# *Indirect Dark Matter searches: What's new?*

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*Montpellier – 13 V 2013*

# *Indirect dark matter detection in the Milky Way*

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
*Astronomy Department, University of California, Berkeley, California 94720, and Institute for Theoretical Physics, University of California, Santa Barbara, California 93106*
and
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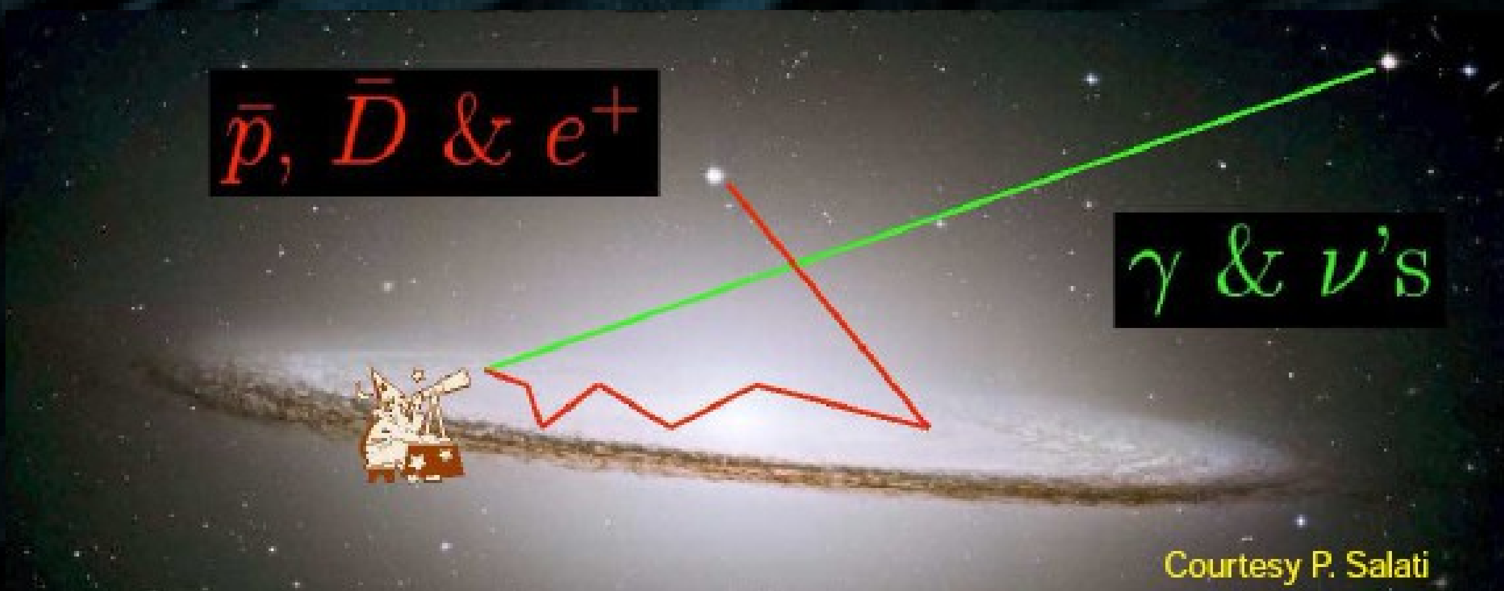
(Received 8 June 1984)




**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?

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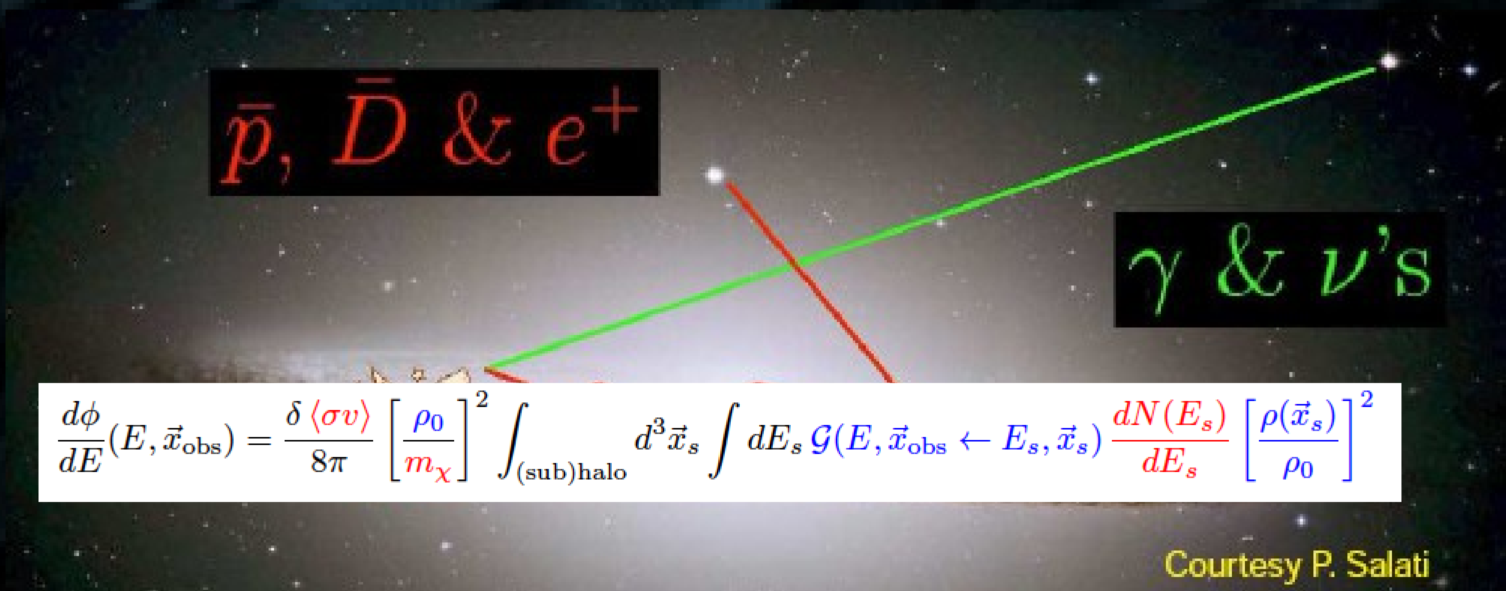


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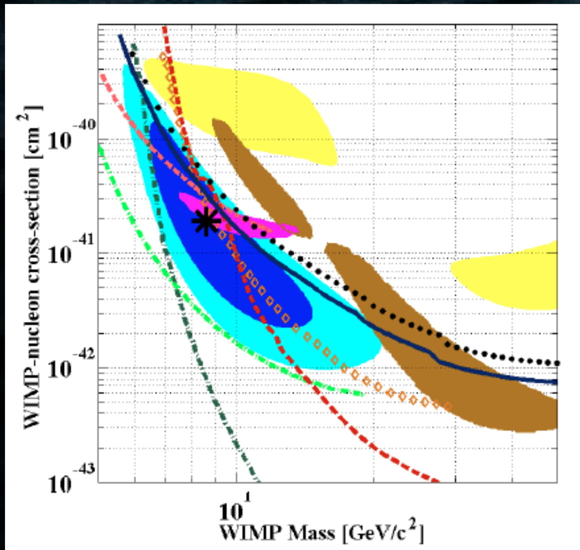
# *Transport of Galactic cosmic rays*
# *The standard picture*

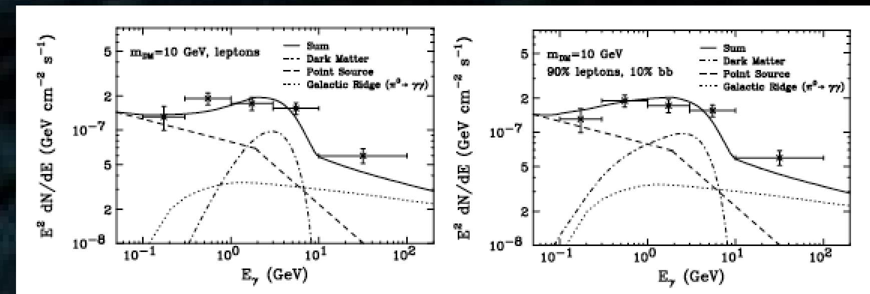
$$
\begin{aligned}
\partial_t \frac{dn}{dE} &= Q(E,\vec{x},t) \\
&+ \left\{ \vec{\nabla}\left(K(E,\vec{x})\vec{\nabla} - \vec{V}_{\rm c}\right) \right\} \frac{dn}{dE} \\
&- \left\{ \partial_E\left(\frac{dE}{dt} - \partial_E E^2 K_{\rm pp} \partial_p E^{-2}\right) \right\} \frac{dn}{dE} \\
&- \left\{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

From Haslam et al data (1982)

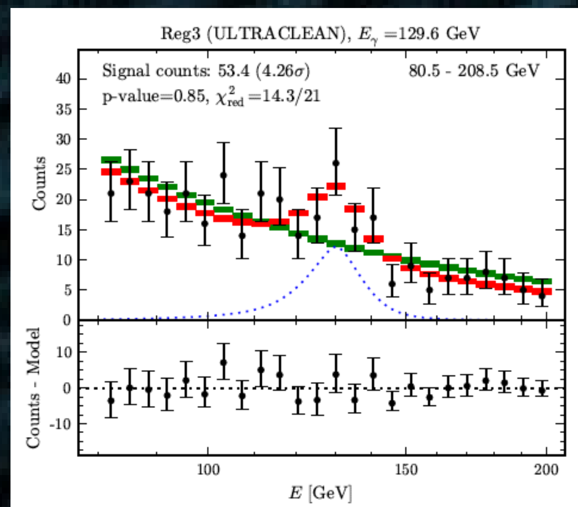
# *Dark matter has long been discovered !*



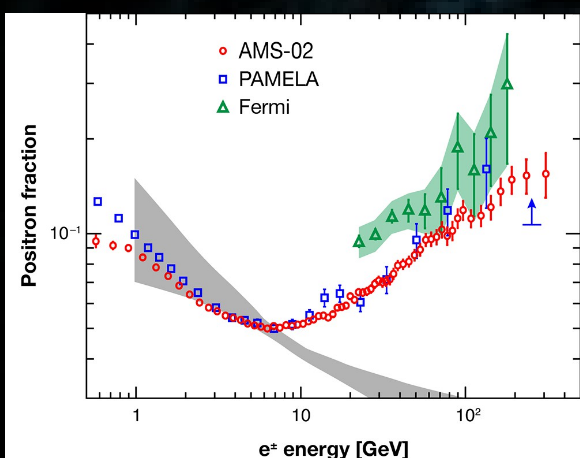

Agnese++ 13
DAMA, CoGenT, CRESST … + CDMSII(SI)
versus XENON-10, XENON-100
→ DM around 10 GeV

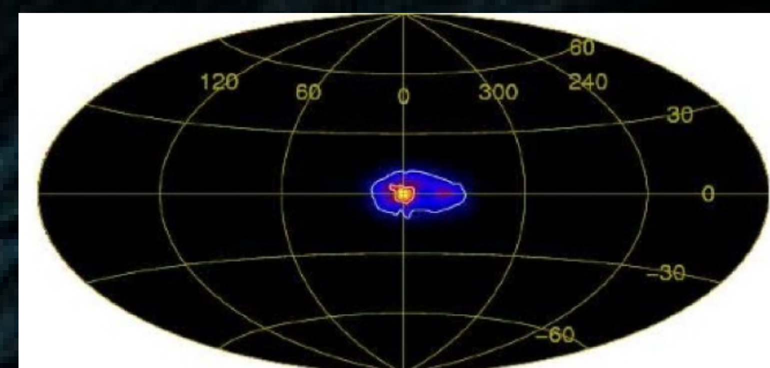



Hooper++ 12: gamma-rays + radio at GC
→ DM around 10 GeV




Around the GC
Weniger++, Finkbeiner++ 12
→ DM around 130 GeV

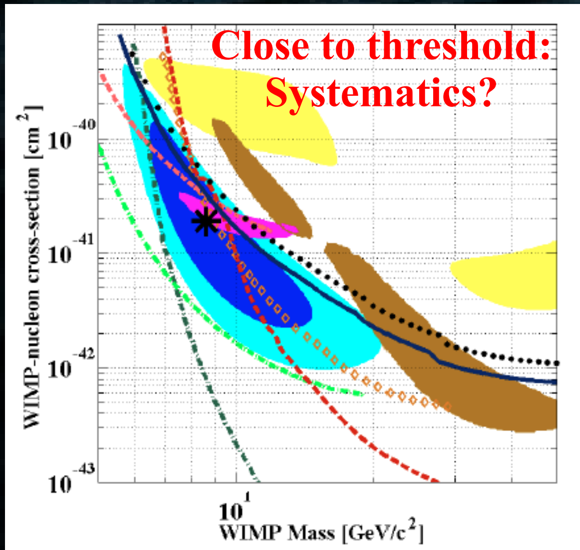



511 keV, Knödlsëder/Weidenspointner++ 05 - 08
Boehm, Hooper++ 04 → DM around 1 MeV

HEAT/PAMELA/AMS positron excess
Bergström++, Cirelli++ 08 → DM around 300-1000 GeV

# *Dark matter has long been discovered !*

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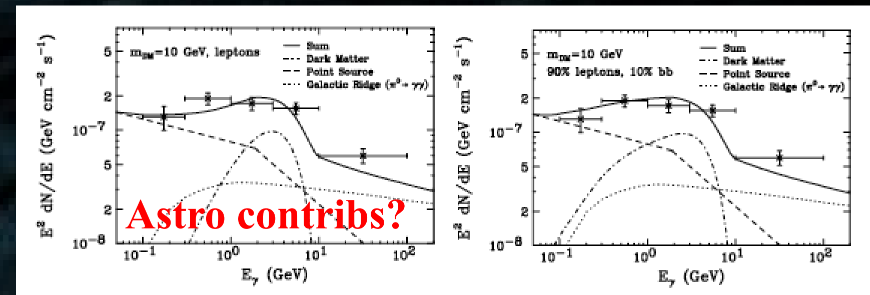


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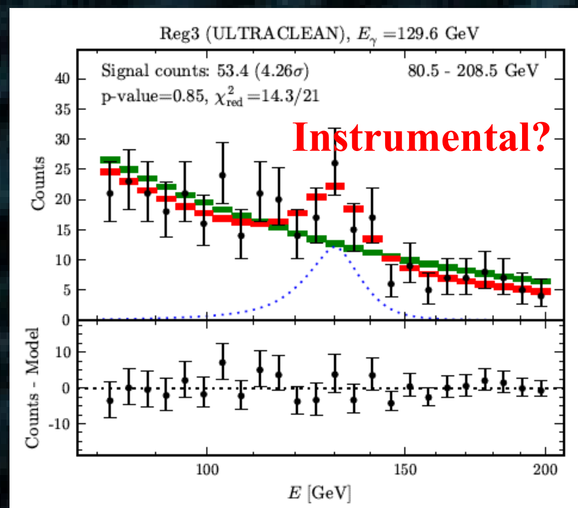
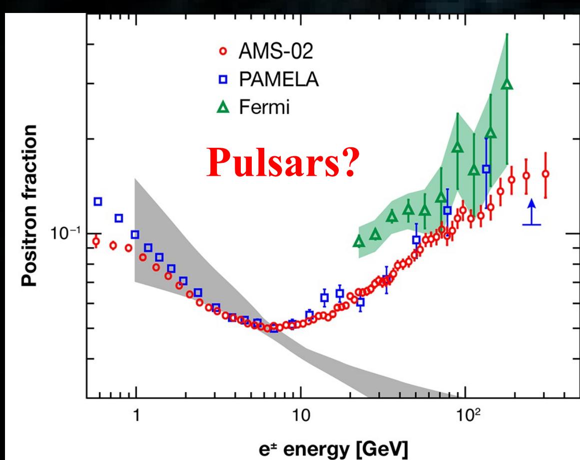



Around the GC
Weniger++, Finkbeiner++ 12
→ DM around 130 GeV

All point toward different mass scales :
1 MeV / 10 GeV / 130 GeV / 500 GeV

Hard to explain with a single DM candidate
(except maybe for XDM,
Weiner++ 04-12, Cline +, etc.)

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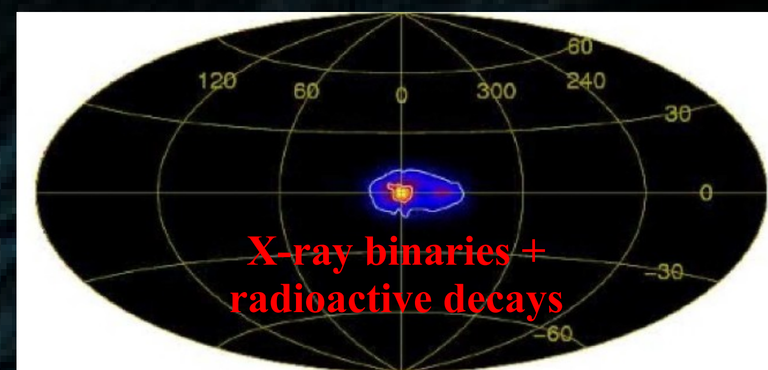


511 keV, Knödlsëder/Weidenspointner++ 05 - 08
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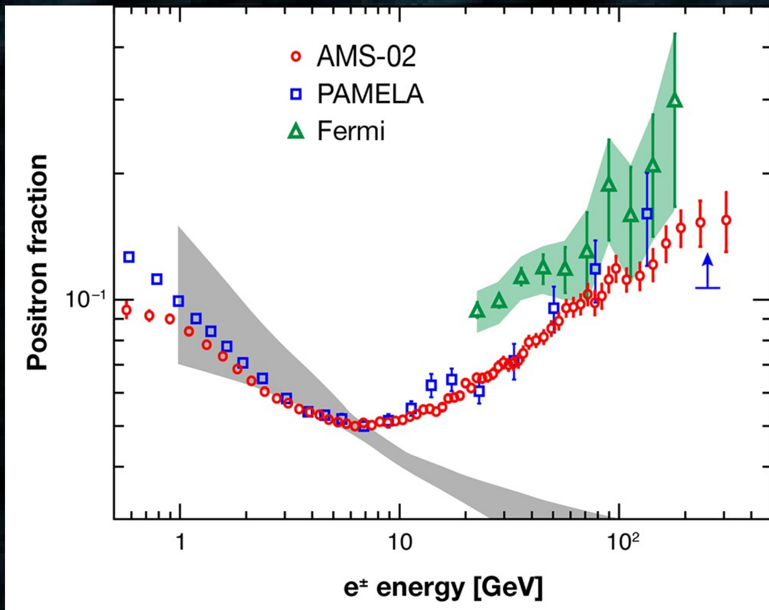
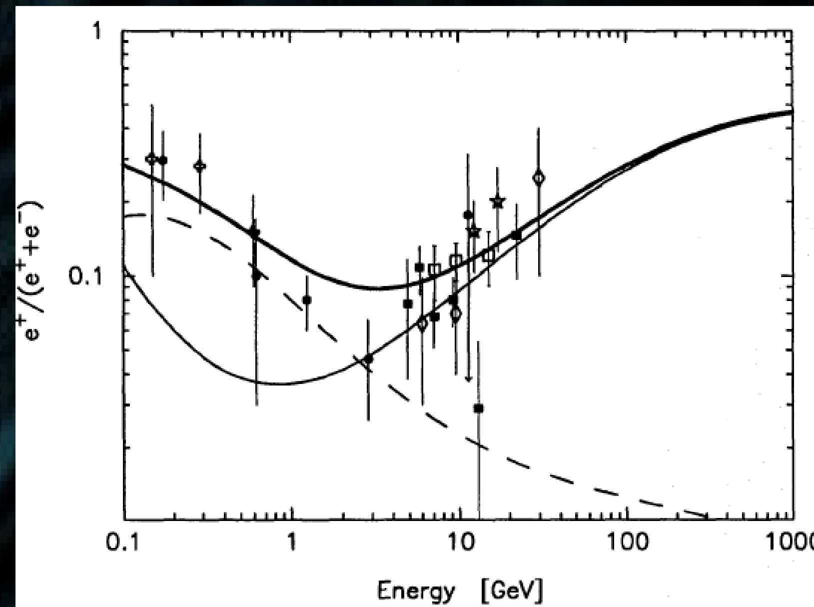
# Comments on the positron fraction

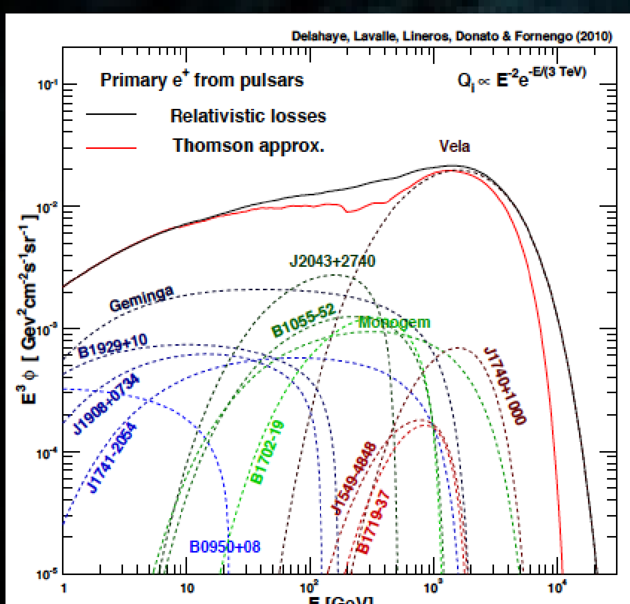
AMS result: nothing really new but impressive precision




AMS Collab (2013)




Aharonian+ (1995)




Pulsars efficiently produce e+/- pairs.
Realistic modeling is complicated (eg Delahaye et al 10).
=> separate distant/local sources, and accommodate the full data (e-, e+, e+e-, e+/e+e-) …

=> Pulsar wind nebulae (PWNe) as HE positron/electron sources
=> SNRs as HE electron sources (each PWN is paired with an SNR)

=> you may fit amplitudes / spectral indices … then what?

** Observational constraints!

=> use pulsar period, multiwavelength data for all observed sources … but … not that simple.

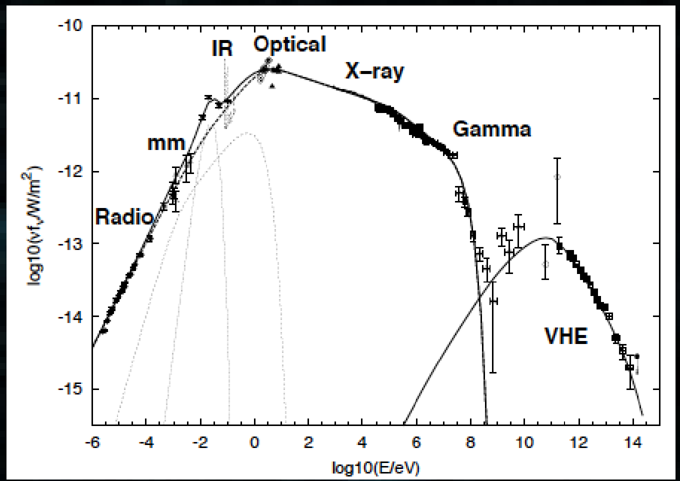
# *Modeling the electron/positron sources?*

Crab nebula (ESA)
(just for illustration,
not relevant for e+/e-)


$$\text{photon obs. time} = \frac{d}{c} \approx 300\,\text{yr}\left[\frac{d}{100\,\text{pc}}\right]$$

$$\text{transport time} \approx \frac{d^2}{K(E)} \approx 30\,\text{kyr}\,\left[\frac{E}{1\,\text{TeV}}\right]^{-1/2}\left[\frac{d}{100\,\text{pc}}\right]^2$$

$$\text{E-loss time} \;=\; \int_E^{E_s} dE'\,b(E') \approx 300\,\text{kyr} \;@\; 1\;\text{TeV}$$




Horns & Aharonian (04)
Crab SED

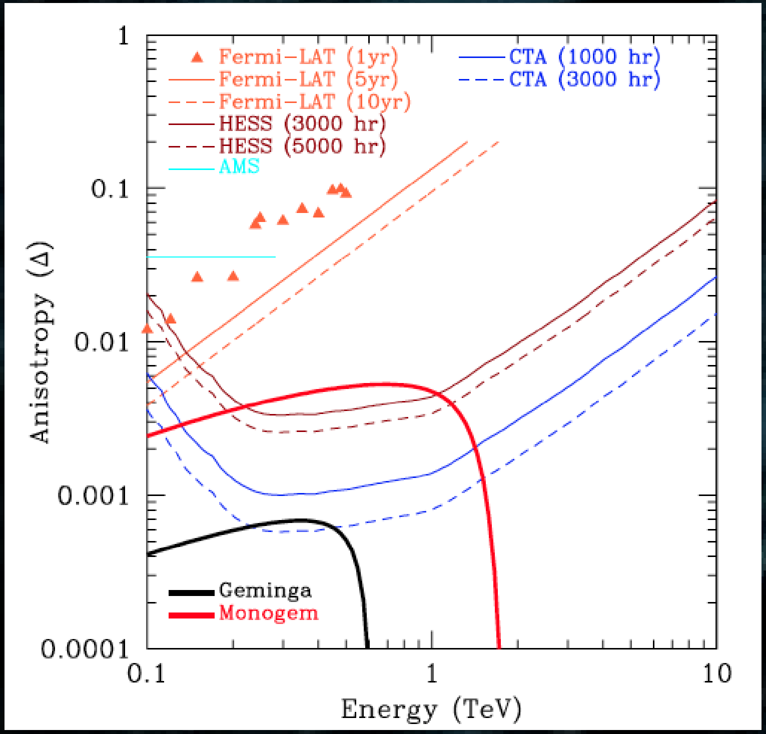
Different timescales:
1) E-loss time > source age > transport time
2) transport time >> photon time
=> cannot directly use photon data
=> requires dynamical models for sources (time evolution)

Very complicated problem:
1) photon data: CRs which are mostly still confined in sources (escape issue)
2) coupled evolution of magnetic fields and CR density

Some attempts at the source level (eg Ohira+ 10-11), but much more work necessary.

Work in prep. with Y. Gallant and A. Marcowith (LUPM).

# *Anisotropy as a test?*




Linden & Profumo (2013)

***Caveats:***

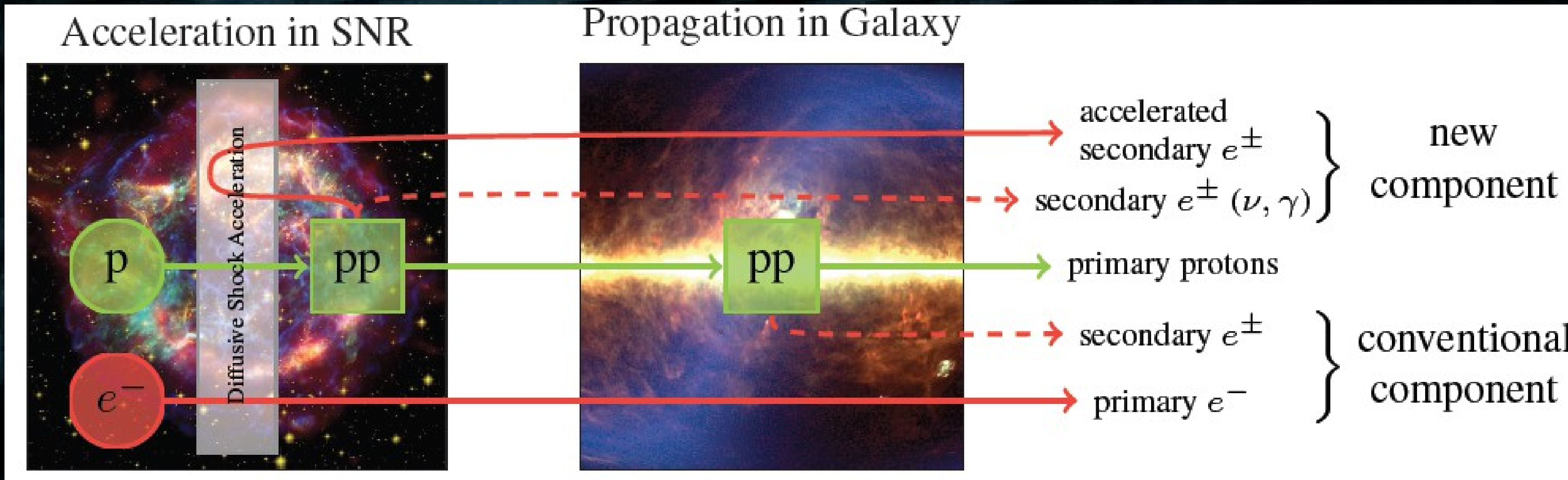
* model-dependent (diffusion halo size again!)
* contributions of other sources (eg dipole from GC/antiGC asymmetry in the source distribution)
* cancellations might occur in the dipole
* multipole analysis necessary

***Still:***

* physically meaningful information
* should be provided for all CR species separately (eg positrons, antiprotons, etc.)
* will provide constraints to the full transport model
* AMS and CTA may reach the necessary sensitivity

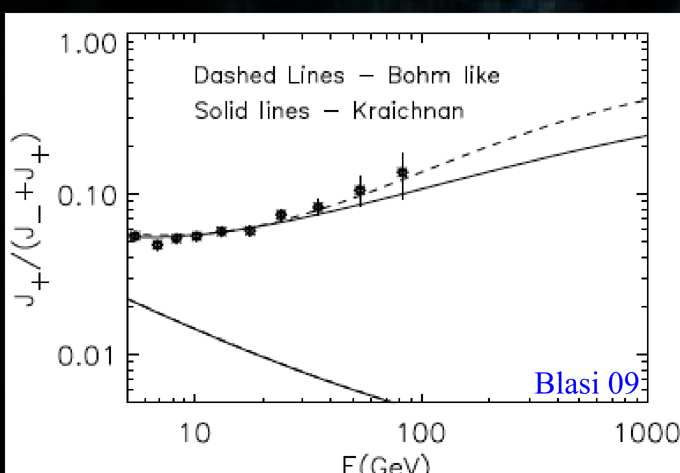
# Other astrophysical solution(s)

Secondaries generated in SNRs are accelerated like primaries:
Berezhko++ 03, Blasi 09, Blasi & Serpico 09,
Mertch & Sarkar 09, Ahler++ 09

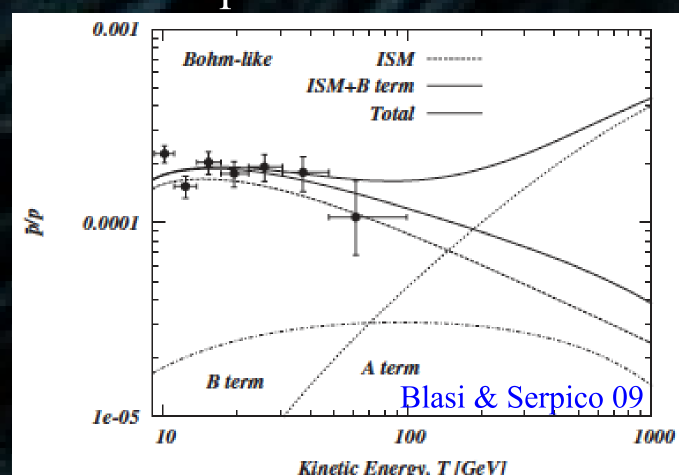



(from Ahler++ 09)

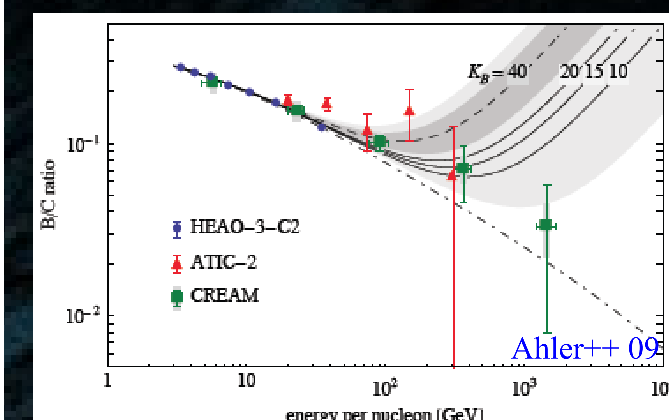
Positron fraction




Antiproton fraction




B/C ratio

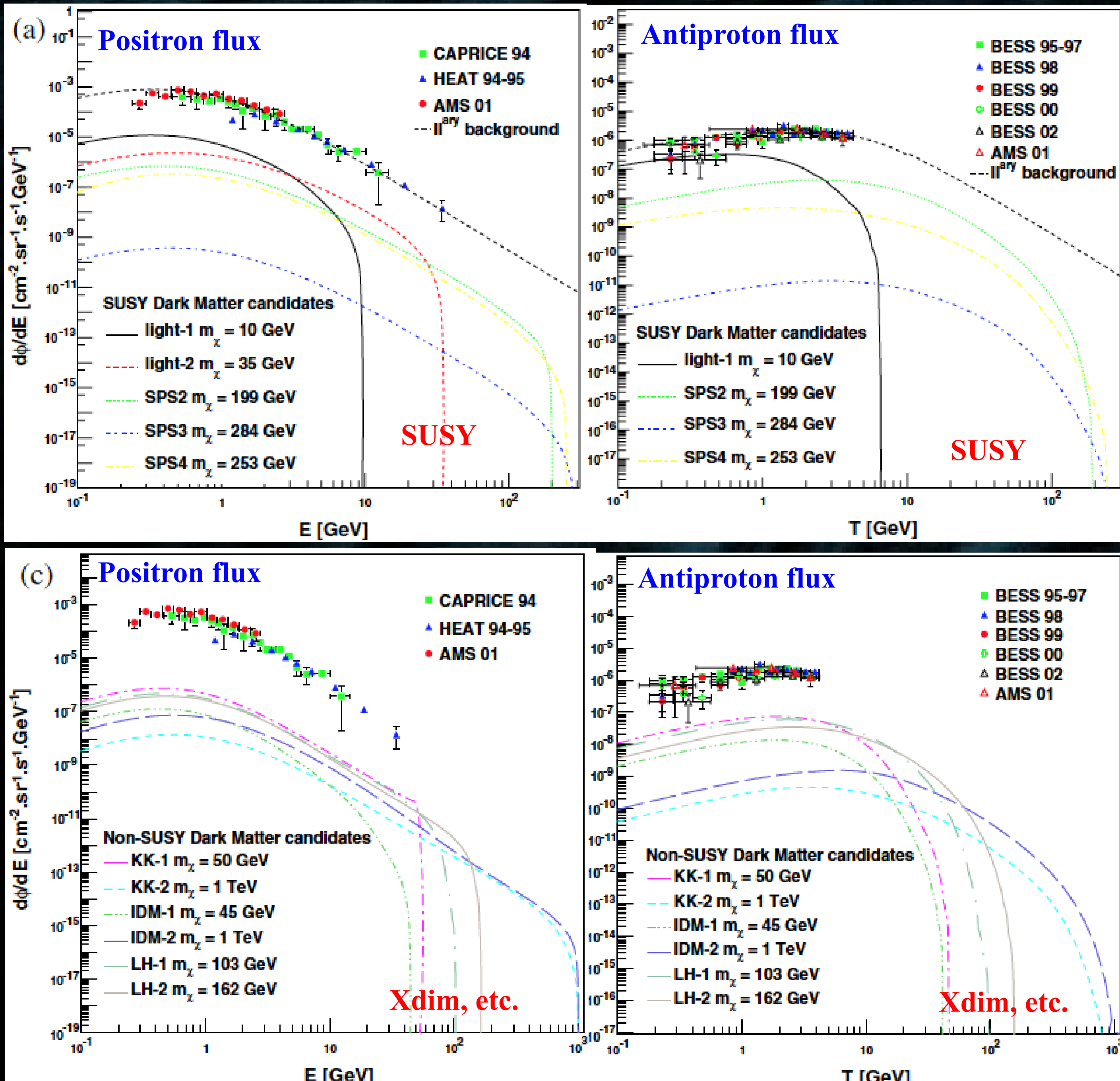



Associated signatures: rising antiproton fraction (like DM) and B/C ratio

*Dark Matter?*

*(indirect searches very important and complementary with other methods ... doesn't mean DM must be the solution to every astrophysical "excess")*

# "Standard" DM models do not fit




Lavalle++ 08

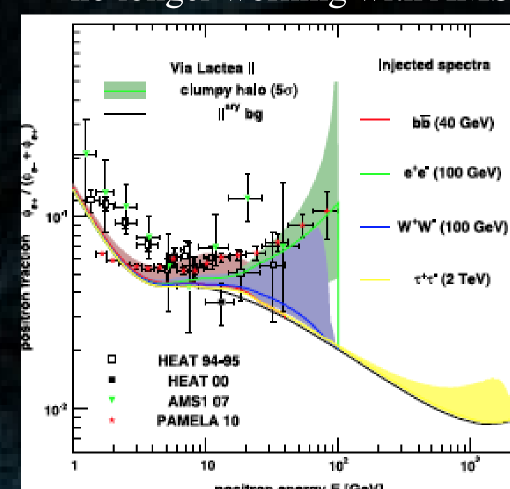
***Main generic points:***

* Annihilation cross section too small

* Associated antiproton flux prevents large positron flux

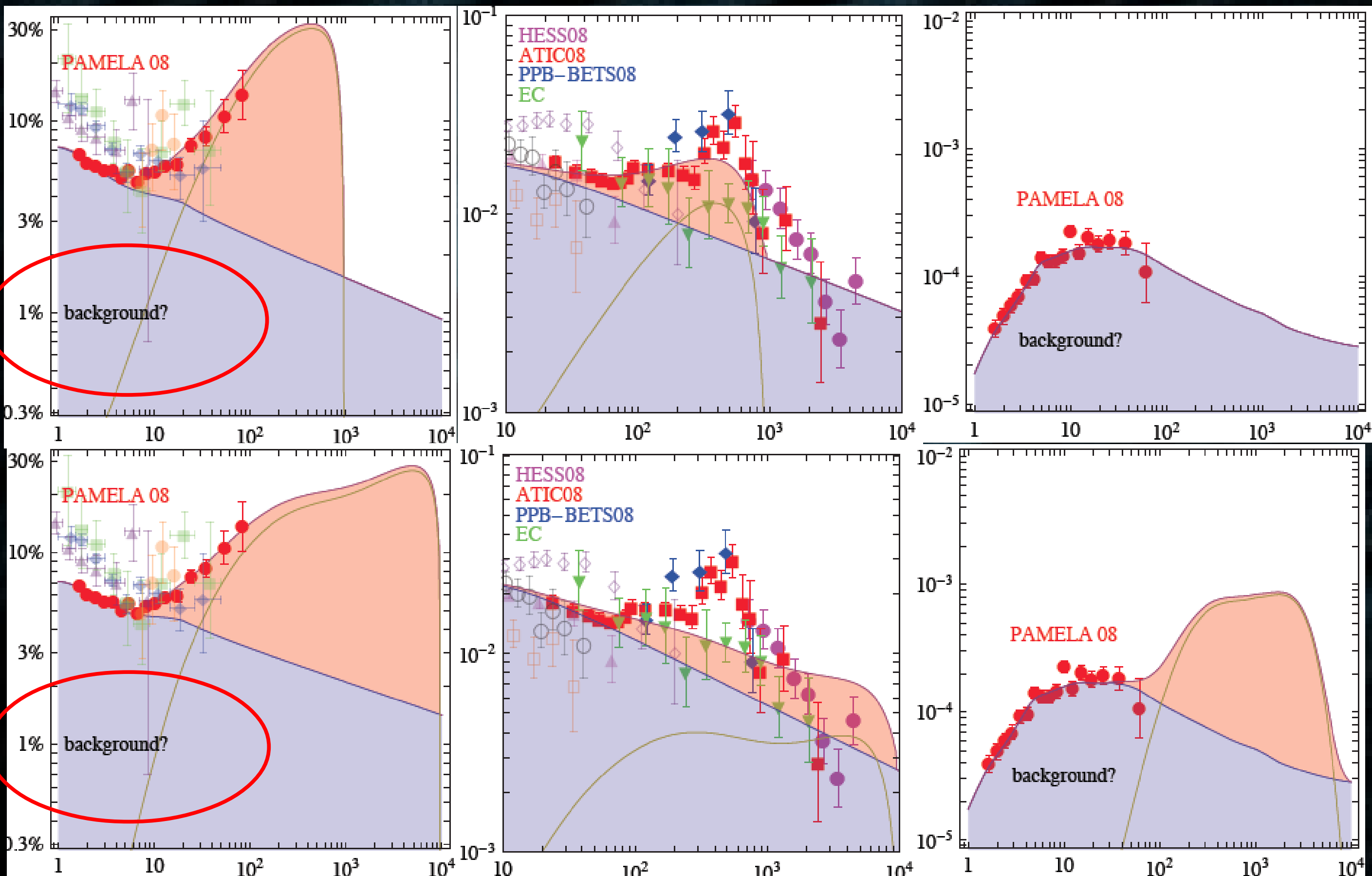
=> boost annihilation rate
=> suppress antiprotons < 100GeV

Example: could fit PAMELA data with 100 GeV DM → e+e- (small boost from DM subhalos).
*** no longer working with AMS

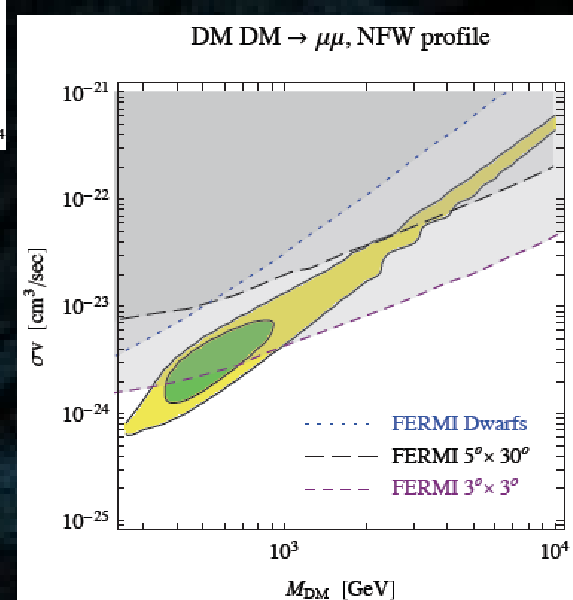



Pieri, Lavalle++ 11

# *Generic DM interpretation of the positron excess*




Cirelli, Strumia++ (2008-2013)

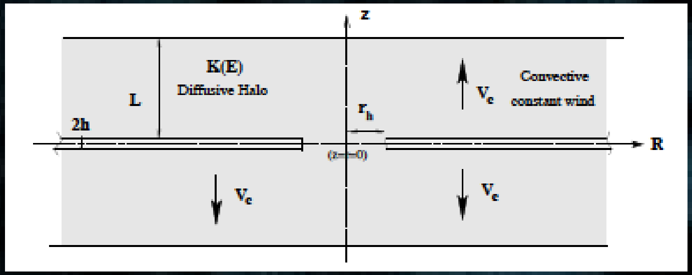



Method:
* background (!!!) + annihilation cross-section as free params.

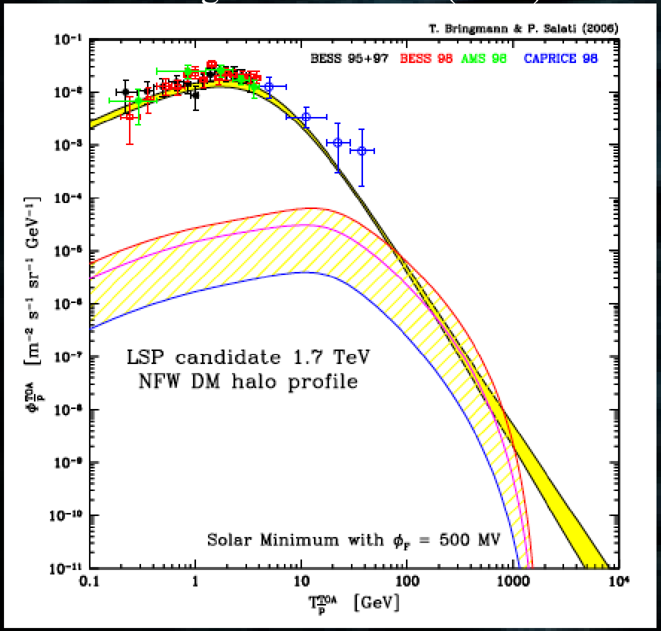
Conclusions:
* severe antiproton constraints => multi-TeV or leptophilic models

=> other constraints from CMB, gamma-rays, etc.

# *Impact of the size of the diffusion zone*




Bringmann & Salati (2007)




The game people usually play:
1) you want your model to survive antiproton constraints:
=> take a small L
2) you want to advertise your model for detection:
=> take L from med to max.

Maurin+ (2001) & Donato+ (2002)
=> attempts to bracket theoretical uncertainties

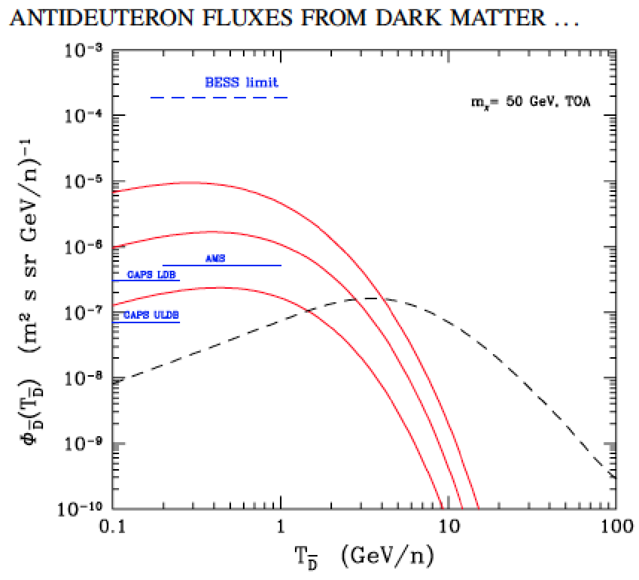
Besides best fit transport model (dubbed *med*), proposal for 2 extreme configurations:

*min*: L = 1 kpc
*med*: L = 4 kpc
*max*: L = 15 kpc

minimizing and maximizing the DM-induced fluxes, respectively.

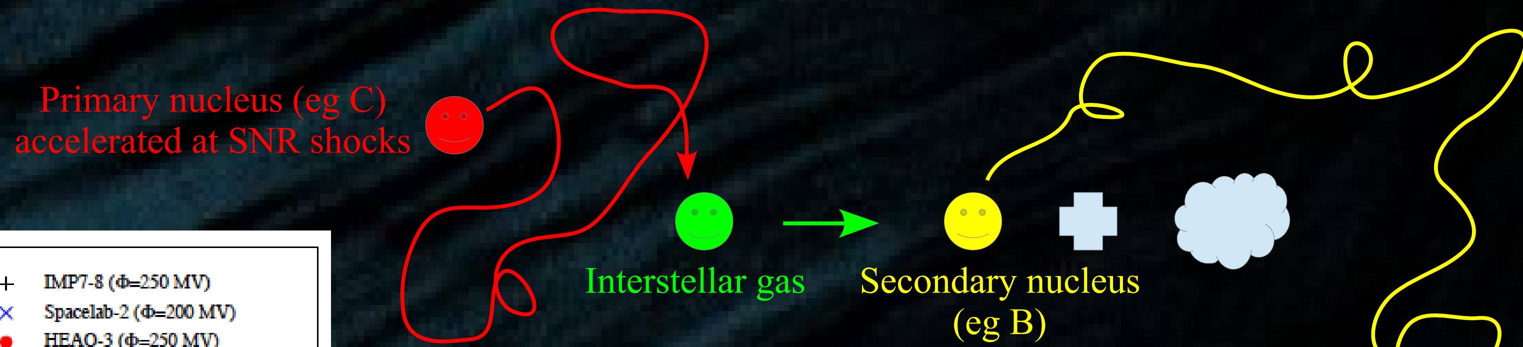
NB: much less effect on high-energy positrons (Lavalle+ 07, Delahaye+ 08) – short propagation scale.

Maurin, Donato, Fornengo (2008)

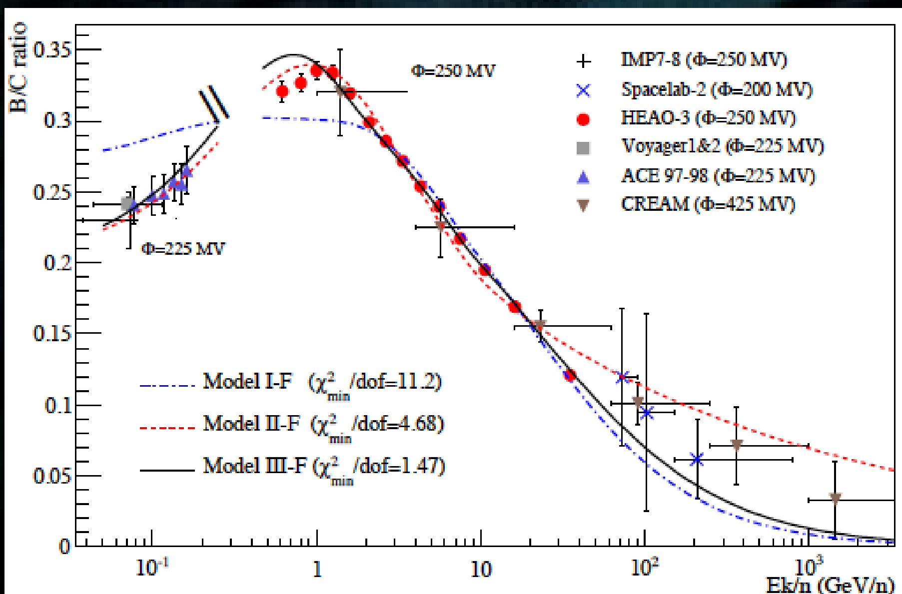



*Julien Lavalle, GDR Terascale @ Montpellier, 13 V 2013*

# *Where do constraints on L come from?*



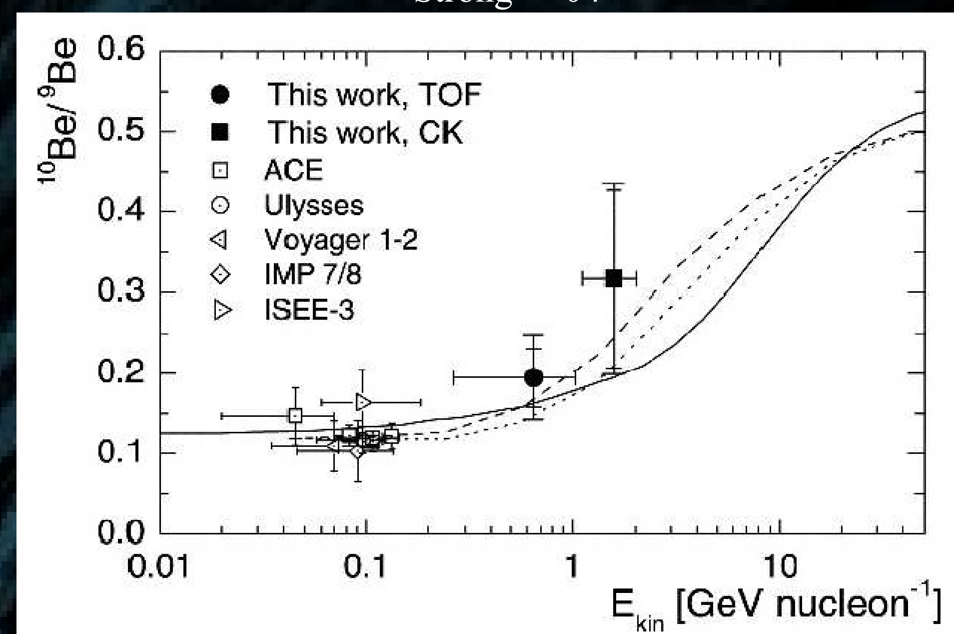

Putze++ 11




Secondary/primary ratios constrain transport history
=> most used is B/C
** provides constraints on K/L

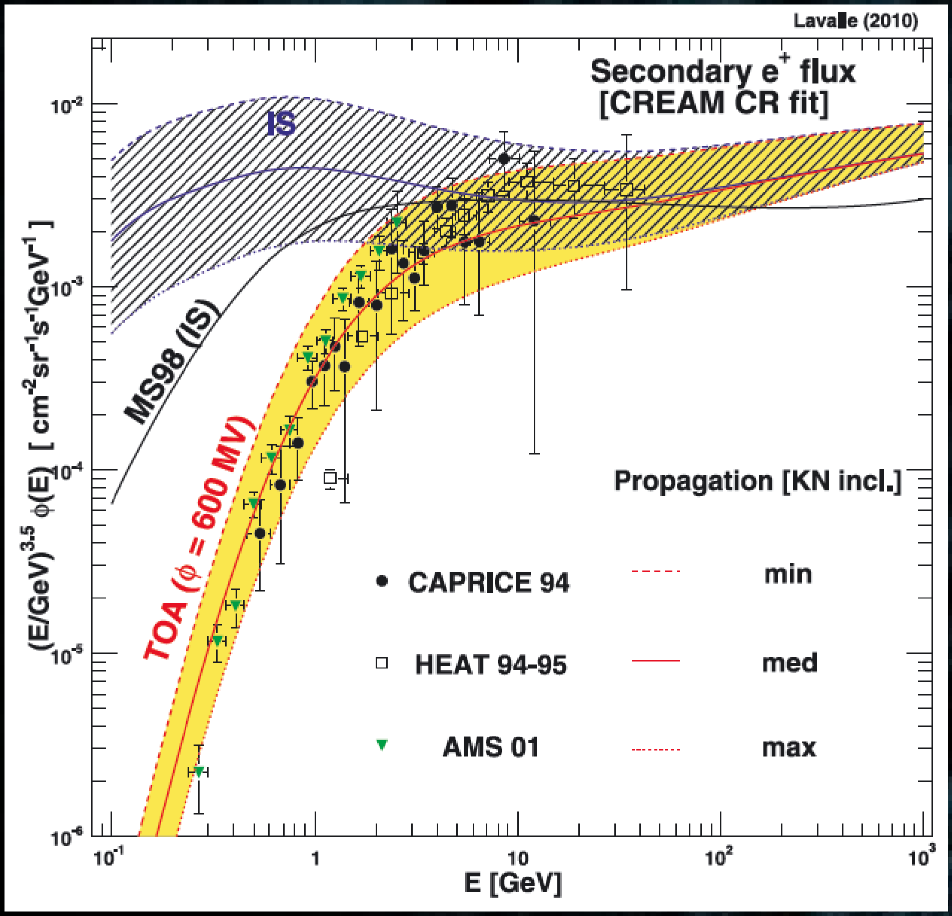
Breaking degeneracy with
radioactive secondaries
=> lifetime too short to reach L

Strong++ 04



# *Uncertainties in the diffusion halo size? Quick digression towards positrons*

Secondary positrons
(eg. Delahaye++09, Lavalle 11)




$$\phi_{e^+} \propto 1/\sqrt{K_0}$$

$$\frac{K_0}{L} \approx \mathrm{Cst}$$

**Small L models in tension with positron data**

=> L > 1 kpc => Very conservative statement!

**Perspectives:**

- PAMELA/AMS data still to come

=> Ongoing work with Maurin and Putze

# *Summary*

- HESS, PAMELA, Fermi, AMS02: GeV-TeV astrophysics has entered the precision era
- AMS02 will provide data with unprecedented precision: big improvements expected in CR physics

- Current GCR models allow for a reasonable understanding of (i) the local CR budget and (ii) the Galactic diffuse emission(s)
- Nota: there is no "standard model" for GCRs so far! (many inputs, lucidity is required)
- Current models are reaching their limits
=> prediction power saturates, need to put more physics in (eg pulsars) ... at the price of increasing theoretical uncertainties (though expected to decrease in the future)

For DM:
- Some existing astrophysical anomalies might (or not) be due to DM annihilation/decay.
- Very contrived/unnatural solution for the positron excess.
- Best indirect detection smoking-gun signals remain:
    1) DSPhs as observed in gamma-rays + gamma-ray lines
    2) HE neutrinos from the Sun
- "second-class" smoking gun: antiproton + antideuteron excesses not seen in B/C
- Antimatter CRs + diffuse emissions more powerful as constraints: other astrophysical processes come in (not completely controlled yet)

***** Complementarity with other detection methods (direct/LHC) is definitely the best strategy.**

# *Diffuse emission: a top bottom approach*

Cosmological simulation:
self-consistent modeling of a galaxy (DM, gas, stars)

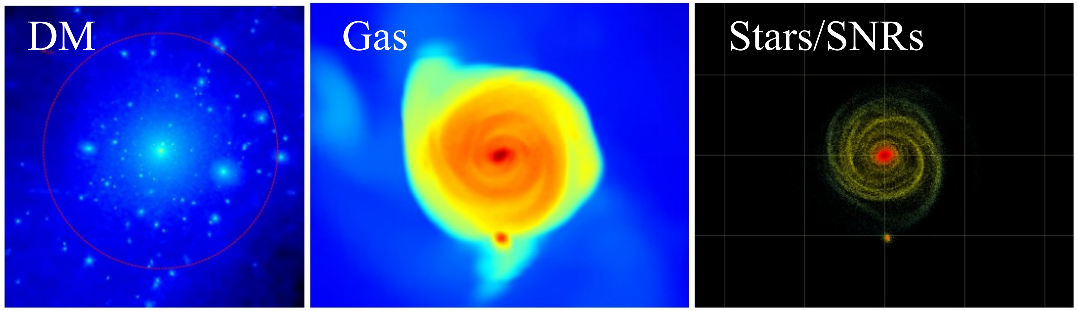
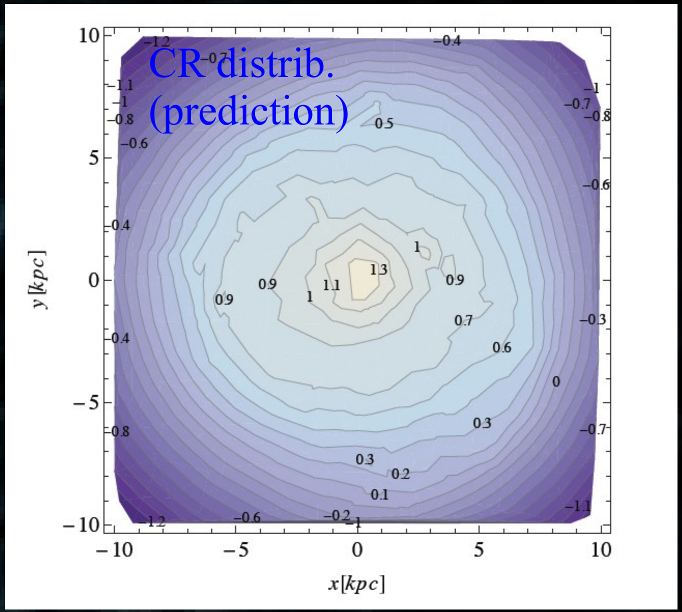
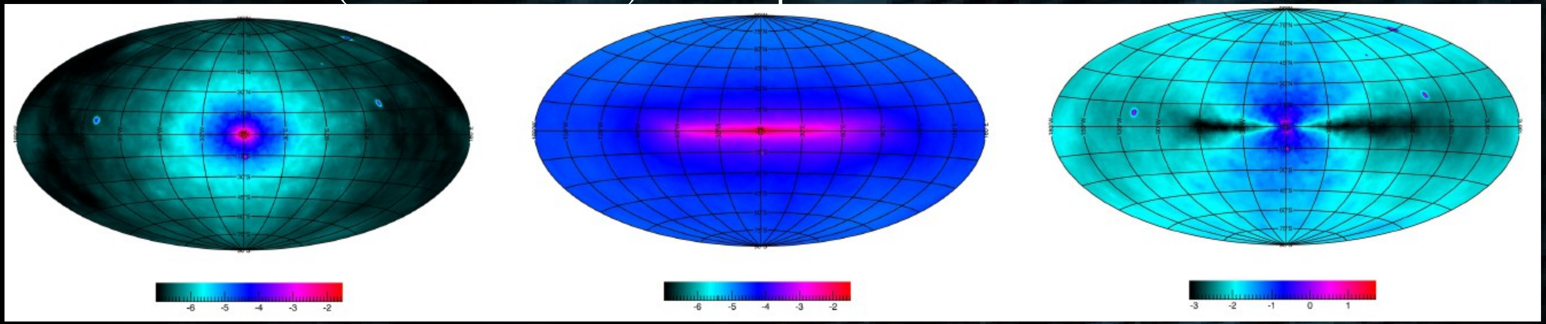



FIG. 1. Left: DM halo and subhalos; the virial radius (264 kpc) appears as a red circle. Middle: top view of the gas content (scaled as in right panel). Right: SN events in the last 500 Myr (10 kpc grid).

1204.4121

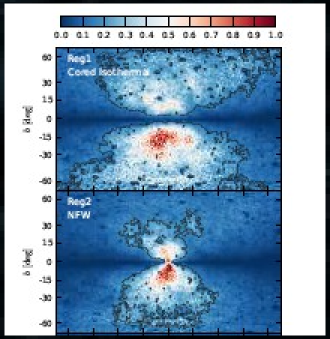



Skymaps:
DM (100 GeV b-bbar) – astro processes – DM/astro



Advantages:
* all ingredients are identified and localized (sources and gas)
* check the relevance of current assumptions
Limits: spatial resolution

=> preliminary results encouraging, work in progress



Compare e.g. with Weniger 12
(optimized region for 130 GeV line)