Polarized Galactic foregrounds: a review

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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, Maik Andre Waelkens, Wolleben

Documents:
The magnetic field

Few uG field in coherent and turbulent parts

Often probed by Faraday rotation of sources and pulsars (e.g. Brown et al, 2008)
Synchrotron emission

- Electrons spiral in B-field
- Radiation is polarized perpendicular to B-field

\[ Q(x) \propto n_e(x) \Pi_s [B_s(x)^2 - B_t(x)^2] \]

\[ n(E) \propto E^{-p} \]
\[ I(\nu) \propto \nu^{\frac{-p+3}{2}} \]

Scale height: \( h_d \sim 1 \text{ kpc} \)
Radial scale length: \( h_r \sim 5 \text{ kpc} \)
Synchrotron observations

23 GHz, $P(\text{synch})$

1.4 GHz, $P(\text{synch})$

$\mathbf{f}(\text{synch}) = \frac{P}{I}$. Up to $\sim45\%$ polarized

Page et al 2007

Miville-Deschenes et al 2008

Hinshaw et al 2008

Wolleben 2007
Synchrotron index

- Index of $\beta \sim -3$ both on and off Galactic plane. Some indication of spectral shallowing.
- Should expect some variation of synch index with frequency and space.
- Not ok to assume same indices for temp and polarization.
Thermal dust emission

Grains align with B-field

Radiation is polarized perpendicular to B-field
Starlight polarized parallel to B-field

Spectral Index: $T(\nu) \propto \nu^2$ for one component
Dust observations (T)
Dust predictions

- **Fractional polarization** ~ few percent (Page et al 2007, Kogut et al 2007). Consistent with QUAD and BICEP (?). Could be ~1-10%.

- **Index**: IRAS data well fit with two components ($\beta_1=1.7$, $\beta_2=2.7$, Finkbeiner et al 1999). Ideally include at least two components, but extrapolating from >300 GHz is dangerous. Index could be between ~1 and 3.
Comparing signal levels (1)

Create simulated maps, draw on Planck Sky Model using WMAP, FDS, Haslam

\[
\ell(\ell + 1)C_\ell^{\text{Synch}} / 2\pi = A_s (\nu / \nu_0)^{2\beta_s} (\ell / \ell_0)^{m_s}
\]

\[
\ell(\ell + 1)C_\ell^{\text{Dust}} / 2\pi = A_d (\nu / \nu_0)^{2\beta_d} (\ell / \ell_0)^{m_d}
\]

Dunkley et al 2008
Comparing signal levels (2)

\[ \ell (\ell + 1) C^\text{Synch}_\ell / 2\pi = A_s (\nu / \nu_0)^{2 \beta_s} (\ell / \ell_0)^{m_s} \]

\[ \ell (\ell + 1) C^\text{Dust}_\ell / 2\pi = A_d (\nu / \nu_0)^{2 \beta_d} (\ell / \ell_0)^{m_s} \]
Template cleaning

- Construct synchrotron and dust templates
- Assume they are perfect tracers and have global index
- Remove scaled template at each channel
- Inflate errors to include noise in template maps
- Used for WMAP (Page et al 2007) and forecast for Planck (Efstathiou & Gratton)

Cleaning: A large amount of work done by many groups. Methods include

1. Template cleaning (WMAP, Efstathiou/Gratton)
2. Parametric cleaning (Eriksen, Dickinson, Dunkley)
3. Blind cleaning (Amblard ILC, Pierpaoli, Delabrouille ICA)
Estimate the CMB, synchrotron, dust Q/U signal and spectral indices in each pixel on the sky (see Eriksen et al 2006, 2007, Dunkley et al 2009).

Impose priors from astrophysical knowledge and external observations.

\[ \mathcal{L} = \sum_{\nu} [d_{\nu} - m_{\nu}]^T N_{\nu}^{-1} [d_{\nu} - m_{\nu}] , \]
Determining prospects for $r$

Using template CMBPol 2m mission, 30\textless nu \textless 350 GHz, 7 bands, 1 uK/arcmin, half-degree resolution

Simple estimates indicate ~5\% residual Galactic emission and detection of $r=0.01$

Extensive analysis by Betoule et al more optimistic, but use B-mode maps

<table>
<thead>
<tr>
<th>Method</th>
<th>Average dust pol fraction (%)</th>
<th>Description</th>
<th>$\ell &lt; 15$</th>
<th>$\ell &lt; 150$</th>
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<tbody>
<tr>
<td>Fisher</td>
<td>0</td>
<td>No foregrounds</td>
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<tr>
<td>Fisher</td>
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<td>10% residual</td>
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<td>Fixed spectral indices</td>
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<td>Power-law indices</td>
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<td>Blind</td>
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<td>SMICA</td>
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<td>0.00055</td>
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</tbody>
</table>

Dunkley et al 2008
Frequency allocation

**Very rough:** should include 100 GHz, should have at least 5 channels below 350 GHz for all sky, preferably >=7. Three is current basic requirement.

**Useful method (from Dickinson):**
- Set constant signal-to-noise at each frequency
- Disperse channels logarithmically
- Scale Ndet to fill focal-plane
- Calculate CMB marginalized errors with e.g. parametric fit

**Frequency range:**
- $\nu$ min ~40GHz
- $\nu$ max ~200-300 GHz

**Galactic model** likely to affect exact choice
(Asantha may report more on this.)
Galactic science goals

Magnetic field
- Uniformity of large-scale magnetic field (origin of field)
- Turbulence of magnetic field on all scales

Dust
- Alignment efficiency with density and temperature
- Dust composition

Cosmic Rays
- Electron cosmic ray spectrum at high and low latitude
- What is the haze? Is there DM annihilation?

Other
- Constrain models of anomalous dust emission: spinning dust, magnetic dust.
• Polarized foregrounds are (at least) synchrotron and dust. Synchrotron measured at low res, up to ~40% polarized. Dust poorly measured, 1-10% polarized.

• Foreground min at ~100 GHz. Based on FDS there are good prospects for measuring $r$ in clean patches of sky.

• In planning for new experiments we should not assume the sky is simpler than it really is, or vice versa.

• Lots of interesting Galactic science questions to keep in mind.