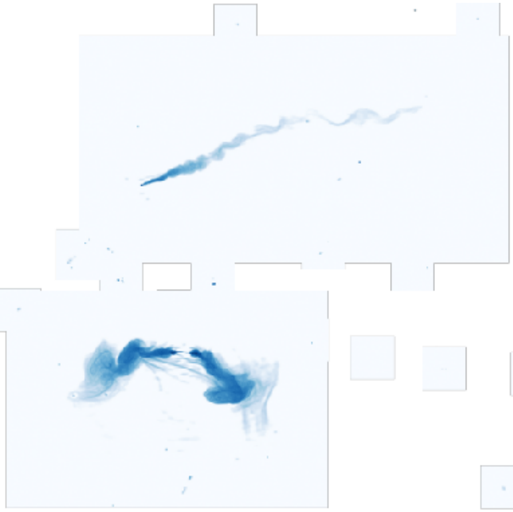
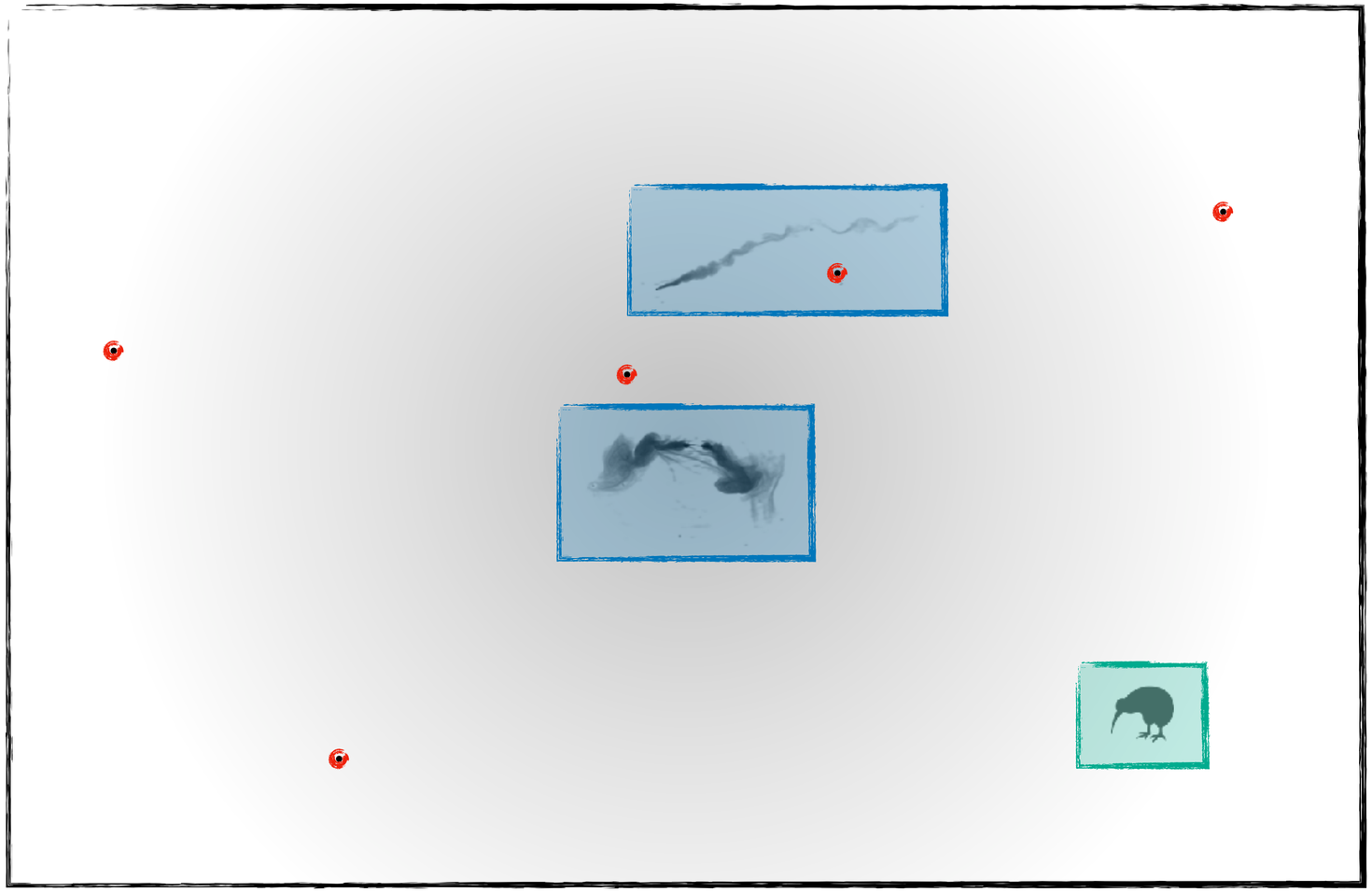
aim-resolve: Automatic Identification and Modeling for Bayesian Radio Interferometric Imaging



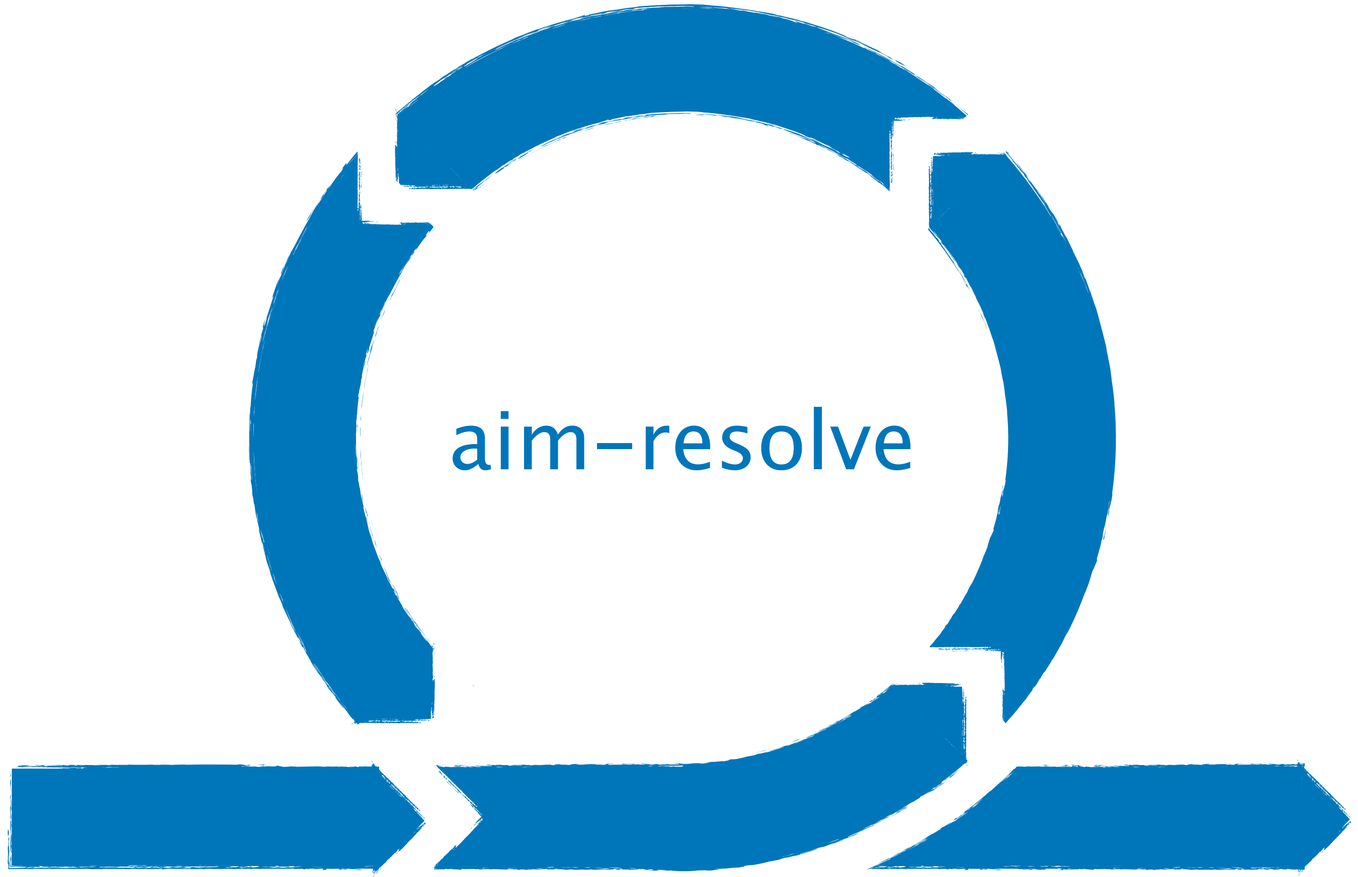
Richard Fuchs,
Jakob Knollmüller, Jakob Roth, Vincent Eberle, Philipp Frank,
Torsten Enßlin, Lukas Heinrich

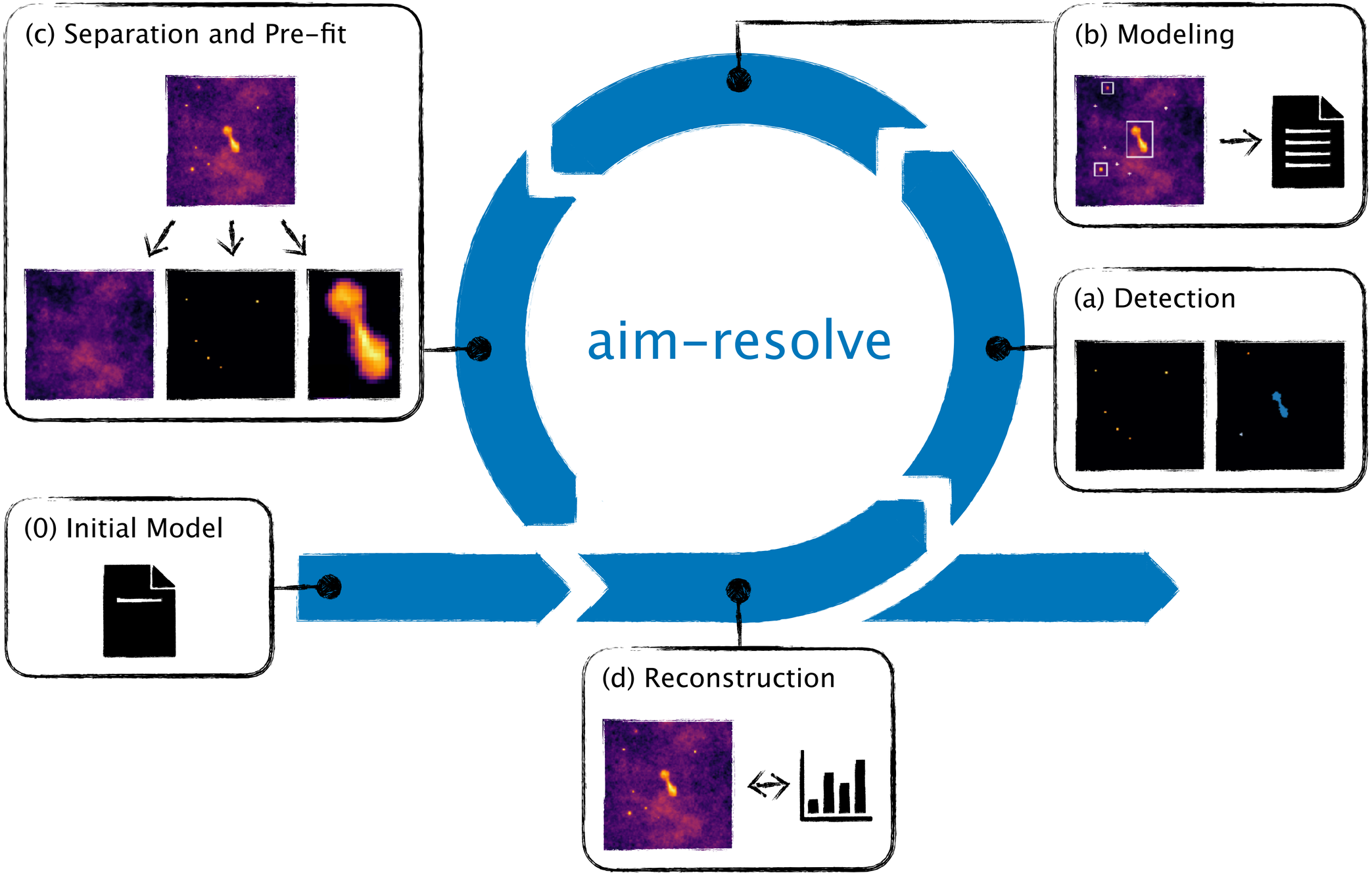
MaxEnt 2025 | Auckland | 19th Dec

Improve Imaging of Wide-field Observations

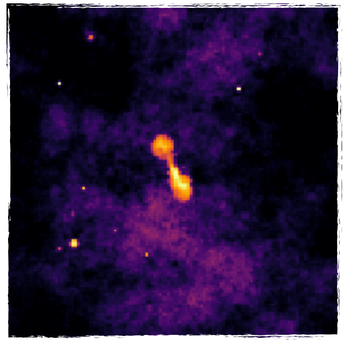


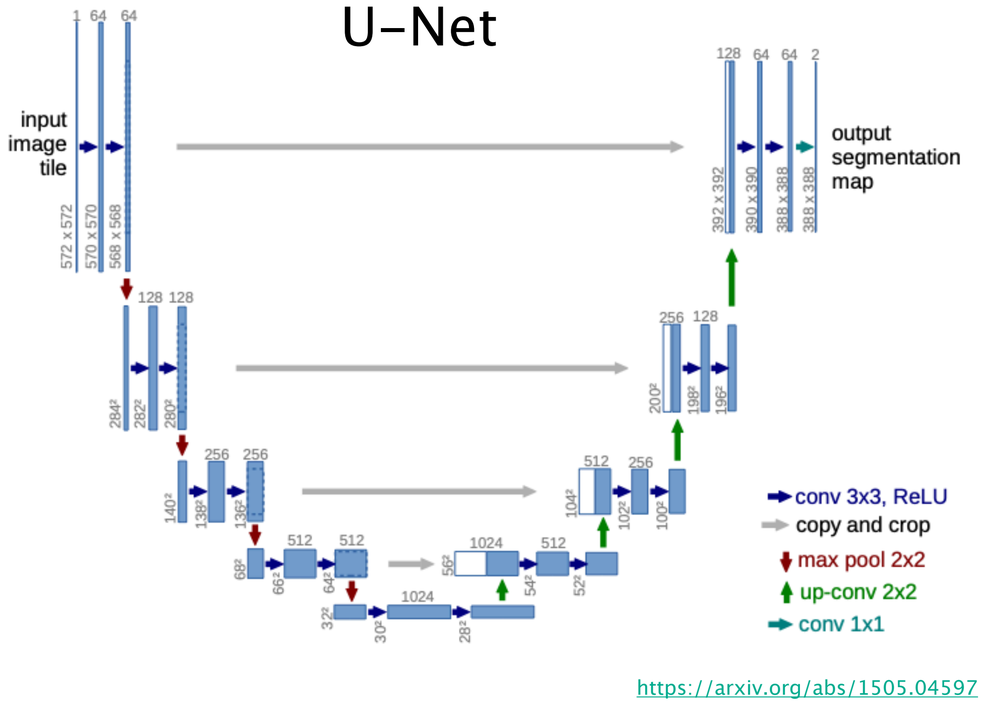
Develop an Iterative Method



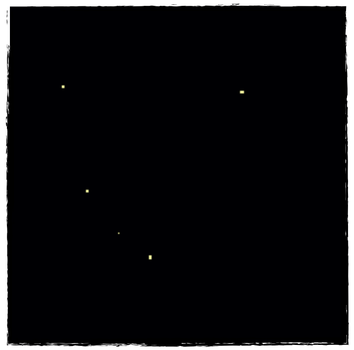

(c) Separation and Pre-fit
(b) Modeling
aim-resolve
(a) Detection
(0) Initial Model
(d) Reconstruction

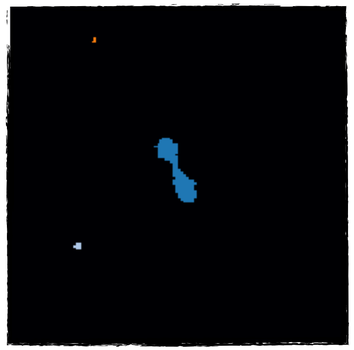
Identify Point Sources & Extended Objects





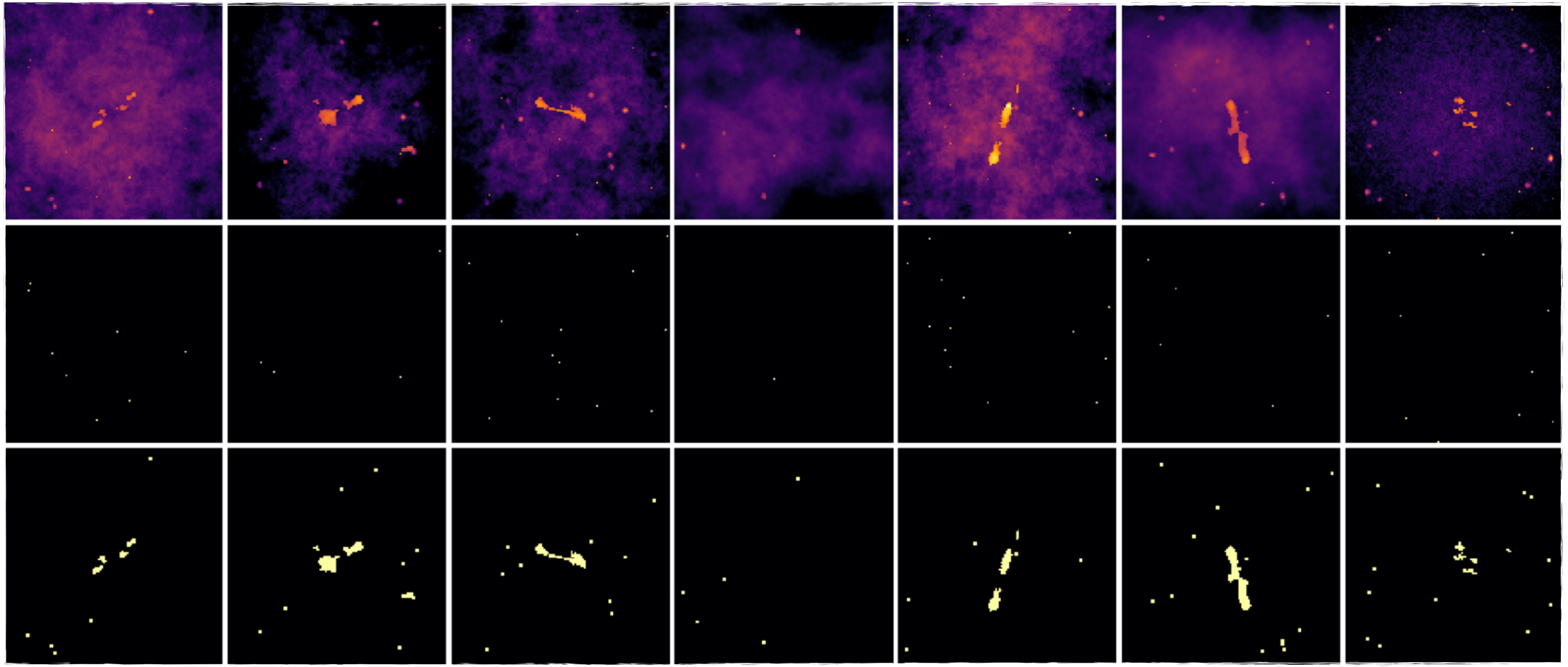
https://arxiv.org/abs/1505.04597



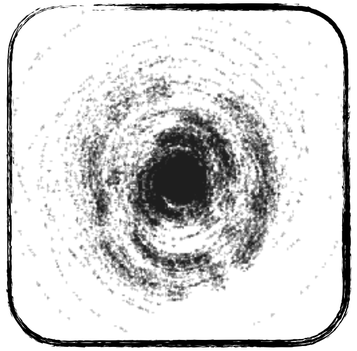


Clustering

A Short Look at the Training Data



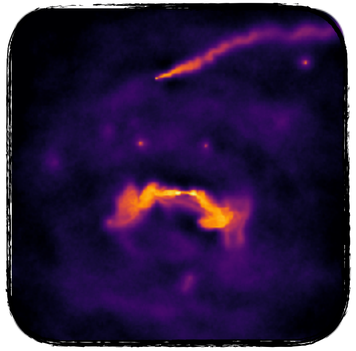
Imaging: Solving an Inverse Problem



Data

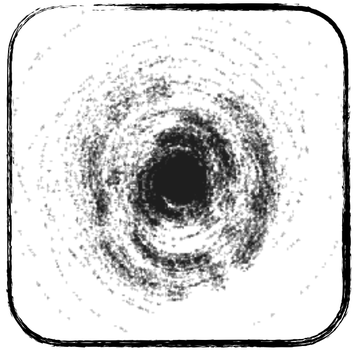
$$d = R(I) + n$$

Problems:
- data corrupted by noise
- incomplete UV-coverage



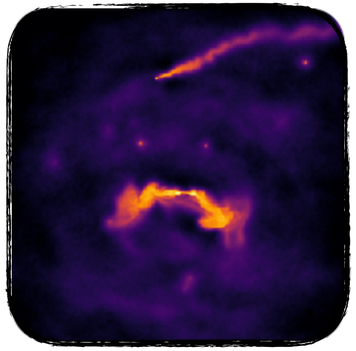
Sky Brightness

Imaging: Solving an Inverse Problem



Data

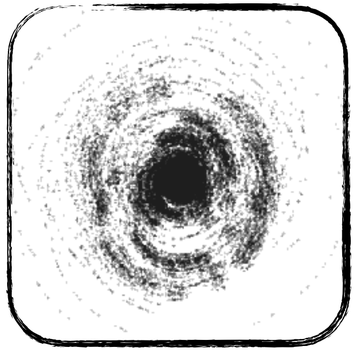
$$d = R(I) + n$$



Sky Brightness

Introduce:
- regularization
- prior knowledge

Use Bayes' Theorem



Data

$$P(\xi \mid d) \propto P(d \mid I(\xi))\ \mathcal{G}(\xi, \mathbb{1})$$

resolve

https://gitlab.mpcdf.mpg.de/ift/resolve

Likelihood

NIFTy

https://github.com/NIFTy-PPL/NIFTy

Variational Inference

NIFTy

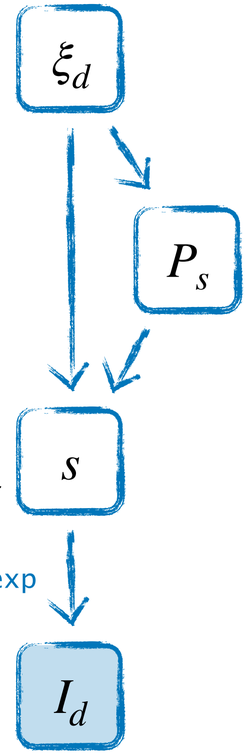
https://github.com/NIFTy-PPL/NIFTy

Prior Model

Compare Different Prior Models

Diffuse Emission

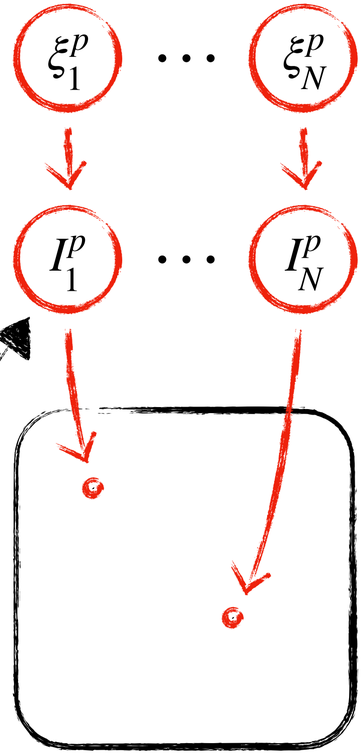
- correlated
- flexible
- positive



Gaussian Process

Point Sources

- independent
- known position
- positive



Lognormal distr.

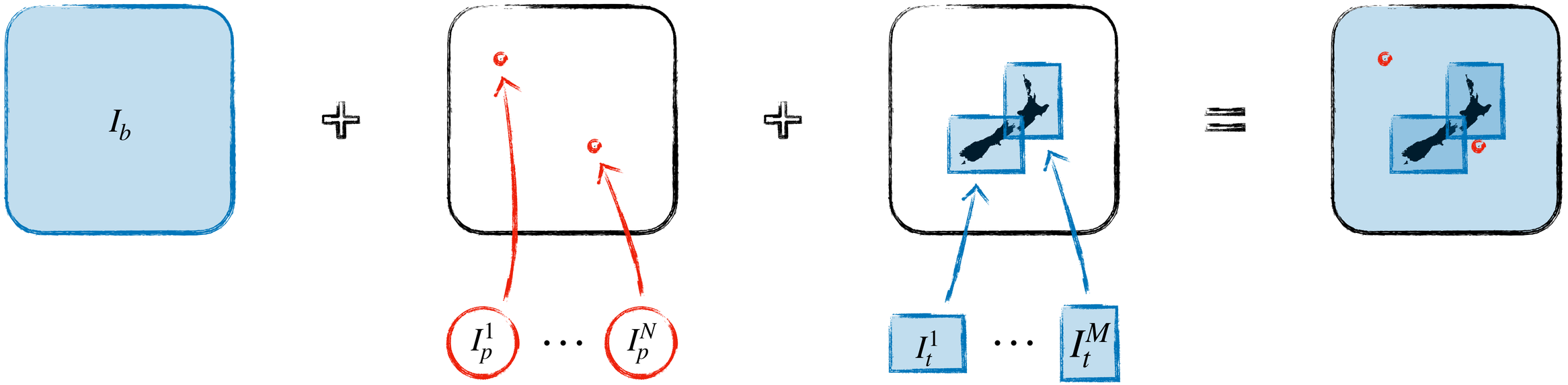
Build a Multi-Component Sky Description

Background

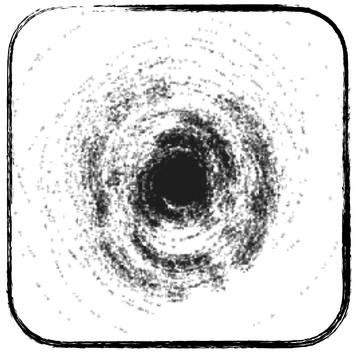
Point Sources

Extended Objects

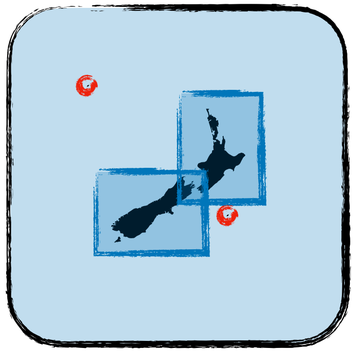
Prior Model



Setup the Likelihood



Data



Prior Model

$$d = R(I(\xi)) + n$$

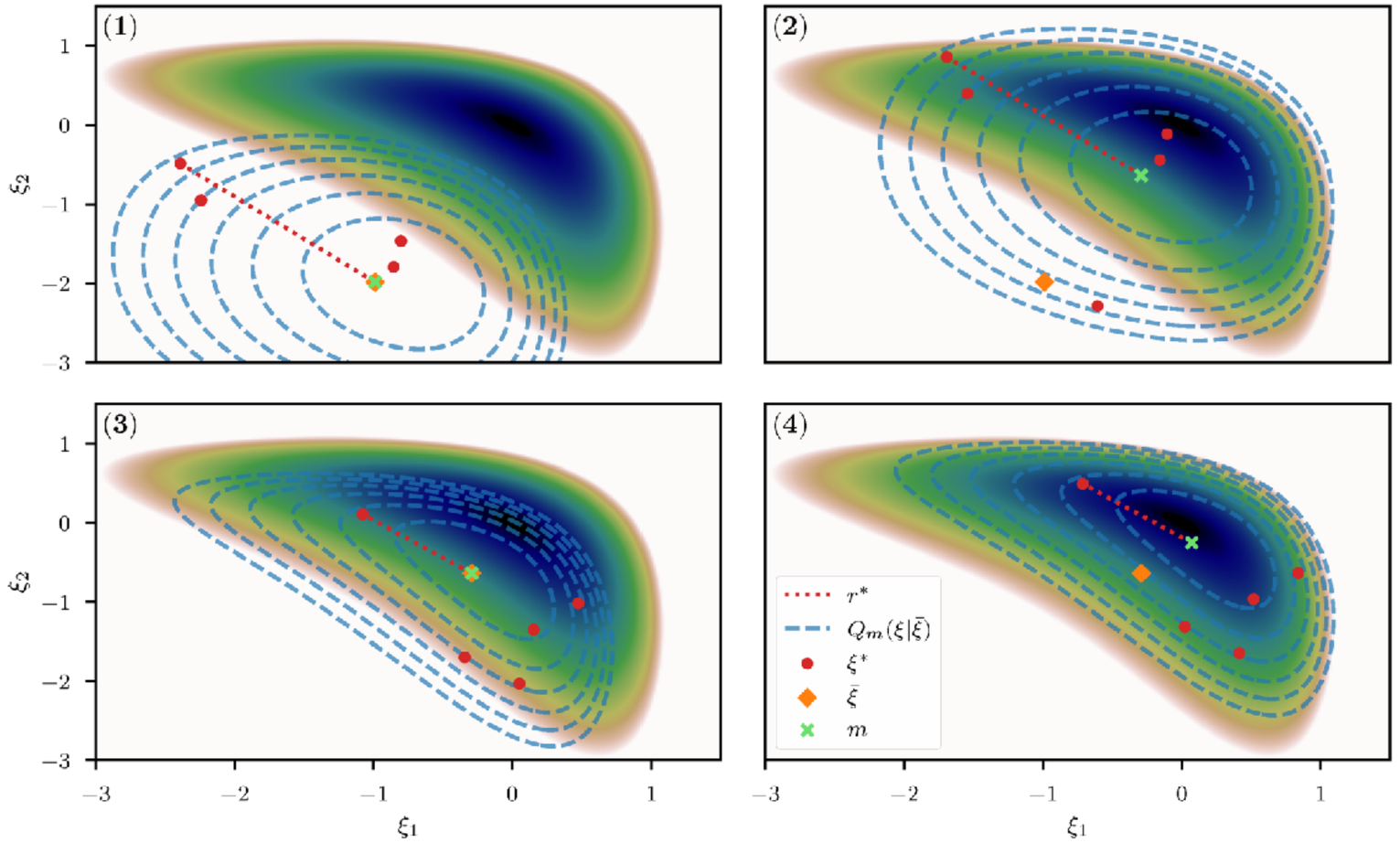
$$P(d \mid I) = \mathcal{G}(d - R(I(\xi)), N)$$

Gaussian Likelihood

$$P(n) = \mathcal{G}(n, N)$$

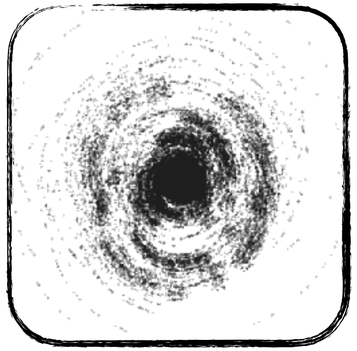
Gaussian Noise

Posterior Approximation with geoVI



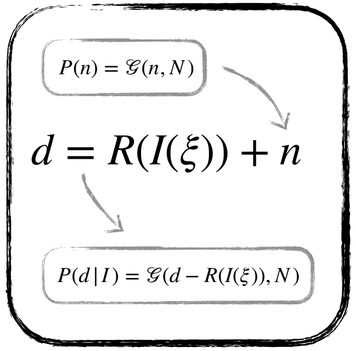
https://www.mdpi.com/1099-4300/23/7/853#

Put Everything Together

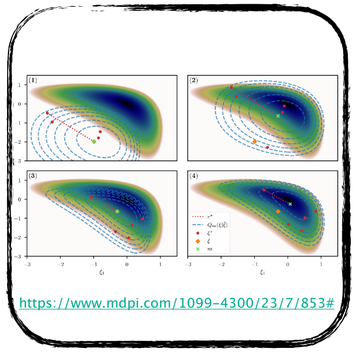


Data

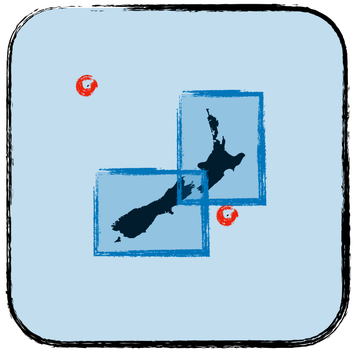
$$P(I(\xi)\,|\,d) \propto P(d\,|\,I(\xi))\;\mathcal{G}(\xi, \mathbb{1})$$



Likelihood

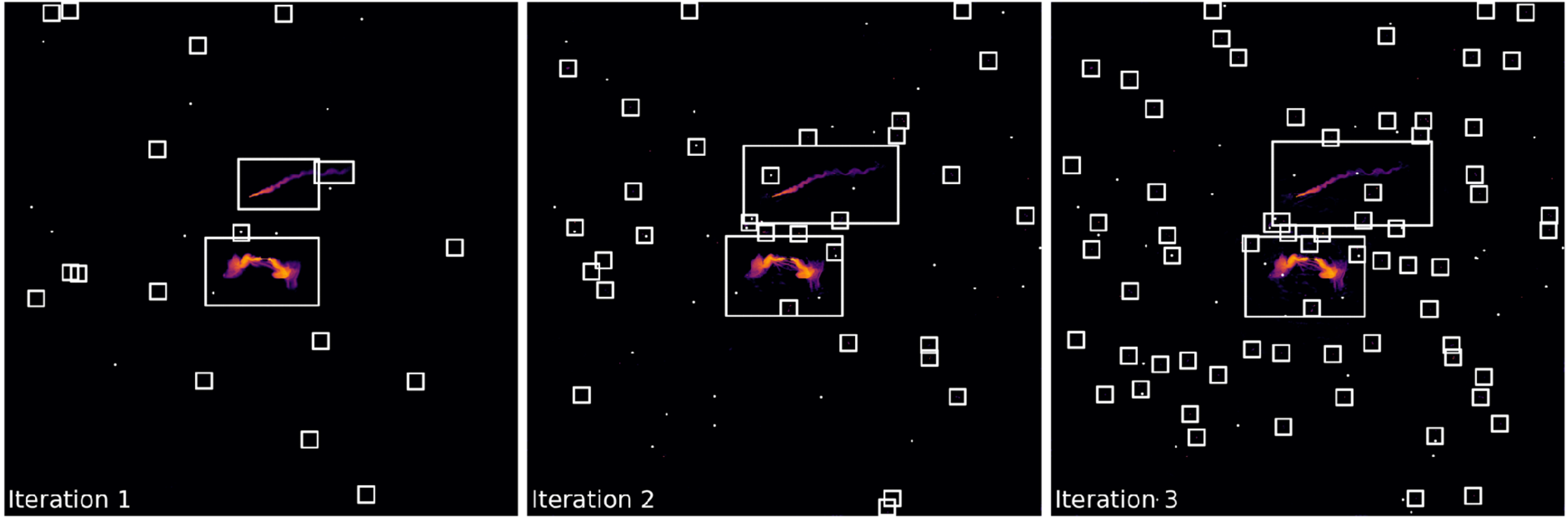


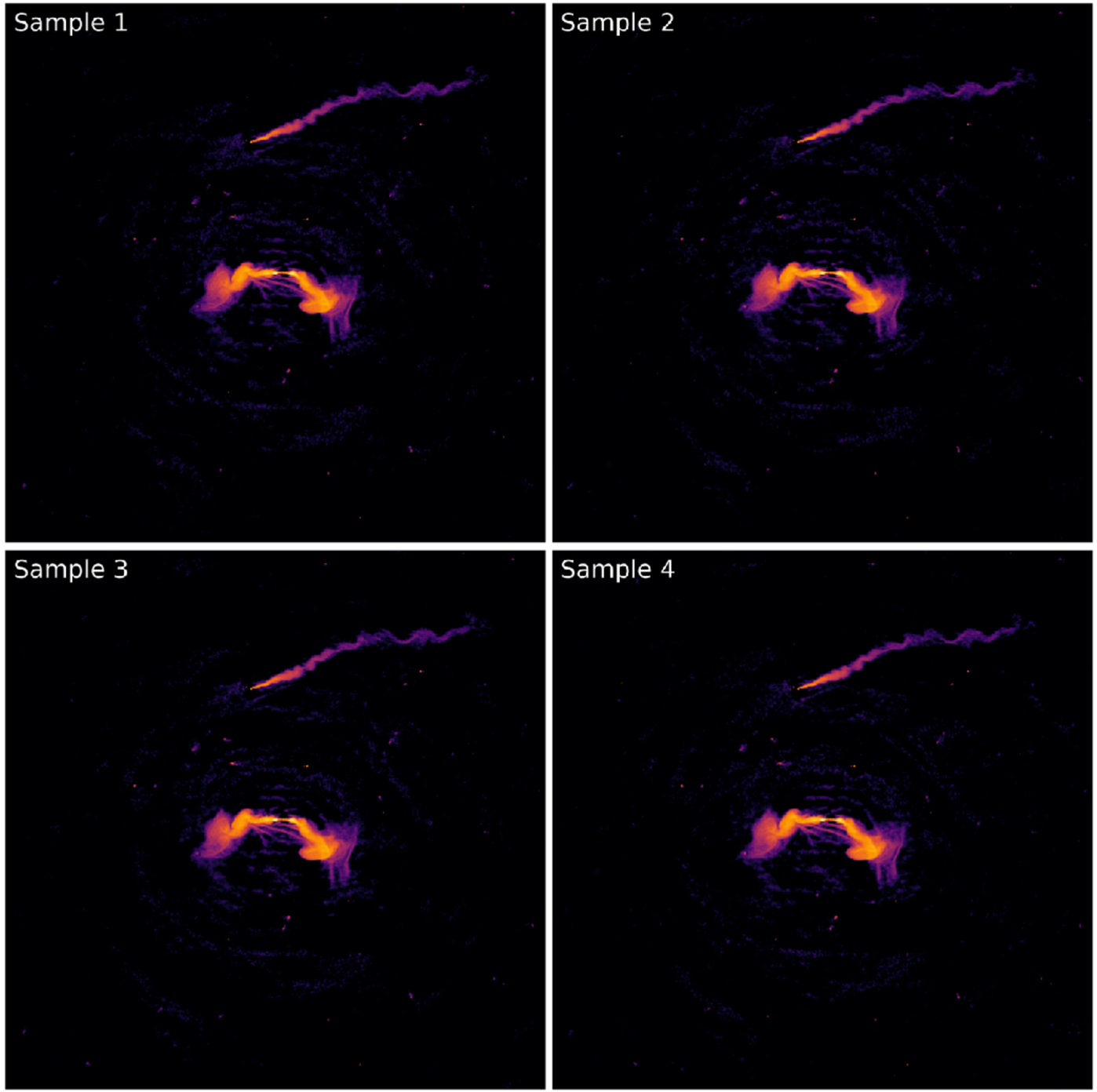
geoVI



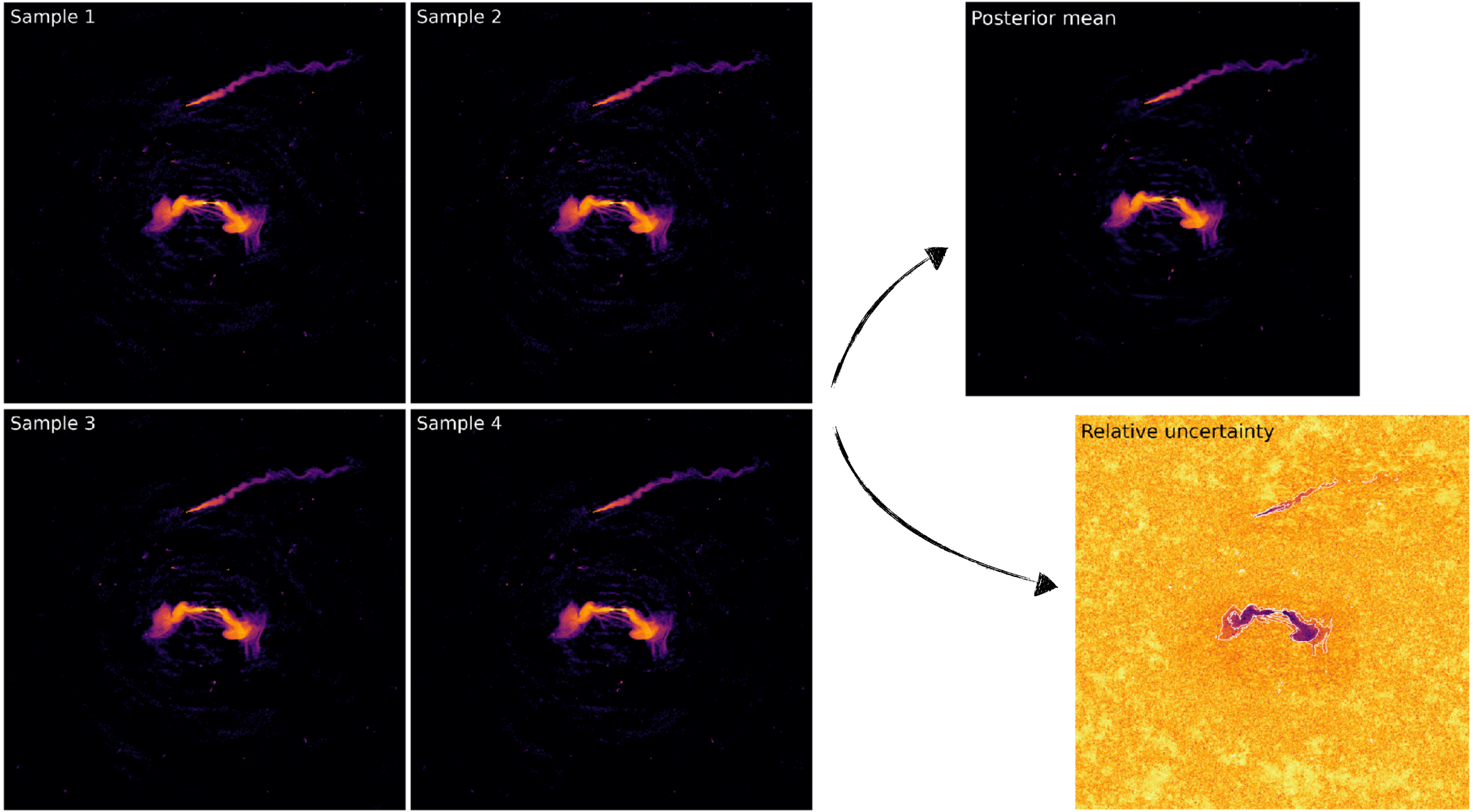
Prior Model

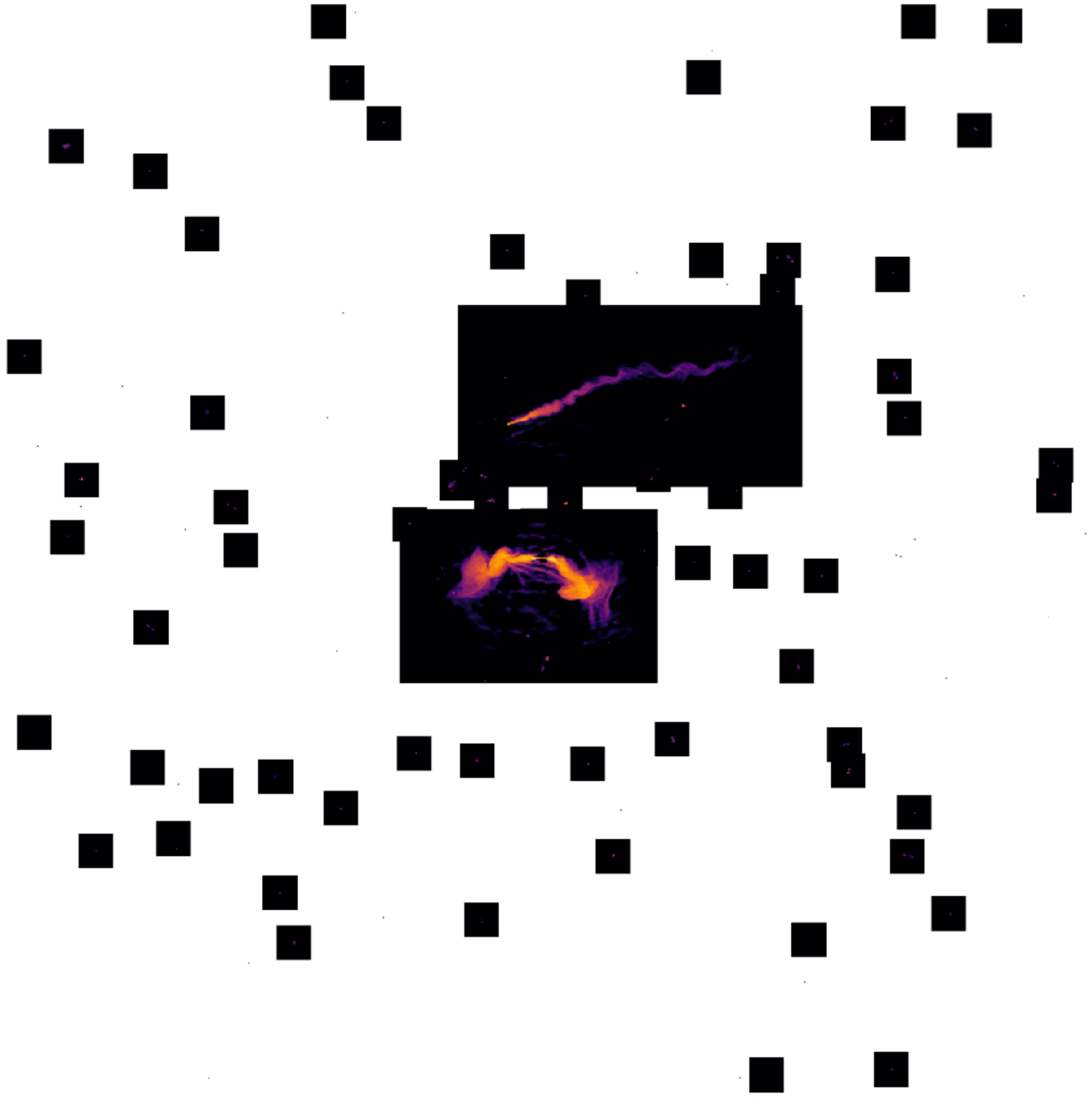
Real Data Results





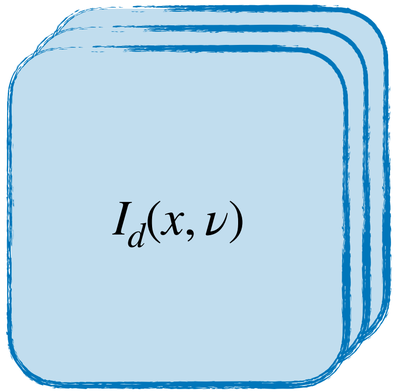
Posterior Samples


Sample 1
Sample 2
Posterior mean
Sample 3
Sample 4
Relative uncertainty



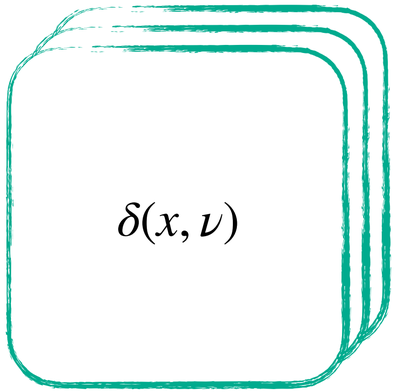
Model Components

Extend Prior Models to Multiple Frequencies

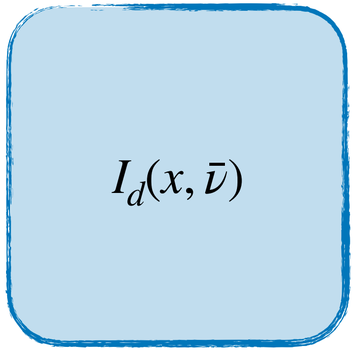


Multi-freq. Sky

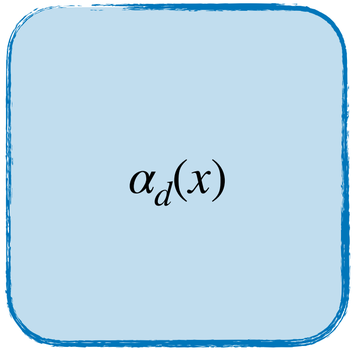
$$I_d(x,\nu) = I_d(x,\bar{\nu})\ (\nu/\bar{\nu})^{\alpha_d(x)}\ \delta(x,\nu)$$



Deviations



Sky @ ref. freq.



Spectral Index

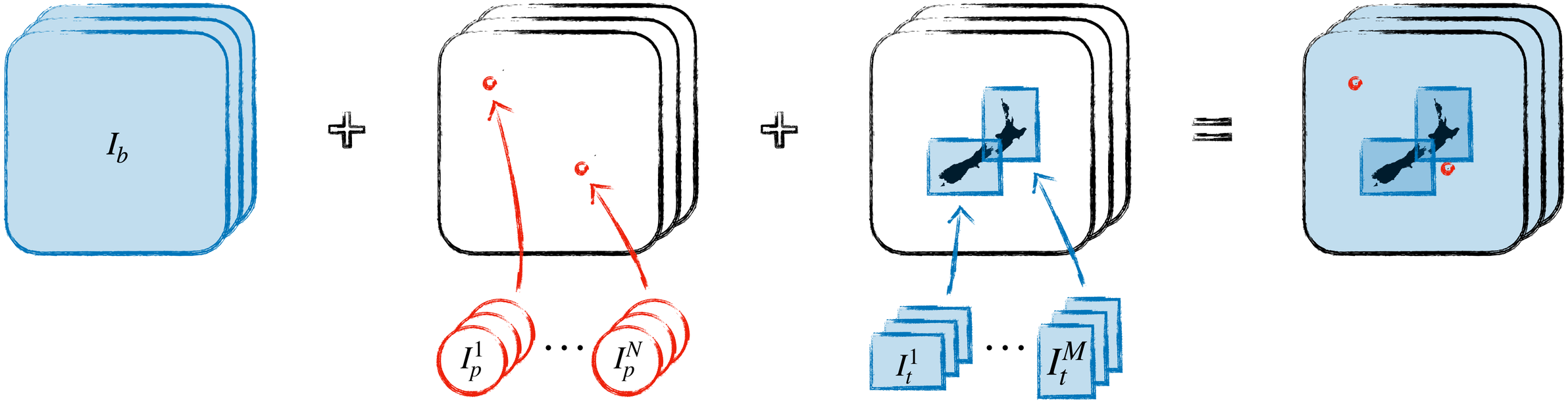
Multi-Component & Multi-Frequency Sky

Background

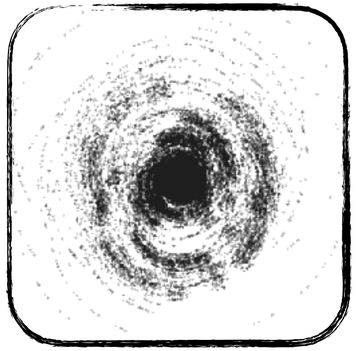
Point Sources

Extended Objects

Prior Model



Put Everything Together



Data

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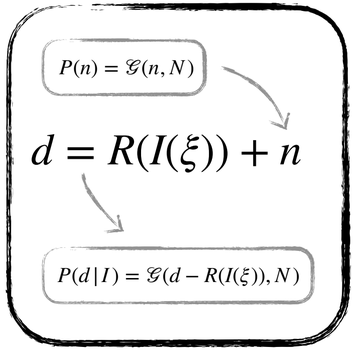
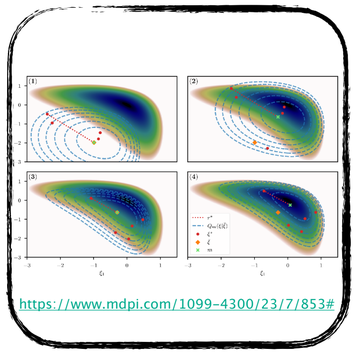
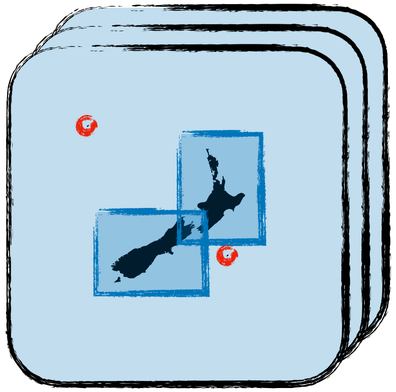


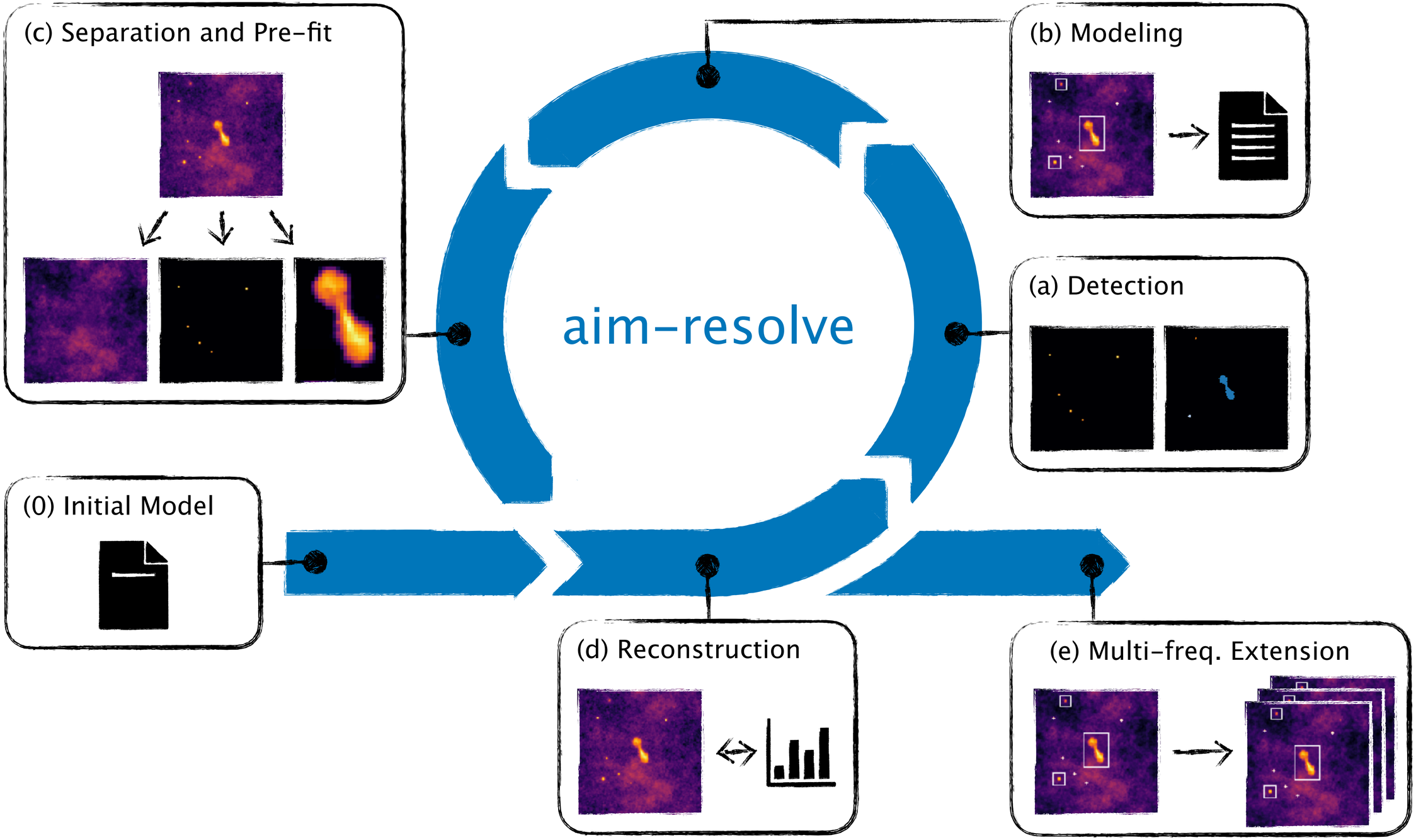
Likelihood



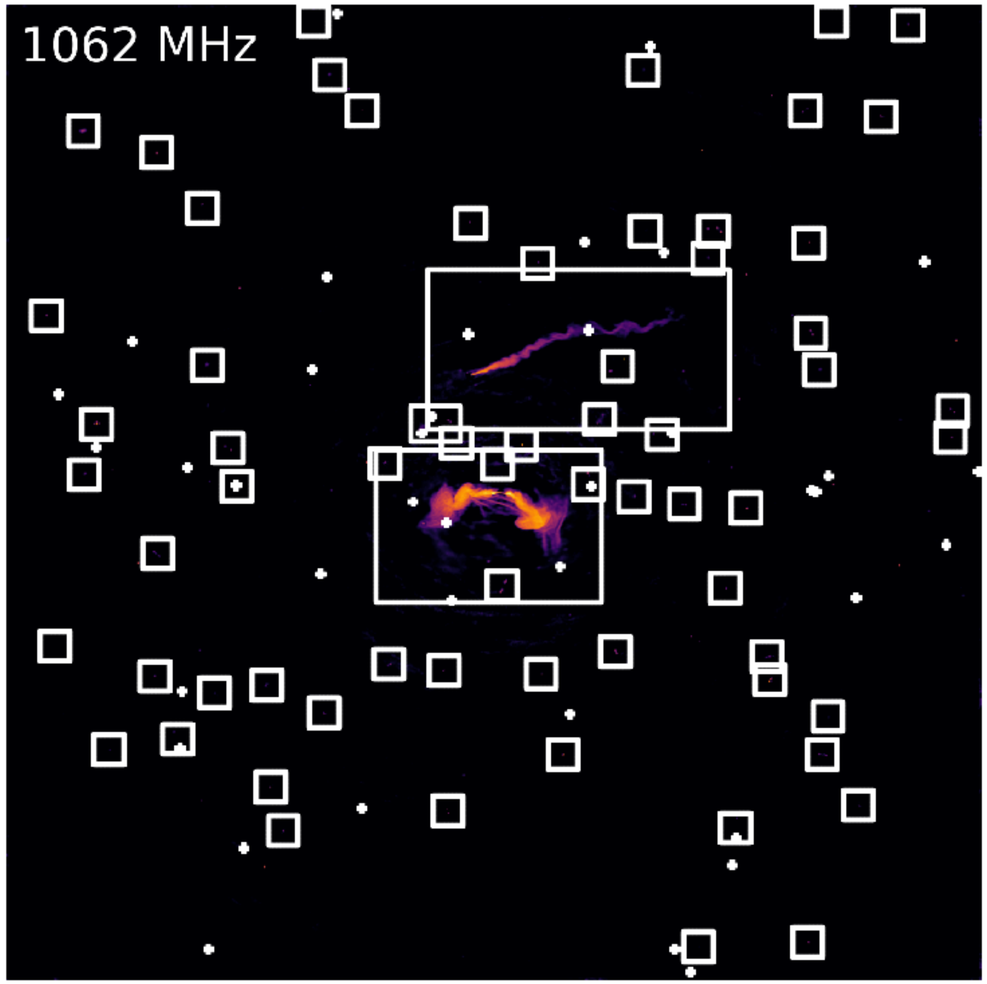
geoVI

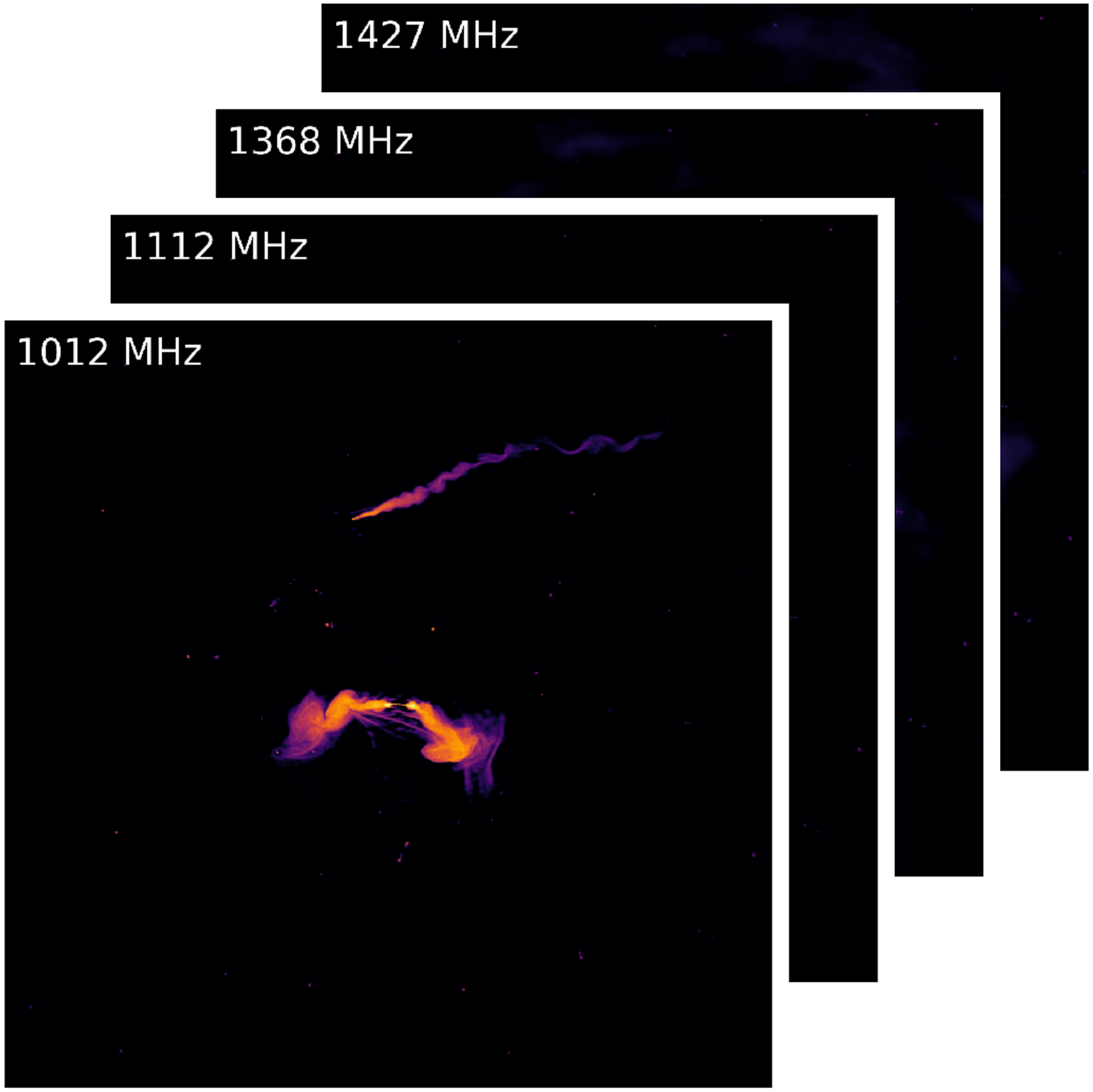


Prior Model

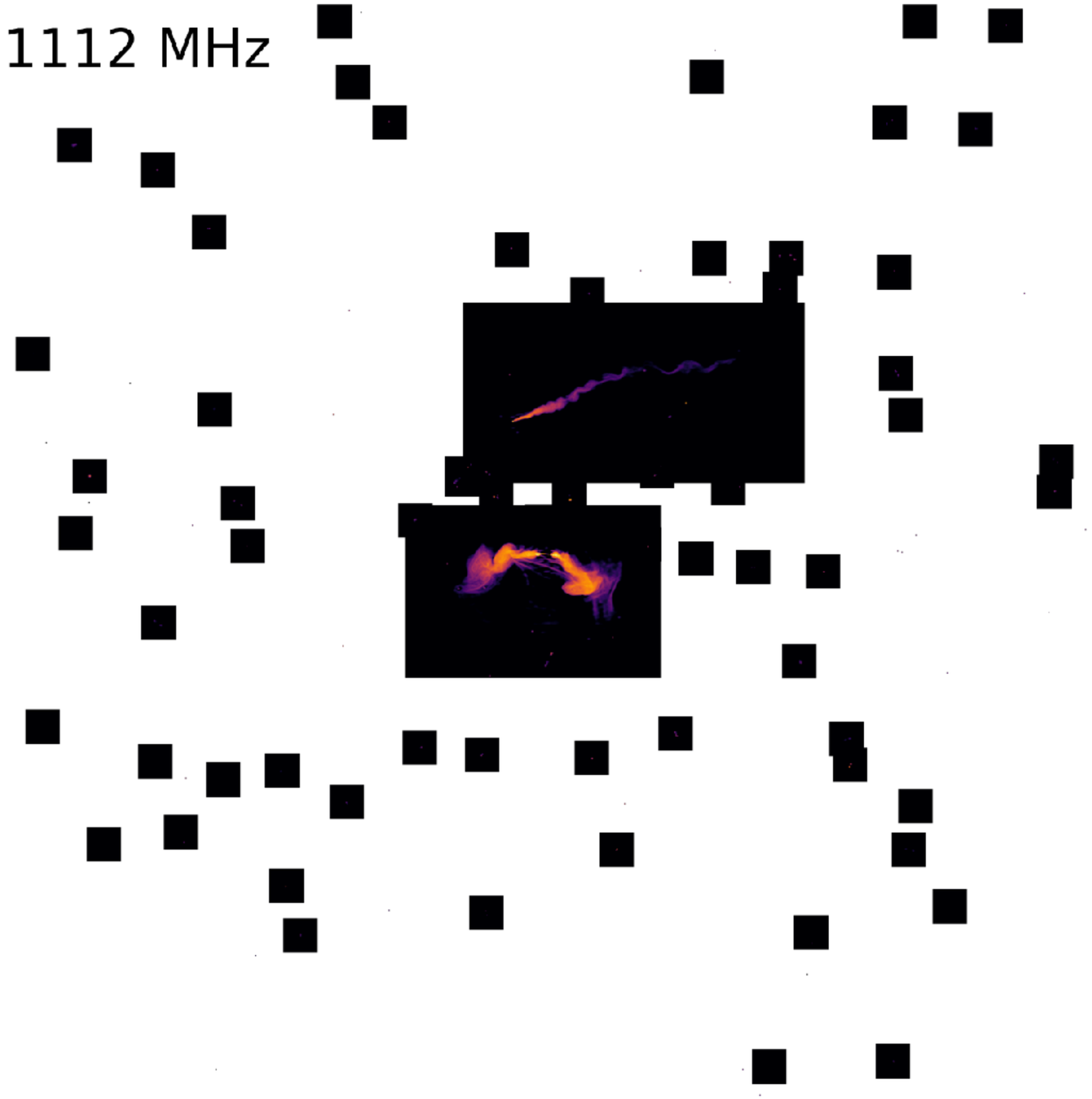

(c) Separation and Pre-fit
(b) Modeling
aim-resolve
(a) Detection
(0) Initial Model
(d) Reconstruction
(e) Multi-freq. Extension

Start with Single-Freq. Model



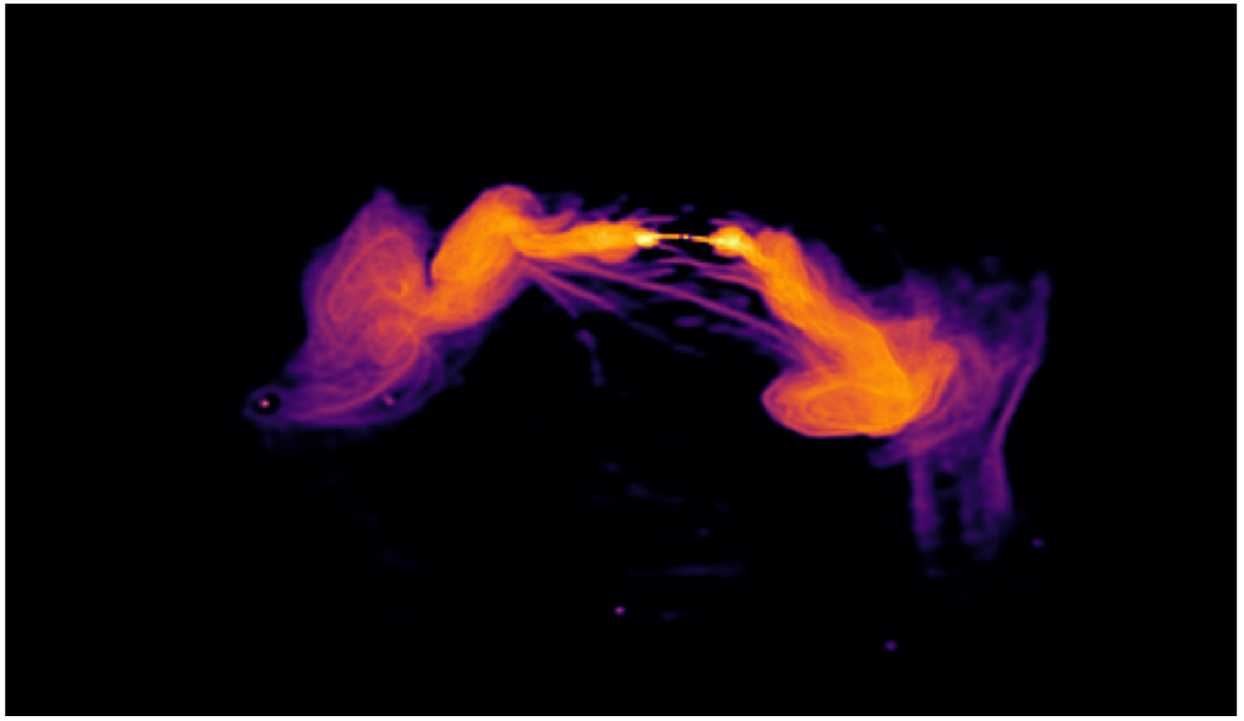


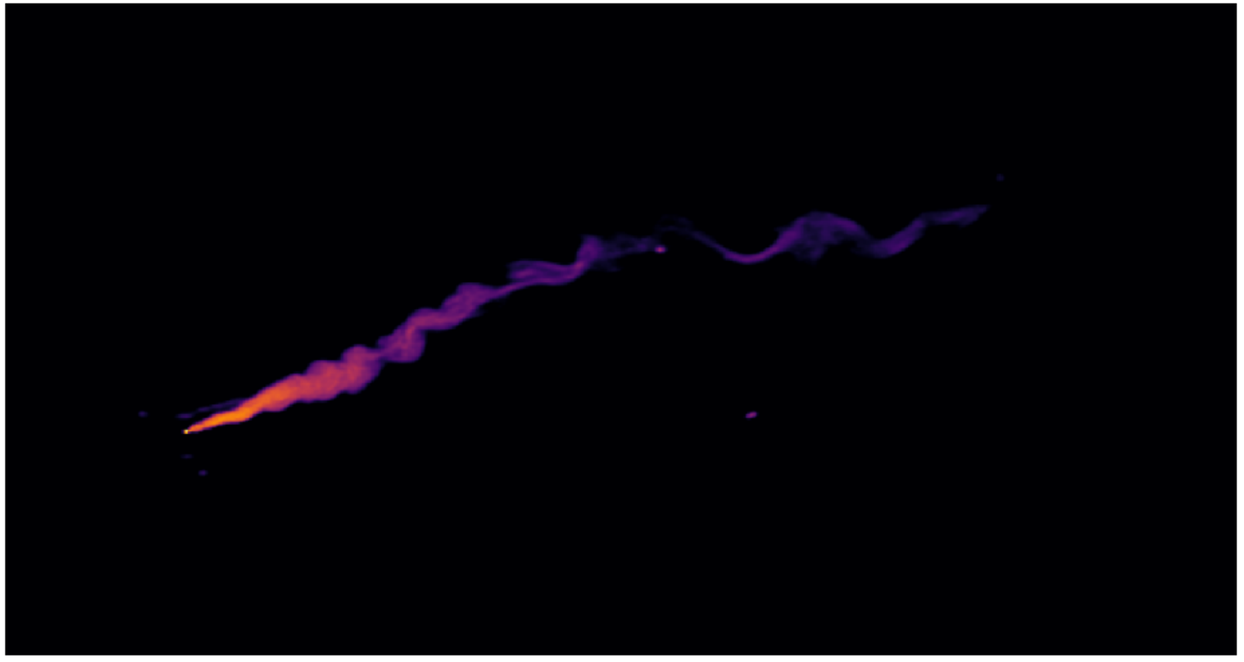
Multi-Freq. Results



Model Components

Spectral Index





Conclusions

aim-resolve

- automatized and iterative method
- separate astrophysical components
- provide uncertainty quantification
- model spectral behavior

=> improve imaging for wide-field observations

Outlook

- unified imaging and calibration
- build source catalogs
- models for Kiwis 

  …

- multi-frequency & multi-instrument reconstructions

Thank You for Your Attention!

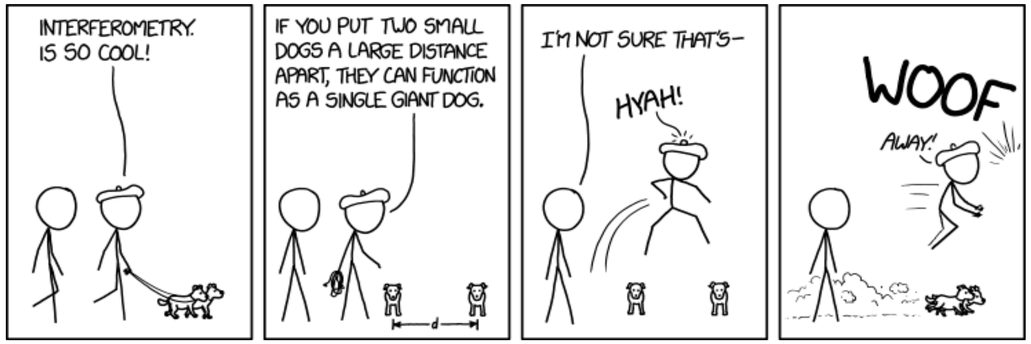
Paper

Astronomy & Astrophysics manuscript no. main
December 5, 2025

aim-resolve: Automatic Identification and Modeling for Bayesian Radio Interferometric Imaging

Richard Fuchs[1], Jakob Knollmüller[1,2], Jakob Roth[3,4], Vincent Eberle[3,5], Philipp Frank[3,6], Torsten A. Enßlin[3,5,7], and Lukas Heinrich[1]

https://arxiv.org/abs/2512.04840



https://xkcd.com/1922

Repositories

aim-resolve

https://github.com/NIFTy-PPL/NIFTy

resolve

https://gitlab.mpcdf.mpg.de/ift/resolve

Get in contact direct or via mail

richard.fuchs@tum.de