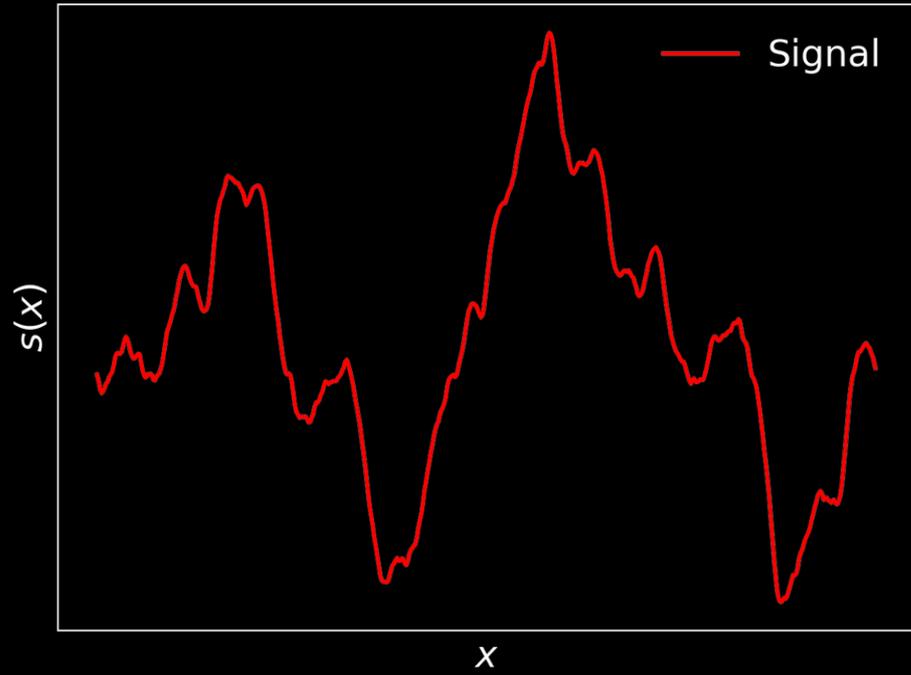


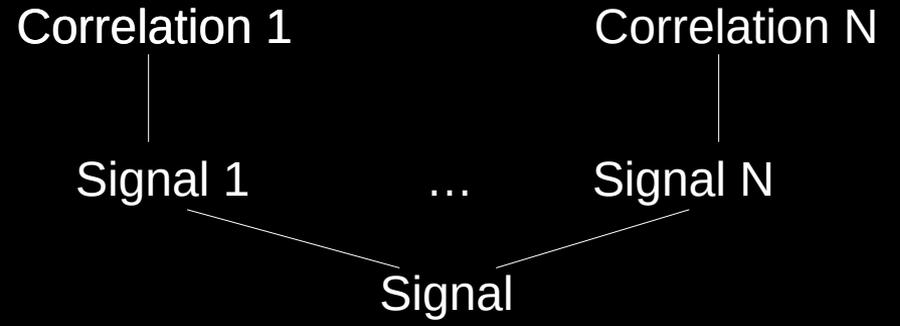
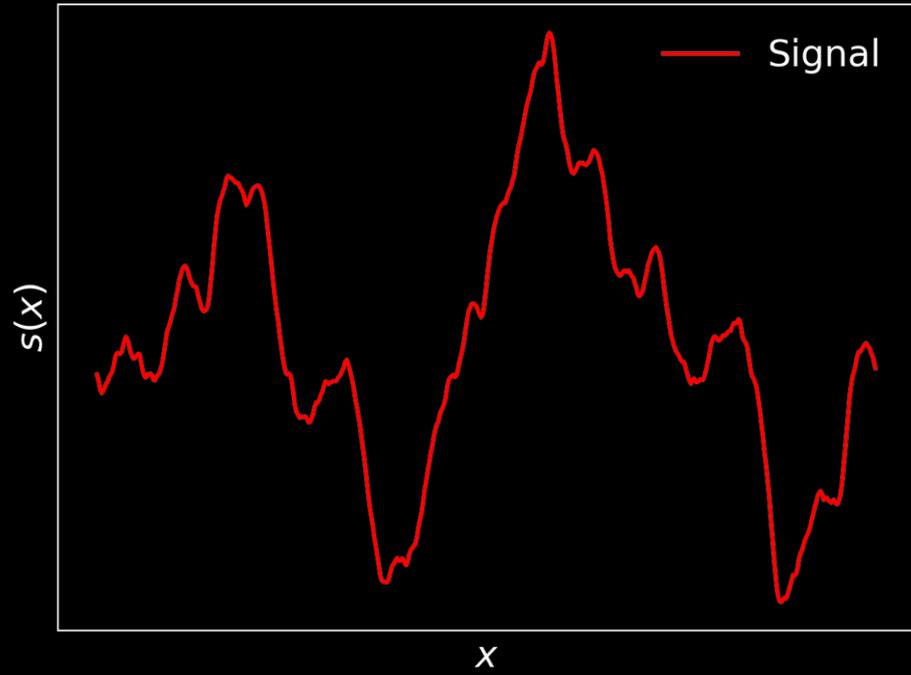
Bayesian Imaging of the Spatio-Spectral X-ray Sky

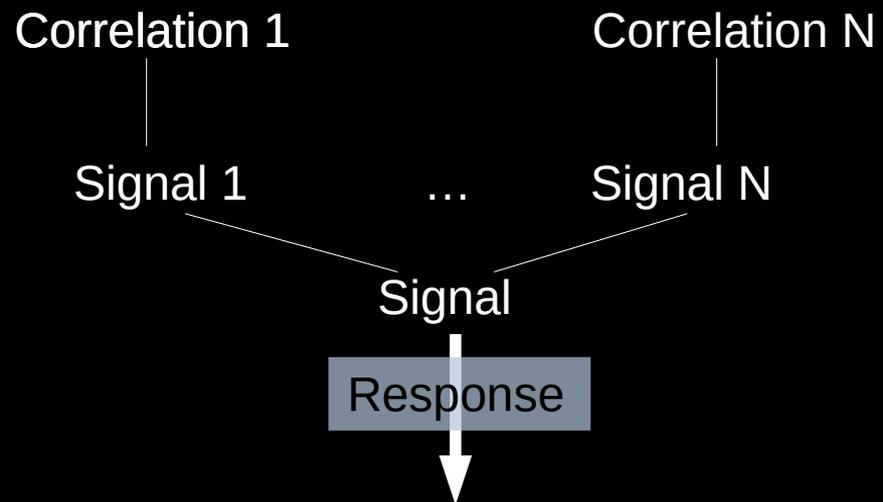
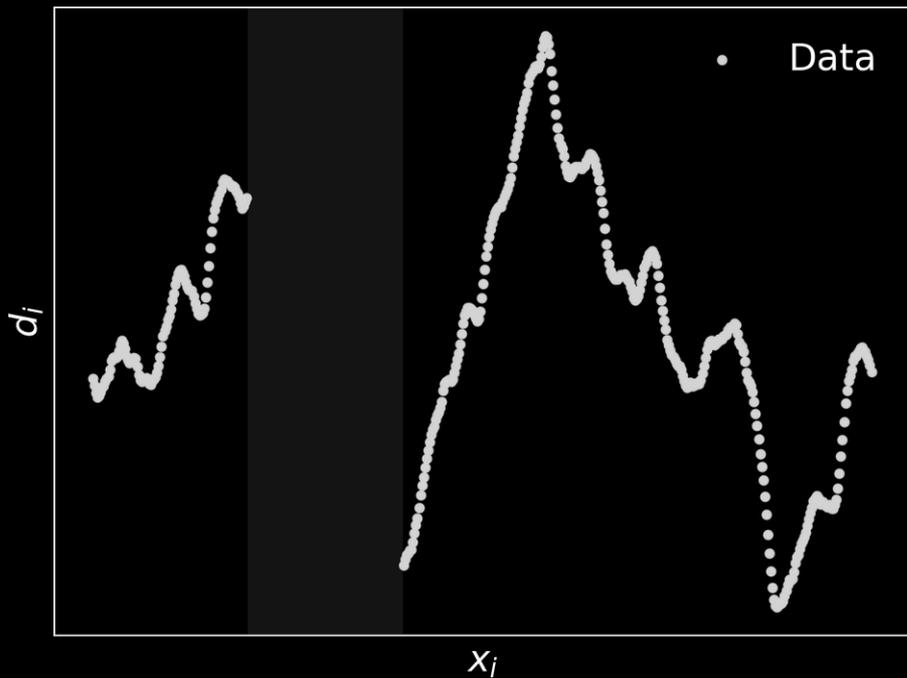
M. Westerkamp, V. Eberle, M. Guardiani, P. Frank, T. Enßlin

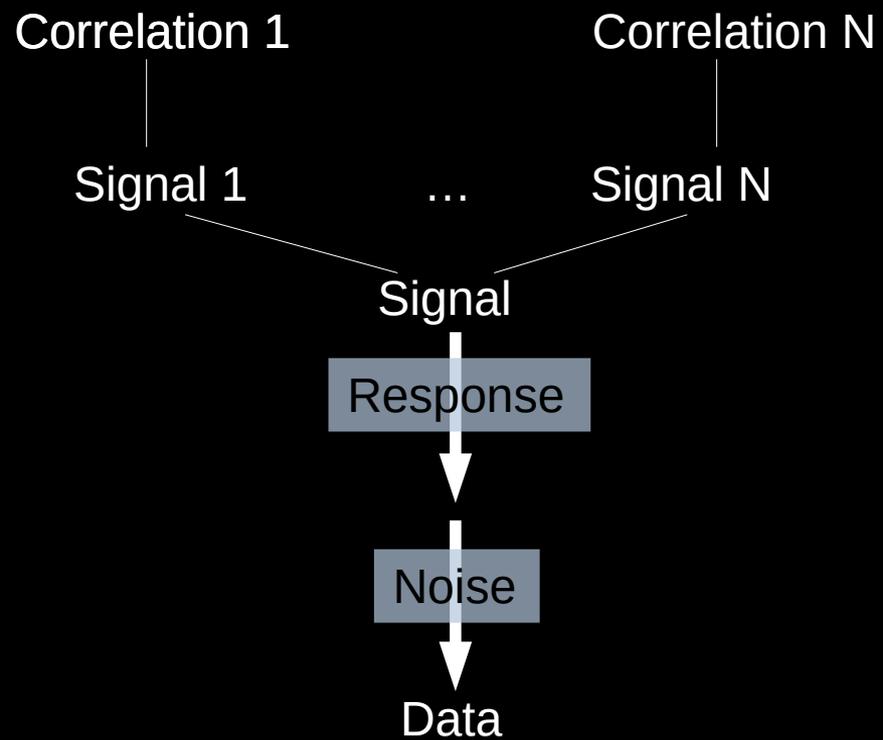
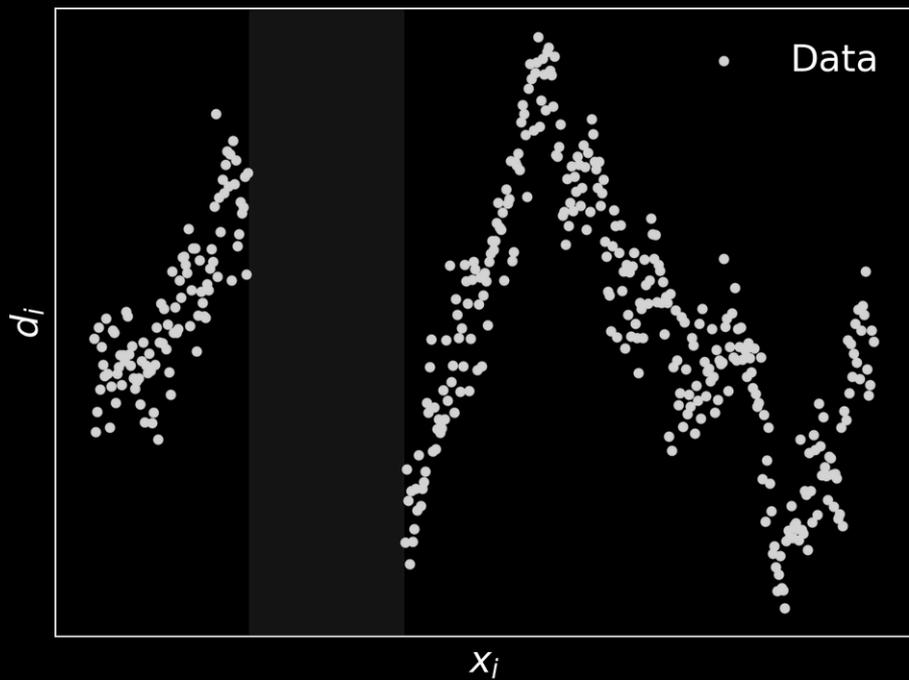
ML4Astro 2024, Catania

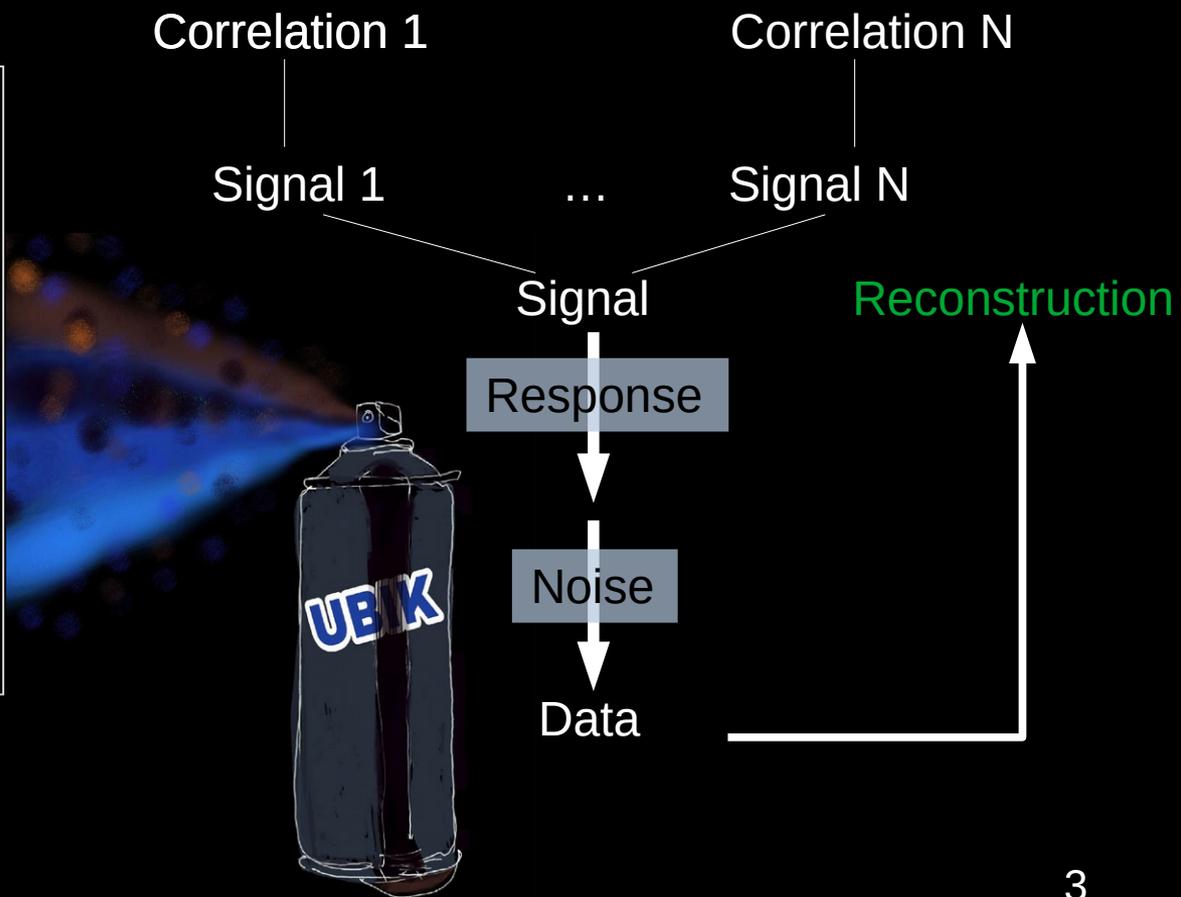
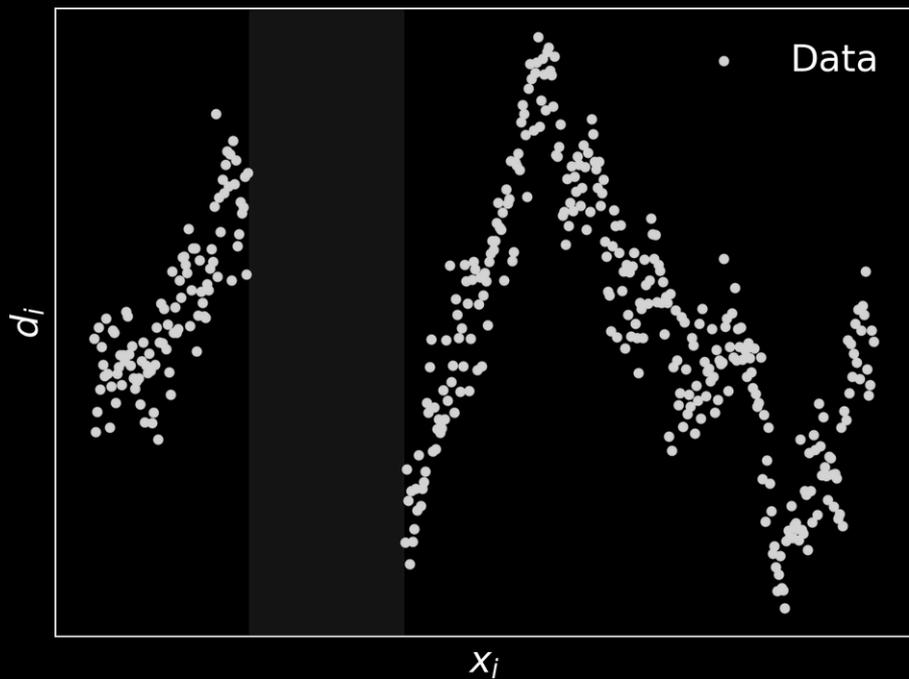












Challenges

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- Non-trivial correlation structures
- Mixture of several components

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- Response representation & application
- Non-Gaussian noise
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Information Field Theory

$$P(s|d) = \frac{P(d|s)P(s)}{P(d)}$$

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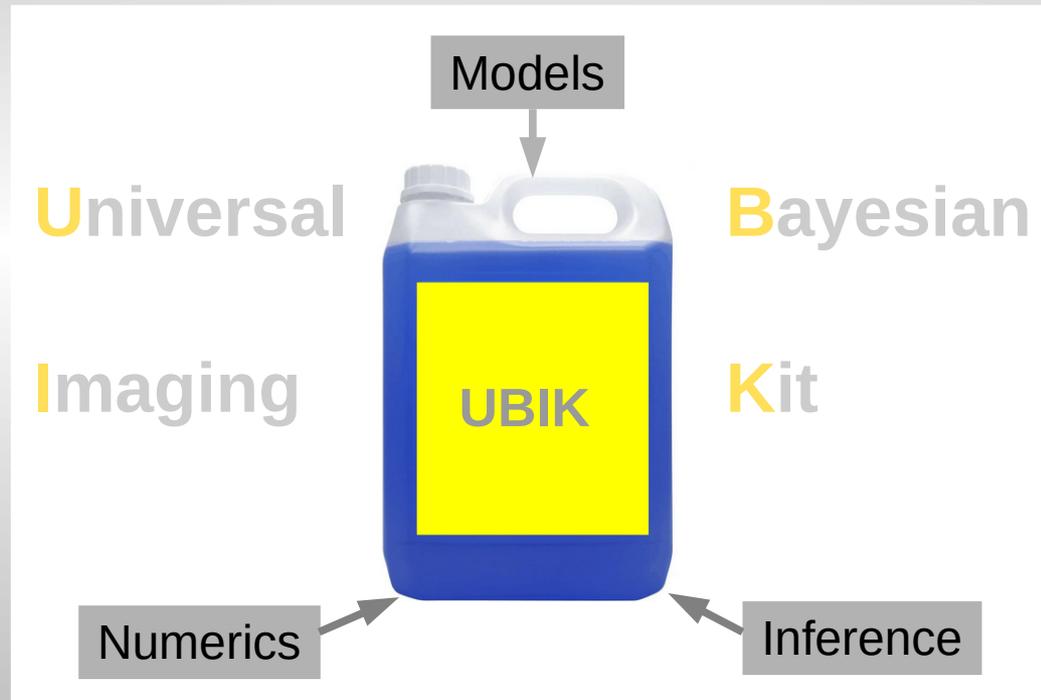
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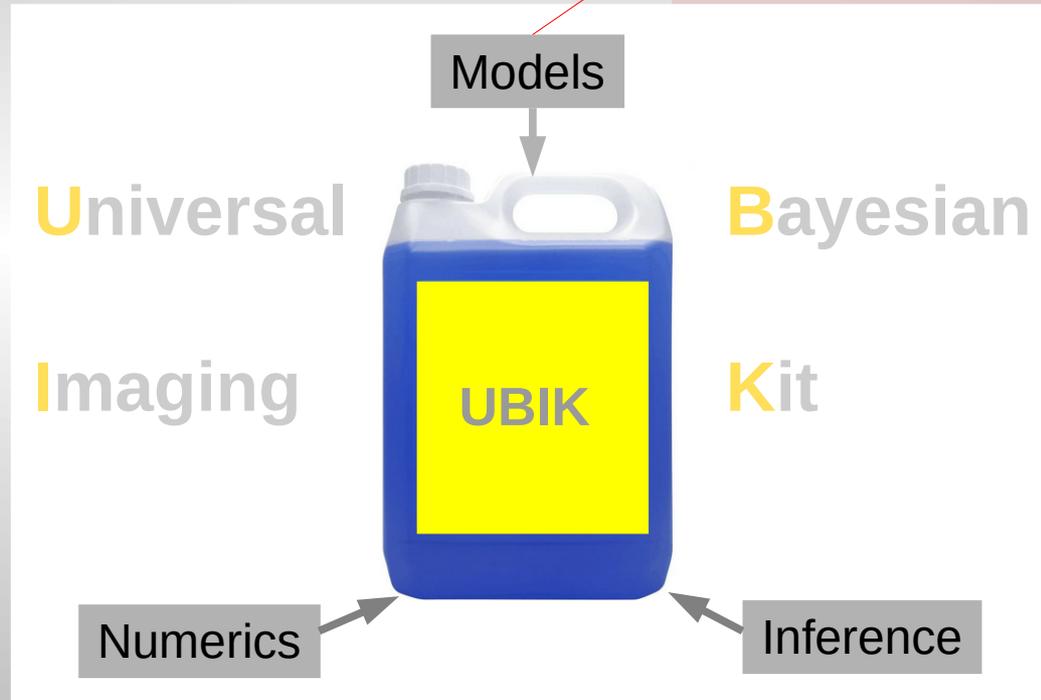
Variational inference:

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$$m = \langle s \rangle_Q$$
$$\sigma^2 = \langle (s - m)^2 \rangle_Q$$



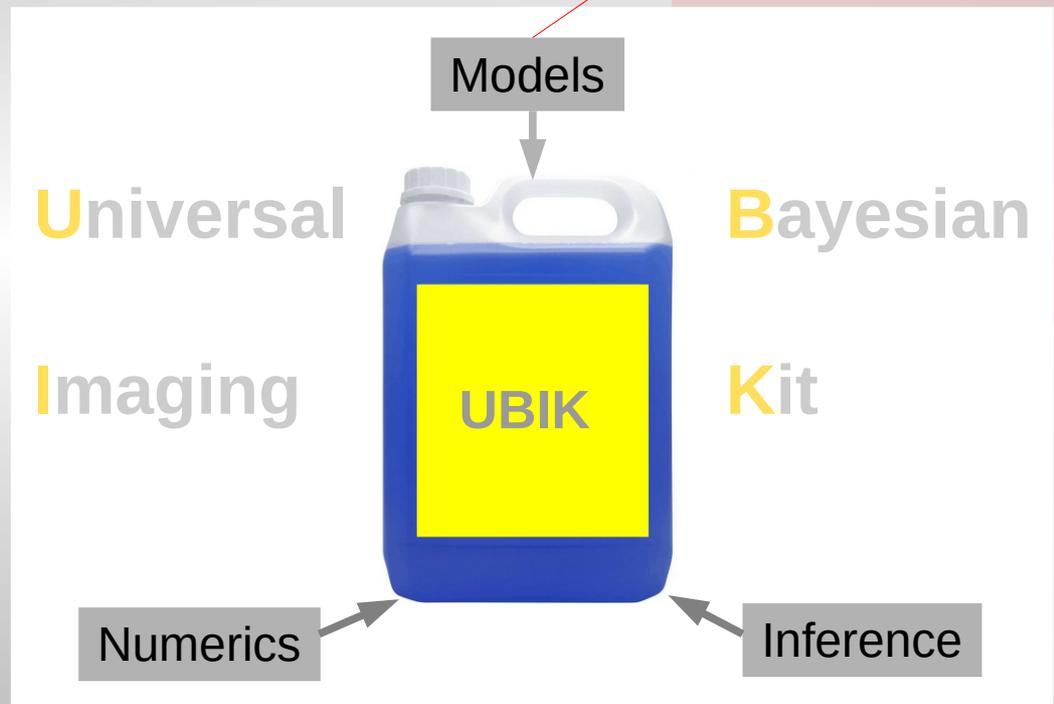
Signal

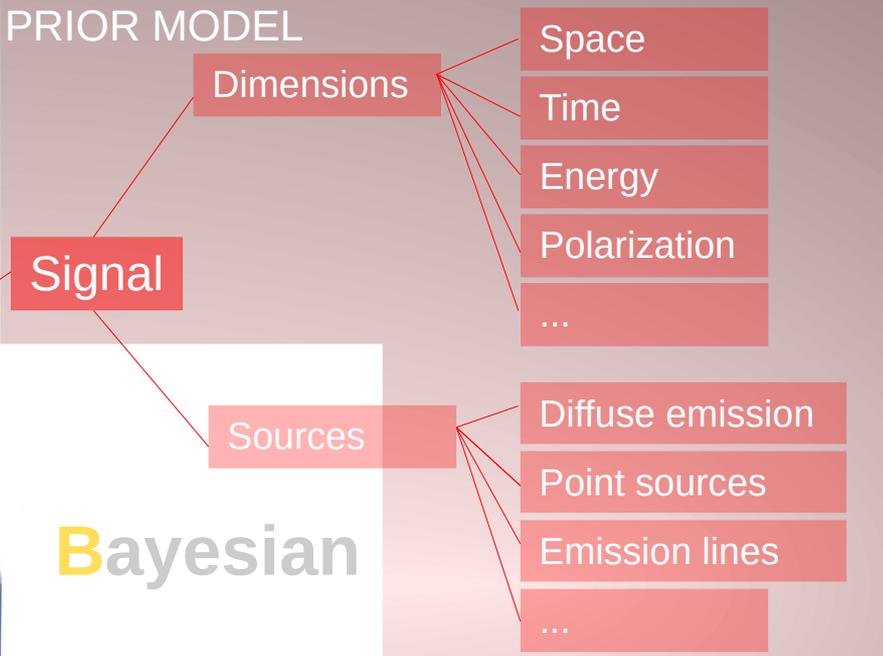
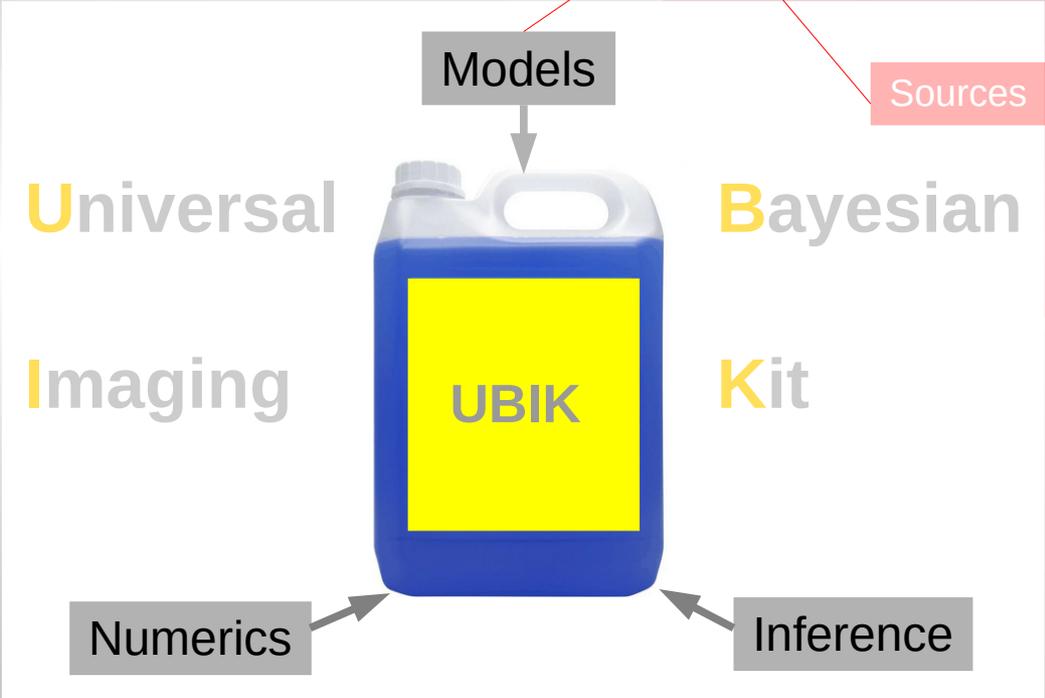


PRIOR MODEL



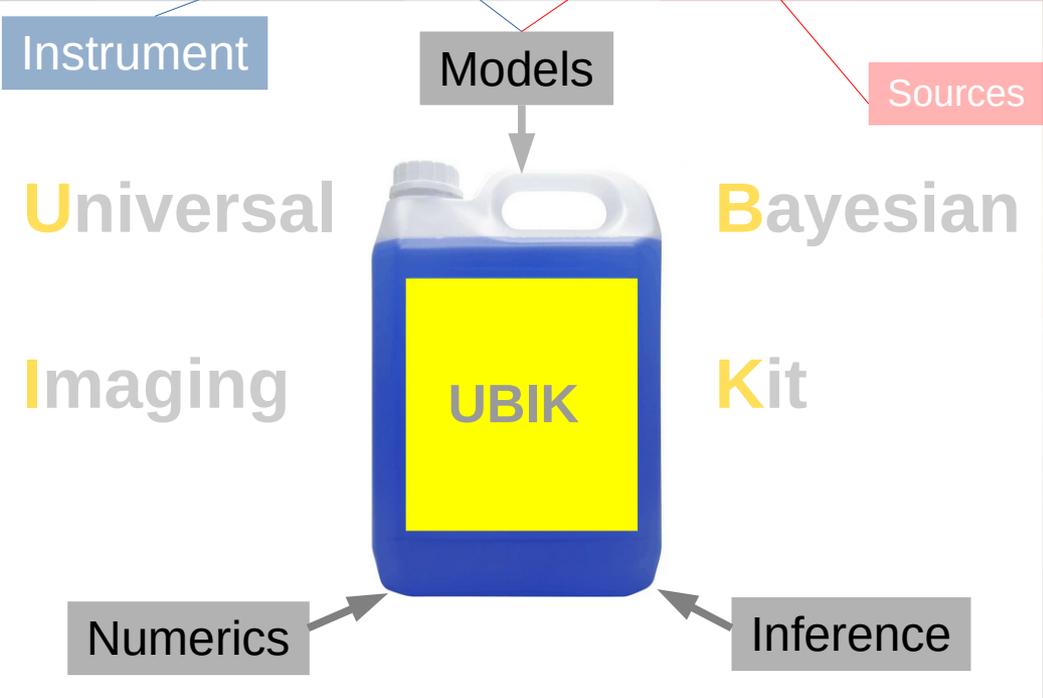
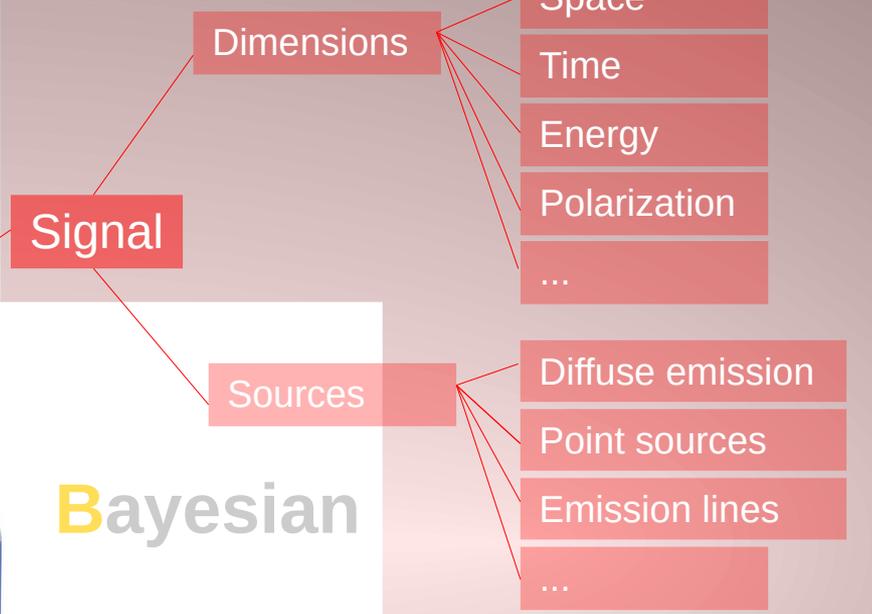
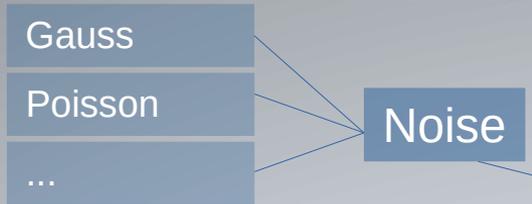
Signal





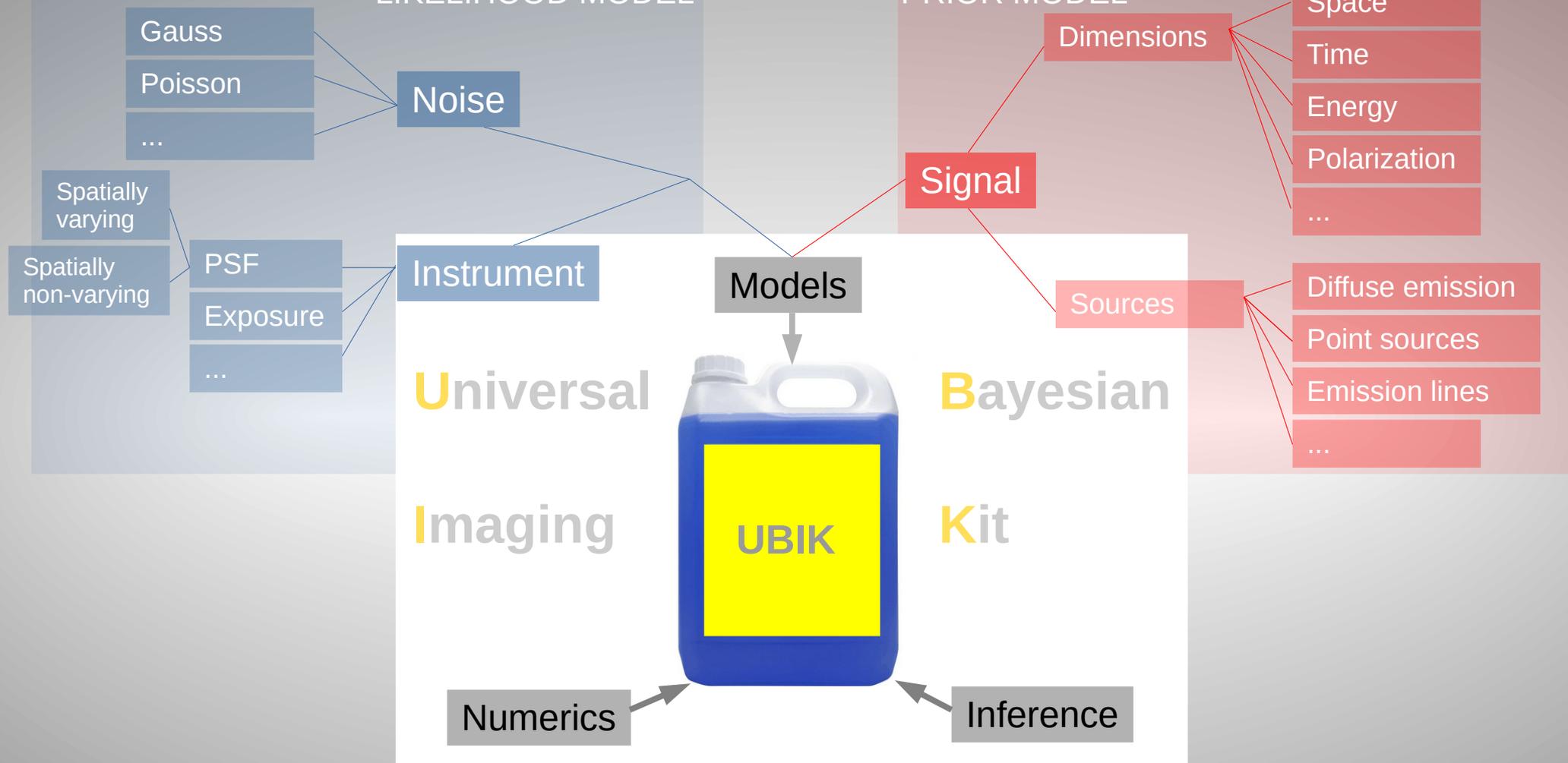
LIKELIHOOD MODEL

PRIOR MODEL



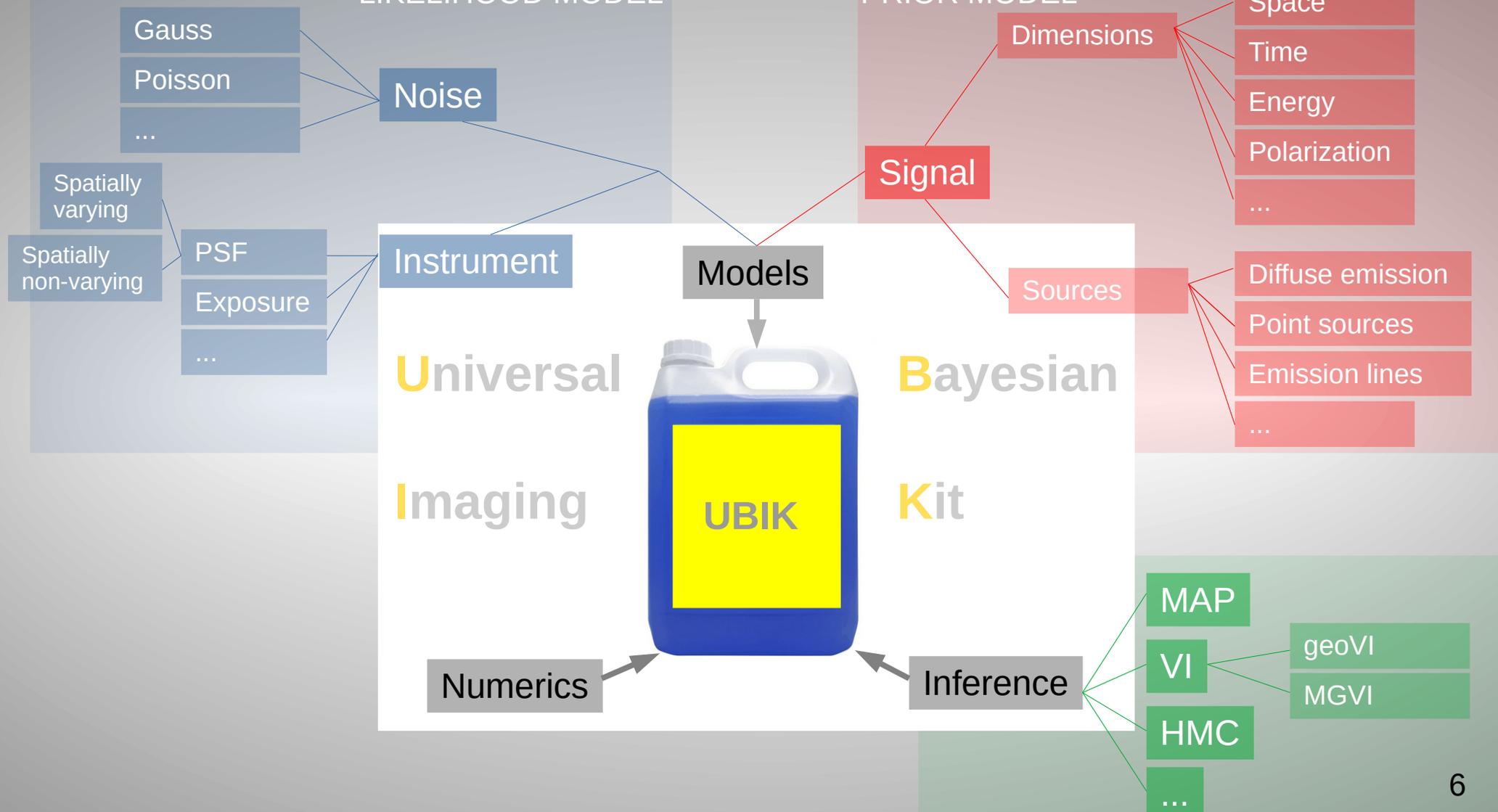
LIKELIHOOD MODEL

PRIOR MODEL



LIKELIHOOD MODEL

PRIOR MODEL



LIKELIHOOD MODEL

PRIOR MODEL

Gauss

Poisson

...

Noise

Spatially varying

Spatially non-varying

PSF

Exposure

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Instrument

Models

Signal

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Time

Energy

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Sources

Diffuse emission

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Emission lines

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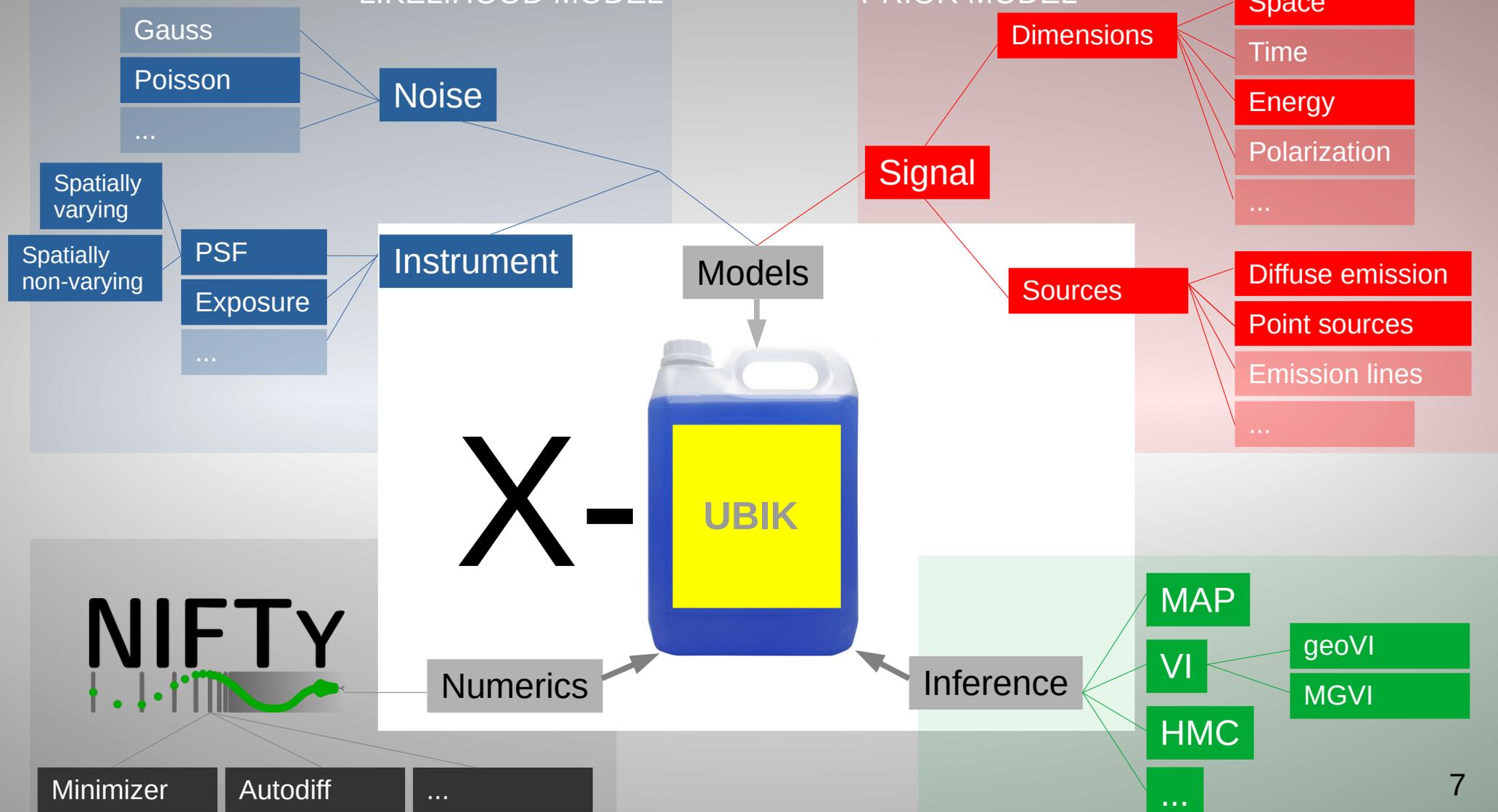
Minimizer

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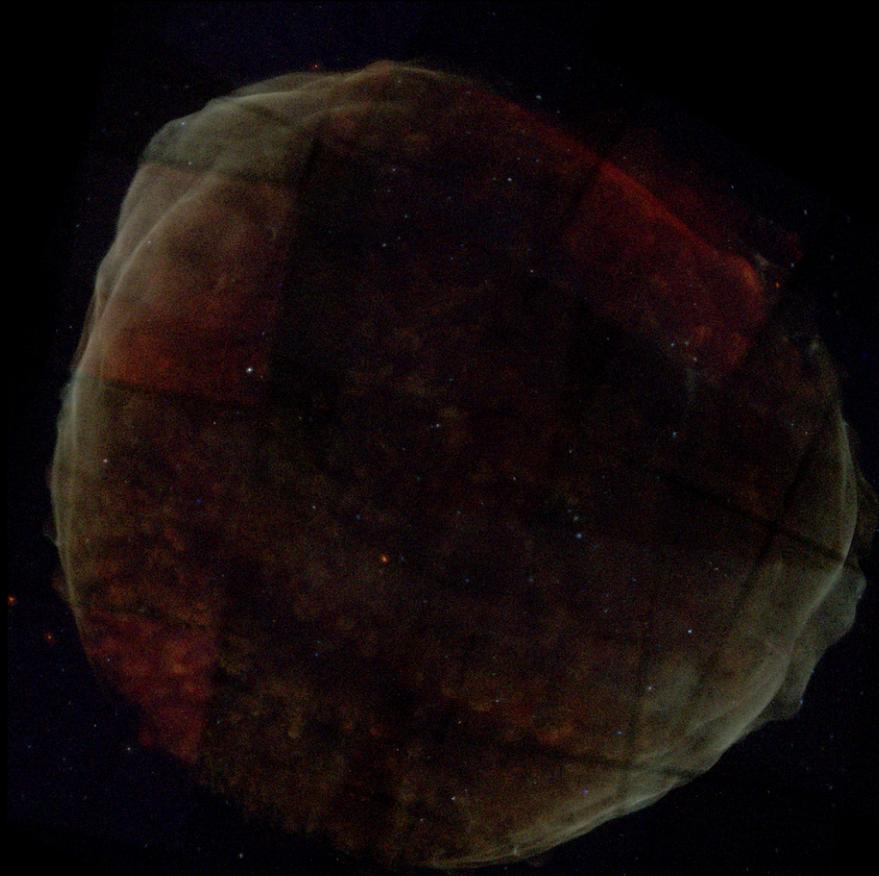
...

LIKELIHOOD MODEL

PRIOR MODEL



Chandra - SN1006



Likelihood Model

Poissonian log-likelihood for observation k:

$$-\ln P(d_k | \lambda_k) = -\sum_{i=1}^N [\lambda_k^i - d_k^i \ln \lambda_k^i + \ln(d_k^i!)]$$

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The diagram illustrates the relationship between the variables in the Poissonian log-likelihood equation. A blue arrow points from the d_k term in the equation to the text "count data d_k ". Another blue arrow points from the λ_k term in the equation to the text "average counts $\lambda_k = R_k s$ ". The R_k term in this equation is highlighted with a yellow background. Two blue arrows point from the R_k term to the text "exposure k " and "psf k ".

Likelihood Model

Poissonian log-likelihood:

$$\sum_{k=1}^{11} -\ln P(d_k | \lambda_k) = \sum_{k=1}^{11} - \sum_{i=1}^N [\lambda_k^i - d_k^i \ln \lambda_k^i + \ln(d_k^i!)]$$

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average counts $\lambda_k = R_k s$

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psf k

Prior Generative Models

$$s = s(\xi), \quad P(\xi) = \mathcal{N}(\xi, 1)$$

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diffuse emission

point sources

background

$s(\xi) =$

+

+

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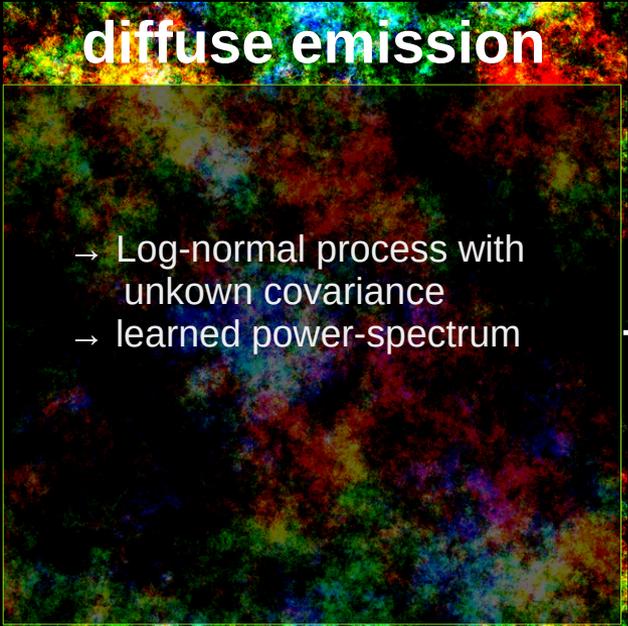
background

$$s(\xi) =$$

- Log-normal process with unknown covariance
- learned power-spectrum

+

+



Prior Generative Models

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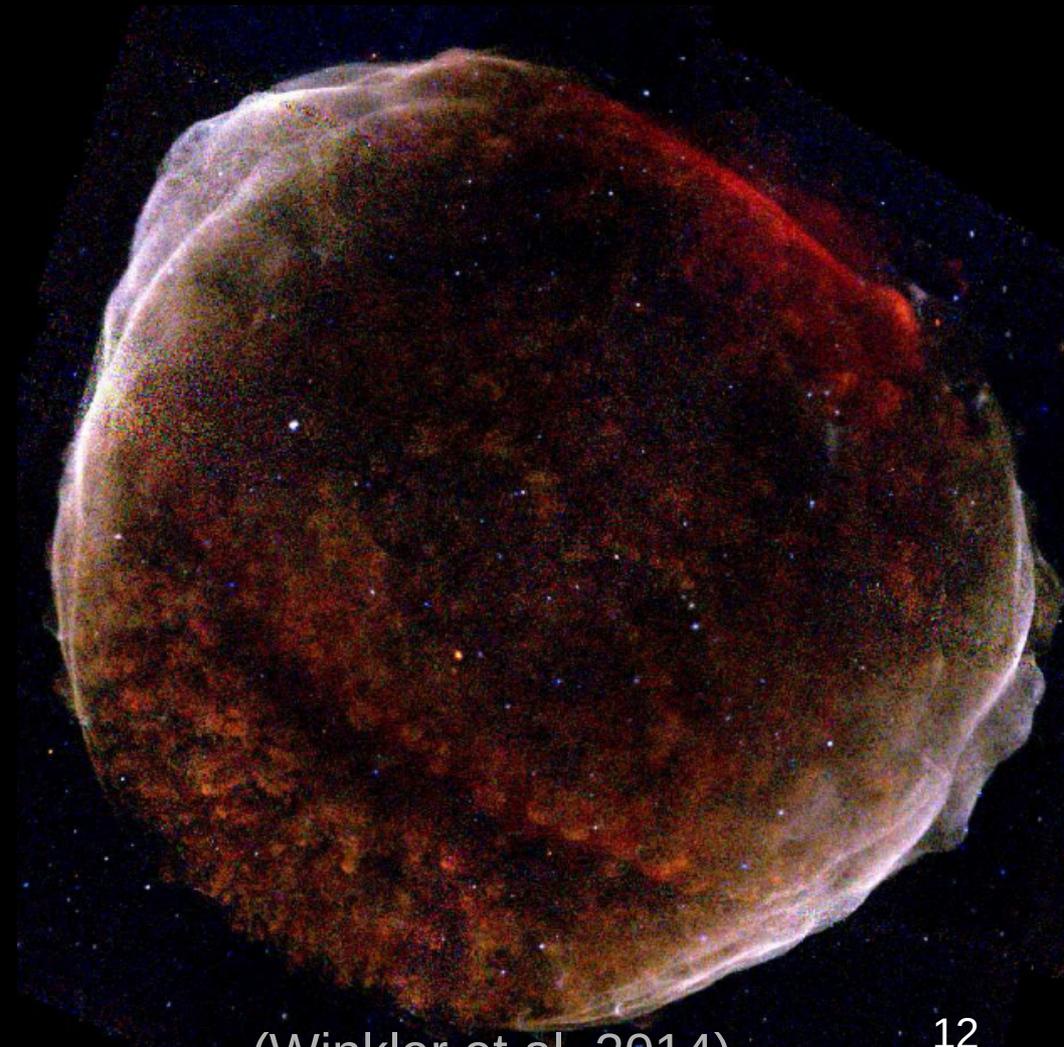
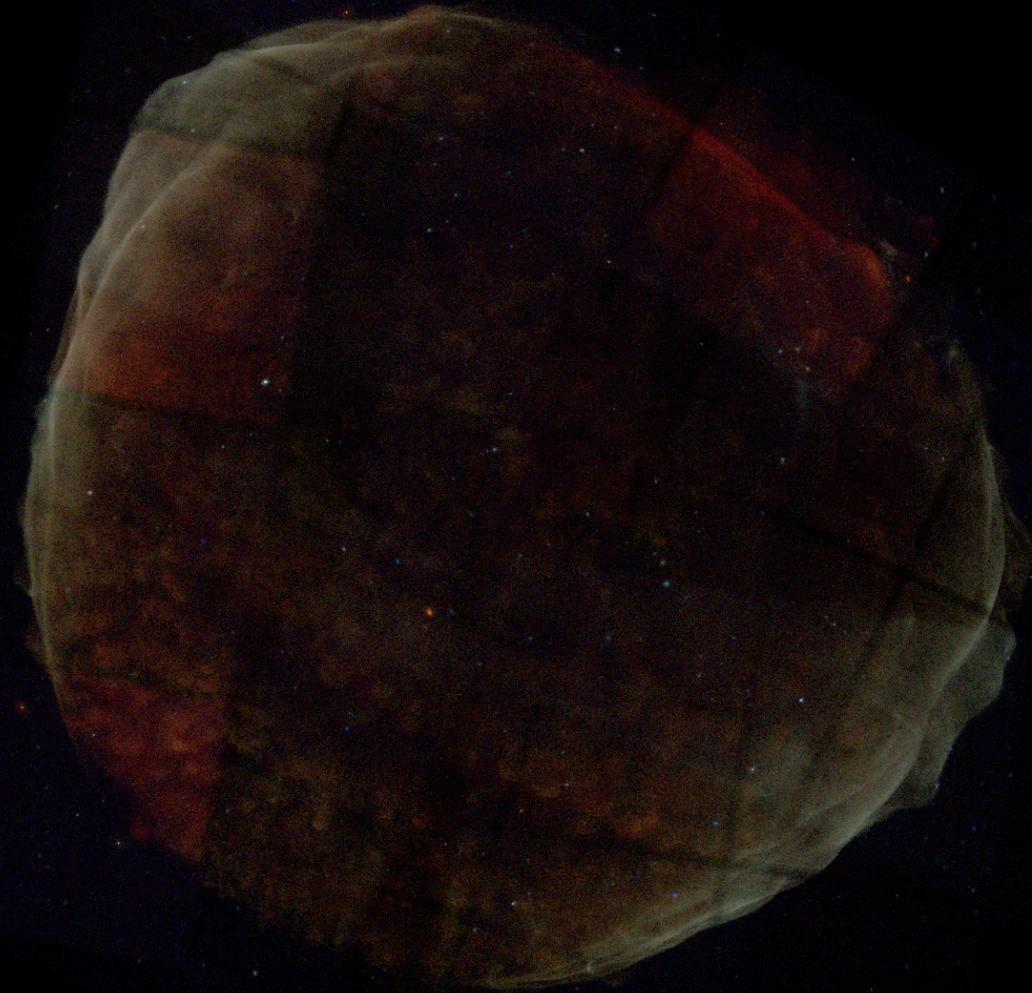
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+

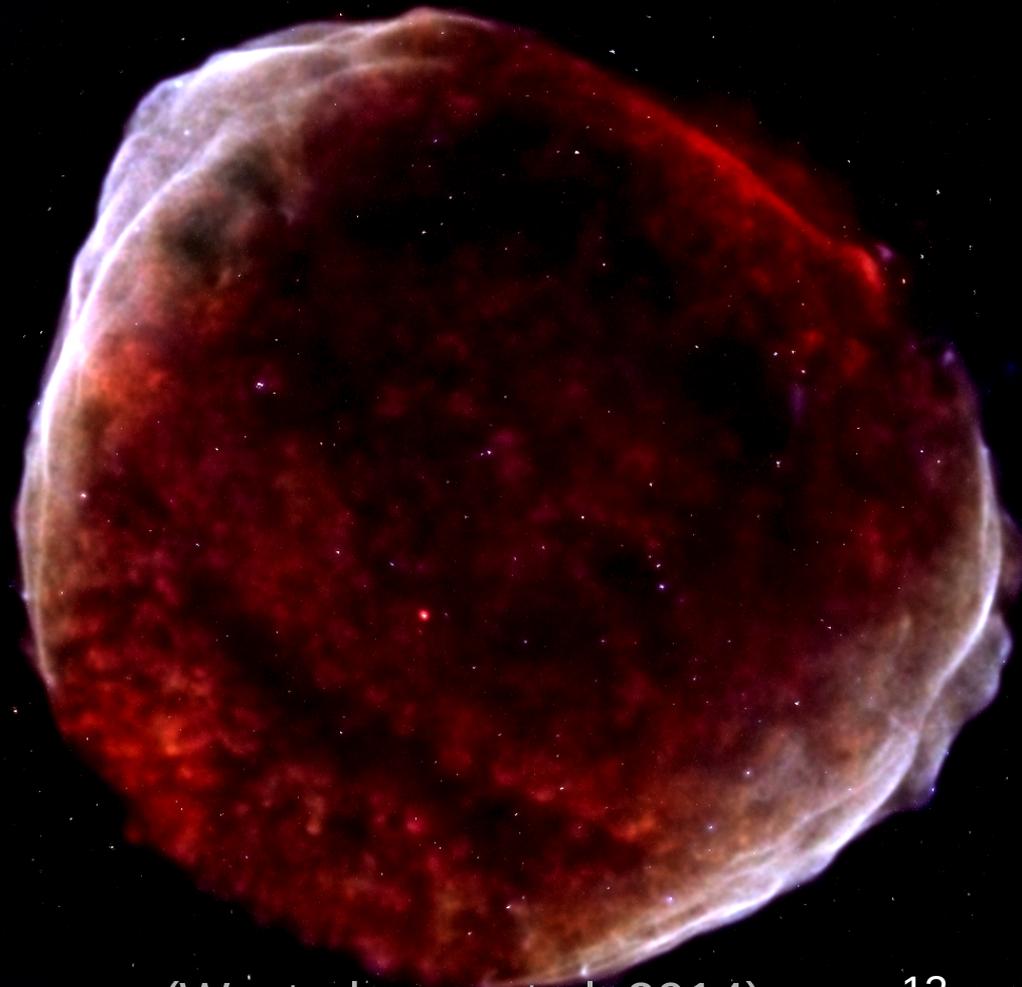
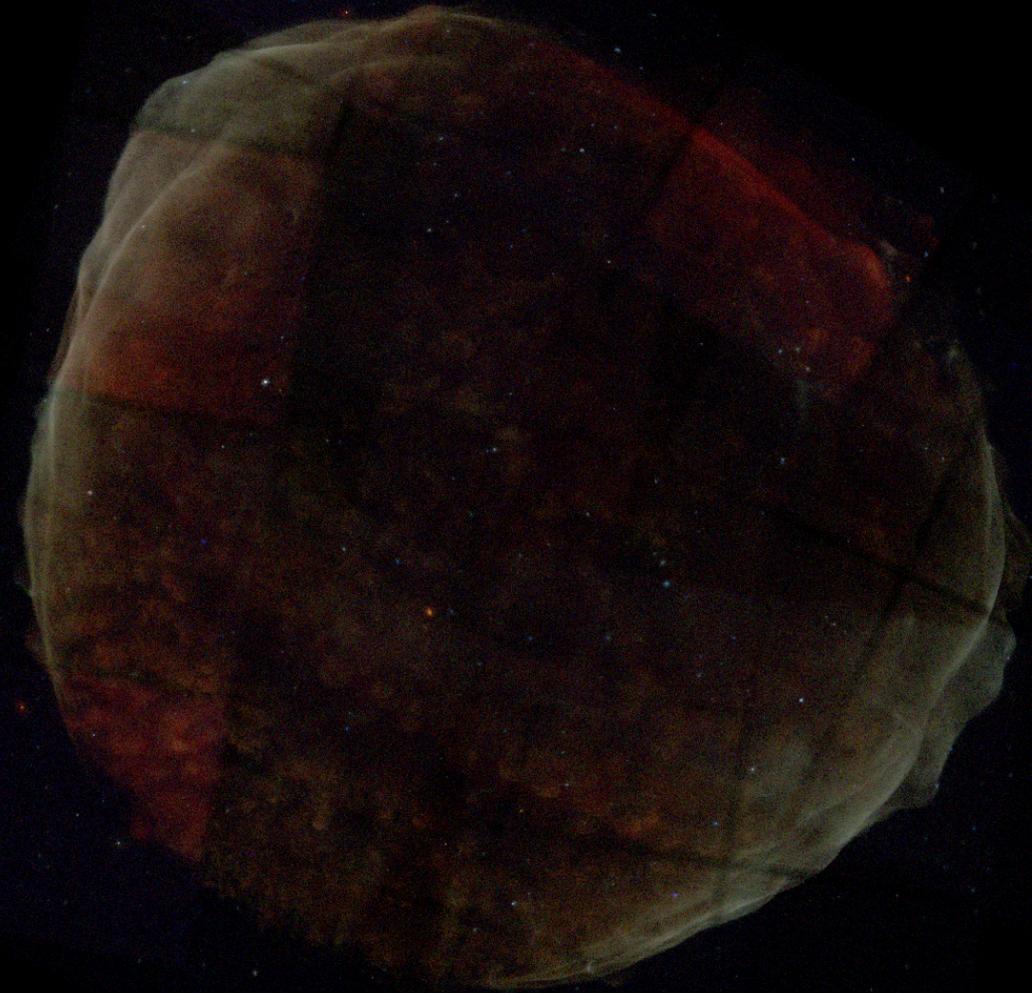
+

Reconstructed Sky



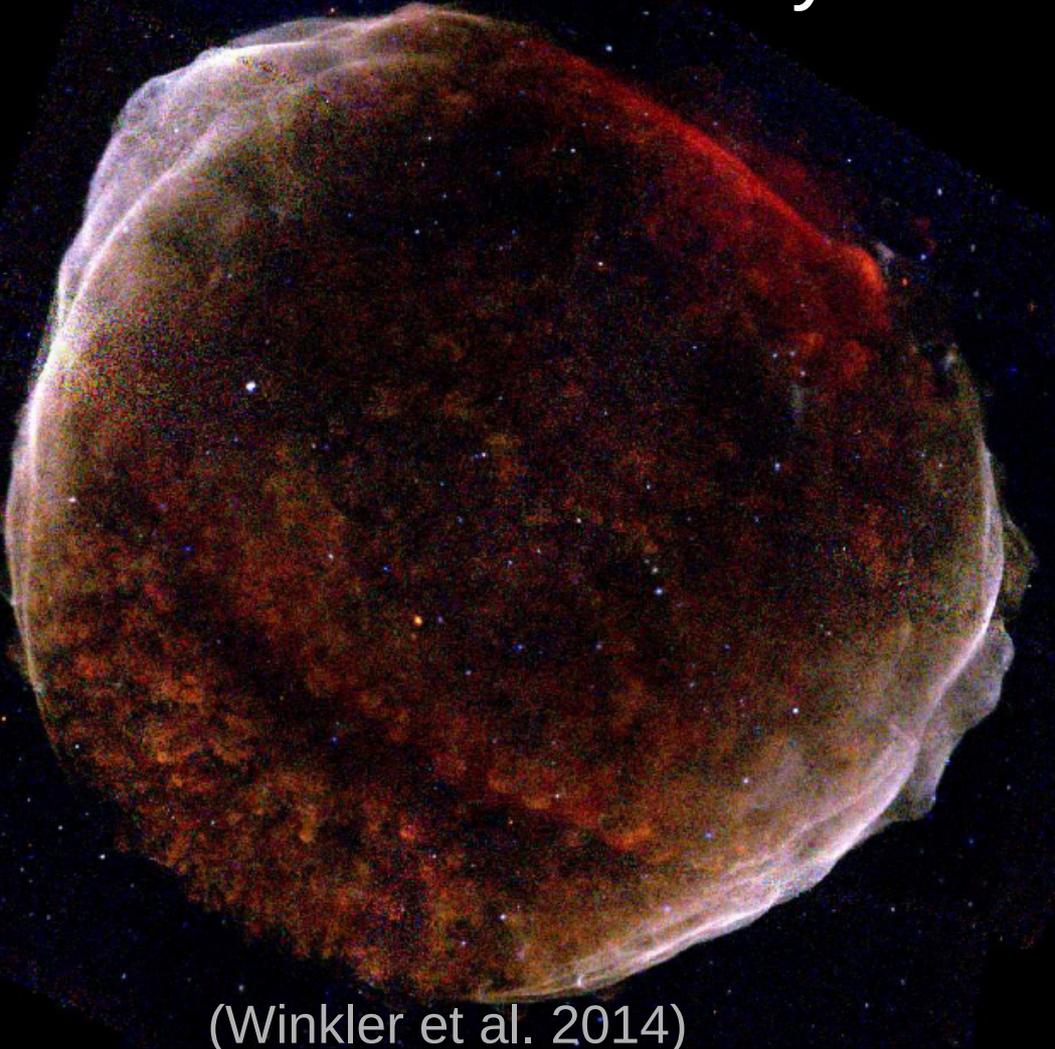
(Winkler et al. 2014)

Reconstructed Sky

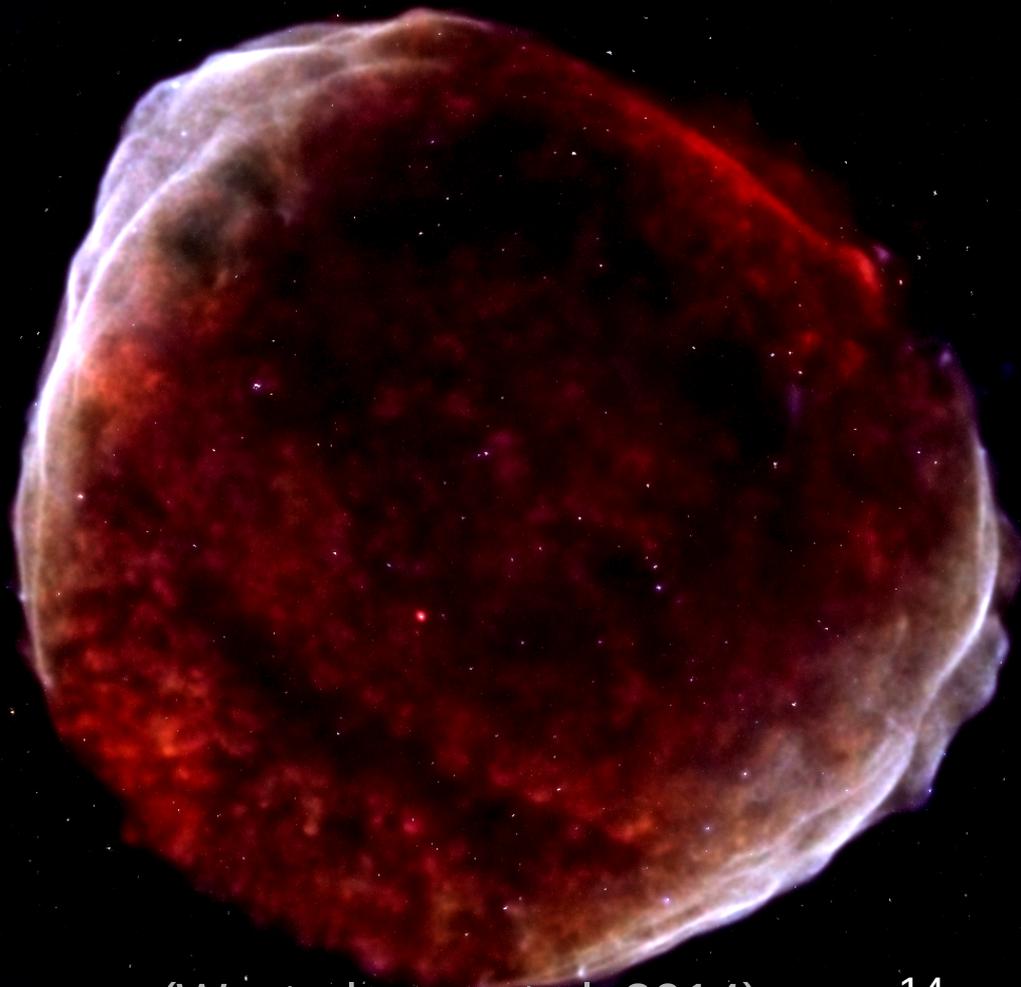


(Westerkamp et al. 2014)

Reconstructed Sky

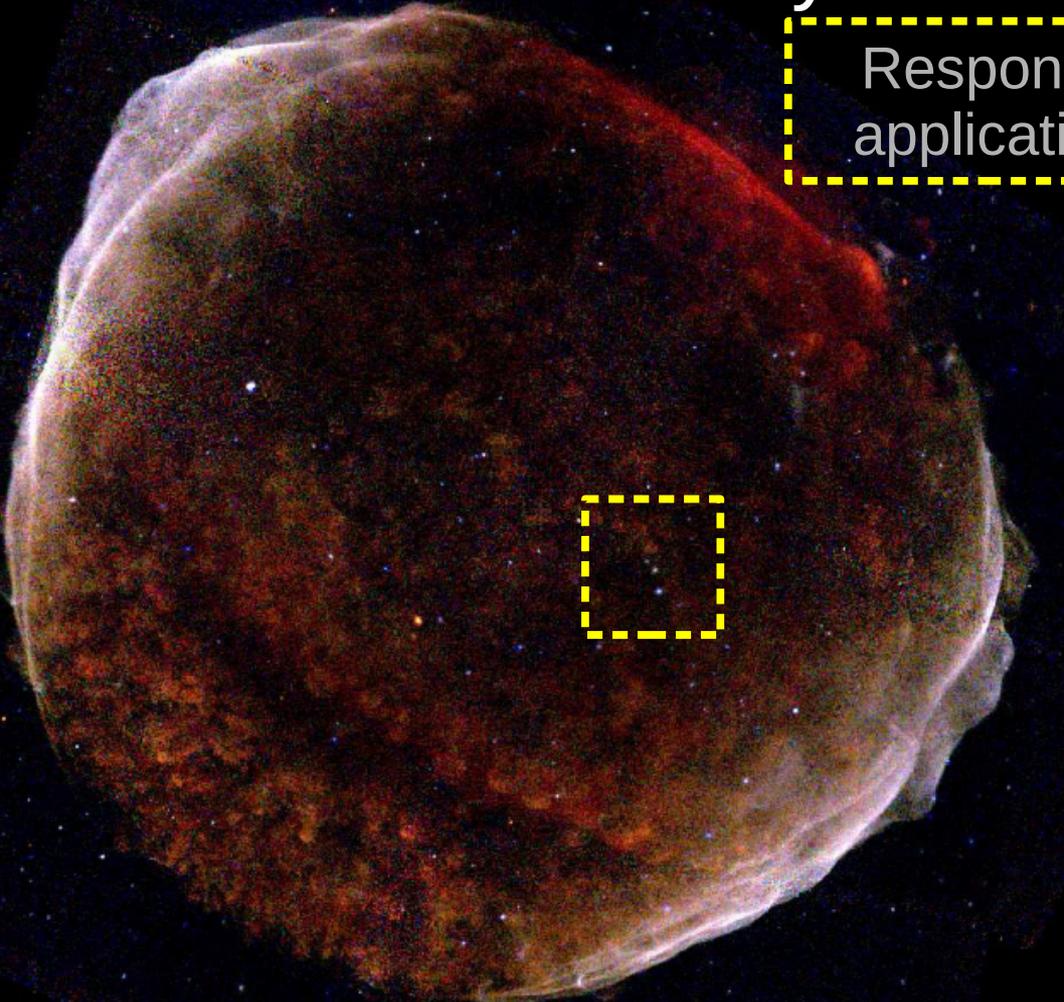


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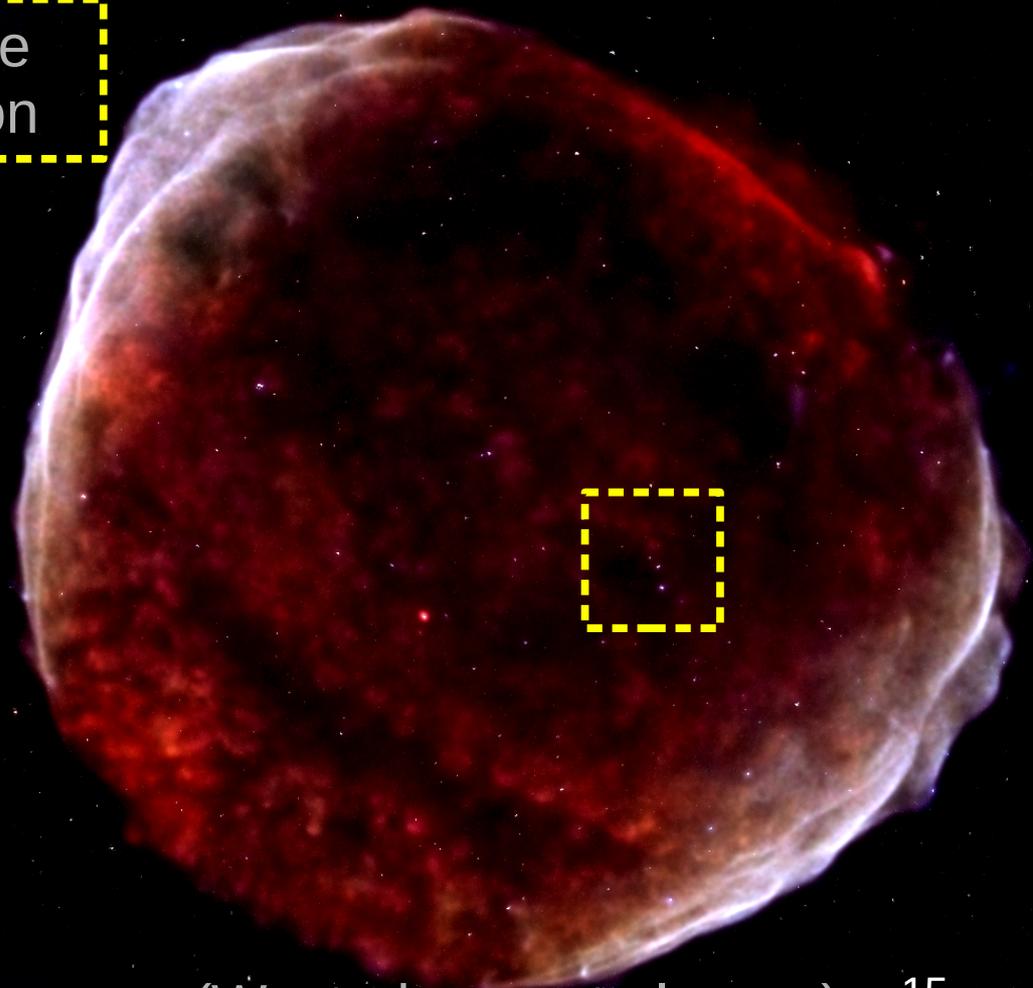
(Westerkamp et al. 2014)

Reconstructed Sky



(Winkler et al. 2014)

Response
application



(Westerkamp et al. 2024)

Reconstructed Sky

Response application

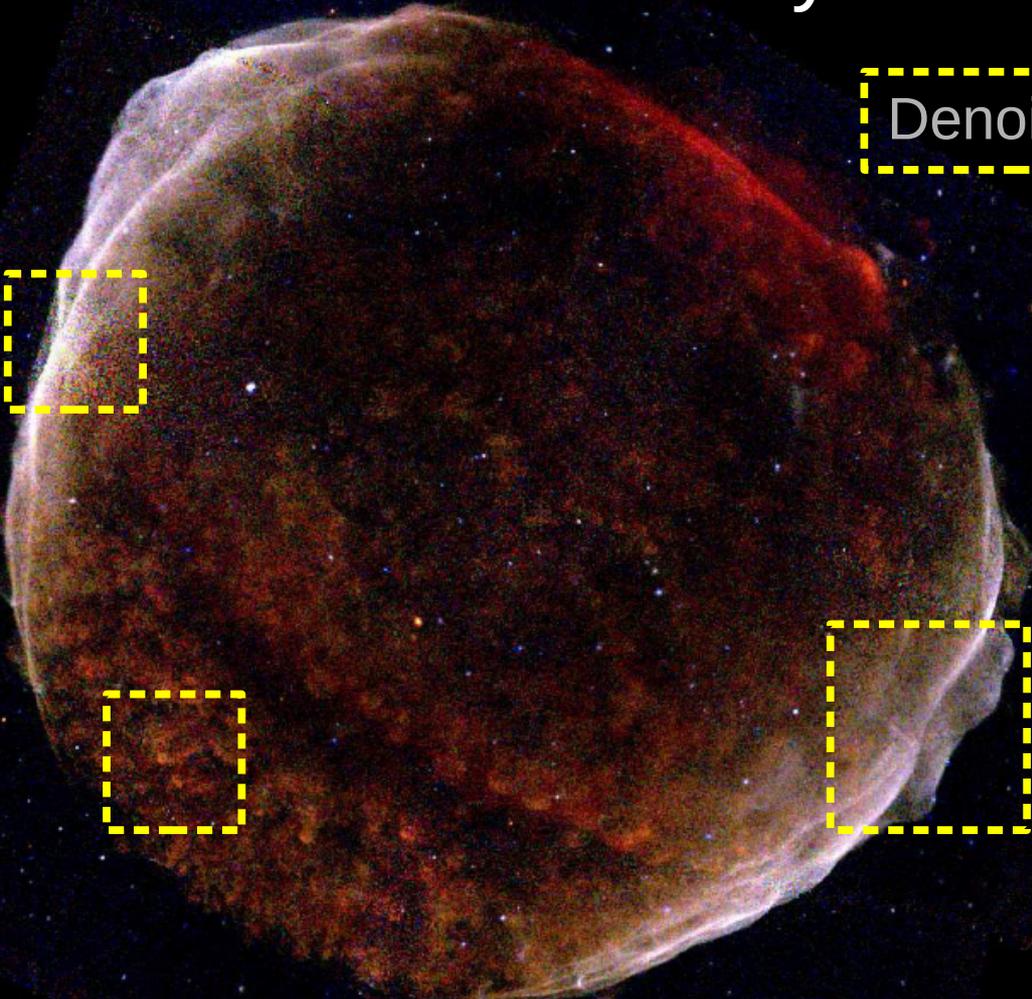


(Winkler et al. 2014)



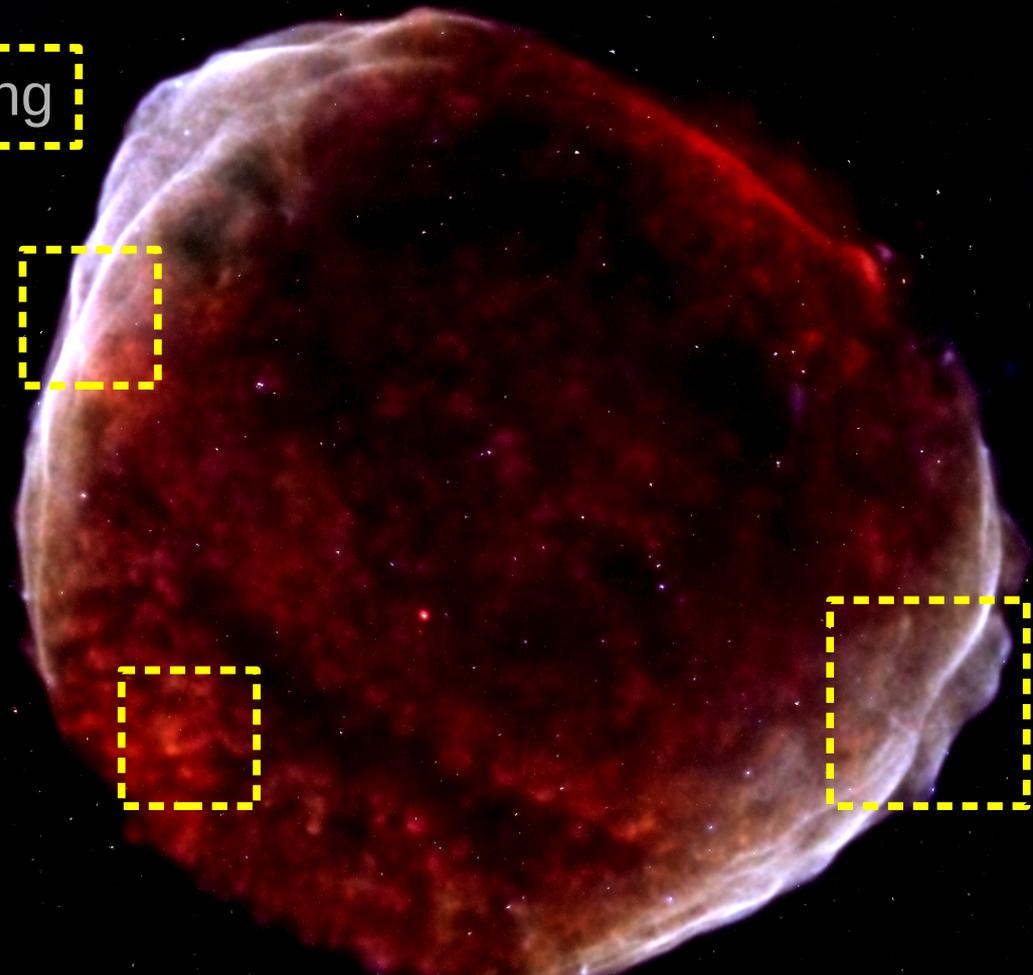
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Reconstructed Sky



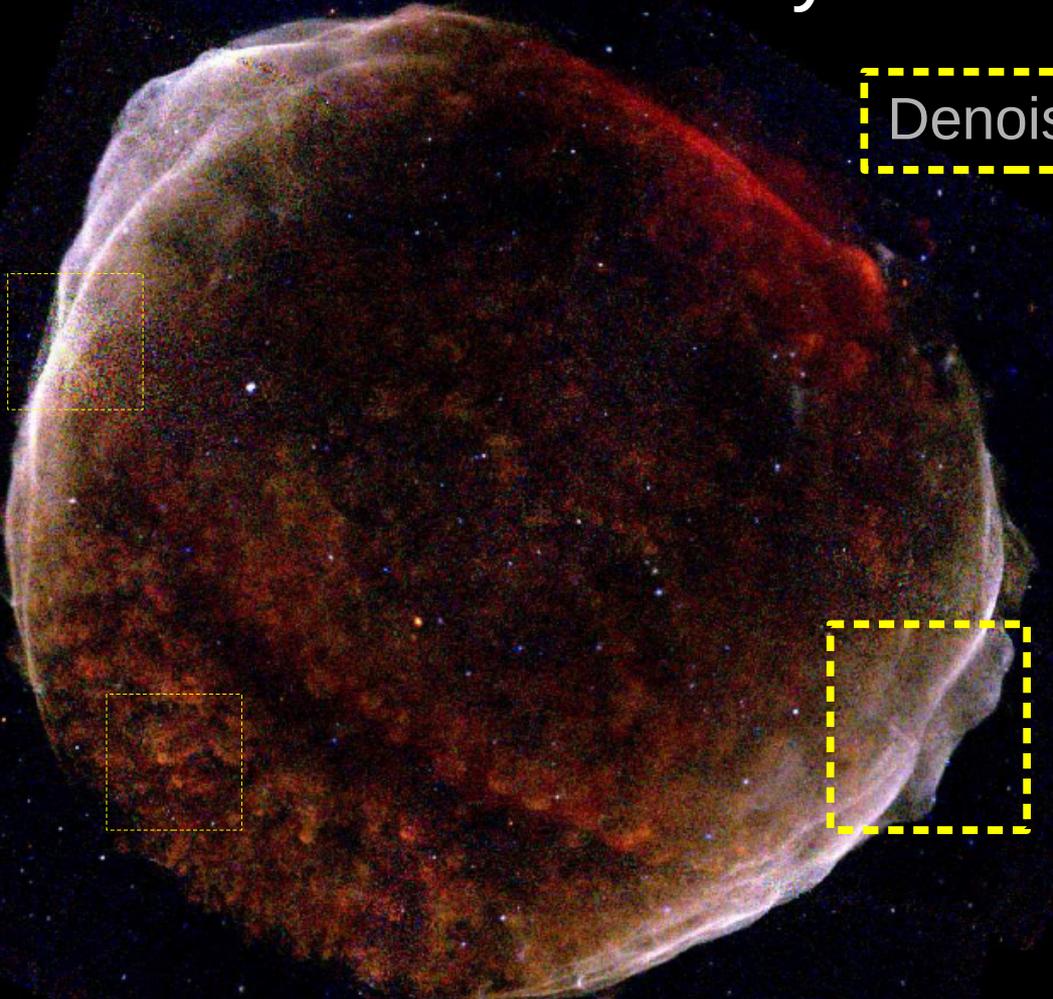
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Denoising



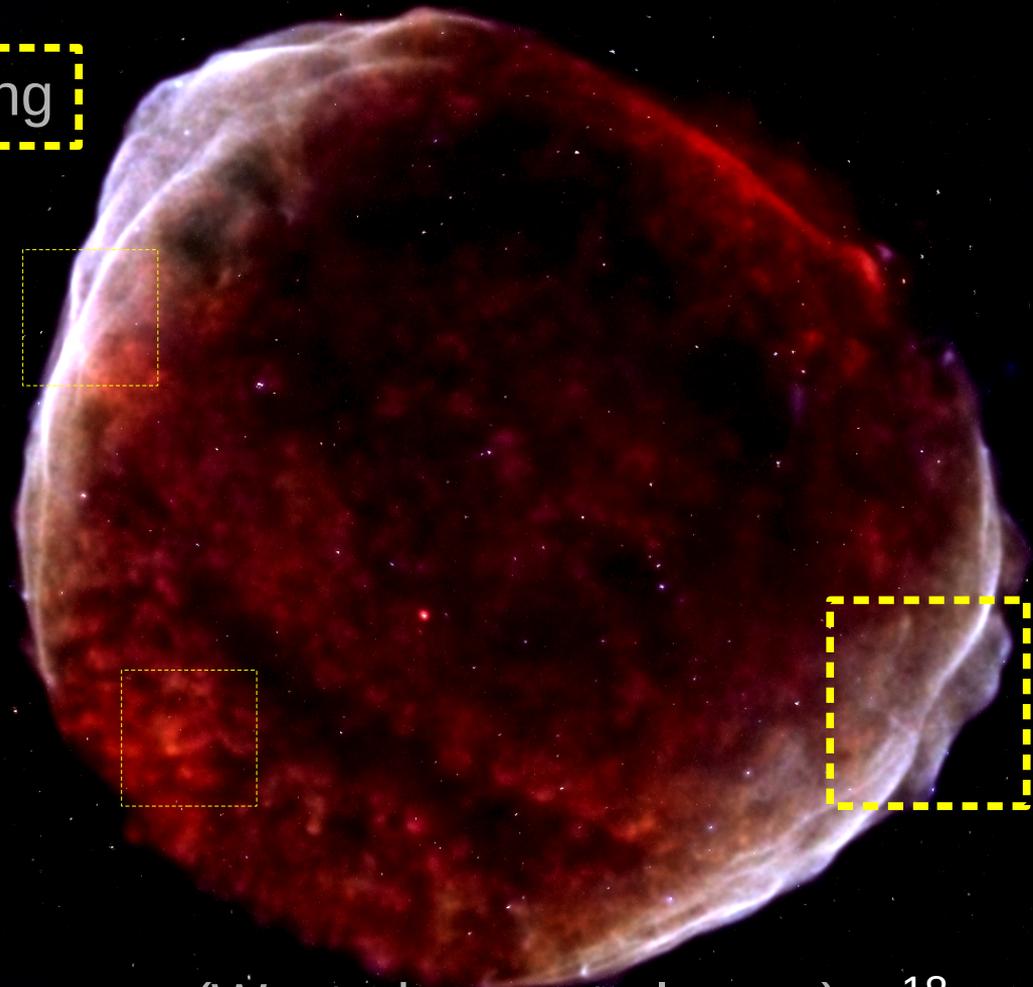
(Westerkamp et al. 2024)

Reconstructed Sky



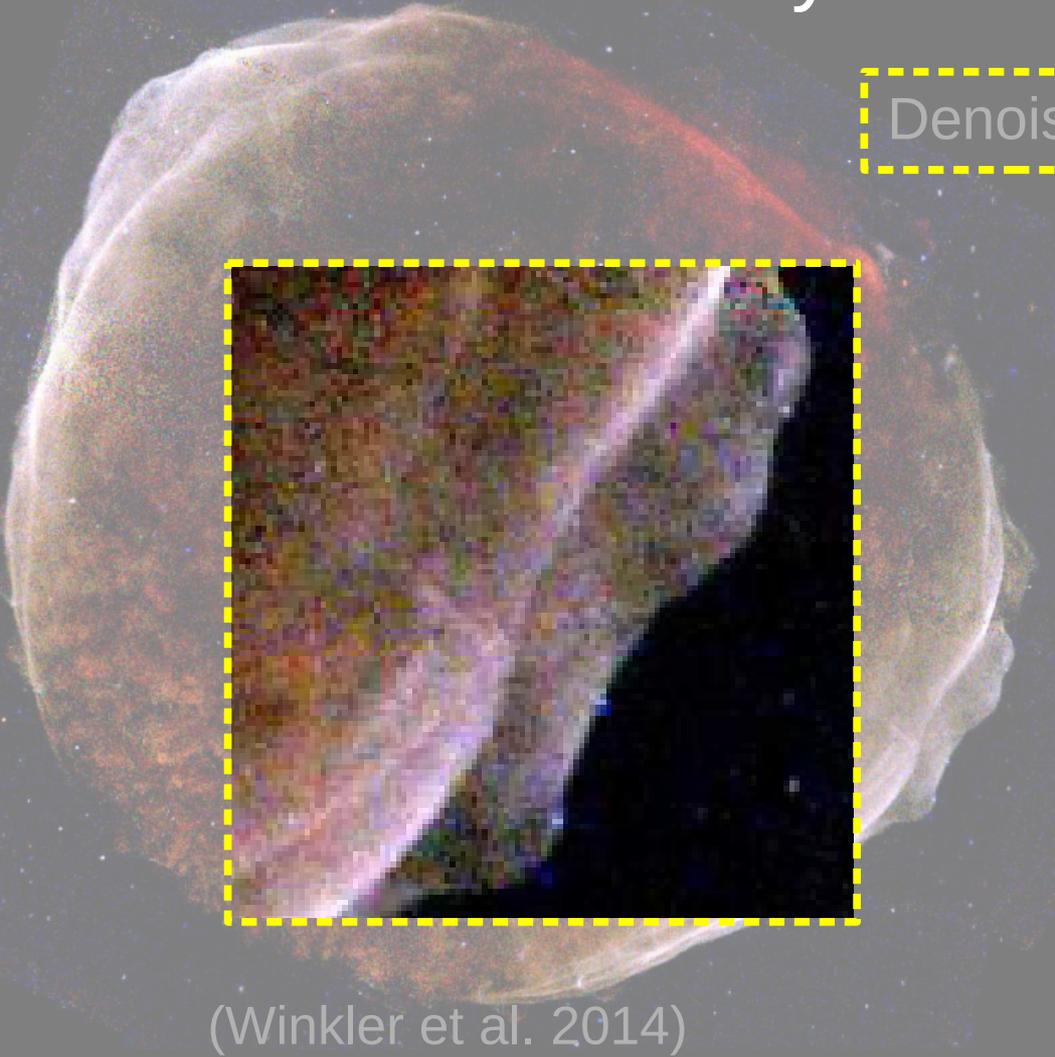
(Winkler et al. 2014)

Denoising

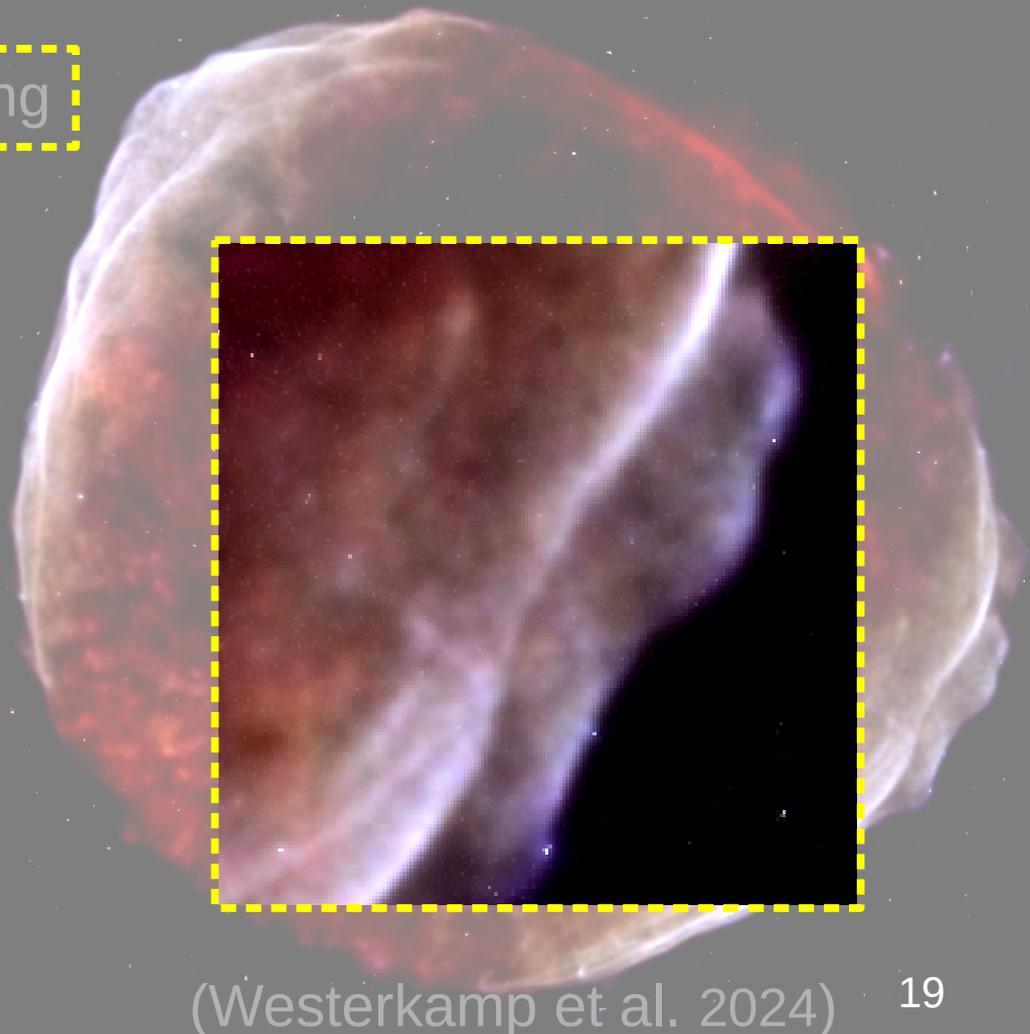


(Westerkamp et al. 2024)

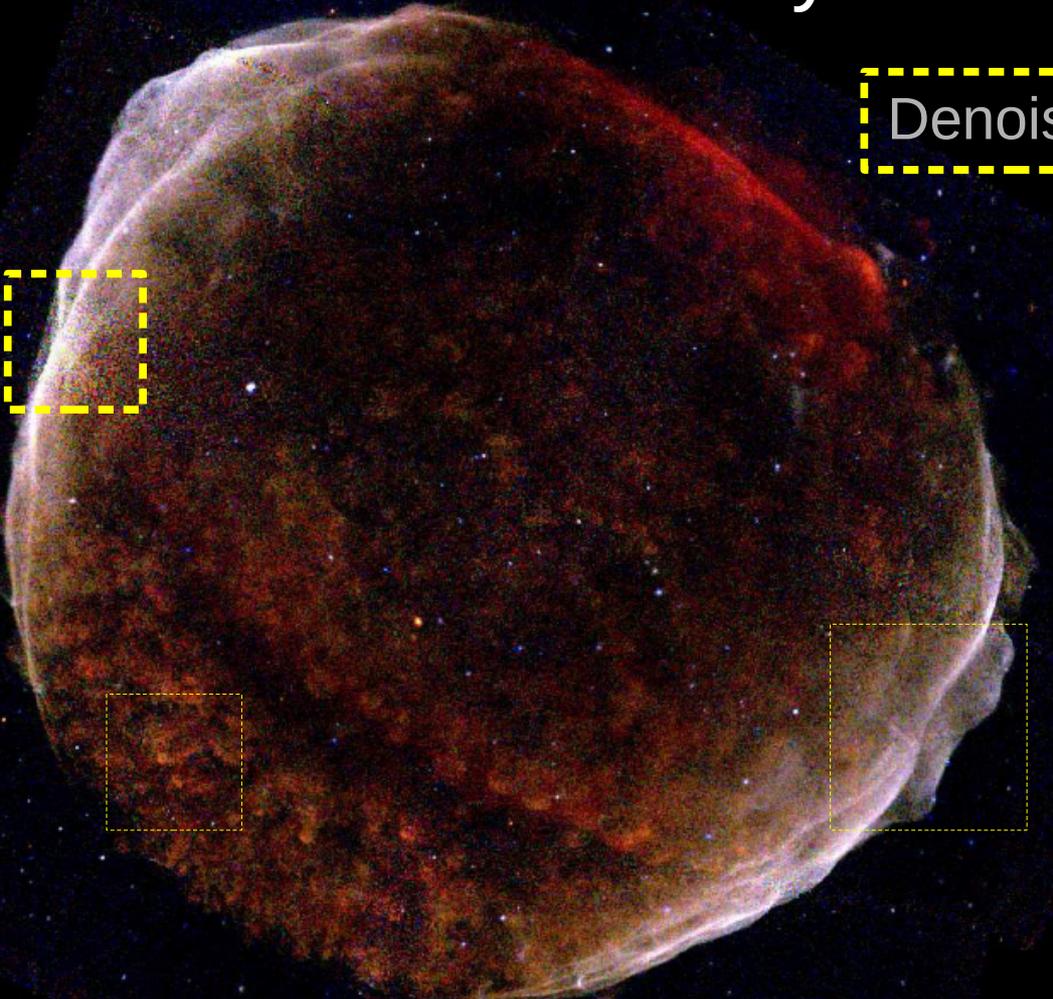
Reconstructed Sky



Denoising

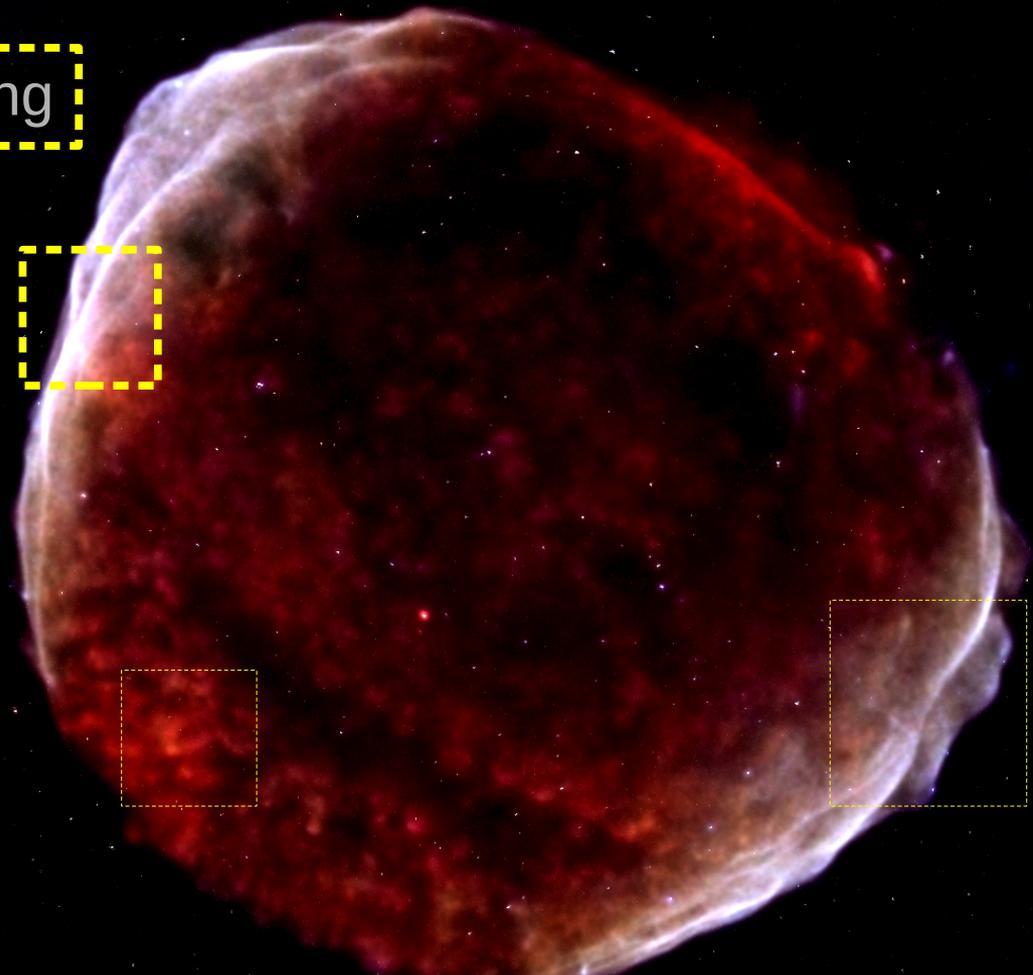


Reconstructed Sky



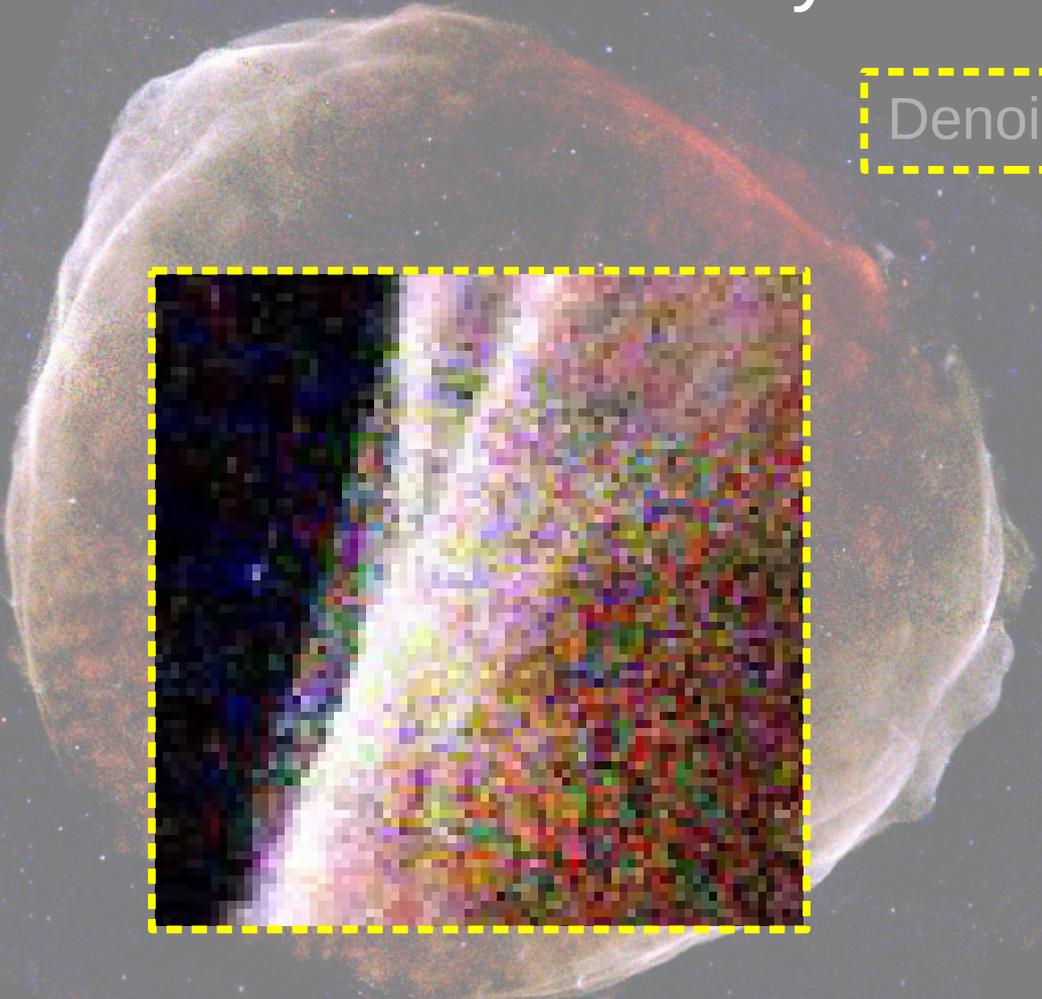
(Winkler et al. 2014)

Denoising

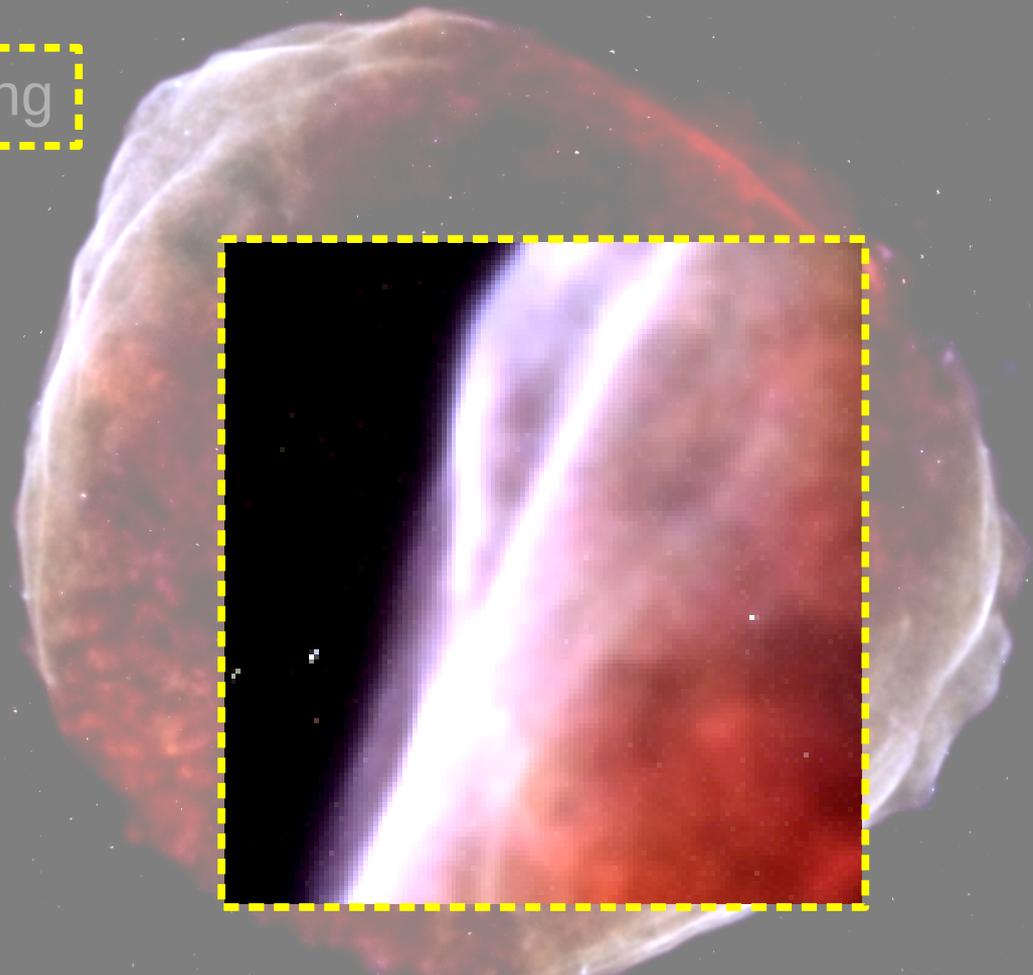


(Westerkamp et al. 2024)

Reconstructed Sky



Denoising



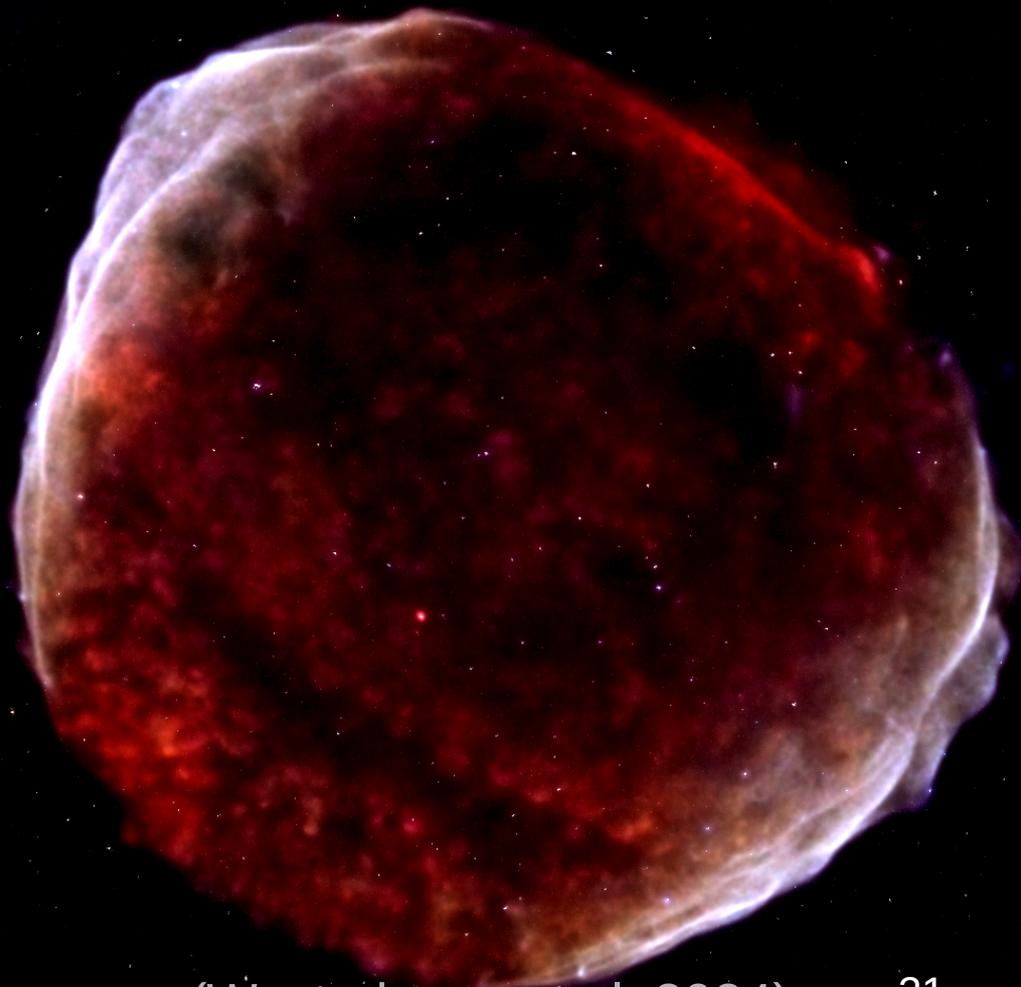
(Winkler et al. 2014)

(Westerkamp et al. 2024)

Reconstructed Sky

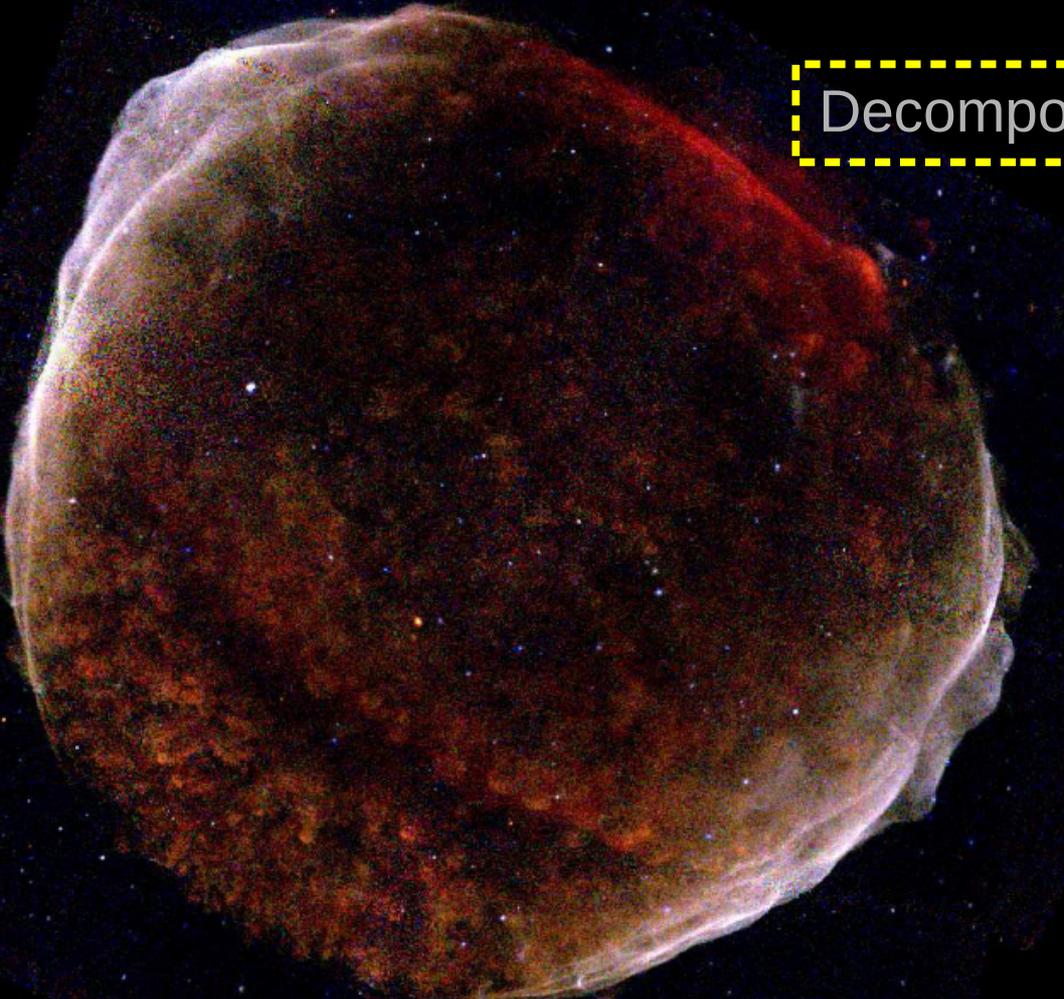


(Winkler et al. 2014)



(Westerkamp et al. 2024)

Reconstructed Point Sources



Decomposition



(Winkler et al. 2014)

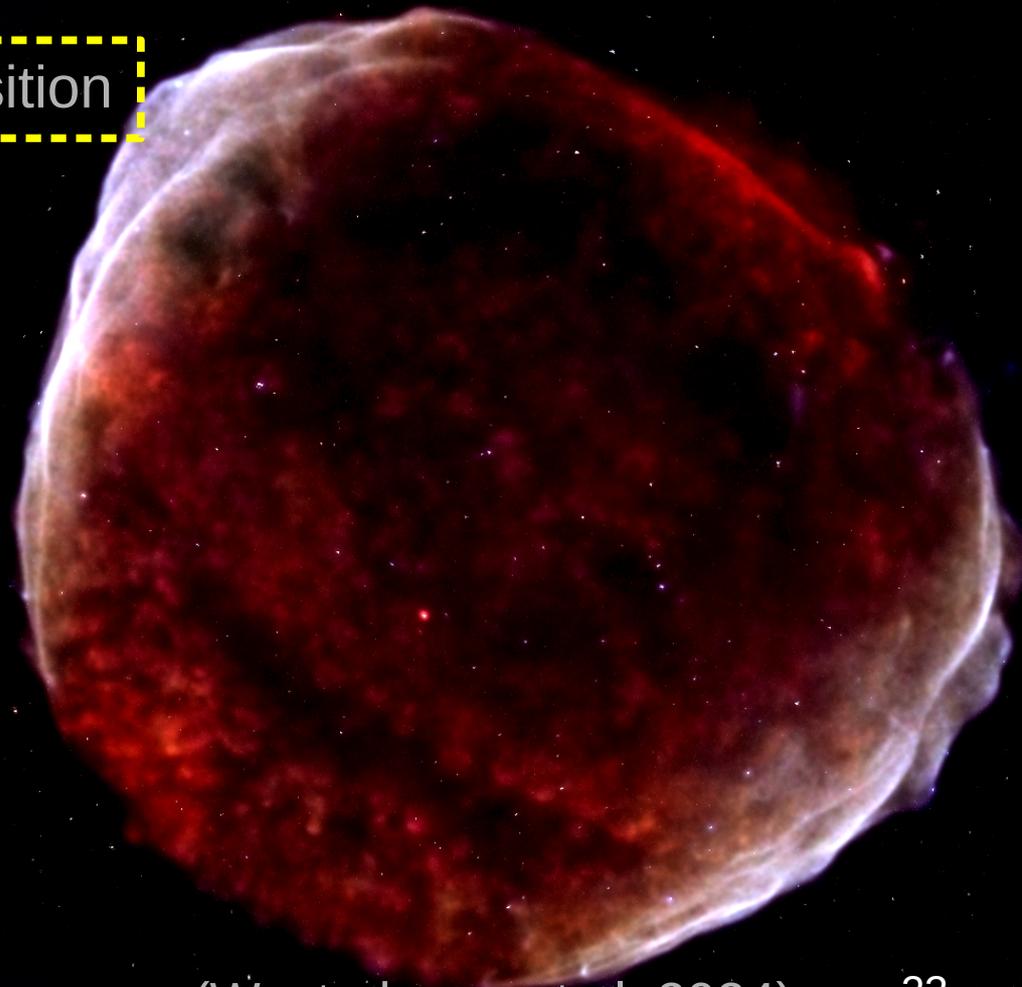
(Westerkamp et al. 2024)

Reconstructed Sky



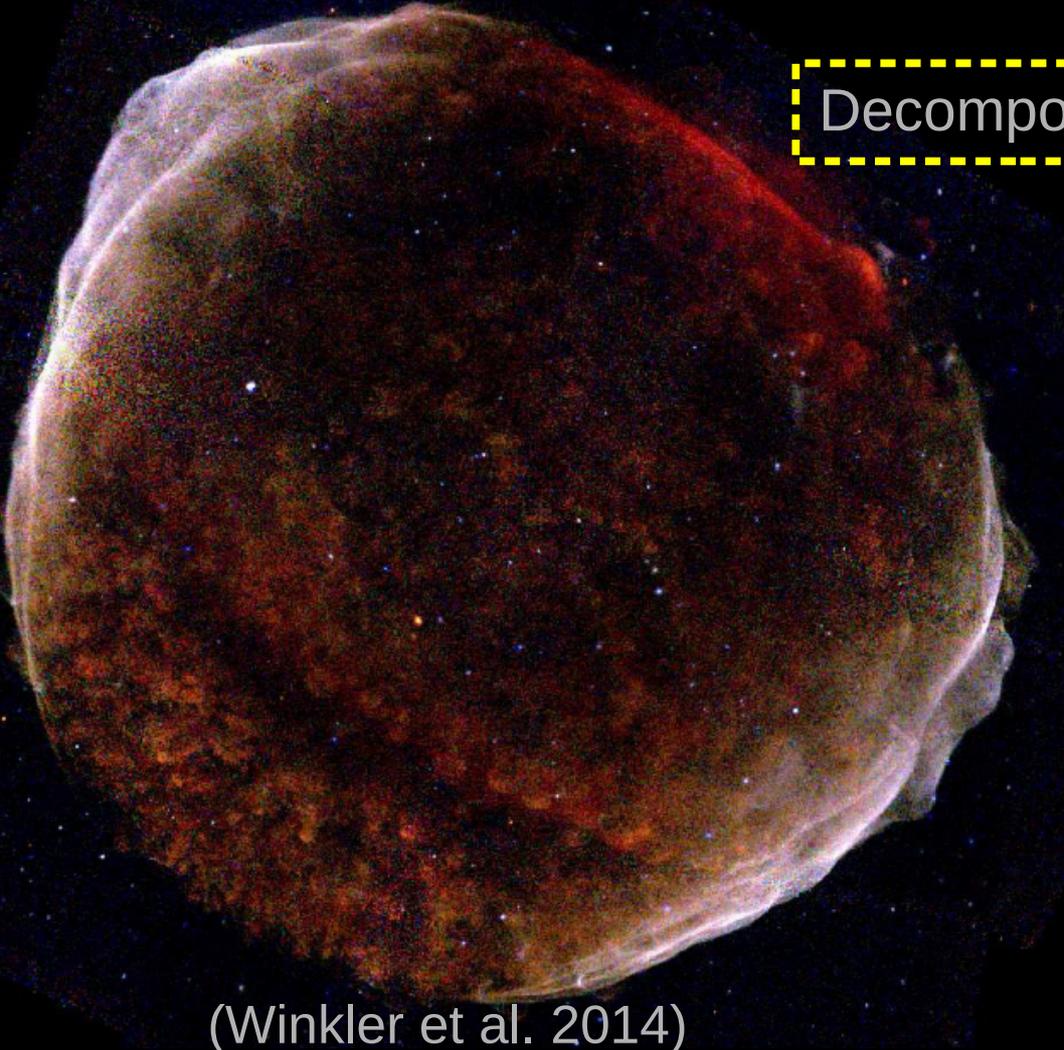
(Winkler et al. 2014)

Decomposition



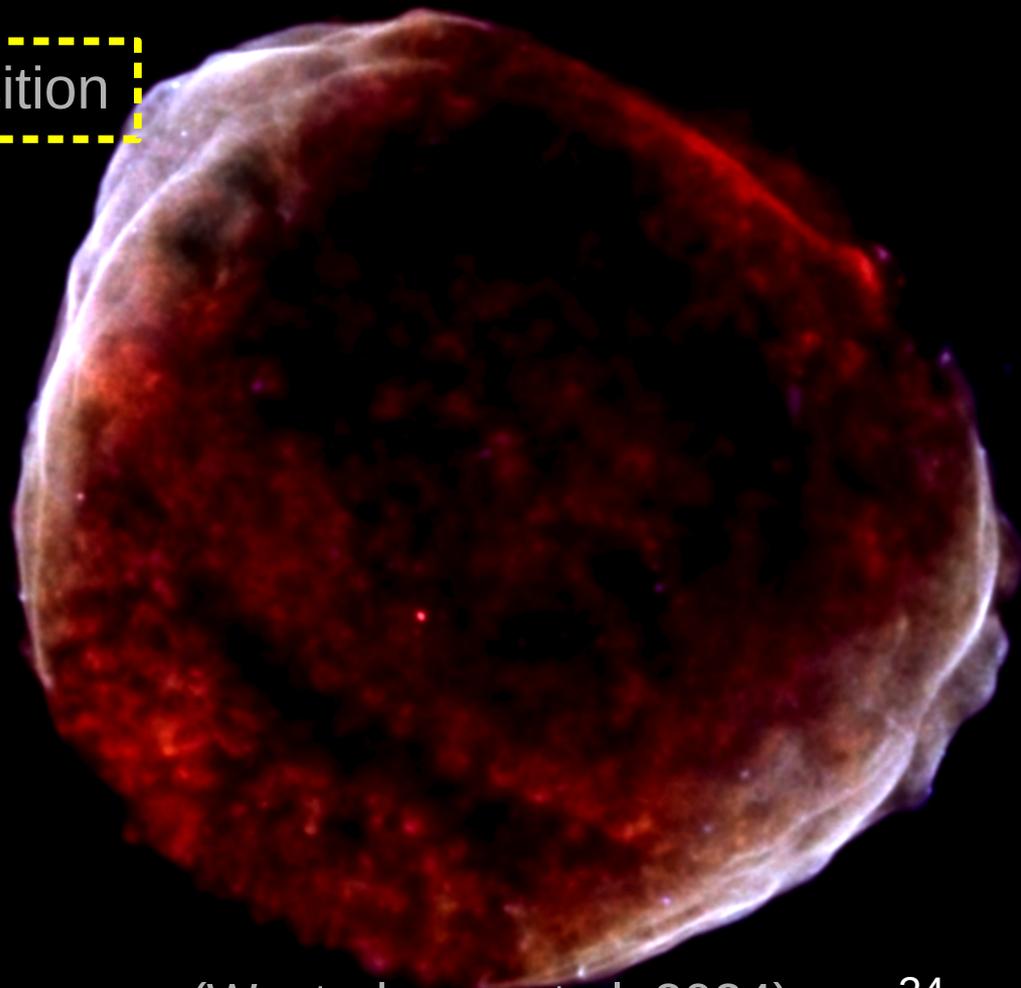
(Westerkamp et al. 2024)

Reconstructed Diffuse Emission



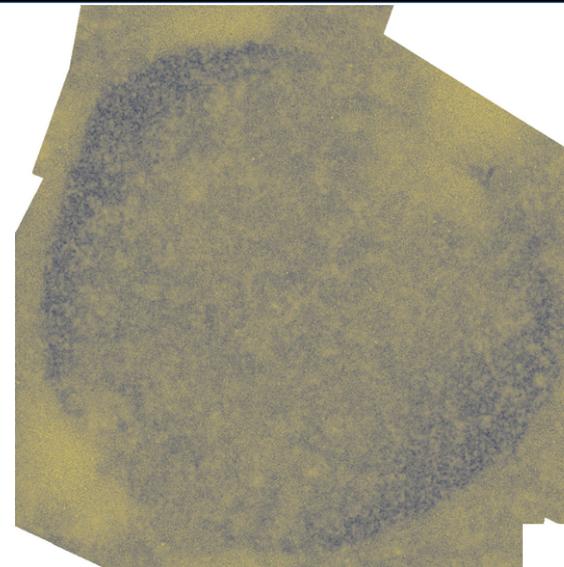
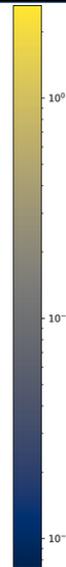
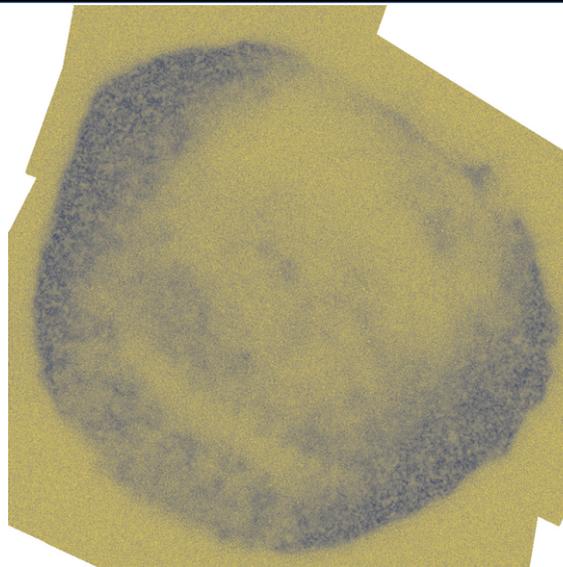
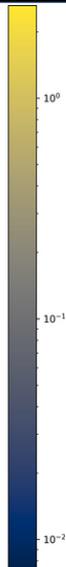
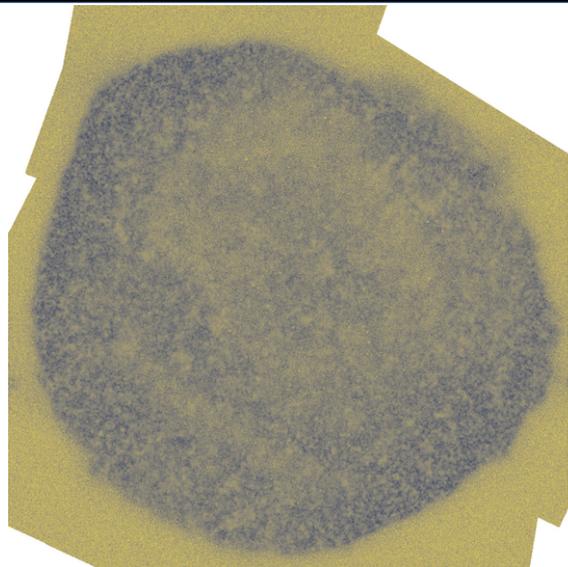
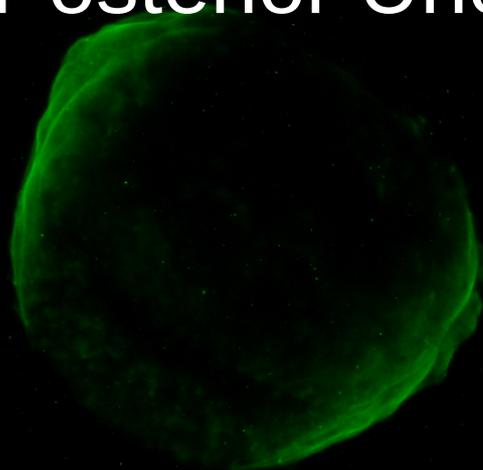
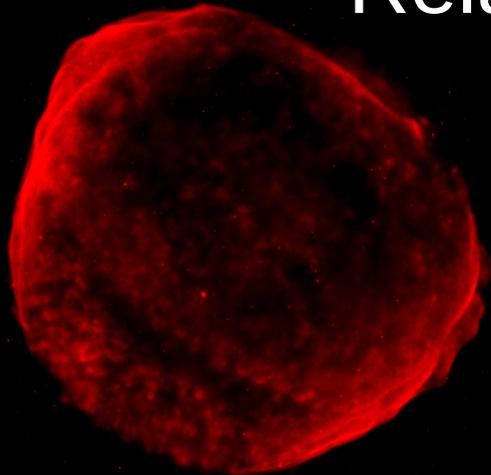
(Winkler et al. 2014)

Decomposition



(Westerkamp et al. 2024)

Relative Posterior Uncertainties



LIKELIHOOD MODEL

PRIOR MODEL

Gauss

Poisson

...

Noise

Spatially varying

Spatially non-varying

PSF

Exposure

...

Instrument

Models

Signal

Dimensions

Space

Time

Energy

Polarization

...

Sources

Diffuse emission

Point sources

Emission lines

...

Universal

Bayesian

Imaging

Kit



UBIK

Numerics

Inference

NIFTY



Minimizer

Autodiff

...

MAP

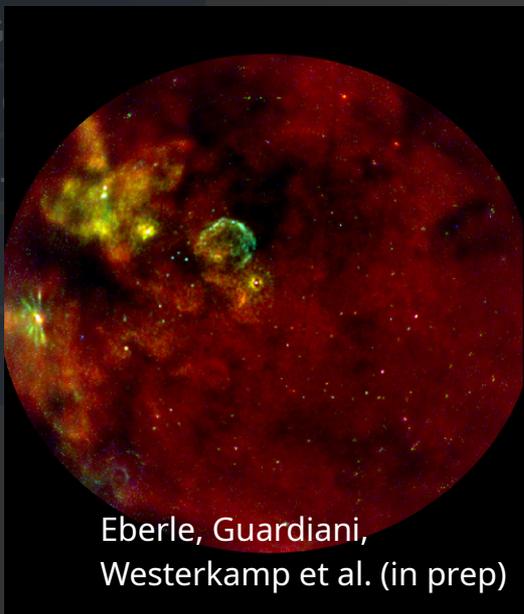
VI

HMC

...

geoVI

MGVI



Eberle, Guardiani,
Westerkamp et al. (in prep)

Spatially
varying

Spatially
non-varying

PRIOR MODEL

Dimensions

- Space
- Time
- Energy
- Polarization
- ...

Signal

Sources

- Diffuse emission
- Point sources
- Emission lines
- ...

Models

Bayesian



Kit

Imaging

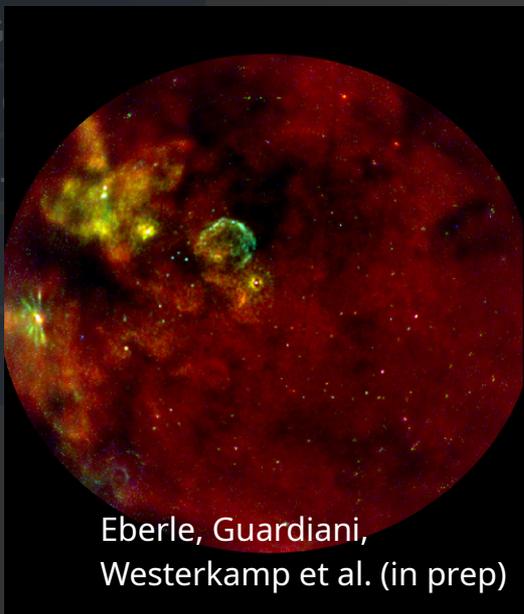
NIFTY

Numerics

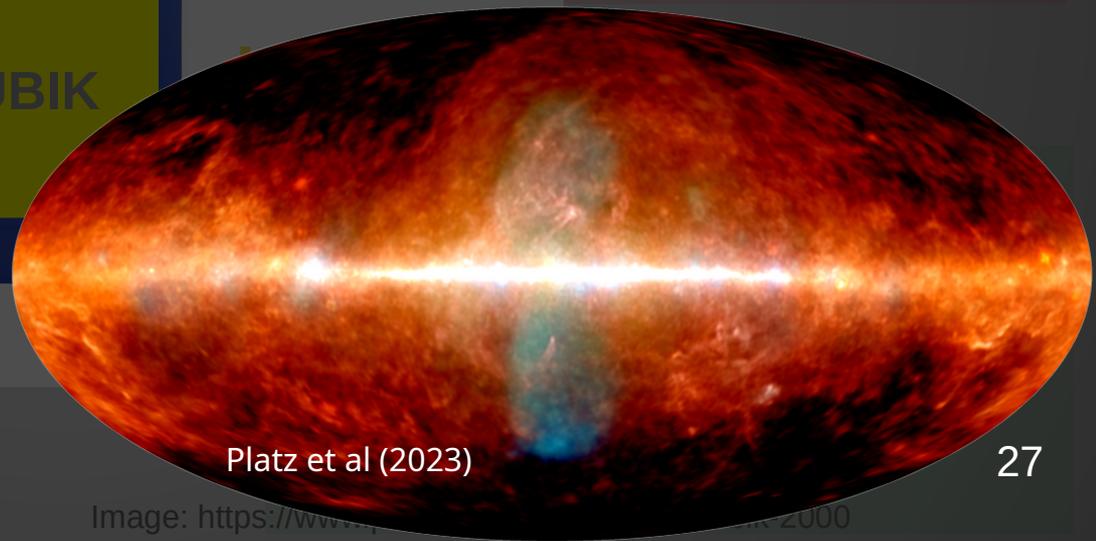
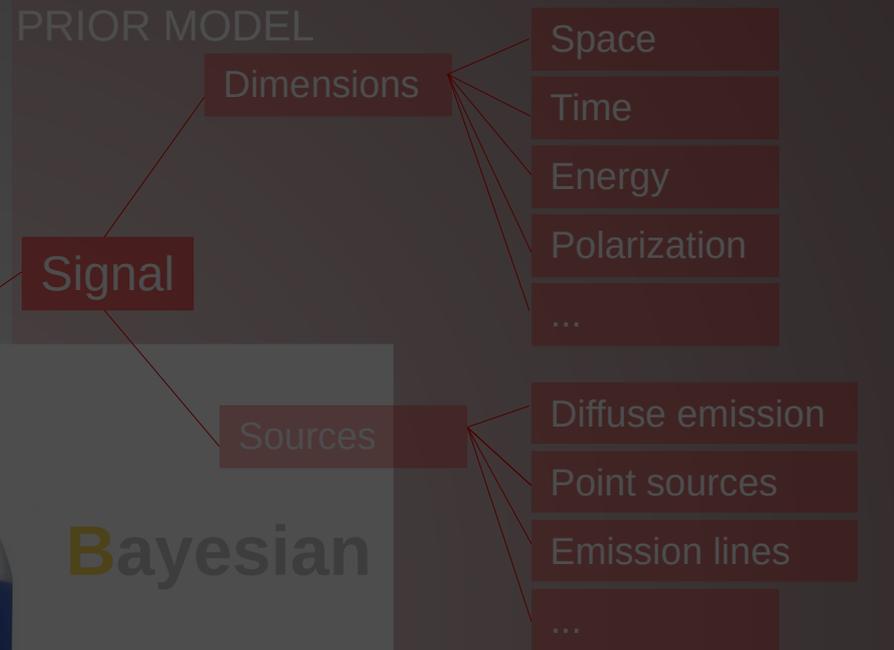
Inference

- MAP
- VI
 - geoVI
 - MGVI
- HMC
- ...

- Minimizer
- Autodiff
- ...

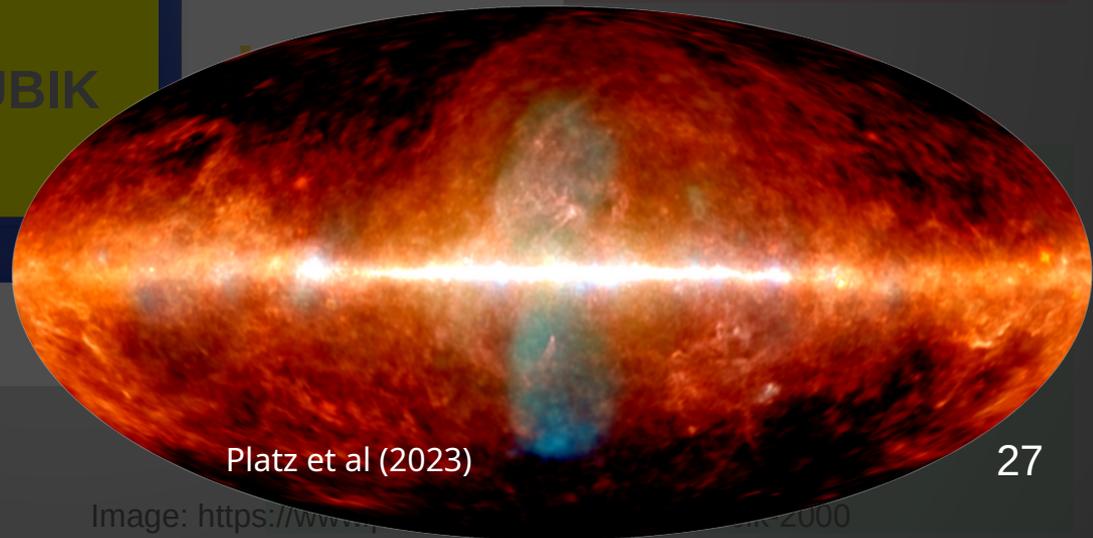
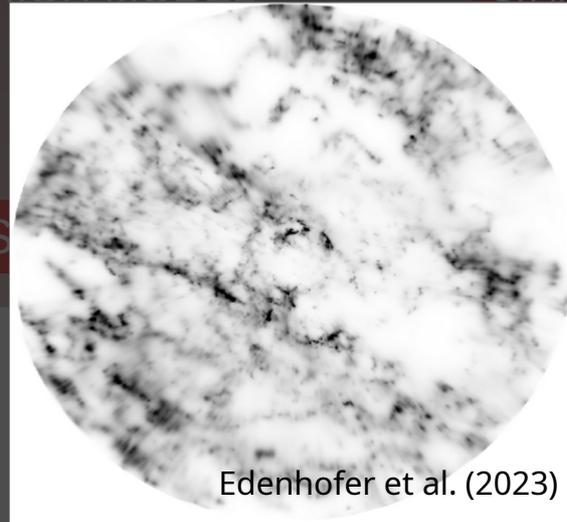
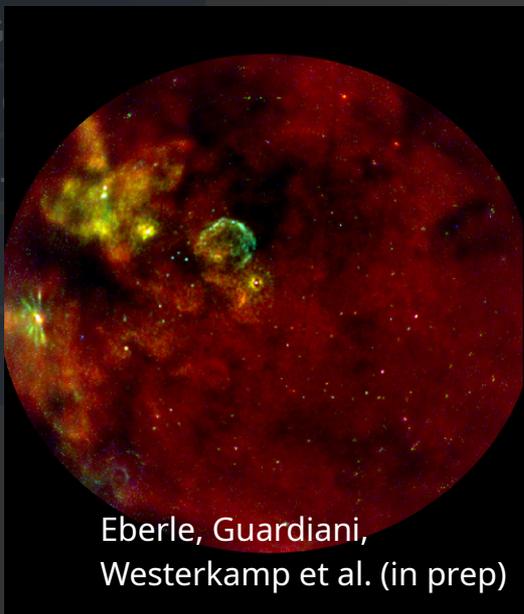


Eberle, Guardiani,
Westerkamp et al. (in prep)



Platz et al (2023)





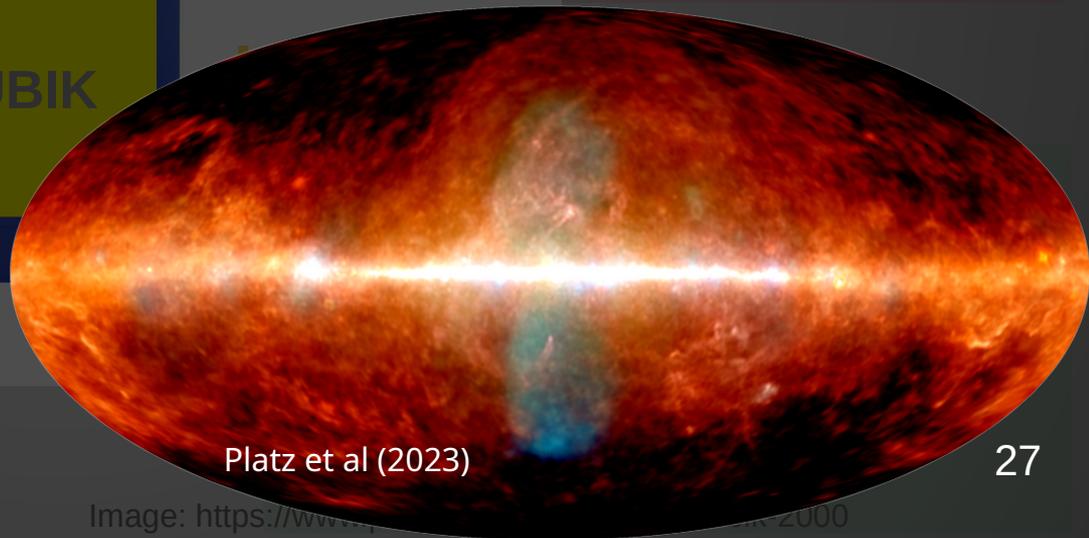
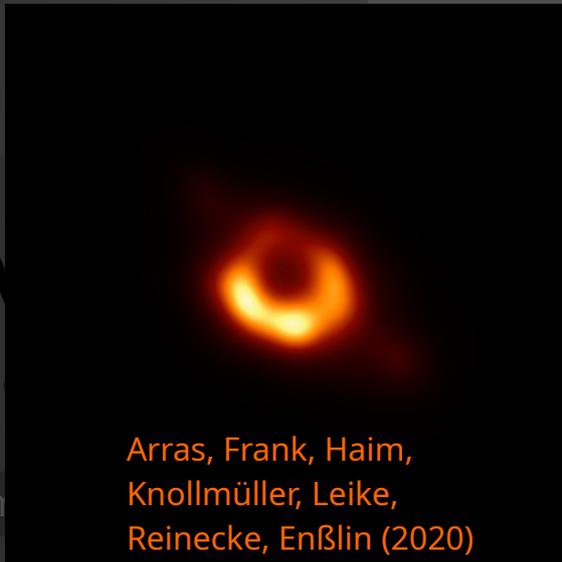
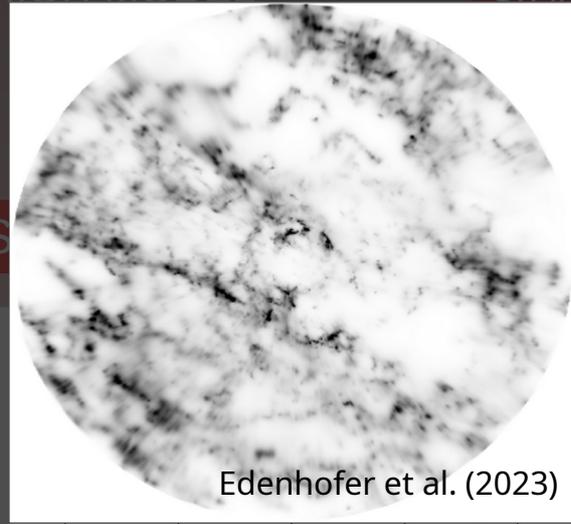
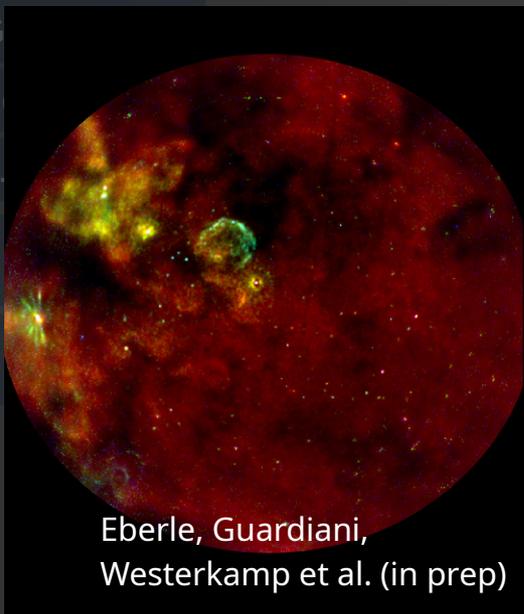
NIFTY

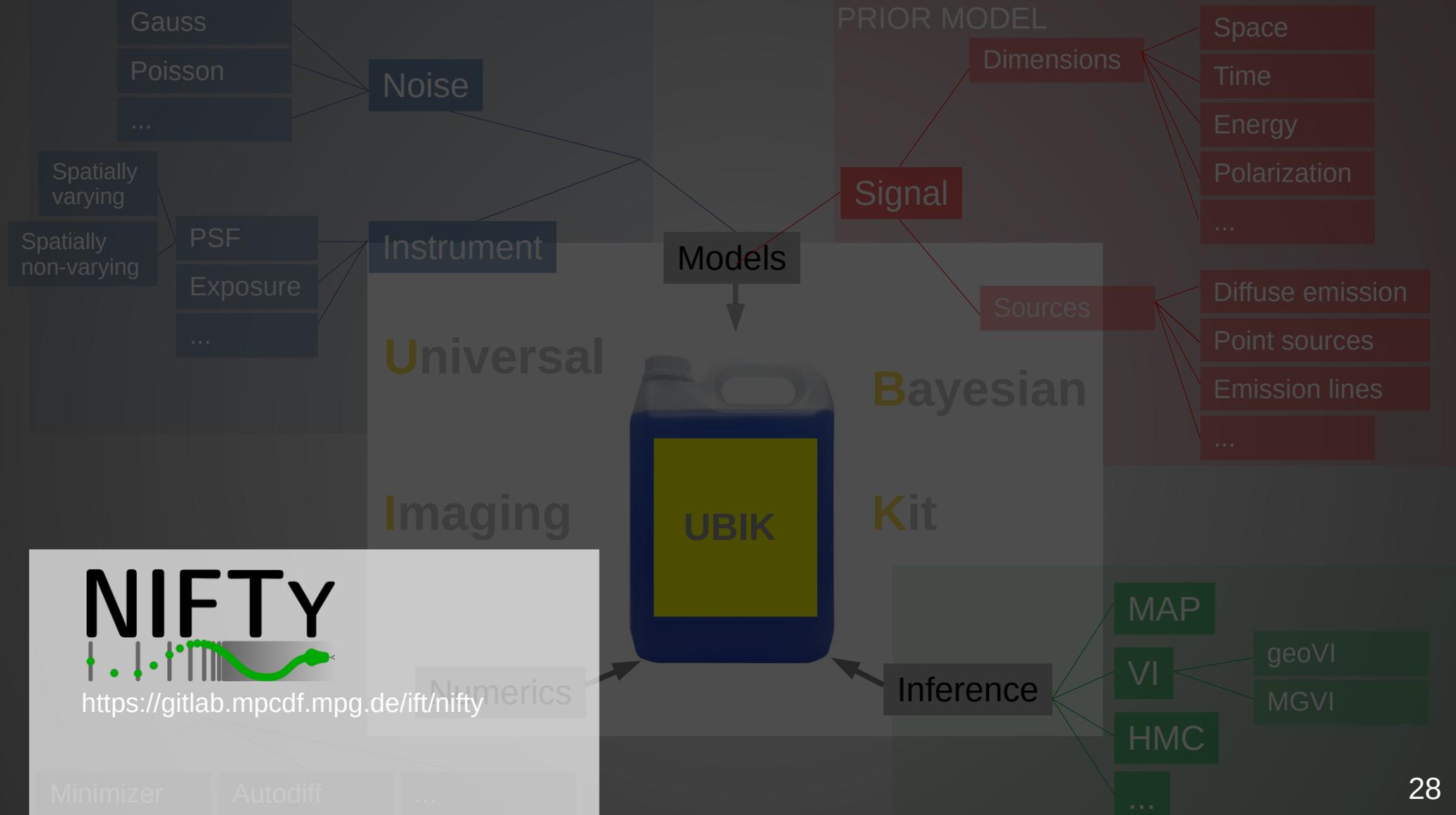
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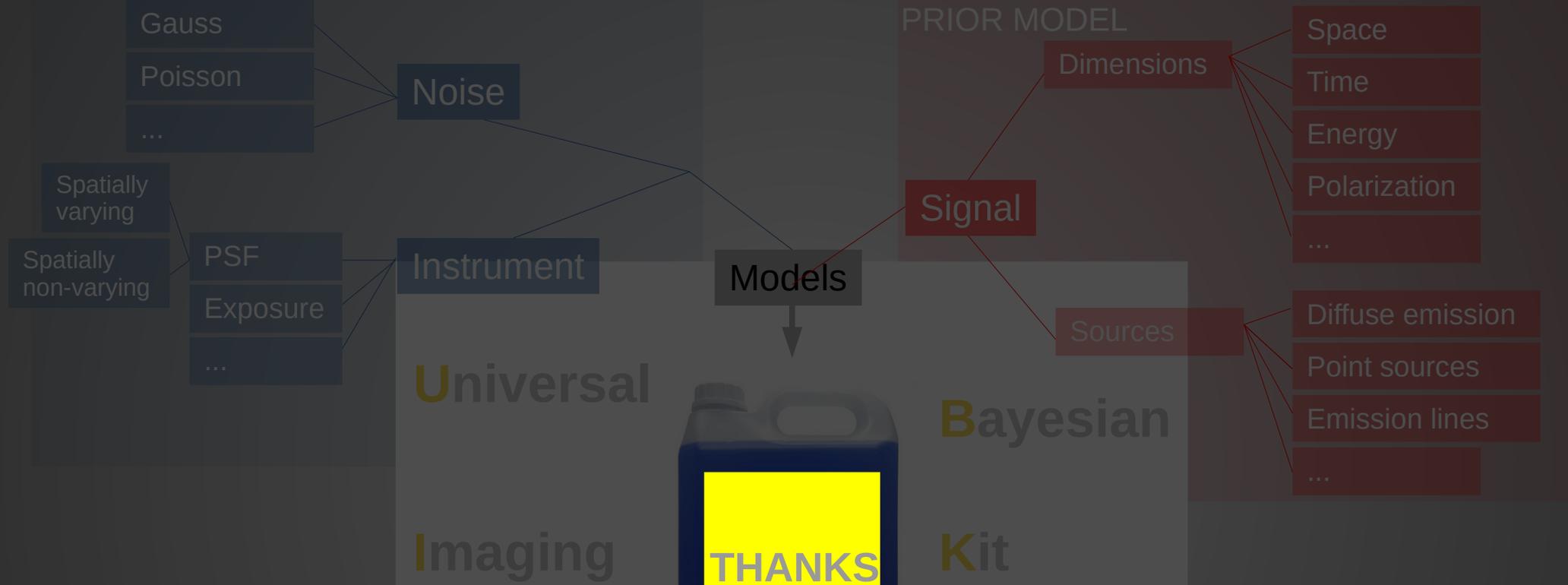
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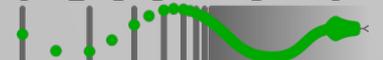


NIFTY

<https://gitlab.mpcdf.mpg.de/ift/nifty>



NIFTY



<https://gitlab.mpcdf.mpg.de/ift/nifty>

Margret Westerkamp
 Mi margret@mpa-garching.mpg.de

