Pinpointing pure-metal ejecta X-ray emission in supernova remnants with NewAthena

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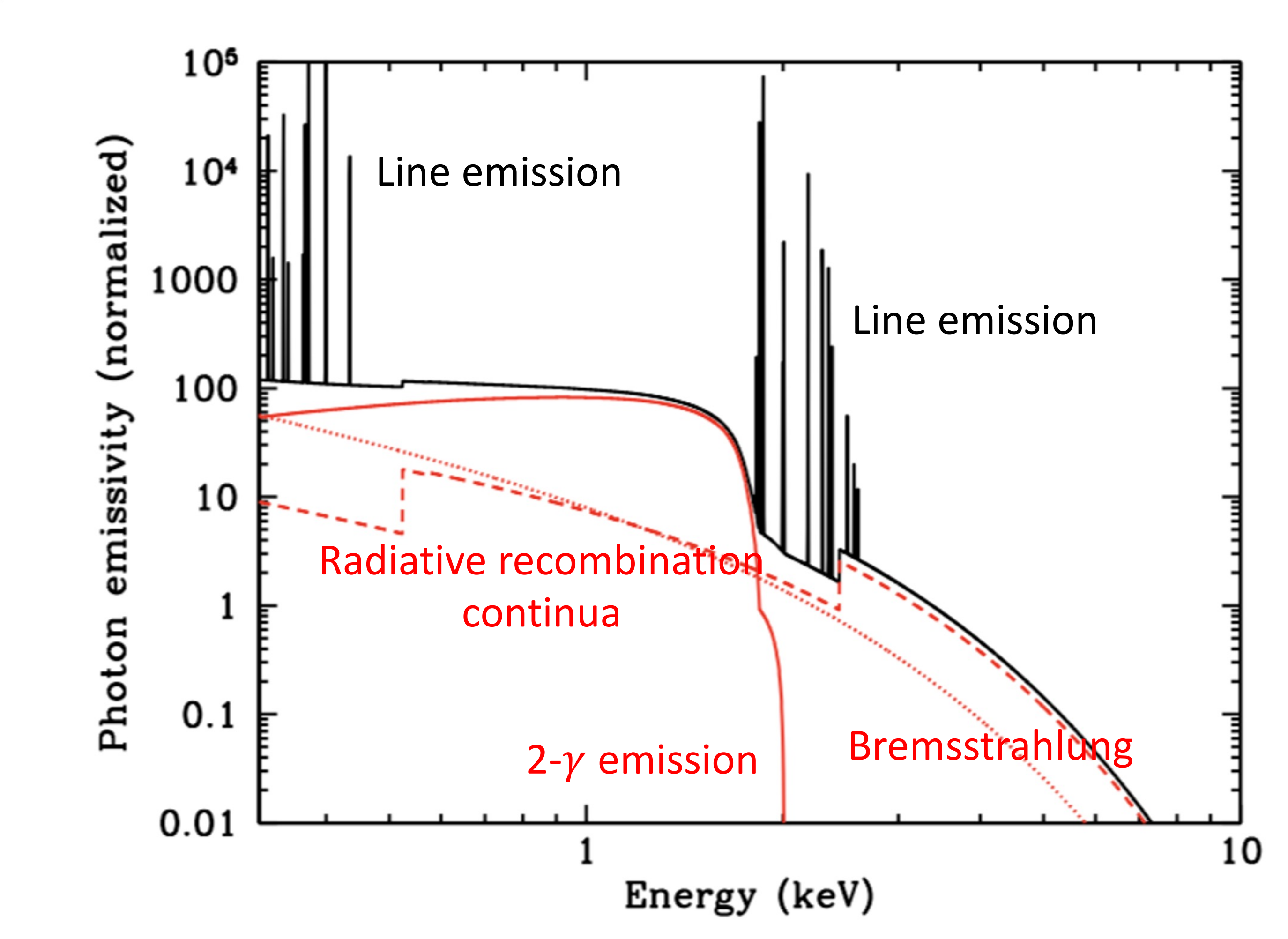
Emission processes in X-ray spectra of SNRs

Main contributions to the thermal emission in an optically thin plasma



Line emission (bound-bound)

$$P_{ji} \propto n_e^2 \, A_z \, F(T) \; \mathrm{phot\,cm^{-3}\,s^{-1}}$$

RRC emission (free-bound)

$$\varepsilon_{fb} \propto n_e n_{i+1} Z_e^2 T^{-\frac{3}{2}} e^{-\frac{e}{kT}} \; \mathrm{erg\,cm^{-3}\,Hz^{-1}}$$

Bremsstrahlung (free-free)

$$\varepsilon_{ff} \propto n_e n_i Z_e^2 T^{-\frac{1}{2}} e^{-\frac{e}{kT}} \; \mathrm{erg\,cm^{-3}\,Hz^{-1}}$$

The abundance problem

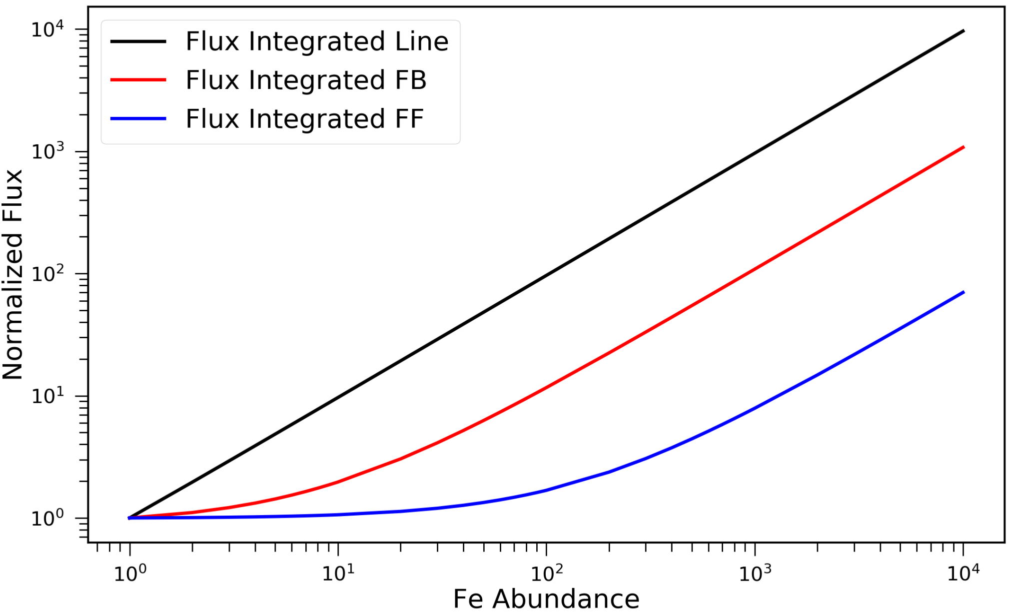
- CCD detectors have a moderate resolving power (R ≈ 5-100)
- The CCD resolution cause line blending and blurring of spectral features
- Degeneracy between EM and abundances
- Obtaining a precise absolute value of abundance is very hard
- Comparison with nucleosynthesis models can be made only by comparing relative abundances (e.g., Mg/Si or Mg/Fe)
- Uncertain absolute abundance means also uncertain mass value

How to fix this problem? Is there any spectral feature or diagnostic that can help us to correctly pinpoint the abundances and mass?

Our approach

- Study the emission of an optically thin plasma in the high abundance regime
- Synthesis of pure-metal spectra using CCD and Micro-calorimeters response matrices
- Looking for spectral differences due to the response matrix
- Investigate possible cases where we could expect presence of pure-metal plasma
- Compare our results with archive X-ray data

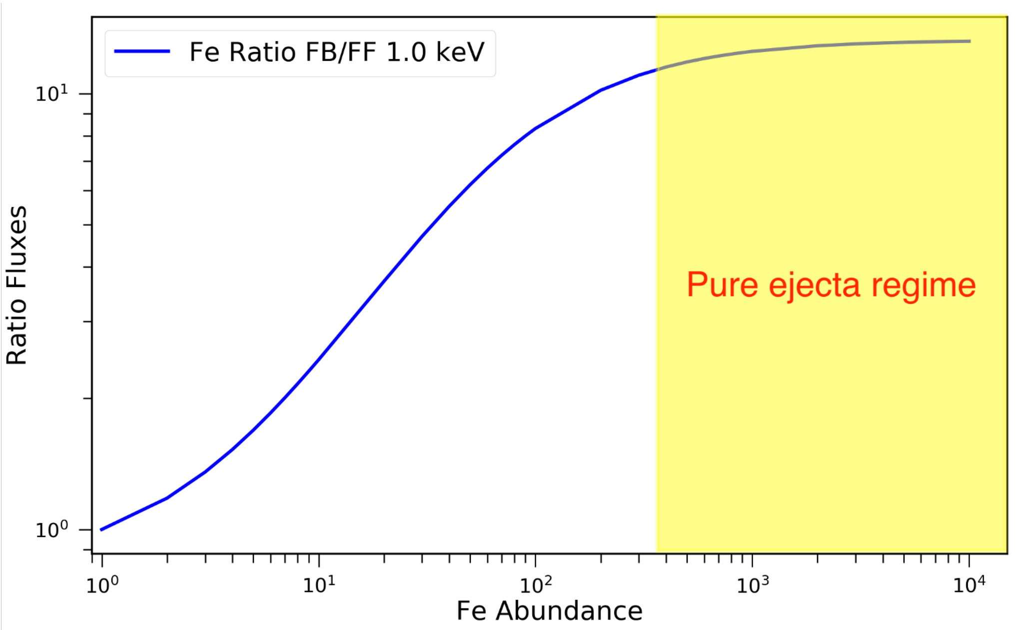
Spectral simulations: dependence on abundance

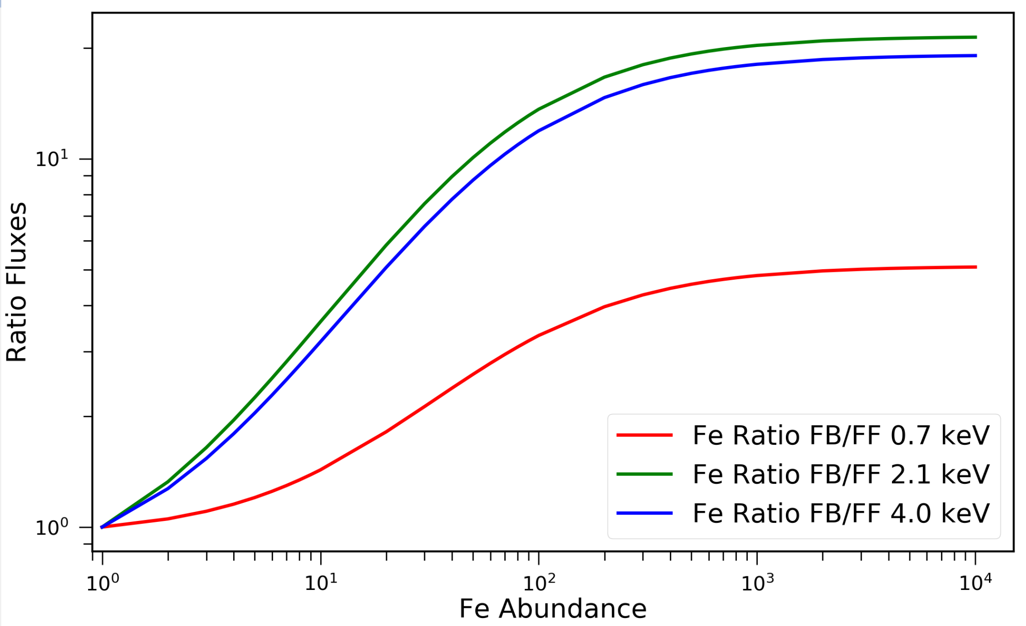


Flux of various emission processes as a function of the abundance

Band name	Energy range (keV)
SiLine	1.79-2.01
SiCont	2.47-2.67
FeLine	1.2-1.4
FeCont	2.05-2.15

Bands chosen for the flux estimates



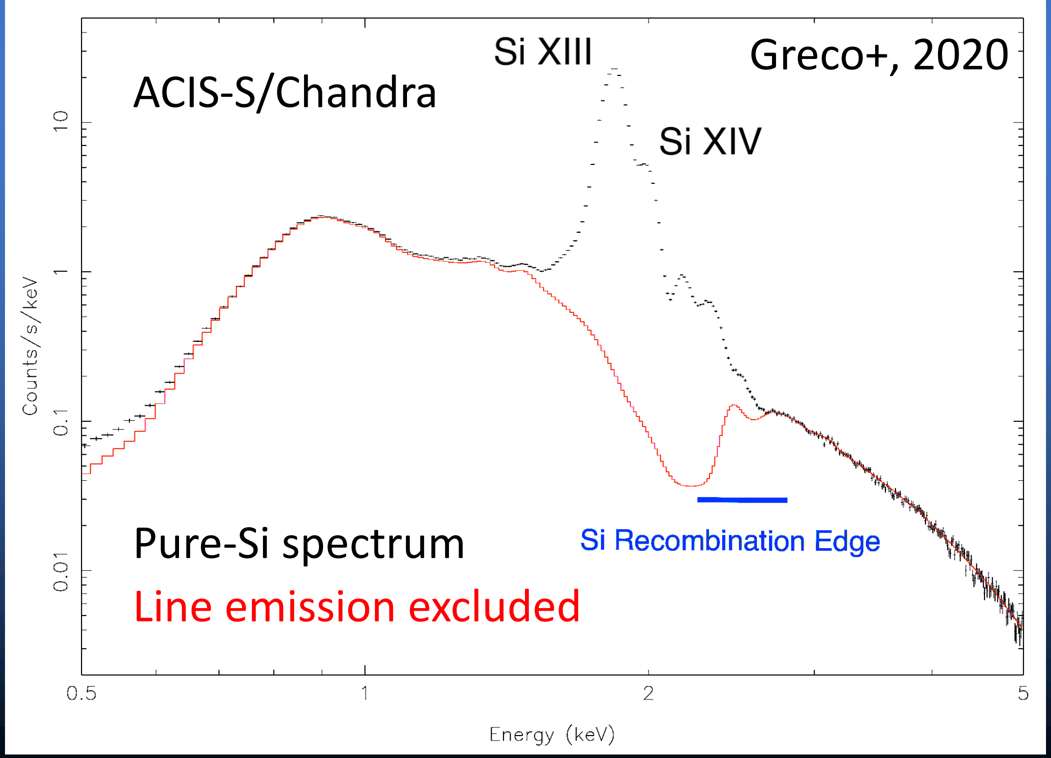


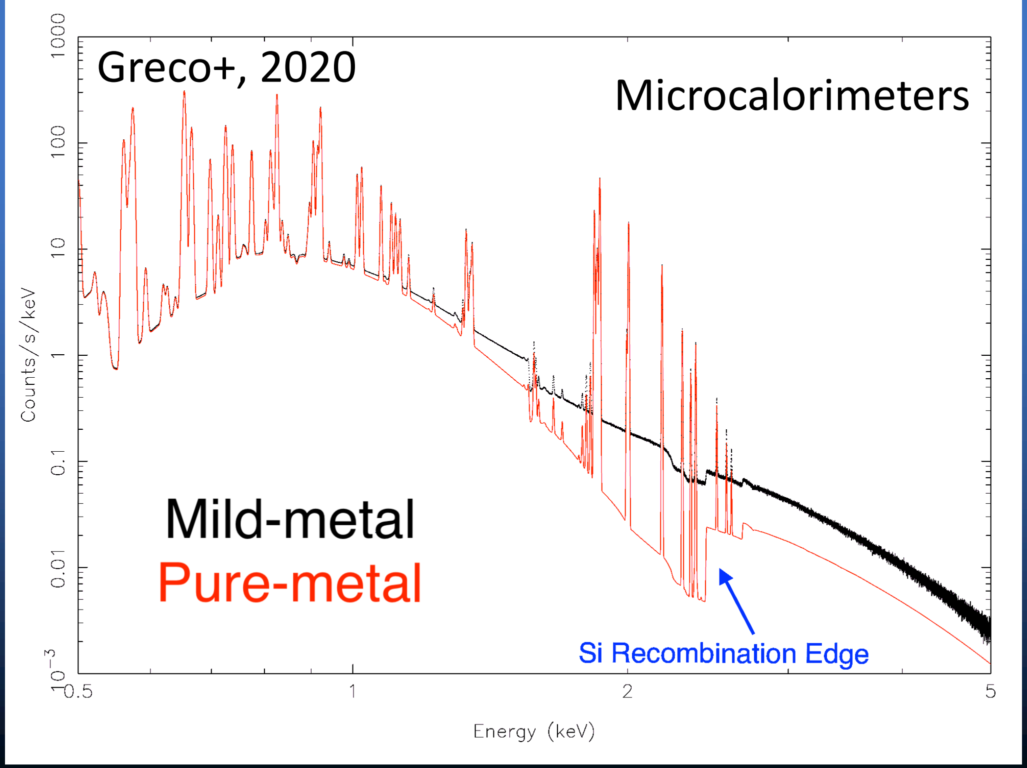
Ratio between the FB and FF fluxes as a function of abundance (left).
Same ratio estimated at various temperatures (right)

CCD vs Microcalorimeters

Moderate spectral resolution of CCD blurs the pure-metal RRCs. A pure-metal spectrum collected by a CCD detector do not show any RRC.

Microcalorimeters will reveal the presence of the RRC thanks to their superior spectral resolution.





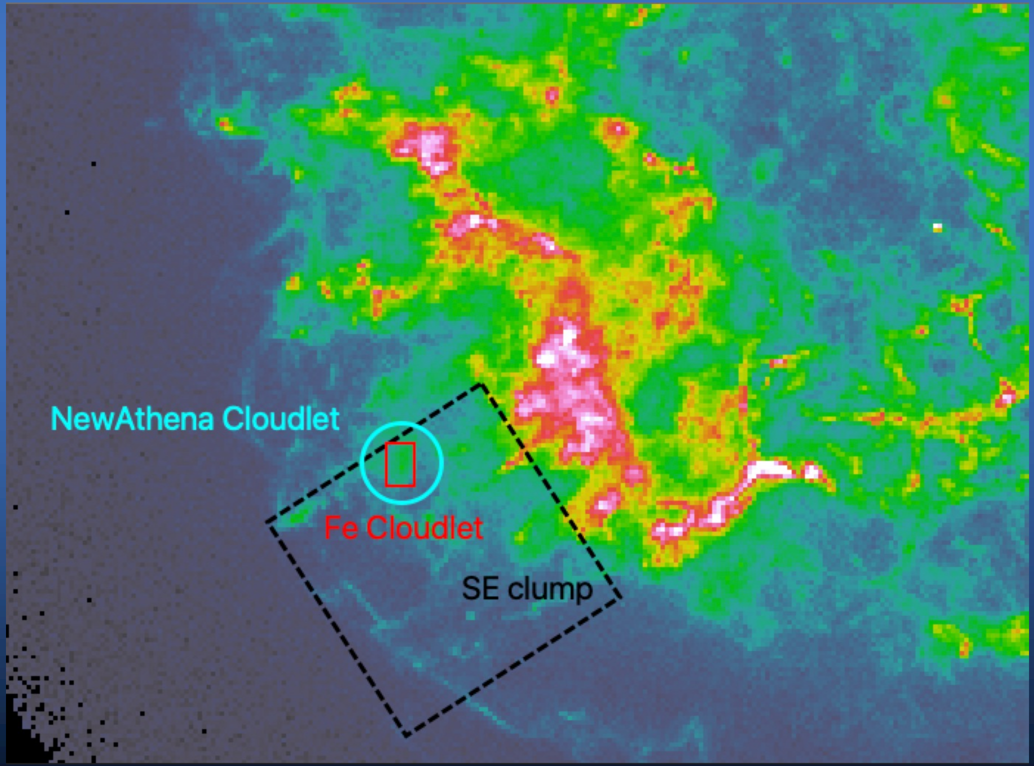
A possible detection: Cas A

Why Cas A?

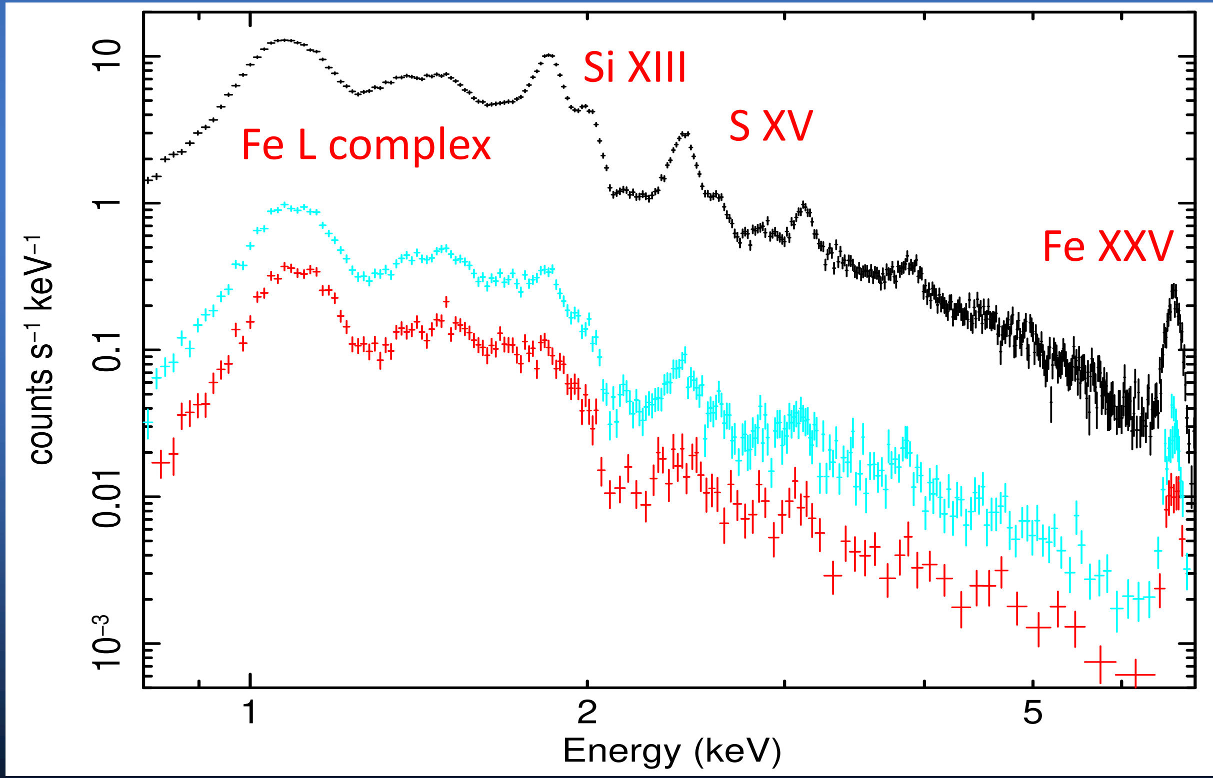
- Strong Si/S and Fe anisotropies richer in ejecta
- Fe Cloudlet in SE area of CasA (Fe/Si ~ 20)
- Hydrodinamic simulations from Orlando et al., 2016

Approach

- Data analysis of Chandra observation
- Self-consistent synthesis of spectra from HD simulation
- Comparing synthetic and observed spectra



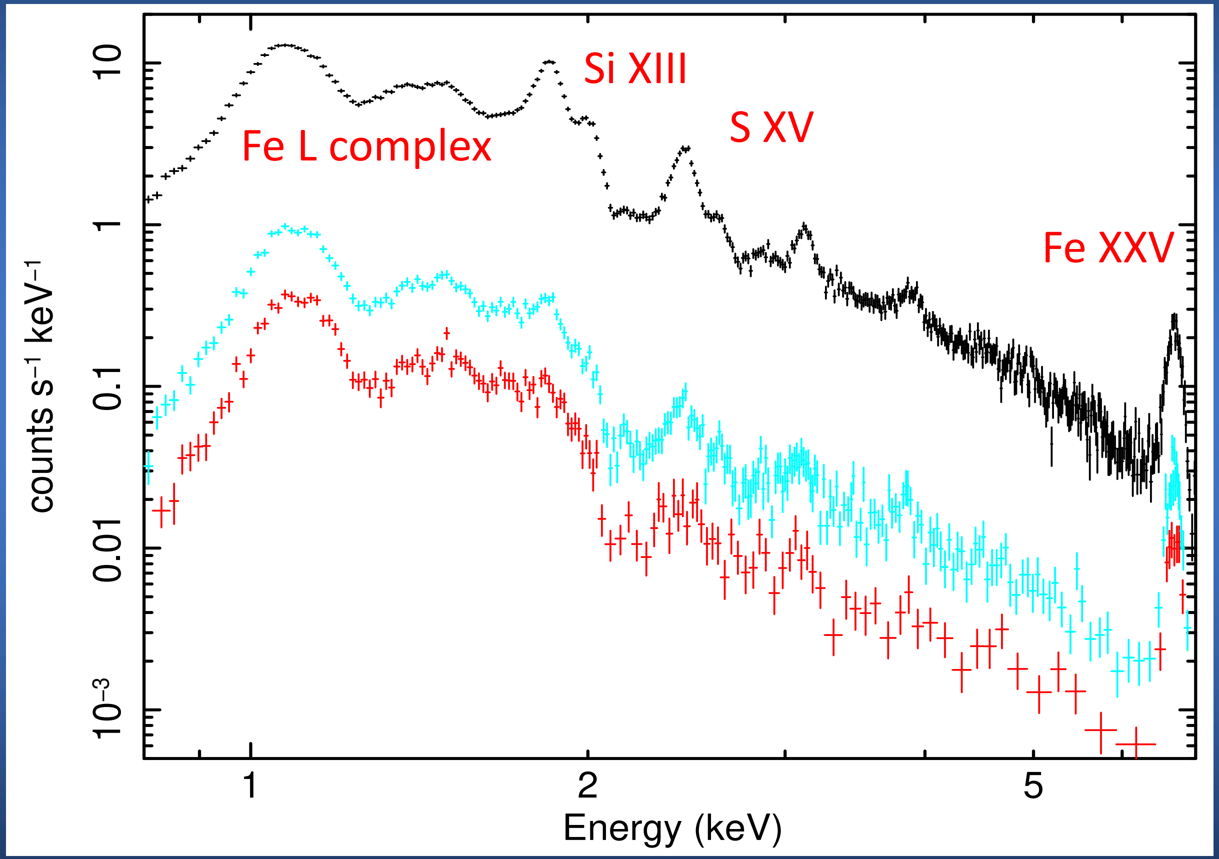
Count-rate Chandra image of Cas A



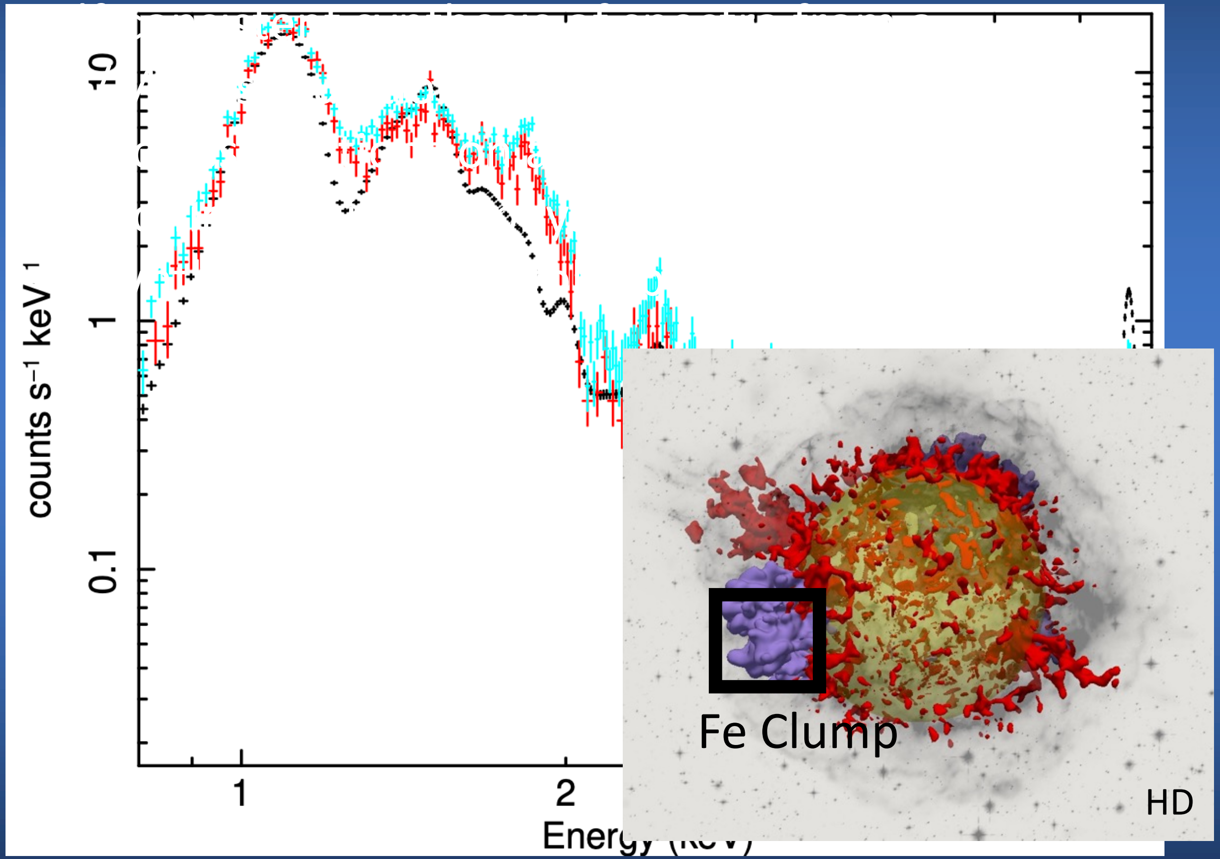
Chandra spectra from the regions shown on the left

Chandra spectra of the SE clump of Cas A

Comparison between synthetic and observed Chandra spectra

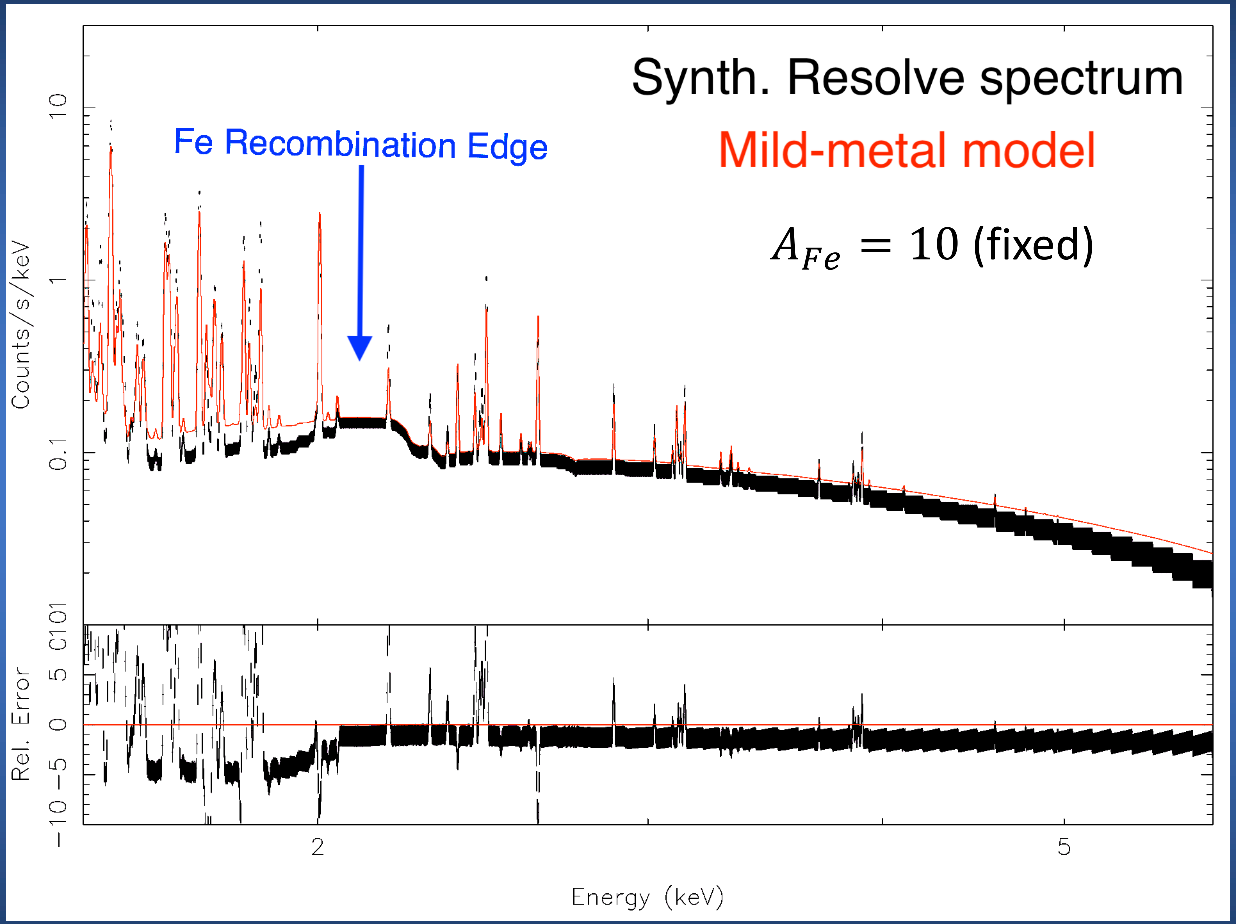


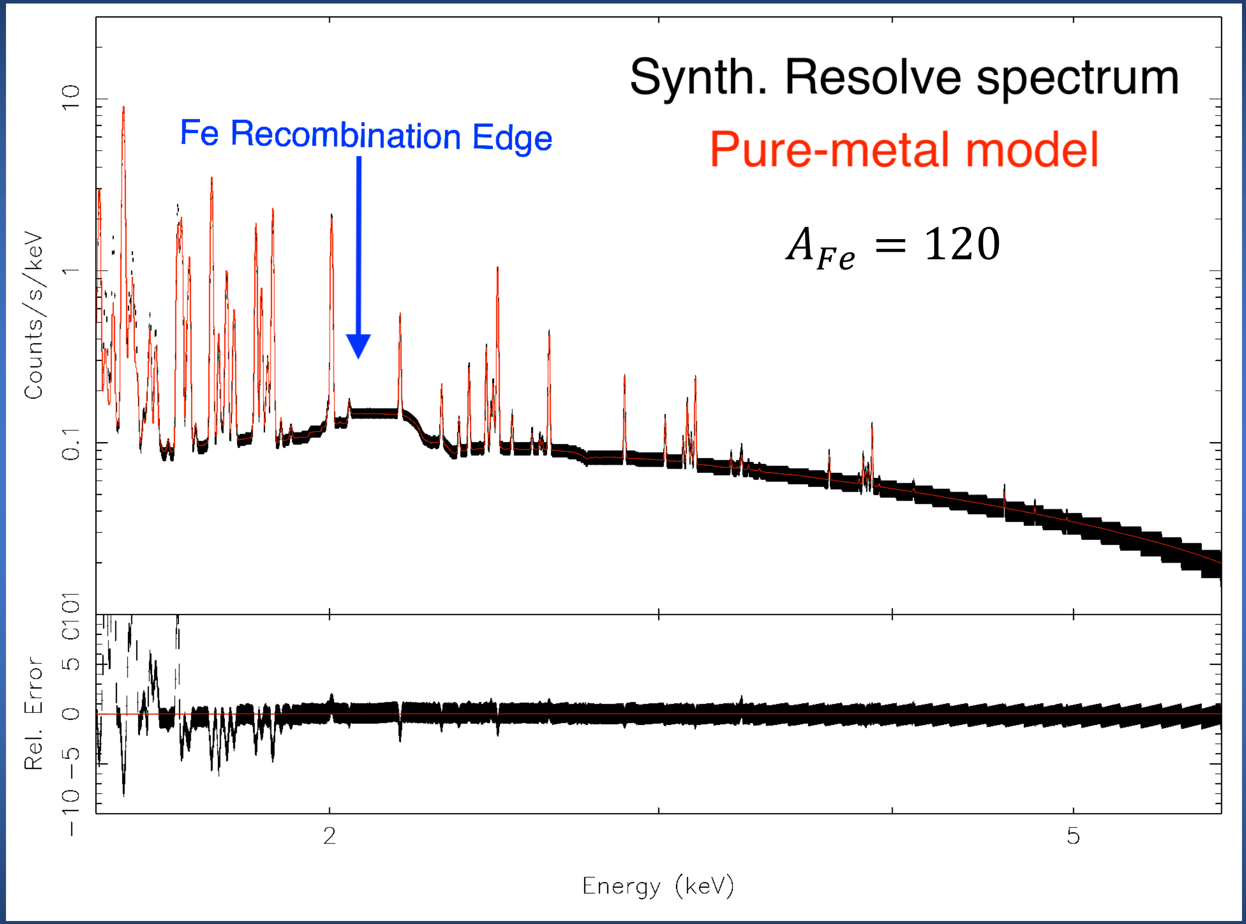
Chandra spectra from observations



Black: synthetic Chandra spectrum of the SE Fe-rich clump
Red and cyan: actual Chandra spectra of the Fe cloudlet renormalized for easy comparison

XRISM/Resolve synthetic spectra





The synthetic spectrum folded with XRISM shows prominent Fe recombination edge
Degeneracy between EM and abundance is solved

Recovering the correct ejecta mass

$M_{Fe} = 4.6 \times 10^{-3}\ M_{Sun}$

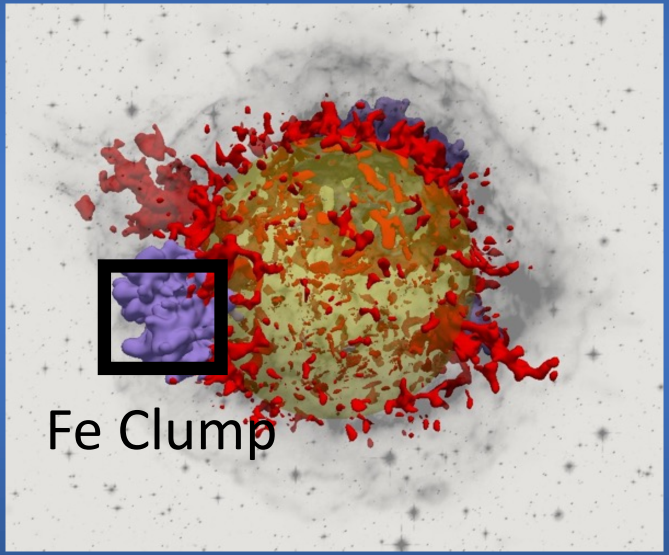
HD value

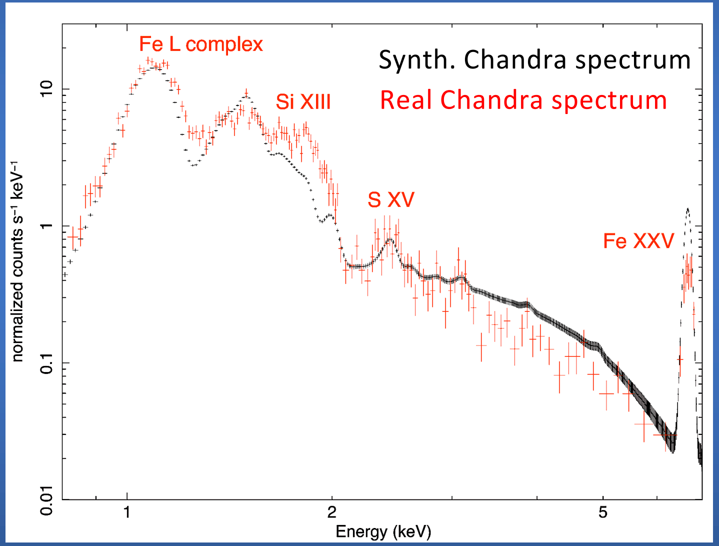
$M_{Fe} = (0.2 - 4) \times 10^{-3}\ M_{Sun}$

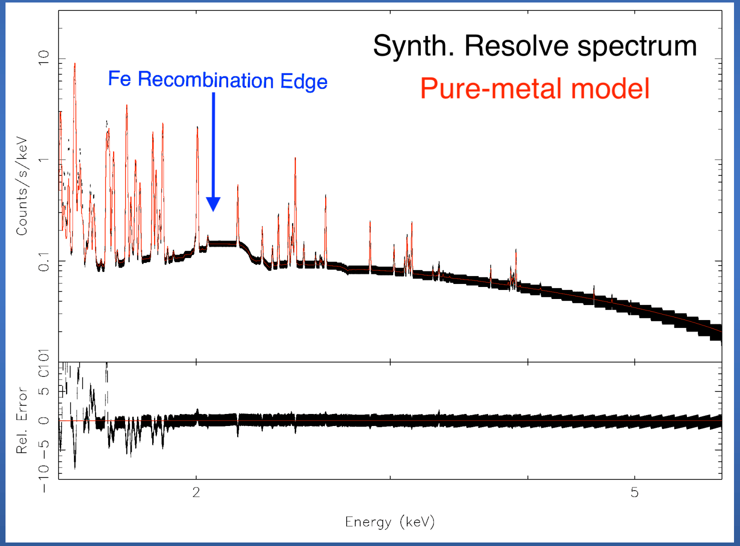
Chandra

$M_{Fe} = 4.8^{+0.5}_{-0.4} \times 10^{-3}\ M_{Sun}$

XRISM





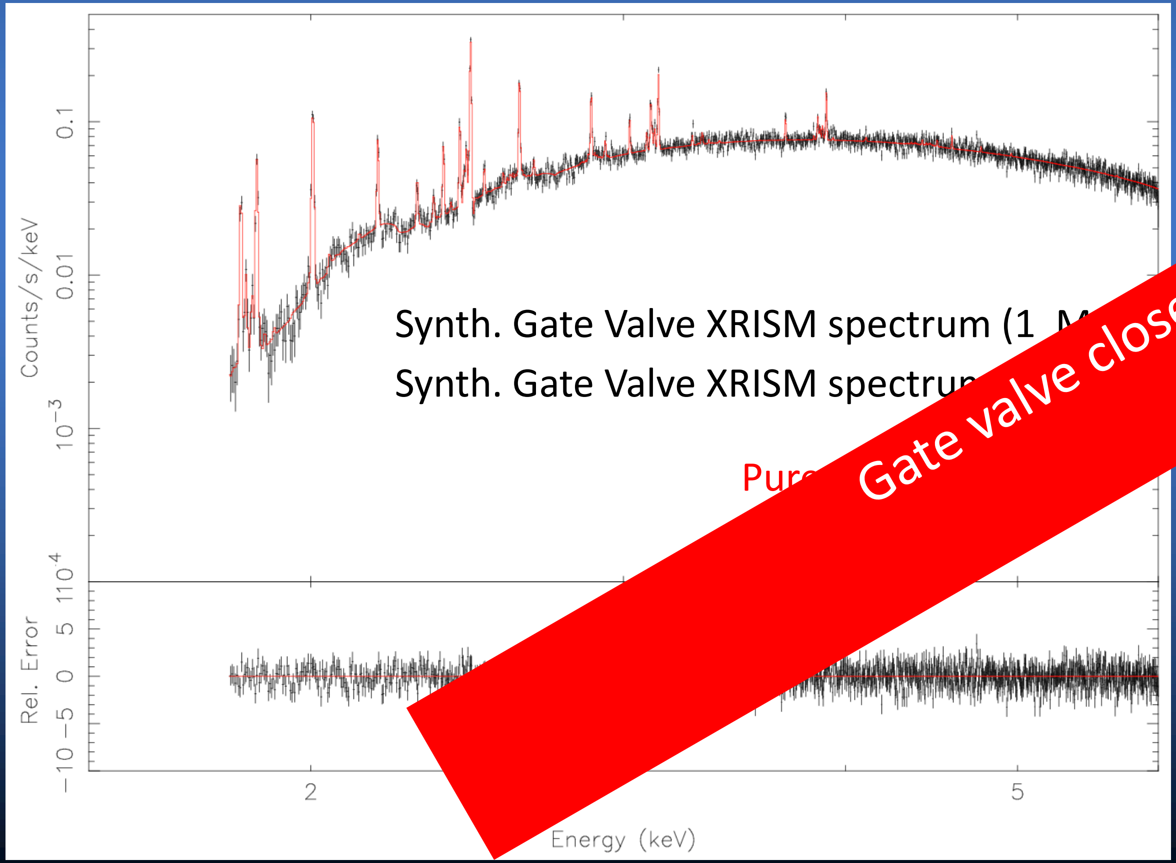


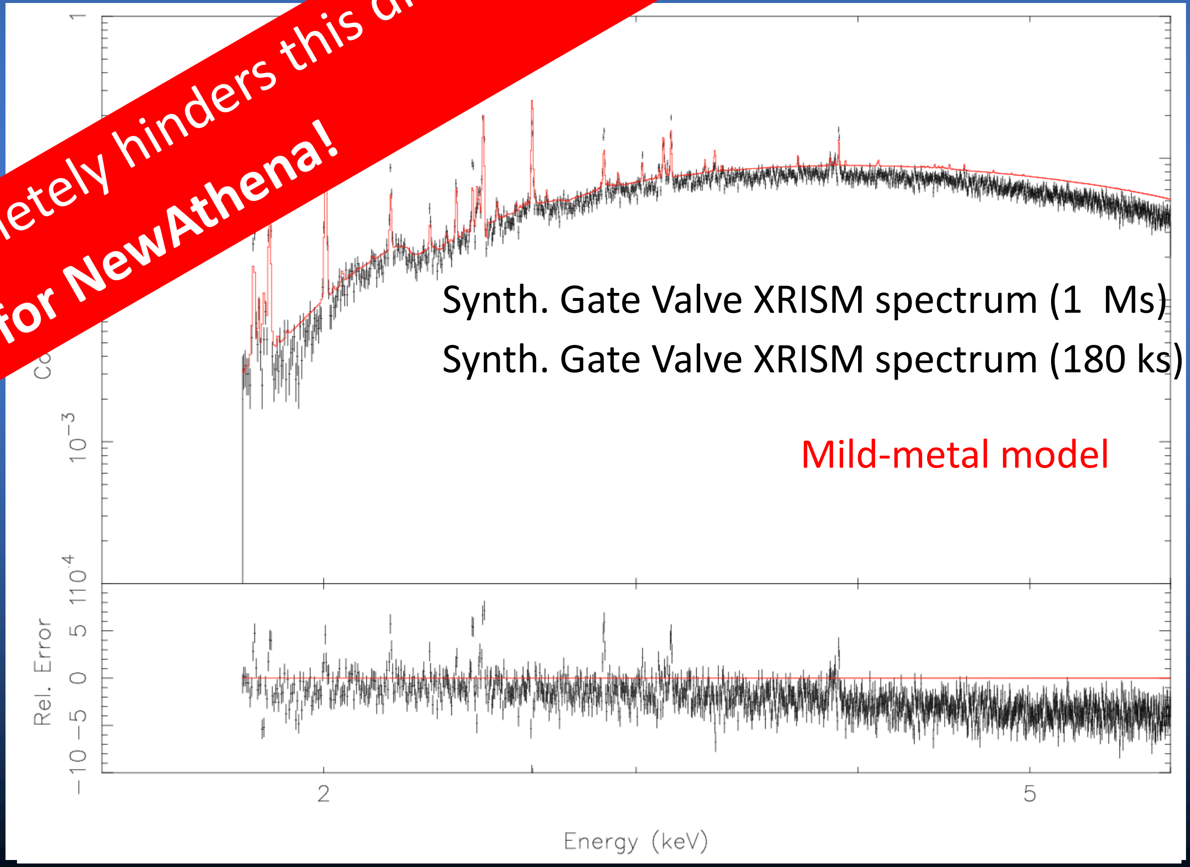
Mass measured with CCDs can be misleading up to a factor 20

Mass measured with microcalorimeters is well constrained

What about actual Resolve data?

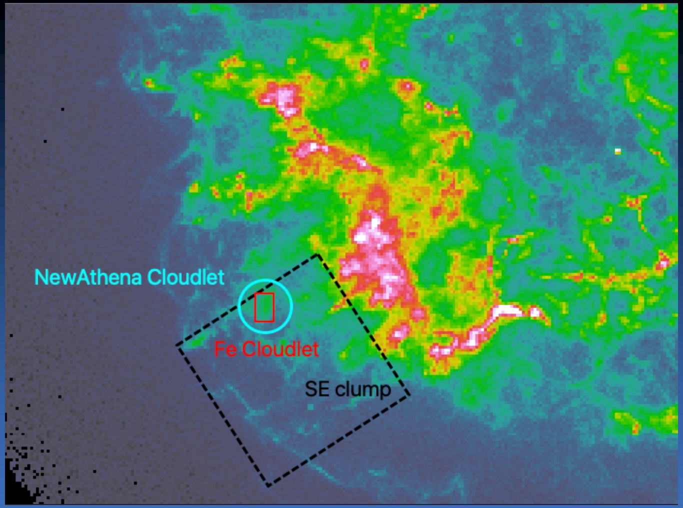
No detection! Why?





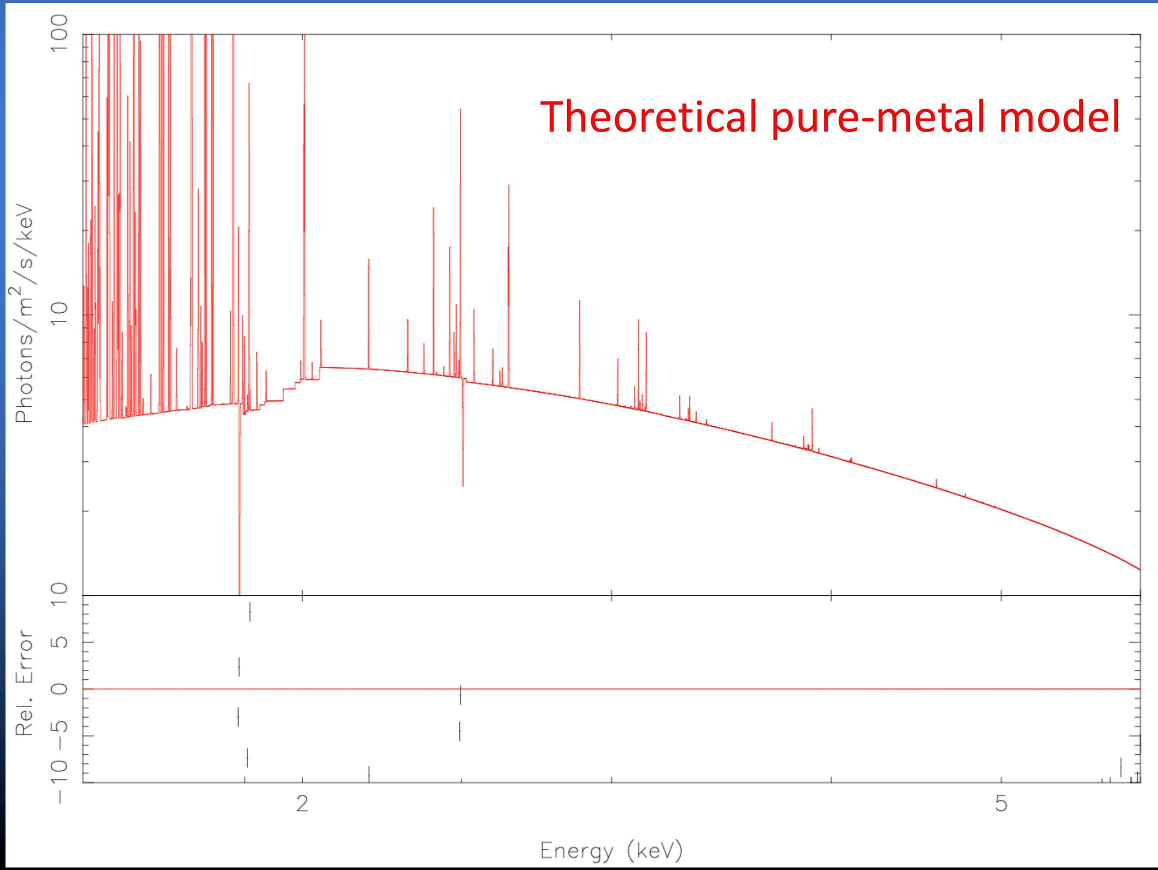
Gate valve close completely hinders this diagnostic

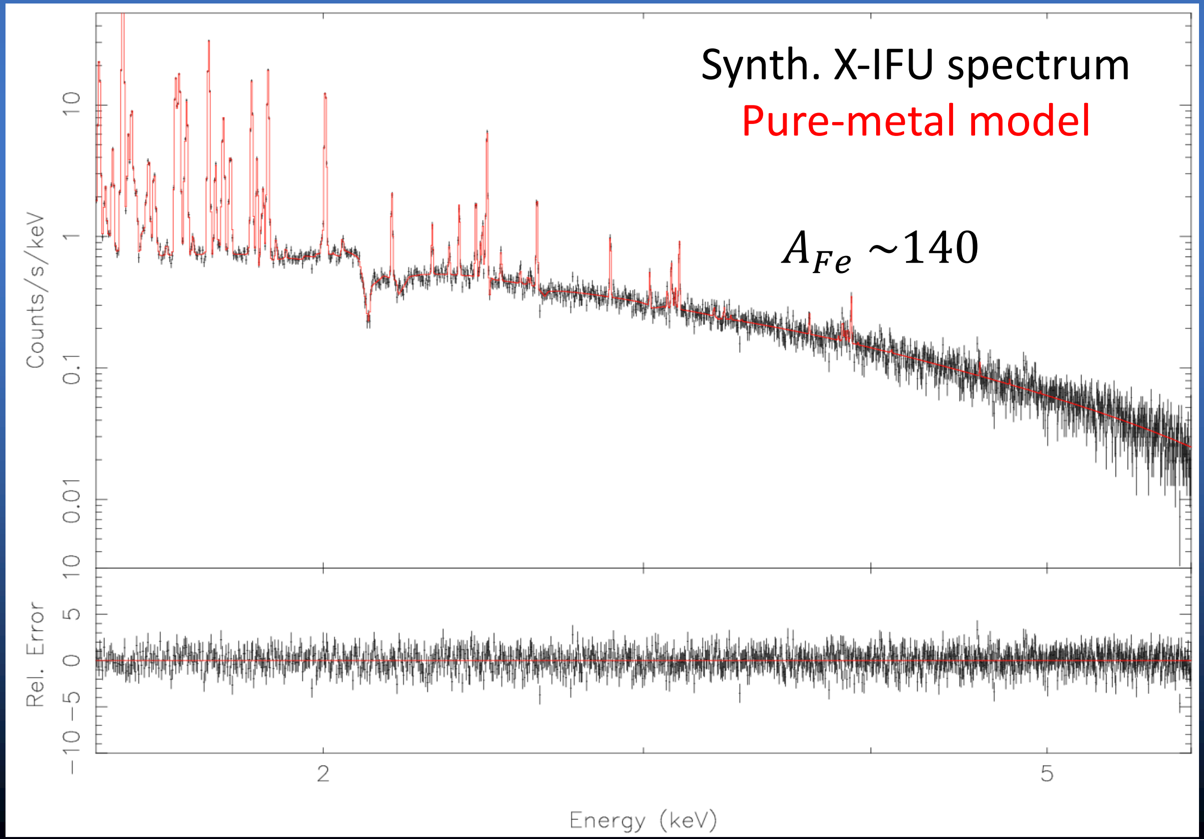
Need for NewAthena!



NewAthena synthetic spectra

With only 75 ks we will be able to pinpoint the pure-metal ejecta emission in much smaller (and less diluted) regions





Summary

- Absolute mass and abundance estimates suffer of a big uncertainty because of CCDs spectral resolution
- RRC can be used as a diagnostic tool to identify pure-ejecta emission
- Due to the Gate Valve issue XRISM is not able to reveal any feature
- NewAthena will be able to correctly pinpoint the ejecta abundance and masses even in small regions with much lower exposure time