The State of Polarized Foregrounds

Al Kogut/GSFC
The Problem In A Nutshell

Galactic foregrounds are 2 orders of magnitude brighter than primordial B-mode polarization from 30 to 200 GHz.
WMAP 5-yr 93 GHz

Intensity
WMAP 5-yr 93 GHz Polarization
This Time It's Different

Temperature Analysis: Signal-Dominated
• Mask brightest foregrounds in plane
• Light cleaning outside mask
• Templates, linear combination, …

Polarization Analysis: Foreground-Dominated
• Percent-level cleaning even at high latitude*
• More rigorous tests of methods
• Greater emphasis on astrophysics

* A few small patches are pretty clean, though
Synchrotron: Status and Issues

\[ T_0^S(\hat{n}, \nu) = T_0^P(\hat{n}, \nu_0) \cos 2\gamma(\hat{n}) \left( \frac{\nu}{\nu_0} \right)^{\beta_S(\hat{n}) + C(\hat{n}) \log(\nu / \nu_0)} \]

- \( T_0^P(\hat{n}, \nu_0) \) Morphology at reference frequency
- \( \gamma(\hat{n}) \) Polarization angle (magnetic field)
- \( \beta_S(\hat{n}) \) Spectral index
- \( C(\hat{n}) \) Spectral curvature

Parameters model superposition of emission along line of sight
Large Angular Scales: WMAP 5-yr Data
- Reasonable S/N ratio at 22 GHz
- 4° pixels: S/N > 3 over 90% of sky
- Measure power spectrum to $l \sim 100$

Fractional Polarization
- Few percent in plane, larger at high lat
- Depolarization via line-of-sight effects
- Confusion from unpolarized stuff

Polarized Synchrotron: Status & Issues
Spectral Index

Just beginning to measure $\beta_S(\hat{n})$
- Flatter in plane, steeper at high lat
- Limited by S/N in polarization
- Limited by confusion in intensity

Room for Improvement:
- S/N in polarization
- Confusion: Multiple components along same line of sight
- Cosmic ray connection (GALPROP project)

Polarized Synchrotron: Status & Issues

Small-Scale Features

- Interferometric maps at low frequencies
- Heavily contaminated by Faraday rotation
- Waiting for sensitive mm-wave survey

Spectral curvature

- No convincing detection yet
- Expected from cosmic ray data
- Curvature variation across sky?

DRAO 1.4 GHz polarization
Dust: Status and Issues

\[ T_d^n(\hat{n},\nu) = \sum_{i=1}^{k} w_i \varepsilon_i(\hat{n},\nu) \cos 2\gamma_d(\hat{n}) \kappa_i \left( \frac{\nu}{\nu_0} \right)^{\beta_i} B_0(T_i(\hat{n})) \]

- \( T_i(\hat{n}) \) Dust temperature
- \( \varepsilon_i(\hat{n},\nu) \) Fractional polarization
- \( \gamma_d(\hat{n}) \) Polarization angle (magnetic field)
- \( \beta_i \) Spectral index
- \( \kappa_i \) Emissivity
- \( w_i \) Weight (normalization)

Admixture of species and emitting regions along line of sight
Large Angular Scales: WMAP 5-yr Data
- Low S/N at high latitude
- $4^\circ$ pixels: S/N < 2 over 97% of sky

Fractional Polarization
- Few percent in plane (depolarized)
- 2--4% at higher latitudes

Polarized Dust: Status & Issues
Small-Scale Morphology

Small Angular Scales: ARCHEOPS
- Low S/N at high latitude
- Fractional polarization ~5% at 345 GHz

New Dust Measurements Coming Soon
- Planck HFI: 100, 143, 217, 353 GHz
- EBEX: 150, 250, 350, 450 GHz
- SPIDER: 100, 150, 220 GHz

… which brings up the question of spectra …

Polarized Dust: Status & Issues
Frequency Dependence: Stokes I


Frequency (GHz)

Dust Emission / $v^2 B_v(T)$

FDS Model Based on COBE Data

Single Component
- $\langle T \rangle = 18.1 \text{ K} \ , \ \beta = 2.0$
- $\beta = 2.2$ is better for $v < 300 \text{ GHz}$

Two Components
- $\langle T_1 \rangle = 9.4 \text{ K} \ , \ \beta_1 = 1.7$
- $\langle T_2 \rangle = 16.2 \text{ K} \ , \ \beta_2 = 2.7$

But ...
- $\chi^2/\text{DOF} = 1.85$ for best model
- Clearly an approximation!

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Polarized Dust: Status & Issues
Frequency Dependence: Fractional Polarization

Molecular Clouds: Minimum near 350 GHz
- Different (local) environments
- Different dust species

Diffuse Cirrus: Monotonic change
- Same environment, different species


Hildebrand & Kirby 2004, ASP Conf Series 309, 515
Polarized Dust: Status & Issues
Polarization Angle

Dust $\gamma(\hat{n})$ mostly traces synchrotron
Differences are real & significant

Foreground Status

Cleaning "machinery" under control

- Algorithms exist and work as advertised
- Multiple methods, multiple sims

Astrophysics not quite there yet

- Just starting to map polarized foregrounds
- Considerable uncertainty in fitted parameters
- Biggest need is more data!
Desired Outcome

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.
Questions for Discussion

1. Where are new observations most needed?
   • What bands, with what sensitivity?
   • Detailed maps of foreground morphology
   • Better measurement of spectral behavior
   • Limits on unwanted line-of-sight effects

Connection with detailed astrophysical models
   • Synchrotron emission ↔ Charged particle propagation
   • Dust emission ↔ Physical properties of dust grains
2. How much can we simplify?

- Worst case parameter scenario: 8+ parameters per pixel
  - Synch: T(n), γ(n), β(n) plus global curvature too
  - Dust: T(n), ε(n) for 2 species plus γ(n) plus global β1 and β2
  - Plus more to account for line-of-sight effects?

Simulations will be very useful here!
Questions for Discussion

3. How will we know what is good enough?
   • Balance number of channels vs cost
   • Principal component analysis, $\chi^2$

Simulations will be very useful here as well!