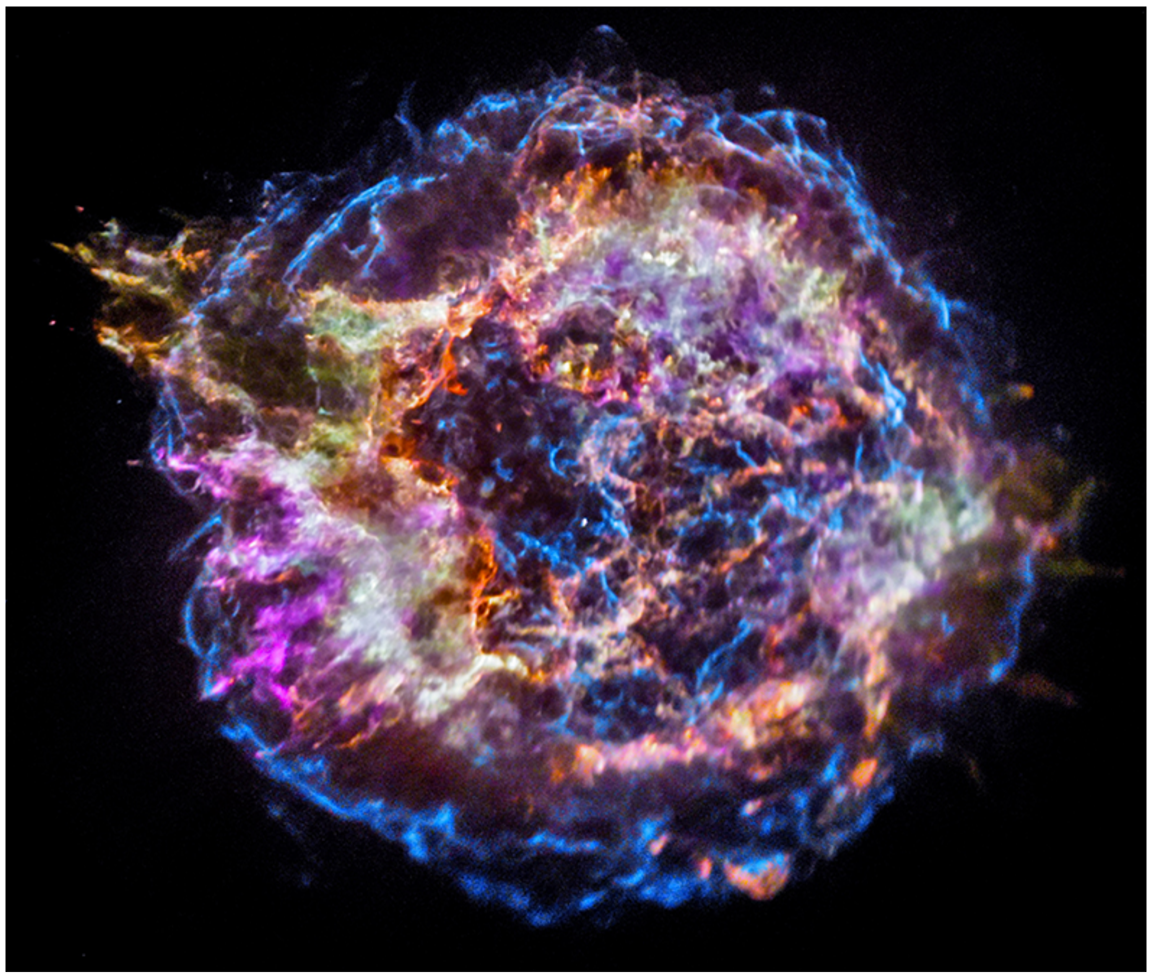
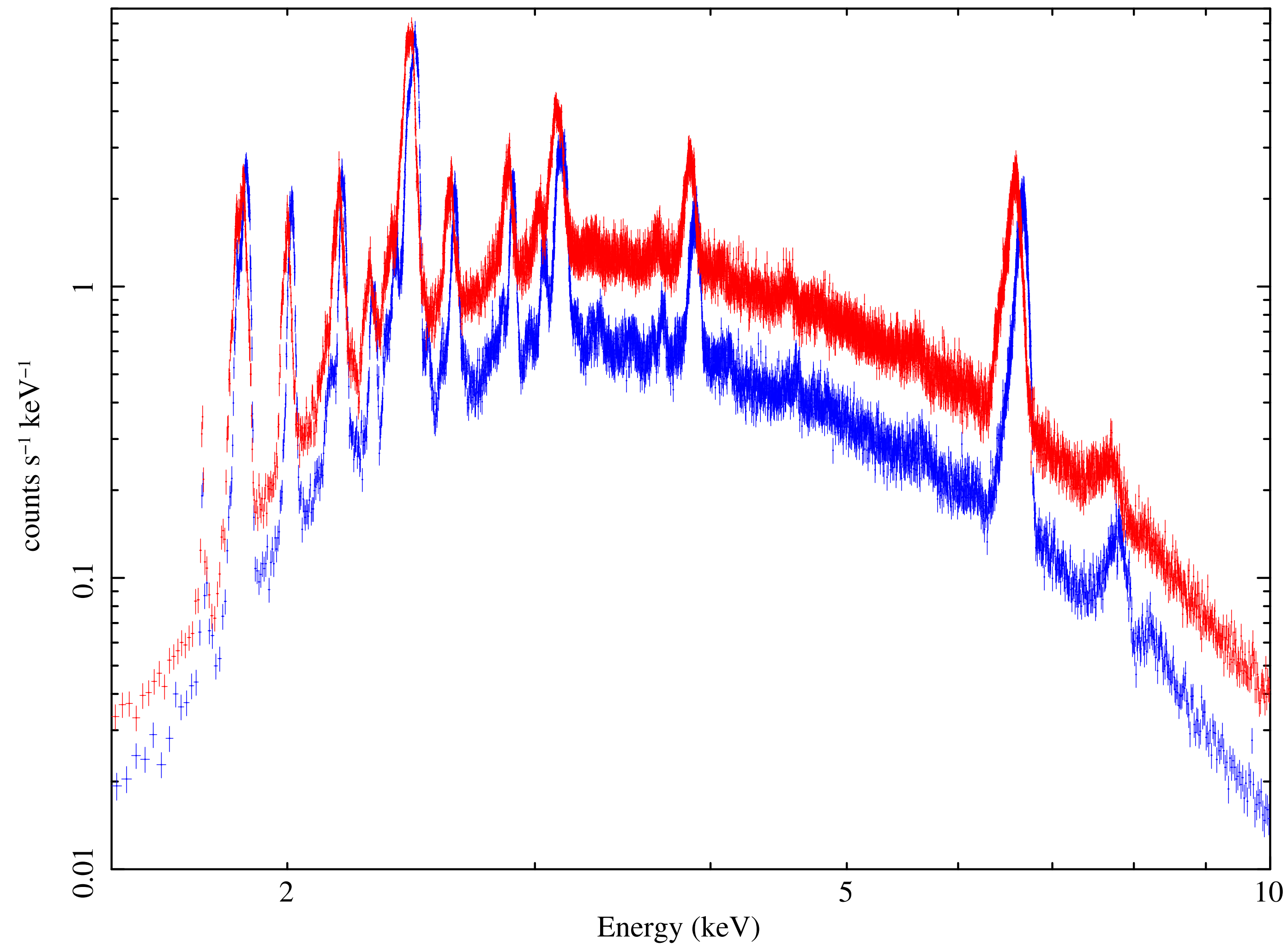
XRISM Observations of Cassiopeia A





XRISM Cas A Target Team

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Hiroyuki Uchida (Kyoto U.)*
Jacco Vink (U. of Amsterdam)*

* In attendance at this meeting

All *XRISM* results are *PRELIMINARY*, please do not quote.
Thank You !!

Cassiopeia A: Introduction

Why *XRISM* Observations of Cas A ?

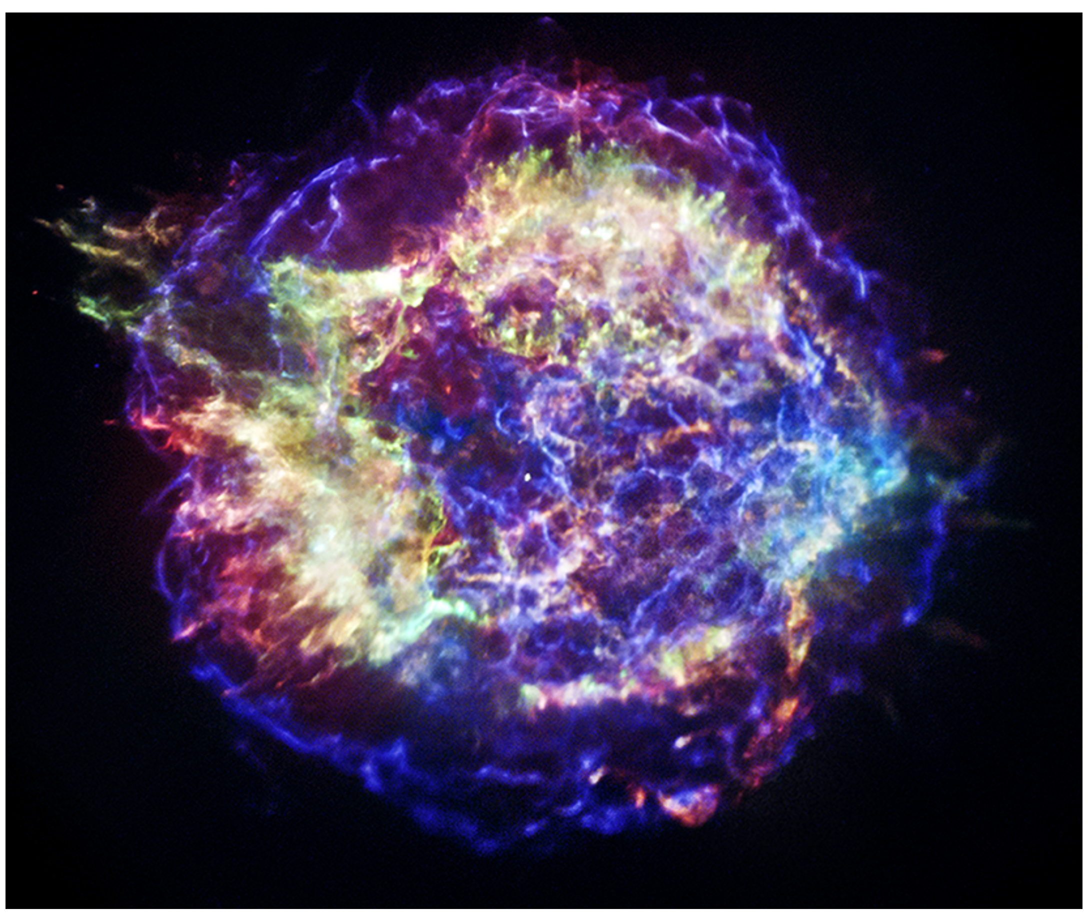
- High L (2.6×10^{36} erg/s) and flux (1.5×10^{-9} erg/s) in the 2.0-10.0 keV band
- Youngest Galactic core-collapse SNR, t~350 yr (Thorstensen 2001, Fesen 2006)
- Type IIb progenitor (Krause et al. 2008, Rest et al. 2008, Rest et al. 2011)
- Progenitor 15-25 $M_{\odot}$ (Young et al. 2006), ejecta mass ~ 2-4 $M_{\odot}$ (Vink 1996, Laming & Teming 2020)
- Complicated morphology in X-rays, SE region is blue-shifted & NW is redshifted (Willingale 2002, Lazendic 2006, Delaney 2010, Picquenot 2021)
- Ejecta have an asymmetric distribution (Hughes et al. 2000, Hwang 2004, Holland-Ashford 2020, Tsuchioka 2022)
- 3D hydro simulations can reproduce most of the structure in Cas A (Orlando 2020)
- Forward and reverse shock velocities have been measured in different locations (Sato 2018, Vink 2023)
- *Chandra* Mn/Cr ratio argues for an energetic (2×10^{51} ergs), sub-solar metallicity explosion (Sato 2020)
- *Chandra* detection of Ti & Cr support the neutrino-driven explosion mechanism (Sato 2021)
- Variable on human timescales (Patnaude 2007, 2011 and Uchiyama 2008)
- P detected in the Fe-rich region in a S-rich ejecta knot (Koo et al. 2023)

The key science goals for the high resolution spectra from the *XRISM* calorimeter called *Resolve are*:

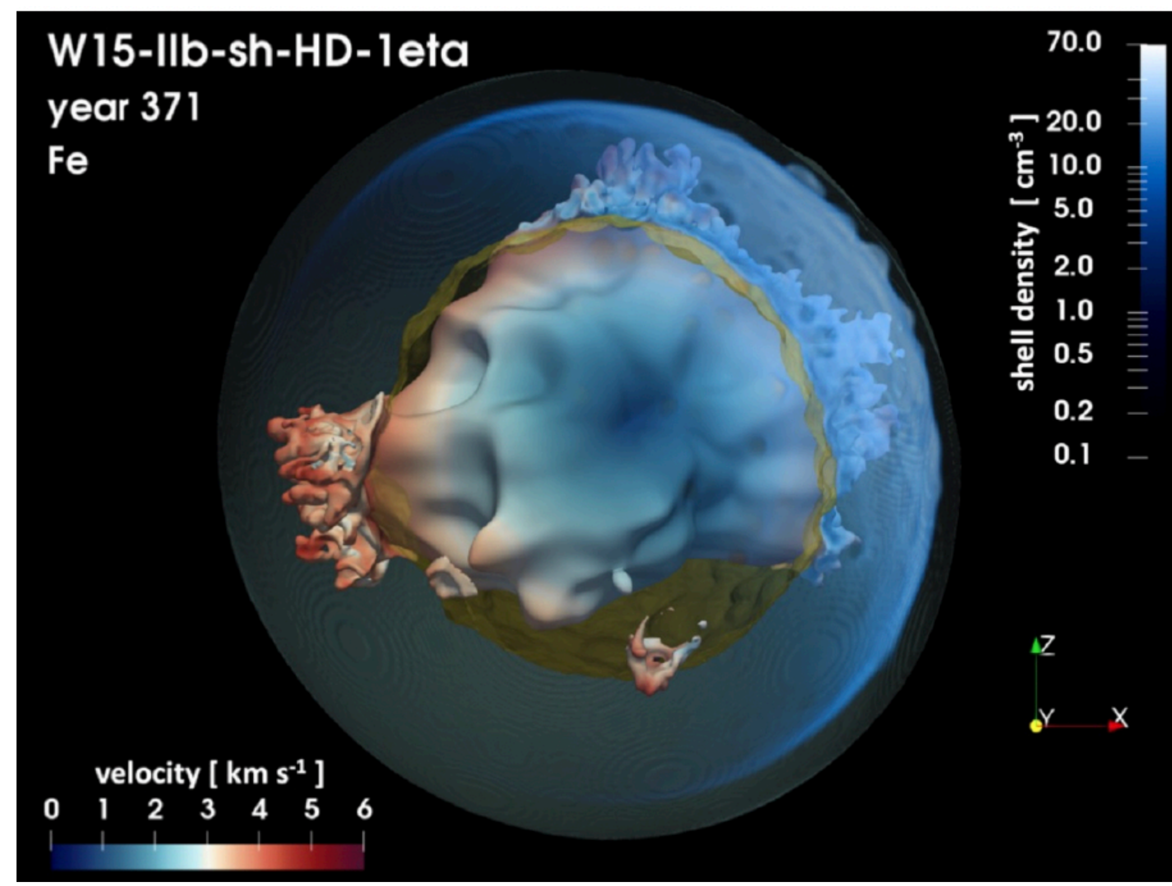
1. **Detect odd-Z or trace elements**
   => compare to nucleosynthesis models for different progenitors
2. **Measure velocity and *broadening* of the bright line/line complexes**
   => compare to 3D models of the remnant and constrain the ion temperatures
3. **Detect & characterize spectral signatures of dust emission or charge exchange**
   => compare to dust destruction models and charge exchange models

***Chandra* three color image**

R: 0.5-1.5 keV G: 1.5-2.5 keV B: 4.0-6.0 keV

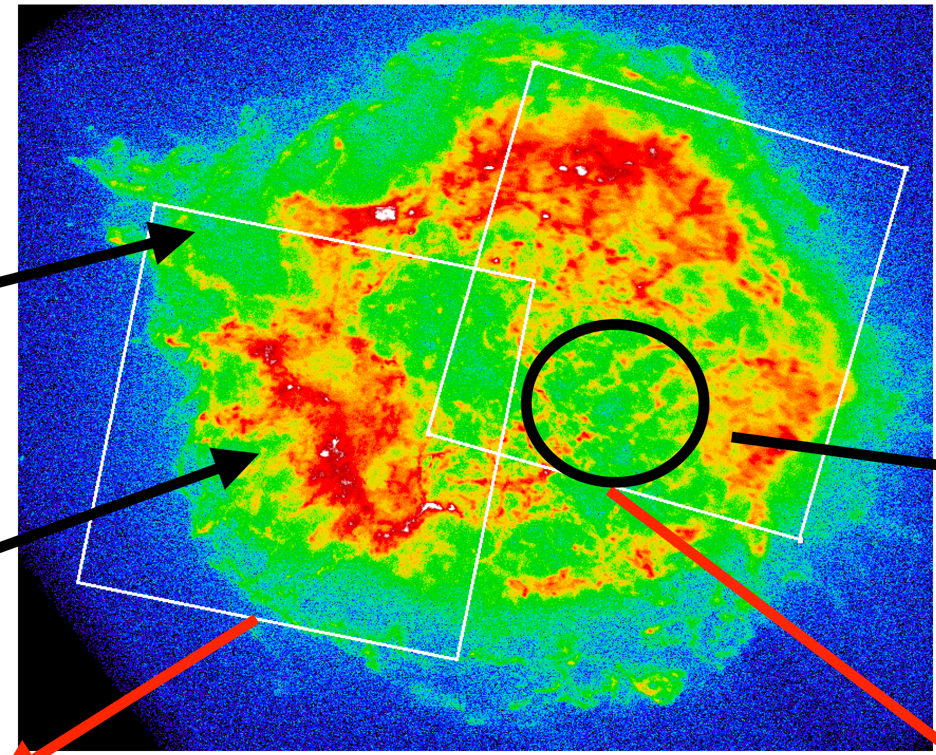


Orlando et al. 2024, 3D Hydro model, Fe distribution



XRISM Resolve Pointings

XRISM **observed Cas A twice in two pointings**



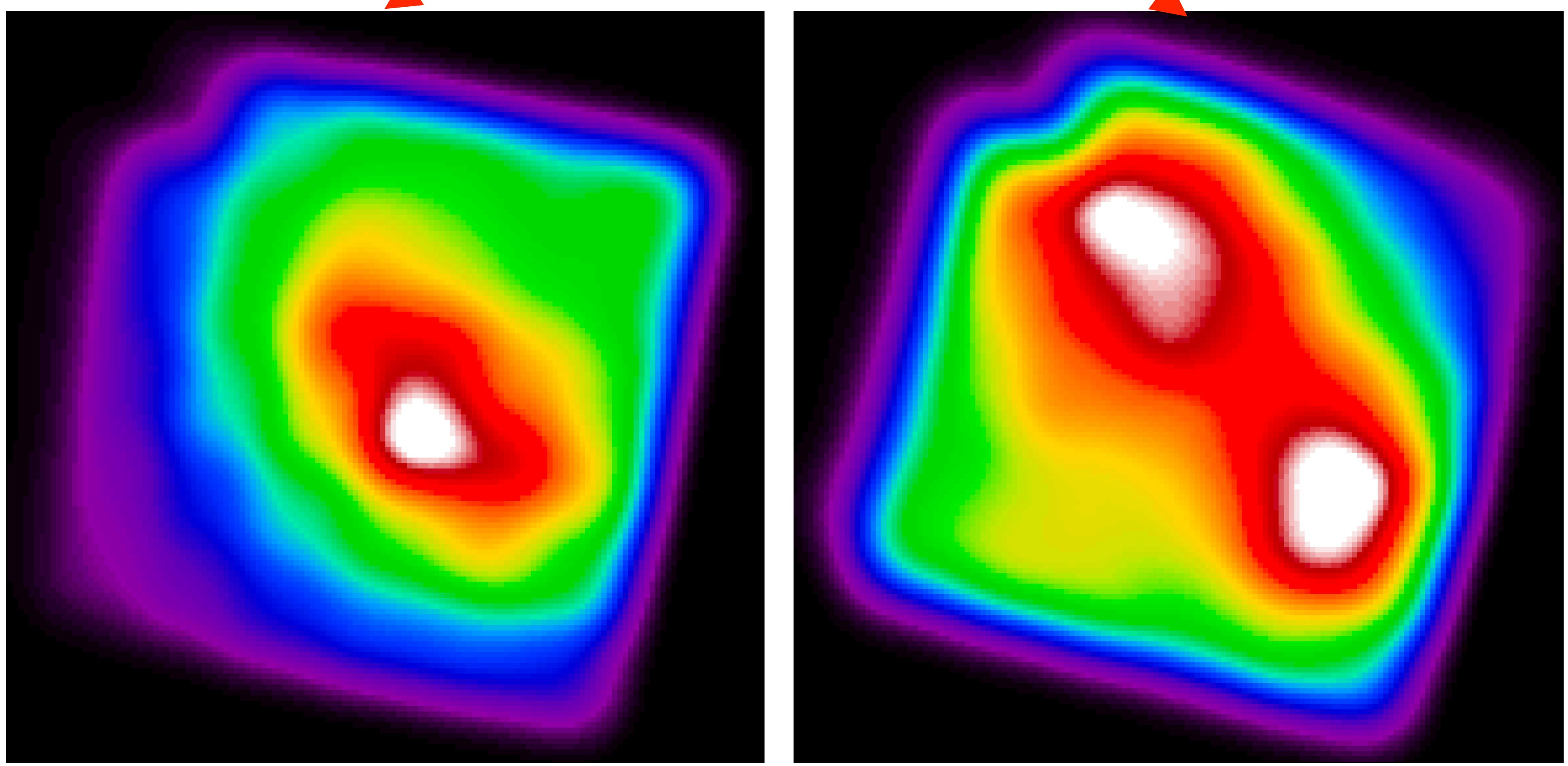
Si jet region

Fe-rich region

Dense CSM interaction

Cas A SE (181 ks)

2-10 keV



Cas A NW (166 ks)

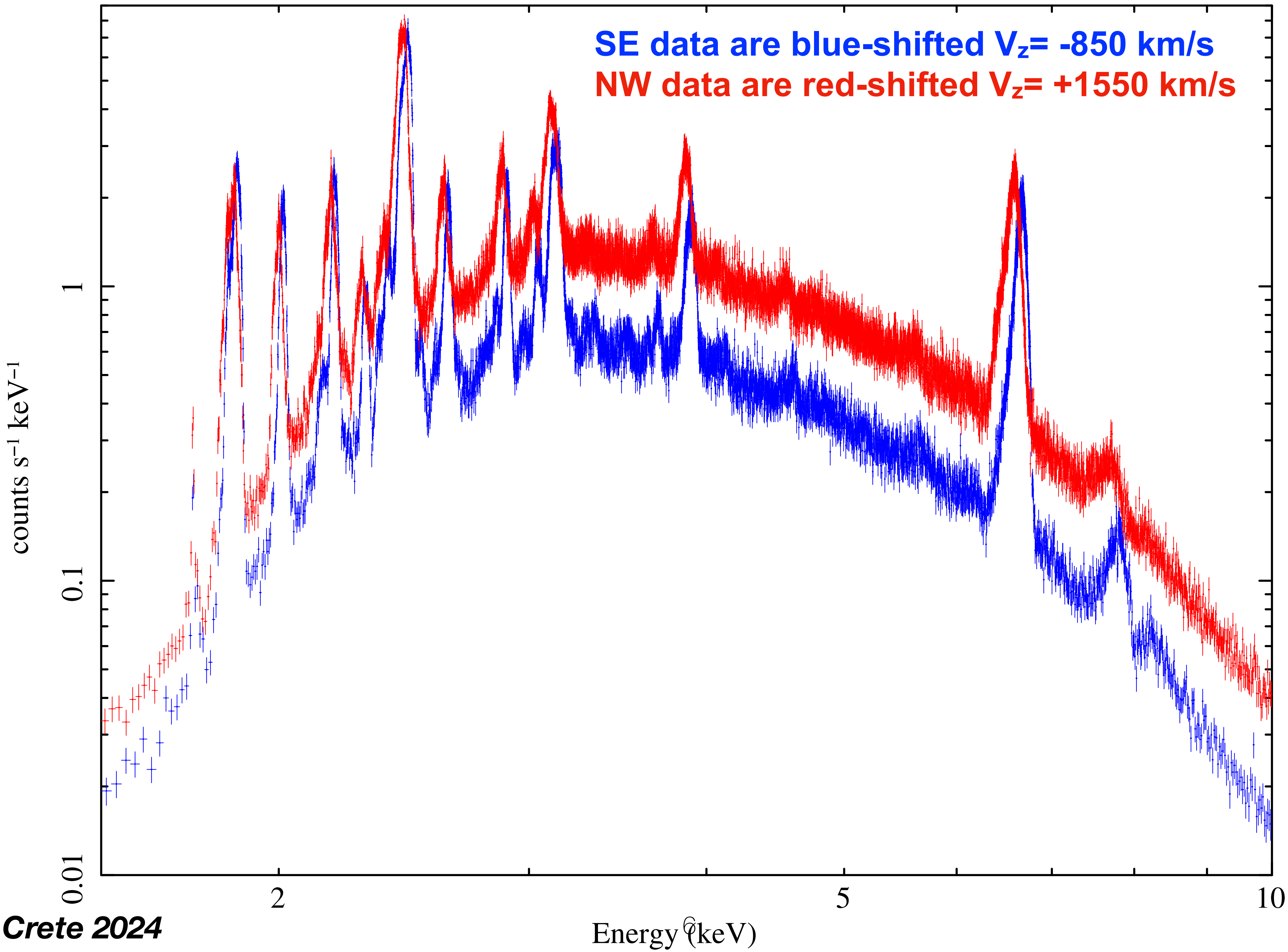
2-10 keV

Resolve Spectra from SE & NW Pointings

XRISM
X-RAY IMAGING AND SPECTROSCOPY MISSION

Cas A: 000129000 SE (Blue, 182 ks) and 0001300000 NW (Red, 167 ks)
all pixels, Hp events, point source arf, L rmf

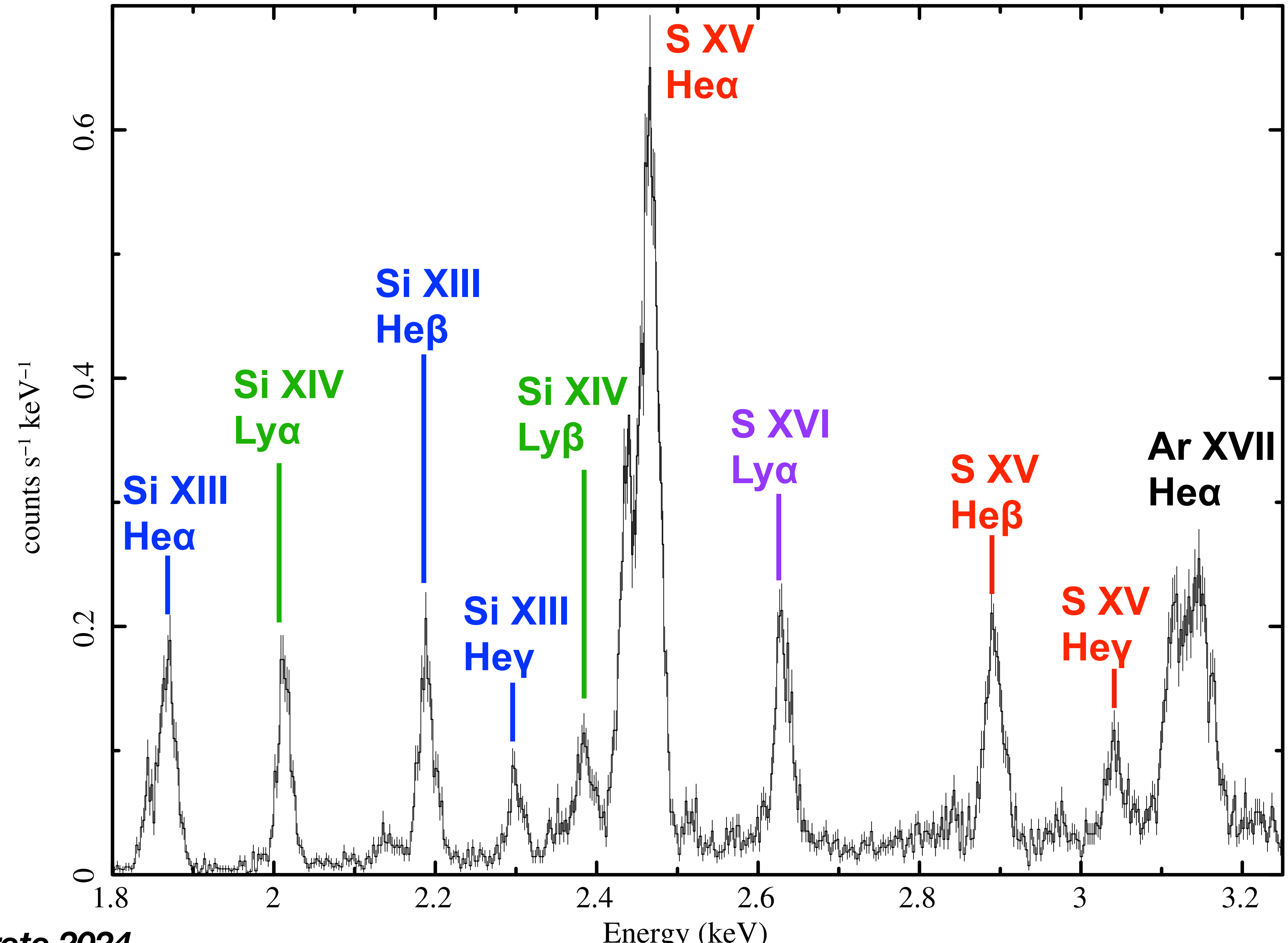
Spectra extracted from the Entire Array



Resolve Si XIII, XIV, S XV & Ar XVII Line Complexes

X-RAY IMAGING AND SPECTROSCOPY MISSION

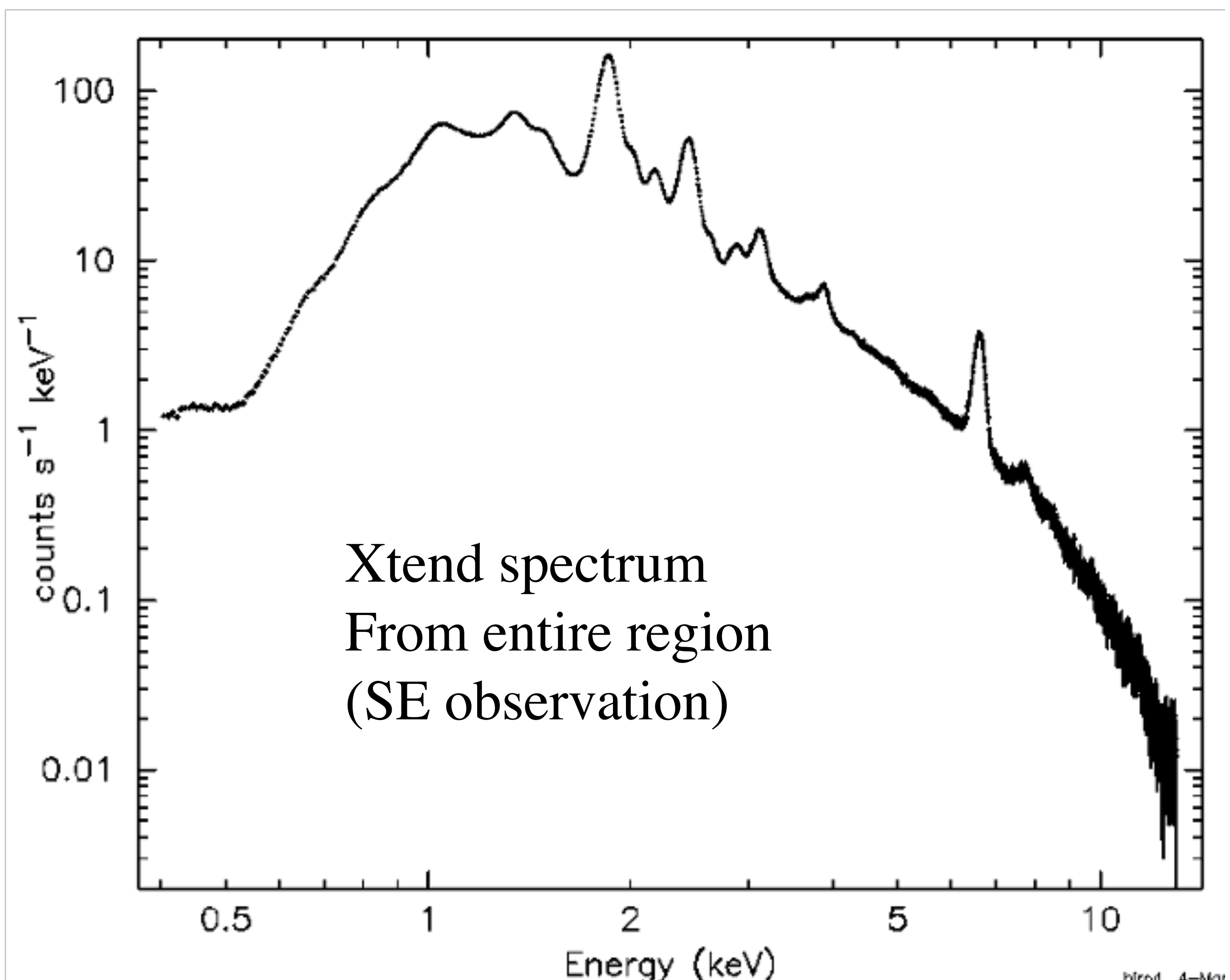
Resolve spectrum from a *single* pixel in the 1.75-3.25 keV bandpass

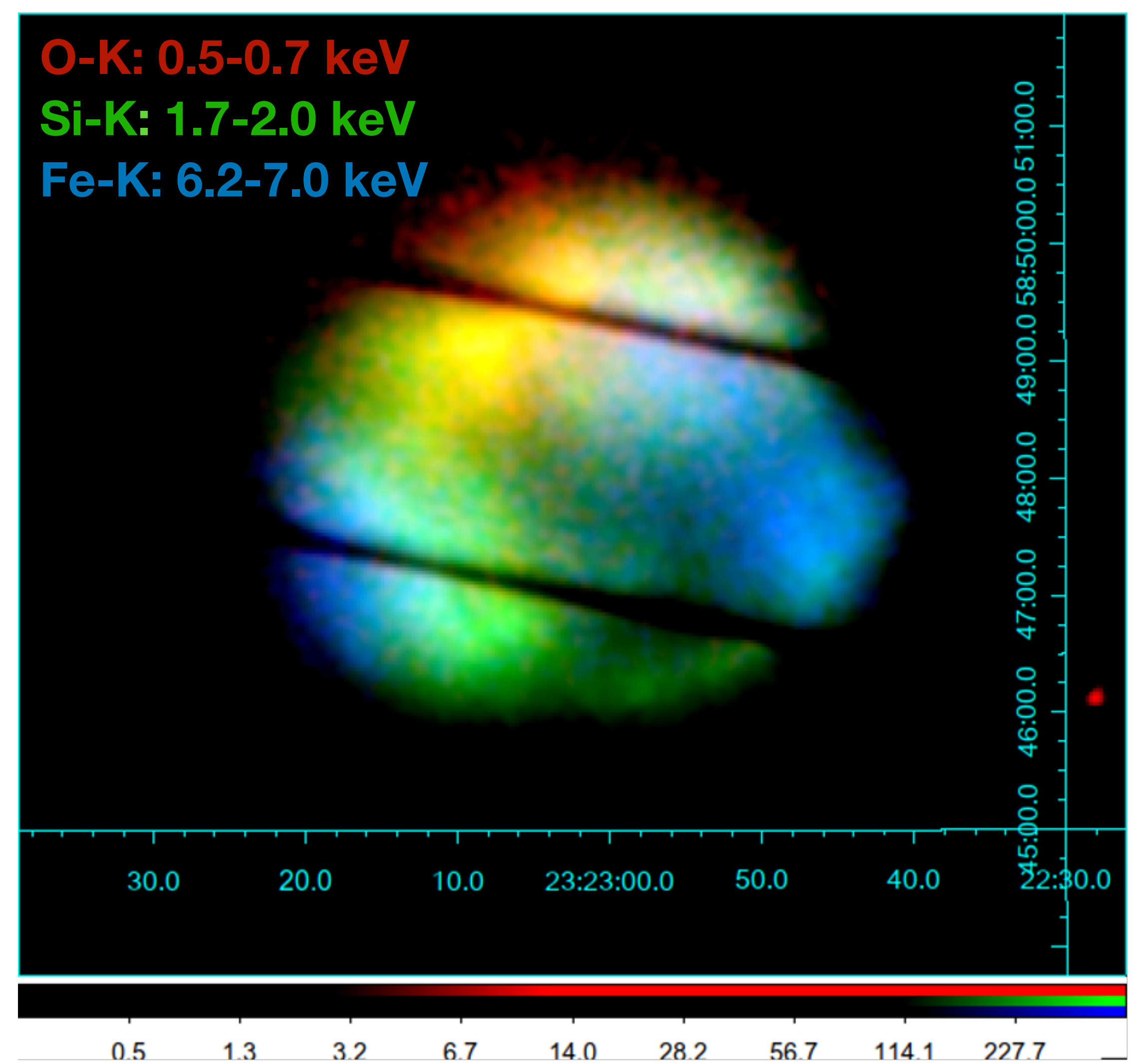


Xtend Spectrum and Image of Cas A

- *Xtend* is the CCD instrument on *XRISM*
- *Xtend* has a 40'x40' FOV so all of Cas A is covered in a single pointing
- Spectral variations with position are apparent
- *Xtend* has lower background than the CCD instruments on *Chandra* and *XMM,* important at energies of Fe-K and above

Nakajima (Kanto Gakuin U.)

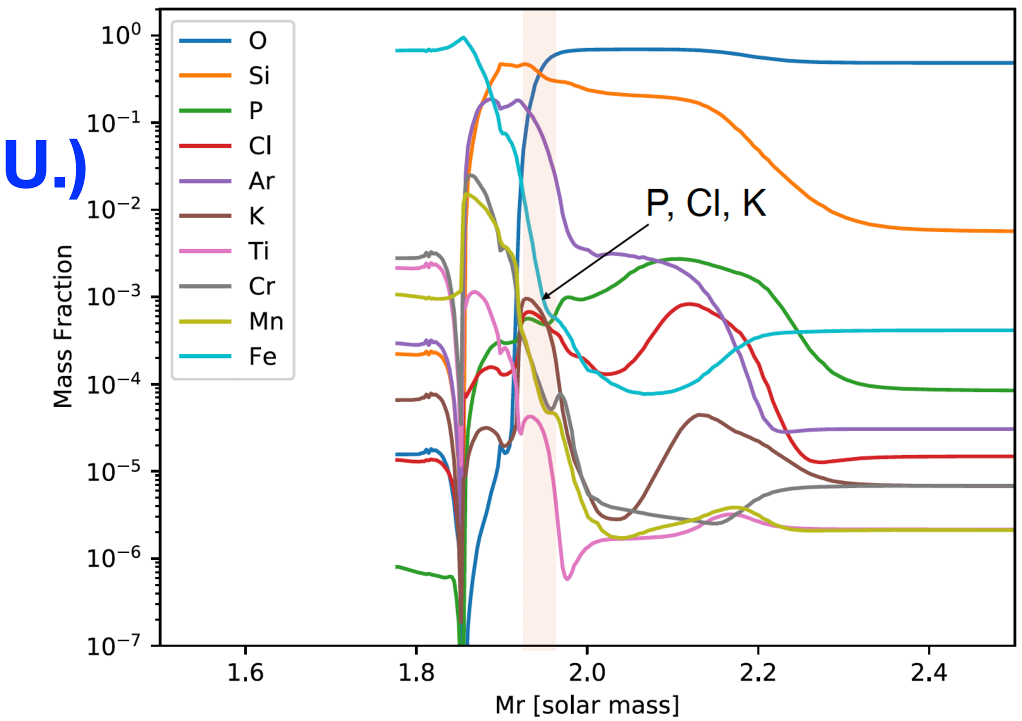




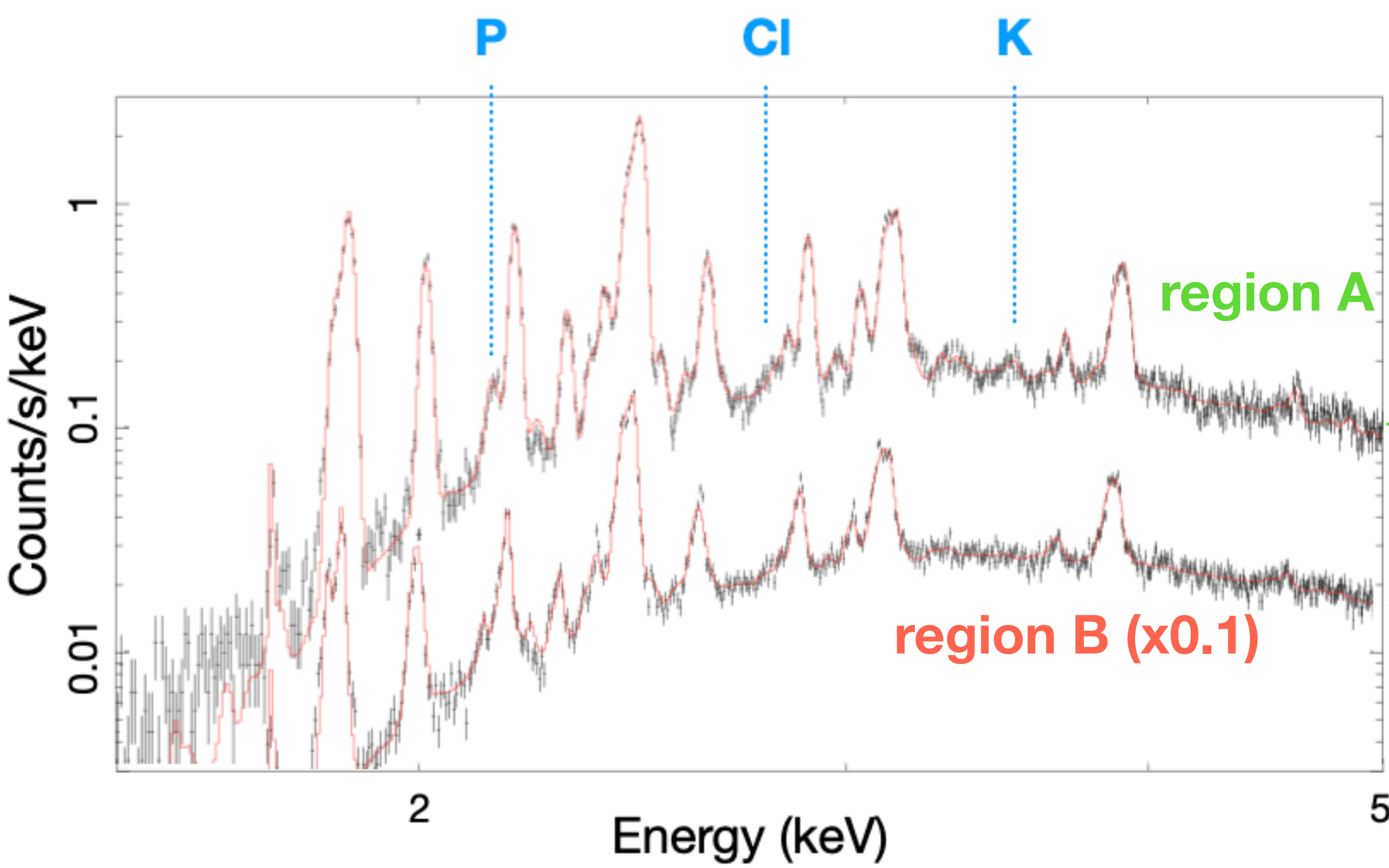
Odd Z and Trace Elements

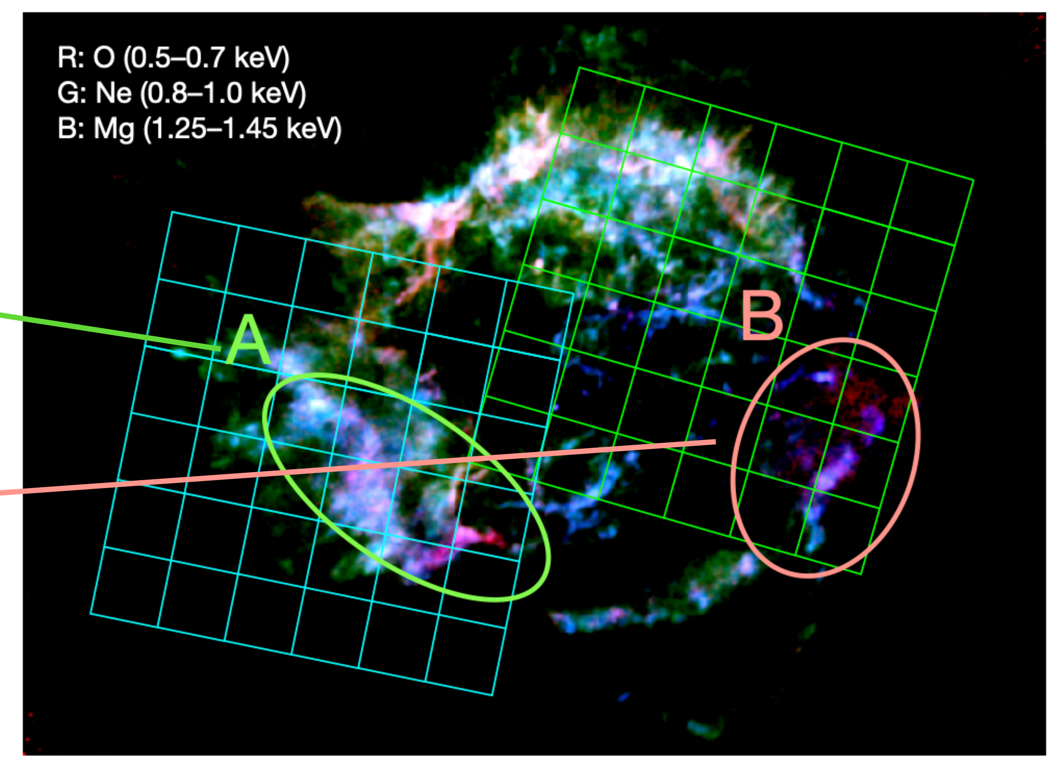
- **P, Cl, & K have not been detected in X-ray spectra of SNRs**
- **Koo et al. 2013,2022 detect P in NIR**
- **P, Cl, & K are thought to be produced in the O burning layer**

Sato (Meiji U.)



Uchida (Kyoto U.)



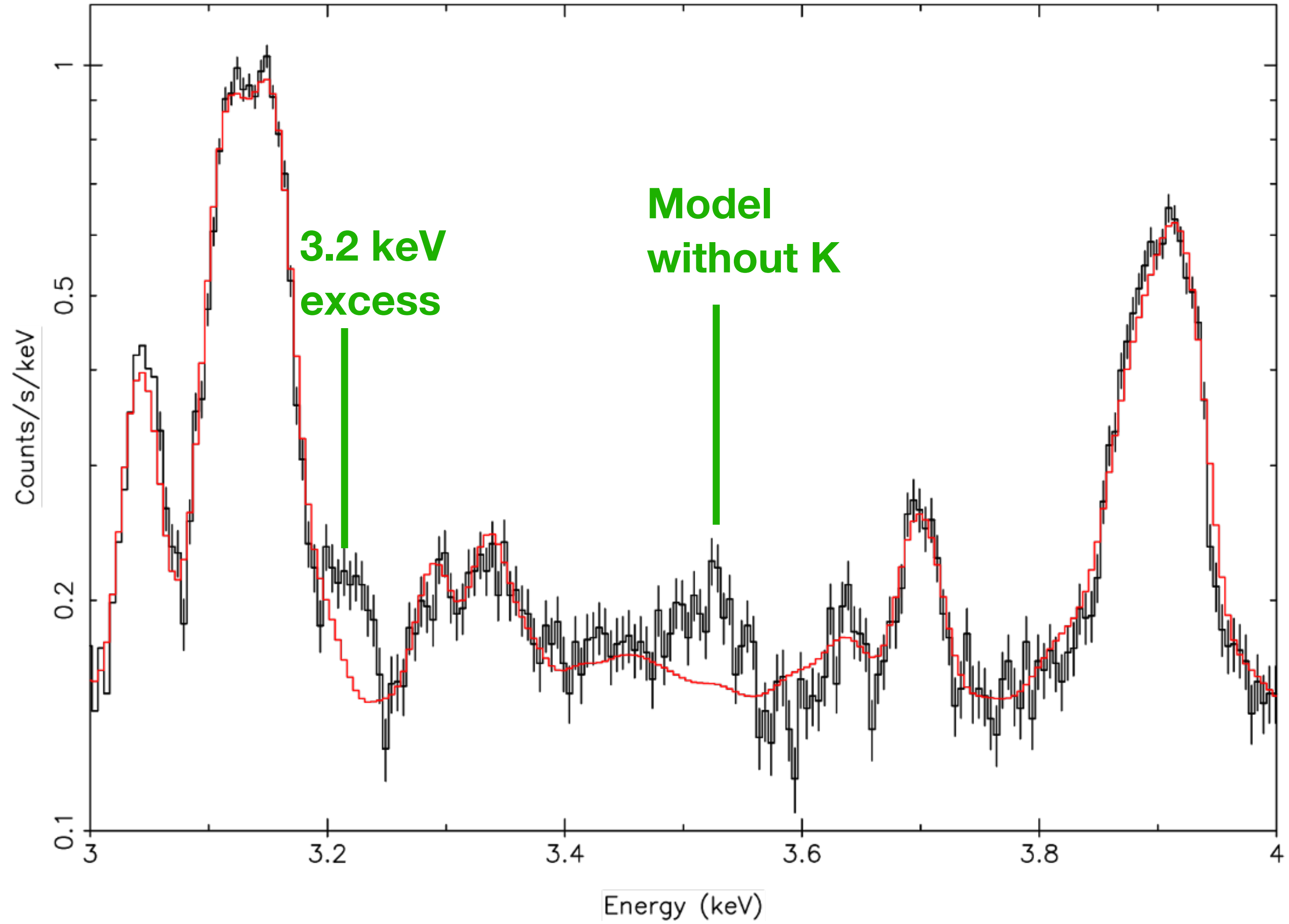


- ***Resolve* spectra show clear enhancements at the expected position of the Cl and K Heα line complexes**
- **The detection of P is complicated by the presence of nearby lines**

Odd Z and Trace Elements II

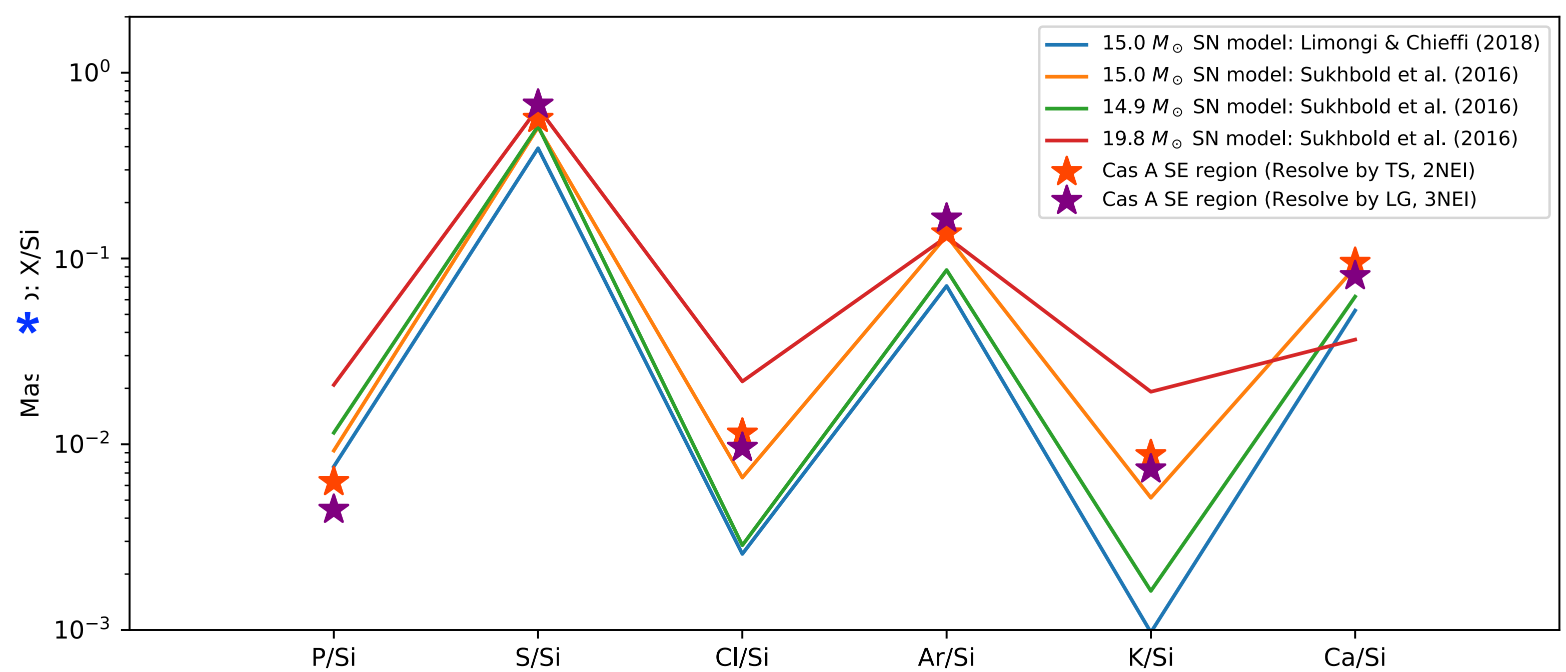
Gu (SRON)

- fit spectra with a 2 vnei model with a variable redshift and broadening
- K abundance set to zero
- bright lines/line complexes are well-fitted
- clear excess at the position of K He α
- interesting excess at 3.2 keV (discussed later)



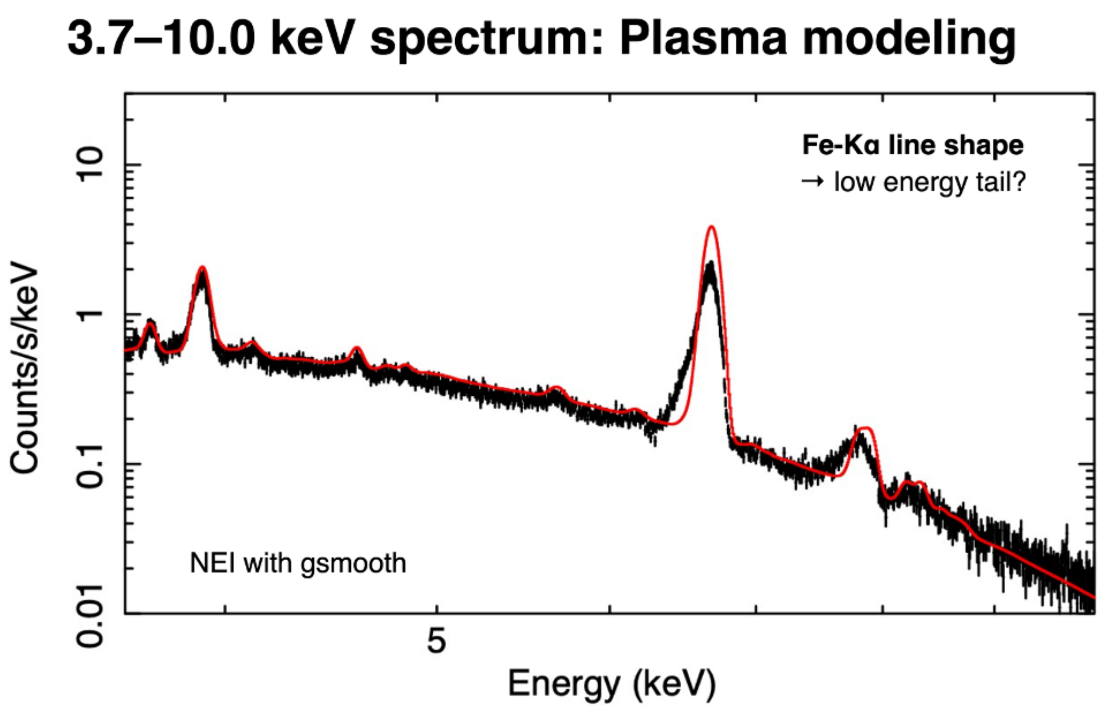
Sato (Meiji U.)

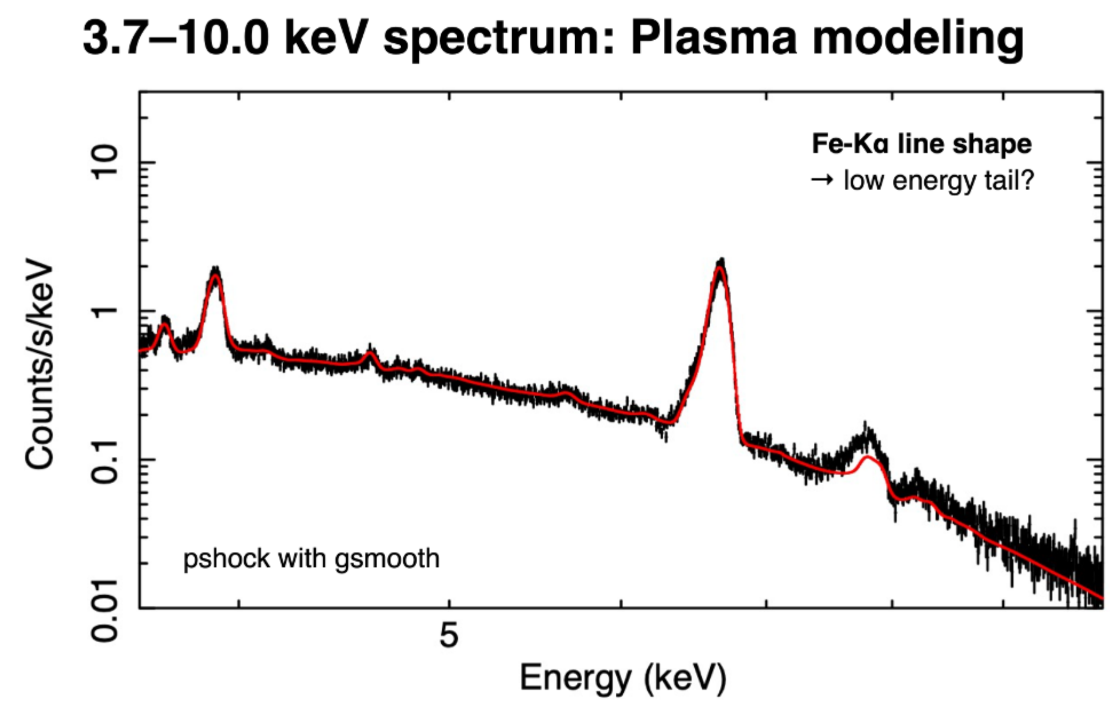
- shell mergers during the final stages of stellar evolution can affect the production of the IMEs and the odd Z elements like P, Cl, K



Fe group Elements

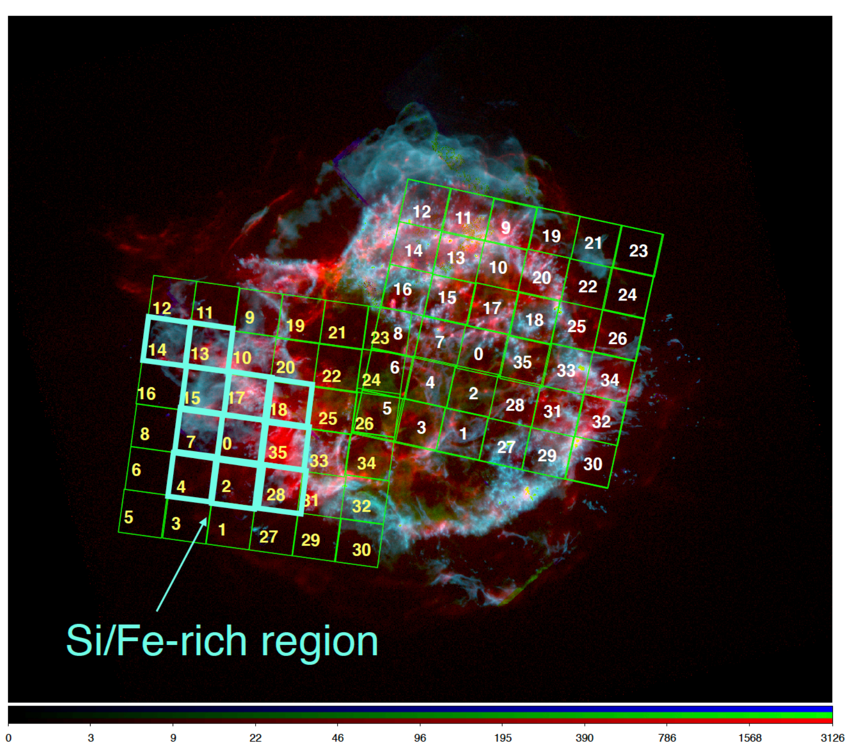
- The broad and asymmetric distribution of the Fe-K complex *requires* the lower ionizations states of the pshock model to fit the low energy side of the peak

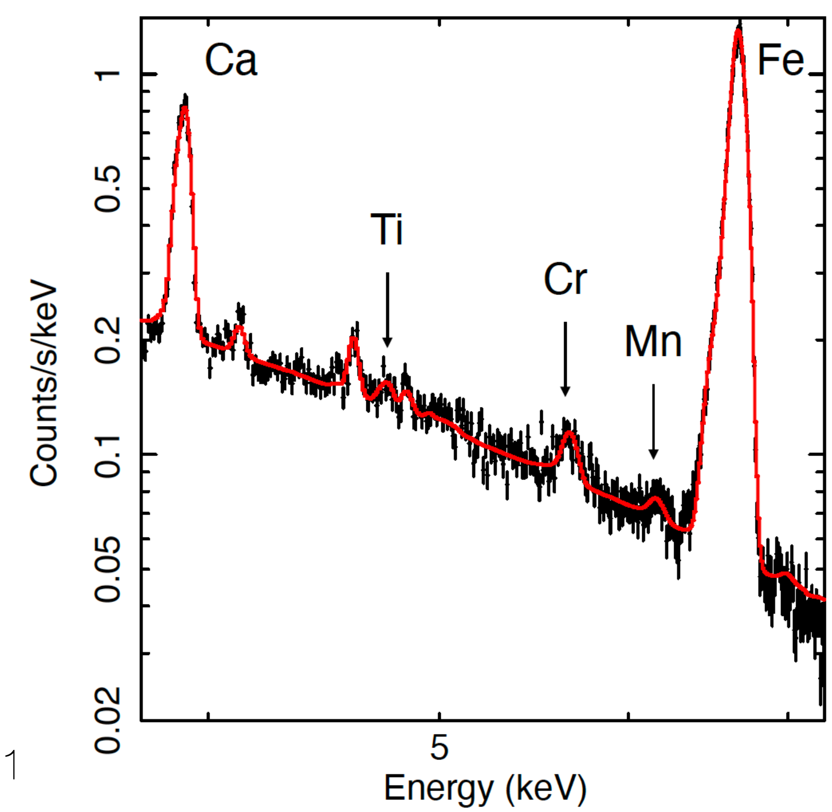




- fit spectra with a 2 vnei model with a variable redshift and broadening
- Ti, Cr, & Mn are relatively stronger in the SE than the NW

Sato (Meiji U.)



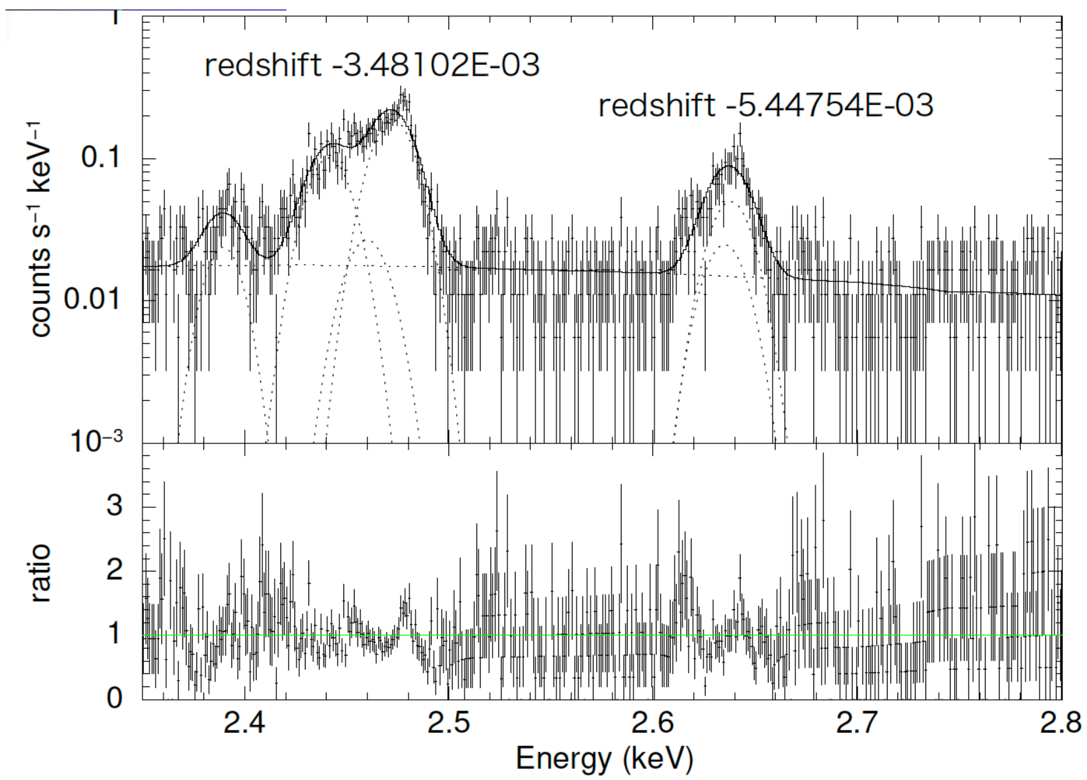


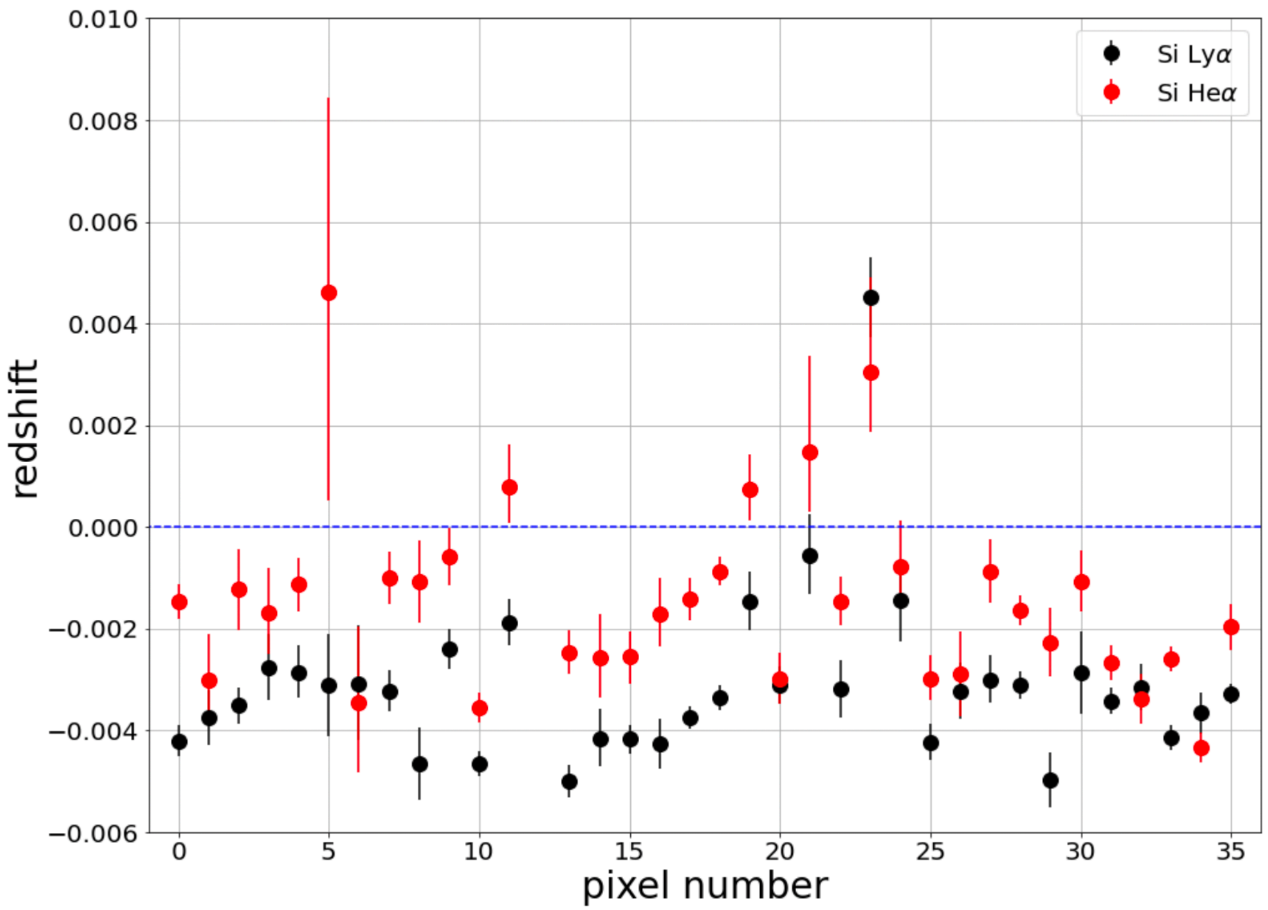
Spectral Differences between Heα and Lyα

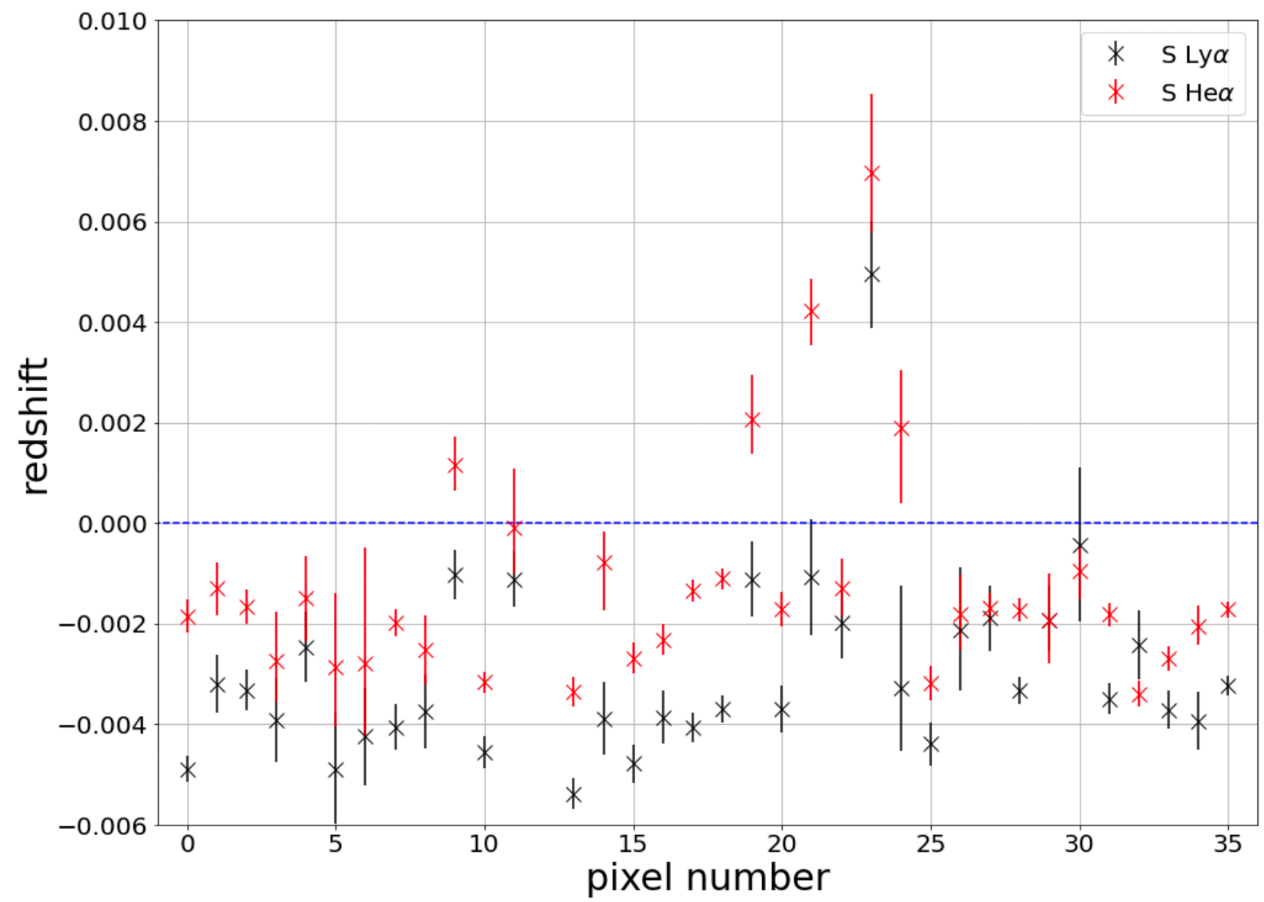
X-RAY IMAGING AND SPECTROSCOPY MISSION

Suzuki & Yamaguchi (ISAS)

- Fitted redshifts for the Heα and Lyα lines for Si and S are different, z for Lyα larger
- Heα and Lyα emission arise from different plasmas with different properties
- One possible explanation is that the Lyα emission predominantly originates from regions that were shocked earlier by the reverse shock when the shock velocity was higher







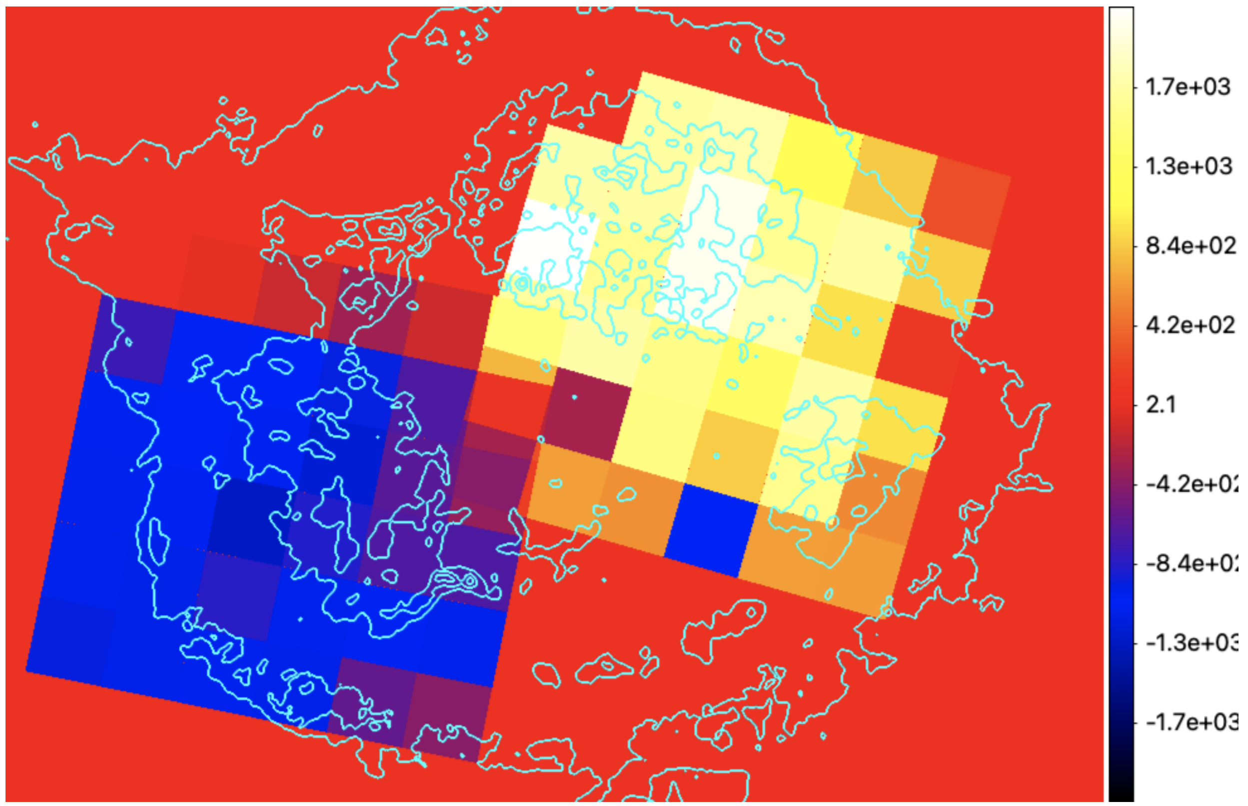
Resolve **Velocity and Broadening Maps**

XRISM
X-RAY IMAGING AND SPECTROSCOPY MISSION

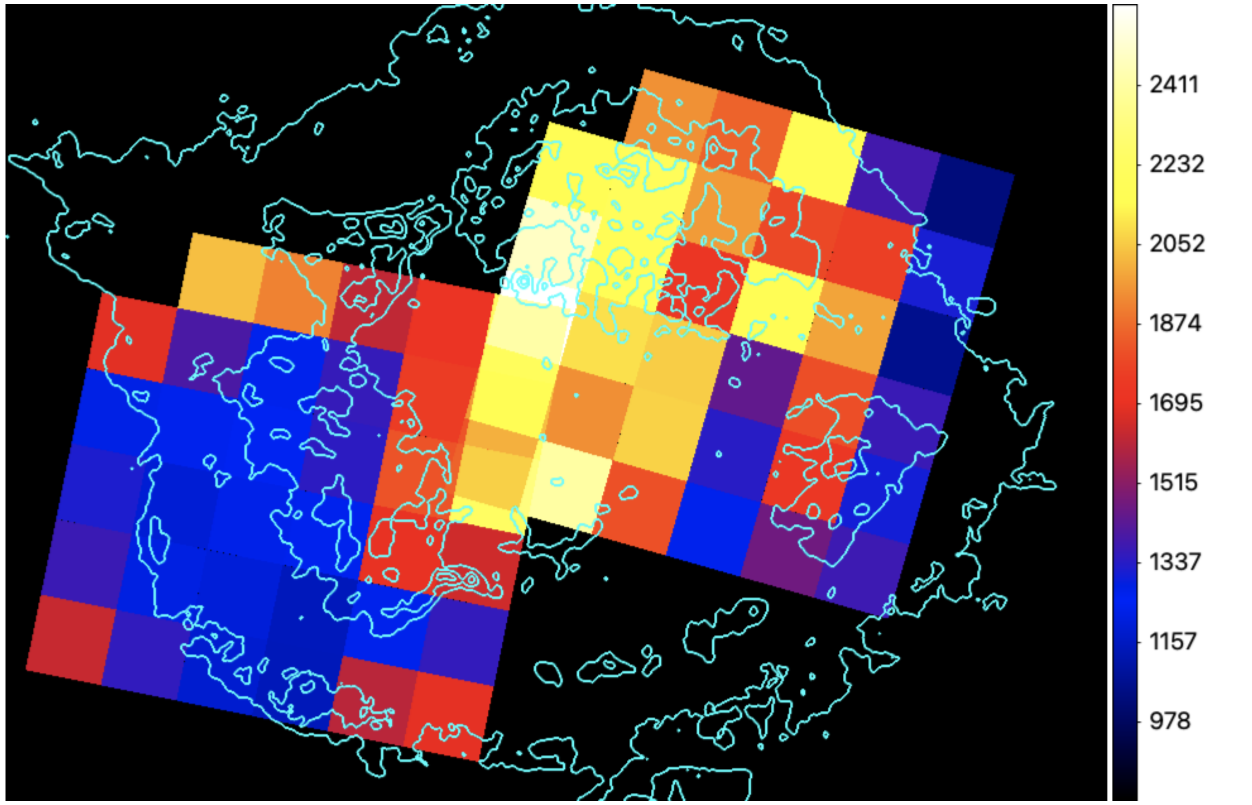
Vink & Agarwal (U. of Amsterdam)

- **Si XIV Lyα and S XVI Lyα lines are fit to determine a redshift and width**
- **NW data are red-shifted up to 2,000 km/s and SE data are blue-shifted up to -1,500 km/s**
- **Broadening is largest in the center and smallest near the edges**
- **Overlap regions between pointings give consistent results**
- **It is *essential* to fit the redshift and the broadening with these high resolution spectra**
- **Earlier broadening measurements made with the gratings on *XMM* for RCW86 and *Chandra* for SN1987A (Broersen et al. 2006, Miceli et al. 2019) were limited**

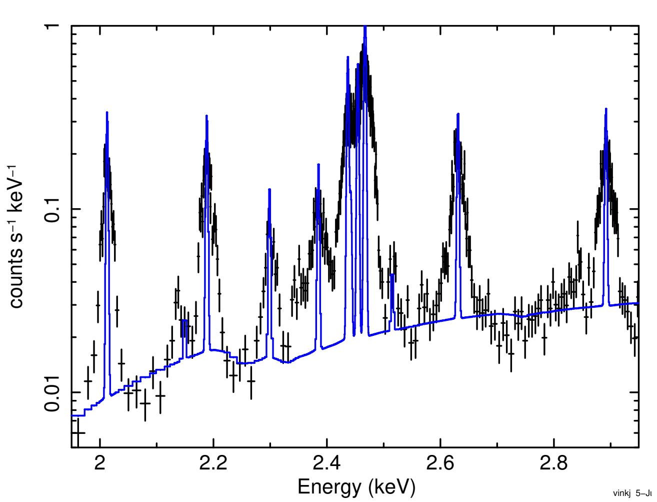
Redshift Map



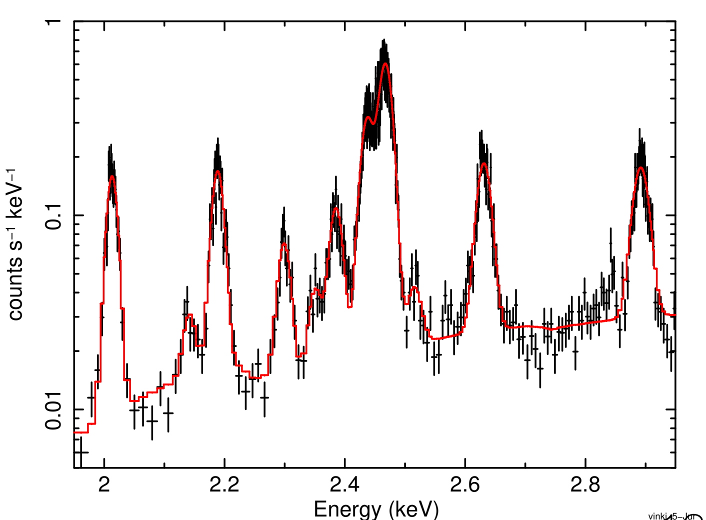
Broadening Map



Model with no broadening



Model with broadening



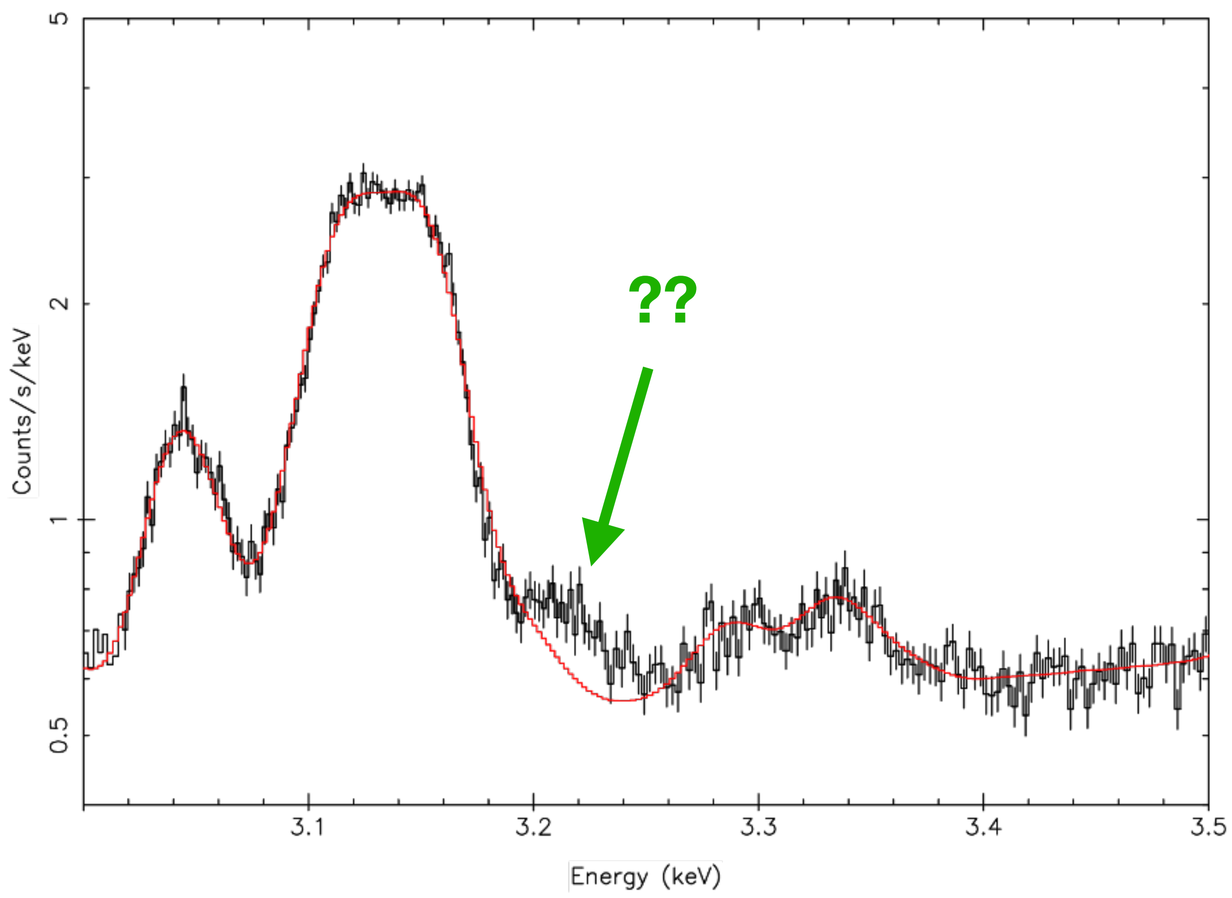
3.2 keV Excess Feature

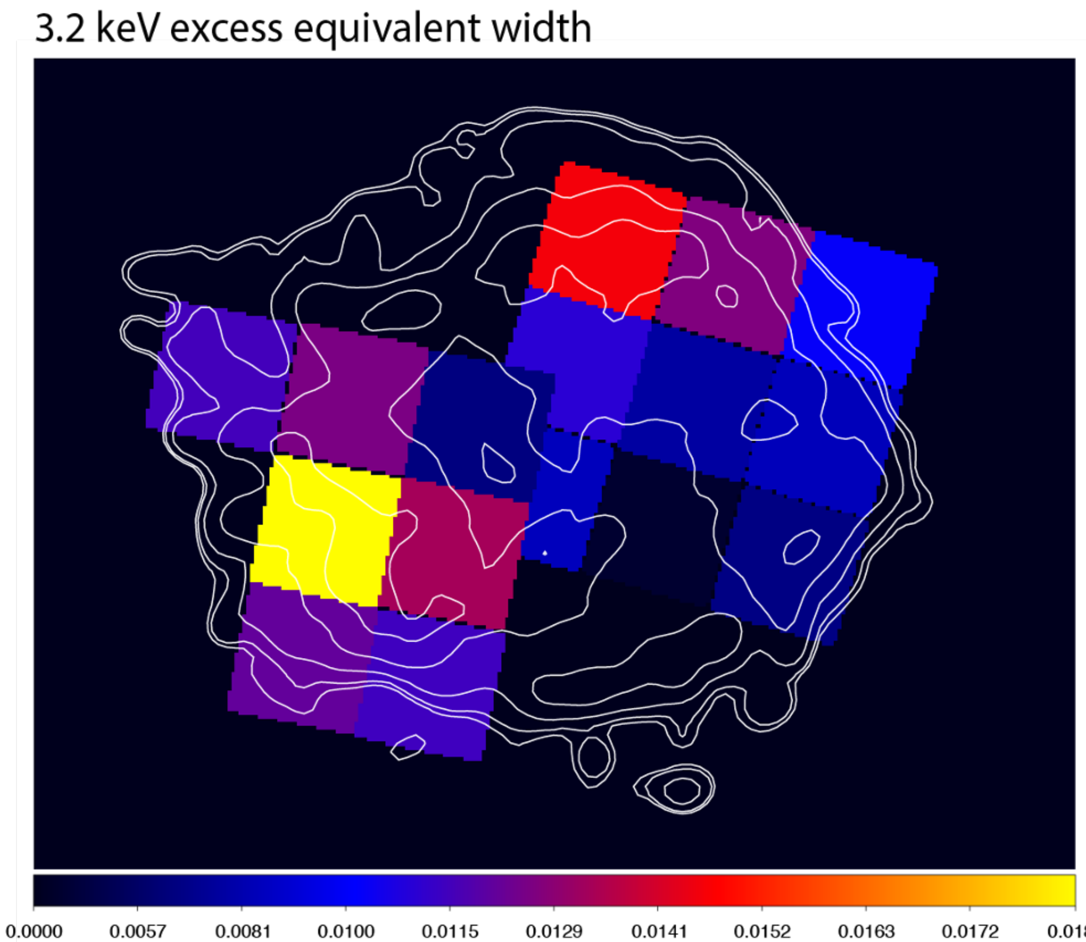
Gu (SRON)

- **fit the spectrum with a two component vnei model, clear excess above 3.2 keV**

Possible Explanations:

1. **free-bound emission from pure metal plasma (likely ionizing)**
2. **free-bound emission from a recombining plasma with normal abundances**
3. **charge exchange emission from S**

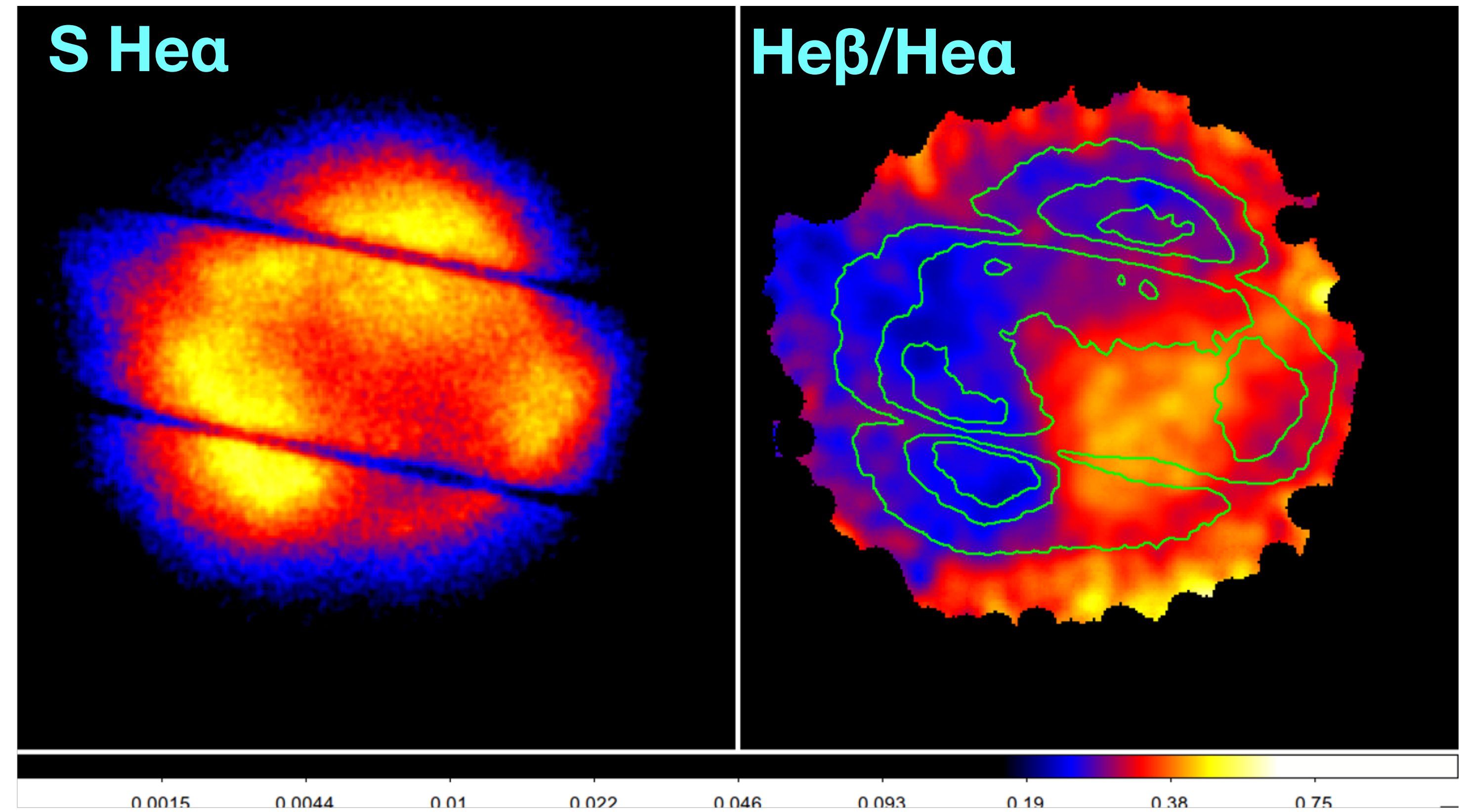


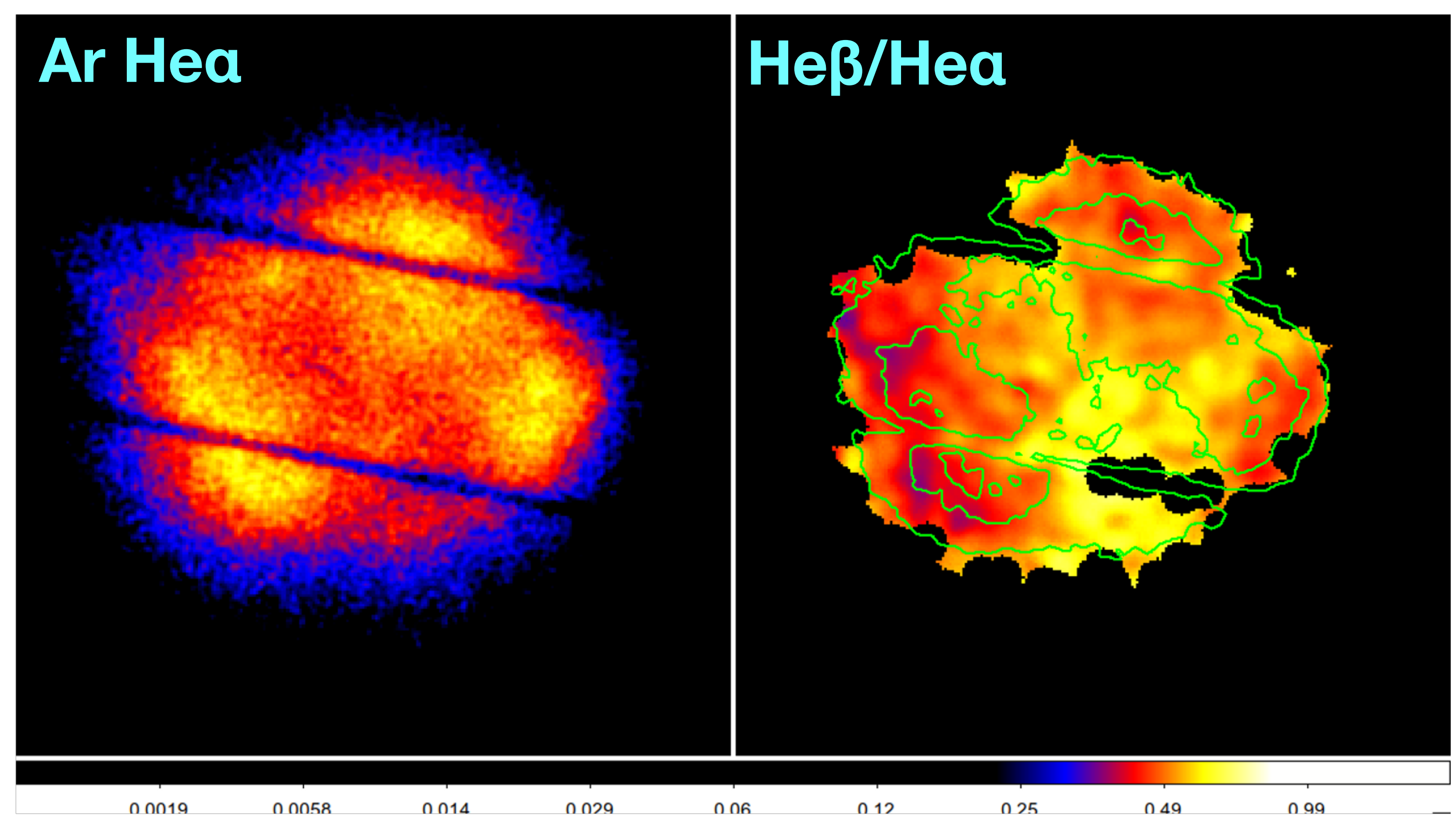


Xtend Heβ/Heα Ratio Maps

Nakajima (Kanto Gakuin U.)

- Heβ/Heα ratios are significantly different for S and Ar
- Higher ratios are present in the region dominated by the interaction with the CSM

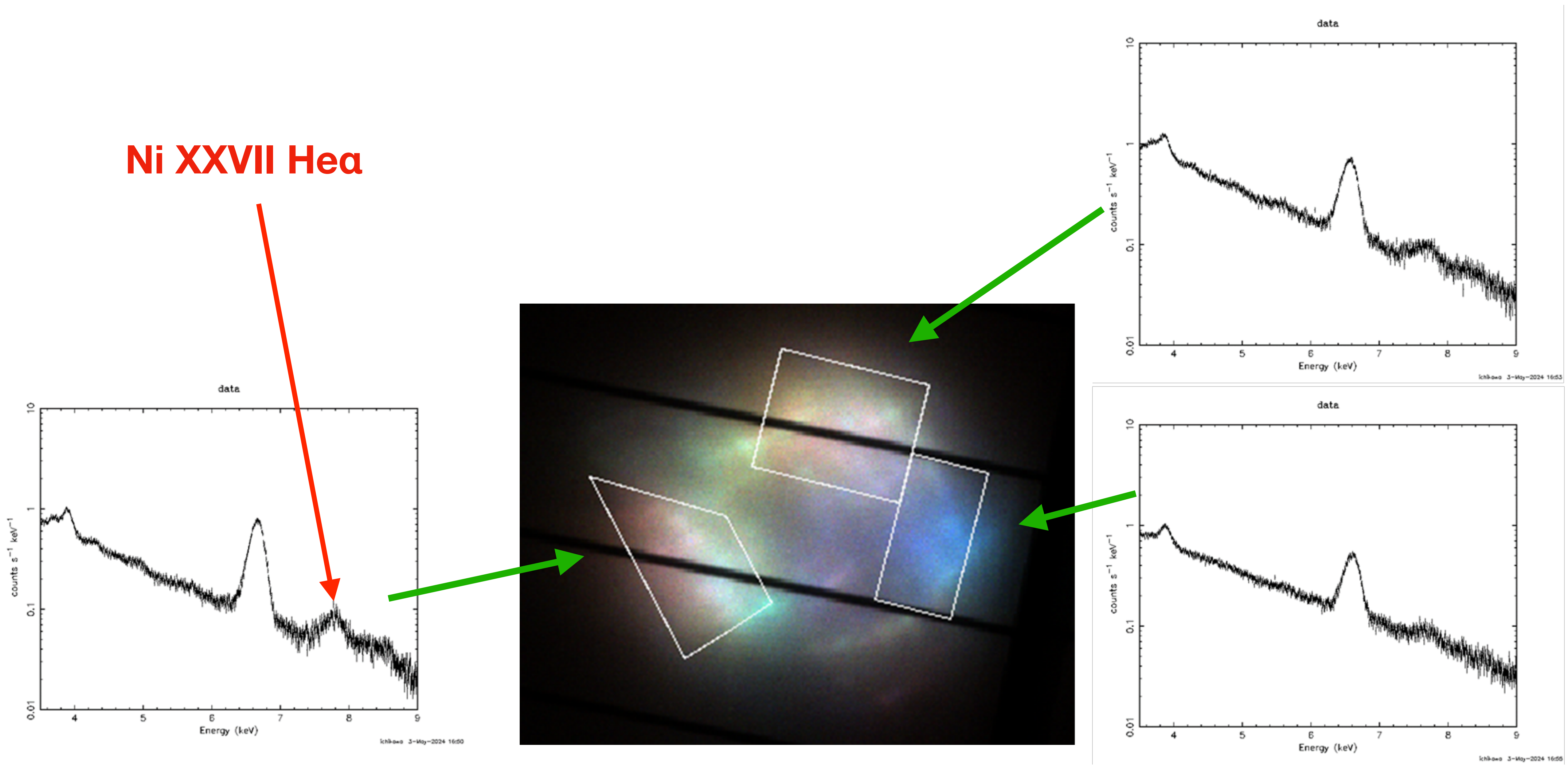




Xtend Spectra from 3.0-10.0 keV

Ichikawa (U. of Miyazaki)

- ***Xtend*** **lower background is advantageous in the higher energy bandpass**
- **Data out to 10 keV provide a better constraint on the continuum**
- **The Ni XXVII Heα triplet & Fe XXV Heβ are relatively stronger in the SE, the Fe-rich region**



Conclusions

X-RAY IMAGING AND SPECTROSCOPY MISSION

The era of high-resolution X-ray spectroscopy for diffuse emission and extended objects has begun !!!

Key Cas A results (*so far*):

- **K and Cl are detected**
- **P might be detected, will need more careful modeling**
- **Ti, Cr, & Mn are clearly detected**
- **Fitted redshifts are different for the Si & S Heα and Lyα lines**
- **Blueshifted emission in the SE and redshifted emission is clearly detected**
- **Broadening is highest in the center (~2,000 km/s) and lowest near the edges (~1,000 km/s)**
- **Ni is relatively strongest in the SE, the Fe-rich region**

Future of High Resolution X-ray Spectroscopy for SNRs

LINE EMISSION MAPPER

Line Emission Mapper (LEM) - https://www.lem-observatory.org/

Mission Concept Proposal for NASA Probe Class

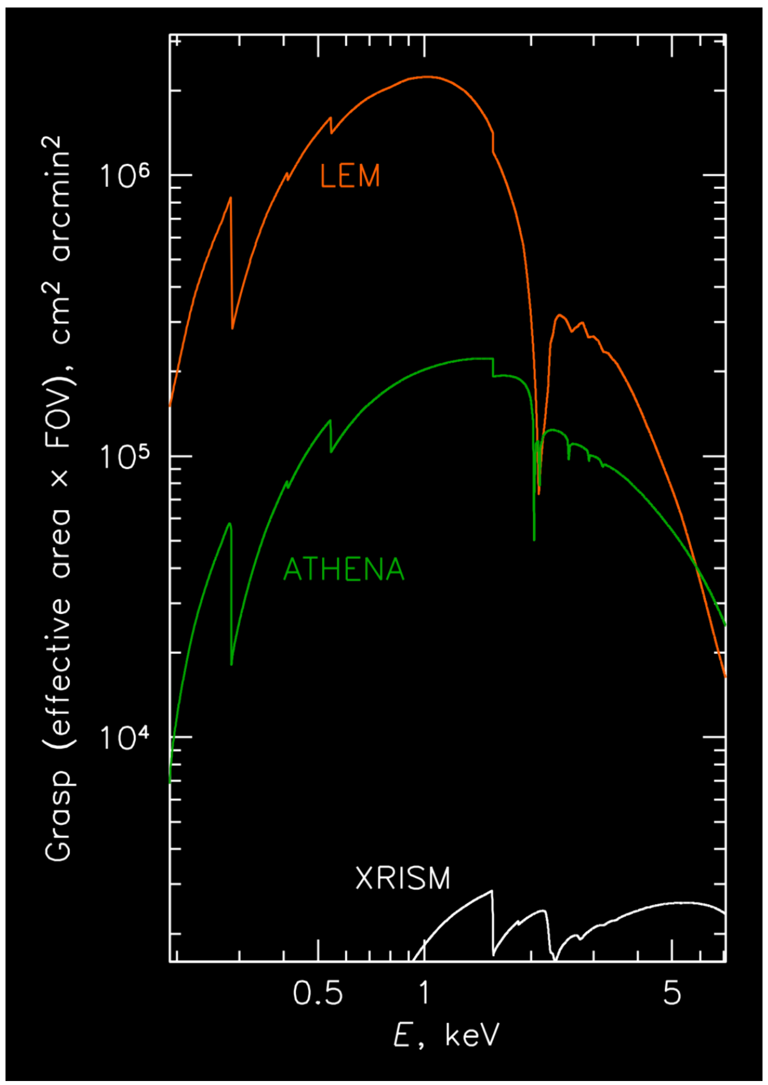
Optimized for spectroscopy of diffuse emission (large grasp) [0.2-2.5 keV]

large FOV (30' diameter), EA: 2,600 cm^{-2} at 1.0 keV, 10" HPD (mirror)

14K 15" pixels, 1.3/2.5 eV resolution inner/outer array

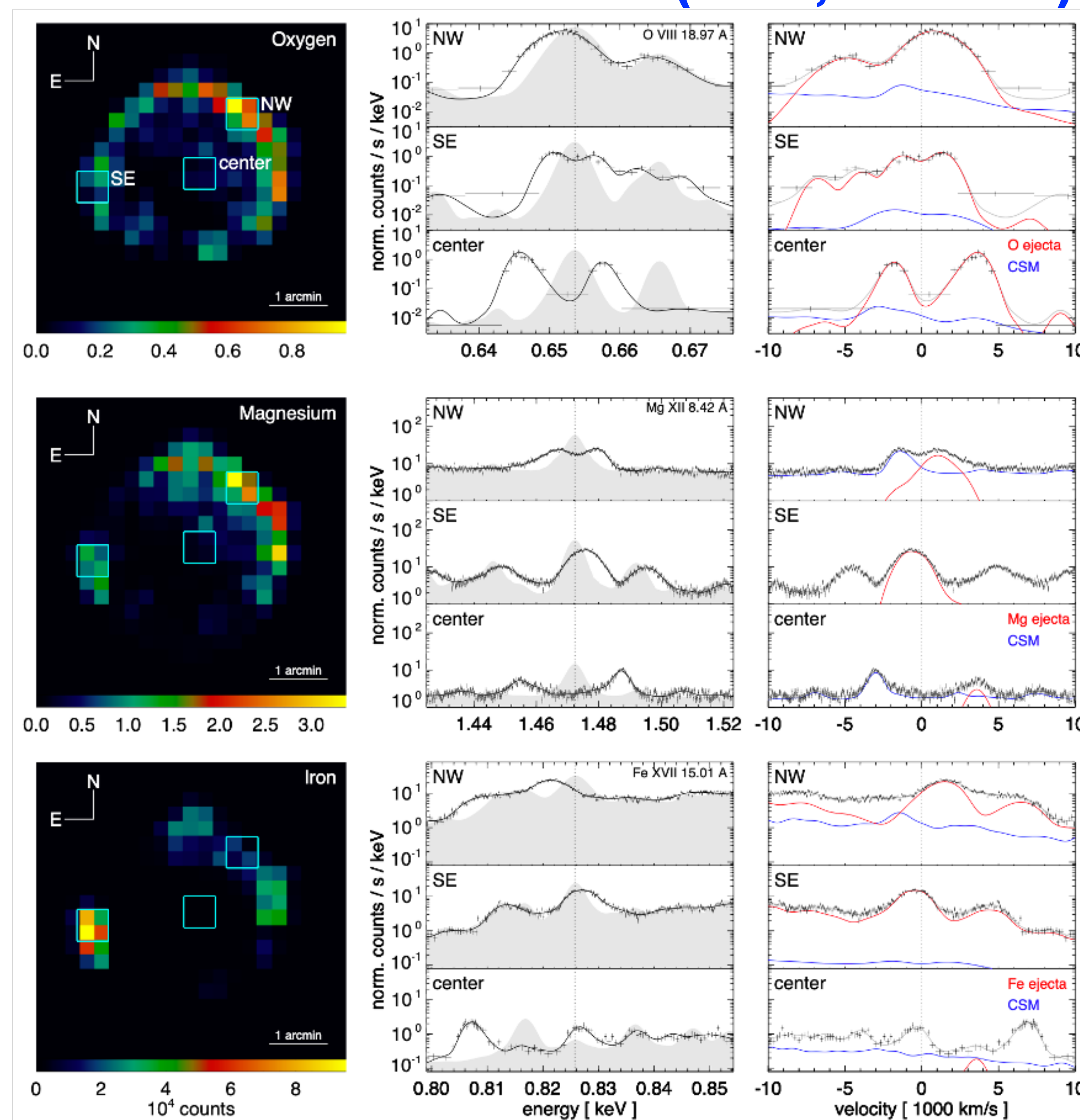
These capabilities are *FANTASTIC* for SNR studies

Please find me if you would like more information



LEM Simulation of Cassiopeia A: Self-consistent description of the whole 3D evolution of a neutrino-driven SN explosion, from the CC to the SNR at the age of Cassiopeia A

Orlando (INAF,Palermo)



with broadening

no broadening