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PR4 foreground maps with GNILC

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Disclaimer: All the work shown here is preliminary results!

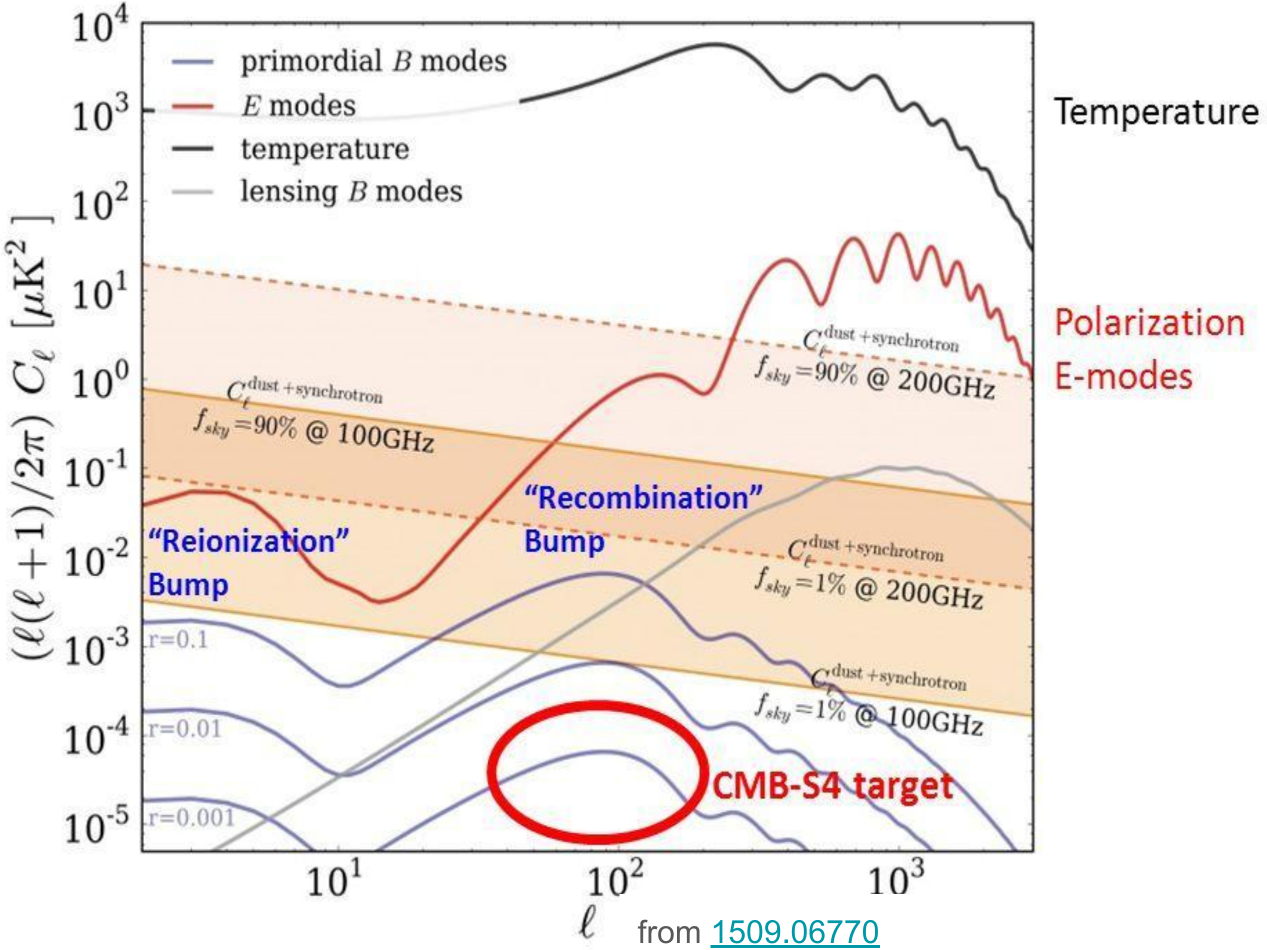
Outline

1. Why should we care about foregrounds?
2. State of the art
3. Strategy to improve foreground maps: extended-GNILC
4. Pipeline and results:
   a. Dust intensity
   b. Polarized foregrounds
5. Future perspectives

The importance of foreground modeling

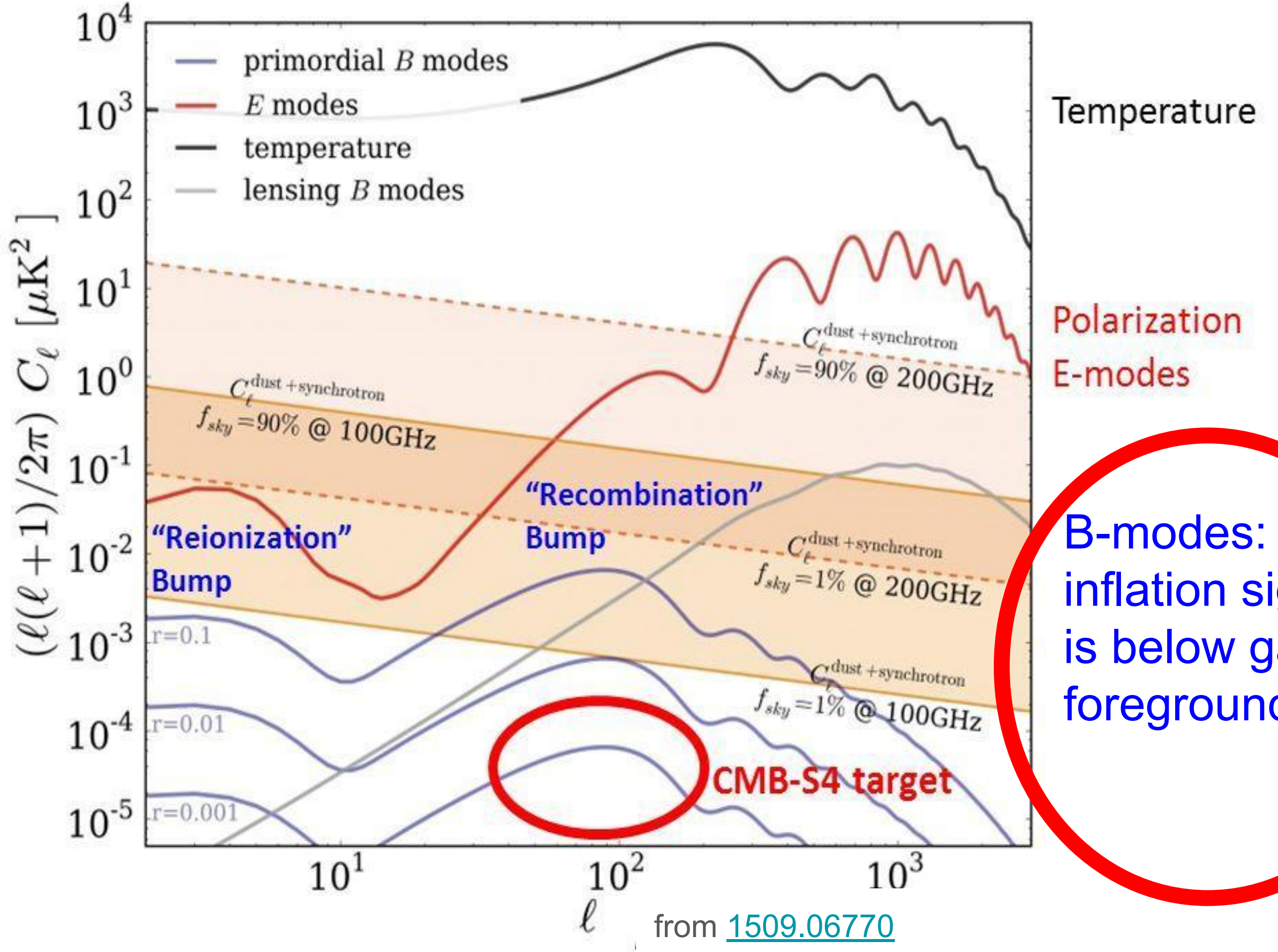
Observations in our Galaxy, which has a bright emission

Polarized dust and synchrotron → B mode polarization measurement complicated



from [1509.06770]

The importance of foreground modeling



from 1509.06770

B-modes: inflation signal is below galactic foregrounds

Focus of this talk:

1) Dust intensity

2) Polarized synchrotron + dust

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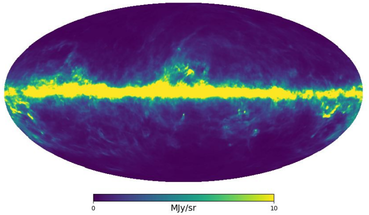
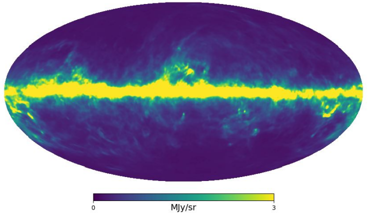
State of the art of foreground maps

- Official dust intensity (polarized foregrounds) Planck products:
  - Commander maps from Planck 2015, Planck 2018
  - SMICA maps from Planck 2018
  - GNILC maps from Planck 2015, Planck 2018

Dust intensity Commander map at 545GHz



Dust intensity GNILC map at 353GHz



What can be improved?

- Cosmoglobe (Commander) polarized synchrotron amplitude 2 degree resolution
- GNILC PR2 map resolution for polarized dust is low (= 80 arcmin)

⇒ We want high resolution maps to better characterize the foreground emissions!

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Our strategy to improve foreground maps

Goal: Obtain higher resolution foreground maps with an extended GNILC pipeline

GNILC method:

- GNILC goal: reconstruct the diffuse emission of a complex component originating from correlated emission sources
- Basic idea: compute a signal-to-noise ratio to conduct a PCA using a needlet (spherical wavelet) decomposition
- Why a needlet approach? To take into account weights in both pixel and harmonic space
- Use of xGNILC: extended GNILC implementation in Python, by Shamik Ghosh (postdoc at LBL)

extended-GNILC:

- Motivation for this pipeline: get both high-resolution and low-noise maps
- Use a generalized least squares (GLS) estimation for the low SNR regions so that the resolution of the map is preserved:
  How? Keep a direction set by a prior, the mixing matrix of the component of interest
  - Dust: T_d = 19.6K, β_d = 1.6
  - Synchrotron: β_s = -3.1

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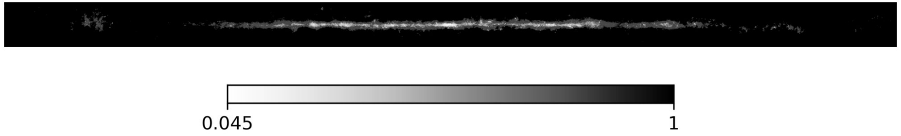
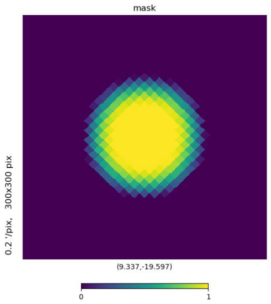
Pipeline: Dust intensity case

1) Signal maps:
    a) Planck npipe: 217, 353, 545, 857 GHz
    b) IRAS IRIS: 100 μm

Preprocessing:

- Subtract from frequency maps:
    - Wiener filtered CMB for 217 GHz and 353 GHz
    - Solar dipole & quadrupole
    - Zodiacal light
- Mask the galactic plane + point sources





Use of PCCS2 & PCCS2E catalogues

Maps preprocessing: Wiener filtered CMB map

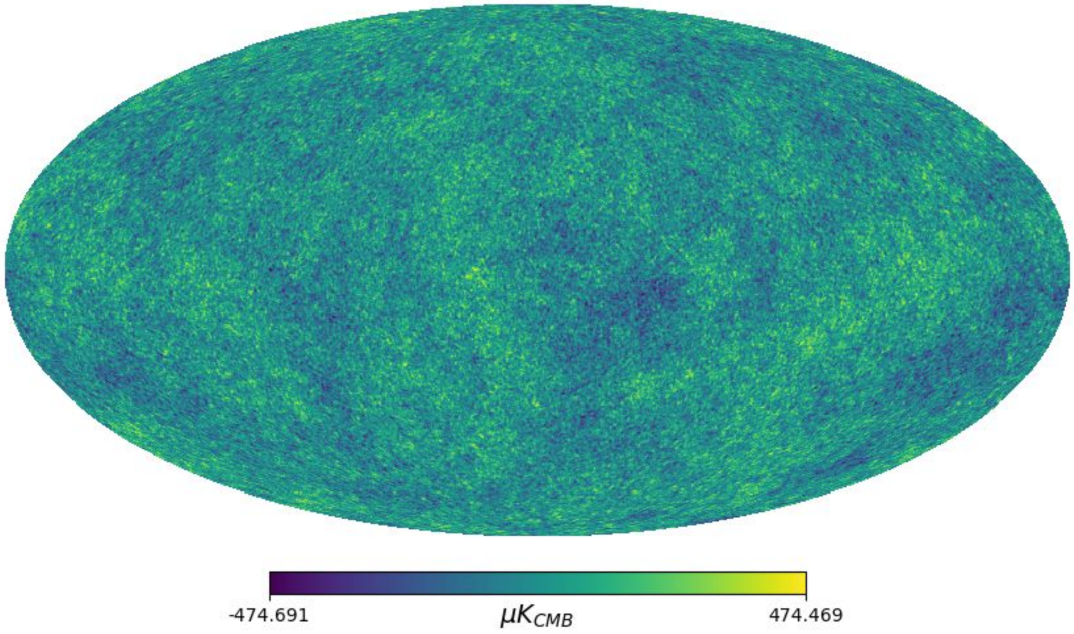
Wiener filter:
W = C / [C + N]
where C is the CMB model spectrum,
[C+N] the CMB+noise spectrum

Why are we subtracting a Wiener filtered CMB map from frequency maps?

CMB temperature fluctuations are not negligible at 217 and 353 GHz!

Why not include the CMB in the nuisance estimation?
Need to use other frequency channels, where CMB is dominant and where other nuisance signals need to be taken into consideration, e.g. tSZ

Wiener filtered CMB temperature



Maps preprocessing: Masks

2 masks:

a) Galactic plane mask

b) Point source masking

Pipeline: Dust intensity case

1) Signal maps:
   a) Planck npipe: 217, 353, 545, 857GHz
   b) IRAS IRIS: 100μm
2) Nuisance maps:
   a) Residual CMB
   b) Instrumental noise
   c) CIB

$$x = A_{gal}s_{gal} + s_{cib} + s_{cmbres} + n$$

Nuisance = all the other components than the component of interest

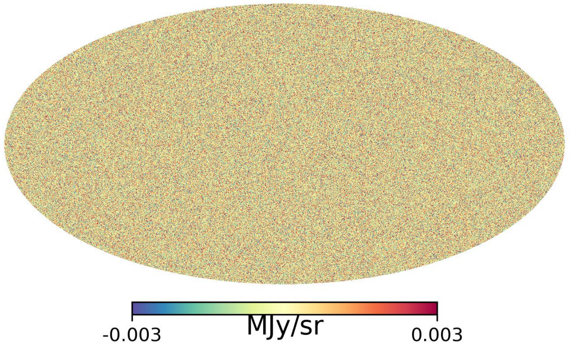
Maps preprocessing: Nuisance maps

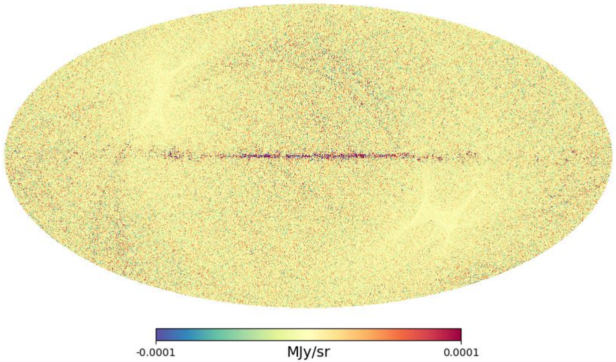
Three contributions to the nuisance:

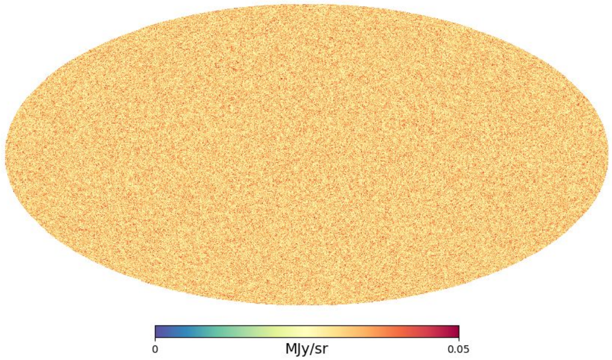
a) Residual CMB at 217 GHz

b) Instrumental noise at 217 GHz

c) CIB at 217GHz







Cl - wiener filtered Cl, with Cls from Planck best fit

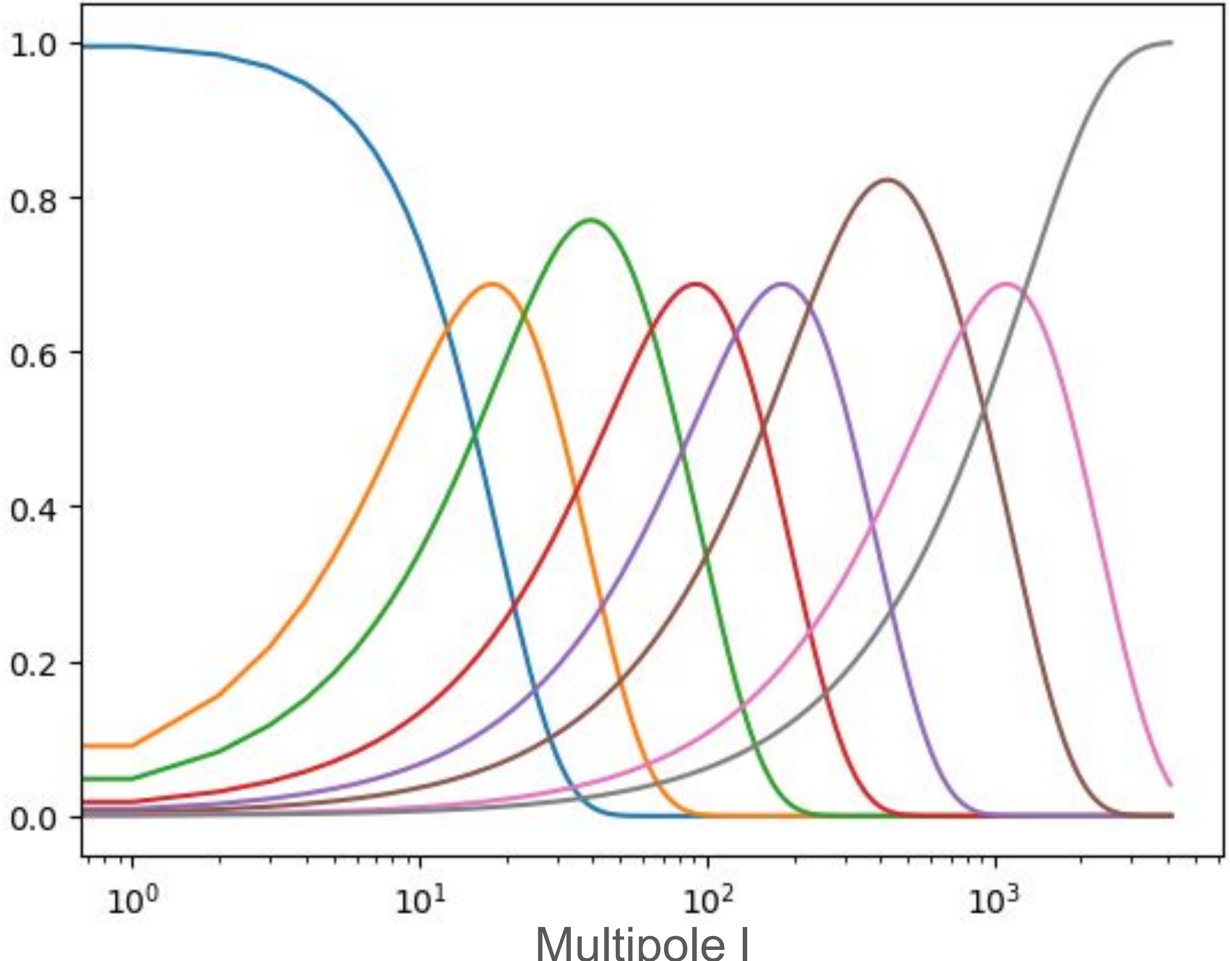
- (npipeA - npipeB)/2 for npipe maps
- Estimate white noise level for IRIS map

Simulated with the Planck Sky Model

Pipeline: Dust intensity case

1) Signal maps:
   a) Planck npipe: 217, 353, 545, 857GHz
   b) IRAS IRIS: 100μm
2) Nuisance maps:
   a) Residual CMB
   b) Instrumental noise
   c) CIB
3) Put all these maps in MJy/sr
4) Run GNILC with 8 needlet bands

Needlet bands

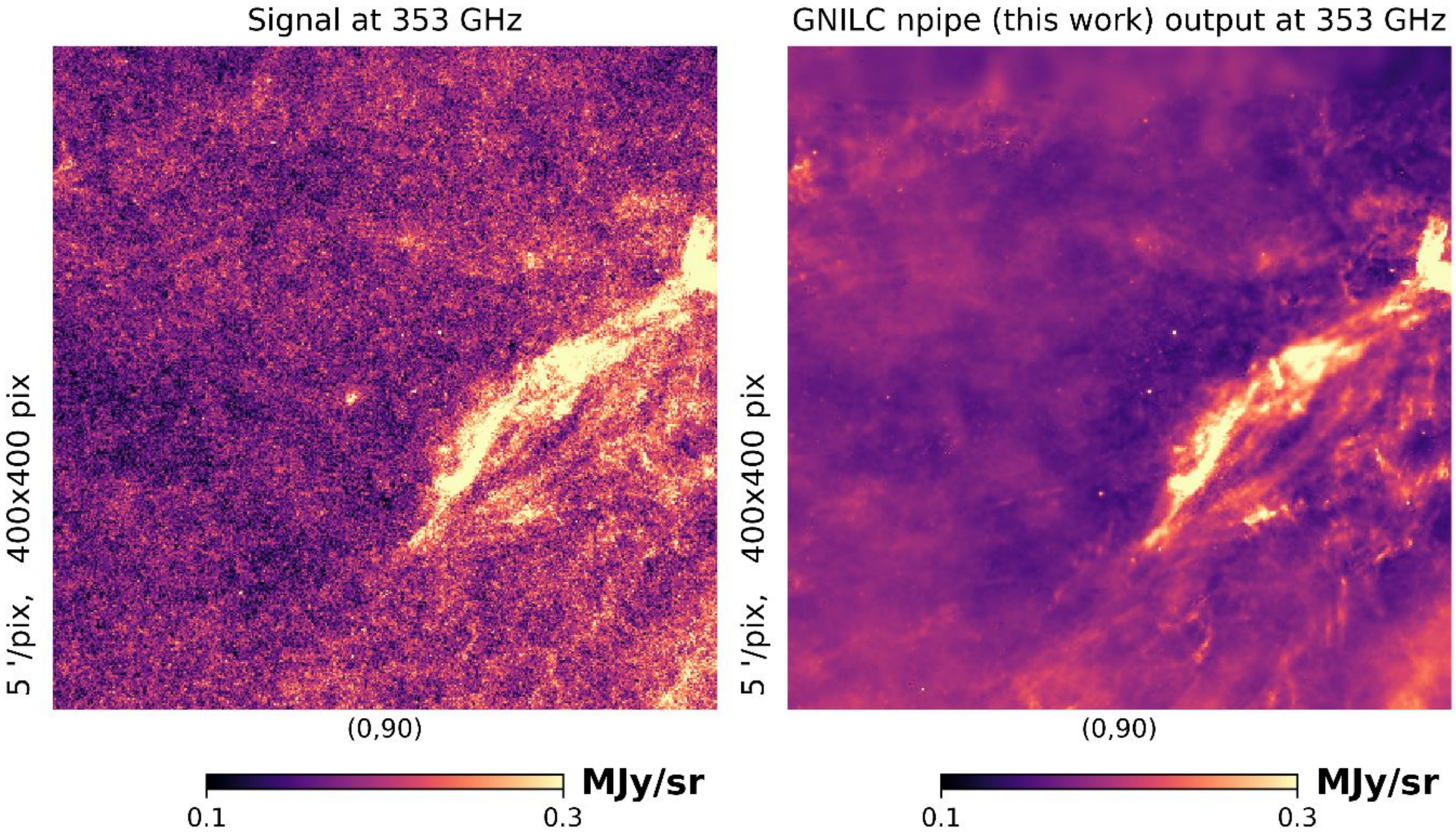


8 needlet bands constructed such that the power of the map is conserved through needlet transforms (SHT + band filtering)

Pipeline: Dust intensity case

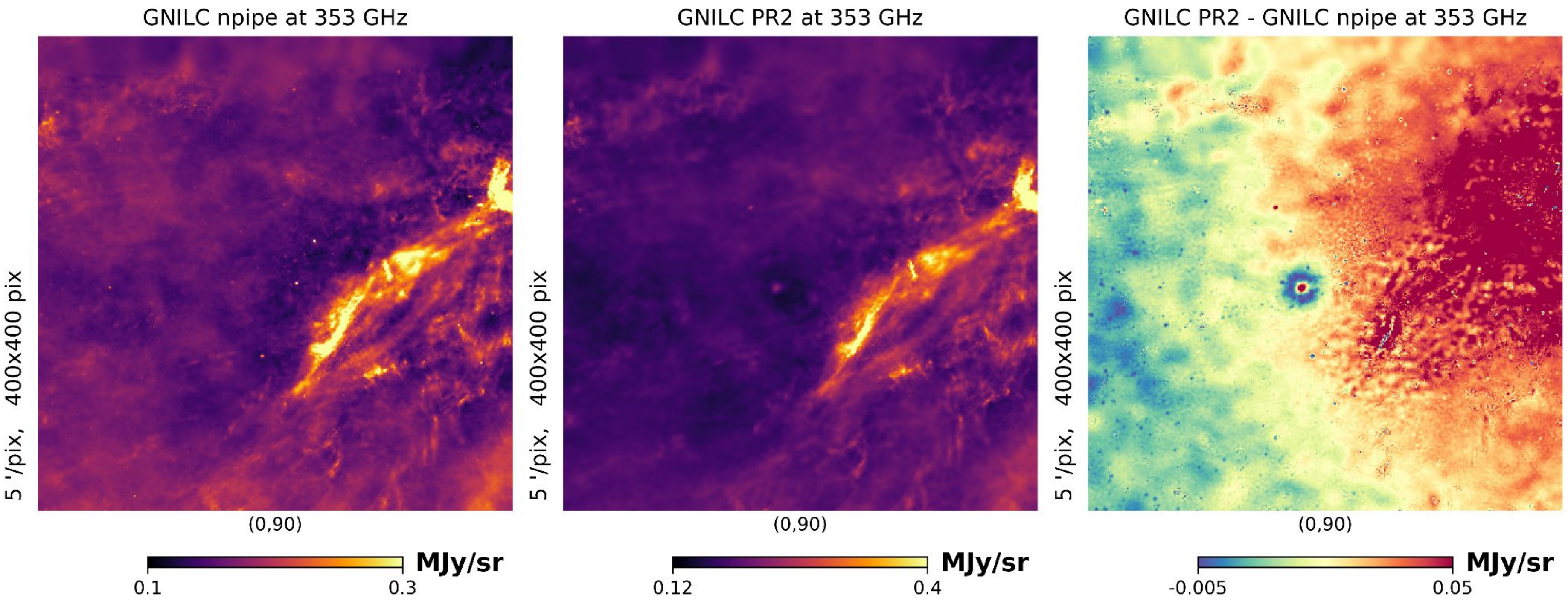
1) Signal maps:
    a) Planck npipe: 217, 353, 545, 857GHz
    b) IRAS IRIS: 100μm
2) Nuisance maps:
    a) Residual CMB
    b) Instrumental noise
    c) CIB
3) Put all these maps in MJy/sr
4) Run GNILC with 8 needlet bands
5) Recombine needlets into intensity maps

Results: Signal maps VS GNILC dust maps



Results: Comparison with GNILC PR2 maps

→ Rescaled npipe maps to match zero level of PR2 maps



Difference between GNILC PR2 vs GNILC PR4

	GNILC PR2 (1605.09387)	GNILC PR4 (this work)
Maps	PR2 HFI 100−857 GHz + IRIS 100µm	PR4 HFI 217−857 GHz + IRIS 100µm
Choice of needlet bands	[300, 120, 60, 45, 30, 15, 10, 5]’	[600,300,120,60,30,10, 5]’

→ These differences in the preprocessing are leading to differences in the output!
→We do not know as yet what is the contribution of each difference in the input to the difference in the output.

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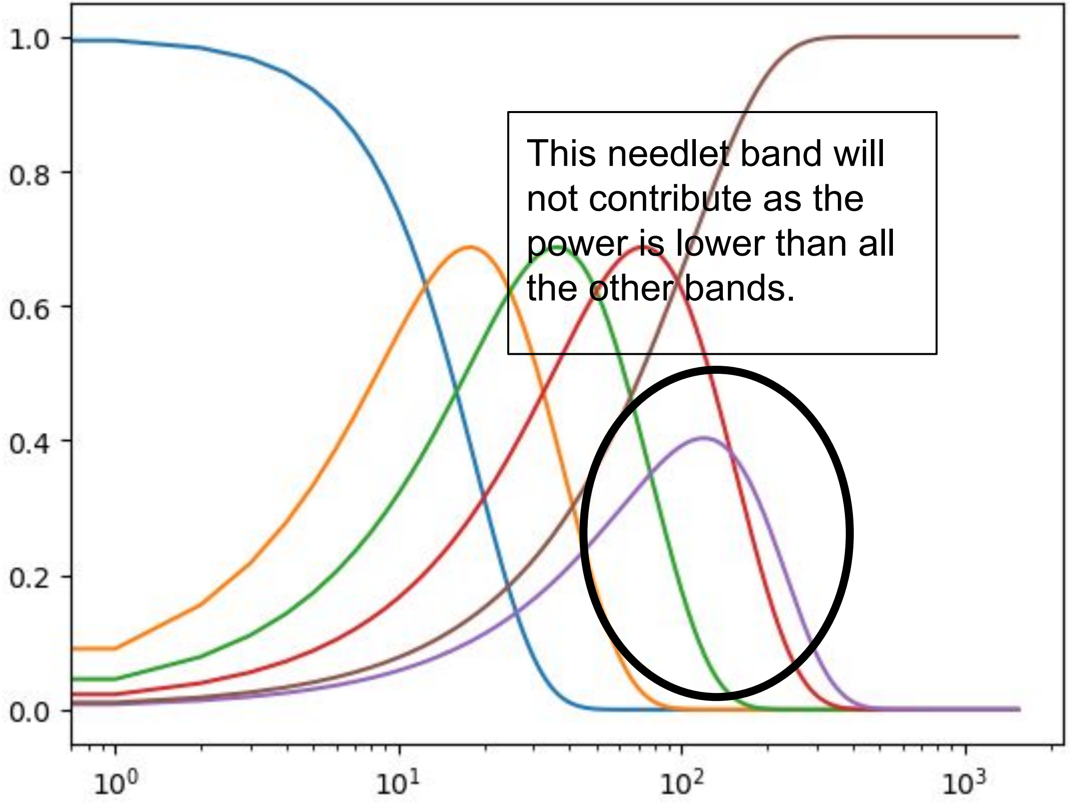
Pipeline: Polarized sky case

differences with the dust intensity case

1) Signal maps: WMAP all channels + Planck LFI+HFI channels up to 353GHz
2) Nuisance maps:
   a) Residual CMB
   b) Instrumental noise
3) Put all these maps to 1 degree resolution for now and in MJy/sr
4) Run GNILC with 5 needlet bands
5) Recombine needlets into polarized galactic signal E, B maps

Needlet bands

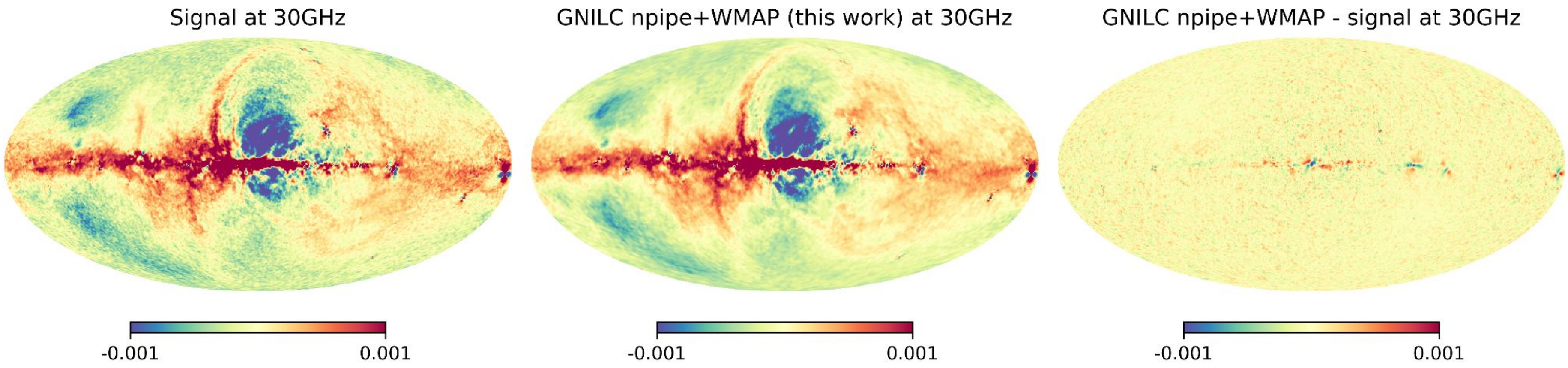


Multipole l

5 needlet bands constructed such that the power of the map is conserved through needlet transforms (SHT + band filtering)

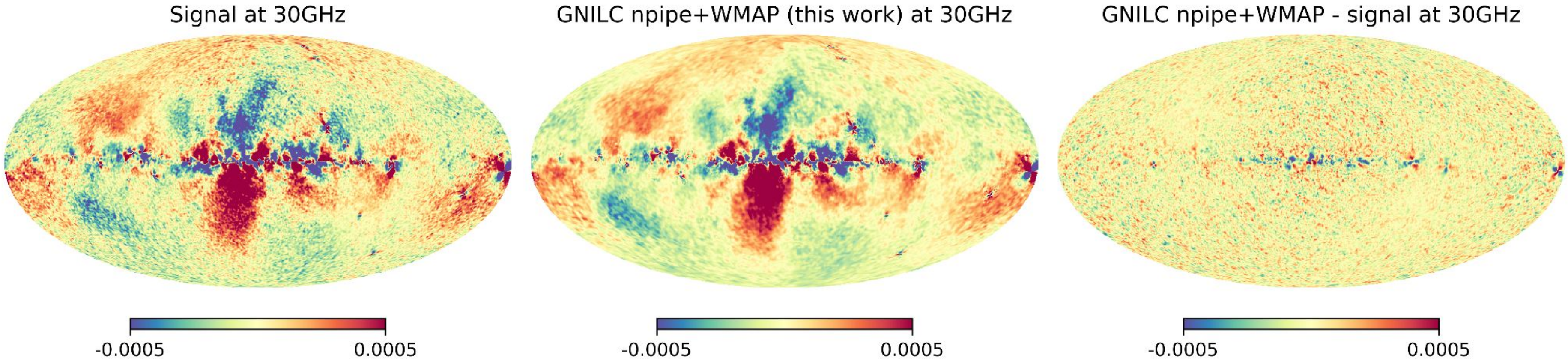
Results: Signal VS GNILC pol galactic maps

E modes at 30 GHz



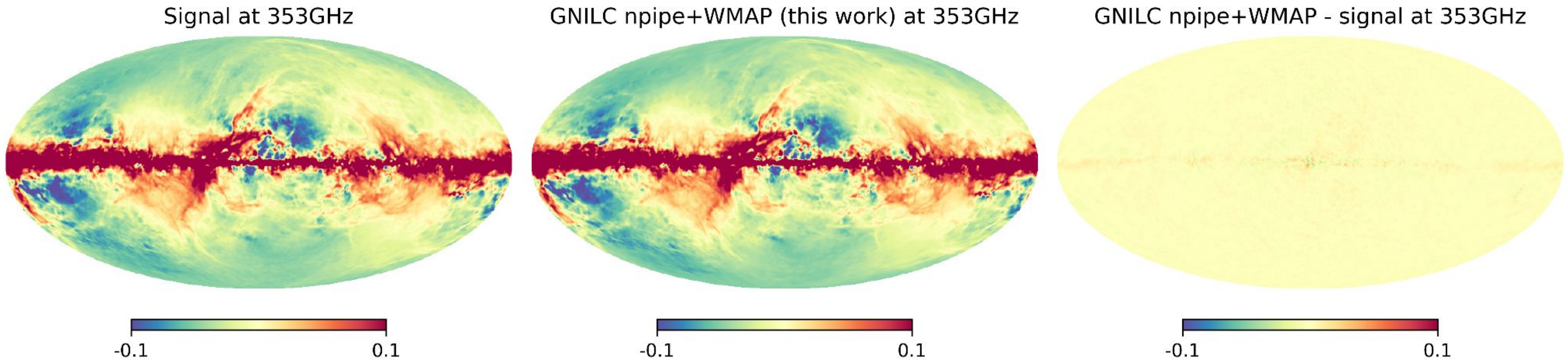
Results: Signal VS GNILC pol galactic maps

B modes at 30 GHz



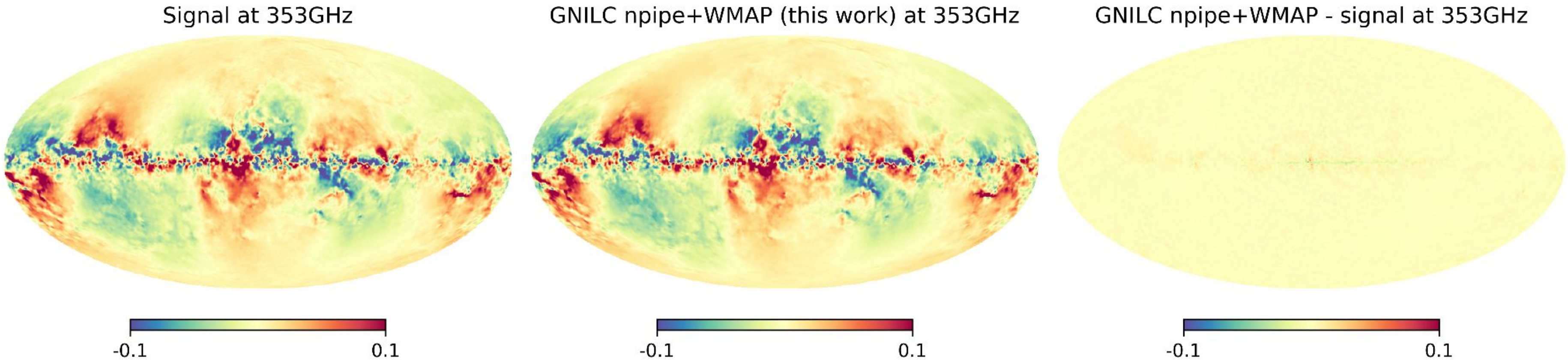
Results: Signal VS GNILC pol galactic maps

E modes at 353 GHz



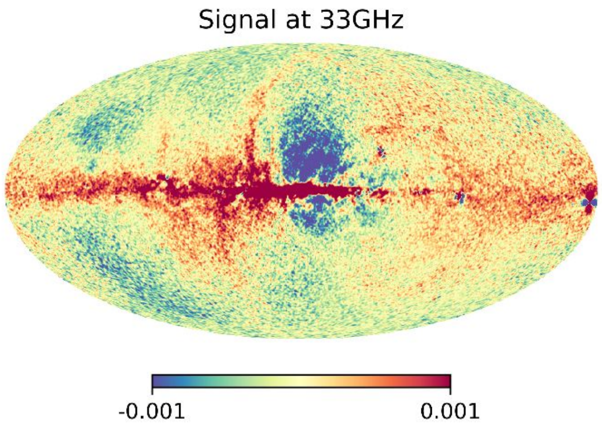
Results: Signal VS GNILC pol galactic maps

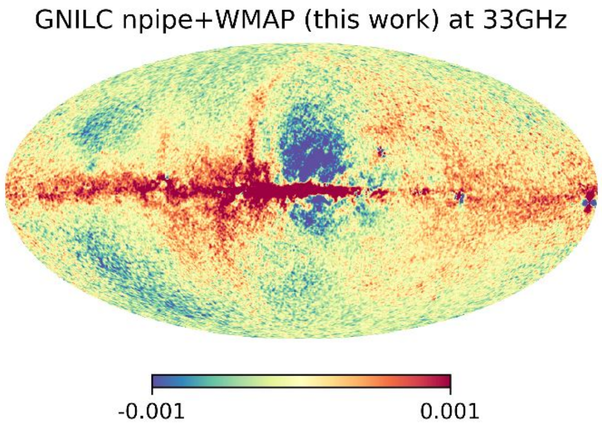
B modes at 353 GHz

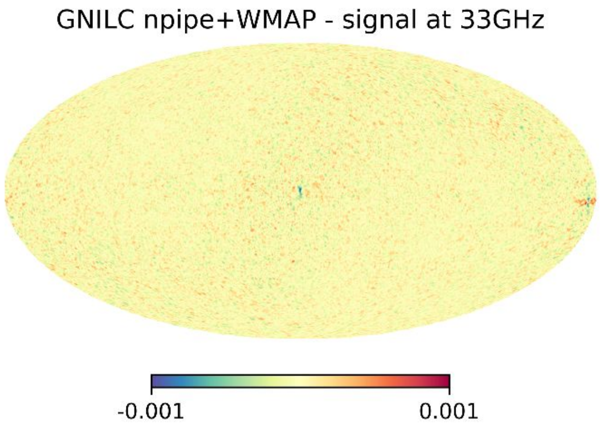


Results: Signal VS GNILC pol galactic maps

E modes at 33 GHz (WMAP Ka band)







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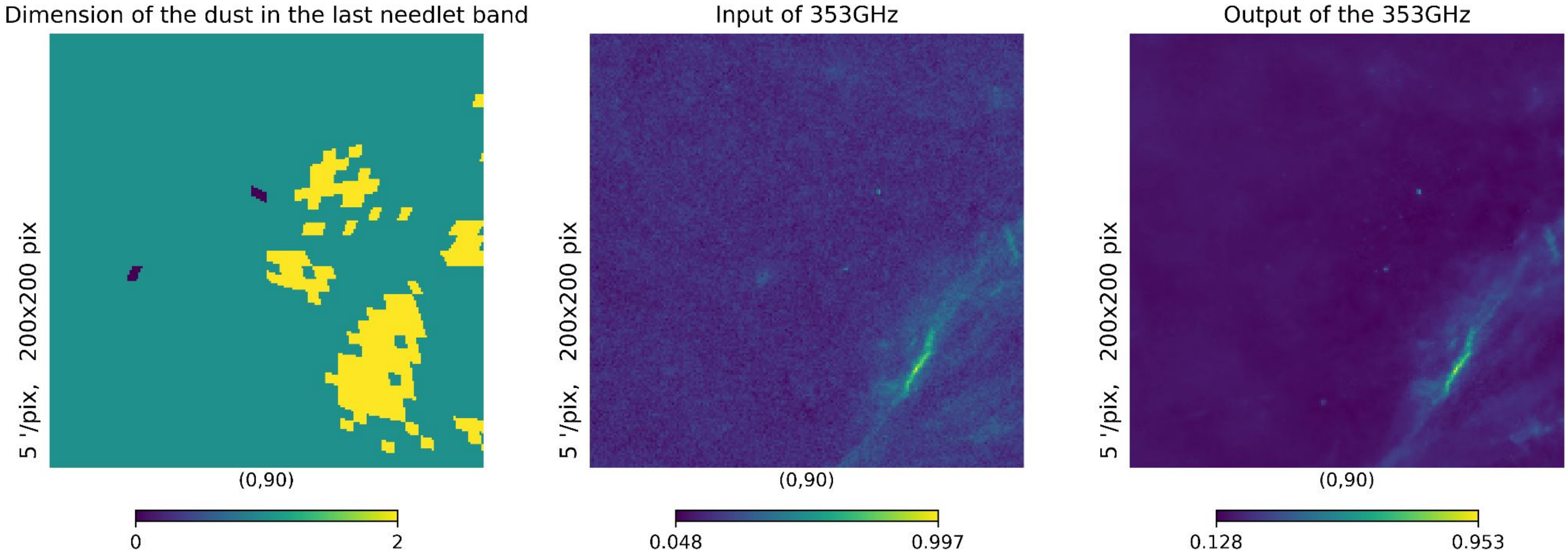
Future perspectives and conclusion

- Better preprocessing: masking
- Intensity: Understand/Add more frequency bands
- Polarization: optimize the choice of needlet bands
- Polarization: Extract the polarized dust and polarized synchrotron signal separately
- Show first results with extended GNILC scheme on intensity and polarization with PR4 maps
- Better resolution with PR4 maps than PR2 maps→still under investigation
- Still work in progress!

ANNEXES

Contribution of GLS in the Galactic North pole



Generalized Least squares method

$$\boldsymbol{y}(p) = \mathbf{A}\boldsymbol{s}(p) + \boldsymbol{n}(p)$$

$$\mathbf{W} = \left[\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}\mathbf{A}\right]^{-1}\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}$$

$$\widehat{\boldsymbol{s}} = \left[\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}\mathbf{A}\right]^{-1}\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}\boldsymbol{y} = \boldsymbol{s} + \left[\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}\mathbf{A}\right]^{-1}\mathbf{A}^{\dagger}\mathbf{R_n}^{-1}\boldsymbol{n}$$

Inverse noise weighted solution

Construction of the masks

b) Point source masking

1) Select the point sources: PCCS2E: take the ones that have SNR > 5
2) map[dist < 1.5*beam] = np.median(1.5*beam < crwn < 3*beam)
3) Cosine apodisation of the mask for map[1.5*beam < dist < 3*beam]
4) Smooth the map by 5 arcmin: map_smooth
5) Final_map = map_smooth*mask + map*(1 - mask)