A breath of fresh air from the old Swan

A detailed Suzaku study of an evolved SNR, the Cygnus Loop

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Suzaku2011@SLAC

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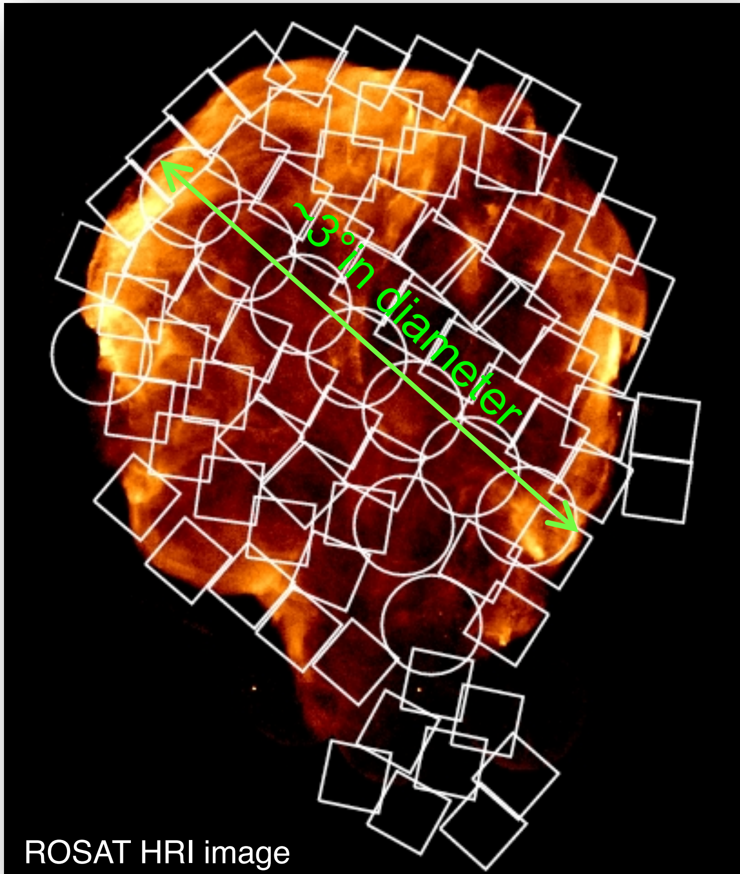
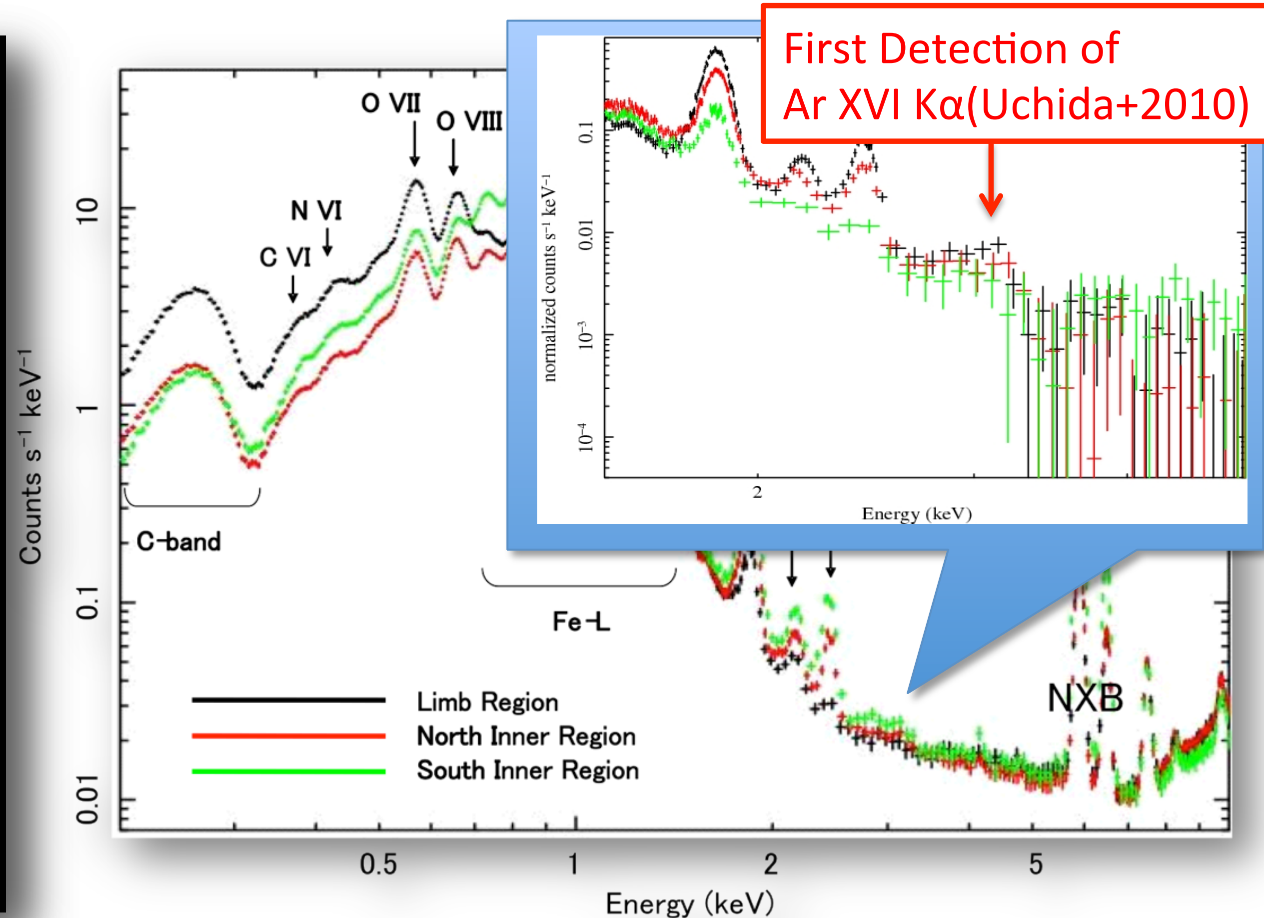
The Cygnus Loop Observations with Suzaku & XMM-Newton





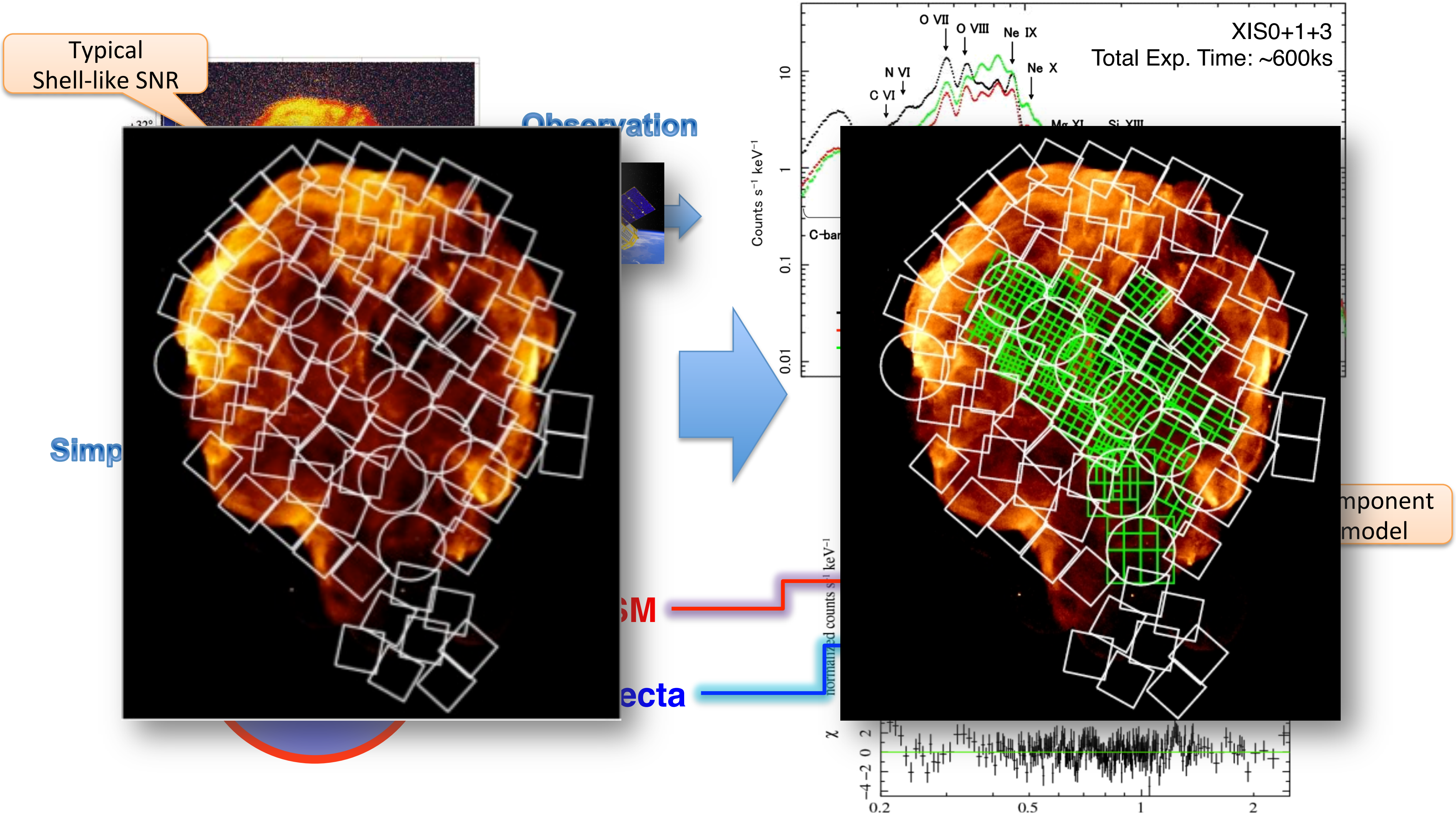
Satellite	Number	Obs. Date	Eff. Exposure Time
Suzaku	72	Nov 2005 – Jun 2011	1676.7 ks
XMM-Newton	9	Nov 2002 – May 2006	93.5 ks

We completely covered this remnant with Suzaku (and XMM) by the AO6 phase.

Outline

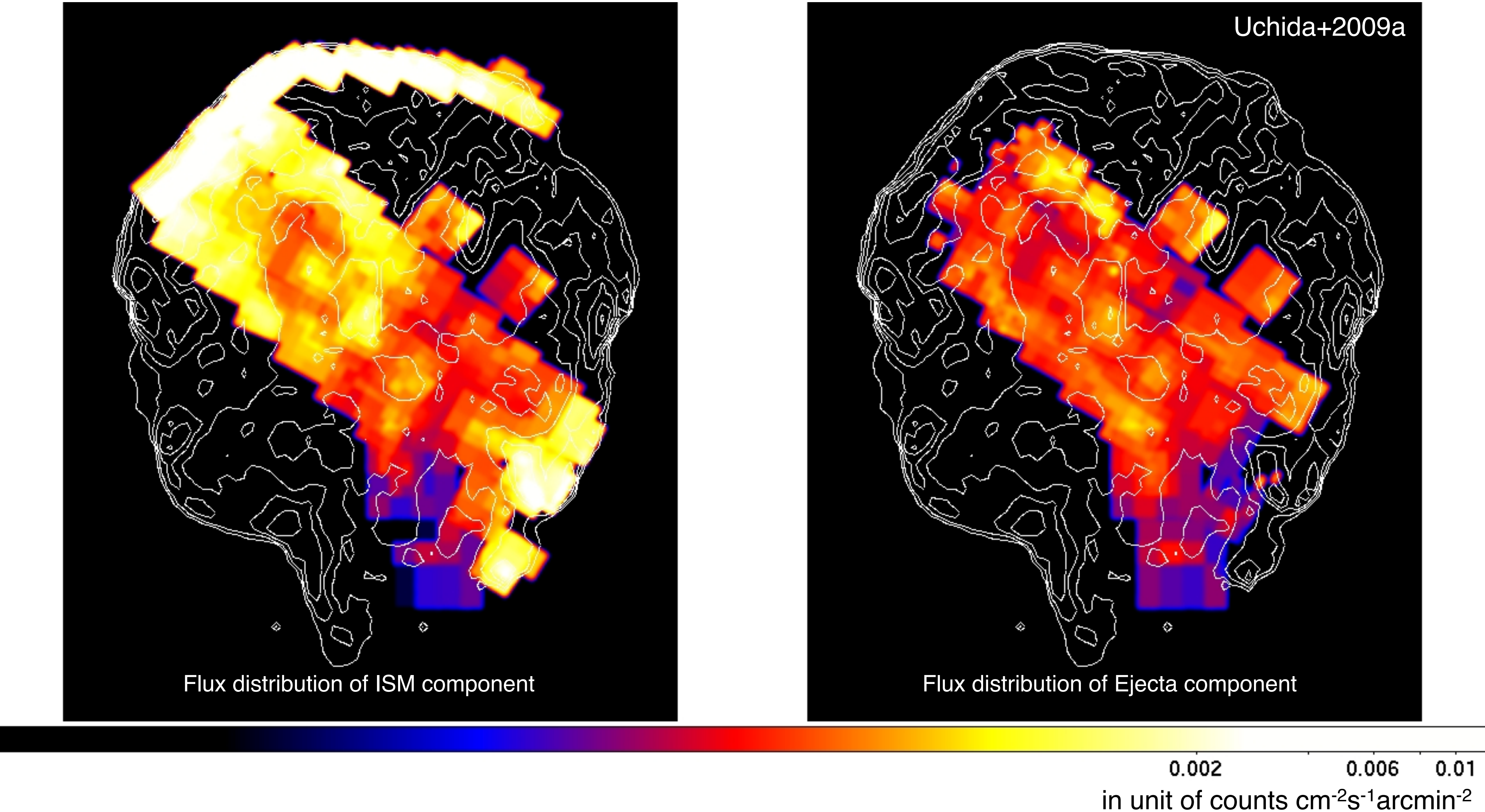
- Introduction
  - – Classical fit with a conventional thin thermal model
- Panoramic X-ray View of the Cygnus Loop
  - – Metallicity structures of the ejecta
  - – North-South inhomogeneity of the heavy element
- "Deep" Observation of the Cygnus Loop
  - – Unknown excess at 0.7keV
  - – 1.2keV (missing) line problem
- Summary

Classical Model Fit for the Spectra of the Cygnus Loop



Basically, the spectra are well fitted with a two-component NEI model.

Swept-up ISM and Ejecta Structures of the Cygnus Loop



Swept-up ISM Structure

Ejecta Structure

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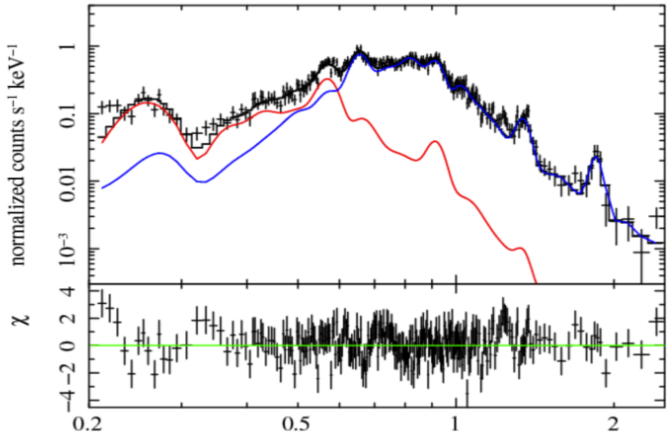
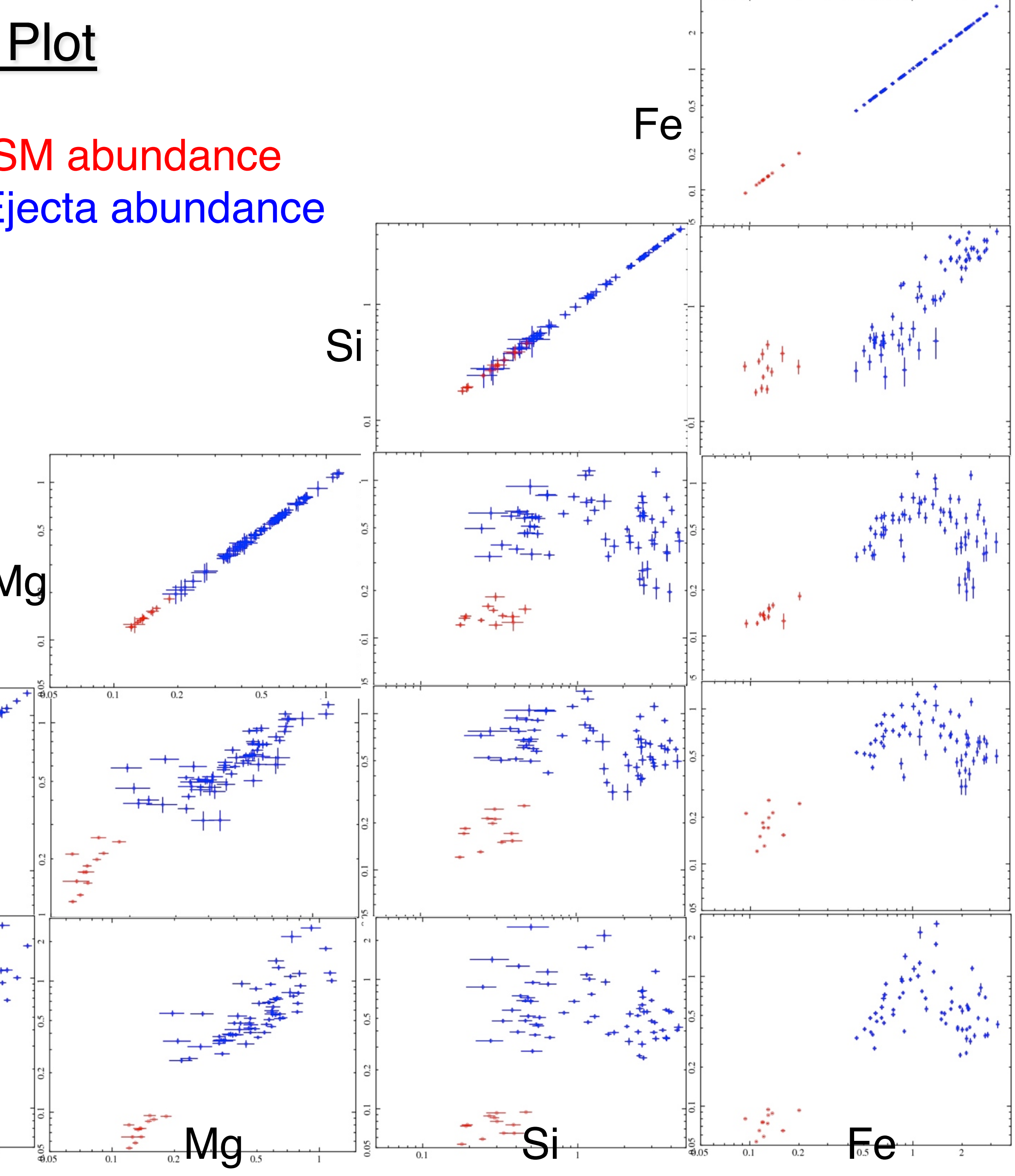
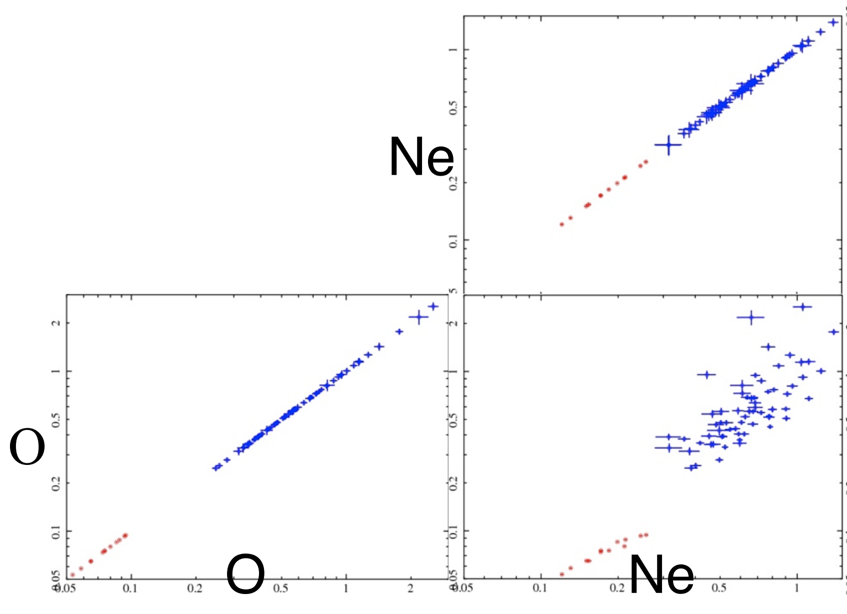
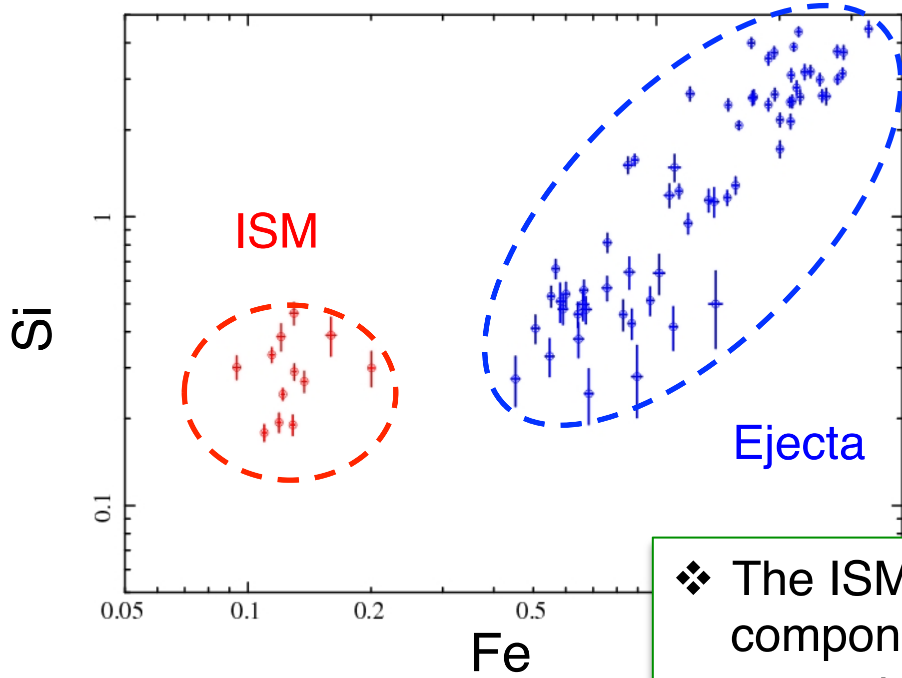
Abundance vs. Abundance Plot

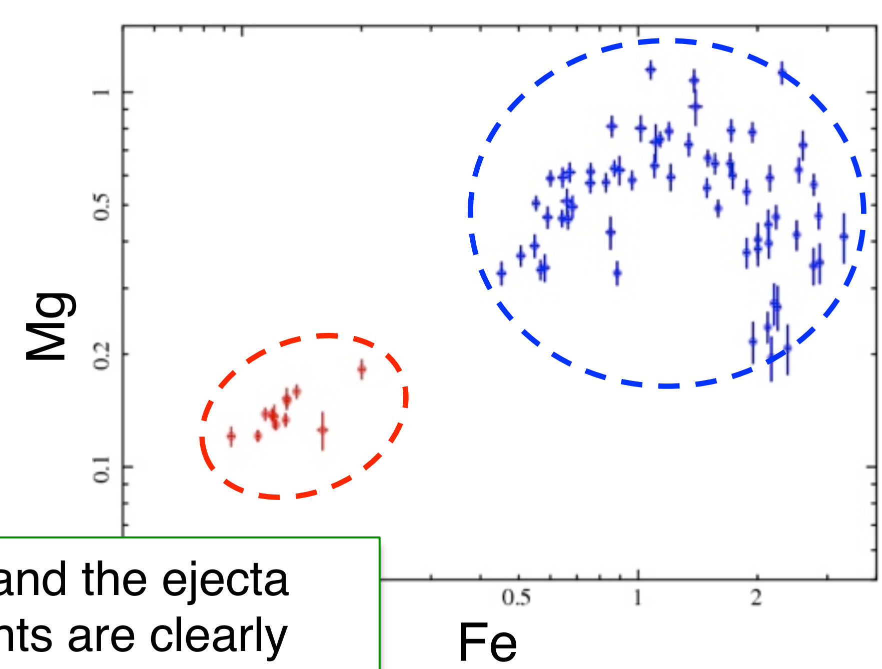


ISM abundance
Ejecta abundance

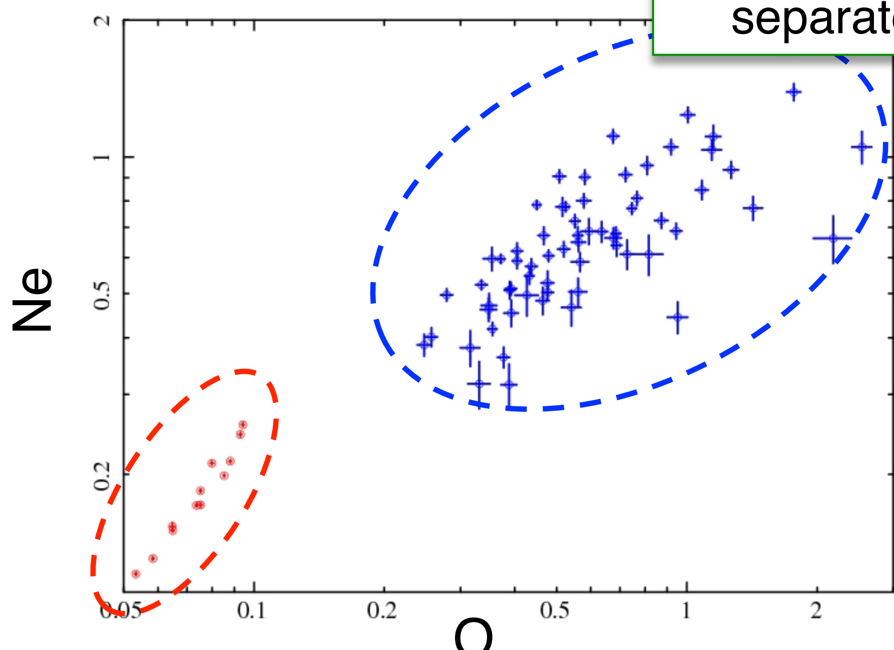



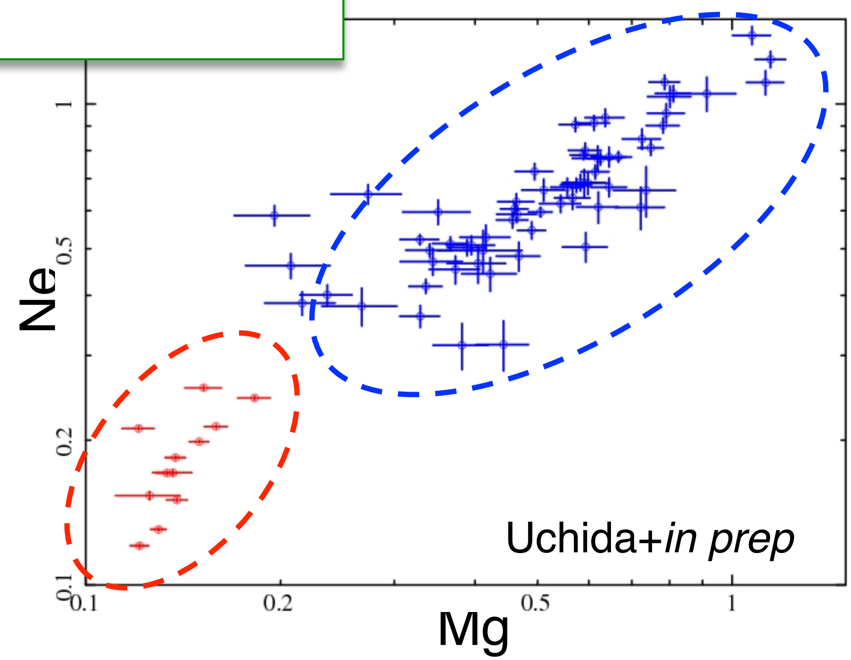
Abundance vs. Abundance Plot



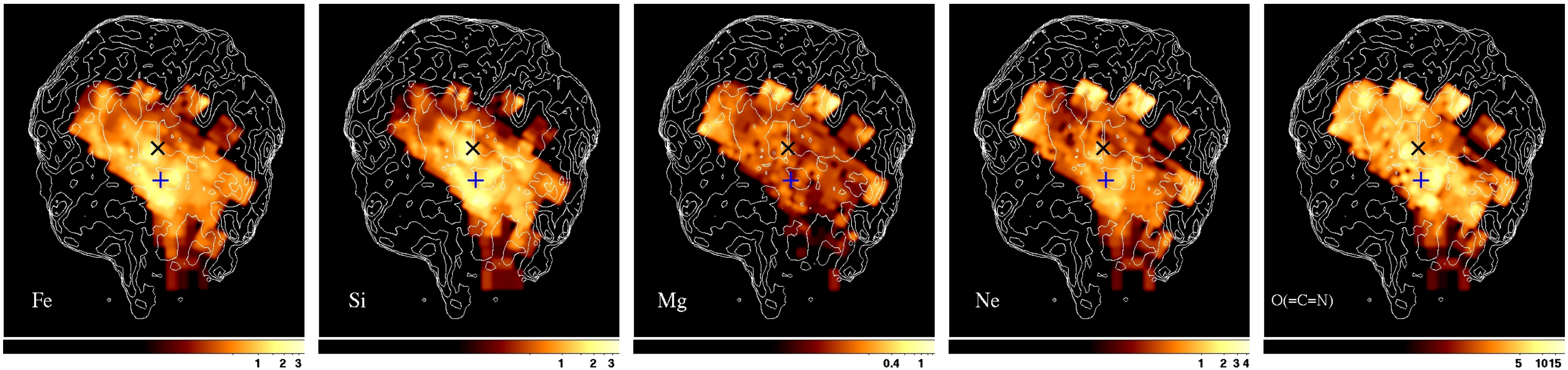


- ❖ The ISM and the ejecta components are clearly separated.

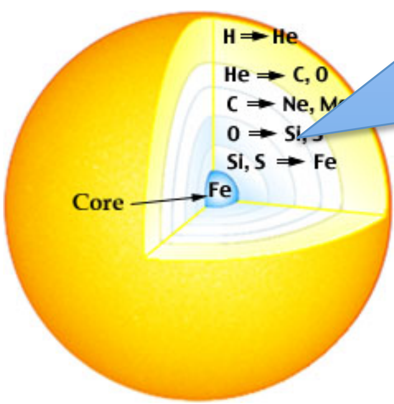


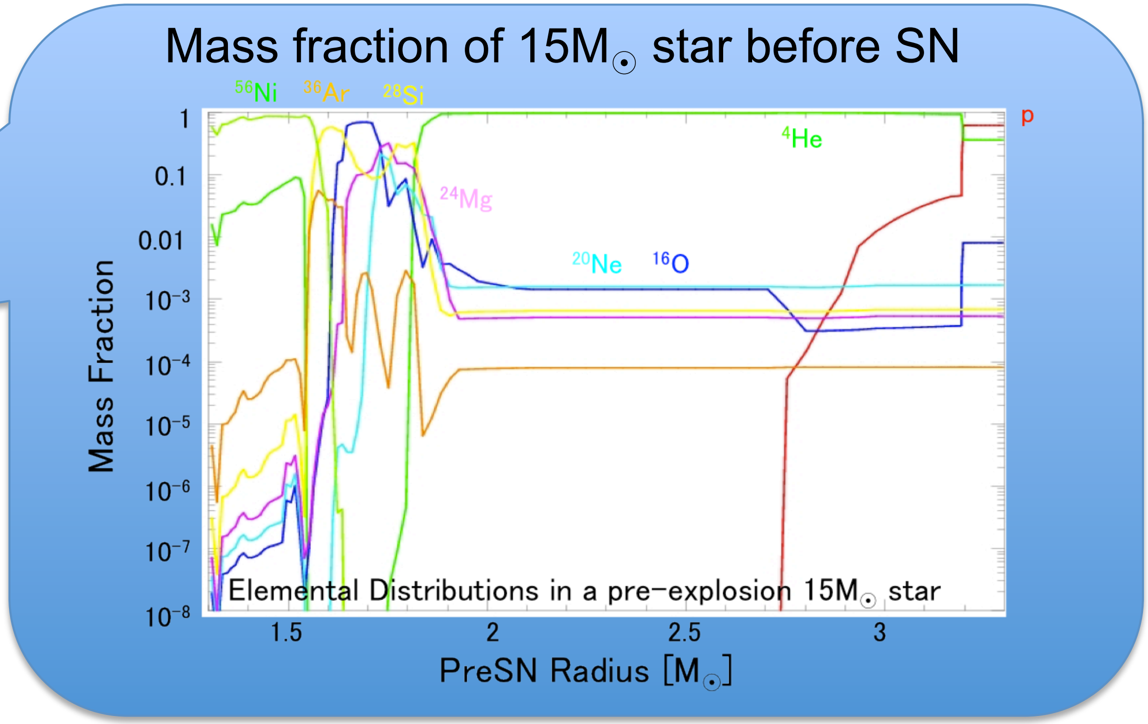


“Onion-like” Structures of the Cygnus Loop

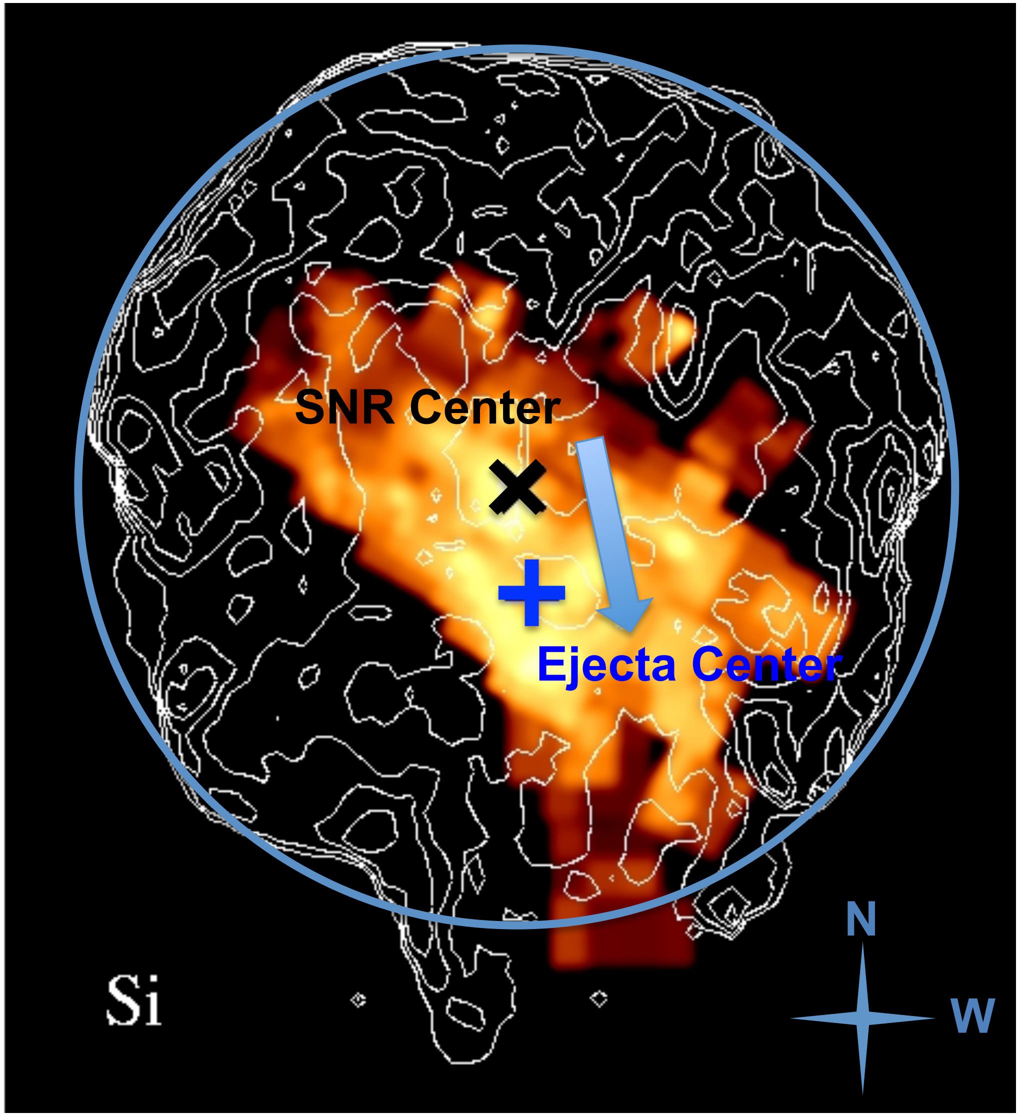


Uchida+2009b

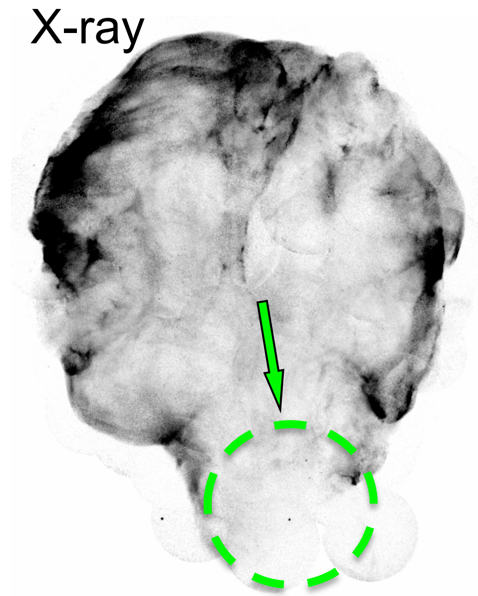


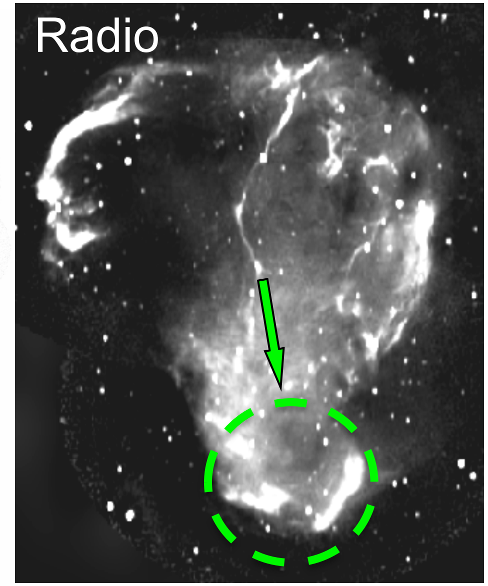


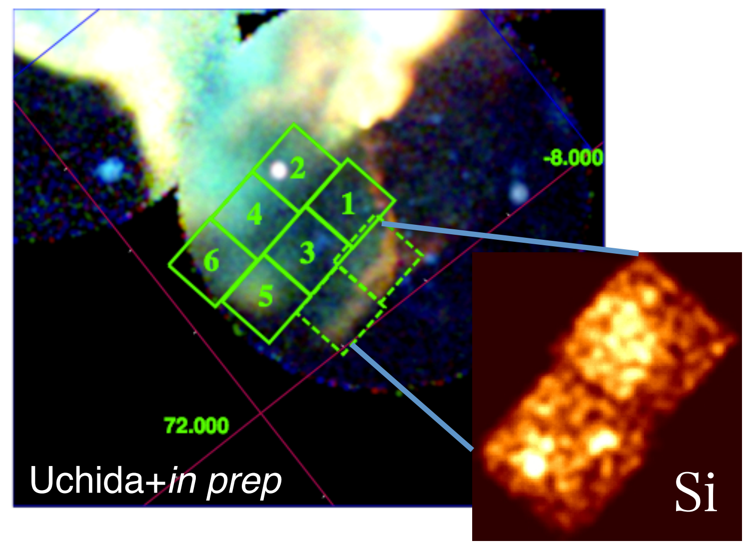
The heavy elements blew out to South?



Si (and Fe) distribution Center shifts toward the South?

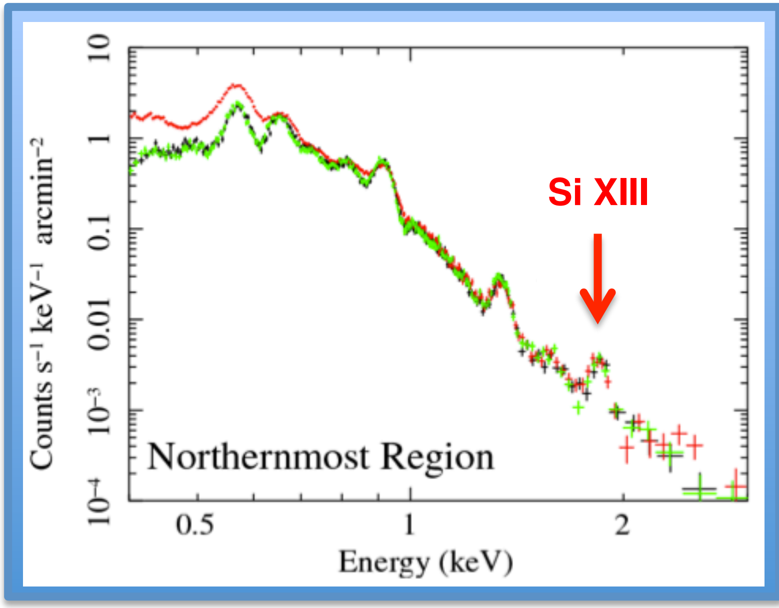


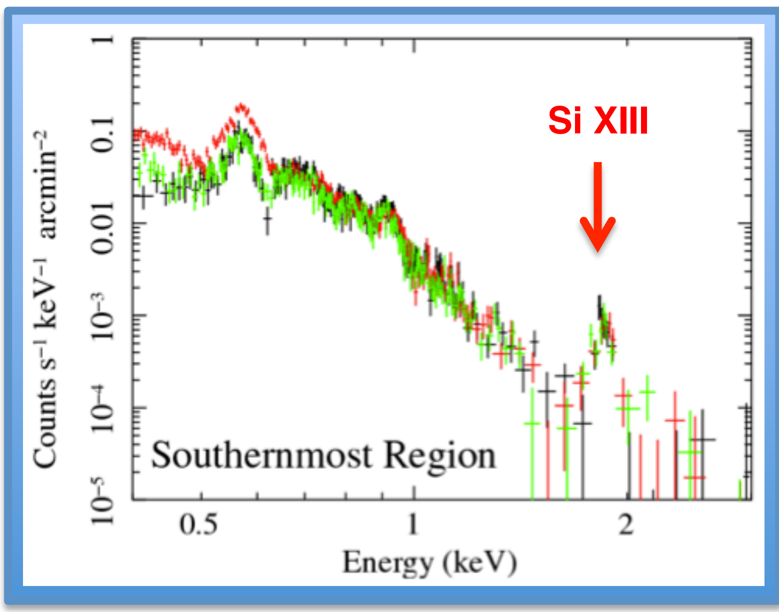


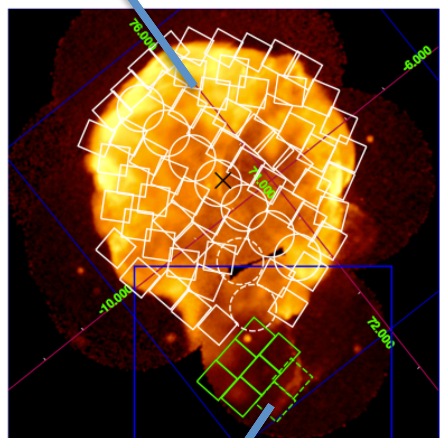


We have observed the blowout region with Suzaku (in AO5 and AO6 phases).

North-South Inhomogeneity of the Heavy Element



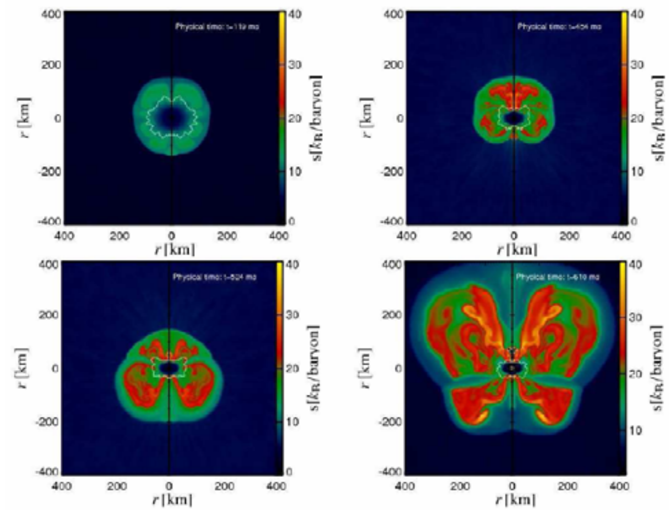




Si Abundance:
0.41±0.05
Si/O: ~1
Fe/O: ~0.5

Si Abundance:
4.2 ±0.6
Si/O: 10-30
Fe/O: 2-3

- The Si abundance in the southernmost region is ten times higher than that in the northernmost region.



- Example: “SASI-aided” SN simulation of 15M$_\odot$ progenitor (Marek & Janka 2005).
- Many theories estimate that the heavy elements eject in one direction.

We are analyzing all the available data to reveal the whole picture of the ejecta structure.

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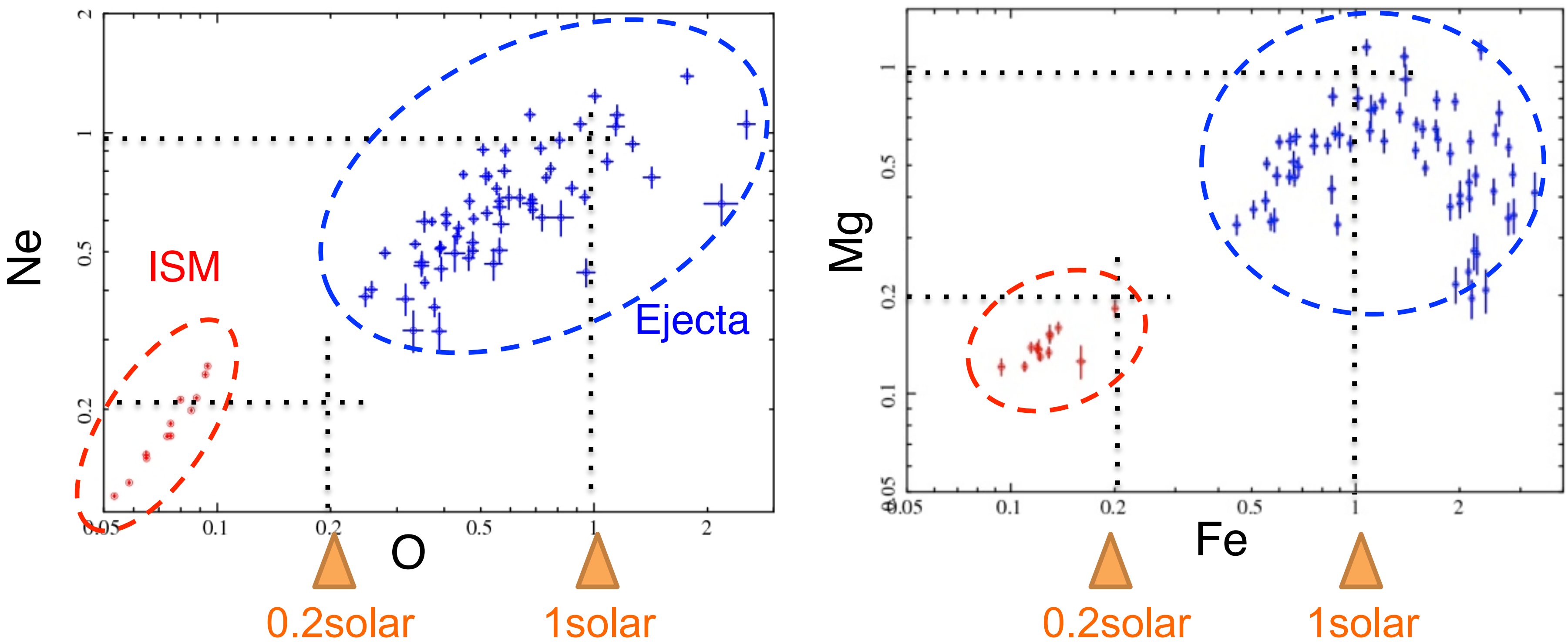
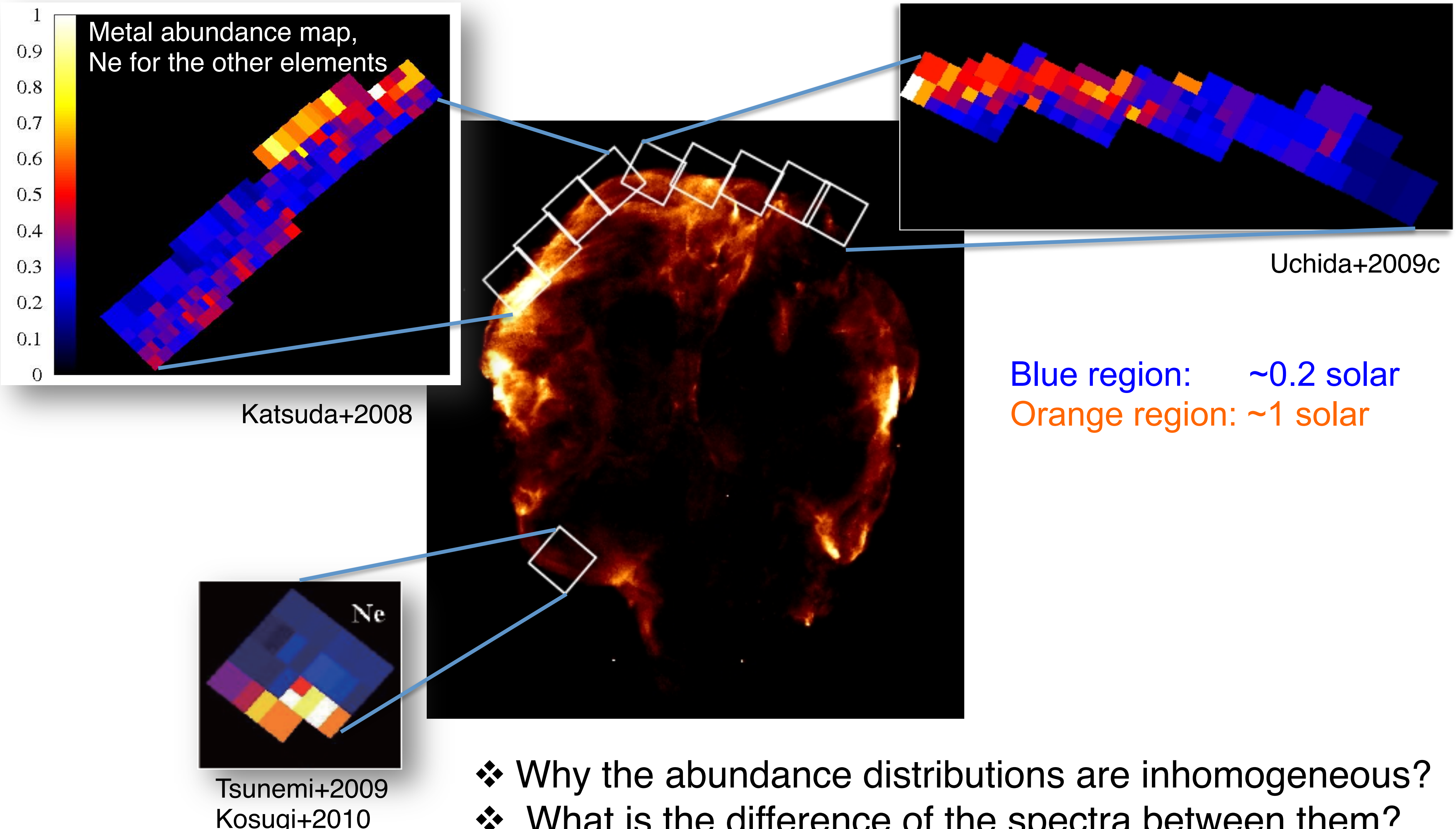
Low abundance problem of the ISM component



- The ISM abundances are significantly lower than the solar abundances.
- Such low abundance ISMs have been reported from some other SNRs;

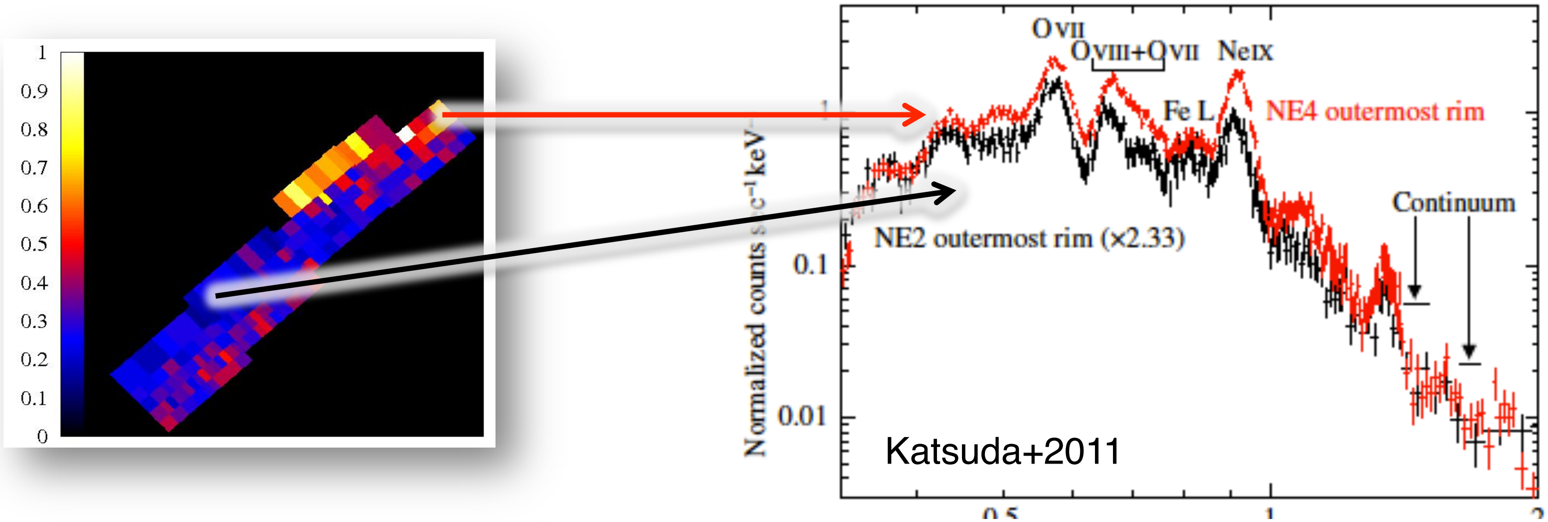
Puppis A:	Hwang et al. 2008
RCW86:	Yamaguchi et al. 2008
Vela SNR:	Miceli et al. 2008

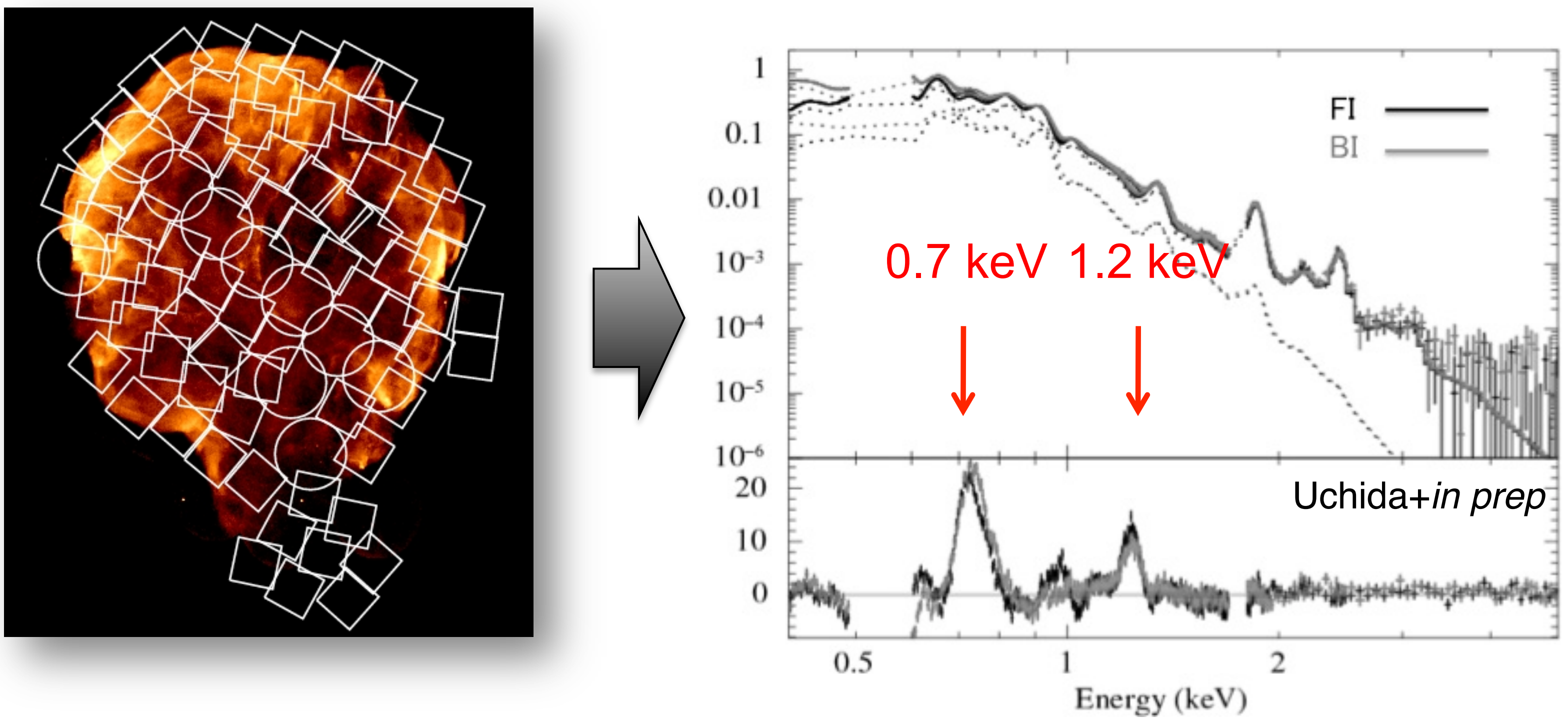
Abundance Enhancement in the Cygnus Loop Rim



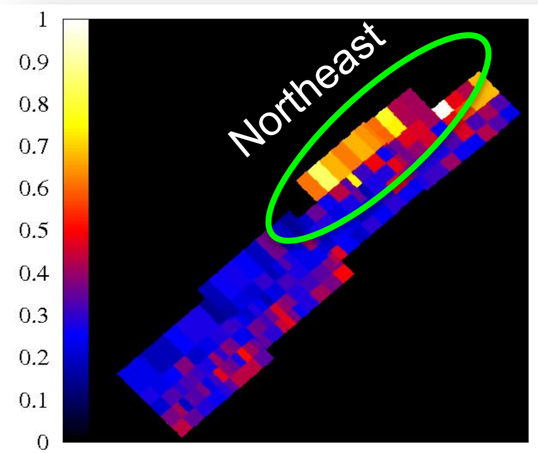
- ❖ Why the abundance distributions are inhomogeneous?
- ❖ What is the difference of the spectra between them?

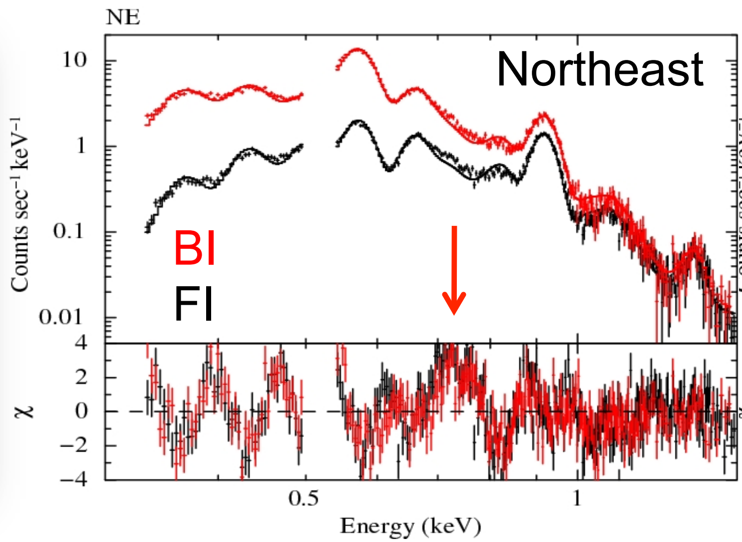
Fitting problems @ 0.7 keV and 1.2 keV in the current NEI model

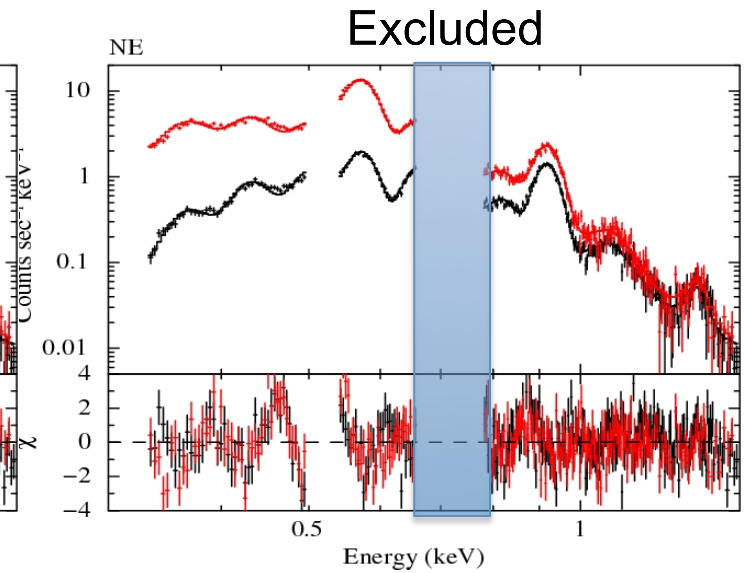




Refit excluding the 0.7 keV excess (Katsuda et al. 2011)







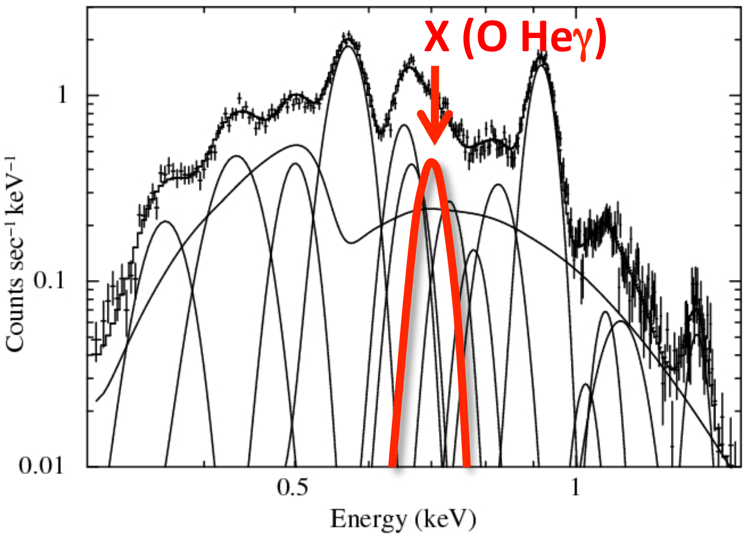
- When we exclude the excess at around 0.7 keV, the values of the abundances decreased significantly.
- The abundance inhomogeneity is resolved. However, what is the origin of the excess which faked the abundance enhancement?

	Original fit	Refit!
N_H:	3×10^{20} (fixed)	3×10^{20} (fixed)
kT_e:	0.31 (0.29-0.33)	0.22 (0.21-0.23)
$\mathrm{Log}(n_e t)$:	10.8 (10.7-10.9)	11.4 (11.3-11.5)
C:	1.2 (0.9-1.4)	0.45 (0.38-0.50)
N:	1.2 (0.9-1.5)	0.49 (0.42-0.54)
O:	0.6 (0.4-0.7)	0.26 (0.23-0.27)
Ne:	0.9 (0.7-1.1)	0.59 (0.53-0.63)
Mg:	0.3 (0.2-0.4)	0.22 (0.17-0.26)
Fe:	0.5 (0.4-0.6)	0.23 (0.20-0.26)
χ^2/dof:	1353/531	758/463

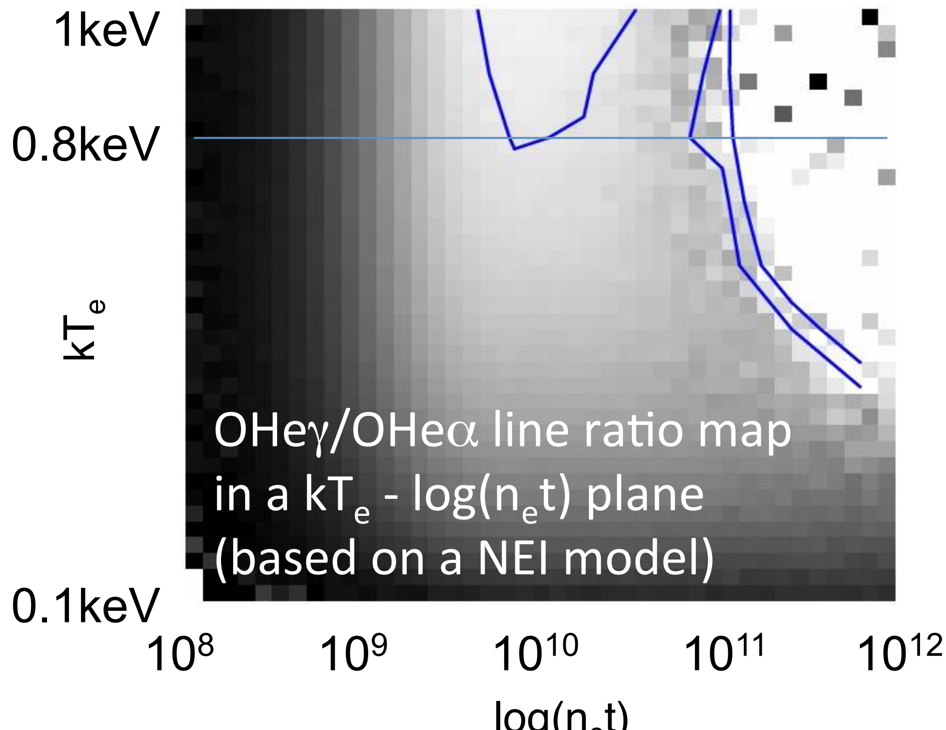
What is the origin of the excess@0.7 keV?

- Thermal Origin?
  - Fe XVII L (3s→2p: 730eV)
  - He-like O Kγ+Kδ+… (e.g., SN1006; Yamaguchi+2008)

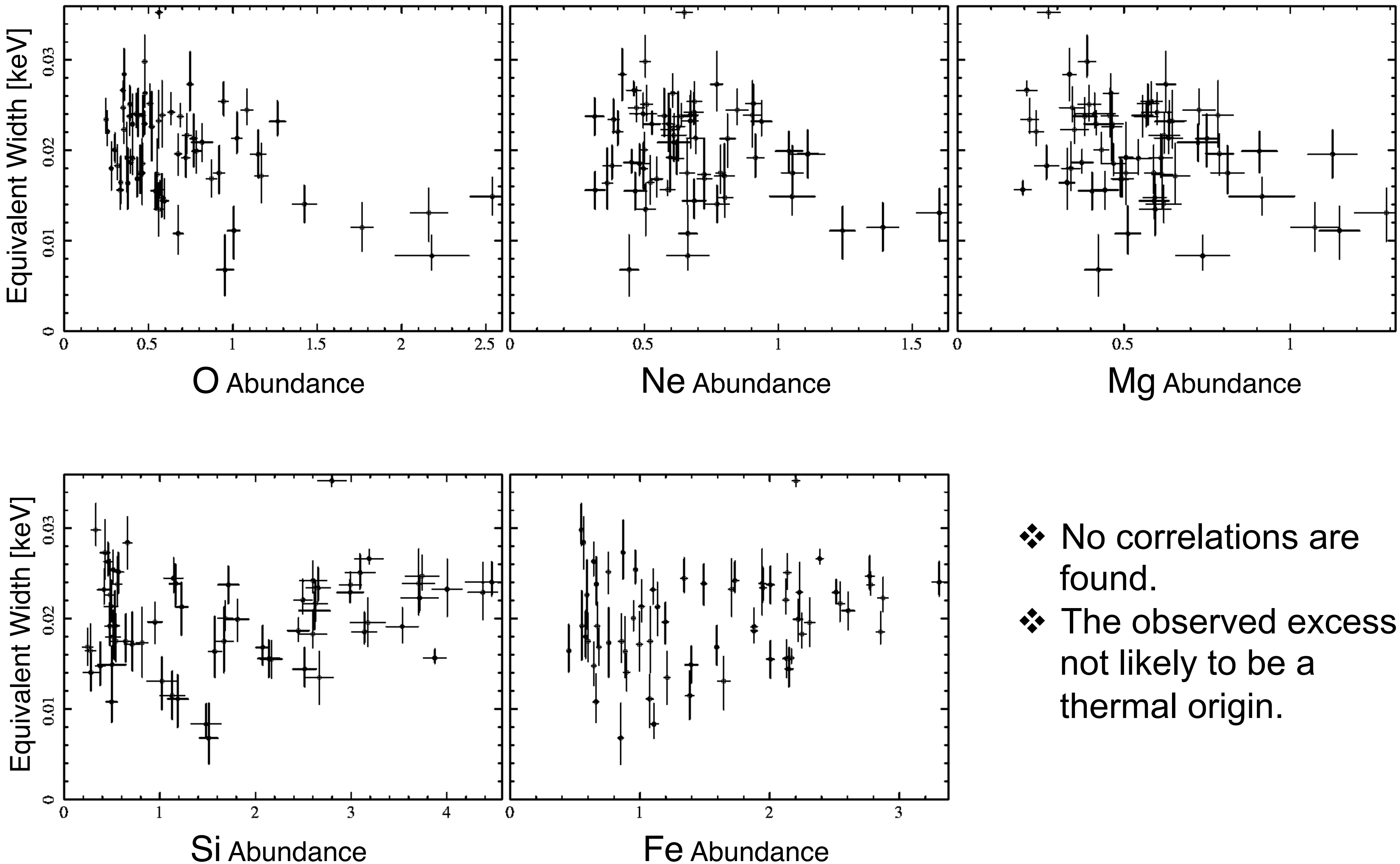
→ Heγ / Heα ratio (~0.045) requires a very high temperature.



Flux ratio of X to O Heα : 0.041-0.049



Abundance vs. EW@0.7 keV Plot in the Cygnus Loop



- ❖ No correlations are found.
- ❖ The observed excess is not likely to be a thermal origin.

What is the origin of the excess@0.7 keV?

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  - Fe XVII L (3s→2p: 730eV)
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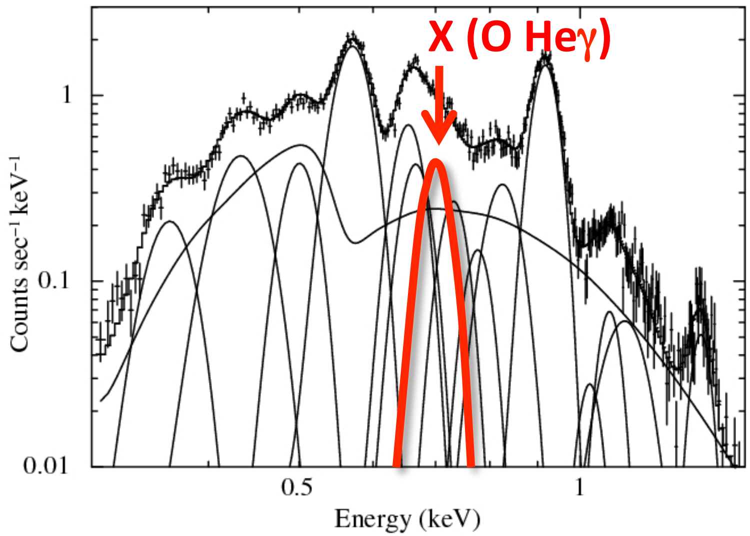

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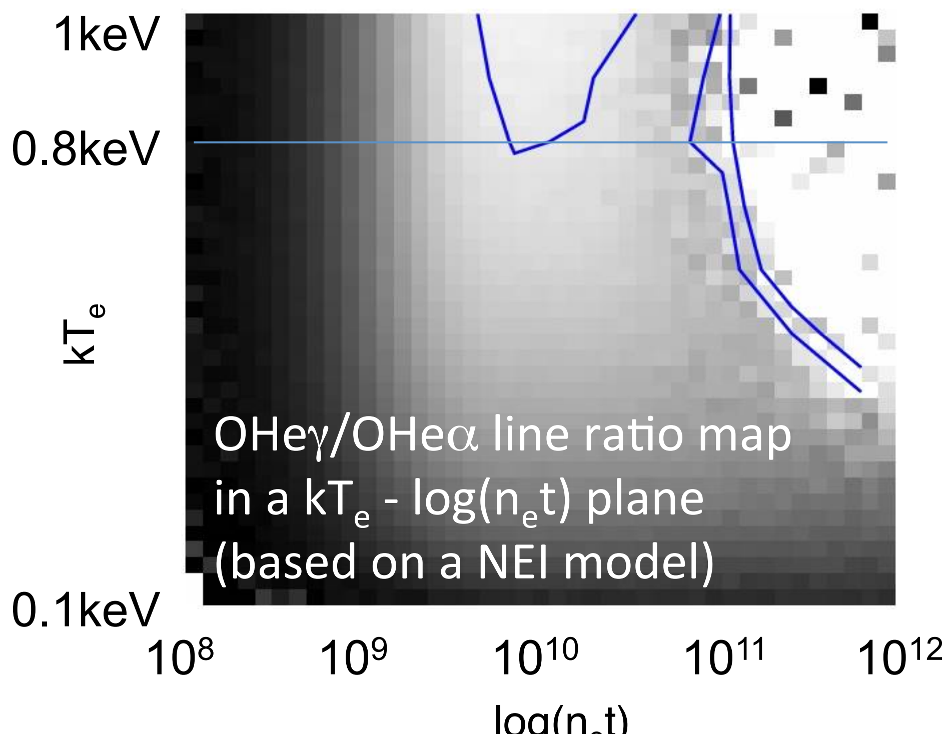
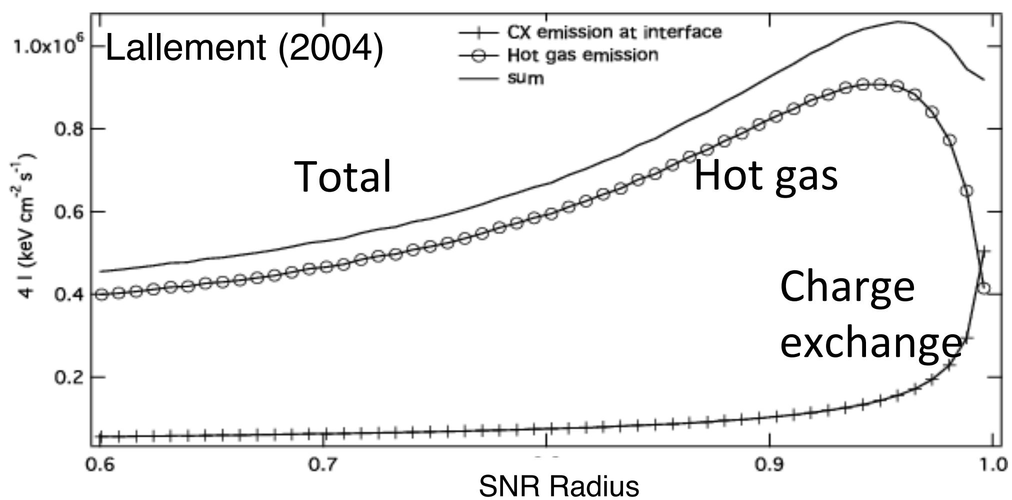


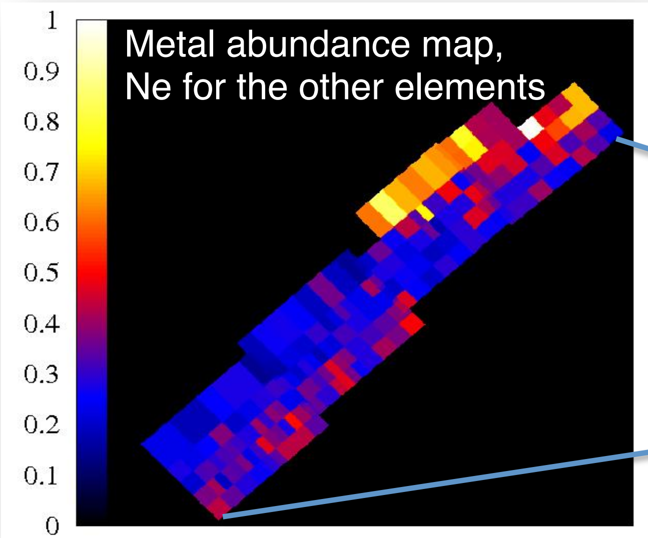
What is the origin of the excess@0.7 keV?

- Thermal Origin?
  - Fe L lines（3s→2p: 730eV, 3d→2p: 820eV）
  - He-like O Kγ+Kδ+… (e.g., SN1007;)
- He-like O K cascade?
  - Recombining Plasma (Yamaguchi-san's talk)
    → No RRC feature is found in the Cygnus Loop spectra.
  - Photoionized Plasma (e.g, Cyg X-3; Kawashima & Kitamoto 1996)
    → There are no strong X-ray sources around the Cygnus Loop.
  - Charge Exchange (Katsuda et al. 2011)

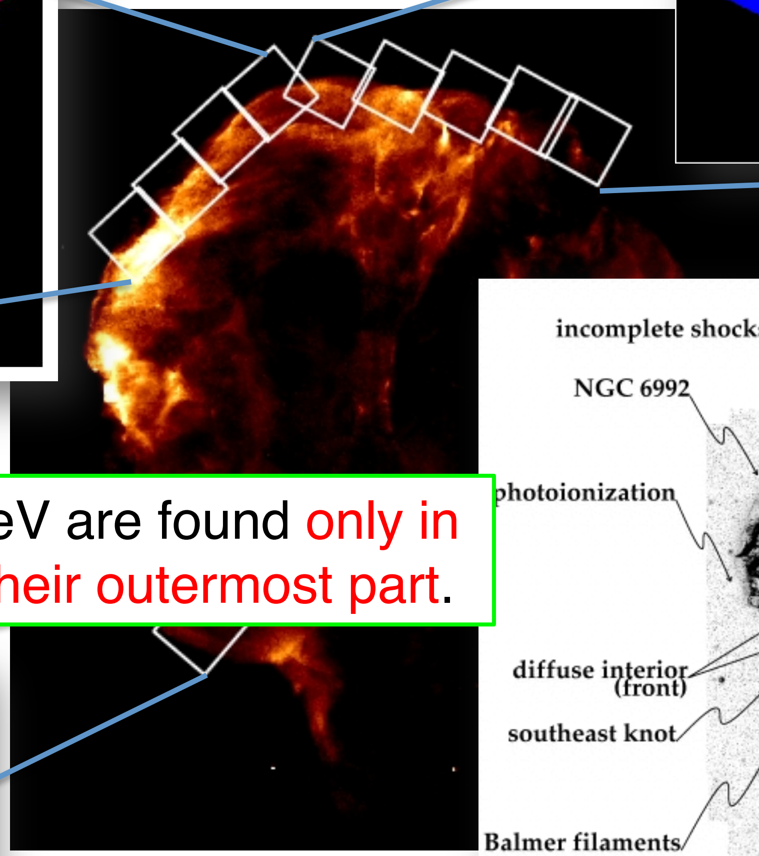
Lallement (2004) claimed that charge exchange emission could be significant at narrow regions just behind shocks.

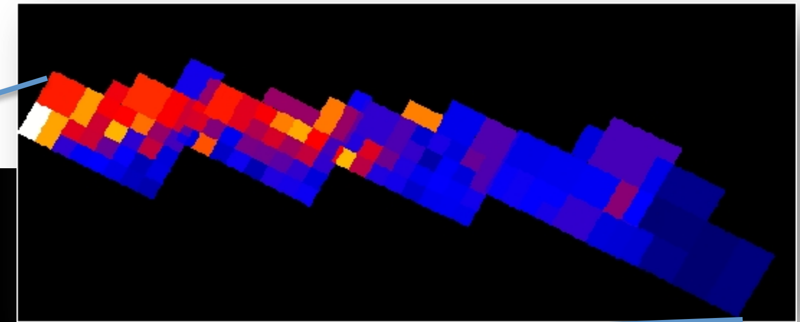


Charge Exchange Region in the Cygnus Loop

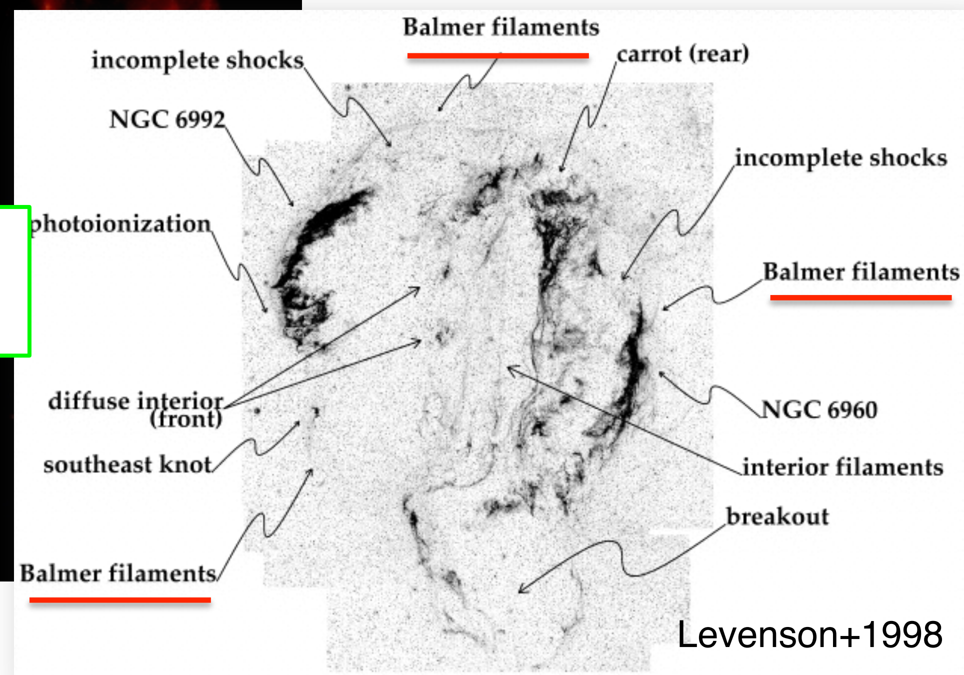


Katsuda+2008



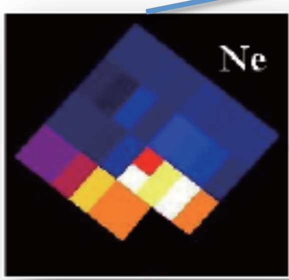


Uchida+2009c



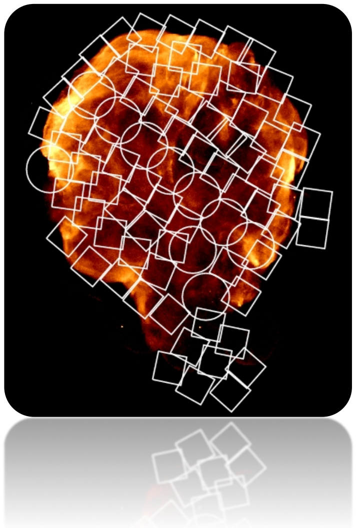
Levenson+1998

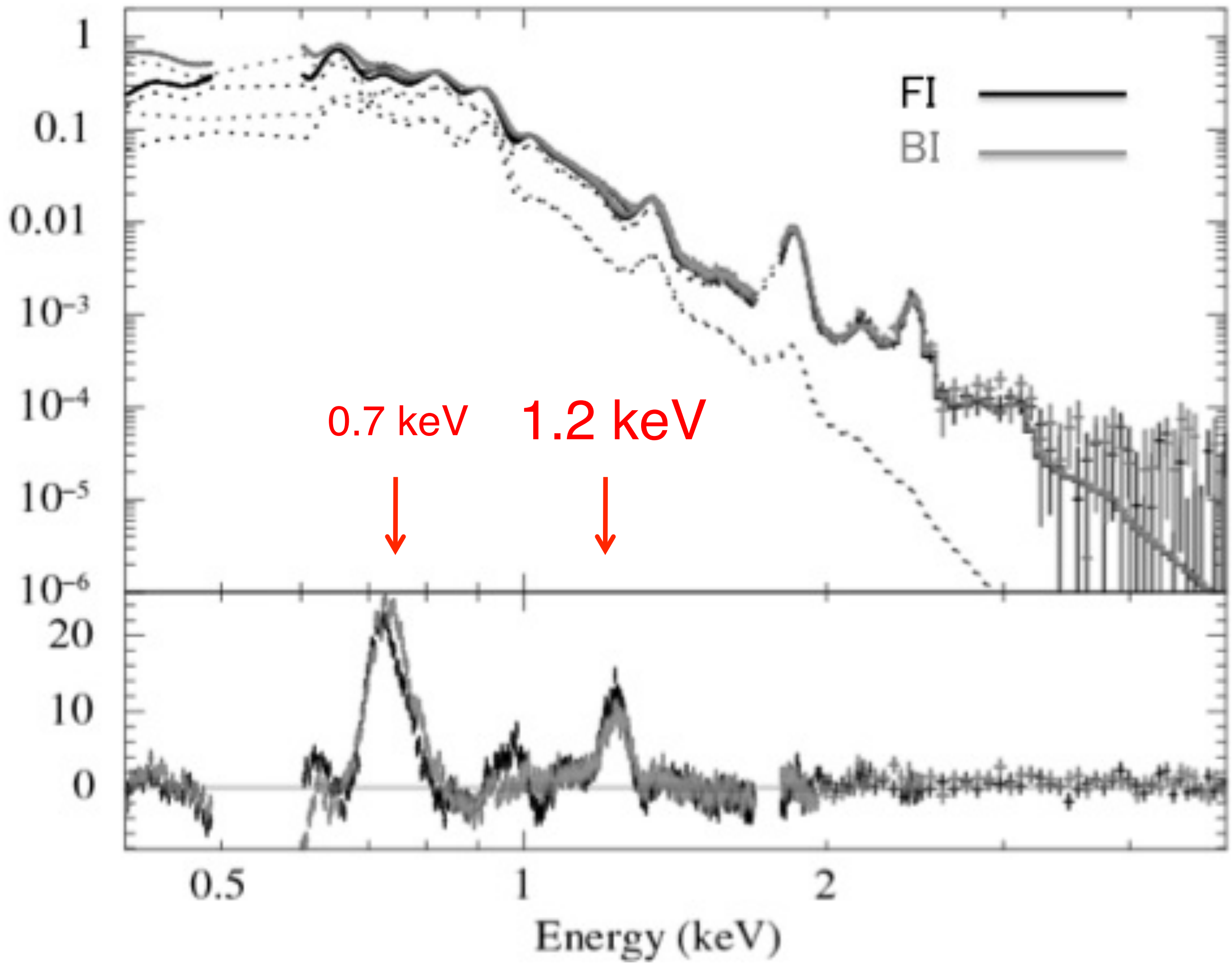
- The excesses@0.7keV are found only in some rims and only their outermost part.



We propose that the excess at 0.7 keV is due to a charge-exchange emission. (Katsuda et al. 2011)

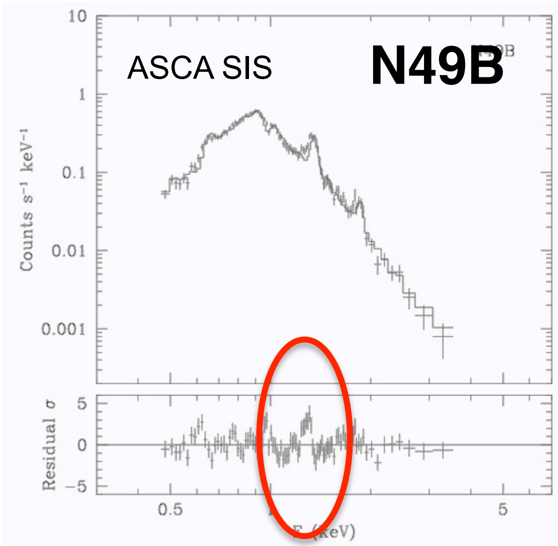
Fitting problems @ 0.7 keV and 1.2 keV in the current NEI model



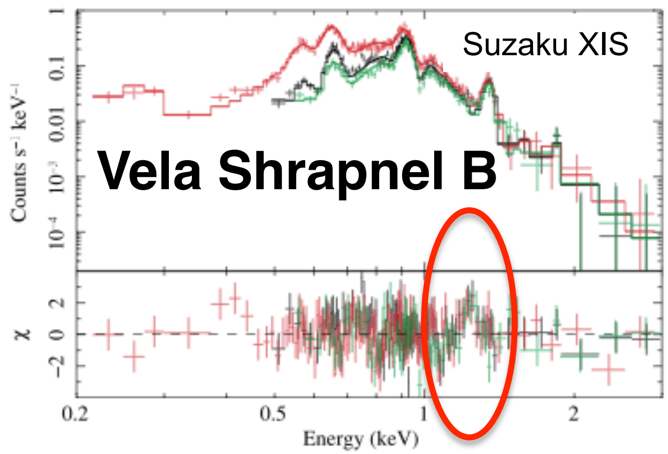


“1.2keV (missing) line problem”

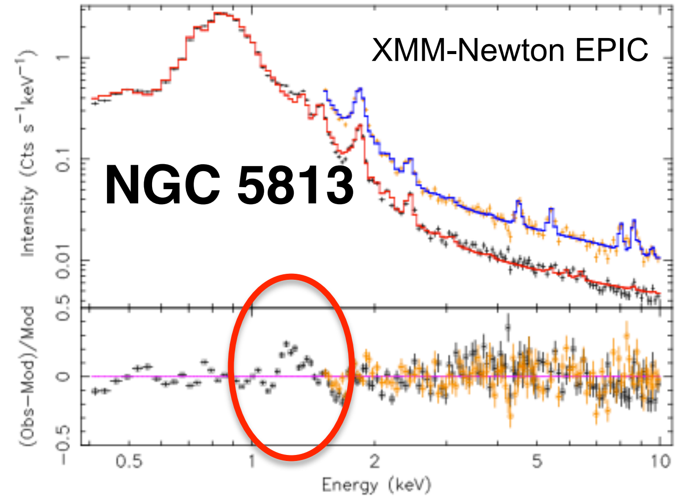
Hughes Hayashi & Koyama 1998 *ApJ* **505** 732



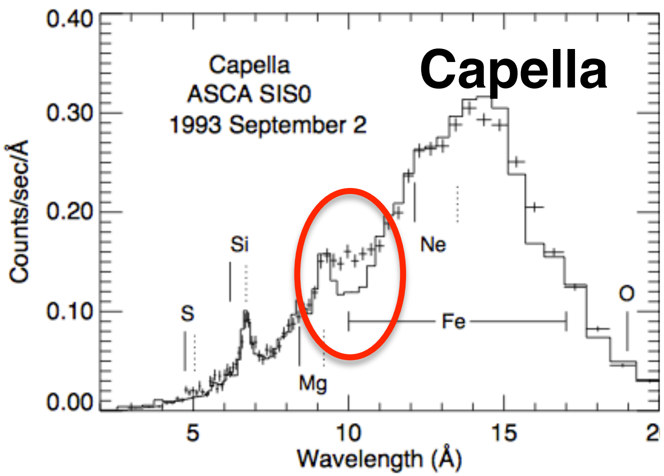
Yamaguchi & Katsuda 2009 *ApJ* **696** 1548



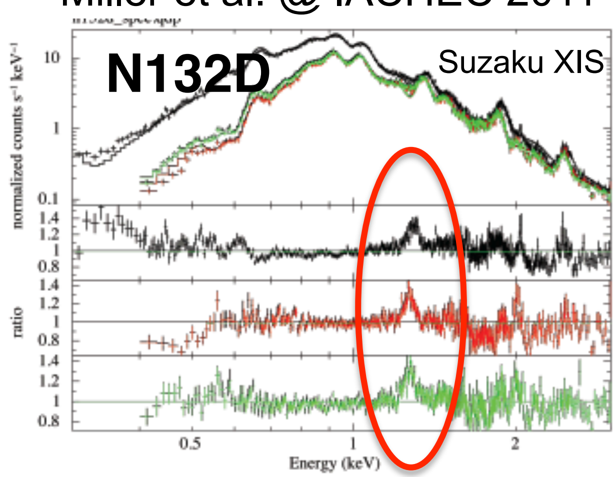
Grange et al. 2011 *submitted*



Brickhouse et al. 2000 *ApJ* **530** 387

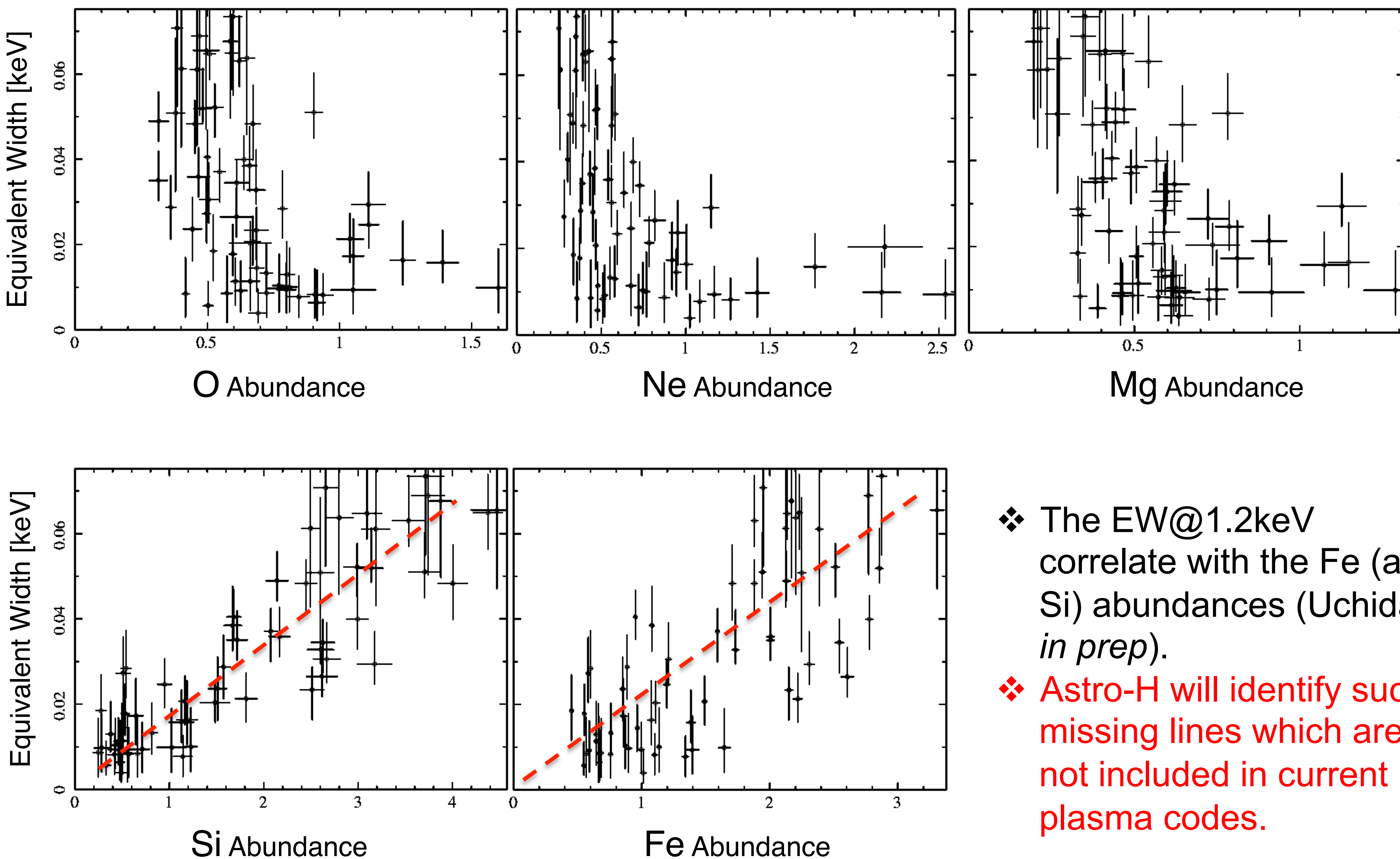


Miller et al. @ IACHEC 2011



- The missing line problem at 1.2 keV is often seen in many spectra with many detectors.
- Most of their sources are “Fe-rich”, which strongly suggests that these lines originate from a missing F-L line.

Correlations between the EW@1.2 keV and elemental abundances



- ❖ The EW@1.2keV correlate with the Fe (and Si) abundances (Uchida+ *in prep*).
- ❖ Astro-H will identify such missing lines which are not included in current plasma codes.

Summary

- We have observed the Cygnus Loop with Suzaku and XMM-Newton. The total exposure time reaches into ~1.7Ms.
- The ejecta structure show a clear “onion-like” structure. The heavy elements such as Si and Fe are much more abundant in the south toward the blowout region.
- We found that the spectra obtained from the enhanced-abundance regions have an excess at 0.7 keV.
- By considering various possibilities, we concluded that the excess at 0.7 keV originates from the charge-exchange emission at the outermost rim of the Loop.
- We also found a line-like feature at 1.2 keV and concluded the line originates from a missing Fe L line which is not included in the current plasma code.
- Astro-H SXS will be a key instrument to confirm the presence of charge exchange emission and a missing Fe L line at 1.2 keV.