Foreground Models Update

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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
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:

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

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

- 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](https://github.com/healpy/pysm/pull/72), Andrea Zonca)
- Synchrotron in progress ([https://github.com/healpy/pysm/pull/73](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-Solaeché 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