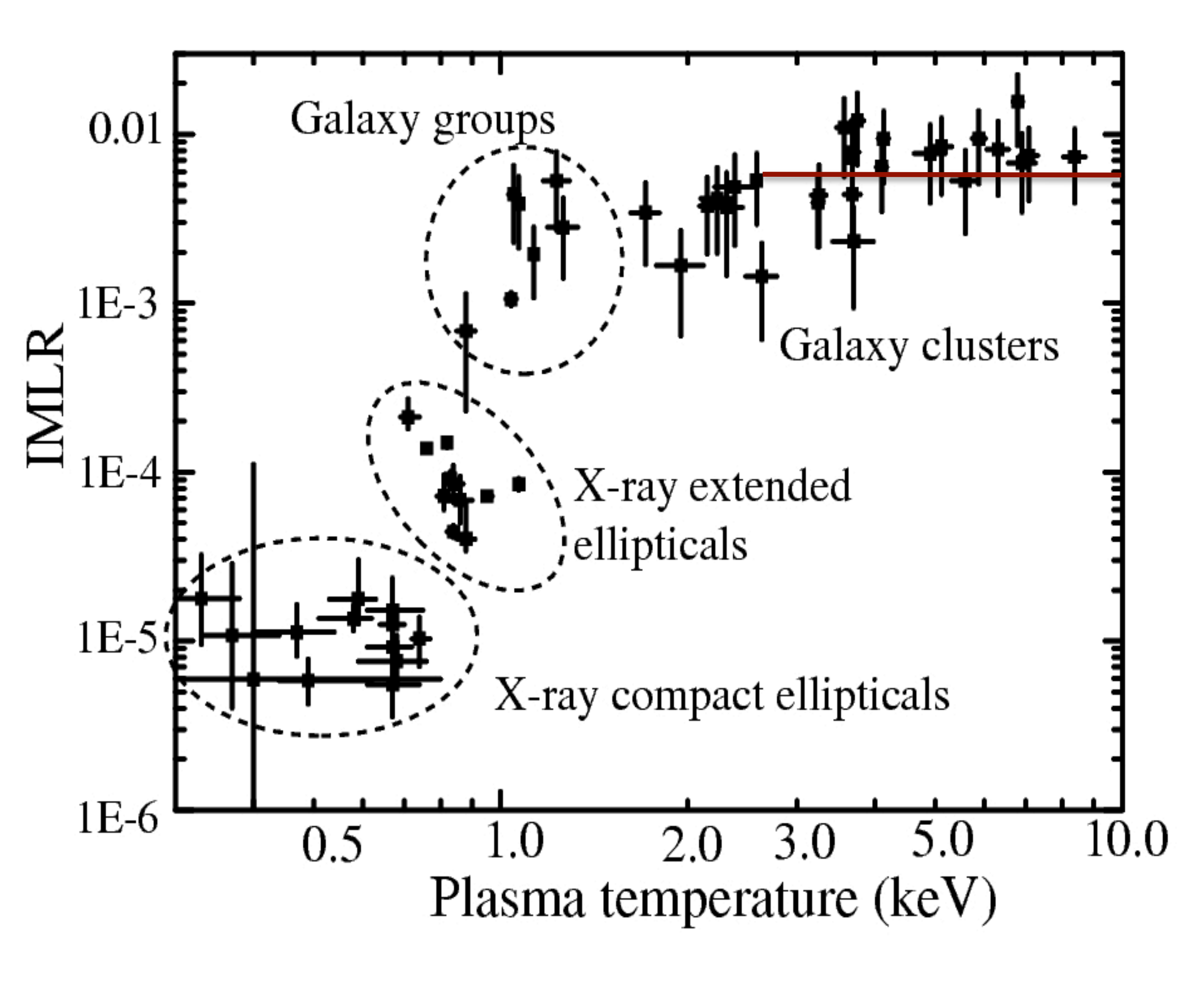
- Radial profiles of Fe abundance up to $0.3\text{-}0.5r_{180}$ with XMM satellite
- O and Mg in the ICM up to $0.2\text{-}0.3r_{180}$ with Suzaku satellite
- Groups vs. clusters observed with Suzaku

Metals in the ICM

$$\frac{\text{Iron mass in the ICM}}{\text{stellar luminosity}}$$

Iron mass in the ICM is comparable to that in stars in cluster galaxies

Clusters of galaxies contain all the metals synthesized in cluster galaxies?



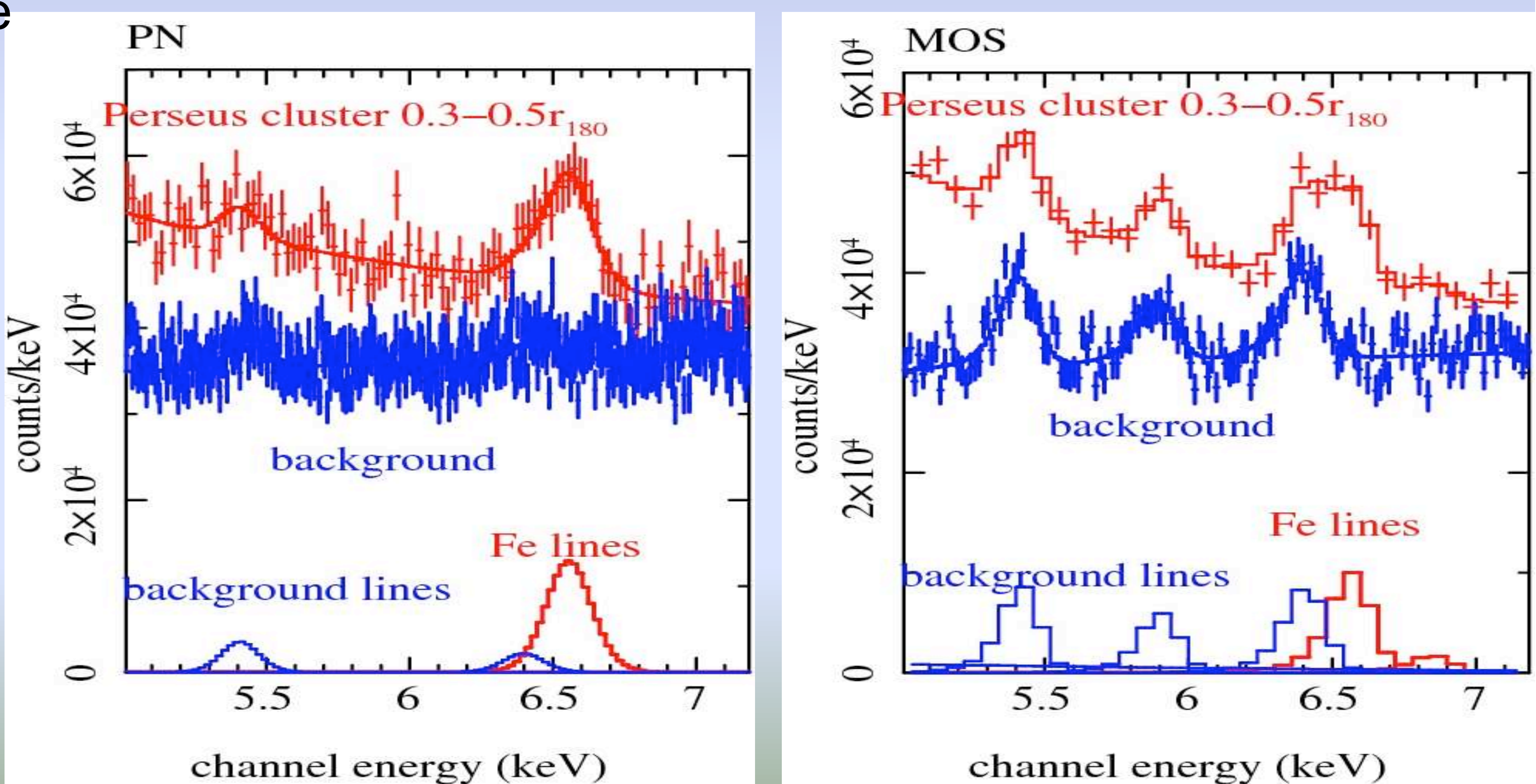
ASCA Makishima et al. (2001)

Fe abundance of the ICM in 28 nearby clusters with XMM z<0.08

Matsushita submitted to A&A

We derived Fe abundances from the flux ratios of Fe lines to the continuum within an energy range of 3.5–6 keV to minimize and evaluate systematic uncertainties due to background and temperature structure

画像の一部



Radial dependence of the Fe abundances

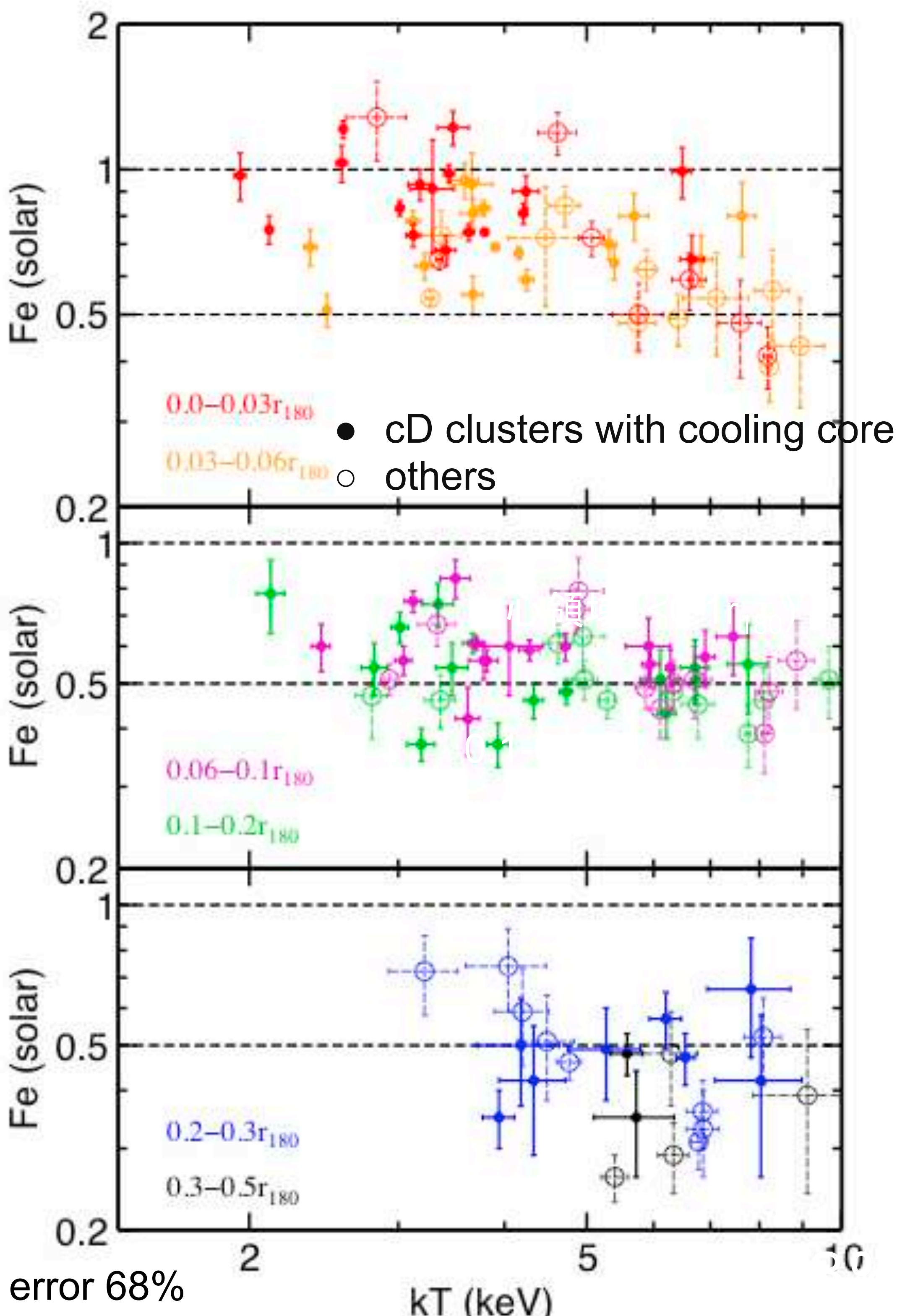
Fe abundances are derived from the flux ratios of He-like Fe line and the contrinuum

$<0.06r_{180}$

- Scatter
- Difference in recent metal enrichment from the cD galaxies

$0.1\text{-}0.3r_{180}$

- Small scatter

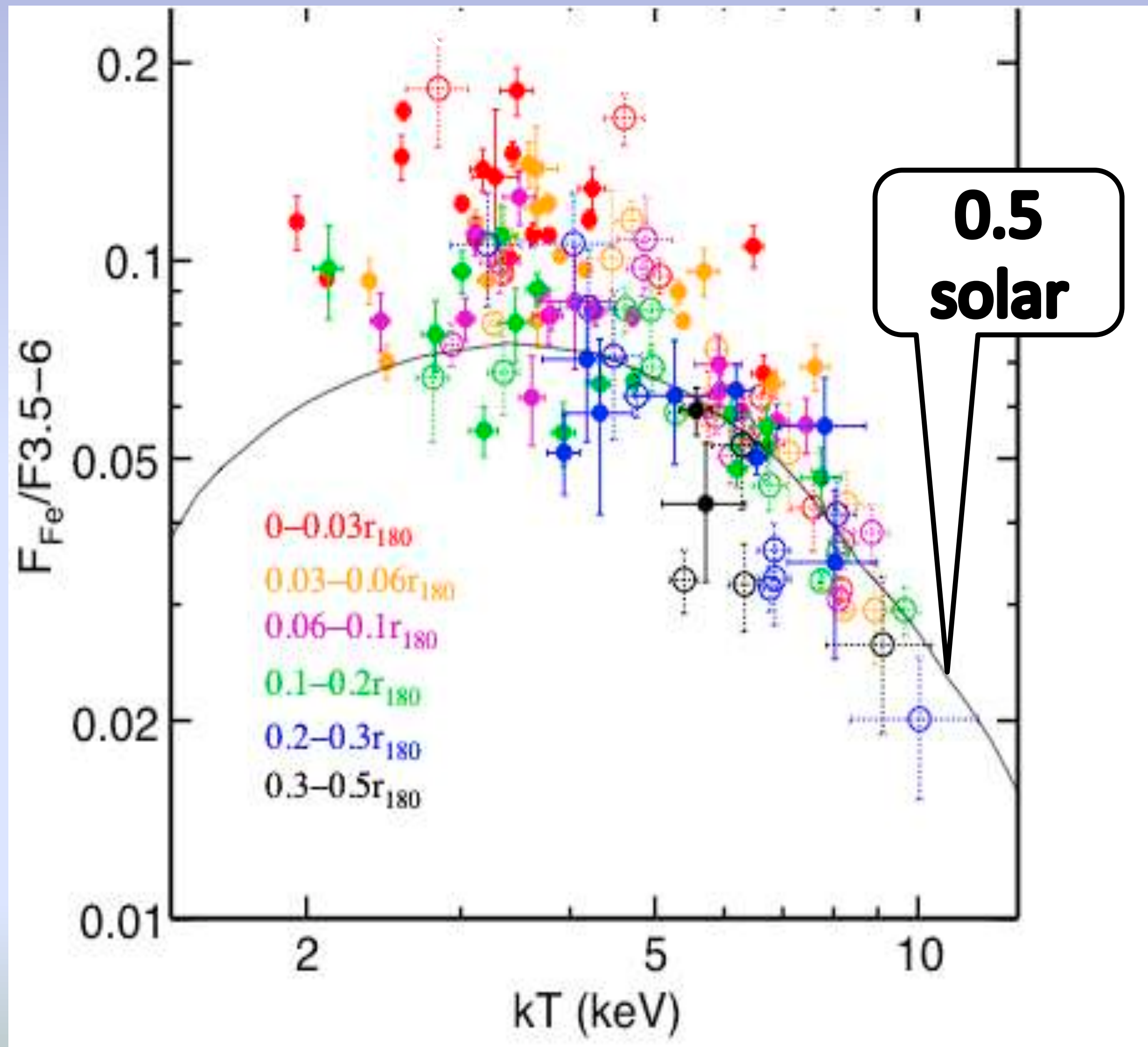


error 68%

Flux ratio of the He-like Fe line and continuum(3.5-6keV)

Dependence of the ratio on the plasma temperature is rather weak within 20% of 2-6 keV.

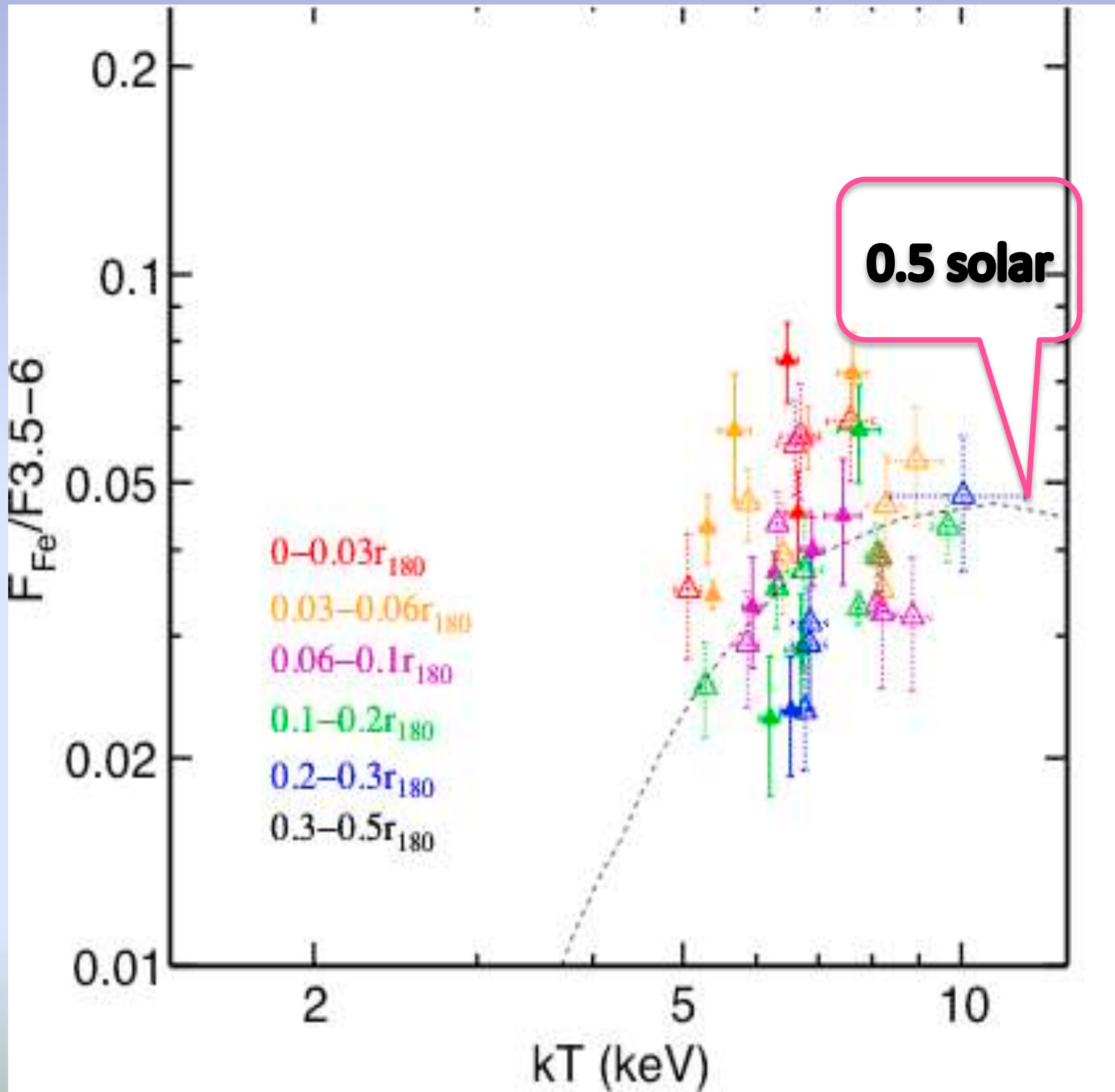
Below 6 kev, the uncertainty in the Fe abundance due to temperature structure is small



Flux ratio of the H-like Fe line and continuum(3.5-6keV)

Weak temperature dependence within 20% of 7-17 keV

The systematic uncertainty in the Fe abundance is smaller above 6 keV



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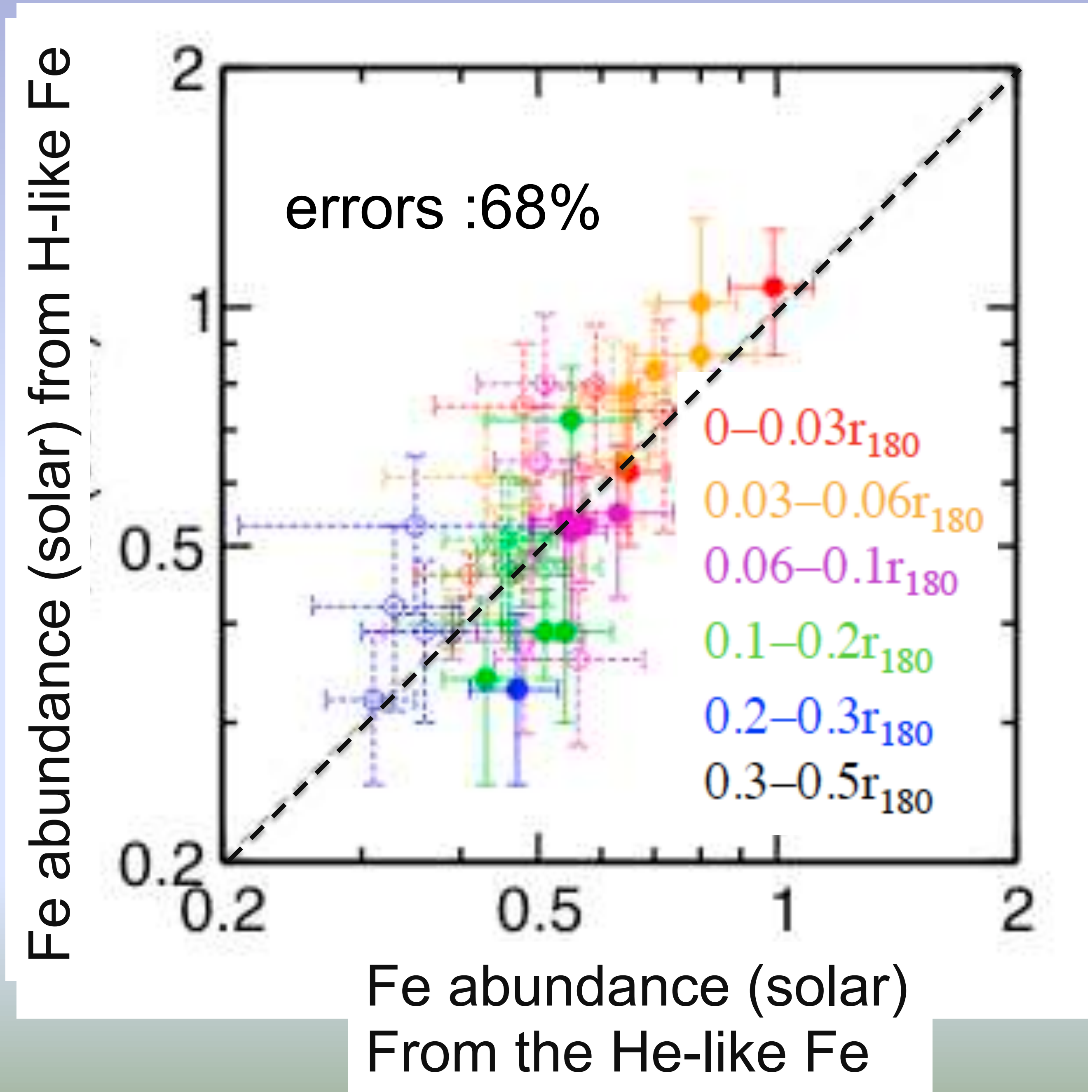
Systematic uncertainty in the Fe abundance
He-like vs. H-like

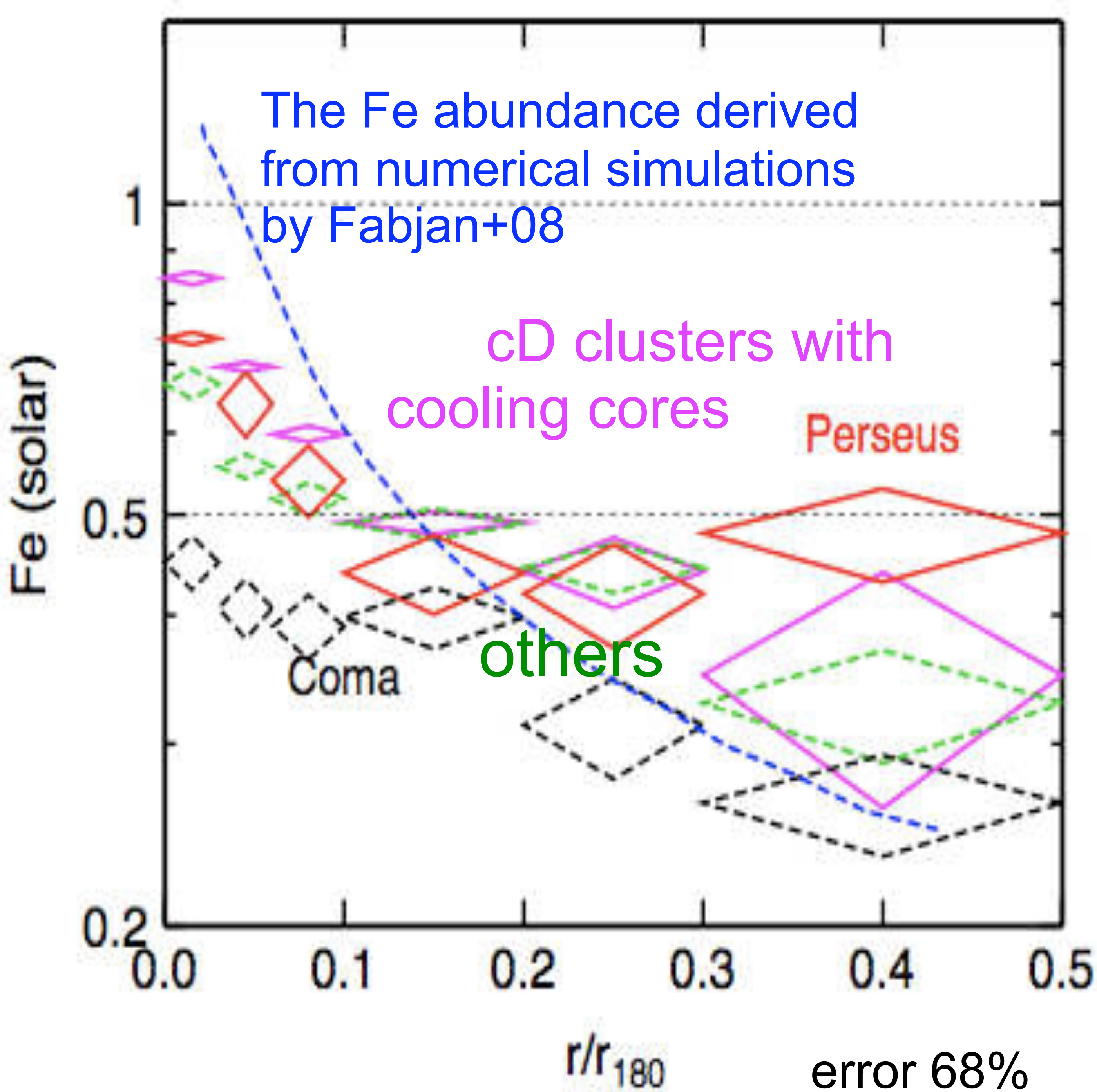
He-like and H-like Fe lines give consistent Fe abundances

Small systematic uncertainty, since temperature dependences of the two lines are different



The average Fe abundance profiles

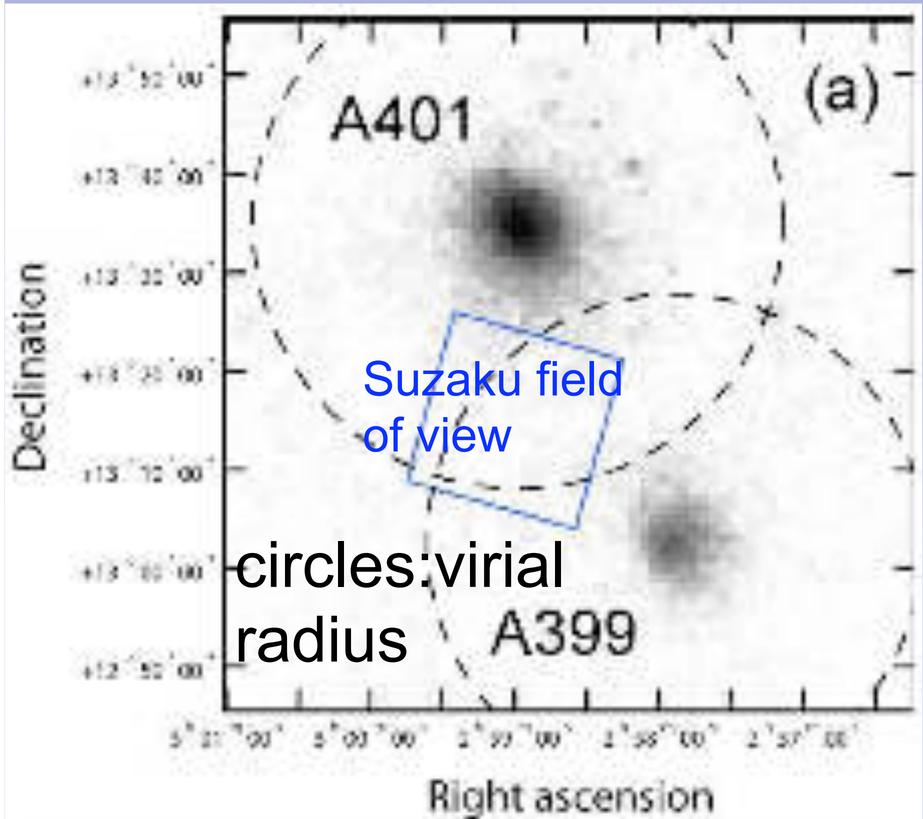
The observed flatter radial profile of the Fe abundance at 0.1-0.5r_{180} indicates early metal enrichment than numerical simulation

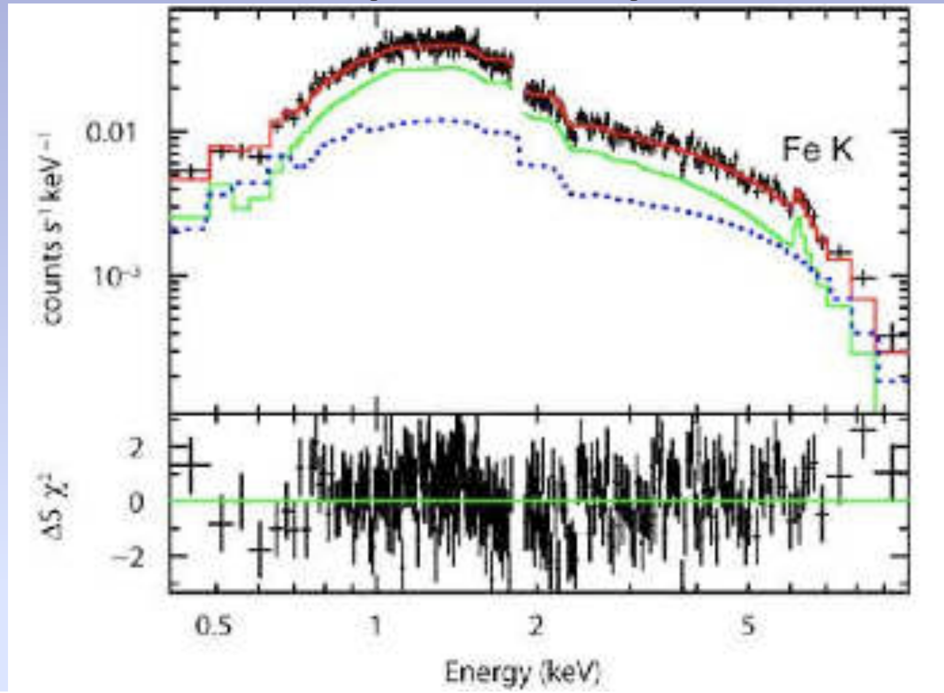


error 68%

solar abundance: loddars (2003)

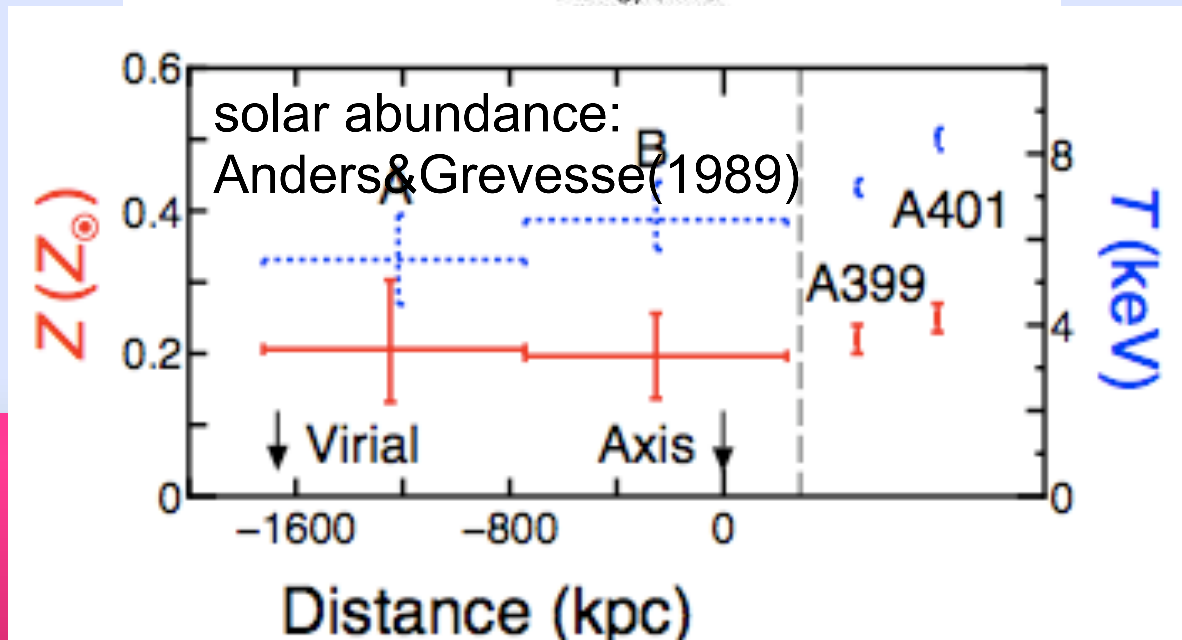
Suzaku detection of Fe line up to the virial radius　Fujita et al. (2008)





High Fe abundance @ 0.5-1.0 r_{180}

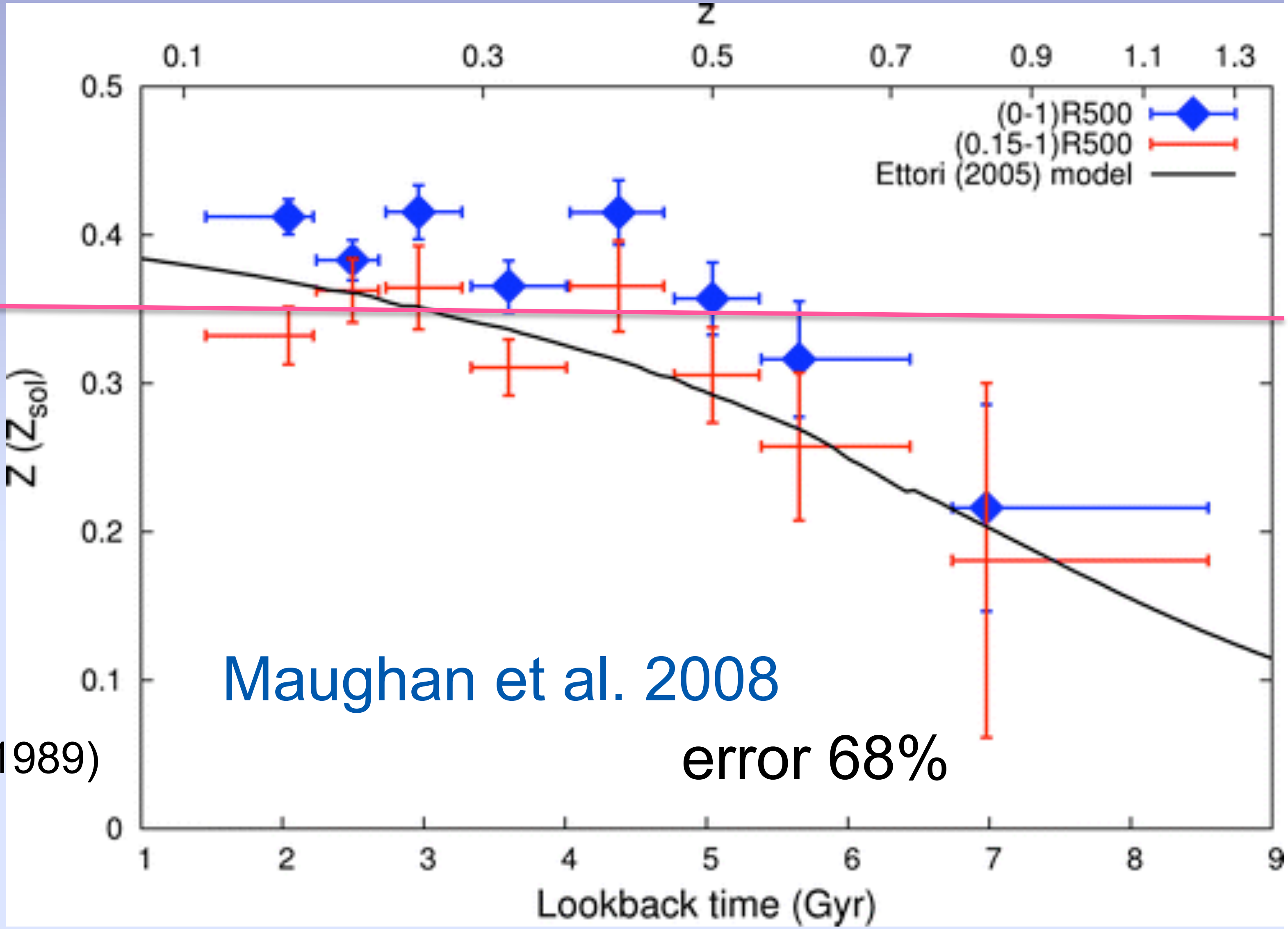
Early metal enrichment



Evolution of Fe abundance of ICM

z<0.08
Matsushita

cooling core
others



solar abundance:
Anders&Grevesse(1989)

Maughan et al. 2008

error 68%

consistent with no evolution at least up to z=0.6 excluding the central region

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

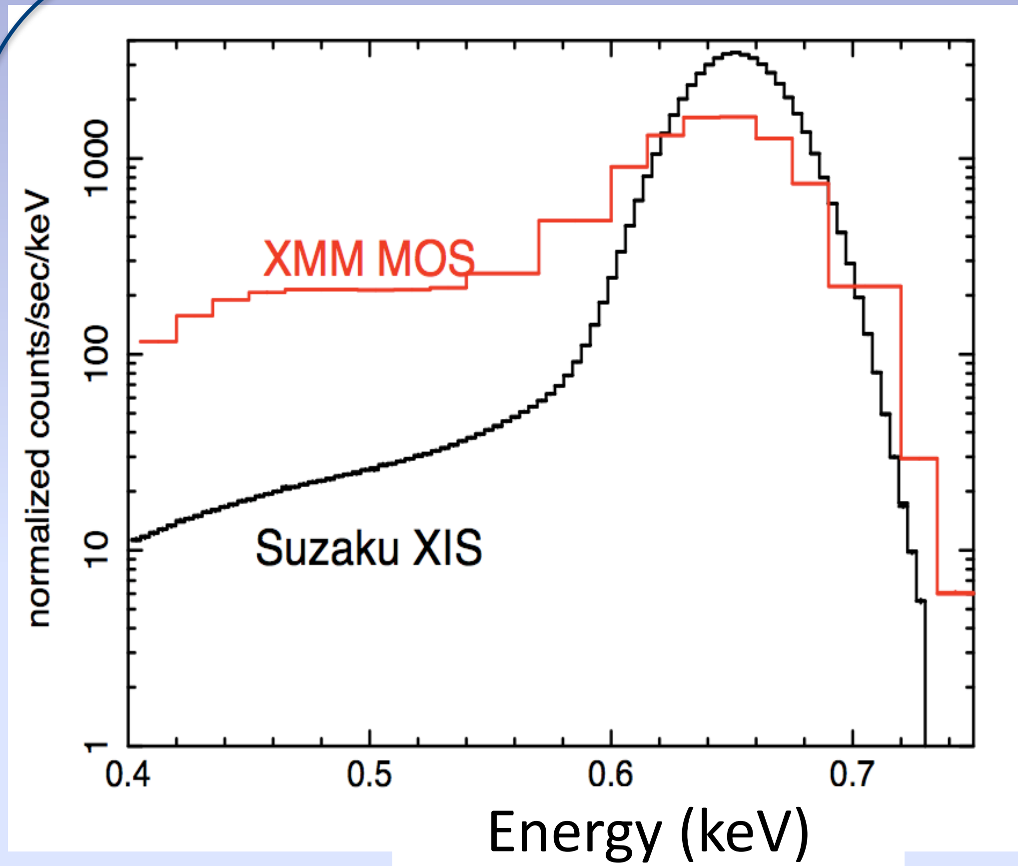
Advantages of Suzaku satellite

The XIS instrument onboard Suzaku (2005-) has

- an better line spread function due to a very small low-pulse-height tail below 1 keV

  energy range around O lines is not suffered by strong Fe-L lines

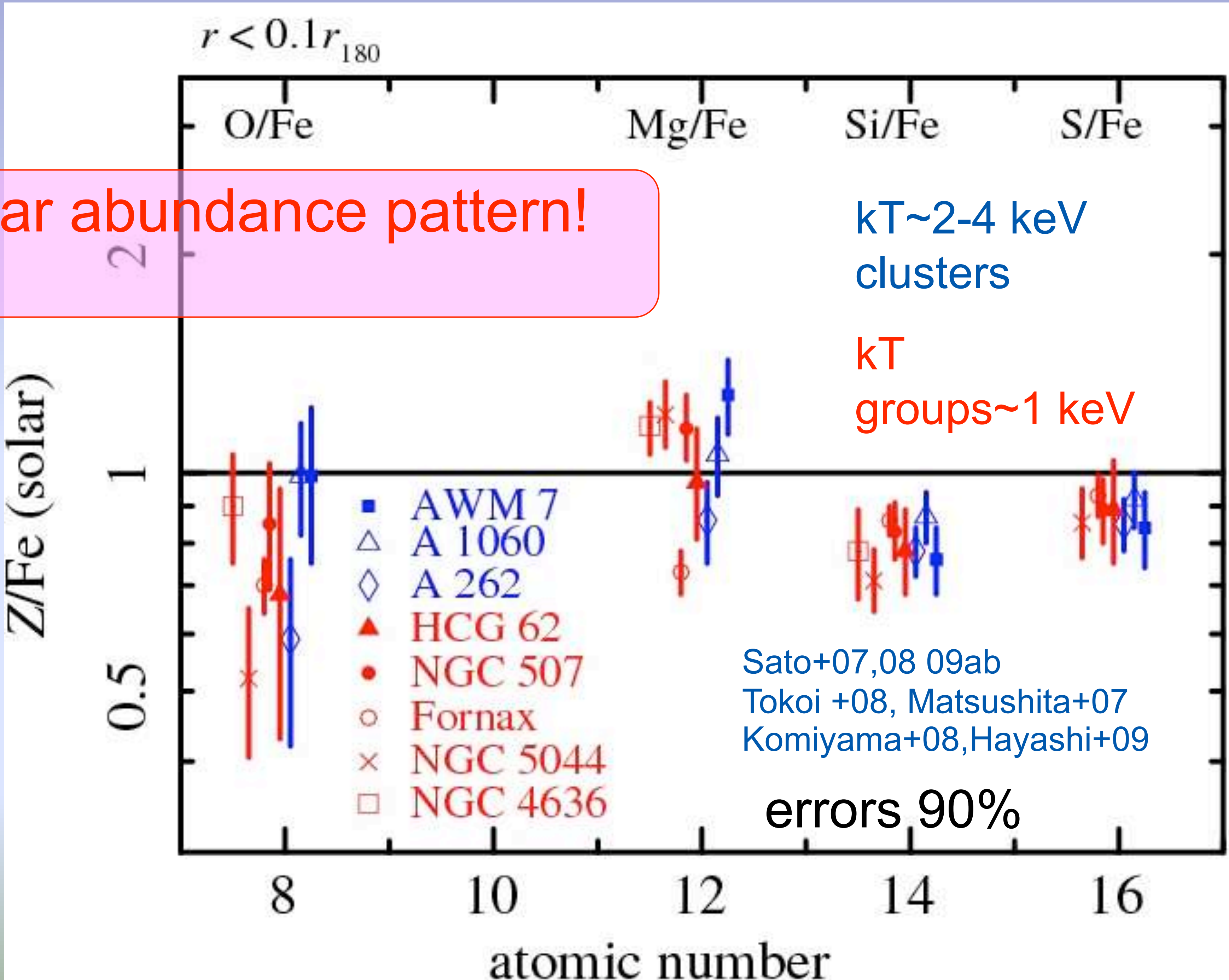
- a very low background.



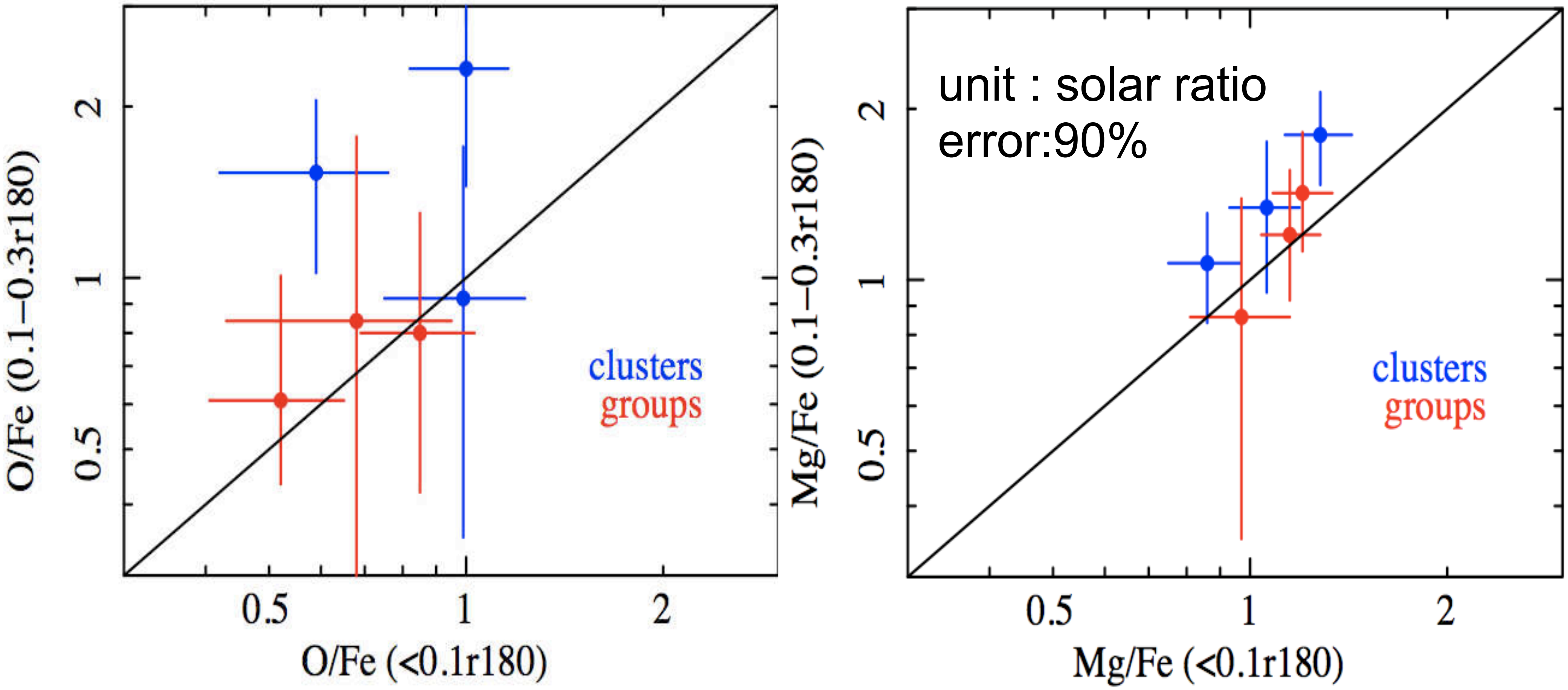
Response of a line at 0.65 keV (Kα line of H-like O) of XMM-MOS and Suzaku XIS detectors

O and Mg in ICM within $0.1r_{180}$ observed with Suzaku

solar abundance table by Loddars (2003)



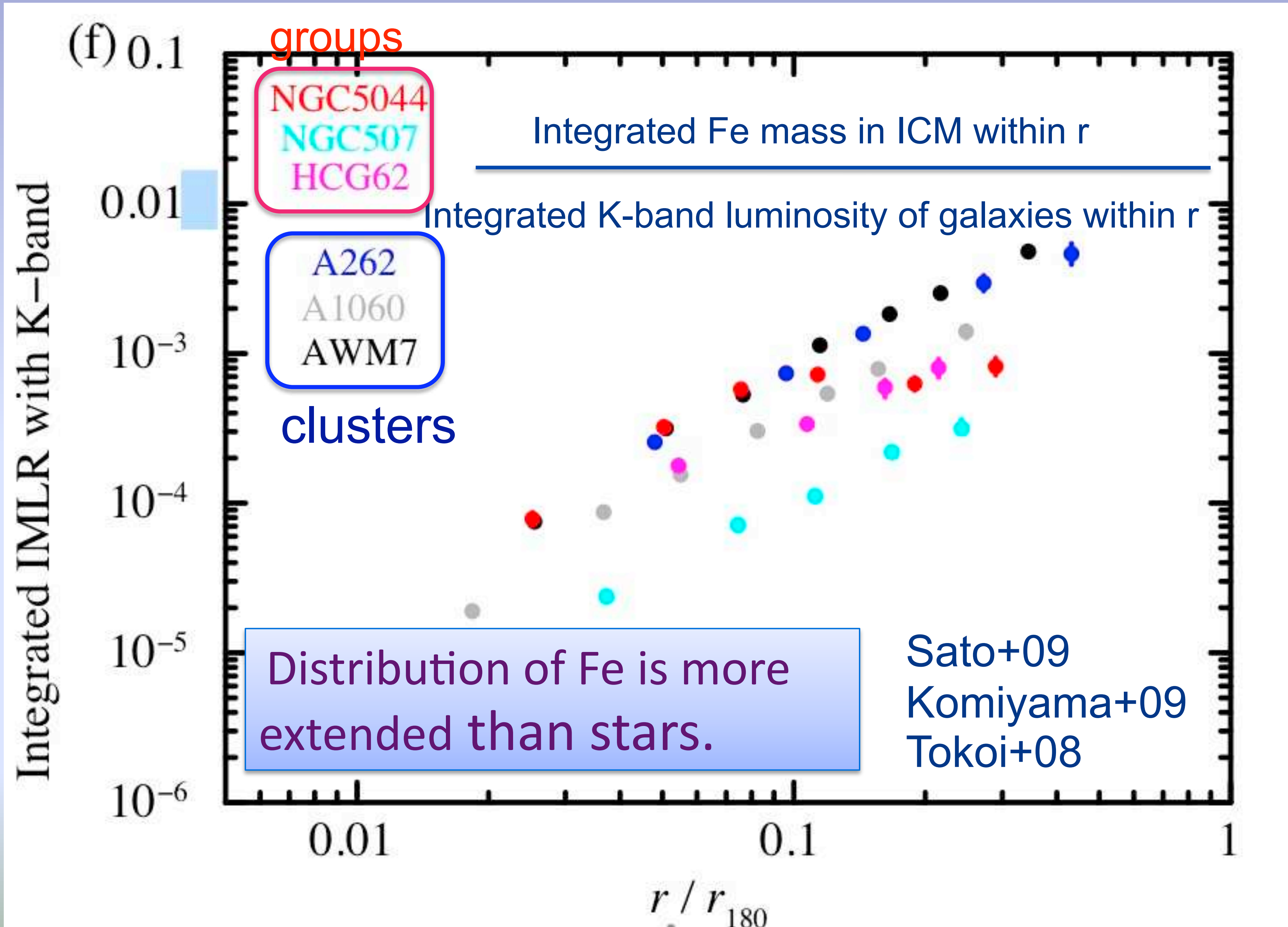
Increase of O/Fe, Mg/Fe ratio at 0.1-0.3r_{180}



In clusters of galaxies, metals synthesized by SN II tend to be more extended than SN Ia products?

Sato+07,08 09,Tokoi +08.Komiyama+08

Integrated Fe mass to light ratios



Origin of metals in ICM

Abundance pattern of ICM within $0.1r_{180}$ is close to the new solar abundance by Loddars (2003)

- 70-80 % of Fe are synthesized by SN Ia (Sato+07)
- metal supply from cD galaxies are important

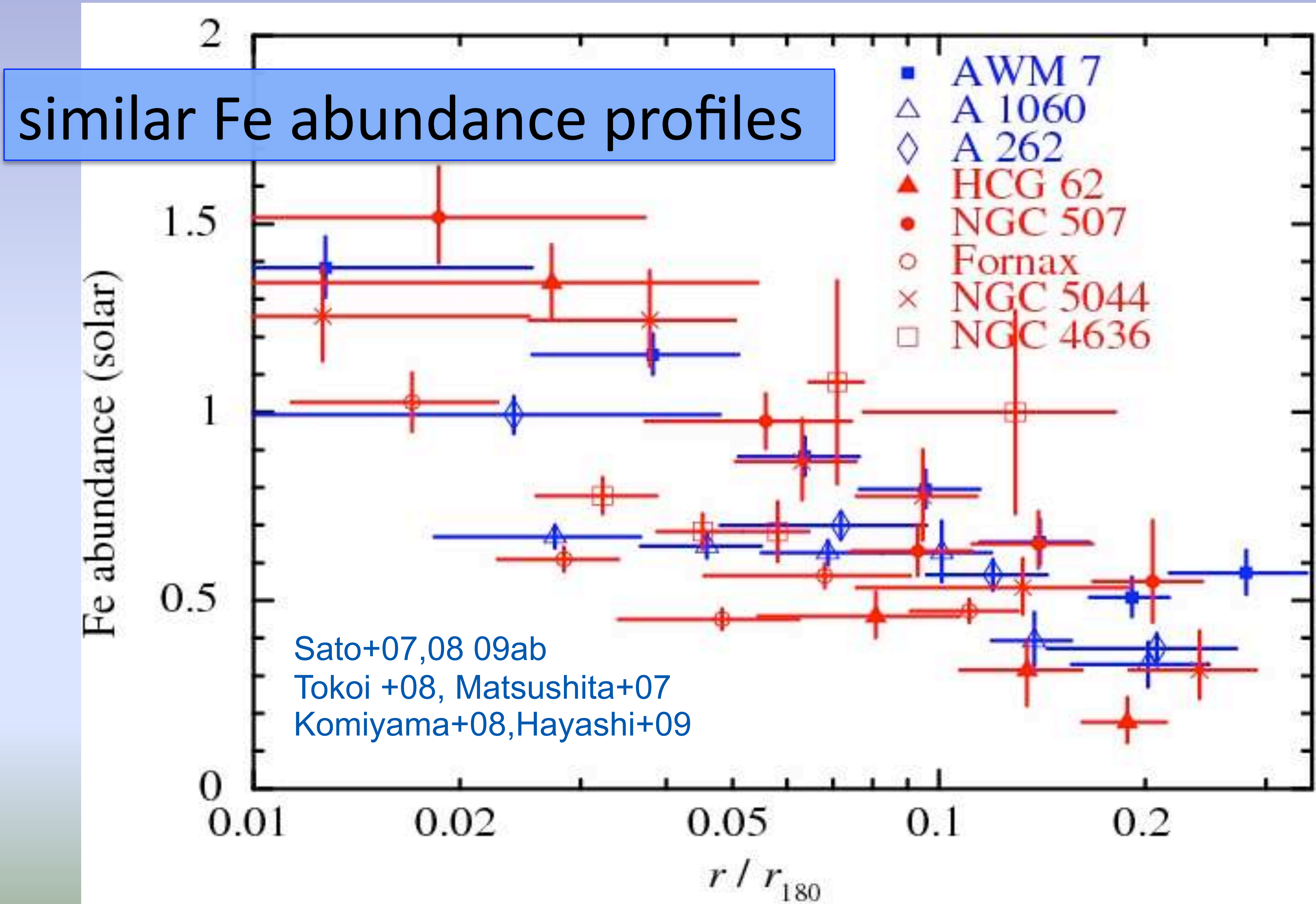
Extended distribution of Fe than stars and flatter Fe abundance profile at $0.1—0.5r_{180}$

no evolution until z=0.6 excluding the central region

SN II products tend to be more extended than SN Ia products?

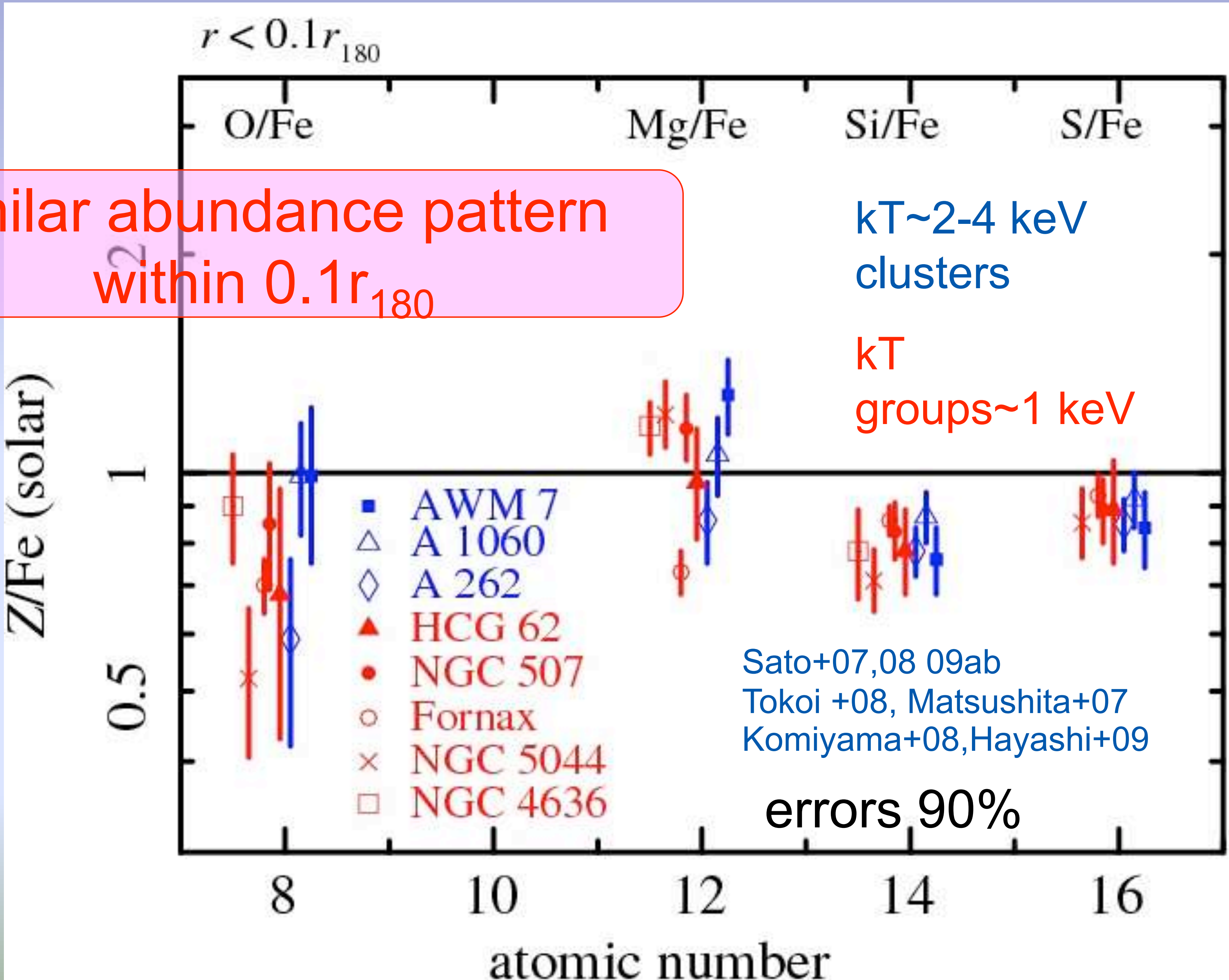
- Metal synthesis in early phase in cluster formation

Suzaku observations of Fe abundance profiles of ICM in clusters and groups



O and Mg in ICM within $0.1r_{180}$ observed with Suzaku

solar abundance table by Loddars (2003)



similar abundance pattern within $0.1r_{180}$

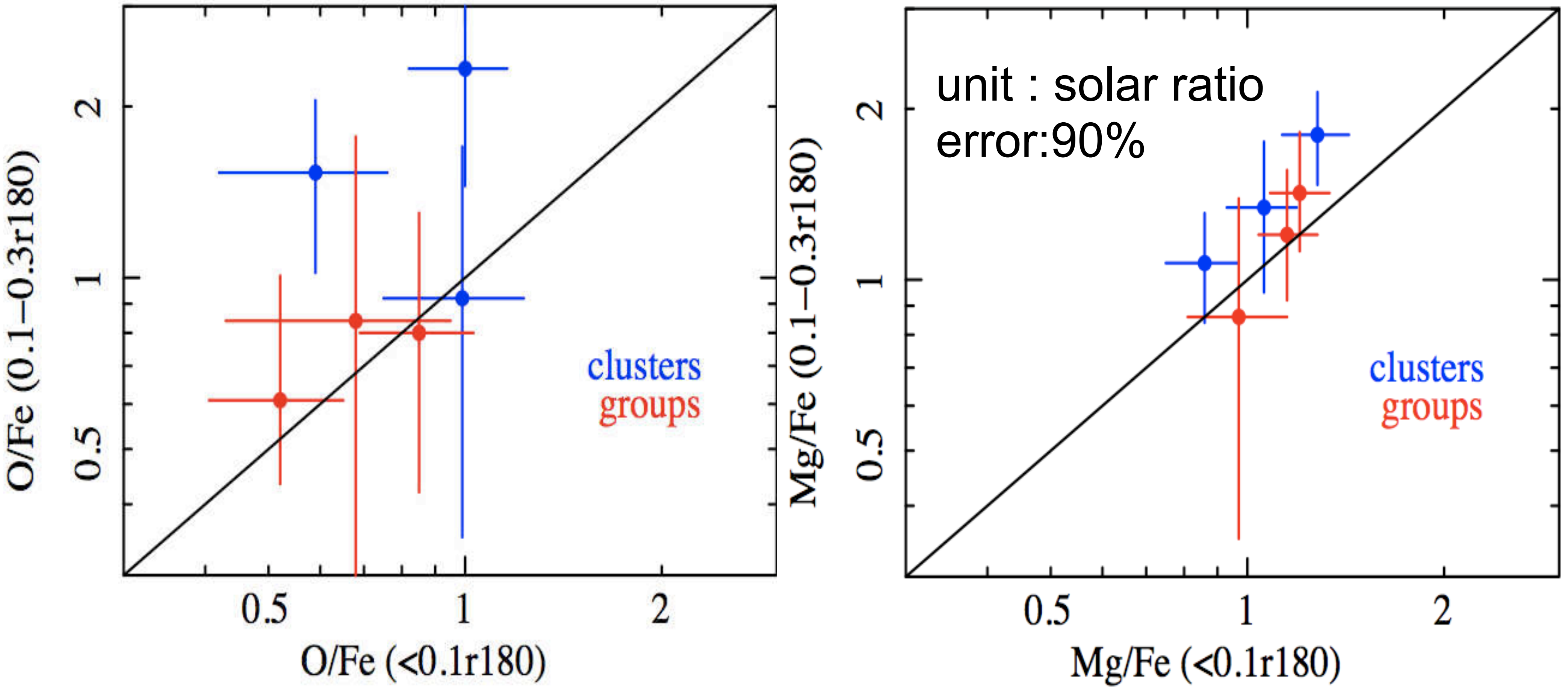
kT~2-4 keV clusters

kT groups~1 keV

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

errors 90%

Increase of O/Fe, Mg/Fe ratio at 0.1-0.3r_{180}



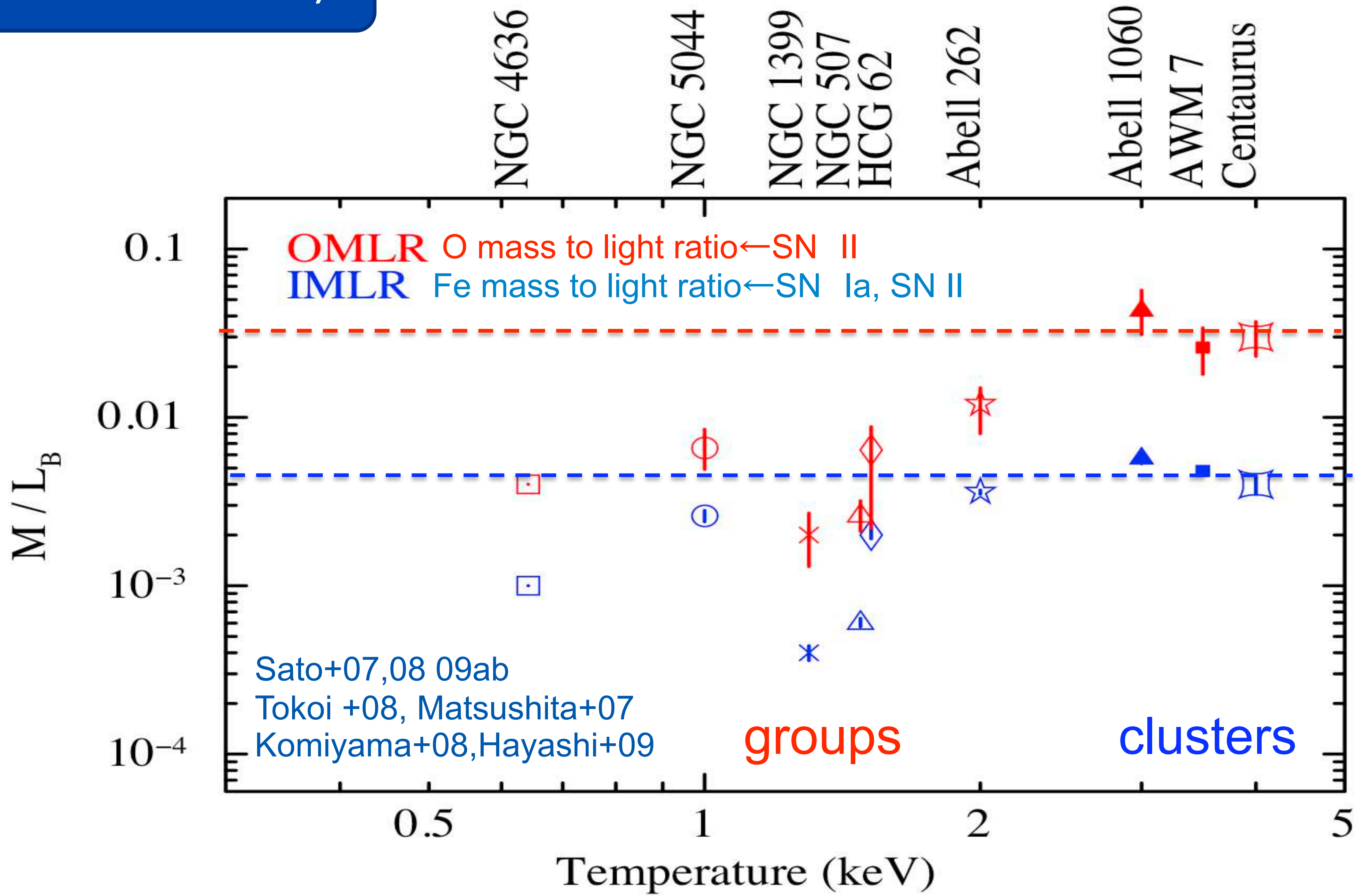
In groups of galaxies, metals synthesized by SN II have similar radial profiles with SN Ia products within 0.3r_{180}

Sato+07,08 09,Tokoi +08.Komiyama+08

Metal mass to light ratio

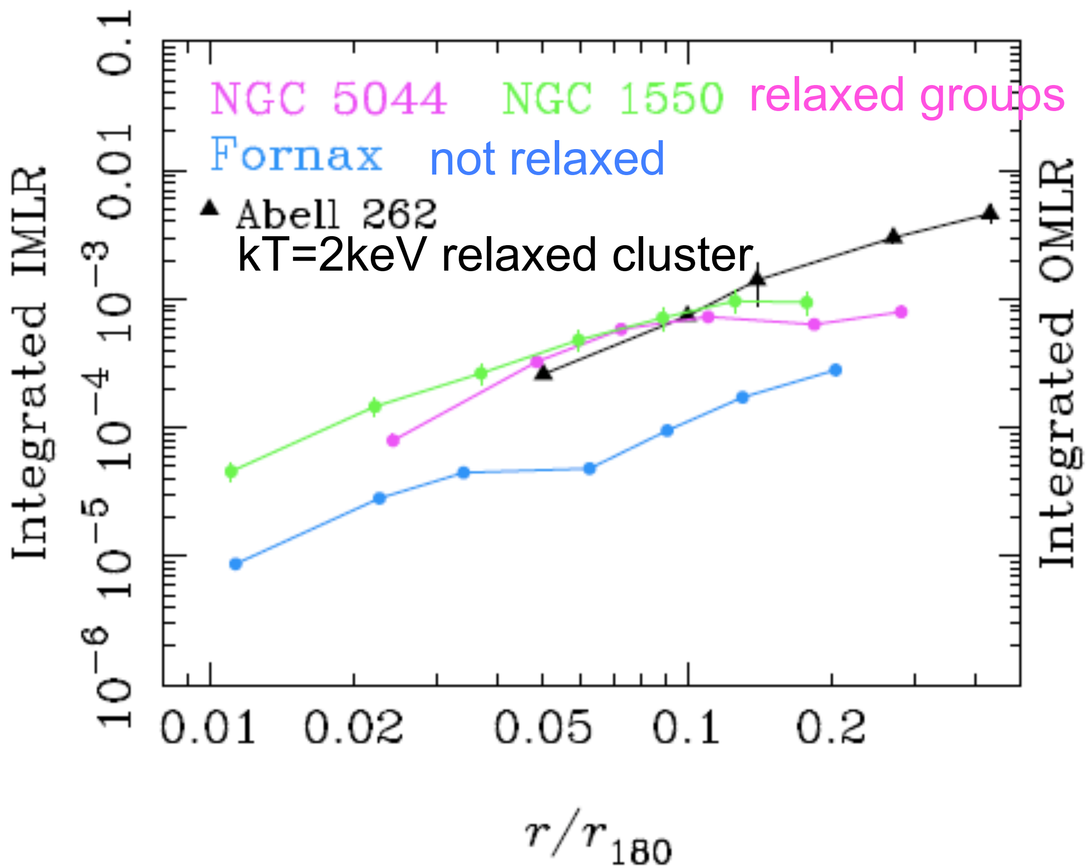
Mainly low mass stars

Suzaku (<0.1r180)

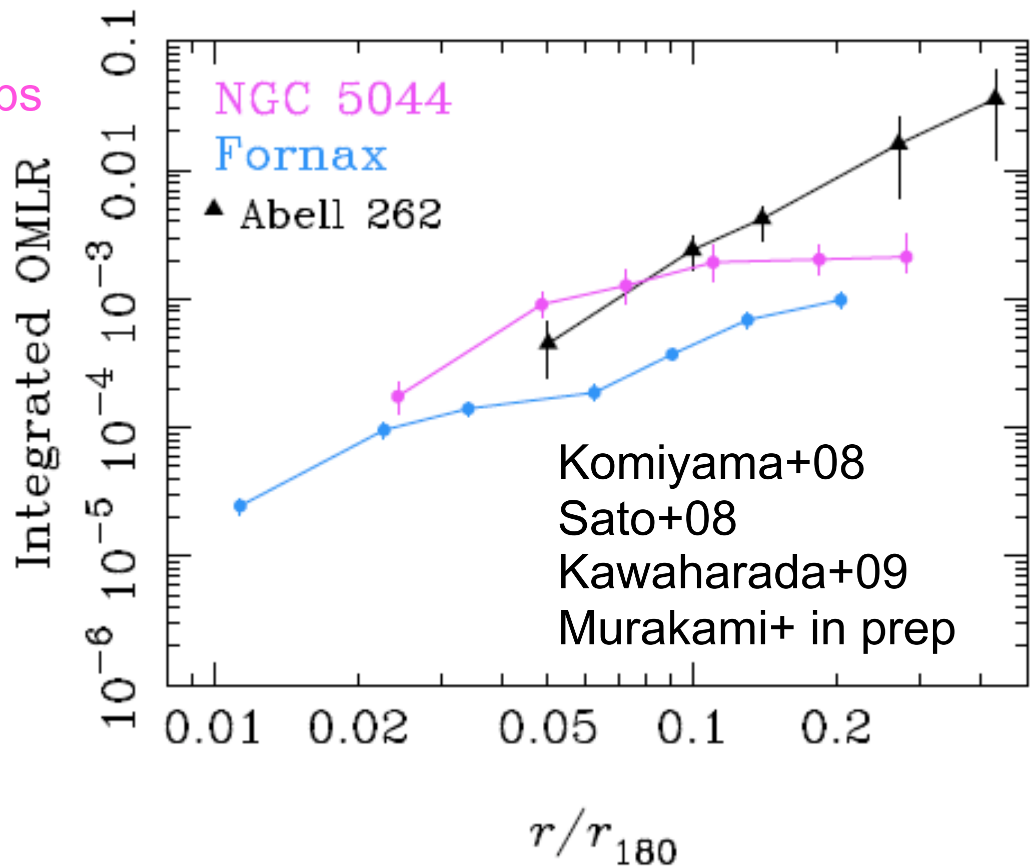


Metal mass to light ratio (<~$0.3r_{180}$)

Iron mass to light ratio



Oxygen mass to light ratio



difference in metal mass-to-light ratio beyond $0.1r_{180}$

central region – similar metal supply from central galaxies in relaxed clusters and groups

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?

Small OMLR, IMLR in groups

- Gas mass/stellar luminosity of the groups are small
  - ICM in groups is more extended than those in rich clusters
    - Excess entropy and heating
  - Metal distribution may be used as a tracer of history of heating since timescales of metal enrichment and heating determine the metal distribution.

- metal enrichment -> preheating
  - Similar abundance and smaller metal mass-to-light ratios
- Preheating -> metal enrichment
  - Similar metal mass to light ratio

- Different timescales O and Fe synthesis

Summary of metals in groups and clusters

With XMM, the Fe abundances of the ICM in 28 nearby clusters were derived

With Suzaku, O and Mg abundances of the ICM in several clusters and groups were derived

- Metal synthesis in early phase in cluster formation
- difference between clusters and groups

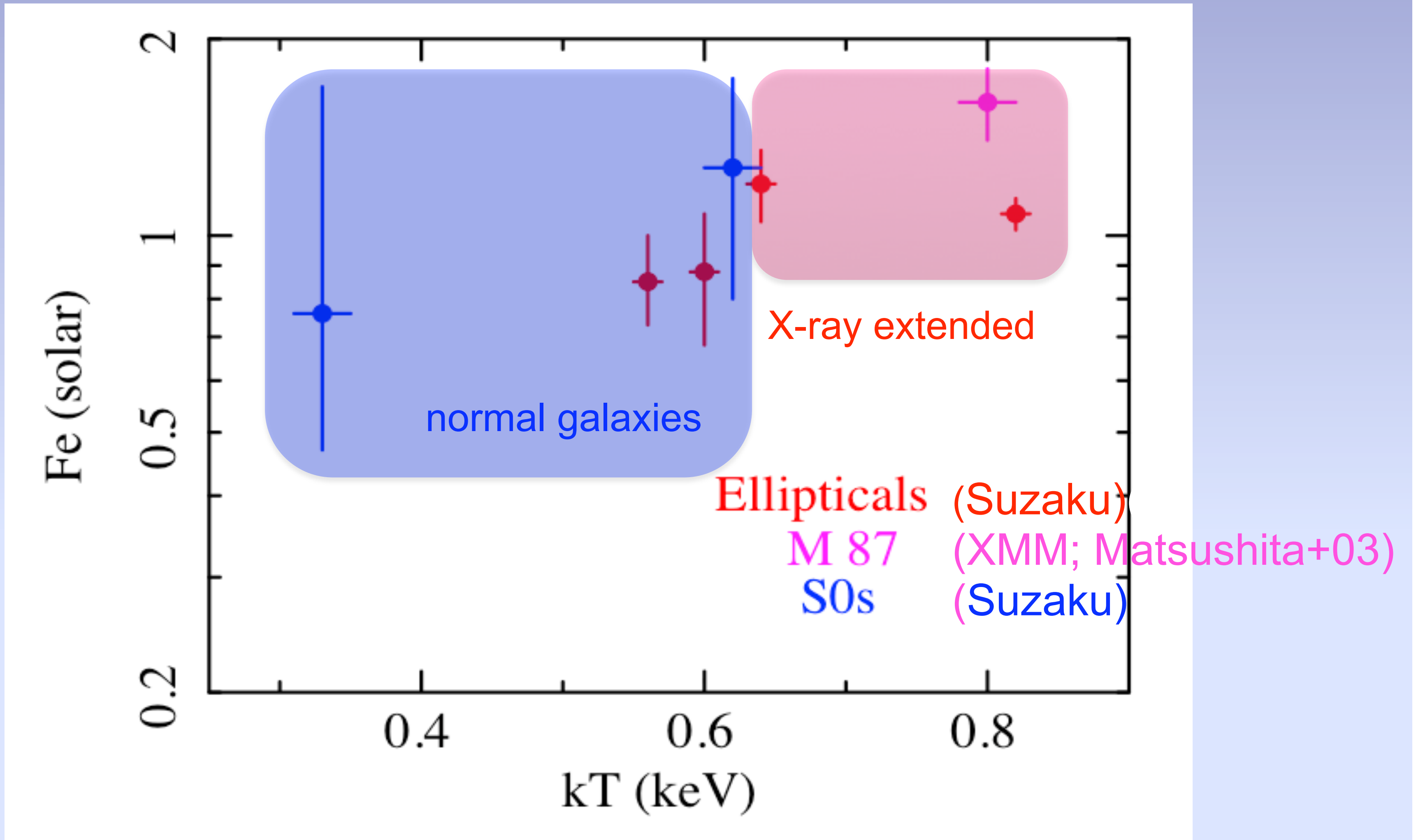
Evolution of SN Ia rate

Accumulating over present SN Ia rate over the Hubble time give observed Fe mass-to-light ratio in clusters?

How to constrain present SN Ia rate in cluster galaxies?

Fe abundances of ISM in early-type galaxies give upper limit in present SN Ia rate

The Fe abundance of ISM vs. kT of ISM



The Fe abundances are about 1 solar, with no temperature dependence, gas in the X-ray extended galaxies (center of larger scale potential) dominated by recent supply from stars and SNe Ia

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

(∝ present SN Ia rate)

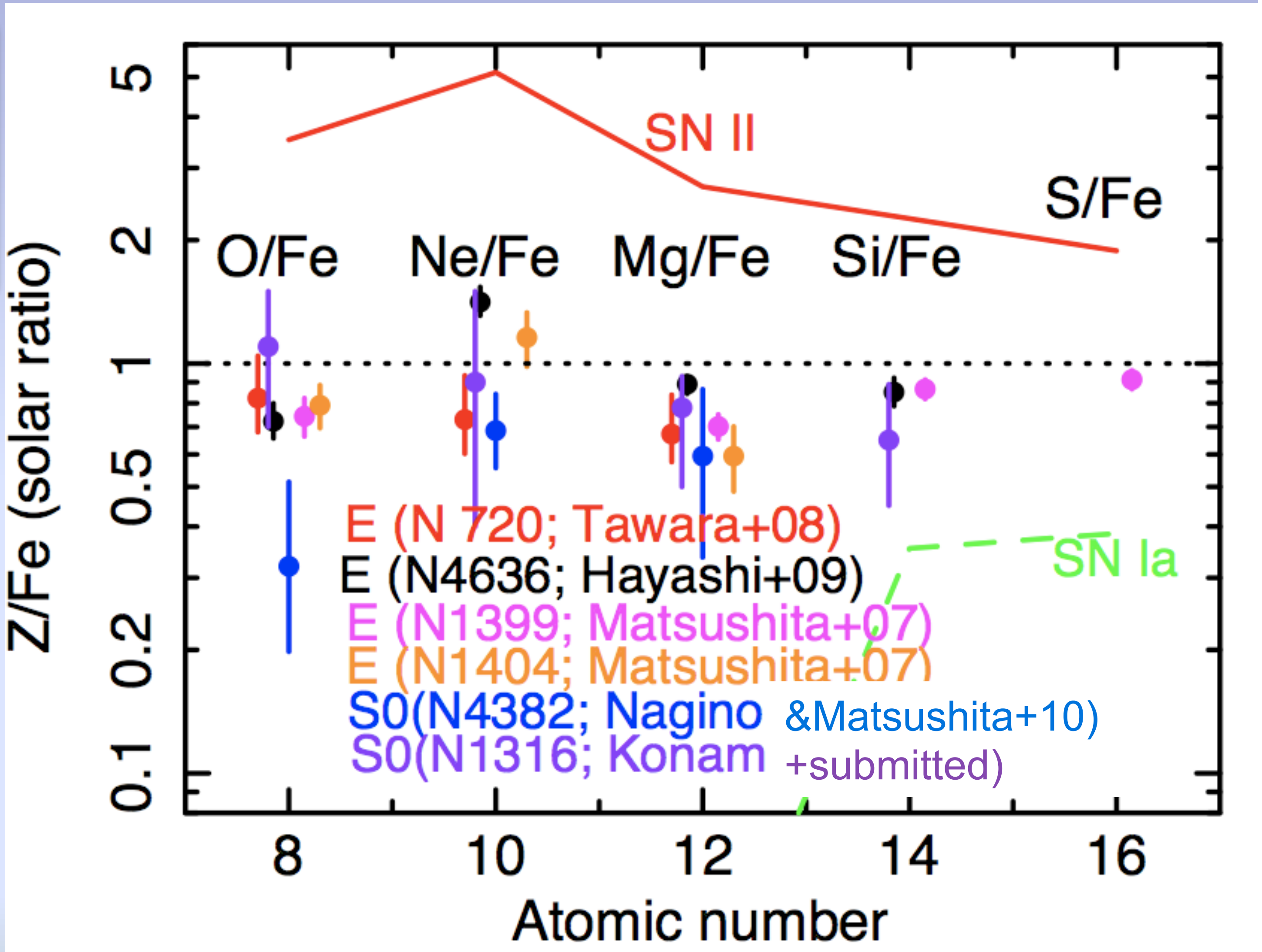
- Integrating the derived present SN Ia rate from the ISM abundances over the Hubble time gives an order of smaller value of Fe mass –to-light ratio than the observed values.
- The result indicates higher SN Ia rate in the past

Abundance pattern of ISM in Es and S0s observed with SUZAKU

Solar abundance pattern!

(except a S0)

most of Fe come from SNe Ia



using the solar abundance by Loddars (2003)

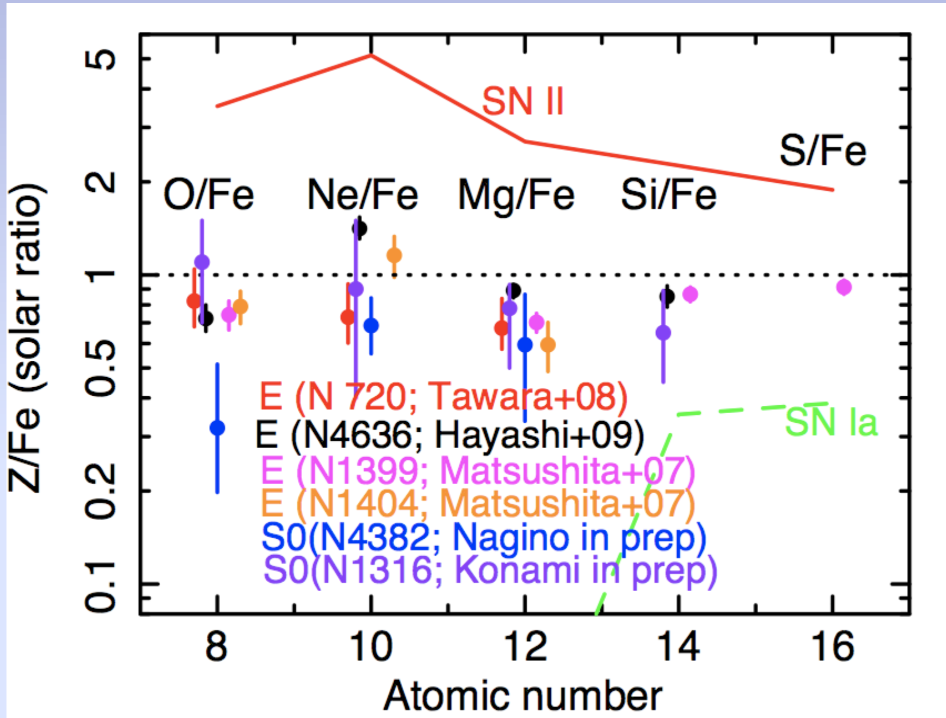
Abundance pattern of ISM in E and S0 observed with SUZAKU

abundance pattern of O, Ne, Mg, Si, Fe is nearly solar except N 4382

Mixture of metals from recent SNe Ia and mass loss

- significant fraction of Fe should come from recent SN Ia

supports enhancement of [α/Fe] of stars in these giant ET galaxies



using the solar abundance by Loddars (2003)

Stellar metallicity in E and S0 galaxies

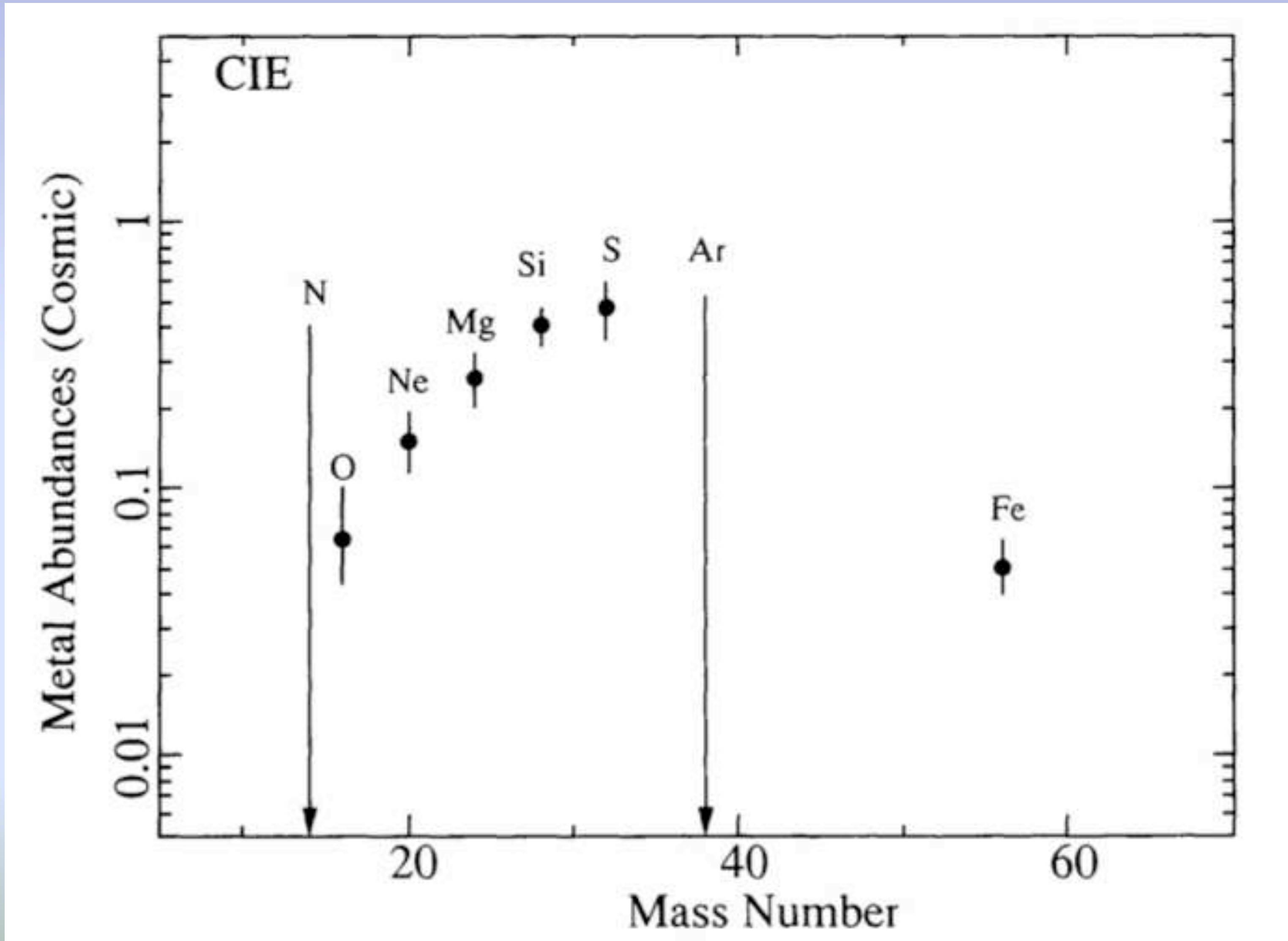
The observed O and Mg abundances of ISM in ellipticals are 0.5-1 solar

- These metals come from stellar mass loss
- The O and Mg abundances of ISM are consistent with stellar metallicity observed with optical Mg2 index

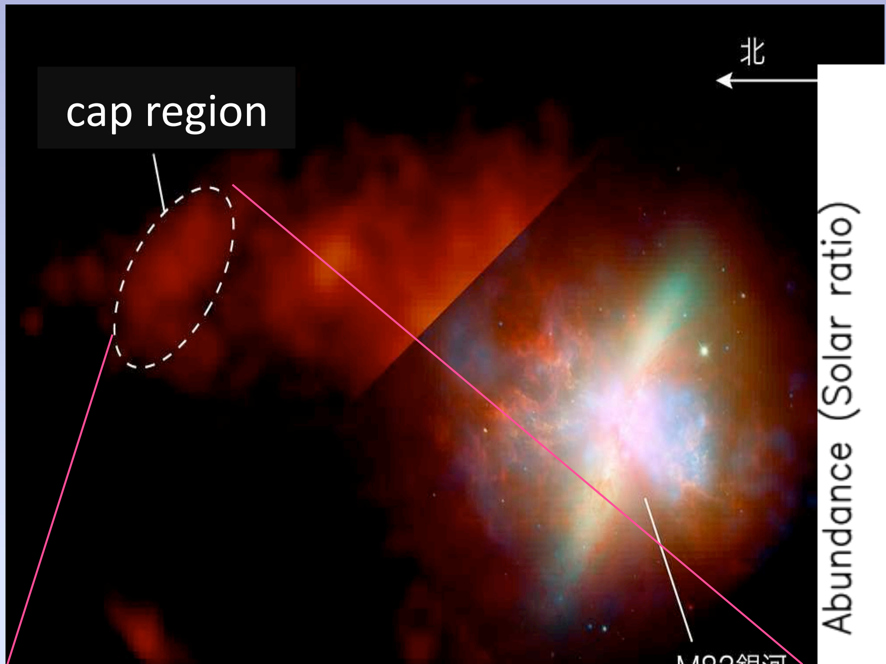
The solar abundance pattern of ISM indicates supersolar α/Fe considering the contribution from SN Ia

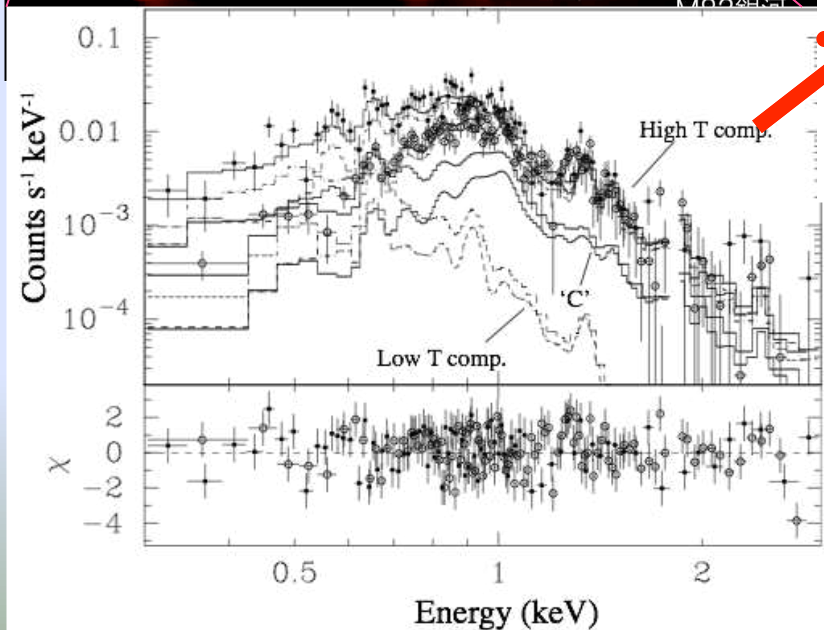
reflecting star formation history in Ellipticals.

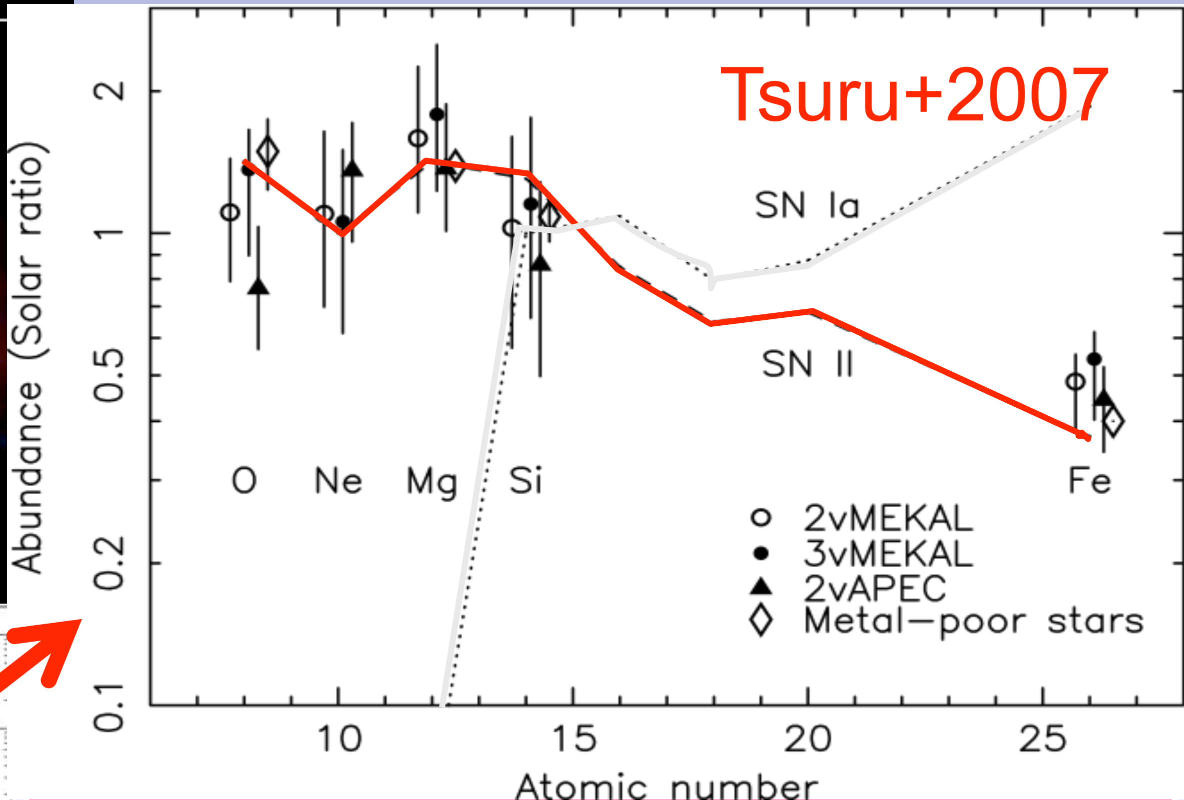
Abundance pattern of hot ISM in M82 observed with ASCA (Tsuru et al. 1997)



SN II like abundance pattern of the cap region of a starburst galaxy, M 82

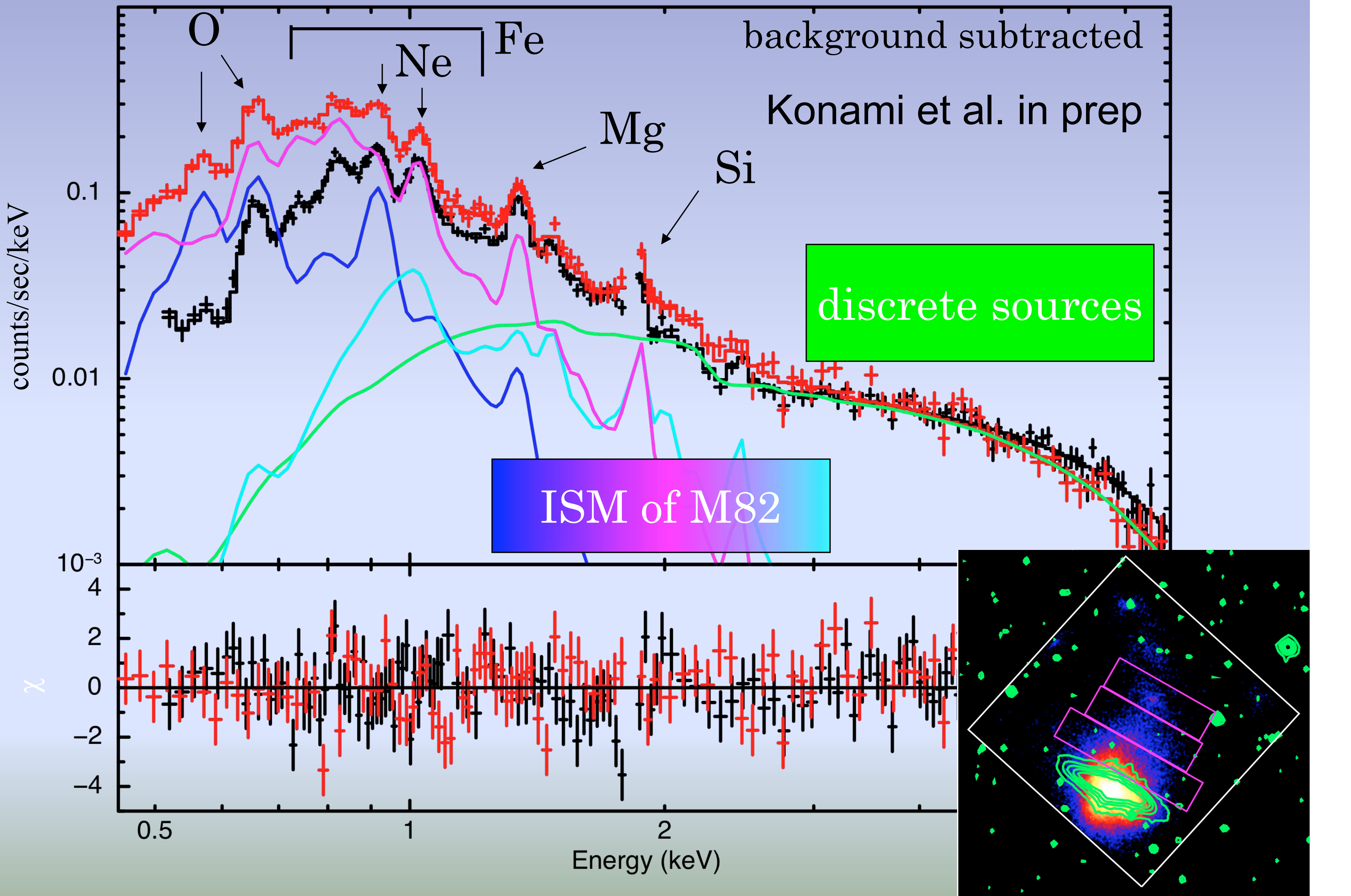




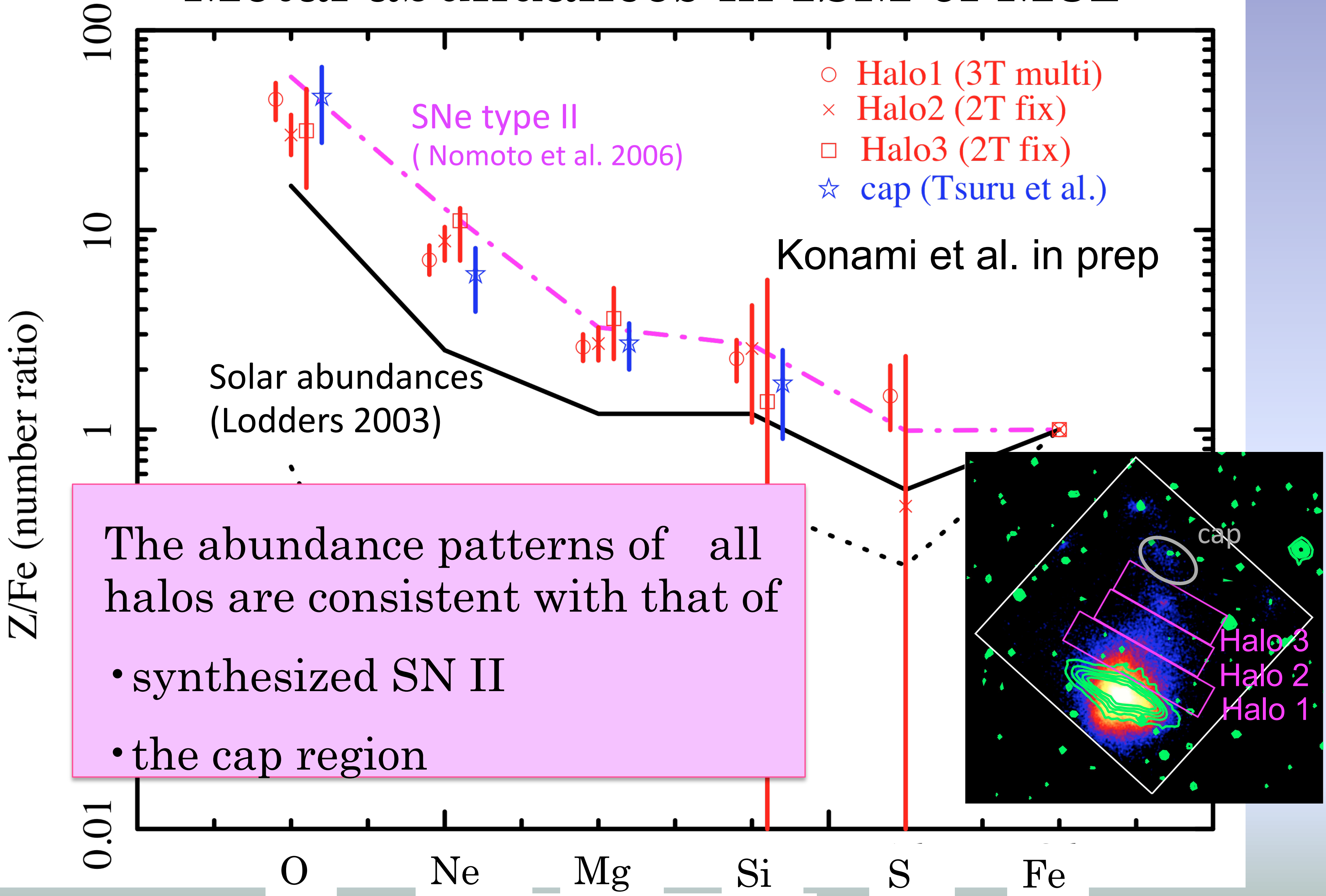


Metals synthesized from SN II escape from starburst galaxies?

Spectral Analysis : M82 Halo1



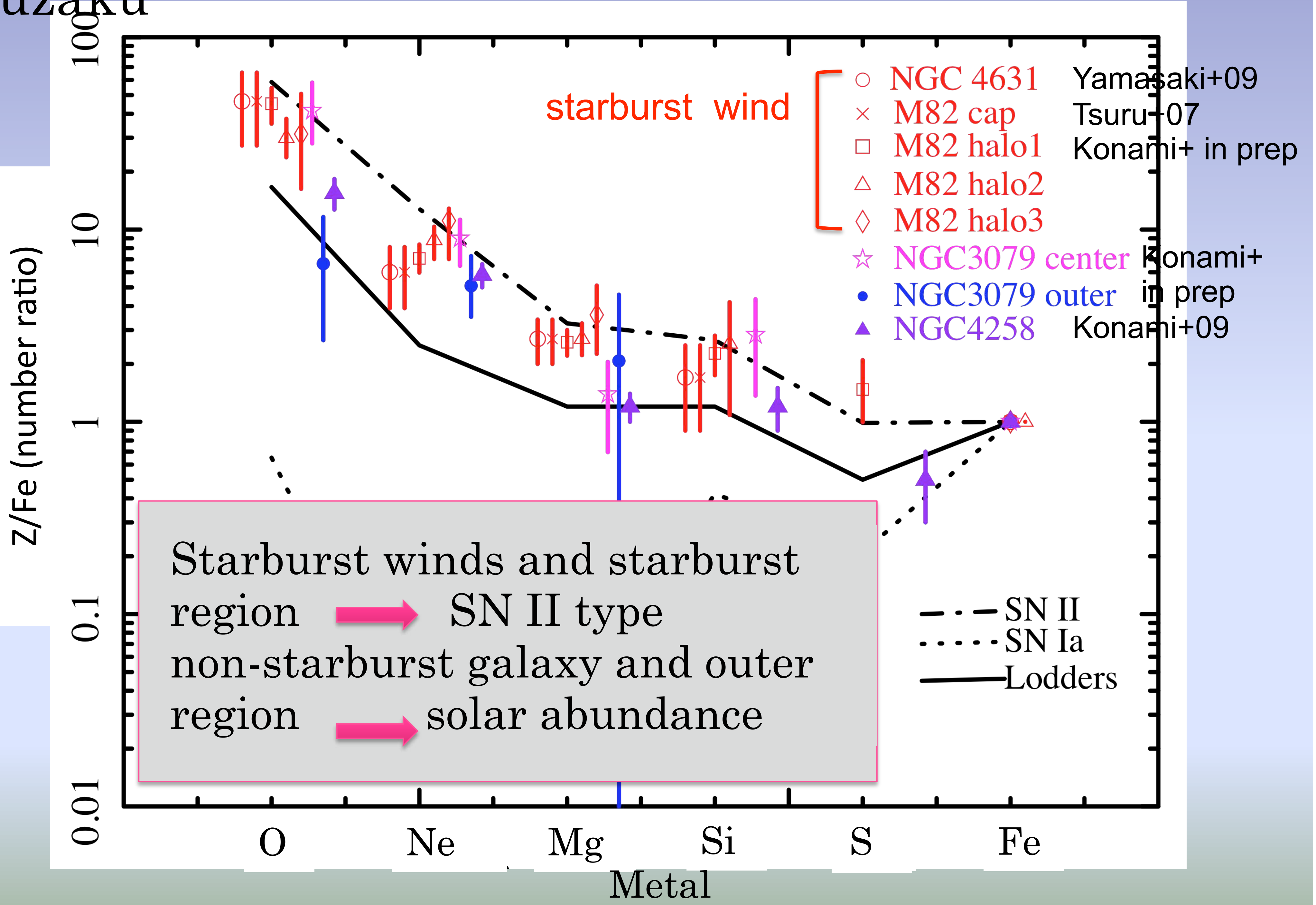
Metal abundances in ISM of M82



The abundance patterns of all halos are consistent with that of

- synthesized SN II
- the cap region

Metal abundances of hot ISM in spiral galaxies with Suzaku



Starburst winds and starburst region → SN II type

non-starburst galaxy and outer region → solar abundance

Abundance pattern of hot ISM in spiral galaxies

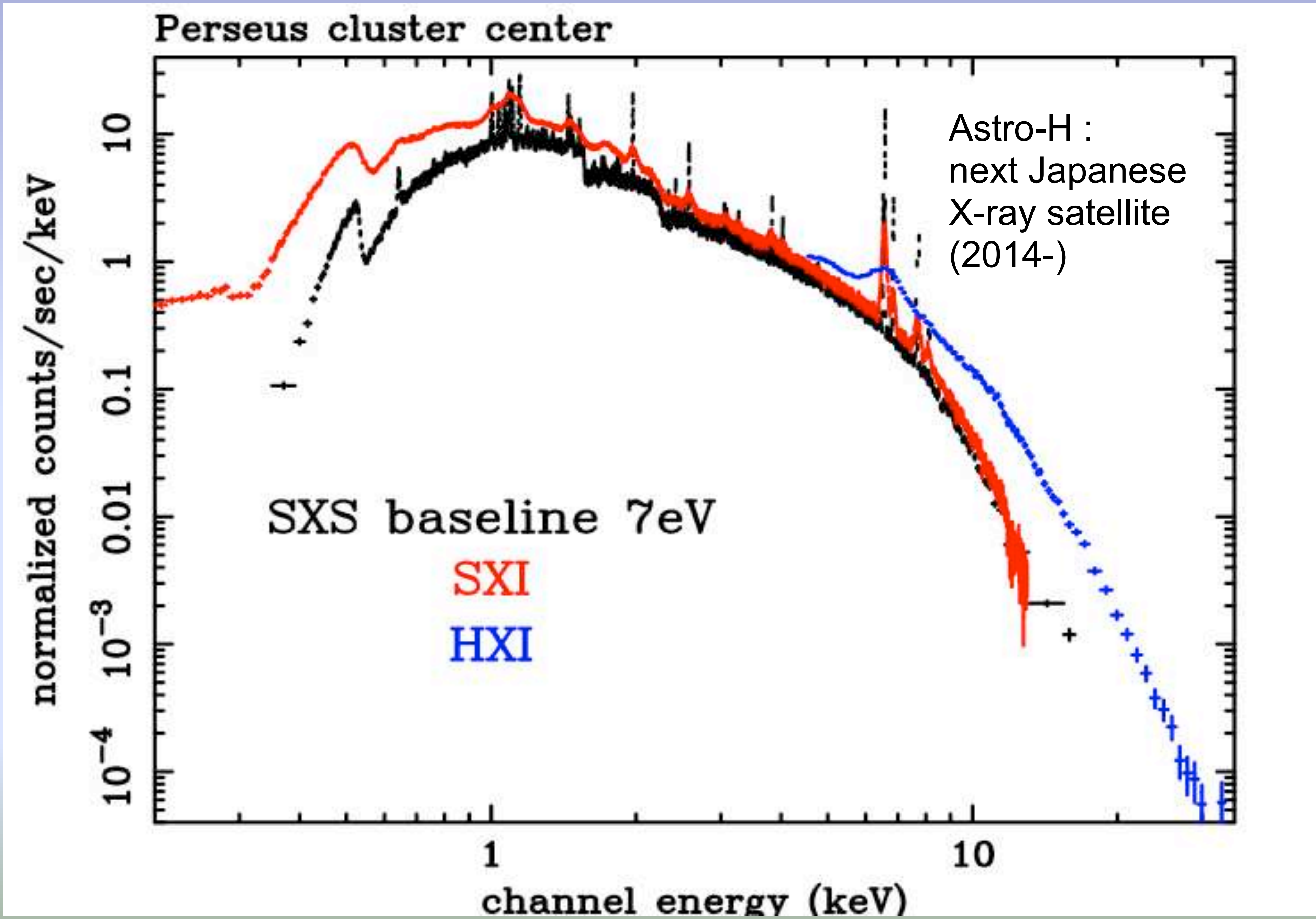
galactic wind of starburst galaxies have SN II like abundance pattern

- starburst activities pollute intergalactic space with SN II products

Without starburst activities, ISM have similar abundance pattern with the new solar abundance table by Loddars (2003)

- The new solar abundance pattern is common among normal spiral galaxies?

Simulated spectra from the Perseus cluster with Astro-H



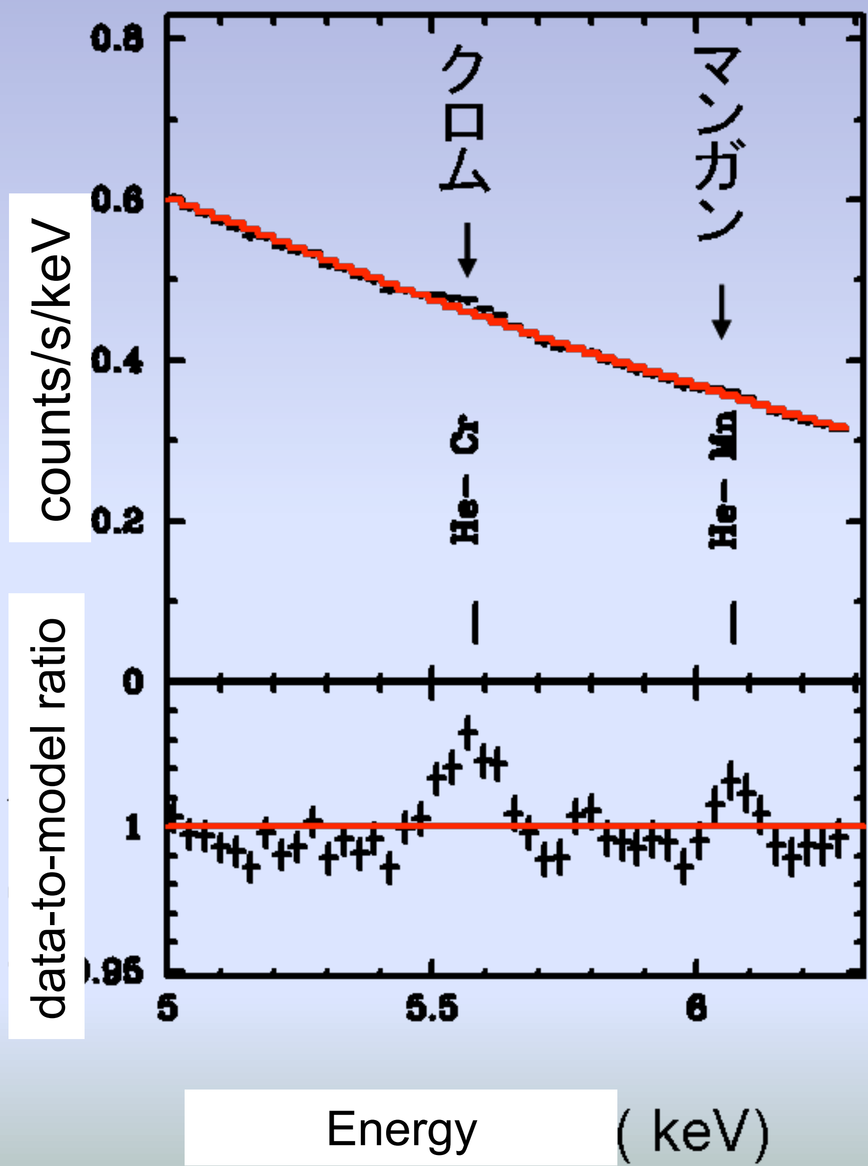
Rare metals in hot gas in clusters and galaxies with Astro-H

- Mn/Fe ratio vs. initial mass function of stars
  - O, Mg are synthesized by SN II.
  - Fe is synthesized by both SN Ia and SN II
  - O/Fe, Mg/Fe ratios from SN II depend on initial mass function of stars
  - SN II do not produce Mn very much
- Al/Mg ratio vs. progenitor metallicity of SN II.
  - Al and Mg are synthesized by SN II
  - Al/Mg ratio increases with progenitor metallicity
- C, N abundances and history of intermediate mass stars

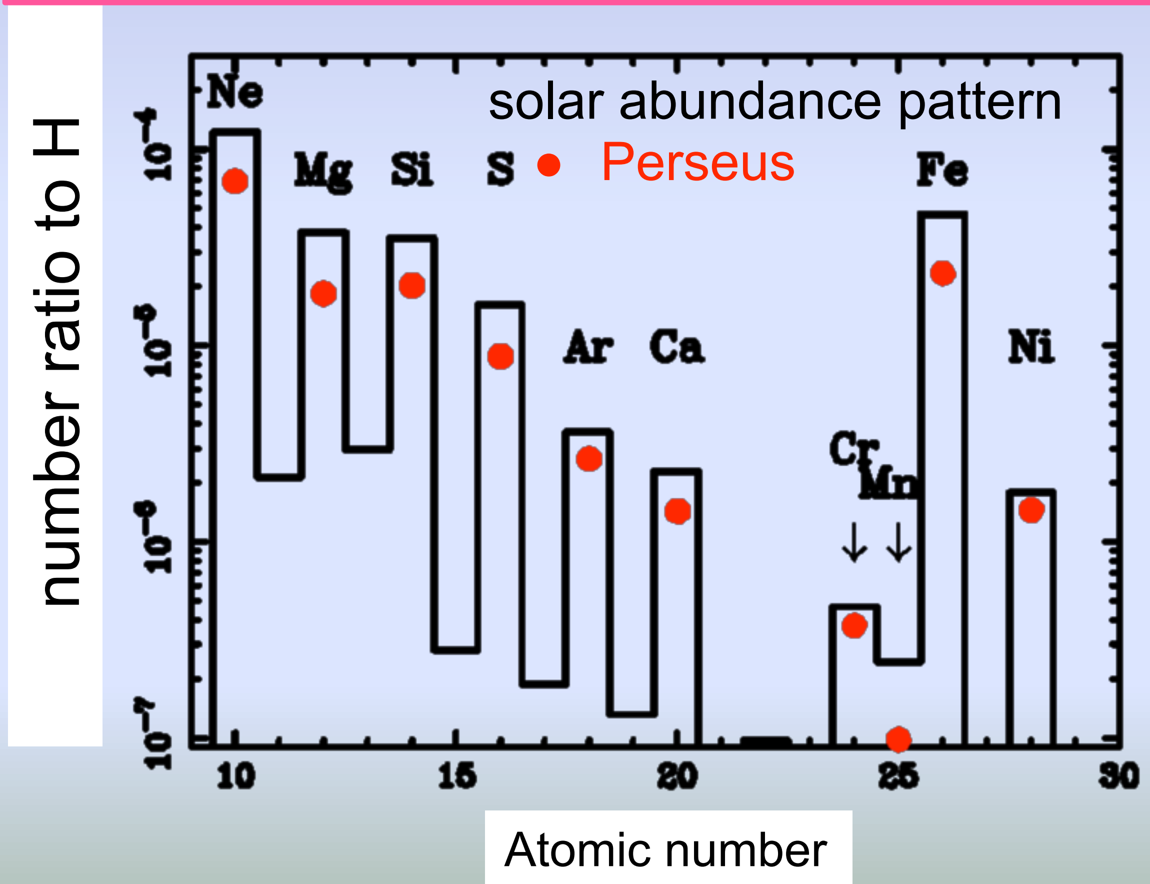
Cr detection from the Perseus cluster with Suzaku

Tamura et al. 2009

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

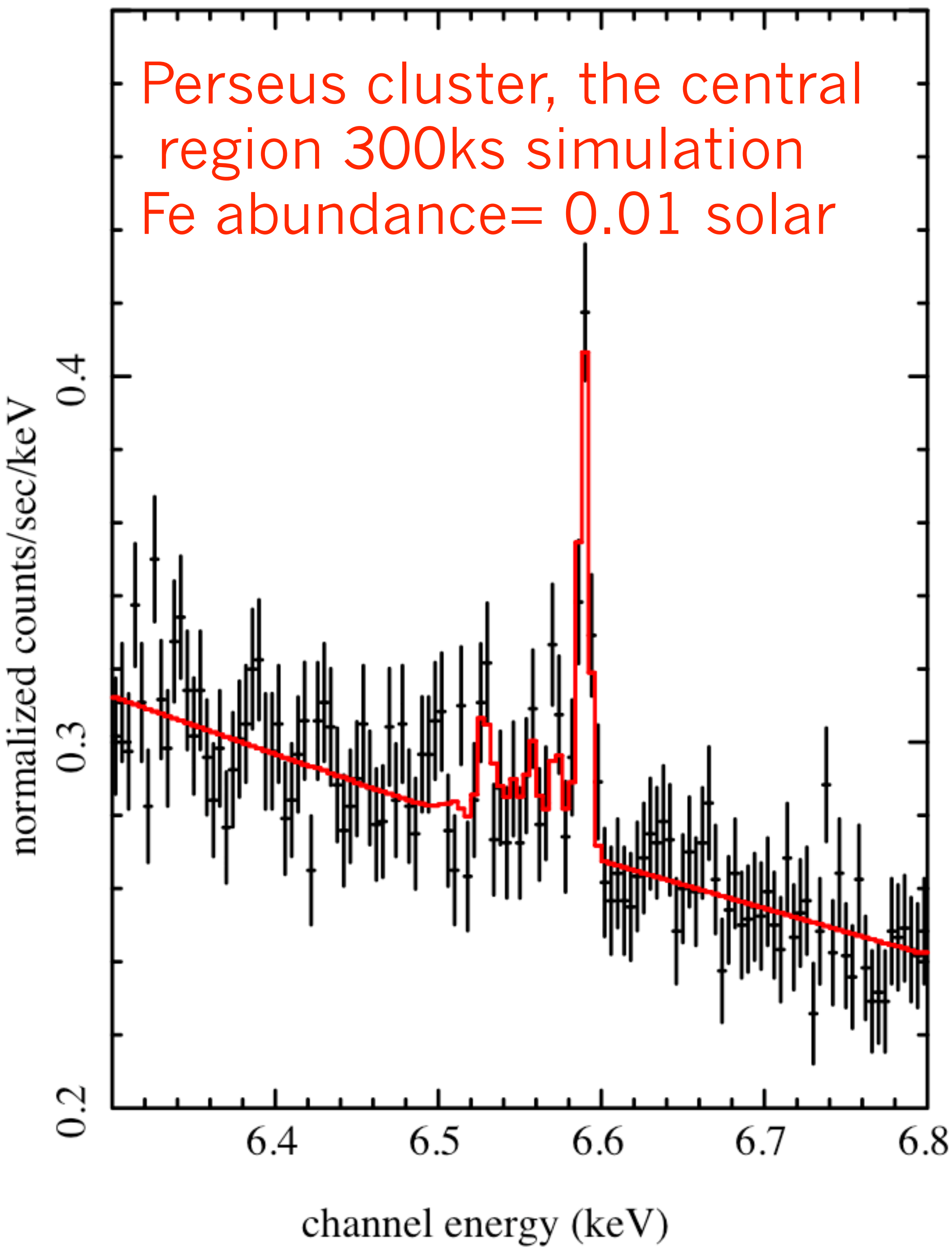


Mn is an indicator of SN Ia, since SN II do not produce Mn very much



Can Astro-H detect Mn lines?

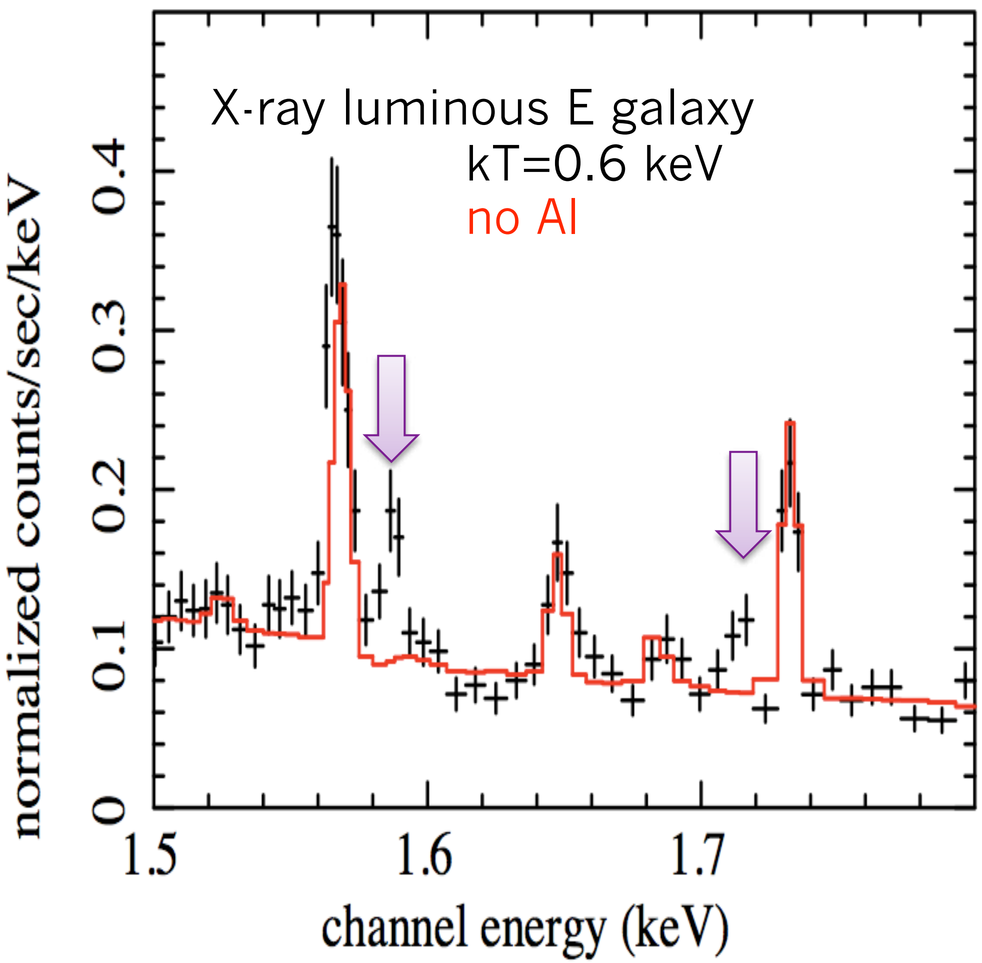
- With the solar abundance, the Mn/Fe ratio is 0.01 by number ratio.
- Since Mn lines are not included in models, we simulated Fe K lines assuming that Fe abundance=0.01 solar



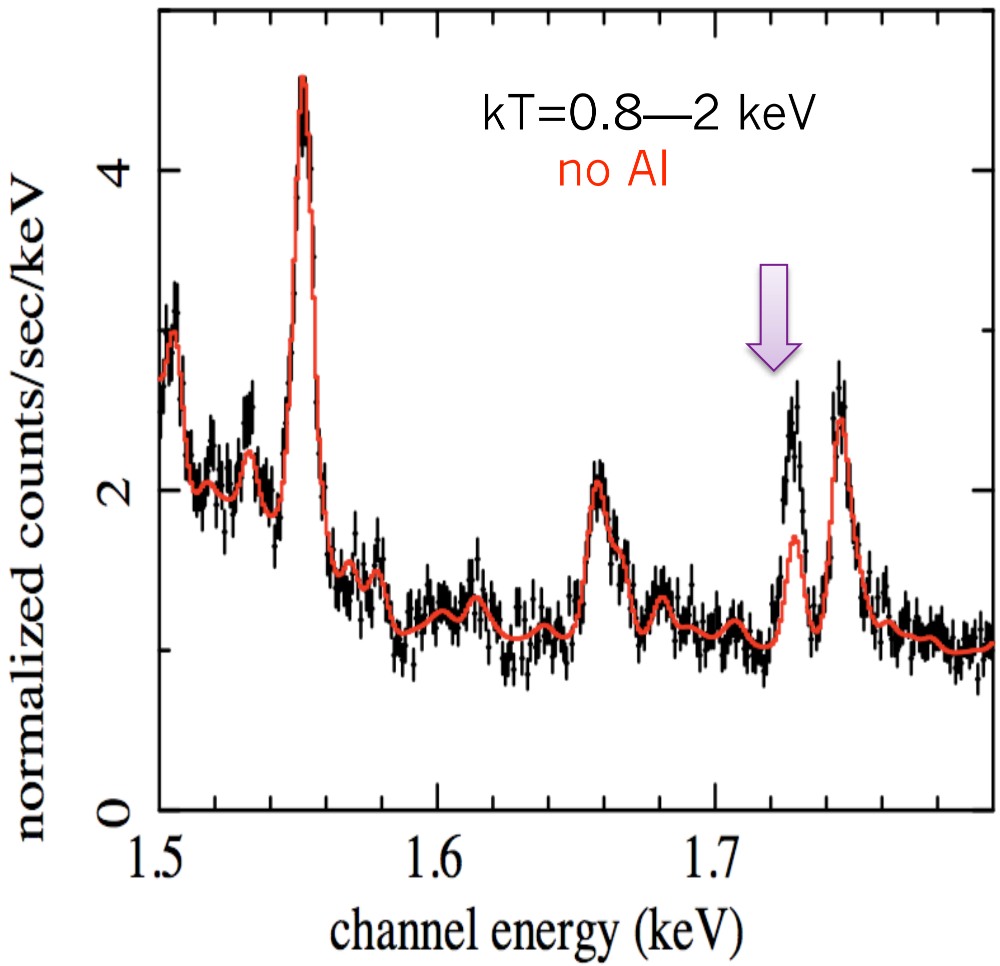
Can Astro-H detect Al lines?

- Al and Mg are synthesized by SN II
- Al/Mg ratio increases with progenitor metallicity

NGC 4636 100ks

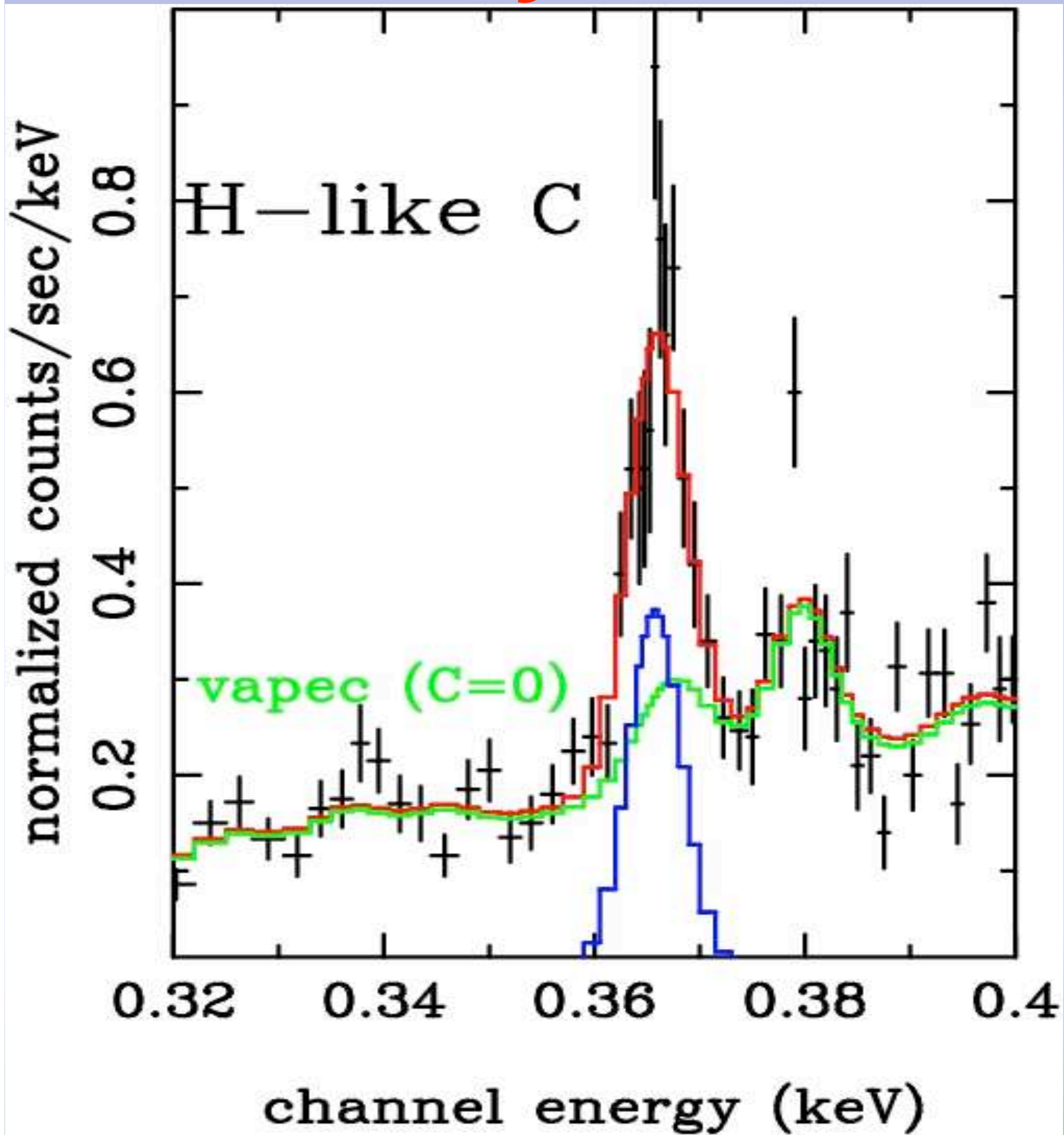


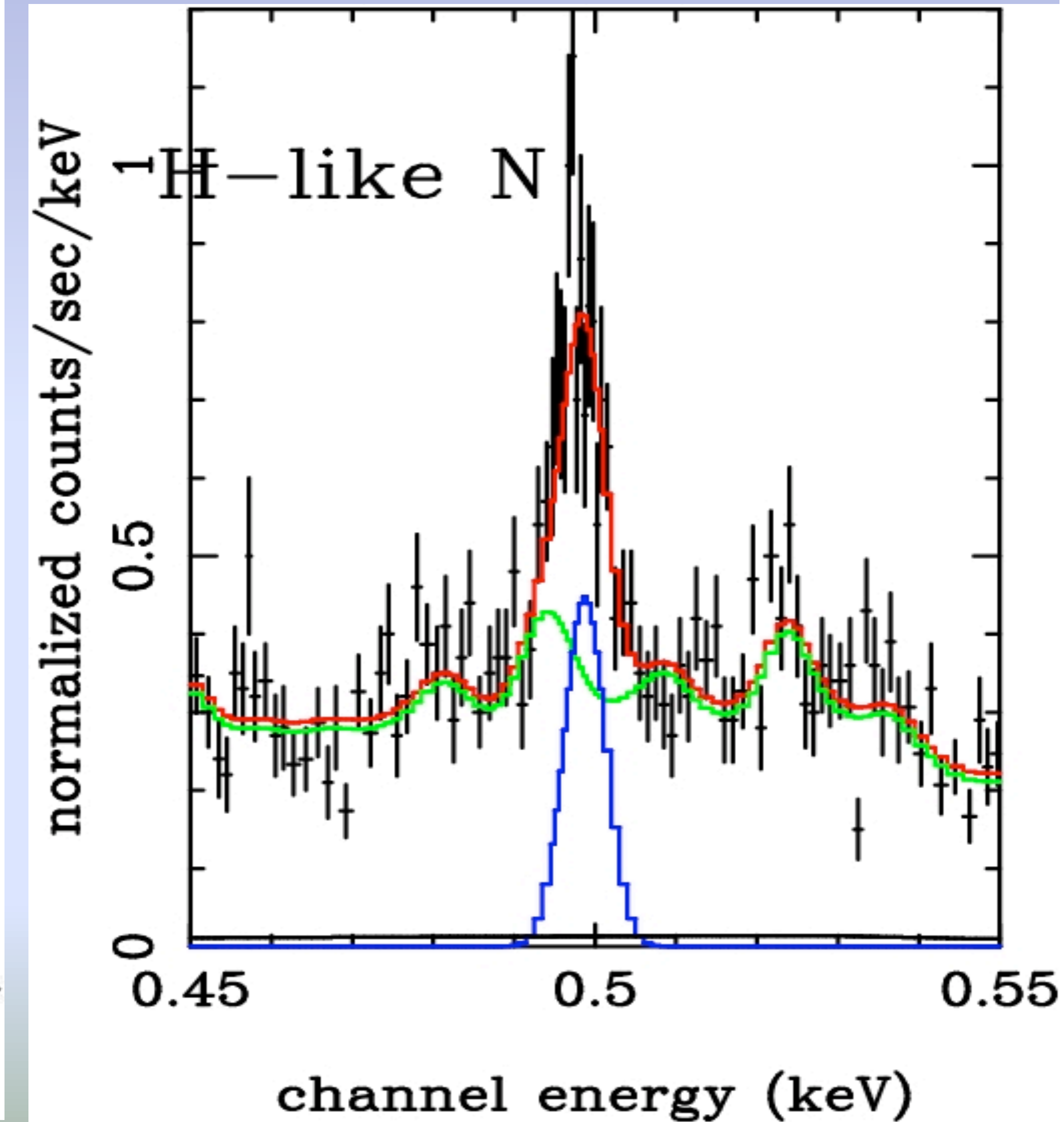
M87 100ks



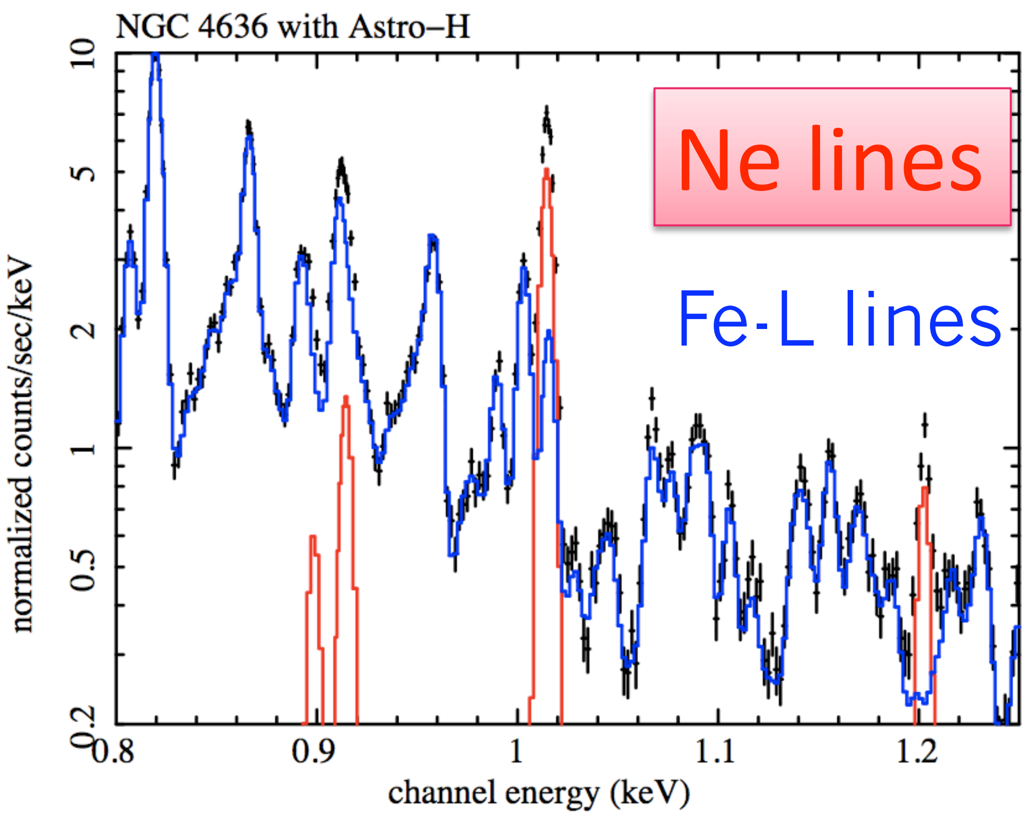
C, N of hot ISM in an X-ray luminous elliptical galaxy, NGC 4636(r<2')

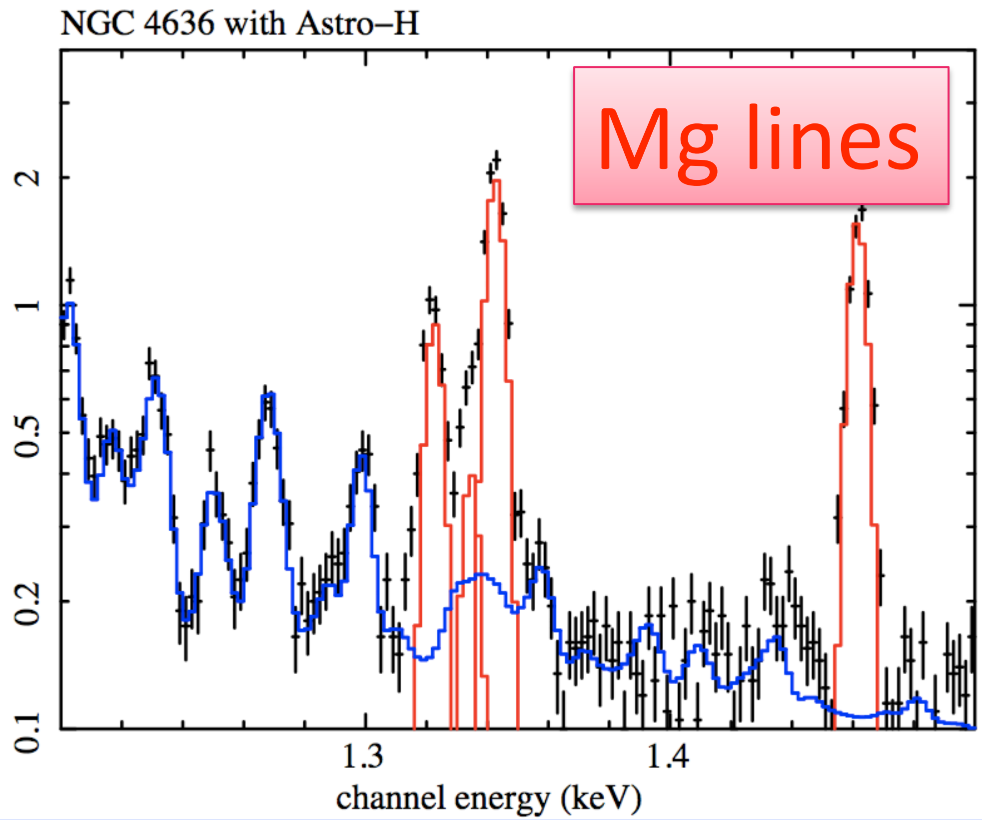
history of intermediate mass stars





Ne and Mg of hot ISM in an X-ray luminous elliptical galaxy, NGC 4636(r<2')





Ne Kβ, Mg Kα lines are free from Fe-L lines

Triplets of He-like Kα will be detected

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)
- 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)

- ISM in Elliptical and S0 galaxies reflect stellar metallicity
- SN II like abundance pattern in galactic winds of starburst galaxies
- the new solar abundance pattern of ISM in normal spiral galaxies

Future missions

- rare metals with Astro-H