Simulating Galactic Foregrounds

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PySM

- Python Sky Model: https://github.com/galsci/pysm
- Tool for generating full sky maps of Galactic emission at any (FIR/microwave/radio) frequency and including a number of emission mechanisms (dust, synchrotron, free-free, spinning dust, CO)
- Different models for each foreground component so level of complexity of simulations can be tuned
- Models constrained by data where well-measured (large angular scales at certain frequencies): want to be as representative of the sky as possible while exploring complexity of what has not yet been measured

Outline

- Updated emission templates
- Stochastic small scales
- Layer model
- Simulation suite

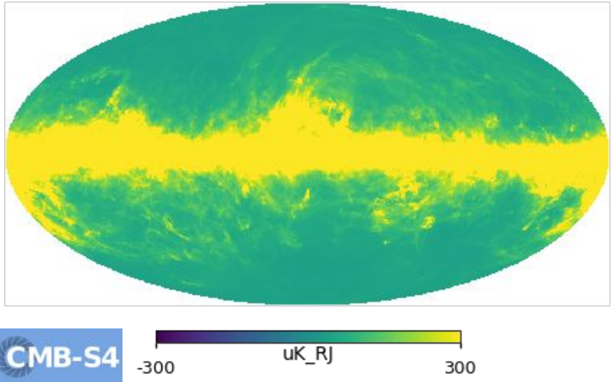
Data-driven Templates

- Large scales in T and P are well-constrained by observational data (Planck, WMAP, Haslam)
- However, templates are often imperfect
  - Galactic dust and CIB are hard to separate: old templates are contaminated
  - Synchrotron beta not well constrained at all by data
  - Likewise synchrotron curvature

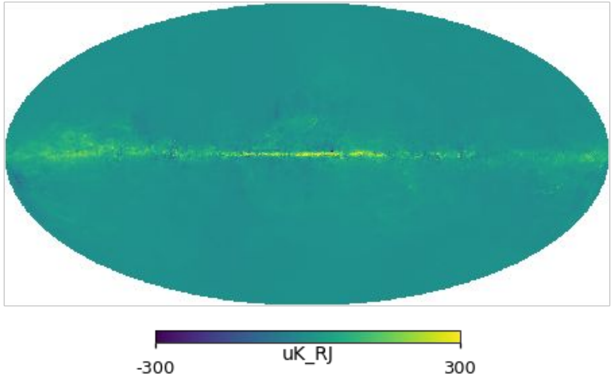
Dust Template

- Dedicated effort to separate Galactic dust from CIB
- Planck GNILC 2015 template for I map at 21.8’ resolution
- QU: Planck GNILC 2018 Variable resolution templates 21.8’ — 80’
- Much improved from old templates, but of course not perfect

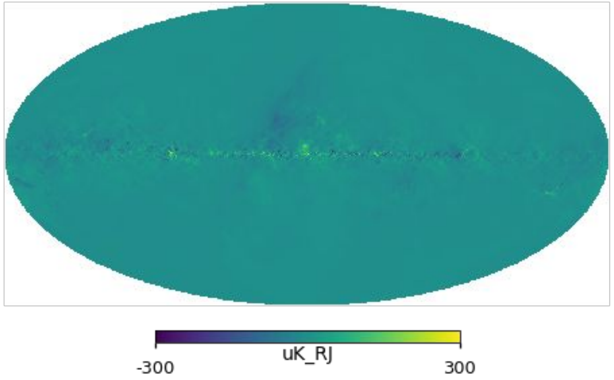
GNILC I



GNILC Q

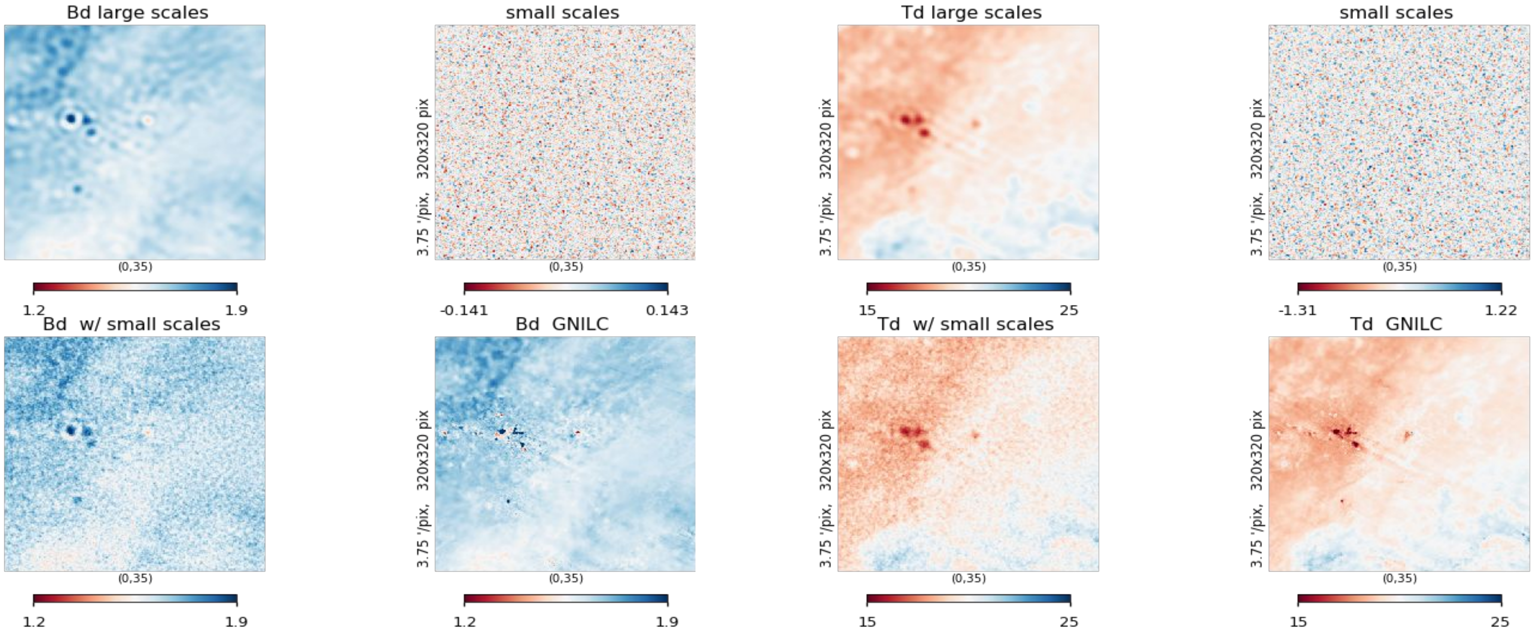


GNILC U



Dust Temperature and Beta

- Use maps from the 2015 GNILC analysis—less affected by CIB contamination
- Add small scale fluctuations in analogy to dust amplitude map



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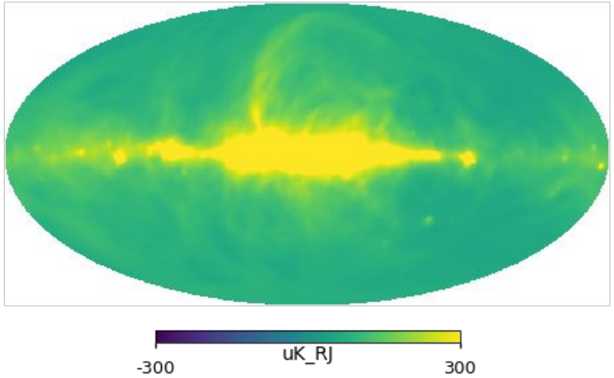
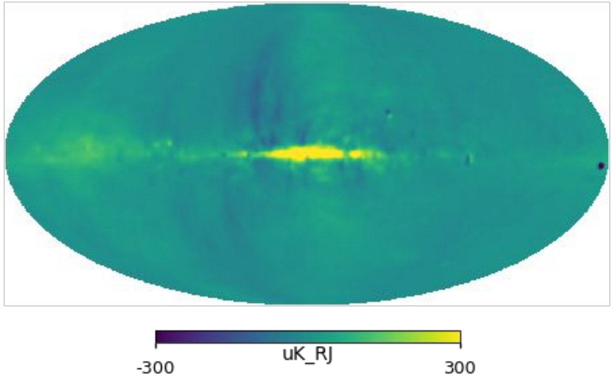
Synchrotron Template

- Haslam map rescaled to 23 GHz for I with Bs= -3.1 , 5 deg reso
- WMAP K-band for QU at 5 deg

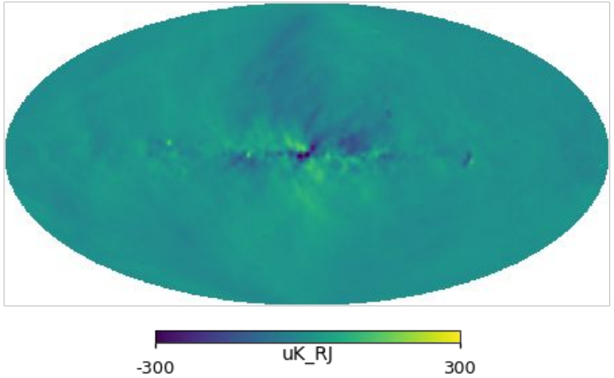
Haslam I



WMAP K Q

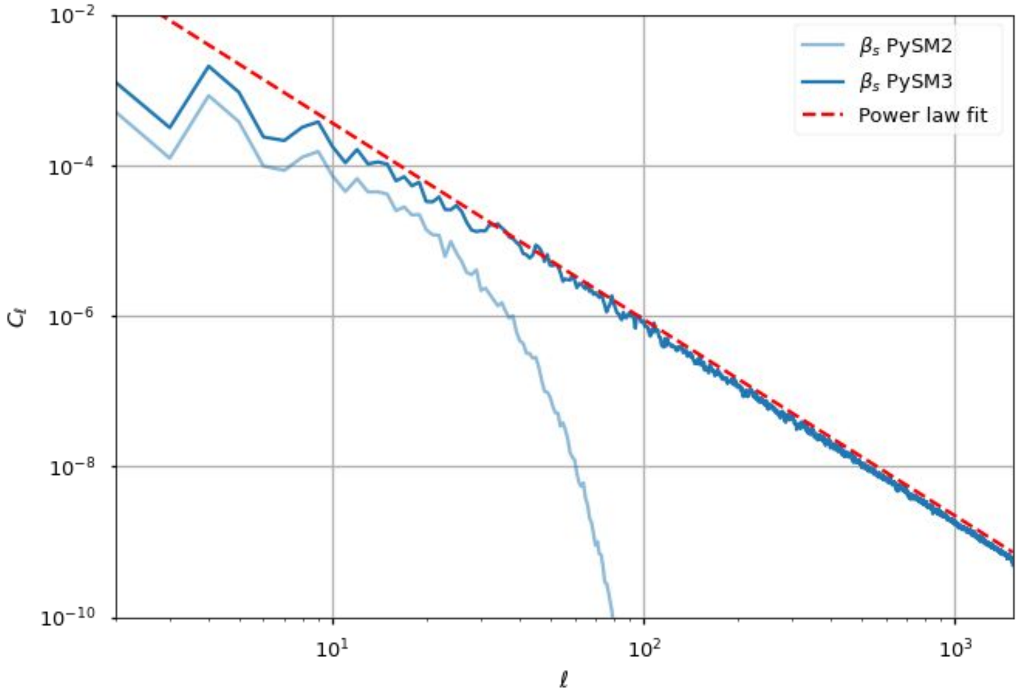


WMAP K U



Synchrotron Beta

- New S-PASS data offer better constraints on synchrotron beta variations
- Only the Southern sky, so we use the information only statistically



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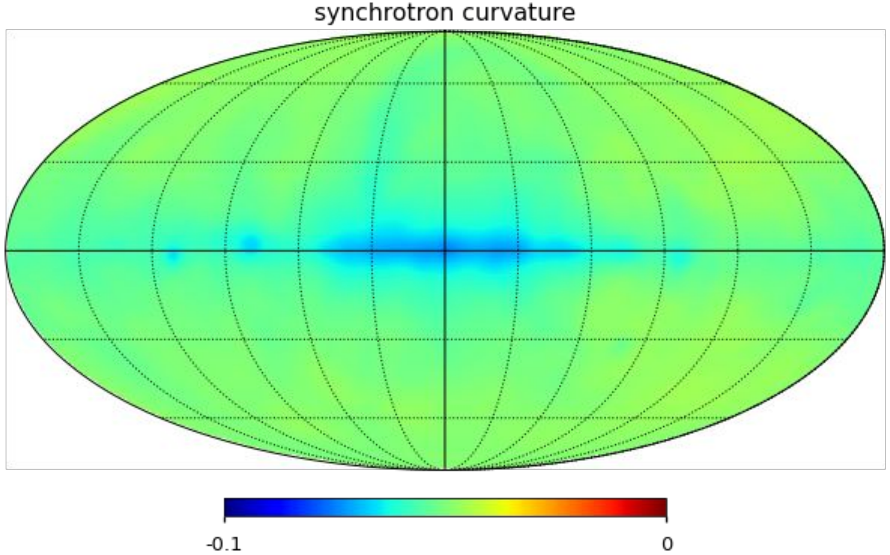
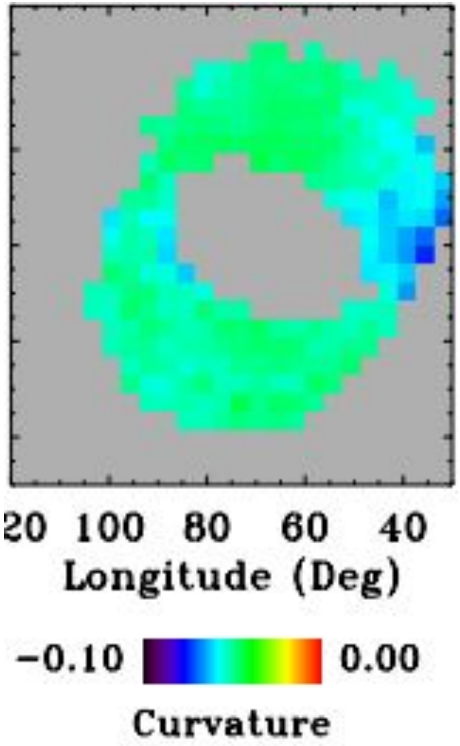
Synchrotron Curvature

- Study of synchrotron curvature using ARCADE data gives some handle on steepening toward high frequencies (Kogut 2012, right)
- We inject curvature to match Kogut estimates
- Smaller angular scales with same power law as β_s





Stochastic Small Scales

- Old version of PySM provides only one realization of the Galactic sky per model
- Okay for well-measured large scales, but we want a way to generate random realizations of small scales
- Approach: combine large scale template with Gaussian random small scales having a fixed power spectrum
- Use polarization fraction tensor formalism to couple T and P, introduce some non-Gaussianity
- Modulation of small scales

Log Pol Tensor Formalism

Transform polarization tensor into polarization fraction tensor:

$$\begin{bmatrix} i+q & u \\ u & i-q \end{bmatrix} = \ln \begin{bmatrix} I+Q & U \\ U & I-Q \end{bmatrix}$$

This is an invertible transformation on IQU maps:

$$i = \frac{1}{2}\ln\left(I^2 - P^2\right), \quad q = \frac{1}{2}\frac{Q}{P}\ln\frac{I+P}{I-P}, \quad u = \frac{1}{2}\frac{U}{P}\ln\frac{I+P}{I-P}$$

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

- Developed by Andrei Frolov
- Polarization fluctuations automatically scale with intensity

Layer Model (MKD)

- Implementation of the MKD model into PySM (Martínez-Solaeche, Karakci, Delabrouille 2018 MNRAS, 476, 1310)
- Models dust emission as coming from six discrete layers, each with its own amplitude, beta, and temperature map
- Constructed to agree with Planck 353 GHz
- Unlike other models, has line of sight frequency decorrelation, i.e., dust polarization angle can change with frequency

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PySM 3.4.0b3 (Slide from Andrea Zonca)

- GNILC Dust + polarization tensor + small scales (N_side 8192)
  - **d9**, **d10**: flat/variable spectral index and dust temperature
  - **d11**: stochastic small scales generated on the fly
- 3D multi-layer dust, MKD model arXiv: 1706.04162 (N_side 2048)
  - **d12**: 6 layers generated by the Planck Sky Model
- WMAP/Haslam Synchrotron + polarization tensor + small scales (N_side 8192)
  - **s4**, **s5**: flat/variable spectral index
  - **s6**: stochastic small scales generated on the fly
  - **s7**: added curvature based on ARCADE
- CO Lines from Planck SMICA, 3 rotational lines (N_side 2048)
  - **co1**: unpolarized emission 115/230/345 GHz
  - **co2**, **co3**: + polarized emission, + cloud maps

Simulation Suite

- Optimistic: d9, s4, f1, a1, co1
  - No decorrelation
- Best Guess: d10, s5, f1, a1, co3
  - Spectral parameter maps from component separation → decorrelation
- Pessimistic: d12, s7, f1, a2, co3
  - MKD layer model for dust (line of sight decorrelation), decorrelation near maximum allowed
  - Spatially varying synchrotron curvature
  - Polarized AME

Accessing the Models

- Available now on Github if you are interested in using these models: https://github.com/galsci/pysm
- Please raise issues and let us know where the documentation is unclear: https://pysm3.readthedocs.io/en/latest/models.html
- PySM3 described in Zonca et al. 2021 (JOSS)
- Paper on these advances (3.1) in progress