

Systematic Effects in the Extraction of the 'WMAP Haze'

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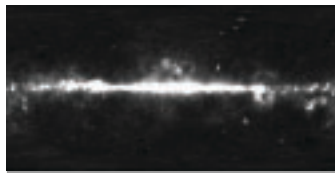
Science & Technology
Facilities Council



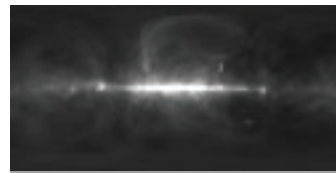
MARIE CURIE ACTIONS

'WMAP haze'

Claim by Finkbeiner (2004)



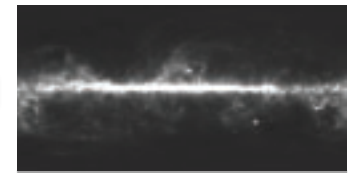
CMB-subtracted
WMAP K-band



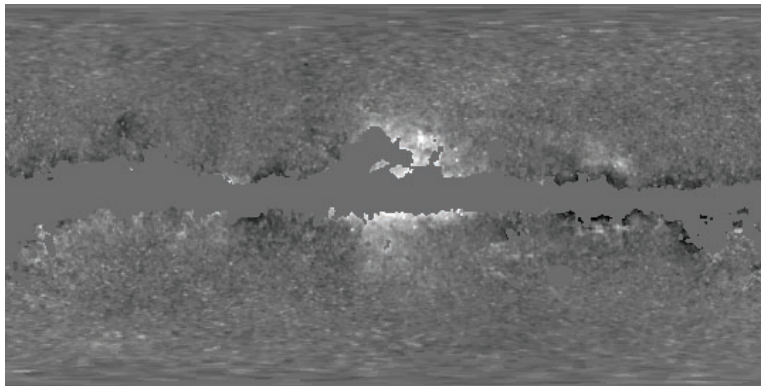
synchrotron



free-free



dust



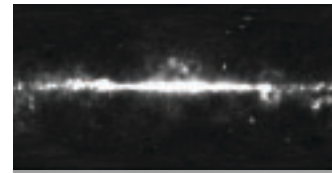
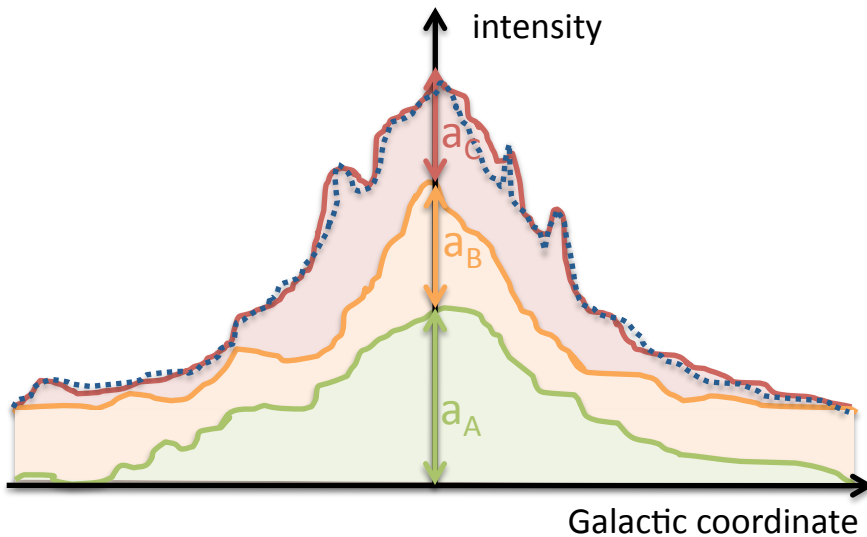
Dobler & Finkbeiner, ApJ **680** (2008) 1222

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

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



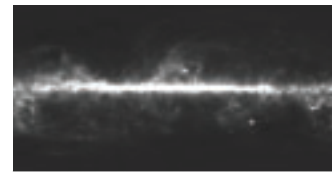
CMB subtracted
WMAP K-band

Hinshaw et al., ApJS 180 (2009) 225



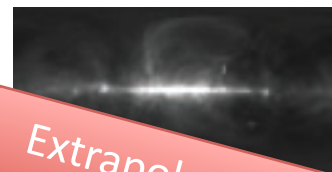
free-free:
H α map

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:

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

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)

$$D_{xx} \propto D_{xx0} \left(\frac{E}{4 \text{ GeV}} \right)^\delta, \quad \vec{v} = \pm \vec{e}_z \frac{dv}{dz} z, \quad D_{pp} \propto v_A^2 D_{xx}$$

diffusion-loss length:

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

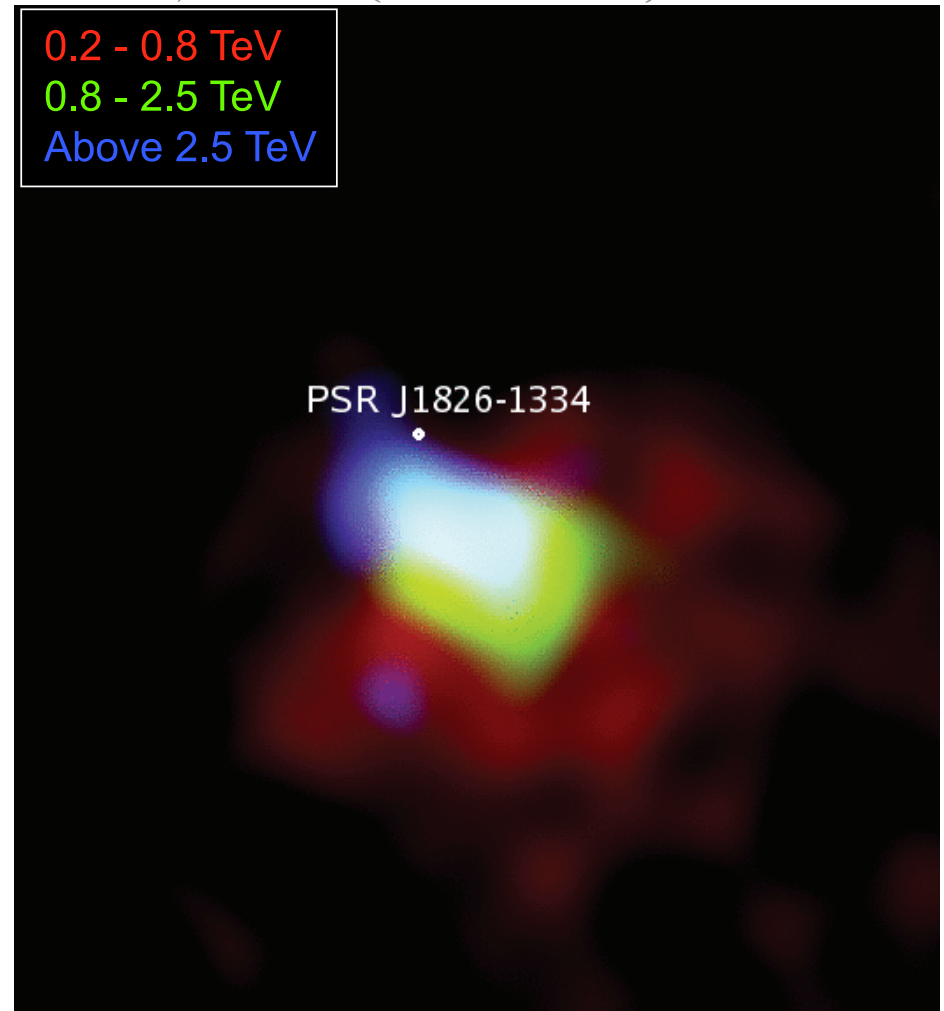
Morphology of synchrotron maps
at WMAP and at radio frequencies
could be quite different!

Energy-Dependent Morphology

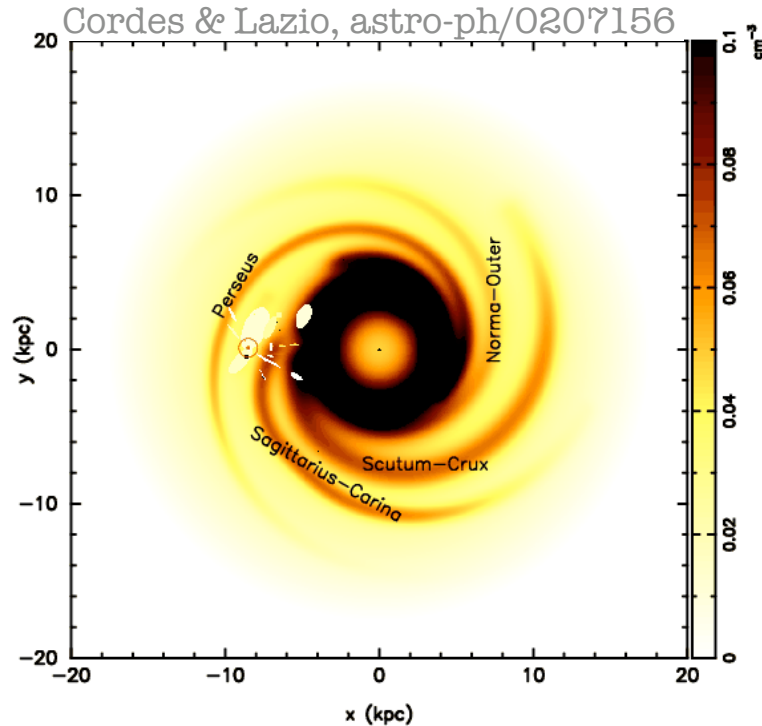
Funk *et al.*, ICRC 2007 (arXiv 0709.3125)

0.2 - 0.8 TeV
0.8 - 2.5 TeV
Above 2.5 TeV

- 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

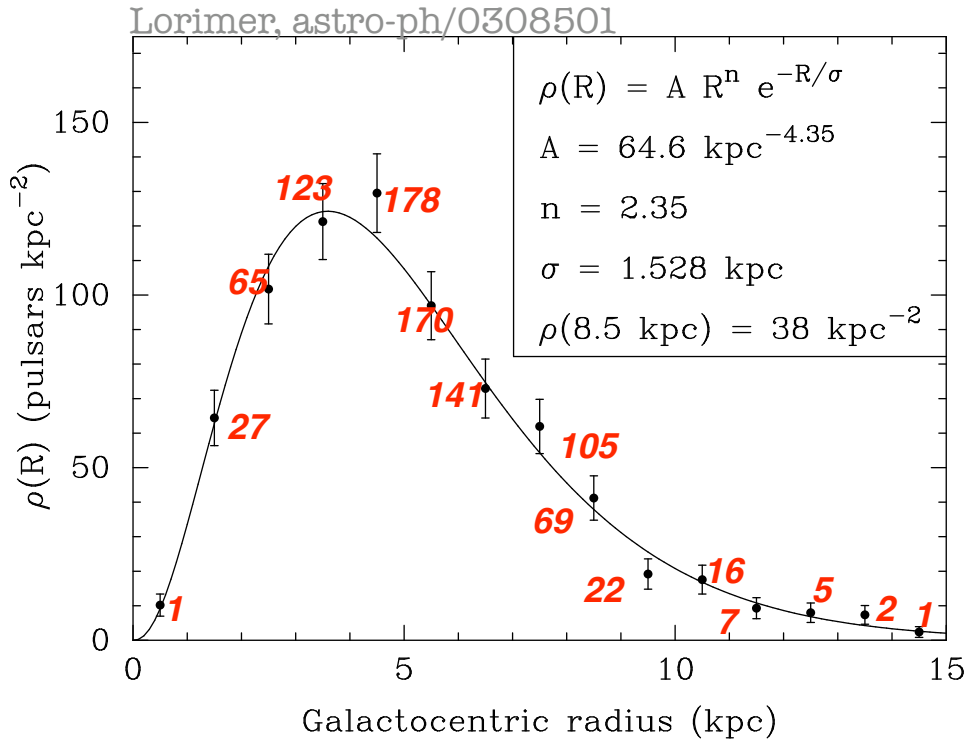


Source Distribution



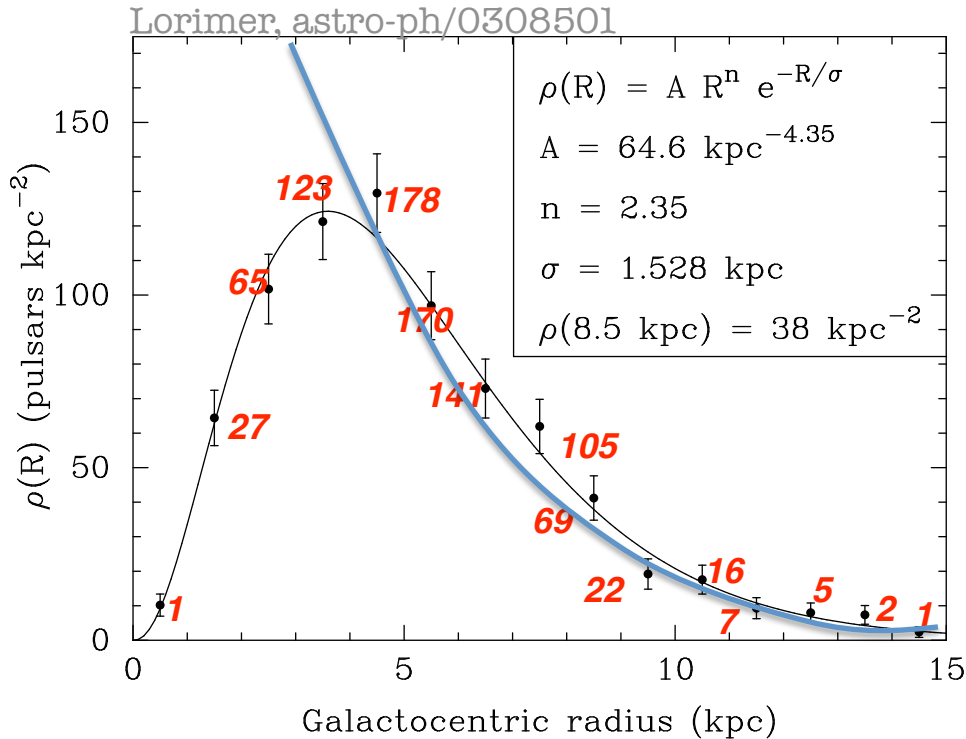
- SNRs traced by pulsars to first approximation
- radial pulsar distribution from rotation and dispersion measure
- depends on thermal electron density

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- radial pulsar distribution from rotation and dispersion measure
- depends on thermal electron density
- likely strong selection effects near Galactic Centre

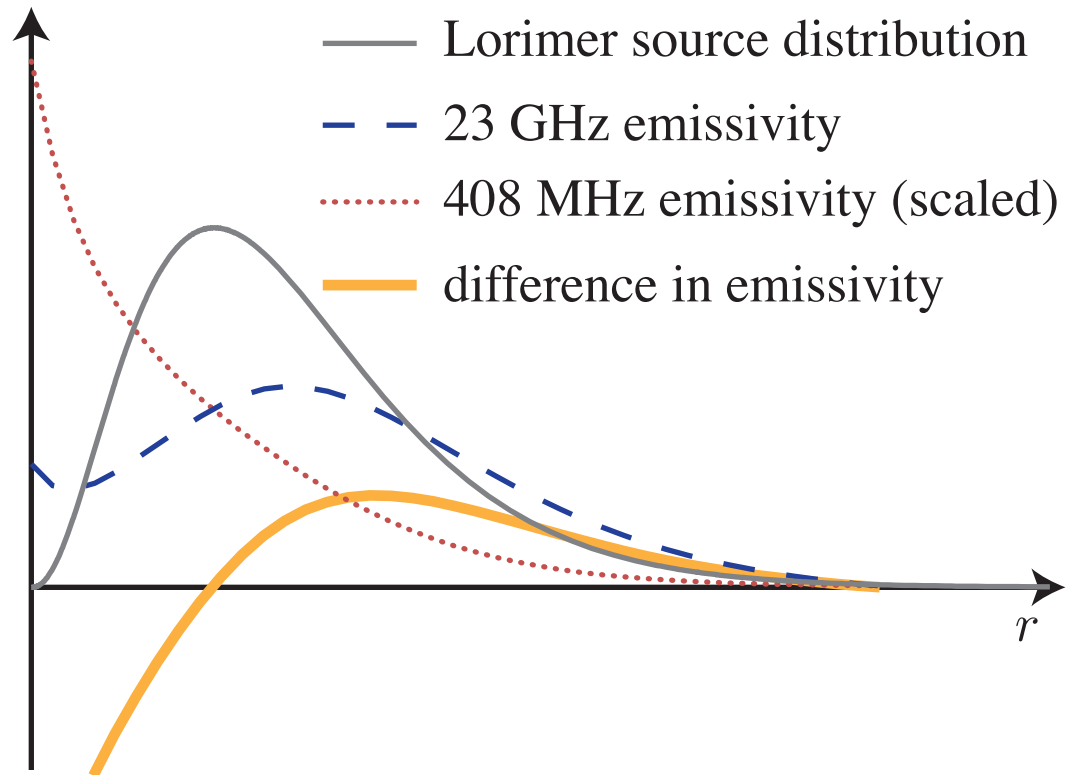
The distribution of e^\pm sources could be very different



consider alternatively exponential distribution

Effect of Invalid Extrapolation I

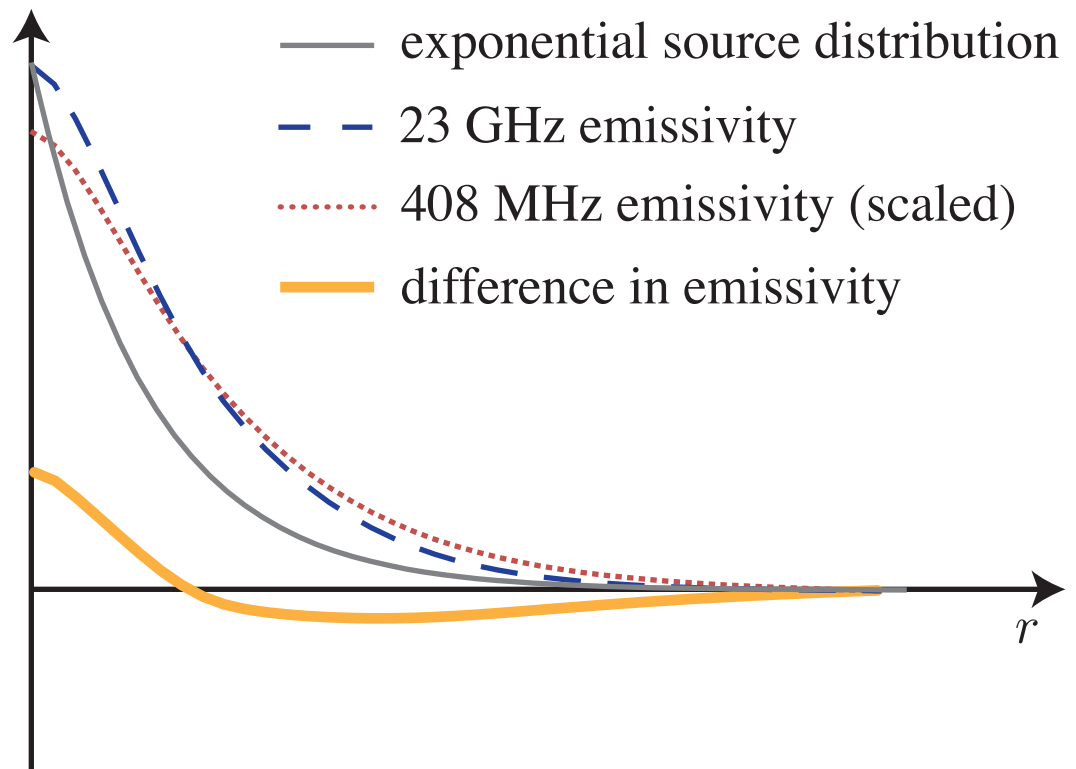
- source distribution peaks at intermediate radii
- 23 GHz e^\pm do not diffuse much and trace sources
- 408 MHz e^\pm diffuse more and wash out source distribution



template subtraction
finds *deficit* at Galactic
centre

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



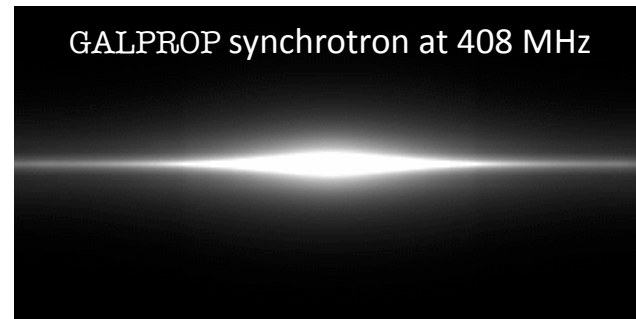
template subtraction
finds *excess* at Galactic
centre

Methodology

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



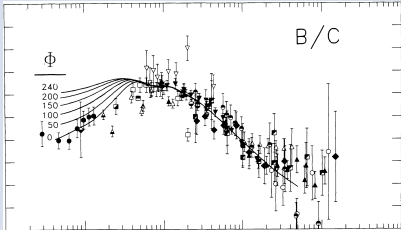

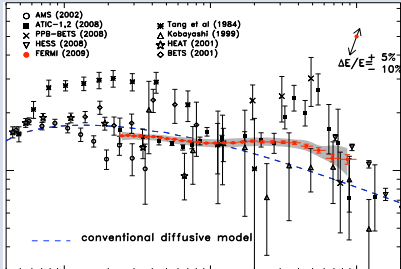
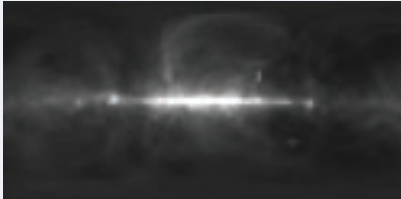
mock WMAP data



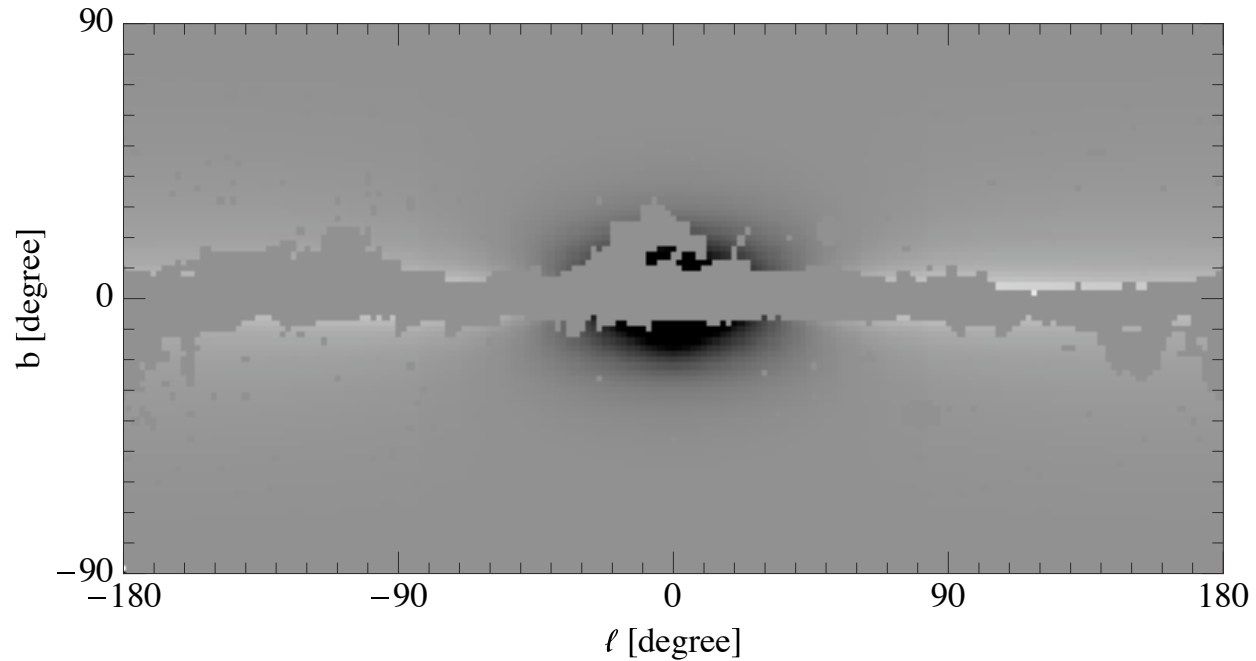
mock 408 MHz template

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

Constraining Input Parameters

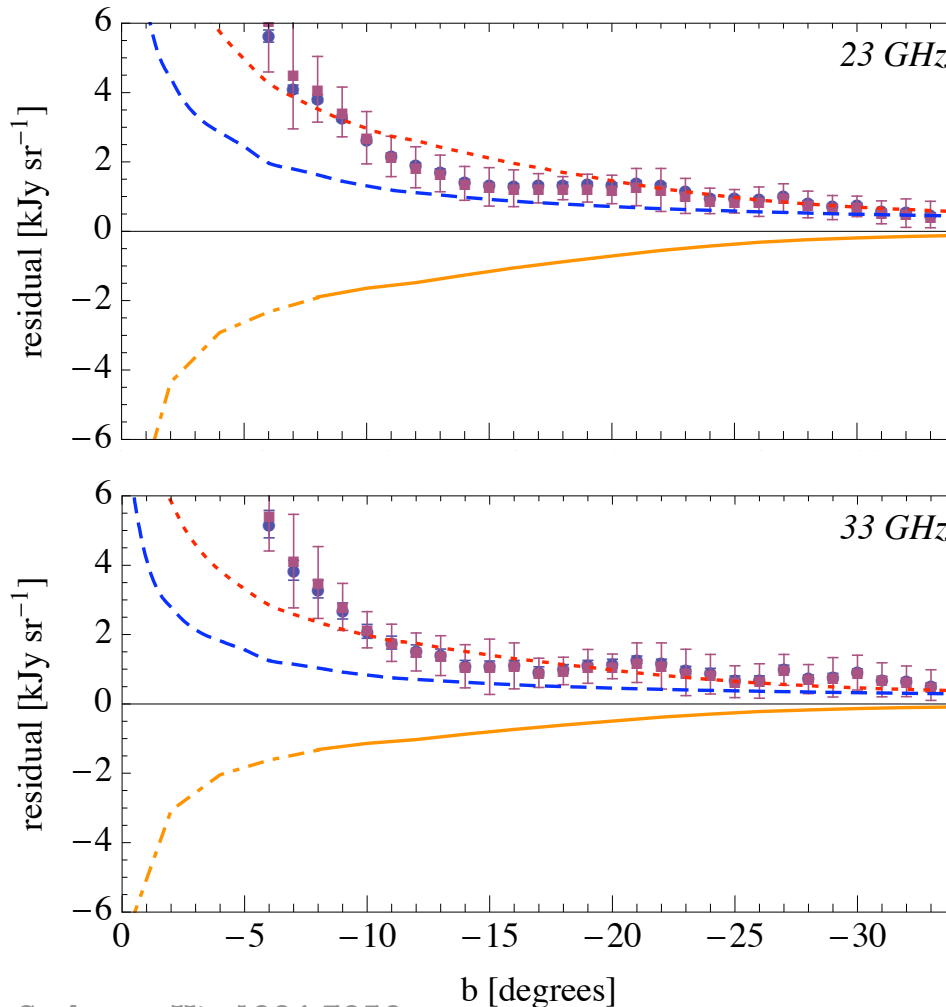
Input parameters		observation
propagation parameters	D_{0xx}, δ $v_A, dv_{conv}/dz$	local CR nuclei <i>some freedom</i> 
source distribution	<i>Lorimer? exponential?</i>	<i>some freedom</i> 
source spectrum	$N_0 E^{\alpha_{1,2}}$	local CR e^{\pm} 
Galactic magnetic field	$B_0 e^{-r/\rho} f(z)$	408 MHz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

Model 1: Morphology



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

Model 1: Intensity

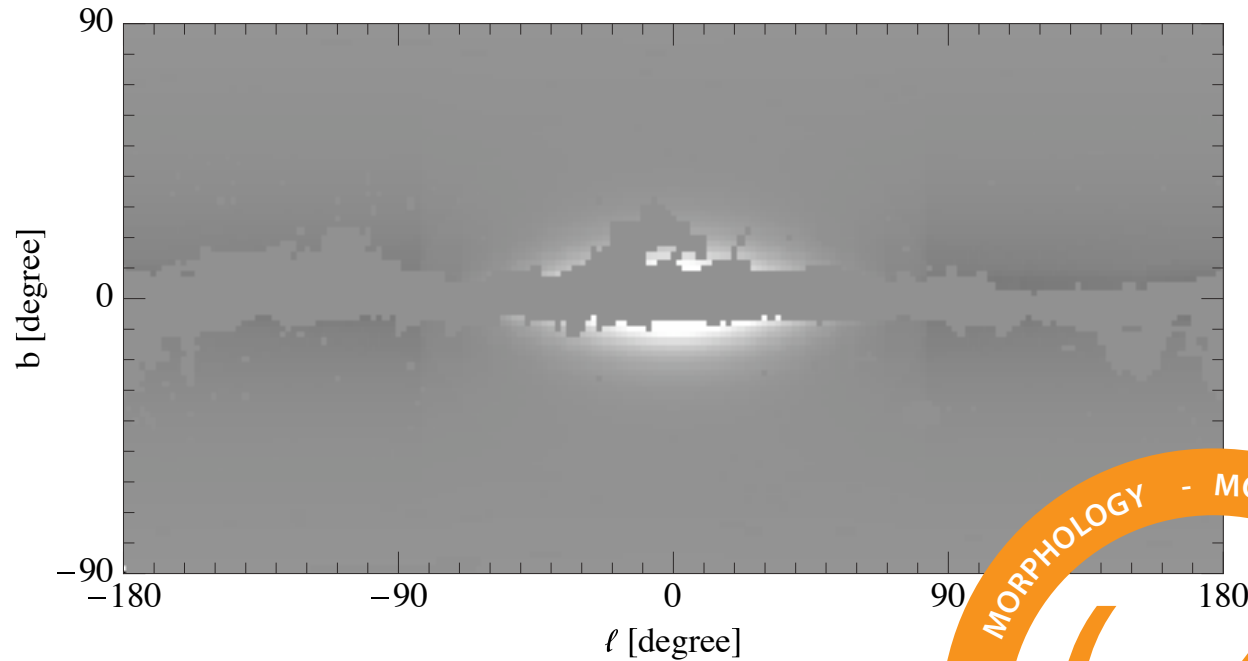


- 23 GHz
- - 408 MHz (scaled)
- residual
- ■ 'WMAP haze'

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

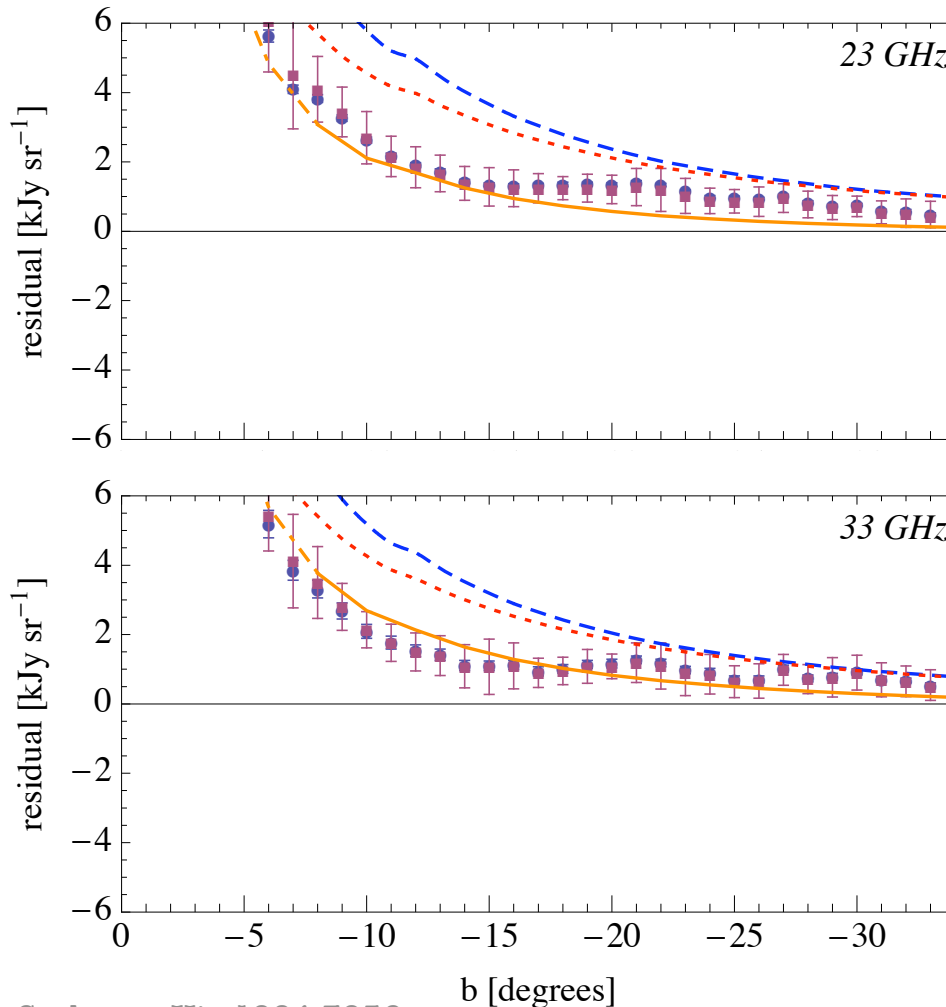
Opposite sign, but same magnitude as haze

Model 2: Morphology



- excess around galactic centre
- more extended in longitude ($\pm 60^\circ$) than in latitude ($\pm 30^\circ$)
- major modification due to local structure expected

Model 2: Intensity

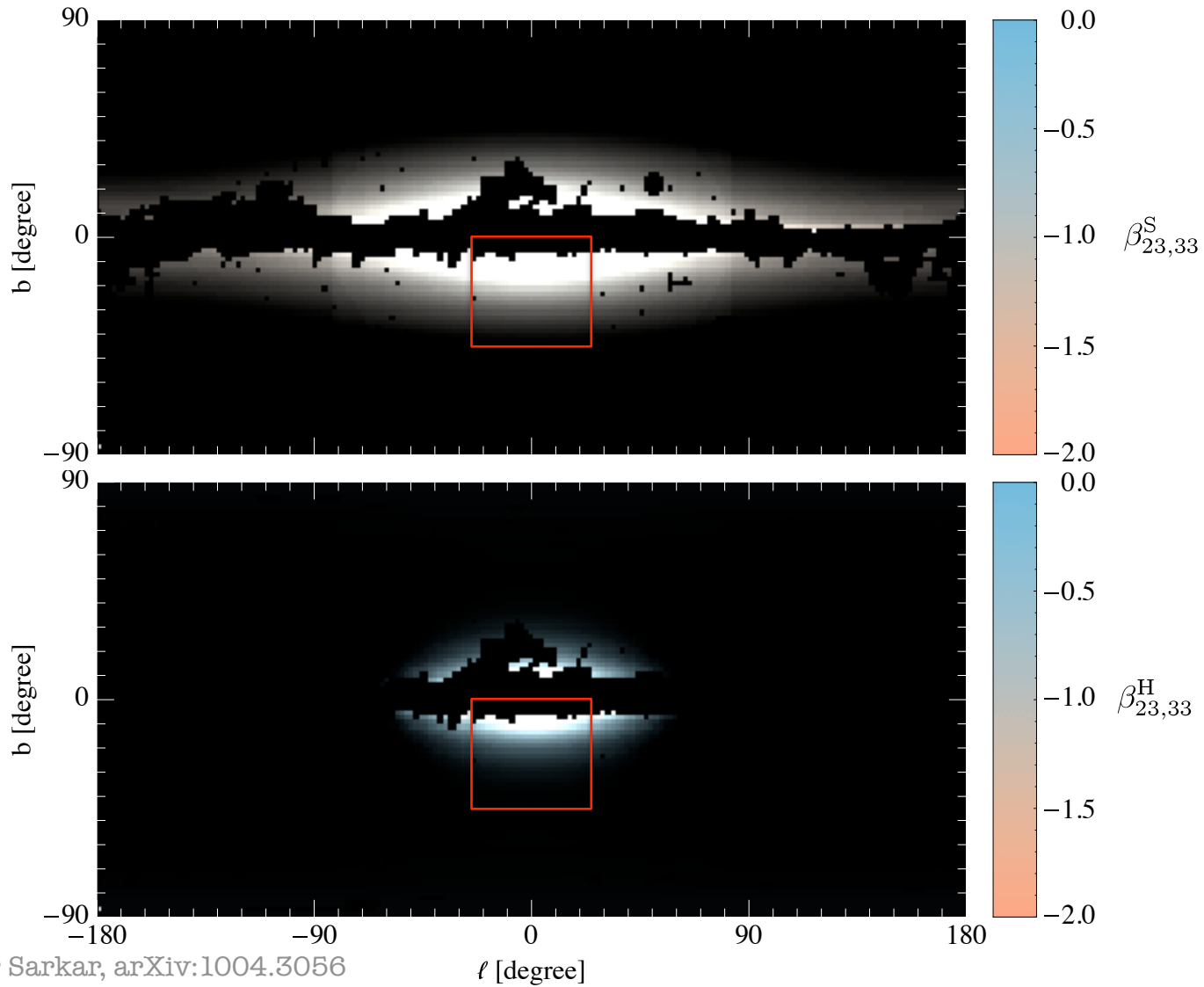


- 23 GHz
- 408 MHz (scaled)
- residual
- 'WMAP haze'

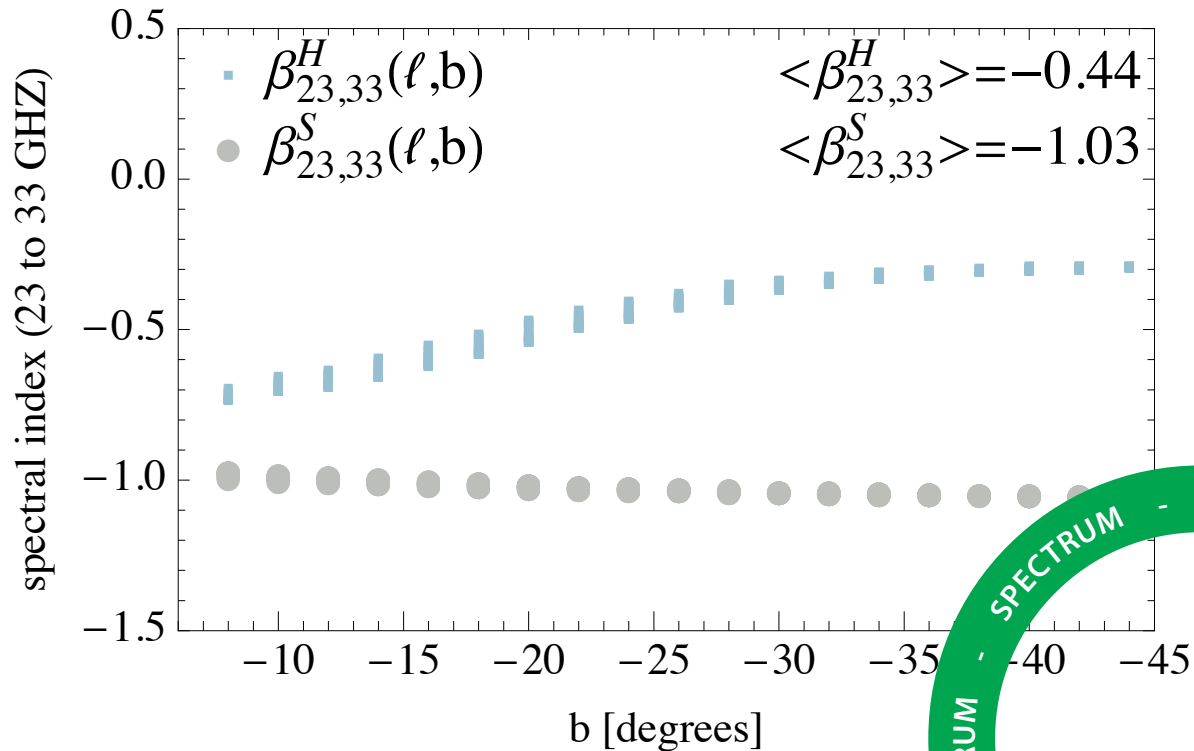
Dobler & Finkbeiner (2008)
Hooper *et al.*, PRD **76** (2007) 083012



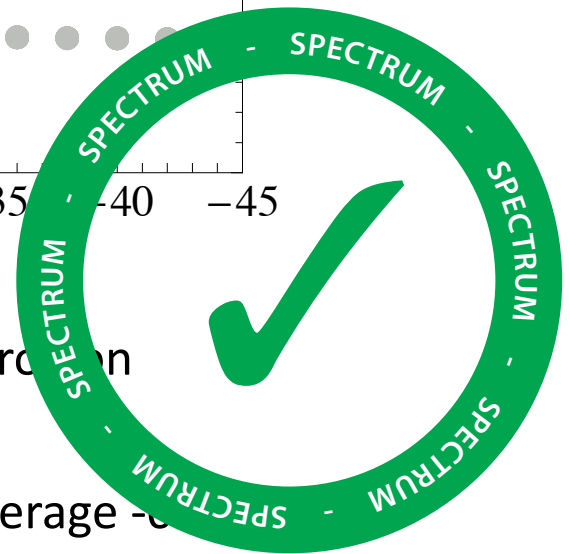
Model 2: Spectral Index



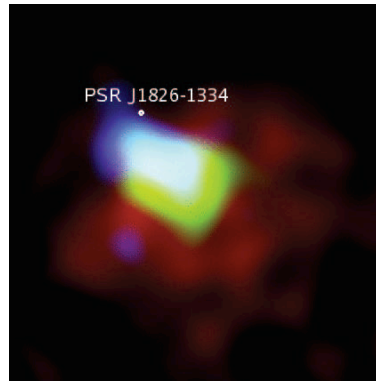
Spectral Index



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



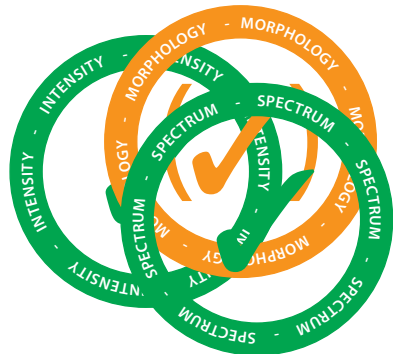
Summary



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