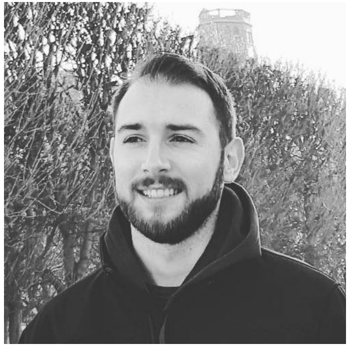
Bayesian lensing, delensing, and foreground cleaning



Marius Millea, Ben Thorne

Ethan Anderes, Kimmy Wu, Lloyd Knox, Karthik Prabhu

CMB-S4 March 2021 Meeting

Building on the SPTpol 100d-deep analysis

MM, Cail Daley Jody Chou, Ethan Anderes, SPT et al. 2012.01709

SPTpol 100d-deep

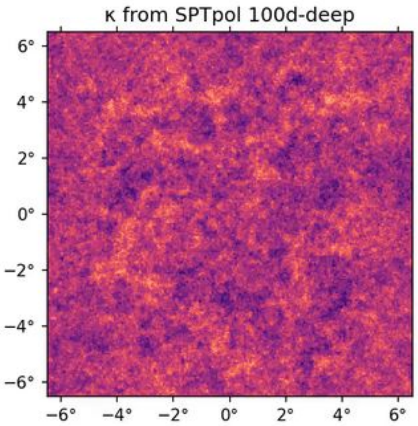
$$\log \mathcal{P}(f,\phi,A_\phi\,|\,d) \propto \frac{(d-\mathbb{A}\,\mathbb{L}(\phi)f)^2}{\mathbb{C}_n} + \frac{f^2}{\mathbb{C}_f} + \frac{\phi^2}{\mathbb{C}_\phi(A_\phi)}$$

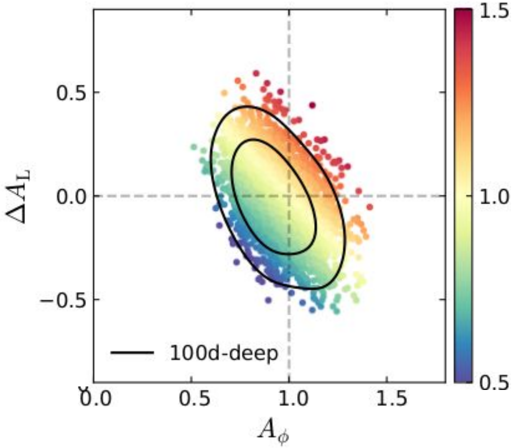
By virtue of working with this, everything is “optimal” automatically

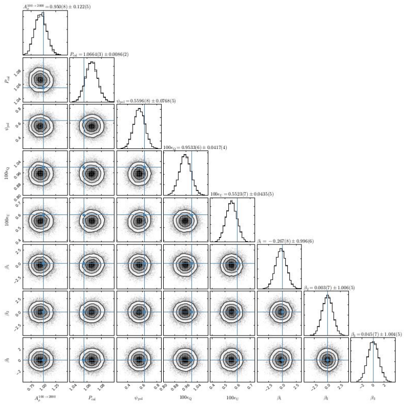
Maps (and non-Gaussian uncertainties)

Parameters

Systematics







Building on the SPTpol 100d-deep analysis

MM, Cail Daley Jody Chou, Ethan Anderes, SPT et al. [2012.01709]

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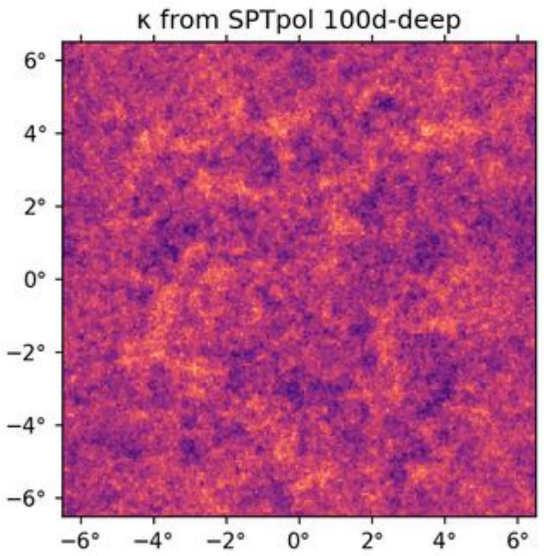
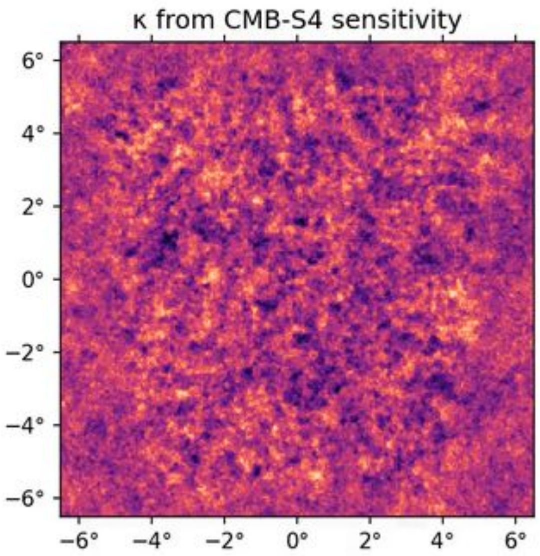
$$\log \mathcal{P}(f, \phi, A_\phi \,|\, d) \propto \frac{(d - \mathbb{A}\,\mathbb{L}(\phi) f)^2}{\mathbb{C}_n} + \frac{f^2}{\mathbb{C}_f} + \frac{\phi^2}{\mathbb{C}_\phi(A_\phi)}$$

By virtue of working with this, everything is “optimal” automatically





Building on the SPTpol 100d-deep analysis

MM, Cail Daley Jody Chou, Ethan Anderes, SPT et al. 2012.01709

SPT3G+Bicep/Keck (SPO), CMB-S4

100d-deep · Maps of dust&sync

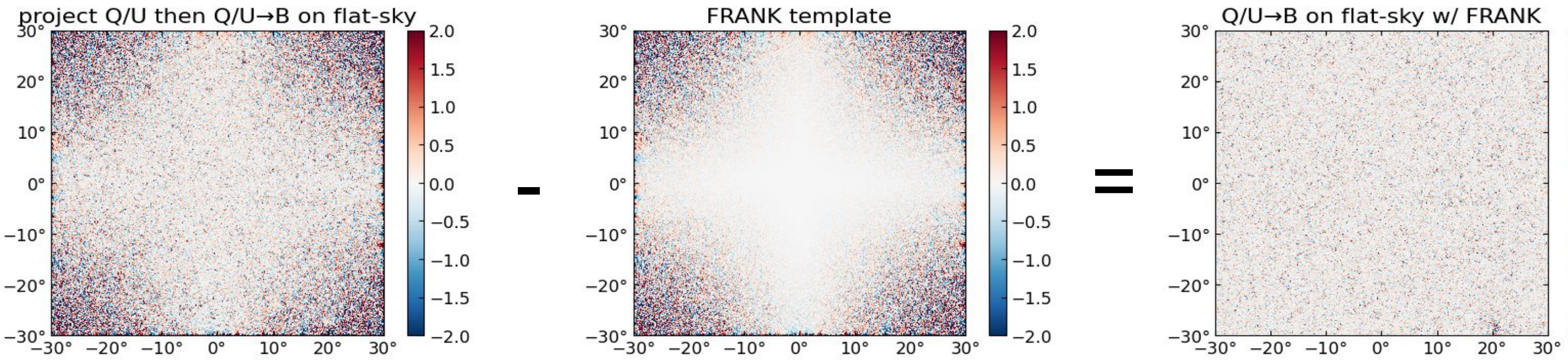
$$\mathcal{P}(f, \phi, A_\phi, r, g_{\rm d}, g_{\rm s}, A_{\rm d}, \alpha_{\rm d}, A_{\rm s}, \alpha_{\rm s} | d) \propto$$

Tensor-to-scalar · Dust&sync model

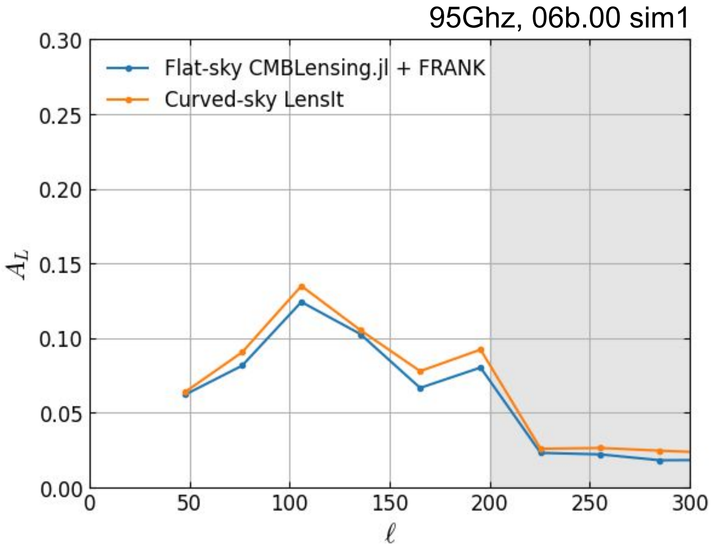
$$\propto \frac{(d - (\mathbb{A}(\mathbb{F}_{\rm CMB}\mathbb{L}(\phi)f + \sum_{i\in {\rm d,s}} \mathbb{F}_{\rm i}(\beta_i)g_{\rm i}))^2}{\mathbb{C}_n} + \sum_{i\in {\rm s,d}} \left[\frac{g_{\rm i}^2}{\mathbb{C}_i(A_i,\alpha_i)} - \log\det \mathbb{C}_i(A_i,\alpha_i)\right] + (f,\phi)\ \text{prior}\ldots$$

BK Observing matrix

Curvature FRANK: delensing template without needing curved-sky



- Julien Carron has generated marginal MAP templates with LensIt with correct handling of sky curvature for 06b sims.
- In a direct comparison, I achieve **slightly better** delensing with CMBLensing.jl using a flat-sky joint MAP analysis and FRANK.
- This is **extremely fast**, 5 minutes on one GPU per run.
- Slight improvement not really relevant for science, but if curious ask me in discussion where I think it comes from.

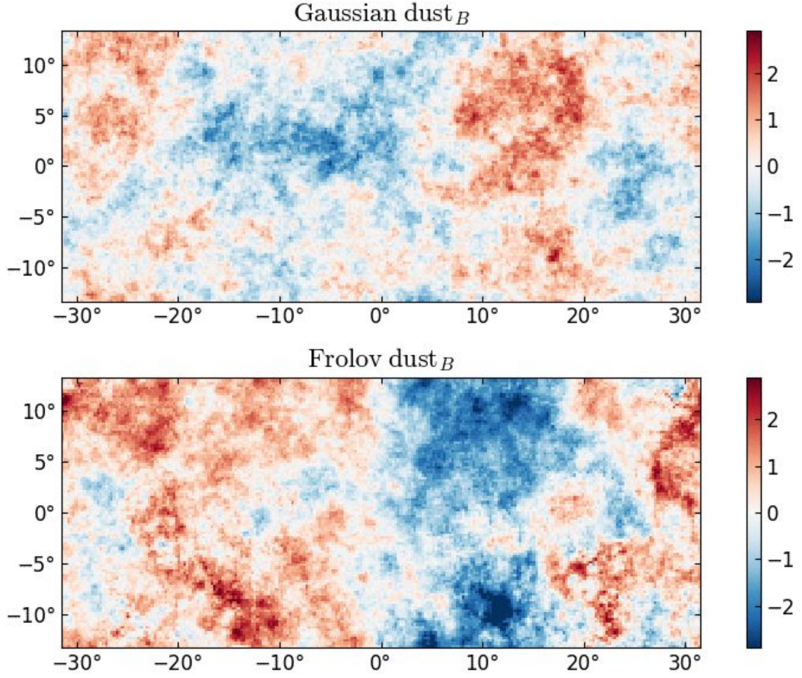


FRANK = SPT-lingo for “**F**irst **R**emove **AN**y **K**nown B modes”

Modeling non-gaussian galactic dust foregrounds

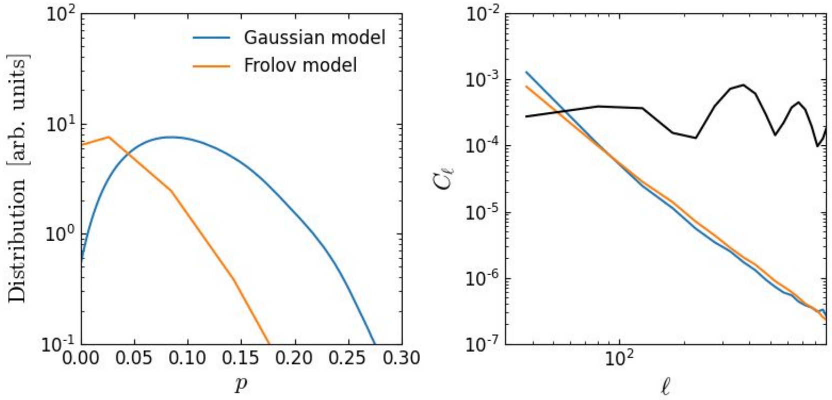
Model suggested by Andrei Frolov

$$I = e^{i} \cosh p, \quad Q = \frac{q}{p} e^{i} \sinh p, \quad U = \frac{u}{p} e^{i} \sinh p$$



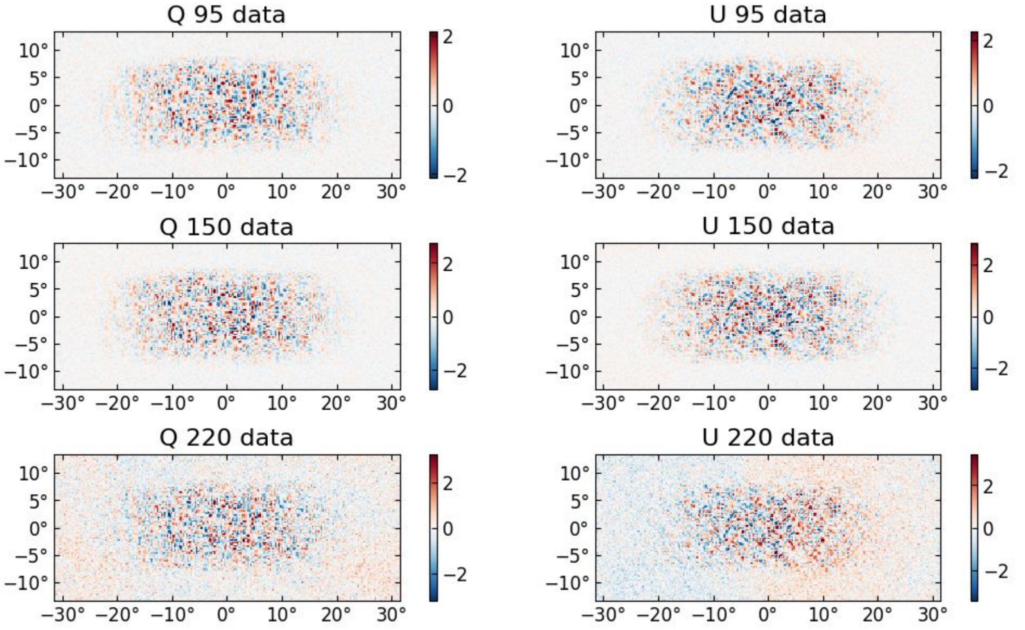
Samples from prior

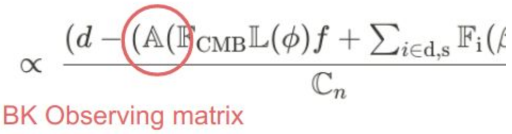
Identical power spectra but different distribution of polarization fractions.

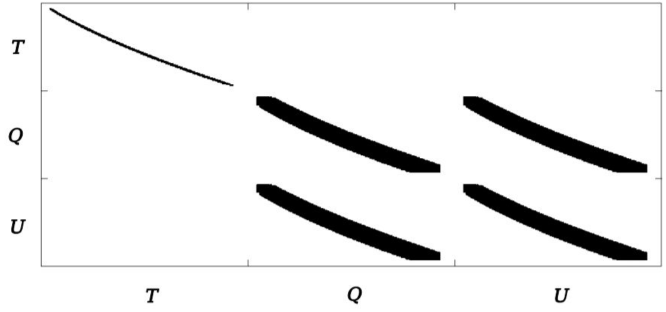


SPO forecasting results (Gaussian dust)

Frequency (GHz)	σ_T (μKamin)	θ_{FWHM} (amin)	ℓ_{knee}	α_{knee}
90	1	20	50	3
150	2	15	50	3
220	3	10	50	3
150	1	2	500	3



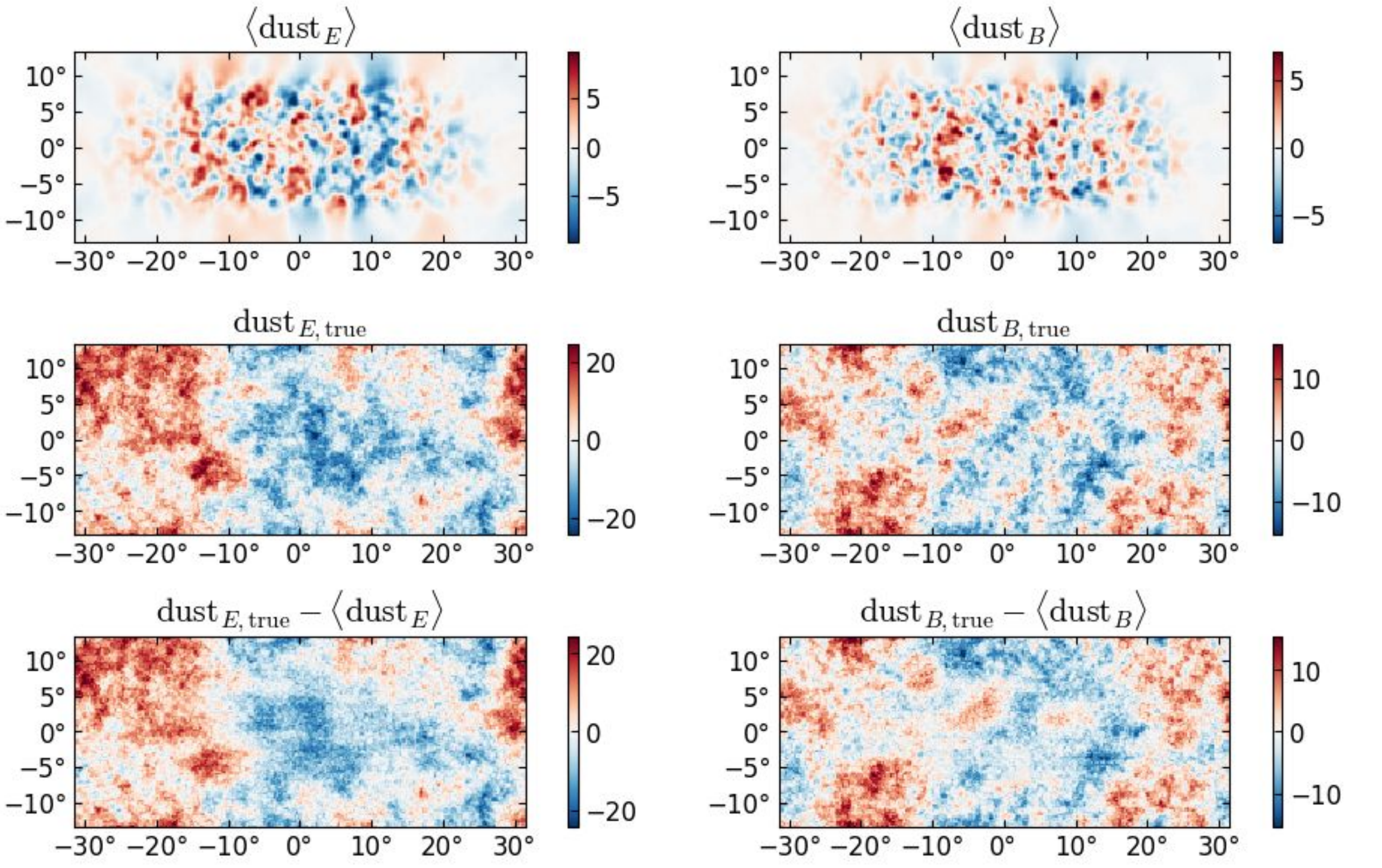




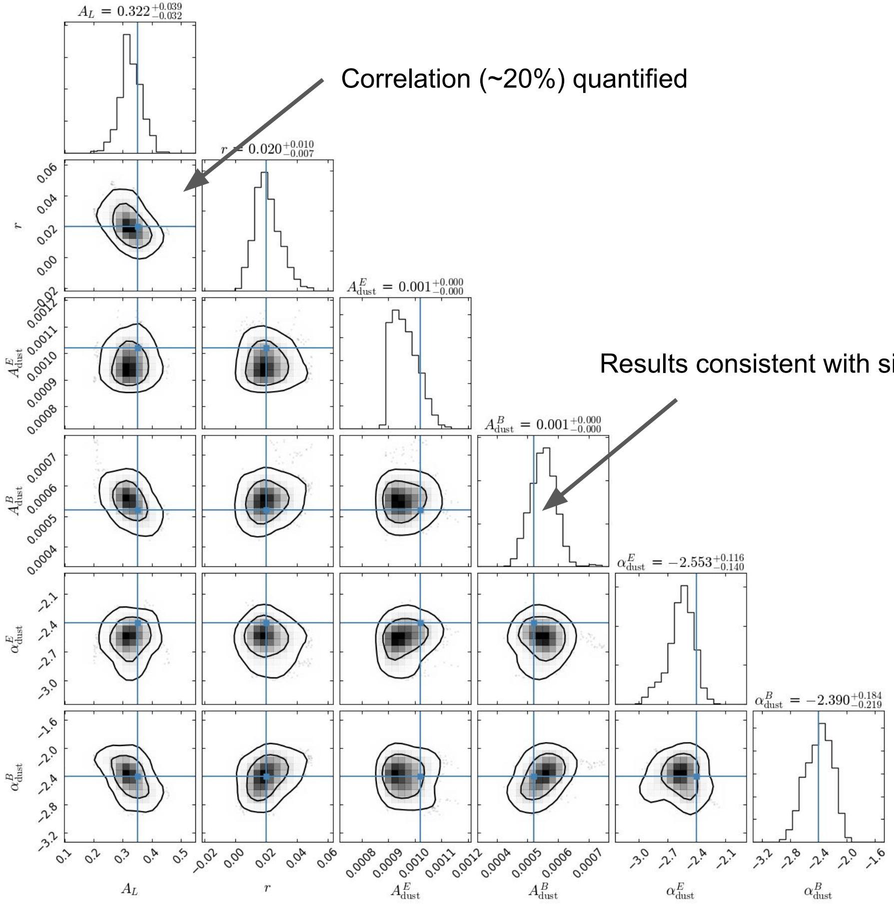
60000×300000 sparse matrix.
One matrix*vector is 5ms (GPU) or 2s (CPU)

Observing matrix is an extremely valuable data product, which we should strive for S4 SAT data.

SPO forecasting results (Gaussian dust)



SPO forecasting results (Gaussian dust)

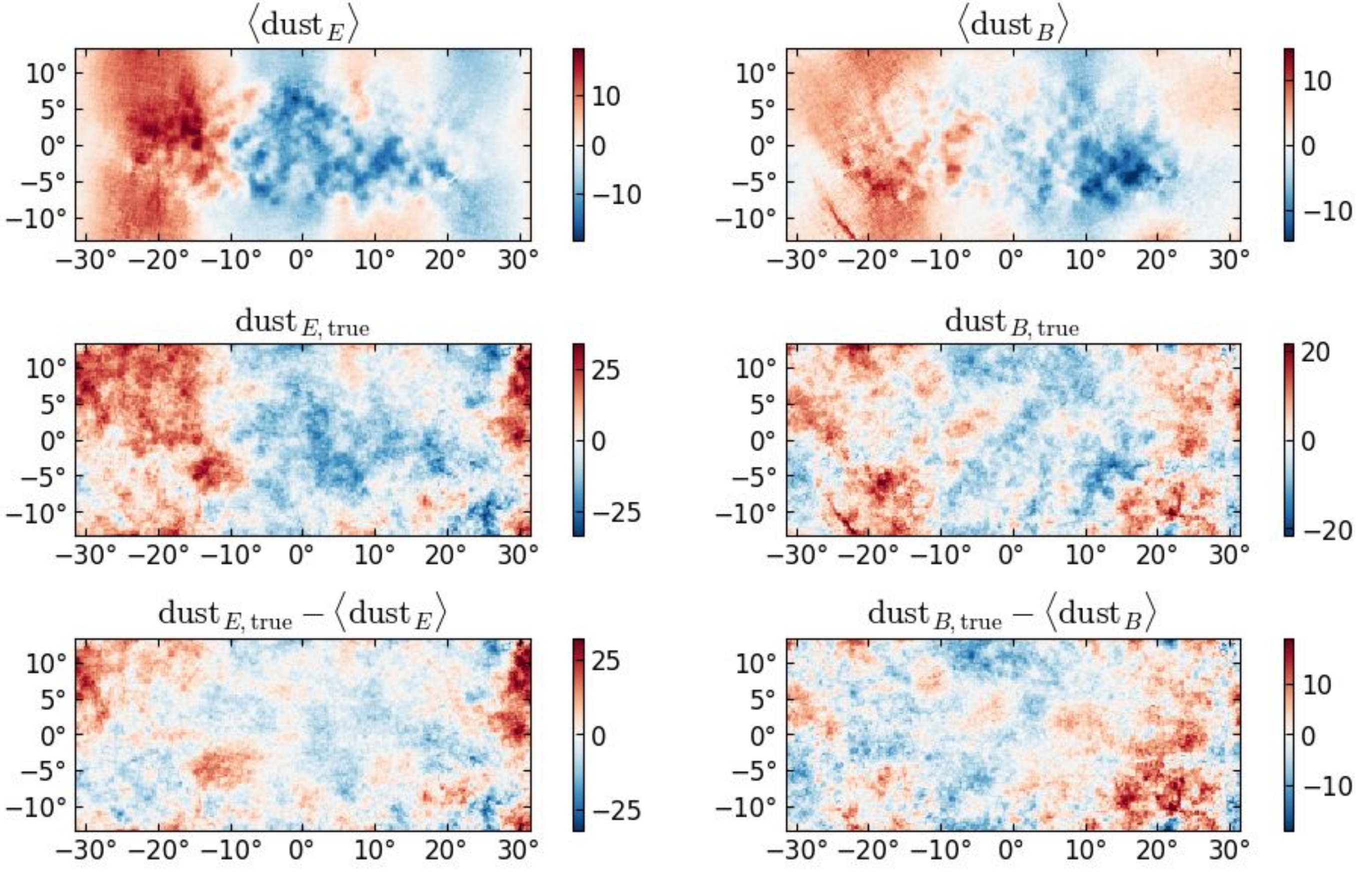


Correlation (~20%) quantified

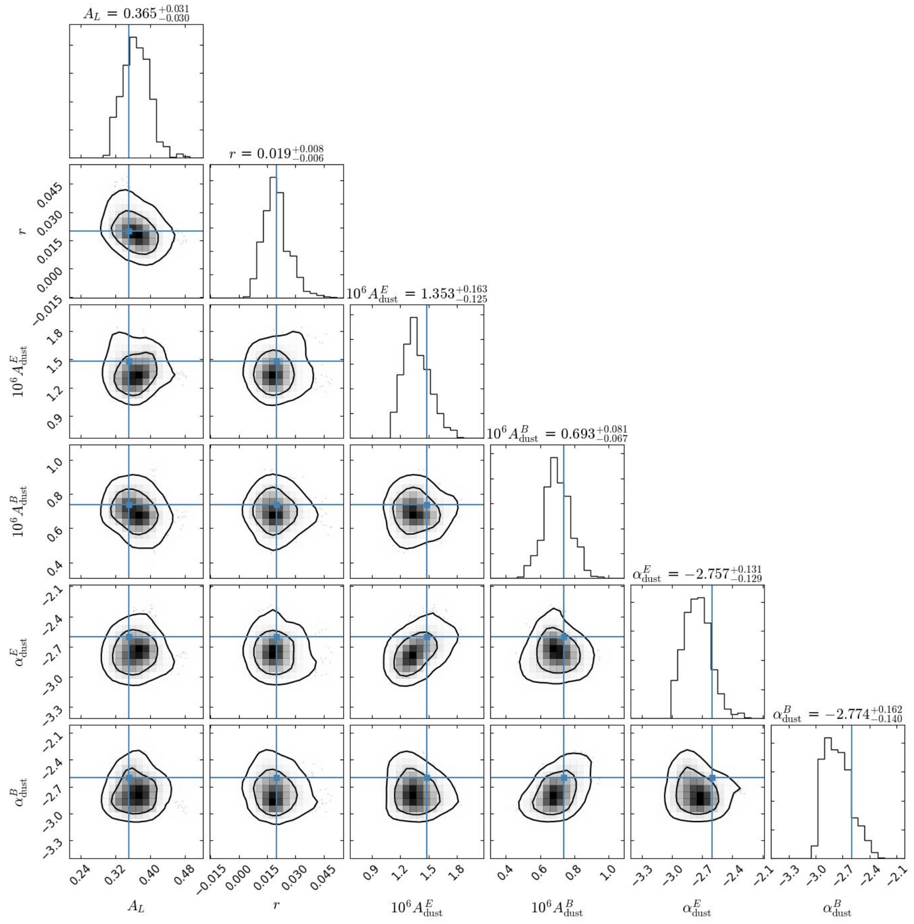
Results consistent with simulation truth.

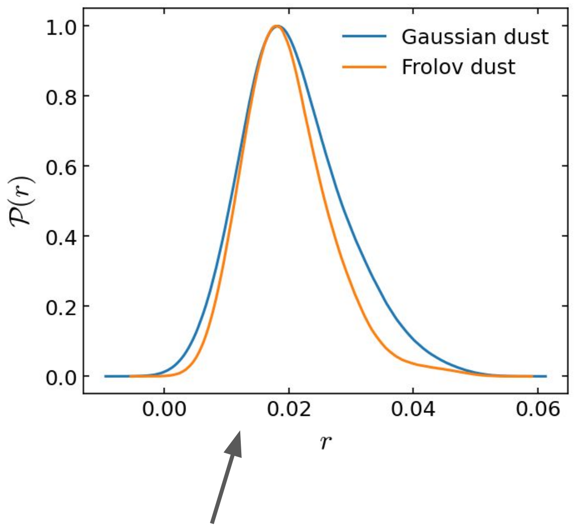
A few hours to run one of these chains across a few GPU.

SPO forecasting results (Frolov dust)



SPO forecasting results (Frolov dust)



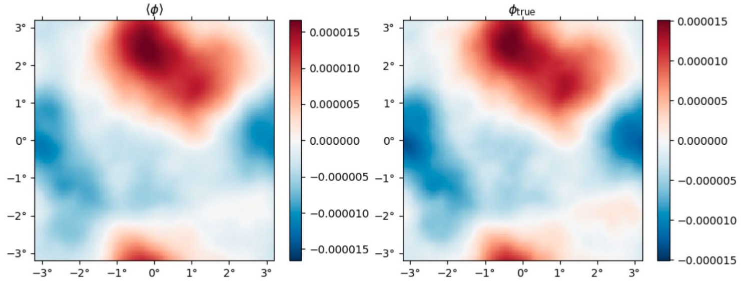


Some sensitivity to statistics of the dust model.

SPO forecasting results (Gaussian dust & real lensing)

Reconstruction Truth

ϕ

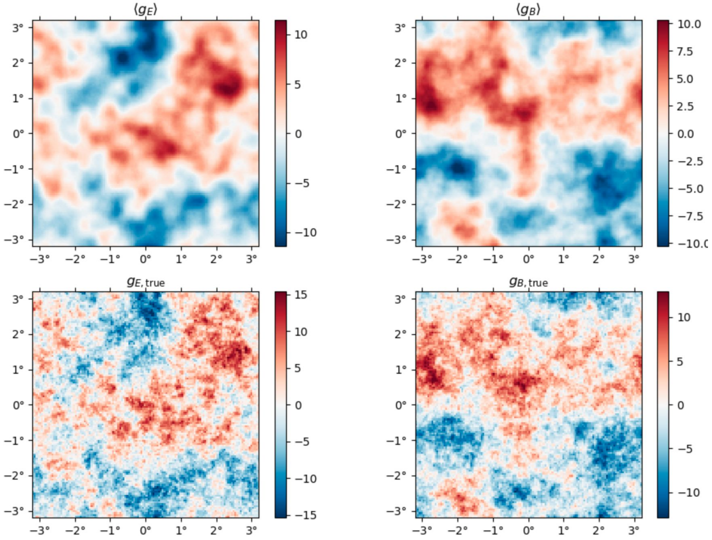


Currently small patch of sky, but optimal joint delensing, foreground estimation, and r estimation.

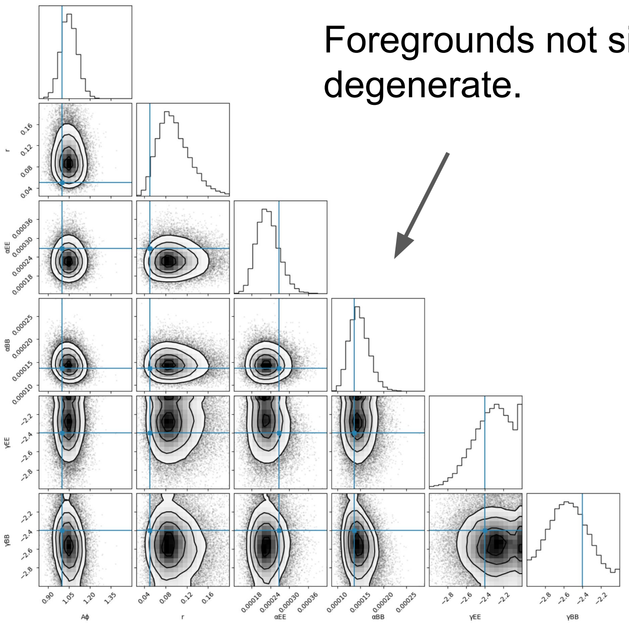
Dust E Dust B

Reconstruction

Truth



Foregrounds not significantly degenerate.

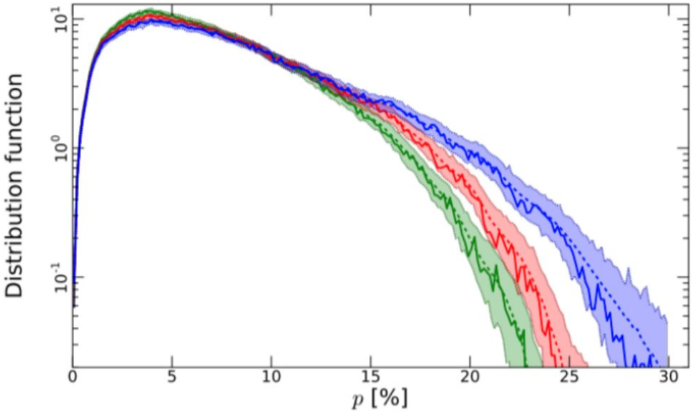


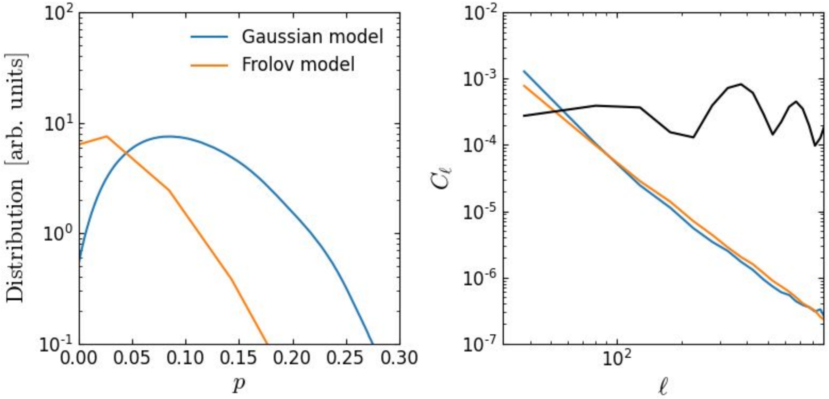
Main points

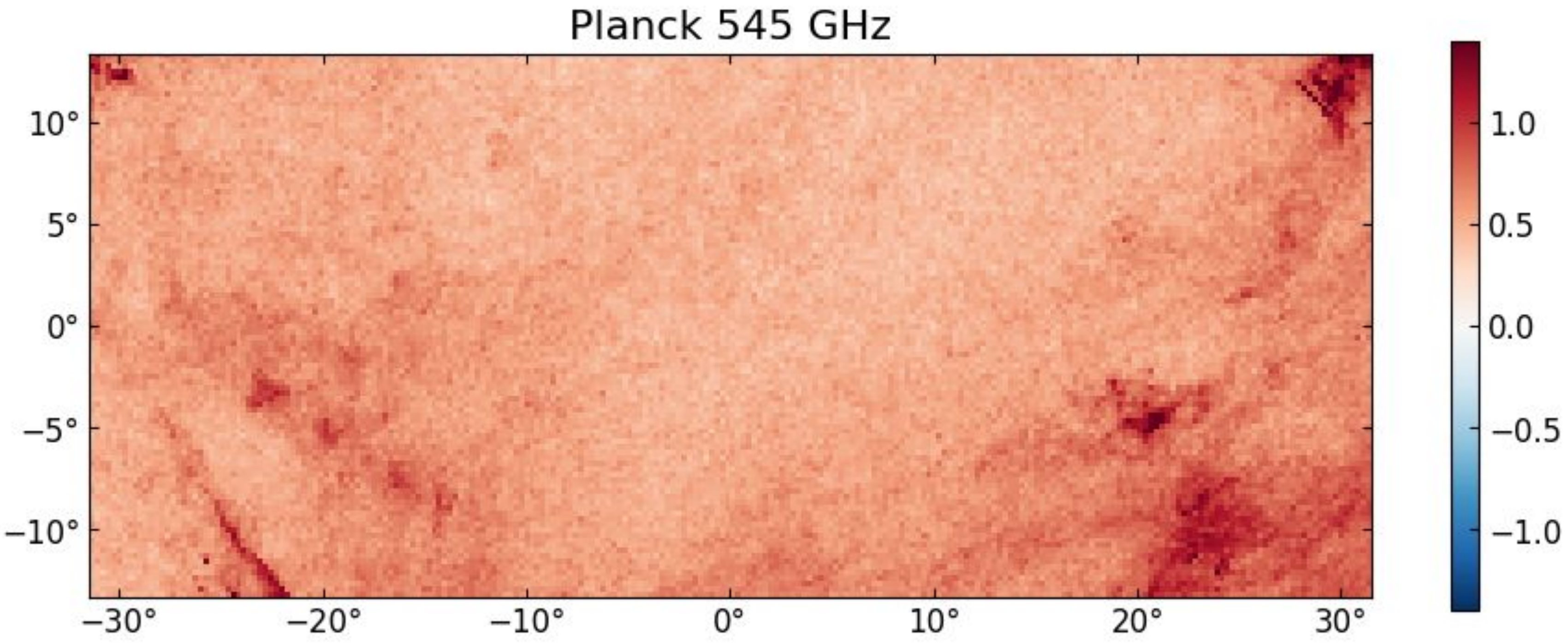
- For at least S4-deep delensing, we can build optimal lensing templates on the flat-sky using FRANK with essentially no information loss (5min/1GPU).
- Full Bayesian sampling possible for at least S4-deep. We should strive for an accurate full forward model (including. BICEP-like observation matrix)
- Given simple models, some evidence that dust statistics impact r constraint for SPO (we will be checking S4-deep as well)
- There are *tons* of important things to explore that we don't have the manpower to do. We encourage others to use this approach, this code (CMBLensing.jl), and to get in touch.

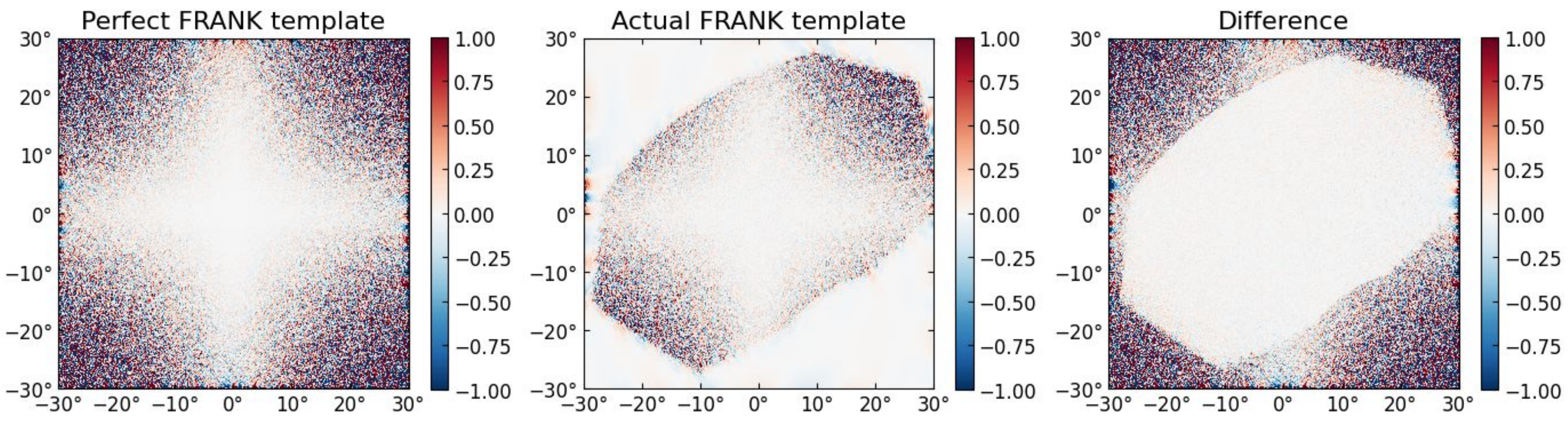
Backup

Fig 5, Planck 2018 XI

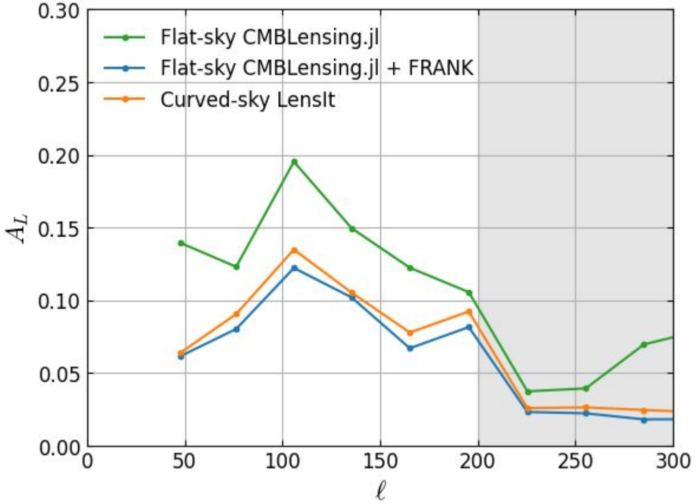




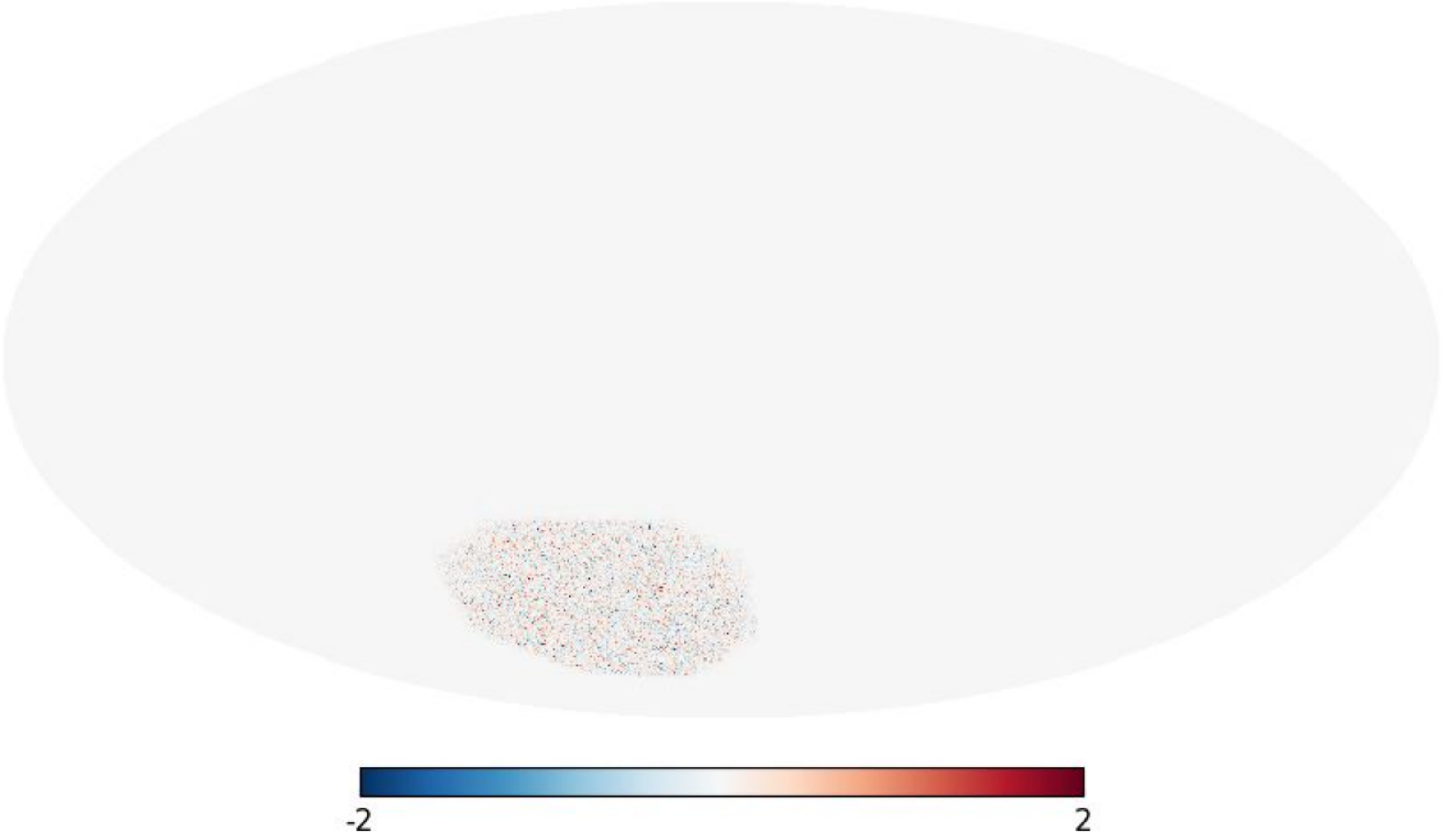

Planck 545 GHz
10°
5°
0°
−5°
−10°
−30°
−20°
−10°
0°
10°
20°
30°
1.0
0.5
0.0
−0.5
−1.0



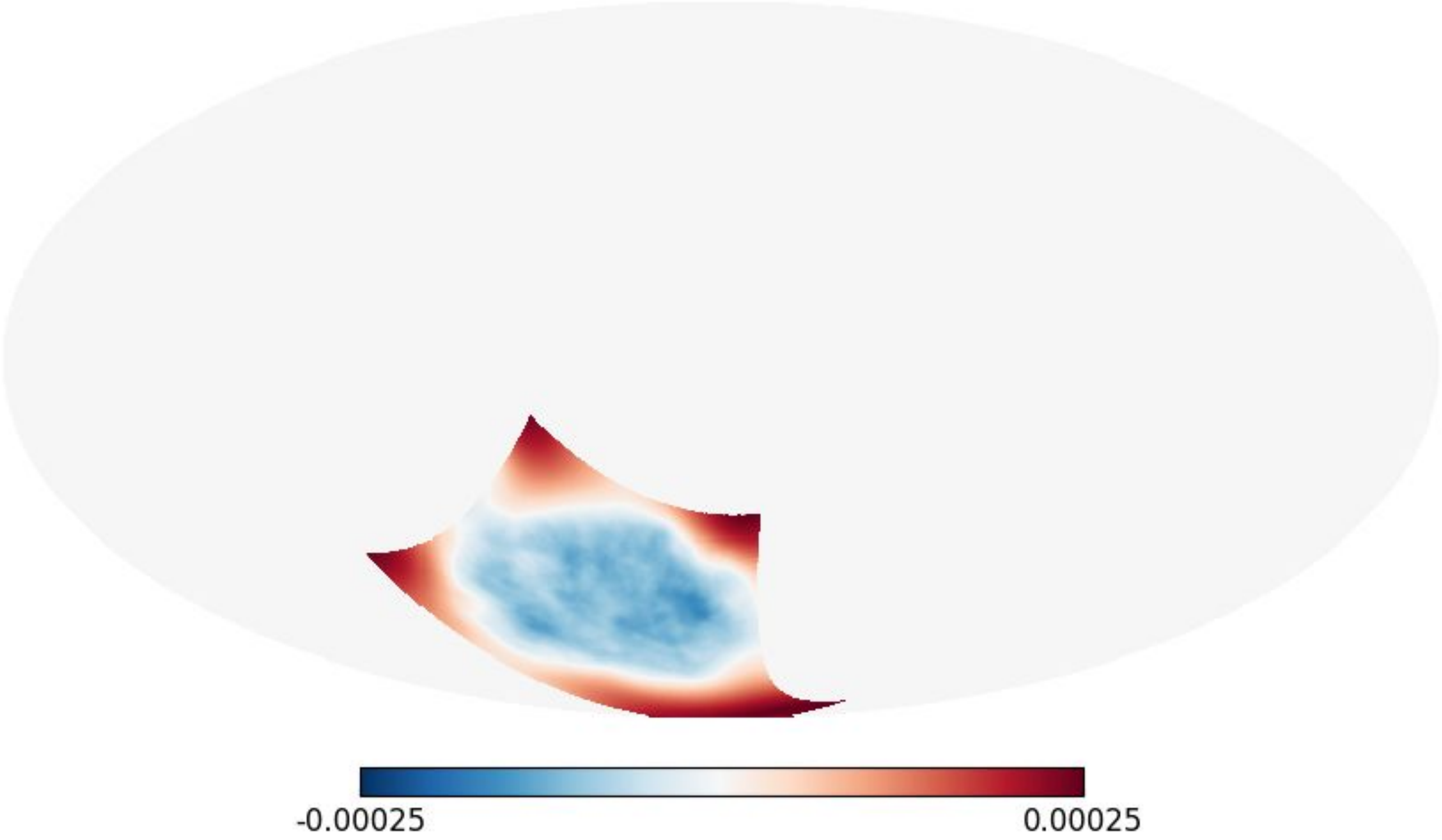
- I've attempted to do everything as identical to Julien's 06b runs as possible, including
    - Noise model is Nhits weighted white-noise
    - E: 30<ℓ<3000
    - B: 200<ℓ<3000
- 15 joint MAP iterations, about 300 steps per WF, 5 minutes on a Tesla V100



Flat-sky CMBLensing.jl + FRANK lensing template



Flat-sky CMBLensing.jl + FRANK ϕ reconstruction



Flat-sky CMBLensing.jl + FRANK κ reconstruction