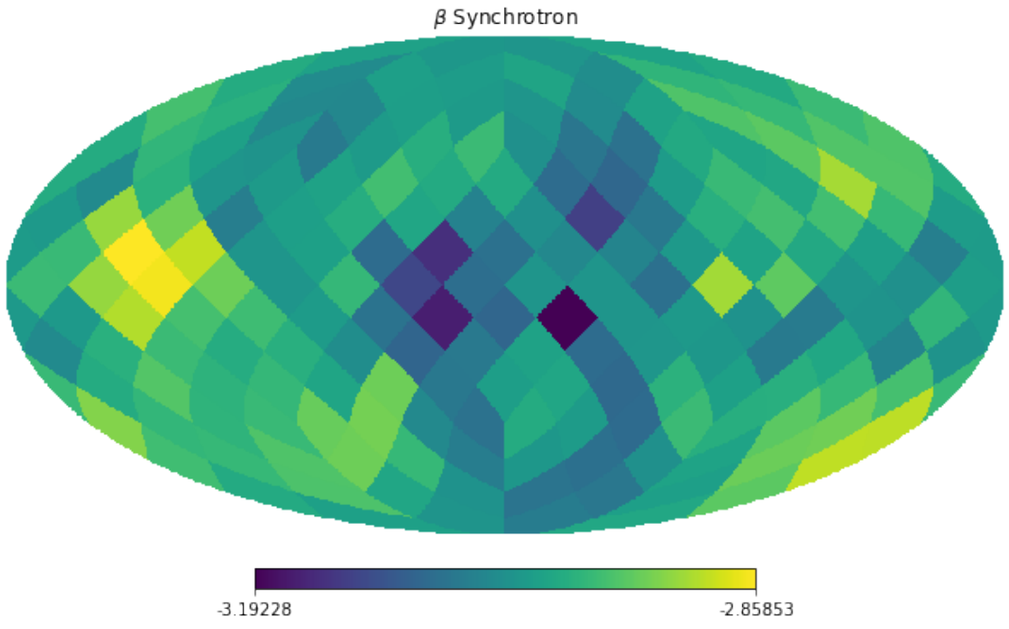
Towards an adaptive parametric component separation

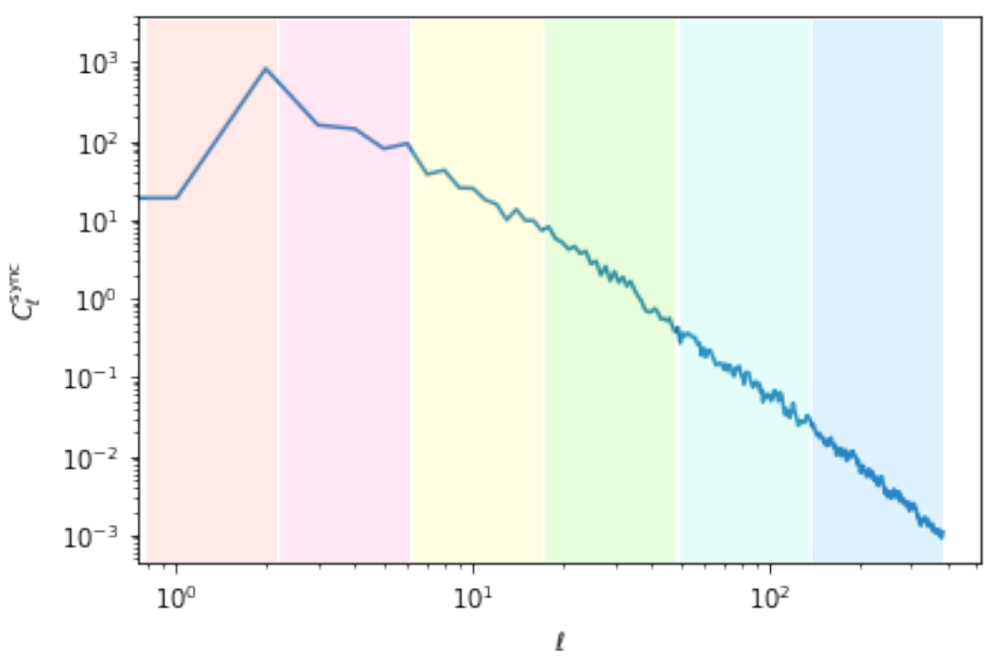
CMB Foregrounds for B-modes studies
Tenerife, 18 October 2018

Davide Poletti (SISSA)

Context

- Invert $d_p = As_p + n_p$ requires assumptions
- Reduce freedom of the components by assuming they have homogeneous properties across some partition of the sky





- Partitioning is sometimes hand-made, isotropic or unnatural for some foregrounds components
- Goal: adapt the morphology of the foregrounds modelling to the data

The framework

- Parametric models for the emission laws: $A(\beta)$ **Assumptions**
- Uncorrelated noise between pixels
- No statistical assumption on the components s

$$\ln \mathcal{L}(s_p, \beta) = -\sum_p (As_p - d_p)^\top N_p^{-1} (As_p - d_p) + const$$

β constant over a pixel set

1. Maximization of the spectral likelihood **Algorithm**

Stompor+ (2009)

$$\ln \mathcal{L}_{spec}(\beta) = \sum_p d_p^\top N_p^{-1} A (A^\top N_p^{-1} A) A^\top N_p^{-1} d_p + const$$

2. Estimation of the components

$$s_p = (A^\top N_p^{-1} A)^{-1} A^\top N_p^{-1} d_p$$

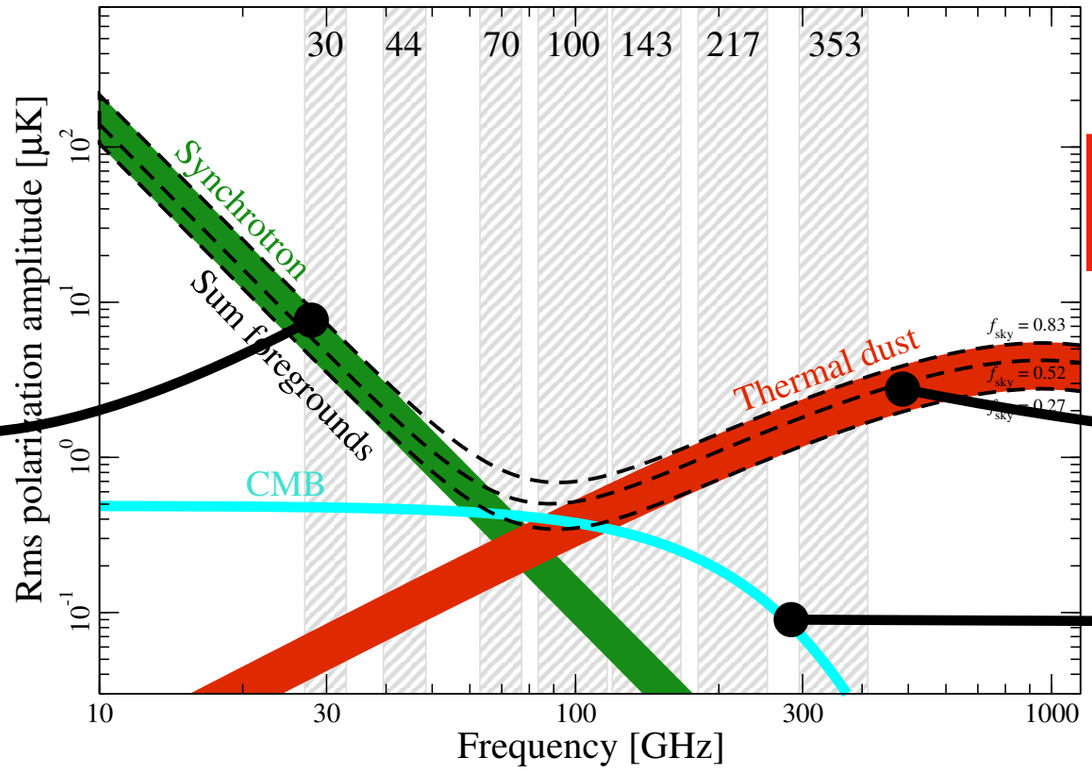
The framework

- Focus: synchrotron, polarization

- Parameters
  6 linear parameters per pixels
  2 non-linear parameters per pixel set

Synchrotron

$$A_s^{Q/U}\left(\frac{\nu}{\nu_0}\right)^{\beta_s}$$



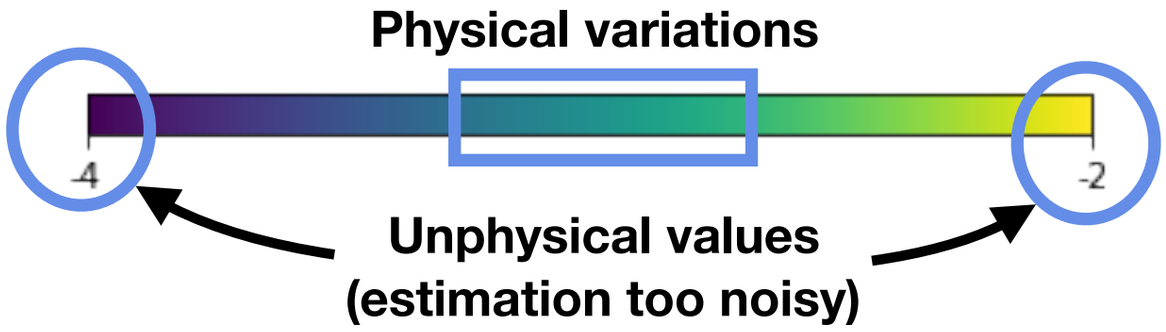
Thermal dust

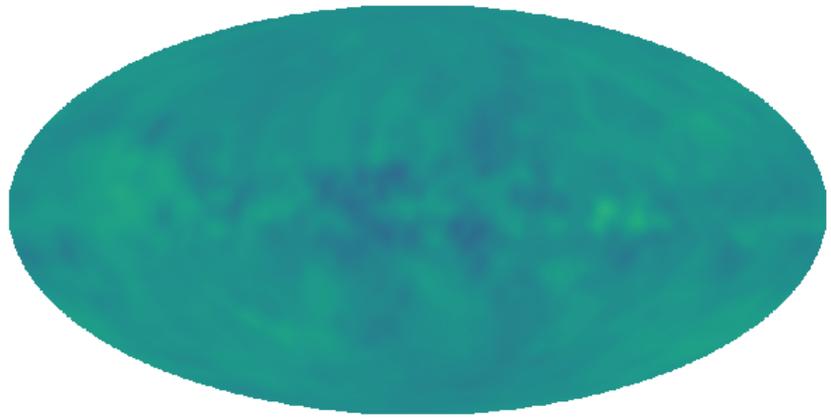
$$A_d^{Q/U}\left(\frac{\nu}{\nu_0}\right)^{\beta_d+1}\frac{\exp(h\nu_0/k_BT_d)-1}{\exp(h\nu/k_BT_d)-1}$$

$$A_{CMB}^{Q/U}\,g(\nu)$$

CMB

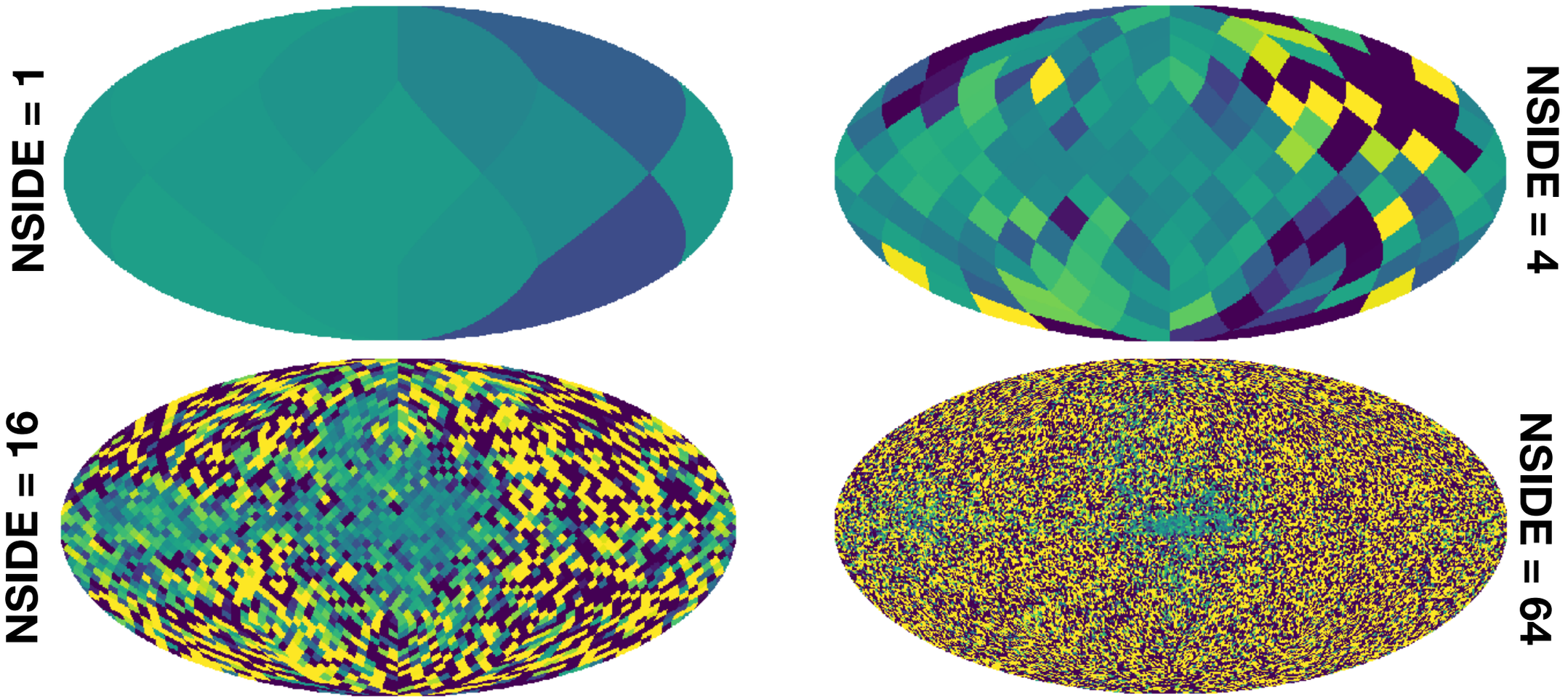
Homogeneous partitioning





Input synchrotron spectral index (PySM)
(Indications of larger fluctuations, see S-PASS/C-BASS talks)

Reconstructed synchrotron spectral index from simulated Planck observation (white noise)



Different sky areas can afford different resolutions

Partitioning technique

Homogeneously distributed dof → homogeneous information content per dof

- Information on beta *(Errard+, 2011)*

$$\left[\boldsymbol{\Sigma}^{-1}\right]_{\beta\beta'} \simeq -\,\mathrm{tr}\left\{\left[\mathbf{A}^t_{,\beta}\mathbf{N}^{-1}\mathbf{A}(\mathbf{A}^t\mathbf{N}^{-1}\mathbf{A})^{-1}\mathbf{A}^t\mathbf{N}^{-1}\mathbf{A}_{,\beta'} - \mathbf{A}^t_{,\beta}\mathbf{N}^{-1}\mathbf{A}_{,\beta'}\right]\sum_p \hat{\mathbf{s}}_p\hat{\mathbf{s}}^t_p\right\}.$$

$$\mathcal{N}_p = (A^T N_p^{-1} A)^{-1} \qquad \text{Uncertainty over } s_p$$

- Partitions based on $x_p = \mathcal{N}^{-1}_{p,\,sync-sync}\; s^2_{p,\,sync}$

- Recipe
  - Component separation with a single partition ➔ s_p
  - Start from highest resolution and keep downgrading (summing over pixels) until **threshold** hit

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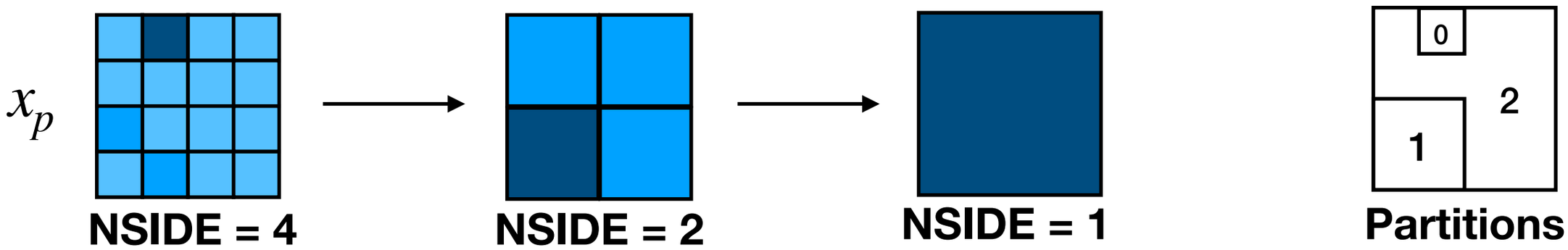
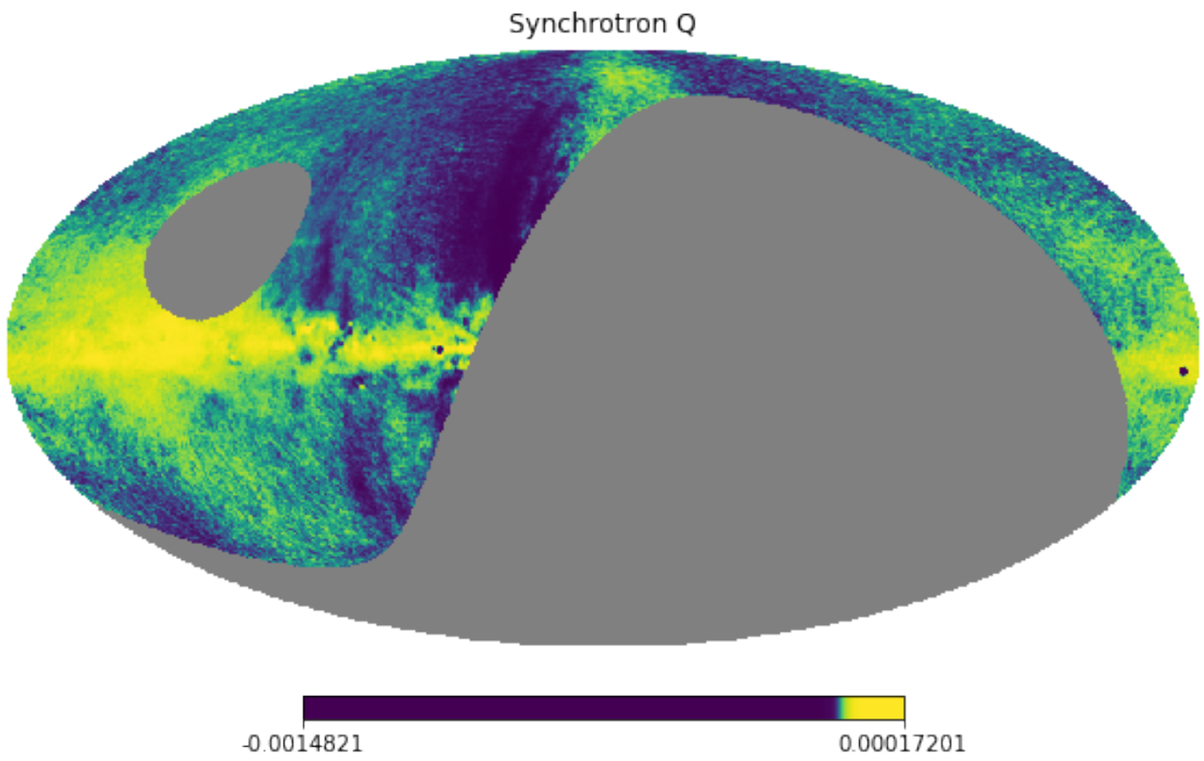


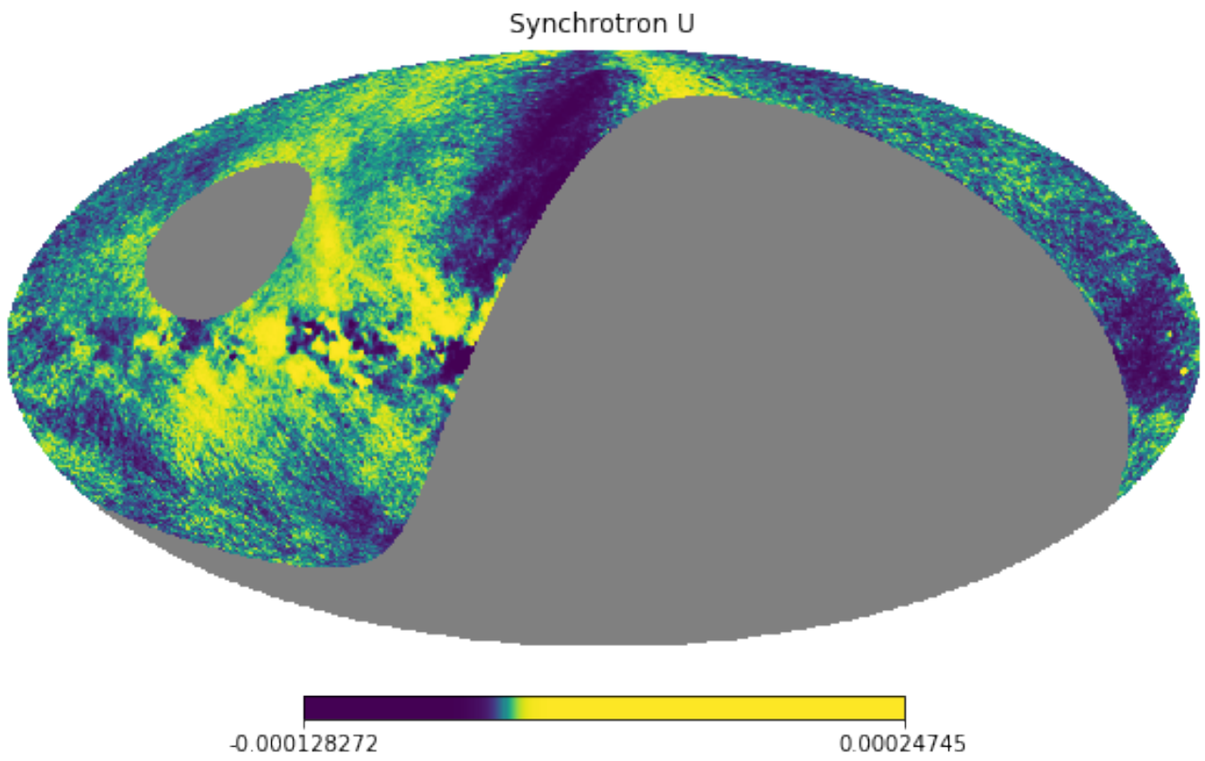
Application to Quijote, Planck and WMAP

Polarization maps and covariance maps (at 1 deg)

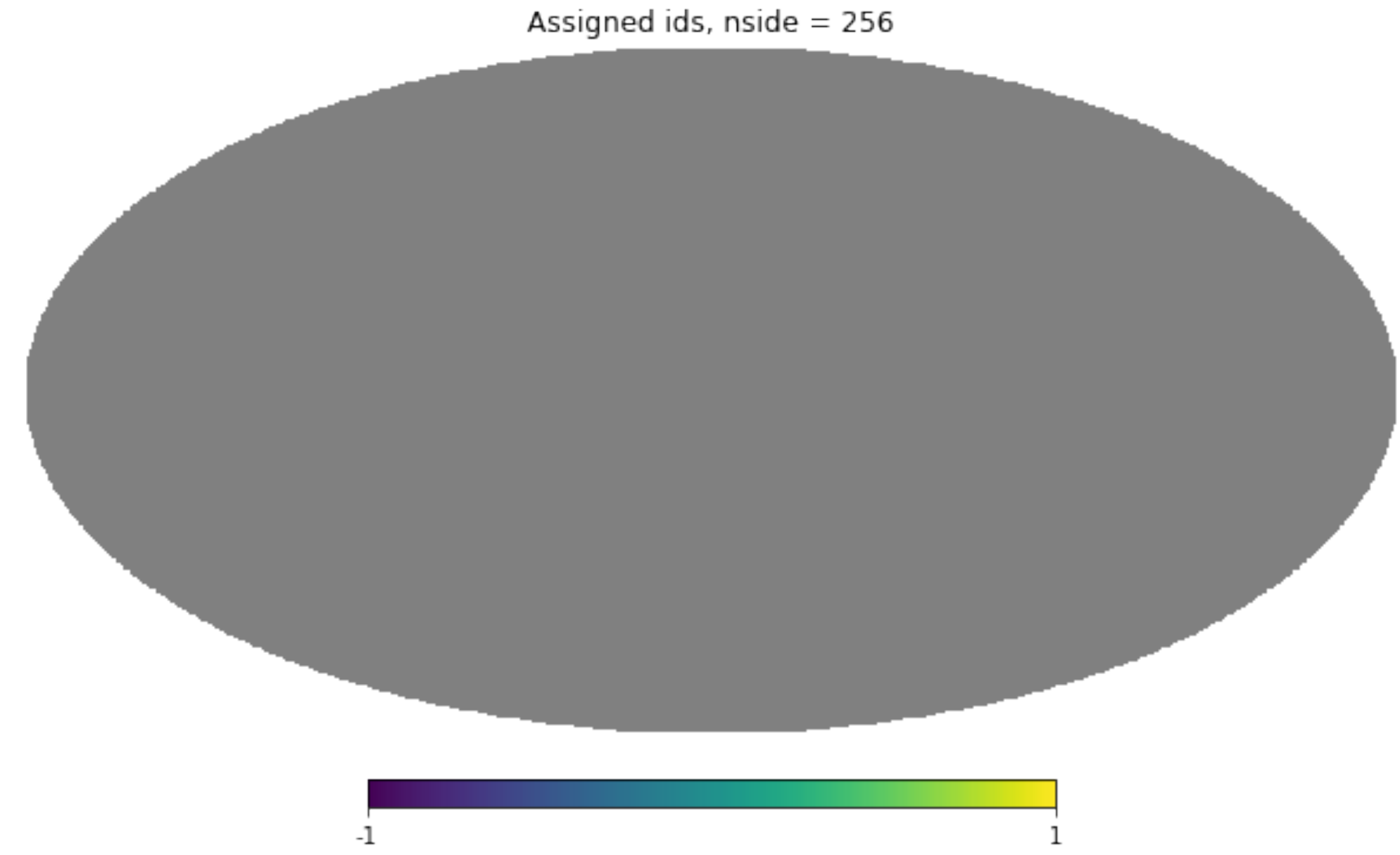
- Quijote 11 and 13 GHz
- Planck 30, 44, 70, 100, 143, 217, 353 GHz
- WMAP K, Ka, Q, V, W

- Preliminary run





Partitioning process



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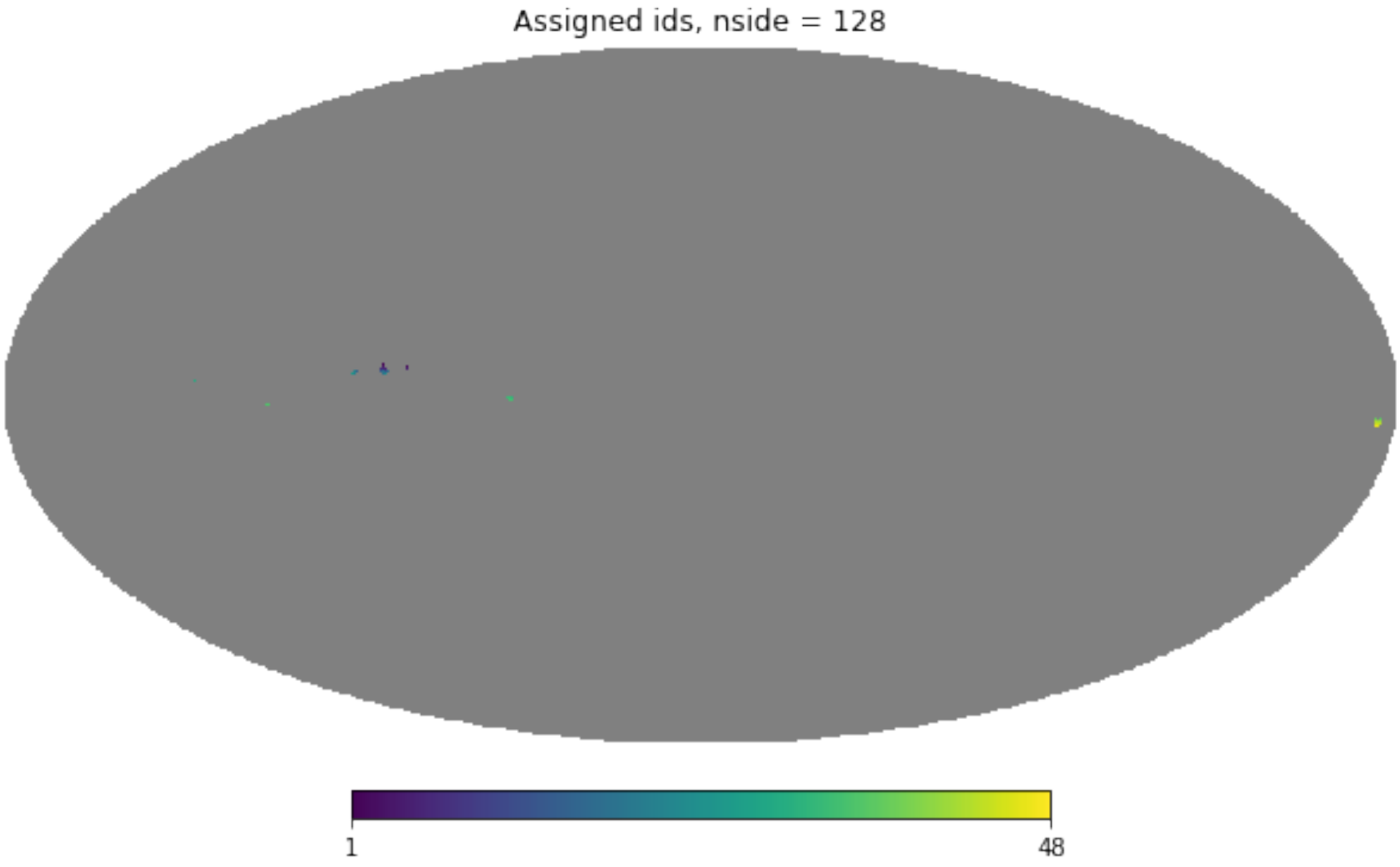

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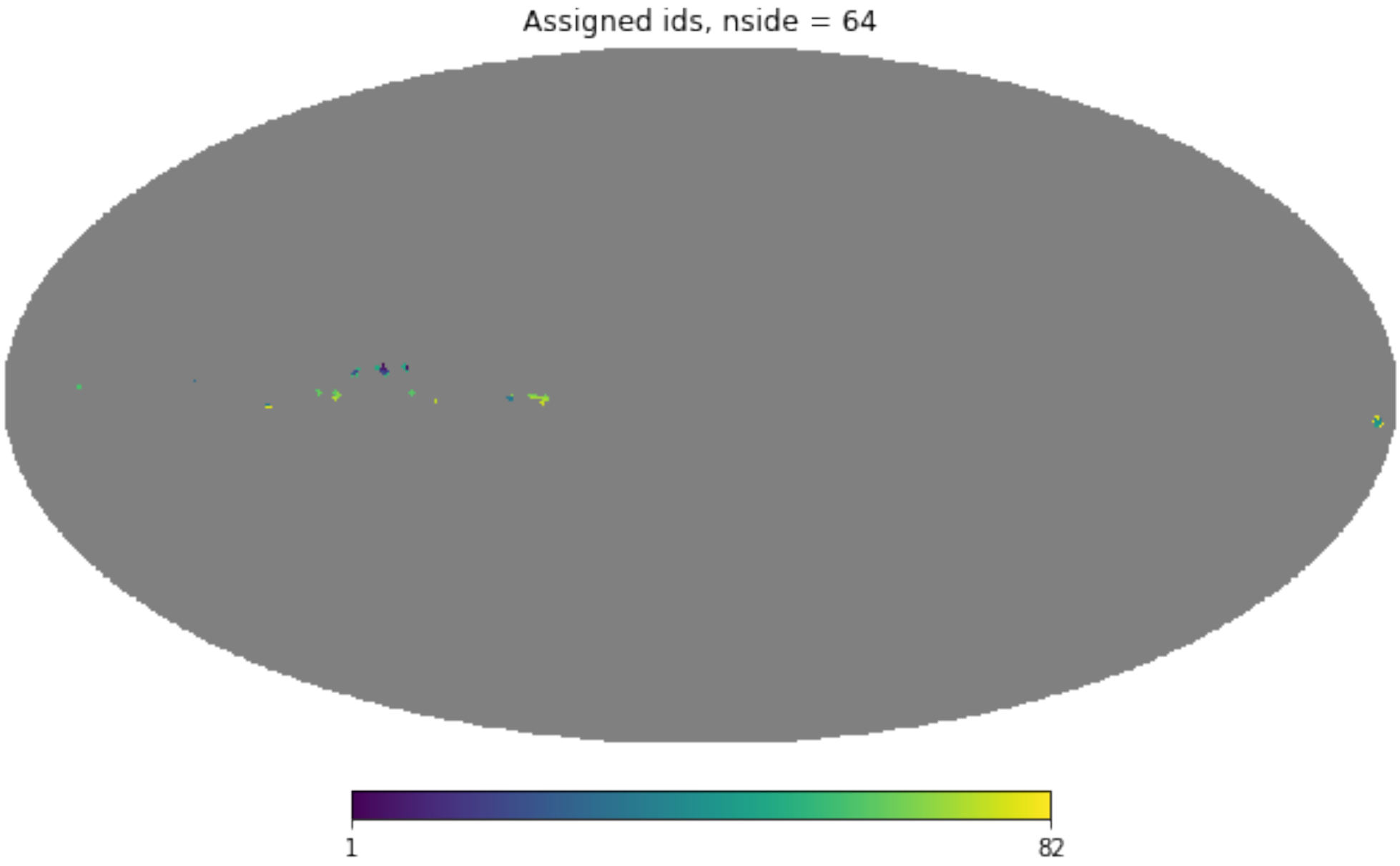

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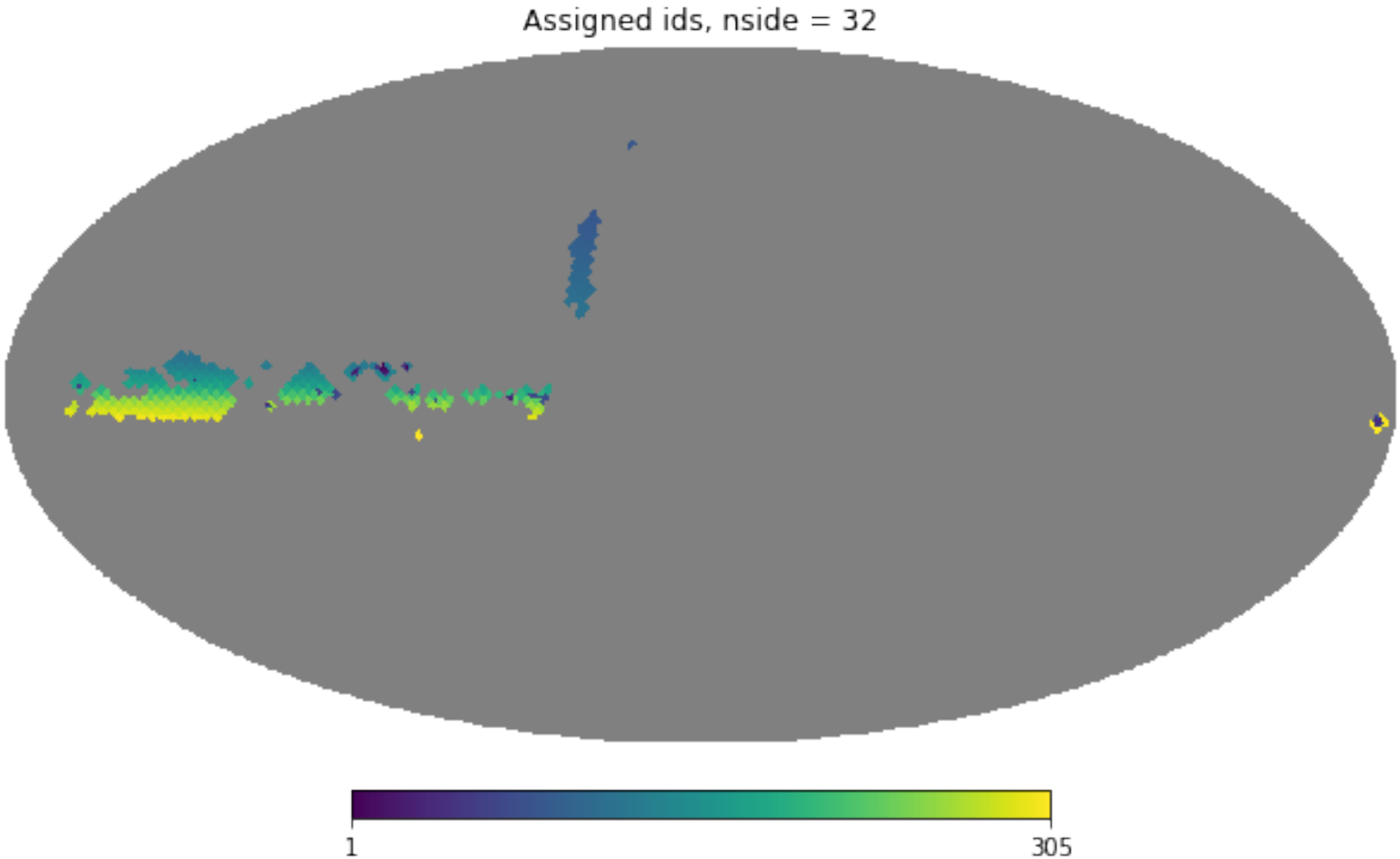

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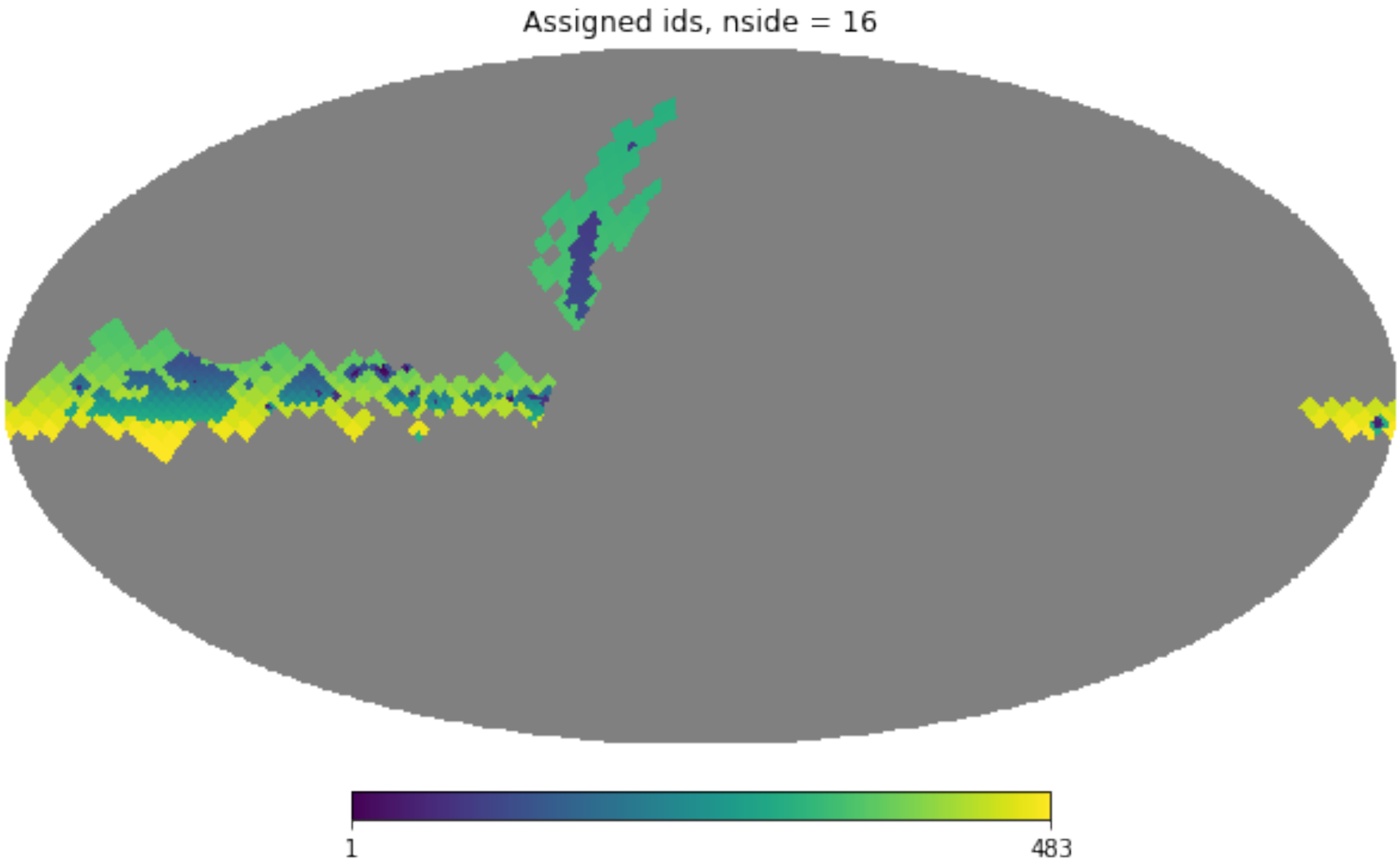

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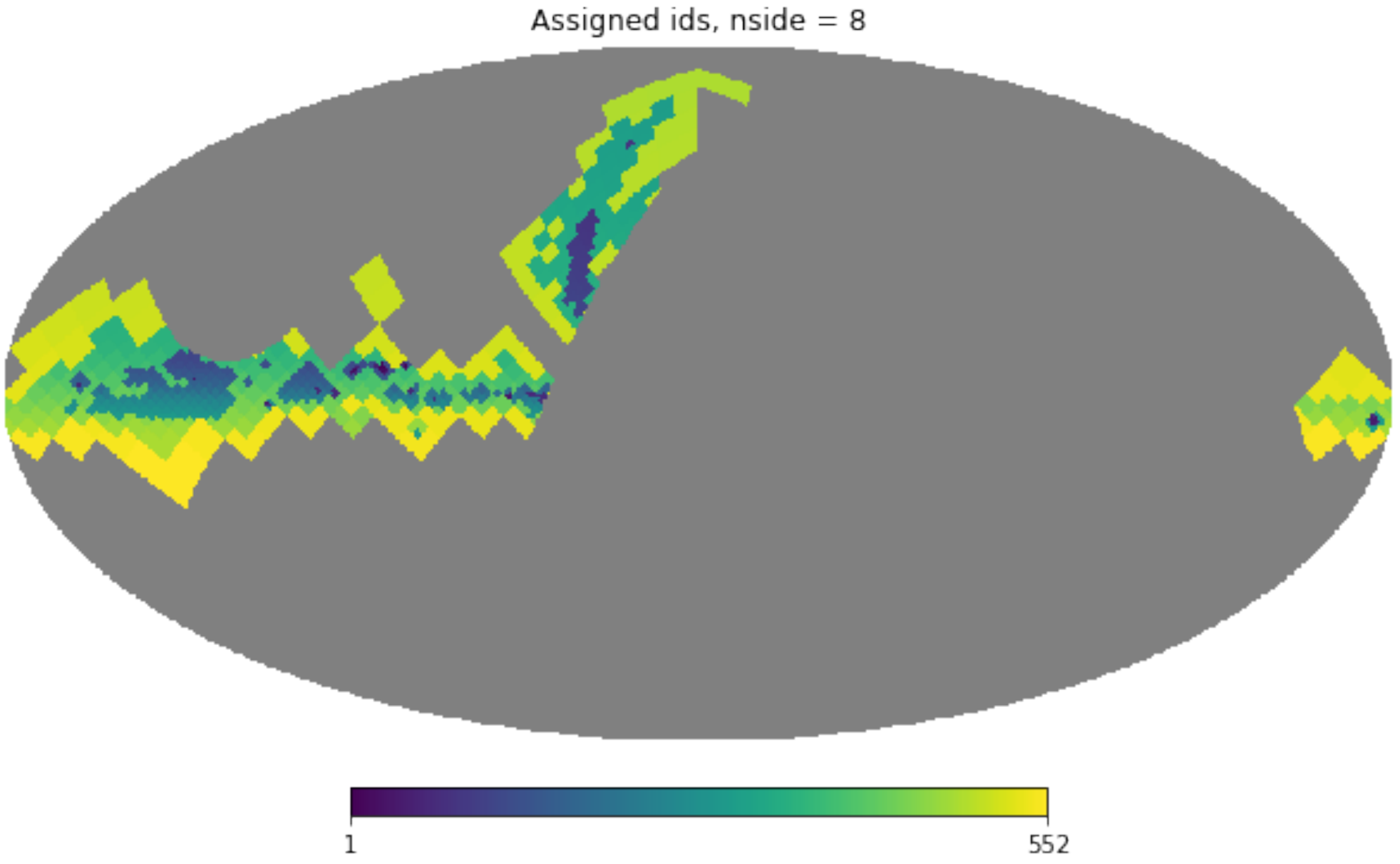

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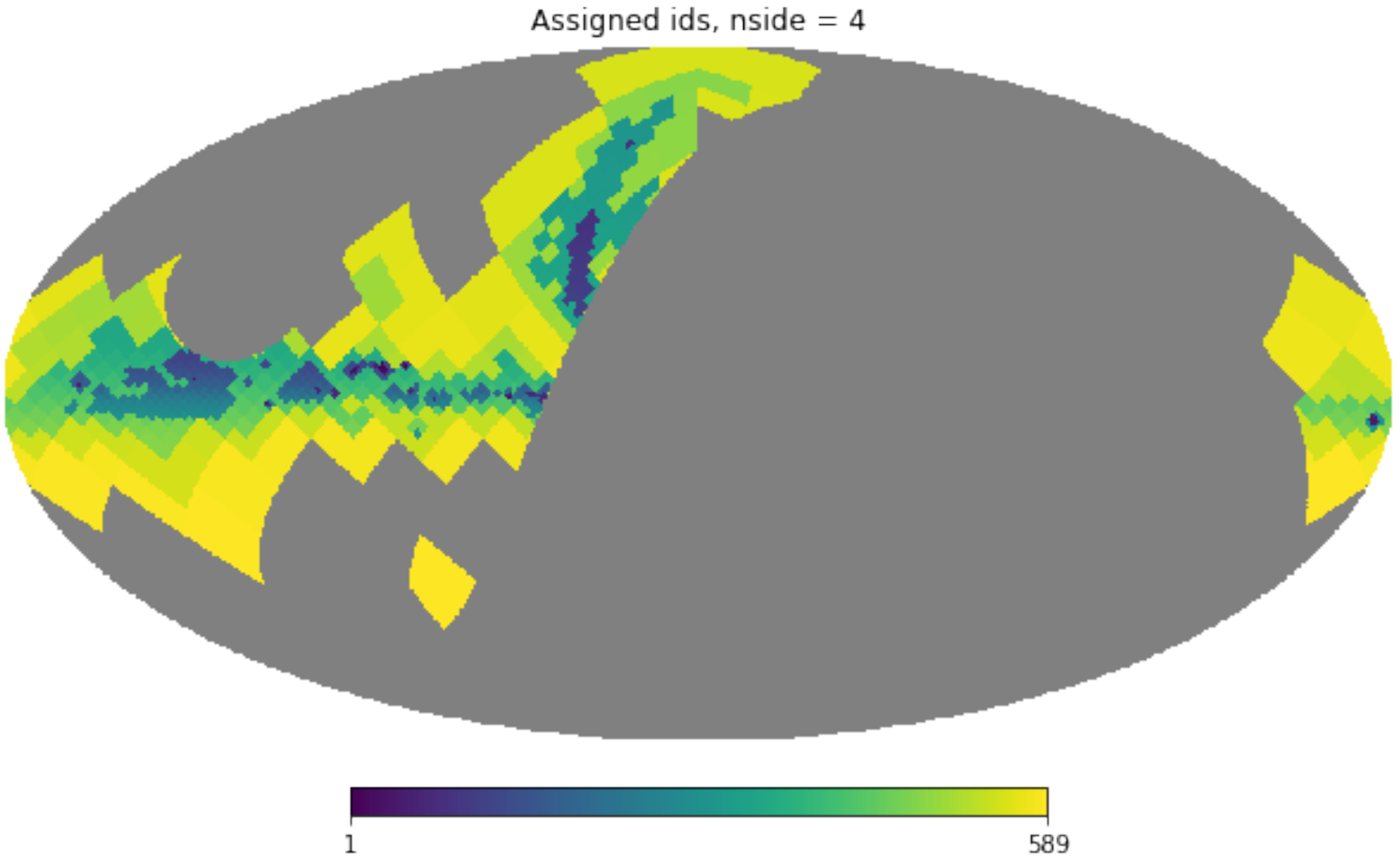

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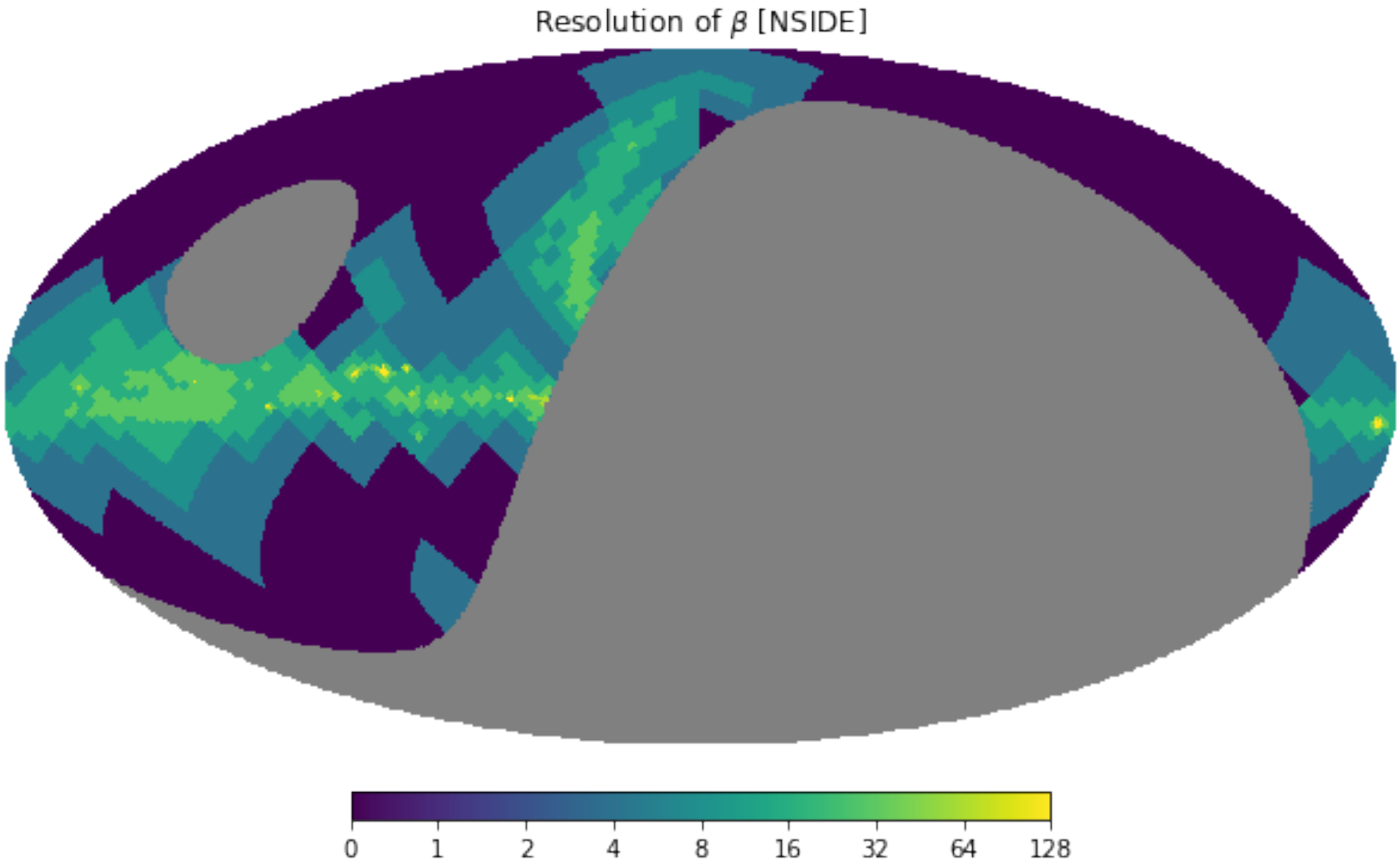
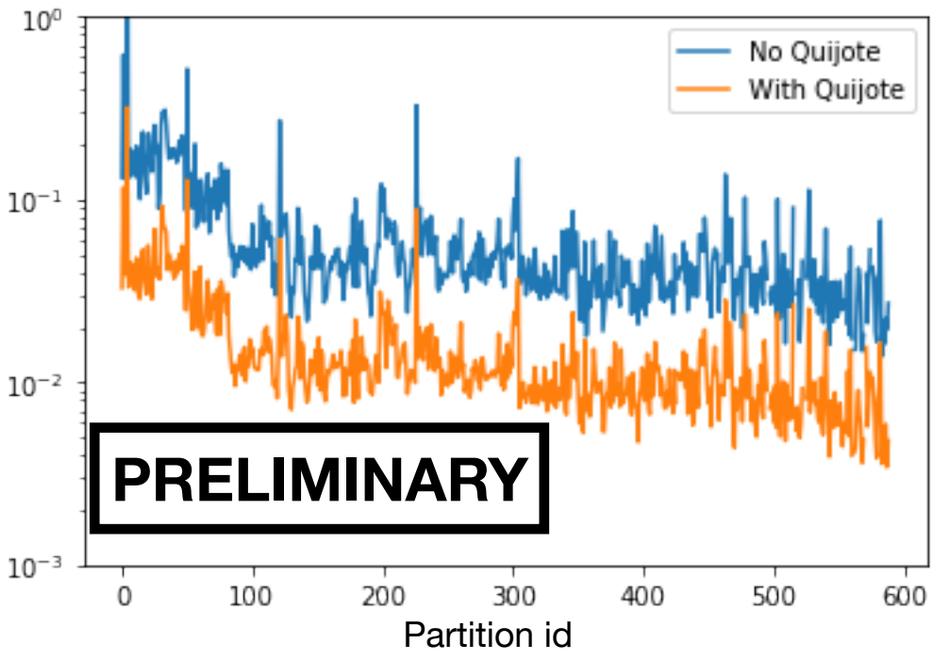
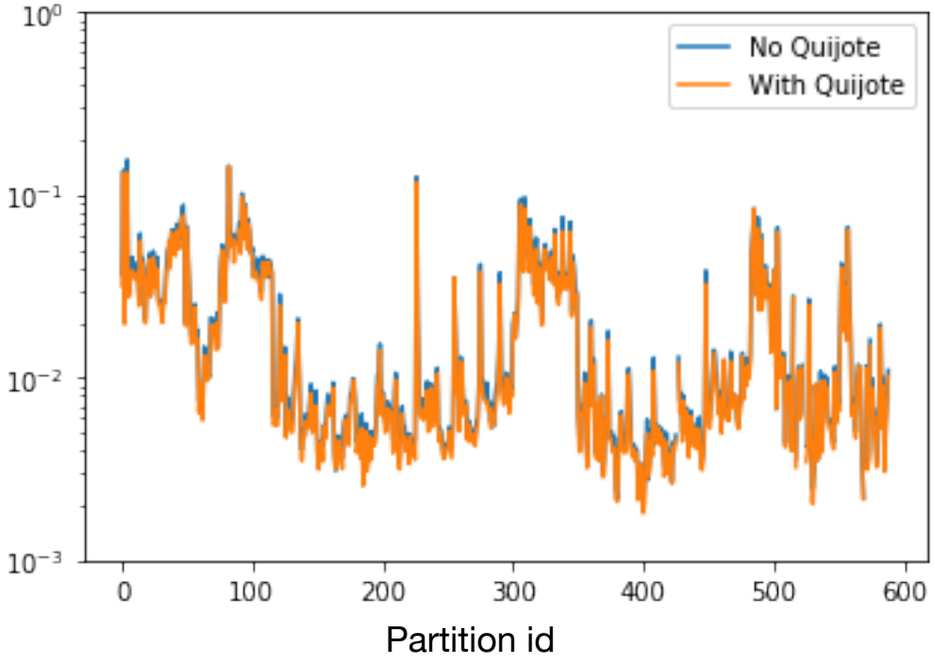


Application to simulations

Std of β_s over simulations

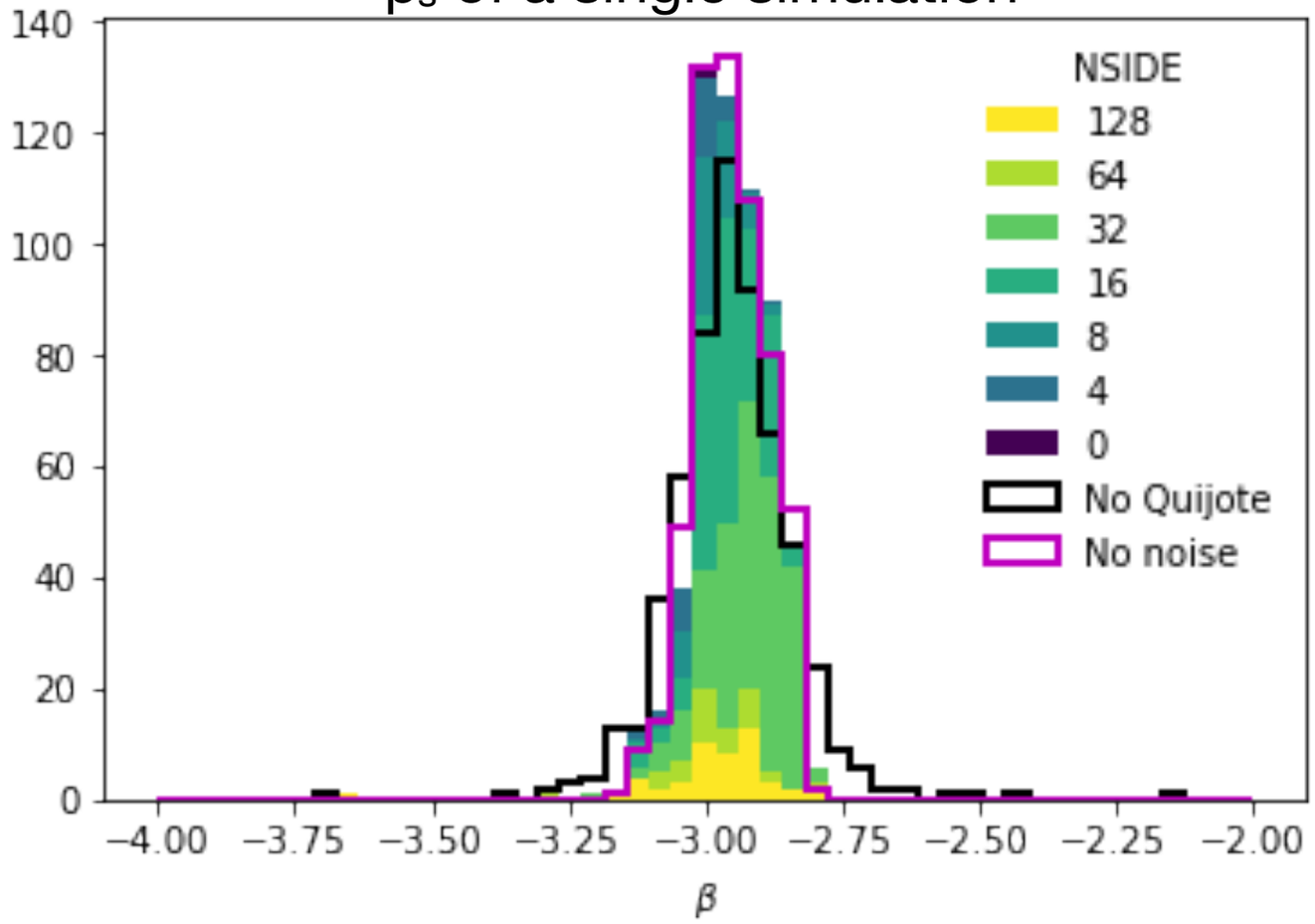


Std of β_d over simulations



- Quijote increases the sensitivity on β_s
  Large improvement relies on
  - Longer lever arm with 11 GHz
  - Realism of the covariance maps
  - Lack of correlated noise in simulations

β_s of a single simulation



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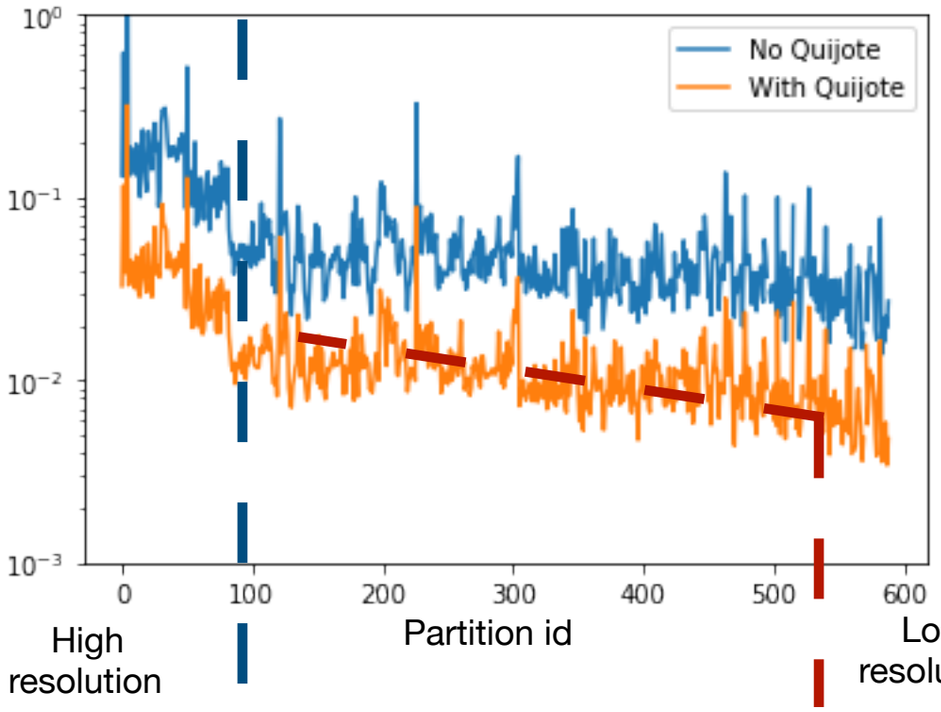
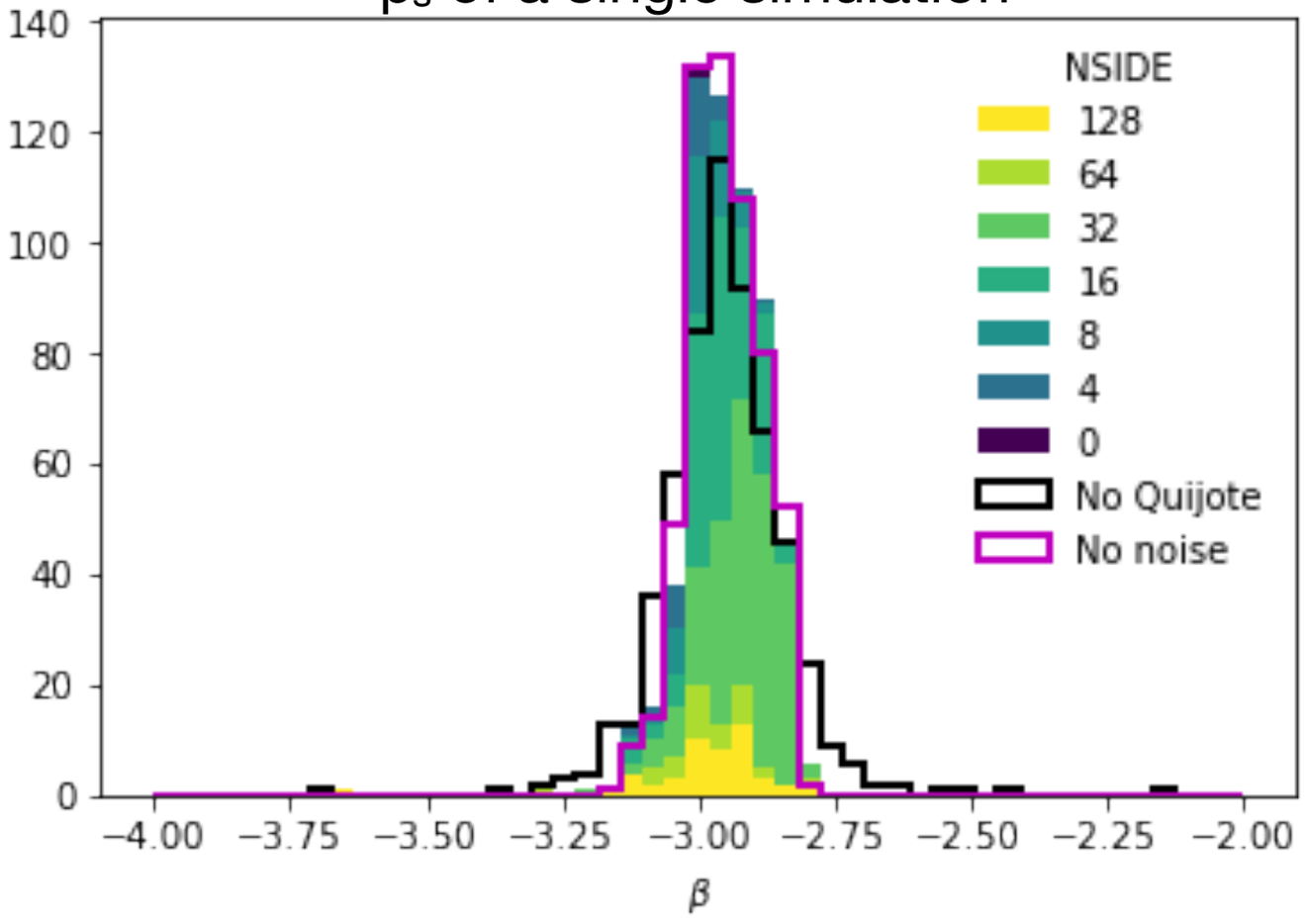


Decreasing, not uniform: attempt to account for correlated noise in the data

Large: point sourced missing in the simulations

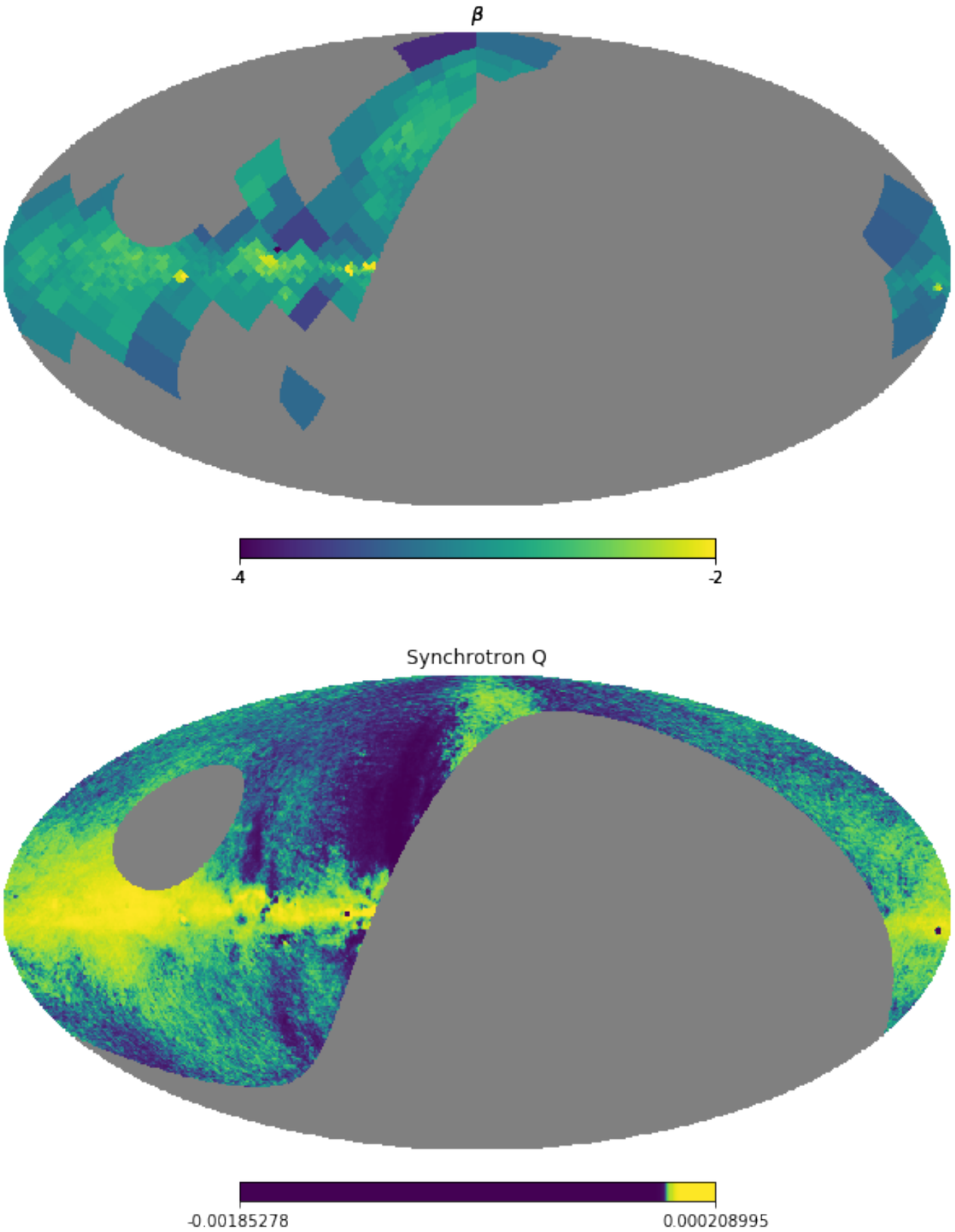
Good signal-to-noise in each patch,
Uncertainty not much smaller than the physical scatter

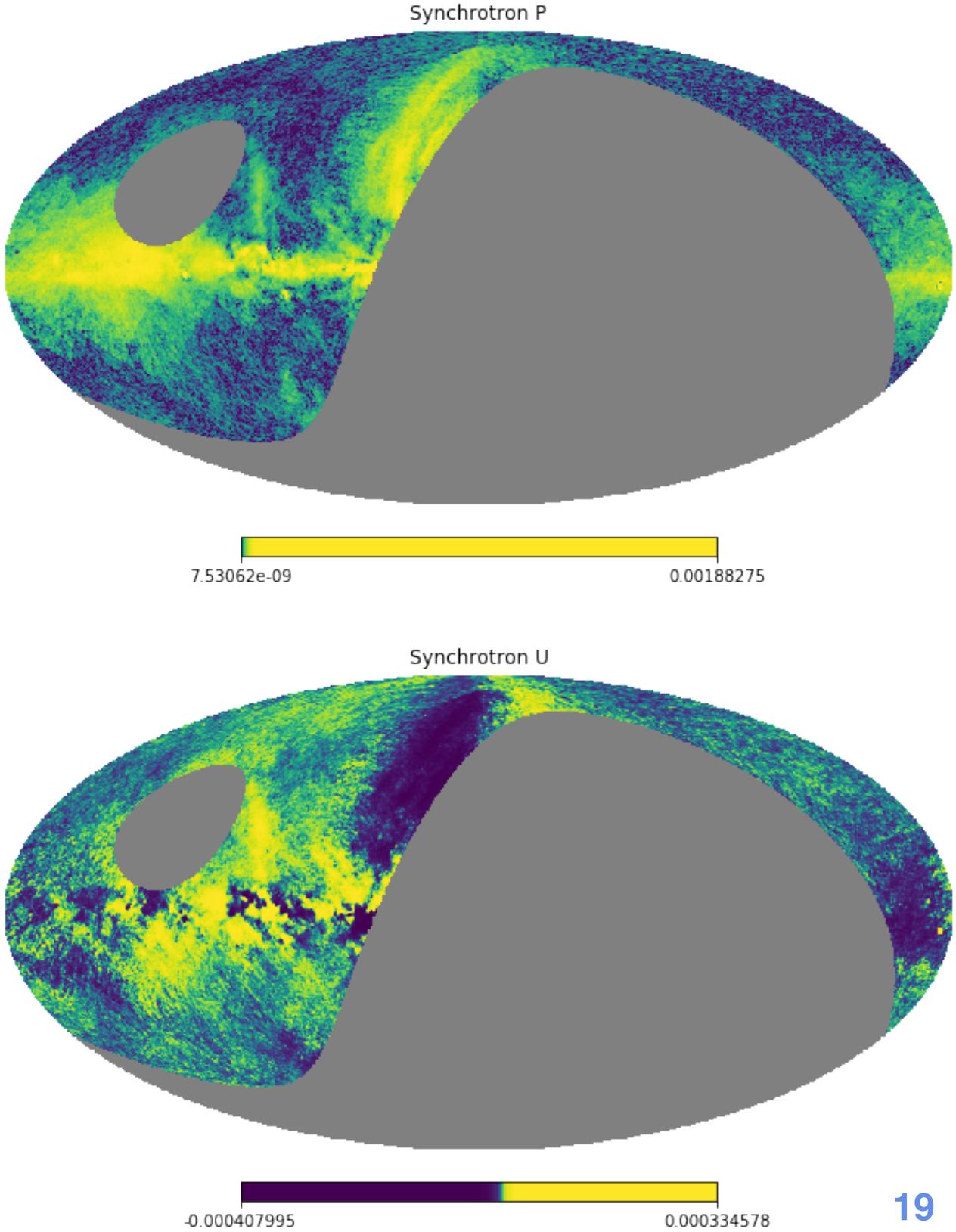
β_s of a single simulation



Component separation output

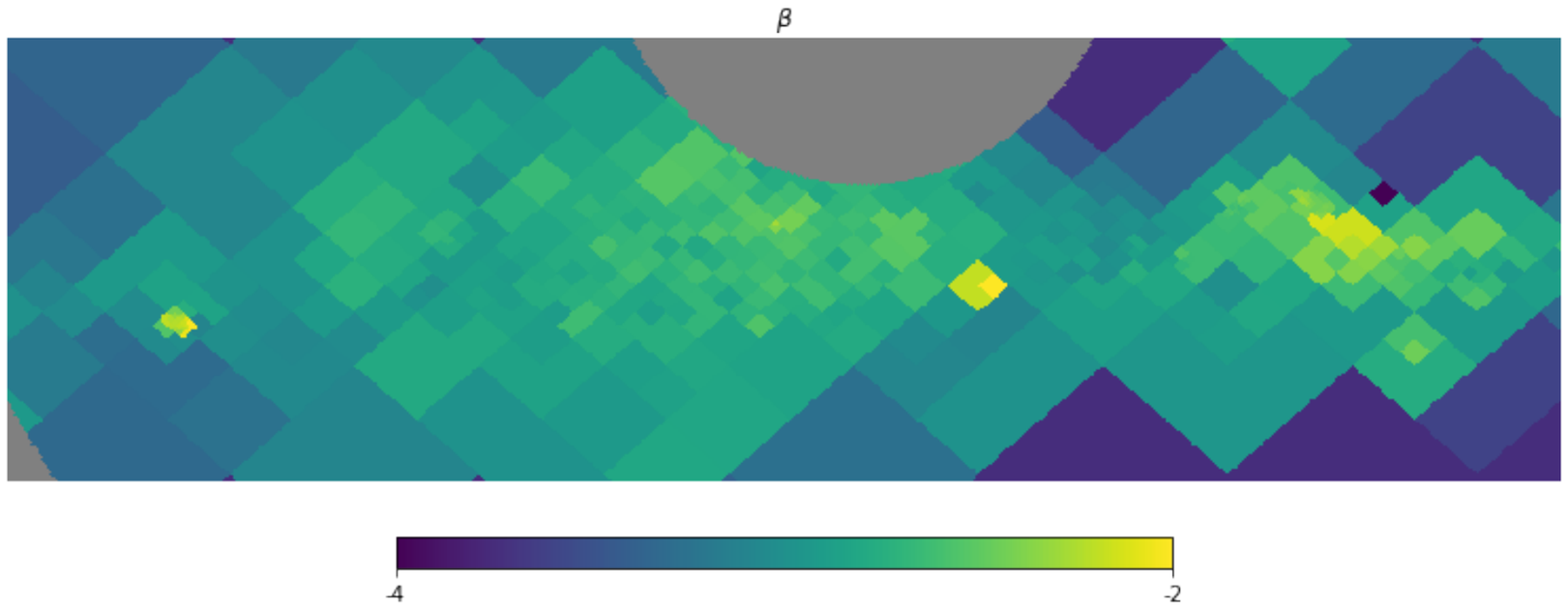
PRELIMINARY





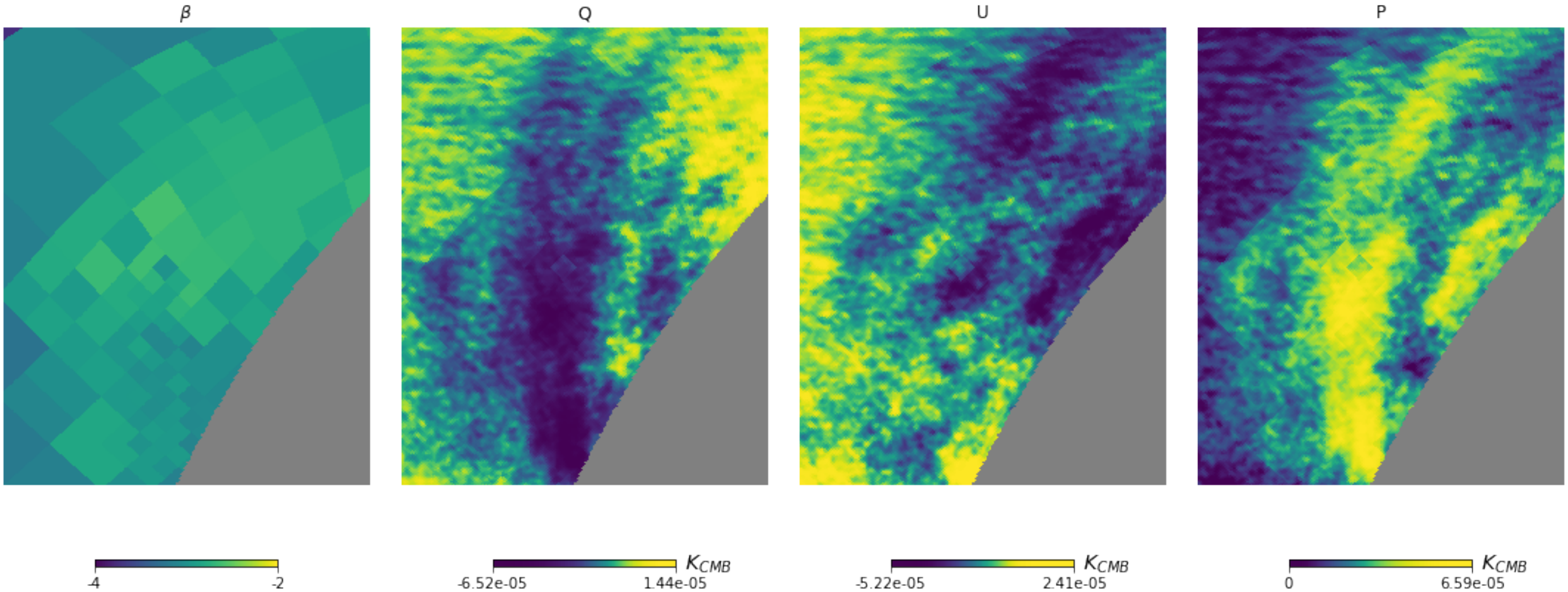
PRELIMINARY

Galactic Plane



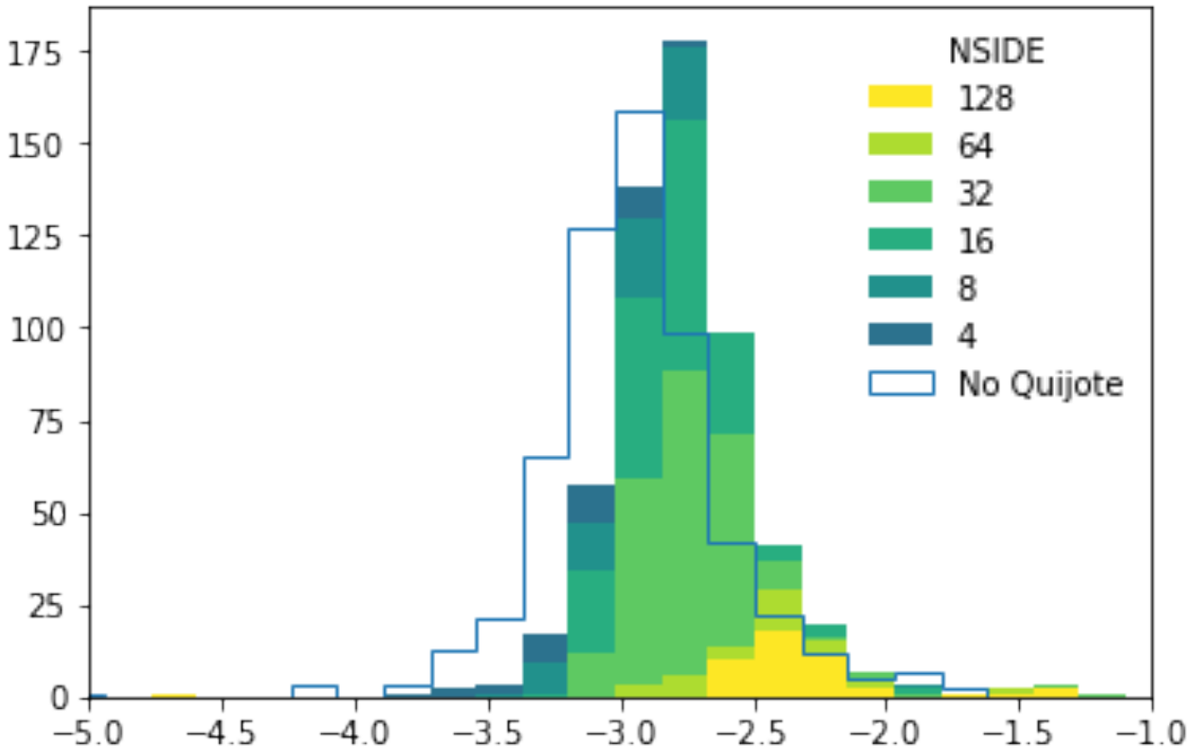
PRELIMINARY

North polar spur

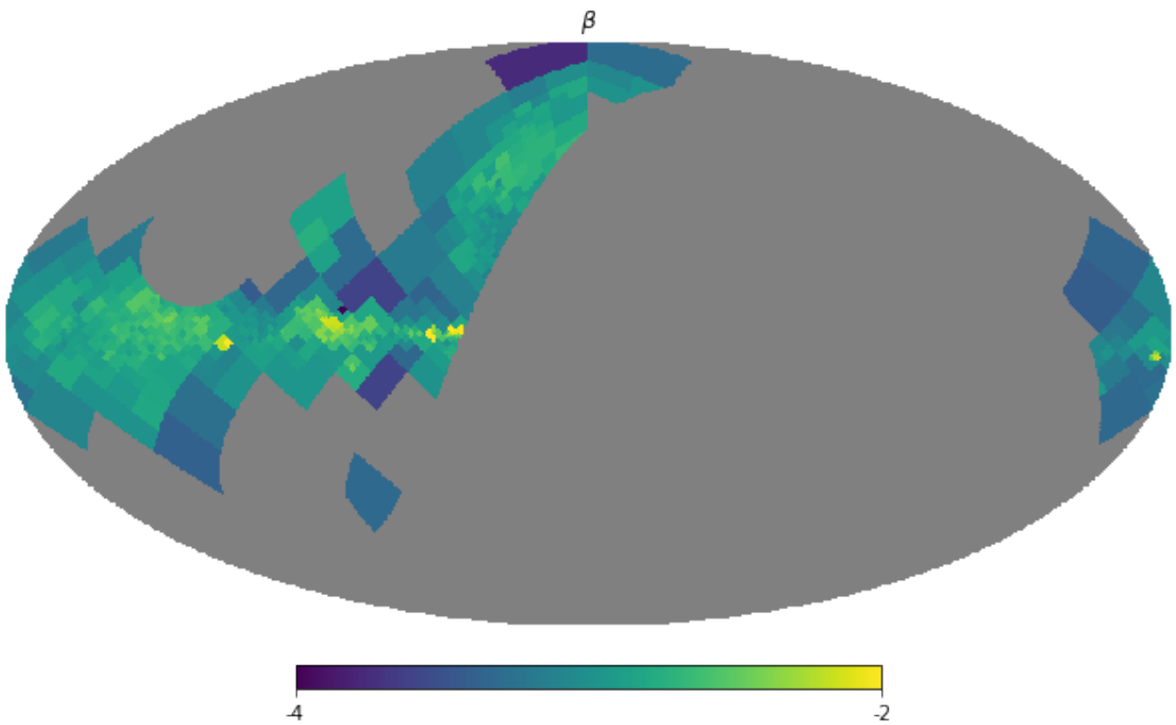


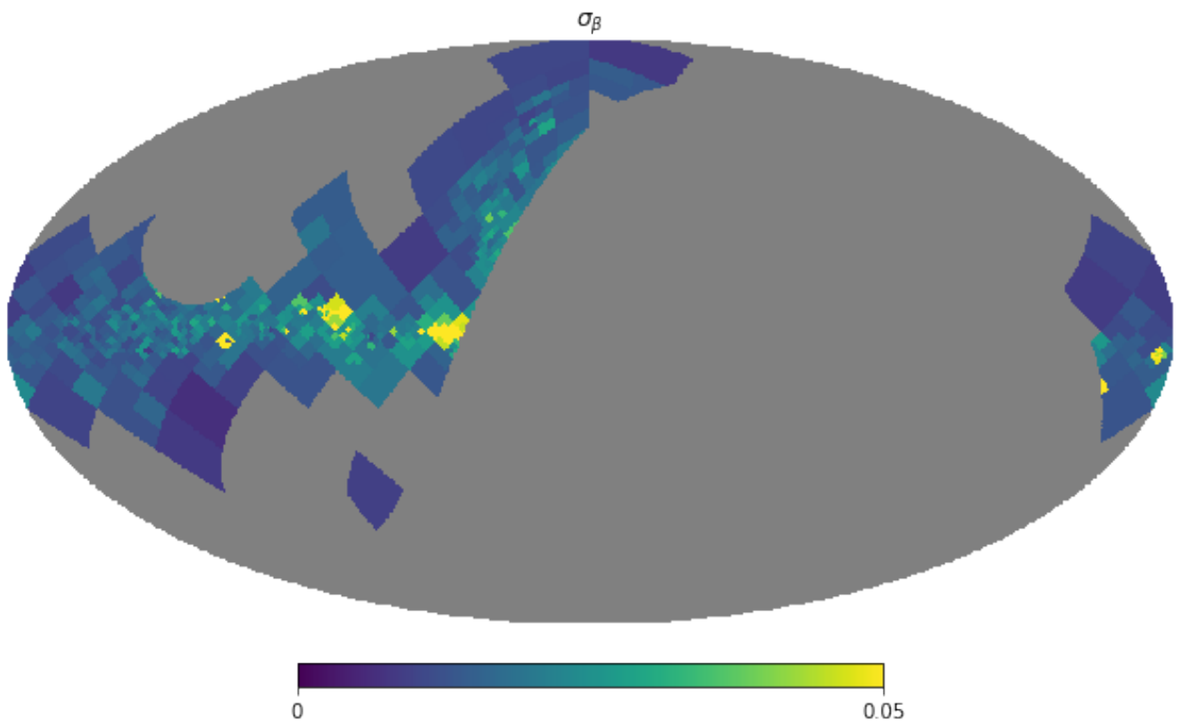
PRELIMINARY

Focusing on beta



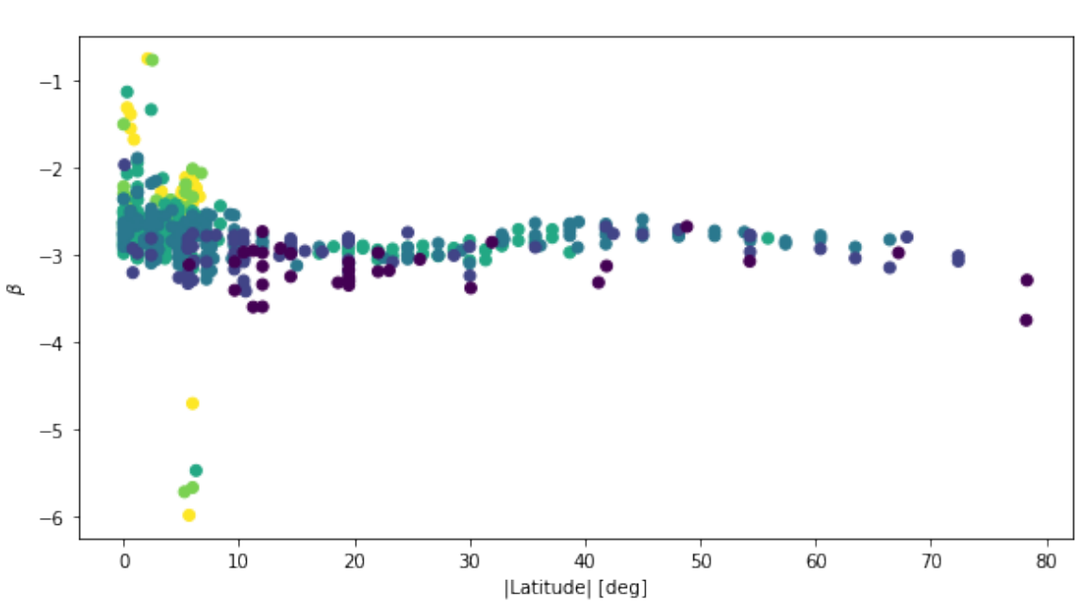
- Higher resolution pixels (i.e. lower latitude) have flatter emission law
- Notice that
  - lower resolution (i.e. darker colours) represents (exponentially) more pixels
- Shift in spectral indices has to be investigated further
- Sigma from white noise simulations

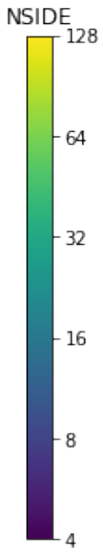




PRELIMINARY

Dependence on galactic latitude





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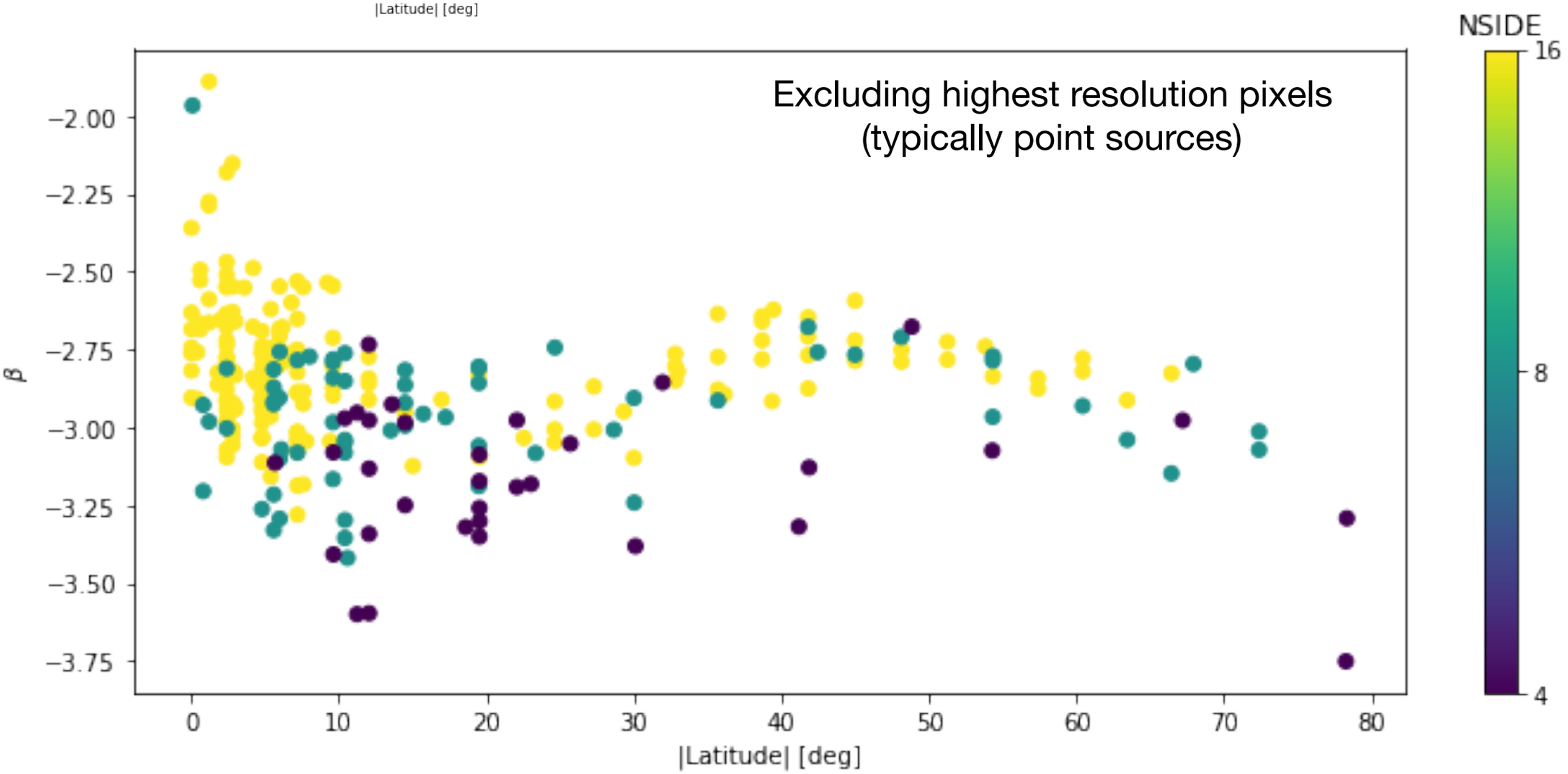
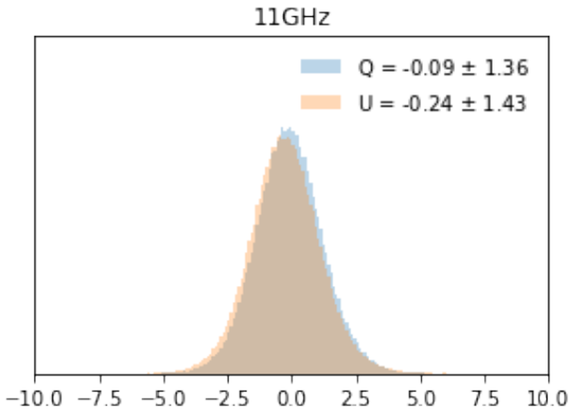
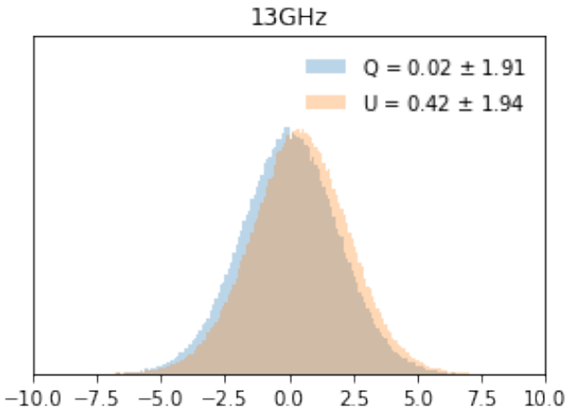
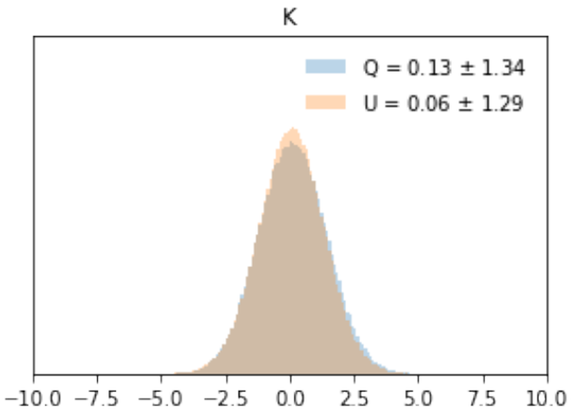


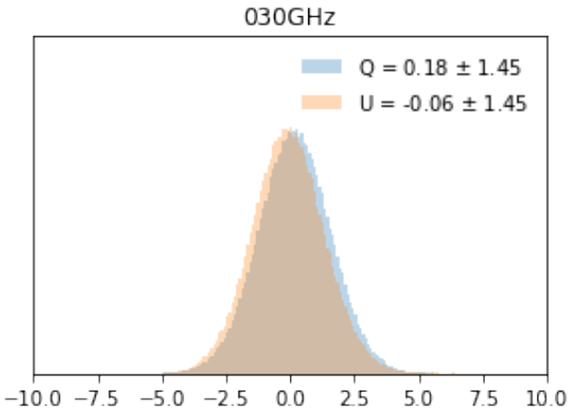
PRELIMINARY

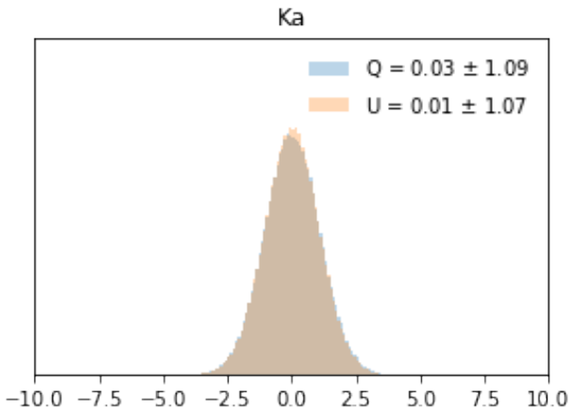
Goodness of fit: normalised residuals

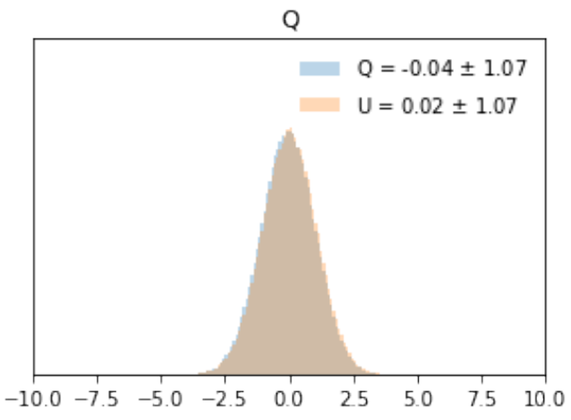


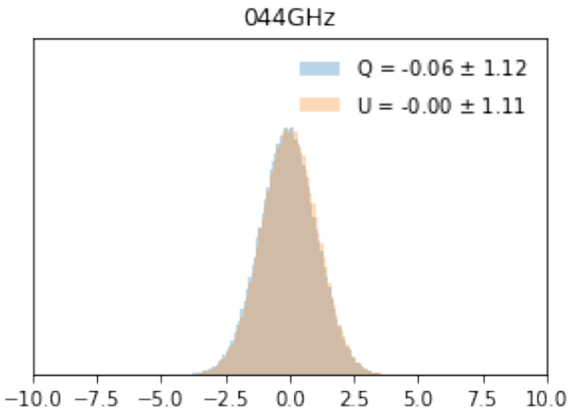


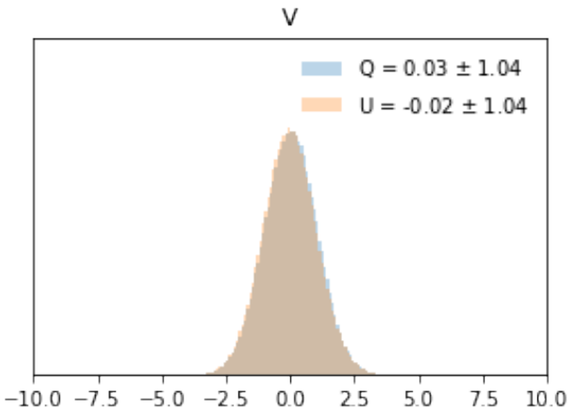


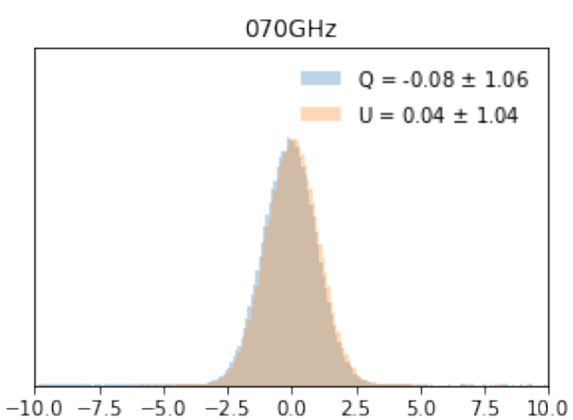


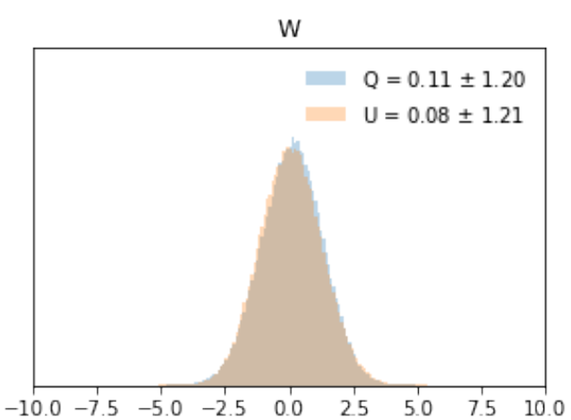


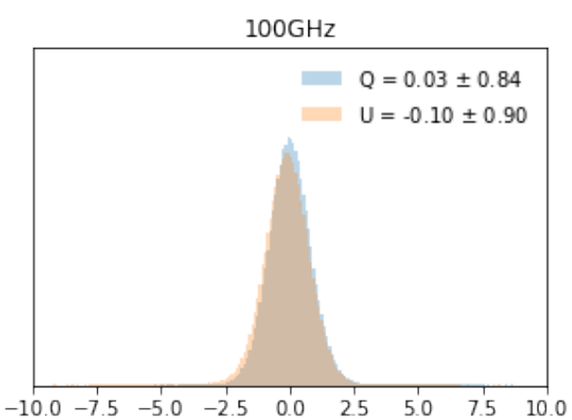


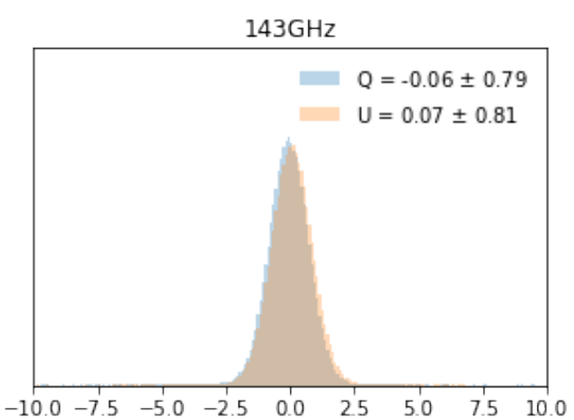


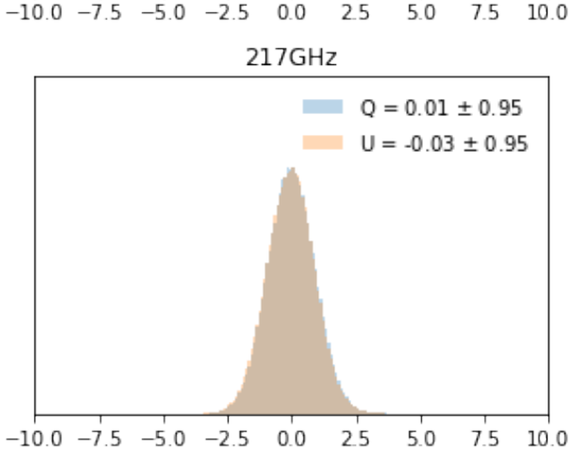


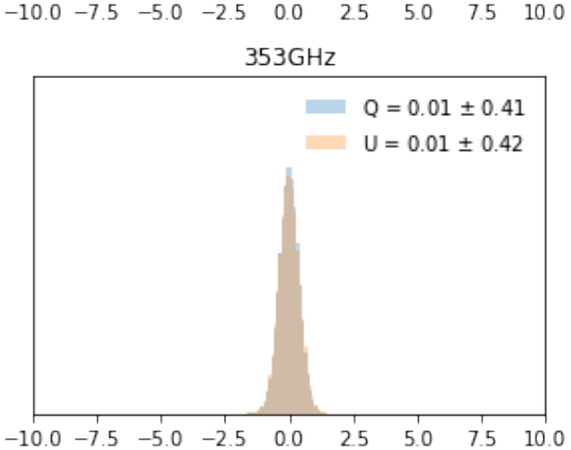








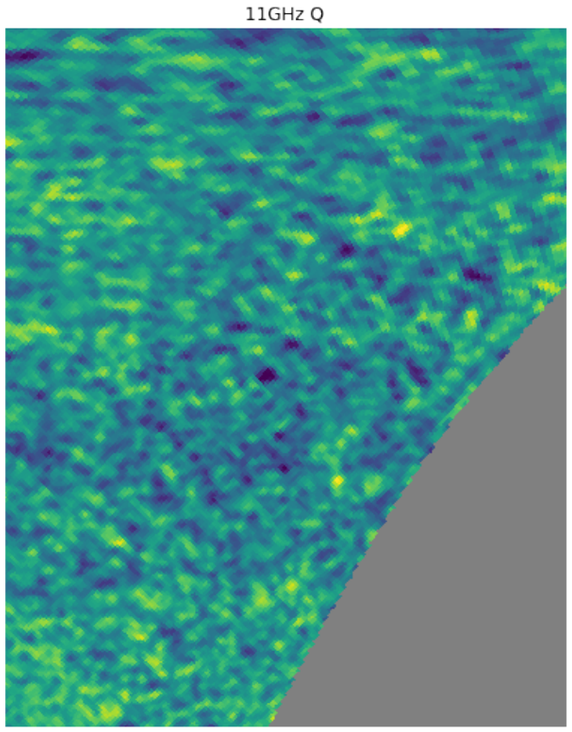


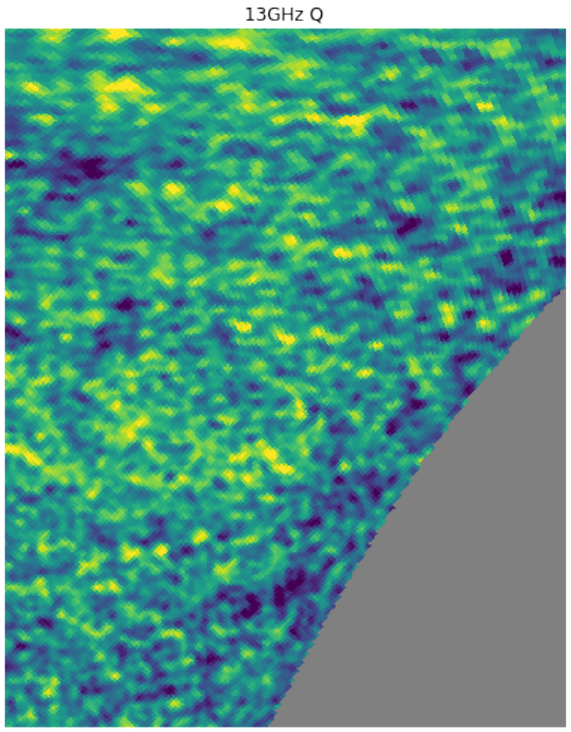


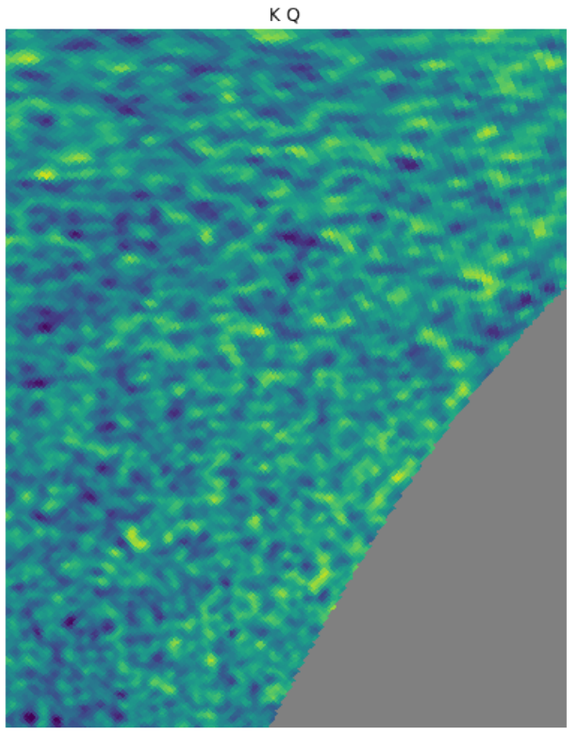
- Good fit overall (no masking was applied)
- 100 and 143 GHz determine CMB, 353 GHz determine dust
- Tension in the low frequencies. Possible interpretation
  - Noise model to be refined
  - Signal model too simple for the data

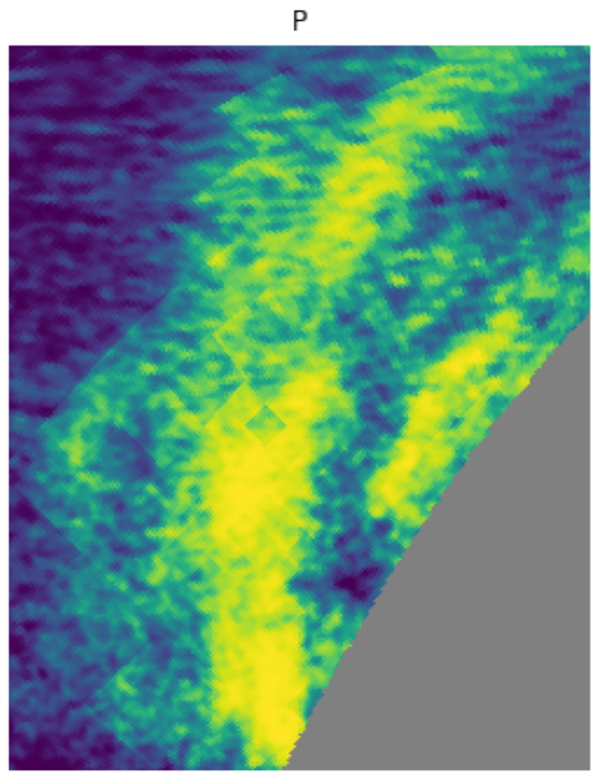
PRELIMINARY

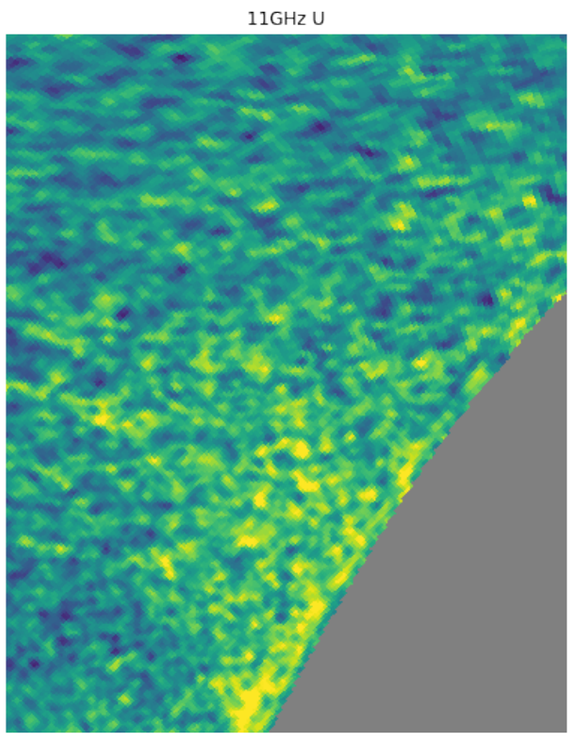
Spur normalised residuals

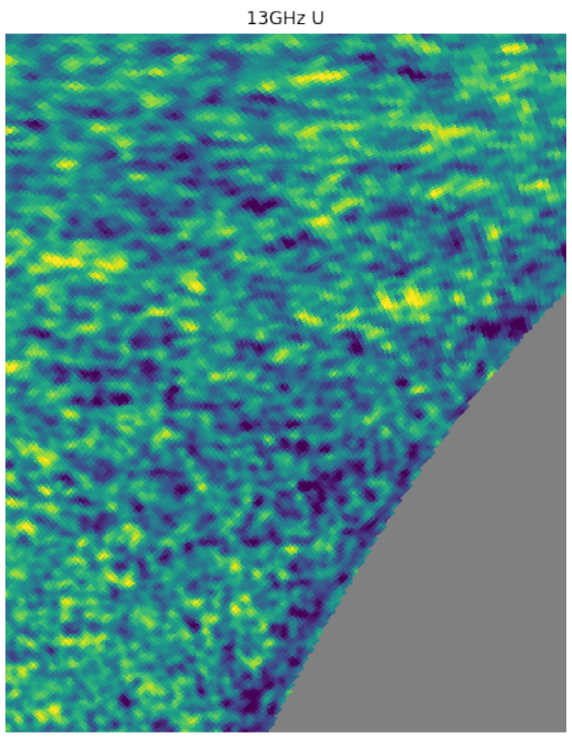


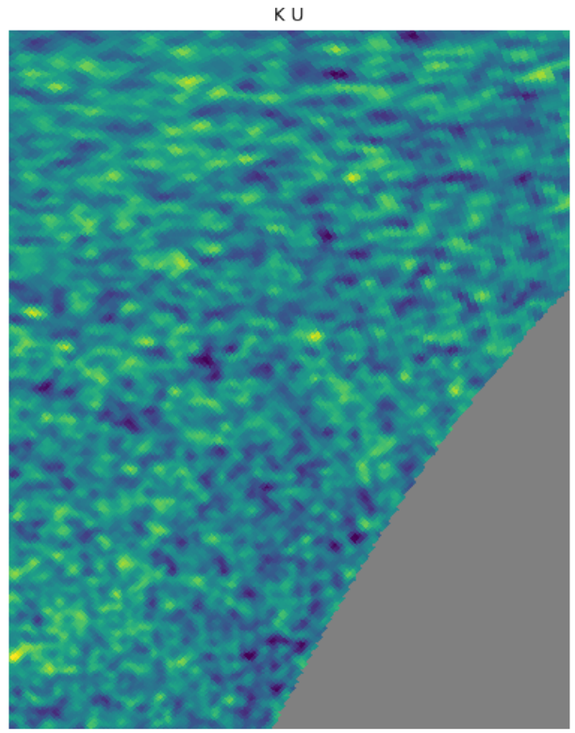












Ongoing work

Methodology

- From *“Trigger a new dof when a given level of information content is reached”* to *“Trigger a new dof when a given level of evidence for its necessity is reached”*
- More flexible geometry for the partition

See also:
J.Errard talk
J. Luke talk?

Quijote analysis

- Investigate the tension at low frequency
- Include more complex noise characterisation

  ➡ Get more information on beta on high galactic latitudes
- Study in detail the regions where there is a tension with the best
- Temperature data

Thank you