DESY Theory Workshop, 27-30 Sep 2011

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

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
  $\rightsquigarrow$ 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
  - ⊖ often used as "black box"

e.g.

Strong, Moskalenko, …

DRAGON

Evoli, Gaggero, Grasso & Maccione

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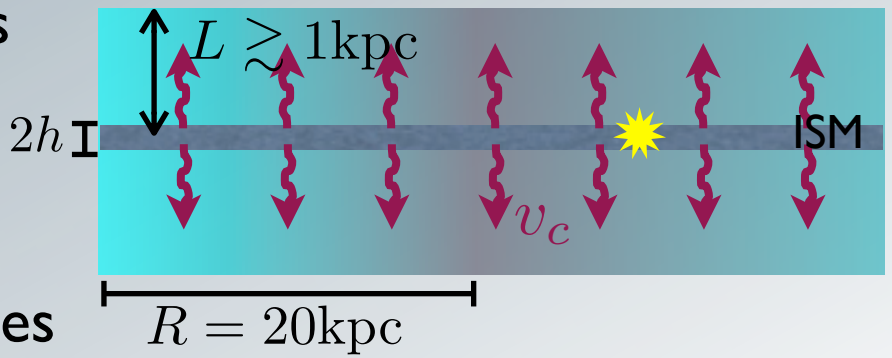
- (Semi-)analytically
  - ⊕ Physical insight from analytic solutions
  - ⊕ fast computations allow to sample full parameter space
  - ⊖ only 2D possible
  - ⊖ simplified gas distribution, energy losses

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

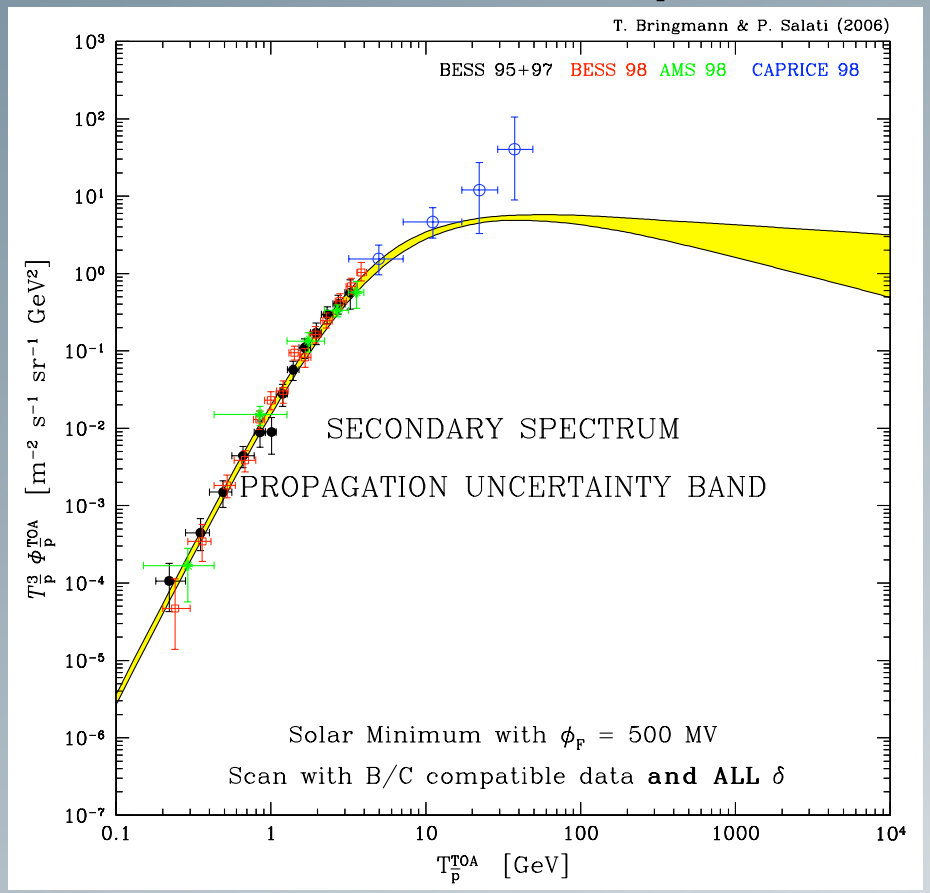


E.g. secondary antiprotons

- 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:



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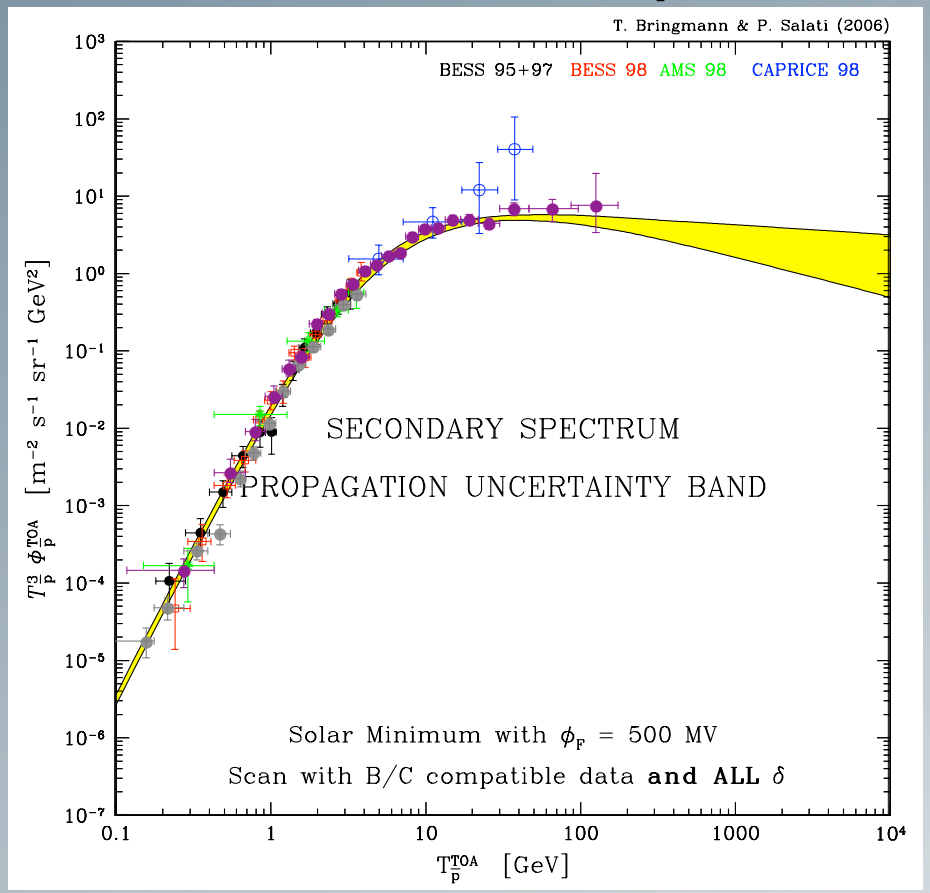

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excellent agreement with new data:

BESSpolar 2004

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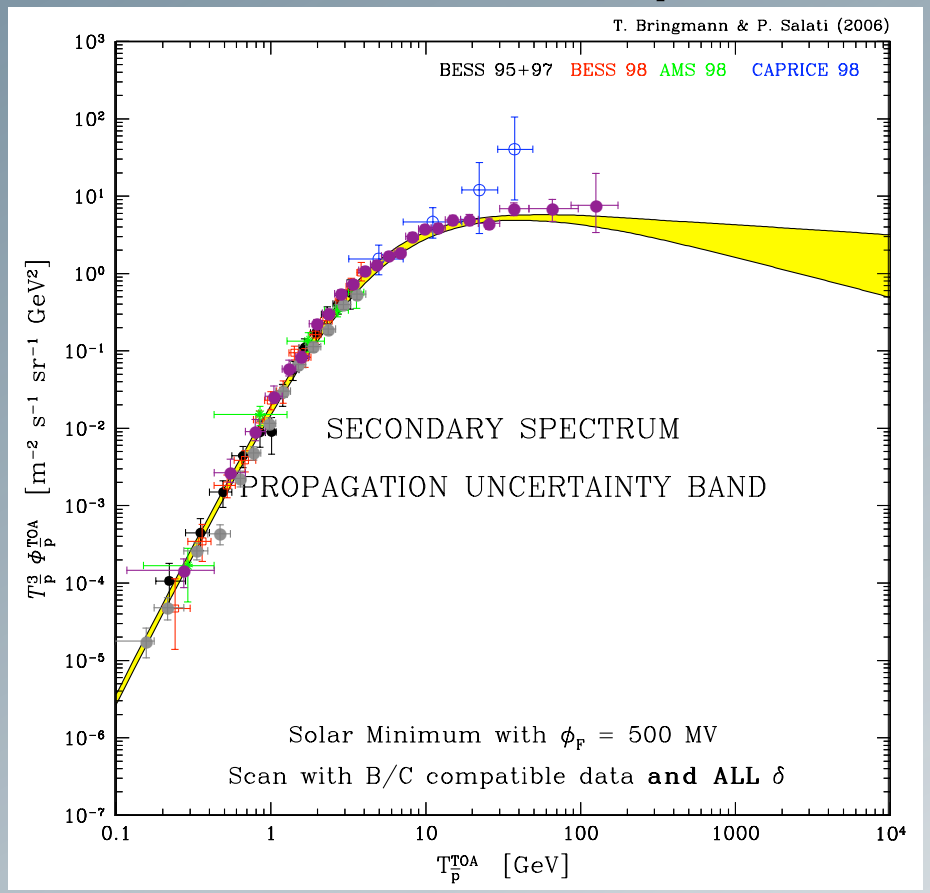

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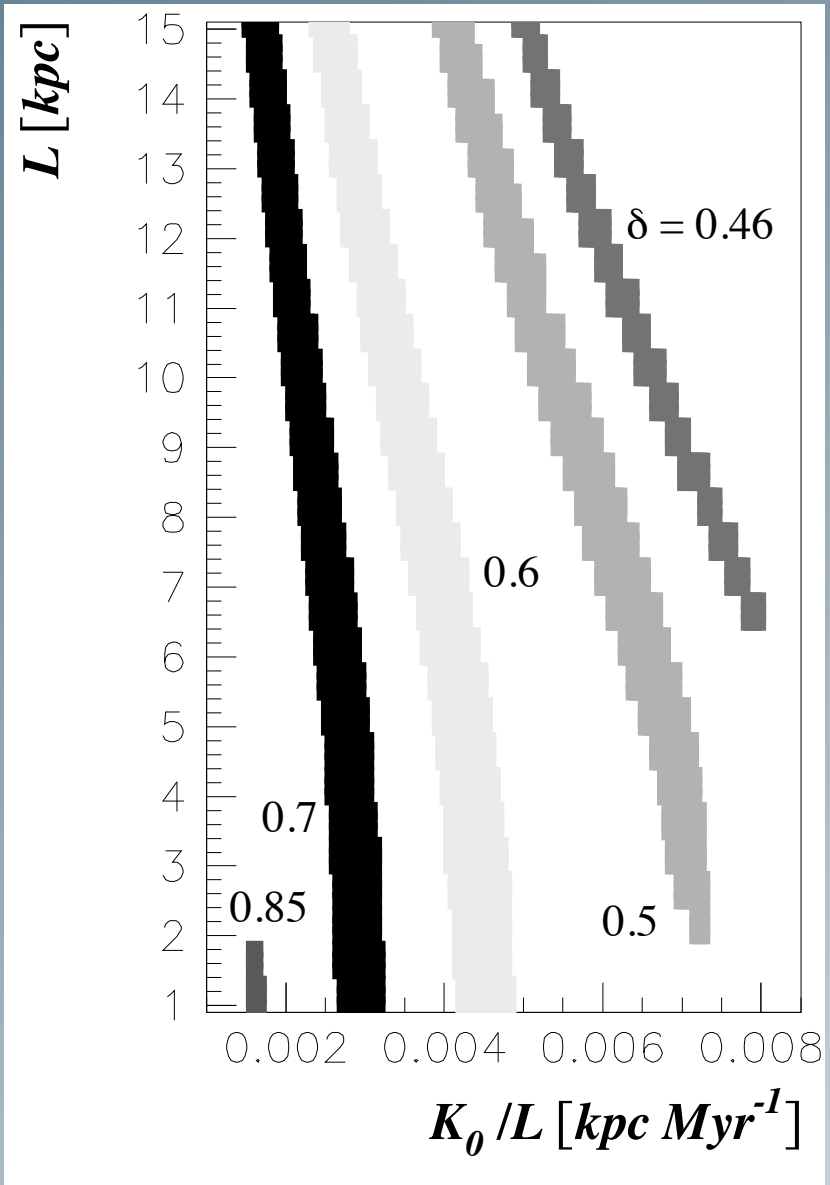
⇨ very nice test for underlying diffusion model!

Degeneracies



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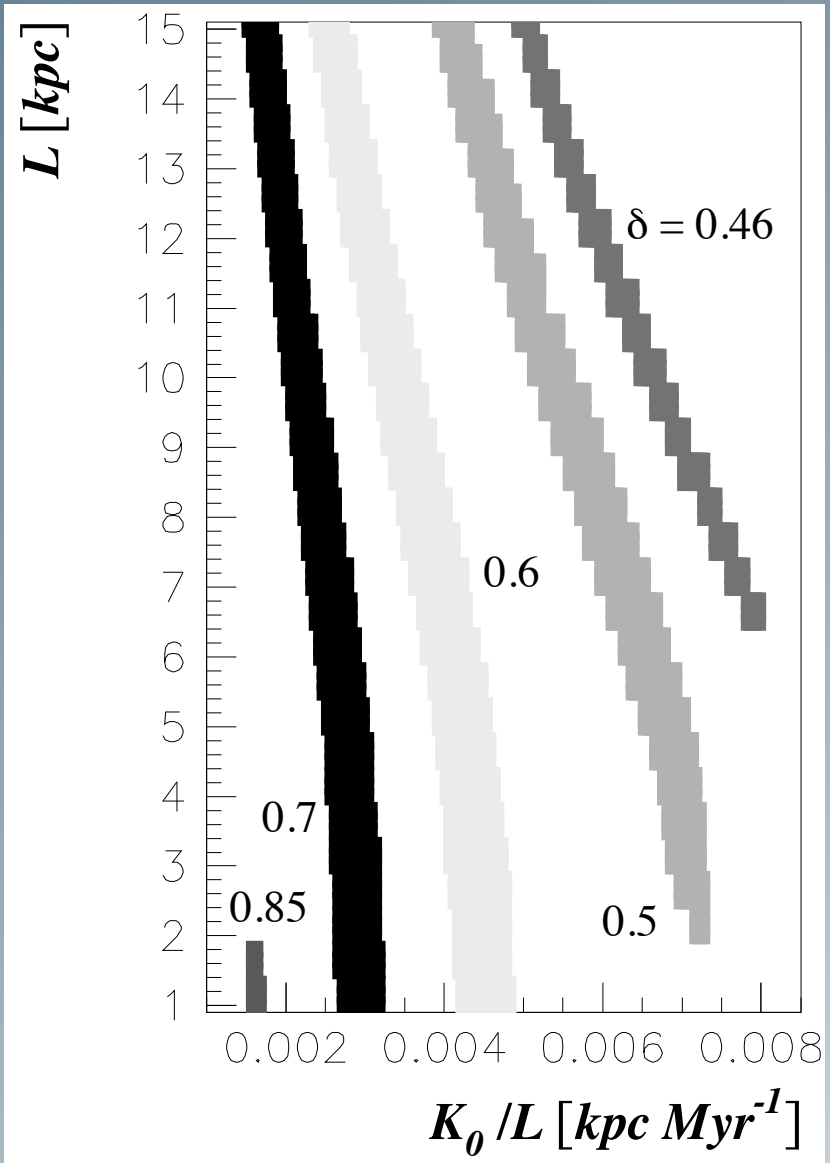

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Donato, Fornengo, Maurin, Salati & Taillet, PRD '04

case	δ	K_0 ($\mathrm{kpc}^2/\mathrm{Myr}$)	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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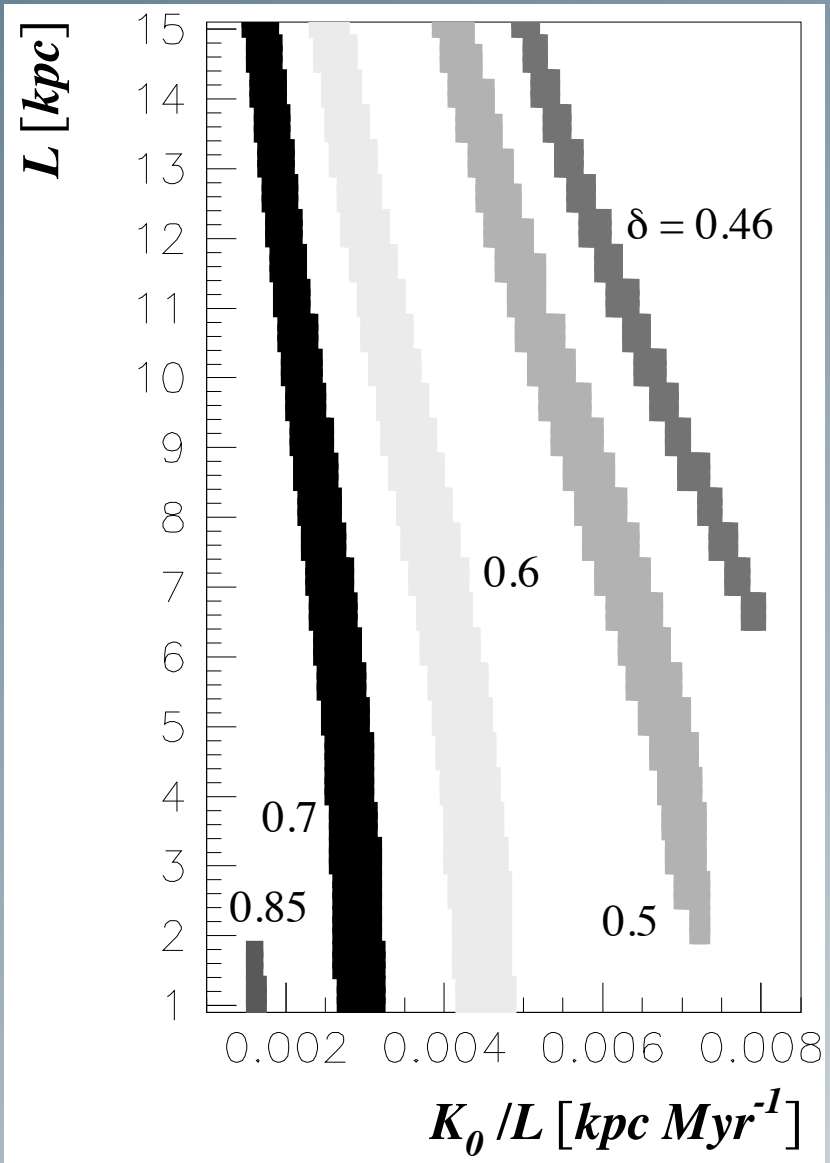

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$\mathcal{O}(10^2)$ change in predicted $\bar{p}$ flux from DM!

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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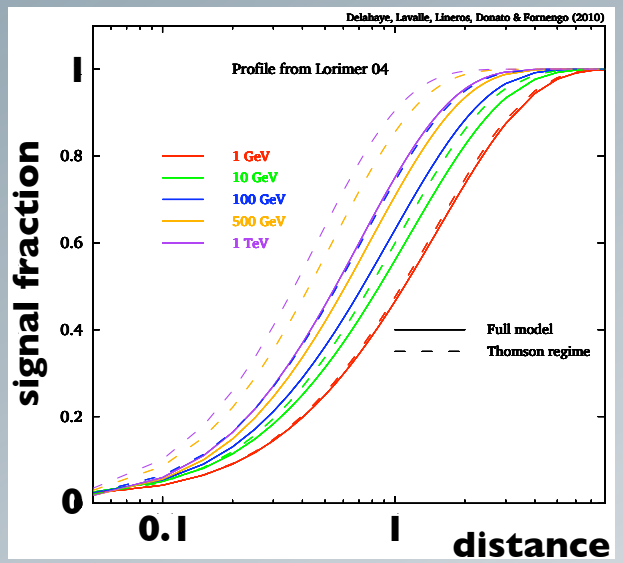
  - ➡ mainly locally produced (~kpc for 100 GeV leptons)



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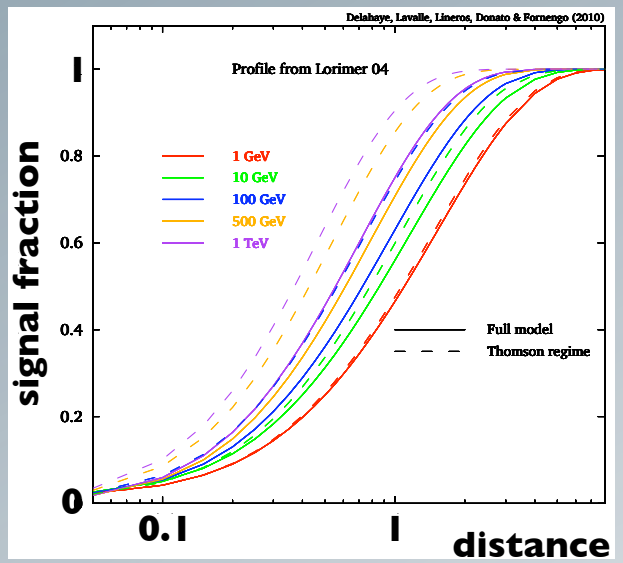
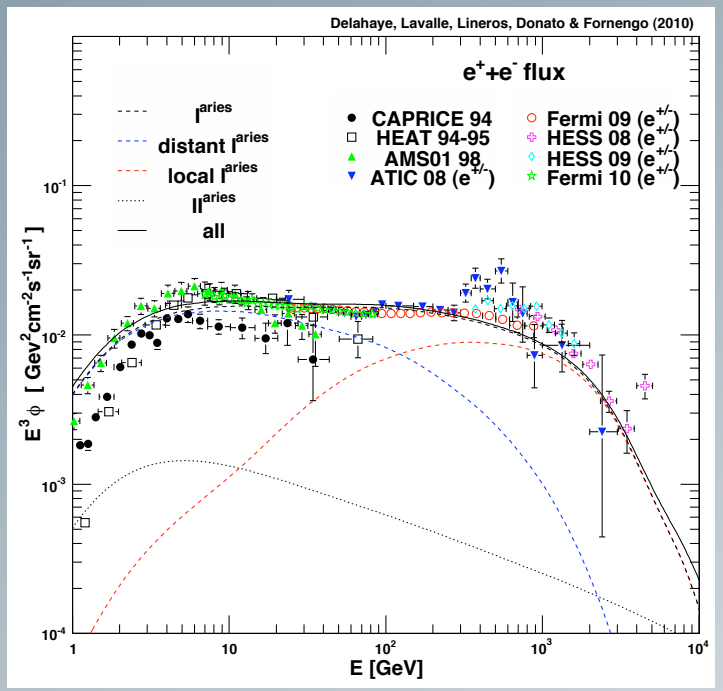
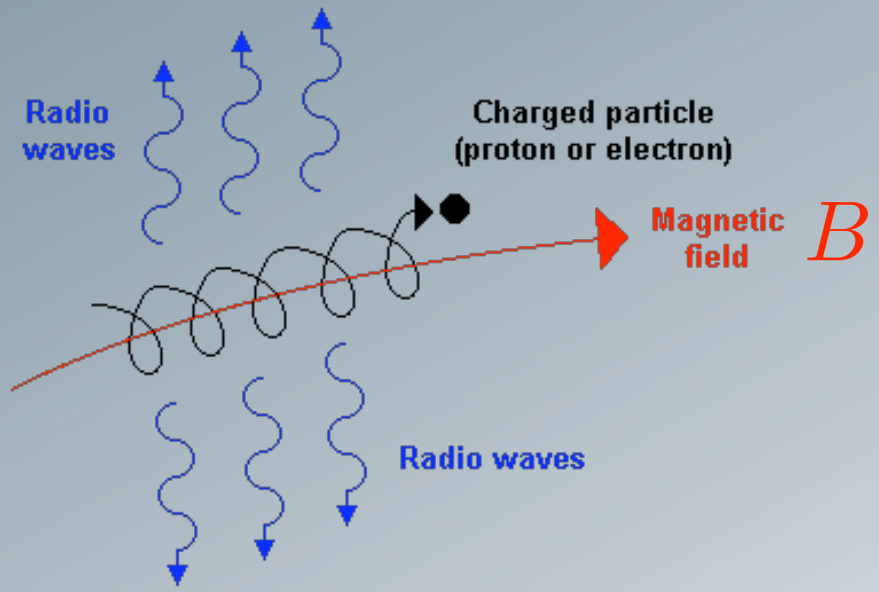




- propagation uncertainties:
  - secondaries ~ 2-4
  - primaries ~5
- ➡ undisputed need for local primary source(s) to describe data well above ~10 GeV

Synchrotron radiation



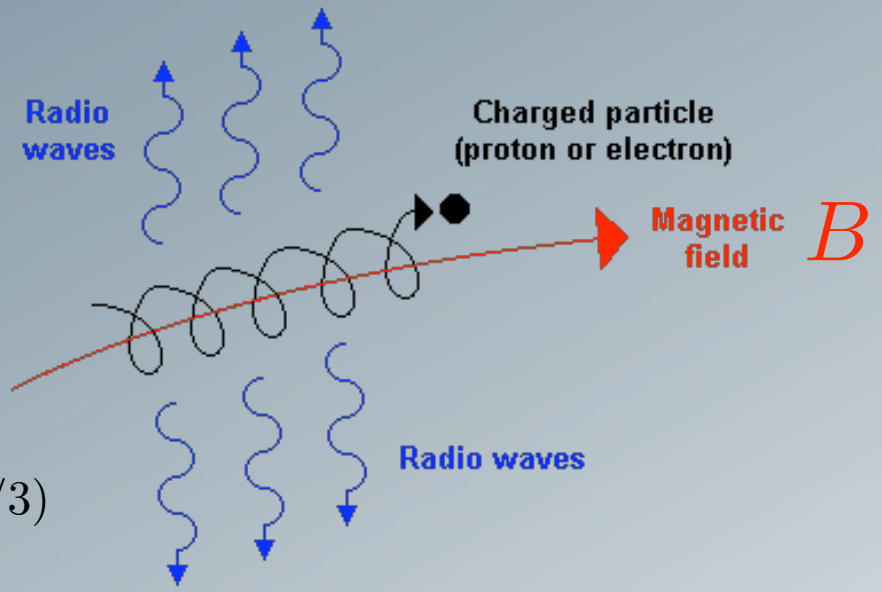
Synchrotron radiation

- 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)

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



nrumiano

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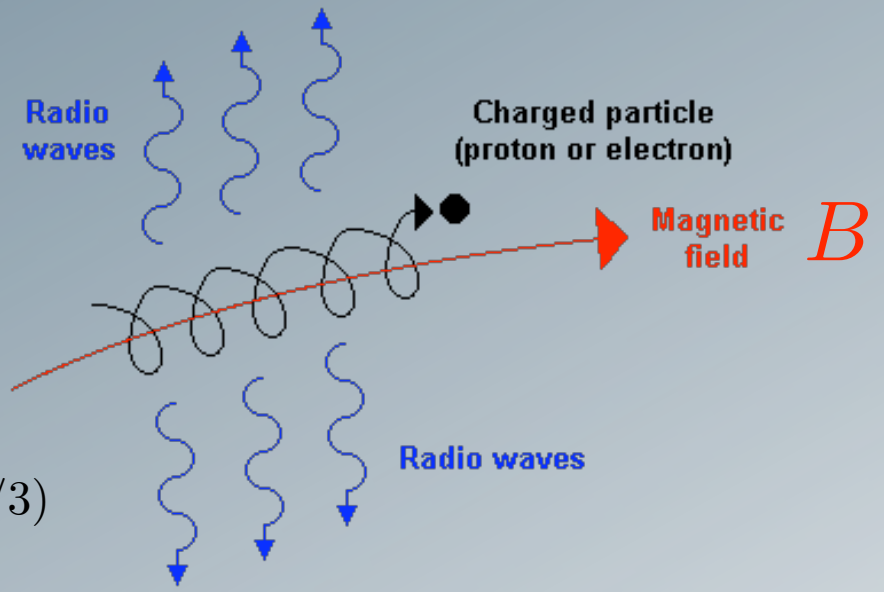

- peak production at resonance $\nu \approx \nu_c$
- power scales roughly like B^2

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

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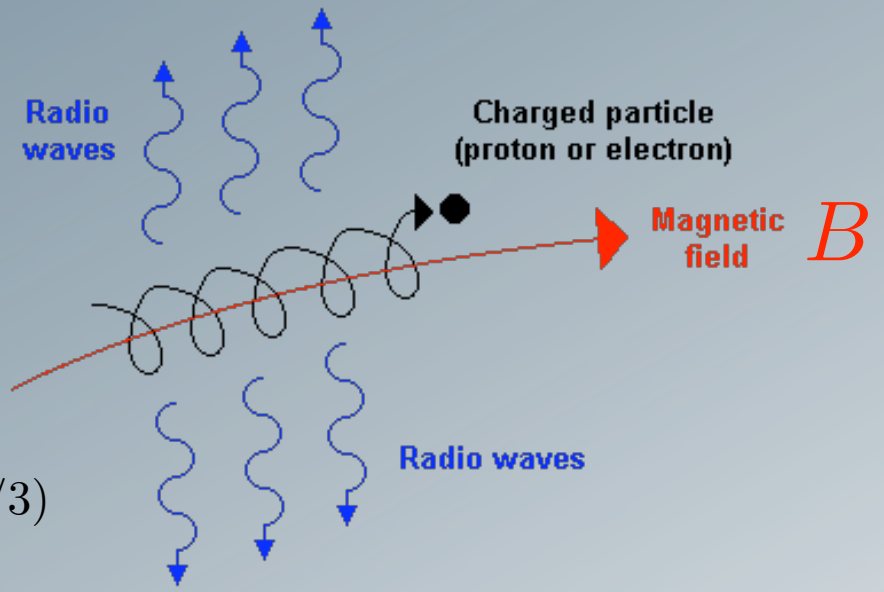

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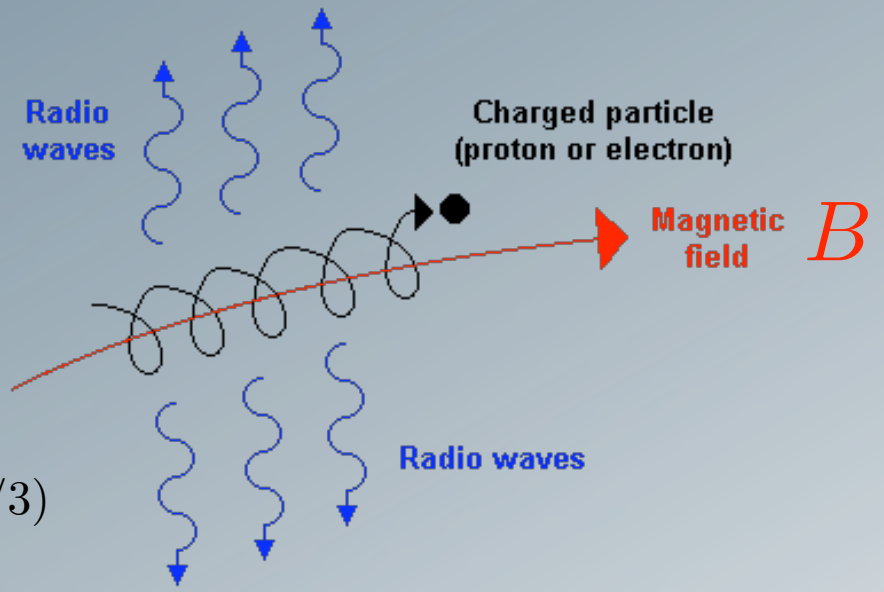

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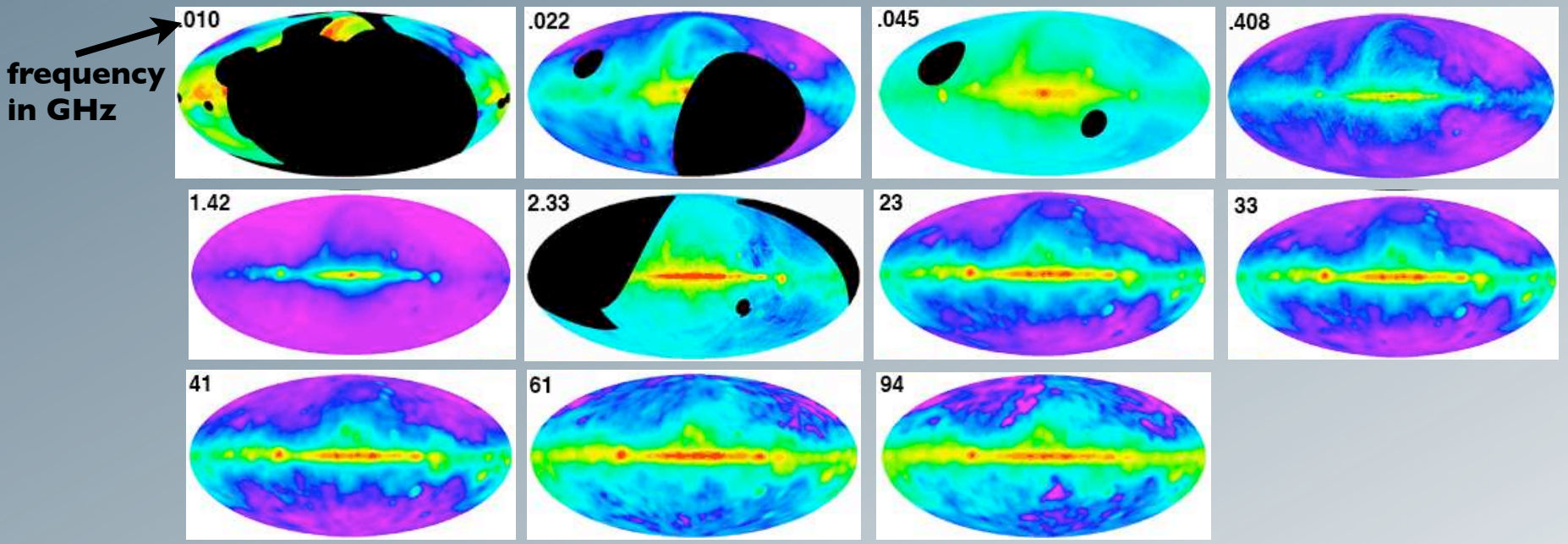
- power laws:

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

Radio data

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

Oliviera-Costa *et al.*, 0802.1525



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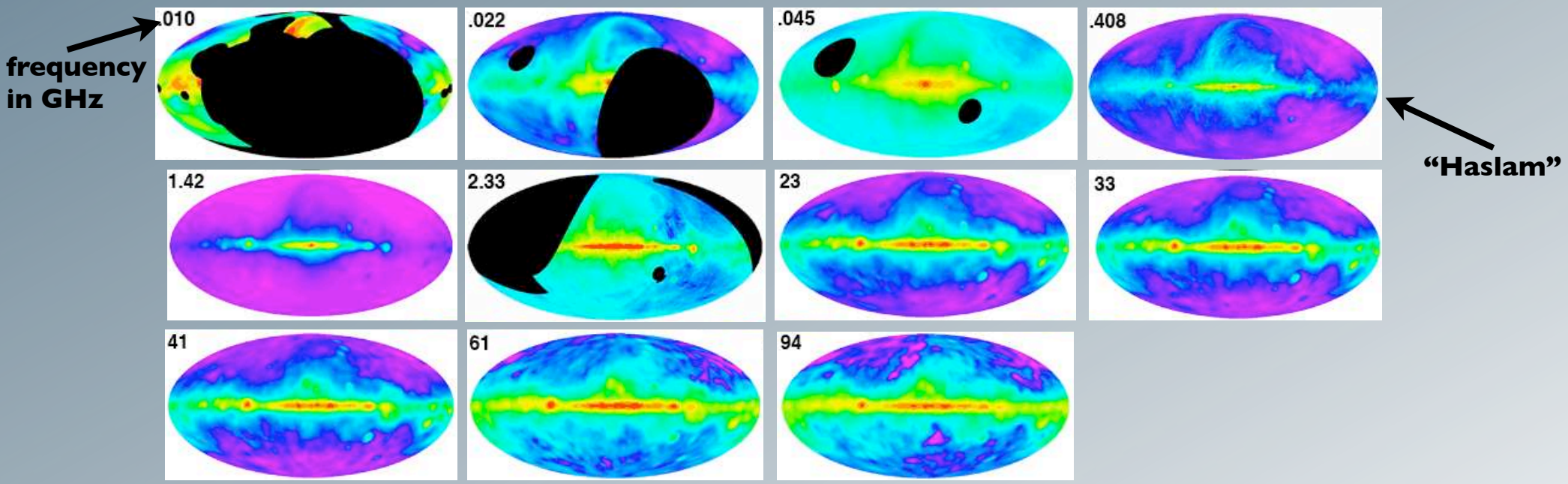

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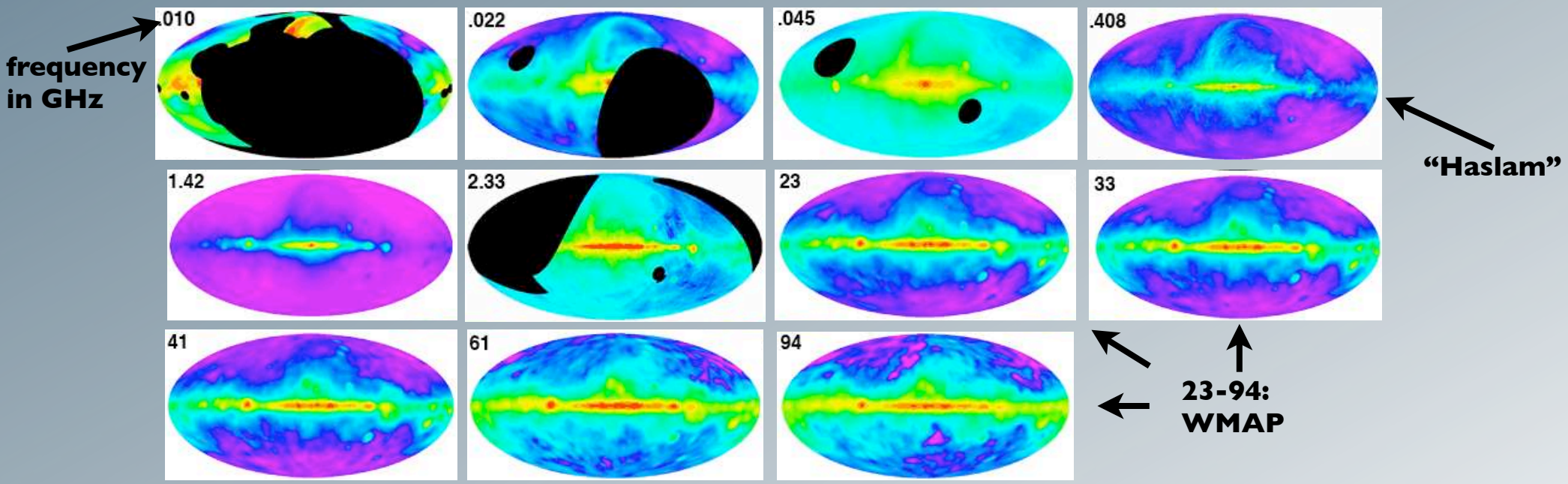

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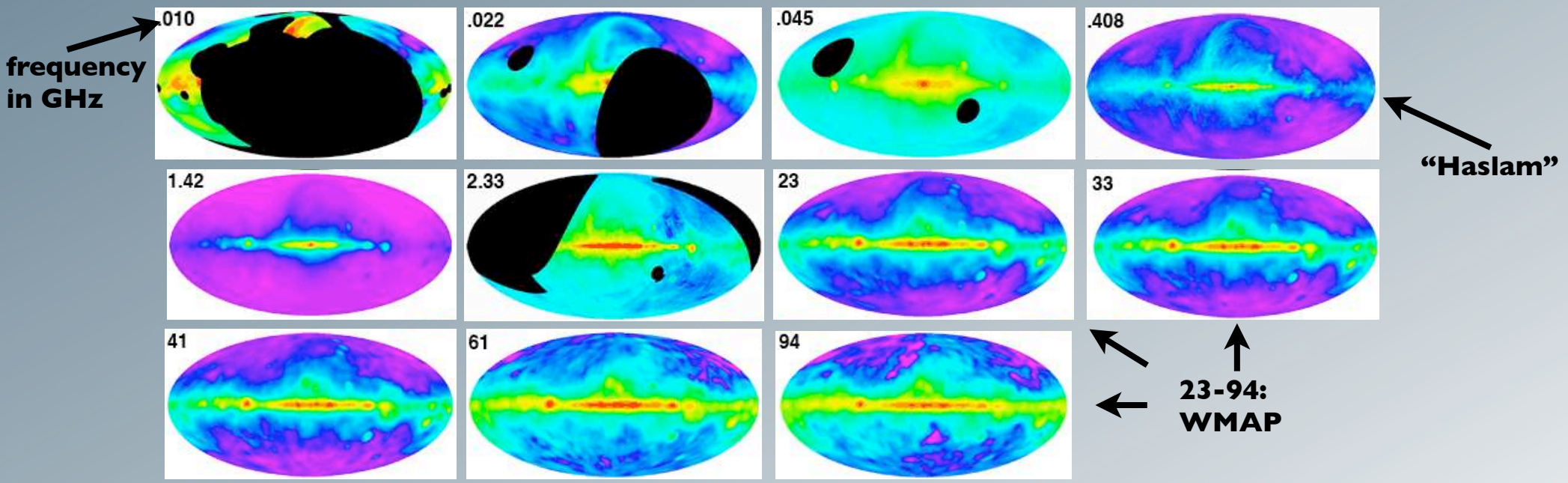
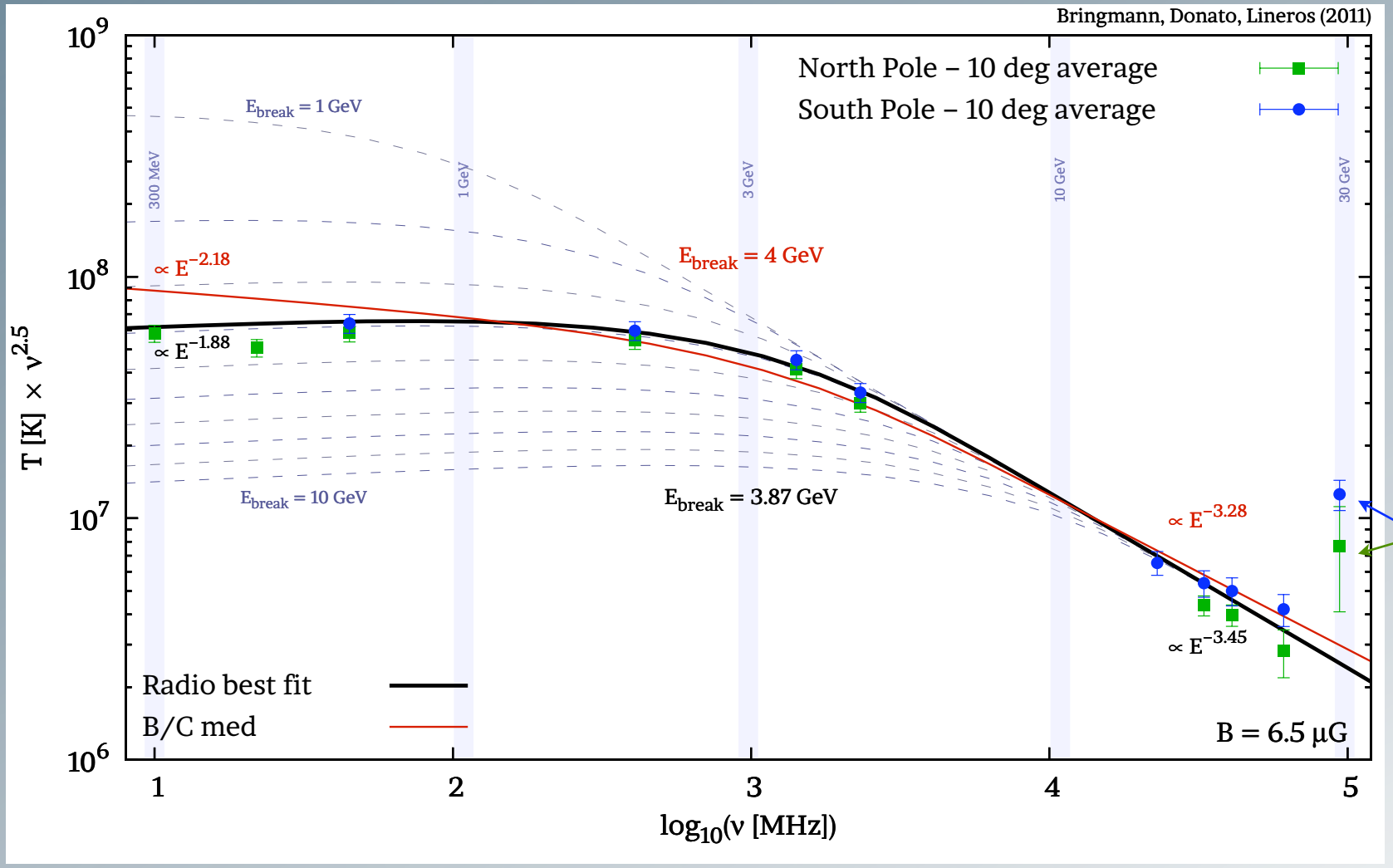


- Intensity measured in brightness temperature
  (i.e. assume Rayleigh-Jeans law even for non-thermal emission)

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

Radio=synchrotron?

- Assume synchrotron dominates at high latitudes:



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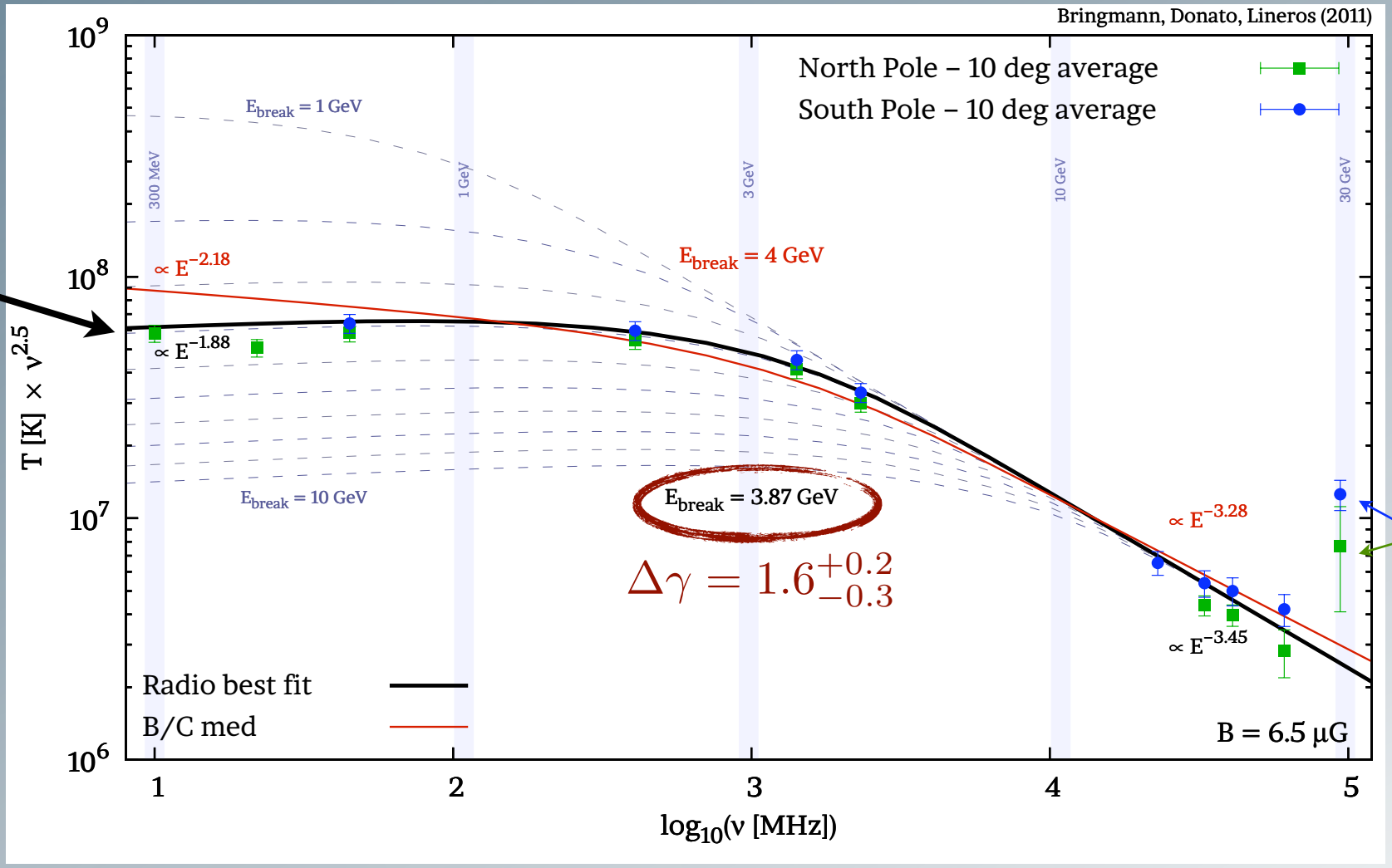


best fit (broken power law for electrons)

spinning dust

➡ Clear need for spectral break in electron distribution!

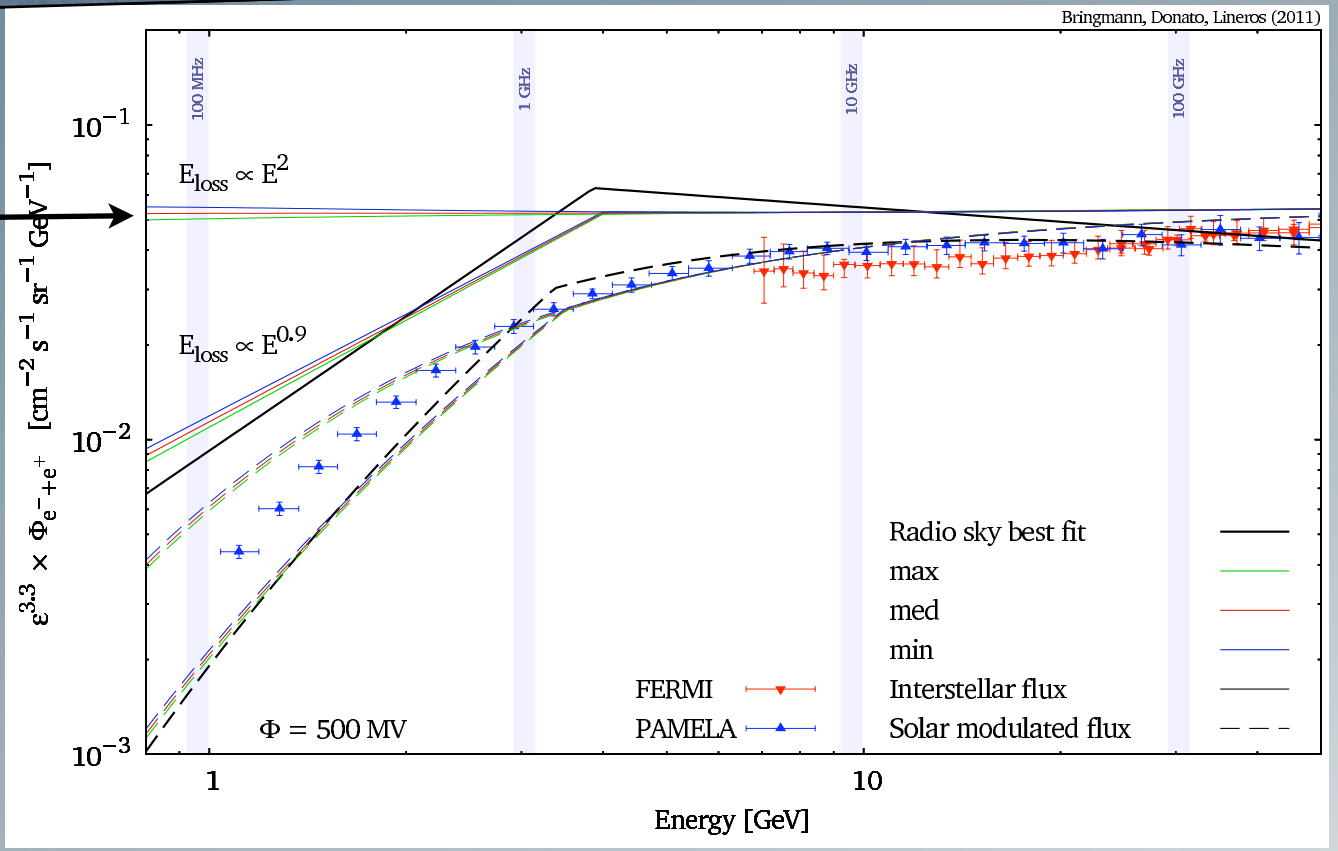
(see also Jaffe *et al.*, 2011)

Connection to lepton data

diffusion models,
no break,
no solar mod.

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

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



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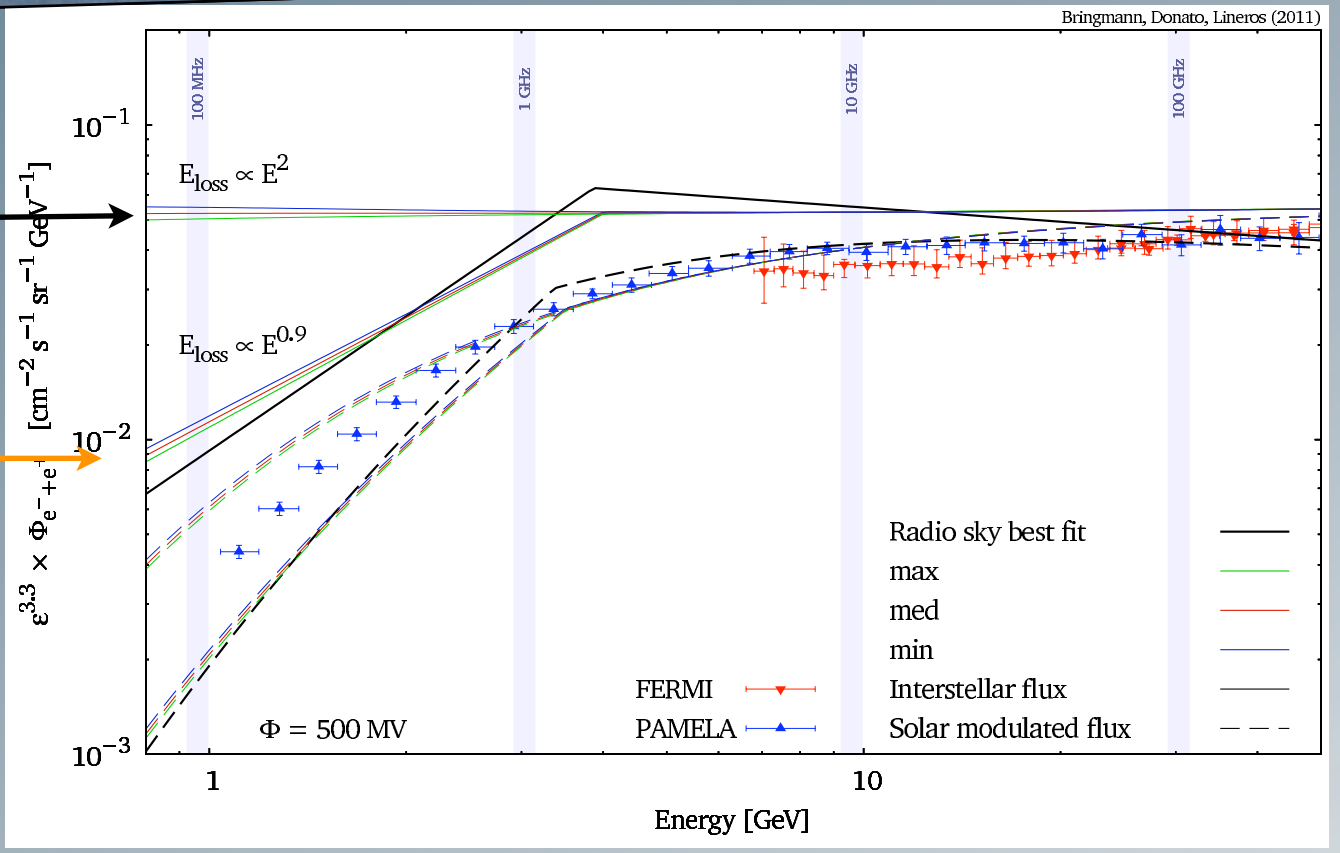

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  (scattering on thermal ions/electrons could start to dominate IC here...)

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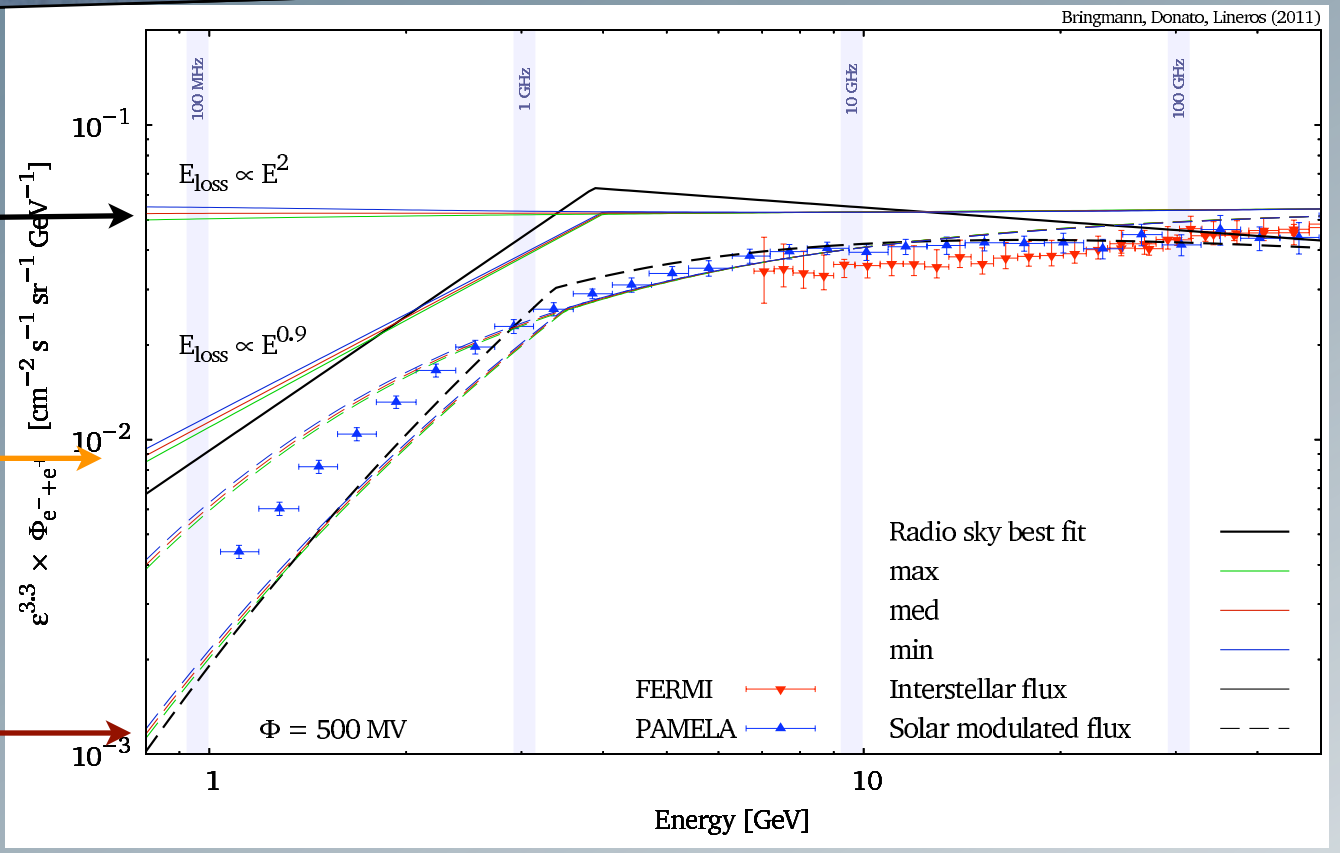

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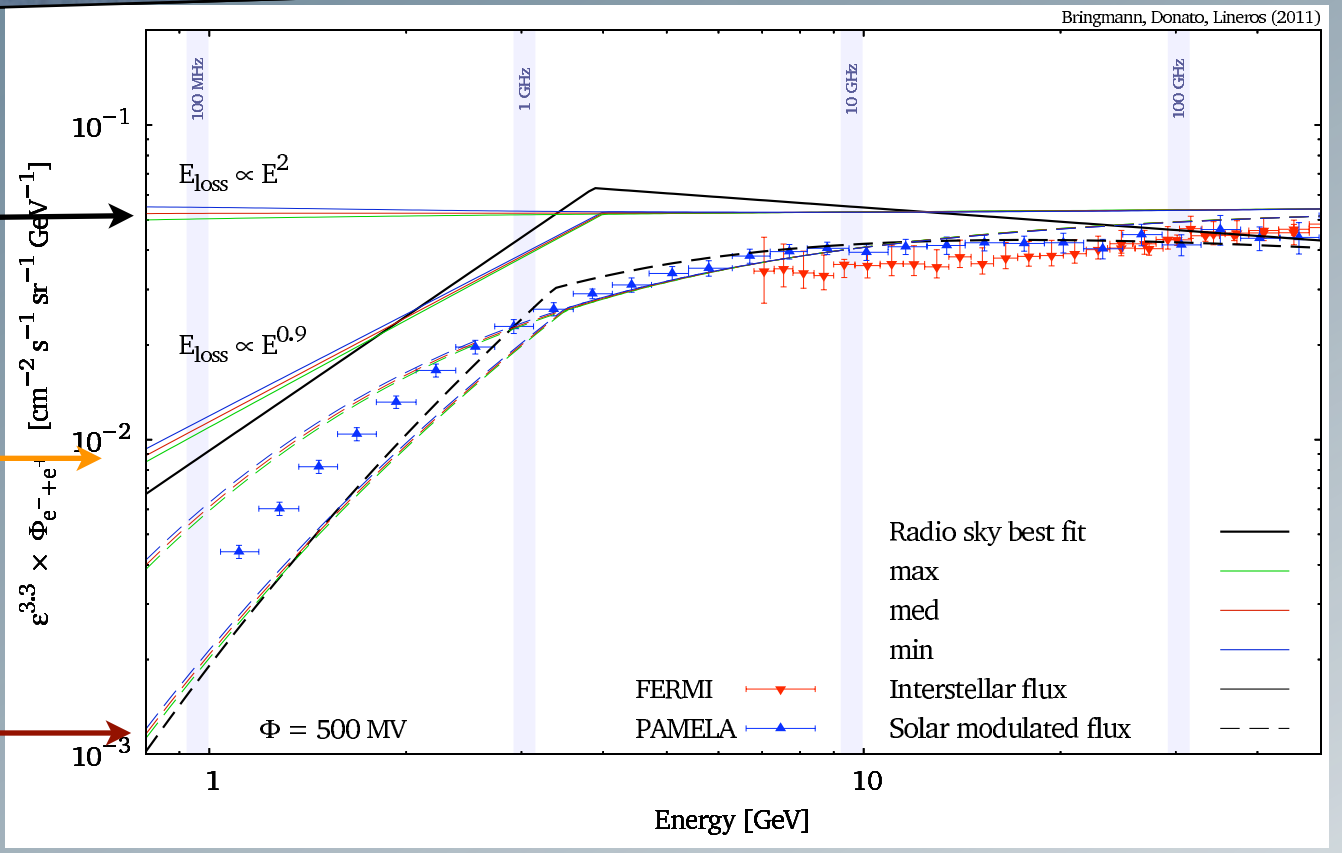

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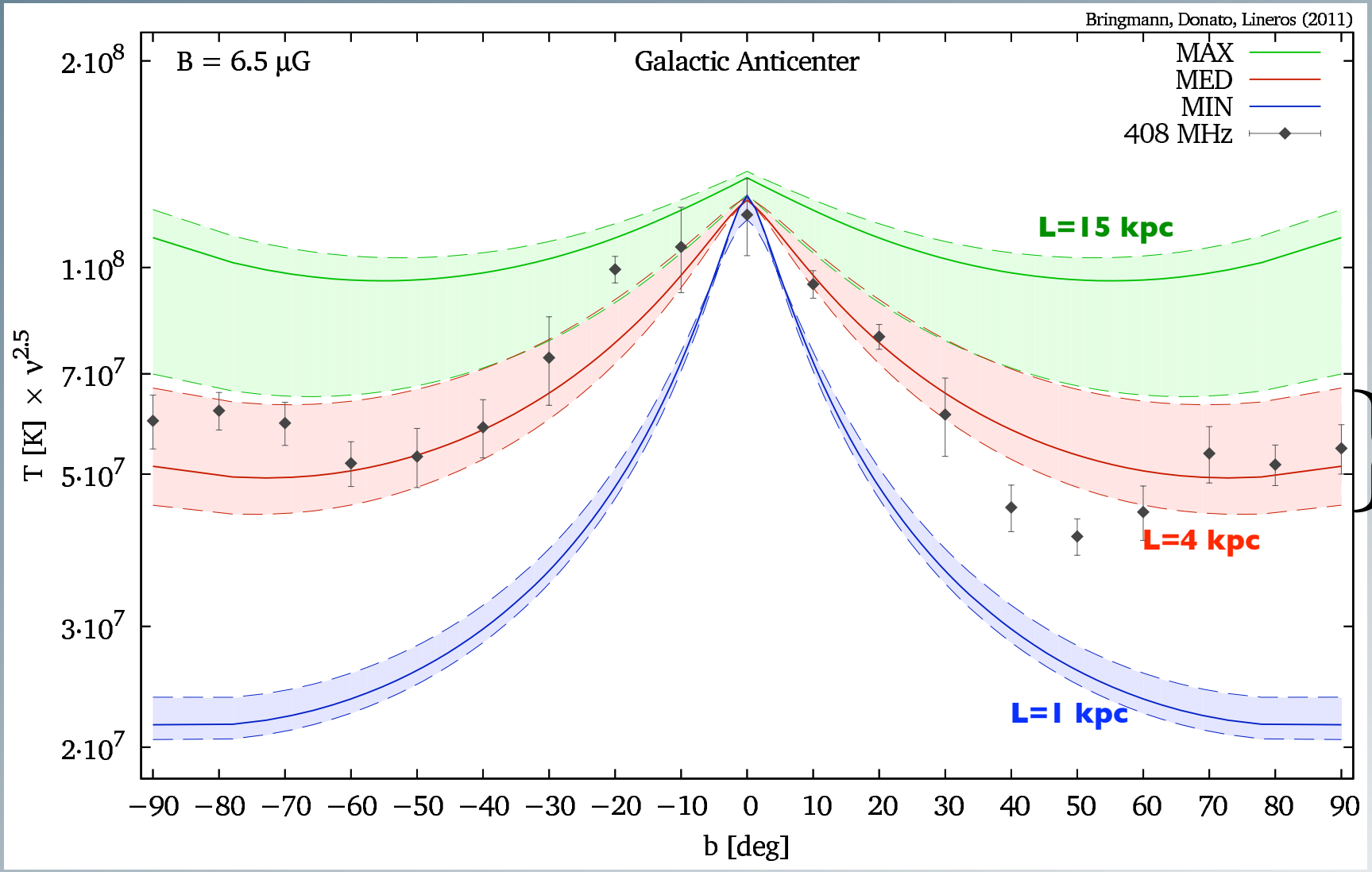
⇒ Rather good agreement with observed electron fluxes!

Angular distribution



➡ clear discrimination between halo sizes possible!

Min/med/max propagation

- Very similar pattern also at other frequencies:
  (vary latitude towards galactic anticenter;
  normalization/ magnetic field as free parameter to minimize χ^2)

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	L [kpc]	K_0 $\left[\frac{\mathrm{kpc}^2}{\mathrm{Myr}}\right]$	δ	408 MHz	1.42 GHz
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max	15	0.0765	0.46	10.8 (4.8)	8.9 (3.9)

angular average 10° (15°)

Min/med/max propagation

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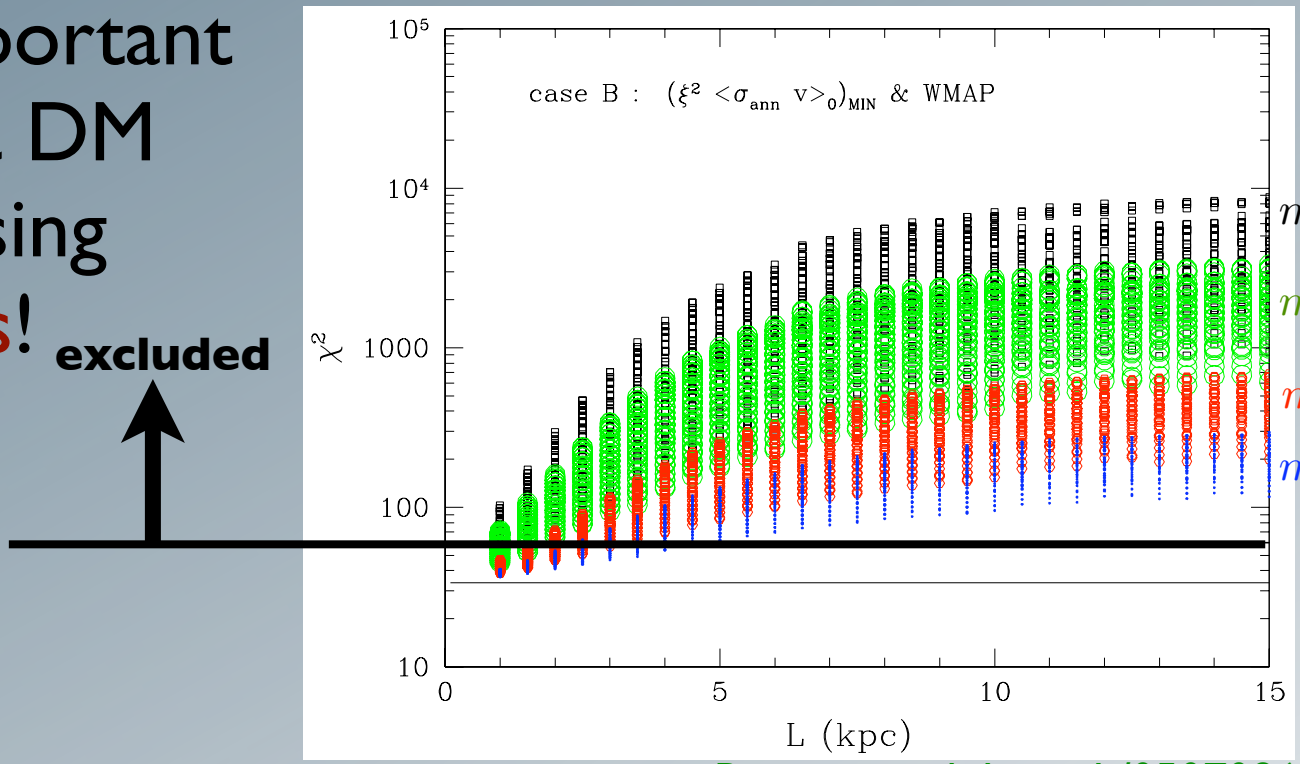
- At frequencies $\nu \gtrsim 2\,\mathrm{GHz}$, synchrotron contribution reproduces radio data significantly worse
  (bremsstrahlung contributions from molecular clouds and pulsars/SNRs !?)

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

- The same holds for antideuterons...

Conclusions

- Synchrotron radiation allows to directly measure the interstellar electron distribution
  - independent of solar modulation effects
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- Radio data can be described in simple diffusion models consistent with cosmic ray observations
- 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

Backup slides

GCR composition

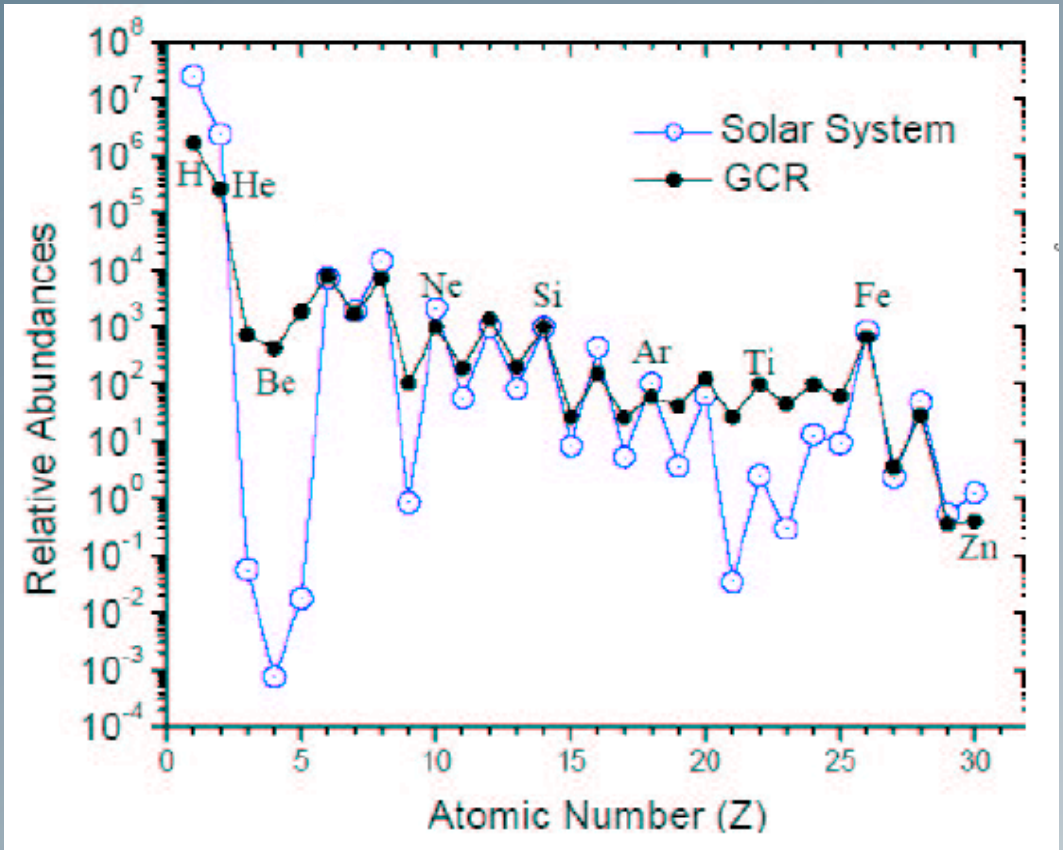

Fig. from D. Maurin

GCR composition

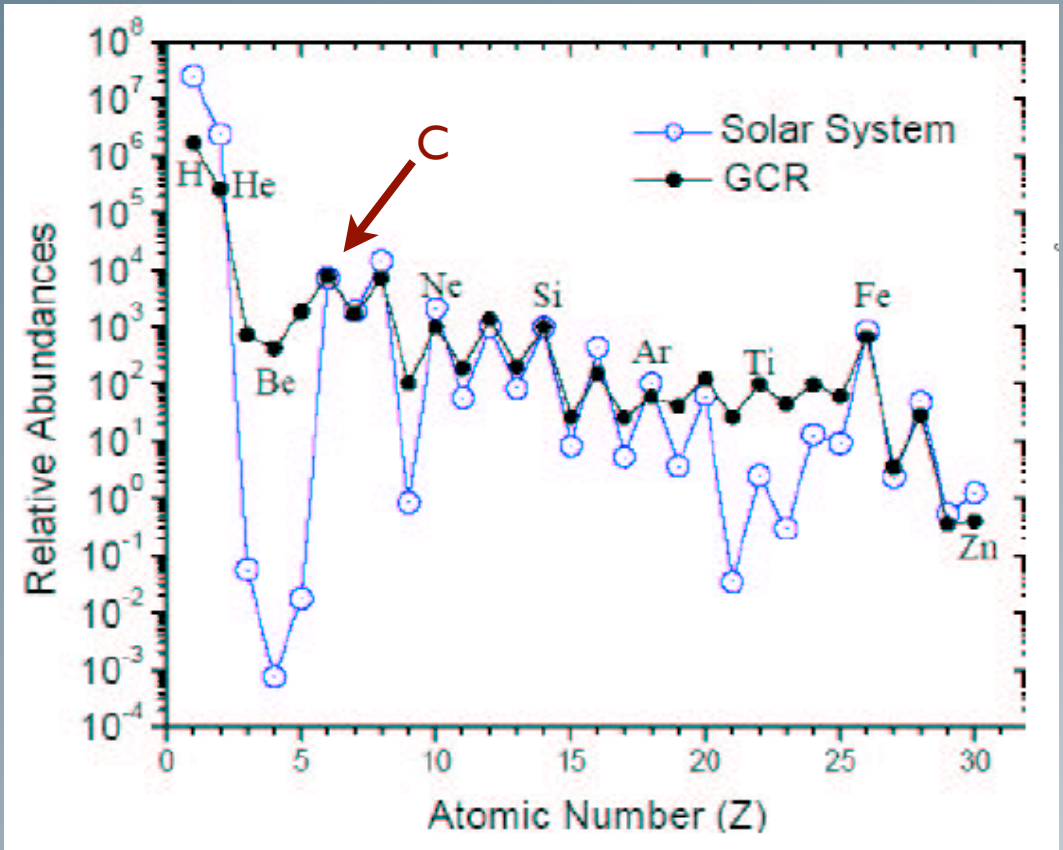

Fig. from D. Maurin

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

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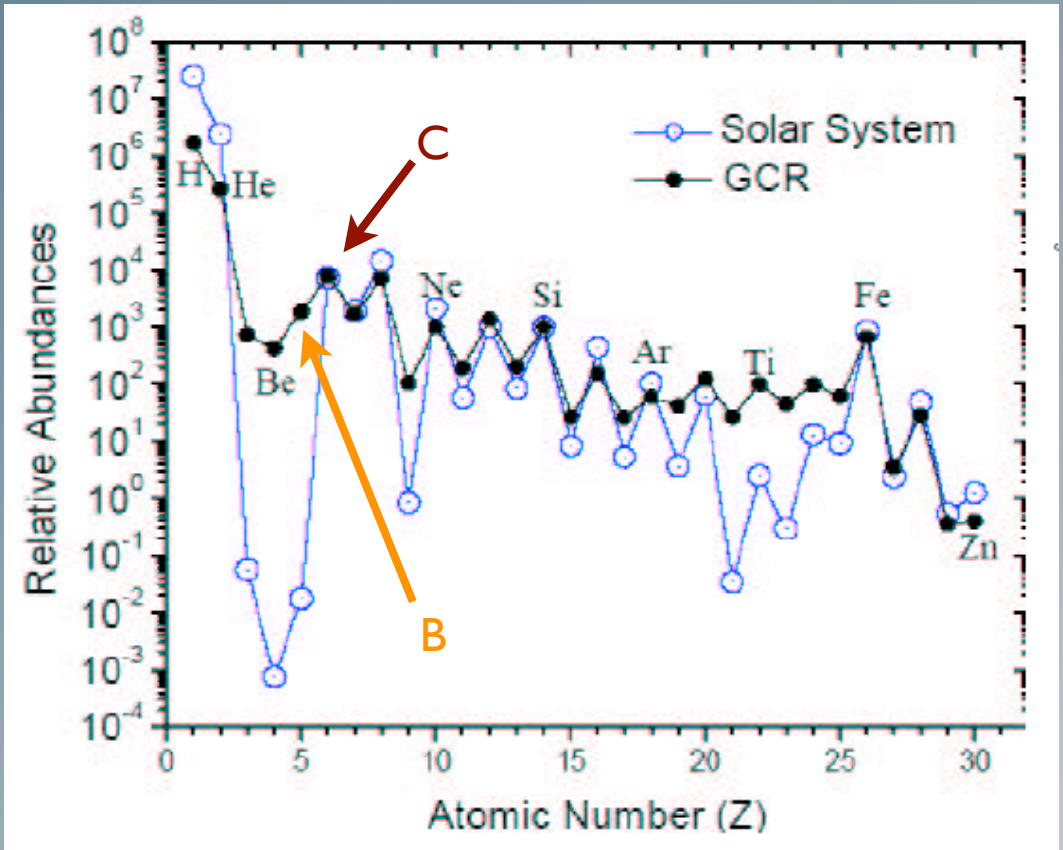

Fig. from D. Maurin

- **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

Antiprotons

- Rather straightforward to handle:
  - no significant astrophysical sources
  - for $E_{\bar{p}} \gtrsim 10\,\mathrm{GeV}$ completely diffusion dominated

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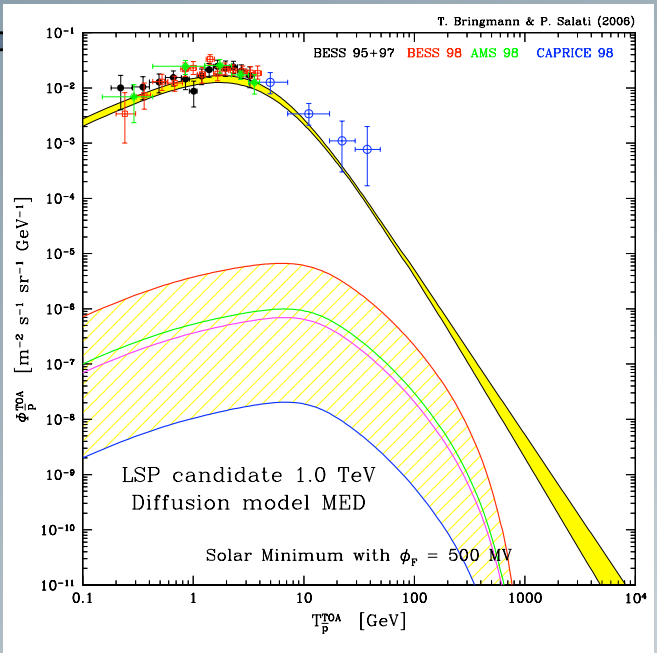

TB & Salati, PRD '09

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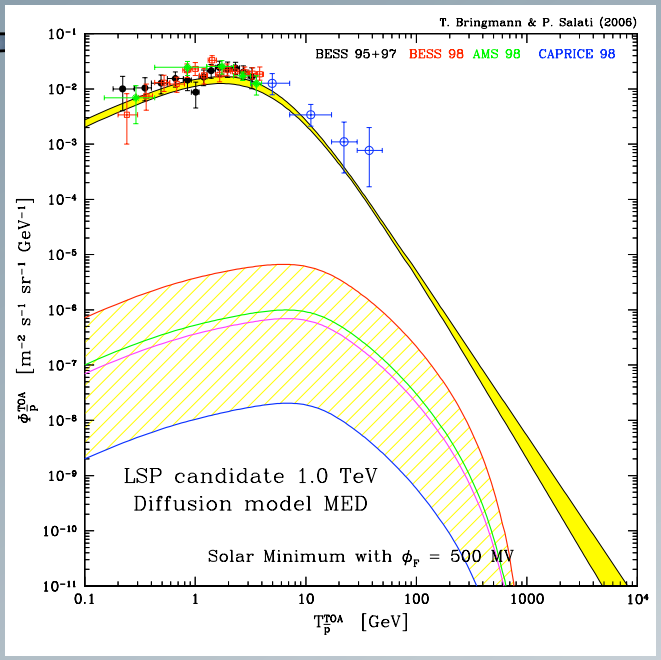
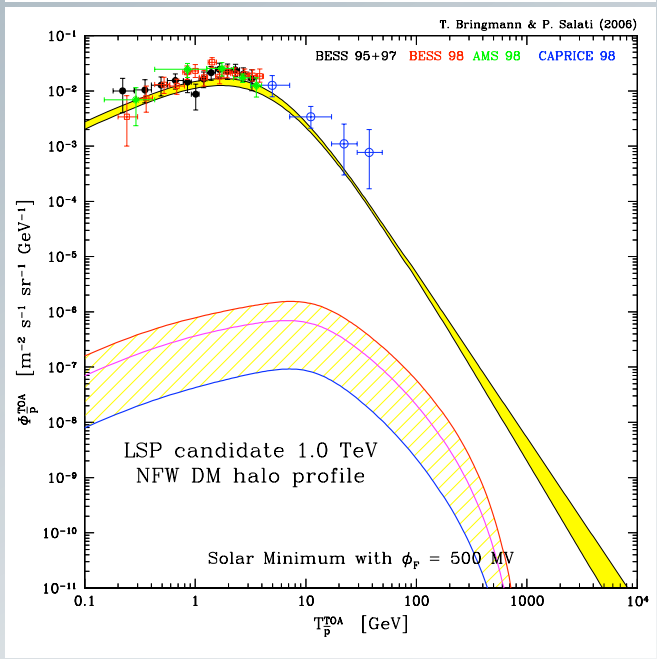
  - up to ~40 from range of propagation parameters compatible with B/C





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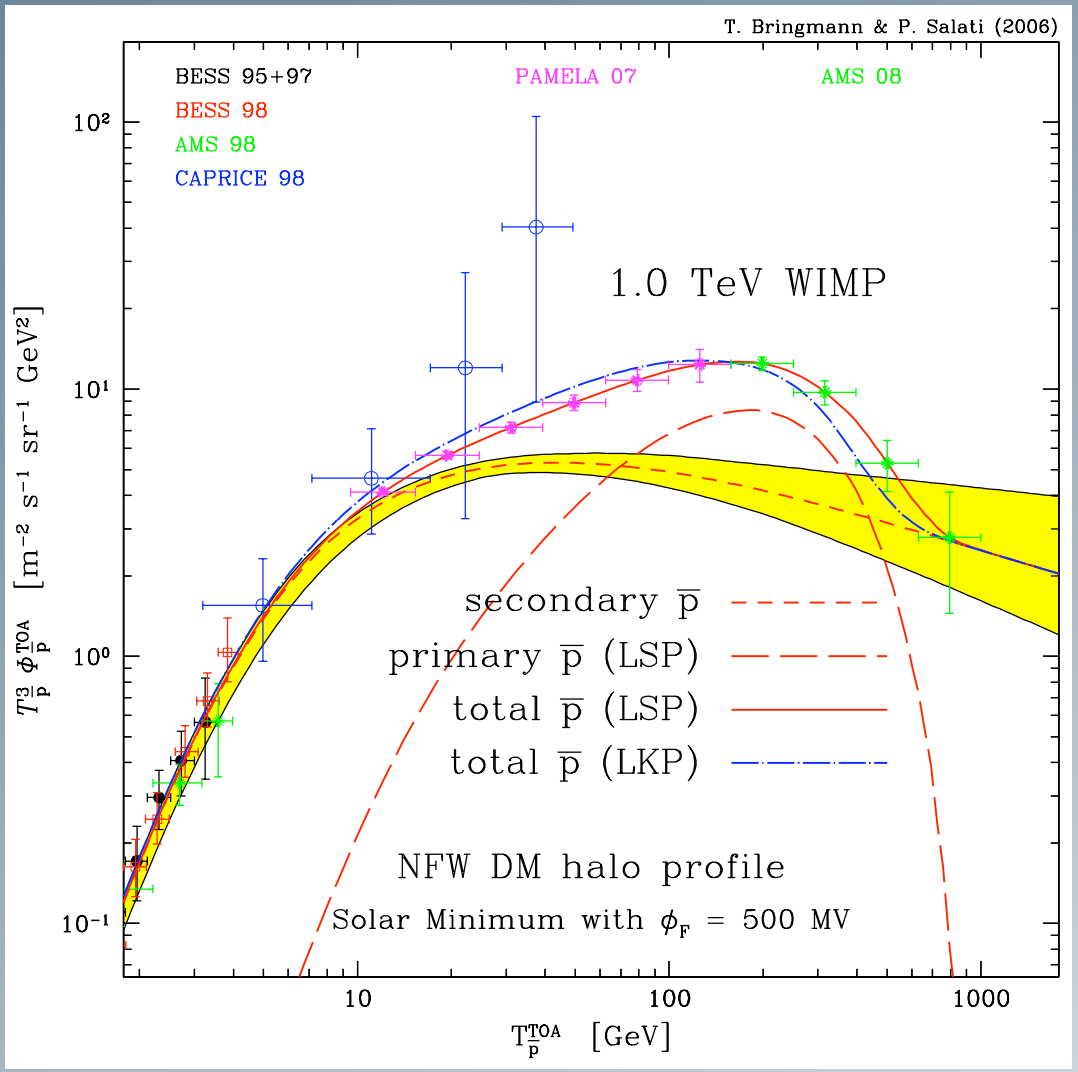

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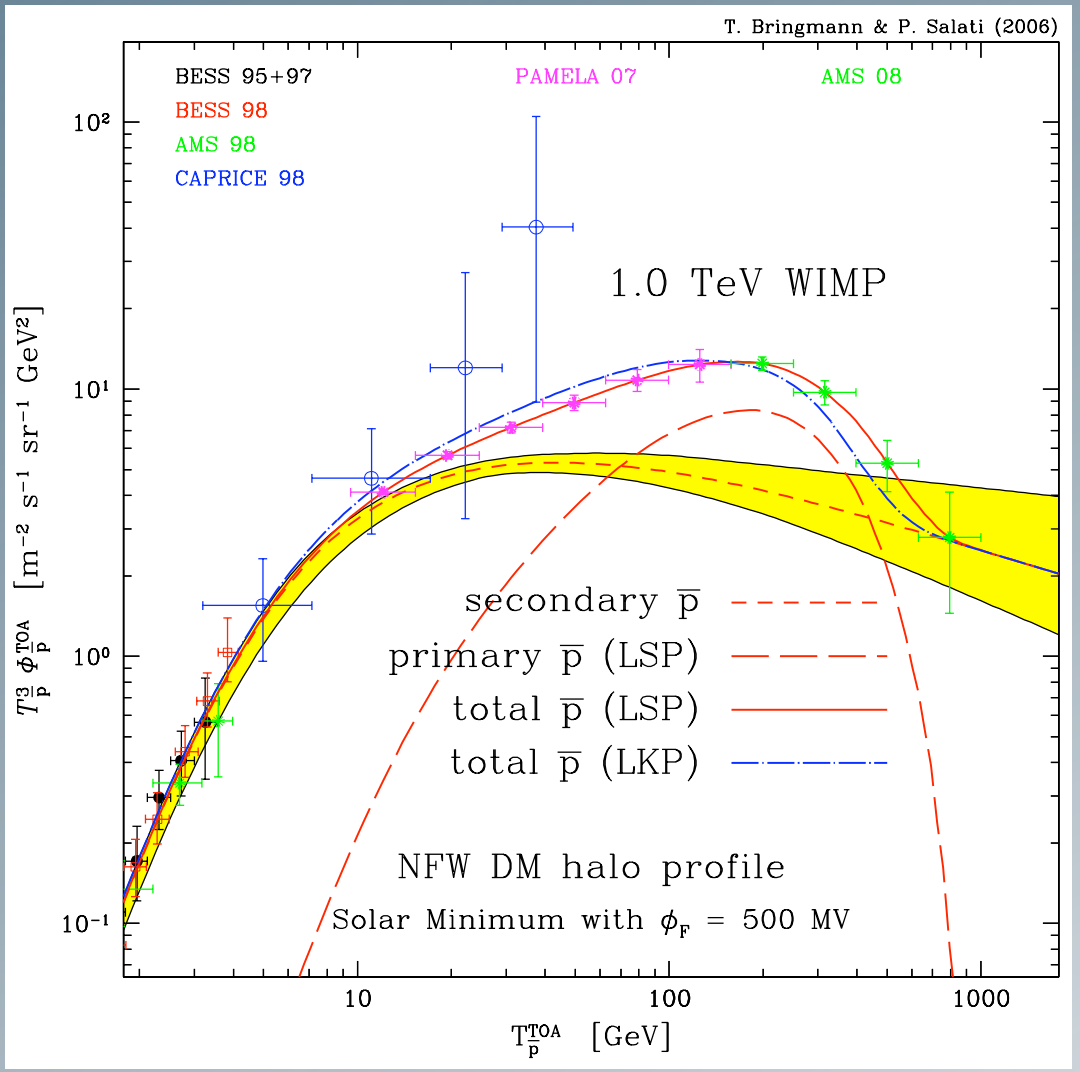

TB & Salati, PRD '09

- Cannot be used to discriminate between DM candidates...
- ...but are quite efficient in settings constraints!
  - light SUSY DM
    Bottino *et al.*, PRD '98+05
  - non-standard DM profile proposed by deBoer
    Bergström *et al.*, JCAP '06
  - DM explanations for the PAMELA e^+/e^- excess
    Donato *et al.*, PRL '09
  - "Evidence" for DM seen in Fermi data towards the GC
    TB, 0911.1124
  - ...