Fingerprints of Galactic Loop I on the Cosmic Microwave Background

Philipp Mertsch
with Hao Liu & Subir Sarkar

COSMO2014
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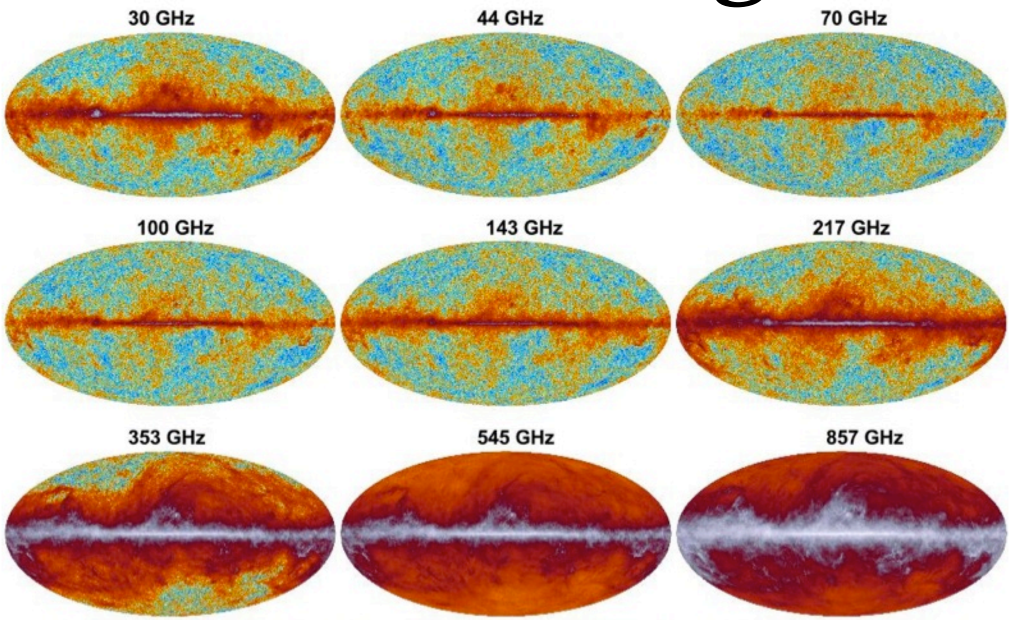
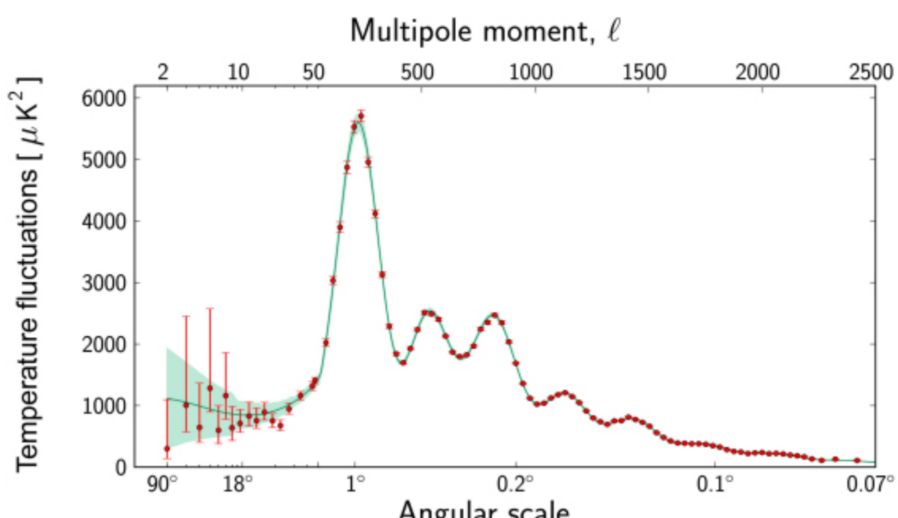
Stanford University
KIPAC

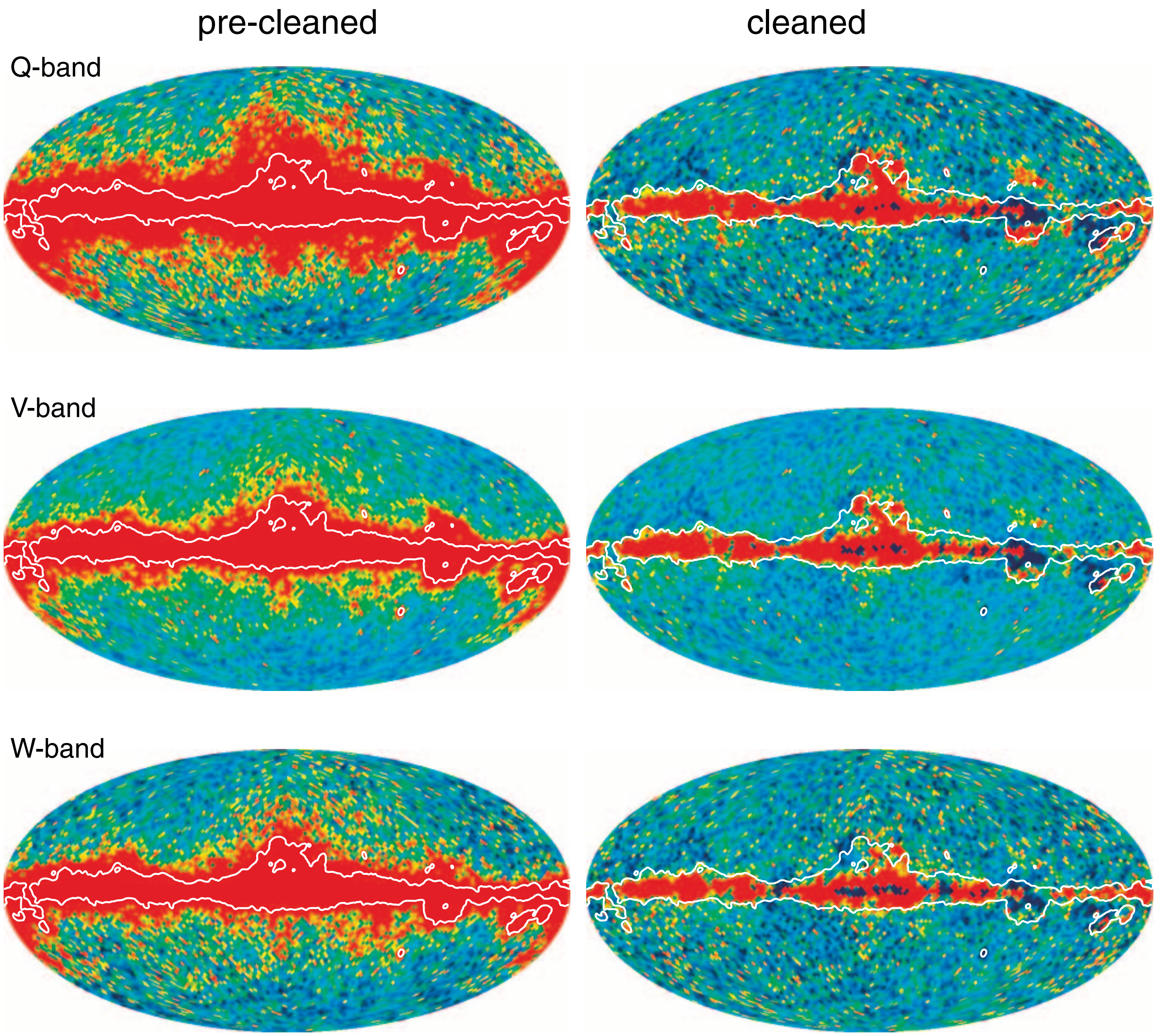
CMB foreground removal



Ade *et al.*, arXiv:1303.5072

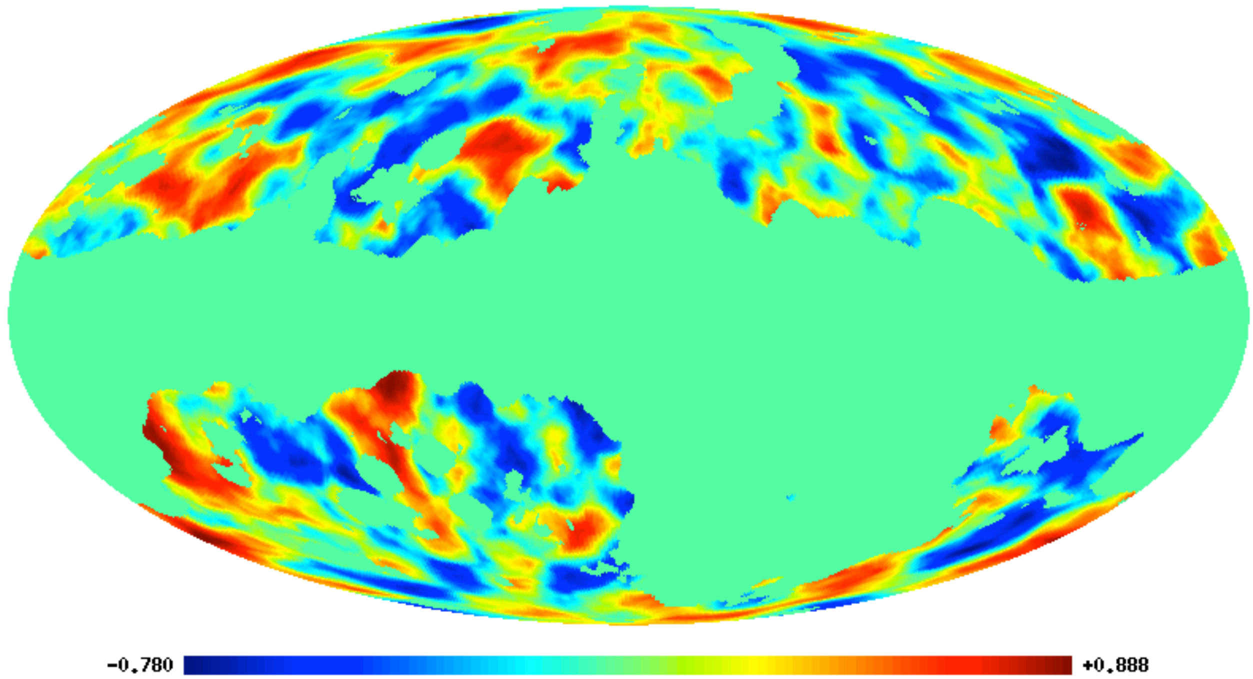


Before and after



Hinshaw *et al.*, ApJS 170 (2007) 288

CMB contamination at high latitude?

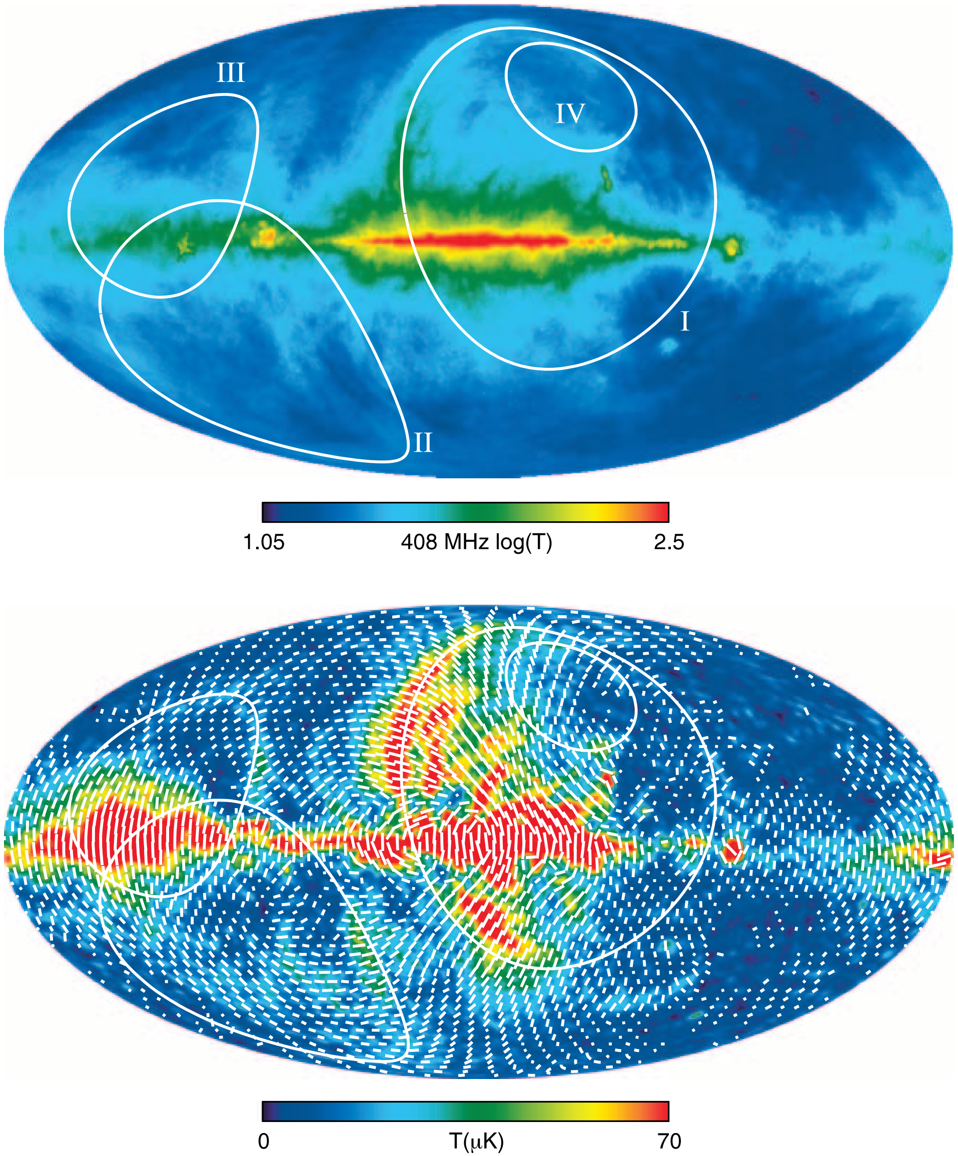


correlation between Faraday depth and WMAP7 ILC

MC simulations: standard deviation of correlation anomalous with p-value $< 5 \times 10^{-4}$

Hansen *et al.*, MNRAS **426** (2012) 57; Dineen & Coles MNRAS **347** (2004) 52

Radio loops

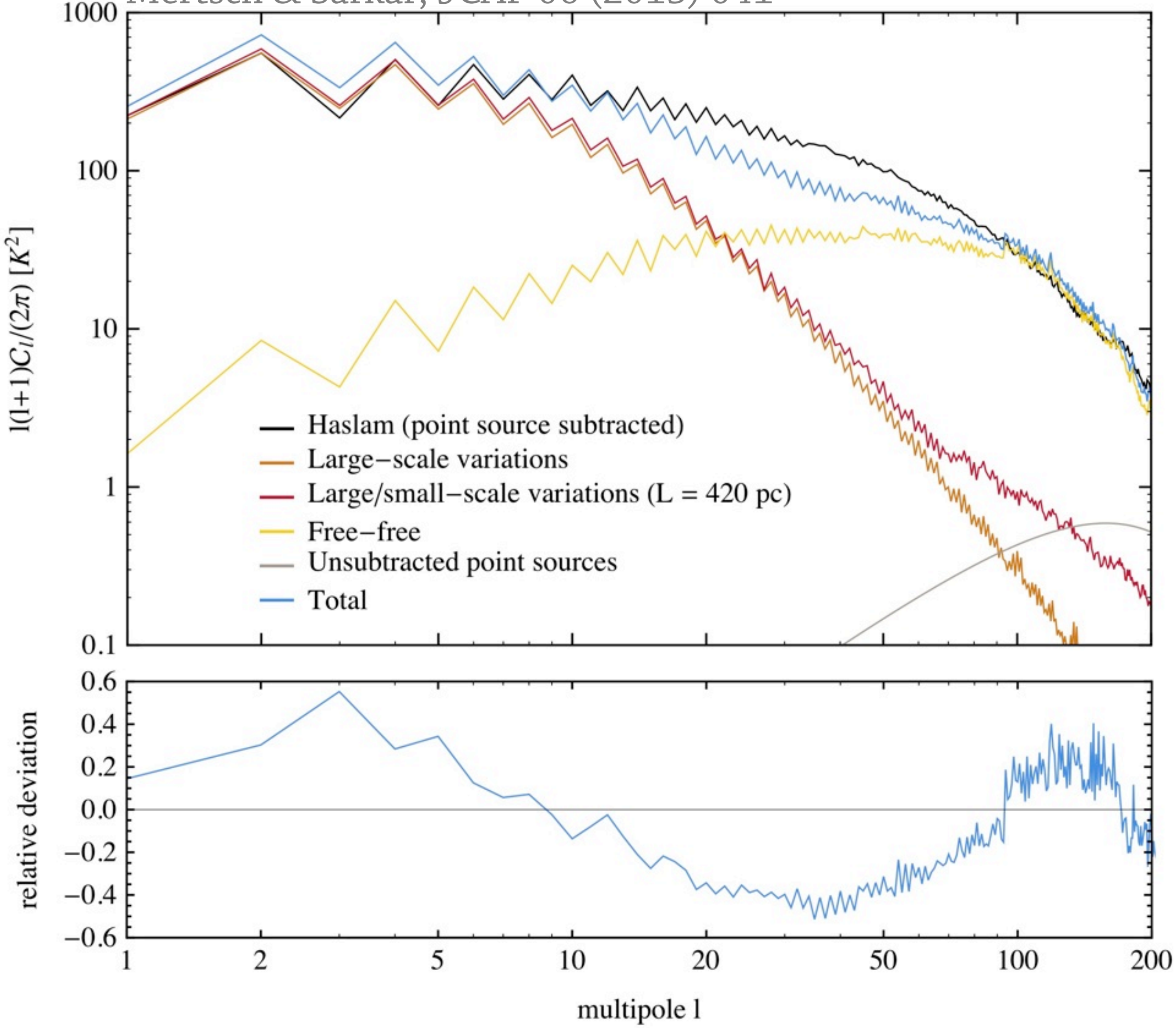


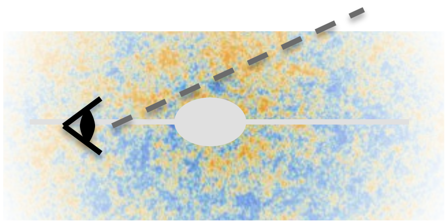
Page *et al.*, ApJS 170 (2007) 335

- probably shells of old SNRs
- can only observe 4 (5) radio loops directly in radio maps
- total Galactic population of up to O(1000) can contribute on *all* scales

Modelling the APS @ 408 MHz

Mertsch & Sarkar, JCAP 06 (2013) 041





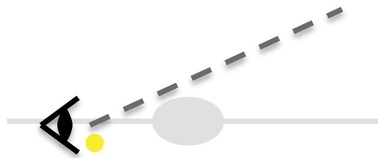
synchrotron:
smooth emissivity
and turbulence

free-free:
WMAP MEM-template

unsubtracted sources:
shot noise

Modelling individual shells

Mertsch & Sarkar, JCAP 06 (2013) 041

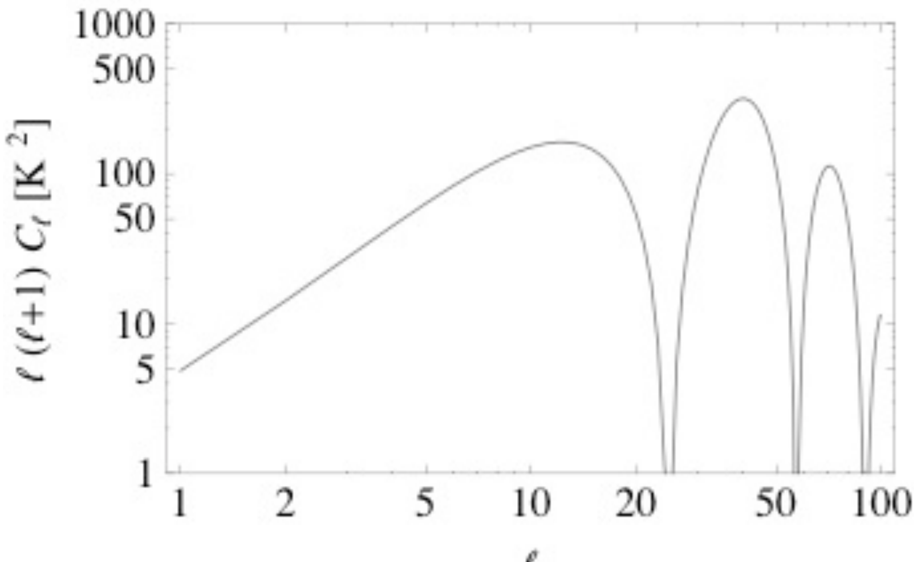


assumption: flux from one shell factorises into angular part and frequency part: $J_{\text{shell } i}(\nu, \ell, b) = \varepsilon_i(\nu) g_i(\ell, b)$

frequency part $\varepsilon_i(\nu)$:
magnetic field gets compressed in SNR shell
electrons get betatron accelerated
emissivity increased with respect to ISM

angular part $g_i(\ell, b)$:
assume constant emissivity in thin shell:

$$a^{i}_{lm}{}' \sim \varepsilon_i(\nu) \int_{-1}^{1} \mathrm{d}z' P_l(z') g_i(z')$$



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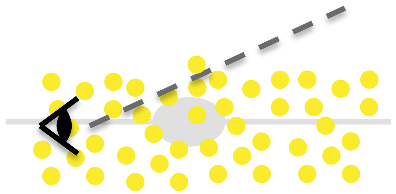
Mertsch & Sarkar, JCAP 06 (2013) 041



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assume constant emissivity in thin shell:

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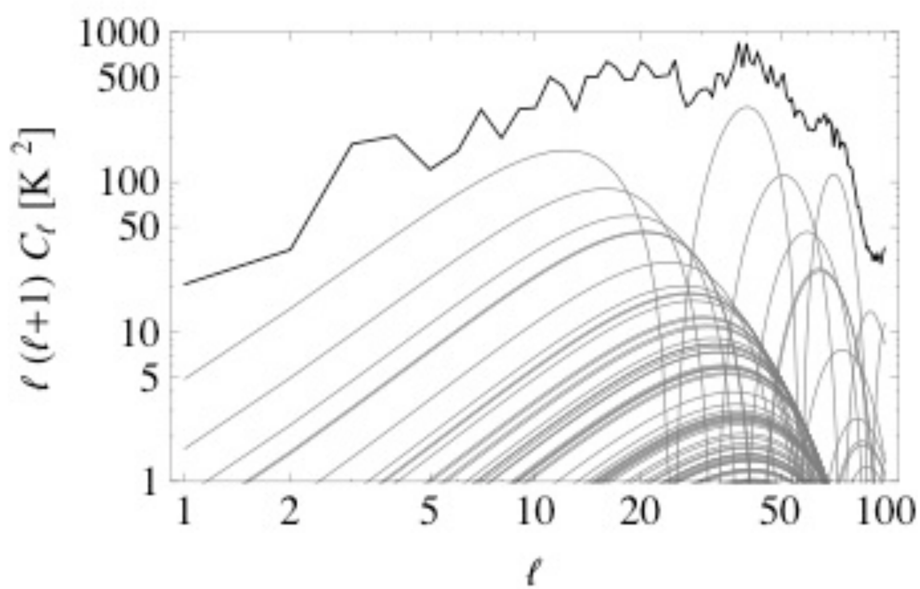
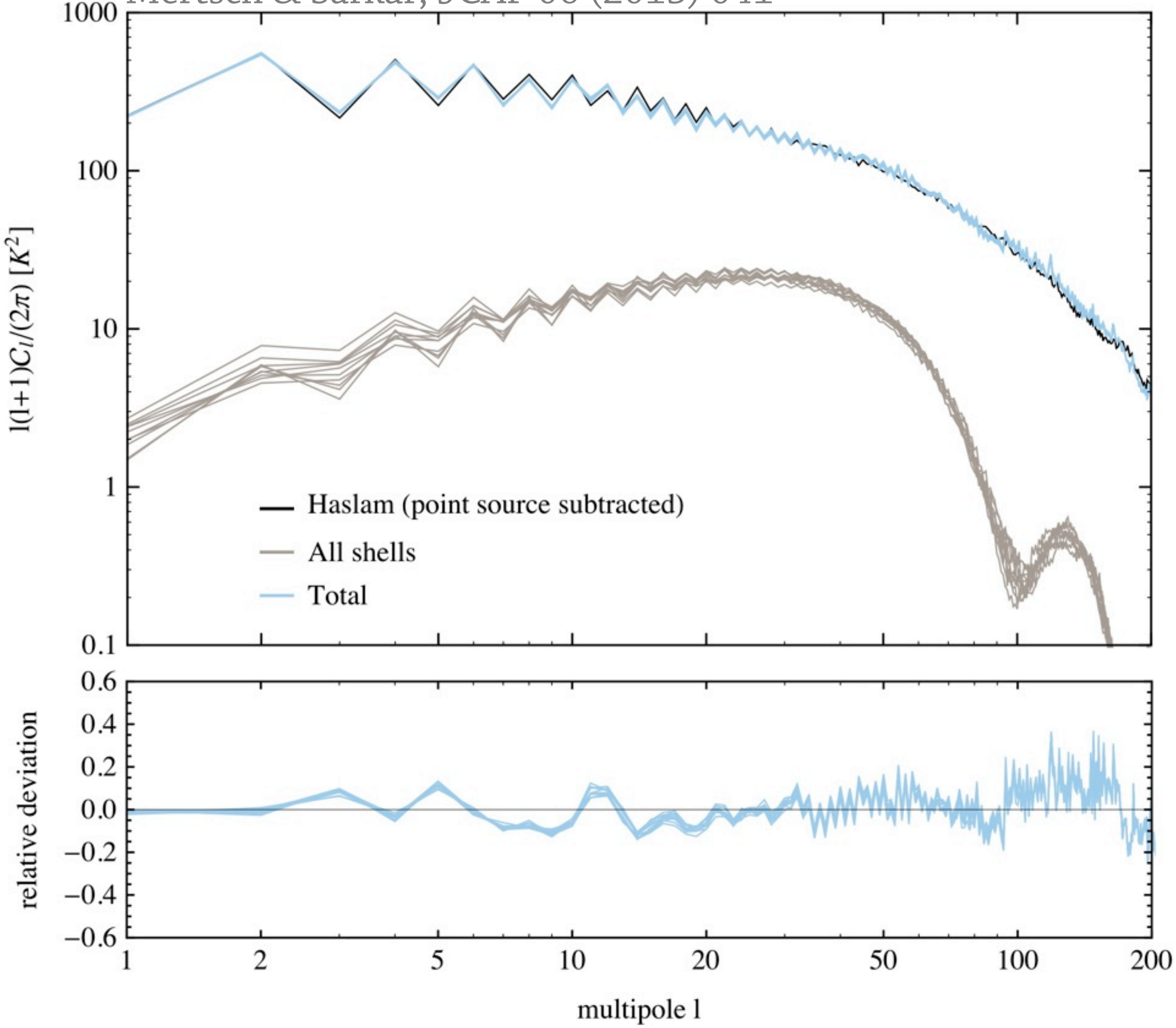


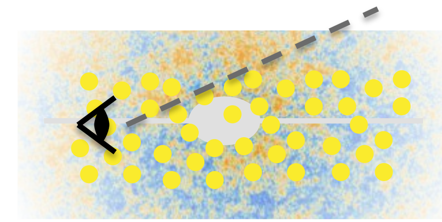
add up contribution from all shells

$$a^{\text{total}}_{lm} = \sum_i a^{i}_{lm}$$

...including ensemble of shells

Mertsch & Sarkar, JCAP 06 (2013) 041





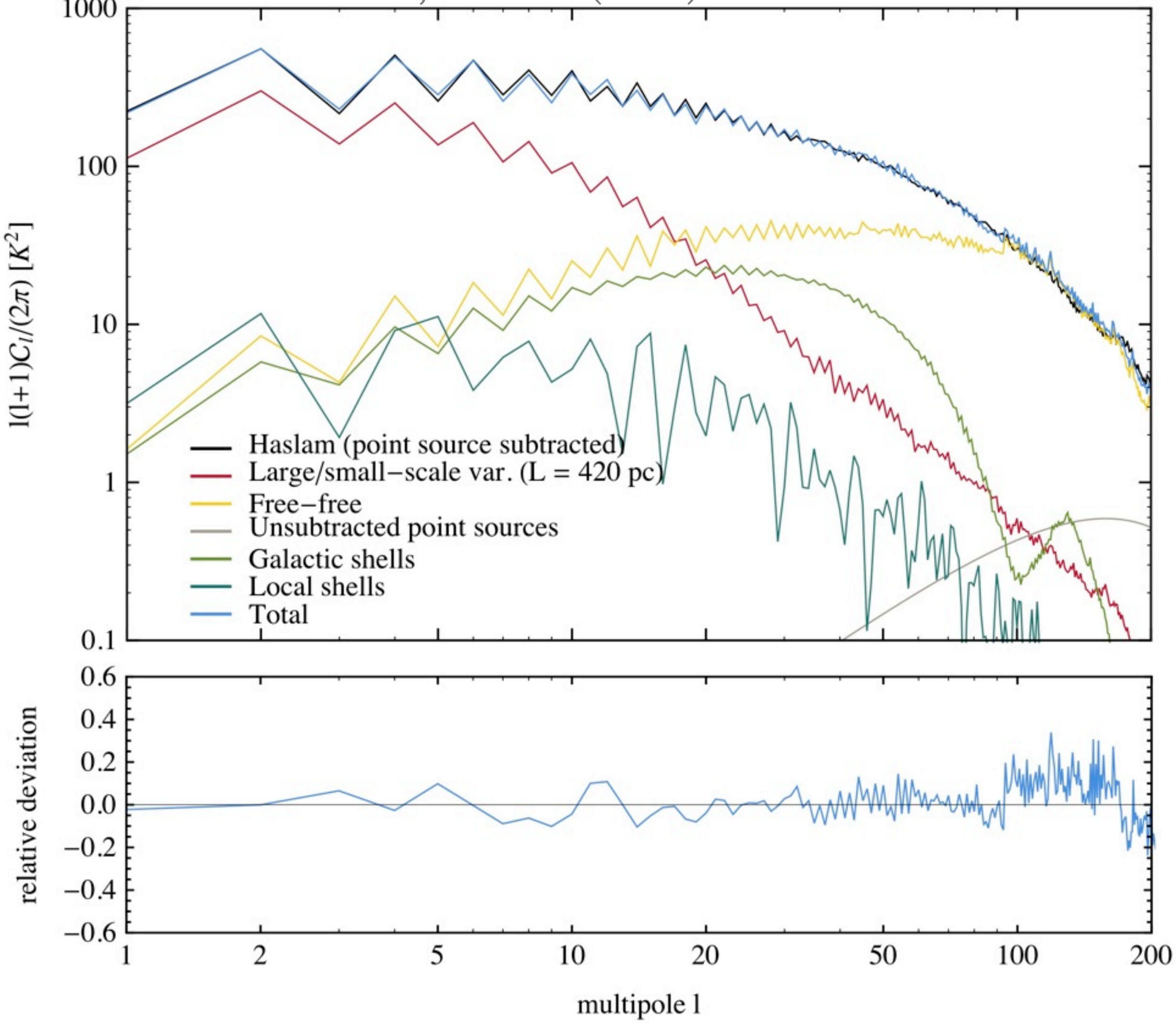
O(1000) shells of old SNRs present in Galaxy

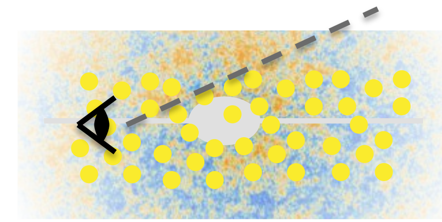
we know 4 local shells (Loop I-IV) but others are modeled in MC approach

they contribute *exactly* in the right multipole

Best fit of local shells and ensemble

Mertsch & Sarkar, JCAP 06 (2013) 041





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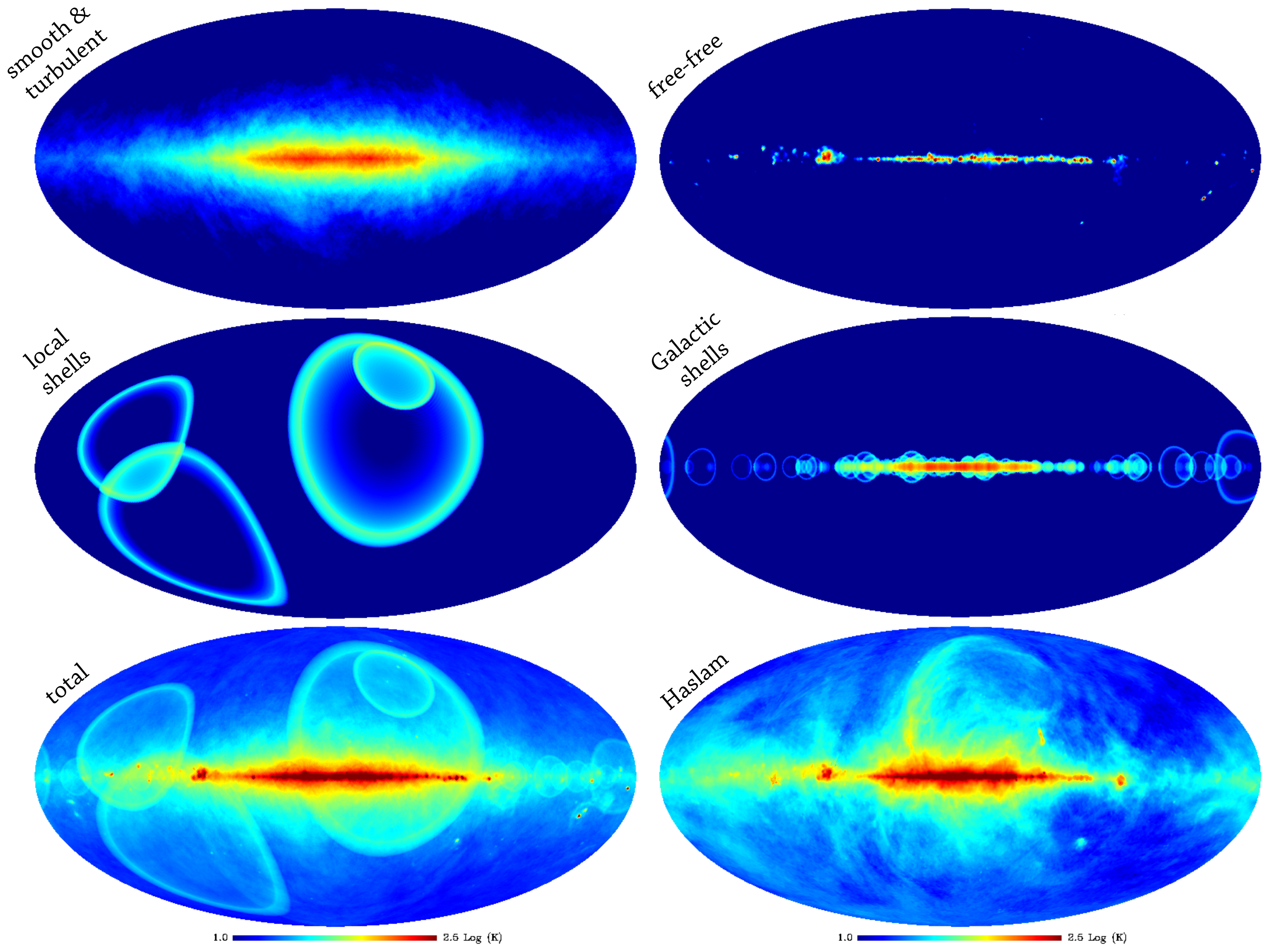
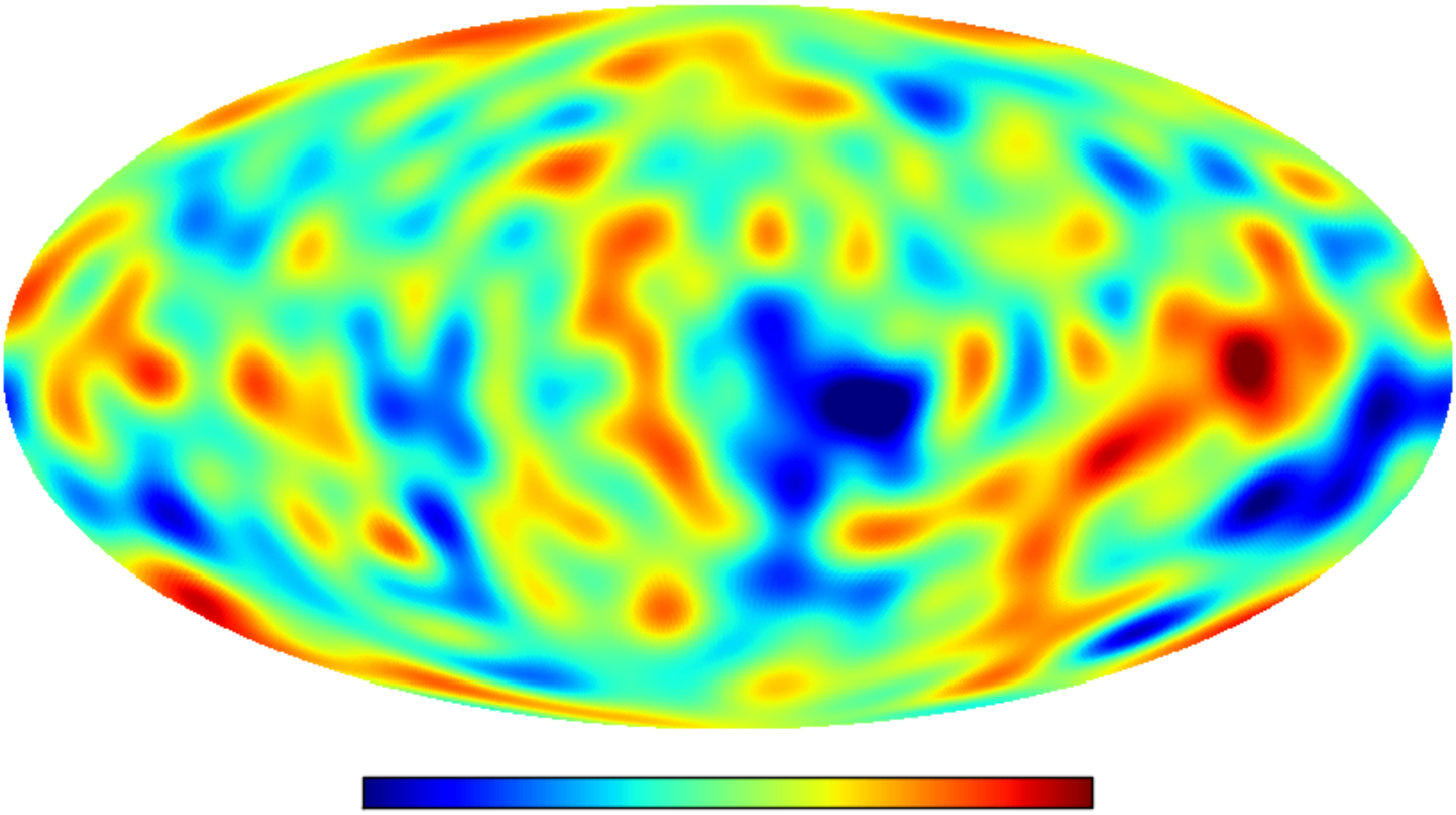

smooth &
turbulent
free-free
local
shells
Galactic
shells
total
Haslam
1.0
2.5 Log (K)
1.0
2.5 Log (K)

Anomalies in ILC9 ($\ell \leq 20$)



Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

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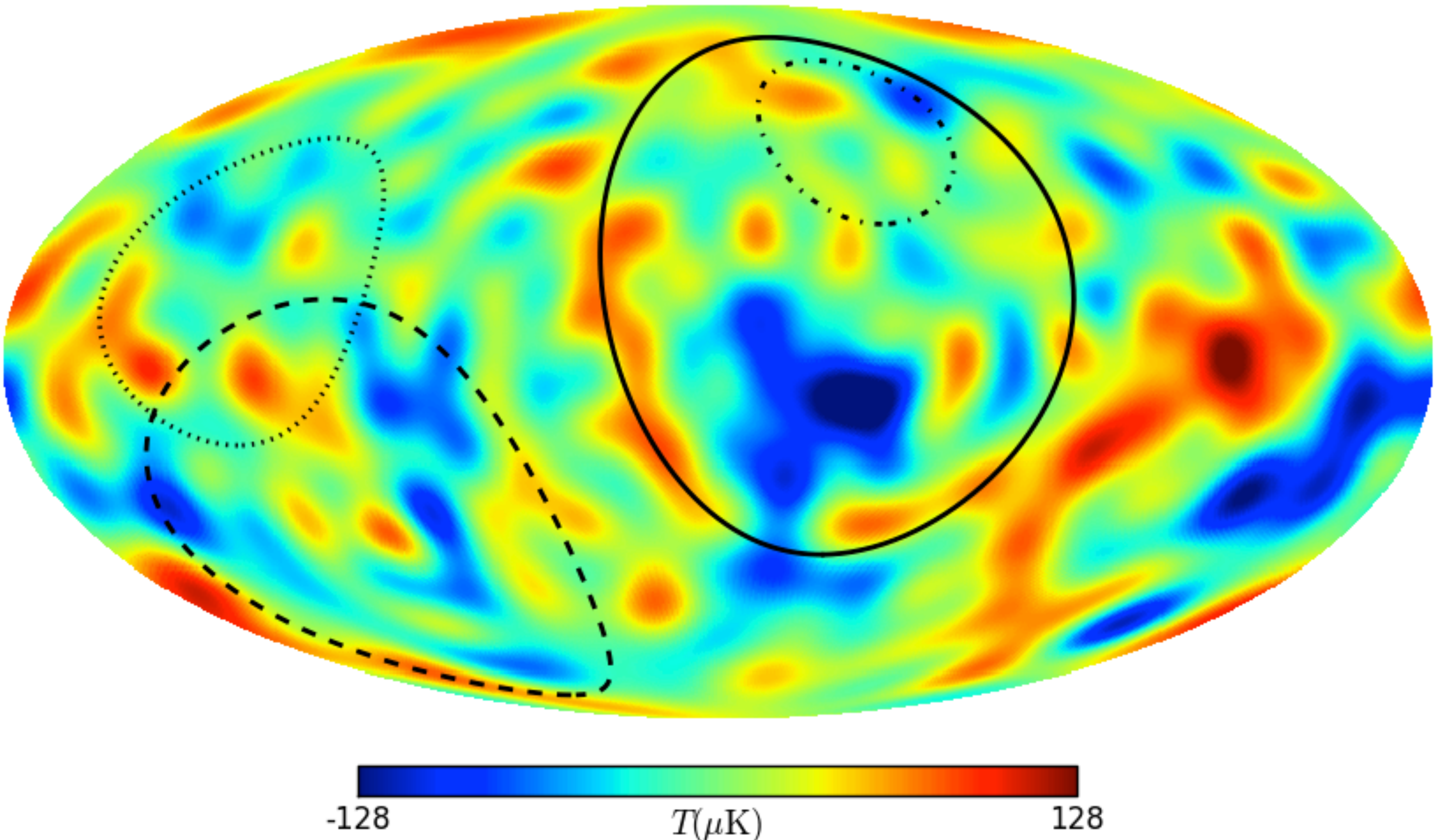

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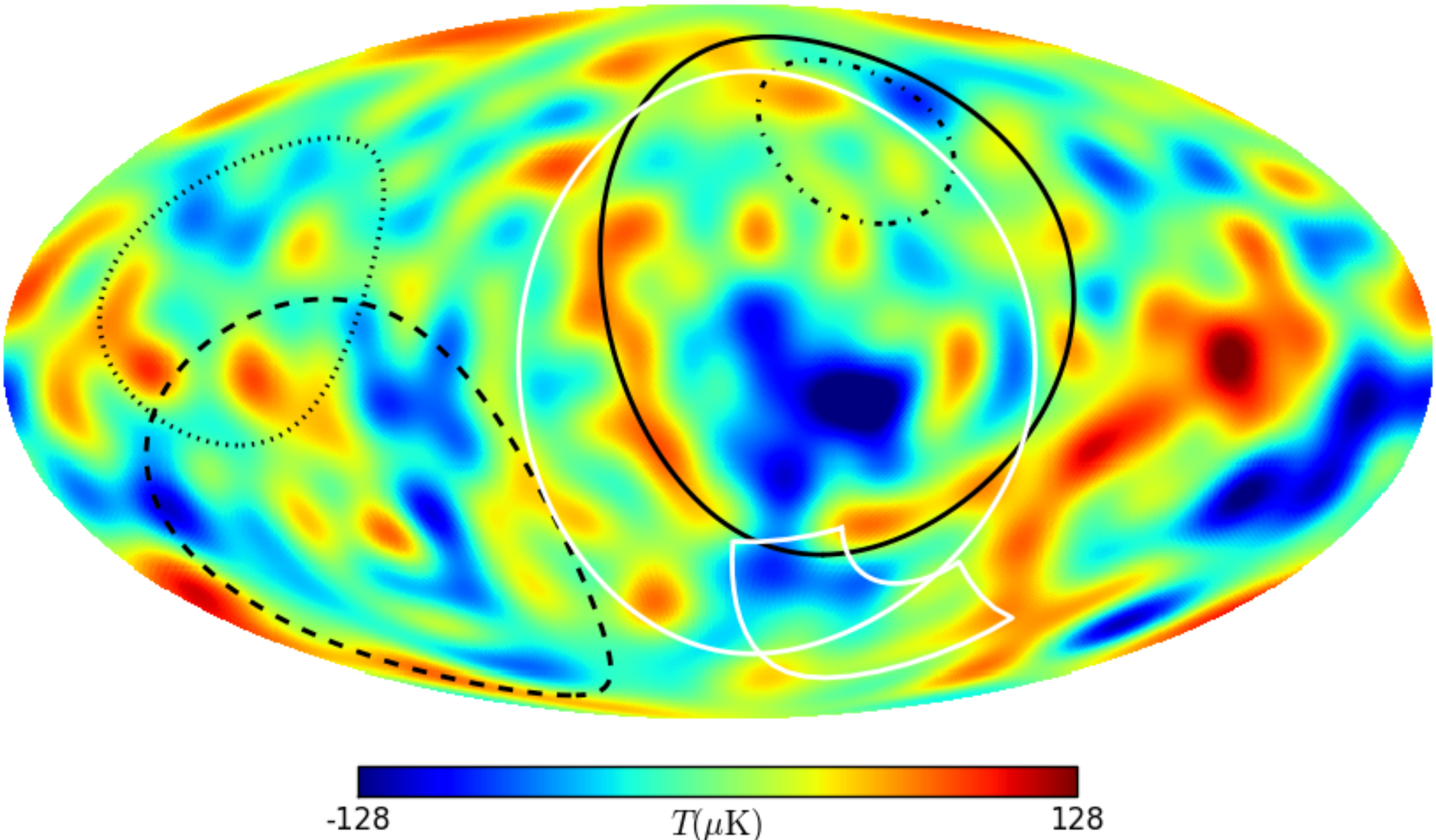
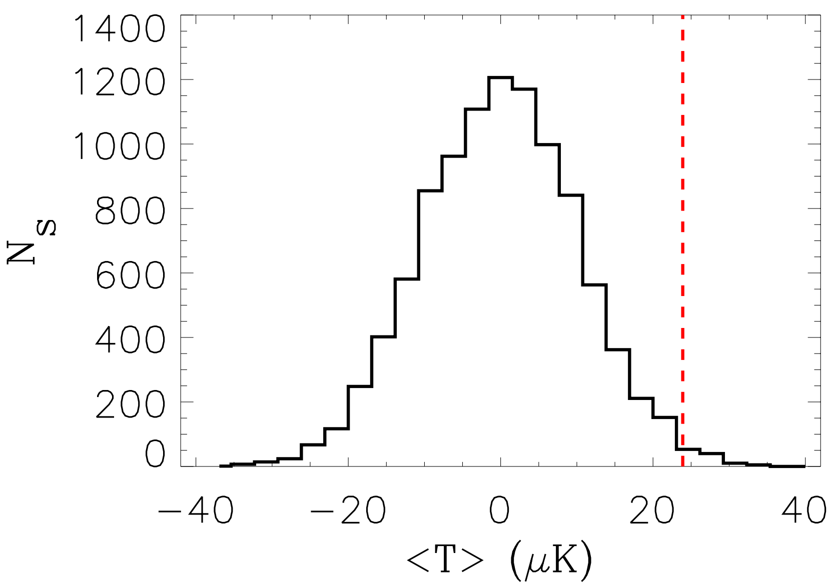


Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

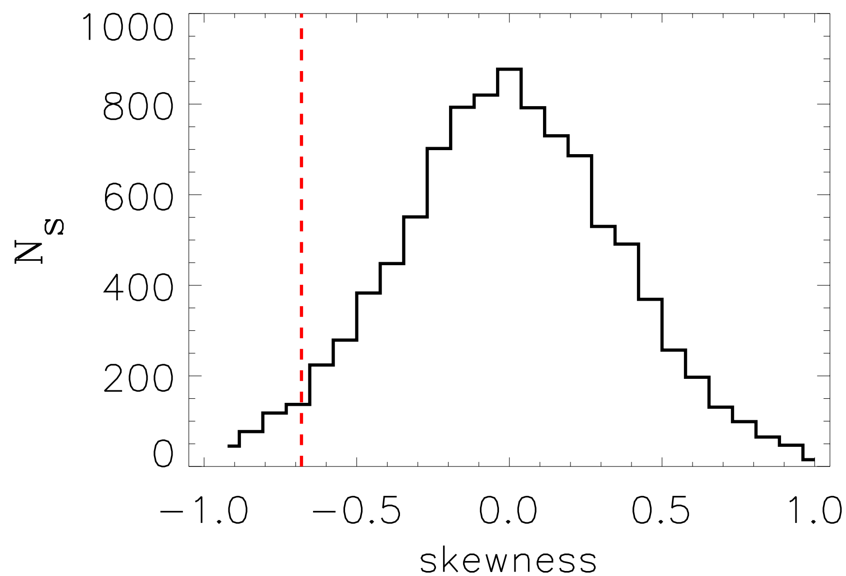
Anomalies in ILC9 ($\ell \leq 20$)

in ring around Loop I

temperature



skewness

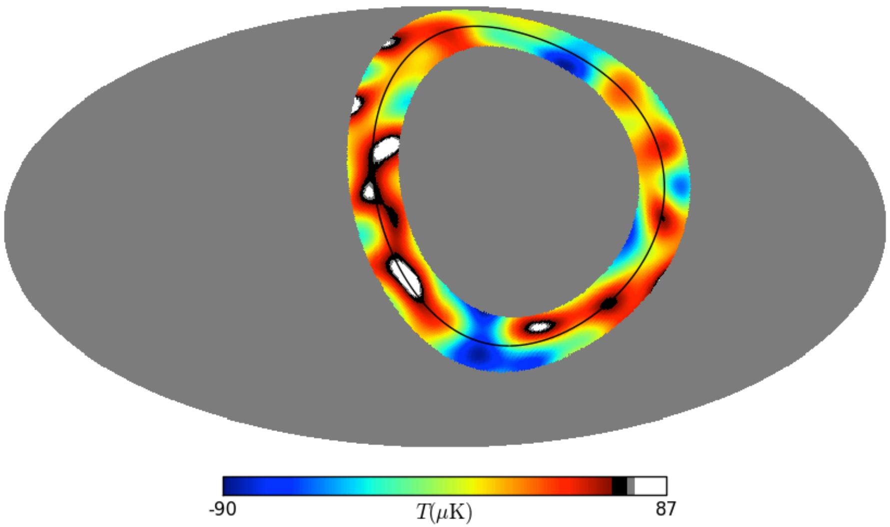


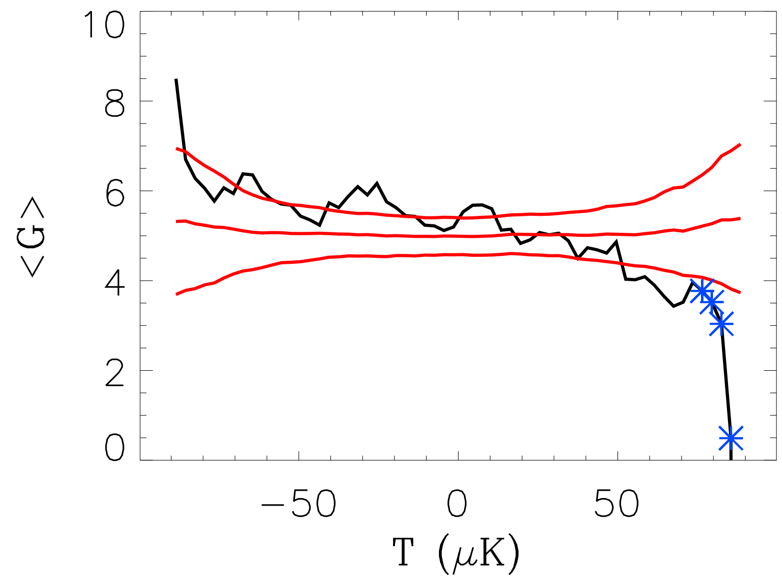
compare with MC → p-values $\mathcal{O}(10^{-2})$

Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

Cluster analysis

Naselsky & Novikov, ApJ. **444** (1995) 1



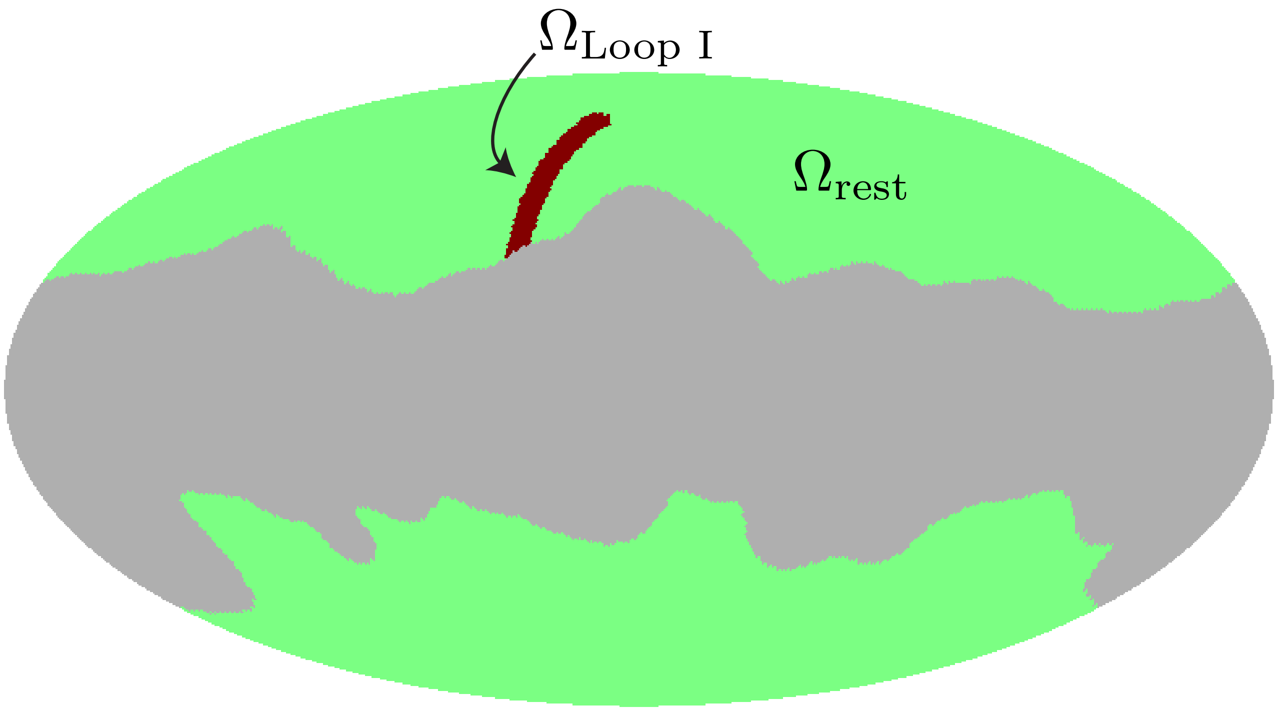


from 100,000 MC runs: probability for smaller $\langle G \rangle$ in last four bins $\sim 10^{-4}$

Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

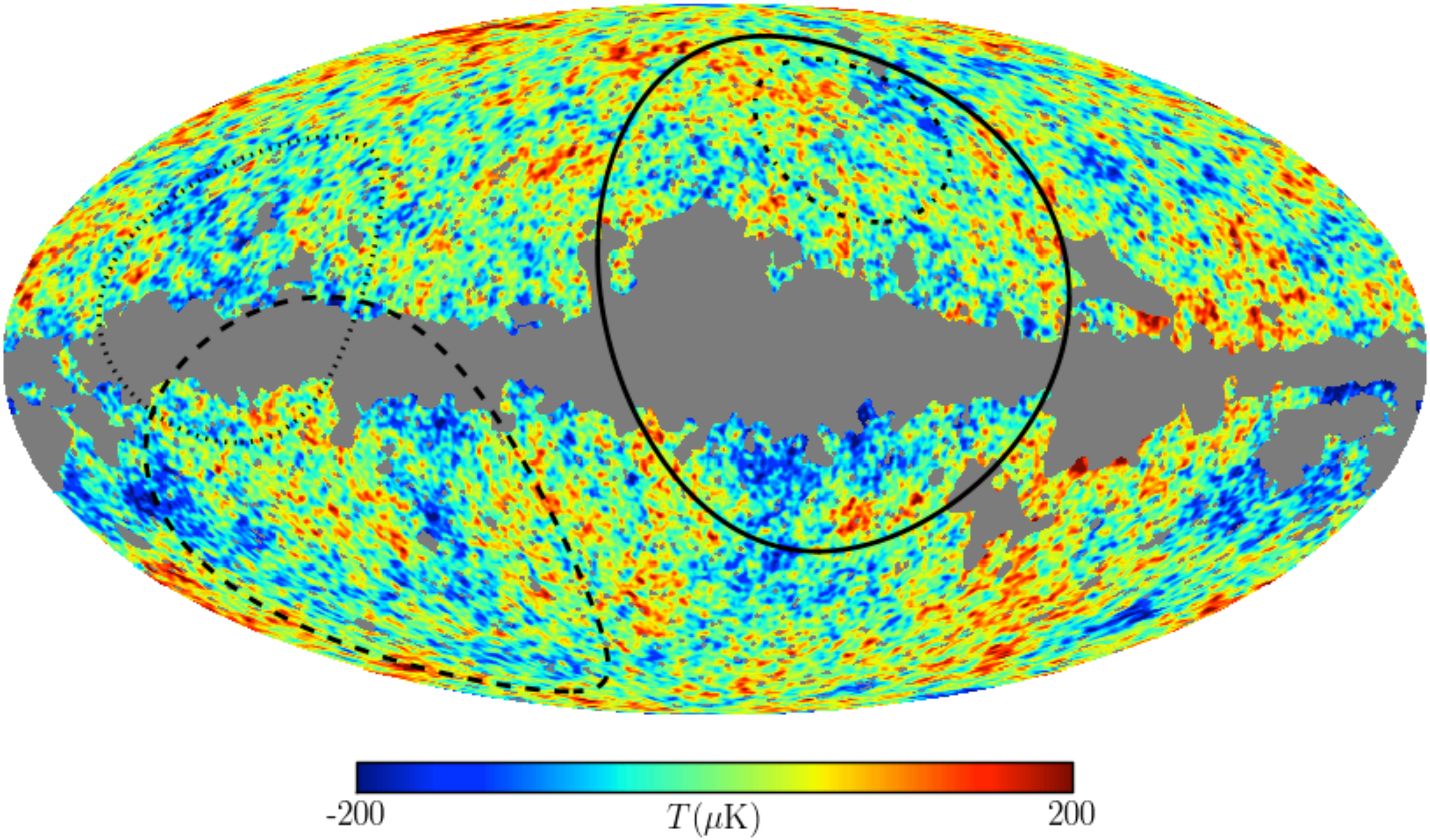
How to evade foreground cleaning:

- ILC coefficients from minimizing variance over whole sky ($\Omega_{\rm rest}$)
- but Loops contribute only locally ($\Omega_{\rm Loop\ I}$)



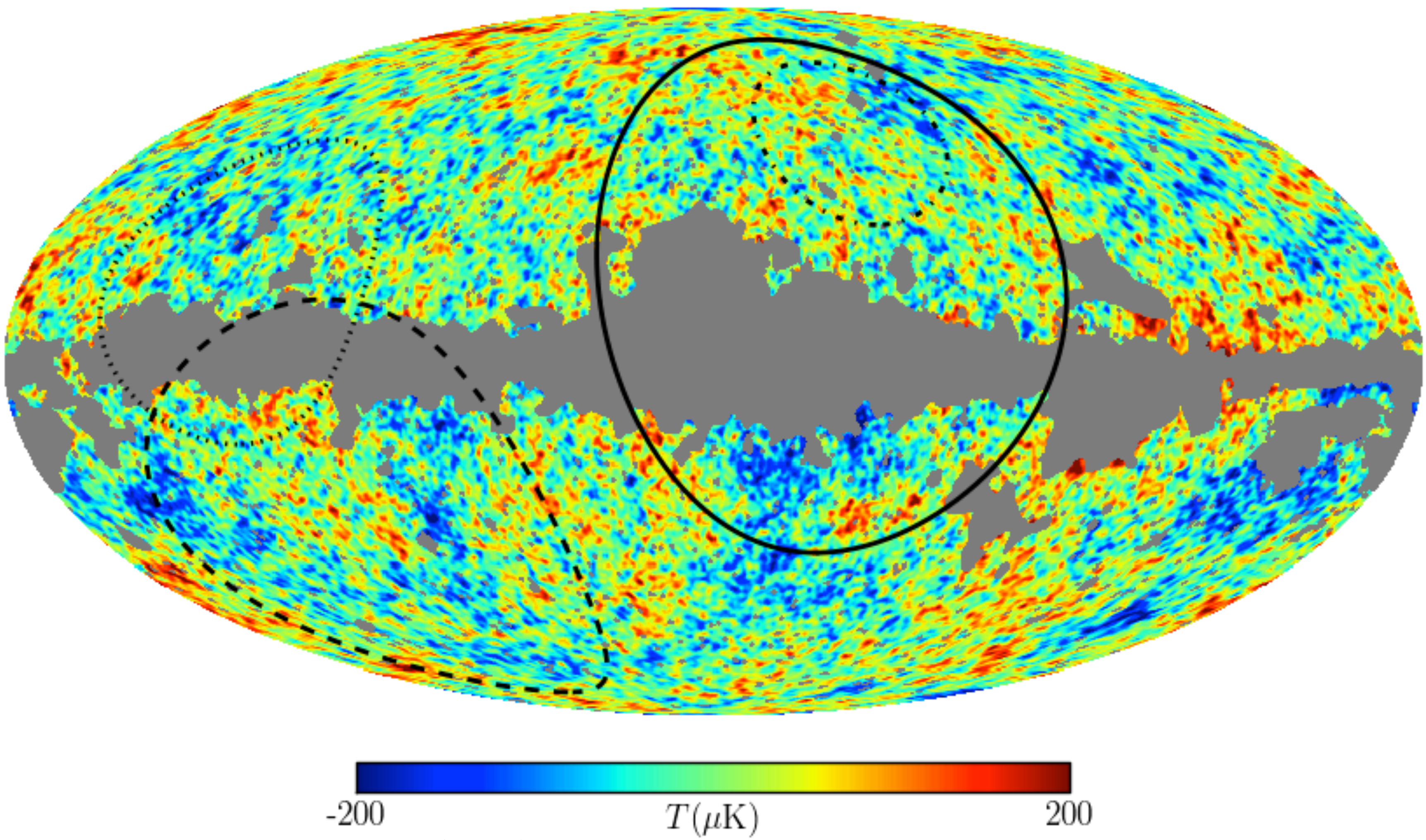
Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

ILC coefficients from Loop I region



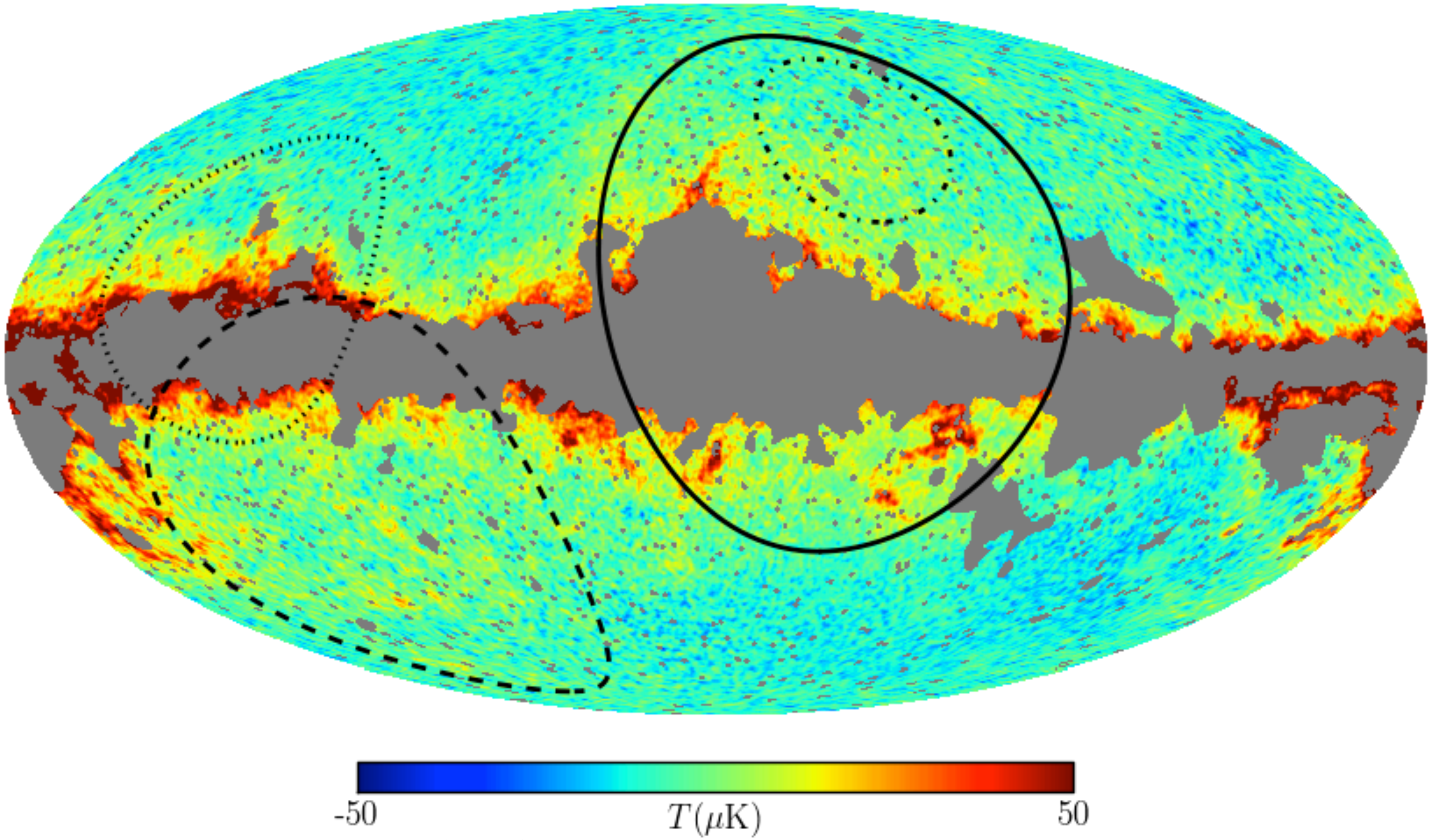
Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

ILC coefficients from rest of sky



Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

difference $ILC_{rest} - ILC_{Loop\ I}$



Liu, Mertsch & Sarkar, ApJL **789** (2014) 29

What do we know about anomaly?

- spatially correlates with Loop I
- unlikely synchrotron (checked with our synchrotron model)
- frequency dependence:

which spectral index β gets "zeroed" by ILC method,

i.e. solve $\displaystyle\sum_{j=\mathrm{K}}^{\mathrm{W}} W_j \nu_j^{\beta} = 0$ for β

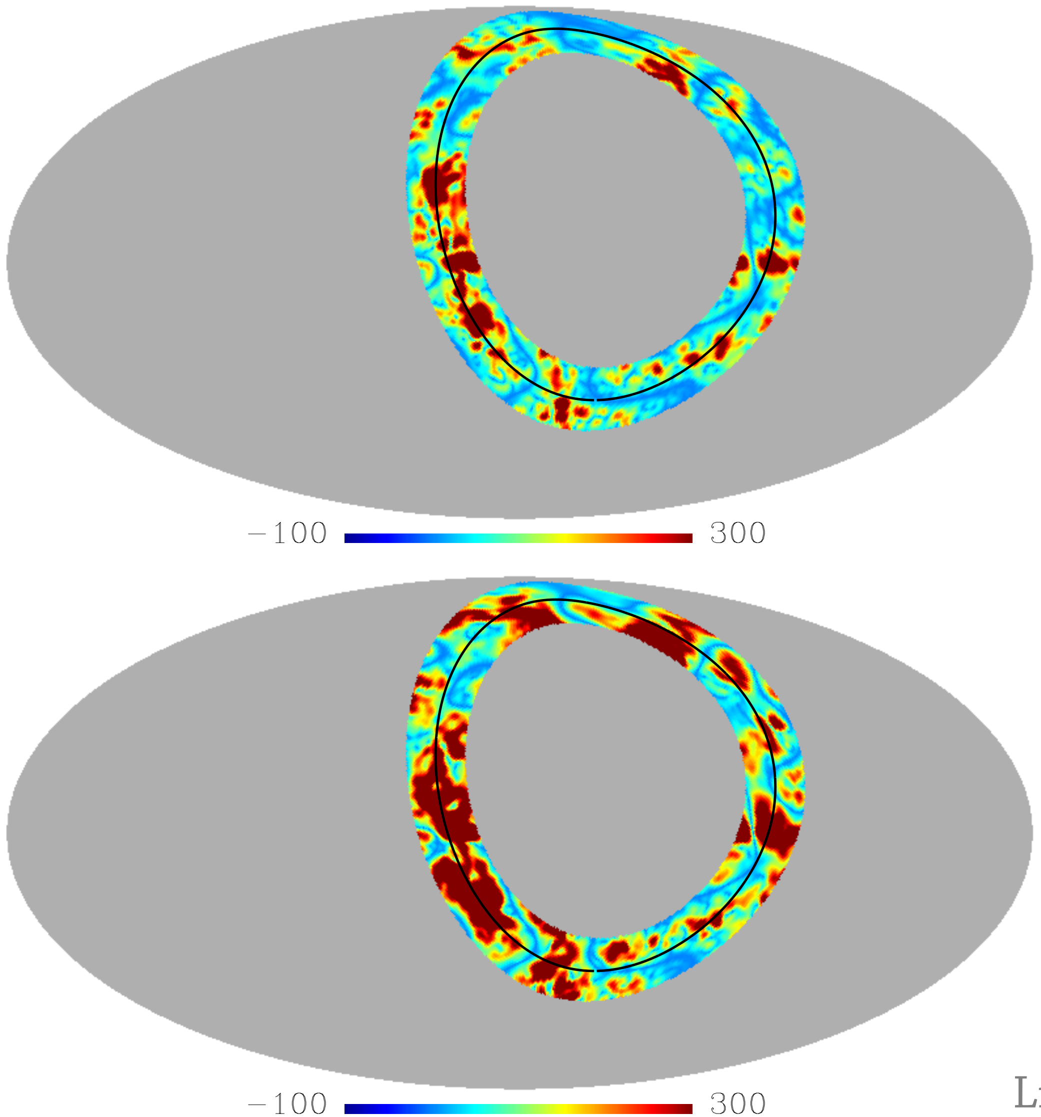
for WMAP9: $\beta \sim -3$, -2 and $1.7 \ldots 1.8$

synch free-free thermal dust

for Loop region: $\beta \sim -3$ and ~ 1.4

Liu, PM & Sarkar, ApJL **789** (2014) 29

Spectral index



- WMAP polarised intensity in
  - W (60 GHz)
  - V (90 GHz)
- correlate with ILC9
- ratio of average intensities in Loop I region: 1.7
- spectral index: ~1.3

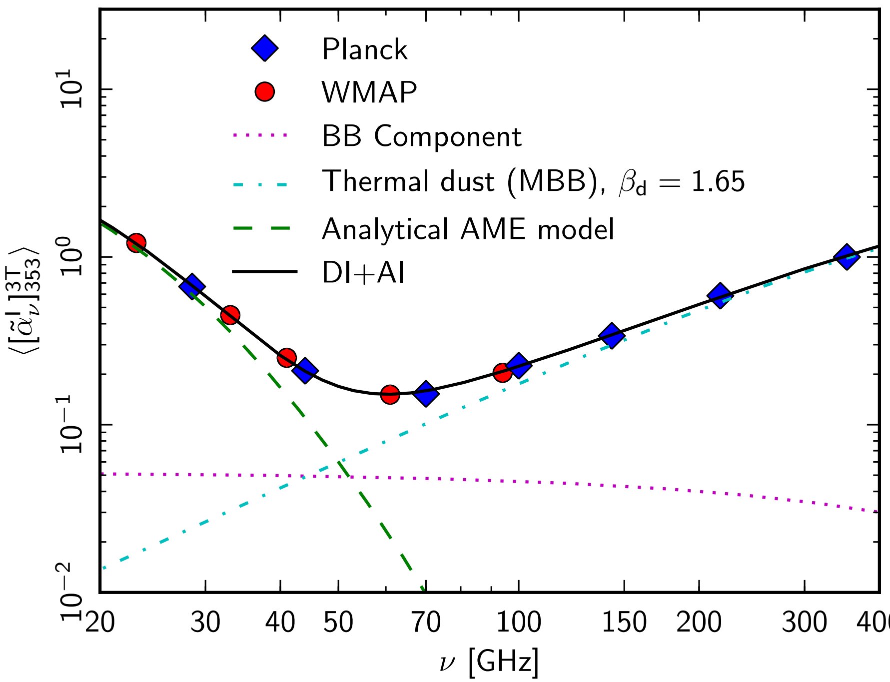
Liu, PM & Sarkar, ApJL **789** (2014) 29


DUST

Evidence for magnetised dust I

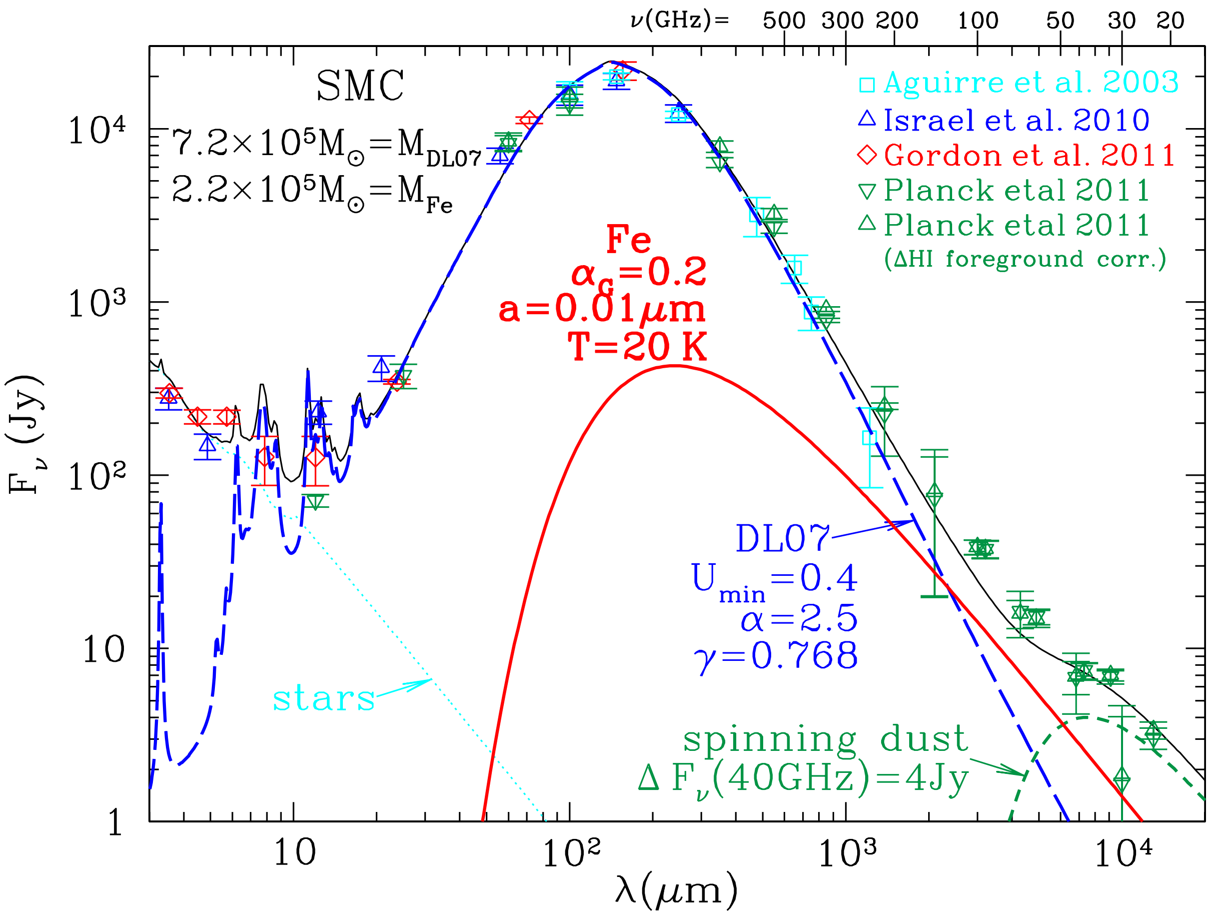
- correlation $\alpha_{353}(\nu)$ of WMAP and *Planck* frequency maps with dust template (353 GHz) in intensity and polarisation
- model as
  - CMB: achromatic
  - synchrotron: $A_s \nu^{\beta_s}$
  - thermal dust: $A_d \nu^{\beta_d} B(\nu, T_d)$
  - AME: spinning dust
- in intensity: $T_d \simeq 19\,\mathrm{K}$ and $\beta_d \simeq 1.52$ (cf. in FIR, $\beta_d \sim 1.7$)
- possible interpretation: magnetised dust, BB spectrum

→ 7σ evidence for magnetised dust?!



Ade *et al.*, arXiv:1405.0874

Evidence for magnetised dust II



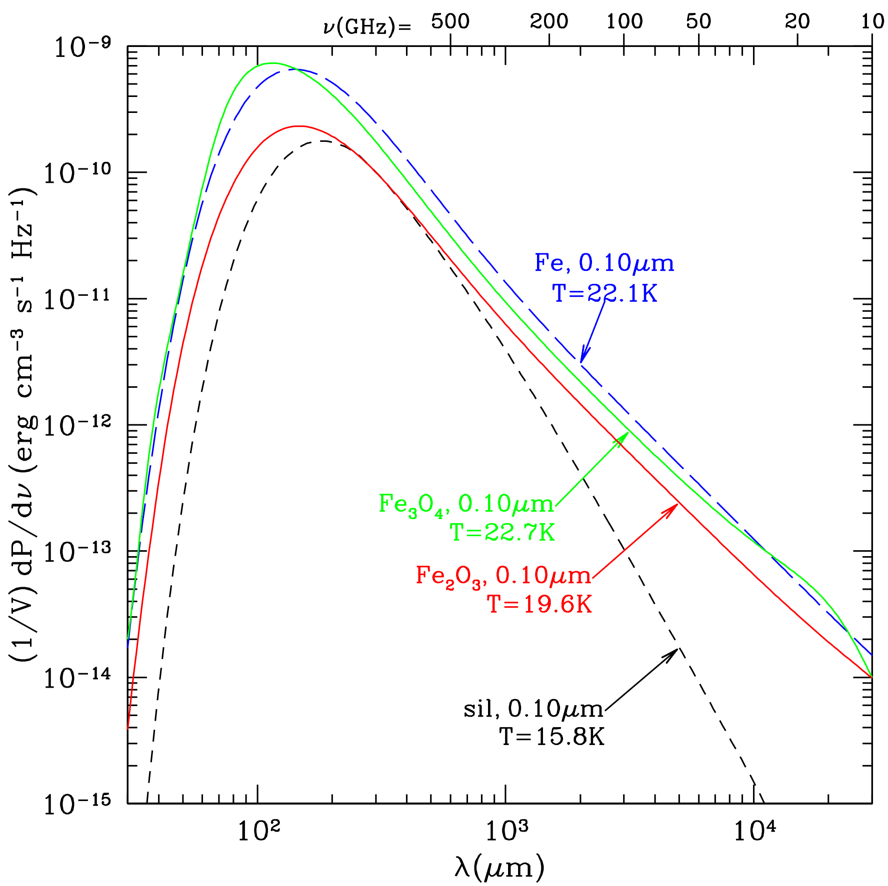
thermal dust
typical $\beta \sim 1.6 \ldots 1.7$

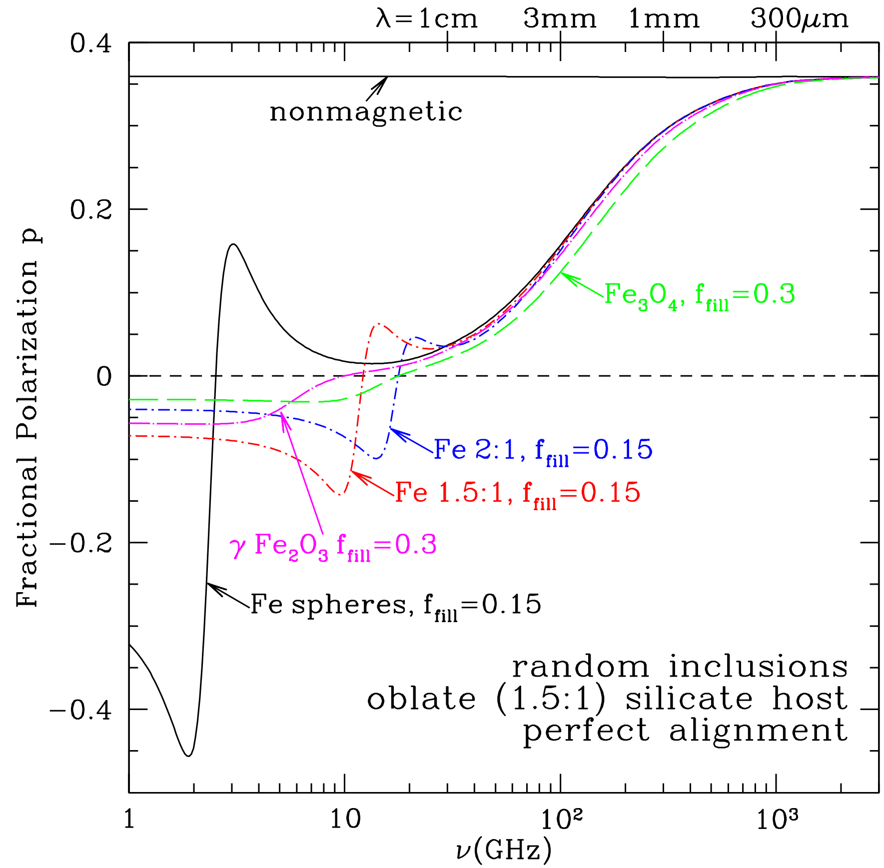
spinning dust
low-ν foreground

magnetic dust
very flat spectra,
$\beta \sim 0$;
dependence on compound, grain size, shape…

Draine & Hensley, ApJ **757** (2012) 103

Magnetic dipole radiation





Draine & Lazarian, ApJ **508** (1998) 157, *ibid.*, ApJ **512** (1999) 740
Draine & Hensley, ApJ **765** (2013) 169

Significance for cosmology

temperature anisotropies

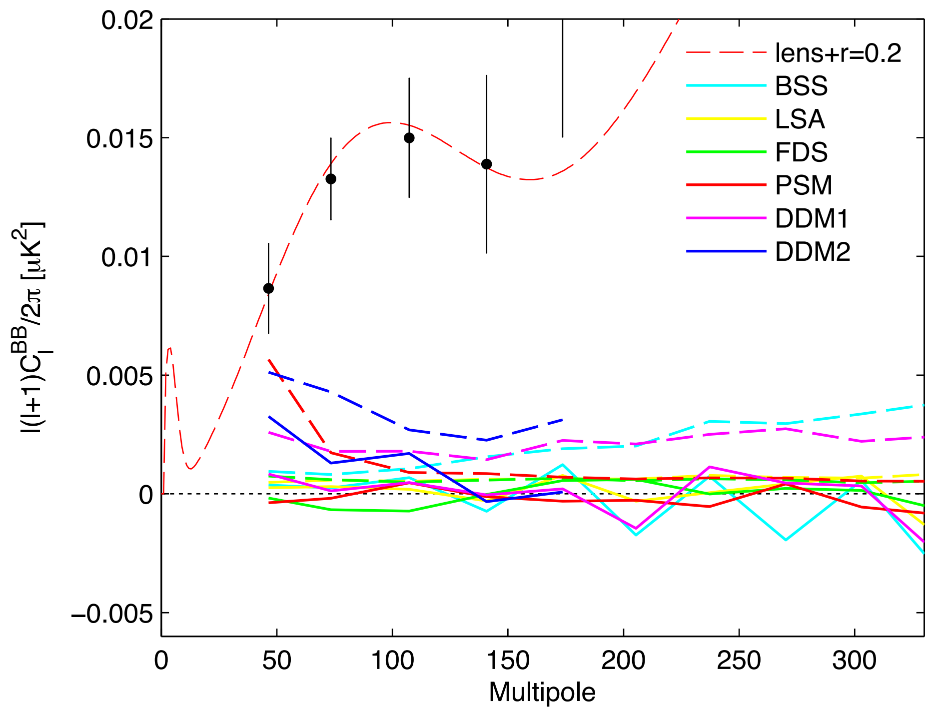
- *observed* loops contribute mostly at $\ell \lesssim 100$

→ no impact at large ℓ?

- low-ℓ anomalies (power deficit, $\ell = 2$, $\ell = 2, 3$ alignment, parity asymmetry)
- CMB power even lower than observed?!

polarisation

- not a power law in ℓ
- dangerous frequency behaviour: BB!
- possibility of small-scale turbulence in loops ➔ variation of polarisation fraction and angle
- none of the "dust models" covers this



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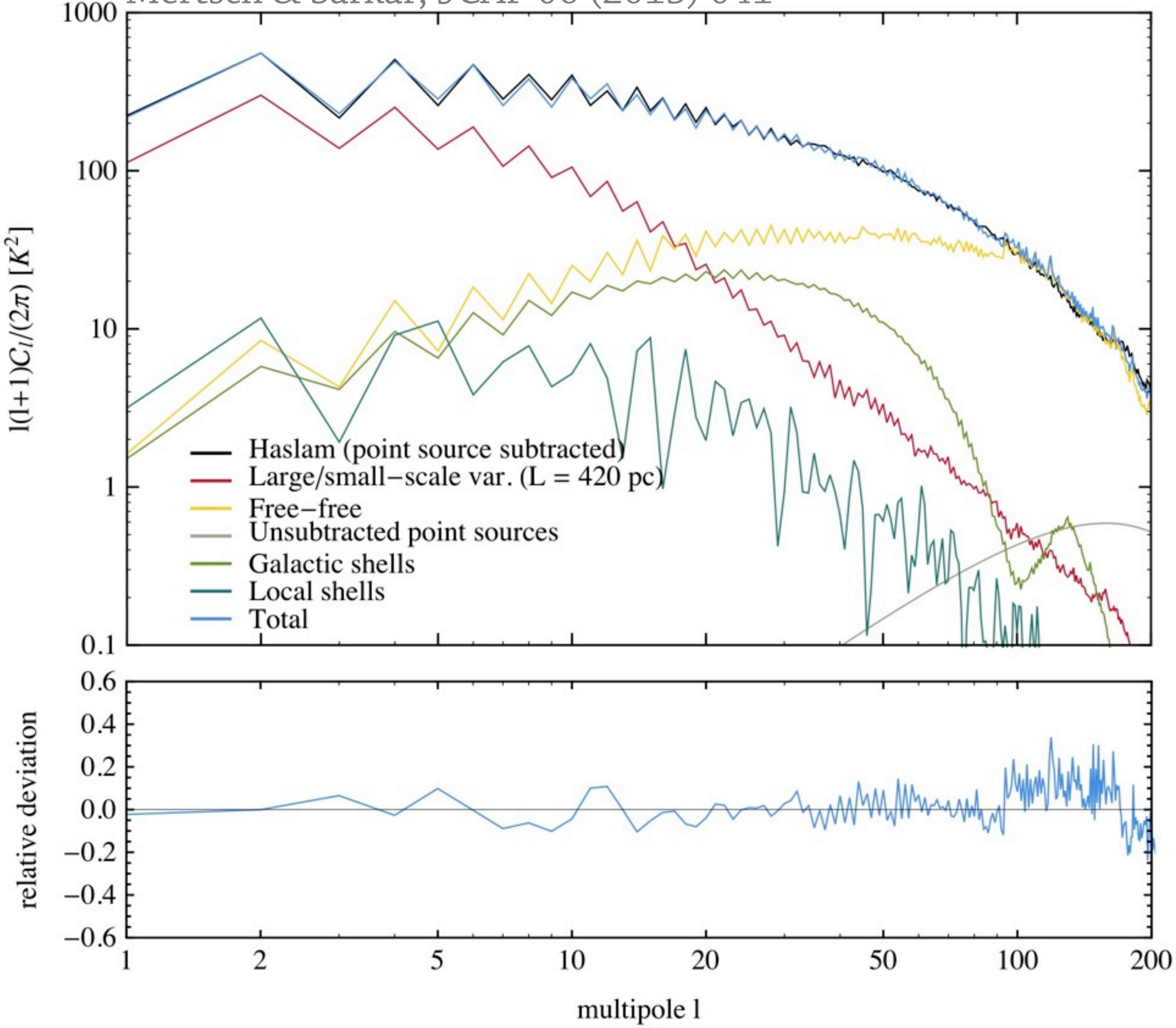
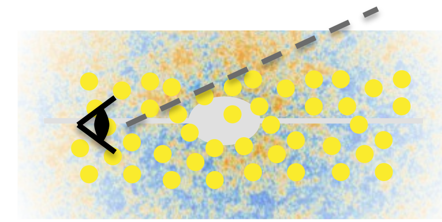
Mertsch & Sarkar, JCAP 06 (2013) 041





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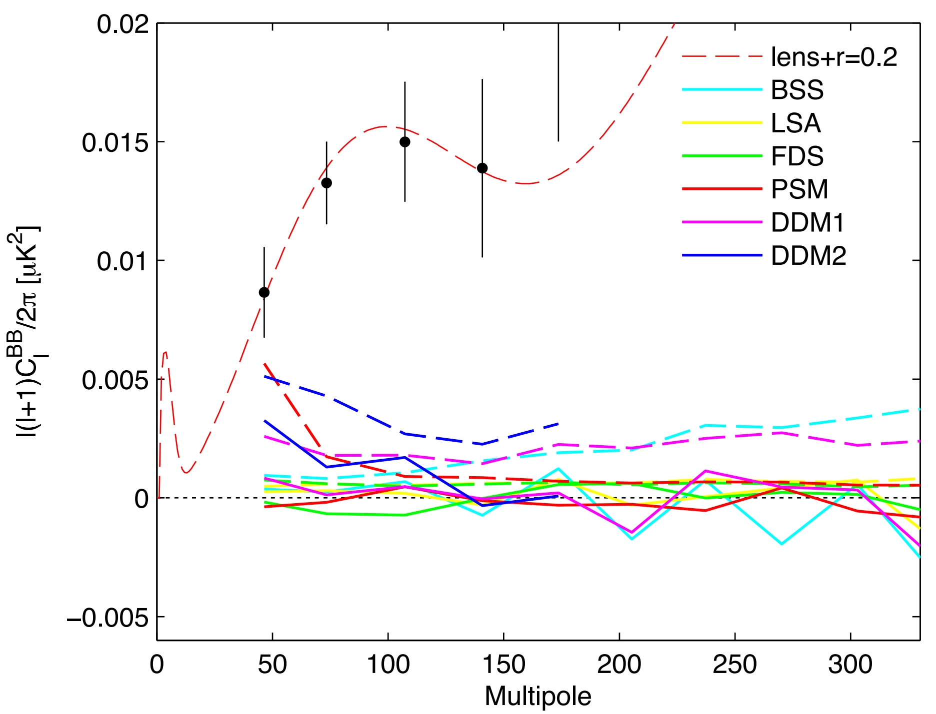
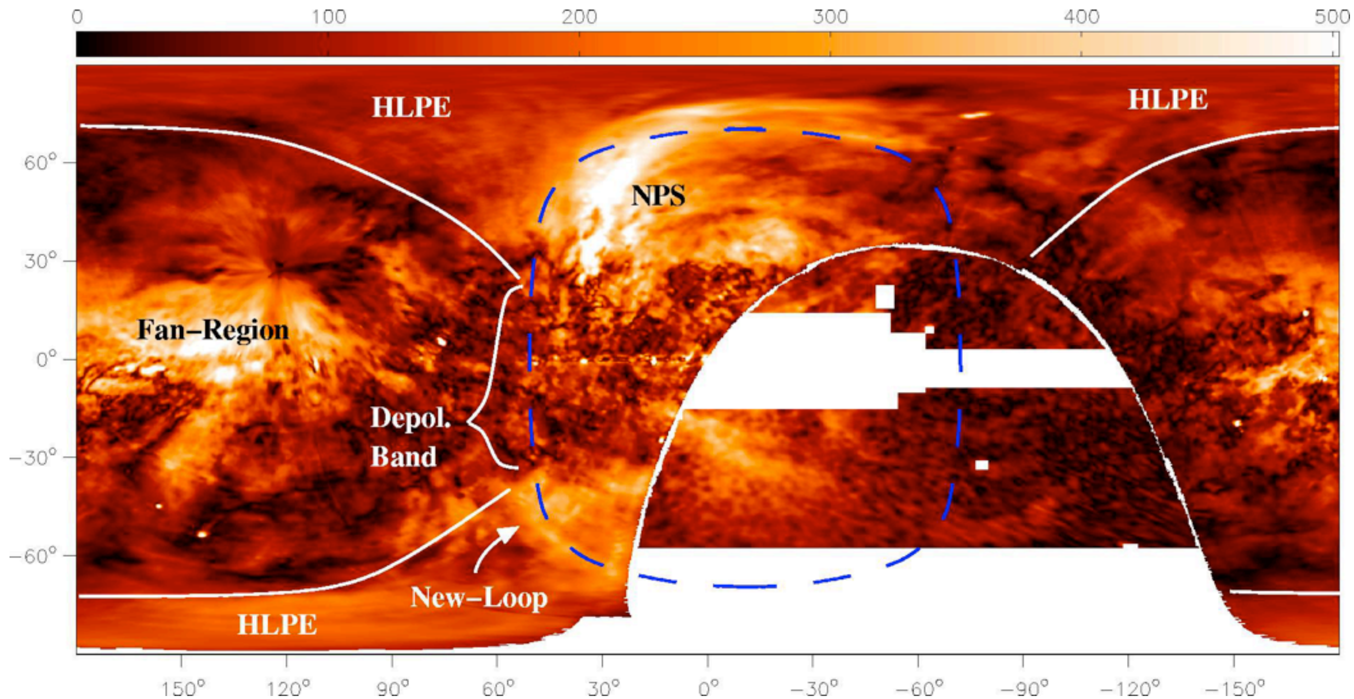
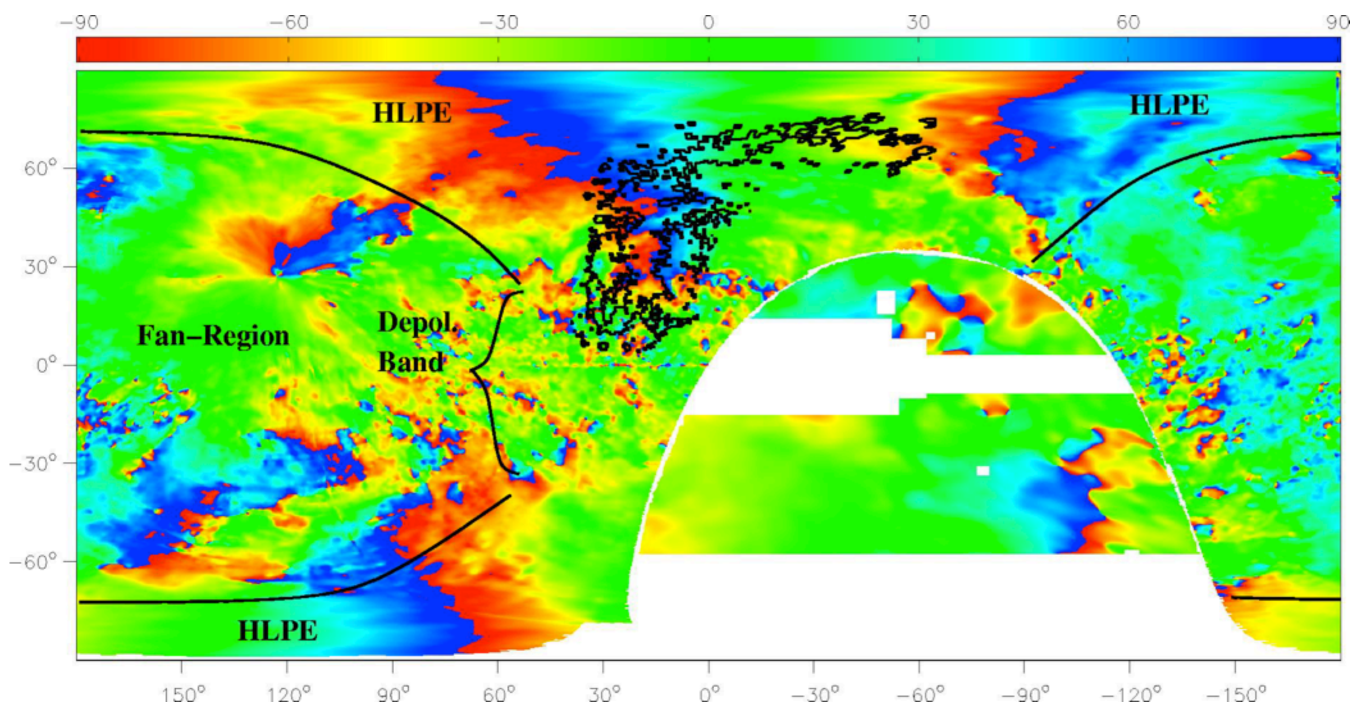


Wolleben, ApJ **664** (2007) 349

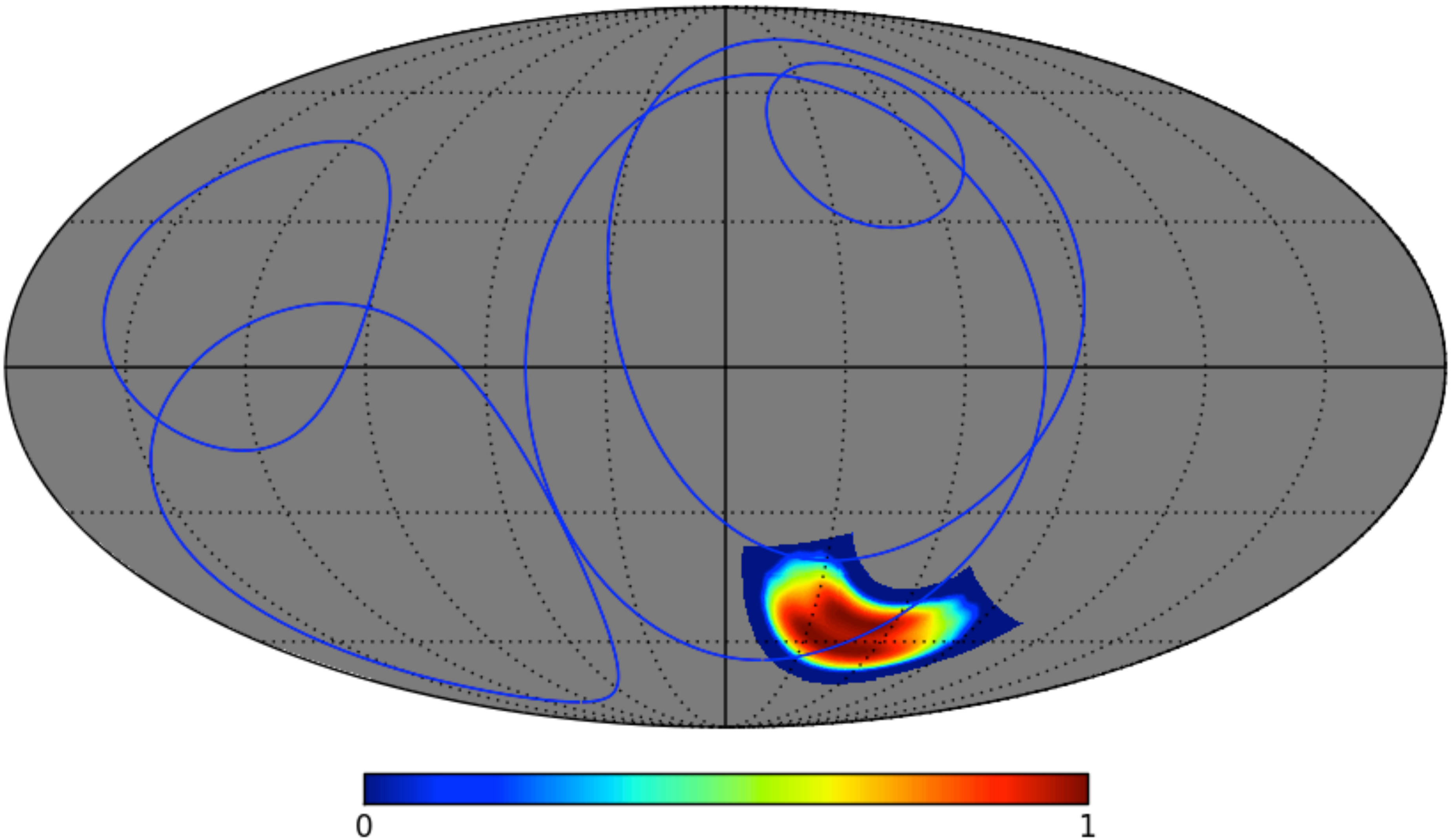


polarisation
(1.4 and 23 GHz)

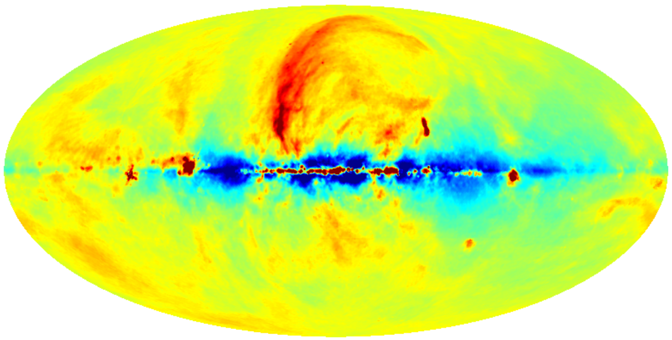


polarisation angle

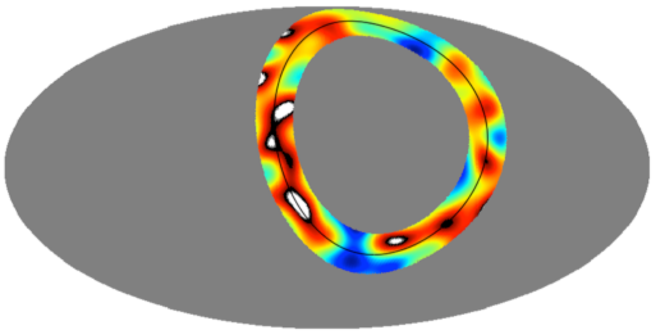
BICEP2 variance-weight map & loops



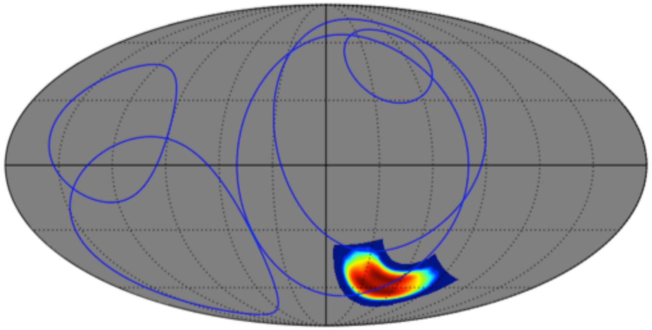
Conlcusion



radioloops
efficiently modelled in angular power spectrum



contamination in CMB maps
anomalous temperature & clustering
⇨ magnetised dust?



Wolleben's "New Loop"
potentially high polarisation fraction, potentially low spectral index