Indirect searches of Dark Matter: Status and prospects

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Outline

General introduction:

Dark Matter (DM) candidates, detection methods, hints (?)

Indirect DM searches (on the Galactic scale):

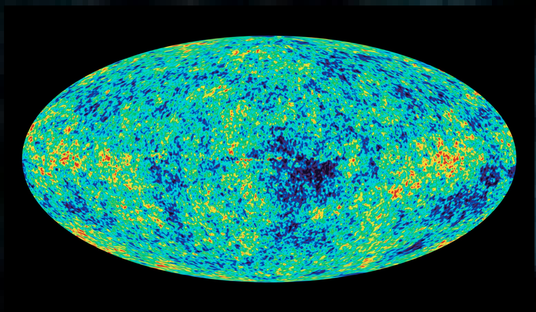
gamma-rays and antimatter (short focus on the PAMELA soap)

The importance of astrophysical backgrounds

The case of cosmic-ray electrons and positrons

Conclusion, perspectives

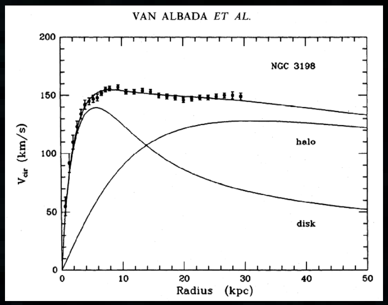
Dark Matter: from gravitational hints to candidates



CMB (WMAP) + LSS + SNe1A

Dark matter seeds structure formation, and still dominates the gravitational potential down to the dwarf galaxy scale.

[Modified gravity hardly forms structures without DM]



Galaxy rotation curves

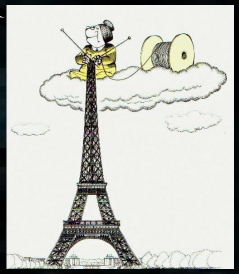
+++ Hot DM excluded

+++ CDM (or/and WDM) favored

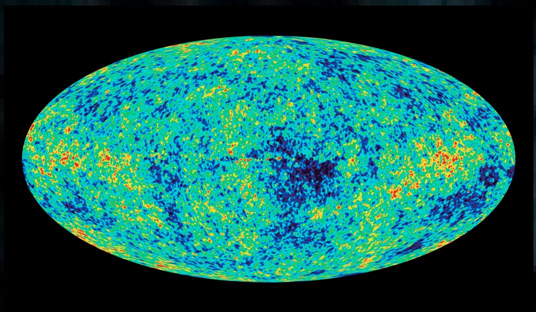
--- **issues:** cusps, power in small scales

(role of baryons ?)

Structure formation also says ...



Dark Matter: from gravitational hints to candidates



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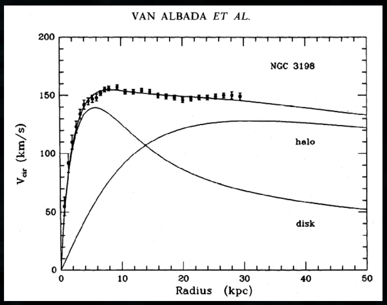
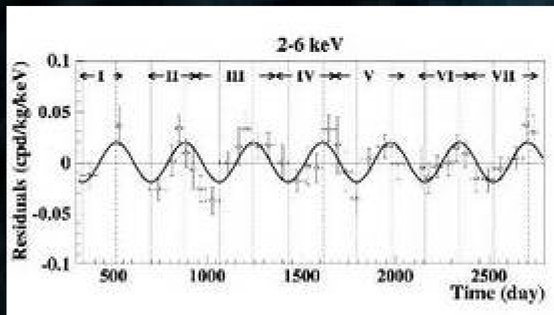


Galaxy rotation curves

What does particle physics say about DM ?

Motivations	**Strong CP problem in QCD**	**Neutrino masses**	**Origin, stability and naturalness of the Higgs sector (EWSB)**	**Dark matter**
Framework & Candidate(s)	**Peccei-Quinn ++ axion ++**	**RH-neutrinos + seesaw ++ sterile neutrino ++ ++ Asymmetric DM ++**	**SUSY, Xdim, IDM ++ LWP ++ (lightest whatever particle)**	**++ Neutral fermion or scalar ++**
Additional benefits		**Leptogenesis + solve small scale issues**	**e.g.: GUT, inflation**	
Detection: colliders/direct/indirect/other	**N/N/Y/Y**	**Y/N/Y/Y**	**Y/Y/Y/N**	**Y/Y/Y/N**

Other hints ? (not necessarily implying DM)

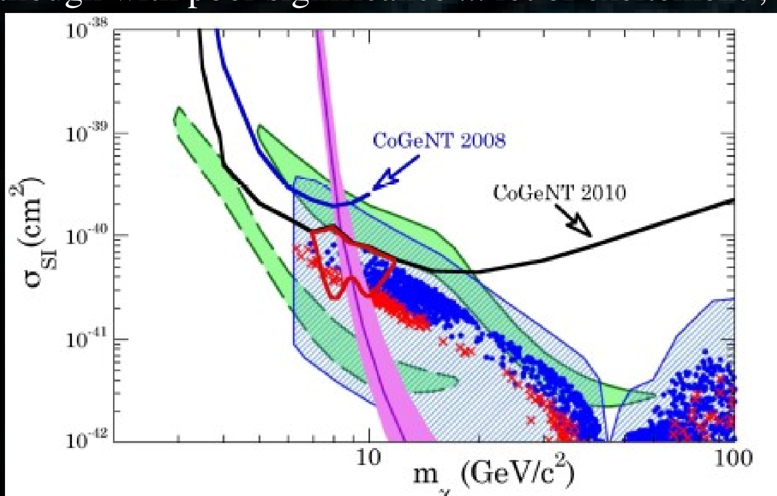


Direct detection:

DAMA oscillation (Bernabei et al), large significance.

Oscillation not yet detected by others.

Few events in other experiments (CDMS and Cogent), though with poor significance ... lot of excitement ;-)



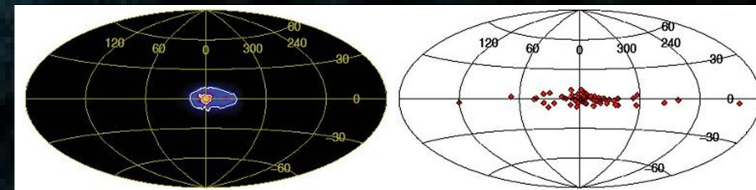
Aaltest et al 10 (Cogent)

see also Ahmed et al 09 (CDMS)

Theoretical prediction: eg Bottino et al 10, Ling et al 10

Interpretation issues: Kopp et al 10

[~10 GeV mass]



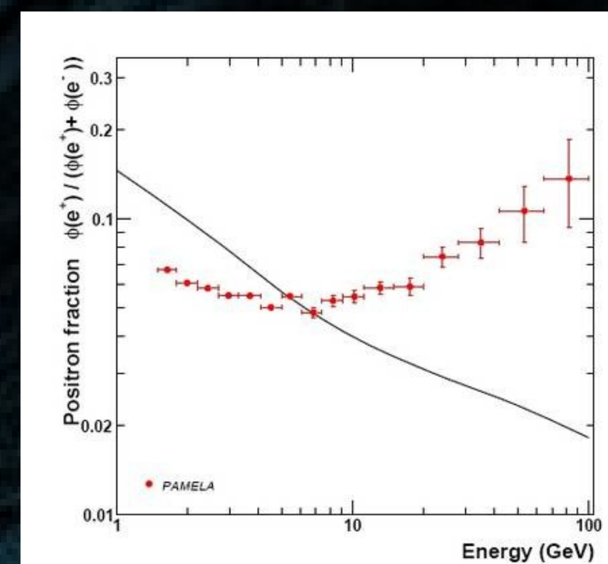
511 keV emission from the GC

Knodlseder et al 05, Weidenspointner et al 08

Spatial association with X-binaries, but positron production rate and transport issues.

MeV dark matter ? Boehm et al 04

[~1 MeV mass]

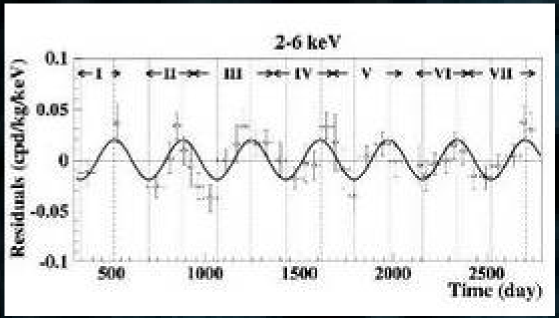


Local positron excess measured by PAMELA (Adriani et al 08)

Astrophysical sources or dark matter ???

[> 100 GeV mass]

Other hints ? (not necessarily implying DM)



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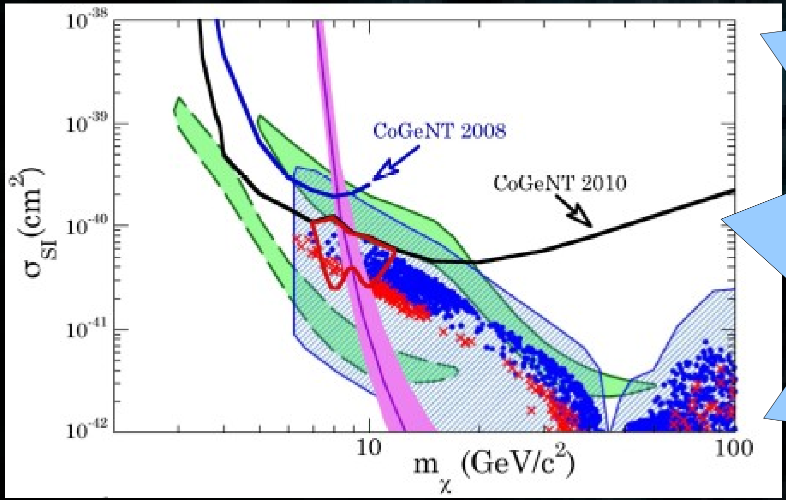

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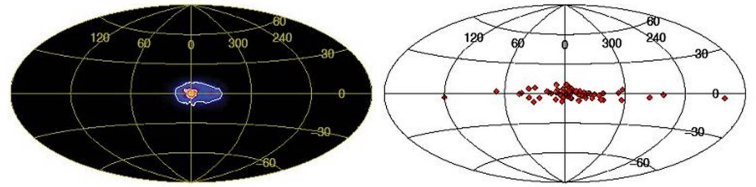

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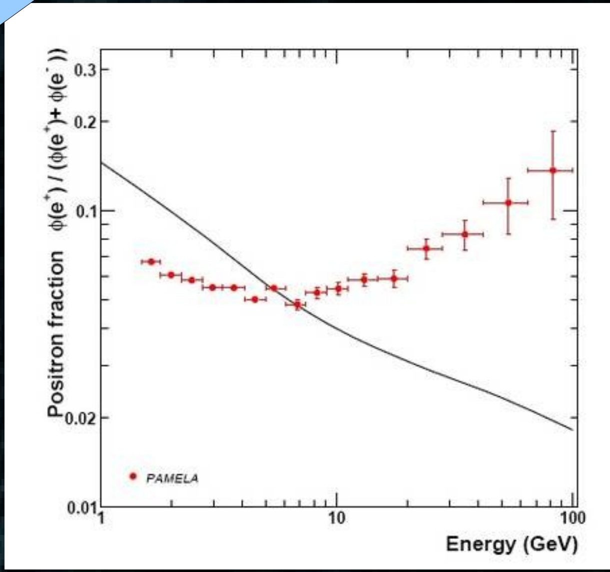
keV dark matter ? Boehm et al 04
[~1 MeV mass]

If interpreted as hints, none points towards the same dark matter particle



Local positron excess measured by PAMELA
(Adriani et al 08)
Astrophysical sources or dark matter ???
[> 100 GeV mass]

Dark matter annihilation as Galactic cosmic ray factory

THE ASTROPHYSICAL JOURNAL, 223:1015–1031, 1978 August 1

SOME ASTROPHYSICAL CONSEQUENCES OF THE EXISTENCE OF A HEAVY STABLE NEUTRAL LEPTON

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Received 1977 December 1; accepted 1978 February 14

VOLUME 53, NUMBER 6 PHYSICAL REVIEW LETTERS 6 AUGUST 1984

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

Joseph Silk
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and

Mark Srednicki
Physics Department, University of California, Santa Barbara, California 93106
(Received 8 June 1984)

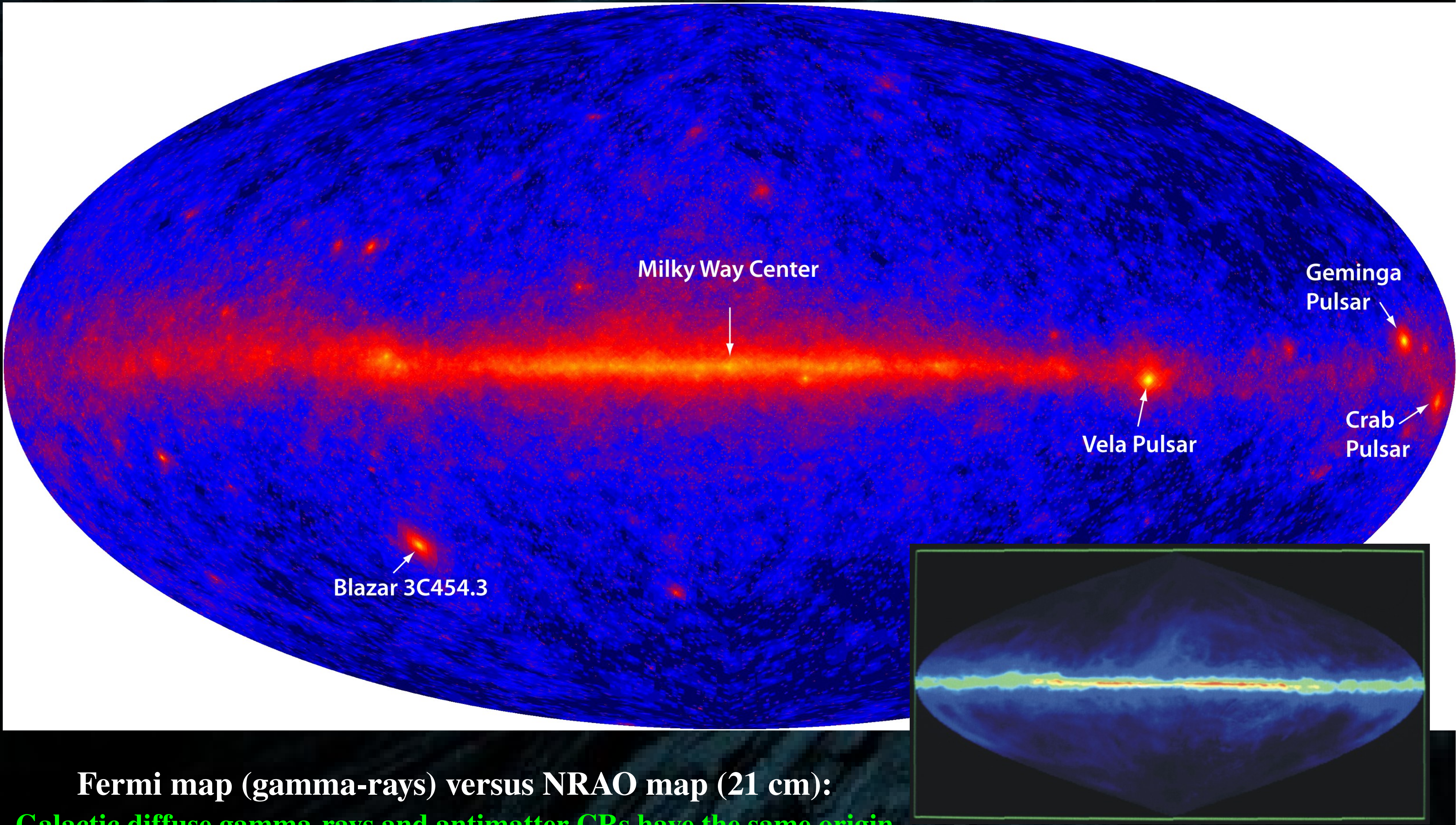
$$\frac{d\phi_{prim}}{dE} = \delta\,\frac{B_{prim} \times <\sigma v>}{8\pi m_{\chi}^2}$$

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

Main arguments:
- Annihilation final states lead to: gamma-rays + antimatter
- γ-rays : lines, spatial + spectral distribution of signals vs bg
- Antimatter cosmic rays: secondary, therefore low bg
- DM-induced antimatter has specific spectral properties

But:
- Do we control the backgrounds?
- Antiprotons are secondaries, not necessarily positrons
- Do the natural DM particle models provide clean signatures?

Background production in the Galaxy: interaction of cosmic rays with the interstellar gas



Fermi map (gamma-rays) versus NRAO map (21 cm):

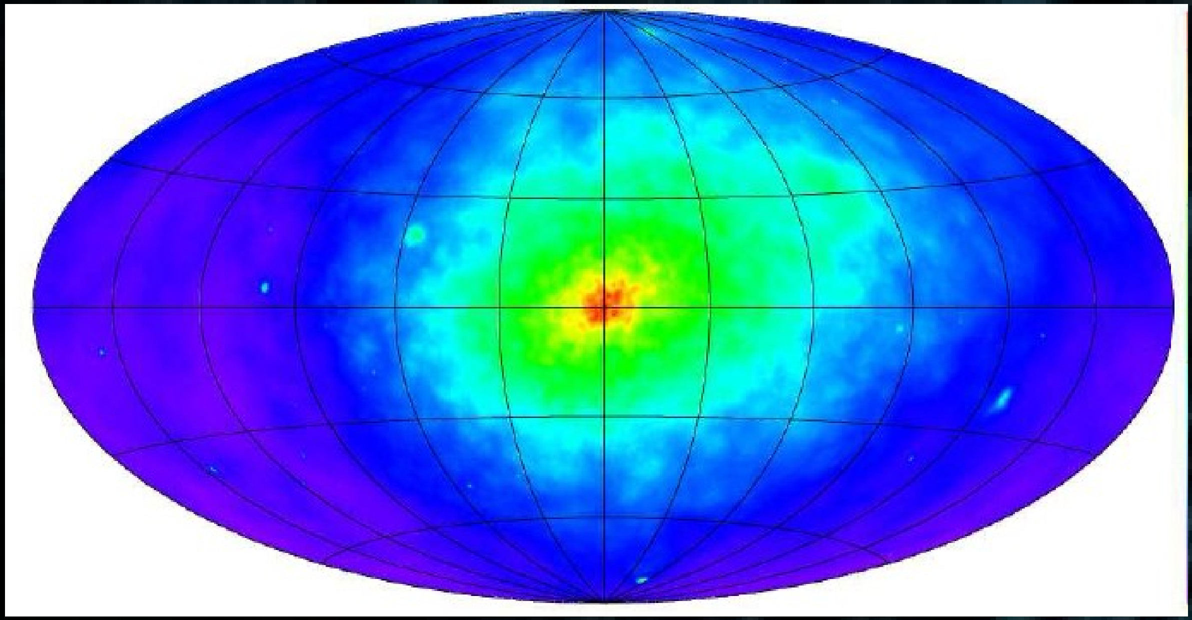
Galactic diffuse gamma-rays and antimatter CRs have the same origin

Indirect searches with gamma rays

γ -rays: a direct probe of the DM distribution

Nbody-simulations allows predictions accounting for the details of the DM distribution: subhalos, tidal streams. Early attempts by Stoehr et al 04, Diemand et al 06-07.

Horizon framework (Teyssier 04): Athanassoula et al 08



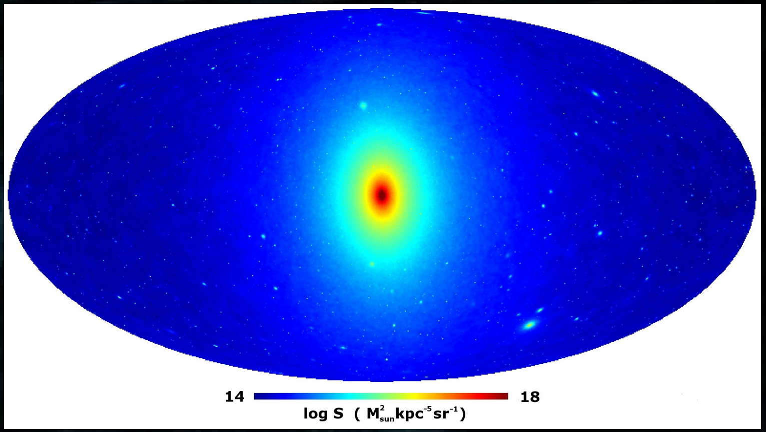
Predictions: usual **WIMP models difficult to detect** except for

(i) specific DM features (nearby **subhalos**, cusp in the GC)

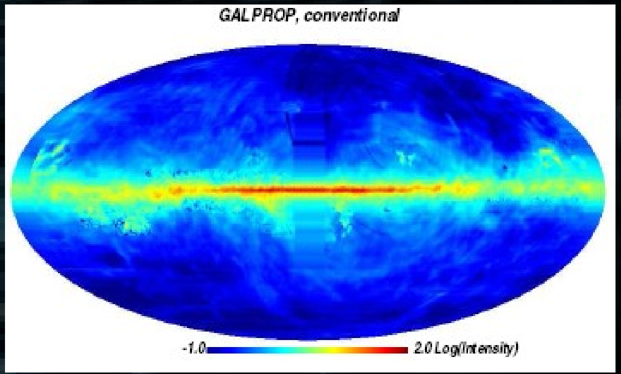
(ii) specific spectral features (lines, heavy masses)

(iii) spatial-dependence of S/N: to improve !

Aquarius project: Springel et al 08



Bg model from Galprop (Springel et al 08)



γ -rays: theoretical uncertainties

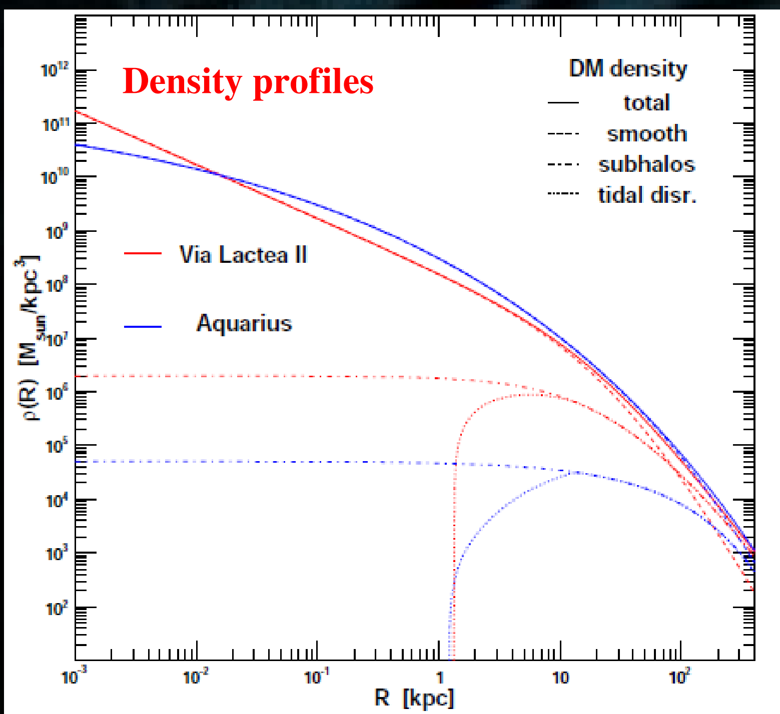
Different simulations give different results, eg:

* Via Lactea II (Diemand et al 08)
* Aquarius (Springel et al 08)

Among differences:
subhalo properties!

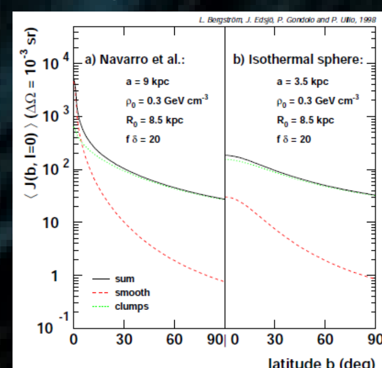
Analytical & MC study of
VLII and Aquarius

Pieri, Lavalle, Bertone & Branchini 09

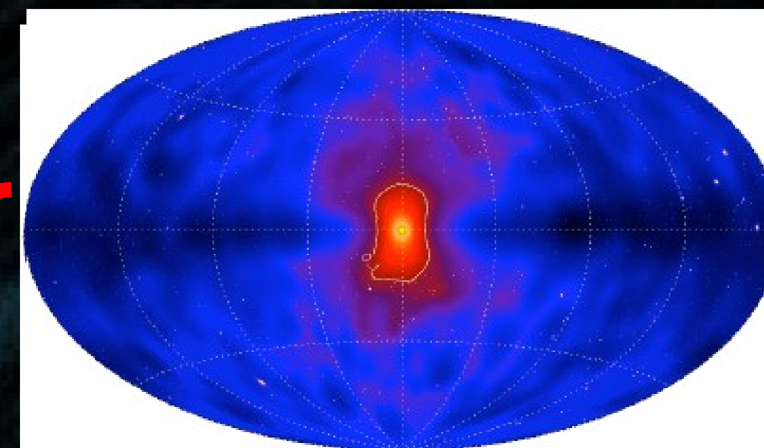


Flux: smooth wins against clumps
on small l, but loses on large l

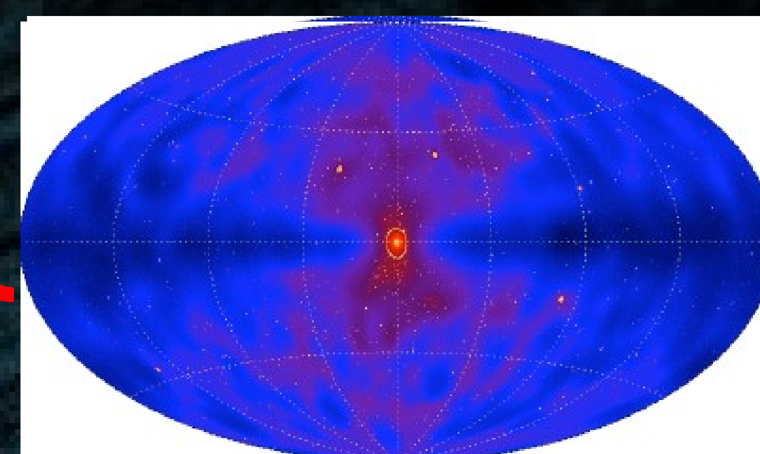
Bergström et al 99



Aquarius



Via Lactea II



<u>Predictions (Fermi 5 yrs):</u>

(i) signal from GC provided understanding of Bg
(ii) few (~ 5) observable subhalos

γ -rays: the advent of Fermi

Milky Way (amazingly close to CR models' predictions!):

Diffuse Galactic emission:
* New Fermi data (Abdo et al 09)
* Consistent with CR models (within theoretical unc).

Diffuse EGB:
* Beware of Galactic CR model subtraction!
* Seems to be saturated by the AGN component
* Subhalo issue ! (full + anisotropy)

Galactic center:
* Fermi data available, features observed (Finkbeiner et al)
* Astrophysical bg issue: Galprop fails
* Interpretation in terms of DM premature

Other targets:

* M31 detected !!!!!
* Subhalos (this requires luck and time)
* Dwarf spheroidals (limits from Fermi)
* Galaxy clusters (limits from Fermi)

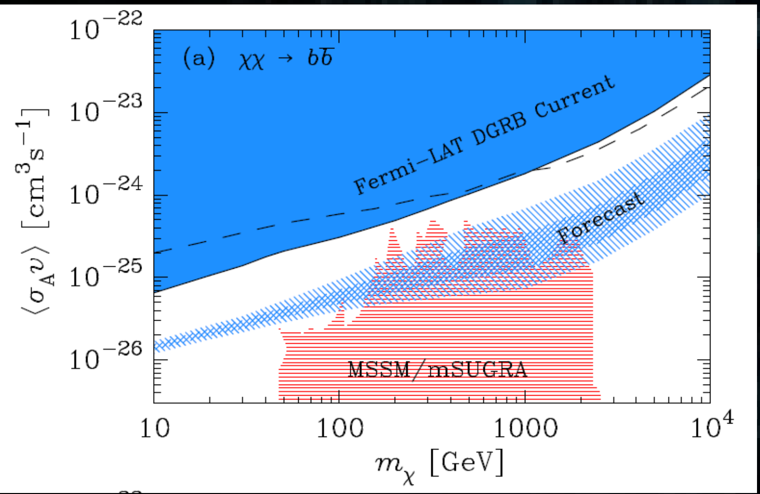
=> Cusps are crucial features

Open issues:

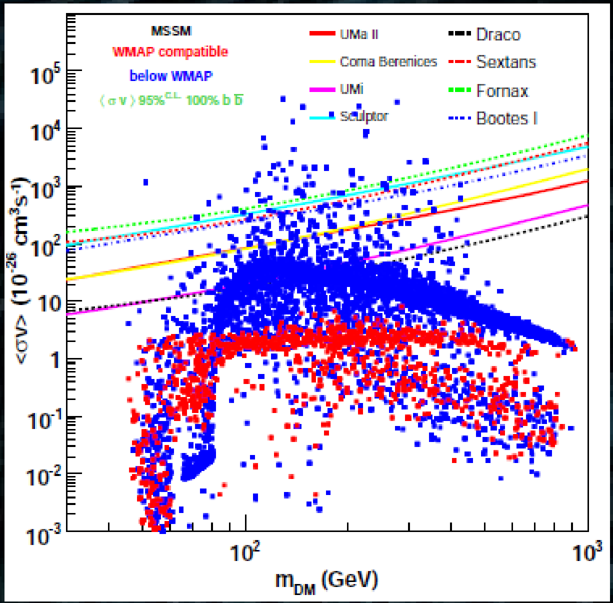
* The role of baryons on DM distribution
* The cosmic ray background in targets

=> CR physics + ISM + ISRF (ICM + ICRF) !!!

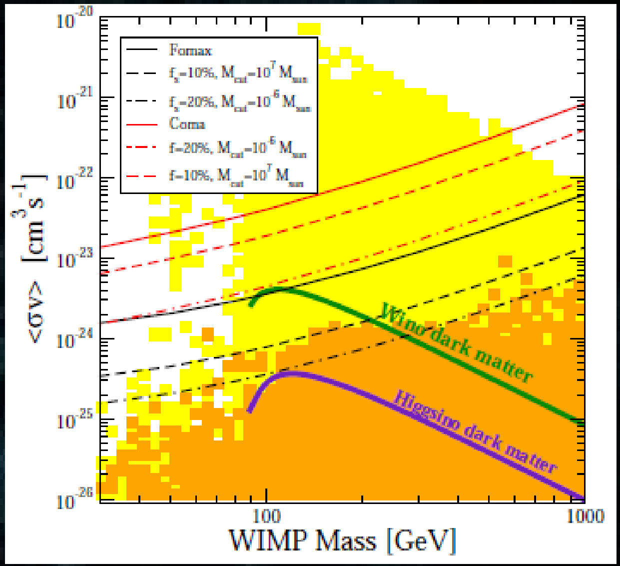
Diffuse EG gamma-rays
Abazajian et al 10



Dwarf galaxies: Abdo et al 10



Clusters: Ackermann et al 10



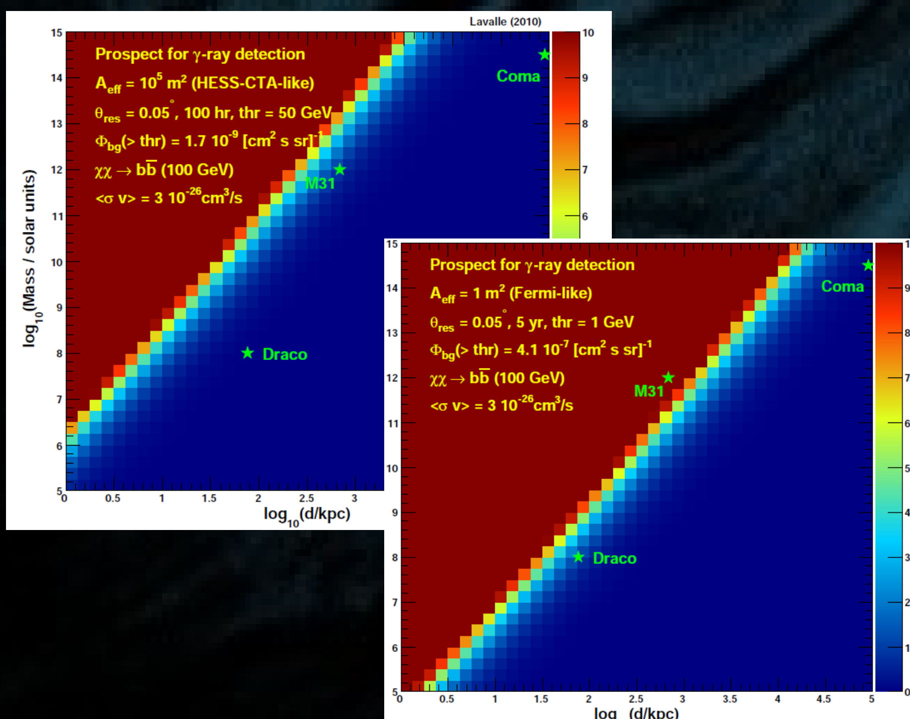
γ -rays: status and perspectives

Targets for discovery:

* Gamma-ray lines [or X-ray lines for sterile neutrinos]
* Nearby dwarf galaxies (e.g. Draco)
* Subhalos
* Galactic center (???)
* [HE neutrinos from the Sun]

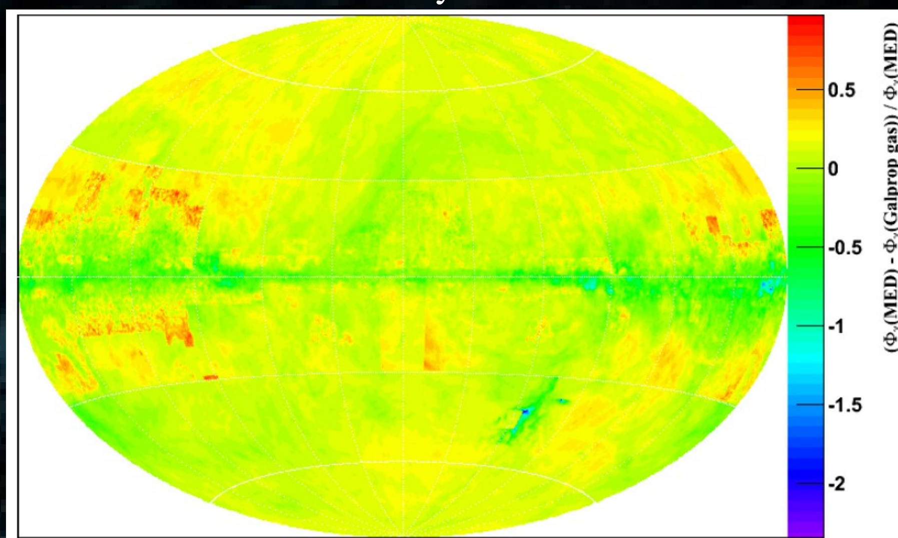
Targets for limits:

+++ Diffuse Gal and EGal emissions
(limited knowledge of CR physics)



Prospects for HESS/Fermi/CTA
(Lavalle, in prep.)
=> at the border of sensitivity !!!

Delahaye et al 11



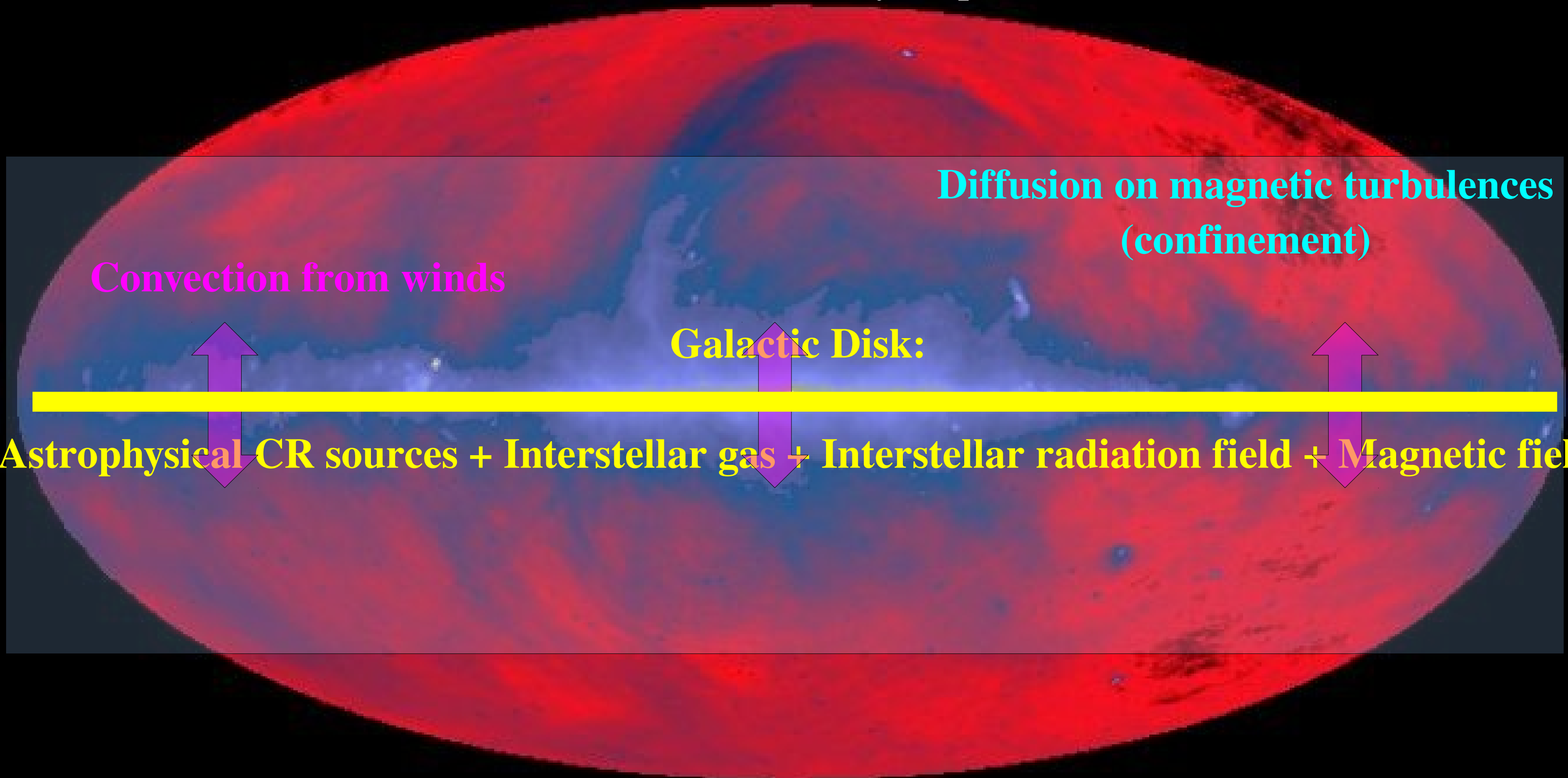
Beware of theoretical and observational uncertainties!
Above:
HI, Galprop map versus Pohl et al map

Issues (short-term solvable):
DM: impact of baryons, subhalos (survival, etc)
Cosmic rays propagation and sources + ISM + ISRF + B-field

Indirect searches with antimatter cosmic rays (focus on the PAMELA excess)

Propagation of Galactic cosmic rays: The standard picture

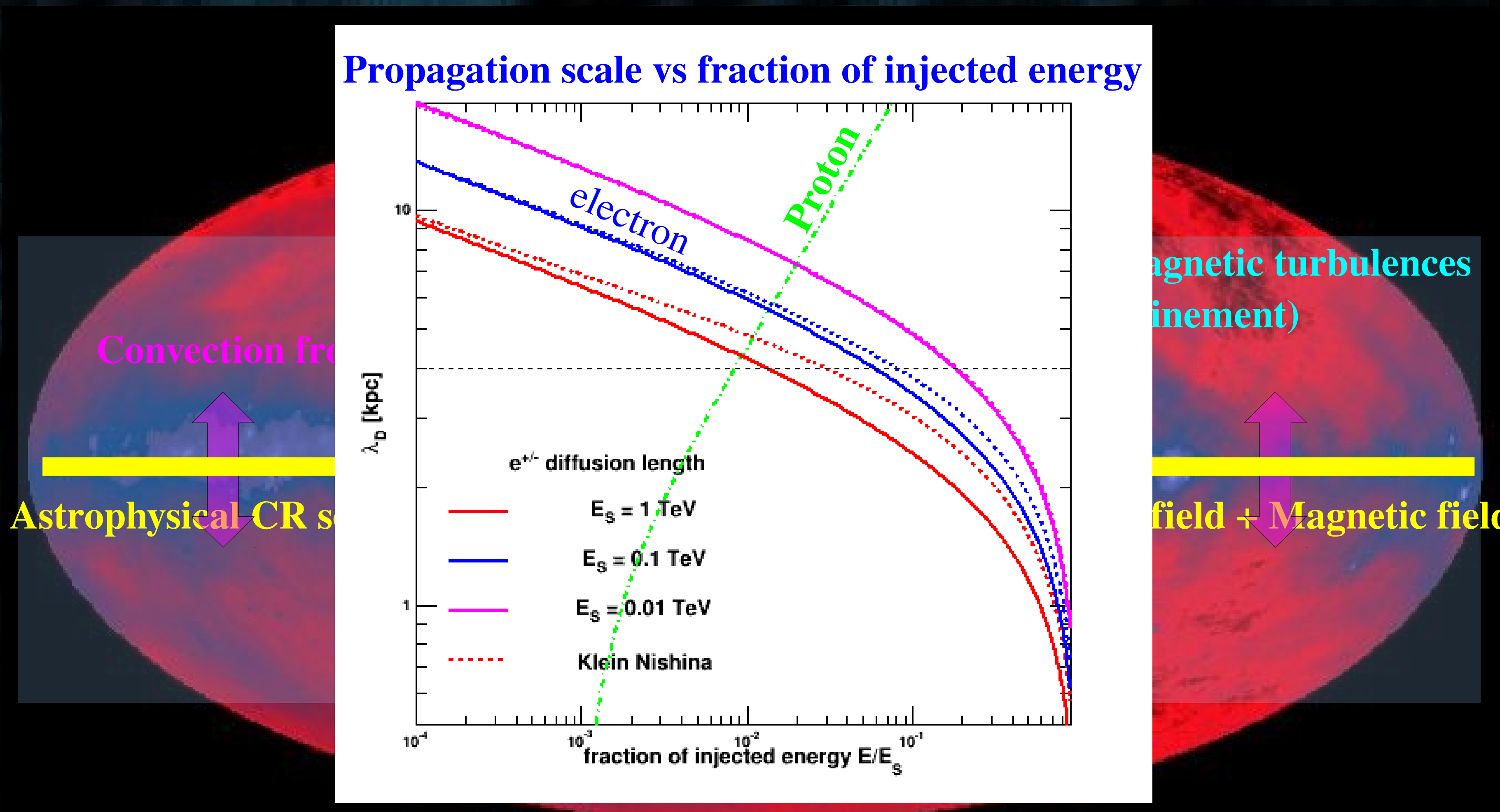
408 MHz all-sky map



From Haslam et al data (1982)

In the GeV-TeV energy range, electrons lose energy quickly as they propagate, protons do not

Propagation of Galactic cosmic rays: The standard picture



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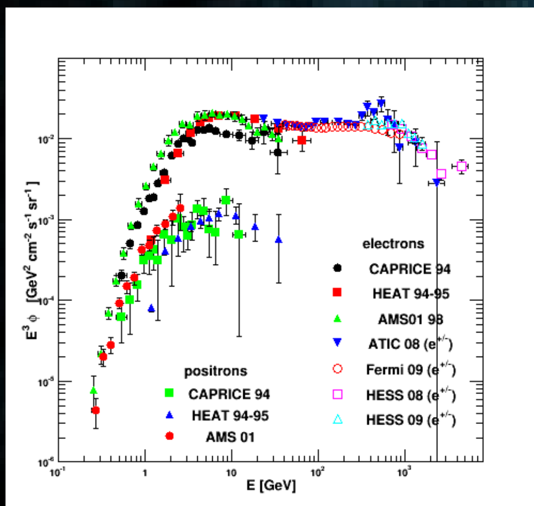
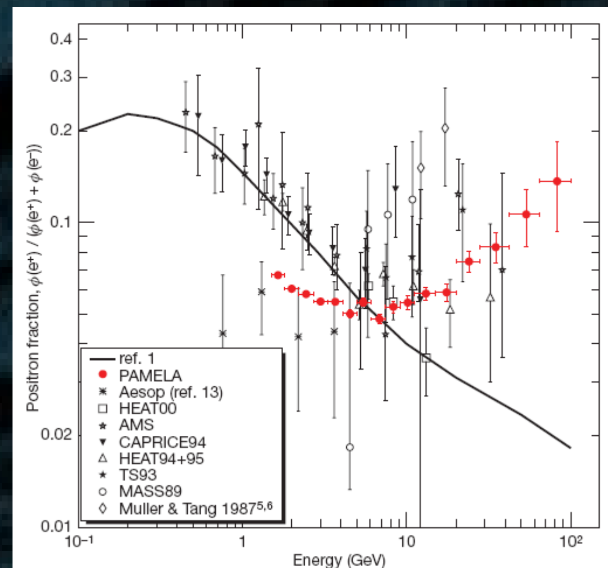
Electron energy loss rate $\propto E^2$ (Compton, synchrotron processes)

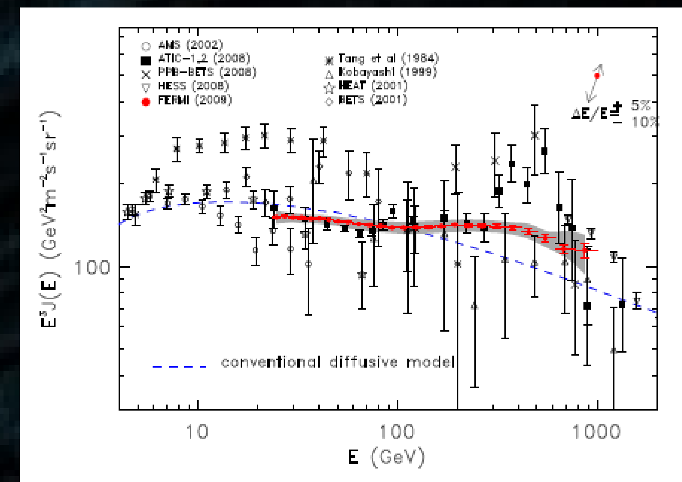
Current measurements of e^+'s and e^-'s



e^+ and e^-
data compilation



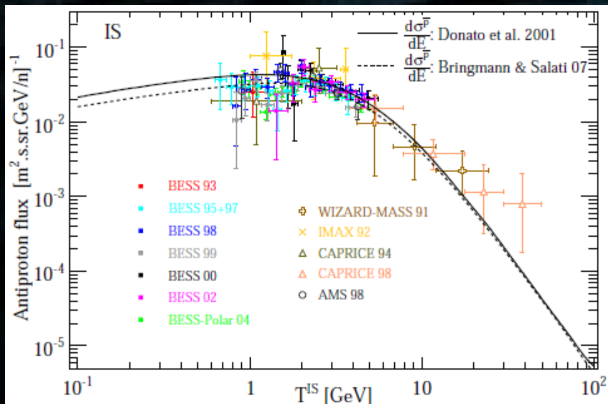
$e^+/(e^+ + e^-)$ PAMELA
Adriani et al (2009)



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

Do we understand all of these measurements ?
(positron excess, spectral features)

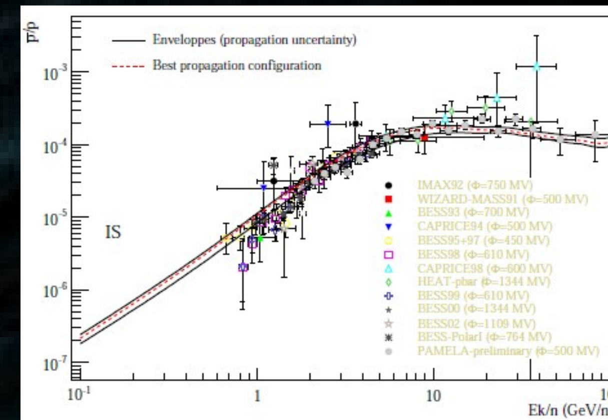
Secondary backgrounds: CRs interaction with ISM
→ Don't forget theoretical uncertainties!



Antiprotons

Donato et al 01, 09

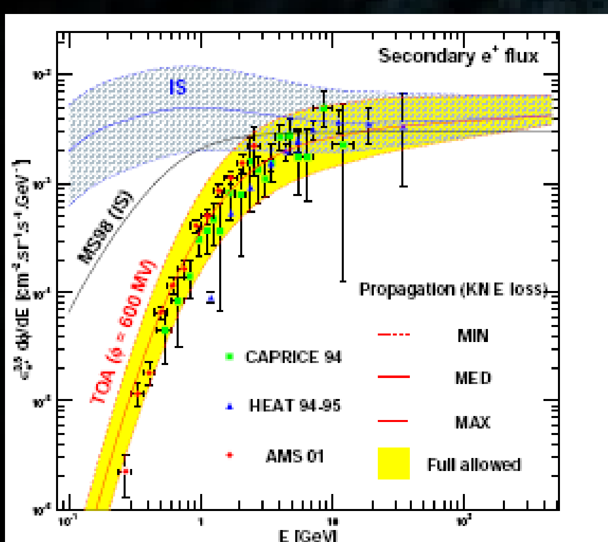
Bringmann & Salati 07



Flux at the Earth

Secondary bg: antiprotons fit, positrons do not

Fraction at the Earth

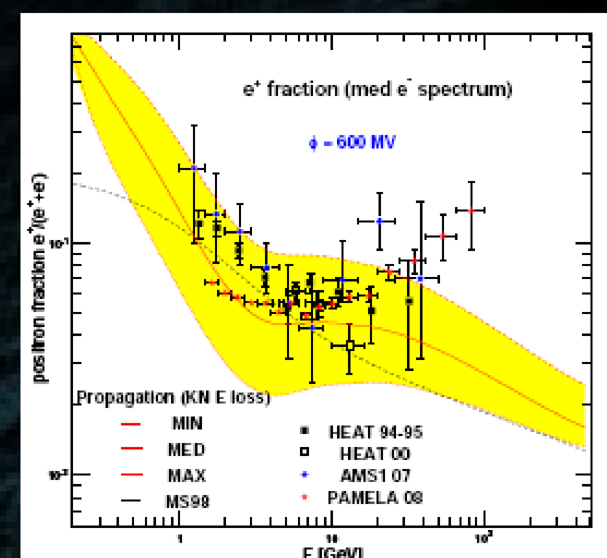


Positrons

Moskalenko & Strong 98

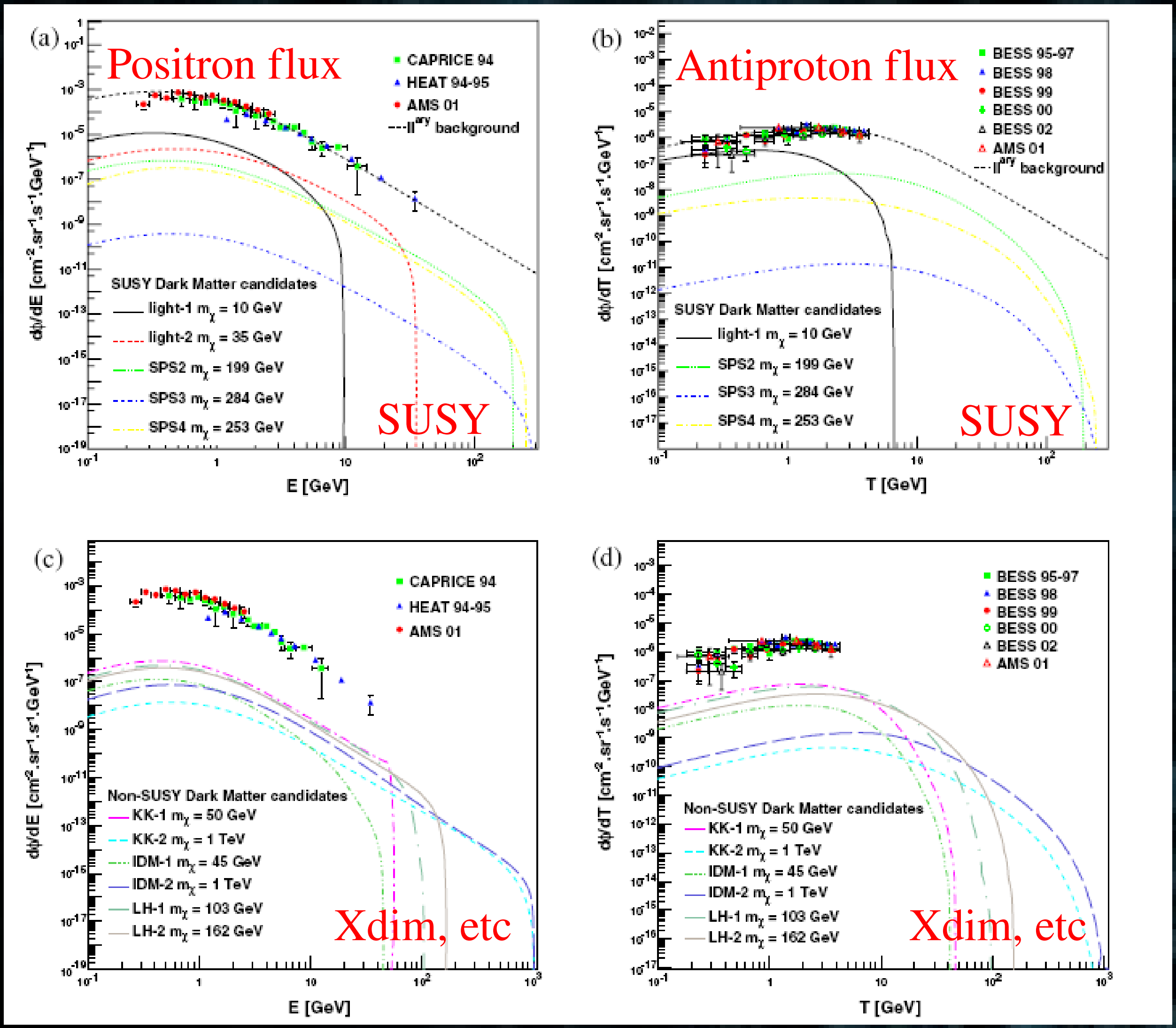
Delahaye et al 09

Lavalle 10



Dark Matter annihilation: generic predictions for positrons

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



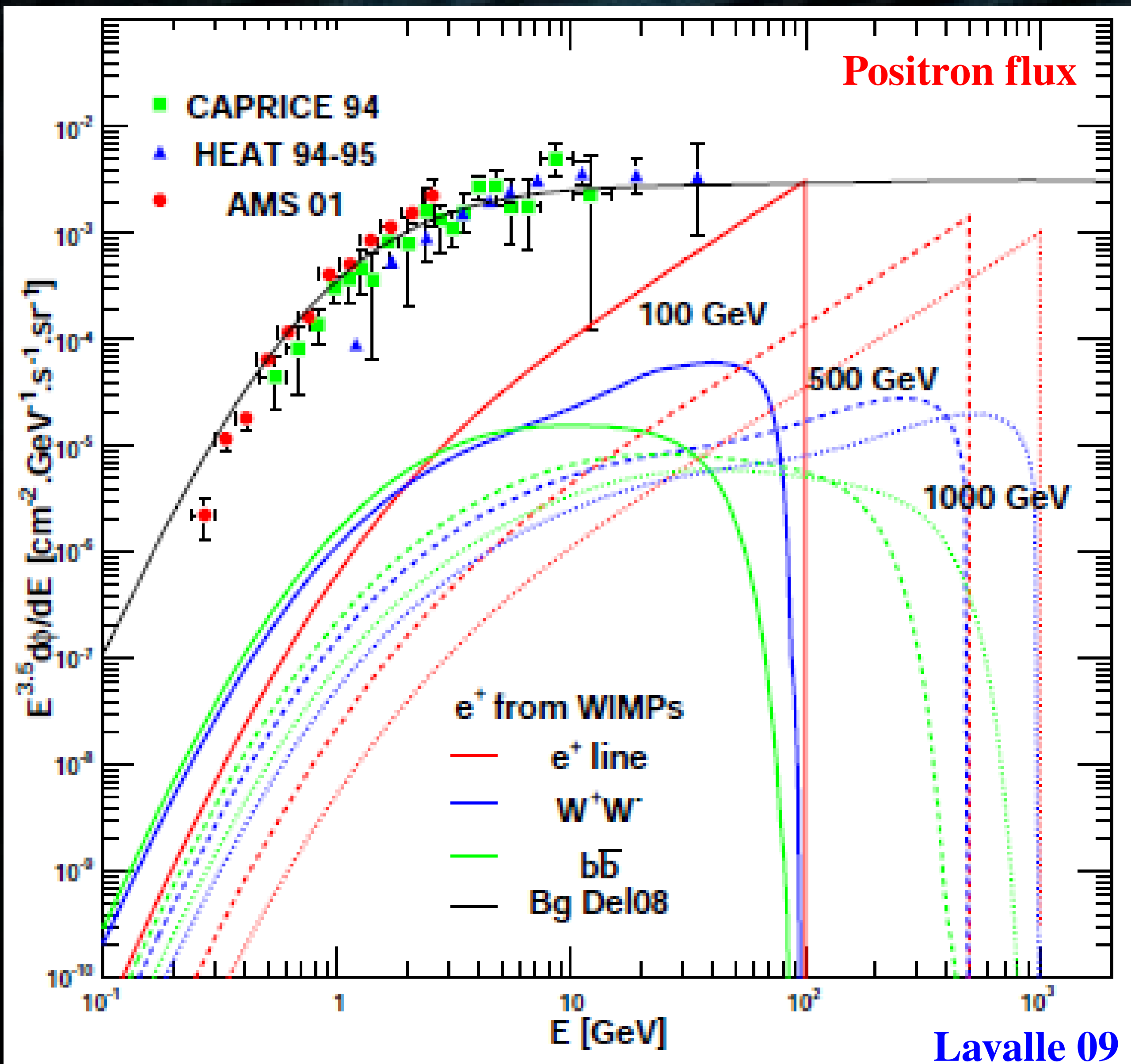
Susy candidates:
positron (left) – antiproton (right)

(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



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

WIMP mass / final state	100 GeV	500 GeV	1 TeV
e^+e^-	10	100	350
W^+W^-	80	500	1000
$b\bar{b}$	250	500	1000

The signal must be boosted:

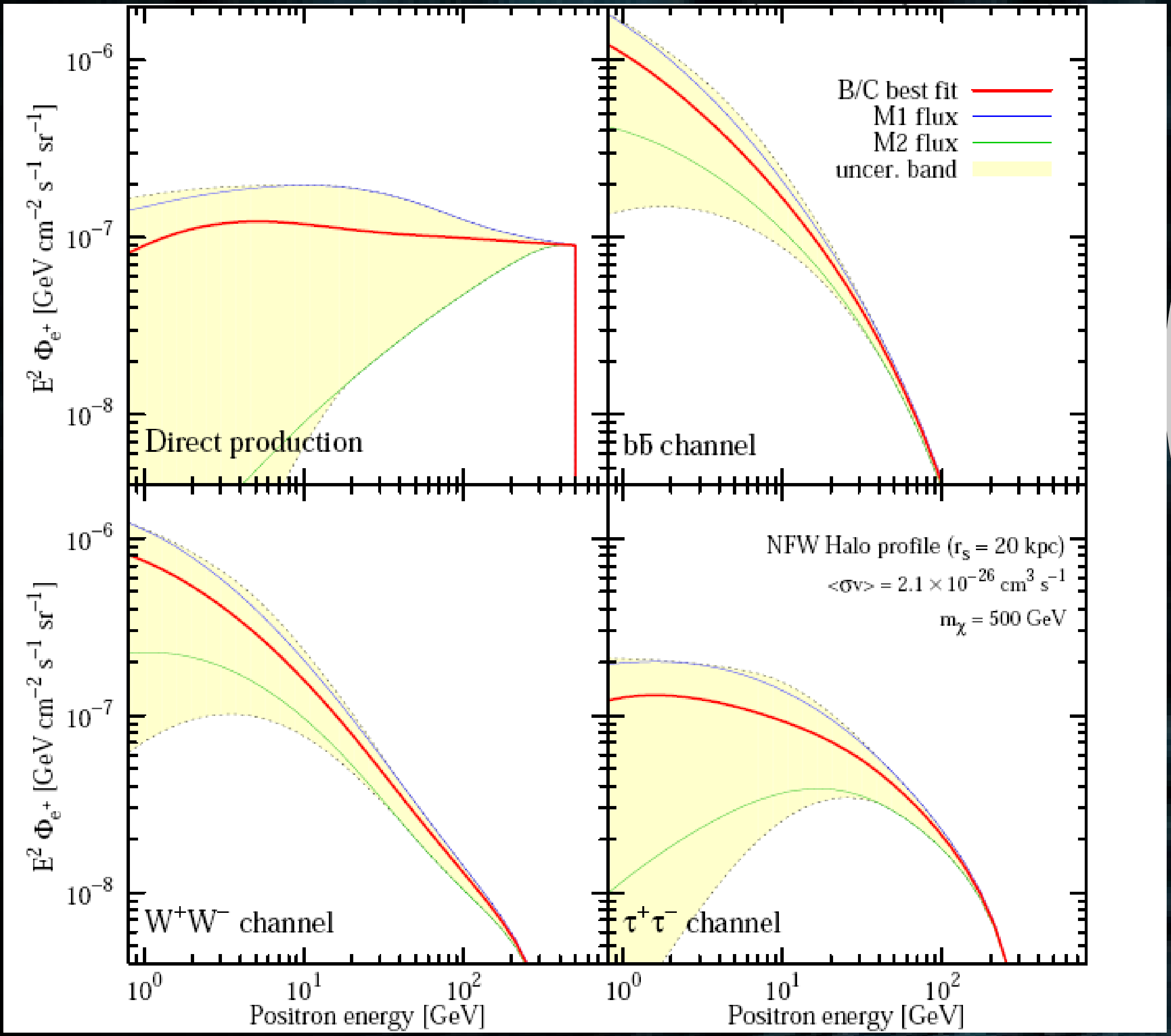
(i) boost the cross section
→ contrived scenarios (¾ of published papers) ~ excluded by antiprotons
(see e.g. Cirelli et al 08, Donato et al 09)

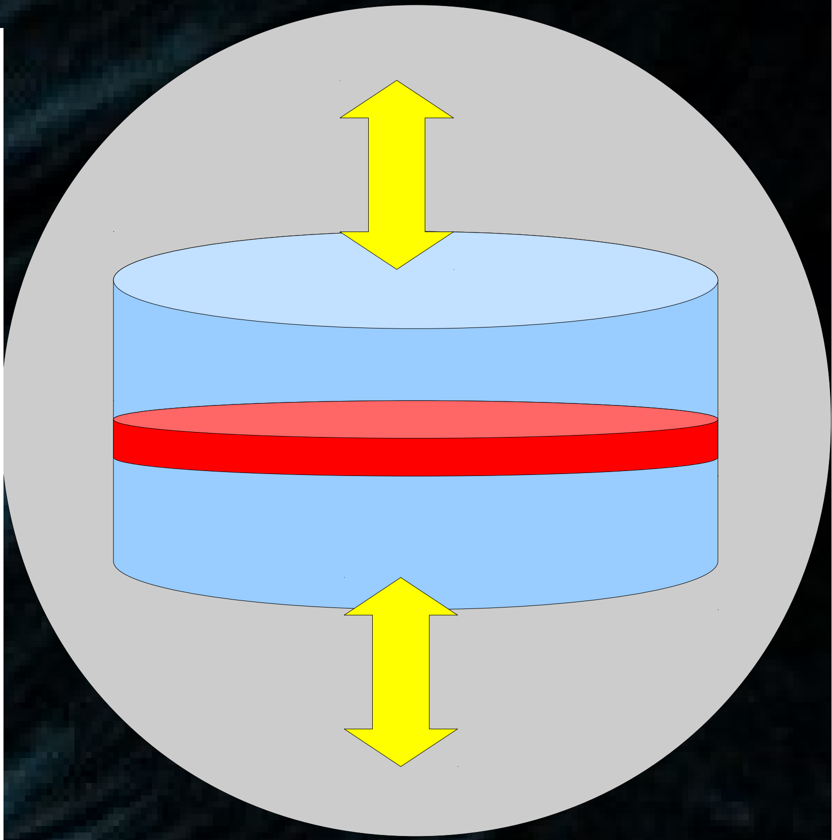
(ii) play with the propagation parameters

(iii) consider extra-sources (subhalos, IMBHs)

Boost: Play with propagation

Delahaye et al (2008)

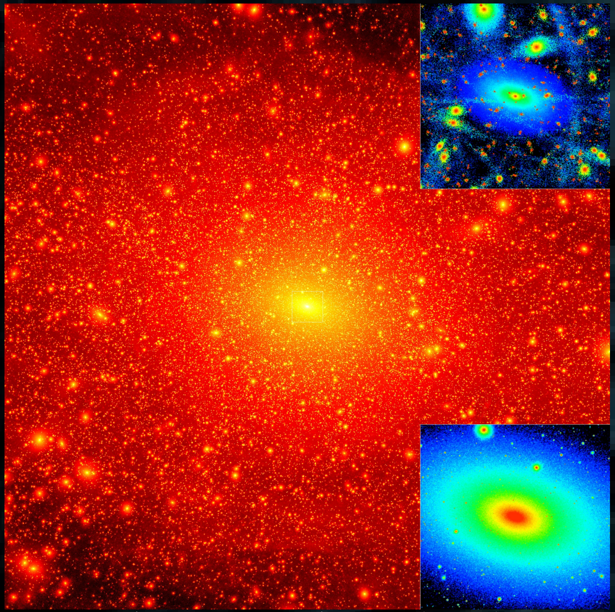




Increasing L implies more DM in the diffusion zone.

Very large effect on antiproton, but not on positrons since energy losses dominate at high energy (short range).

Dark matter inhomogeneities wandering around ?



Via Lactea (Diemand et al)

CLUMPY COLD DARK MATTER

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Received 1992 March 25; accepted 1992 December 16

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.

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

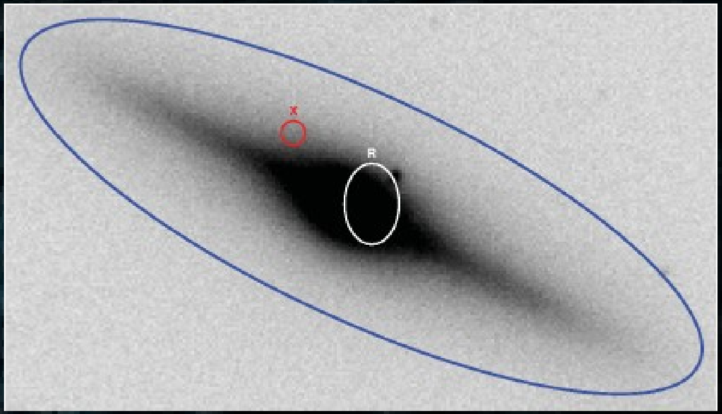
Vol 460 | 2 July 2009 | **doi:10.1038/nature08083**

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

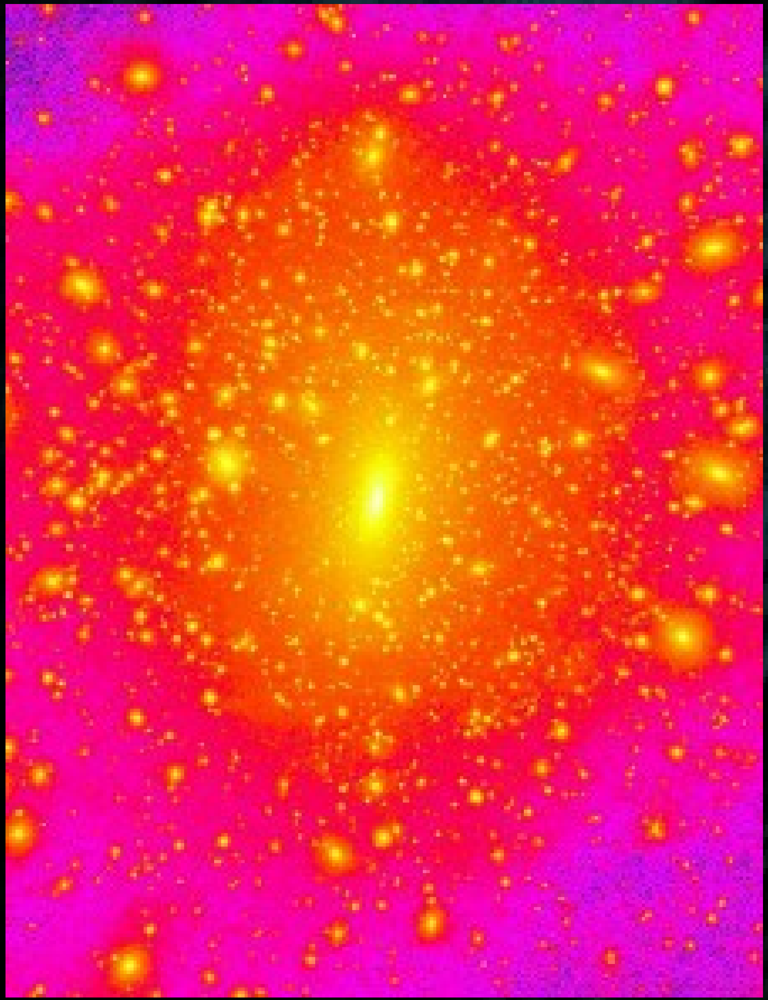
Sean A. Farrell[1,2]†, Natalie A. Webb[1,2], Didier Barret[1,2], Olivier Godet[3] & Joana M. Rodrigues[1,2]

Two main cases:

- Collective effect.
- A very bright single objects
- (excluded from gamma-ray data,
- Bringmann, Lavalle & Salati 09)



Collective effect: clumpiness boost factor



Diemand et al 04

- Clumps are predicted by the current theory of structure formation (Peebles and others)
- They are observed in N-body simulations at all resolved scales, as predicted.
- The minimal mass scale is set by the WIMP properties (free streaming) ~ Earth mass.
- Smallest objects collapse first: they are more DM concentrated !

$$< n_{\rm dm}^2 > \geq < n_{\rm dm} >^2 \quad \Rightarrow \quad B_{\rm ann} \sim \frac{< n_{\rm dm}^2 >}{< n_{\rm dm} >^2}$$

Clumps are numerous: statistical properties

The flux from an object is a stochastic variable

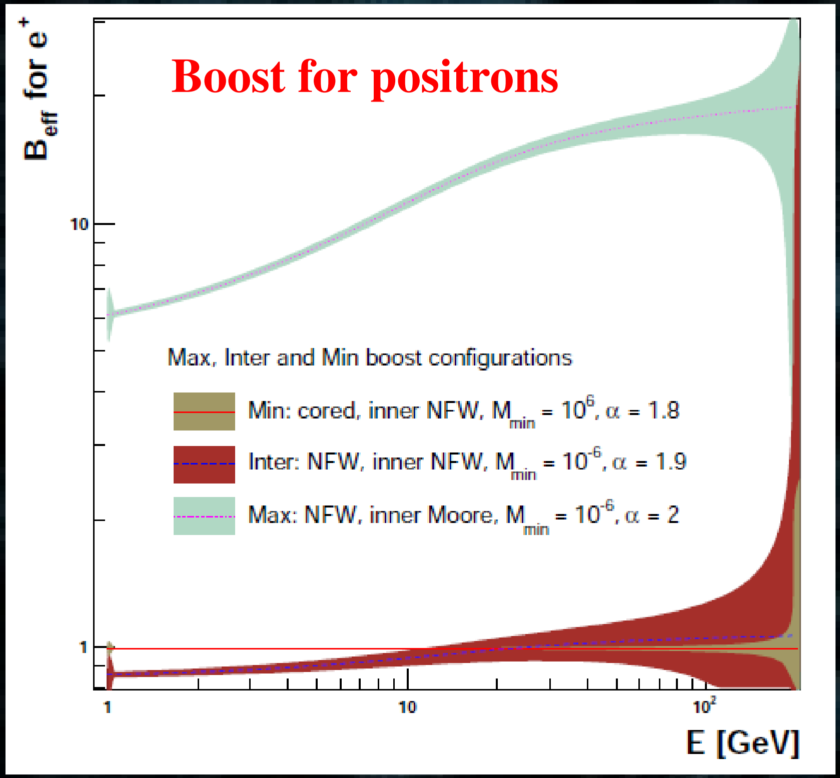
$$\phi_i(E, \vec{x}_\odot) = S \times \xi_i \times \tilde{\mathcal{G}}_i(E, \vec{x}_\odot \leftarrow \vec{x}_i, E_S)$$

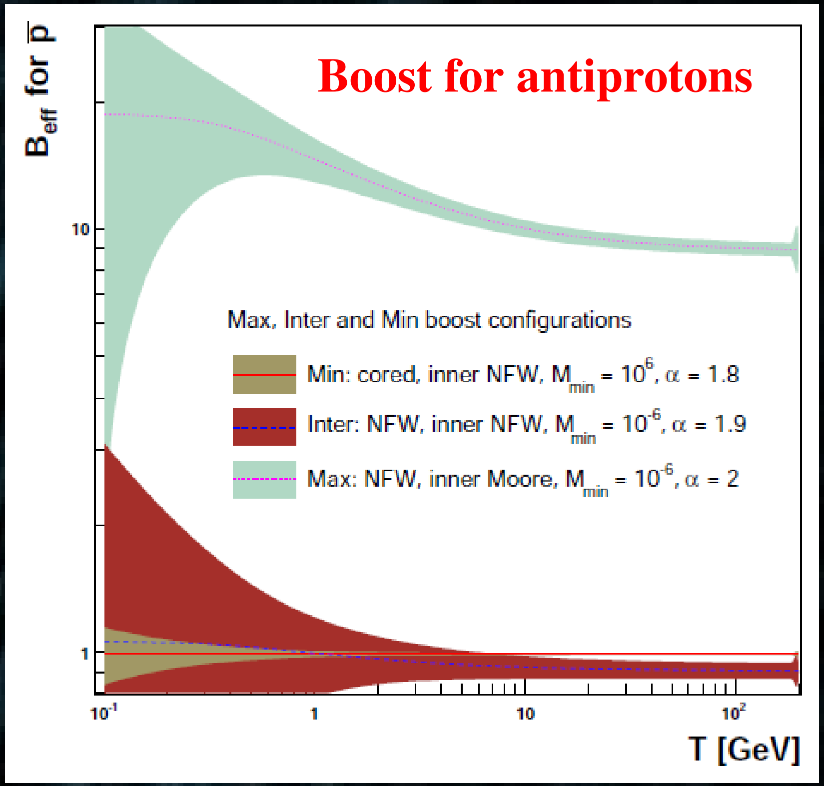
$$\updownarrow$$

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

Clumpiness boost: Span over extreme cosmological configurations

Lavalle et al (2007)



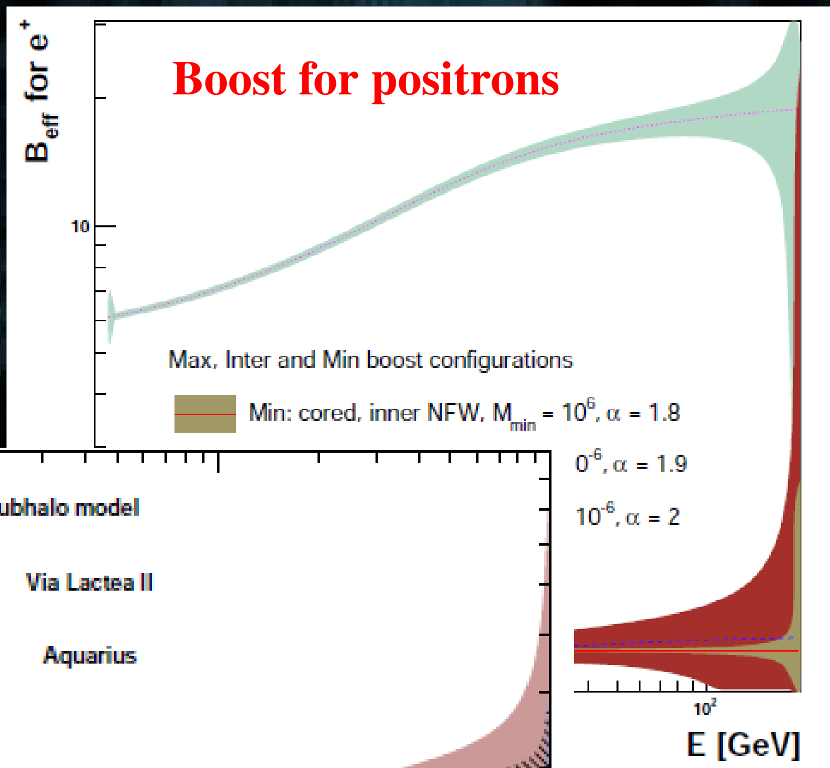


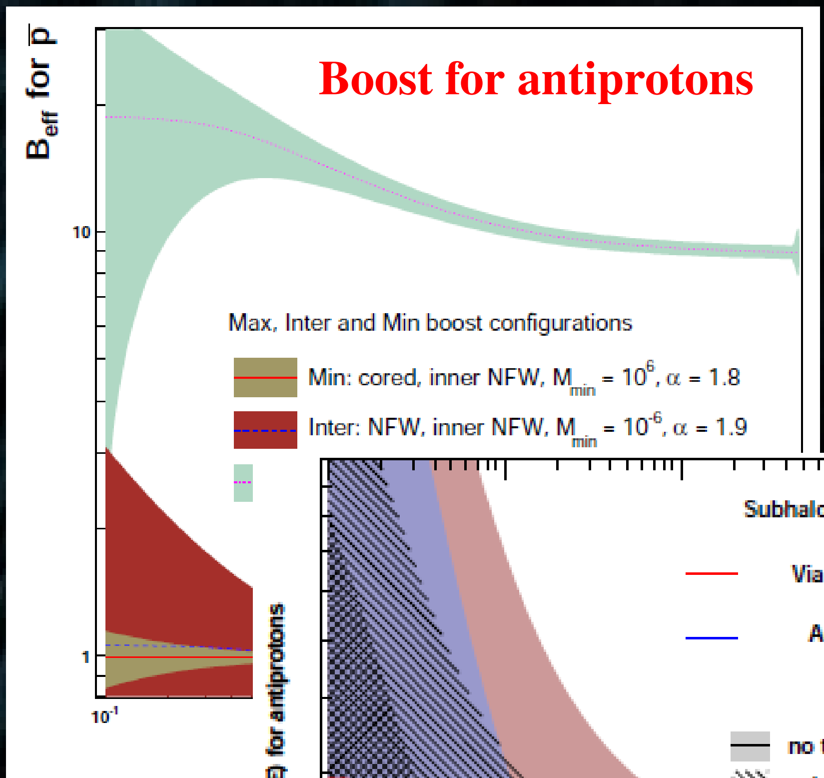
The average boost cannot be too large

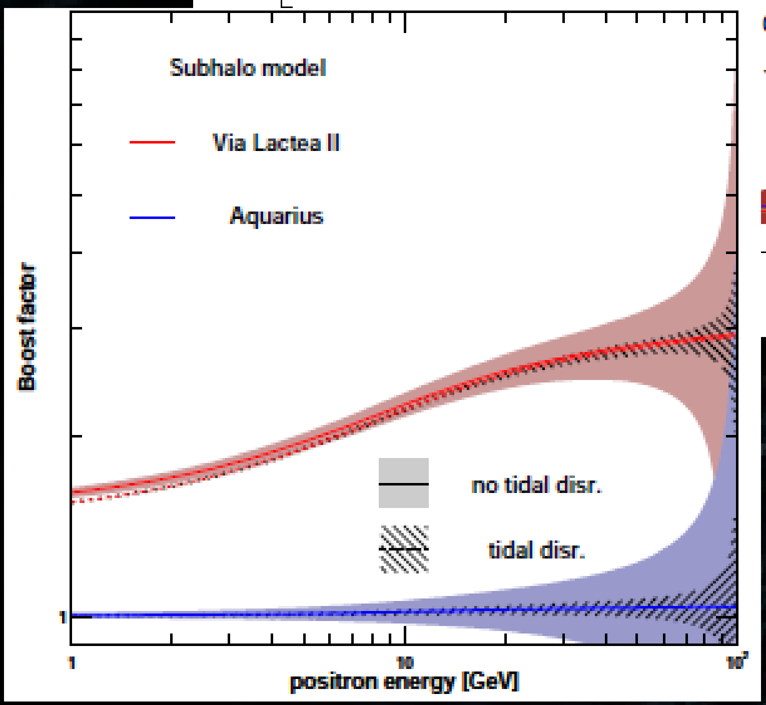
B < 20

Clumpiness boost:
Span over extreme cosmological configurations

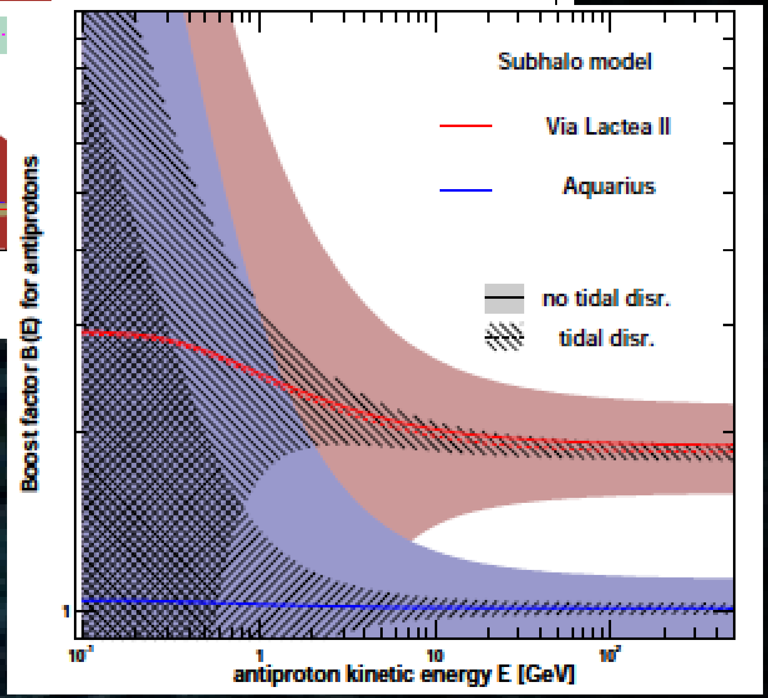
Lavalle et al (2007)





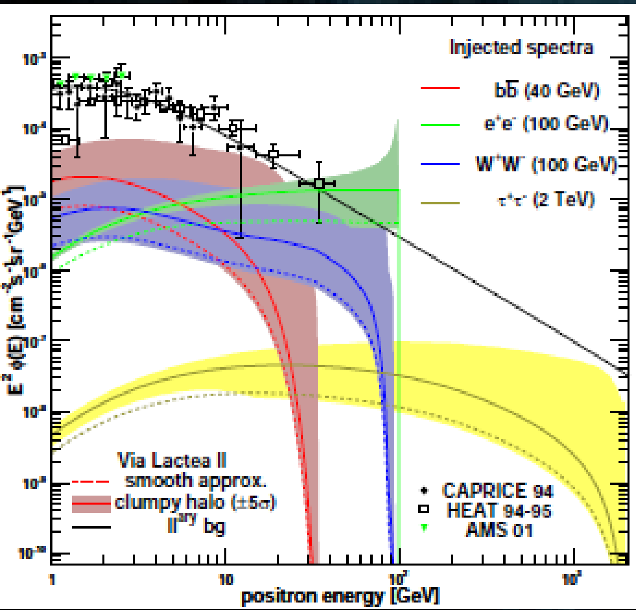


VLII and Aquarius setups
Pieri et al (2009)

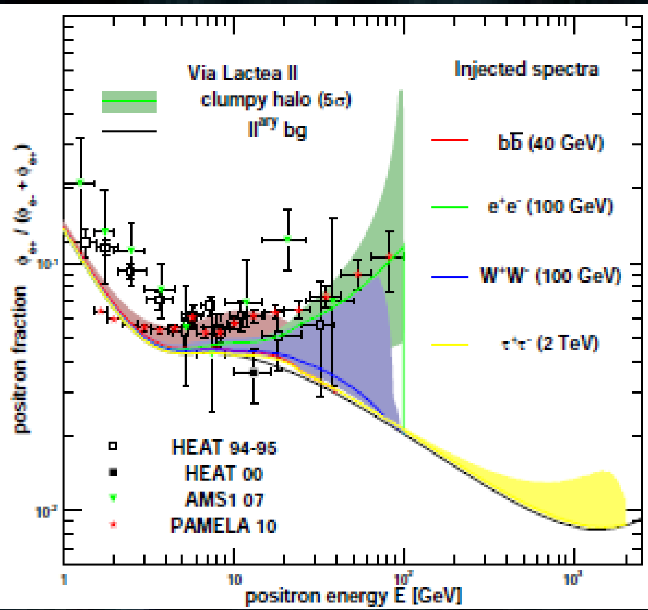


Clumpiness summary: Predictions with VL2 configuration

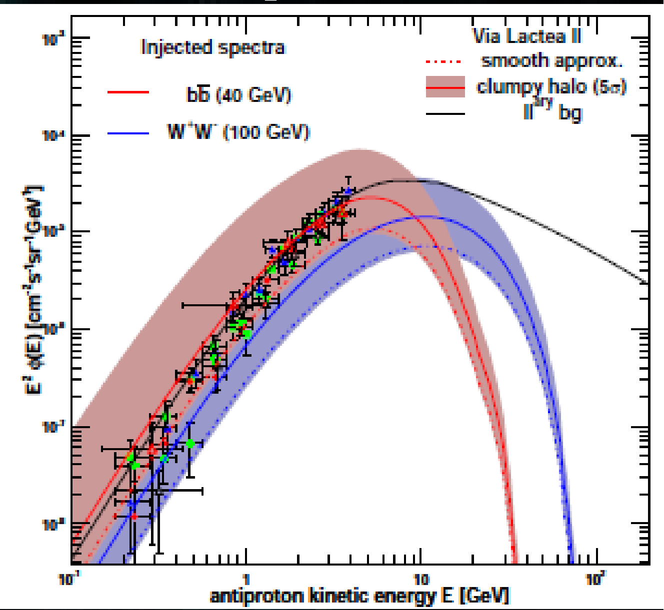
Positron flux



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) --

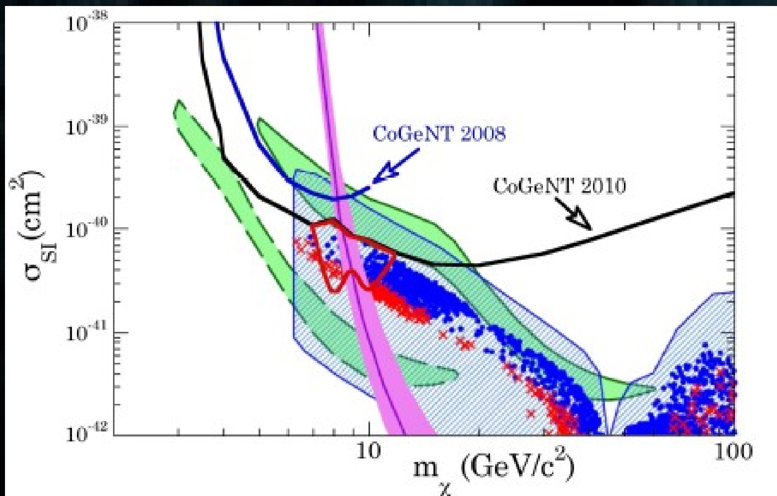
$\langle \sigma v \rangle = 3\,10^{-26}\ \mathrm{cm}^3/\mathrm{s}$

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

Important features:

- 40 GeV WIMP (b-bbar) 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.

(Parenthesis: antiprotons versus small WIMP masses)

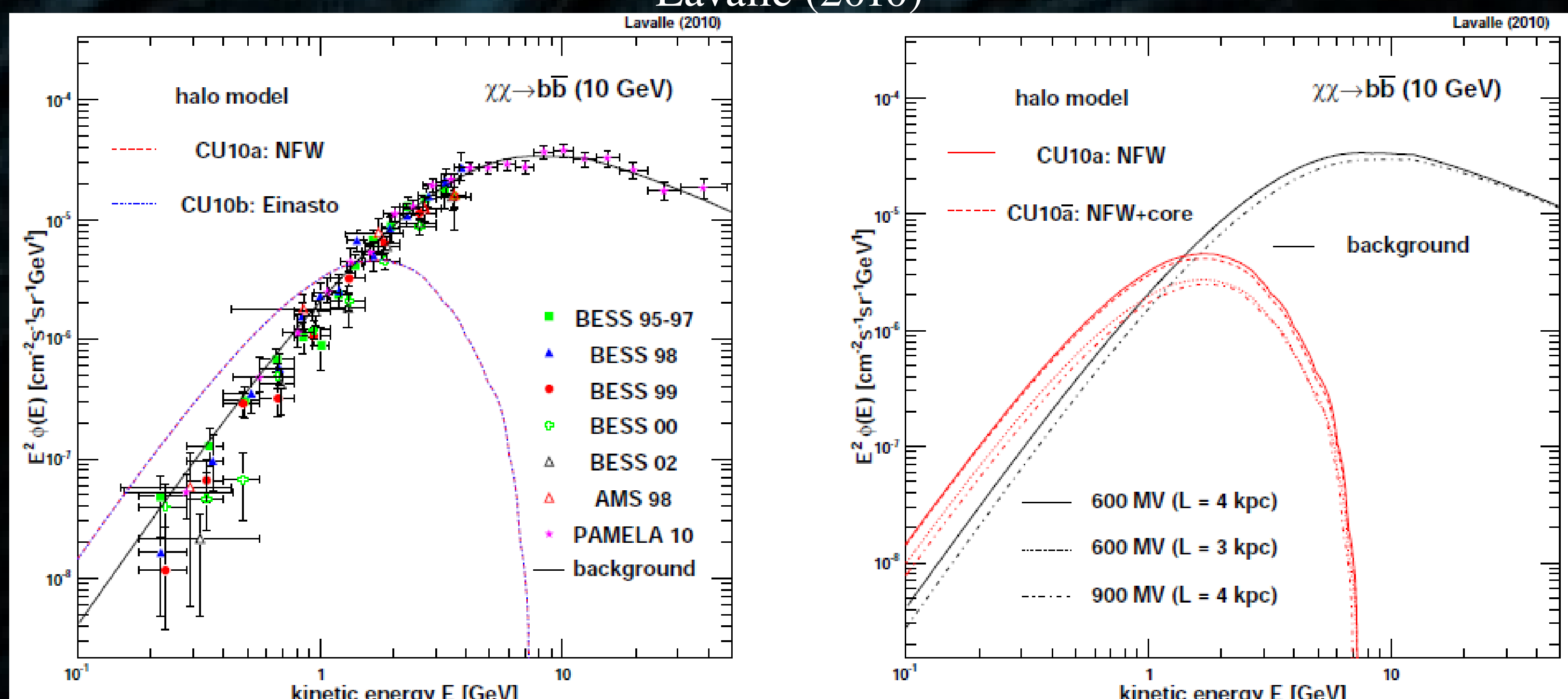


DAMA+CDMS+COGENT mass regions
=> WIMP mass ~10 GeV

If WIMPs couple to quarks, annihilation can produce antiprotons if $m_{wimp} > m_p$

Large antiproton flux expected (it scales like 1/m2)
New constraints on propagation (Putze et al 10) => excess wrt data

Lavalle (2010)



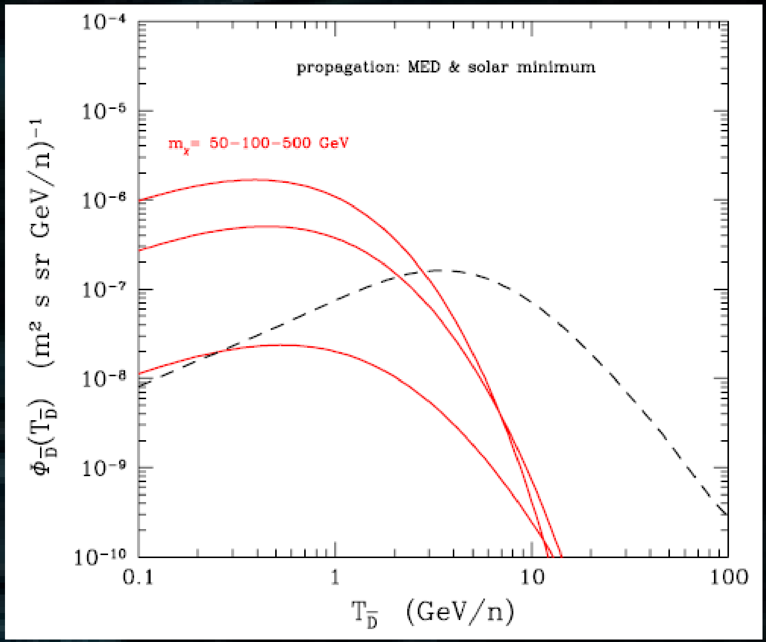
An optimistic view about non-discovery (yet): WIMP candidates are not excluded !

Status of WIMP searches:

- WIMPs are fairly well motivated from particle physics beyond the Standard Model.
- From generic predictions, they are not expected to show up in current data.
- Interesting constraints from antiprotons: complementarity required! (multiwavelength, multimessenger)
- Most promising sources in the future: dwarf spheroidal galaxies and subhalos (gamma-rays).
- Cosmic-ray antideuterons below 1 GeV ? (Salati et al, 00)

Astrophysical issues:

- Backgrounds ! (to come ...)
- The impact of baryons on dark matter distribution:
  - Adiabatic contraction in galaxy centers ? Or cores ? (see Governato et al 10)
  - Local dark matter density and velocity distribution ? (Catena & Ullio 10, Salucci et al 10)
  - Subhalo survival ? Power in small scales vs reionization ? (Klypin et al 10)

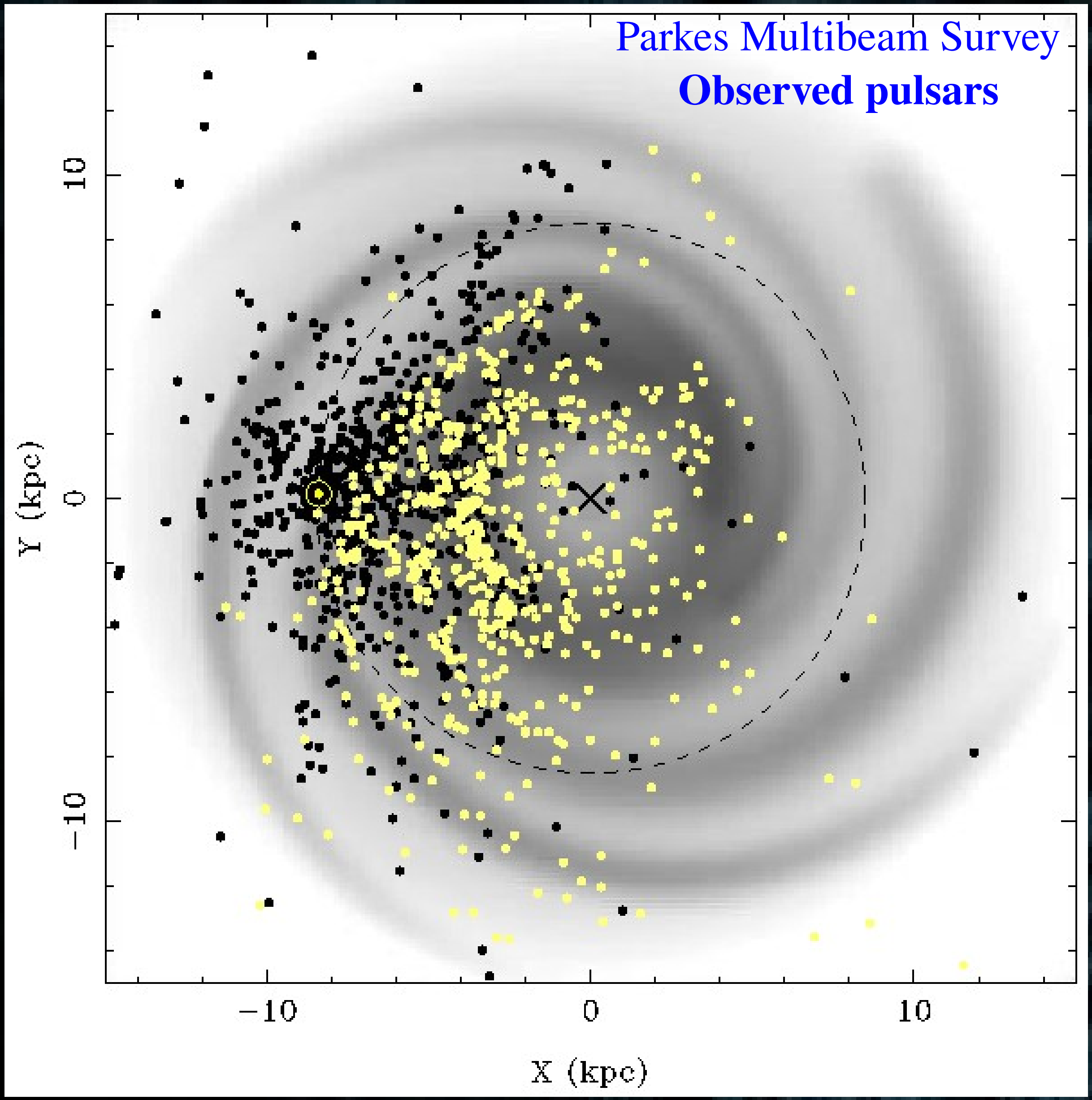


Donato, Fornengo & Salati 00
Donato, Fornengo & Maurin 08

PAMELA: what else if not Dark Matter ?

(the nose on one's face)

Galactic sources of cosmic rays: supernova outcomes



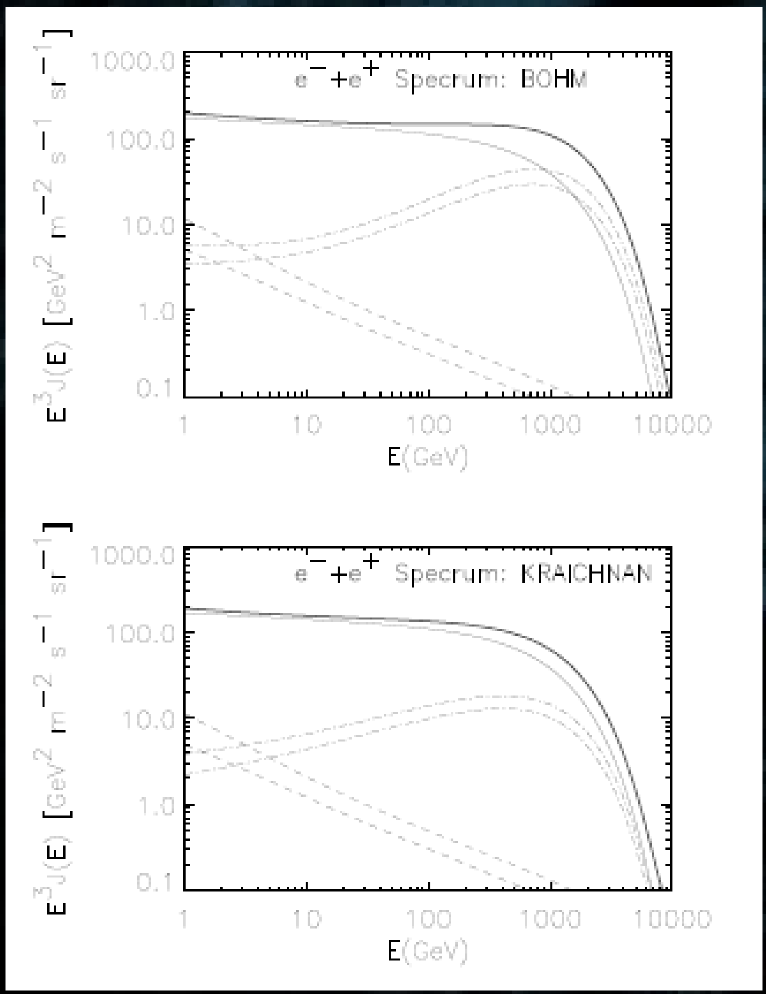
- CRs accelerated by SNR and pulsar shocks (observation + theory)
- SN explosion rate ~ 1/century
- ~1900 pulsars and ~280 SNRs observed (ATNF and Green catalogs)

Sources of positrons ?

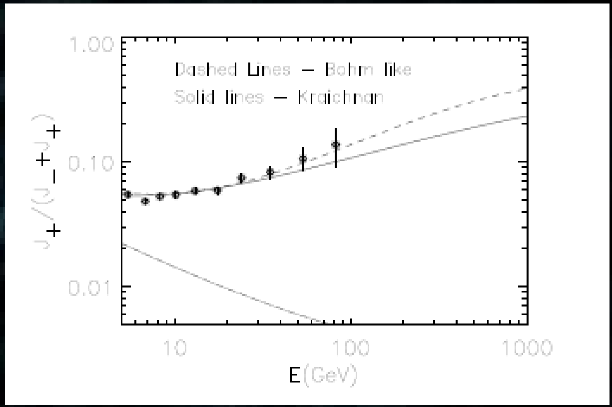
"Primary" secondaries ?

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

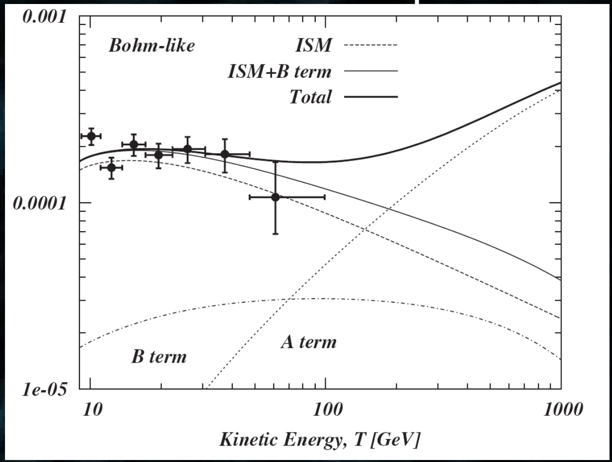
Secondaries created in SNRs are accelerated like primaries



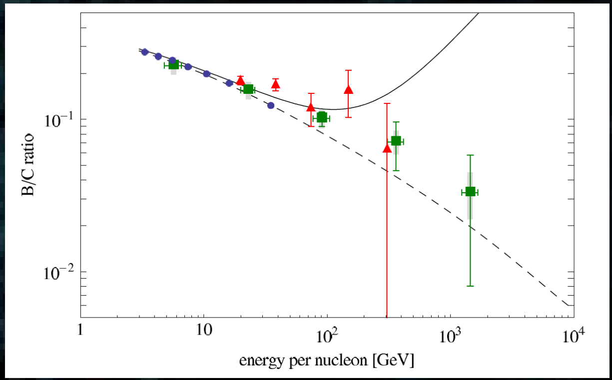
Positron fraction



Antiproton fraction



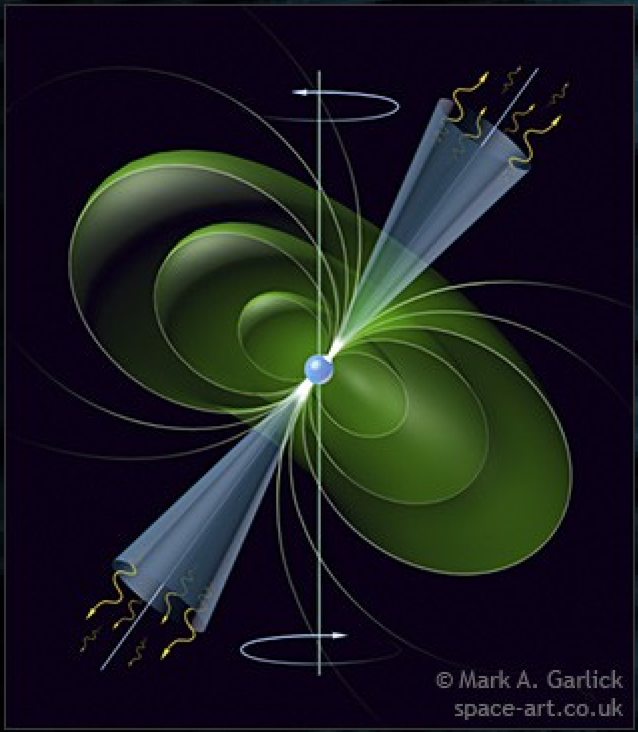
B/C measurements

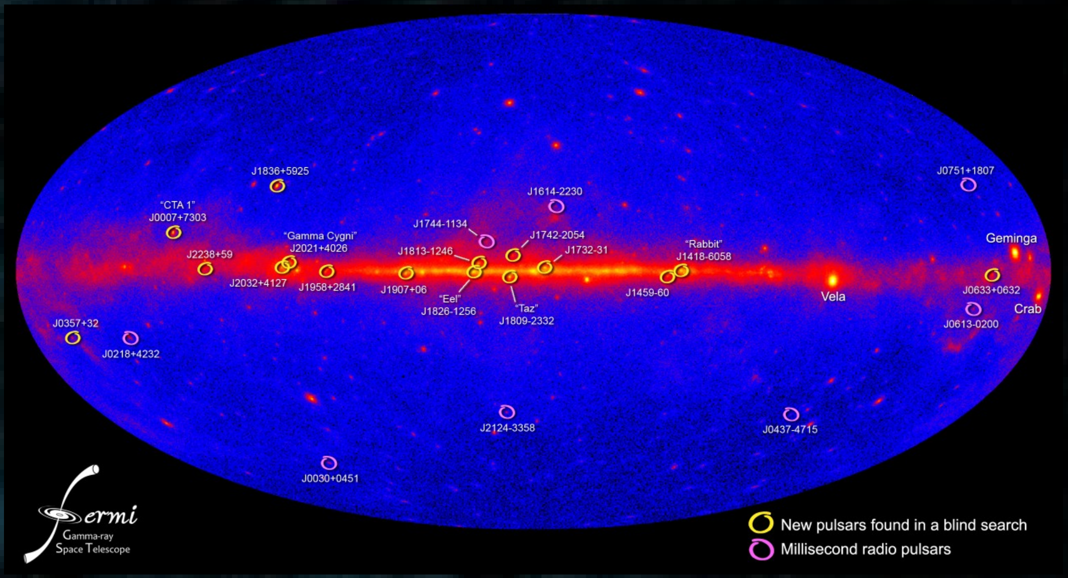


Specific signatures:

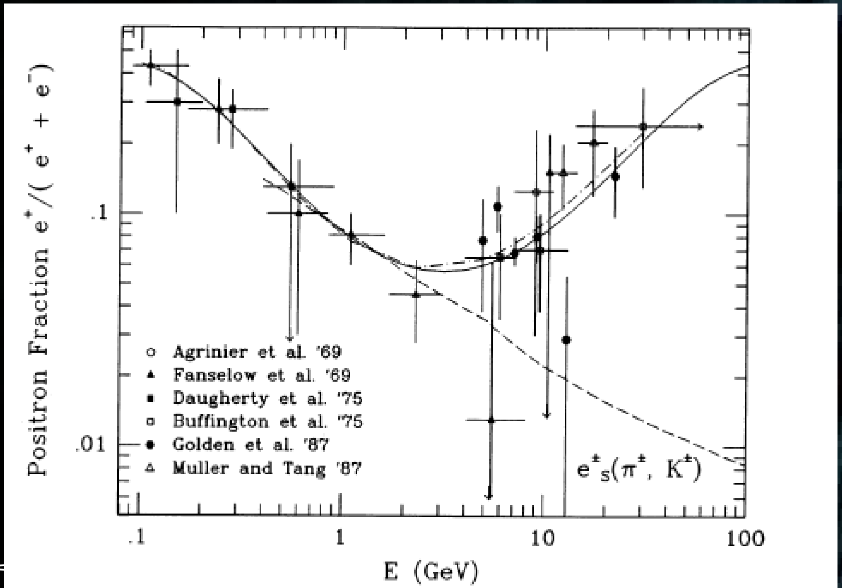
rising antiproton fraction (like DM) and B/C ratio

"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



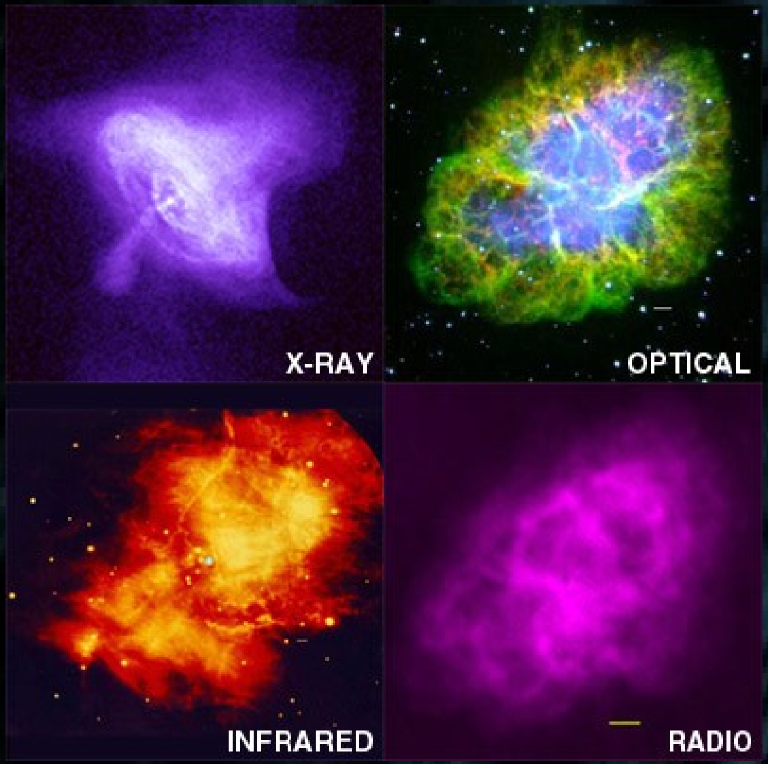
THE ASTROPHYSICAL JOURNAL, 342:807–813, 1989 July 15

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).

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

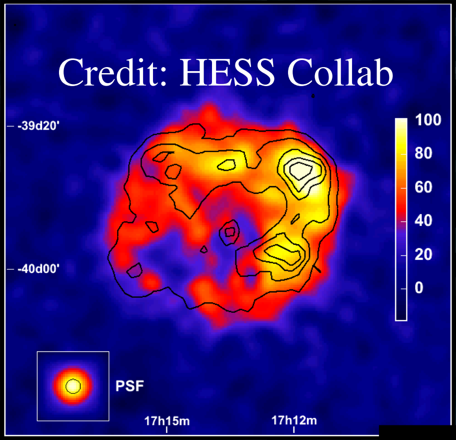
Low energy electrons (< 20 GeV):

- 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

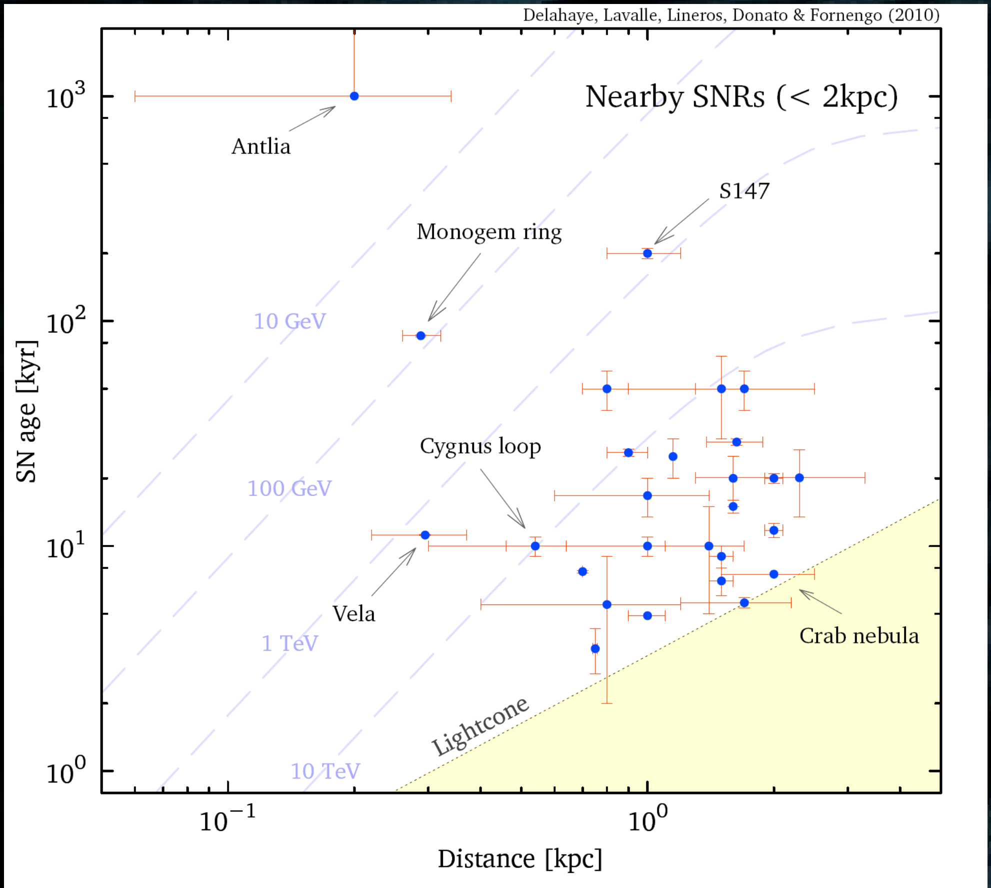
- Modeling of local sources (many degeneracies)
- More general: release of CRs in the ISM

Standard paradigm, but not standard model!

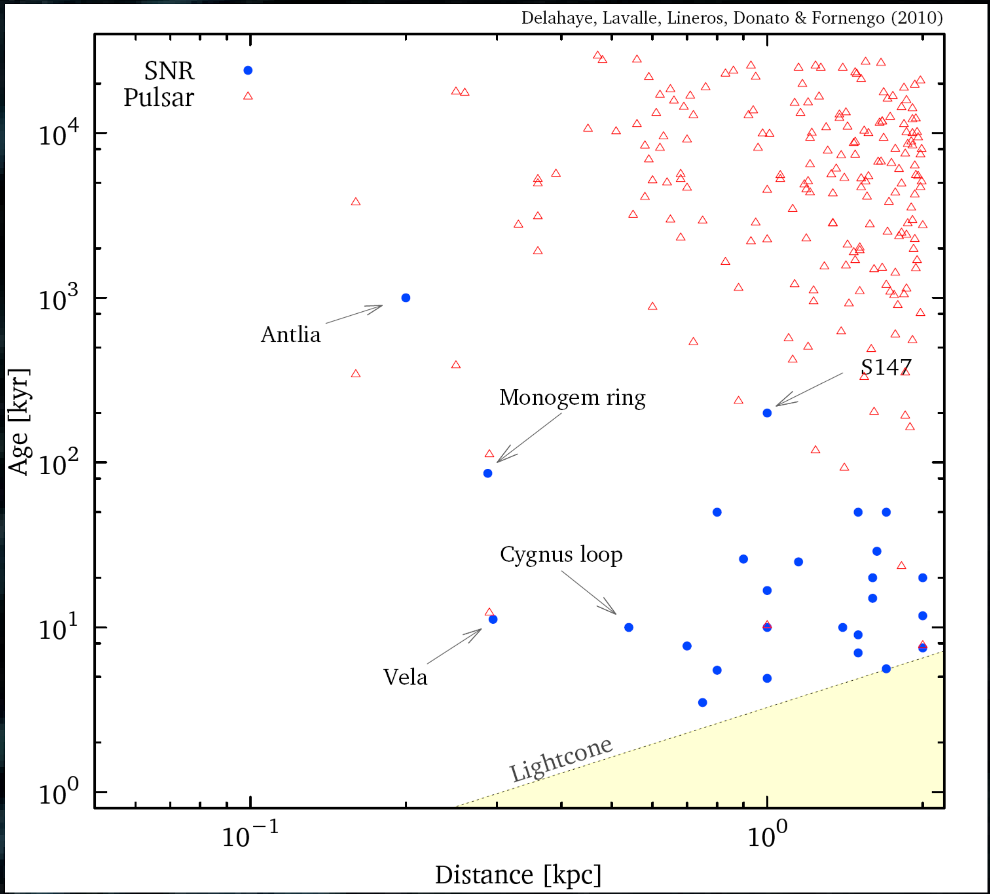
Deal with the complexity of Nature: Include all known local sources self-consistently

Delahaye et al 10
arXiv:1002.1910

27 obs SNRs within 2 kpc



~200 obs pulsars within 2 kpc



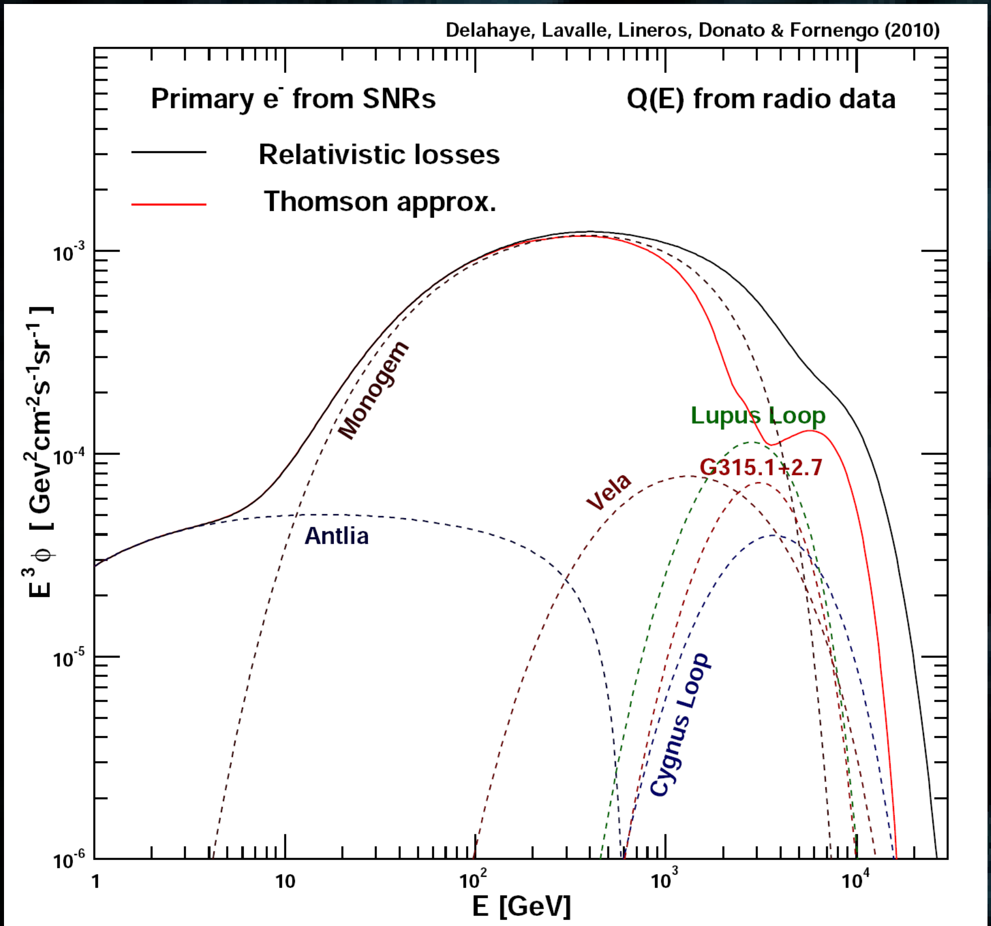
SNRs contribute to e^-, pulsars inject e^+e^- pairs ...

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

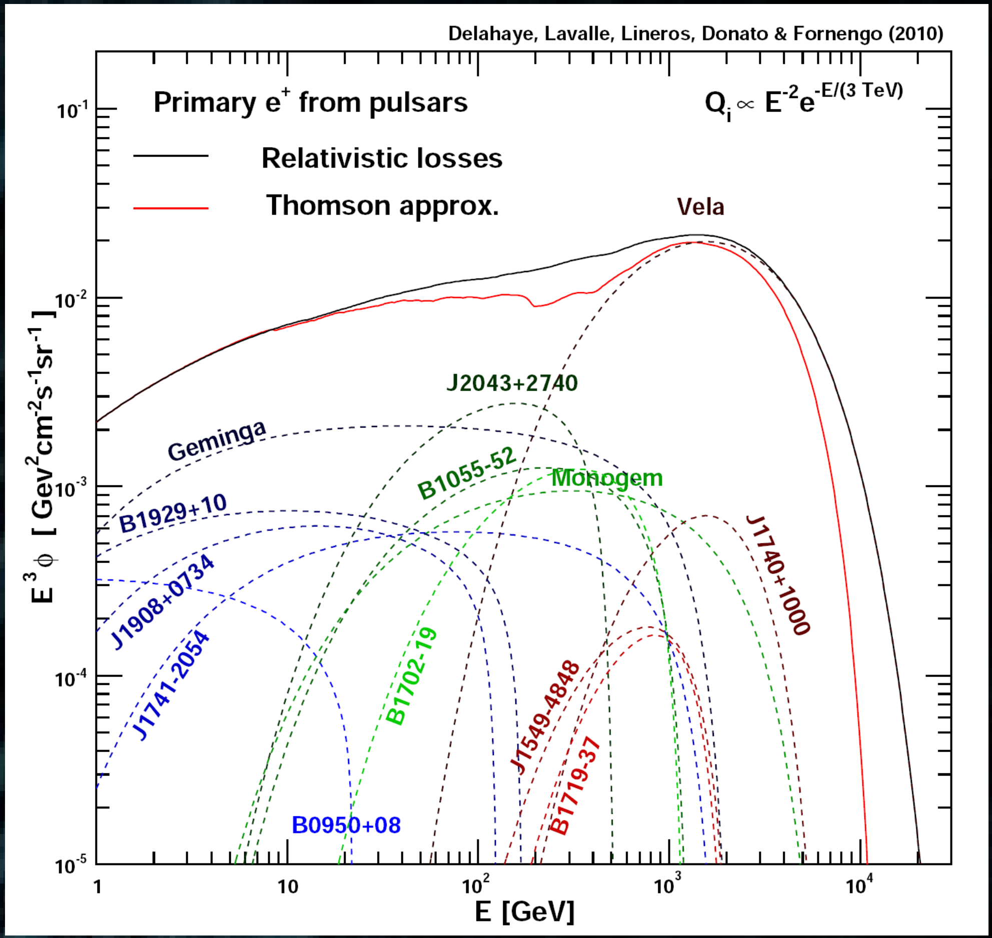
Deal with the complexity of Nature: Include all known local sources self-consistently

Delahaye et al 10
arXiv:1002.1910

27 obs SNRs within 2 kpc



~200 obs pulsars within 2 kpc



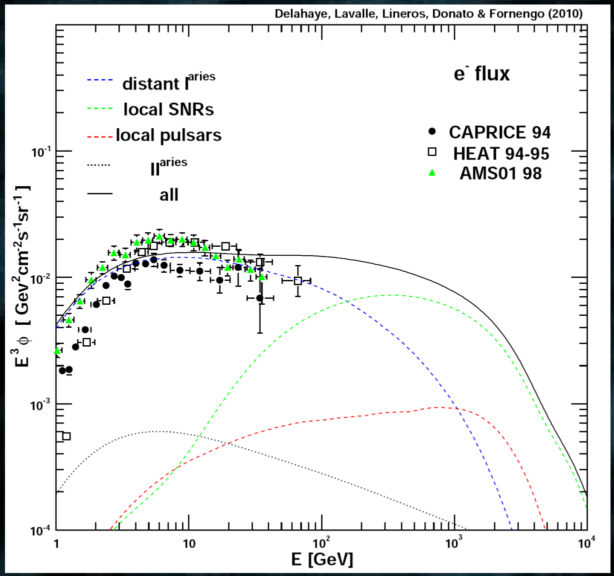
SNRs contribute to e⁻, pulsars inject e⁺e⁻ pairs ...

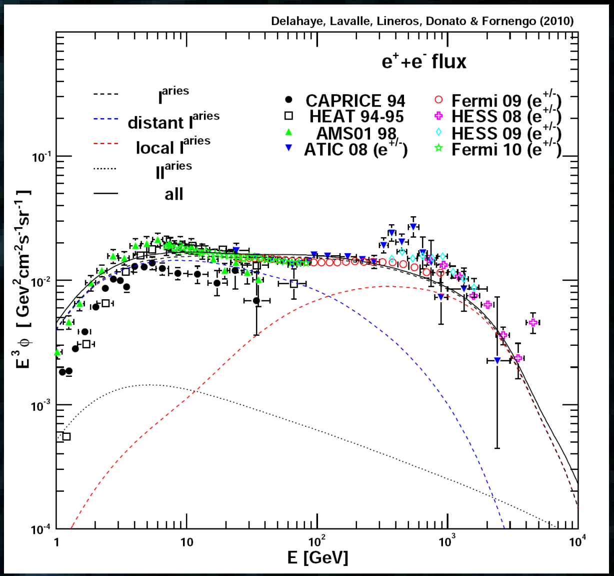
... but each pulsar should be associated with a SNR => Add missing SNRs !

<footer>

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

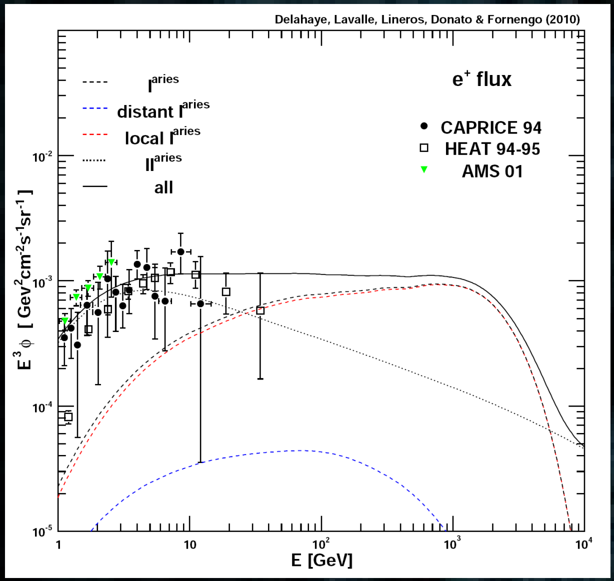
electrons

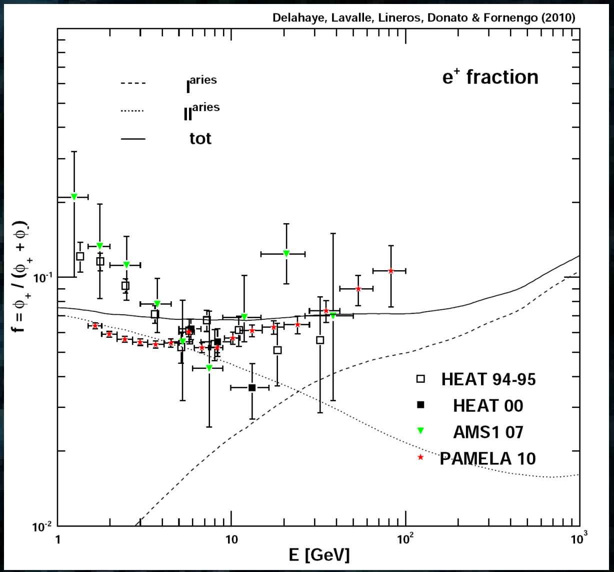




electrons + positrons

positrons





positron fraction

Delahaye et al 10 (arXiv:1002.1910 a

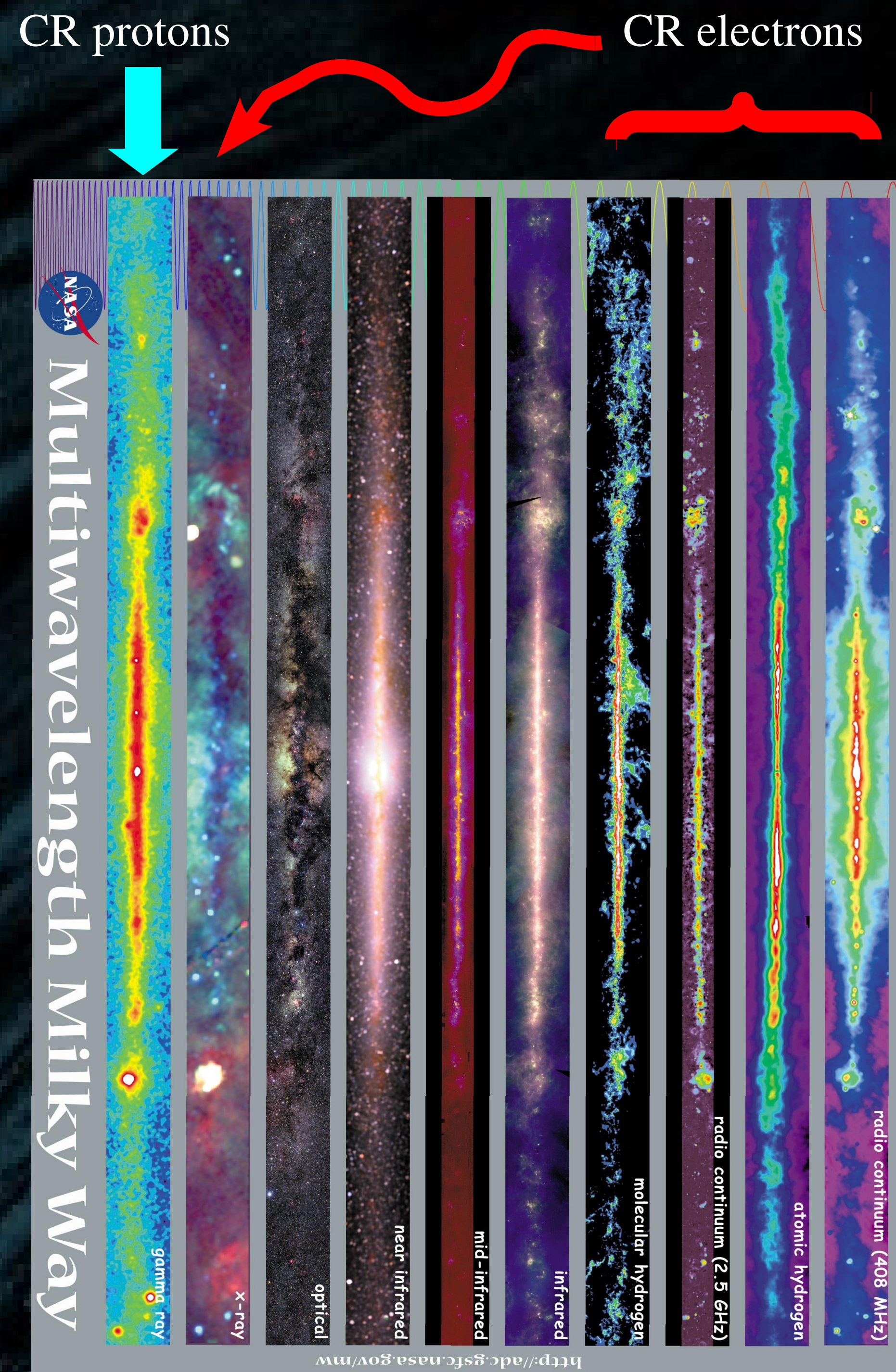
Standard astrophysical sources make it!

Perspectives

One can hardly talk about a *standard model of cosmic rays* at the moment, but more fairly about a *standard paradigm*.

Still, spatial distribution of Galactic CR electrons is important to probe: diffuse synchrotron emission (Planck), diffuse gamma-ray emission (Fermi).

Many scientific by-products: Dark matter, Galactic center, Galactic magnetic field, CR propagation, extrapolation to larger scales (clusters), etc.



Conclusions

Indirect searches for Dark matter:

• Not as easy as expected: require multimessenger, multilambda, multiscale studies (but background issues)

• Complementarity with other detection methods required. LHC results!

• Gamma-rays: (Fermi, HESS, CTA) Dsphs & GC are priority targets (at the edge of relevant experimental sensitivity)

• Cosmic rays (general): unlikely in local antimatter data. Need higher energy + antideuteron observations (AMS, GAPS).

• Astrophysical constraints powerful, but "proofs" important to solve the DM issue.

Cosmic ray physics: (promising for new physics studies, but improvements required)

• Propagation models to improve: numerical + analytical approaches necessary

• A consistent high-energy picture of the Galaxy emerges through multiwavelength predictions/observations: all ingredients connected, very rich (and complicated) physics.

Perspectives: The current-future experimental landscape

• LHC, direct detection, neutrino experiments

• Gamma rays: Fermi, many IACTs, CTA coming (2015-2020)

• Lower frequencies: Planck + Herschel + X-ray

• Cosmic rays : PAMELA, AMS2 (2011), GAPS (2011)

• Neutrinos: SuperK, Antares, Icecube

2010-2020: the WIMP hypothesis likely confirmed or excluded

Backup slides

Propagation of Galactic electrons
2. Phenomenology of transport (GeV-TeV)

$$\hat{D}\mathcal{J} = \mathcal{Q}$$

$$D_\mu \mathcal{J}^\mu + D_E \mathcal{J}^E = \mathcal{Q}$$

Current conservation
(continuity equation)

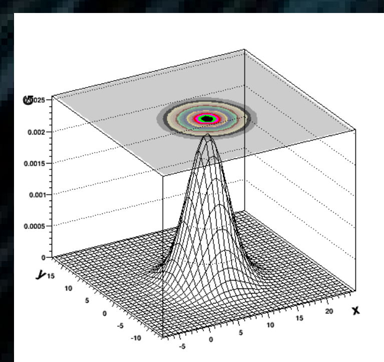
$$\partial_t \mathcal{N} = \mathcal{Q}(\vec{x}, E, t) + \vec{\nabla}\left\{\left(K_x(E)\vec{\nabla} + \vec{V}_c\right)\mathcal{N}\right\} + \partial_E\left\{\left(\frac{dE}{dt} + K_E(E)\partial_E\right)\mathcal{N}\right\}$$

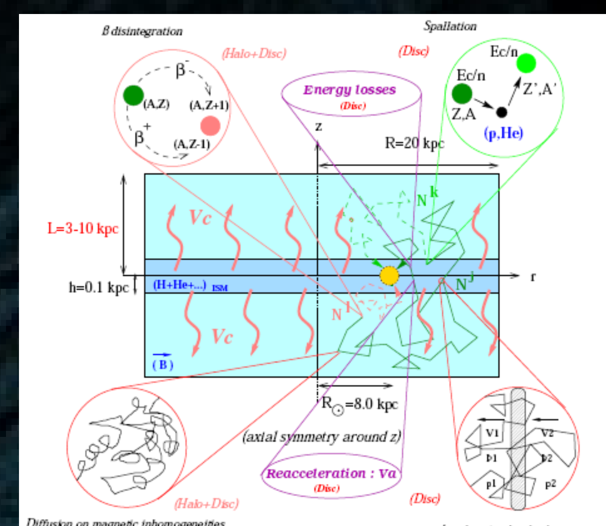
Spatial current (diffusion + convection)
Momentum current (losses + reacceleration)

See formalism for electrons in:
Ginzburg & Sirovatskii (1964)
Berezinskii et al (1990)
Lavalle et al (2007)

$$\mathcal{G}(\vec{x}, E \leftarrow \vec{x}_s, E_s) = \frac{1}{\pi^{\frac{3}{2}}\lambda^3\, b(E)} \exp\left\{-\frac{|\vec{x}_s - \vec{x}|^2}{\lambda^2}\right\}$$

$$\lambda^2 \equiv 4K_0\left(\tilde{t} - \tilde{t}_s\right) = 4\int_E^{E_s} dE' \,\frac{K(E')}{b(E')}$$



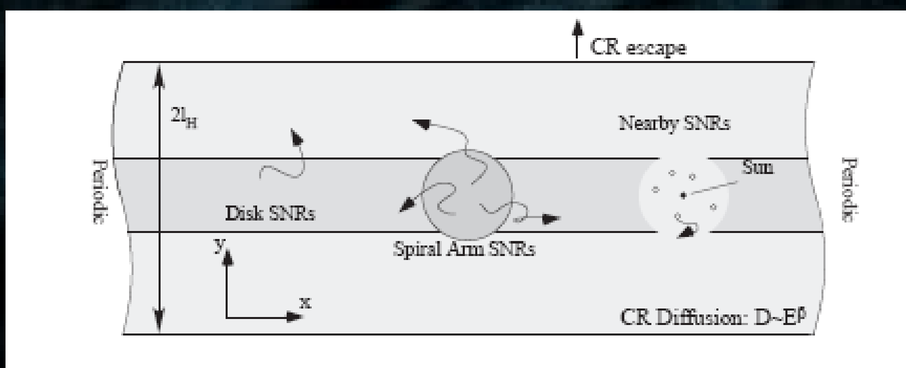


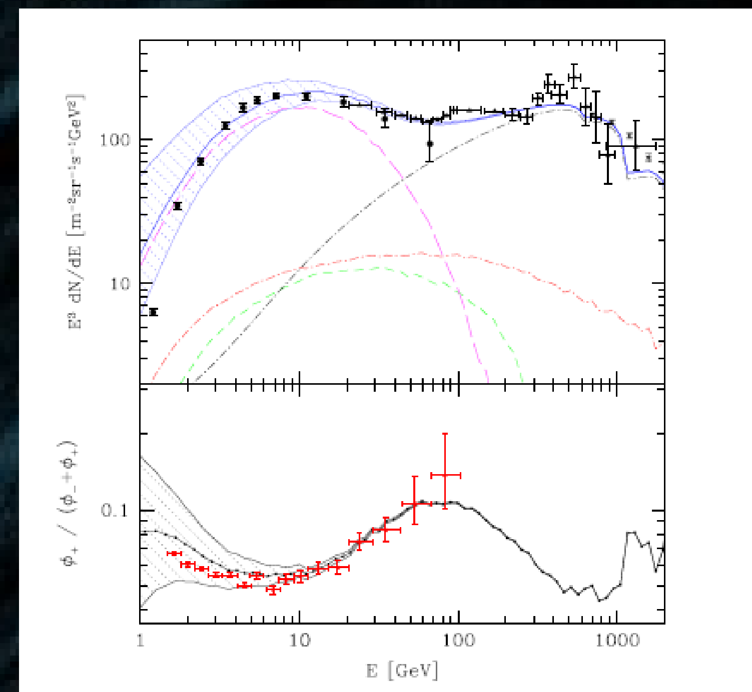
Maurin et al (2002)

Program:
- Constrain the different parameters (diffusion zone extent, diffusion coefficient, etc)
- Make predictions, compare with data

Spatial effects ?

Shaviv et al (2009)





3 populations of electrons:

- From sources in the nearest arm
- From the disk
- From nearby SNRs

+ secondary positrons ... this might make it.

Short recipe for secondaries

Proton and alpha fluxes

ISM gas distribution

The source term

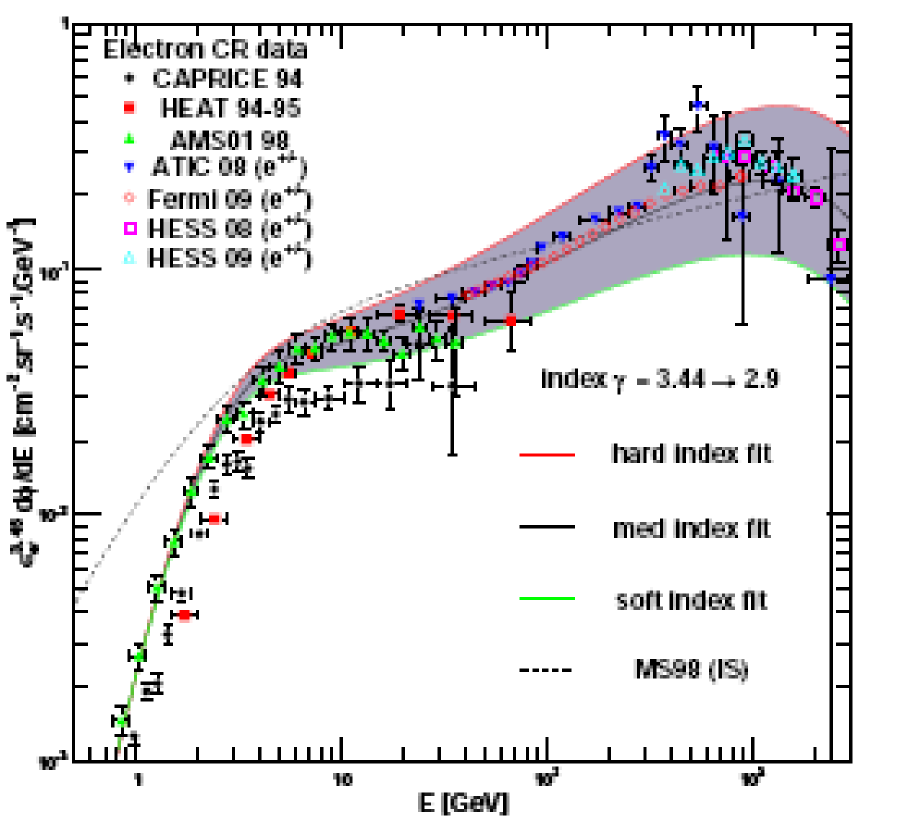
Inclusive nuclear cross section
$p+p \rightarrow e^{+} + X$

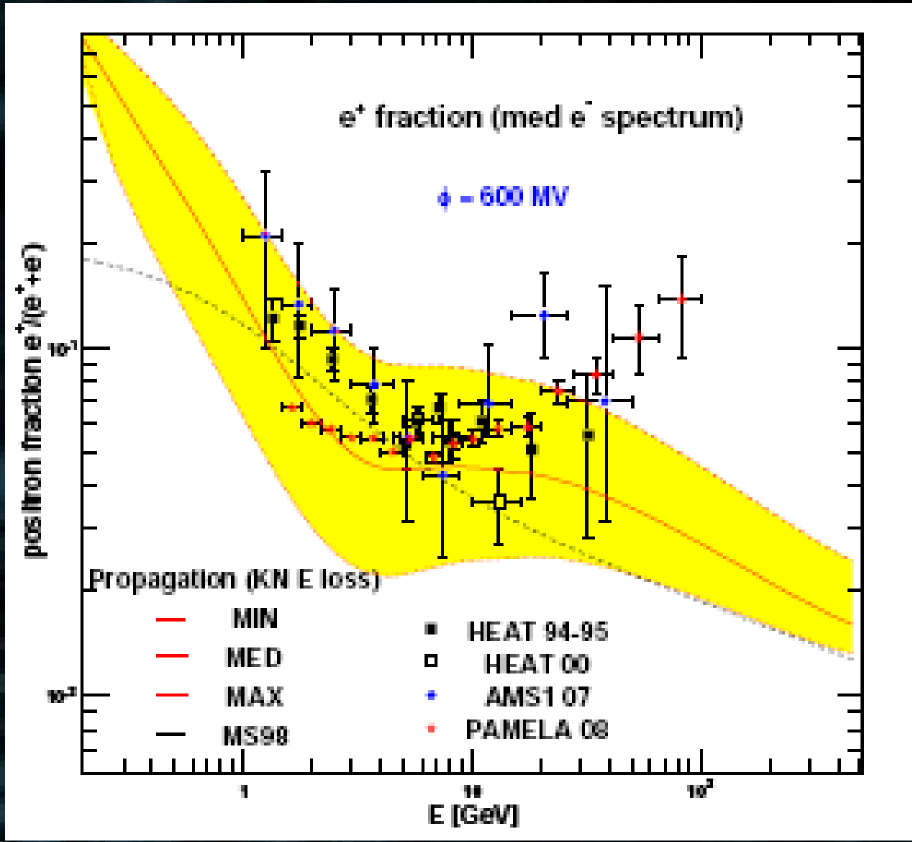
Propagation
from (x_s, E_s) to (x, E)

Flux at the Earth

Each box contains uncertainties !!!

Fermi has just released the denominator





Uncertainties are still large ... (relevance of analysis for additional primaries ?)
Yet, a conventional secondary origin seems unlikely ...

Clusters

Different possible contributions from DM annihilation:

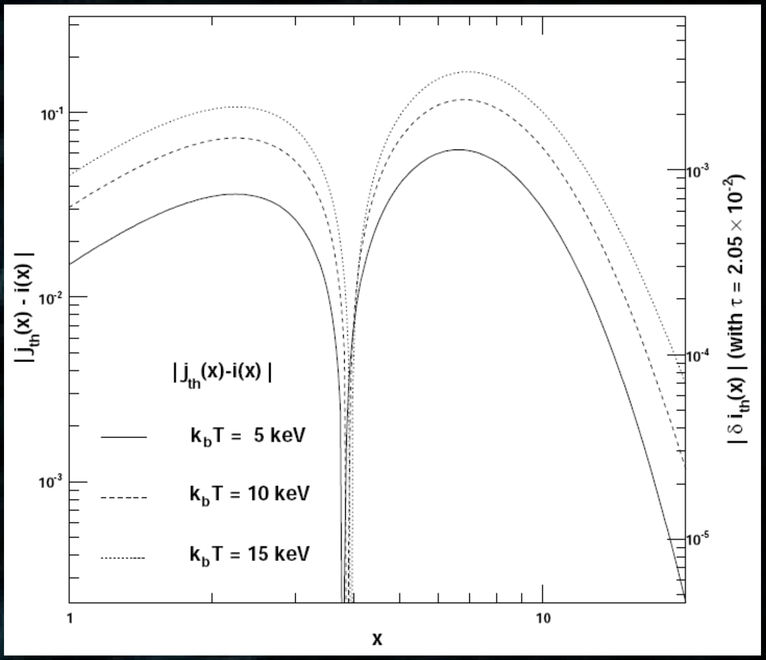
* gamma-rays (Fermi)
* radio & X-rays
* SZ

SZ advertized by Colafrancesco et al, not confirmed byLavalle et al 09, Yuan et al 09. (Key ingredients: optical depth and angular resolution).

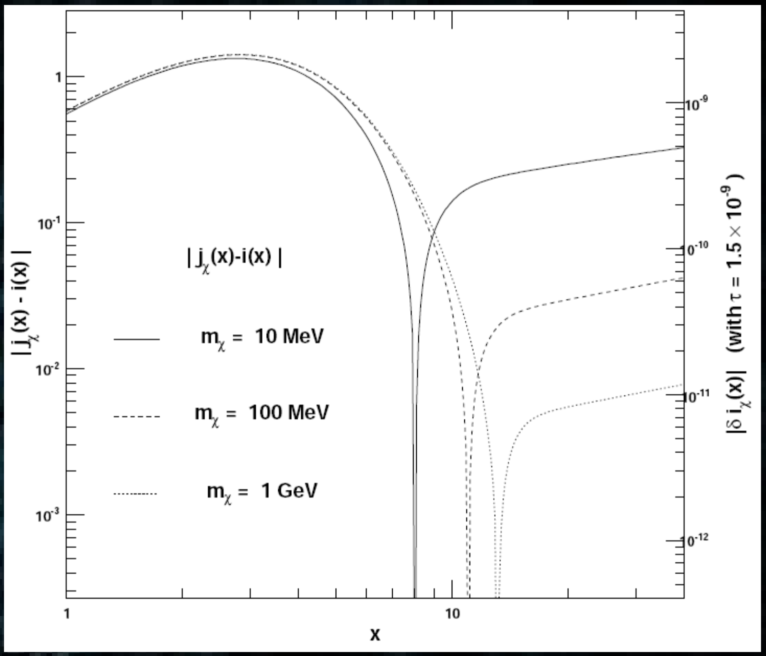
Role of standard CRs in clusters ?

* radio halos ?
* pressure ?
* tracers of merging processes

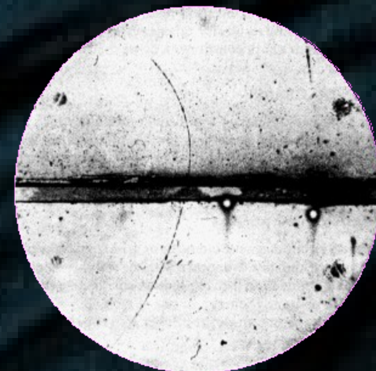
Thermal SZ



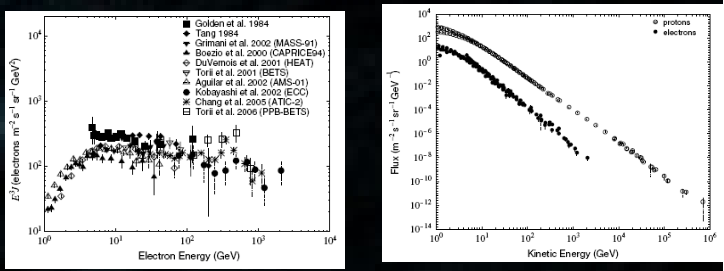
DM SZ



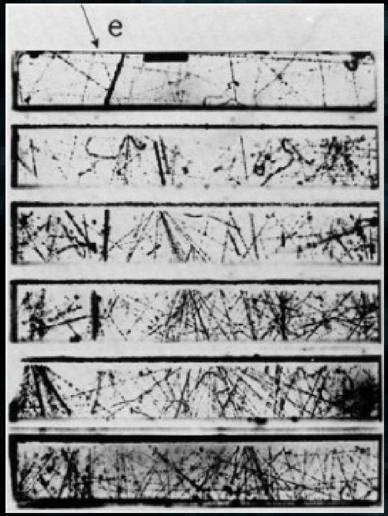
Cosmic e^-s and e^+s: Brief historical review



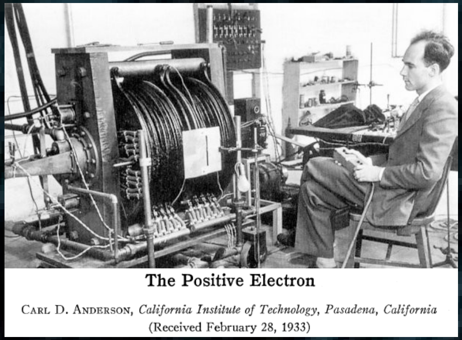
Discovery of the positron
Anderson, Phys. Rev. (1933)



Review by Yoshida (2008)

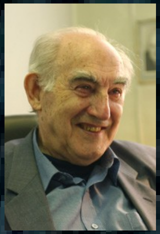


1st observation of cosmic ray
electrons > 0.5 GeV
Earl (1961): e/p ~ 3%



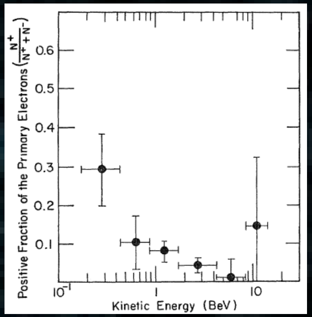
AMS-01 (1998)

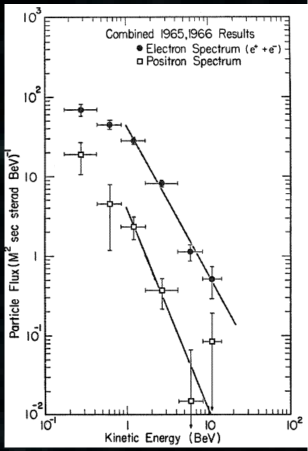
$$-D\Delta N + \frac{\partial}{\partial \varepsilon}[b(\varepsilon)N] = Q(\varepsilon, \mathbf{r}).$$



The origin of cosmic rays
Ginzburg & Sirovatsky (1964)

Positron fraction
Fanselow et al (1969)





Translate losses in propagation scale

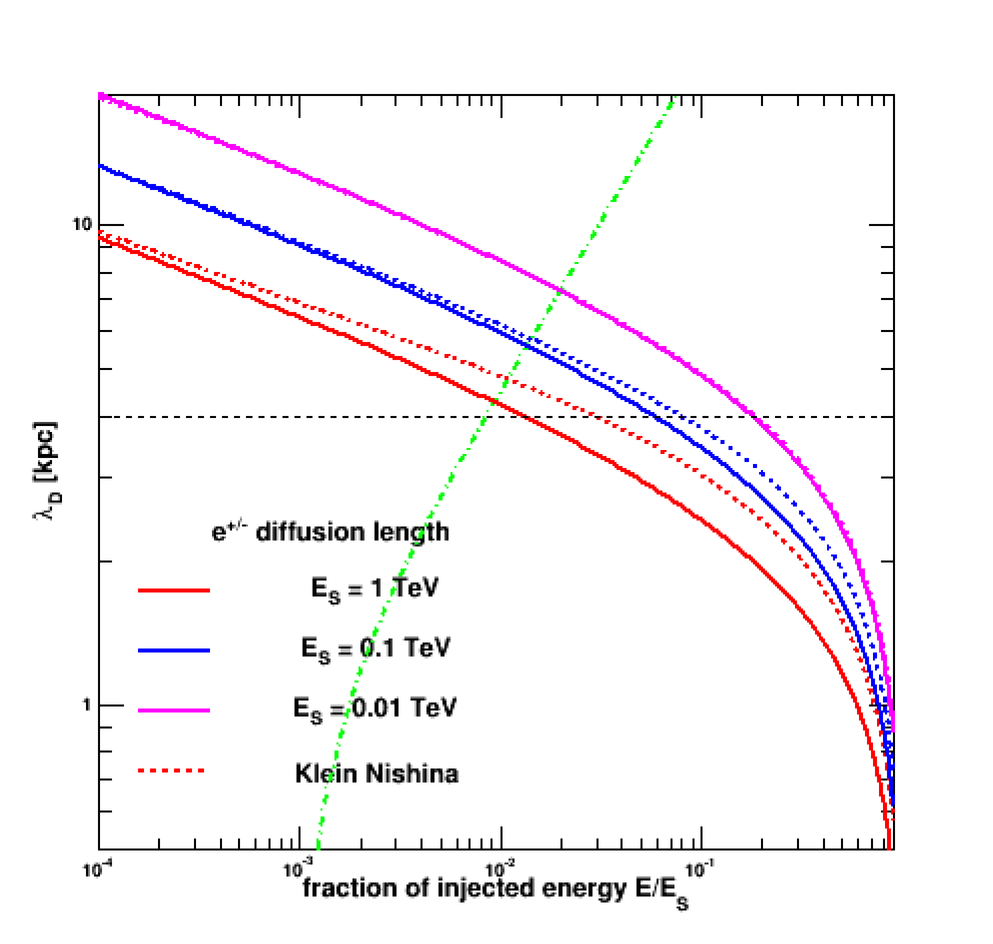
Transport mostly set by **spatial diffusion** and **energy losses**

$$K(E) = K_0 k(E) = K_0 \beta \left(\frac{\mathcal{R}}{1\,\mathrm{GV}}\right)^{\delta}$$

$$b(E) \equiv -dE/dt \approx \frac{E_0}{\tau_0}\left(\frac{E}{E_0}\right)^{\alpha}$$

Propagation scale: a very useful quantity

$$\lambda^2 \equiv 4\int_E^{E_s} dE' \, \frac{K(E')}{b(E')} = \frac{4\,K_0\,\tau_0}{1+\delta-\alpha}\left(\frac{\epsilon}{1\,\mathrm{GeV}}\right)^{1+\delta-\alpha}\Bigg|_E^{E_s}$$



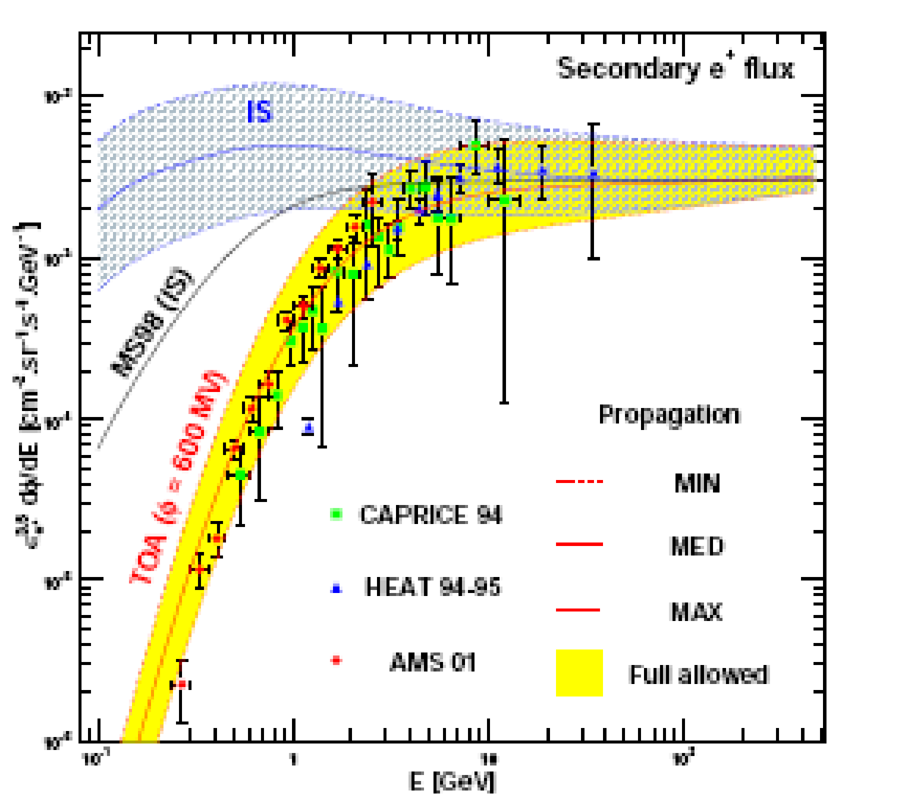
Electron horizon limited to a few kpc

$$K_0 = 0.012\,\mathrm{kpc}^2/\mathrm{Myr};\ \tau = 10^{16}\mathrm{s};\ \delta = 0.7$$

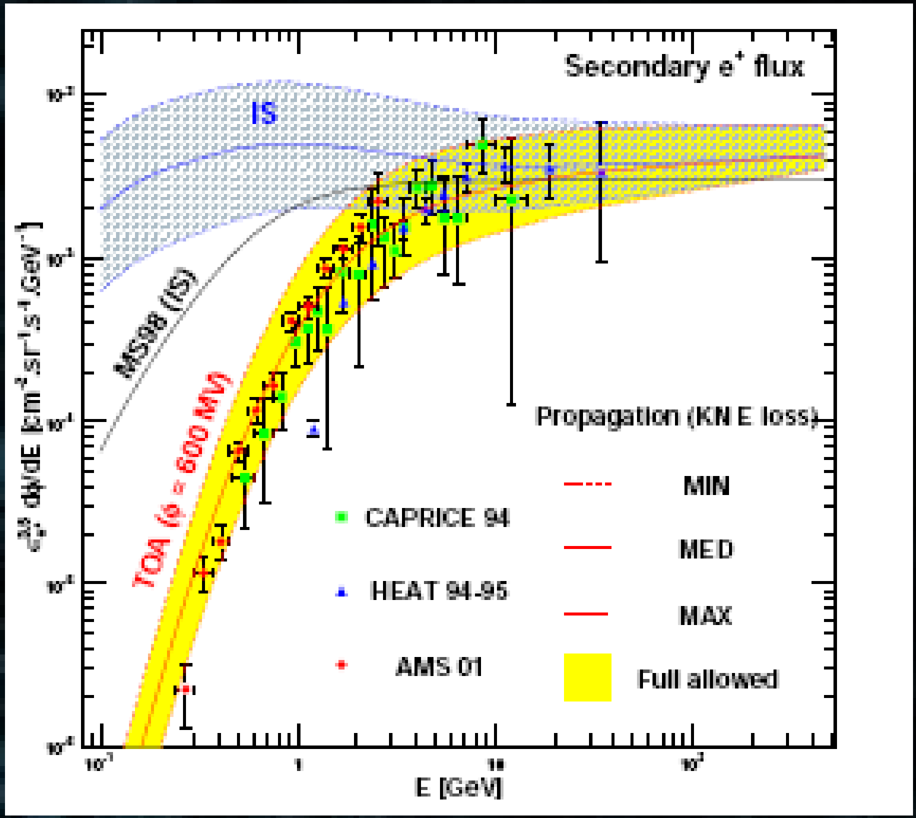
$$\lambda(E = 1\,\mathrm{GeV} \leftarrow E_s \gg E) \approx 6\,\mathrm{kpc}$$

Uncertainties from propagation parameters

Delahaye et al (2009)



Same but with relativistic losses

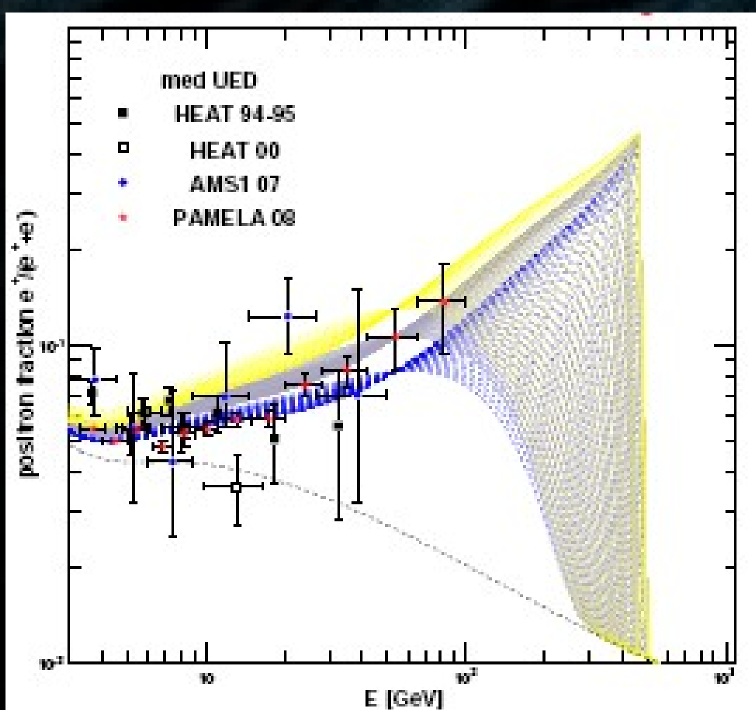


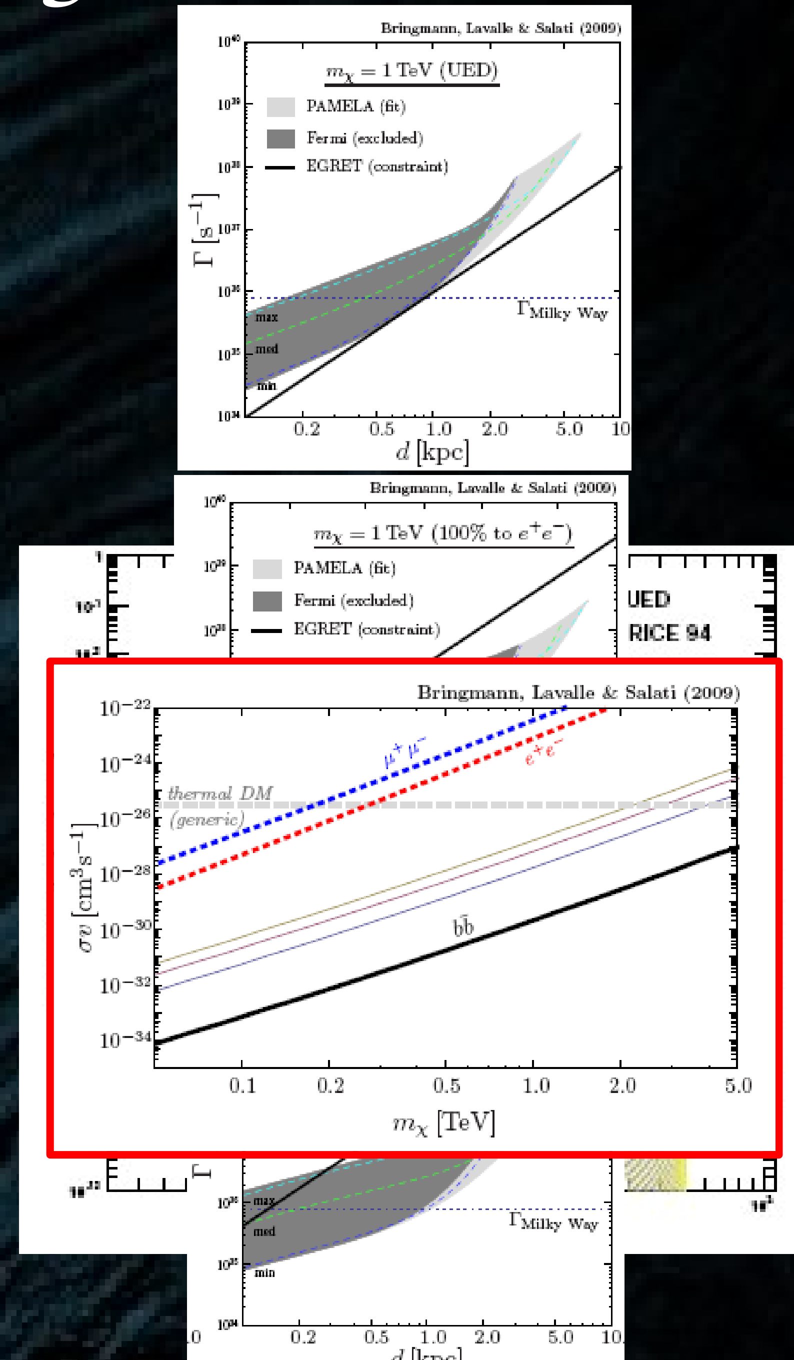
Single object wandering around

The game one can play:

- Assume a single DM source at any distance d to the Earth.
- Assume a WIMP mass and its annihilation final states.
- Search for the brightness necessary to fit PAMELA.
- Check against other data (gamma, antiprotons, etc.)

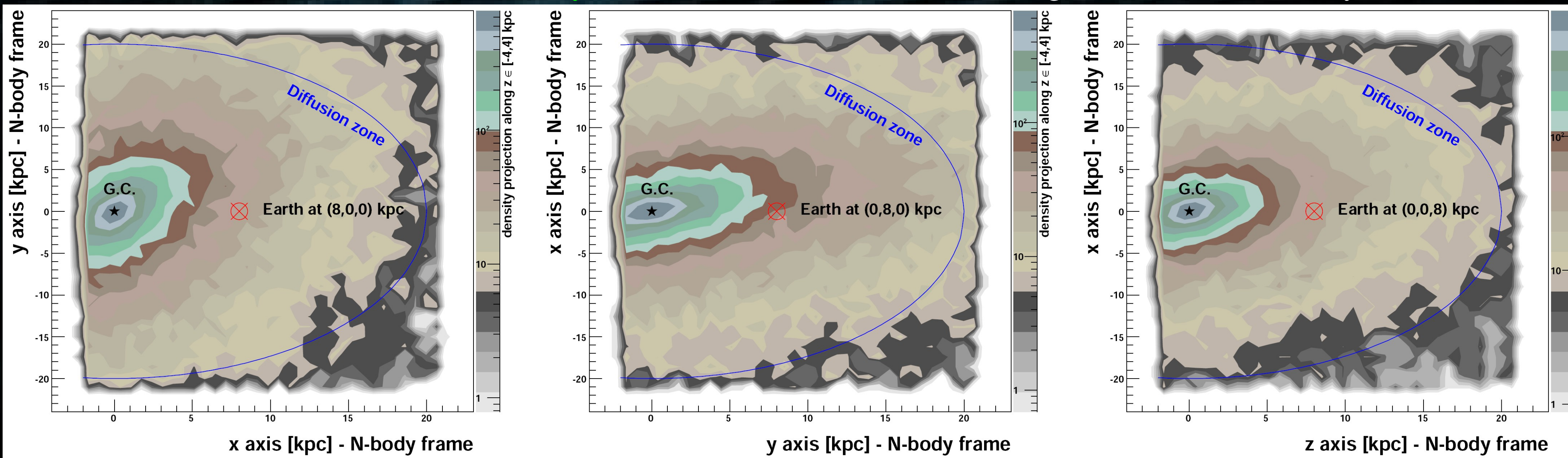
Bringmann, Lavalle & Salati (2009)

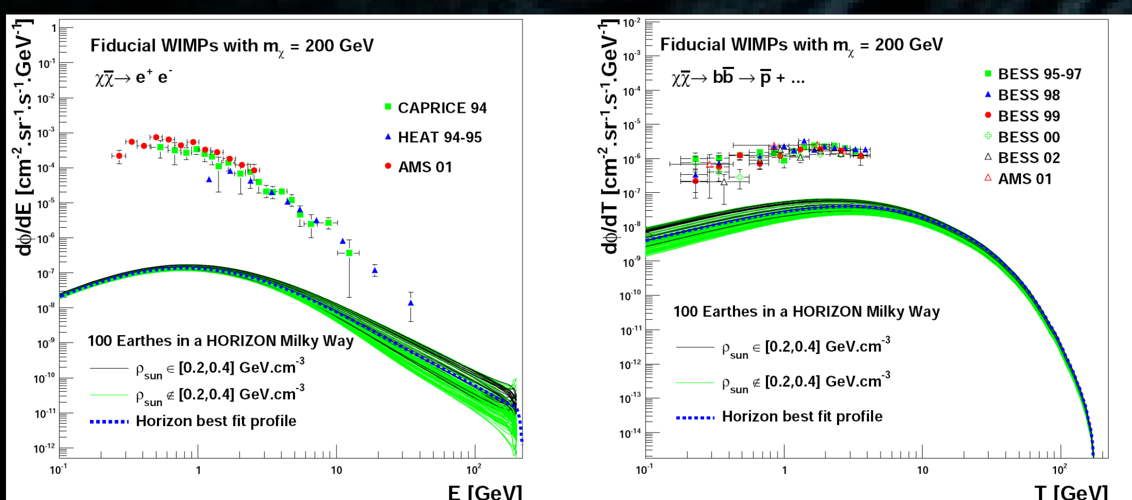




(The local DM issue)

Fluctuations of DM density in Horizon: Lavalle, Nezri, Ling, Athanasoula & Teyssier 08





Latest predictions:
Catena & Ullio 09
Salucci et al 10
0.3 – 0.5 GeV/cm3

Relevant scale ? Role of baryons ?
Impacts on positron predictions
& direct detection

Limits of N-body simulations: the smallest scales of DM structures

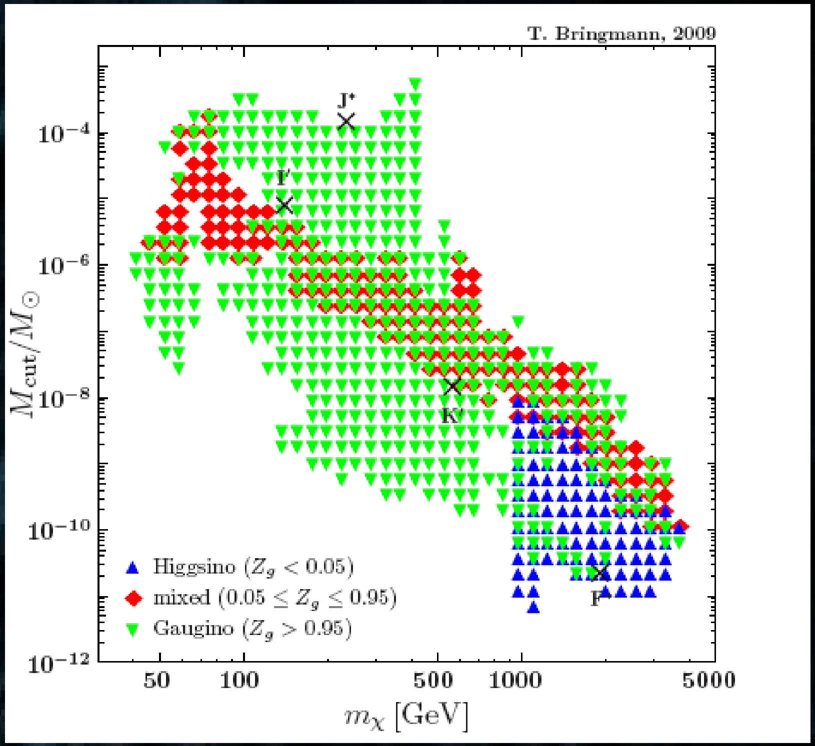
(see review by T. Bringmann (2009))

The free streaming scale depends on the time of kinetic ($\neq$ chemical) decoupling of WIMPs from the primordial soup.

The weaker the collision rate, the earlier the gravitational collapse, the smaller the cut-off mass.

Subhalo mass down to 10^{-11}-10^{-3} $M_\odot$ (SUSY). The lighter the denser.

Tidal effects ? Large survival fraction (Berezinsky et al, 2008)



T. Bringmann arXiv:0903.0189

	M_{sub}^{res} $[10^4 M_\odot]$	N_{sub}^{res} $[10^4]$	Mass slope	f_{sub}^{res} [%]
VL2	$\sim 10^2$	5.3	2	10
AQ	3.24	30	1.9	13.2

Extrapolation

down to 10^{-6} Msun

	M_{sub}^{min} $[10^{-6} M_\odot]$	N_{sub}^{tot} $[10^{15}]$	Mass slope	f_{sub}^{tot} [%]
VL2	1	28	2	54.2
AQ	1	1.1	1.9	17.1

Via Lactea II versus Aquarius

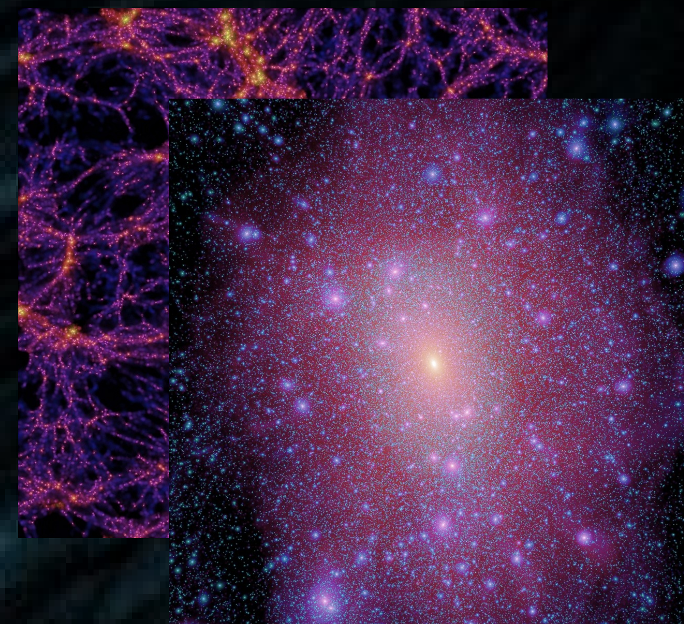
Via Lactea II: Diemand et al (2008)
Aquarius: Springel et al (2008)

MW-like halos with ~ 1 billion particles of $\sim 10^3\ M_\odot$

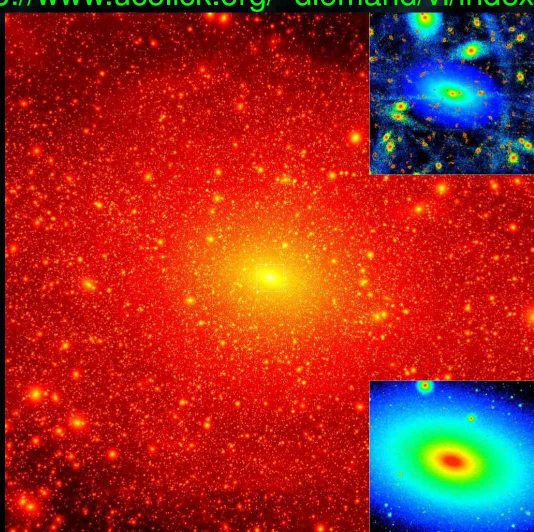
> 50,000-300,000 subhalos with masses > 10^6 -$10^{4.5}$ $M_\odot$

Slightly different cosmologies: WMAP3 vs WMAP5
($\sigma_8 = 0.74$ vs 0.9)

http://www.mpa-garching.mpg.de/aquarius/



http://www.ucolick.org/~diemand/vl/index.html



Gamma-ray studies in:

Kuhlen et al (2008) – VL2
Springel et al (2008) – AQ

					Overall DM		Subhalos			
	$M_{\rm part}$ $[10^3 M_\odot]$	$N_{\rm part}$ $[10^8]$	M_{50} $[10^{12} M_\odot]$	R_{50} [kpc]	Density profile	$\rho_\odot$ [GeV/cm^3]	$M_{\rm sub}^{\rm res}$ $[10^4 M_\odot]$	$N_{\rm sub}^{\rm res}$ $[10^4]$	Mass slope	$f_{\rm sub}^{\rm res}$ [%]
VL2	4.1	4.7	1.9	402	NFW	0.42	$\sim 10^2$	5.3	2	10
AQ	1.7	14.7	2.52	433	Einasto	0.57	3.24	30	1.9	13.2