Foreground Summary

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Foreground Working Groups

Removal:

Science:
Aurelien Fraisse, Joanne Brown, Greg Dobler, Glennys Farrar, Doug Finkbeiner, Priscilla Frisch, Marijke Haverkorn, Chris Hirata, Ronnie Jansson, Alex Lazarian, Mario Magalhaes, Xiaohui Sun, John Vaillancourt, Andre Waelkens, Maik Wolleben
Goals

Strong statement that the foreground problem, while not solved, is under control, and that anticipated new measurements, including a CMB polarization satellite, will allow detection of primordial B modes to a cosmologically interesting level even after foreground correction. (Al Kogut)

Numerical goals:

1. ‘Signal-to-noise’ numbers (here noise=foreground) at different scales and sky coverage (Chris Hirata).
2. Degradation of the error on r due to foreground marginalization, and how it depends on modeling assumptions.
3. How many parameters is good enough for complicated Galactic emission
4. Optimal frequency allocation
What do we know?
(notes from Al Kogut)

**Synchrotron (WMAP K-band, Haslam)**

- WMAP data at 22 GHz. 4° pixels: S/N > 3 over 90% of sky.
- Fractional polarization few percent in plane, larger at high latitude.
- Index: not significant variation. Some evidence for steepening off the plane.

**Dust (IRAS, Archeops, WMAP, starlight)**

- Fractional polarization ~ few percent (Page et al 2007, Kogut et al 2007)
- Index: IRAS data well fit with two components ($\beta_1=1.7, \beta_2=2.7$) (Finkbeiner et al 1999)
Quick look at signal levels

75% of the sky, at 60GHz BB $r=0.01$ is $\sim 30$ times smaller at $l=4$, and $\sim 10$ times smaller at $l=100$

3% of the sky, at 150GHz BB $r=0.01$ is bigger than expected dust signal at $l=100$
Methods for forecasting
(Propagation of error bars is critical)

Parametric fitting

- **Dickinson** - pixel-by-pixel model fitting (FGFit) uses MCMC to sample
- **Eriksen** - extends to sample power spectra, using Gibbs sampling (Commander)
- **Dunkley** - Gibbs samples maps in pixels plus spectral indices in larger pixels
- **Finkbeiner** - test goodness of fit of models to various sims (looks for bias)

Blind component separation

- **Amblard** - ILC-type (weighting in harmonic space). Foreground residual becomes extra noise term.

\[
\ln L = -\frac{1}{2} \sum_{\nu=1}^{N} \left[ \frac{d_{\nu} - S_{\nu}(\theta)}{\sigma_{\nu}} \right]^2 = -\frac{1}{2} \chi^2.
\]

\[
a_{\ell m} = \sum_{\text{freq}=i} w_{i} a_{\ell m}^{i}
\]
# Specifications

(ν2 ‘fiducial’ noise levels from EPIC, Jamie Bock)

<table>
<thead>
<tr>
<th>Freq (GHz)</th>
<th>Noise (nK, 120’ pix)</th>
<th>FWHM (‘)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>160</td>
<td>26</td>
</tr>
<tr>
<td>45</td>
<td>39</td>
<td>17</td>
</tr>
<tr>
<td>70</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>100</td>
<td>27</td>
<td>8</td>
</tr>
<tr>
<td>150</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>220</td>
<td>40</td>
<td>3.5</td>
</tr>
<tr>
<td>340</td>
<td>180</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Plus 2 higher frequencies we are not including for forecasts.
Simulated maps

Started with various models (Dunkley, Amblard, PSM). Reached consensus. Made at Nside=16, 128.

Simple Galactic model (Clive, from PSM)
- Synchrotron: Haslam with angles and pol fraction from fitting model to WMAP.
- Dust: FDS, 5% polarized, angles from galactic field model, index 1.6-1.7.

‘Complicated’ Galactic model (not yet made)
- Synchrotron index curvature, magnetic dust, free-free, multi-component dust

CMB plus noise (Jo, using synfast)
- $r=0$ and $r=0.01$
- Gaussian random noise, uniform Nobs
Sim v1.0 maps (EPIC LC specs, Dunkley maps, \(N_{\text{side}}=16\), uK antenna units

- In the process of upgrade to Sim v1.1 (as previous page)
Results from earlier work

- **Amblard**: 3 sigma upper limits $r<0.01$ for LC and $r<0.003$ for HC
- **Eriksen**: if you fix indices to input, marginalizing over foreground amplitudes hardly affects errors for $r=0.1$. Still in test phase.

**Table 2.2.2 Estimated Sensitivities After Foreground Removal**

<table>
<thead>
<tr>
<th>Case</th>
<th>Planck</th>
<th>EPIC/NTD</th>
<th>EPIC/TES</th>
</tr>
</thead>
<tbody>
<tr>
<td>No foregrounds</td>
<td>325</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>$\beta_s$ and $\beta_d$ fixed</td>
<td>592</td>
<td>77</td>
<td>26</td>
</tr>
<tr>
<td>$\beta_s$ and $\beta_d$ fitted in 15° pixels</td>
<td>595</td>
<td>81</td>
<td>26</td>
</tr>
<tr>
<td>$\beta_s$ and $\beta_d$ fitted in 10° pixels</td>
<td>599</td>
<td>85</td>
<td>28</td>
</tr>
<tr>
<td>$\beta_s$ and $\beta_d$ fitted in 5° pixels</td>
<td>621</td>
<td>108</td>
<td>34</td>
</tr>
<tr>
<td>$\beta_s$ and $\beta_d$ fitted in 2° pixels</td>
<td>751</td>
<td>203</td>
<td>62</td>
</tr>
</tbody>
</table>

$nK$, Dickinson from Bock et al.

**5 Sigma= 0.01**

Preliminary, EPIC LC, Dunkley
Frequency allocation
(work by Clive Dickinson)

Study with C. Dickinson & JPL group
Also see Amblard et al, 2007

Clive (et al)'s method:
Set constant signal-to-noise at each frequency
Scale Nfeed to fill focal-plane
Calculate CMB marginalized errors

Frequency range:
- If 200GHz fixed, \( \nu_{\text{min}} \sim 40 \text{GHz} \)
- If 30GHz fixed, \( \nu_{\text{max}} \sim 350 \text{GHz} \)
- Modelling errors likely to affect this

<table>
<thead>
<tr>
<th>Freq range (GHz)</th>
<th>Q,U error ((\mu K))</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-250</td>
<td>2.40</td>
</tr>
<tr>
<td>40-200</td>
<td>2.82</td>
</tr>
<tr>
<td>50-150</td>
<td>3.88</td>
</tr>
<tr>
<td>60-100</td>
<td>11.7</td>
</tr>
</tbody>
</table>

Constant signal-to-noise ratio, 7 frequencies, logarithmic spacing
Modeling issues
(particular input from Vaillancourt, Finkbeiner, Waelkens, Kogut, Fixsen, Magalhaes)

Dust
- Should include at least two components
- Index could be between ~1 and 3
- Polarization angle likely to change with frequency
- Extrapolating from very high frequencies is dangerous
- Should use starlight information and encourage more observations

Cosmic Rays/Synchrotron
- Should expect some variation of synch index with frequency

Magnetic field
- Not ok to assume same indices for temp and polarization

Other/general
- Should consider polarized free-free, magnetic dust, spinning dust
- Try to minimize number of parameters
Forecast work in progress

- Limits on \( r \) for CMBPol fiducial case. We would like a figure like this. (3 sigma upper limit for \( r=0 \))
- Separate reionization/recombination/both
- Test for pessimistic map: does simple model still work? How biased does it get?
- Use FGFit (and/or ILC) to determine optimal freq allocation.
Galactic Science Goals

(notes from Doug Finkbeiner)

**Magnetic field**
- Uniformity of large-scale magnetic field (e.g. Loop I)
- Turbulence of magnetic field on all scales.
- Magnetic field structure through cirrus and dense clouds

**Dust**
- Dust polarization spectrum: alignment efficiency with density & temperature.
- Dust composition
- Limits on uniformly distributed dust in heliosphere

**Cosmic rays**
- Electron cosmic ray spectrum at high and low latitude
- What is the haze? Synchrotron, and if so, DM annihilation?

**Other**
- Constrain models of anomalous dust emission: spinning dust; magnetic dust emission - is it detectable? Are there resonances?
- Unknown emission
• **Forecasting:** we decided on a set of simple simulated maps, and a more complex case. There are a handful of methods. We started with EPIC LC but moved on to the mid-cost mission. Finding limits on $r=0.01$ and $r=0$ sims.

• **Modeling issues** are key. We should not assume the sky is simpler than it really is, or vice versa.

• **Frequency allocation** - being tested in single pixels (FGFit). Low helps synchrotron, too high (>~350) not so useful for dust.

• **Galactic science case:** clear goals, but prefer high resolution, and hard to make quantitative statements beyond Planck.