Abundance patterns in the Interstellar Medium of early-type galaxies observed with Suzaku

(Konami et al. 2014 ApJ, 783, 8)

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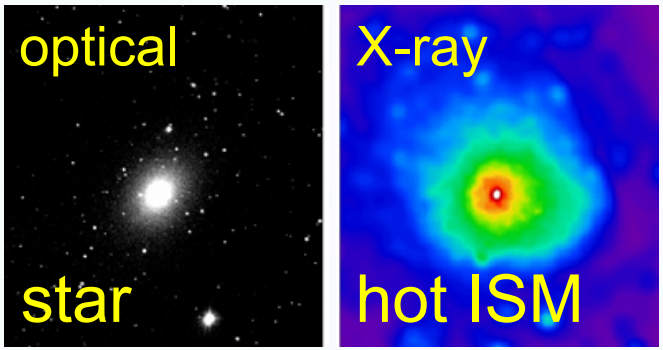
Metals of Early-type galaxy



Early-type galaxy

- star formation activity is low
- most stars are old population
- expanded hot interstellar medium (ISM) emitting X-ray

Metal in the ISM

Stellar mass loss (O, Ne, Mg, Si, Fe) + present SN Ia (Fe)

- The stellar metallicity reflects the past activity of star formation.
- The metal abundances in hot ISM have information of star formation histories of galaxies.

Inconsistencies in previous results of metal abundances

Fe abundance

Method	**Fe**
X-ray observations (e.g., Mushotzky+94, Matsushita+00, Ji+09)	~ 1 solar
Optical observations (stars) + present SN Ia rate (e.g., Matsushita+03, Nagino+09, Konami+09)	~ 3 solar

"Fe" from stars + present SN Ia ≠ "Fe" in the hot ISM

O/Fe, Mg/Fe, Si/Fe ratios

O and Mg come from stars.

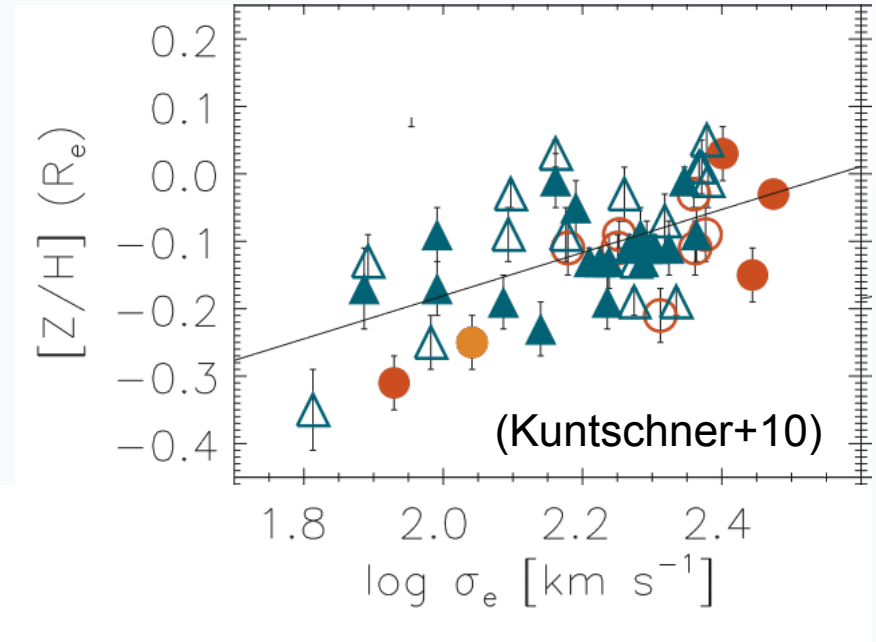
	Mg/Fe, Si/Fe	O/Fe
Hot ISM (X-ray)	~ 1 solar	~ 0.5 solar

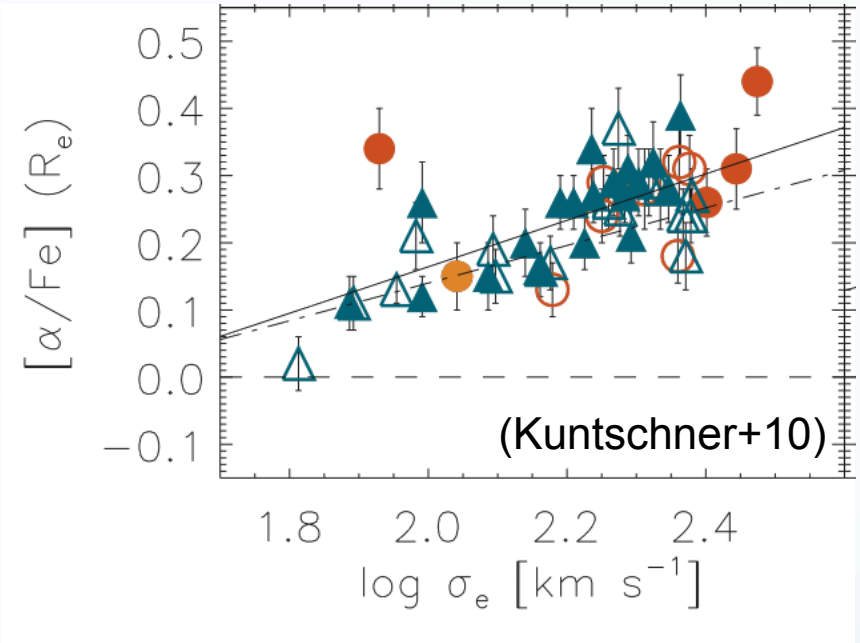
(e.g., Ji+09)

O/Fe:

Only O in the hot ISM is low ?

Optical observations of metals in stars





The both of metal abundances and abundance ratios are correlated with the velocity dispersion of stars.

Comparison of optical and X-ray observations

(r_e: half-light radius)

	target	region	merit	demerit
optical	star	$< r_e$	measure metals in only stars	1. limited to center region 2. degeneracy between metals and star ages
X-ray	hot ISM	~4—6 r_e	measure metals in entire galaxy	measure metals summed from stars and SN Ia

X-ray measurements of metal abundances in the hot ISM

optical measurements of stellar metallicity

Purpose of this study

Previous results:
- inconsistency Fe abundances
- low value of O/Fe ratio in the hot ISM
- optical and X-ray observations are complementary

We investigate the metal abundances and abundance ratios in the hot ISM of 17 early-type galaxies observed with Suzaku

In this study:
- The largest number of samples to measure metal abundance ratios
- Suzaku can measure O and Mg with high sensitivity

Targets

17 early-type galaxies

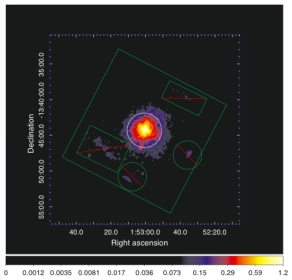
- 14 ellipticals and 3 S0s
- 11 in clusters and 6 in the field

Spectral analysis regions

a circle with radius of each $4r_e$

X-ray images (0.4 –5 keV)

NGC720



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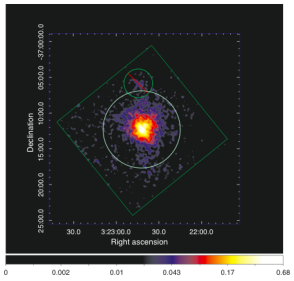

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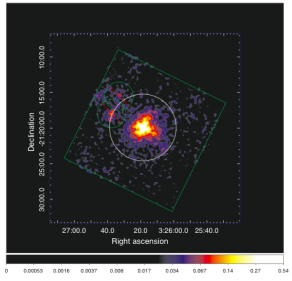
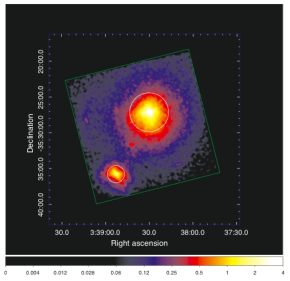


NGC1399 & NGC1404



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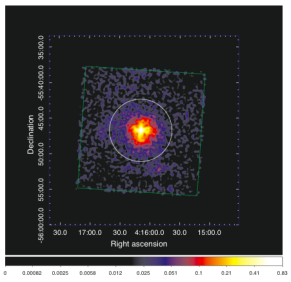
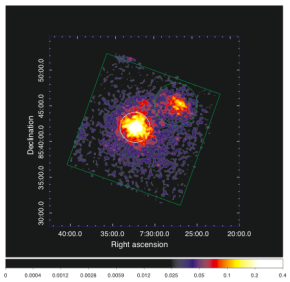


NGC2300



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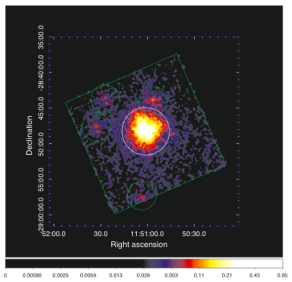
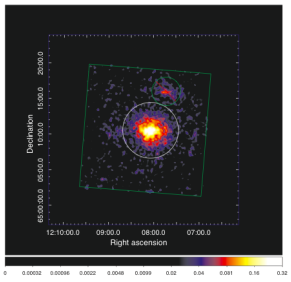
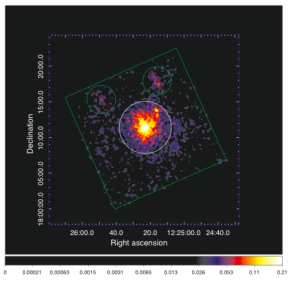


NGC4125



NGC4382



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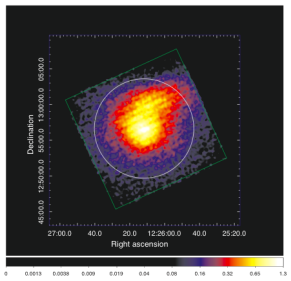
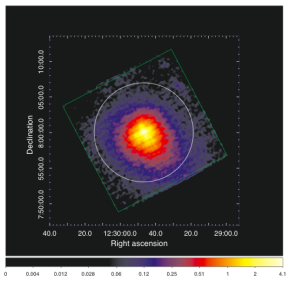
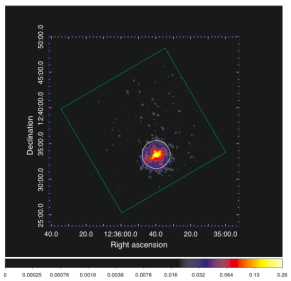


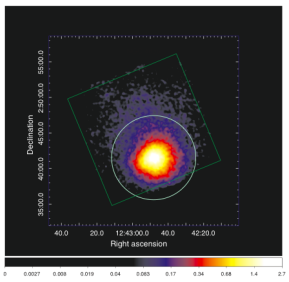
NGC4472



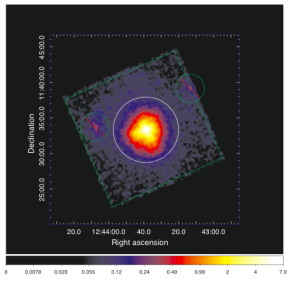
NGC4552



NGC4636



NGC4649



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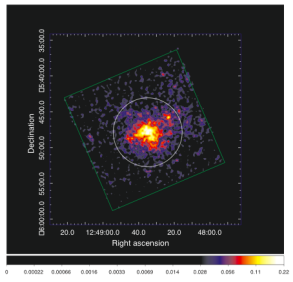
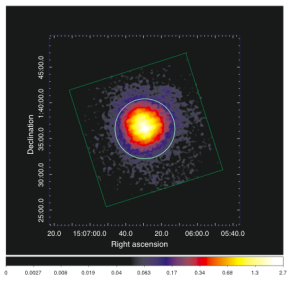
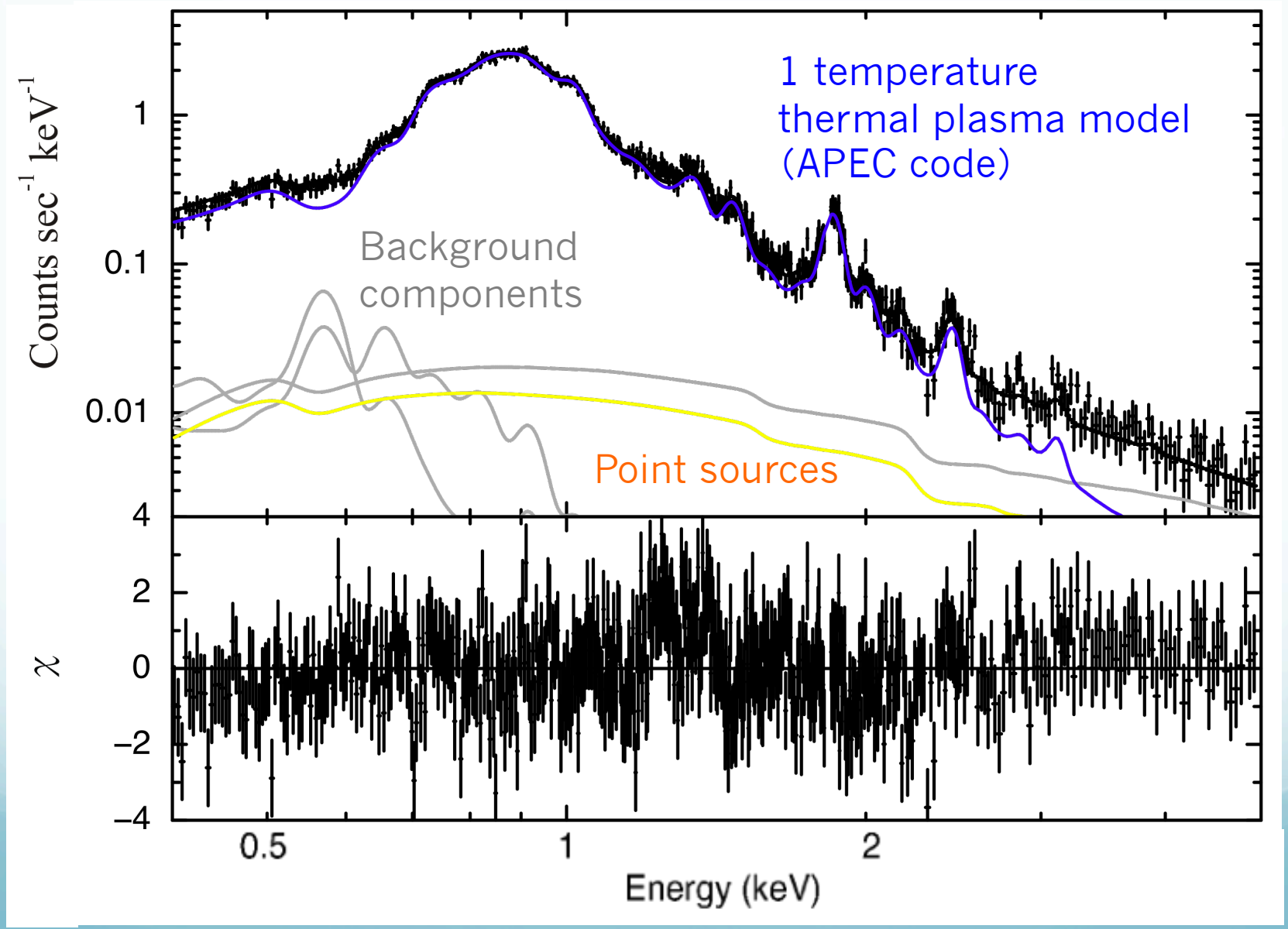


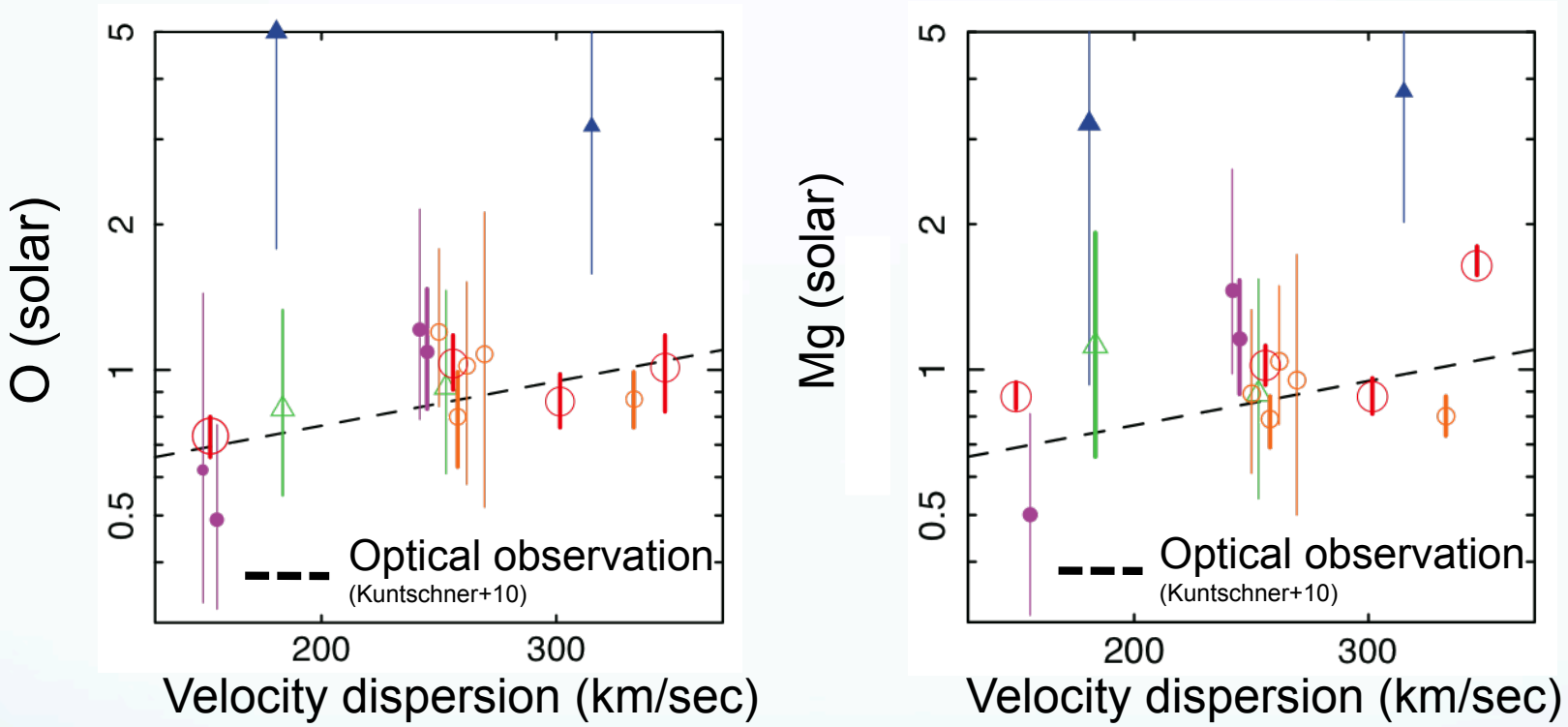
NGC5846



Spectral analysis: NGC4636

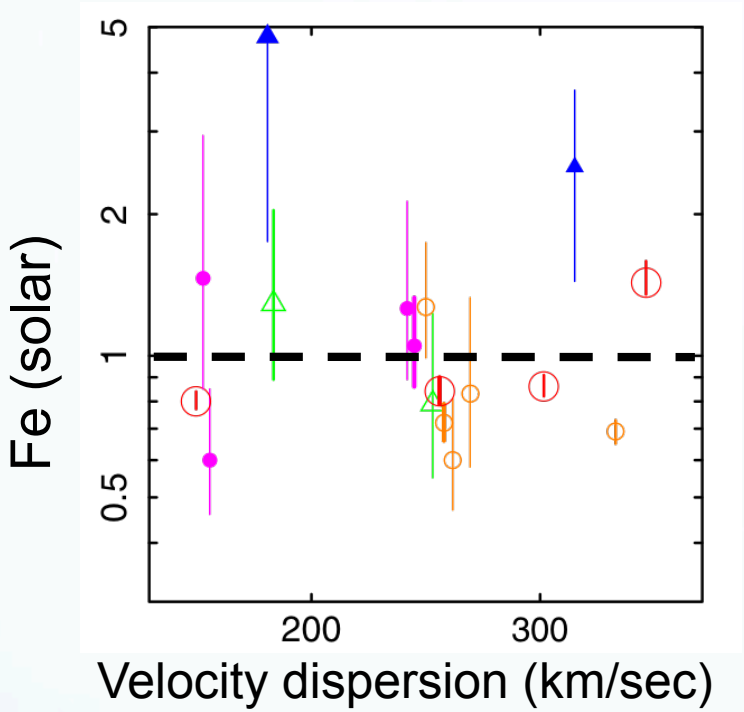


Metal abundance v.s. velocity dispersion (∝ system mass)

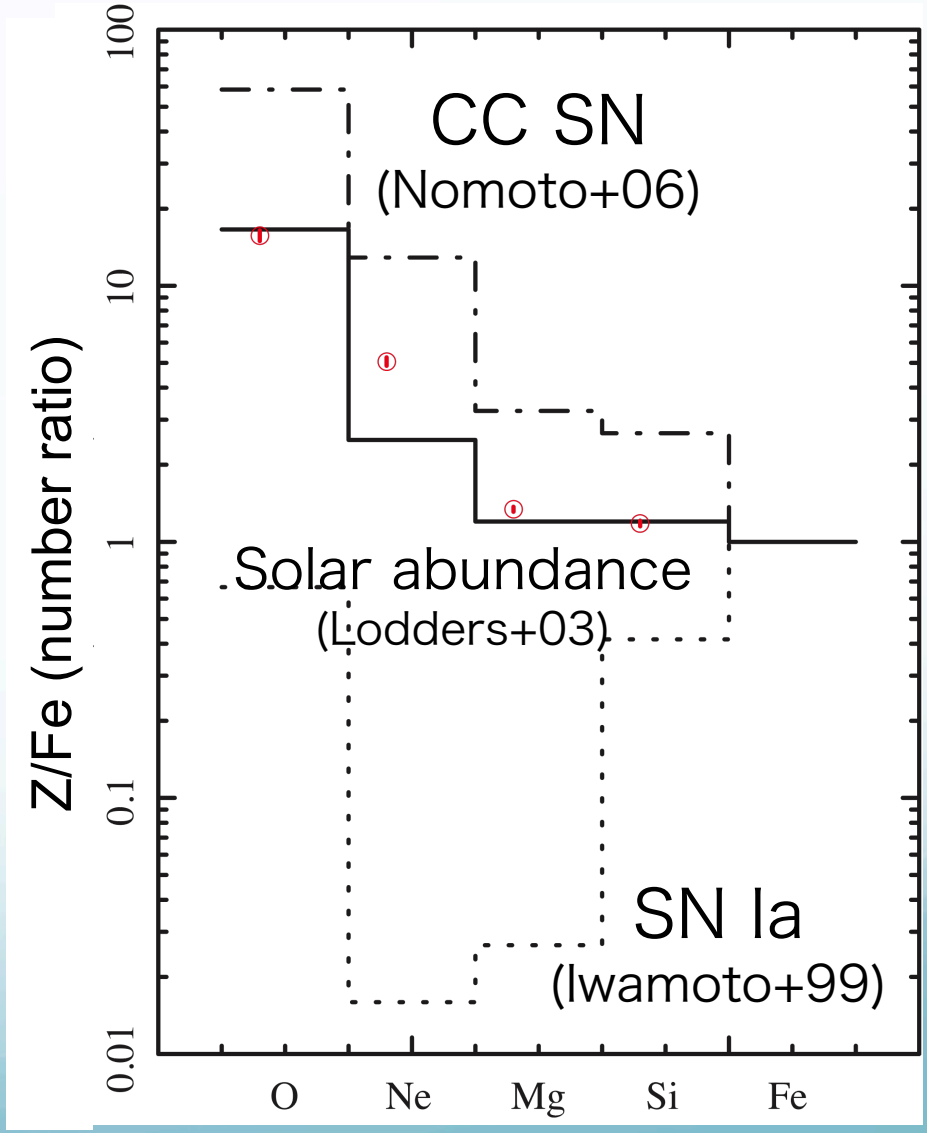


* Metal abundances are correlated with velocity dispersion
* This relation is consistent to those of optical observation
  - The stellar relation within the center region (<re) agree with those in the entire galaxies.
  - The two results (by optical and X-ray observations) are consistent, although they have very different systematic uncertainties.

Fe abundance from present SN Ia



weighted averages of abundance ratios



- Fe is synthesized by SN Ia: 70%
  CC SN: 30%
- The weighted average of Fe abundance: 0.8 solar → 0.6 solar of Fe come from SN Ia

Fe abundance from SN Ia

- Suzaku (this study) 0.6 solar
- Calculation using the SN Ia rate 3—13 solar

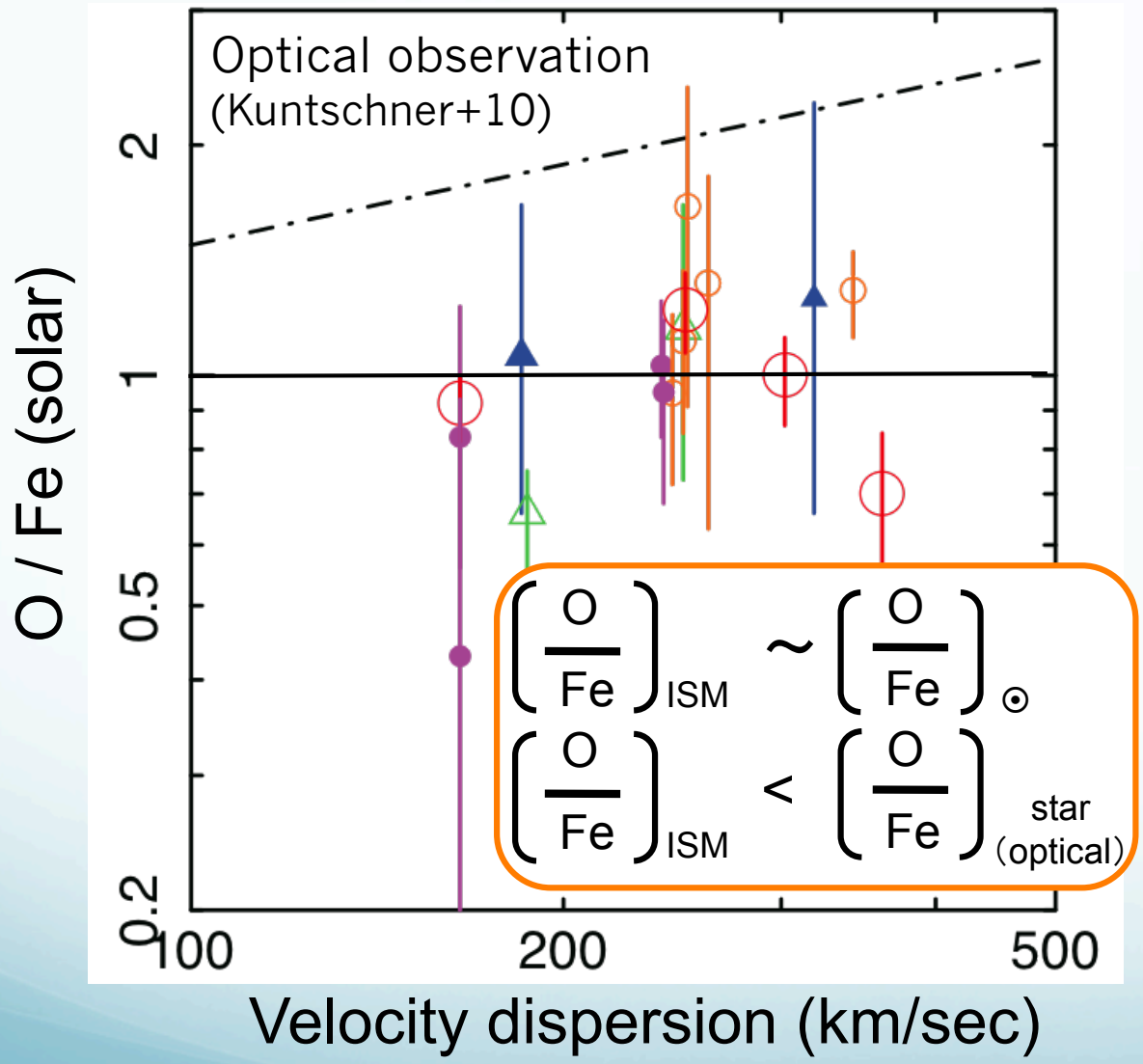
→ Fe in the hot ISM is less?

＊SN Ia ejecta escape from the ISM before being fully mixed into the ISM ? (e.g., Matsushita+2000)

- Tang & Wang (2010) simulated Fe escaped to outside via outflow.

- In the intra-cluster medium of cluster of galaxies, Fe abundance derived from X-ray spectra are larger than those calculated using SN Ia rate (Sato+12, Matsushita+12).

O/Fe ratio of stars in the entire galaxy



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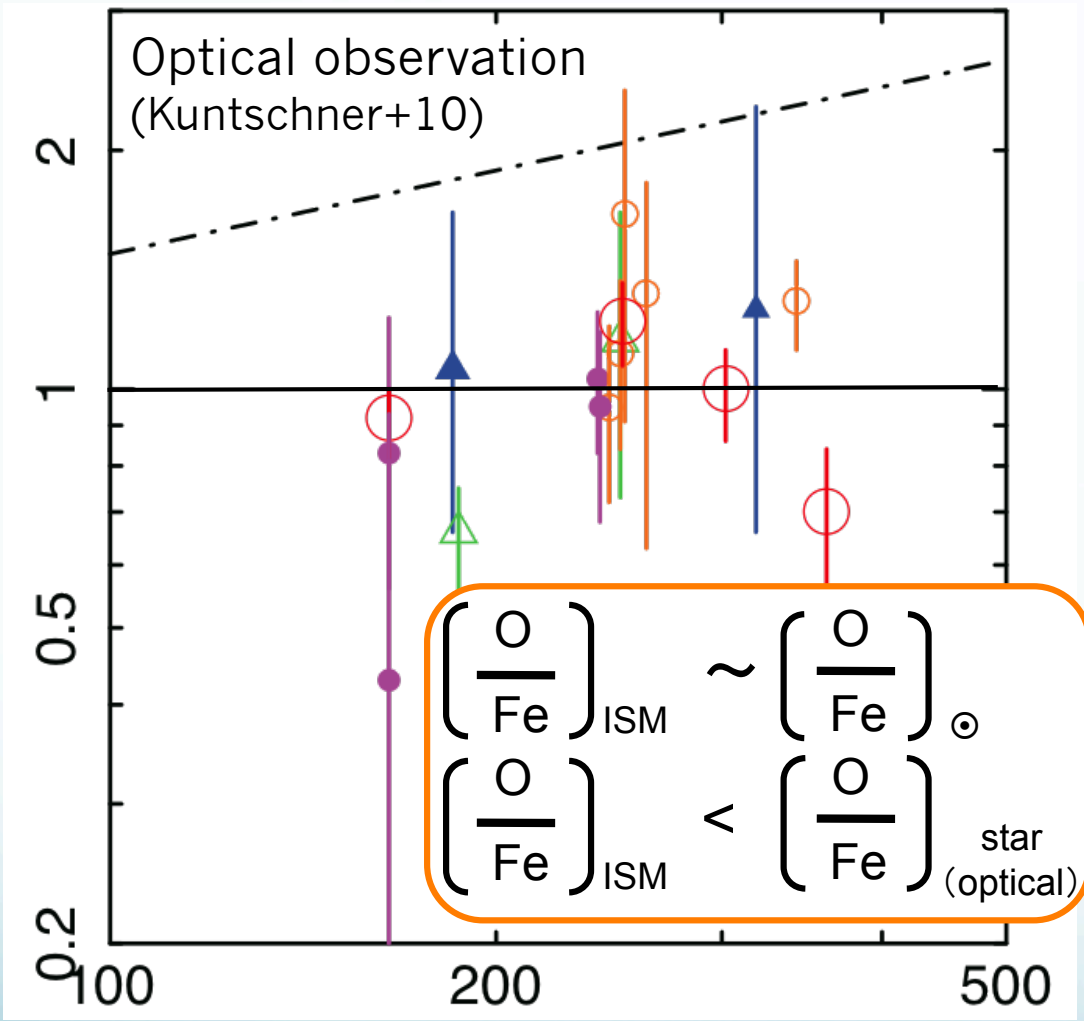

$$\left(\frac{O}{Fe}\right)_{ISM} = \frac{O_{star}}{Fe_{star} + Fe_{present\ SN\ Ia}} = \left(\frac{O}{Fe}\right)_{\odot}$$

$$\left(\frac{O}{Fe}\right)_{star} > \left(\frac{O}{Fe}\right)_{\odot}$$

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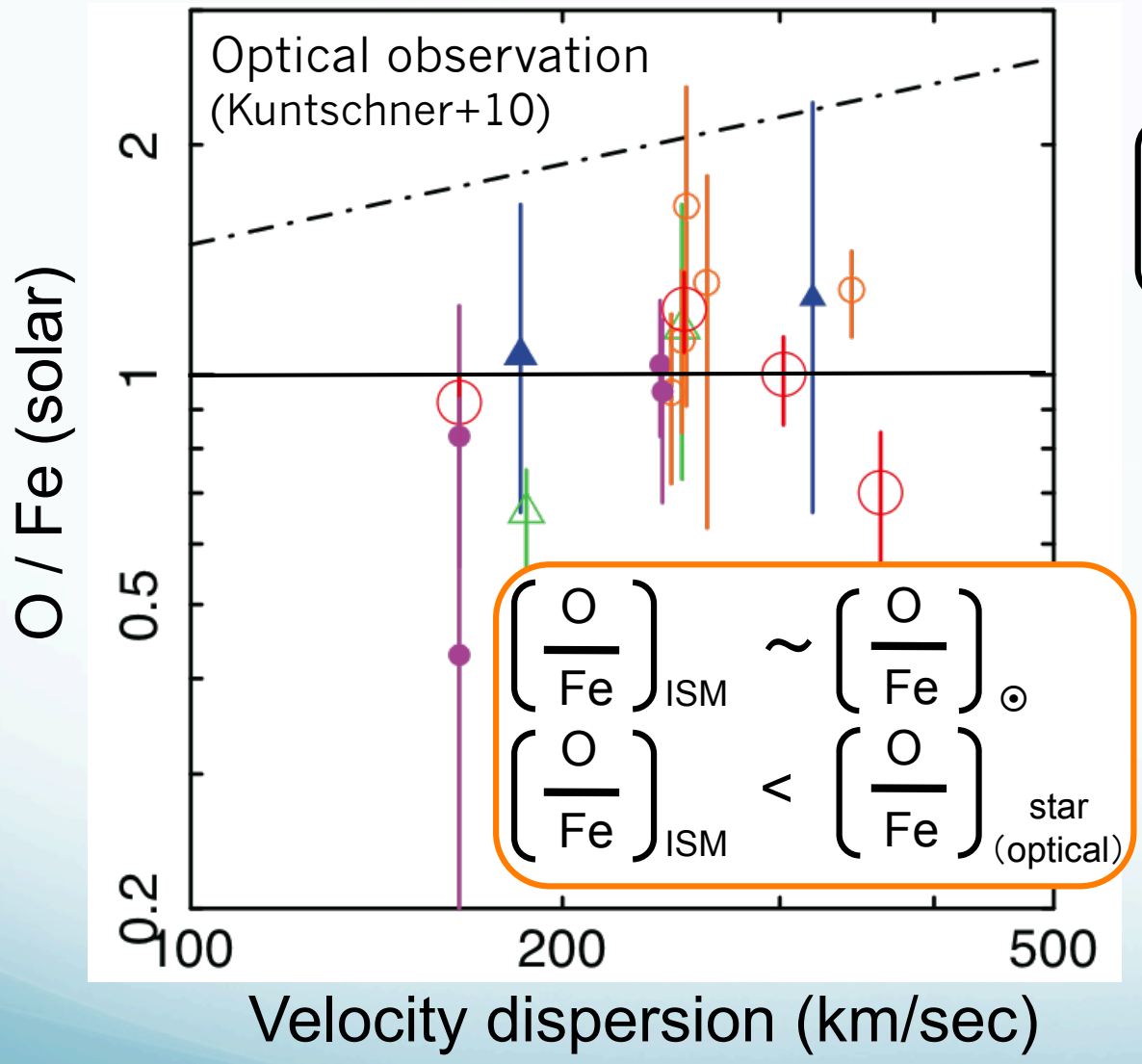

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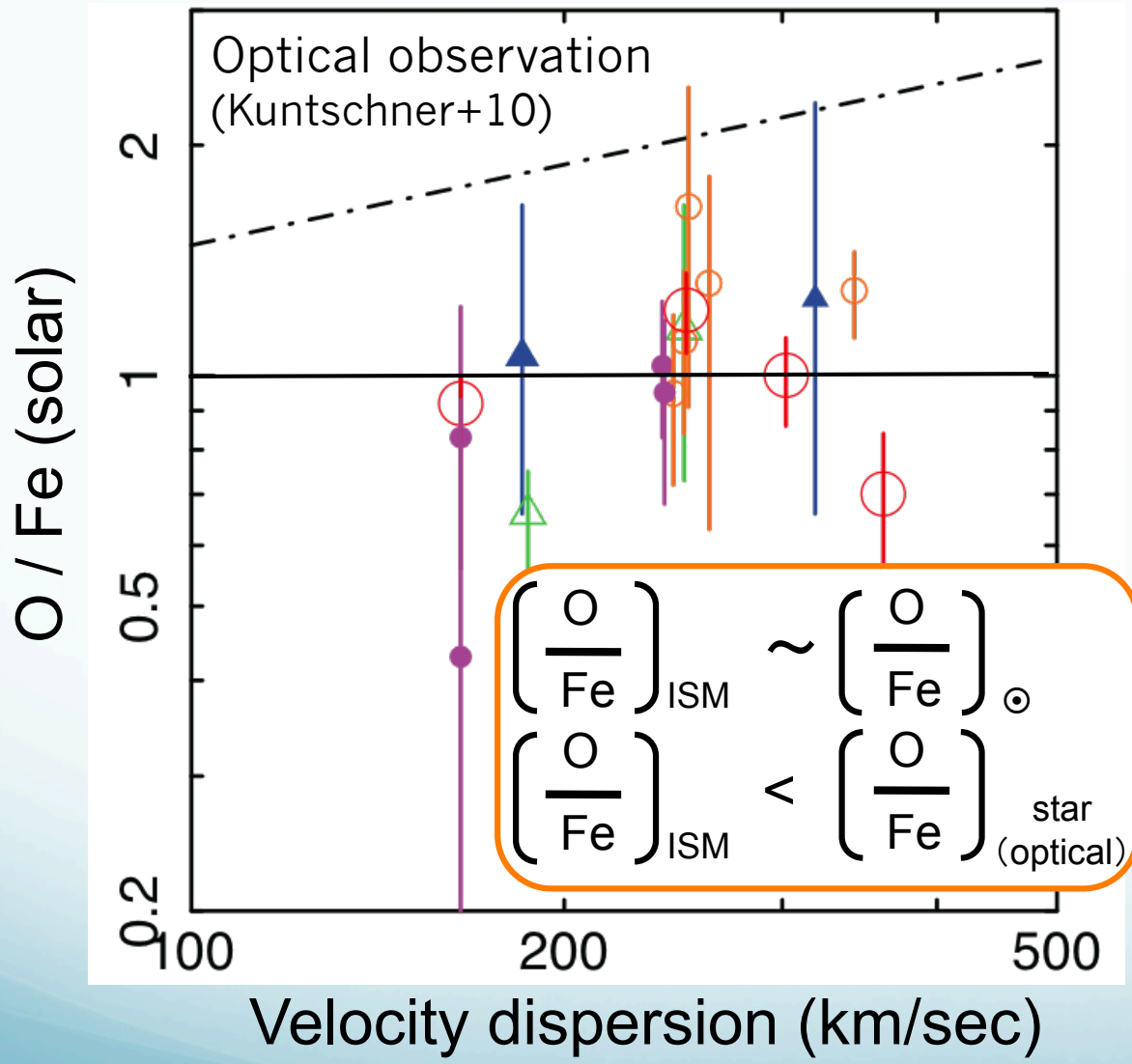

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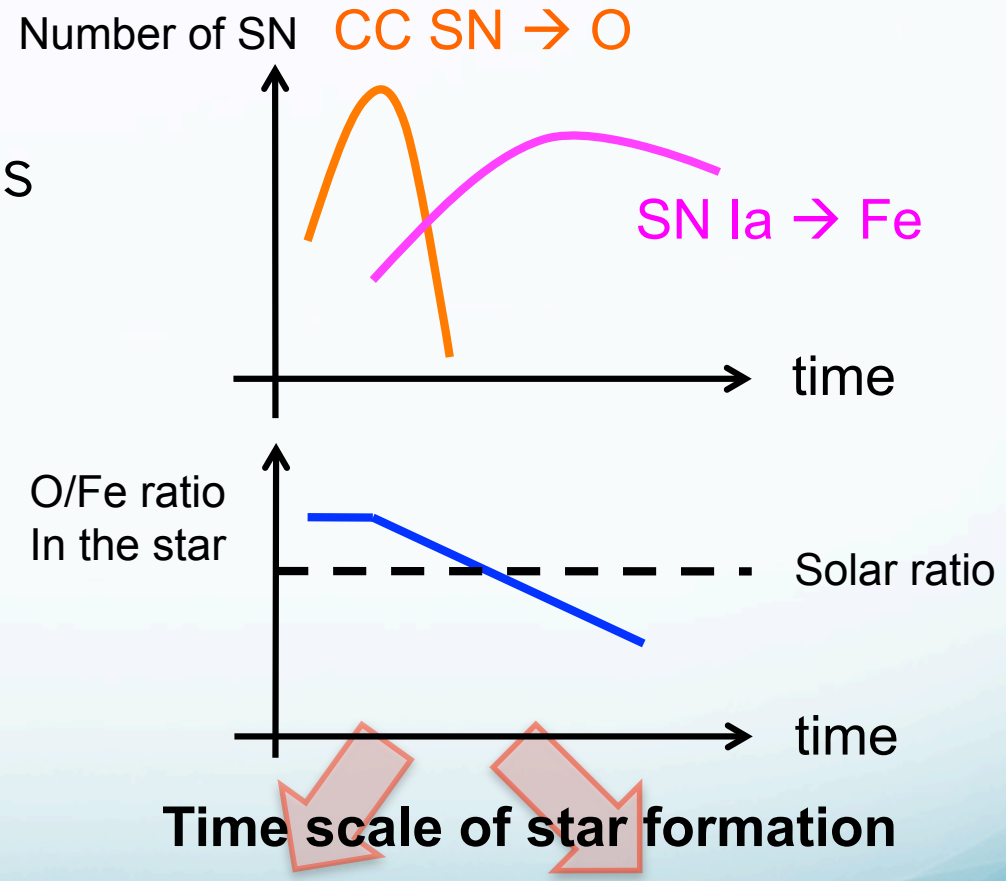
Consistent with optical results.

O/Fe ratios in the stars

$$\left(\frac{O}{Fe}\right)_{star} > \left(\frac{O}{Fe}\right)_{\odot}$$

O/Fe in the stars indicate the time scale of star formation

- consistent with the results of optical observations
- in the entire galaxy agree with that within the center region (<r_e).



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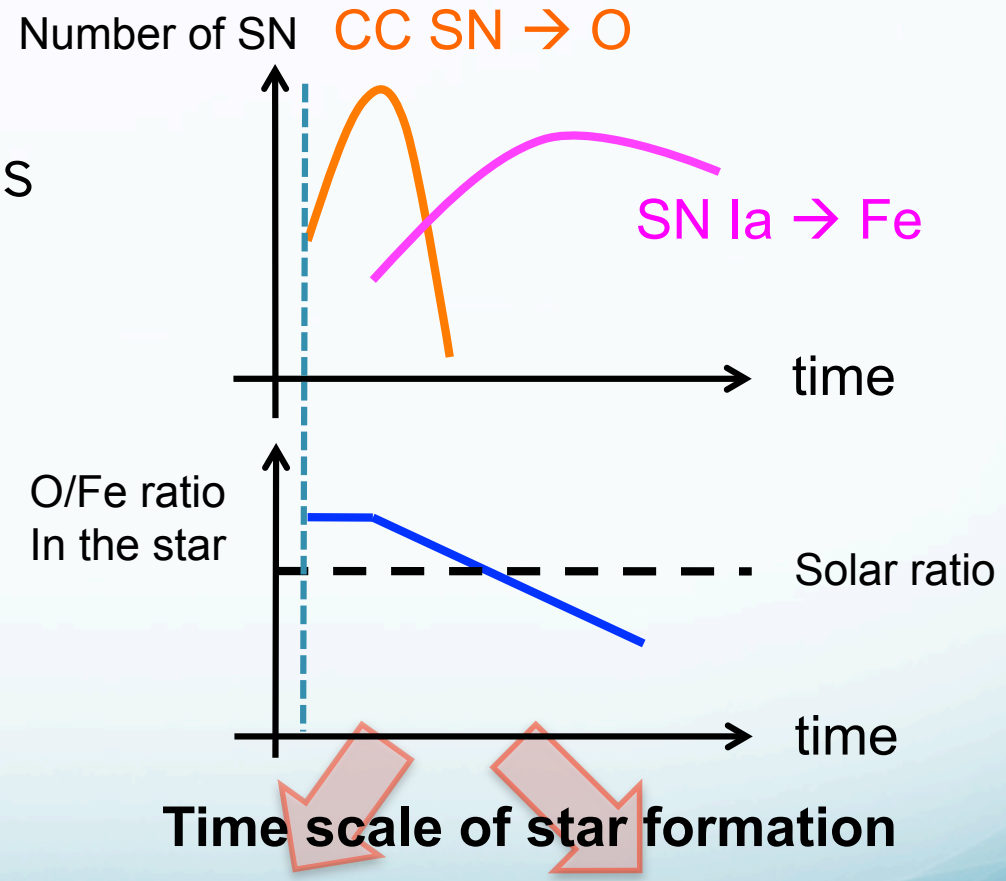

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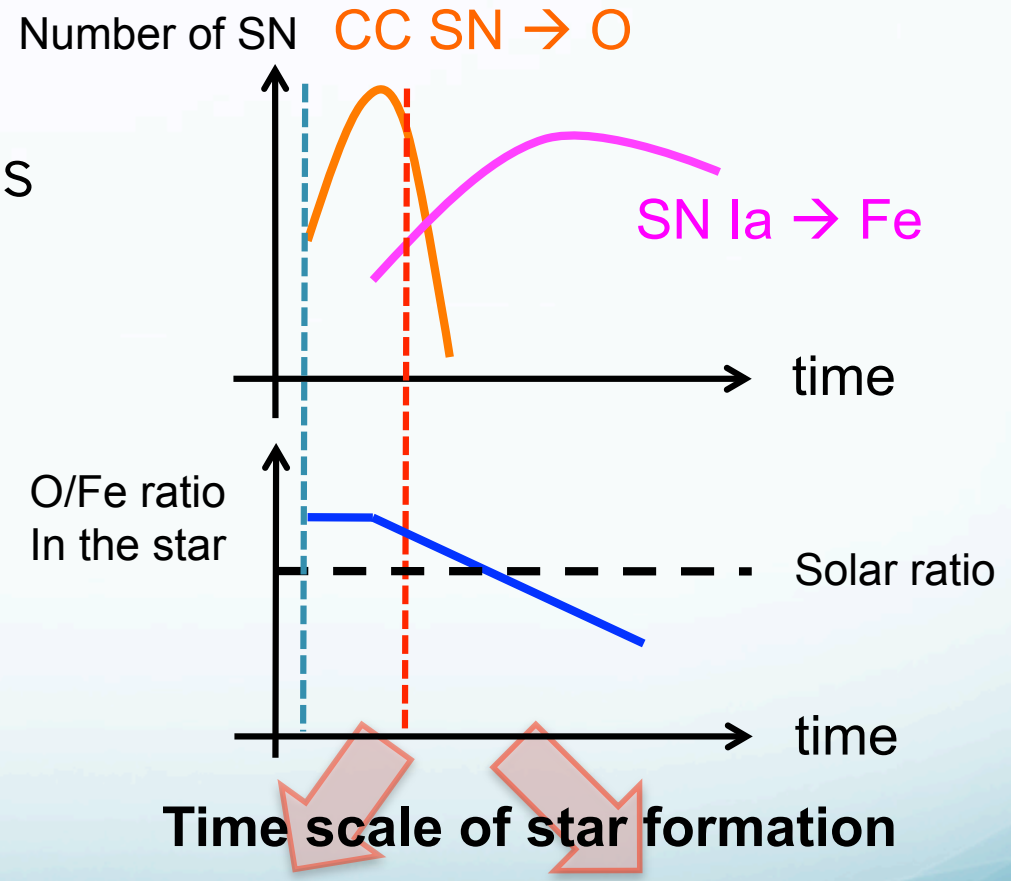

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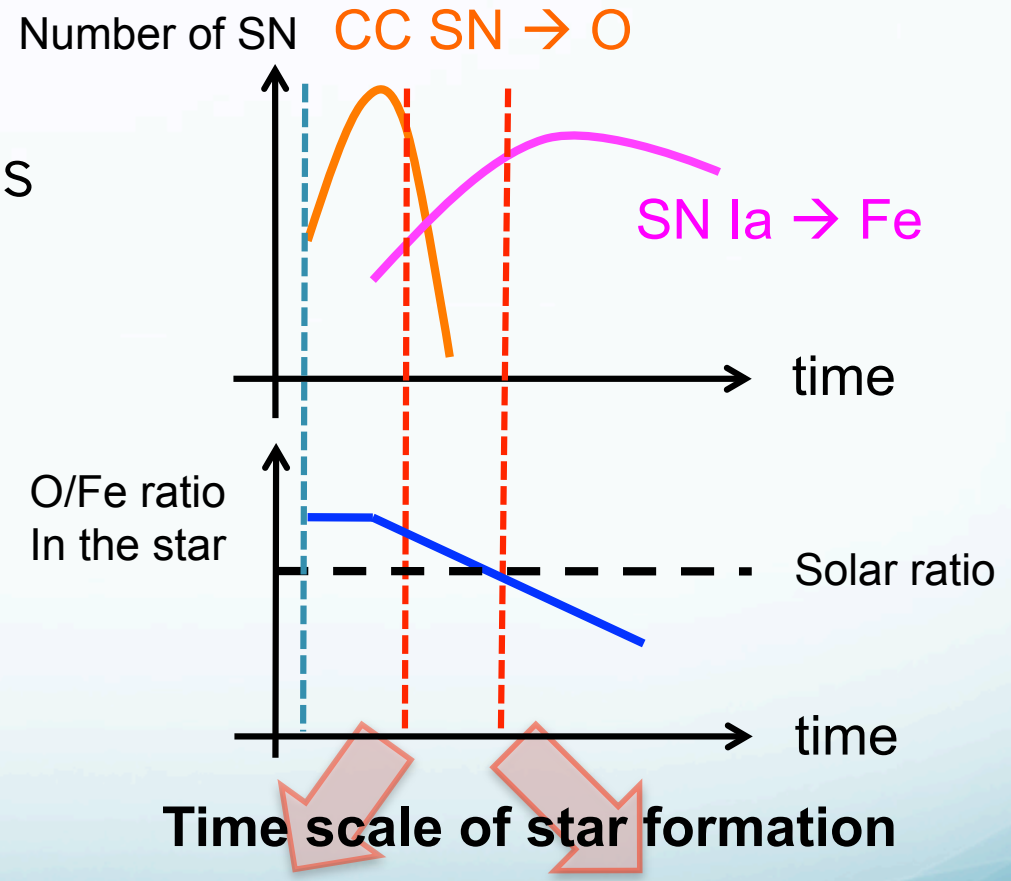

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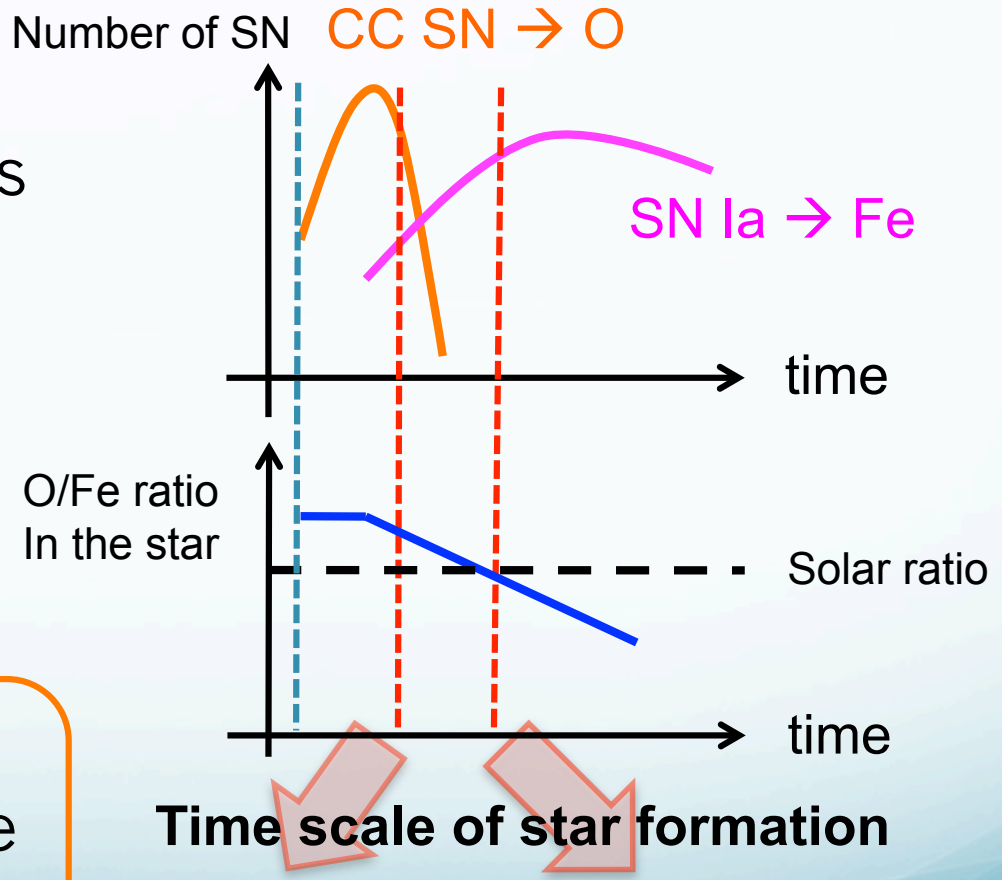
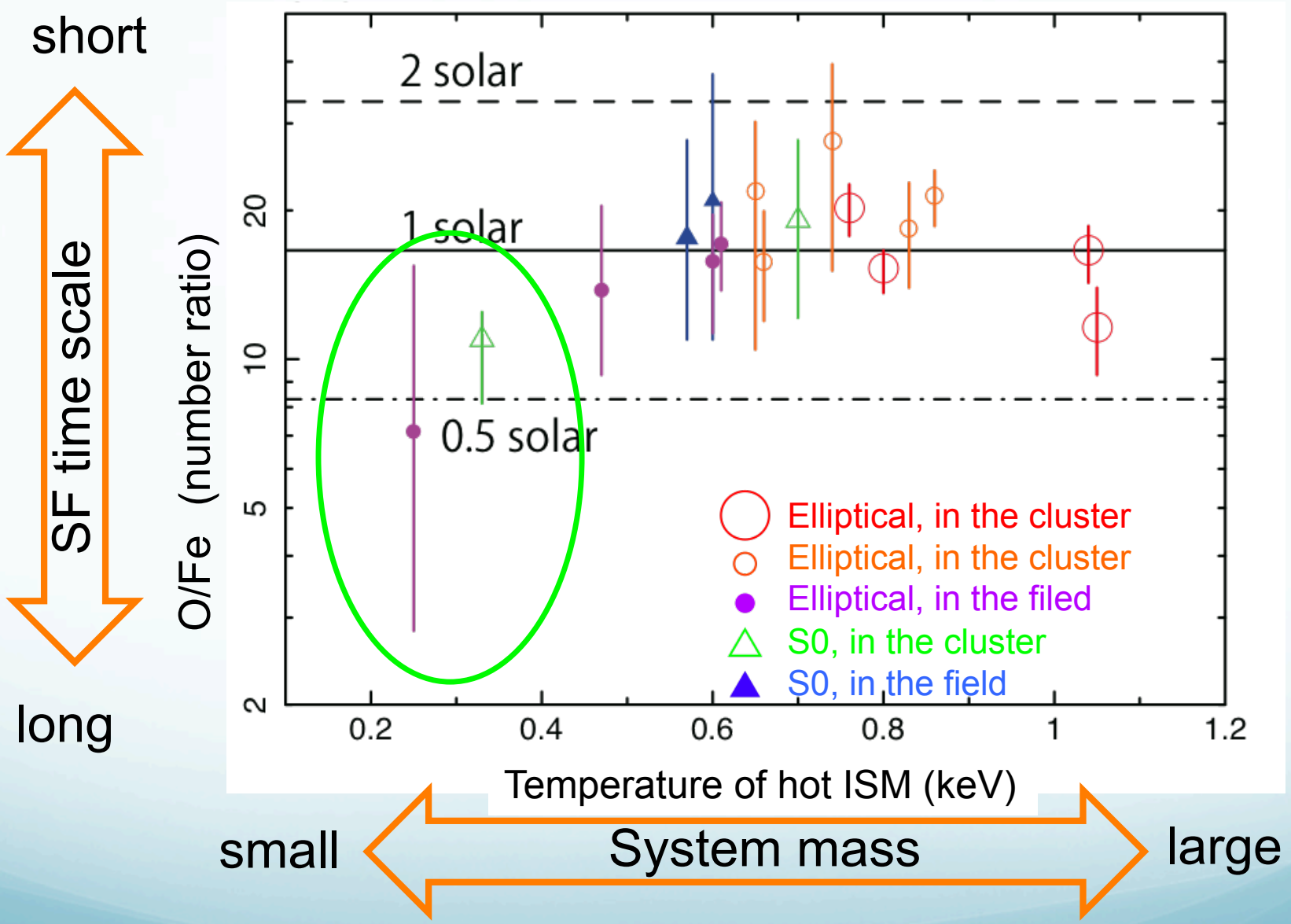


The time scale of star formation in the early-type galaxies are shorter than the that of our galaxy

Metal abundance ratios



The smaller galaxies have shorter star formation time scale?

Summary

- We have analyzed 17 early-type galaxies, 13 ellipticals and 4 S0s.
- Metal abundance and abundance ratios in the ISM of the galaxies are solar and solar ratios, respectively.
- The relation of metal (O, Mg) and velocity dispersion is consistent with those from optical observations.
  - The stellar relation within the center region ($<r_e$) agree with those in the entire galaxies.
  - The two results (by optical and X-ray observations) are consistent, although they have very different systematic uncertainties.
- The amount of Fe from SN Ia is less than those calculated using the rate of present SN Ia.
- Metal abundance ratios (O/Fe, Mg/Fe) in stars are larger than solar ratio
  - The results are consistent with those of optical observations.
  - The time scale of star forming in early-type galaxies are shorter than those of our galaxy (spiral galaxy).