Positrons and antiprotons from dark matter

Pierre Salati – Université de Savoie & **LAPTH**

Outline

1) Zwicky's legacy

2) CR propagation – uncertainties in the modeling

3) Antiprotons – a robust probe for indirect searches

4) The positron excess – Ockham's triumph

Positrons in Astrophysics – Mürren, Switzerland – March 22, 2012

1) Zwicky's legacy

THE ASTROPHYSICAL JOURNAL

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ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

The determination of the masses of extragalactic nebulae constitutes at present one of the major problems in astrophysics. Masses of nebulae until recently were estimated either from the luminosities of nebulae or from their internal rotations. In this paper it will be shown that both these methods of determining nebular masses are unreliable. In addition, three new possible methods will be outlined.

Fritz Zwicky and the Coma cluster – 1933

As a first approximation, it is probably legitimate to assume that

$$-\overline{E_p} = 2\overline{K_T} = \overline{\sum_\sigma M_\sigma v_\sigma^2} = \sum_\sigma M_\sigma \overline{v_\sigma^2}$$

average square of the velocities of the individual nebulae which con-
stitute this cluster.[5] But even if we drop the assumption that clus-

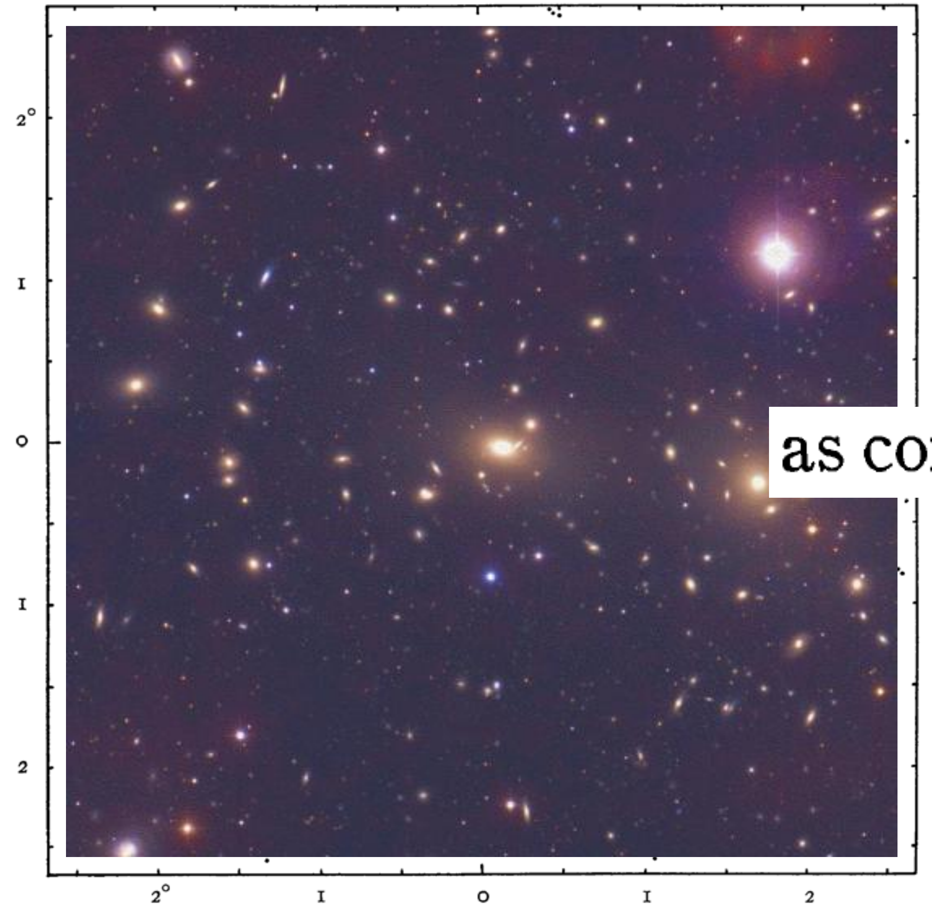


FIG. 3.—The Coma cluster of nebulae

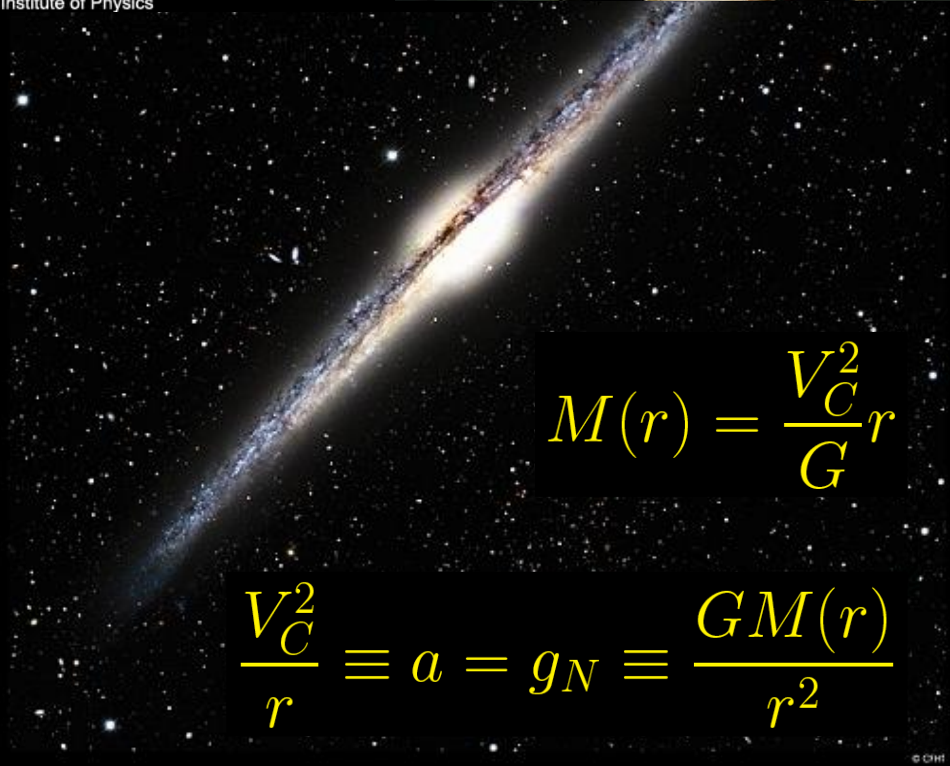
$$\mathcal{M} = \frac{5R\overline{\overline{v^2}}}{3\Gamma}$$

$$\gamma = 500$$

as compared with about $\gamma' = 3$

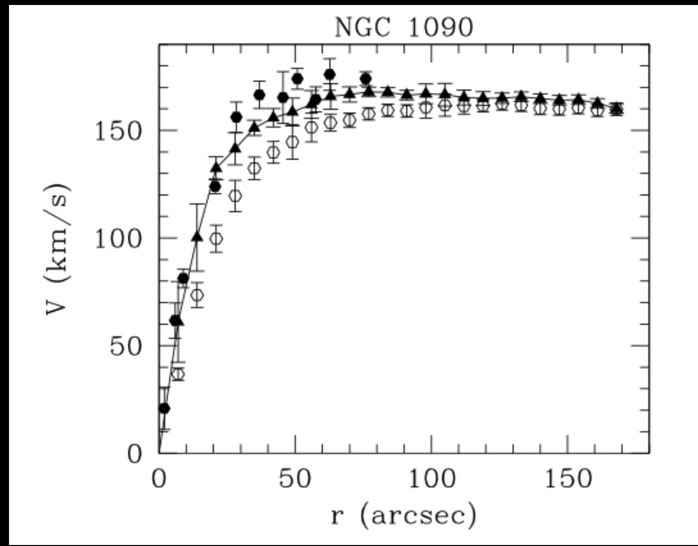
Flat rotation curves of spiral galaxies

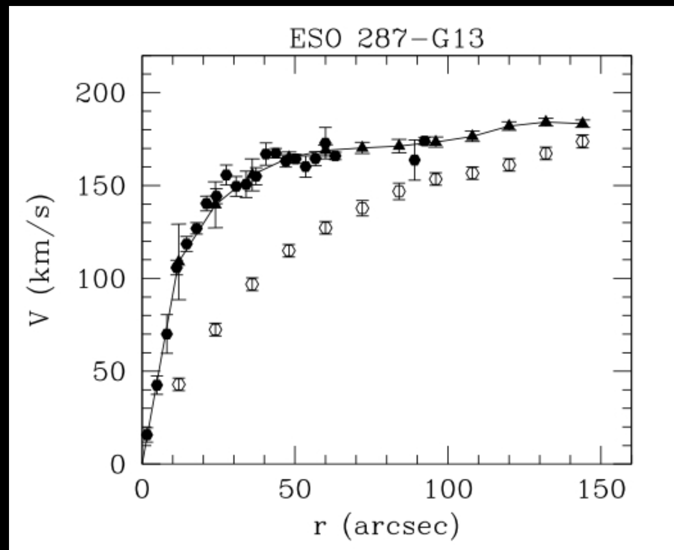
Scanned at the American Institute of Physics



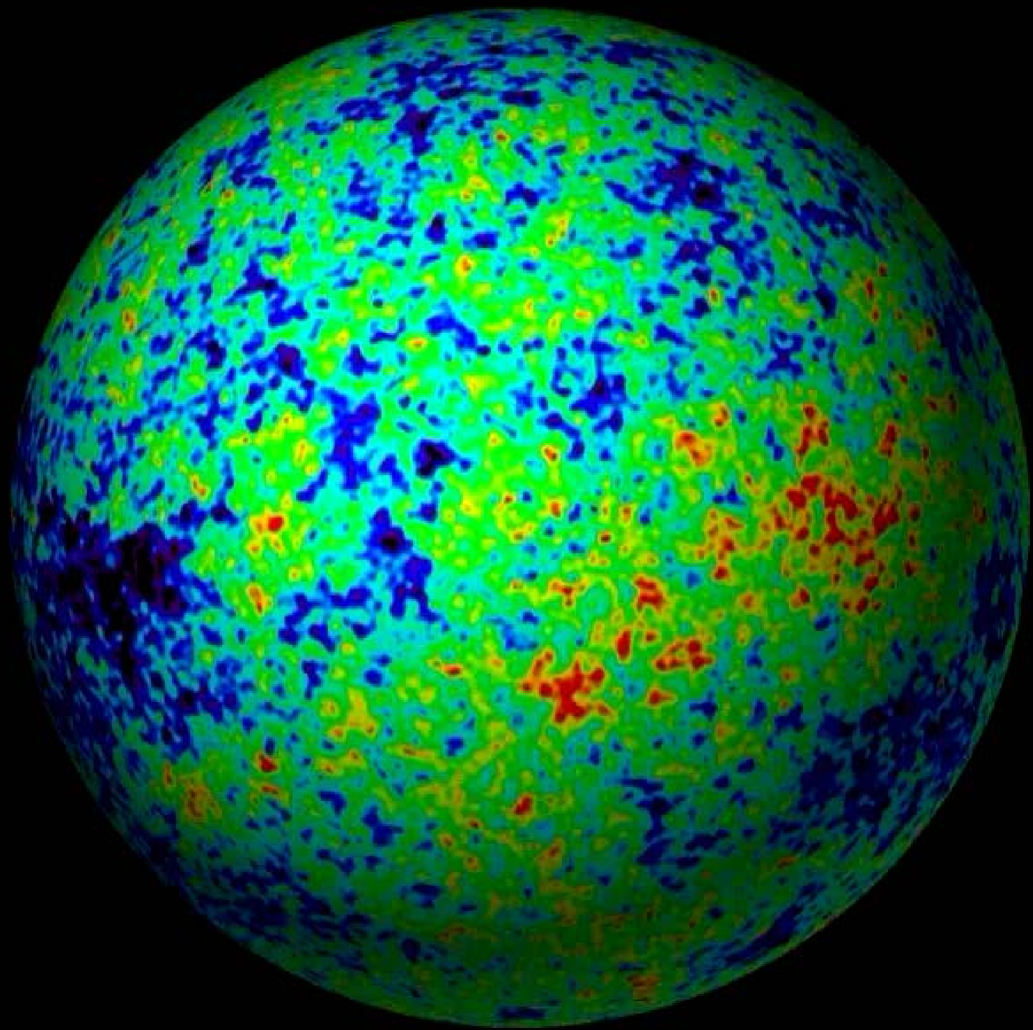
$$M(r) = \frac{V_C^2}{G} r$$

$$\frac{V_C^2}{r} \equiv a = g_N \equiv \frac{GM(r)}{r^2}$$



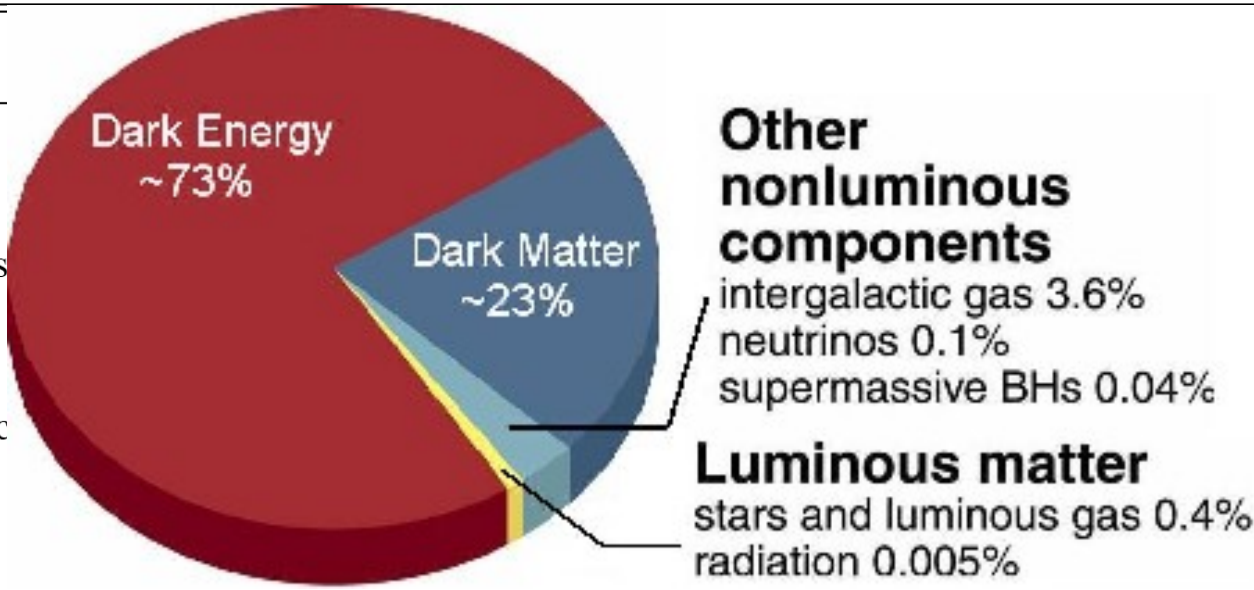


Cosmological micro–wave background



WMAP observations

	y	– uncertainty
Total density		0.02
Equation of state		—
Dark energy dens		0.04
Baryon density		0.0009
Baryon density		0.004
Baryon density (c		0.1×10^{-7}
Matter density		0.009
Matter density		0.04



- The Univers is **flat** $\Omega_{\rm tot} = 1.02$
- A new intriguing component – dark energy – $\Omega_\Lambda = 0.73$
- Dark and **exotic** matter on cosmological scales since

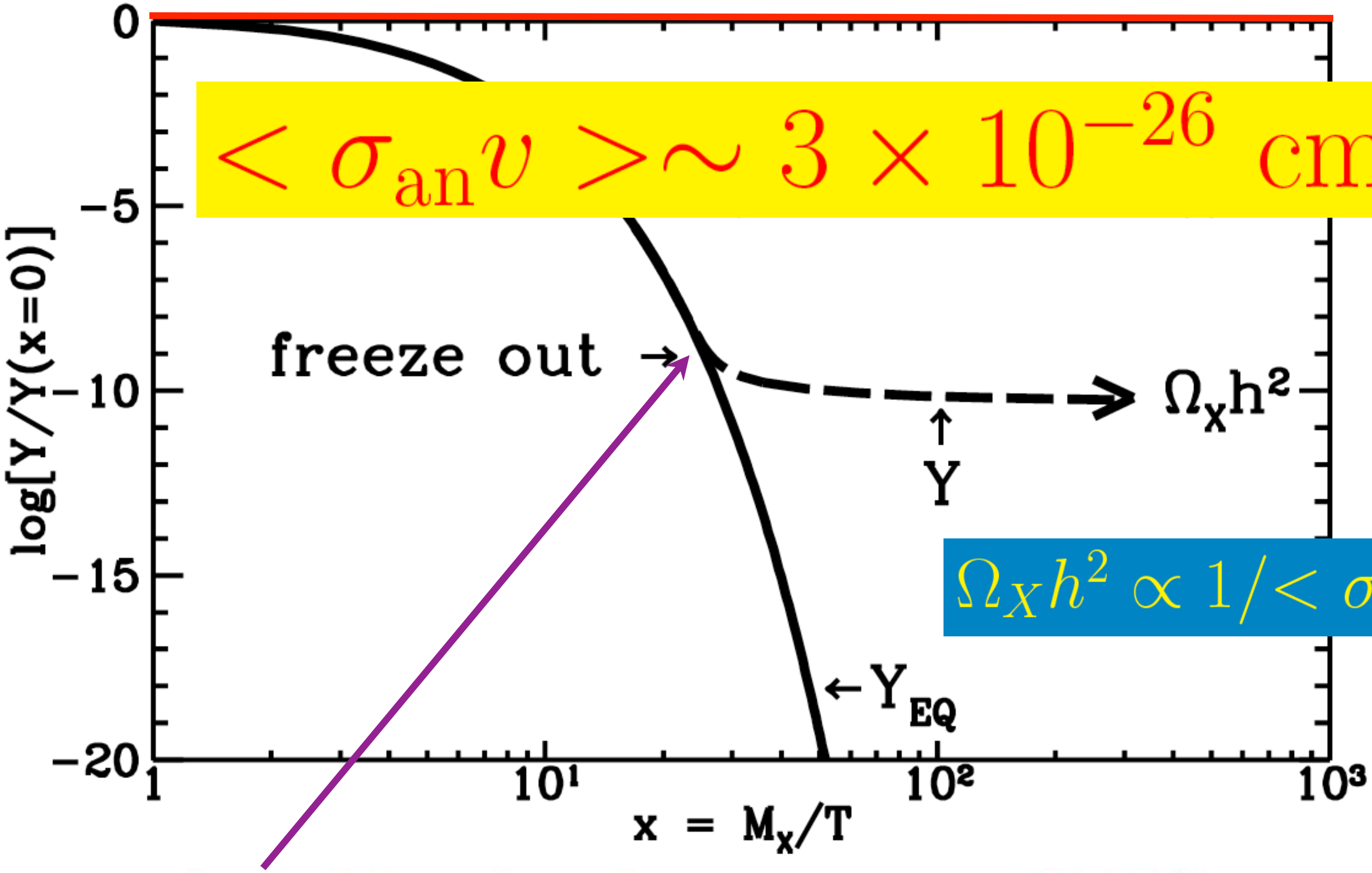
$$\Omega_{\rm M} = 0.27 > \Omega_{\rm B} = 0.044$$

Thermodynamical equilibrium production

$$A + \overline{A} \rightleftharpoons f + \overline{f}$$

$$\frac{dn_X}{dt} = -3Hn_X - <\sigma_{\rm an}v> {n_X}^2 + <\sigma_{\rm an}v> {n^0_X}^2$$

thermal decoupling when $\Gamma_{\rm coll} \sim H_F$ (UR)



$$< \sigma_{\rm an} v > \sim 3 \times 10^{-26}\ {\rm cm}^3\ {\rm s}^{-1}$$

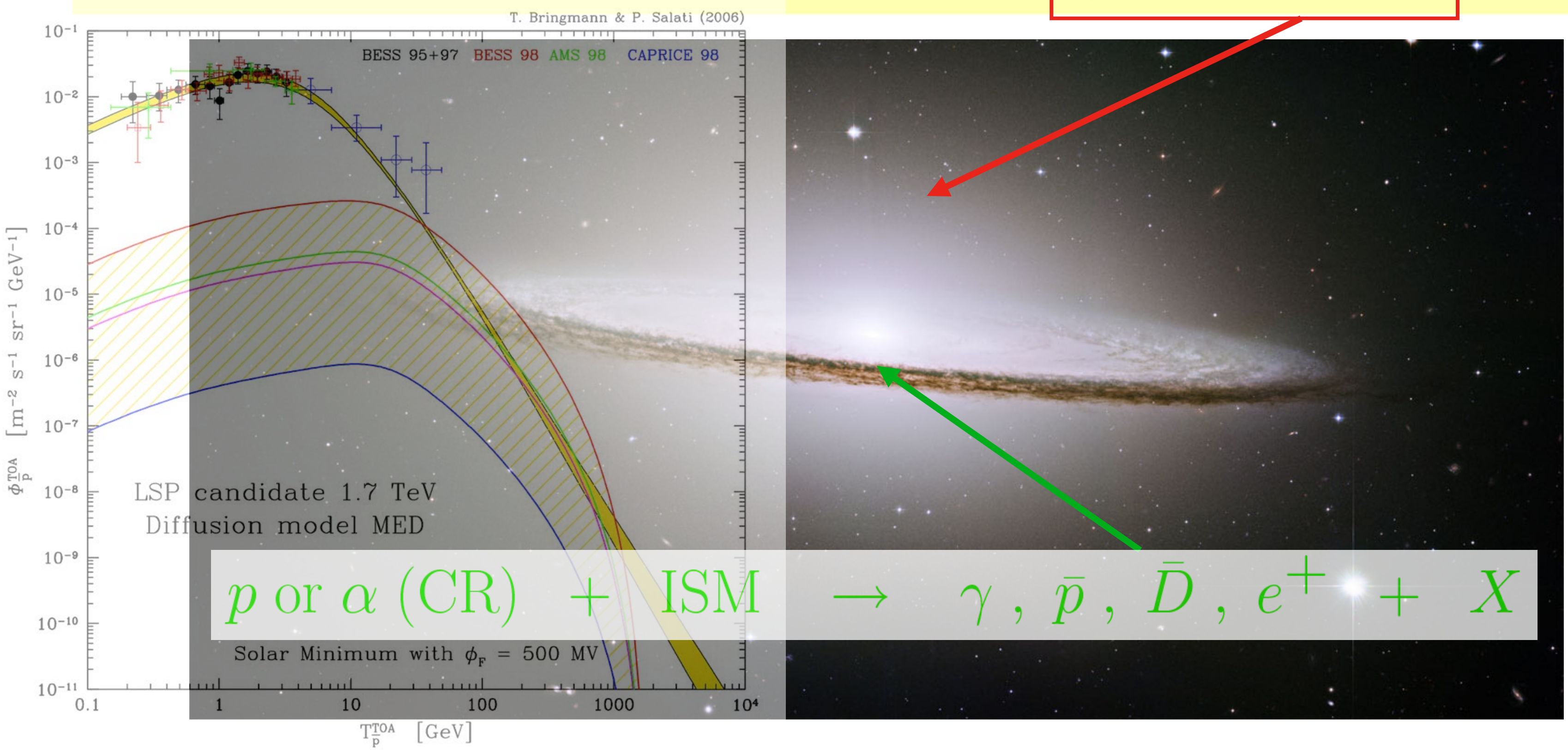
$$\Omega_X h^2 \propto 1/<\sigma_{\rm an} v>$$

chemical decoupling when $<\sigma_{\rm an}v> n_X \sim H_F$ (NR)

Indirect signatures of DM species

Weakly Interacting Massive particles – WIMPs – may be the major component of the haloes of galaxies. Their mutual annihilations would produce an indirect signature of high–energy cosmic rays :

$$\chi + \chi \to q\bar{q}, W^{+}W^{-}, \ldots \to \gamma, \bar{p}, \ \bar{D}, \ e^{+} \ \& \ \nu's$$

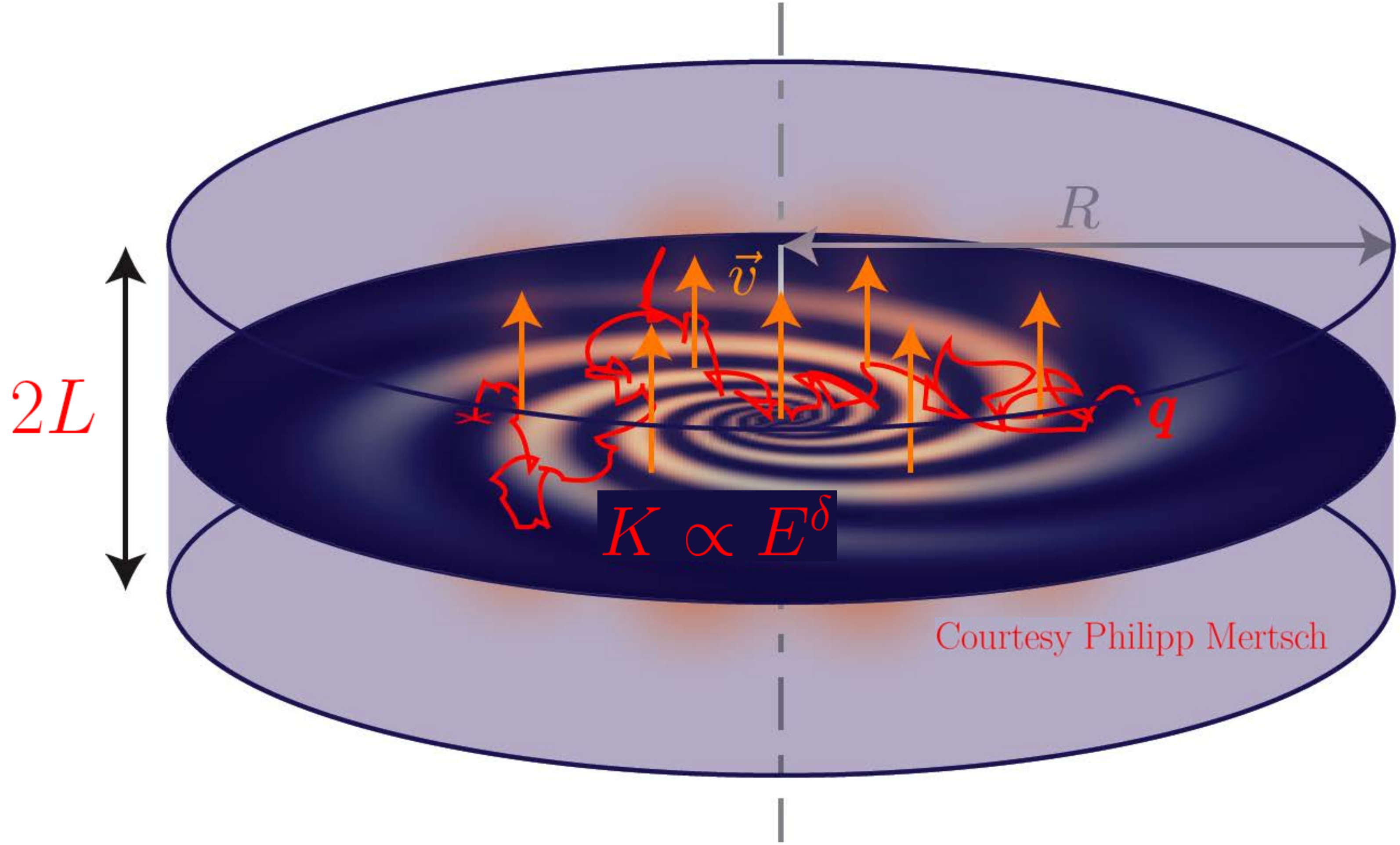


$$p \text{ or } \alpha \text{ (CR)} \ + \ \text{ISM} \ \to \ \gamma \, , \, \bar{p} \, , \, \bar{D} \, , \, e^{+} \ + \ X$$

CR particles are already manufactured inside the galactic disc

2) CR propagation – uncertainties in the modeling

Milky–Way seen by a cosmic–ray physicist



Cosmic rays propagate inside a diffusive halo

D. Maurin, R. Taillet, F. Donato, P. Salati, A. Barrau and G. Boudoul, *Galactic cosmic ray nuclei as a tool for astroparticle physics*, [astro-ph/0212111].

Cosmic–rays diffuse in space and energy

- A propagation model is characterized by the set δ, K_0, L, V_C, V_a

Case	δ	K_0 [kpc^2/Myr]	L [kpc]	V_C [km/s]	V_a [km/s]
max	0.46	0.0765	15	5	117.6
med	0.70	0.0112	4	12	52.9
min	0.85	0.0016	1	13.5	22.4

- Different methods to solve the CR diffusion equation

The semi–analytic approach – radial Bessel expansion & Green functions

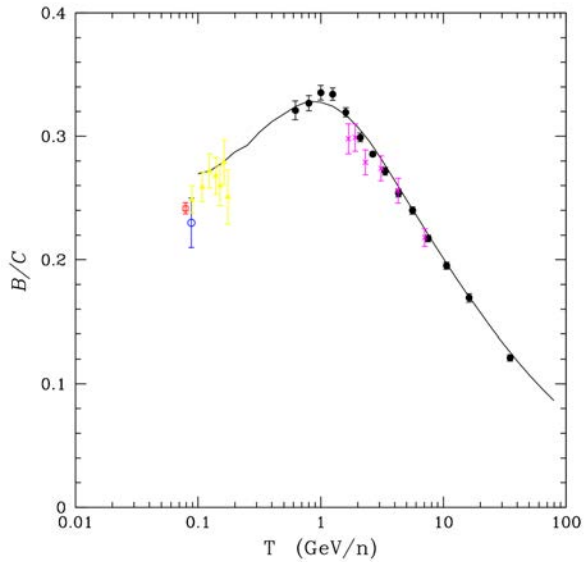
The numerical Galprop code – Crank–Nicholson semi–implicit scheme

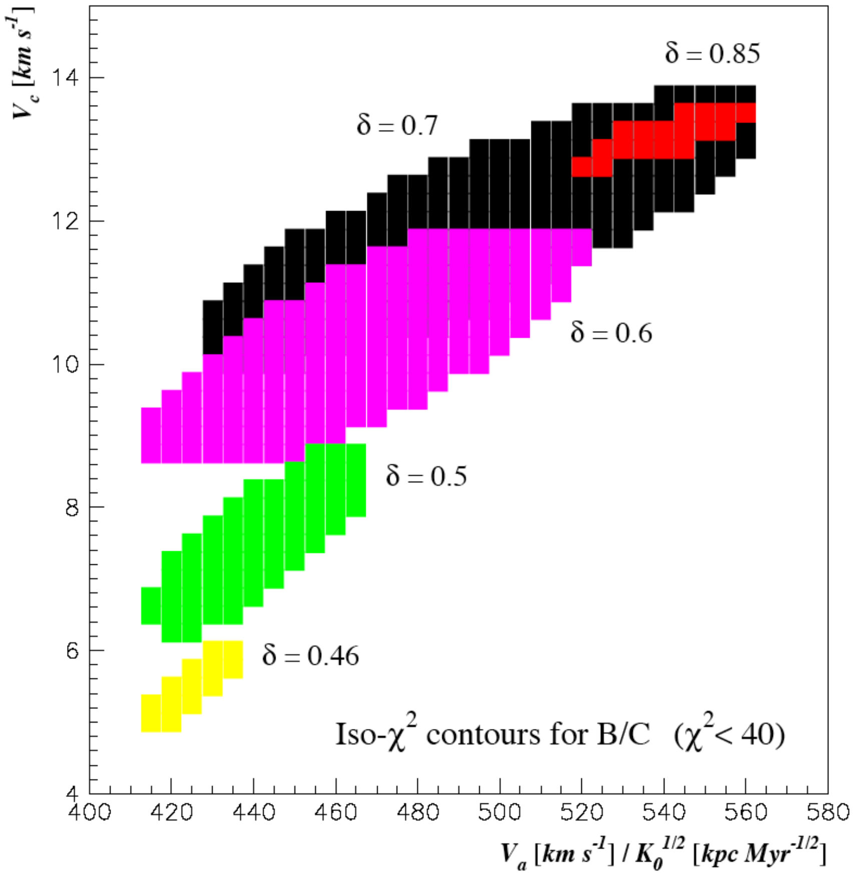
- Constraints from the typical secondary to primary B/C ratio

$$V_C \partial_z \Psi \; - \; K \, \Delta\Psi \; + \; \partial_E \left\{ b^{\rm loss}(E) \, \Psi \; - \; K_{EE}(E) \, \partial_E \Psi \right\} \; = \; Q$$

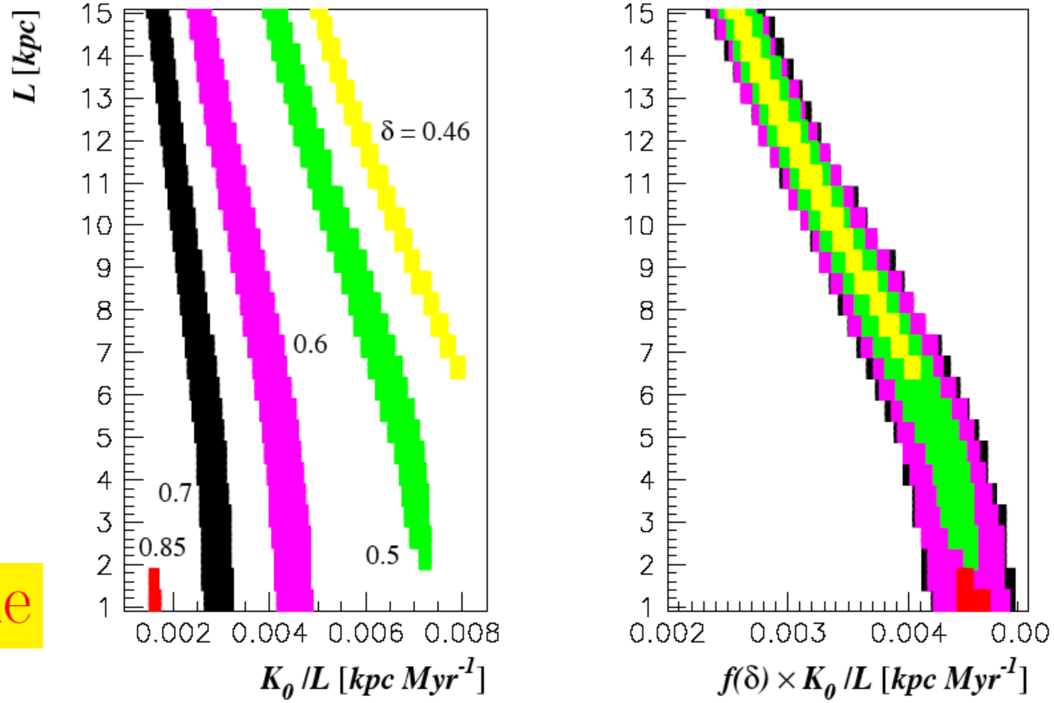
B/C ratio analysis – D. Maurin et al.

THE ASTROPHYSICAL JOURNAL, 555:585–596, 2001 July 10





Iso-χ^2 contours for B/C ($\chi^2 < 40$)

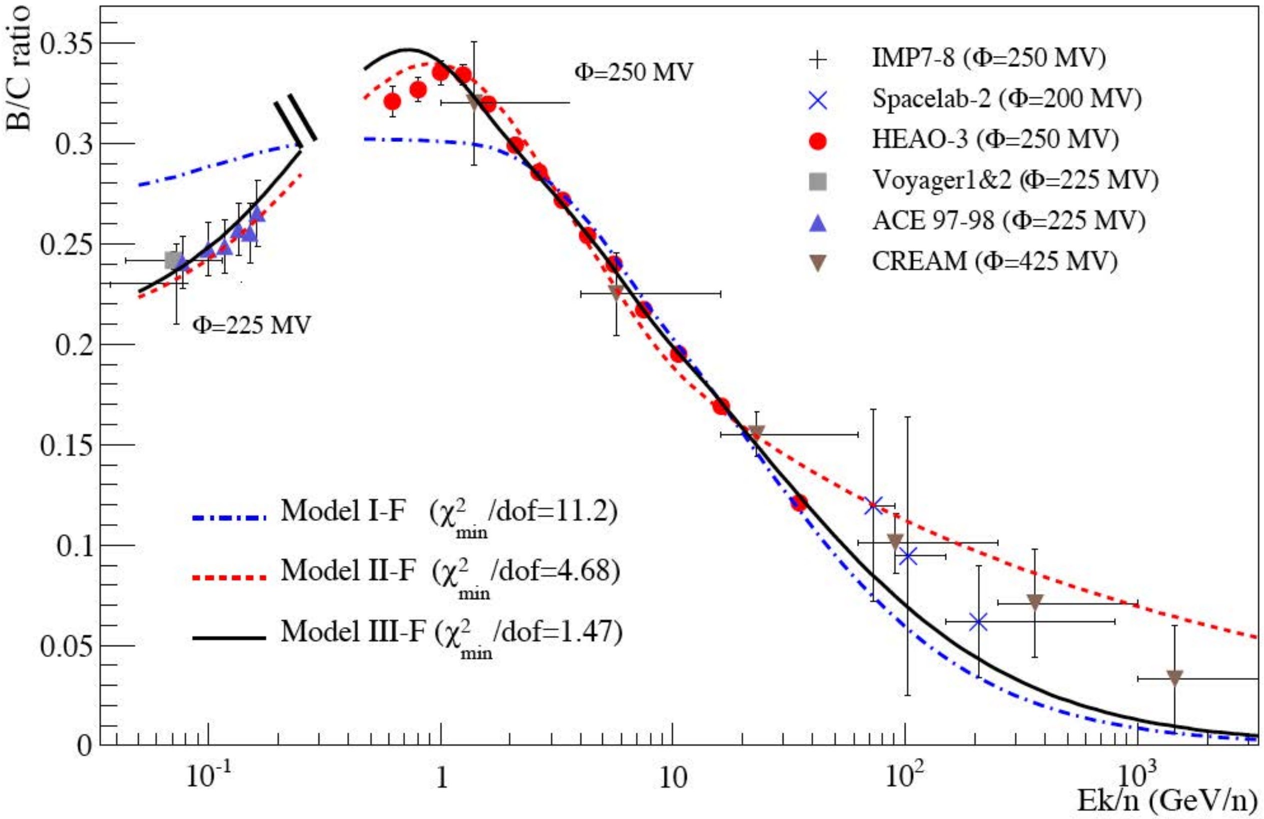


∼ 1,600 models are compatible

A Markov Chain Monte Carlo technique to sample transport and source parameters of Galactic cosmic rays

II. Results for the diffusion model combining B/C and radioactive nuclei

A. Putze[1,2], L. Derome[2], and D. Maurin[3,4,5]



USINE code soon public !

arXiv:1001.0551v1 [astro-ph.HE] 4 Jan 2010

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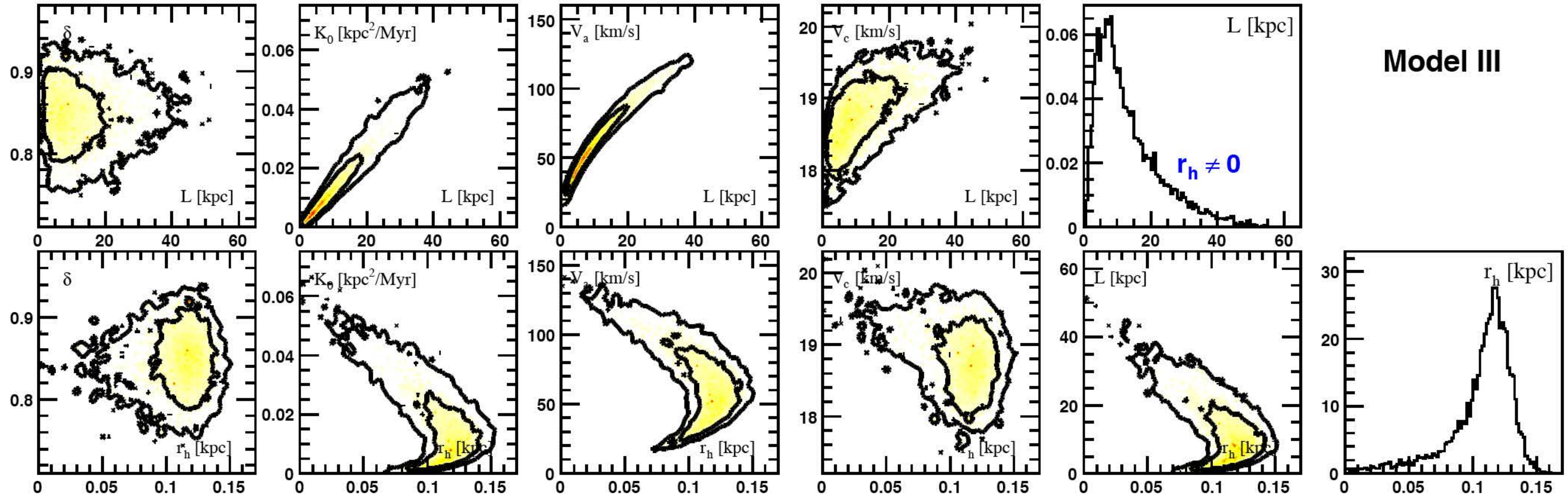

Fig. 7. Model III (diffusion/convection/reacceleration): same as in Fig. 6. The transport parameters are now δ, K_0, V_a and V_c, with the geometrical parameters L and r_h.

	$K_0 \times 10^2$ $(\mathrm{kpc^2 Myr^{-1}})$	δ	V_c $(\mathrm{km\,s^{-1}})$	V_a $(\mathrm{km\,s^{-1}})$	L (kpc)	r_h (pc)
III	$0.8^{+1}_{-0.7}$	$0.86^{+0.03}_{-0.04}$	$18.7^{+0.5}_{-0.4}$	55^{+31}_{-21}	8^{+8}_{-7}	120^{+20}_{-20}

CONSTRAINTS ON COSMIC-RAY PROPAGATION MODELS FROM A GLOBAL BAYESIAN ANALYSIS

R. TROTTA[1], G. JÓHANNESSON[2], I. V. MOSKALENKO[3,4], T. A. PORTER[3], R. RUIZ DE AUSTRI[5], AND A. W. STRONG[6]

Draft version January 10, 2011

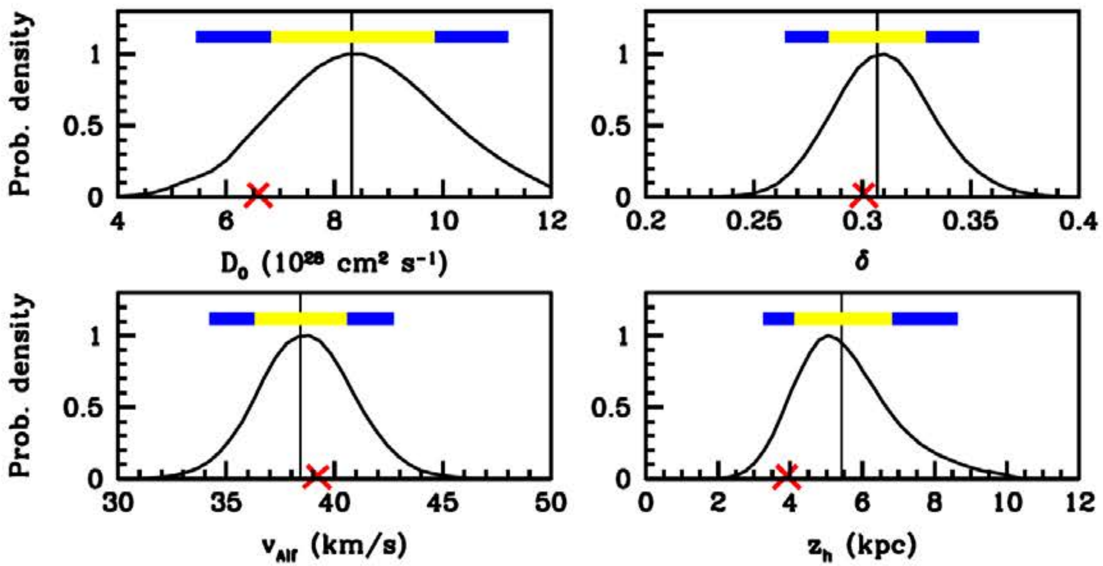

FIG. 1.— 1D marginalized posterior pdf normalized to the peak for the diffusion model parameters, with uniform priors assumed over the parameter ranges as in Table 1. The red cross represents the best fit, the vertical thin line the posterior mean, and the horizontal bar the 68% and 95% error ranges (yellow/blue, respectively). The bottom-right panel shows the pdf for the spectral index break.

Quantity	Best fit value	Posterior mean and standard deviation	Posterior 95% range
DIFFUSION MODEL PARAMETERS Θ			
$D_0 (10^{28}\ \mathrm{cm}^2\ \mathrm{s}^{-1})$	6.59	8.32 ± 1.46	$[5.45, 11.20]$
δ	0.30	0.31 ± 0.02	$[0.26, 0.35]$
v_{Alf} (km s^{-1})	39.2	38.4 ± 2.1	$[34.2, 42.7]$
z_h (kpc)	3.9	5.4 ± 1.4	$[3.2, 8.6]$
ν_1	1.91	1.92 ± 0.04	$[1.84, 2.00]$
ν_2	2.40	2.38 ± 0.04	$[2.29, 2.47]$
N_p (10^{-9} cm^2 sr^{-1} s^{-1} MeV^{-1})	5.00	5.20 ± 0.48	$[4.32, 6.23]$

 $V_C = 0$

A Markov Chain Monte Carlo technique to sample transport and source parameters of Galactic cosmic rays

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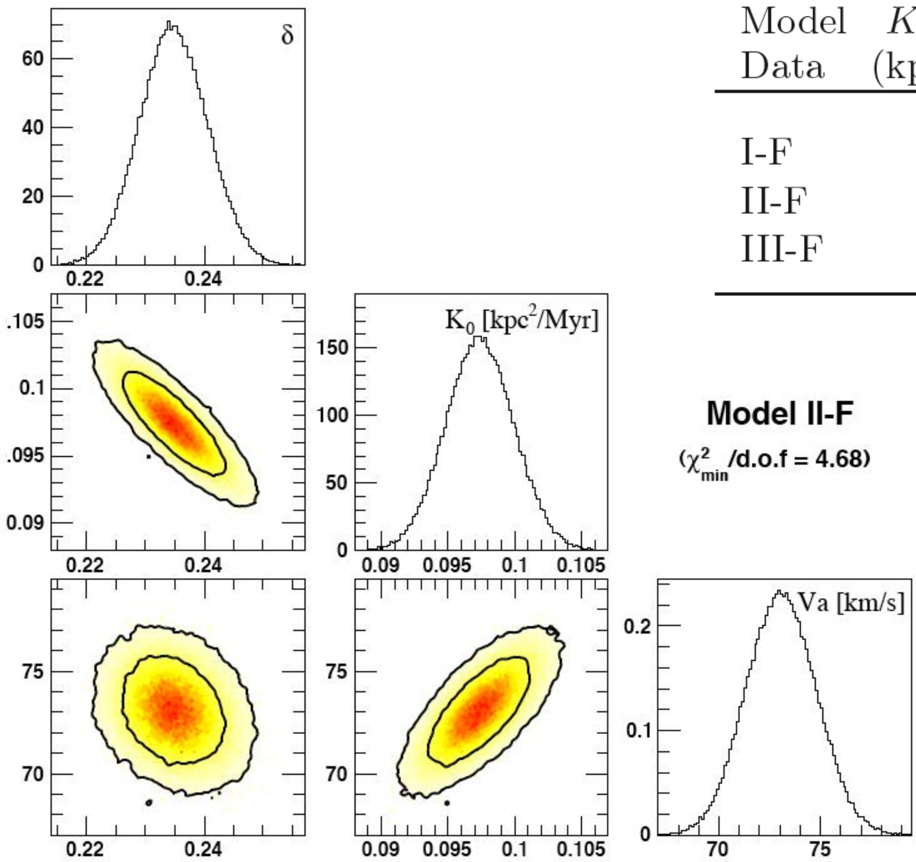

Model Data	$K_0^{best} \times 10^2$ (kpc^2 Myr^{-1})	δ^{best}	V_c^{best} (km s^{-1})	V_a^{best} (km s^{-1})	χ^2/d.o.f
I-F	0.42	0.93	13.5	...	11.2
II-F	9.74	0.23	...	73.1	4.68
III-F	0.48	0.86	18.8	38.0	1.47

$$V_C = 0$$

$$\Downarrow$$

USINE & GALPROP agree

Model Data	$K_0^{\rm best} \times 10^2$ (kpc^2 Myr^{-1})	$\delta^{\rm best}$	$V_c^{\rm best}$ (km s^{-1})	$V_a^{\rm best}$ (km s^{-1})	χ^2/d.o.f
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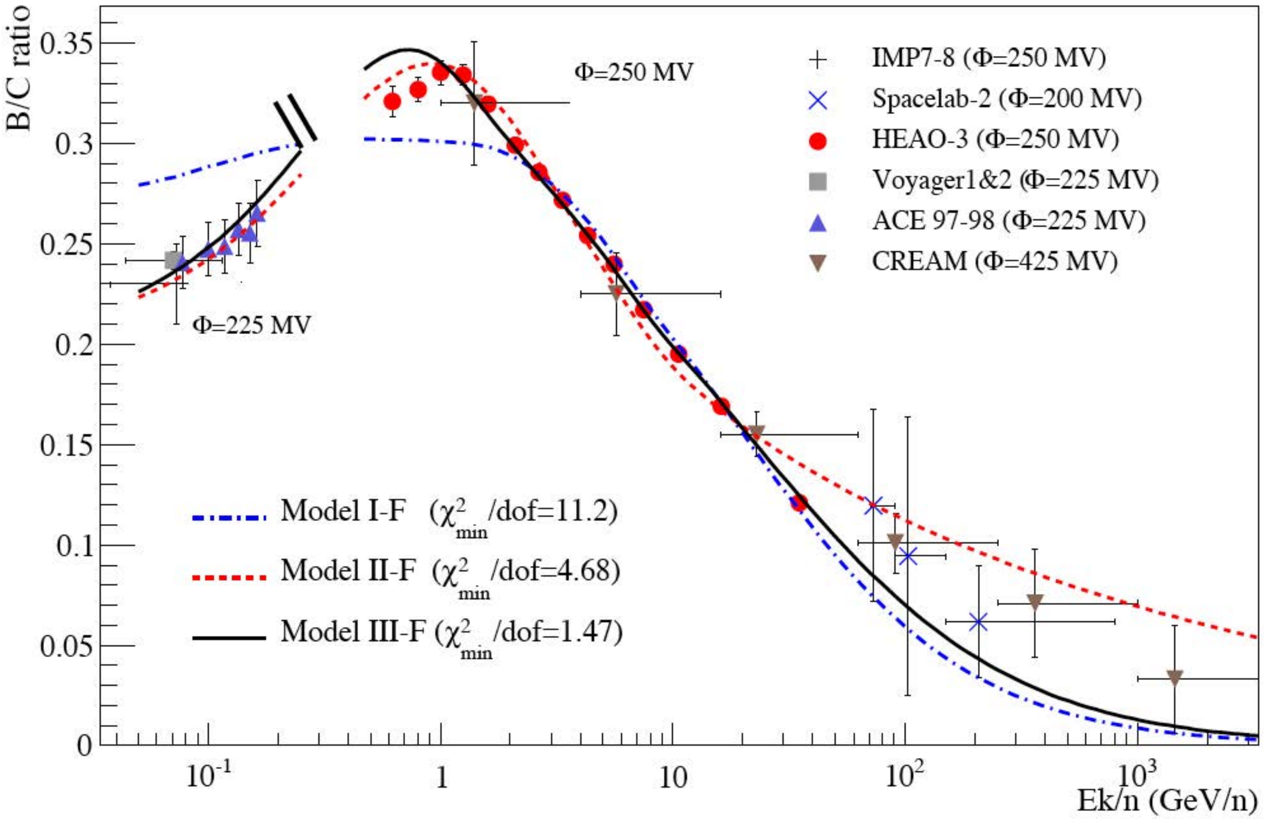


USINE code soon public !

arXiv:1001.0551v1 [astro-ph.HE] 4 Jan 2010

3) Antiprotons – a robust probe for indirect searches

Space diffusion dominates in the master equation

$$V_C\,\partial_z\Psi \;-\; K\,\Delta\Psi \;+\; \partial_E\left\{b^{\rm loss}(E)\,\Psi \;-\; K_{EE}(E)\,\partial_E\Psi\right\} \;=\; Q$$

Poisson equation $K\,\Delta\Psi \;+\; Q \;=\; 0$

$$\Downarrow$$

Long range with $G_{\bar{\rm p}}^{\rm 3D}(r) \;=\; \dfrac{Q}{4\pi K r}$

- Evaporation at the vertical boundaries $\pm L$
- Leakage at the radial boundaries $R = 20$ kpc
- Evaporation from convective wind V_C
- Annihilations inside the MW gaseous disk
- Energy losses and mild diffusive reacceleration

Antiproton Production in the Galaxy

- **Secondary** antiprotons are produced through the spallations of cosmic–ray protons on the interstellar material.

$$p\,(\mathrm{CR}) \;+\; H\,(\mathrm{ISM}) \;\;\rightarrow\;\; \bar{\mathrm{p}} \;+\; X$$

$$\Downarrow$$

$$q_{\bar{\mathrm{p}}}^{\mathrm{sec}}(r, E_{\bar{\mathrm{p}}}) \;=\; \int_{E_{\mathrm{p}}^{0}}^{+\infty} \frac{d\sigma_{\mathrm{pH}\rightarrow\bar{\mathrm{p}}}}{dE_{\bar{\mathrm{p}}}} \left\{E_{\mathrm{p}} \rightarrow E_{\bar{\mathrm{p}}}\right\} \; n_{\mathrm{H}} \, v_{\mathrm{p}} \, \psi_{\mathrm{p}}(r, E_{\mathrm{p}}) \, dE_{\mathrm{p}}$$

- **Primary** antiprotons originate from the annihilations of the dark matter particles – LKP and LZP species here – concealed inside the galactic halo.

$$\chi \;+\; \chi \;\;\rightarrow\;\; q \;+\; \bar{q} \;\;\rightarrow\;\; \bar{\mathrm{p}} \;+\; X$$

$$\Downarrow$$

$$q_{\bar{\mathrm{p}}}^{\mathrm{susy}}(r, z, E_{\bar{\mathrm{p}}}) \;=\; \frac{1}{2} \langle \sigma_{\mathrm{ann}} v \rangle \, g\left(T_{\bar{\mathrm{p}}}\right) \, \left\{ \frac{\rho_{\chi}(r, z)}{m_{\chi}} \right\}^{2}$$

Retropropagating CR p and α nuclei throughout the DH

Master CR propagation equation

$$\partial_z (V_C \psi) - K \Delta\psi = q(\mathbf{x}, T)$$

T and $\mathbf{x}$ disentangled in source production term

$$q(\mathbf{x}, T) = 2h\,\delta(z)\,\{\rho(r,z)\,Q_{\rm tot}(T) - \Gamma\psi\}$$

$$\Gamma_p = v_p \left\{\sigma_{p\rm H}\, n_{\rm H} + \sigma_{p\rm He}\, n_{\rm He}\right\}$$

5 minutes of CPU time on a PC to scan 1,600 models

$$\psi(r,z,T) = \sum_{i=1}^{\infty} P_i(T) \times \exp\left(\frac{V_C |z|}{2K}\right) \times \left\{\sinh\left[\frac{S_i}{2}(L-|z|)\right] / \sinh\left[\frac{S_i}{2}L\right]\right\} \times J_0(\alpha_i\, r/R_{\rm Gal})$$

$$P_i(T) = \frac{q_i}{A_i} \times Q_{\rm tot}(T)$$

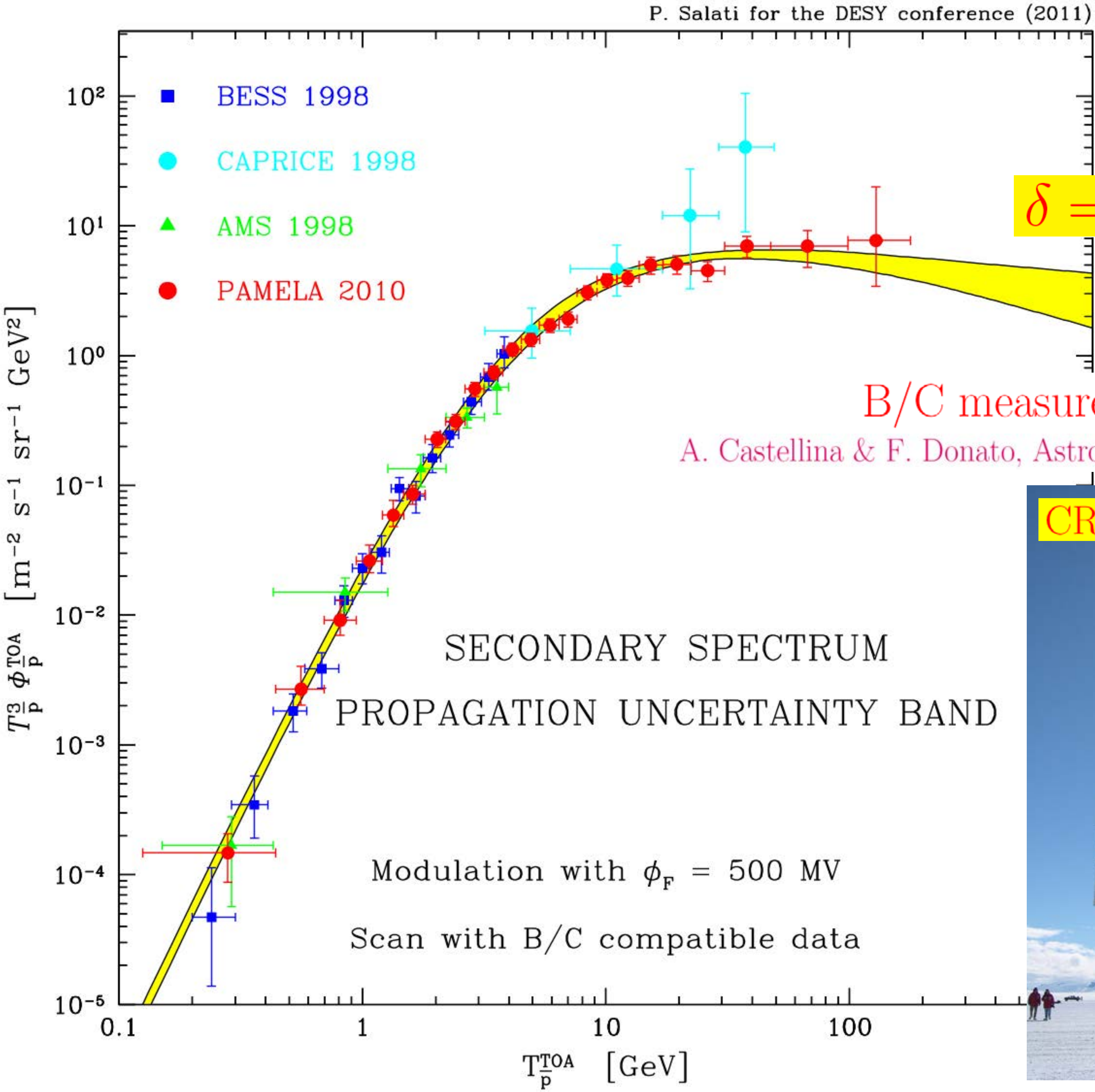
$$S_i(T) = \sqrt{\left(\frac{2\alpha_i}{R_{\rm Gal}}\right)^2 + \frac{V_C^2}{K^2}}$$

$$A_i(T) = K S_i \coth\left(\frac{S_i L}{2}\right) + V_C + 2h\Gamma$$

$$q_i = \frac{1}{J_1^2(\alpha_i)} \times \frac{1}{\pi R_{\rm Gal}^2} \times \left\{\int_0^1 u\,du\, J_0(\alpha_i u)\,\rho(r = uR_{\rm Gal}, 0)\right\} / \left\{\int_0^1 u\,du\,\rho(r = uR_{\rm Gal}, 0)\right\}$$

(SNR radial profile) (SNR radial profile)

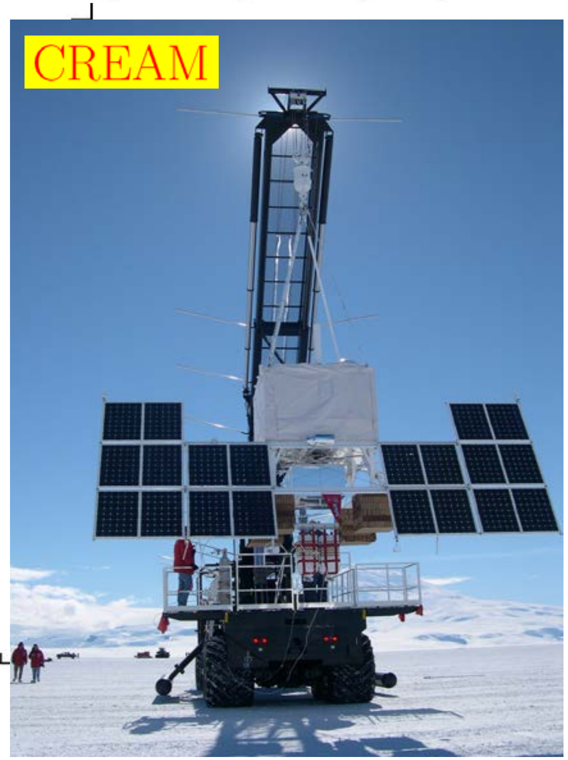
$$\Phi_p(\odot, T) = \frac{1}{4\pi} v_p\, \psi_p(\odot, T) \quad \text{and} \quad \Phi_\alpha(\odot, T) = \frac{1}{4\pi} v_\alpha\, \psi_\alpha(\odot, T)$$



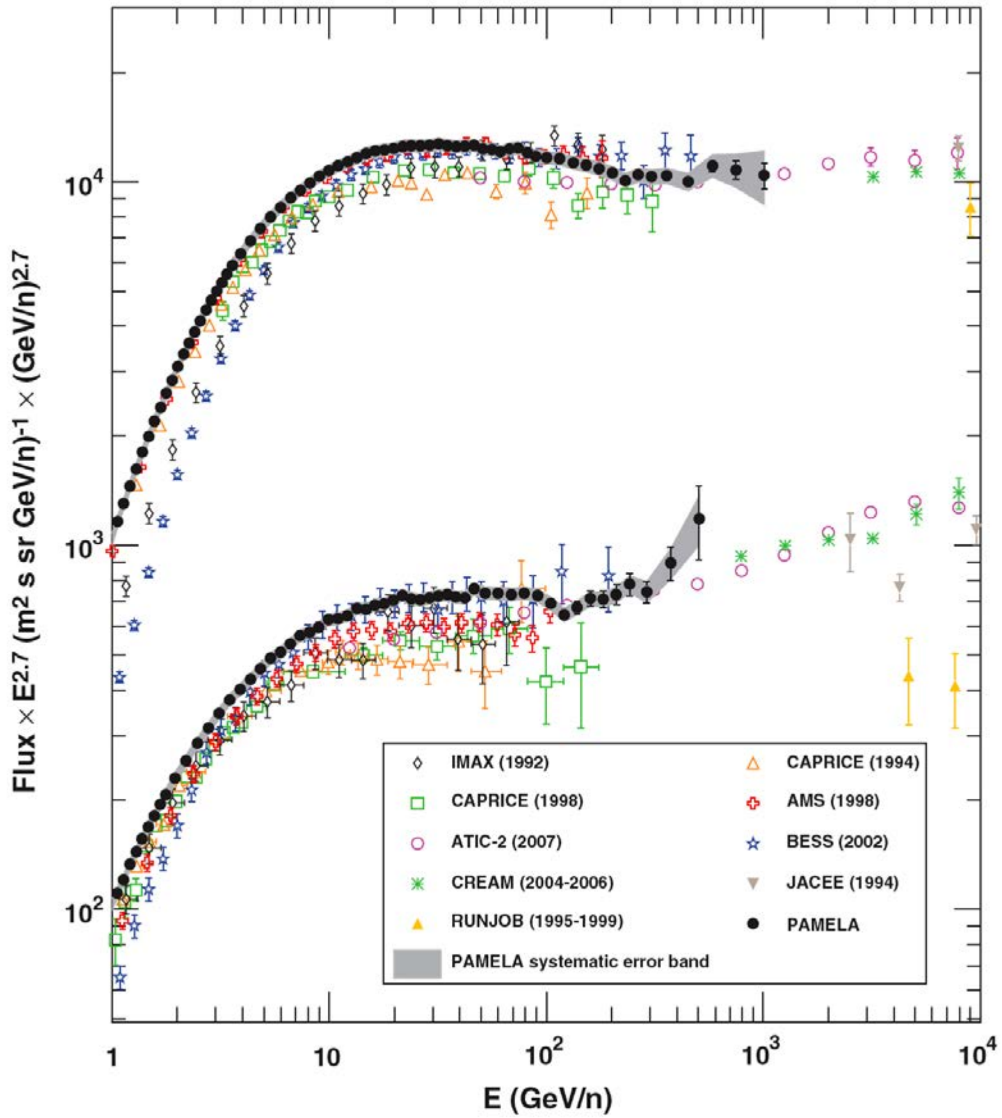
$\delta = 0.46$ to 0.85

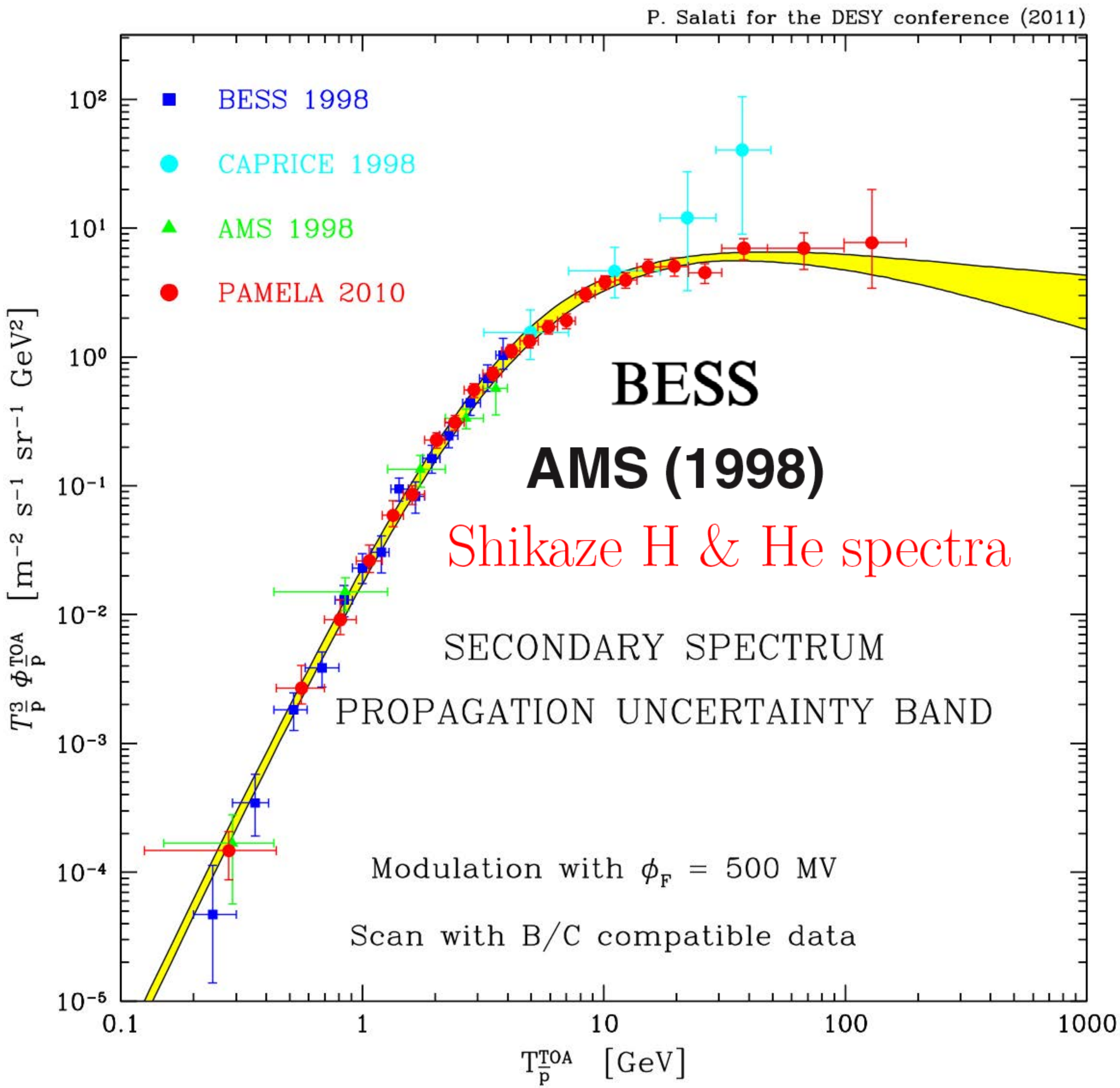
B/C measurements @ high E

A. Castellina & F. Donato, Astropart. Phys. **24** (2005) 146-159

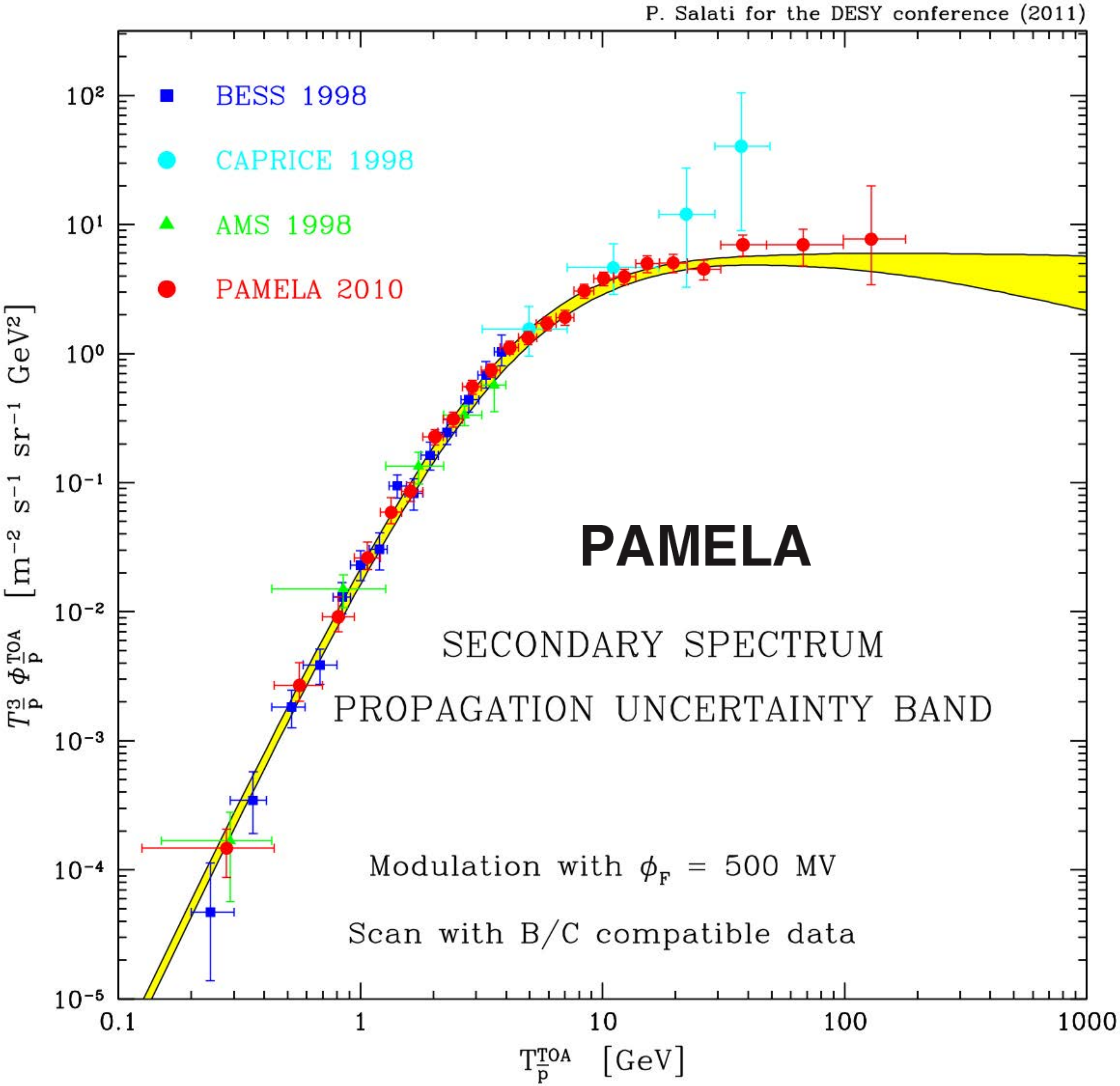


PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra





P. Salati for the DESY conference (2011)
BESS 1998
CAPRICE 1998
AMS 1998
PAMELA 2010
BESS
AMS (1998)
Shikaze H & He spectra
SECONDARY SPECTRUM
PROPAGATION UNCERTAINTY BAND
Modulation with ϕ_F = 500 MV
Scan with B/C compatible data
$T^3_{\bar{p}} \Phi^{TOA}_{\bar{p}}$ [m^{-2} s^{-1} sr^{-1} GeV^2]
$T^{TOA}_{\bar{p}}$ [GeV]



www.sciencemag.org **SCIENCE** VOL 332 1 APRIL 2011

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$$p\,(\mathrm{CR}) \;+\; H\,(\mathrm{ISM}) \;\rightarrow\; \bar{\mathrm{p}} \;+\; X$$

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$$\Downarrow$$

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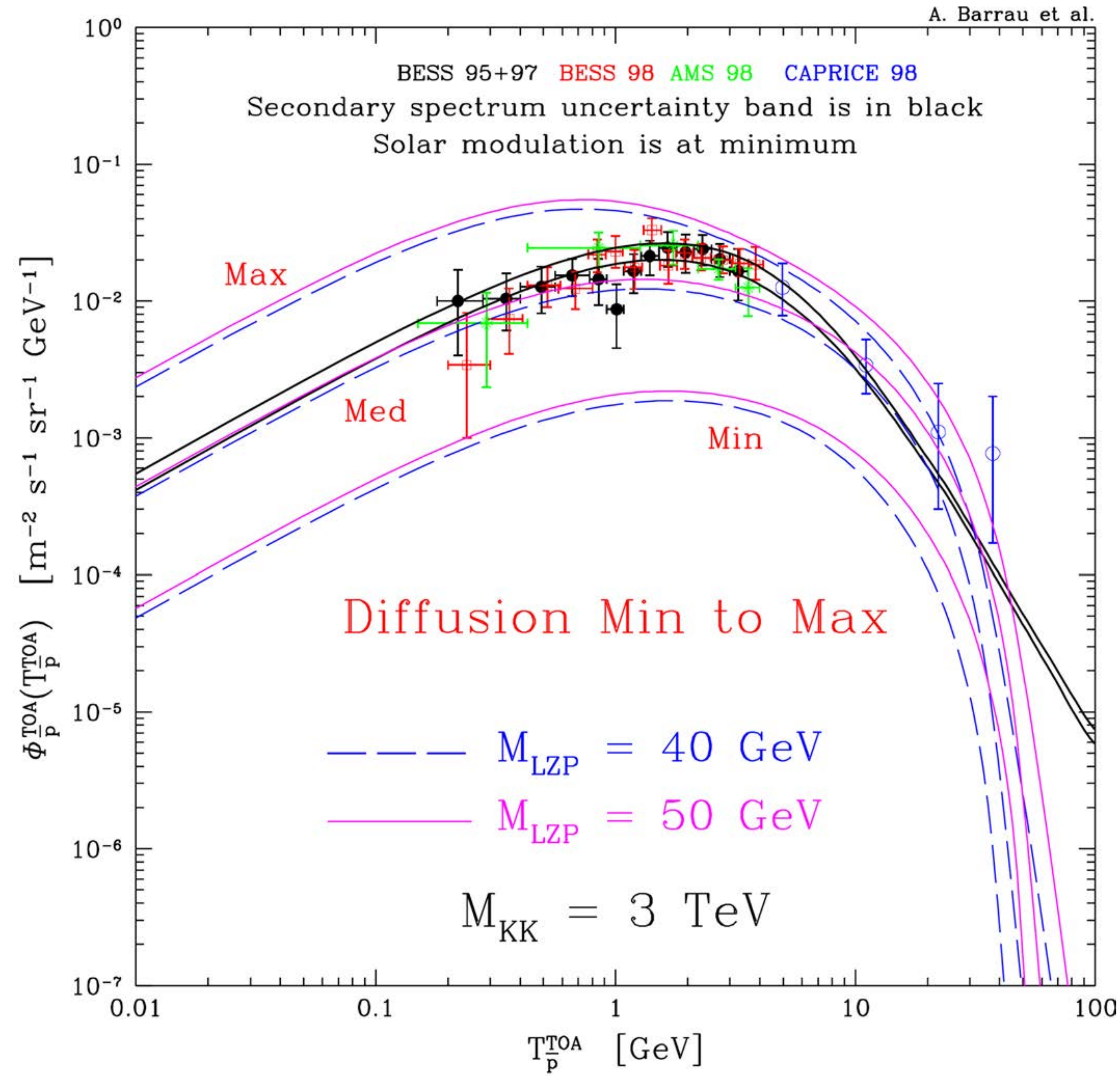
Galactic CR propagation is uncertain

case	δ	K_0(kpc^2/Myr)	L(kpc)	V_c(km/sec)	V_A(km/sec)
max	0.46	0.0765	15	5	117.6
med	0.70	0.0112	4	12	52.9
min	0.85	0.0016	1	13.5	22.4

Astrophysical parameters giving the maximal, medium and minimal LZP antiproton flux and compatible wih B/C analysis


A. Barrau et al.
BESS 95+97 BESS 98 AMS 98 CAPRICE 98
Secondary spectrum uncertainty band is in black
Solar modulation is at minimum
Max
Med
Min
Diffusion Min to Max
M_LZP = 40 GeV
M_LZP = 50 GeV
M_KK = 3 TeV
Φ_p̄^TOA(T_p̄^TOA) [m^-2 s^-1 sr^-1 GeV^-1]
T_p̄^TOA [GeV]
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.01
0.1
1
10
100

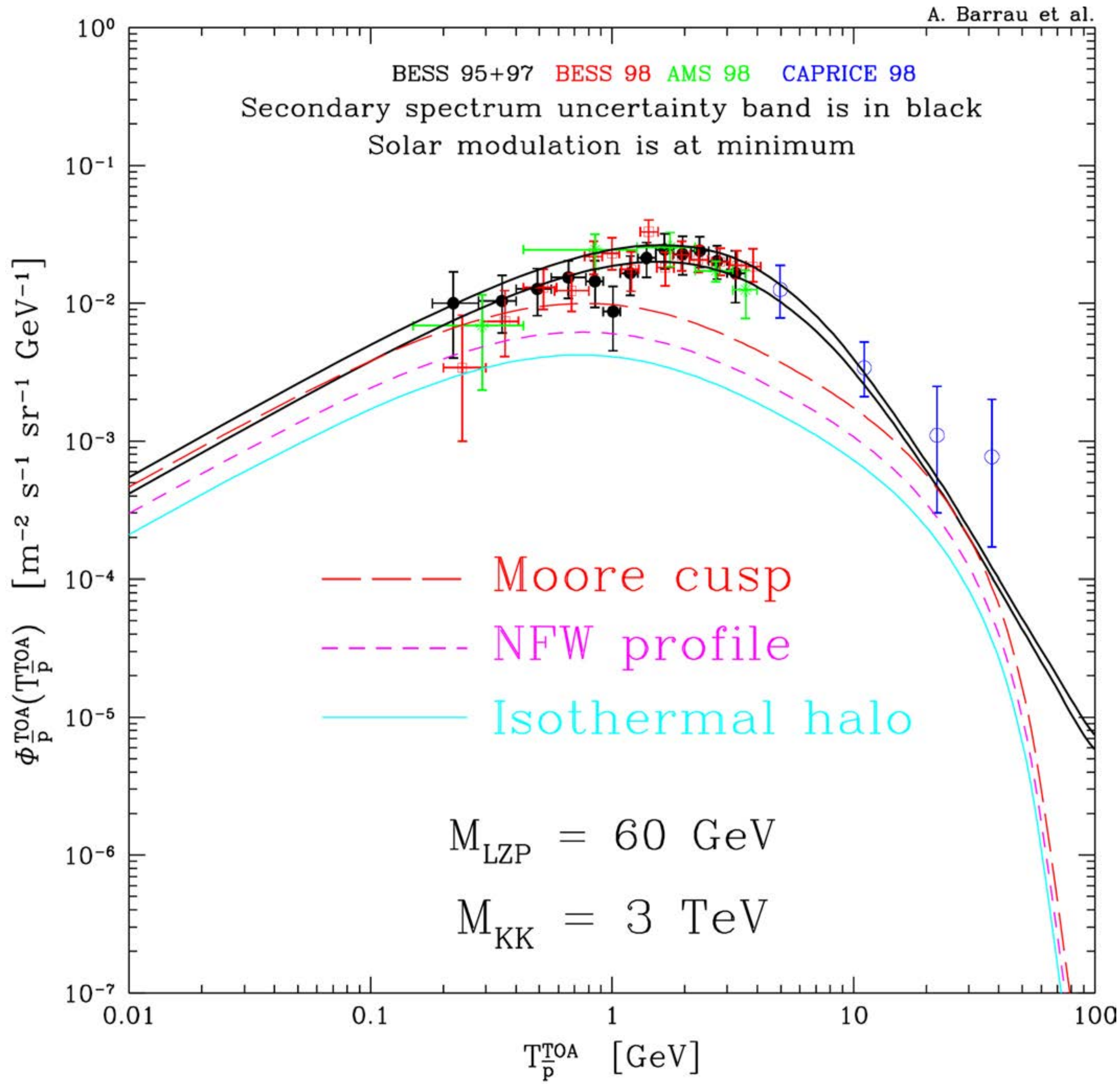
Halo profile is unknown

$$\rho_{\rm CDM}(r) \;=\; \rho_{\rm CDM\,\odot} \left\{\frac{r_\odot}{r}\right\}^{\gamma} \left\{\frac{1\,+\,(r_\odot/a)^{\alpha}}{1\,+\,(r/a)^{\alpha}}\right\}^{(\beta-\gamma)/\alpha}$$

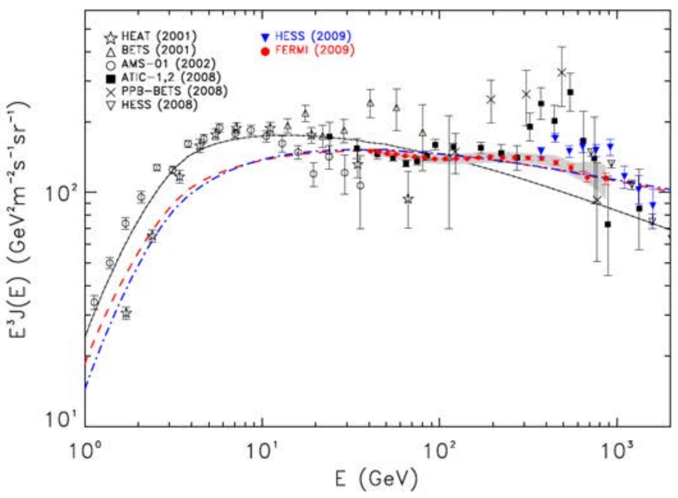
$$\rho_{\rm CDM\,\odot} = 0.3 \text{ GeV cm}^{-3}$$

Halo model	α	β	γ	a [kpc]
Cored isothermal [43]	2	2	0	4
Navarro, Frenk & White [32]	1	3	1	25
Moore [34]	1.5	3	1.3	30

Various models for the DM distribution within the Milky Way


A. Barrau et al.
BESS 95+97 BESS 98 AMS 98 CAPRICE 98
Secondary spectrum uncertainty band is in black
Solar modulation is at minimum
Moore cusp
NFW profile
Isothermal halo
M_LZP = 60 GeV
M_KK = 3 TeV
Φ_p̄^TOA(T_p̄^TOA) [m^-2 s^-1 sr^-1 GeV-1]
T_p̄^TOA [GeV]
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.01
0.1
1
10
100

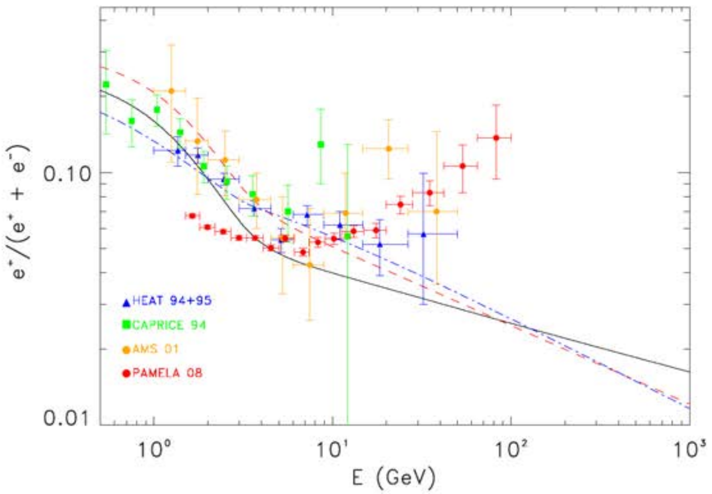
4) The positron excess – Ockham's triumph



- Primary e$^-$ from SN driven shock waves
- Secondary e$^-$ & e$^+$ from CR spallations

$$\Phi_e \propto E^{-\alpha - 1/2 - \delta/2}$$

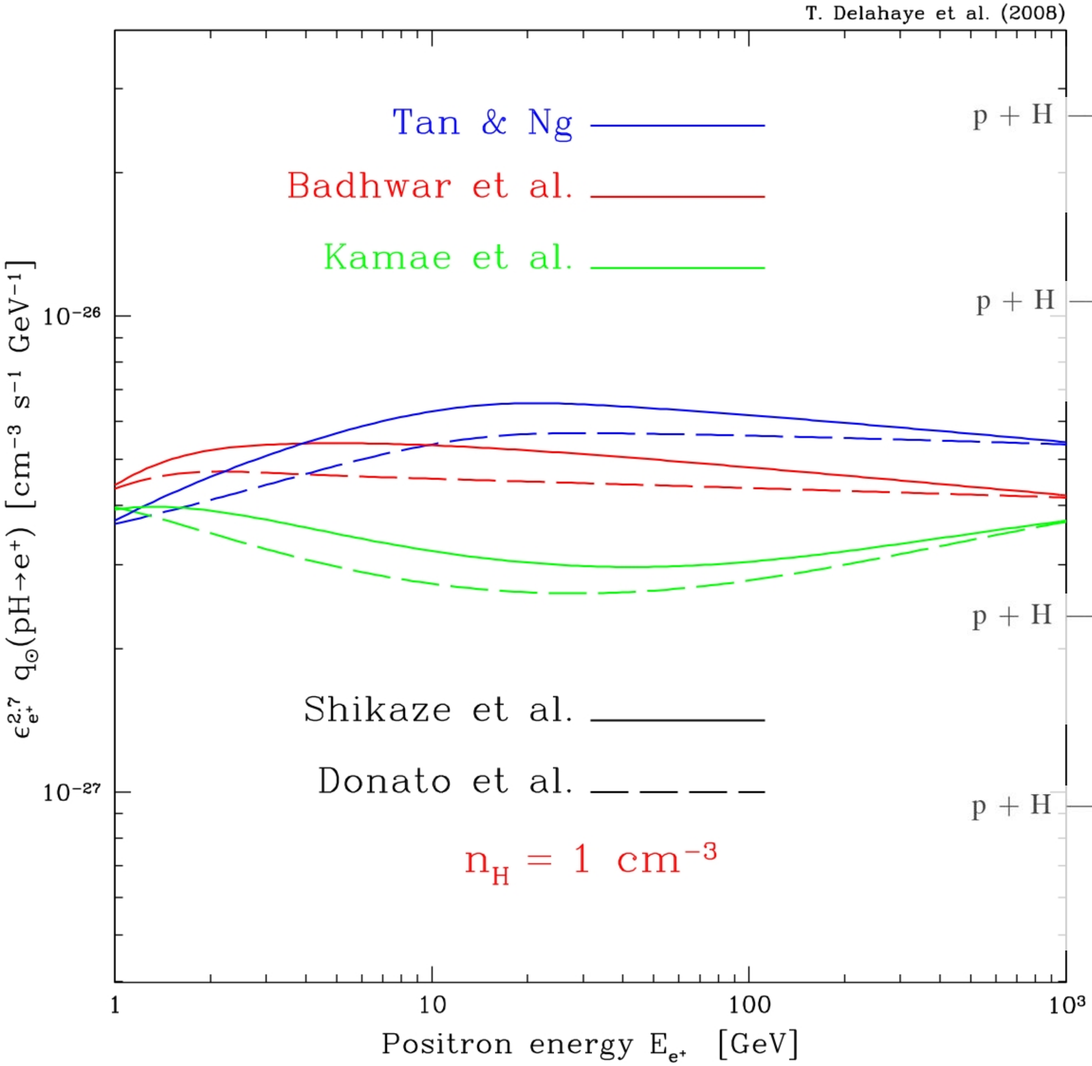
$$K(E) = K_0 \, \beta \, \mathcal{R}^{\delta}$$



- $\Phi_{\text{primary e}^-} \propto E^{-3}$
- $\Phi_{\text{secondary e}^\pm} \propto E^{-3.5}$

$$J_{e^\pm} = (175.40 \pm 6.09) \left(\frac{E}{1 \text{ GeV}} \right)^{-(3.045 \pm 0.008)} \text{GeV}^{-1}\text{m}^{-2}\text{s}^{-1}\text{sr}^{-1}$$

Positron source term



$p + H \longrightarrow p + \Delta^+$
$\Delta^+ \longrightarrow p + \pi^0$
$\Delta^+ \longrightarrow n + \pi^+$

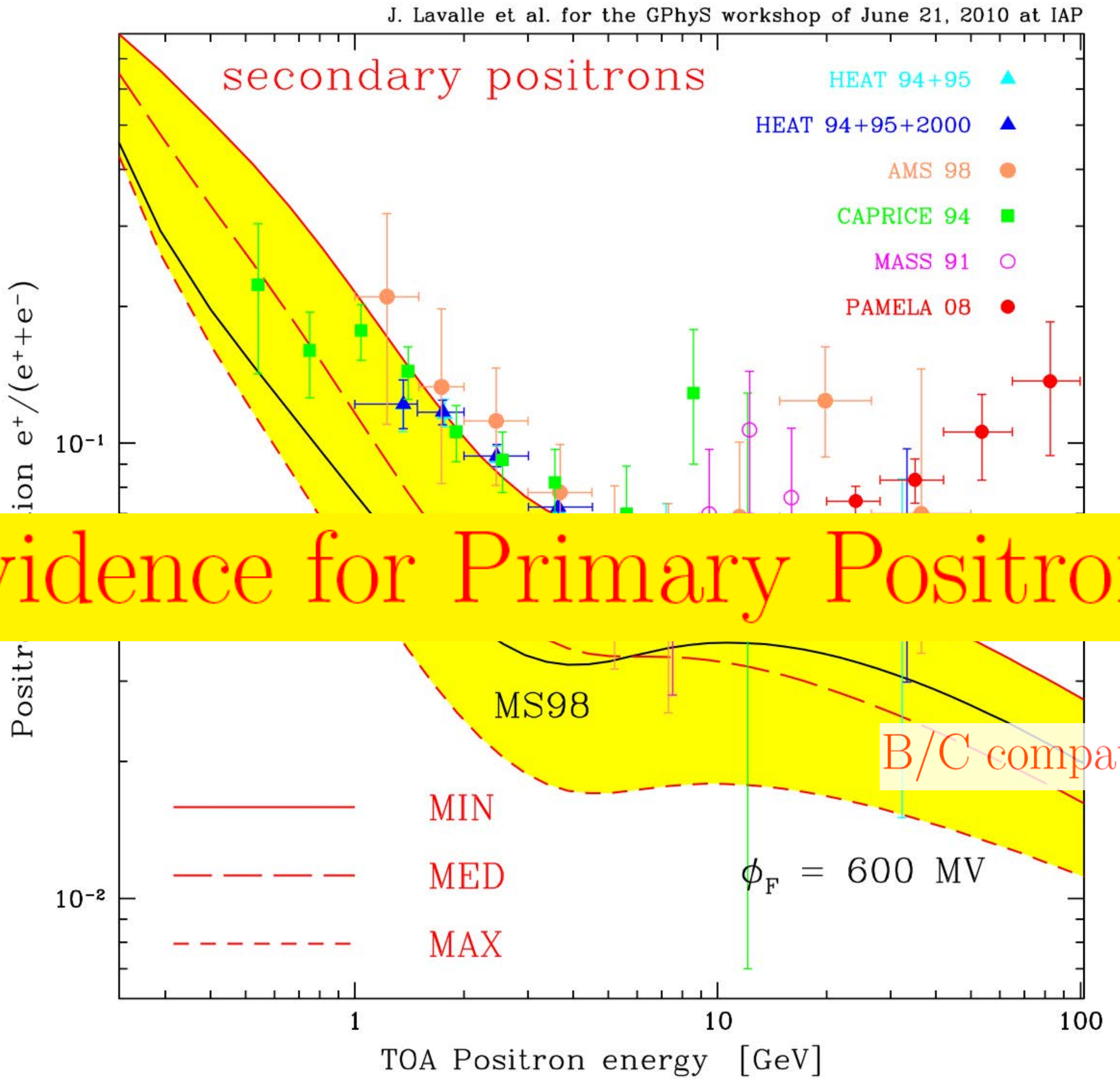
$p + H \longrightarrow X + \pi^\pm$
$\pi^\pm \longrightarrow \nu_\mu + \mu^\pm$
$\mu^\pm \longrightarrow \nu_\mu + \nu_e + e^\pm$

$p + H \longrightarrow X + K^\pm$
$K^\pm \longrightarrow \nu_\mu + \mu^\pm$
$\mu^\pm \longrightarrow \nu_\mu + \nu_e + e^\pm$

$p + H \longrightarrow X + K^\pm$
$K^\pm \longrightarrow \pi^0 + \pi^\pm$
$\pi^\pm \longrightarrow \nu_\mu + \mu^\pm$
$\mu^\pm \longrightarrow \nu_\mu + \nu_e + e^\pm$

Delahaye T. et al. – arXiv:0809.5268 – **A&A** 501 (2009) 821

Evidence for Primary Positrons



B/C compatible band

Delahaye T. et al. – arXiv:0809.5268 – **A&A** 501 (2009) 821

PAMELA positron excess

May be the first indirect hint that DM species annihilate in the MW

$$q_{e^+} = \frac{1}{2} \langle \sigma v \rangle \times \left\{ n_\chi \equiv \frac{\rho_\chi}{m_\chi} \right\}^2 \times \frac{dN_e}{dE_e}$$

A few remarks are in order

(i) The WIMP mass $m_\chi \sim 100$ GeV (PAMELA) up to 1 TeV (Fermi)

(ii) The annihilation rate needs to be considerably enhanced

- Thermal freeze–out cross section $\langle \sigma v \rangle = 3 \times 10^{-26}$ cm^3 s^{-1}
- Local e$^+$ production means DM density given by $\rho_\odot = 0.3$ GeV cm^{-3}

$$m_\chi = 1 \text{ TeV needs } \Gamma_{\text{ann}} \equiv \frac{1}{2} \langle \sigma v \rangle \times \frac{\rho_\chi^2}{m_\chi^2} \text{ boosted by } B = 10^3$$

(iii) DM species are **leptophilic**, id est q channels are suppressed

(iii) DM species are **leptophilic**, id est q channels are suppressed

M. Cirelli et al., Nucl. Phys. **B 813** (2009) 1

Constraints on WIMP Dark Matter from the High Energy PAMELA $\bar{p}/p$ data

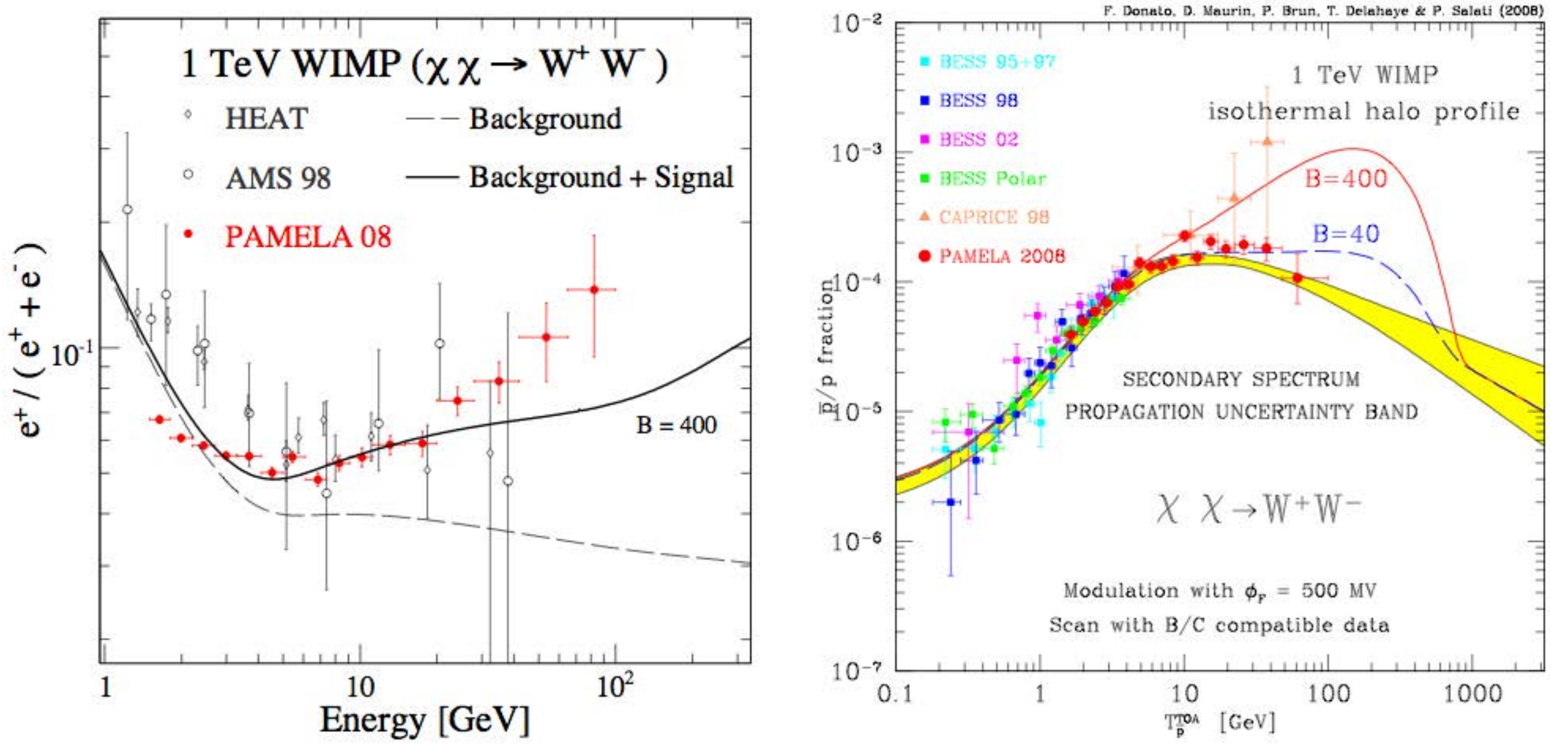


FIG. 3: The fiducial case of a 1 TeV LSP annihilating into a W^+W^- pair is featured. In the left panel, the positron signal which this DM species yields has been increased by a factor of 400, hence the solid curve and a marginal agreement with the PAMELA data. Positron fraction data are from HEAT [18], AMS-01 [5, 22] and PAMELA [2]. If the so-called Sommerfeld effect [7] is invoked to explain such a large enhancement of the annihilation cross section, the same boost applies to antiprotons and leads to an unacceptable distortion of their spectrum as indicated by the red solid line of the right panel.

F. Donato et al. – PRL **102** (2009) 071301

- Peculiar and ad'hoc WIMP models

Leptophilic DM particles

$$\Downarrow$$

$$\chi\,\chi \rightarrow l^+ l^-$$

or

$$\chi\,\chi \rightarrow \phi\,\phi \rightarrow l^+ l^- l^+ l^- \quad \text{through} \quad \phi \rightarrow l^+ l^-$$

- Even though, strong constraints from the other **messengers** :

✓ Synchrotron radio emission from $e^{\pm}$ spiraling in **B**.

✓ Inverse Compton Scattering on CMB and stellar light.

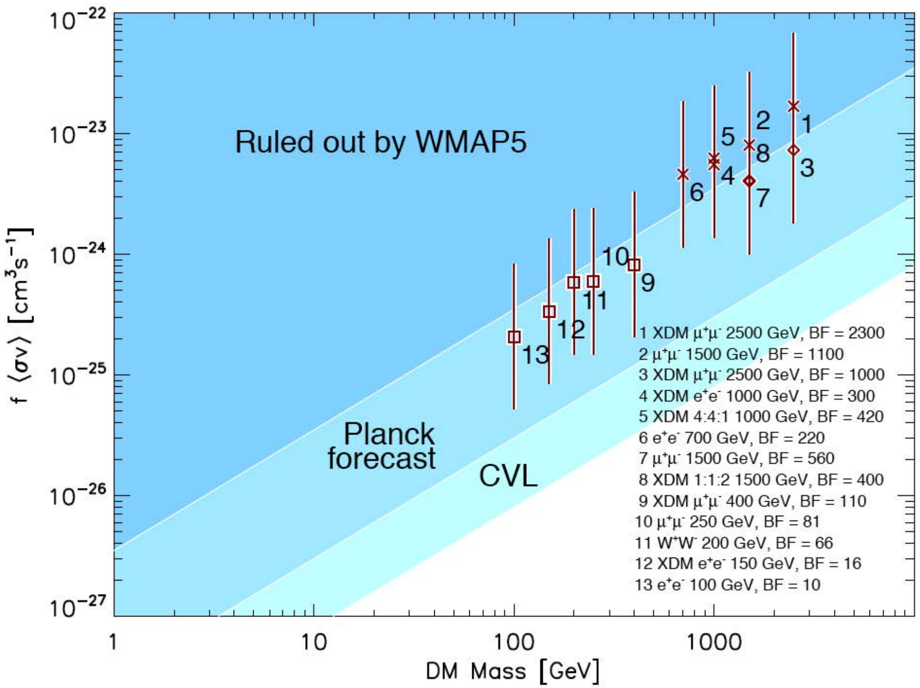
✓ Final State Radiation γ-rays in the absence of quarks.

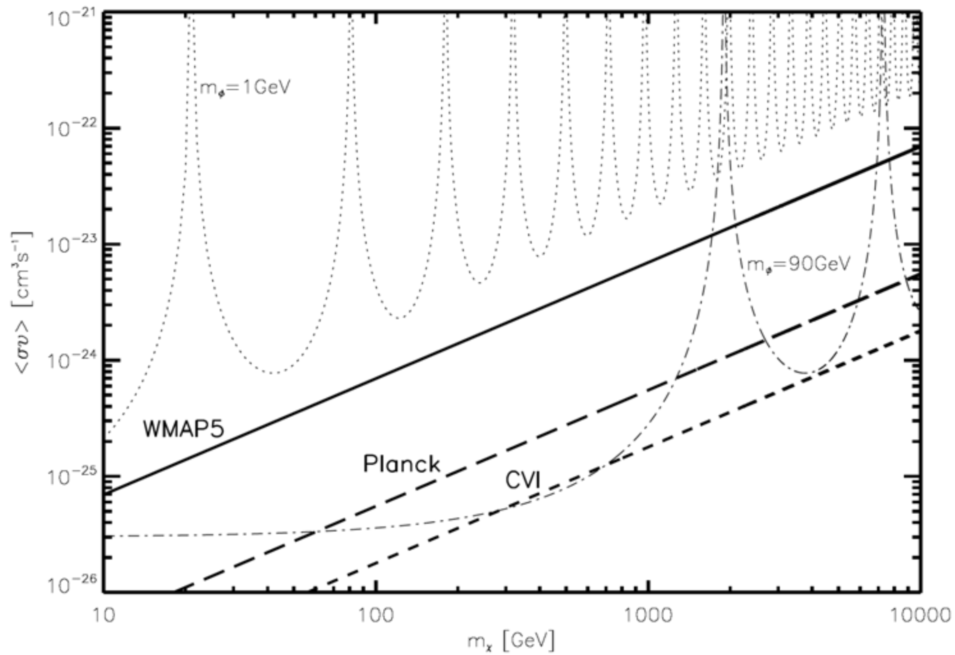
$$\chi\,\chi \rightarrow l^+ l^- \gamma \quad \text{or} \quad \phi \rightarrow l^+ l^- \gamma$$

✓ Energy release in the primordial plasma – constraints from CMB chemical potential, optical depth and spectrum.

S. Gallia, F. Iocco, G. Bertone & A. Melchiorri, arXiv:0905.0003

T. Slatyer, N. Padmanabhan & D. Finkbeiner, arXiv:0906.1197





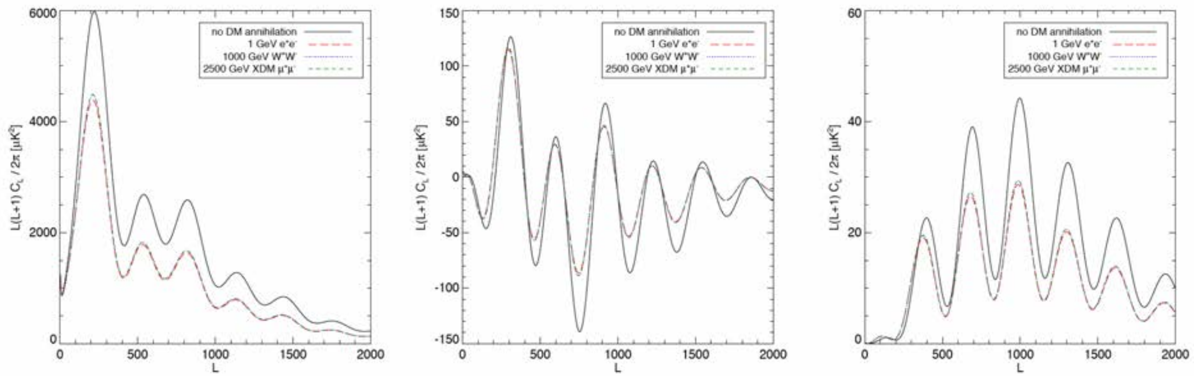


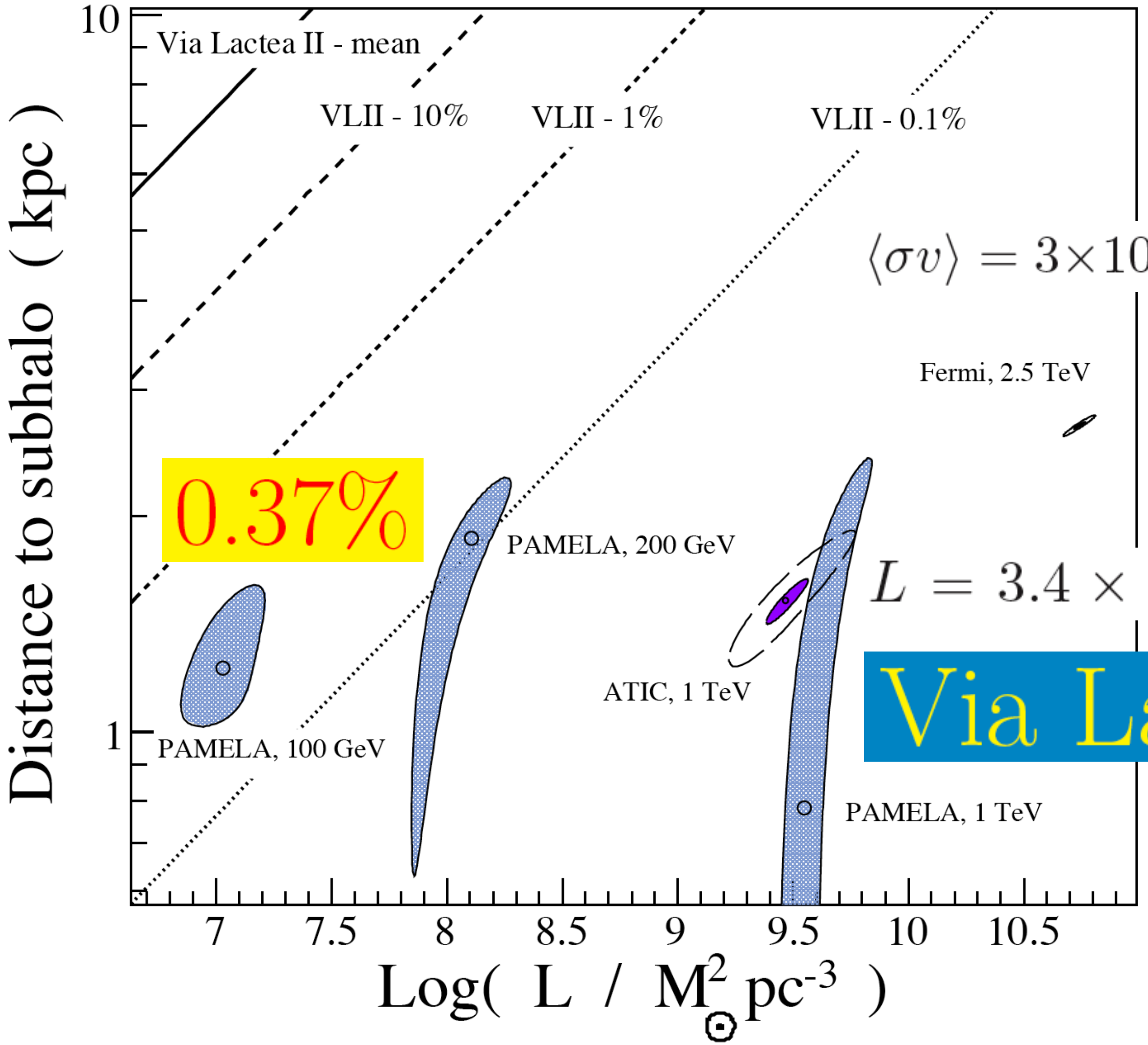
FIG. 5: CMB power spectra for three different DM annihilation models, with power injection normalized to that of a 1 GeV WIMP with thermal relic cross section and $f = 1$, compared to a baseline model with no DM annihilation. The models give similar results for the TT (*left*), TE (*middle*), and EE (*right*) power spectra. This suggests that the CMB is sensitive to only one parameter, the average power injected around recombination. All curves employ the WMAP5 fiducial cosmology: the effects of DM annihilation can be compensated to a large degree by adjusting n_s and σ_8 [4].

Boost factors : a hazardous kind of magic

FIG. 2.— Projected dark matter density-squared map of our simulated Milky Way-size halo ("Via Lactea") at the present epoch. The image covers an area of 800 × 600 kpc, and the projection goes through a 600 kpc-deep cuboid containing a total of 110 million particles. The logarithmic color scale covers 20 decades in density-square.

The cosmic ray lepton puzzle in the light of cosmological N-body simulations

P. Brun, T. Delahaye, J. Diemand, S. Profumo & P. Salati, **arXiv:0904.0812**

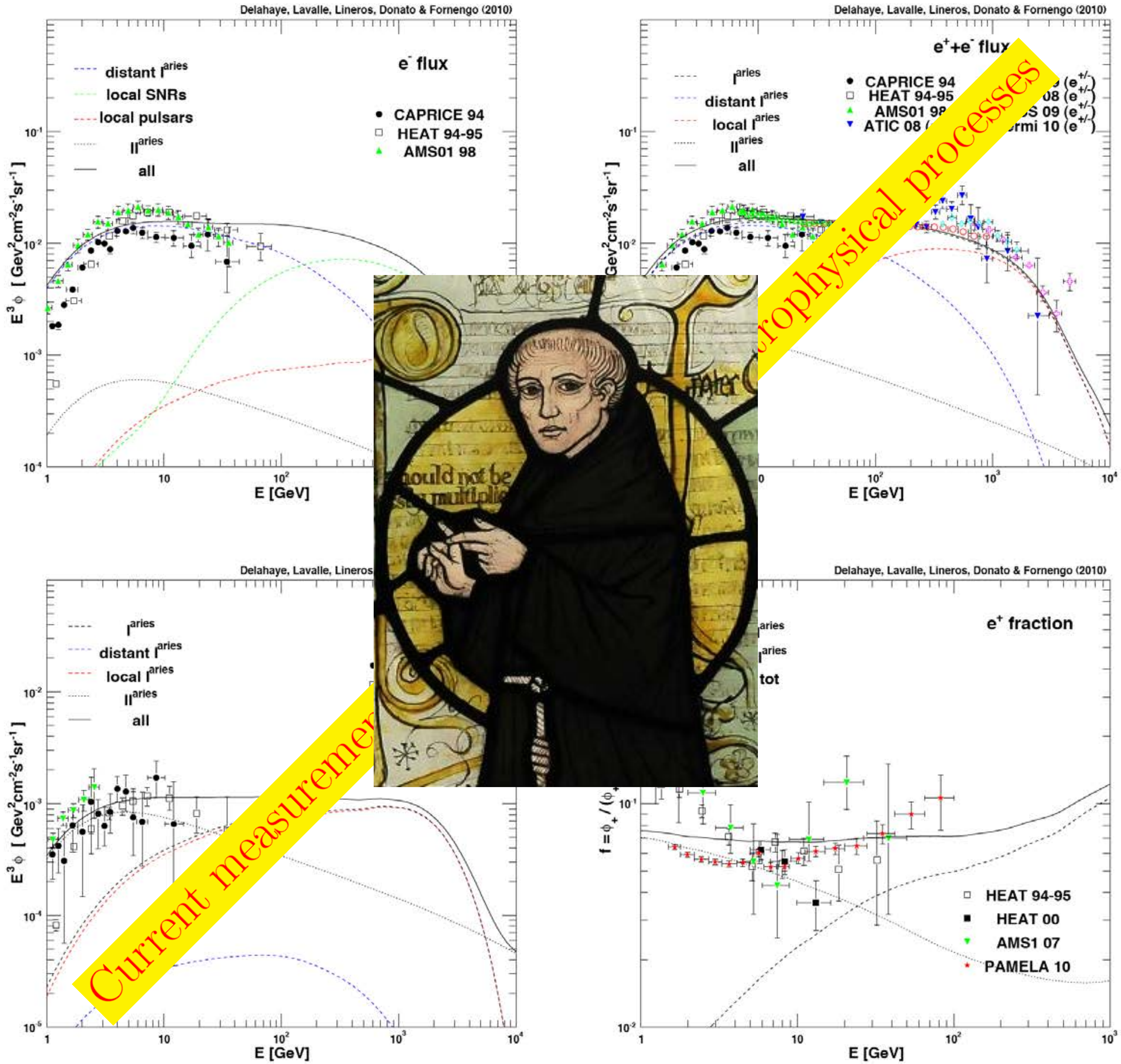


$\langle \sigma v \rangle = 3\times 10^{-26}\ \mathrm{cm^3\ s^{-1}}$

$L = 3.4 \times 10^9\ M_\odot^2\ \mathrm{pc}^{-3}$

Via Lactea II

arXiv:1002.1910 – A&A **524** (2010) A51



Conclusions and perspectives

- Galactic CR propagation is a key ingredient
  - ✓ Gross agreement between the models – convection & reacceleration
  - ✓ Life will soon become harder with better data – steady state assumption & solar modulation
- Antiproton measurements in good agreement with a pure secondary origin
  - ✓ Theoretical uncertainty is small compared to secondary positrons and diffuse photons

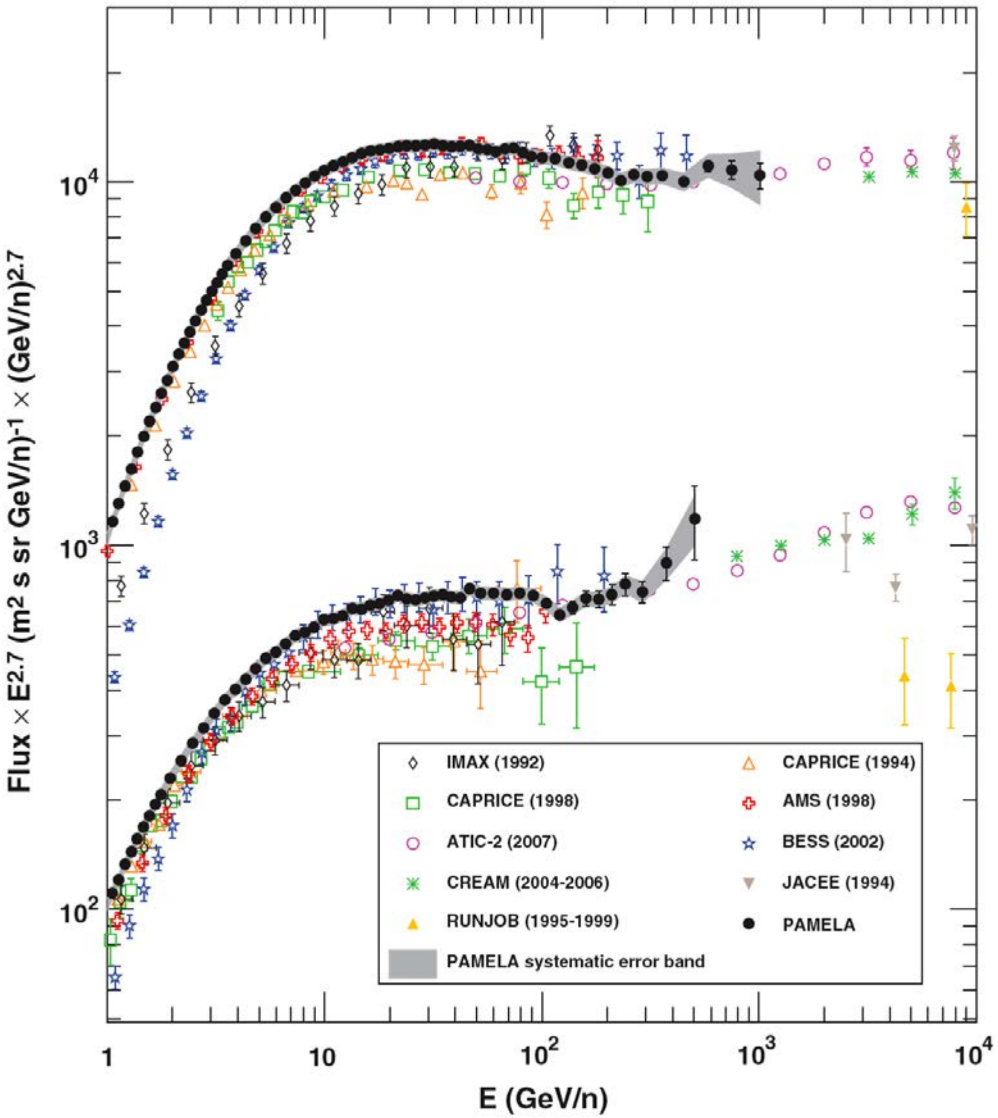
A robust probe for DM indirect searches

- Lepton CR anomalies can be explained by pure astrophysical processes
- Galactic γ-ray background is CR sensitive – DSPh observations

Effect of the discreteness of the CR sources on DM signals and backgrounds

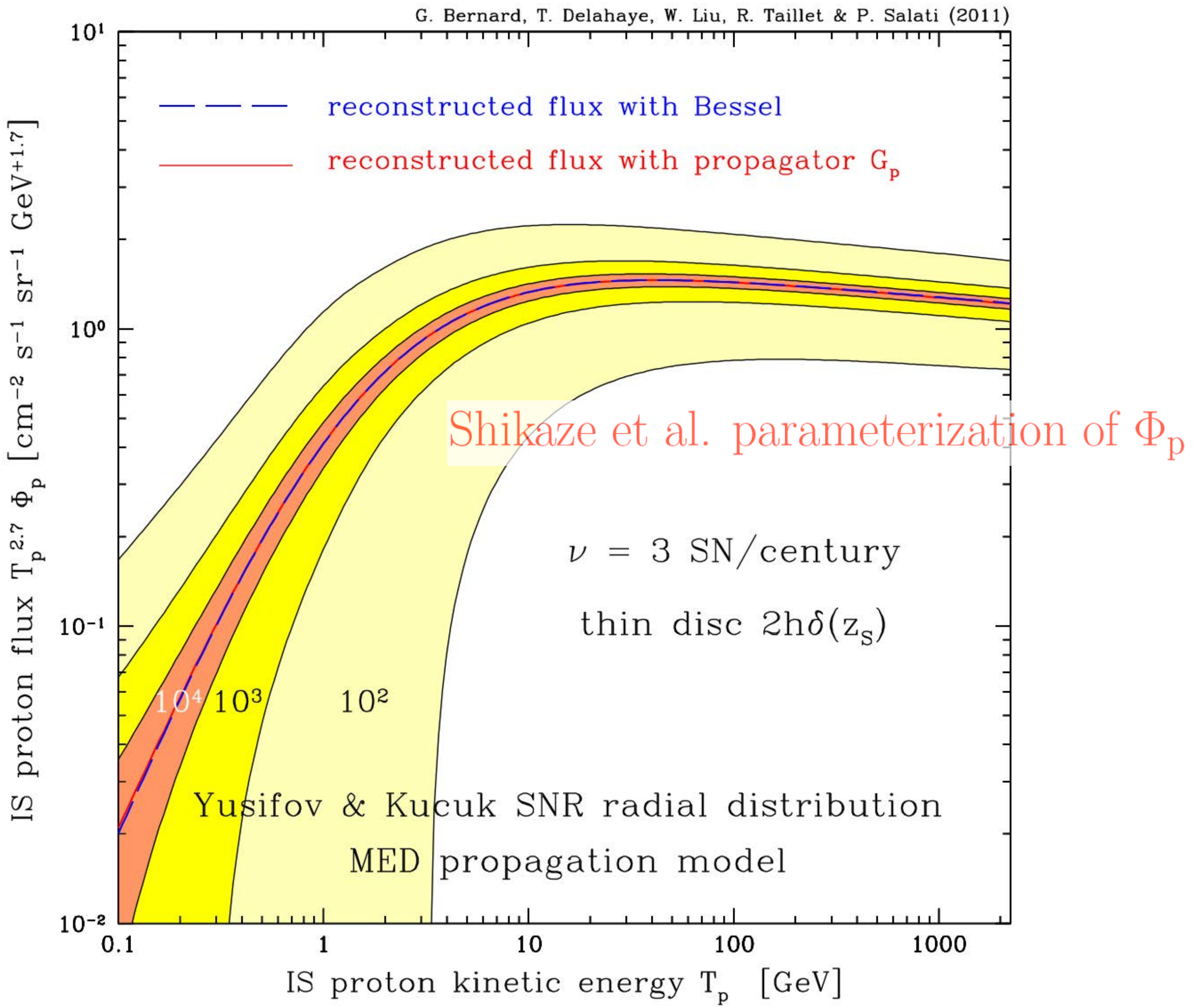
The new challenge

PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

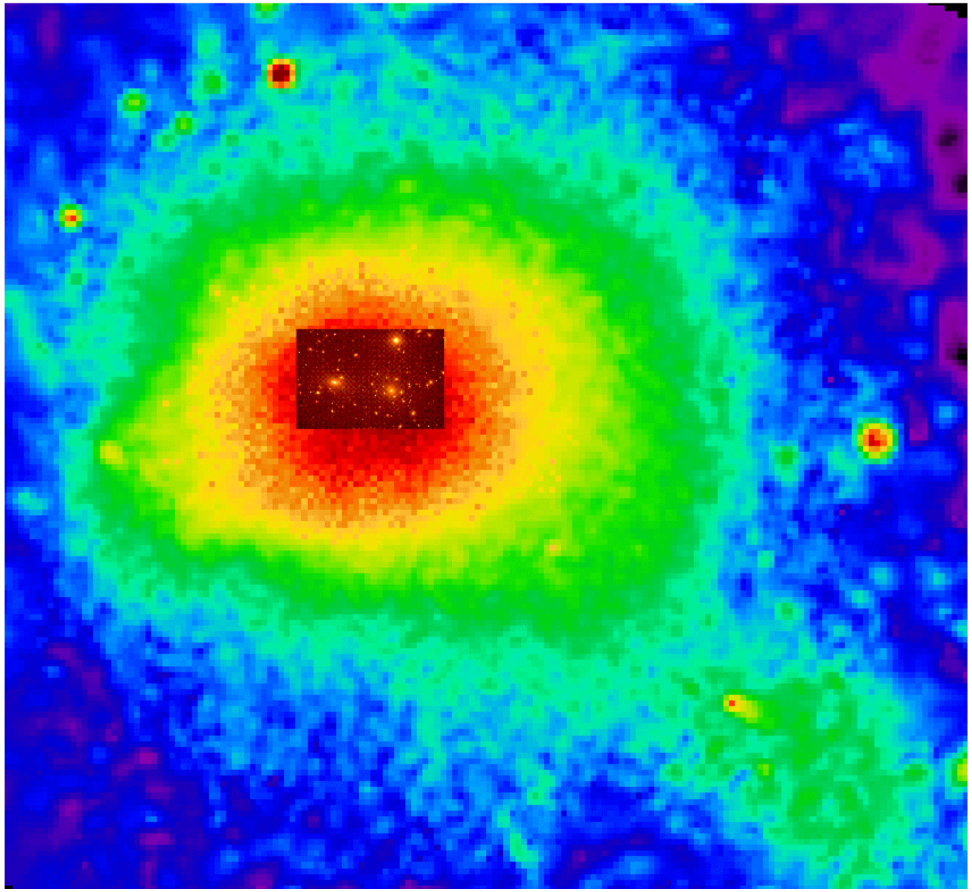


Sources of primary CR are **discret**

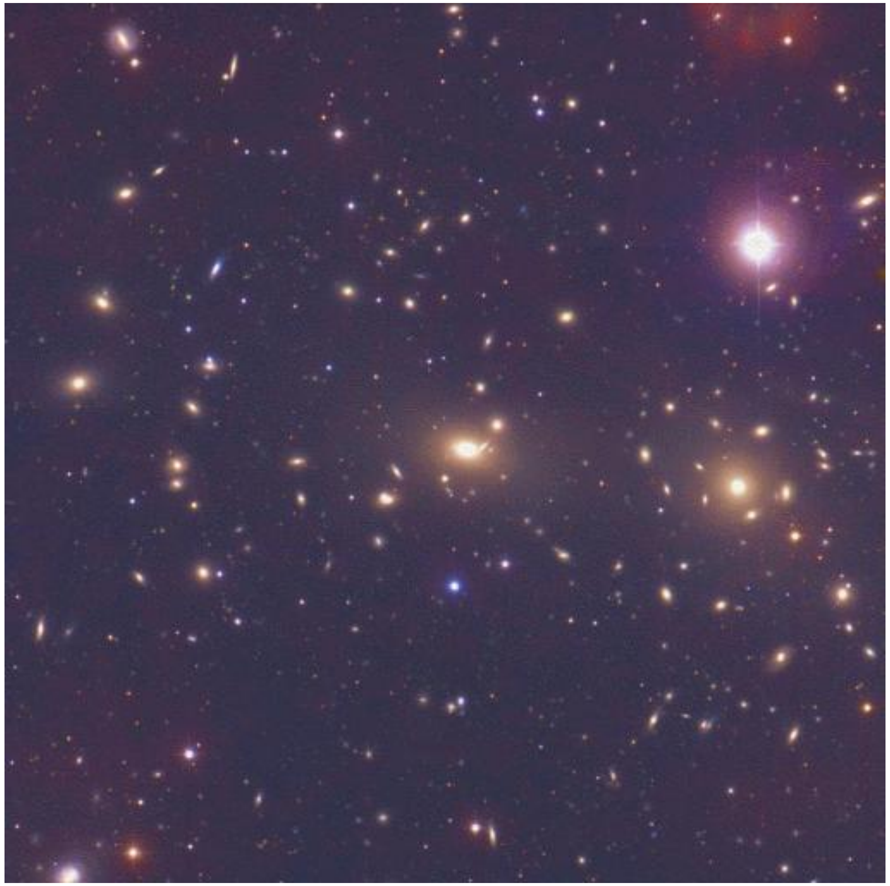
Statistical analysis on all possible populations of Galactic SN



- X–ray observations ⇒ presence of hot gas (T, n_e)



Coma – X ray image



Coma – Optical

Abell 2218 is located at 1 Gpc in Draco

Prehistoric leaky box model and the B/C ratio

$$\dot{\psi}_C = q_C - \frac{\psi_C}{\tau_{\rm esc}} - (\sigma v n_H)\,\psi_C \quad \text{and} \quad \dot{\psi}_B = -\frac{\psi_B}{\tau_{\rm esc}} + (\sigma v n_H)\,\psi_C$$

$$\psi_C = \frac{\tau_{\rm esc}}{1 + (\sigma\lambda/m_H)} \times q_C \quad \text{and} \quad \psi_B = \frac{\sigma\lambda}{m_H} \times \psi_C$$

$$\text{grammage } \lambda = 1.6\,{\rm g\,cm^{-2}} \times \beta \times \left\{\frac{\tau_{\rm esc}}{1\,{\rm Myr}}\right\}$$

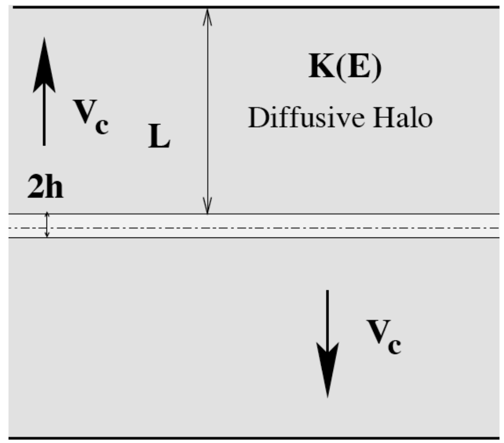
Infinite slab and 1D vertical (over)simplified CR model

$$\dot{\psi} + \vec{\nabla}\cdot\left\{-K\,\vec{\nabla}\psi + \psi\,\vec{V}_C\right\} = Q$$

$$-K\,\partial_z^2\psi + \partial_z(\psi\,V_C) = 2h\,\delta(z)\,Q$$

$$\psi(0) = \tau_{\rm esc} \times Q$$

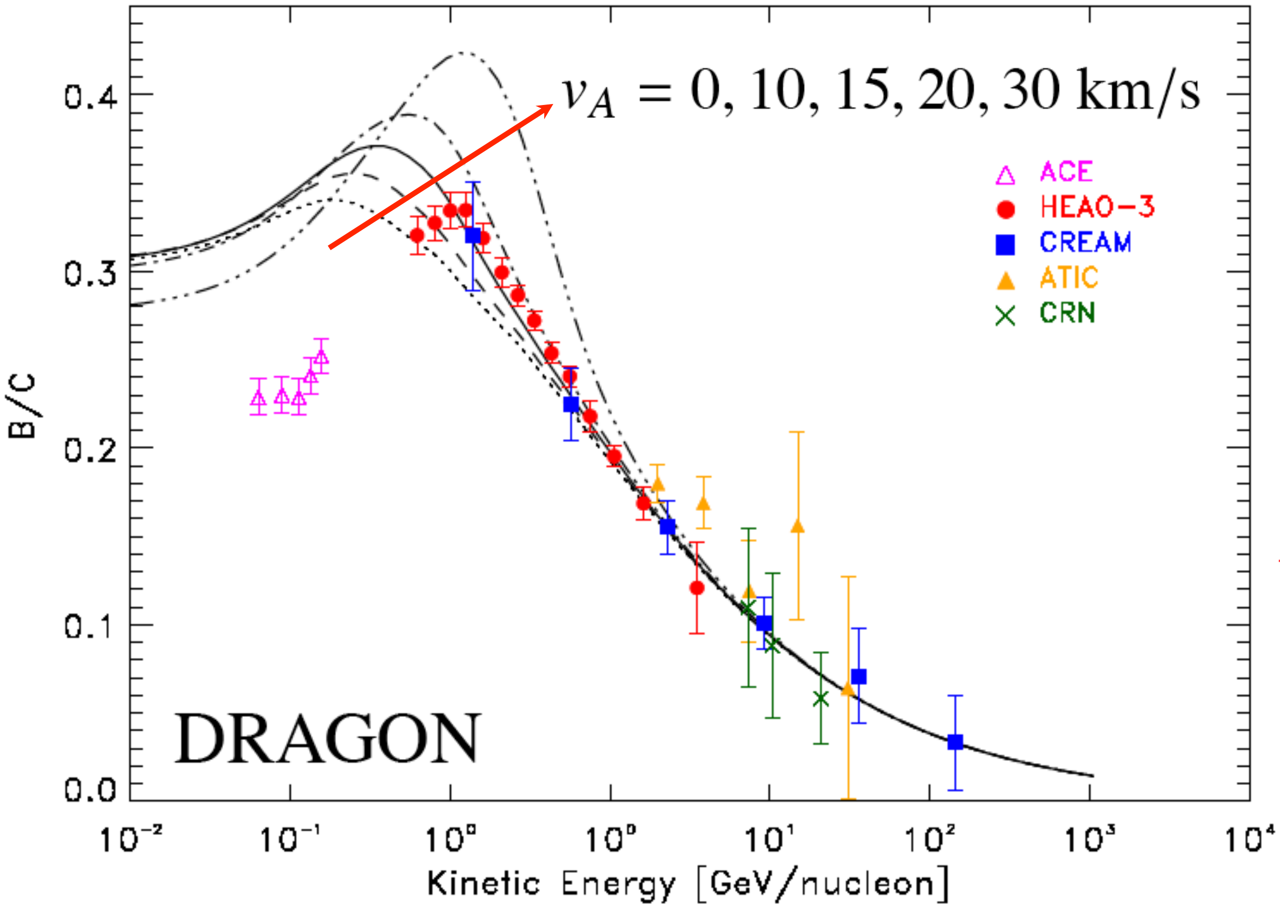
$$\tau_{\rm esc} = \frac{h}{V_C}\left\{1 - e^{-V_C L/K}\right\}$$



$$\tau_{\rm esc}(\text{low T}) = \frac{h}{V_C} \quad \text{while} \quad \tau_{\rm esc}(\text{high T}) = \frac{hL}{K} \propto \mathcal{R}^{-\delta}$$

Unified interpretation of cosmic-ray nuclei and antiproton recent measurements

Giuseppe Di Bernardo[1,2], Carmelo Evoli[3], Daniele Gaggero[1,2], Dario Grasso[2], Luca Maccione[4]



$$V_C = 0$$

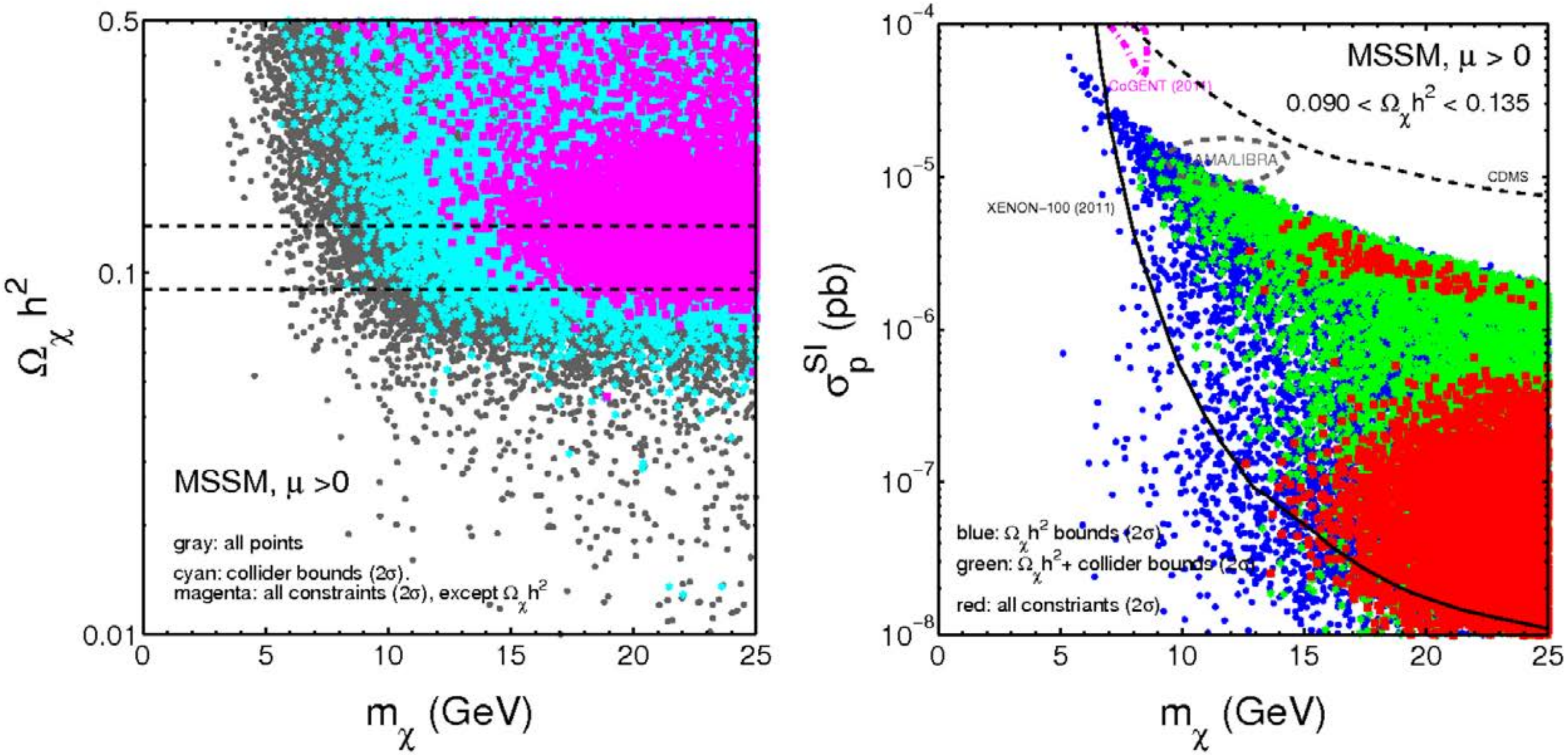
$$\Downarrow$$

$$B/C \propto \frac{\sigma\beta}{K} \propto \frac{\sigma}{\mathcal{R}^{\delta}}$$

arXiv:0909.4548v4 [astro-ph.HE] 6 Aug 2010

Is light neutralino as dark matter still viable?

Daniel T. Cumberbatch[1 a], Daniel E. López-Fogliani[1,2 b], Leszek Roszkowski[1,3 c], Roberto Ruiz de Austri[4 d], Yue-Lin S. Tsai[1,3e]



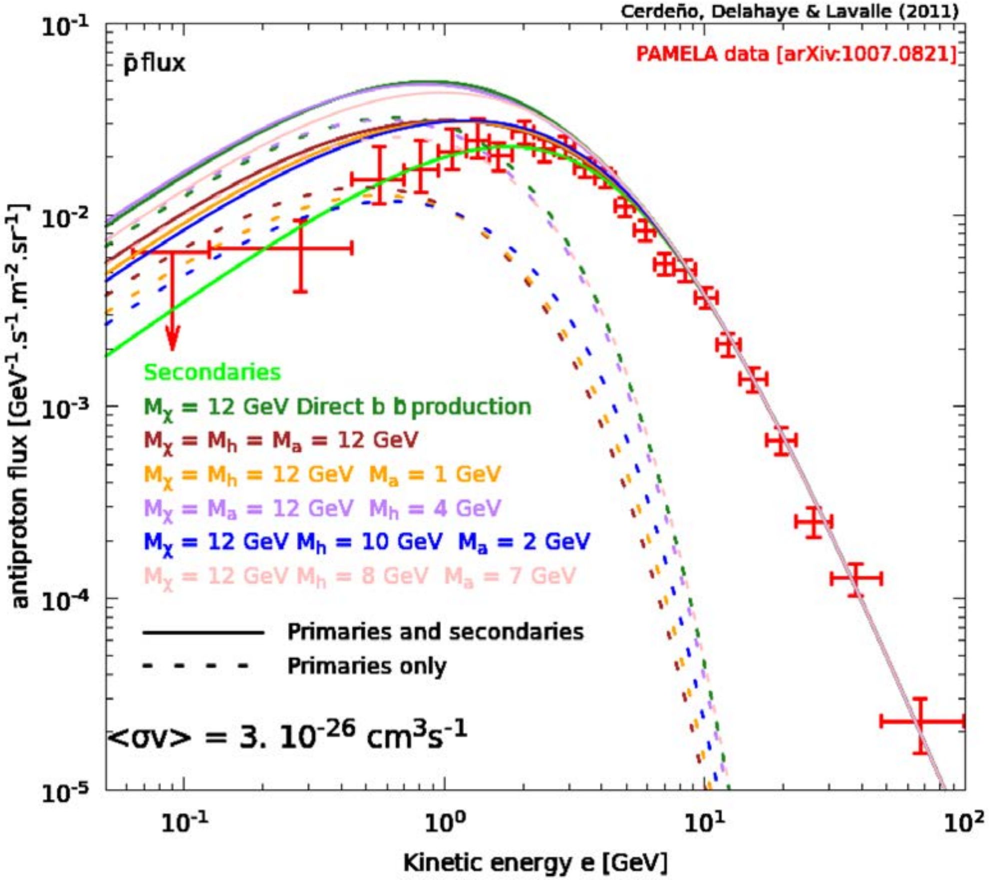
CDMS-II & CoGENT have a few events compatible with light WIMPs

no MSSM model inside the COGENT region

Cosmic-ray antiproton constraints on light singlino-like dark matter candidates

David G. Cerdeño[a,b], Timur Delahaye[a], Julien Lavalle[a,b,1]

arXiv:1108.1128 [hep-ph] 4 Aug 2011



CDMS-II & CoGENT have a few events compatible with light WIMPs

Excess of primary p̄ at low T for $m_\chi \lesssim 10$ GeV