

# A Brief Review of Suzaku Results on Supernova Remnants

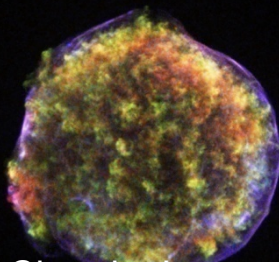
~Thermal Emission from SN Ejecta~

Satoru KATSUDA (GSFC / Osaka U. Japan)

Young SNRs:

=> **Detection of Ar, Ca, Cr, Mn,  
and Fe K-shell lines from Ejecta:**

Tycho's SNR



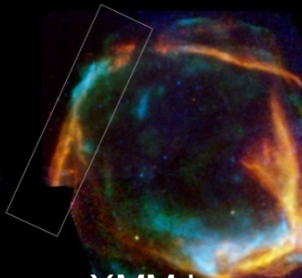
Chandra image  
(Credit: CXC)

SN1006



Chandra image  
(Credit: NASA)

RCW86

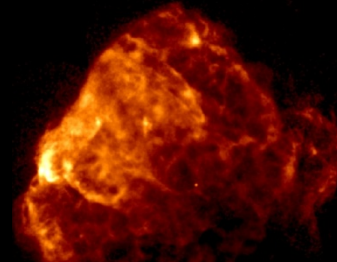


XMM image  
(Vink+ 2006)

Evolved SNRs:

=> **Detailed Spatial  
Structure of Ejecta:**

Puppis A

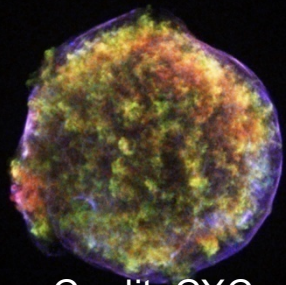


HRI image

Cygnus Loop



HRI image

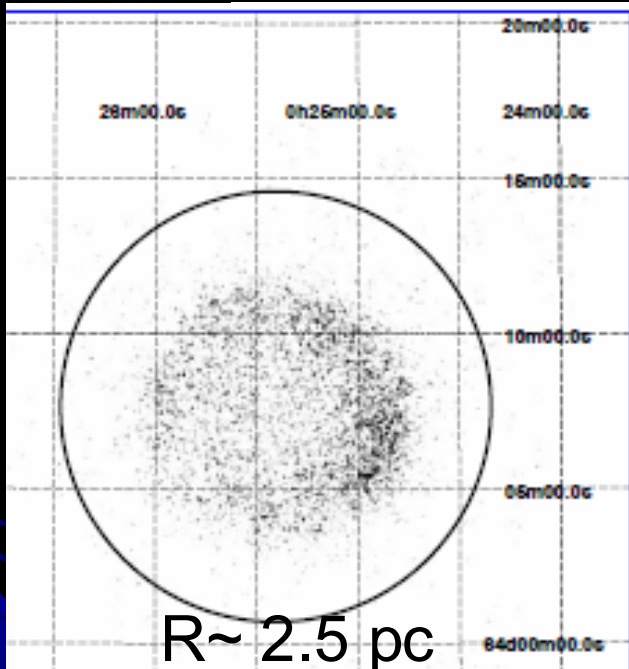


Credit: CXC

# Tycho's SNR: ~430 yrs old

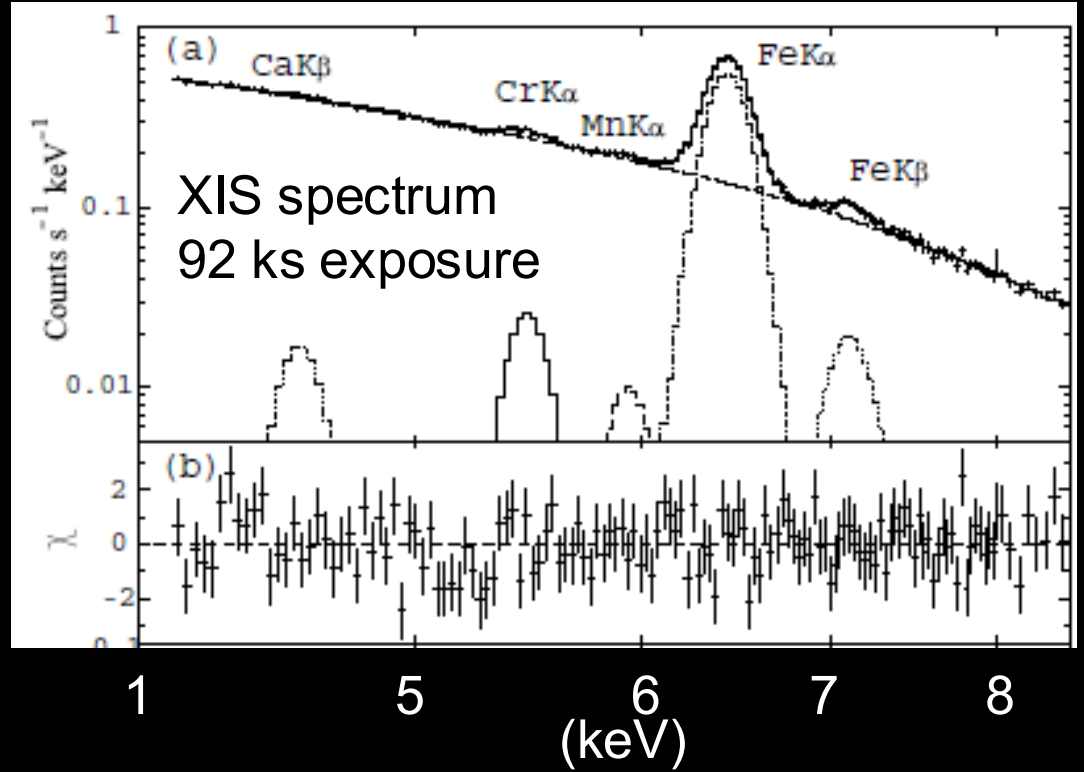
Tamagawa+ 2009, PASJ in press

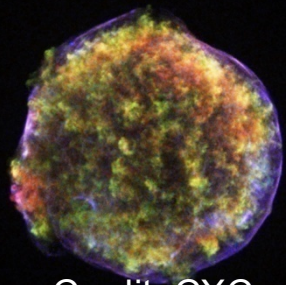
Furuzawa+ submitted to ApJ



$R \sim 2.5$  pc

XIS Image



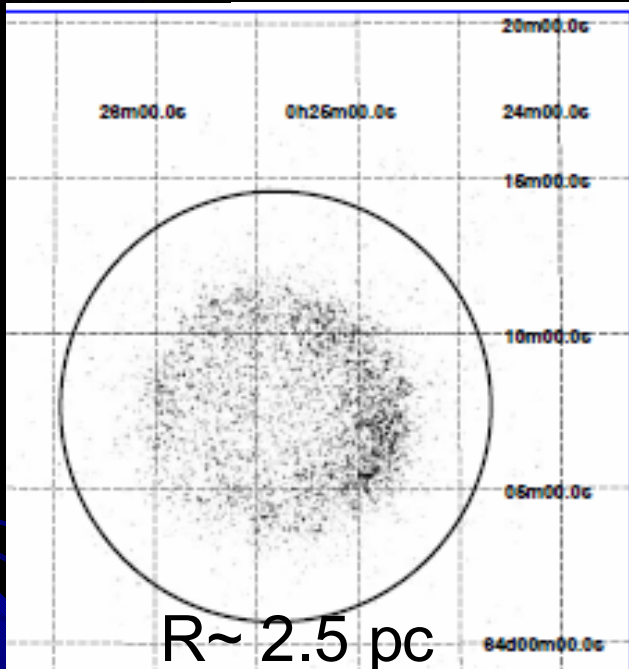


Credit: CXC

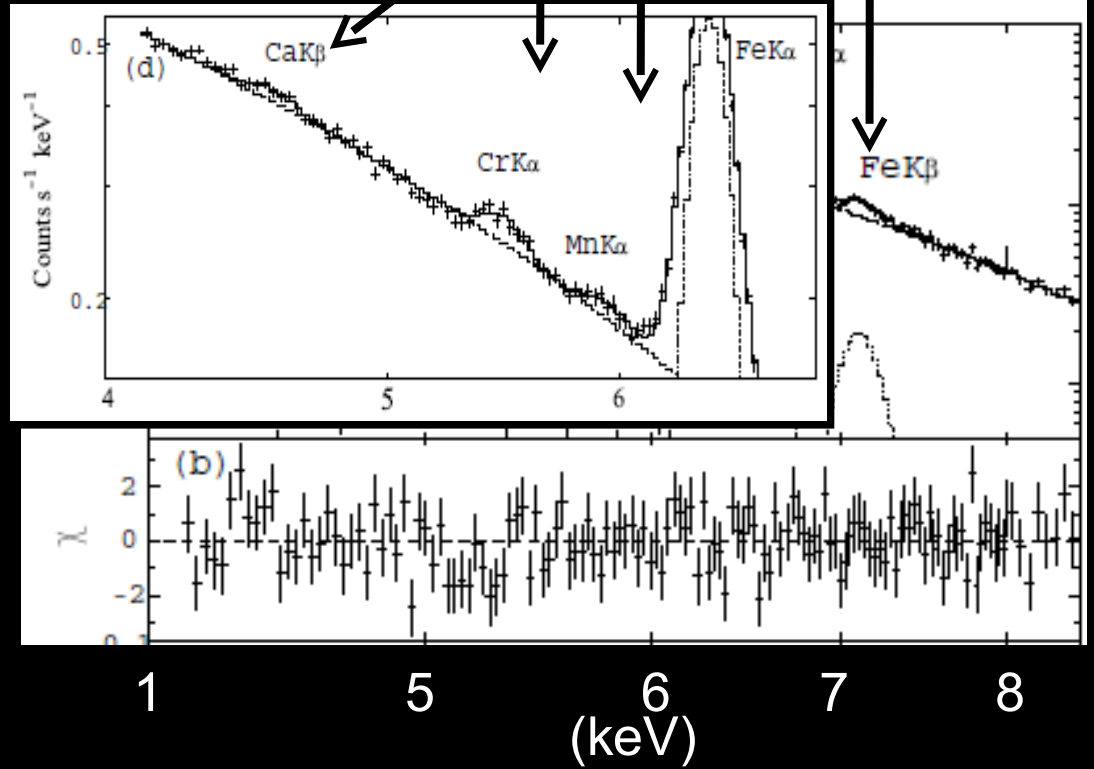
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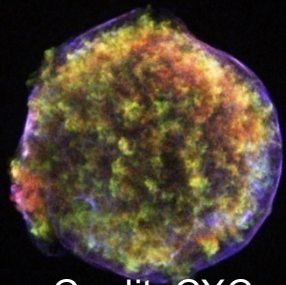
Tamagawa+ 2009, PASJ in press  
Furuzawa+ submitted to ApJ

First detection



R ~ 2.5 pc  
XIS Image



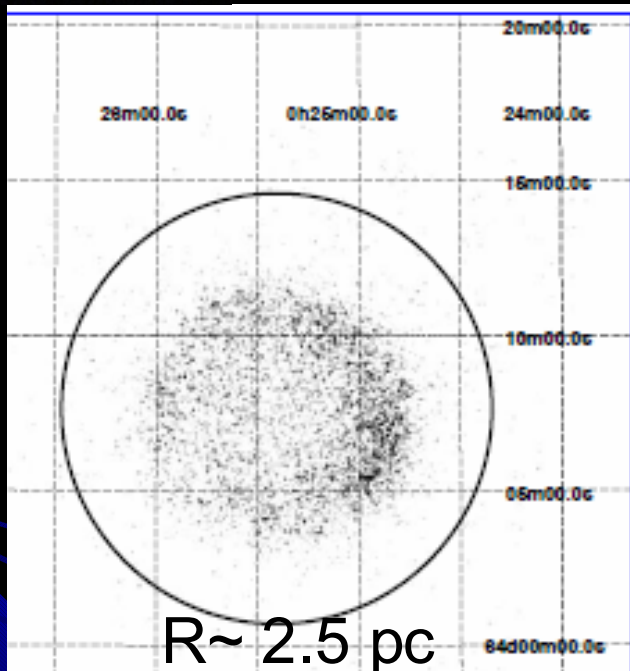


Credit: CXC

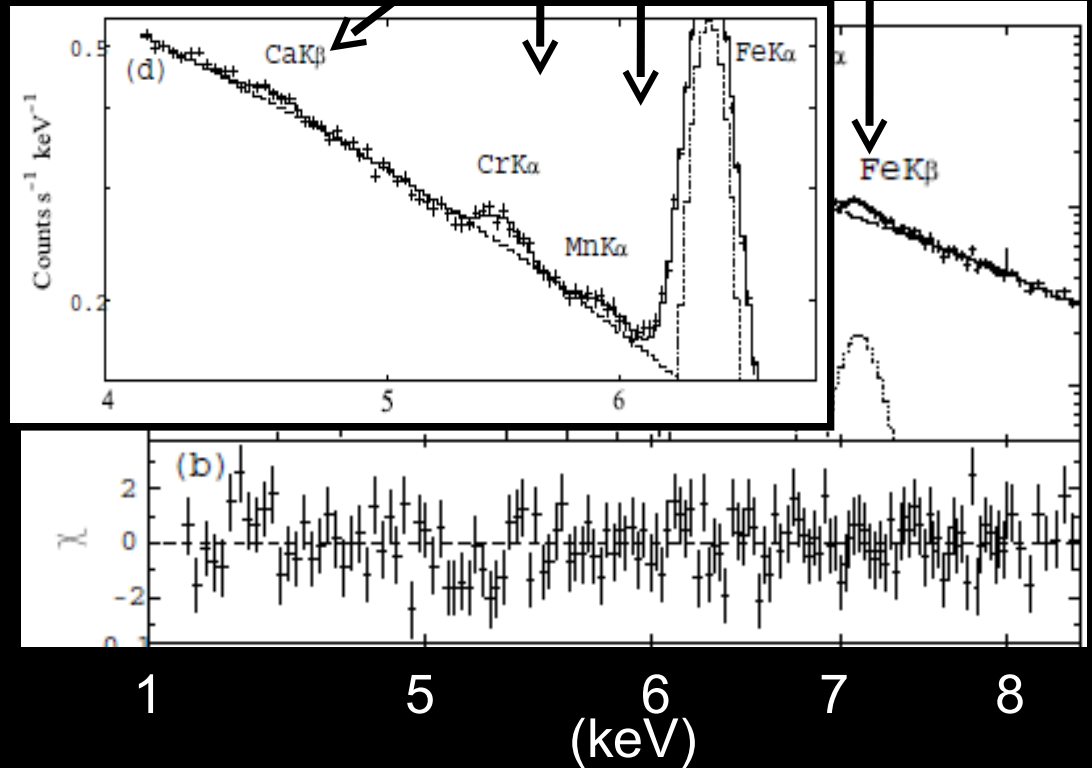
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Tamagawa+ 2009, PASJ in press  
Furuzawa+ submitted to ApJ

First detection



R ~ 2.5 pc  
XIS Image



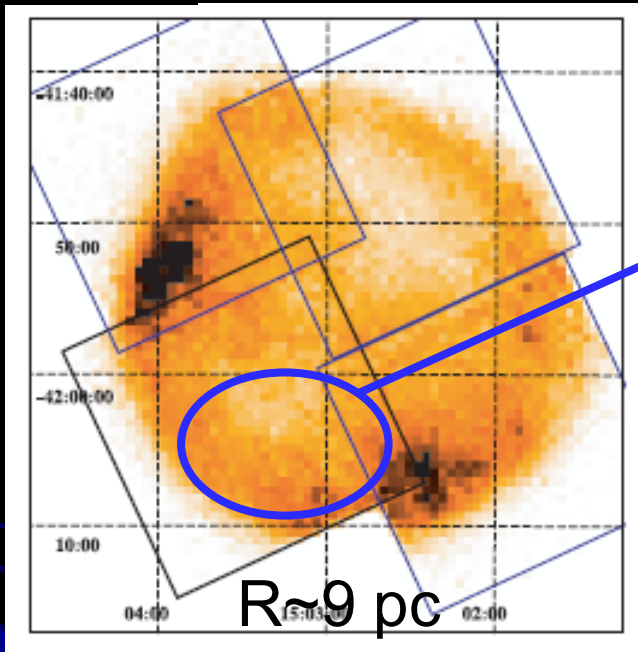
The first detection of lines at 4.56 keV => He-like Ca K $\beta$   
5.48 keV => Ne-like Cr K $\alpha$   
5.95 keV => Ne-like Mn K $\alpha$   
7.11 keV => Ne-like Fe K $\beta$



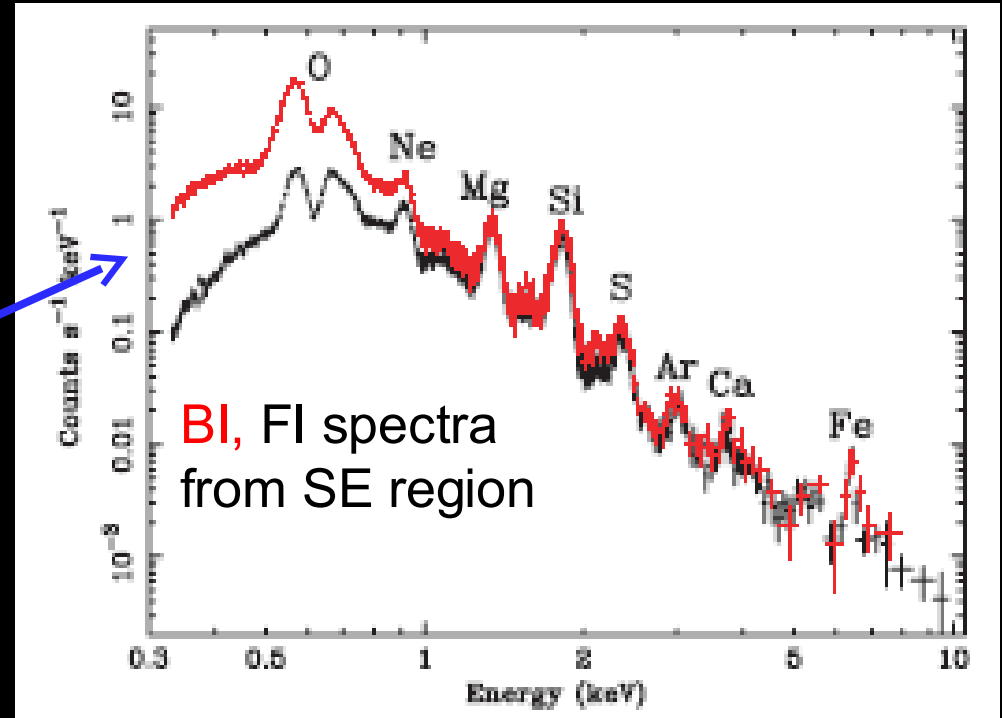
# SN1006: ~1,000 yrs old

Yamaguchi+ 2008, PASJ, 60, S141

Credit: NASA



XIS image

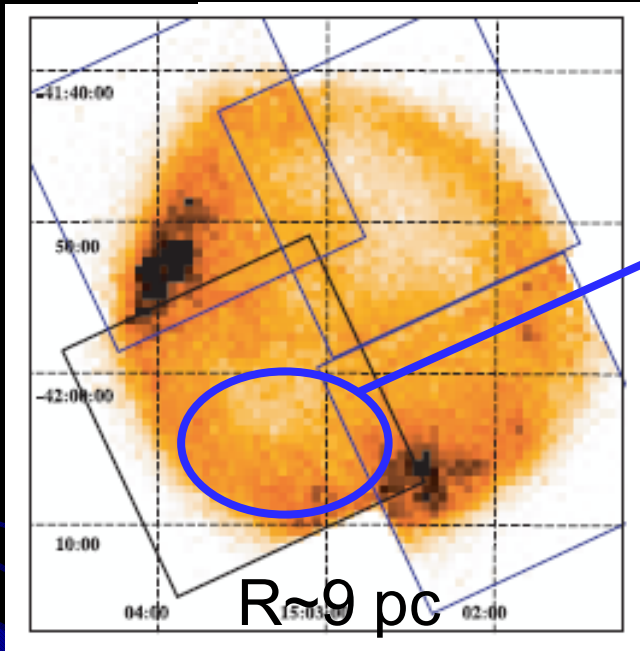




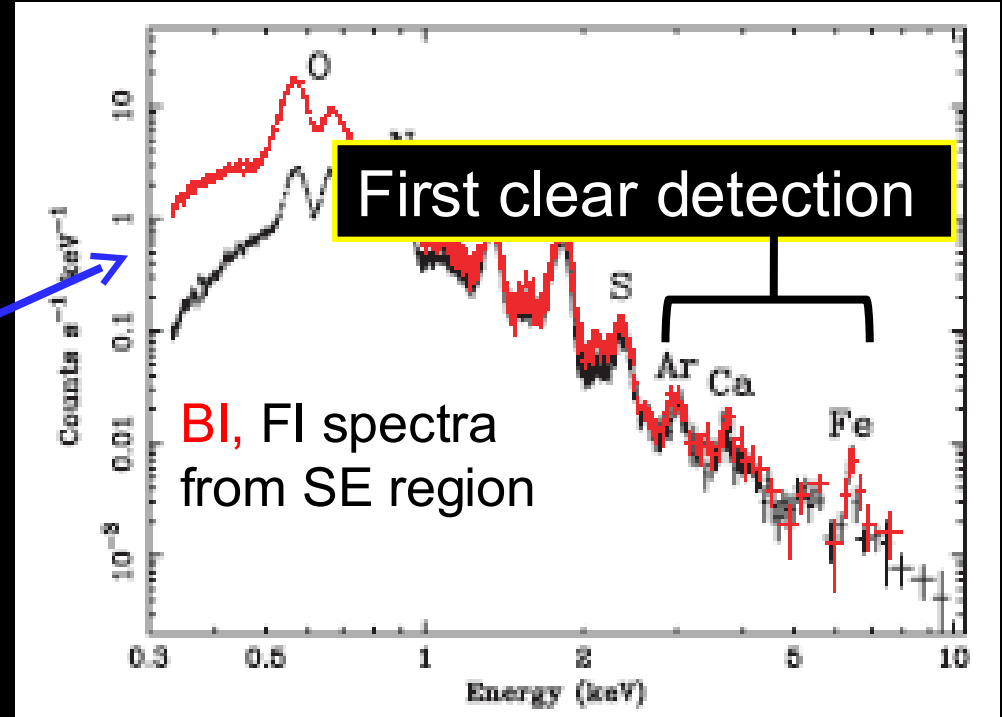
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XIS image

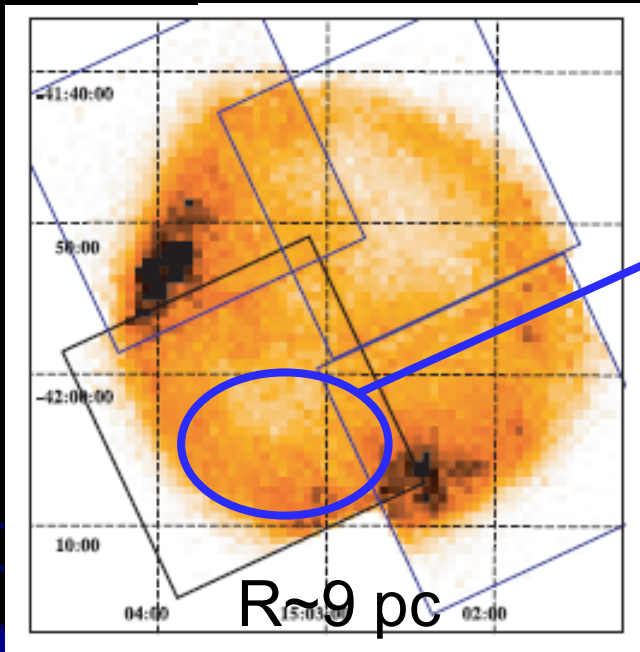




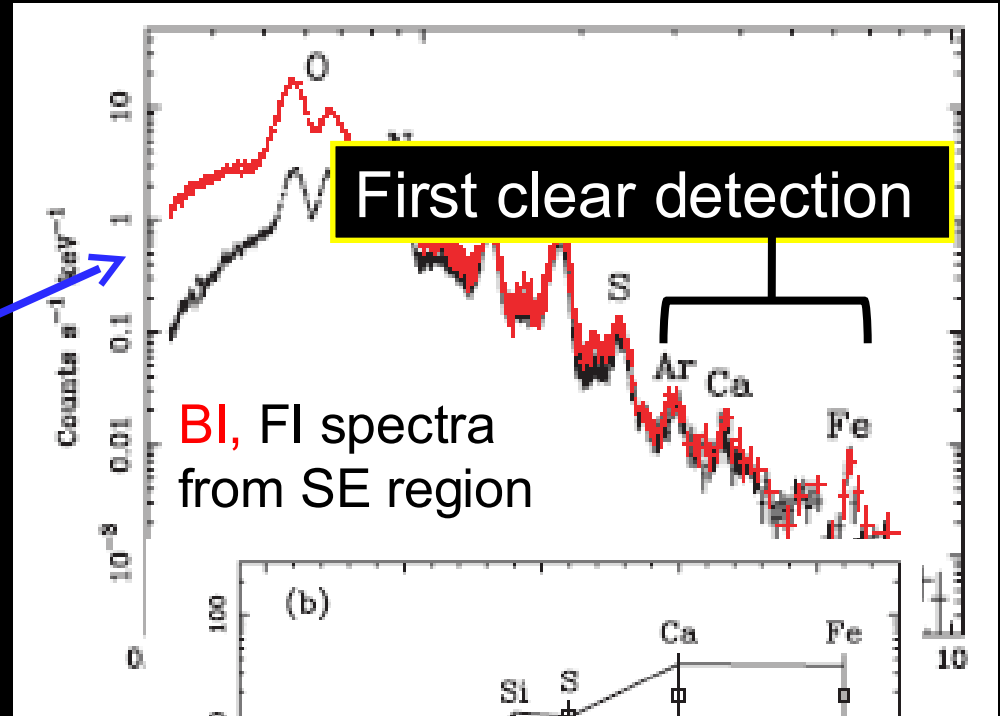
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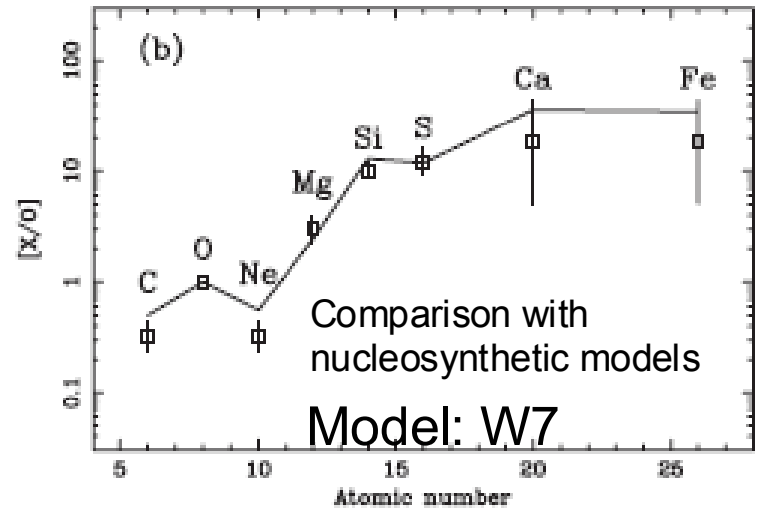


XIS image



BI, FI spectra from SE region

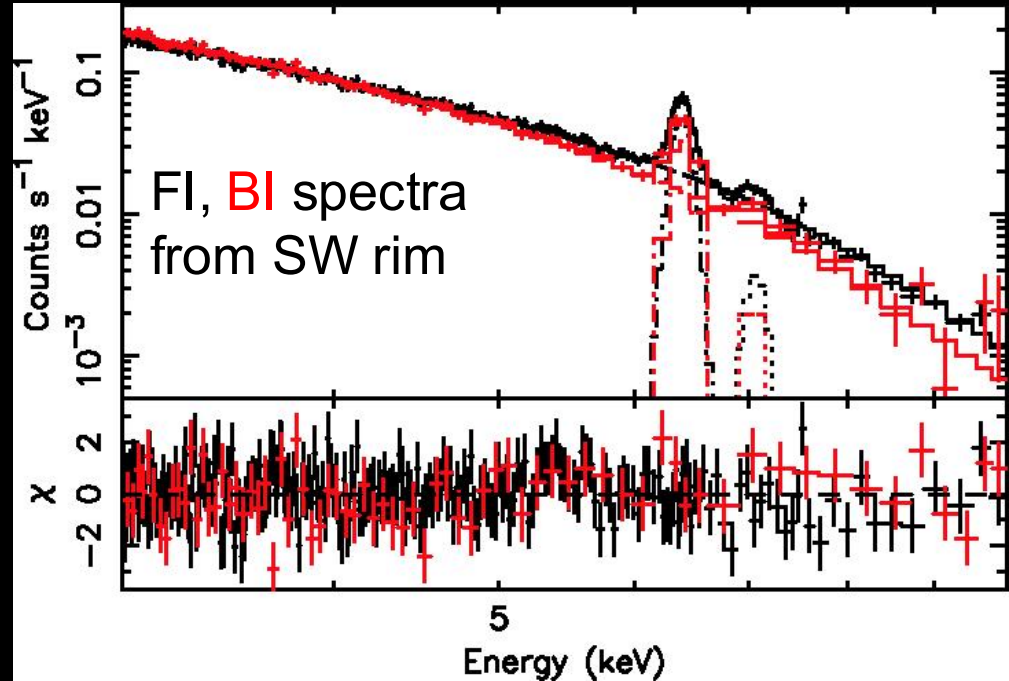
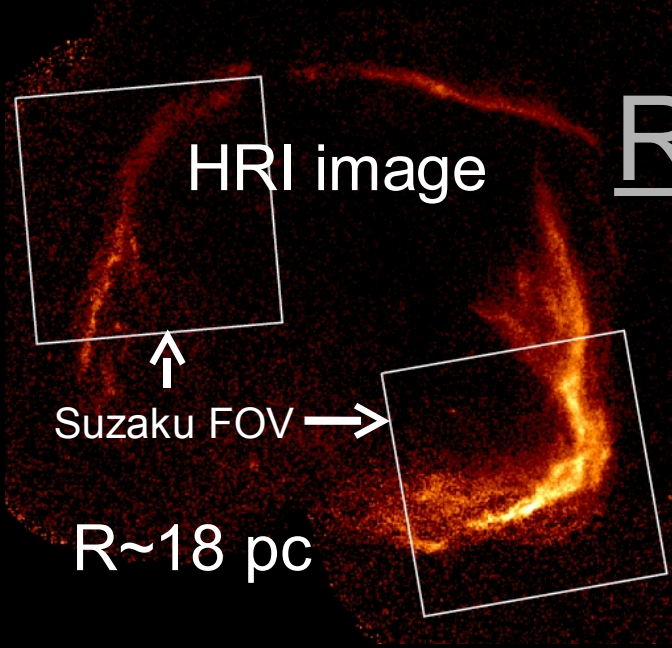
The **relative abundances** support Type-Ia origin.



# RCW 86: ~2,000 yrs old

Ueno+ 2007, PASJ, 59, S171

Yamaguchi+ 2008, PASJ, 60, S123

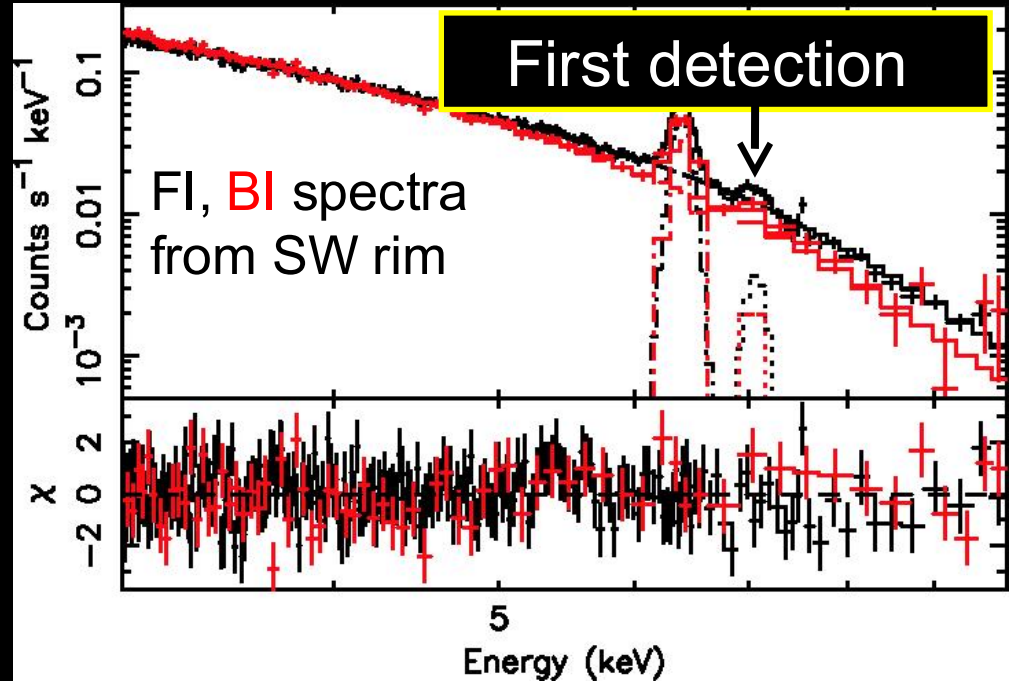
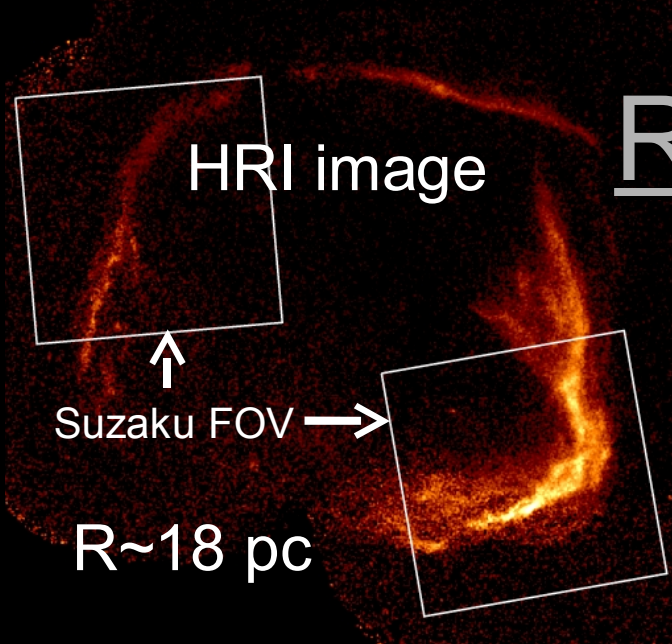




# RCW 86: $\sim 2,000$ yrs old

Ueno+ 2007, PASJ, 59, S171

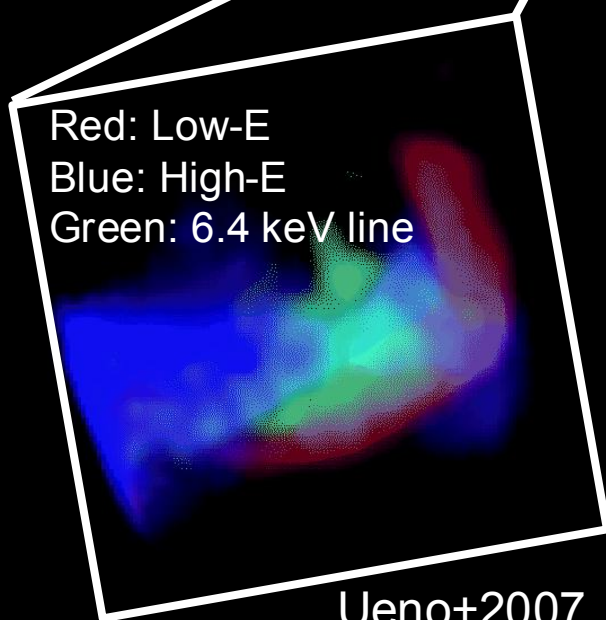
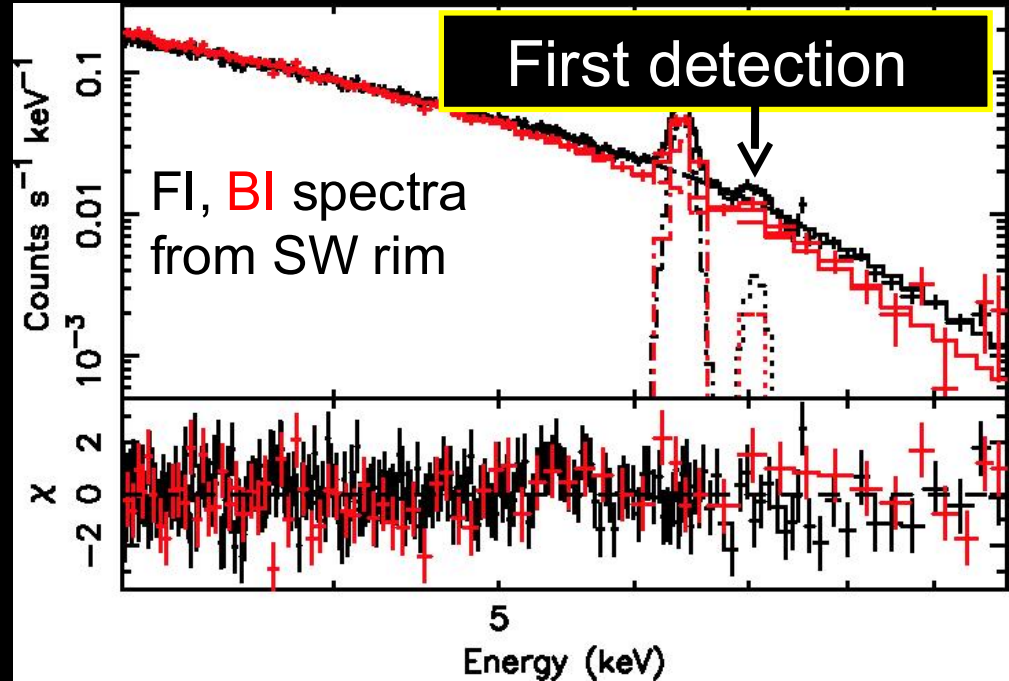
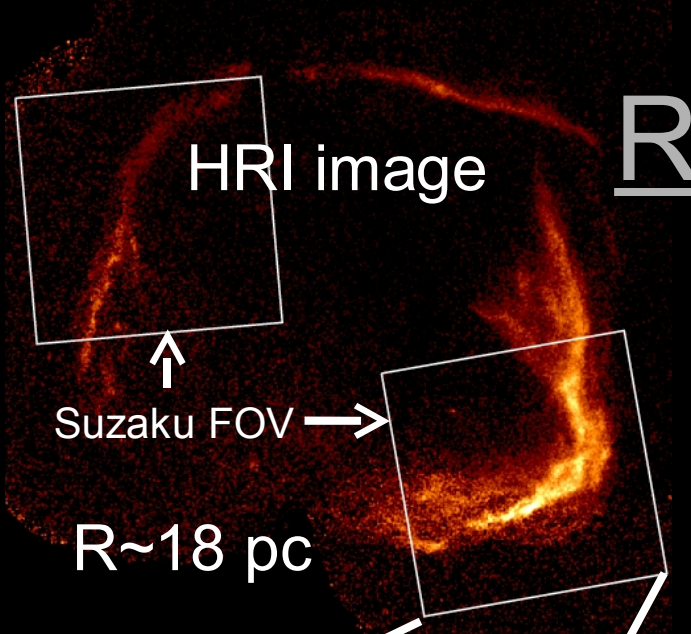
Yamaguchi+ 2008, PASJ, 60, S123



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Ueno+ 2007, PASJ, 59, S171

Yamaguchi+ 2008, PASJ, 60, S123

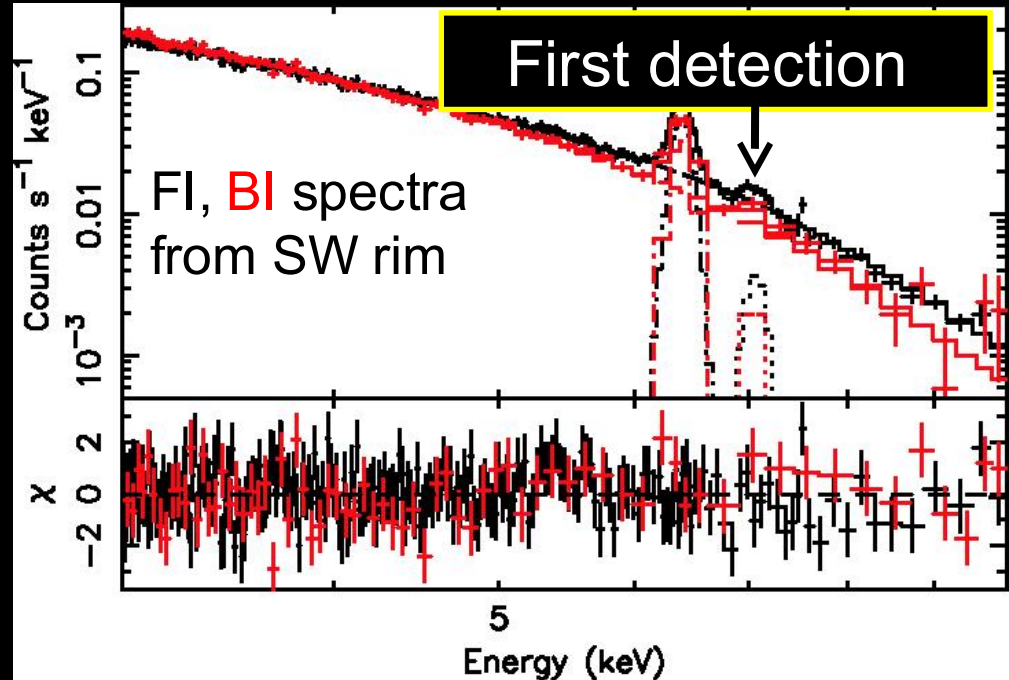
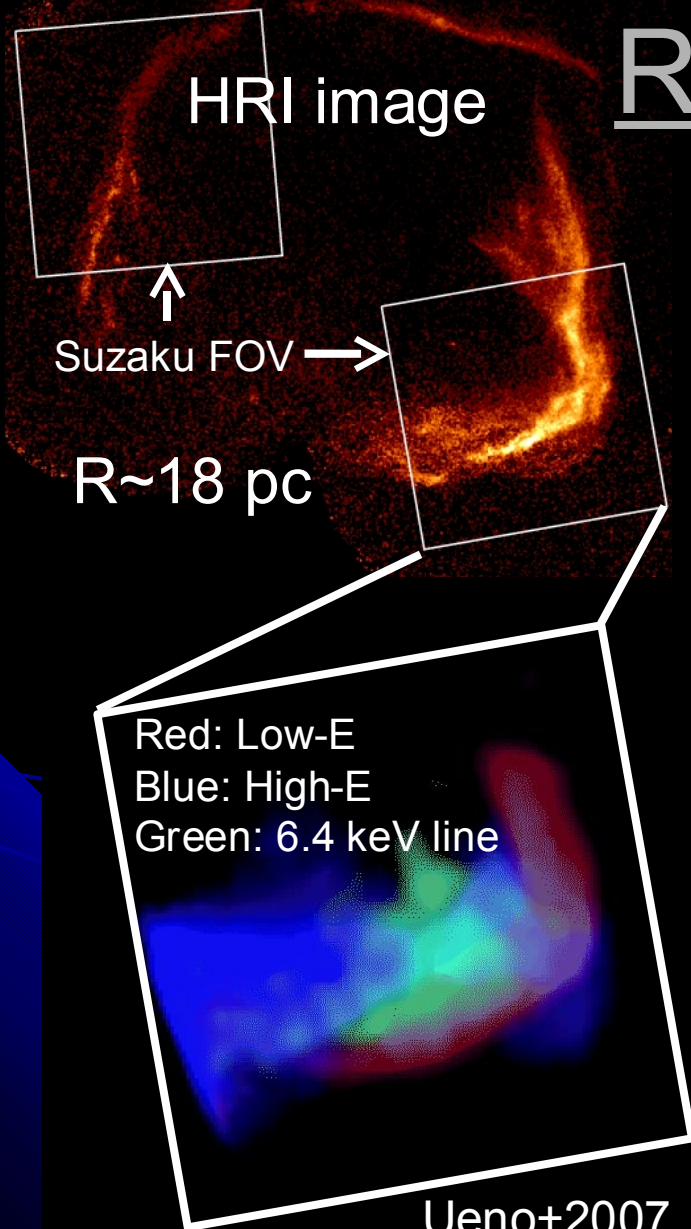


XIS three-color image

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Ueno+ 2007, PASJ, 59, S171

Yamaguchi+ 2008, PASJ, 60, S123



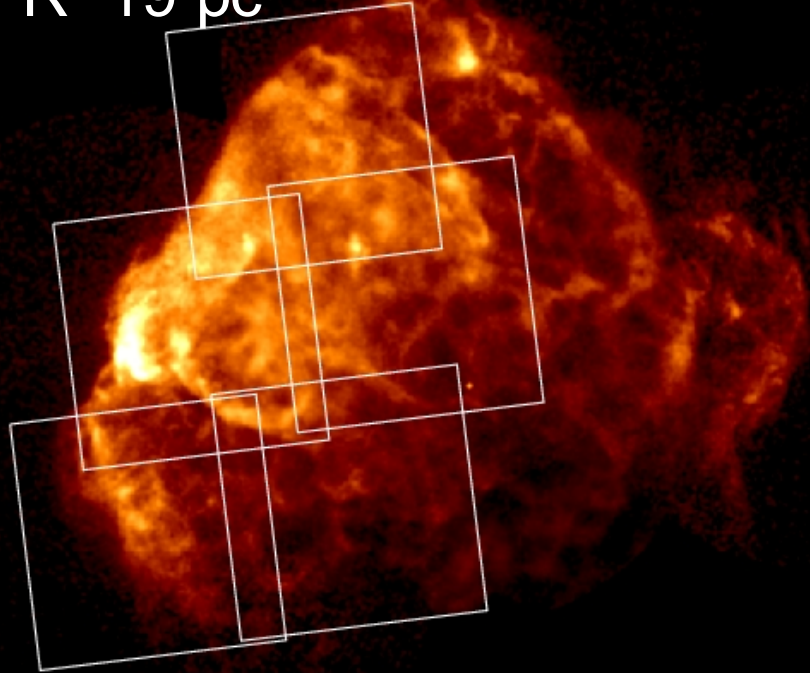
**Distinct distributions** of low-E, high-E, Fe K.

Fe-K line originates from the ejecta heated by a reverse shock.

# Puppis A SNR: ~4,000 yrs old

Hwang, Petre, & Flanagan 2008, ApJ, 676, 378

R~19 pc

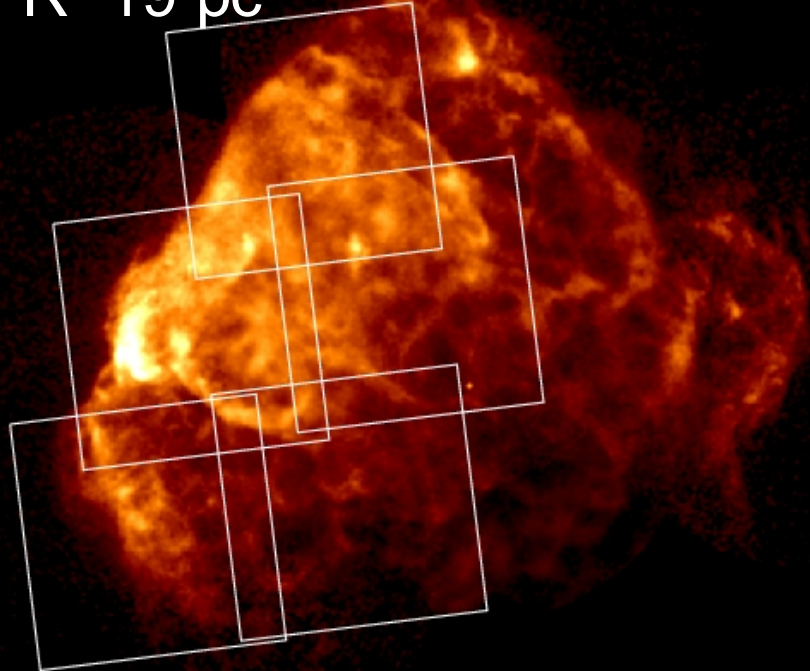


HRI image

# Puppis A SNR: ~4,000 yrs old

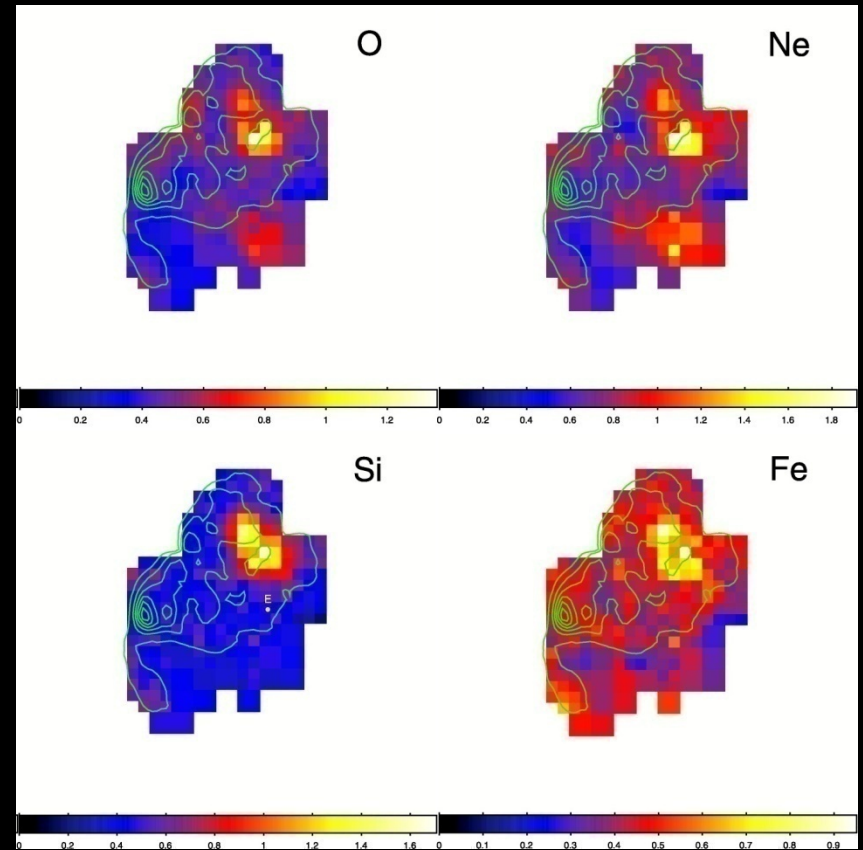
Hwang, Petre, & Flanagan 2008, ApJ, 676, 378

R~19 pc



HRI image

## Detailed Spatial Spectral Analysis

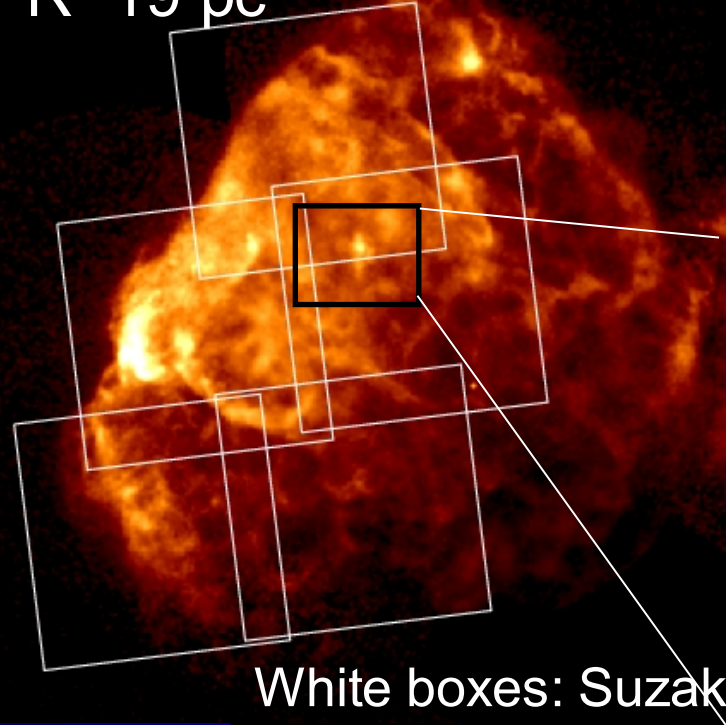


Abundance maps

# Puppis A SNR: ~4,000 yrs old

Hwang, Petre, & Flanagan 2008, ApJ, 676, 378

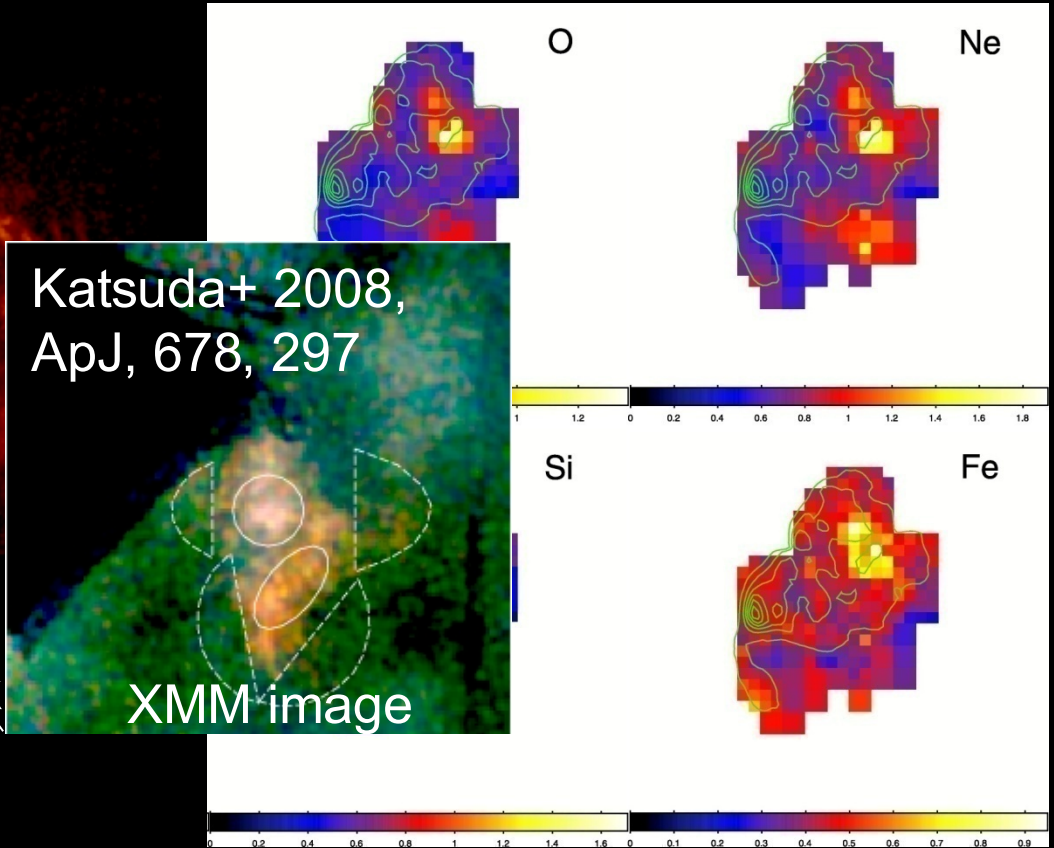
R~19 pc



White boxes: Suzaku

HRI image

## Detailed Spatial Spectral Analysis



Katsuda+ 2008,  
ApJ, 678, 297

XMM image

Abundance maps

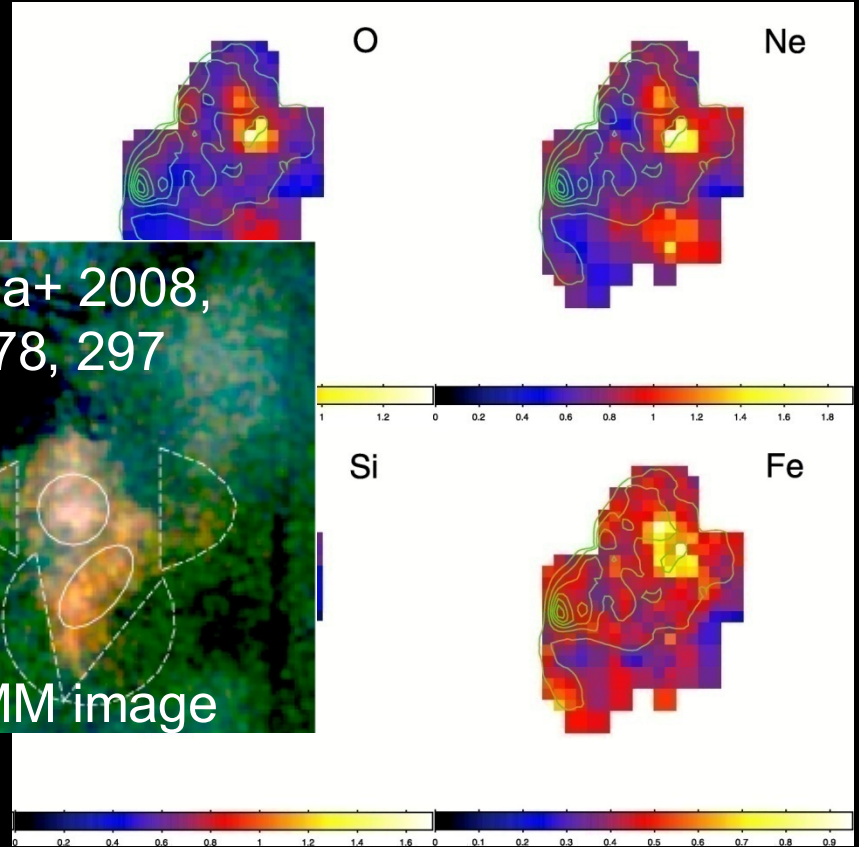
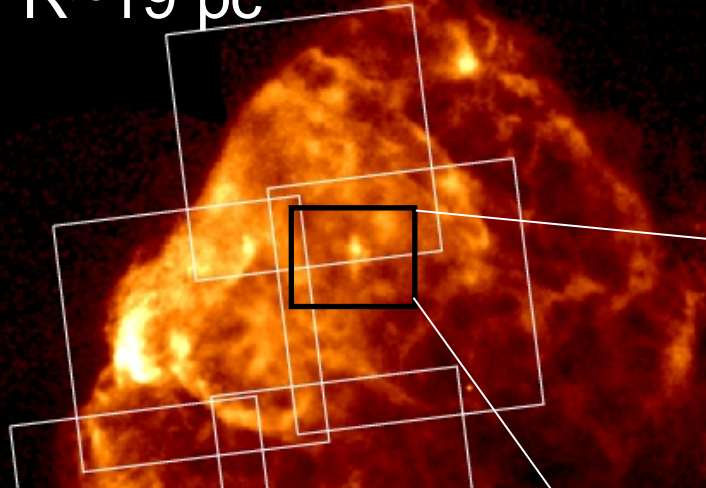
Local enhancements of metal abundances are found at NE region.

# Puppis A SNR: ~4,000 yrs old

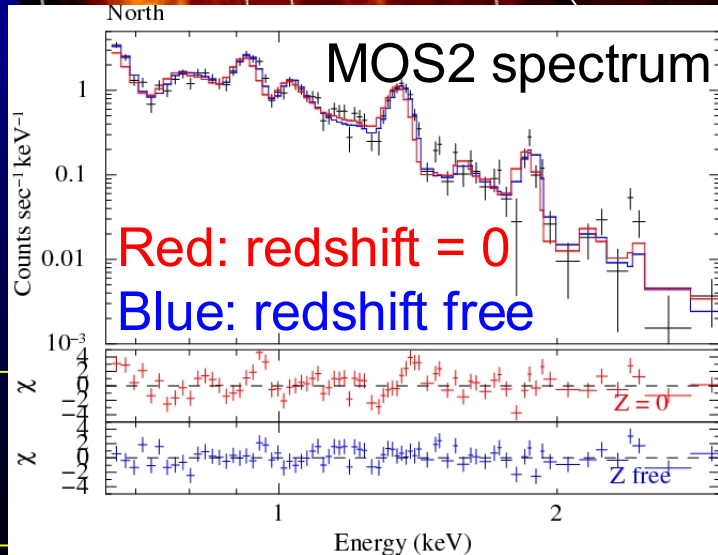
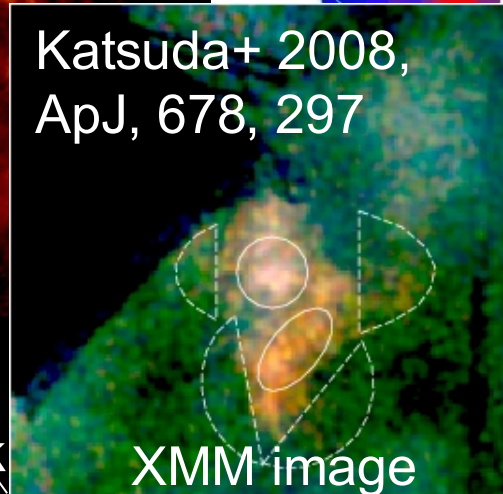
Hwang, Petre, & Flanagan 2008, ApJ, 676, 378

R~19 pc

Detailed Spatial Spectral Analysis



Katsuda+ 2008,  
ApJ, 678, 297



metal  
NE region.

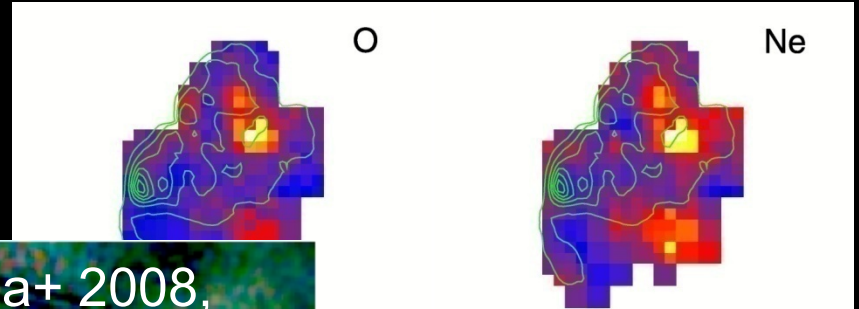
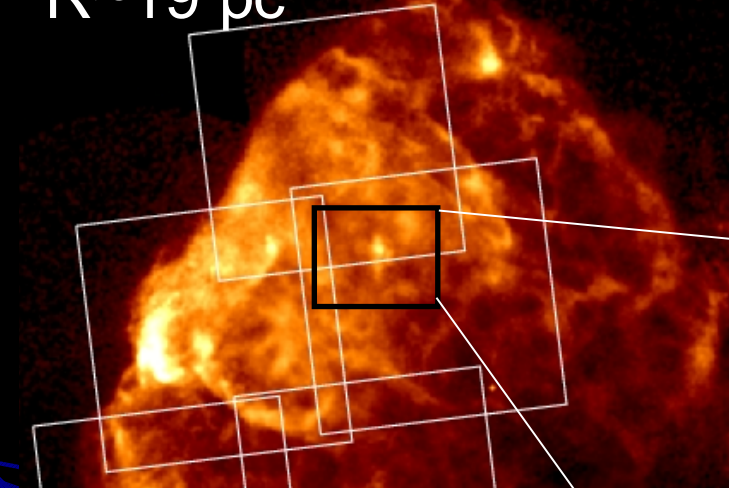
Abundance maps

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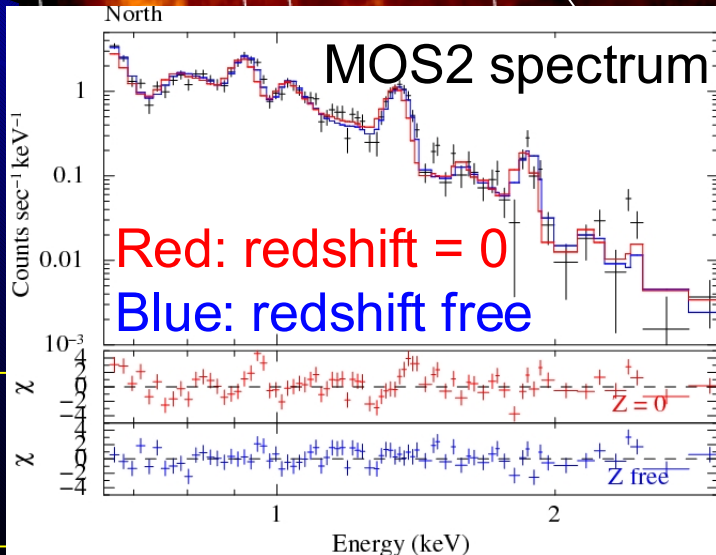
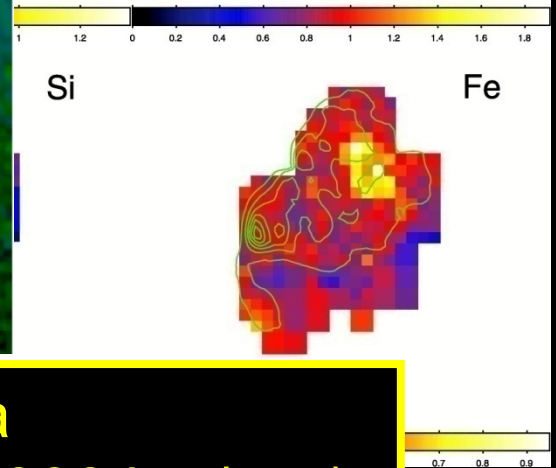
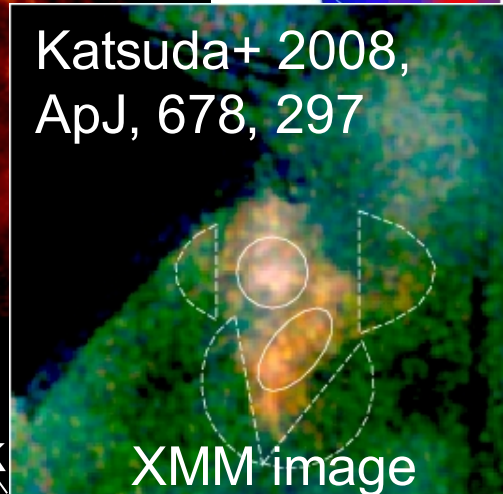
Hwang, Petre, & Flanagan 2008, ApJ, 676, 378

R~19 pc

## Detailed Spatial Spectral Analysis



Katsuda+ 2008,  
ApJ, 678, 297



- Metal-rich ejecta
- Fast moving (~3000 km/sec)

NE region.

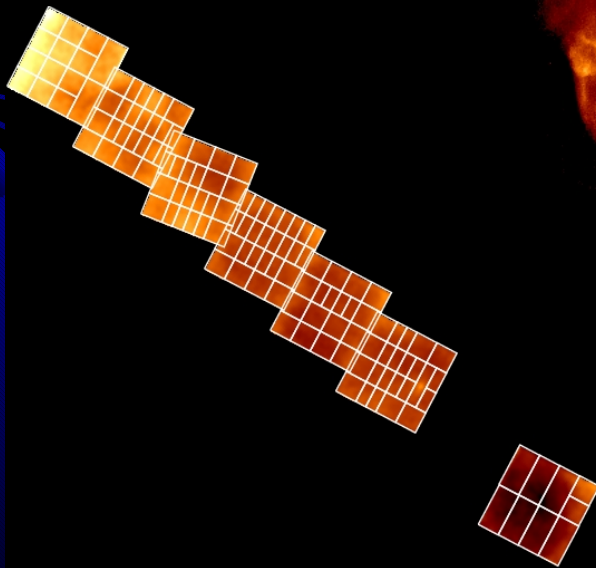
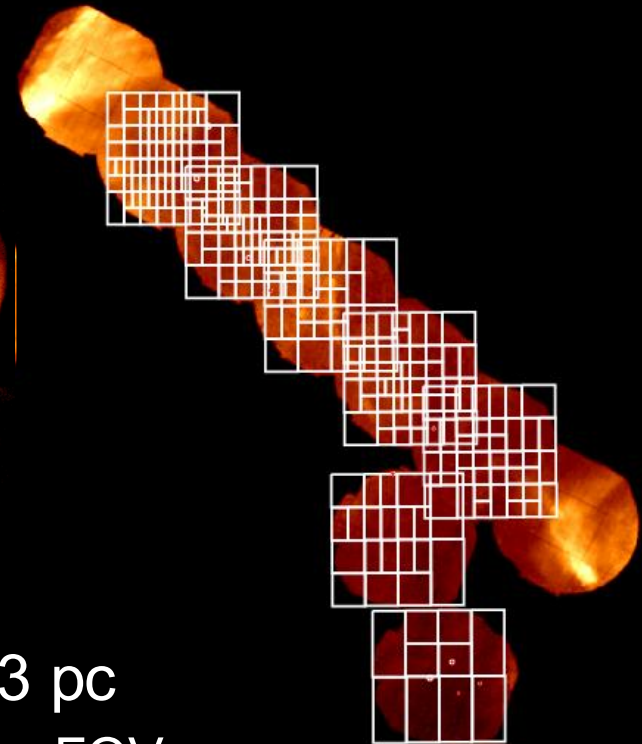
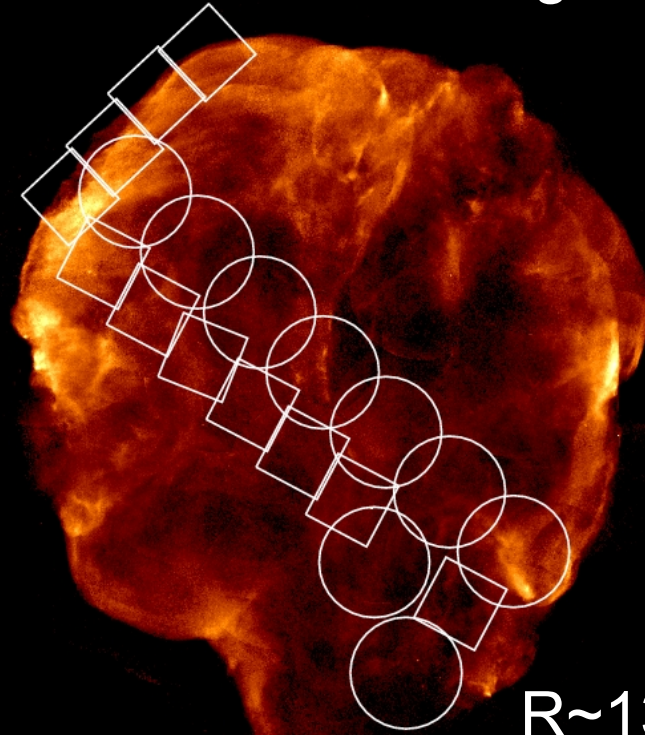


# Cygnus Loop: ~10,000 yrs old

ROSAT HRI image

XMM-Newton image

Suzaku images



$R \sim 13$  pc

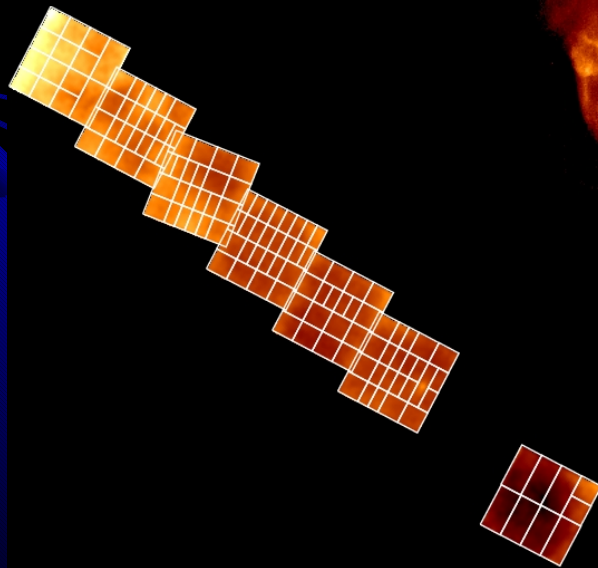
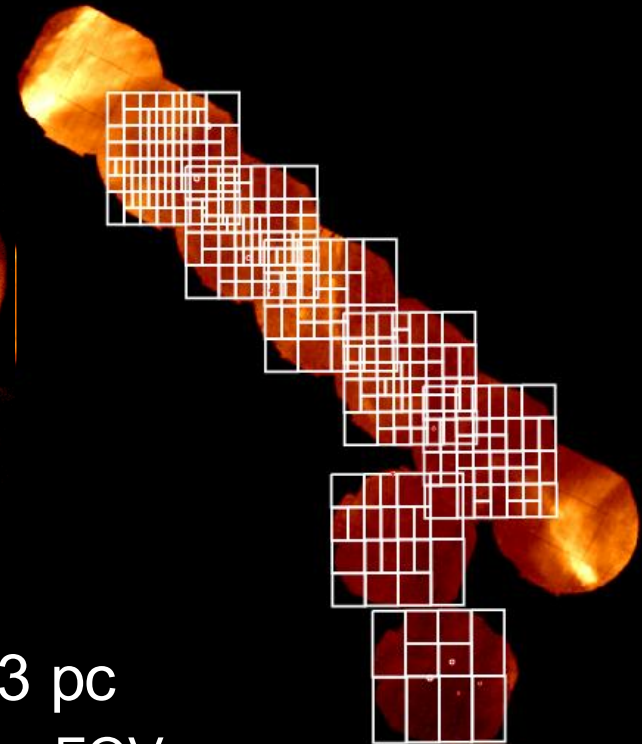
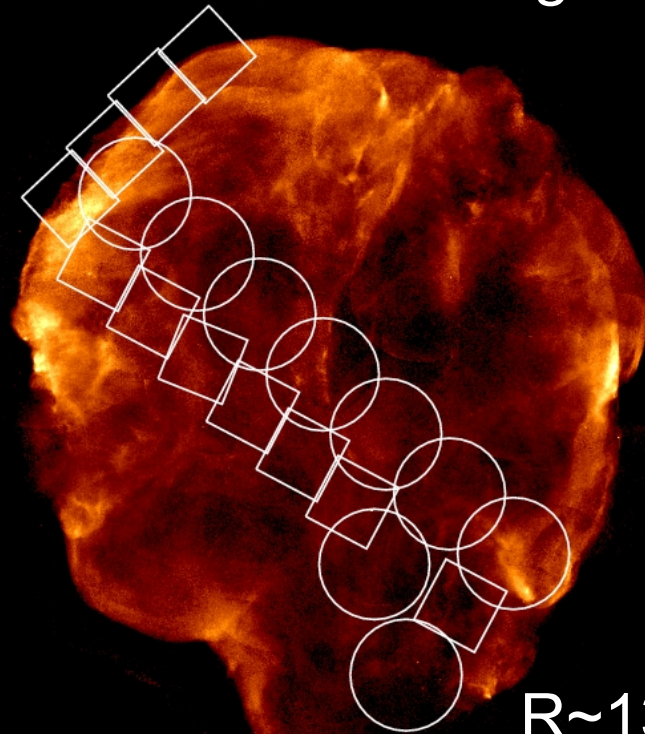
- : Suzaku FOV
- : XMM-Newton FOV

# Cygnus Loop: ~10,000 yrs old

ROSAT HRI image

XMM-Newton image

Suzaku images

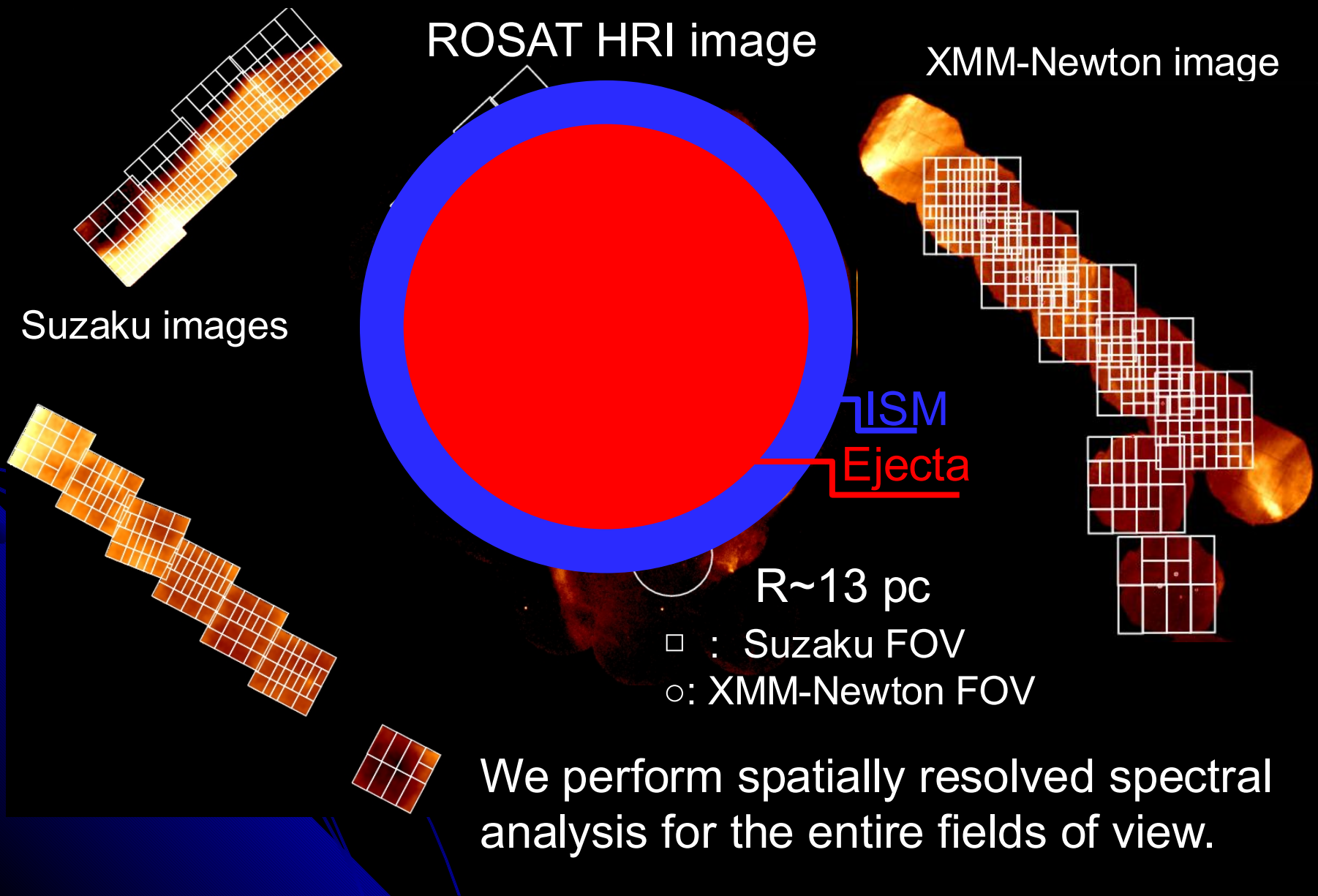


$R \sim 13$  pc

- : Suzaku FOV
- : XMM-Newton FOV

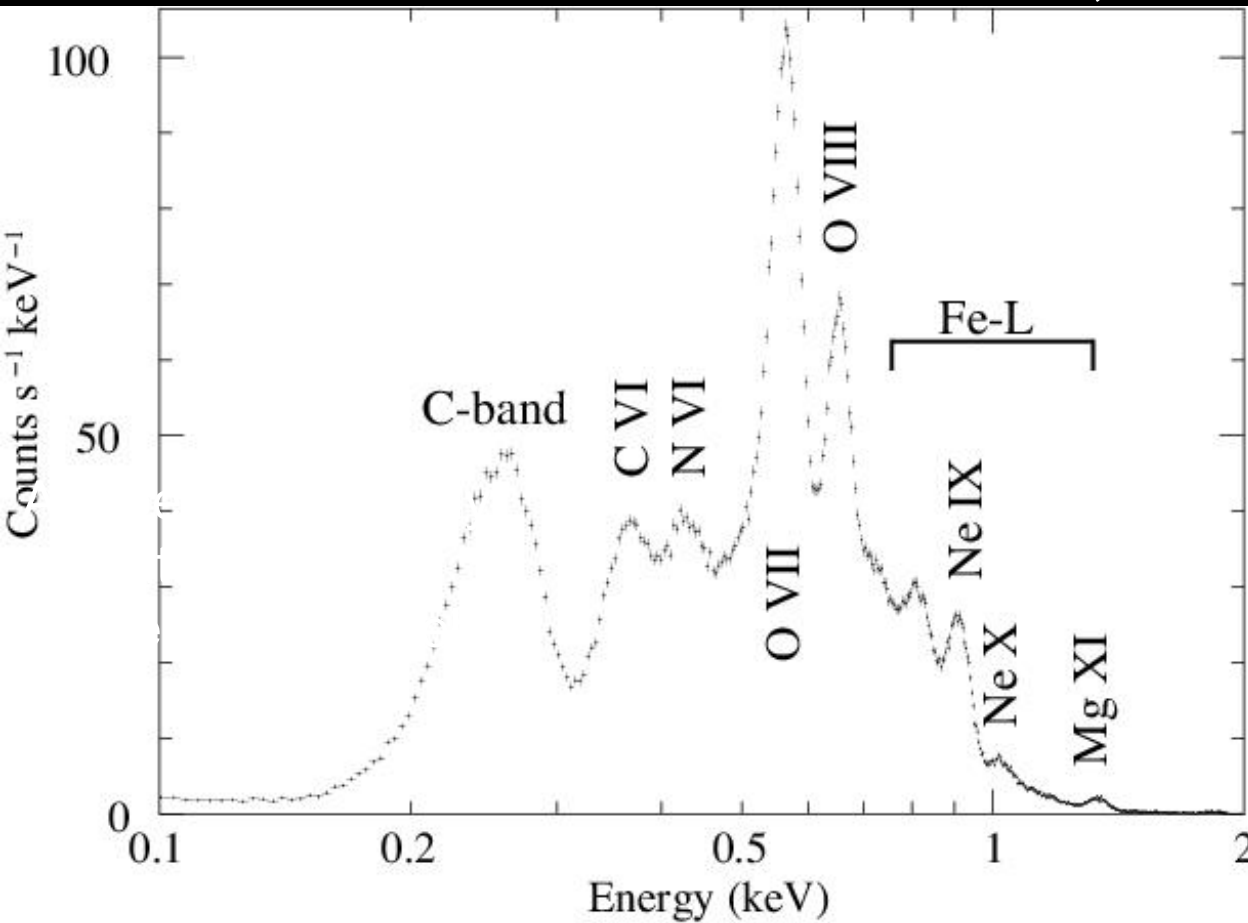
We perform spatially resolved spectral analysis for the entire fields of view.

# Cygnus Loop: ~10,000 yrs old



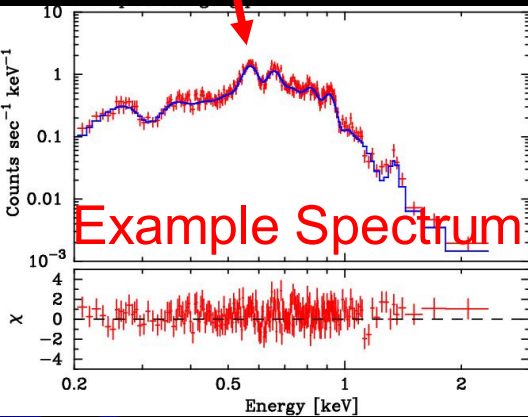
# Northeast Rim (ISM shell): Abundance Inhomogeneity

Miyata+ 2007, PASJ, 59, S163  
Katsuda+ 2008, PASJ, 60, S115



# Northeast Rim (ISM shell): Abundance Inhomogeneity

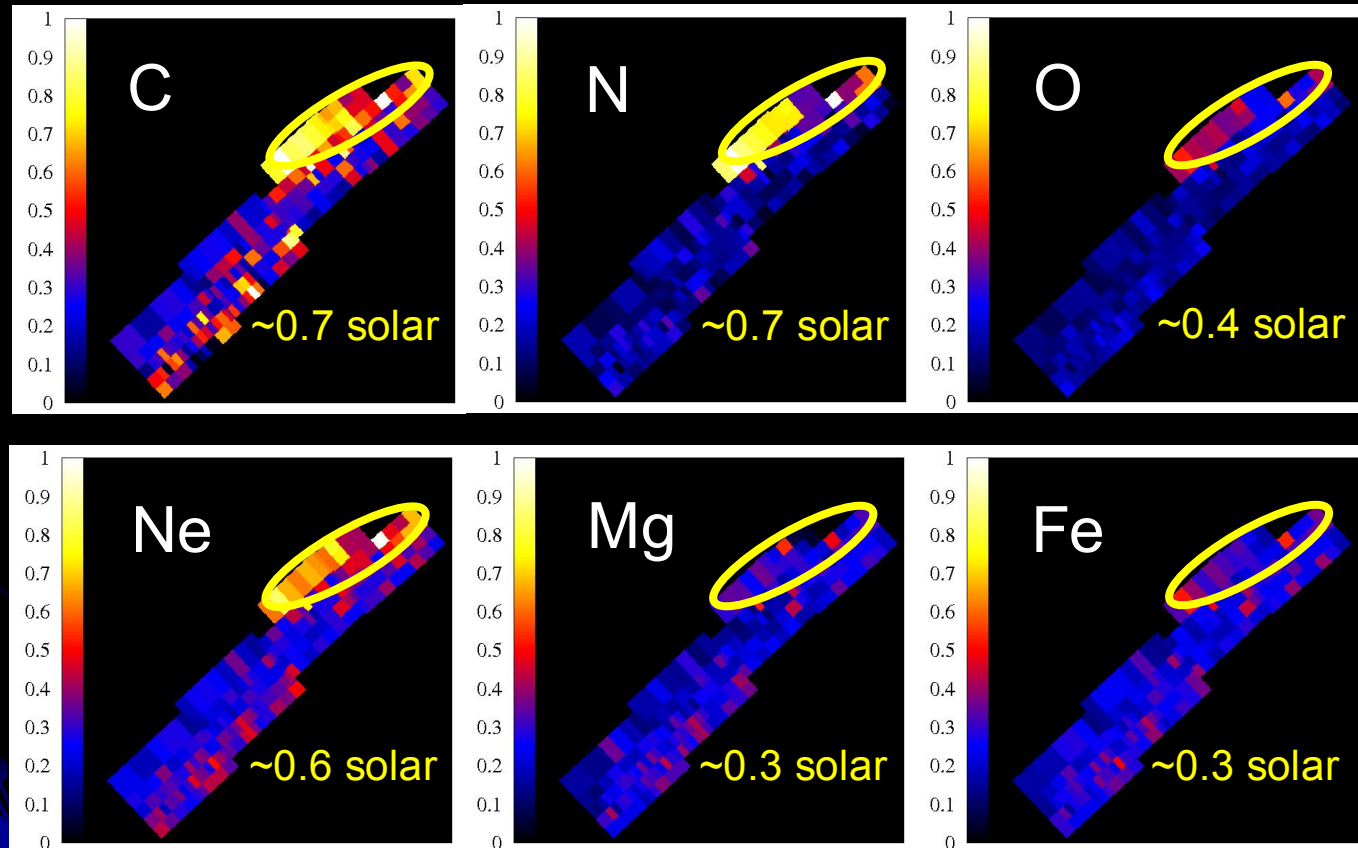
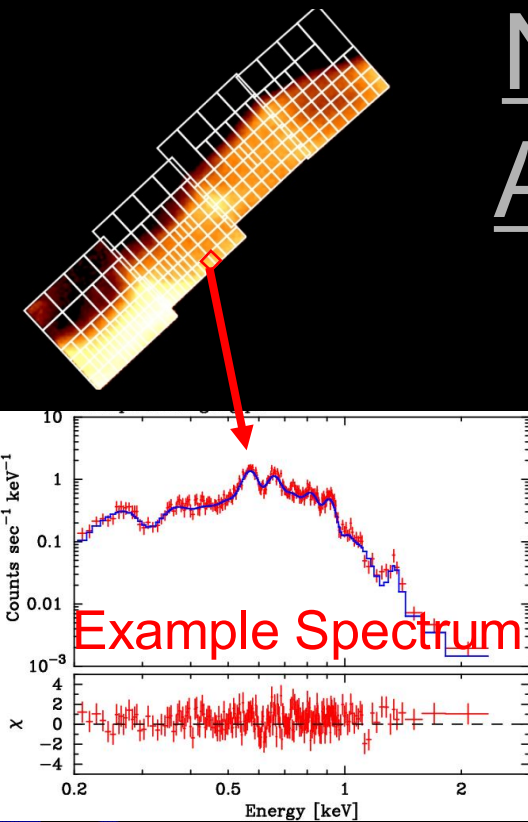
Miyata+ 2007, PASJ, 59, S163  
Katsuda+ 2008, PASJ, 60, S115



All spectra are fairly well fitted with a single VNEI model.

# Northeast Rim (ISM shell): Abundance Inhomogeneity

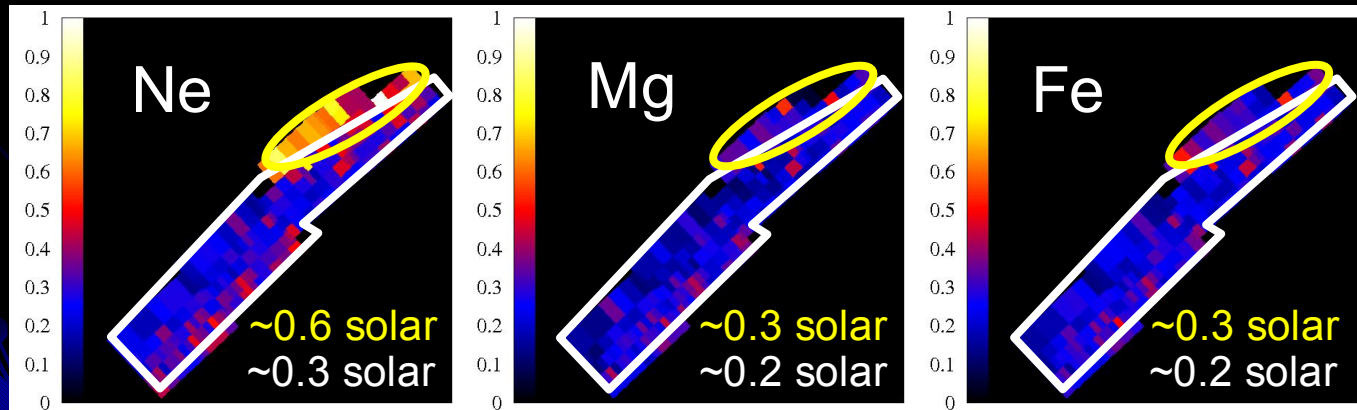
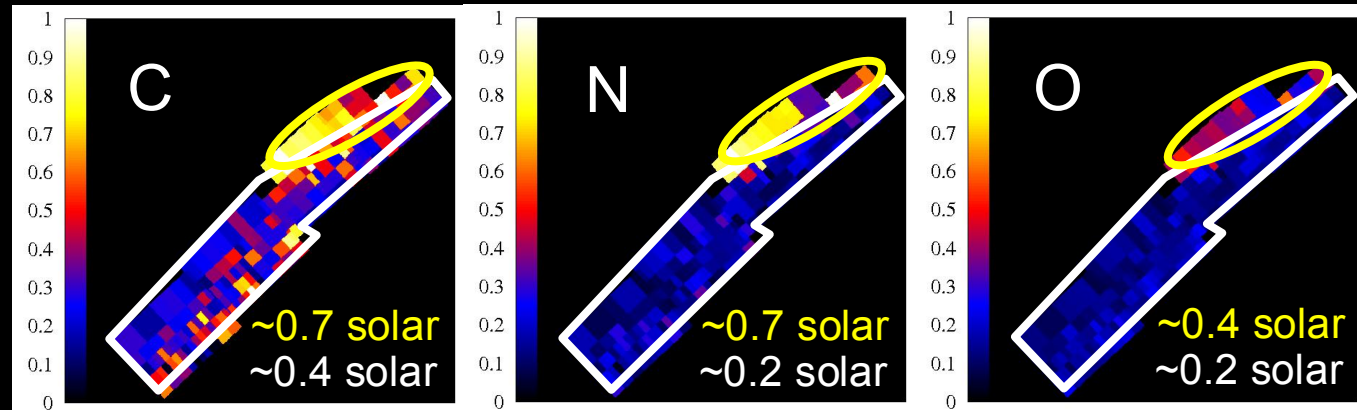
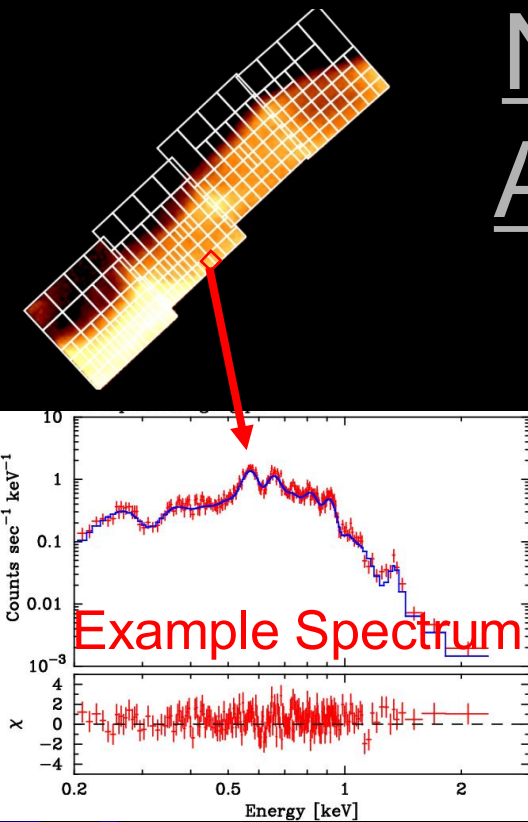
Miyata+ 2007, PASJ, 59, S163  
Katsuda+ 2008, PASJ, 60, S115  
-- Abundance maps --



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Miyata+ 2007, PASJ, 59, S163  
Katsuda+ 2008, PASJ, 60, S115  
-- Abundance maps --



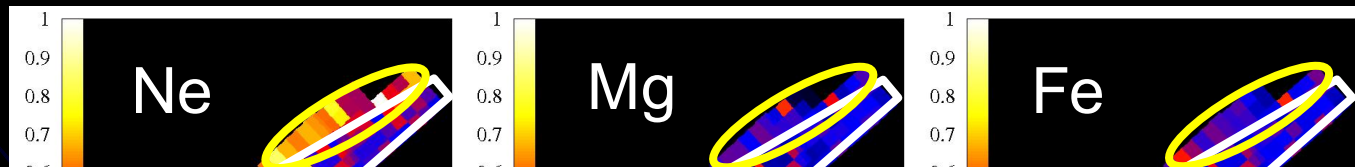
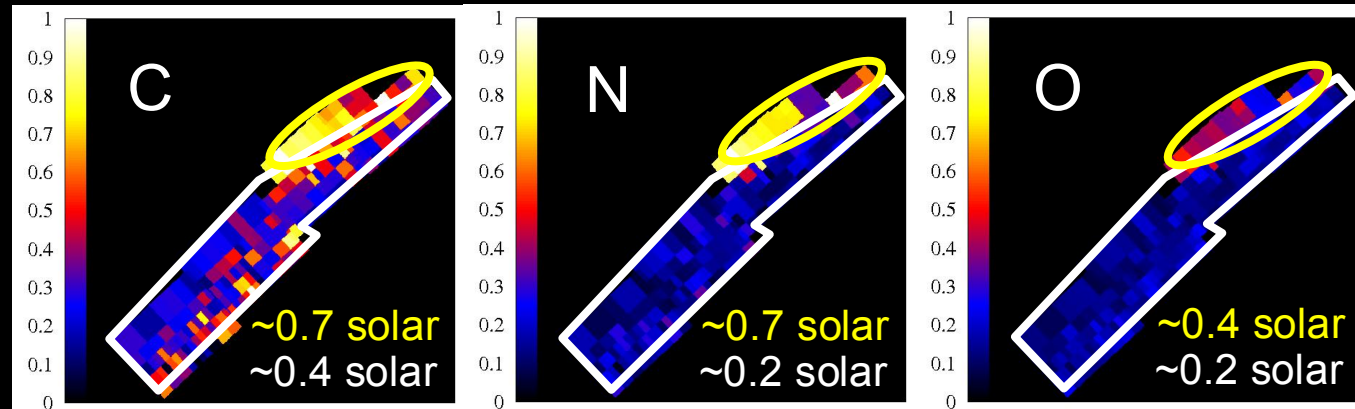
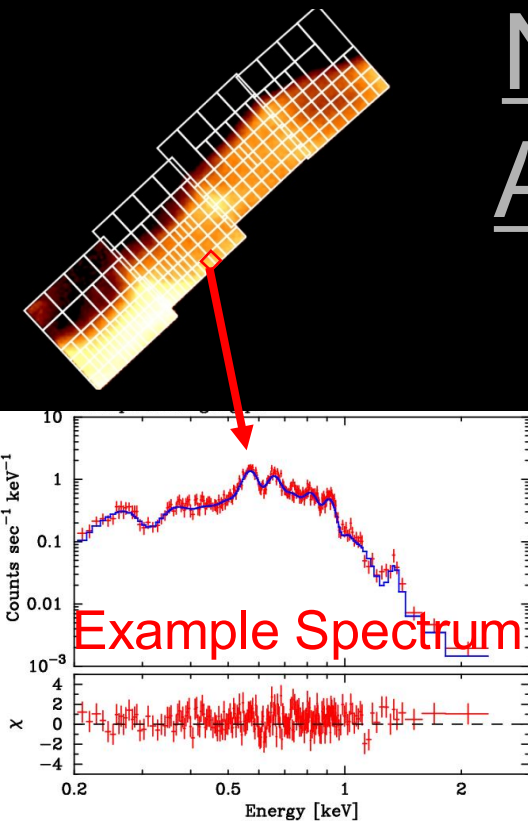
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-- Abundance maps --



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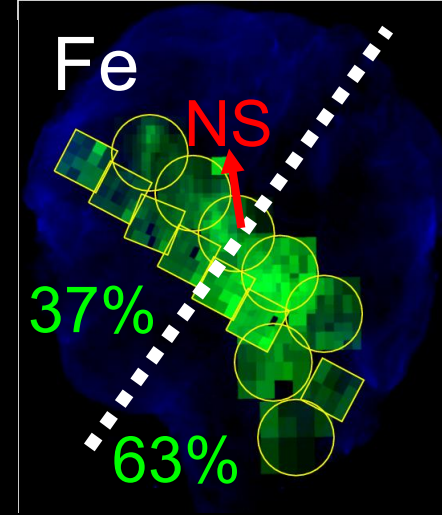
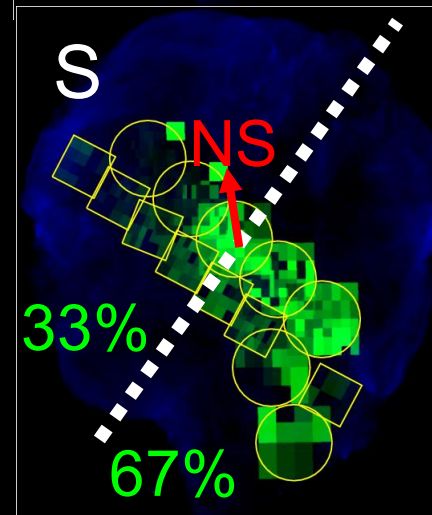
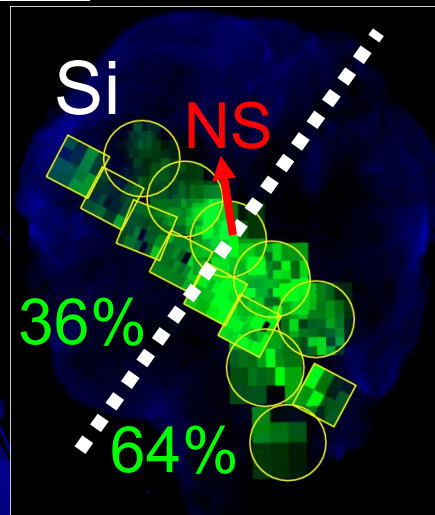
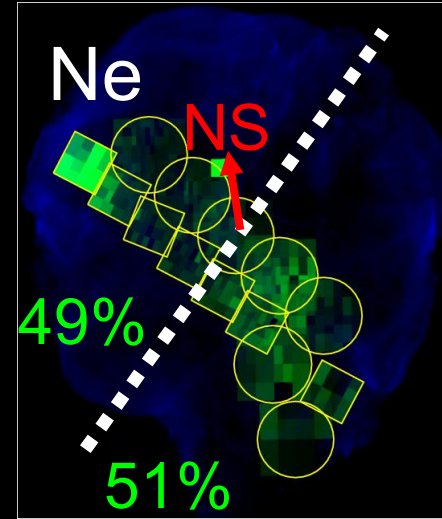
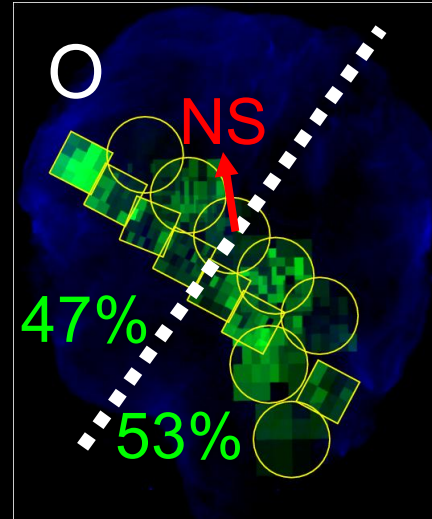
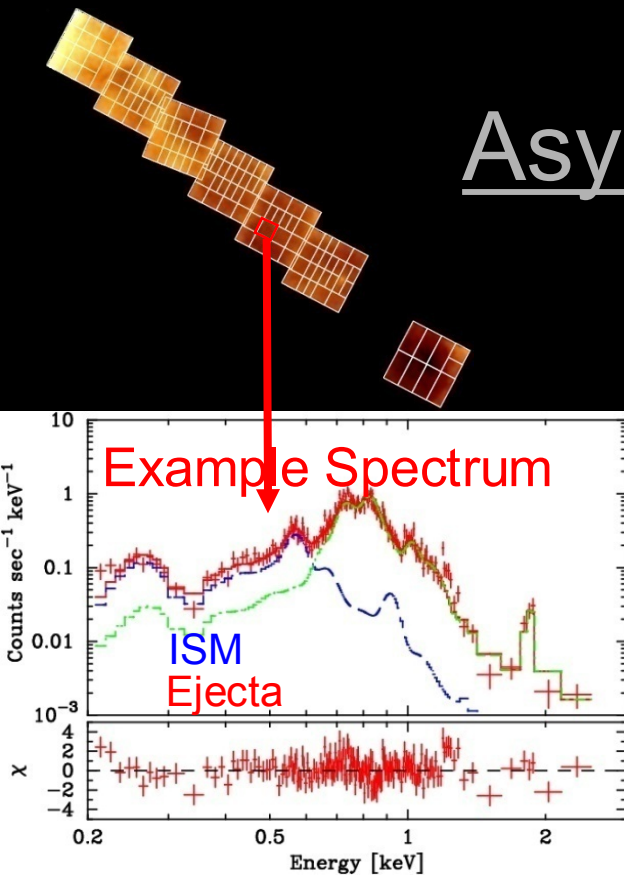
RCW86 & Vela SNR also show such depleted ISM abundances.  
=>Is the depleted ISM abundance (~0.2 solar) a common feature in several Galactic SNRs?



# Inner Region (Ejecta): Asymmetric Ejecta Distributions

Katsuda+ 2008, PASJ, 60, S107

-- EM maps of ejecta --

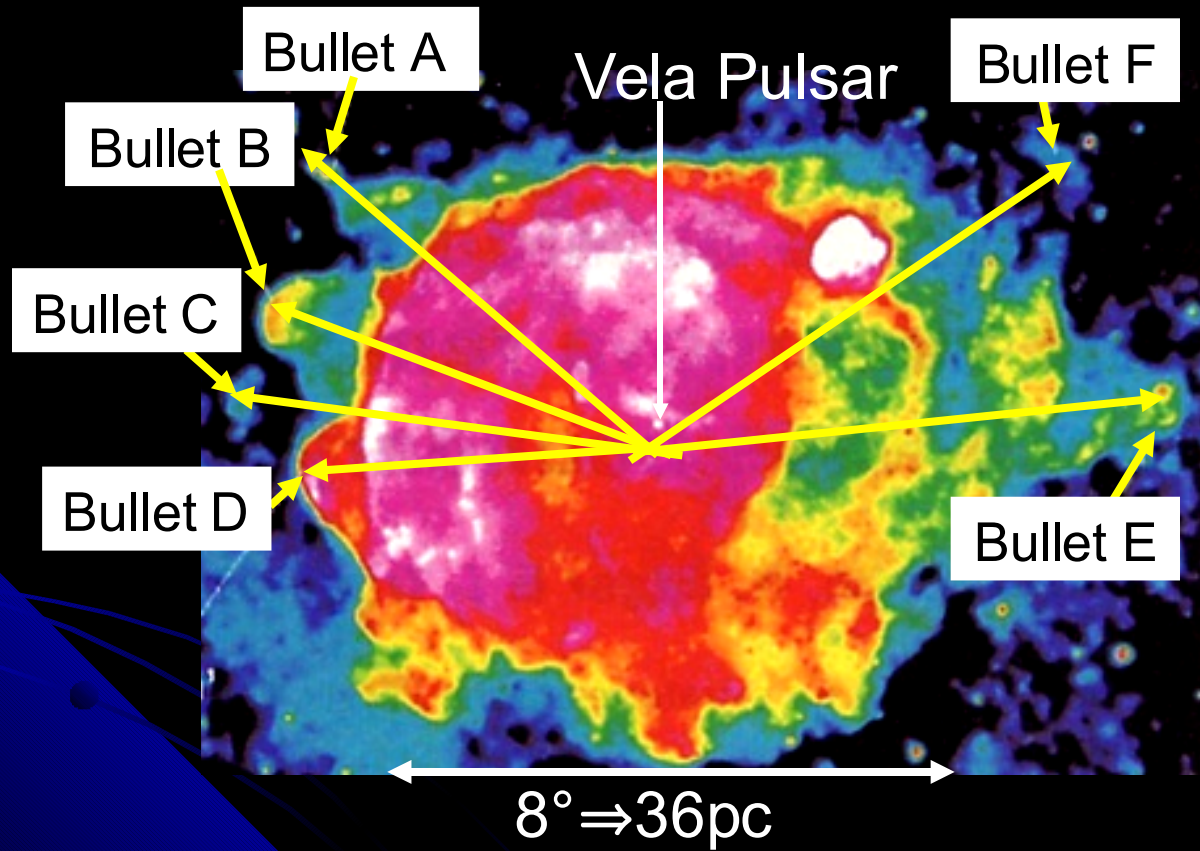


All spectra are fairly well fitted with a two-component (ISM and ejecta) NEI model.

# Summary

- Suzaku, for the first time, detected K-lines from **Ar, Cr, Mn, and Fe** for young SNRs.
  - Line detections of such elements are essential for studies of SN nucleosynthesis, SN type diagnostics, and SNR evolution.
- Suzaku revealed detailed **ejecta distributions** in evolved SNRs.
  - Ejecta distribution is a key to study SN explosion mechanisms. Evolved, hence large, SNRs are suitable for this purpose.

# Bullets around the Vela SNR



ROSAT all-sky survey image ( Aschenbach et al. 1995 )

## - The Vela SNR

Distance:  $\sim 250 \text{ pc}$

Age:  $\sim 10,000 \text{ yrs}$

SN Type: Core-collapse

## - Vela Bullets

Boomerang-shaped X-ray emission outside the general boundary of the Vela SNR

The center line of each boomerang structures can be traced back toward the center of the SNR.

=> They are considered to be originated from explosion fragments of the SN event.

# XMM-Newton Observations of the shrapnels A and D

