

Astrophysical issues in the cosmic ray $e^{+/-}$ spectra: Have we seen dark matter annihilation?

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Collab:

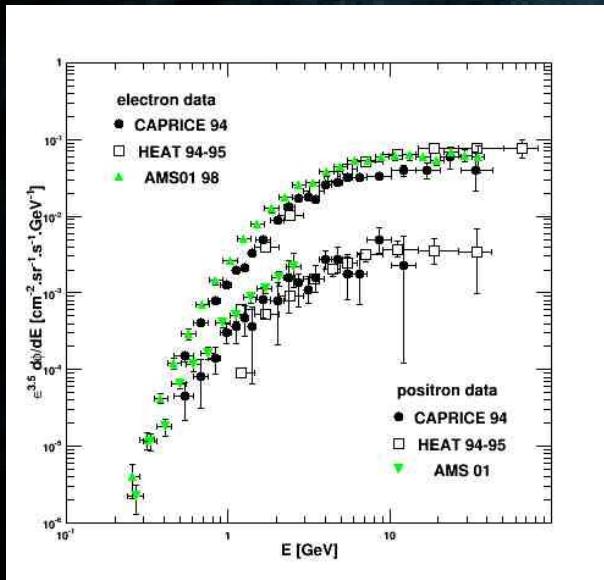
Torino: R. Lineros, F. Donato, N. Fornengo

Annecy: T. Delahaye, P. Salati, R. Taillet

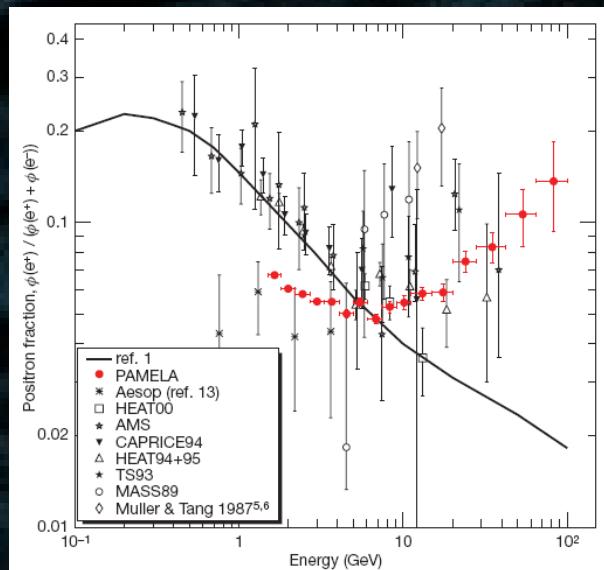
+++: T. Bringmann, D. Maurin, E. Nezri, L. Pieri, G. Bertone, E. Branchini, etc.

IDM 2010 @ Montpellier - 26/VII/2010

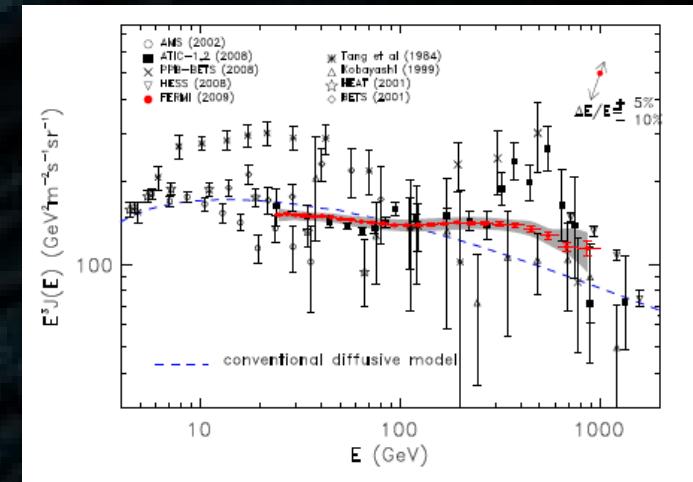
The data: Current local measurements of cosmic-ray $e^+/-$



e^+ and e^-
data compilation



$e^+/(e^+ + e^-)$ PAMELA
Adriani et al (2009)



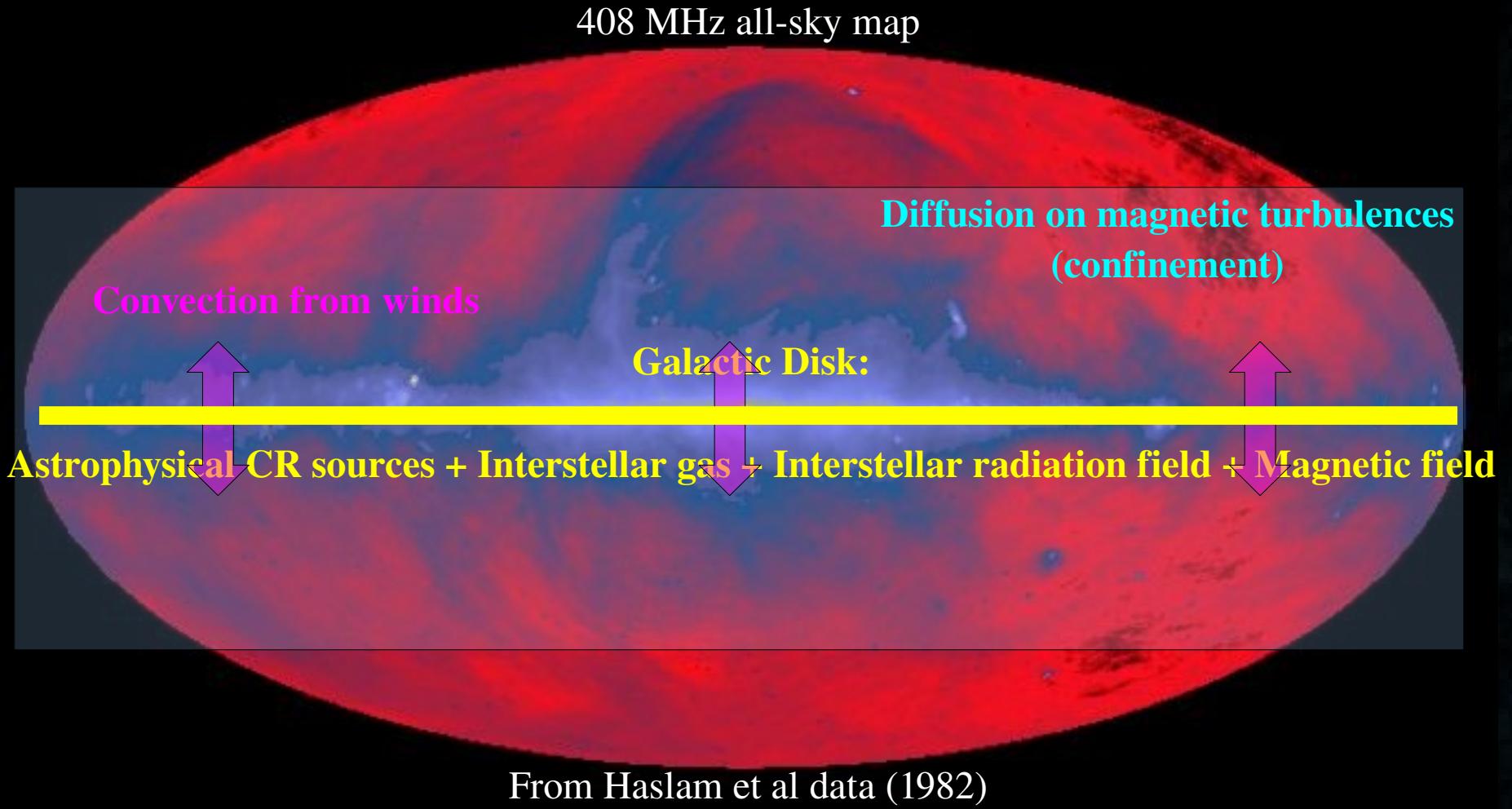
$(e^+ + e^-)$ HESS and Fermi
Aharonian et al (2009)
Abdo et al (2009)

Do we understand all these measurements ?
(e^+ excess, spectral features in e^+e^-)

Outline

- Propagation in brief, and secondary positrons
- Dark matter annihilation (or decay) ?
- Astrophysical sources:
the “QCD” background for indirect searches
- Conclusions & perspectives

Propagation of Galactic cosmic rays (electrons): The standard picture



See Richard Taillet's talk

Propagation of Galactic cosmic rays (electrons): The standard picture

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

Ast

es

field

From Haslam et al data (1982)

See Richard Taillet's talk

The case for electrons: Energy losses

Electrons lose their energy through electromagnetic interactions

- (I) with the **interstellar medium** (ISM)
- (ii) with the **interstellar radiation fields** (ISRF) and the **magnetic fields**
(see Blumenthal & Gould, 1970)

(i) Interactions with the ISM :

Bremsstrahlung (braking radiation),
ionisation – for $E <$ few GeV

$$b_{\text{ion}}(E) \propto n_{\text{gas}} \ln(E)$$

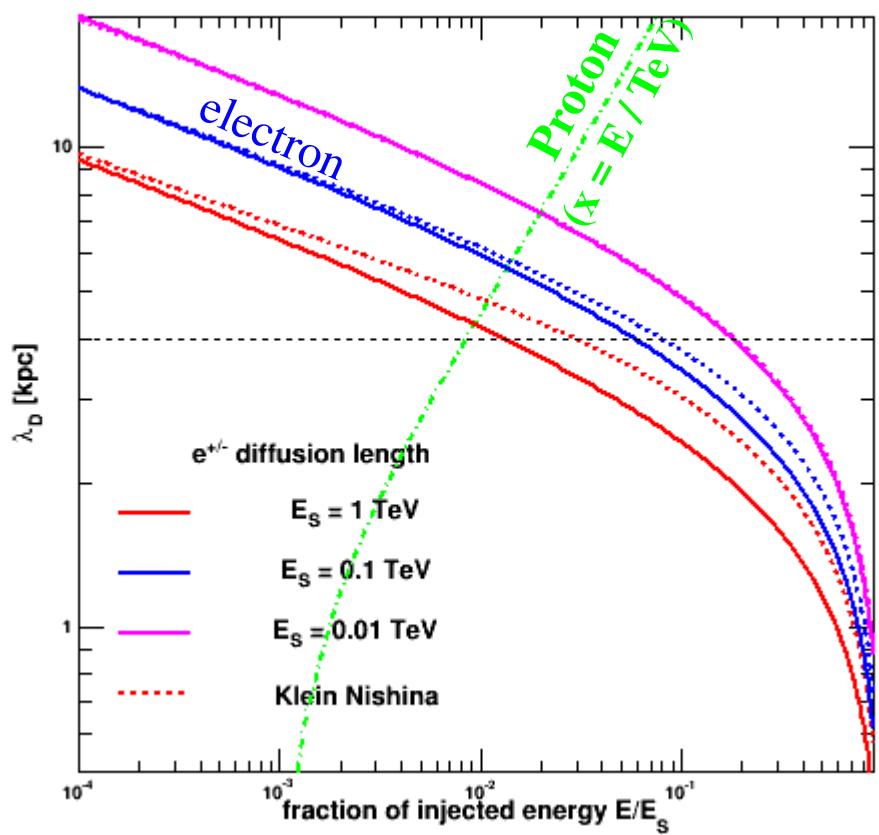
$$b_{\text{brem}}(E) \propto n_{\text{gas}} E \ln(E)$$

(ii) Interactions with the ISRF (including CMB) and magnetic fields: (inverse) Compton processes

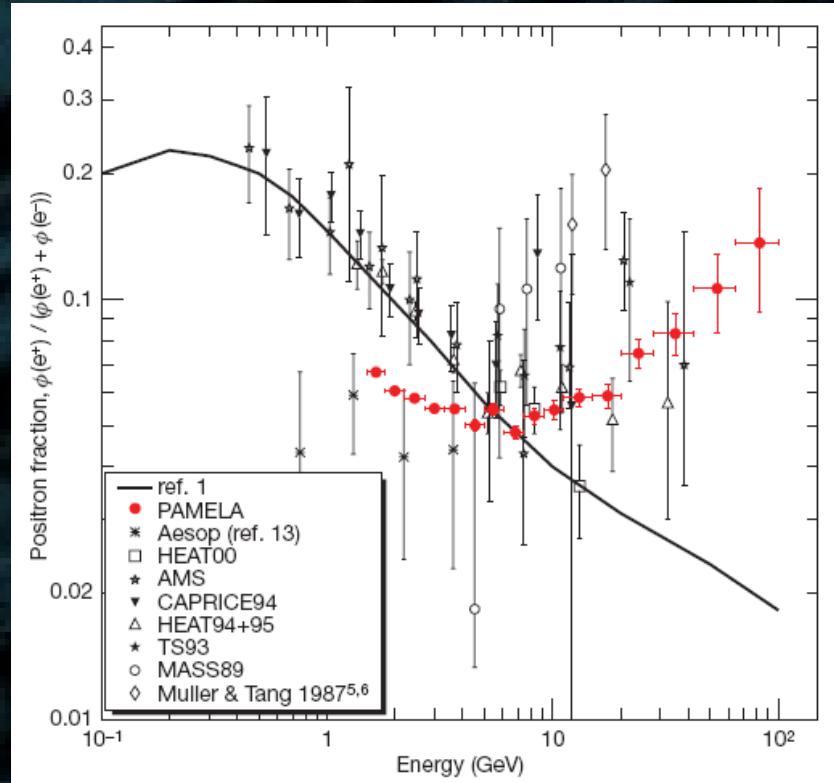
$$b_{\text{sync/ic}} \propto U_{\text{mag/rad}} E^2$$

→ Need for accurate description of ISRF and magnetic fields:
high energy => local fields

Propagation scale vs fraction of injected energy



Can secondary e^+ 's explain the PAMELA data ?



$e^+/(e^+ + e^-)$ PAMELA
Adriani et al (2009)

Is there any standard model for secondary e^+ 's ?

Short recipe for secondaries

Proton and alpha fluxes

$$\phi_p(E) \approx \phi_0 (E/1\text{ GeV})^{-2.75}$$

ISM gas distribution

The source term

Inclusive nuclear cross section



$$Q(E) \propto \int dE n_H \phi_p(E) \frac{d\sigma}{dE} \approx Q_0 (E/1\text{ GeV})^{-2.75}$$

Propagation
from (x_s, E_s) to (x, E)

diff. + E-loss

ANTIMATTER

10

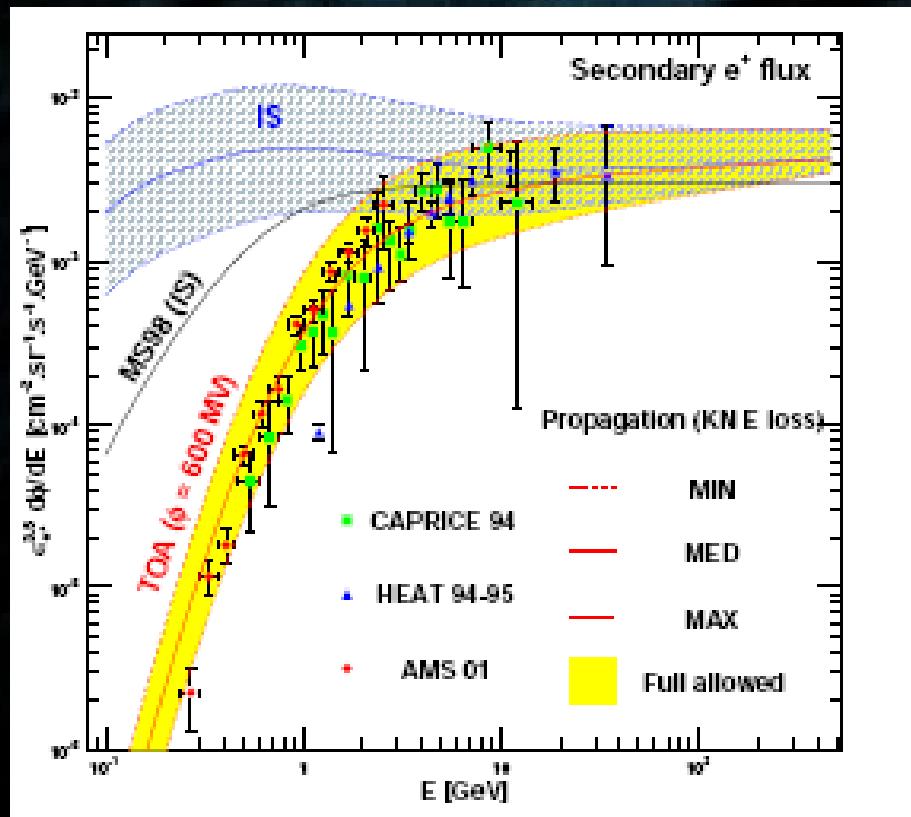
Flux at the Earth

$$\gamma_{\odot} \approx \gamma_p + \frac{1}{2}(\delta + 1) \approx 3.5$$

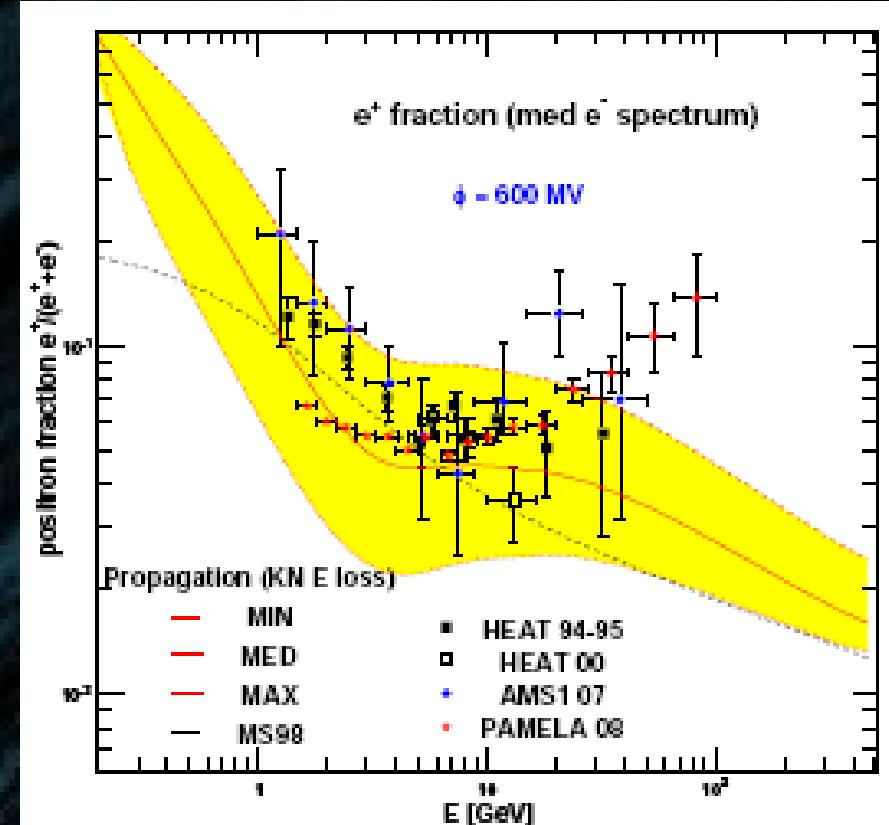
Each box contains
uncertainties !!!

Can secondary positrons account for the PAMELA data?

Secondary positron flux



Secondary positron fraction



Uncertainties are still large ...

Yet, a conventional secondary origin seems unlikely ...

Need a primary contribution 5–10 times the secondary one at ~100 GeV

The Dark Matter interpretation attemptSSSS

(about 250 papers on the arXiv)

Dark matter annihilation as antimatter factory (complementary to gamma rays)

VOLUME 53, NUMBER 6

PHYSICAL REVIEW LETTERS

6 AUGUST 1984

Cosmic-Ray Antiprotons as a Probe of a Photino-Dominated Universe

Joseph Silk

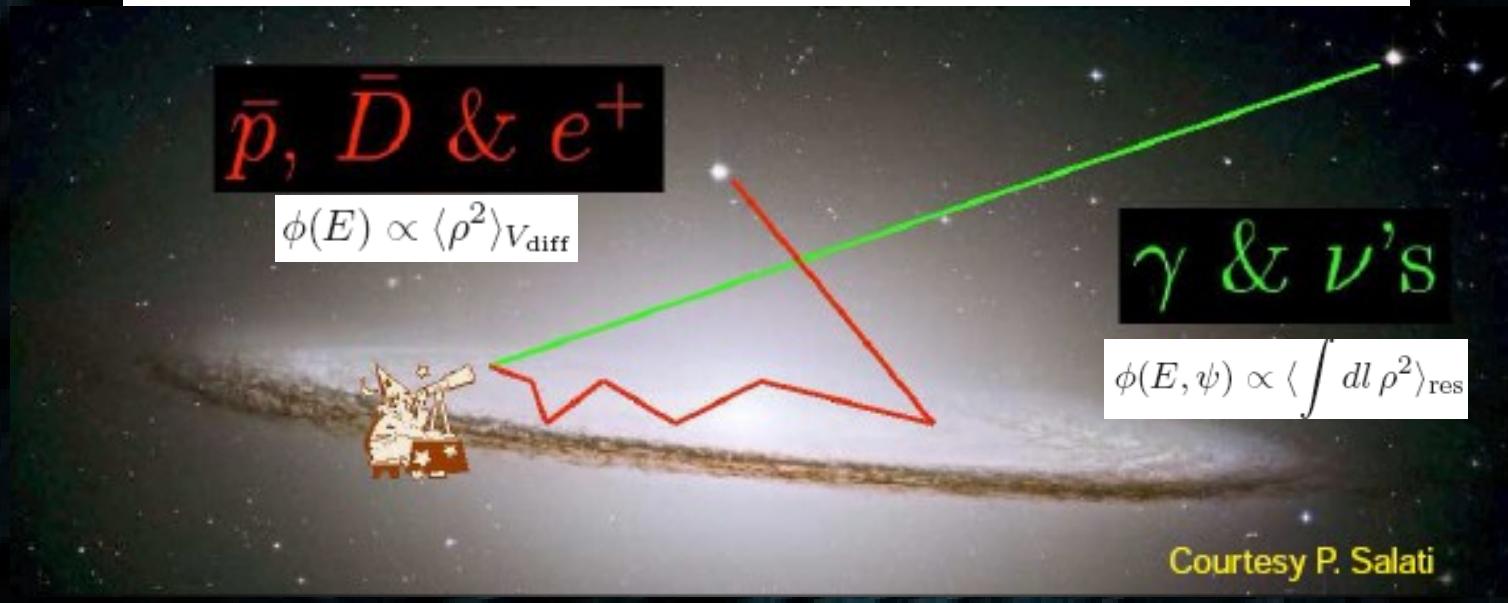
*Astronomy Department, University of California, Berkeley, California 94720, and Institute for Theoretical Physics,
University of California, Santa Barbara, California 93106*

and

Mark Srednicki

Physics Department, University of California, Santa Barbara, California 93106

(Received 8 June 1984)



Main arguments:

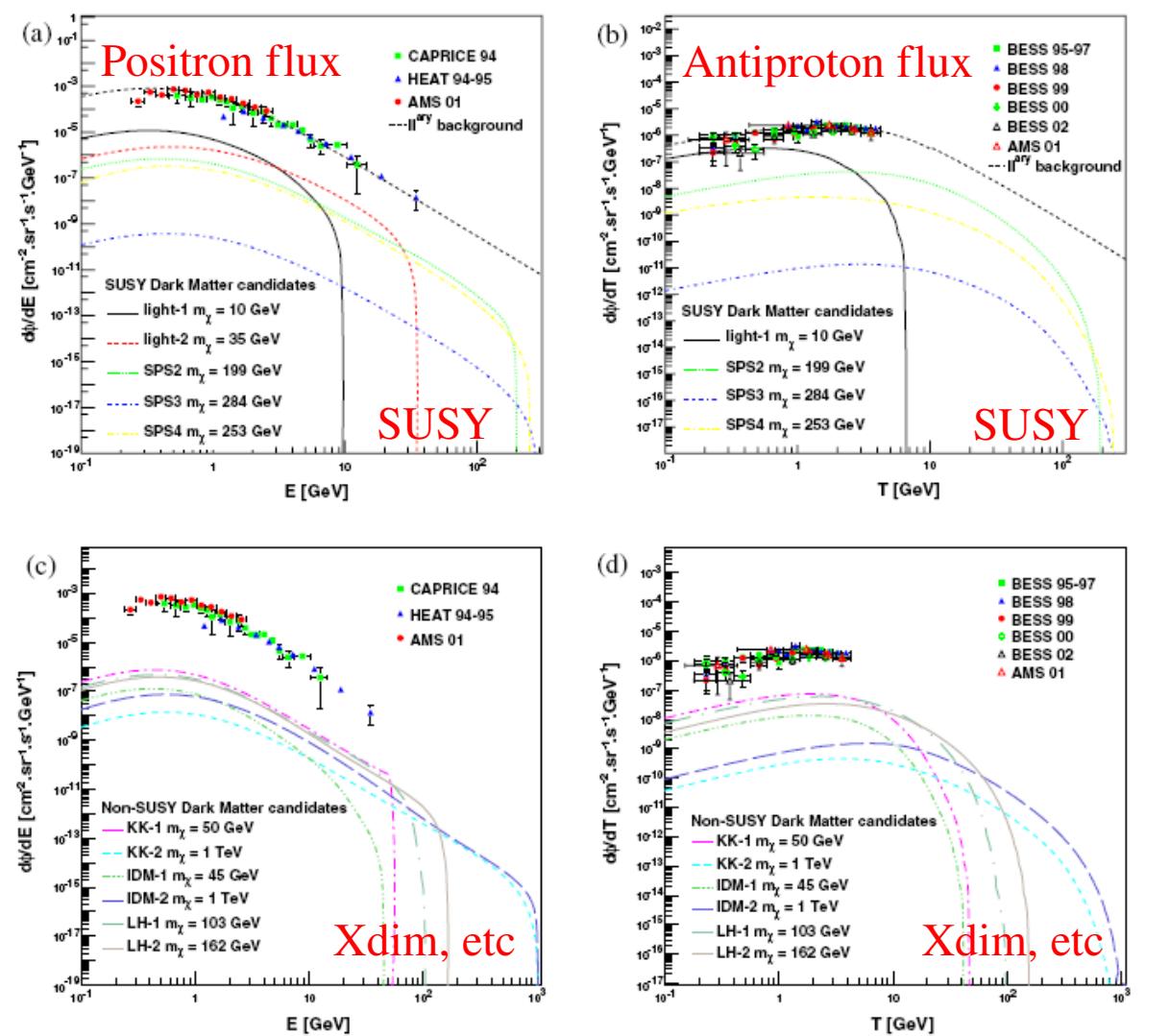
- DM annihilation provides as many particles as antiparticles
- Antimatter cosmic rays are rare because secondary products
- DM-induced antimatter CRs may have specific spectral properties

But:

- We must control the backgrounds
- Antiprotons are secondaries, what about positrons ?
- Do the natural DM particle models provide clean signatures?

Dark Matter annihilation: generic predictions for positrons

Lavalle, Nezri, Ling et al (2008) – using a Horizon MW-like Galaxy



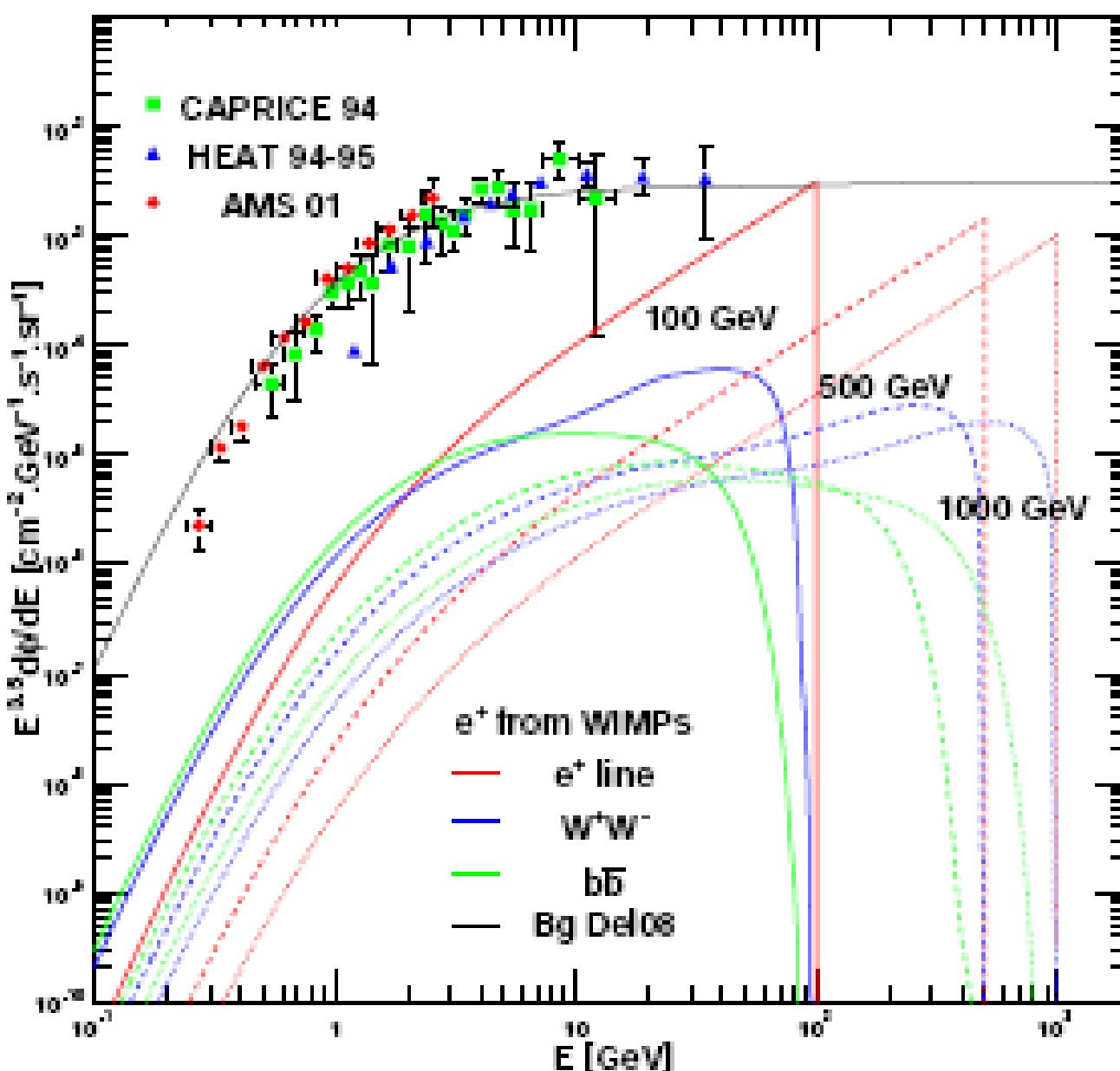
Susy candidates:
positron (left) – antiproton (right)

(see e^+ study in eg Baltz & Edsjo 98
(pbars in eg Chardonnet et al 96,
Bottino et al 98)

Non-Susy candidates (KK, etc):
positron (left) – antiproton (right)

Most motivated thermal models (**SUSY**, **X-dim**, **LH**, **IDM**) are
usually not predicted observable in the antimatter spectrum.

Dark Matter annihilation: generic predictions for positrons



y

Boost to get $\sim 5 \times \phi_{\text{bg}}$ at $\sim 100 \text{ GeV}$:

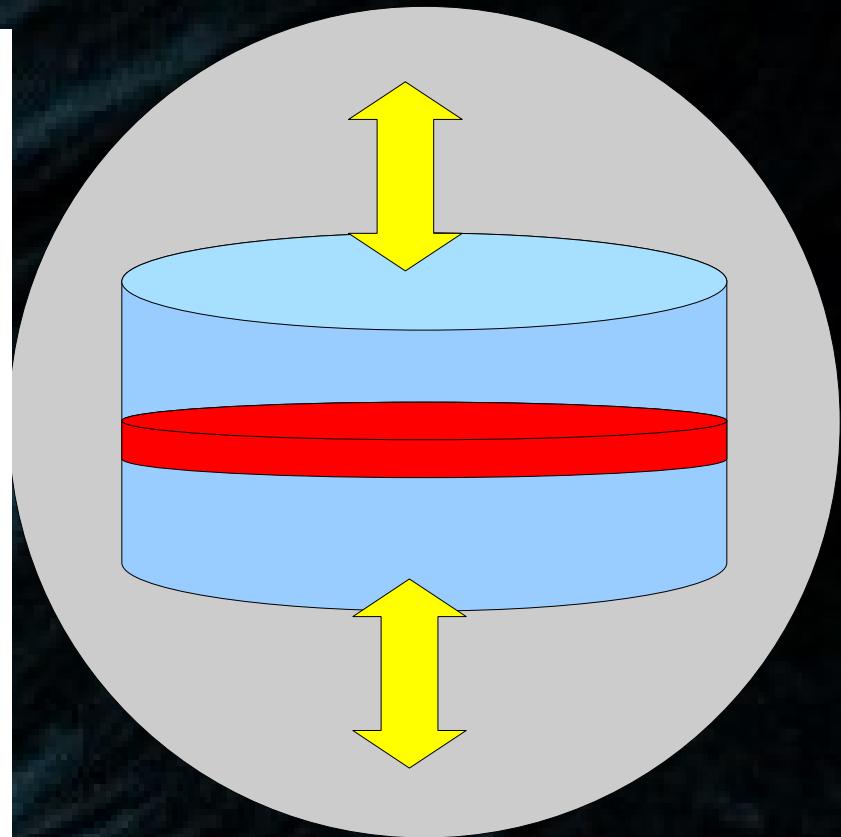
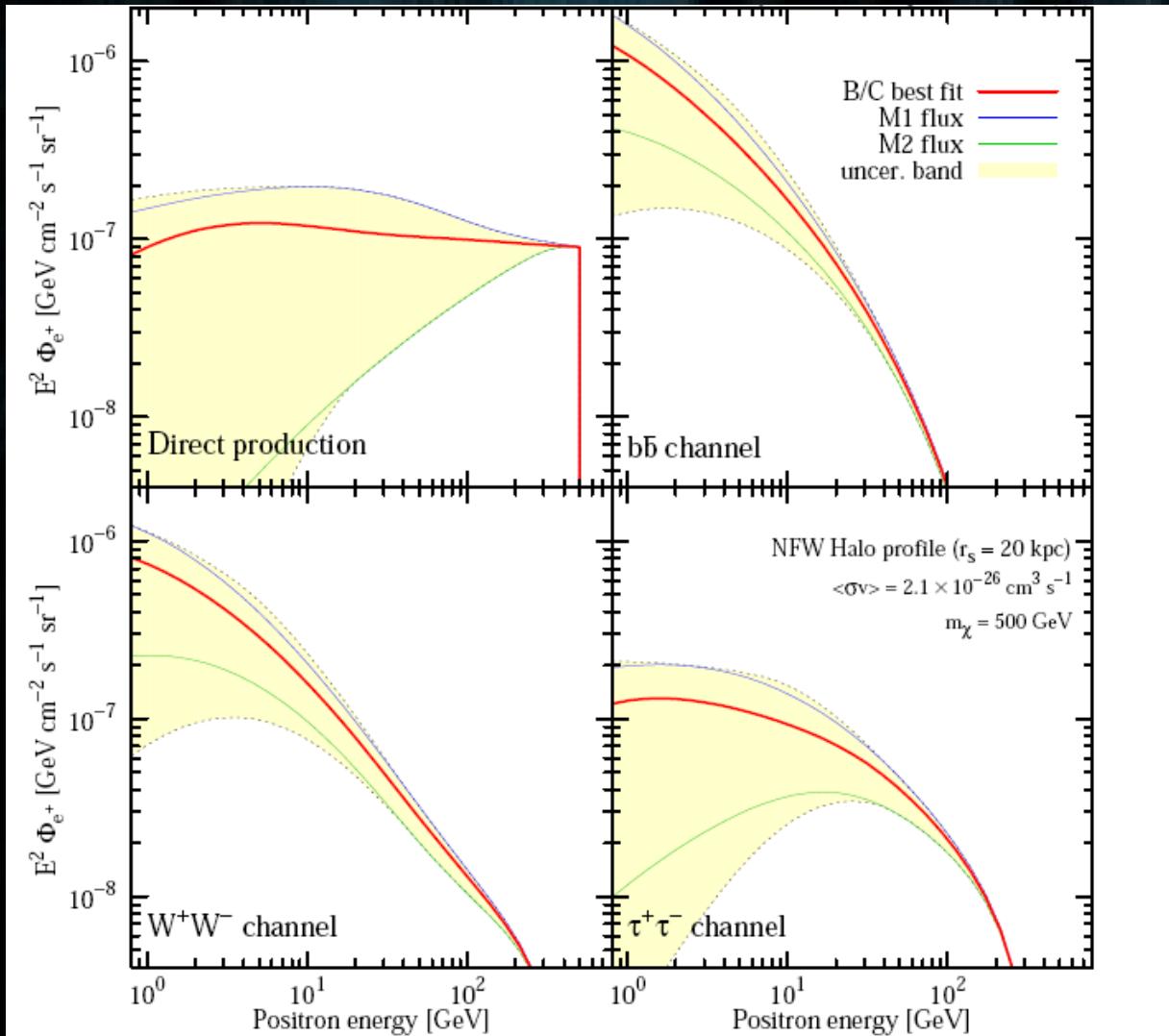
WIMP mass	100 GeV	500 GeV	1 TeV
final state			
e^+e^-	10	100	350
WW	80	500	1000
bb	250	500	1000

The signal must be boosted:

- (i) boost the cross section
→ contrived scenarios ($\frac{3}{4}$ of published papers) \sim excluded
(see e.g. Cirelli et al)
- (ii) play with the propagation parameters
- (iii) consider extra-sources
(subhalos, IMBHs)

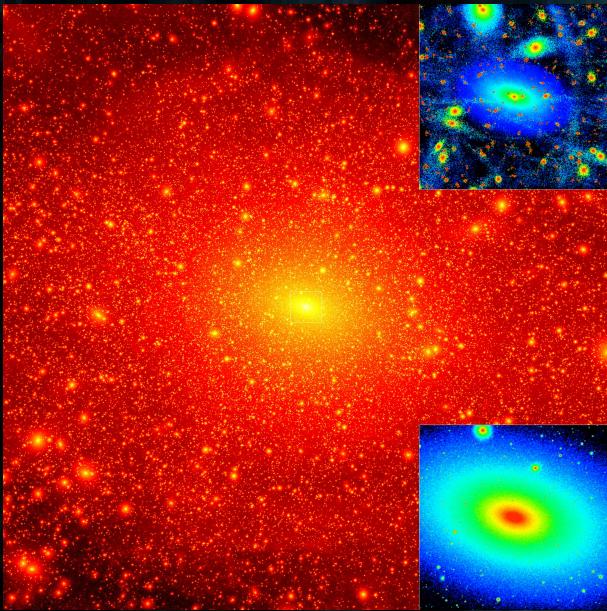
Play with propagation

Delahaye et al (2008)



Increasing L implies more DM in the diffusion zone.
 Translation into flux not that simple, since B/C imposes K/L ~ cst.
 Low energy effect for positrons (large propagation scale), but small.

Dark matter inhomogeneities wandering around ?



Via Lactea (Diemand et al)

Mini-dark halos with intermediate mass black holes

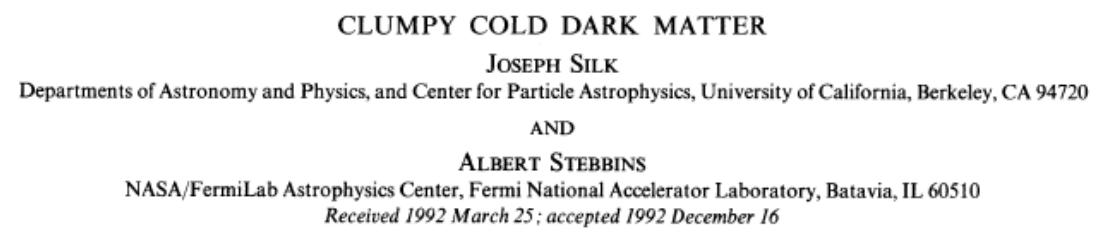
HongSheng Zhao and Joseph Silk
(Dated: 1 June 2005 on Phys. Rev. Letters 95, 011301)

Further developed by Bertone et al

Vol 460 | 2 July 2009 | doi:10.1038/nature08083

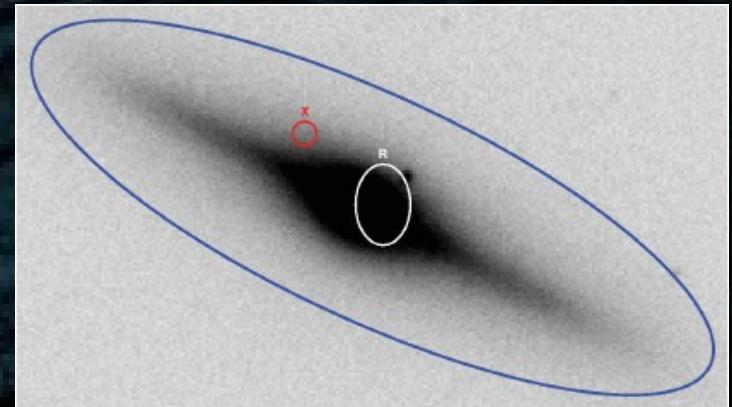
An intermediate-mass black hole of over 500 solar masses in the galaxy ESO 243-49

Sean A. Farrell^{1,2†}, Natalie A. Webb^{1,2}, Didier Barret^{1,2}, Olivier Godet³ & Joana M. Rodrigues^{1,2}



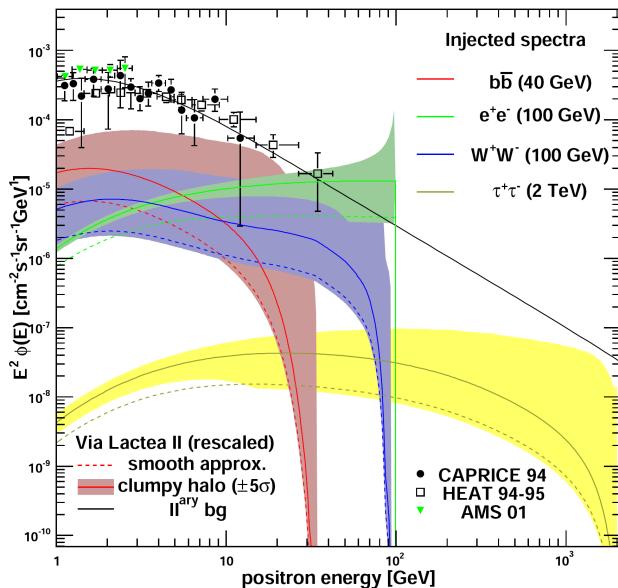
cores in globular clusters, and in galactic nuclei. The enhanced annihilation rate in clumps can lead to a significant contribution to the diffuse γ -ray background, as well as emission from the Galactic center. Results from terrestrial dark matter detection experiments might be significantly affected by clumpiness in the Galactic halo.

- Two main cases:**
- Collective effect.
 - A very “bright” single object ?
(excluded from gamma-ray data,
Bringmann, Lavalle & Salati 09)

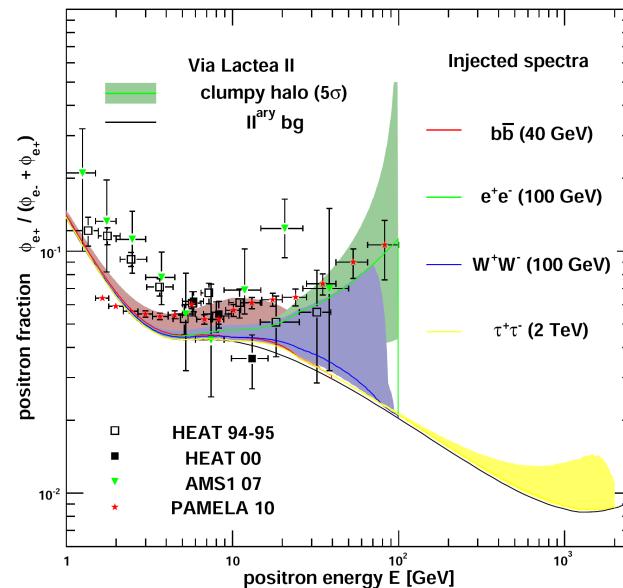


Dark Matter subhalos: energy-dependent boost factor < 5 (modulo variance)

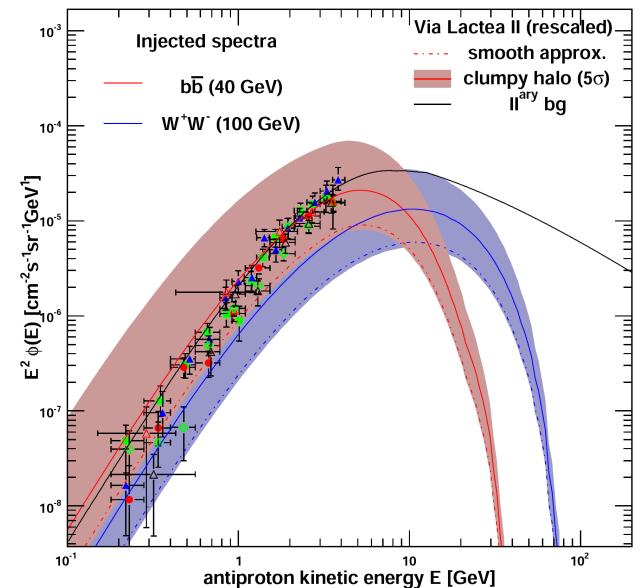
Positron flux



Positron fraction



Antiproton flux



Pieri, JL, Bertone & Branchini (2009)

using results from Via Lactea II (Diemand et al) and Aquarius (Springel et al)
-- see early calculations in Lavalle et al (2007-2008) --

$$\langle \sigma v \rangle = 3 \cdot 10^{-26} \text{ cm}^3/\text{s}$$

model	m_χ [GeV]	final state
A	40	$b\bar{b}$
B	100	W^+W^-
C	100	e^+e^-
D	2000	$\tau^+\tau^-$

Important features:

- 40 GeV WIMP ($b\bar{b}$) excluded by antiproton constraints
- 100 GeV WIMP (WW) at the edge of tension with the antiproton data
- 100 GeV WIMP going to e^+e^- can fit the PAMELA data; but pulsars not included => background must be known before any claim.

Astrophysical explanations

... the nose on one's face ...

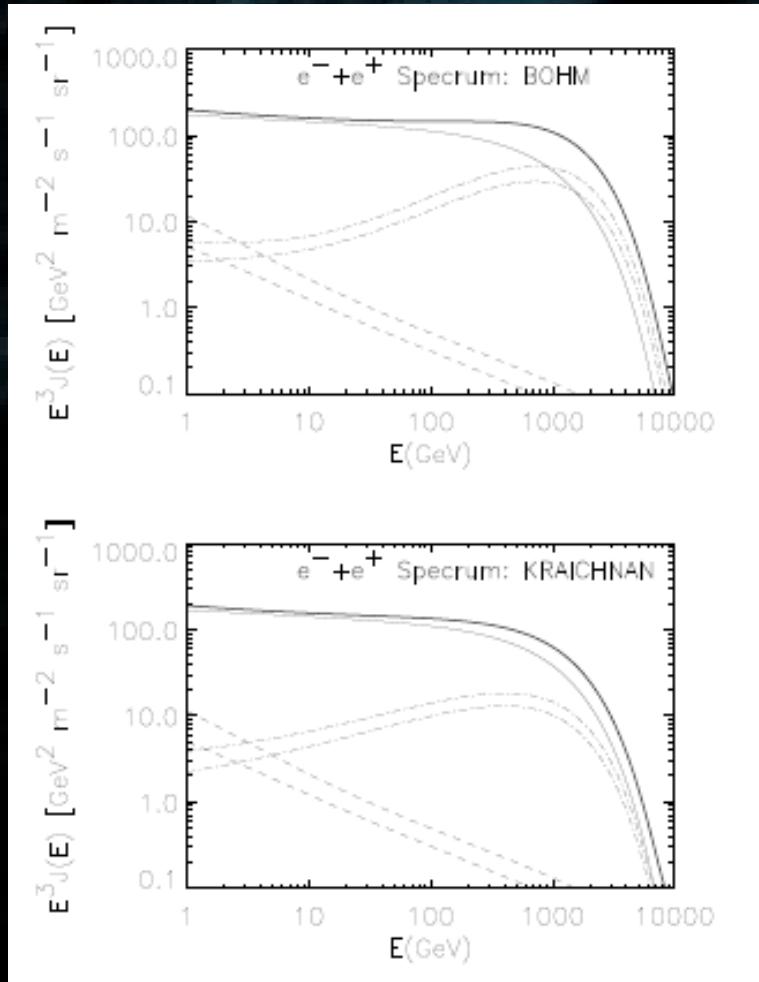
(a few tens of papers on the arXiv)

“Primary” secondaries ?

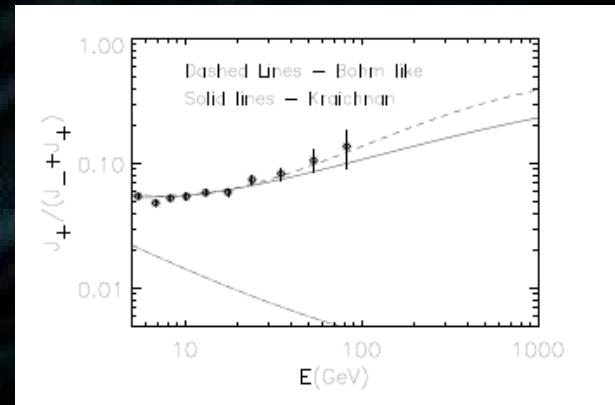
Positron fraction

Berezhko et al (2003), Blasi (2009), Blasi & Serpico (2009),
Mertch & Sarkar (2009), Ahler et al (2009)

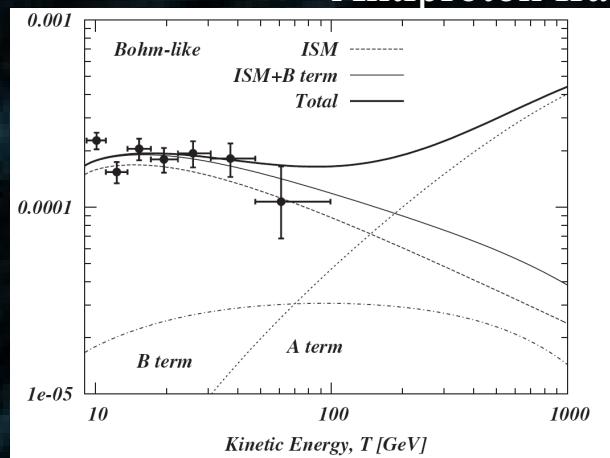
Secondaries created in SNRs are accelerated like primaries



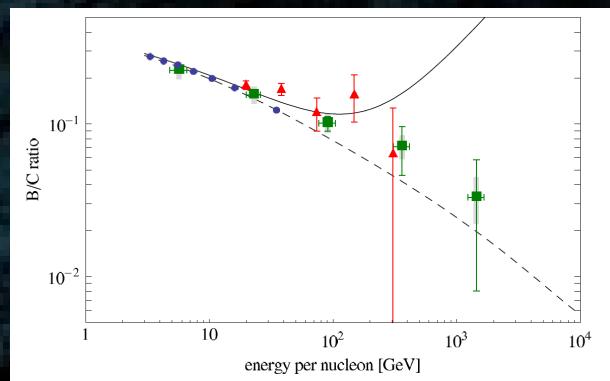
Specific signatures: rising antiproton fraction
(like DM) and B/C ratio



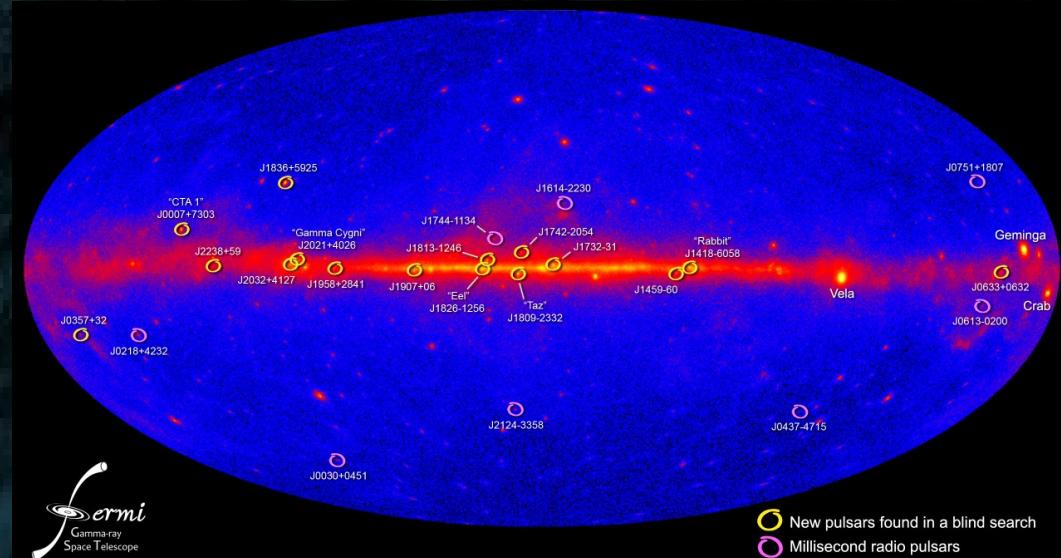
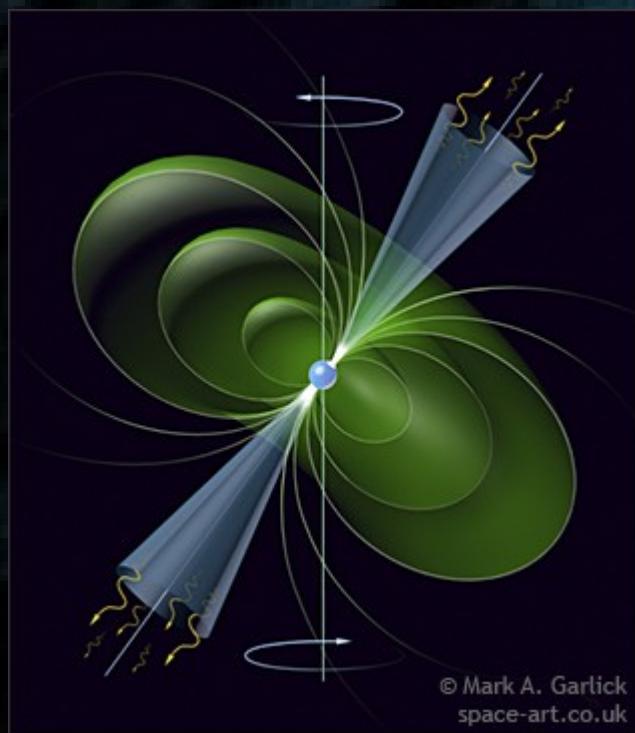
Antiproton fraction



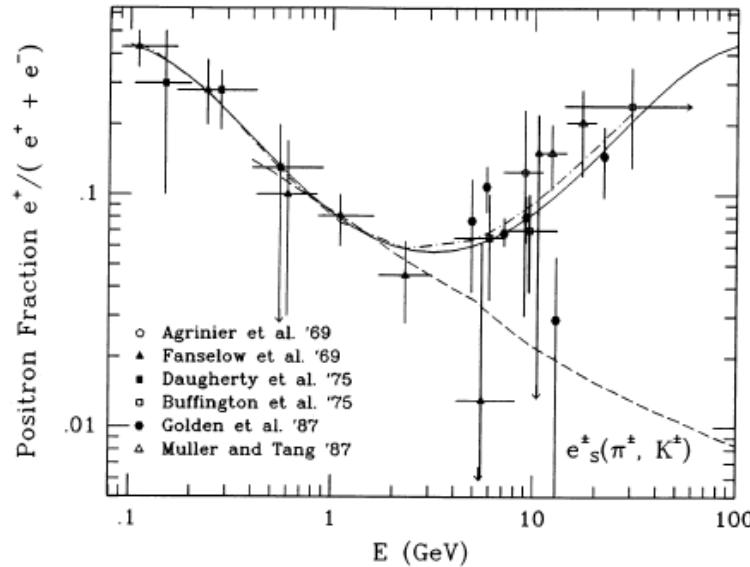
B/C measurements



“Standard” positron sources ? ... Pulsars !



A Population of Gamma-Ray Millisecond Pulsars Seen with the Fermi Large Area Telescope
A. A. Abdo, et al.
Science 325, 848 (2009);
DOI: 10.1126/science.1176113



THE ASTROPHYSICAL JOURNAL, 342:807–813, 1989 July 15
© 1989. The American Astronomical Society. All rights reserved. Printed in U.S.A.

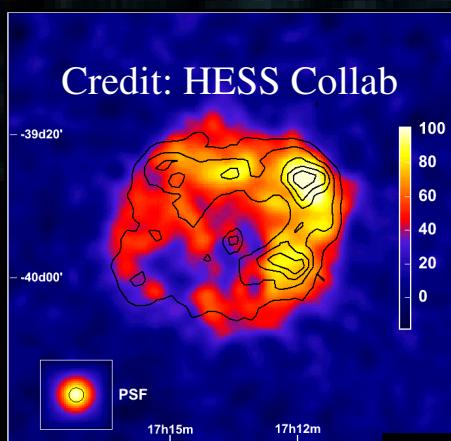
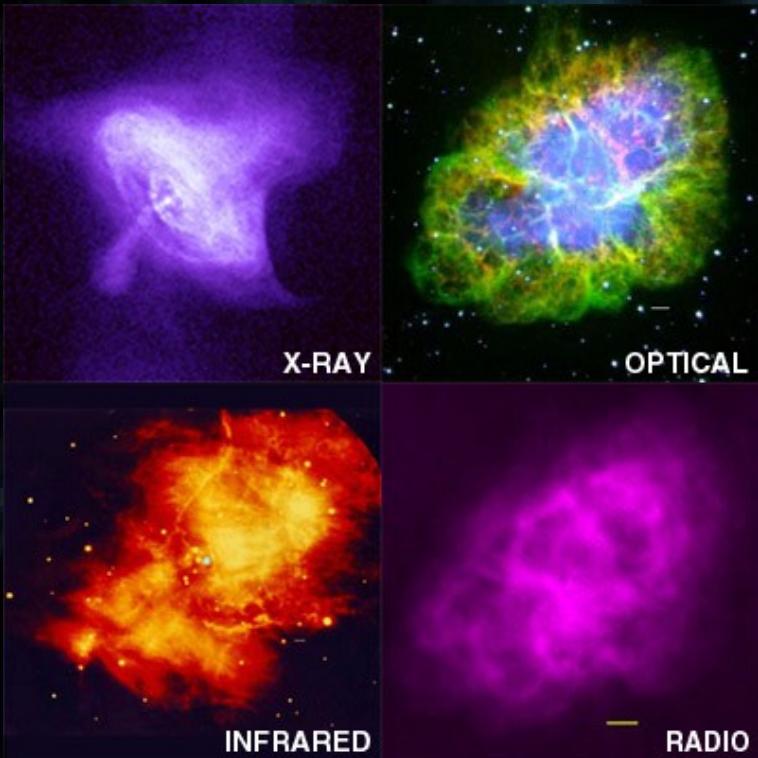
THE NATURE OF THE COSMIC-RAY ELECTRON SPECTRUM, AND SUPERNOVA REMNANT CONTRIBUTIONS

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

radio, γ -rays) suggest this possibility. In fact, if the recent $e^+/(e^+ + e^-)$ measurements are reliable, this will definitely require a pulsar source, because no other nearby conventional astrophysical sources (within 100–500 pc) can generate both e^- and e^+ at high energies (of course, dark matter annihilation may be important if it exists).

See also Shen 70, Aharonian et al 95, Chi et al 96

Towards a consistent picture



Include all primaries:

- SNRs accelerate electrons mostly
- Pulsars accelerate electrons + positrons
- Each pulsar must be paired with a SNR
- Many pulsars are not observable

Low energy electrons (< 20 GeV):

Contribution of distant sources (collective effects) :
average properties

High energy electrons (> 20 GeV)

- Consider local sources: large fluctuations expected
- Use multi-wavelength observational constraints

(see Shen 70, Kobayashi et al 04)

Issues

- Modeling of local sources (many degeneracies)
- More general: release of CRs in the ISM

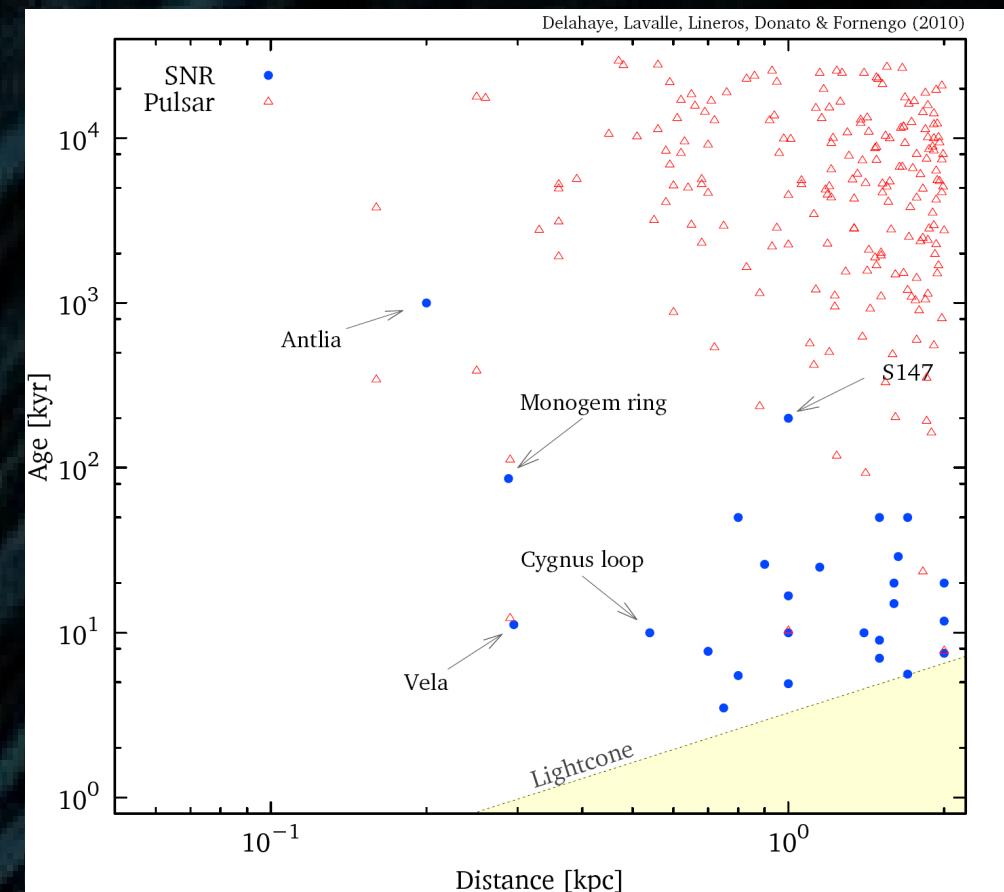
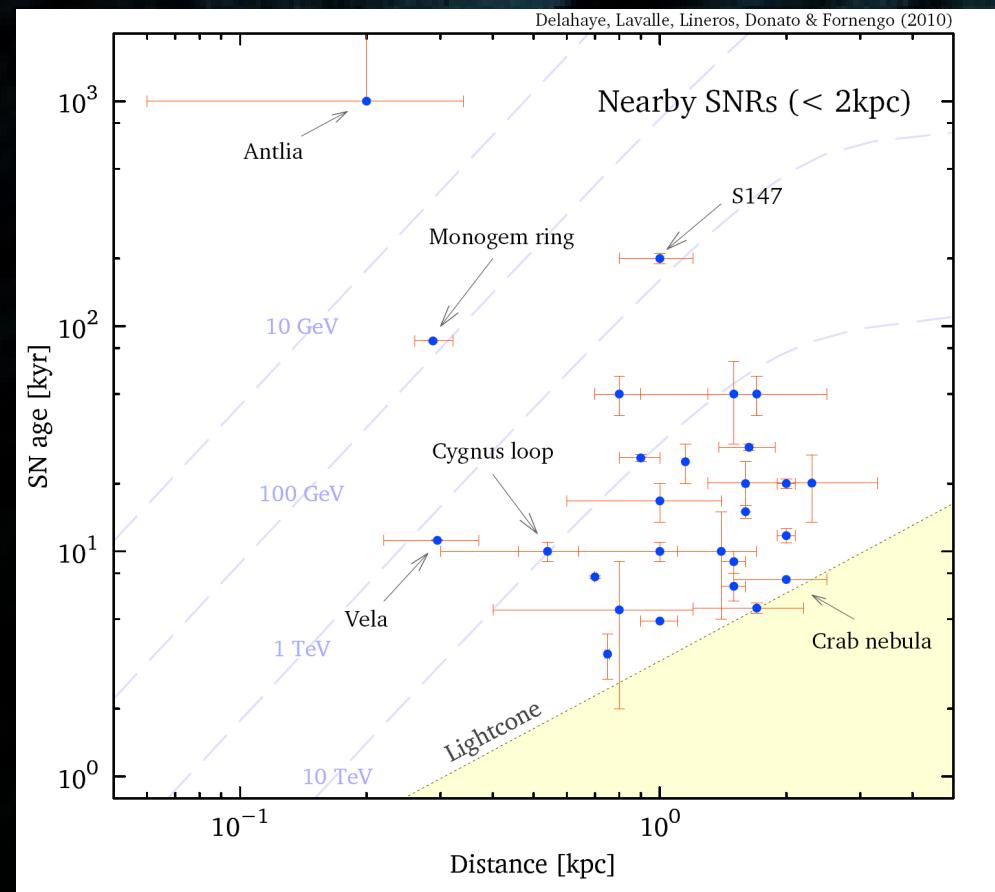
standard paradigm, but not standard model!

Deal with the complexity of Nature: Include all known local sources self-consistently

27 obs SNRs within 2 kpc

**Delahaye et al 10
arXiv:1002.1910**

~200 obs pulsars within 2 kpc



SNRs contribute to e^- , pulsars inject e^+e^- pairs ...

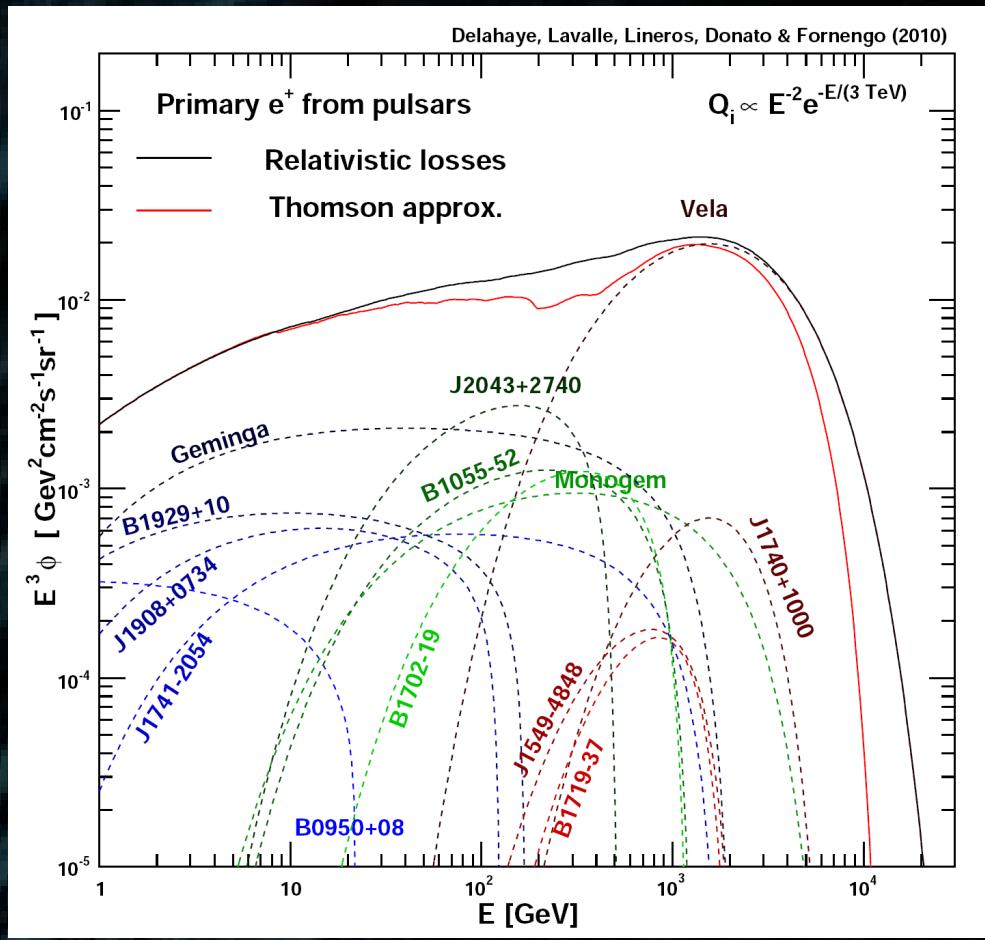
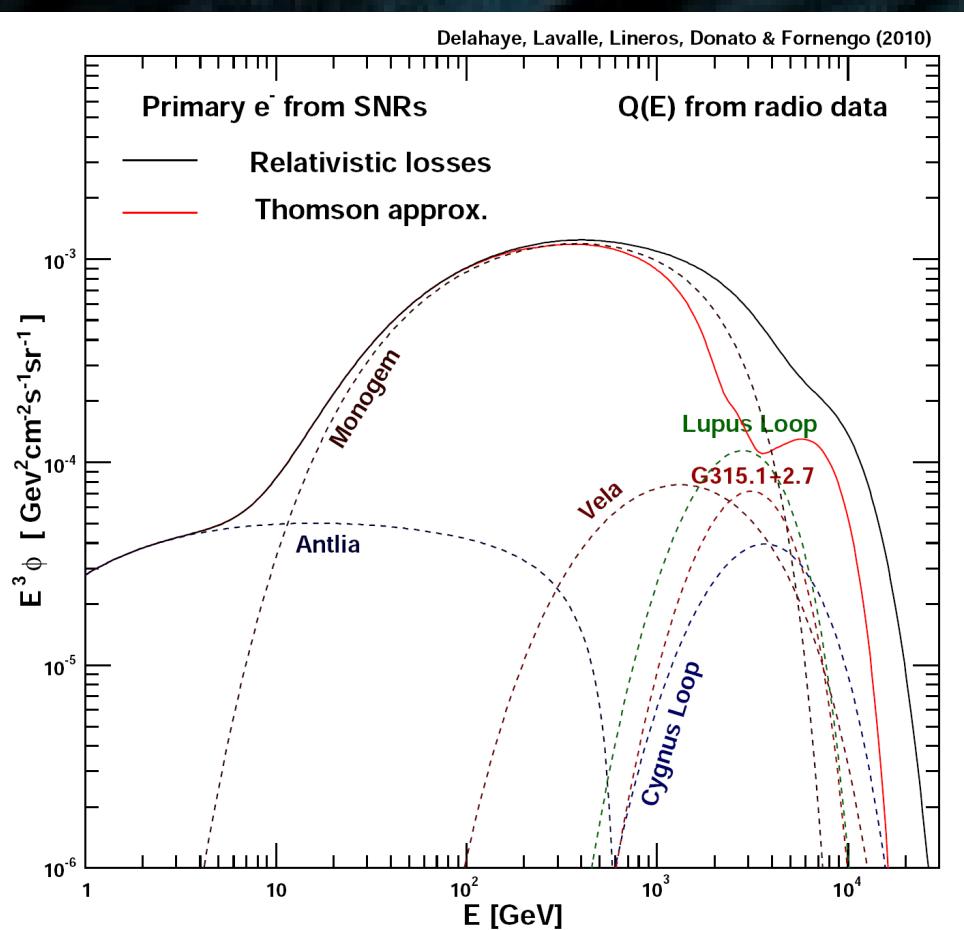
... but each pulsar should be associated with a SNR => Add missing SNRs !

*Deal with the complexity of Nature:
Include all known local sources self-consistently*

27 obs SNRs within 2 kpc

**Delahaye et al 10
arXiv:1002.1910**

~200 obs pulsars within 2 kpc

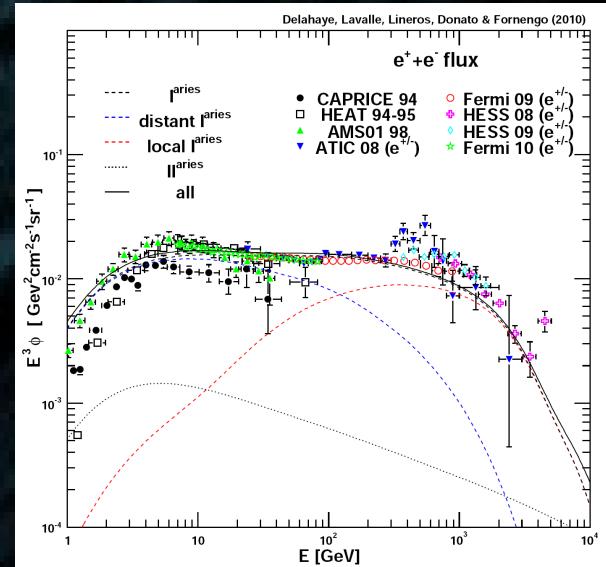
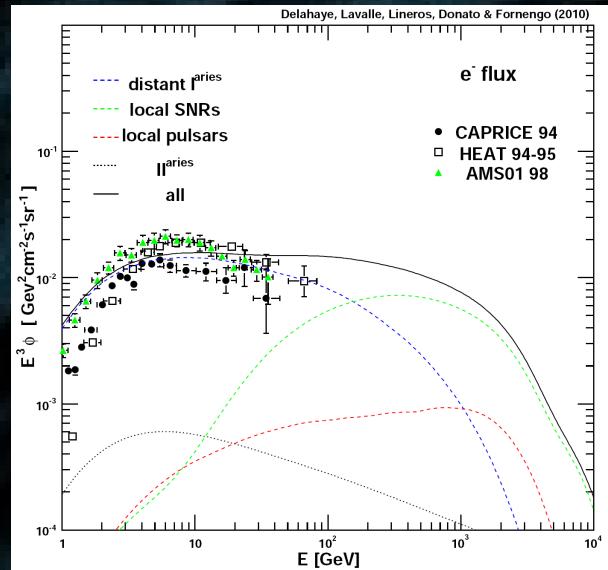


SNRs contribute to e⁻, pulsars inject e⁺e⁻ pairs ...

... but each pulsar should be associated with a SNR => Add missing SNRs !

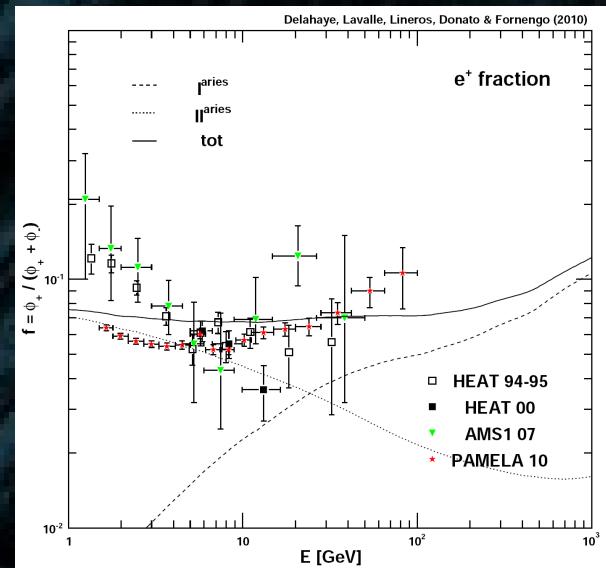
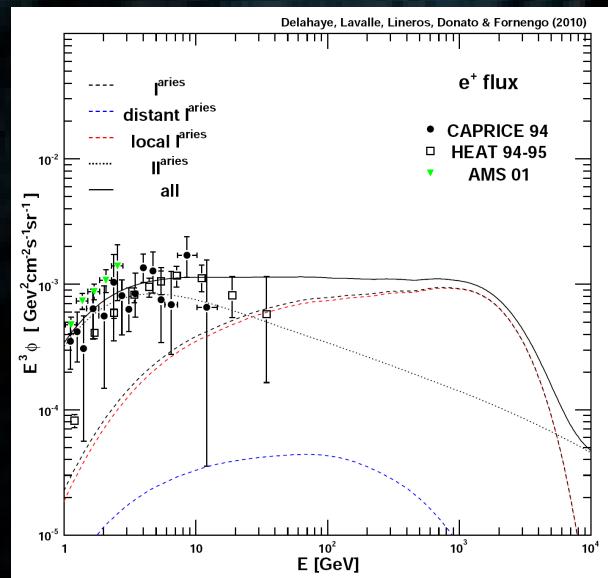
*No choice, Nature is observed to be complex:
Include all known local sources self-consistently*

electrons



electrons
+
positrons

positrons



positron
fraction

standard astrophysical sources make it!

The local $e^{+/-}$ anomalies: Summary and conclusions

Dark matter interpretation

- Unnatural for most of DM candidates in particle physics: fluxes far too low
- Other contrived models likely excluded (gamma-ray data, synchrotron, early universe)
- **Caveats:** background not under control! Use the data as constraints only.

Perspectives: combine LHC + astrophysics (multi-messenger, multi- λ , multi-scale) + direct detection ... some smoking guns soon hopefully, **many experiments running!**

Astrophysical explanations

- High energy e^+e^- pairs naturally created from strong magnetic fields around pulsars
- **Minimal assumptions lead to the correct amount of positrons**
- A consistent model of >20 GeV CR electrons must include local sources (SNRs & pulsars)
- A complete model, though still too simplistic, can explain the data all together

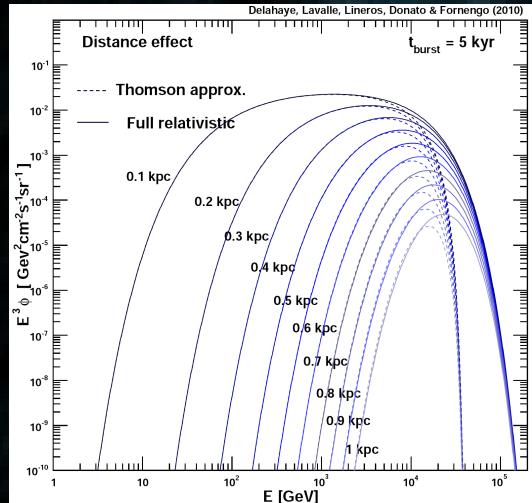
Perspectives: (local) source modeling, propagation to refine, electrons at the GC or at high latitudes

General

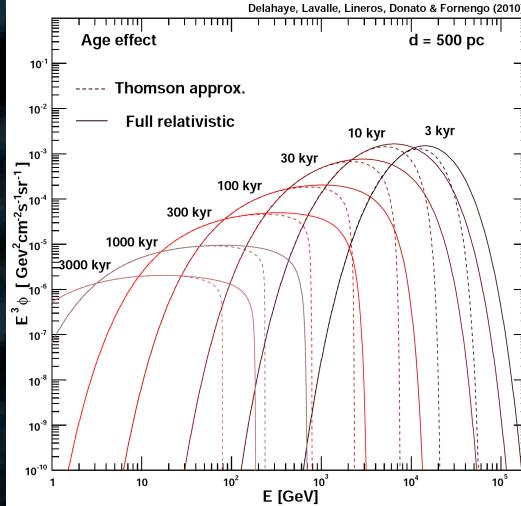
- Improving our understanding of high energy CR electrons will provide new insights on: magnetic fields (synchrotron), diffuse emissions (**Galactic center**), etc.

Backup slides

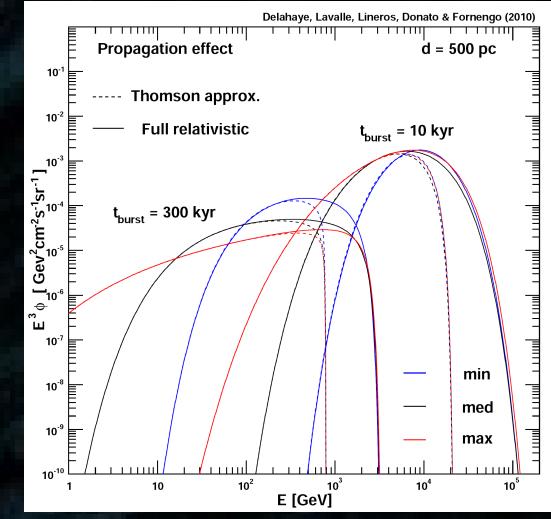
Time, spatial and spectral fluctuations at HE: Origin of uncertainties for local bursting sources



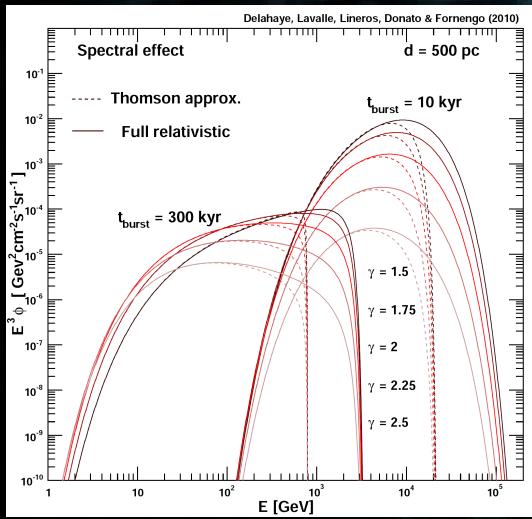
Distance effect



Age effect



Propagation effect



Spectral effect

arXiv:1002.1910

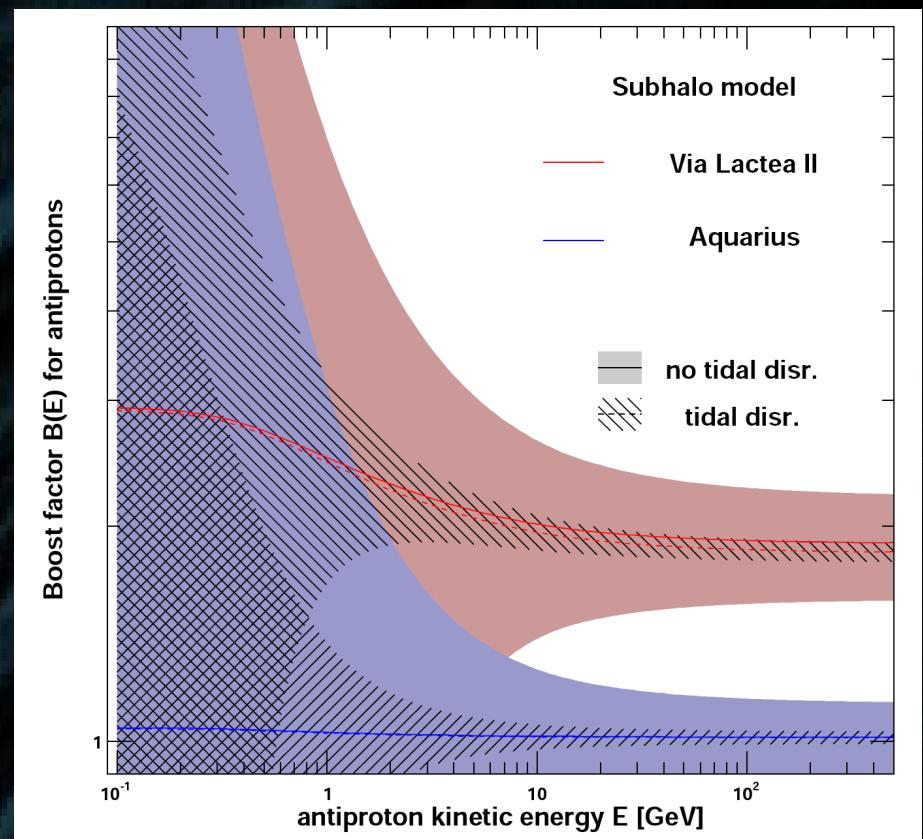
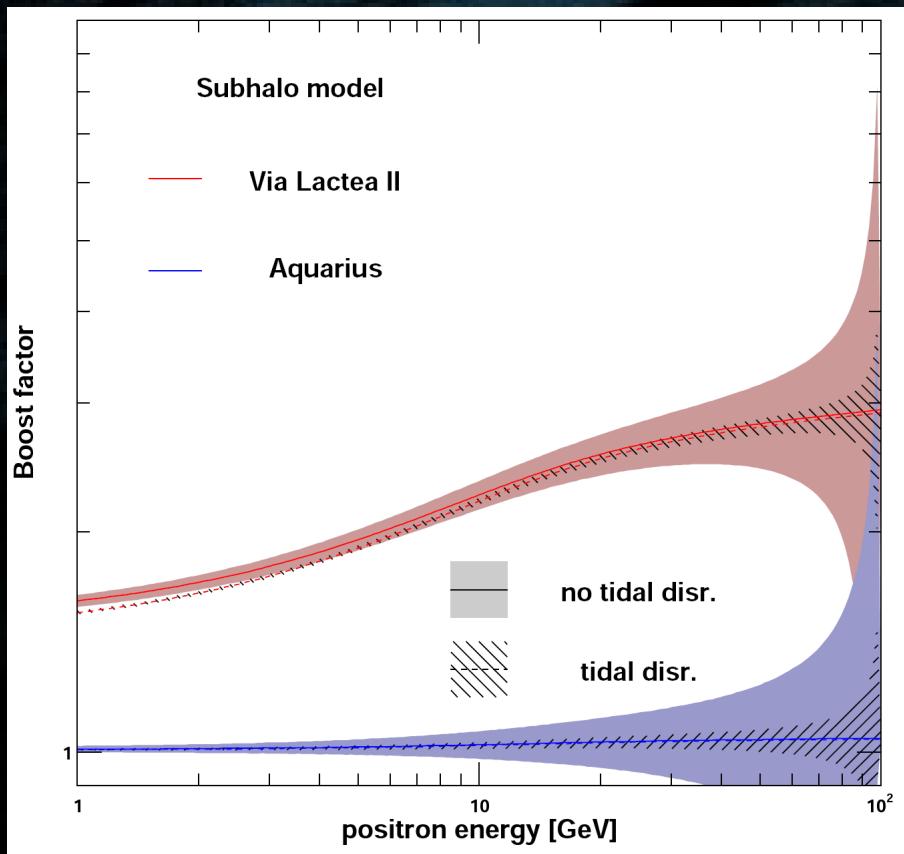
Time-dependent propagator

$$\mathcal{G}_t(t, E, \mathbf{x} \leftarrow t_s, E_s, \mathbf{x}_s) = \frac{\delta(\Delta t - \Delta\tau)}{b(E)} \frac{\exp\left\{-\frac{(\mathbf{x}-\mathbf{x}_s)^2}{\lambda^2}\right\}}{(\pi\lambda^2)^{3/2}}$$

Although observational constraints exist,
uncertainties are very large

Boost factors for positrons and antiprotons

Pieri, JL, Bertone & Branchini (2009)



See also Lavalle et al (2007,2008)