Systematic Effects in the Extraction of the 'WMAP Haze'

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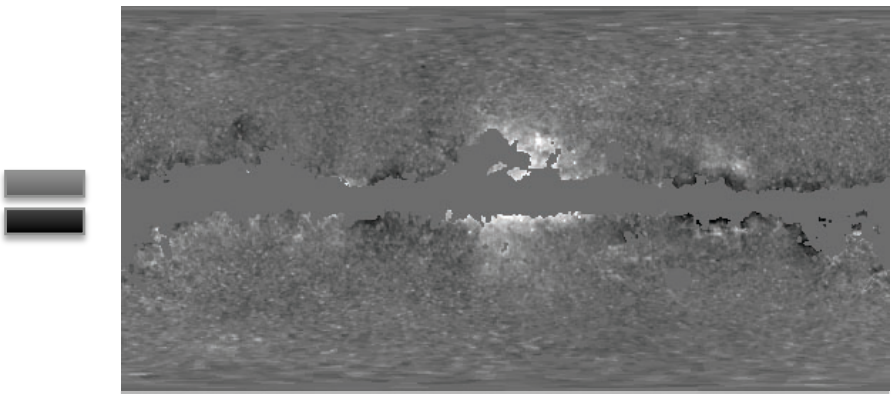
‘WMAP haze’

Claim by Finkbeiner (2004)

CMB-subtracted WMAP K-band — synchrotron — free-free — dust



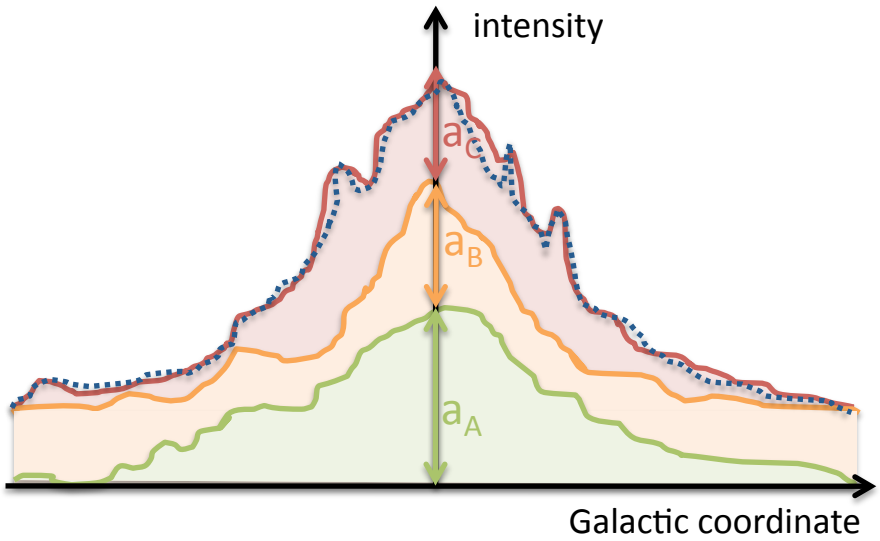
Dobler & Finkbeiner, ApJ **680** (2008) 1222

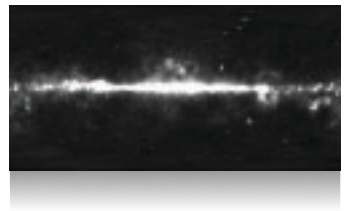
1. morphology: roughly spherical
2. power: few kJy sr^{-1}
3. spectrum: harder than usual synchrotron

Template Subtraction

Based on multi-linear regression for each band

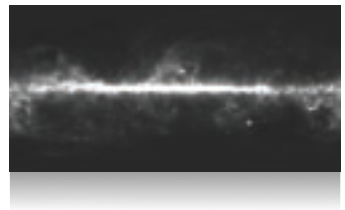
$$\chi^2 \propto \left(\text{data} - \sum_{i=\text{A,B,C}} a_i \, \text{map}_i\right)^2$$



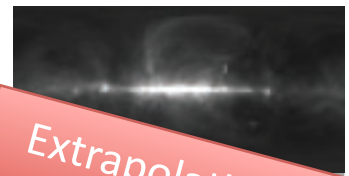


CMB subtracted
WMAP K-band
Hinshaw *et al.*, ApJS **180** (2009) 225

free-free:
Hα map
Finkbeiner, ApJS **146** (2003) 407



dust:
94 GHz map
Finkbeiner *et al.*, ApJ **524** (1999) 867



synchrotron:
408 MHz survey
Haslam *et al.*, A&AS **47** (1982) 1

Extrapolation over 2 orders of magnitude!

Energy-Dependent $e^{\pm}$ Diffusion

GeV $e^{\pm}$ produce GHz synchrotron:

$$\nu_{\rm max}(E_{e^\pm}) \simeq 0.29\,\nu_c(E_{e^\pm}) \simeq 23\left(\frac{B}{6\,\mu{\rm G}}\right)\left(\frac{E_{e^\pm}}{30\,{\rm GeV}}\right)^2\,{\rm GHz}$$

diffusive convective transport:

$$\frac{\partial n}{\partial t} = \vec{\nabla}\cdot\left(D_{xx}\vec{\nabla}n - \vec{v}\,n\right) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}n - \frac{\partial}{\partial p}\left(\dot{p}\,n - \frac{p}{3}\left(\vec{\nabla}\cdot\vec{v}\right)n\right) + q$$

(numerically solved with GALPROP code)

$$D_{xx} \propto D_{xx0}\left(\frac{E}{4\,{\rm GeV}}\right)^{\delta}, \quad \vec{v} = \pm\vec{e}_z\,\frac{{\rm d}v}{{\rm d}z}|z|\,, \quad D_{pp} \propto v_{\rm A}^2 D_{xx}^{-1}$$

diffusion-loss length:

$$\ell(E) \approx 5\left(\frac{E}{\rm GeV}\right)^{(\delta-1)/2}\,{\rm kpc}$$

Morphology of synchrotron maps at WMAP and at radio frequencies could be quite different!

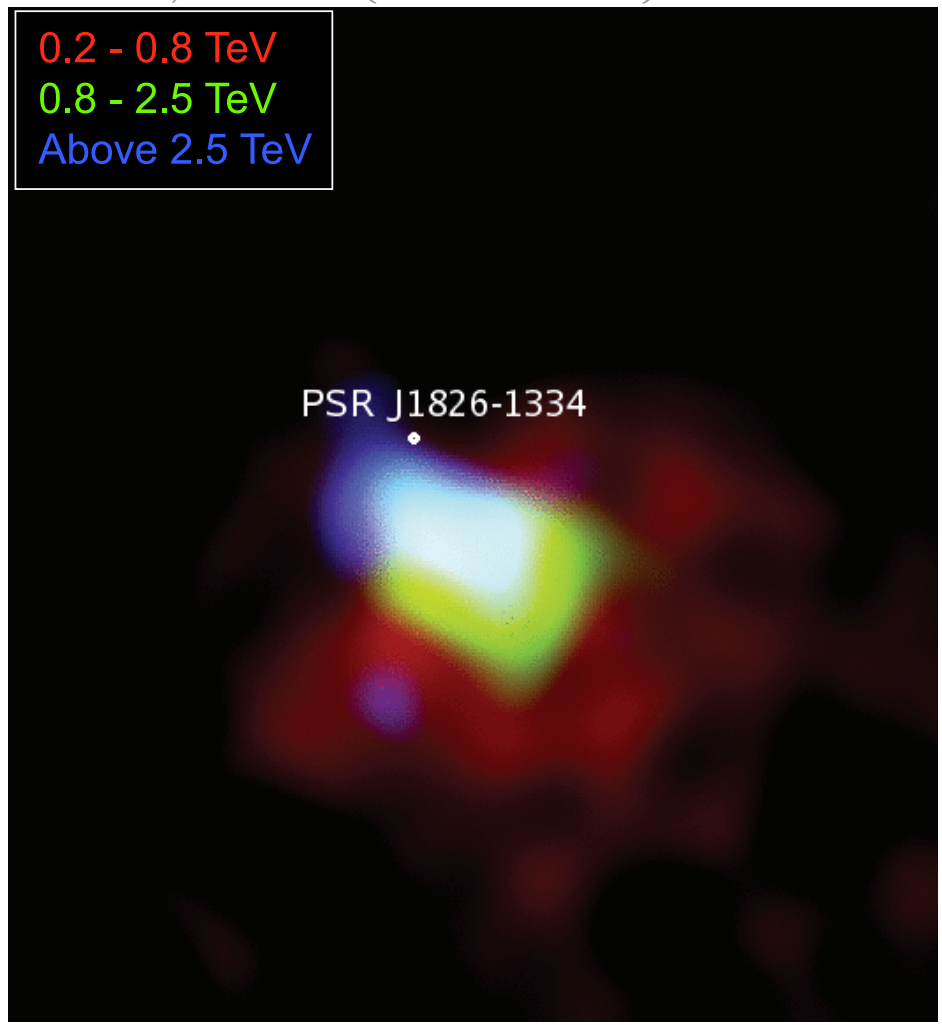
Energy-Dependent Morphology

- HESS source J1825-137
- association with PSR J1826-1334

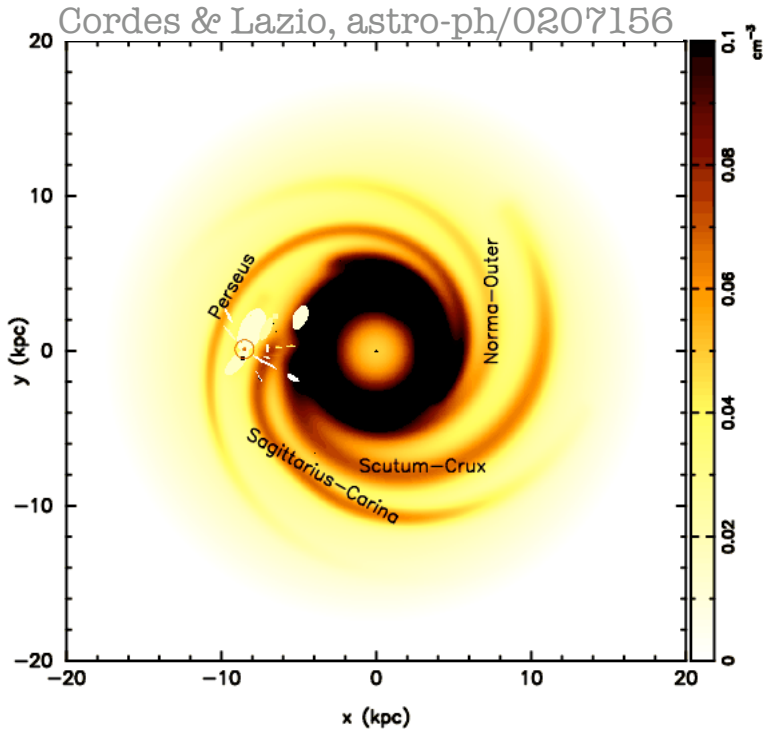
⇨ asymmetric PWN, IC by $e^{\pm}$

- energy-dependent morphology due to: energy-dependent diffusion and cooling

Funk *et al.*, ICRC 2007 (arXiv 0709.3125)

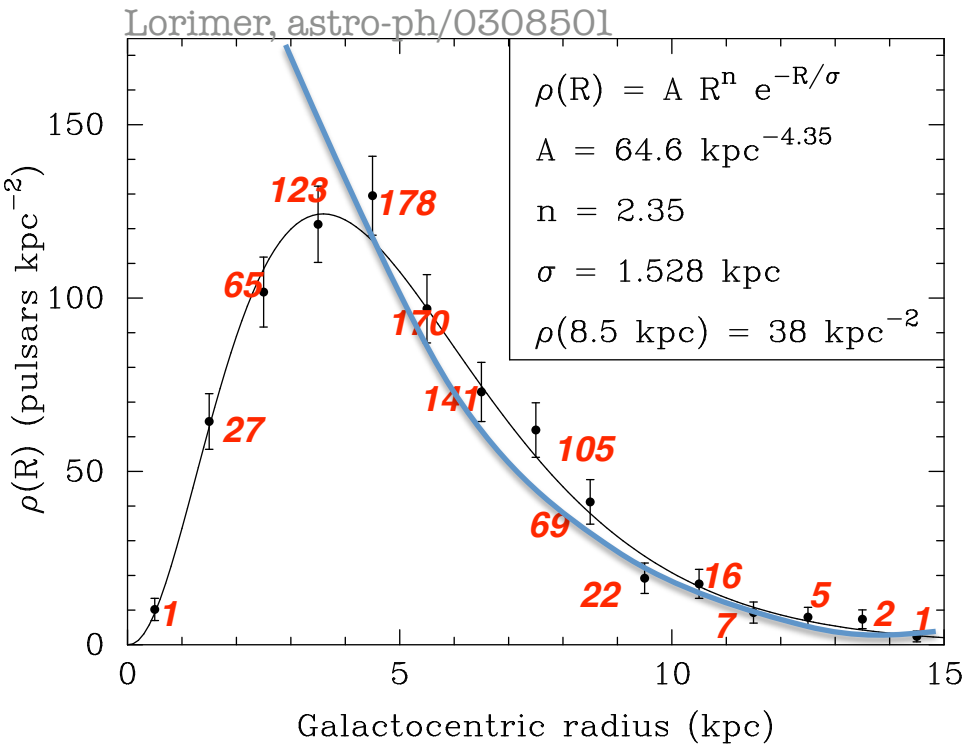


Source Distribution



- SNRs traced by pulsars to first approximation
- radial pulsar distribution from rotation and dispersion measure
- depends on thermal electron density

Source Distribution



The distribution of $e^{\pm}$ sources could be *very* different

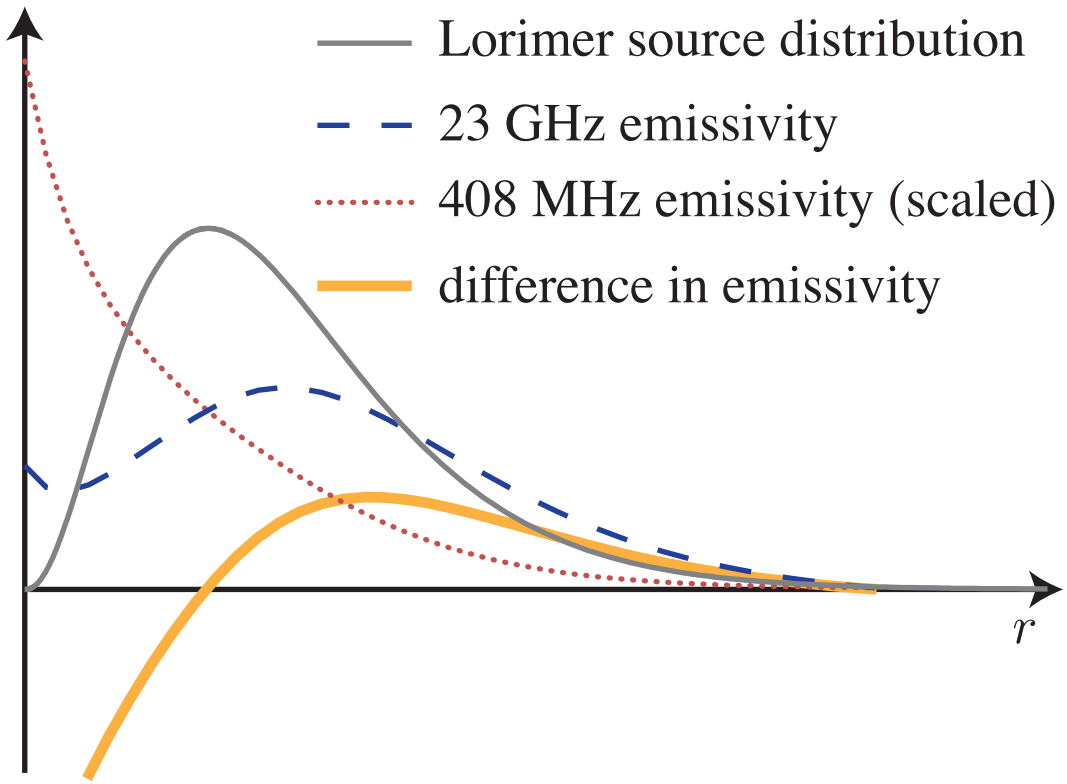
- SNRs traced by pulsars to first approximation
- radial pulsar distribution from rotation and dispersion measure
- depends on thermal electron density
- likely strong selection effects near Galactic Centre

➡ consider alternatively exponential distribution

Effect of Invalid Extrapolation I

- source distribution peaks at intermediate radii
- 23 GHz $e^{\pm}$ do not diffuse much and trace sources
- 408 MHz $e^{\pm}$ diffuse more and wash out source distribution

template subtraction finds ***deficit*** at Galactic centre

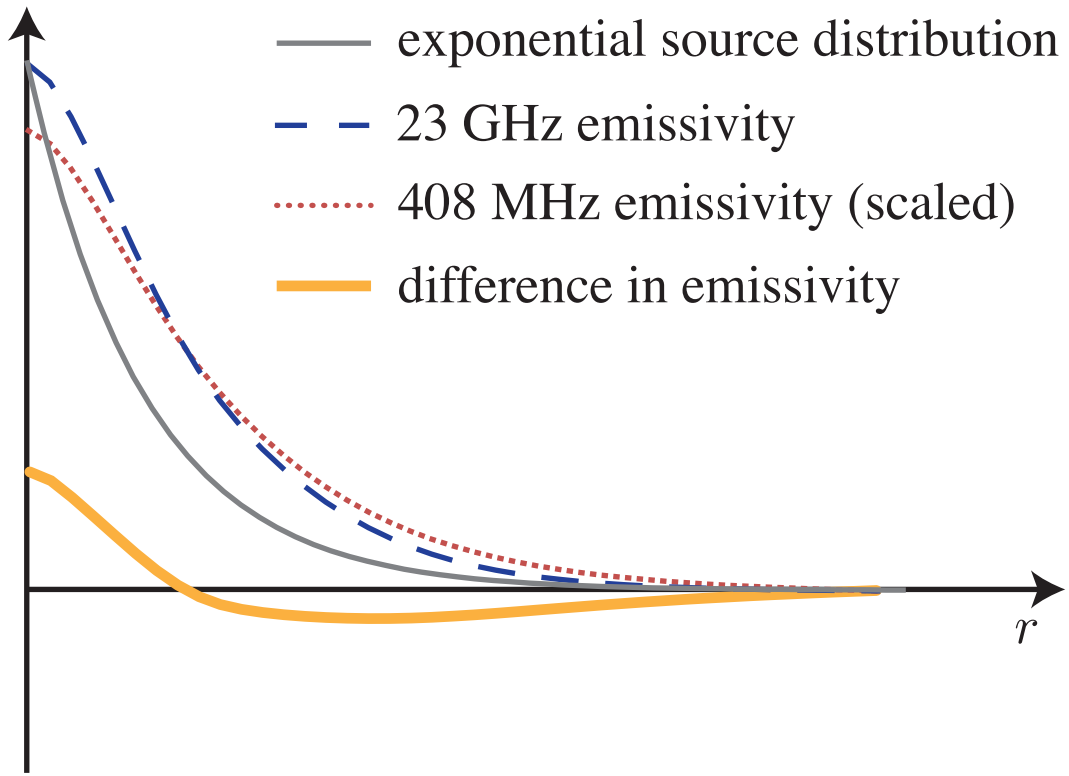


Mertsch & Sarkar, arXiv:1004.3056

Effect of Invalid Extrapolation II

- source distribution peaks at Galactic centre
- 23 GHz $e^{\pm}$ do not diffuse much and trace sources
- 408 MHz $e^{\pm}$ diffuse more and do not trace sources well

template subtraction finds ***excess*** at Galactic centre

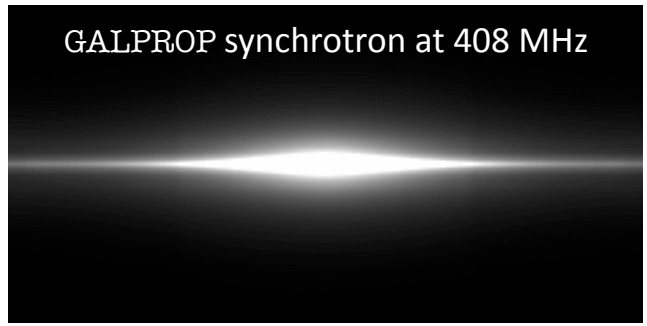


Mertsch & Sarkar, arXiv:1004.3056

Methodology

- Cannot determine synchrotron content in WMAP skymaps independently
- Model synchrotron emission with GALPROP:

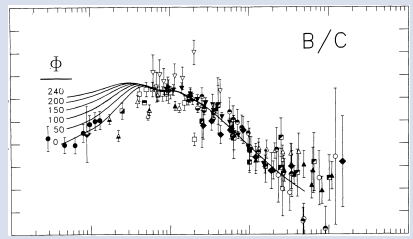
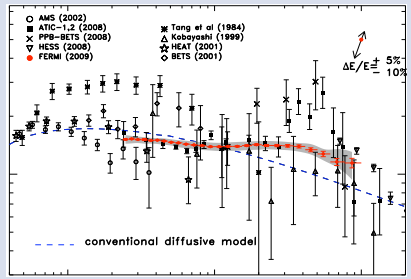
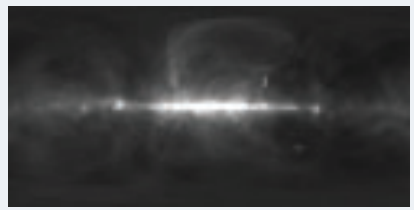
mock WMAP data



mock 408 MHz template

- Perform template subtraction (FS 8) as in Dobler & Finkbeiner ApJ **680** (2008) 1222 but without free-free and dust

Constraining Input Parameters

Input parameters		observation	
propagation parameters	D_{0xx}, δ v_A, dv_{conv}/dz	local CR nuclei *some freedom*	
source distribution	*Lorimer? exponential?*	*some freedom*	
source spectrum	$N_0 E^{\alpha 1,2}$	local CR $e^{\pm}$	
Galactic magnetic field	$B_0 e^{-r/\rho} f(z)$	408 MHz survey	

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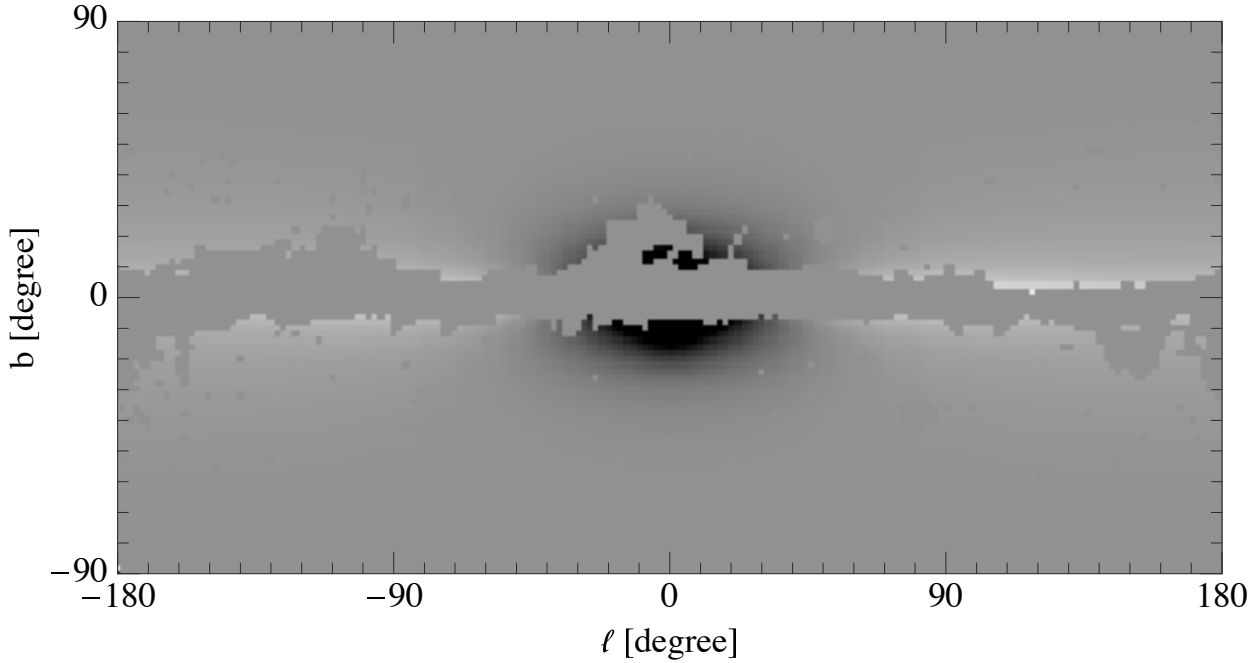
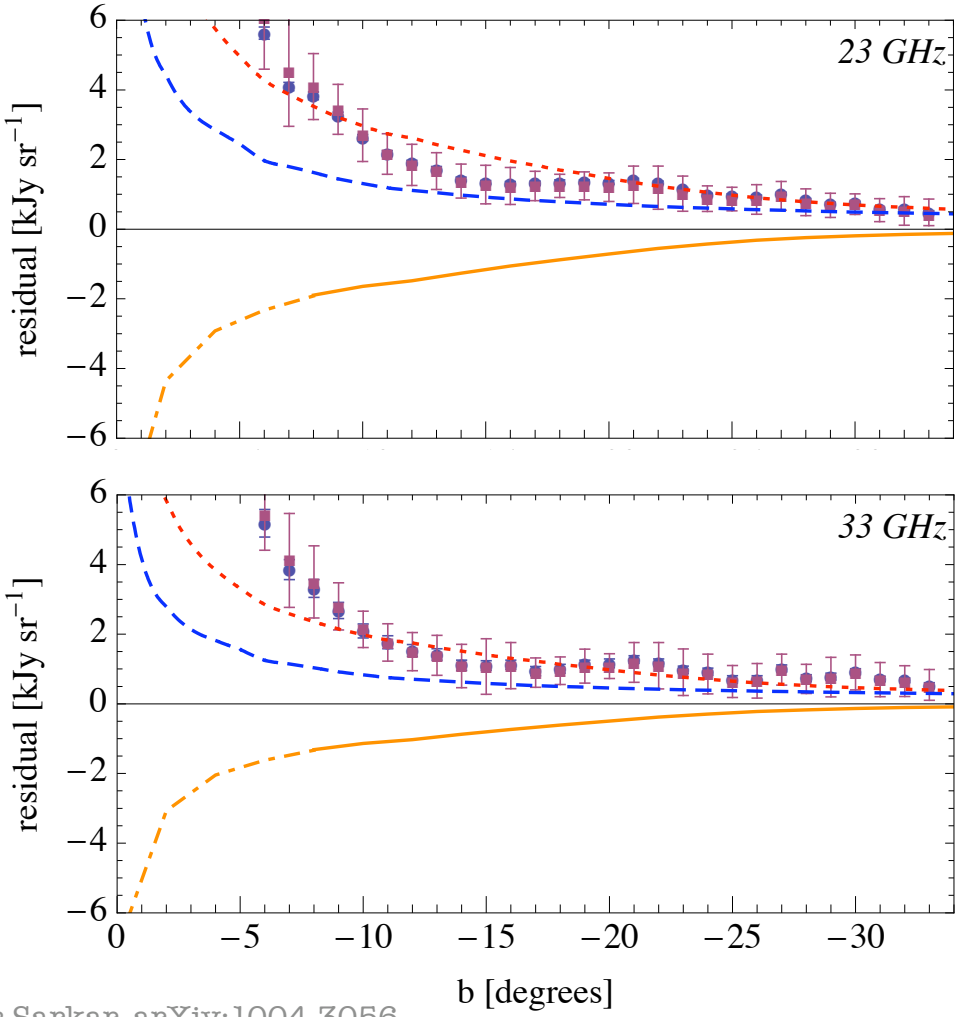
Model 1: Morphology



- deficit around galactic centre
- roughly spherical
- of opposite sign to ‘haze’

Mertsch & Sarkar, arXiv:1004.3056

Model 1: Intensity



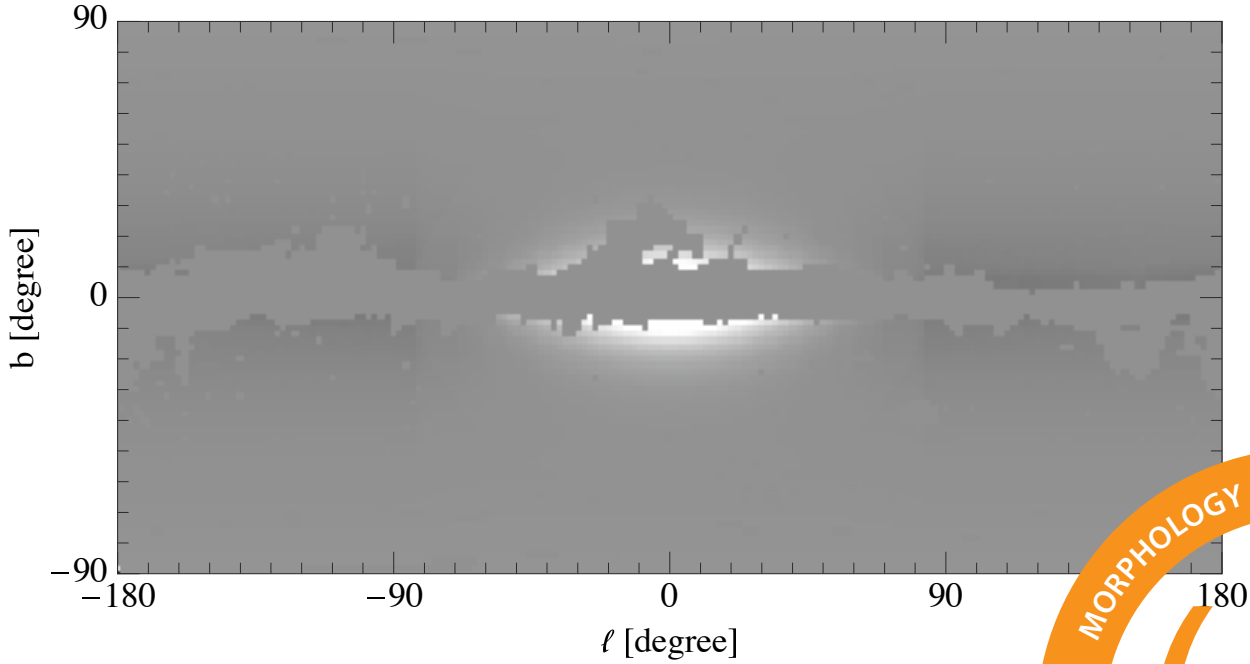
23 GHz
408 MHz (scaled)
residual
'WMAP haze'

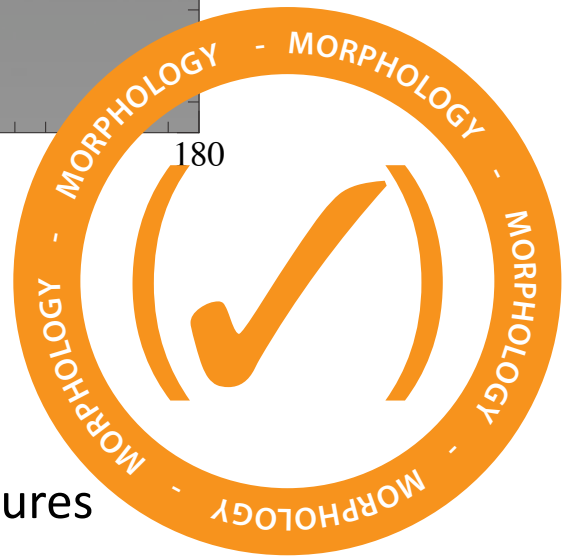
Dobler & Finkbeiner (2008)
Hooper *et al.*, PRD **76** (2007) 083012

Opposite sign, but same magnitude as haze

Mertsch & Sarkar, arXiv:1004.3056

Model 2: Morphology

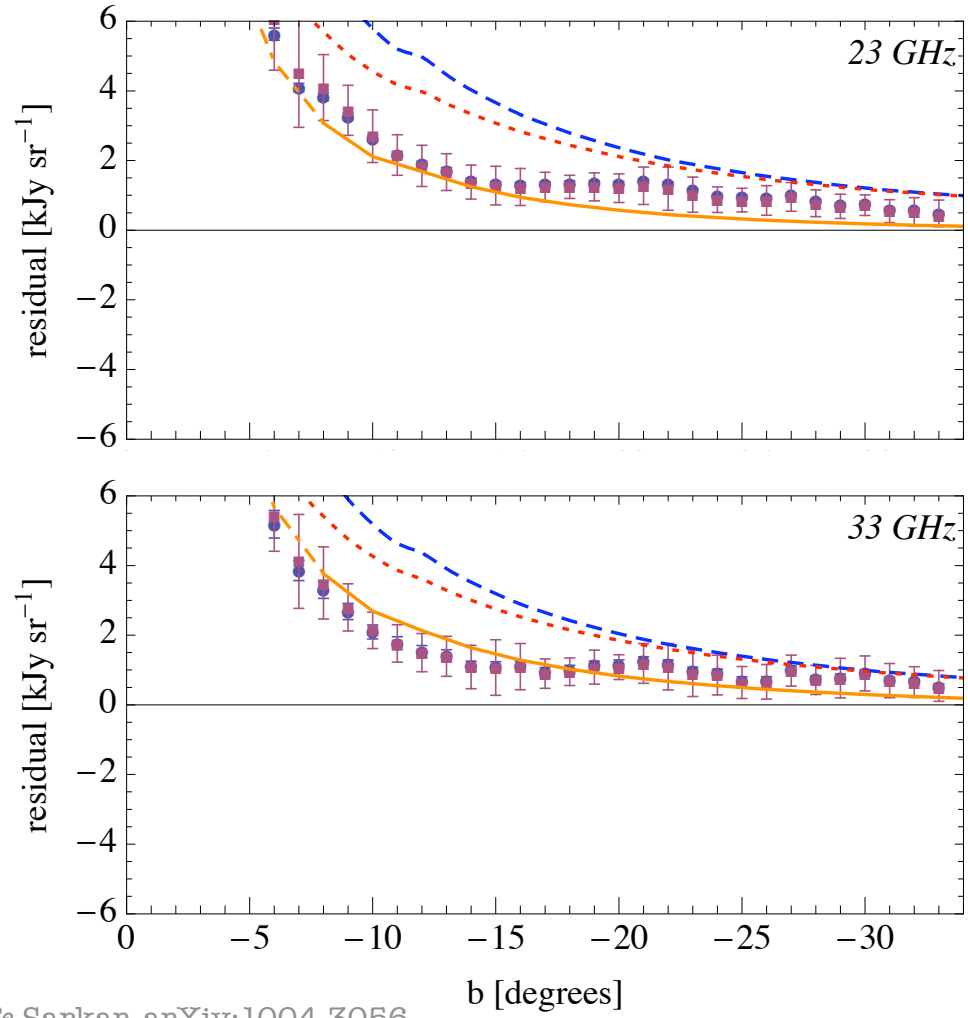




- excess around galactic centre
- more extended in longitude (±60°) than in latitude (±30°)
- major modification due to local structures expected

Mertsch & Sarkar, arXiv:1004.3056

Model 2: Intensity

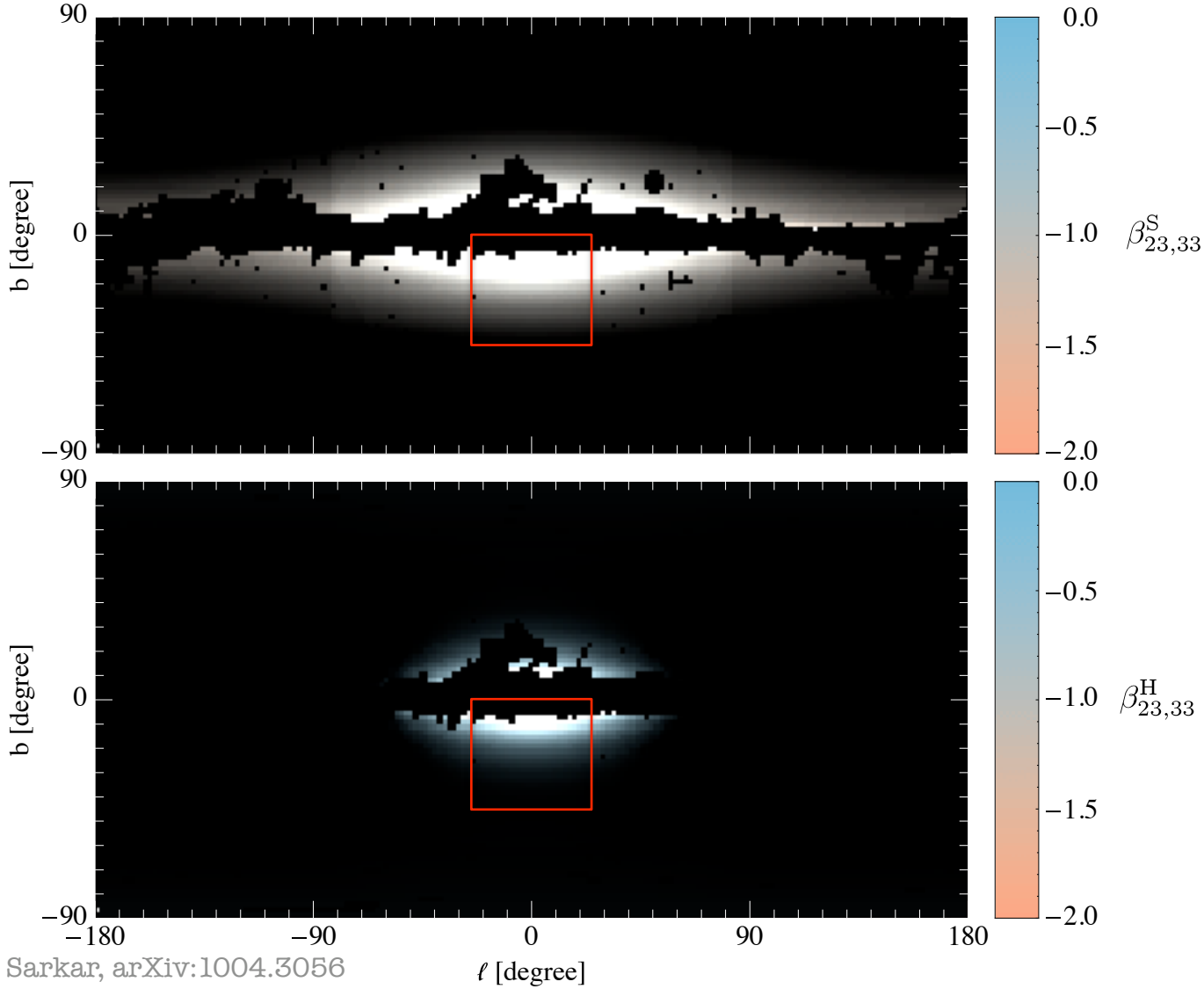


23 GHz
408 MHz (scaled)
residual
'WMAP haze'

Dobler & Finkbeiner (2008)
Hooper *et al.*, PRD **76** (2007) 083012

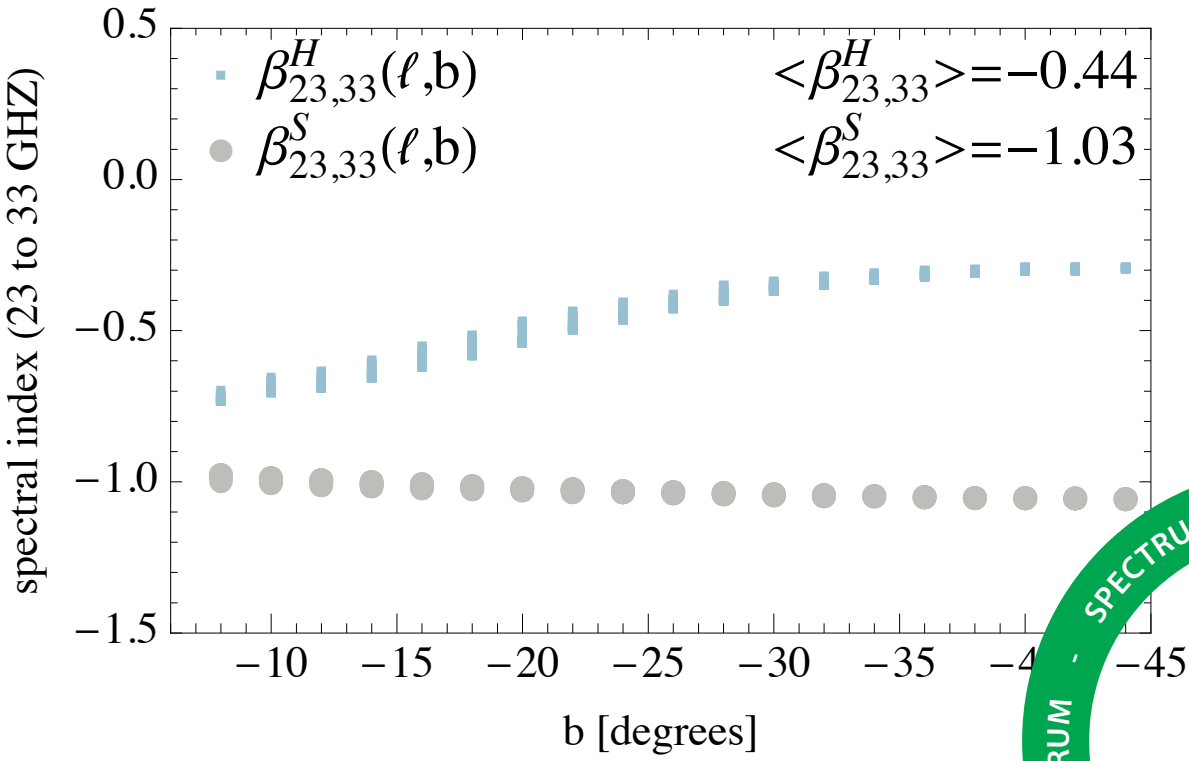
Mertsch & Sarkar, arXiv:1004.3056

Model 2: Spectral Index

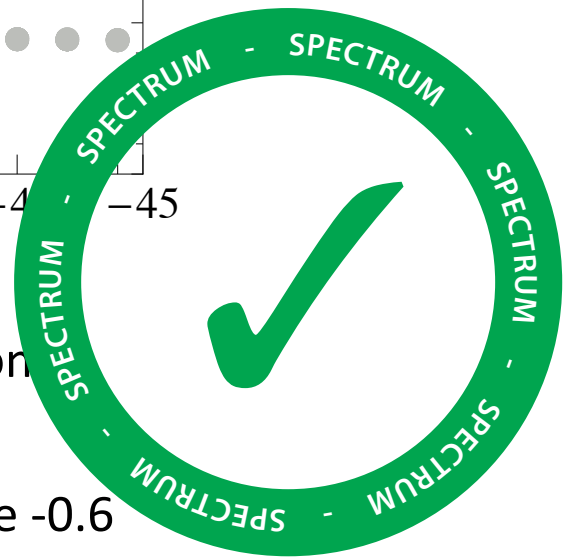


Mertsch & Sarkar, arXiv:1004.3056

Spectral Index



- 'haze' globally harder than synchrotron
- $\beta^H(\ell,b)$ slightly hardening with b
- difference in spectral index on average -0.6



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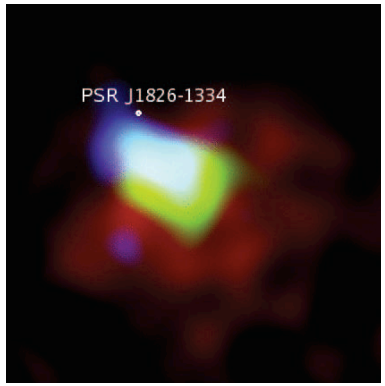
Summary



Energy-dependent diffusion of $e^{\pm}$ leads to systematic effects in template fitting of synchrotron skymaps

For Lorimer source distribution (model 1): deficit around galactic centre; same intensity as `haze'

For exponential source distribution (model 2): excess around galactic centre; right intensity and spectrum