Polarized Galactic foregrounds: a review

Joanna Dunkley
University of Oxford

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Foreground Working Groups

Removal: Alex Amblard, Carlo Baccigalupi, Marc Betoule, David Chuss, Asantha Cooray, Clive Dickinson, Greg Dobler, Jo Dunkley, Hans-Kristian Eriksen, Doug Finkbeiner, Dale Fixsen, Pablo Fosalba, Aurelien Fraisse, Al Kogut, Charles Lawrence, Mario Magalhaes, Steve Meyer, Amber Miller, Lyman Page, Hiranya Peiris, Nicholas Phillips, Elena Pierpaoli, Radek Stompor, Licia Verde, Chris Hirata

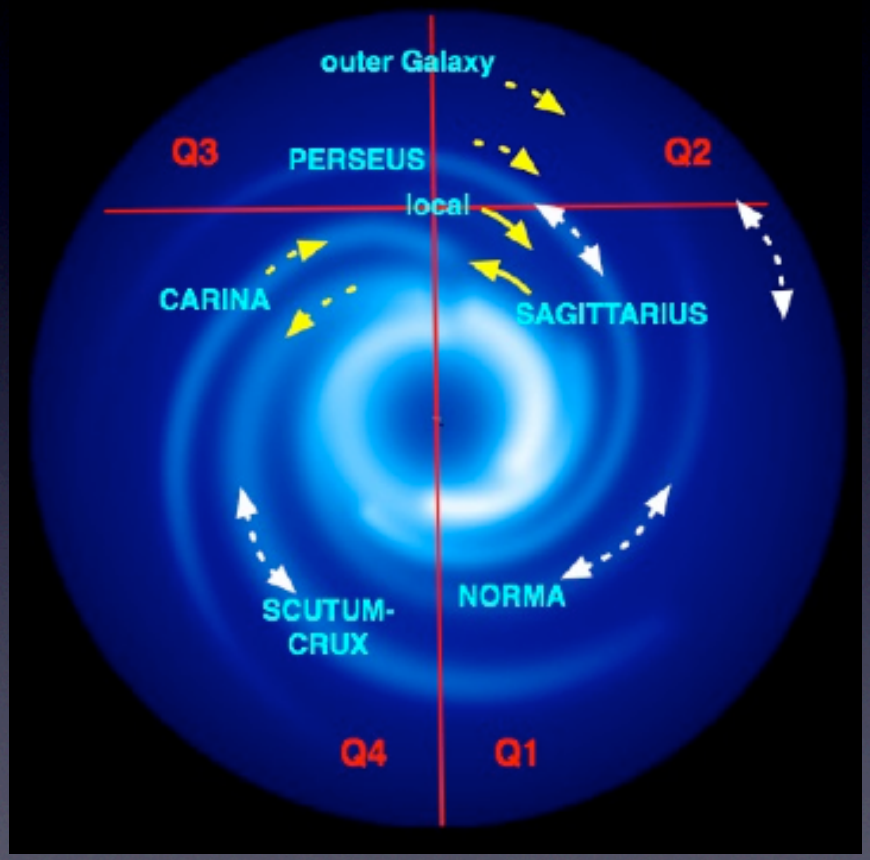
Science: *Aurelien Fraisse, Joanne Brown, Greg Dobler, Glennys Farrar, Doug Finkbeiner, Priscilla Frisch, Marijke Haverkorn, Chris Hirata, Ronnie Jansson, Alex Lazarian, Mario Magalhaes, Xiaohui Sun, John Vaillancourt, Maik Andre Waelkens, Wolleben*

Documents:

CMBPol Mission Concept Study: Prospects for polarized foreground removal, Dunkley et al 2008, astro-ph/0811.3915

CMBPol Mission Concept Study: Foreground Science Knowledge and Prospects, Fraisse et al 2008, astro-ph/0811.3920

The magnetic field



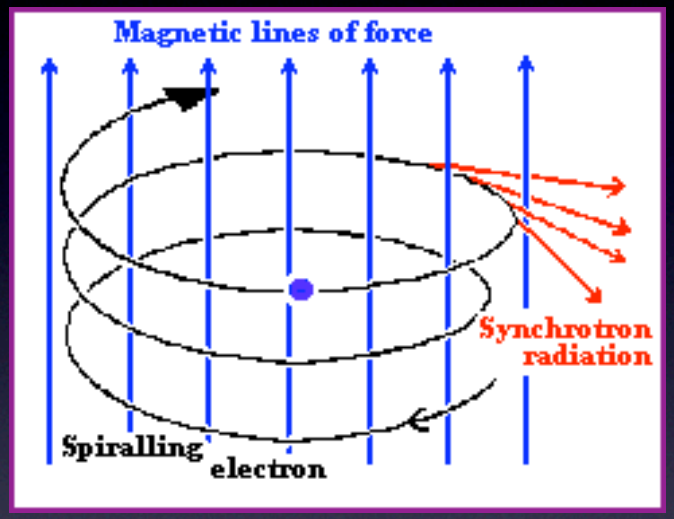
Haverkorn

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



$$Q(\mathbf{x}) \propto n_e(\mathbf{x})\Pi_s[B_s(\mathbf{x})^2 - B_t(\mathbf{x})^2]$$

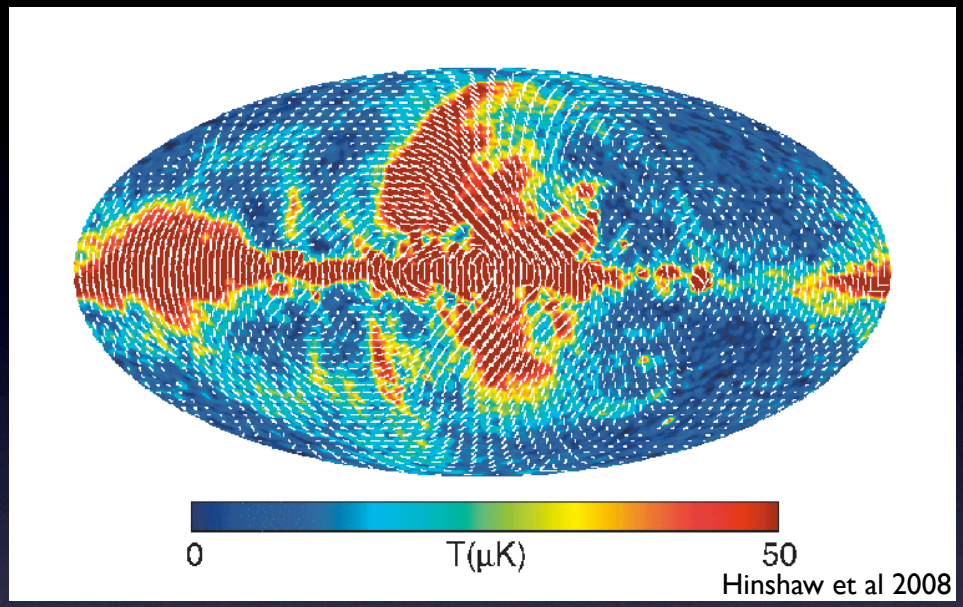
$$n(E) \propto E^{-p}$$

$$I(\nu) \propto \nu^{-\frac{p+3}{2}}$$

Scale height: $h_d \sim 1$ kpc

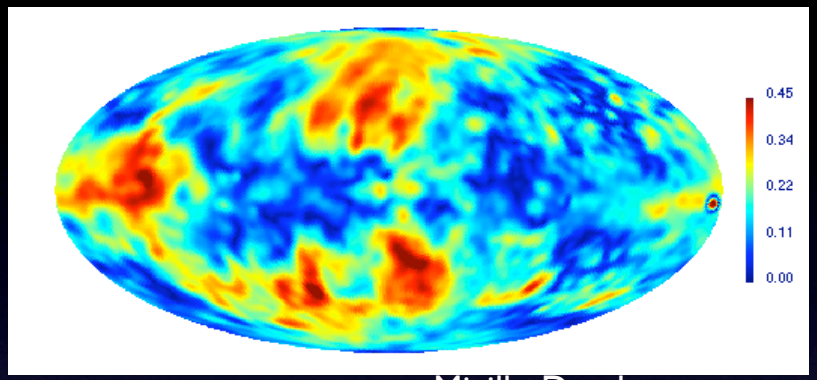
Radial scale length: $h_r \sim 5$ kpc

Synchrotron observations



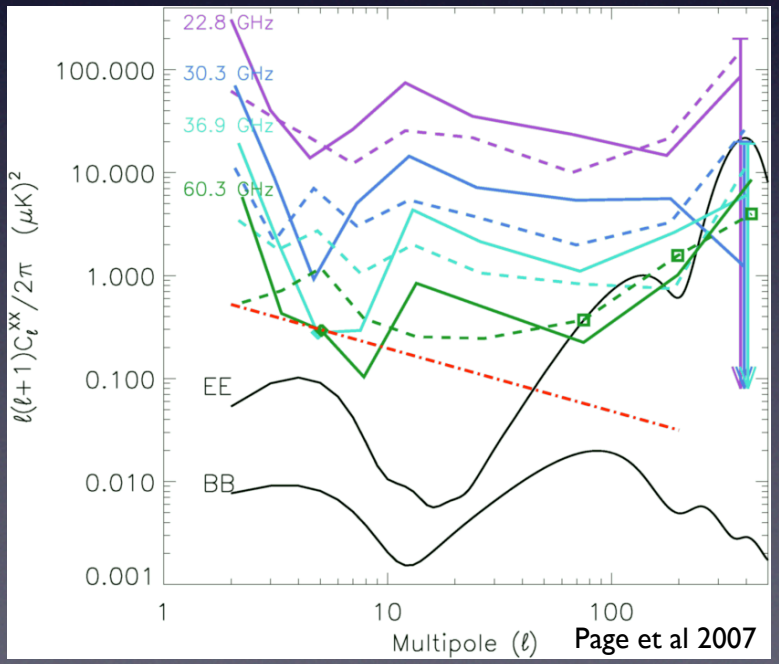
Hinshaw et al 2008

23 GHz, P(synch)

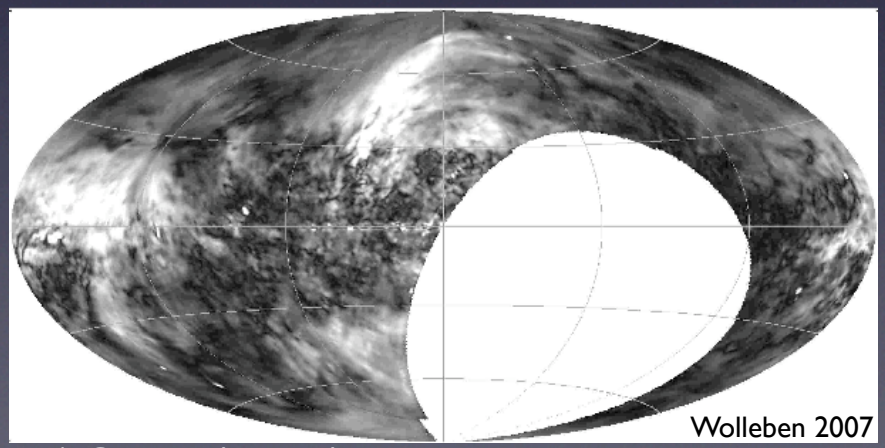


Miville-Deschenes et al 2008

f(synch) = P/I. Up to ~45% polarized



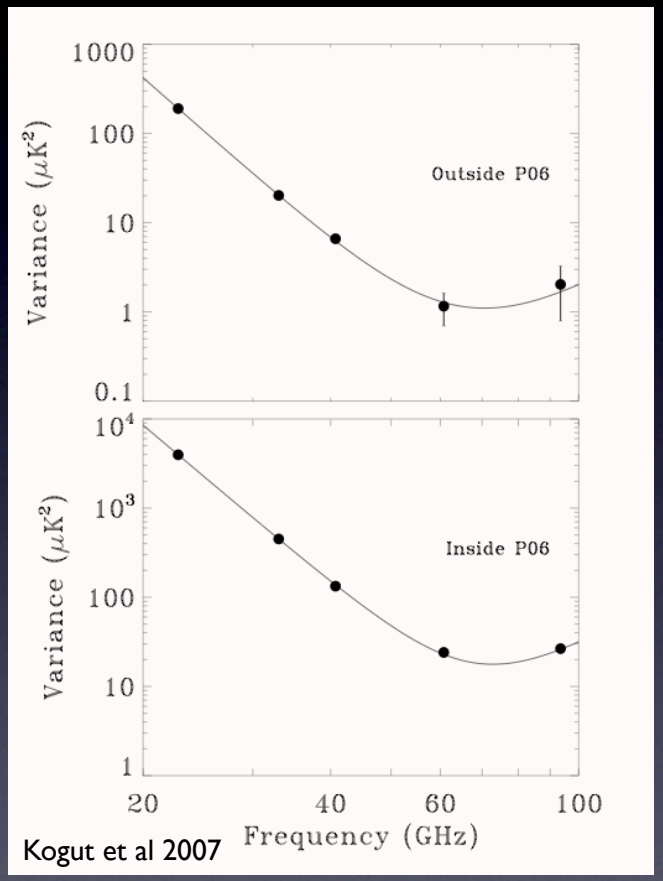
Page et al 2007



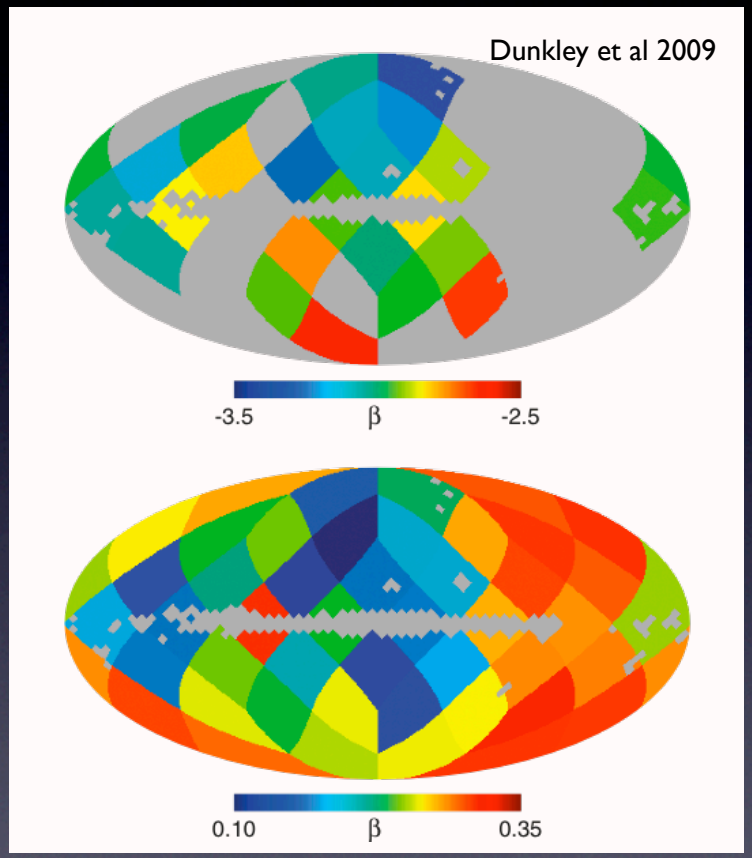
Wolleben 2007

1.4 GHz, P(synch)

Synchrotron index

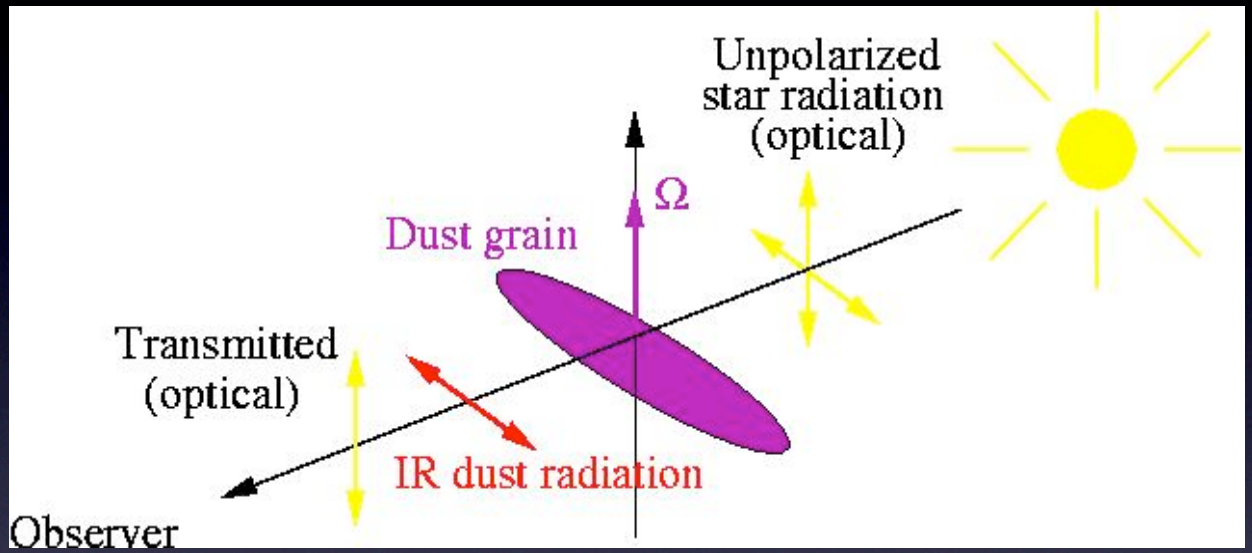


Kogut et al 2007



- Index of β~-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



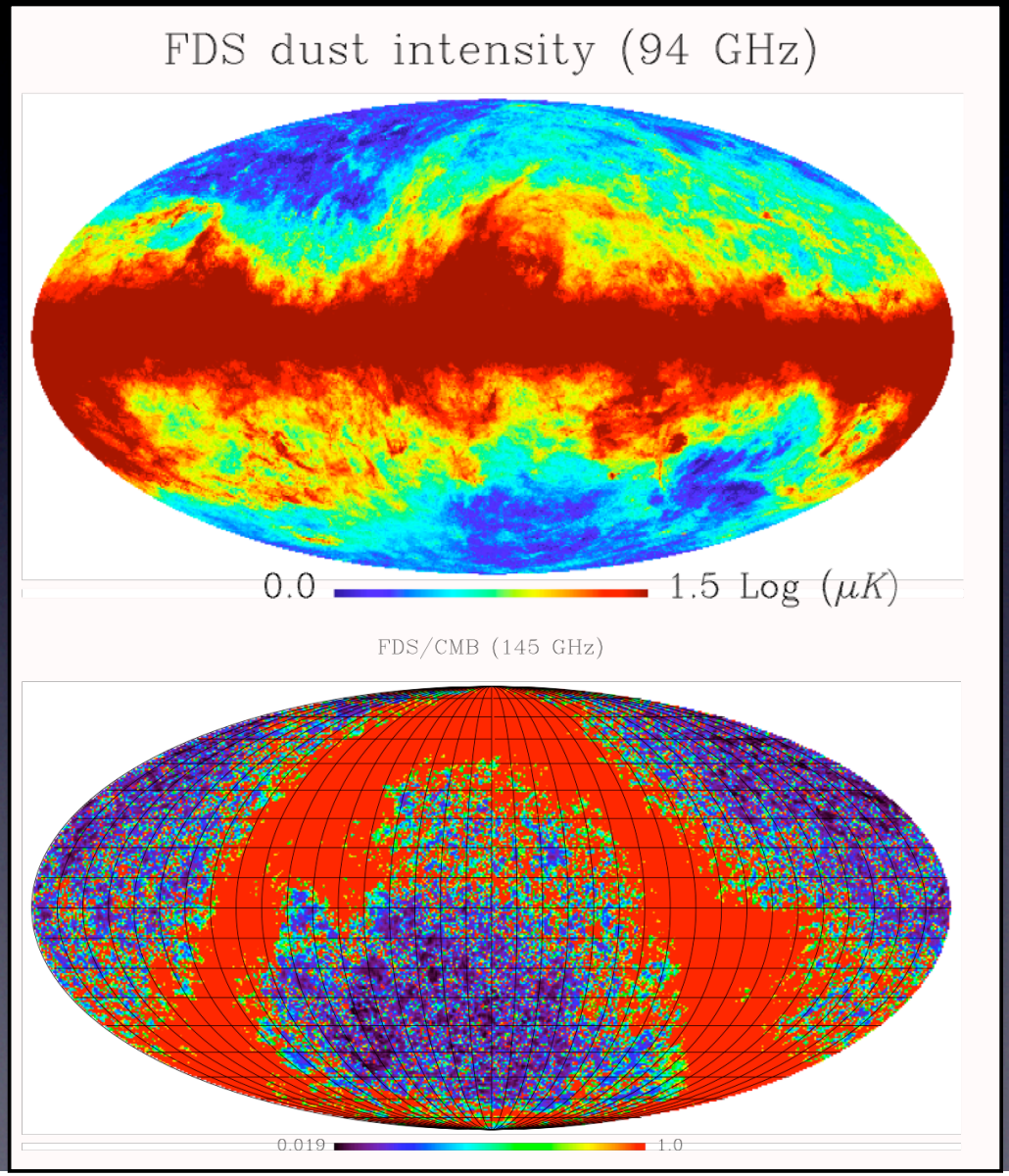
Grains align with B-field

Spectral Index: $T(\nu) \propto \nu^2$ **for one component**

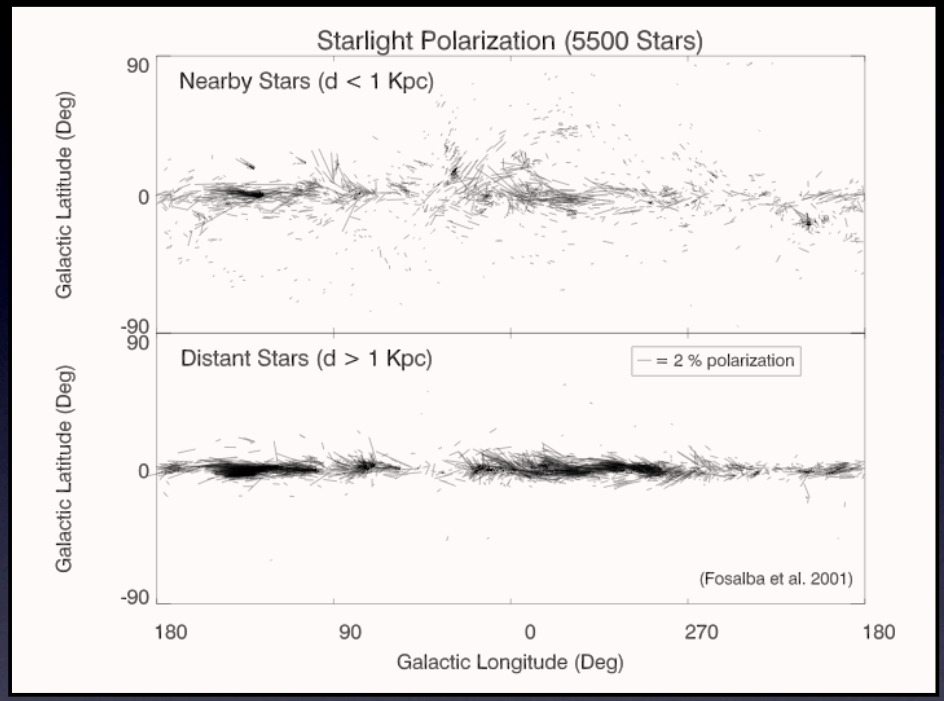
Radiation is polarized perpendicular to B-field

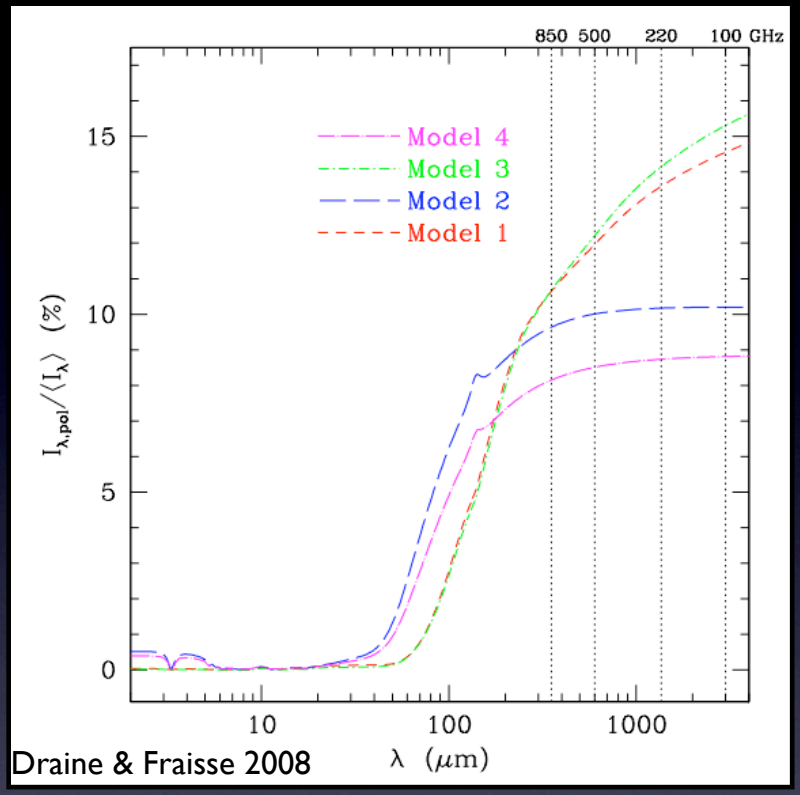
Starlight polarized parallel to B-field

Dust observations (T)



Dust predictions



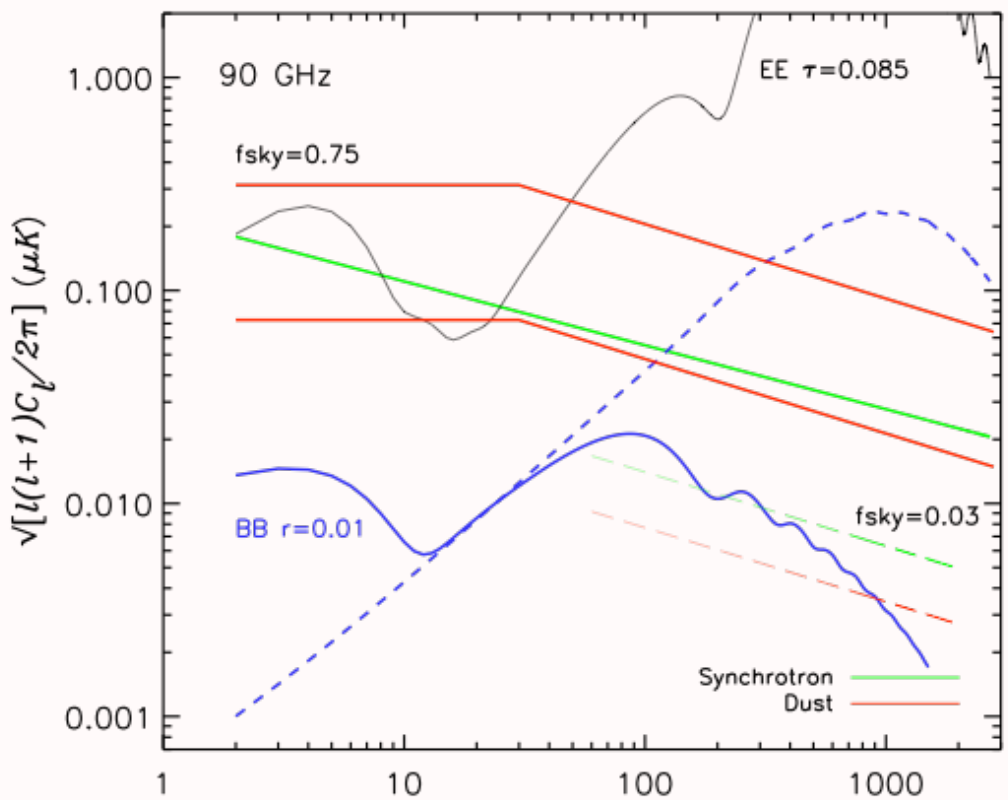


- Fractional polarization ~ few percent (Page et al 2007, Kogut et al 2007). Consistent with QUAD and BICEP (?). Could be ~1-10%.

- Index: IRAS data well fit with two components (β 1=1.7, β 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

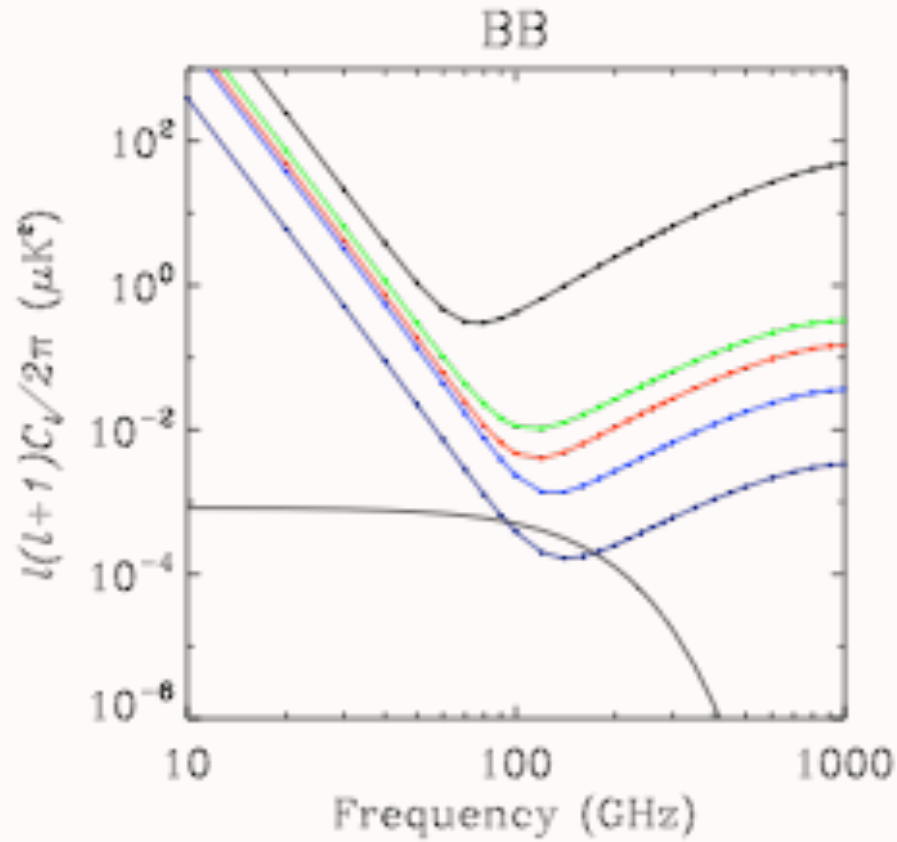


Dunkley et al 2008

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

$$\ell(\ell+1)C_\ell^{\rm Dust}/2\pi = A_d(\nu/\nu_0)^{2\beta_d}(\ell/\ell_0)^{m_s}$$

Comparing signal levels (2)



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

$$\ell(\ell+1)C_\ell^{\rm Dust}/2\pi = A_d(\nu/\nu_0)^{2\beta_d}(\ell/\ell_0)^{m_s}$$

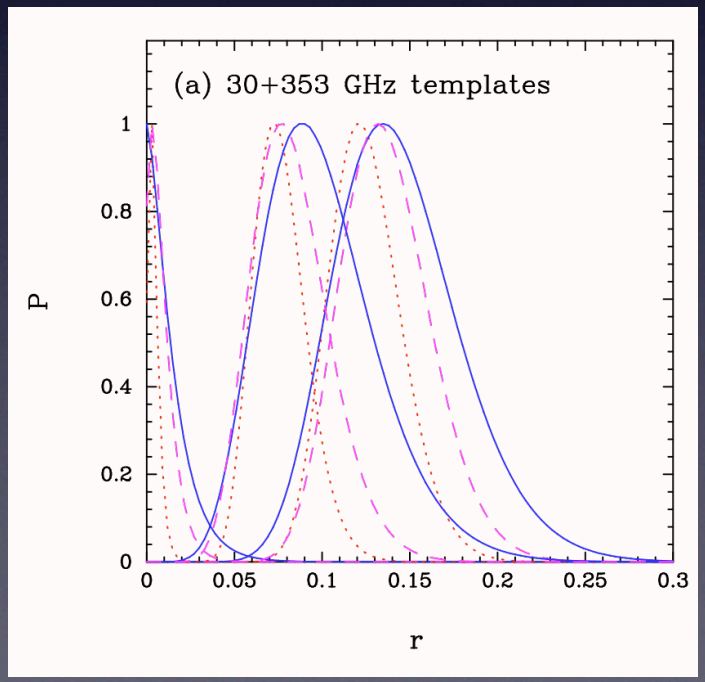
Clive Dickinson

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)

Template cleaning

$$a_{\ell m} = \sum_{\text{freq}=i} w_\ell^i a_{\ell m}^i \,,$$



- 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)

Parametric cleaning

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.

Q/U maps at each frequency *(data)*

→

Q/U CMB and Galactic maps, e.g. amplitude at 'pivot' frequency and spectral indices *(model)*

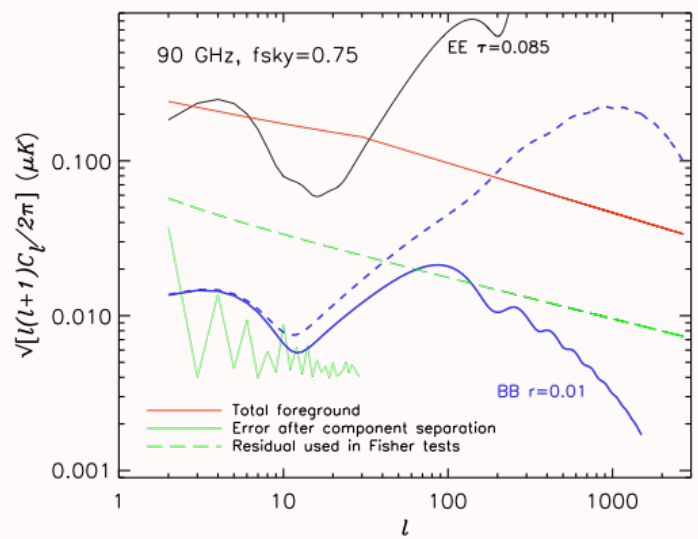
$$\mathcal{L} = \sum_{\nu} [\mathrm{d}_{\nu} - \mathrm{m}_{\nu}]^{T} \mathrm{N}_{\nu}^{-1} [\mathrm{d}_{\nu} - \mathrm{m}_{\nu}],$$

Determining prospects for r

Using template CMBPol 2m mission, 30<nu<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



Dunkley et al 2008

Method	Average dust pol fraction (%)	Description	$\ell < 15$	$\ell < 150$
Fisher	0	No foregrounds	0.0015	0.00046
Fisher	5	10% residual	0.014	0.00052
Parametric	1	Fixed spectral indices	0.0015	0.0005
Parametric	1	Power-law indices	0.0025	—
Parametric	5	Power-law indices	0.003	—
Blind	4	SMICA	—	0.00055

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:

- ν min ~40GHz
- ν 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.

Summary

- 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.