Universal Bayesian Imaging Kit

Vincent Eberle, Torsten Enßlin,
Matteo Guardiani, Margret Westerkamp

DLR

MAX PLANCK INSTITUTE
FOR ASTROPHYSICS

DZA

“Safe when taken as directed.” Philip K. Dick

Universal **B**ayesian **I**maging **K**it

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"I came over to Ubik after
trying weak,
out-of-date reality supports.
My pots and pans
were turning into
heaps of rust.
The floors of my
conapt were
sagging."
ubik
But now I use economical
new powerful
today's Ubik,
and with miraculous results.
ubik
Entirely harmless if used as directed!

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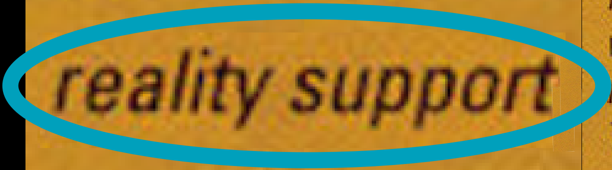
reality support


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Universal

Bayesian

Imaging

Kit

Digital Perception of Reality

Digital Perception of Reality

sky signal

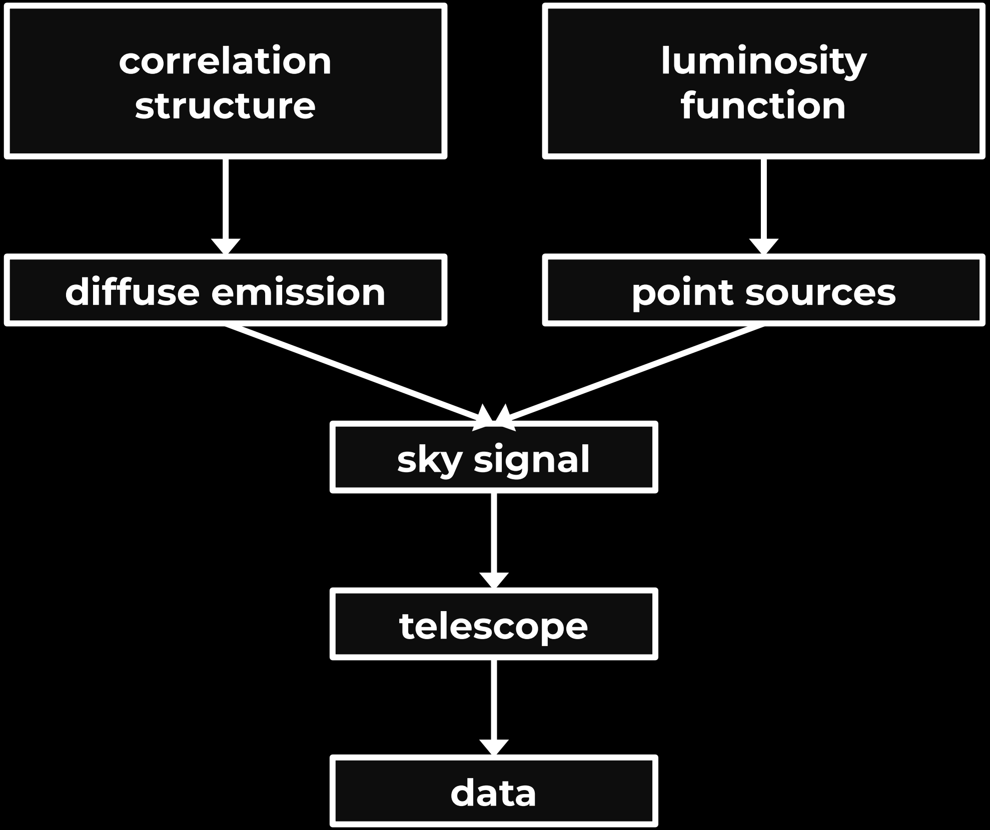
↓

telescope

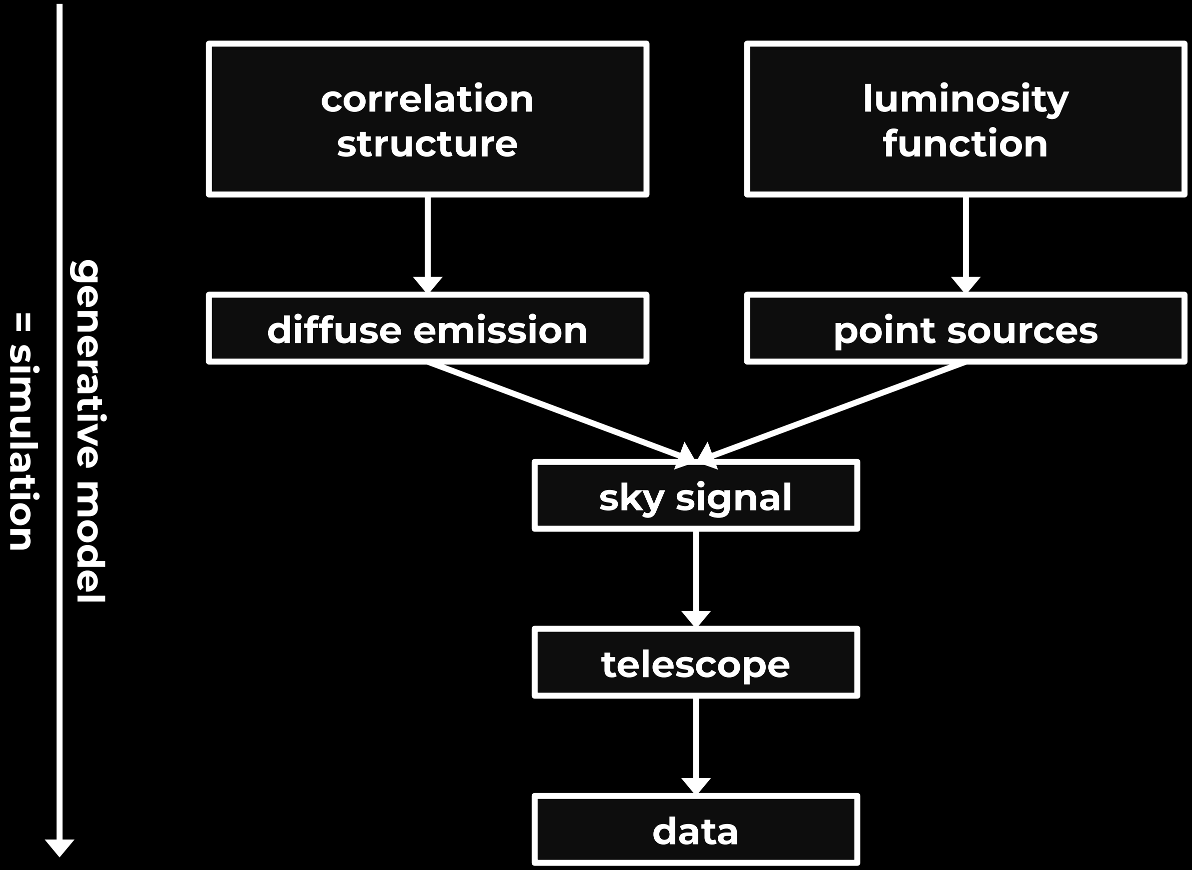
↓

data

Digital Perception of Reality



Digital Perception of Reality



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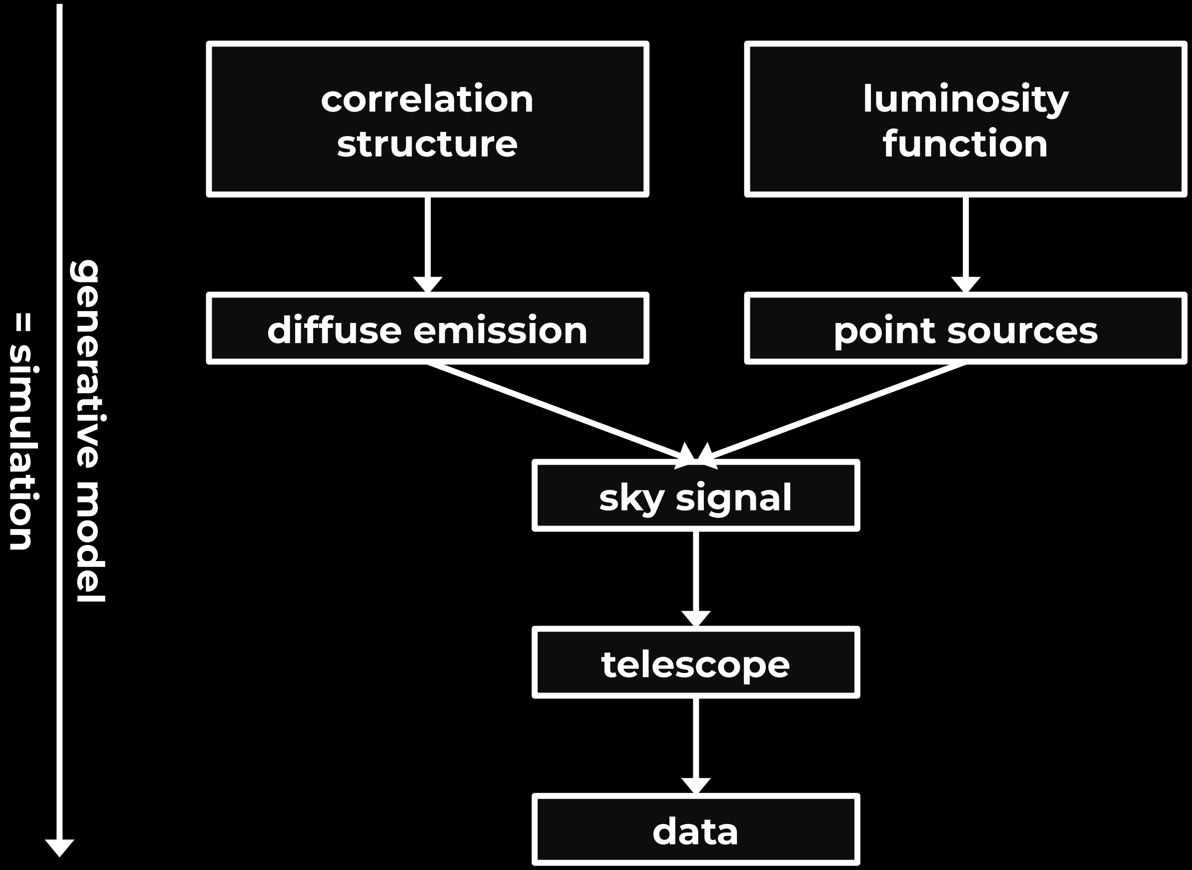

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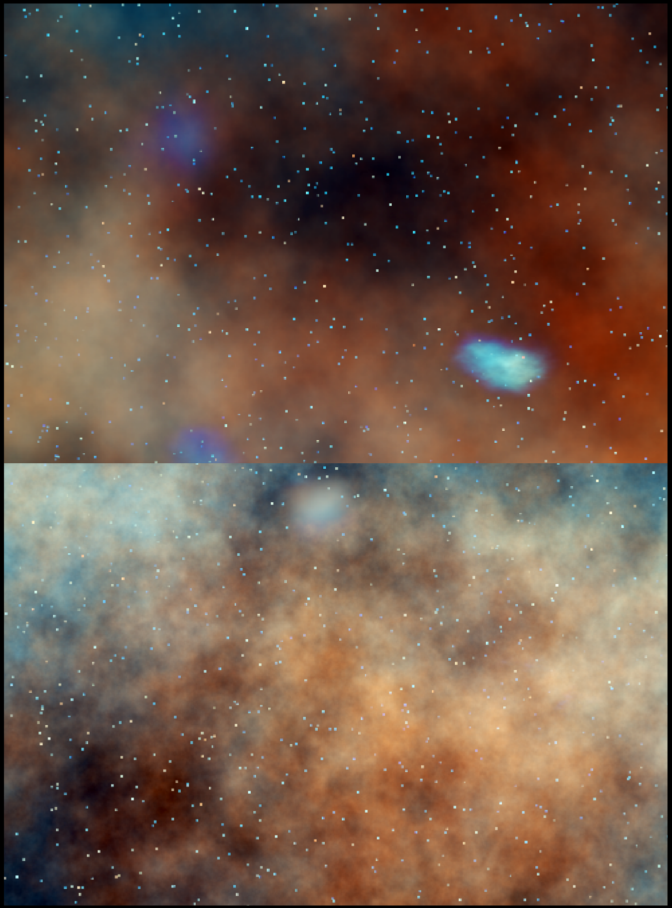

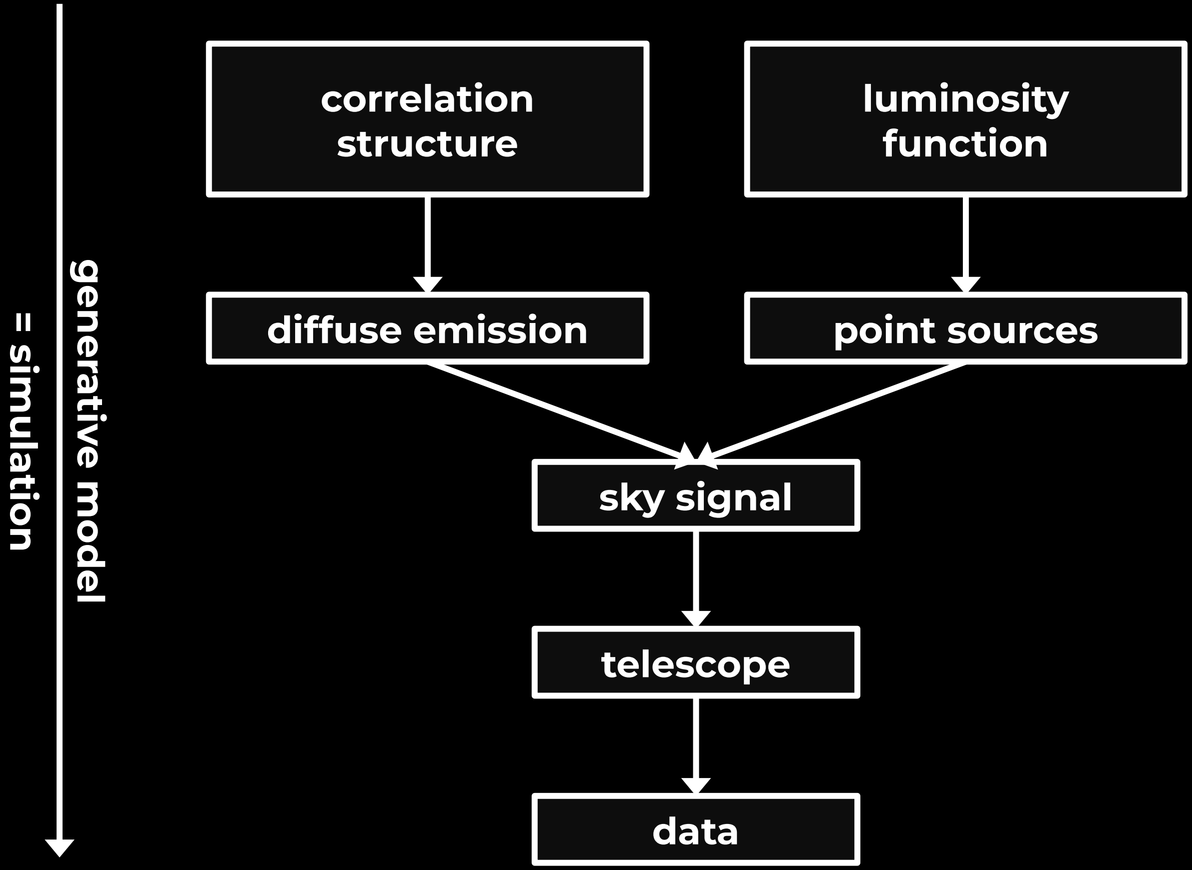

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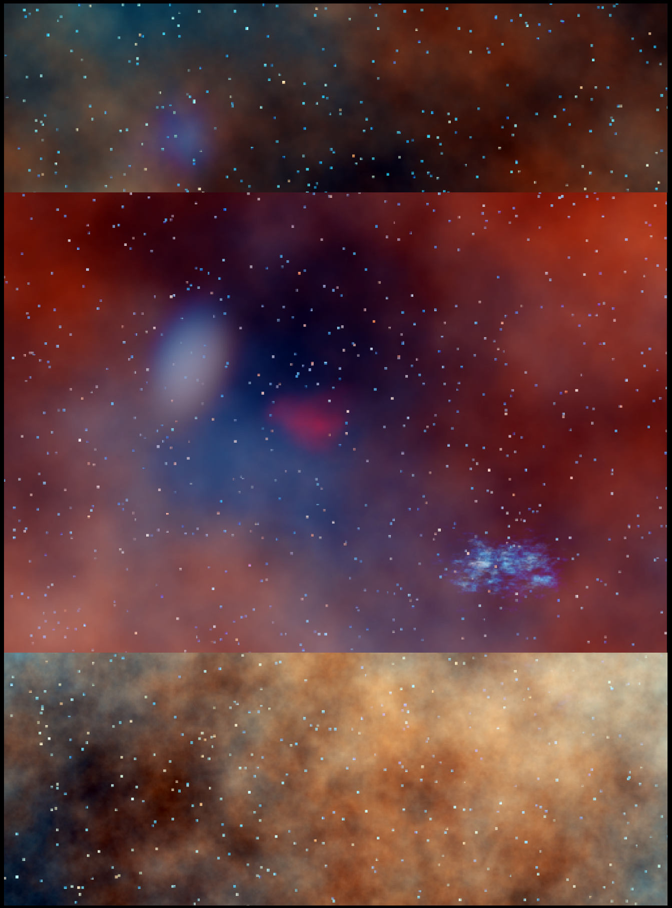

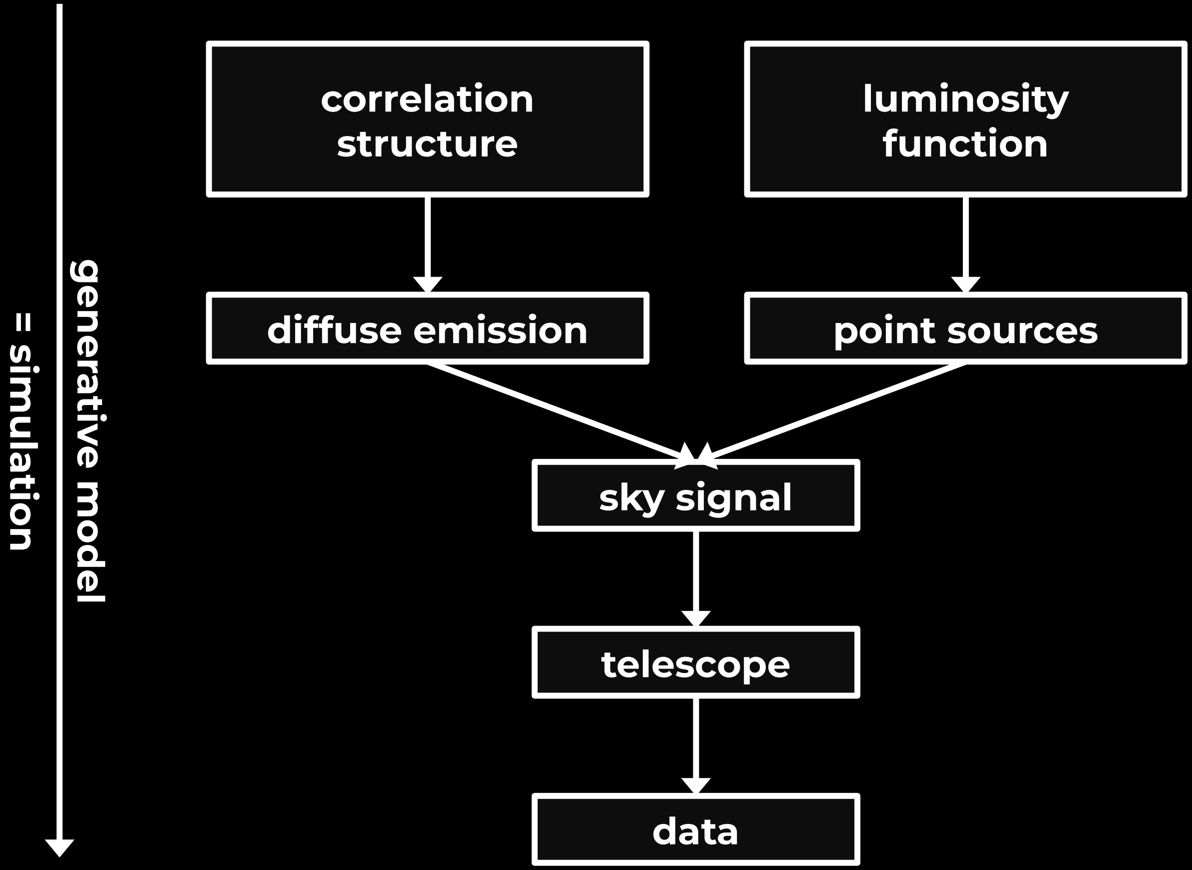

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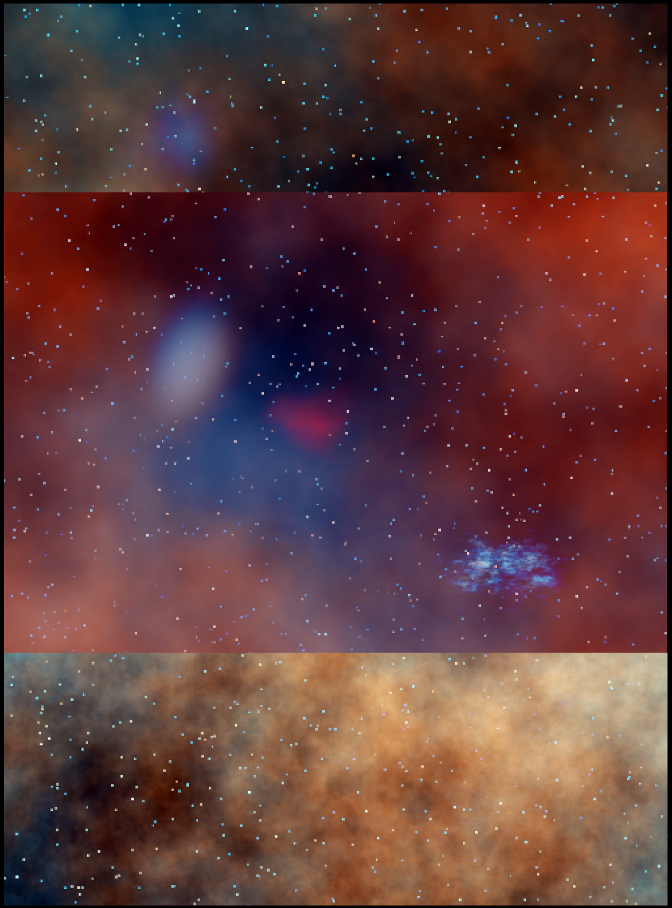

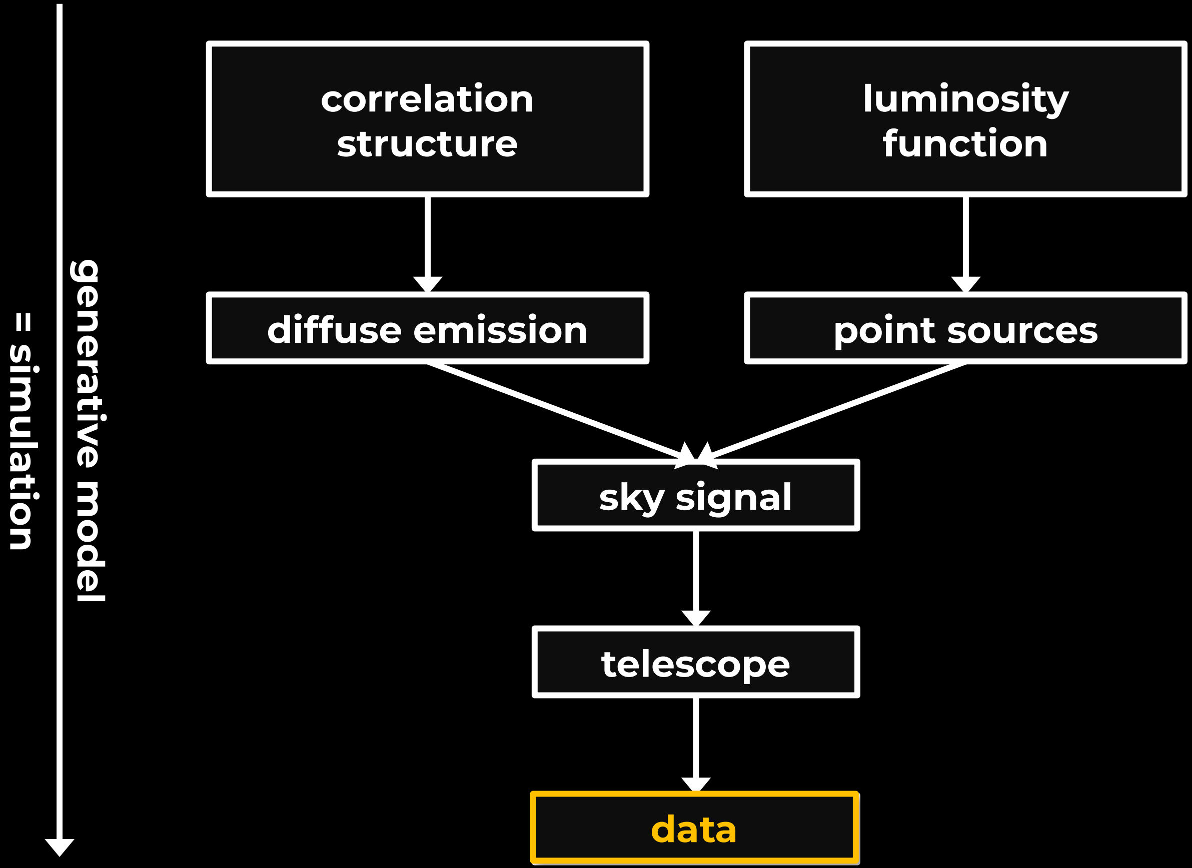

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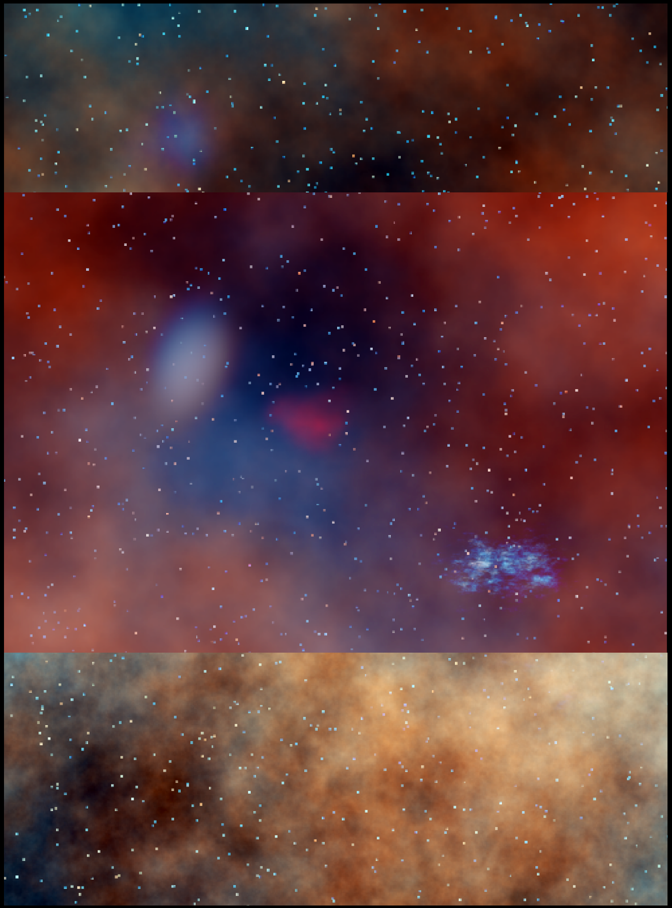
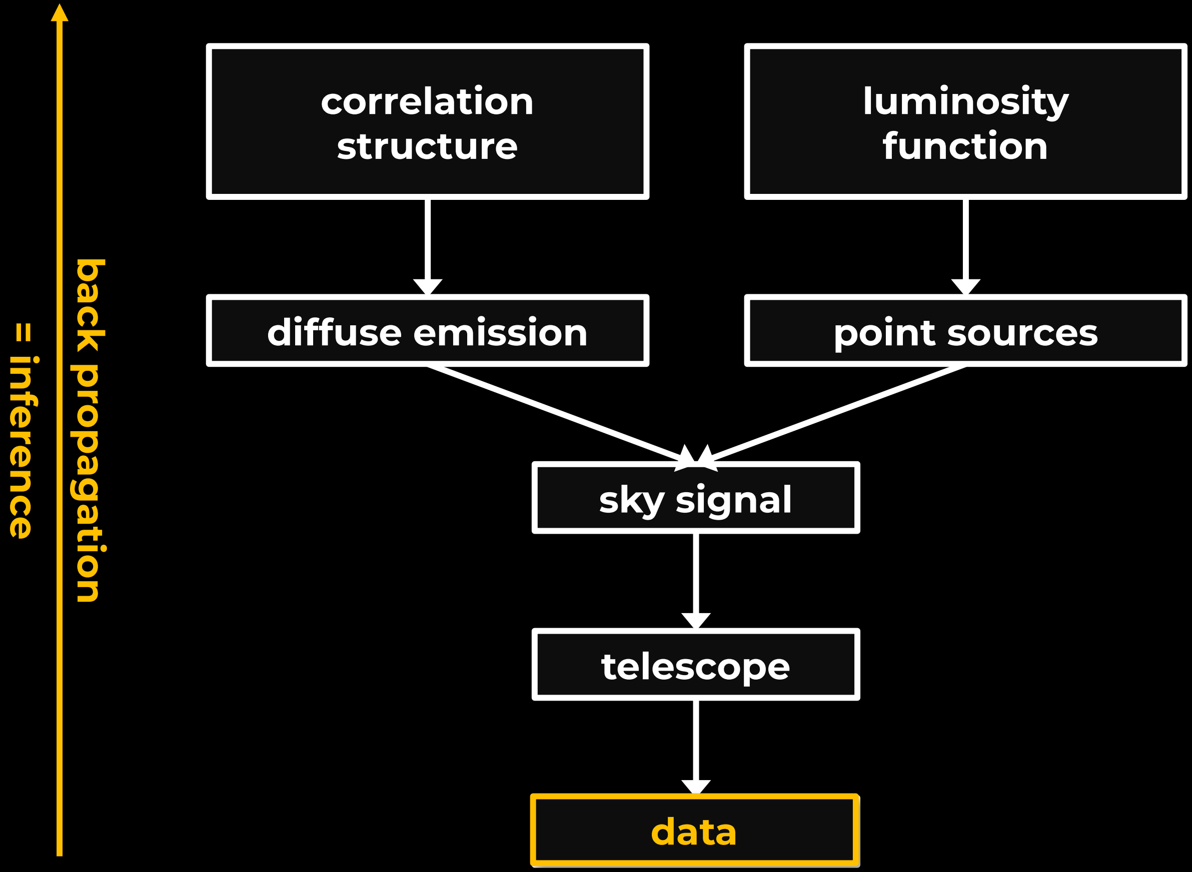
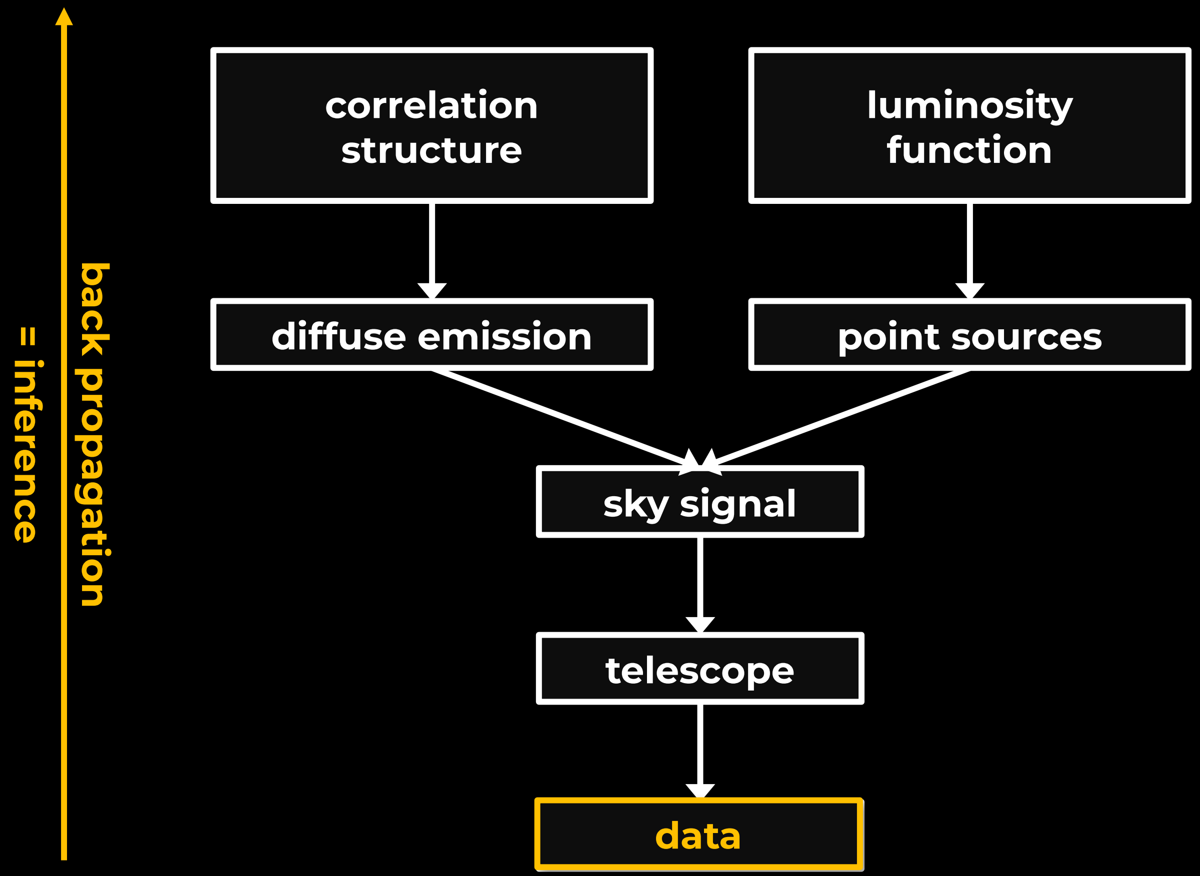
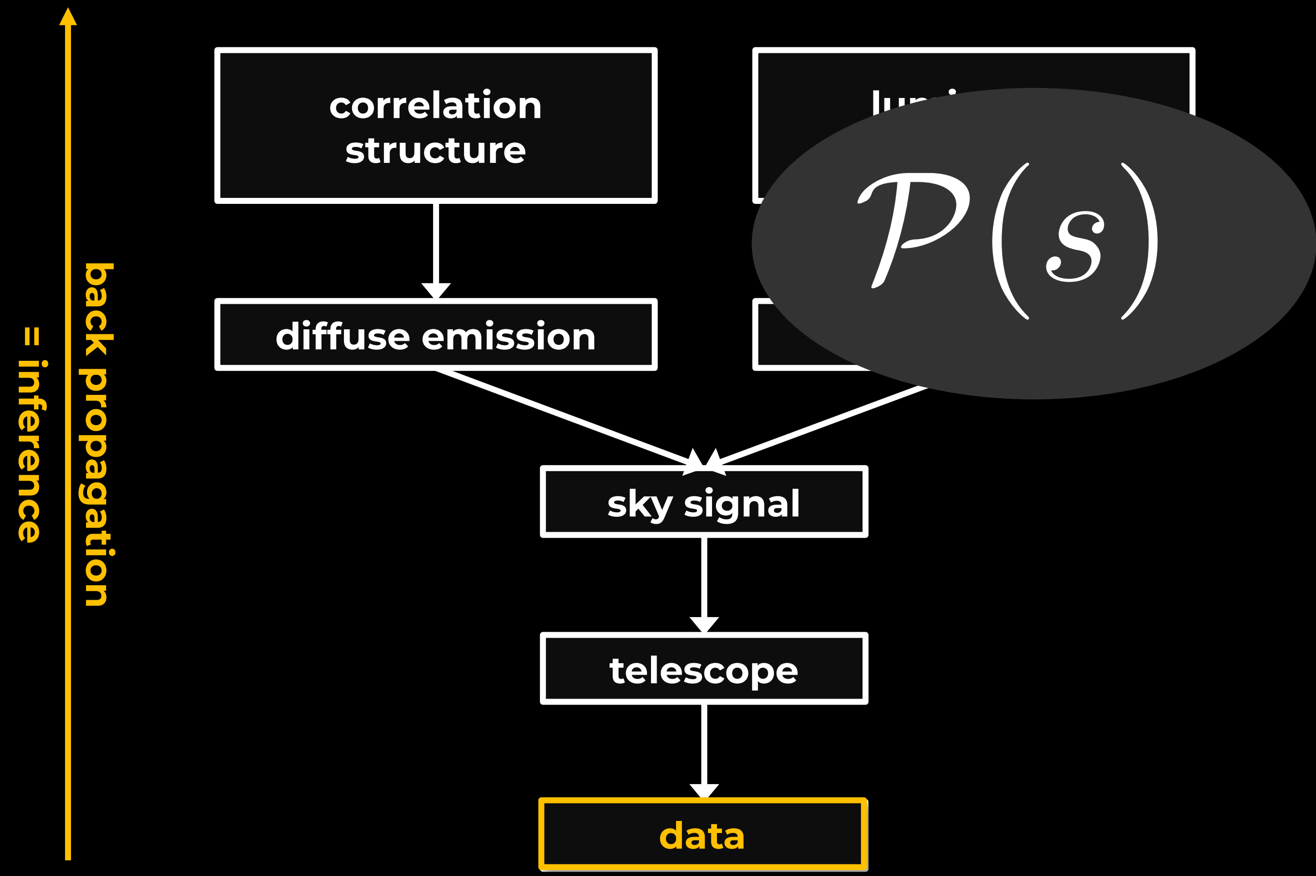





back propagation
= inference
correlation structure
luminosity function
diffuse emission
point sources
sky signal
telescope
data


= inference
back propagation
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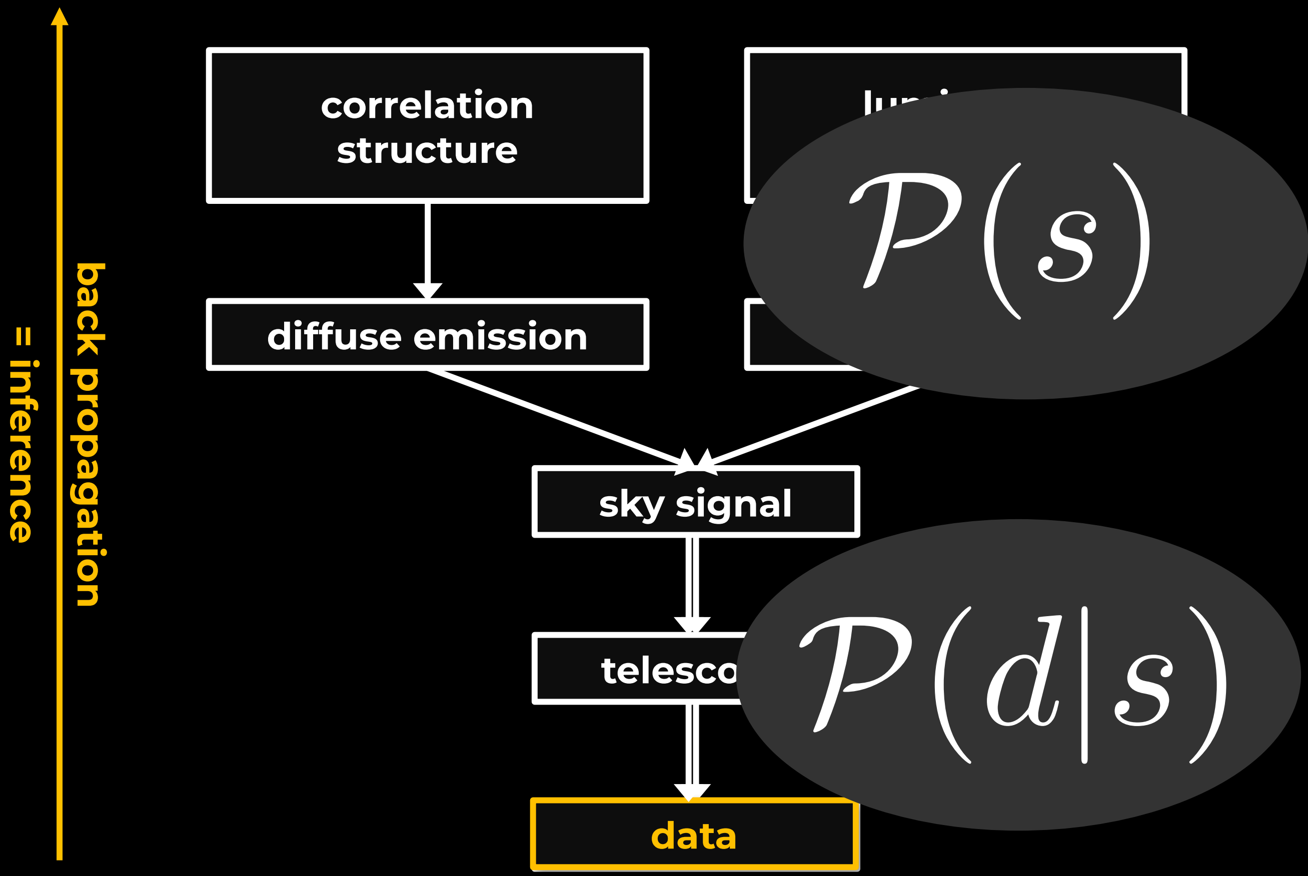
data
$\mathcal{P}(s)$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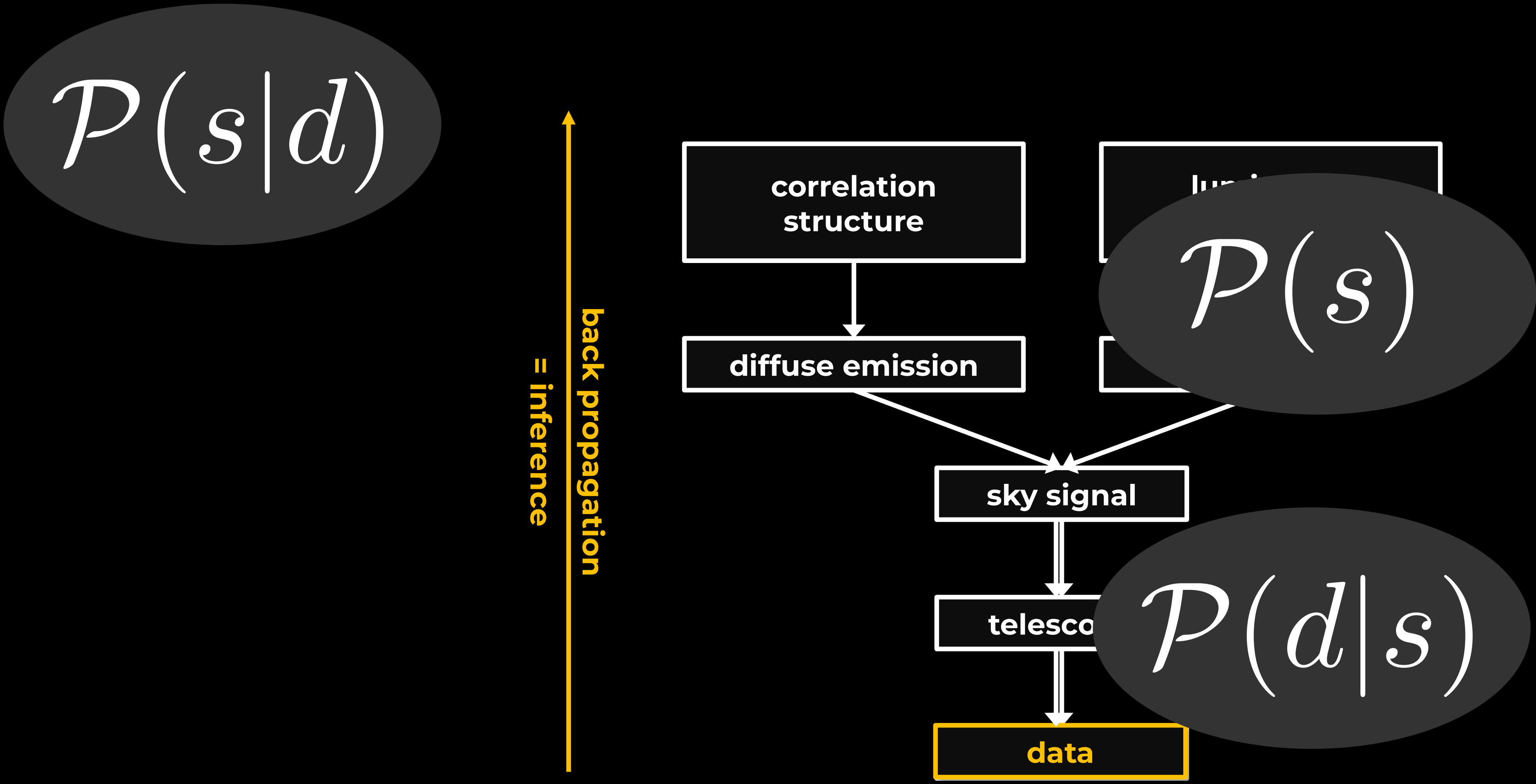
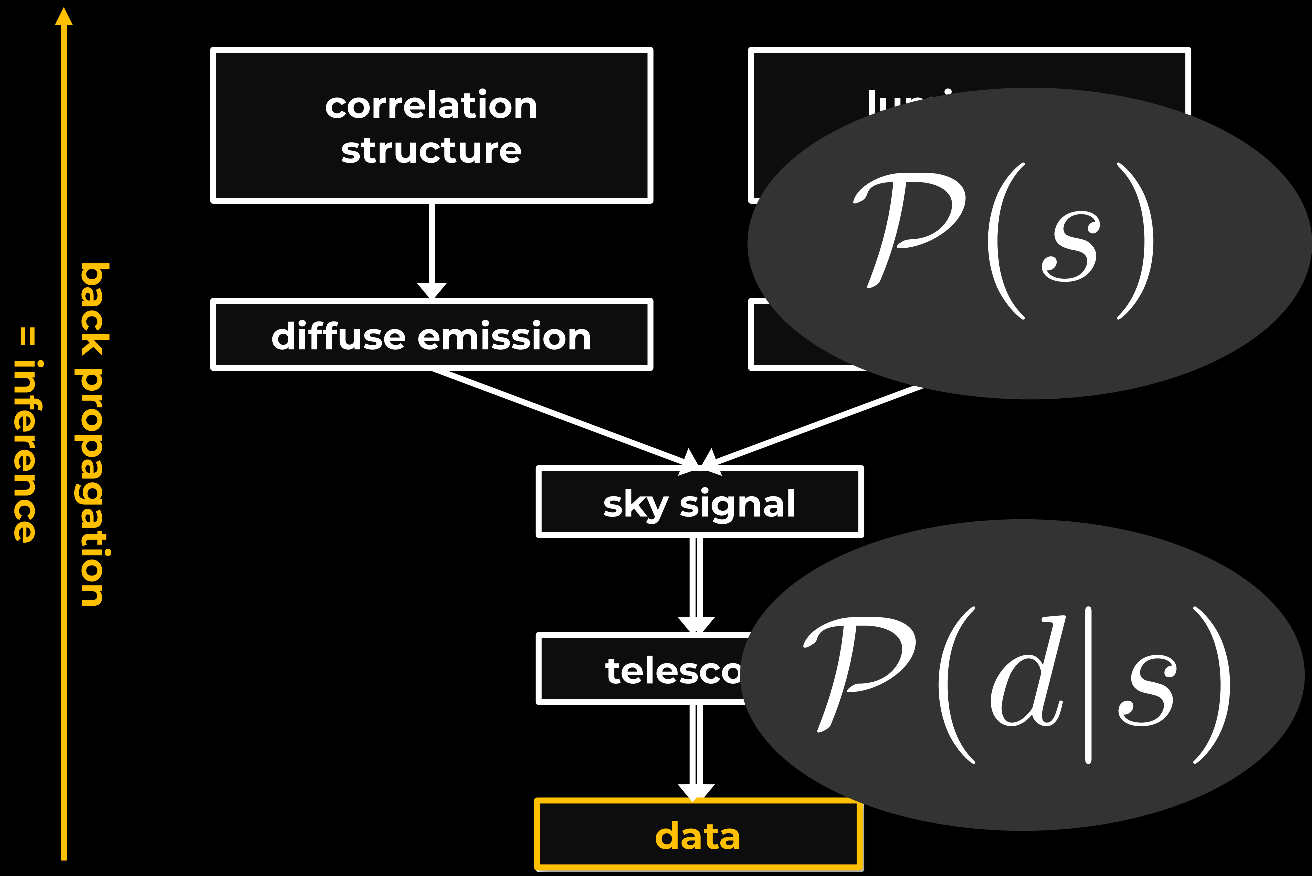
$\mathcal{P}(s)$
$\mathcal{P}(d|s)$



$\mathcal{P}(s|d)$
back propagation
= inference
correlation structure
diffuse emission
$\mathcal{P}(s)$
sky signal
$\mathcal{P}(d|s)$
data

$$\mathcal{P}(s|d)$$

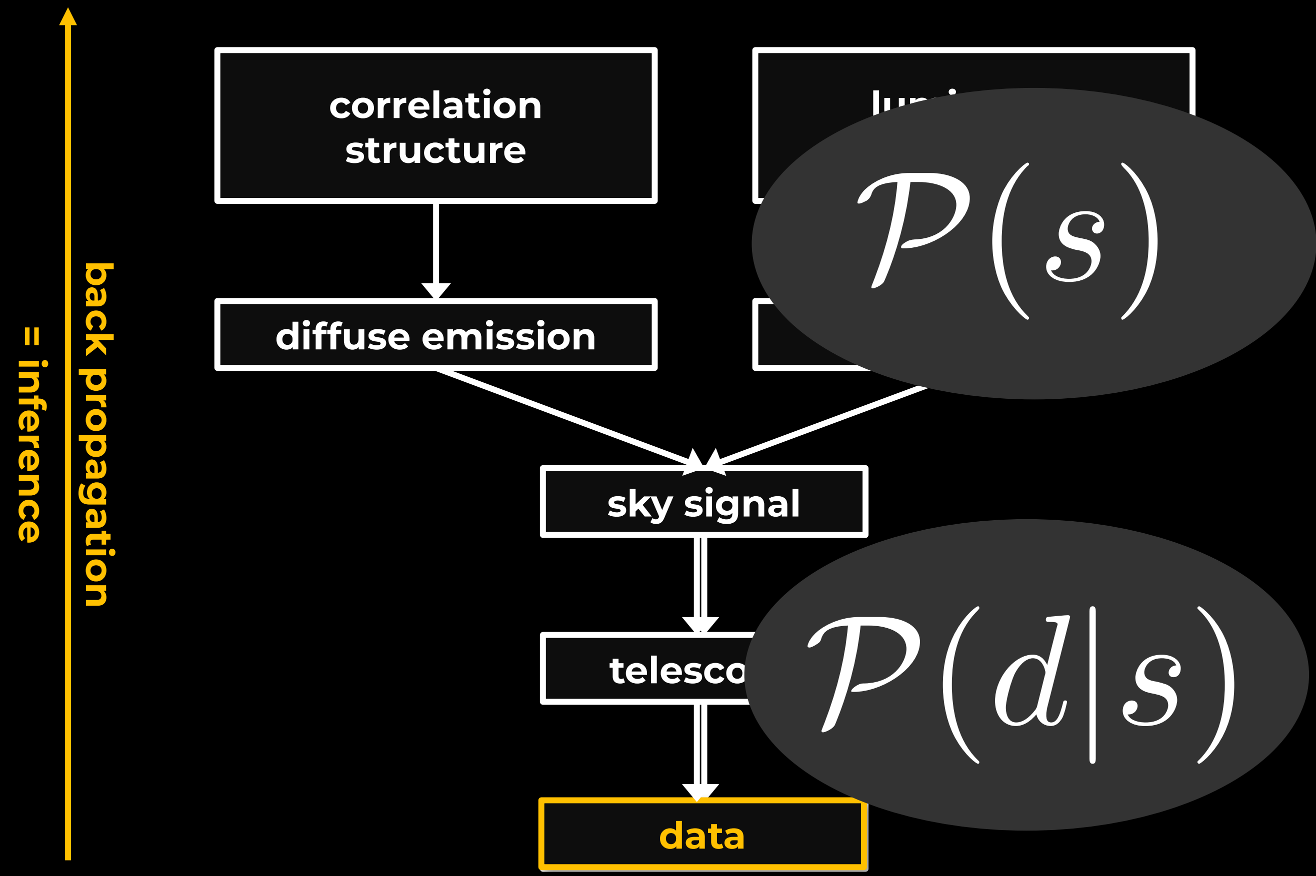
$$s = f(\xi)$$



$$\mathcal{P}(s|d)$$

$$s = f(\xi)$$

$$\mathcal{P}(\xi) = \mathcal{G}(\xi, \mathbb{1})$$



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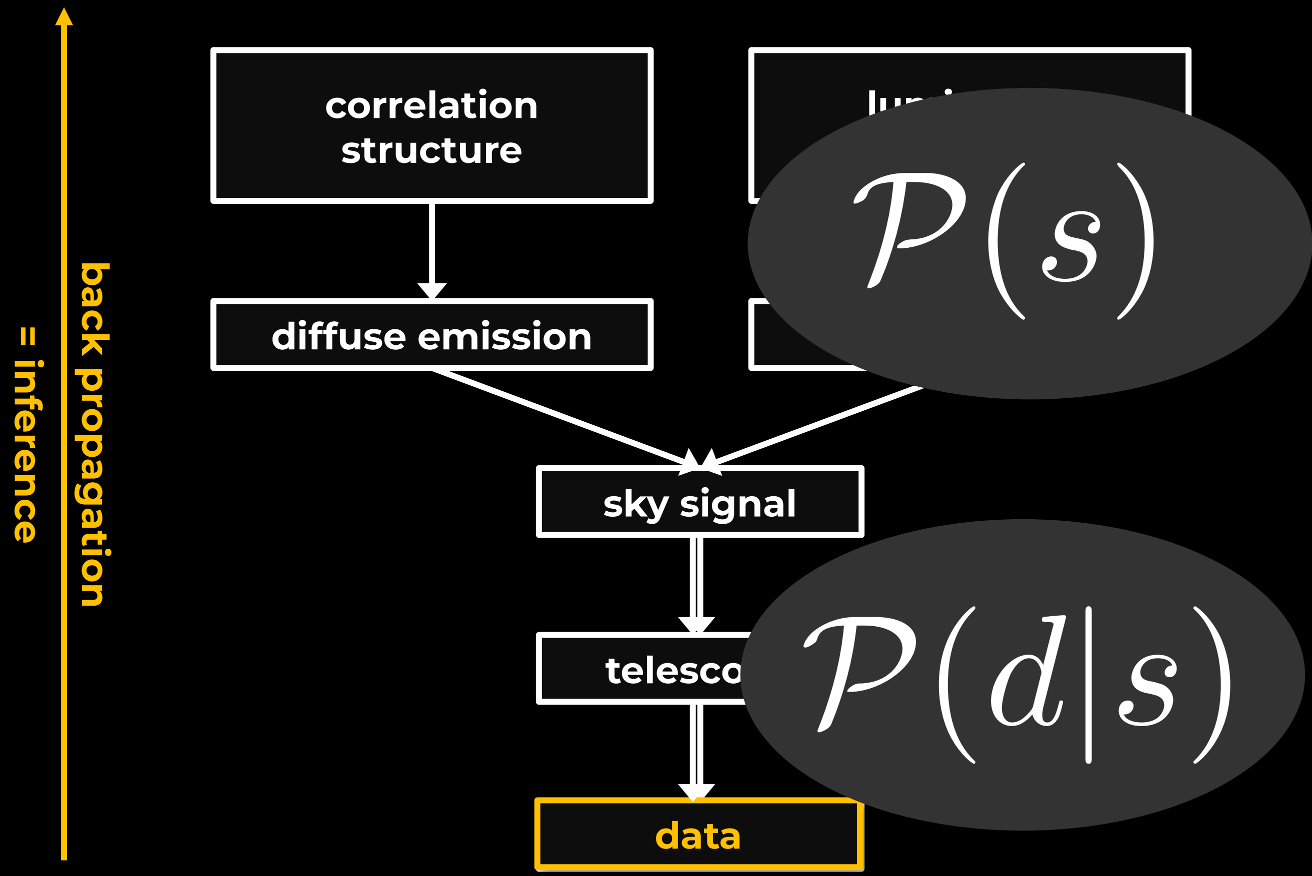

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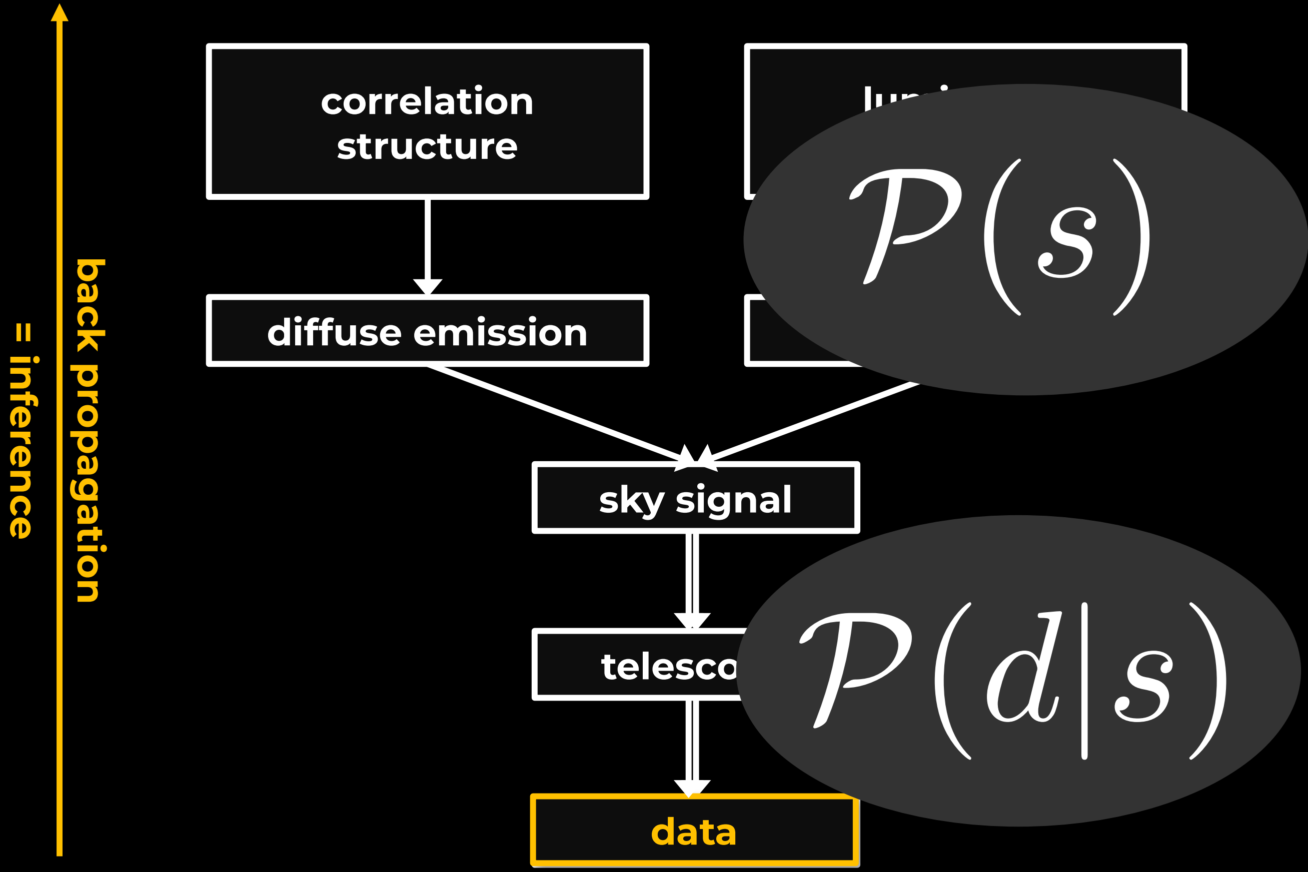

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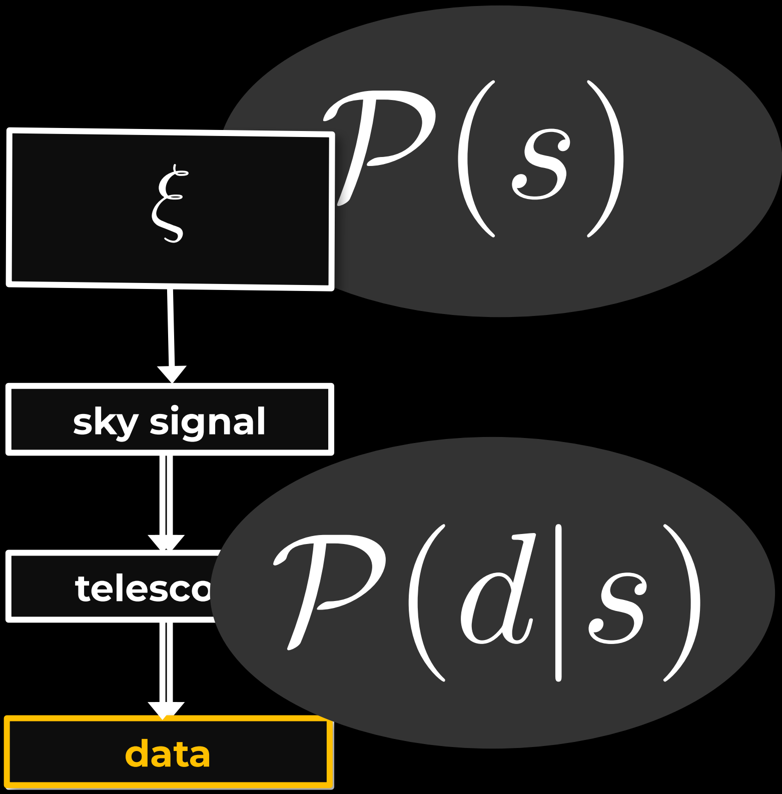


$$\mathcal{P}(s|d)$$

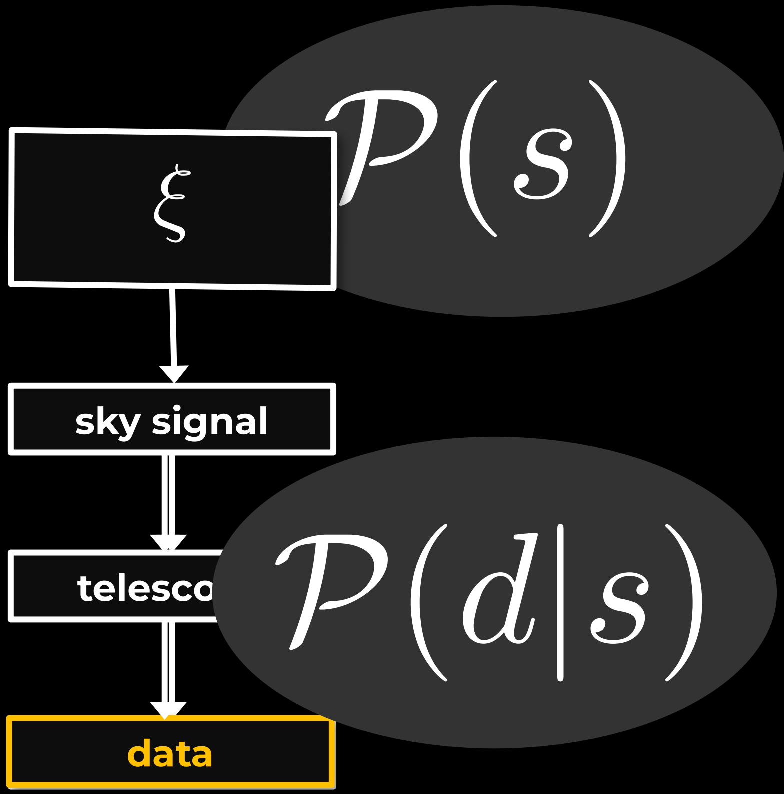
$$s = f(\xi)$$

$$\mathcal{P}(\xi) = \mathcal{G}(\xi, \mathbb{1})$$

$$\mathcal{P}(\xi|d) \approx \mathcal{G}(\xi - \bar{\xi}, [\mathbb{1} + \mathcal{M}_{d|\bar{\xi}}]^{-1})$$

back propagation

= inference



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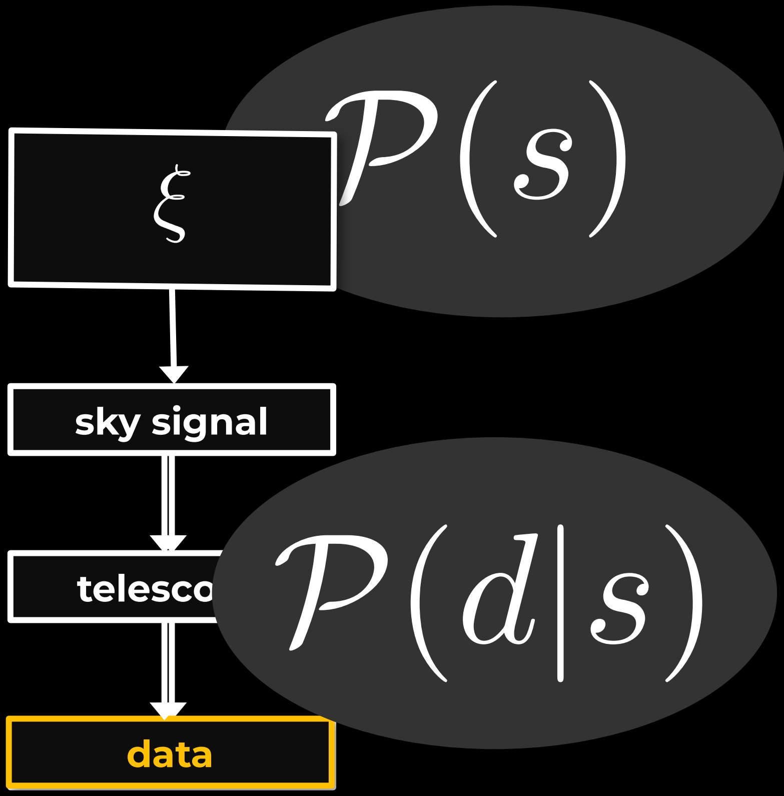

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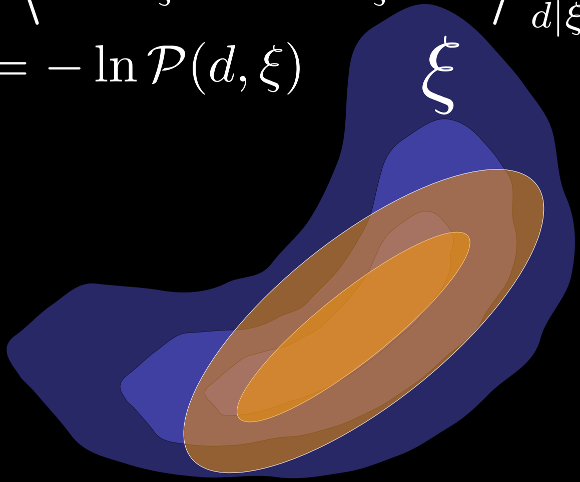
$$\mathcal{M}_{d|\bar{\xi}} = \left\langle \frac{\partial \mathcal{H}(d,\xi)}{\partial \xi} \frac{\partial \mathcal{H}(d,\xi)}{\partial \xi}^{\dagger} \right\rangle_{d|\bar{\xi}}$$

$$\mathcal{H}(d,\xi) = -\ln \mathcal{P}(d,\xi)$$



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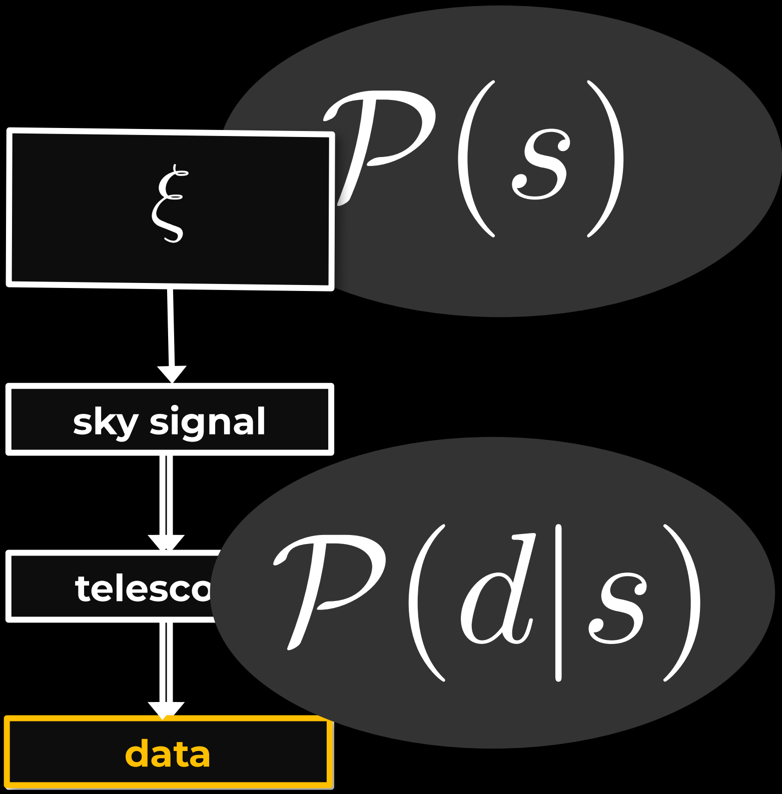

Metric Gaussian Variational Inference

Knollmüller & Enßlin (arXiv:1901.11033)

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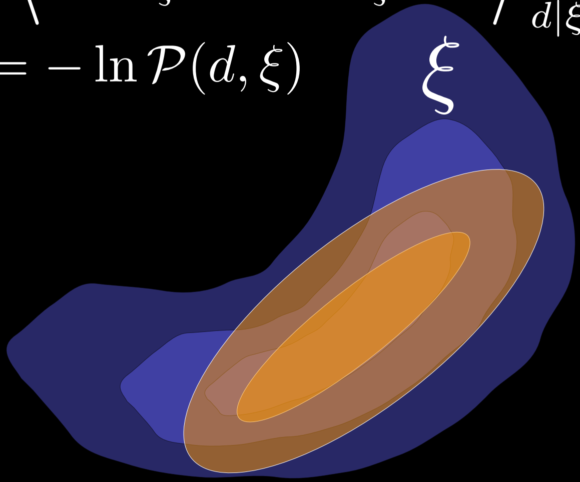
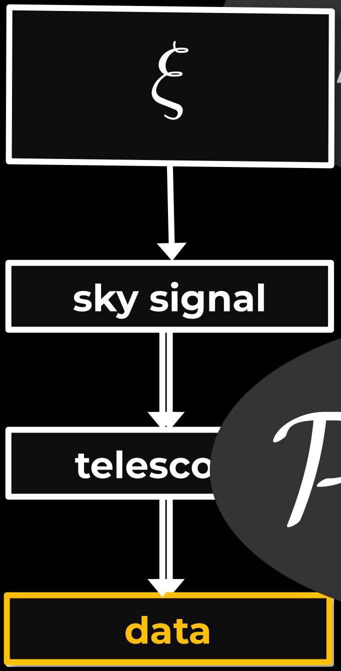


back propagation

= inference

$$\mathcal{P}(s)$$



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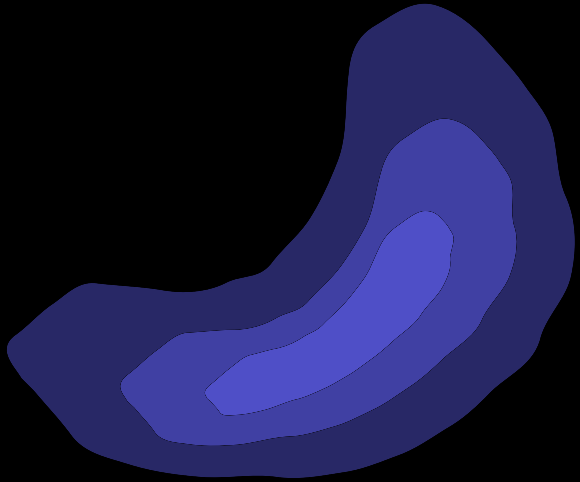

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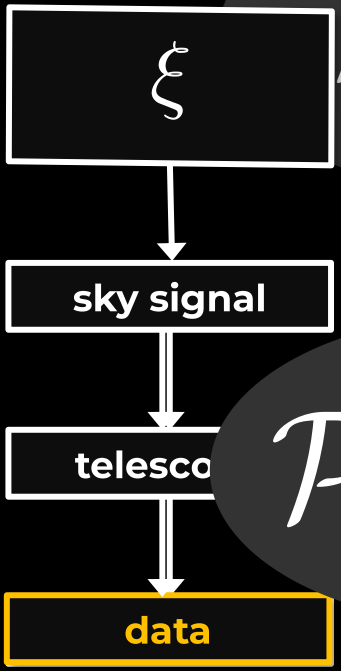

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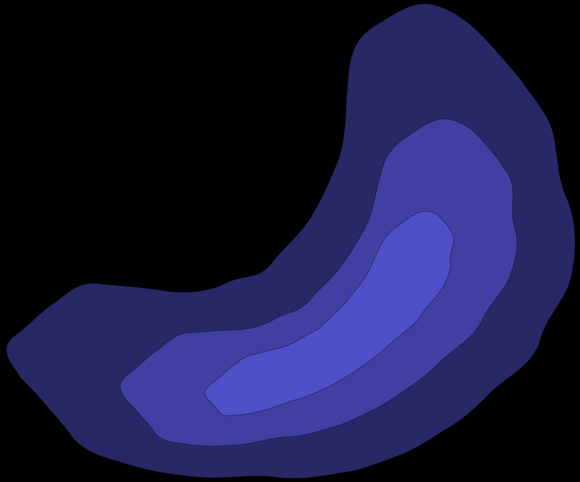

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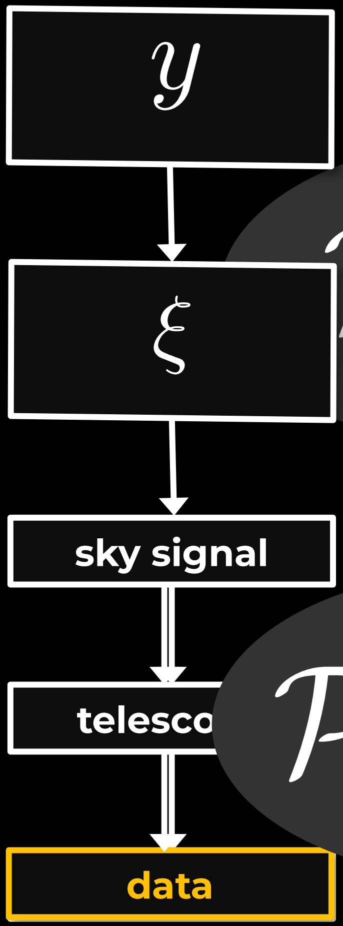

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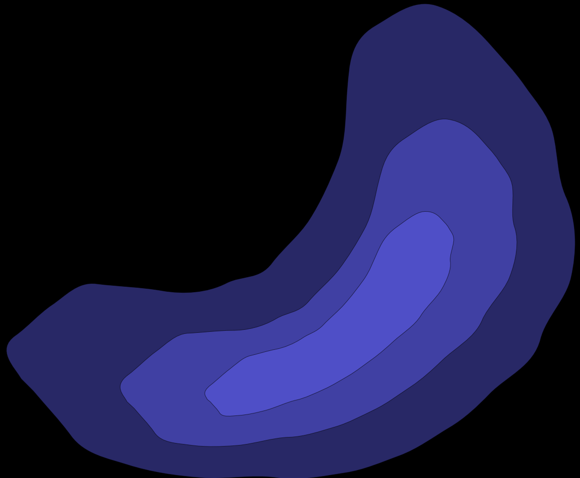

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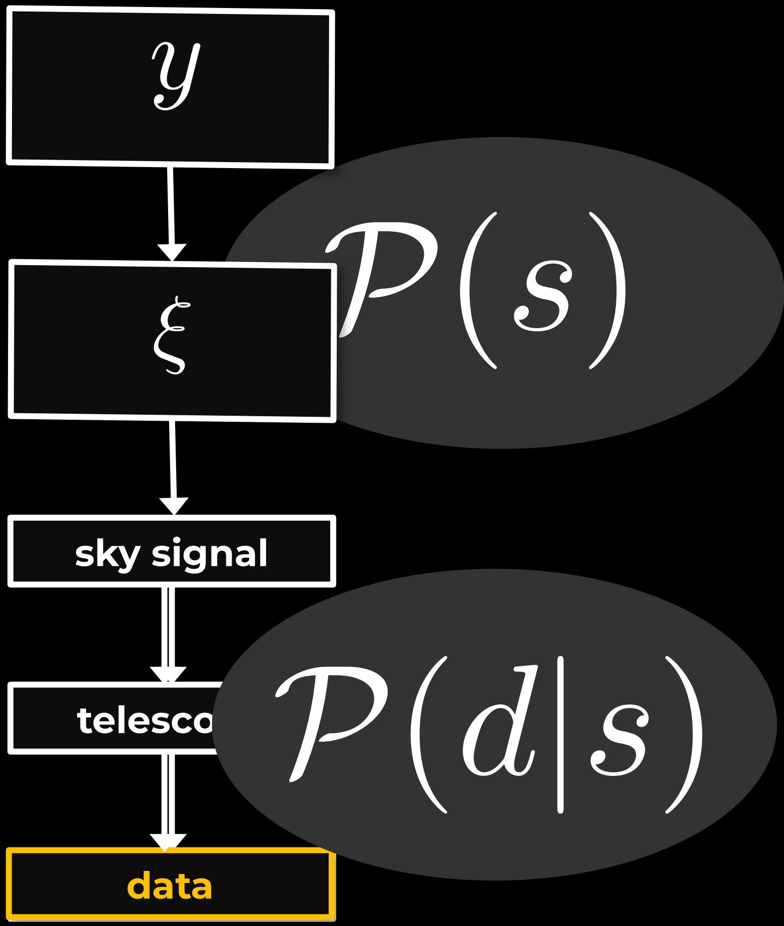

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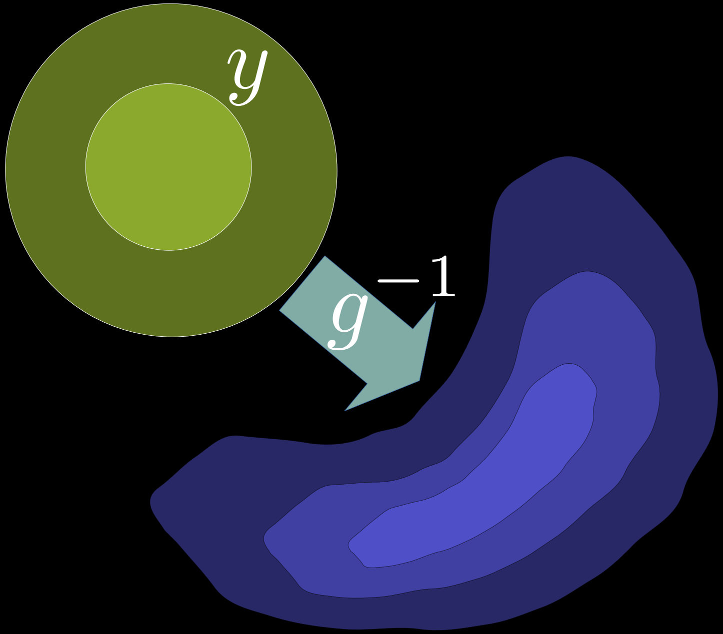

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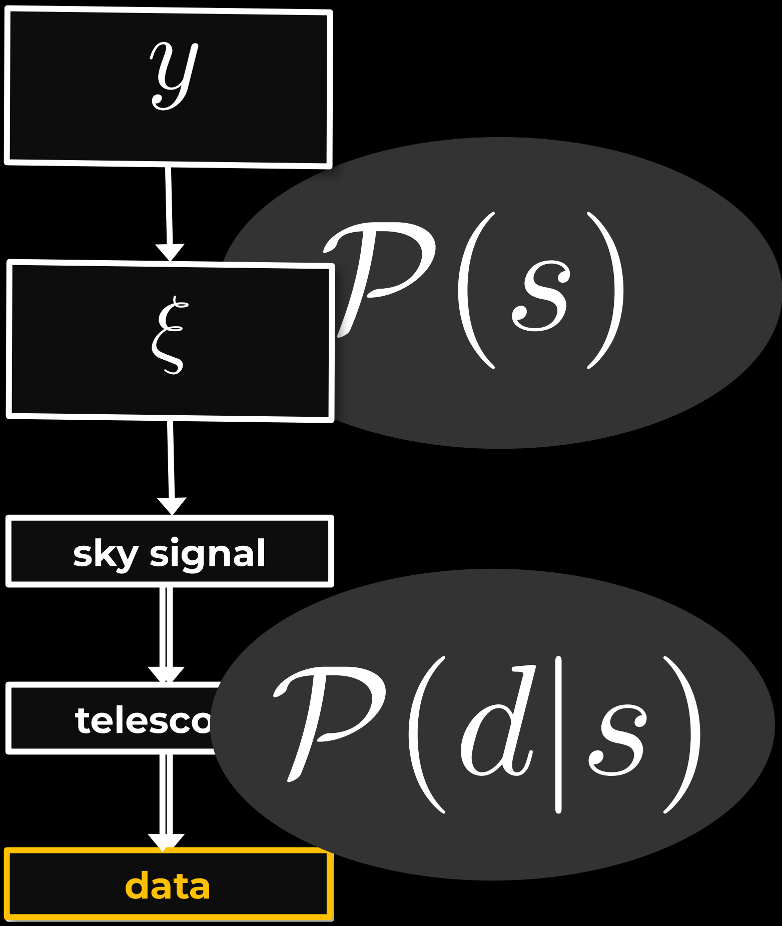

Geometric Variational Inference

Frank, Leike, & Enßlin (arXiv:2105.10470)

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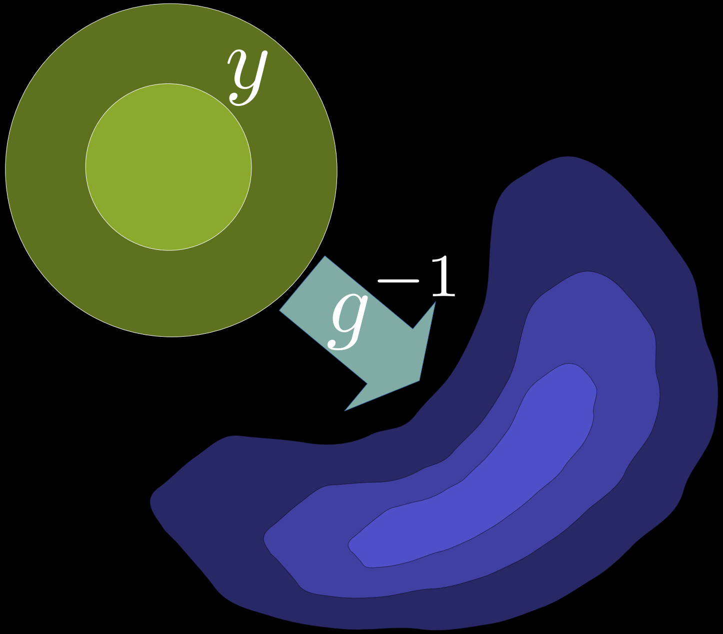

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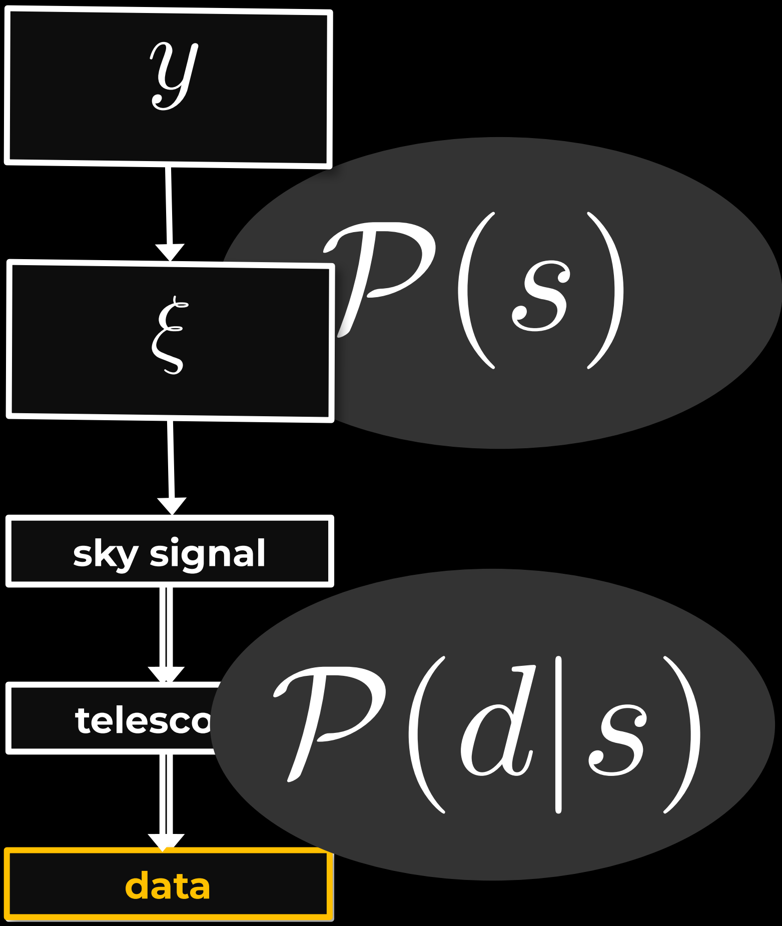

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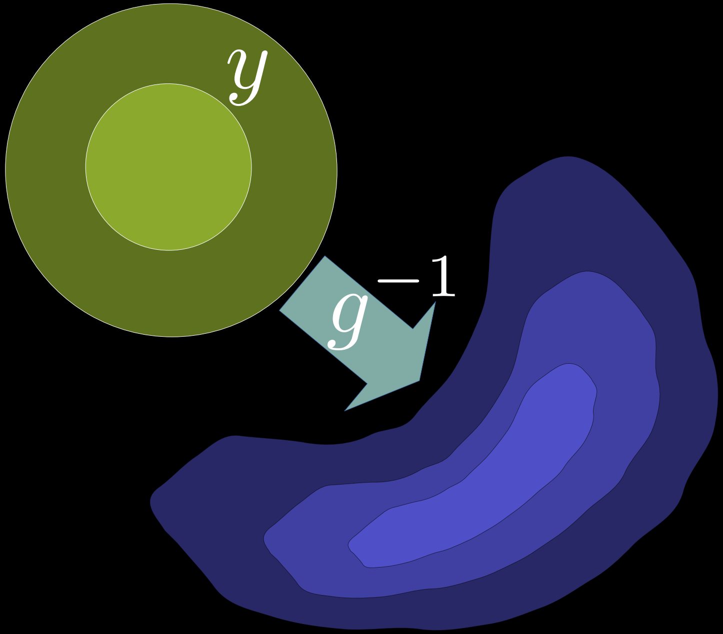
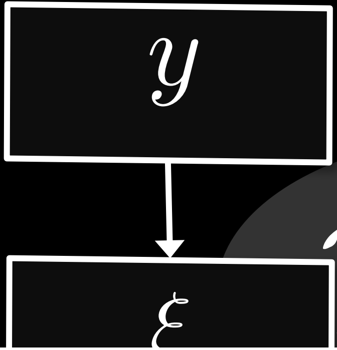
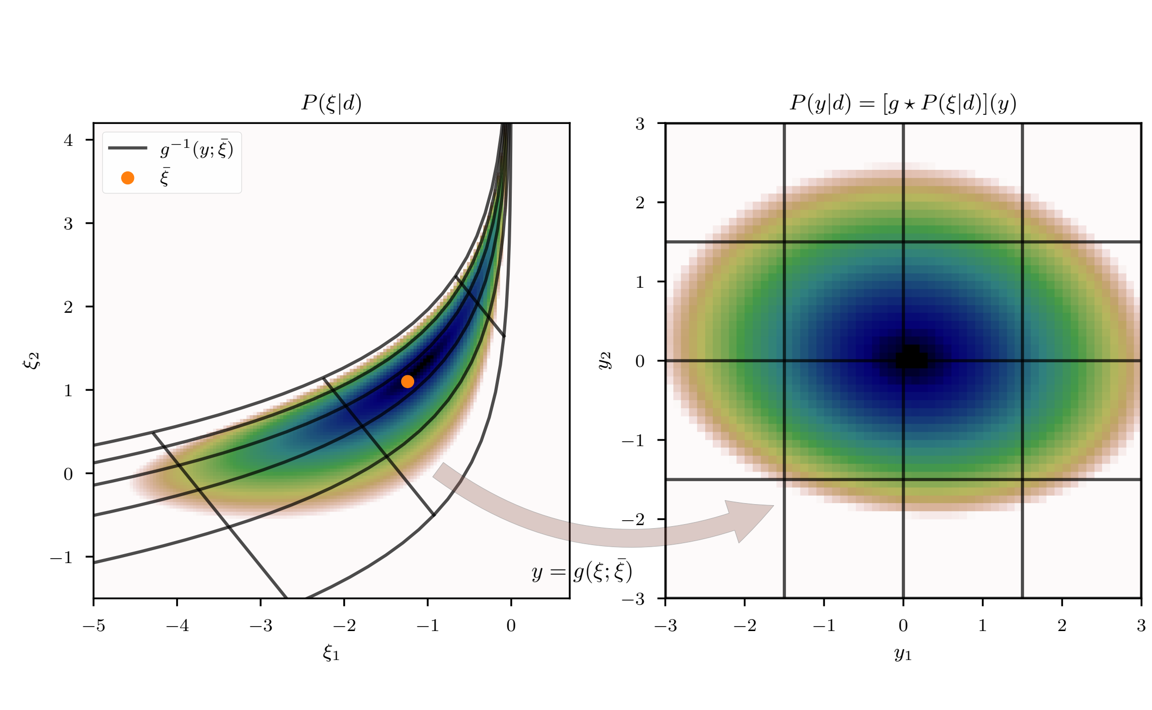




$$\mathcal{P}(s)$$




UBIK
Restores Reality

Models

Instrument

Models

LIKELIHOOD MODEL

Instrument

Models

LIKELIHOOD MODEL

- Gauss
- Poisson
- ...

Noise

Instrument

Models

LIKELIHOOD MODEL

Gauss

Poisson

...

Noise

Spatially varying

Spatially non-varying

PSF

Instrument

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LIKELIHOOD MODEL

Gauss

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Spatially varying

Spatially non-varying

PRIOR MODEL

Dimensions

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

Signal

Sources

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

Models

LIKELIHOOD MODEL

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- PSF
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PRIOR MODEL

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Models

Inference

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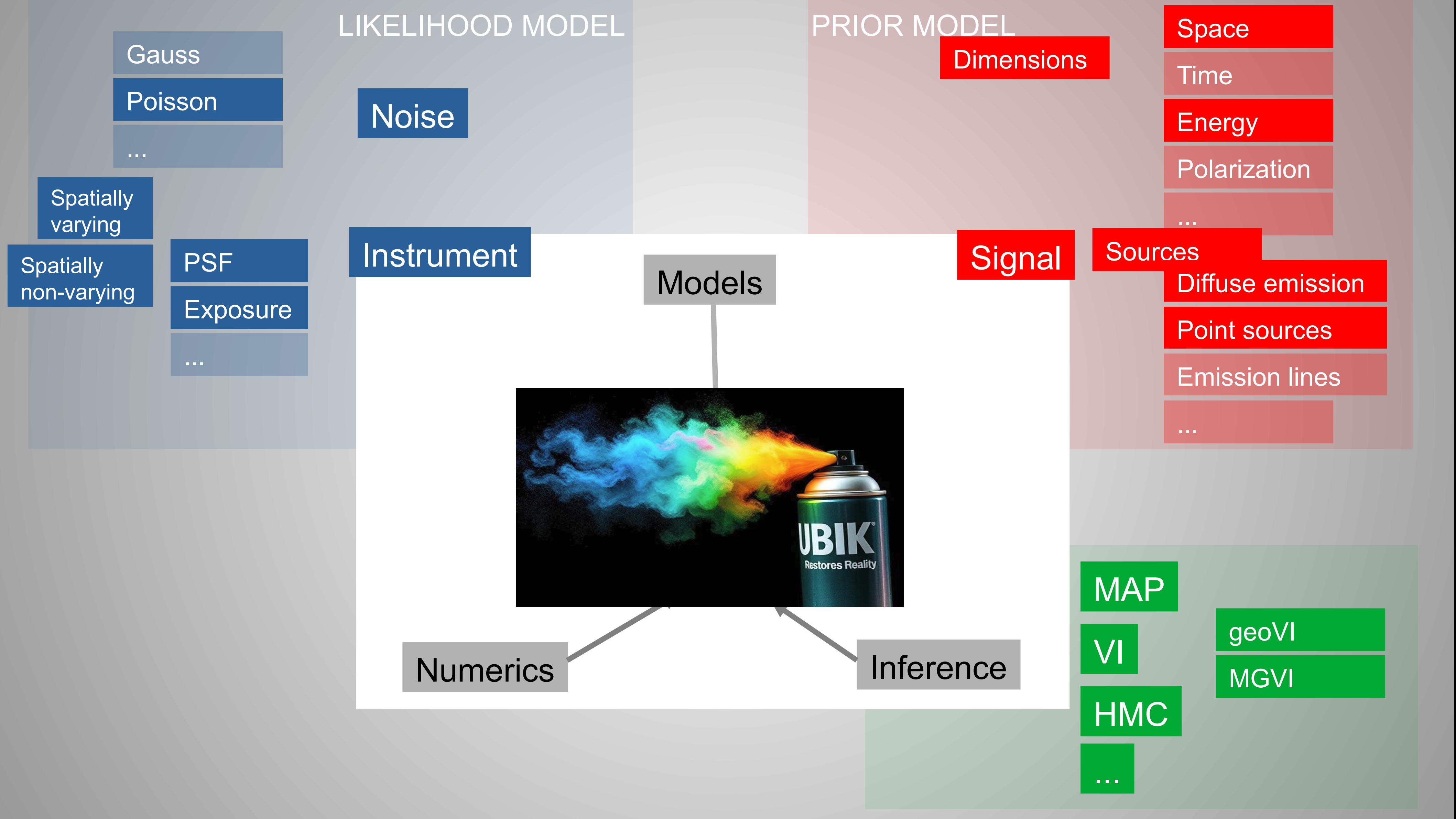
Models

Inference

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


LIKELIHOOD MODEL
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Numerics

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NIFTy
- Minimizer
- Autodiff
- ...

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LIKELIHOOD MODEL

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geoVI

MGVI

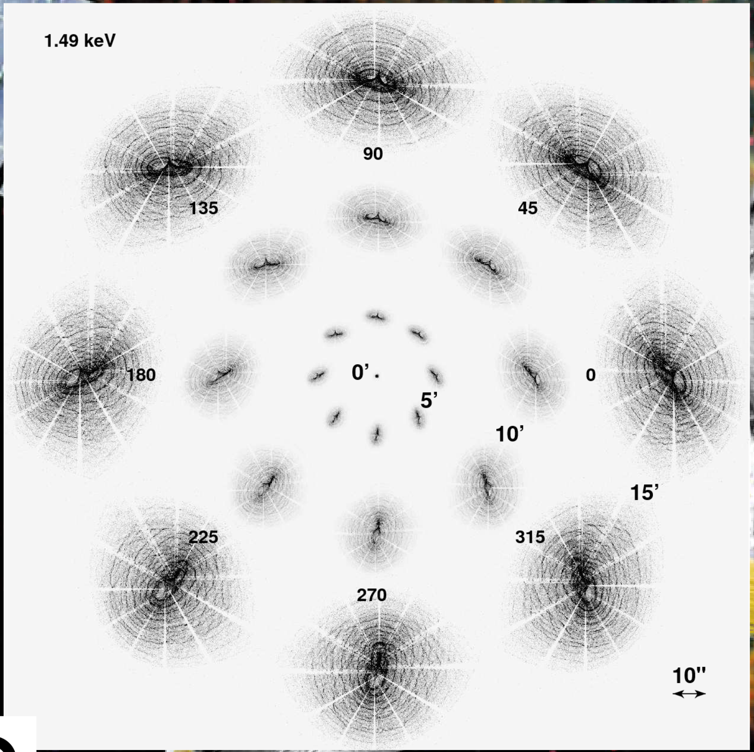
Autodiff

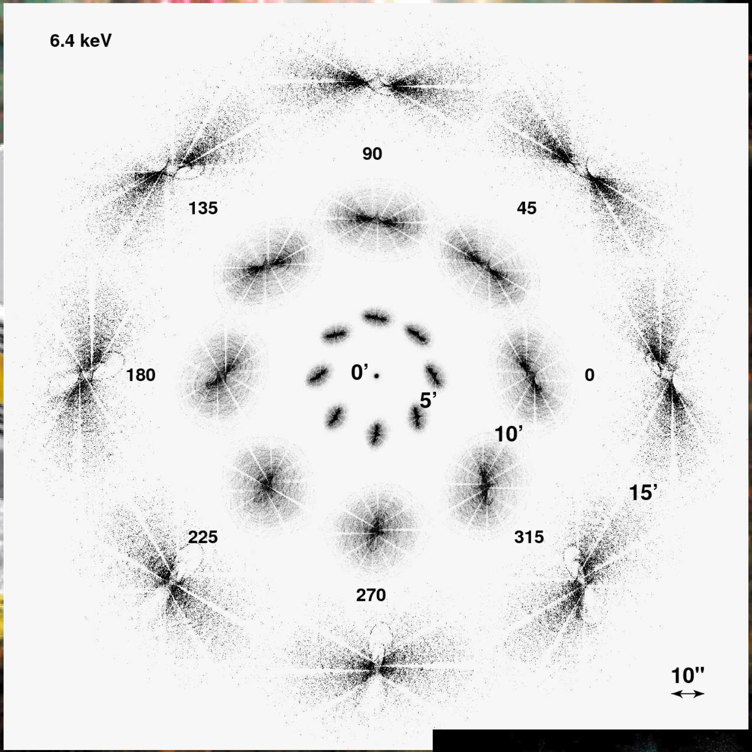
...

Eberle at al. et al. (2024)


UBIK
Restores Reality

Chandra

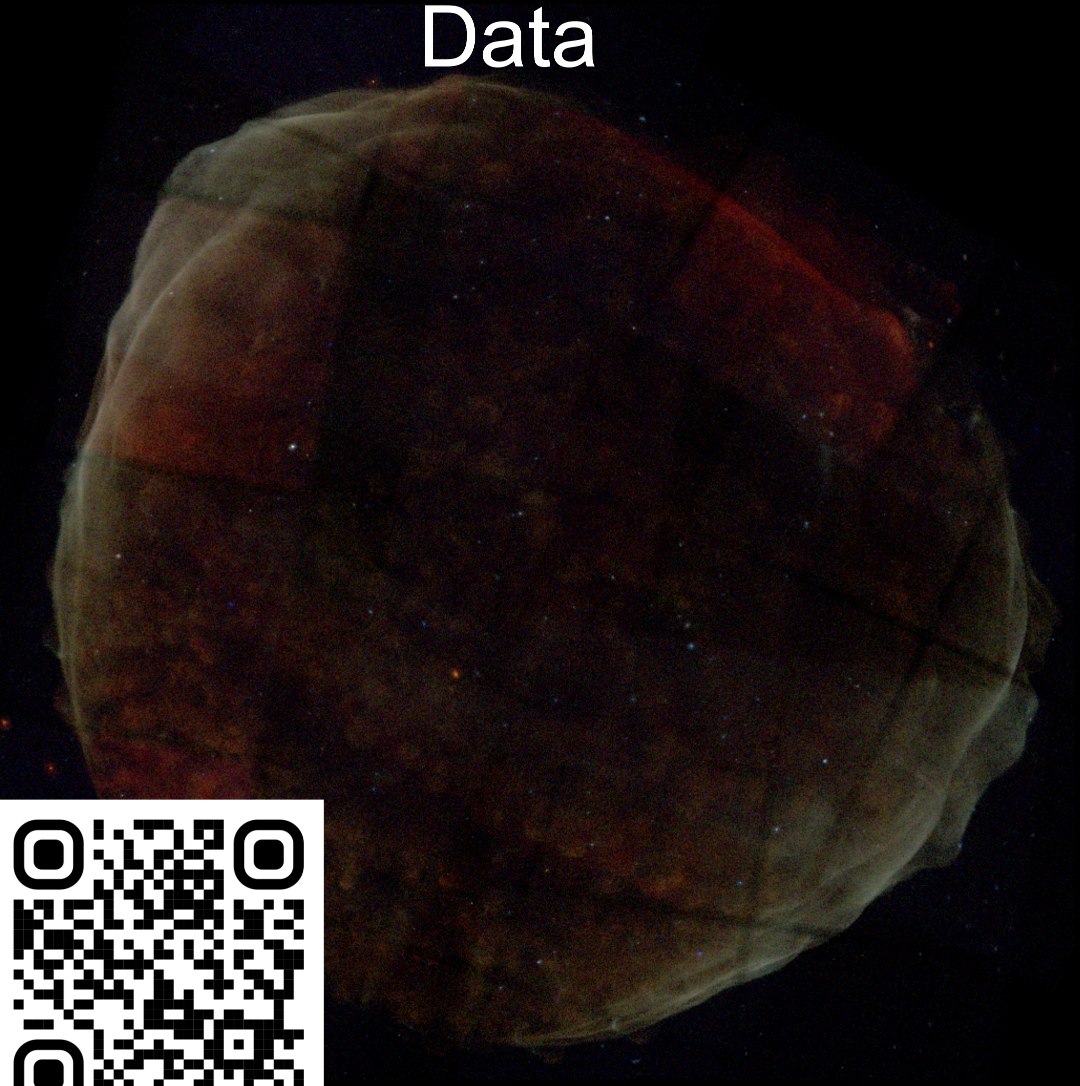




https://cxc.harvard.edu/proposer/P
chap4.html

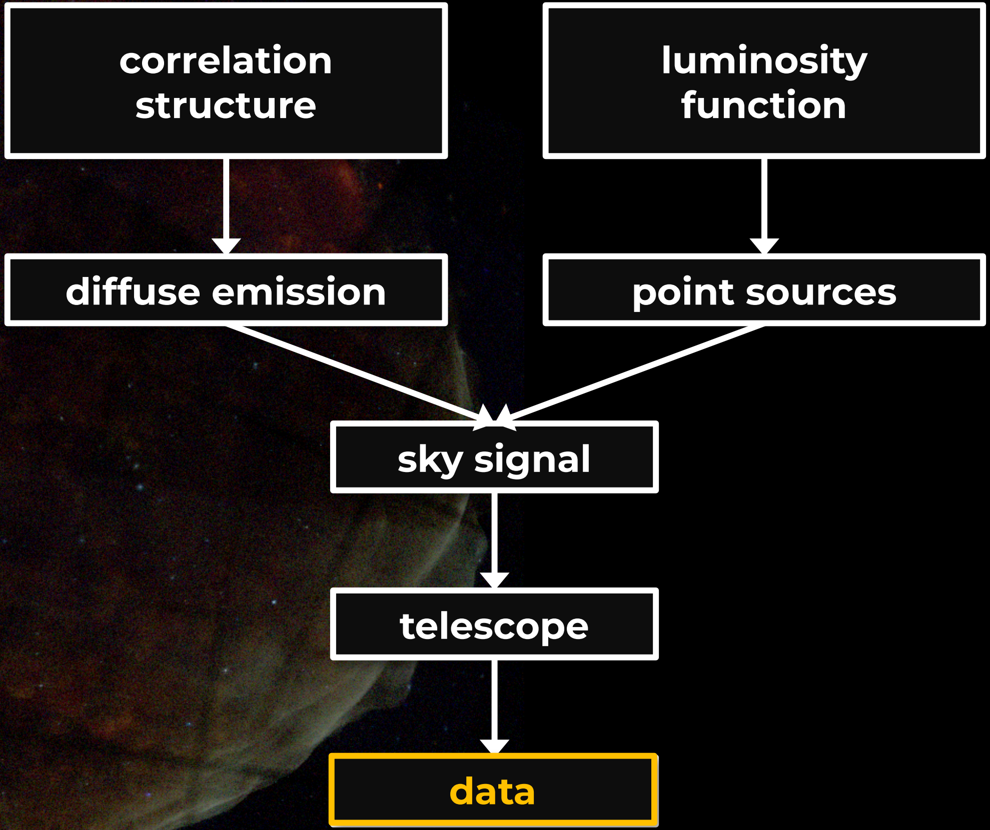
Chandra

Data



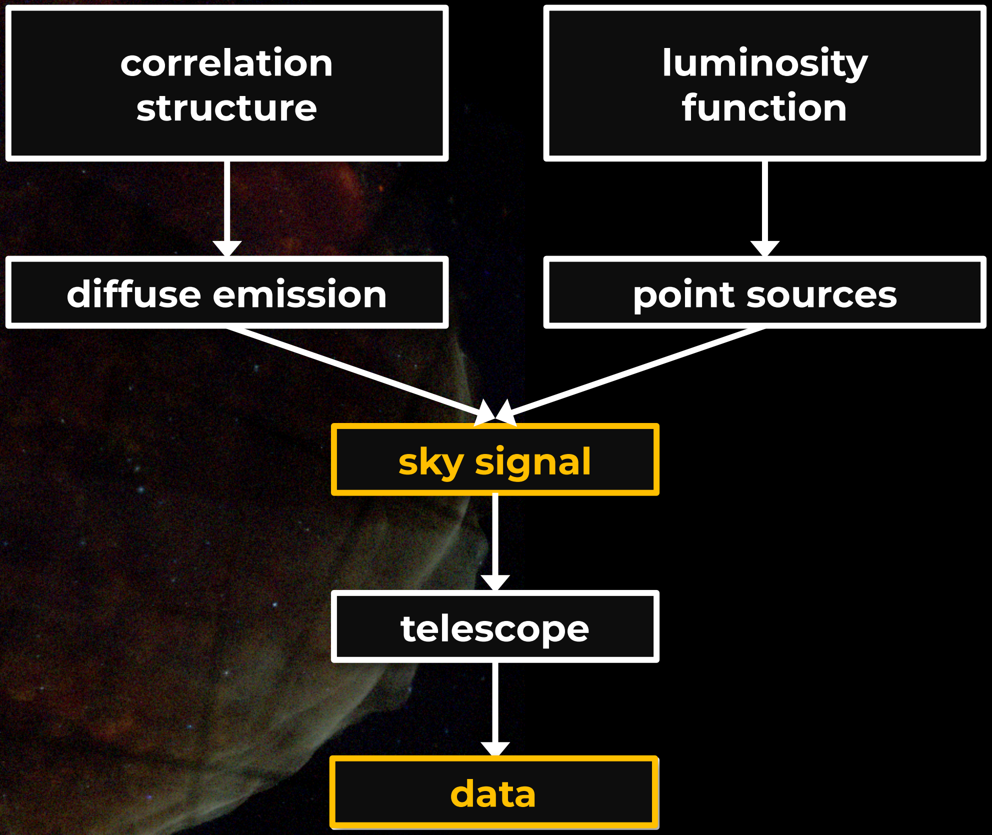
(Westerkamp et al. 2024)

Data



(Westerkamp et al. 2024)

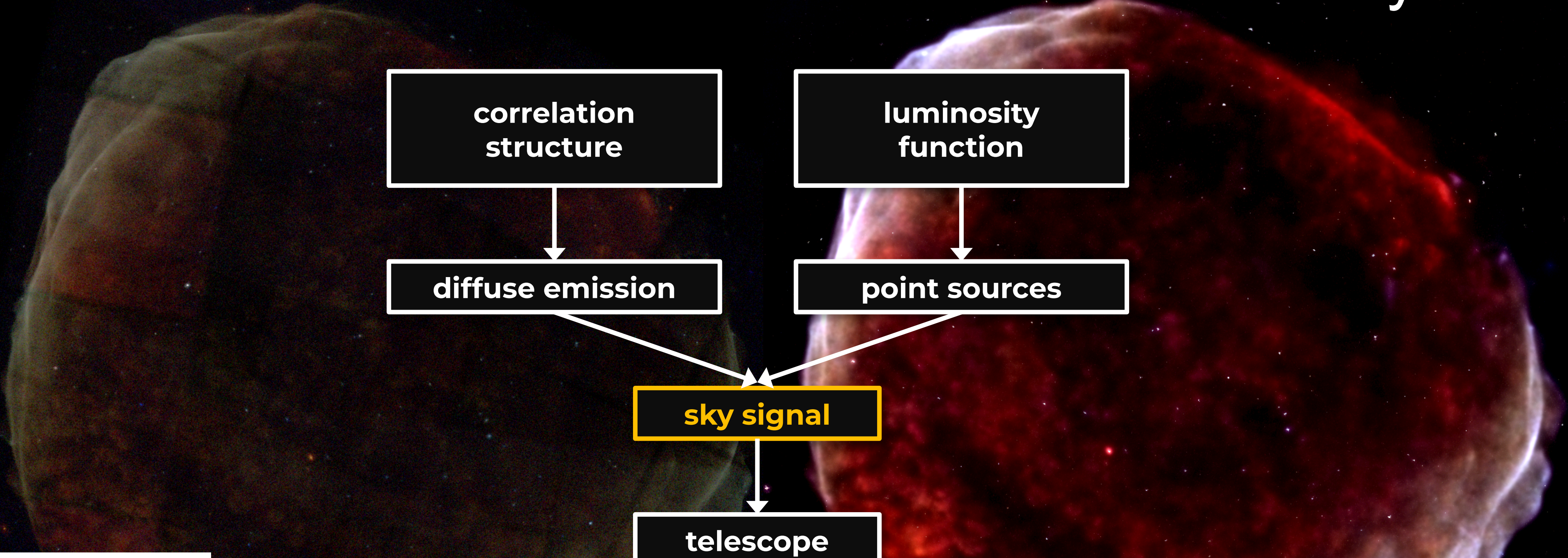
Data



(Westerkamp et al. 2024)

Data

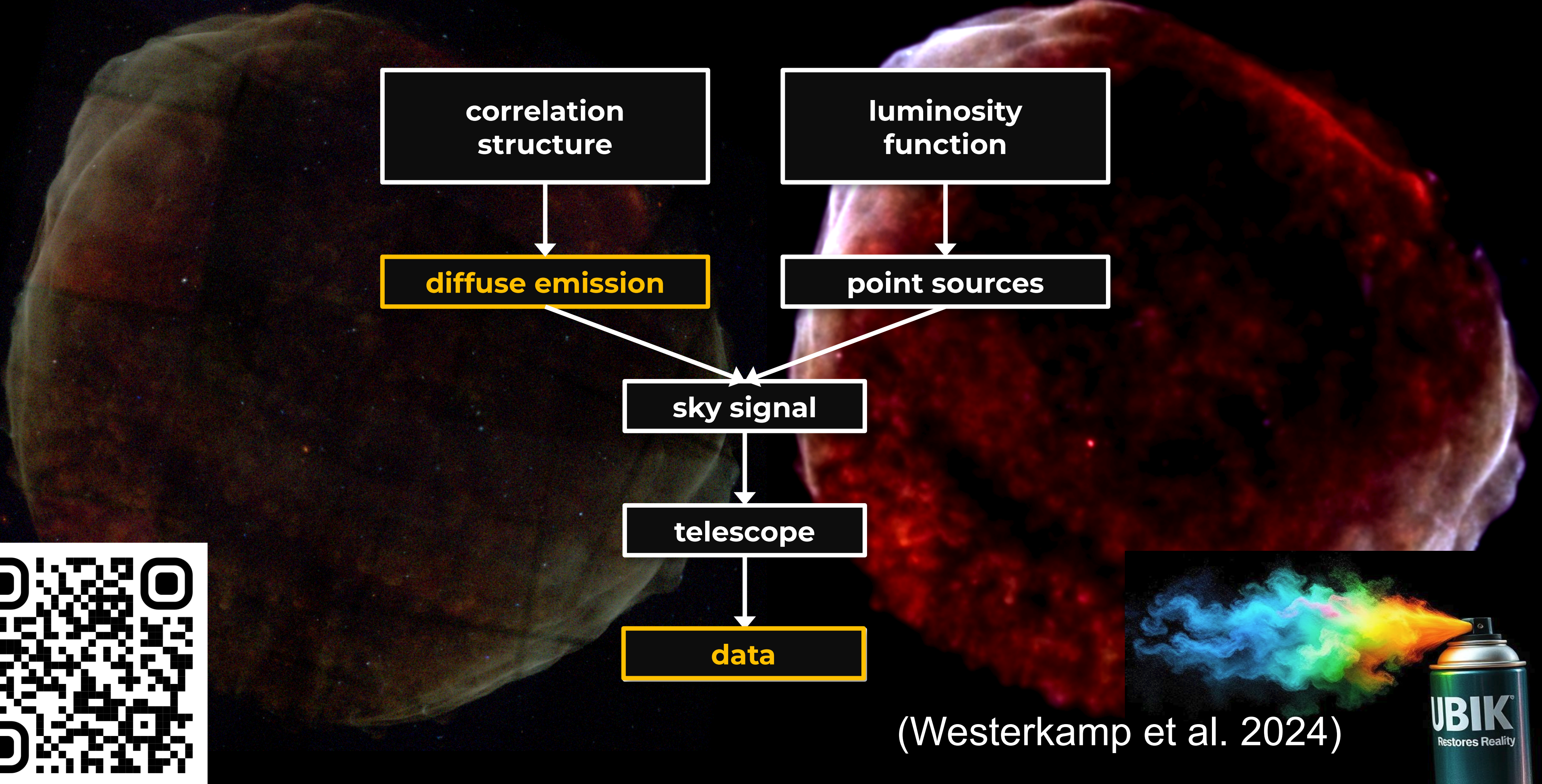
Reconstructed Sky



(Westerkamp et al. 2024)

Data

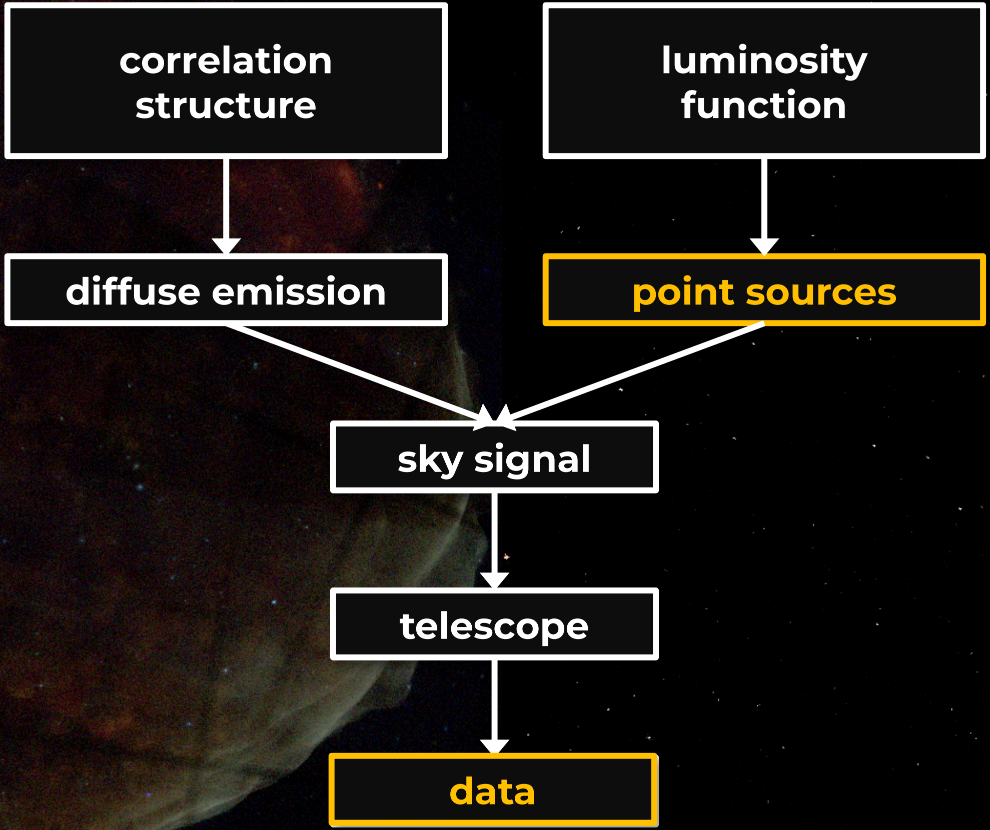
Diffuse Emission



(Westerkamp et al. 2024)

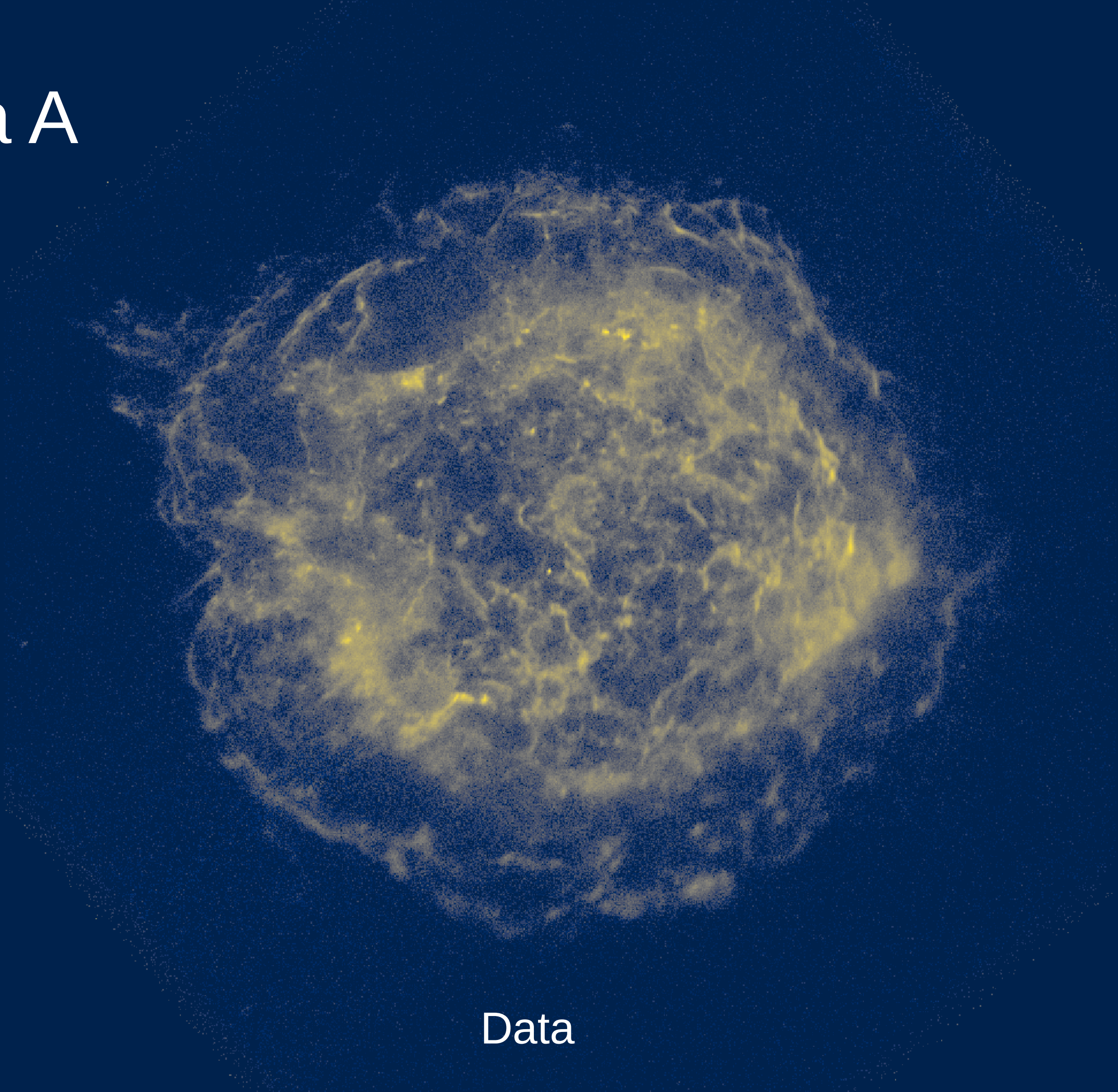
Data

Point Sources



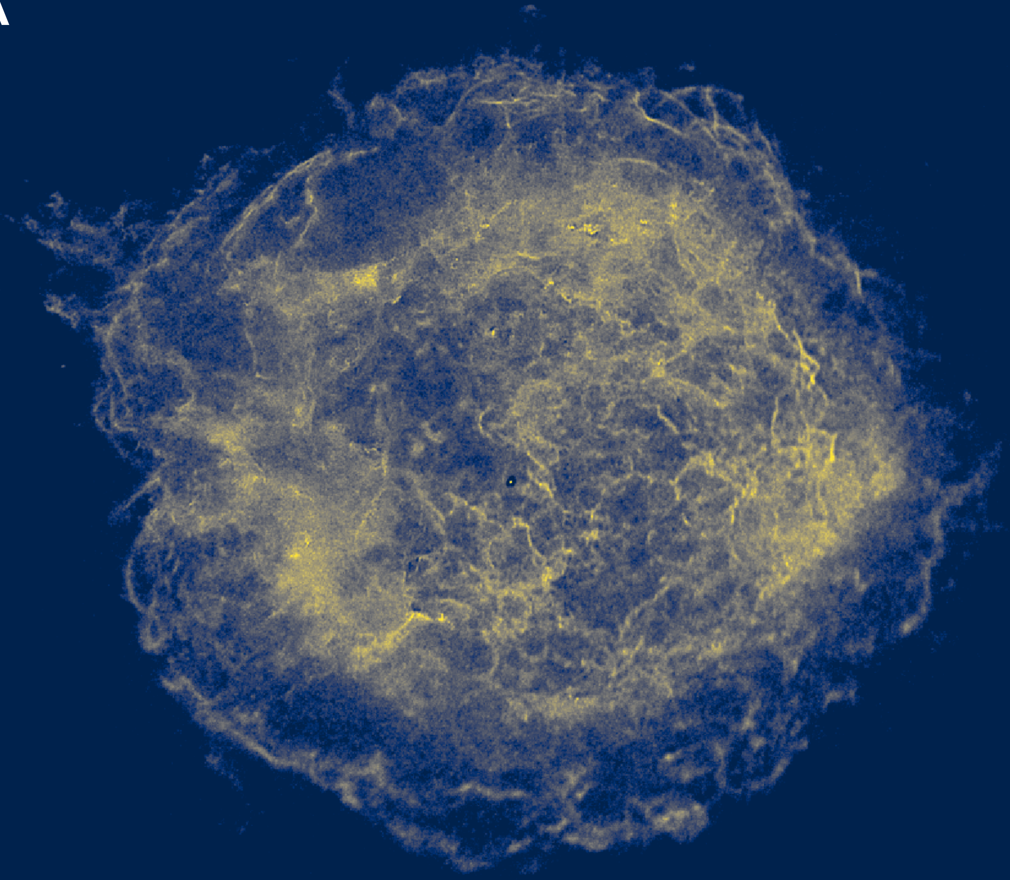
(Westerkamp et al. 2024)

Cassiopeia A



Data

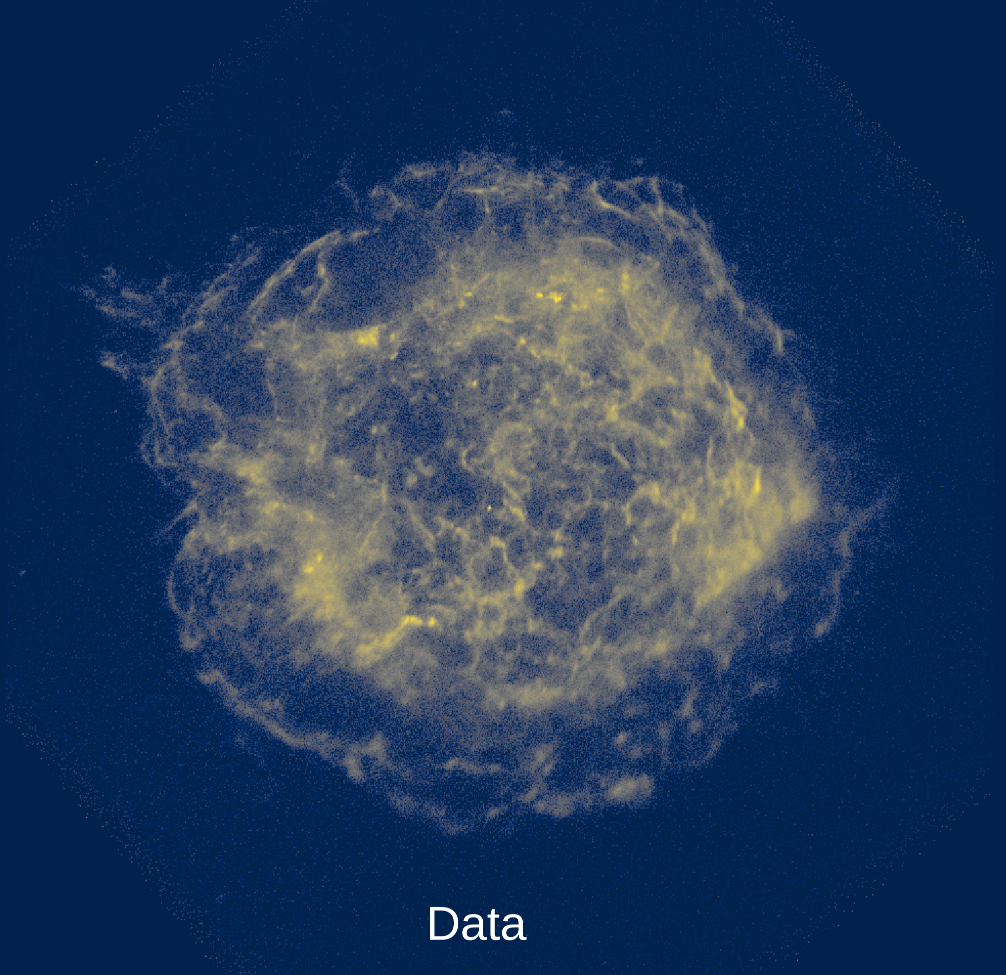
Cassiopeia A



Reconstruction

Cassiopeia A

Eberle et al. in preparation



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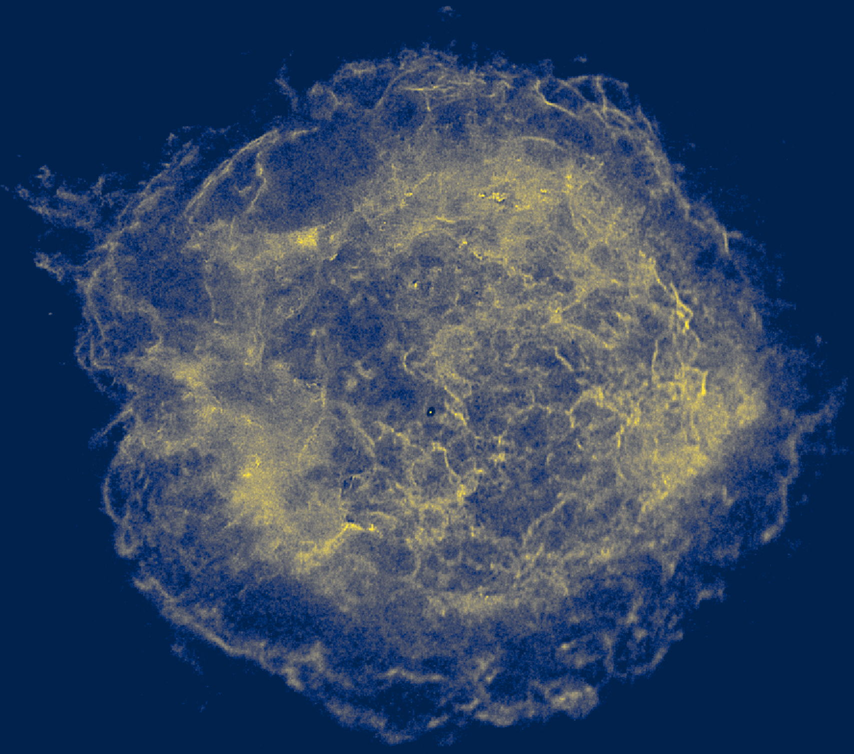

Reconstruction

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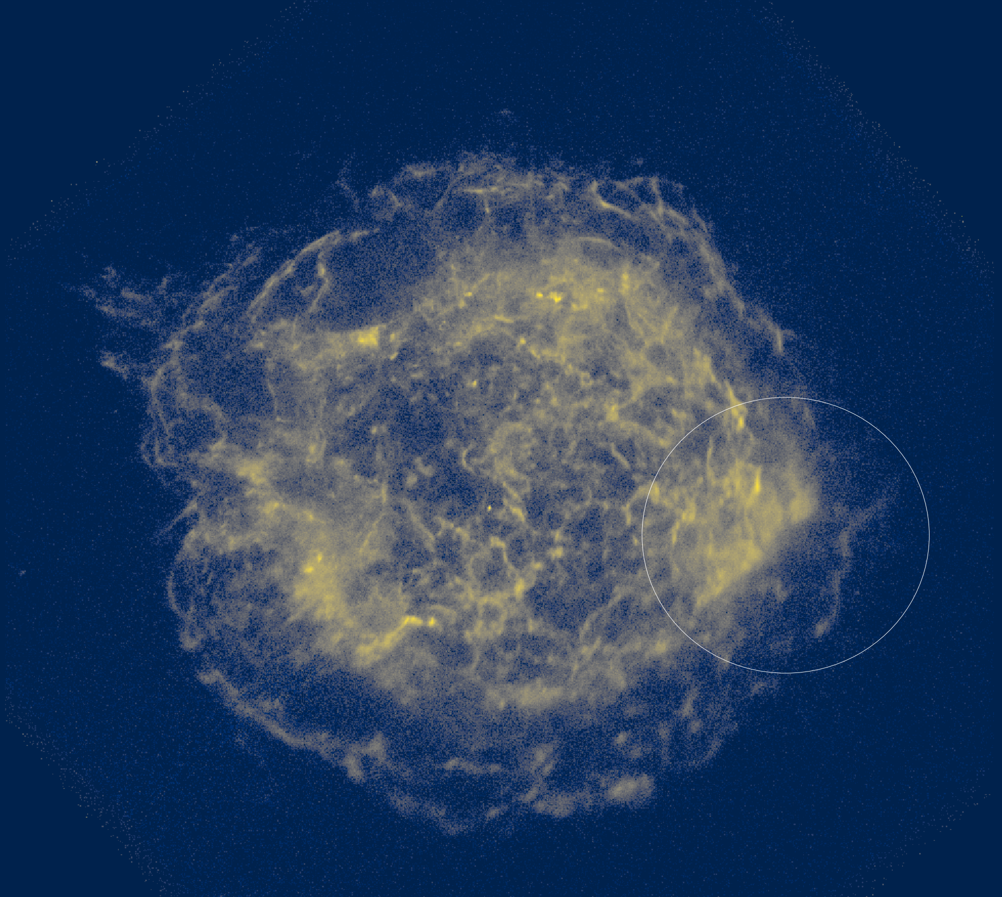
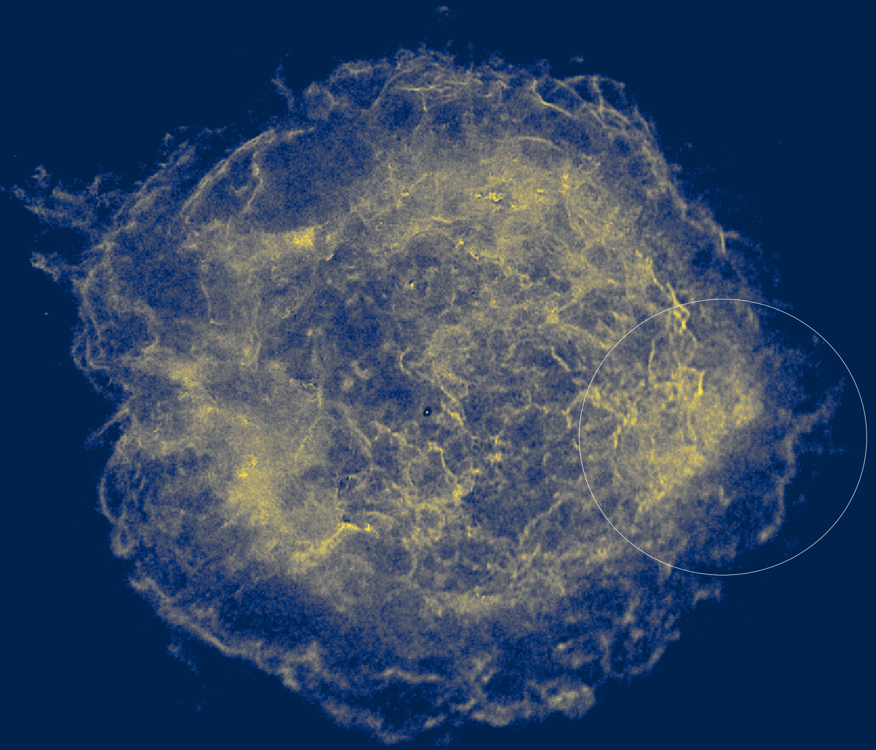


Data



Reconstruction

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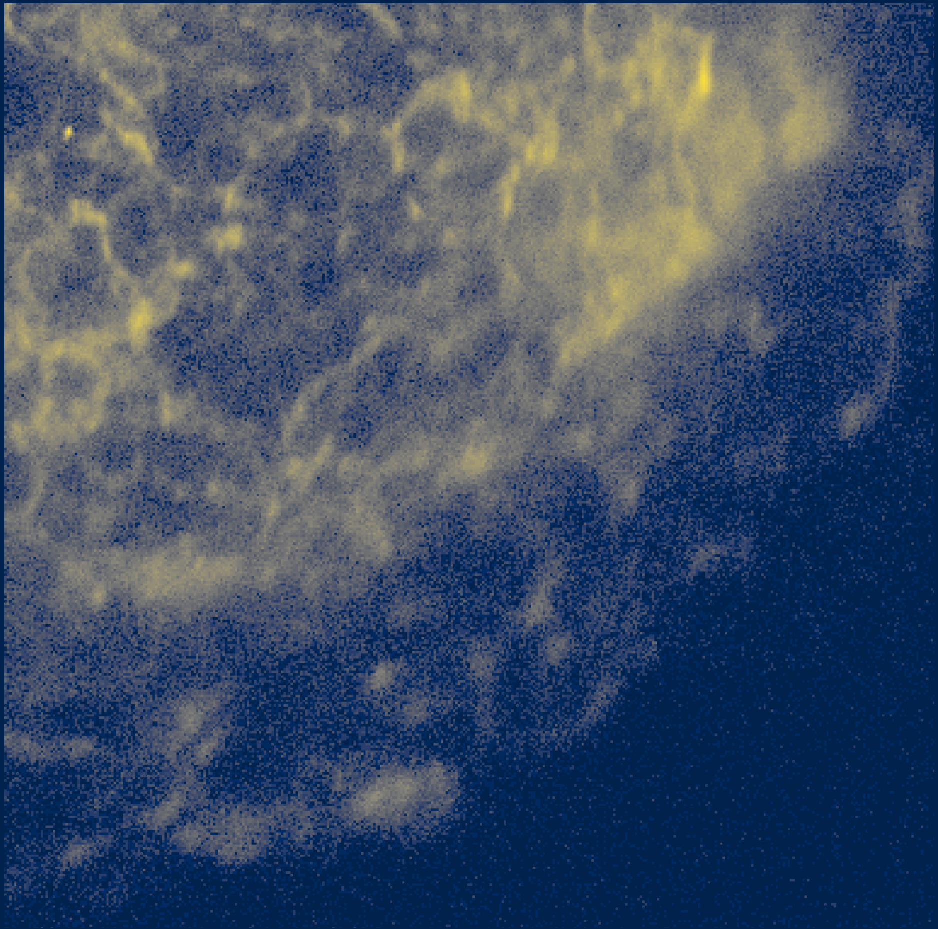

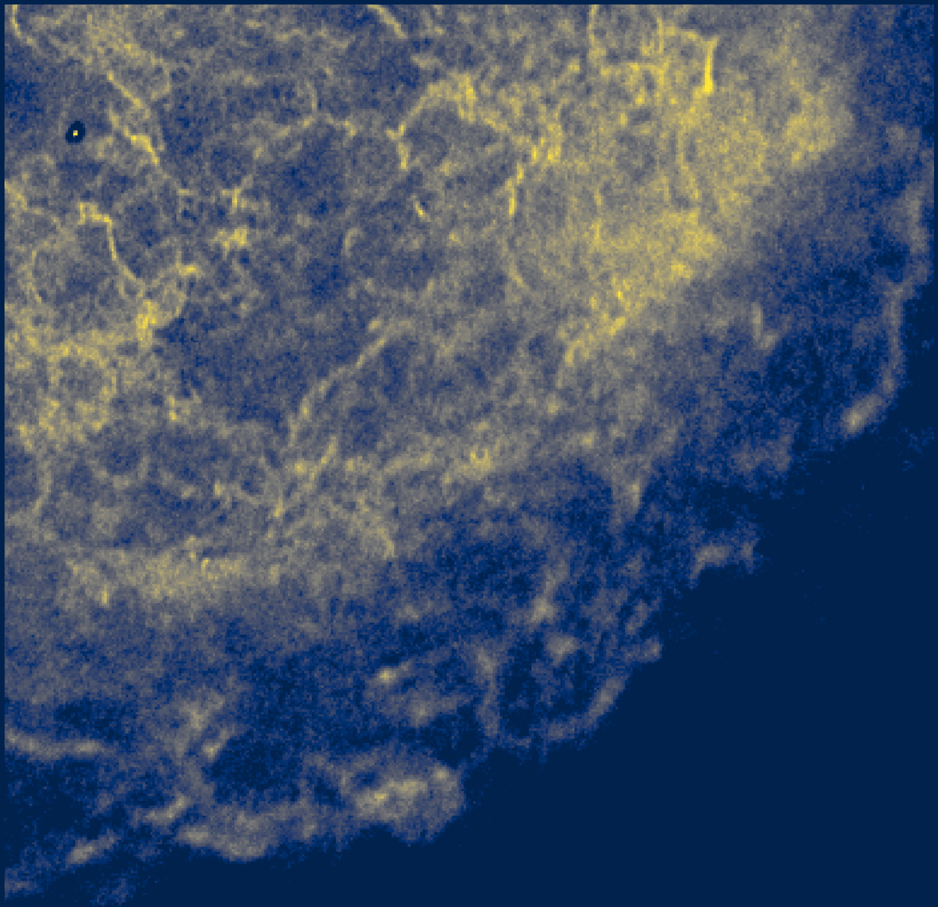

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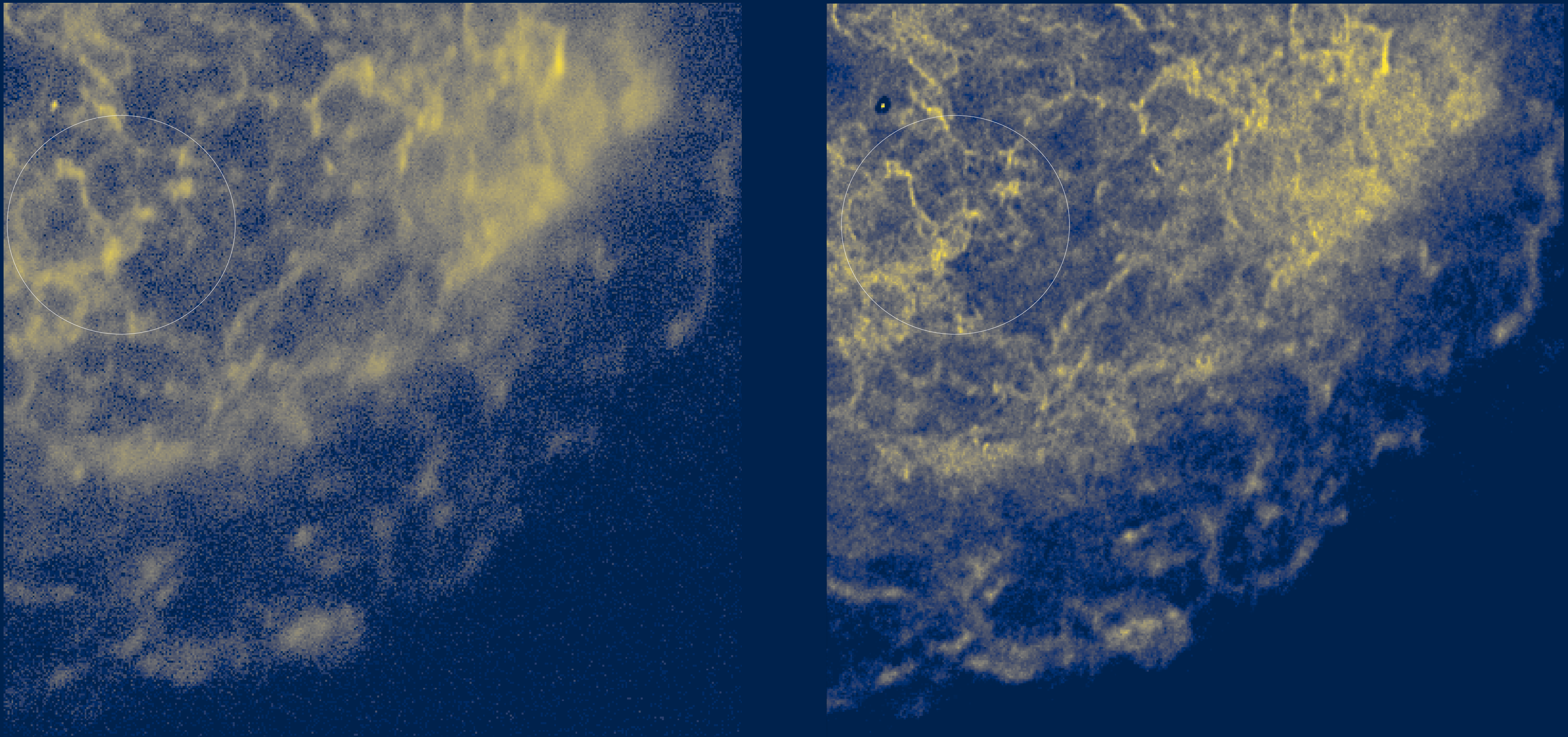
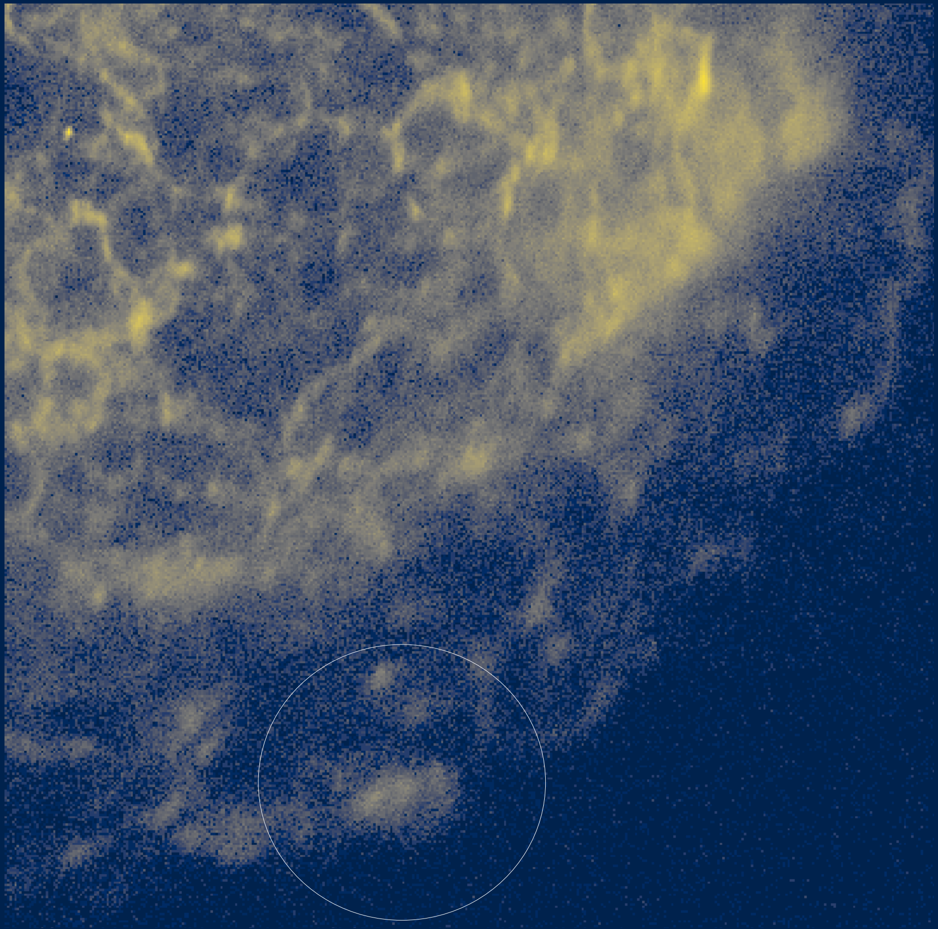
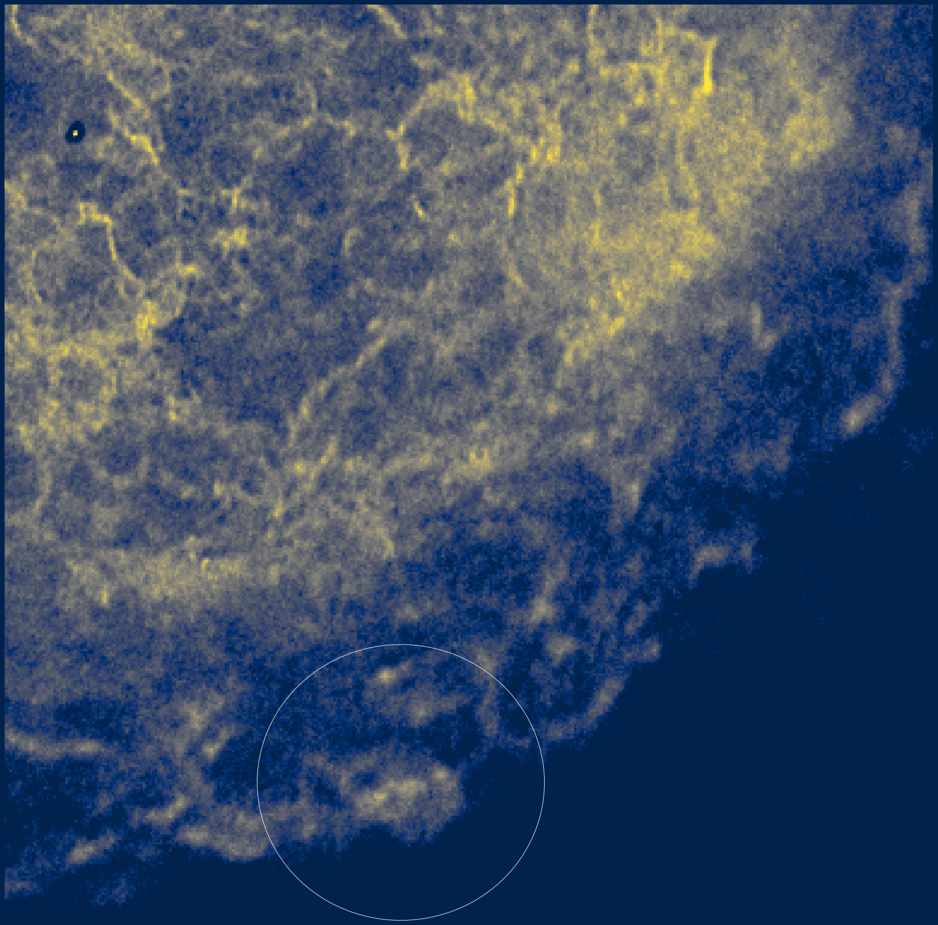
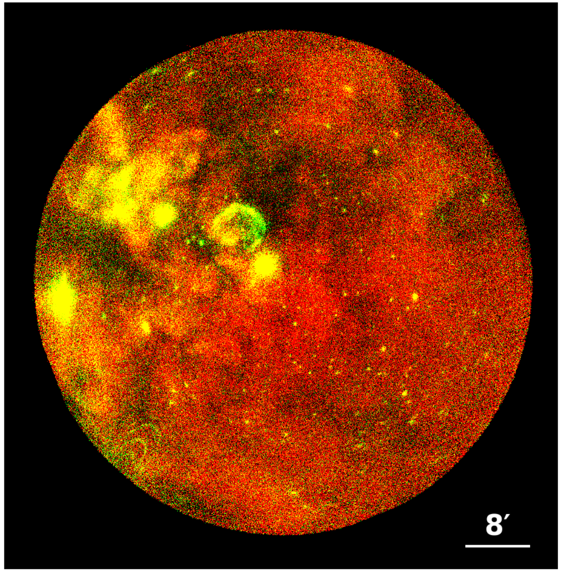


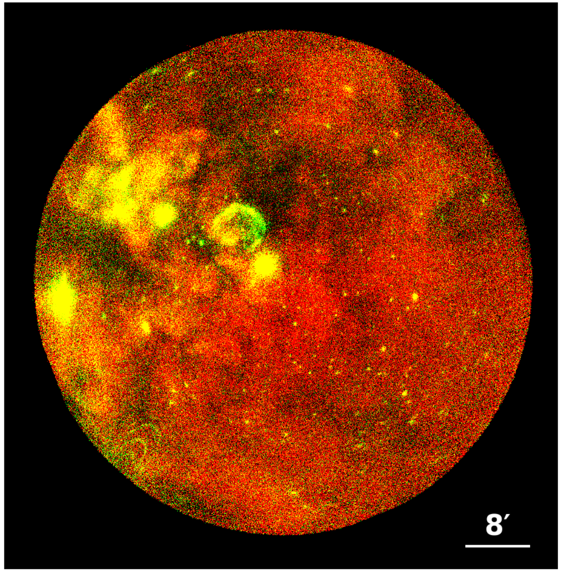



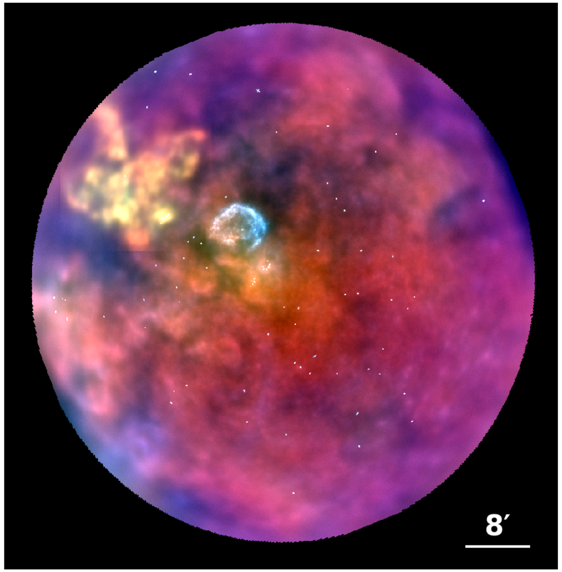

eROSITA



LMC

Guardiani et al. (2025)

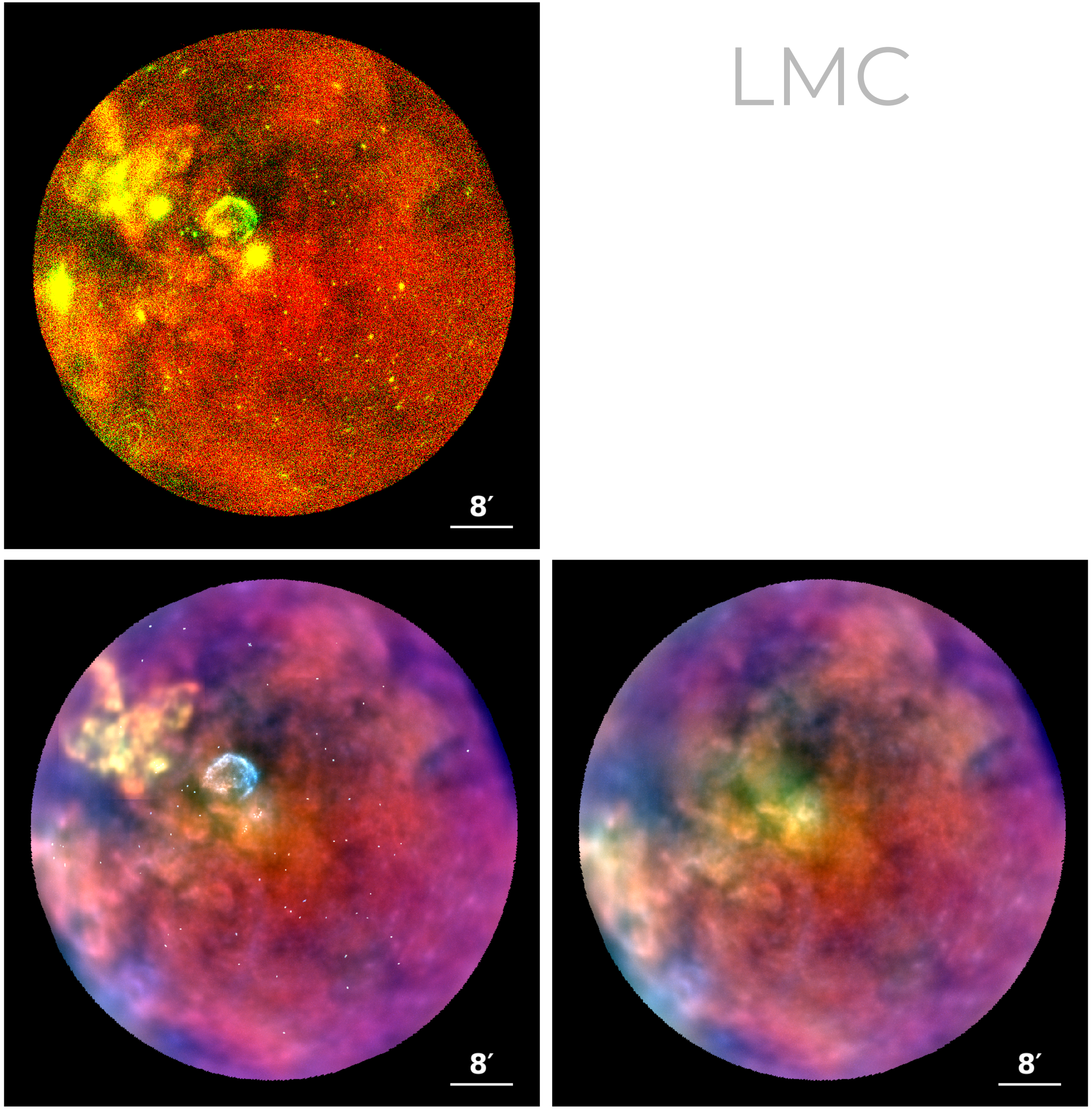




LMC

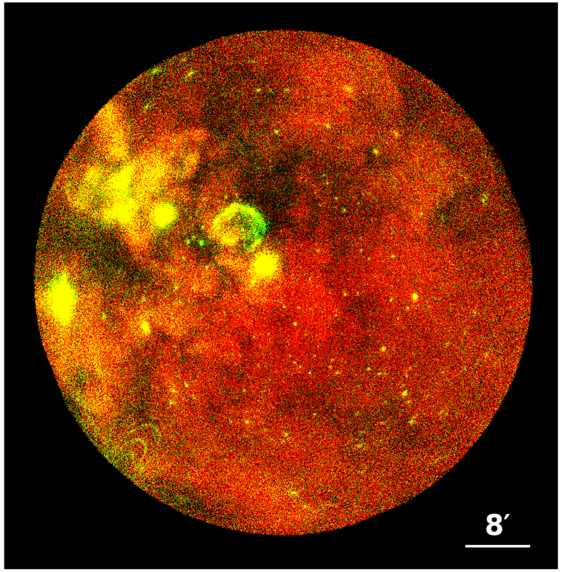
Guardiani et al. (2025)

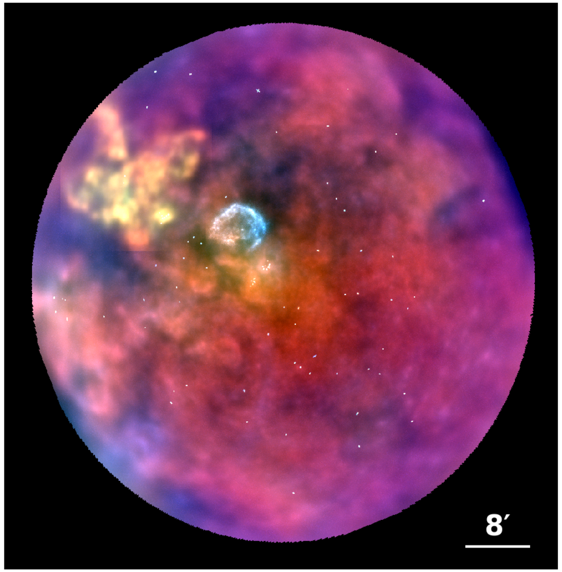
LMC

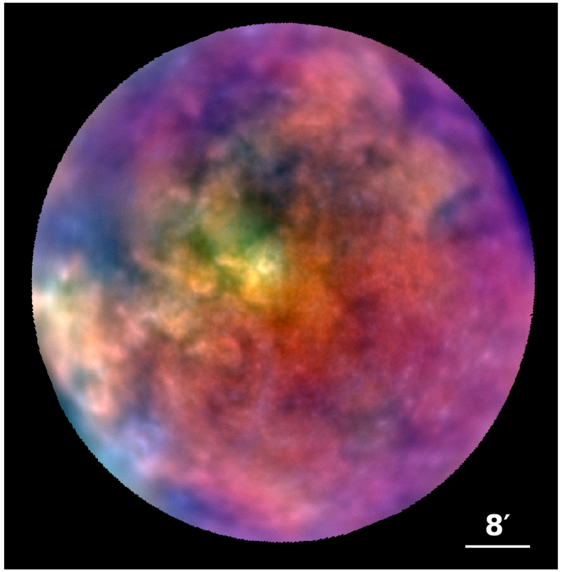


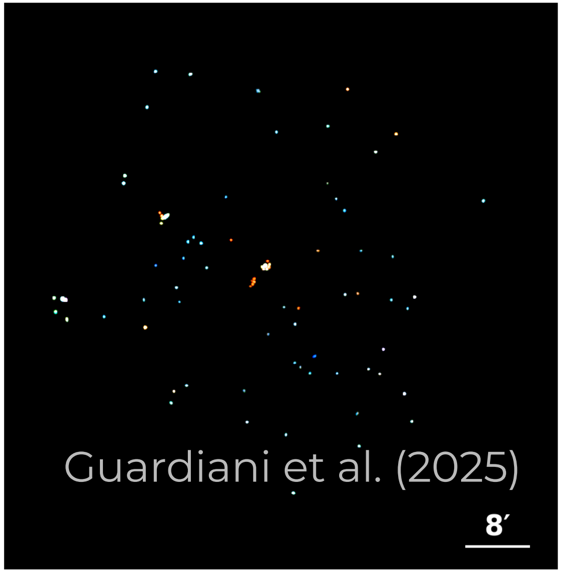
Guardiani et al. (2025)

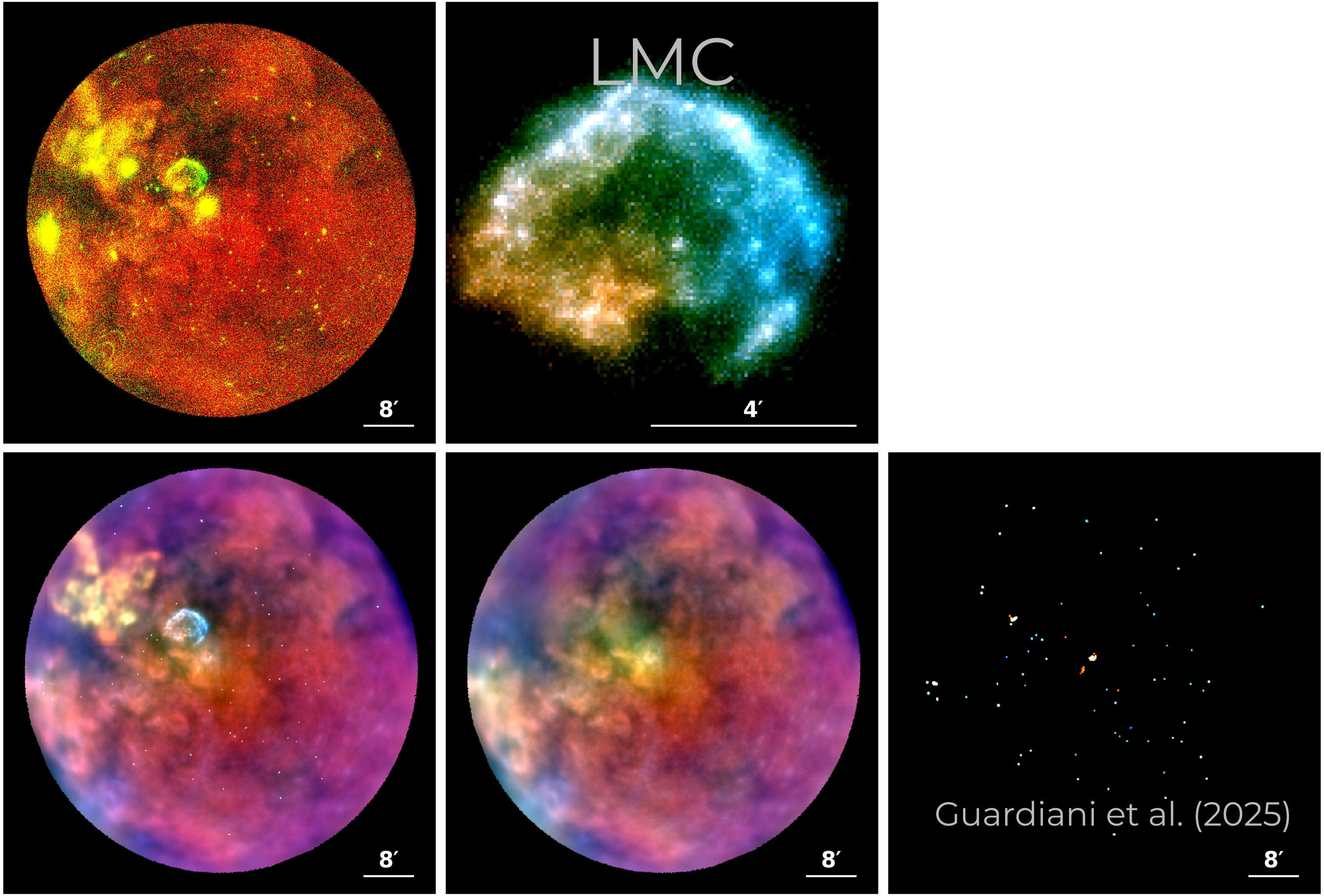
LMC

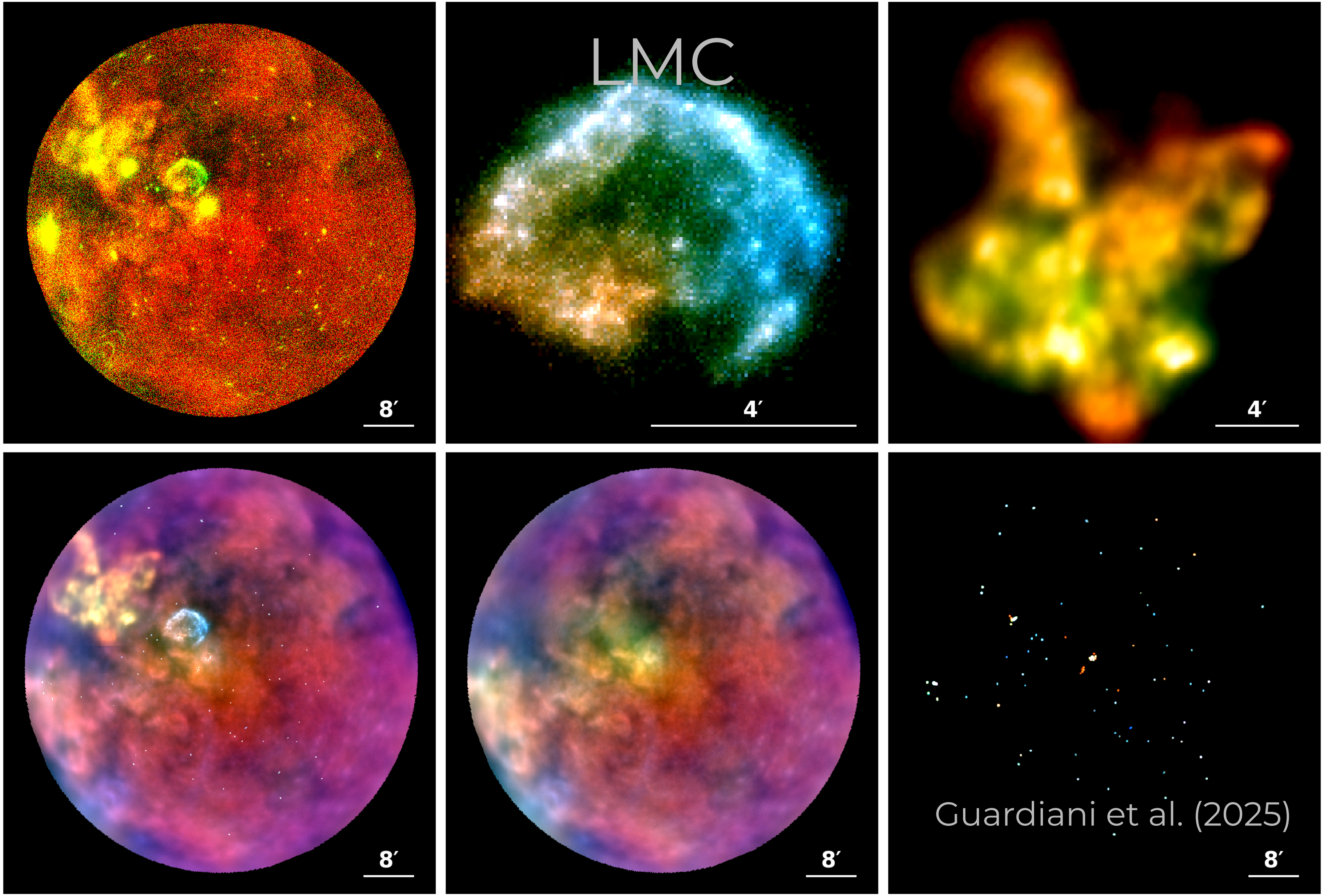









LMC
8′
4′
8′
8′
Guardiani et al. (2025)
8′



LMC
8′
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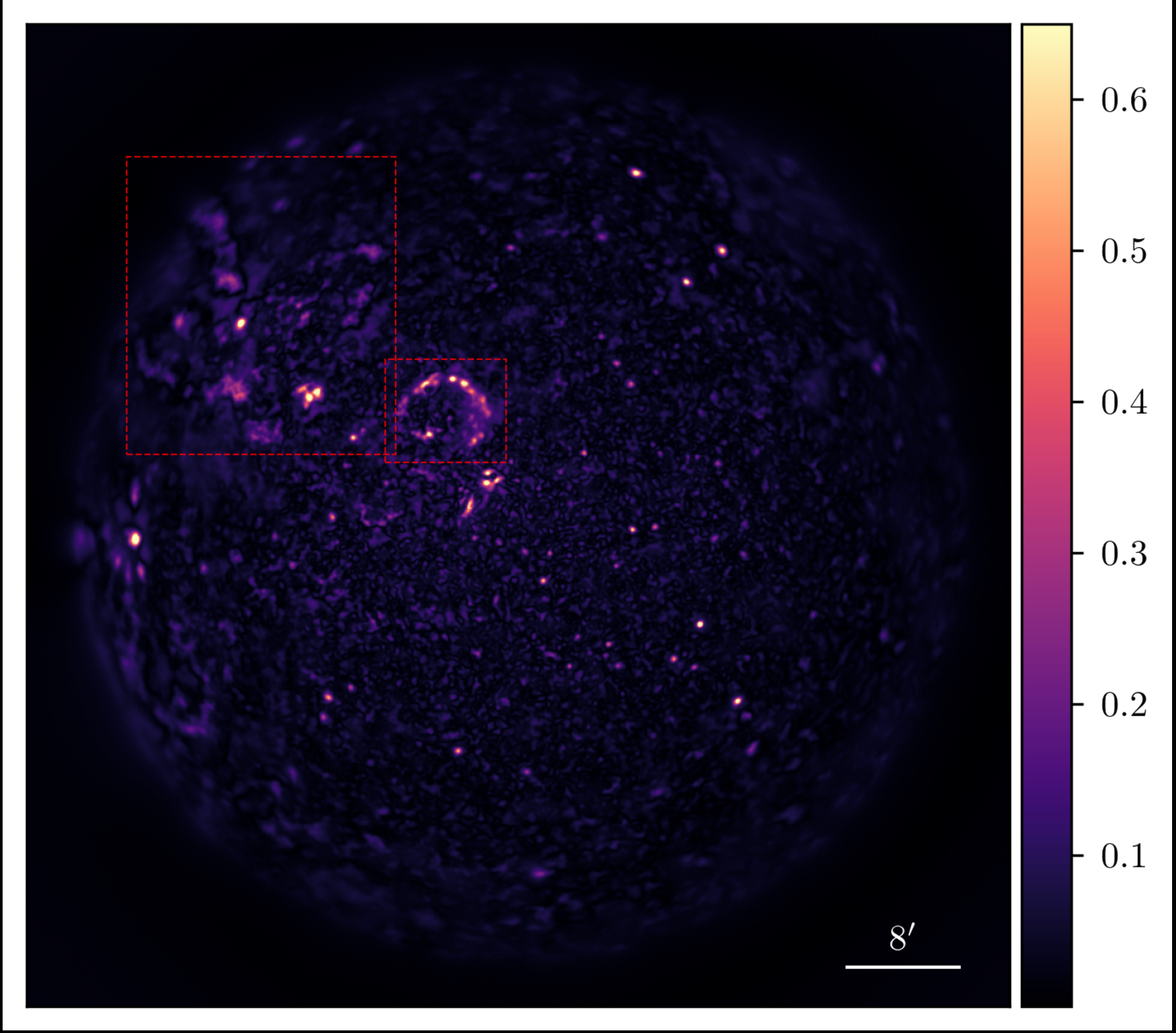
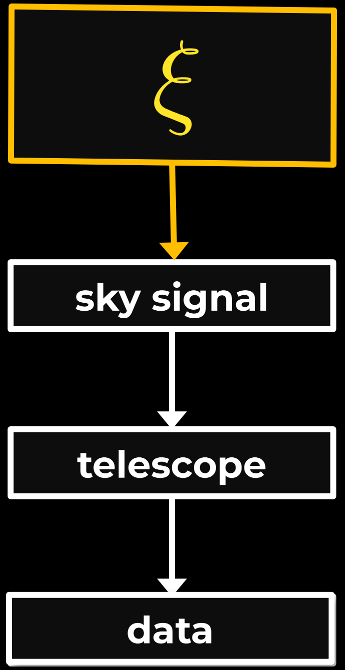
8′
Guardiani et al. (2025)
8′

Matteo Guardiani et al.
(arXiv:2506.20758)





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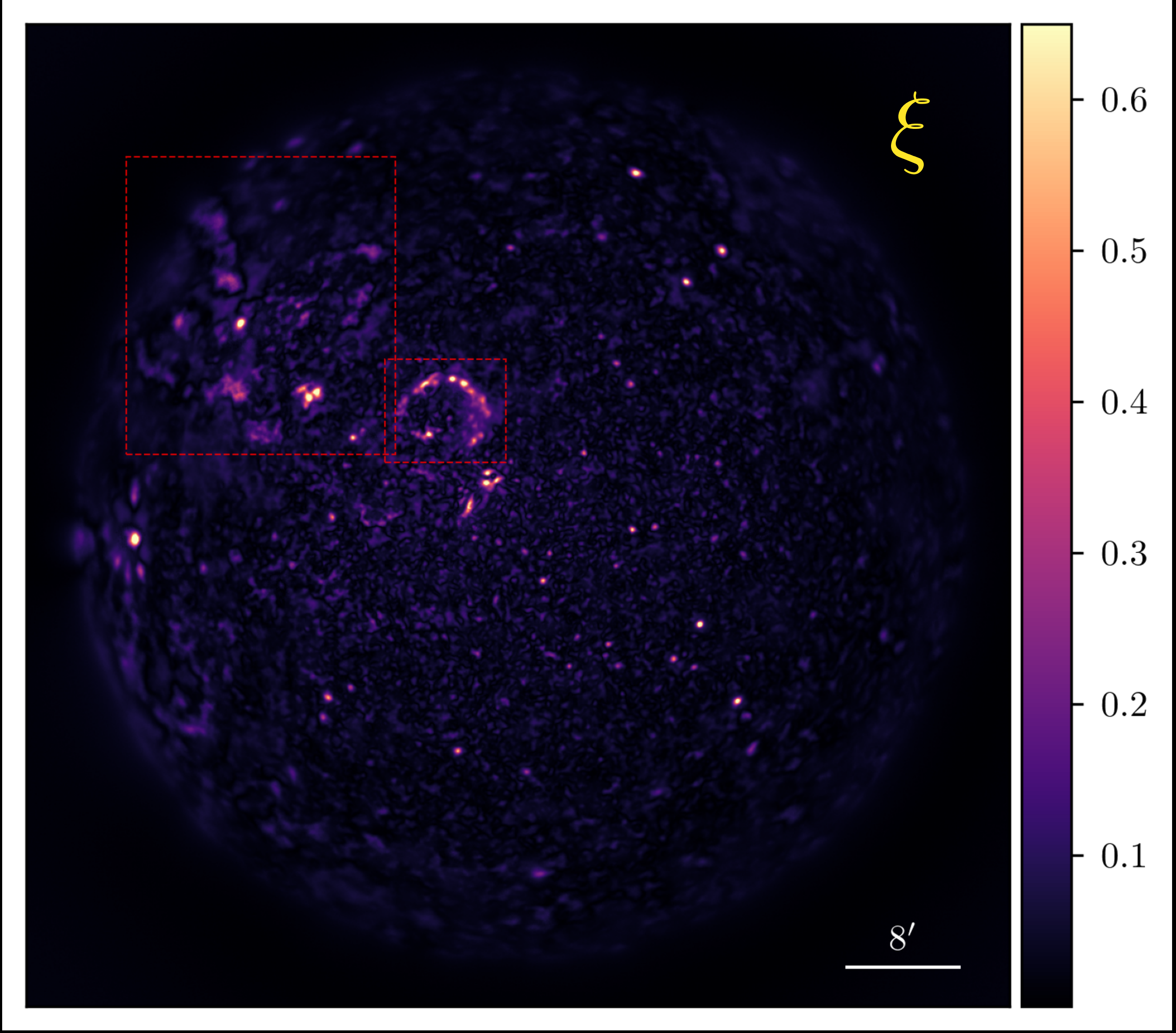

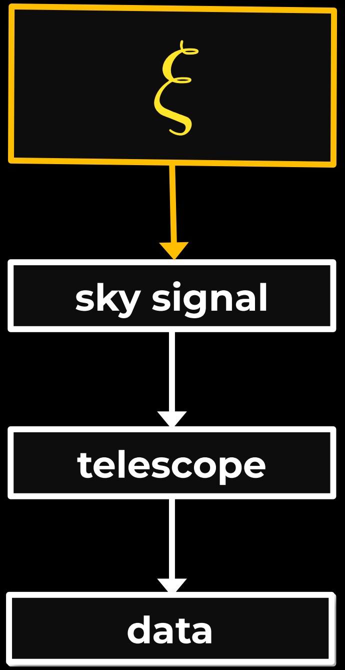


James Webb Space Telescope

Soon: Radio Telescopes (VLA, Meerkat, ALMA)

Universal

Bayesian

Imaging

Kit

Universal
Bayesian
Imaging
Kit

UBIK

Universal
Bayesian
Imaging
Kit

UBIK

- unifies imaging for a growing number of instruments

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Universal **B**ayesian **I**maging **K**it

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Universal Bayesian Imaging Kit

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- is open source
- "… Safe when taken as directed." – Philip K. Dick