TeVPA2011, Stockholm, 1 - 5 August

Radio data and synchrotron emission in consistent cosmic ray models

Torsten Bringmann, University of Hamburg

based on

TB, F. Donato & R. Lineros, arXiv:1106.4821

Outlook

- Cosmic ray propagation
- B/C determination of propagation parameters
- Radio data
- Synchrotron radiation
- Bringing it all together…
- Consequences for indirect DM searches
- Outlook & conclusions

Cosmic ray propagation

- Little known about Galactic magnetic field distribution
- Magnetic fields confine CRs in galaxy for $E \lesssim 10^3\,\mathrm{TeV}$
- Random distribution of field inhomogeneities
  $\leadsto$ propagation well described by diffusion equation

$$\frac{\partial\psi}{\partial t} - \nabla\cdot(D\nabla - v_c)\psi + \frac{\partial}{\partial p} b_{\mathrm{loss}}\psi - \frac{\partial}{\partial p} K \frac{\partial}{\partial p}\psi = q_{\mathrm{source}}$$

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Sources (primary & secondary)

Analytical vs. numerical

How to solve the diffusion equation?

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- Numerically
  - ⊕ 3D possible
  - ⊕ any magnetic field model
  - ⊕ realistic gas distribution, full energy losses
  - ⊖ computations time-consuming
  - ⊖ “black box”

e.g.

GALPROP

Strong, Moskalenko, …

DRAGON

Evoli, Gaggero, Grasso & Maccione

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DRAGON

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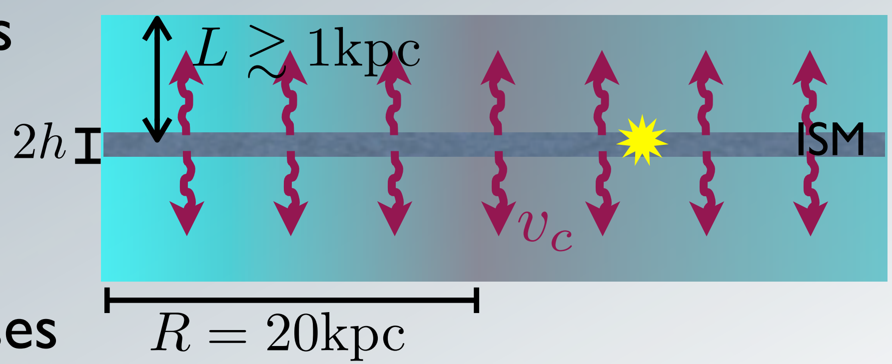
- (Semi-)analytically
  - ➕ Physical insight from analytic solutions
  - ➕ fast computations allow to sample full parameter space
  - ➖ only 2D possible
  - ➖ simplified gas distribution, energy losses

e.g. Donato, Fornengo, Maurin, Salati, Taillet, ...



GCR composition

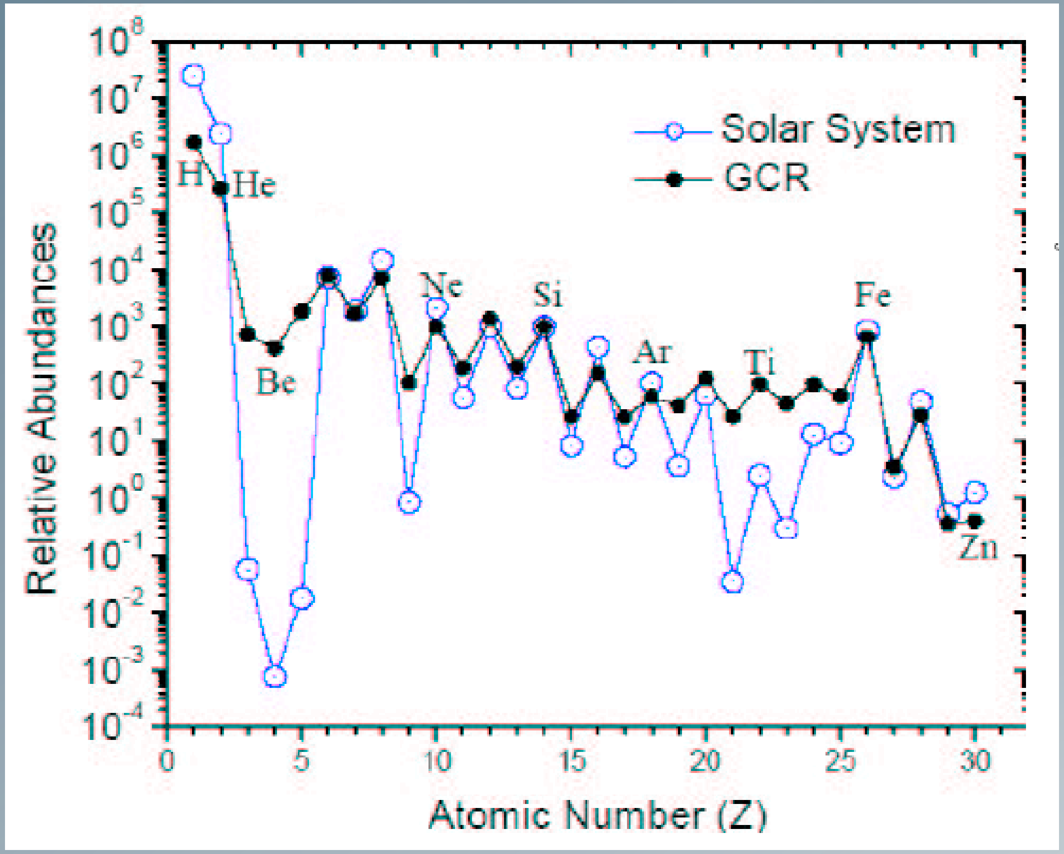


Fig. from D. Maurin

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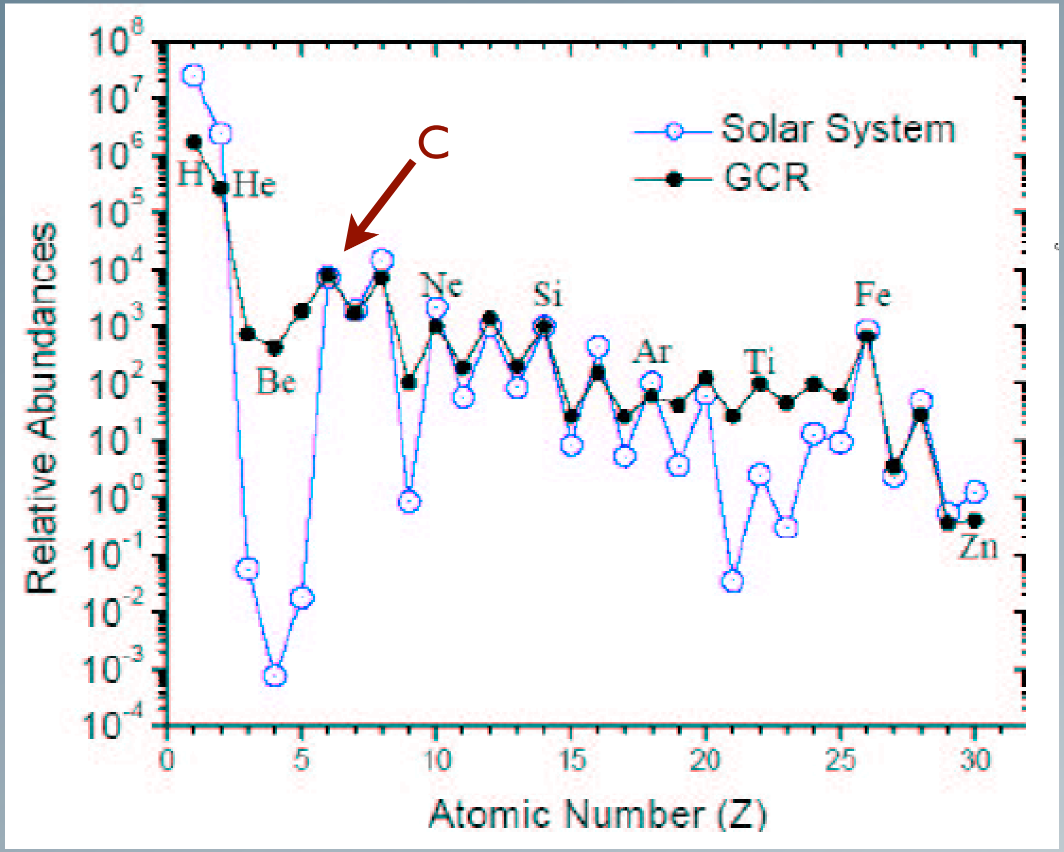

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- Primary species
  - present in sources
  - element distribution following stellar nucleosynthesis
  - accelerated in supernova shockwaves

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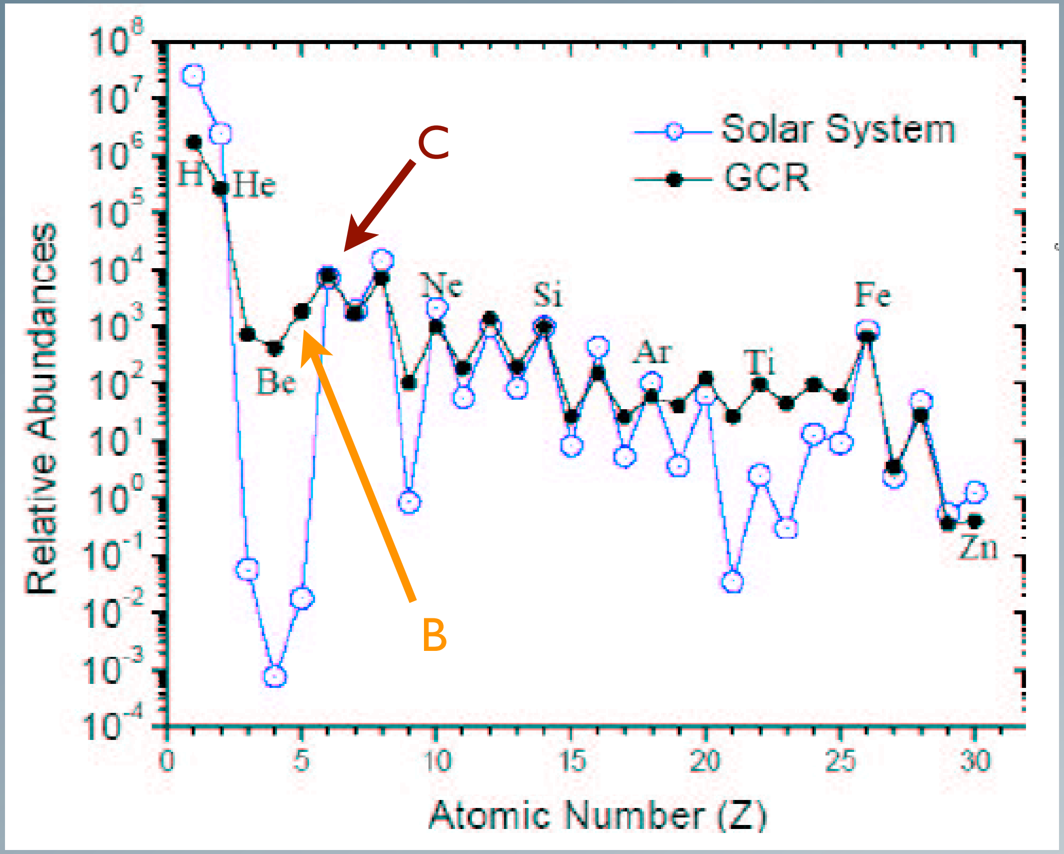


Fig. from D. Maurin

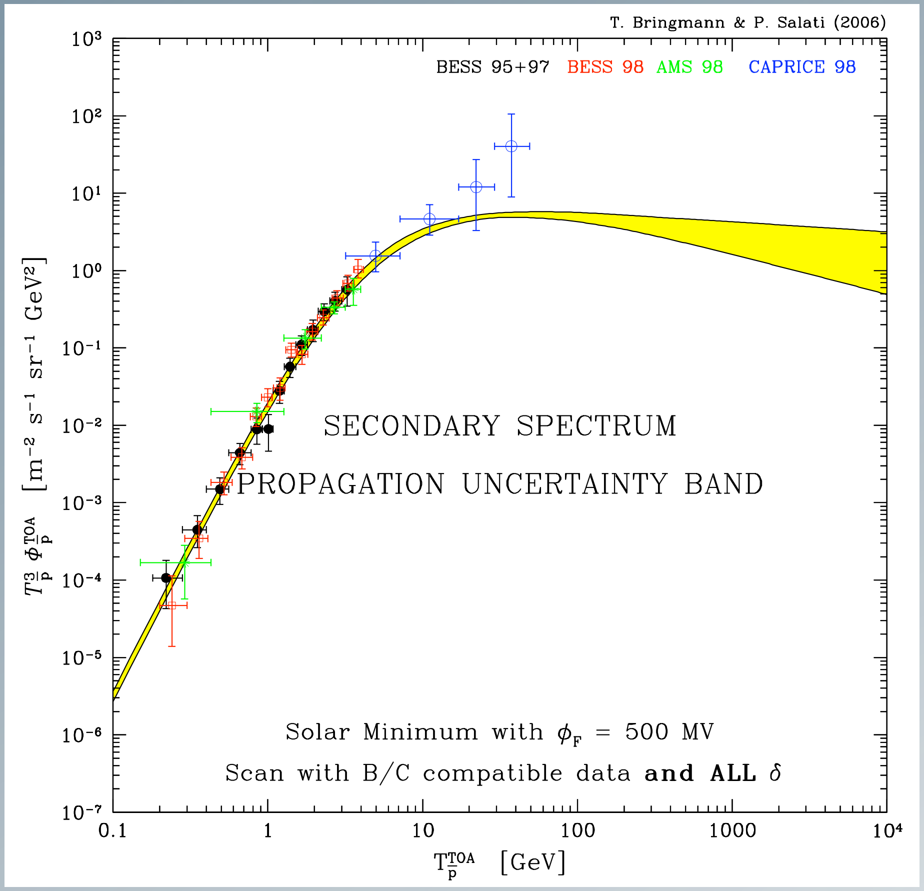
- **Primary species**
  - present in sources
  - element distribution following stellar nucleosynthesis
  - accelerated in supernova shockwaves
- **Secondary species**
  - much larger relative abundance than in stellar environments
  - produced by interaction of primary cosmic rays with interstellar medium

E.g. secondary antiprotons

- Propagation parameters $(K_0, \delta, L, v_a, v_c)$ of two-zone diffusion model strongly constrained by B/C

  Maurin, Donato, Taillet & Salati, ApJ '01

- This can be used to predict fluxes for other species:



TB & Salati, PRD '07

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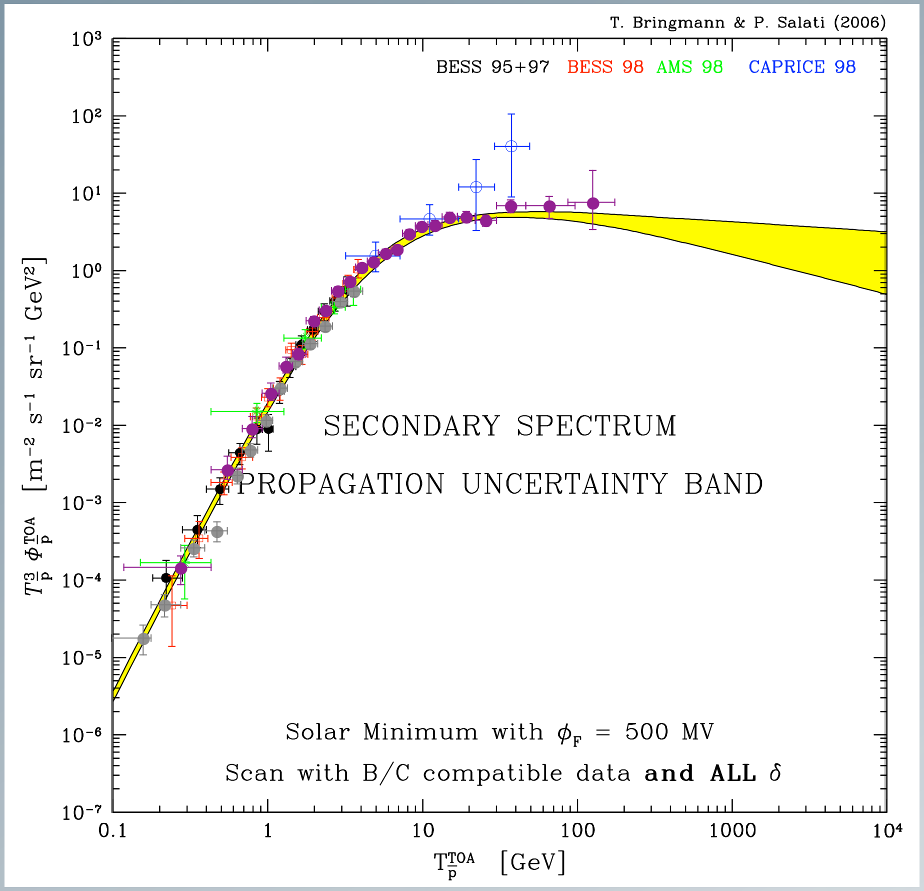

TB & Salati, PRD '07

excellent agreement with new data:

BESSpolar 2004
Abe *et al.*, PRL '08

PAMELA 2008
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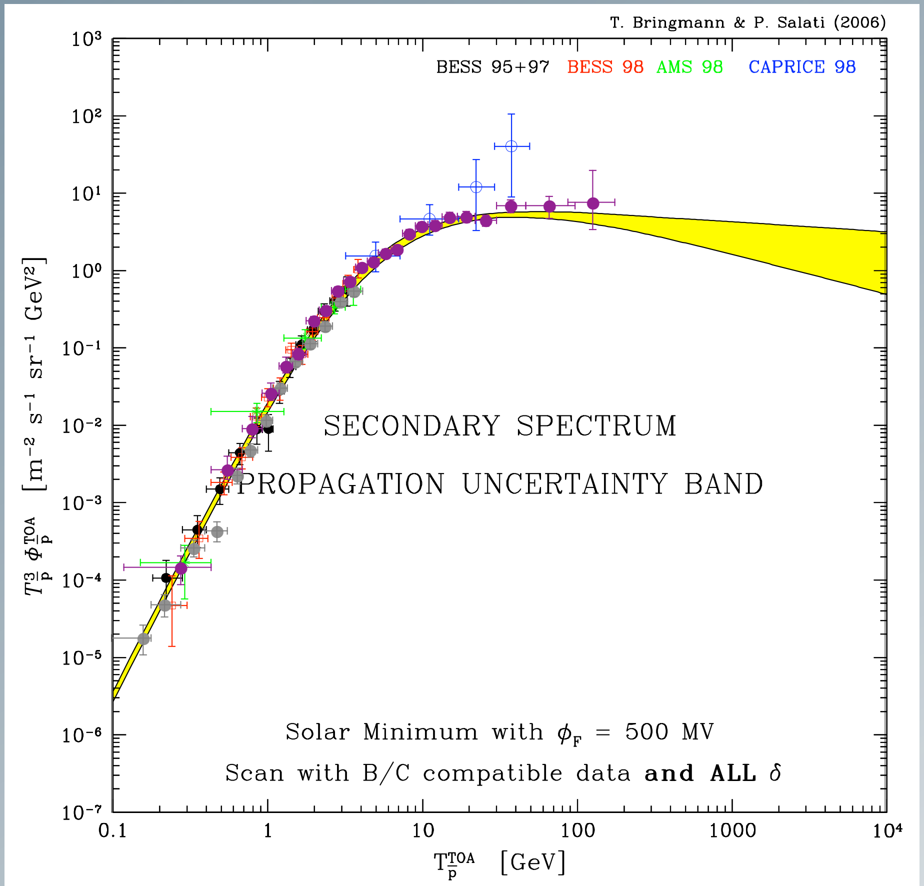

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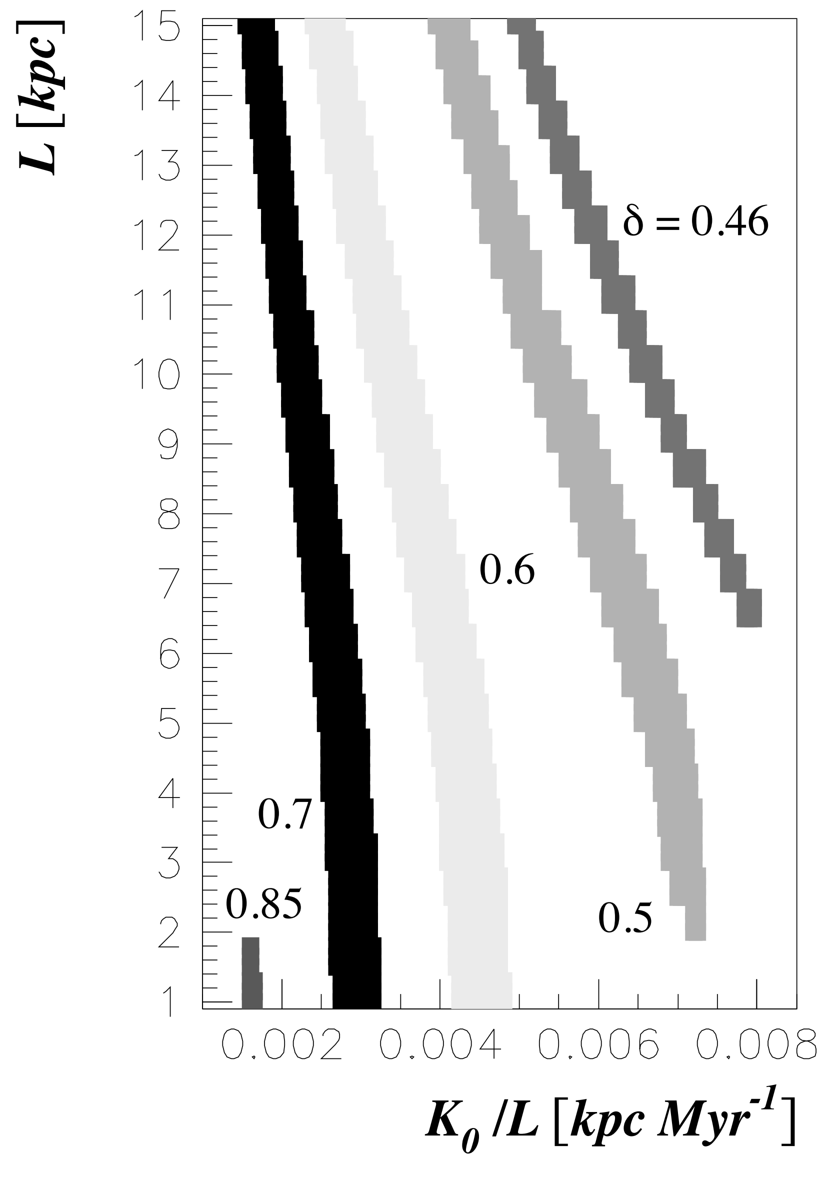
➪ very nice test for underlying diffusion model!

Degeneracies



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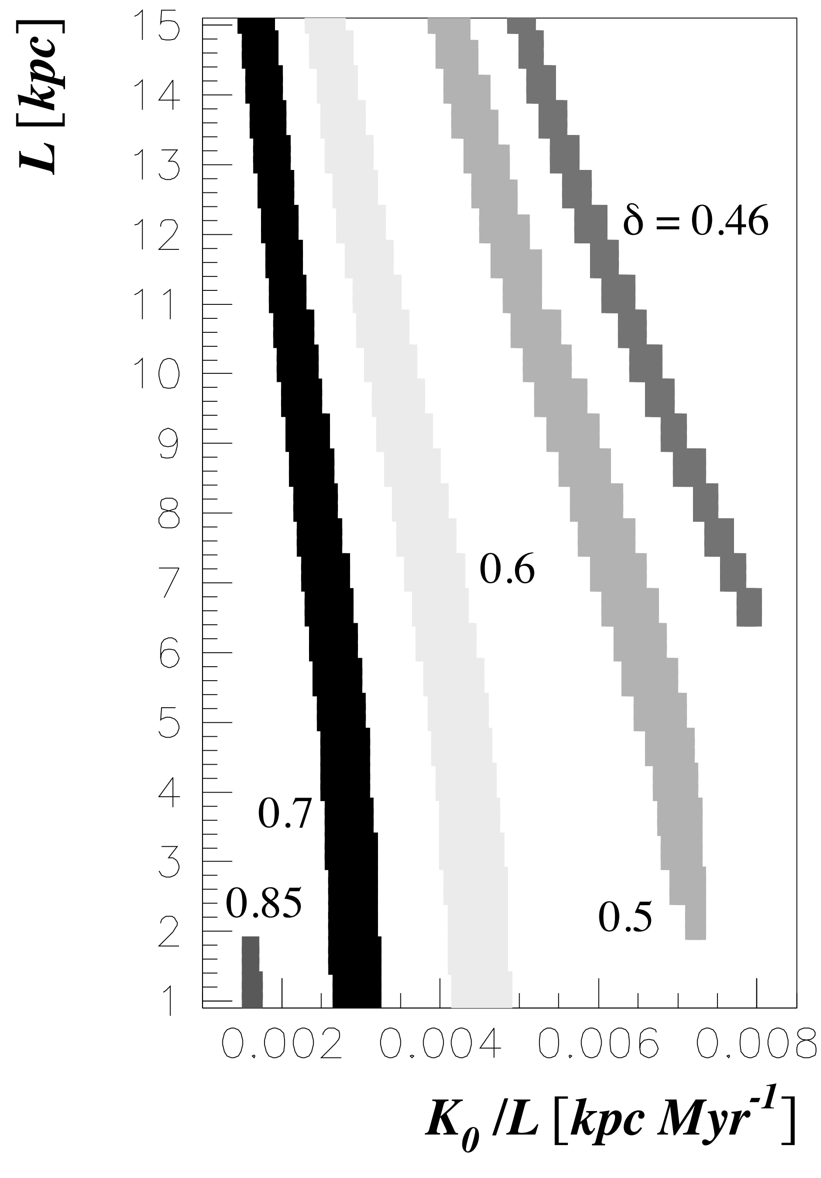

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Donato, Fornengo, Maurin, Salati & Taillet, PRD '04

case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)
max	0.46	0.0765	15	5	117.6
med	0.70	0.0112	4	12	52.9
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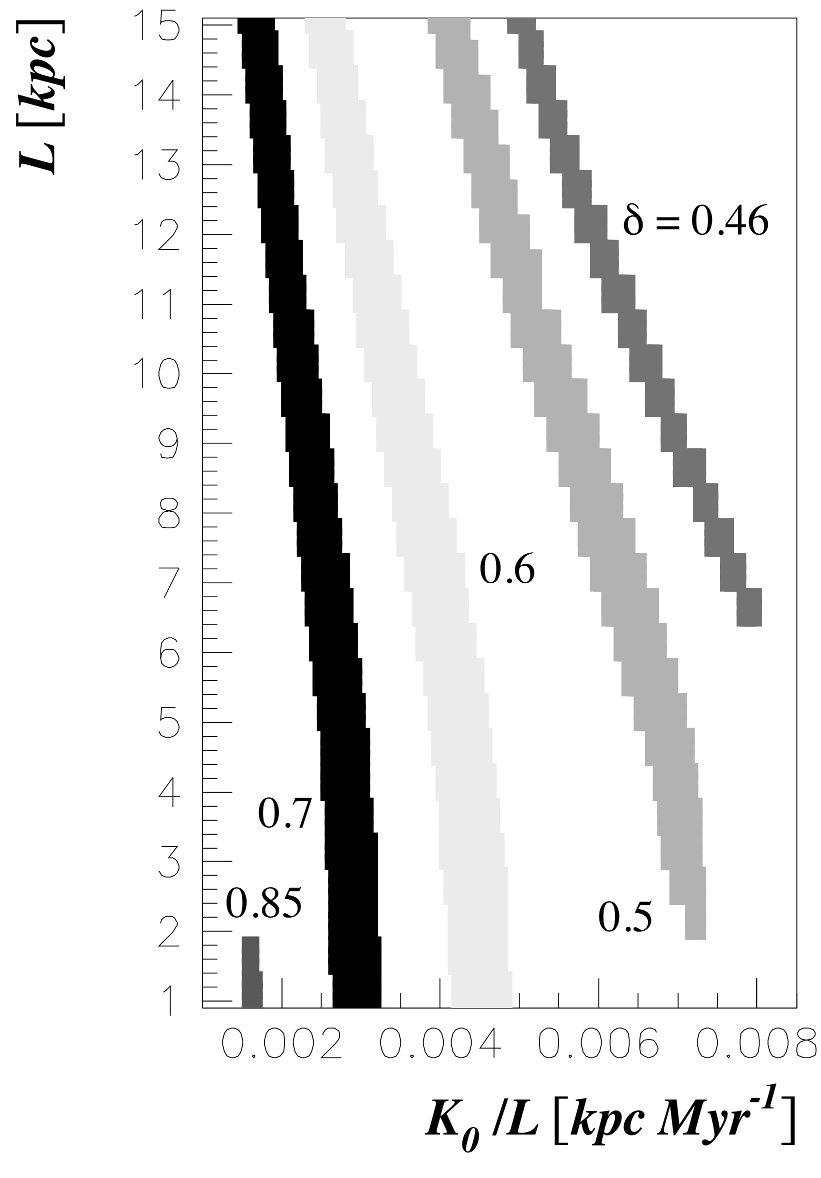

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⇩

$\mathcal{O}(10^2)$ change in predicted $\bar{p}$ flux from DM!

Lepton propagation

- $e^{\pm}$ can also be described in this framework!

Delahaye *et al.*, PRD '08, A&A '09, A&A '10

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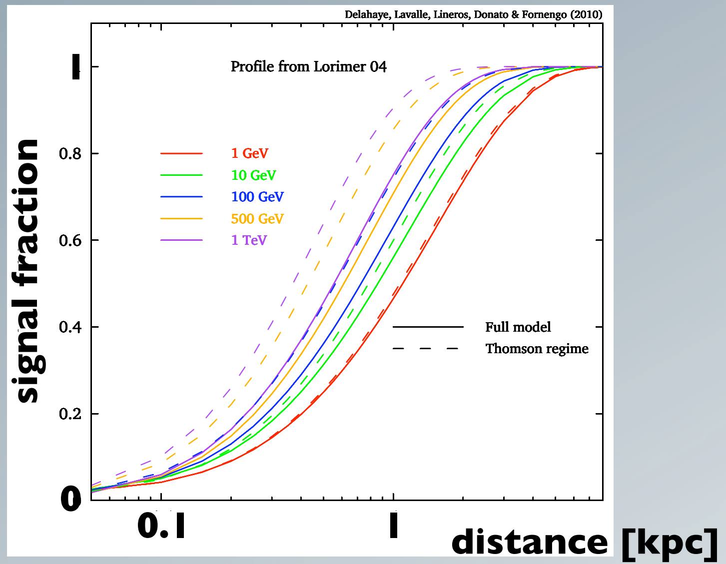
- Main difference to nuclei: energy losses are dominant
  ➡ mainly locally produced (~kpc for 100 GeV leptons)



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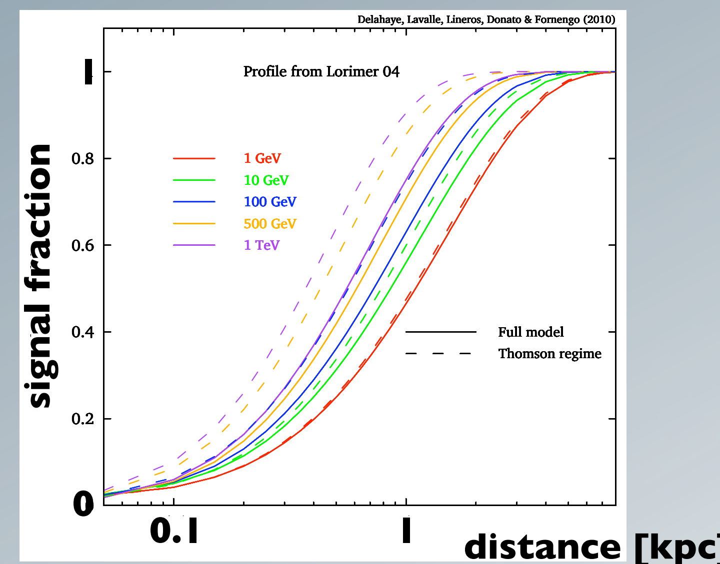
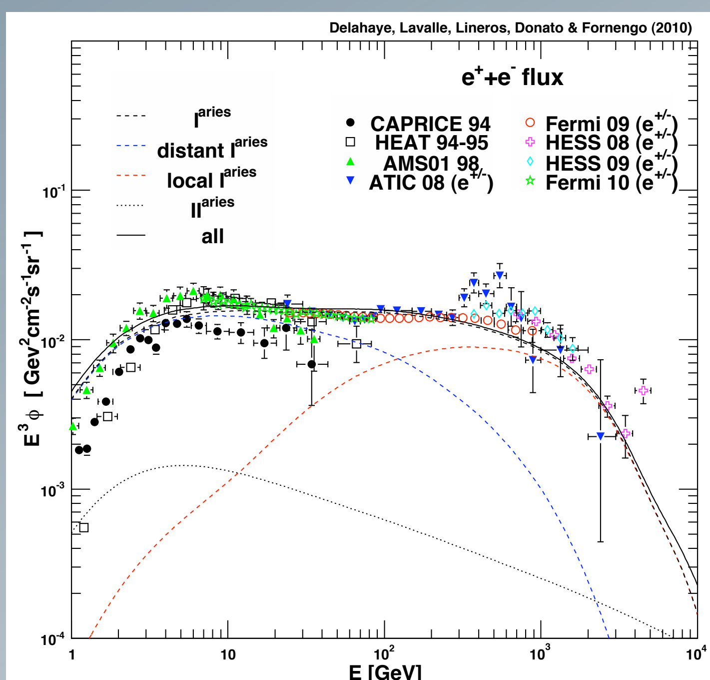




- propagation uncertainties:
  - secondaries ~ 2-4
  - primaries ~5

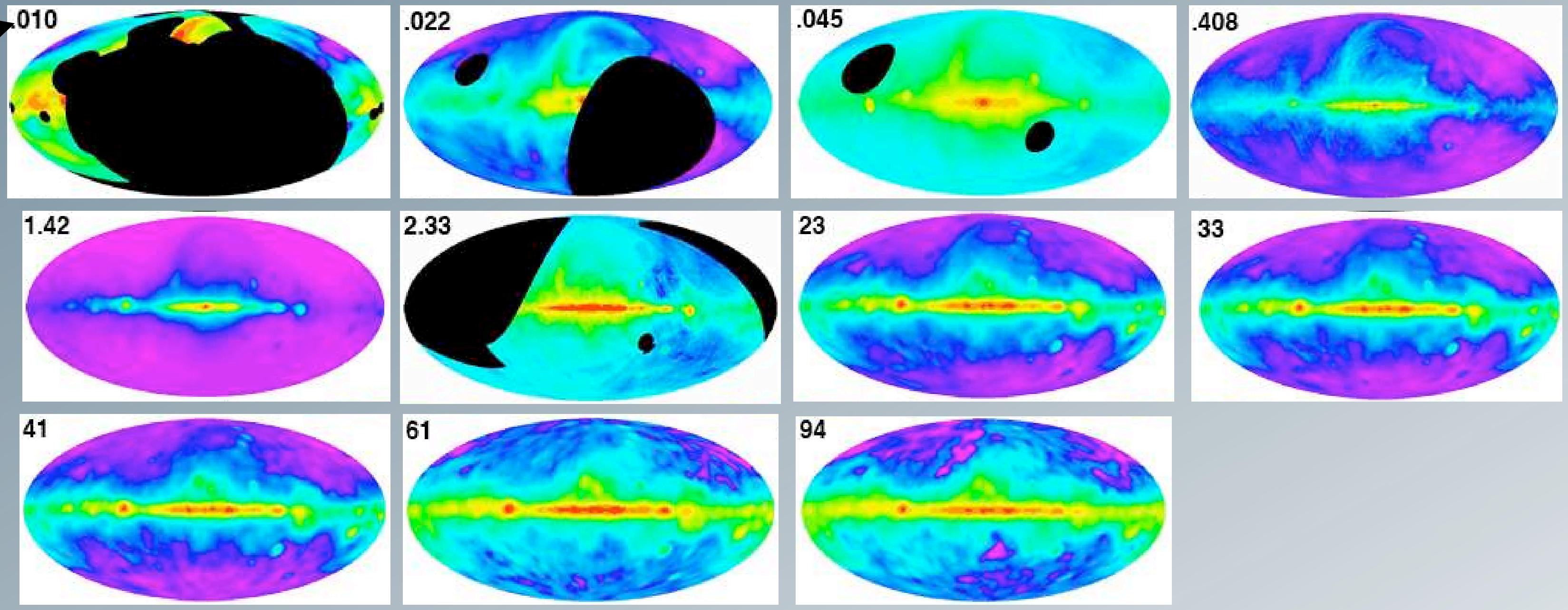
⇨ undisputed need for local primary source(s) to describe data well above ~10 GeV

Radio data

- Several large-scale surveys performed since 1960s
- Convenient HQ sample, fully digitalized:

Oliviera-Costa *et al.*, 0802.1525

frequency in GHz



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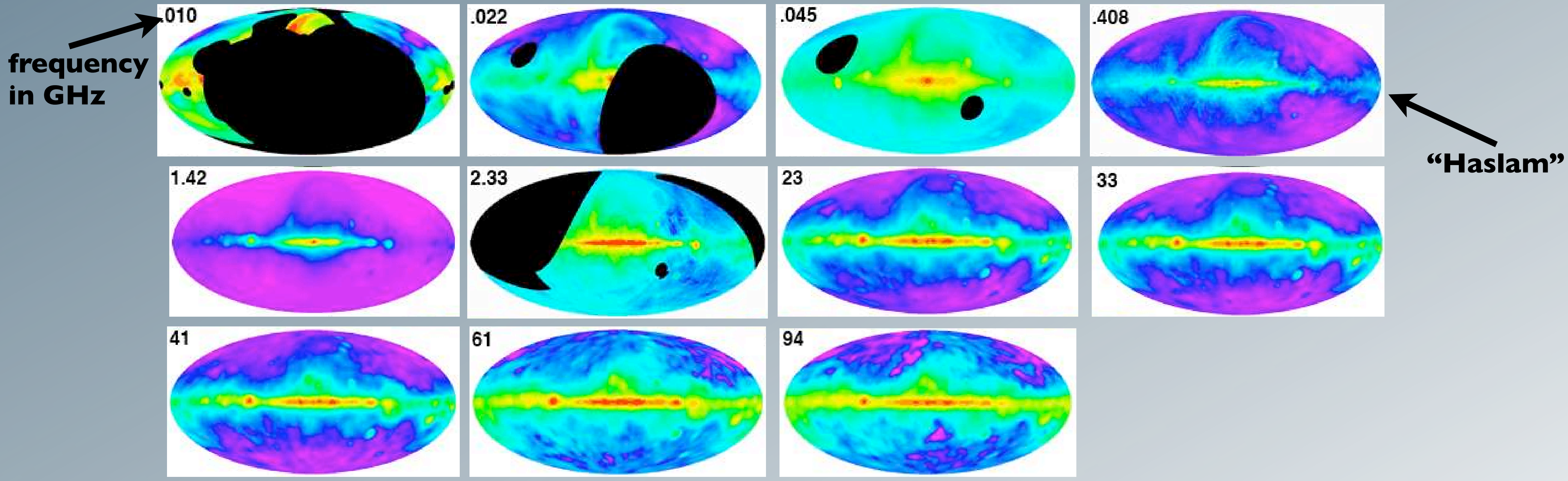

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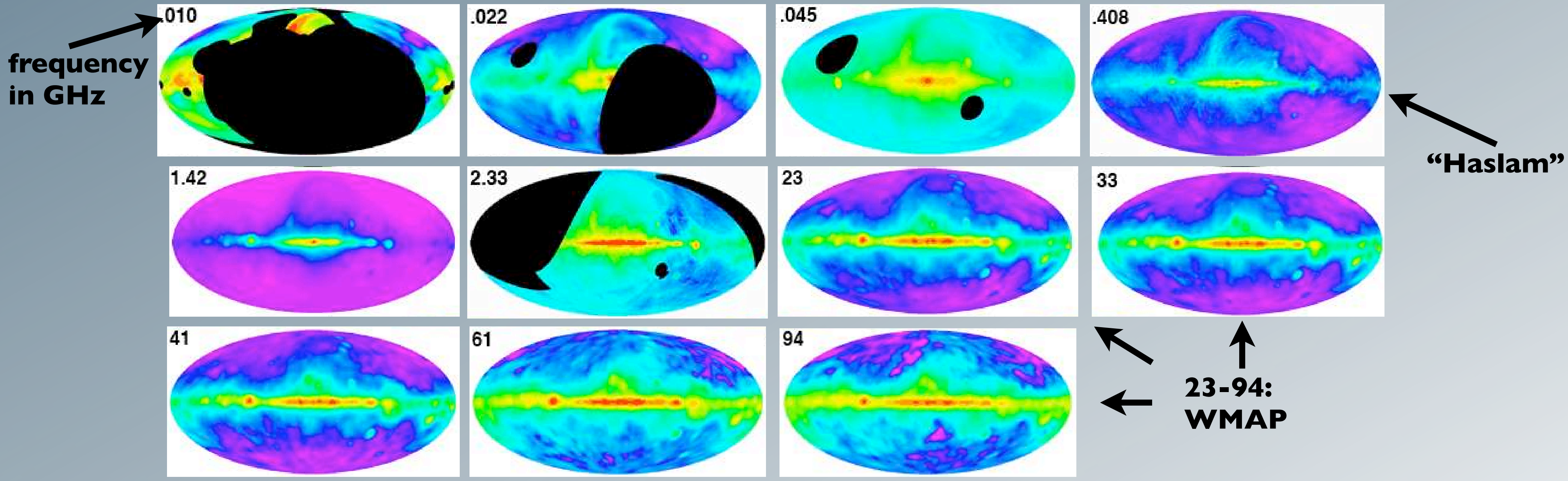

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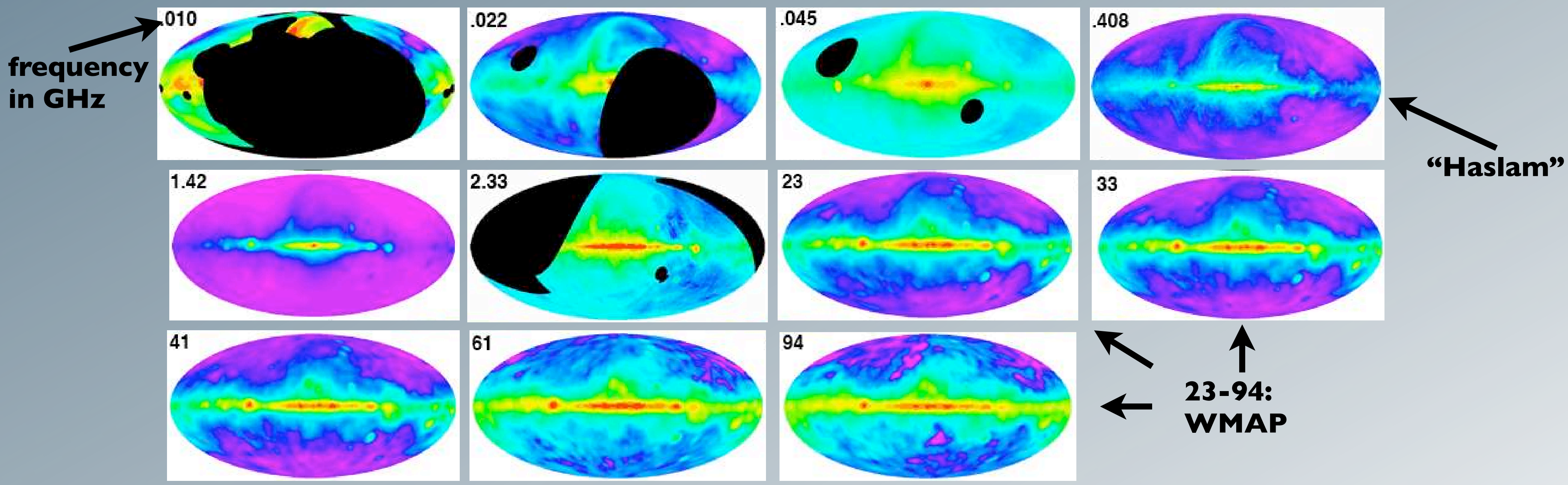
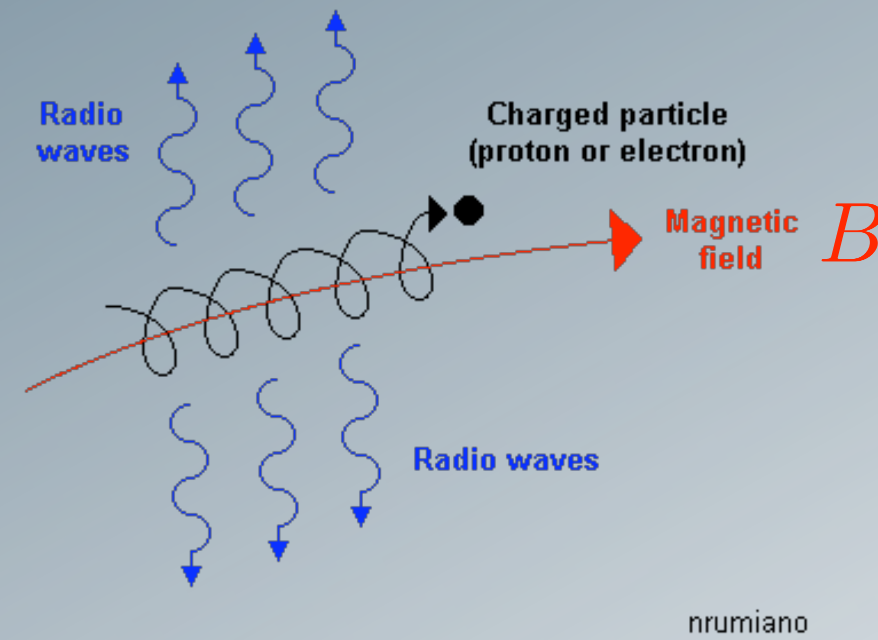


- Intensity measured in brightness temperature
  (i.e. assume Rayleigh-Jeans law even for non-thermal emission)

$$T_b \equiv \epsilon I_\nu c^2/(2\nu^2 k_B)$$

Synchrotron radiation



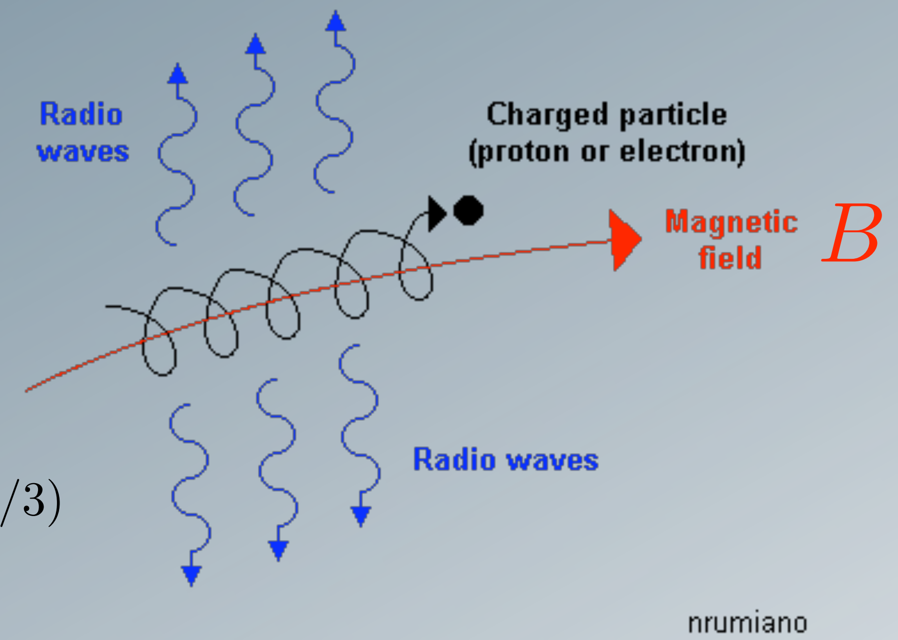
Synchrotron radiation

- Synchrotron emission power:

$$\frac{dw}{d\nu} = \frac{\sqrt{3}\,e^3 B}{m_e c^2}\,\frac{2}{\pi}\int_0^{\pi/2} d\theta\,\sin\theta\;F\left(\frac{\nu}{\nu_c \sin\theta}\right)$$

(angular average for isotropic e⁻ distribution)

$$F(x) = x\int_x^\infty d\zeta\;K_{5/3}(\zeta) \approx \frac{8\pi}{9\sqrt{3}}\delta(x-1/3)$$



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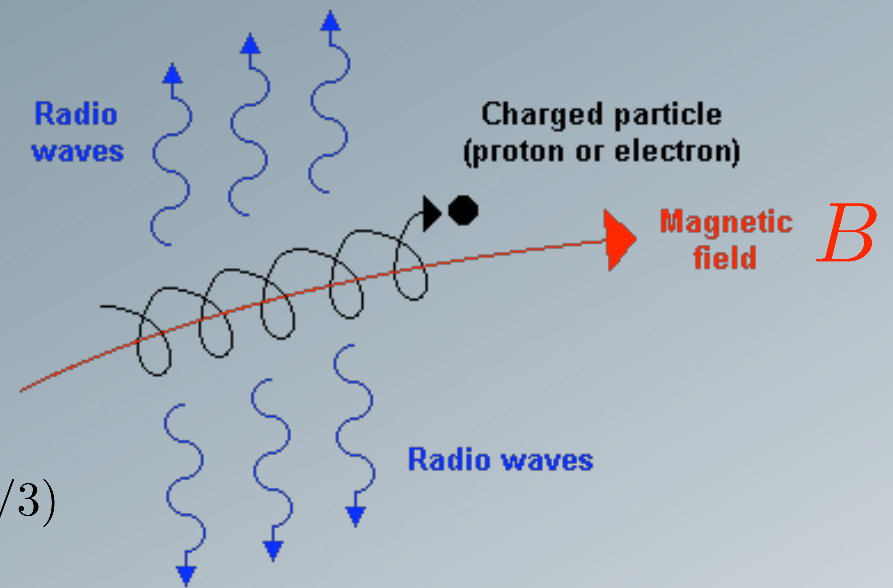

➩
- peak production at resonance $\nu \approx \nu_c$
- power scales roughly like B^2

$$\nu_c = \frac{3eBp_e^2}{4\pi m_e^3 c} = 16\,\mathrm{MHz} \left(\frac{B}{\mu\mathrm{G}}\right) \left(\frac{E_e}{\mathrm{GeV}}\right)^2$$

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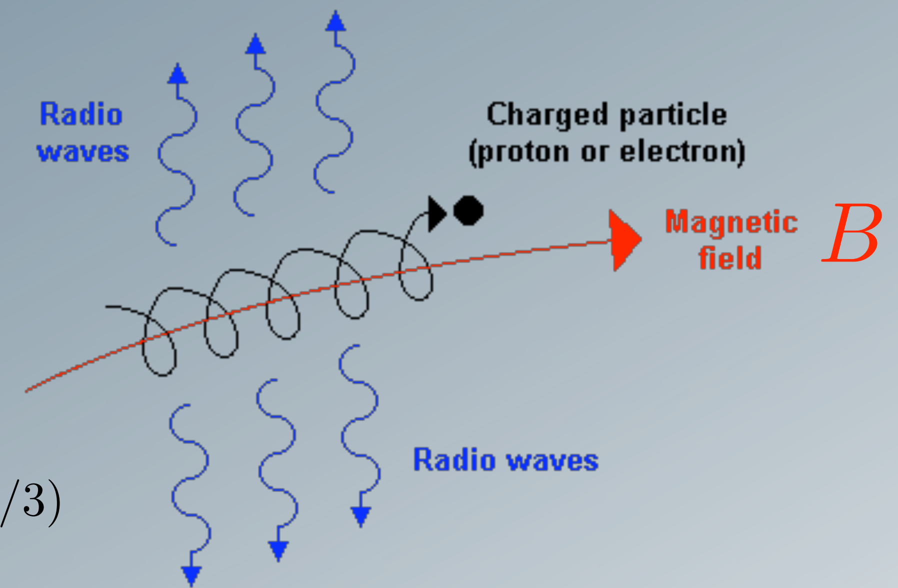

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emissivity $J_\nu = \int \frac{dn_e}{dE}\frac{dw}{d\nu}\,dE$

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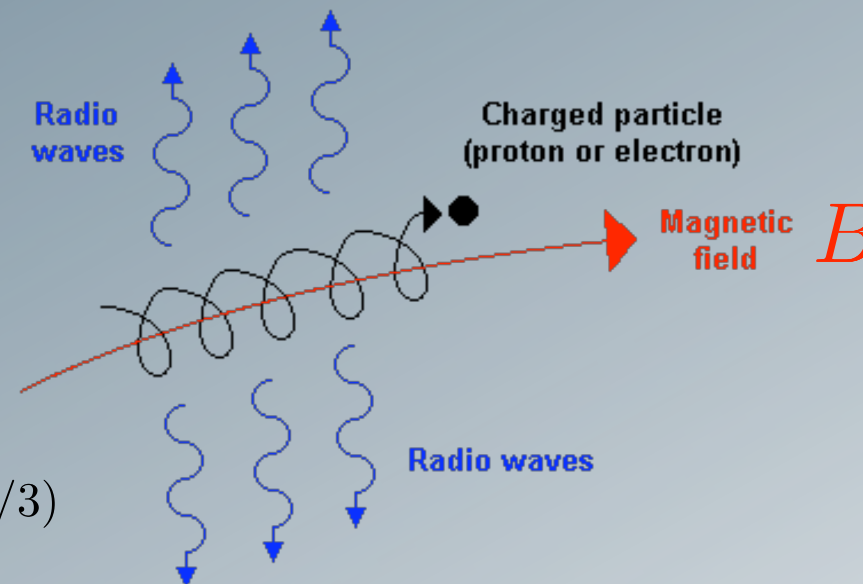

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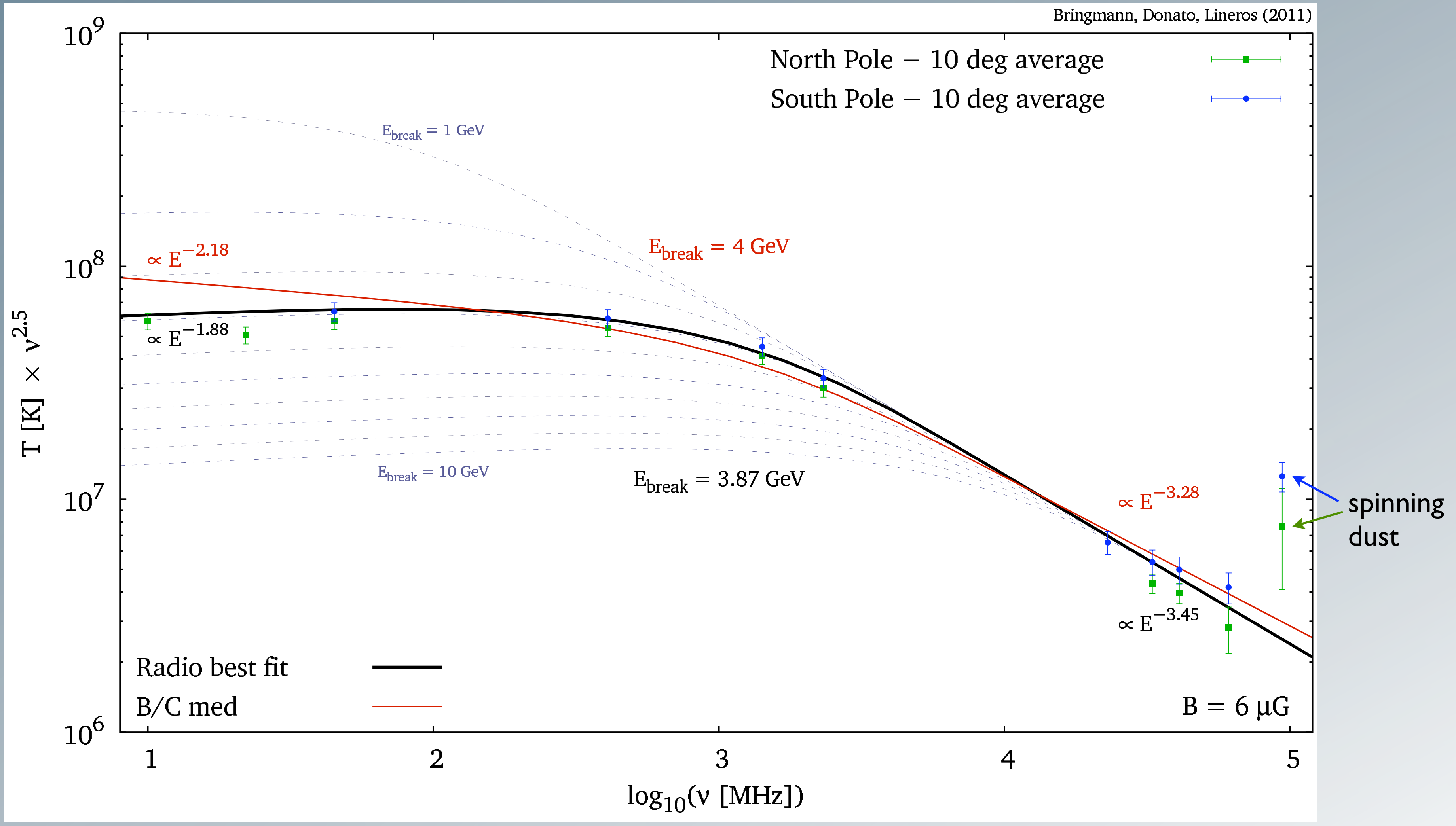
- power laws:

$$\frac{dn_e}{dE} \propto E^{-\gamma} \quad \Rightarrow \quad T_b \propto \nu^{-\frac{\gamma+3}{2}}$$

Radio=synchrotron?

- Assume synchrotron dominates at high latitudes:



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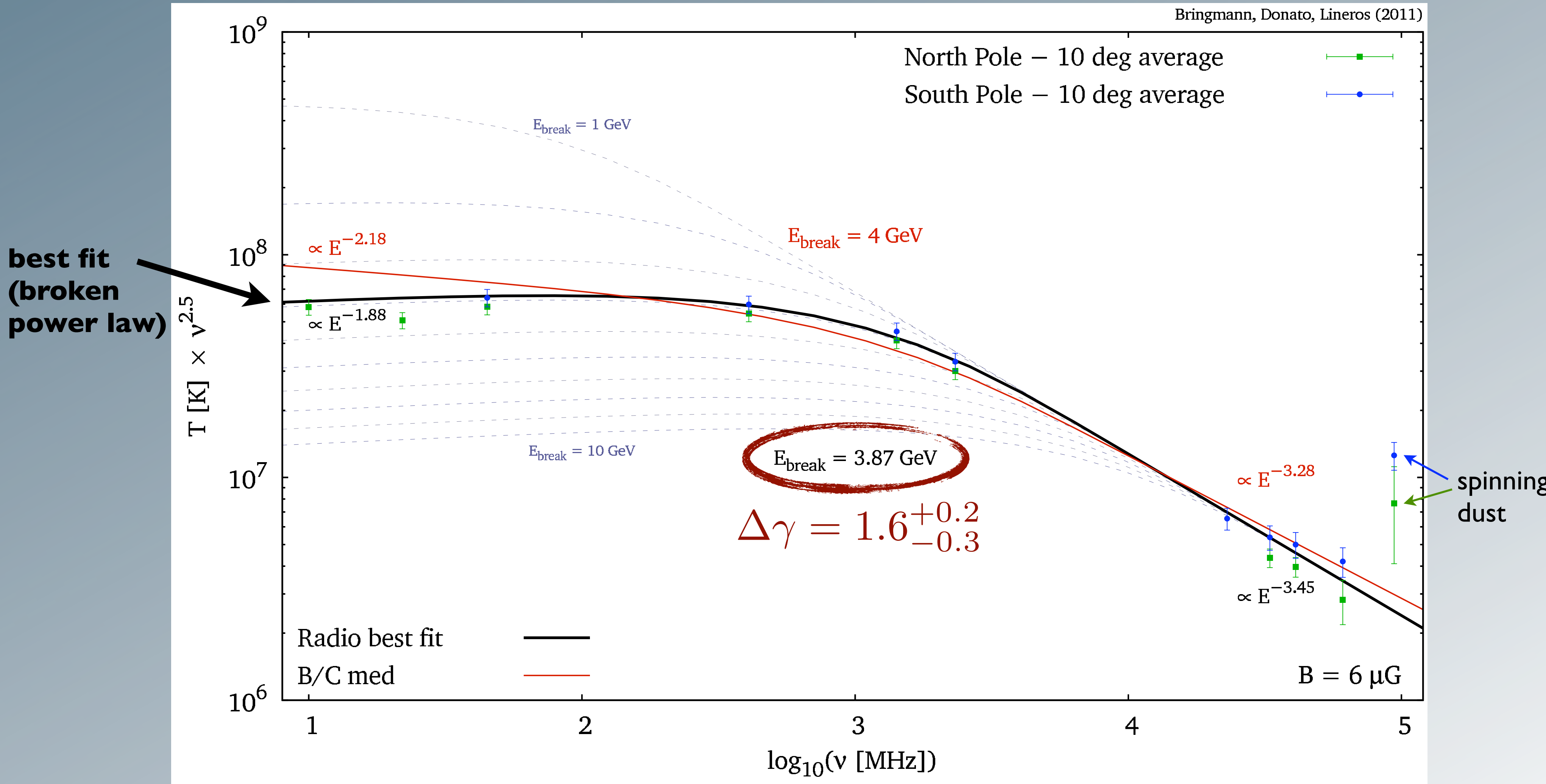


⇨ Clear need for **spectral break** in electron distribution!

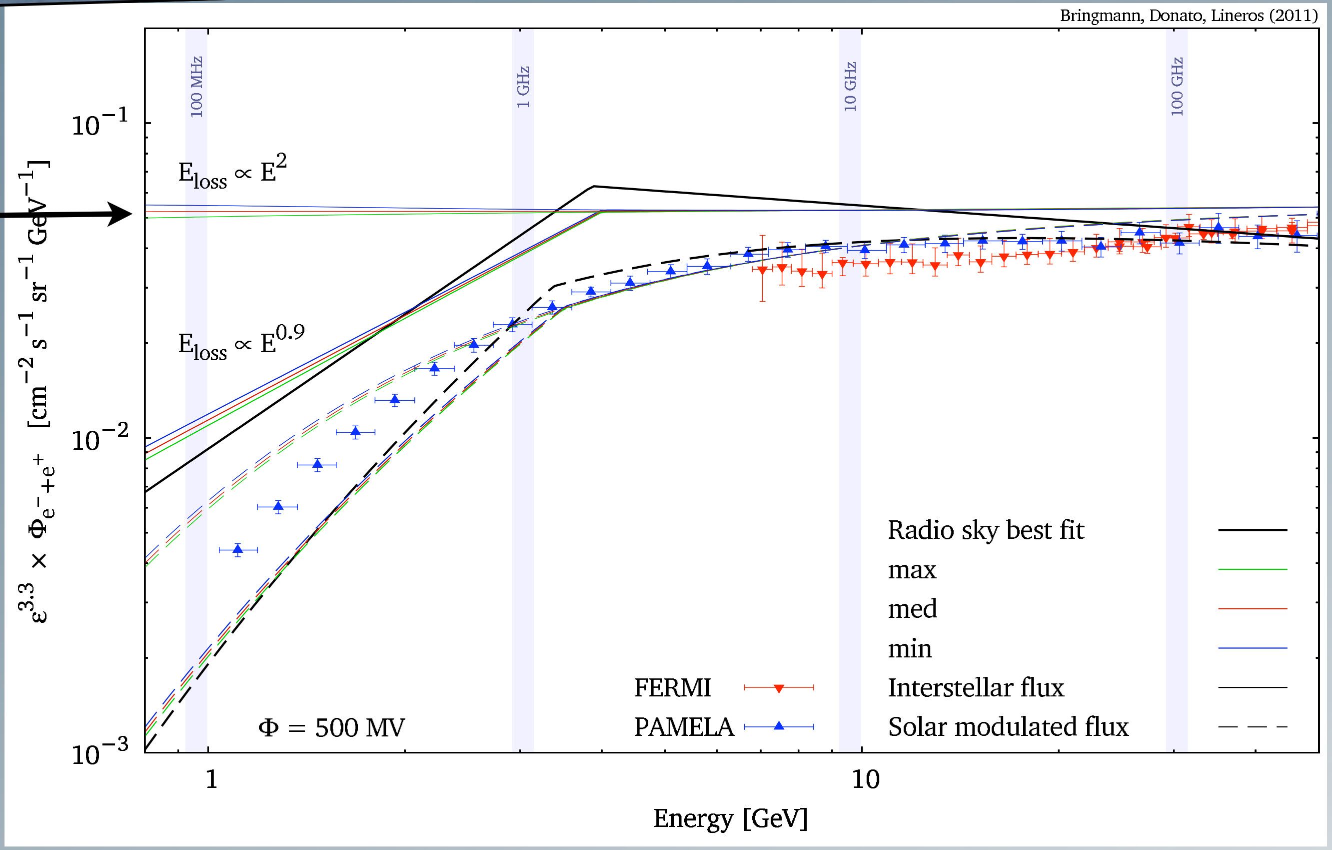
(see also Jaffe *et al.*, 2011)

Connection to lepton data

diffusion models,
no break,
no solar mod.

$dn_e^{\rm diff}/dE \propto E^{-3.3}$

$(\hat{=}\, \gamma^{\rm inj} = 2.3 - 2.5)$



(flux at higher energies probably dominated by local sources)

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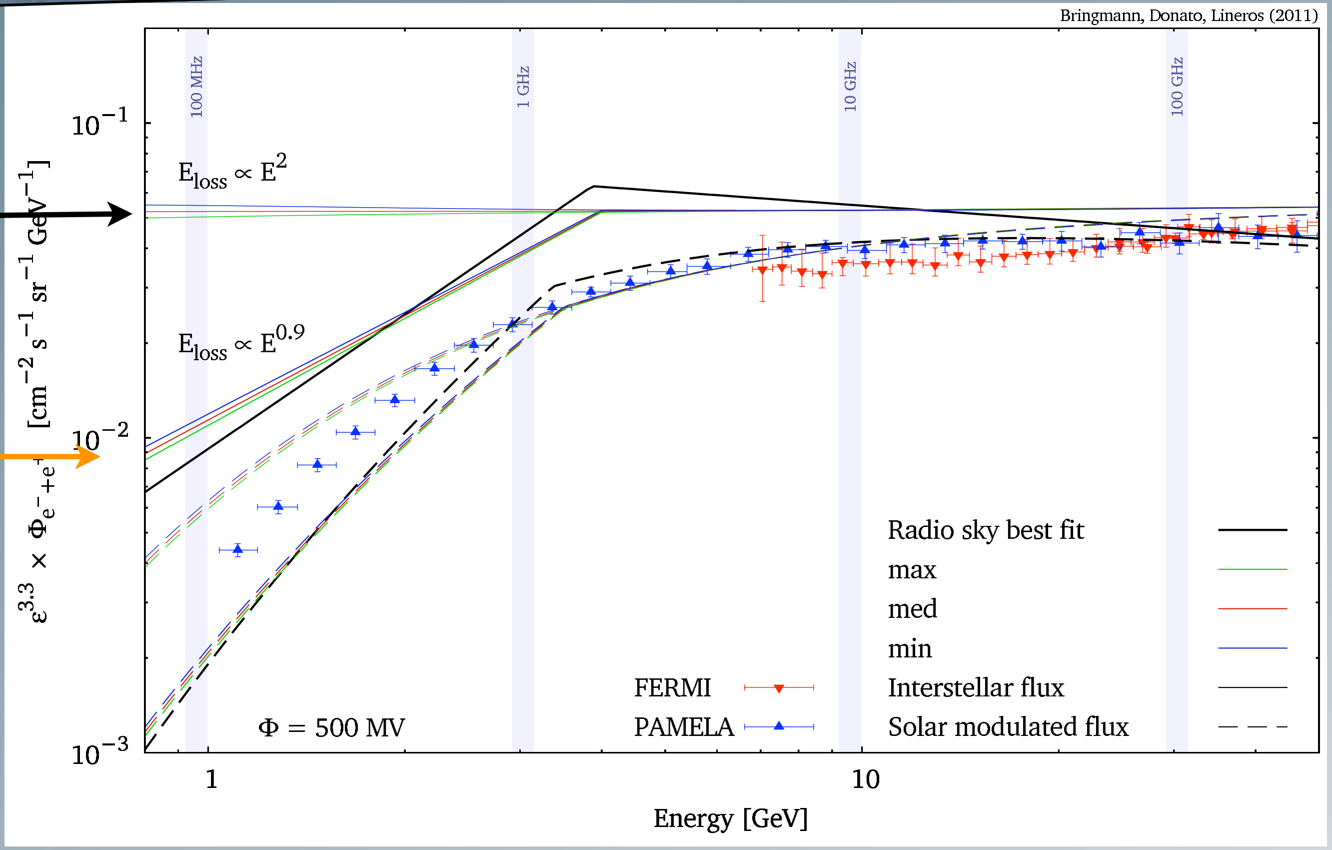

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- Break in e$^-$ distribution due to break in energy losses?
  (scattering on thermal ions/electrons could start to dominate IC here...)

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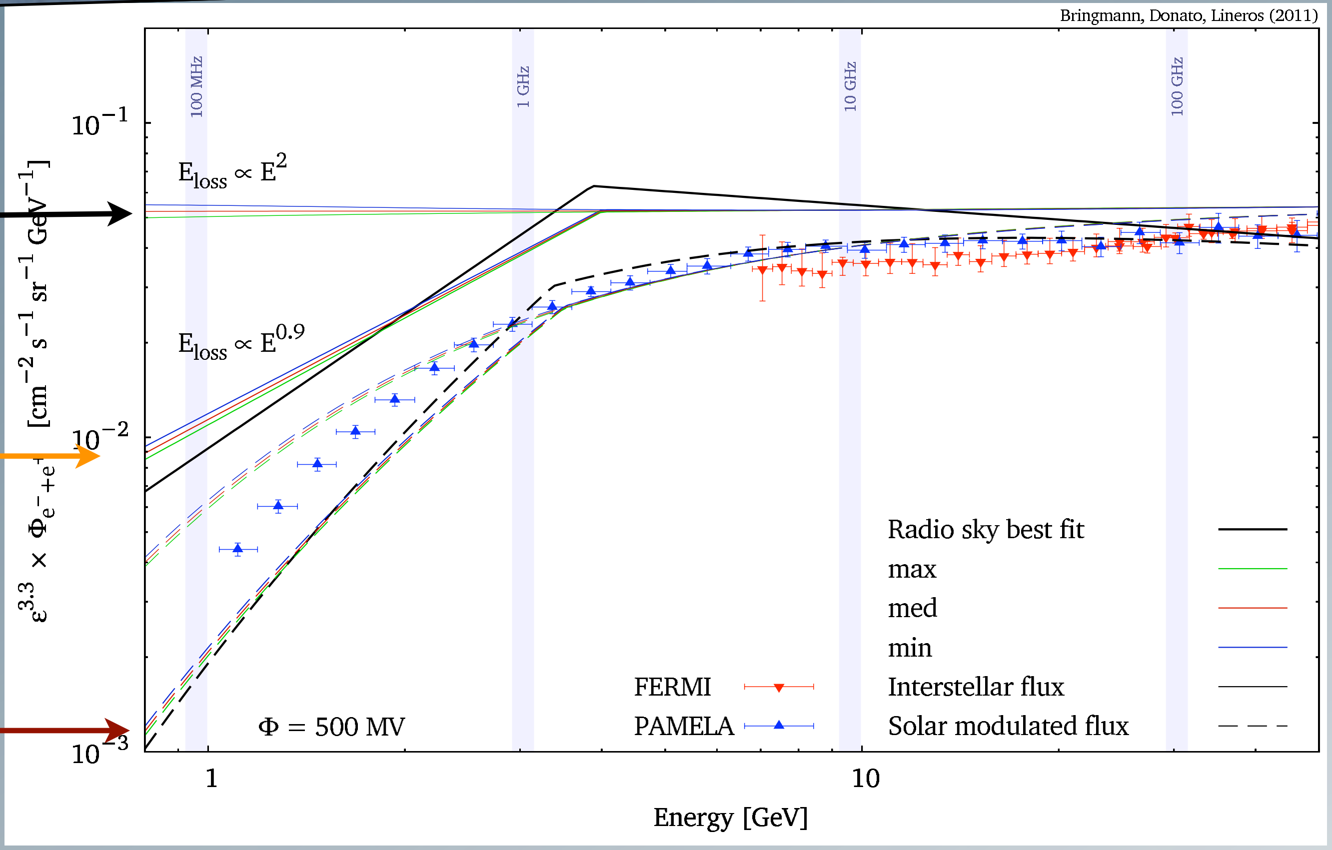

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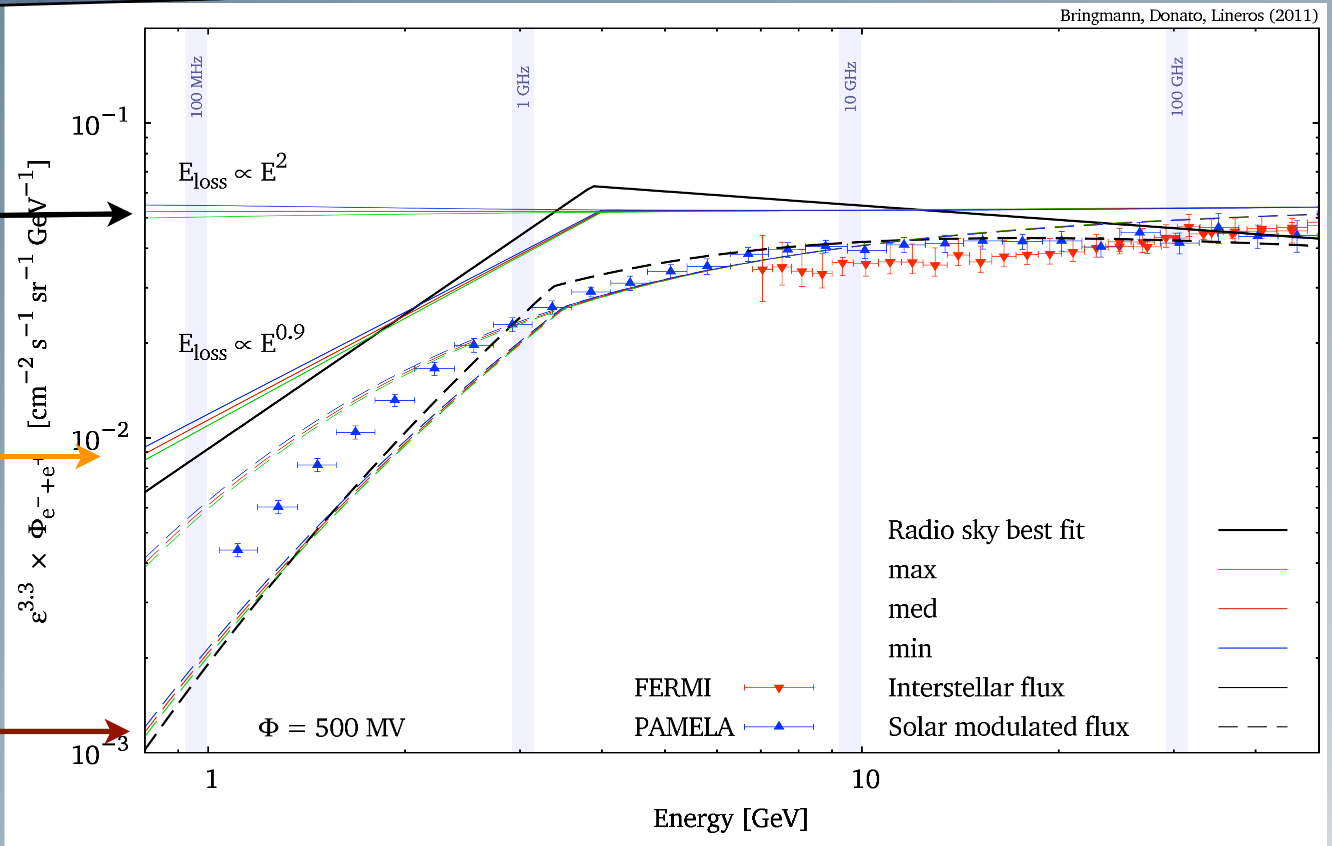

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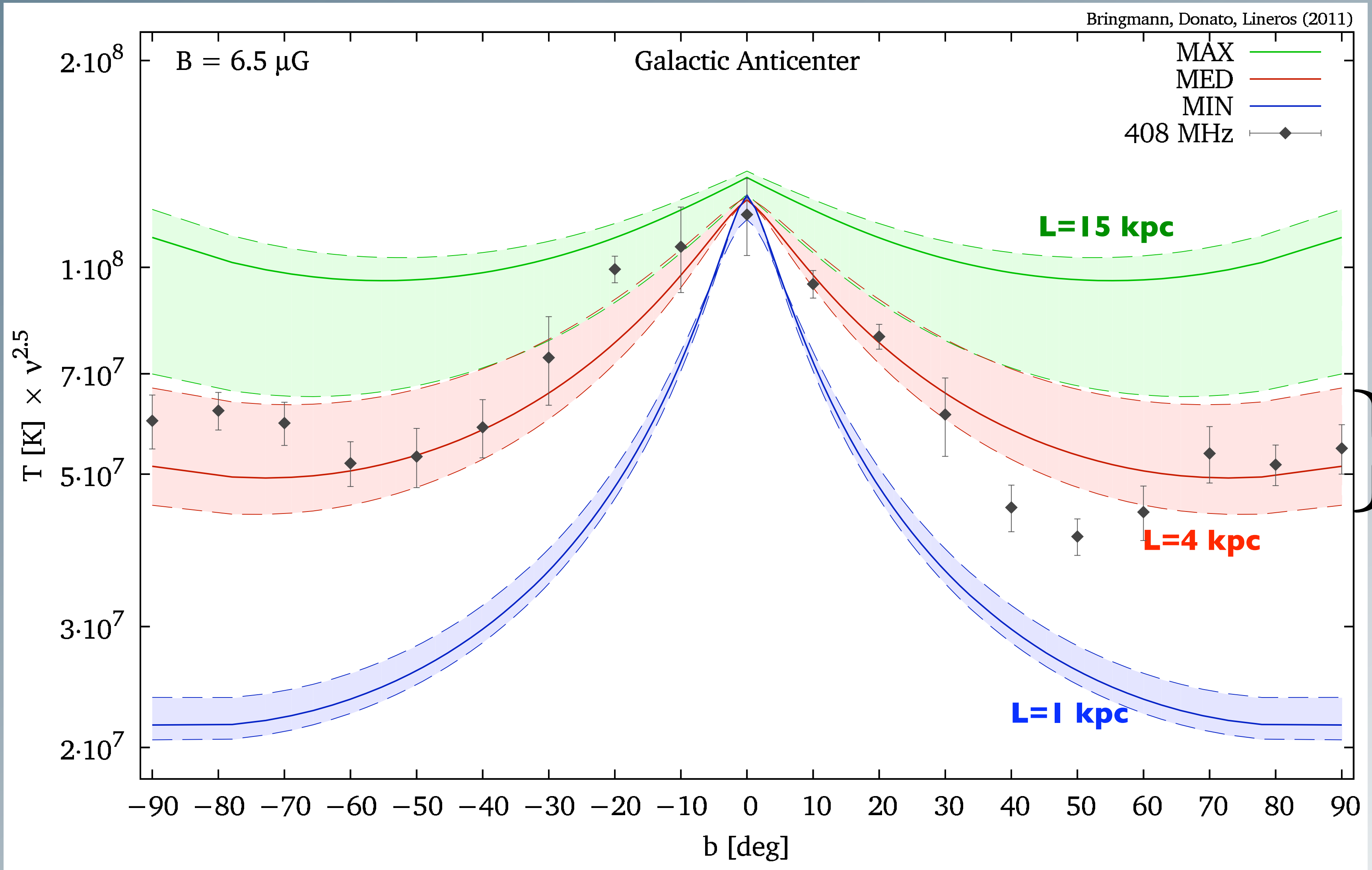
⇨ Rather good agreement with observed electron fluxes!

Angular distribution



range allowed by B/C

➡ clear discrimination between halo sizes possible!

Min/med/max propagation

- Very similar pattern also at other frequencies:

(10 ° average towards anticenter;
normalization/ magnetic field as free parameter to minimize χ^2)

Mod.	prop. parameters			radio data (χ^2/d.o.f.)		
	L [kpc]	K_0 $\left[\frac{\mathrm{kpc}^2}{\mathrm{Myr}}\right]$	δ	22 MHz	408 MHz	1.42 GHz
min	1	0.0016	0.85	14.4	13.4	13.5
med	4	0.0112	0.70	4.4	4.7	4.7
max	15	0.0765	0.46	15.4	10.6	8.7

⇨ "min" and "max" strongly disfavored!

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  (10 ° average towards anticenter;
  normalization/ magnetic field as free parameter to minimize χ^2)

Mod.	prop. parameters			radio data (χ^2/d.o.f.)		
	L [kpc]	K_0 $\left[\frac{\text{kpc}^2}{\text{Myr}}\right]$	δ	22 MHz	408 MHz	1.42 GHz
min	1	0.0016	0.85	14.4	13.4	13.5
med	4	0.0112	0.70	4.4	4.7	4.7
max	15	0.0765	0.46	15.4	10.6	8.7

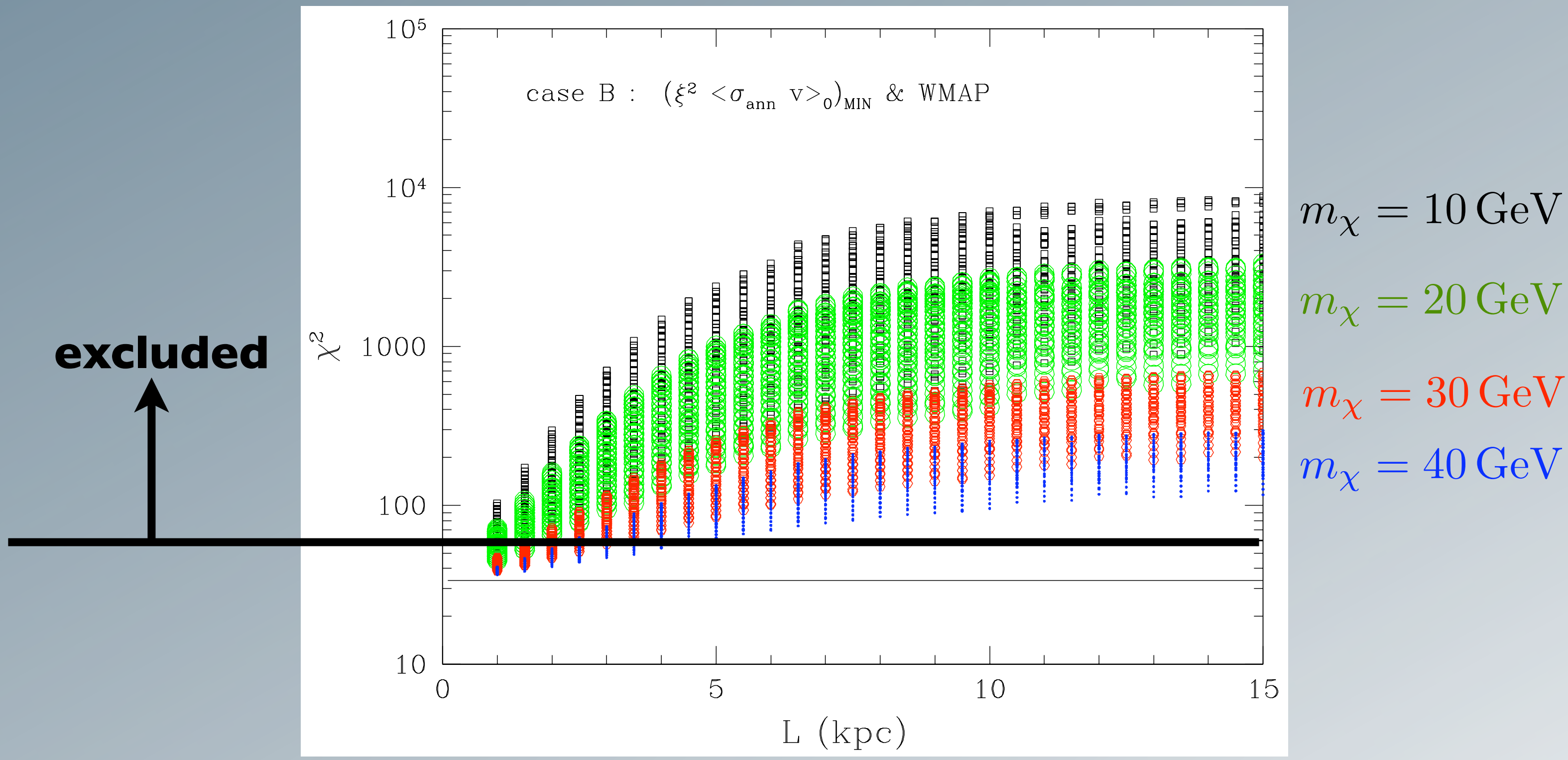
⇨ "min" and "max" strongly disfavored!

- At frequencies $\nu \gtrsim 2\,\mathrm{GHz}$, synchrotron contribution reproduces radio data significantly worse

  (bremsstrahlung contributions from molecular clouds and pulsars/SNRs !?)

Indirect DM searches

- A lower bound on L is quite important for indirect DM searches using antiprotons!



Bottino *et al.*, hep-ph/0507086

- This is particularly relevant for low-mass WIMPs
  (c.f. claimed DM signals in direct detection or from the galactic center...)

See also TB, 0911.1124; Lavalle, 1007.5253

Conclusions

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  - independent of solar modulation effects
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- Can be used to lift degeneracies from B/C analysis and further constrain propagation parameters
- Lower limit on height of diffusive halo has profound implications for indirect dark matter searches
  - resulting constraints (in particular for light DM!) should be taken into account for a consistent picture