Indirect detection of Dark Matter with Antimatter cosmic rays: principles, effect of cosmological sub-halos and uncertainties

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

Refs (arXiv) : 0603796, 0712.0677, 0712.0468, 0709.3634, 0704.2543, 0808.0332, 0809.5268

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

LPNHE-Jussieu Paris

Thursday, December 04$^{\rm th}$ 2008

Outline

- **General introduction**
- **Why antimatter ? Comment on the positron excess**
- **Computing the odds of the Galactic Lottery: clumpiness boost factors**
  - Cosmological sub-halos: Analytical vs N-body approach
- **Electrons and positrons in clusters**
- **Conclusion**

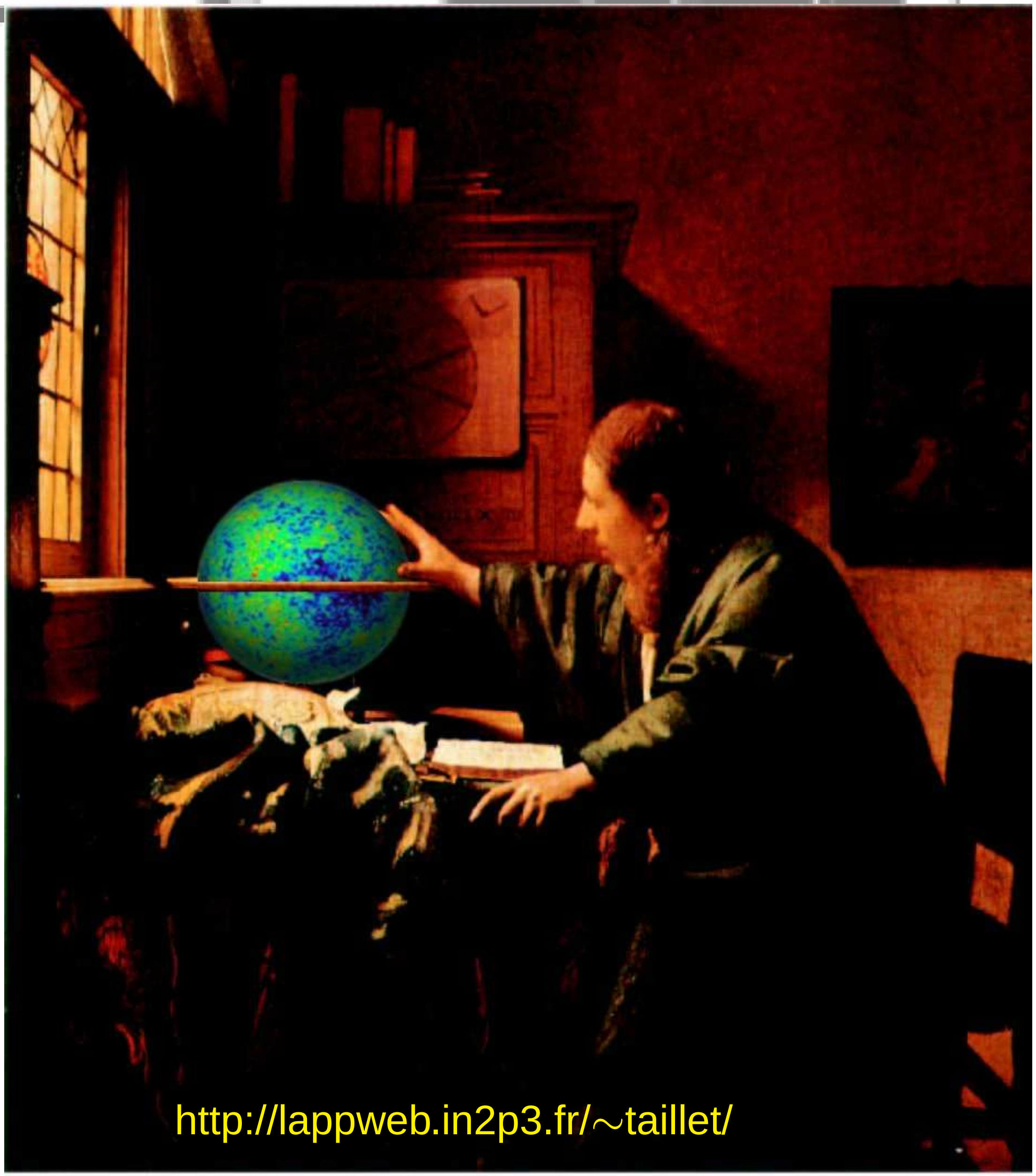
The Dark Matter problem : connecting cosmological to microscopic scales

Cosmological data (WMAP, etc) :

$$\Omega_{\rm matter} \sim 0.3$$
$$\Omega_{\Lambda} \sim 0.7$$

85% of the matter is of unknown origin (non-baryonic)$\rightarrow$ New particles or modified gravity. WIMPs naturally arise from beyond standard model theories (SUSY, ED), without asymmetry matter/antimatter

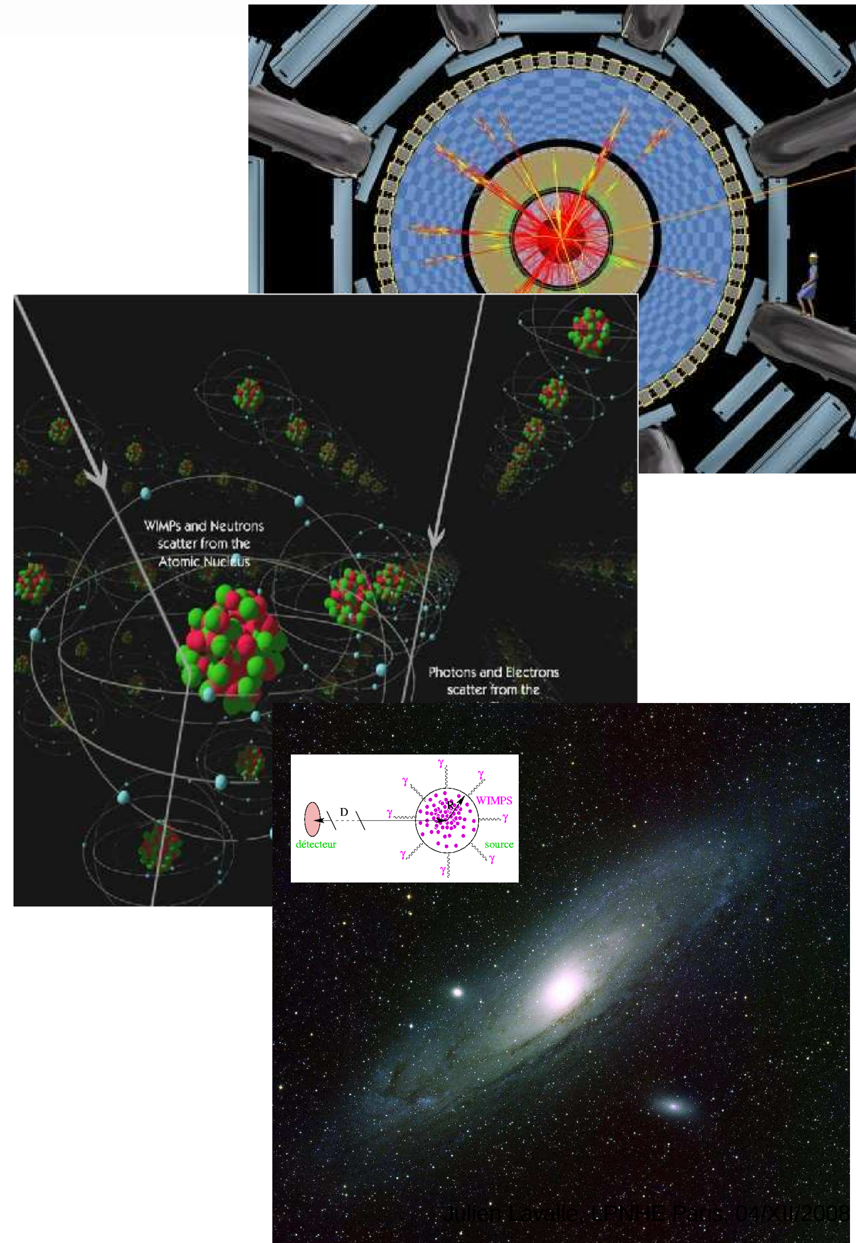
- Relic density (thermal hypothesis): $\Omega_\chi \propto \frac{1}{\langle \sigma v \rangle} \propto \frac{m_{\rm EW}^2}{g_{\rm EW}^4}$
- DM couples to standard matter (direct detection)
- Annihilation in high density regions (indirect detection)



Detection methods

If dark matter couples to ordinary matter, it could be detected thanks to:

- **Particle colliders: (LHC!)**
  (no difference between any meta-stable particle and a wimp)
- **Direct detection: (many!)**
  (mainly sensitive to scalar interactions and low wimp masses)
- **<u>Indirect detection:</u>**
  (HESS, PAMELA, GLAST)
  (γ**-rays, antimatter cosmic rays, neutrinos**)



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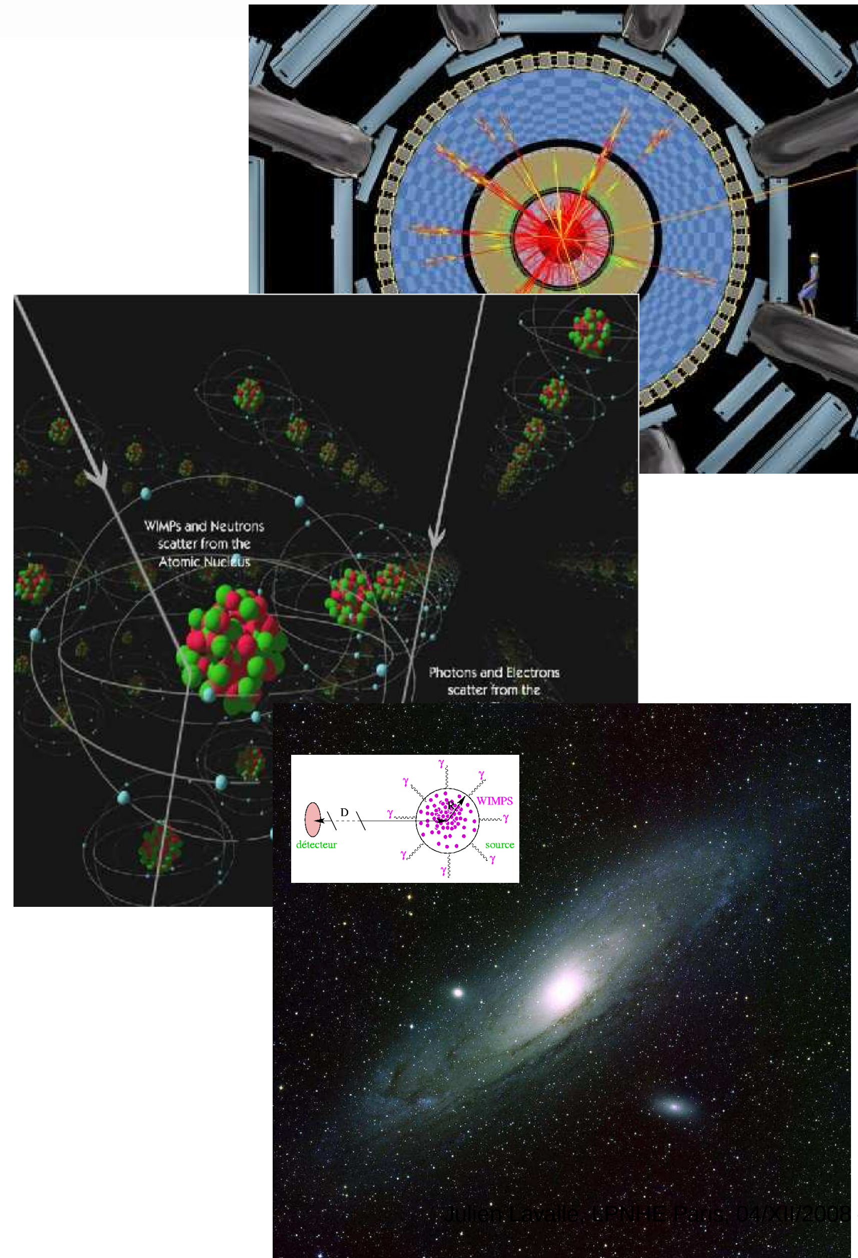
Complementary searches are mandatory for consistent answers

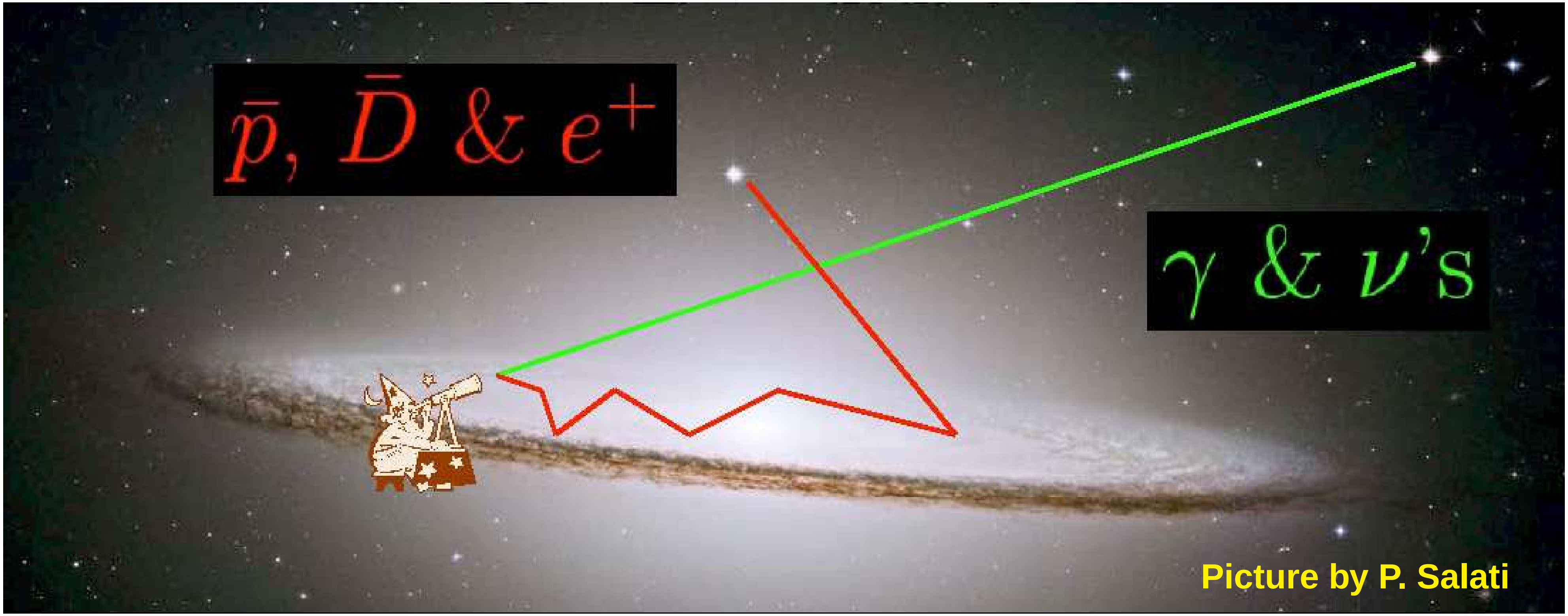


Some candidates

- **Supersymmetry**
  - neutralino (MSSM & mCHOUGRA) – DM:
    $\rightarrow b\bar{b}$ ($t\bar{t}$), W^+W^-, ZZ, marginally l^+l^- (small slepton masses)
  - gravitino (GMSB & mCHOUGRA) – DM & SUSY breaking & nucleosynthesis:
    $\rightarrow$ phenomenology of nLSP
  - sneutrino (MSSM) – DM & neutrino masses & leptogenesis:
    $\rightarrow \nu\bar{\nu}$, W^+W^-
- **Extra-dimensions**
  - LKP (UED) – DM:
    $\rightarrow l^+l^-$ (60%), up $q\bar{q}$ (35%)
  - LZP (warped GUT) – DM:
    $\rightarrow$ (depends on LZP mass and KK scale)
- **Other (minimal) models**
  - Inert doublet model, little Higgs, light DM, etc.

Indirect detection of Dark Matter

Non-baryonic DM may explain a **large fraction of the masses of galaxies and clusters**: If made of **exotic annihilating particles**, we might detect indirect signatures by means of astronomical device

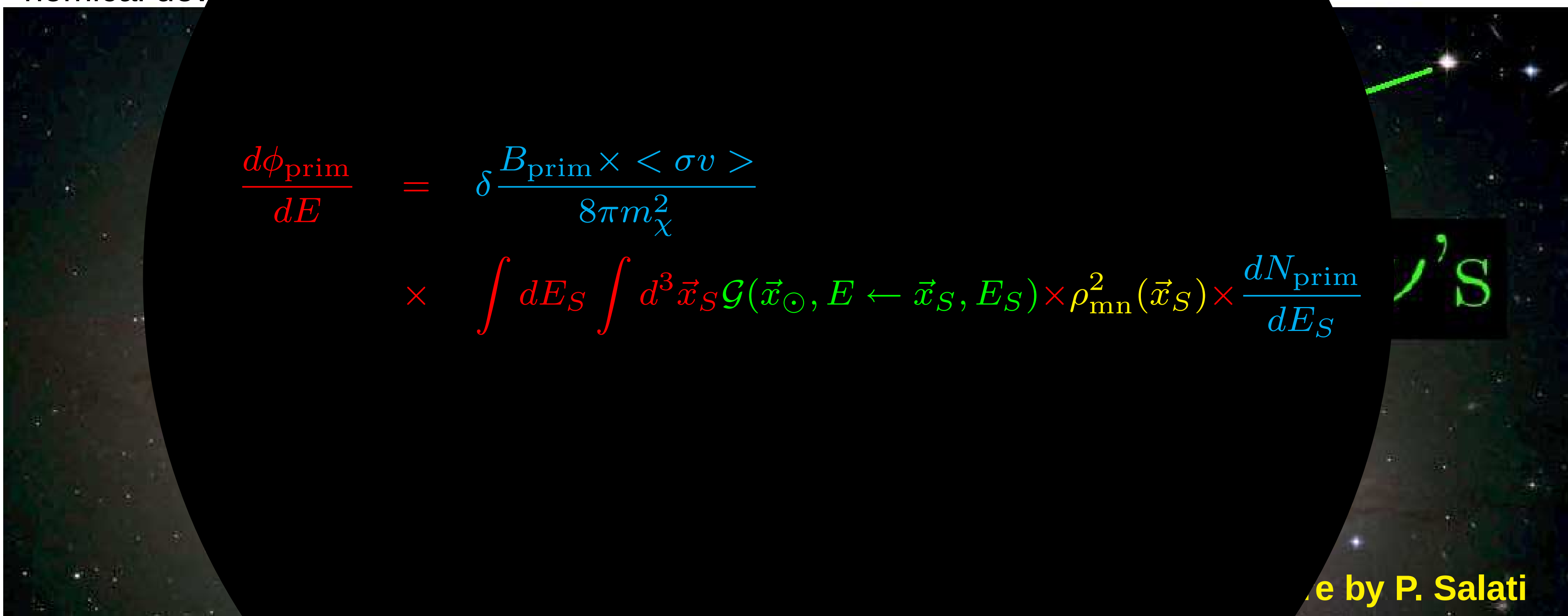


- γ **and** ν**: travel directly from the source to the observer**
- **Antimatter cosmic rays: diffuse on the magnetic turbulences**

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

[redacted] of Dark Matter

Non-baryonic D[redacted] **and clusters**: If made of **exoti**[redacted]eans of astro-nomical devi[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]**M density regions** [redacted]**es)**
- **Antimatter cosmic** [redacted] **magnetic turbulences**

of Dark Matter

and clusters: If

means of astro-

Flux measurements:

PAMELA satellite data is coming

GLAST (gamma) soon

AMS-02 still not sure to operate

background predictions

BSM particle physics:

SUSY, KK, etc.

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

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Dark matter distribution:

Prescriptions from N-body cosmological simulation

Found to not be smooth: clumpiness effects ?

e by P. Salati

- γ **and** ν**: tr**
  to the observ

Propagation Green function

density regions

es)

- **Antimatter cosmic**
  magnetic turbulences

# of Dark Matter

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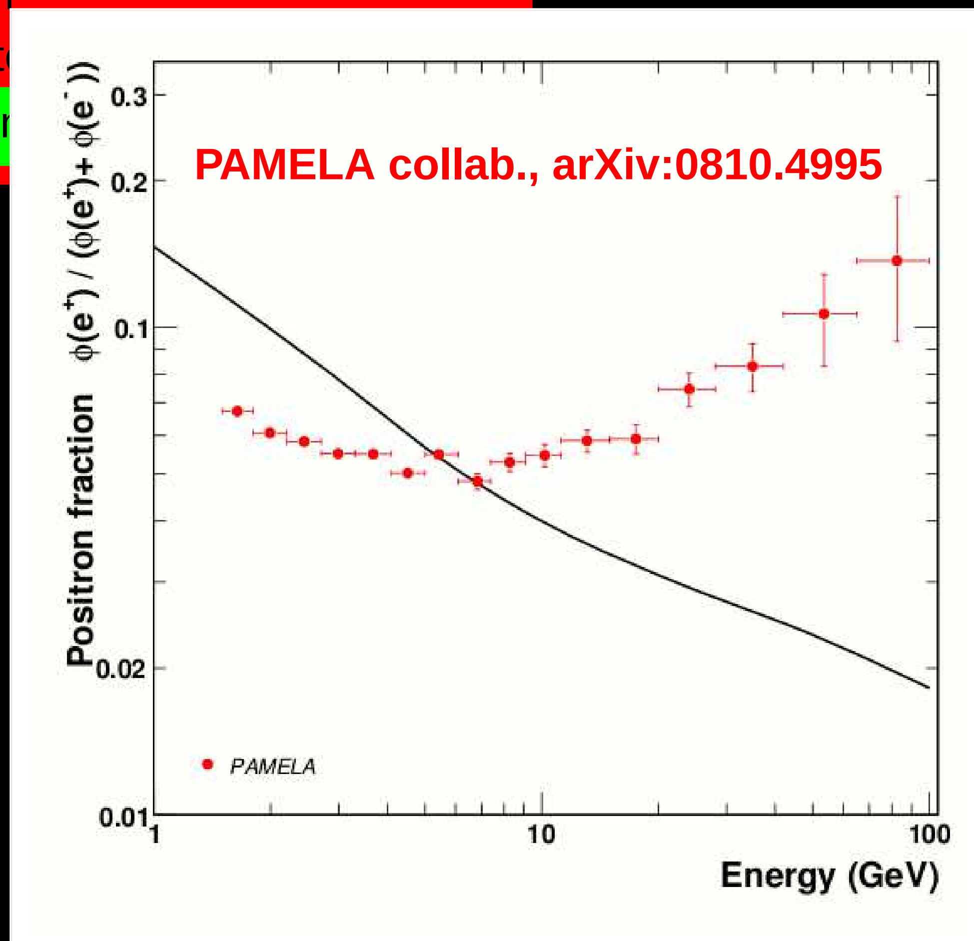

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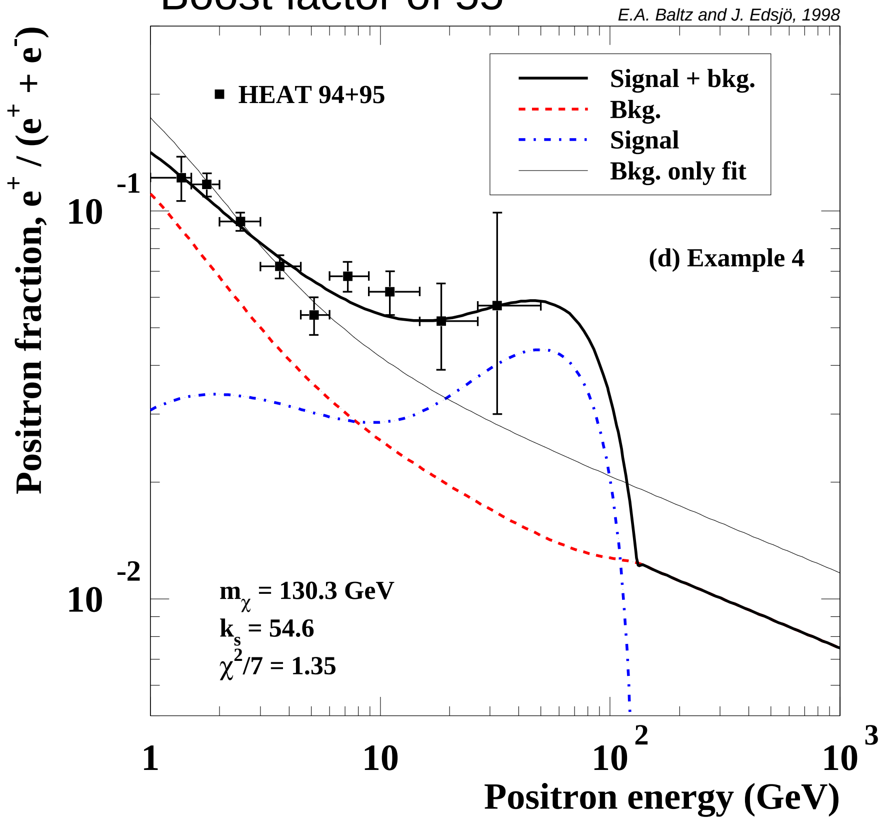
Baltz & Edsjö, 98

Boost factor of 55



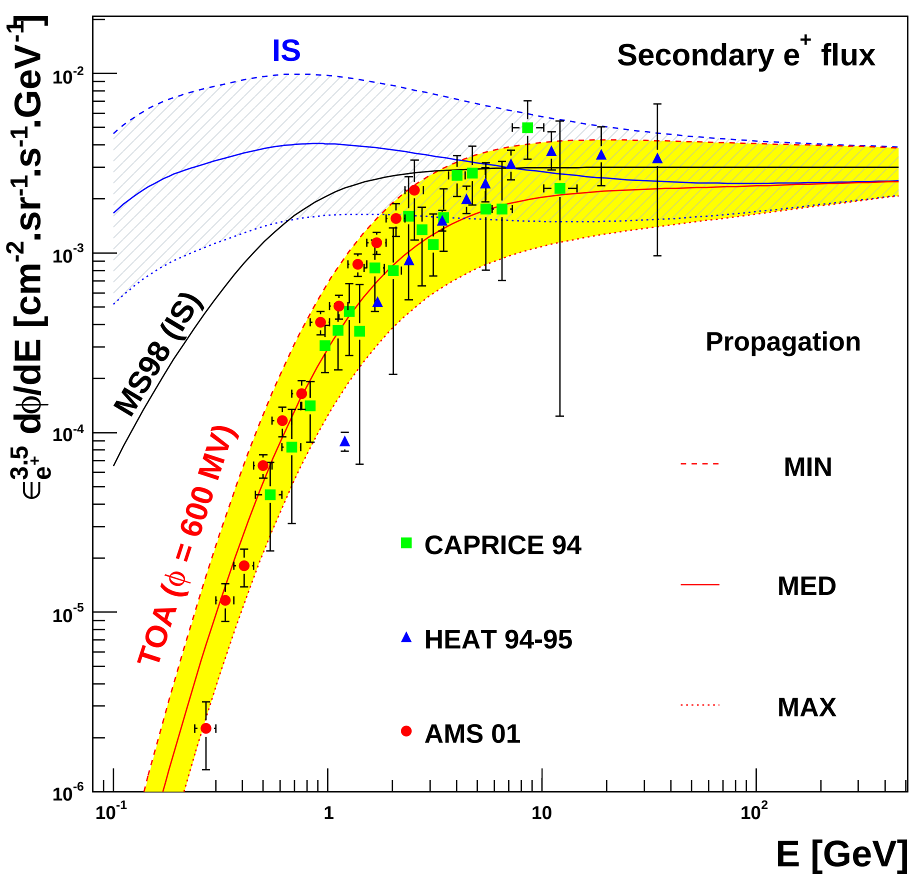
- **γ and ν: tr ... to the observ** ... **density regions** ... **es)**
- **Antimatter cosmic ... magnetic turbulences**

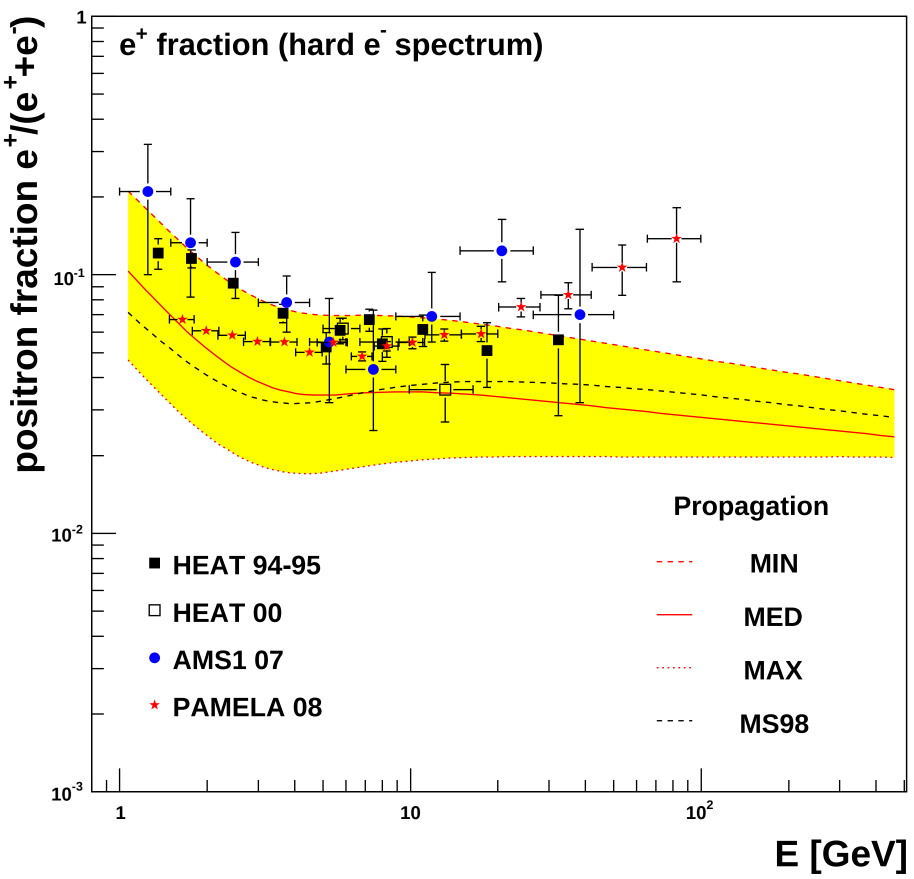
PAMELA: to predict the e^+ fraction, we need e^-s!

The Alpine connection e^+ background

(Annecy & Torino)

Delahaye et al, arXiv:0809.5268





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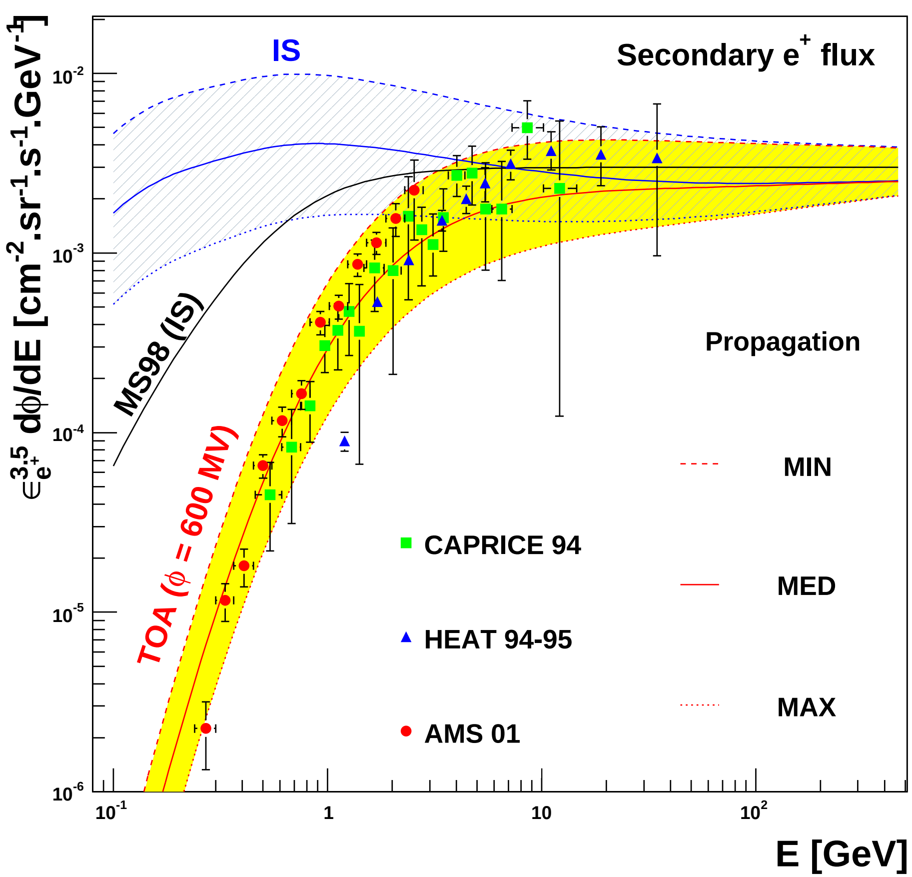
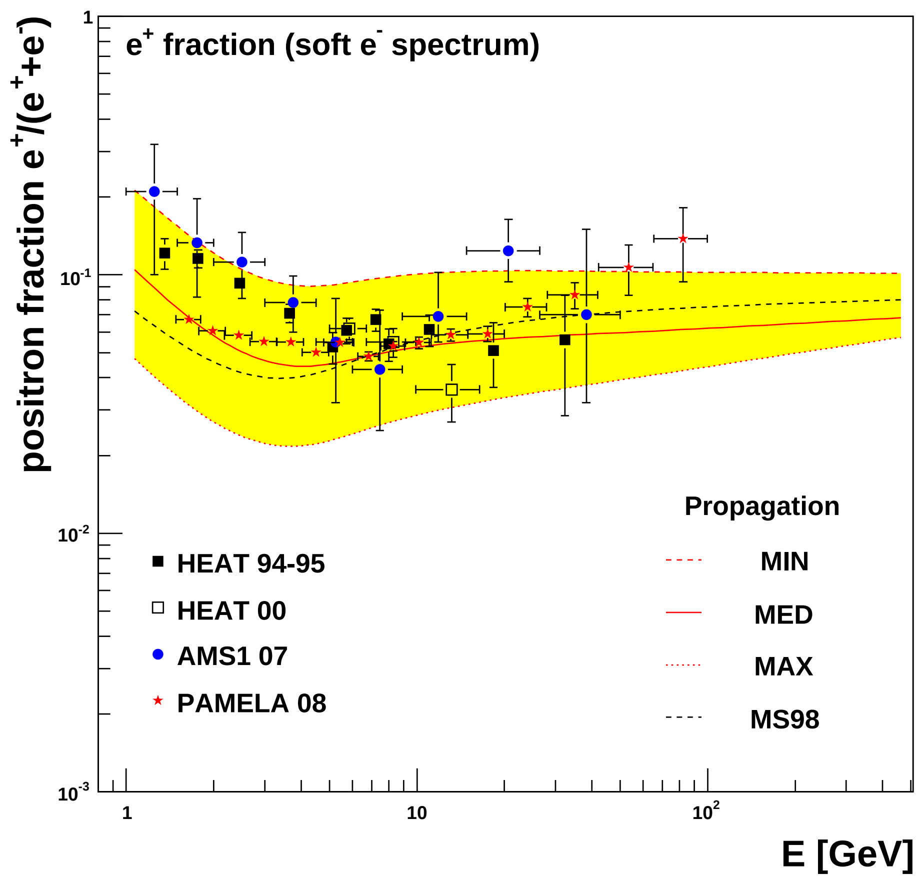
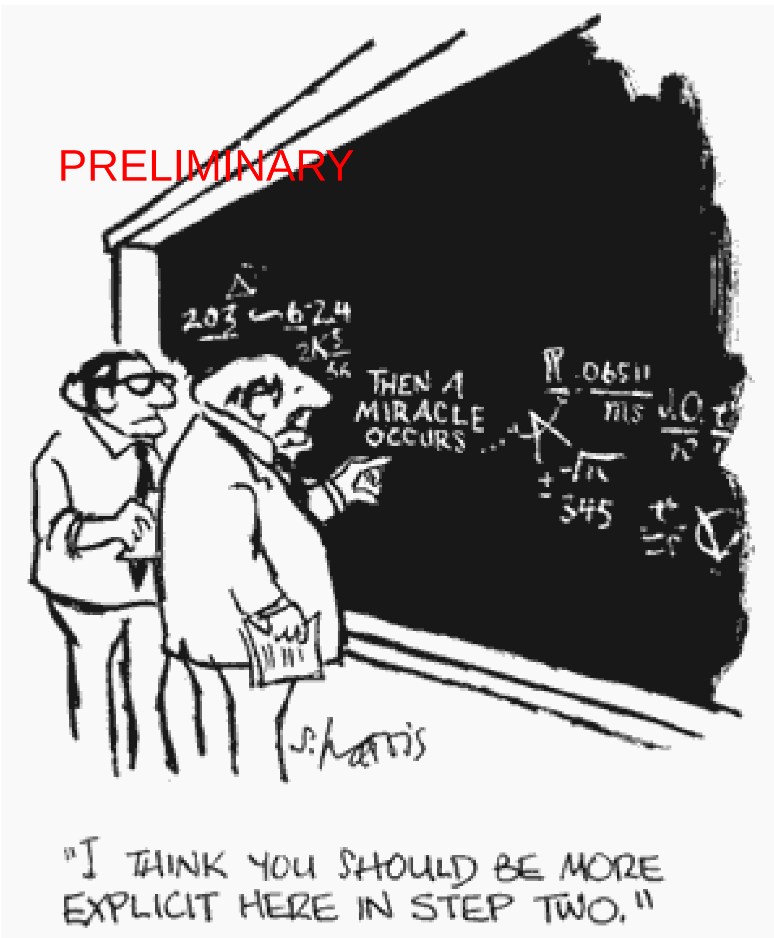


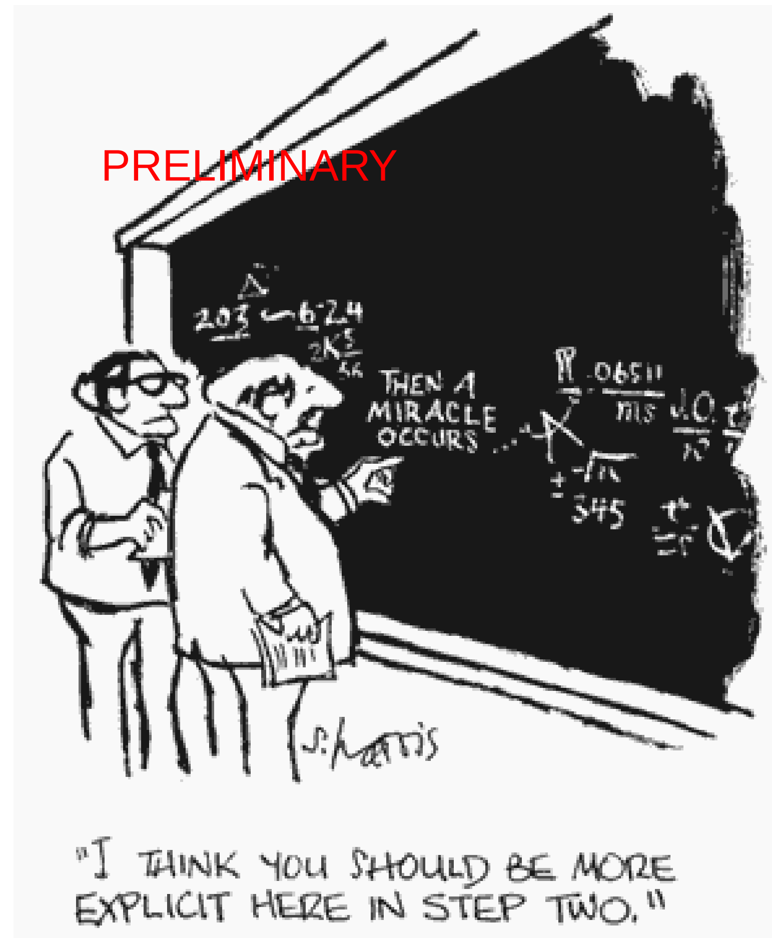


PAMELA: single local dark source ?

IMBH solution ...

Bringmann, Lavalle & Salati (in prep)





PAMELA: single local dark source ?

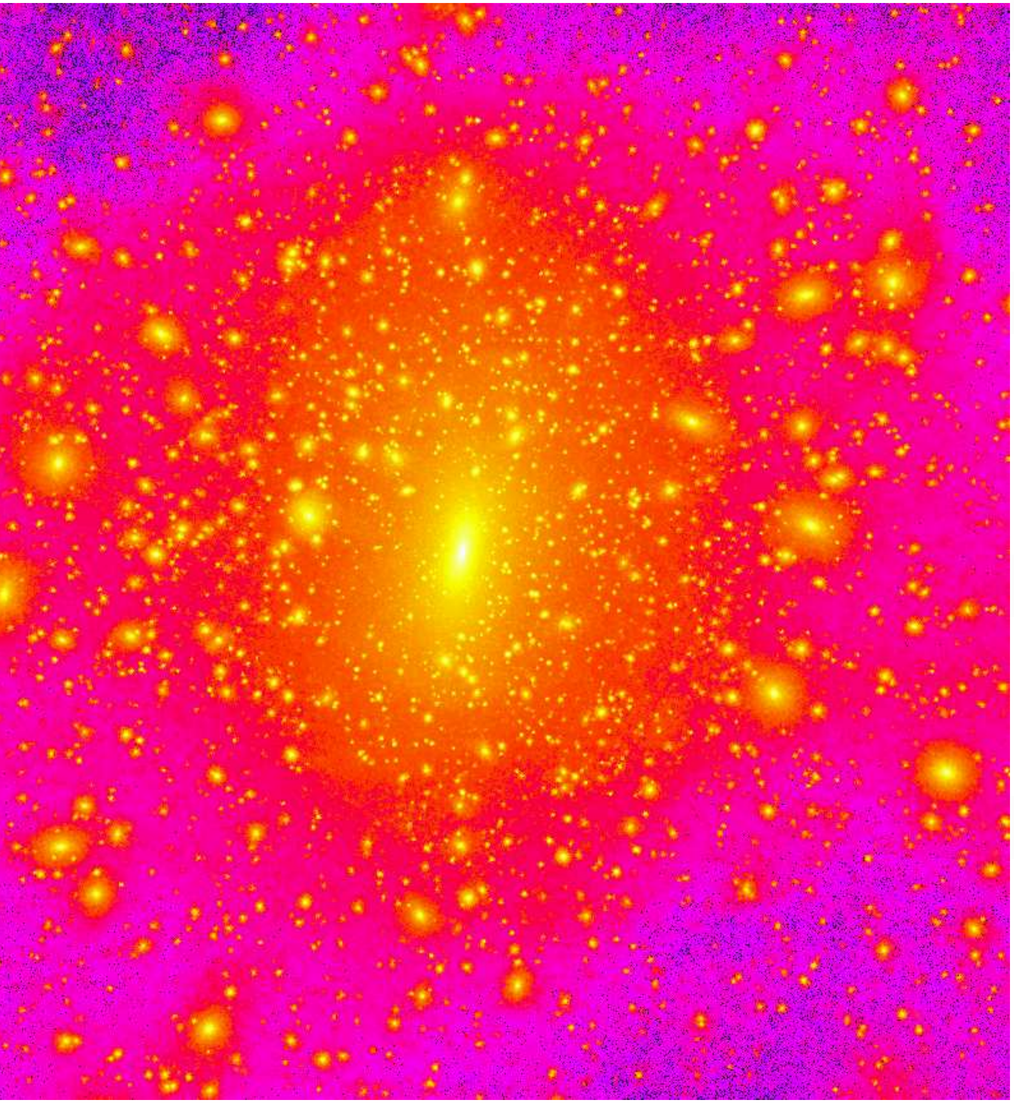
Appealing solution from pulsars ...

Boulares (1989), Grimani (2001-2007), Hooper et al (arXiv:08...)

but no consistent predictions at the moment

The Clumpiness issue

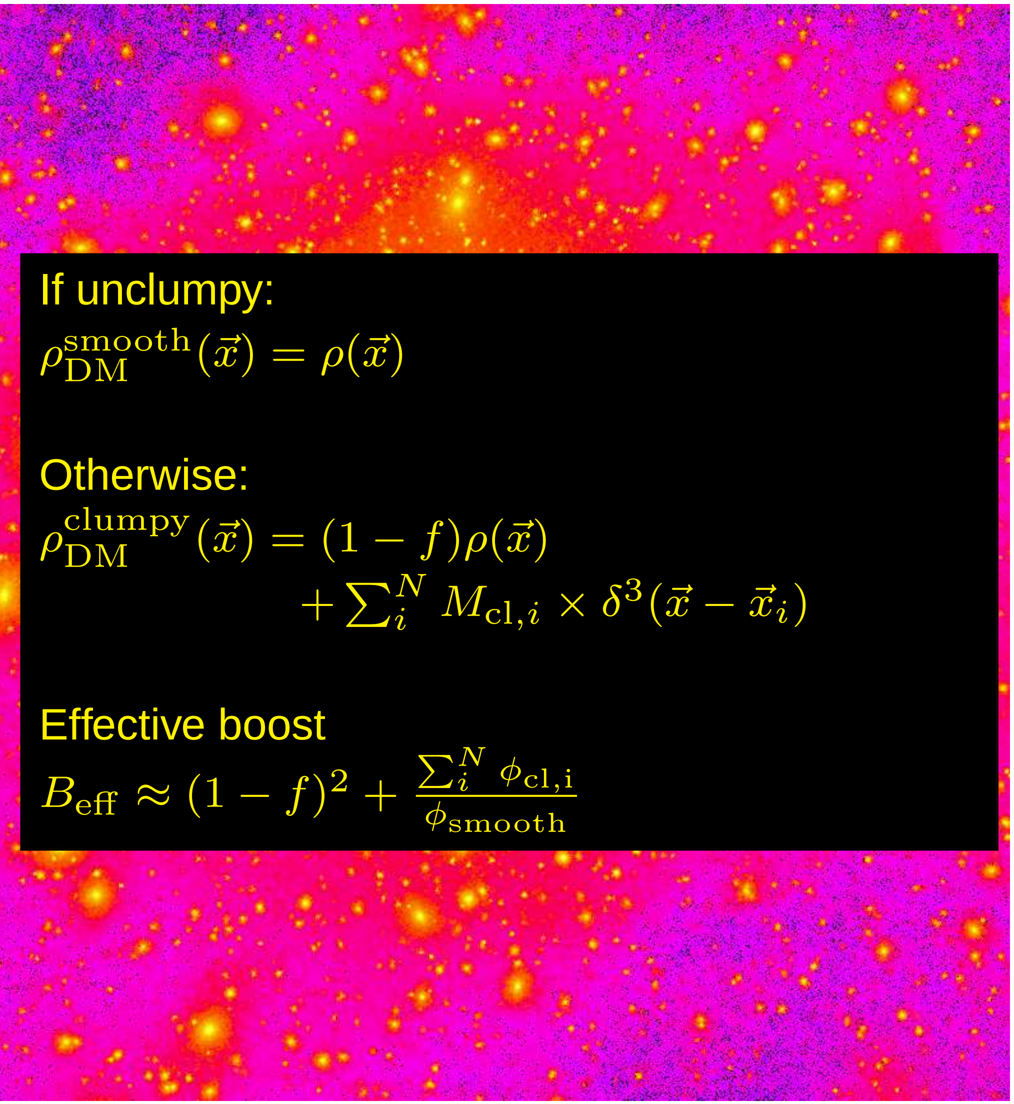
Inhomogeneous halo and boosted annihilation rate



(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 ?**

Inhomogeneous halo and boosted annihilation rate



If unclumpy:

$$\rho_{\rm DM}^{\rm smooth}(\vec{x}) = \rho(\vec{x})$$

Otherwise:

$$\rho_{\rm DM}^{\rm clumpy}(\vec{x}) = (1-f)\rho(\vec{x}) + \sum_i^N M_{{\rm cl},i} \times \delta^3(\vec{x}-\vec{x}_i)$$

Effective boost

$$B_{\rm eff} \approx (1-f)^2 + \frac{\sum_i^N \phi_{\rm cl,i}}{\phi_{\rm smooth}}$$

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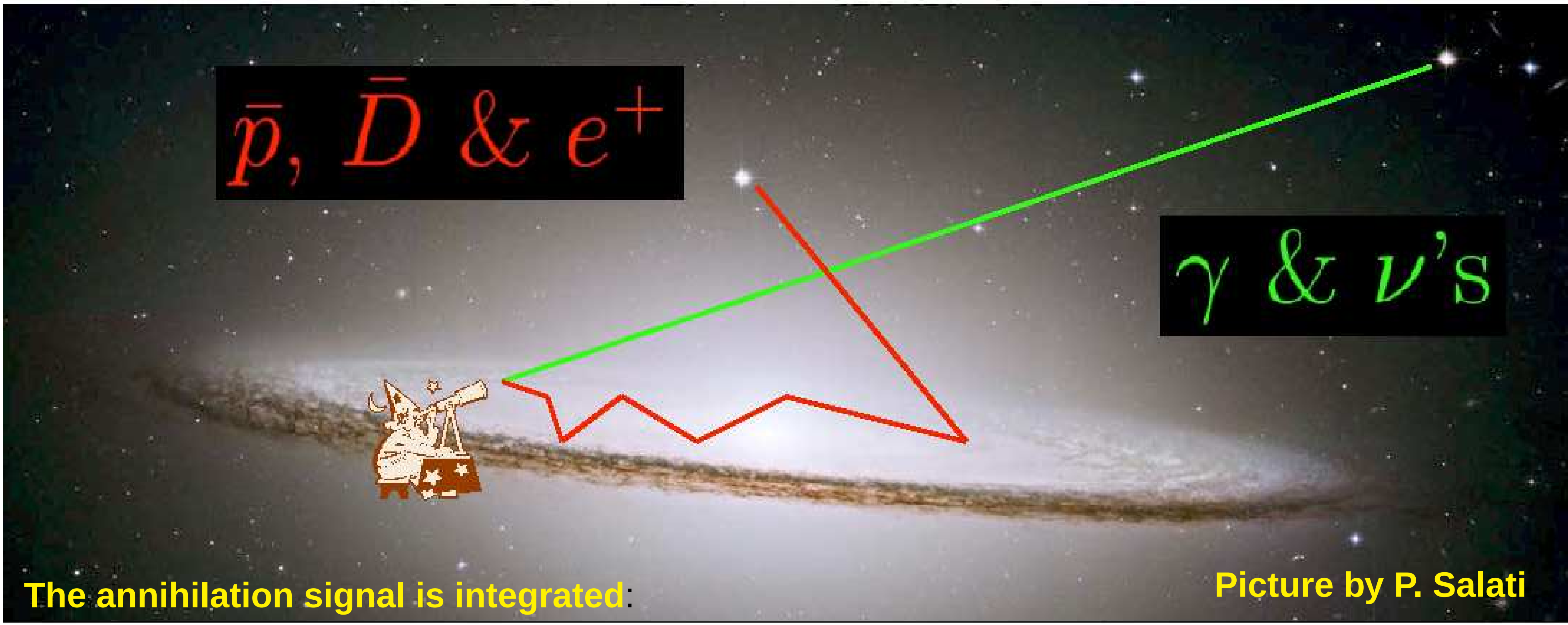
Gamma-rays versus antimatter cosmic rays



The annihilation signal is integrated:

- over a small solid angle around the line of sight for $\gamma-$rays and neutrinos
- over a rather small volume around the Earth for antimatter CRs, due to diffusion processes

$\Longrightarrow$ **Boost factors are not the same !**

Sub-TeV Cosmic ray propagation in the Galaxy

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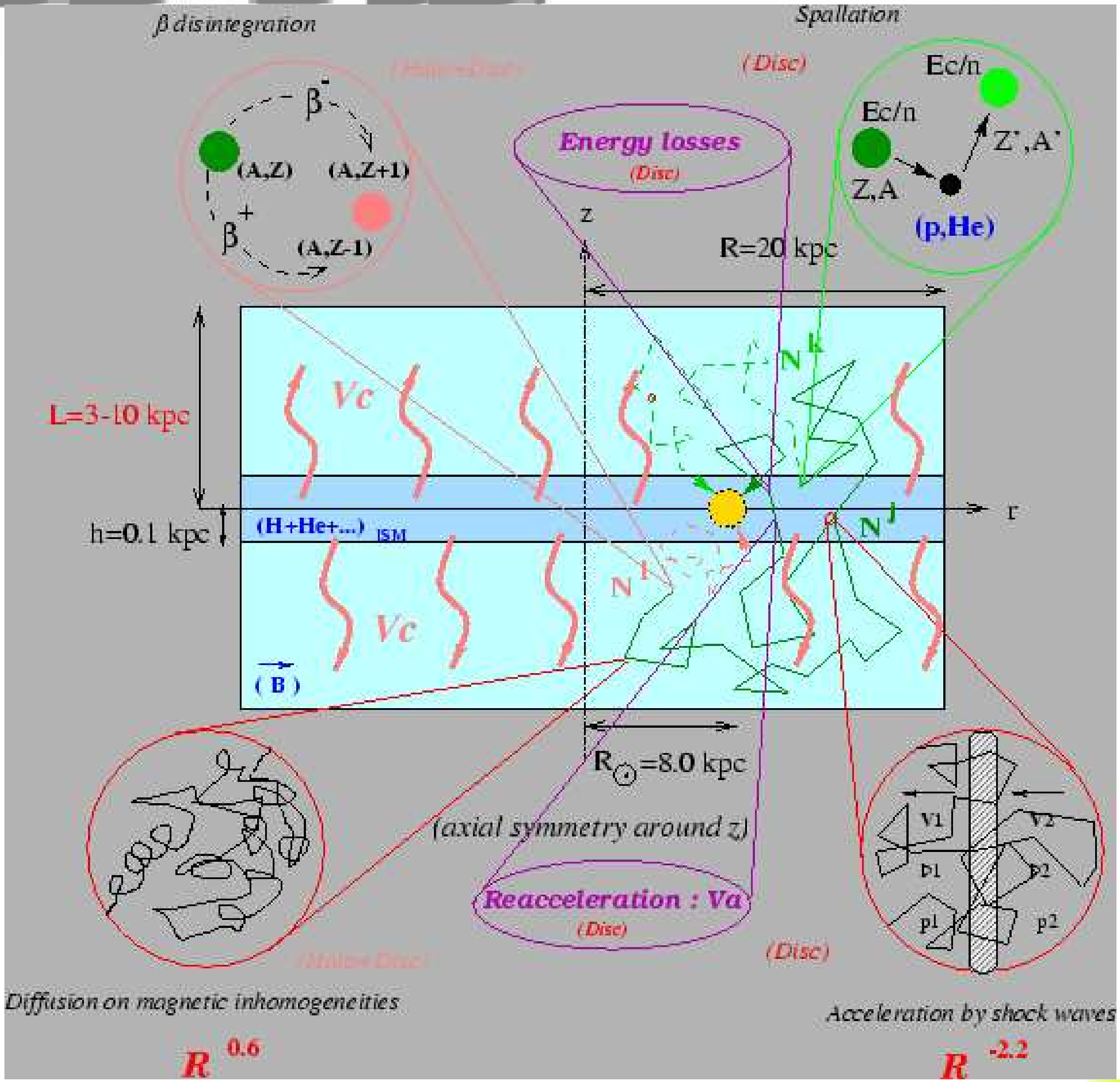
cf. e.g. Berezinsky (1990)

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

.... (Figure by D. Maurin)



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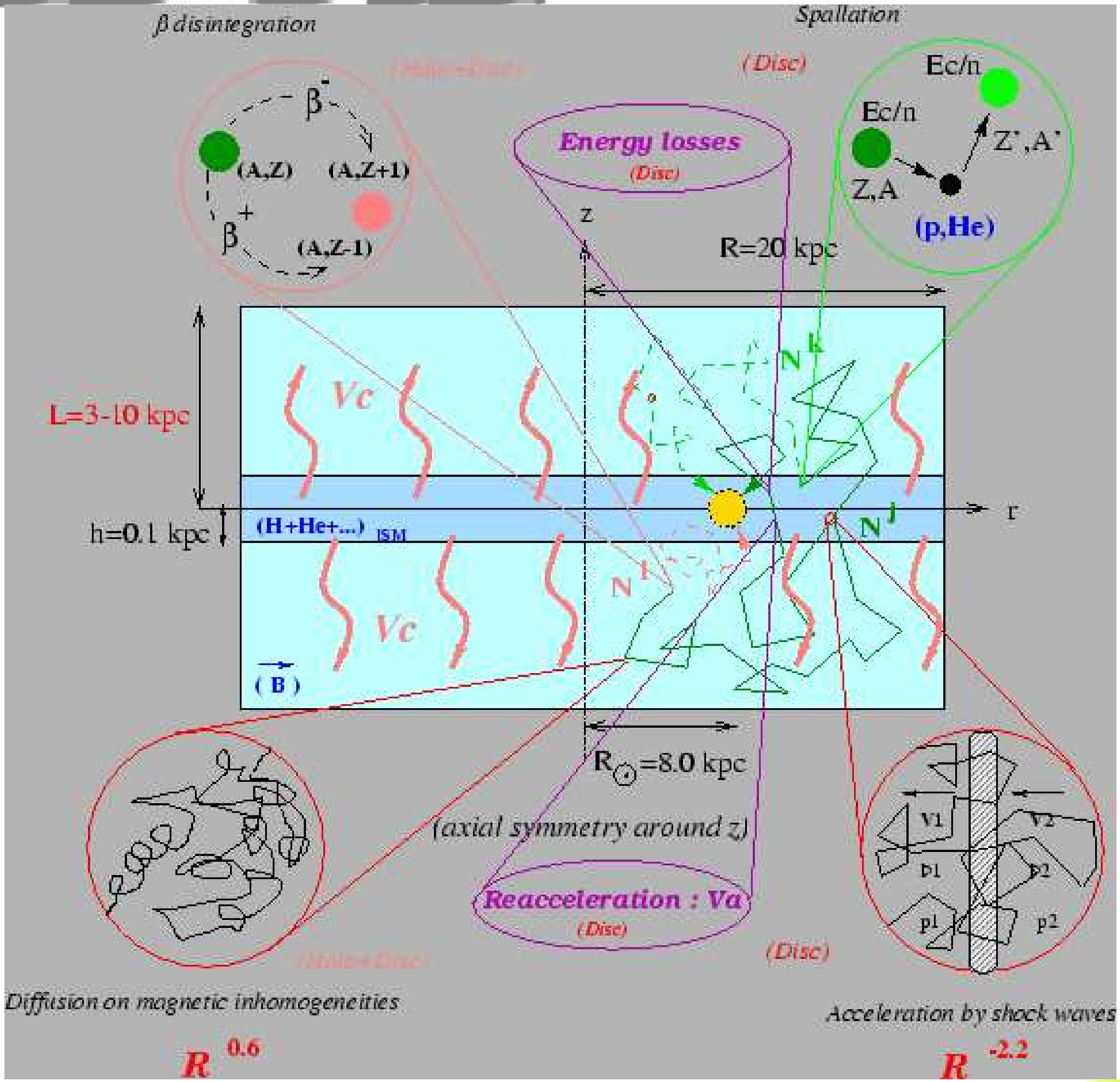


Diffusion equation for $e^{+/-}$ or $p\bar{p}$

$e^{+/-}$, *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)

$$\partial_t \frac{dn}{dE} = Q(E,\vec{x},t) + \left\{ \vec{\nabla}(K(E,\vec{x})\vec{\nabla} - \vec{V}_c) \right\} \frac{dn}{dE} - \left\{ \partial_E (\frac{dE}{dt} - \partial_E E^2 K_{pp} \partial_p E^{-2}) \right\} \frac{dn}{dE}$$

spatial current: diffusion and convection

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

$\vec{V}_c(z) = sign(z) \times V_c$

Energy losses and reacceleration :

Inverse Compton on IR and CMB

+ synchrotron

+ Bremsstrahlung

+ Adiabatic losses

source :

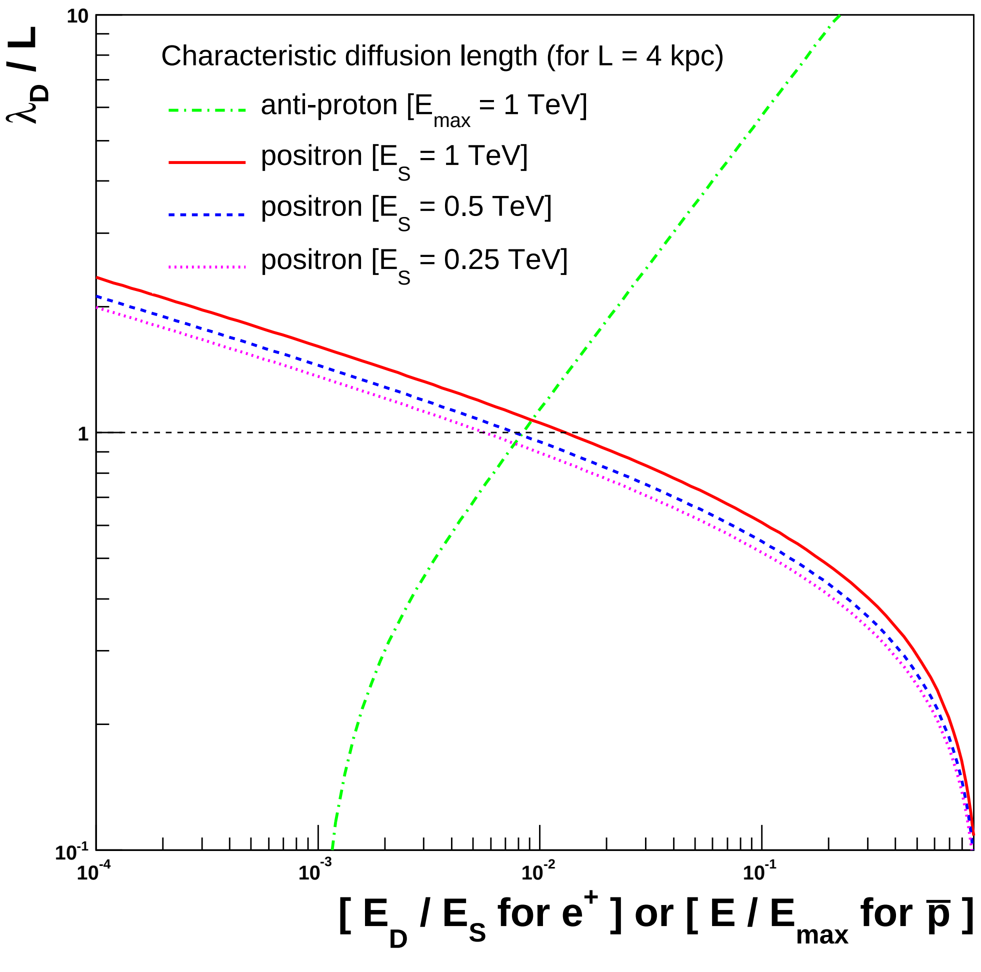
injected spectrum

Uncertainties and degeneracies in parameters (Maurin et al 01)

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

Energy-dependent diffusion scales for e^+ and $\overline{p}$

- e^+**'s lose energy**: survey larger and larger volumes when detected at lower and lower energies
- $\overline{p}$'s do not lose energy, **but convective wind and spallation processes very efficient at low energy**: survey larger volume at high energies



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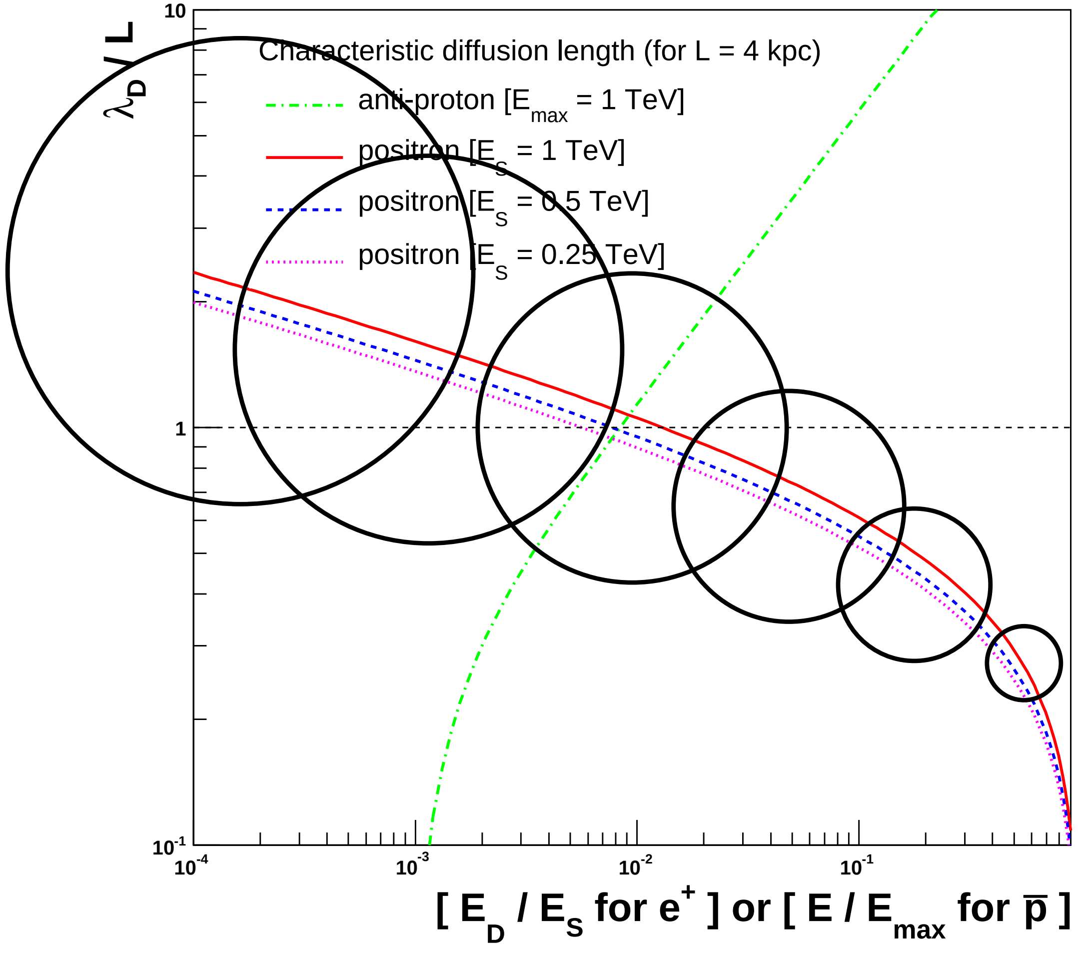

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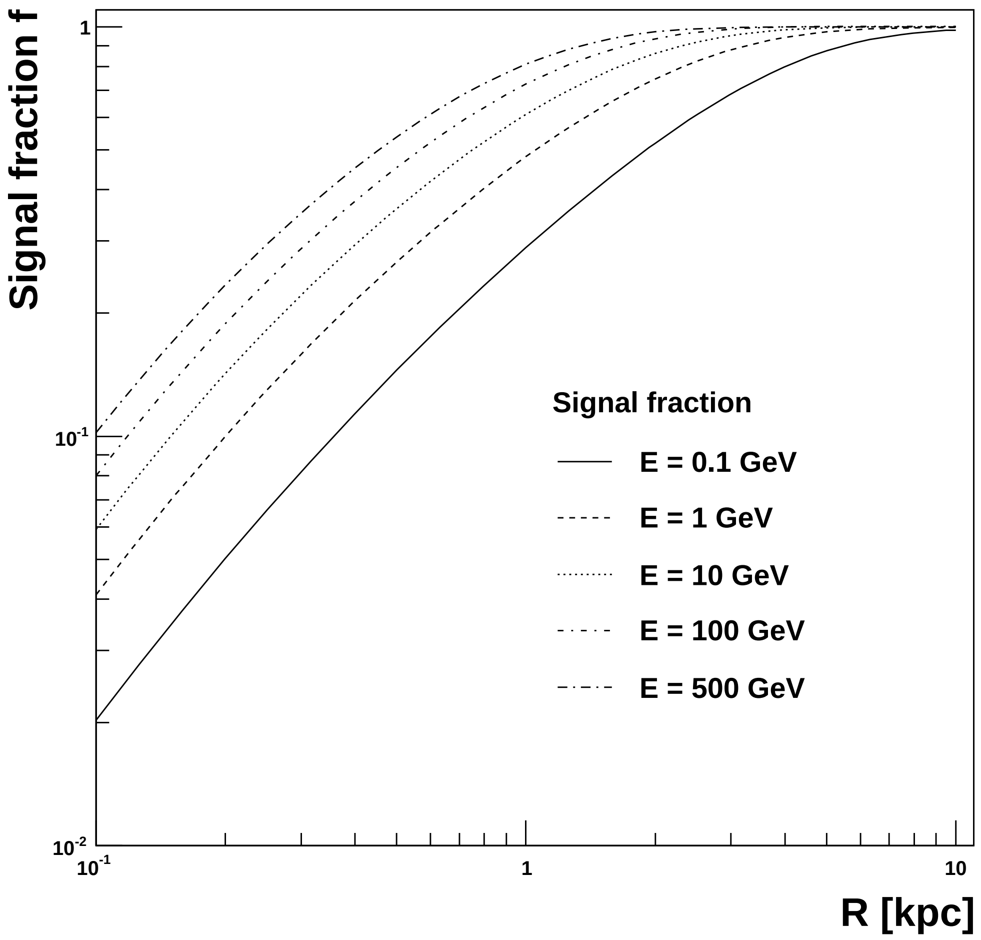

Effective volume picture for the smooth contribution

Inject a 200 GeV e^+ with $Q(r) = \rho^2(r) \propto r^{-2}$ ...

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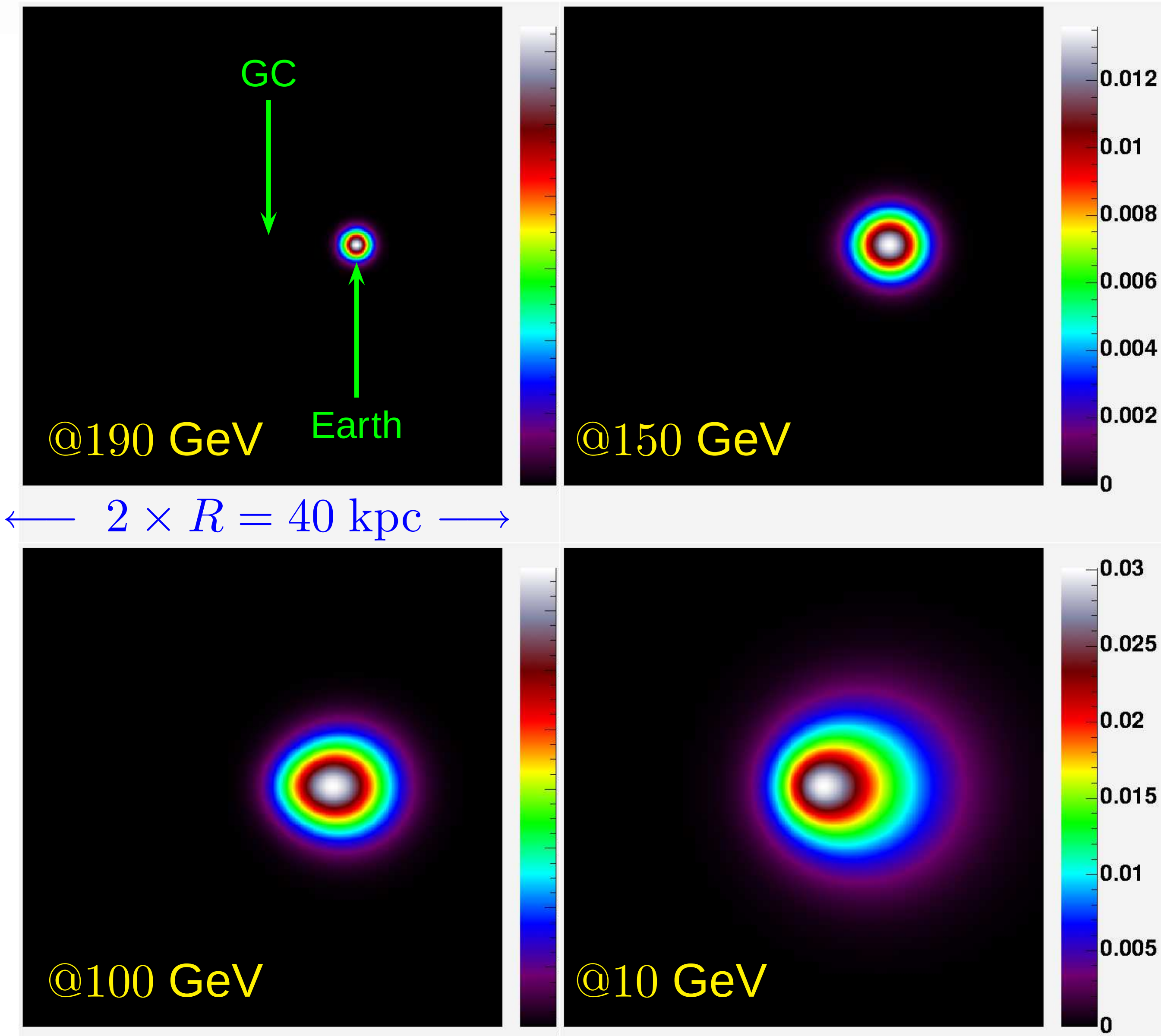
Simplest view of propagation

$$G \propto \exp\left(-\frac{|\vec{x}_S - \vec{x}_\odot|^2}{\lambda_D^2}\right)$$

with $\lambda_D = \sqrt{4K_0\Delta\tilde{t}} = f(E_S, E_D)$

$\rightarrow$ **Detection volume scaling a sphere of radius λ_D**



Figures:
galactic plane at z=0 kpc
x and y from -20 to 20 kpc
Earth located at $(x = 8, y = 0)$ kpc
2D plots of
$G(\vec{x}, 200\mathrm{GeV} \rightarrow \tilde{x}_\odot, \mathrm{E}) \times \rho^2$

Two main approaches for clumpiness

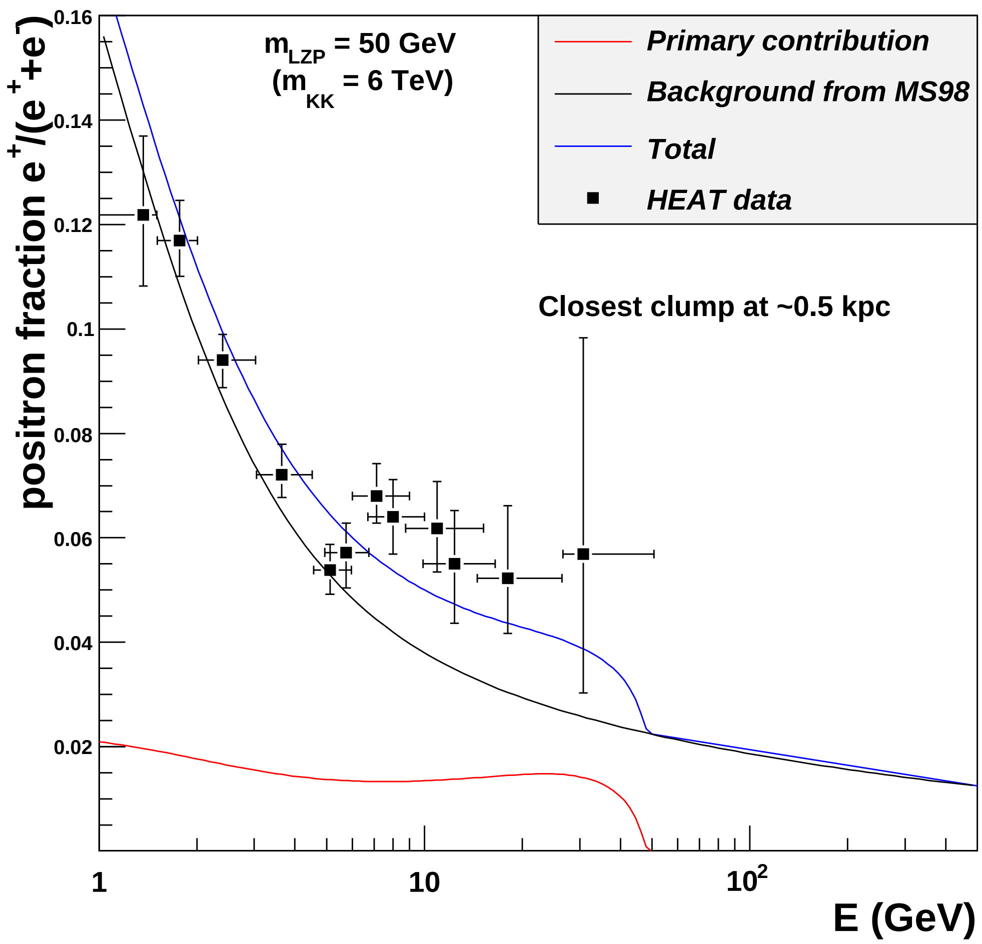
Small number of objects:

- Make sure that your scenario does not involve many other objects likely to contribute to the signal
- Search for isolated objects: OK if locations are known (DSPh), otherwise **quantify probability wrt theoretical spatial distribution** – needs of large *fov* experiments
- **If unknown, make a bet on the location, compute the fluxes, and send your predictions to the International Galactic Lottery**

Large number of objects:

- Perform a statistical analysis, **taking into account the whole phase space properties** (PDFs)
- Give **predictions associated with systematic/statistical uncertainties**: this **provides indications on the best places to search for signatures**

A single nearby source: Play the Galactic Lottery



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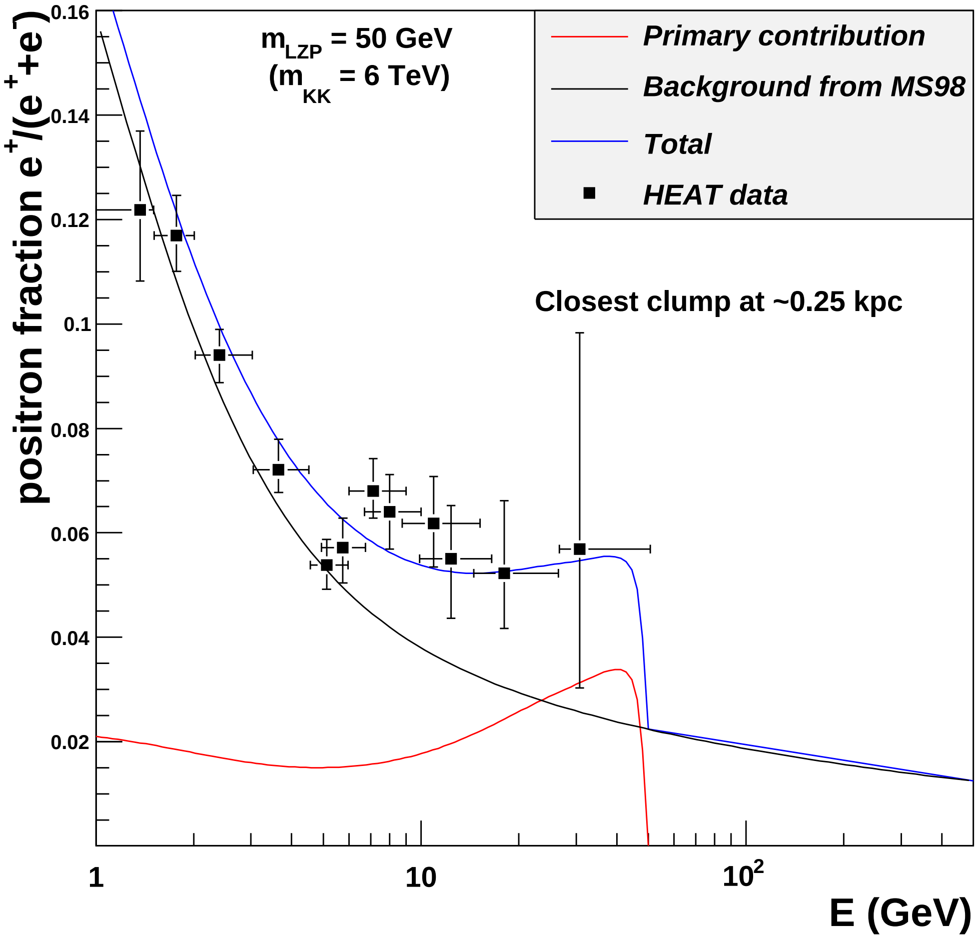

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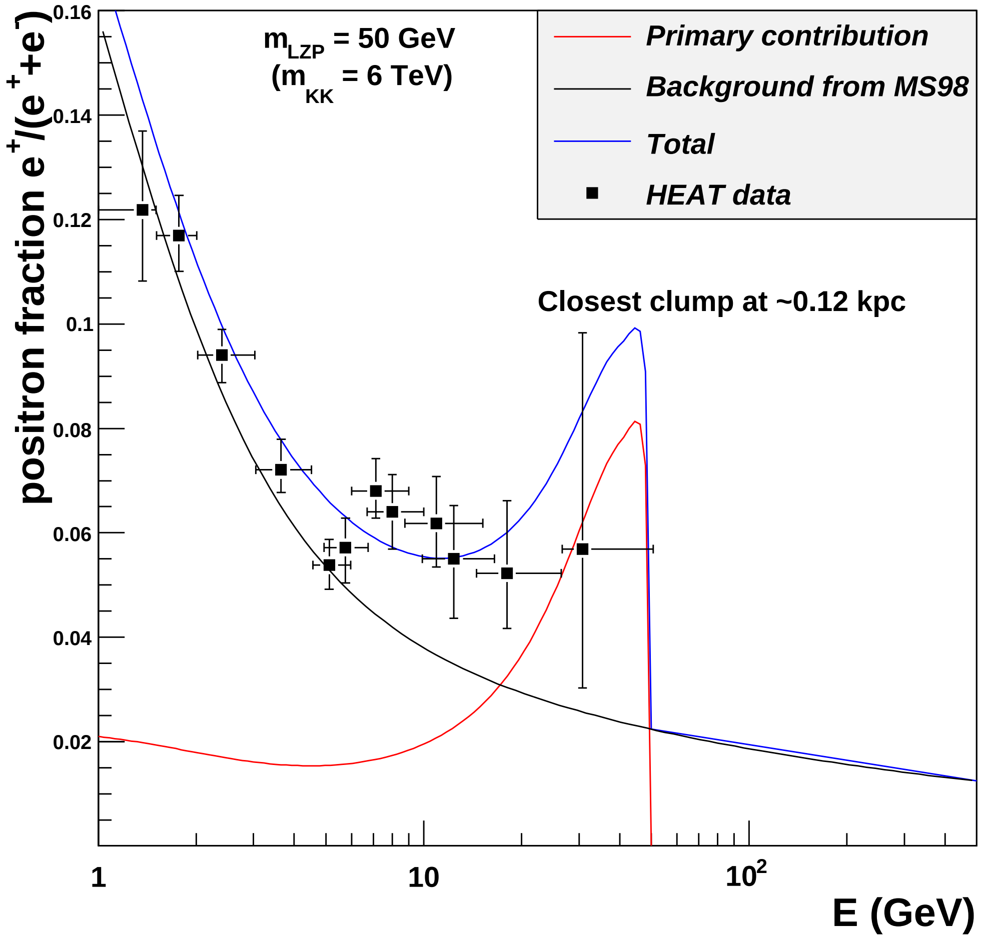

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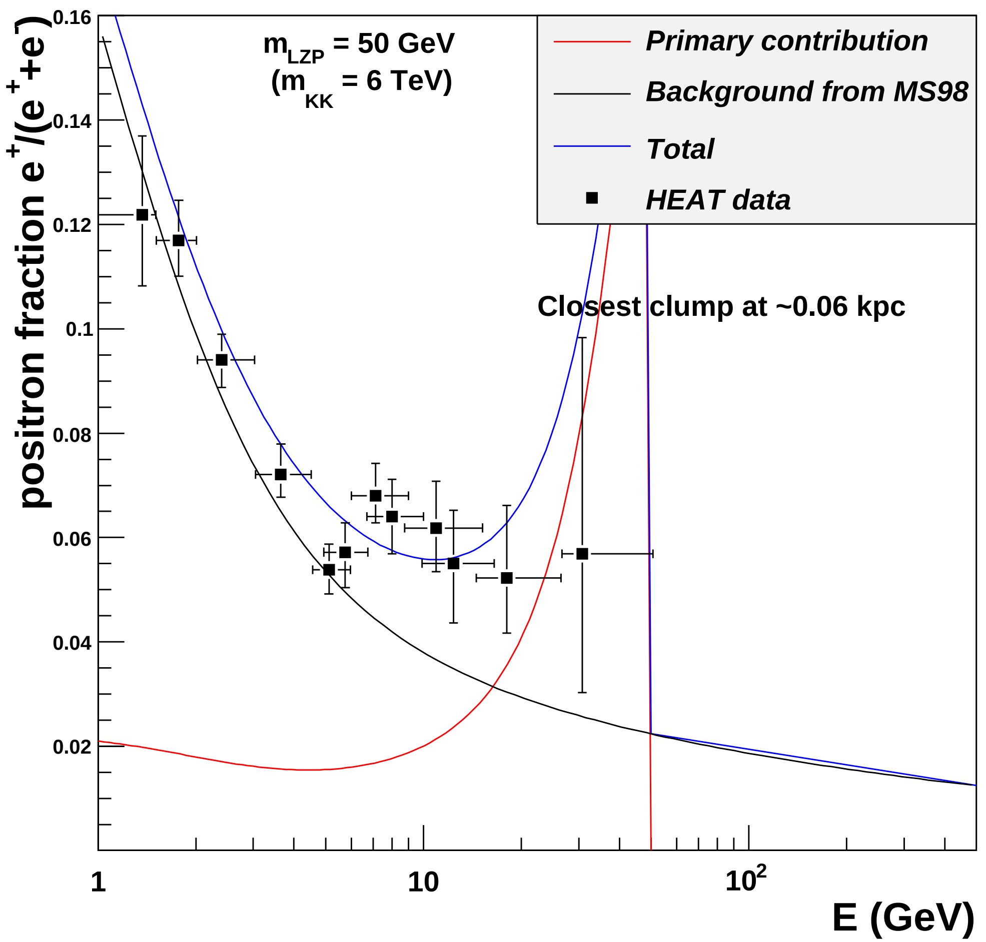

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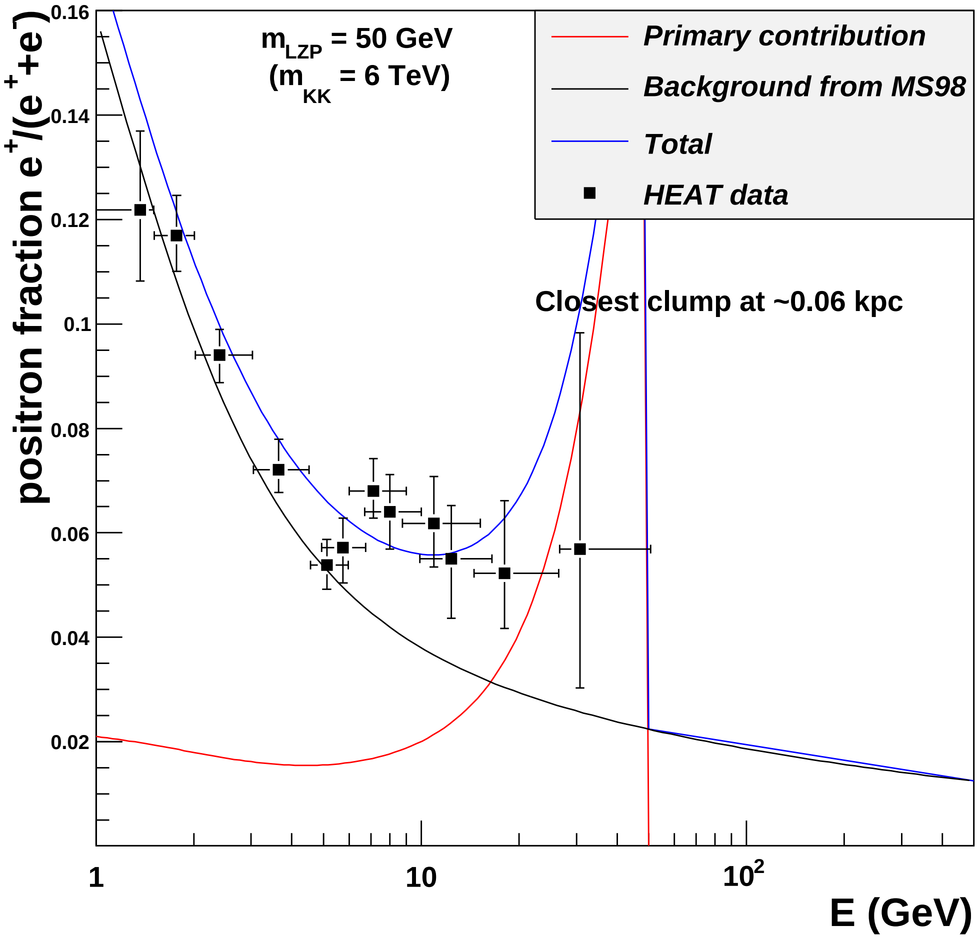

HOW PROBABLE IS THAT ????

Many-object method:
Define the phase space of substructures

The phase space distribution depends on two main quantities:

- the **spatial distribution** of objects
- the **luminosity function** of objects

$$\frac{dn_{\rm cl}}{d\mathcal{L}}(\mathcal{L},\vec{x}) = \frac{dN_{\rm cl}}{dV\,d\mathcal{L}}(\mathcal{L},\vec{x}) = N_0 \times \frac{d\mathcal{P}}{dV}(\vec{x}) \times \frac{d\mathcal{P}}{d\mathcal{L}}(\mathcal{L},\vec{x})$$

PDFs allow to compute mean values and associated statistical variances for some physical quantities

Connecting primary fluxes to the main quantities

A general expression for the **primary flux from a single clump** reads:

$$\phi_i(E,\vec{x}_\odot) = S \times \xi_i \times \tilde{\mathcal{G}}_i(E,\vec{x}_\odot \leftarrow \vec{x}_i, E_S)$$

- Particle physics factor:

  $S \equiv \frac{\delta}{4\pi}\frac{<\sigma v>}{2}\left(\frac{\rho_\odot}{m}\right)^2$

- Effective annihilation volume (internal clump properties)

  $$\xi_i \equiv \int_{V_i} d^3\vec{x}\left(\frac{\rho_i(\vec{x})}{\rho_\odot}\right)^2$$

- Propagation (GCRs) or dilution (γ-rays):

$$\tilde{\mathcal{G}}_{i,\gamma}(E_\gamma,\psi) \propto \frac{f(E_\gamma)}{4\pi|\vec{x}_i - \vec{x}_\odot|^2}$$

$$\tilde{\mathcal{G}}_{i,\mathrm{CR}}(E) \propto \int dE_S\, G(E,\vec{x}_\odot \leftarrow E_S,\vec{x}_i) \times f(E_S)$$

In a many clump scenario, ϕ_i **is a stochastic variable** !
PDFs of ξ and G translate to the PDF of $\phi \Rightarrow$ **Compute $\langle\phi_{\rm cl}^{\rm tot}\rangle$ and $\sigma_{\phi_{\rm cl}^{\rm tot}}$!!!**

$$\frac{d\mathcal{P}}{d\phi} = \frac{d^2\mathcal{P}}{dV\, d\xi}(\vec{x},\xi) \approx \frac{d\mathcal{P}_V}{dV}(\vec{x}) \times \frac{d\mathcal{P}_\xi}{d\xi}(\xi)$$

$$\phi_{\rm cl}^{\rm tot} = \sum_i \phi_i = N_{\rm cl} \times \langle\phi\rangle = N_{\rm cl} \times S \times \langle \xi \times \tilde{\mathcal{G}}\rangle \approx N_{\rm cl} \times S \times \langle\xi\rangle \times \langle\tilde{\mathcal{G}}\rangle$$

Computing the odds of the Galactic Lottery: Identical clumps tracking the smooth halo

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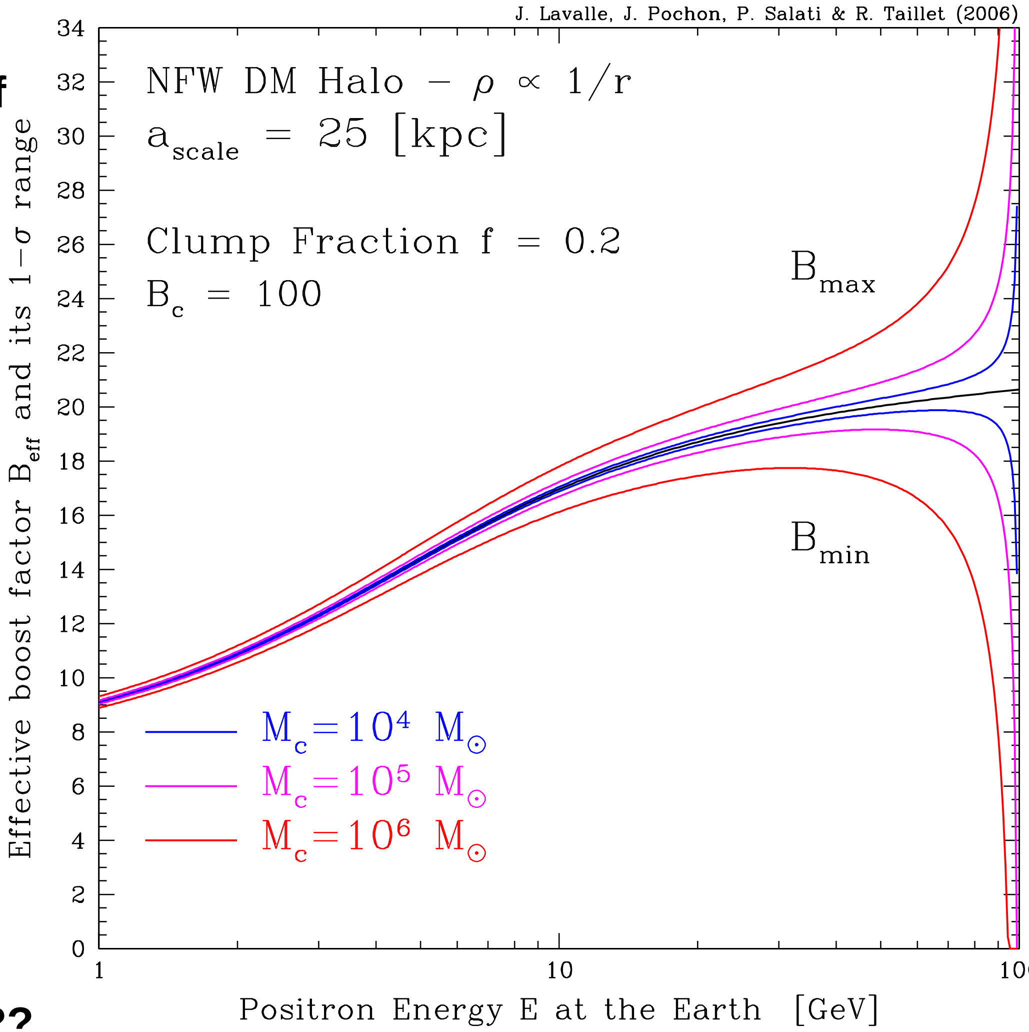
Boost for antimatter CRs:

- Long believed to be **simple rescaling of fluxes** ...
- **This picture is wrong**. Due to propagation effects, ***boost* is a non-trivial function of energy** (J.L, Pochon, Salati & Taillet, 2006).
- Variance depends on the number of clumps within the volume bounded by diffusion length λ_D: increases when the population when λ_D decreases ($\sim 1/\sqrt{N_{\rm eff}}$).
- **The recipe applies to any kind of sources**
- **Predictions for N-body-like models ???**



Cosmological sub-halos: Results of the state-of-the-art N-body experiments

Cosmological sub-halos:
Results of the state-of-the-art N-body experiments

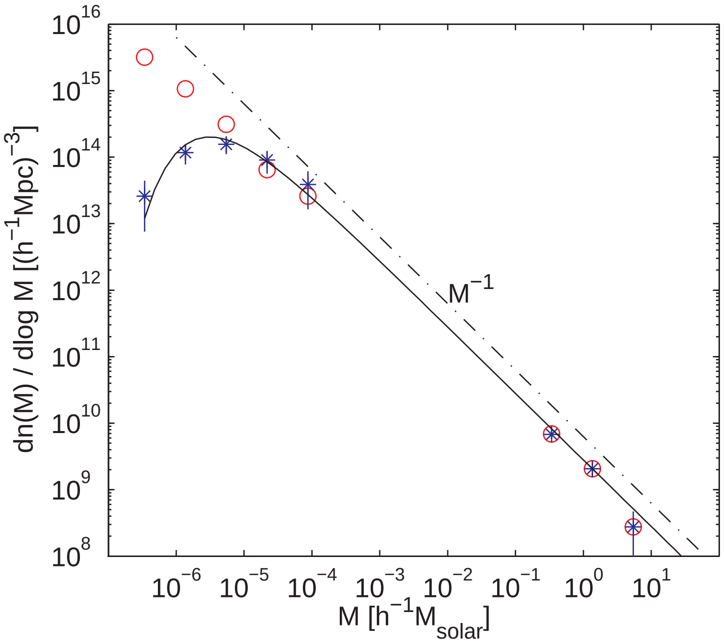
N-body results as input ingredients, and allowed [ranges]:

- **Mass distribution**:
  minimal clump mass $M_{\rm min}$
  $[10^6 - 10^{-6} M_\odot]$,
  logarithmic slope $\alpha_{\rm m}$ [1.8-2.0]

- **Spatial distribution**:
  . [cored isothermal – smooth-like]

- **Spherical inner profile(s)** for clumps
  $\propto r^{-\gamma}$, with $\gamma \in$[NFW-Moore]=[1,1.5]
  and **concentration** [Eke et al 01 – Bullock et al 01]

Diemand et al (2005)



Cosmological sub-halos:
Results of the state-of-the-art N-body experiments

N-body results as input ingredients, and allowed [ranges]:

- **Mass distribution**:
  minimal clump mass $M_{\rm min}$
  $[10^6 - 10^{-6} M_\odot]$,
  logarithmic slope $\alpha_{\rm m}$ [1.8-2.0]
- **Spatial distribution**:
  . [cored isothermal – smooth-like]
- **Spherical inner profile(s)** for clumps
  $\propto r^{-\gamma}$, with $\gamma \in$[NFW-Moore]=[1,1.5]
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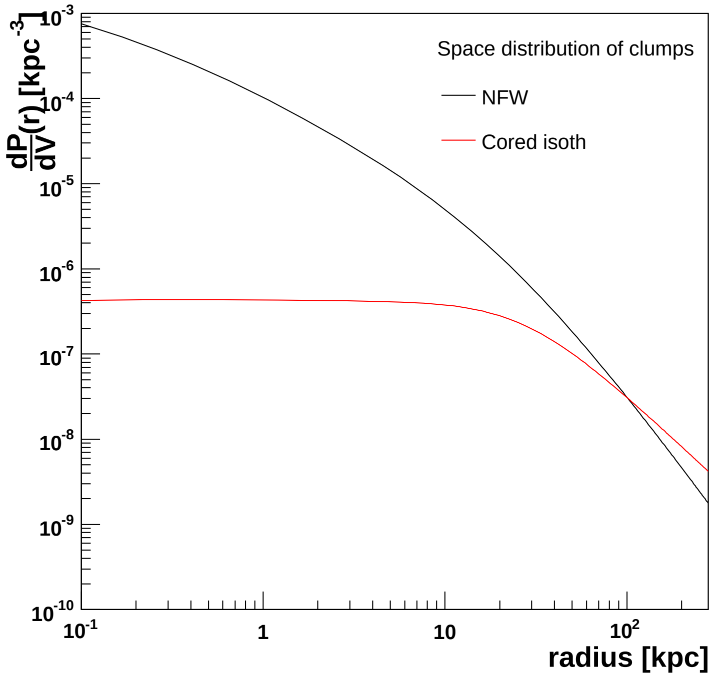
NFW vs cored isothermal



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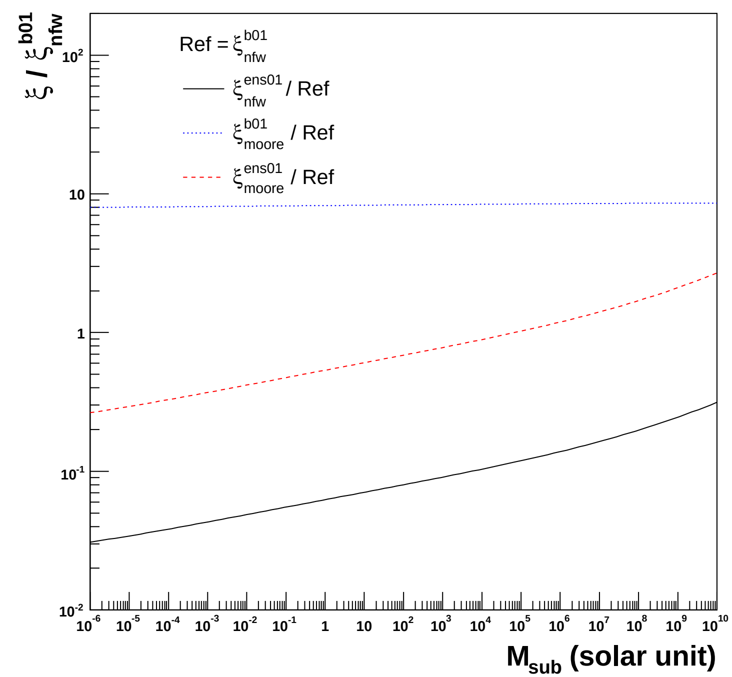
$$\xi^{\rm B01}_{\rm NFW} \simeq 0.1 \times \xi^{\rm B01}_{\rm Moore} \simeq 10 \times \xi^{\rm ENS01}_{\rm NFW}$$



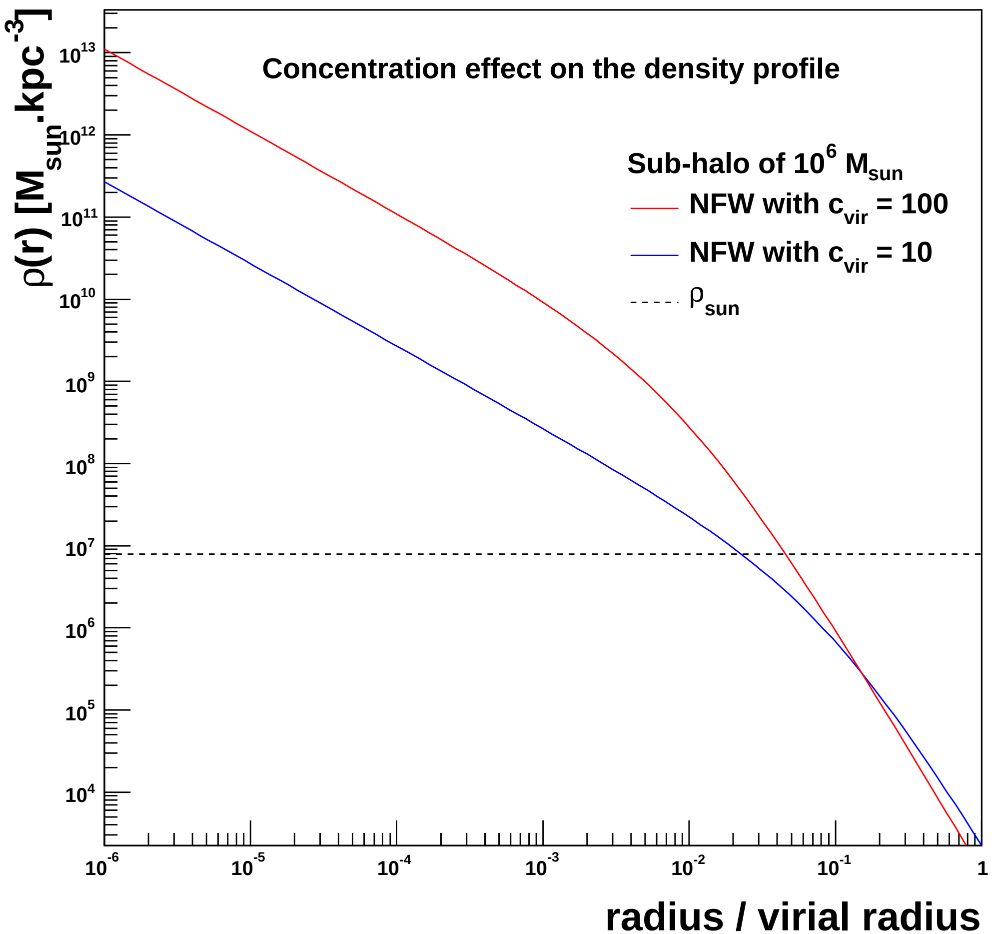
Draw me a clumpy sheep

Some statements:

- Any Sub-halo forms when the Universe is matter-dominated, when an overdensity collapses (a fluctuation of the critical density at this time): its characteristic density is larger when it has formed earlier.
- It can be (very roughly) modelled as a spherical object, with typical power law density profiles ($r^{-\gamma}$, with $\gamma \sim 1-1.5$ up to a scale radius)
- The concentration is a key parameter

Some definitions:

- Concentration: $c_{\rm vir} \equiv \frac{R_{\rm vir}}{r_{-2}}$
- Luminosity volume: $\xi \equiv \int_{V_{\rm sub}} \left(\frac{\rho_{\rm sub}}{\rho_0}\right)^2$



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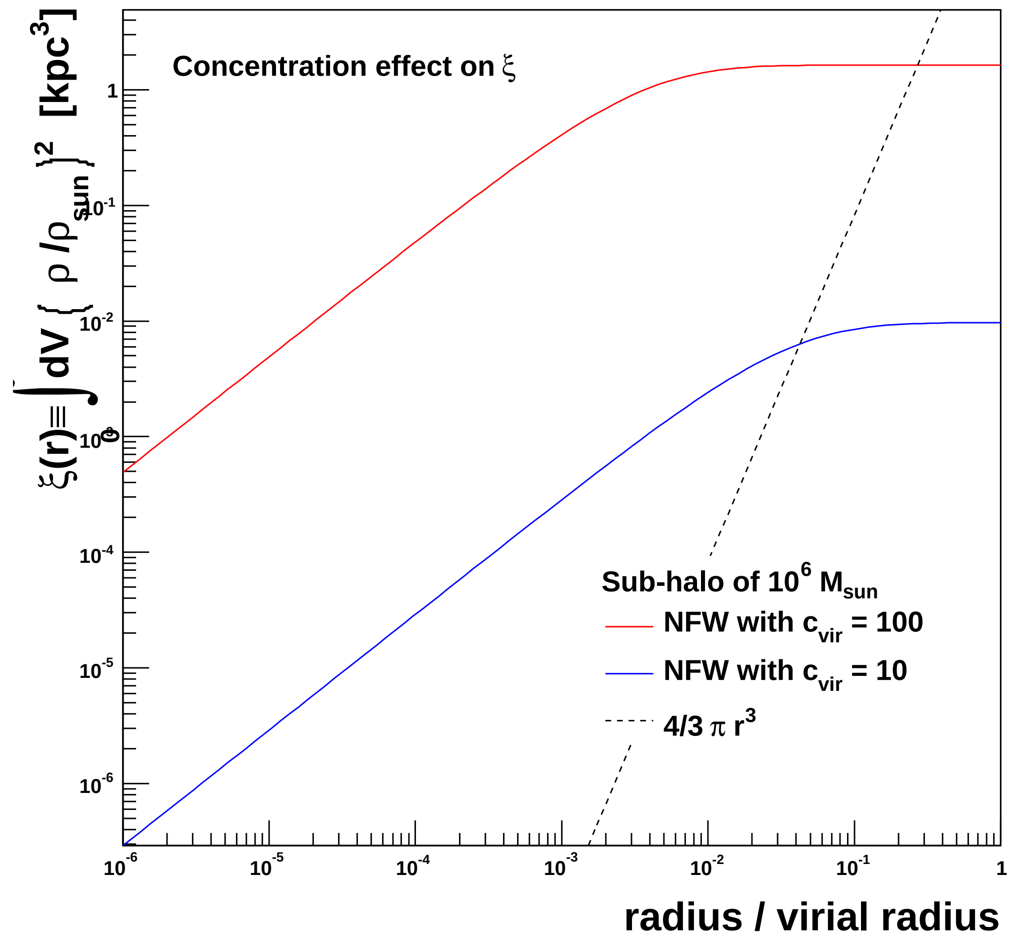


Results for e^+ and $\bar{p}$ using different models of N-body-like clumps

Next slides: (i) Fluxes – smooth & clumps (ii) Boosts

Positrons:

- Source: injection of a 200 GeV line

Antiprotons:

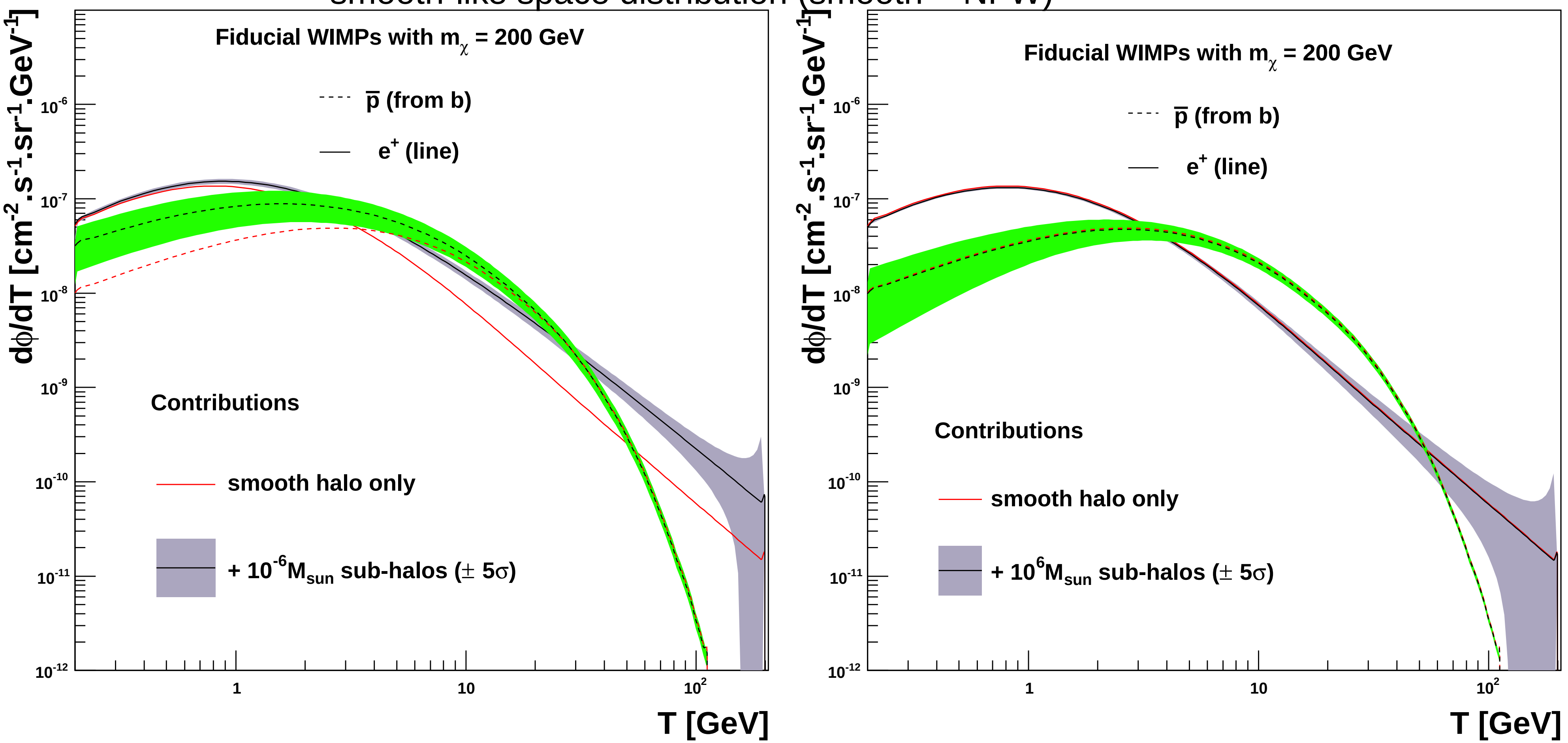
- Source: flat spectrum (1/GeV)

Both:

- Assume annihilation rate of $m_\chi = 200 GeV$ and $\langle \sigma v \rangle = 3 \times 10^{-26} \mathrm{cm}^3/\mathrm{s}$
- Spectra between 0.1-200 GeV

Primary fluxes for a 200 GeV e^+ line / antiprotons

Configurations: $M_{\rm min} = 10^{-6}|10^6 M_\odot$, $\alpha_{\rm m} = 2.0$, inner-NFW, B01,
smooth-like space distribution (smooth = NFW)

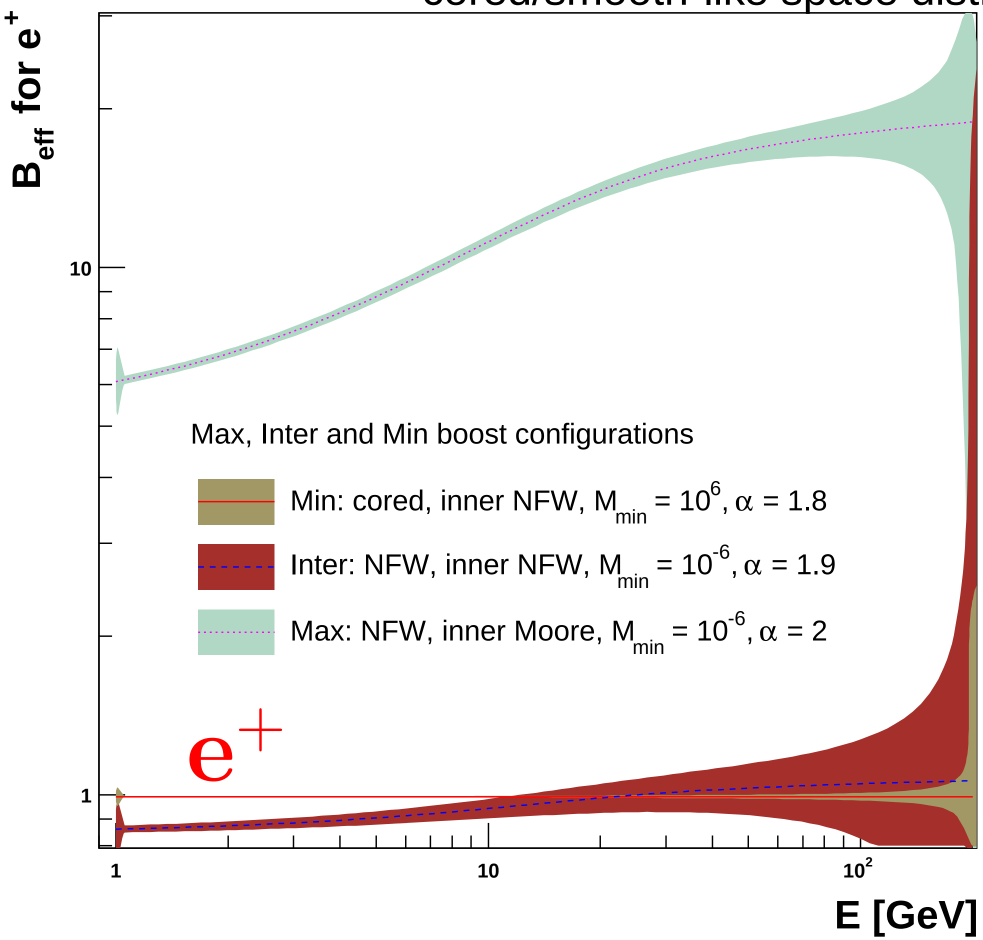


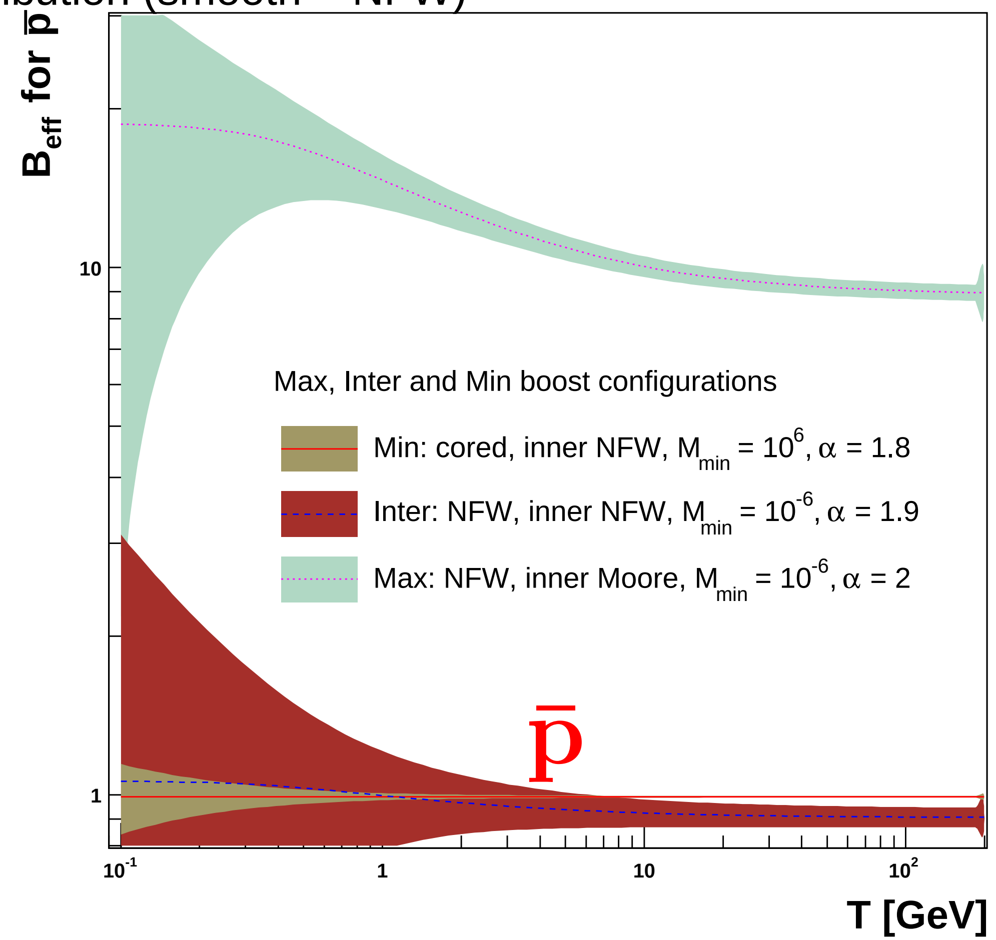
Lavalle, Maurin et al – A&A 429, 427 (2008)

Lavalle, Nezri et al – PRD 78 (2008)

Boost factors for a 200 GeV e^+ line / antiprotons

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)





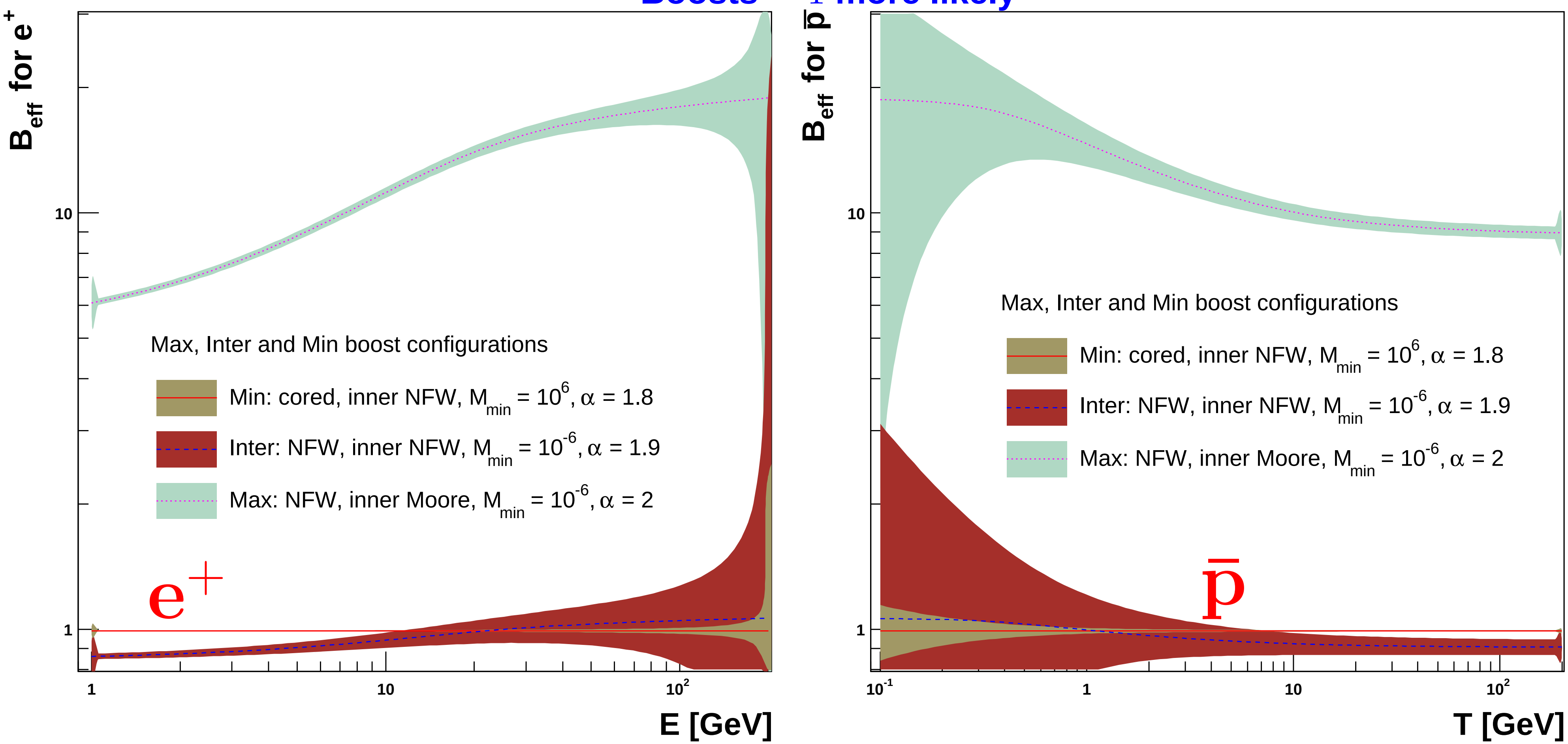
Lavalle, Yuan, Maurin & Bi – A&A 429, 427 (2008)

Boost factors for a 200 GeV e^+ line / antiprotons

Small concentration models favored !!!

(e.g. Neto et al (2007), Springel et al (2008) – Aquarius)

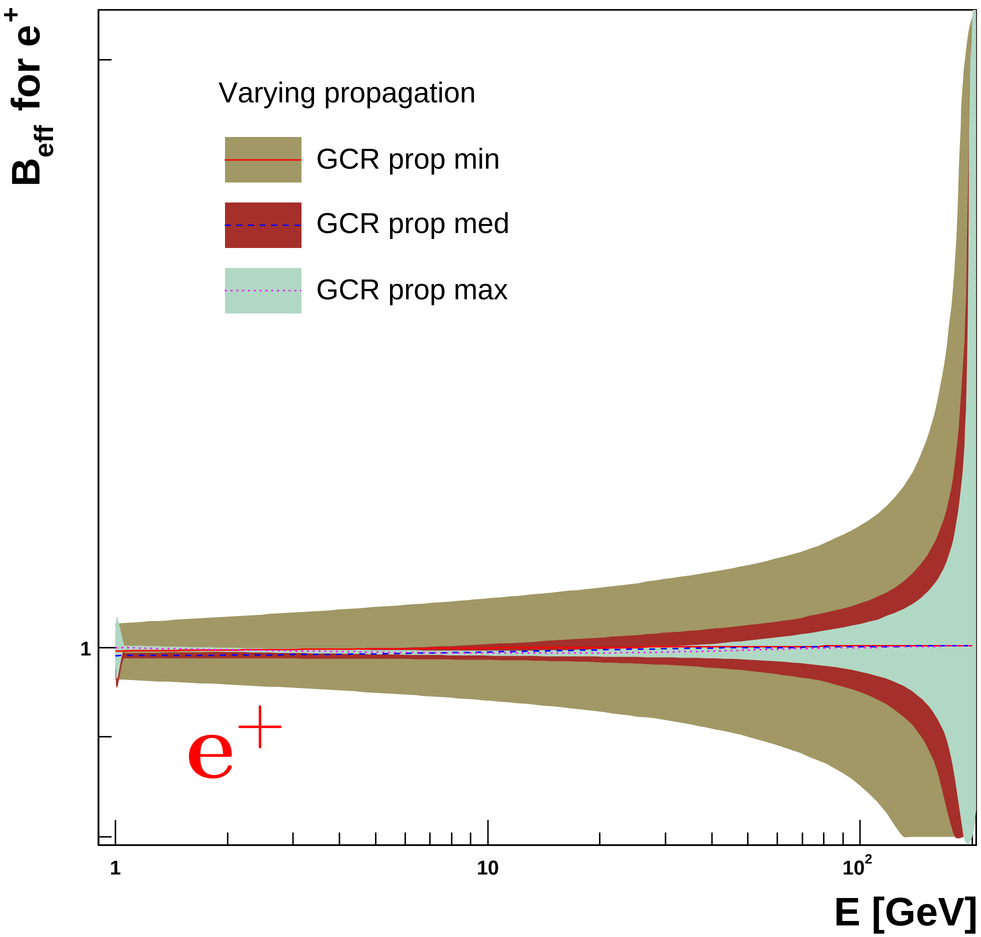
Boosts ~ 1 more likely

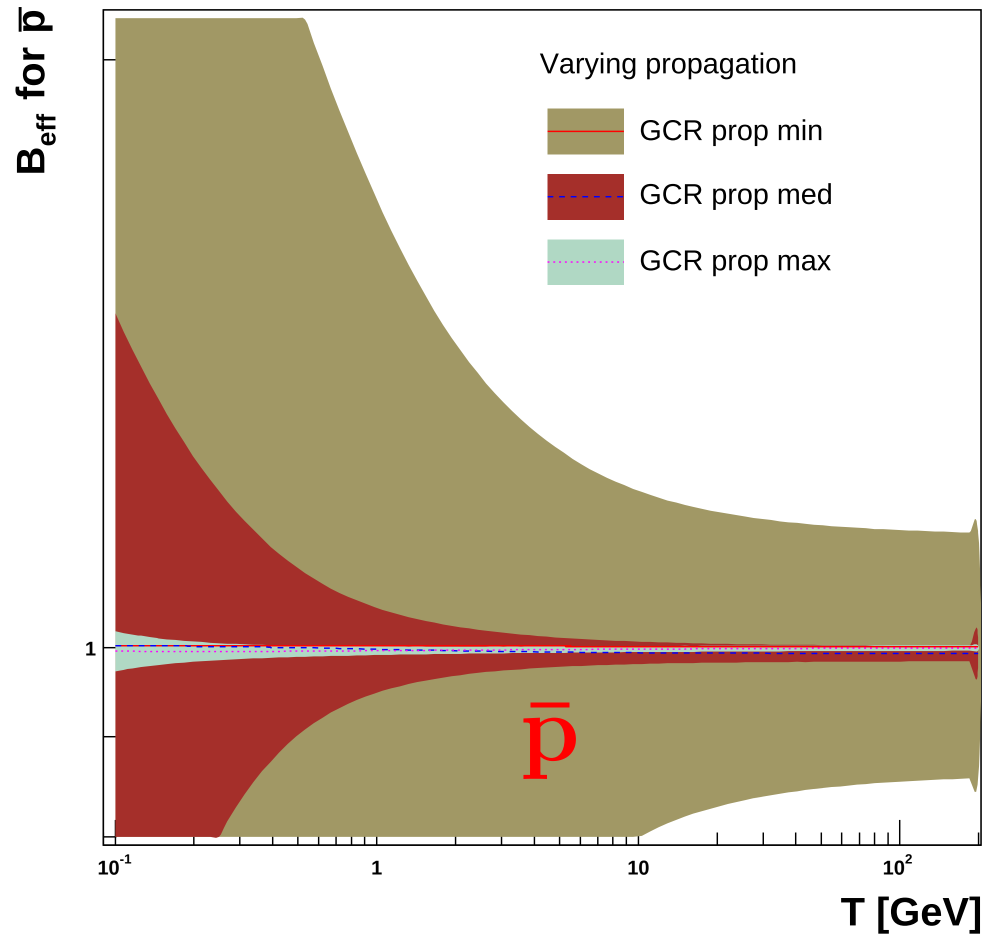


Lavalle, Yuan, Maurin & Bi – A&A 429, 427 (2008)

Propagation effects on boost factors

$M_{\rm min} = 10^{-6} M_{\odot}$, $\alpha_{\rm m} = 1.9$, inner-NFW, B01, cored space distribution, *min*, *med* and *max* propagation sets of Maurin et al 01





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Going farther :

3D map of DM density from N-body simulations

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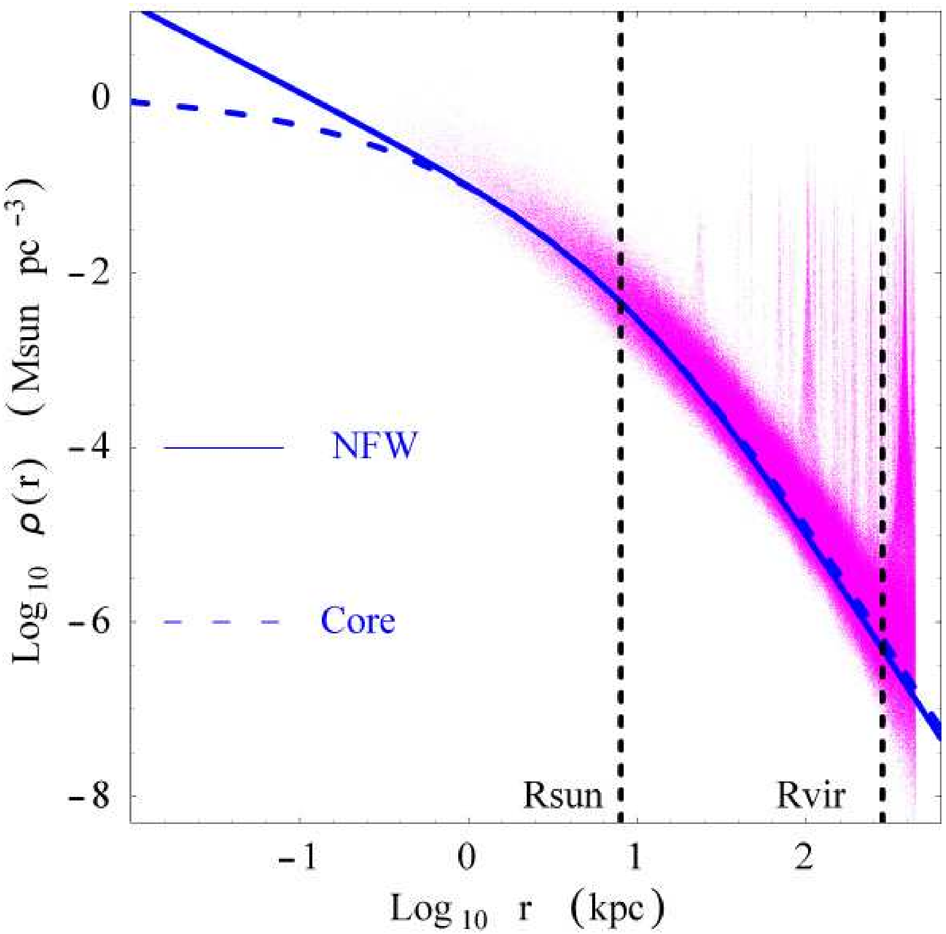

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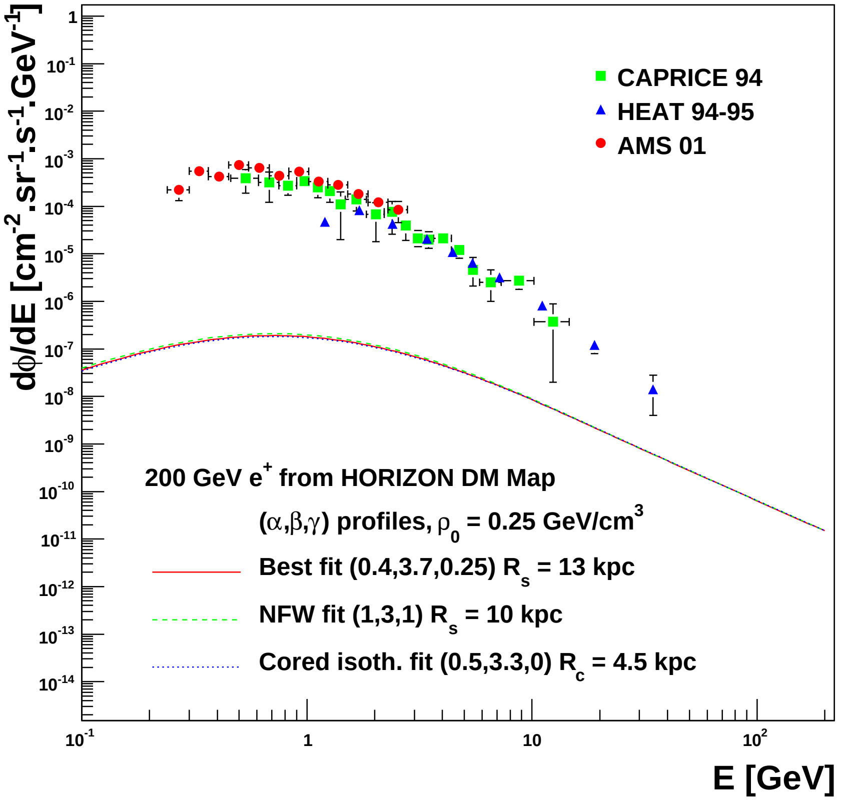
Different spherical fits give $\sim$ the same fluxes



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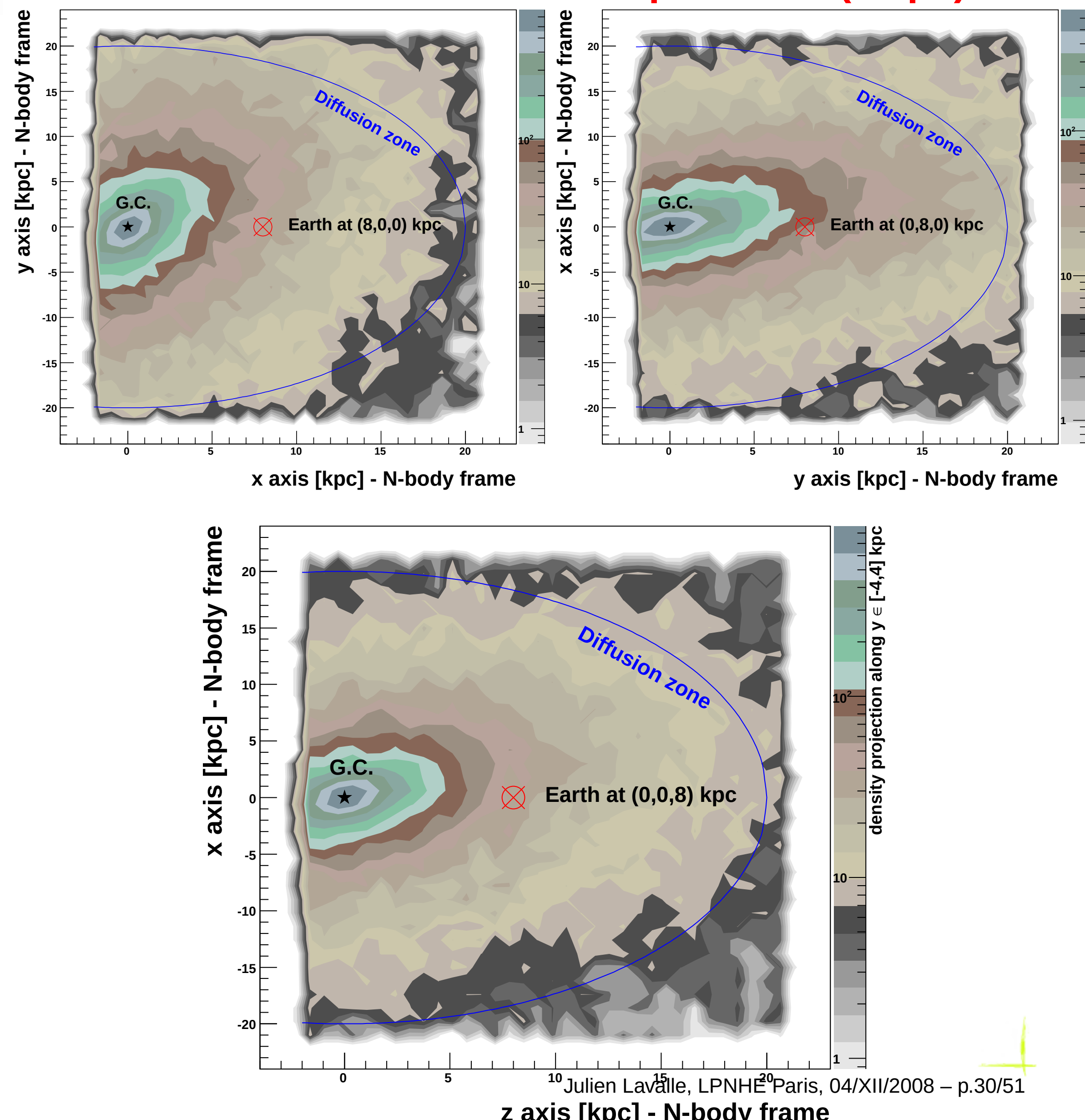
Earth at different 3 positions (8 kpc)



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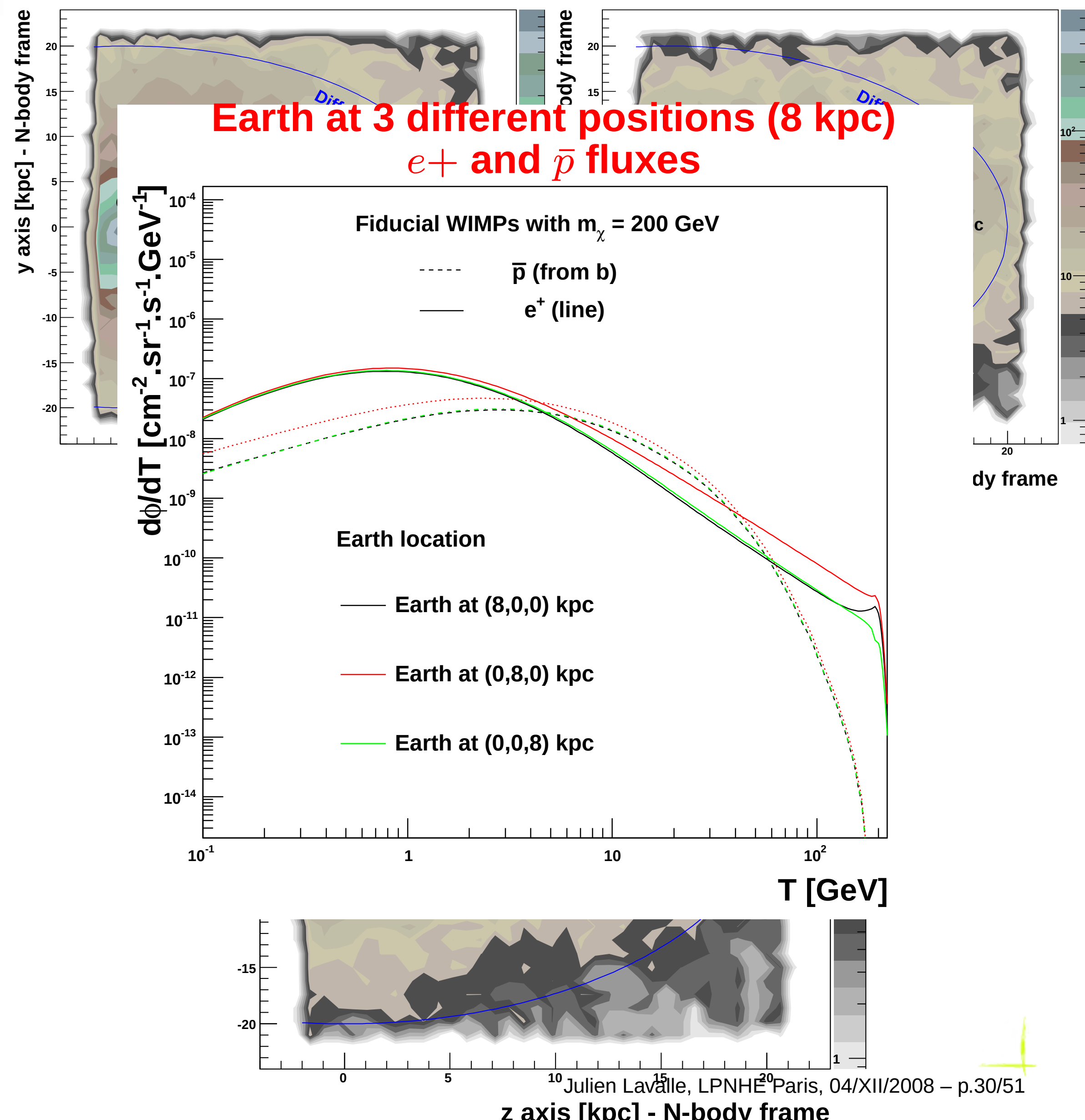

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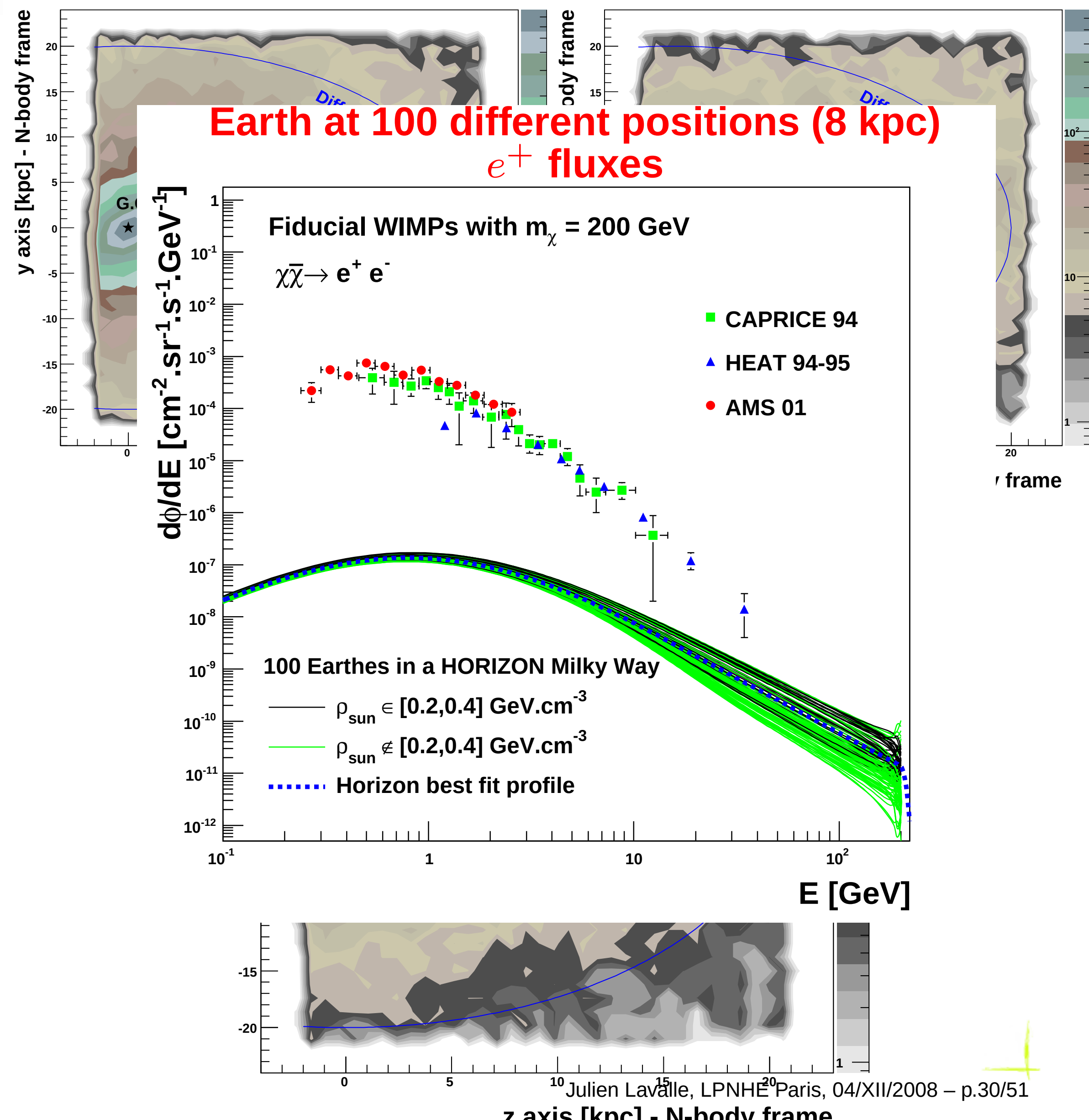

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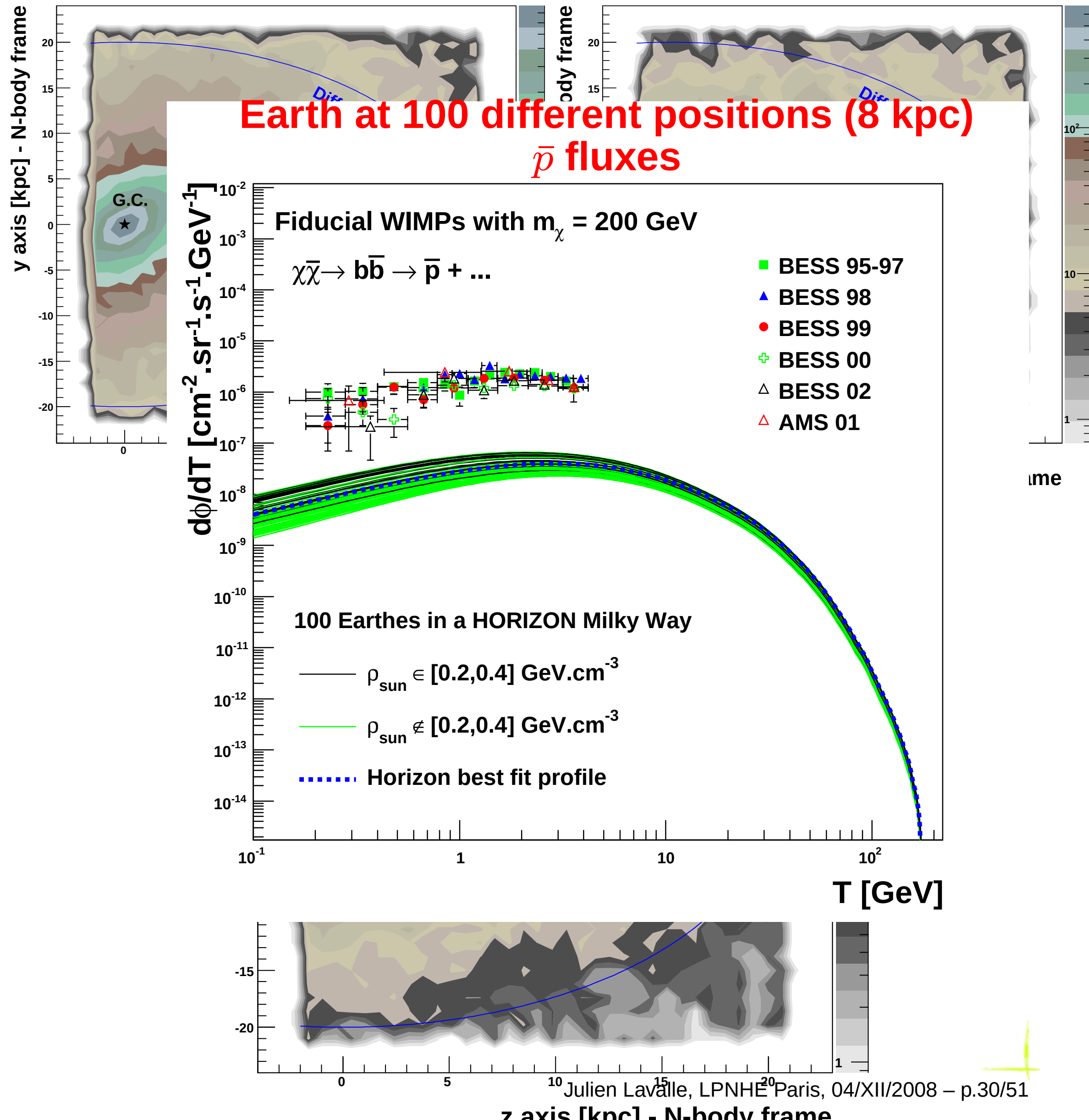

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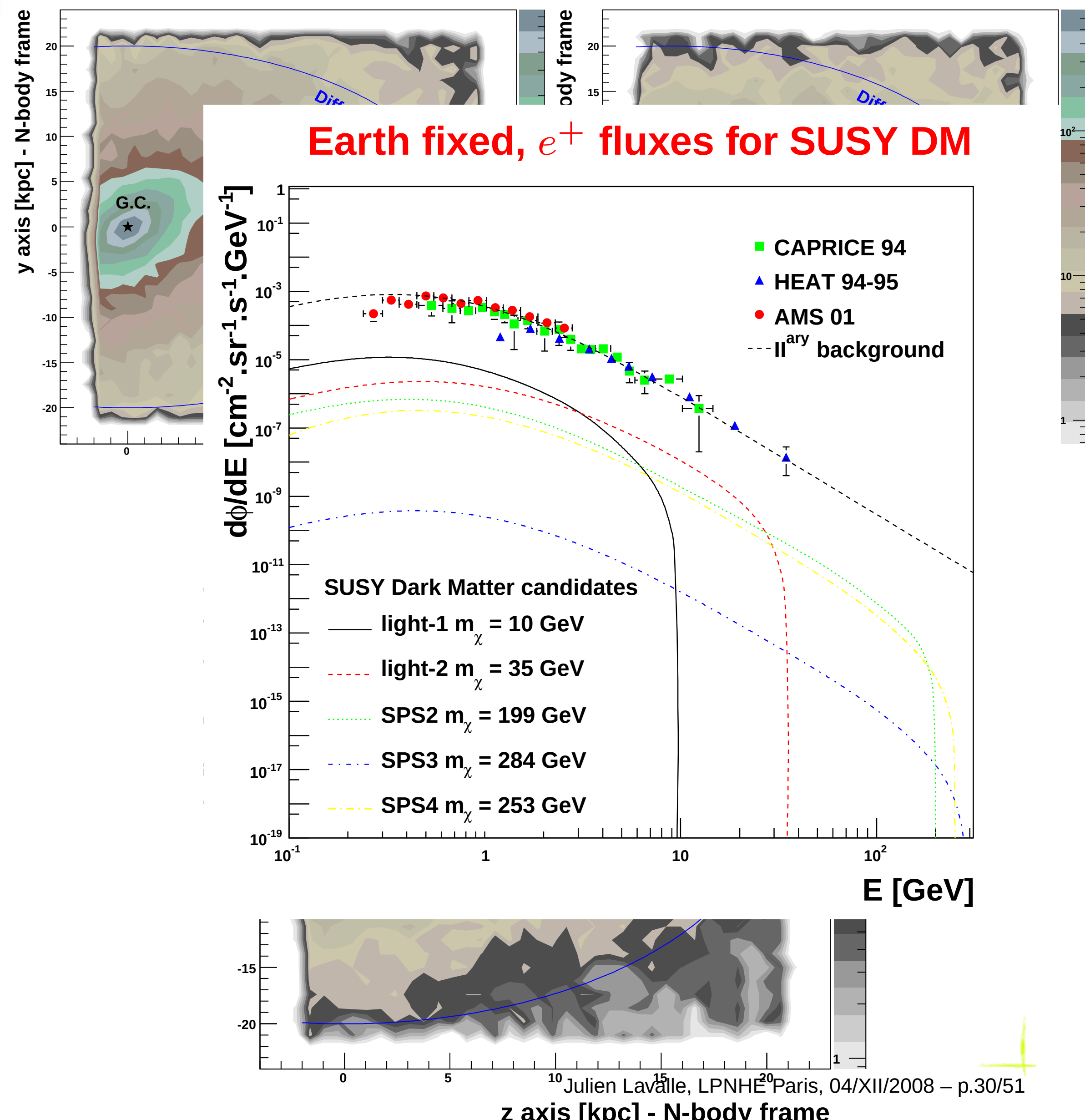

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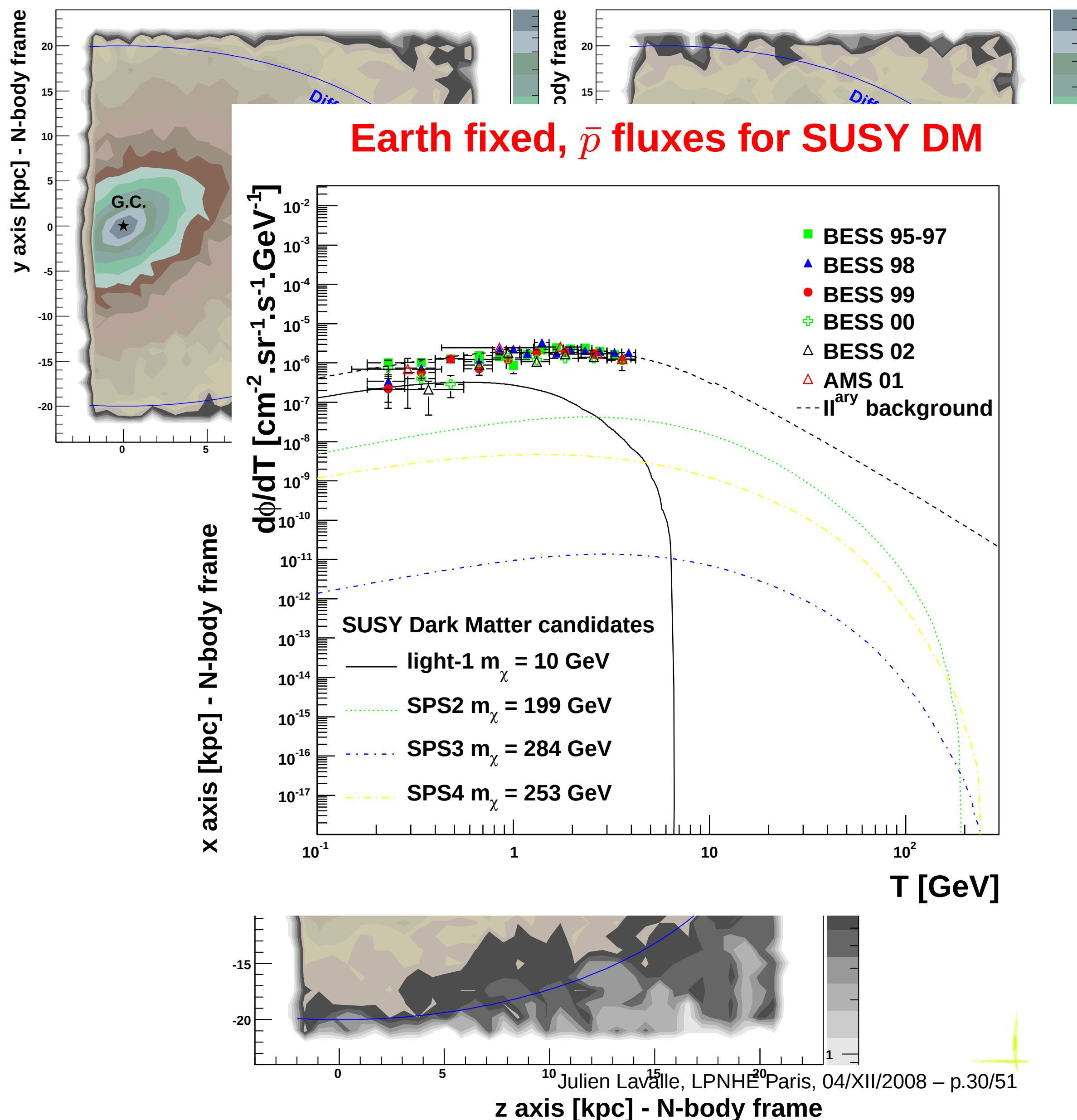

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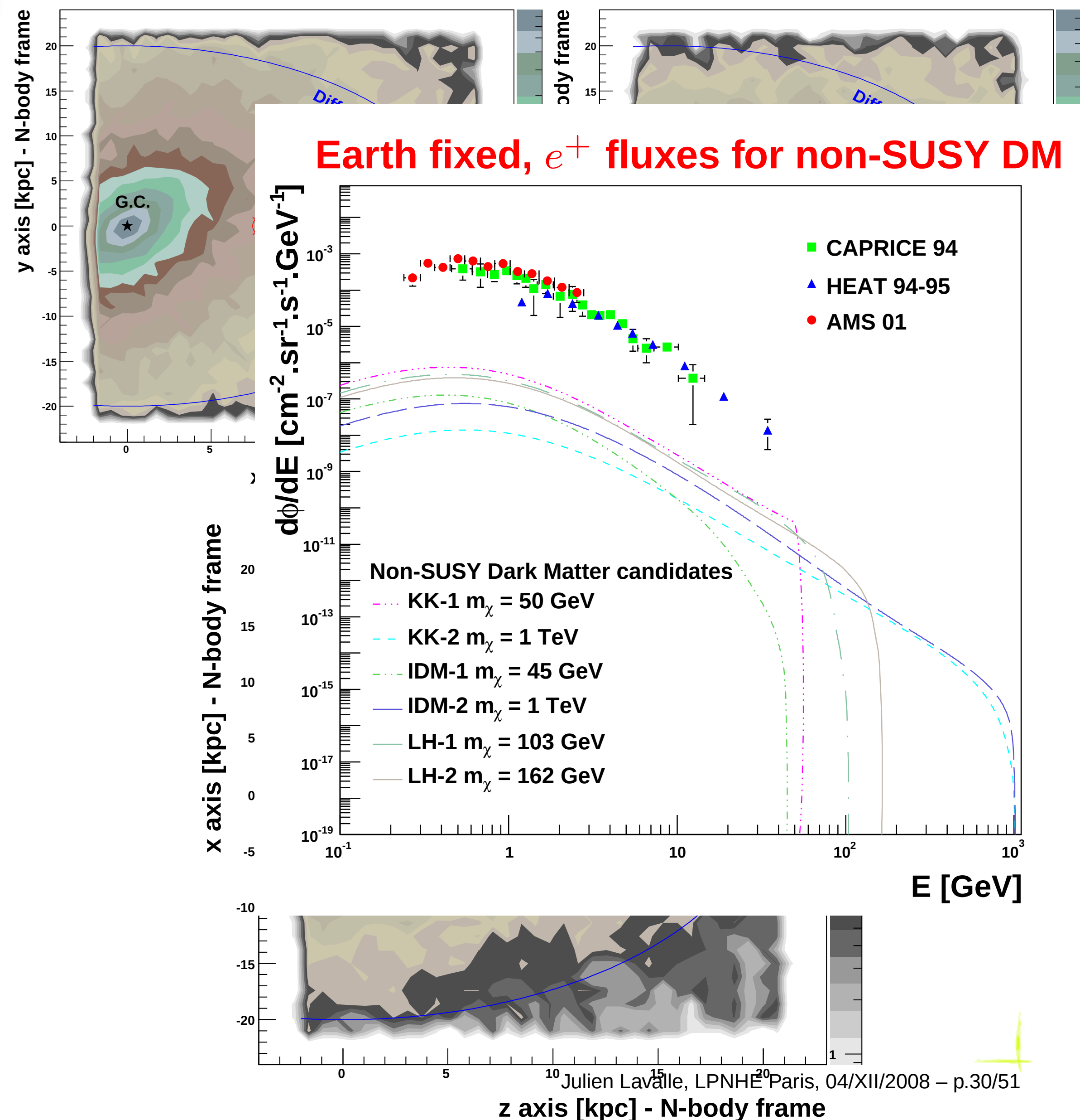

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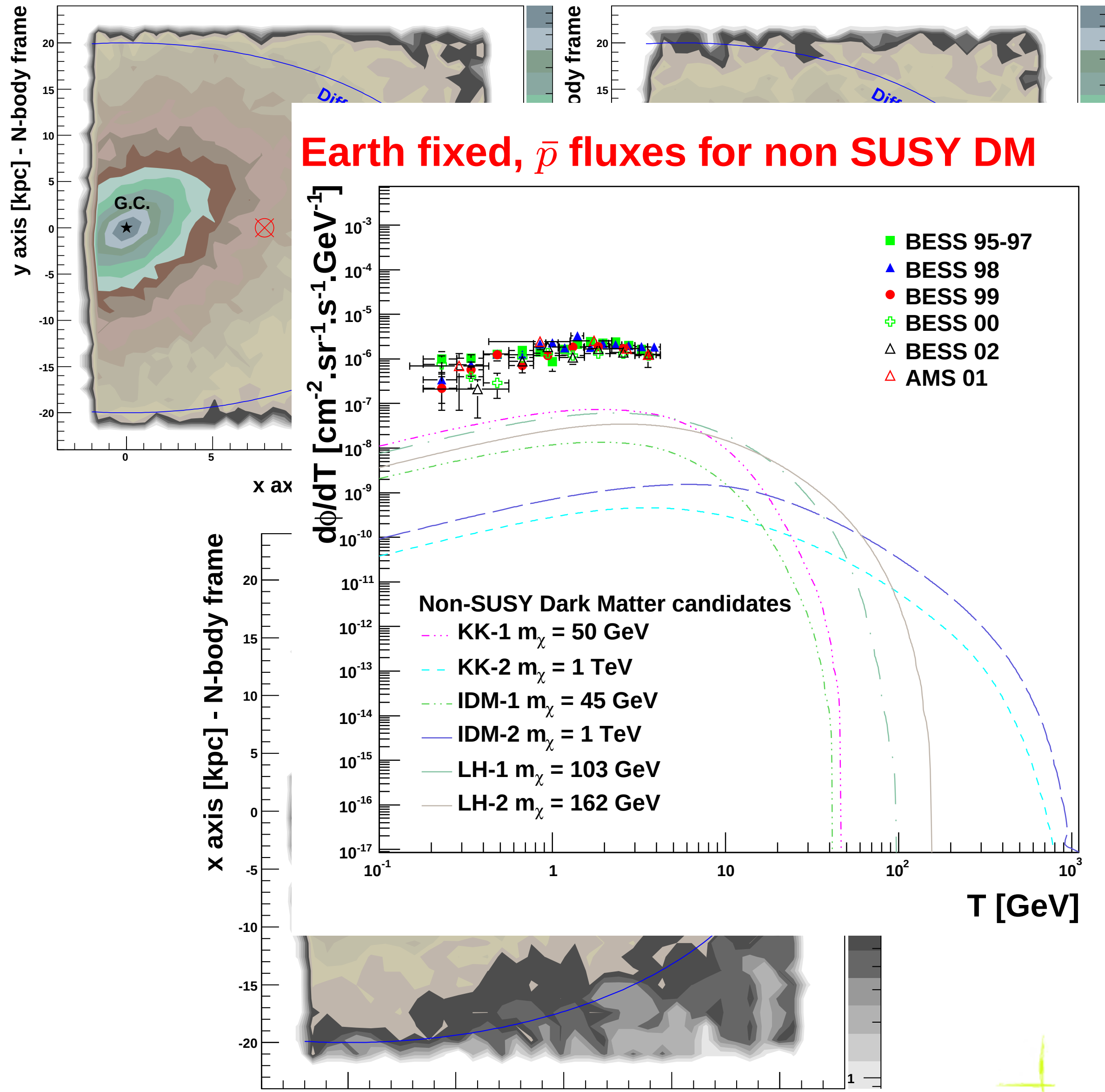

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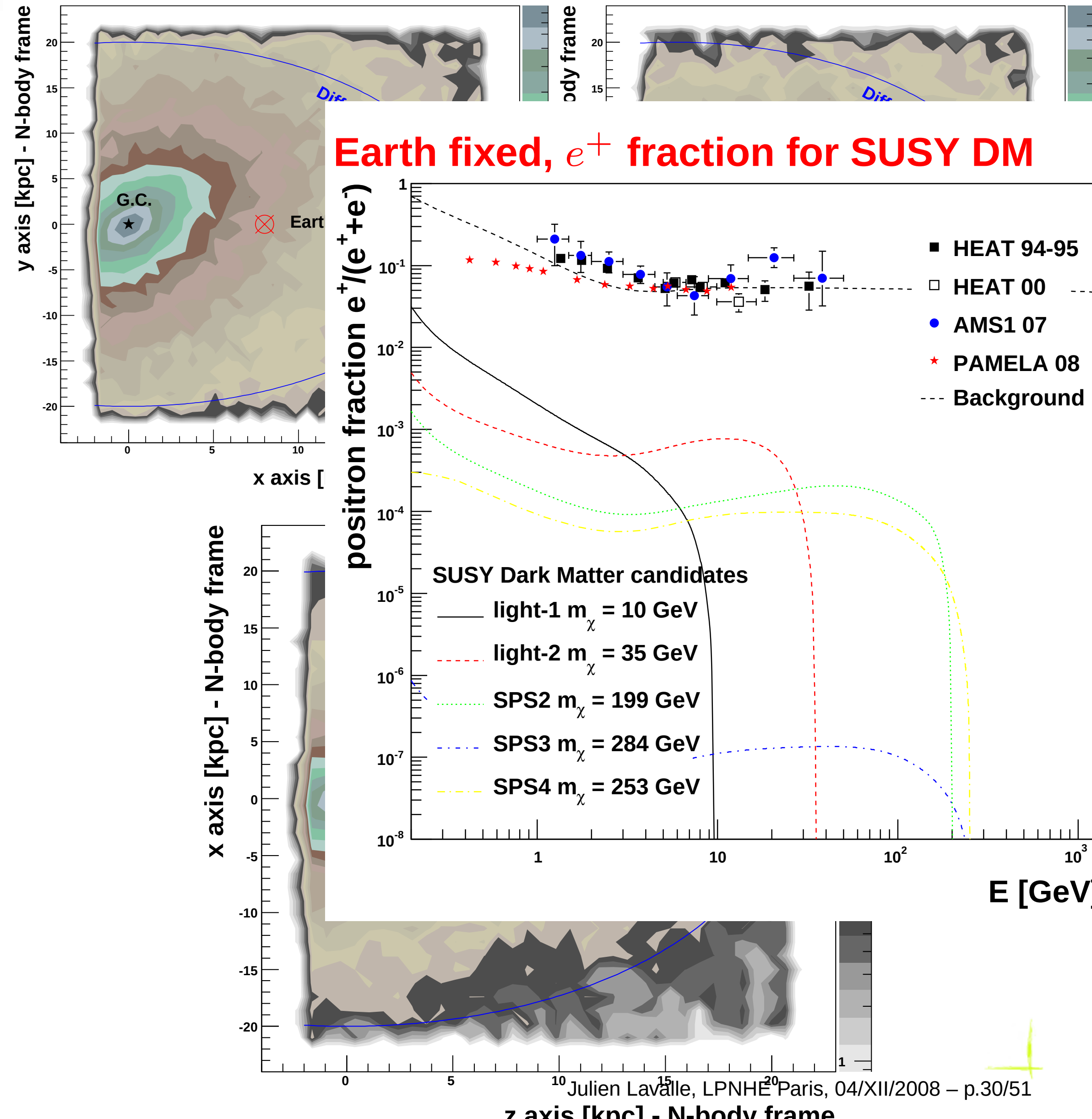

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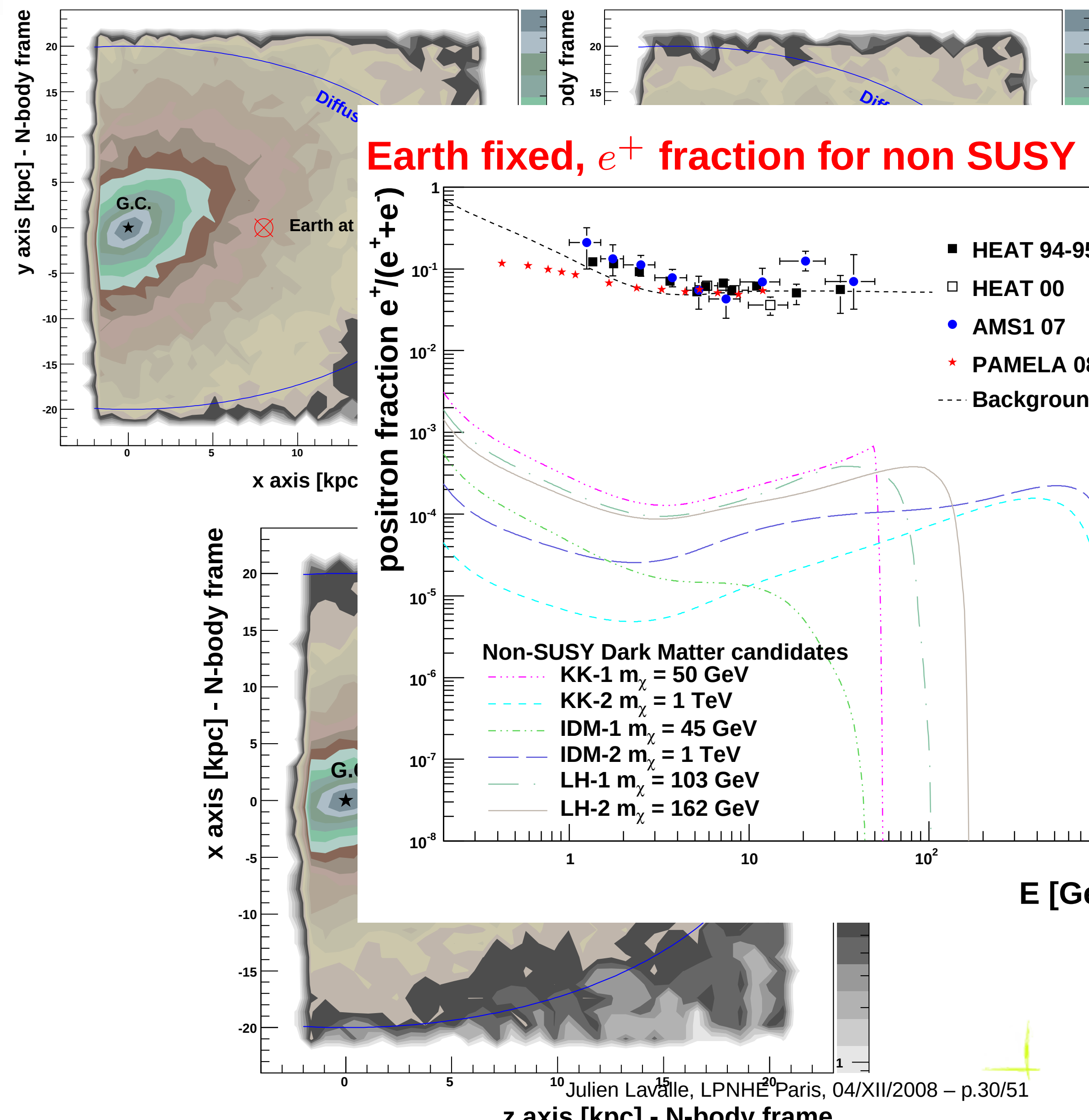
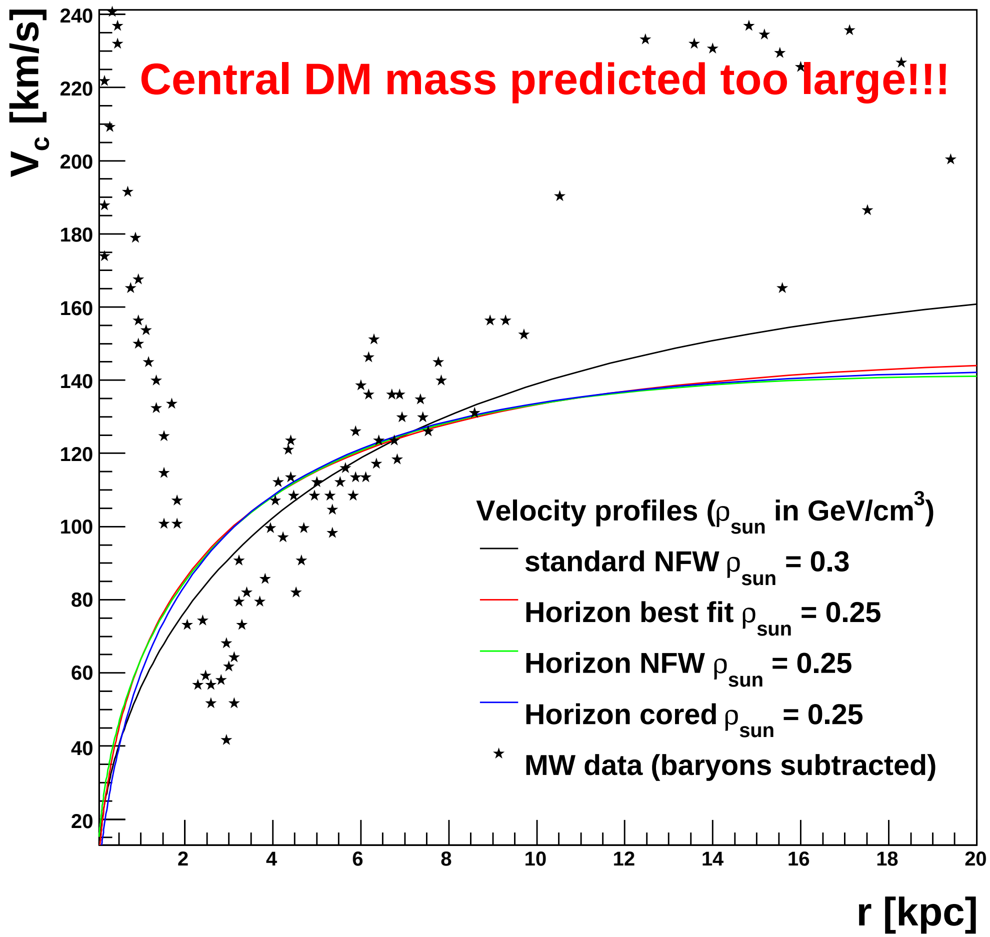


CAVEATS: too simplistic galaxy model

Rotation curves with baryon contribution subtracted

(Englmaier & Gerhard 2006, Bissantz & Gerhard 2002)



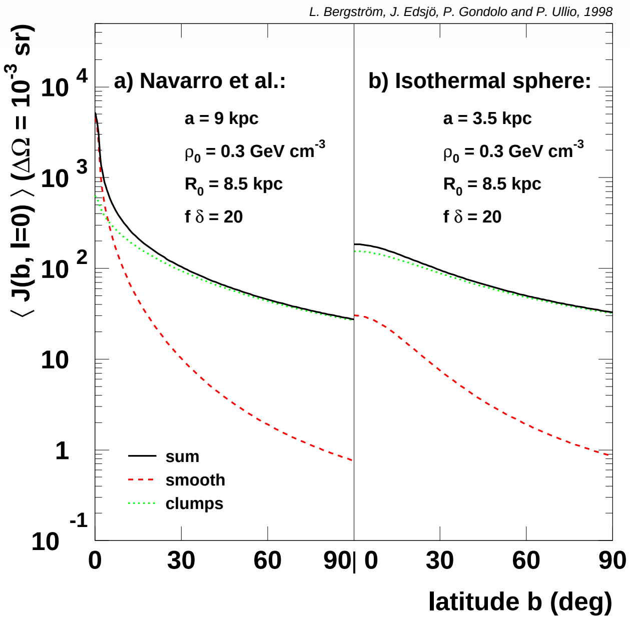
Lavalle, Nezri, Ling, Athanassoula & Teyssier – arXiv:0808.0332

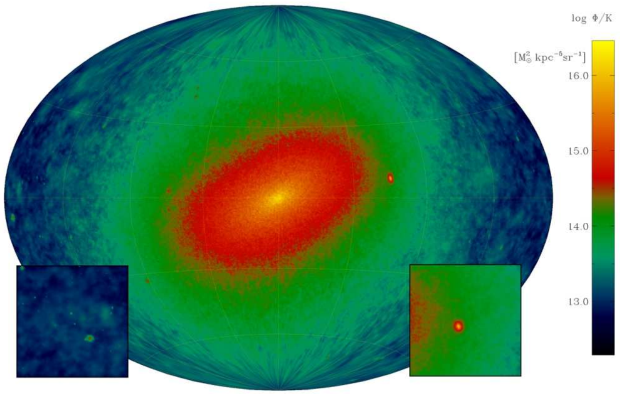
Differences with γ-rays ?

Sub-halos and γ-rays

Boost for γ-rays (studied for many years):

- **Factor to the smooth flux** which depends on the angle between GC direction and line of sight (*cf.* Bergström et al, 1998) ; main effects at high latitude regions (see figure)
- Very small additional contribution to the smooth flux in the GC direction (*cf.* Stoerh et al (2004), **Berezinsky et al (2003-2008)**) – but possibly large contribution to the diffuse flux at high latitudes.
- Statistical M-C analysis by Bi (2006), Pieri et al (2007)
- **A very few objects** could perhaps be resolved **with GLAST** towards the anti-center (Diemand et al, 2006 | see figure).





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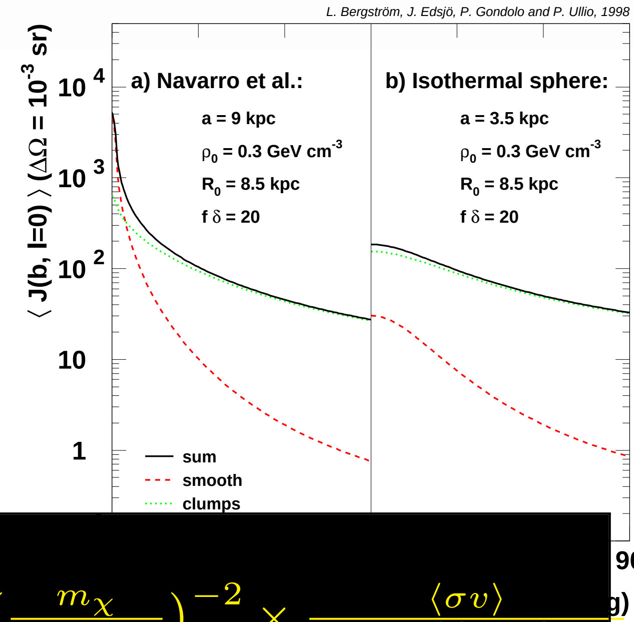

- Very small additional contribution to the smooth flux in the GC direction (*cf.* Stoerh

More quantitatively:

$$\frac{\phi_{\rm cl}(>E_{\rm th})}{[{\rm cm}^{-2}.{\rm s}^{-1}]} \approx \frac{6\times 10^{-12}}{(d/(1\ {\rm kpc}))^2} \times N_\gamma(>E_{\rm th}) \times \left(\frac{M_{\rm cl}}{10^6 M_\odot}\right) \times \left(\frac{m_\chi}{100\ {\rm GeV}}\right)^{-2} \times \frac{\langle\sigma v\rangle}{3\times 10^{-26}\ {\rm cm}^3{\rm s}^{-1}}$$

contribution to the diffuse flux at high latitudes.

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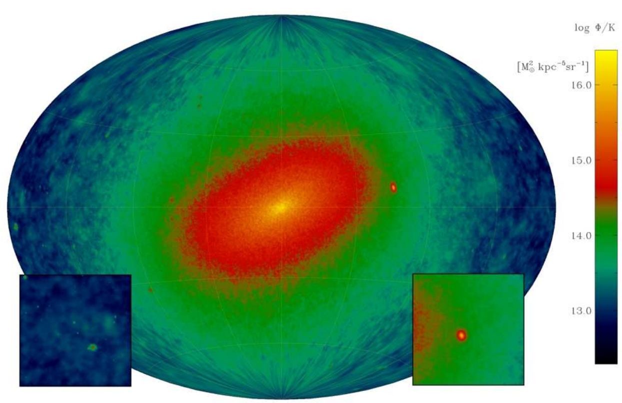

Primary e^-s and e^+ from DM annihilation in clusters

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Sunyaev - Zel'dovich effect (e.g. 1972):

- distortion of the CMB black-body spectrum due to Compton scattering with electrons in clusters (independent on z)
- dominant contribution from thermal e^-s
- what about $e^{+/-}$ injected by DM annihilation ?

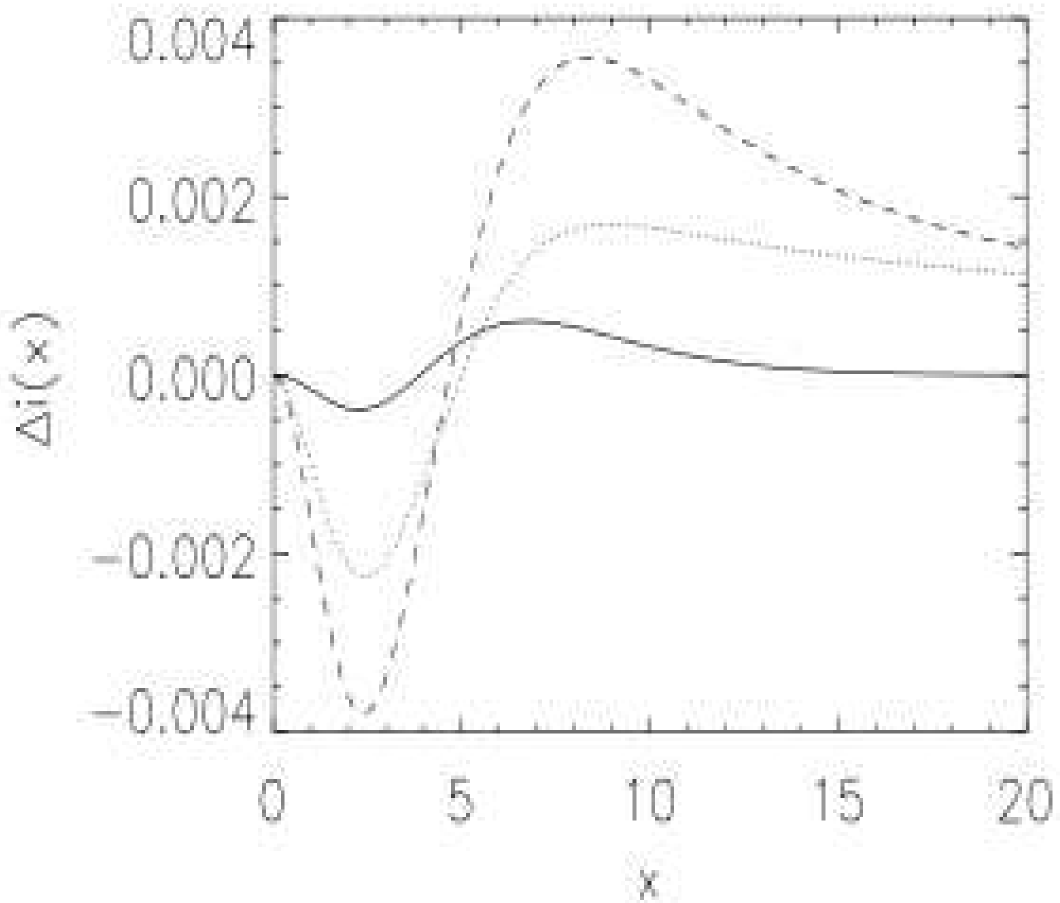
Primary e^-s and e^+ from DM annihilation in clusters

Proposal by Colafrancesco (2003-2007):

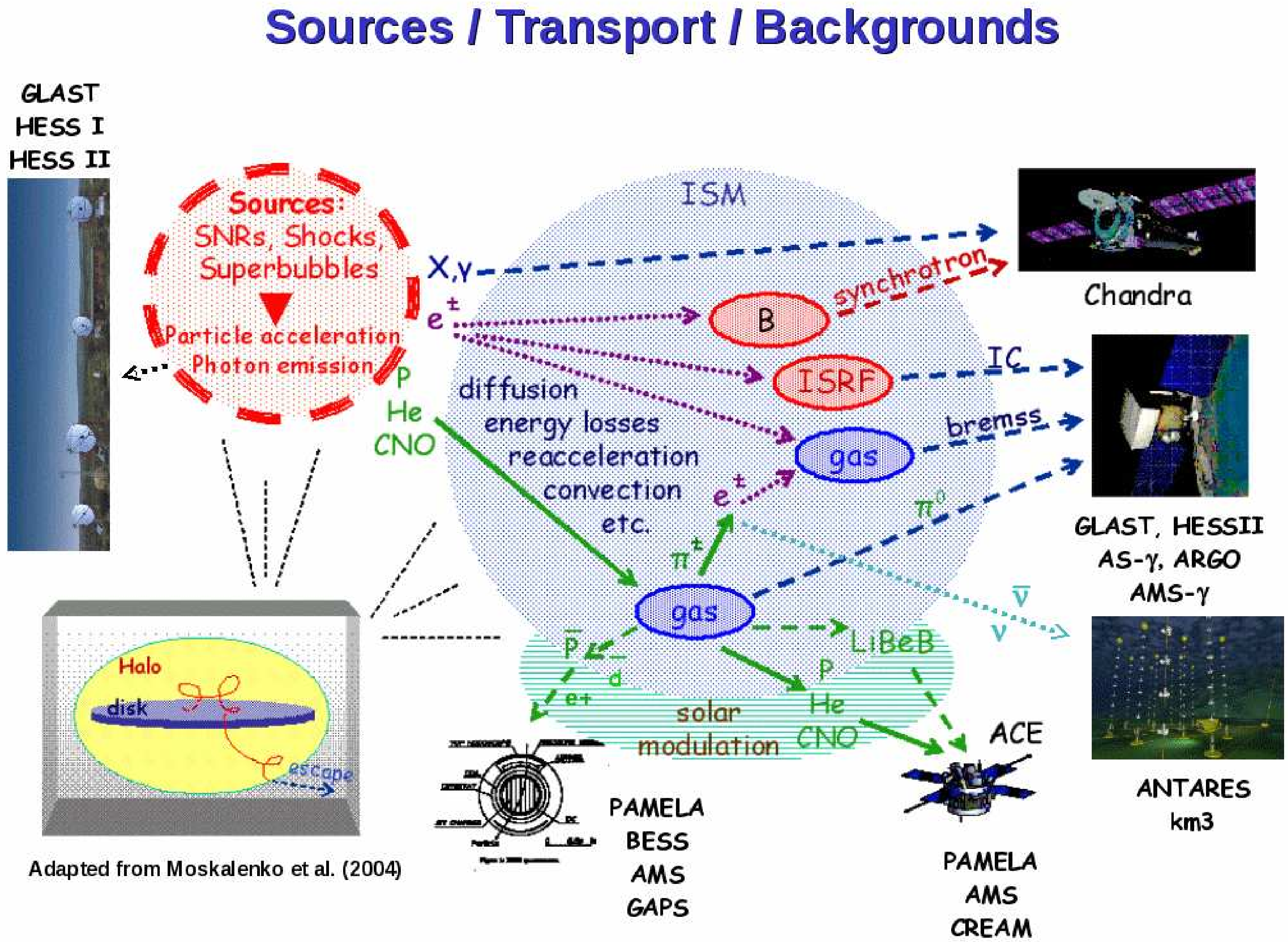
- relativistic calculation based on Birkinshaw (1999) and Wright (1979) — inspired from Chandrasekhar (1950)
- the effect increases when the WIMP mass decreases
- potentially observable with coming instruments (Planck)

Preliminary from Boehm & Lavalle (in prep):

- new covariant method for relativistic cosmic rays
- different predictions: no observable effect



the necessity/tools to understand the backgrounds



Adapted from Moskalenko et al. (2004)

Summary

- Dark Matter: a link between LHC physics, astrophysics and cosmology
- Antimatter cosmic rays are interesting messengers to study new physics

We derived a robust method to account for DM inhomogeneity properties:

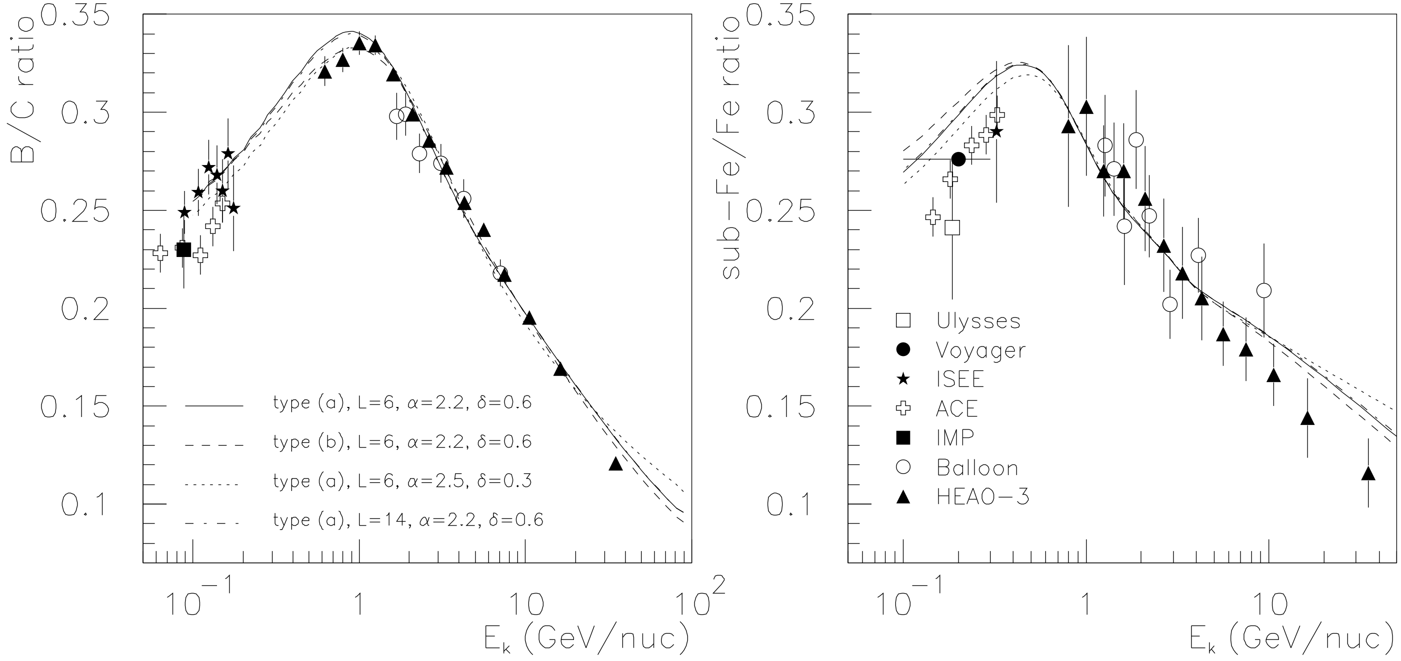
- **Clump properties are still under debate, though their presence is now well accepted**
- **Within the standard view of clumpiness, and constraints coming from N-body simulations, boost factors are too low to significantly enhance the primary flux**
- **This study somewhat demystifies the substructure effect for antimatter signatures**
- **DM signatures more likely at high energies, if so (or anti-d at low energy)**
- **Renewed estimate of the positron background and uncertainties**
- **Need for better constraints on propagation parameters: PAMELA results soon (AMS-02 later)**
- **Complementarity with other messengers (γ, ν) and detection methods!**

Backup

Cosmic ray diffusion: Constraints

Secondary/Primary : $I^{\text{ary}} + (p, \text{He}, ...) \rightarrow ... + \text{II}^{\text{ary}}$ (spallation). Better knowledge of nuclear cross sections for B/C : usually used to fit the propagation parameters

Maurin, Taillet et al., 2002



Propagators for $e^+/\bar{p}$

$\bar{p}$ (see e.g. Maurin et al 2001)

$$\mathcal{G}_{\odot}^{\bar{p}}(r,z) = \frac{\exp^{-k_v z}}{2\pi K L} \times \sum_{n=0}^{\infty} c_n^{-1} K_0(r\sqrt{k_n^2+k_v^2}) \sin[k_n L]\, \sin[k_n(L-z)] \quad (-9)$$

e^+ (see e.g. Lavalle et al 2006)

$$\hat{\mathcal{G}}_{\odot}(r,z,\hat{\tau}) = \frac{\theta\left(\hat{\tau}\right)}{4\pi K_0 \hat{\tau}}\ \exp\left(-\frac{r^2}{4K_0\hat{\tau}}\right) \times\ \mathcal{G}^{1D}(z,\hat{\tau})$$

with $\mathcal{G}^{1D}$ image-like or Shrödinger-like depending on the source location.

The Effective Boost factor

Pure smooth flux:

$$\phi_{\rm sm}(E,\vec{x}_\odot) \propto S \times \int_{\rm halo} d^3\vec{x}\,\tilde{\mathcal{G}}(\vec{x}_\odot \leftarrow \vec{x}) \times \left(\frac{\rho(\vec{x})}{\rho_\odot}\right)^2$$

$$\boxed{B_{\rm eff}(E) = (1-f_\odot)^2 + \frac{\phi_{\rm cl}^{\rm tot}}{\phi_{\rm sm}} \;\approx\; 1 + N_{\rm cl}\times < \xi > \frac{d\mathcal{P}}{dV}(\vec{x}_\odot)}$$

Total sub-halo flux:

$$\phi_{\rm cl}^{\rm tot}(E,\vec{x}_\odot) \propto N_{\rm cl} \times S \times < \xi > \times < \tilde{\mathcal{G}}(\vec{x}_\odot \leftarrow \vec{x}) >$$

Statistical variance !:

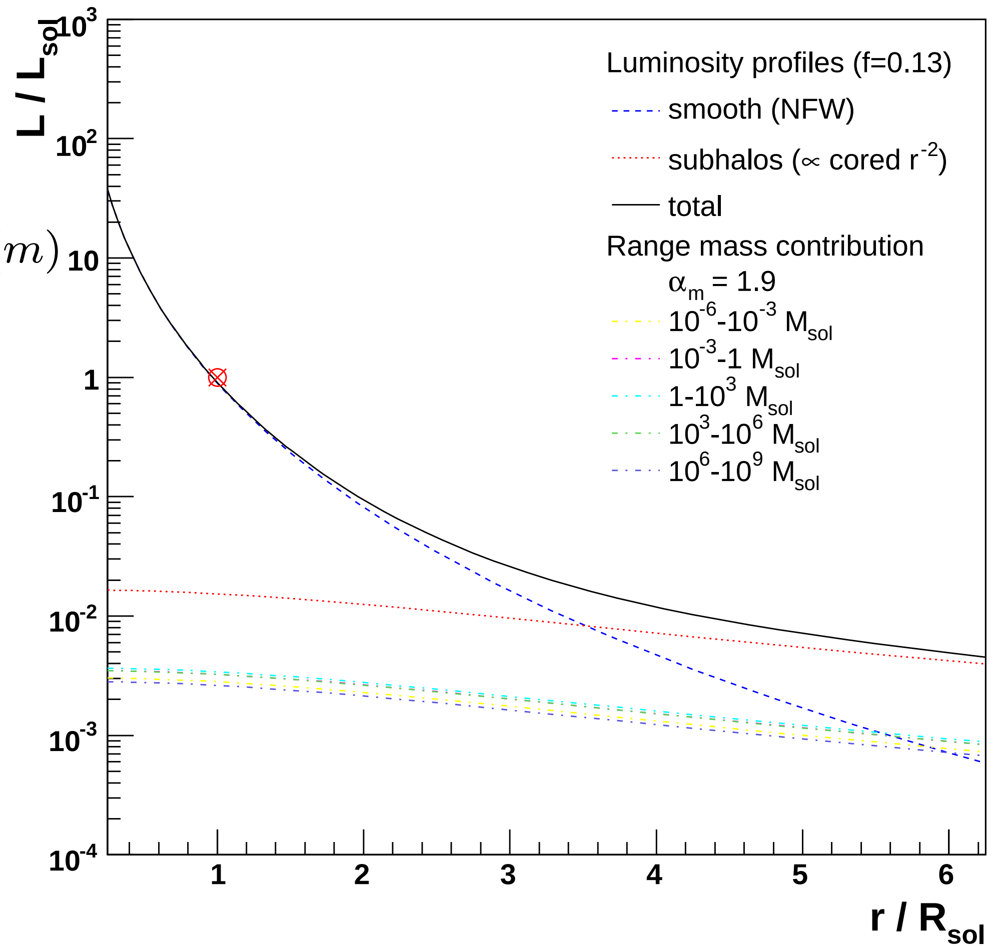
$$\boxed{\left(\frac{\sigma_{\rm cl}^{\rm tot}}{\phi_{\rm cl}^{\rm tot}(E,\vec{x}_\odot)}\right)^2 = \frac{1}{N_{\rm cl}} \times \left(\frac{\sigma_G^2}{<\tilde{\mathcal{G}}>^2} + \frac{\sigma_\xi^2}{<\xi>^2} + \frac{\sigma_G^2}{<\tilde{\mathcal{G}}>^2} \times \frac{\sigma_\xi^2}{<\xi>^2}\right)}$$

Luminosity profiles: effects of α_m

Luminosity profiles for different mass ranges

$$\mathcal{L}_i = N_0 \times \frac{dP_V(r)}{dV} \int_{\Delta_i = 3} d\log(m) \frac{dP_m}{d\log(m)} \xi(m)$$

- luminosity $\propto$ local number of annihilations
- $N(> M_{\rm ref}) \propto M^{1-\alpha_{\rm m}}$: if $\xi \propto M^{\beta}$ and each decade of mass contributes the same to the annihilation rate when $\alpha_{\rm m} - \beta = 1$ (for B01, $\beta \sim 0.9$)



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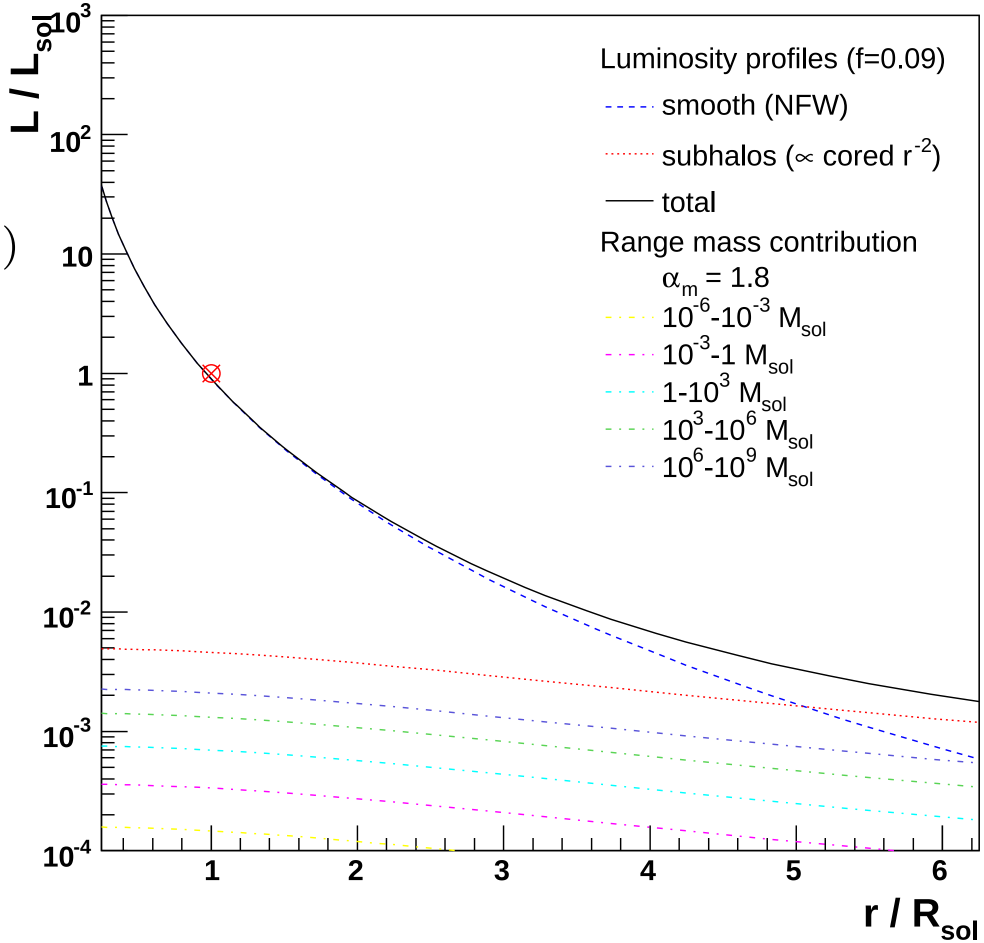

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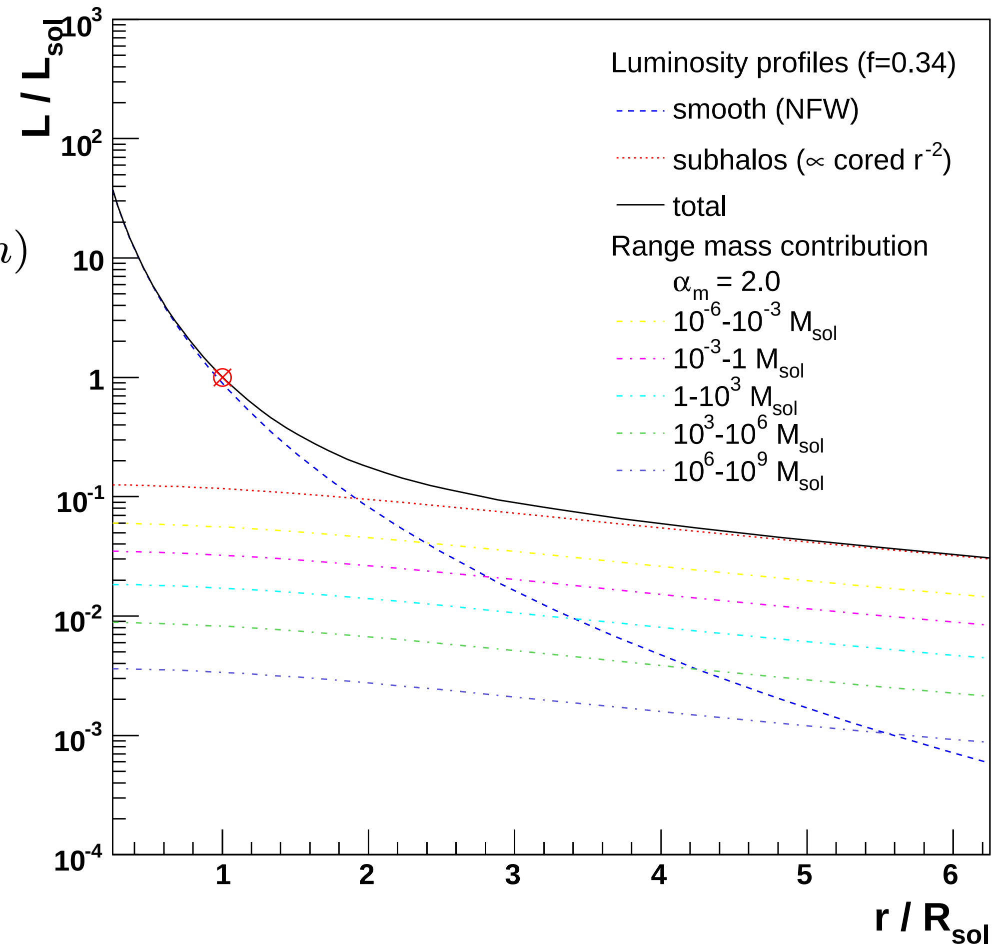
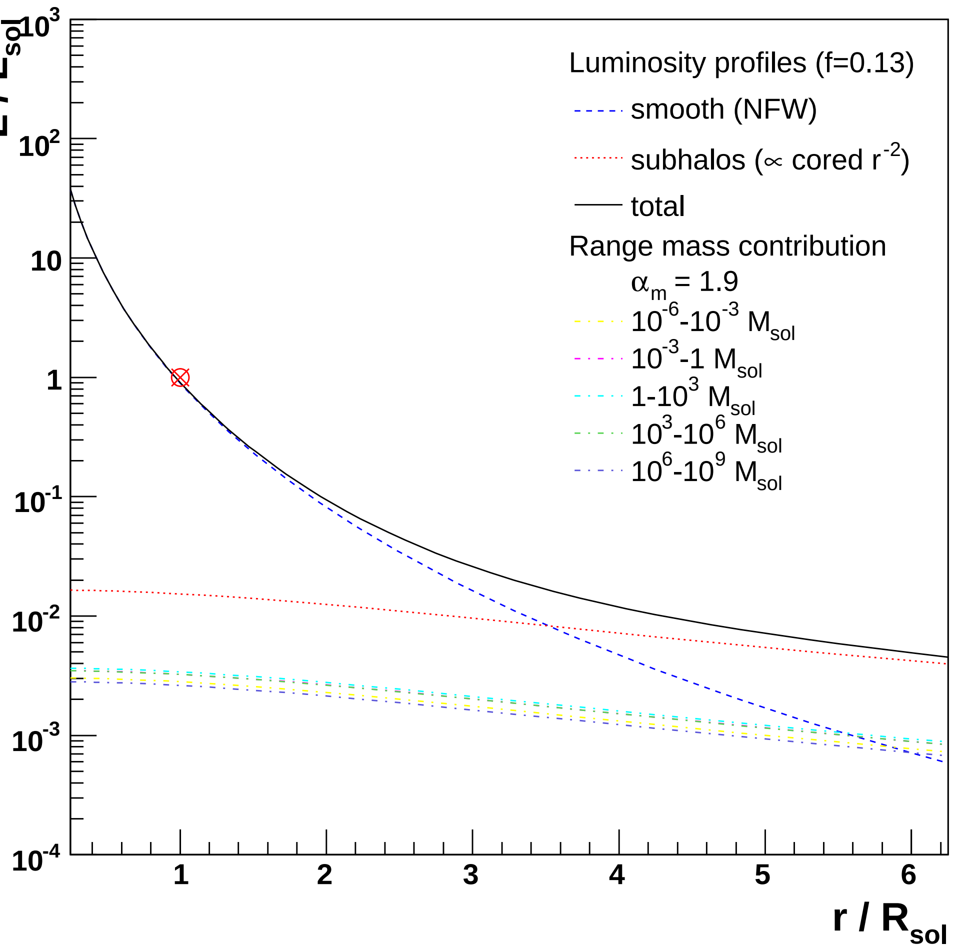
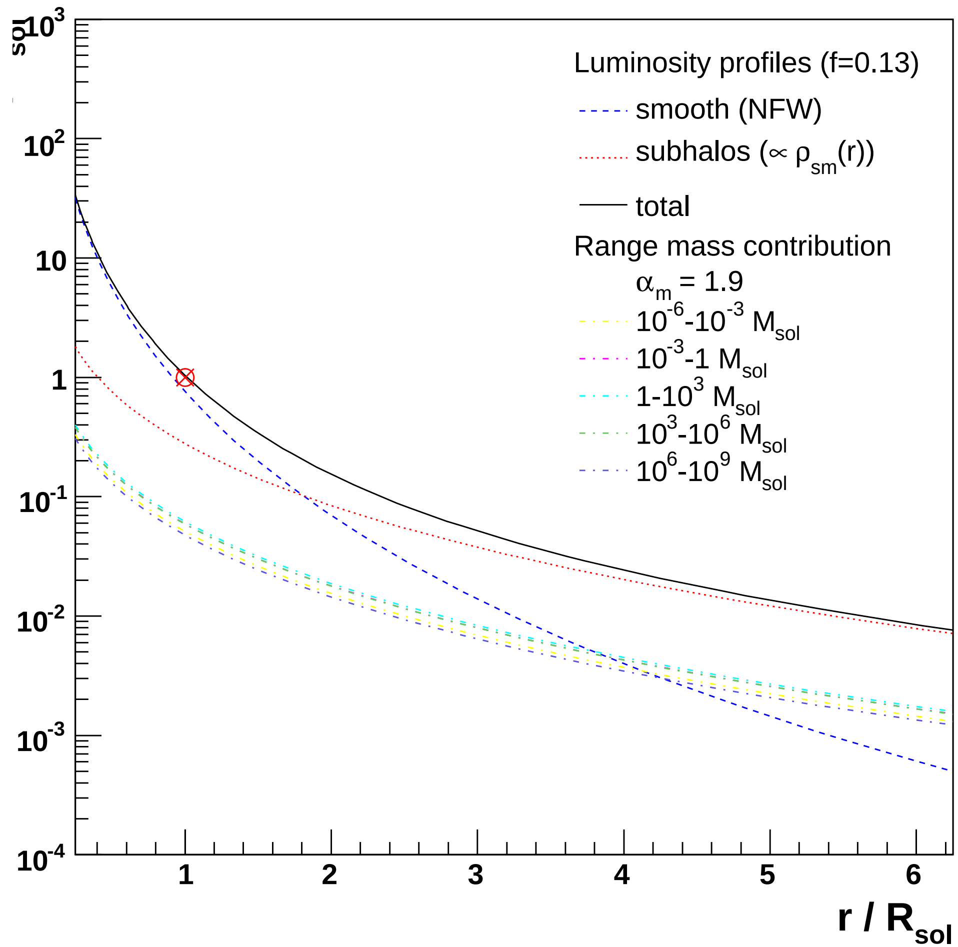


Luminosity profiles: effects of dP/dV





Mass distribution

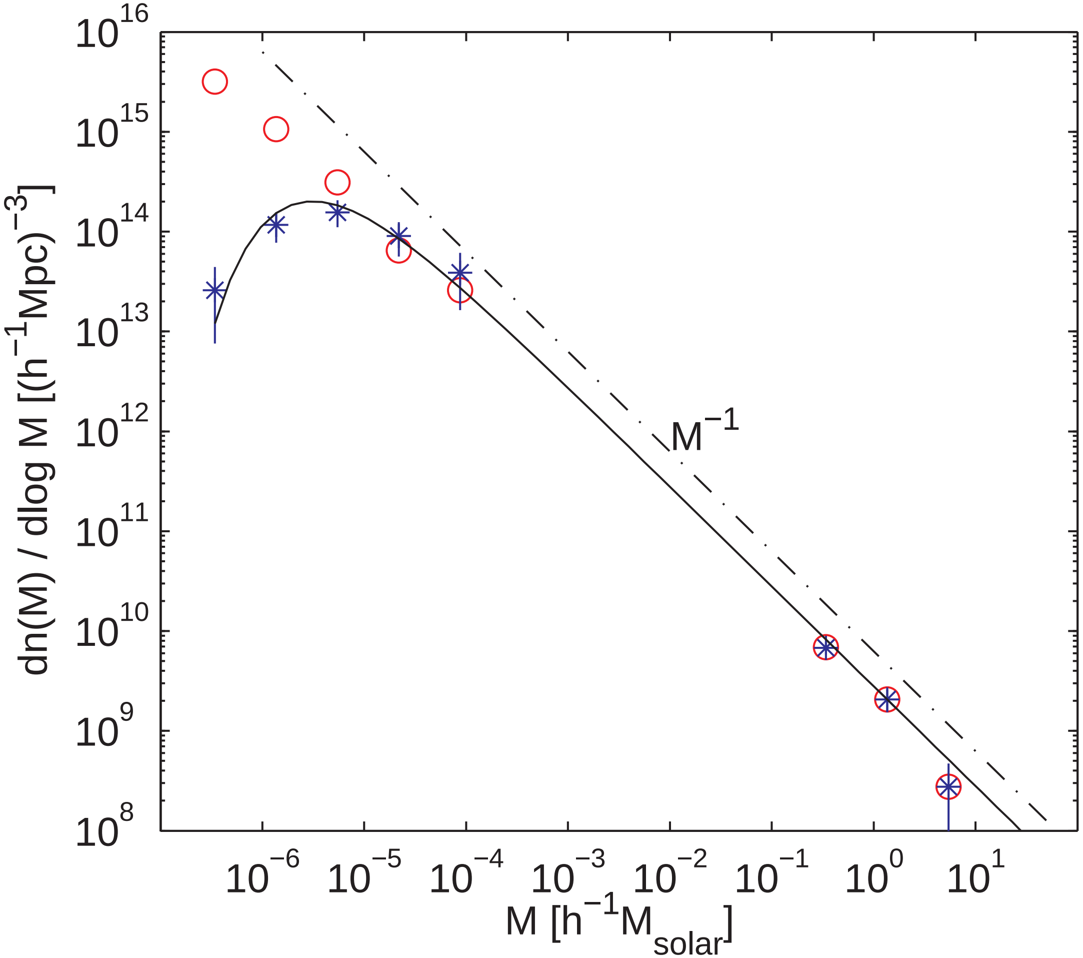
- $\frac{dP_M}{dM} = K_M \left(\frac{M}{M_\odot}\right)^{-\alpha_m}$
  with $\alpha_m \sim 1.7 - 2.1$ (Shaw et al, 2007), and $K_M = f(M_{min}, M_{max}, \alpha_m)$ allows normalization to 1 in the mass range

- The mass range ??? $M_{max} \sim 10^{10} M_\odot$
  $M_{min} \gtrsim M_{fs} \sim 10^{-12} - 10^{-4}$ depending on the particle physics model (Profumo et al, 2006). Diemand et al (2005) resolve masses down to $10^{-6} M_\odot$ at $z = 26$. Survival to tidal stripping from GC ? Encounters with stars ? $\longrightarrow M_{min}$ is a free parameter, lying between $\sim 10^{-6} - 10^4$

- N_0 fixed by number of well resolved objects in various N-body experiments:
  $N_{ref}(> M_{ref} = 10^8 M_\odot) \simeq 100$ =>
  $N_0 = f(N_{ref} M_{ref}, M_{min}, M_{max})$

- The mass fraction depends on M_{min} and α_m

Diemand et al (2005)

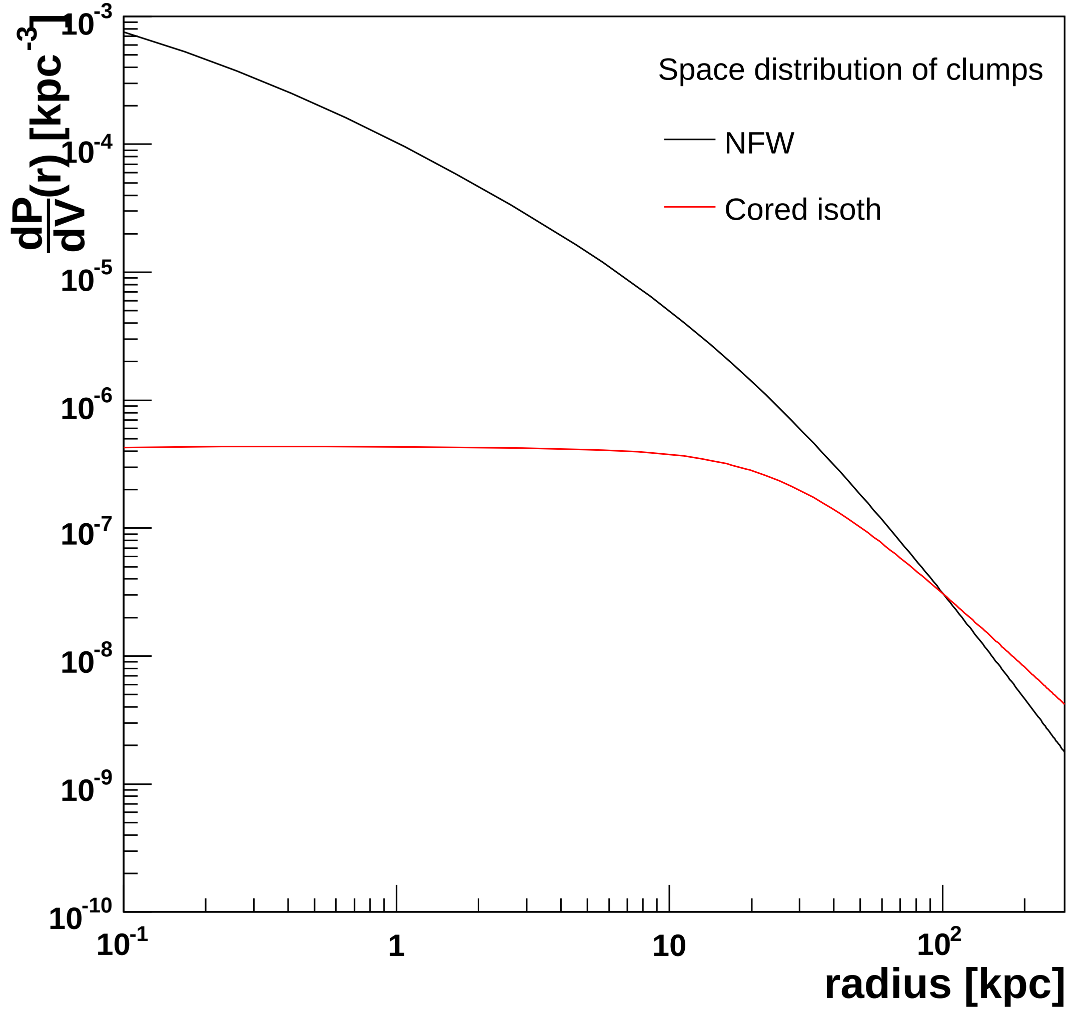


Space distribution of clumps

The space distribution of clumps is found to be well approximated with a **spherical cored isothermal distribution** with $r_h \simeq 0.1 \times R_{\rm vir}^{\rm h} \sim r_s$:

- $$\frac{dP_V(r)}{4\pi r^2 dr} = K_V \left(1 + \left(\frac{r}{r_h}\right)^2\right)^{-1}$$
  where K_V normalizes the distribution to 1 within the halo extension $R_{\rm vir}^{\rm h}$.

- Caution: many authors use the same space distribution for the smooth halo and clumps. There are arguments for very light clumps (Berezinsky et al, 2004), but it is not seen is simulations



Clump internal properties: profiles and concentration models

Clump profile $\sim$ **NFW** $\propto r^{-1}(r+r_s)^{-2}$

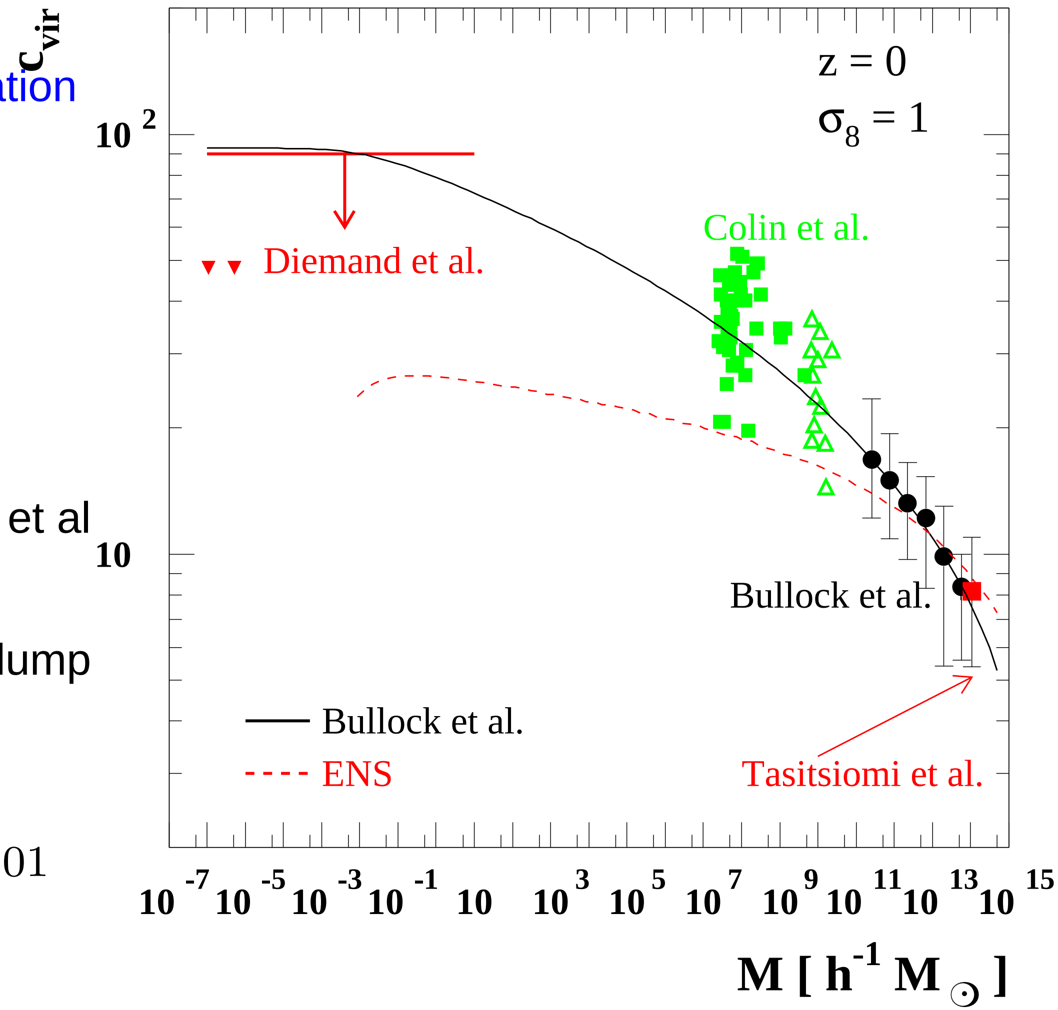
- Virial radius given by mass:
  $R_{\rm vir} \propto M_{\rm vir}{}^{1/3}$
- Scale radius r_s fixed by the concentration parameter:
  $c_{\rm vir} \equiv \frac{R_{\rm vir}}{r_{-2}} = \frac{R_{\rm vir}}{r_s^{nfw}}$
- Concentration parameter given by simulations:
  $c_{\rm vir} = f(M_{\rm vir})$
  2 extreme parameterizations: Bullock et al (2001), Eke et al (2001)

Once the relation $c_{\rm vir} - M_{\rm vir}$ is known, clump internal properties are fixed by its mass.

$$\xi = \frac{B(M)\times M}{\rho_\odot} \rightarrow \propto M^{0.9} \text{ for B01}$$

$$\frac{dP_\xi}{d\xi} = \frac{dP_M}{dM}$$

Colafrancesco et al (2005)



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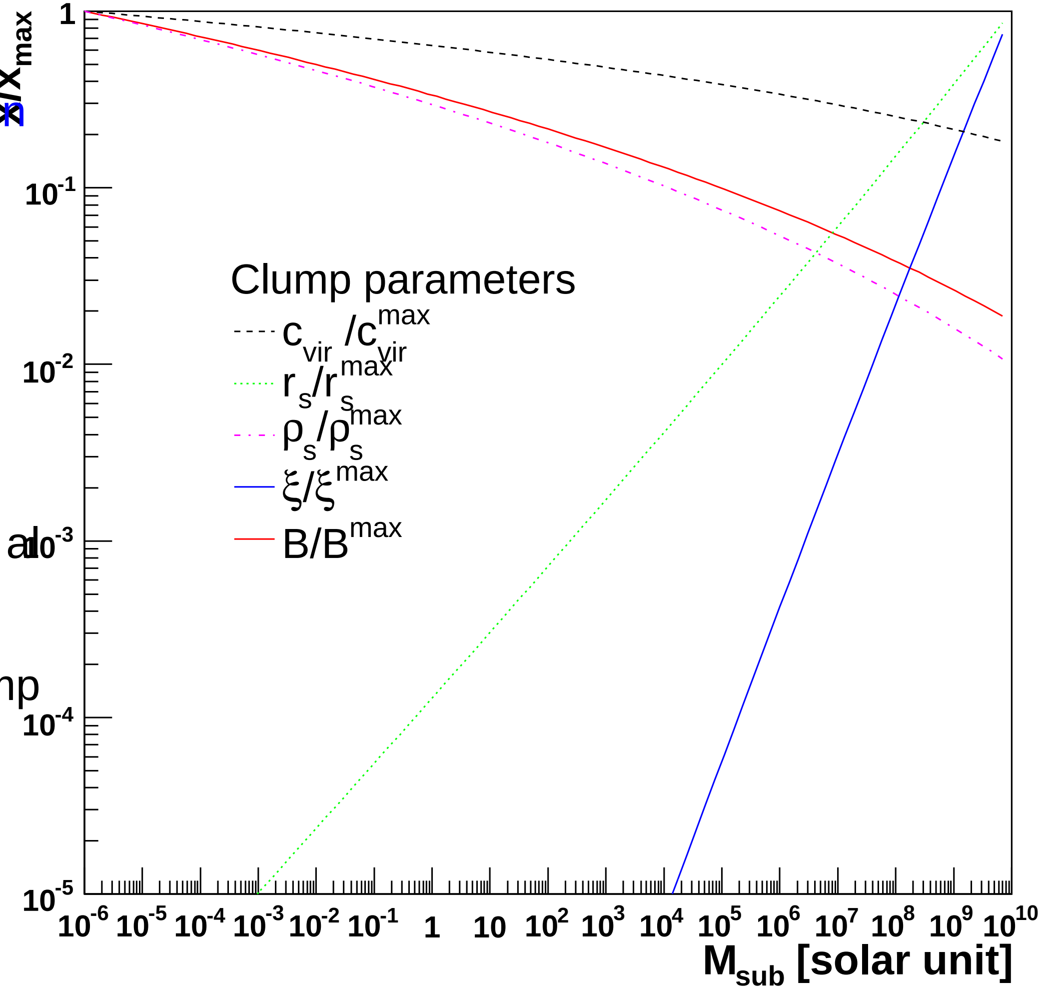

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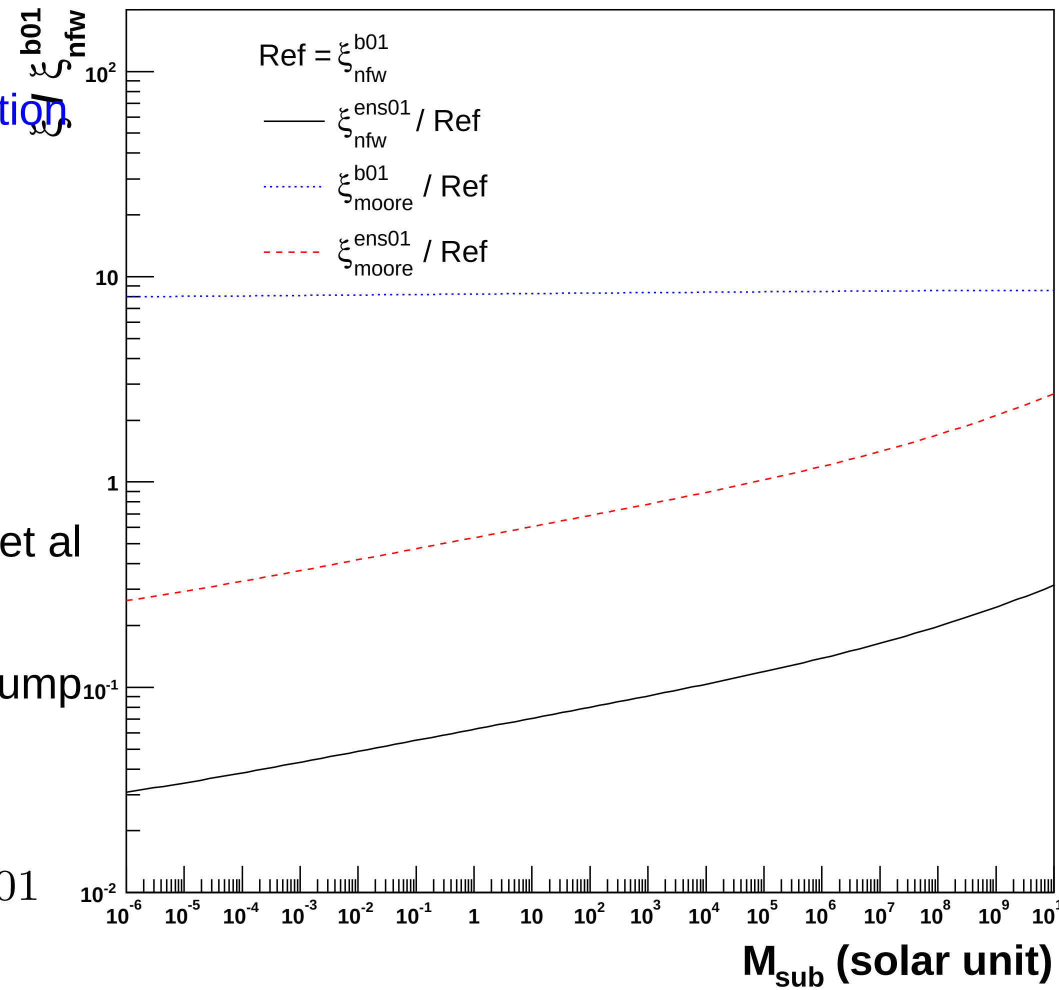


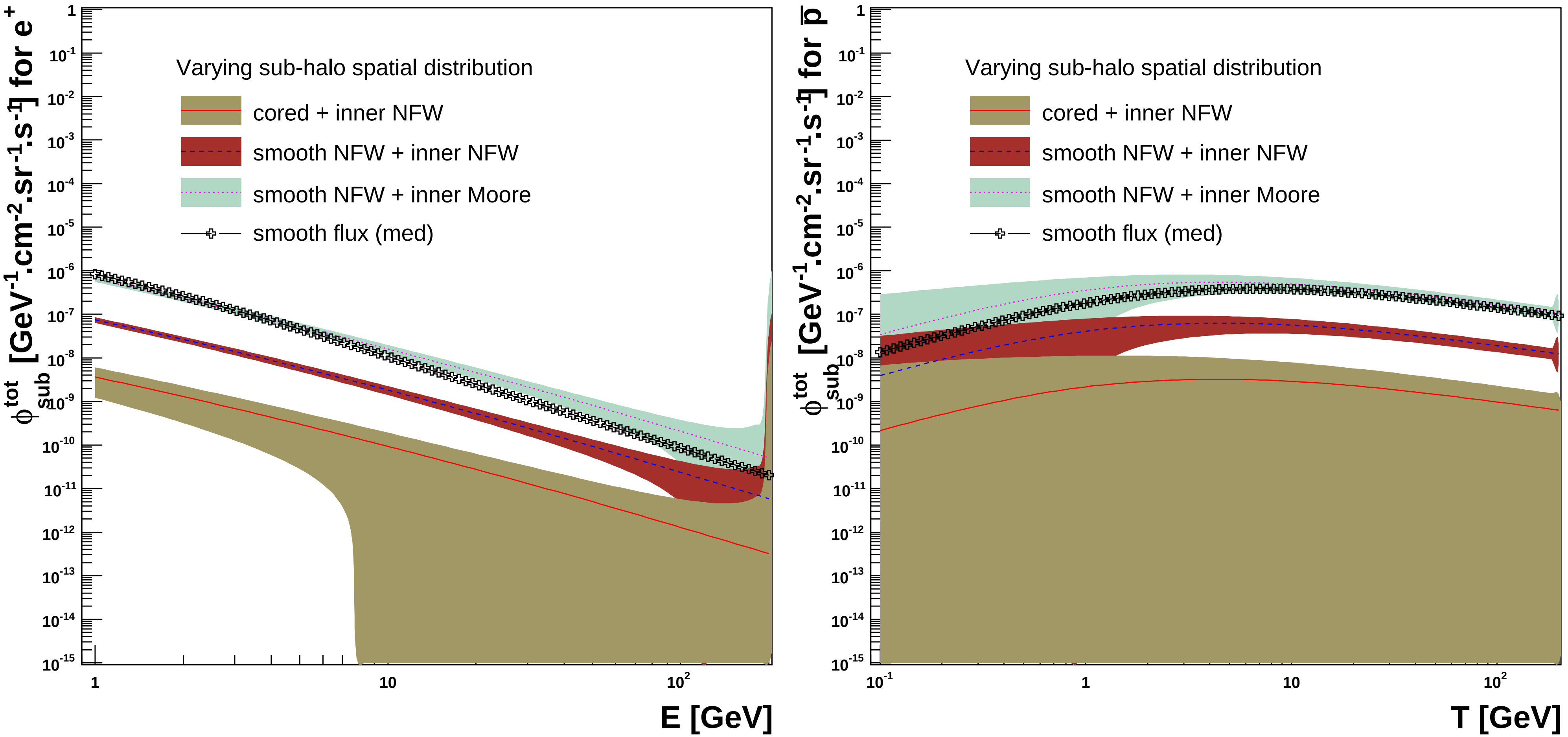
Important features

$M_{\rm sub}$ ($M_\odot$)	r_v (kpc)	r_s (kpc)	ρ_s ($M_\odot$/kpc^3)	c_v	ξ (kpc^3)	B
10^{-6}	2×10^{-4}	1.7×10^{-6}	4.1×10^{9}	120	5.8×10^{-12}	46
10^{-3}	2×10^{-3}	2.1×10^{-5}	2.3×10^{9}	98	3.5×10^{-9}	27
1	2×10^{-2}	2.7×10^{-4}	1.2×10^{9}	77	1.9×10^{-6}	15
10^{3}	0.2	3.6×10^{-3}	5.6×10^{8}	58	9.8×10^{-4}	8
10^{6}	2	5.1×10^{-2}	2.2×10^{8}	41	0.43	3
10^{9}	20	0.8	6.7×10^{7}	26	153	1

Table 0: *Sub-halo parameters for different masses: virial radius r_v, scale radius r_s, scale density ρ_s, concentration parameter c_v, effective volume ξ, intrinsic boost B.*

Primary fluxes for a 200 GeV e^+ line / antiprotons

$M_{\rm min} = 10^{-6} M_\odot$, $\alpha_{\rm m} = 1.9$, inner-NFW vs Moore, B01, cored vs smooth-like space distribution (smooth = NFW)



Lavalle, Yuan, Maurin & Bi (arXiv:0709.3634)

Boost factors for a 200 GeV e^+ line / antiprotons

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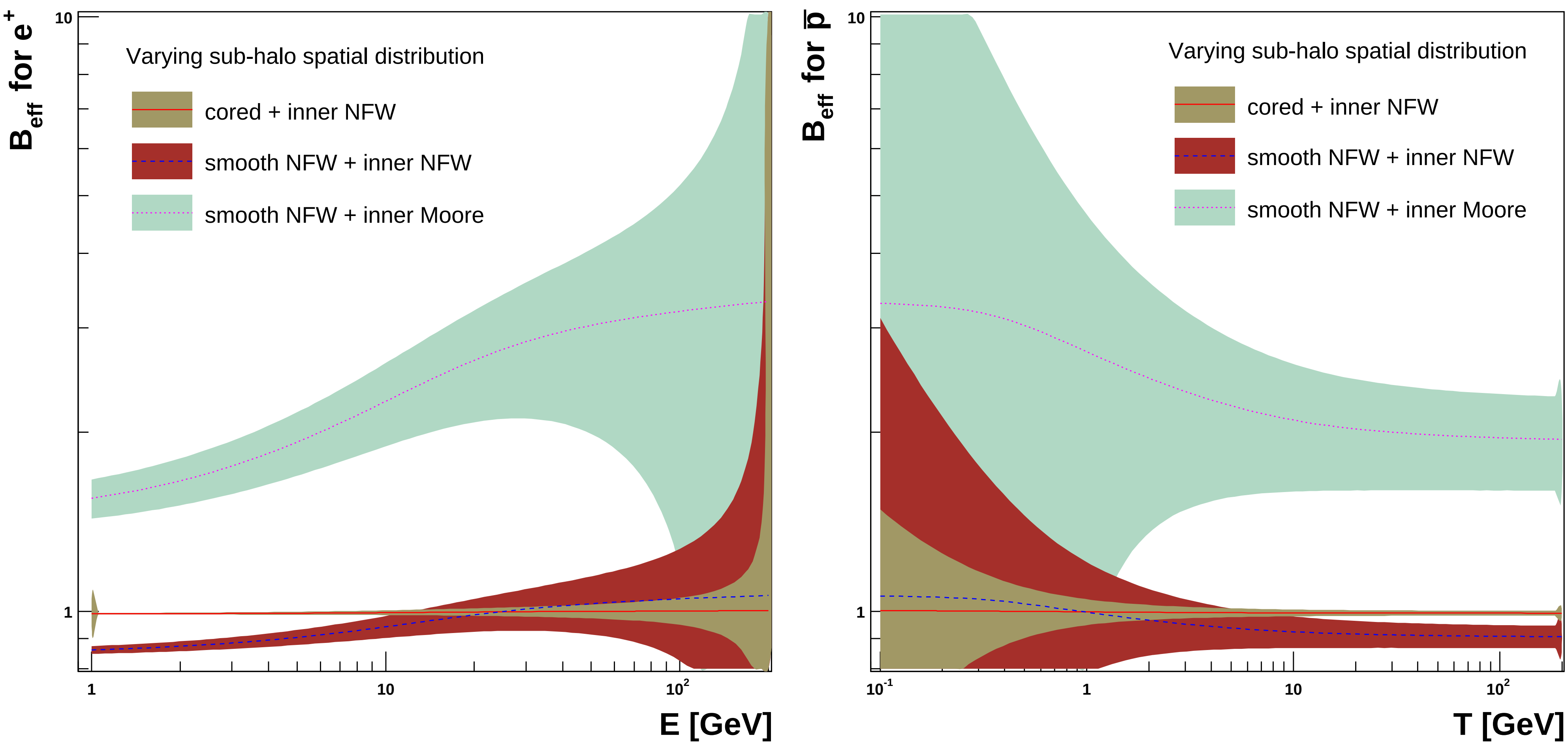
vs smooth-like space distribution (smooth = NFW)



Lavalle, Yuan, Maurin & Bi | A&A 429, 427 (2008)

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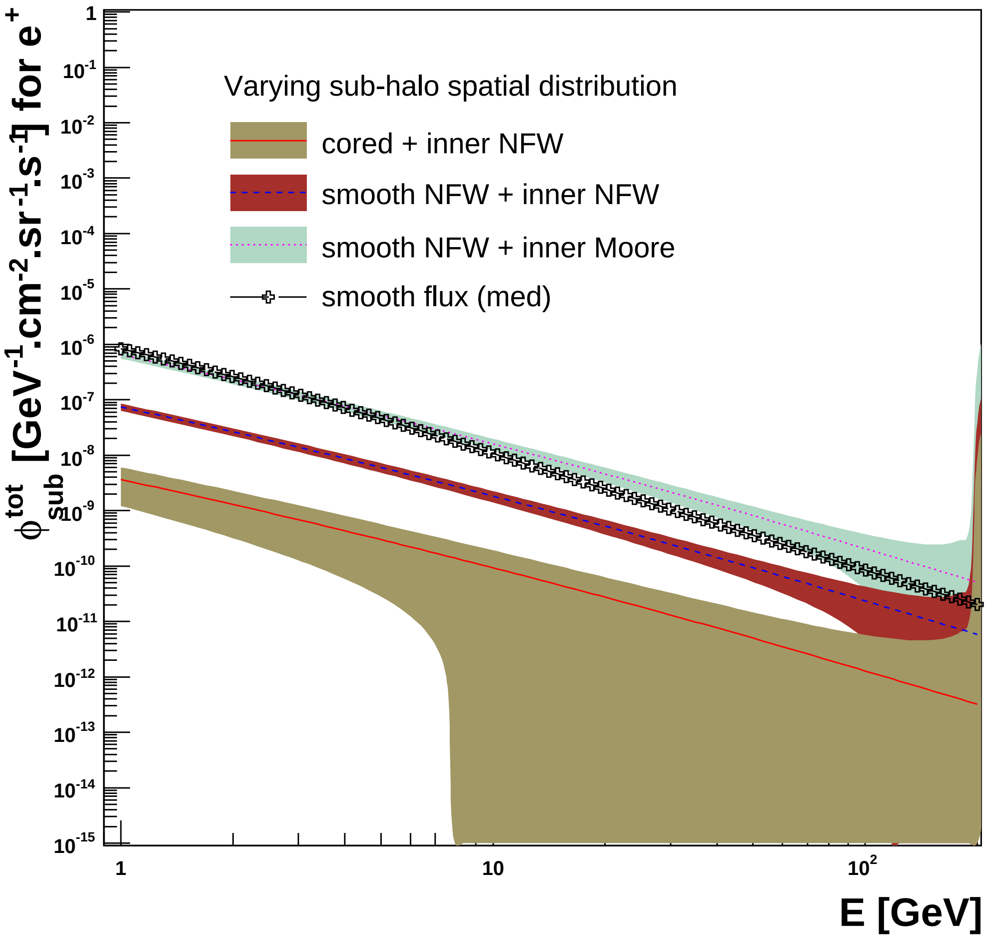

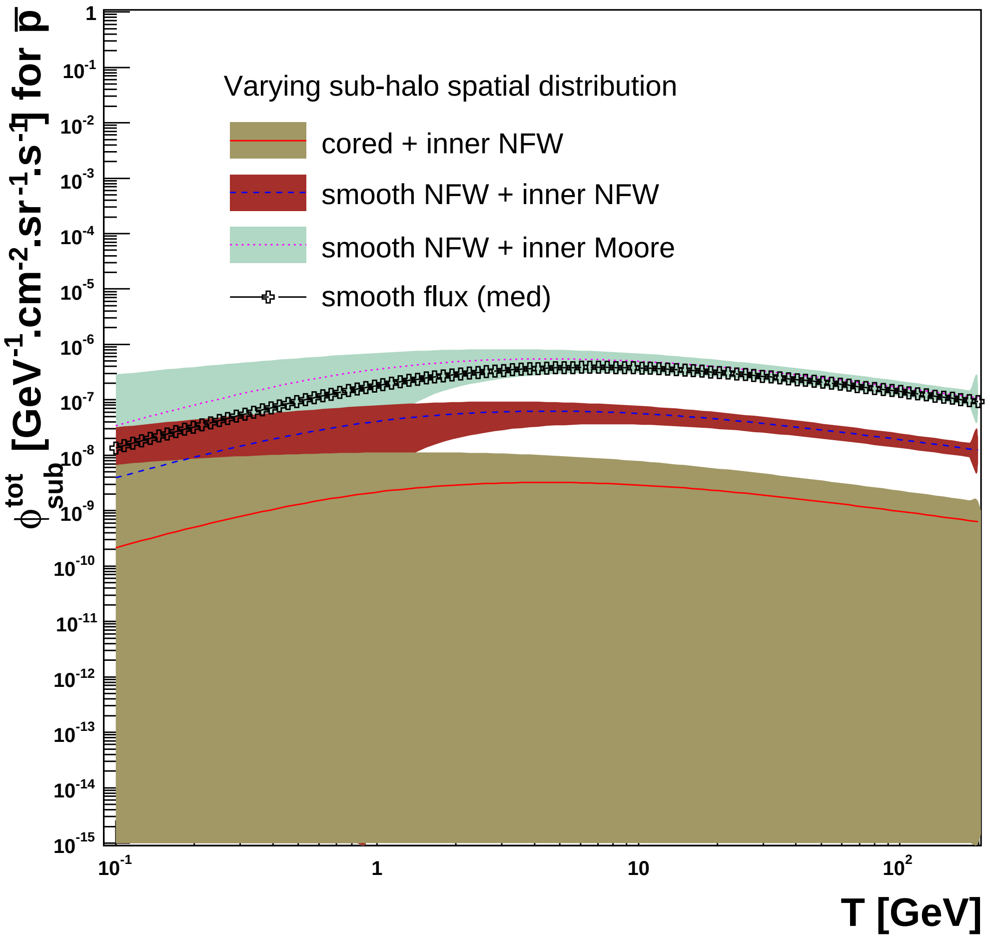

Interesting WIMP candidates for detection with e^+

Interesting candidates for the e^+ bump (spectrally speaking) are those yielding hard spectra:

- SUSY
  - **Higgsino neutralino: $W^\pm$ production ($\tau^\pm$)**
  - **Sneutrinos: $W^\pm$ production**
- Extra-dimensions
  - **Universal Extra dimensions (B^1 LKP): non-suppressed couplings to leptons, $m \sim$ TeV**
  - **Warped-GUT extra-dimensions (RS, LZP): non-suppressed couplings to leptons, $m \lesssim 100$ GeV**

Interesting WIMP candidates for detection with e^+

Interes… those yielding
hard s…

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