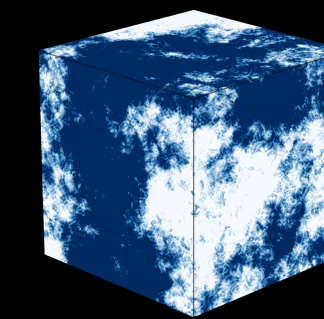
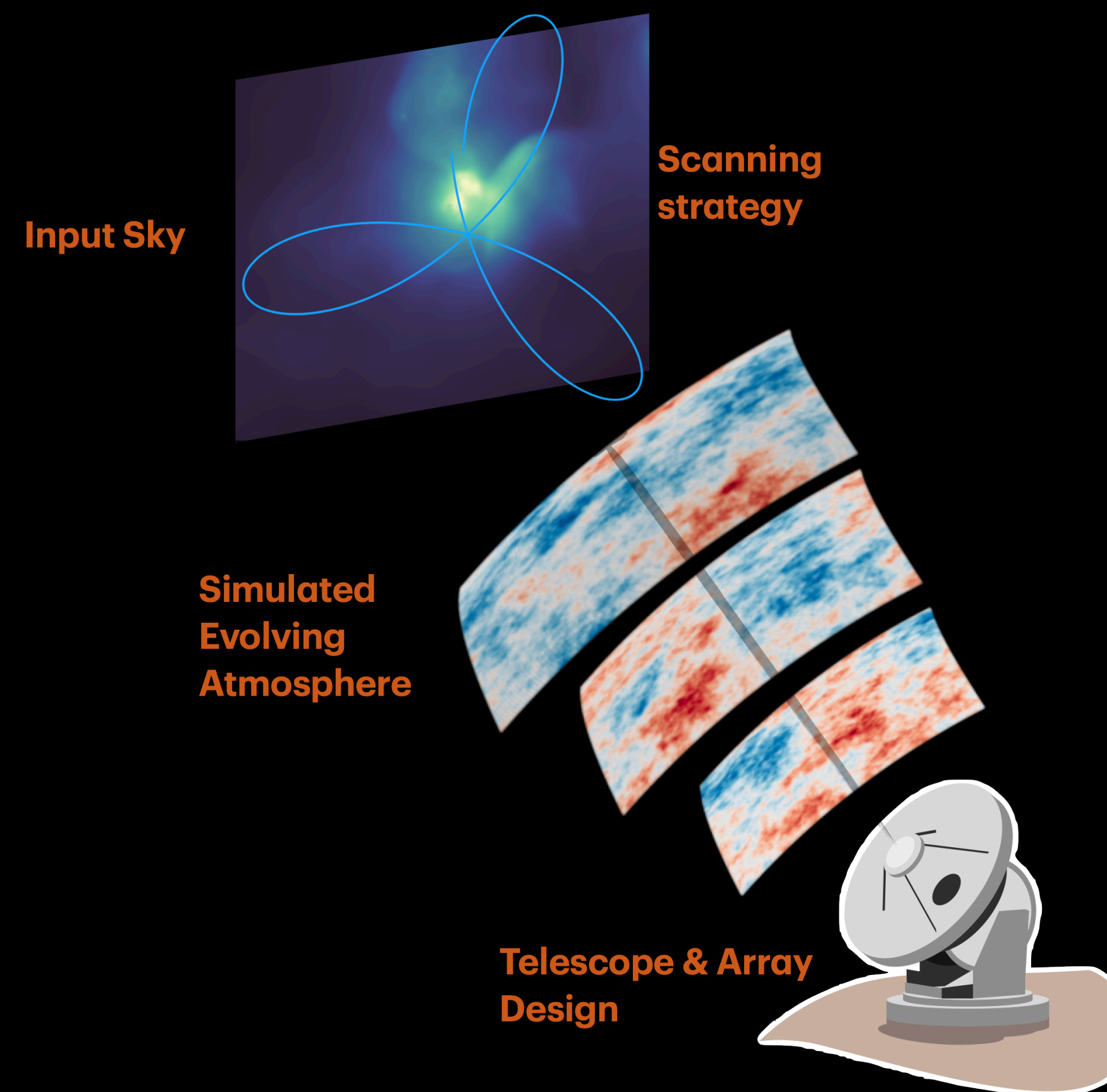


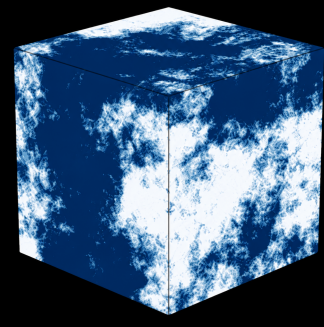
maria–nifty

Gaussian Process–based Imaging of (Sub–)Millimeter Single–Dish Telescope Data

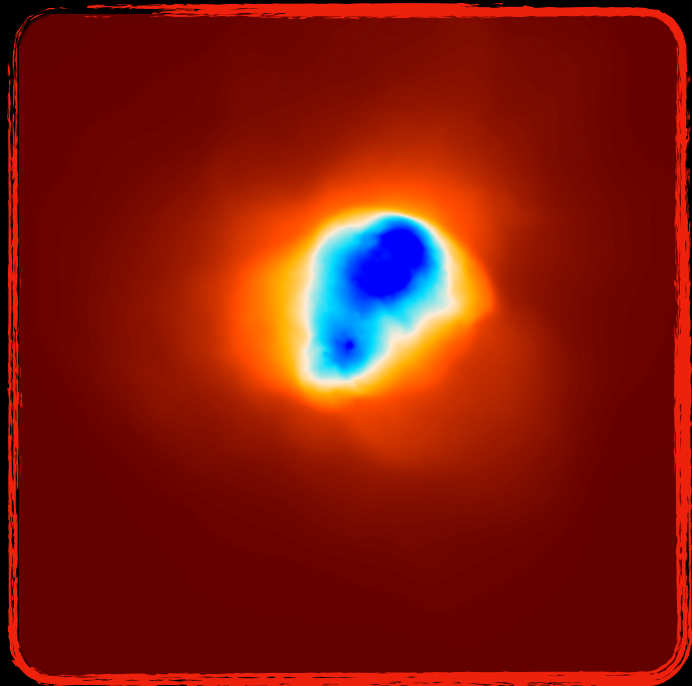
R. Fuchs, J. Würzinger, J. van Marrewijk, T.W. Morris, T. Mroczkowski and L. Heinrich

Observing (sub-)mm single-dish data

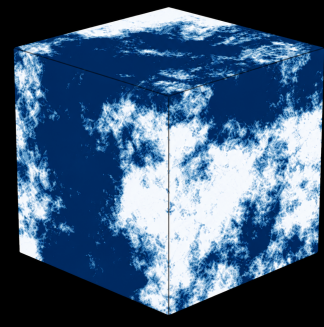




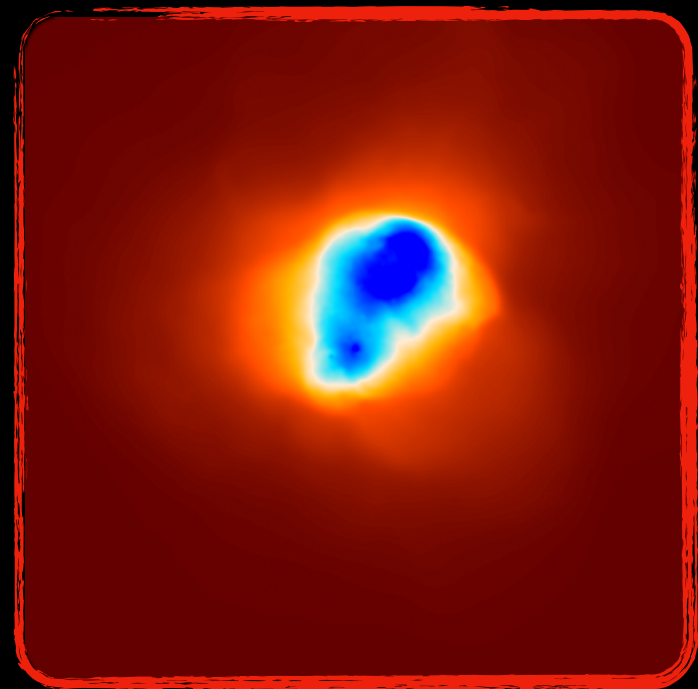
maria: simulate (sub-)mm single-dish data



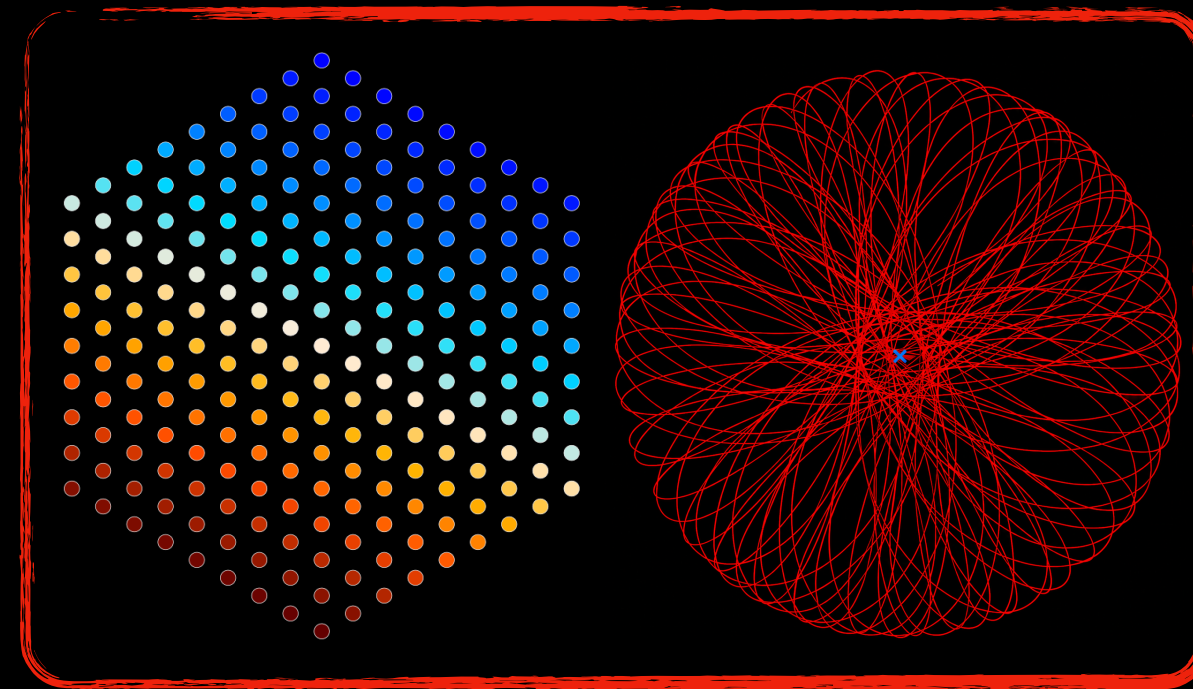
Input map



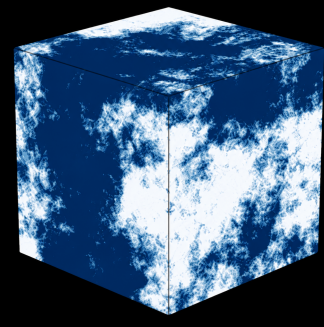
maria: simulate (sub-)mm single-dish data



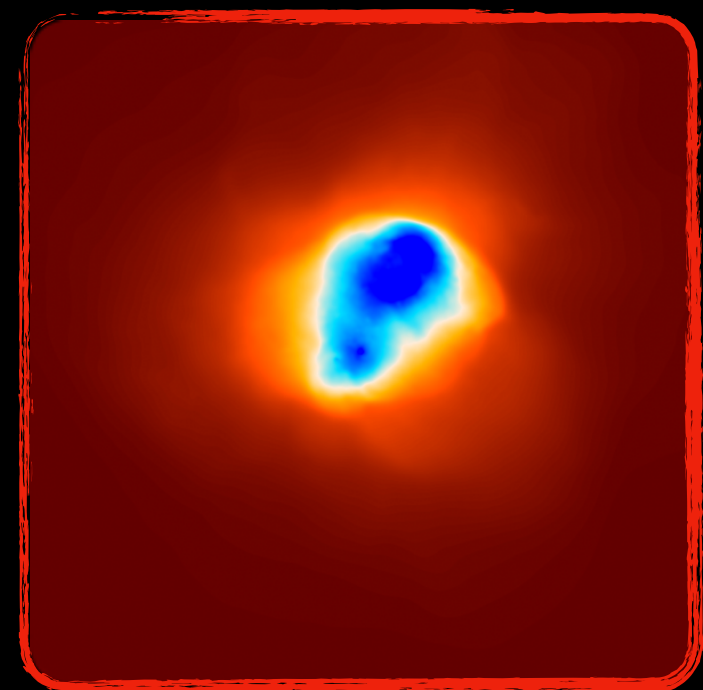
Input map



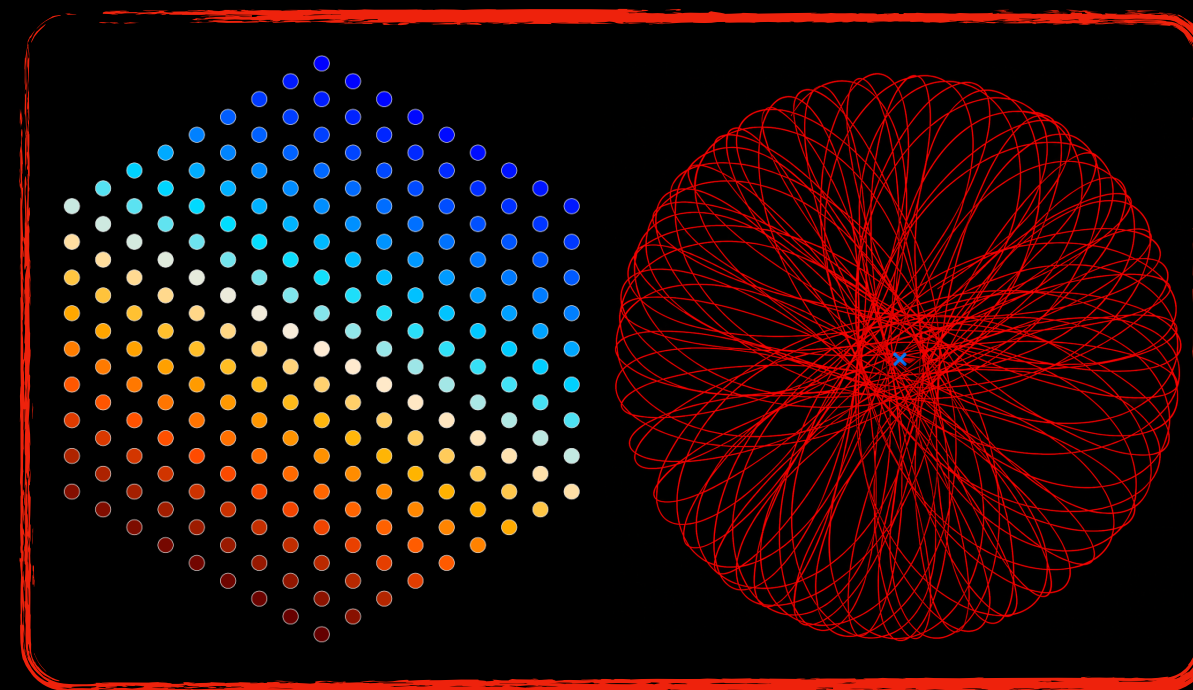
Instrument & scanning strategy



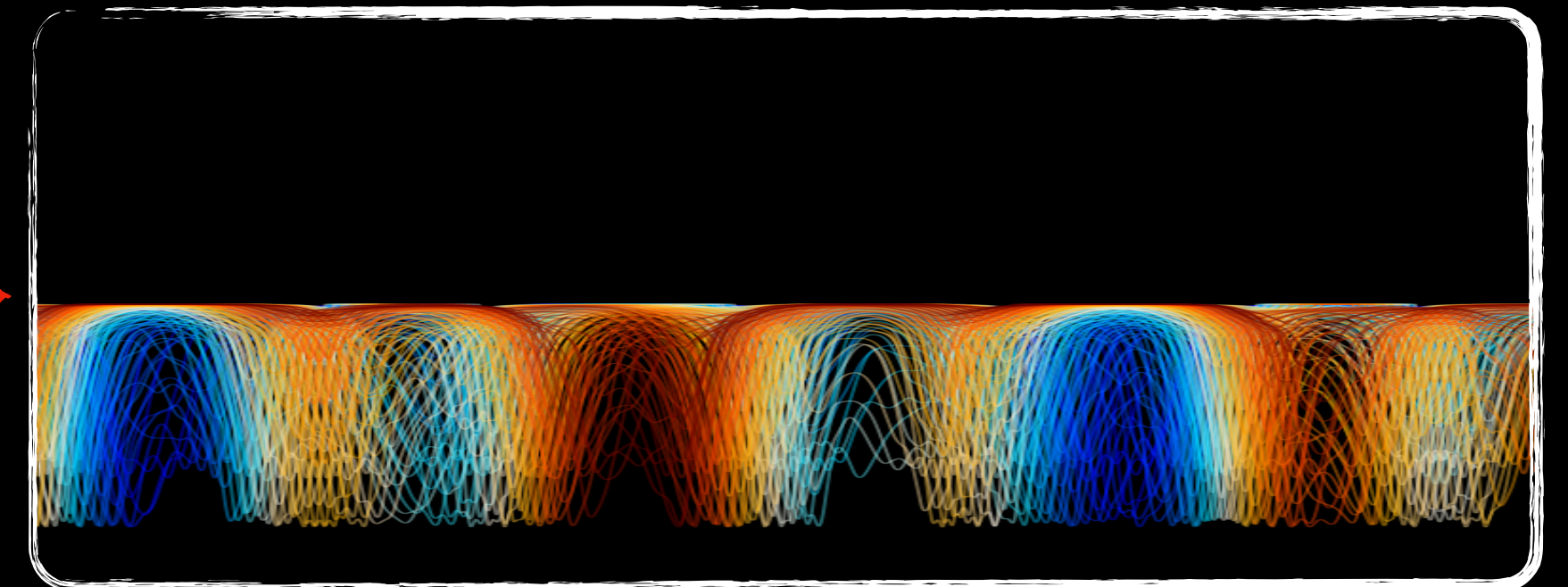
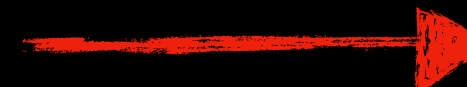
maria: simulate (sub-)mm single-dish data



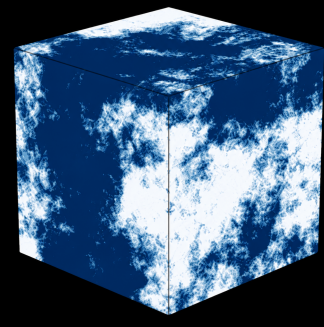
Input map



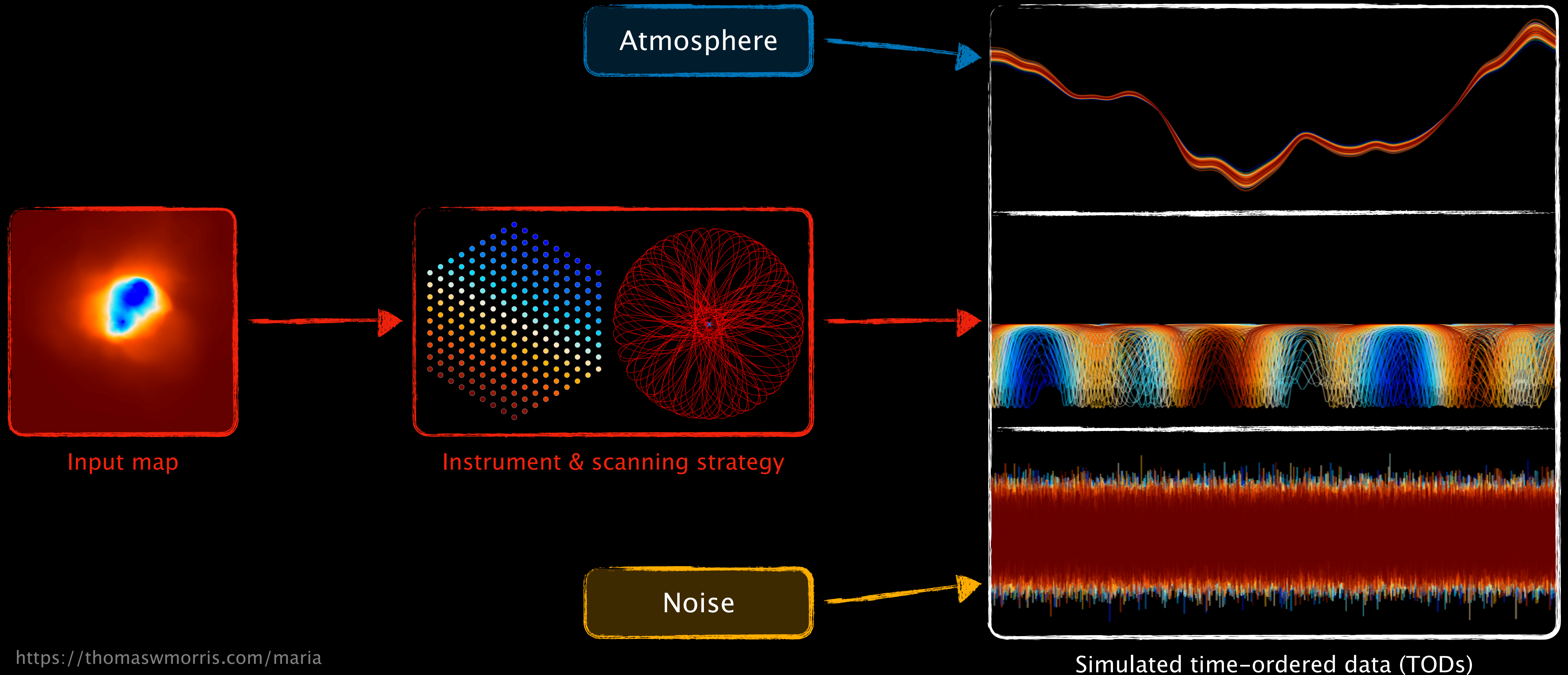
Instrument & scanning strategy

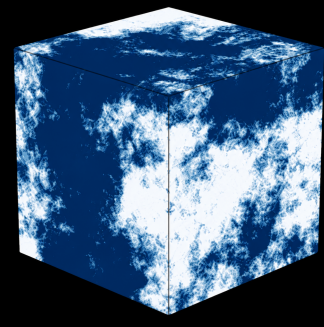


Simulated time-ordered data (TODs)

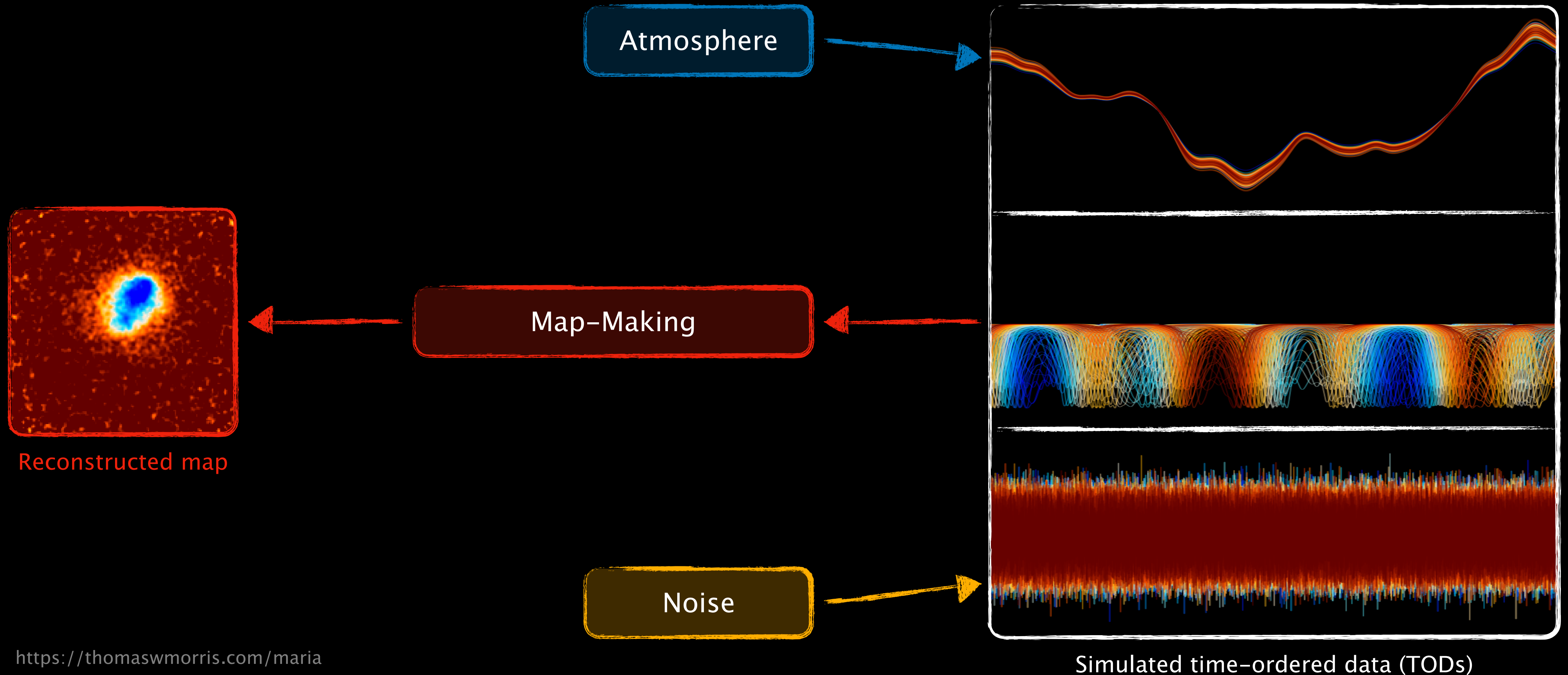


maria: simulate (sub-)mm single-dish data

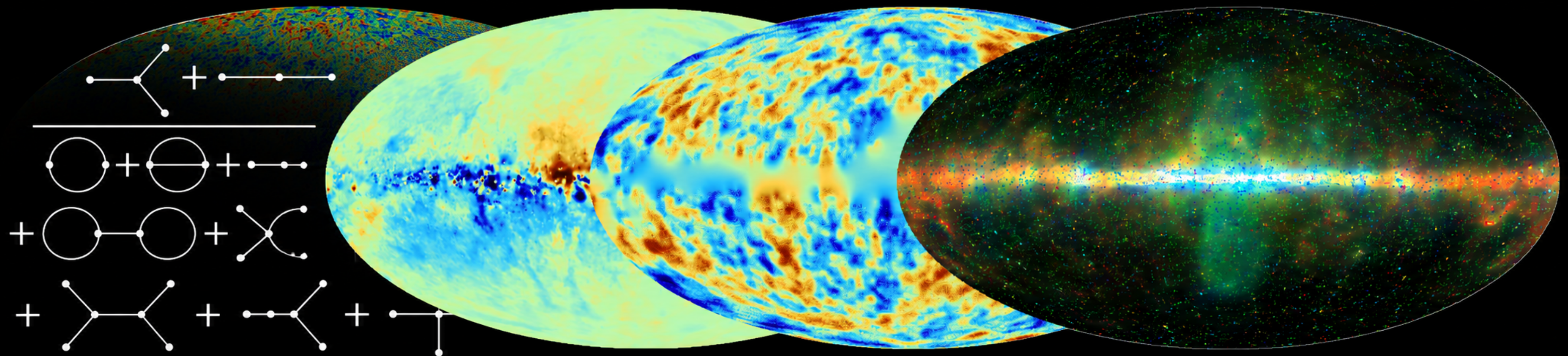
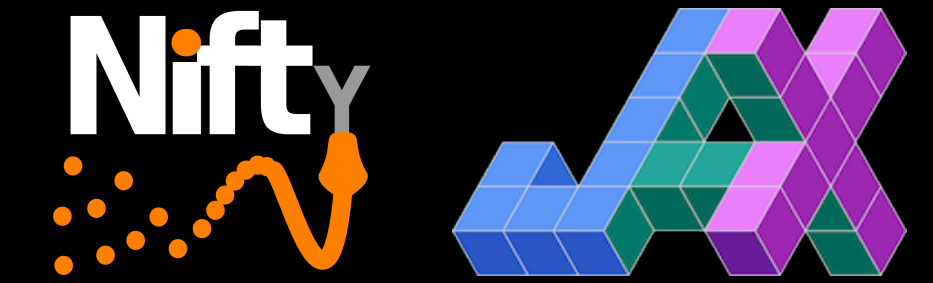




maria: simulate (sub-)mm single-dish data



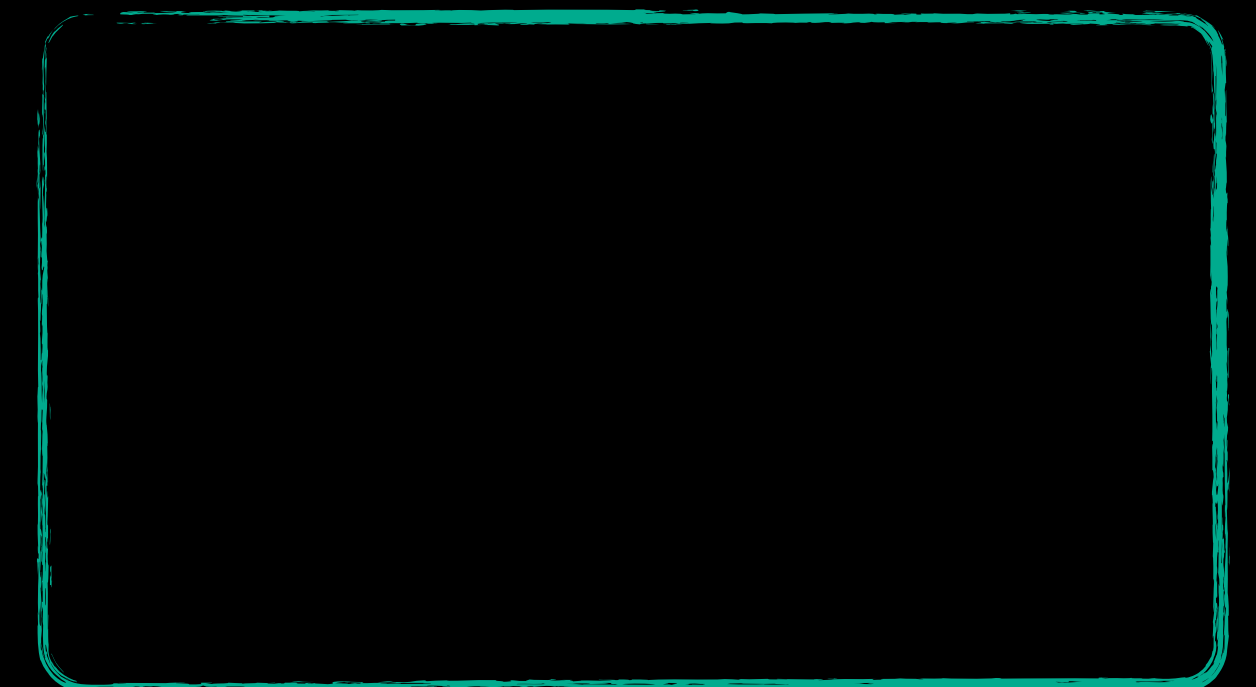
nifty: Bayesian imaging



Numerical Information Field Theory

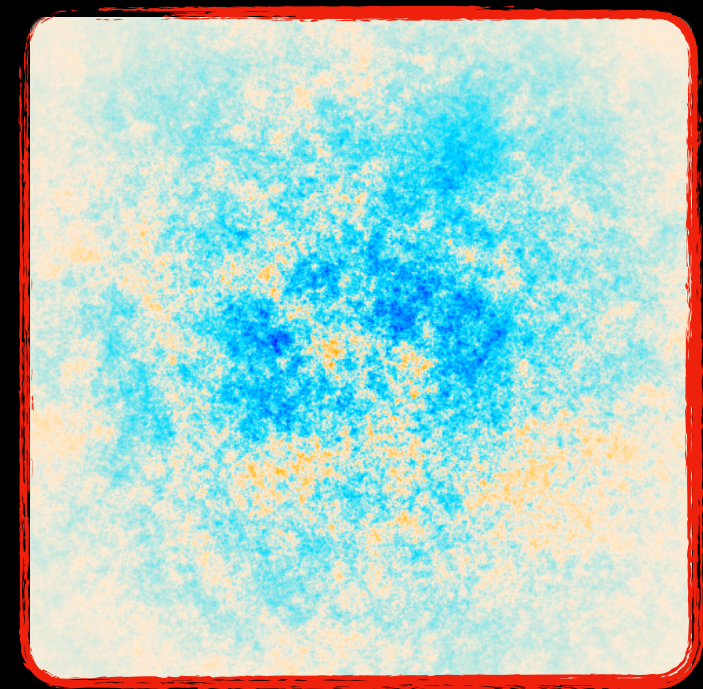
maria-nifty: forward model

$$= d(t)$$



Model TODs

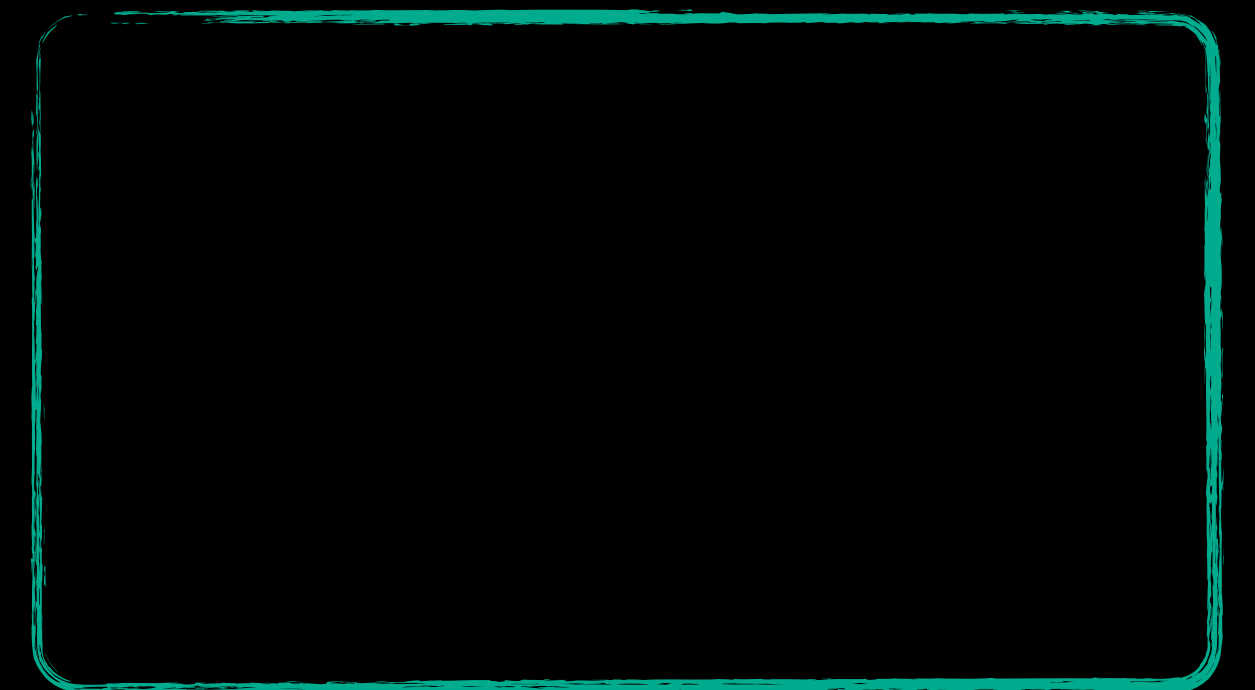
maria-nifty: forward model



Map prior (GP)

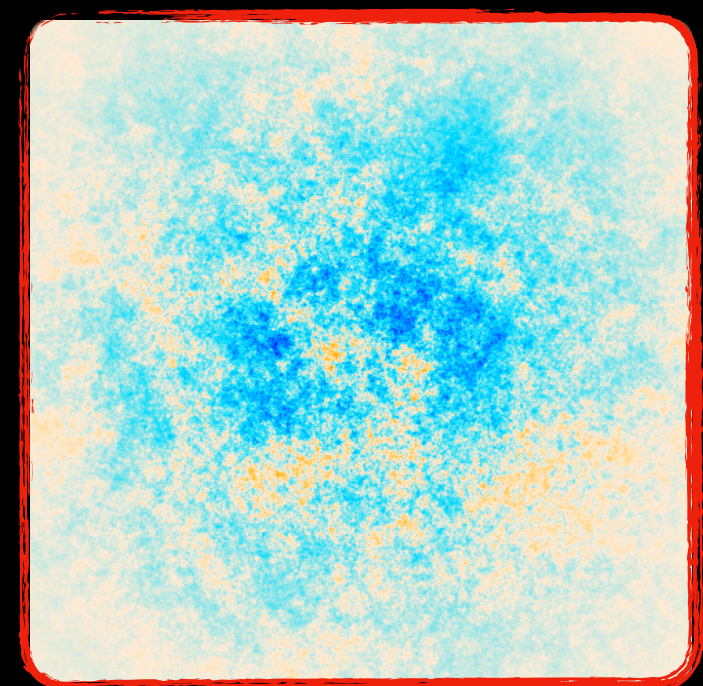
S

$= d(t)$



Model TODs

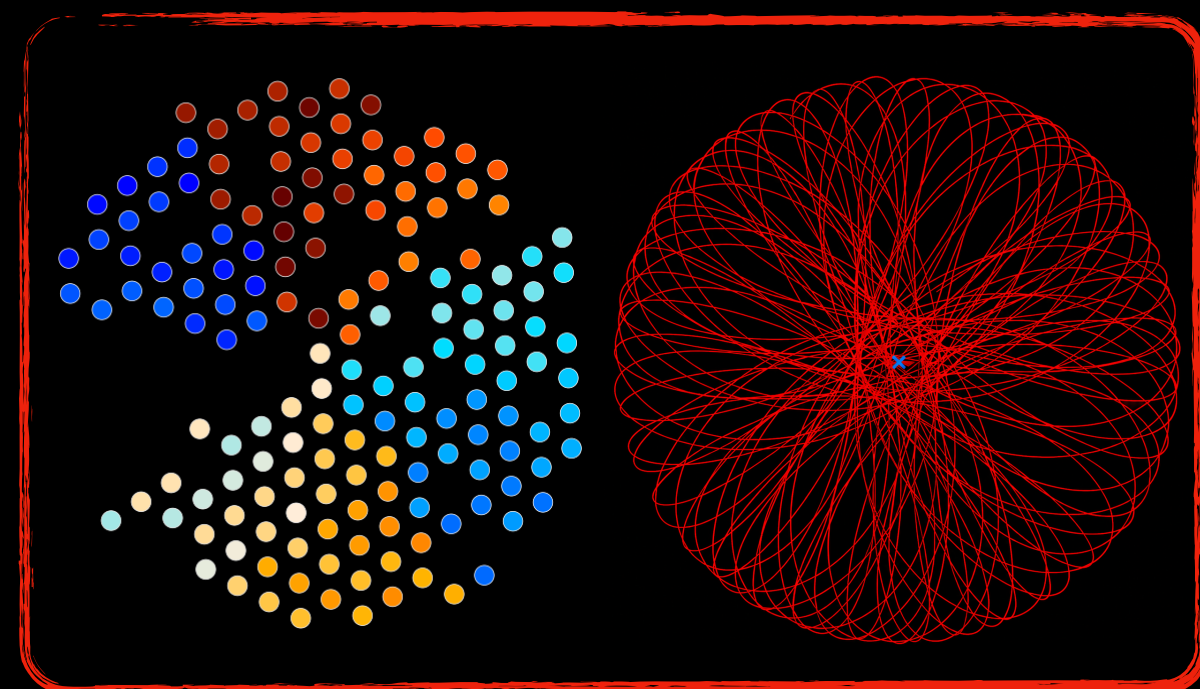
maria-nifty: forward model



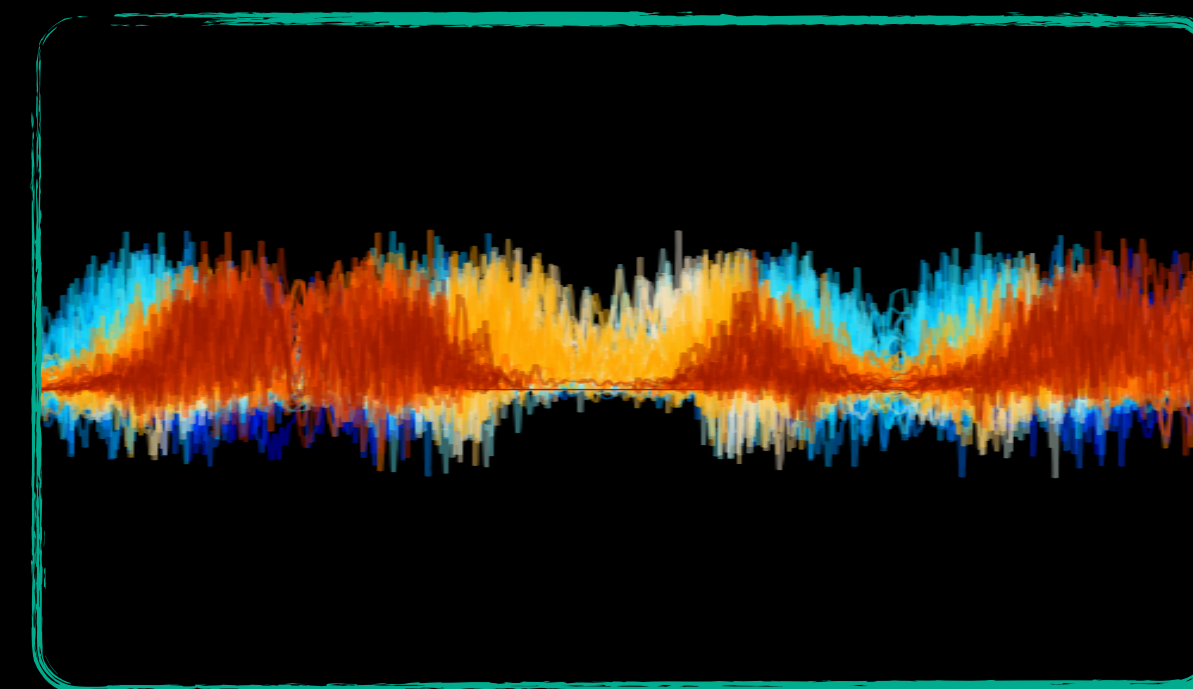
Map prior (GP)

$$R(s, t)$$

$$= d(t)$$

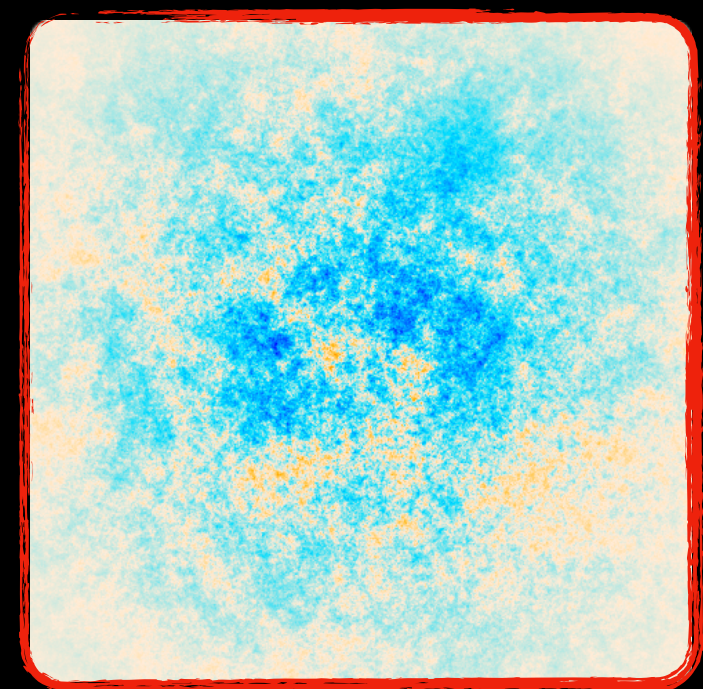


Instrument & scanning strategy



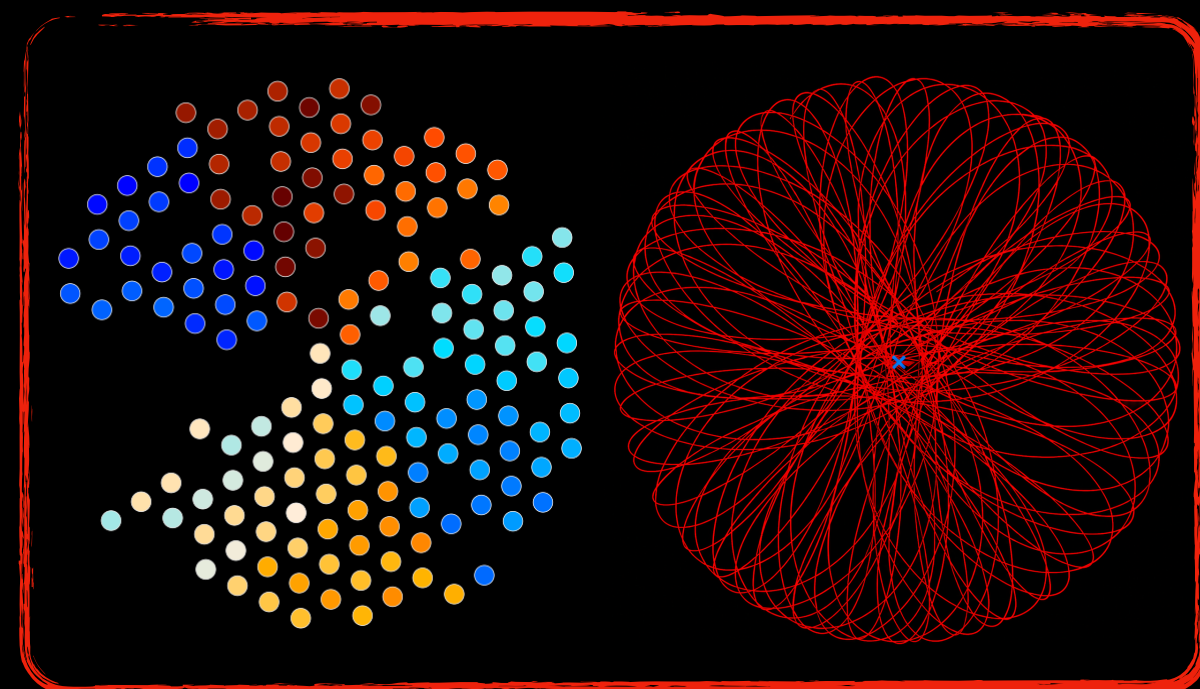
Model TODs

maria-nifty: forward model

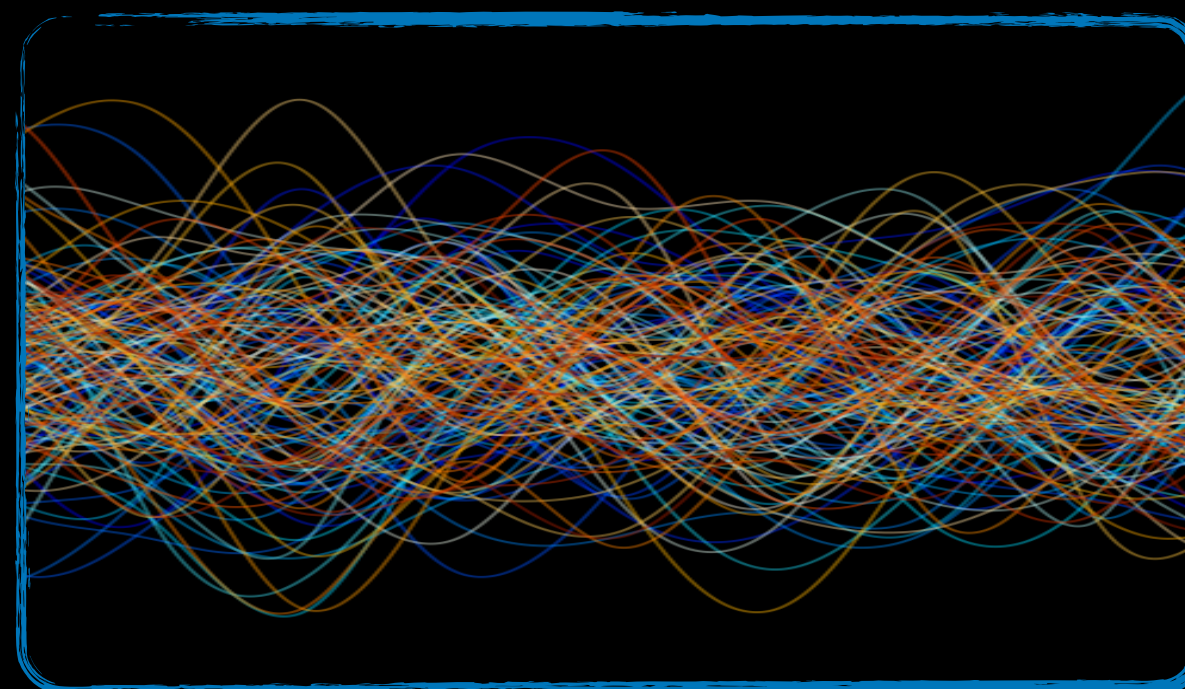


Map prior (GP)

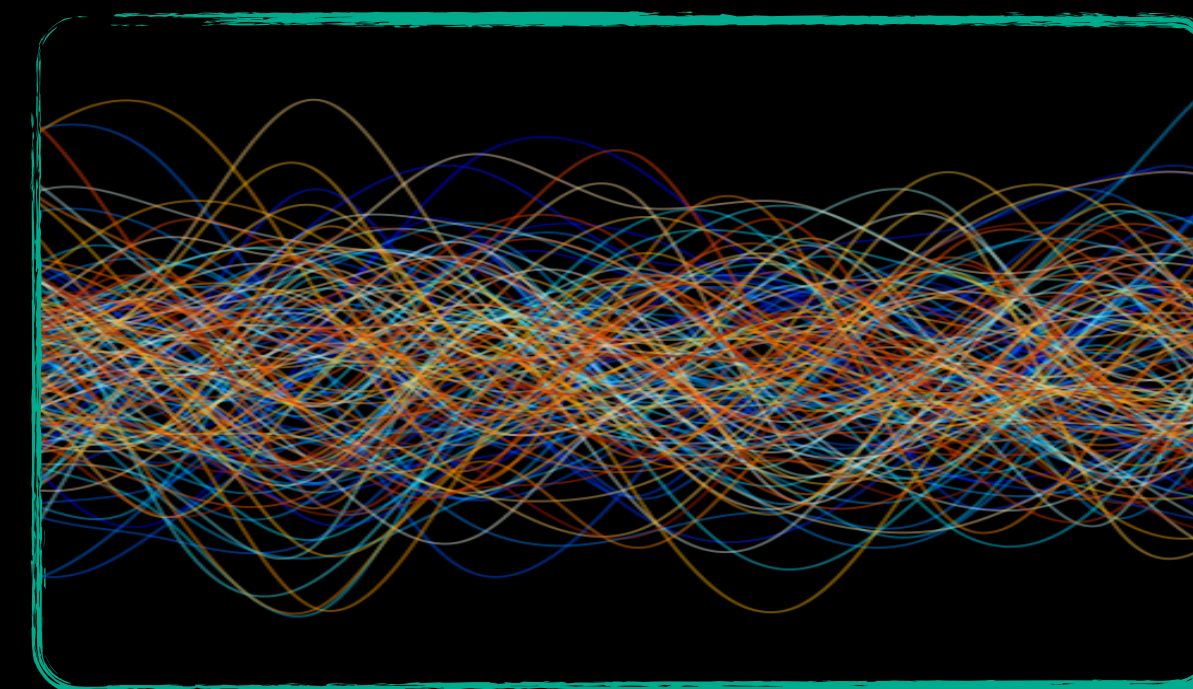
$$R(s, t) + a(t) = d(t)$$



Instrument & scanning strategy

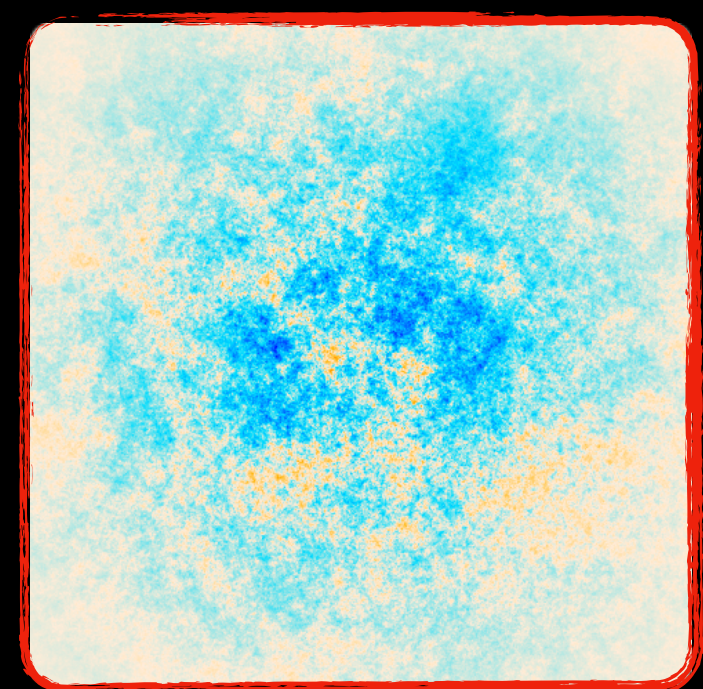


Atmospheric prior (splines)

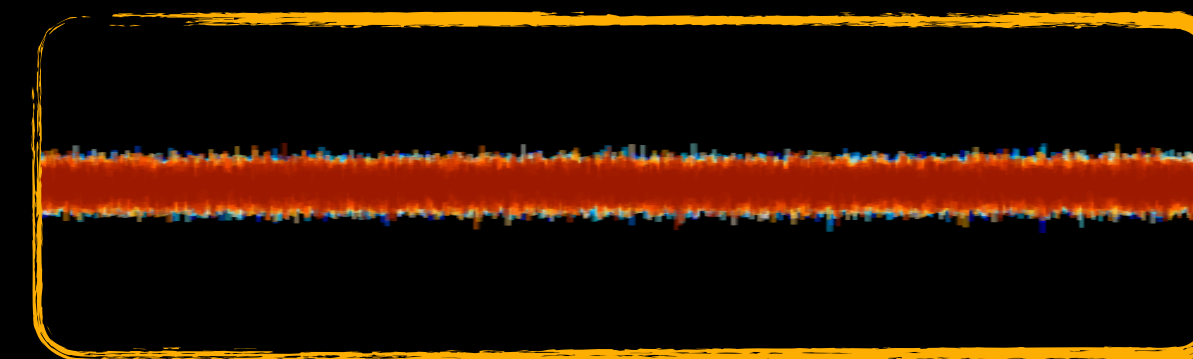


Model TODs

maria-nifty: forward model

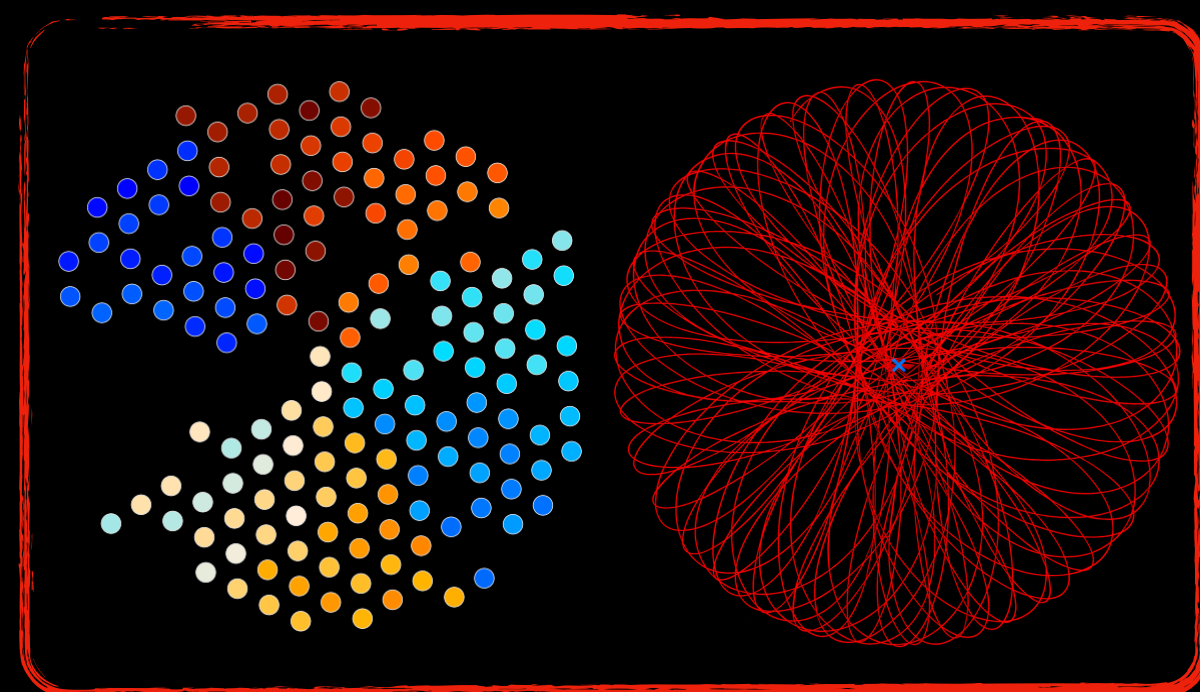


Map prior (GP)

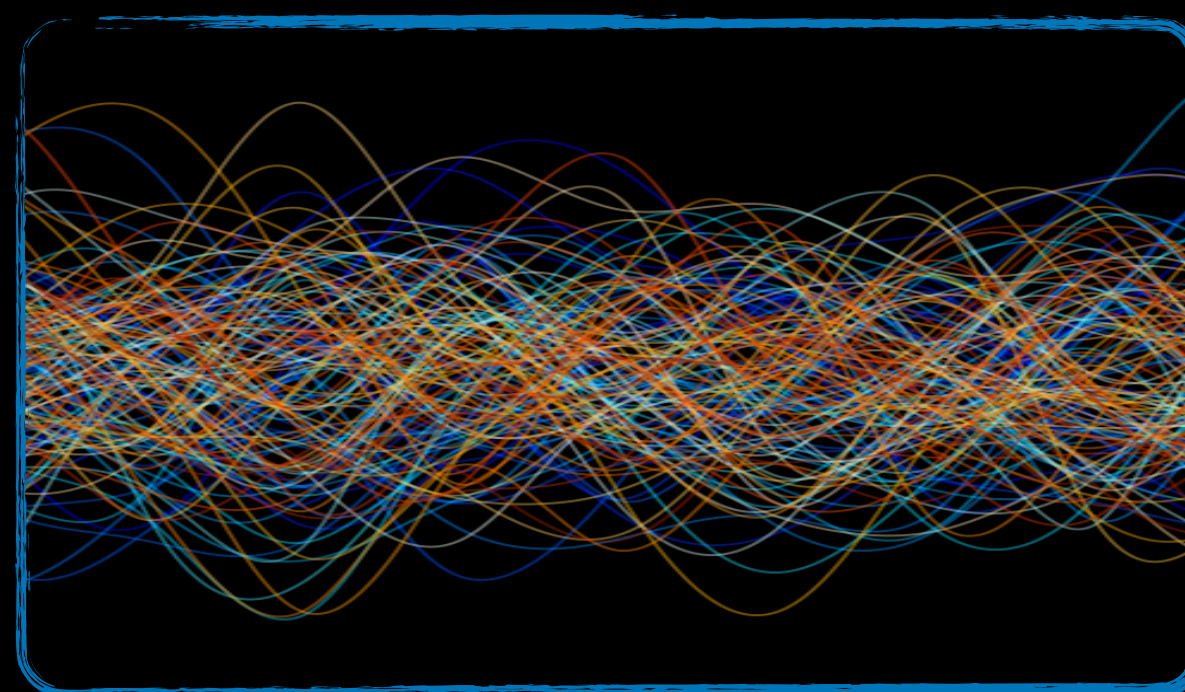


Gaussian noise

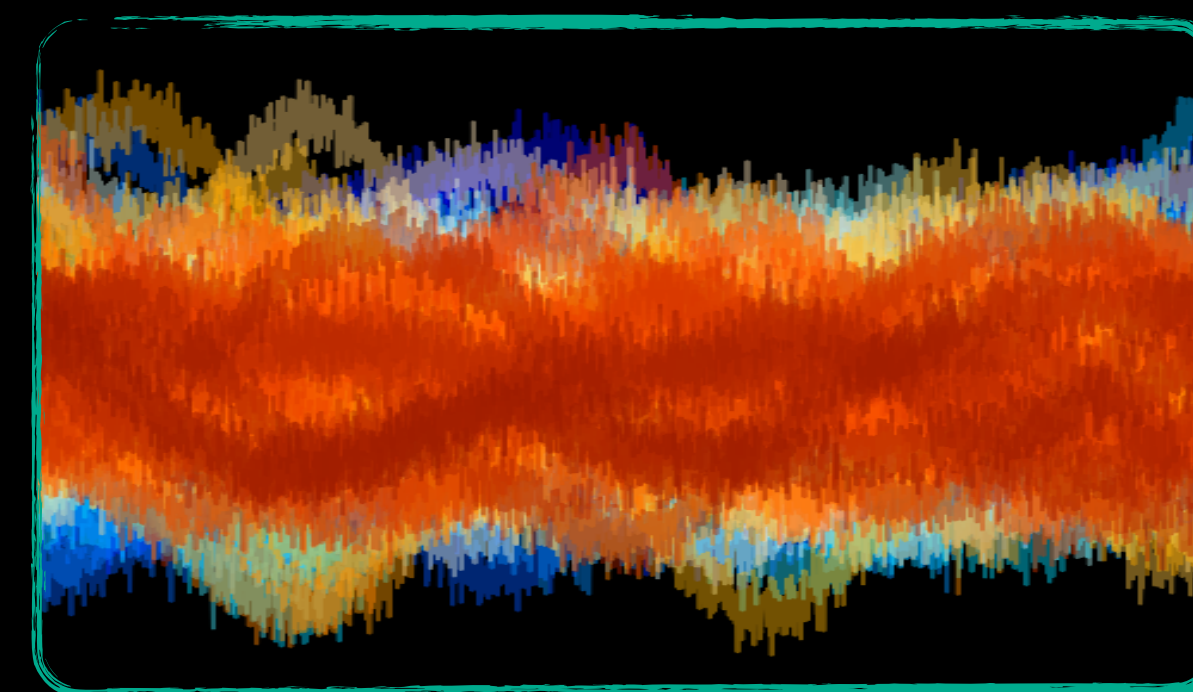
$$R(s, t) + a(t) + n = d(t)$$



Instrument & scanning strategy

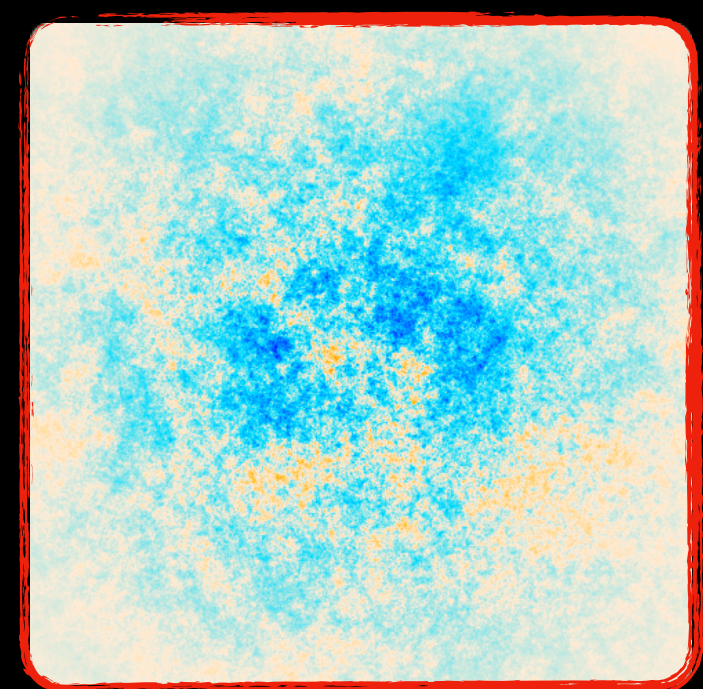


Atmospheric prior (splines)

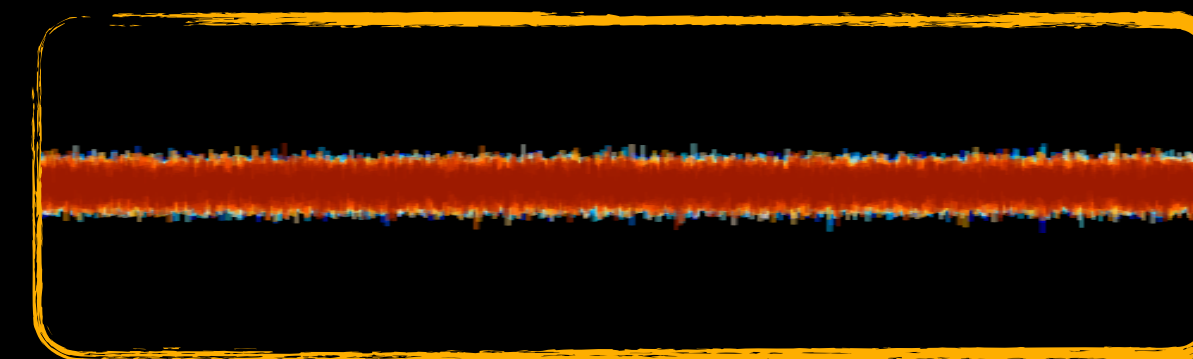


Model TODs + noise

maria-nifty: forward model



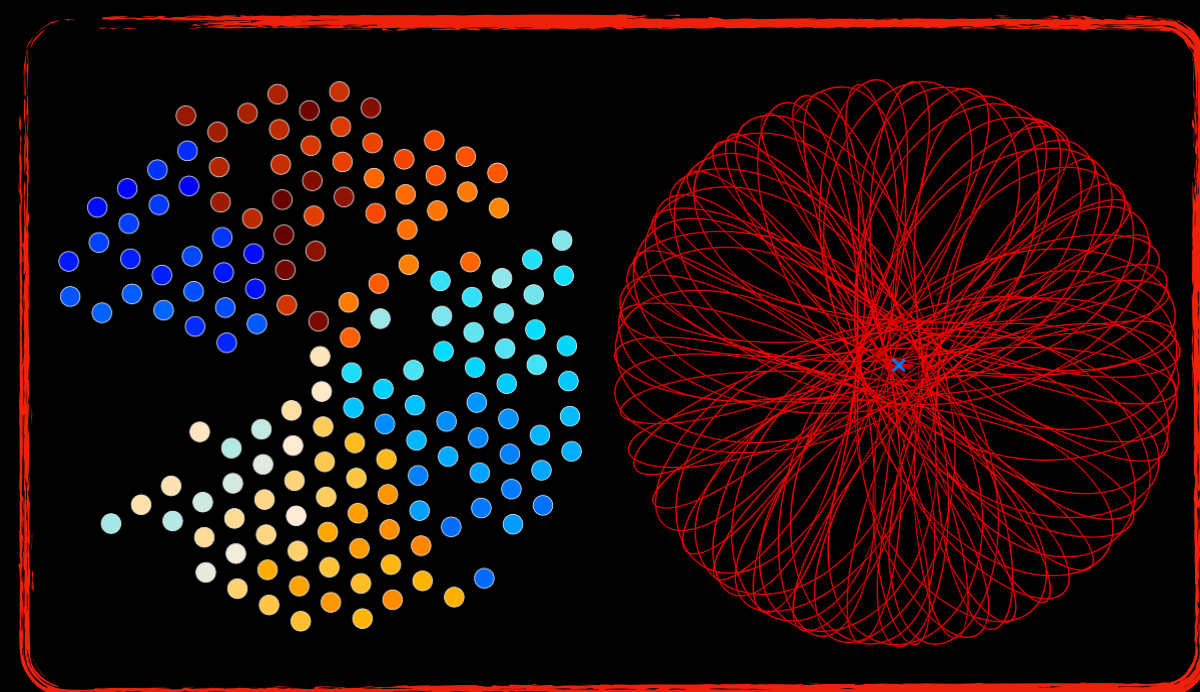
Map prior (GP)



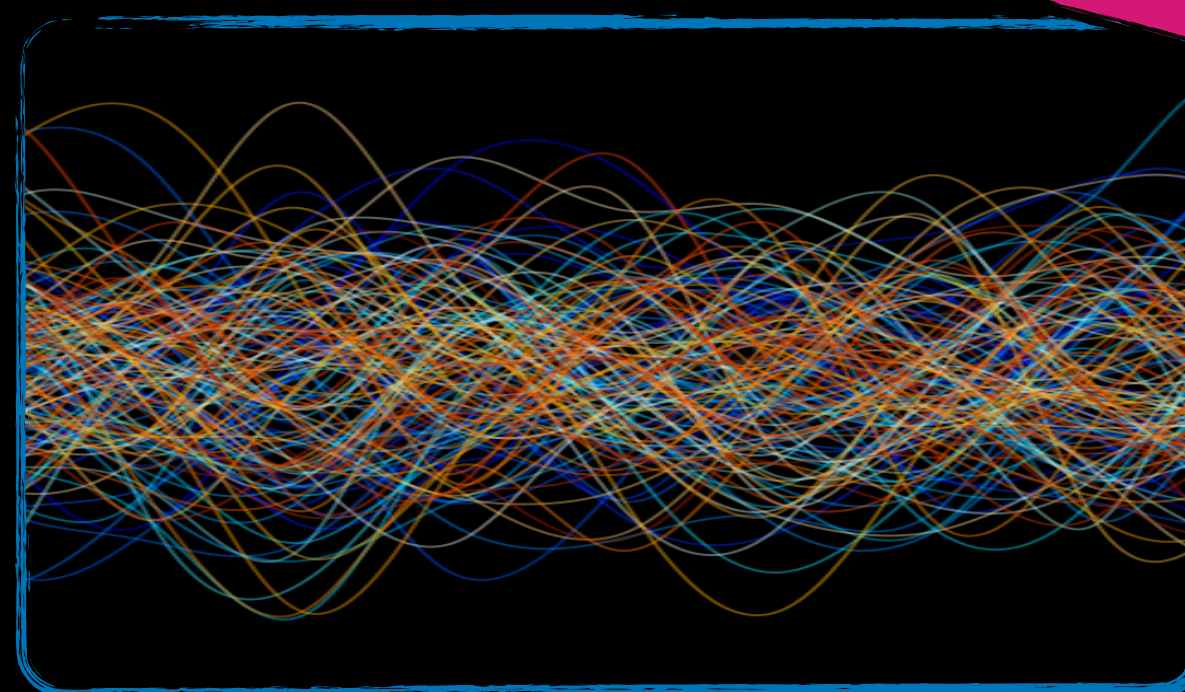
Gaussian noise

$$s(t) + a(t) + n = d(t)$$

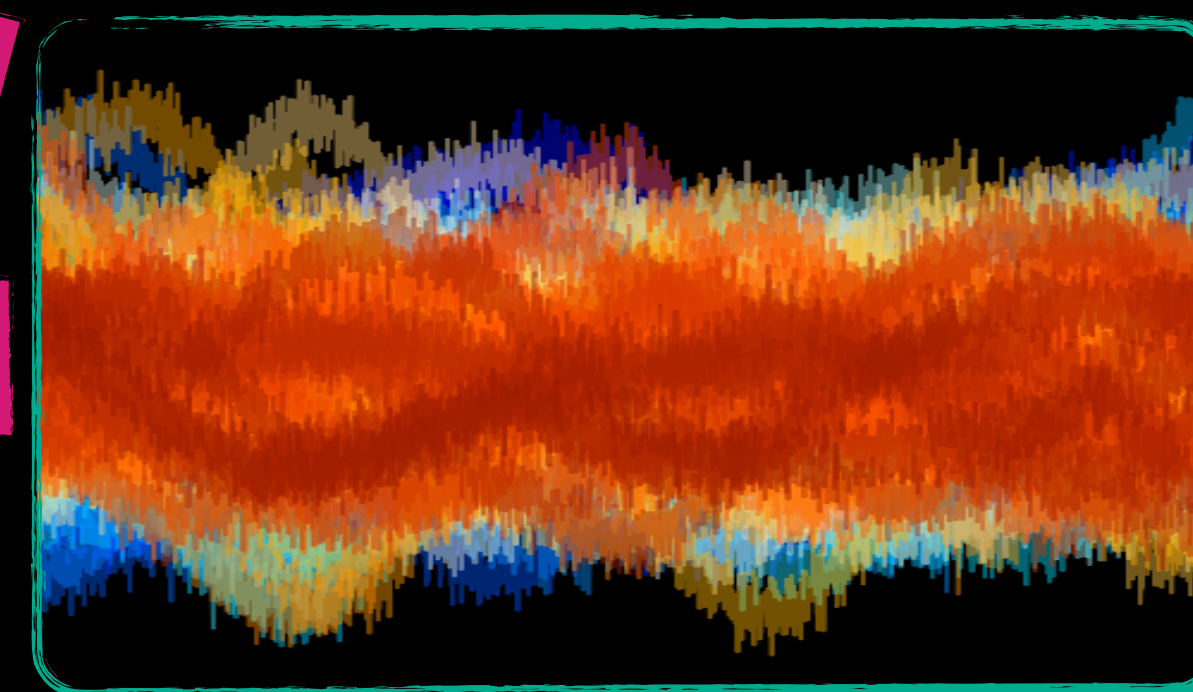
Gradients ∇



Instrument & scanning strategy

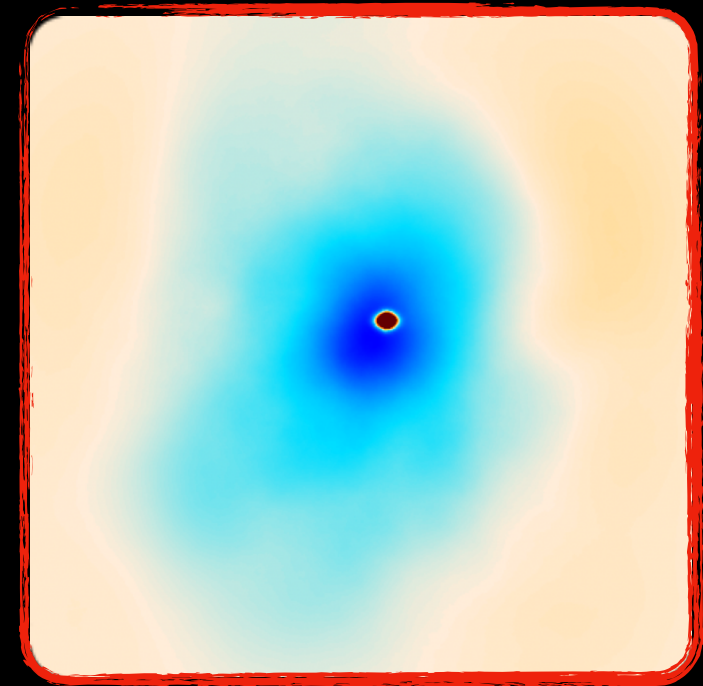


Atmospheric prior (splines)



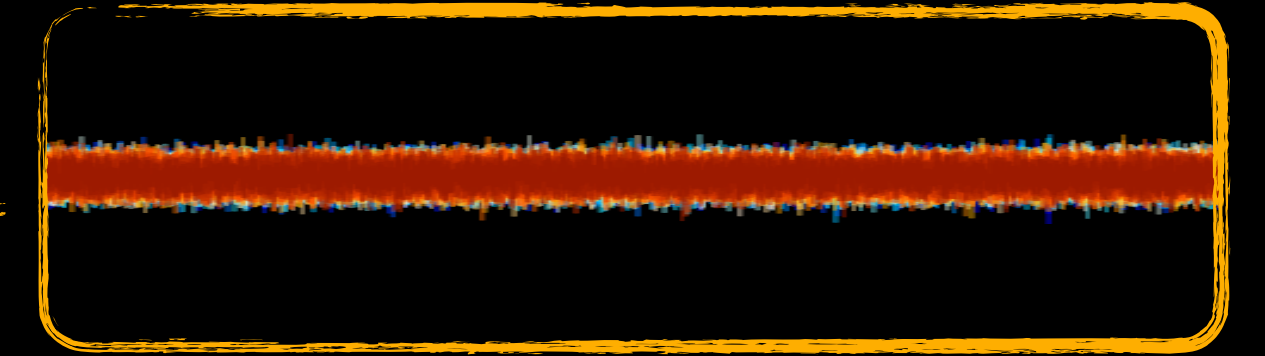
Model TODs + noise

maria-nifty: reconstruction

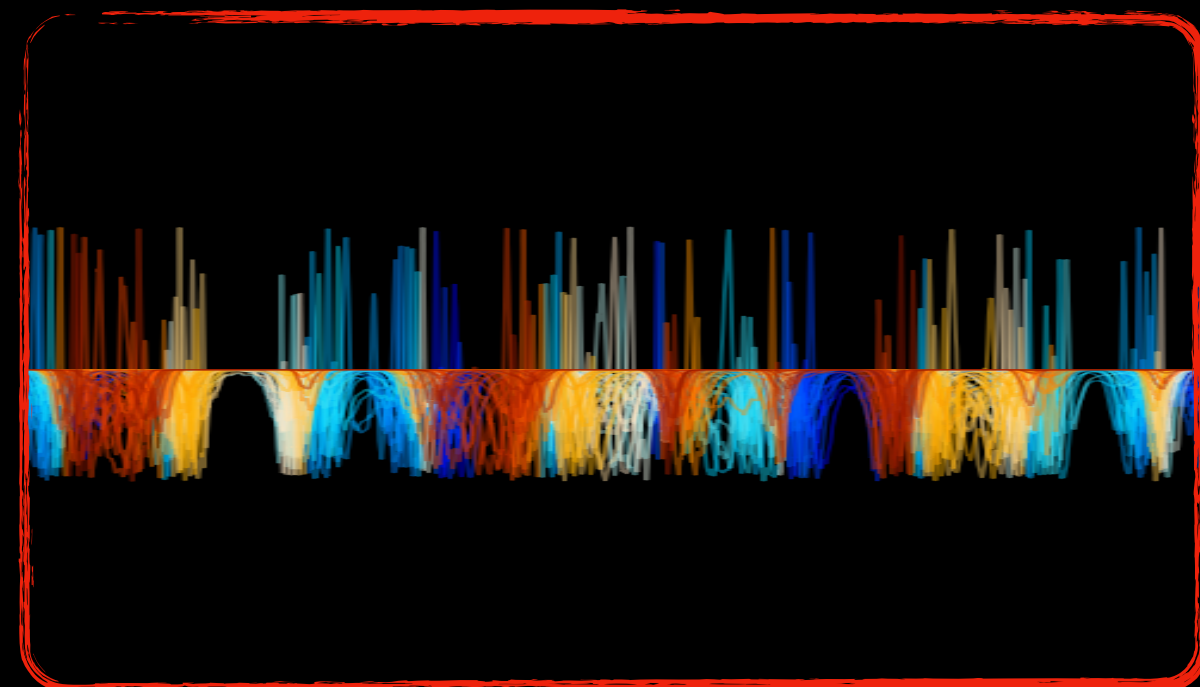


Map posterior

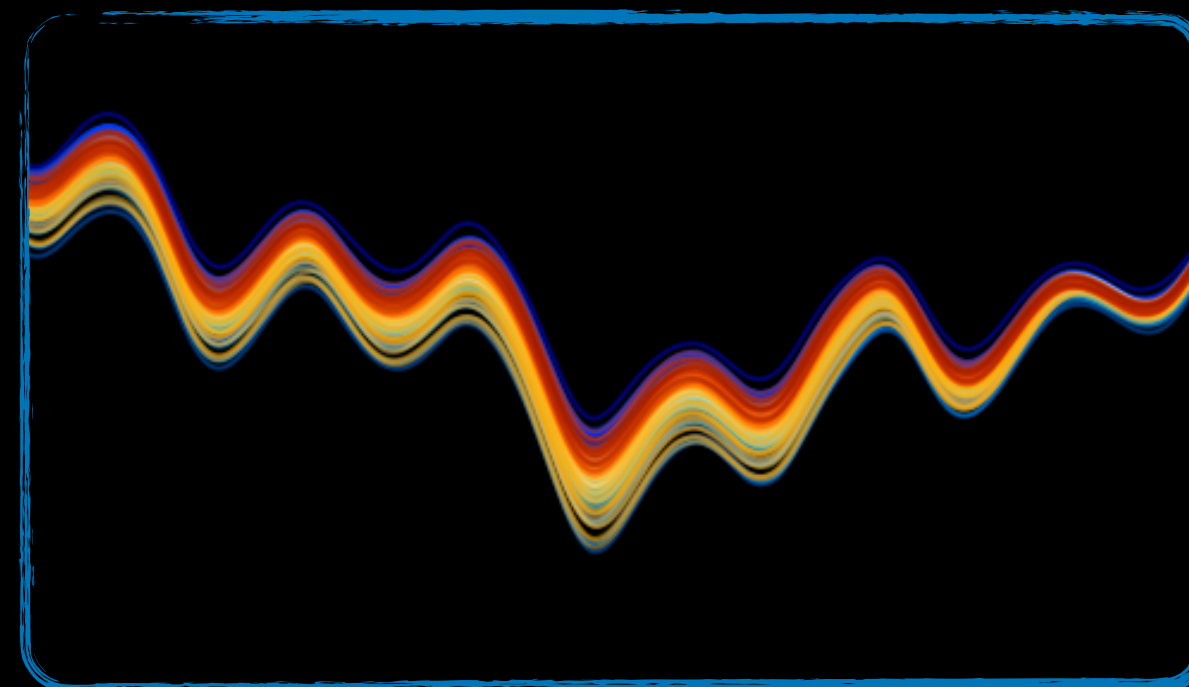
$$R(s, t) + a(t) + n = d(t)$$



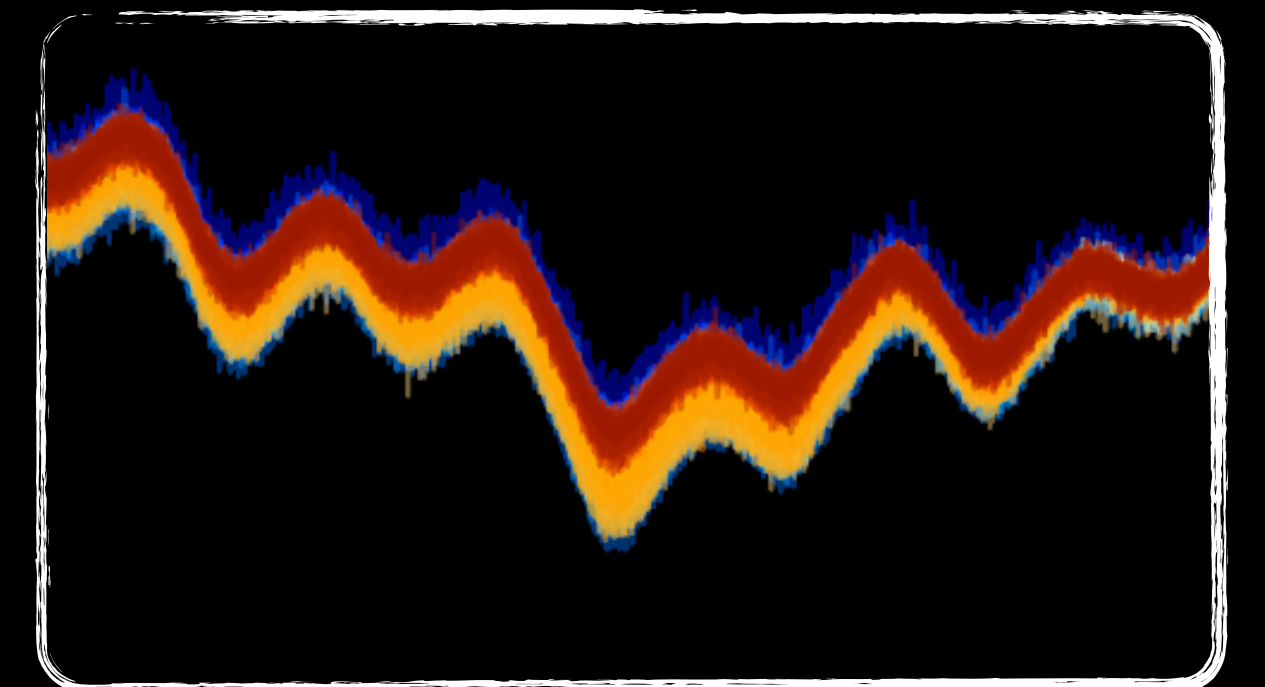
Residuals (model - data)



Map response posterior

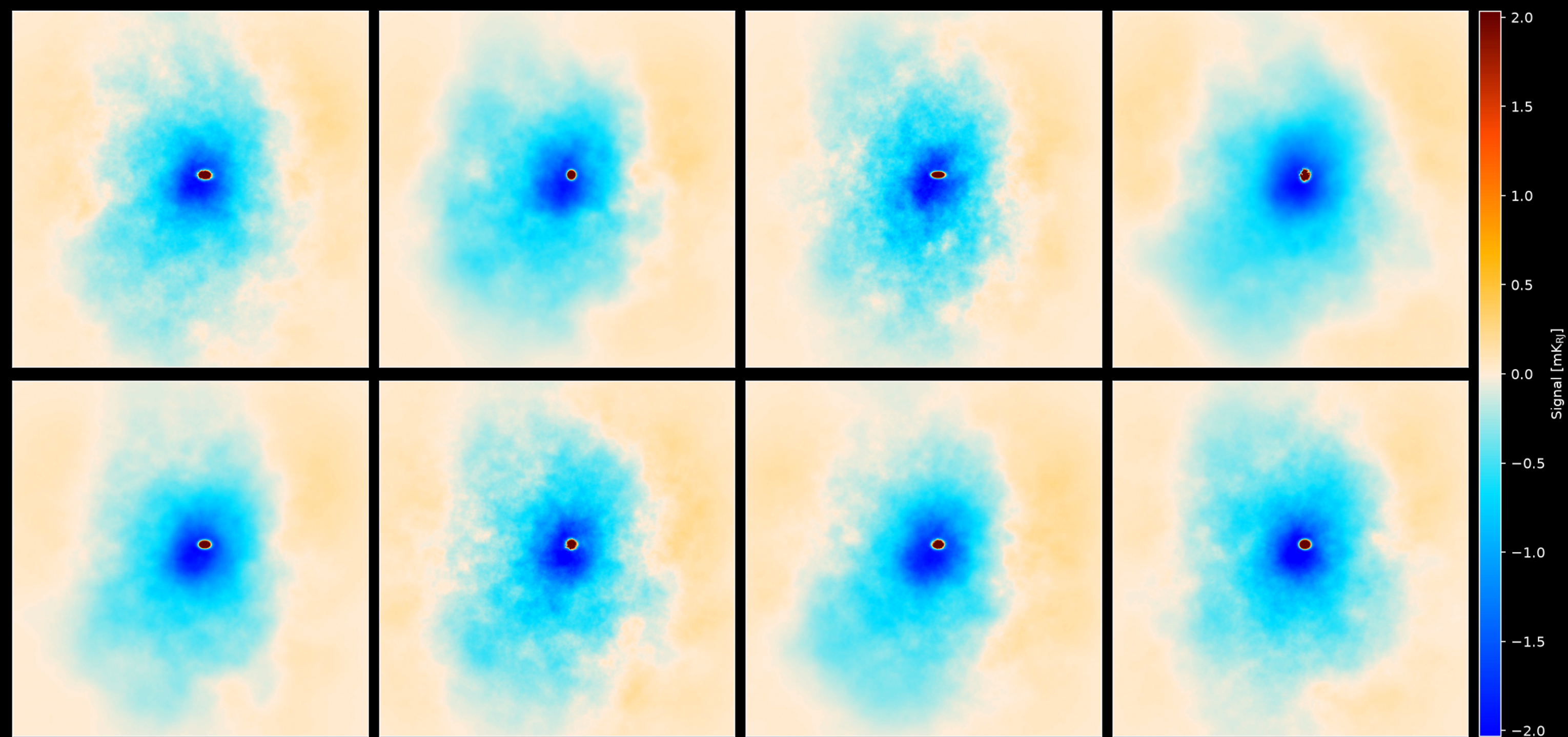


Atmospheric posterior



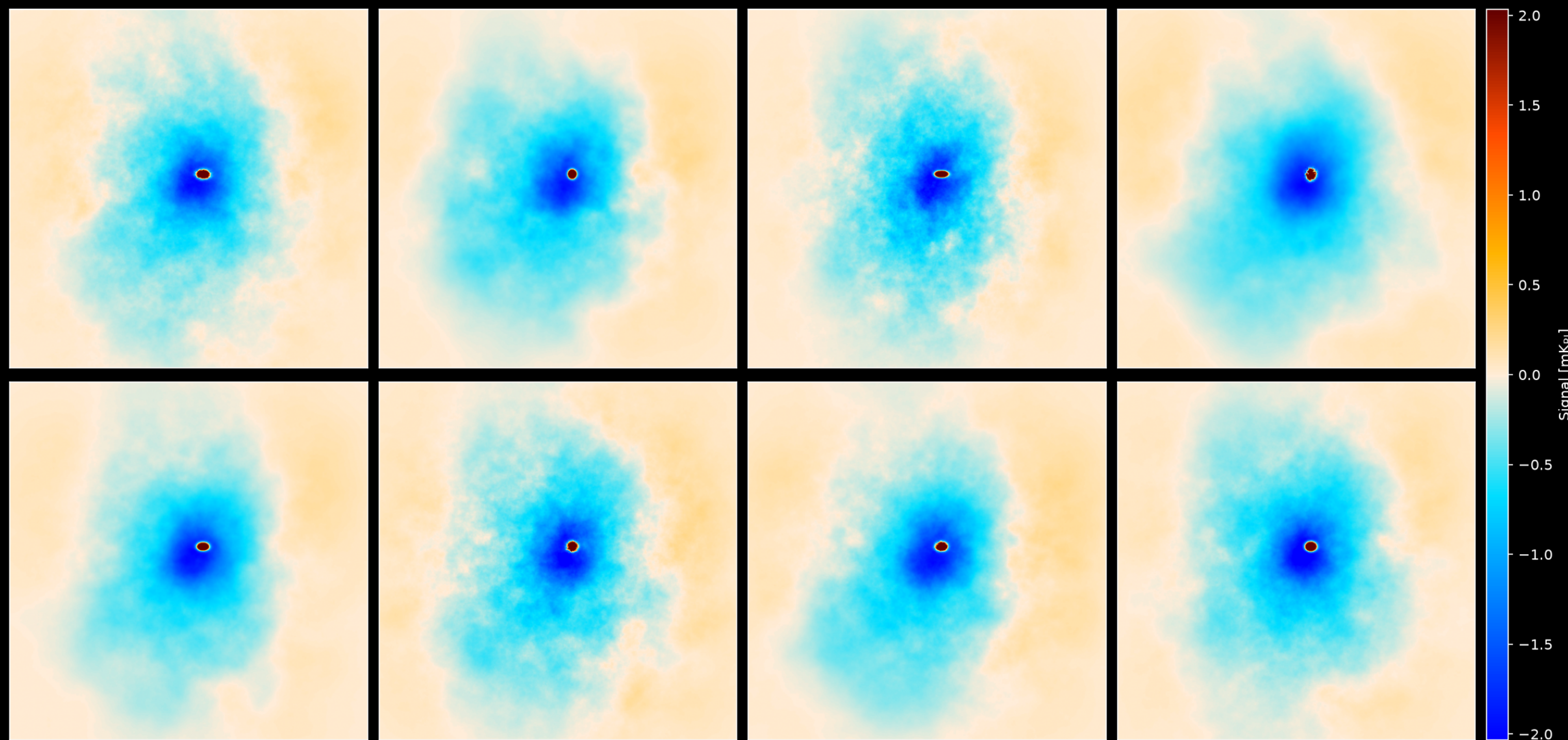
Mustang-2 TODs

Map reconstruction

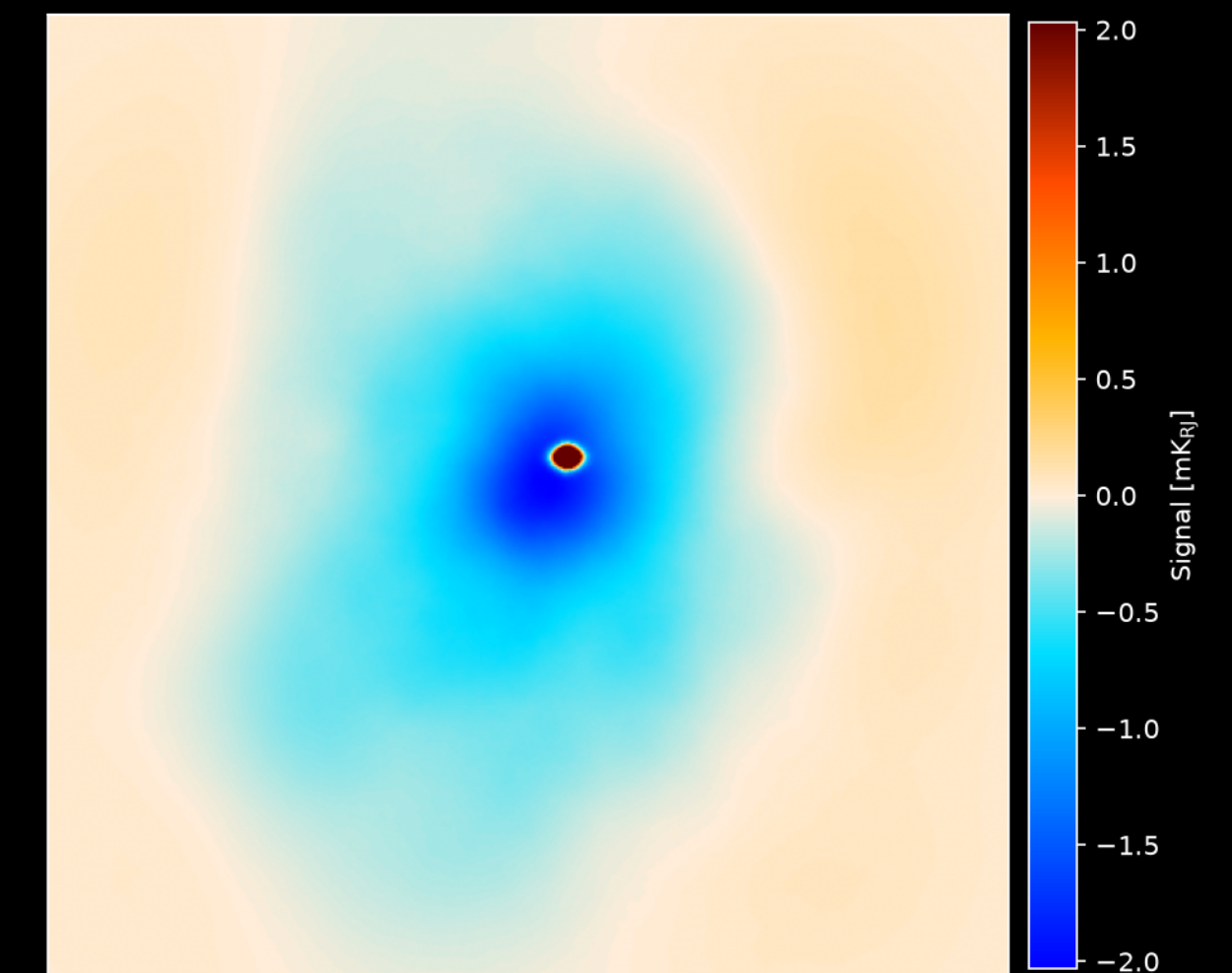


Posterior samples

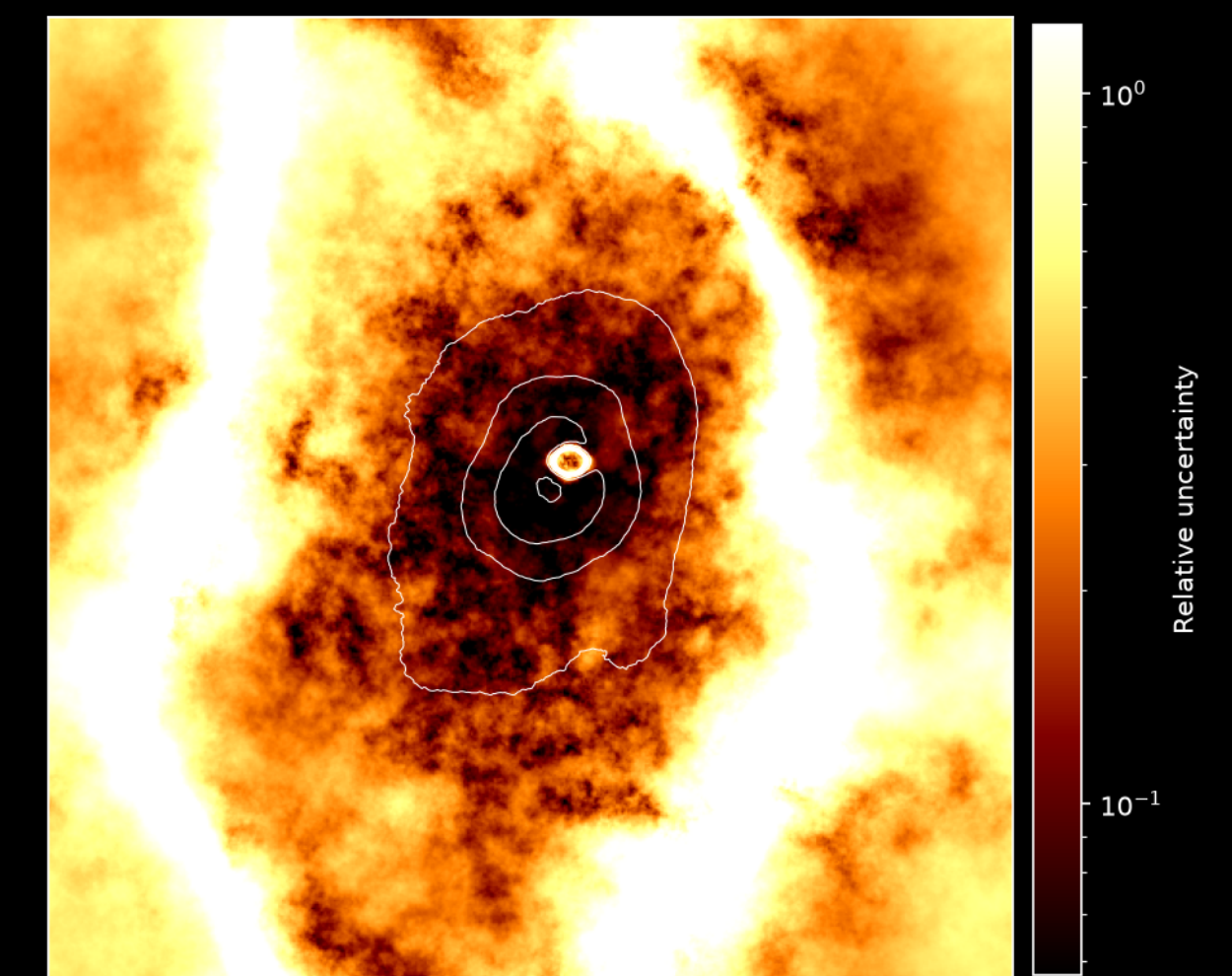
Map reconstruction



Posterior samples



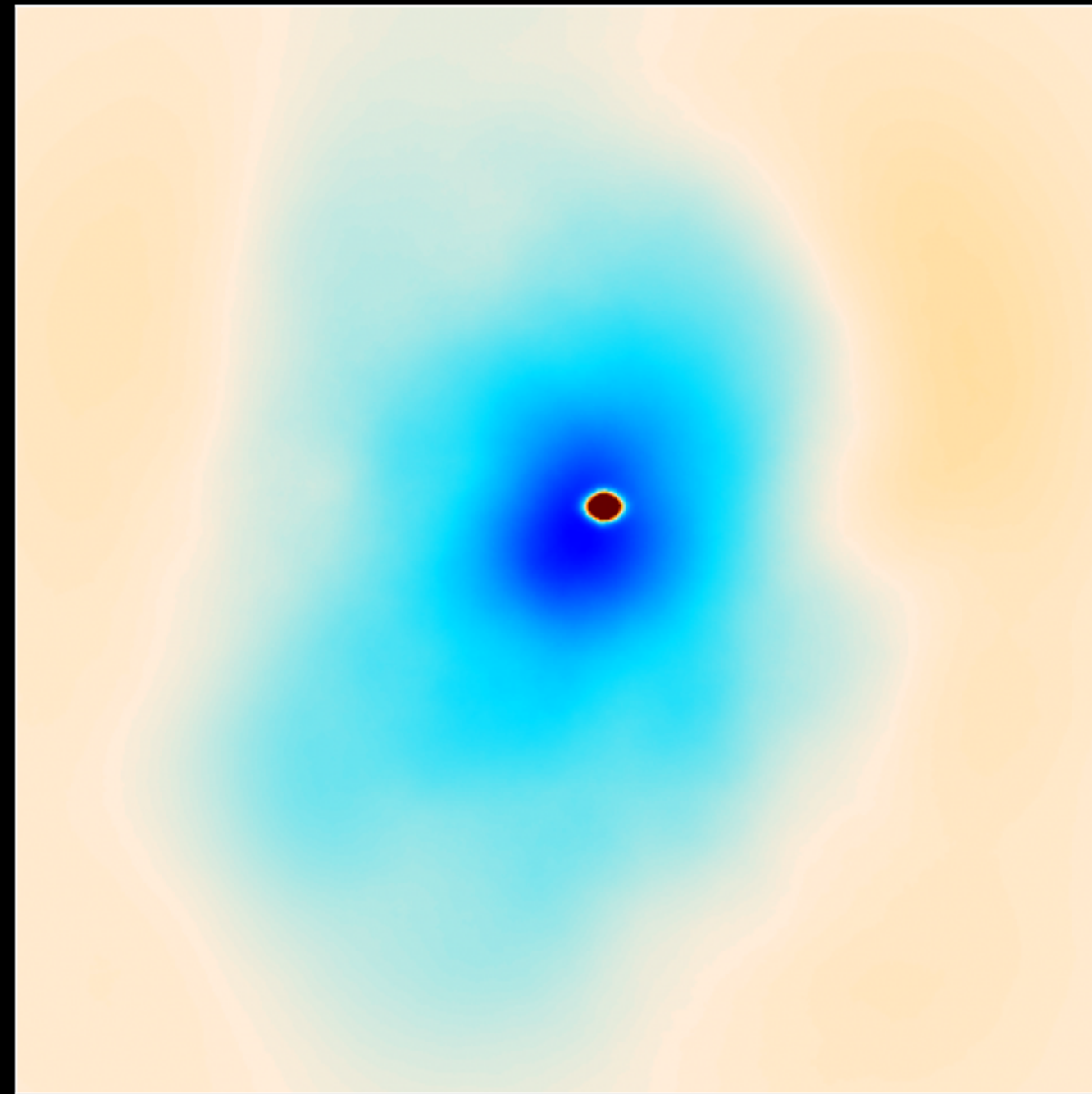
Posterior mean



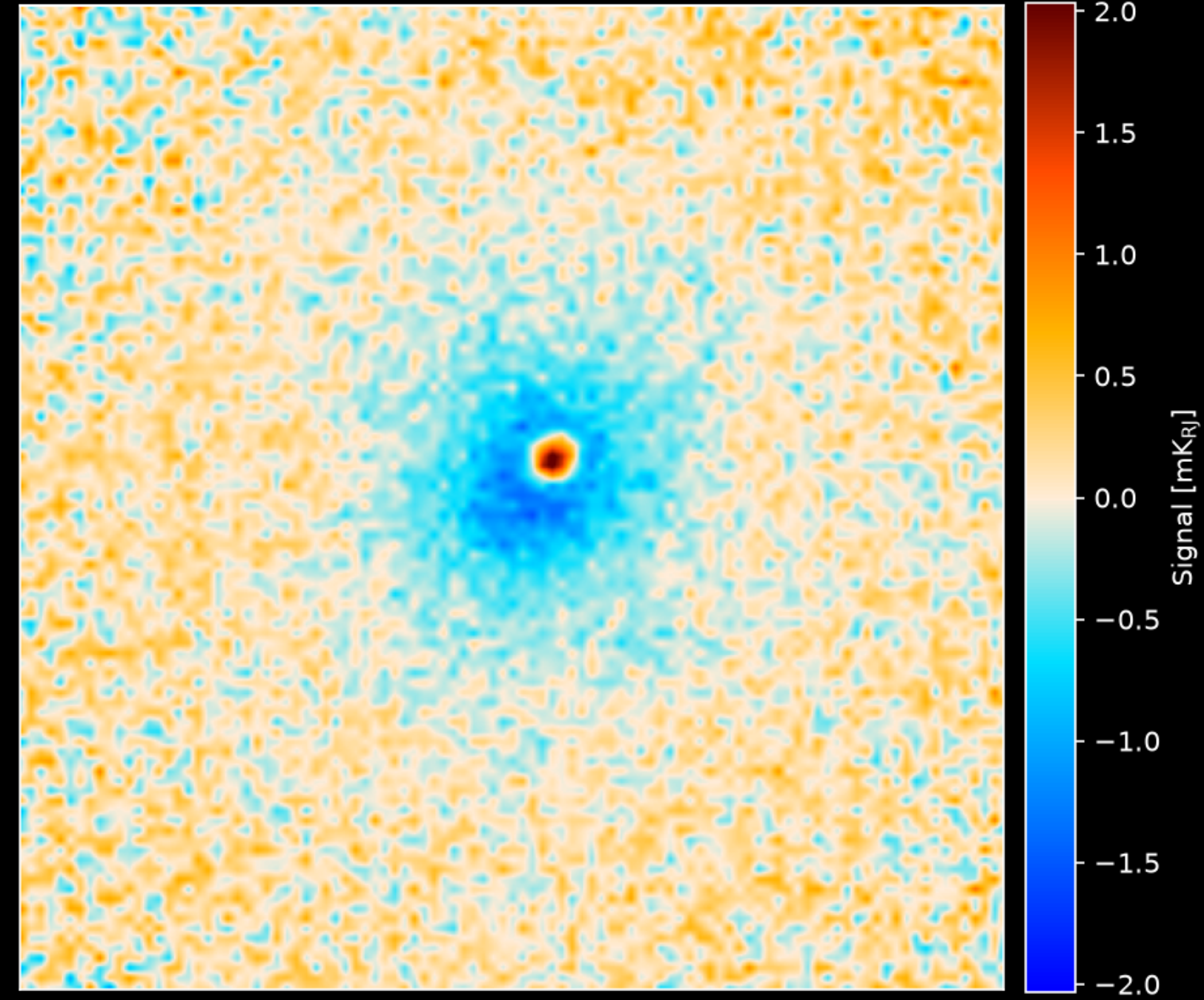
Relative uncertainty

Comparison to state-of-the-art method

maria-nifty



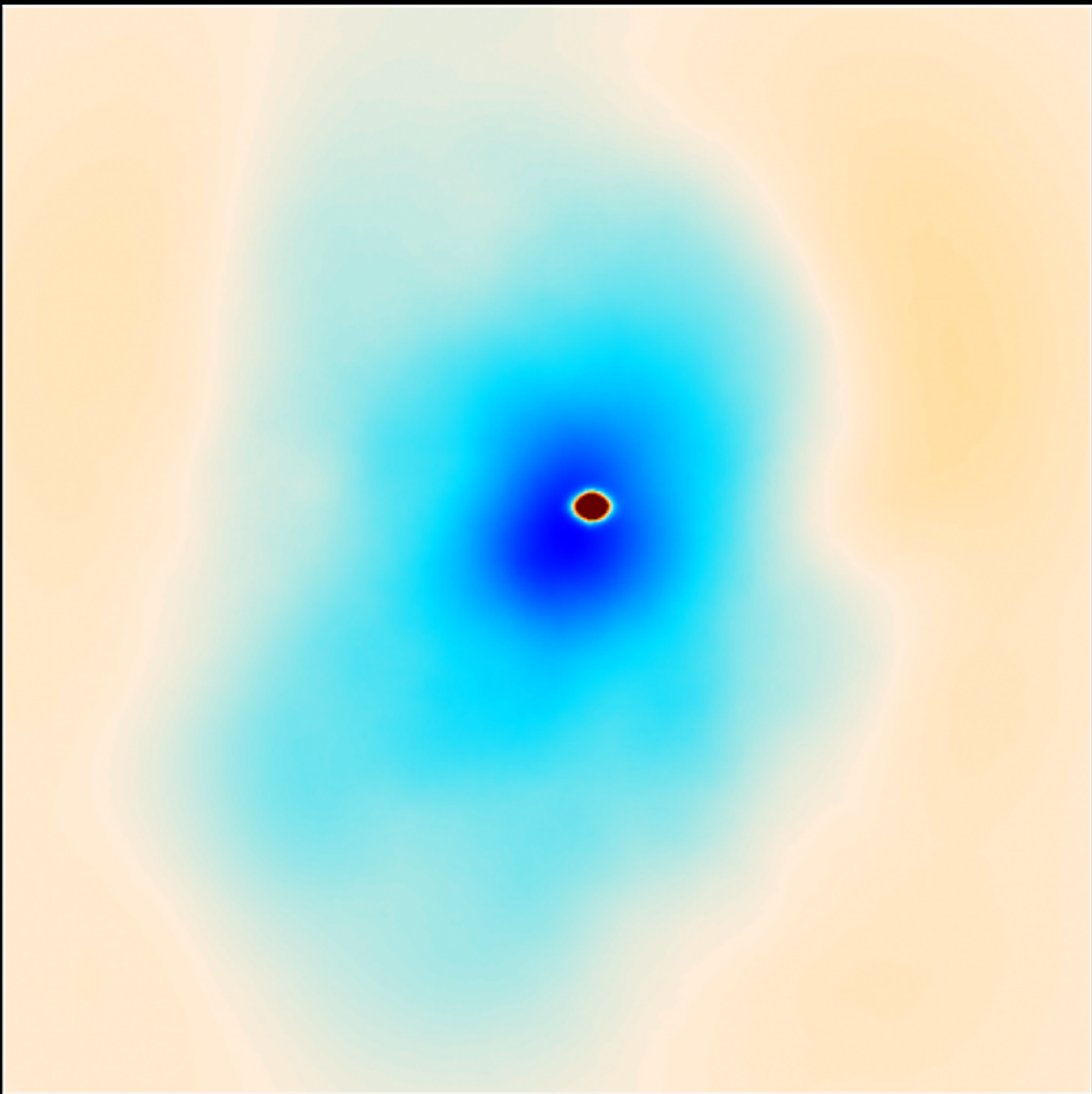
minkasi



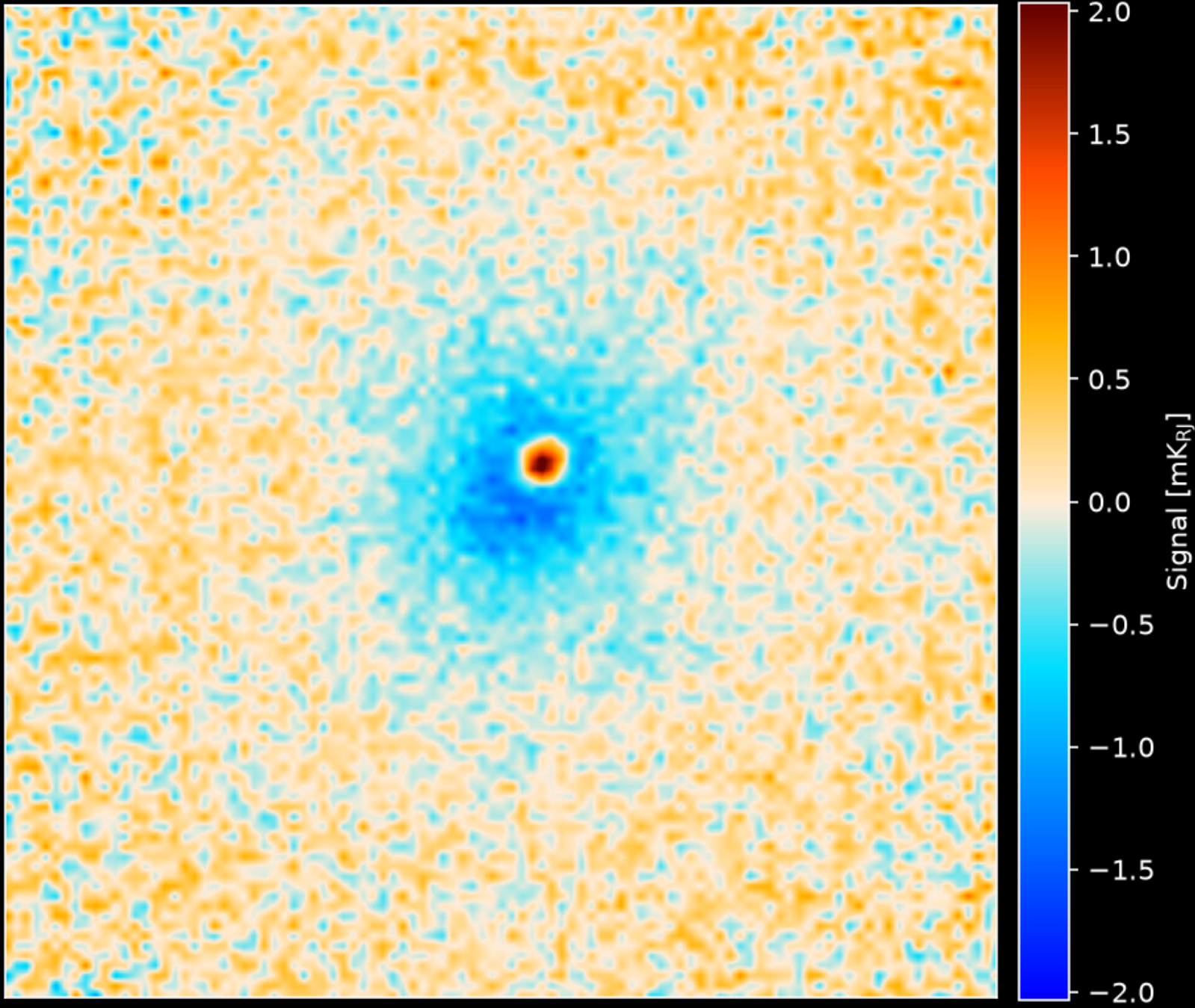
Sievers et al. (in prep.): <https://github.com/sievers/minkasi>

Comparison to state-of-the-art method

maria-nifty



minkasi



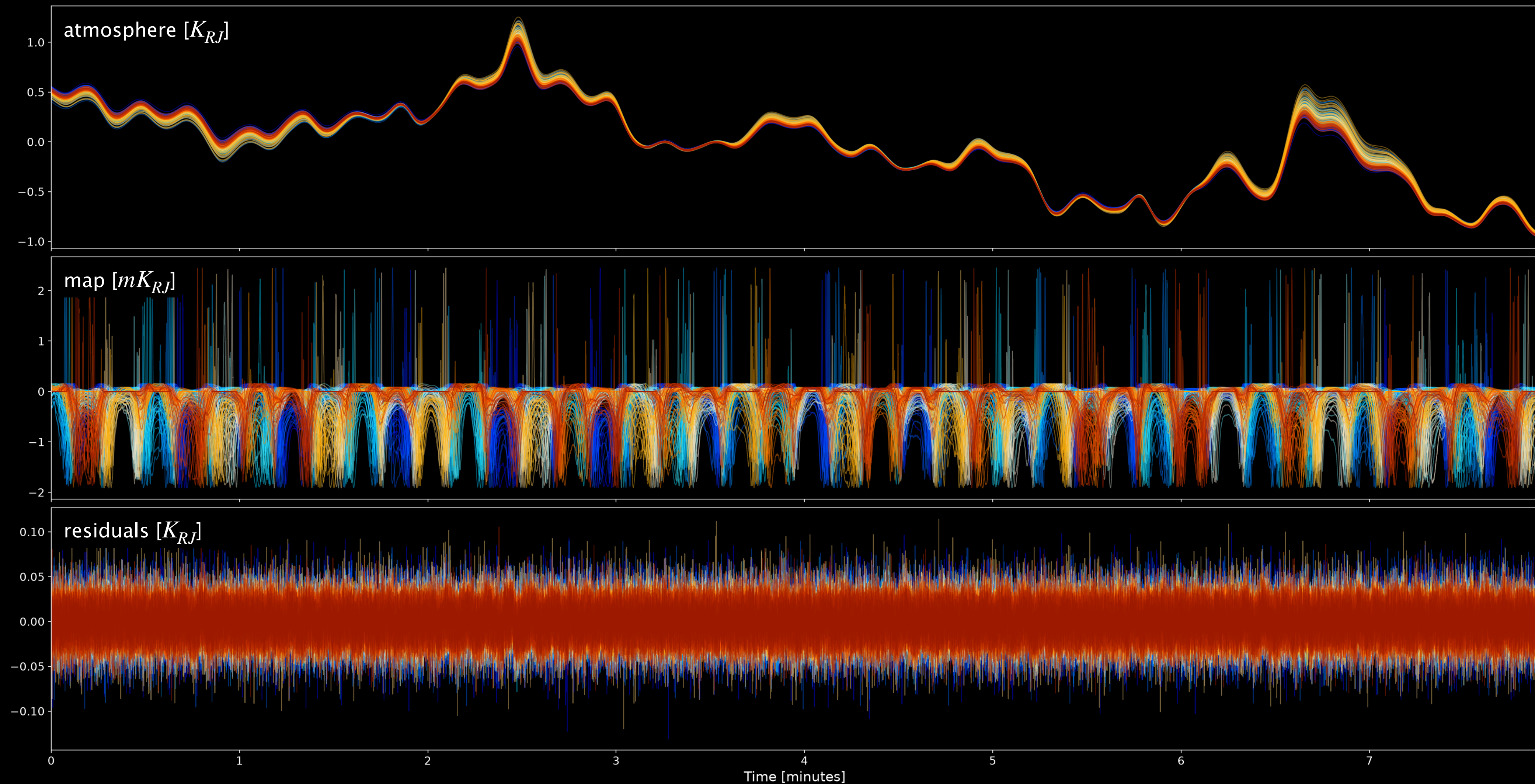
Sievers et al. (in prep.): <https://github.com/sievers/minkasi>

maria-nifty

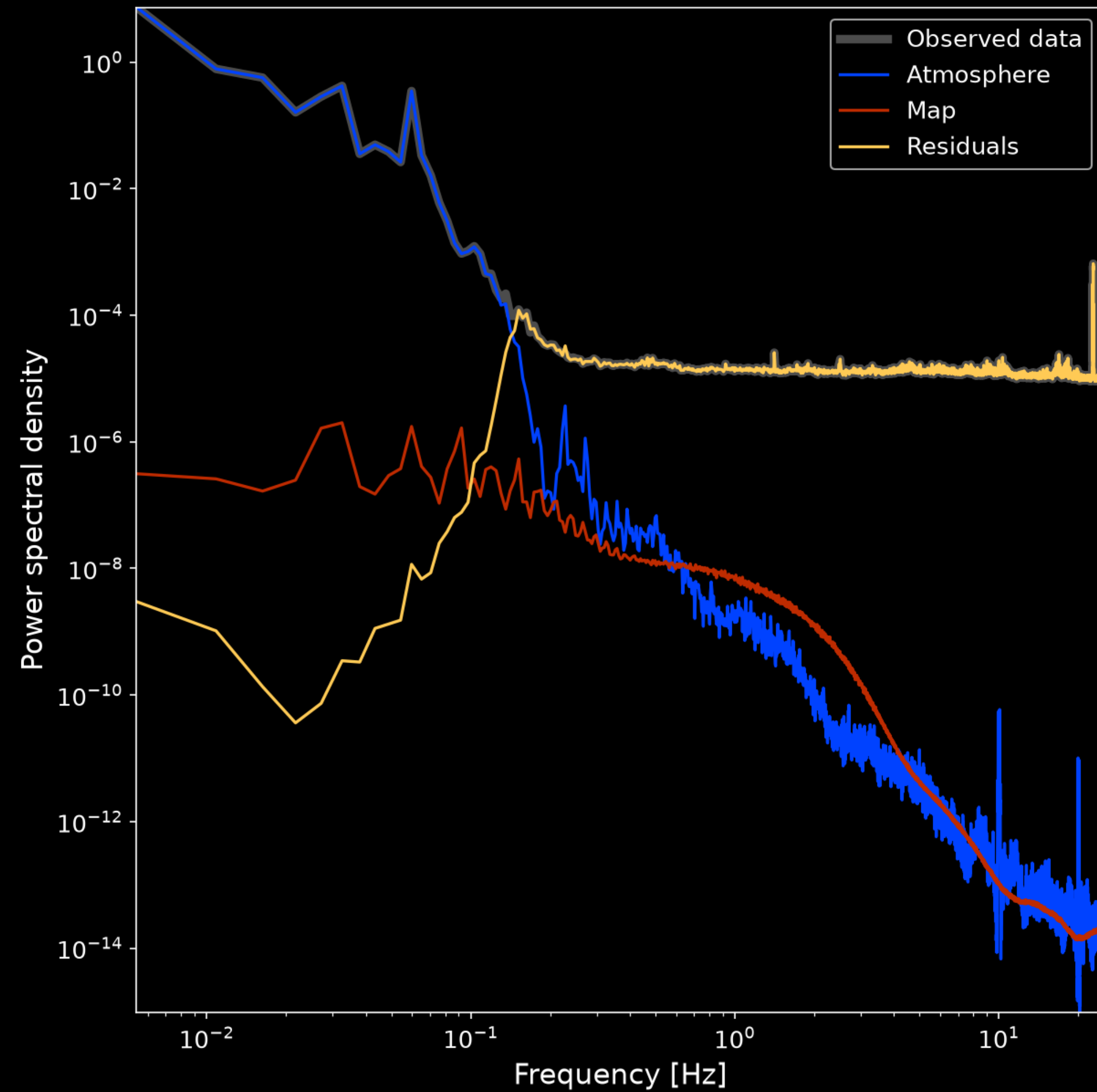
minkasi

Resolution	500 x 500	100 x 100
Smoothness	✓	✗
Samples	✓	✗
Uncertainty	✓	✗
Atmos. Rec.	✓	✗
Compute	💰💰💰	💰
Needed Time	🕒	🕒

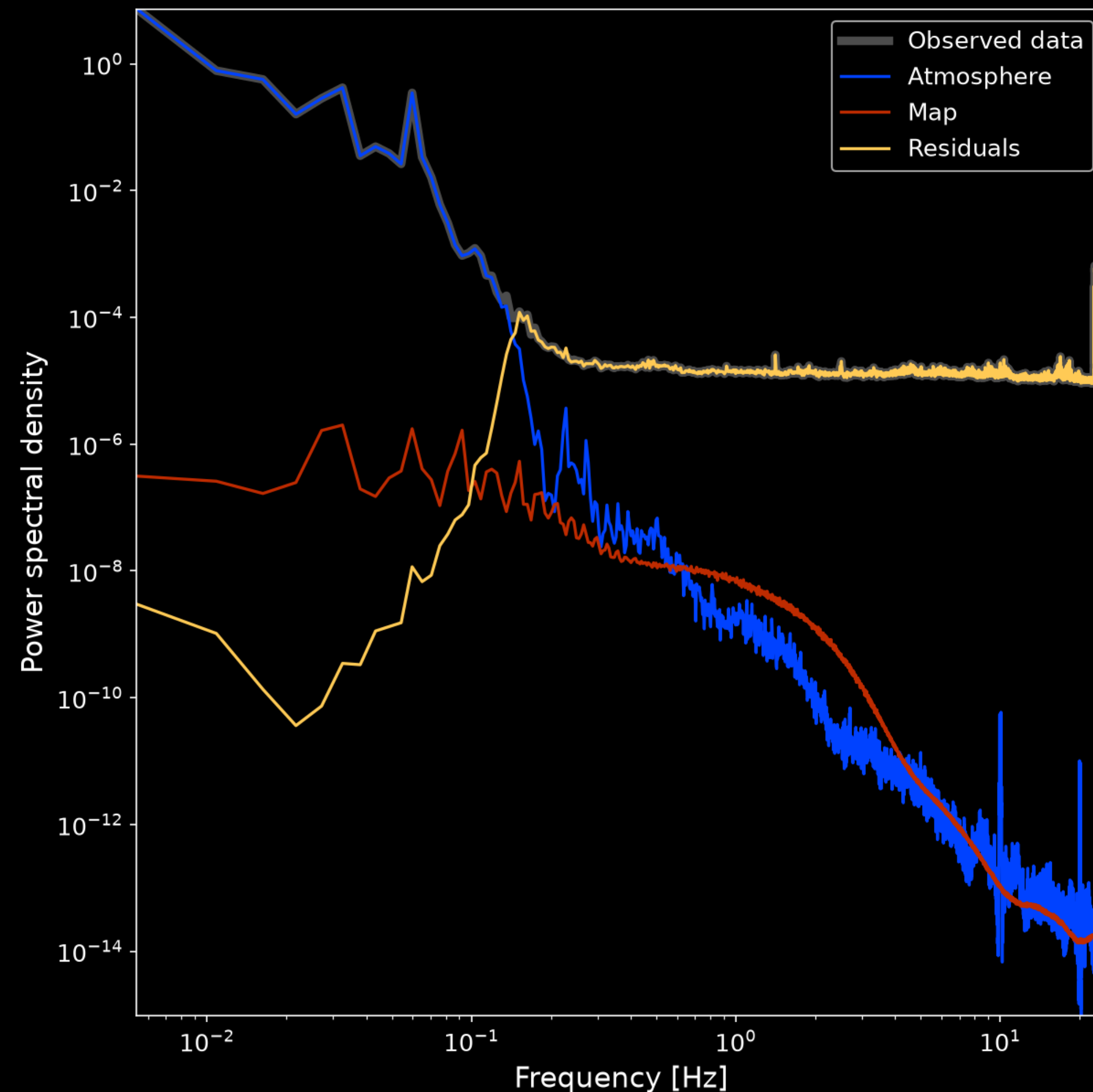
Contributions of atmosphere, map & noise



Contributions of atmosphere, map & noise



Contributions of atmosphere, map & noise



Outlook

- scale up to larger datasets
- multi-frequency observations
- scale up to future arrays:
~200 $\rightarrow$ ~300k detectors

Thank you for your attention

Paper

SciPost Physics Proceedings

Submission

maria goes NIFTy: Gaussian Process-Based Reconstruction and Denoising of Simulated (Sub-)Millimetre Single-Dish Telescope Data

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¹ Technical University of Munich, Arcisstrasse 21, 80333 Munich, Germany

² Excellence Cluster ORIGINS, Boltzmannstrasse 2, 85748 Garching, Germany

³ Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands

⁴ Yale University, New Haven, CT 06511, USA

⁵ Brookhaven National Laboratory, Upton, NY 11973, USA

⁶ European Southern Observatory, Karl-Schwarzschild-Str 2, Garching 85748, Germany

⁷ Institute of Space Sciences (ICE, CSIC), Carrer de Can Magrans, s/n, 08193 Cerdanyola del Vallès, Barcelona, Spain

★ jonas.wuerzinger@tum.de



EuCAIF

*The 2nd European AI for Fundamental Physics Conference (EuCAIFCon2025)
Cagliari, Sardinia, 16-20 June 2025*

<https://arxiv.org/abs/2509.01600>

Repositories

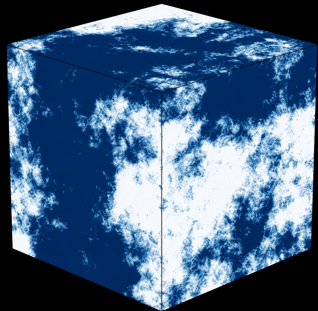


maria-nifty

Mail: richard.fuchs@tum.de



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



<https://github.com/thomaswmorris/maria>

Backup

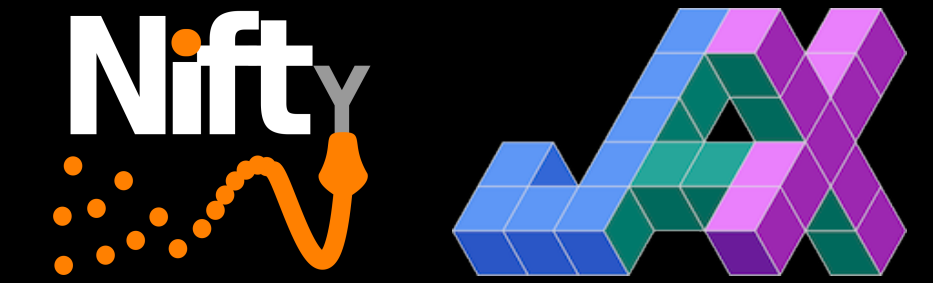
nifty: Bayesian imaging



Gaussian processes (GPs)

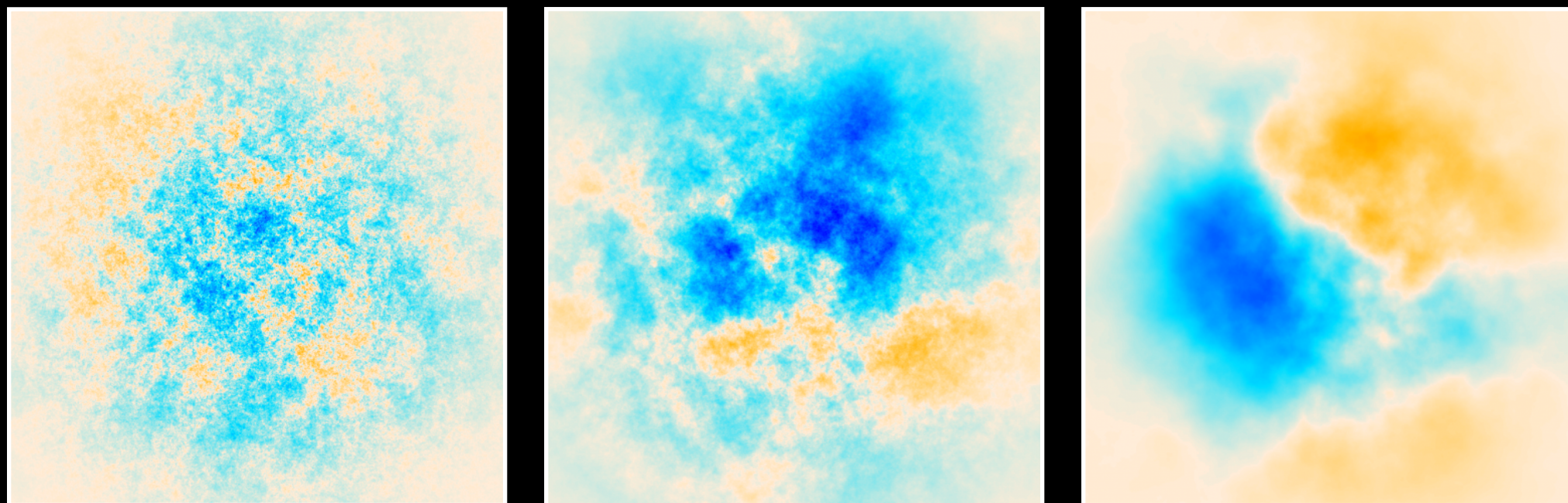
Variational inference (VI)

nifty: Bayesian imaging



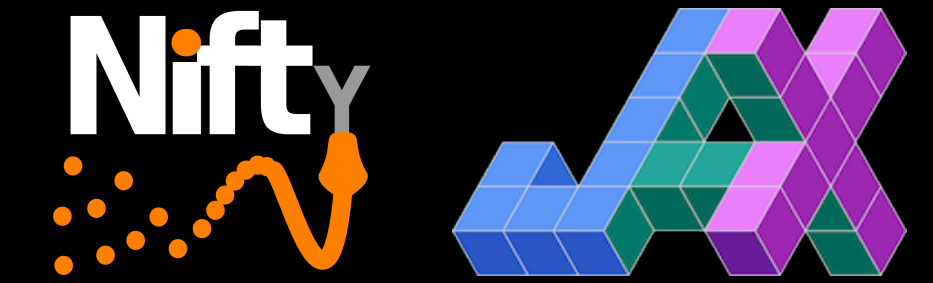
Gaussian processes (GPs)

- model correlations
- describe various signals
- build complex prior models



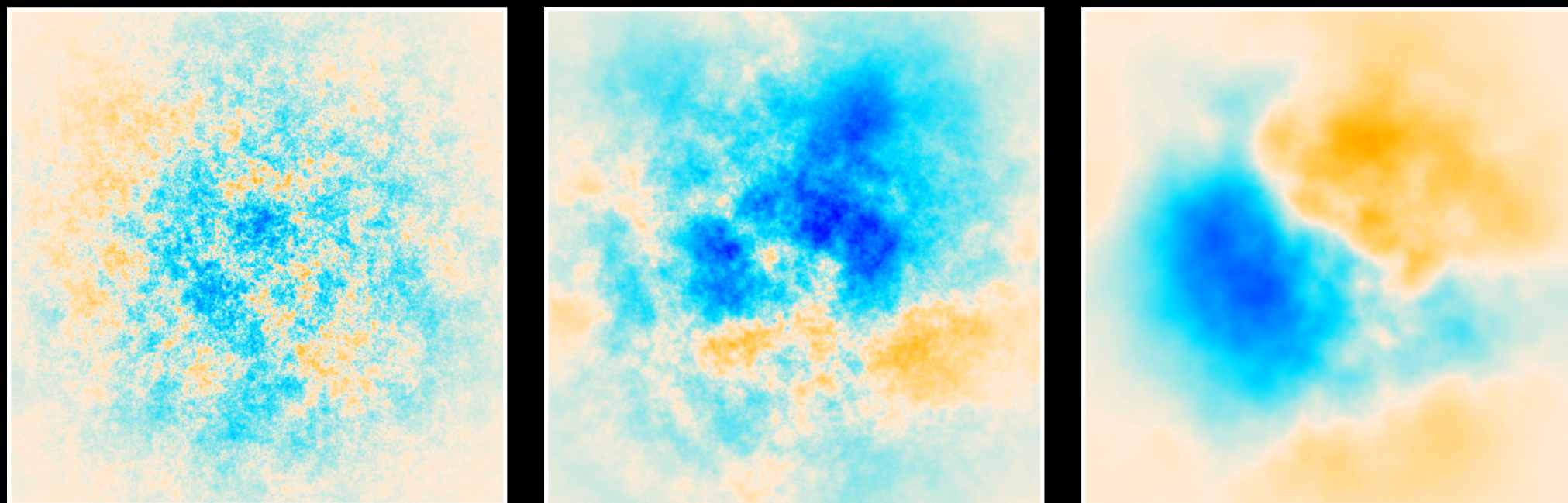
Variational inference (VI)

nifty: Bayesian imaging



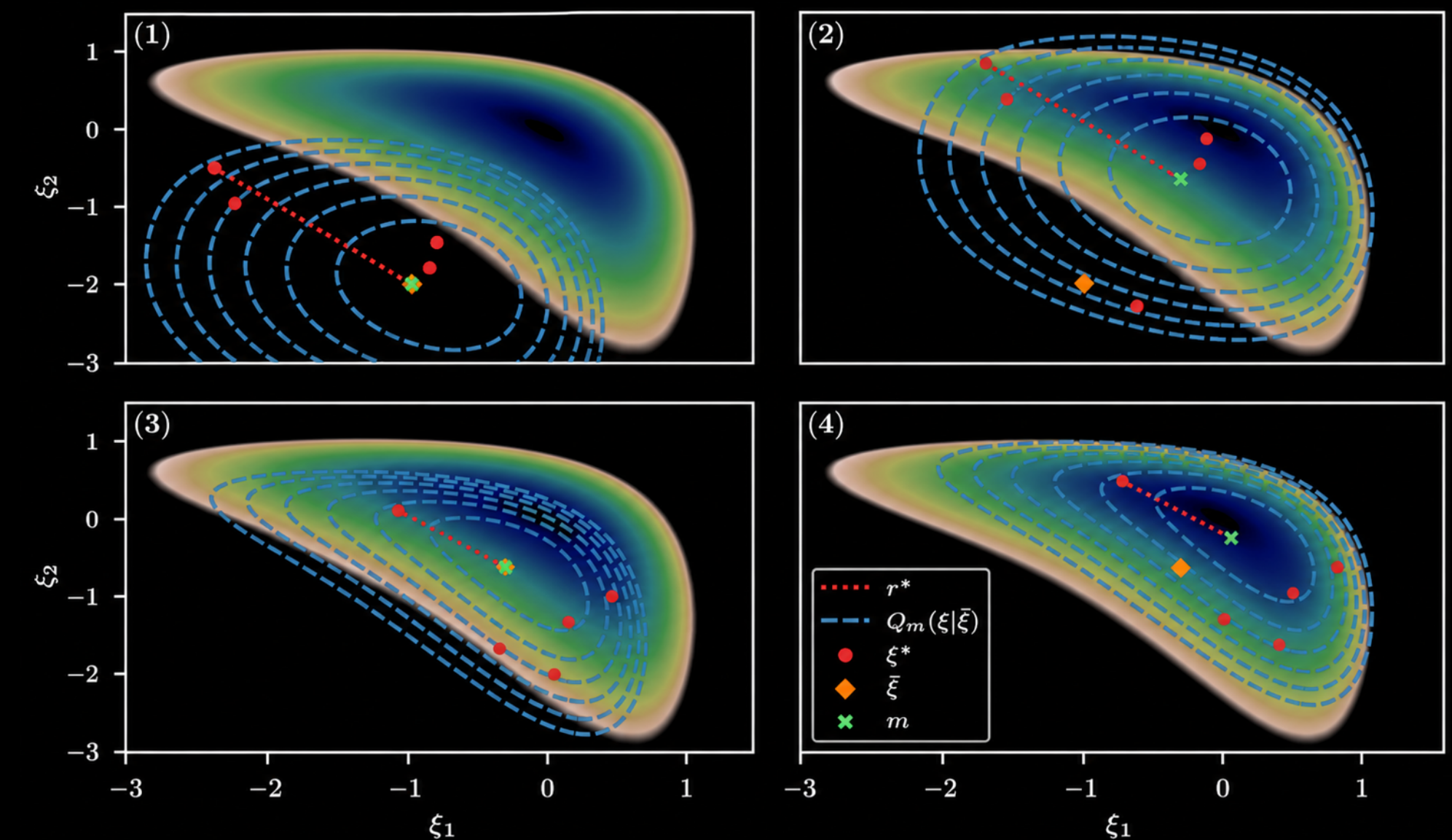
Gaussian processes (GPs)

- model correlations
- describe various signals
- build complex prior models



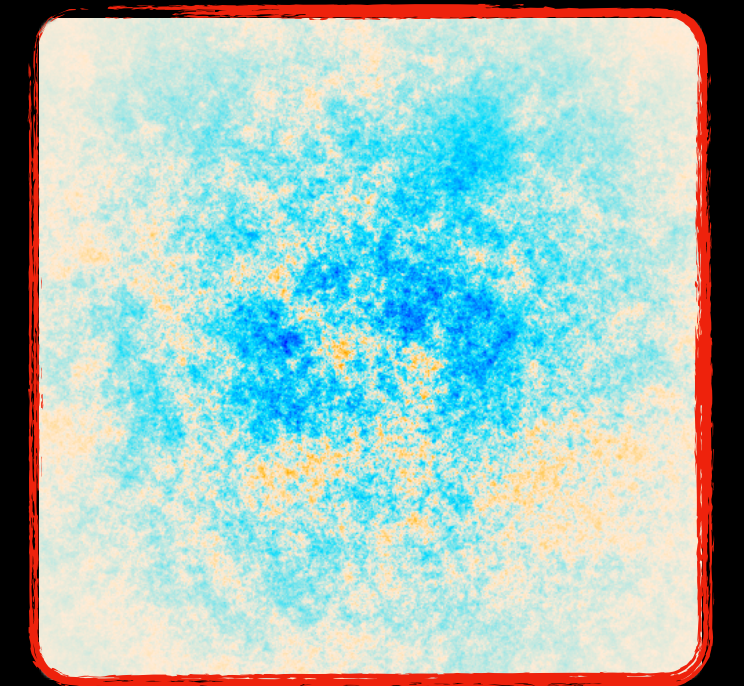
Variational inference (VI)

- approximate very high-dimensional posteriors with a set of samples



maria-nifty: map prior

$$s(\xi^s) = \sum_i s_i(\xi_i^s)$$

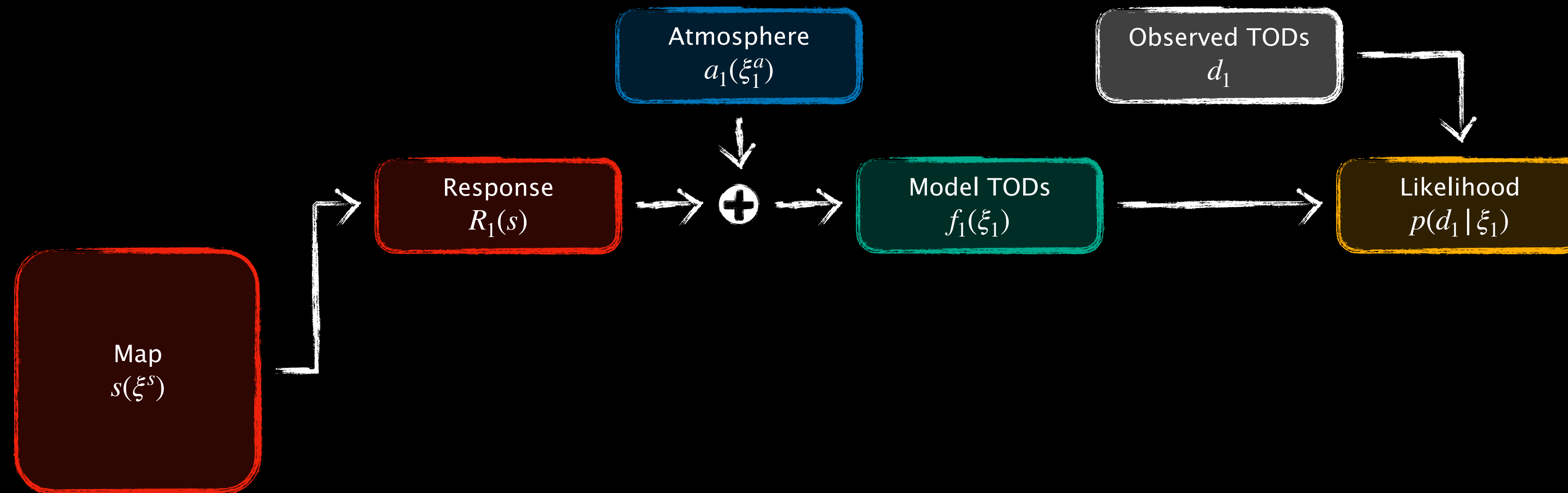


Source 1

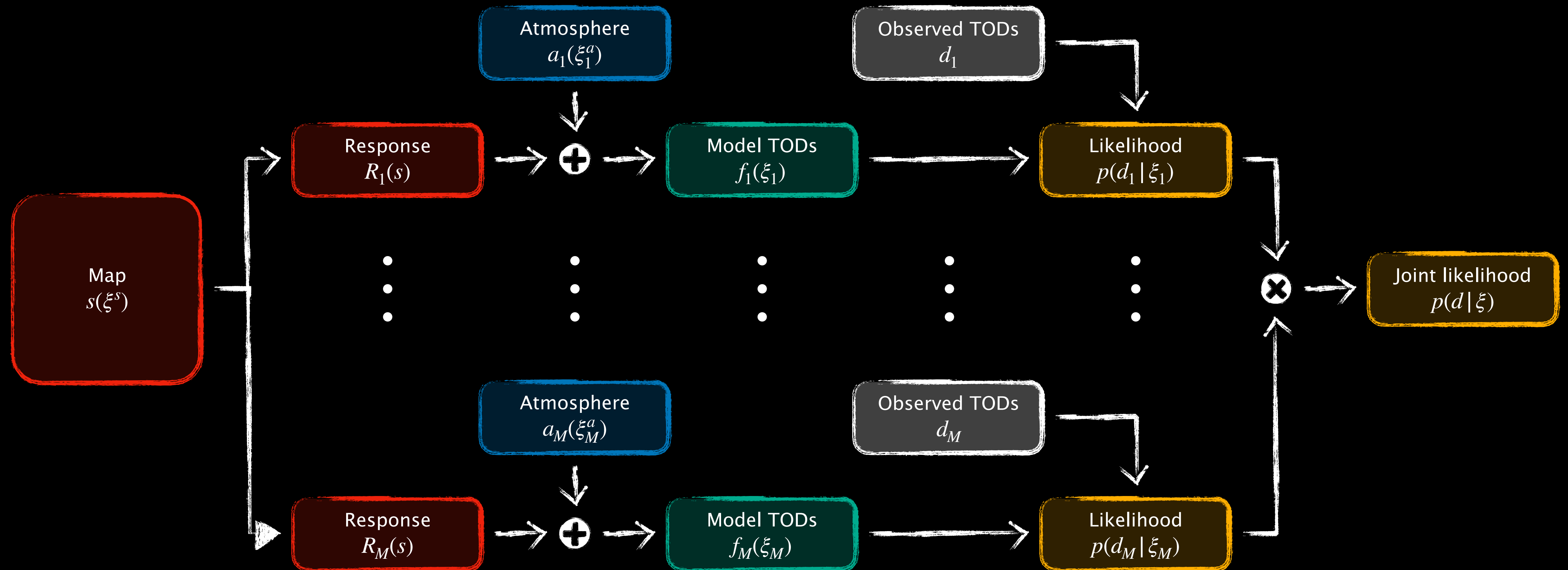


Source 2

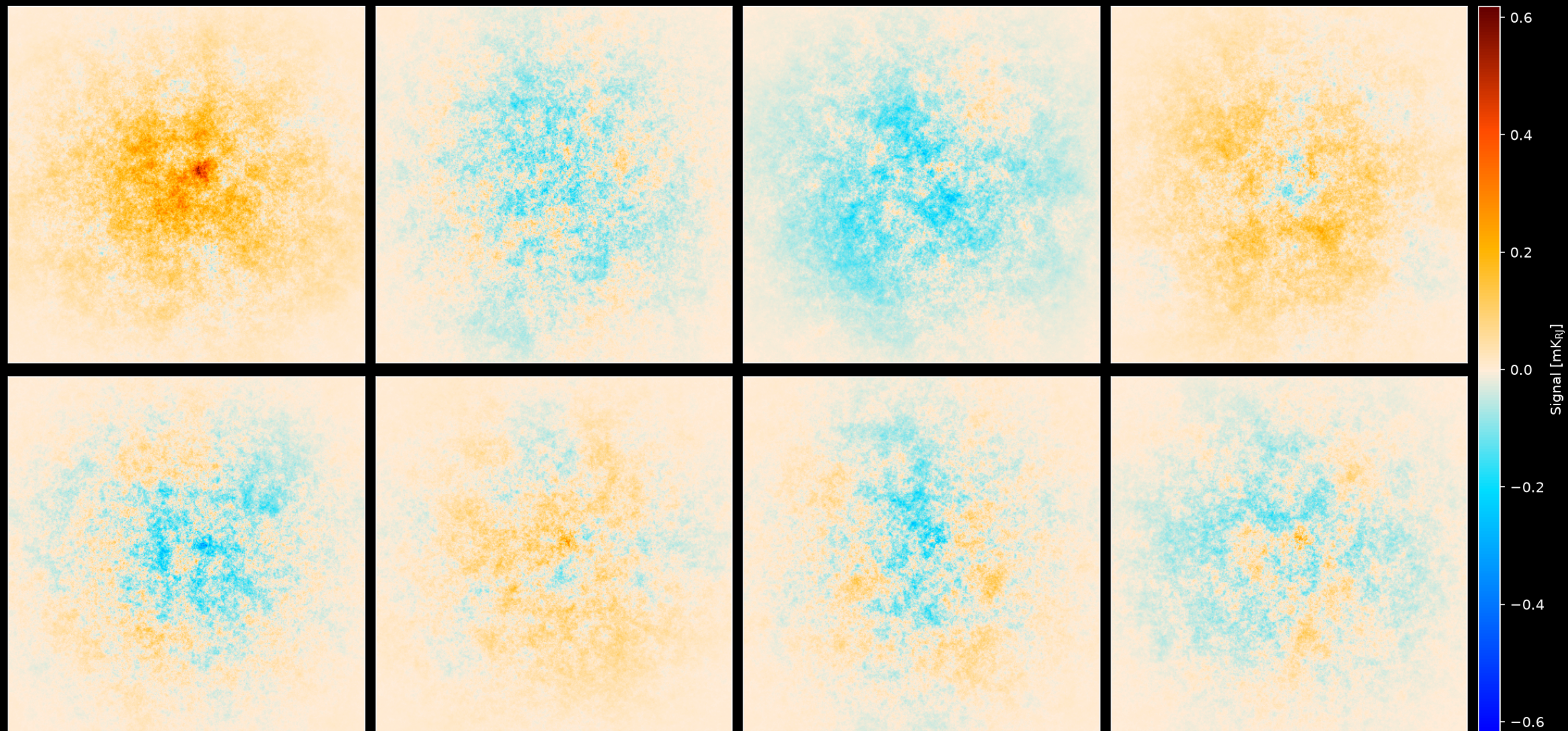
maria-nifty: likelihood



maria-nifty: likelihood



Map prior samples



Map posterior samples

