

# Galactic cosmic rays propagation and dark matter indirect detection

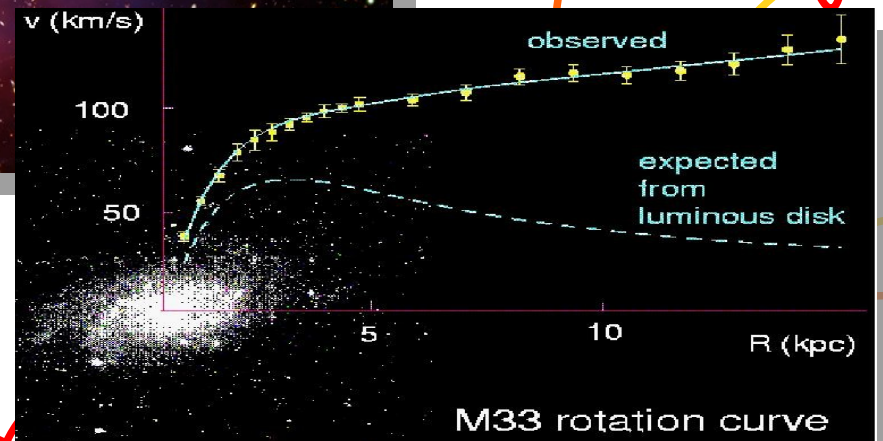
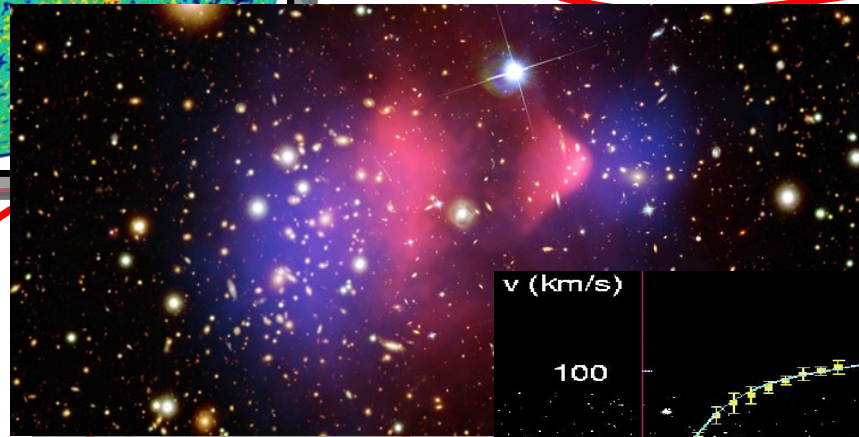
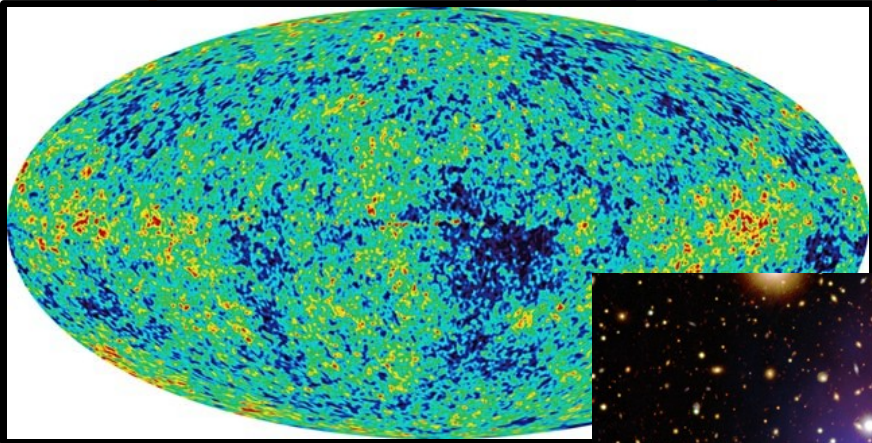
Timur Delahaye



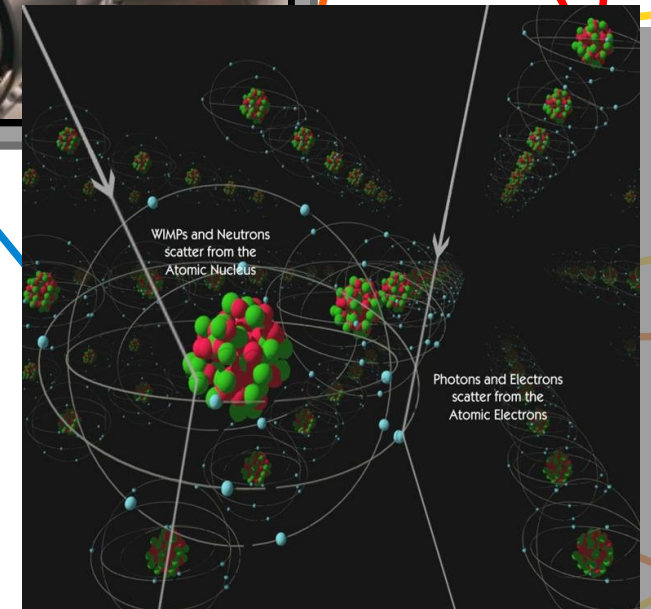
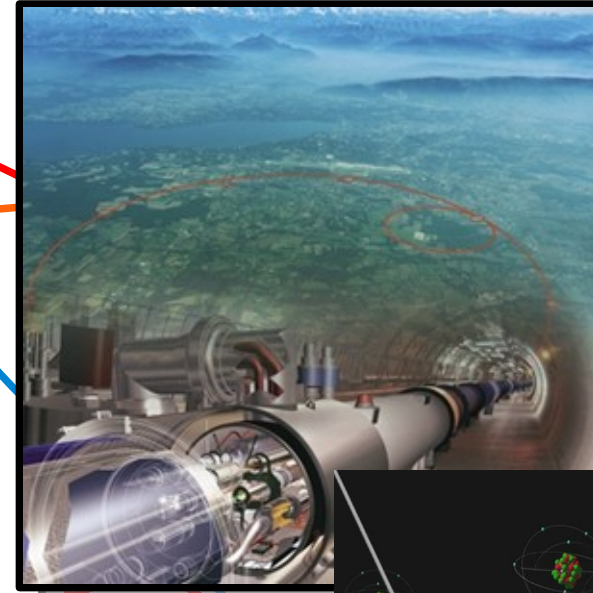
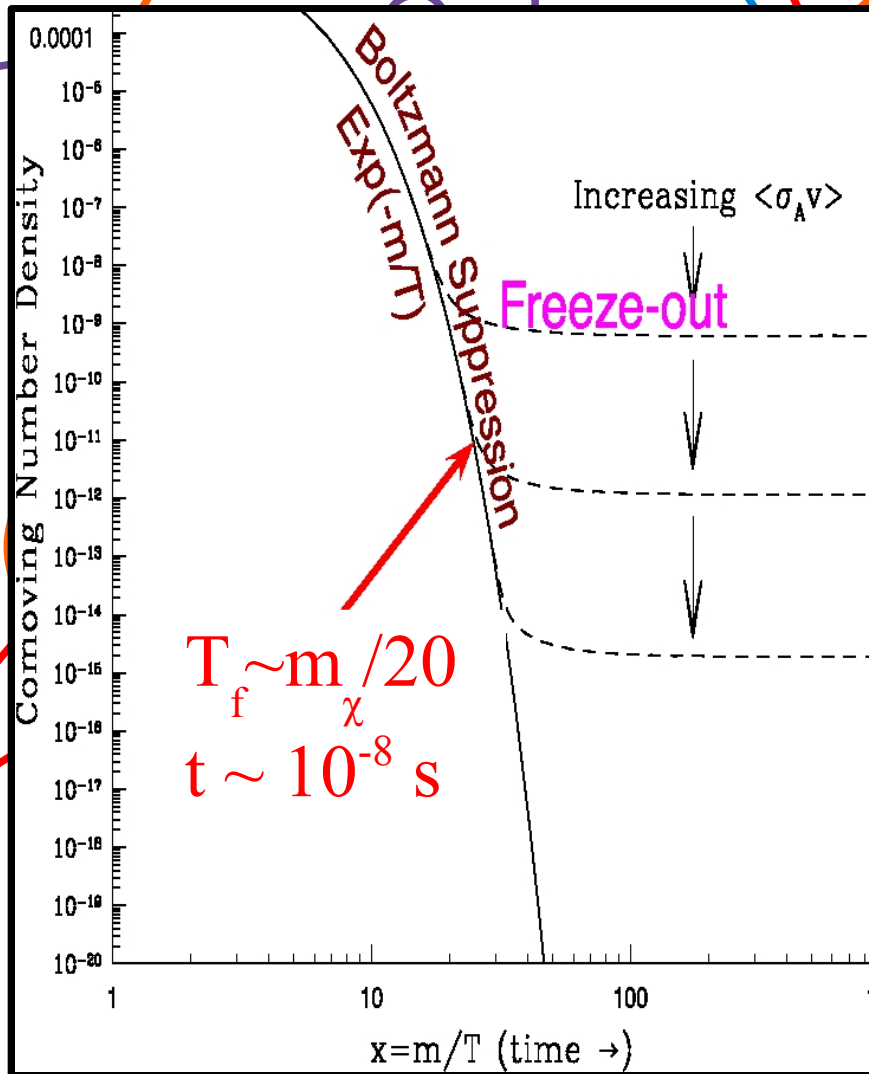
IDAPP



# Dark matter



# Dark matter detection



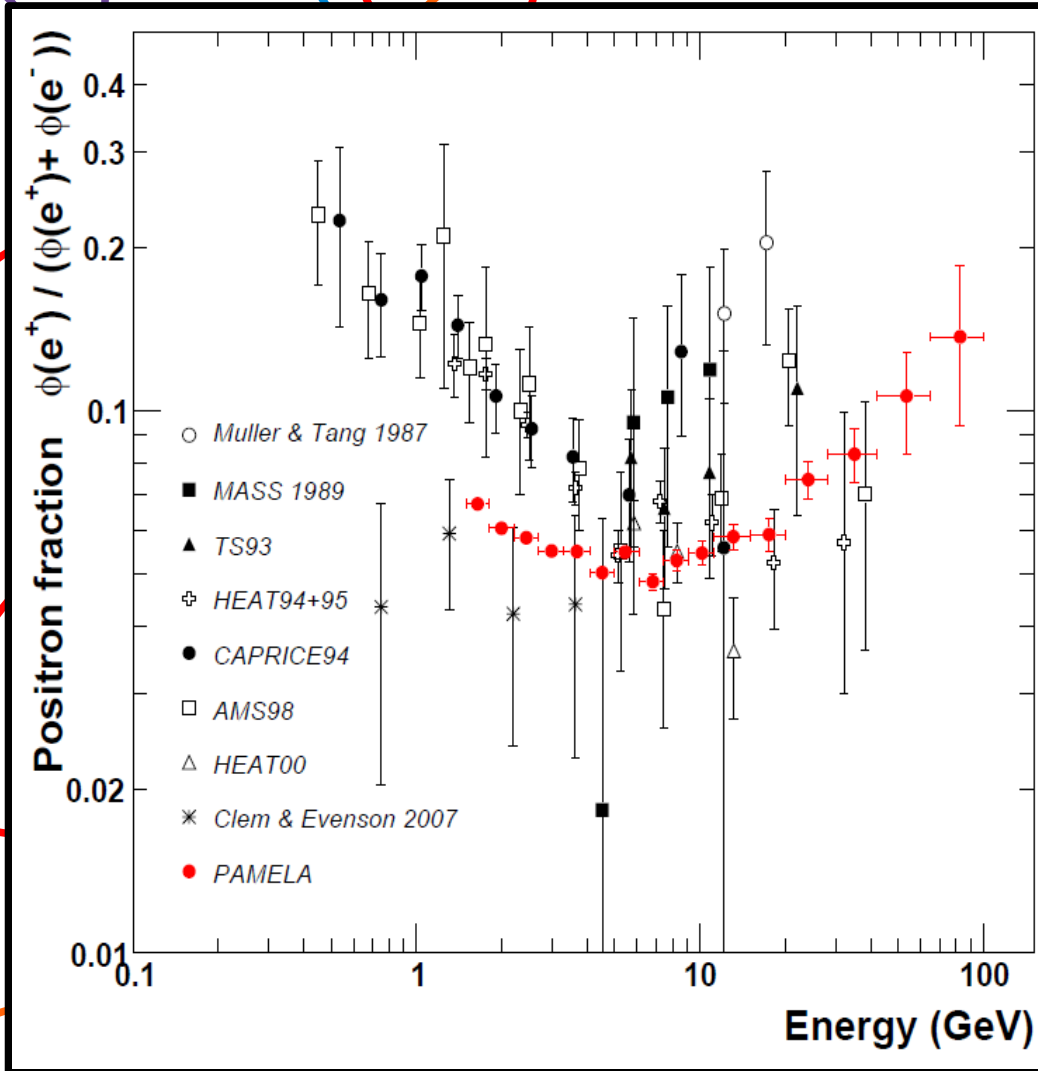
# Outline

- Recent data
- Cosmic ray propagation
- Electrons and positron
- $\gamma$  rays

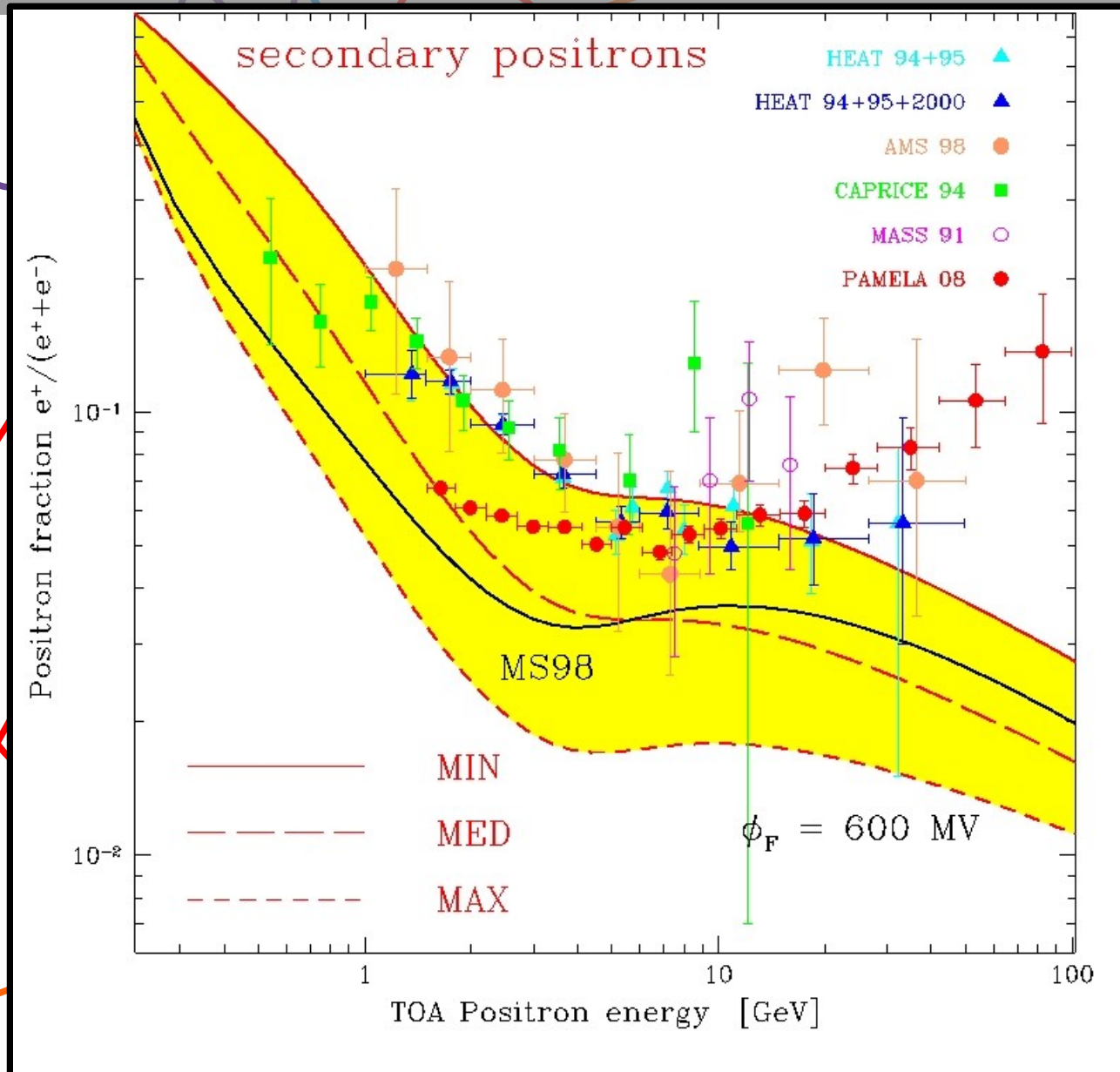


# Pamela

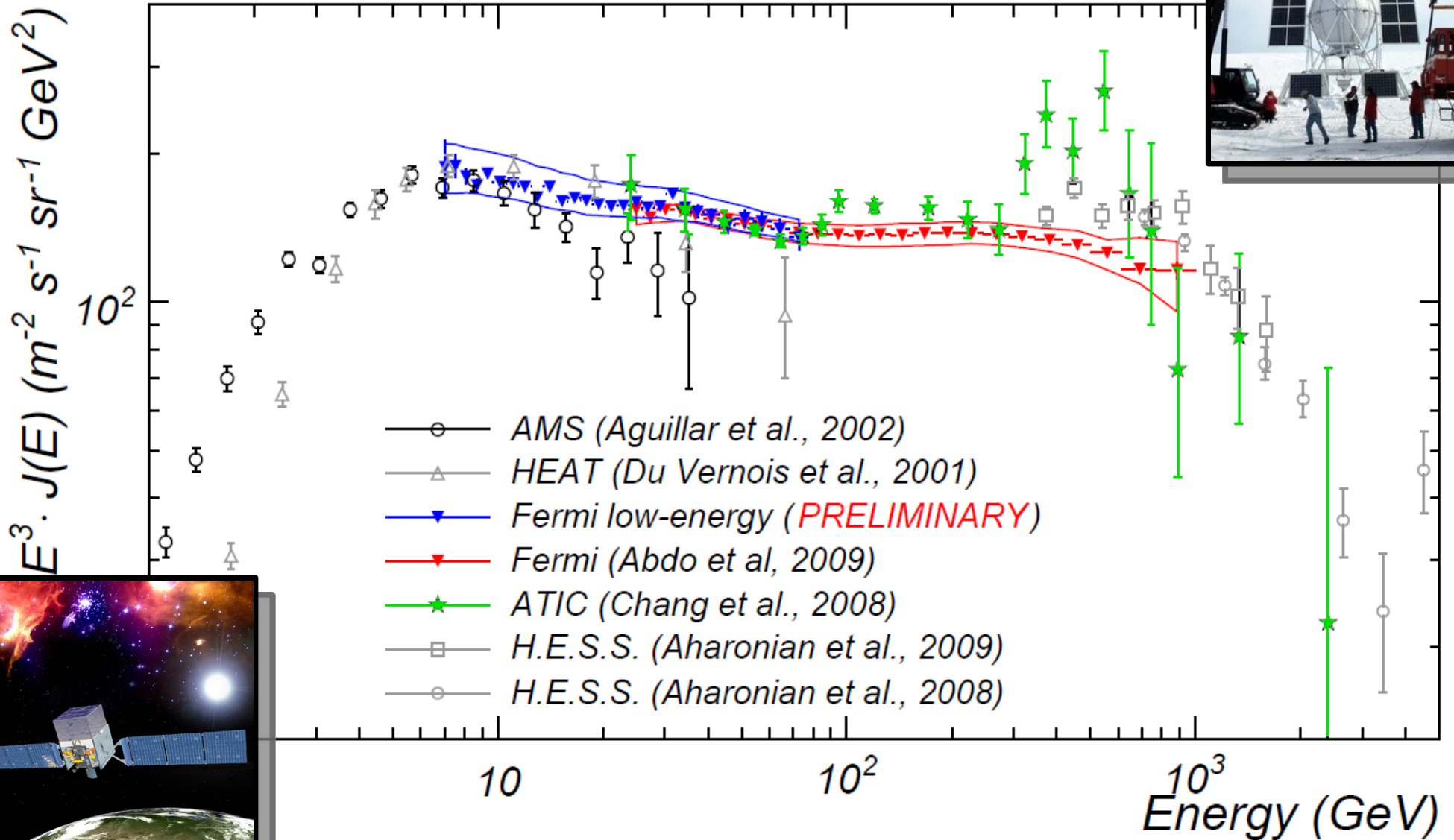
Adriani et alii  
Nature 2009



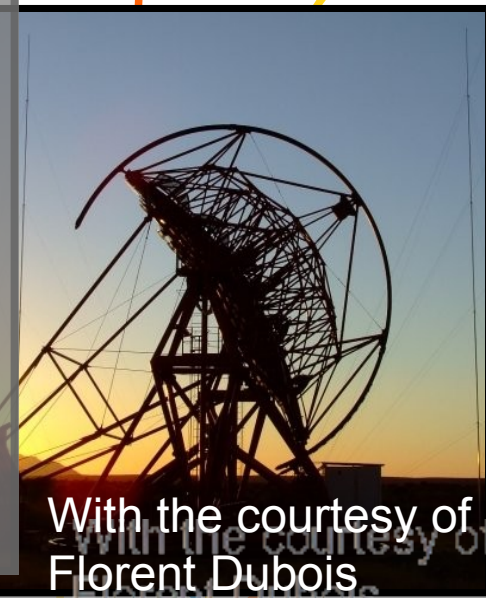
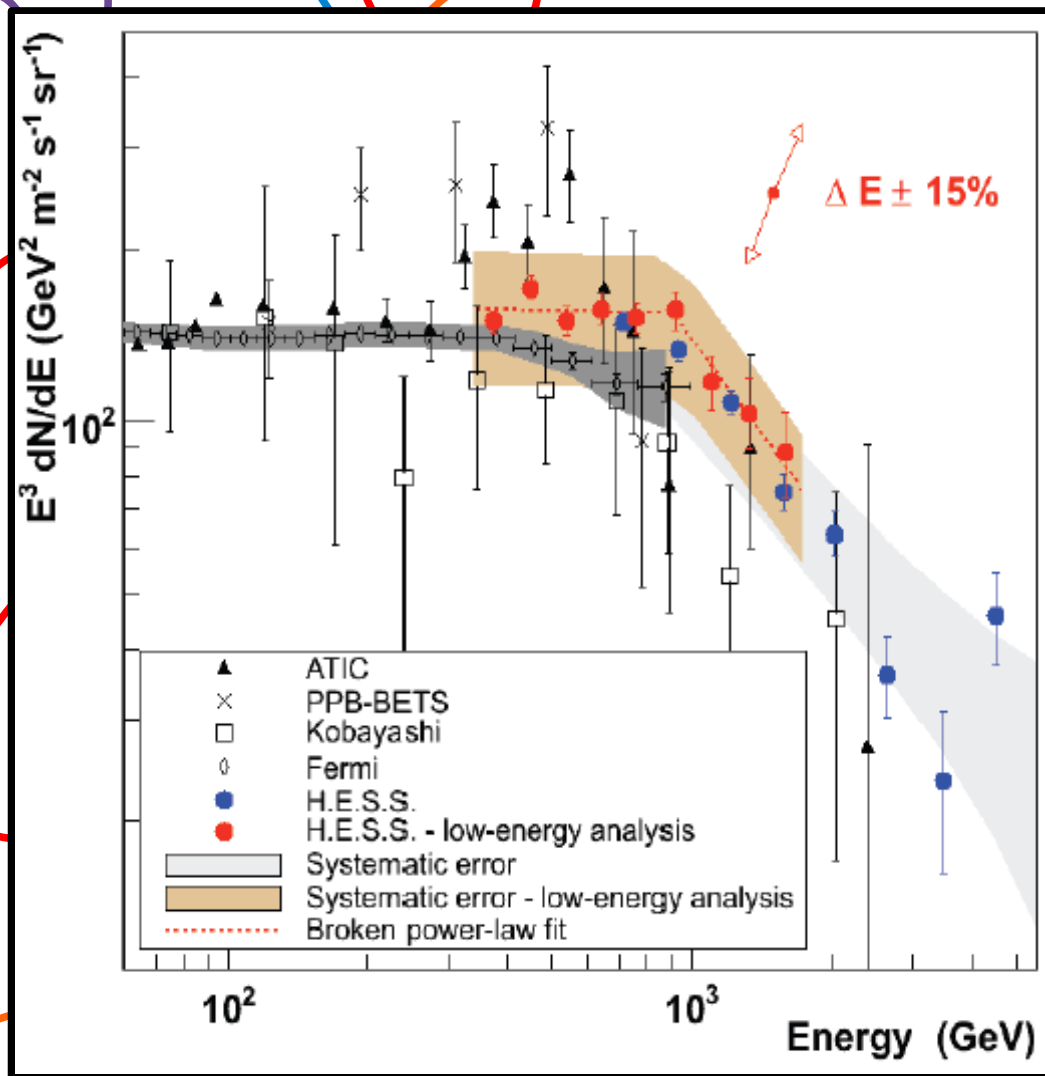
# Former expectations



# Fermi & ATIC



# HESS

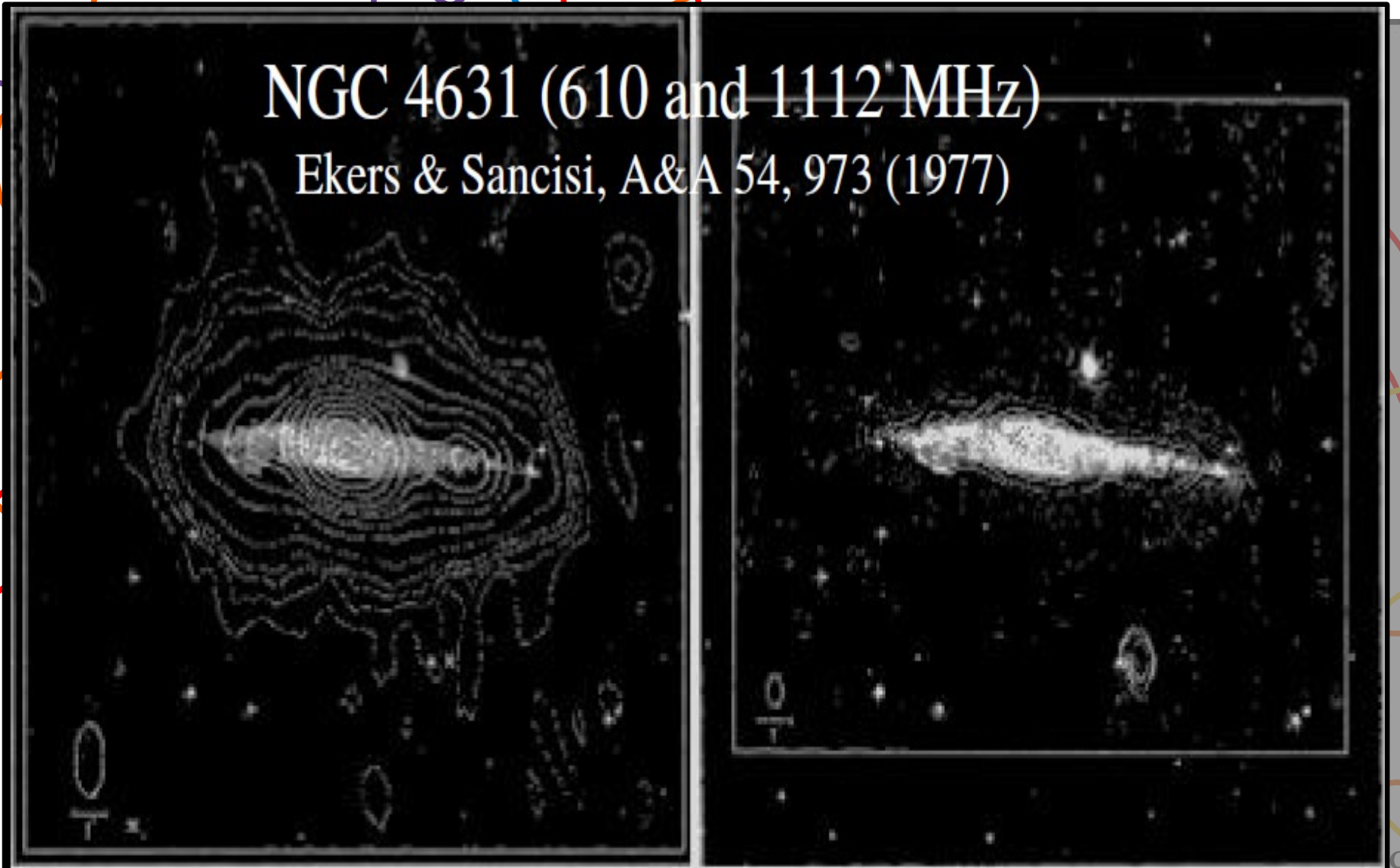




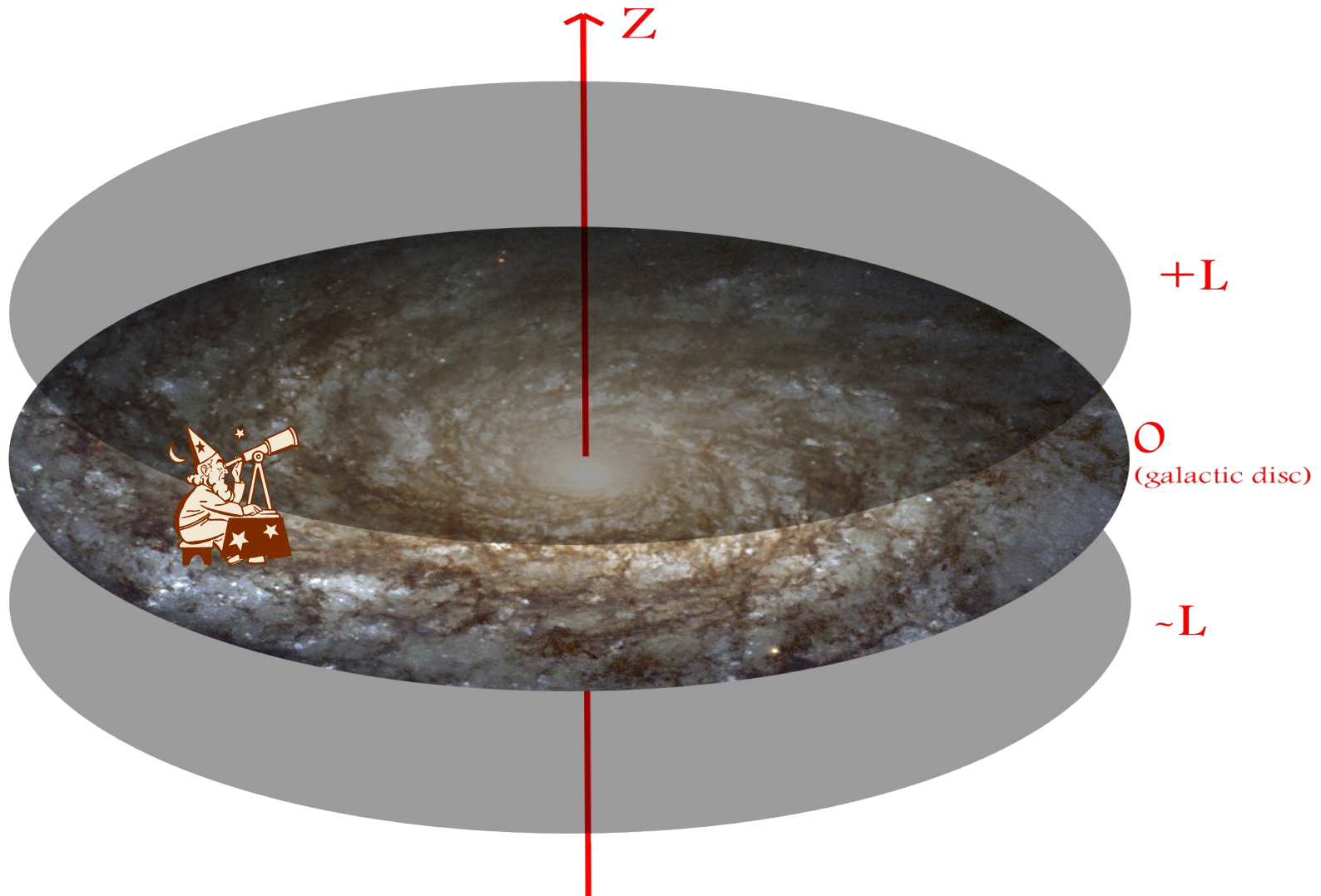
# Cosmic ray propagation

NGC 4631 (610 and 1112 MHz)

Ekers & Sancisi, A&A 54, 973 (1977)

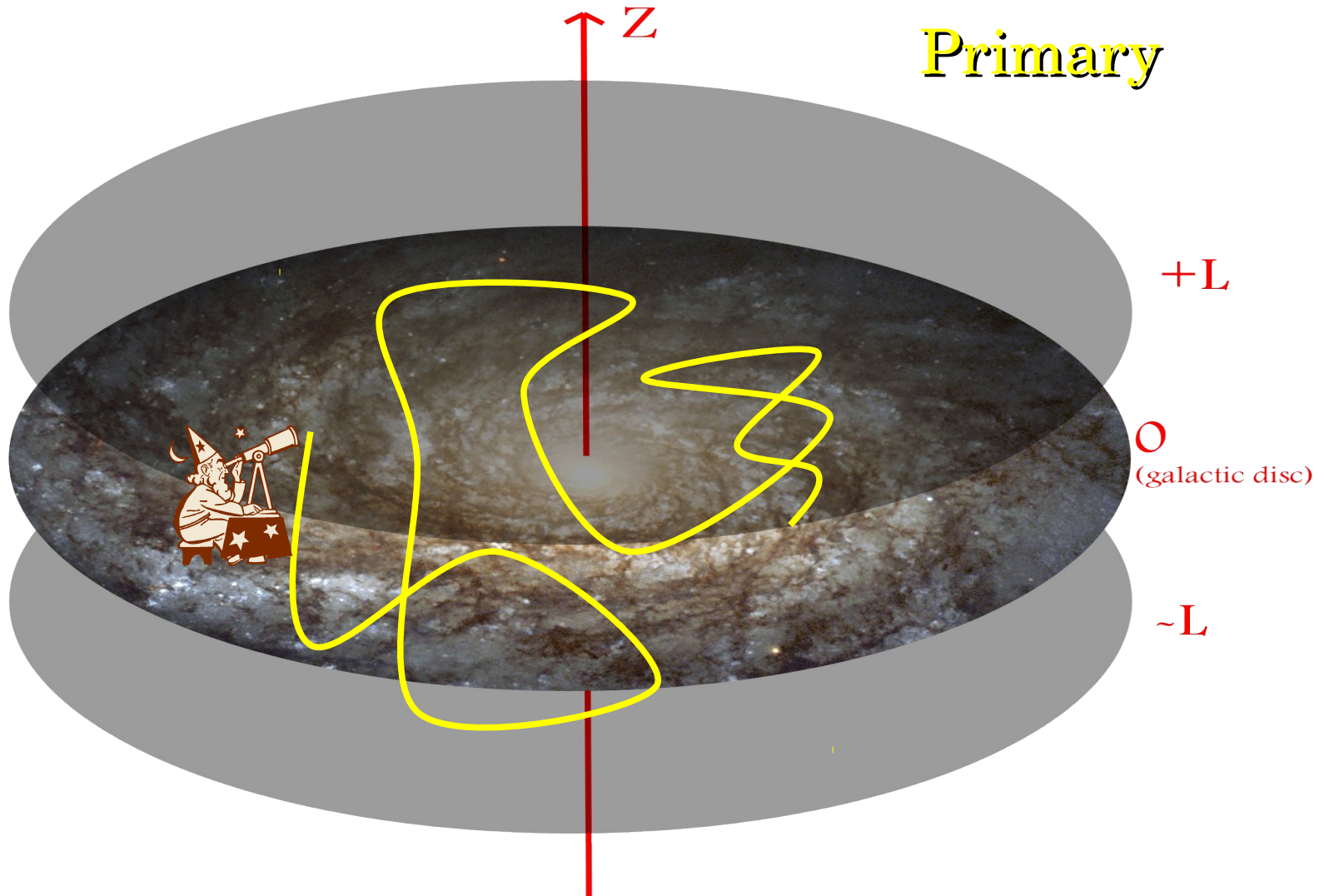


# Cosmic ray propagation



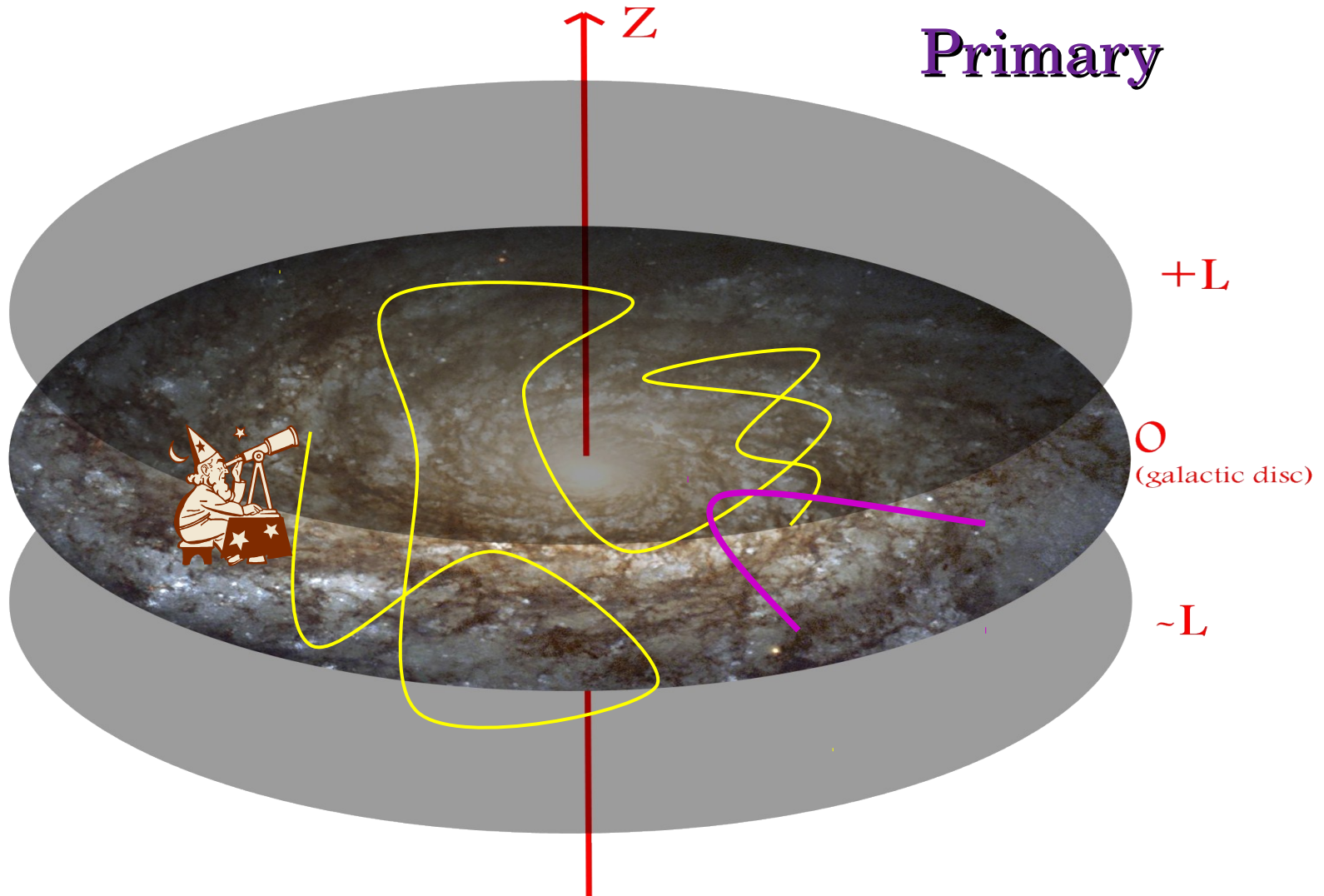
# Cosmic ray propagation

Primary



# Cosmic ray propagation

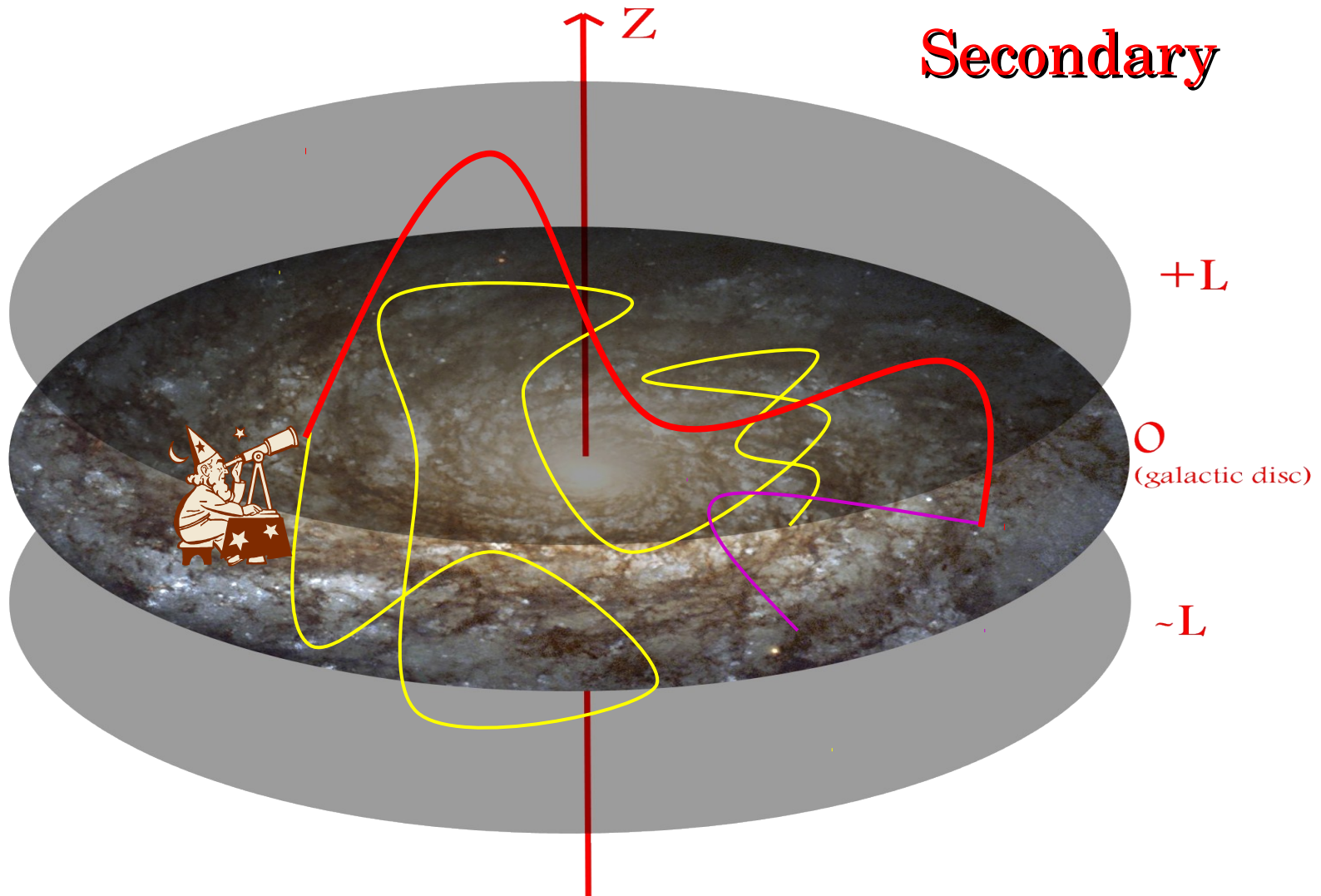
Primary





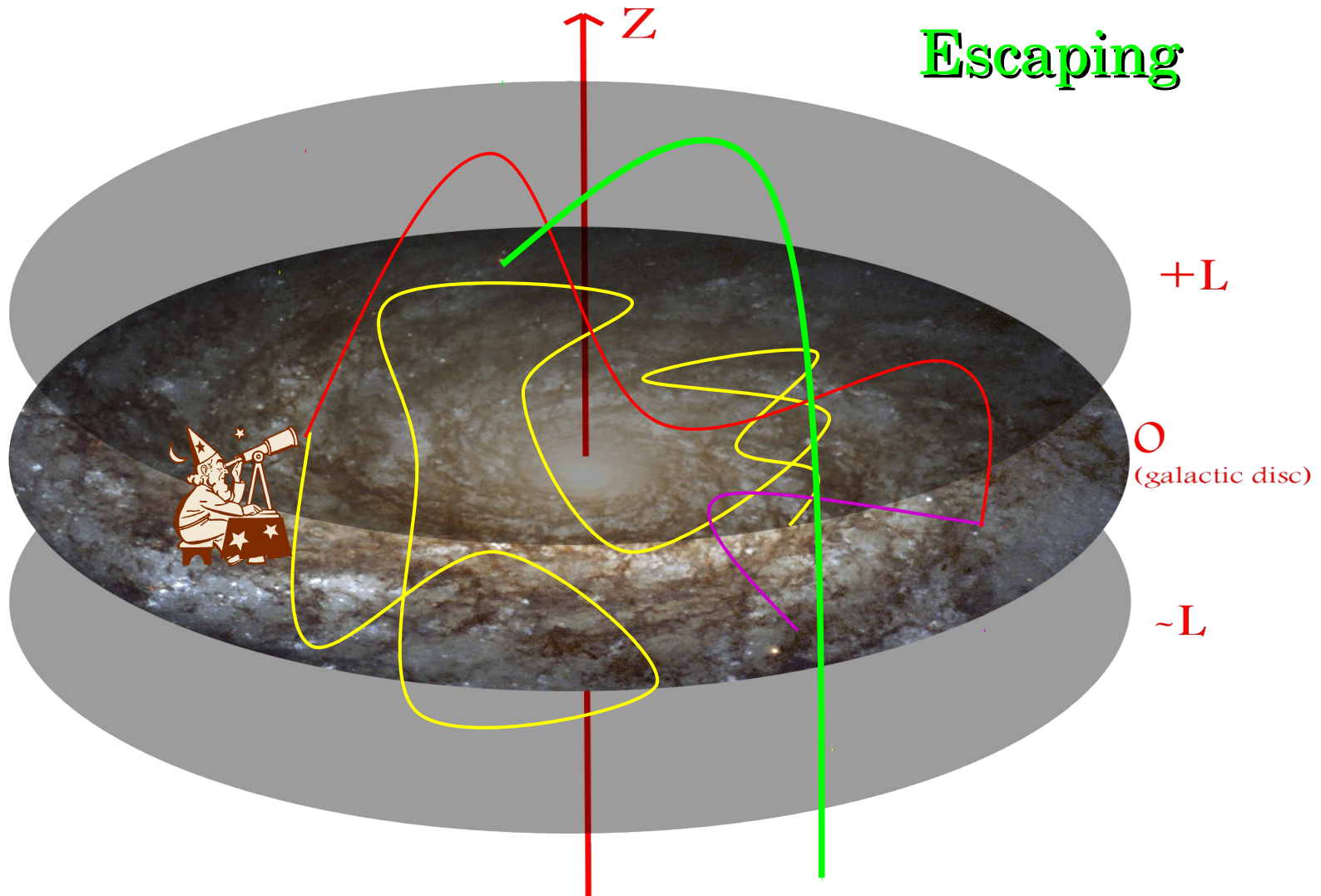
# Cosmic ray propagation

**Secondary**



# Cosmic ray propagation

Escaping



# Cosmic ray propagation

$$\Psi(\vec{x}, E, t) = \frac{d^4 N}{d^3 \vec{x} dE}$$

$$\partial_t \Psi + \partial_\mu J^\mu = Q$$

$$\vec{J} = \vec{V}_c \Psi - K \vec{\nabla} \Psi$$

$$J_E = b_{\text{loss}} \Psi - D_{EE} \partial_E \Psi$$

# Cosmic ray propagation

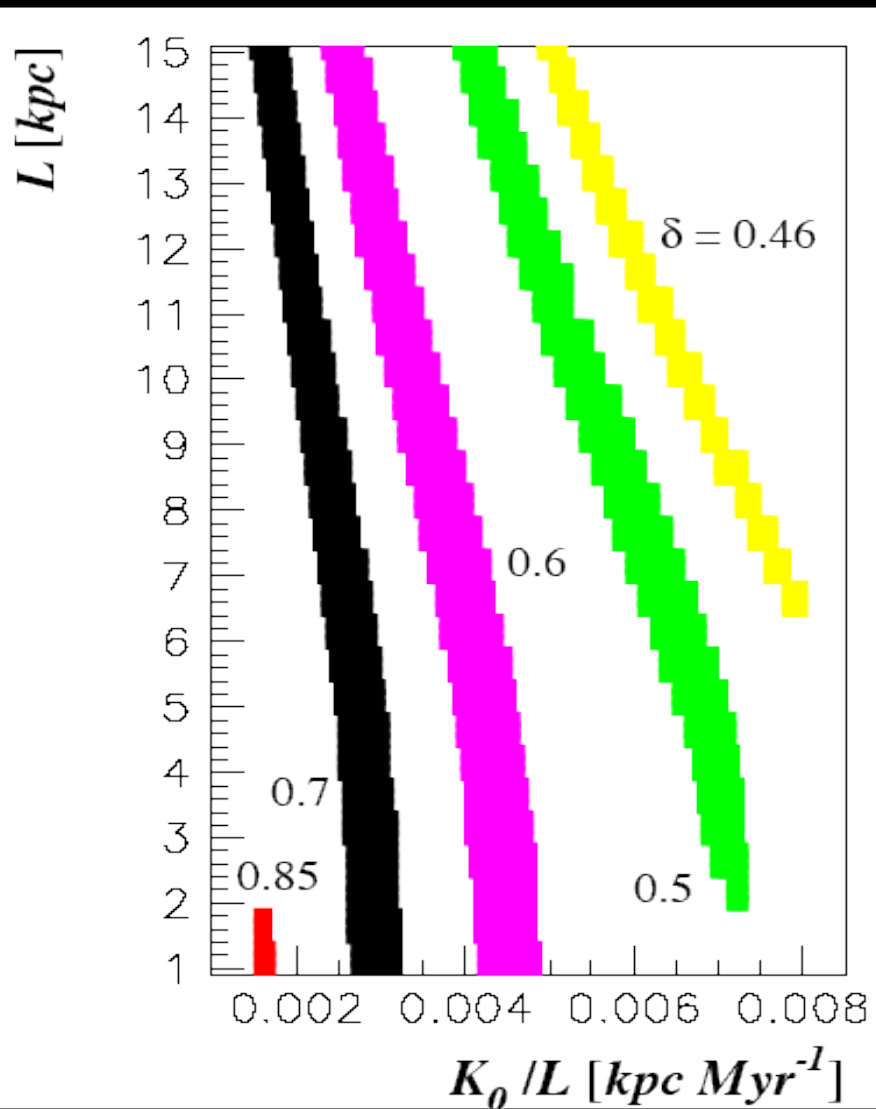
$$\partial_t \Psi - \vec{\nabla} \cdot (K \vec{\nabla} \Psi - \vec{V}_c \Psi) + \partial_E (b_{loss} \Psi - D_{EE} \partial_E \Psi) = Q(\vec{x}, E, t)$$

+ boundary conditions



# Diffusion parameters

Iso- $\chi^2$  contours for B/C ( $\chi^2 < 40$ )



Maurin et alii  
ApJ 2001

# Energy losses

Adiabatic expansion

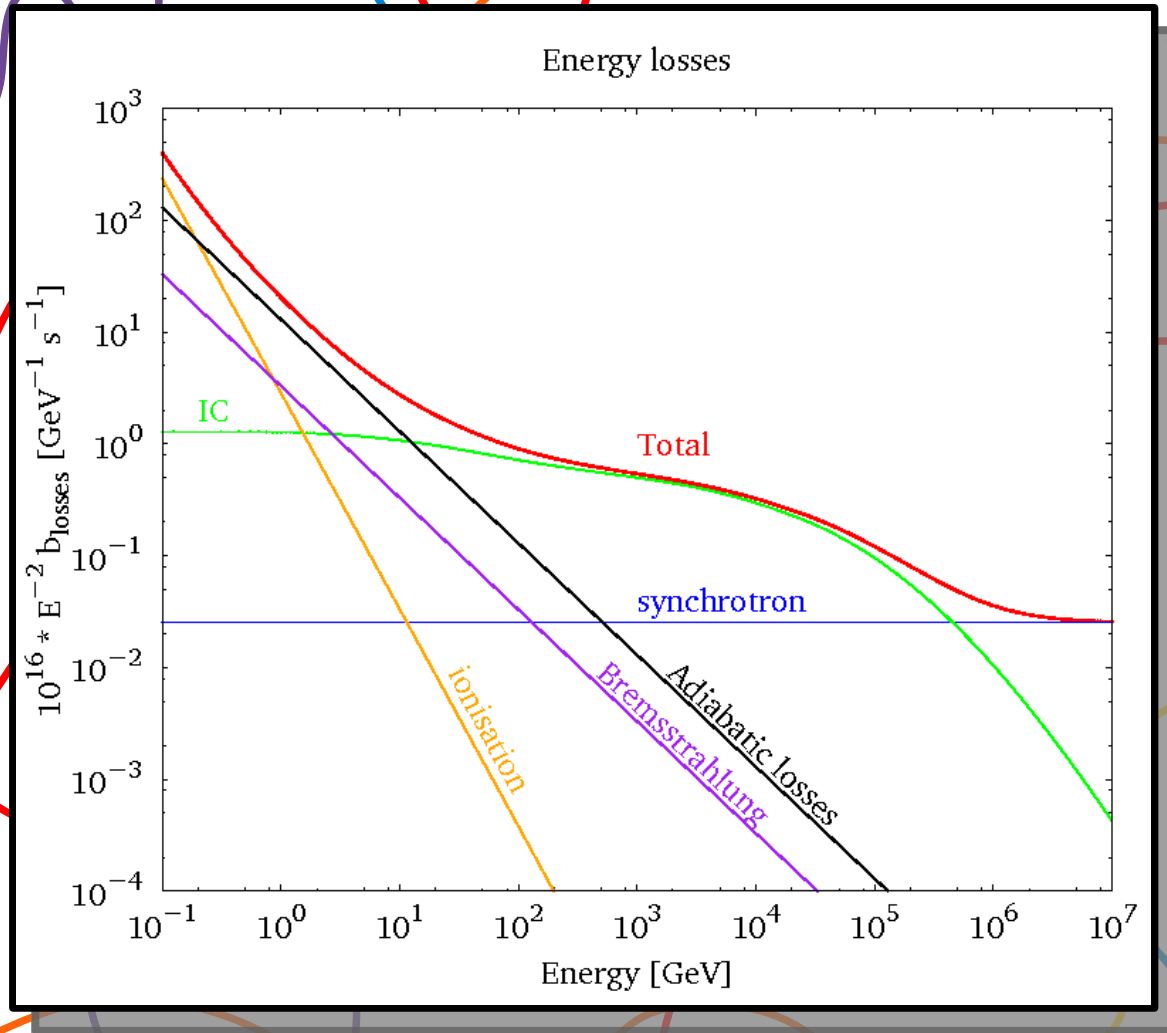
Bremsstrahlung

Inverse Compton

Ionisation

Synchrotron

# Energy losses

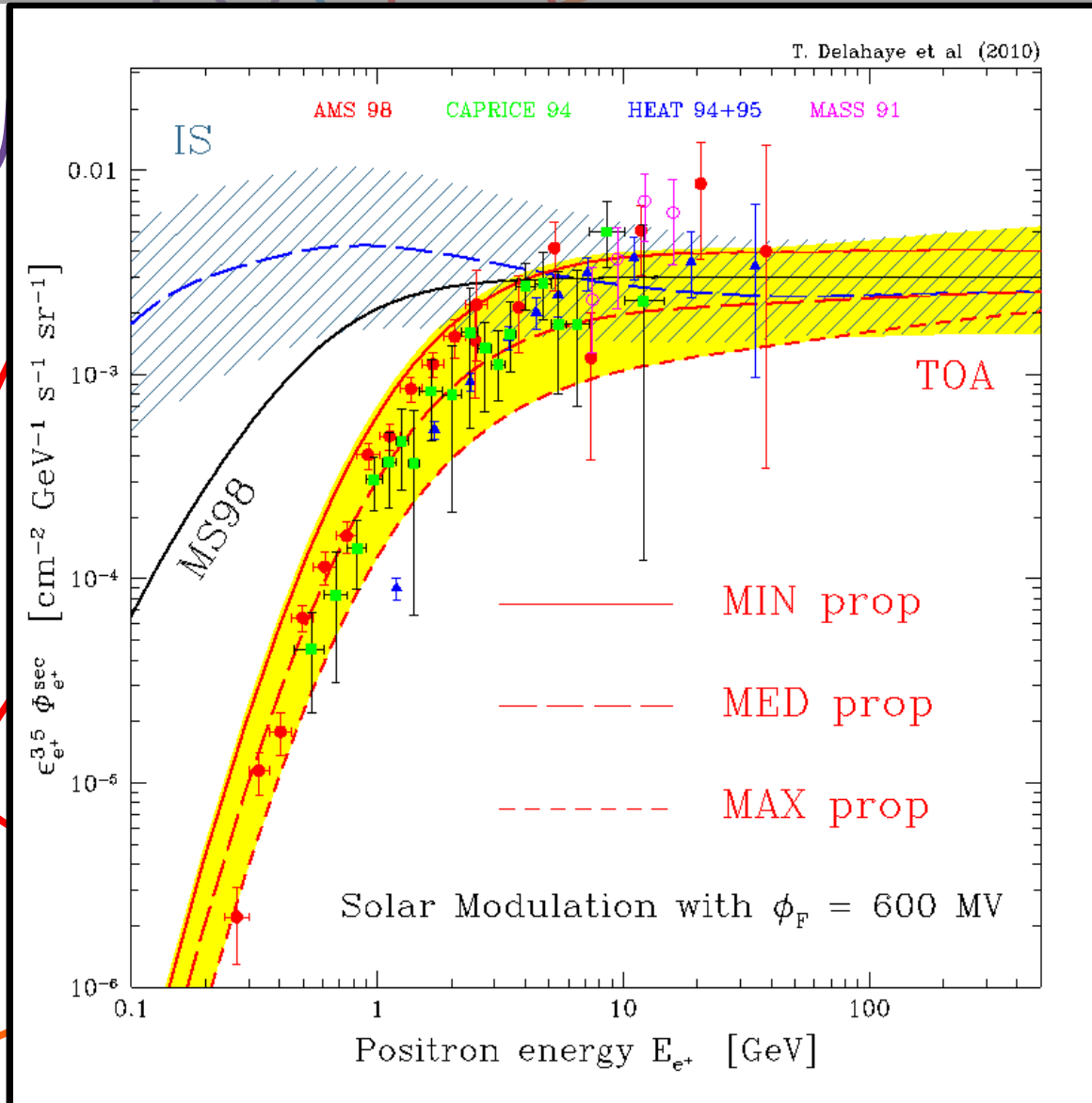




# Secondary positrons (and electrons)

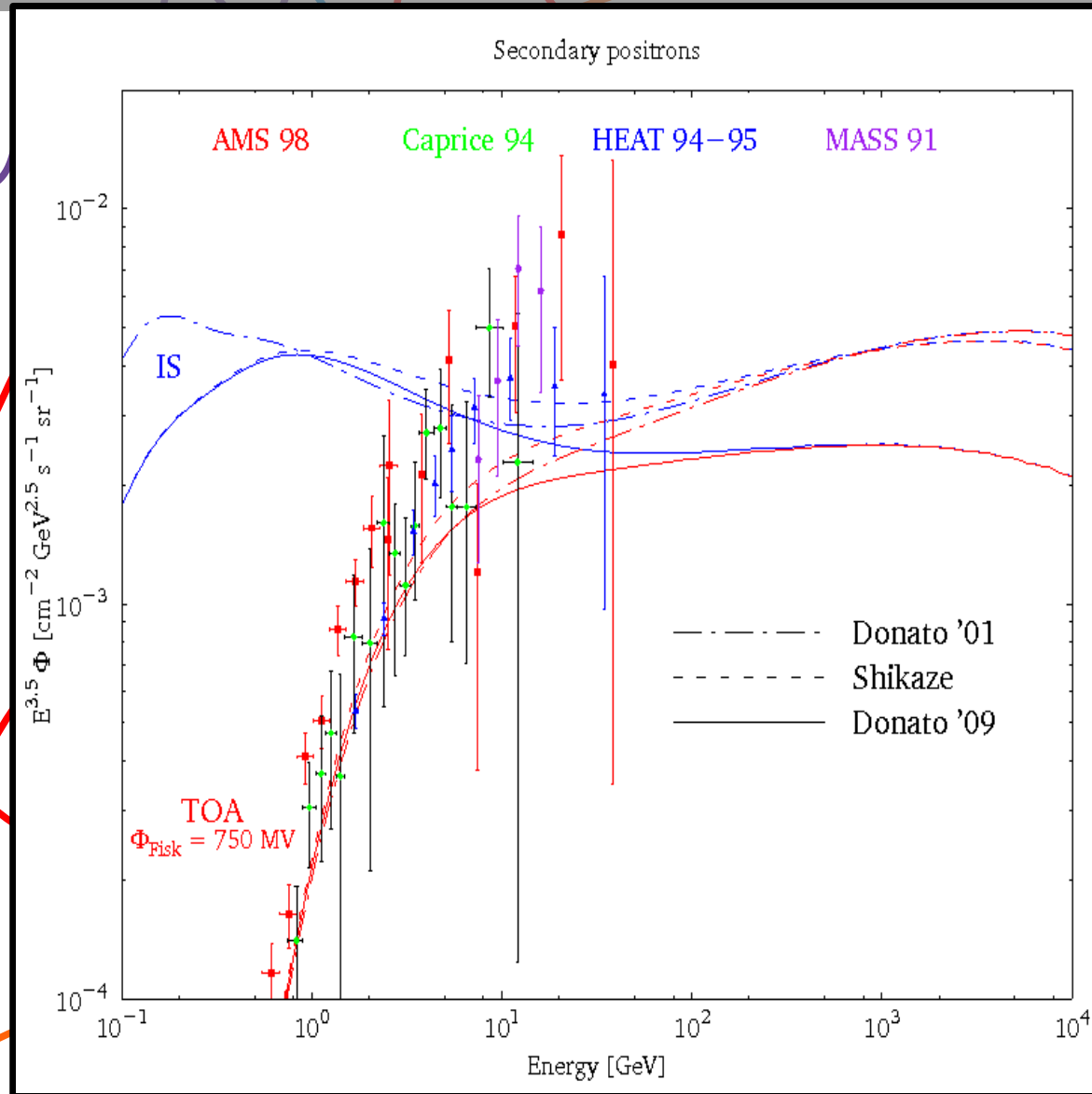


# Propagation influence



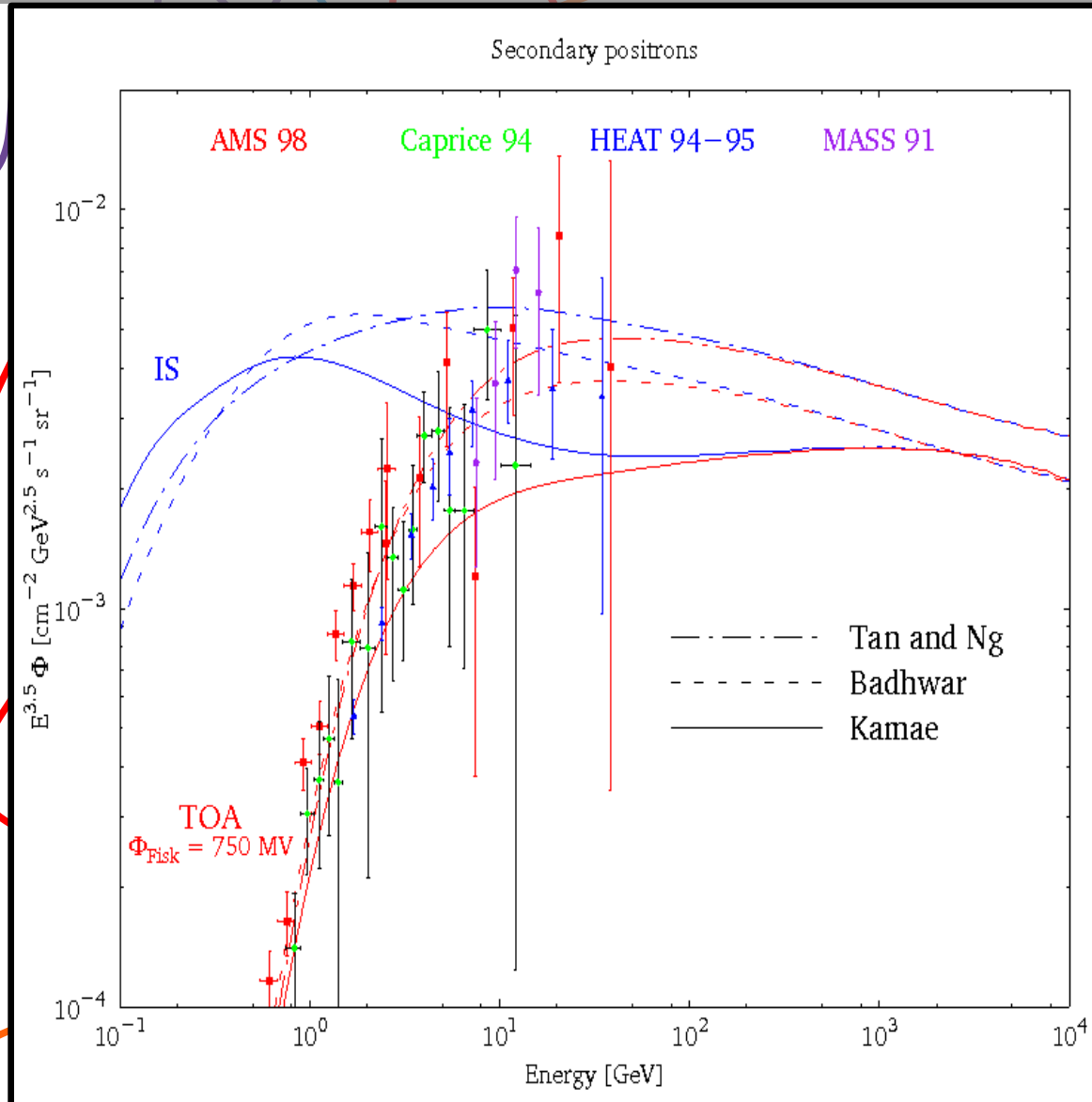
T.D., Lineros,  
et alii  
A&A 2009

# Proton flux influence



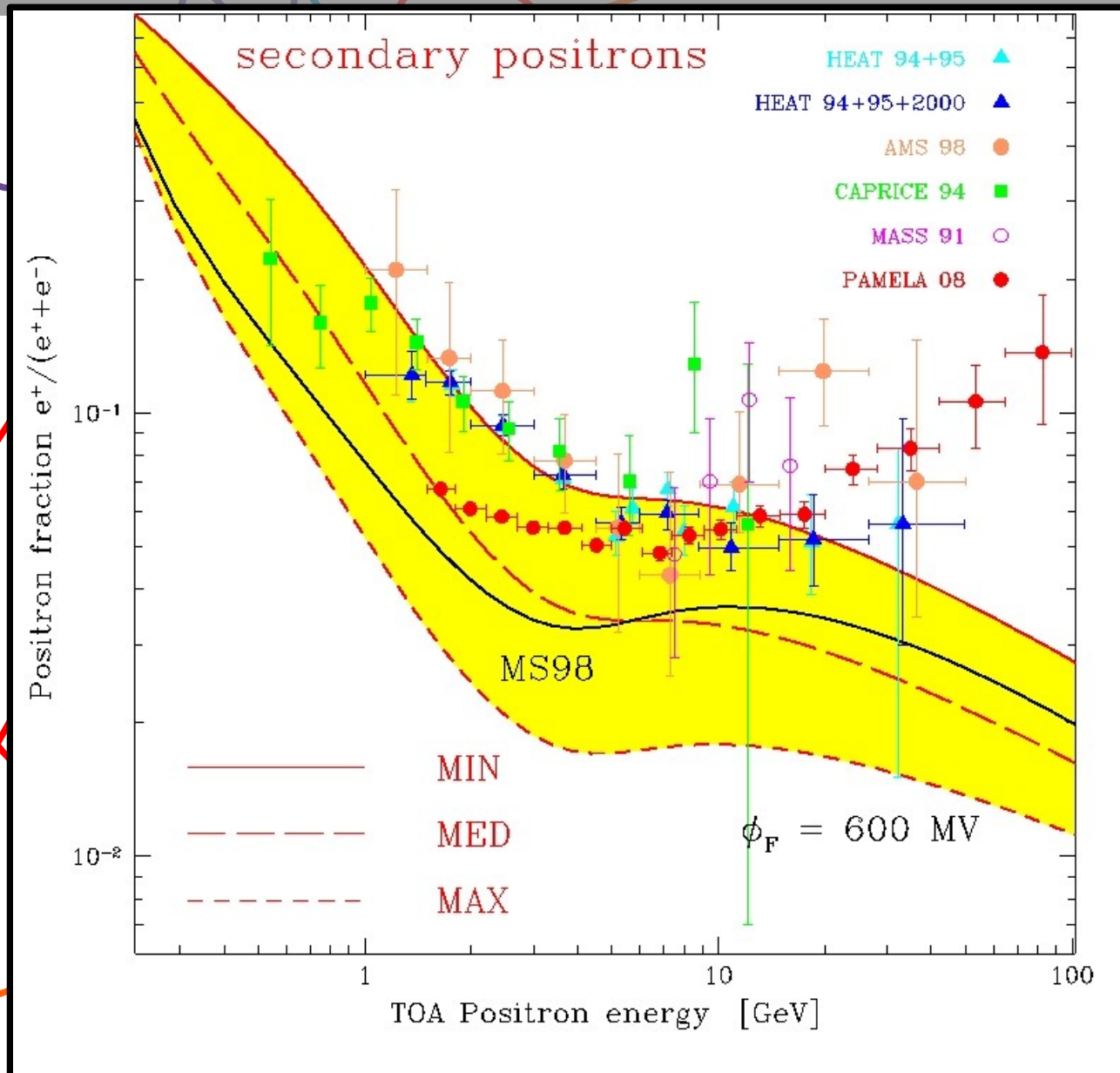
T.D., Lineros,  
et alii  
A&A 2009

# Cross-section influence



T.D., Lineros,  
et alii  
A&A 2009

# Secondary $e^+$





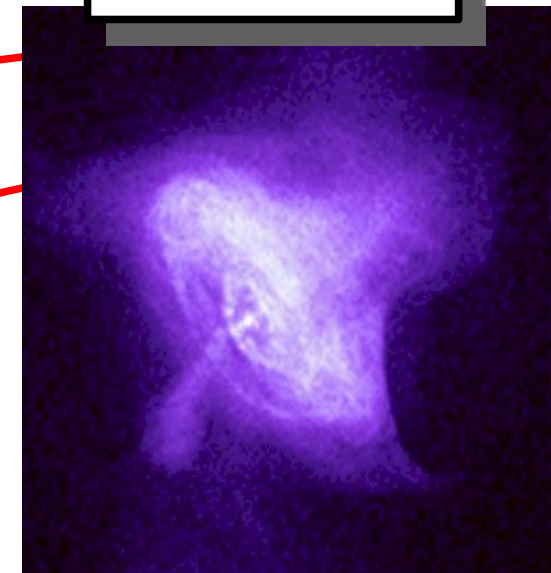
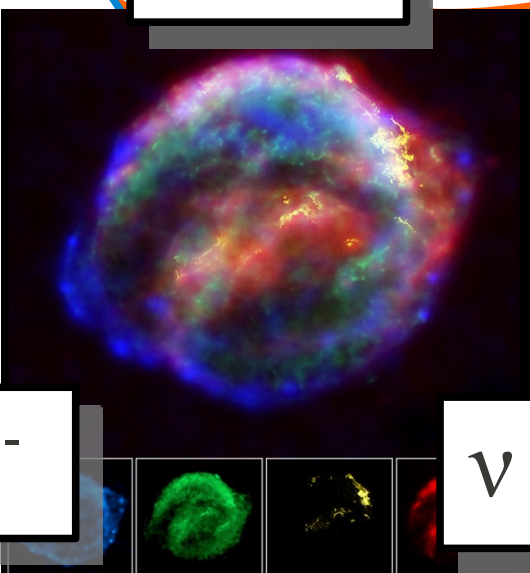
# Primary sources

DM

SNR

Pulsar

?



$\gamma$

$\nu$

$e^-$

$\nu$

$e^+$

$e^-$

$p$

$\bar{p}$

$\gamma$

$p$

$\alpha$

$e^+$

$e^-$

$\gamma$

# Source term

$$Q(E) = \eta \langle \sigma v \rangle \left( \frac{\rho}{m_x} \right)^2 f(E)$$

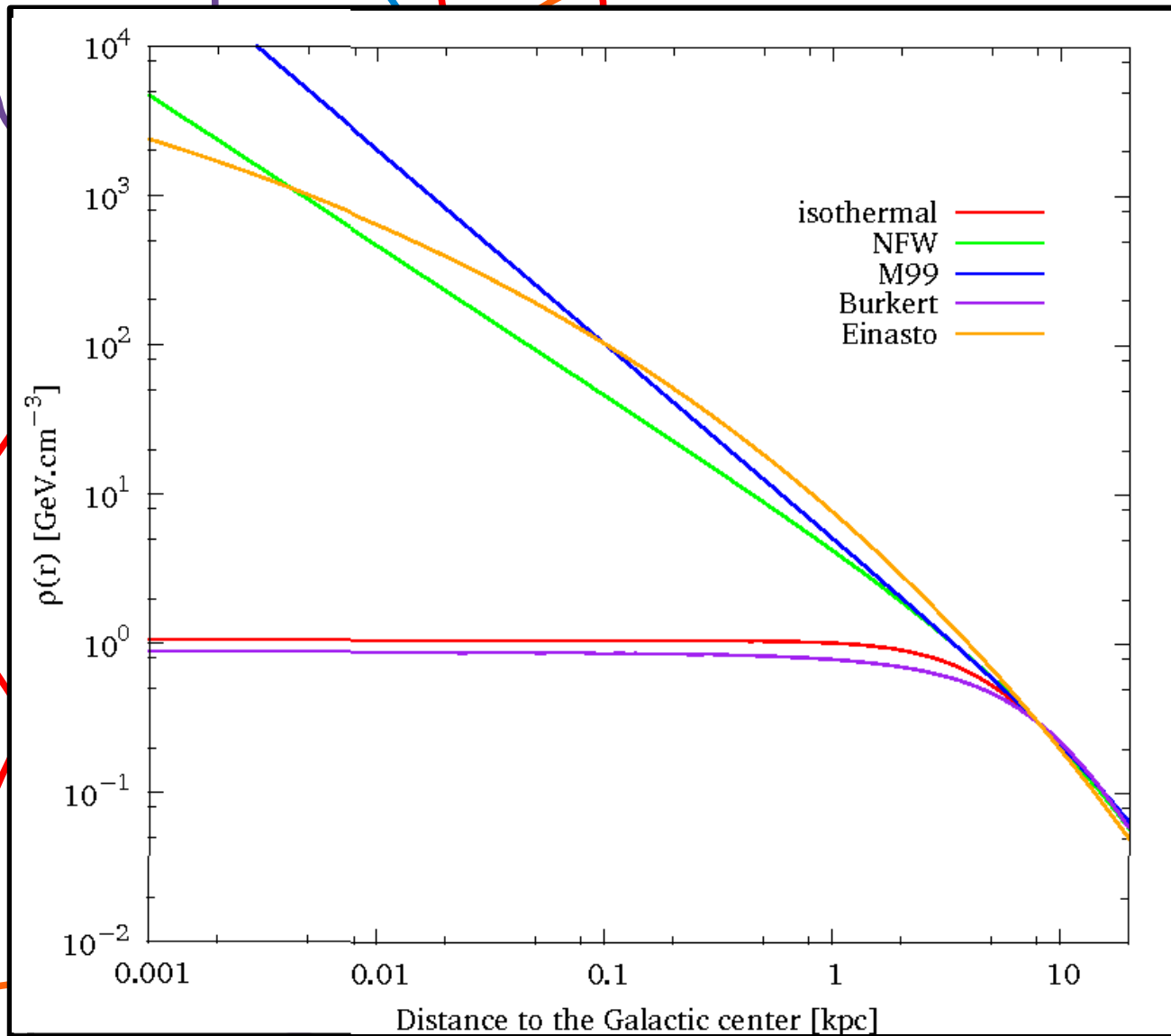
$$Q(E) = \Gamma \left( \frac{\rho}{m_x} \right) f(E)$$

# Source term

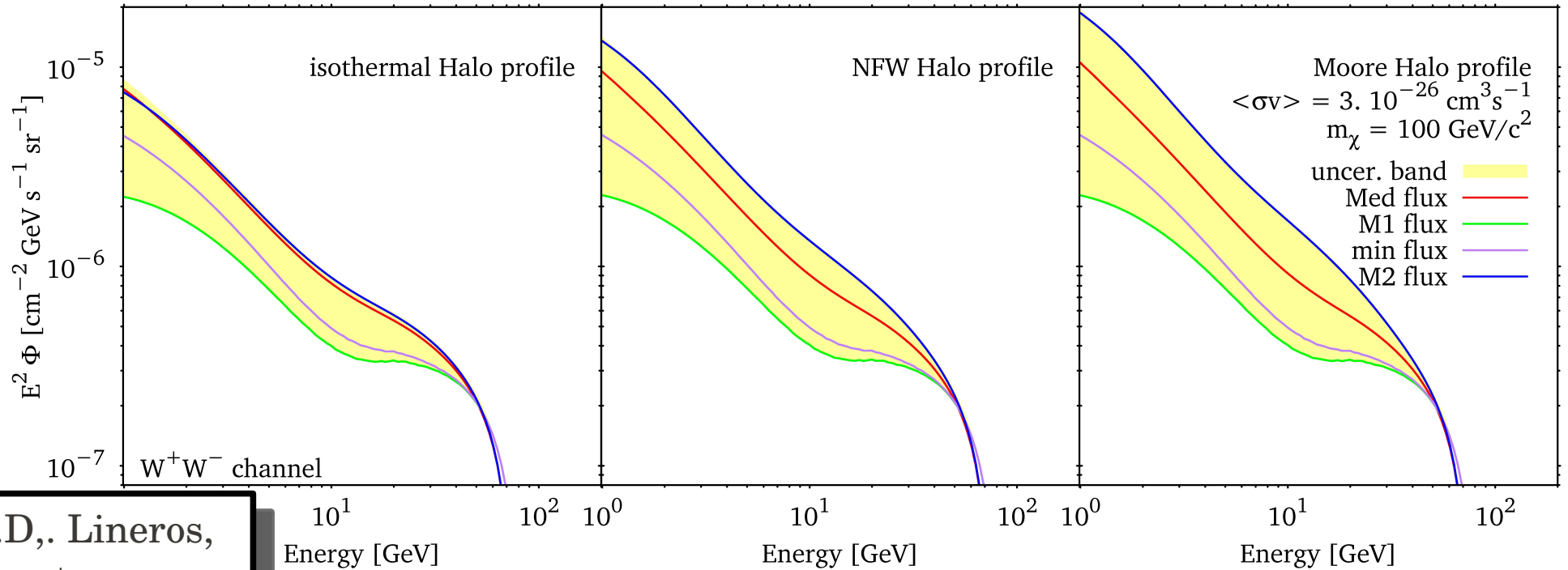
$$Q(E) = \eta \langle \sigma v \rangle \left( \frac{\rho}{m_x} \right)^2 f(E)$$

$$Q(E) = \Gamma \left( \frac{\rho}{m_x} \right) f(E)$$

# Dark matter distribution



# Dark matter distribution



T.D., Lineros,  
Donato,  
Fornengo, &  
Salati  
PRD 2008

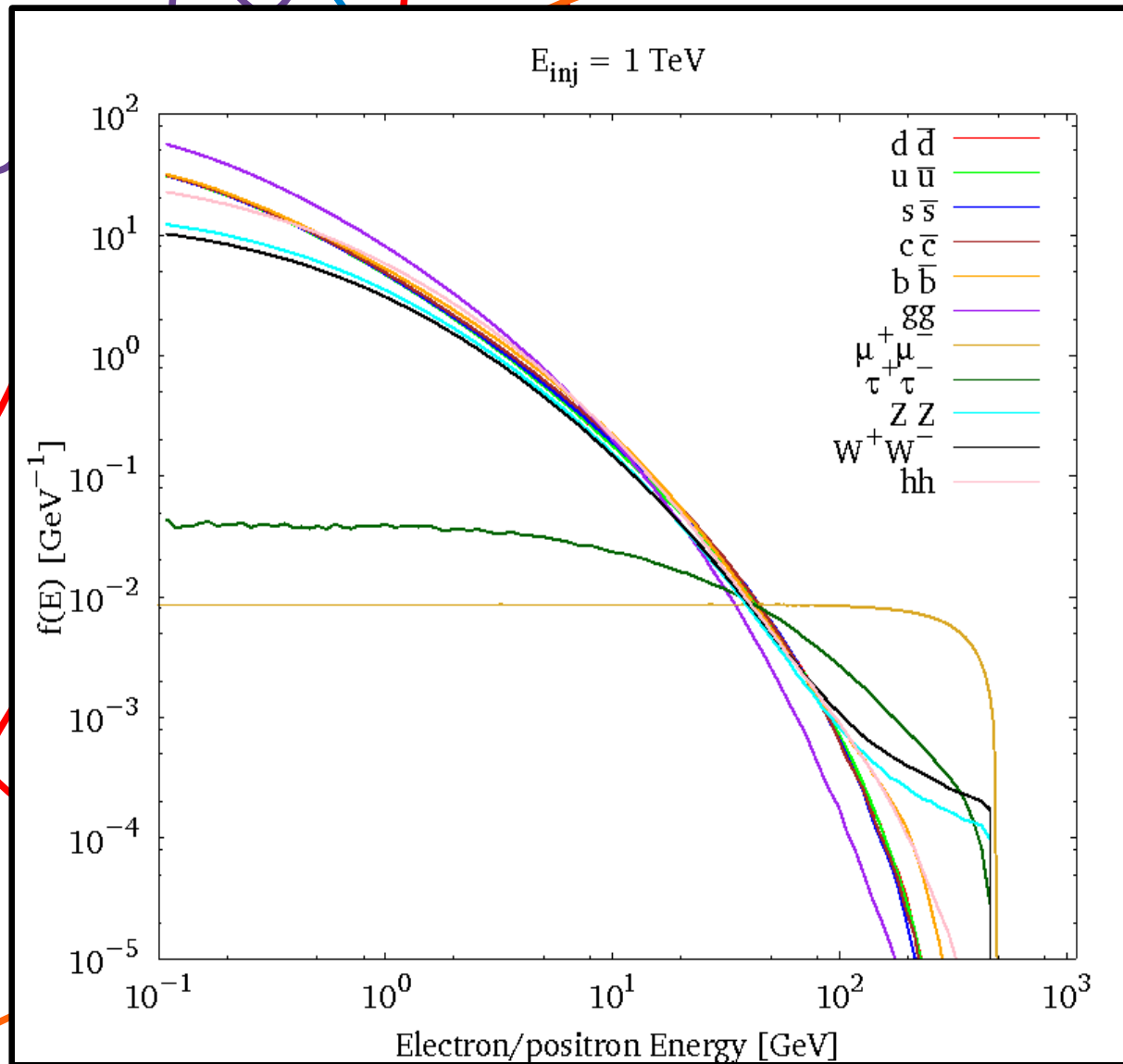
# Source term

$$Q(E) = \eta \langle \sigma v \rangle \left( \frac{\rho}{m_x} \right)^2 f(E)$$

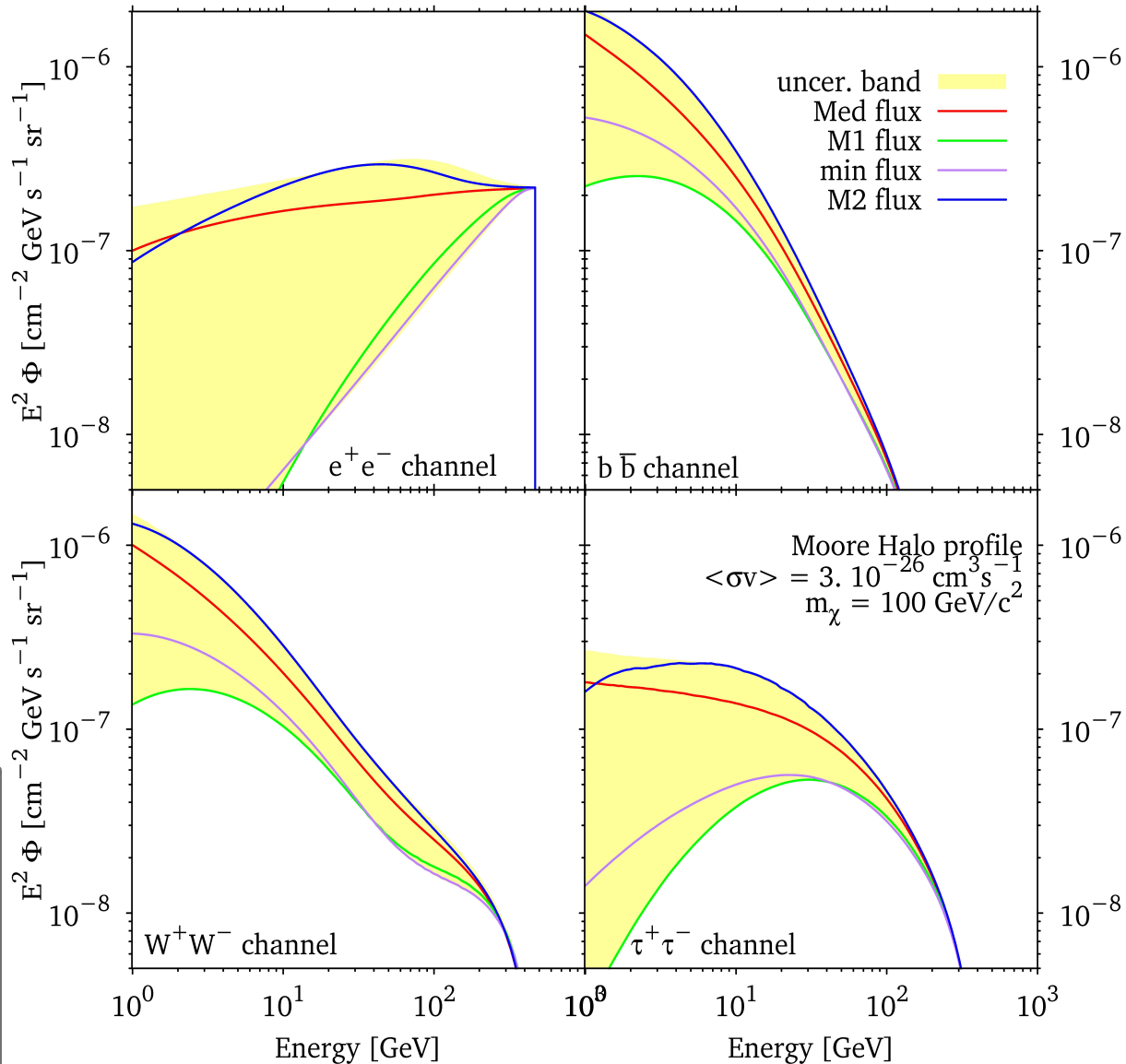
$$Q(E) = \Gamma \left( \frac{\rho}{m_x} \right) f(E)$$



# Annihilation channel



# Annihilation channel



T.D., Lineros,  
Donato,  
Fornengo, &  
Salati  
PRD 2008

# Boost factor

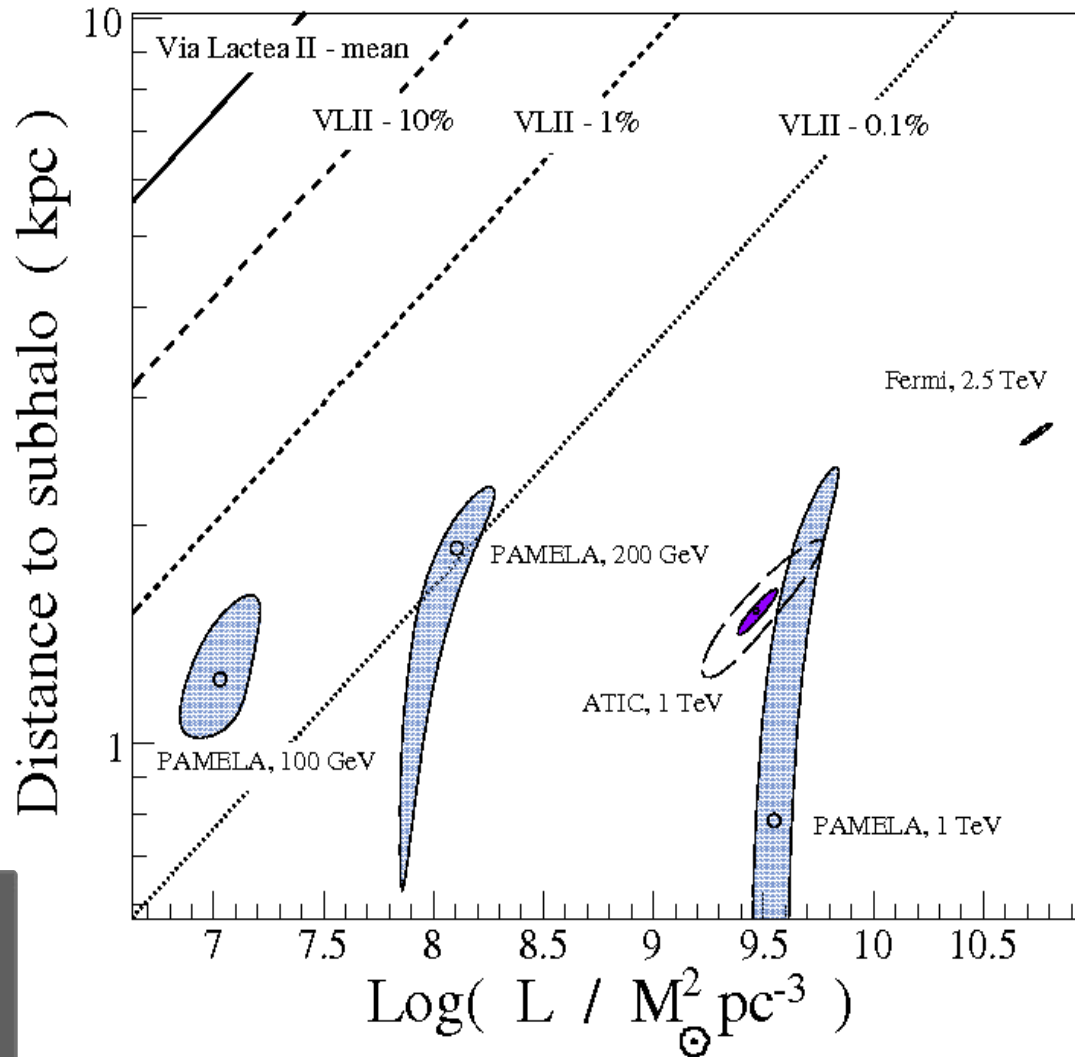
- Particle physics
  - Sommerfeld effect
  - Resonances
- Cosmology
  - Non-thermal production
  - Modification of cosmology
- Astrophysics
  - Clumps
  - Caustics

# Clumps



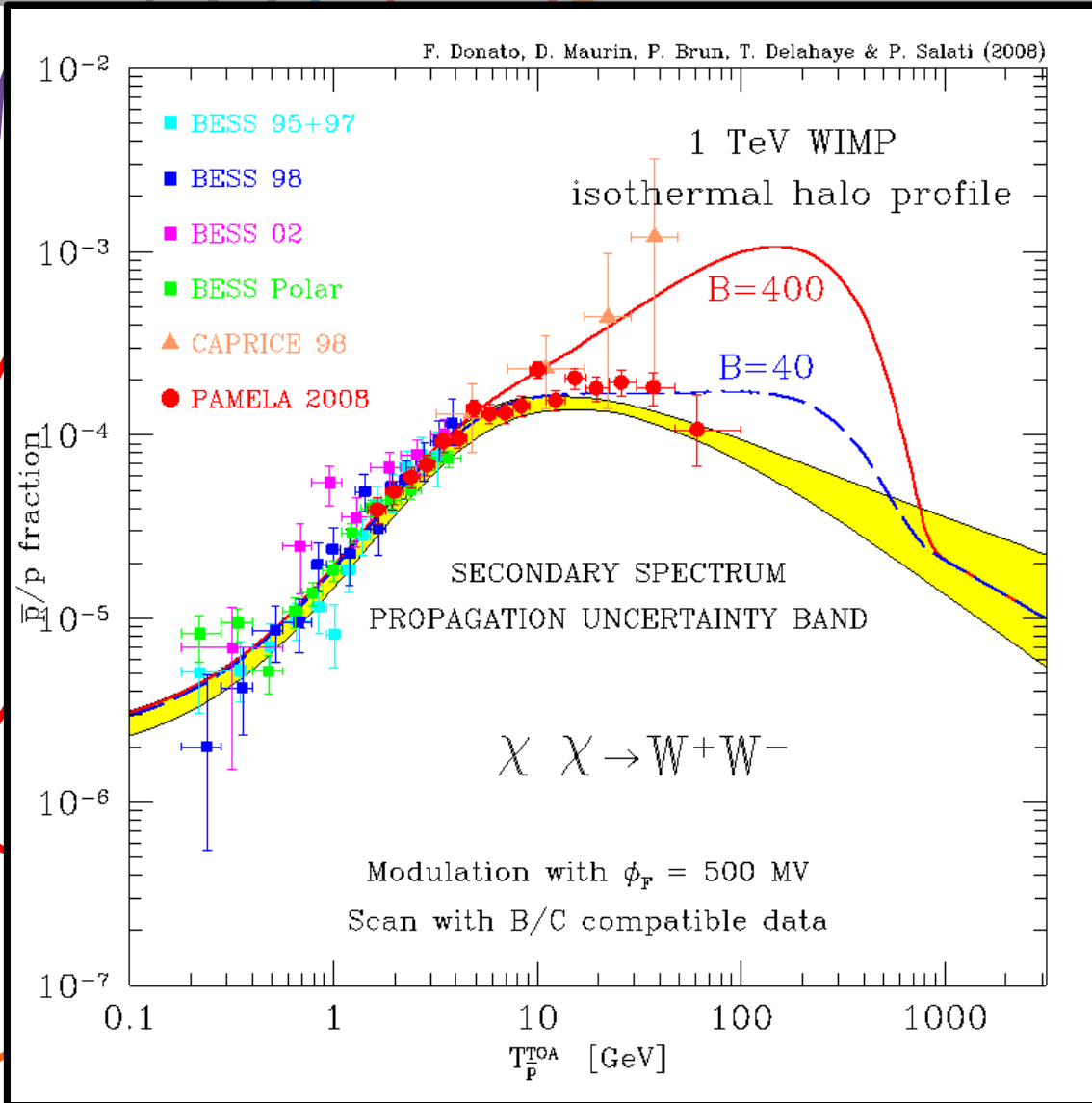
Via Lactea 2  
Diemand et alii

# A nearby clump



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

# Antiprotons



Maurin,  
Donato, Brun,  
T.D., & Salati  
PRL 2008



# Dark matter problems

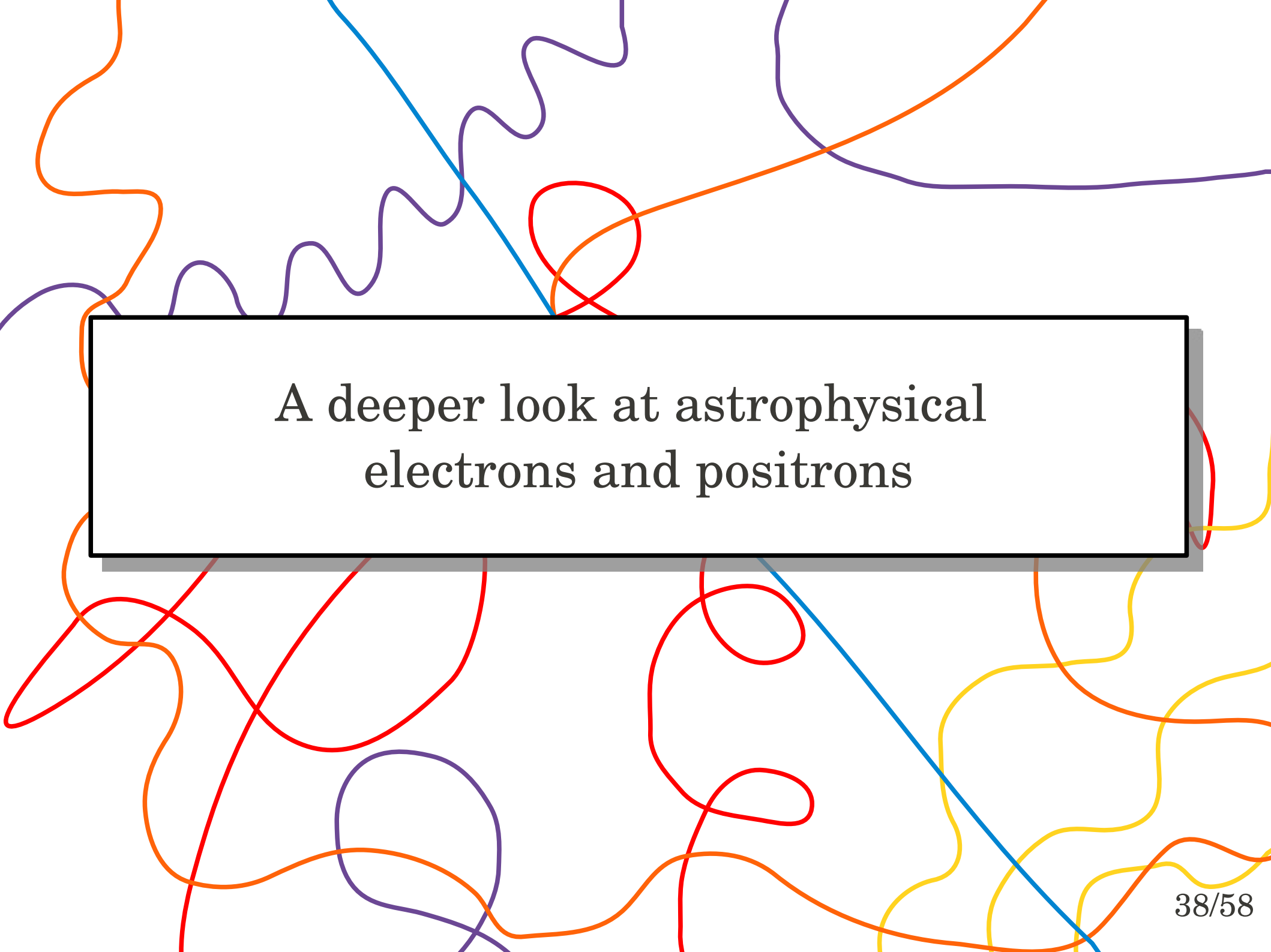
Dark matter can explain the data

**BUT**

- Boost factor
- Antiproton data



**Naturalness ?**



A deeper look at astrophysical  
electrons and positrons

# Primary sources

DM

SNR

Pulsar

?

$\gamma$

$\nu$

$e^-$

$\nu$

$e^+$

$e^-$

$p$

$\bar{p}$

$\gamma$

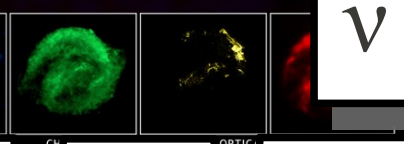
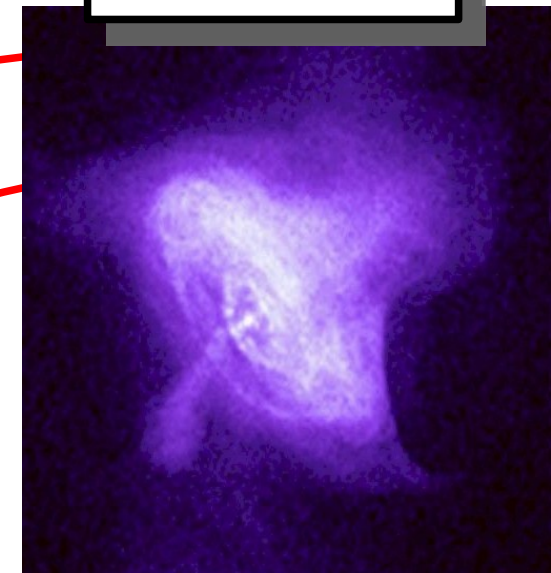
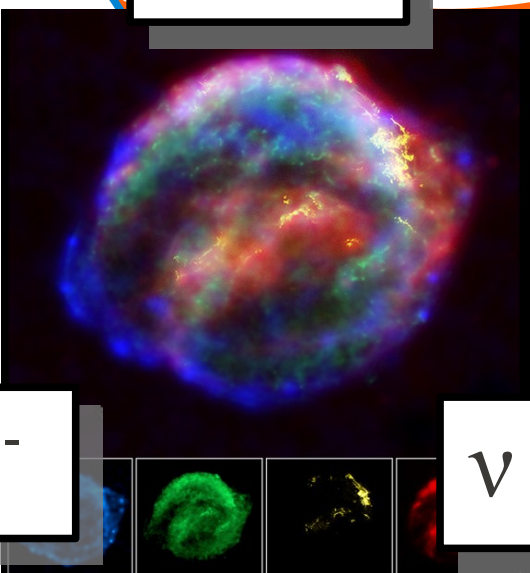
$p$

$\alpha$

$e^+$

$e^-$

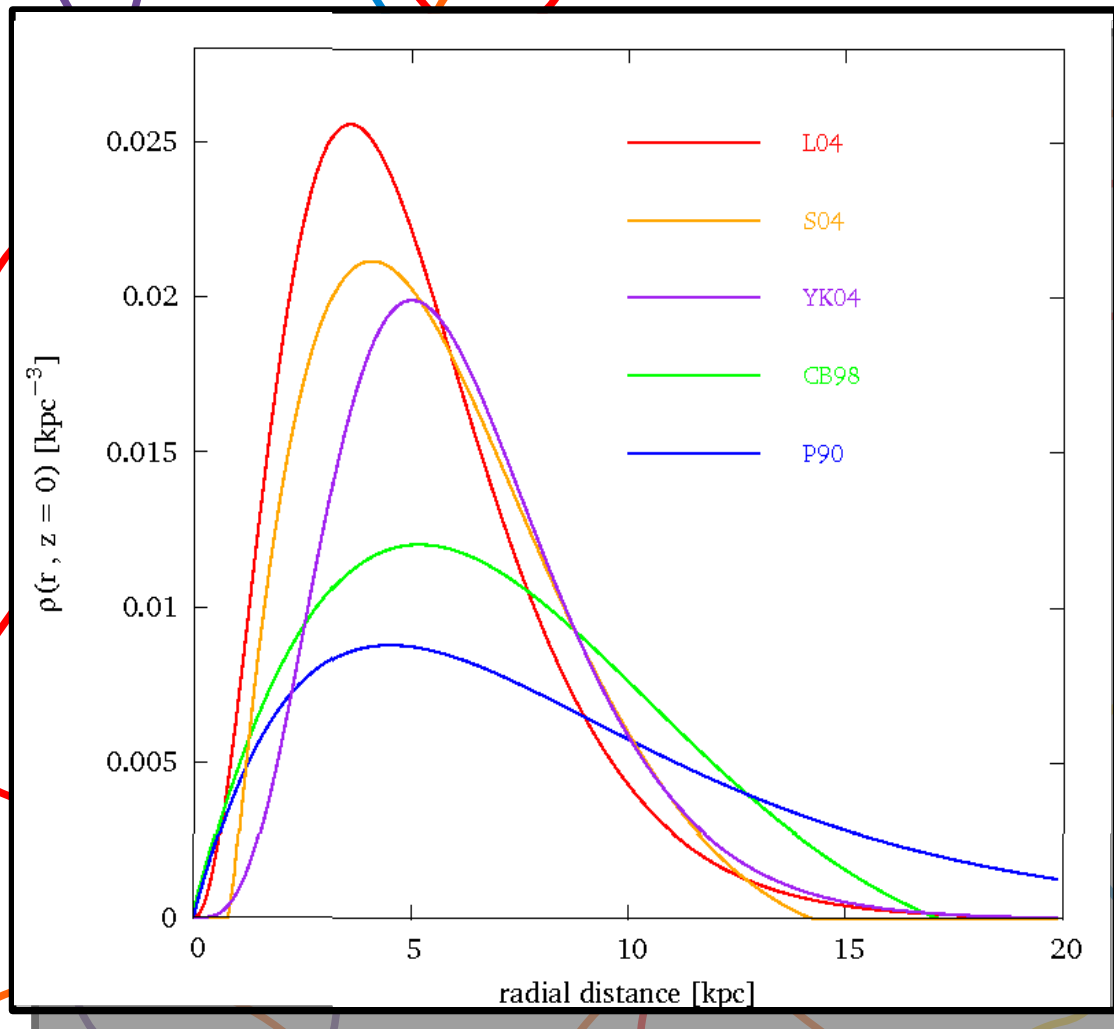
$\gamma$



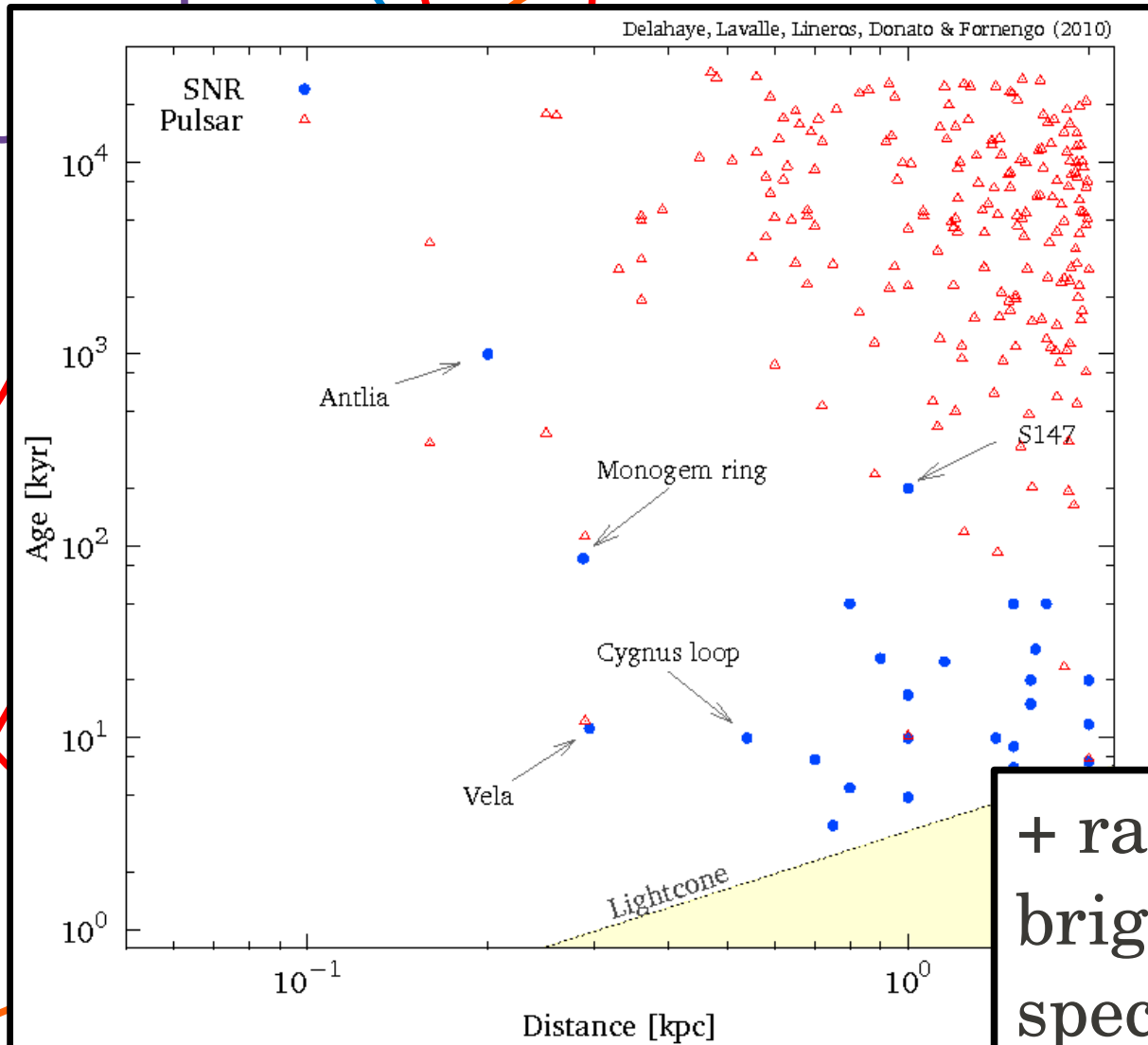
# Astrophysical sources

$$Q(\vec{x}, E, t) = Q_0 E^{-\sigma} e^{-E/E_c} \delta(\vec{x} - \vec{x}_s) \delta(t - t_s)$$

# Distant sources



# Nearby sources

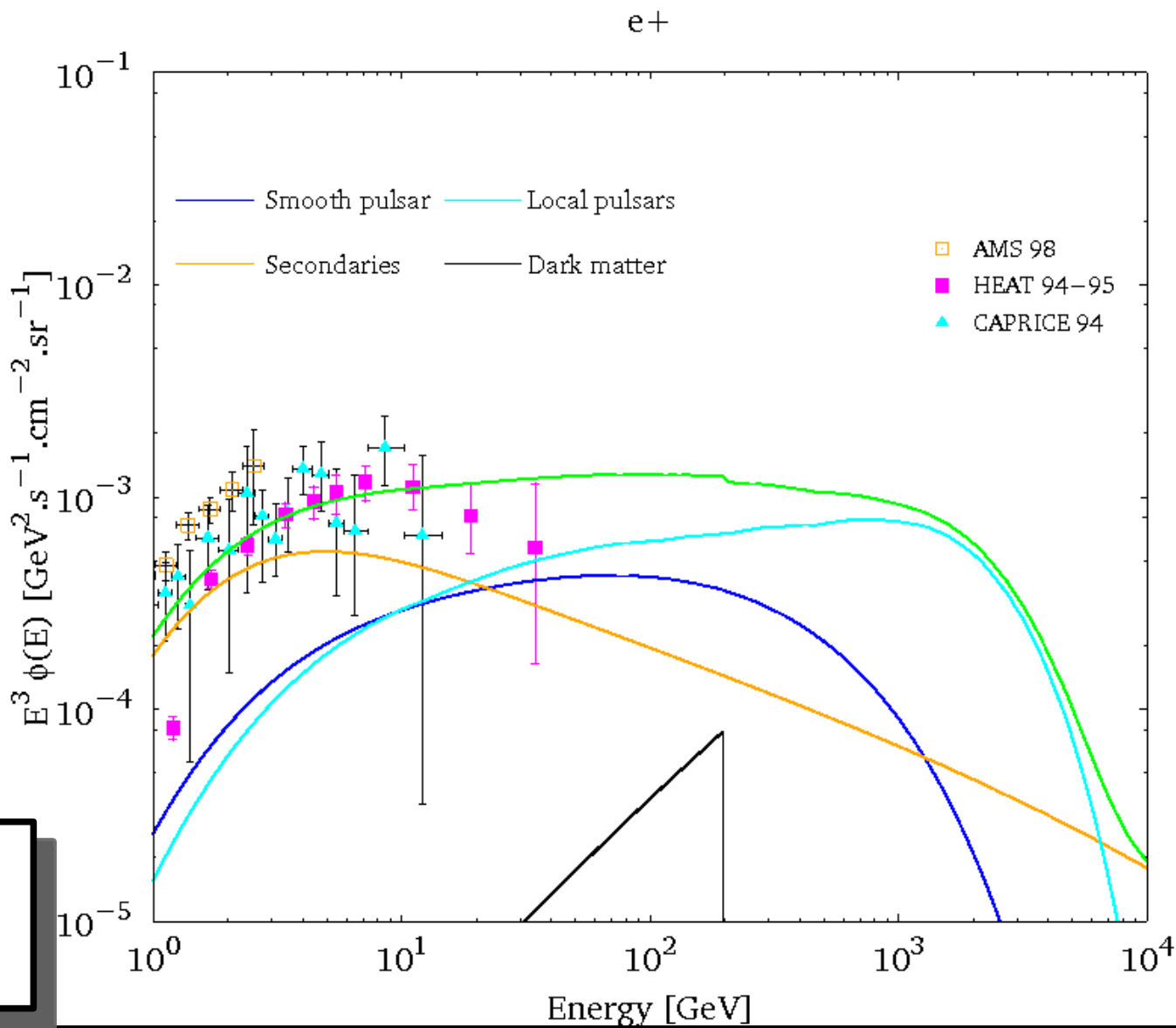


T.D., Lineros,  
Lavalley et alii.  
A&A in press

+ radio  
brightness and  
spectral index

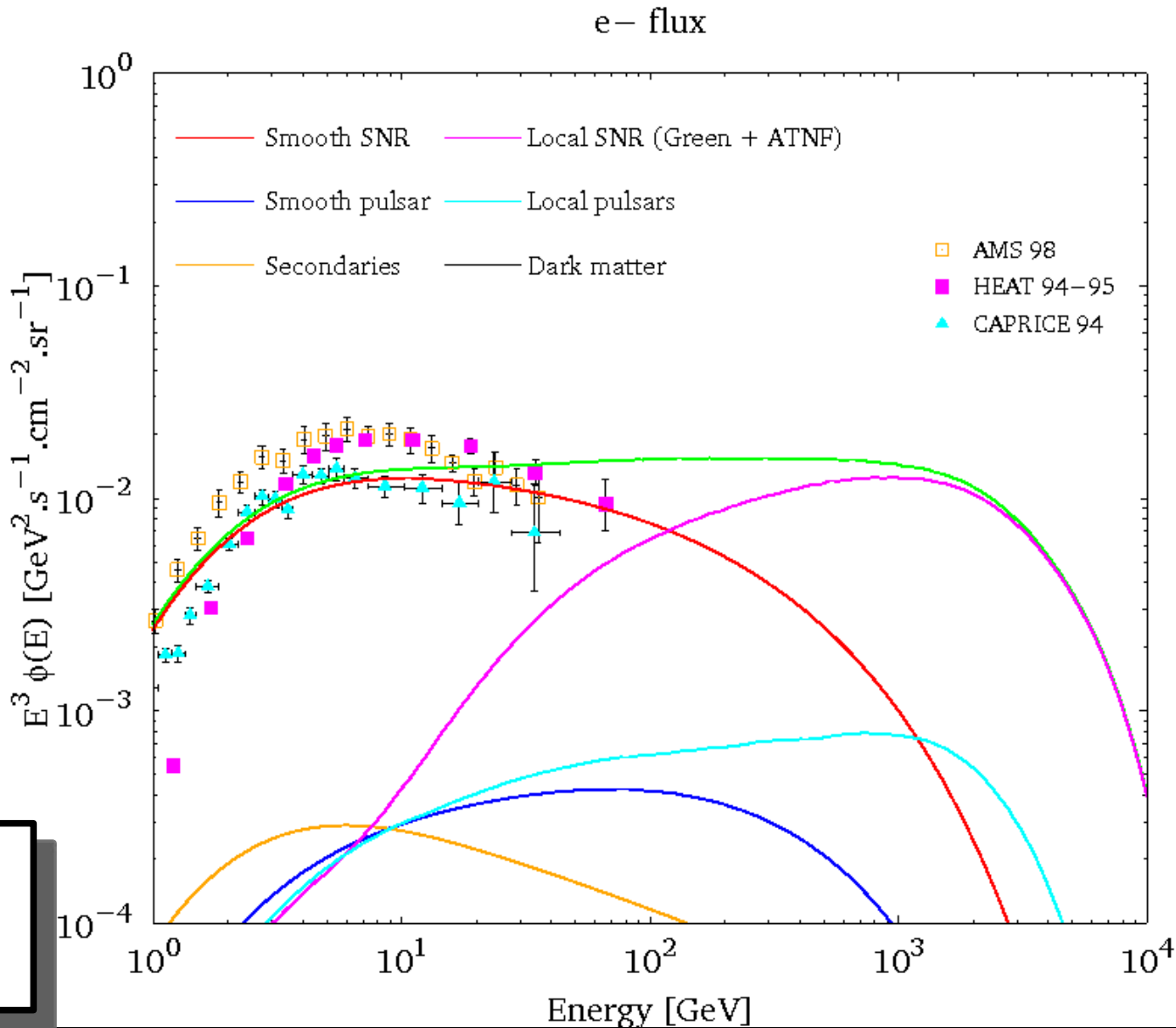


# Results: $e^+$



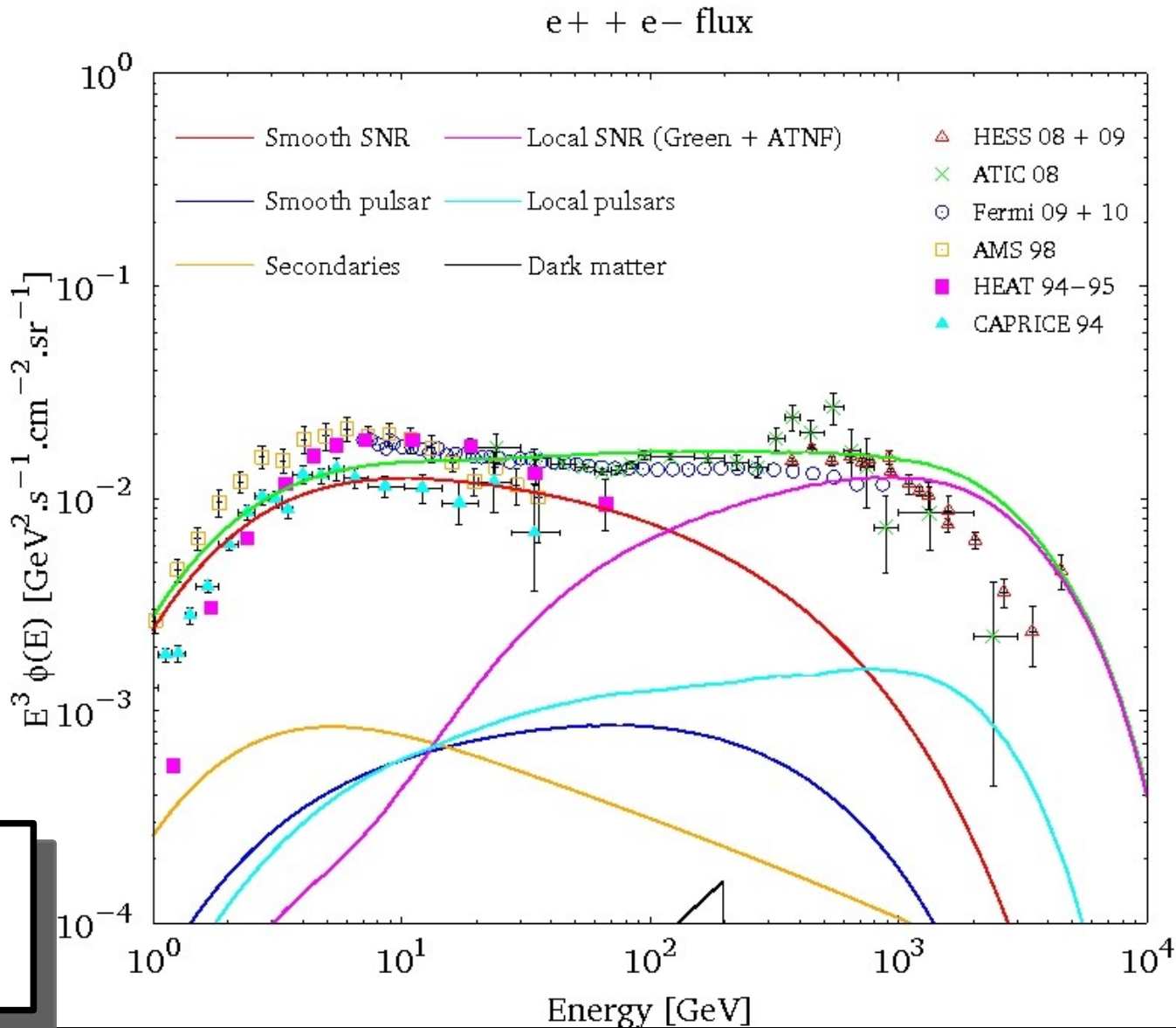
T.D., Lineros,  
Lavalle et alii.  
A&A in press

# Results: $e^-$



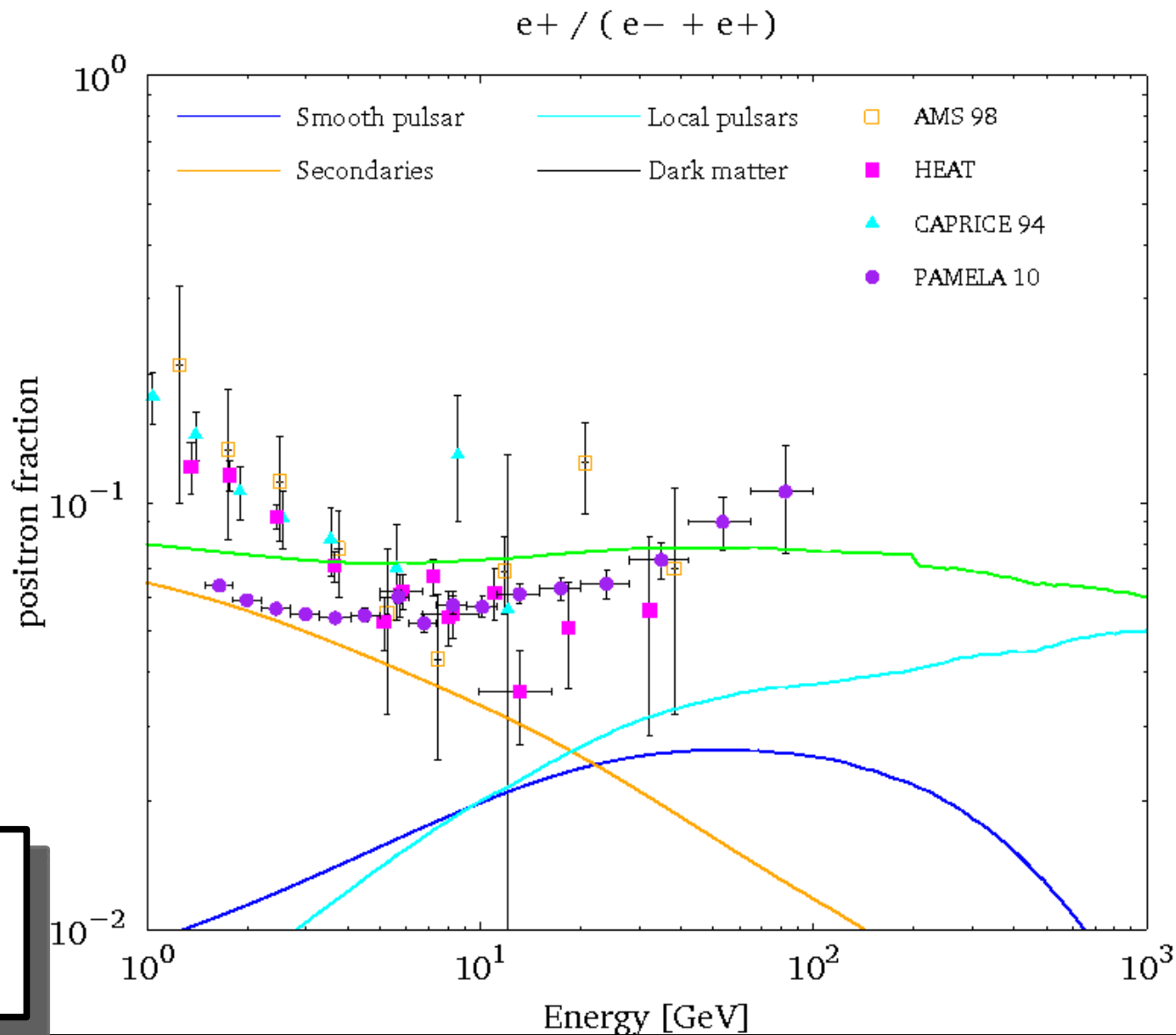
T.D., Lineros,  
Lavalle et alii.  
A&A in press

# Results: $e^- + e^+$



T.D., Lineros,  
Lavalle et alii.  
A&A in press

# Results: $e^+$ fraction



T.D., Lineros,  
Lavalle et alii.  
A&A in press

# Recent data

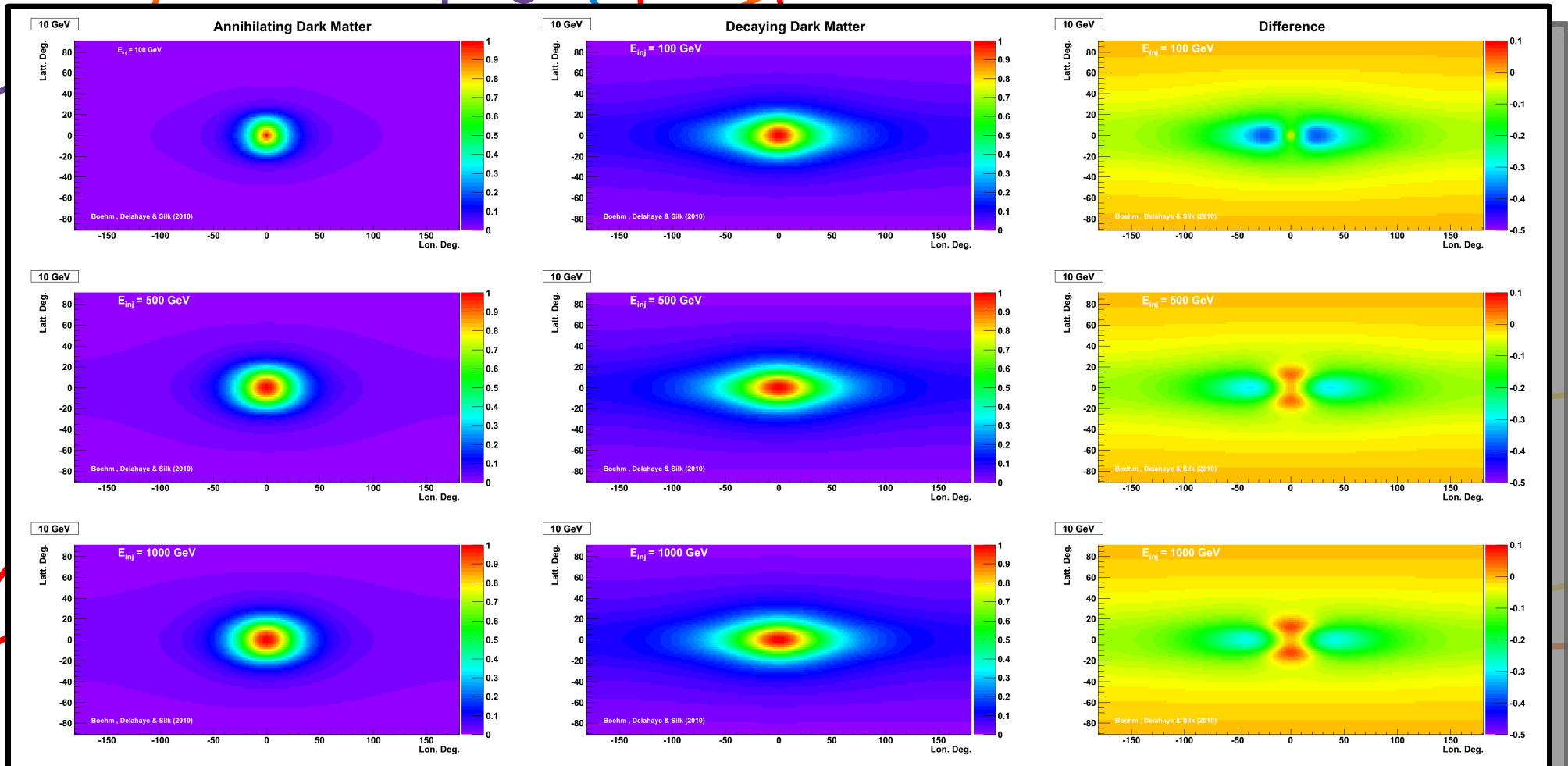
- Astrophysical sources can account for all recent data
- There is too much freedom to dismiss a dark matter interpretation nevertheless



$\gamma$  rays : a new hope  
for dark matter?

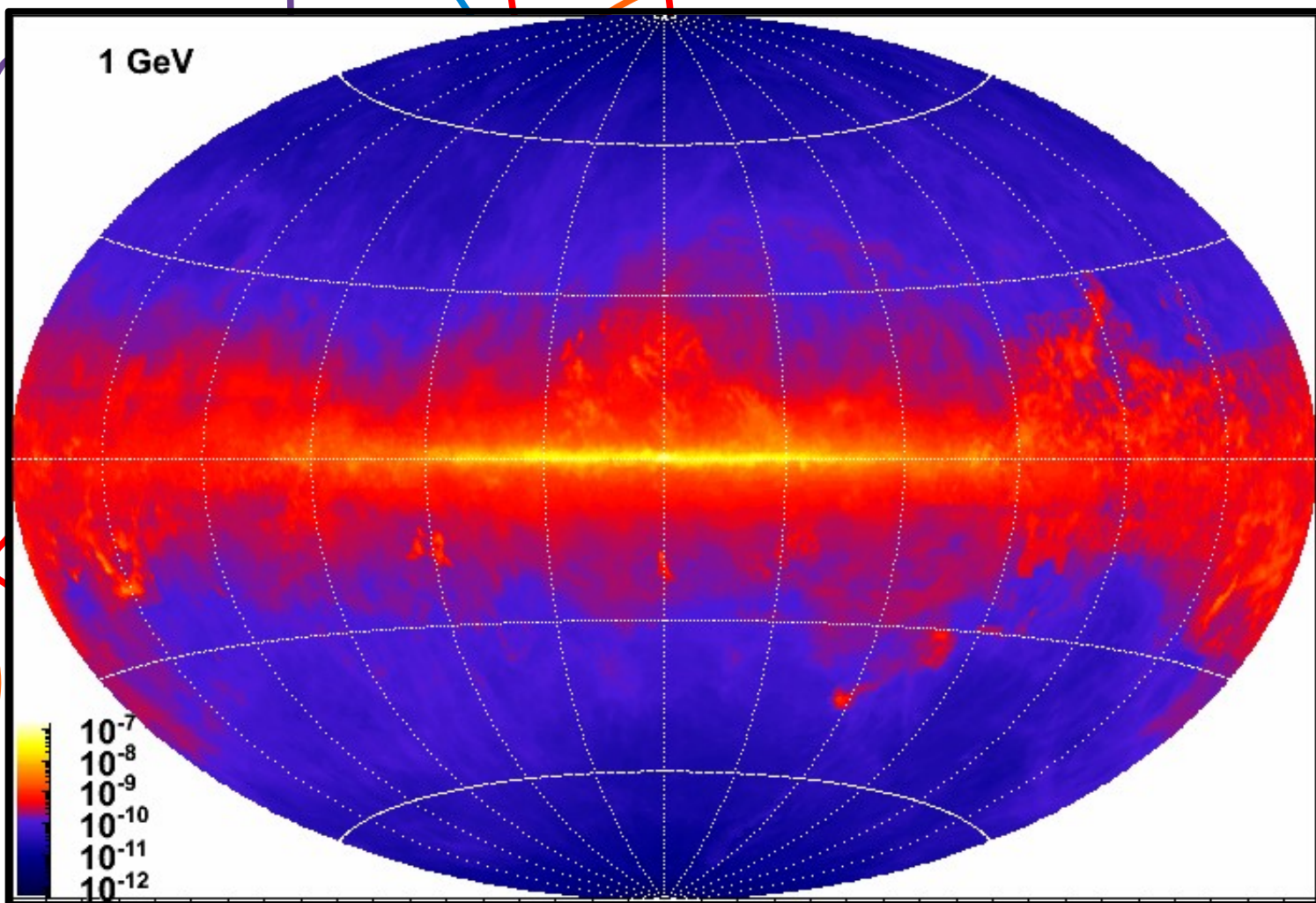


# Inverse Compton and dark matter



Boehm, T.D. & Silk,  
submitted to PRL

# $\pi^0$ sky



Fiasson, T.D., Salati,  
& Pohl, in prep.

# Other $\gamma$ ray components

- Bremsstrahlung
- Inverse Compton
- Synchrotron

electrons

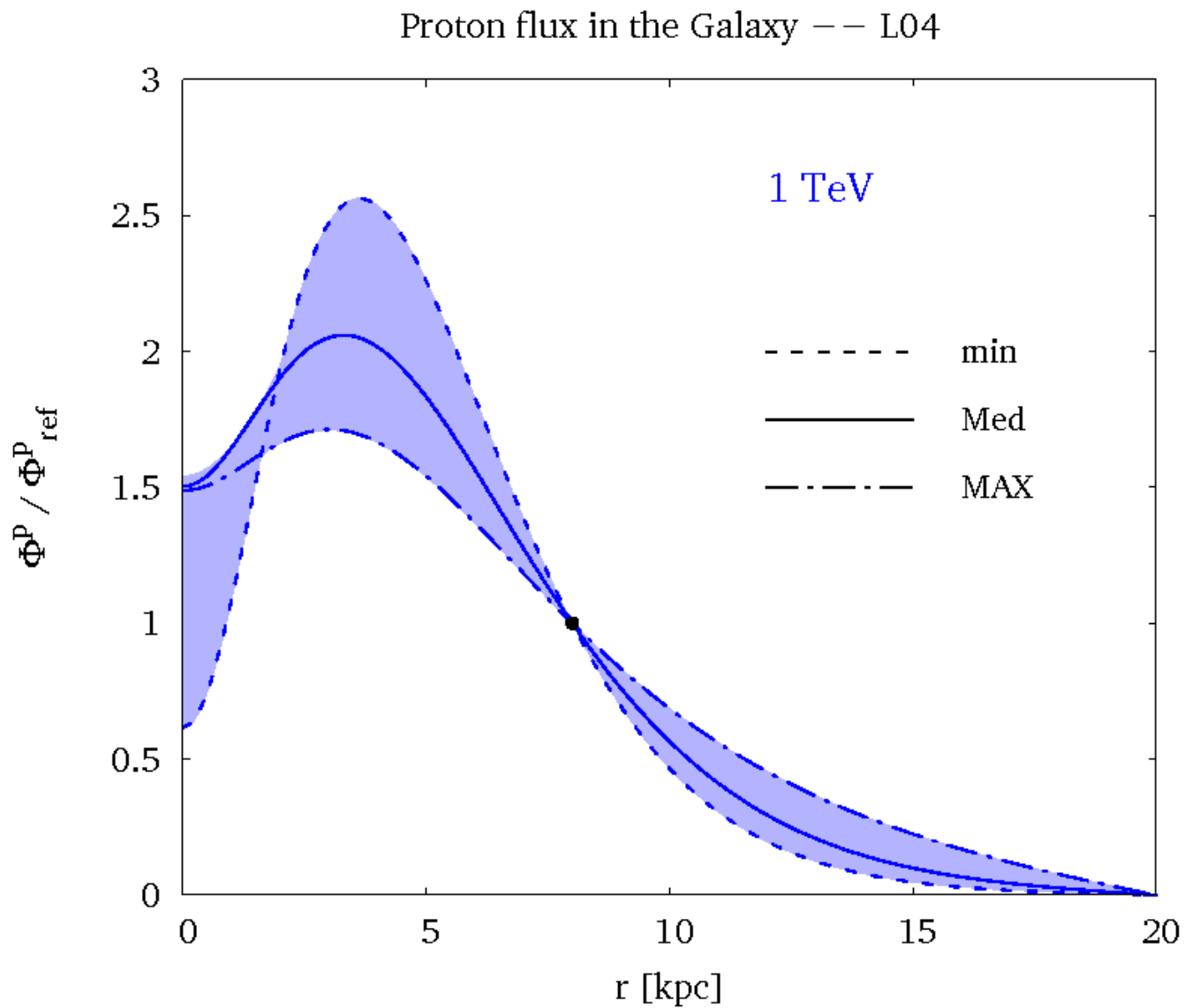
# Conclusions

- Fast analytical methods allow to size all sources of uncertainties in current understanding of cosmic rays.
- Recent data can be explained by astrophysical sources without fine tuning the parameters and Dark matter explanation seems unnatural.
- Dark matter indirect detection is promising but difficult.



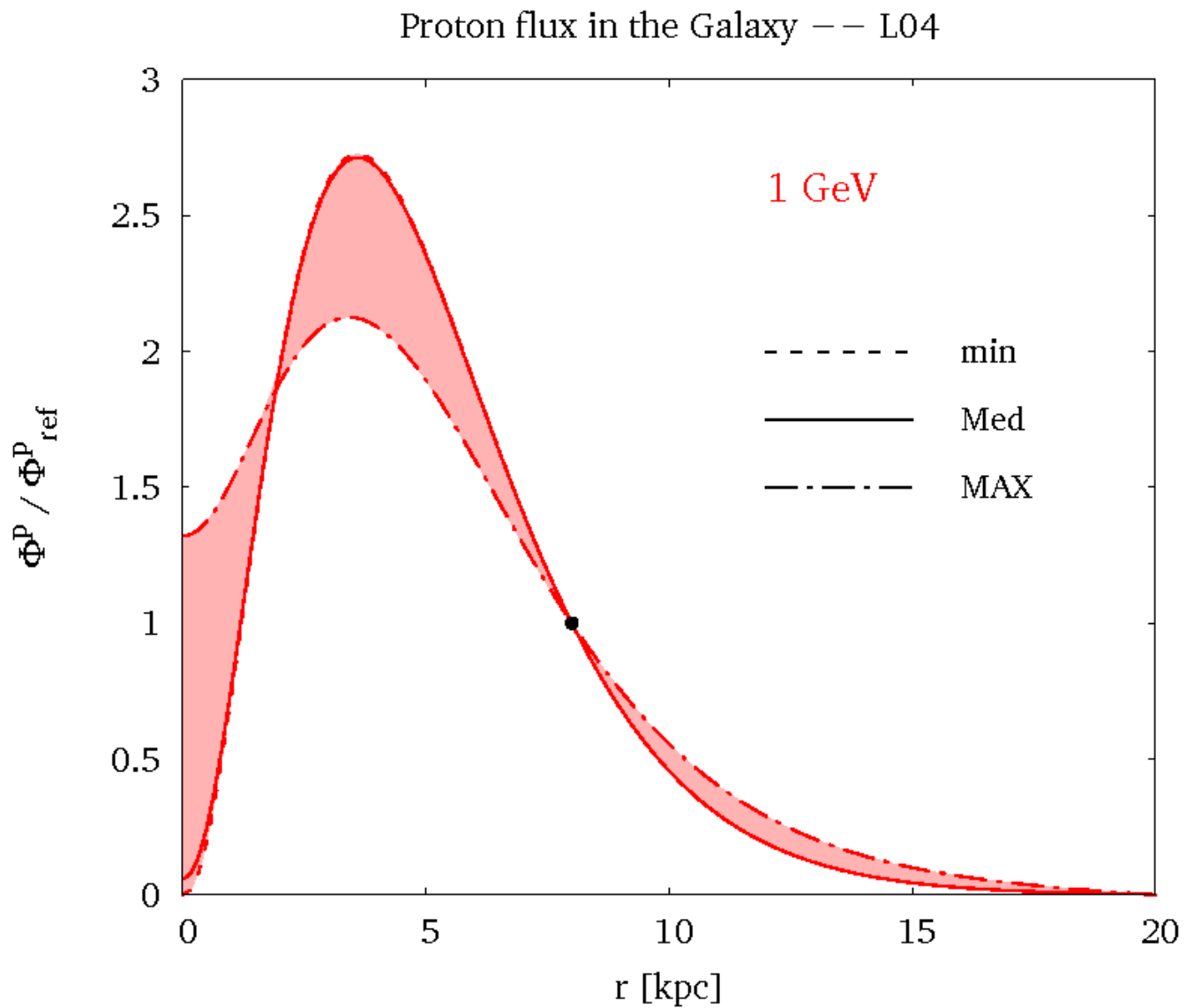
**Bonus**

# Proton flux

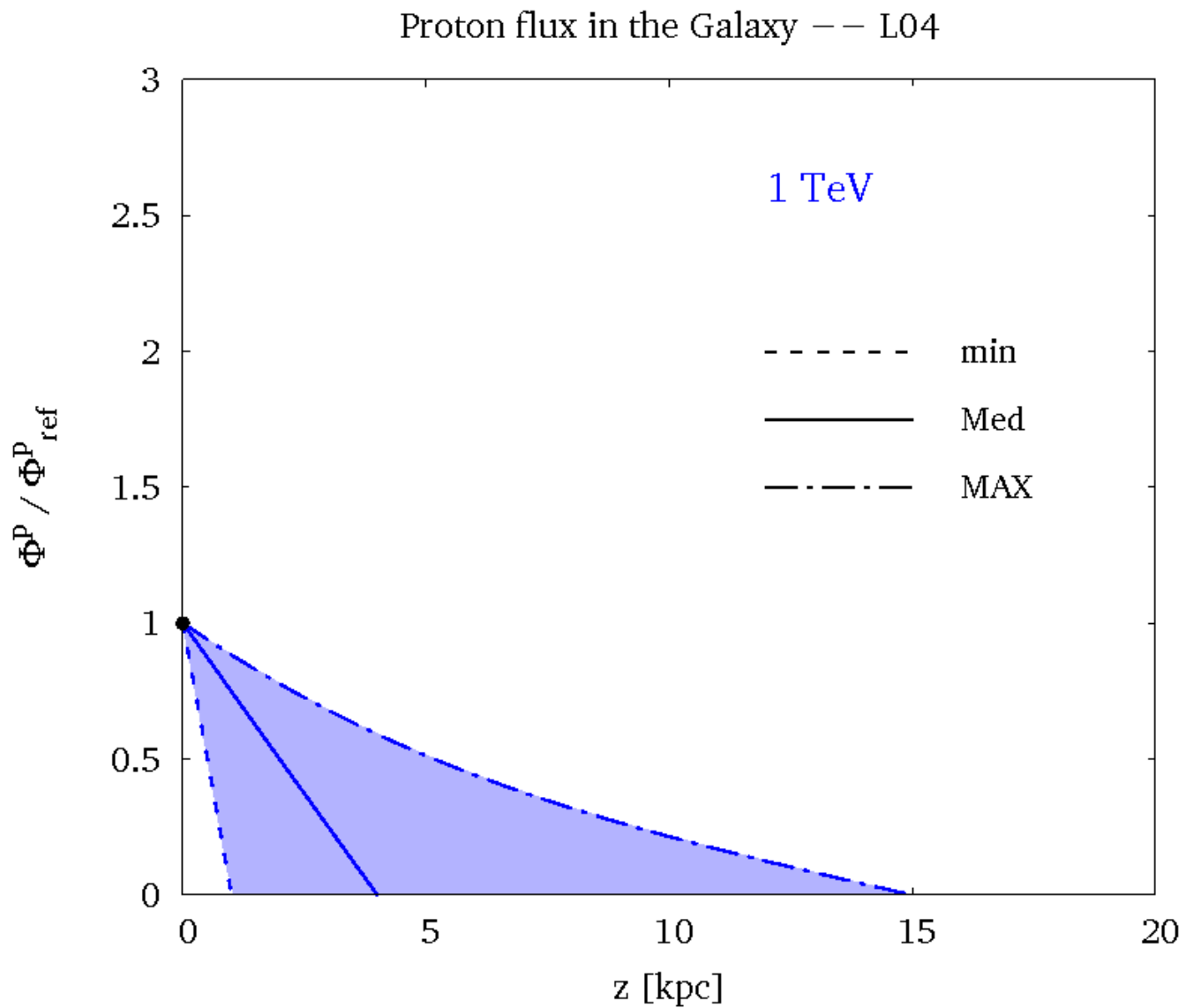




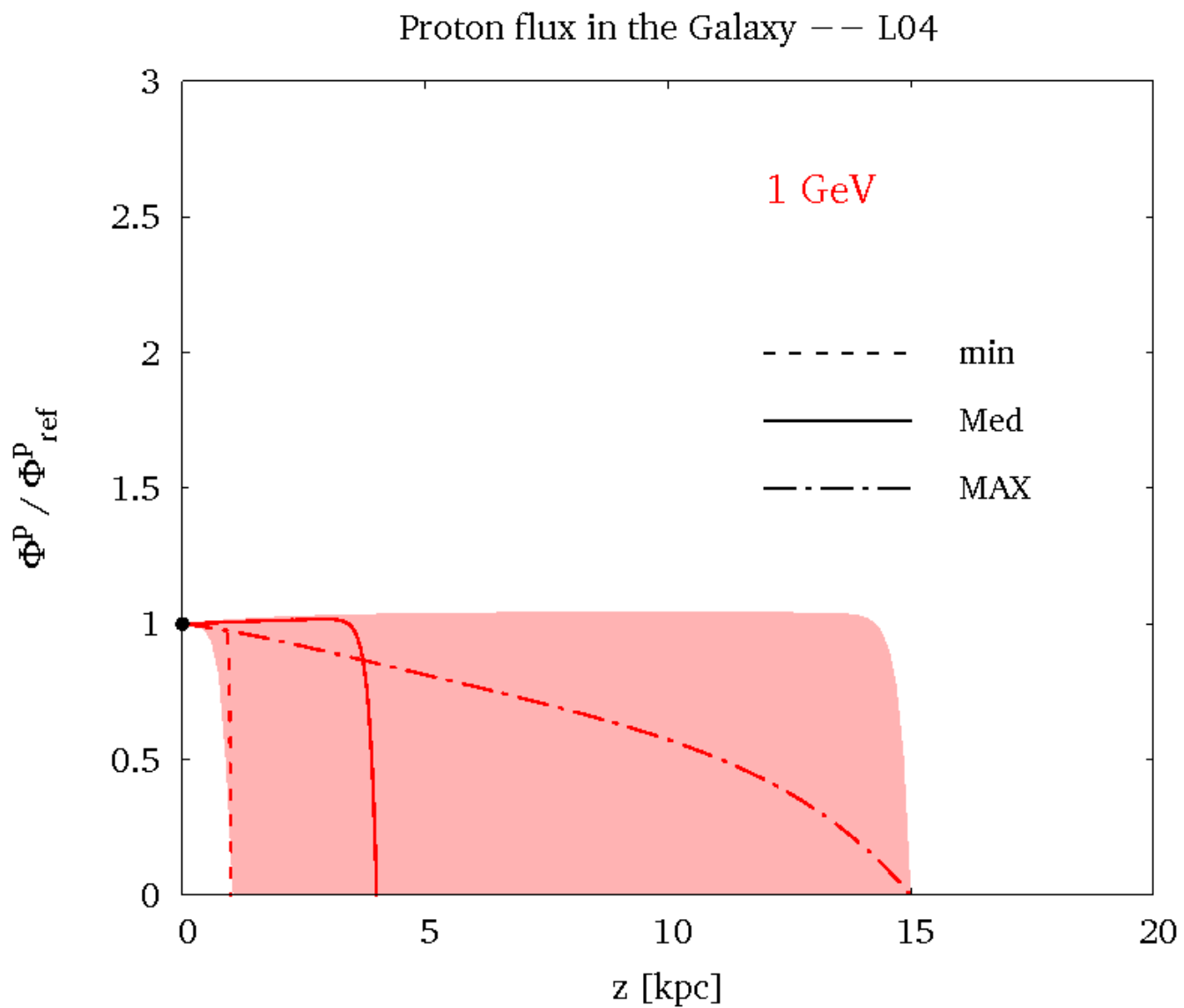
# Proton flux



# Proton flux



# Proton flux



# Local sources

