Metals in the intracluster medium

Kyoko Matsushita, K.Sato,T. Sato,R. Nagino
T.Tamura,H.Murakami, E. Sakuma, S. Konami, N. Ota

Metals in intracluster medium in clusters of galaxies

- Sato+2007,2008,2009a, Sakuma+ submitted, Fujita+08, Tamura+09,Sato+submitted, Matsushita 2011, Matsushita&Tamura in prep.

Metals in groups

- Matsushita+2007, Sato+2009b,Komiyama+2009, Tokoi+2008, Hayashi+2009, Sato +2010, Murakami+submitted,

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

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

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

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

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

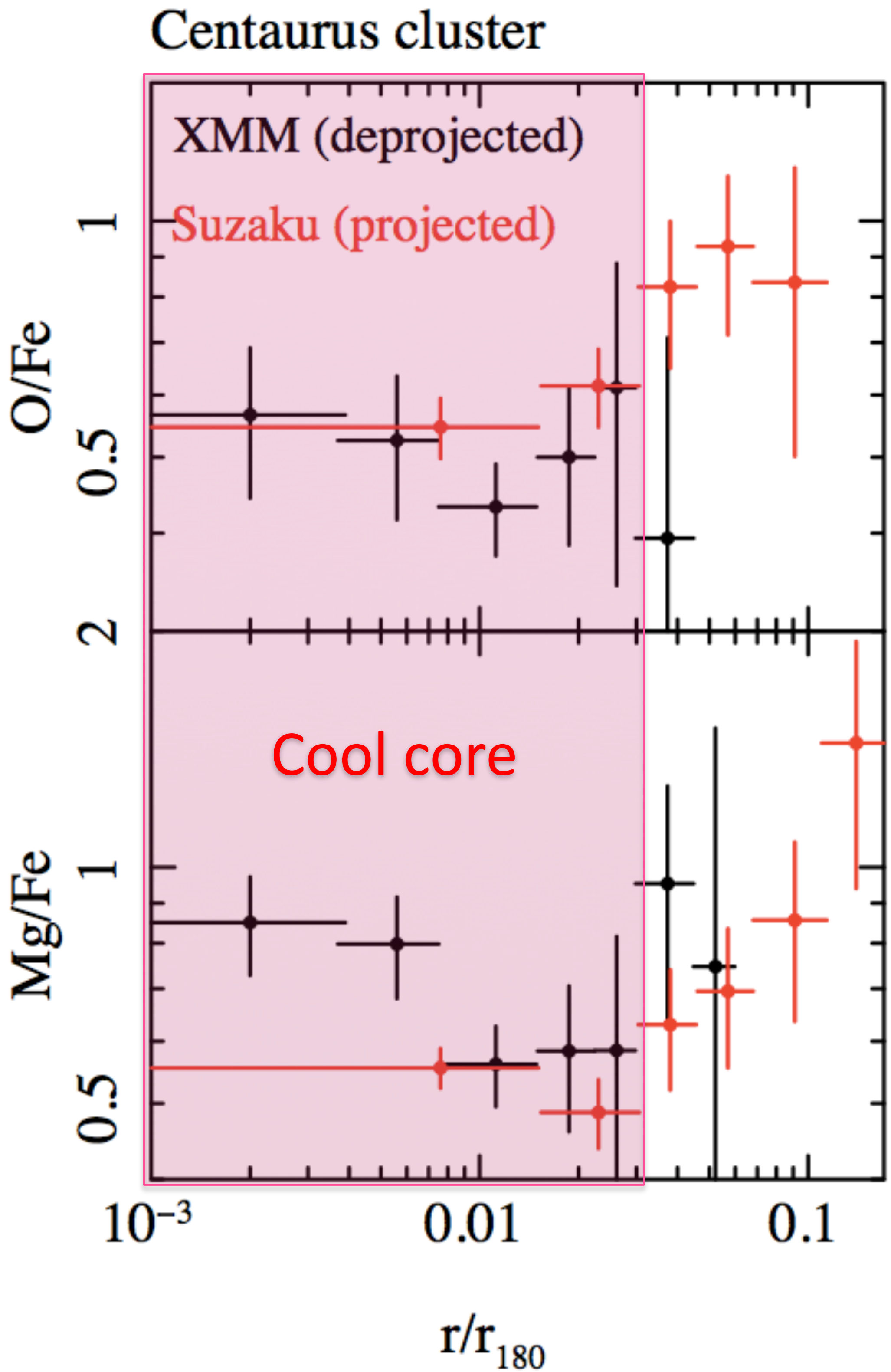
Suzaku satellite provides better sensitivity to O and Mg lines

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

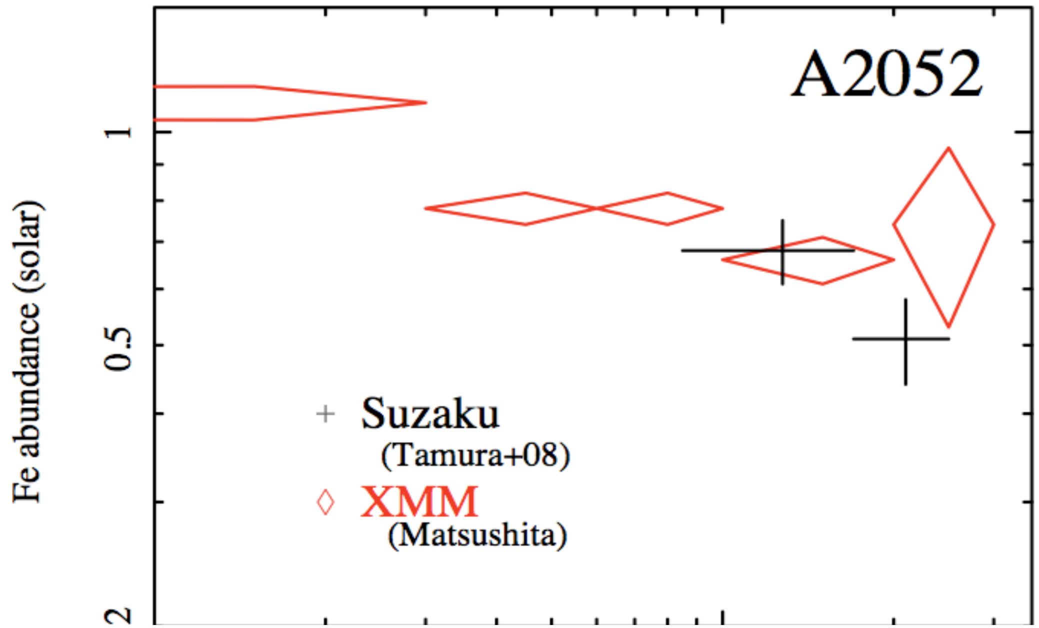
Matsushita&Tamura

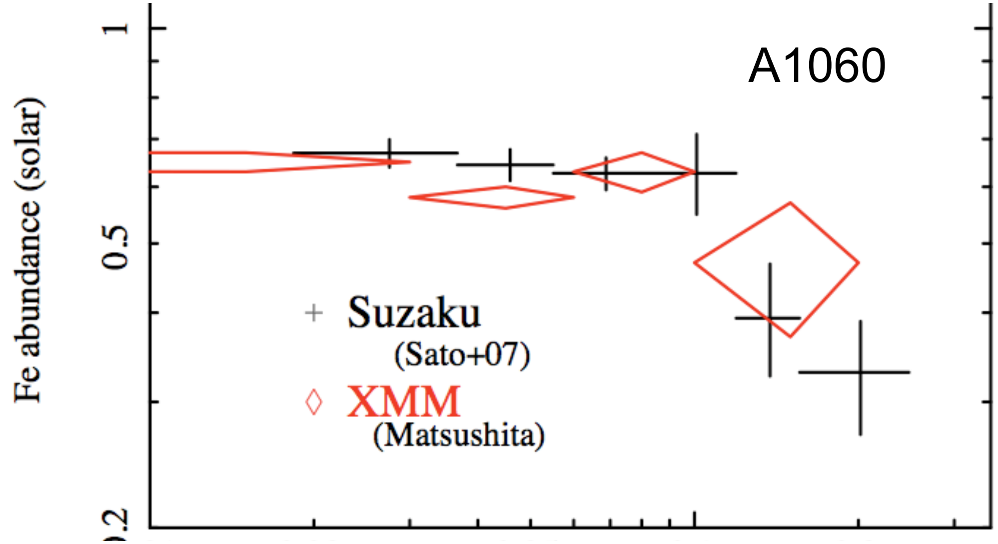


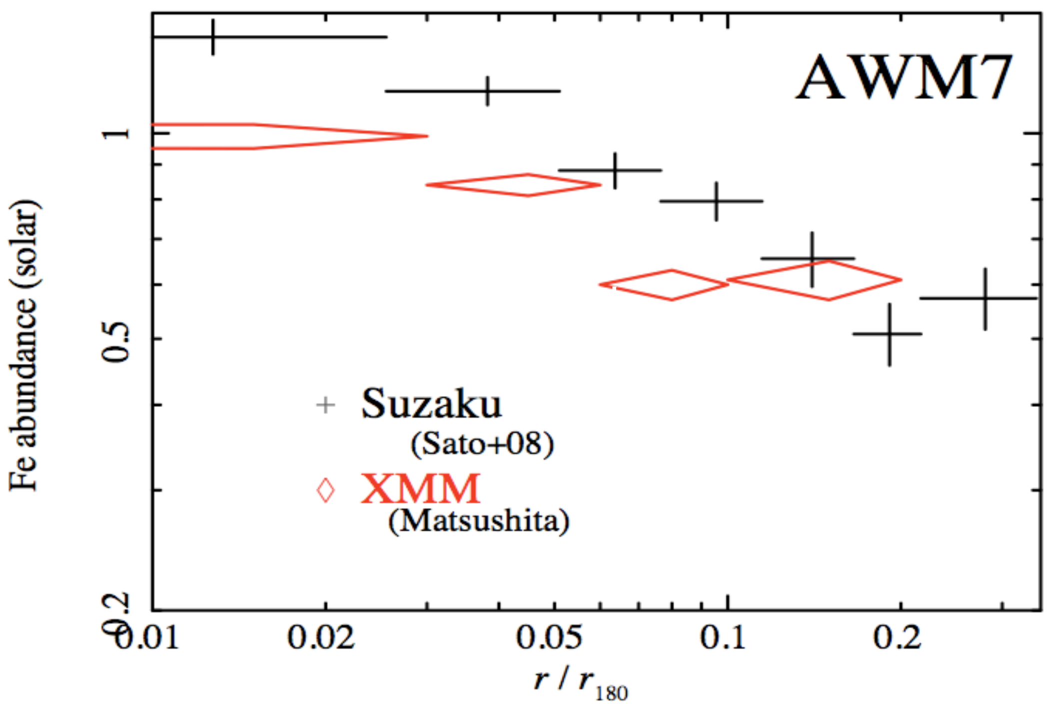
Fe abundances derived from Suzaku and XMM

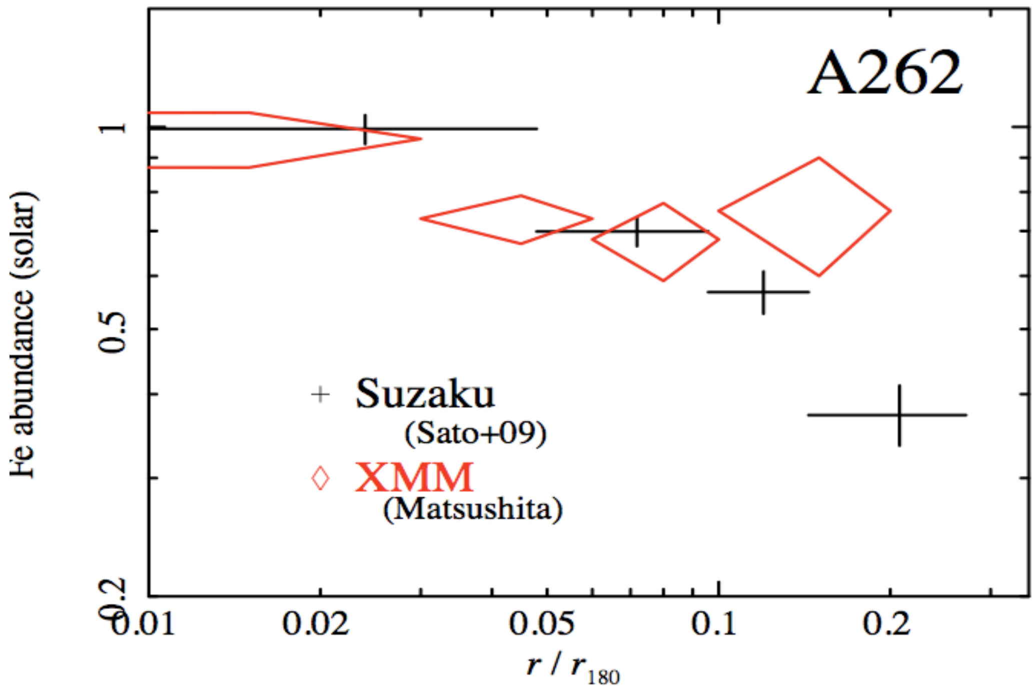
Errors –Suzaku:90% XMM:68%

Suzaku gives smaller error bars at > 0.1r180



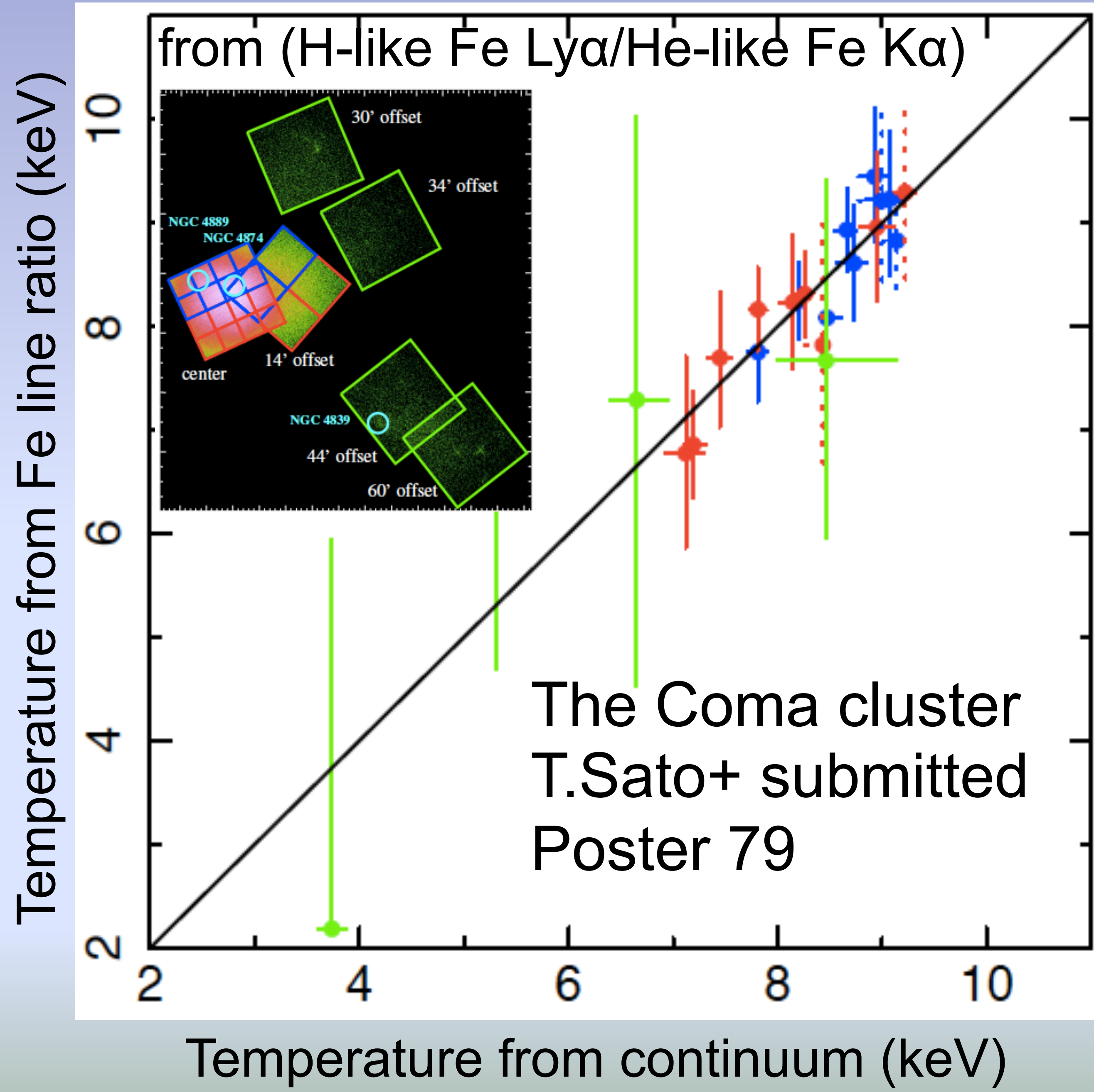






Temperature measurement with Suzaku

- 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*



Metals outside cool cores

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

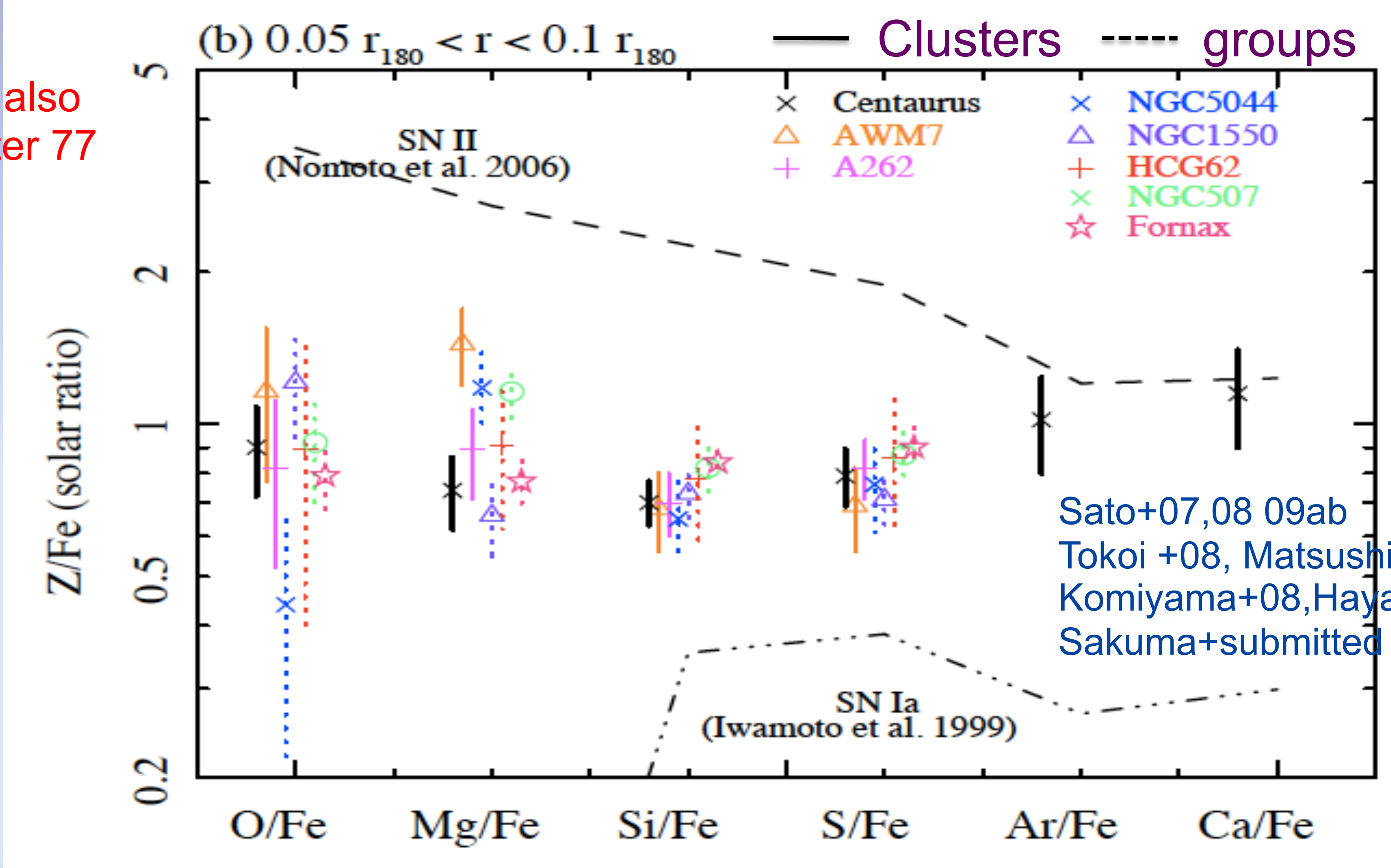
flatter Fe abundance profile at 0.1—0.5r_{180} than expected

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

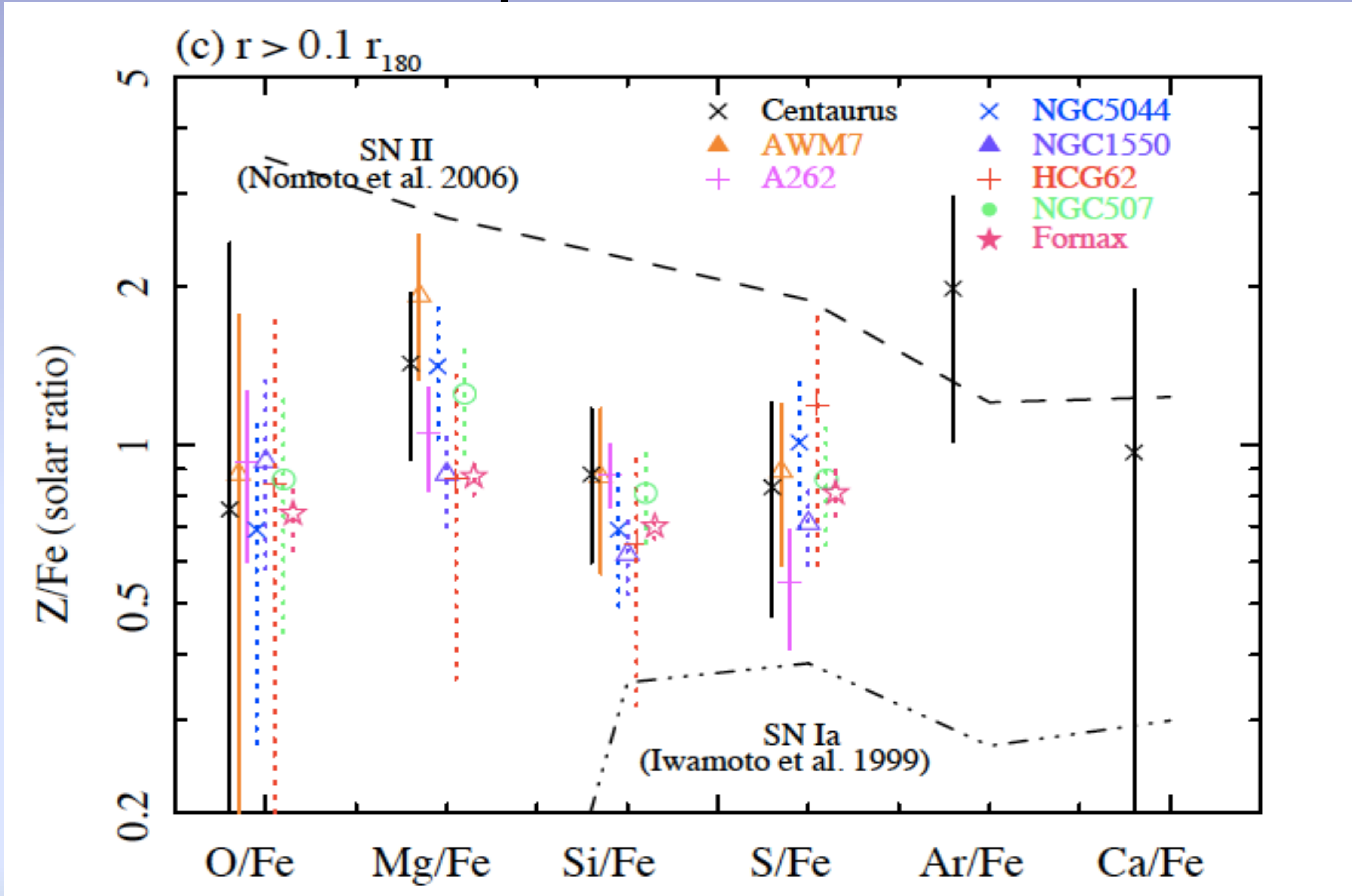
See also Poster 77



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

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>0.1r180



O, Mg, Si, S, Ar, and Fe ratios are close to the solar ratio

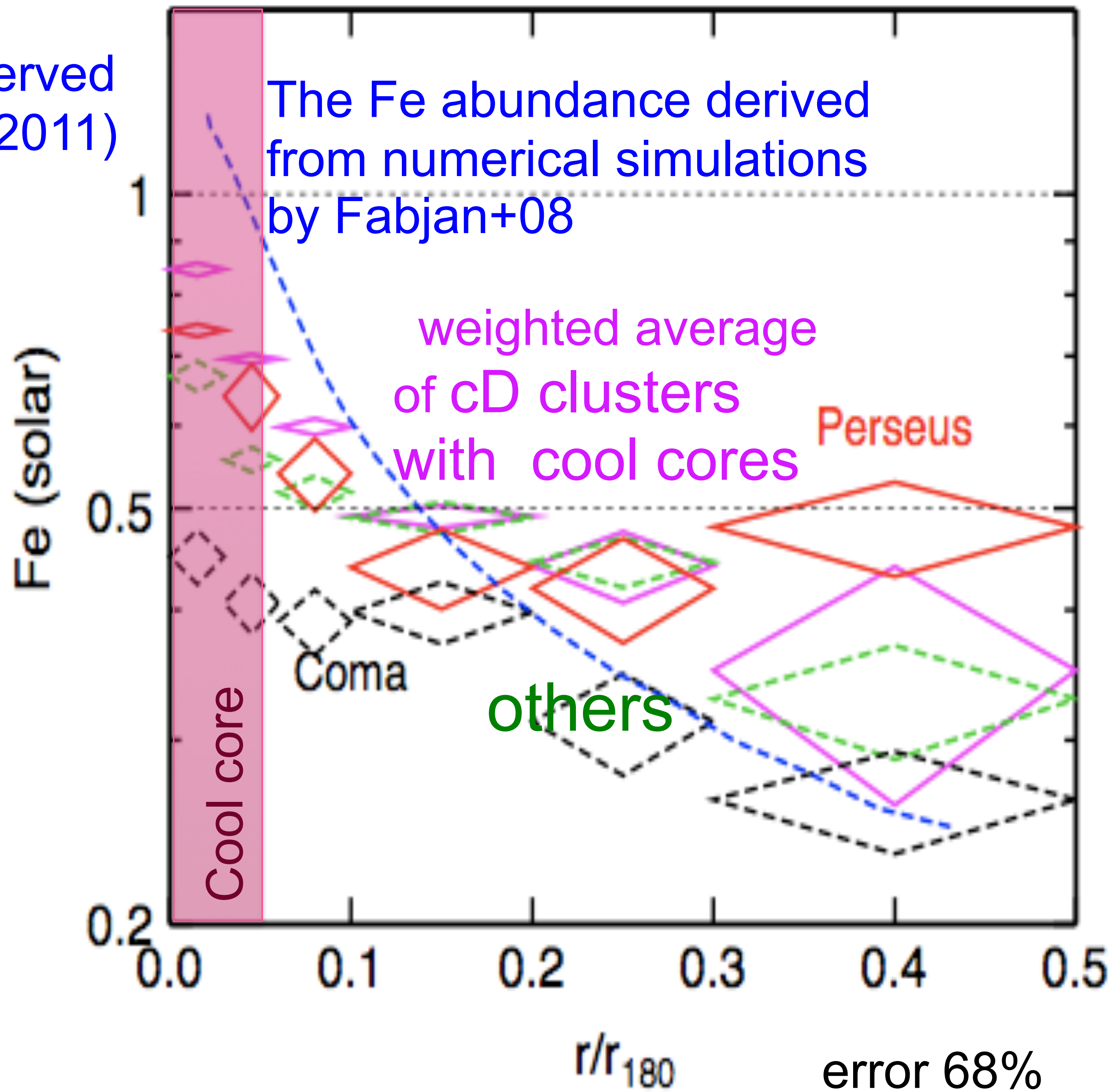
A significant fraction of Fe come from SN Ia

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

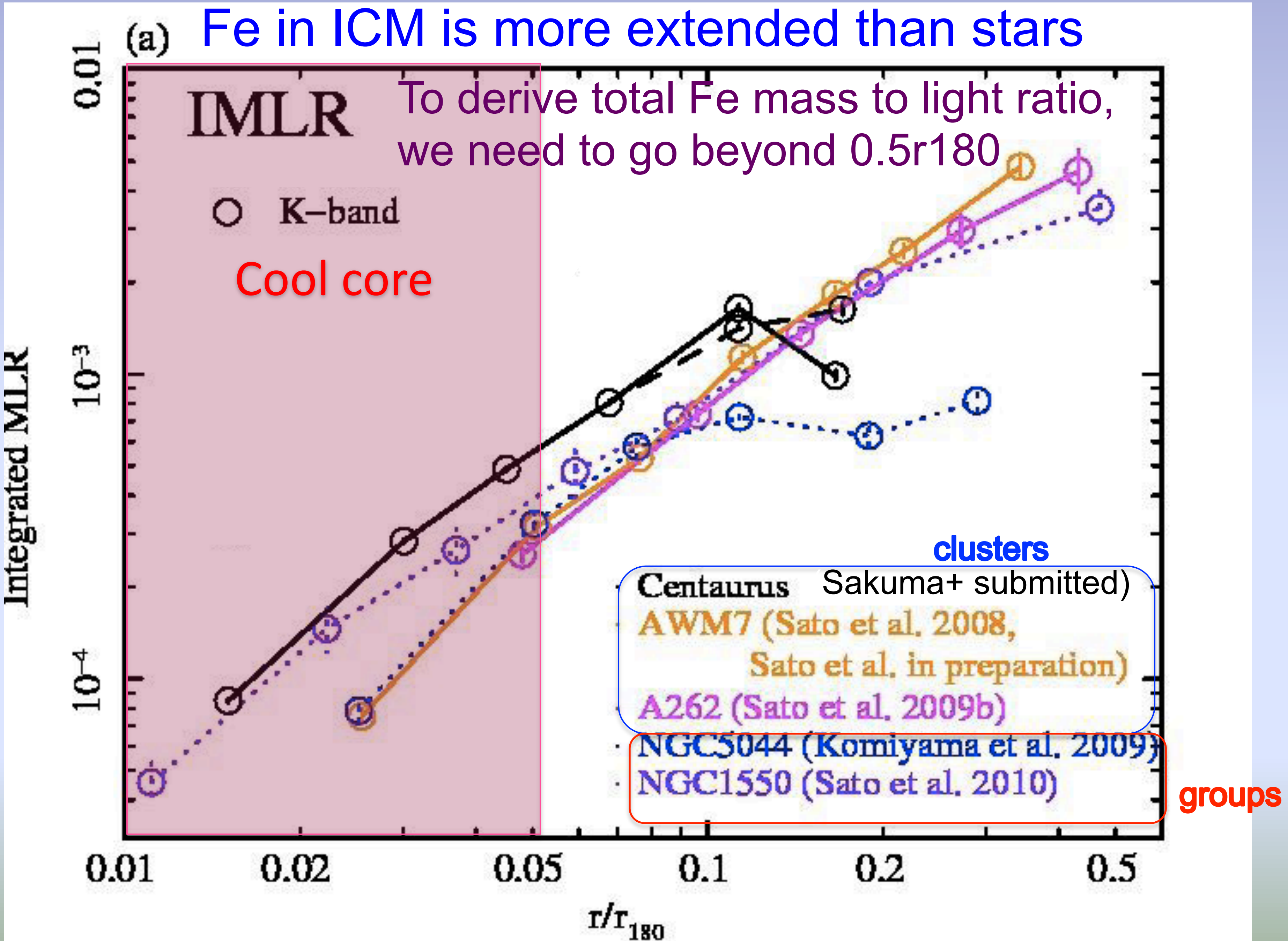
solar abundance: lodders (2003)



Integrated Iron mass to light ratios: $M_{Fe}(<r)/L_K(<r)$

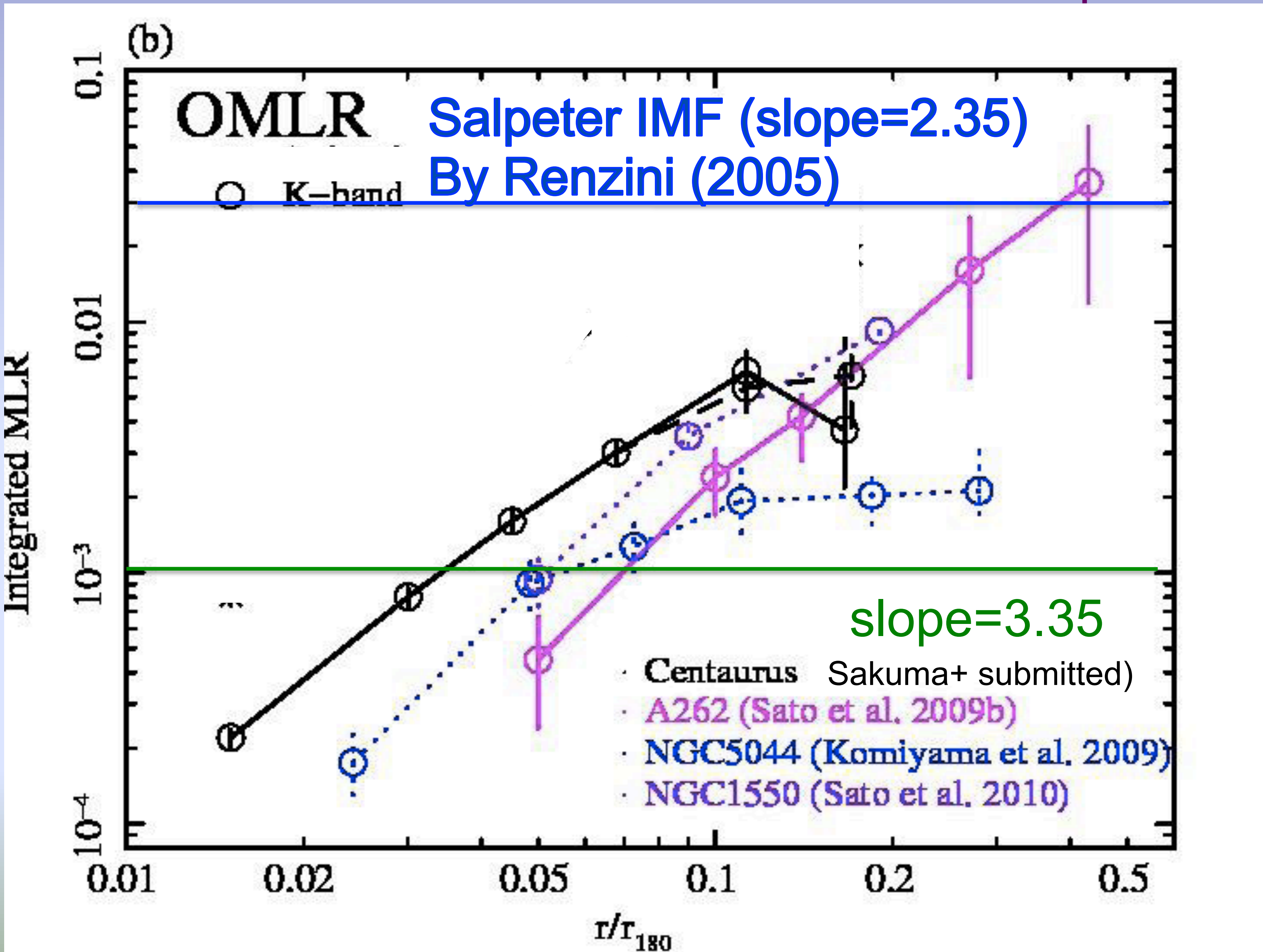
Increases with radius at least up to 0.5r180

Fe in ICM is more extended than stars



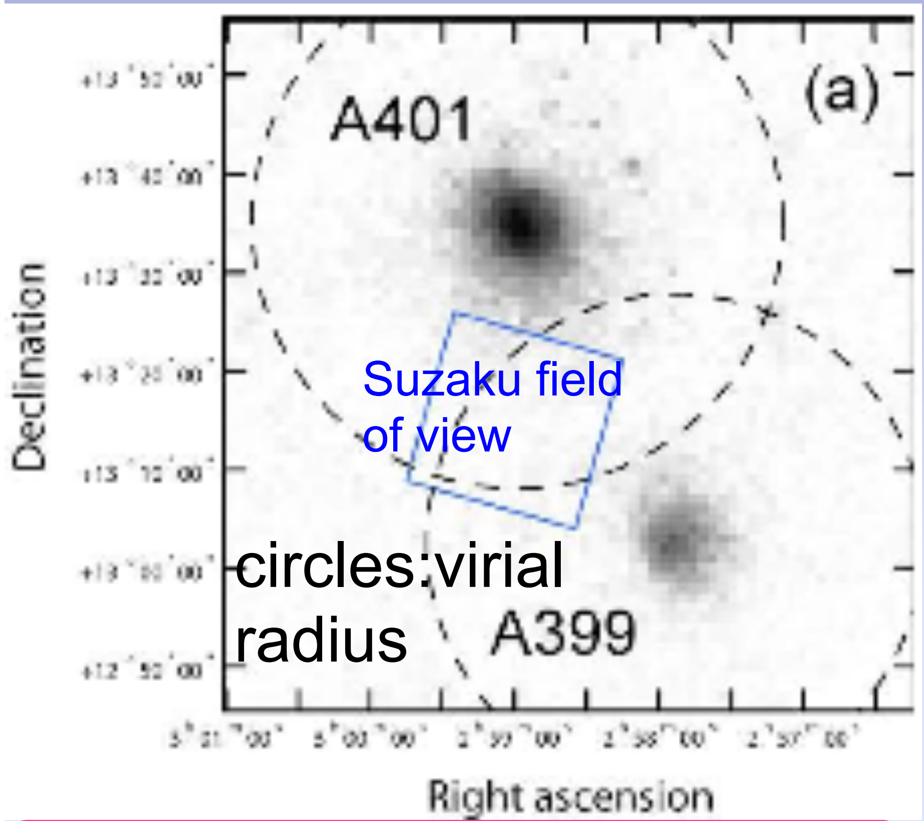
O Mass to light ratio – sensitive to IMF

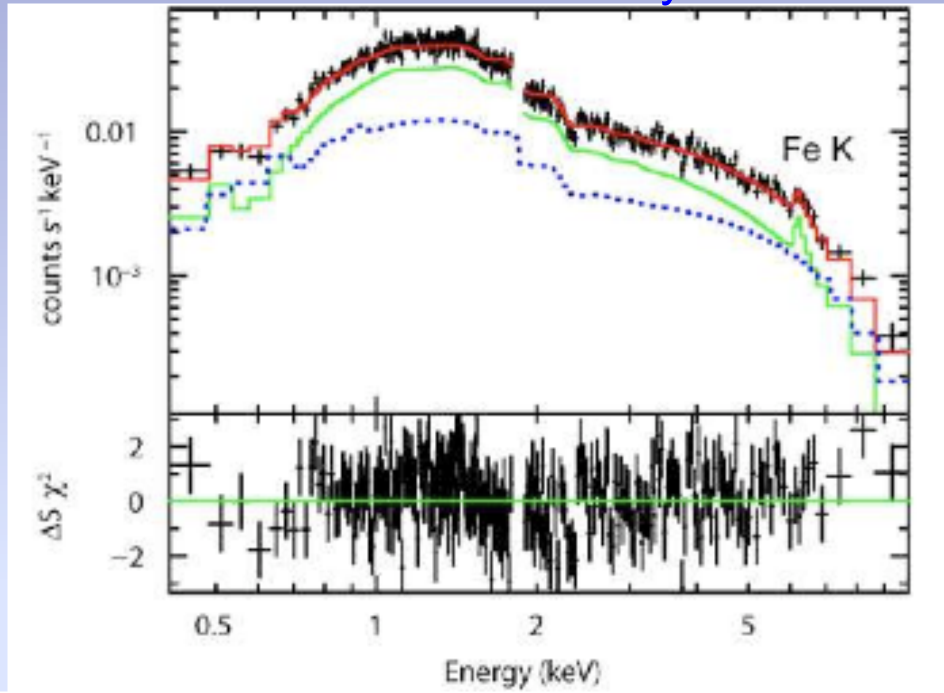
OMLR within 0.5r180 is consistent with Salpeter IMF



Suzaku detection of Fe line up to the virial radius

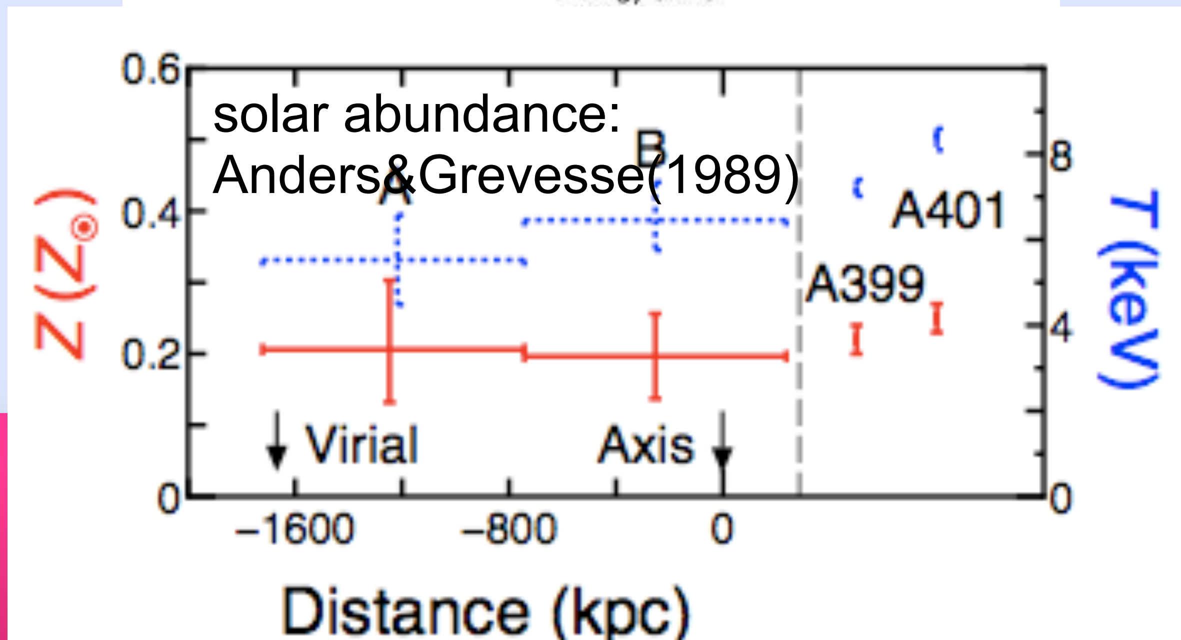
Fujita et al. (2008) see also a flat Fe profile of the Perseus cluster
By Simionescu+11





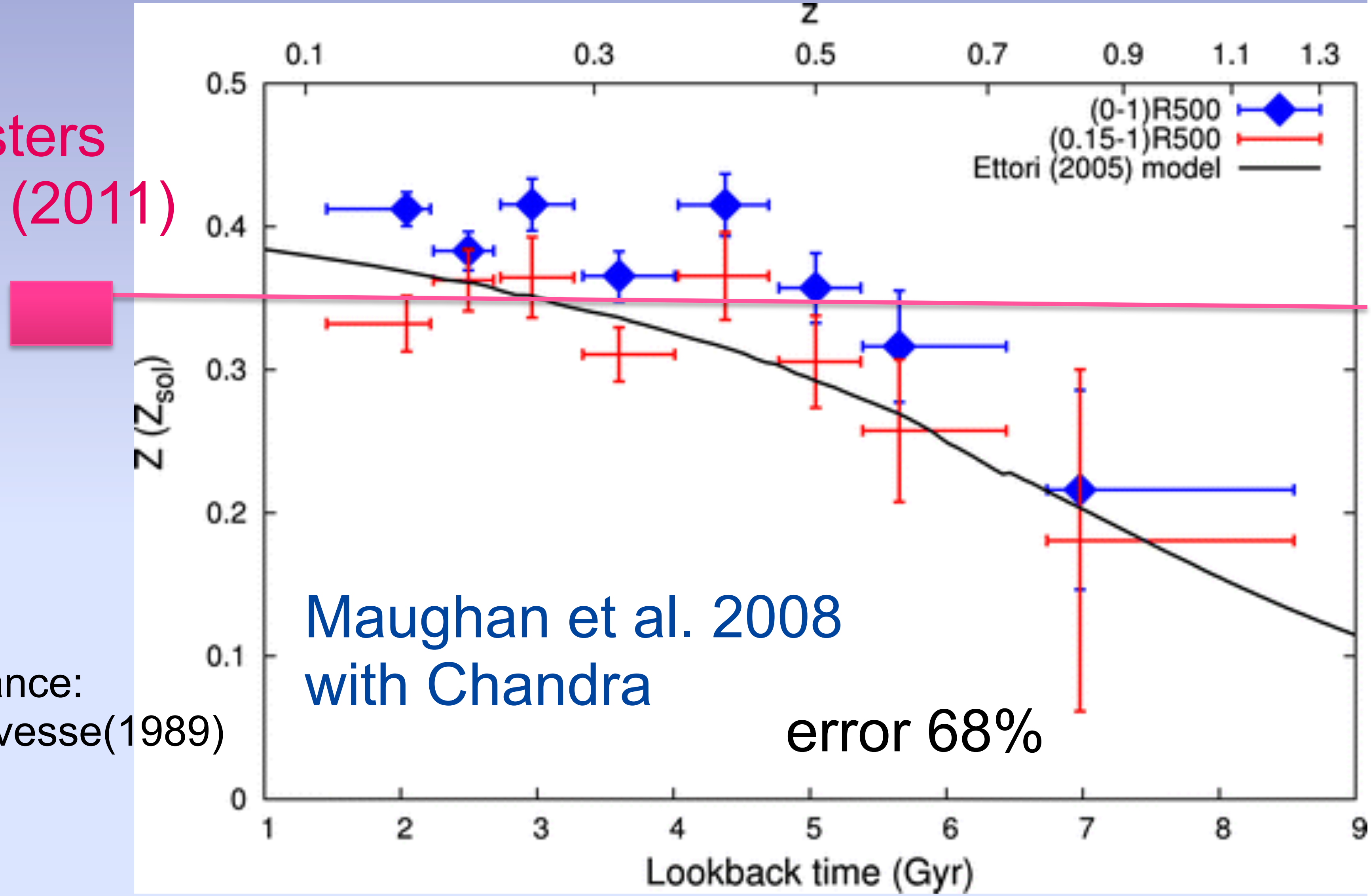
High Fe abundance @ 0.5-1.0 r_{180}

Early metal enrichment



Evolution of Fe abundance of ICM

z<0.08 clusters
Matsushita (2011)



solar abundance:
Anders&Grevesse(1989)

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?

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—0.5r_{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

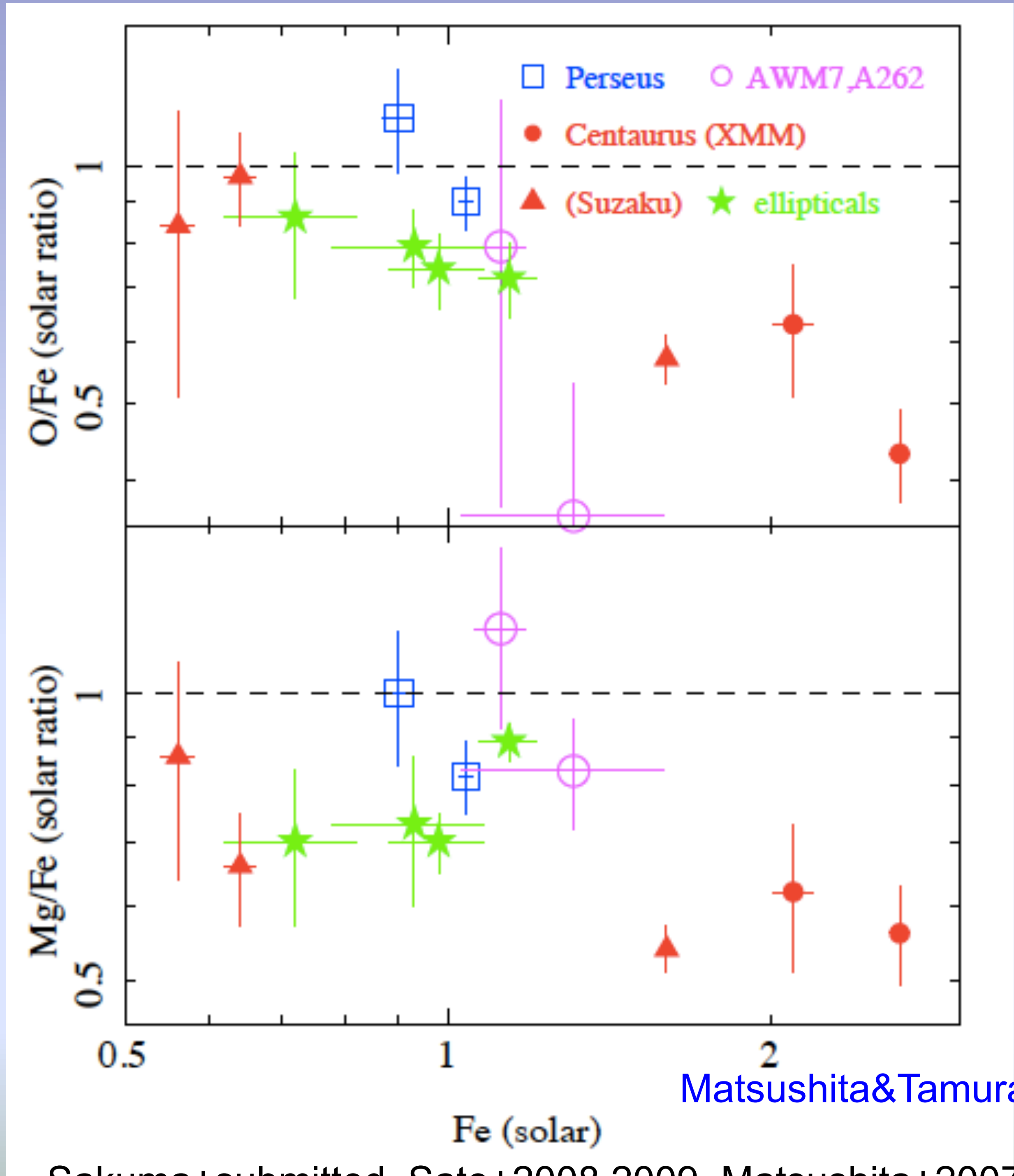
Cr and Mn abundances from the Perseus and the Centaurus cluster

Differences between the Perseus and the Centaurus

O/Fe, Mg/Fe vs. Fe abundance in cool cores and ellipticals

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

Sakuma+submitted, Sato+2008,2009, Matsushita+2007
Tawara+08, Hayashi+09

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

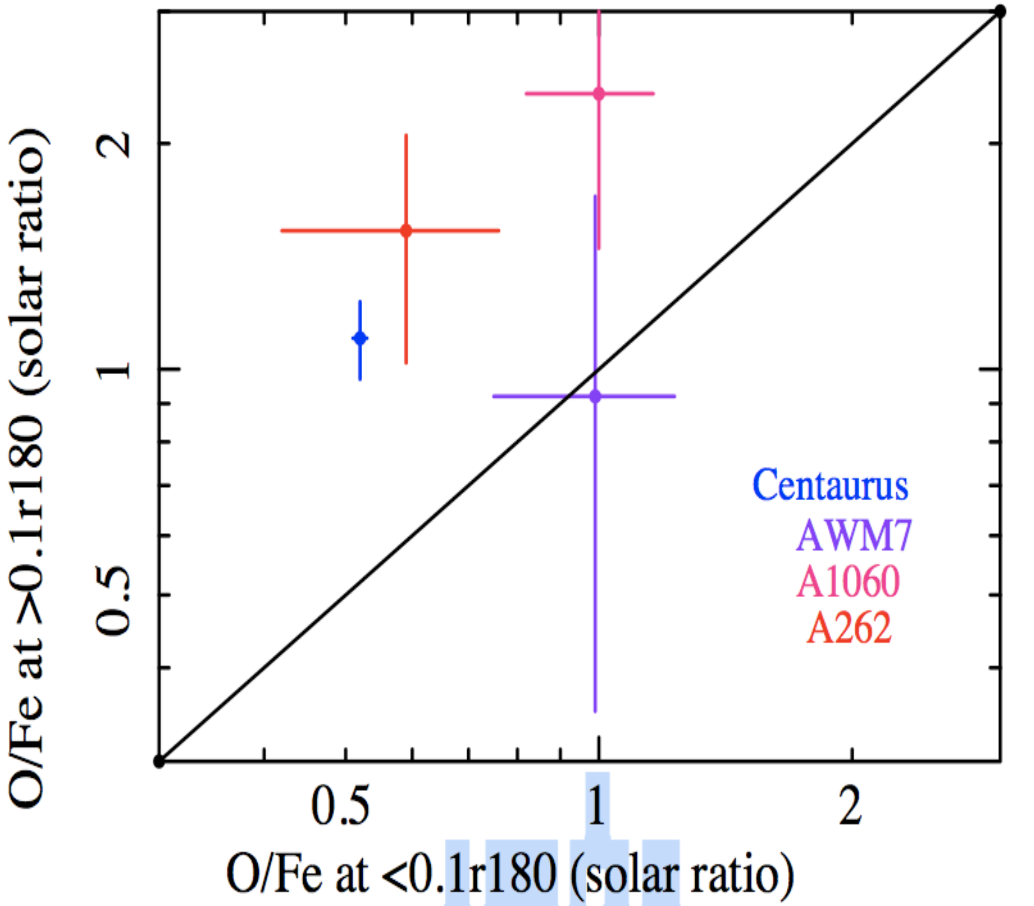
($\propto$ present SN Ia rate)

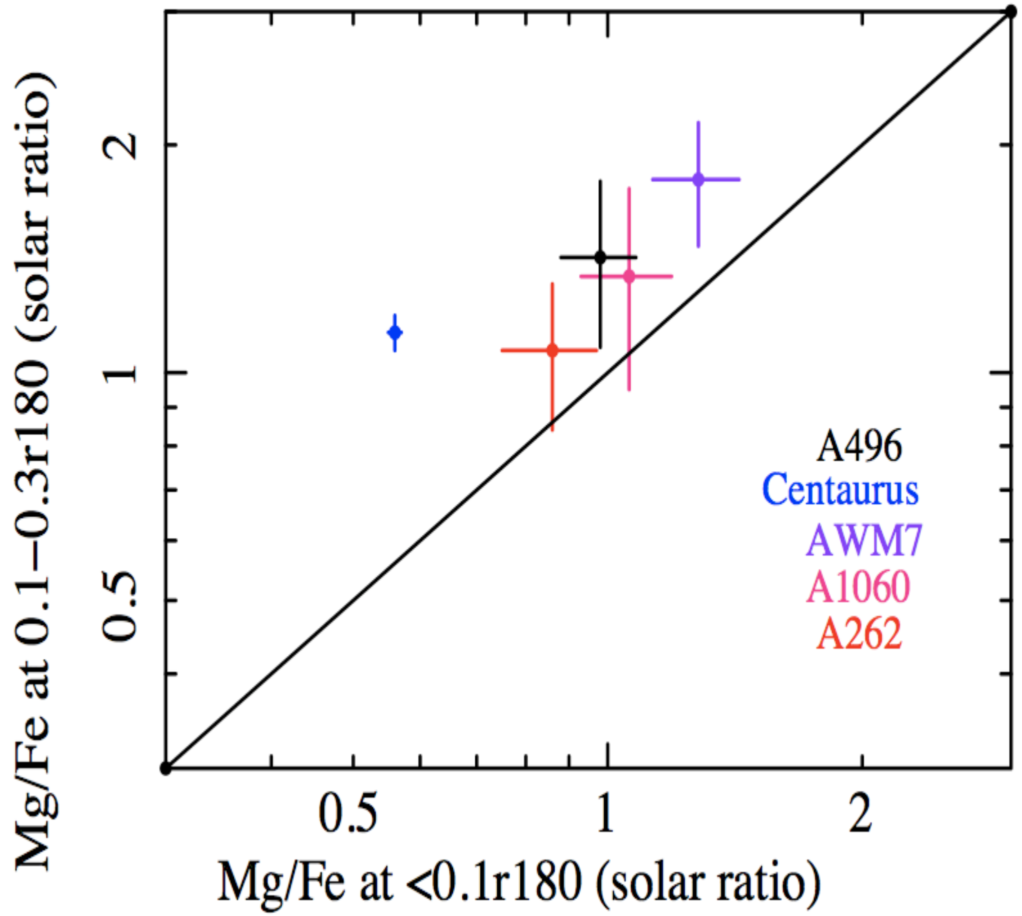
Fe abundance of ISM is

stellar Fe abundance + <u>present SN Ia contribution</u>

- 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 Centurus 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

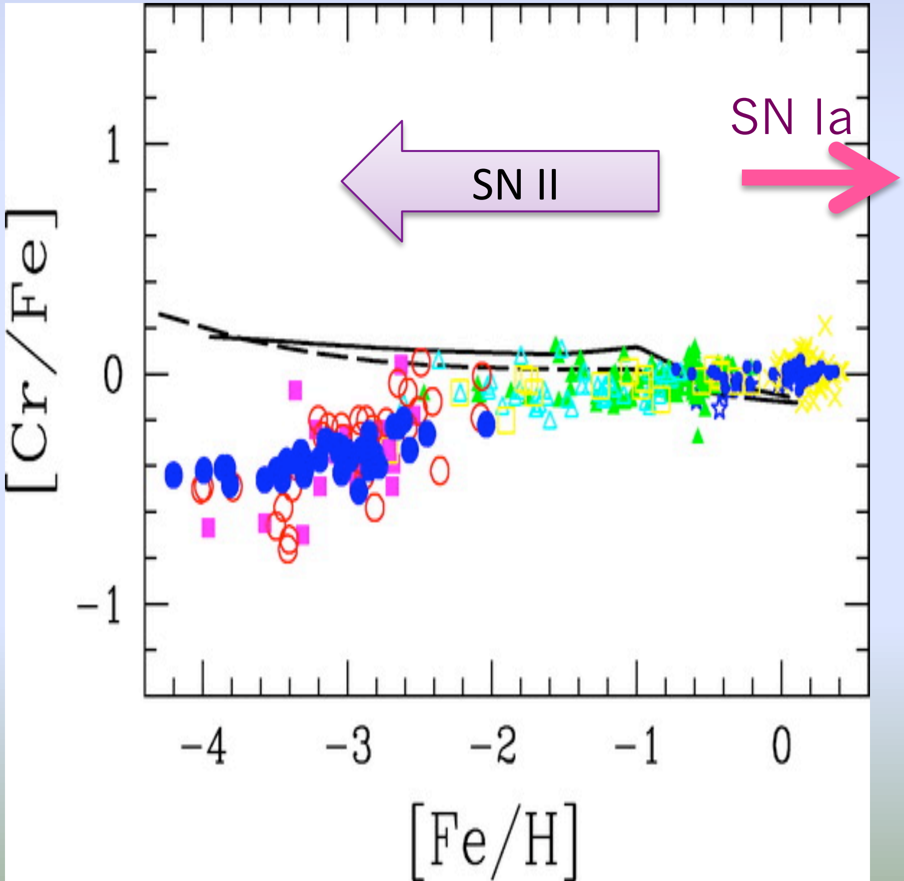
Increase of O/Fe, Mg/Fe ratio at 0.1-0.3r_{180}

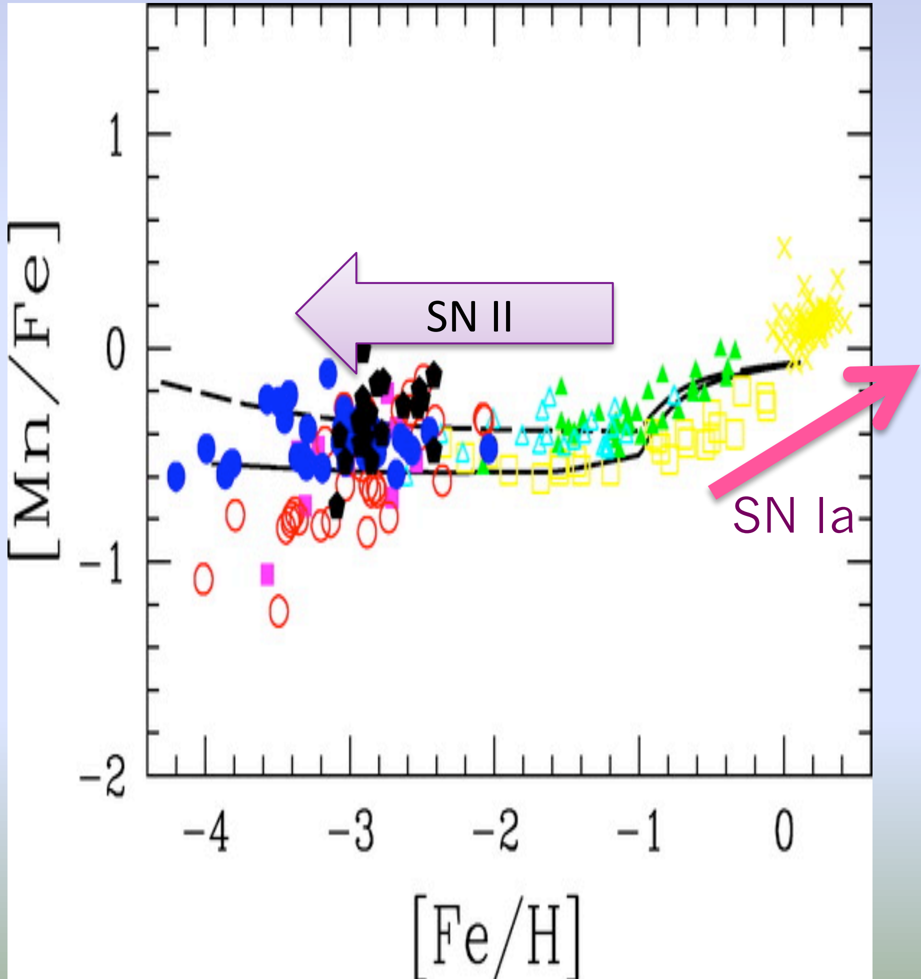




Metal supply from central galaxies by SN Ia and stellar mass loss is important at the central region

- 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

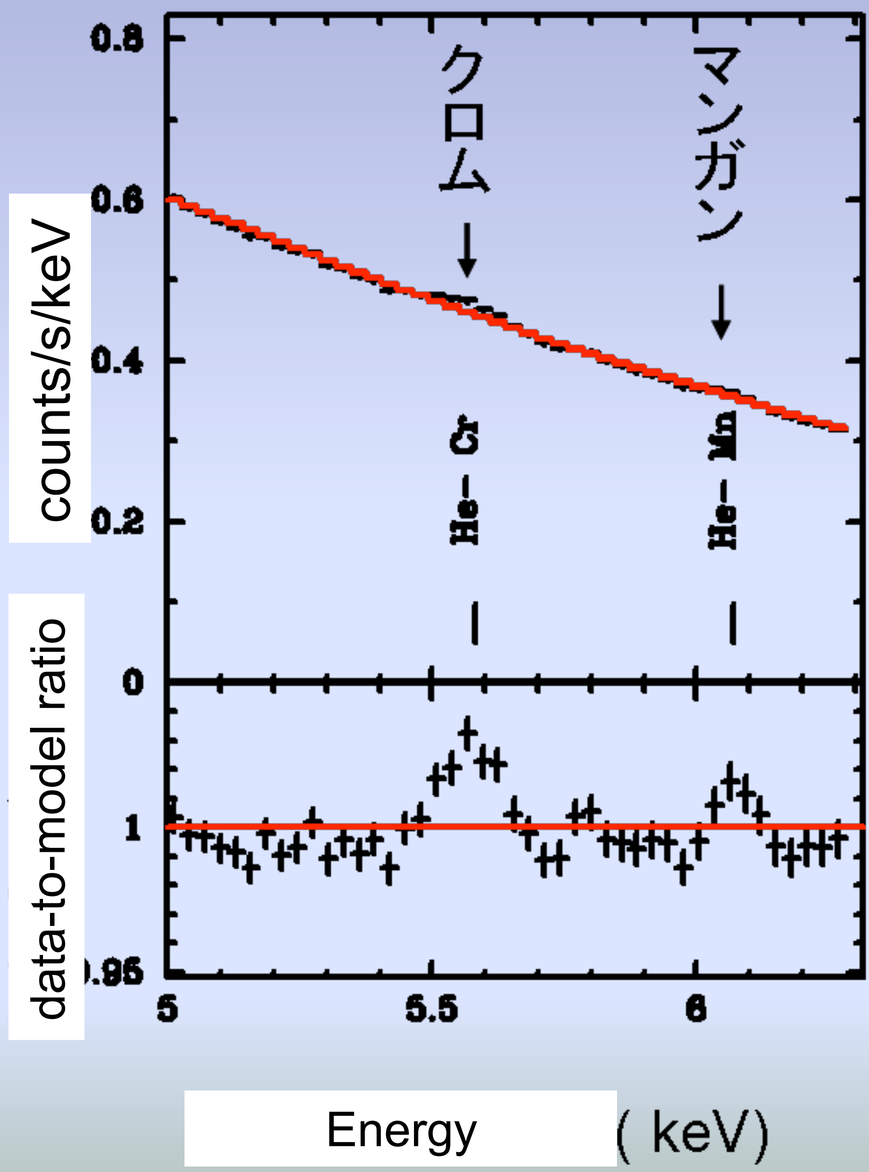




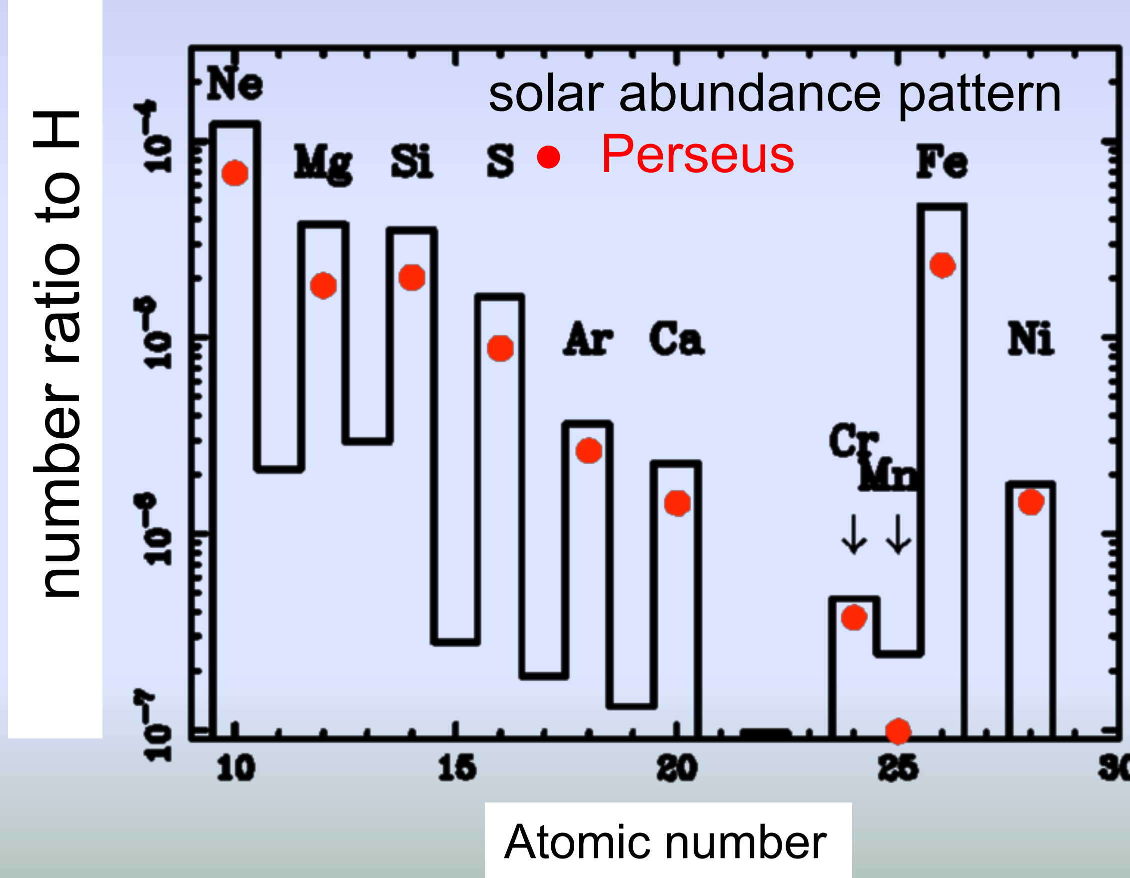
Cr and Mn detection from the Perseus cluster with Suzaku

Tamura et al. 2009

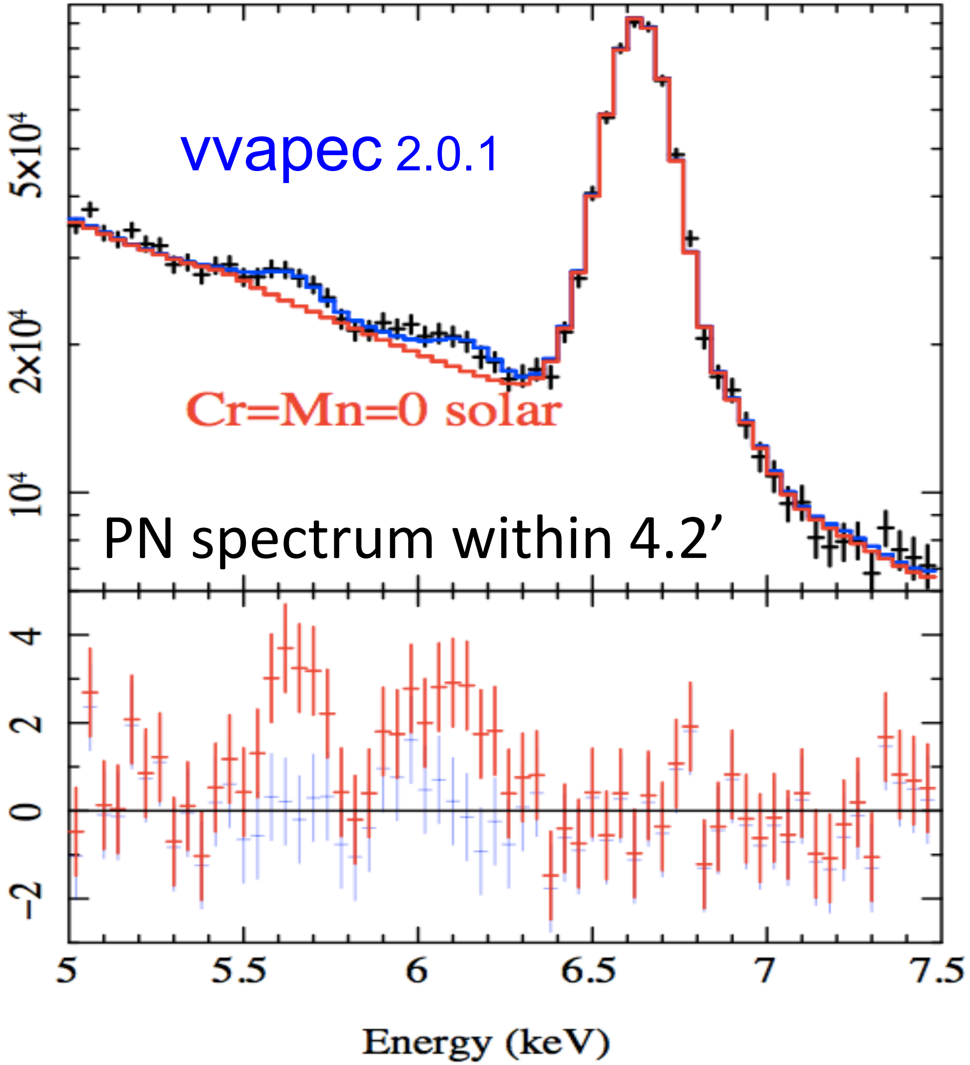
also XMM detectinon from **2A 0335+096** by Werner et al. (2006)

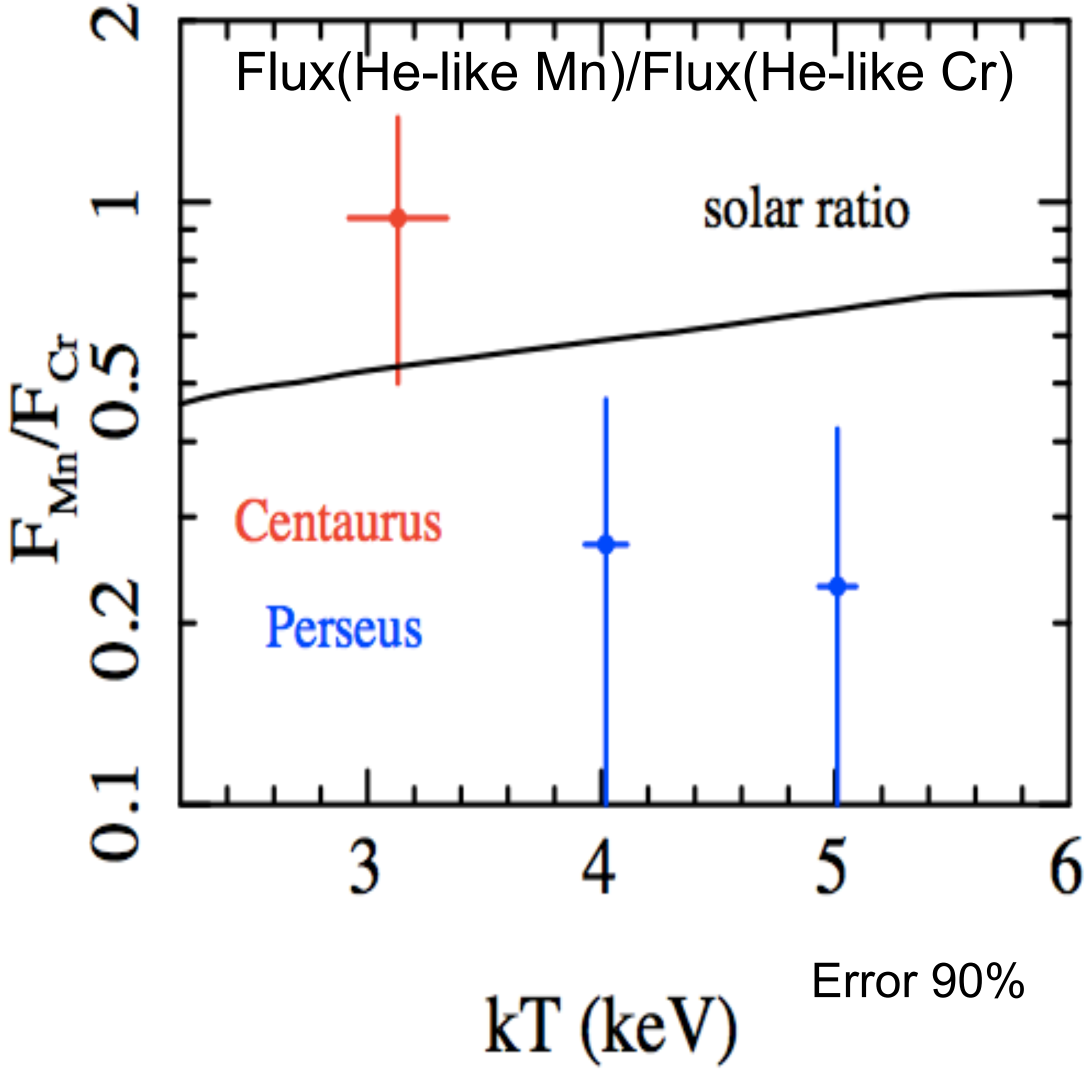


Mn is an indicator of SN Ia, since SN II do not produce Mn very much



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





Mn/Cr(Centaurus)>Mn/Cr(Perseus) ➔ higher contribution of SN Ia in the Centaurus cluster

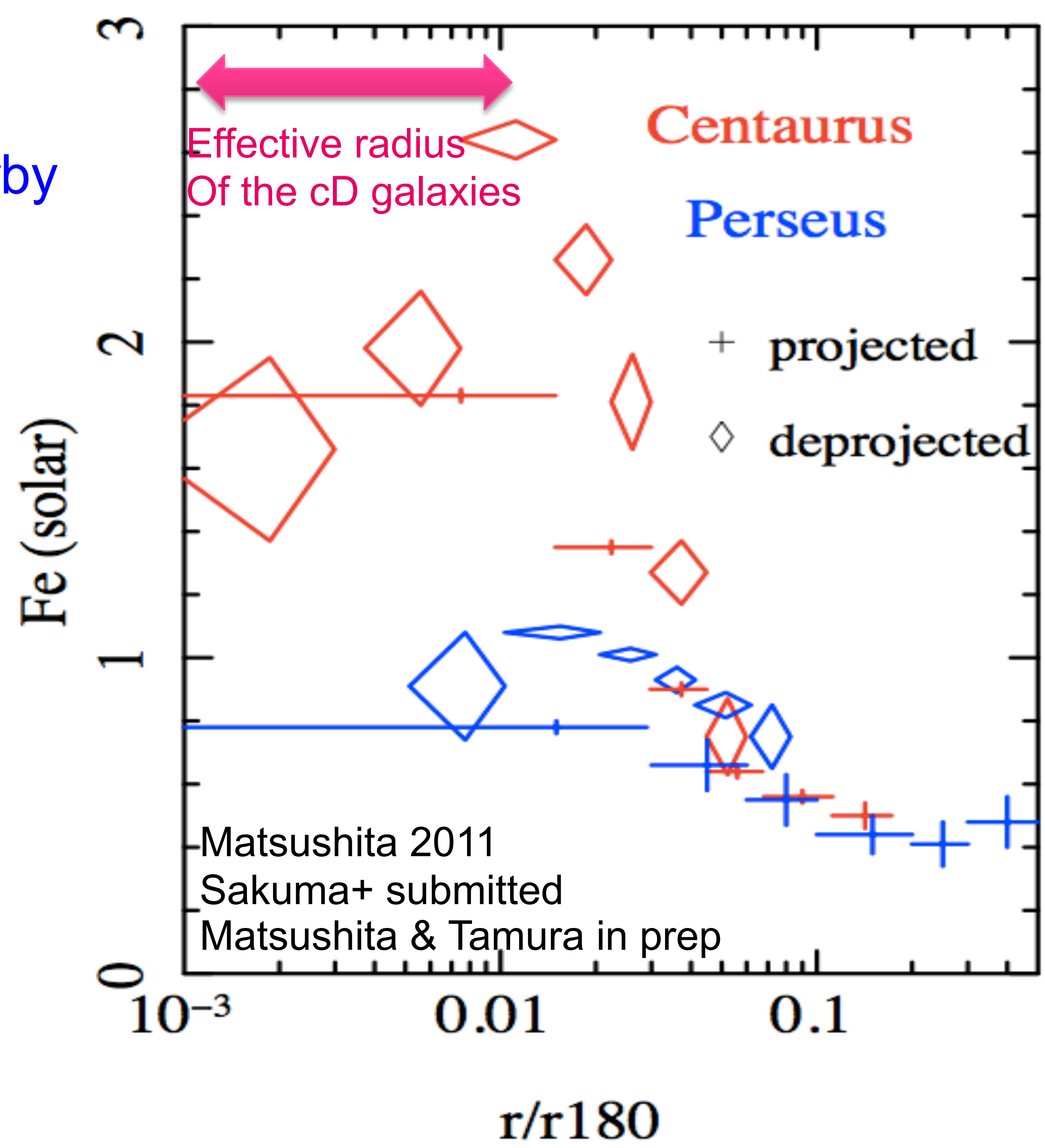
Fe abundance profiles of the Centaurus cluster and the Perseus cluster

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?

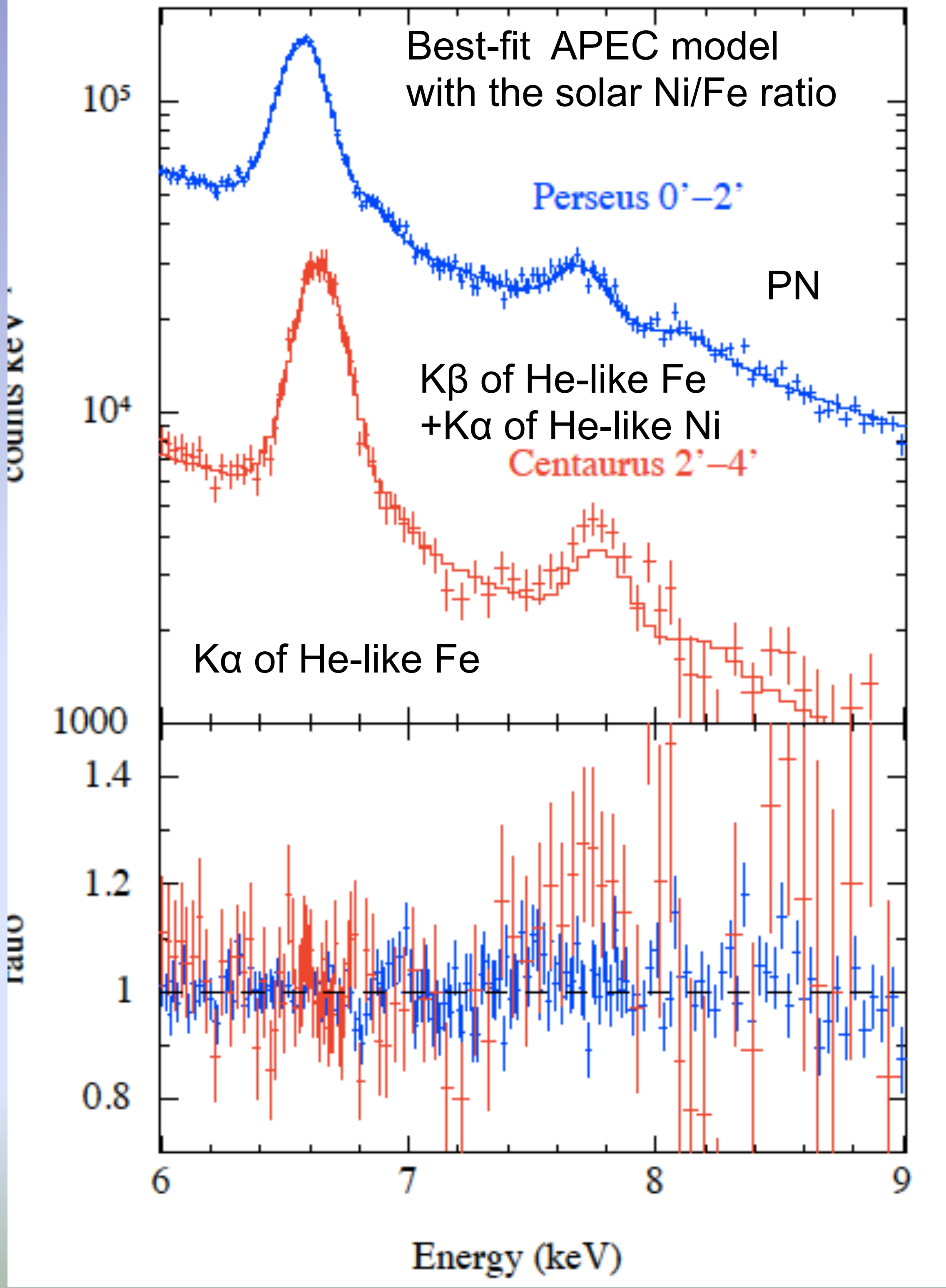
These abundance profiles are Consistent with Sanders +06, Churazov+04,Tamura+09, Sanders+07, adpoting the same model



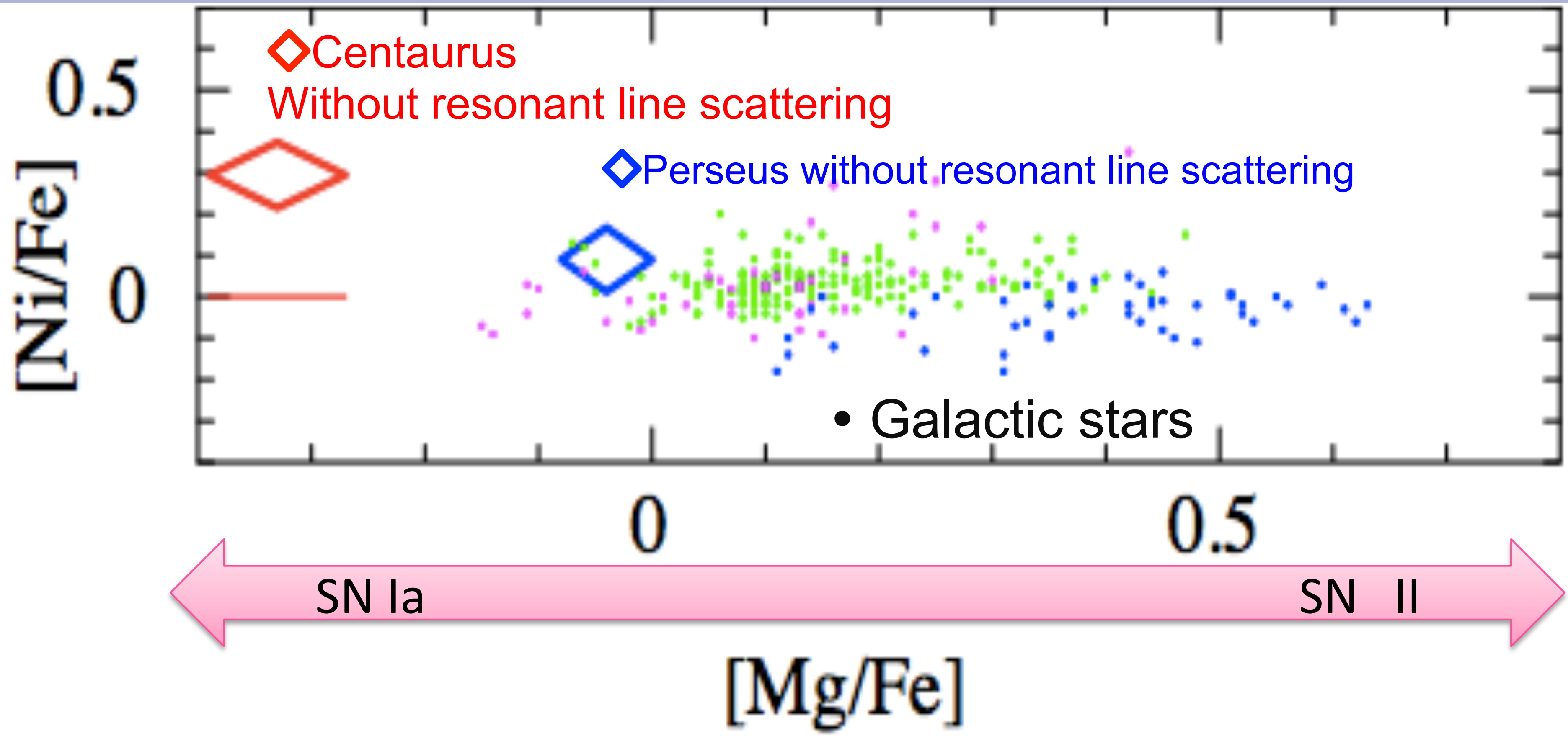
Enhancement of 7.8 keV line

- 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



[Ni/Fe] of the Galactic stars



- In our Galaxy, Ni/Fe (SN Ia) = 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 $0.3r_{180}$

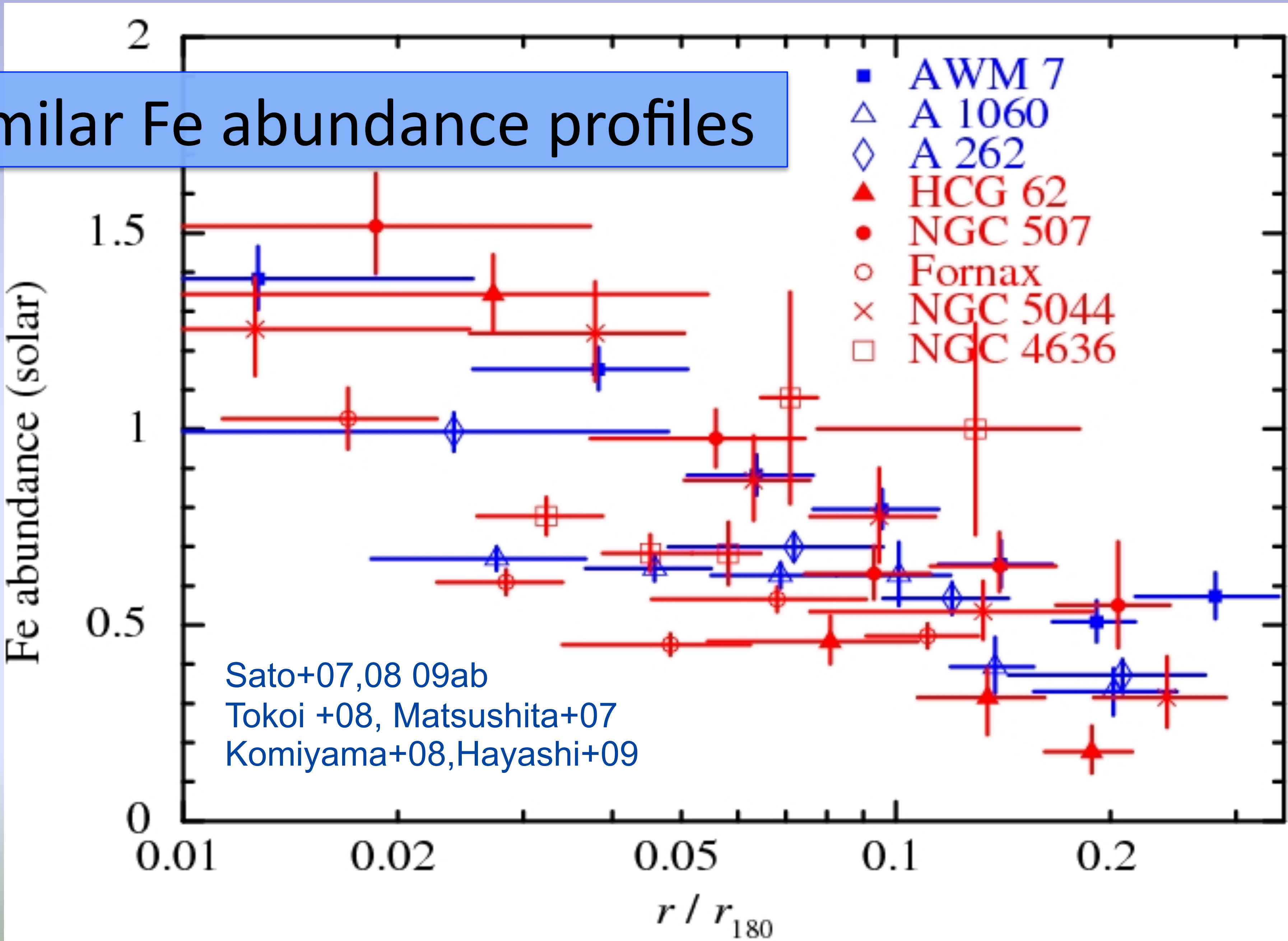
SN II products tend to be more extended in clusters?

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

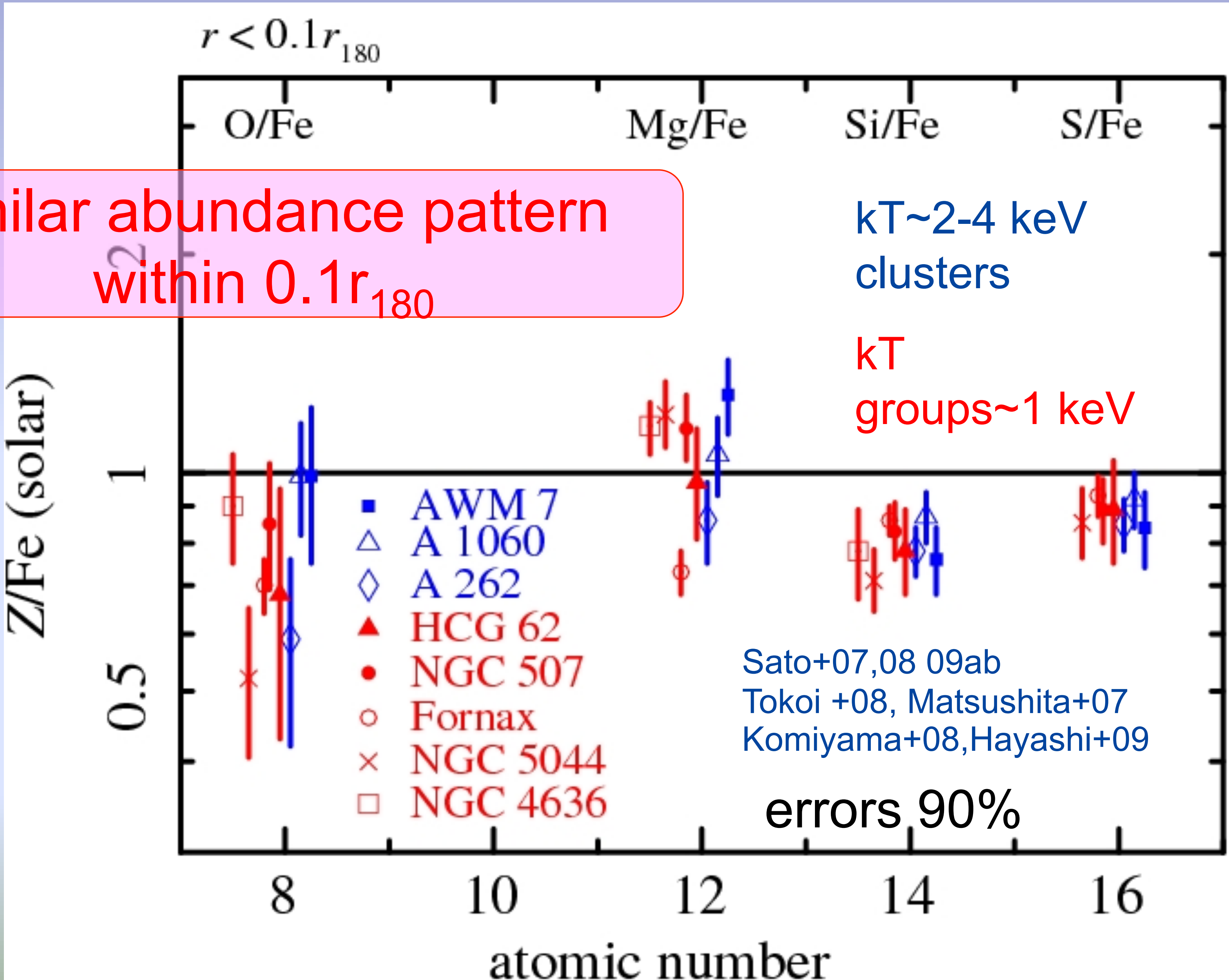
similar Fe abundance profiles



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

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

solar abundance table by Loddars (2003)



similar abundance pattern within $0.1r_{180}$

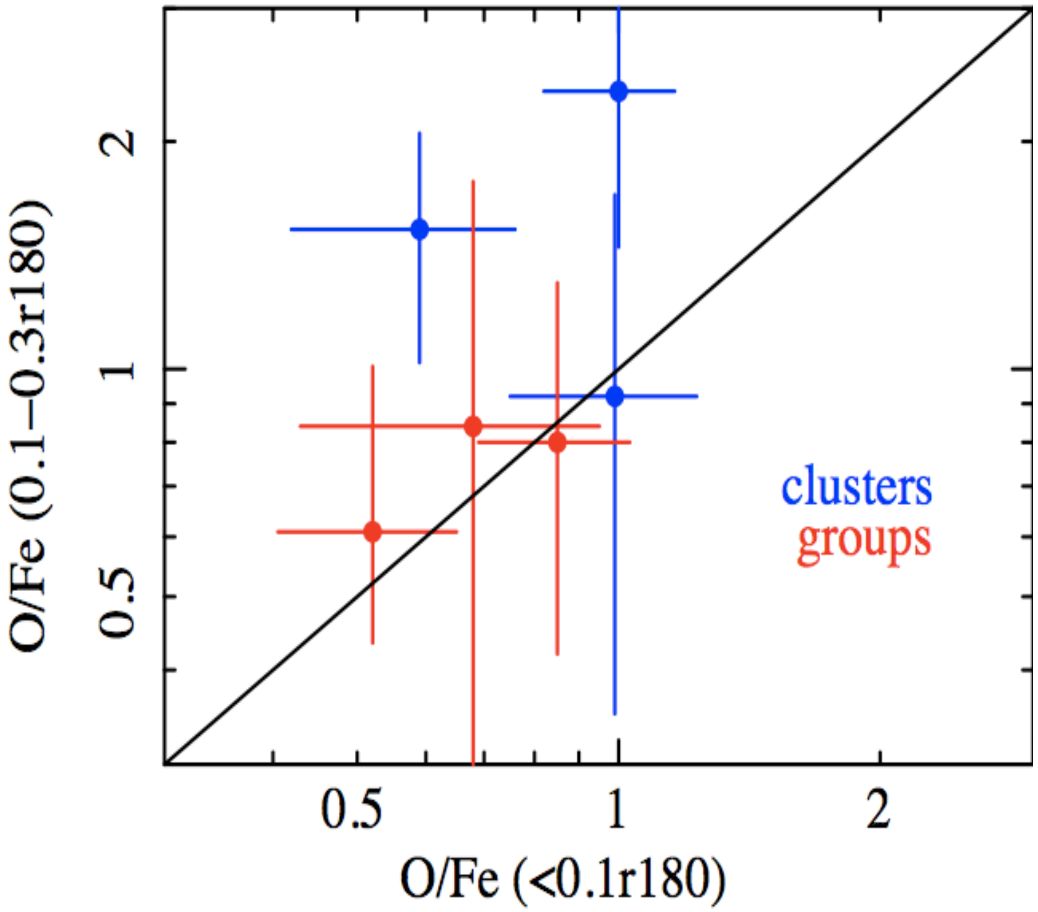
kT~2-4 keV clusters

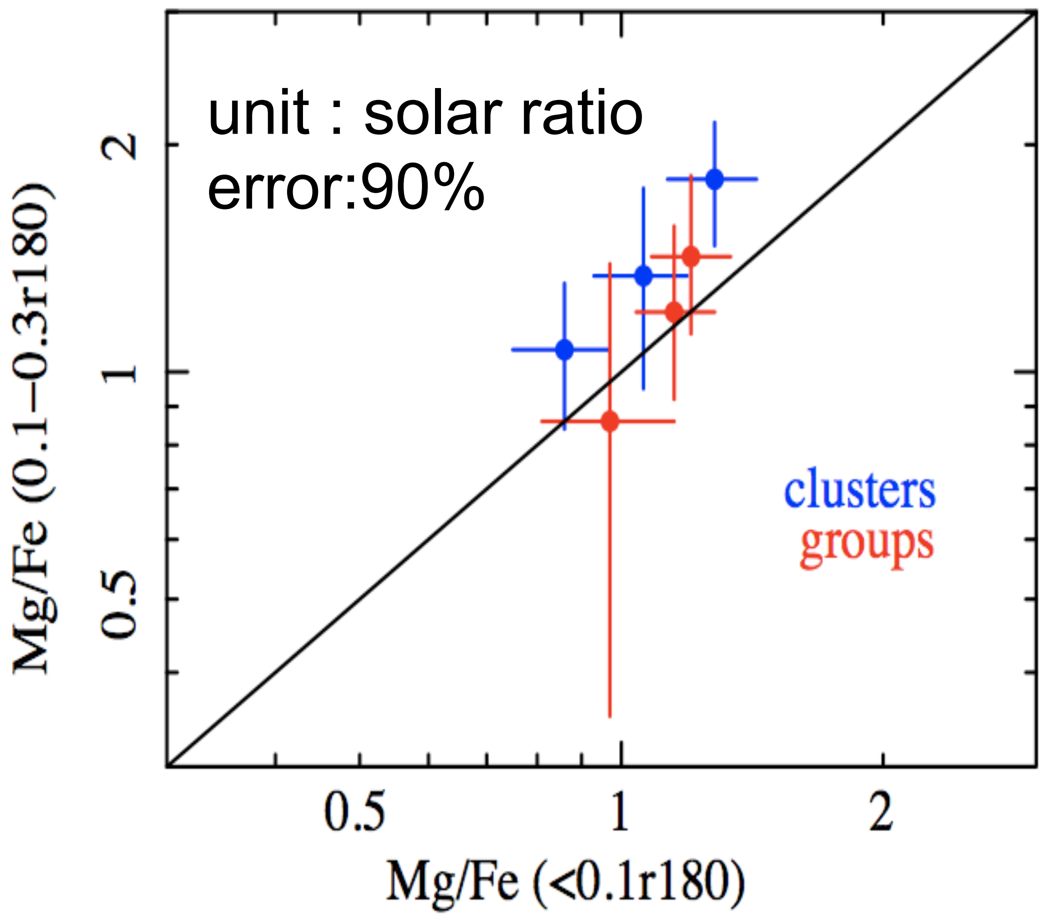
kT groups~1 keV

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}





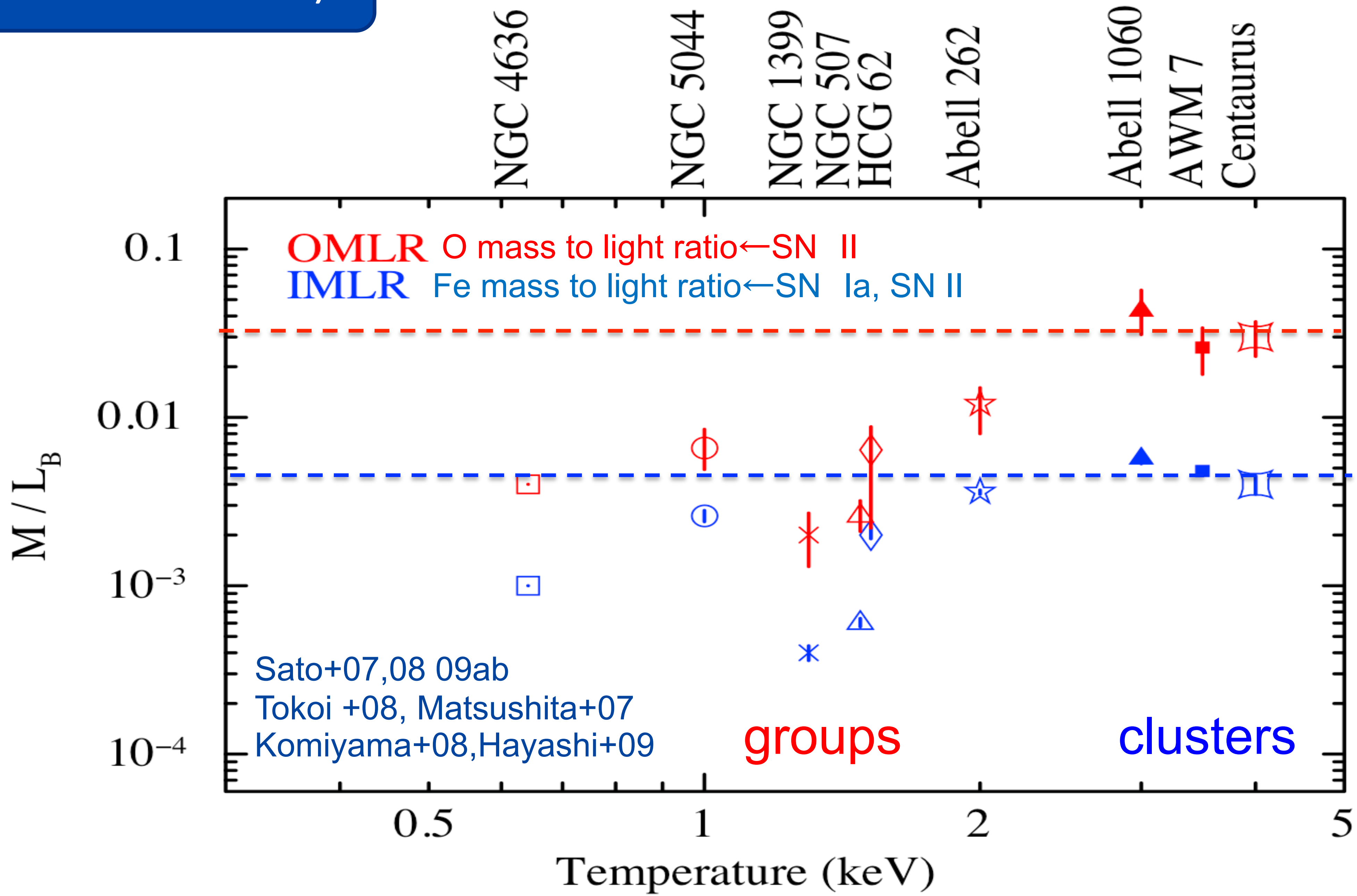
In groups of galaxies, metals synthesized by SN II have similar radial profiles with SN Ia products within 0.3r_{180}

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

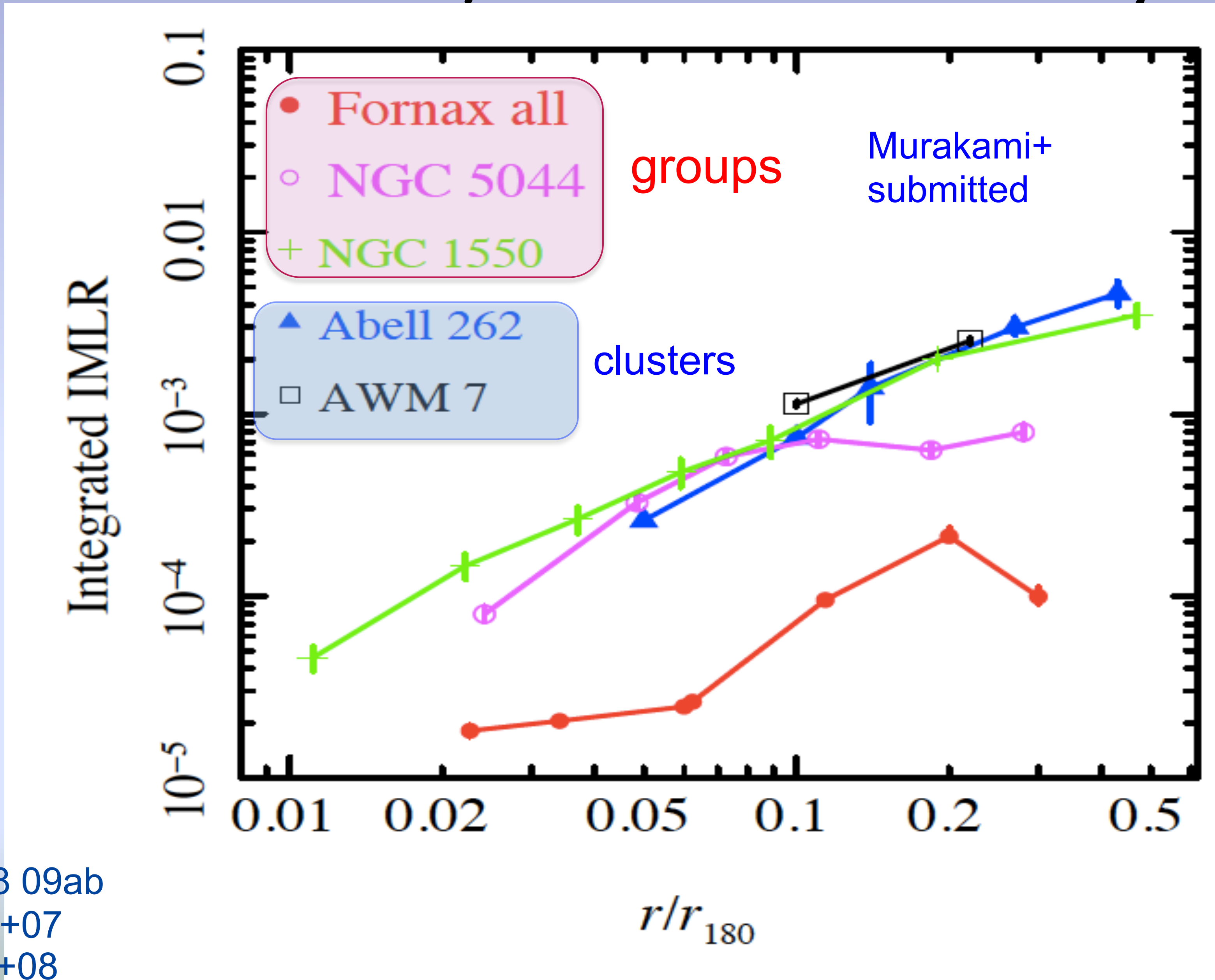
Metal mass to light ratio

Mainly low mass stars

Suzaku (<0.1r180)



Integrated profiles of Iron mass/K band luminosity



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

Groups vs. clusters

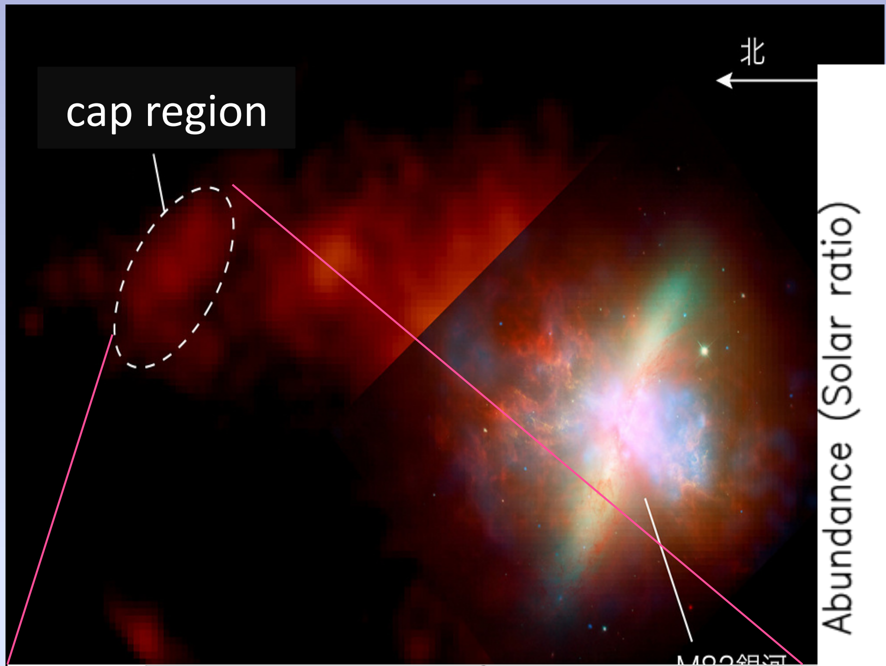
similar Fe abundance profiles up to $0.3r_{180}$

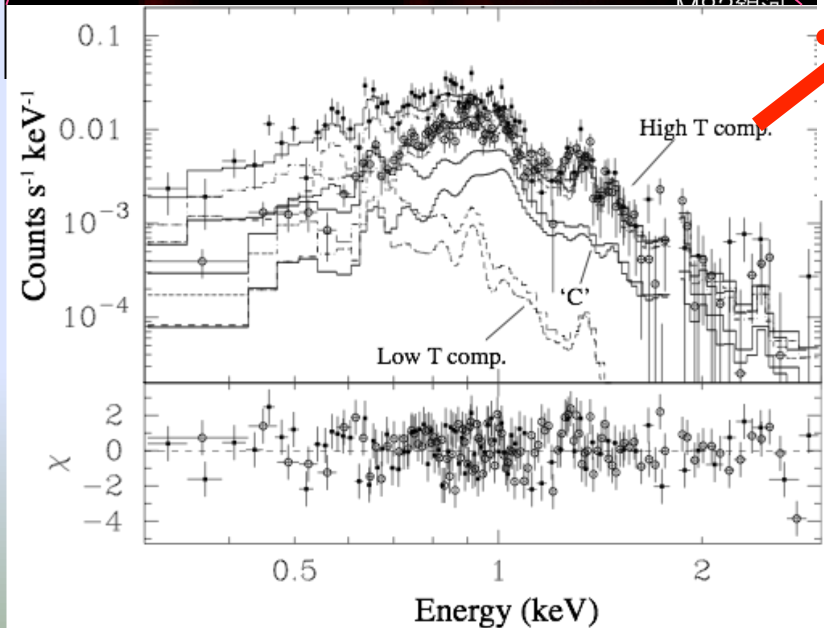
SN II products tend to be more extended in clusters?

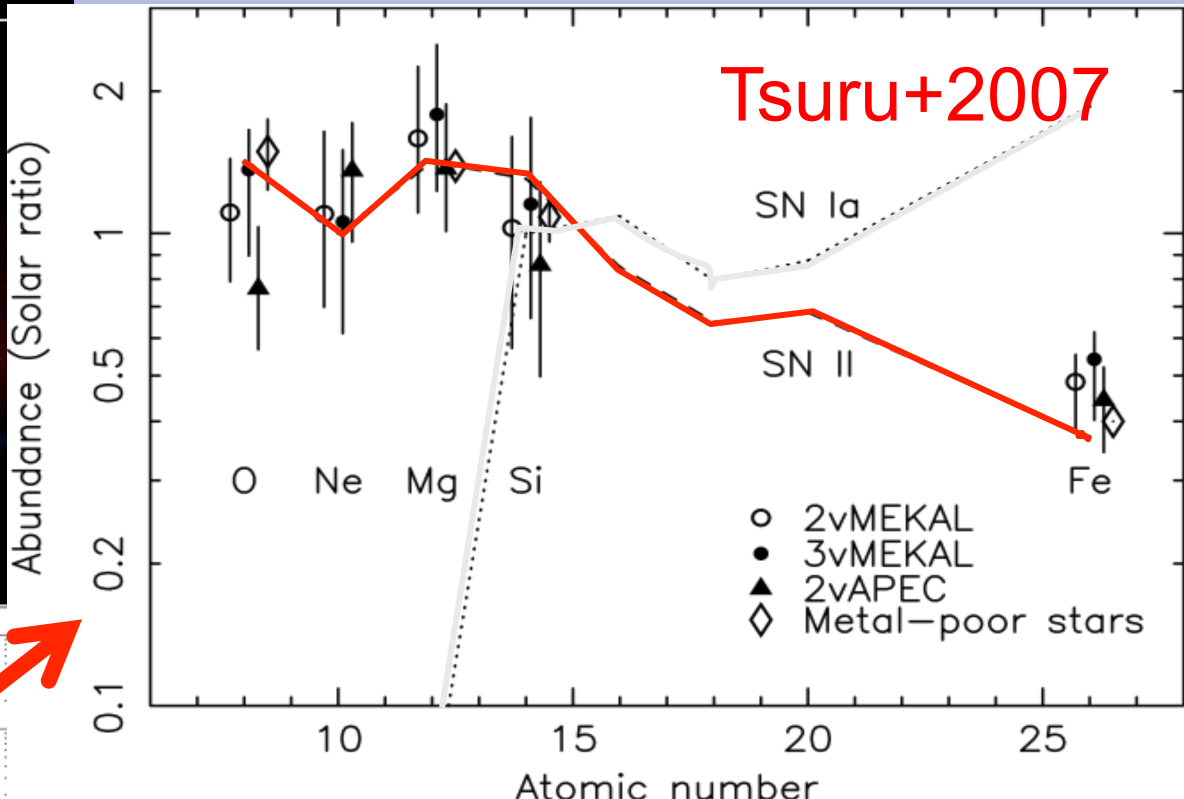
The observed metal mass-to-ratio are smaller in groups and poor clusters reflecting that gas fraction is smaller in groups

- difference in star formation history?
- same star formation history but difference in the effect of feedback?

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

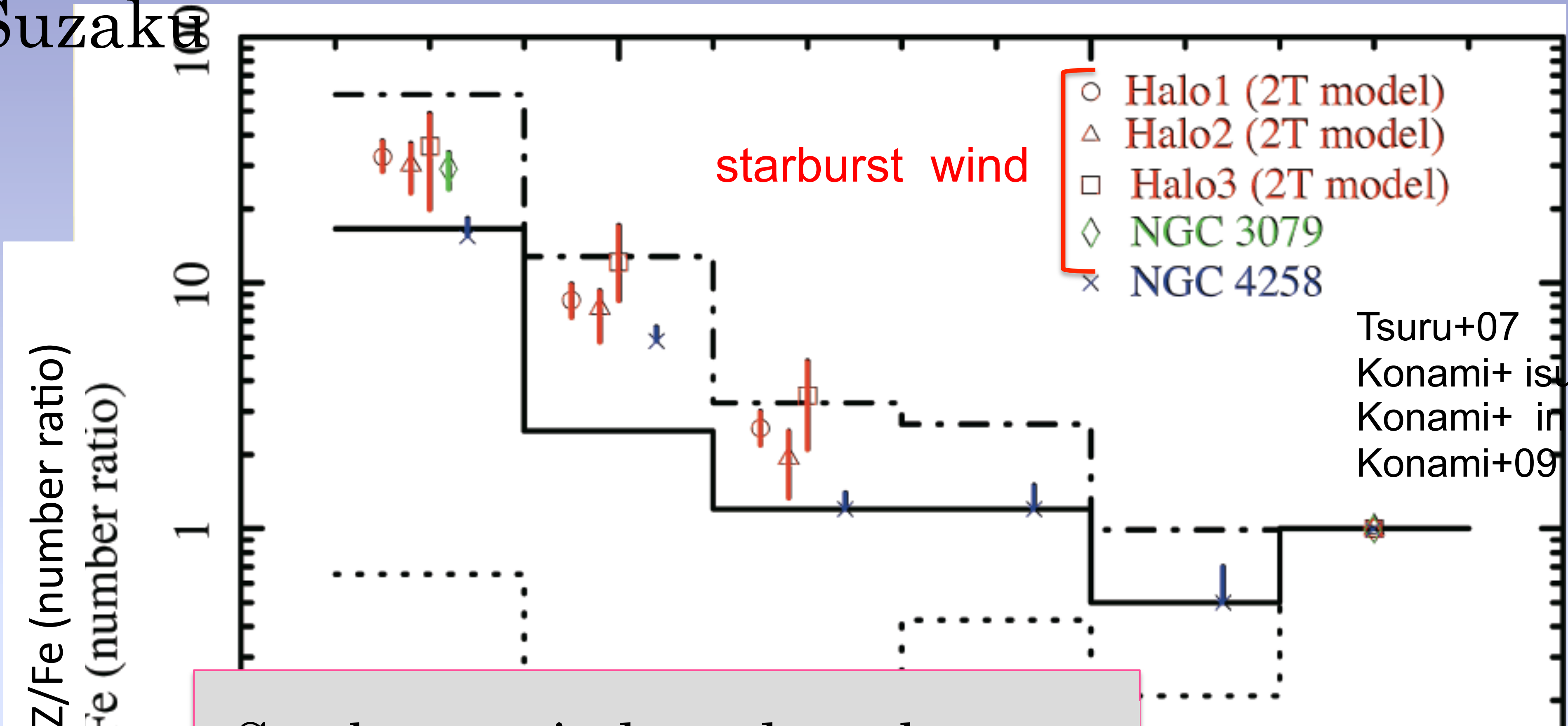






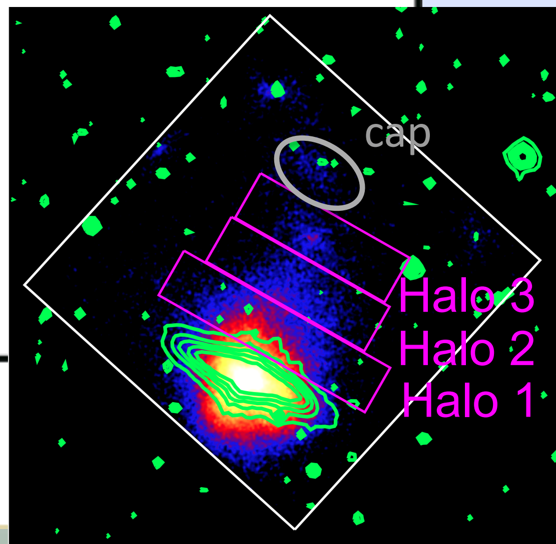
Metals synthesized from SN II escape from starburst galaxies?

Metal abundances of hot ISM in spiral galaxies with Suzaku



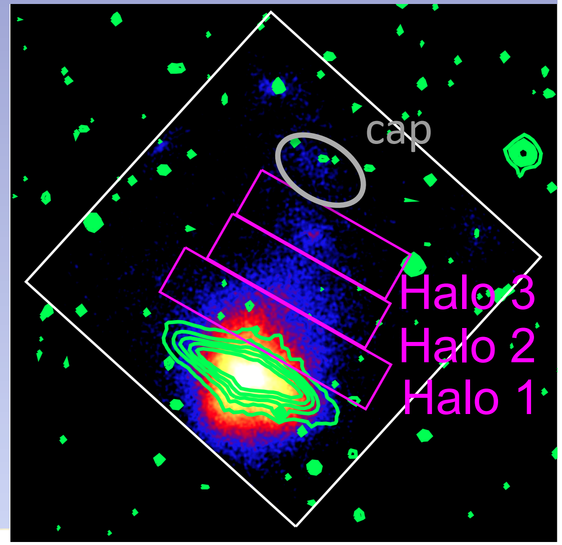
Tsuru+07
Konami+ isubmitted
Konami+ in prep
Konami+09

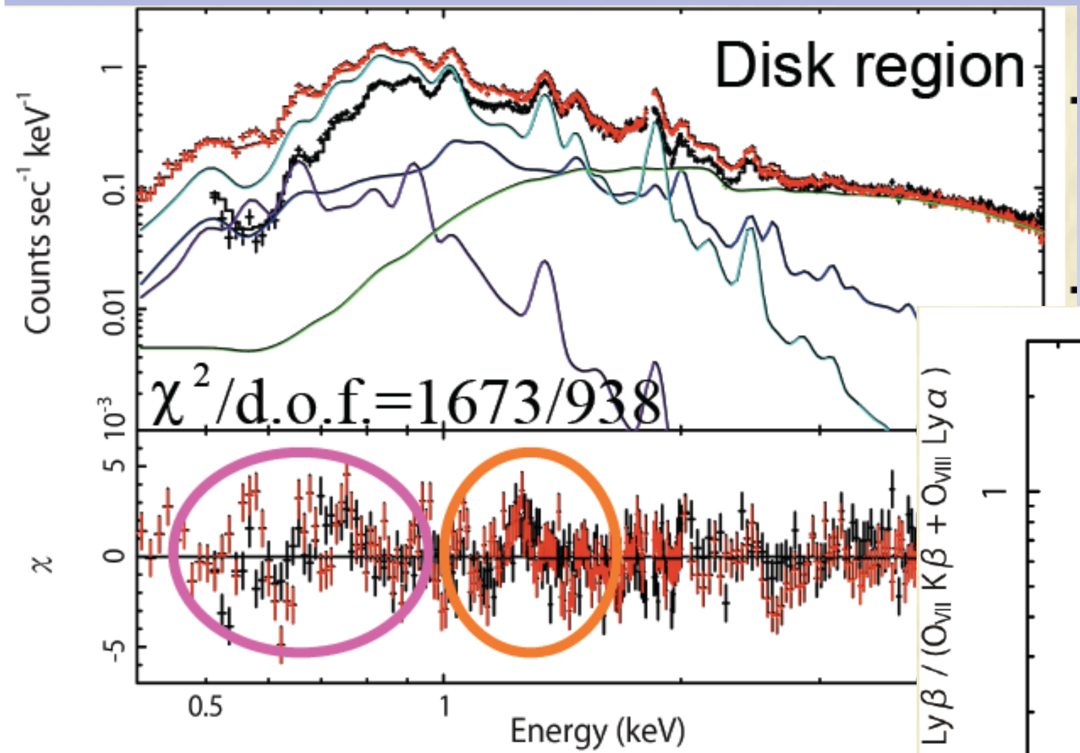
Starburst winds and starburst region → SN II type
non-starburst galaxy (N 4258)
→
solar abundance

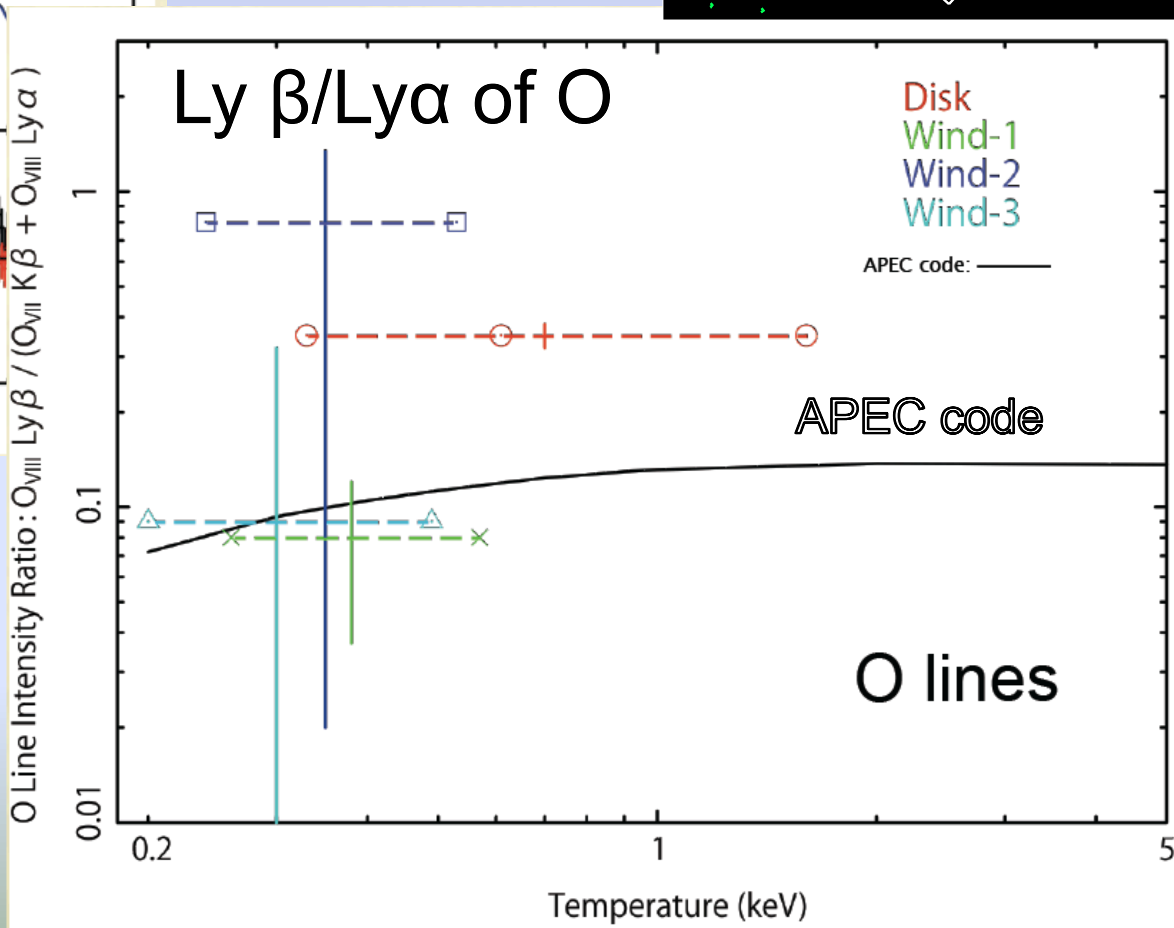


Charge exchange in the disk of M82?

Konami et al. submitted







- Enhancement of Ly β 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