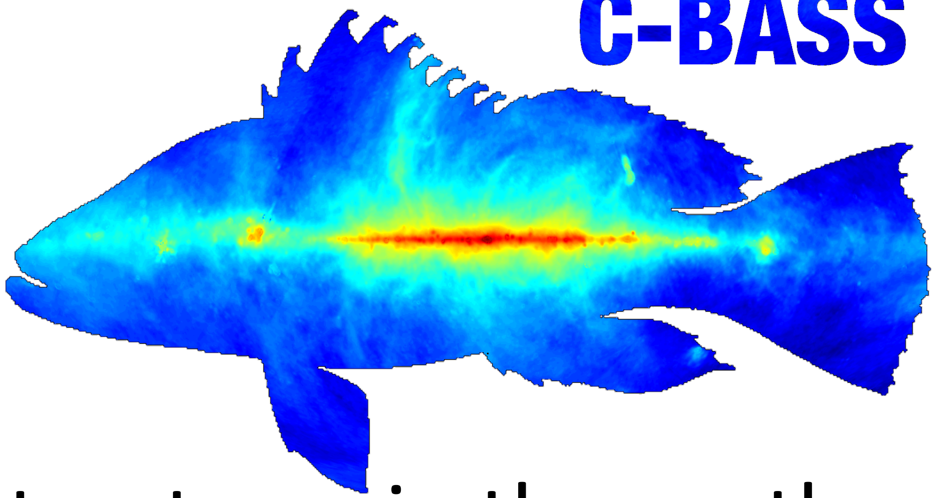
C-BASS



Polarization structures in the northern hemisphere: fractional polarization and constraints on field tangling

Paddy Leahy and Roke Cepida-Arriota

University of Manchester

for the C-BASS collaboration

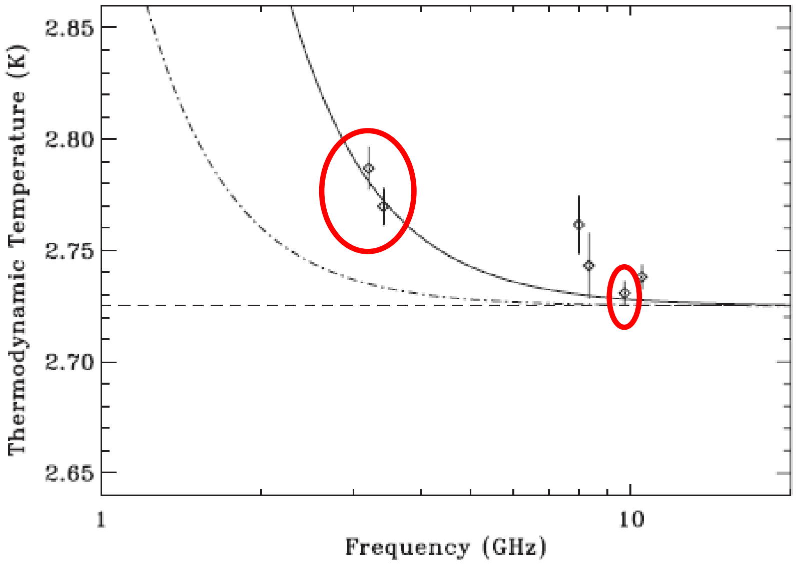
Abstract

- Estimates of all-sky fractional polarization rely on an accurate zero-level: we bootstrapped from ARCADE2
- Digression: $\csc|b|$ disk + monopole is a terrible fit at high latitude.
- High latitude ($b > 30°$) synchrotron emission away from the prominent spurs and loops is weakly polarized, implying strong "tangled" component.
- In the same regions, the polarization vectors are remarkably well-organized, showing little small-scale structure not due to noise, implying weak "tangled" component.
- Illustrated by pre-release C-BASS data
  - Similar points could be made from earlier surveys right back to Brouw & Spoelstra (1976)
- Possible explanations:
  - unpolarized synchrotron-like component (cosmological or local)
  - Fine-scale structure unresolved by C-BASS at $1°$ FWHM (unlikely)
  - Fortuitous cancellation of polarization due to coherent large-scale structure (e.g. halo vs. disk fields).

Absolute Zero Level

- C-BASS continuously compares observed total intensity to internal cold load
  - suppresses $1/f$ noise
  - Not accurate enough to set absolute zero level
  - Data zero level is discarded by the destriping map-maker, DESCART (Sutton et al 2010)
- Instead, set zero level using ARCADE2 absolute measurements (Fixsen et al. 2011)
  - 6 channels from 3 to 10.5 GHz
  - Interpolate to C-BASS centre frequency of 4.76 GHz.

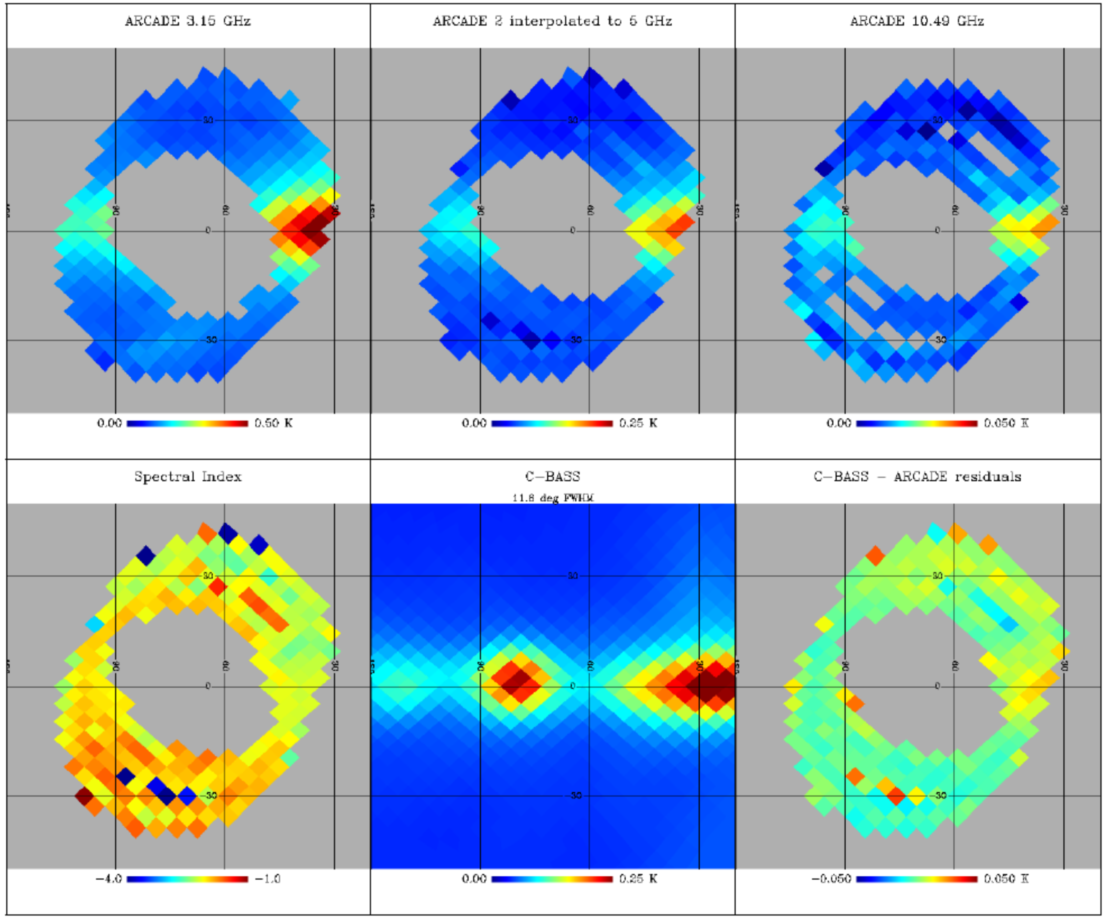
ARCADE2 data (Seiffert et al 2011)



- Offsets between channels are systematic and much larger than the noise.
- 8.0 GHz channel high by 22 mK
- Used 3 channels with most consistent offsets

ARCADE/C-BASS Bootstrap

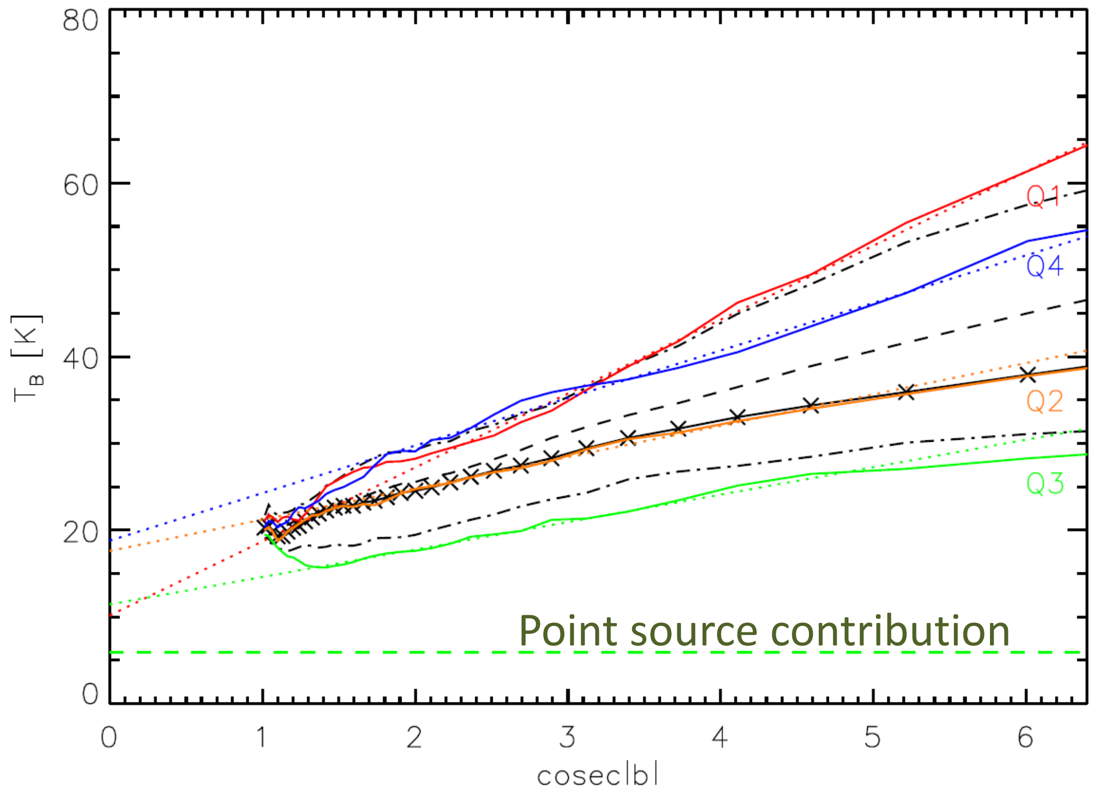
- Assume CMB has blackbody spectrum with 2.7255 K monopole and 3.36 mK dipole
  - No spectral distortions
- Subtract CMB from ARCADE frequency maps and fit power law at each pixel; interpolate to 4.76 GHz (C-BASS).
- Subtract dipole from C-BASS & fit to get zero-level of synchrotron(-like) intensity.
- We use this to calculate the fractional polarization at 1°resolution
  - Implicitly assuming that "ARCADE background" is part of Galactic synchrotron emission.



Slab model analysis

- Plane-parallel galactic disk implies brightness $T \propto \csc b$
- Reasonable fit to distribution of Pop I layer (HI, dust, CII)
- Shklovsky (1952): terrible fit to Galactic synchrotron emission.
- Actual **excess** of emission near Galactic poles
- Minimum synchrotron brightness near $b \approx 30°$
- $\csc b$ fits give radically different offsets in different galactic quadrants

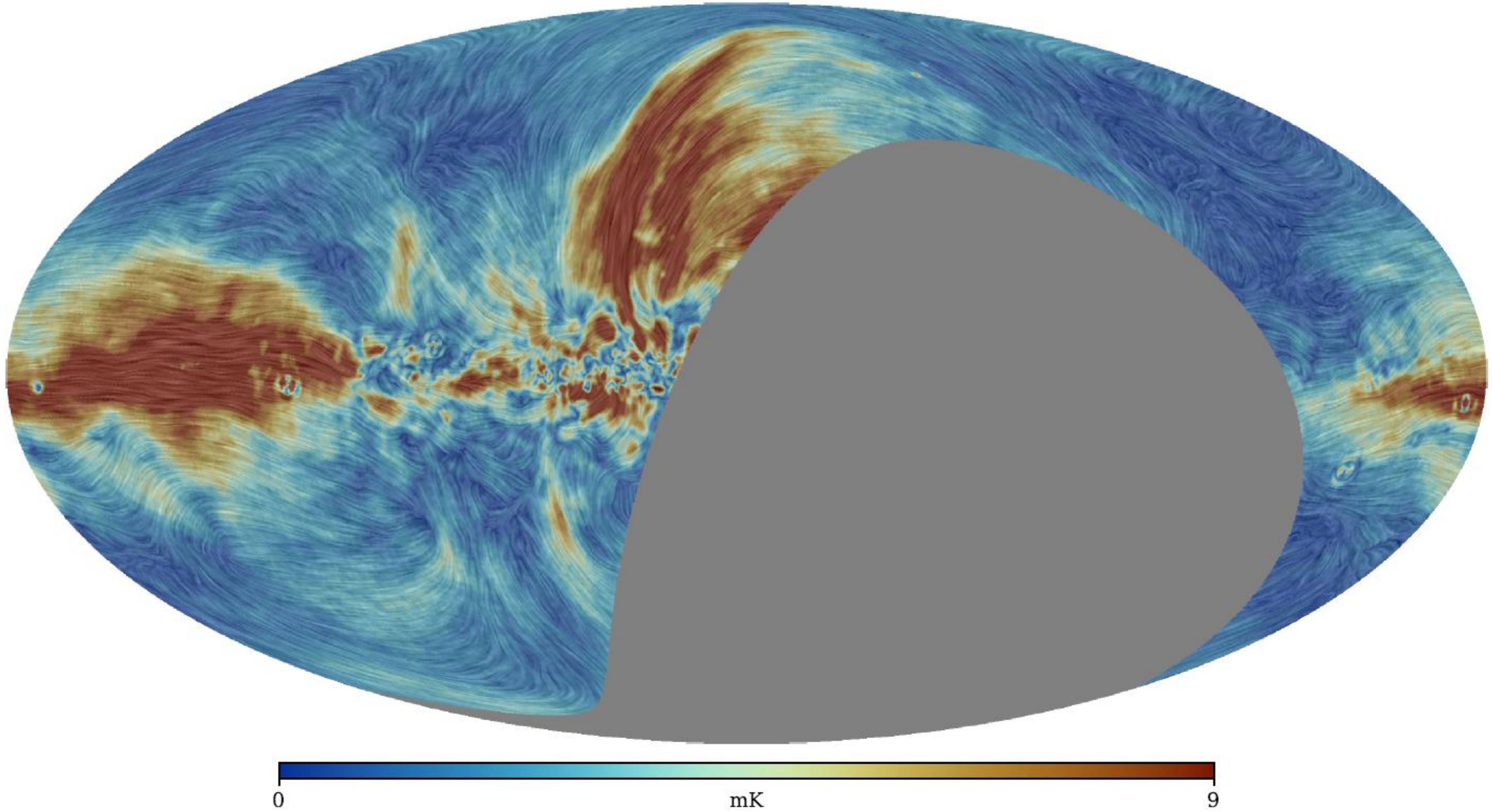
Fits to 408 MHz Haslam map (Remezailles version)



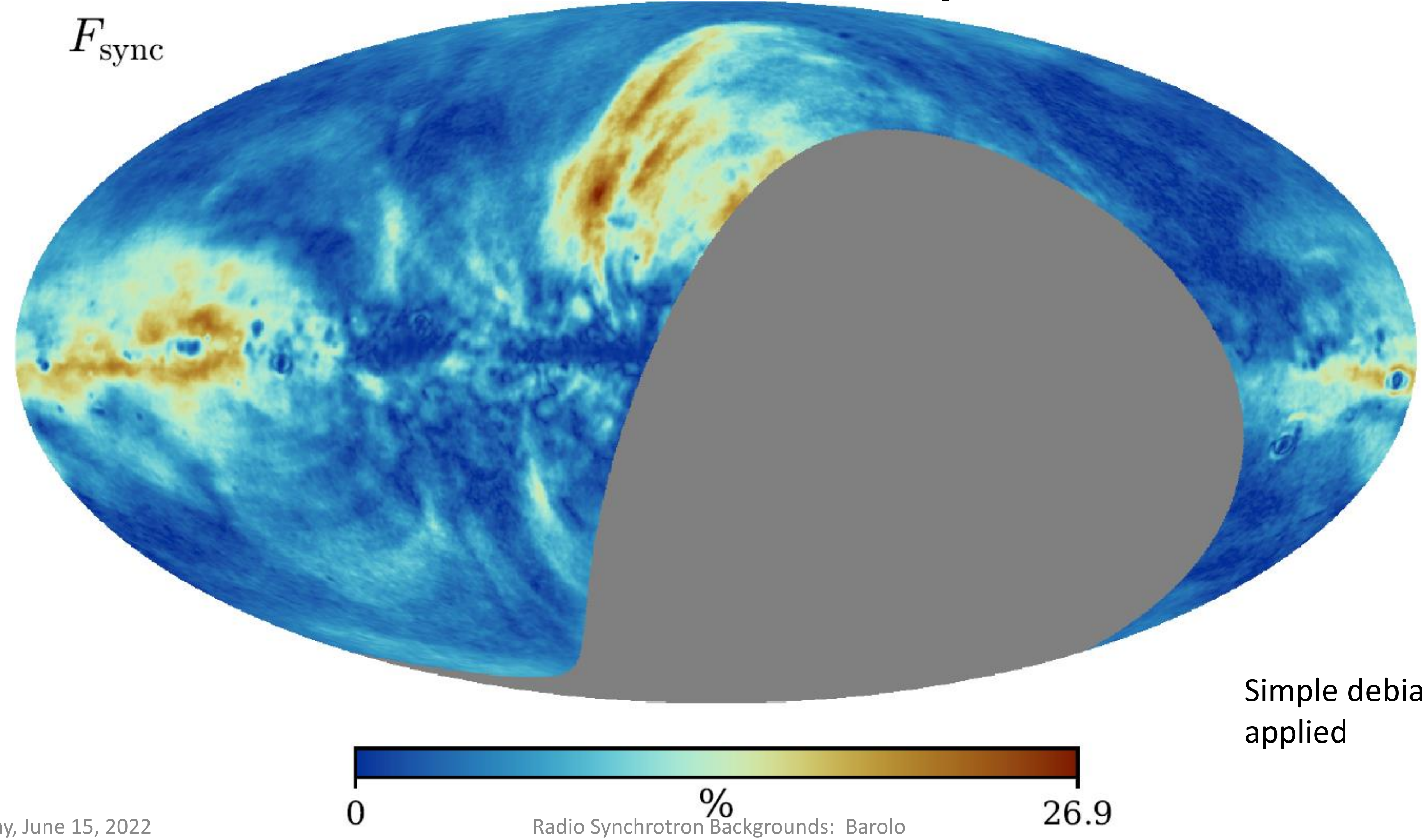
Reasons for scepticism about extragalactic excess background

- Excess emission at poles implies that **at least** there must be an anisotropic component present in addition to a disk model.
- Anisotropic $\rightarrow$ local (i.e. Galactic)
  - NB: eROSITA map strongly suggests North Polar Spur is Galactic-scale feature associated with Fermi bubbles.
- Any physical emission component is positive-only $\rightarrow$ the anisotropic Galactic component has a significant monopole.
- Beuermann et al. (1988) made a 3D Galactic emission model to fit the Haslam map. They explained the high-latitude excess emission by
  1. a finite thick disk with radial intensity distribution, and allowance for arm-interarm emissivity differences gives significantly more emission at high latitude than infinite slab, reducing apparent excess by a factor of about 2.
  2. They assigned slightly enhanced emissivity ($\sim \times 1.6$) to the local spiral arm.

C-BASS North Polarization

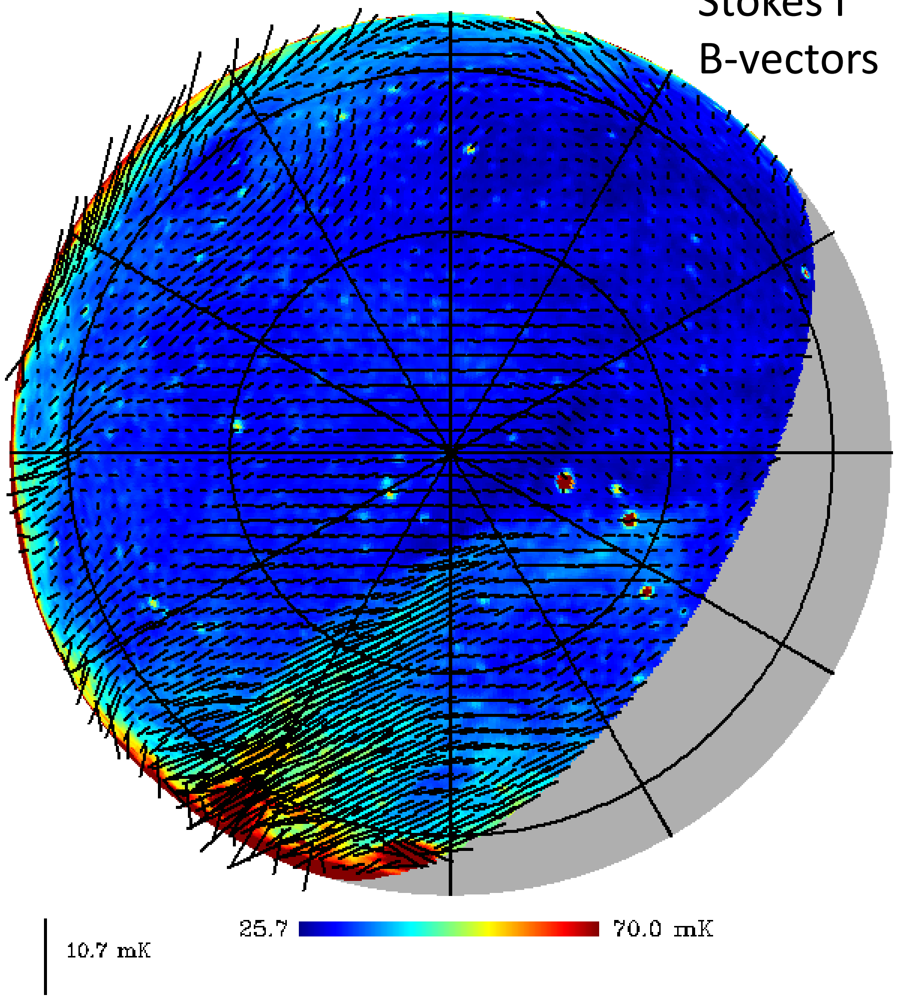


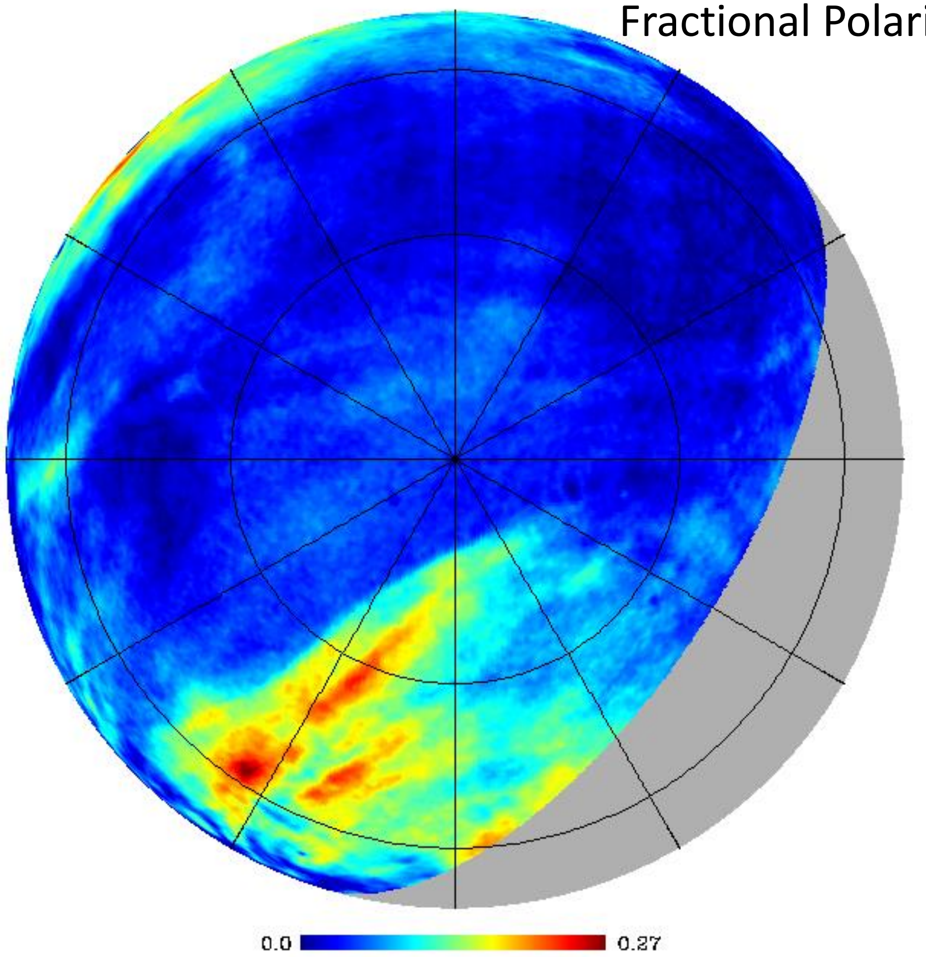
C-BASS North Fractional polarization



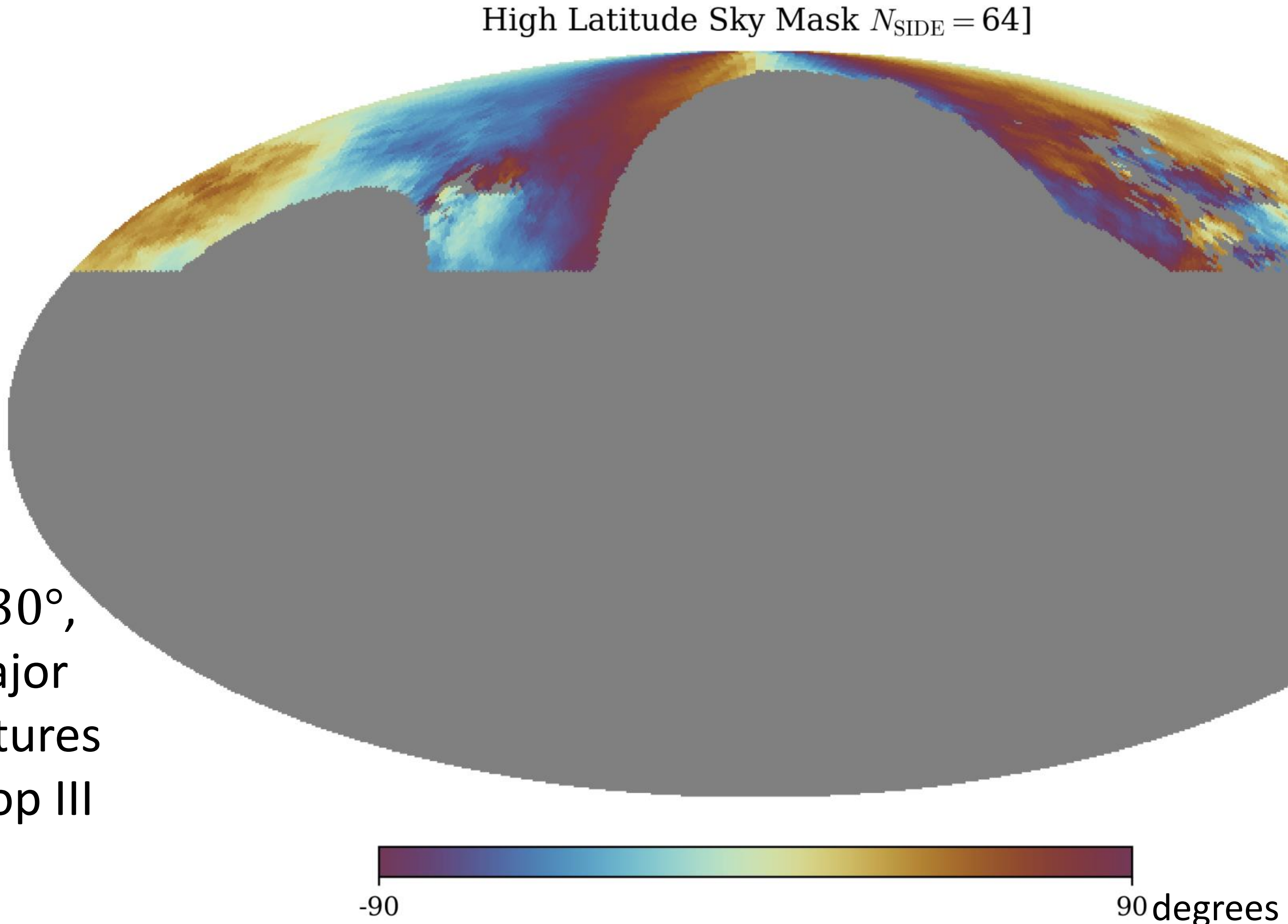
Simple debiasing applied

North Galactic Pole projection





High-latitude Polarization angles

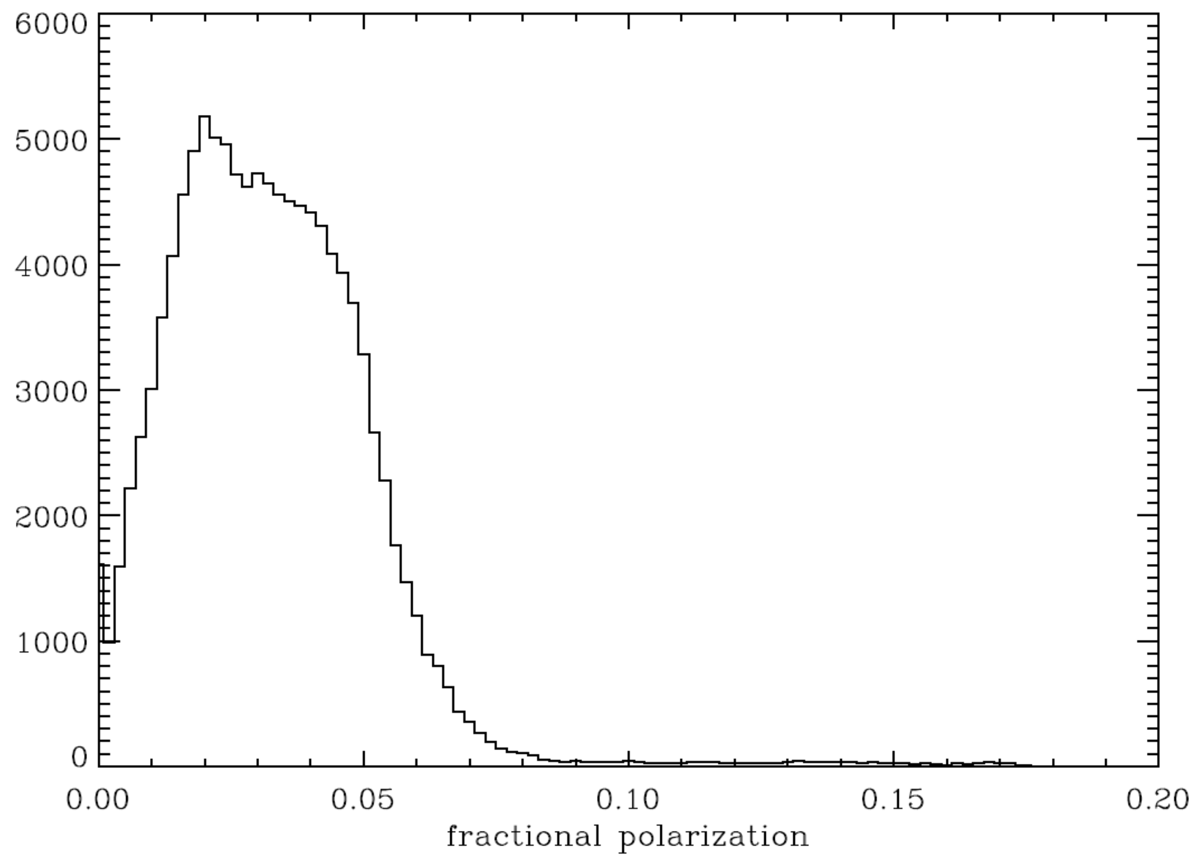


degrees

Mask: $b > 30°$, excludes major local (?) features Loop I & Loop III

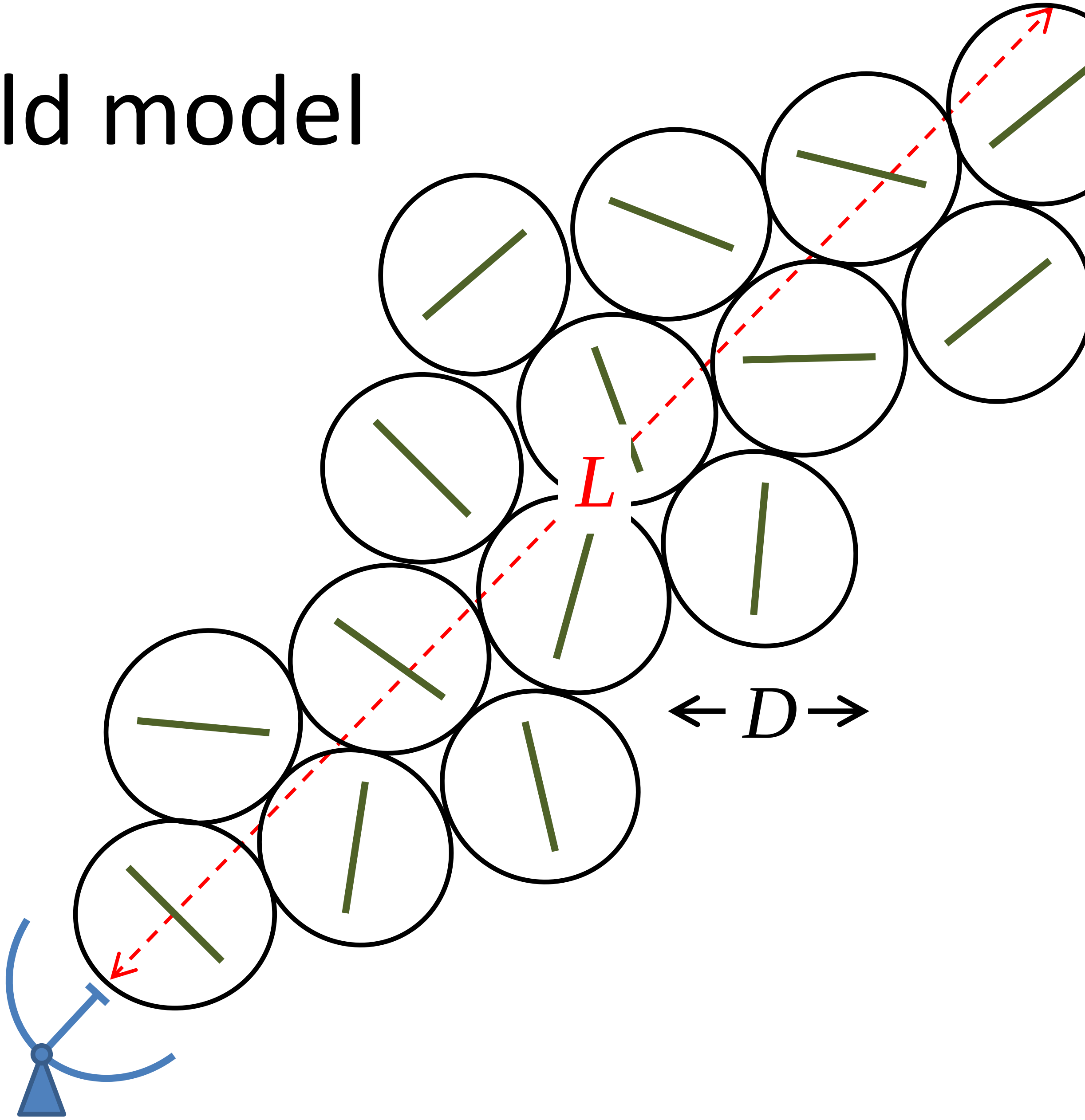
Low fractional polarization

- Median m in our high-latitude zone $= 3.1\%$; $\langle m \rangle = 3.3\%$
- Nearly all pixels < 10%
- Strong contrast with polarization in the Spurs, and Fan region (up to 30%)
- NB: due to high SNR, our debiasing correction makes almost no difference to these results.



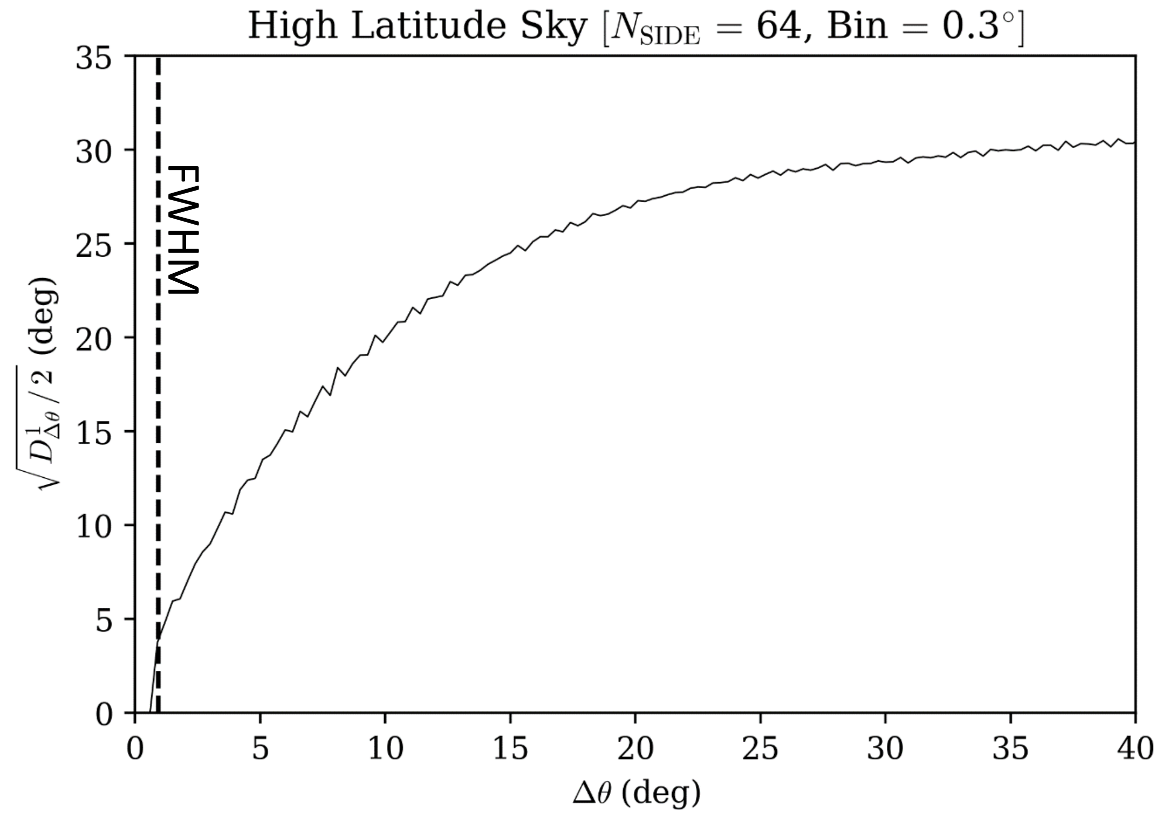
Tangled-field model

- Consider a toy model where the Galactic synchrotron emission consists of cells of coherent magnetic field with scale size D, with field direction uncorrelated between cells.
- Emission from one cell has the theoretical maximum fractional polarization, $m_0 = \frac{6\alpha+6}{6\alpha+10} \approx 75\%\ (\alpha = 1)$.
- On a line of sight of length L, there are $N \approx L/D$ cells, and the net polarization is a random walk in (Q, U) with N steps, so $m = m_0/\sqrt{N}$.
- Typical angular scale of polarization change is $2\sin\Delta\theta_0/2 \approx \frac{D}{L/2} = \frac{2}{N}$



Polarization Position Angle Structure Function

- …actually square root of structure function/2, i.e. random scatter in difference in PA between pixels separated by $\Delta\theta$.
- Parallel transport corrected to avoid singularity at pole
- Spherical cat theorem: even emission from uniform magnetic field gives apparent PA structure.
- Main takeaways:
  - Typical scale for PA variation $\Delta\theta_0 \approx 15°$
  - Slight residual order on larger scale: for random angles expect $\sqrt{D^1_{\Delta\theta}/2} = 37°$



Implications of tangled field model

- $\Delta\theta_0 = 15°$ implies $N = 7.7$
- Hence we expect

$$m = \frac{75\%}{\sqrt{N}} \approx 27\%$$

- Highly inconsistent with observed $\langle m \rangle = 3.3\%$

Possible resolutions

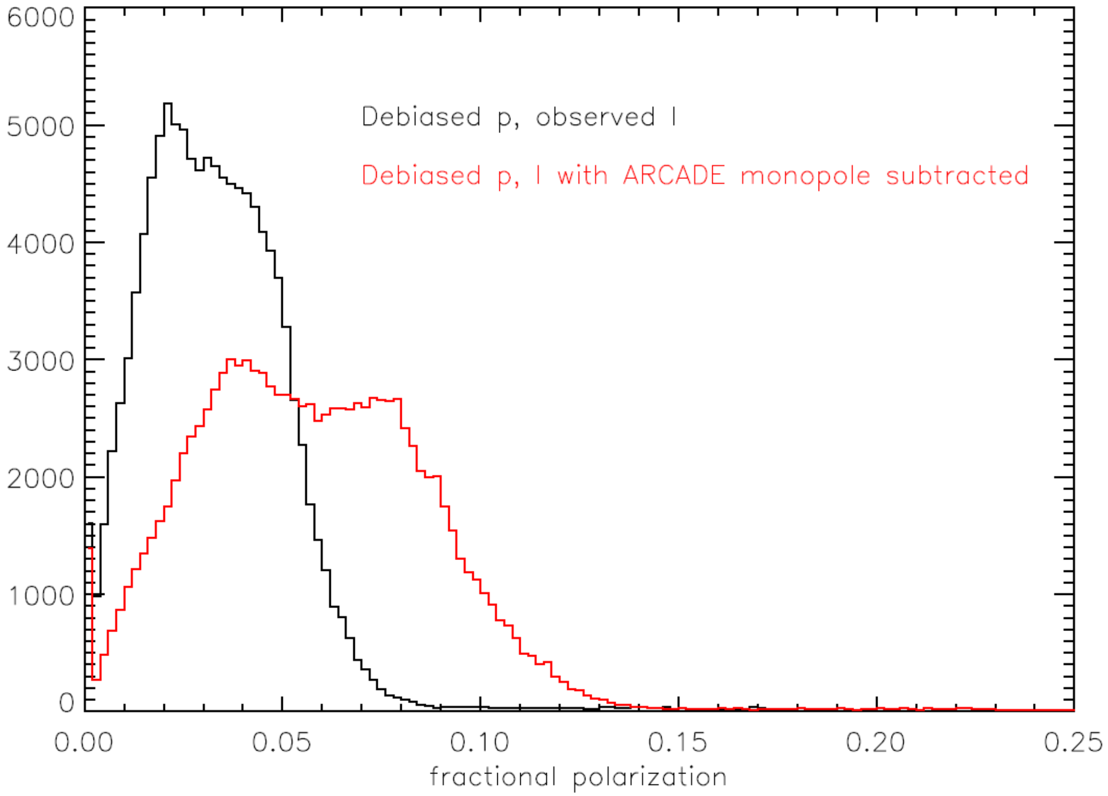
1. Extra unpolarized isotropic background?
   - known population of extragalactic sources (Vernstrom et al 2014): ≈ 4 mK.
   - nowhere near enough.
   - ARCADE2 estimate contributes ≈ 16.4 mK at 4.76 GHz
   - Subtracting this would increase mean high-latitude m to 5.6% (see later)

2. Second scale of fluctuations unresolved by C-BASS?
   - Would require enhanced fluctuations on scales $< 1°$
   - Absolutely no evidence for this in polarization, e.g. preliminary results from GALFACTS

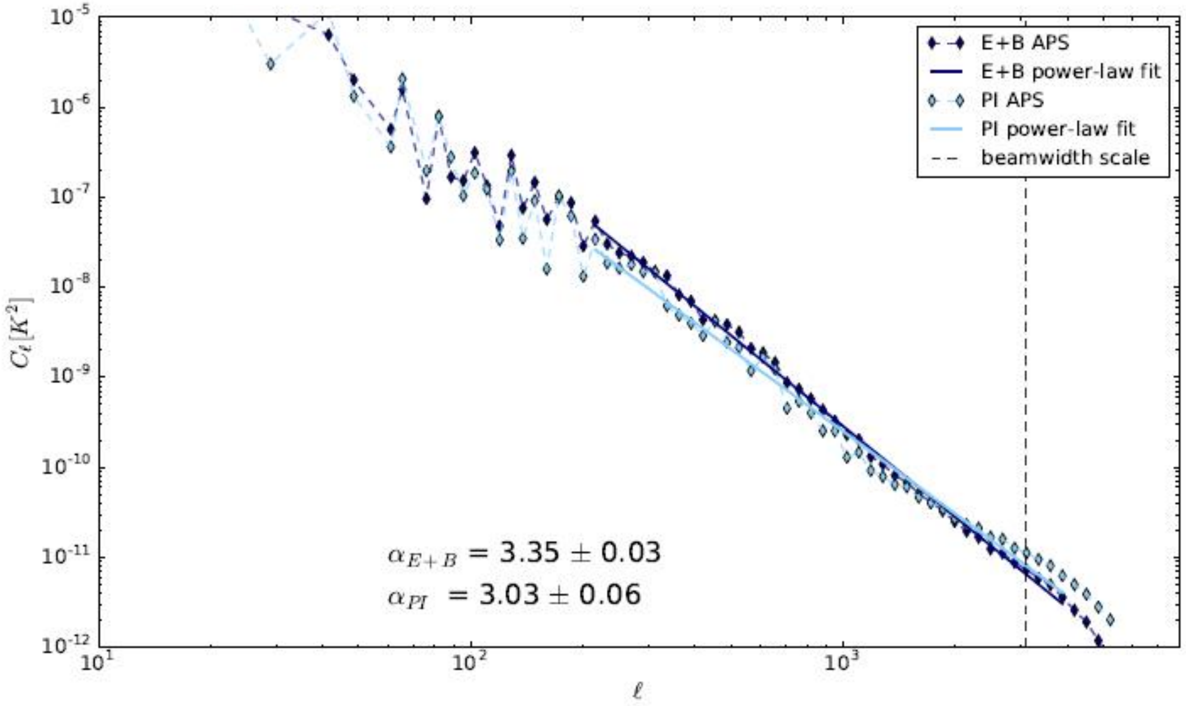
3. Fortuitous cancellation of polarization due to coherent large-scale structure
   - E.g. halo vs disk magnetic field

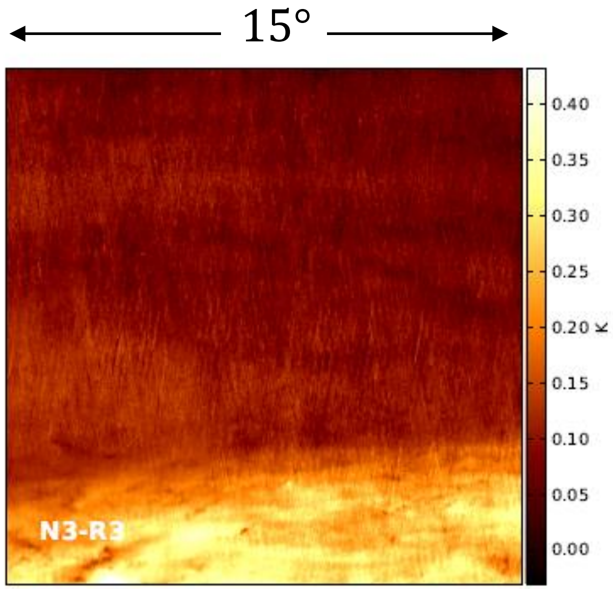
Impact of removing unpolarized monopole

- Subtracting nominal ARCADE2 monopole:
- Median $m = 5.6\%$
- $\langle m \rangle = 5.8\%$
- We still have a problem with surprisingly low fractional polarization, even if there is such an unpolarized component.
  - maybe its amplitude is actually higher in the polar regions?



Example GALFACTS result





- from Indy Leclercq PhD thesis (2016).
- Polarization power spectrum of region centred at $b = 54°$, featuring edge of North Polar Spur
- Arecibo data, 3.4 arcmin beam. Subsection of $92° \times 18°$ survey field.
- Analysis of 31 regions found only one with $\ell^2 C_\ell$ rising with ℓ, and none with significant kink near $\ell = 200$ corresponding to C-BASS resolution.

Conclusions

- High latitude polarization is weak but ordered
- Interpretations:
  1. Large scale difference between ordered and turbulent field. Turbulence outer scale < 2% of scale height.
  2. Two components, one nearly unpolarized
     - E.g. emission from synchrotron shell around local bubble?
  3. Two components with nearly-orthogonal polarization: disk vs halo?
- Just one more thing…

L-BASS

- Will make an absolutely calibrated sky map at $\lambda 21$ cm.
- For very well defined beam with minimal sidelobes, observe sky directly with horn antenna
- Very low resolution, $\approx 20°$
- Differential measurement:
  - NCP vs scanning horn
  - NCP vs cryogenic cold load
- Currently being commissioned at Jodrell Bank