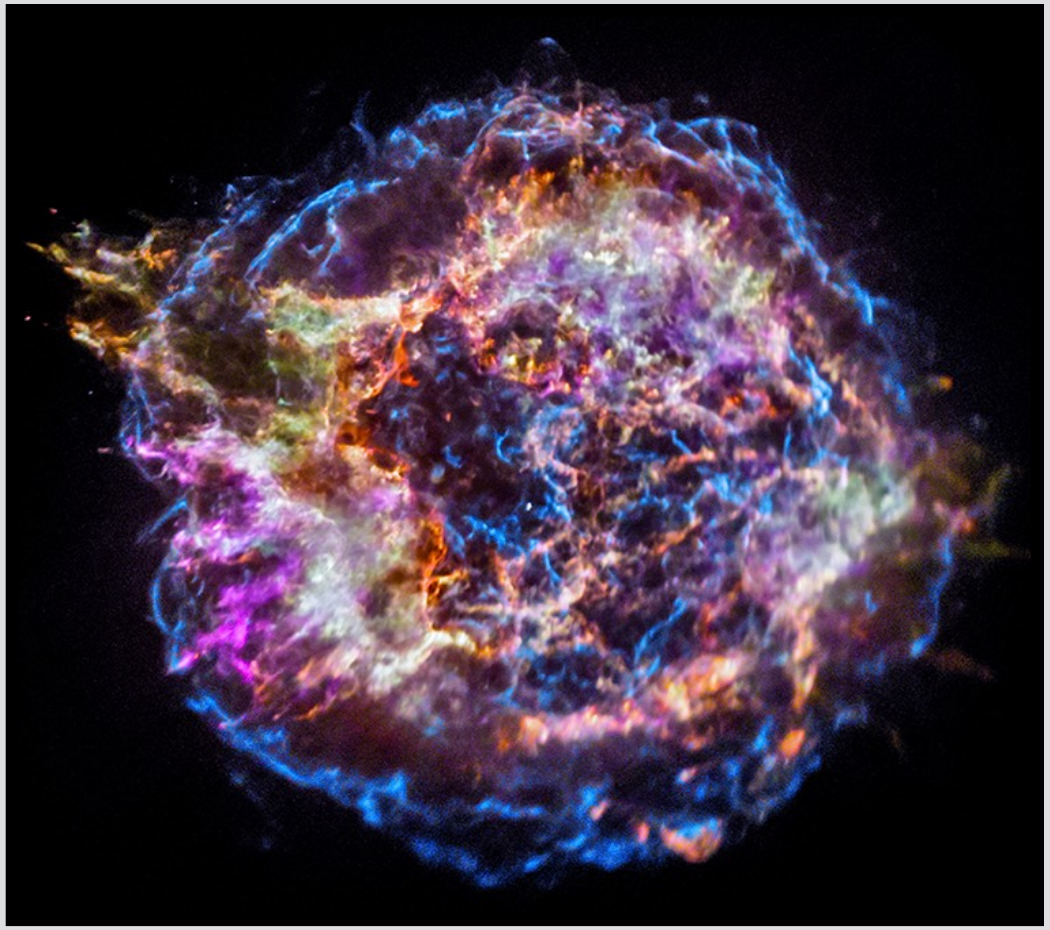
Revisiting the ejecta asymmetries in Cassiopeia A with a novel method for component separation in X-ray astronomy



Adrien Picquenot Fabio Acero Jérôme Bobin

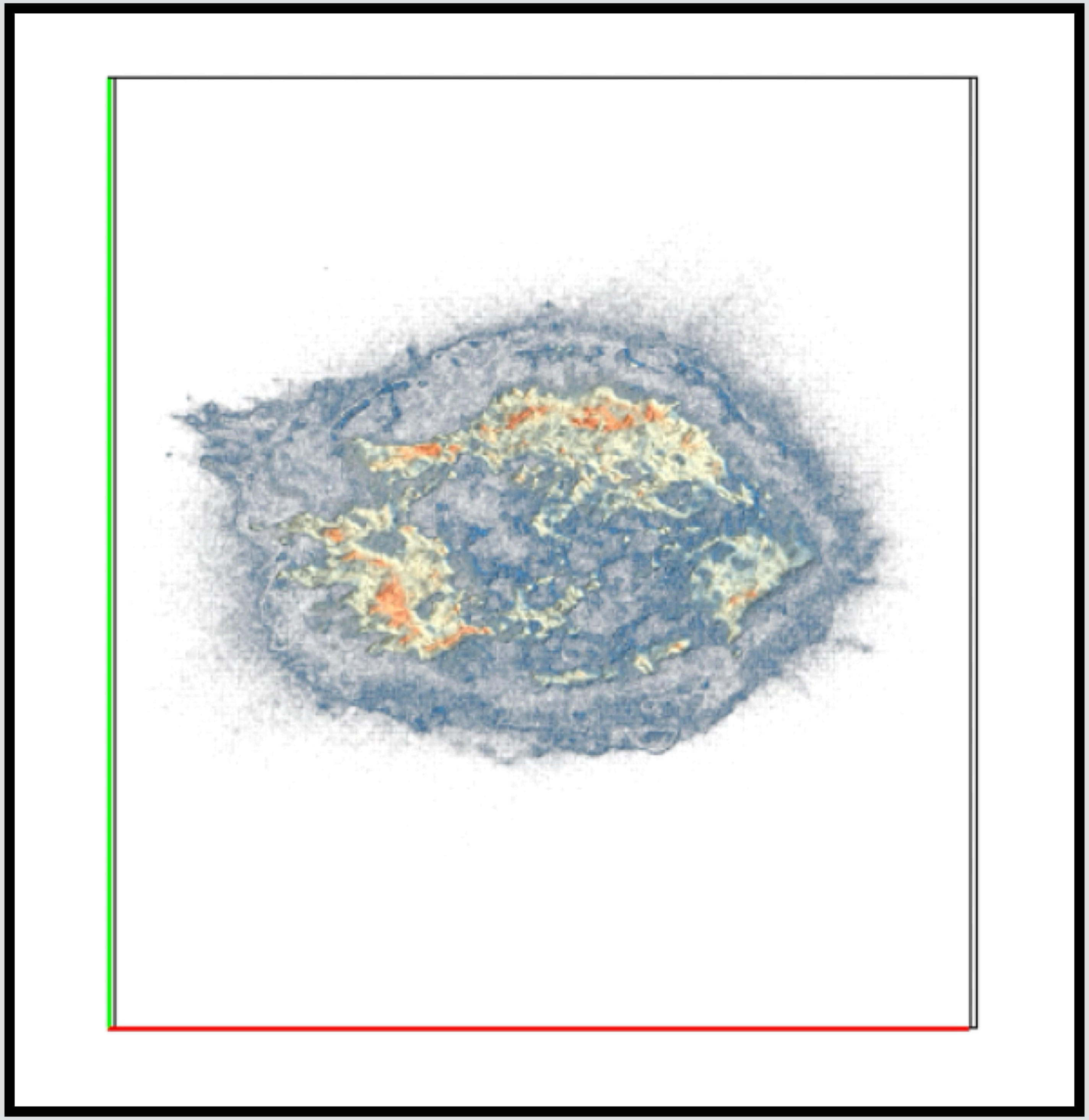
Jean Ballet Gabriel Pratt Pierre Maggi

Summary

- Traditional analysis methods of spectro-imaging instruments
- An introduction to the Generalized Morphological Components Analysis
- Benchmarking the method with SNR Cas A Toy models
- Application to real data : Asymmetries in Cas A

Supernova Remnants in X-rays

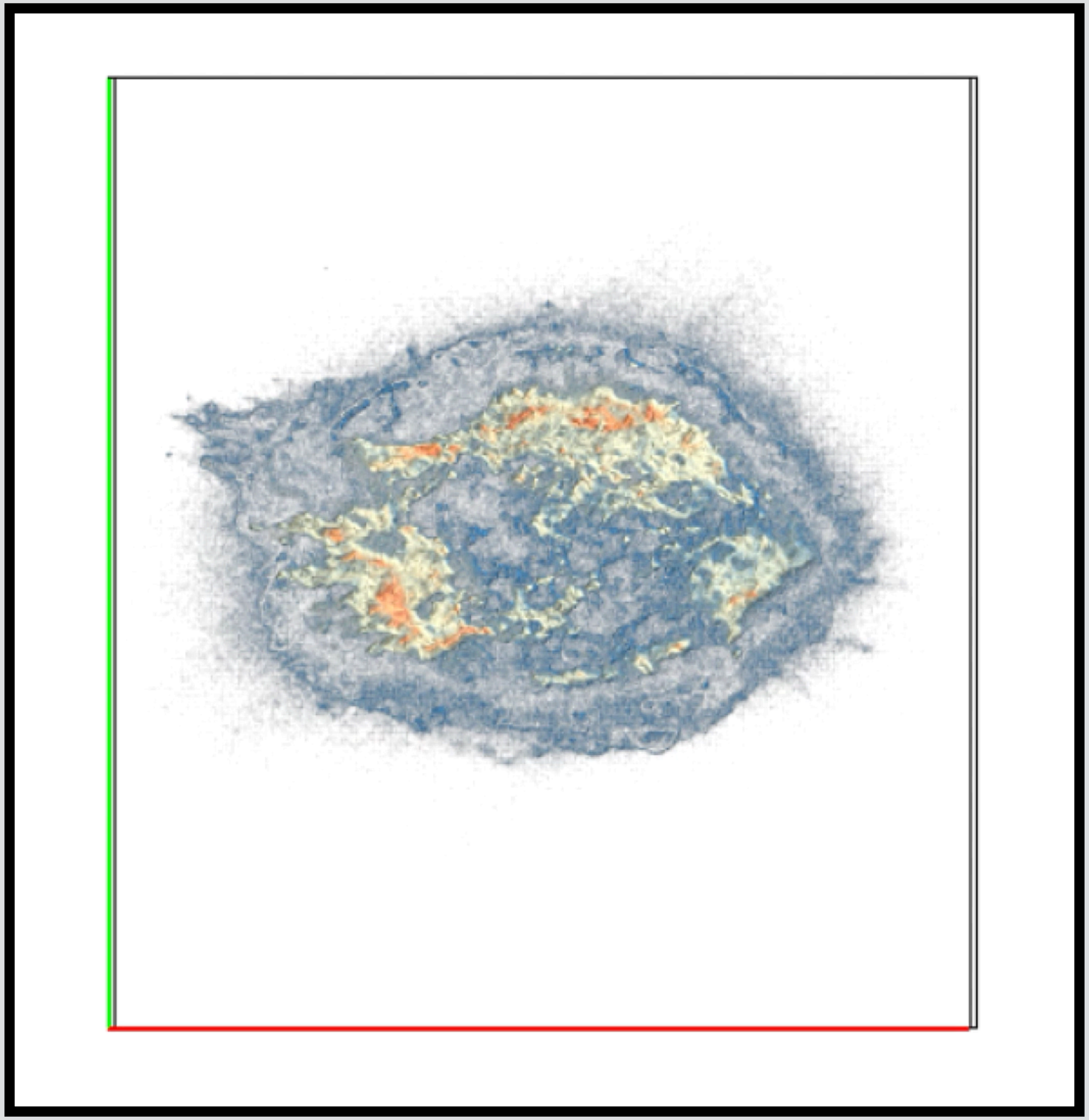
Cas A data cube (x,y,E)



Chandra data (1Ms, 2004), visualized with vaex

Supernova Remnants in X-rays

Cas A data cube (x,y,E)



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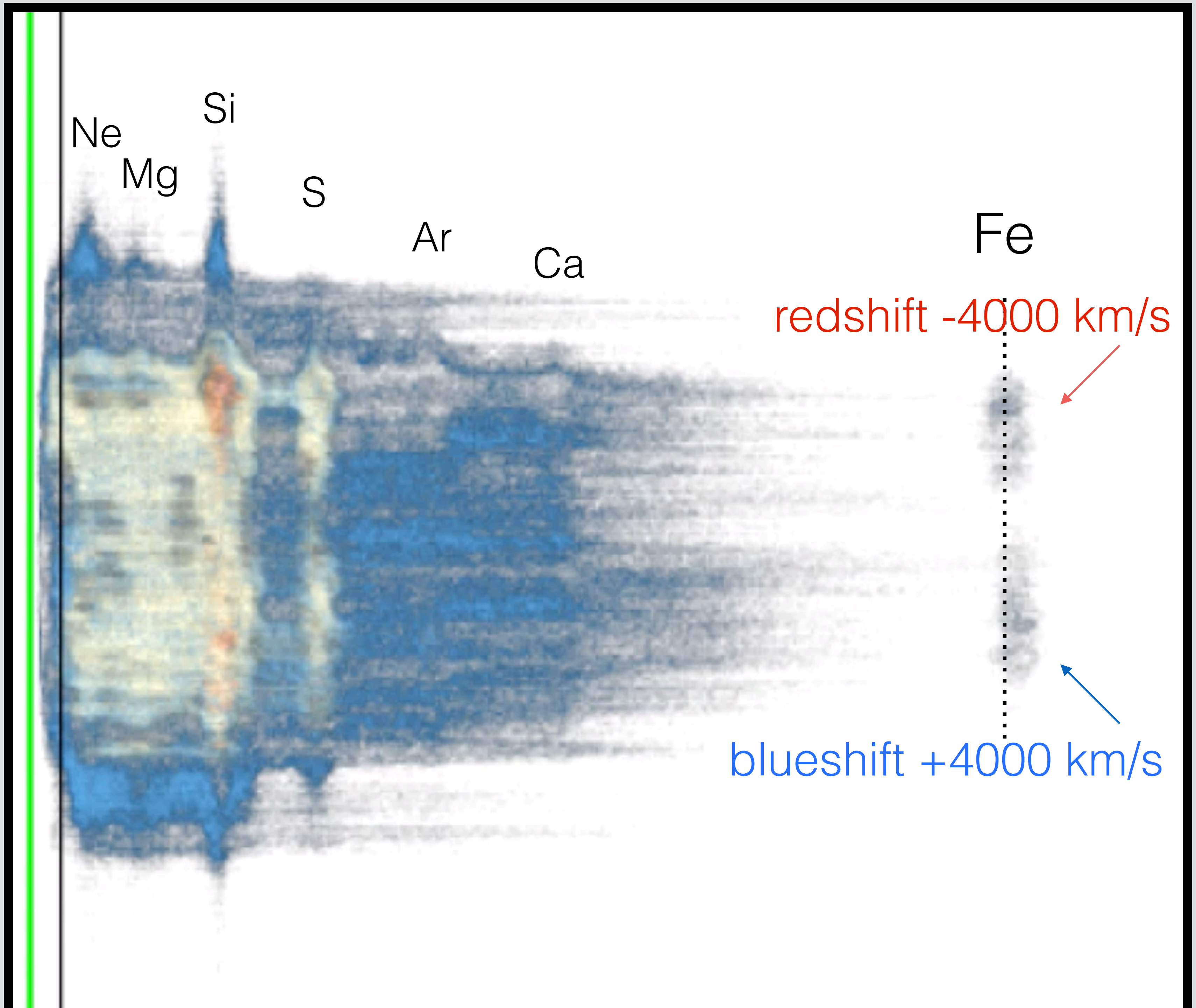

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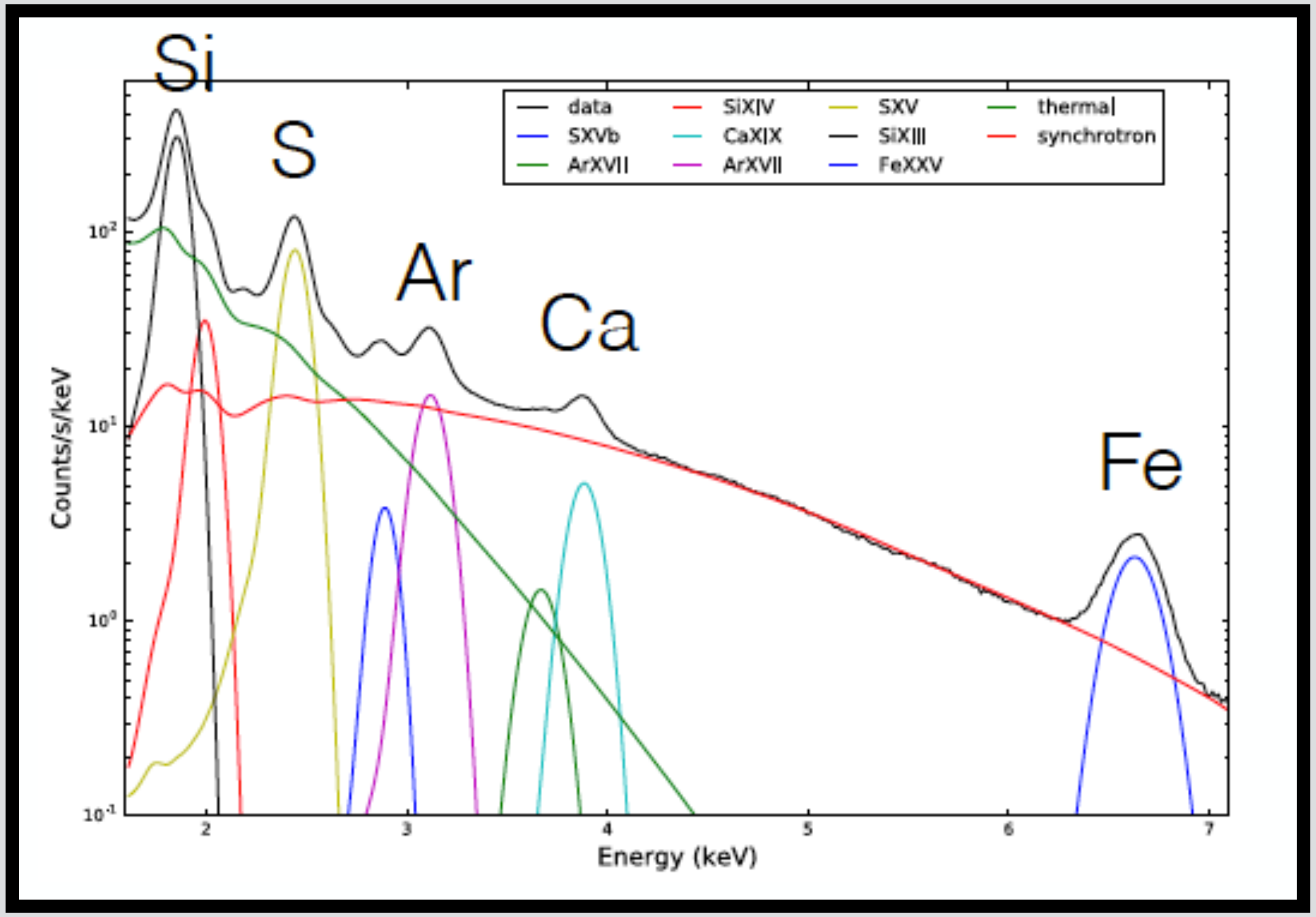
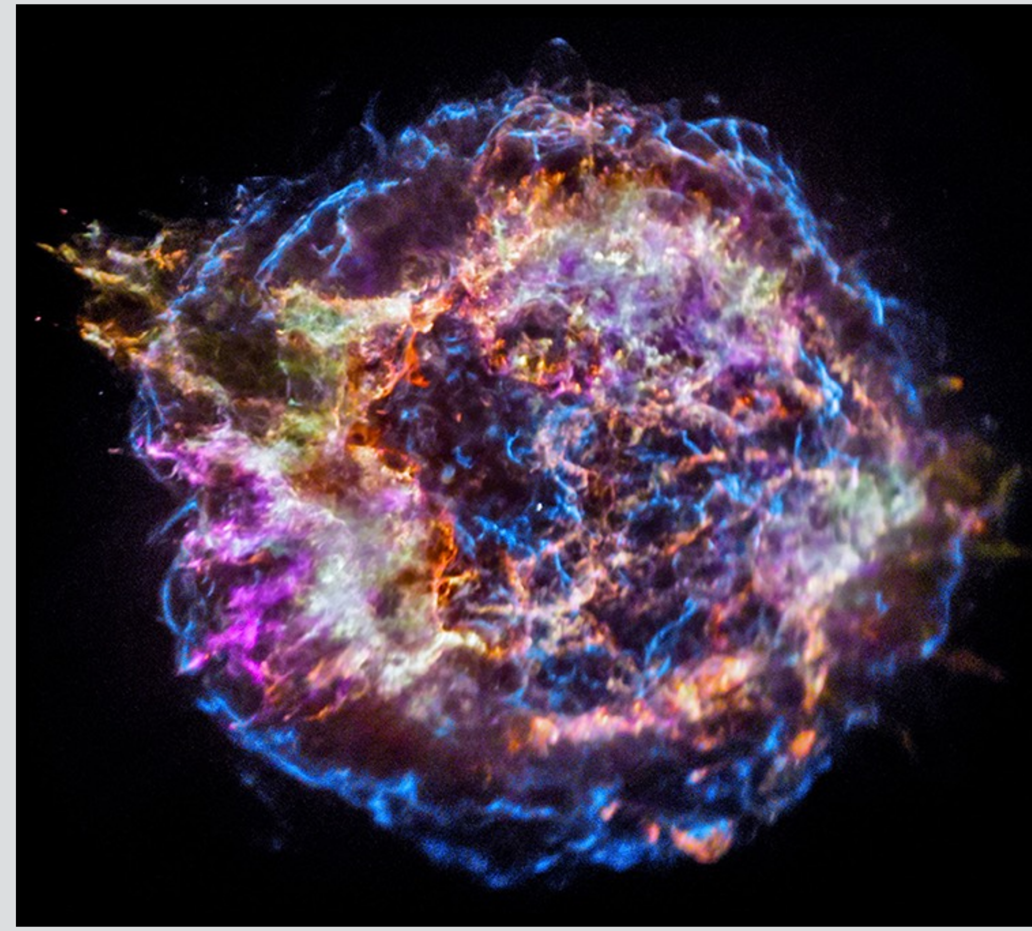
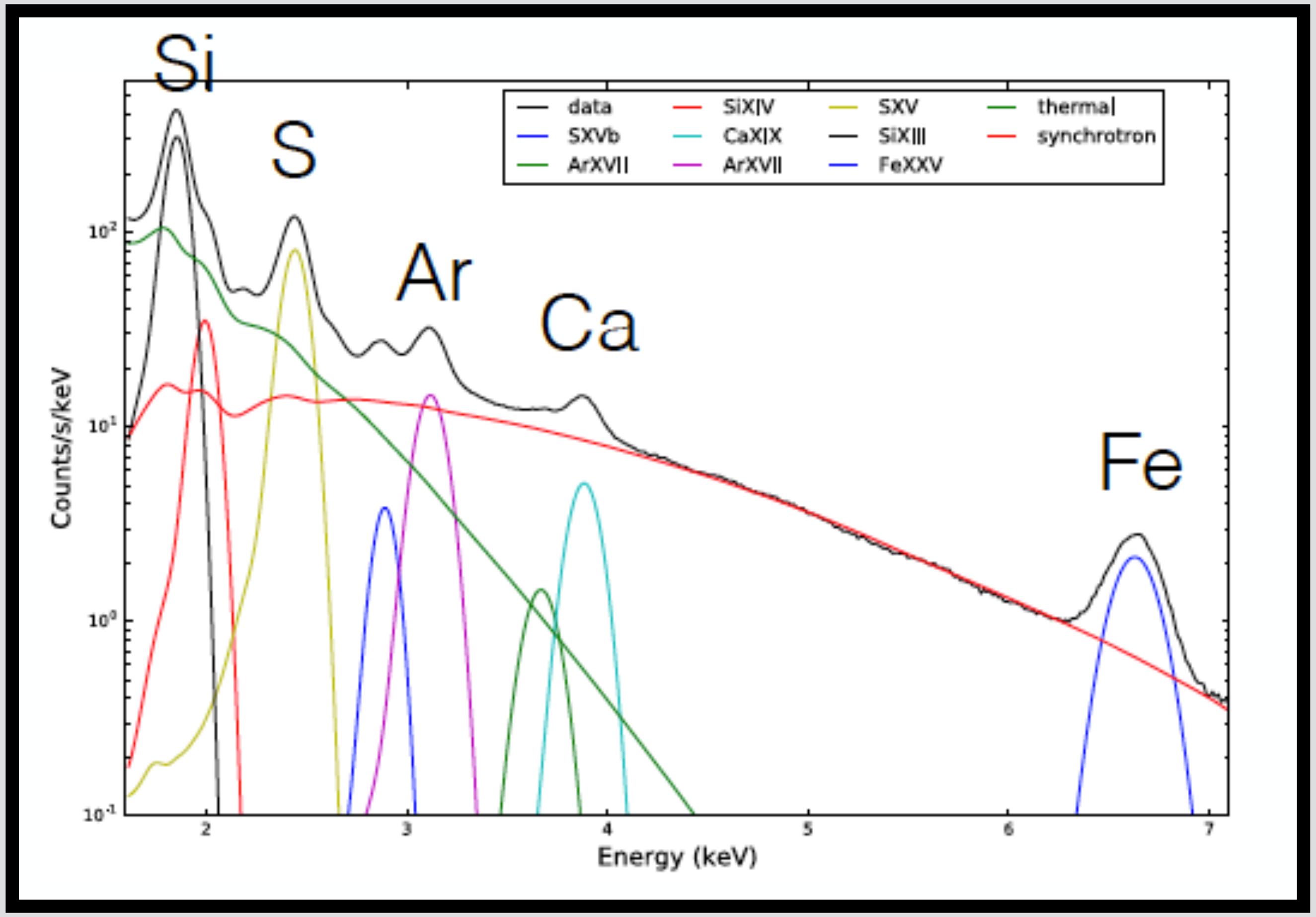


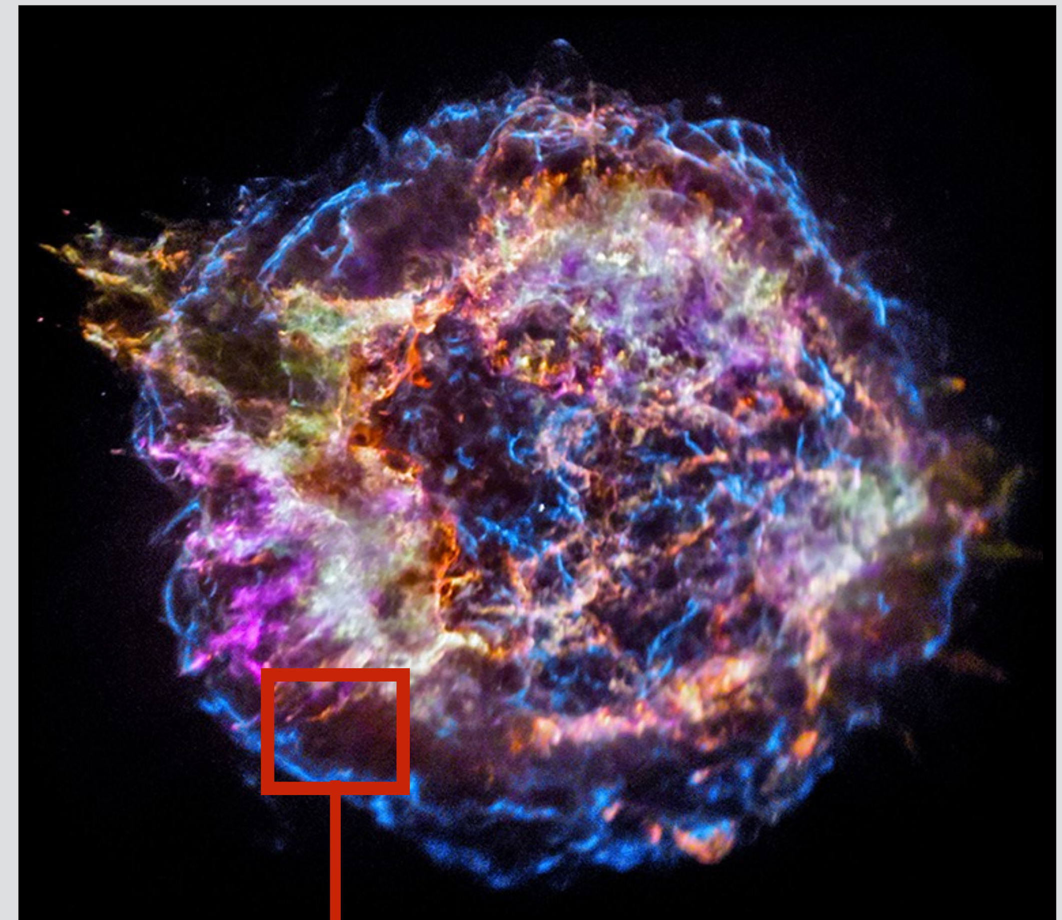


- Thermal emission continuum
- Synchrotron emission continuum
- Line emissions

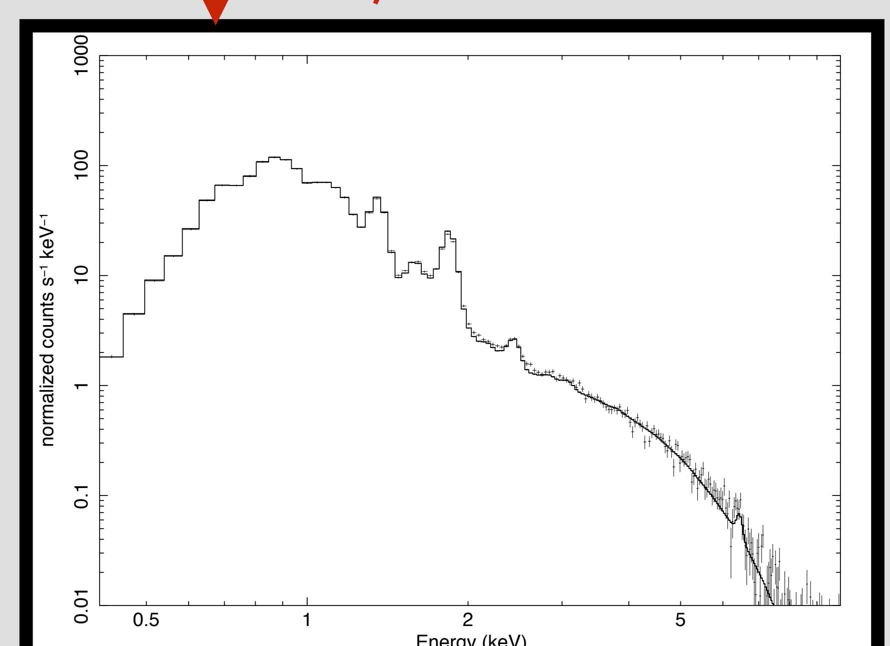
How to obtain a clear image of those components ?

Traditional Analysis Methods



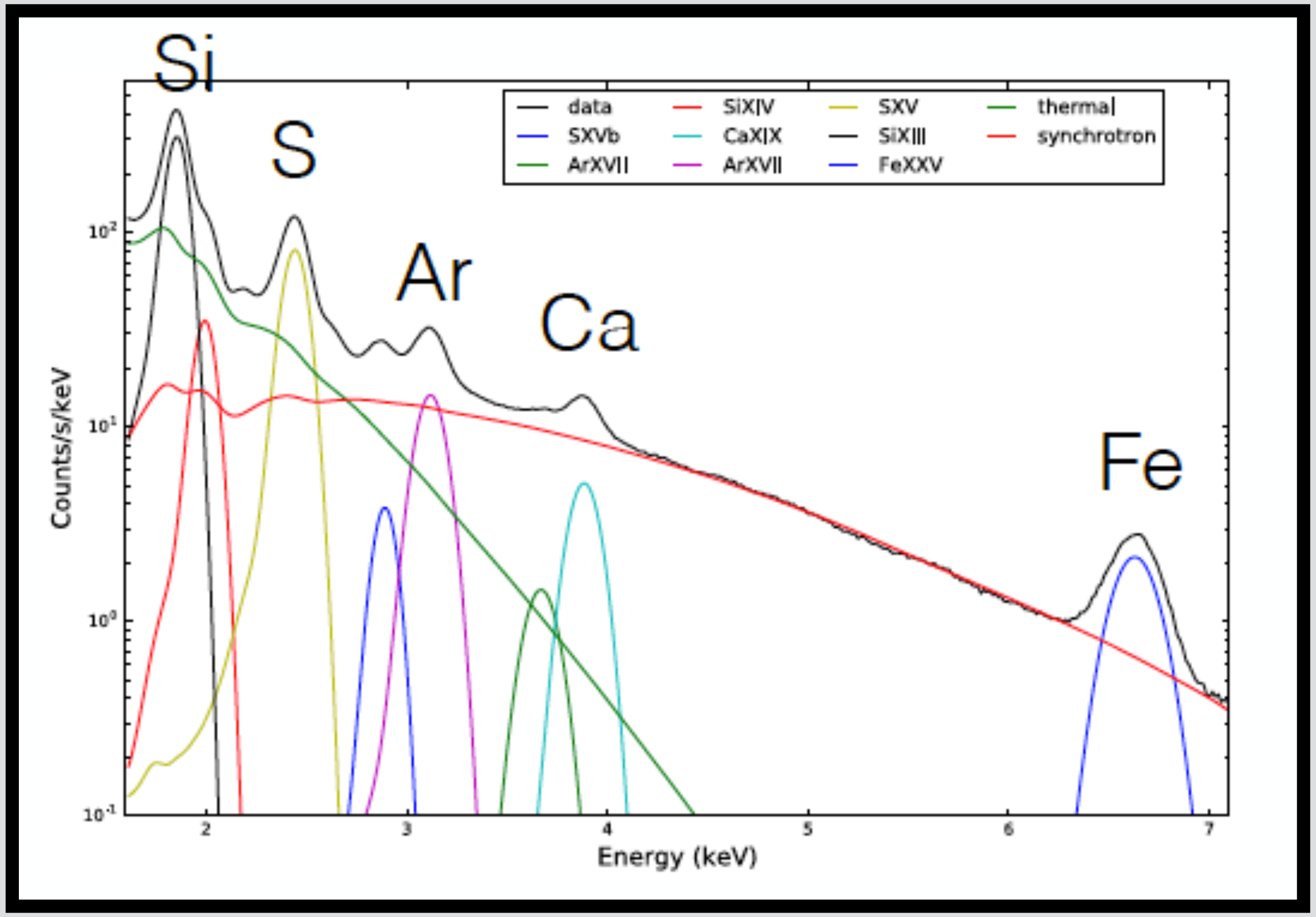


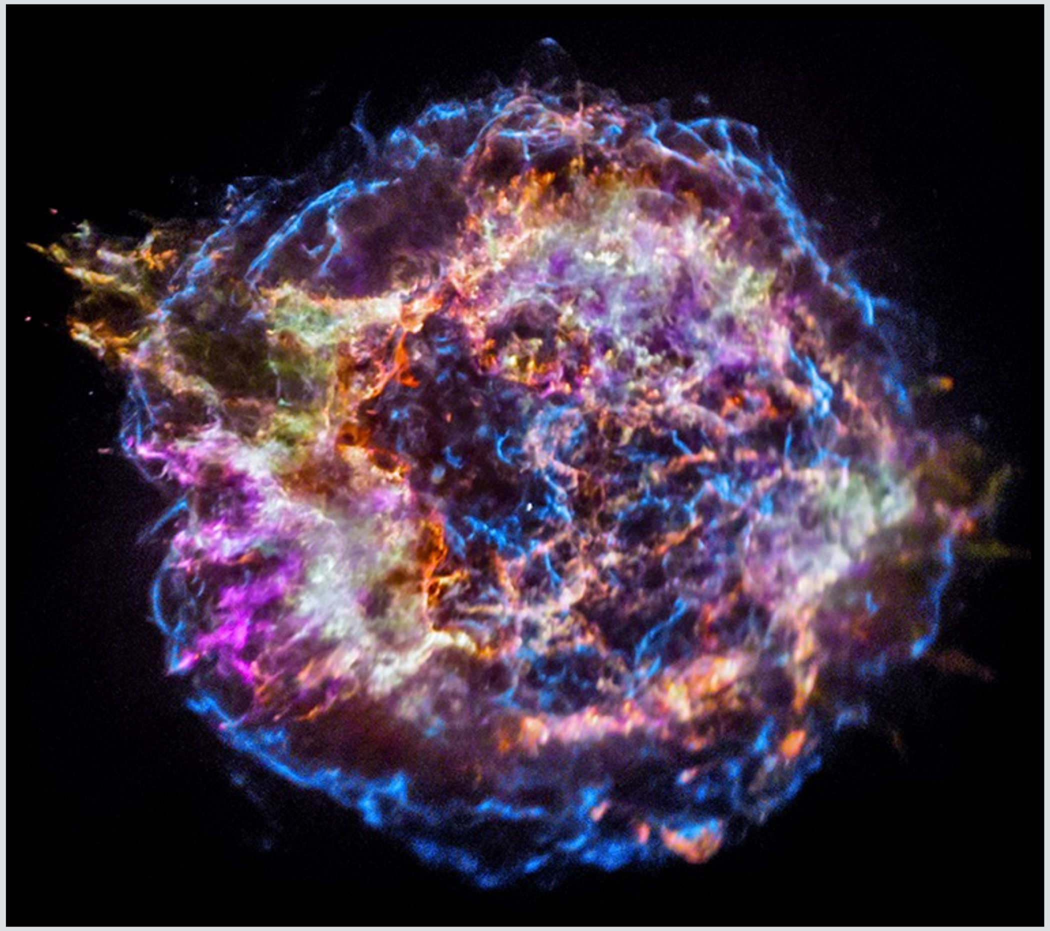
2D, then 1D

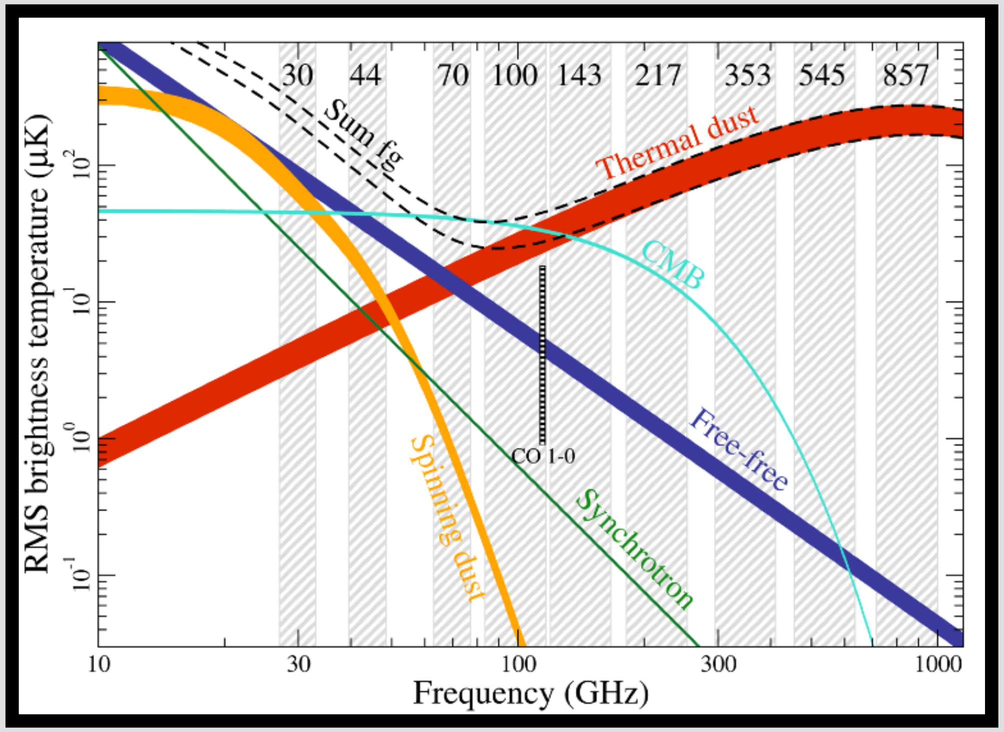


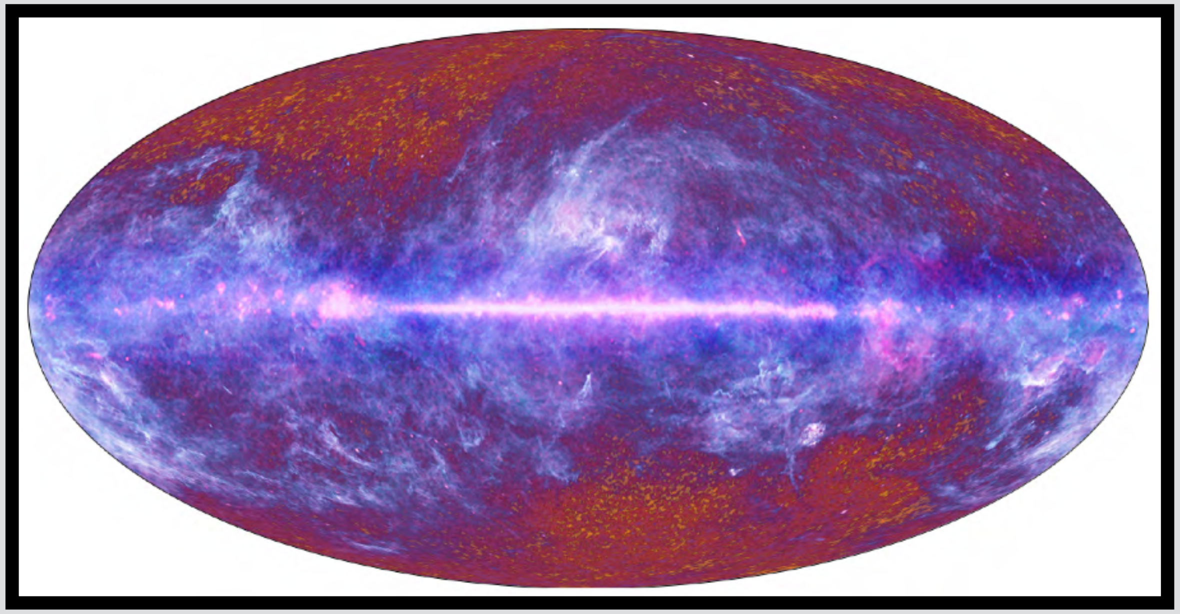
Decomposition is made on the spectra retrieved from particular places defined on the images, without leveraging Chandra's great spatial resolution.

Analogy with the CMB









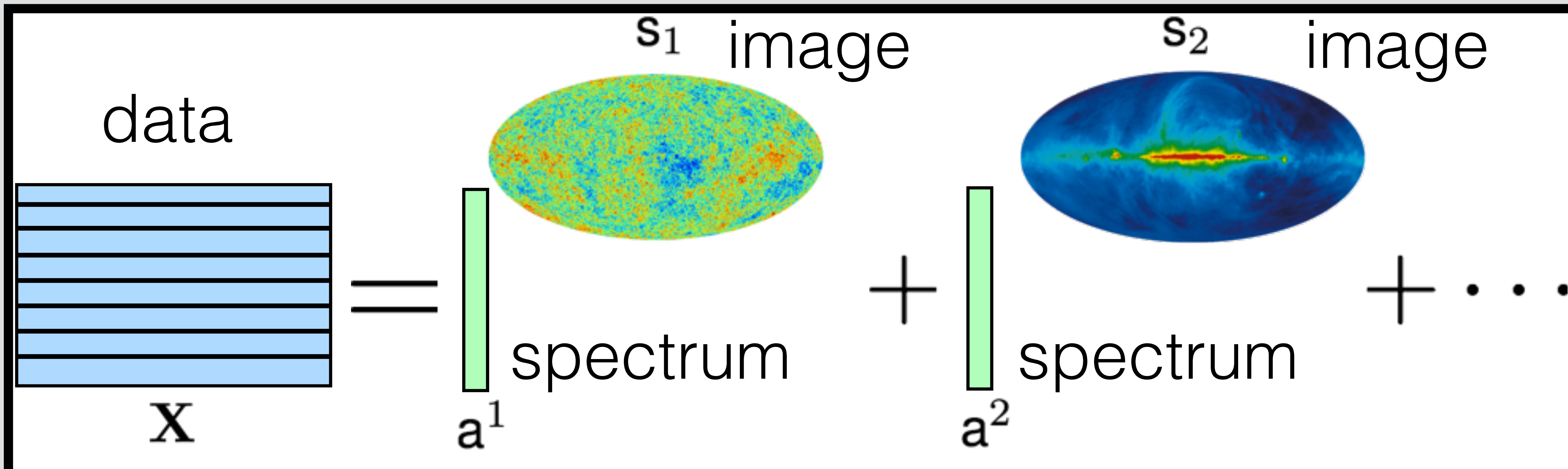
Planck survey of the sky

GMCA

Generalized Morphological Components Analysis (Bobin et al. 2016)

$$X = AS + N = \sum_{i=1}^{n} A_i S_i + N$$

Blind Source Separation algorithm : The aim is to retrieve n images (x,y) and spectra (E) from the initial (E,x,y) data set without prior instrumental or physical knowledge.



GMCA

$$X = AS + N = \sum_{i=1}^{n} A_i S_i + N$$

Without any information on A and S,
this problem is ill-posed.

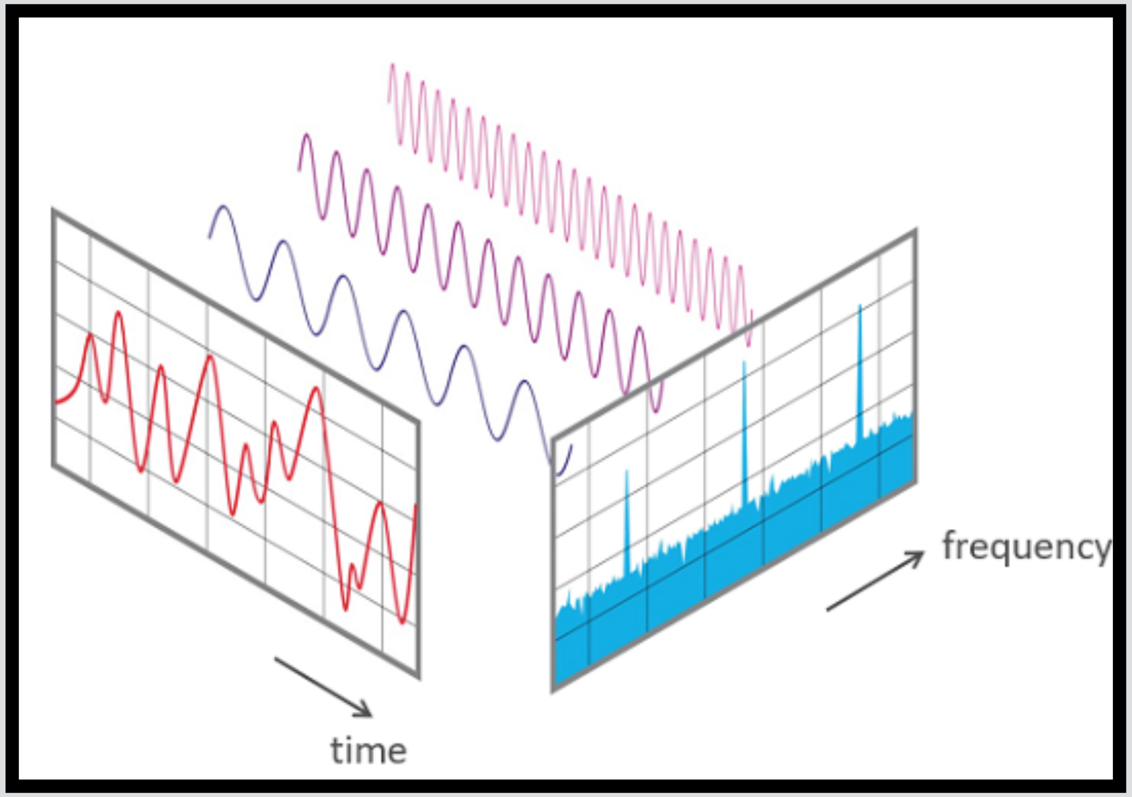
$$\min_{A,S} \|X - AS\|_F^2$$

How can we add a constraint that will help disentangling?

GMCA

The concept of sparsity

Analogy with 1-D :



The Fourrier transform allows to describe periodic signals with only a few non zero coefficients.

It makes the different components easier to disentangle by diminishing the overlapping.

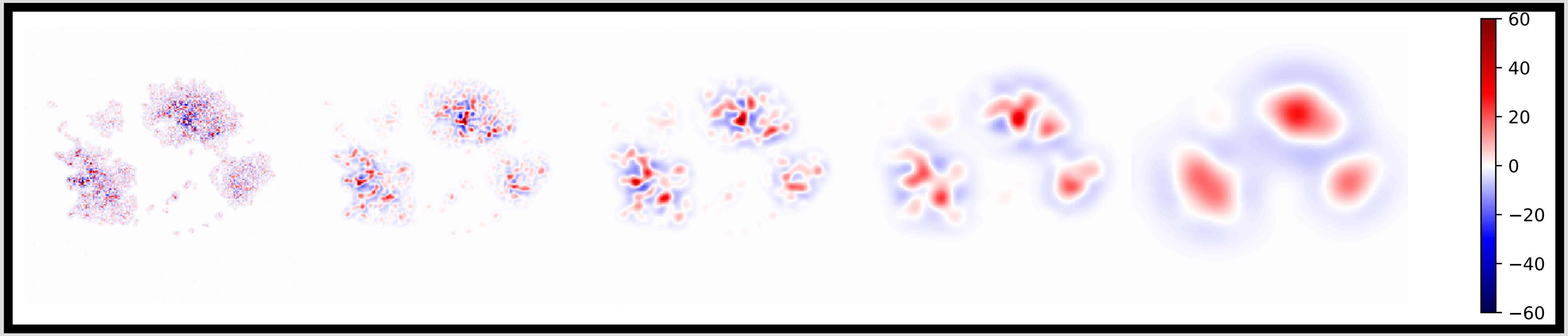
GMCA

The concept of sparsity

In 2-D :

Wavelet transforms give sparse representations of images. In particular, *Starlets* are well adapted for astrophysical images.

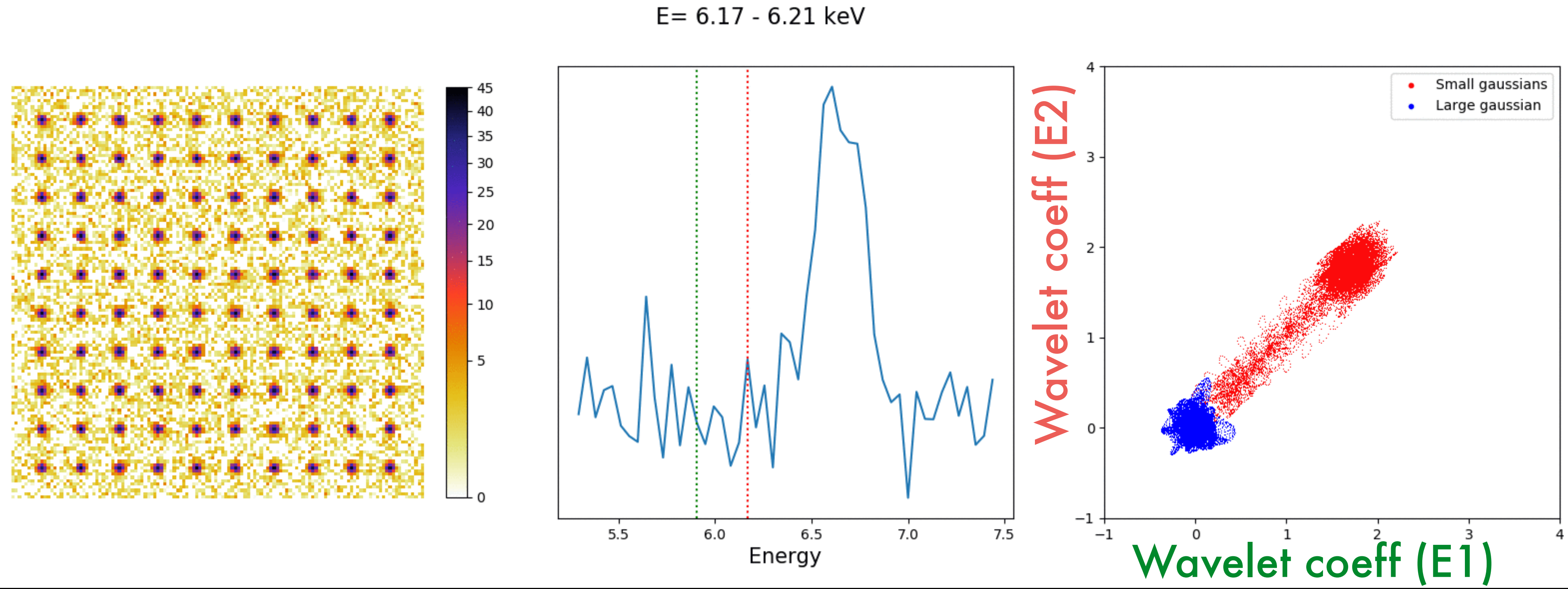
Small scales Large scales



Starlet transform of the Fe structure in Cassiopeia A

The concept of sparsity

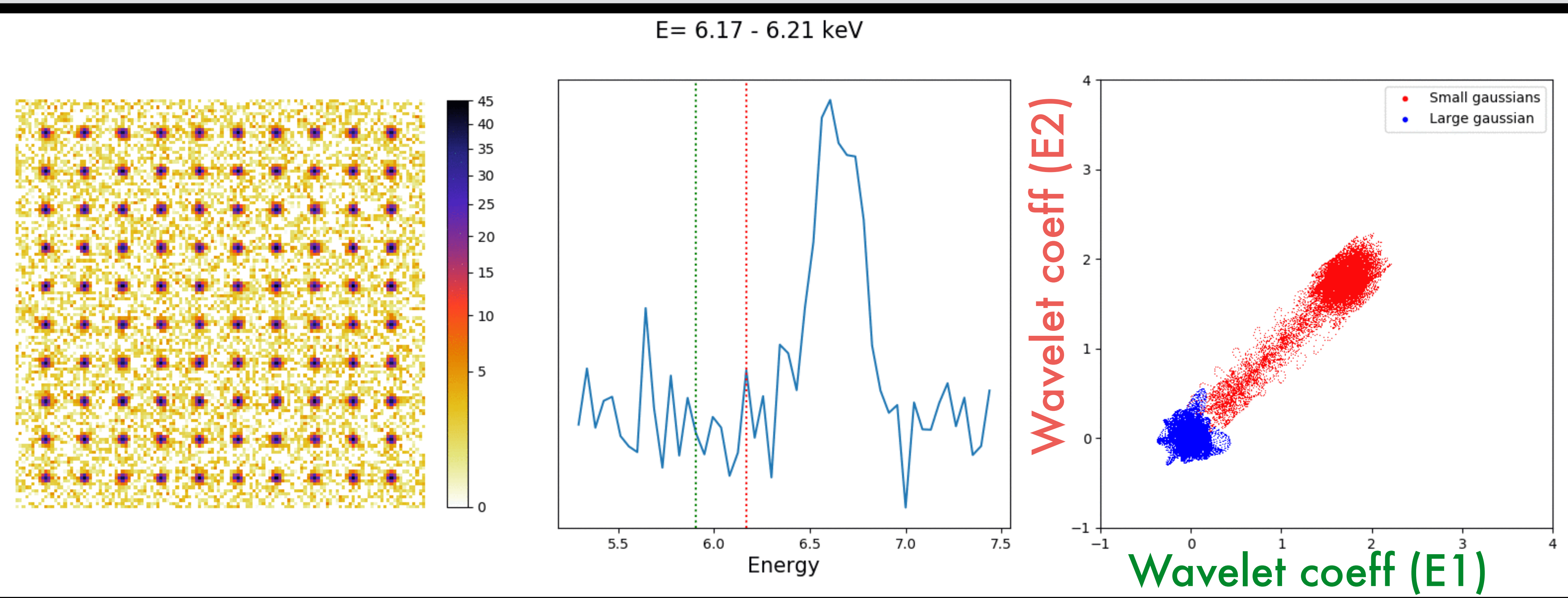
In 2-D :



Starlet transform third scale coefficients of gaussians of different sizes

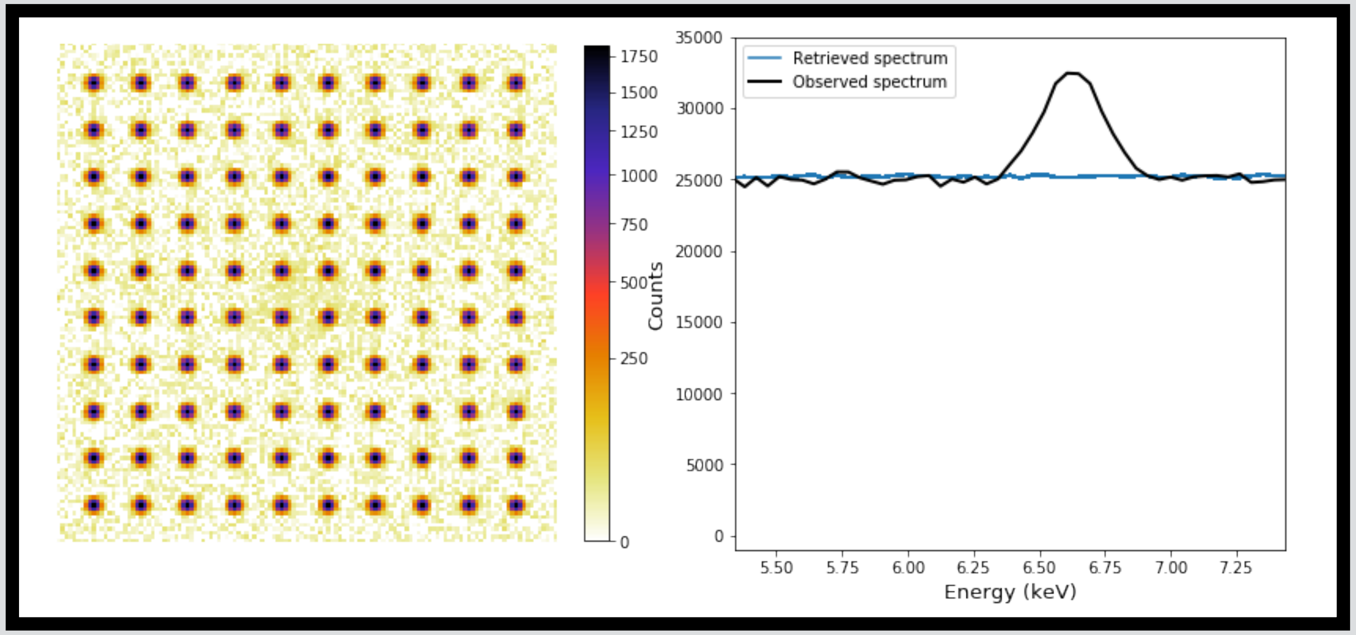
The concept of sparsity

In 2-D :

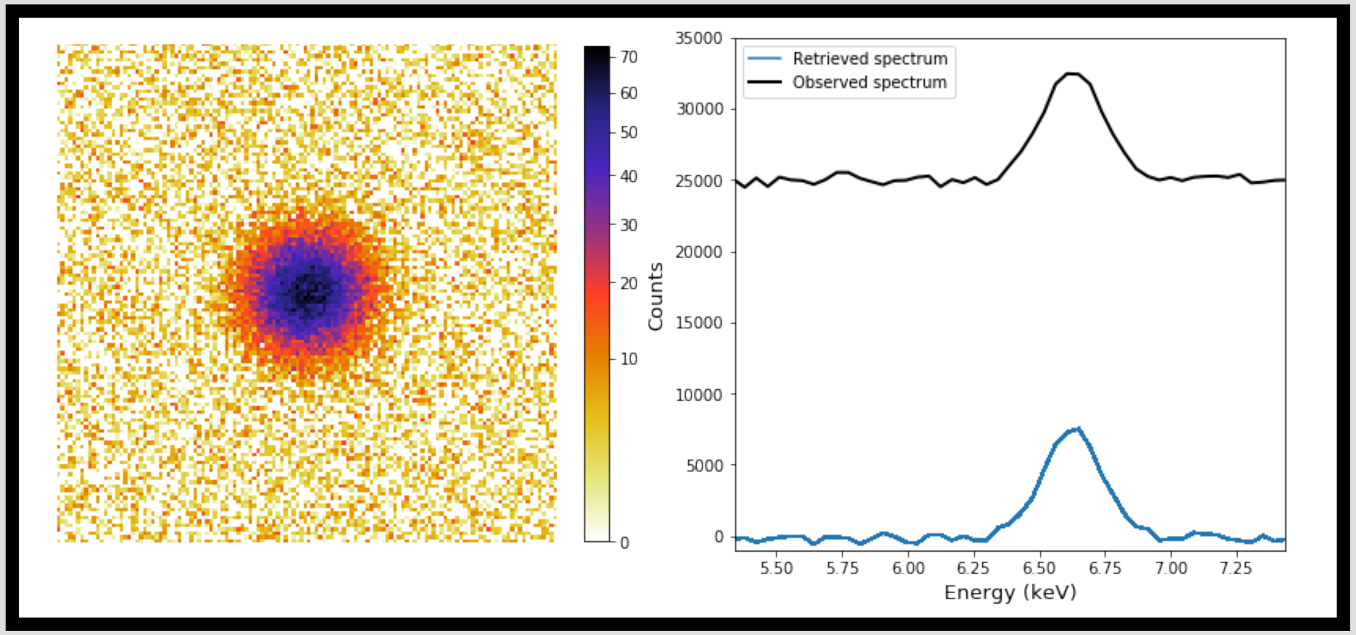


Starlet transform third scale coefficients of gaussians of different sizes

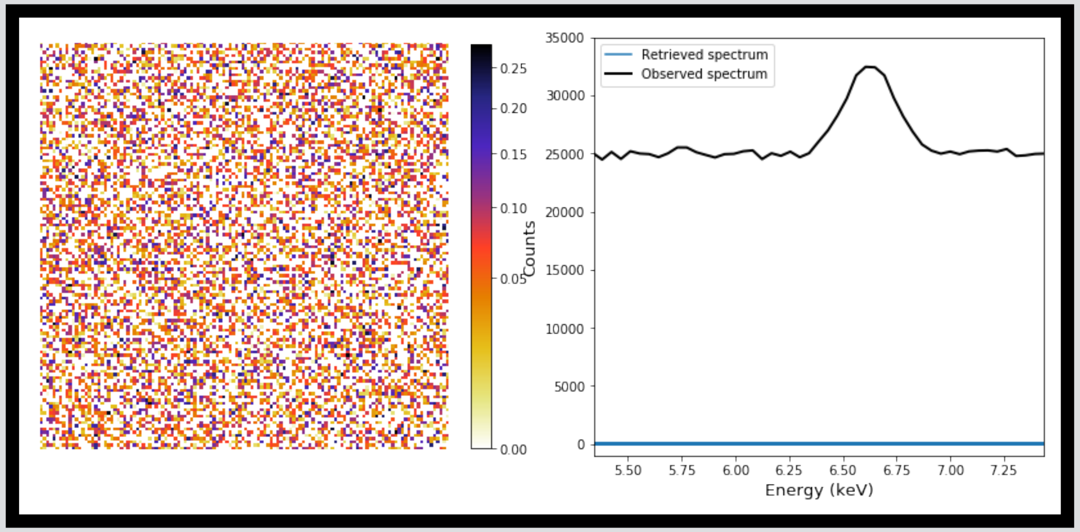
GMCA



A grid of small gaussians with a constant spectrum



A large gaussian with a gaussian spectrum



Noise

GMCA

$$X = AS + N = \sum_{i=1}^{n} A_i S_i + N$$

Without any information on A and S, this problem is ill-posed.

$$\min_{A,S} \| X - AS \|_F^2$$

GMCA

$$X = AS + N = \sum_{i=1}^{n} A_i S_i + N$$

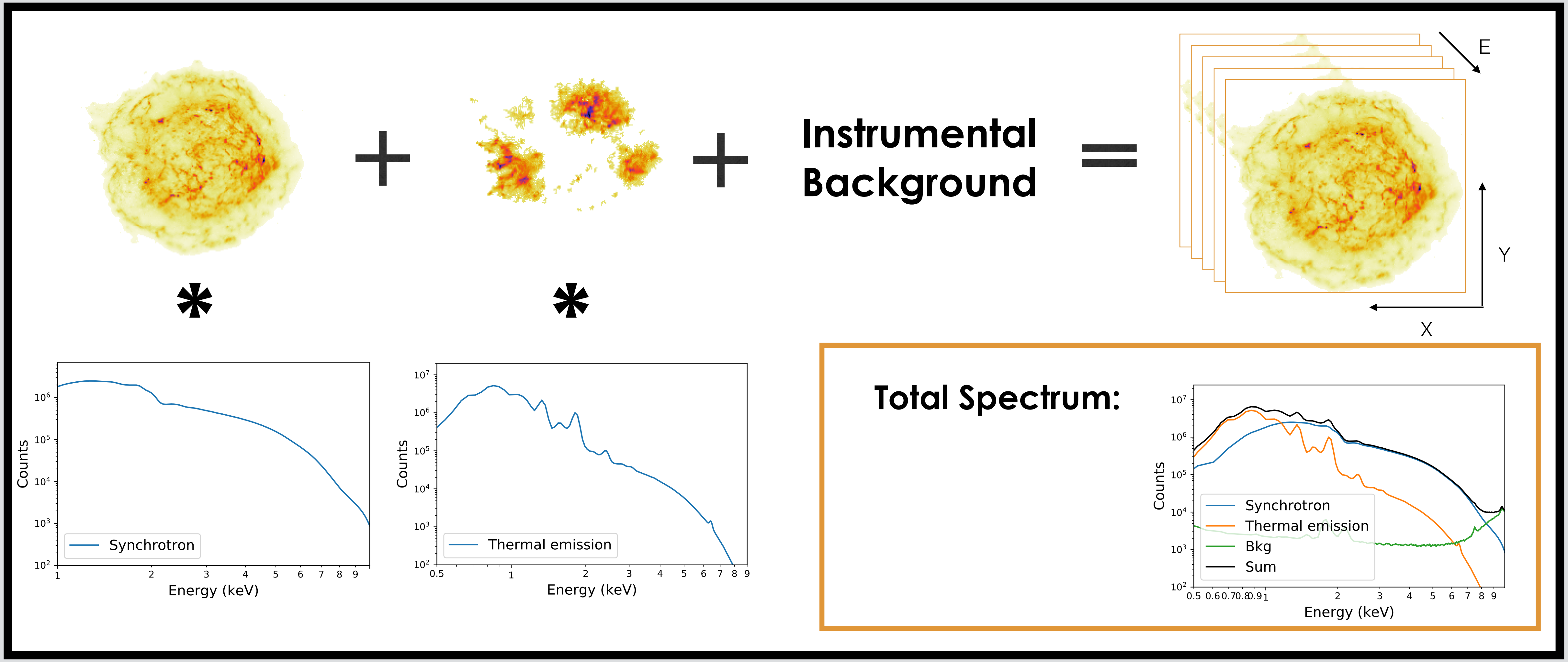
With a sparsity constraint term :

$$\min_{A,S} \sum_{i=1}^{n} \lambda_i \|S_i\|_p + \|X - AS\|_F^2$$

A constraint using morphological diversity.

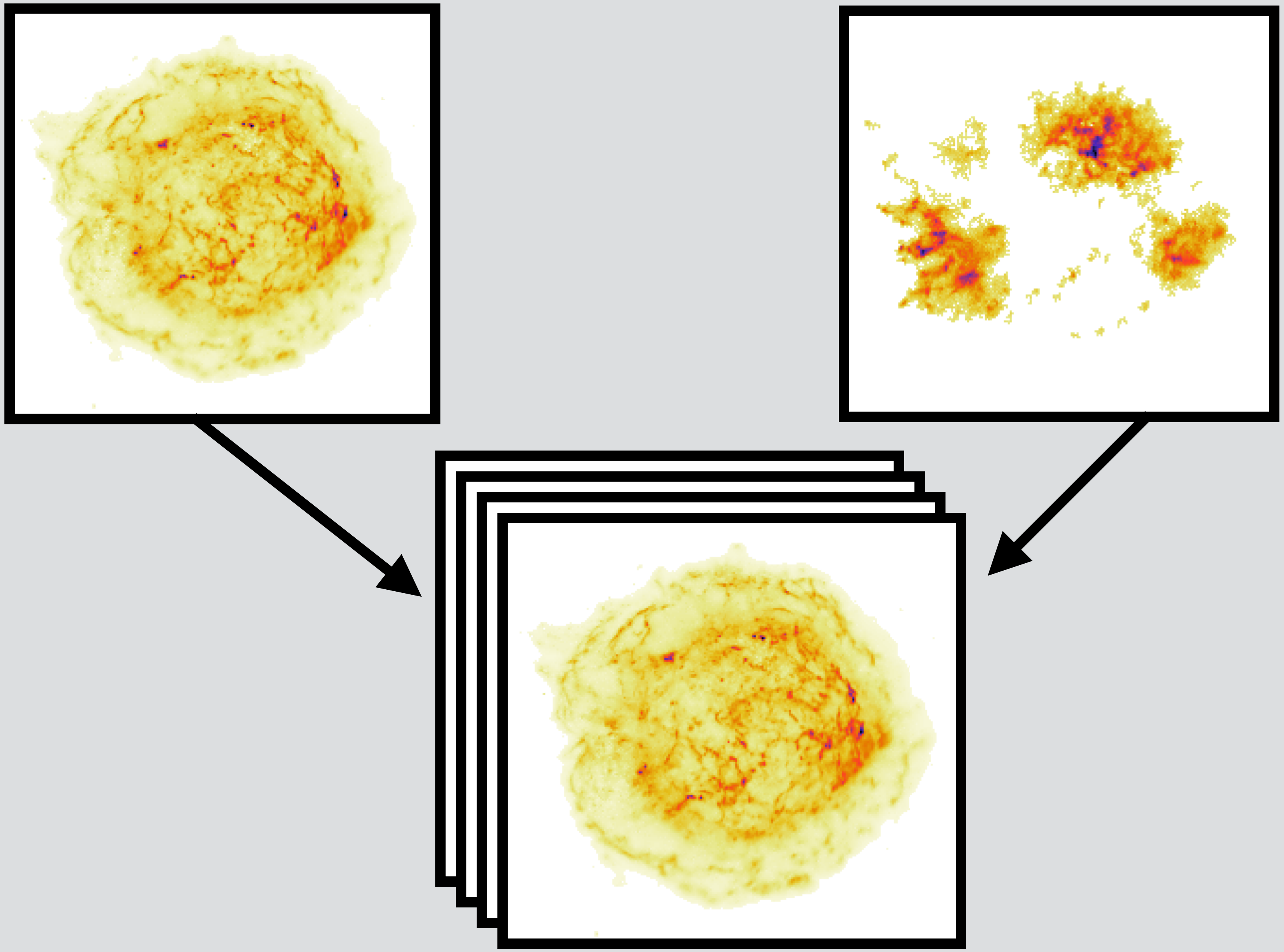
Test on toy models

Our two toy models have two components :



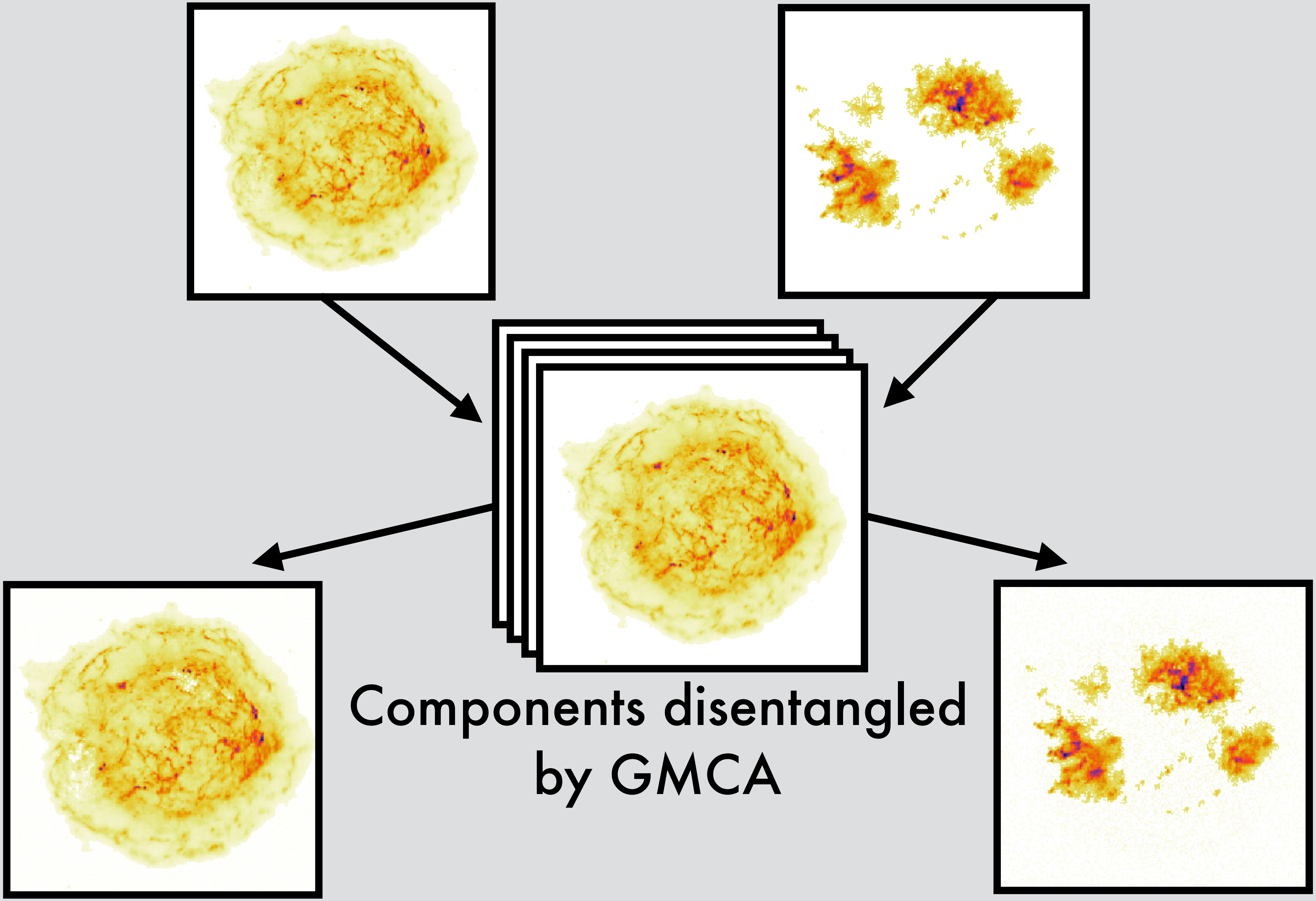
The first component is a synchrotron emission, the second one is either a thermal emission or a line emission. We generate Poisson noise.

Test on toy models

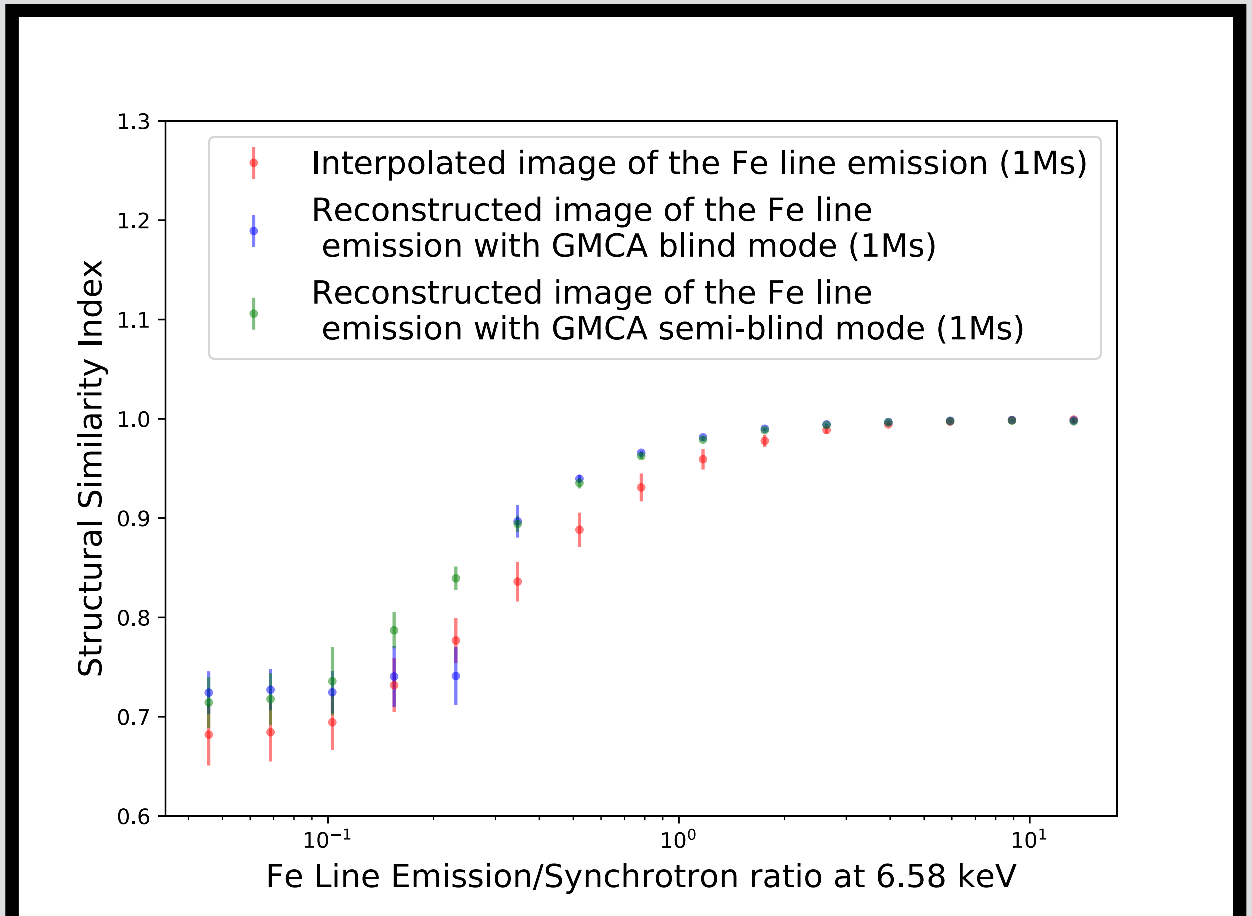


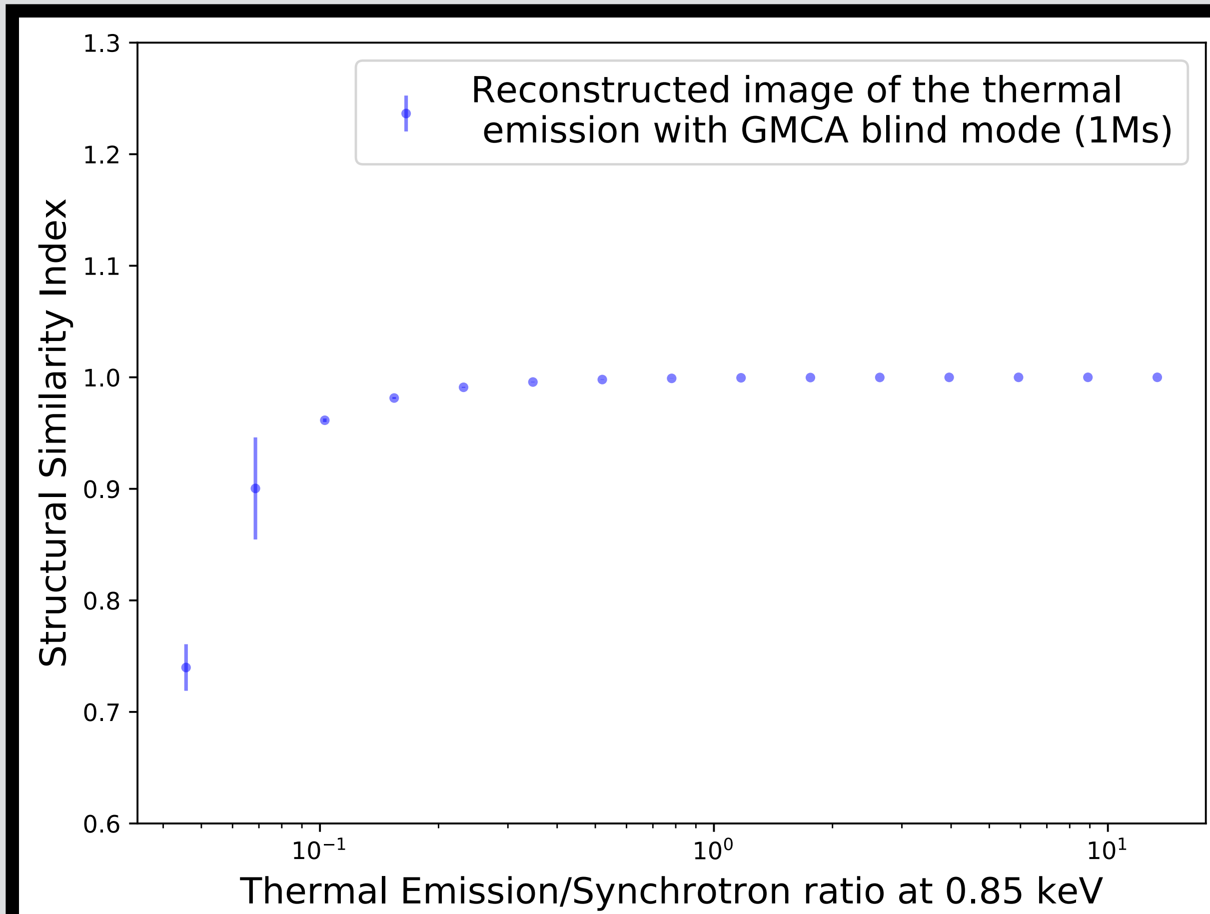
Both components are entangled in our toy model

Test on toy models

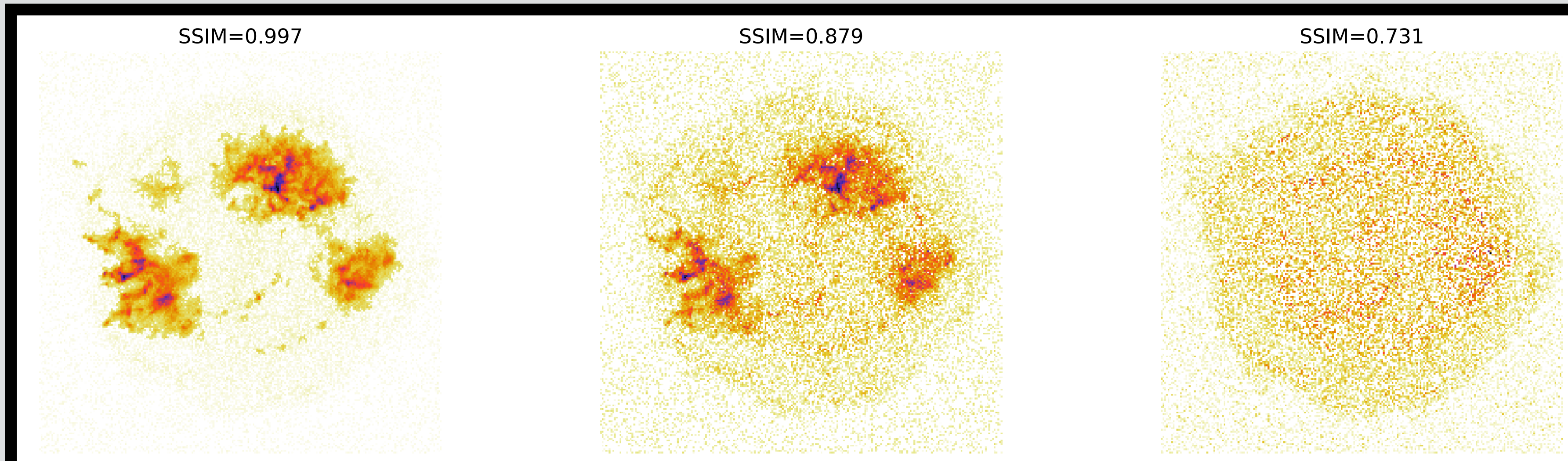


Reconstructed image accuracy



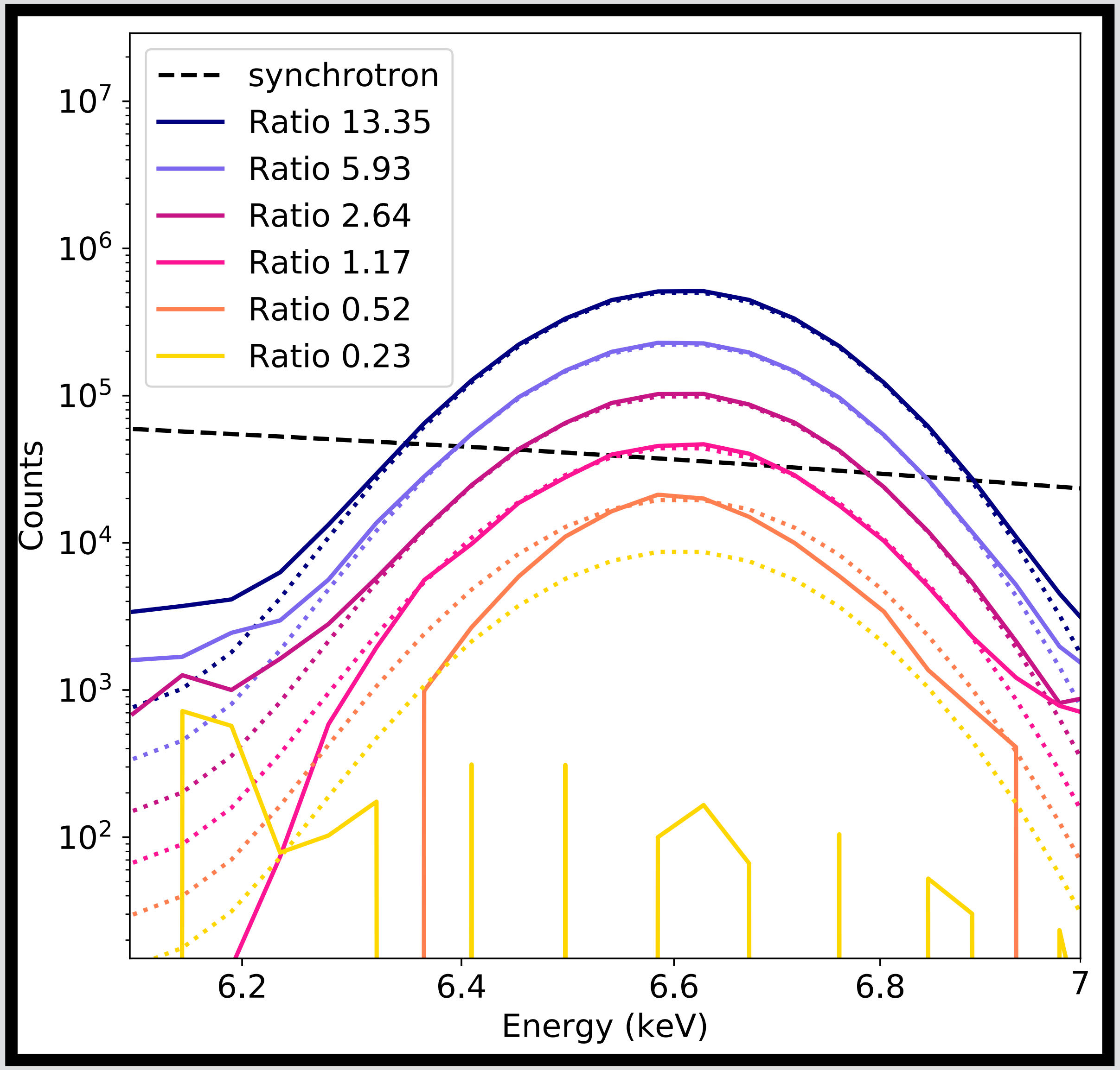


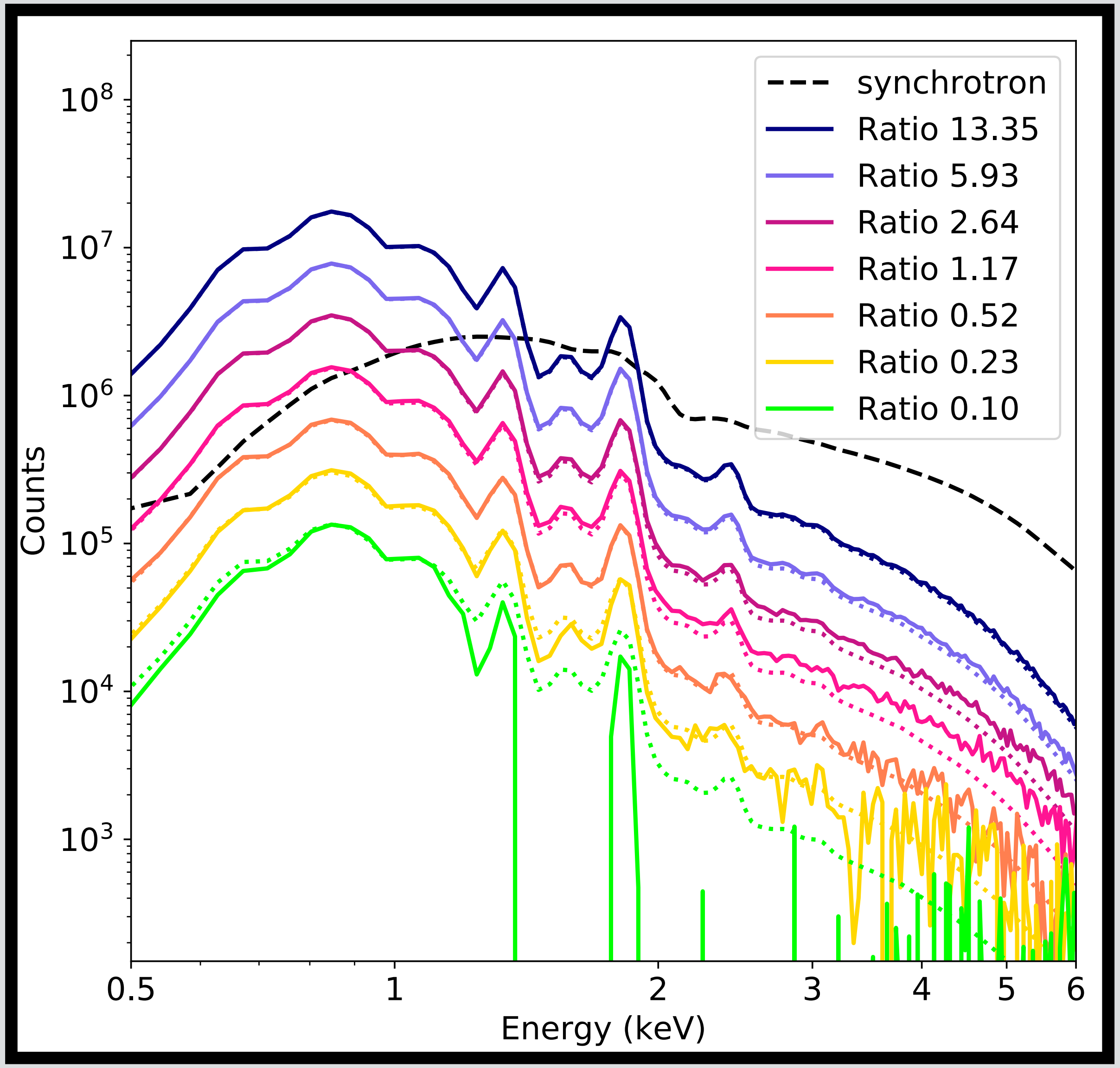
SSIM coefficients of the images of the retrieved second component in both toy models



Examples of SSIM coefficients associated with the corresponding images

Spectral accuracy

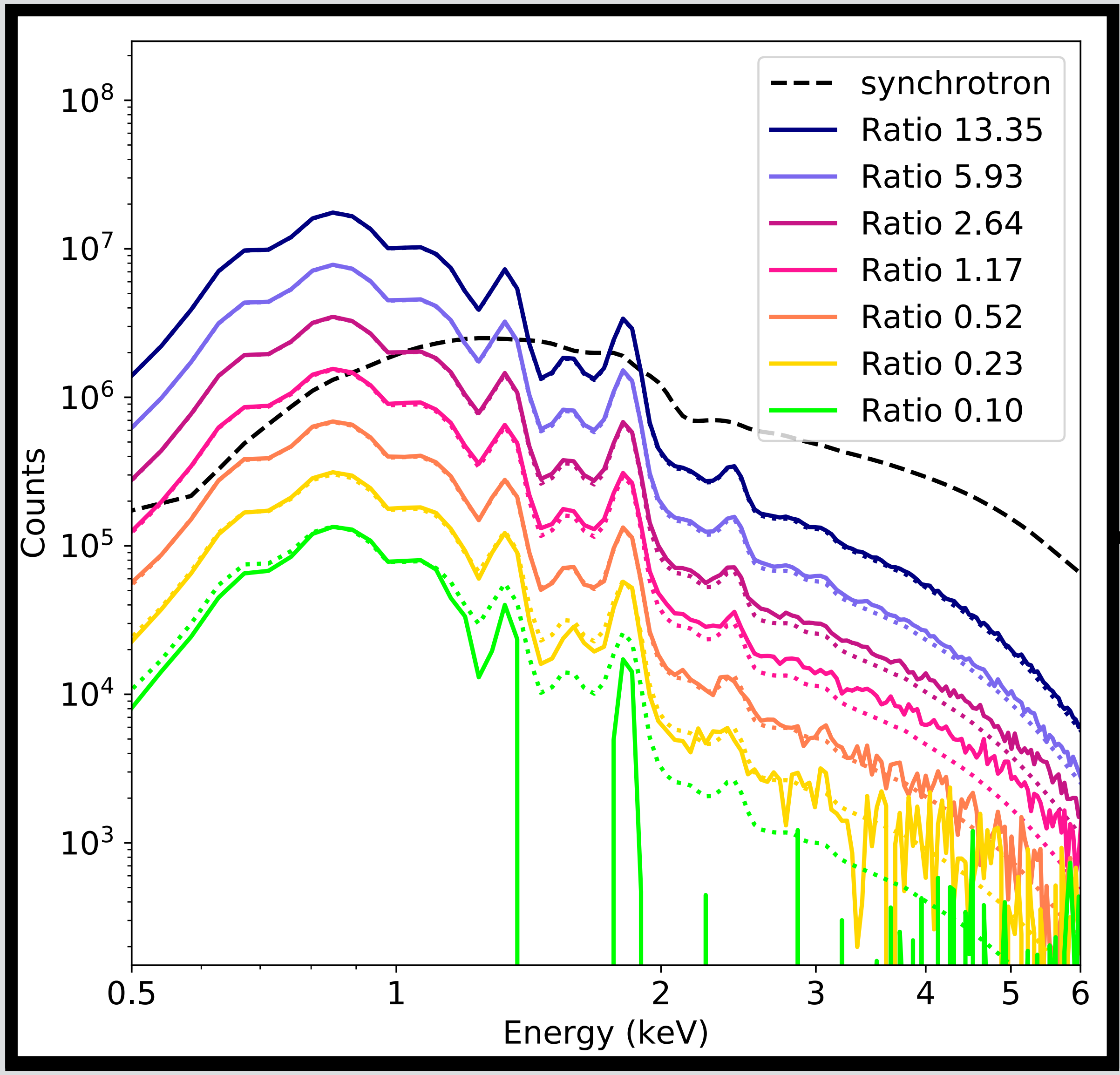


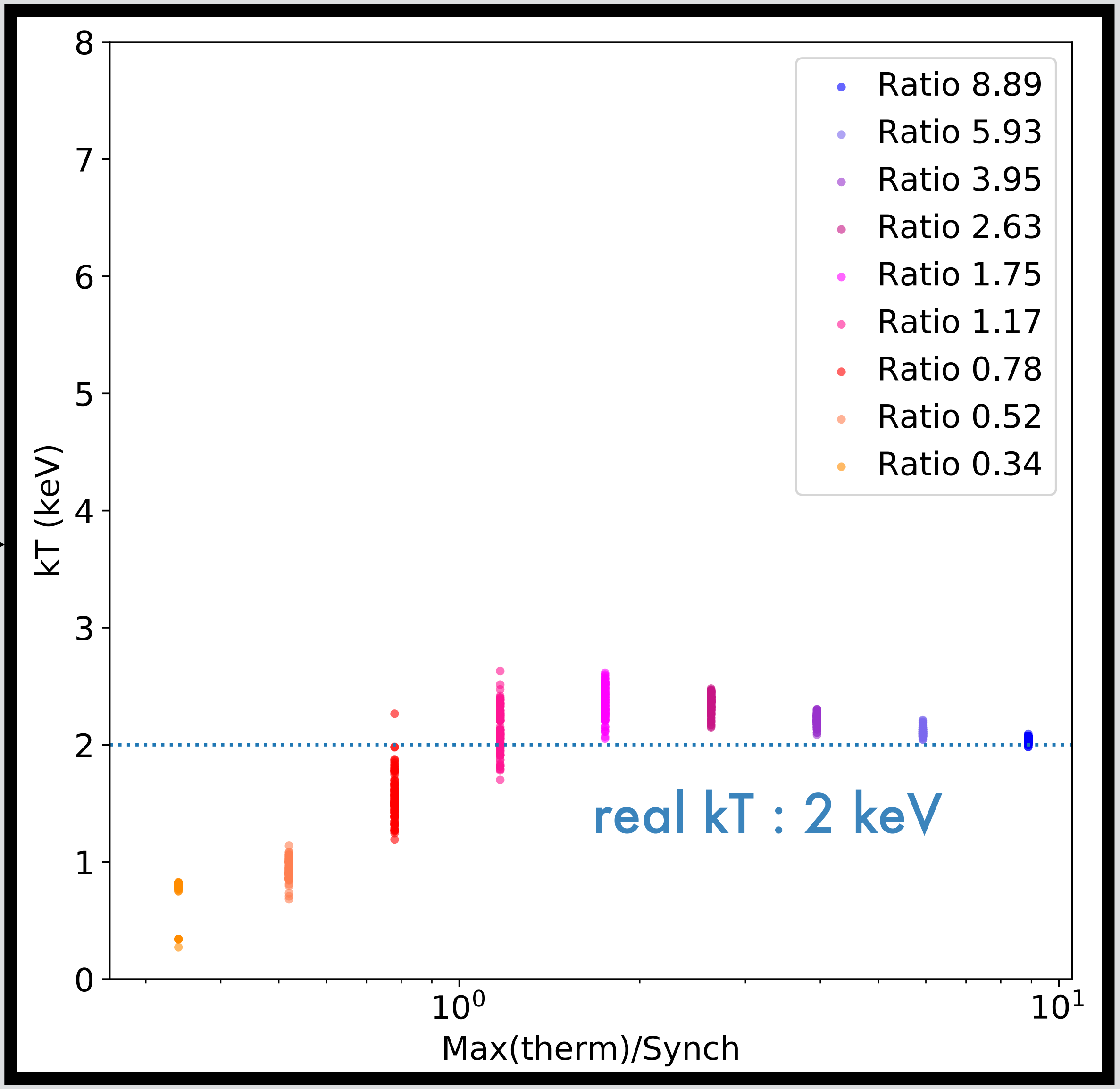


Spectra of second component retrieved by GMCA in both toy models

The dashed lines represent theoretical models. On the right, we can see important deviations in high energy from the model.

Spectral accuracy





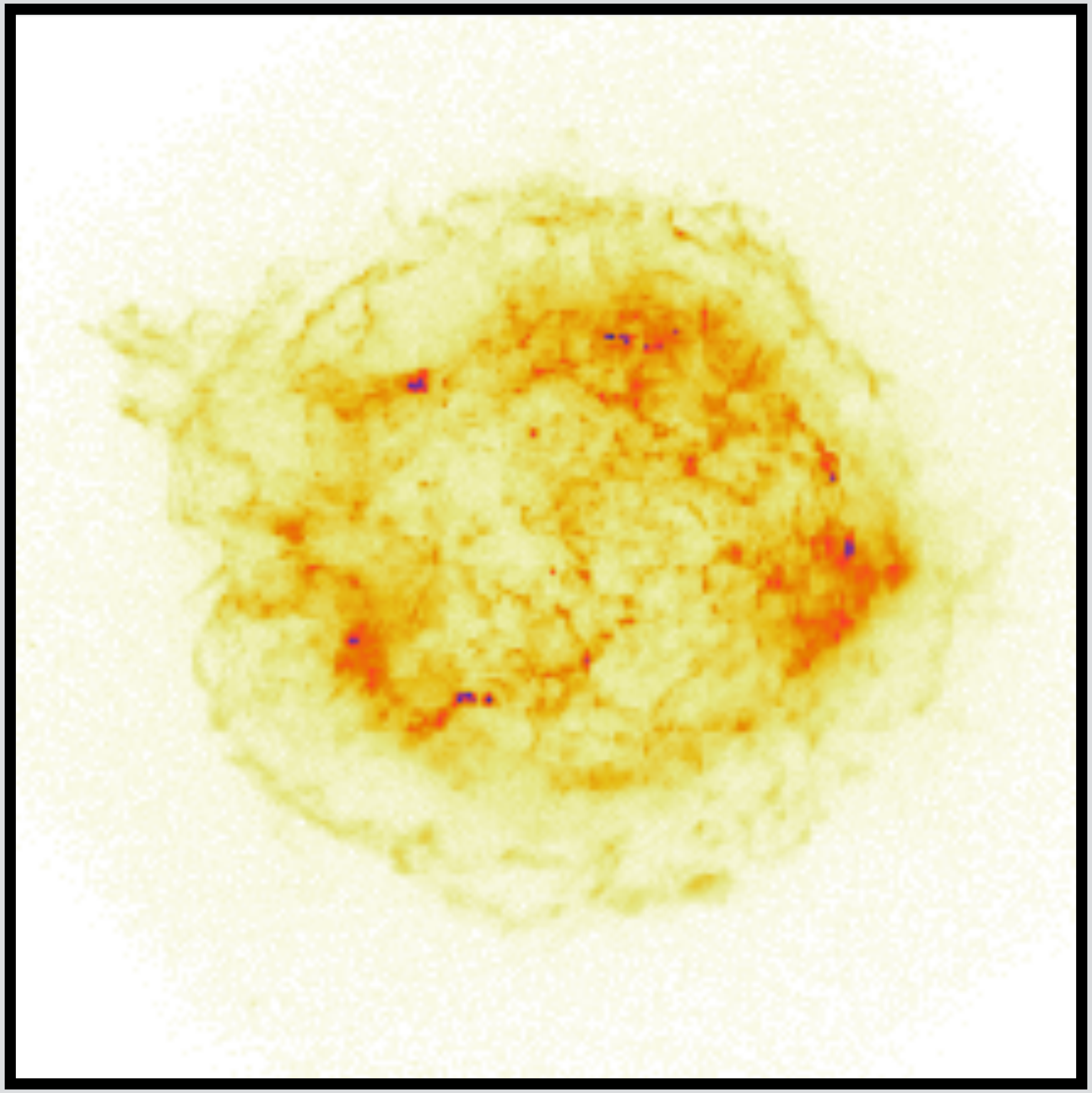
Retrieved kT

After a fitting in Xspec.

Application on real data of Cas A

Ca line emission :

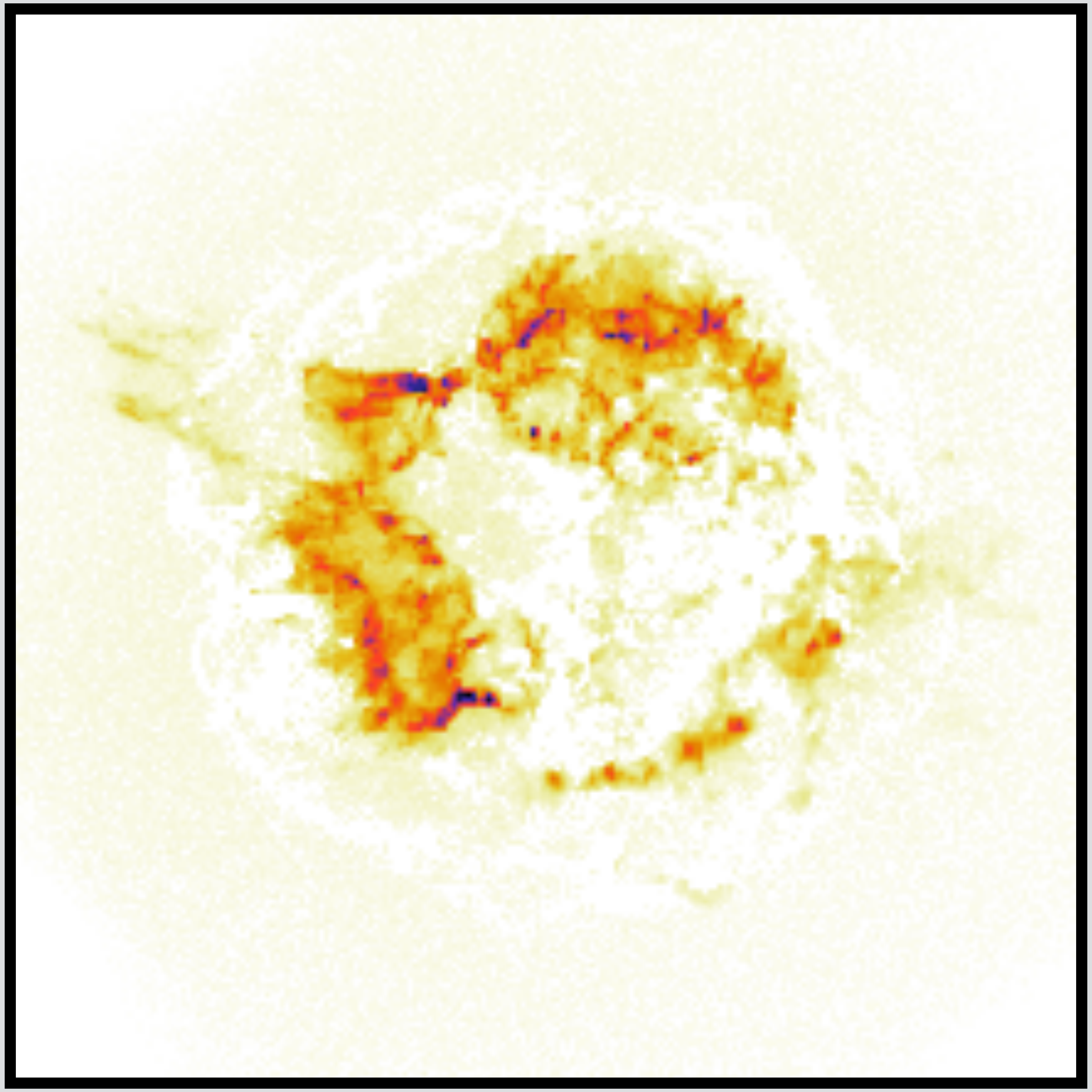
Integration on 3.75-3.95 keV



Application on real data of Cas A

Ca line emission :

GMCA on 3.6-4.1 keV



Application on real data of Cas A

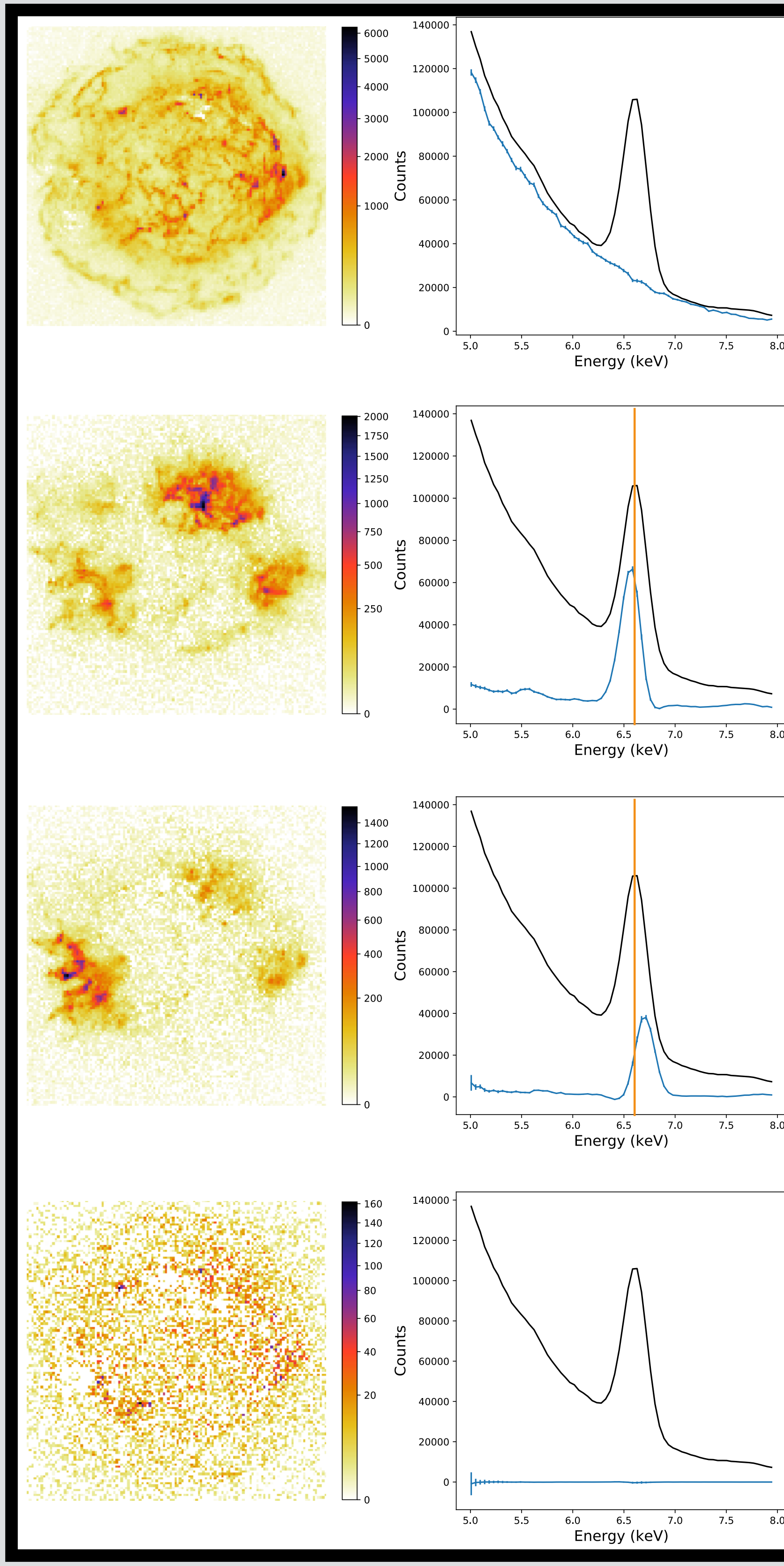
Application between 5 and 8 keV :

Synchrotron

Red-shifted Fe structure

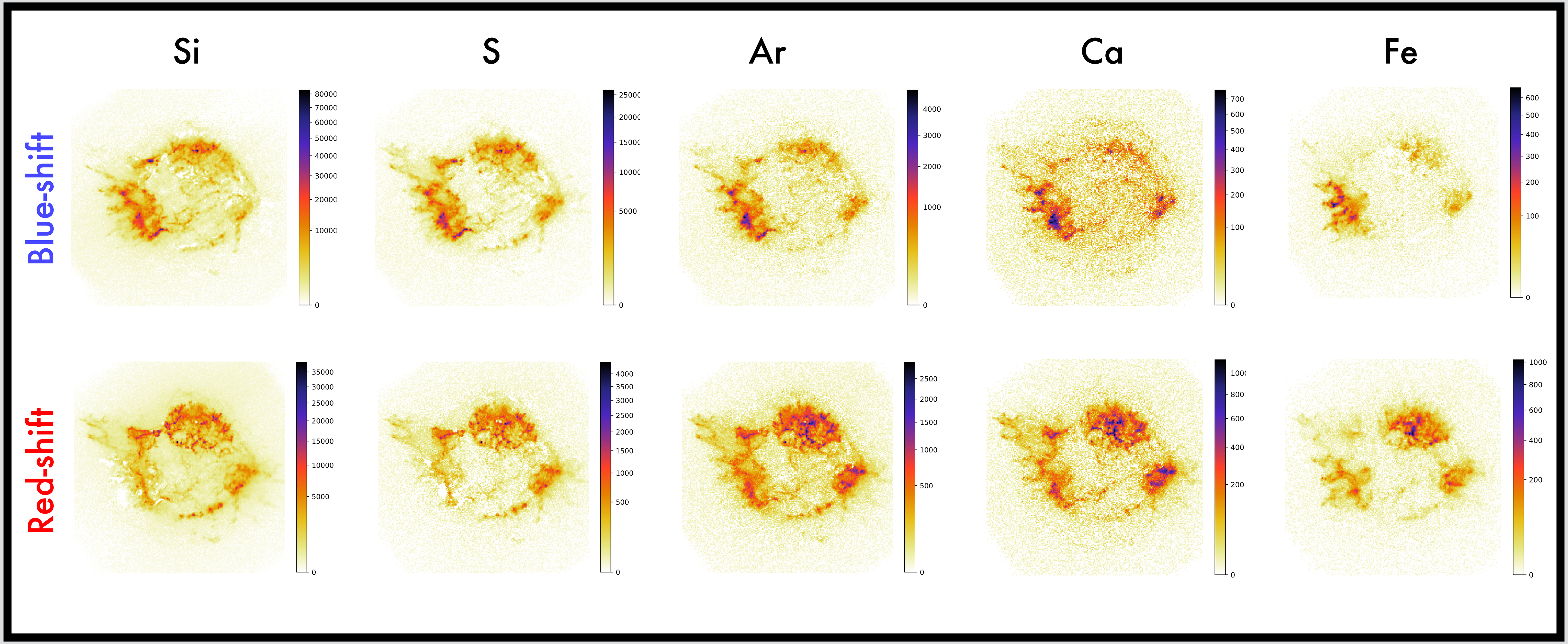
Blue-shifted Fe structure

Noise

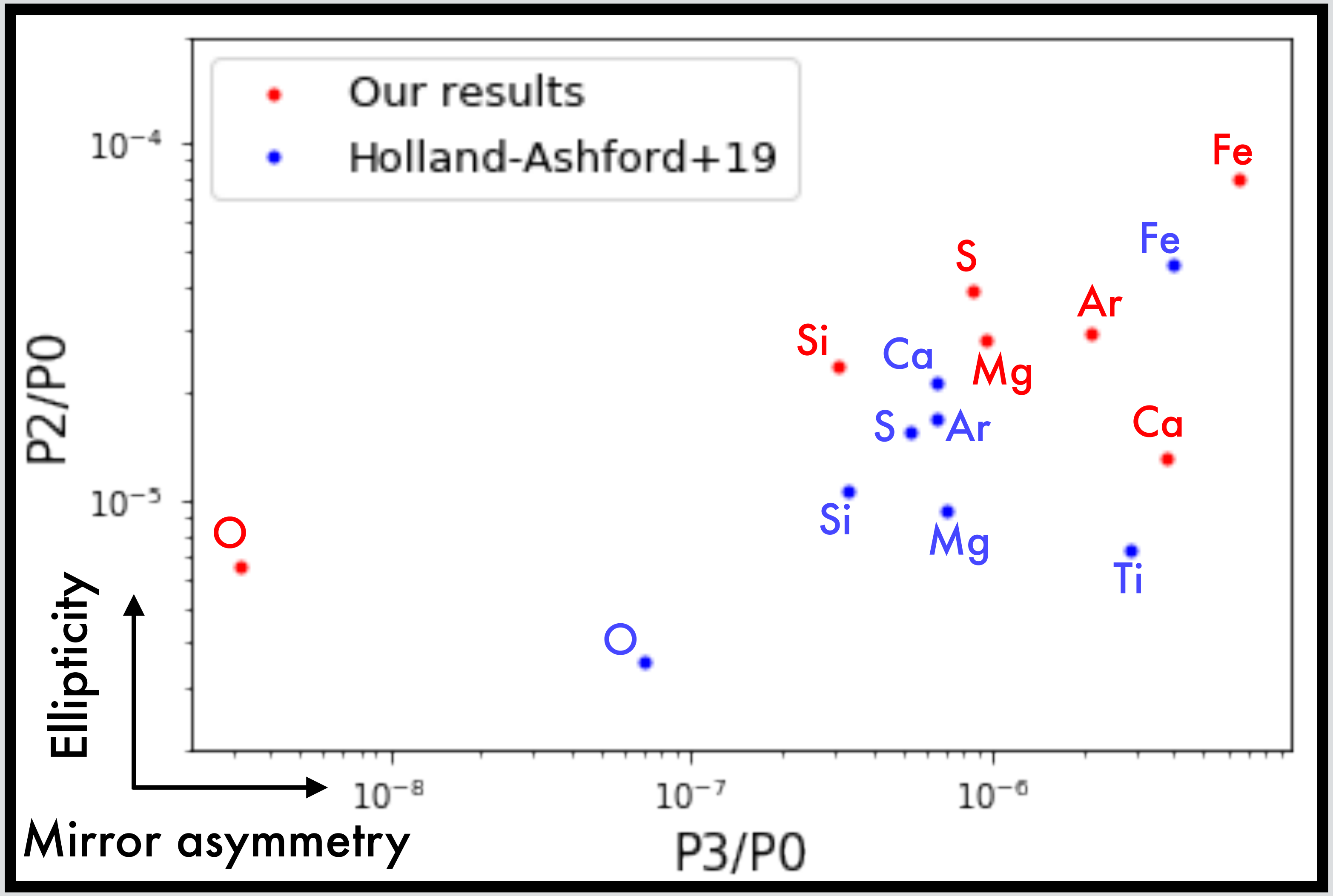


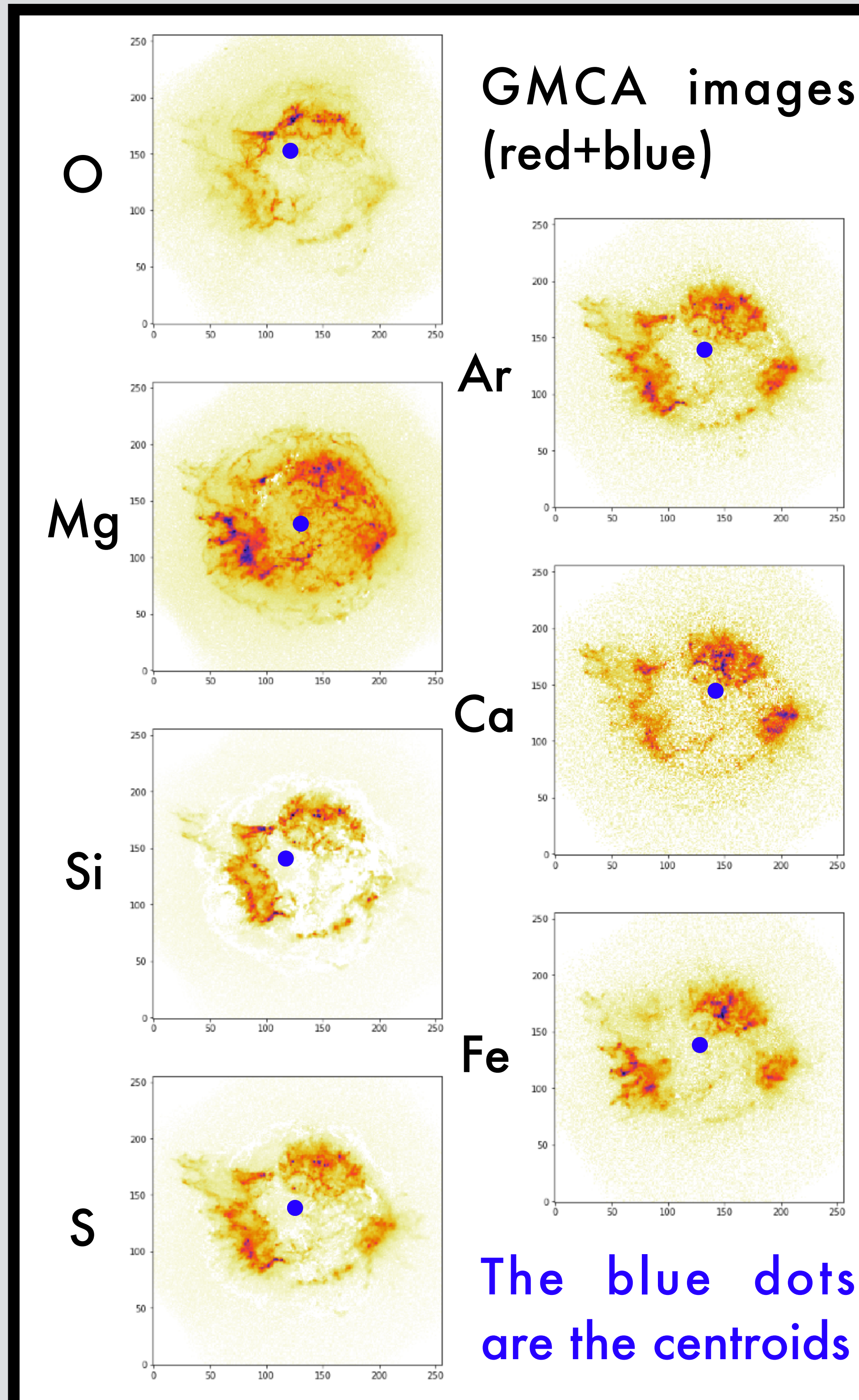
Velocity Asymmetries

Application around some major line emissions:



Morphological Asymmetries

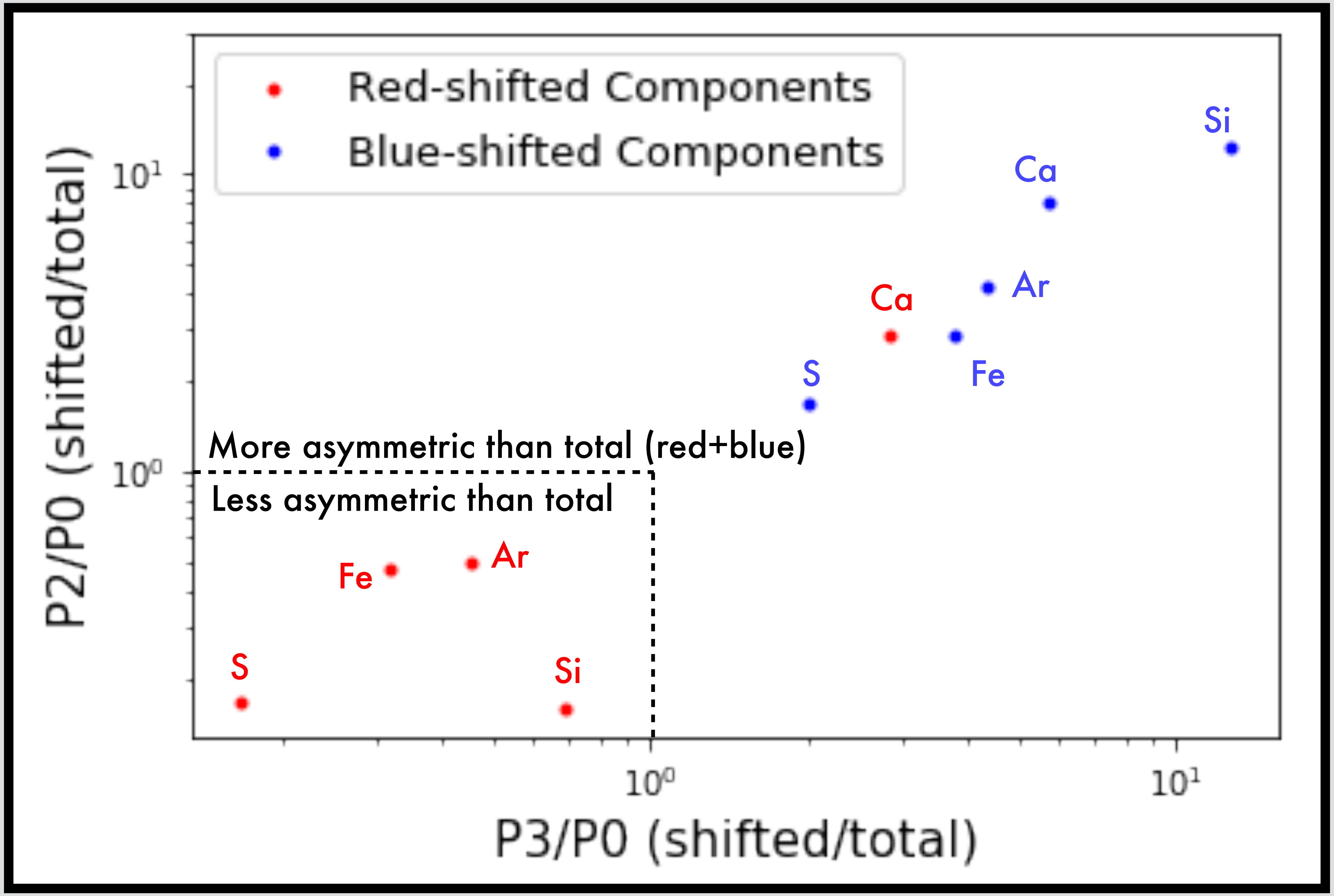




The Power-Ratio method characterizes the distribution asymmetries of elements in Cas A.

Morphological Asymmetries

<u>Distribution asymmetries in Blue or Red shifted components :</u>



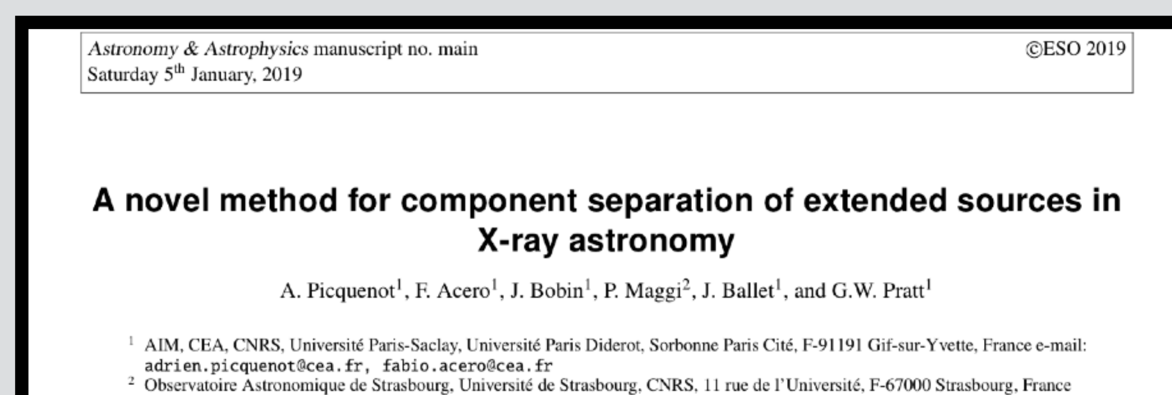
The Blue-shifted components are more asymmetric than the red-shifted ones : line of sight effect ?

Conclusion

- GMCA retrieves morphologically and spectrally accurate components.
- The performances of the algorithm are very case-specific
- Bootstrap resamplings give accurate error bars
- First applications on real data are very promising, offering a lot of new information to do science !
- Can be applied to any spectro-imaging data (MUSE, ATHENA, FERMI, CTA...)

Four scales of the *Starlet* transform of *Thank you !*

The methodology paper has been accepted:
arXiv:1905.10175



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A novel method for component separation of extended sources in X-ray astronomy

A. Picquenot[1], F. Acero[1], J. Bobin[1], P. Maggi[2], J. Ballet[1], and G.W. Pratt[1]

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[2] Observatoire Astronomique de Strasbourg, Université de Strasbourg, CNRS, 11 rue de l'Université, F-67000 Strasbourg, France

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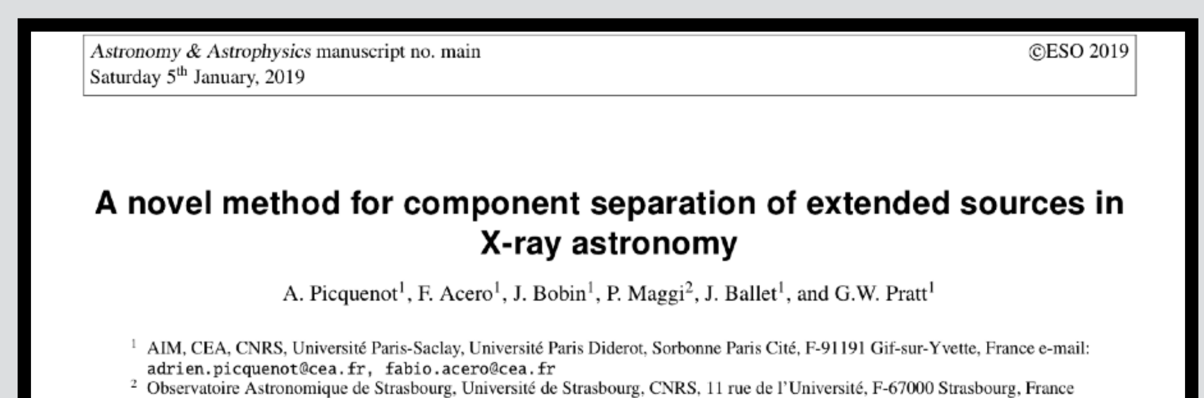

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