The abundance pattern of O, Ne, Mg, and Fe in the X-ray emitting interstellar medium of a spiral and starburst galaxies

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Metals in the hot ISM of starforming galaxies

The metals in ISM…

- have star formation (chemical evolution) histories in the galaxies
- supplied to the inter galactic space

Merits with X-ray observation…

- The atomic data for lines at X-ray wavelengths are relatively simple
  (K-shell lines from hydrogen- or helium-like ions)
- We can derive O, Ne, Mg, Si, and Fe abundances in the ISM

Contents

We analyzed the X-ray spectra of hot plasma in the ISM of three galaxies observed with Suzaku.

non-starburst galaxy

NGC4258
(Konami et al. 2009)

starburst galaxy

M82
(Konami et al. 2011)

NGC3079
(Konami et al. in press)

We compared the derived abundance patterns of galaxies with different star formation rates.

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Suzaku satellite

◆the fifth X-ray satellite of Japan

◆broad energy range (0.2-700 keV)

Detector : XIS

◆X-ray CCD camera (0.2-12 keV)

◆four sensors XIS0, 1, 2, and 3

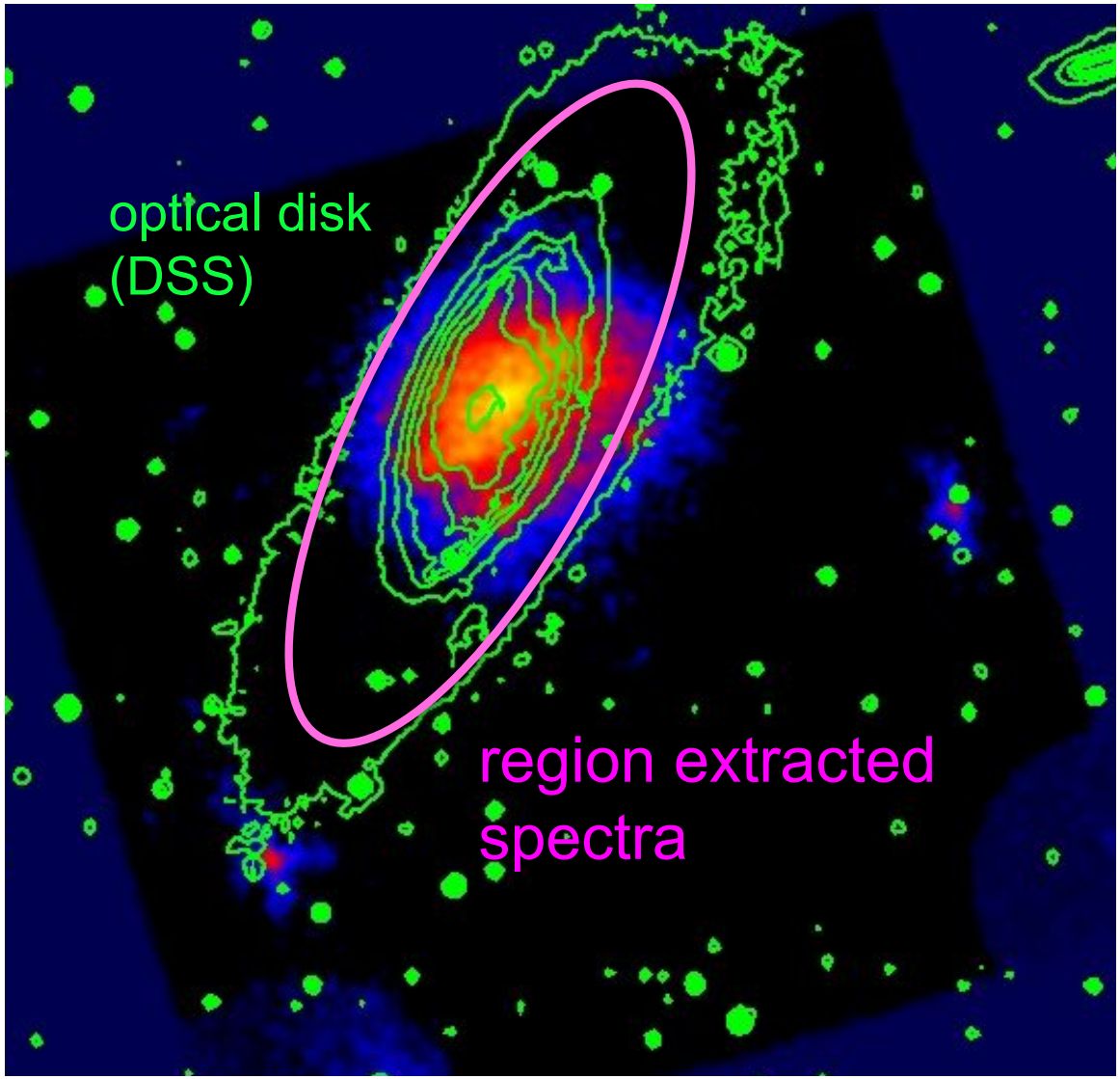
(but now only three sensors are operation because XIS2 suffer catastrophic damages)

◆Low and stable background, and good energy resolution and sensitivity under 1 keV

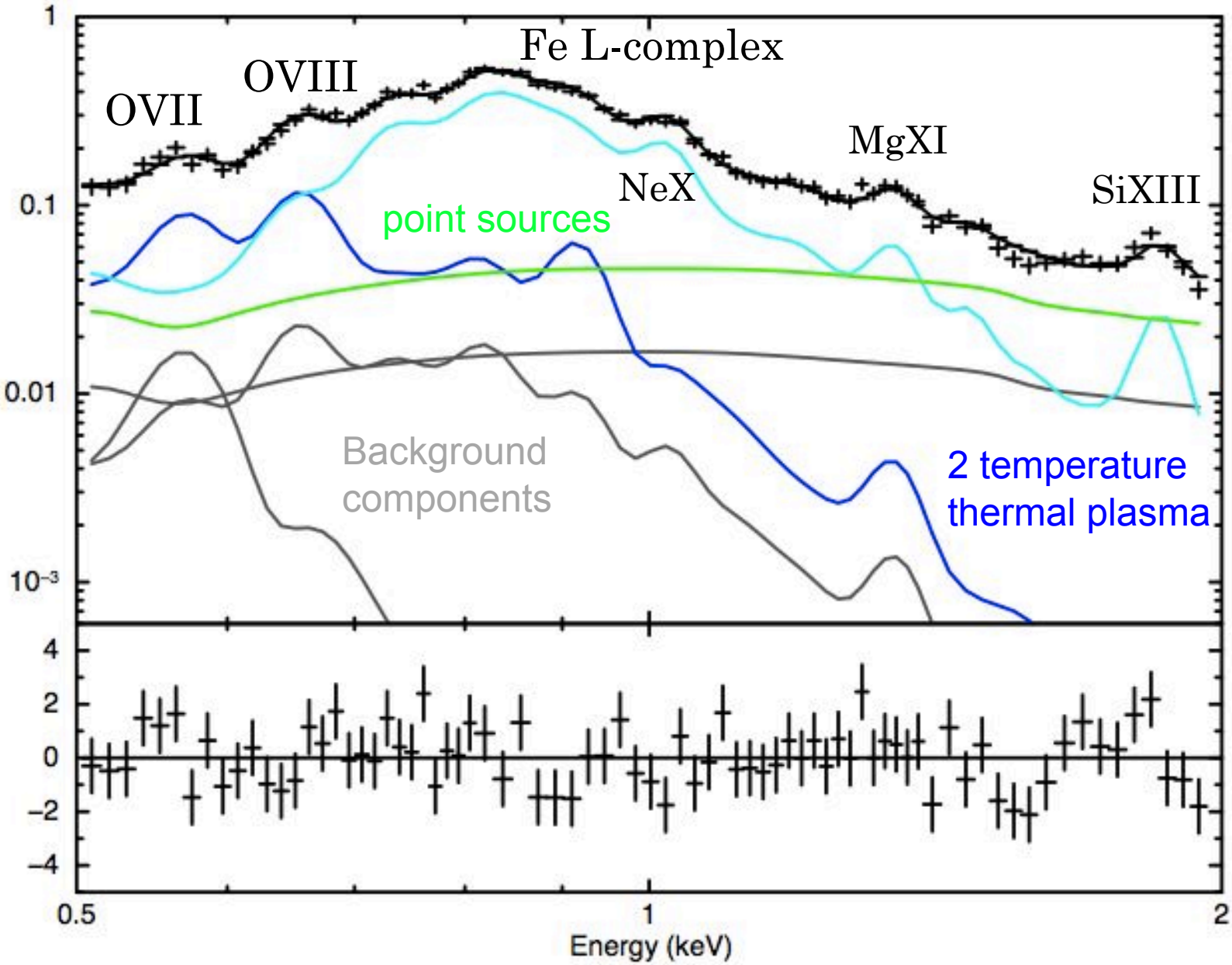
➡ We can detect Oxygen and Magnesium lines with high sensitivity!!

non-starburst galaxy : NGC4258

Suzaku image (0.3-2 keV)



Spectral analysis: NGC4258



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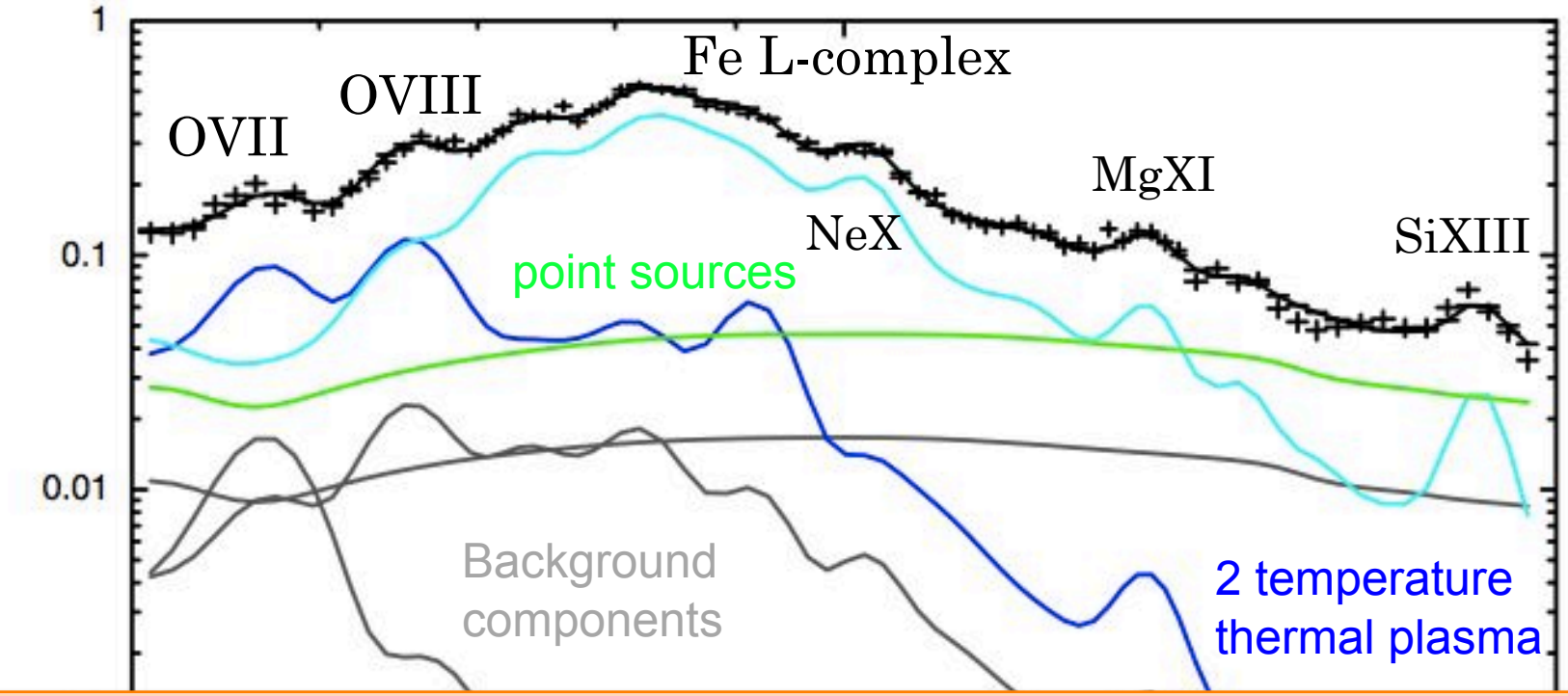
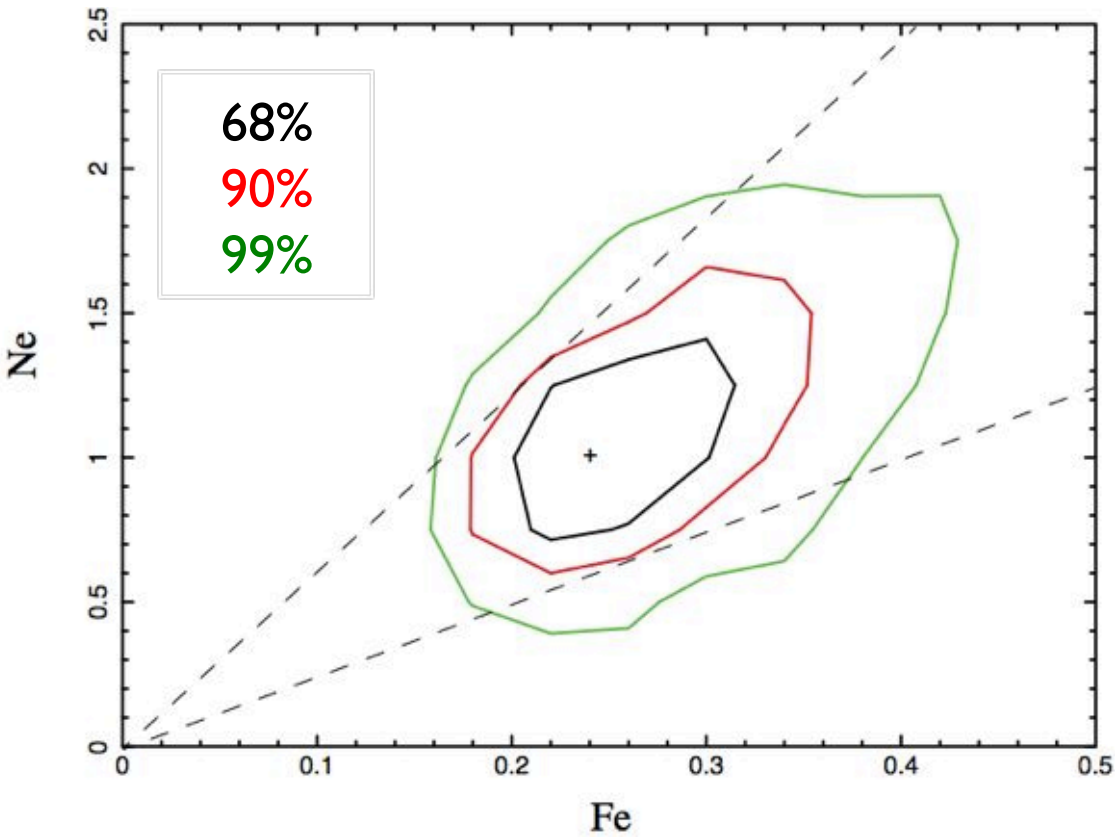


＊The X-ray spectra of thermal plasma are composed of continua (bremsstrahlung between proton and electron) and emission lines (highly ionized ions) components.

＊The metal abundances (O, Ne, Mg, Si, and Fe) are derived from the intensity ratios of emission lines and continua of thermal plasma model.

Metal abundances : absolute v.s. relative value

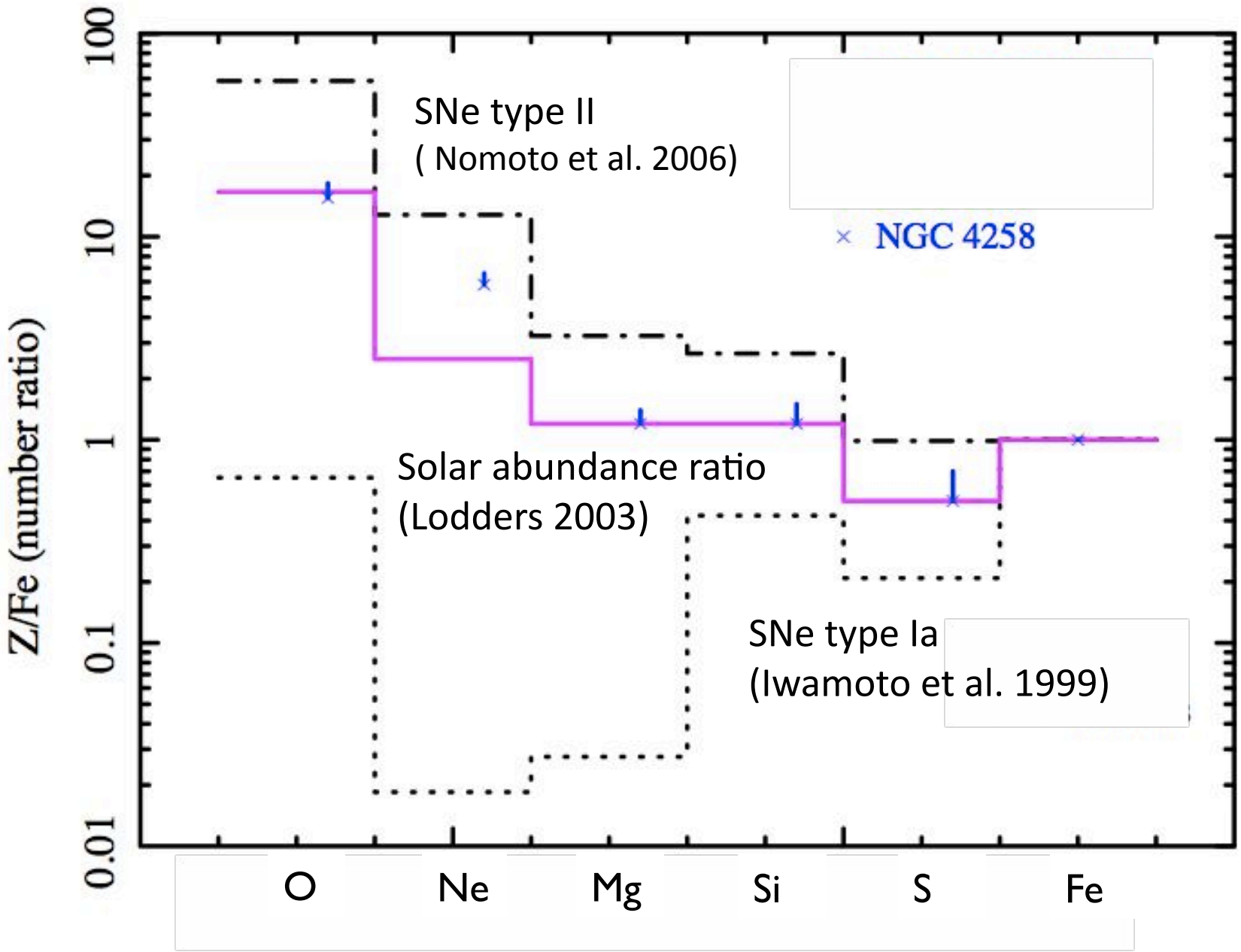
The absolute values have large systematic error because these values are sensitive to the intensities of continua .



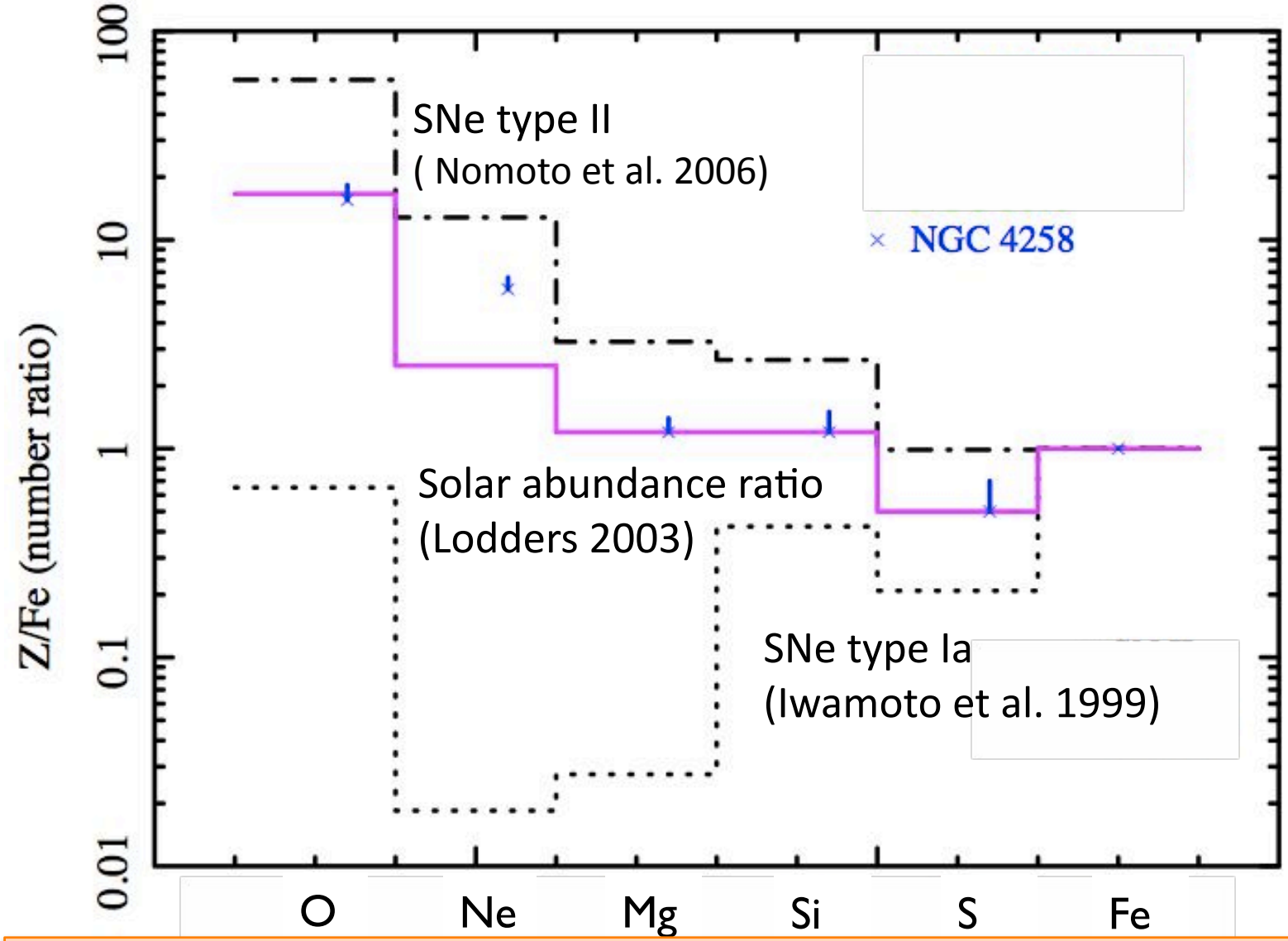
The contour shapes indicate relative values are better determined than the absolute values.

We discuss abundance patterns using these relative values.

Metal Abundances in the ISM of NGC4258



Metal Abundances in the ISM of NGC4258



The abundance patterns in the ISM of NGC4258 is consistent to the solar abundance.

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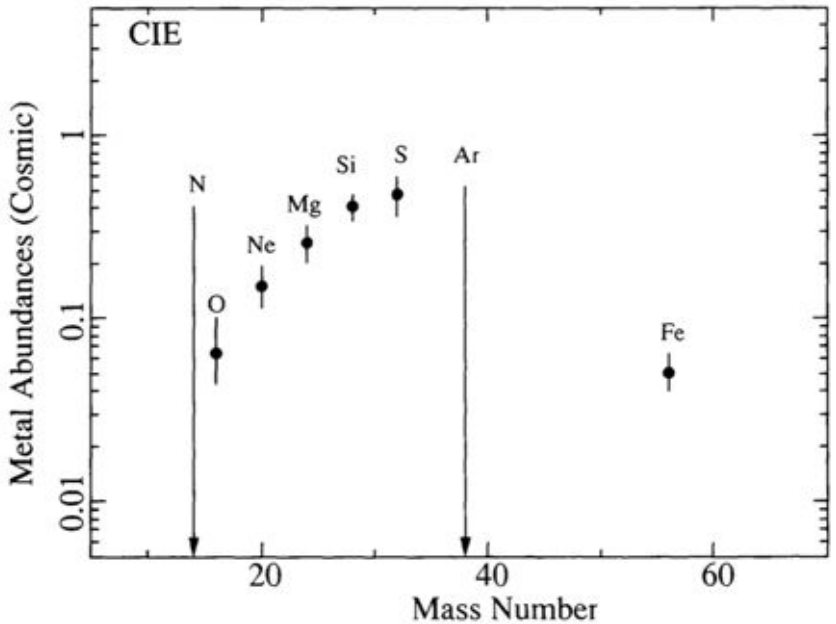
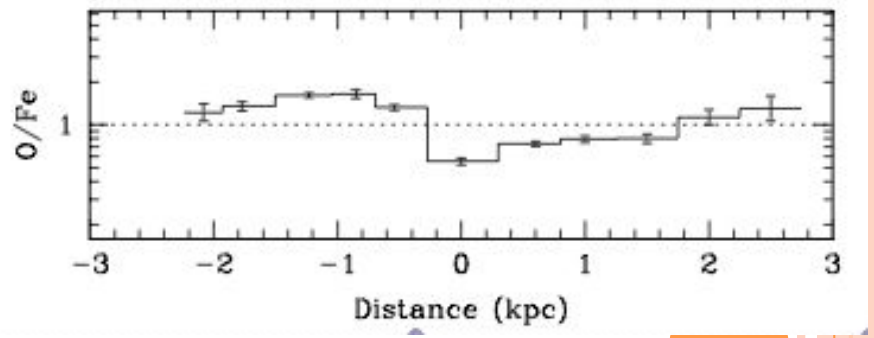
We compared the derived abundance patterns of galaxies with different star formation rates.

Previous results: peculiar metal abundances

(Tsuru et al. 1997)



(Ranalli et al. 2008)



∗ prototype starburst galaxy with an X-ray emitting outflow

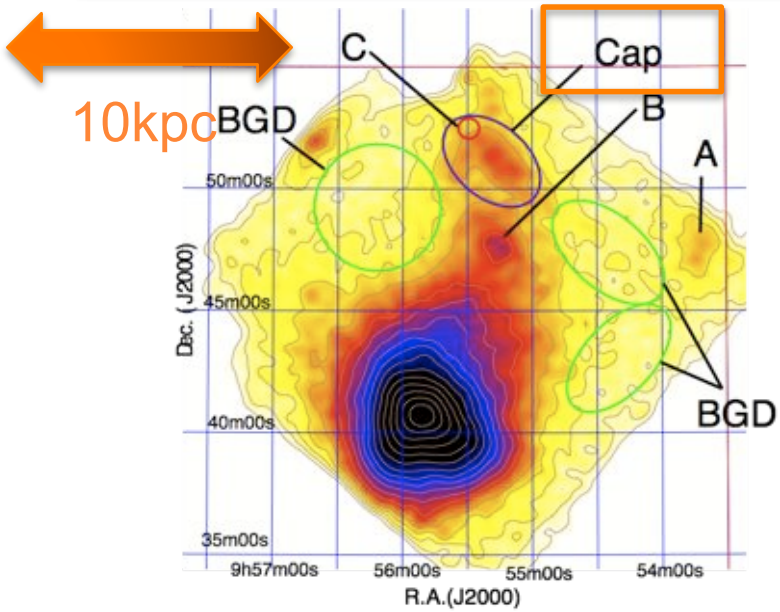
∗ In the center region, ASCA and XMM-Newton derived the metal abundances in the ISM, which are peculiar. (O and Ne are extremely low relative to Fe.)

The abundance patterns in the ISM of starburst galaxies are not SN II like?

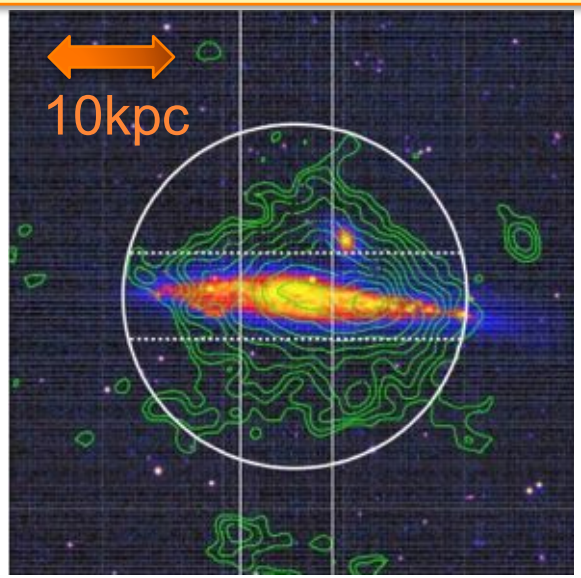
Previous results: Galactic wind

The metal abundance patterns in hot X-ray emitting ISM of Starburst Galaxy winds have been revealed with Suzaku.

M82 (Tsuru et al. 2007)

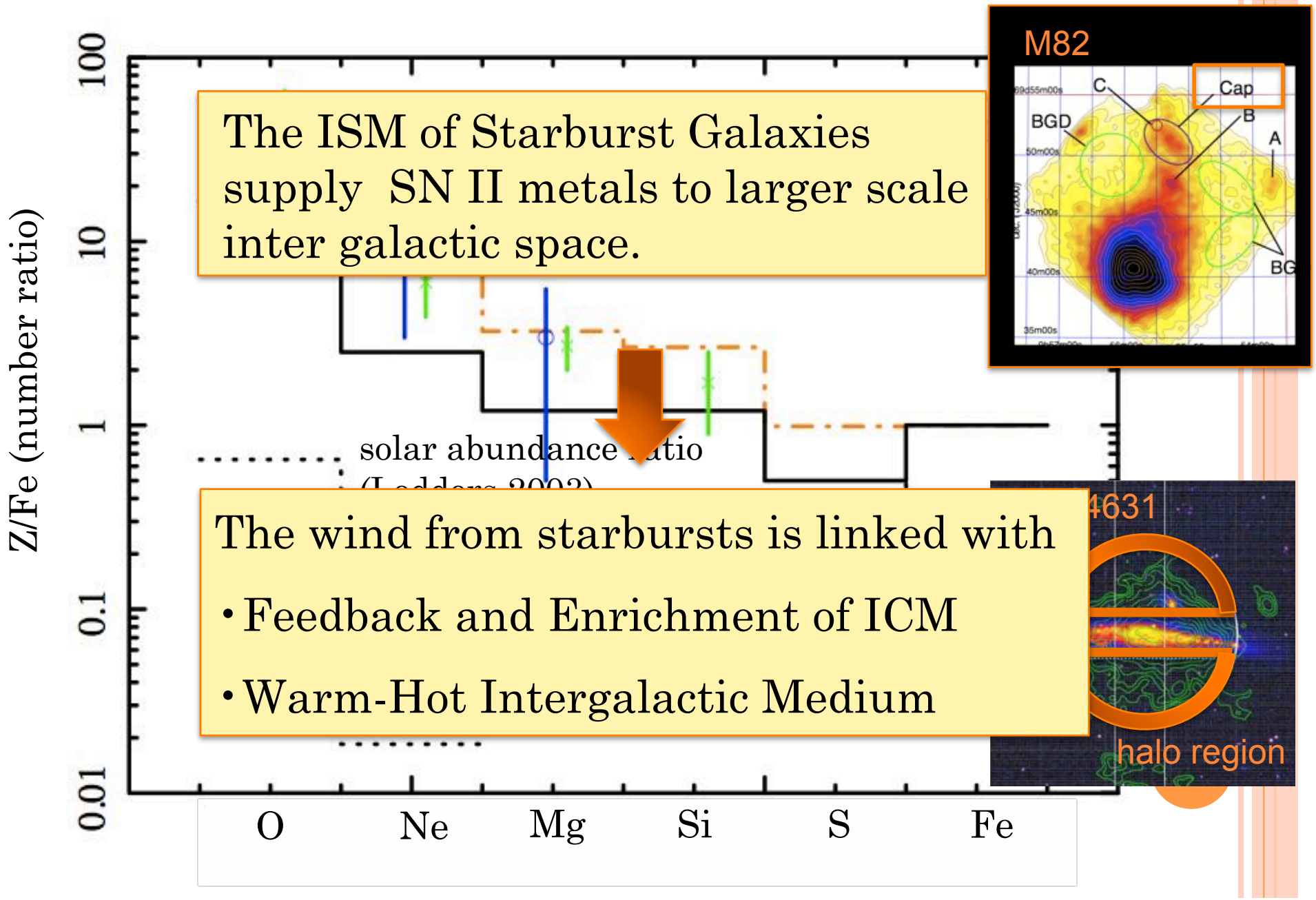


NGC4631 (Yamasaki et al. 2009)



Suzaku has revealed the metal abundances of the hot plasma, which is escaping from star burst galaxies.

Previous results: metal abundances



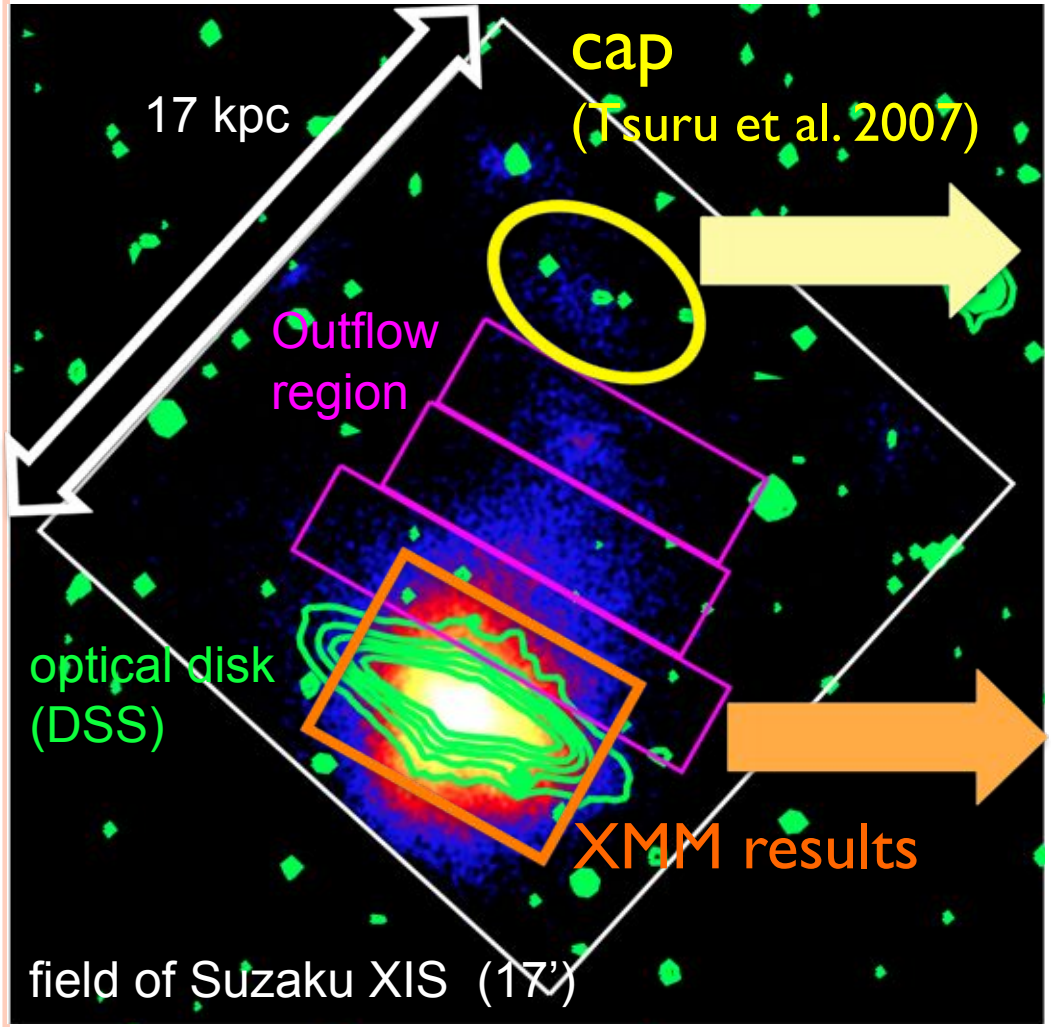
The ISM of Starburst Galaxies supply SN II metals to larger scale inter galactic space.

The wind from starbursts is linked with

- Feedback and Enrichment of ICM
- Warm-Hot Intergalactic Medium

Previous results of M82 with X-ray

Suzaku image (0.3-3 keV)



"cap" region (Tsuru et al. 2007)

* SN II like abundance pattern is derived with Suzaku
* SN II metals eject into intergalactic medium
* Lallement (2004) predicted the CX may occur

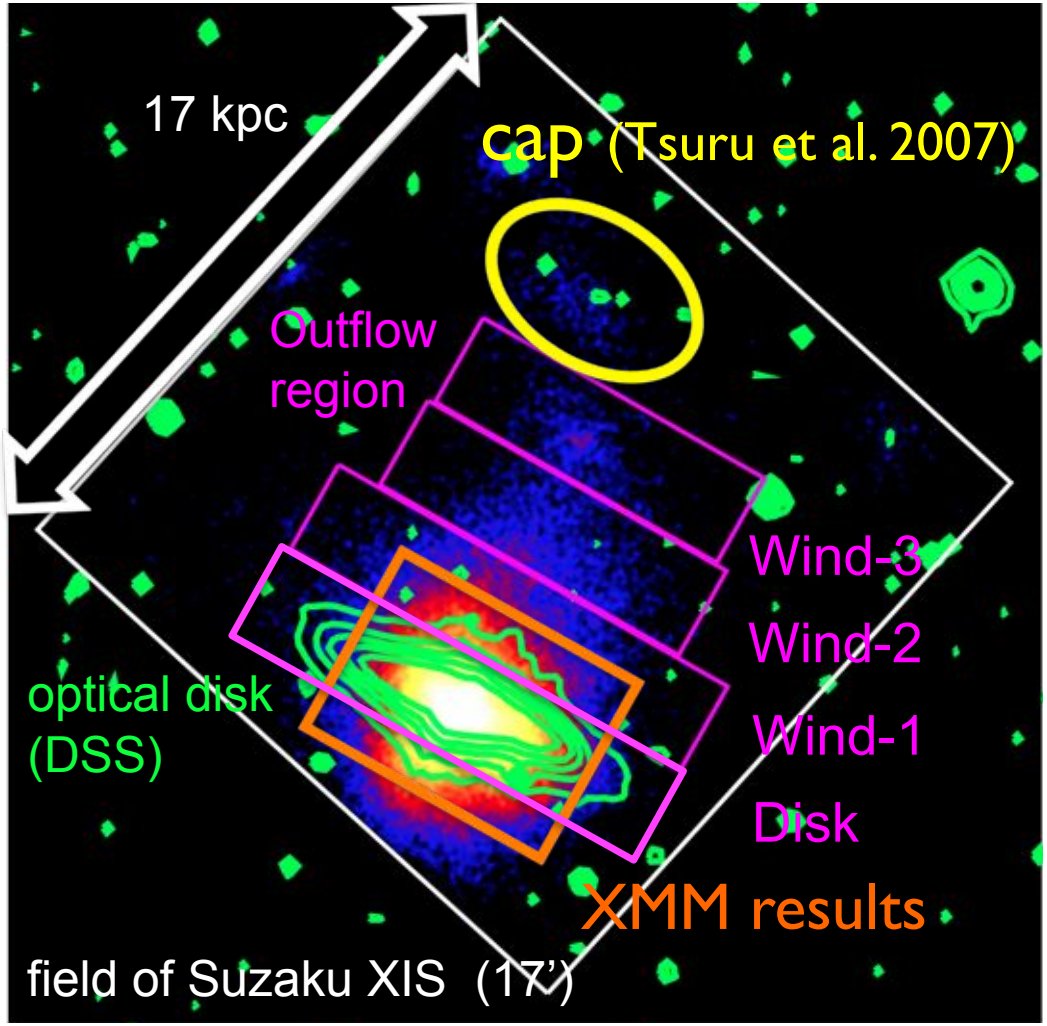
center region

* Absolute abundances of O and Ne are extremely low relative to Fe (Tsuru et al. 1997, Ranalli et al. 2008)
* Liu et al. (2011) detected the CX emission of O VII, Ne VIX, and Mg VXI triplets

We investigated the metal abundance patterns from galactic center to outflow region with Suzaku

M82 Analysis with Suzaku

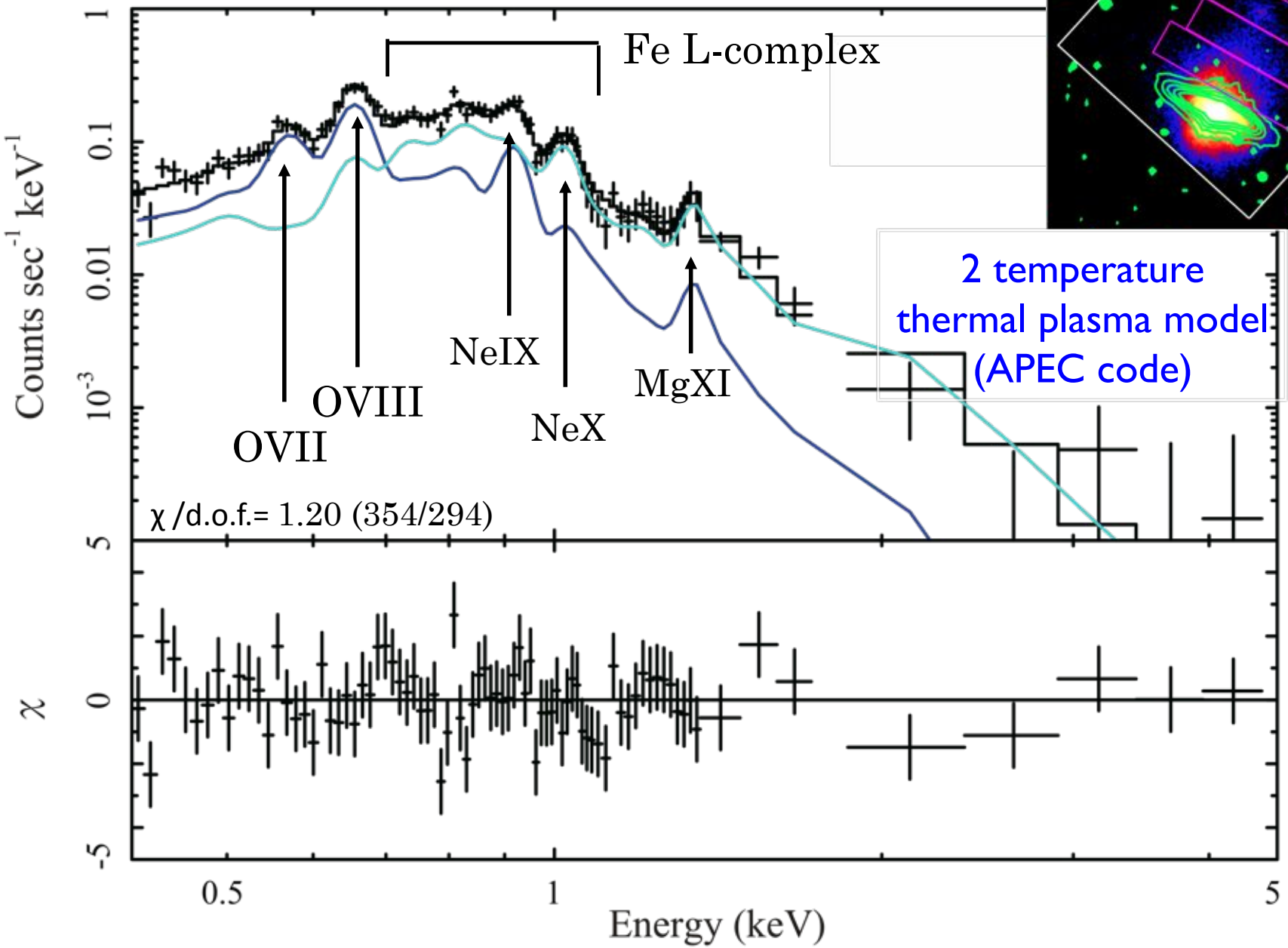
Suzaku image (0.3-3 keV)

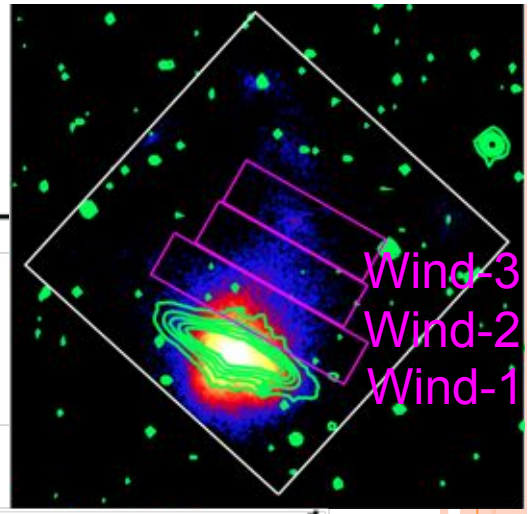


Purpose:
measurement of the metal abundance patterns in the region between the center and the cap (outflow region)

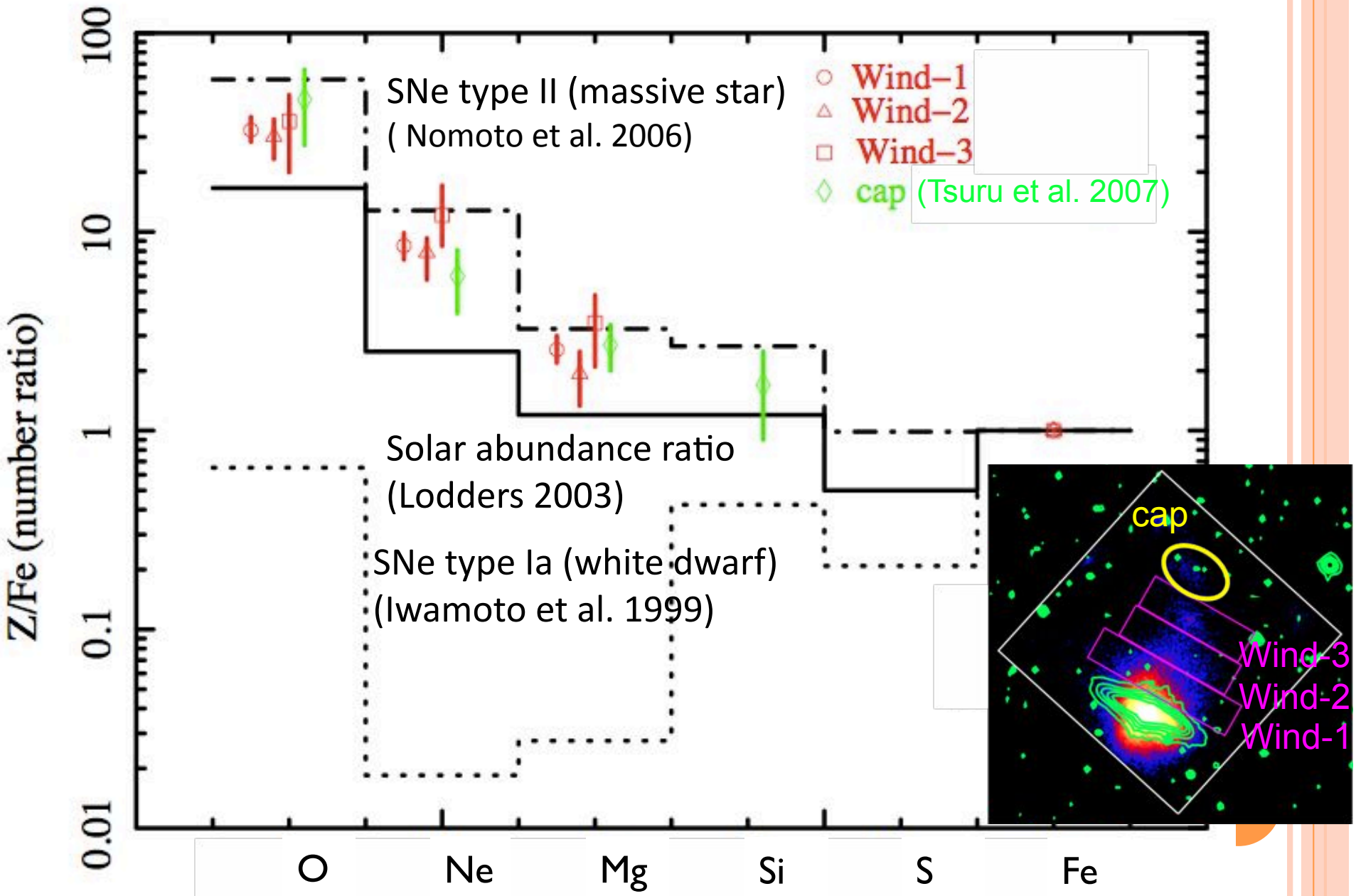
Regions:
We divided the outflow into four regions labeled Disk, Wind-1, Wind-2, and Wind-3 from the center

Spectral Analysis: M82 Wind-1

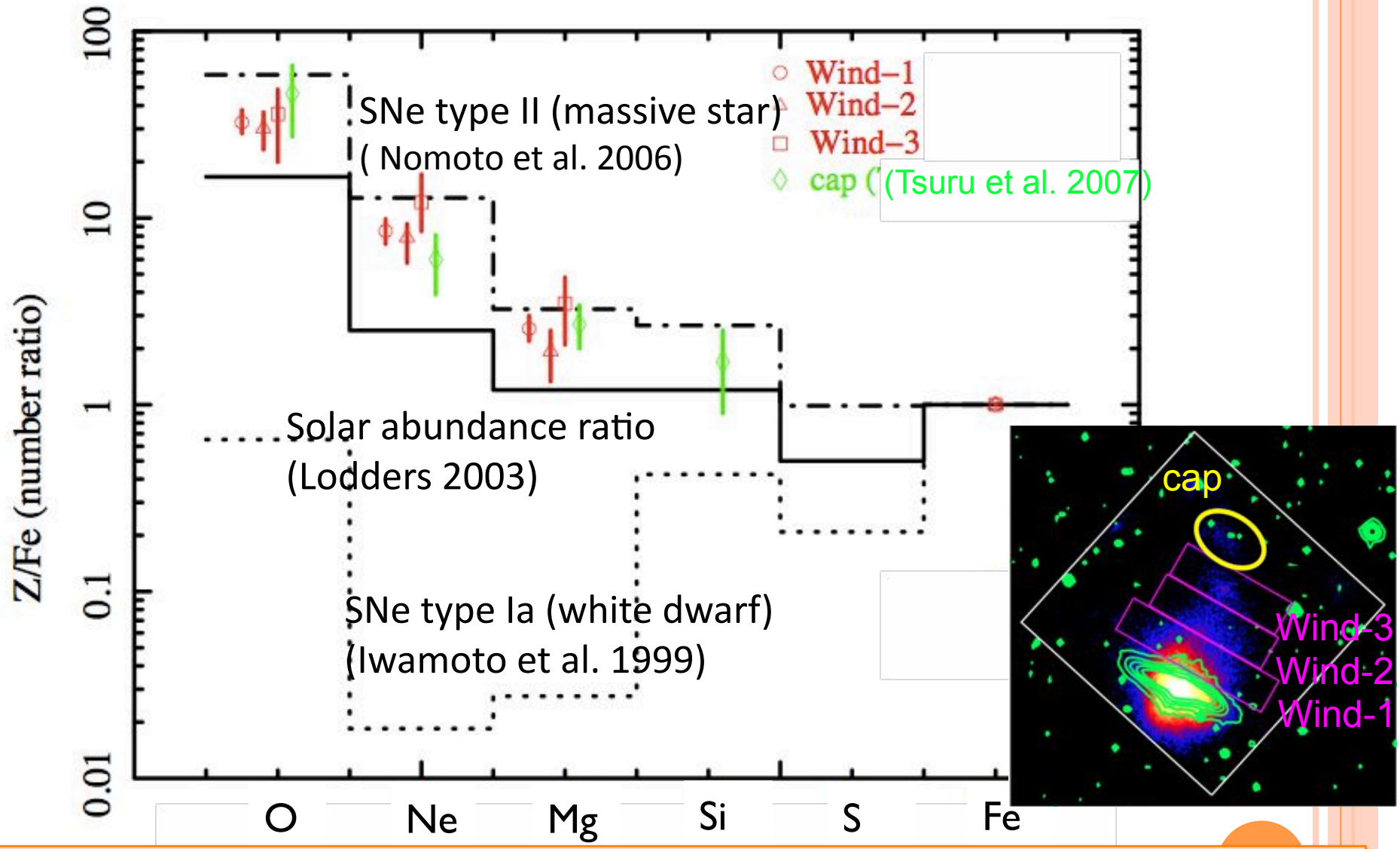




Metal Abundances in M82 Wind Regions



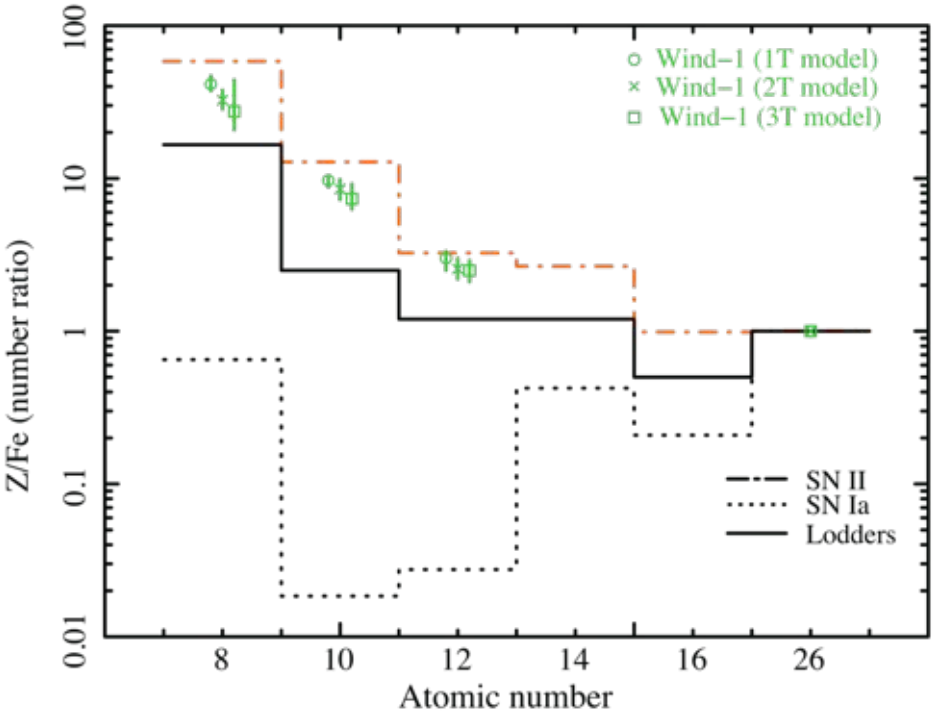
Metal Abundances in M82 Wind Regions

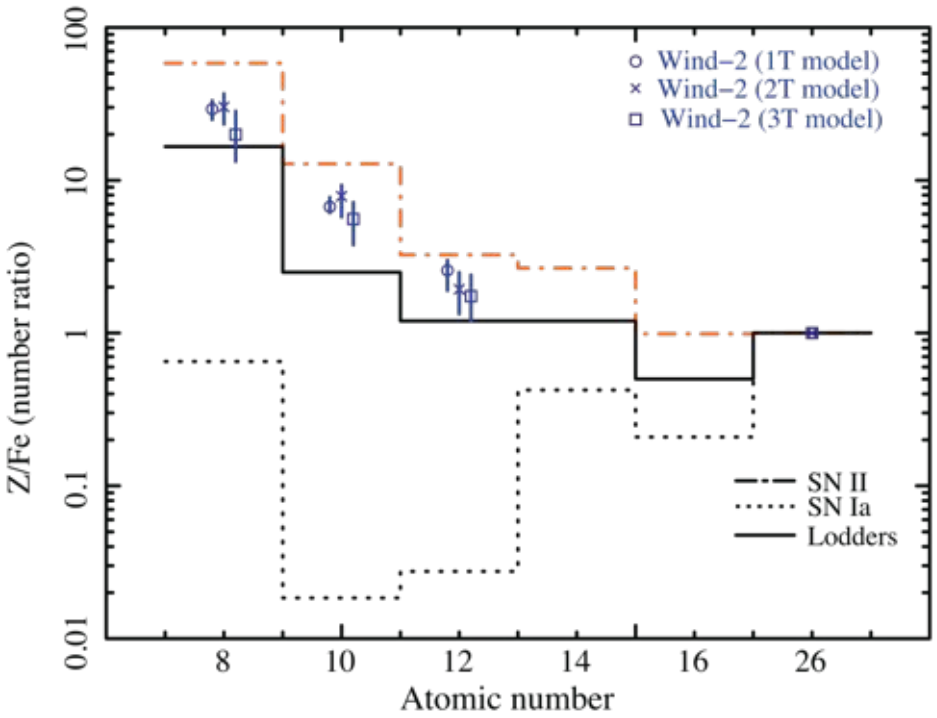


The abundance patterns in all the Wind regions are close to those of SN II and consistent with those of the cap region.

Uncertainties of metal abundances with the temperatures of plasma model

Realistically, the hot plasma has multi temperatures.

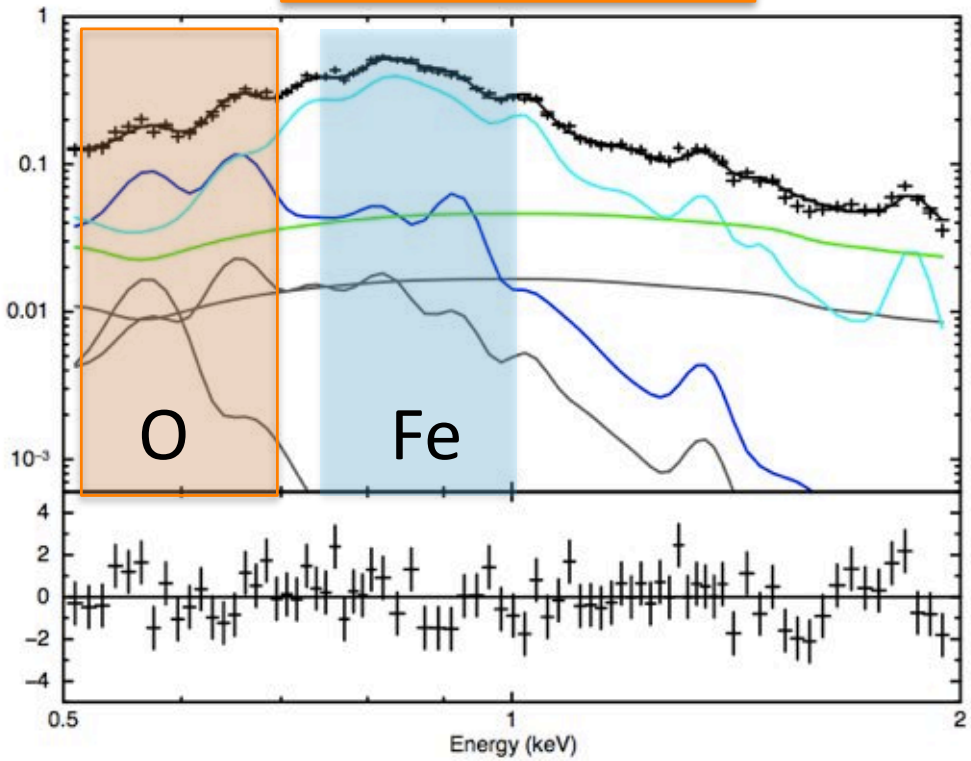




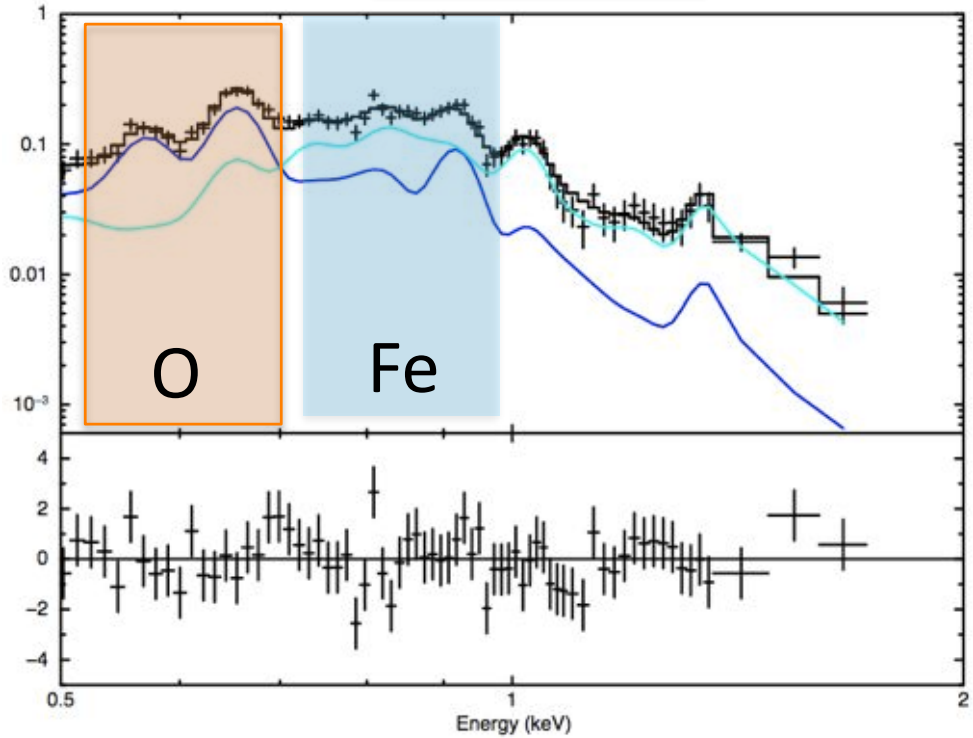
The abundance ratios are not sensitive to the assumed temperature structure.

Compare the spectra

NGC4258

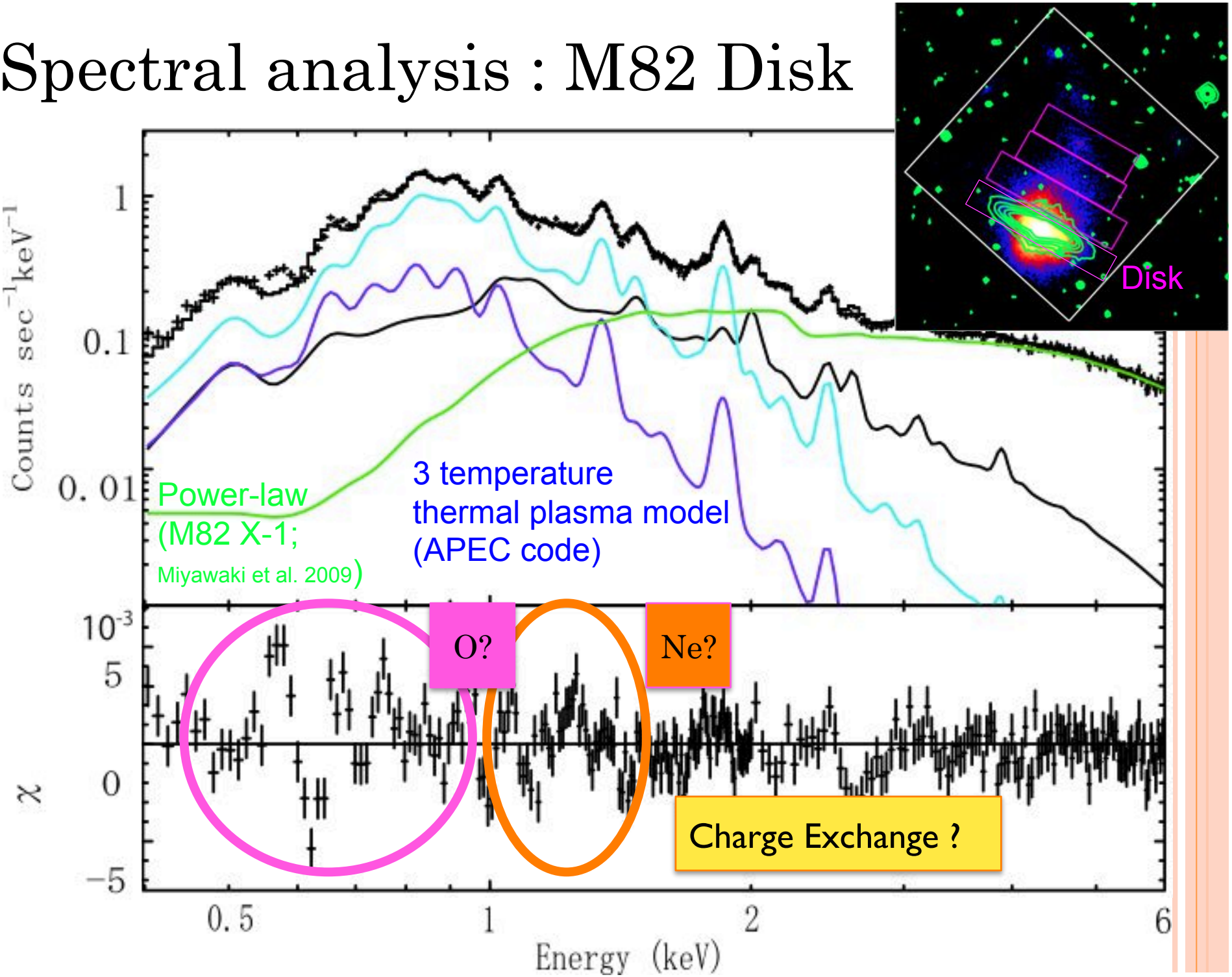


M82



From the feature of spectra, the ratios O/Fe of M82 is higher than the NGC4258.

Spectral analysis : M82 Disk



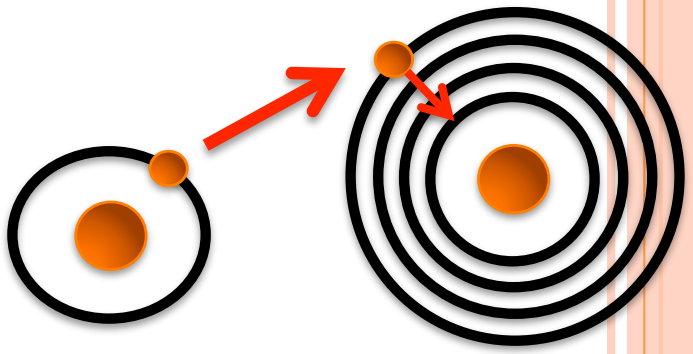
Plasma emission and ratio of line intensities

Collisional Ionization Equilibrium (CIE) plasma (thermal equilibrium plasma)

⇨ The ratios of Kβ/Kα or Kγ/Kα of metals depend on temperatures of thermal plasma.

Charge Exchange (CX)

The electron of nutrals (e.g., hydrogen and helium) moves to highly ionized ion due to collision.



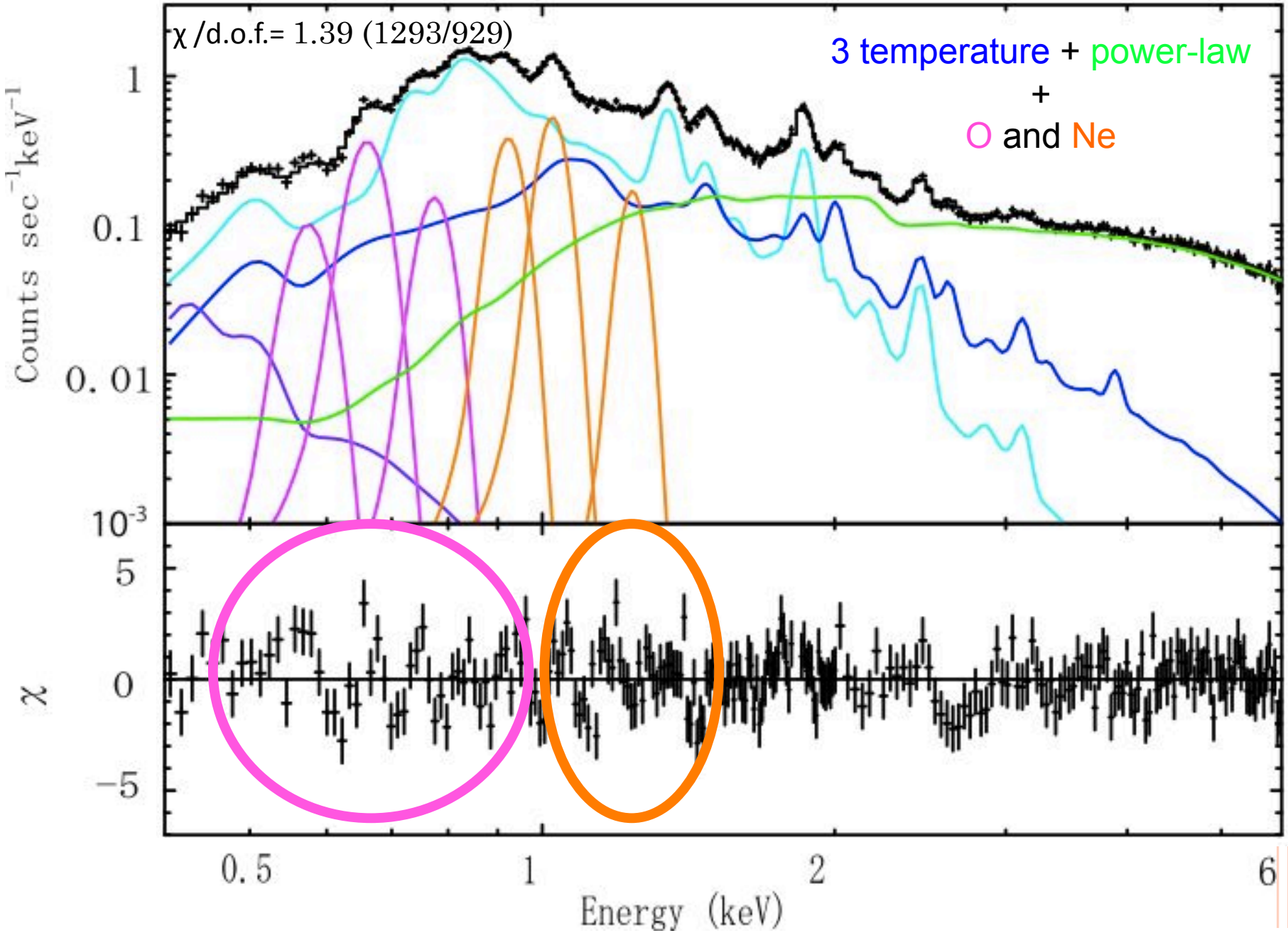
Nutrals (molecular and atomic gas in the center region)

Highly ionized ion [hot plasma]

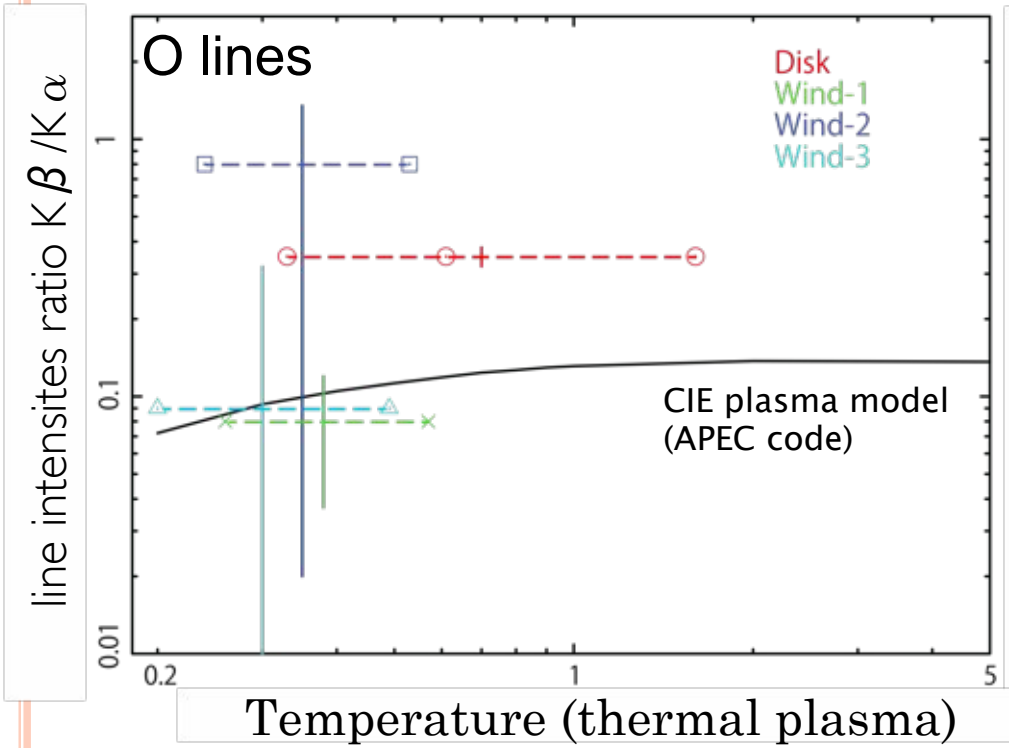
⇨ The ratios of Kβ/Kα or Kγ/Kα are larger than those of CIE plasma.

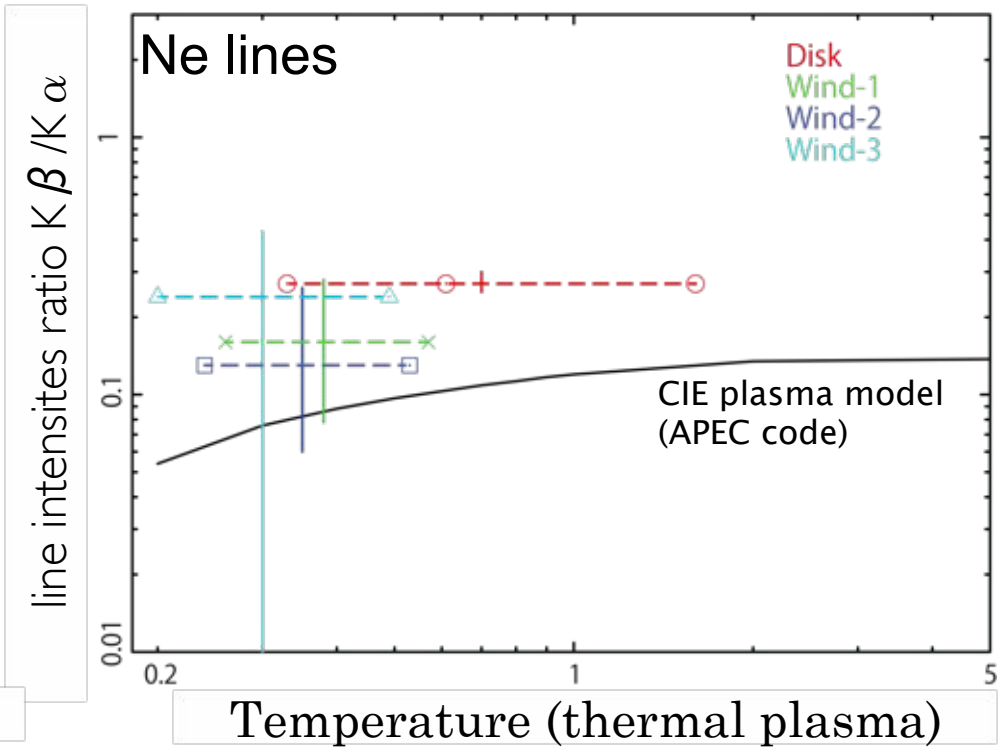
How is the ratios of Kβ/Kα of spectra in the Disk region?

Spectral analysis : M82 Disk region



Ratios of O and Ne K β /K α of M82





* Disk region: the ratios are larger than those of the CIE plasma
  → this indicates that CX process may occur in Disk region
  → It is difficult to derive metal abundances from X-ray spectra
* Wind regions: the ratios are consistent with those for the CIE plasma
  → the derived metal abundances would be more significant

Summary : M82

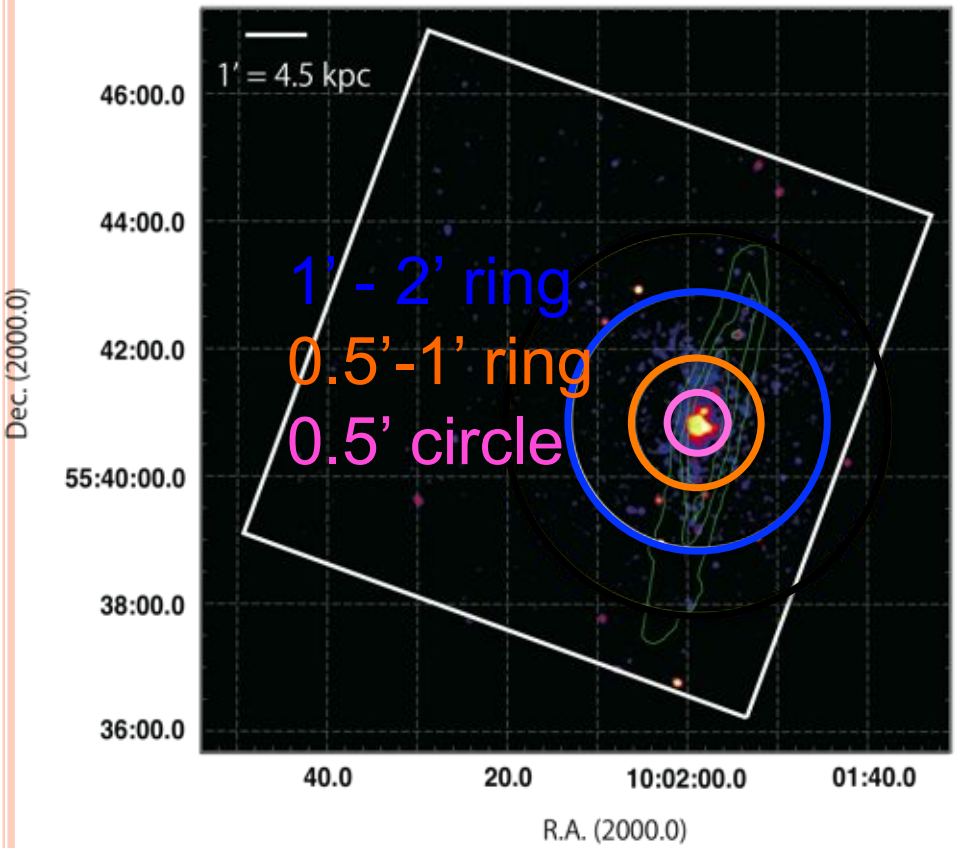
- Wind regions: eject metals synthesized by SN II into the intergalactic medium via outflows.
- Disk region:

  -- excess Kβ lines of O and Ne may be caused by CX process.

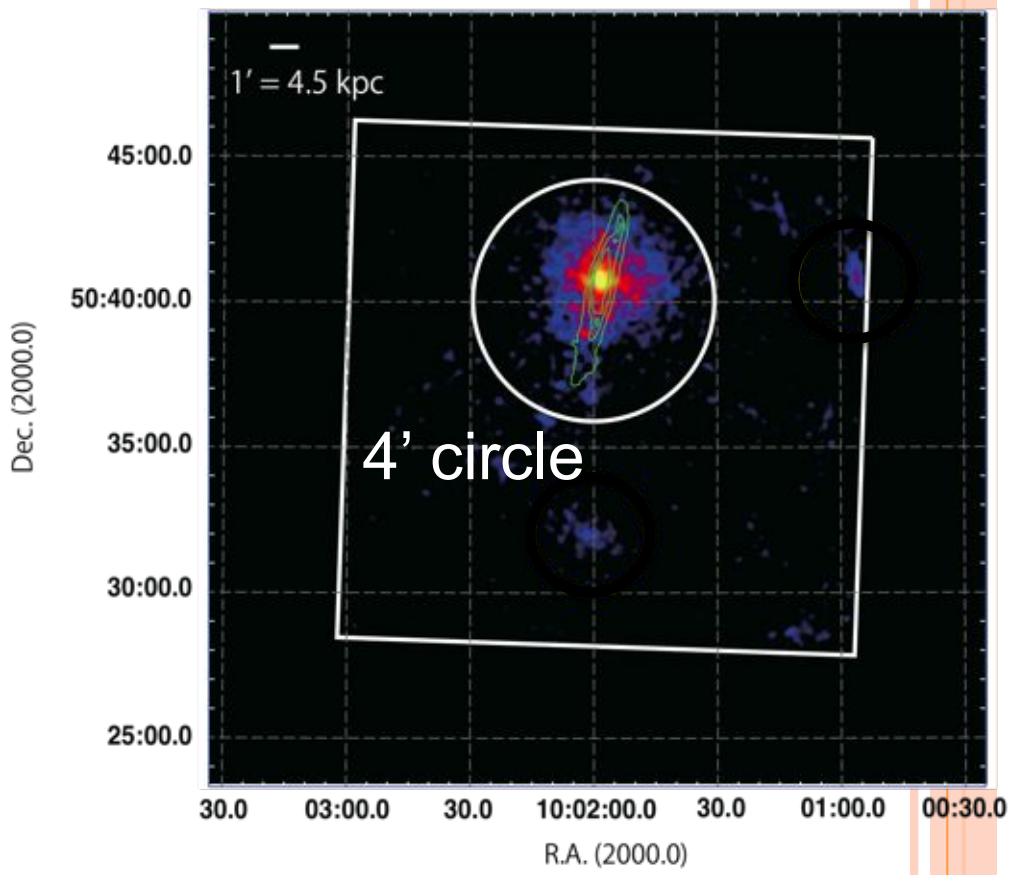
  -- very complicated condition (e.g., starburst region, multi-absorption) may mislead the peculiar metal abundances.
- In the Wind regions, since there are no excess Kβ emission, the metal abundances should be more reliable than those in the Disk and 'cap' region.

NGC3079: Starburst galaxy

Chandra



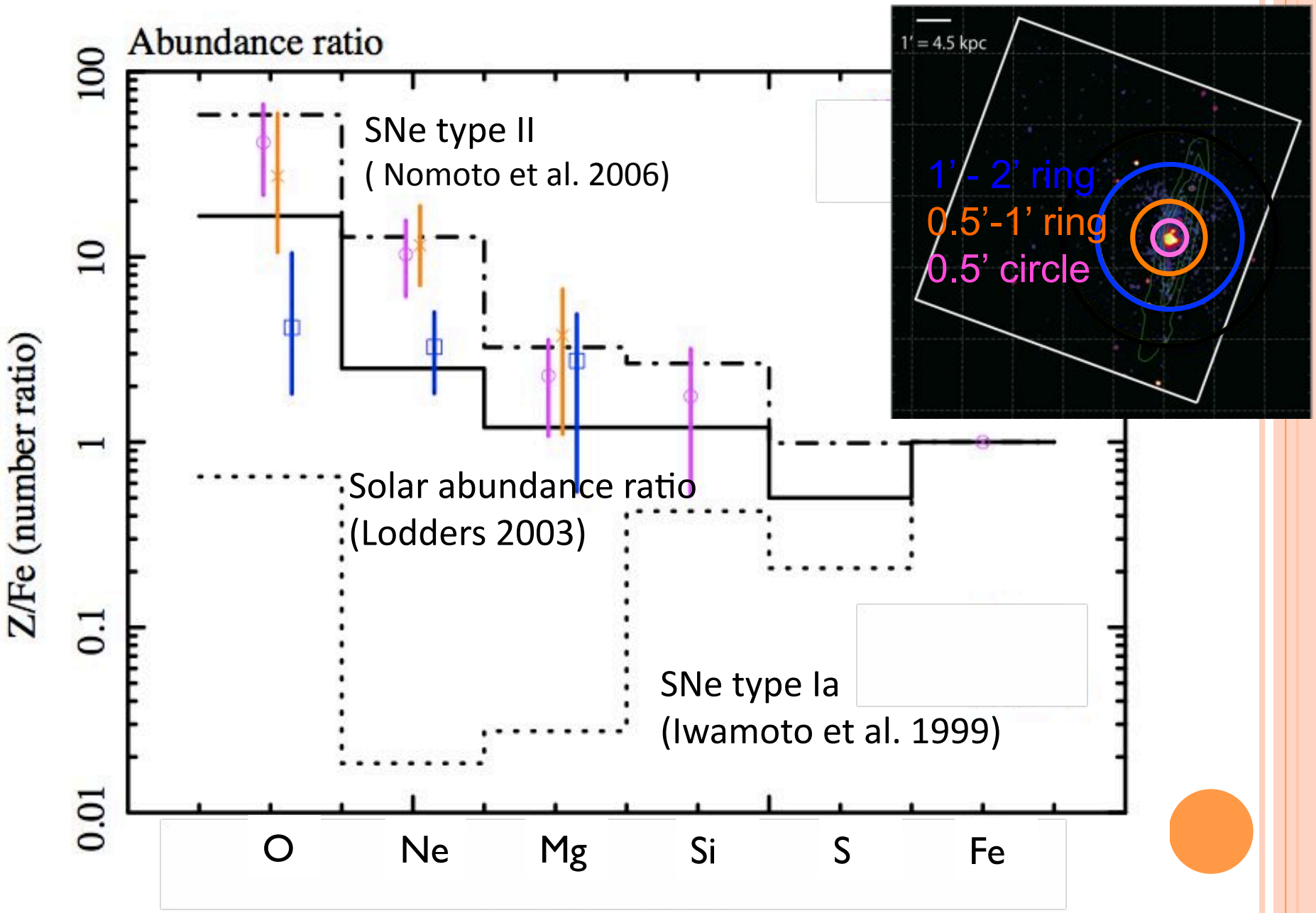
Suzaku



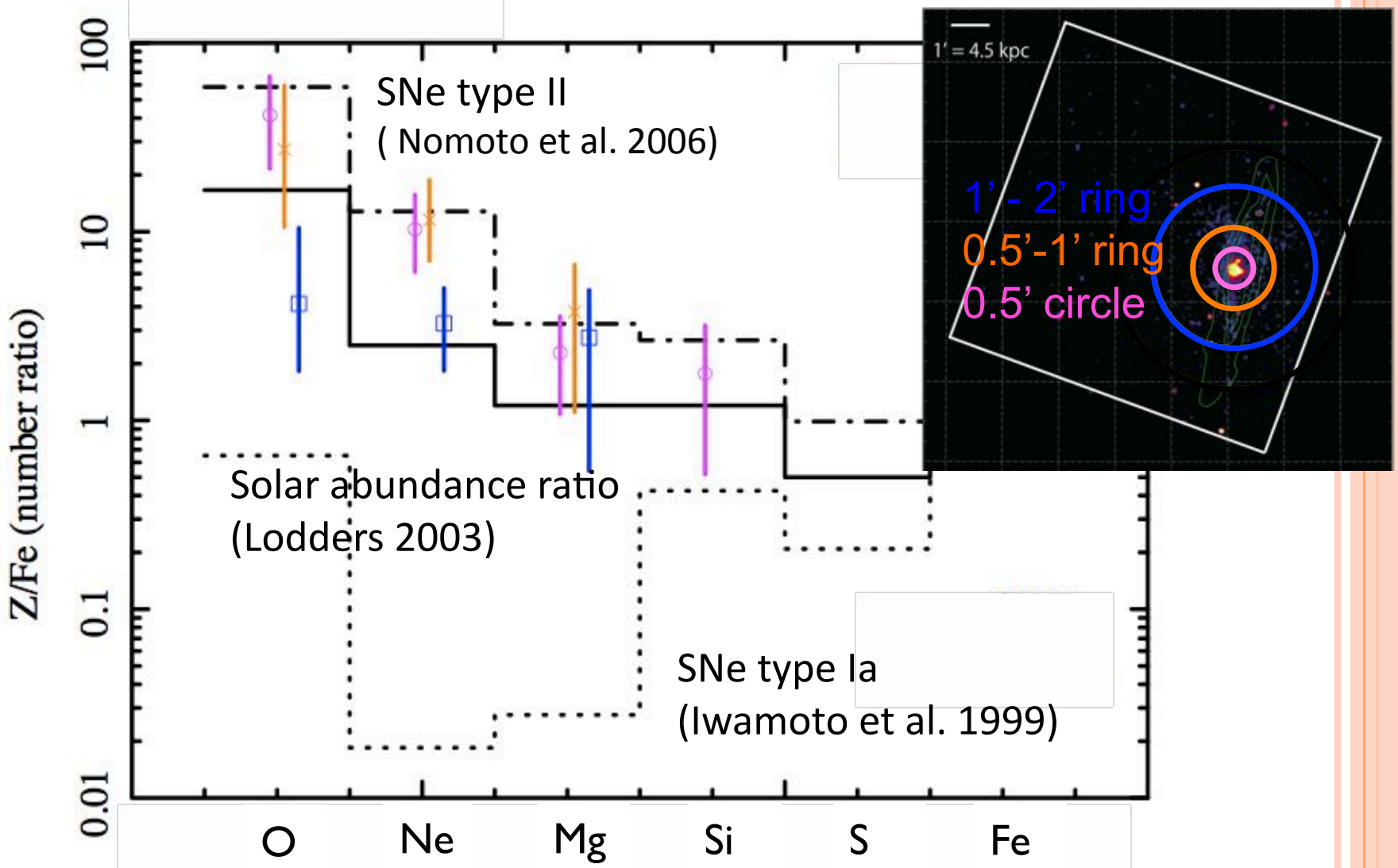
High angular resolution ✚ Good spectral sensitivity

⇨ We can spatially measure the metal abundance pattern.

Metal Abundances in NGC3079



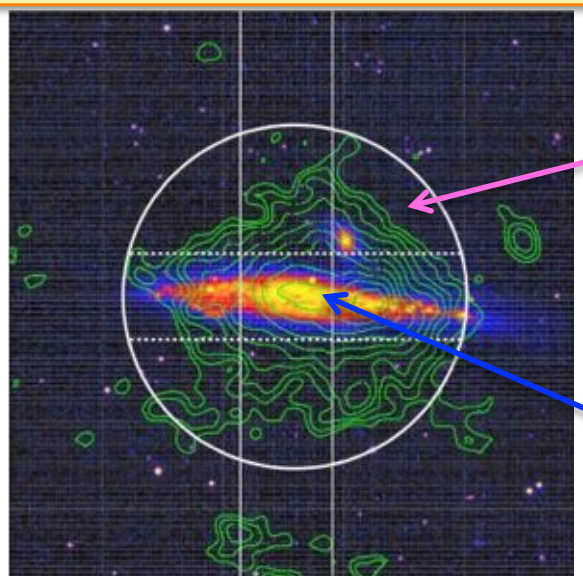
Metal Abundances in NGC3079



center region → SN II like abundance pattern
outer region → close to the solar abundance
The abundance patterns have spatial distribution?

Spatial distributions of metal abundances -- indicate of the starburst phase?

NGC4631
(Yamasaki et al. 2009)



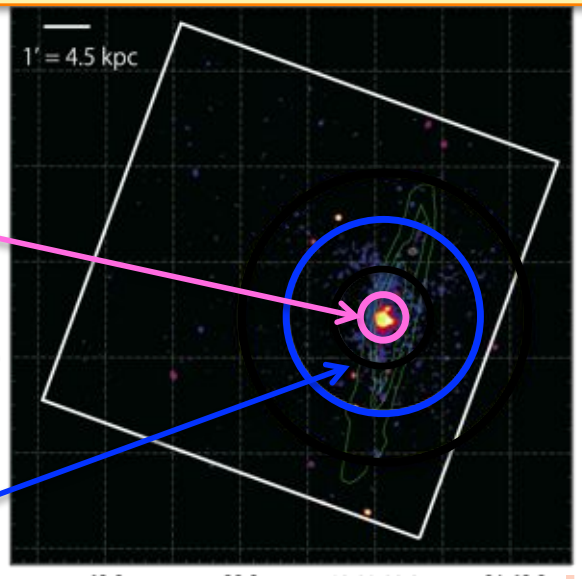
SN II-type

halo region
center region

solar abundance

disk region
outer region

NGC3079
(Konami et al. in publish)



The metal abundances like SN II escape to intra galactic space and in the disk region metal abundance is close to solar after starburst era.

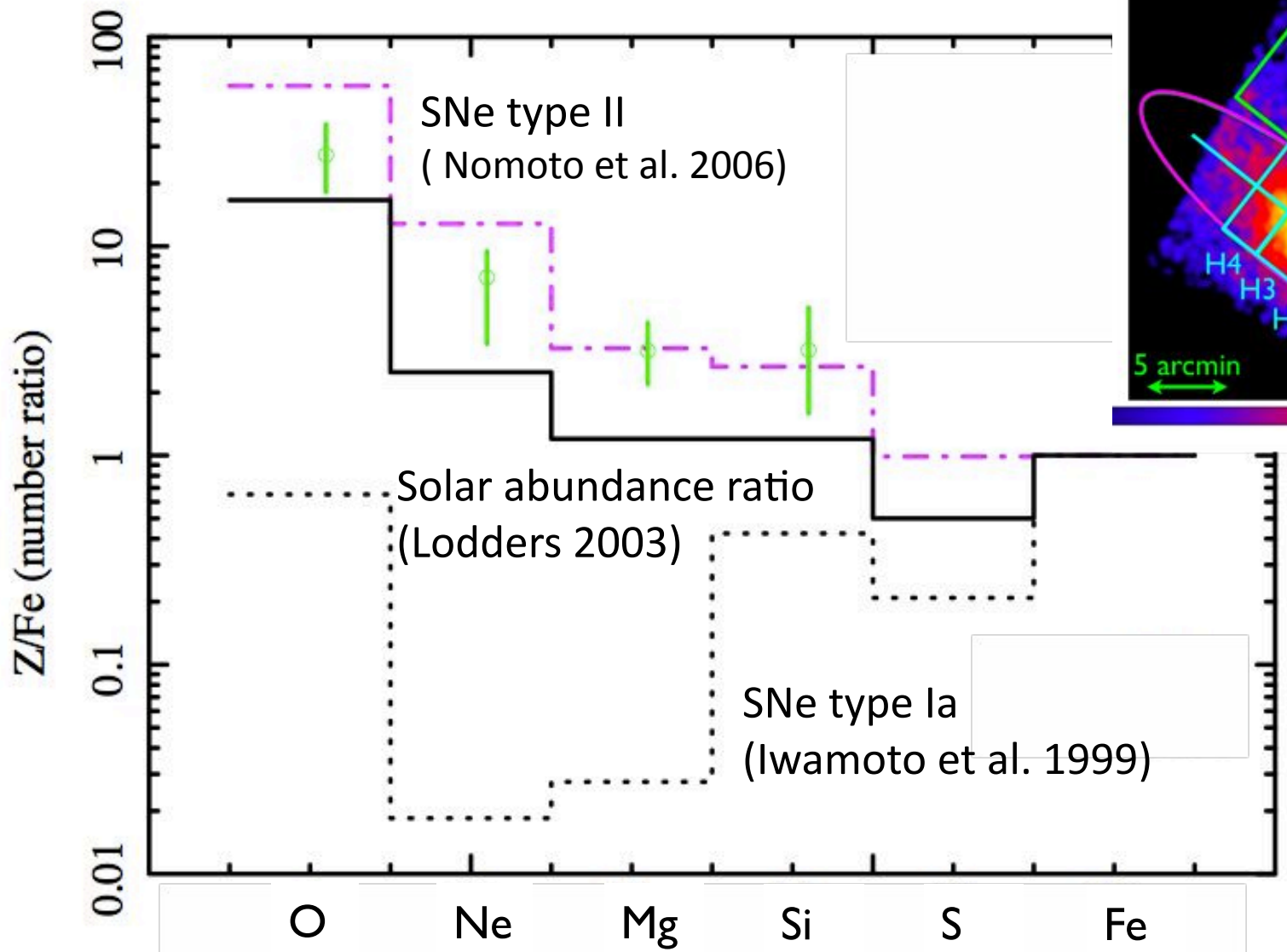
⇨ late phase of starburst activity

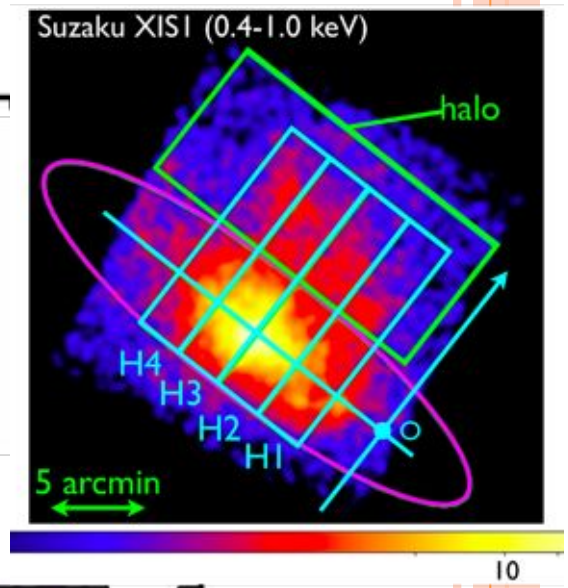
The starburst activity affect the metal abundances in the only center not outer region.

⇨ early phase of starburst activity

NGC253: Starburst galaxy with Suzaku

(Mitsuishi D thesis)





The abundance patterns in the halo region is also close to those of SN II.

Summary

- We investigated the metal abundances in the hot X-ray emitting plasma of starburst and non-starburst galaxies
- Starburst galaxy

(M82 outflow or NGC3079 center region)

⇨ SN II like abundance pattern

- non-starburst affect galaxy

(NGC4258 or NGC3079 outer region)

⇨ solar abundance pattern (Lodders 2003)