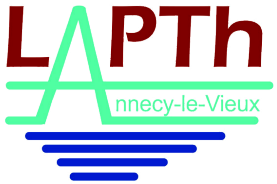
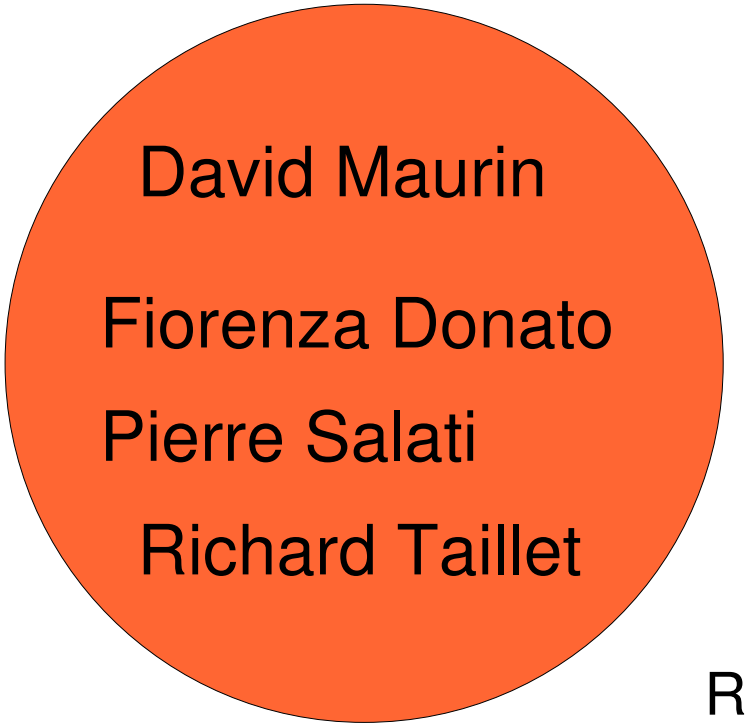
Cosmic Ray Propagation
& analytical resolution

Timur Delahaye

LAPTh(Annecy) & Univ. Turin



Speaking for...



Julien Lavalle

Pierre Brun

Antje Putze

Nicolao Fornengo

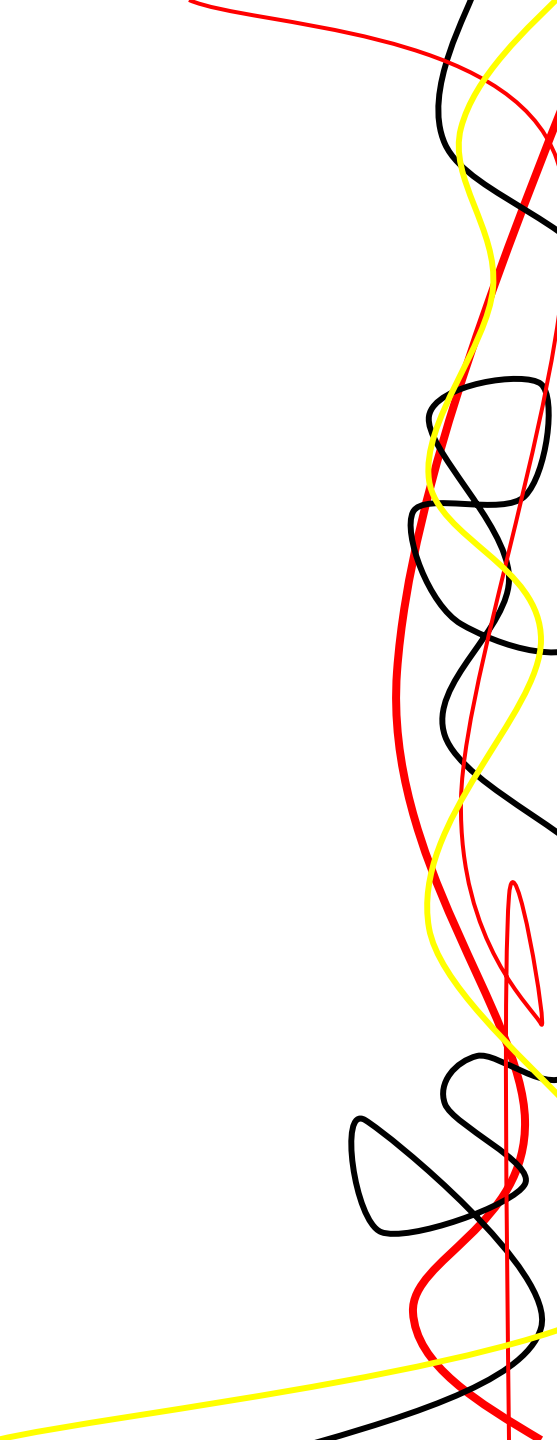
T.D.

Roberto Lineros

Laurent Derôme

Outline

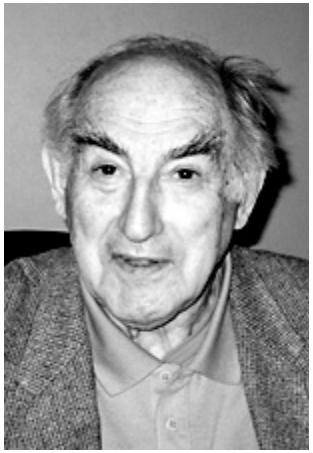
- Propagation Model
- Hadrons
- Leptons
- Gamma rays



Cosmic Rays

Charles Wilson

Pierre Auger



Vitaly Ginzburg

Victor Hess

Carl Anderson

Discoveries in Cosmic Rays

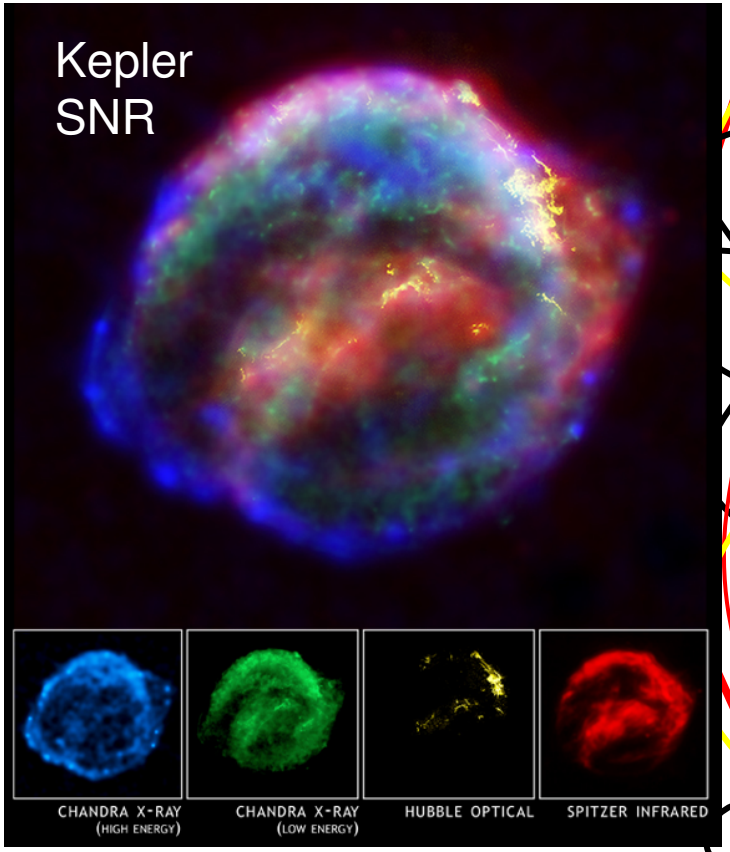
- Positron (1932)
- Muon (1936)
- Pion (1947)
- Kaon (1947)
- Lambda (1951)

- Neutralino (201x) ?

Source

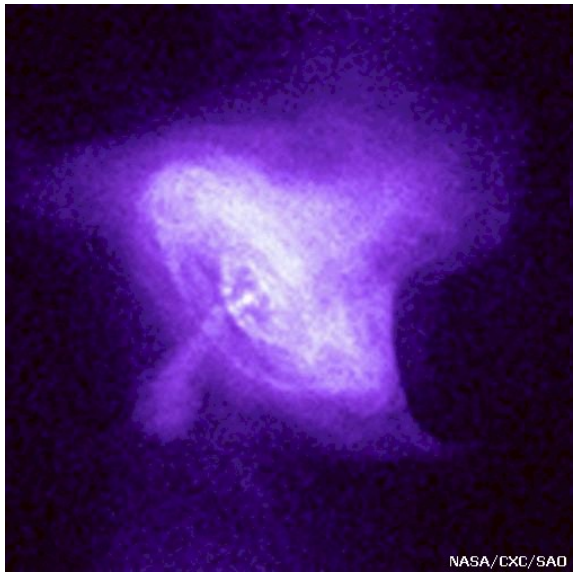
- Supernova remnants

$$Q_0 E^{-\gamma} e^{-E/E_c}$$



Source

- Supernova remnants
- Pulsars



$$Q_0 E^{-\gamma} e^{-E/E_c}$$

Source

- Supernova remnants
- Pulsars
- Cosmic rays

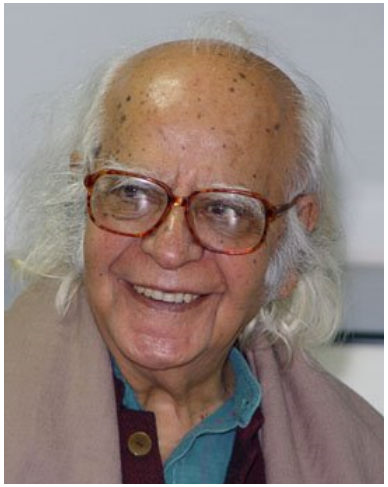
$$\sigma\left(p_{CR} + H_{ISM} \Rightarrow \text{C.R.}\right)$$

Sources

- Supernova remnants
- Pulsars
- Cosmic rays
- Dark Matter

$$\eta \langle \sigma v \rangle \frac{\rho^2}{m_\chi^2} f(E)$$

Propagation

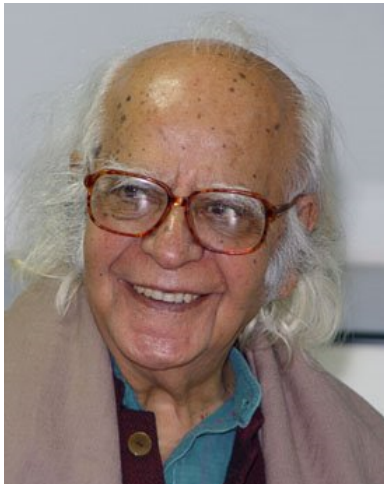


Yash Pal

Leaky Box

$$\frac{N}{\tau_{esc}} + \bar{n} v \sigma N = Q$$

Propagation



Yash Pal

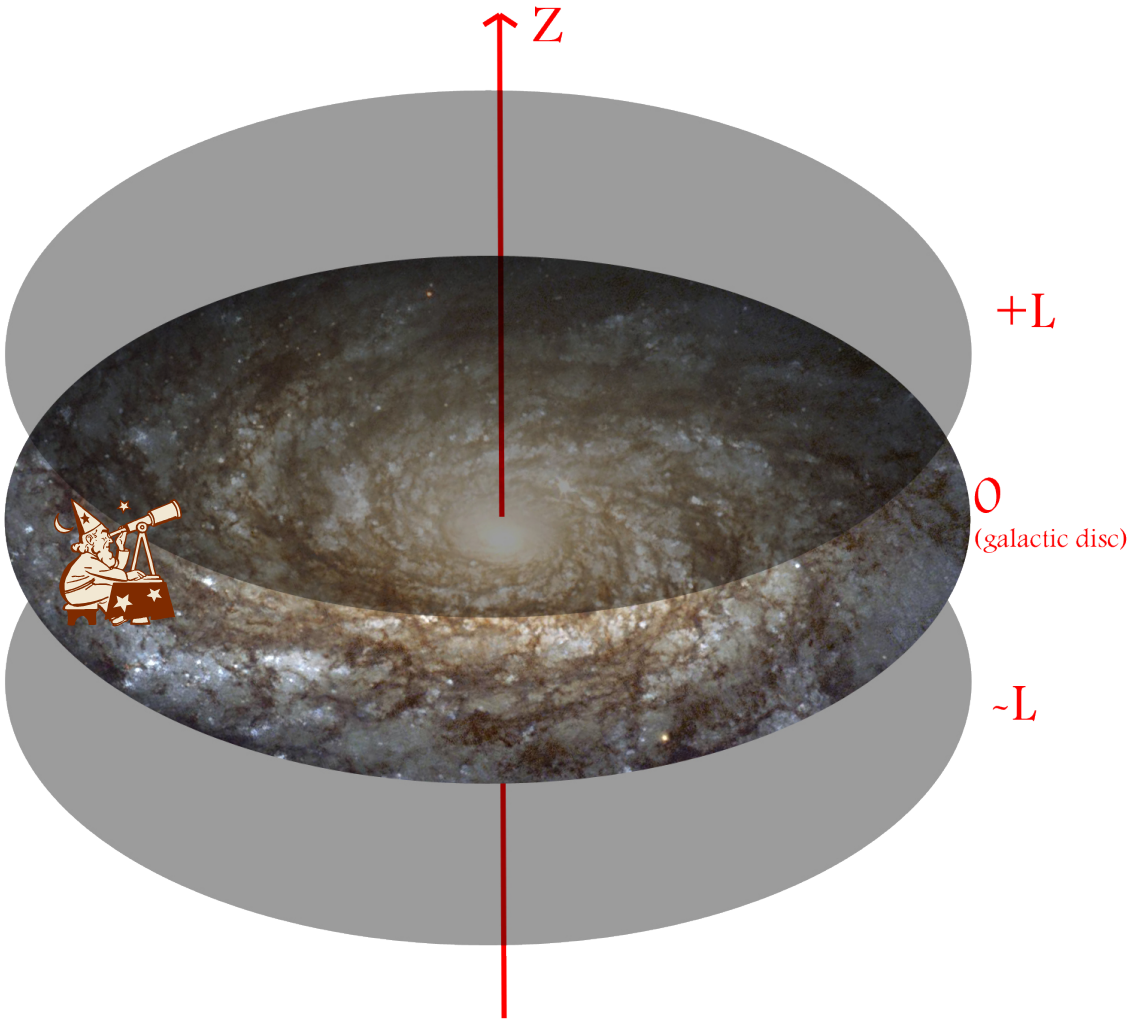
Leaky Box

$$\frac{N}{\tau_{esc}} + \bar{n} v \sigma_{in} N = Q$$

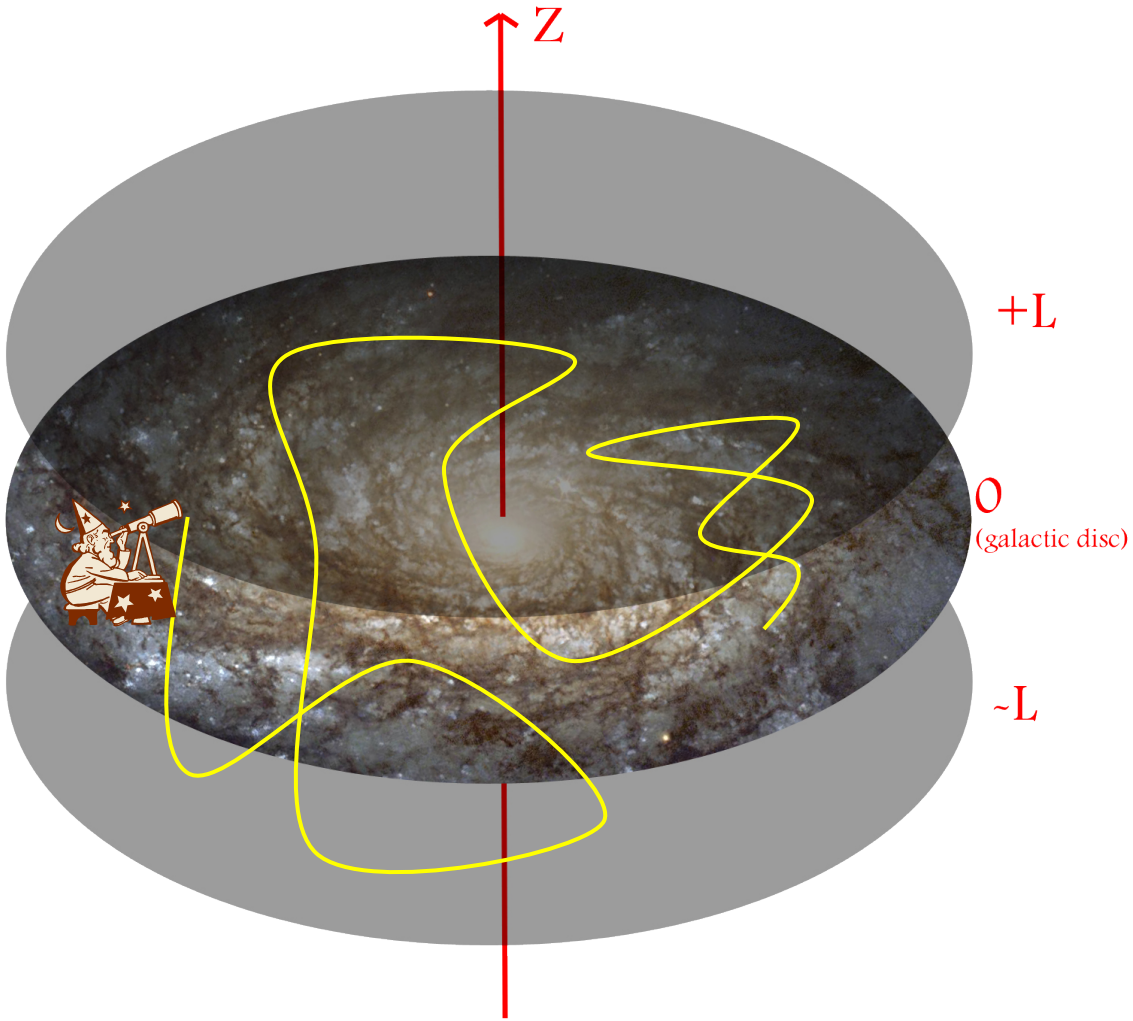
Outdated

Unfit for low grammage, radio-active elements, electrons & gamma rays

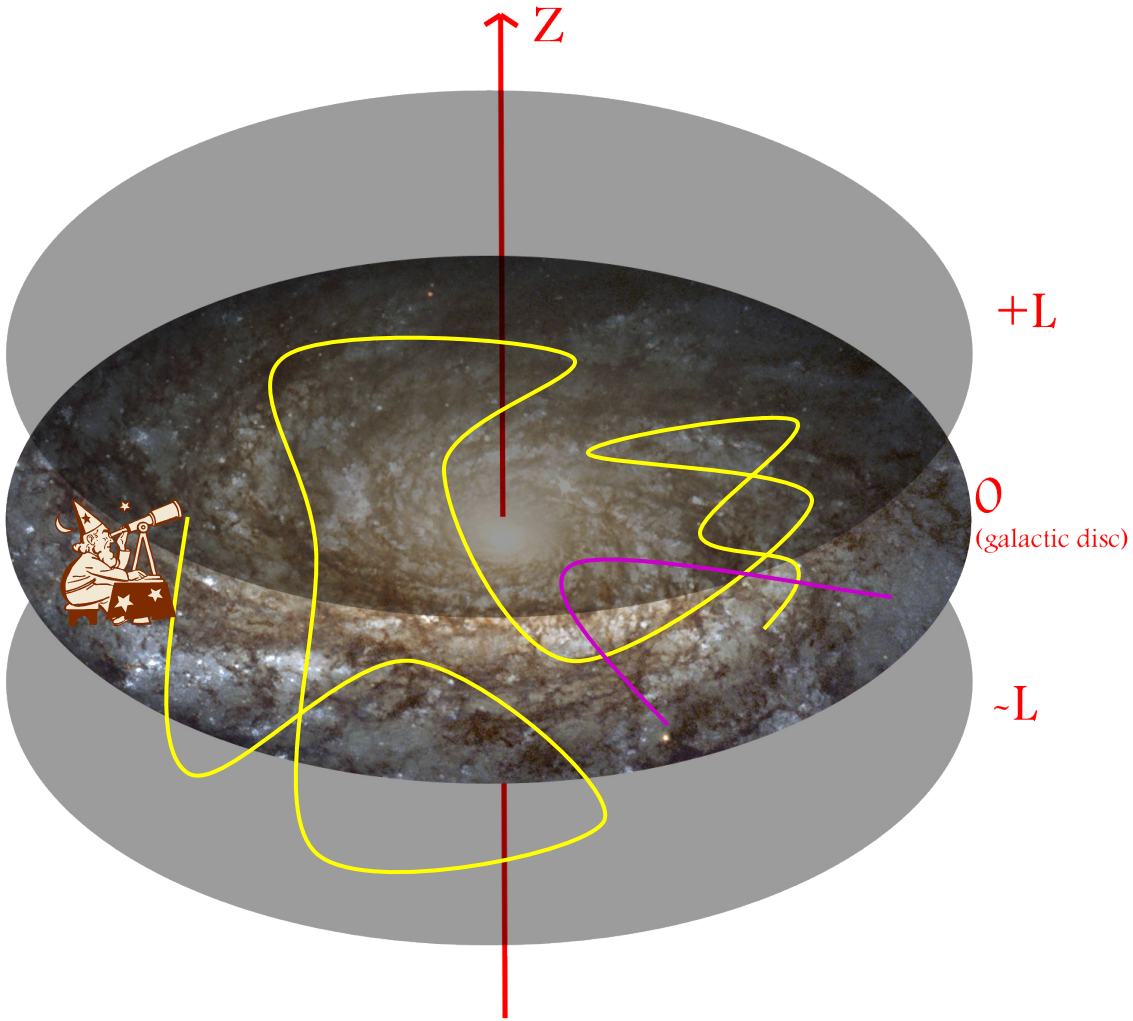
Diffusion Model



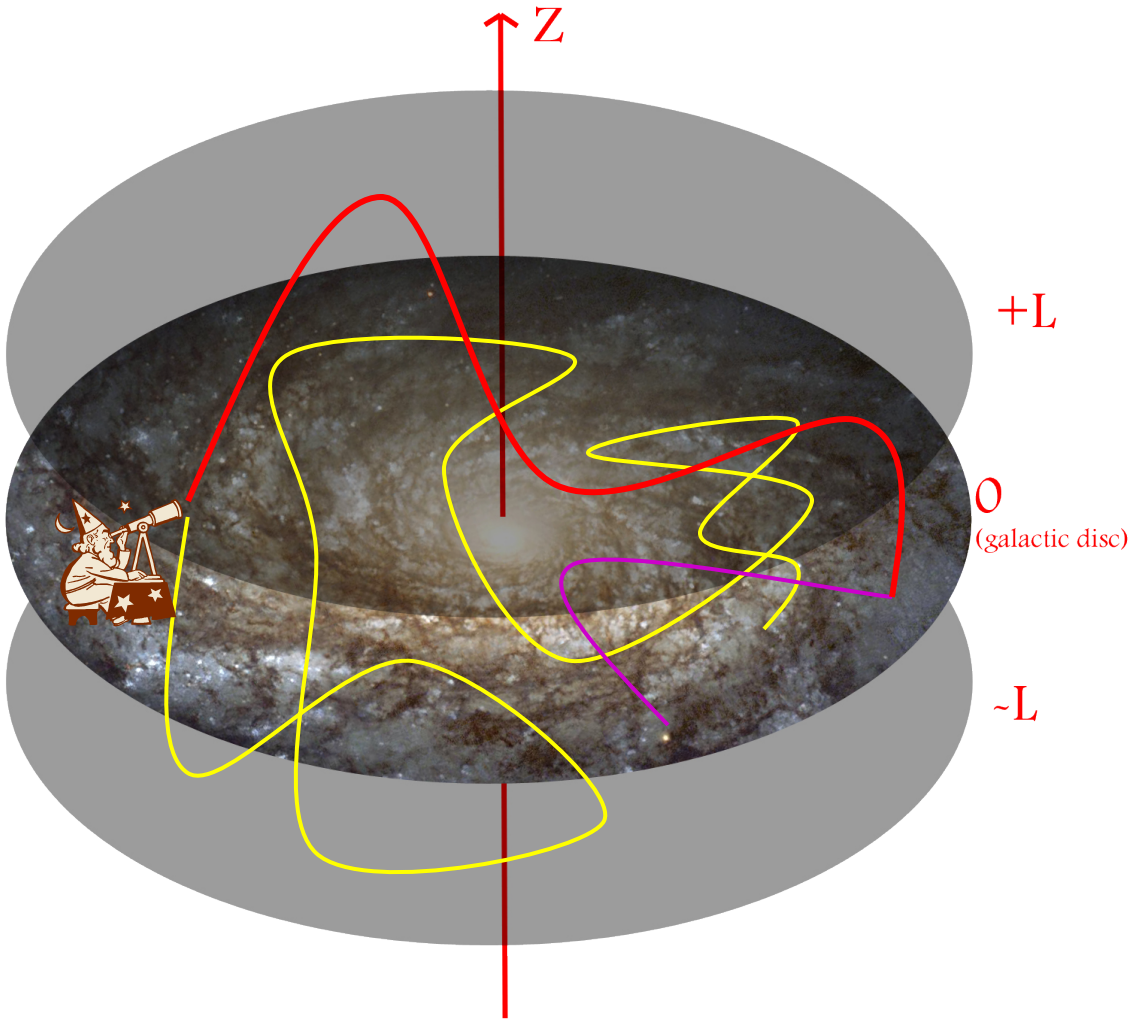
Diffusion Model



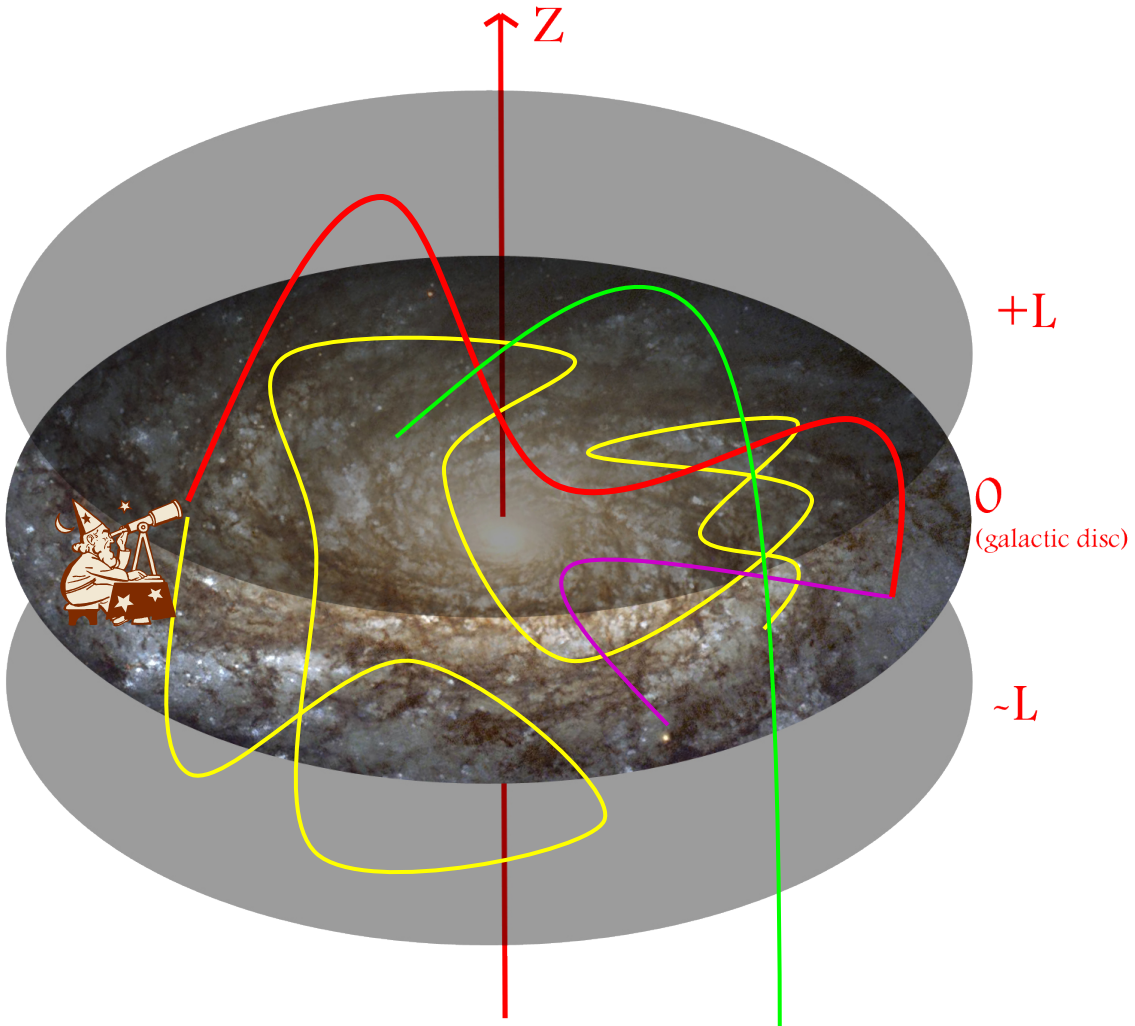
Diffusion Model



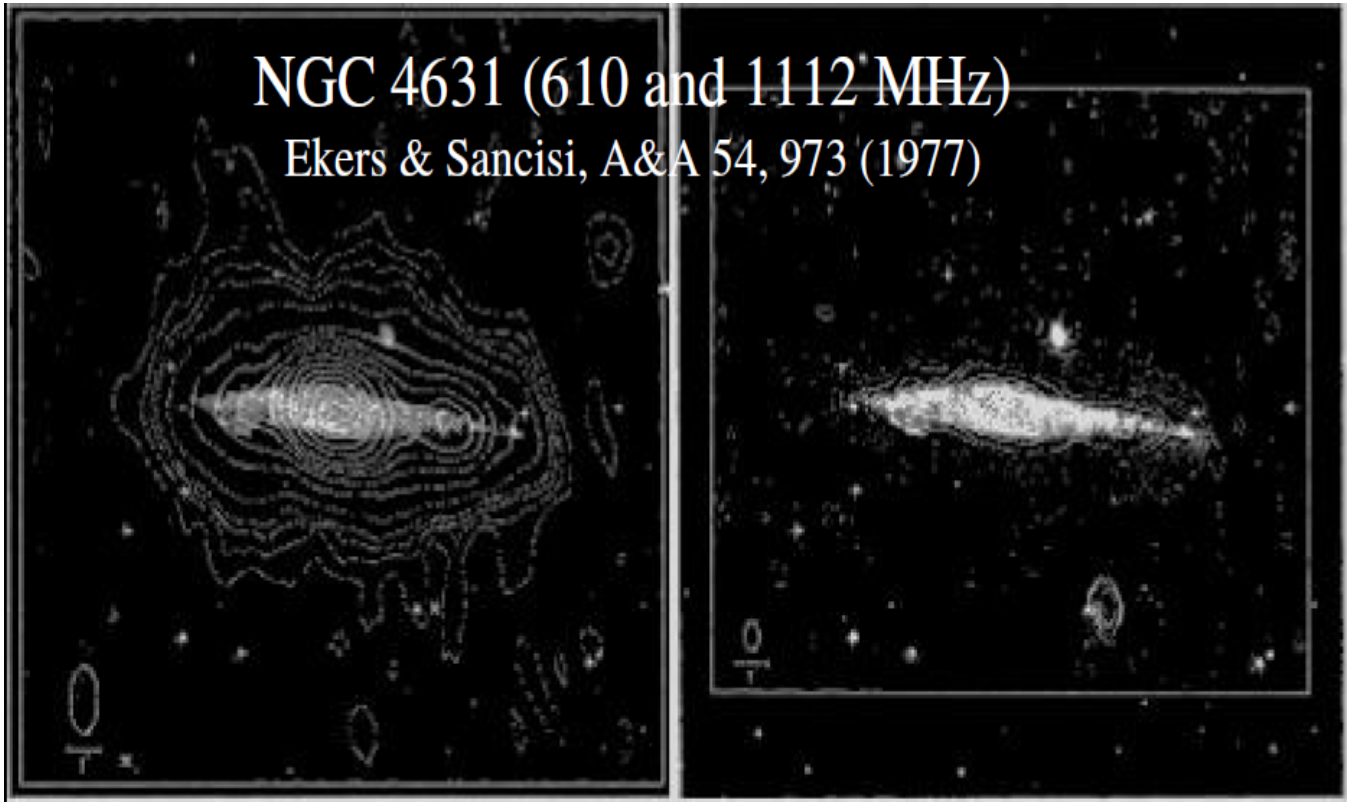
Diffusion Model



Diffusion Model



Diffusion Model



Diffusion Model

$$\Psi(\vec{x}, E, t) = \frac{d^4N}{d^3\vec{x}dE} \qquad \partial_t \Psi + \partial_\mu J^\mu = Q$$

$$\vec{J} = -K\vec{\nabla}\Psi + \vec{V}_c\Psi \qquad J_E = b_{loss}\Psi + D_{EE}\partial_E\Psi$$

$$\partial_t\Psi - \vec{\nabla}\cdot\left(K\vec{\nabla}\Psi + \vec{V}_c\Psi\right) + \partial_E\left(b_{loss}\Psi + D_{EE}\partial_E\Psi\right) = Q(\vec{x}, E, t)$$

+ Boundary conditions

Hadrons

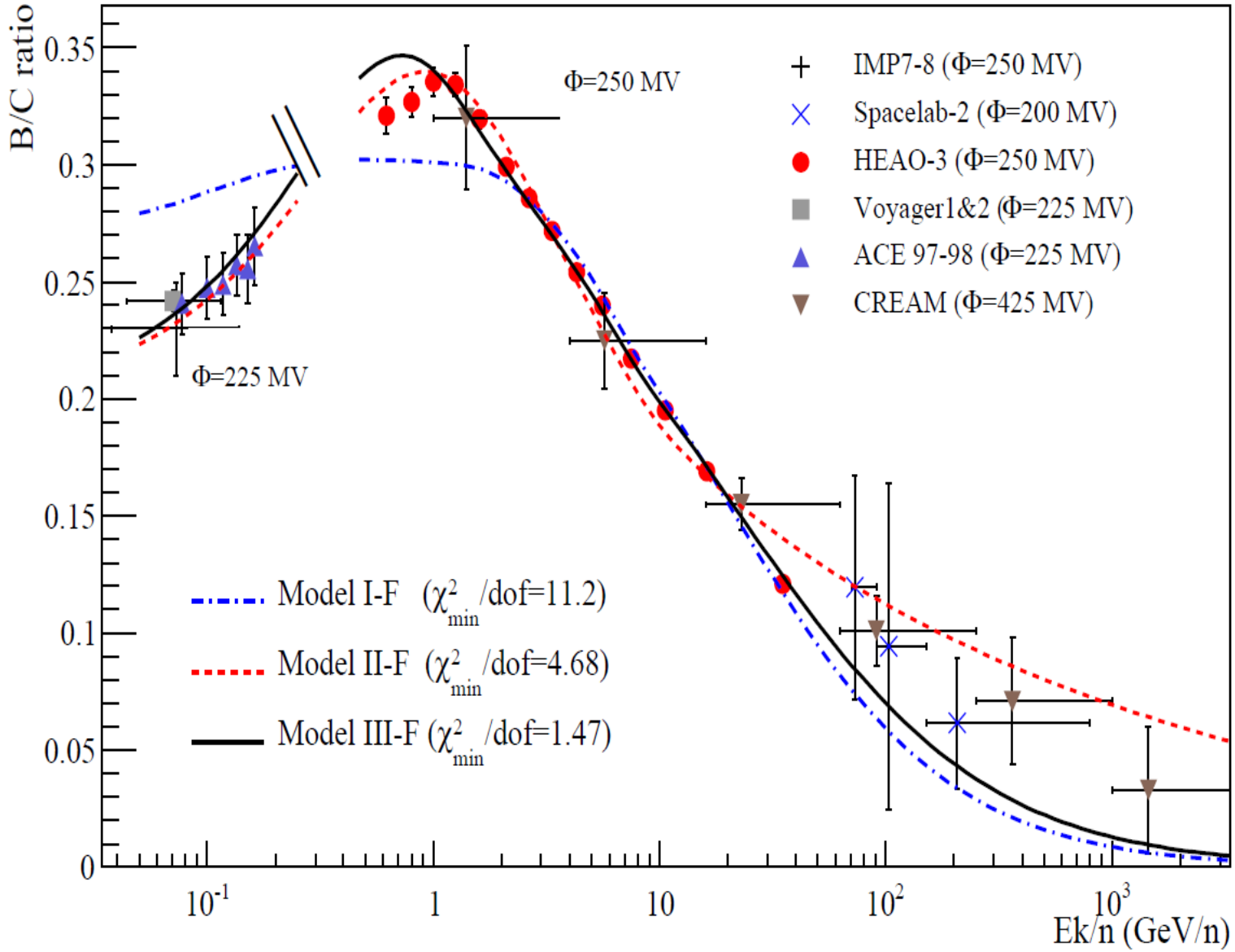
- Protons / Anti-protons
- Ions (α, B, C, O, N … Fe…)

$$-K_0\beta\mathbf{R}^{\delta}\Delta\Psi(r,z,E)+V_c\partial_z\Psi(r,z,E)$$

$$+\ 2h\delta(z)\partial_E\left[b_{loss}(E)\Psi(r,z,E)+D_0E^{2-\delta}\partial_E\Psi(r,z,E)\right]$$

$$=\ 2h\delta(z)Q(r,E)$$

Secondaries to Primaries



Putze, Derome & Maurin ArXiv:1001.0551

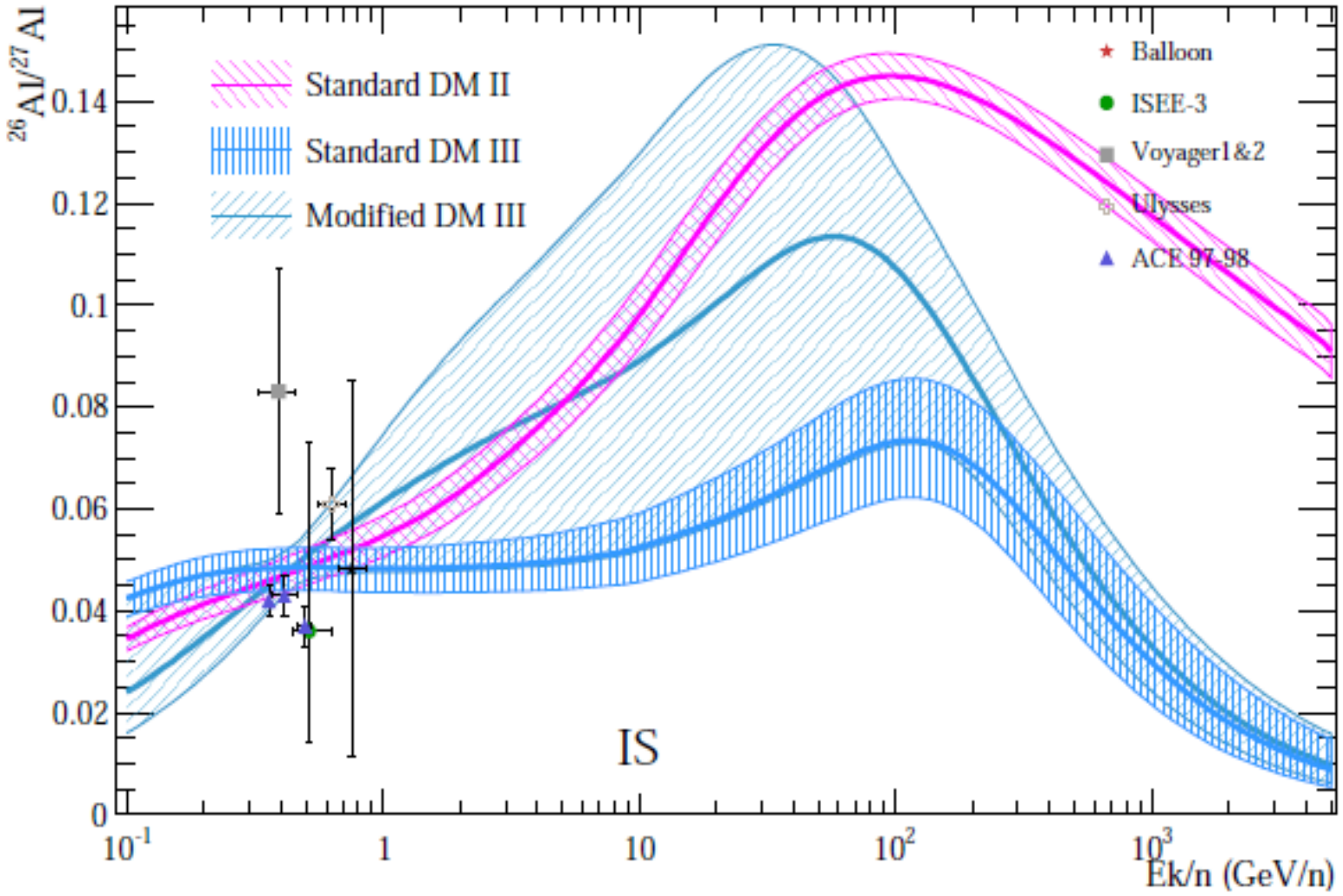
Secondaries to Primaries

- K_0/L
- V_A
- V_C
- δ

MCMC points towards
*large δ and L
*reacceleration AND convection

Radio-active species

Putze, Derome & Maurin ArXiv:1001.0551

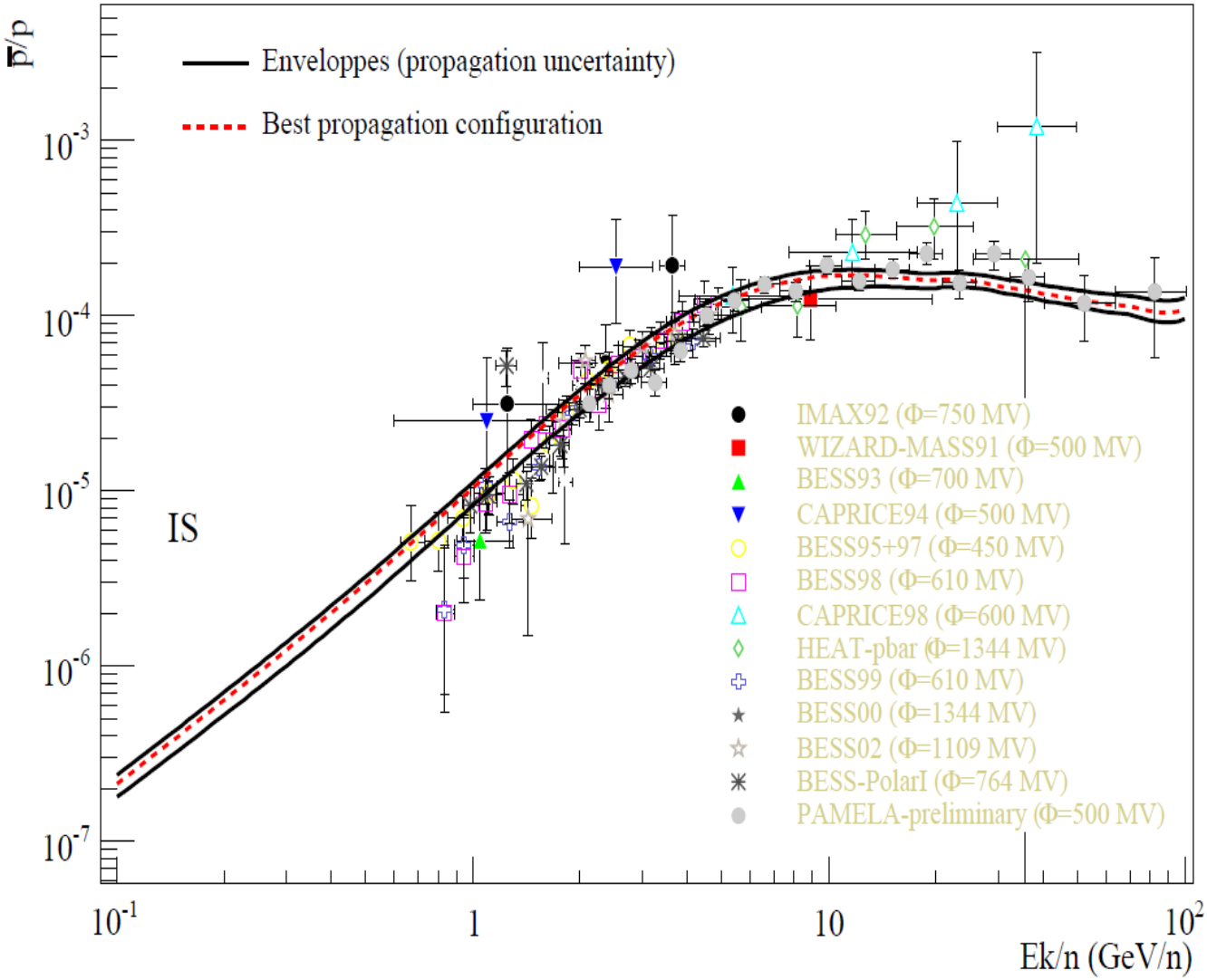


Radio-active species

- Sensitive to a local bubble
- Unsensitive to L (with some restrictions)

- But poor data available

$\overline{P}/P$

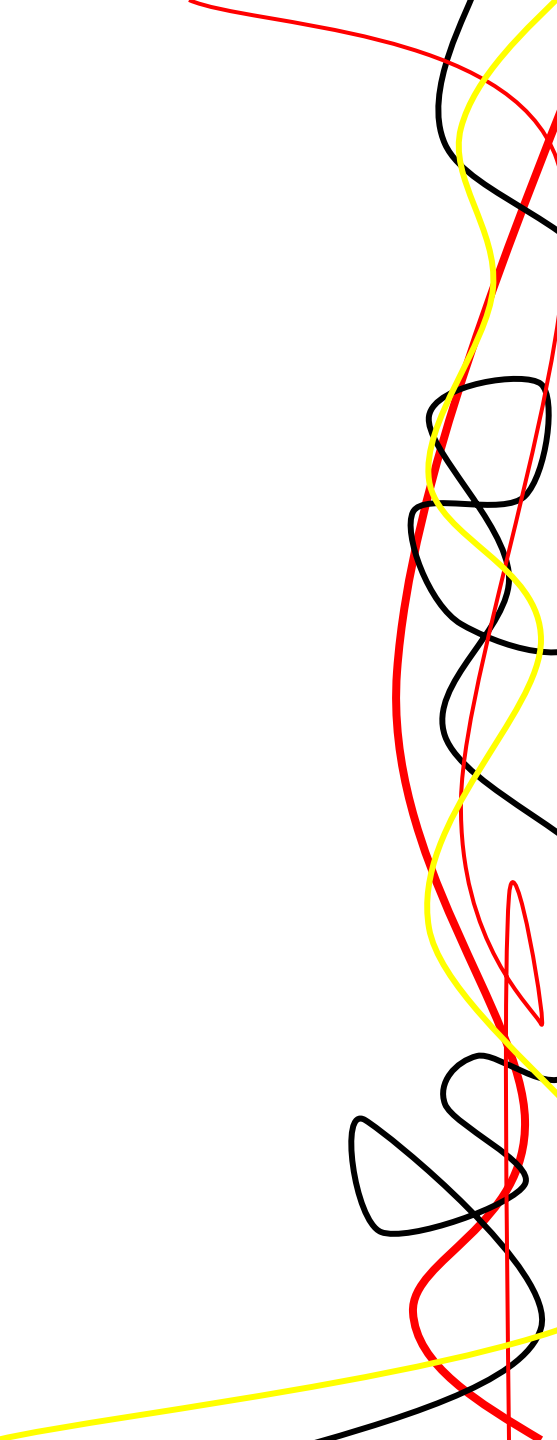


Donato, Maurin et alii PRL 2009

$\bar{P}/P$

Uncertainties

- Propagation
- Cross-sections
- Primary flux
- Source distribution



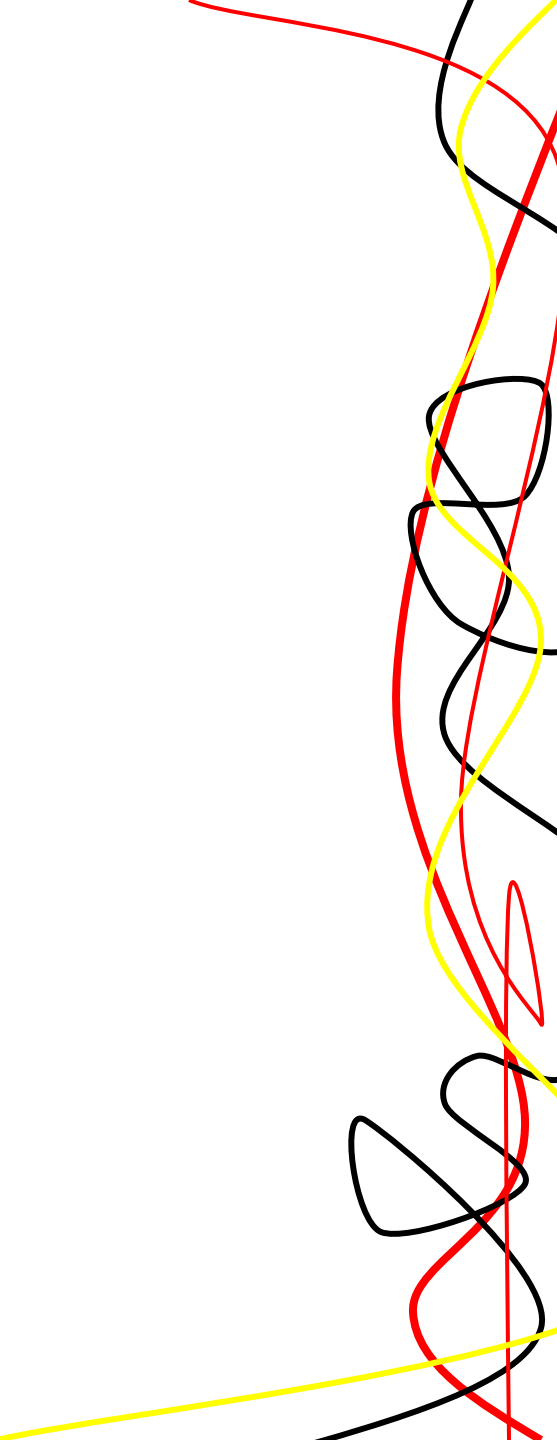
Leptons

- Electrons & Positrons

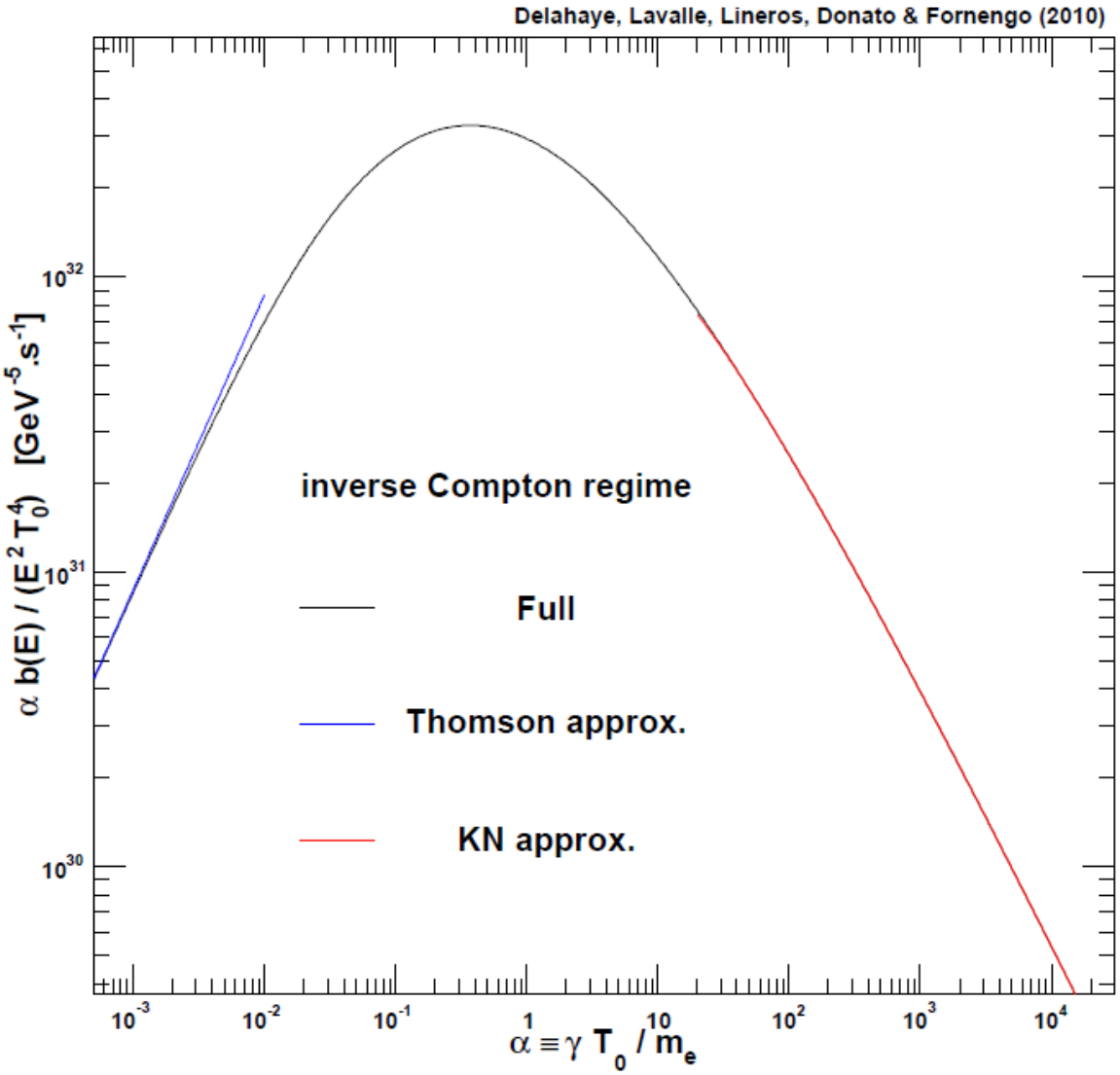
$$-K_0 E^{\delta} \Delta \Psi(r,z,E) + \partial_E \left[b_{loss}(E) \Psi(r,z,E) \right] = Q(r,z,E)$$

Energy losses

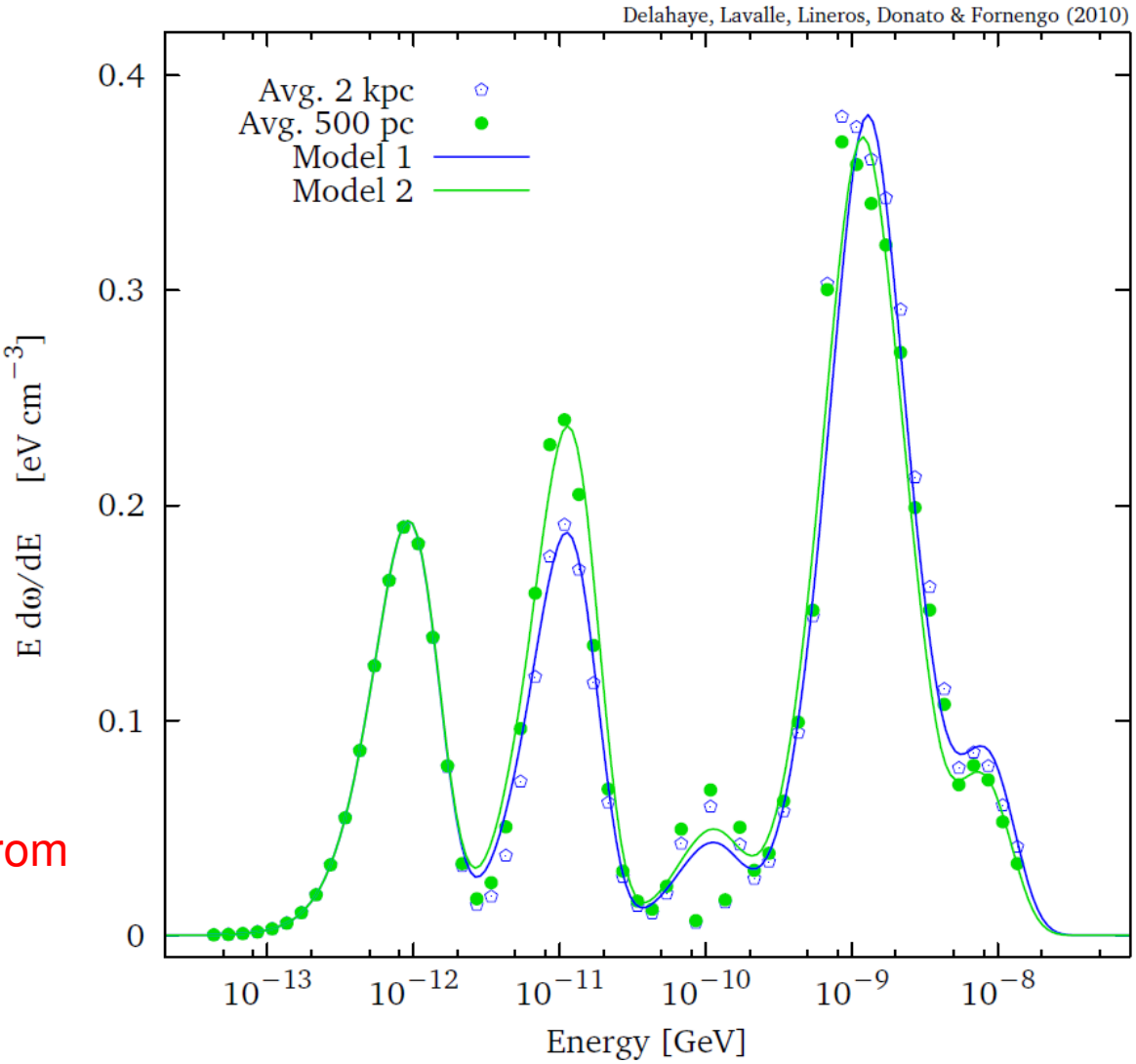
- Adiabatic expansion
- Annihilation
- Ionisation
- Brehmsstrahlung
- Synchrotron
- Inverse Compton



Inverse Compton

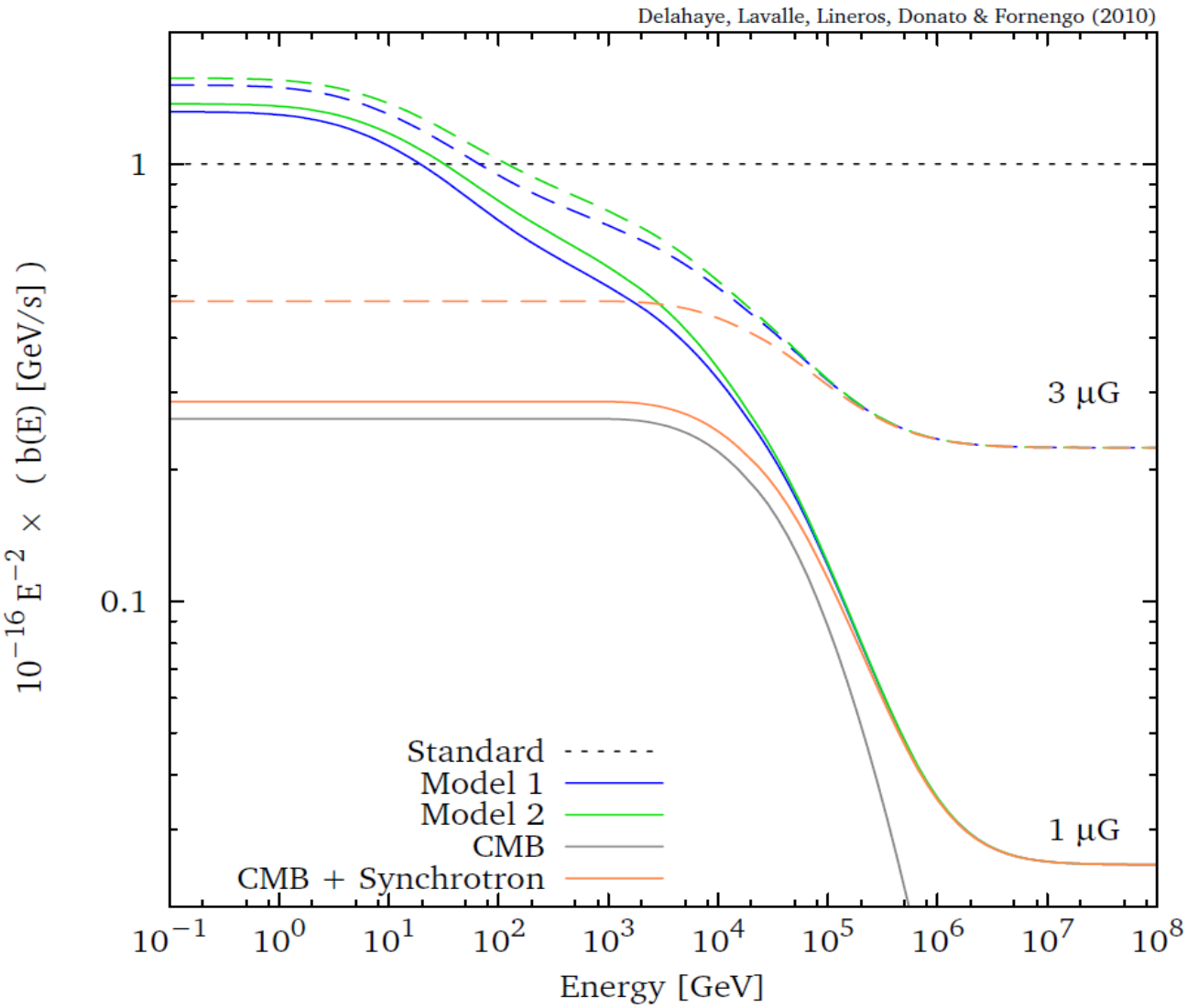


Interstellar Radiation Field

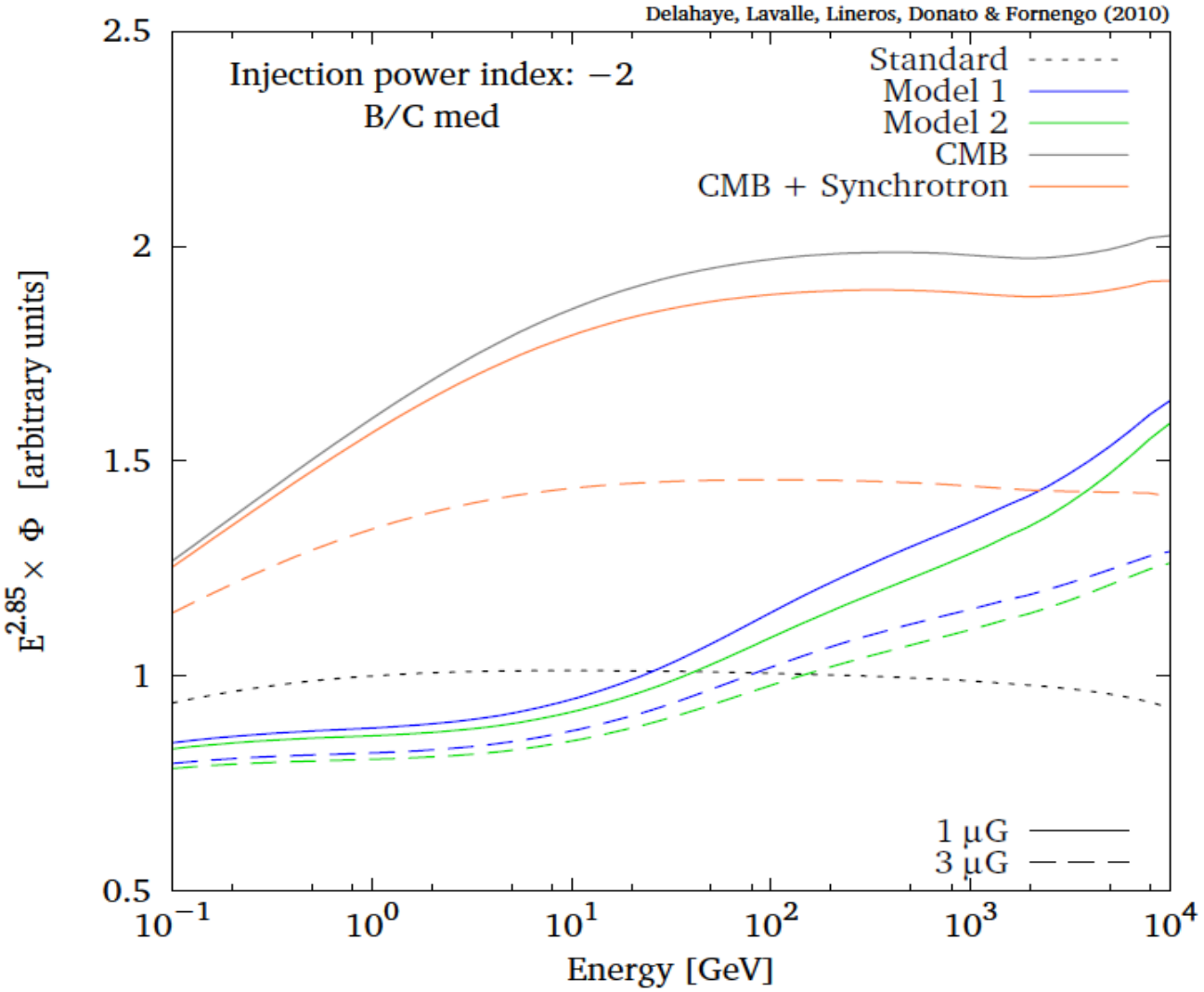


See Porter from GALPROP

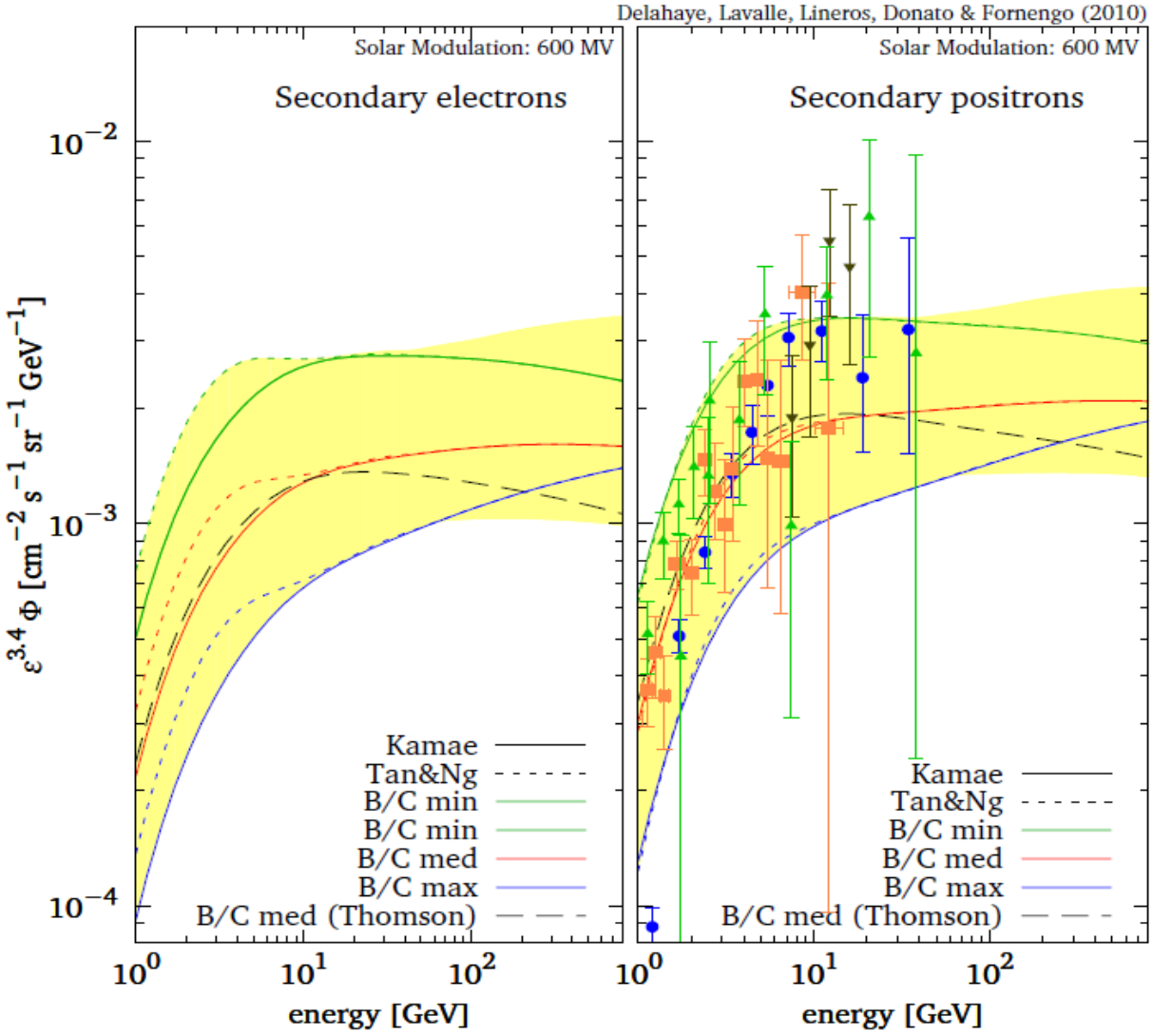
Energy losses



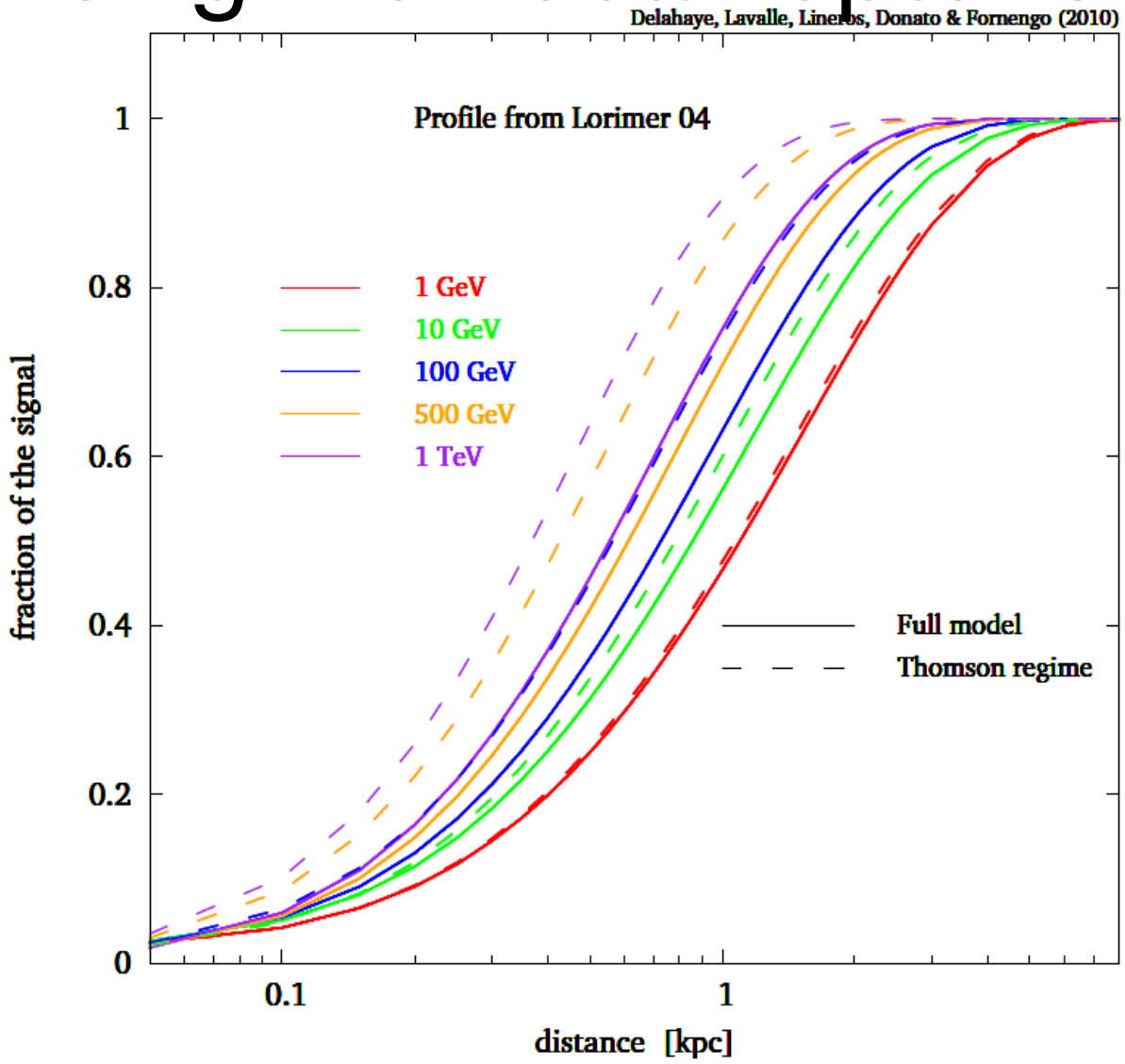
Enery losses



Secondaries



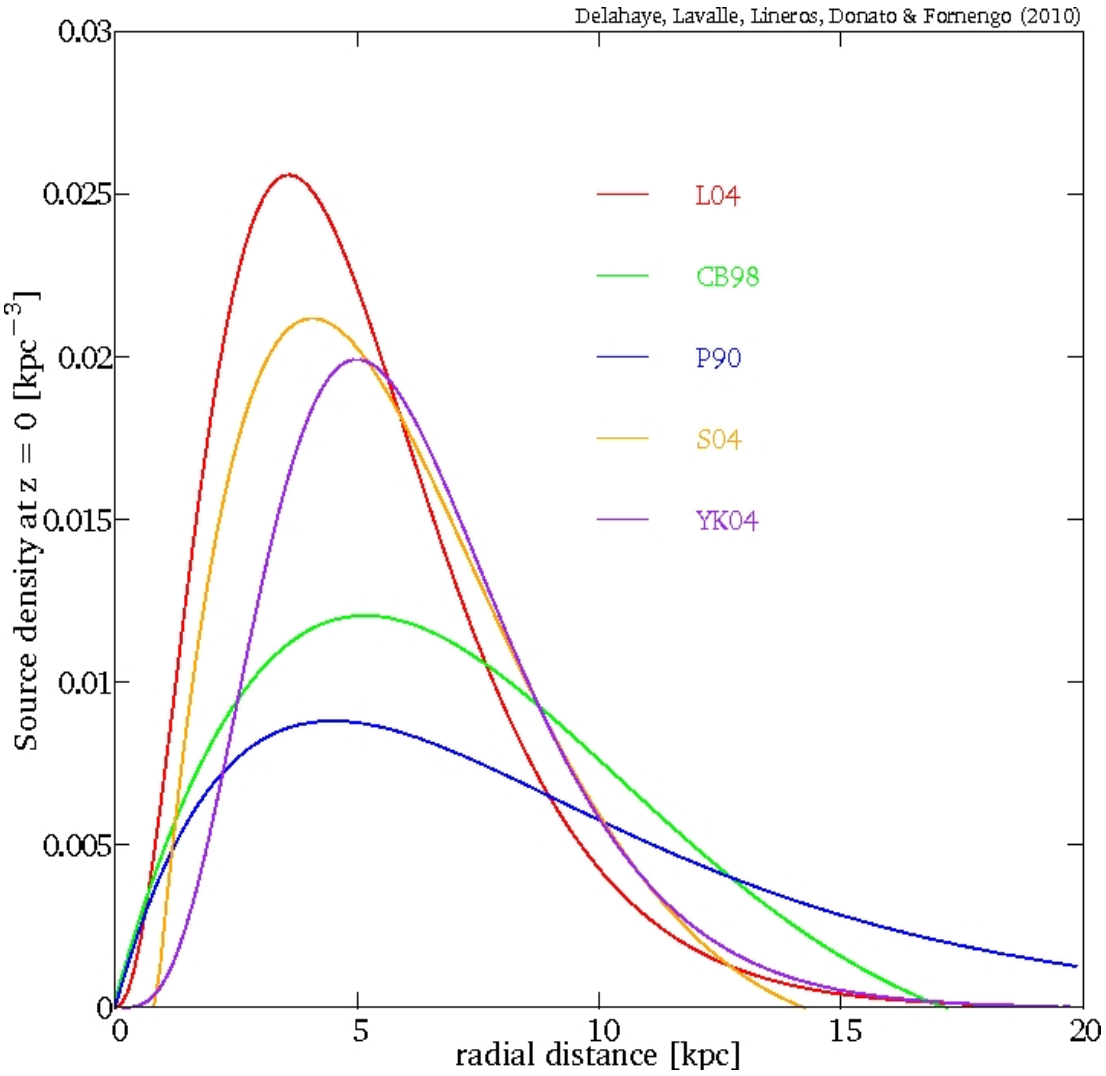
Origin of local leptons



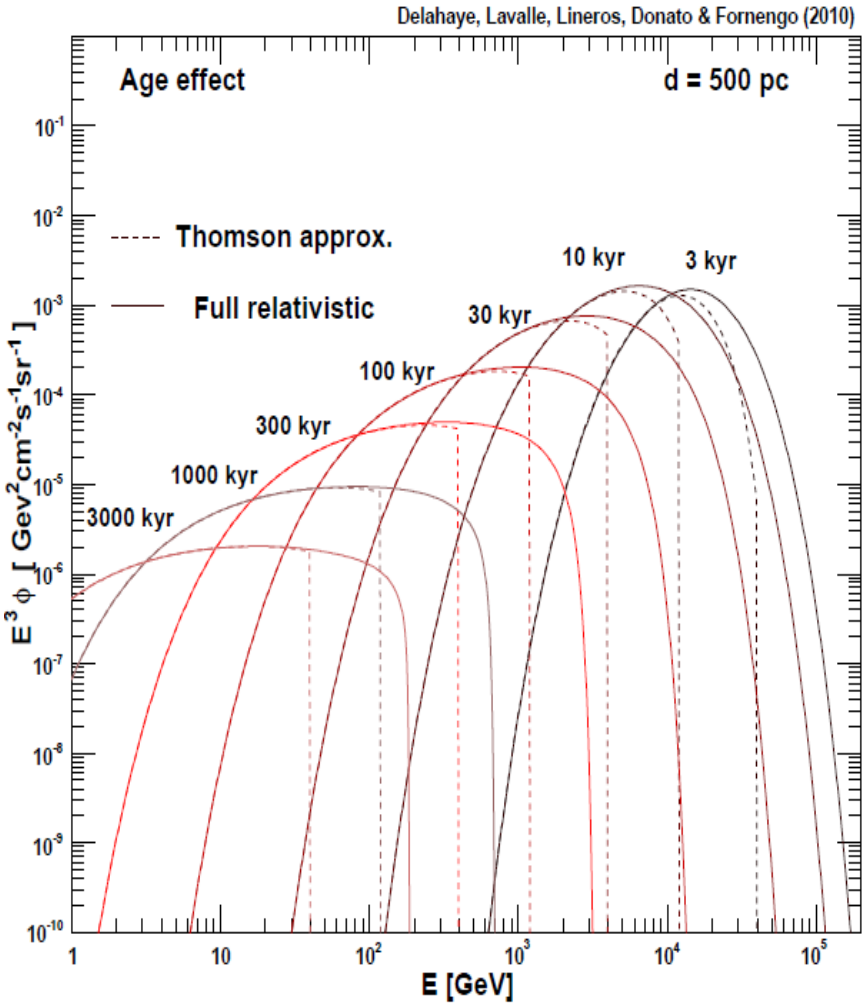
Primaries

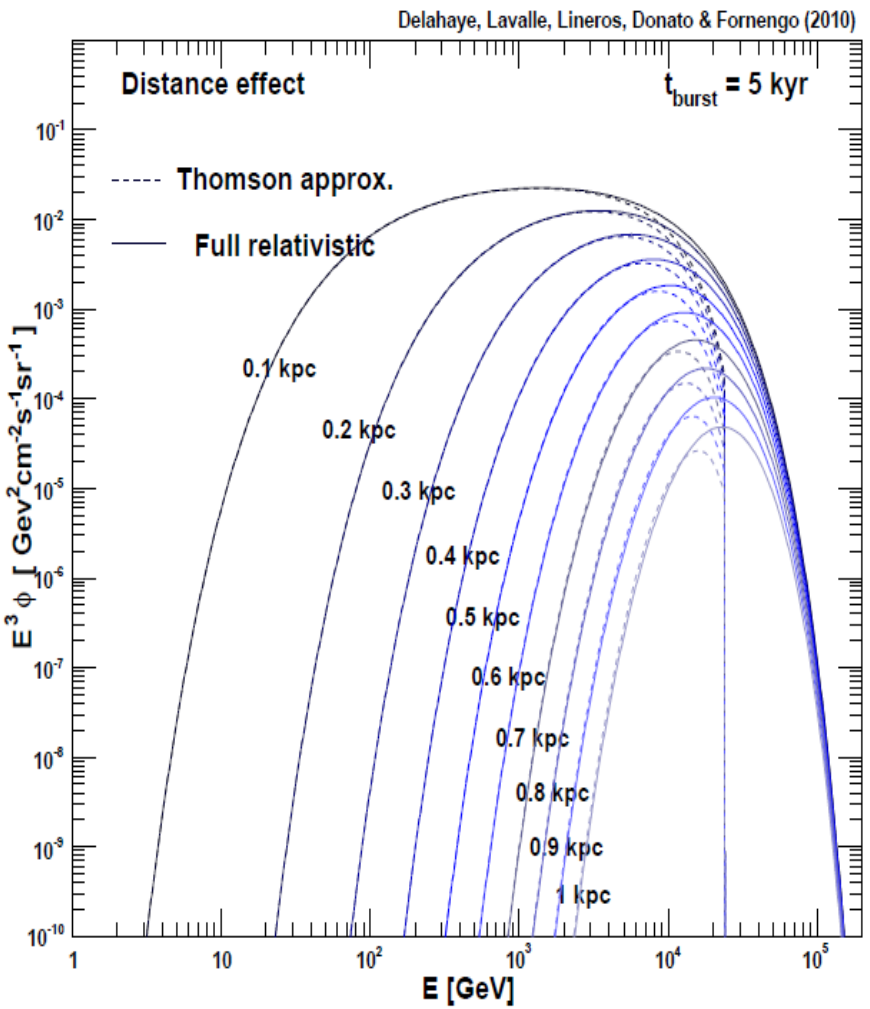
- Astrophysical => c.f. Roberto's talk
  - From smooth far away SNR and pulsars
  - From local SNR and pulsar

Source distribution



Discreteness





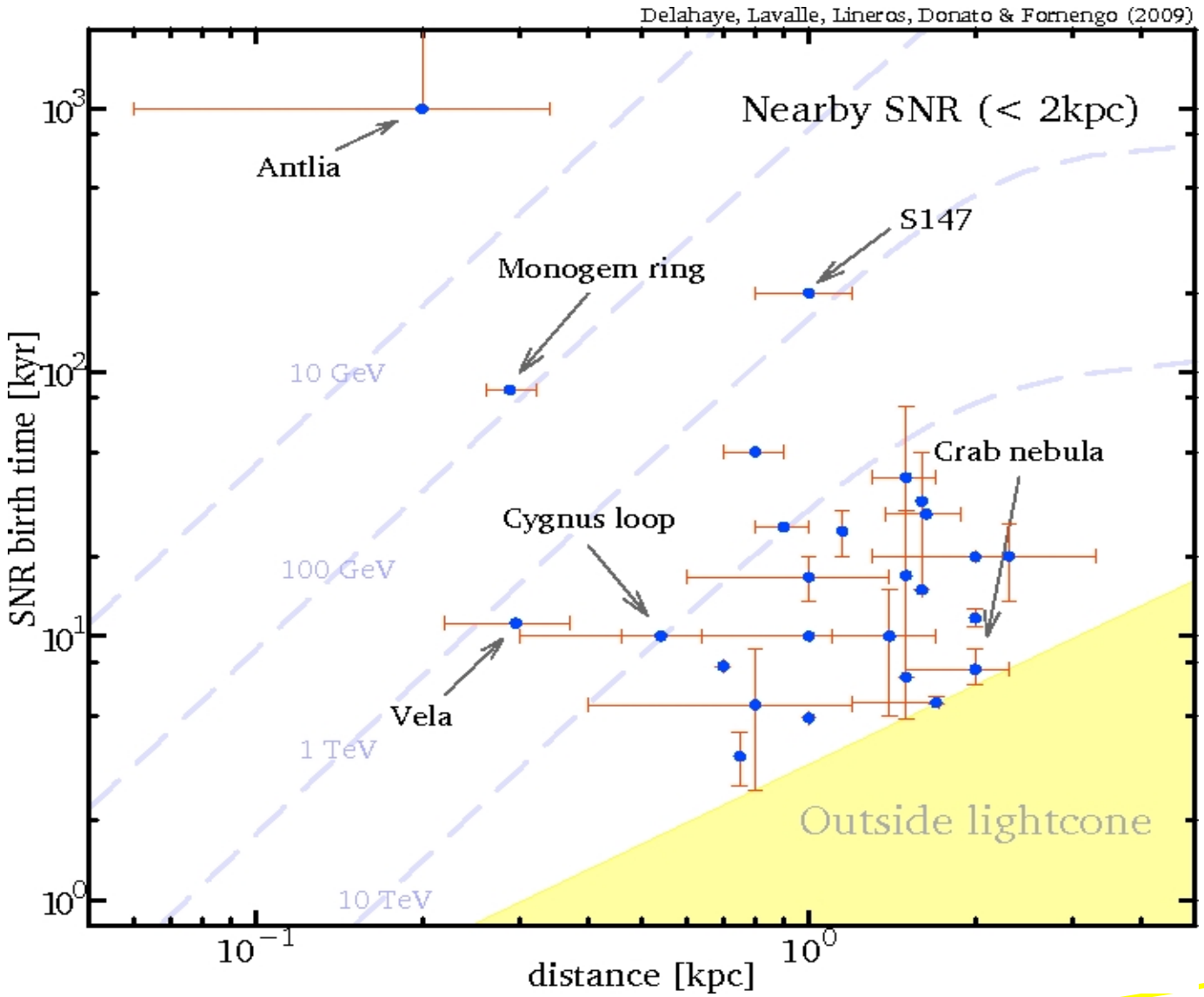
Super Nova Remnant catalogues

- Green catalogue
  http://www.mrao.cam.ac.uk/surveys/snrs/

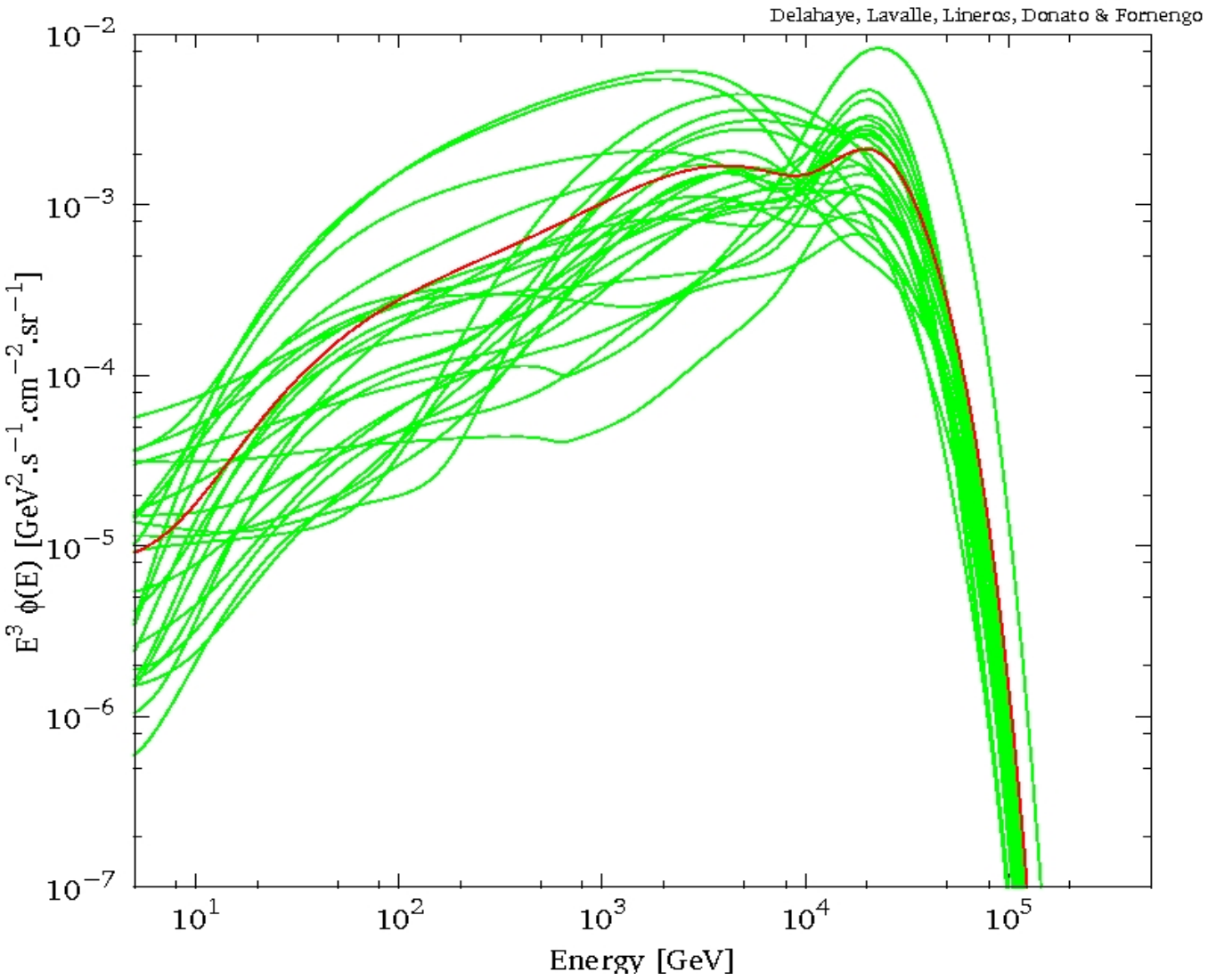
- About 275 known Galactical remnants with: coordinates, distance, luminosity at 1GHz, spectral index.

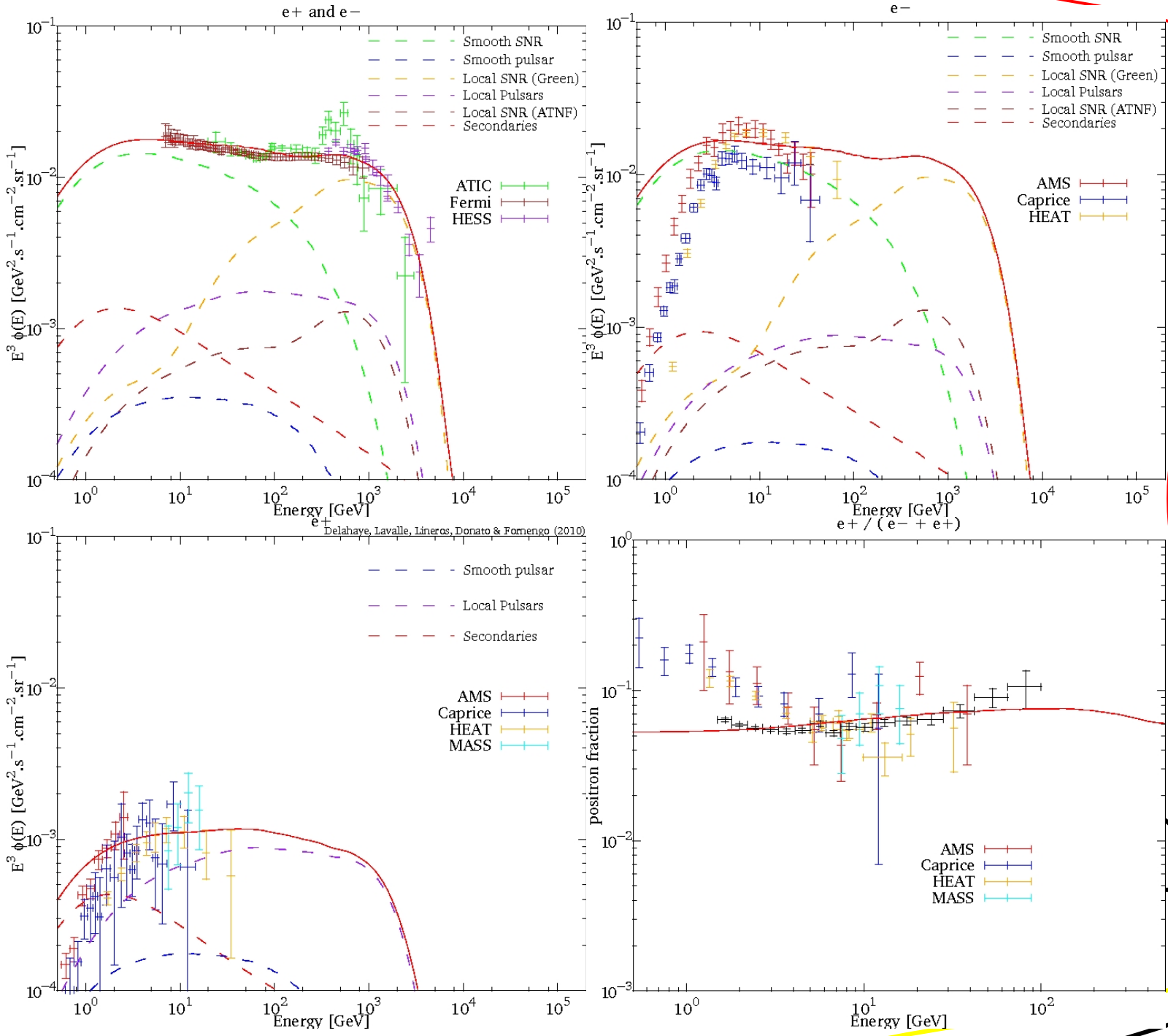
- Some bibliography provides the age.

Local sources



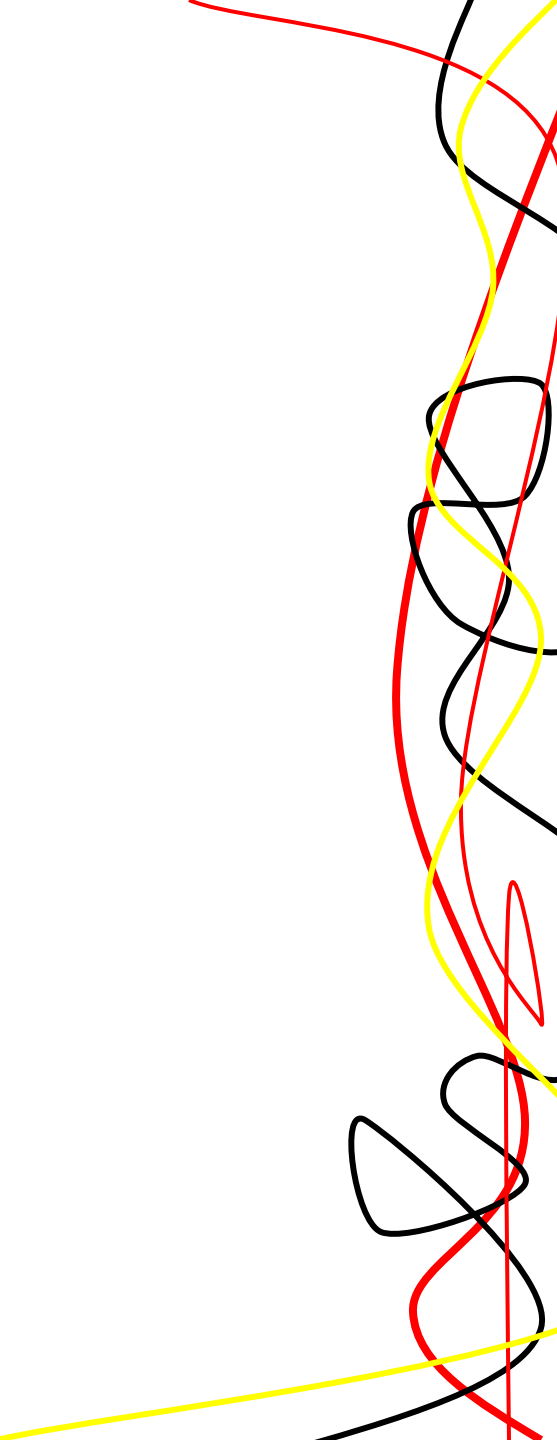
Local sources



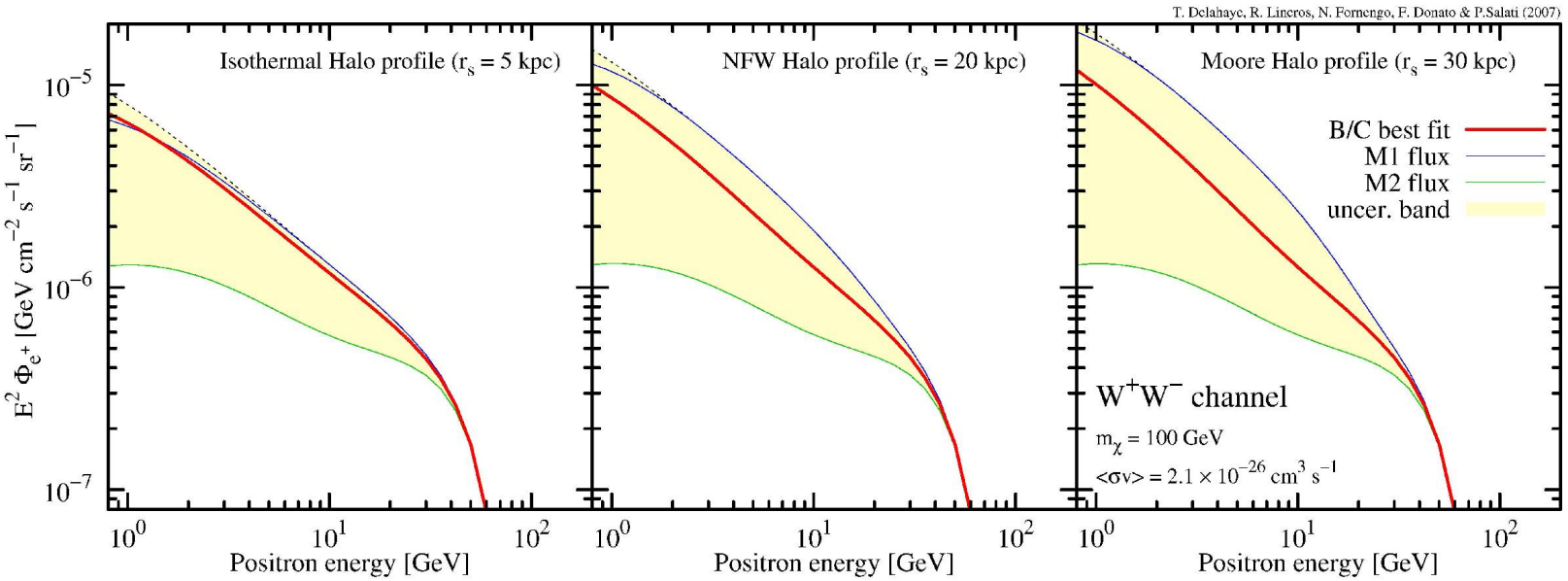

e+ and e−
Smooth SNR
Smooth pulsar
Local SNR (Green)
Local Pulsars
Local SNR (ATNF)
Secondaries
ATIC
Fermi
HESS
E³ ϕ(E) [GeV².s⁻¹.cm⁻².sr⁻¹]
Energy [GeV]
e−
AMS
Caprice
HEAT
e+
Delahaye, Lavalle, Lineros, Donato & Fornengo (2010)
MASS
e+ / (e− + e+)
positron fraction

Primaries

- Dark Matter
  - The usual uncertainties
  - Density profile
  - Local clumps
  - Energy spectrum at emission

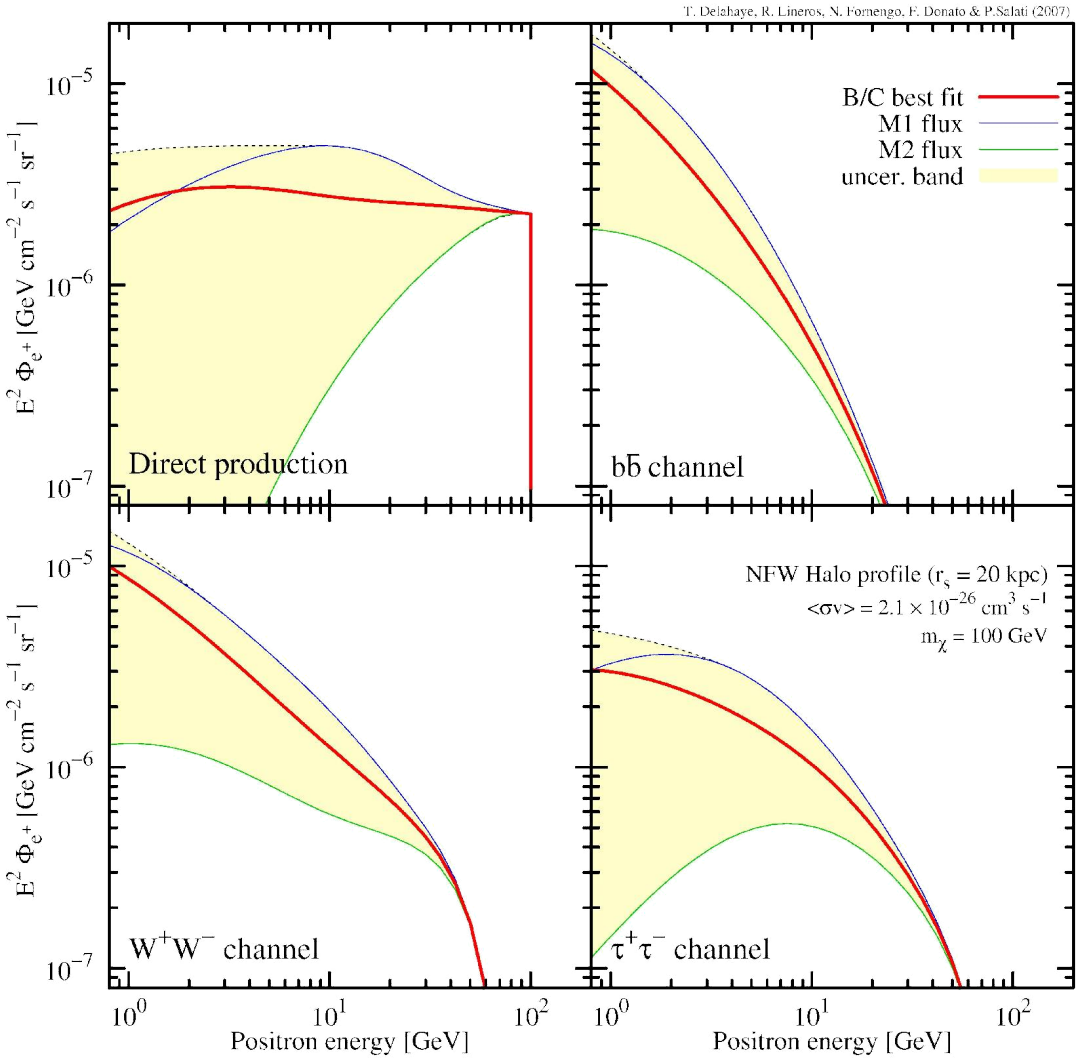


Influence of the halo profile



PRD77 (2008) 063527

Influence of the channel



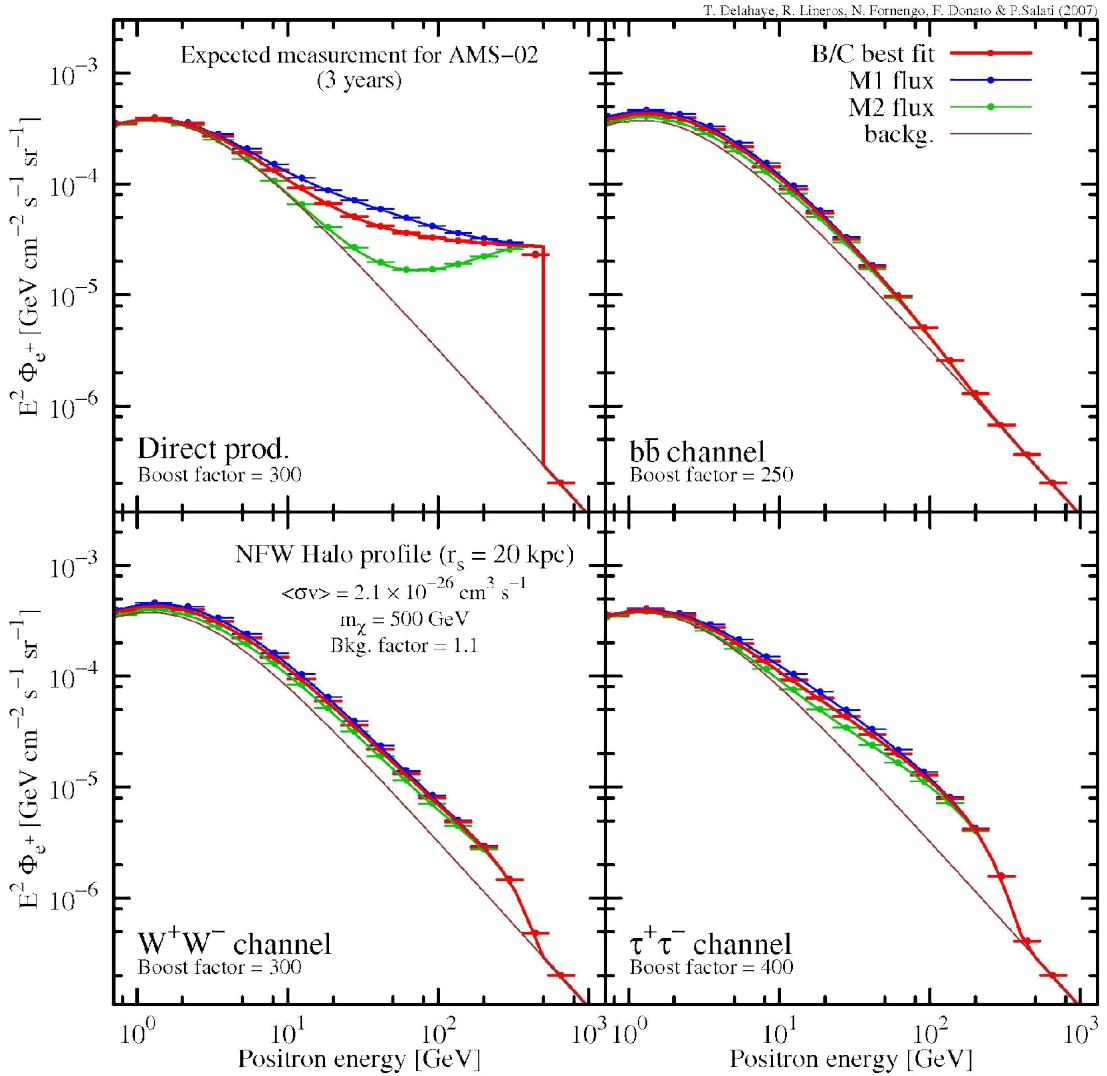
PRD77 (2008) 063527

Total flux

Secondaries from

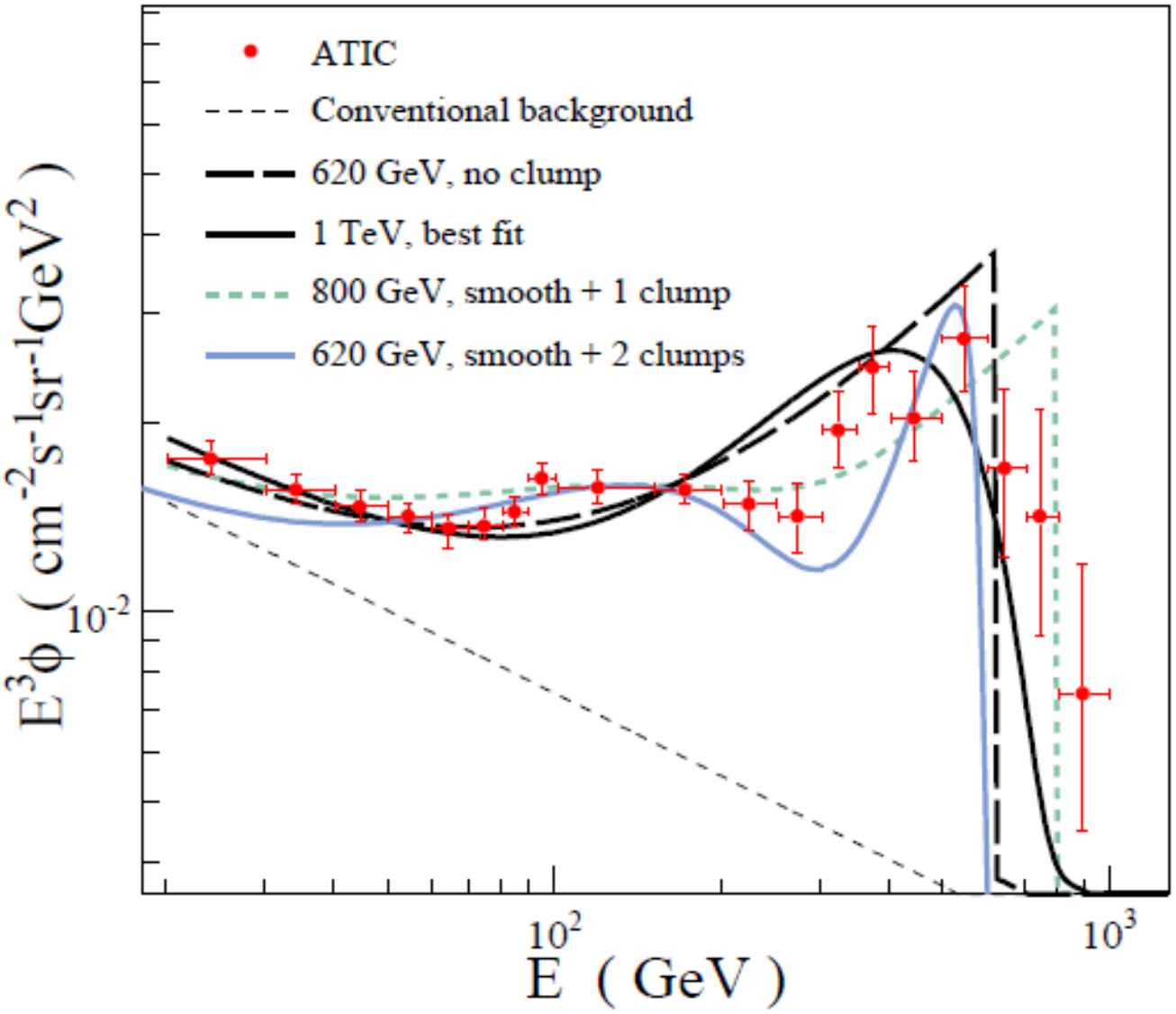
GALPROP APJ 493 (1998) 694

PRD77 (2008) 063527



Clumps

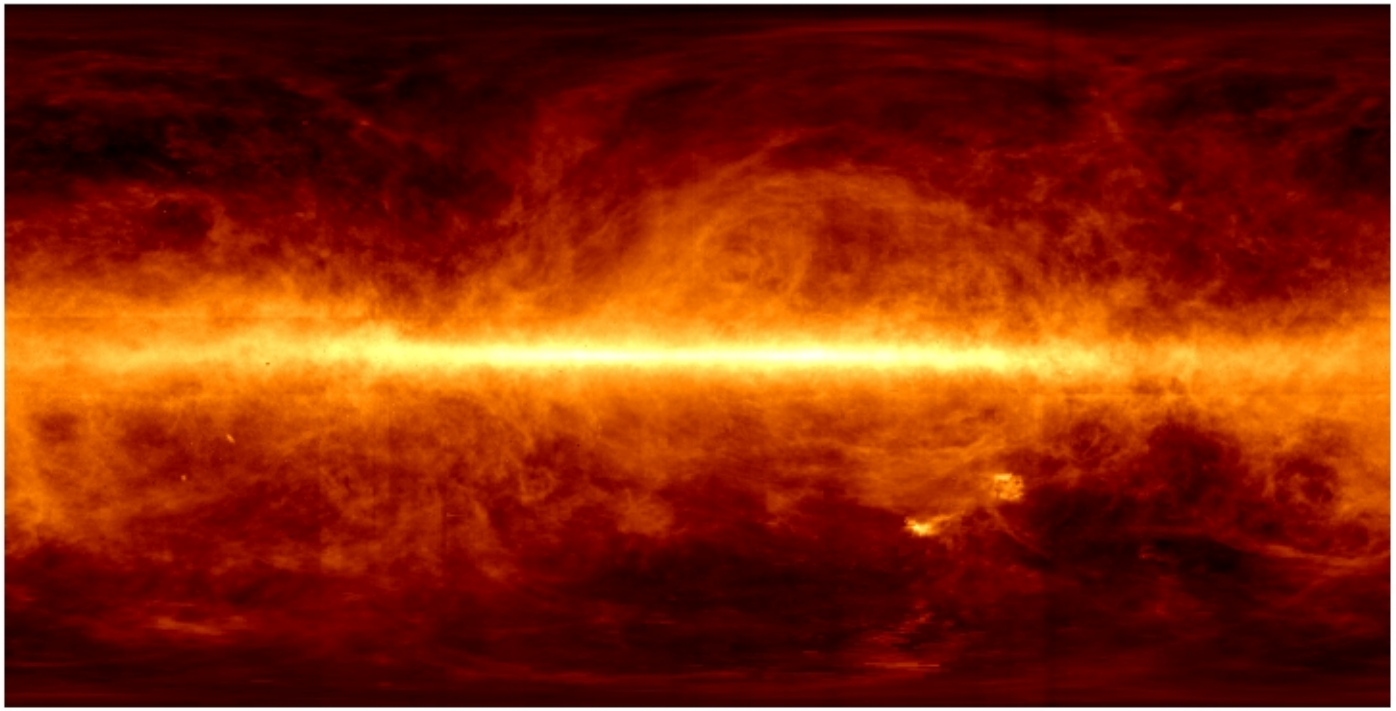
Brun, T.D, Diemand, Profumo & Salati PRD 2009



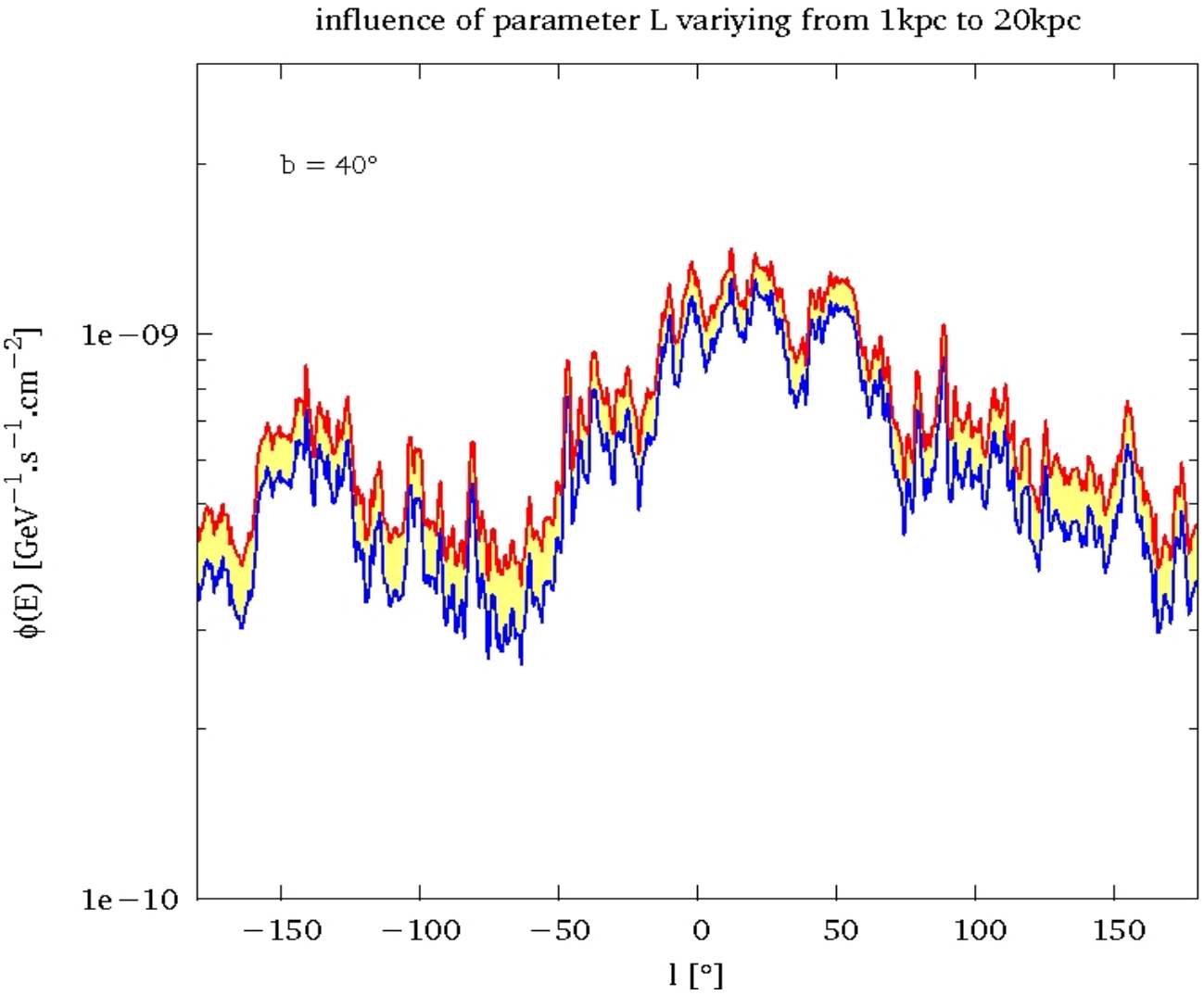
Gamma rays

- π_0 decay => p and gas
- Bremsstrahlung => e and gas
- Inverse Compton => e and ISRF

Pion decay



Pion decay


influence of parameter L variying from 1kpc to 20kpc
b = 40°
1e−09
1e−10
ϕ(E) [GeV^{-1}.s^{-1}.cm^{-2}]
−150
−100
−50
0
50
100
150
l [°]

Pros and cons of analytical resolution

- Pros
  - Allows MCMC
  - Local bubble
  - Sizing uncertainties
  - Convection AND reacceleration
- Cons
  - Distribution of gas
  - Magnetic fields
  - ISRF

Conclusions

- There is a standard paradigm for Galactic Cosmic Rays,

  BUT

  there is NO standard model.

Conclusions

- Uncertainties come from
  - Propagation parameters
  - Sources
  - Cross sections