Foreground Models Update

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March 10, 2020

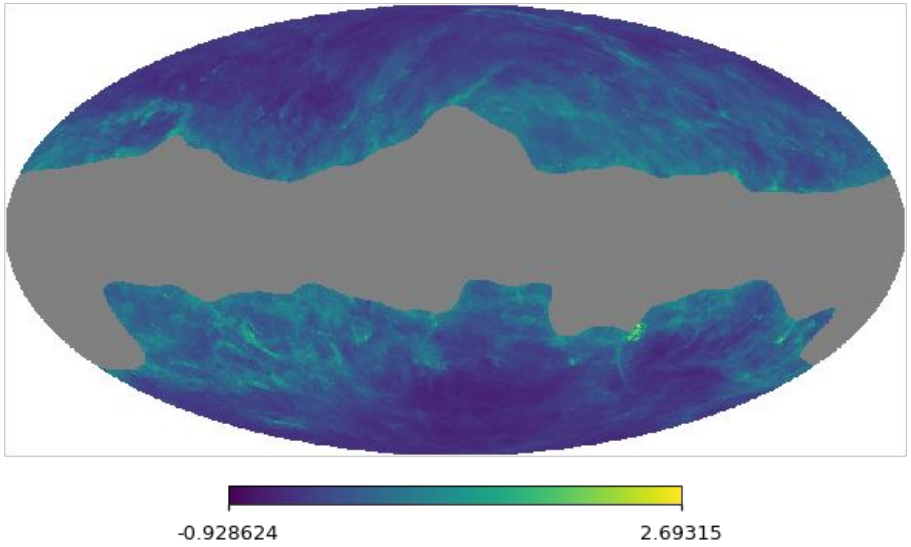
Areas of Improvement

1. Updated templates
2. Non-Gaussian small scales
3. CO lines module
4. Multi-layer modeling

Updated Templates

- Large scales based on data (Planck, WMAP, Haslam), but component separation required
- Use of GNILC dust maps to avoid CIB contamination in dust templates (CIB itself implemented separately) https://github.com/healpy/pysm/pull/72
- Ensuring we are using best data products for each foreground

GNILC Dust Intensity with Galactic Plane Mask



Non-Gaussian Small Scales

- Old method: fit EE and BB power spectrum with power law, extrapolate in ell, generate Gaussian fluctuations
- Problems:
  - T and P not properly coupled
  - Small scales perfectly Gaussian by construction
- A solution: polarization fraction tensor framework

Polarization Fraction Tensor

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:

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

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

- Adding Gaussian fluctuations to transformed quantities results in non-Gaussian fluctuations in real quantities upon inverse transform

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- Amplitude of polarization fluctuations modulated by I, as is physical (see Tuesday fireslide from Andrei Frolov)

Polarization Fraction Tensor: Progress

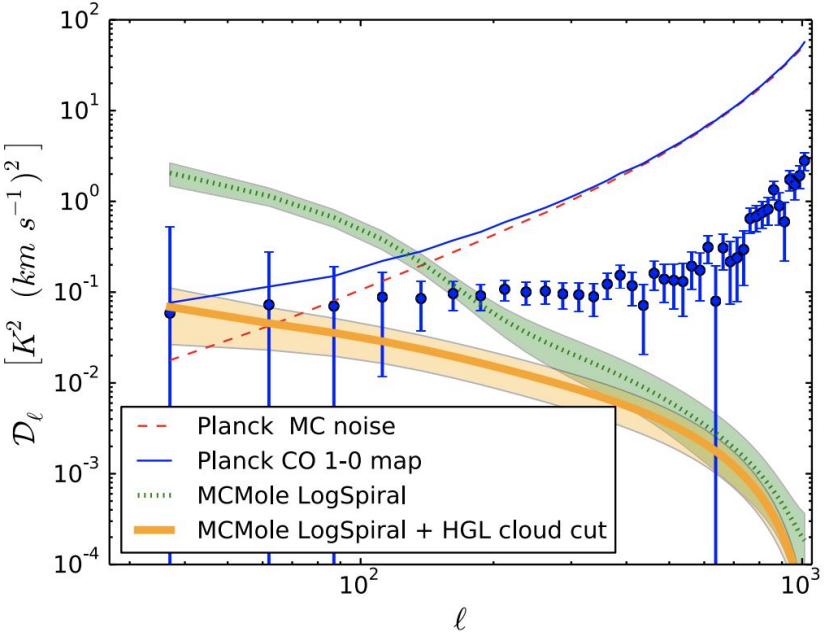
- Implementation of this framework complete for dust (https://github.com/healpy/pysm/pull/72, Andrea Zonca)
- Synchrotron in progress (https://github.com/healpy/pysm/pull/73, Ben Thorne)
- Idea from Ben Thorne and Marius Millea (see previous talk) to perform fitting and extrapolation in a more rigorous and robust way, development in progress!

Non-Gaussian Small Scales: Future

- Characterize/learn non-Gaussian statistics where they can be measured and extrapolate to where they cannot be
  - ML models (e.g., Krachmalnicoff & Puglisi 2020, Thorne et al. 2021)
  - More elaborate summary statistics (e.g., Regaldo-Saint Blancard et al. 2021)
- High resolution MHD simulations?
- Ancillary data at high resolution? (HI, WISE, others?)

CO Lines

- New to PySM3, based on Planck CO maps
- Can supplement with mock map of clouds at high Galactic latitudes (see Puglisi et al. 2017)
- Both intensity and polarization



CO(1-0) power spectrum at high Galactic latitudes from Puglisi et al. 2017

CO Next Steps

- Combine dust + HI information to model CO emission at small scales
- Initial results are promising!

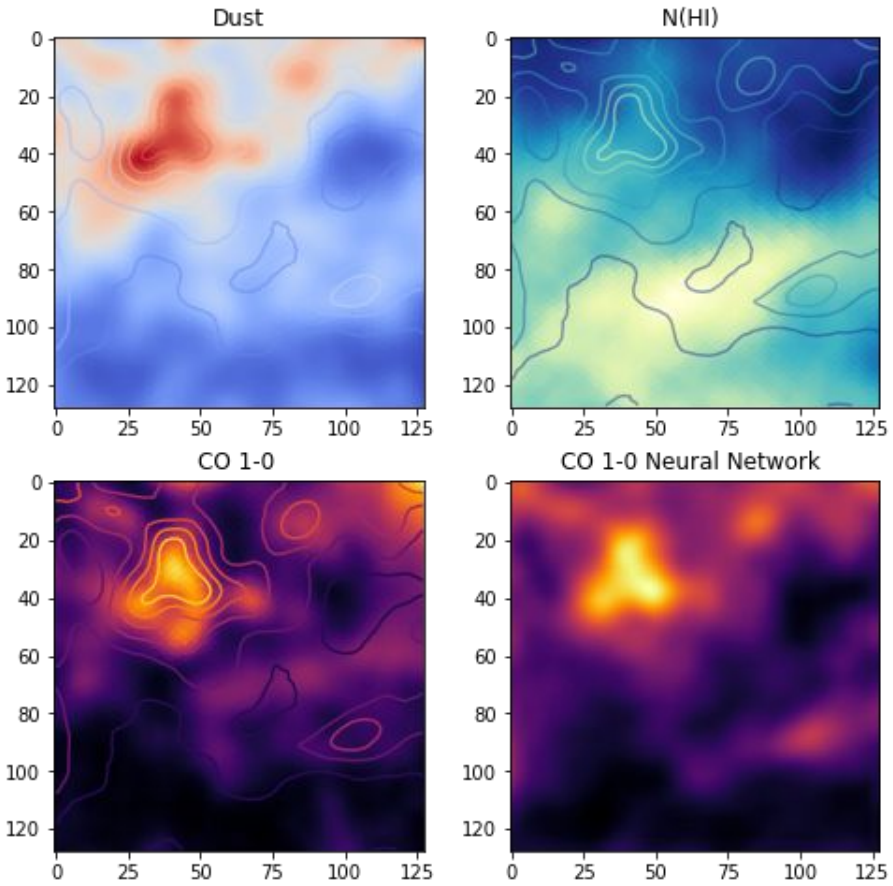


Figure from Giuseppe Puglisi

Multilayer Modeling

- Even if parametric models are perfect locally, integration within the beam and along the line of sight will alter them (e.g., Chluba et al. 2017)
- We *know* the ISM is 3D, and there is evidence in Planck data that dust spectral parameters vary along the line of sight (Pelgrims et al. 2021; see Susan Clark's fireslide on Friday)
- Goal: build on 3D "layer" models like Martinez-Solaeche et al. 2018 ("MKD") to introduce these effects into PySM
- Will produce realistic departures from idealized frequency dependence
- Next major action item!

Looking Ahead

- Have already improved PySM simulations to use best available data templates, include non-Gaussian small scales, and proper coupling of T-P in added fluctuations
- Next milestone: multi-layer modeling to capture LOS integration effects
- Active development on the Pan-Experiment Galactic Science Group telecons (see my fireslide from Tuesday). Interested? Sign up here: https://forms.gle/E2vGobSpZWSr1PjT7