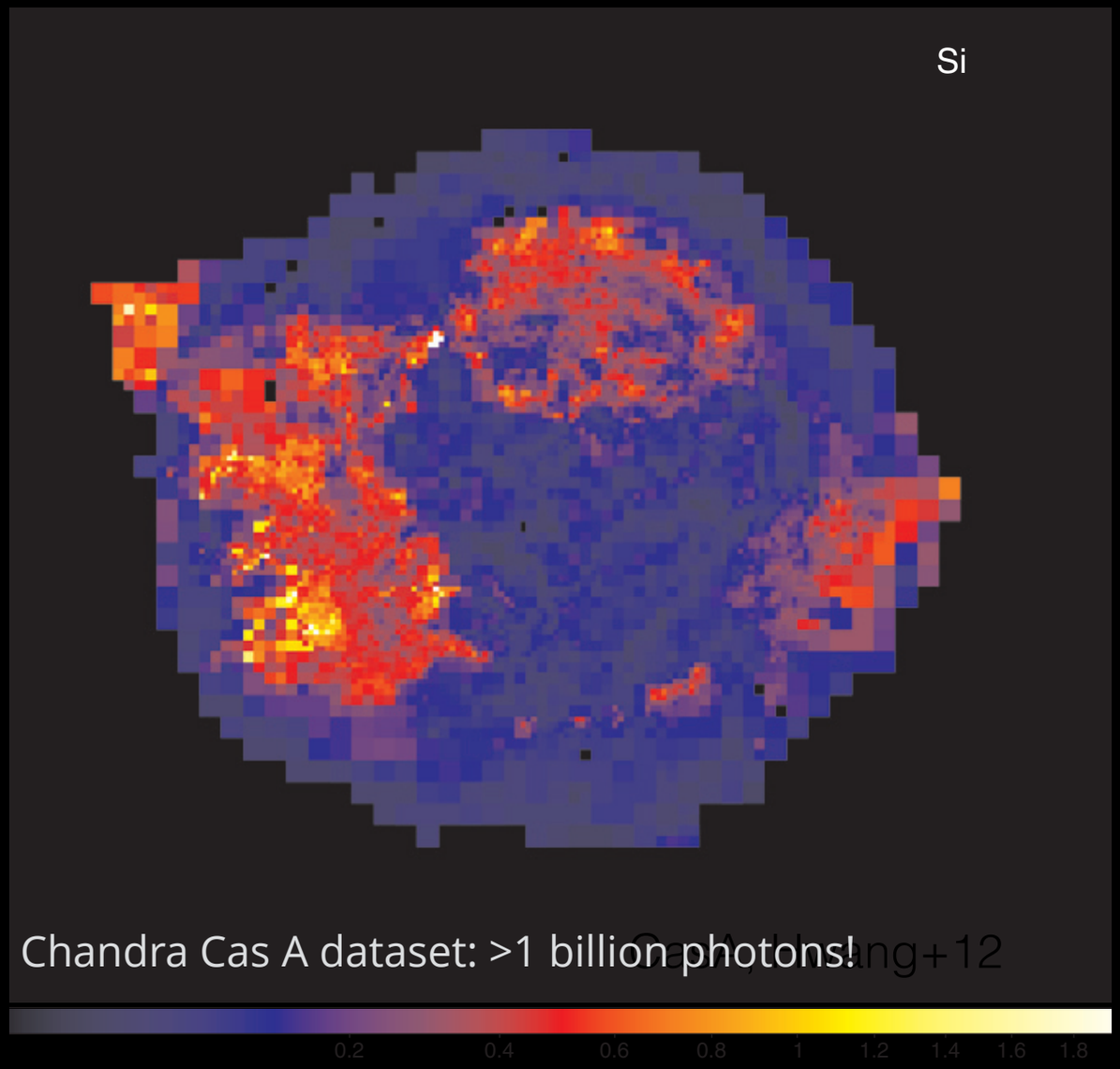
# Component separation and reconstruction in extended X-ray sources

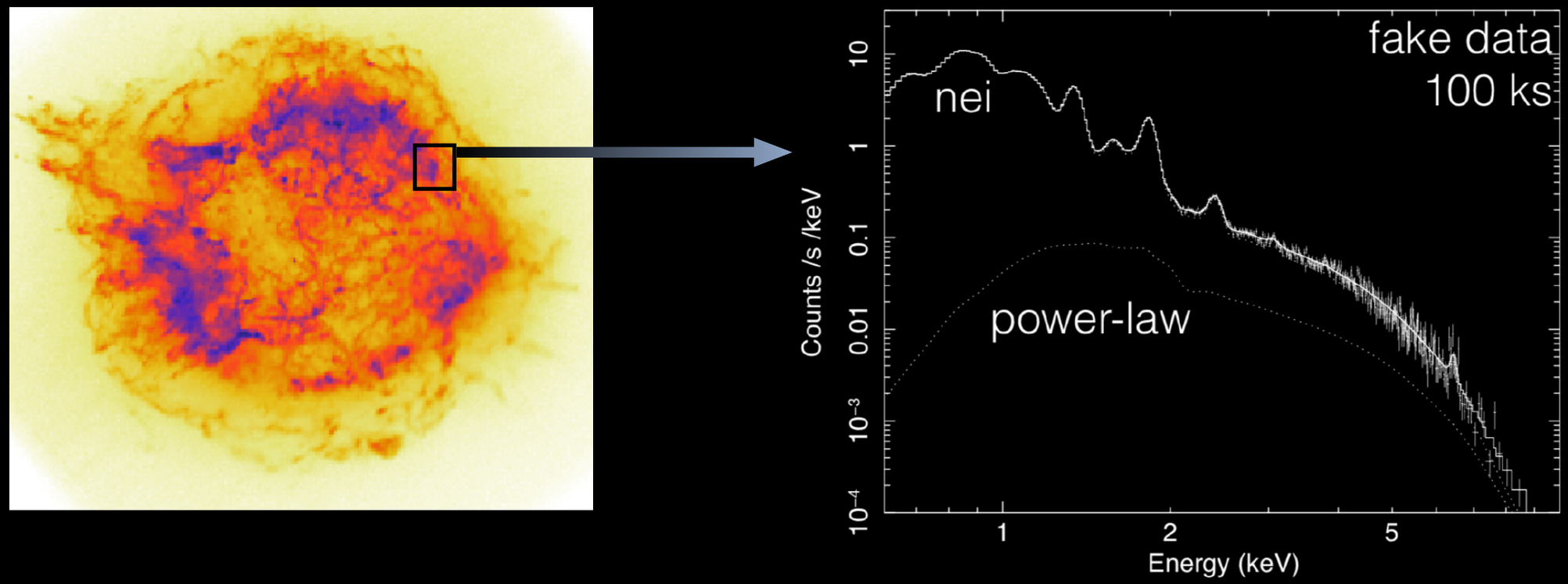
F. Acero, A. Picquenot,
L. Godinaud, J. Bobin,
G.W. Pratt
CEA Saclay, Département d'Astrophysique

# Data analysis of extended sources



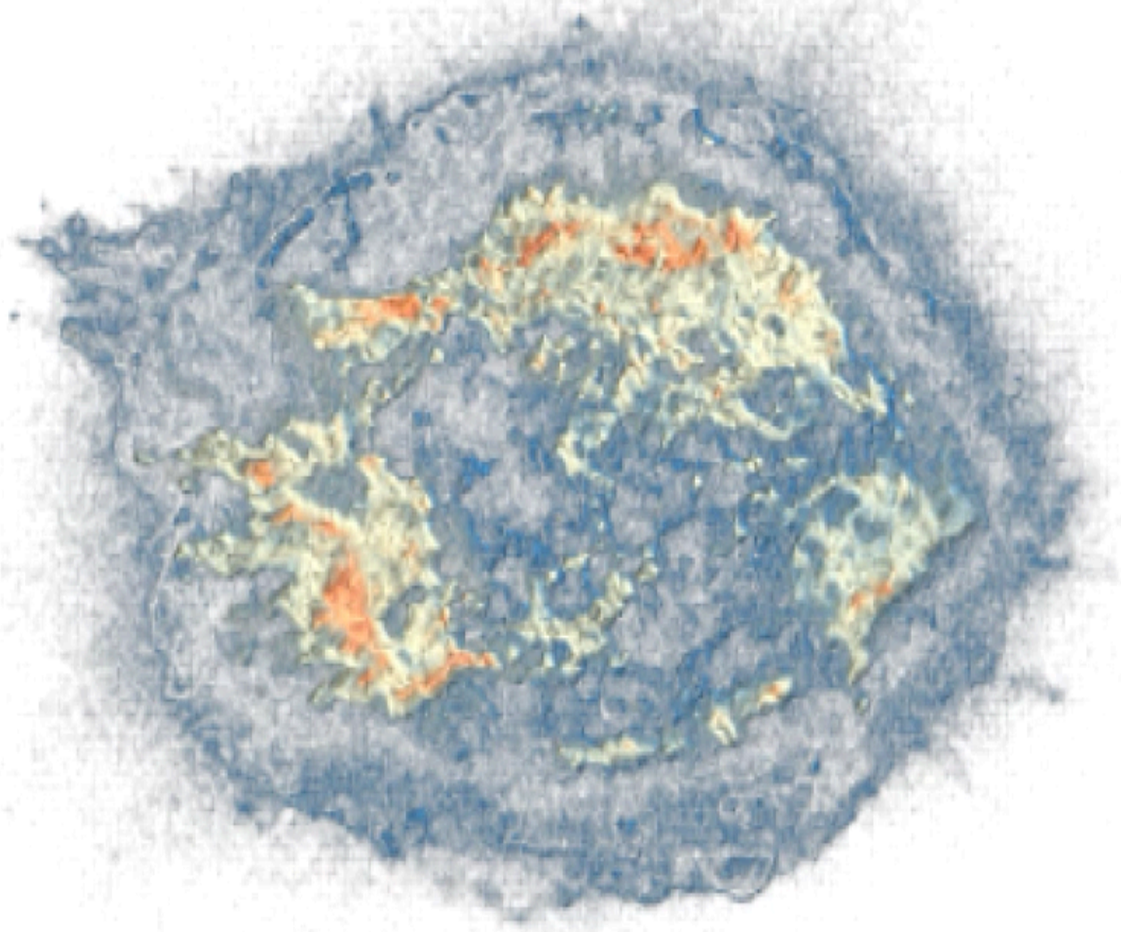

- Multiple, entangled physical components
  - Mixed /nested ejecta, synchrotron emission
  - Projection effects
- Region definition impacts spectral results

# Data analysis of extended sources

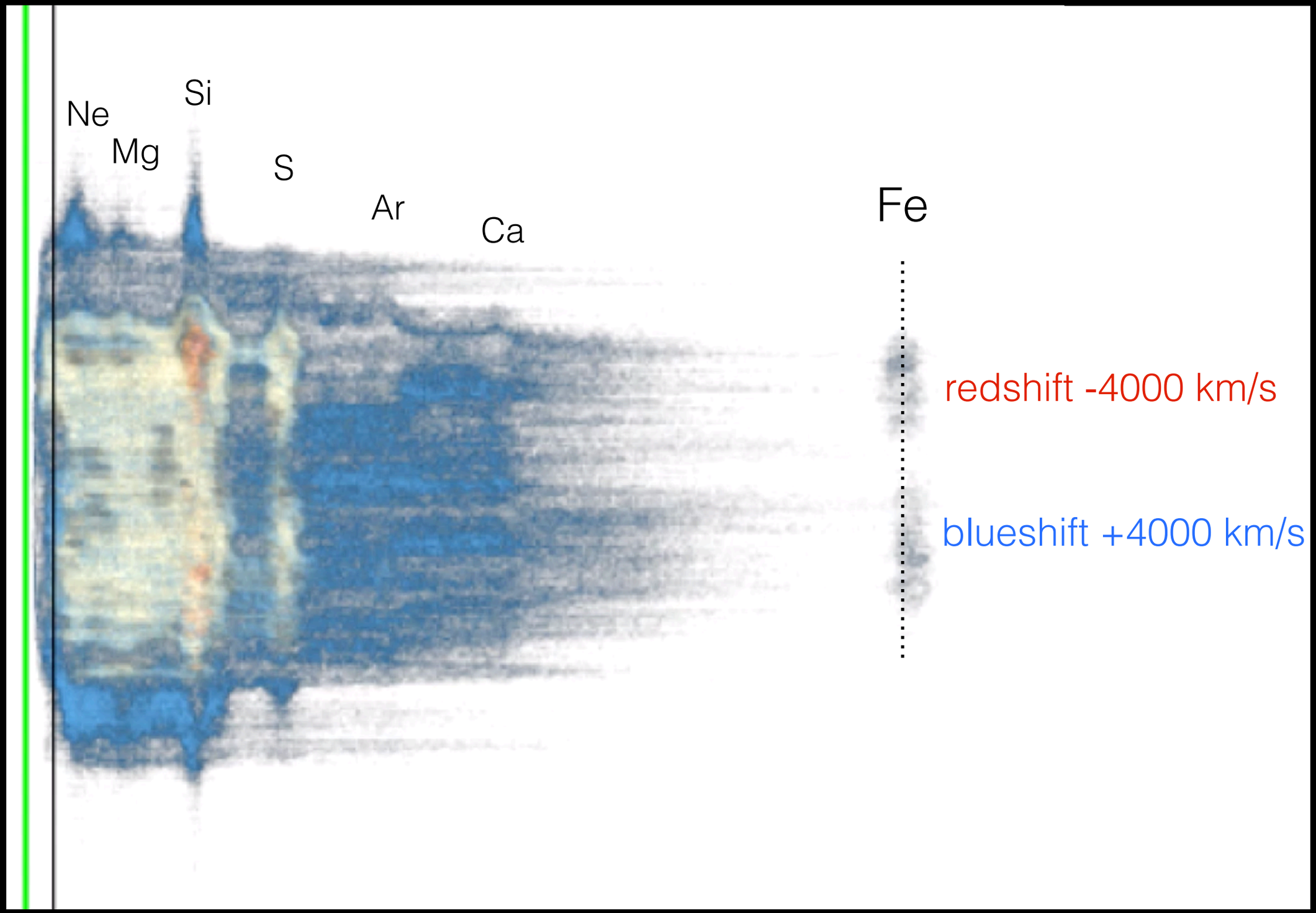



- Typically (Voronoï, adaptive binning, etc):
  - cells defined on surface brightness, not intrinsic distribution of physical components
  - cell definition for lines is not ideal for synchrotron/continuum emission
  - Large-scale analysis (>$10^4$ spectra to fit)
- Issue:
  - each cell is treated independently
  - 2D then 1D, not fully exploiting the data

Cas A Chandra X,Y,E cube
(F. Acero)



# Cas A (X, Y, E) Chandra data cube (F. Acero)



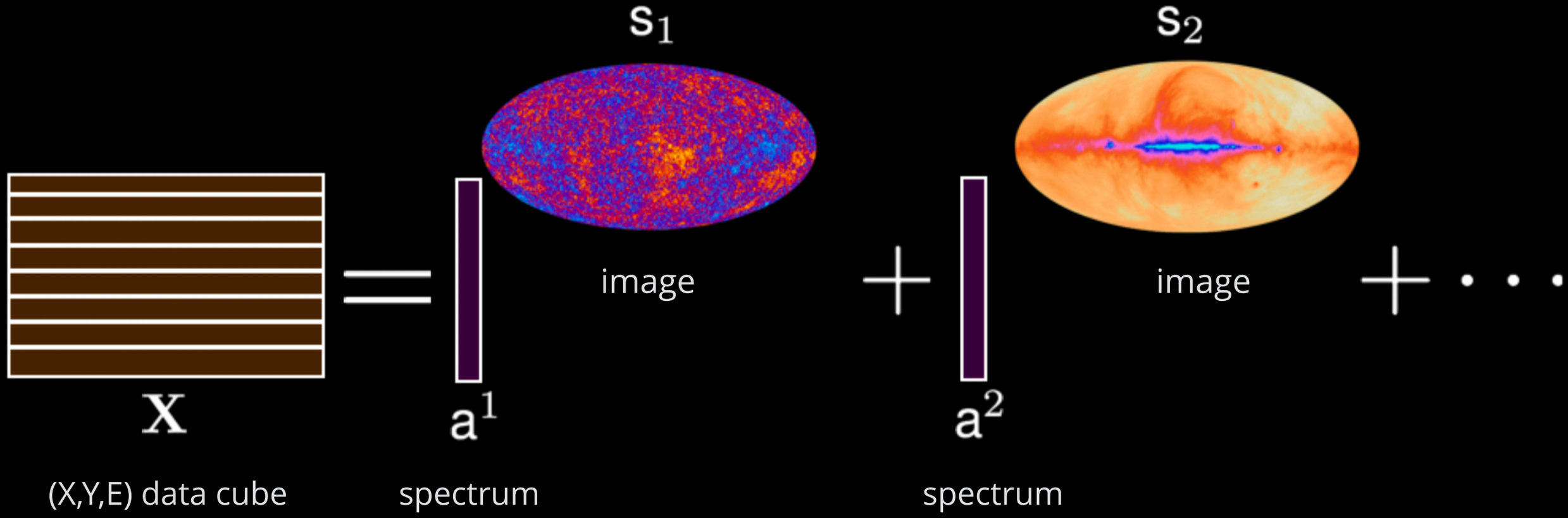

Energy

# One possible approach

Picquenot, Acero, Bobin, Ballet, Maggi, Pratt, 2019, A&A, 627, A139

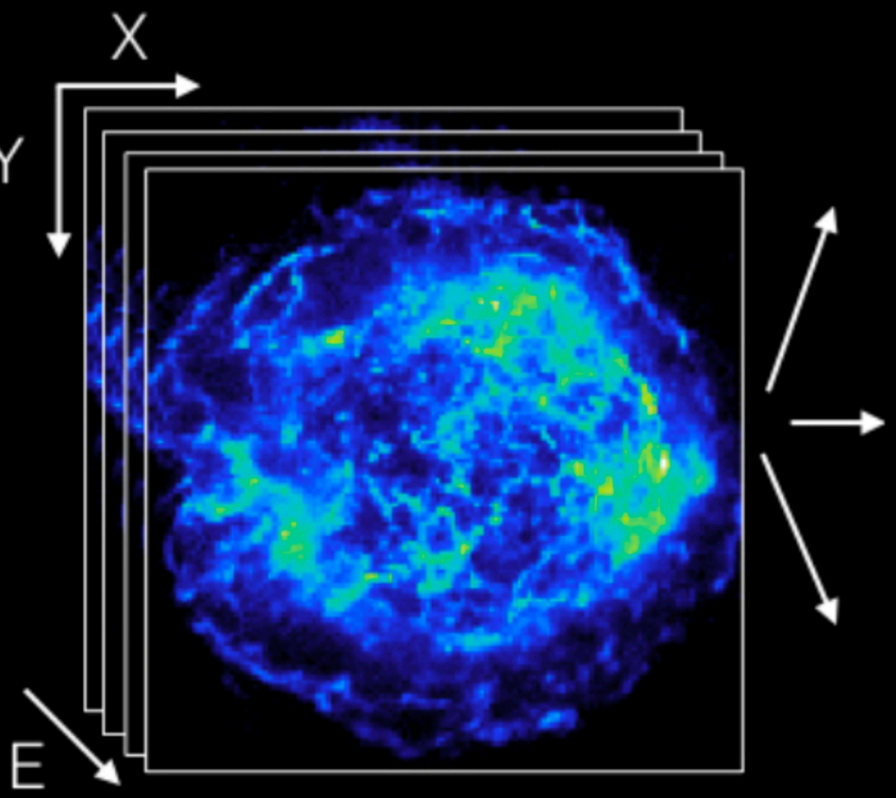
# Generalised morphological component analysis (GMCA)

- Bobin et al. (2016)
- **Assumption**: Linear combination of Spec*Image

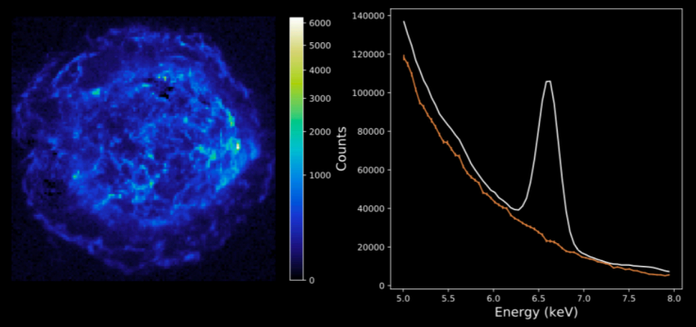



- **Blind source**: estimate all $a_i$ & $s_i$ with no prior info
- Semi-blind: use some physical information
- GMCA is an unsupervised ML clustering algorithm
  Outputs**:** images and spectra in counts (directly usable in Xspec)
- **Limitation**: assume morphology does not change with energy

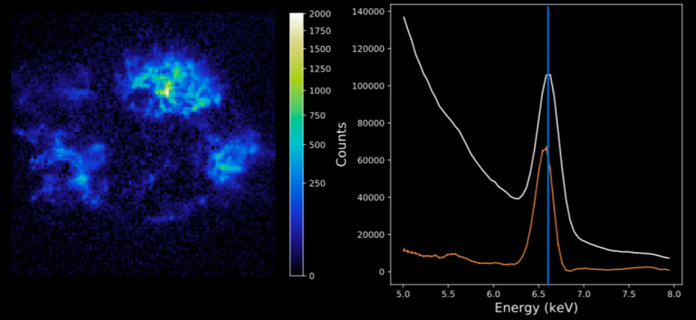
# Cas A [5-7] keV (1 Ms Chandra data)



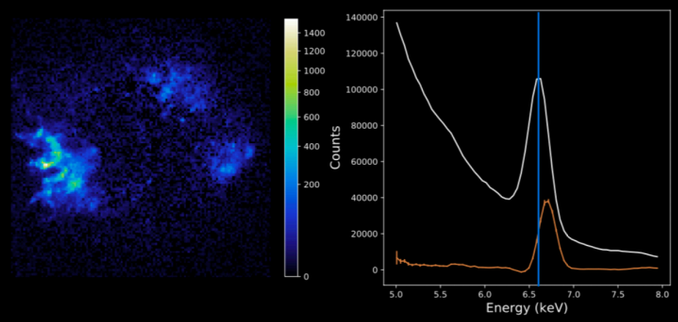

Synchrotron



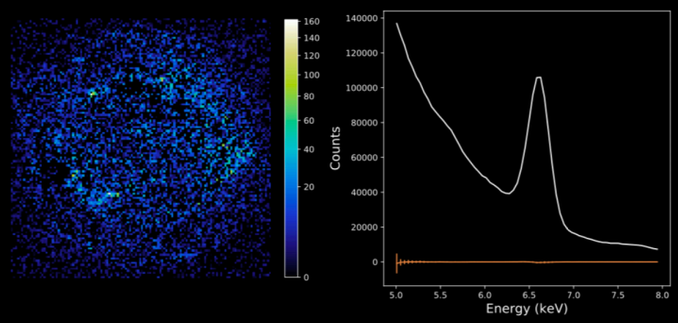

Red-shifted Fe structure




Blue-shifted Fe structure

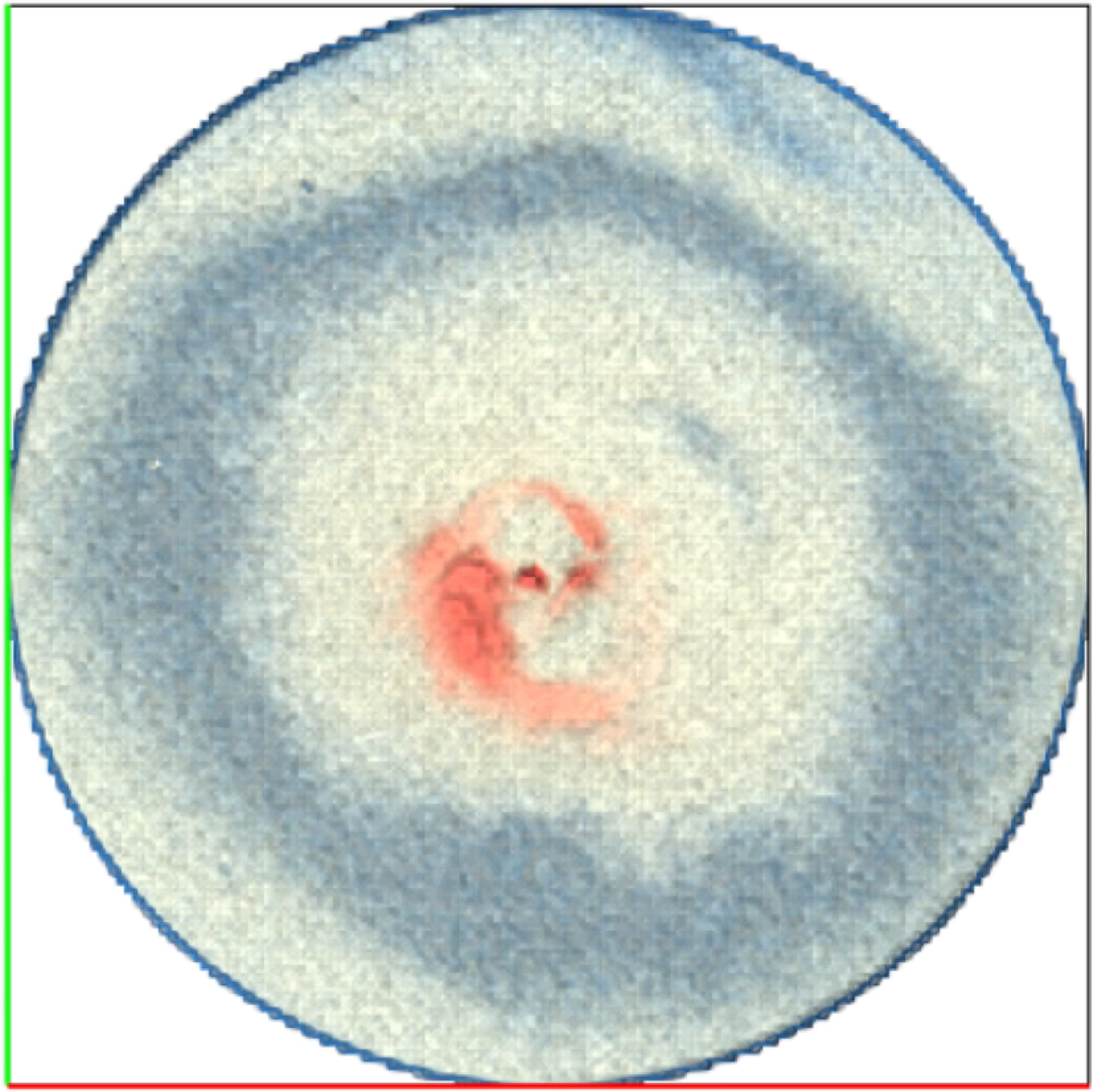



Noise




- 3 significant components: “continuum”; redshifted, blue shifted Fe K
- Very robustly retrieved: no significant additional components

# Perseus 1 Ms Chandra X,Y,E cube (F. Acero)

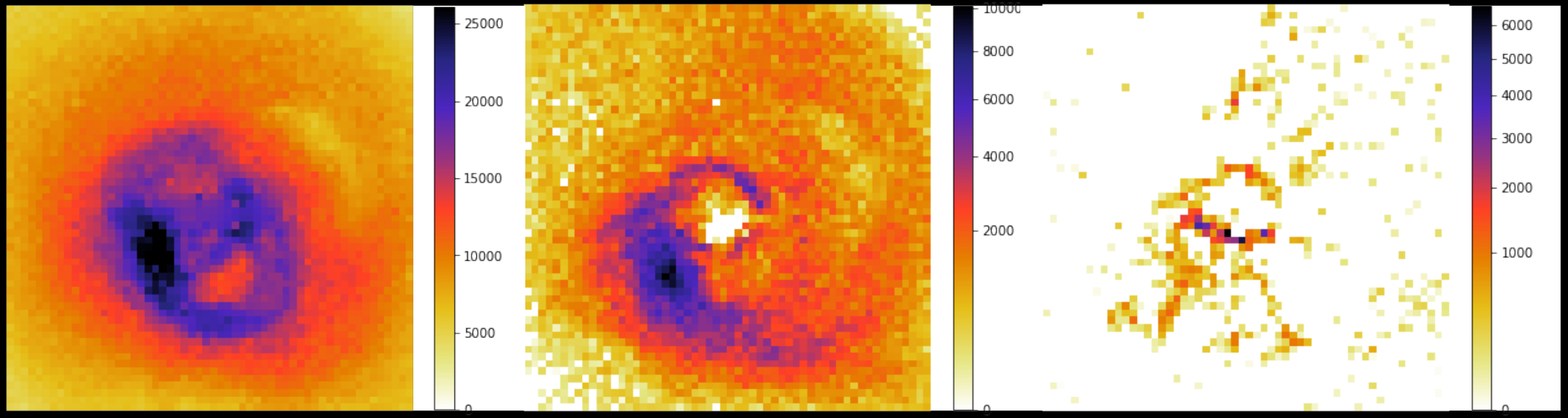


# Perseus [0.5-3] keV

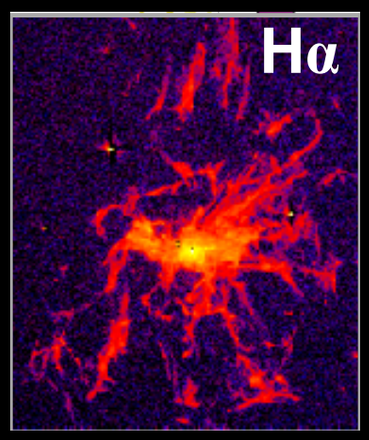
GMCA component 1

GMCA component 2

GMCA component 3



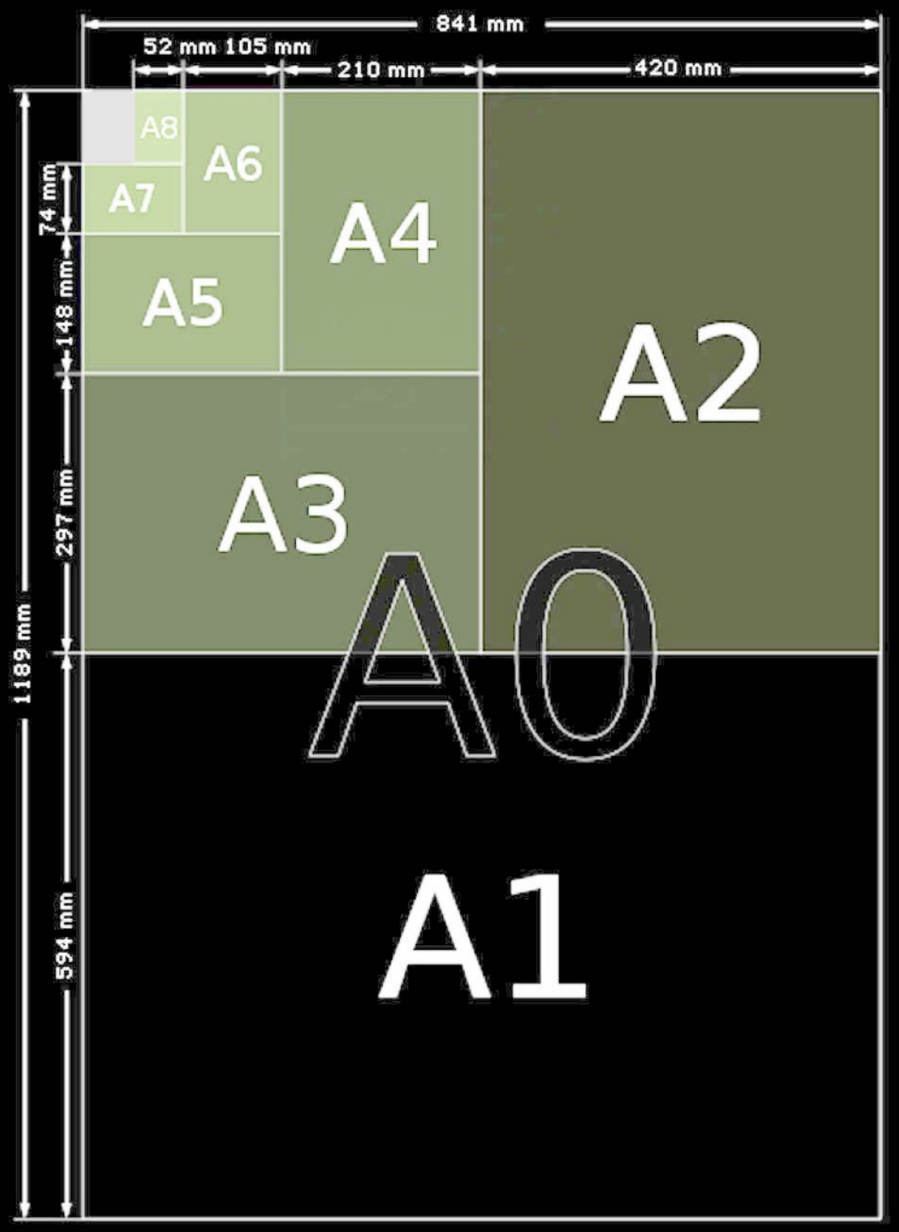

5 arcmin
central region of Perseus




- Direct spectro-imaging of X-ray filaments
- Spiral structure probably due to sloshing

# Athena

- Athena
  - Increased $A_{eff}$ (A0 [1 $m^2$] vs A4 [Chandra])
  - Many more counts

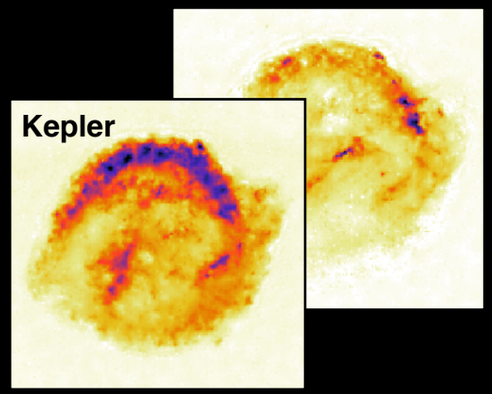


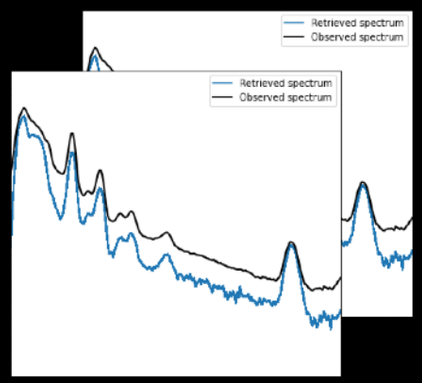
# Using GMCA for SIXTE simulations

Chandra data cube

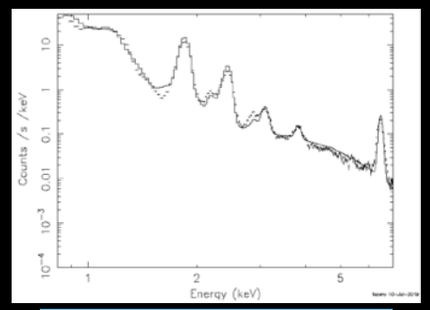
GMCA

N (image, spec)




Xspec




**XSPEC model**
model TBabs(powerlaw + vnei)
1.50531 0.001 …
2.28824 0.01 …
…

SIMPUT

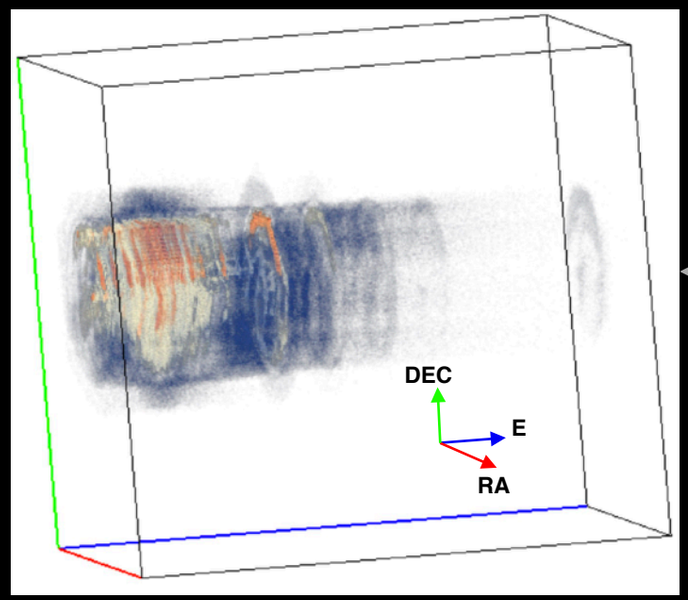
SIXTE

SIXTE simulation by Gamil Cassam-Chenaï

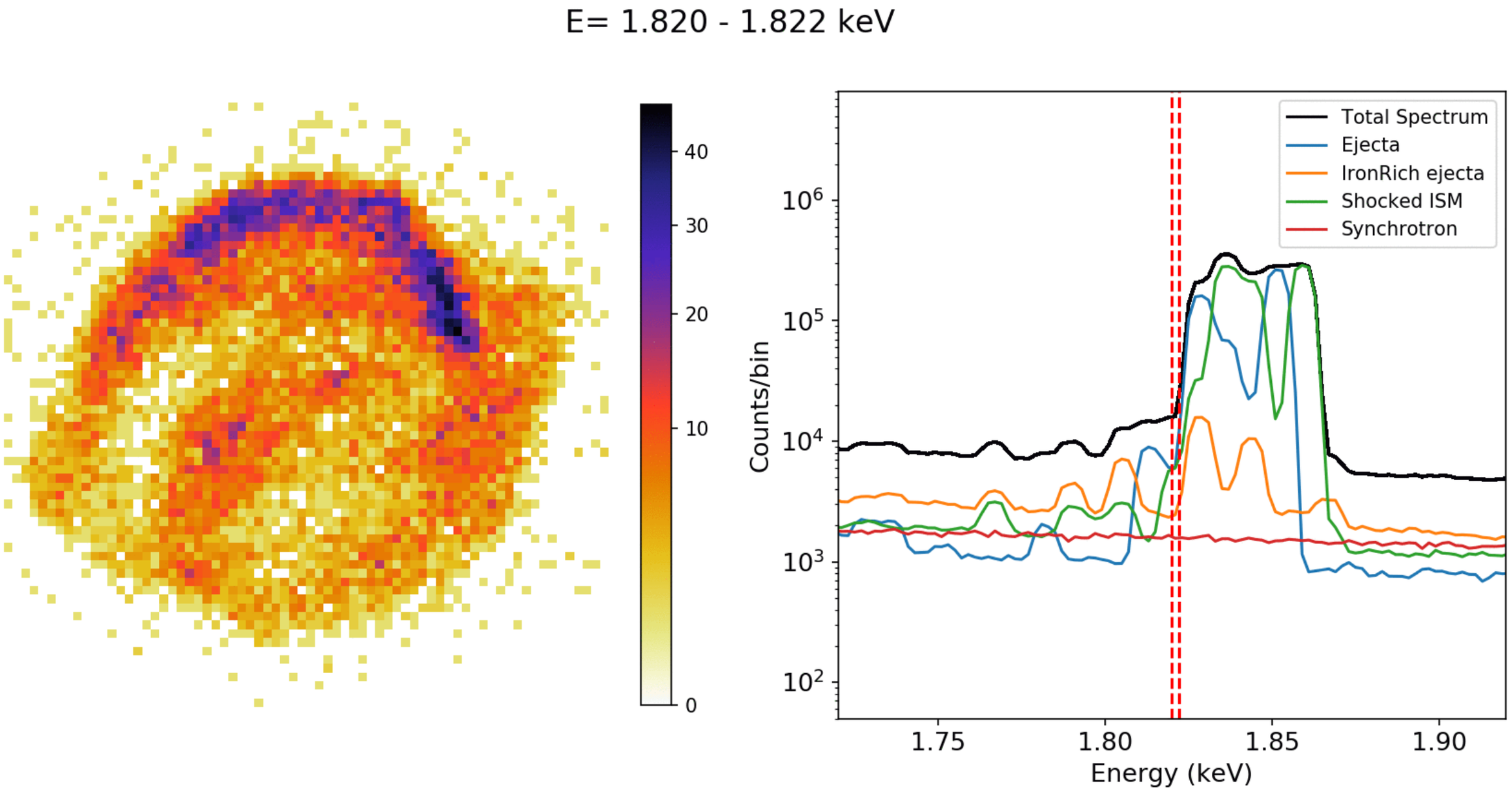
**Event list**

| | RA | DEC | E |
|---|---|---|---|
| 1 | … | … | … |
| 2 | … | … | … |
| 3 | … | … | … |

**Data cubes**

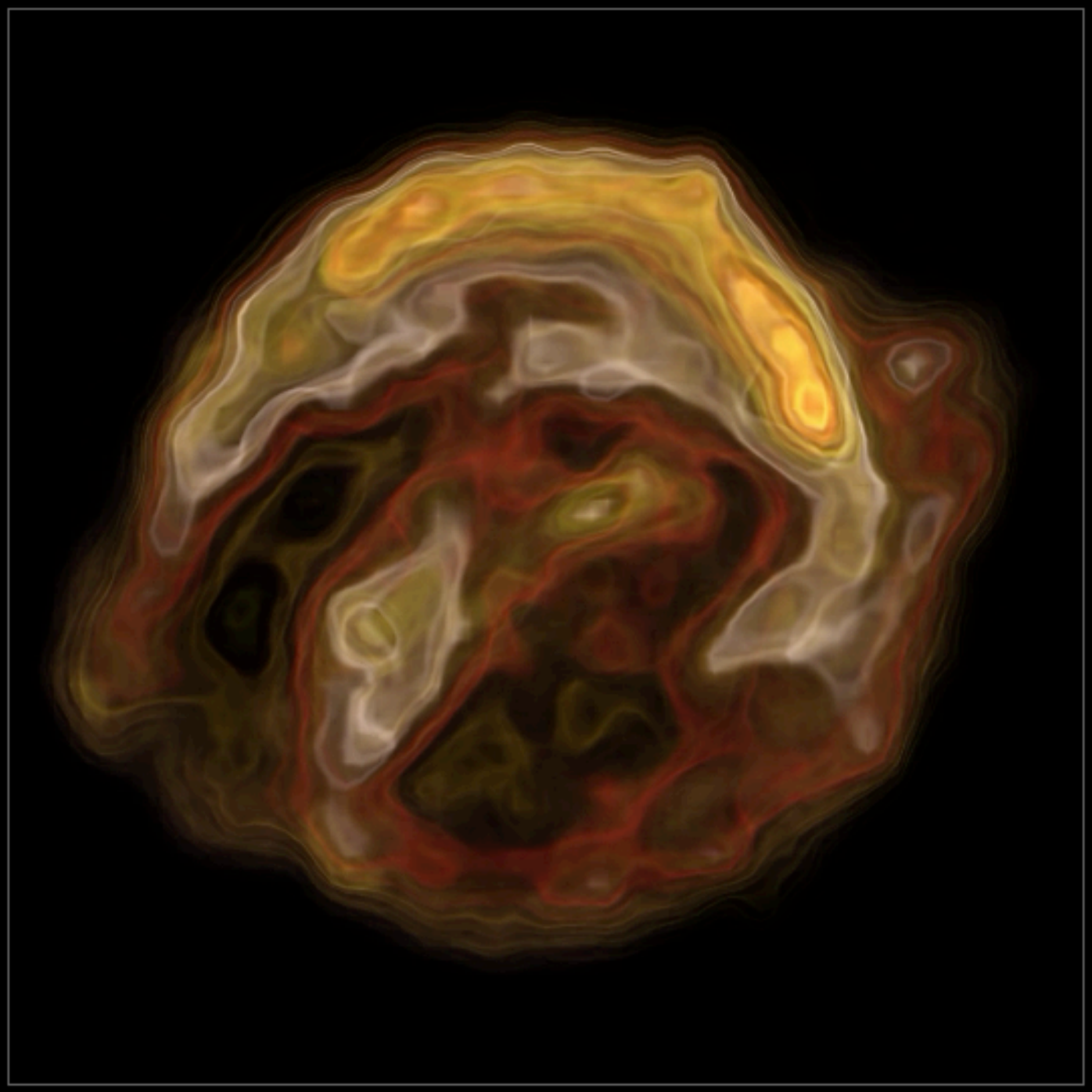


# Kepler X-IFU simulation around Si XIII line

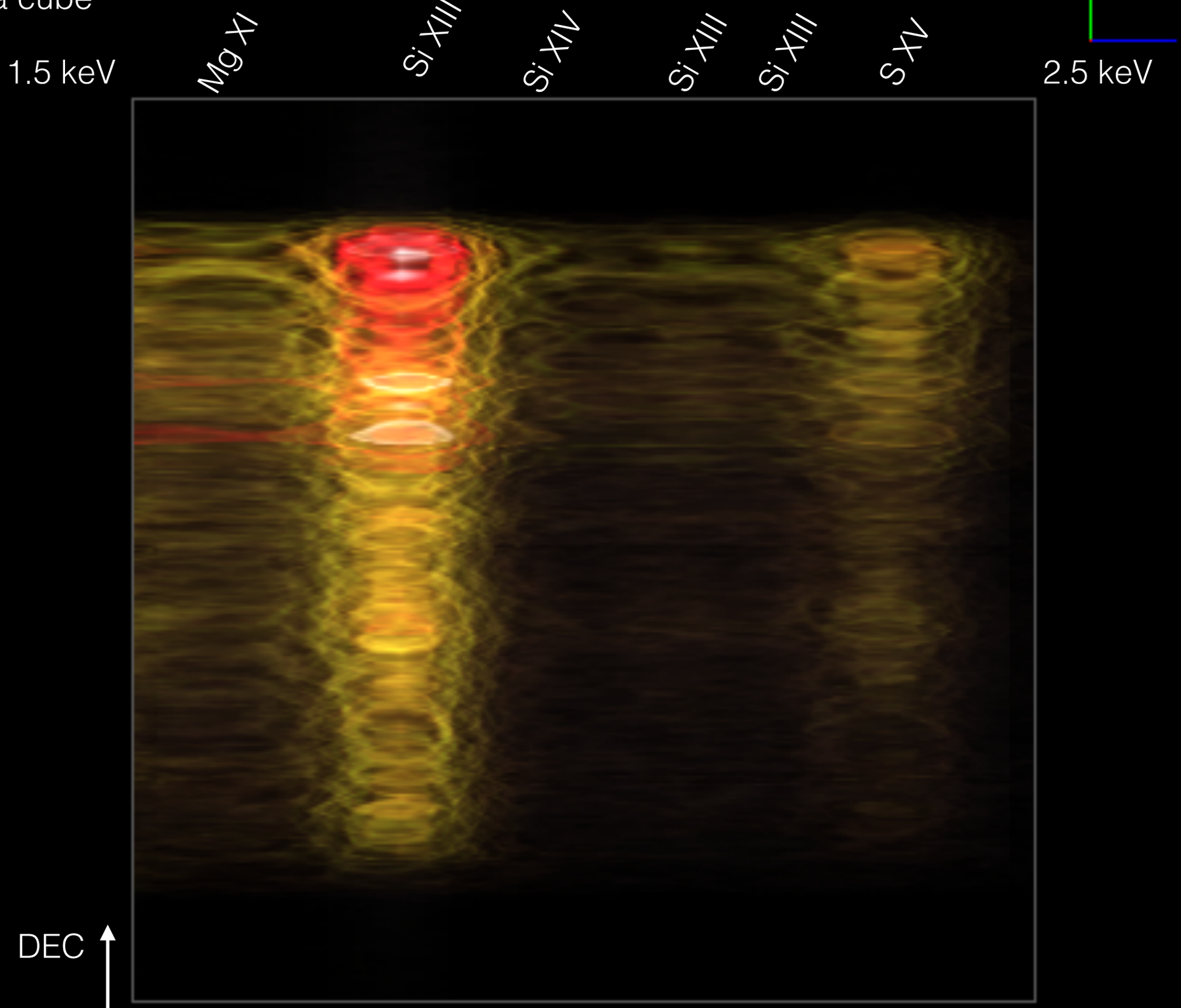



Kepler fits in X-IFU FoV
100 ks

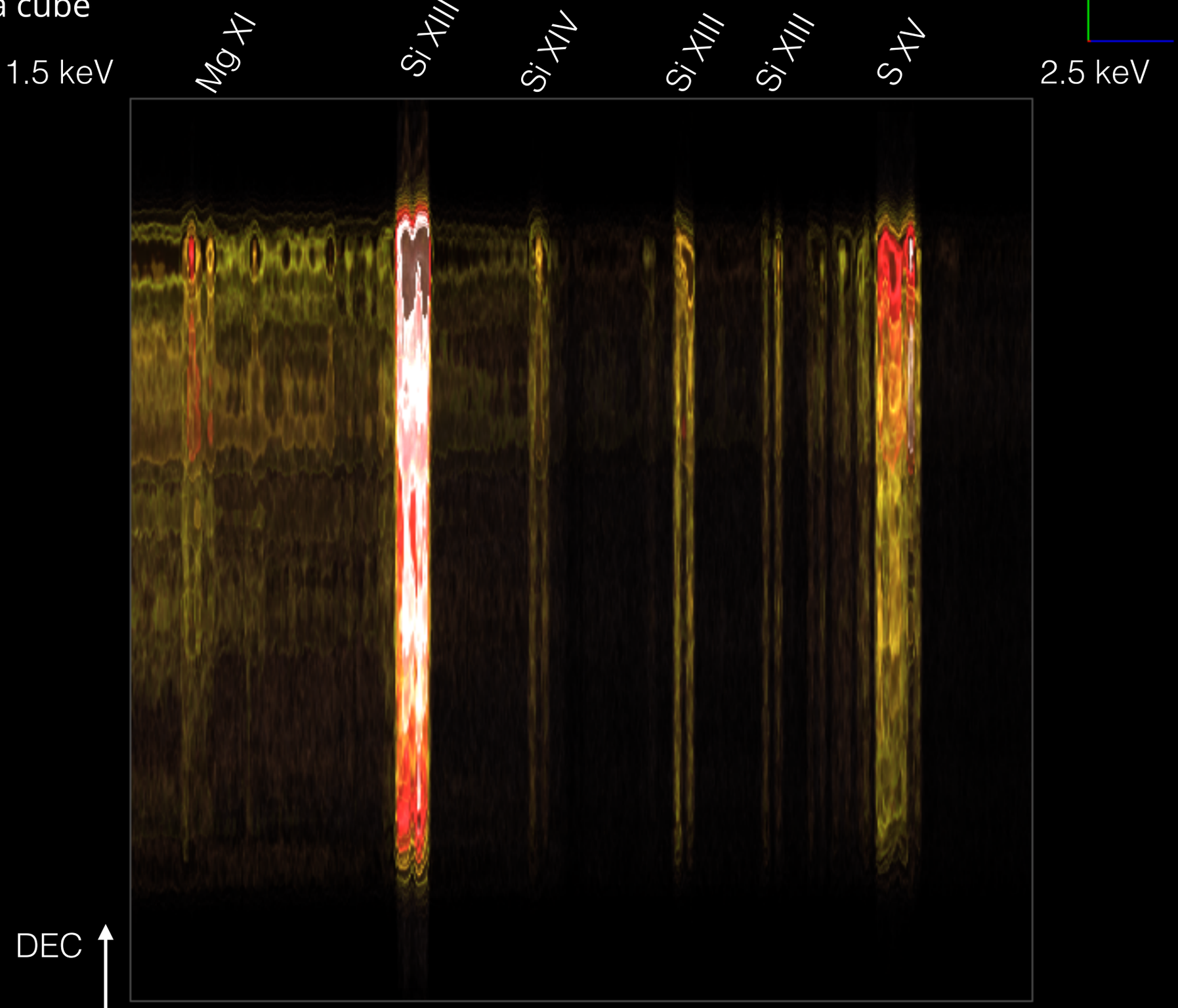
X-IFU Kepler SIXTE simulation
1.5-2.5 keV  data cube



Chandra observations
1.5-2.5 keV data cube



X-IFU Kepler SIXTE simulation
1.5-2.5 keV data cube



# Conclusion

- Huge amount of data in deep XMM & Chandra observations but analysis methods have stalled in the last 20 years

- GMCA: a blind source separation method for X/Gamma-rays
  - Exploit the 2D-1D info from spectro-imagers (MUSE, Fermi, CTA)
  - Applicable to SNR, PWN, clusters, galaxies or time cubes (X, Y, T)

- Clustering algorithm providing useful ‘human’ outputs

- Promising results on archival data for SNRs and clusters
  - revealing new features, useful outputs for SIXTE simulations

- Caveats
  - Assumes each component is Spec*Image
  - Need deep observations of bright sources (> 1 millions counts)
  - Can only differentiate if structured emission (not ~gaussian blobs)