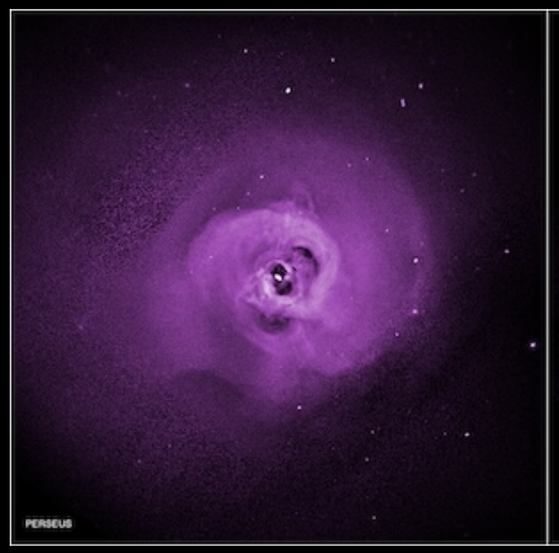
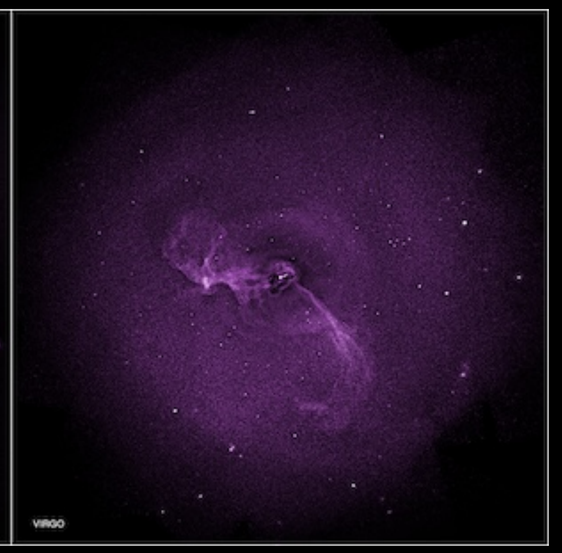
Exploring 3d fitting method for extended sources in X-rays using gammapy

Fabio Acero
A.Picquenot
R. Terrier



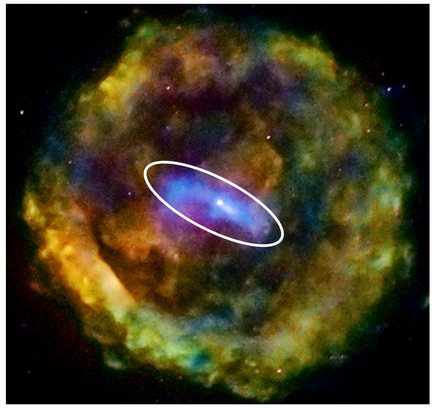


Status of high-energy workflows

2D then 1D

Spatial selection
then spectral analysis

a)



SNR G11.2-0.3

Spectro-morphology drawn by *eye*

X-ray, TeV analysis

Issue:
ON region contains SNR + PWN

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2D + 1D
spatial + spectral
parametric analysis

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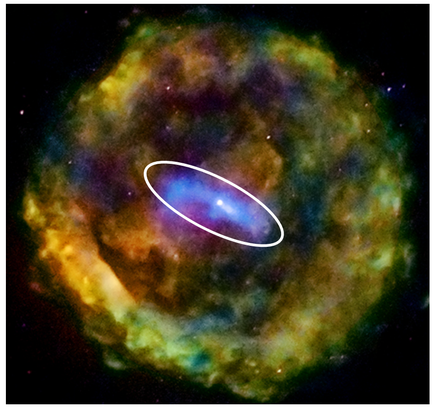

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b)

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parametric morphology (gaussian, disk)
parametric spectra (Power-Law, etc)

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GeV analysis

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Which morphology ?
Reality is not disk & gaussians

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Component separation (eg GMCA):
2D + 1D non parametric

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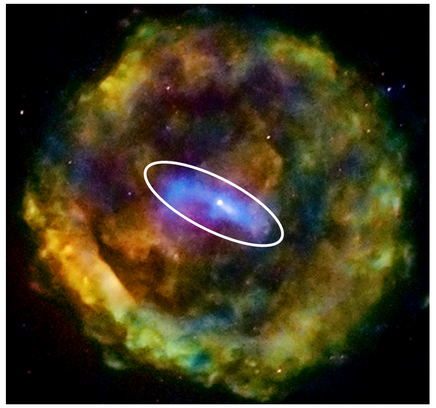

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morphology of spectral features

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New method
disentangle components
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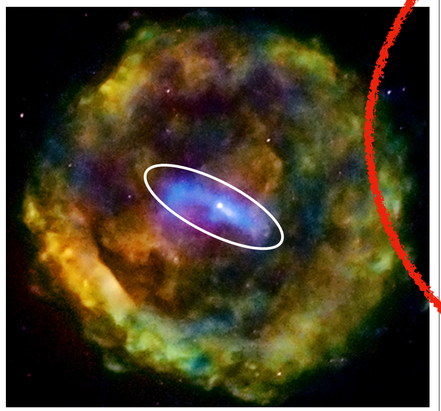

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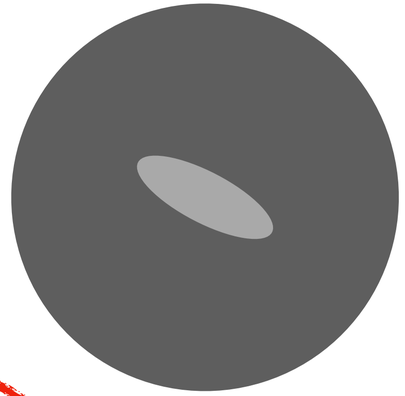

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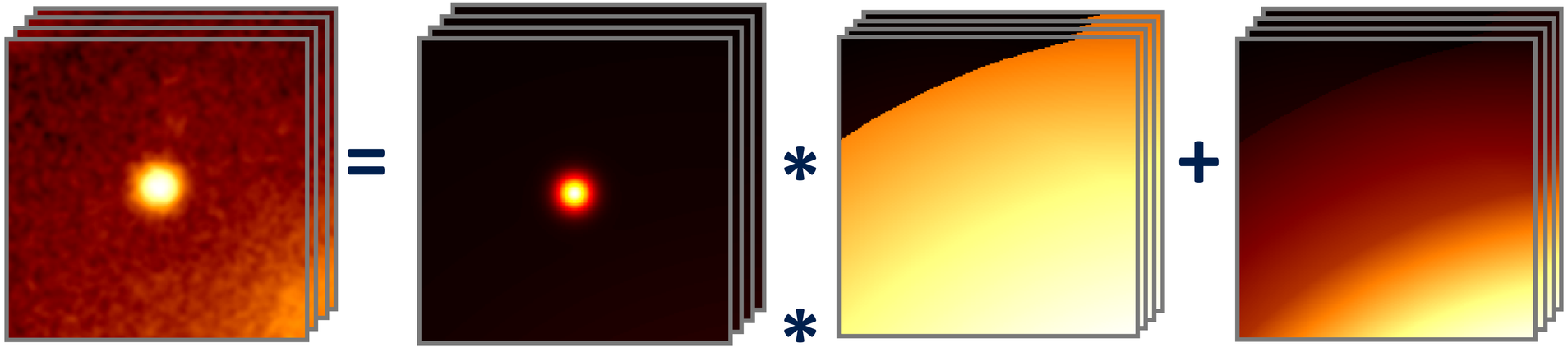
3D analysis : Lesson 101

Counts cube (X,Y,E) | Parametric source model | Exposure cube | Bkg cube

Free params:

X, Y, Sigma, Norm, Γ



(PSF, EDISP)

N_{obs} N_{pred}

- Minimization of *-LogLikelihood(N_{pred}, N_{obs})*
- MINUIT in gammapy. Stable, robust and well tested. Minos assym errors (important for Ecut).
- Can use other fitting backends (UltraNest now implemented in gammapy)

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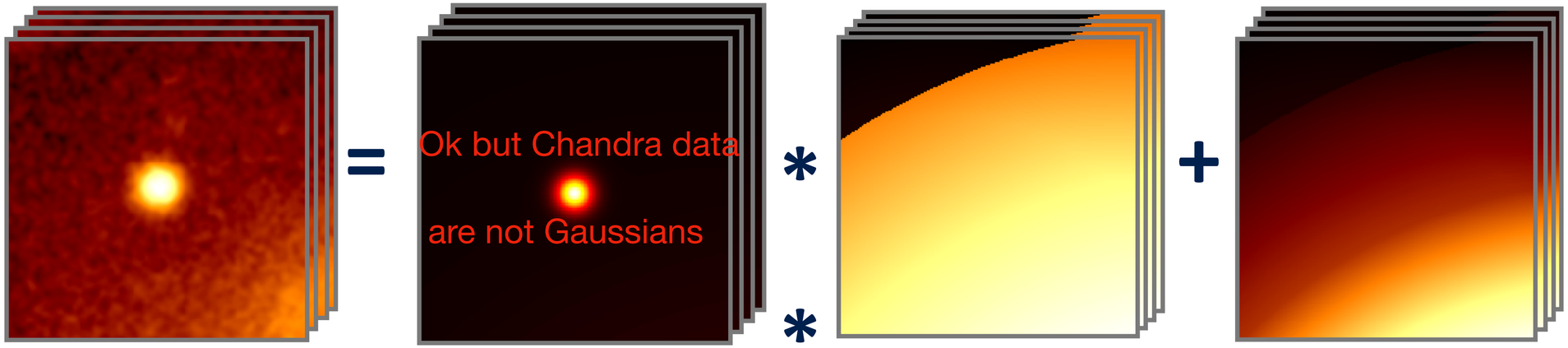

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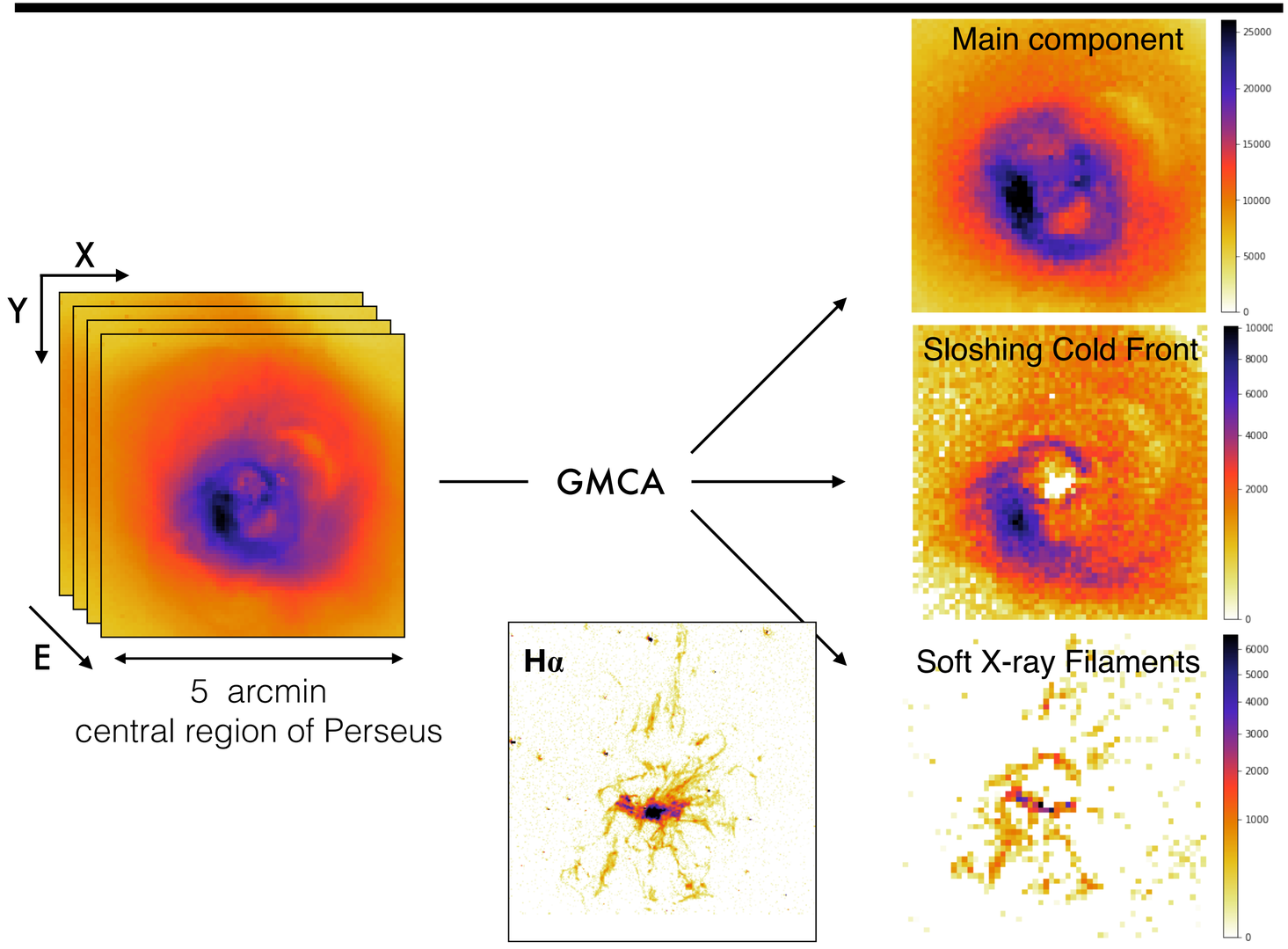
Galaxy cluster: Perseus 0.5-3 keV



Picquenot, 2025

First time imaging of X-ray filaments
Ability to obtain image+spectrum

A 3D analysis for classical fitting of each Perseus component

Counts cube (X,Y,E)

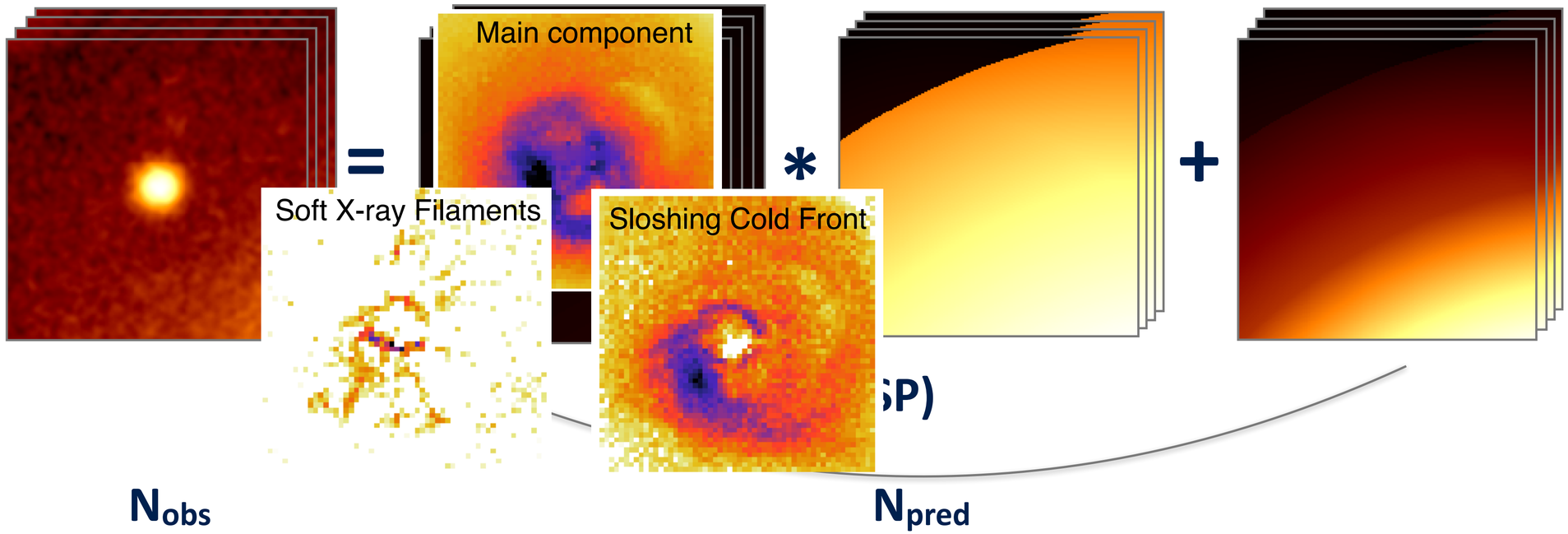
Parametric source model

Free params:

X, Y, Sigma, Norm, Γ

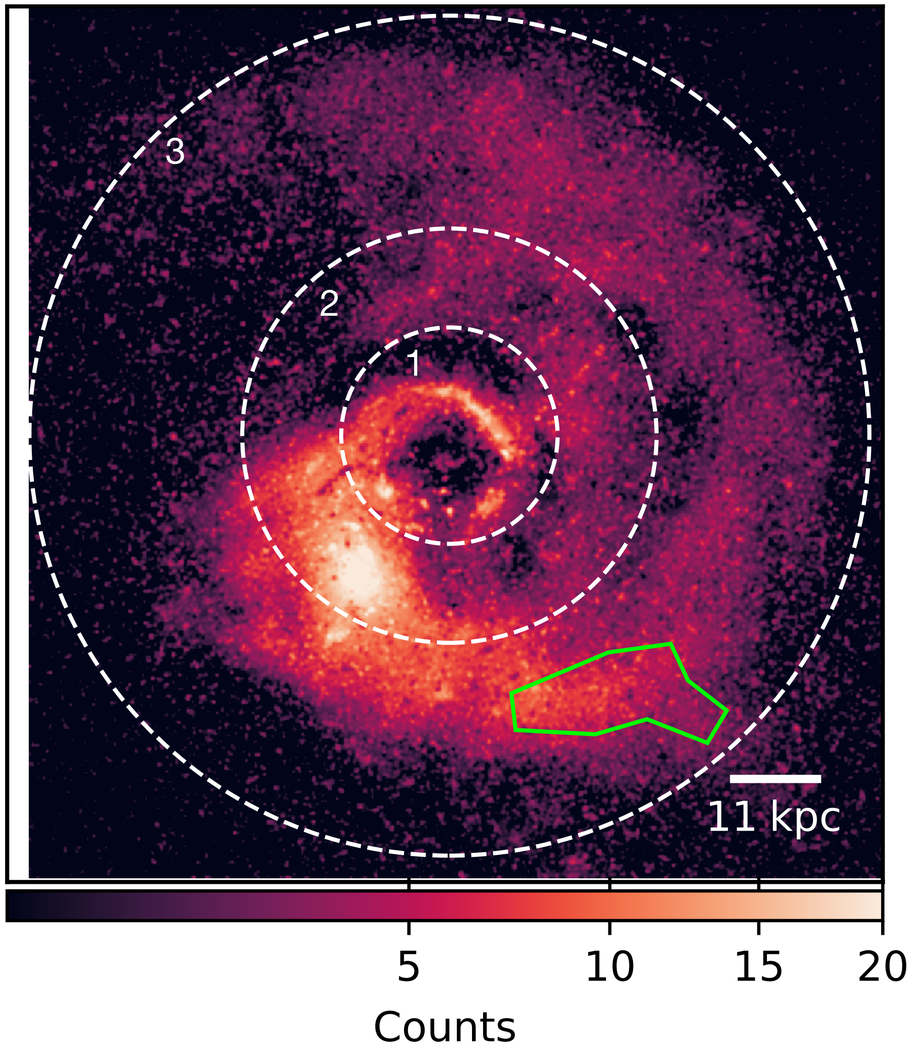
Exposure cube

Bkg cube



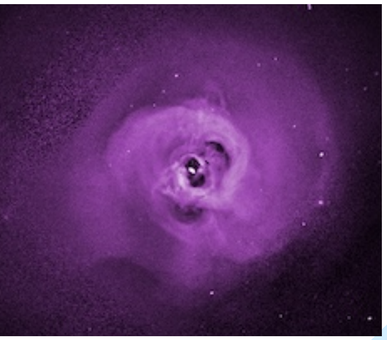
- **Minimization of -LogLikelihood(Npred, Nobs)**
- **Replacing spatial parametric model with GMCA spatial templates**

3d gammapy Perseus fit

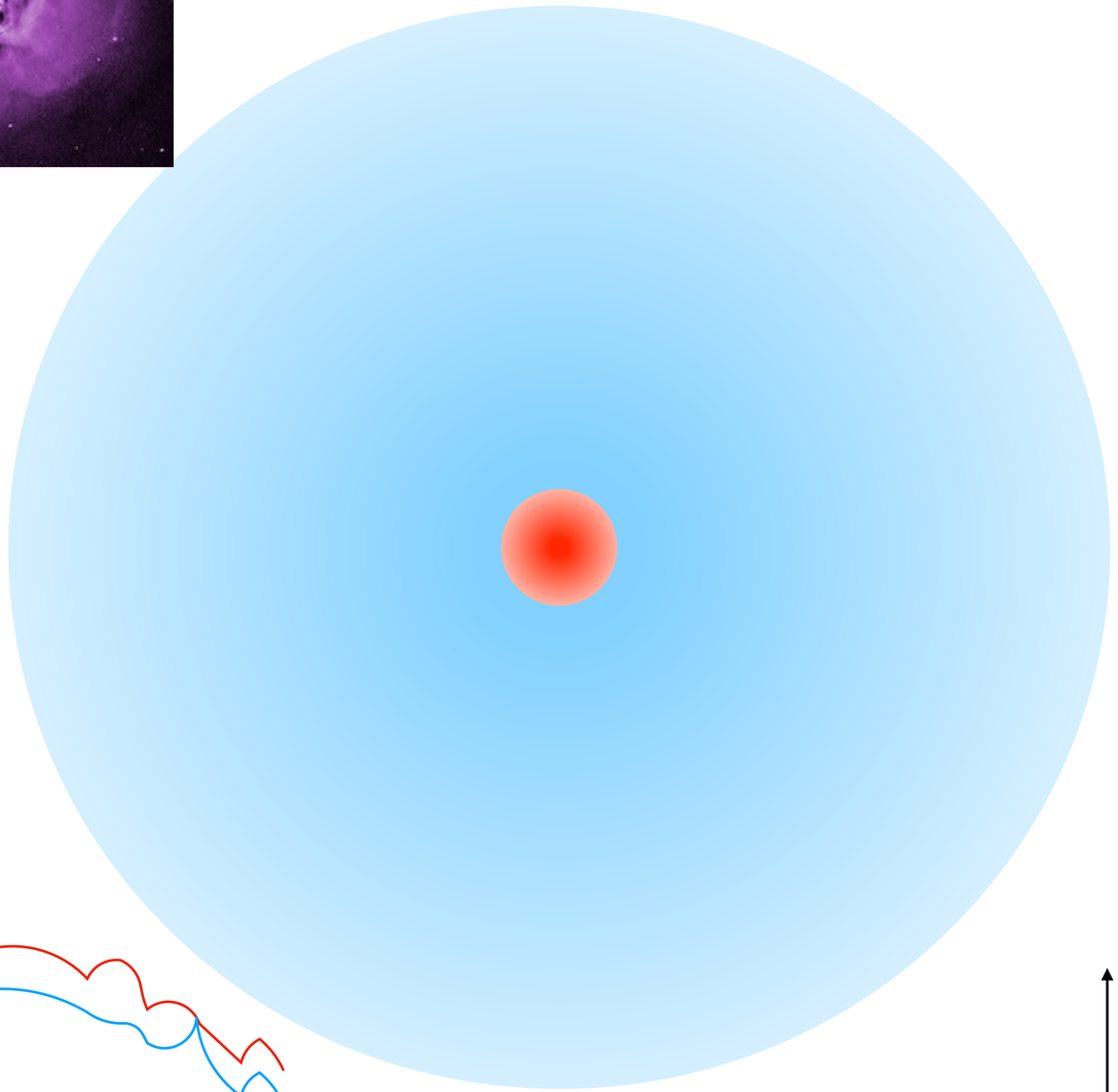


Picquenot, 2025

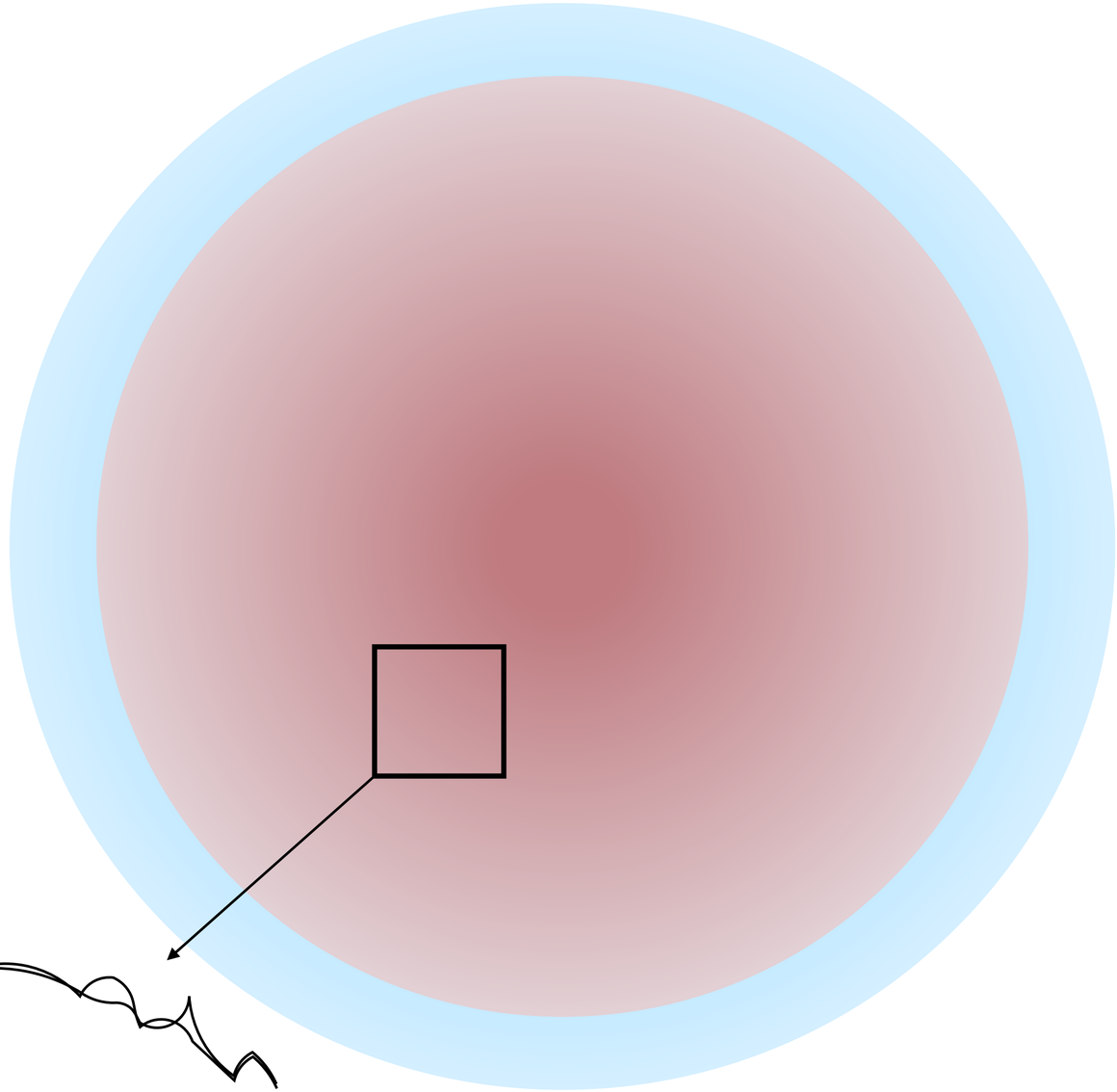
Component	Parameter	All regions	Region 1	Region 2	Region 3
Main	kT (keV)	3.18	3.30	3.07	3.22
	Abundance	0.77	0.84	0.67	0.75
	norm	1.68	1.61	1.68	1.64
Filaments	kT (keV)	0.76	0.80	0.78	0.70
	Abundance	0.77 (tied)	0.84 (tied)	0.67 (tied)	0.75 (tied)
	norm	0.001	0.002	0.0004	0.001
Sloshing spiral	kT (keV)	1.37	1.41	1.37	1.29
	Abundance	2.1	2.98	1.65	0.71
	norm	0.006	0.007	0.008	0.019

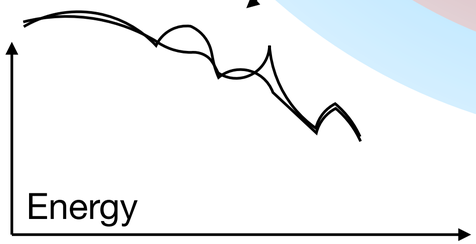


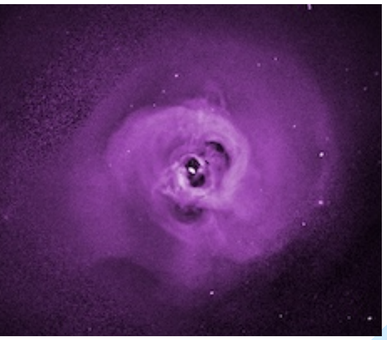
Simplified reality



Simplified XRISM obs







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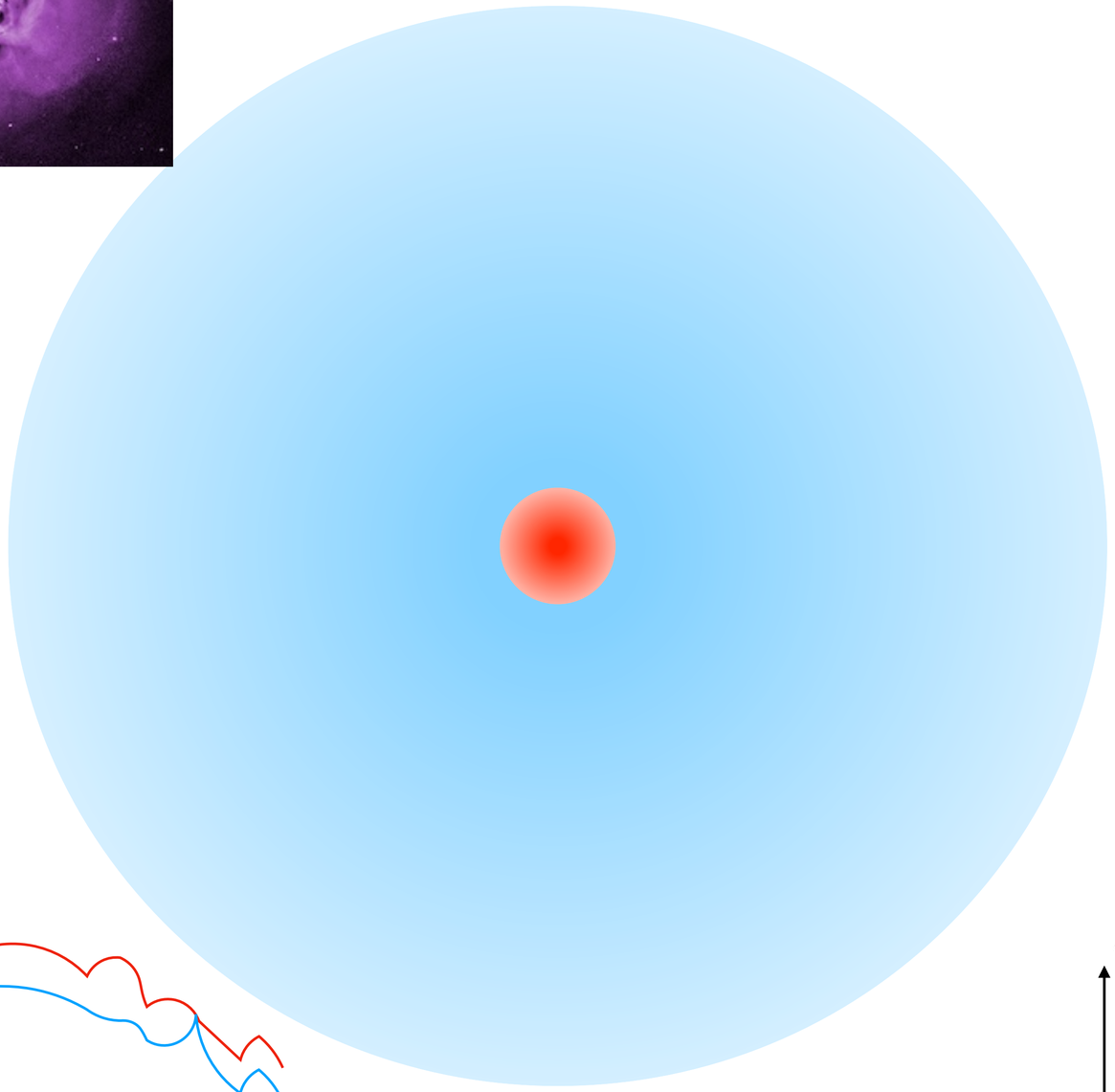
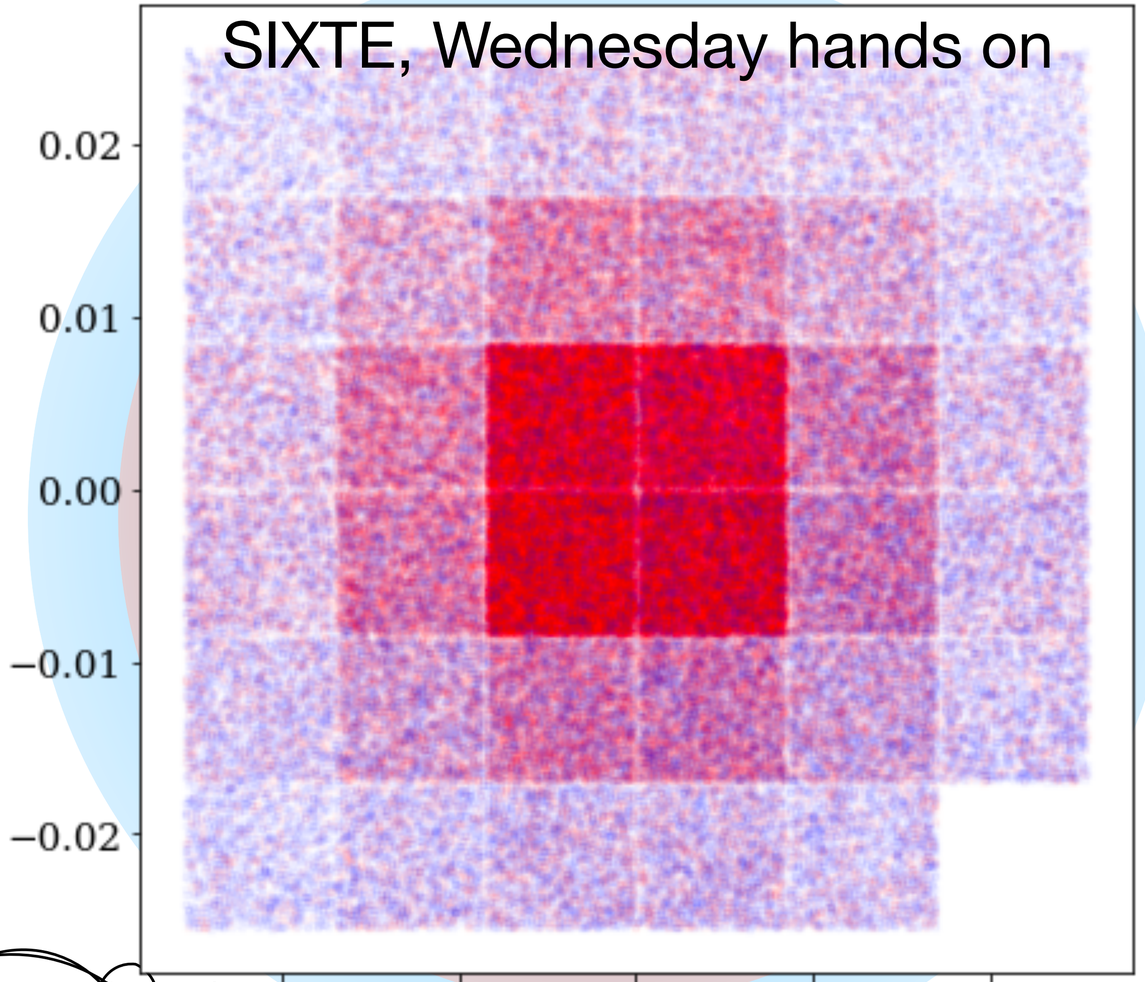
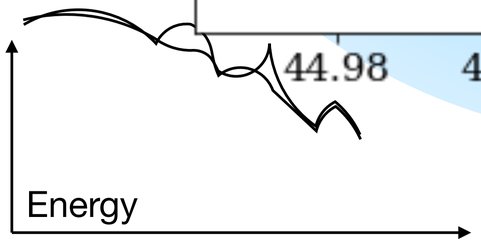
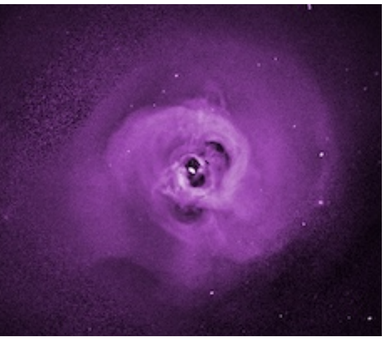


Simplified XRISM obs

SIXTE, Wednesday hands on







Simplified reality

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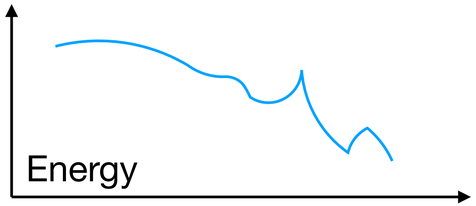
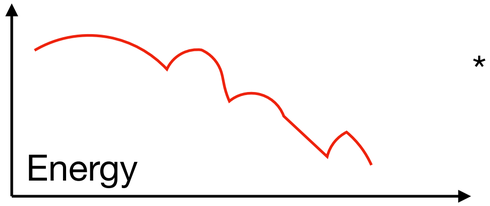
*



* (PSF,ARF,RMF)

*



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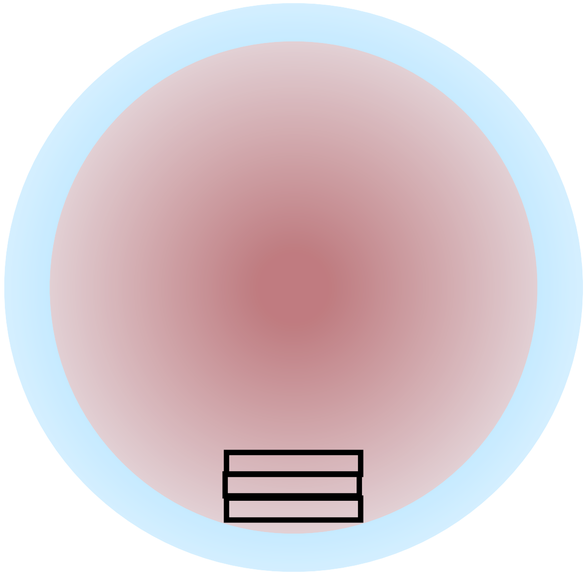
2D, or 3D
Spatial model

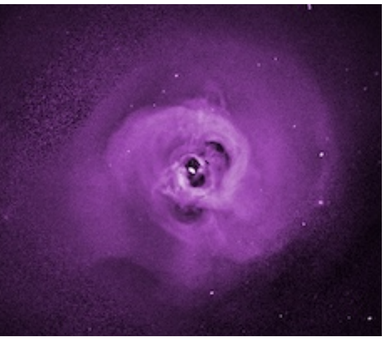
Spectral model

Vs



N_{pred} cube

N_{obs} cube



Simplified reality

Simplified XRISM obs

The retrieved spectrum for each region does not suffer from SSM

What you need in input :

- Observed Resolve Cube (6x6x1000's)
- 1 ARF (full enclosure), 1 RMF (assuming same over all pixels)
- 1 PSF (assuming does not vary spatially, can vary spectrally)
- Spectral model (apec, pow, etc) + spatial model (Chandra /XMM)

Output :

- The model cube (Npred) and the best fitted spectral parameters

2D, or 3D
Spatial model

N_{pred} cube

N_{obs} cube

Conclusions

- **Our X-ray data are 3D and new analysis methods should be explored to maximize the scientific return of the instrument**

- **3D (X,Y,E) are standard in gamma-ray analysis and allow to use the spatial information to disentangle the contribution from source confusion**

- **Can be used to :**
  - **1) provide better constraints for faint spectral component (using the spatial information)**
  - **2) separate the spectral signature from confused source (eg Resolve)**

- **For XRISM application can be slow due to large RMF but worth exploring**