Cosmic positron and electron excesses: is the dark matter solution a good bet? (principles, backgrounds, effect of cosmological subhalos and uncertainties)

Julien Lavalle
(Dept of Theoretical Physics, University of Turin)

Refs (arXiv) : 0603796, 0712.0468, 0709.3634, 0704.2543, 0808.0332, 0809.5268, 0902.3665

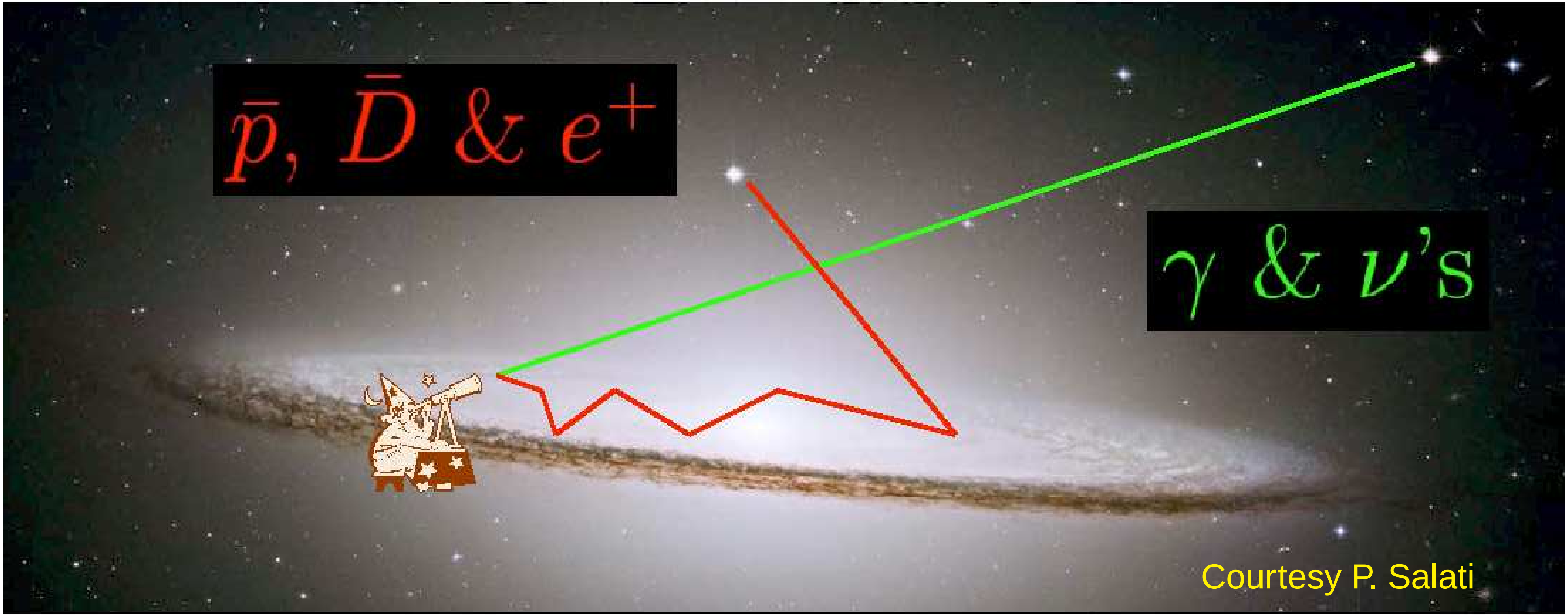
Collab: Delahaye, Salati, Taillet (LAPTH) - Maurin (LPNHE) - Nezri (LAM) - Bertone, Pieri (IAP)
Ling (Brussels) – Donato, Fornengo, Lineros (Turin) – Bi, Yuan (Beijing) – Bringmann (Stockholm)

Vth Patras Workshop — Durham

Tuesday, July 14th 2009

Indirect detection of Dark Matter

If dark matter is made of exotic annihilating or decaying particles, we might detect indirect signatures by means of astronomical devices

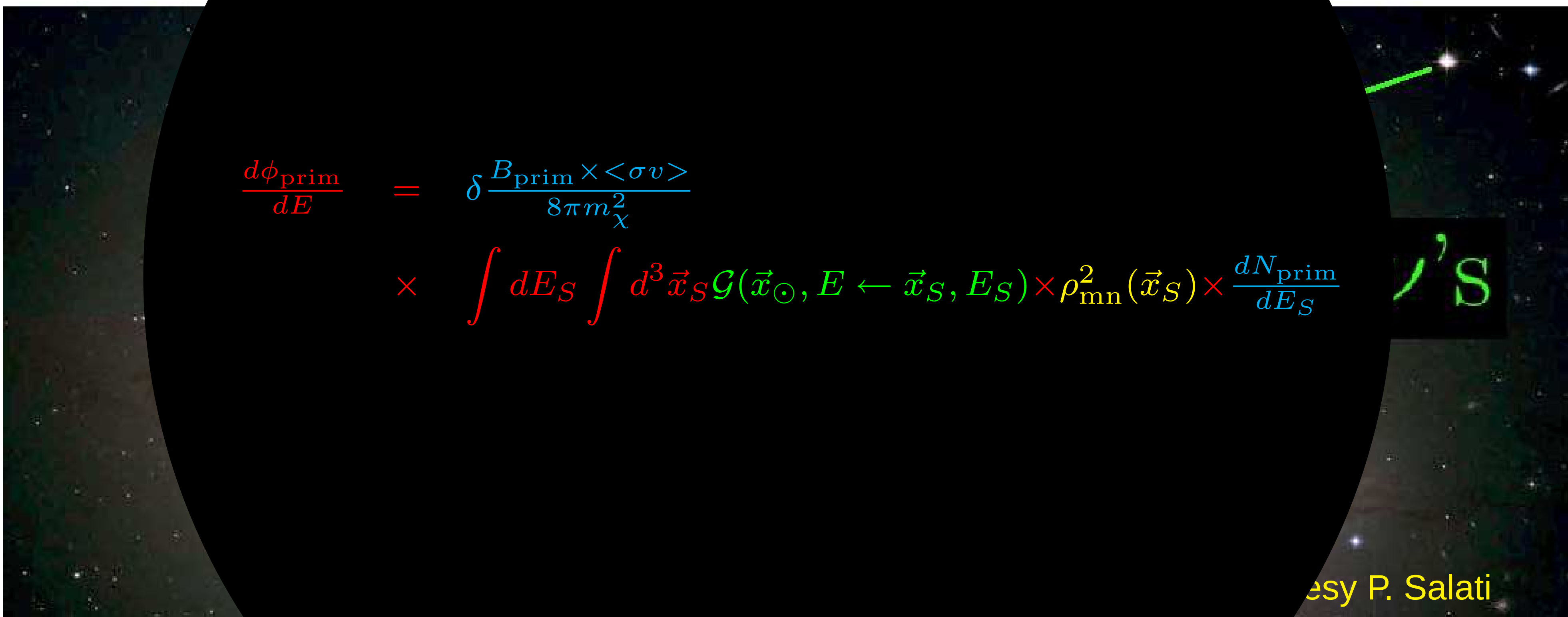


- γ and ν: travel directly from the source to the observer
- Antimatter cosmic rays: diffuse on the magnetic turbulences

$\Longrightarrow$ Needs of large DM density regions (Centers of galaxies)

[redacted] of Dark Matter

If dark matter [redacted]ht detect indirect signatures by [redacted]



$$\frac{d\phi_{\rm prim}}{dE} = \delta \frac{B_{\rm prim}\times<\sigma v>}{8\pi m_\chi^2}$$

$$\times \int dE_S \int d^3\vec{x}_S \, \mathcal{G}(\vec{x}_\odot, E\leftarrow \vec{x}_S, E_S)\times\rho^2_{\rm mn}(\vec{x}_S)\times\frac{dN_{\rm prim}}{dE_S}$$

- **γ and ν: tr** [redacted] **to the observ** [redacted] **l density regions** [redacted] **es)**
- **Antimatter cosmic** [redacted] **magnetic turbulences**

... of Dark Matter

Decaying DM:
See next talk by C. Weniger

... ht detect indirect

Flux measurements:
PAMELA satellite — antimatter (ongoing)
Fermi satellite — γ-rays (ongoing)
AMS-02 (2010 ?)
background predictions

BSM particle physics:
SUSY, KK, etc.

$$\frac{d\phi_{\rm prim}}{dE} = \delta\frac{B_{\rm prim}\times\langle\sigma v\rangle}{8\pi m_\chi^2}$$

$$\times \int dE_S \int d^3\vec{x}_S\,\mathcal{G}(\vec{x}_\odot, E \leftarrow \vec{x}_S, E_S)\times\rho_{\rm mn}^2(\vec{x}_S)\times\frac{dN_{\rm prim}}{dE_S}$$

... ’s

Dark matter distribution:
Prescriptions from N-body cosmological simulation
Found to not be smooth: clumpiness effects ?

... esy P. Salati

- γ and ν: tr... to the observ...
- Antimatter cosmic ... magnetic turbulences

... density regions ... es)

Propagation Green function
(merely $\frac{1}{4\pi r^2}$ for γ-rays)

of Dark Matter

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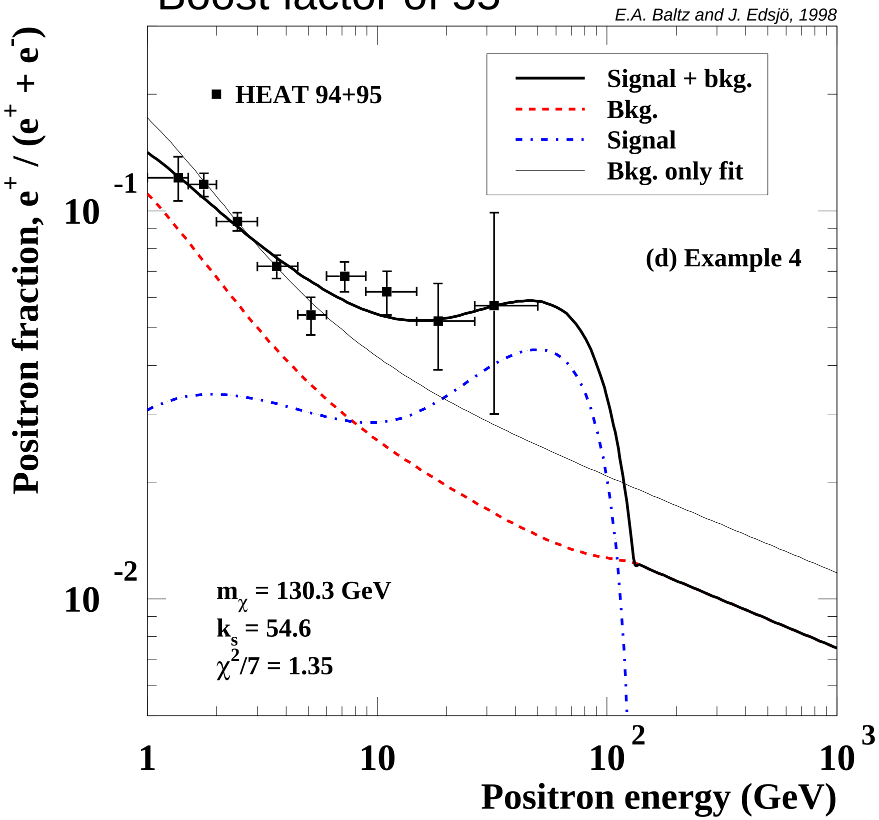
background prediction

Baltz & Edsjö, 98

Boost factor of 55



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K, etc.

$\frac{d\phi_{\rm prim}}{dE}$

$s) \times \frac{dN_{\rm prim}}{dE_S}$

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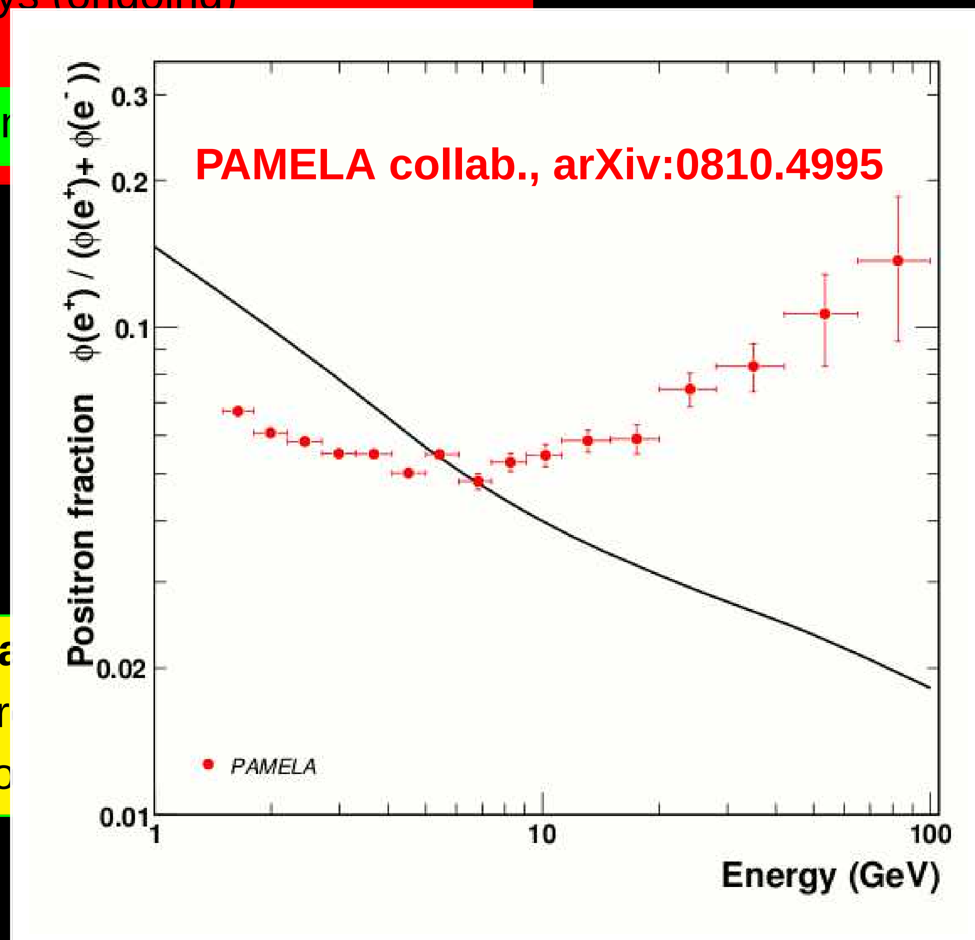

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- **γ and ν: tr...**
  to the observ...

(merely $\frac{1}{4\pi r^2}$ for γ-rays)

...l density regions
...es)

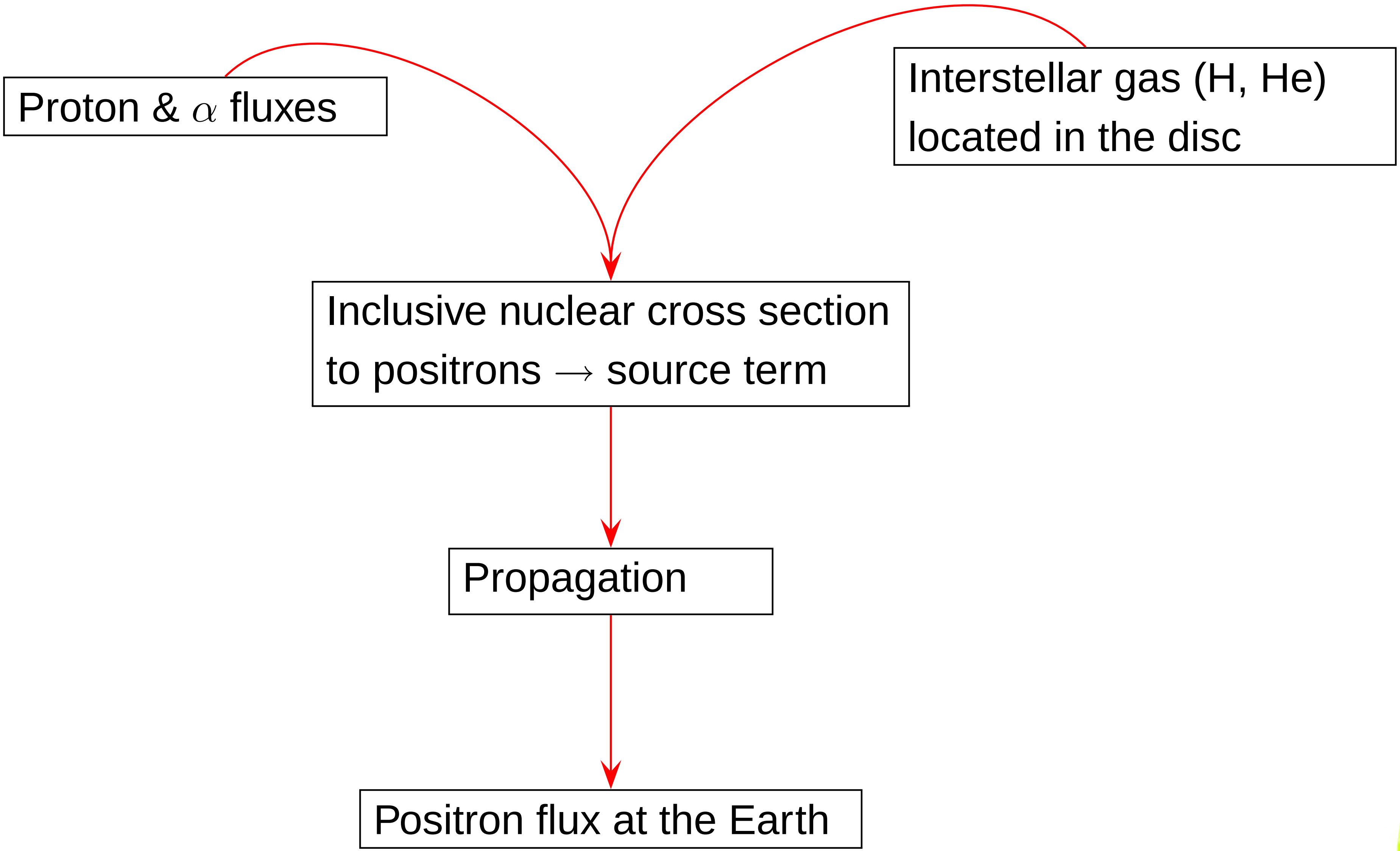
- **Antimatter cosmic ...**
  magnetic turbulences

On the positron fraction

Before inferring an excess from the data, one needs to:

- properly estimate the secondary positron background;
- properly measure the electron flux (prediction not necessary if measurements!!!);
- ++++ theoretical uncertainties !!!

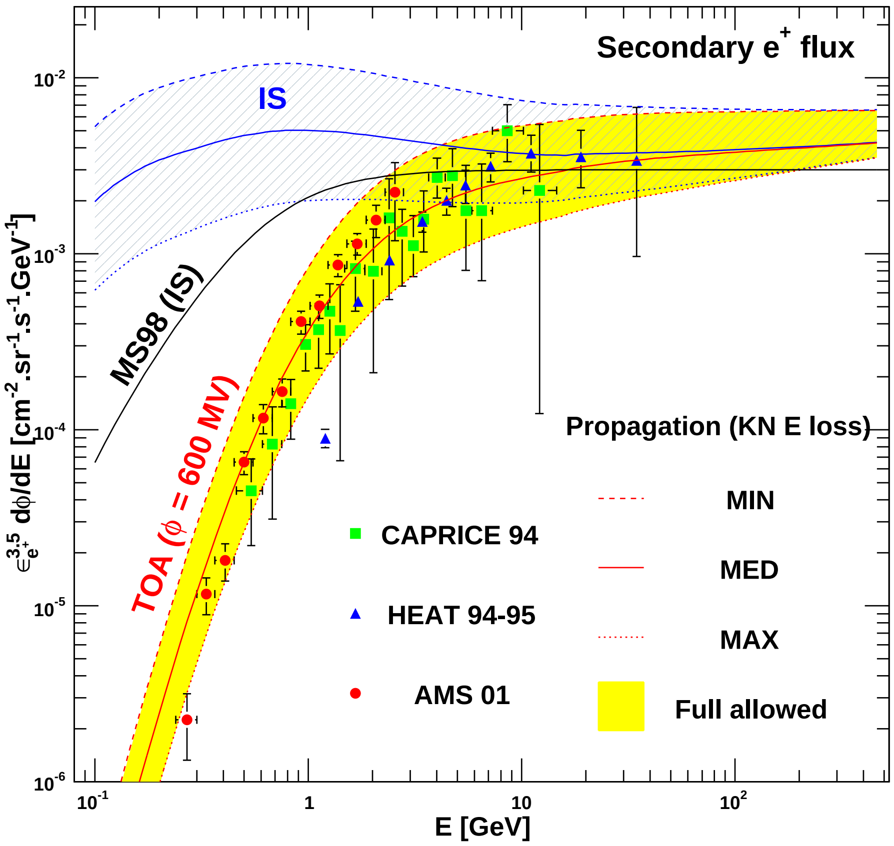
Short recipe for secondary positrons

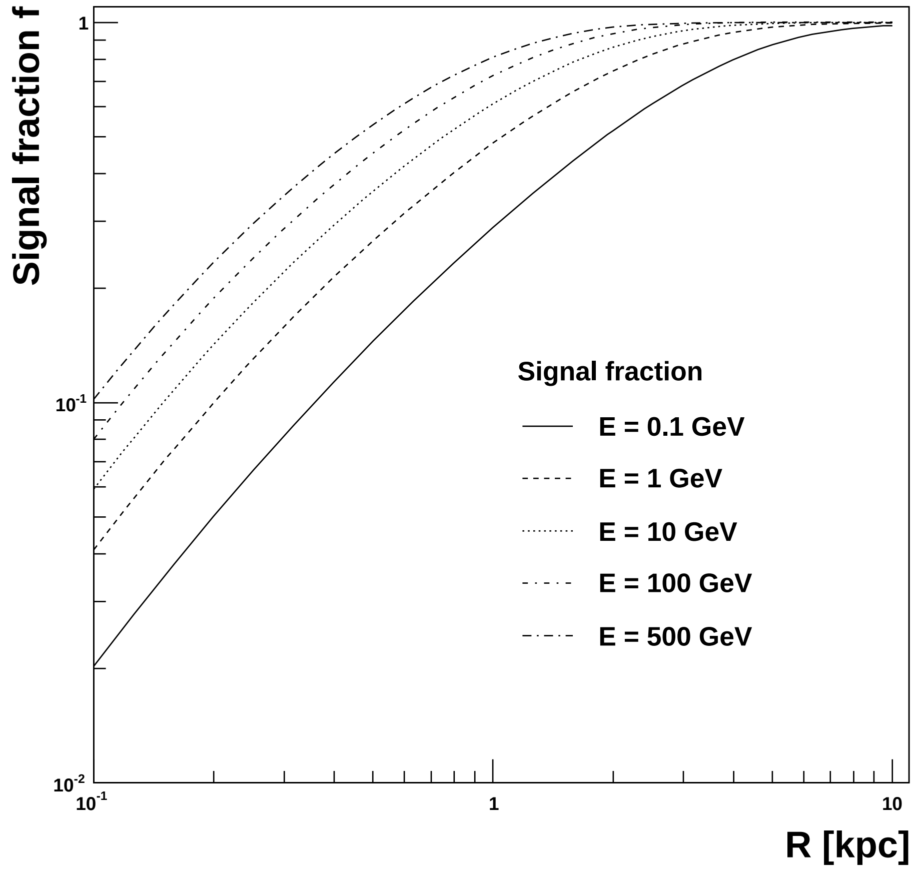


PAMELA: to predict the e^+ fraction, we need e^-s!

The Alpine connection e^+ background (Annecy & Torino)

Delahaye et al, arXiv:0809.5268





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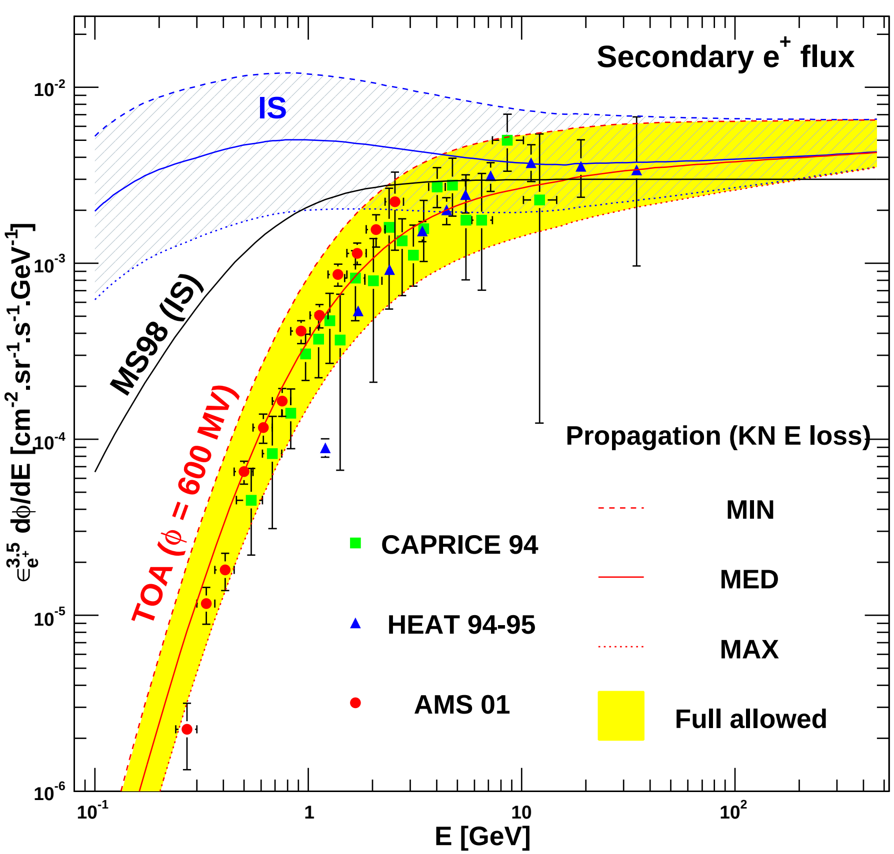

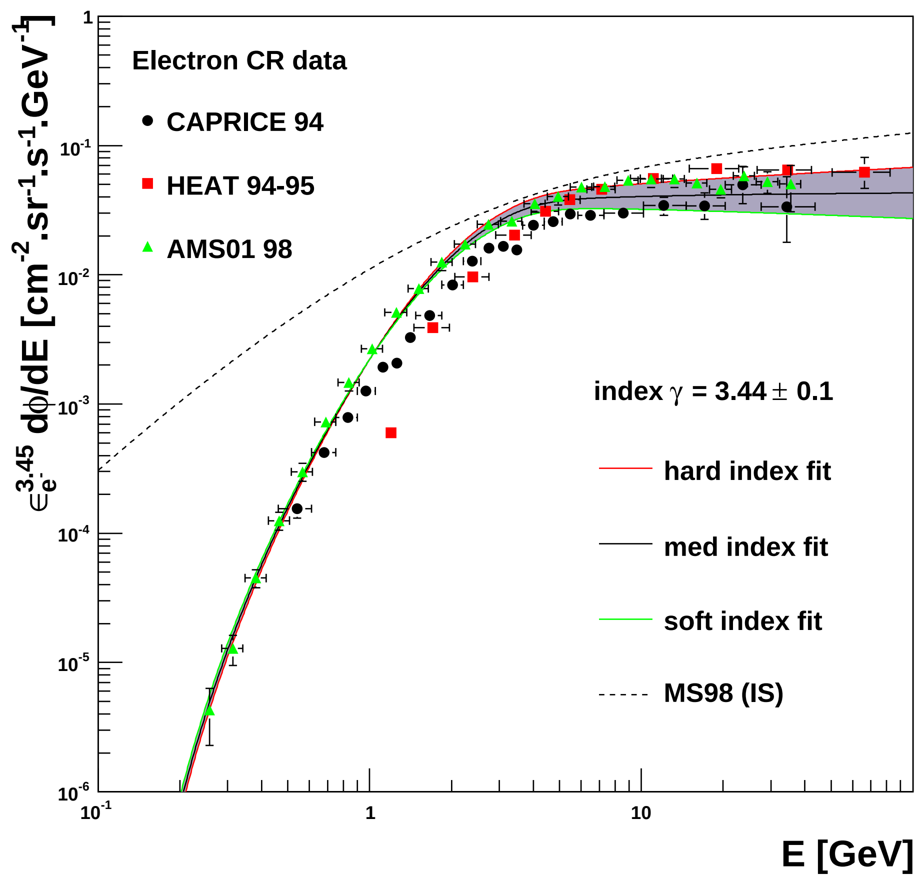

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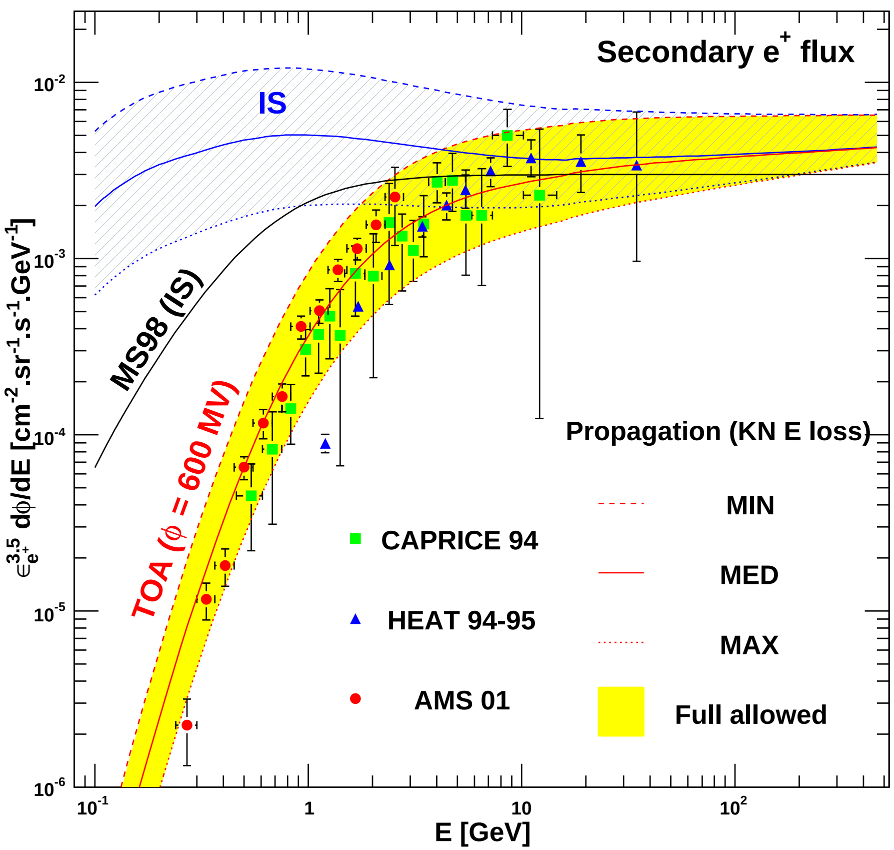

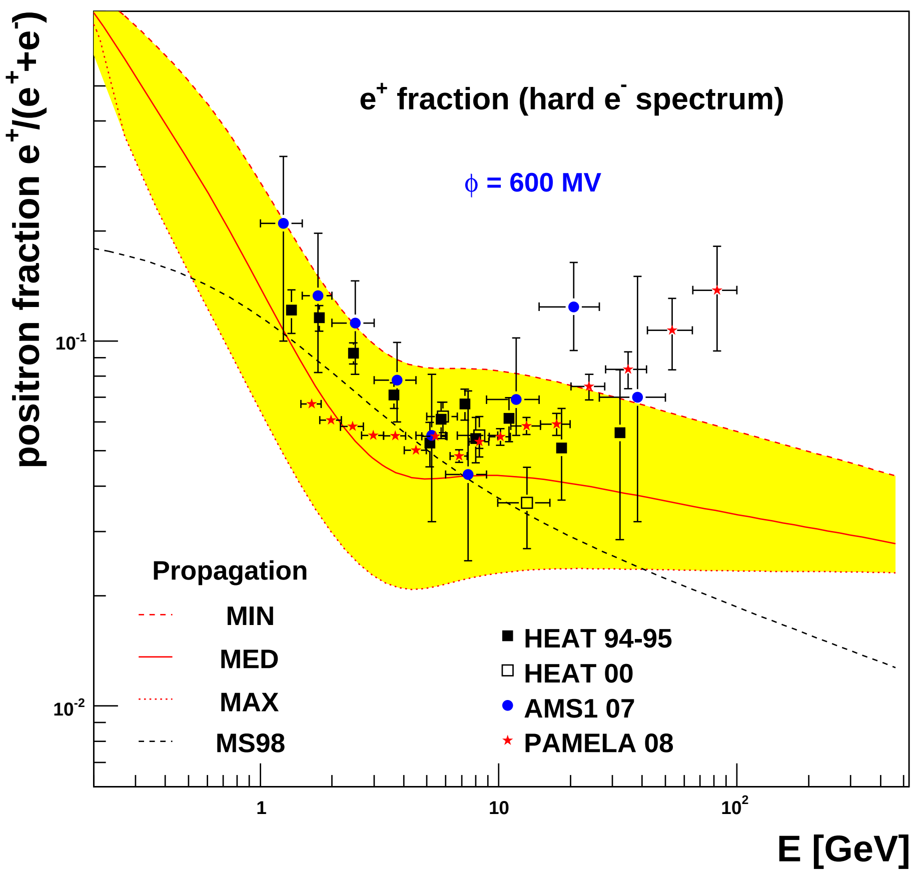

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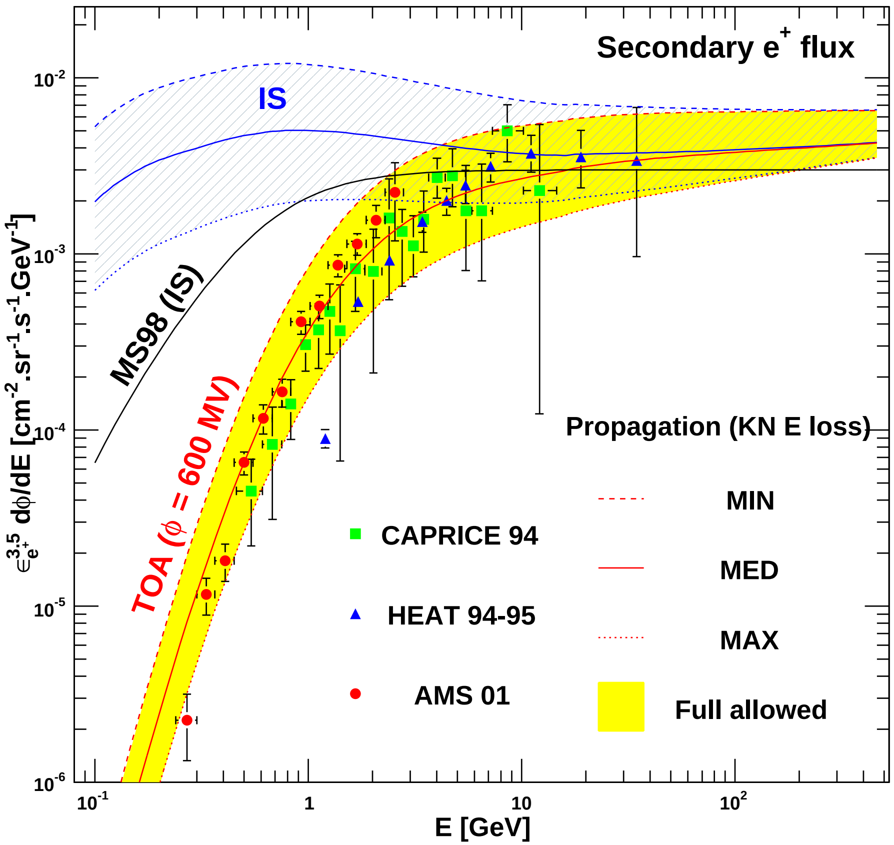

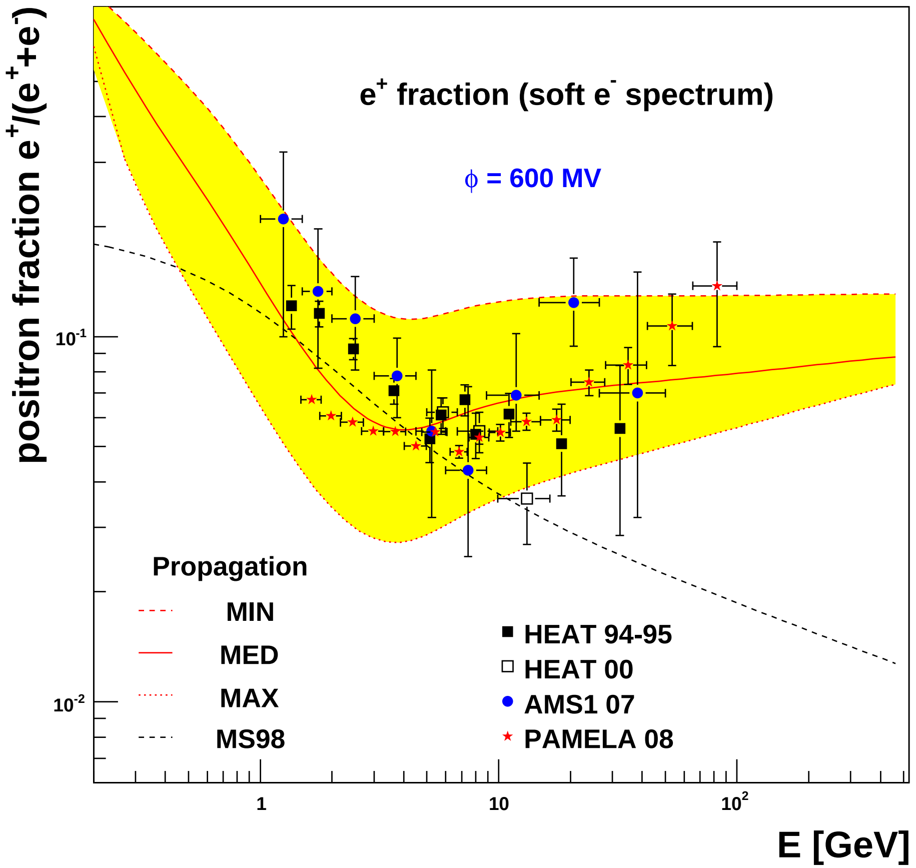

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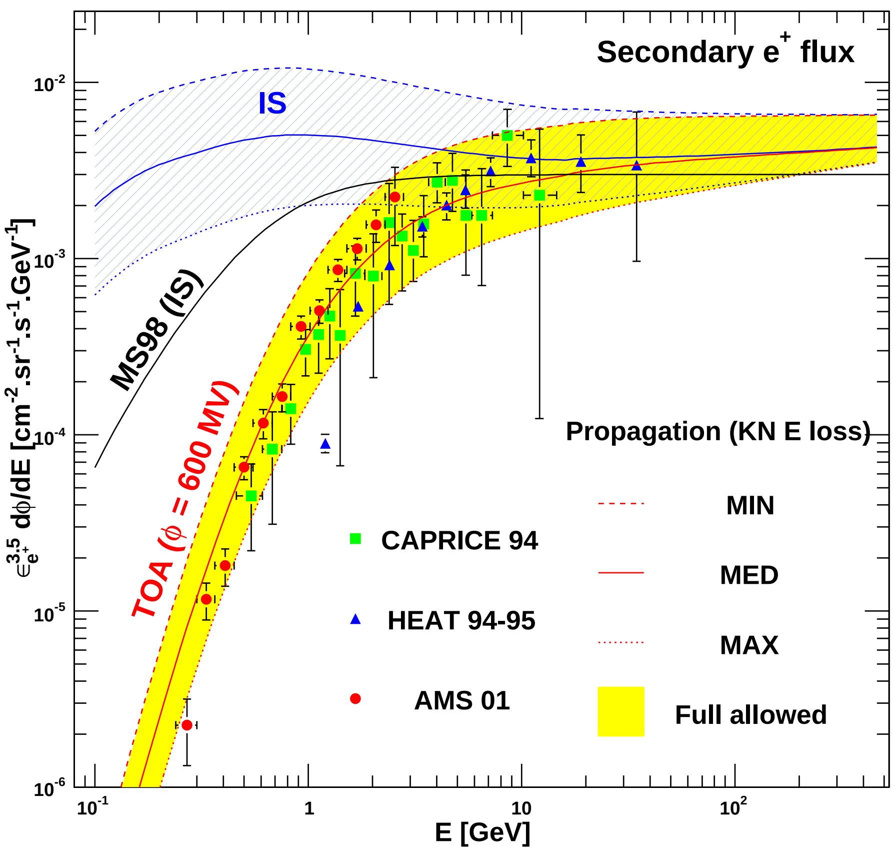

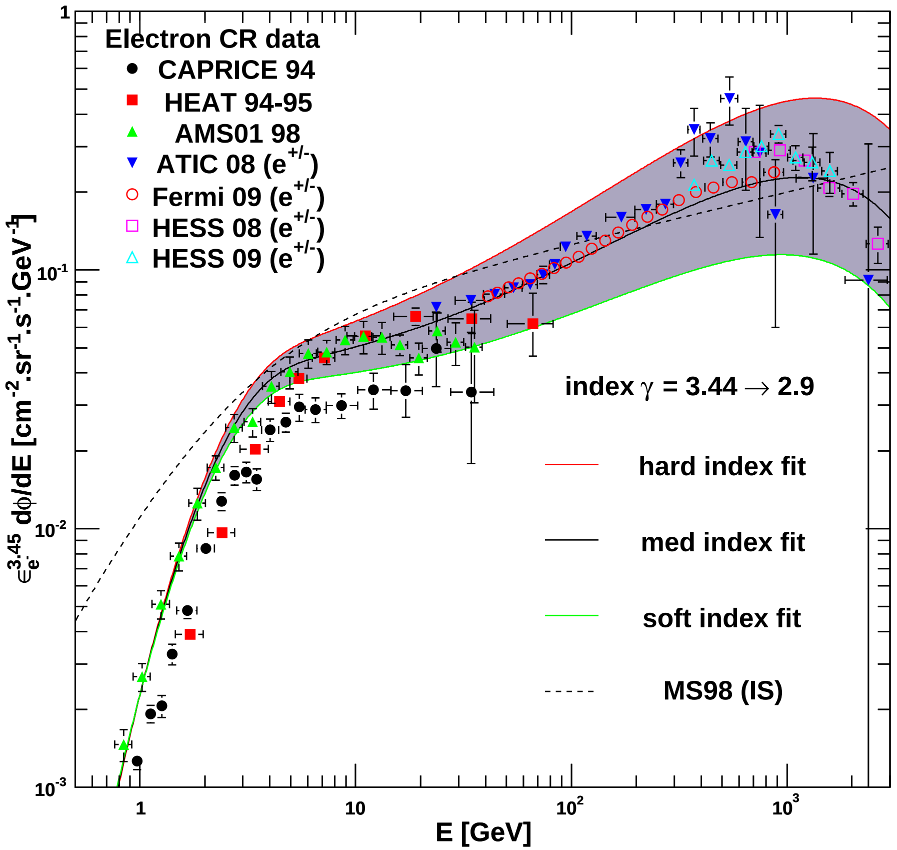

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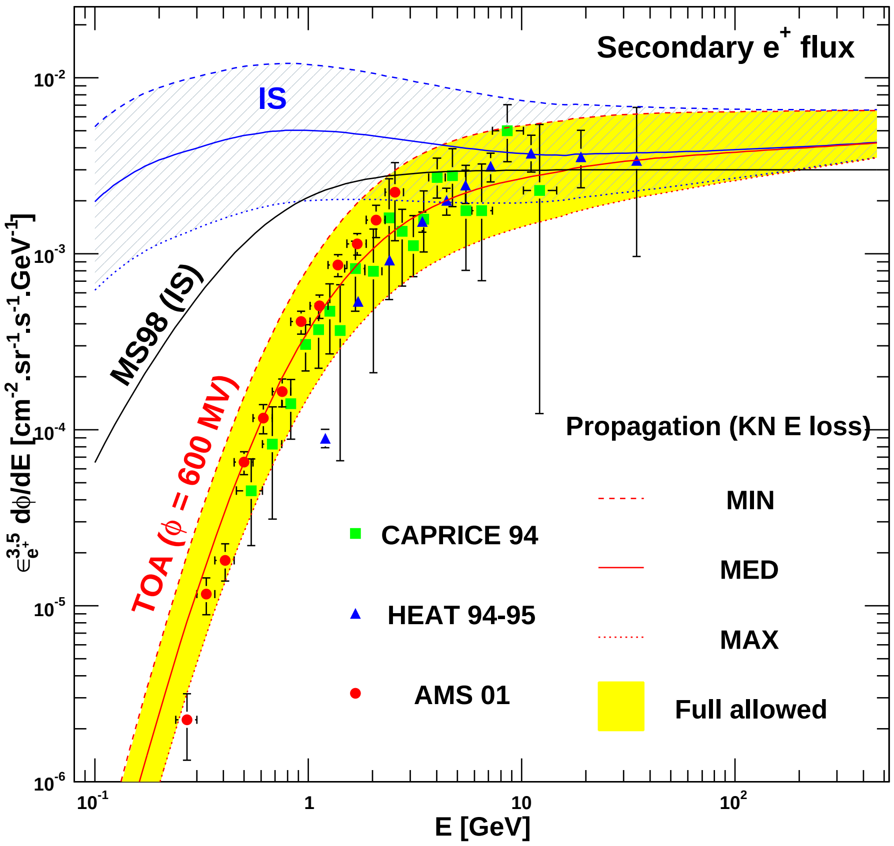

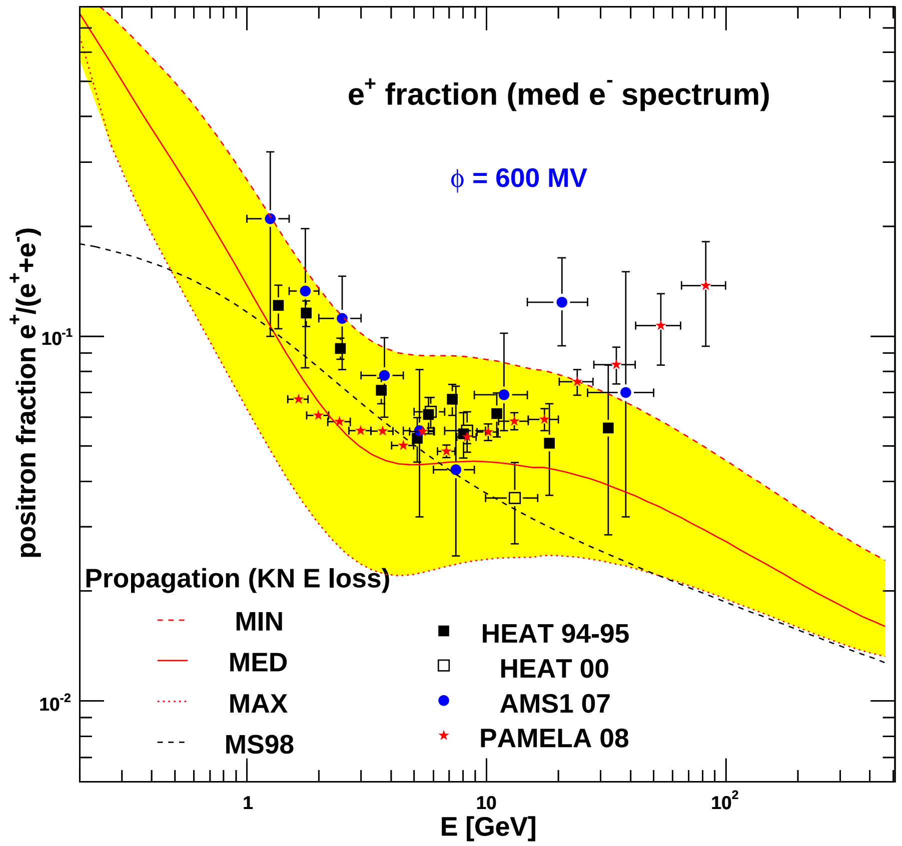

PAMELA excess: standard astrophysical sources?

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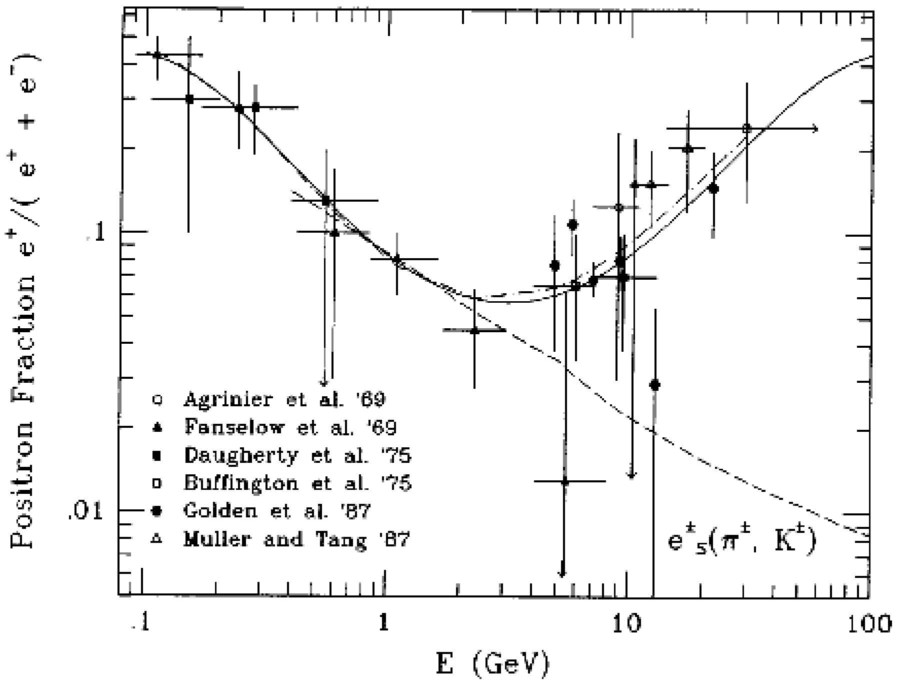
THE ASTROPHYSICAL JOURNAL, 342:807–813, 1989 July 15

THE NATURE OF THE COSMIC-RAY ELECTRON SPECTRUM, AND SUPERNOVA REMNANT CONTRIBUTIONS

AHMED BOULARES
Physics Department, Space Physics Laboratory, University of Wisconsin–Madison
Received 1988 October 24; accepted 1988 December 29

BOULARES



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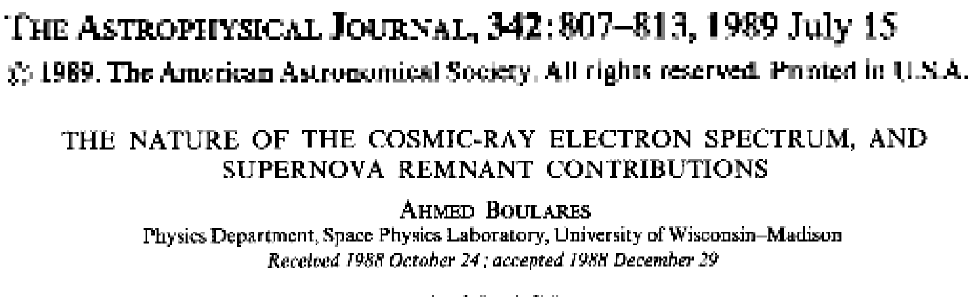
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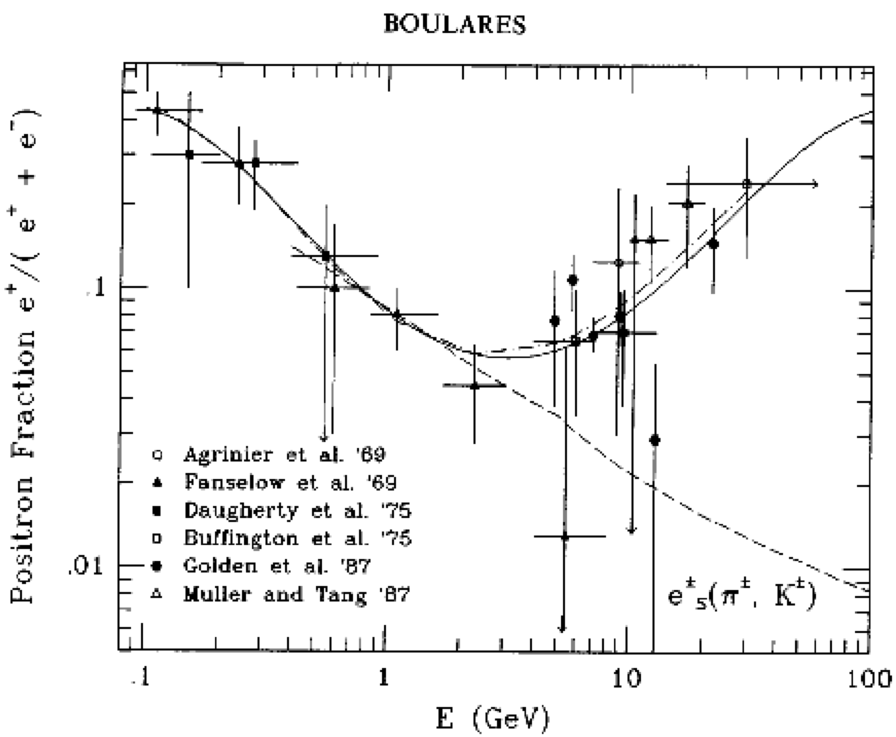
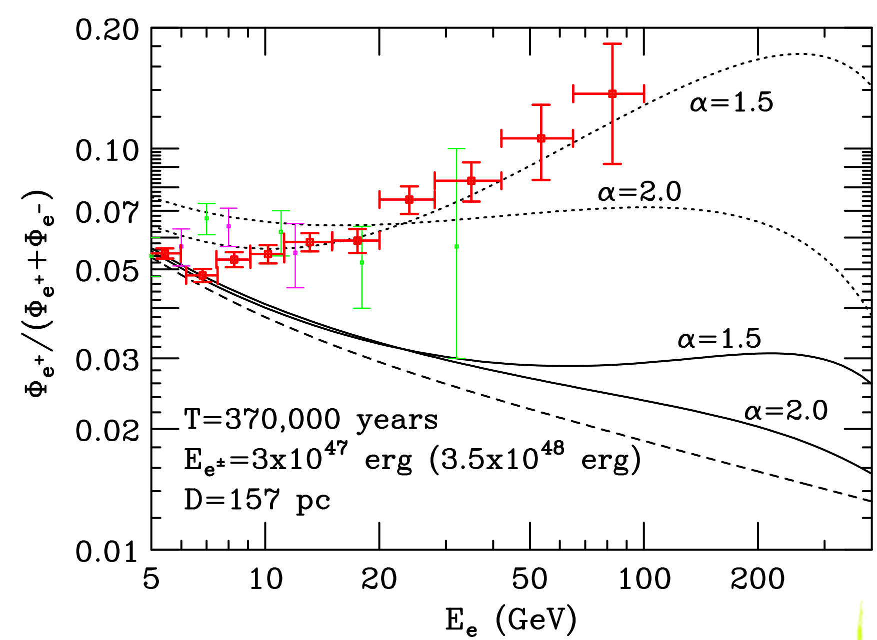


Hooper et al arXiv:0810.1527



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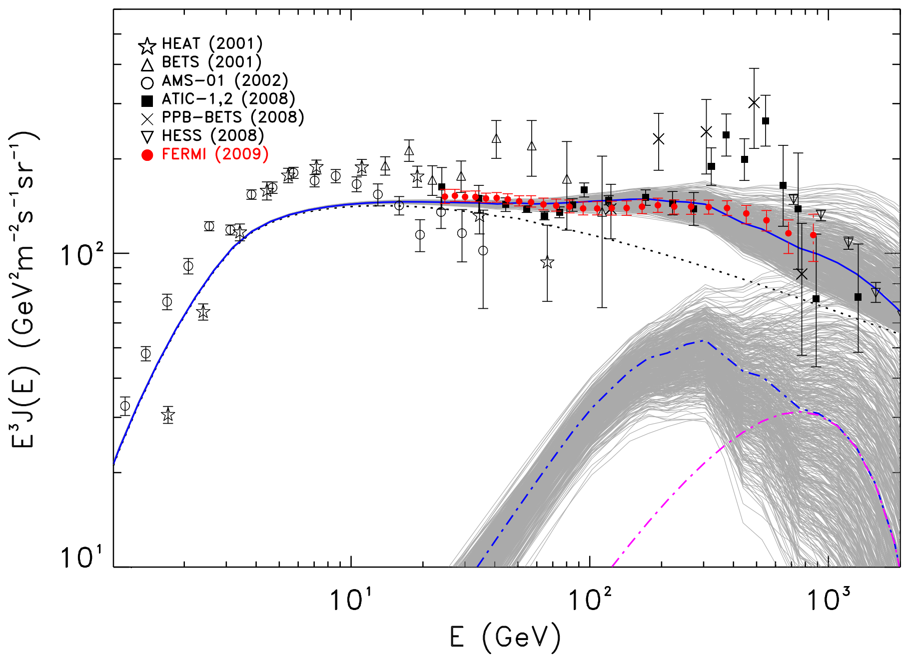
Fermi Collab + Grasso et al (2009)



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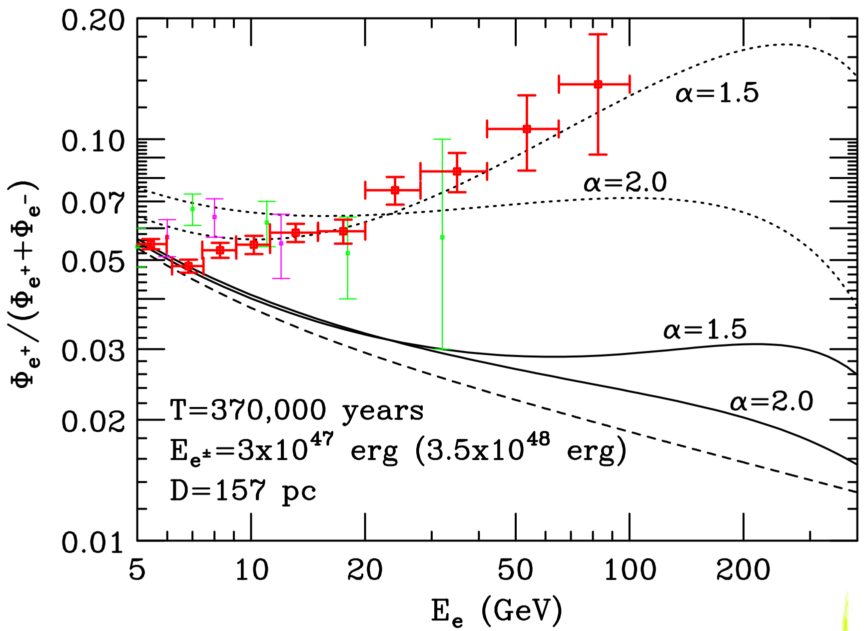

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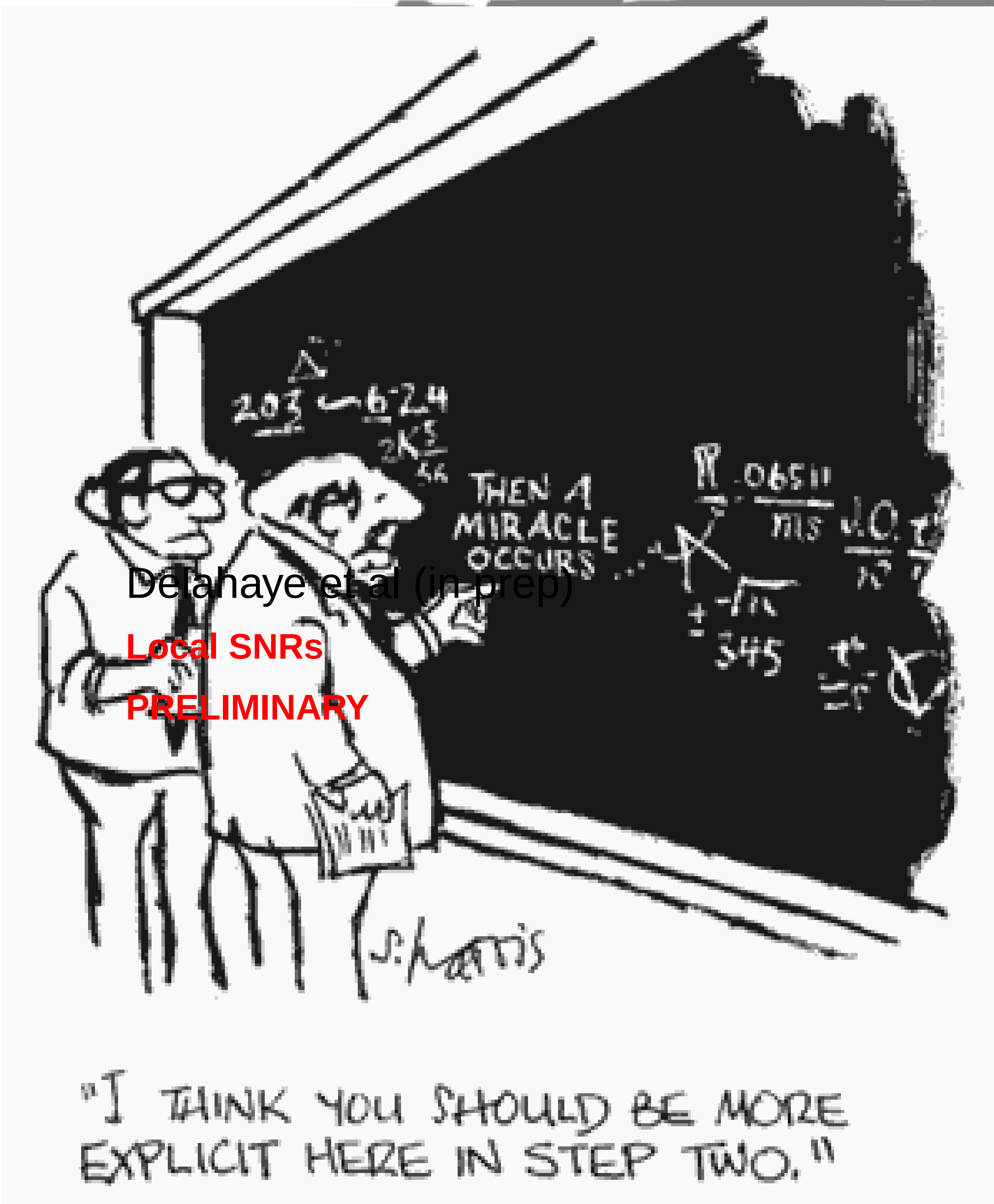

Delahaye et al (in prep)

Local SNRs

PRELIMINARY

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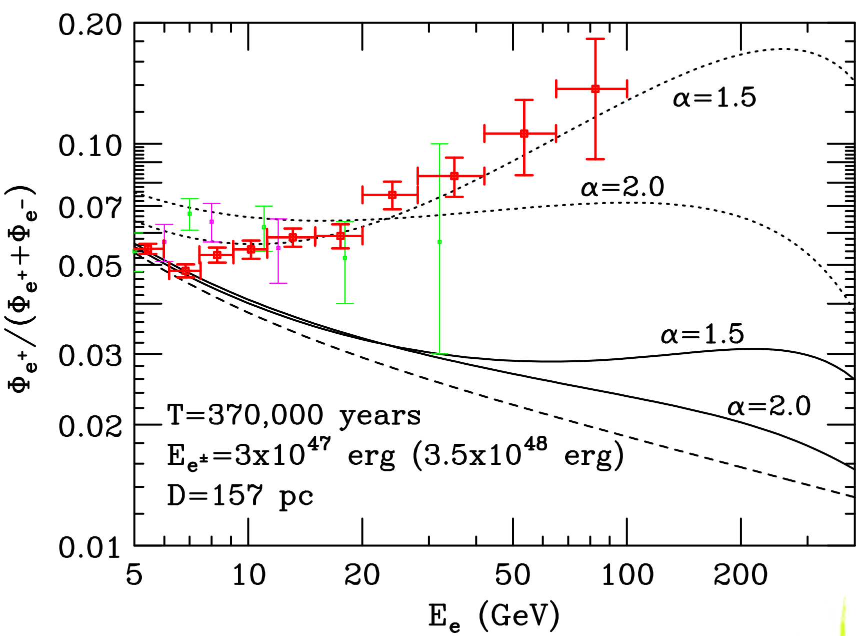
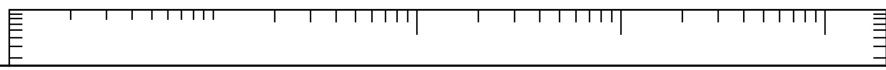


Generic predictions for annihilating WIMPs

Generic predictions for annihilating WIMPs



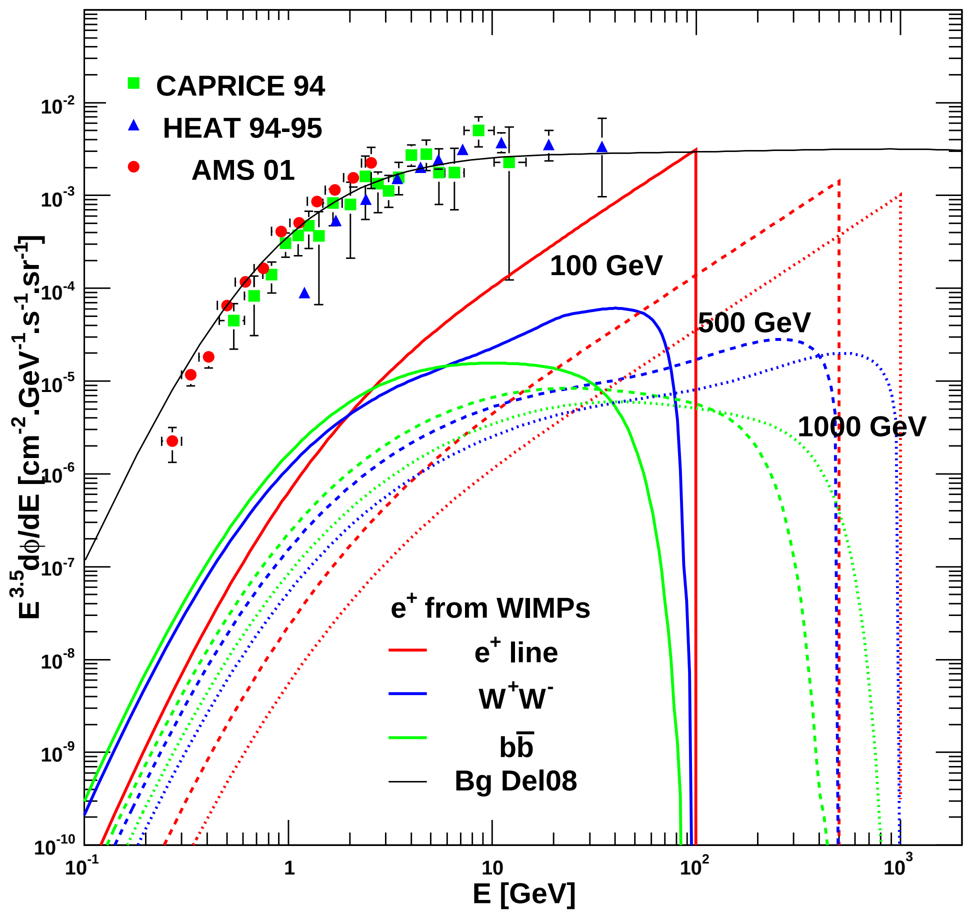
Orders of magnitude for $\chi\chi \rightarrow e^+e^-$ (for $E \rightarrow m_\chi = 100$ GeV).

From PAMELA, the excess is $\lesssim 5 - 10 \times \phi_{\rm bg}(100\ {\rm GeV}) \sim 1.5 - 3.0 \cdot 10^{-9}{\rm cm}^{-2}.{\rm s}^{-1}.{\rm GeV}^{-1}.{\rm sr}^{-1}$.

$$
\begin{aligned}
\phi_{\rm bg}(100\ {\rm GeV}) &\simeq 3 \cdot 10^{-10} \left(\frac{E}{100\ {\rm GeV}}\right)^{-3.5} {\rm cm}^{-2}.{\rm s}^{-1}.{\rm GeV}^{-1}.{\rm sr}^{-1} \\
\phi_{\chi\chi}(E \rightarrow m_\chi) &\simeq \frac{\delta\beta c}{4\pi} \frac{\tau_{\rm loss} E_0}{E^2} \frac{\langle\sigma v\rangle}{2} \left(\frac{\rho_\odot}{m_\chi}\right)^2 \\
&\simeq 3 \cdot 10^{-10} \left(\frac{\tau_{\rm loss}}{10^{16}{\rm s}}\right) \left(\frac{\rho_\odot}{0.3\ {\rm GeV/cm}^3}\right) \left(\frac{100\ {\rm GeV}}{m_\chi}\right)^4 \left(\frac{\langle\sigma v\rangle}{3 \cdot 10^{-26}{\rm cm}^3/{\rm s}}\right)
\end{aligned}
$$

For $\chi\chi \rightarrow e^+e^-$ and $m_\chi \simeq 100$ GeV, need for an enhancement of: $\mathcal{B} \simeq 5 - 10$.

Generic predictions for annihilating WIMPs



Boost to get $\sim 5 - 10 \times \phi_{\rm bg}$ **at ∼100 GeV**:

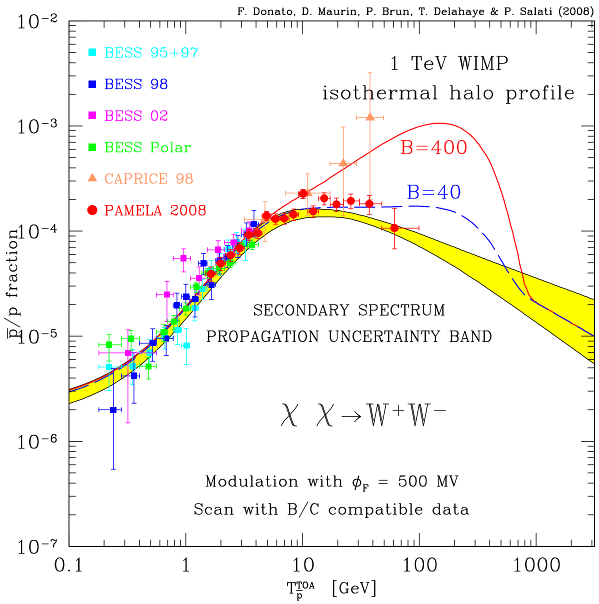
WIMP mass final state	100 GeV	500 GeV	1 TeV
e^+e^-	5-10	100	350
W^+W^-	100	500	1000
$b\bar{b}$	250	500	1000

PAMELA excess: dark matter?

Possible, but **needs huge annihilation rate**. Several limits exists.

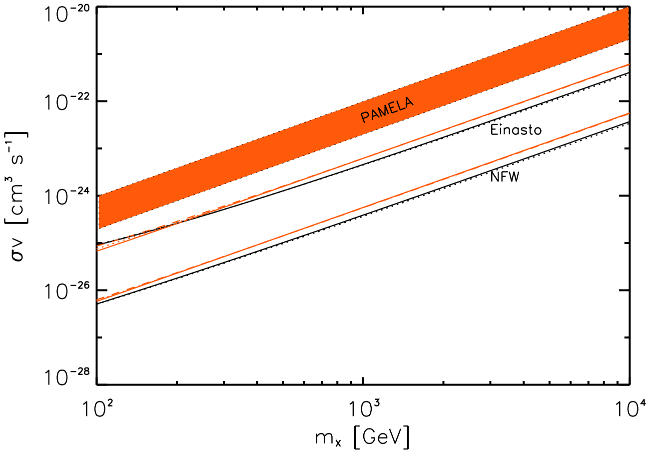
If dark matter annihilates into quarks or heavy bosons

- gamma-rays (next slide)
- antiprotons
  (cf Donato et al arXiv:0810.5292)



If dark matter annihilates into leptons:

- gamma-rays (cf next slide)
- radio emission from GC
  (cf Bergström et al arXiv:0812.3895)



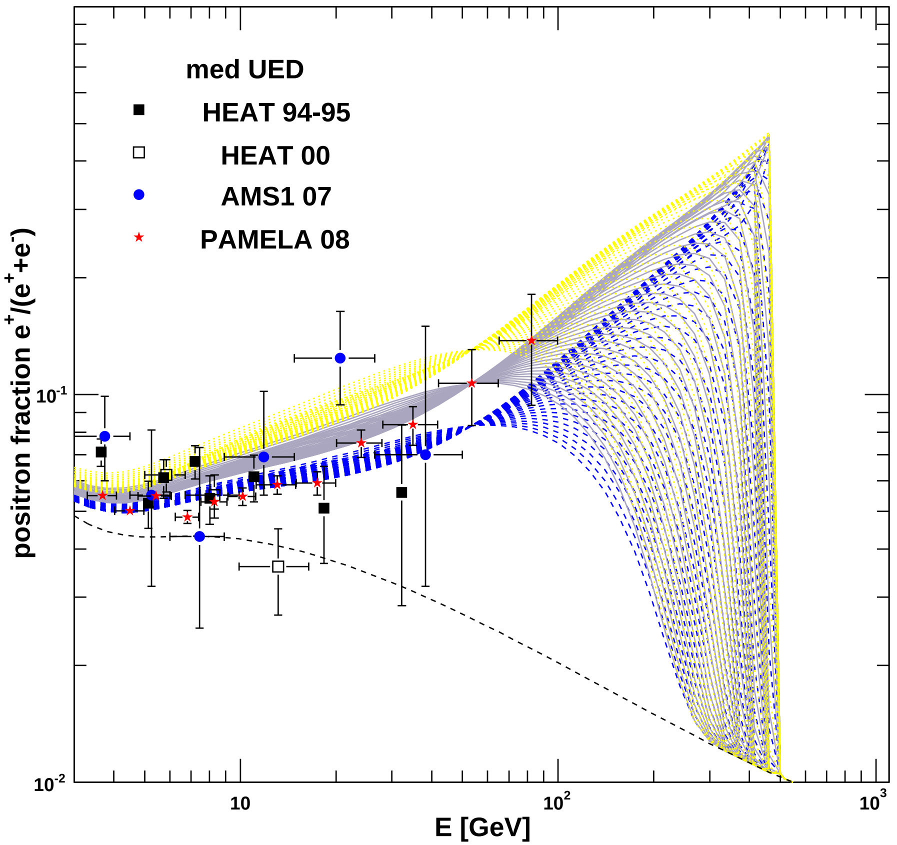
In any case, boosting the annihilation rate without fine-tuning is a serious issue.

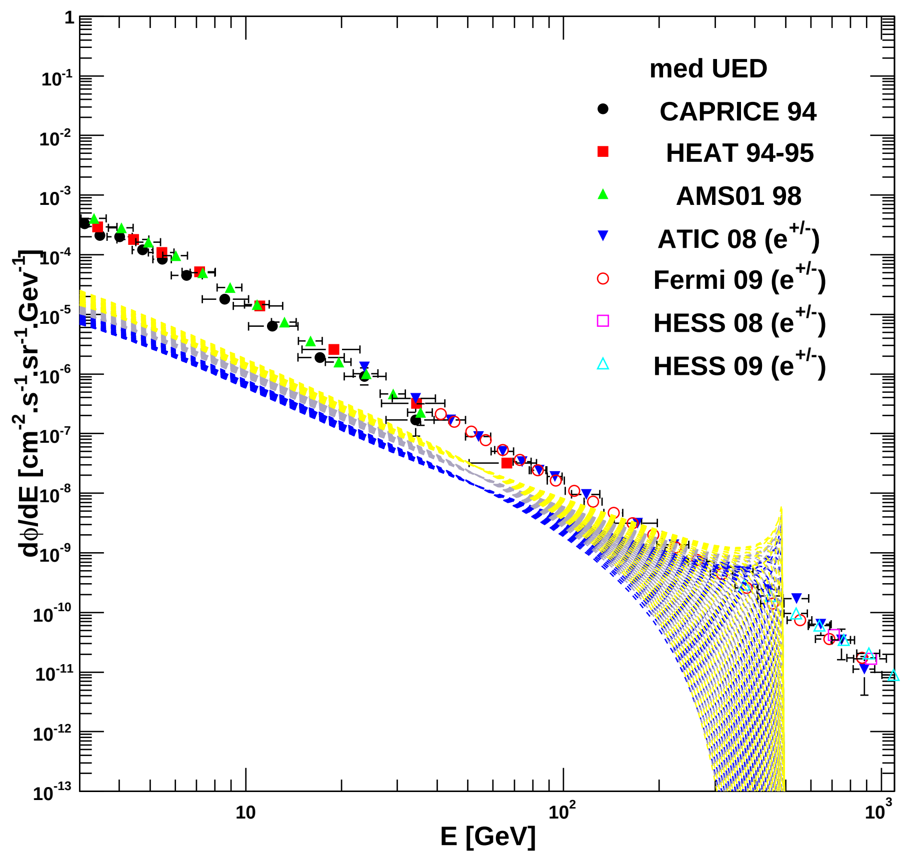
PAMELA excess: nearby dark sources?

Dark point sources (IMBHs, big clumps) ...

but conventional scenarios **excluded by EGRET+Fermi**

Single DM object wandering around





Bringmann, Lavalle & Salati arXiv:0902.3665

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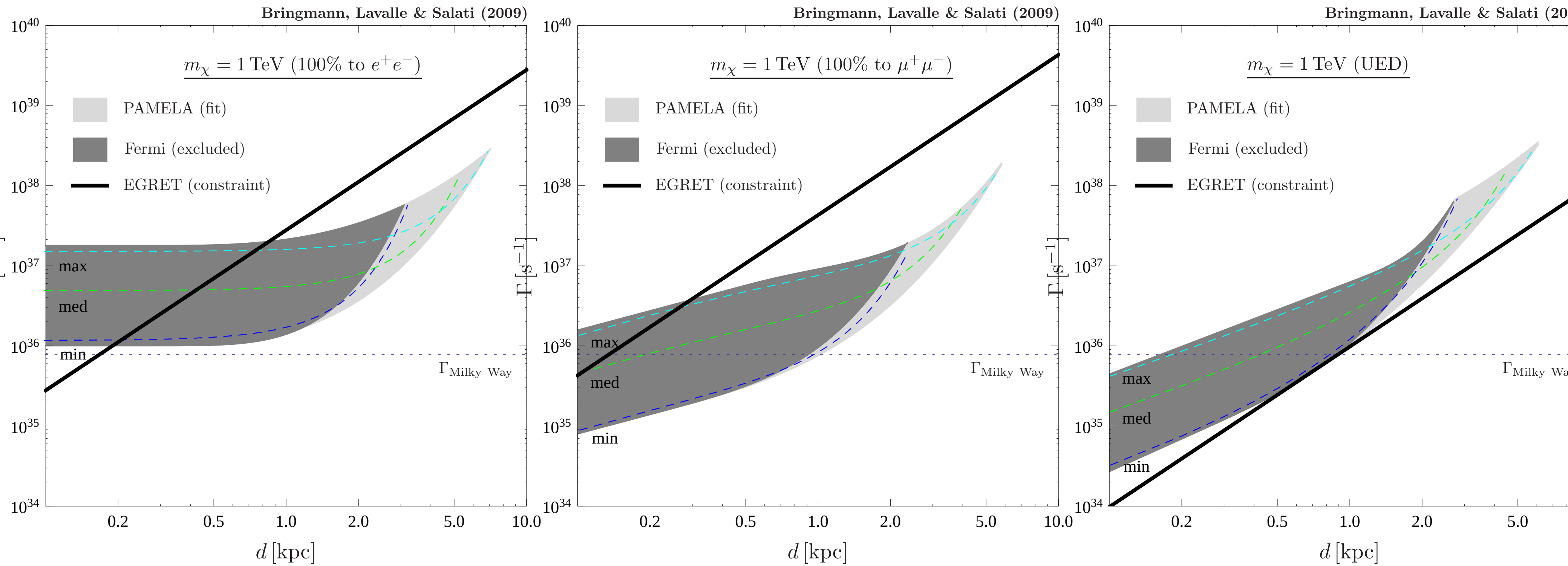
Any single DM object wandering around



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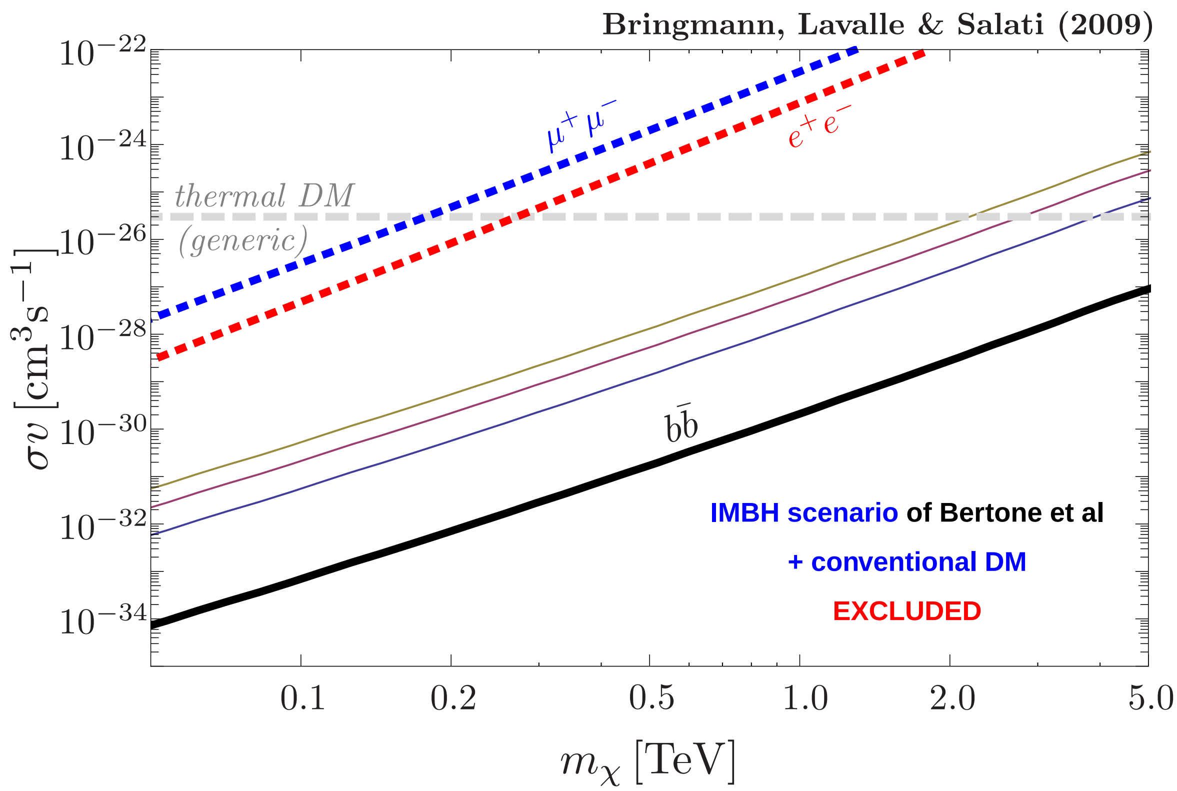

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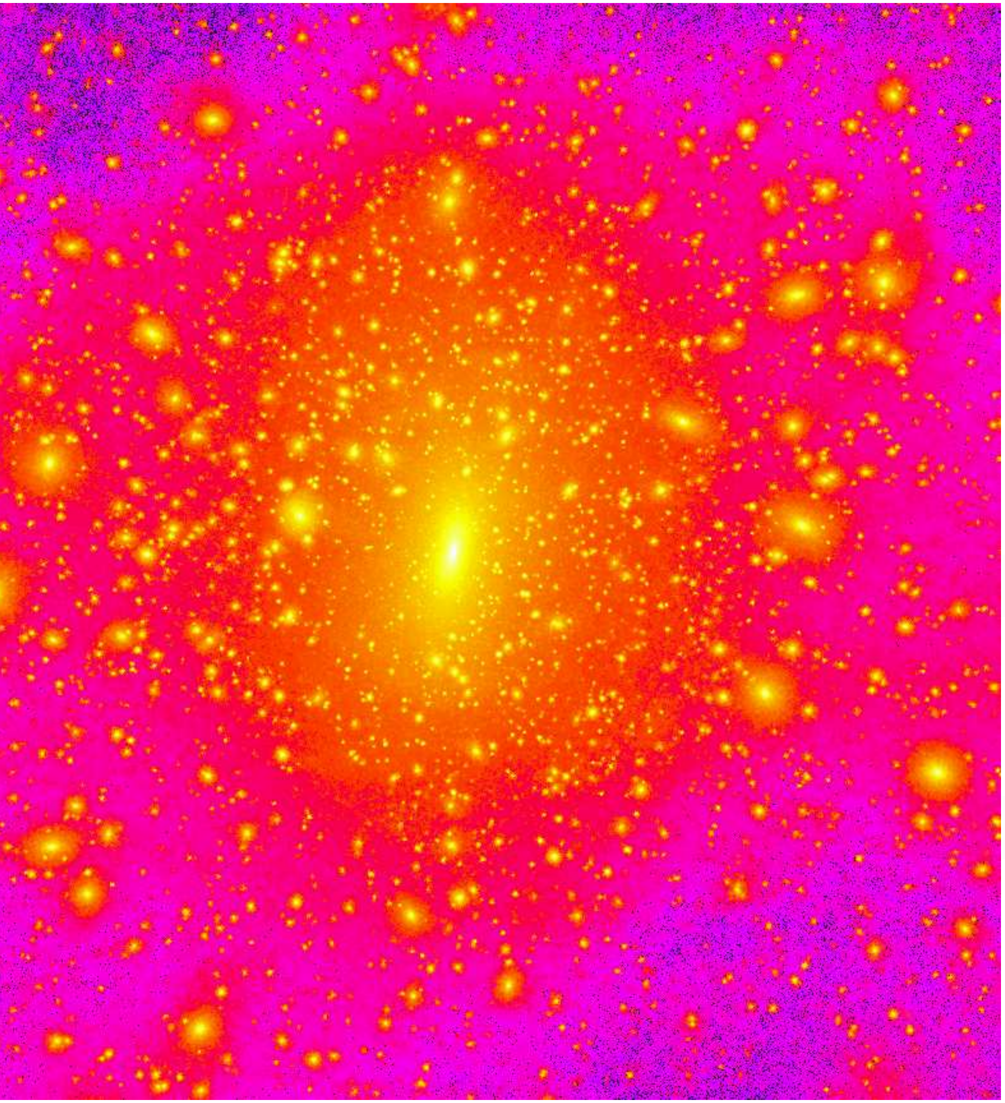
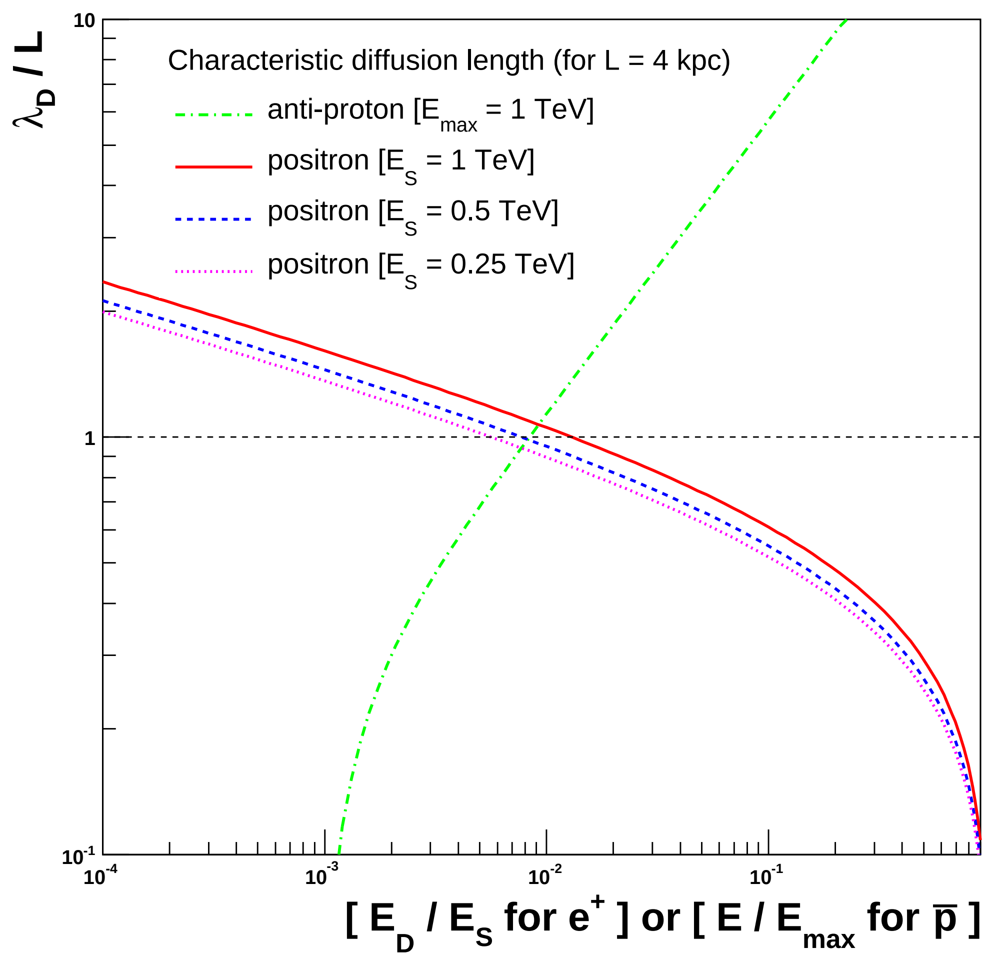
The Clumpiness issue



(Fig. from Diemand et al, MNRAS'04)

- Though the topic is controversial, **clumps are predicted by theory and simulations of hierarchical formation of structures** (in the frame of ΛCDM)
- Annihilation rate is increased in a characteristic volume, because $< n_{\rm dm}^2 > \geq < n_{\rm dm} >^2$ (Silk & Stebbins ApJ'93)
- The boost factor to the annihilation rate is related to the statistical variance via $B_{\rm ann} \sim \frac{< n_{\rm dm}^2 >}{< n_{\rm dm} >^2}$
- **There is some scatter in N-body experiments: how to translate theoretical uncertainties to flux uncertainties ? what and where are the less ambiguous signatures, if so ?**

The Clumpiness issue



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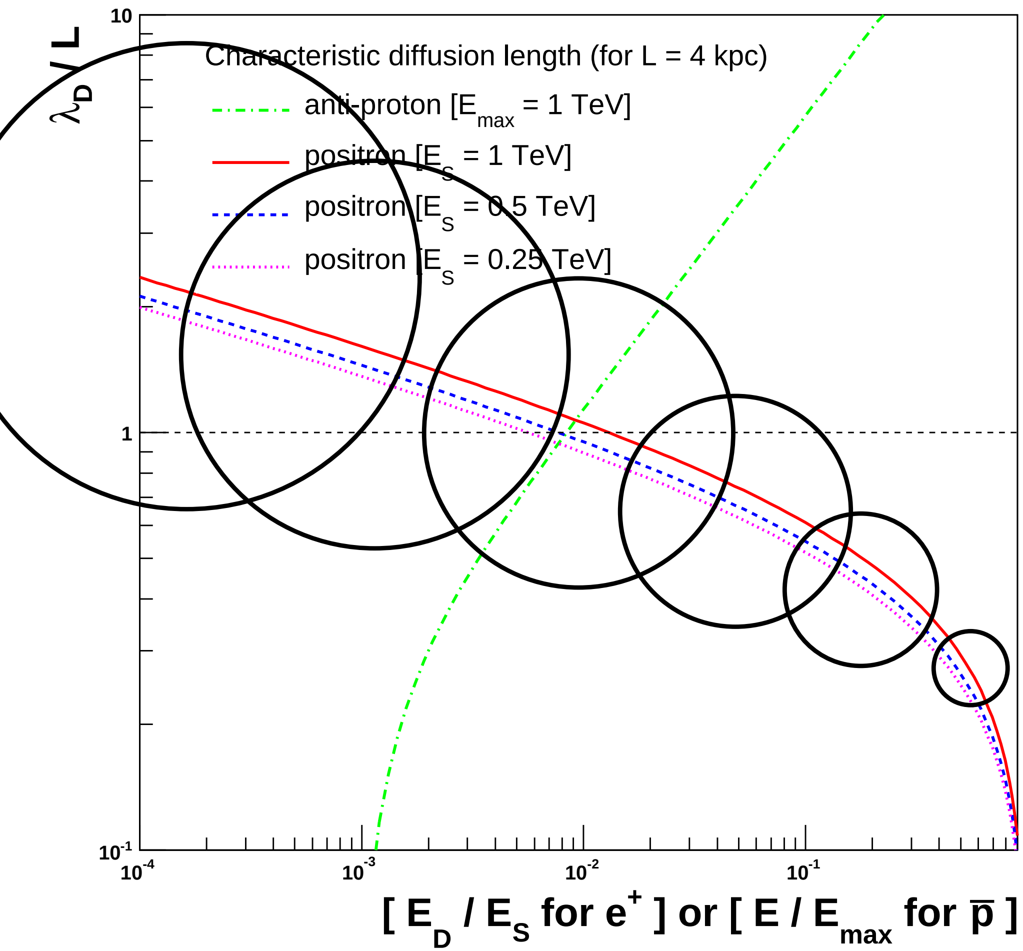
The Clumpiness issue

BOOST FOR CRs $\neq$ BOOST FOR γ-rays!!!!



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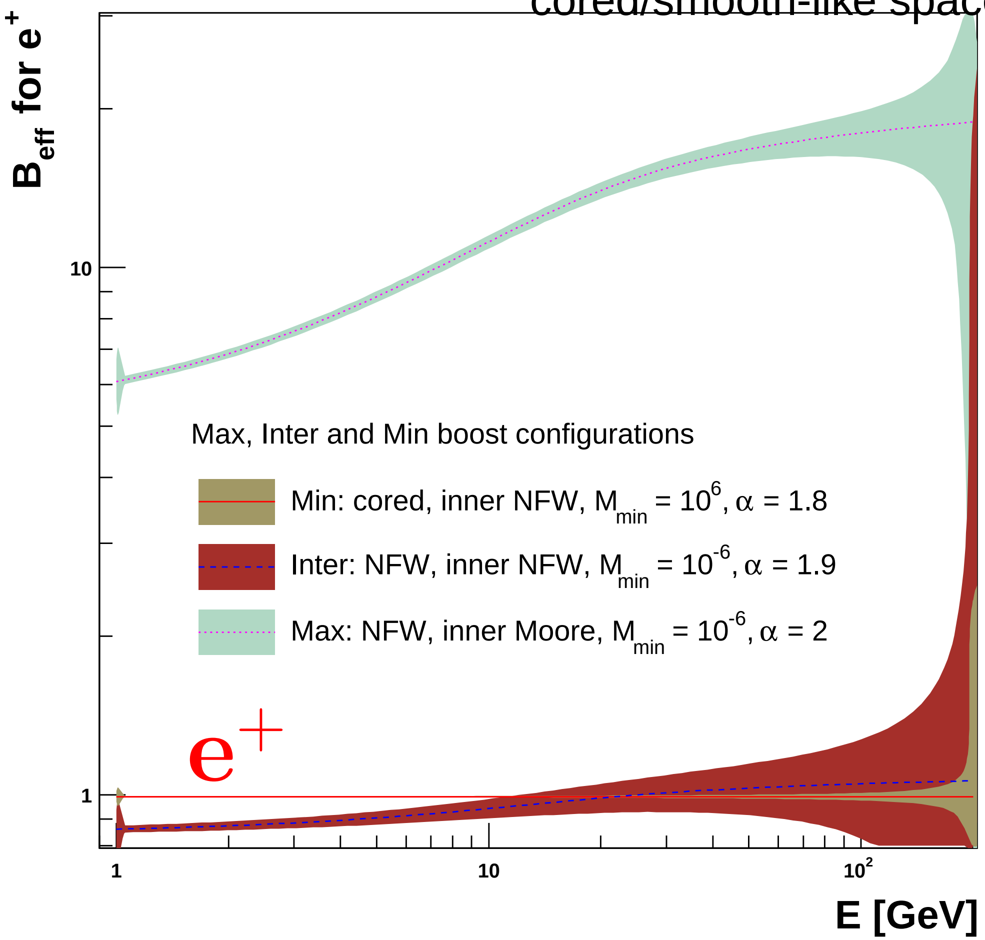
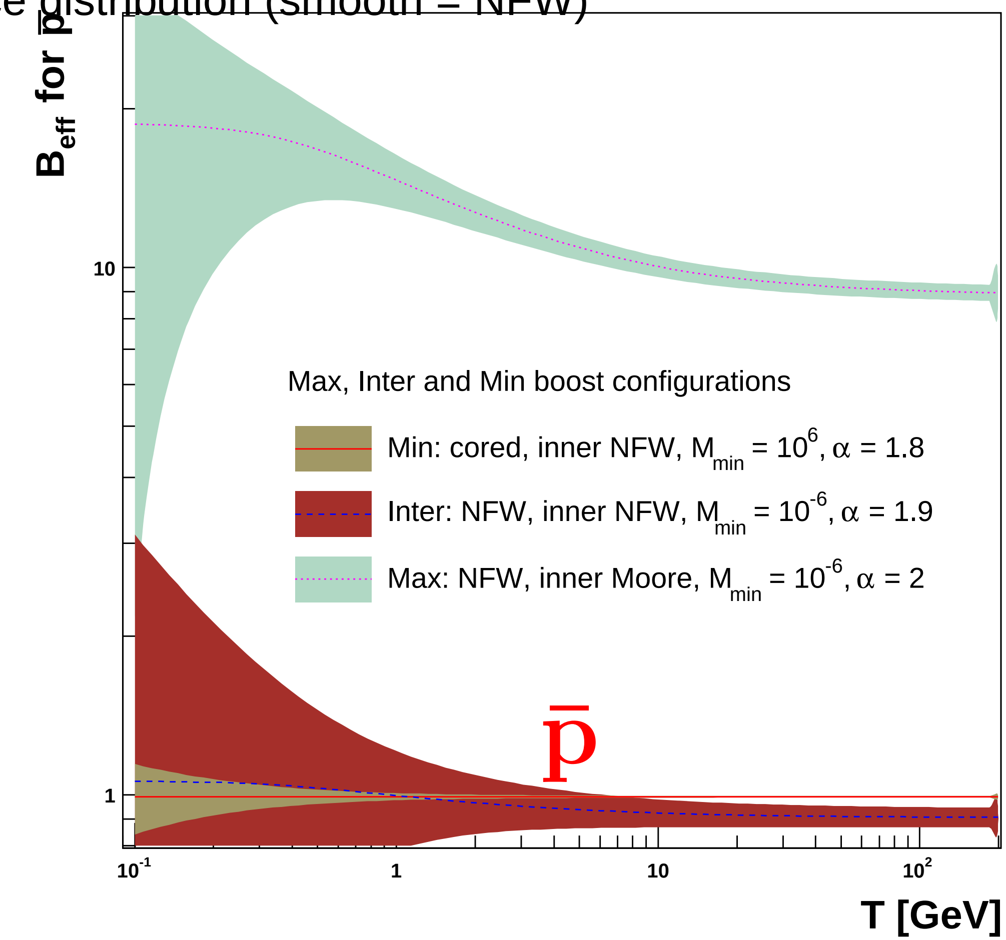
Clumpiness boost factors for e^+s & $\bar{p}$s

Extreme configurations $M_{\rm min} = 10^{-6}|10^{6} M_{\odot}$, $\alpha_{\rm m} = 1.8|2.0$,

inner-NFW/Moore, B01/ENS01,

cored/smooth-like space distribution (smooth = NFW)





Lavalle, Pochon, Salati & Taillet — A&A 462 (2007)

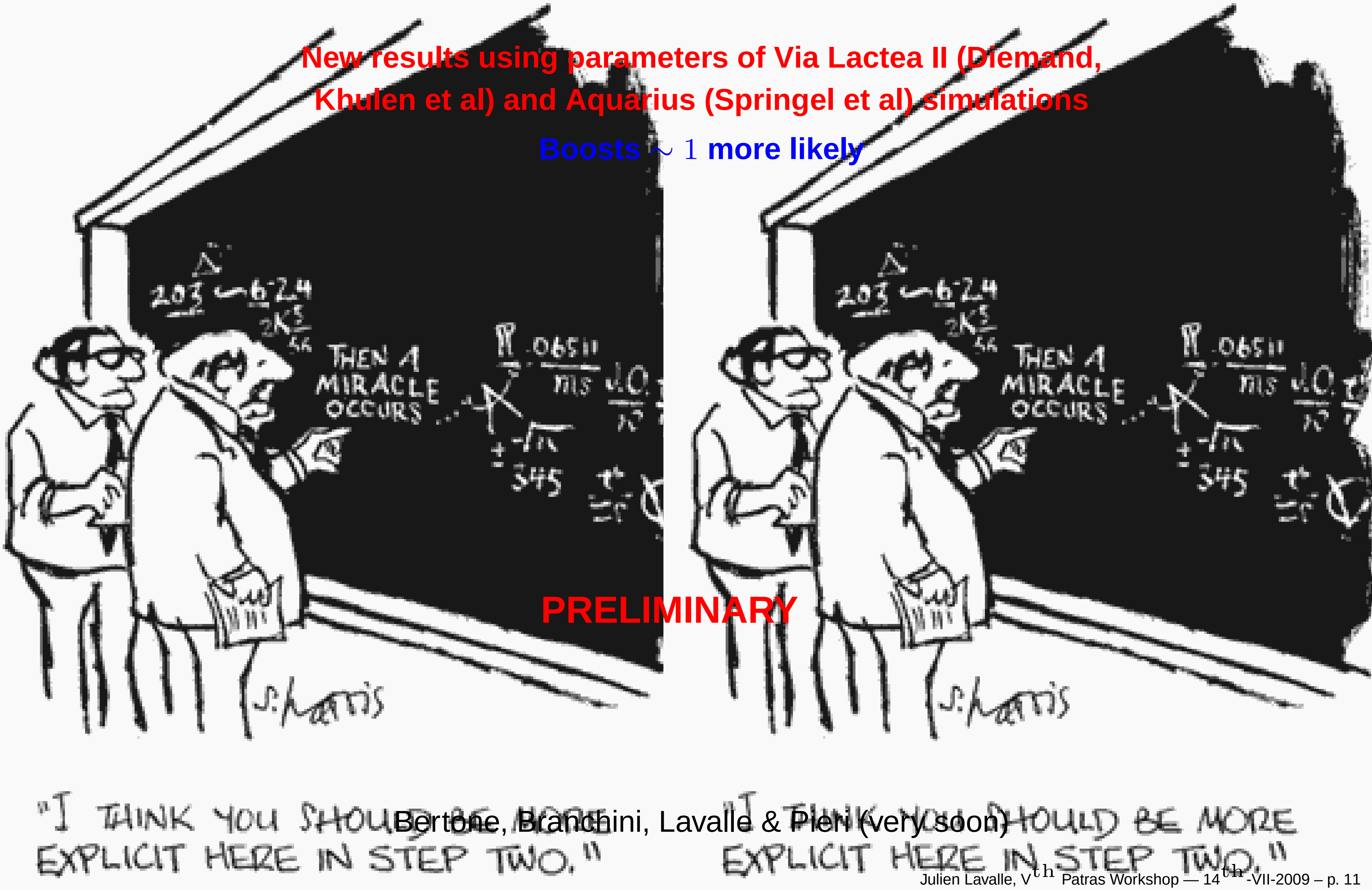
Lavalle, Yuan, Maurin & Bi — A&A 479 (2008)

Lavalle, Nezri, Ling, Athanassoula & Teyssier — PRD 78 (2008)

Clumpiness boost factors for e^+*s &* $\bar{p}$*s*

New results using parameters of Via Lactea II (Diemand, Khulen et al) and Aquarius (Springel et al) simulations

Boosts ~ 1 more likely



PRELIMINARY

Bertone, Branchini, Lavalle & Pieri (very soon)

Summary

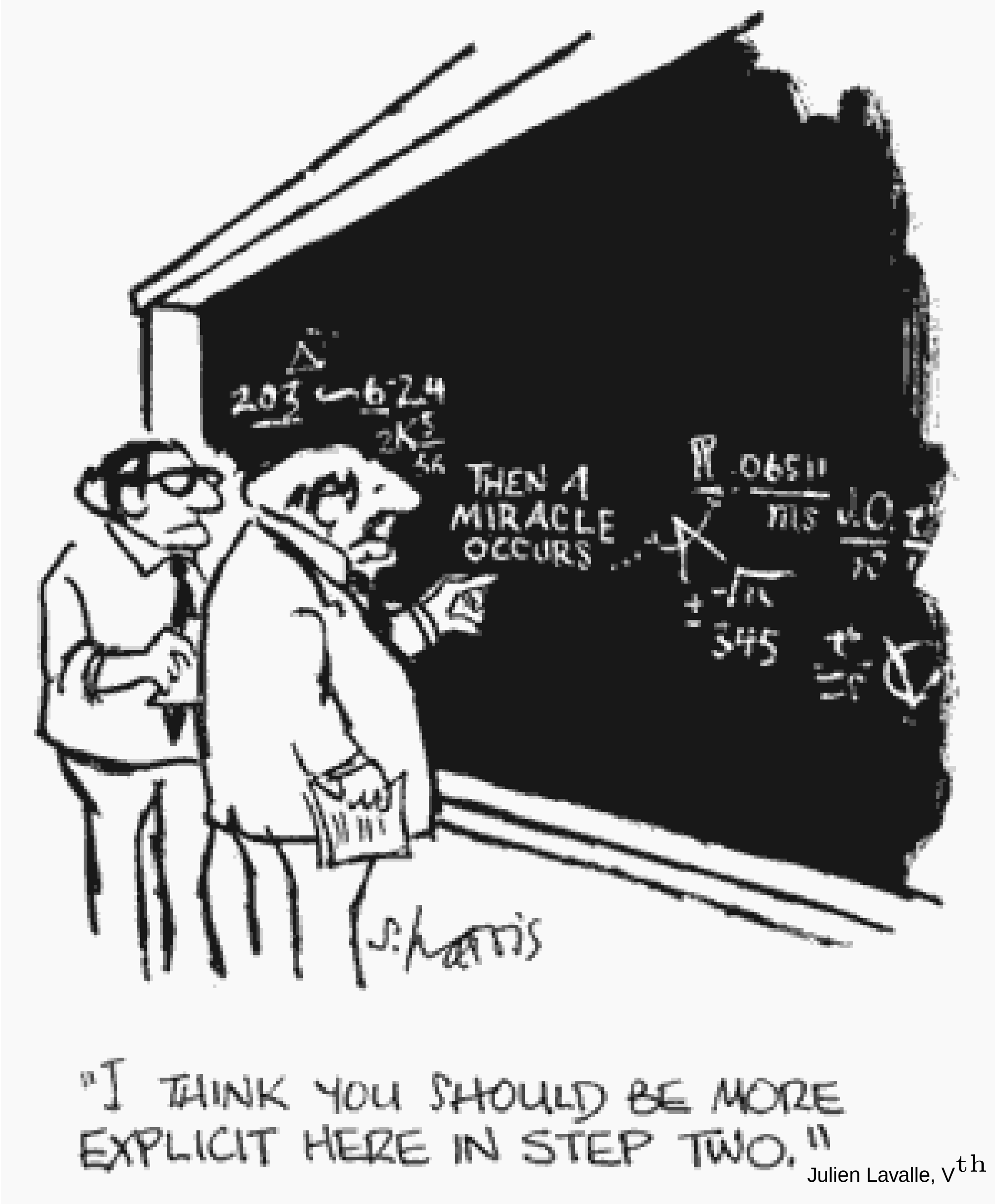
ON POSITRONS:

- **BAD NEWS FOR DM FINDERS (not searchers)**
  - **DM explanation unlikely (i) fine-tuned (ii) unnecessary: pulsars can fit the excess!**
  - **Could DM still contribute? Multimessenger constraints + hard to separate from astrophysical signals: need better understanding of the latter, better constraints on the former (LHC?).**
- **GOOD NEWS FOR DM SEARCHERS**
  - **Most of independently-motivated models (neutralino-like) still fully viable, because hardly contributing to the cosmic ray spectra.**

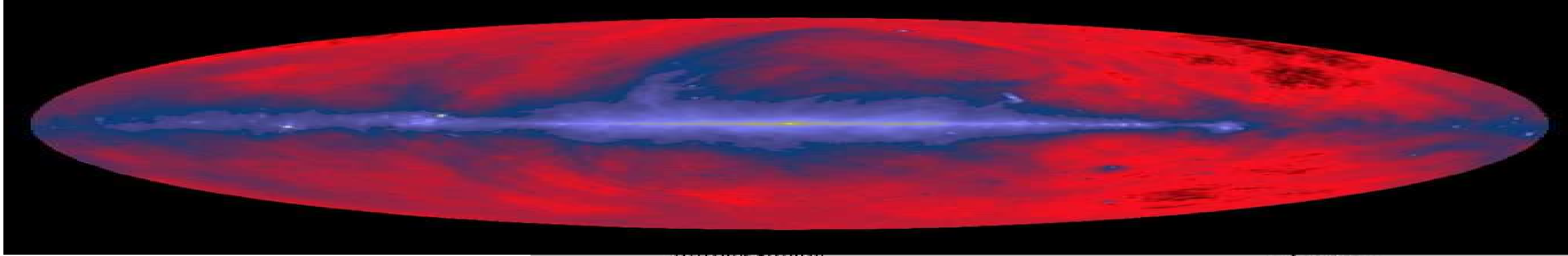
MORE GENERAL STATEMENTS, PERSPECTIVES:

- **Clear DM signature? (i) $\bar{d}'s$! (ii) Fermi + IACTs: diffuse γ-rays or γ-rays from DSphs.**
- **Complementarity with other detection methods + multimessenger analysis still to improve if LHC finds new physics.**
- **Need much better understanding of CR propagation, backgrounds and standard sources: Theory + PAMELA, CREAM, Fermi + higher energy data (AMS-02 later)**
- **Constraints on DM distribution (smooth & subhalos): impact of baryons? link to standard cosmic rays?**

Backup


THEN A MIRACLE OCCURS . . .
"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

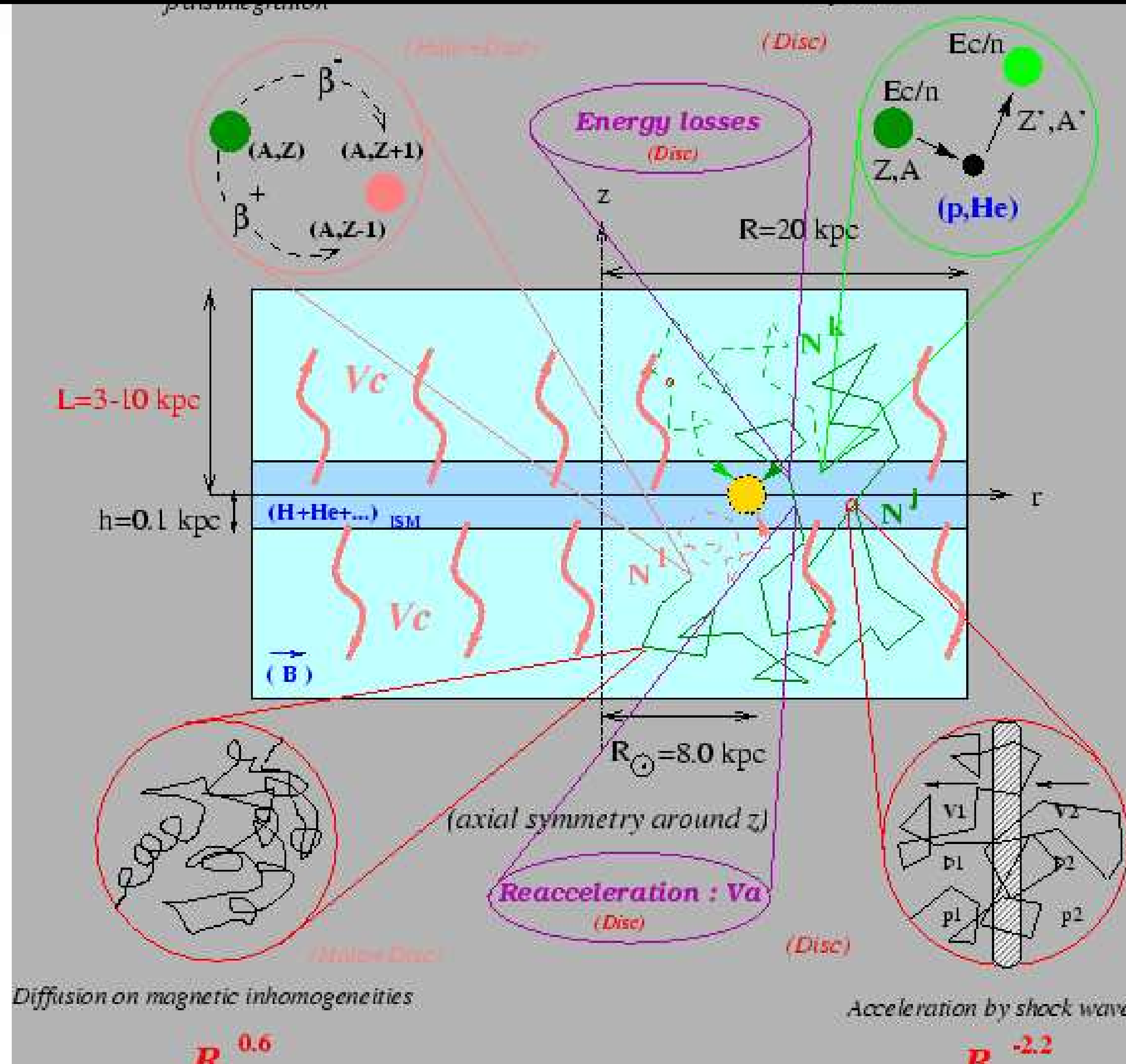
Sub-TeV Cosmic ray propagation in the Galaxy

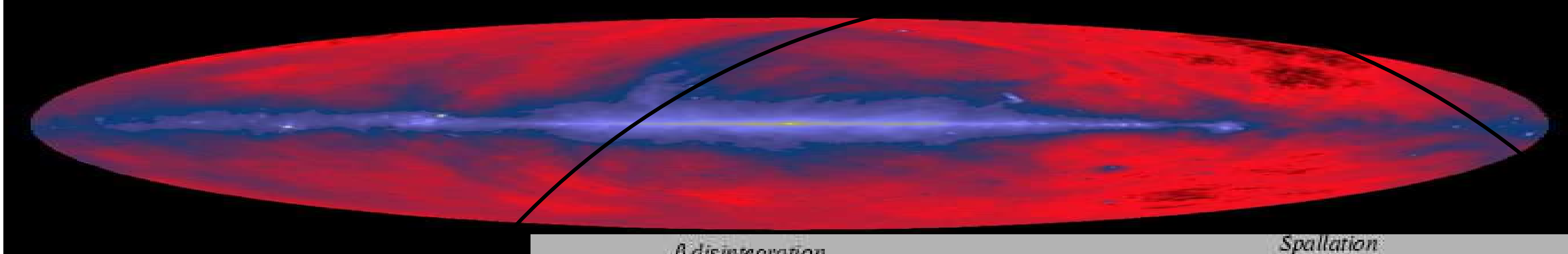


cf. e.g. Berezinsky (1990)

- **Cylindrical diffusive halo** : $R \sim 20\mathrm{kpc}, \mathrm{L} \sim 3\mathrm{kpc}$ diffusion off magnetic inhomogeneities, reacceleration.
- **Gaseous disc** ($h \sim 0.1\mathrm{kpc}$) : spallation + convection upside down.
- **free parameters**: $K(E), L, R, V_C, V_A$

...... (Figure by D. Maurin)





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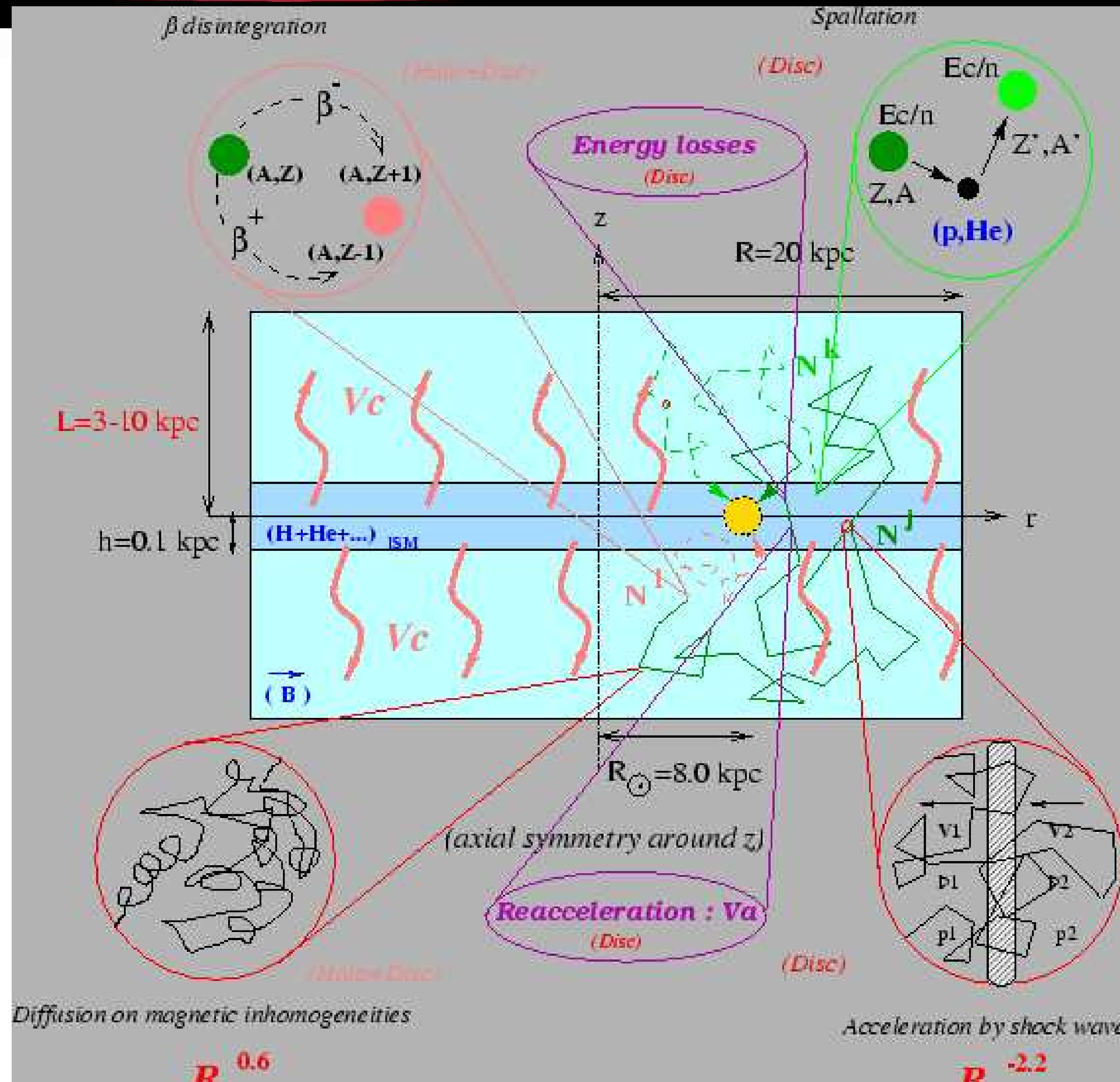

Diffusion equation for $e^{+/-}$ or $p\bar{p}$

$e^{+/-}$, *cf.* Bulanov & Dogel 73, Baltz & Edsjö 98, Lavalle et al 07, Delahaye et al 08

Nuclei, *cf.* Strong et al (98-08), Maurin et al (01-08)

$$\begin{aligned} \partial_t \frac{dn}{dE} &= Q(E,\vec{x},t) \\ &+ \left\{ \vec{\nabla}(K(E,\vec{x})\vec{\nabla} - \vec{V}_{\rm c}) \right\} \frac{dn}{dE} \\ &- \left\{ \partial_E \left(\frac{dE}{dt} - \partial_E E^2 K_{\rm pp} \partial_p E^{-2} \right) \right\} \frac{dn}{dE} \\ &- \left\{ \Gamma_{\rm spal} \right\} \frac{dn}{dE} \end{aligned}$$

source: injected spectrum

spatial current: diffusion and convection

$K(E) = K_0 \left(\frac{E}{E_0} \right)^{\alpha}$

$\vec{V}_{\rm c}(z) = sign(z) \times V_{\rm c}$

Energy losses and reacceleration

spallation (nuclei)

Uncertainties and degeneracies in parameters (Maurin et al 01)

(Complementary & full numerical: **Galprop**, Strong et al)