SUSHI Science

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SUSHI

Semi-blind Unmixing with Sparsity for Hyperspectral Images

A tool for unmixing with spectral variations, using a learnt model

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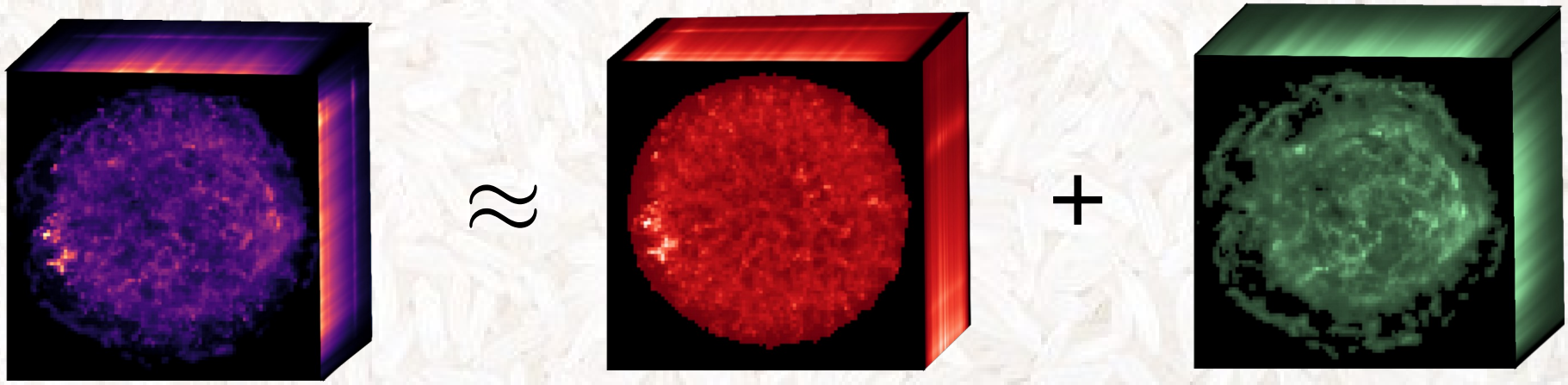
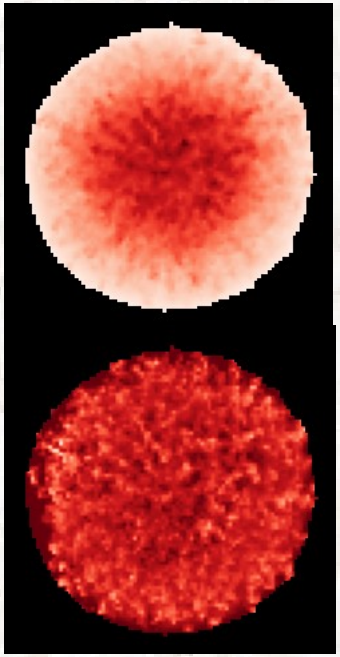
Aim 1: decompose images into spectral comp.

- Use Hyperspectral images (2 spatial 1 spectral dimension)
- Study extent and location of distinct spectral components
- E.g. separate image into thermal + non-thermal component



Aim 2: find spatial variation of spectral pars.

- How does the photon index vary within the image?
- Fitting spectrum independently in different pixels not ideal
- Want to use information of gradual trends in image
- But still be sensitive to small regions that deviate
- So need small pixel size, but that means limited statistics



Solution: SUSHI!

- Take an X-ray hyperspectral image, and define sets of spectral models.
- Compute log likelihood of spectral fit to all pixels
- Minimise log likelihood + a spatial regularisation term

$$\min_{\theta, A \geq 0} \text{Cost}\left(X_{data} \middle|_c^{n_c} A_c \times M_c(\theta_c)\right) + \rho_c^{n_c} \phi(\theta_c)$$

log likelihood regularization term

- Spatial regularisation is the magic ingredient
- Penalises large deviations from one pixel to the next, unless strongly preferred

SUSHI: Strengths and Weaknesses

Pros:

- Great at separating image into maps of distinct spectra
- Finds small and large-scale trends in spectral parameters
- Reliable at high resolution
- Fast (runs on jax)
- More accurate than comparable methods

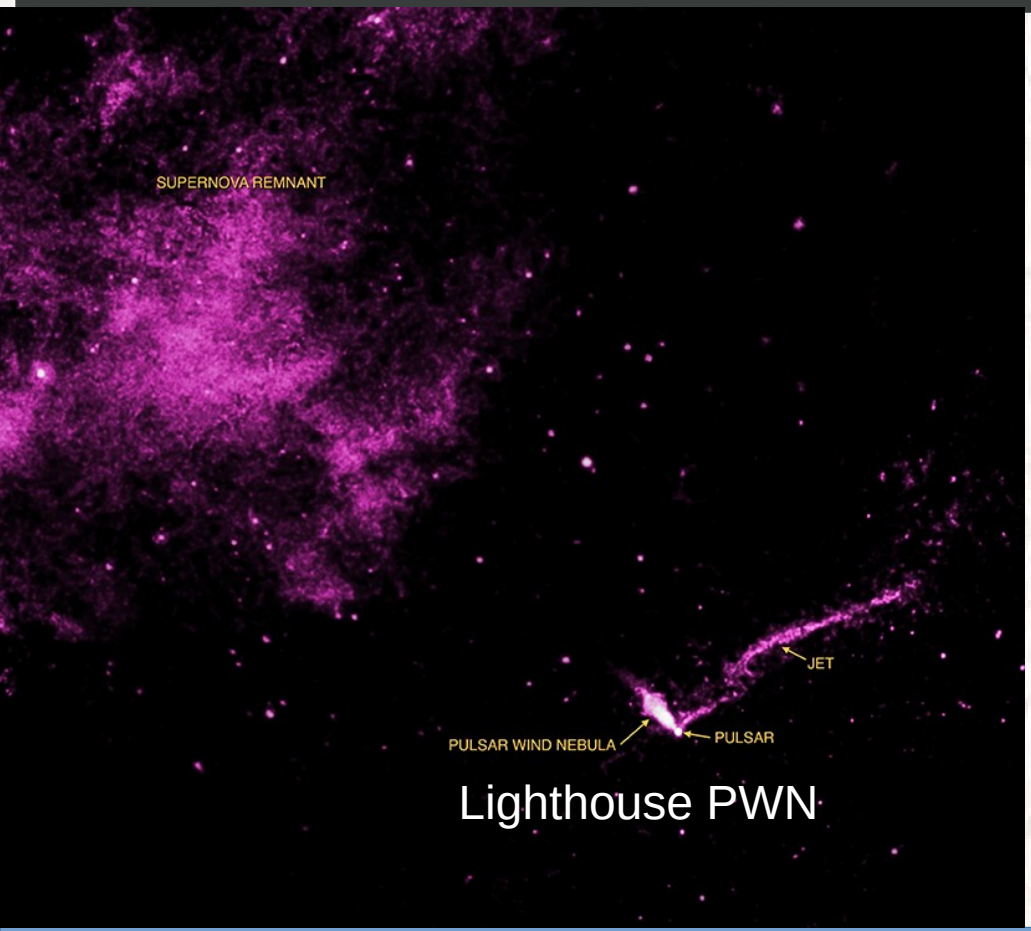
Cons:

- Does not provide errors
- Can be biased by input parameter values and fall into local minima
- Uses a single arf and bkg
- Needs reliable surrogate model
- (Can produce unphysical values, No tieing parameters together) *in progress*

SUSHI: Use in Science

- Cleanly separate images of different spectral components
- Discover trends of spectral parameters within image
- Find regions of interest for further analysis
- Avoid fitting average of a varying spectral parameter
- Create pretty pictures
- Verify trends and evaluate significance with other tools

Lighthouse PWN and Filament



Lighthouse PWN

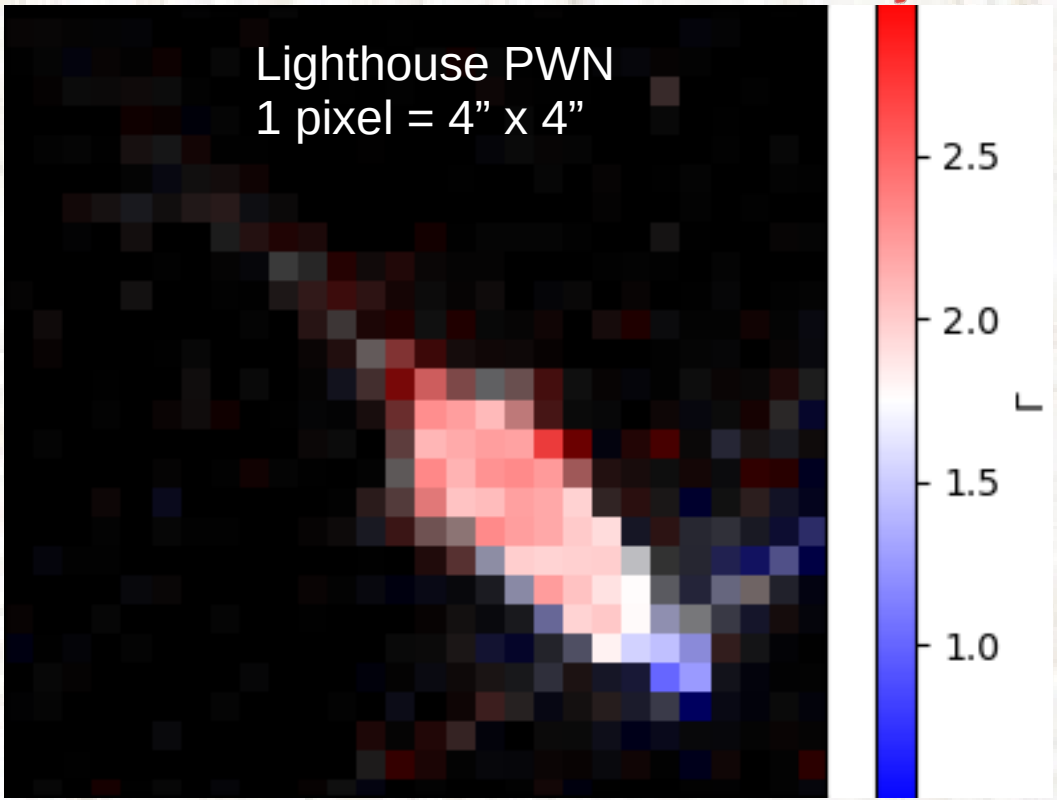
Pulsar Wind Nebula

- Plasma accelerated by magnetic field of pulsar
- Interact with ISM, stream behind pulsar
- Often in or near SNR
- Size ~ pc
- Synchrotron radiation

Lighthouse PWN and Filament

Pulsar Wind Nebula

- See increasing Γ with distance – measure of particles losing energy
- See asymmetry (top right higher Γ)
- Plot shows Γ in colour, transparency indicates fewer counts



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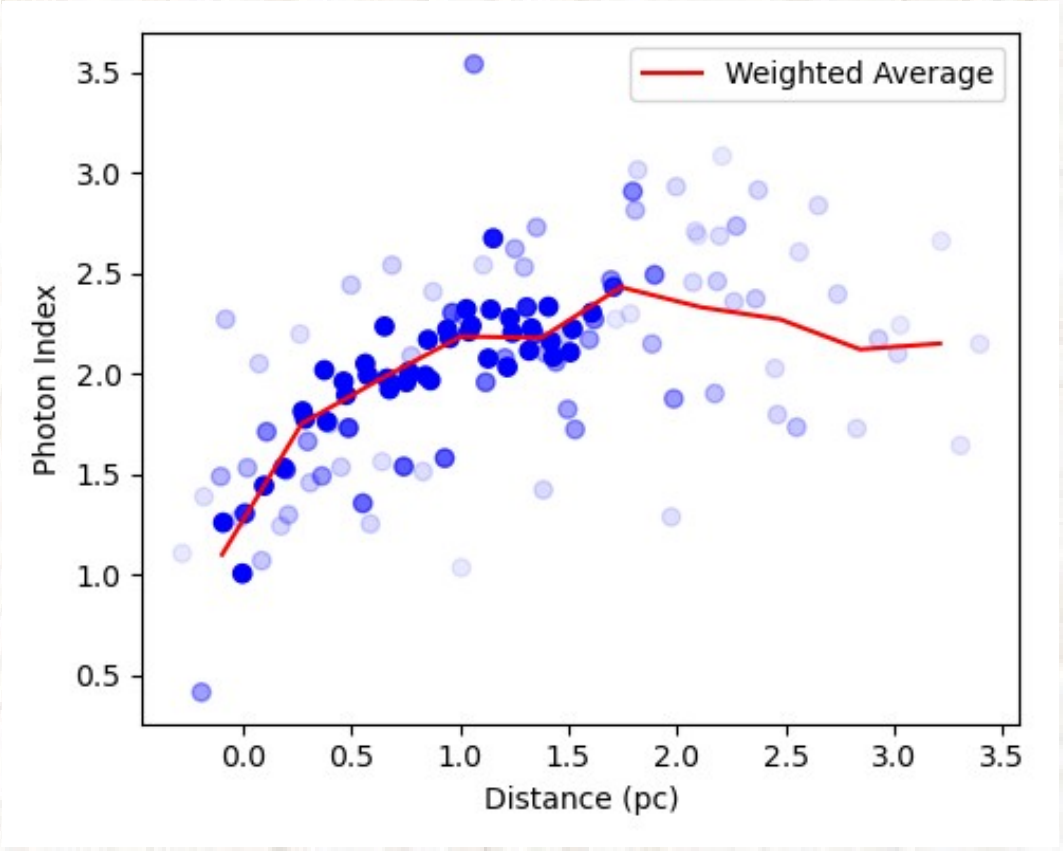

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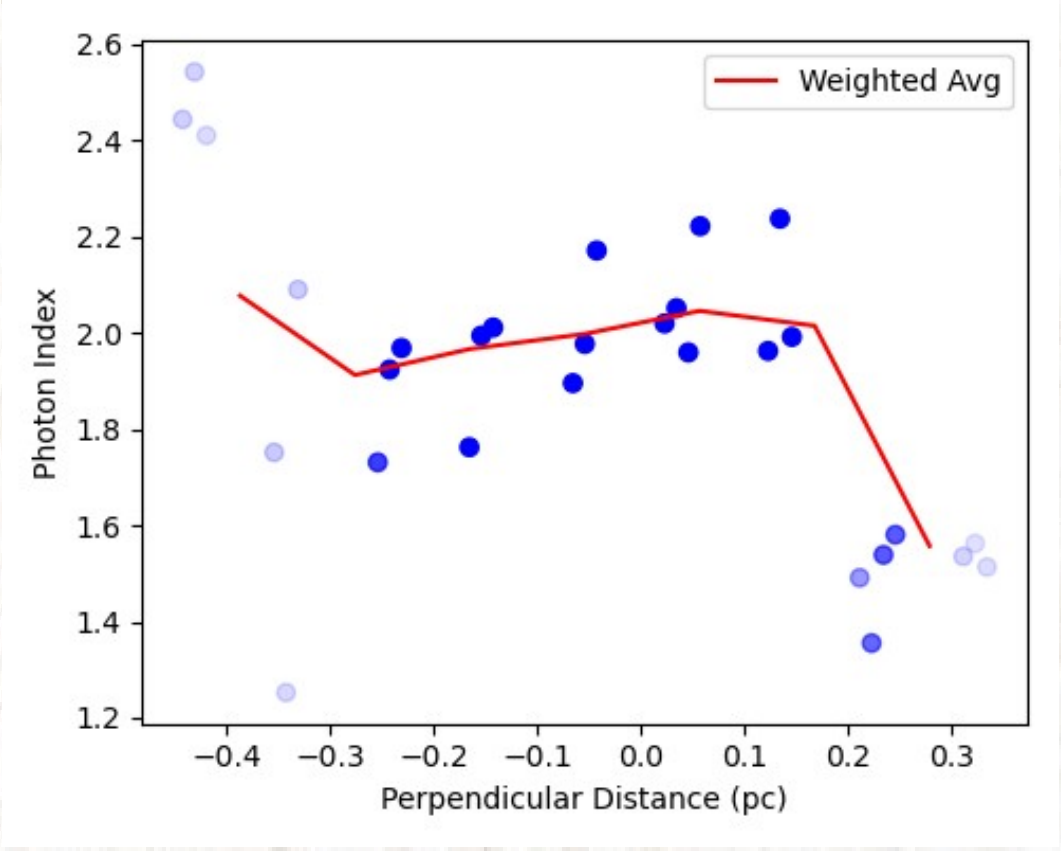

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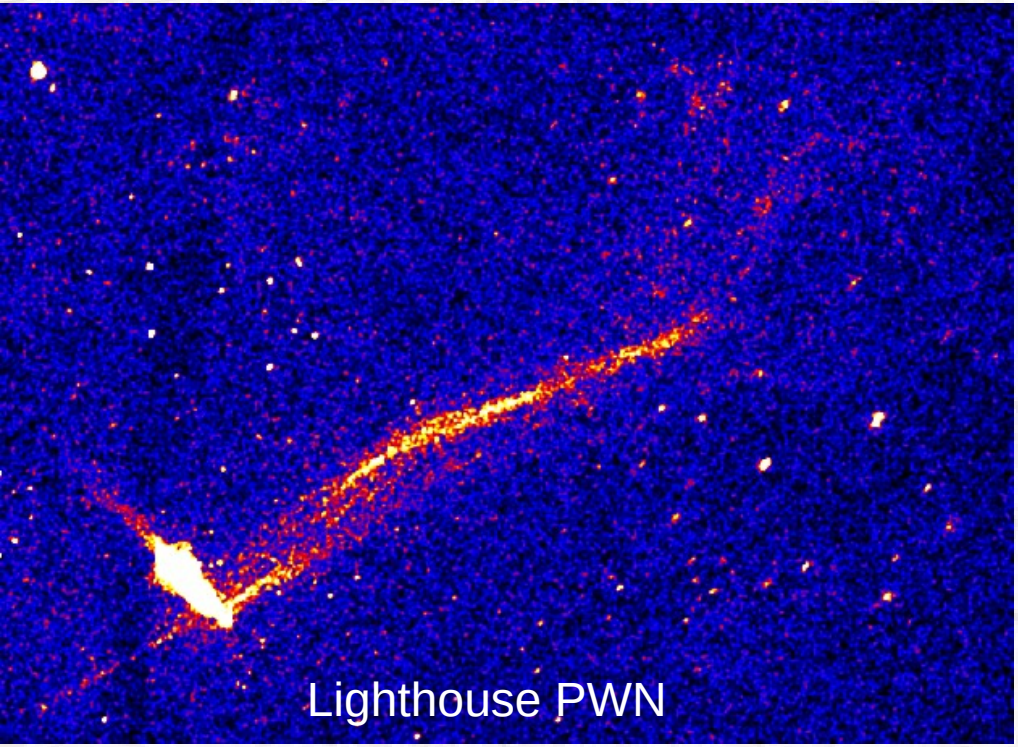


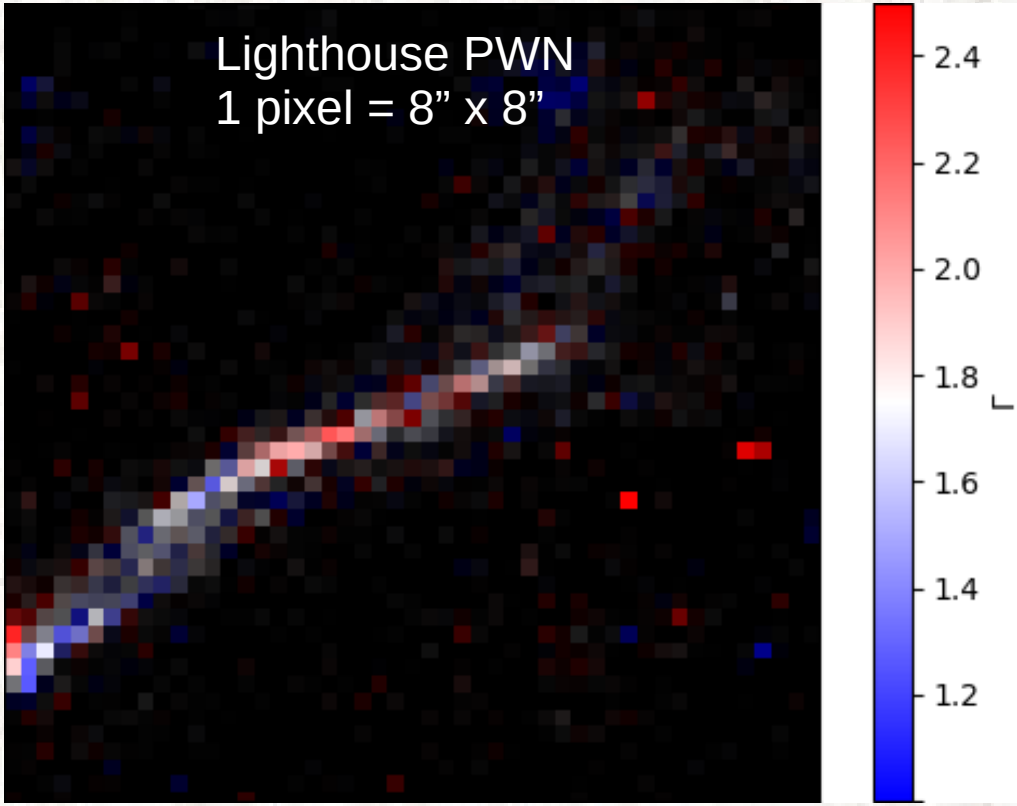
PWN Filament (Jet)

- Only seen in a few PWN
- Size ~ 10 pc
- Electrons / positrons streaming along magnetic field lines ?
- Synchrotron radiation

Lighthouse PWN and Filament

PWN Filament (Jet)

- Γ increases with distance, (then decreases)
- Close to pulsar, brightest part hardest
- Far away, Γ increases in direction of motion



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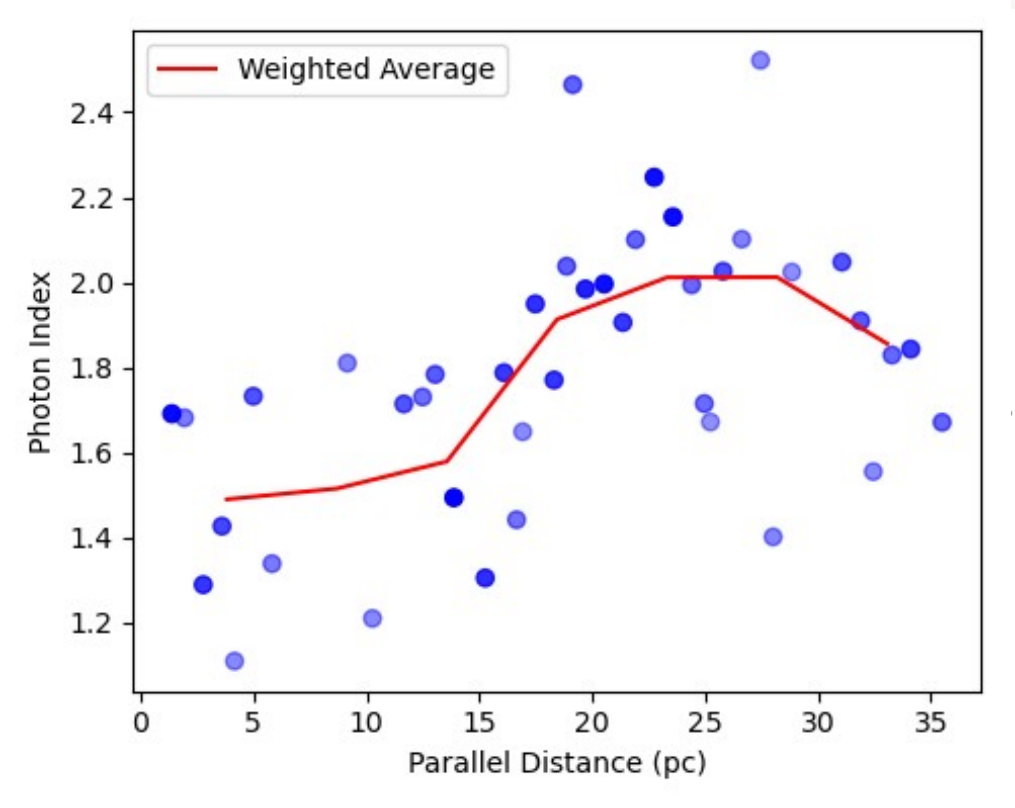

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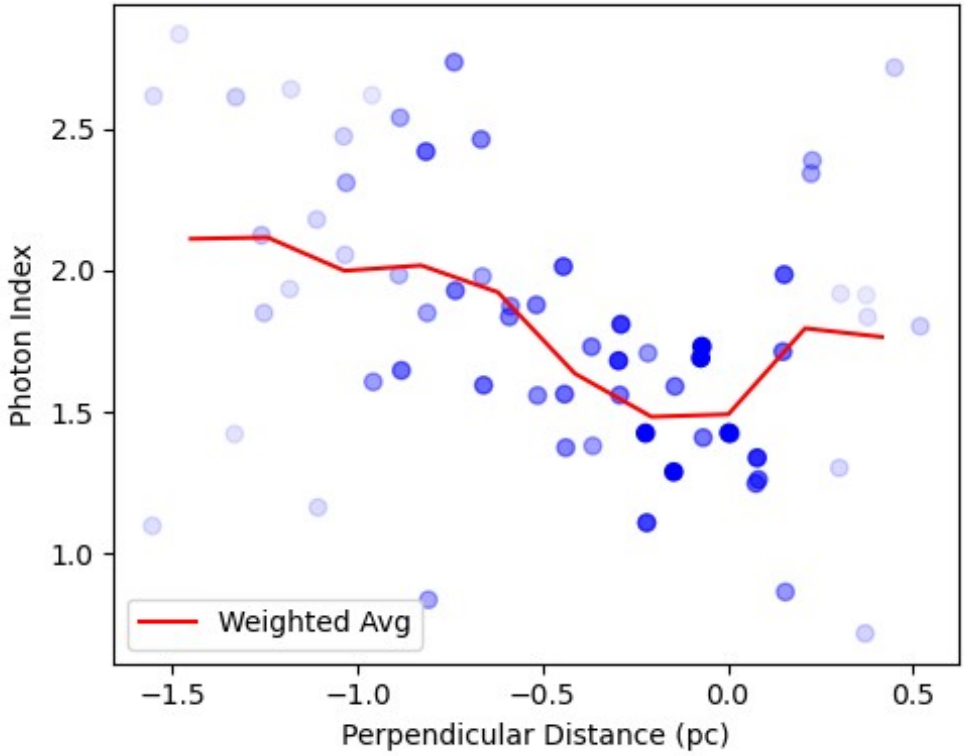
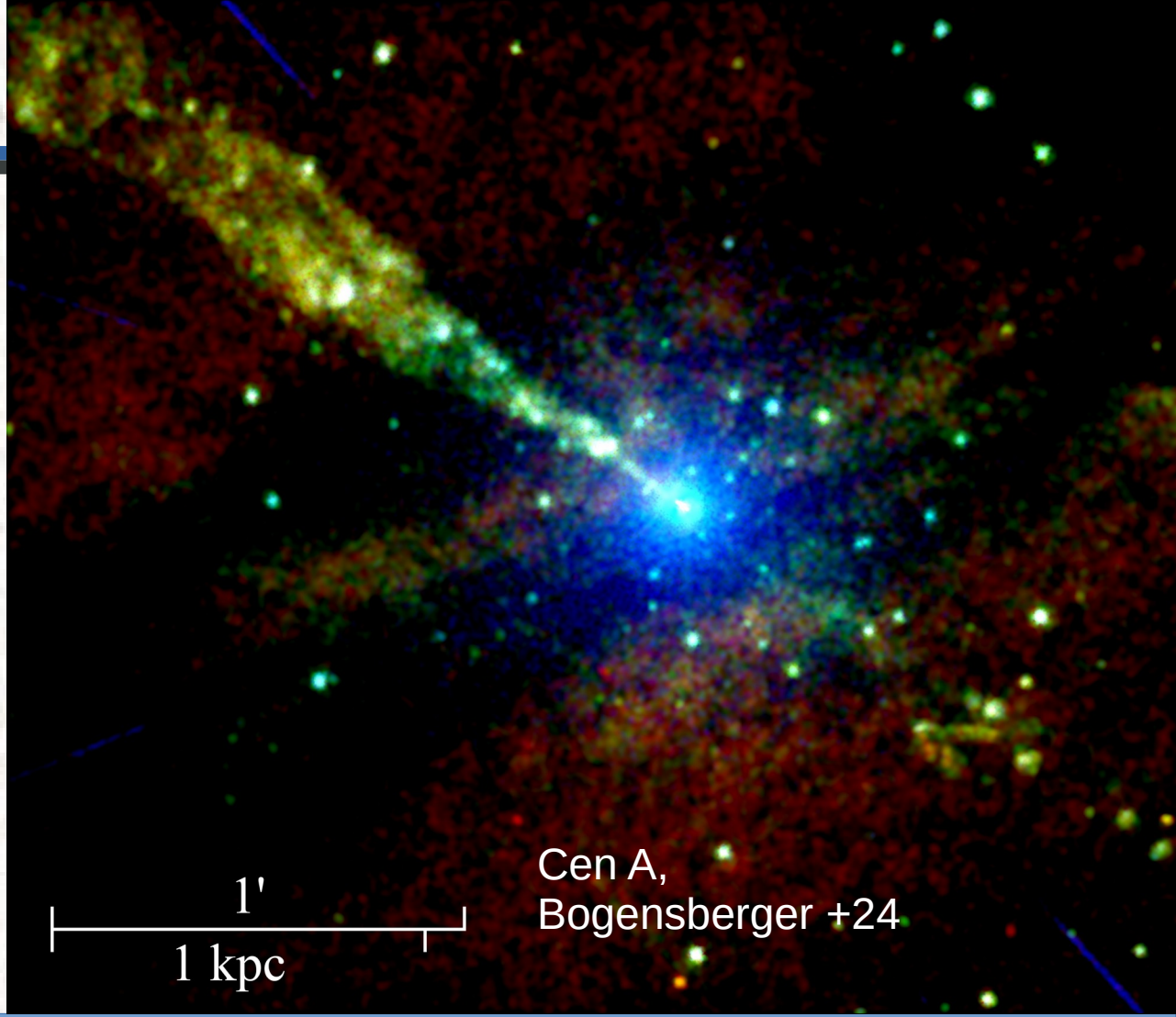


Centaurus A

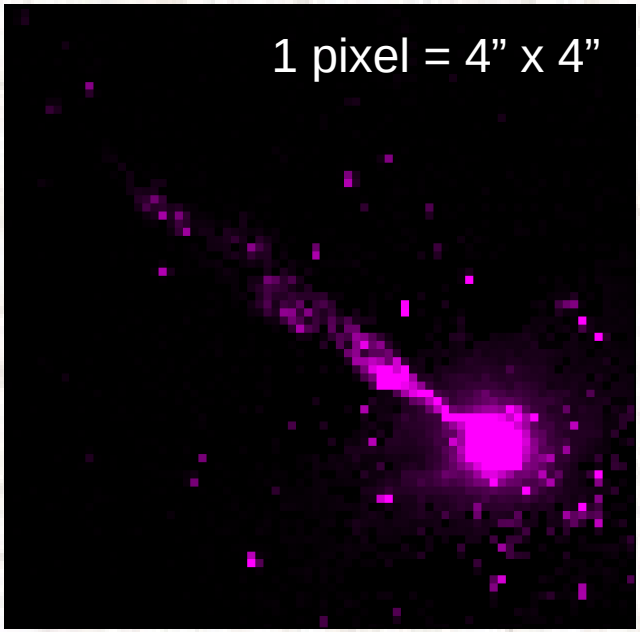
AGN Jet

- Accretion onto supermassive black hole launches relativistic plasma jet
- Size ~ kpc
- Inverse Compton & Synchrotron

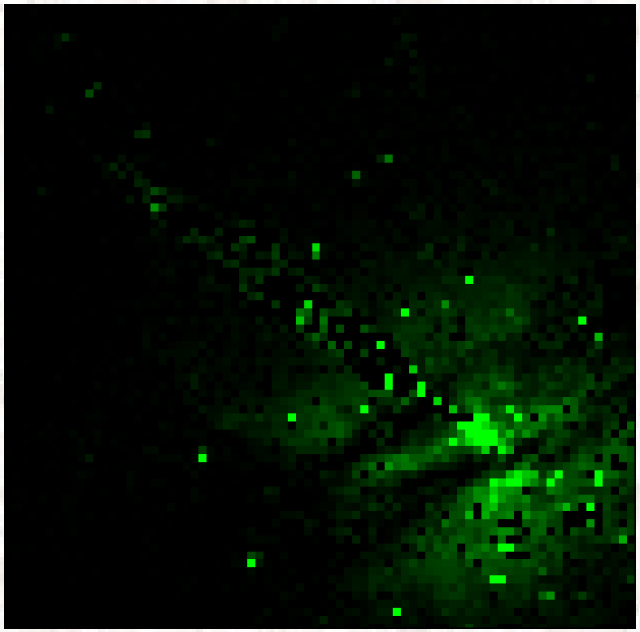


Centaurus A

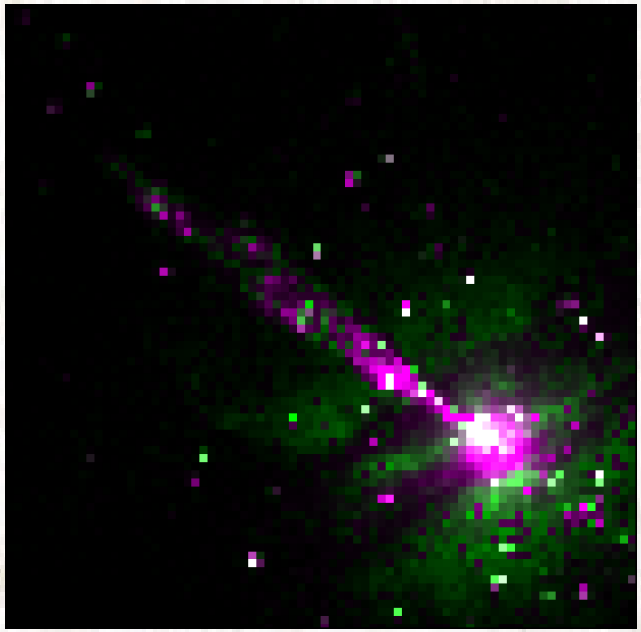
Powerlaw



Apec



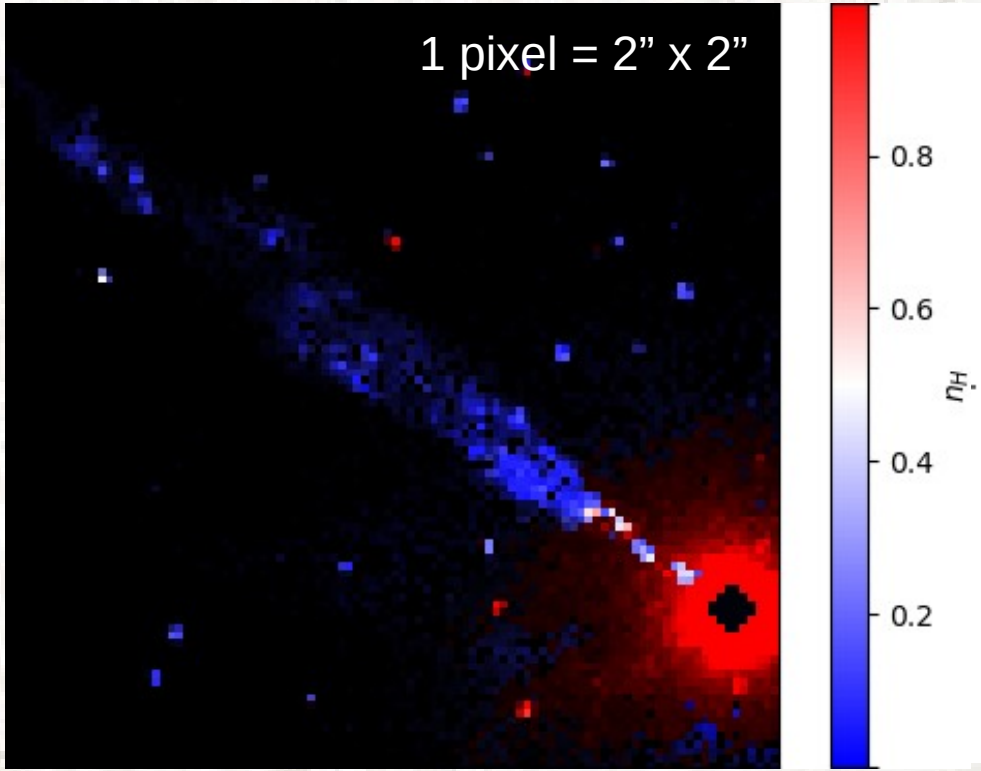
Combined



Centaurus A

AGN Jet

- Γ increases with distance, then plateaus
- Local Γ trend within smaller regions of jet
- Distinguish jet from other sources
- New way to constrain jet inclination and speed?



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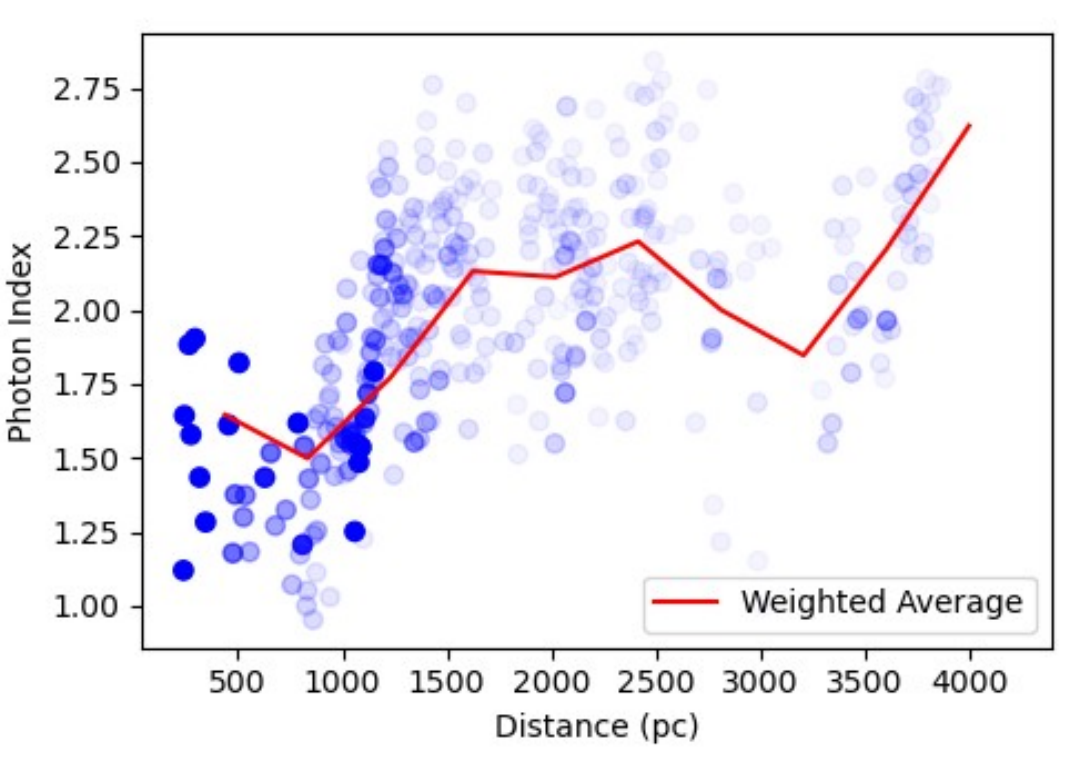

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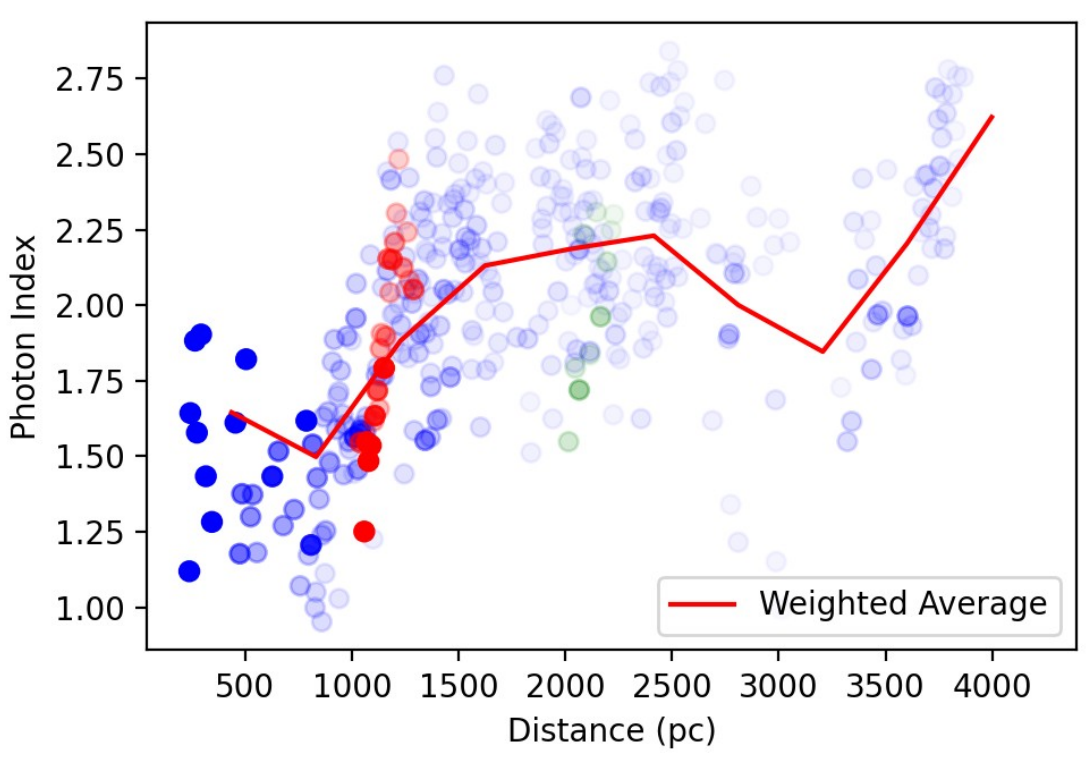
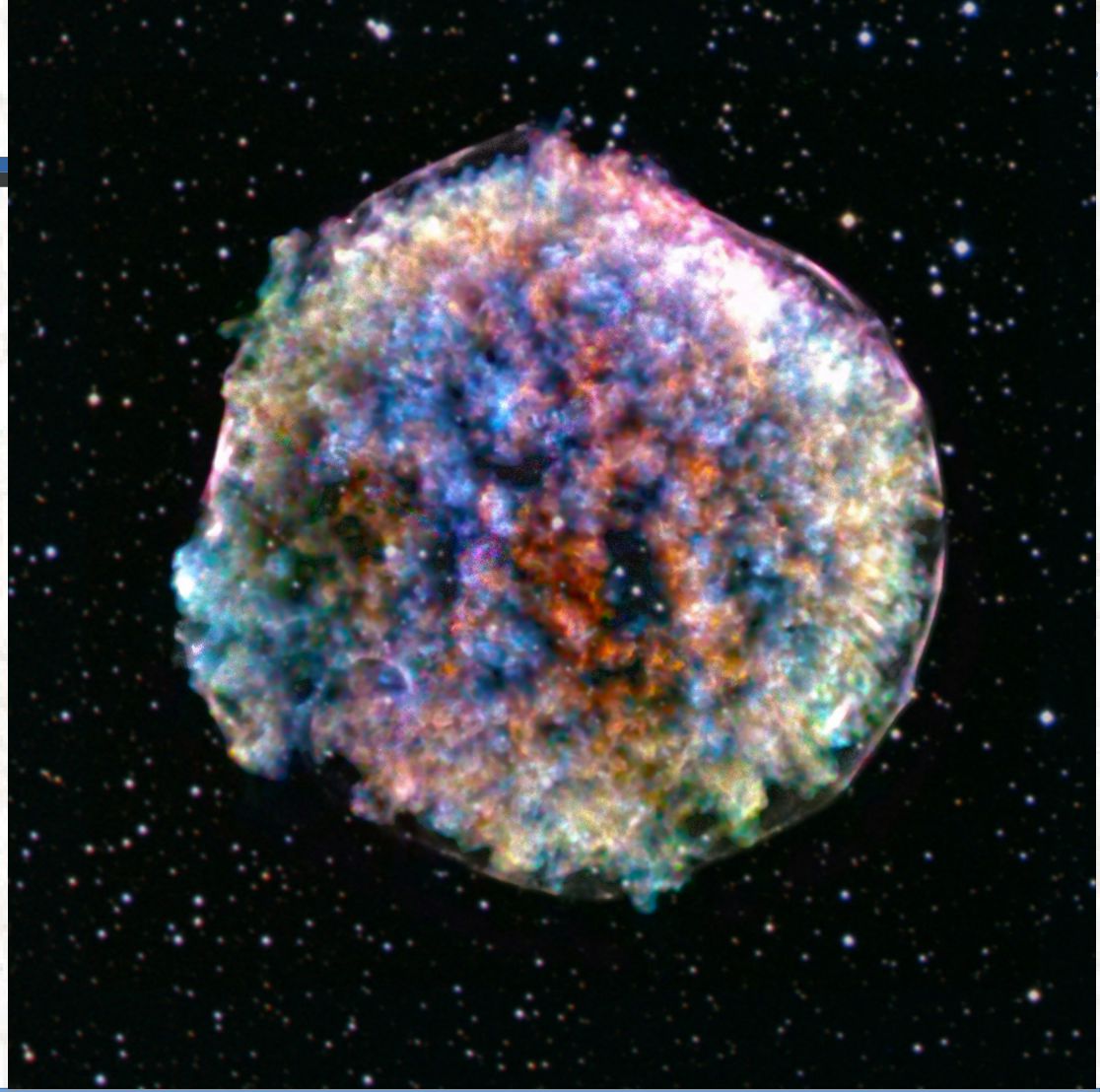


Tycho SNR

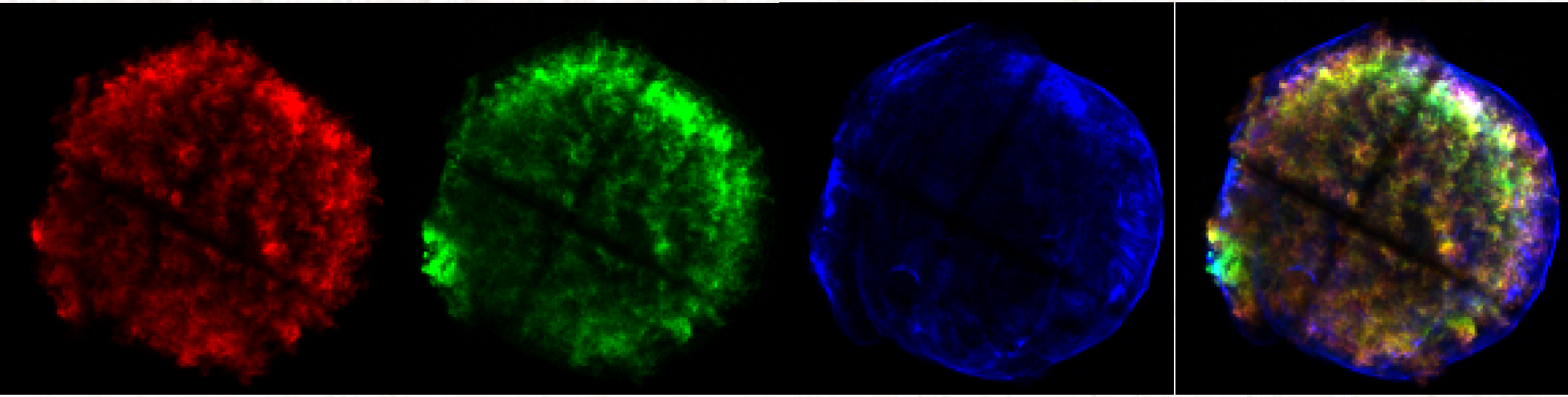
Supernova remnant

- Synchrotron radiation at forward shock
- Thermal component with many strong lines
- Challenging spectrum, but lots of data
- Size ~10 pc



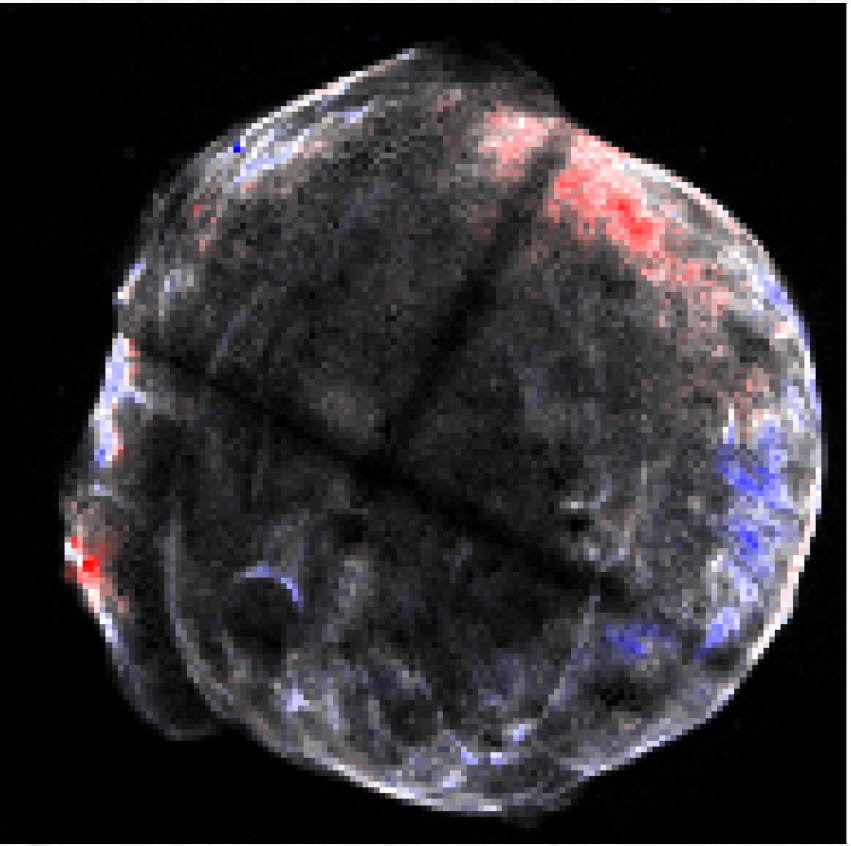
Tycho SNR

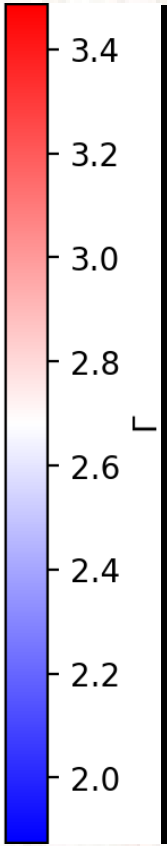
VNEI1 VNEI2 Powerlaw Combined

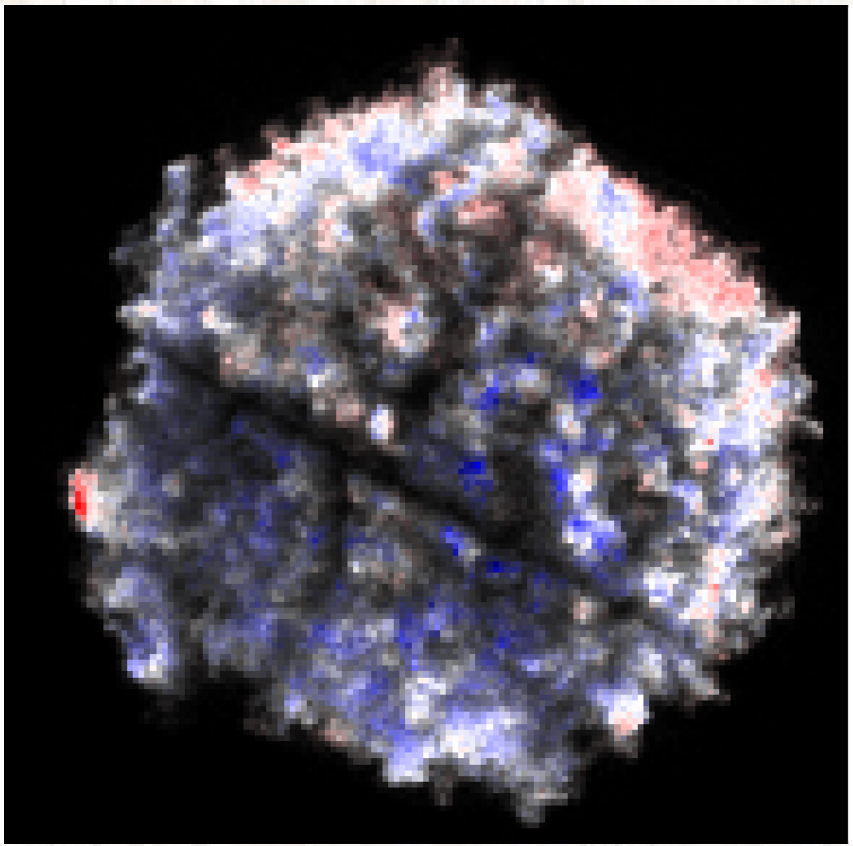


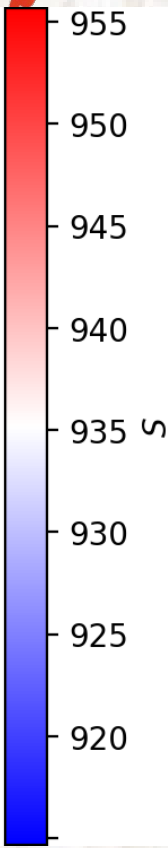
1 pixel = 4” x 4”

Tycho SNR









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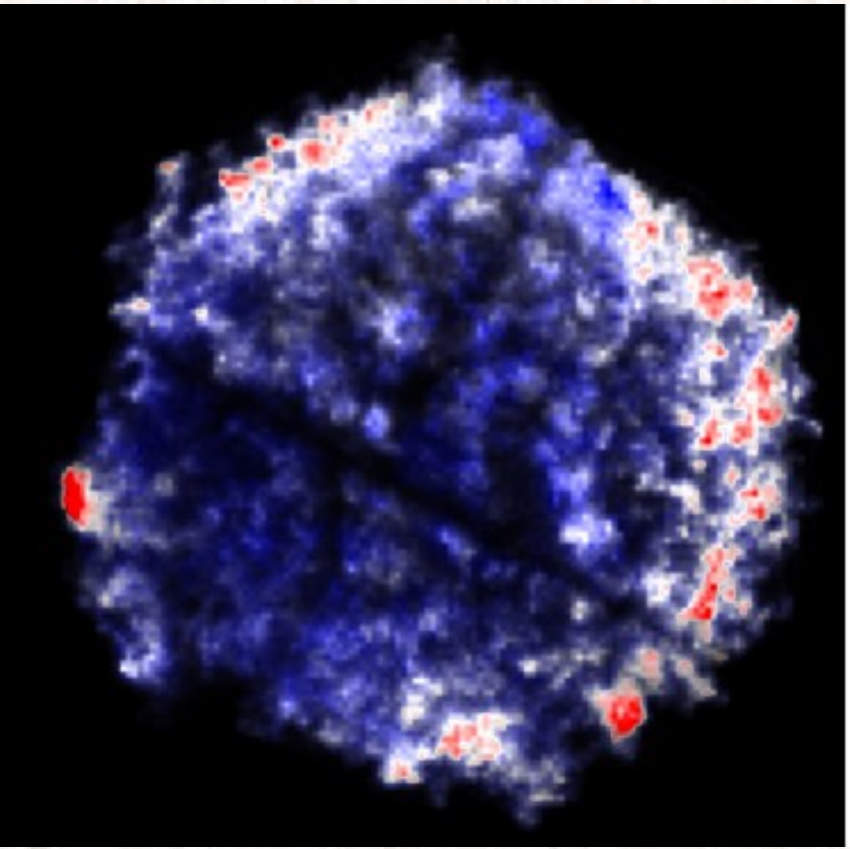
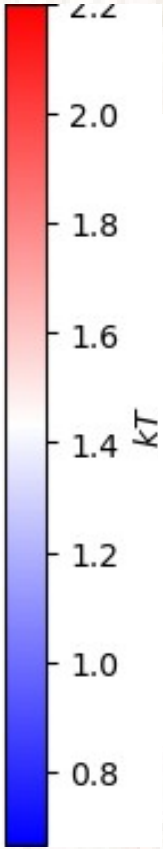
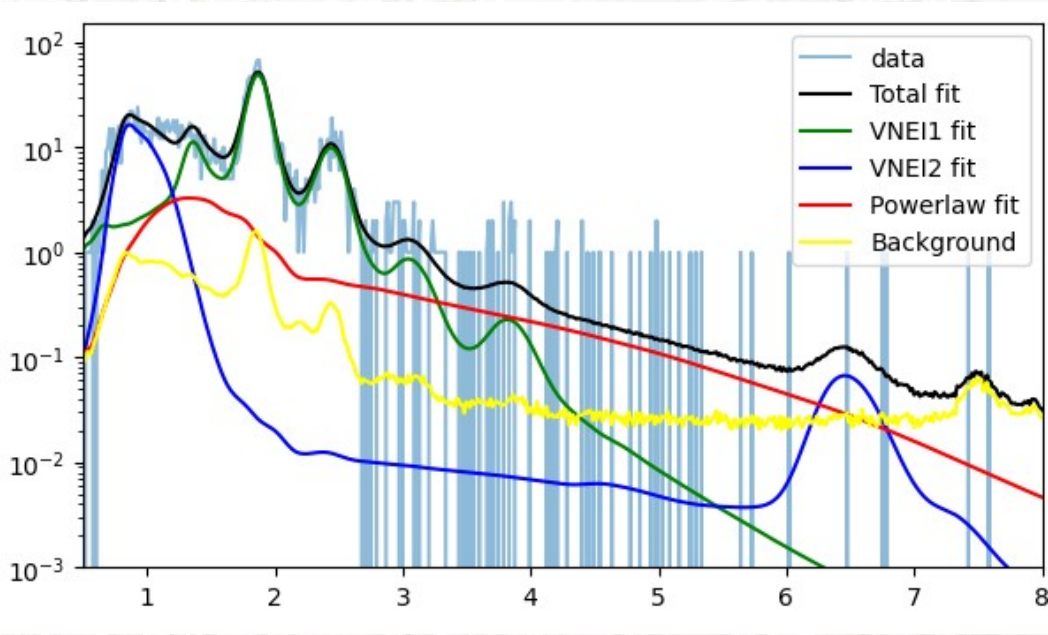



2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
kT


data
Total fit
VNEI1 fit
VNEI2 fit
Powerlaw fit
Background
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8

SUSHI Summary:

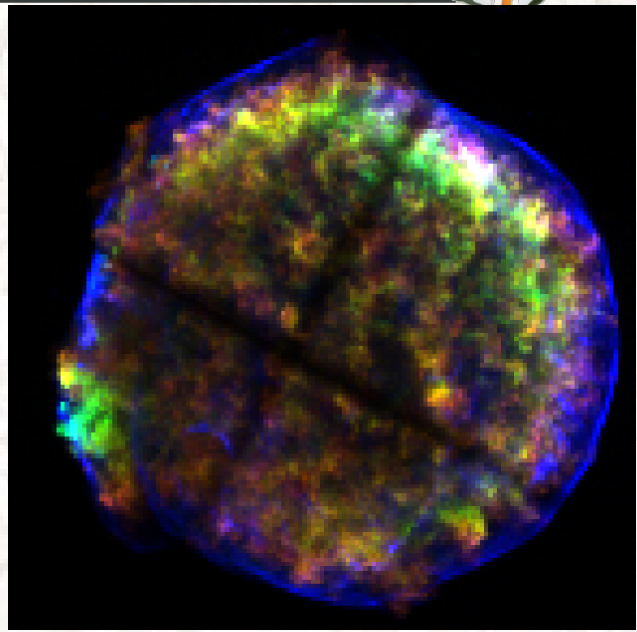
- SUSHI CAN identify interesting & unexpected trends
- SUSHI CAN tell you where to look for interesting science further analysis
- SUSHI MAY indicate a more accurate distribution of parameter values than other methods
- SUSHI DOES NOT find the best fit in every pixel (and that is a good thing!)
- SUSHI DOES NOT tell you the significance of a trend (use other tools to verify)

Challenge: Think about what SUSHI could do for your research, and for your favourite source

Thank you for your attention!

Summary:

- SUSHI is a powerful new tool to decompose hyperspectral images into images of component spectra, and determine more accurate parameter maps
- It identifies trends in the data, and tells us where to look for new science
- Applied to archival Chandra data of the Lighthouse PWN, Cen A and Tycho, it has already delivered exciting new science



https://github.com/JMLascar/SUSHI
Lascar J., Bobin J., Acero, F., 2024 A&A, 686, 259