Positron excess status: Dark Matter vs Pulsars

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Exploring the Dark Universe - Quy Nohn
24-07-2017

Based on:

MB, E. F. Bueno, S. Caroff, Y. Genolini, V. Poulin, V. Poireau, A. Putze, S. Rosier, P. Salati and M. Vecchi
(arXiv:1612.03924)

MB, J. Lavalle and P. Salati
(arXiv:1612.07698)

LPTHE
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erc NewDark

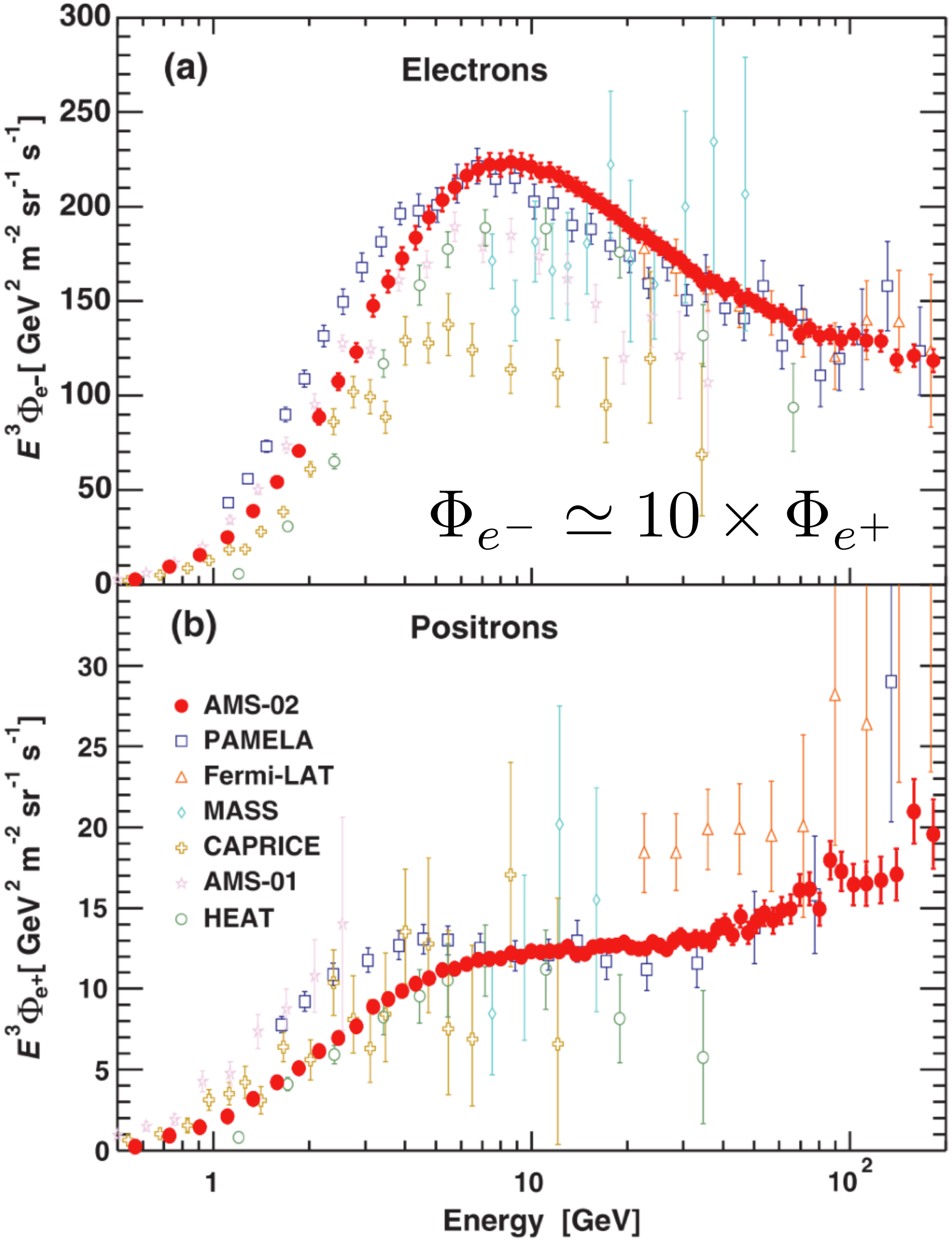
Positron excess… with respect to what?

Positrons flux and positron fraction

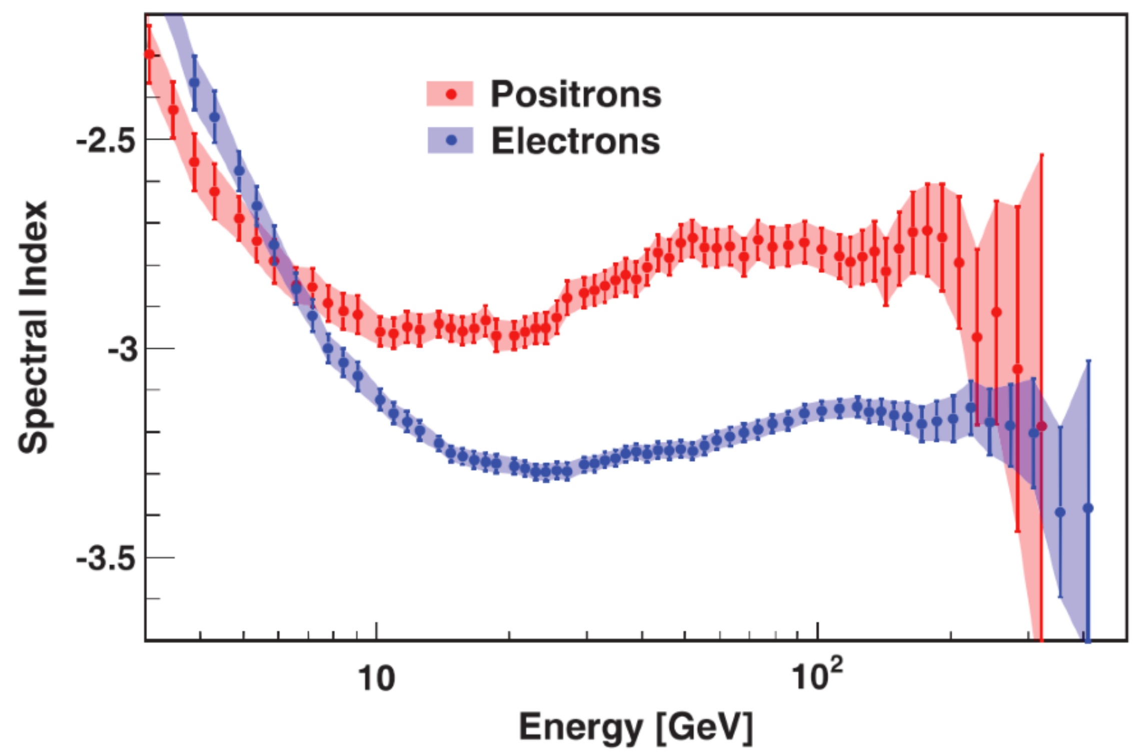
AMS-02 collaboration published the electrons, positrons flux and the positron fraction from ~ 0.5 GeV up to ~ 500 GeV with an unprecedented high accuracy.

$$\mathrm{PF} = \frac{\Phi_{e^+}}{\Phi_{e^- + e^+}}$$

PRL113,121102 (2014), PRL113,121101 (2014)



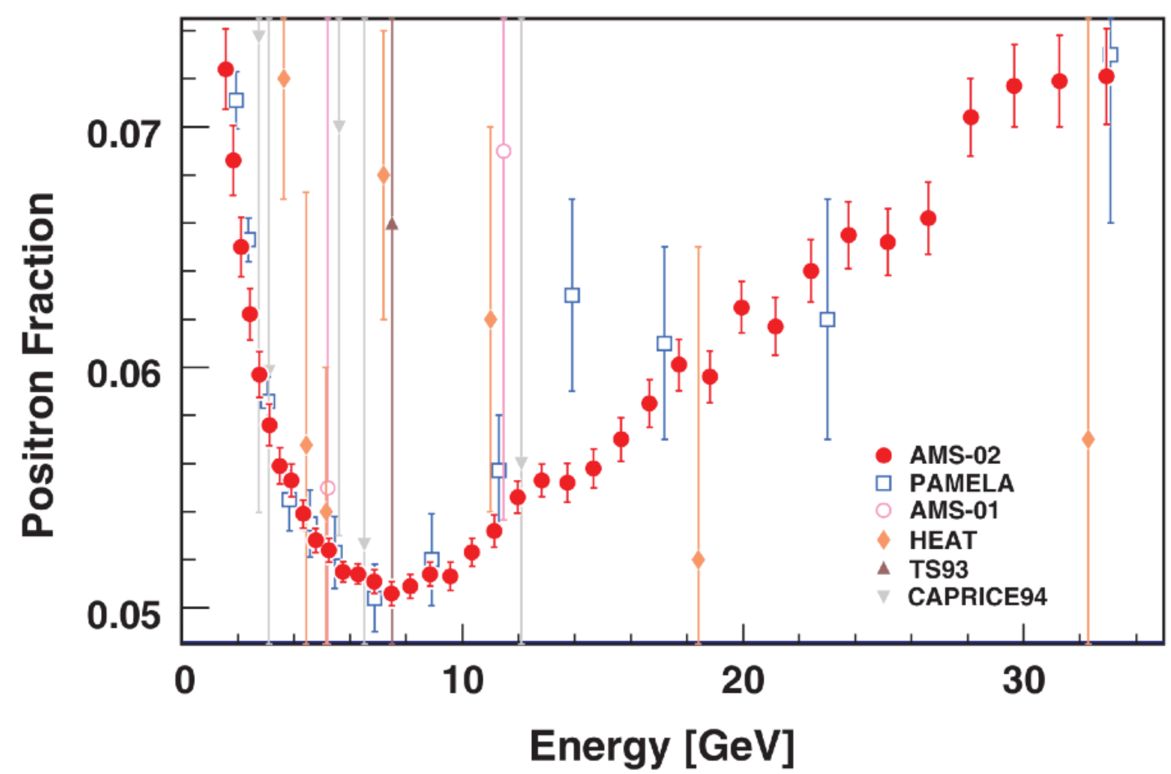
$$\Phi_{e^-} \simeq 10 \times \Phi_{e^+}$$

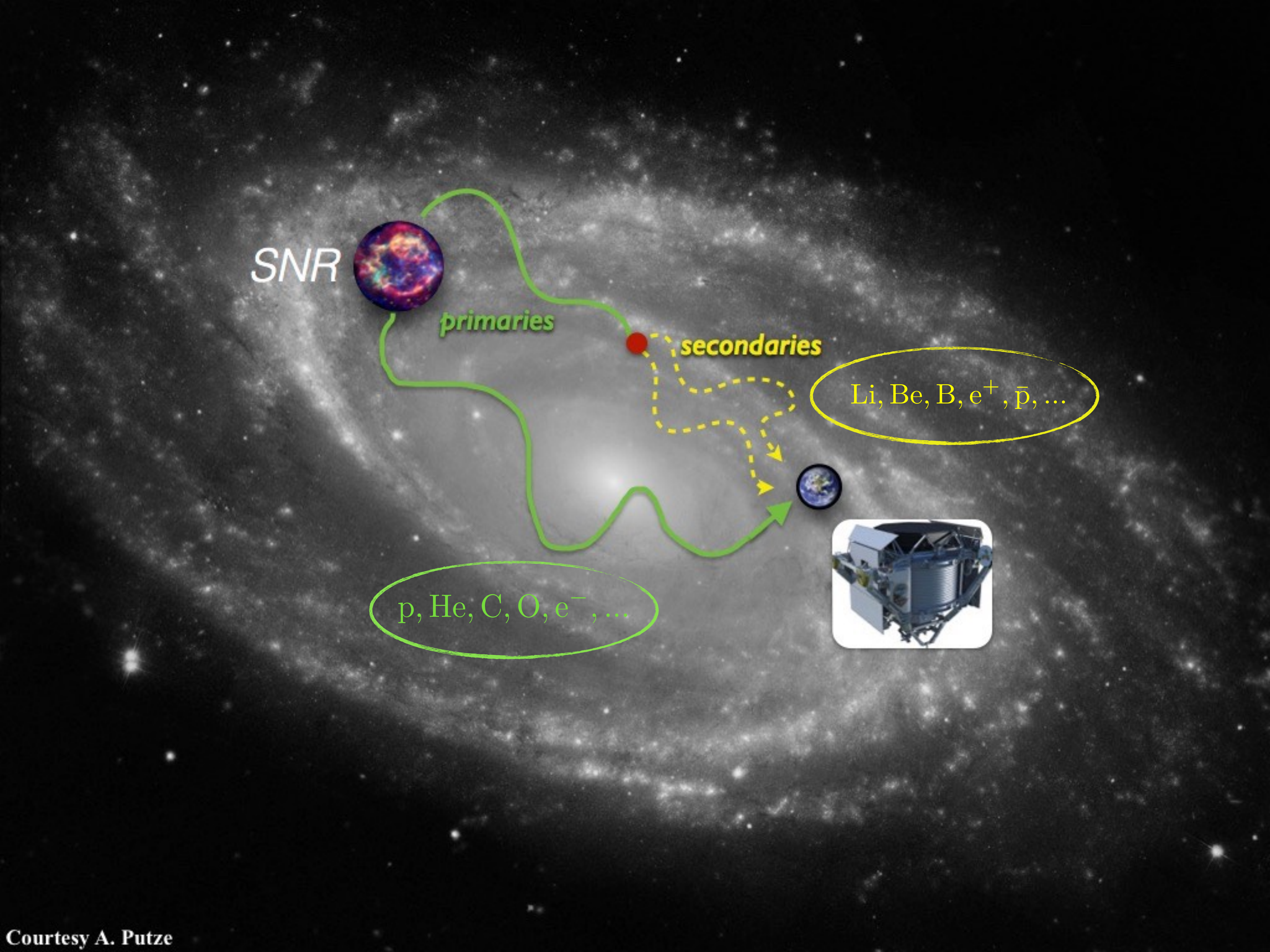


E ~ 100 GeV

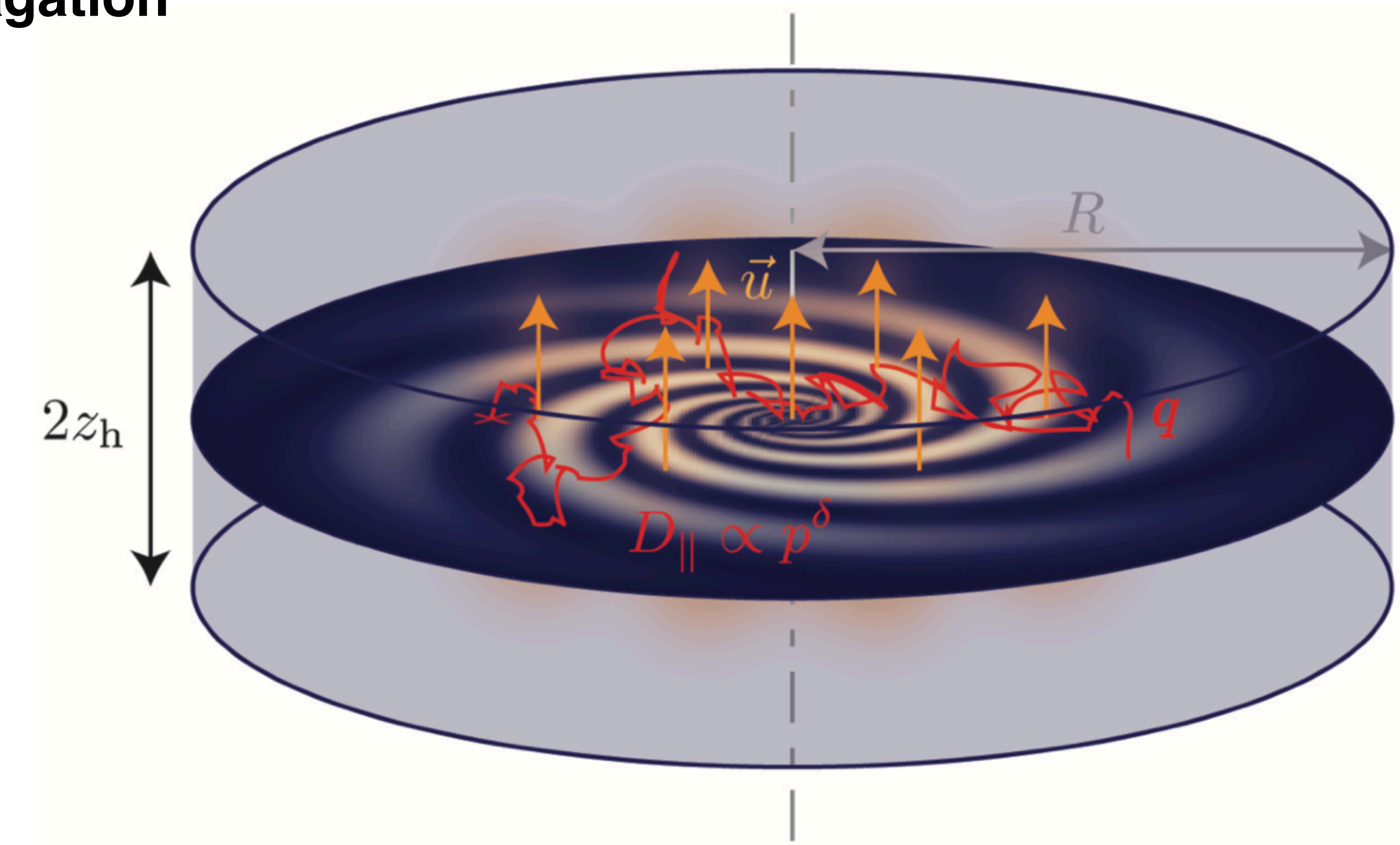
$$\gamma_{e^+} \simeq 2.75$$

$$\gamma_{e^-} \simeq 3.15$$




SNR
primaries
secondaries
Li, Be, B, e^+, $\bar{p}$, ...
p, He, C, O, e^-, ...
Courtesy A. Putze

Cosmic rays propagation



- **Space diffusion** $K(E,\vec{x})$
- **Convection** $\vec{V}_C(\vec{x})$
- **Destruction** $Q^{sink}(E,\vec{x})$
- **Energy losses** $b(E,\vec{x})$
- **Diffusive reacceleration** $D(E,\vec{x}) = \frac{2}{9}\, V_A^2\, \frac{E^2\,\beta^4}{K(E,\vec{x})}$

$$\psi(E,t,\vec{x}) = \frac{\mathrm{d}^4 N}{\mathrm{d}^3 x\,\mathrm{d}E}$$

$$\boxed{\partial_t\psi - K(E,\vec{x})\Delta\psi + \vec{\nabla}\cdot\left[\vec{V}_C(\vec{x})\psi\right] + \partial_E\left[b(E,\vec{x})\psi - D(E,\vec{x})\partial_E\psi\right] = Q^{source}(E,t,\vec{x}) - Q^{sink}(E,\vec{x})}$$

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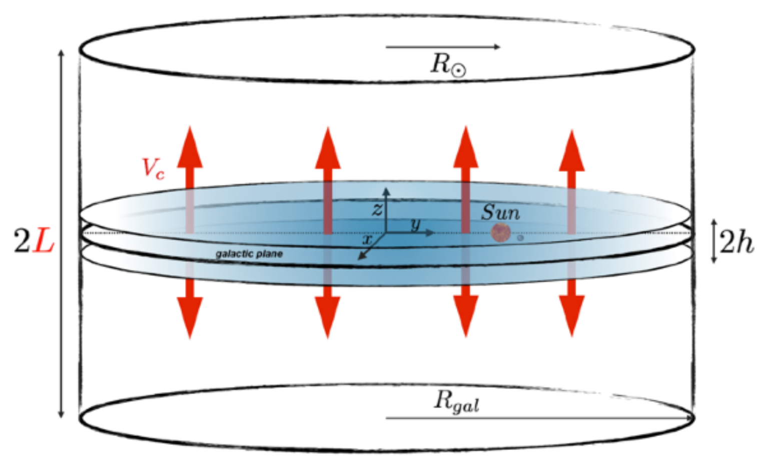
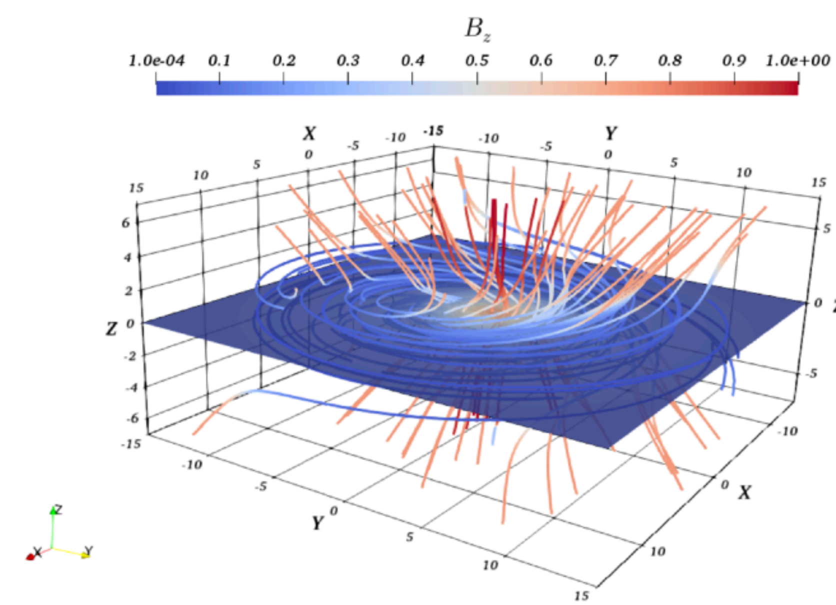
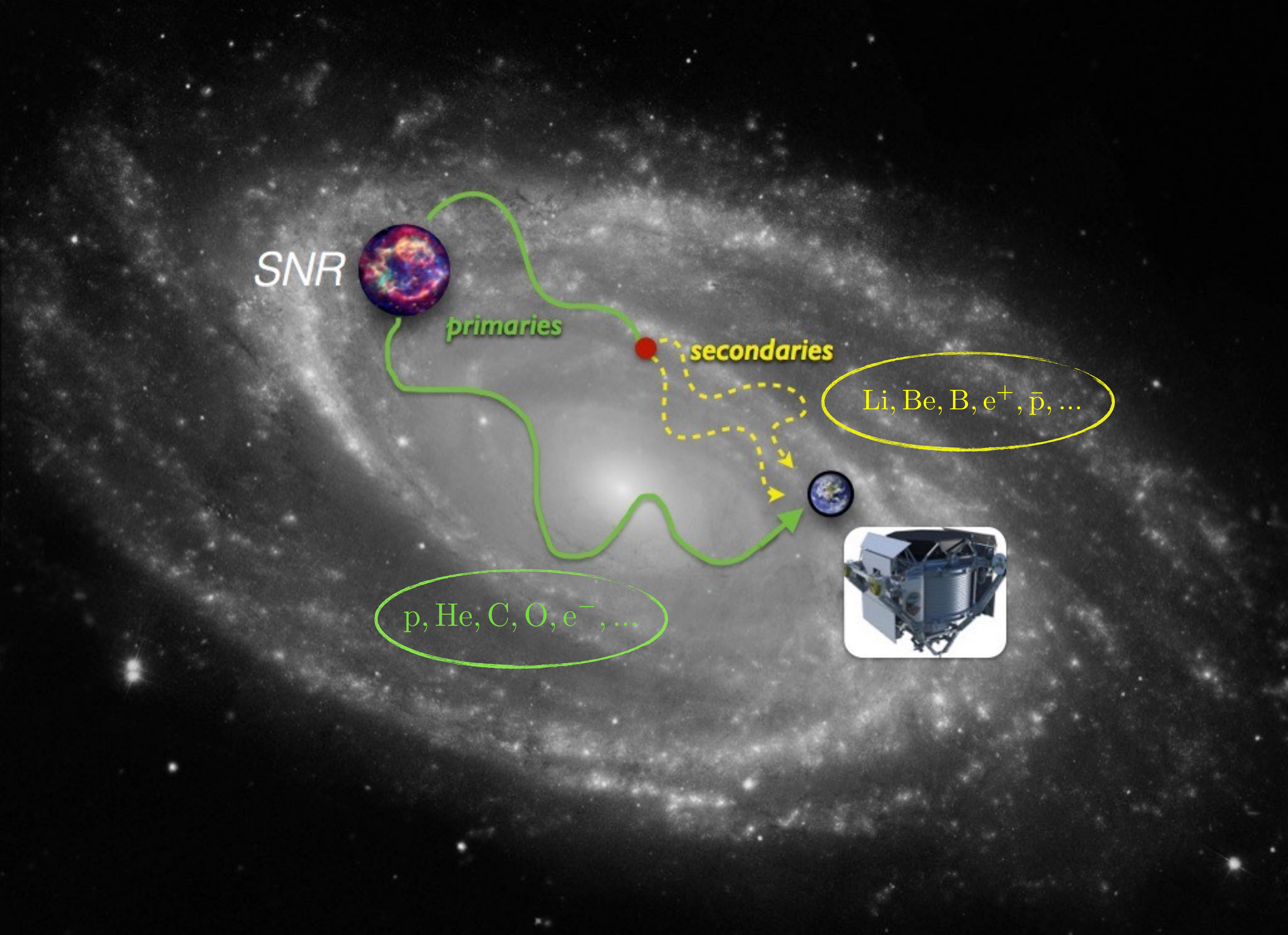
	Semi-analytical	**Numerical**
Approach	*Simplify the geometry* *Green functions, Bessel and Fourier expansion*	*Discretise the equation* *Numerical solvers*





	Semi-analytical	**Numerical**
Pros	*Useful to understand the physics* *Fast-running time (extensive scans)*	*Structure of the Galaxy* *Any new input easily included*
Cons	*Only solve approximate model*	*Slow-running time*
Codes	*USINE, PPPC4DMID, my code, etc.*	*GALPROP, DRAGON, PICARD, etc.*



Courtesy A. Putze

The propagation parameters

The semi-analytical model depends on **5** propagation parameters.

$$1 < L < 15 \text{ kpc}$$

$$\vec{V}_C = V_C \, \mathrm{sign}(z) \, \vec{e}_z$$

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

$$D(E) = \frac{2}{9} \, {V_A}^2 \, \frac{E^2 \beta^4}{K(E)}$$

These parameters can be constrained using the ratio between secondary to primaries species (B/C, etc.)

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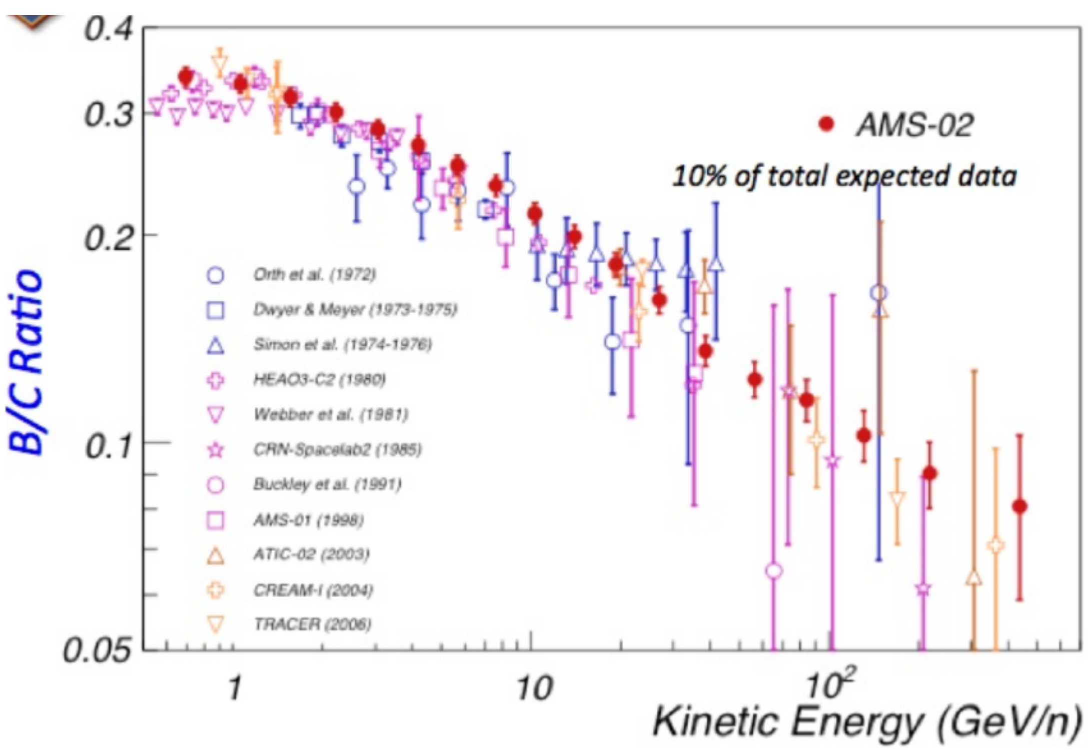


Maurin et al. (2001)
Donato et al. (2003)

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

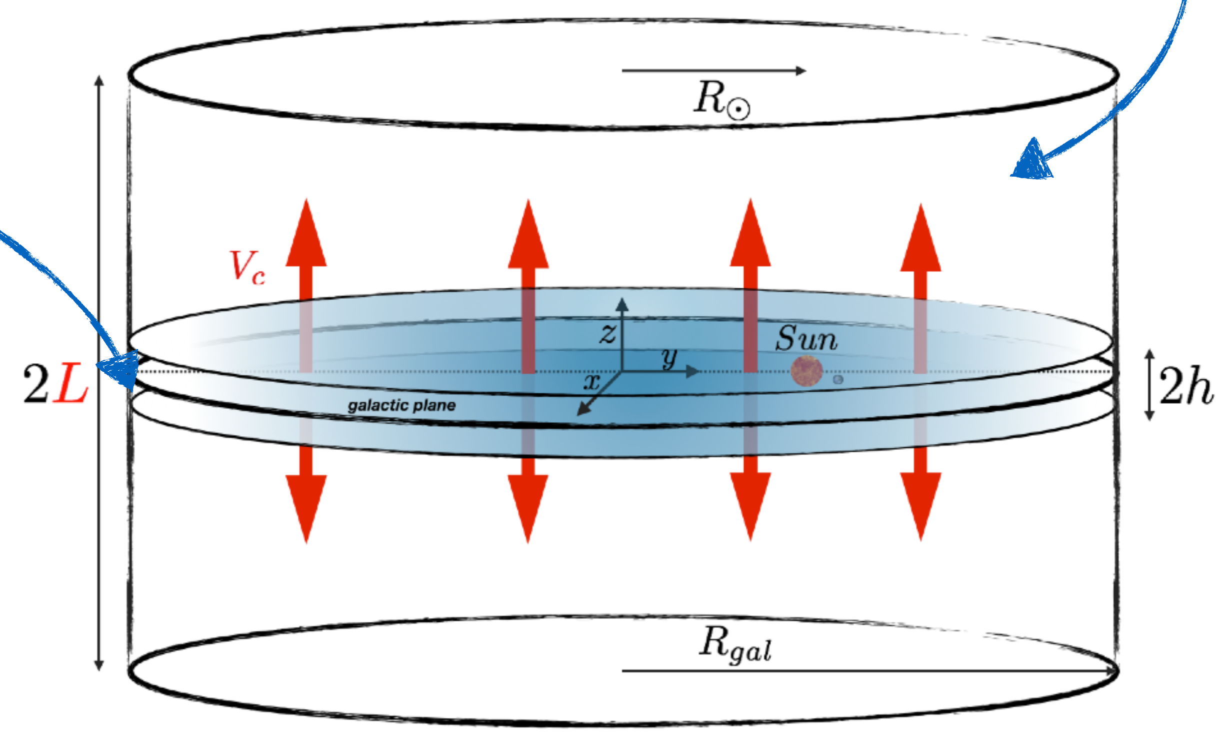
Electrons and positrons: the high-energy approximation

Cosmic rays transport equation (steady state)

$$\partial_z[V_C\,\mathrm{sign}(z)\,\psi] - K(E)\,\Delta\,\psi + 2h\,\delta(z)\,\partial_E\,[b_{\mathrm{disc}}(E)\,\psi] - D(E)\,\partial_E\,\psi] + \partial_E[b_{\mathrm{halo}}(E)\,\psi] = Q(E,\vec{x})$$

$$b_{\mathrm{disc}} = b_{\mathrm{adia}} + b_{\mathrm{ioni}} + b_{\mathrm{brem}} + b_{\mathrm{coul}}$$

$$b_{\mathrm{halo}} = b_{\mathrm{IC}} + b_{\mathrm{sync}}$$



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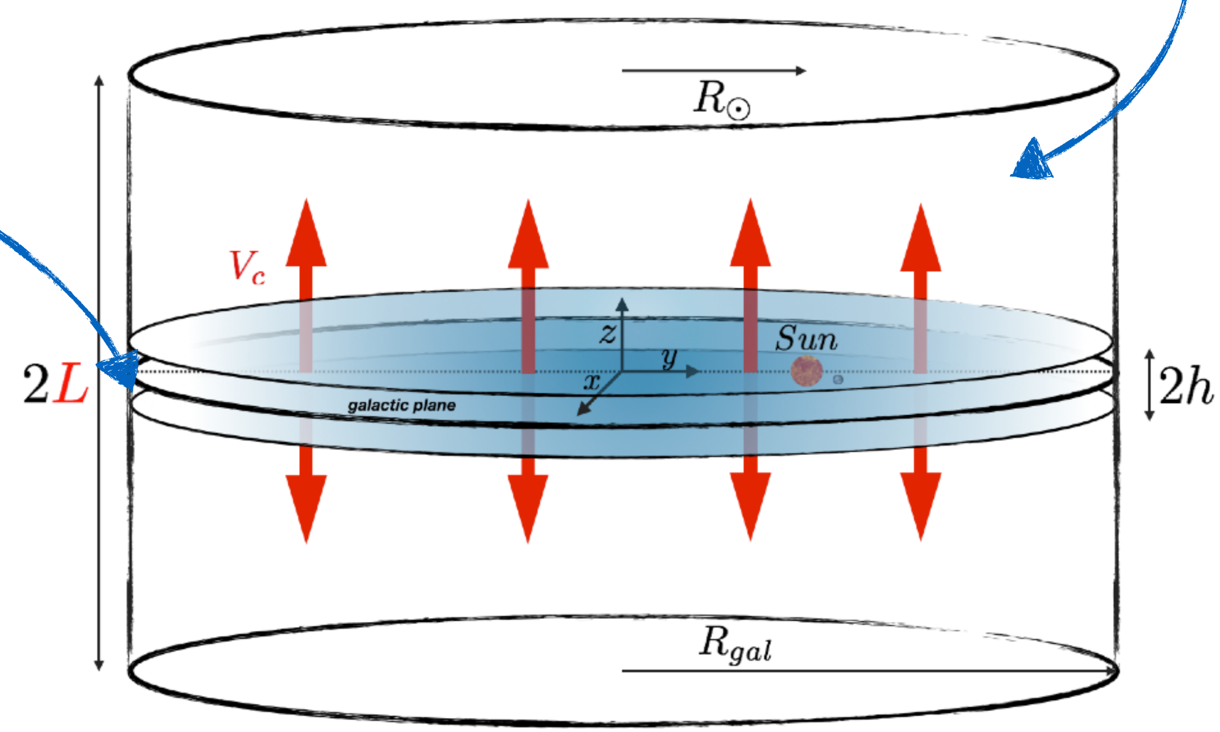

We cannot solve analytically the transport equation when energy losses processes take place in different places in the Galaxy.

We need a **numerical** algorithm to solve the transport equation (GALPROP, DRAGON, PICARD, etc.)

Electrons and positrons: the high-energy approximation

Cosmic rays transport equation (steady state)

$$\partial_z [V_C \cancel{\mathrm{sign}}(z)\,\psi] - K(E)\,\Delta\psi + 2h\,\delta(z)\,\partial_E\,[b_{\cancel{\mathrm{disc}}}(E)\,\psi] - D(\cancel{E})\,\partial_E\,\psi] + \partial_E[b_{\mathrm{halo}}(E)\,\psi] = Q(E,\vec{x})$$

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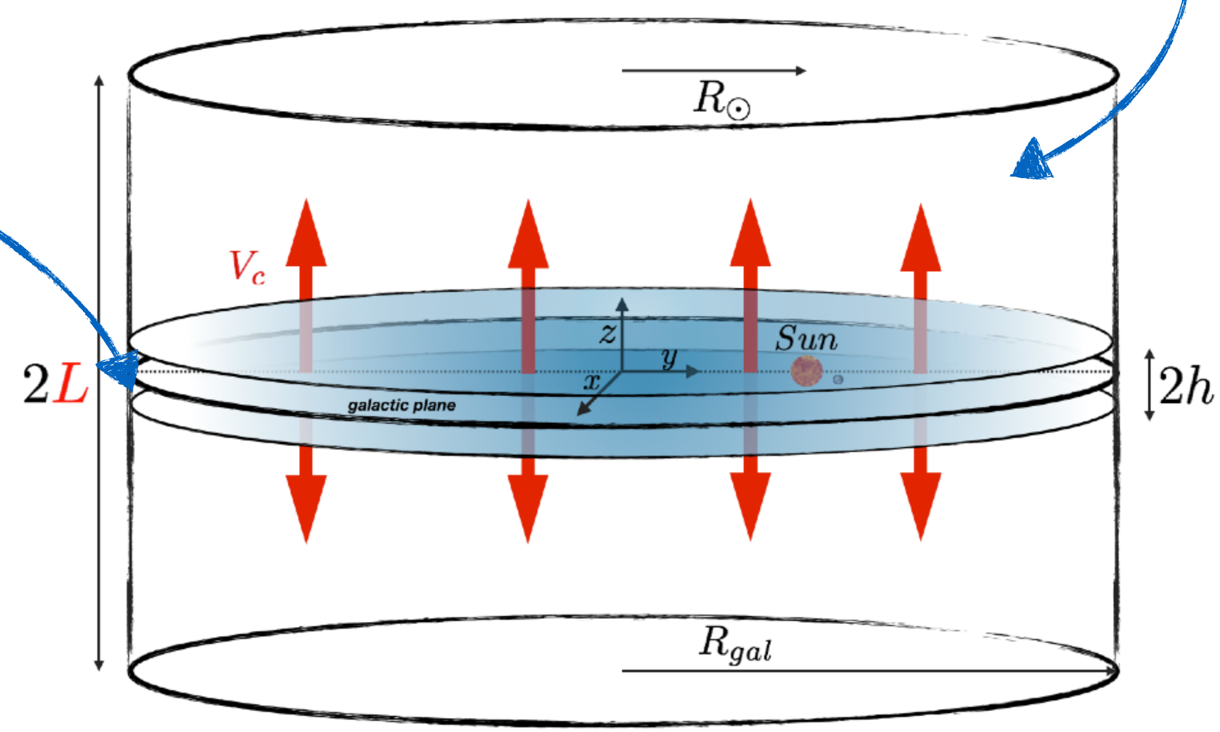


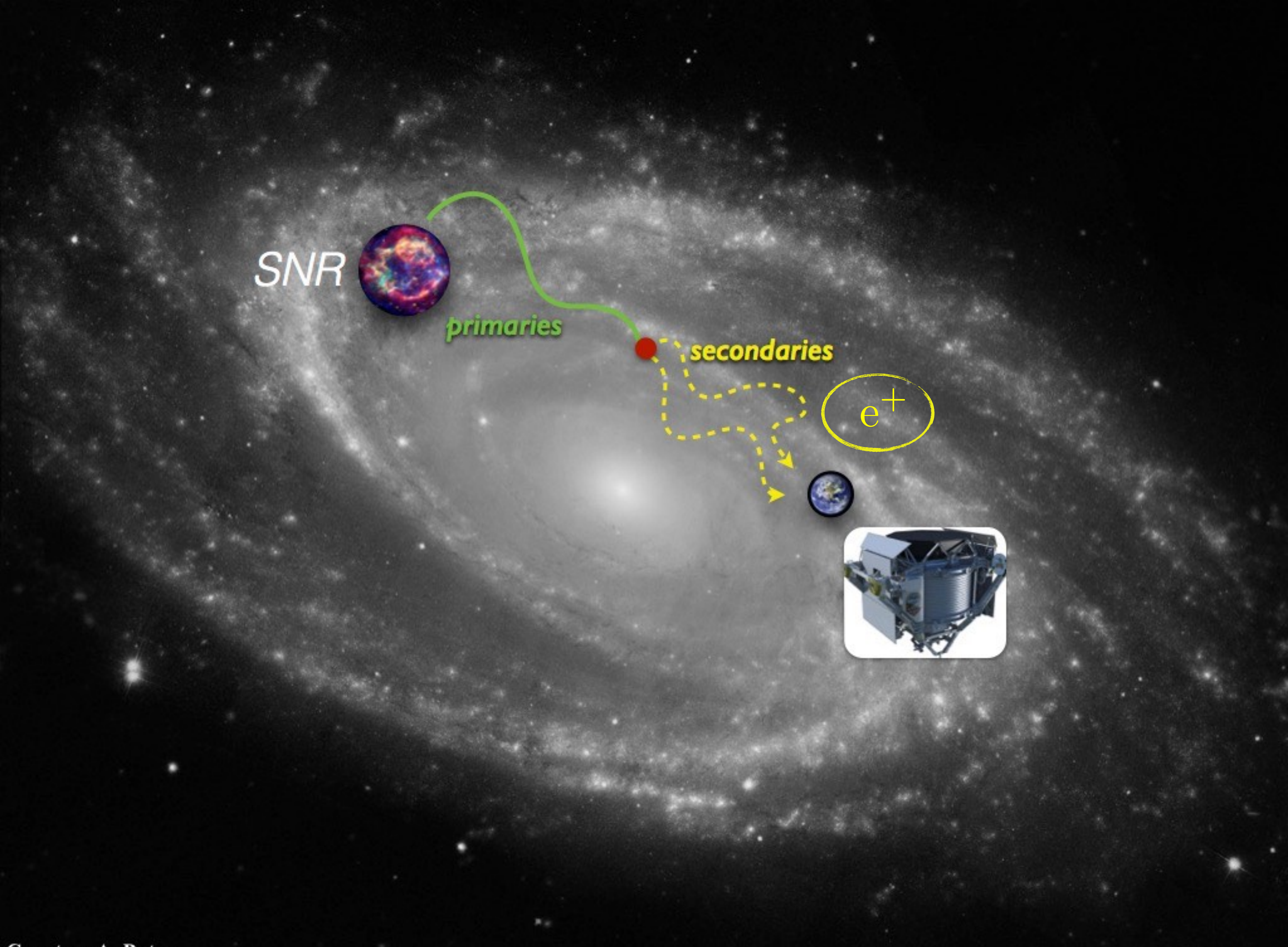
***E* > 10 GeV**

High energy approximation

$$-K(E) + \partial_E\,[b_{\mathrm{halo}}(E)\psi] = Q(E,\vec{x})$$

Baltz & Edsjö (1998)
Delahaye+(2008)
MB+(2014)
etc.

Is E = 10 GeV a correct threshold to get rid of low energy effects?
(Especially with the high accuracy of the AMS-02 data at E ~ 10 GeV)

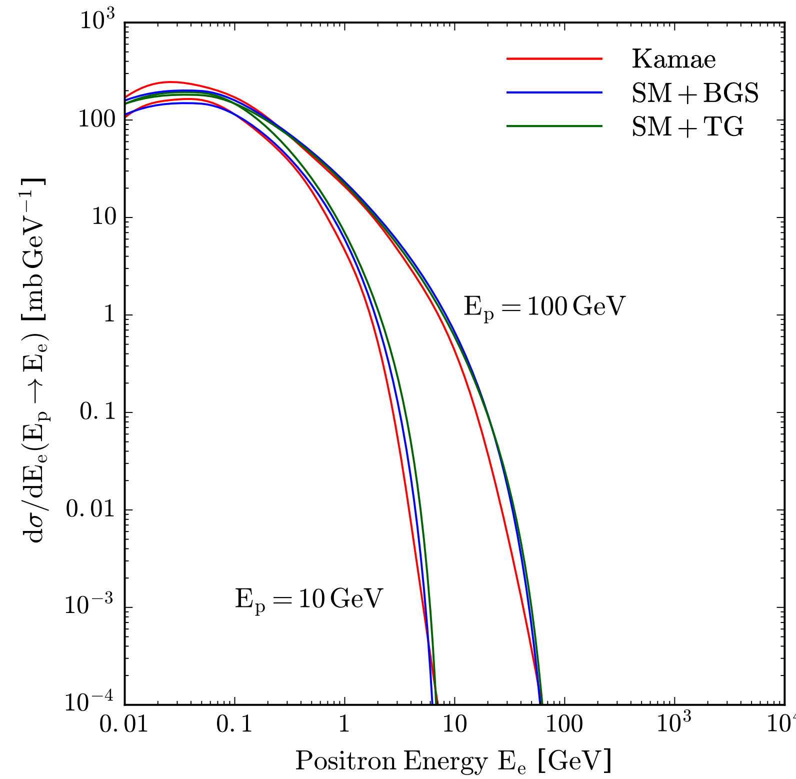


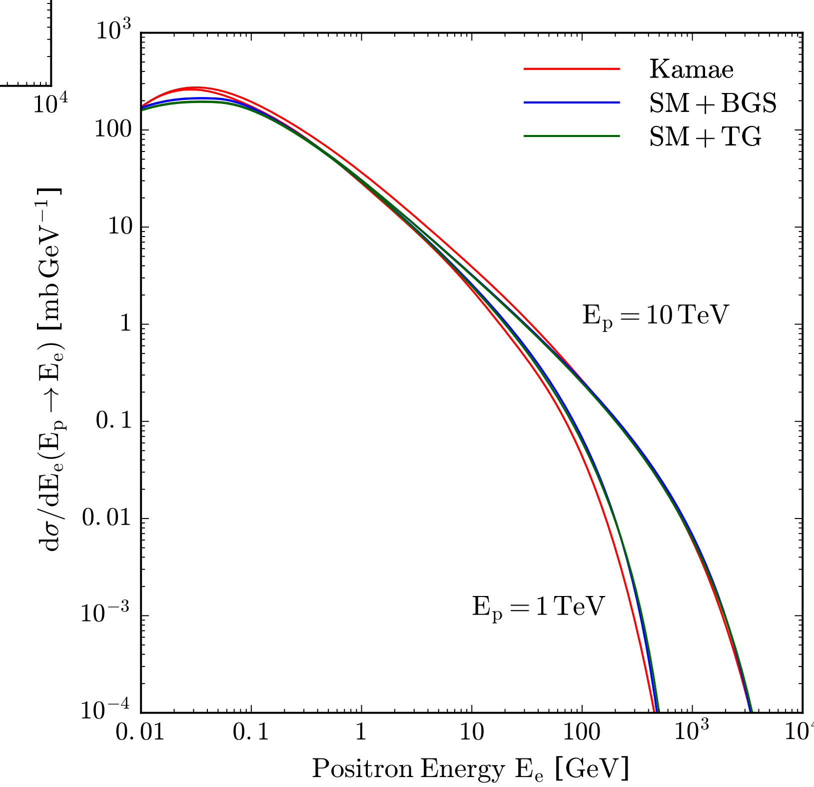
Courtesy A. Putze

Astrophysical secondary positrons

$$Q^{\mathrm{II}}(E,\vec{x}) = 4\pi \sum_{i=p,\alpha}\sum_{j=H,He} n_j \int_{E_0}^{+\infty} dE_i\,\phi_i(E_i,\vec{x})\,\frac{d\sigma}{dE_i}(E_j \to E) \qquad \begin{cases} i = projectile \\ j = target \end{cases}$$

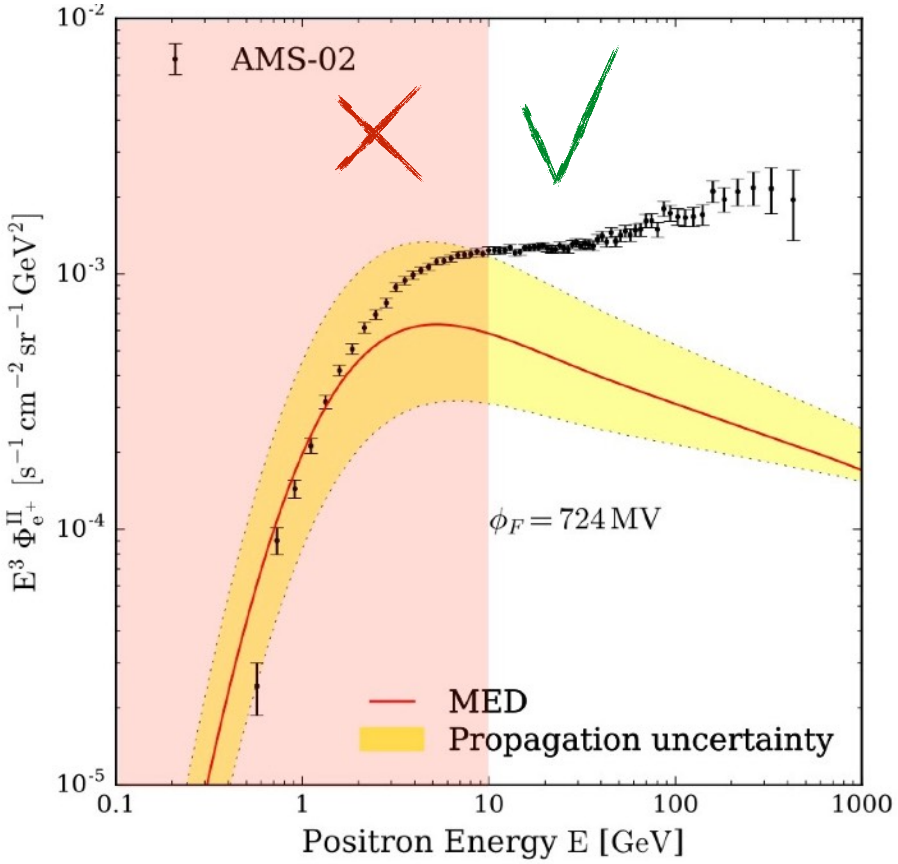
$$p+p \longrightarrow \begin{cases} p+\Delta^+ \\ \quad \Delta^+ \longrightarrow n+\pi^+ \\ \qquad \pi^+ \longrightarrow \nu_\mu+\mu^+ \\ \qquad\quad \mu^+ \longrightarrow \bar{\nu}_\mu+\nu_e+e^+ \\ \\ X+\pi^+ \\ \quad \pi^+ \longrightarrow \nu_\mu+\mu^+ \\ \qquad \mu^+ \longrightarrow \bar{\nu}_\mu+\nu_e+e^+ \\ \\ X+K^+ \\ \quad K^+ \longrightarrow \begin{cases} \nu_\mu+\mu^+ \\ \quad \mu^+ \longrightarrow \bar{\nu}_\mu+\nu_e+e^+ \\ \\ \pi^0+\pi^+ \\ \quad \pi^+ \longrightarrow \nu_\mu+\mu^+ \\ \qquad \mu^+ \longrightarrow \bar{\nu}_\mu+\nu_e+e^+ \end{cases} \end{cases}$$



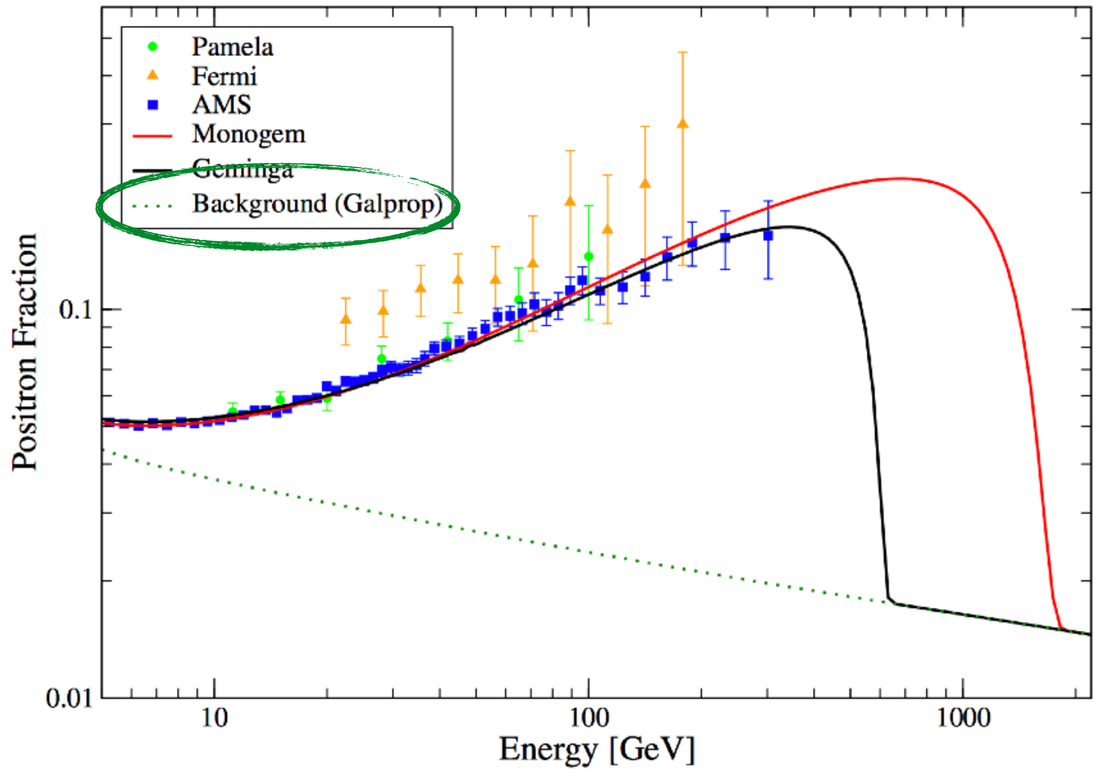


Astrophysical secondary positrons

Semi-analytic (HE approx.) *MB (2014)*



Numerical (GALPROP) *Linden & Profumo (2013)*



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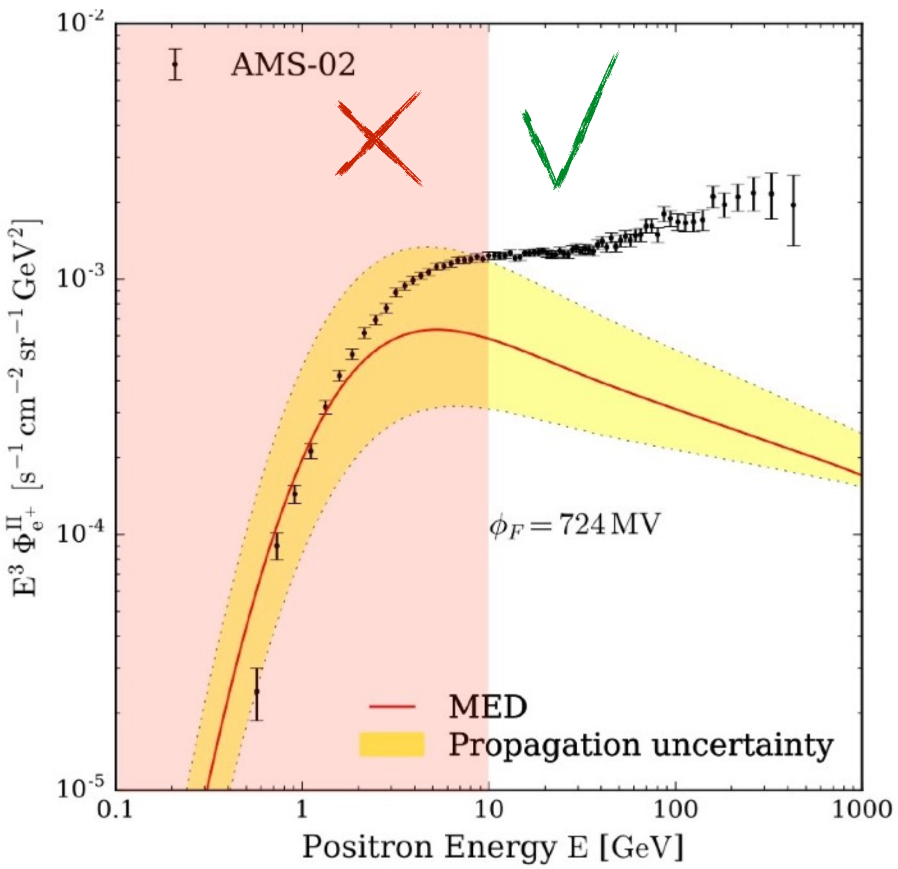

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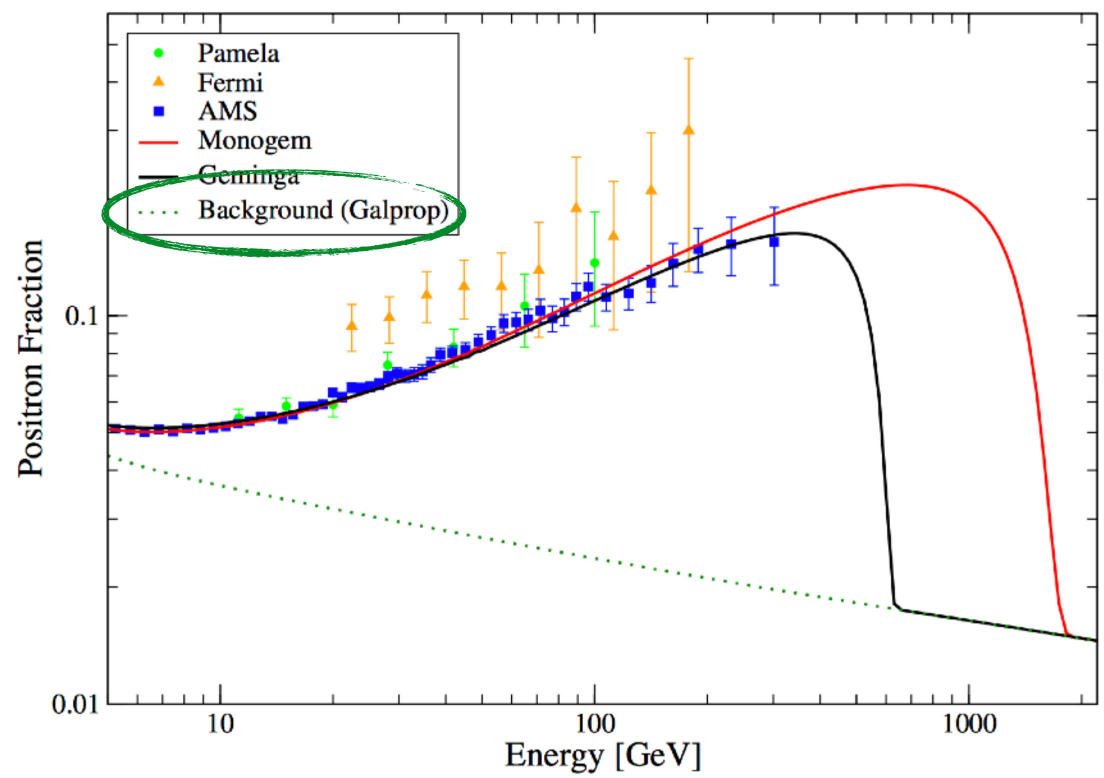

High energy regime

$$\Phi^{II}_{e+} \propto E^{-\gamma}$$

$$\gamma = \gamma_p + \frac{1}{2}(\alpha + \delta - 1)$$

$\gamma_p \simeq 2.8$ *Measured by AMS-02*

$\alpha = 2$ *Thomson regime for e+ ɣ interactions*

$\delta = 0.7$ *MED model*

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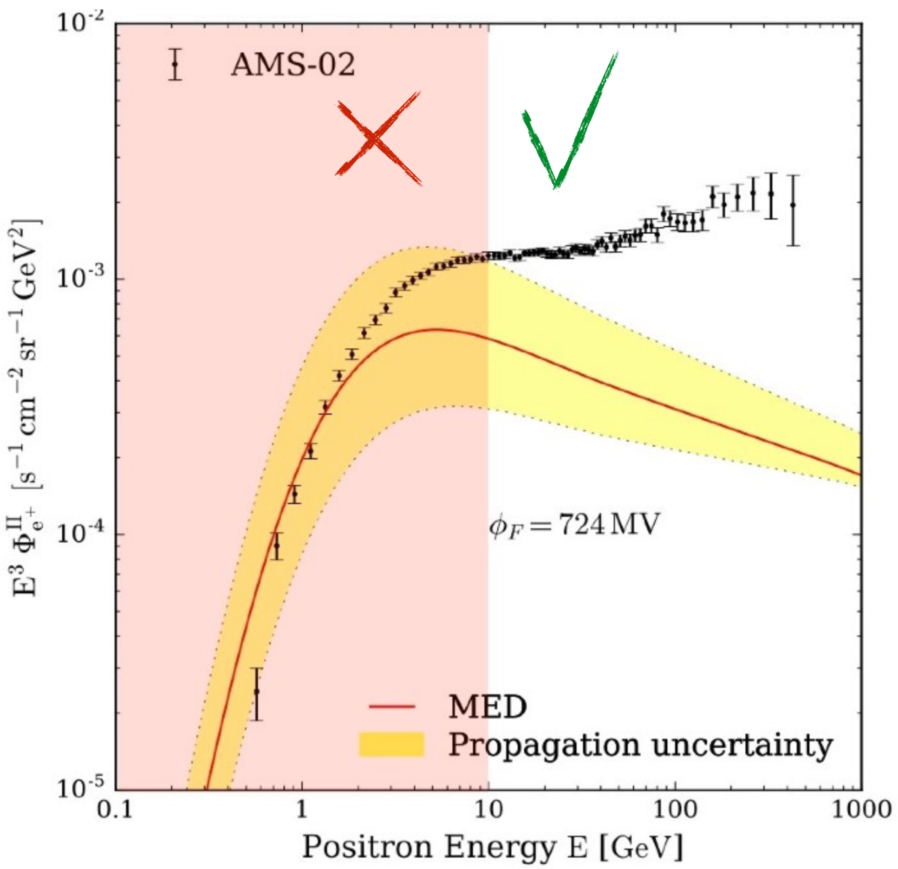

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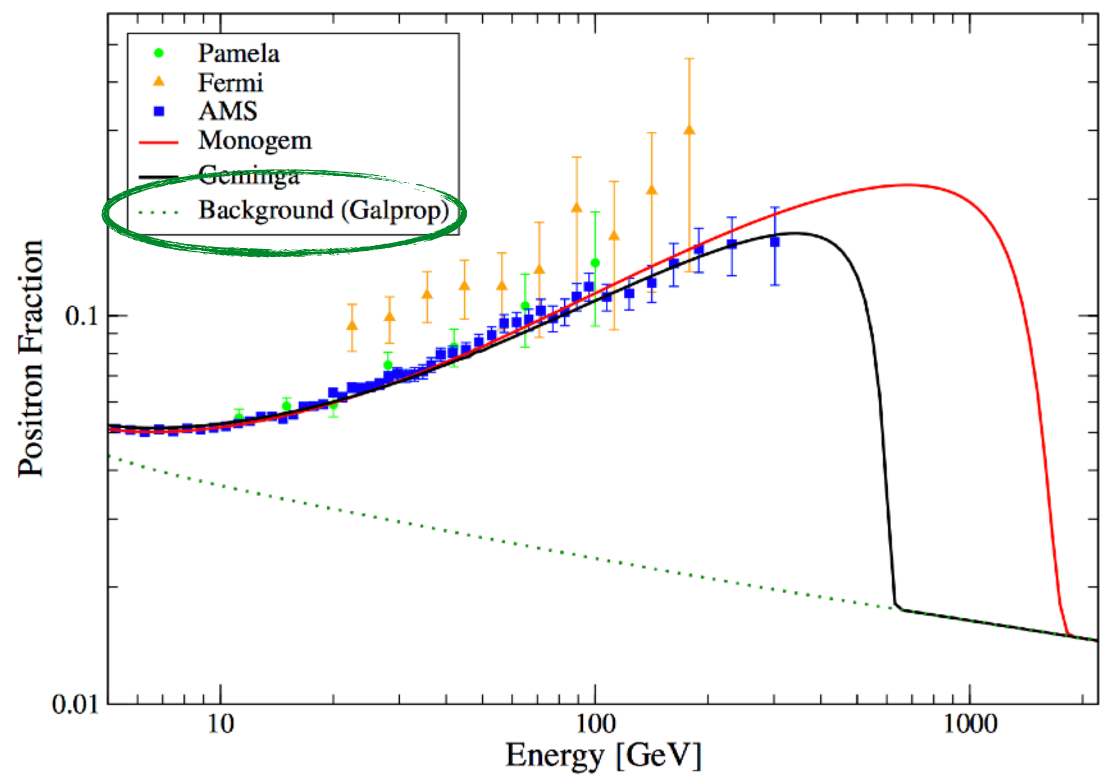

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$$\Rightarrow \quad \gamma \simeq 3.5$$

Astrophysical secondary positrons

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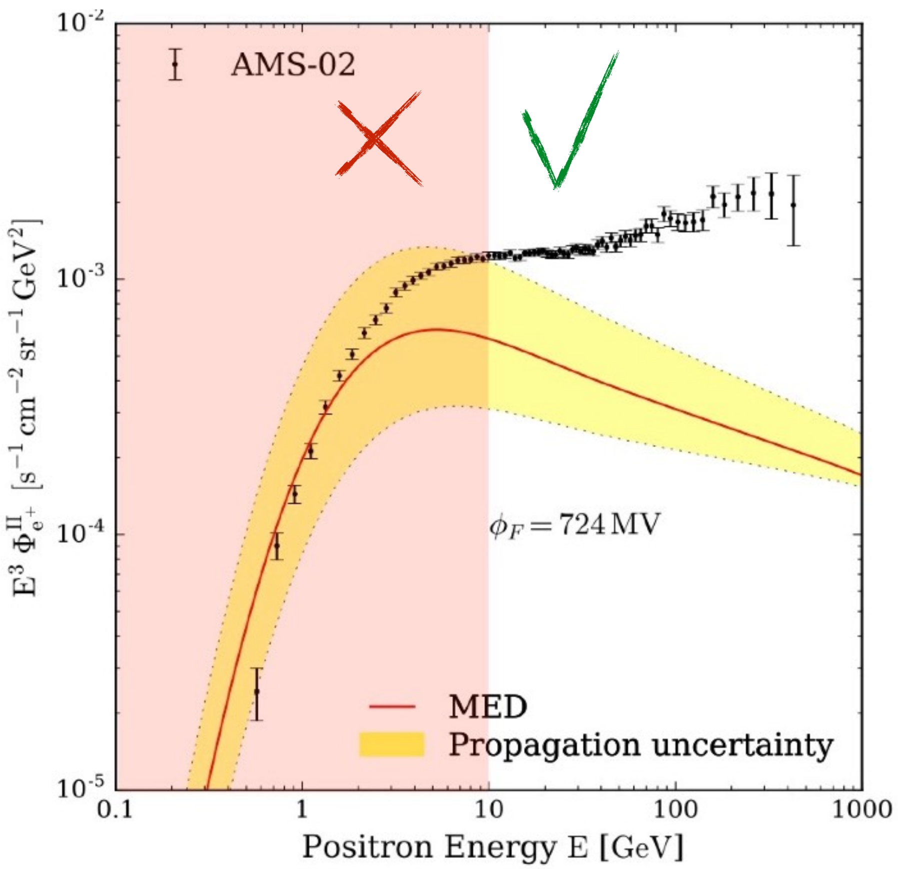

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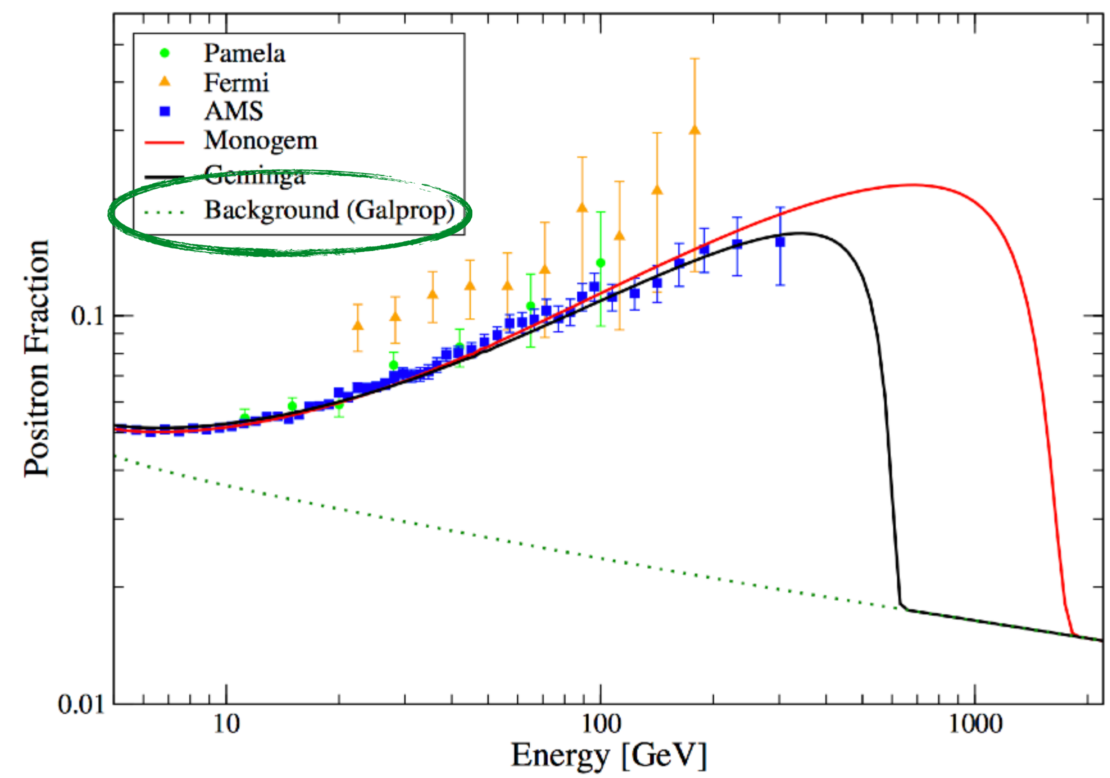

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$$\Rightarrow \gamma \simeq 3.5 \neq \gamma_{e^+} \simeq 2.75$$

This is the positron anomaly (excess)!

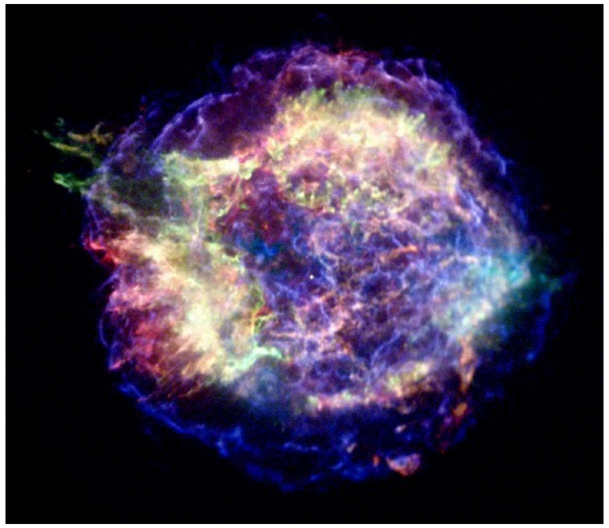
Another source of positrons is required to explain the data.

Where do come from the high energy positrons?

Nearby astrophysical sources (SNRs and PWNe)

Primary positrons

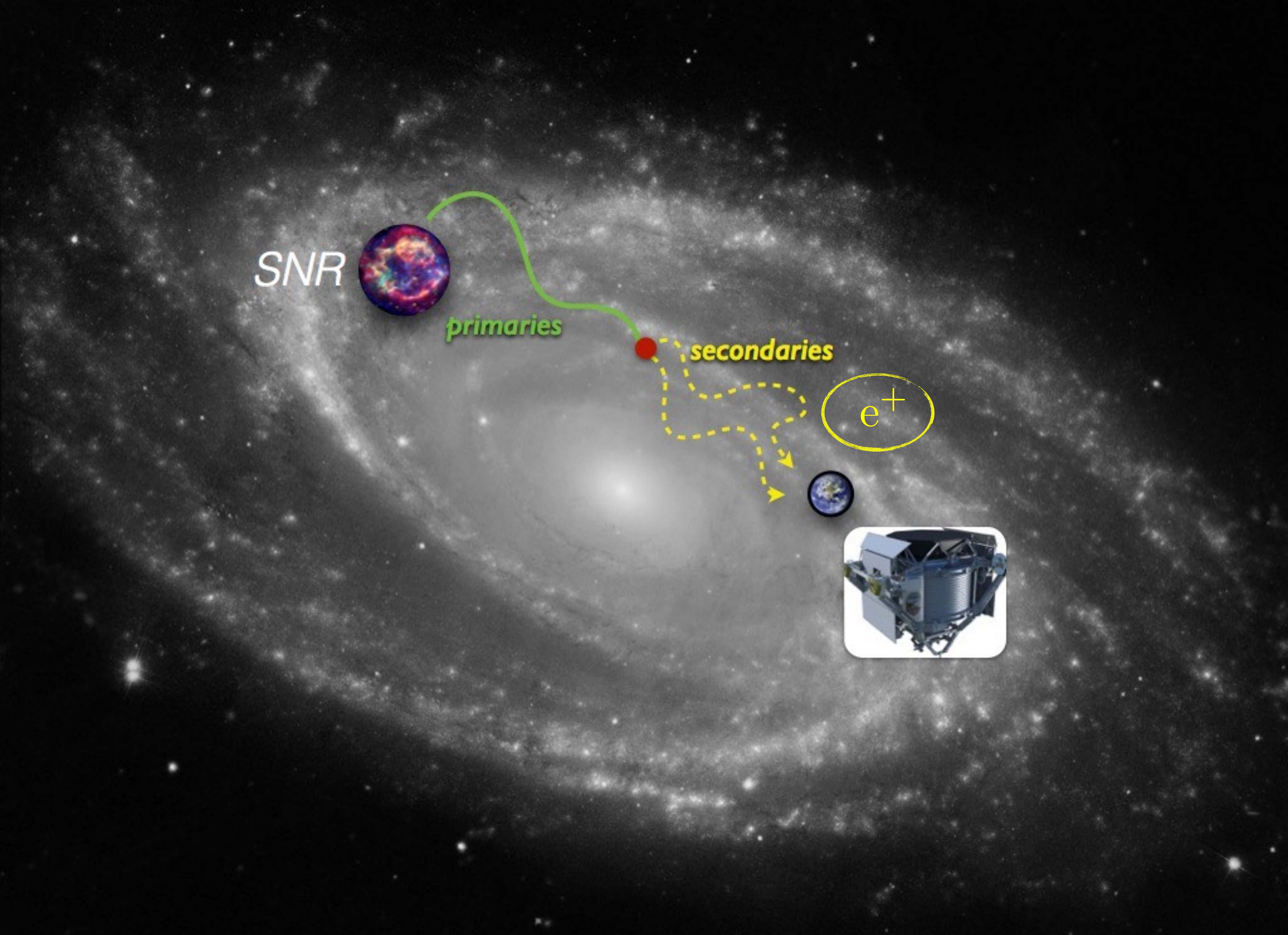
Primary positrons = production in the shocks of supernova remnants (SNRs)



1- Positrons are produced close to the shock $p + p \longrightarrow e^{+} + ...$

2- Positrons are accelerated in the shock by diffusive stochastic acceleration (DSA)

Blasi & Serpico (2009), Mertsch & Sarkar (2014)



Courtesy A. Putze

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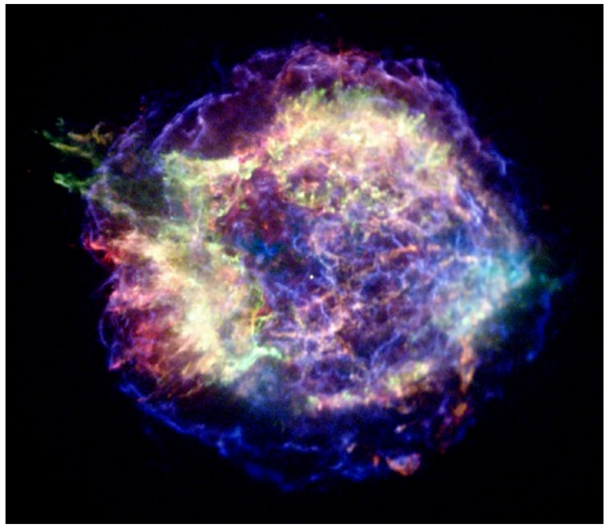

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Common belief: secondaries from propagation are much more abundant since the grammage in the ISM is much larger than in the source.

Secondaries

$$\tau_{\rm esc} \sim 10^7 \ {\rm yr}$$

$$n_{\rm ISM} \simeq 1 \ {\rm cm}^{-3}$$

$$\langle \rho_{\rm halo} \rangle \sim 10^{-26} {\rm g \, cm}^{-3}$$

$$\lambda_{\rm II} \sim 1 \ {\rm g \, cm}^{-2}$$

Primaries

$$\tau_{\rm SNR} \sim 10^4 \ {\rm yr}$$

$$n_{\rm SNR} = (r \leq 4) \times n_{\rm ISM}$$

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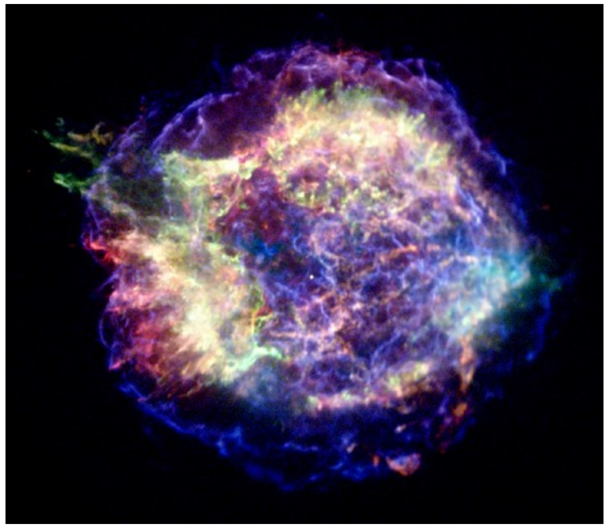

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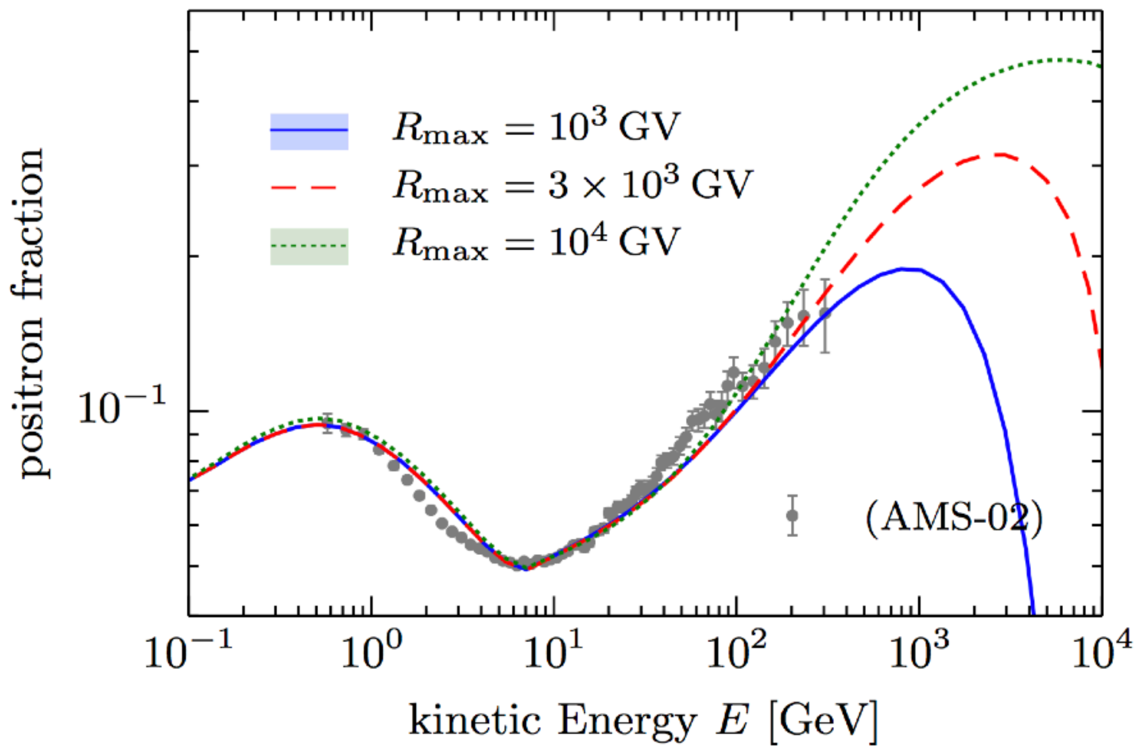
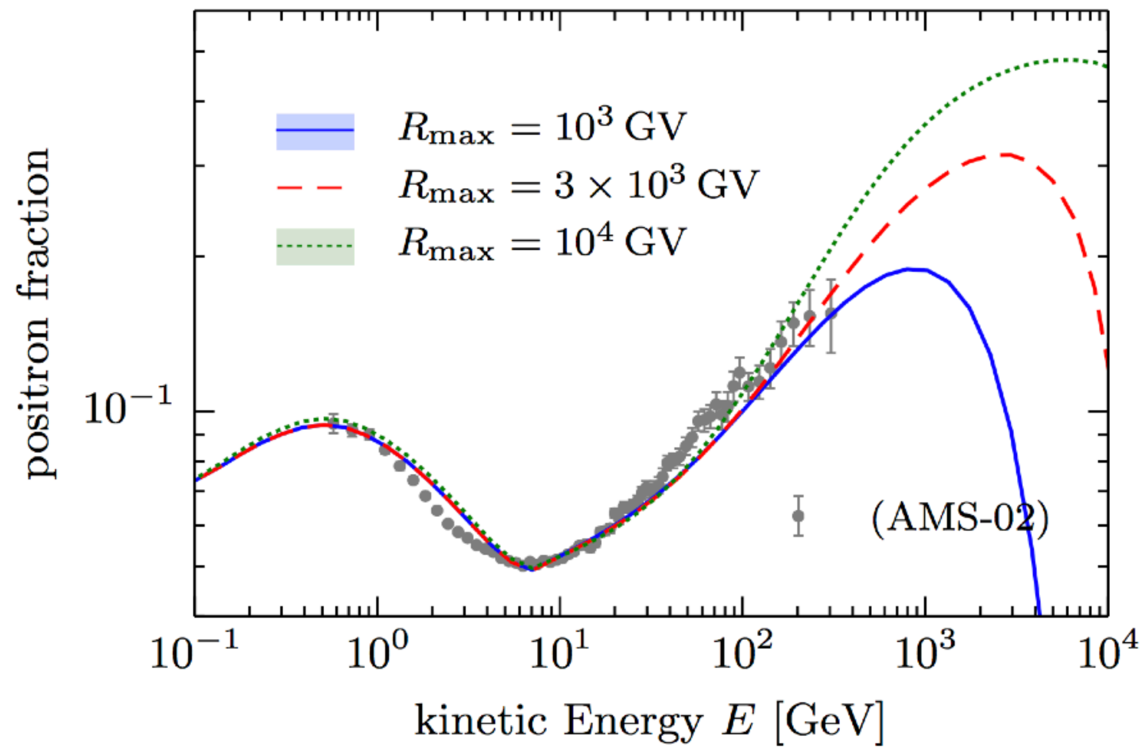
However, the primaries can have a much harder spectrum!

Primary positrons



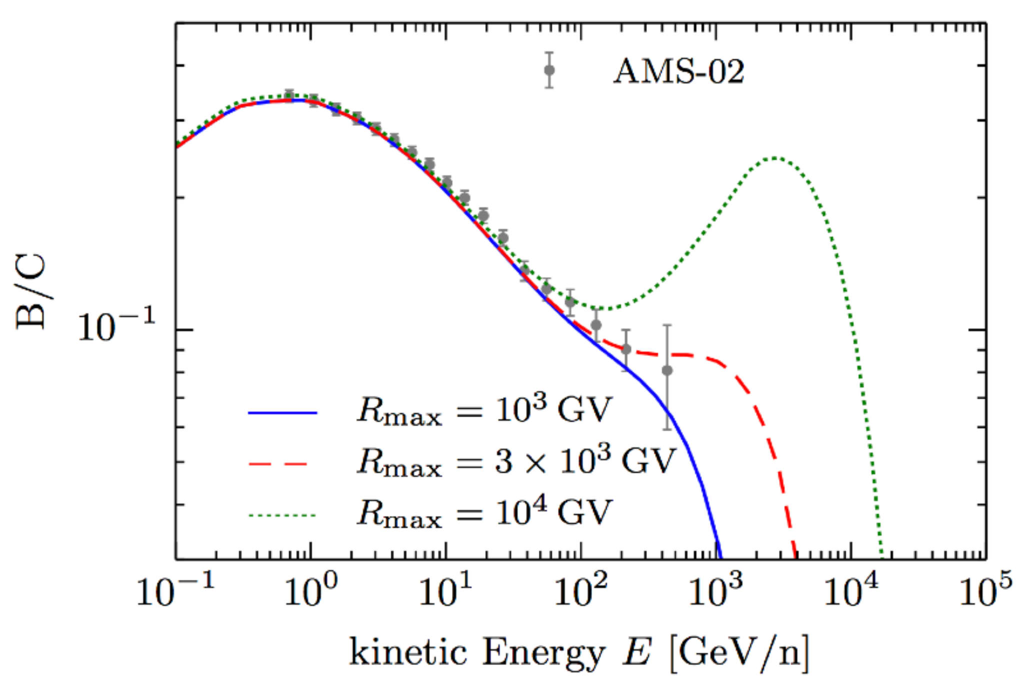
Mertsch & Sarkar (2014)

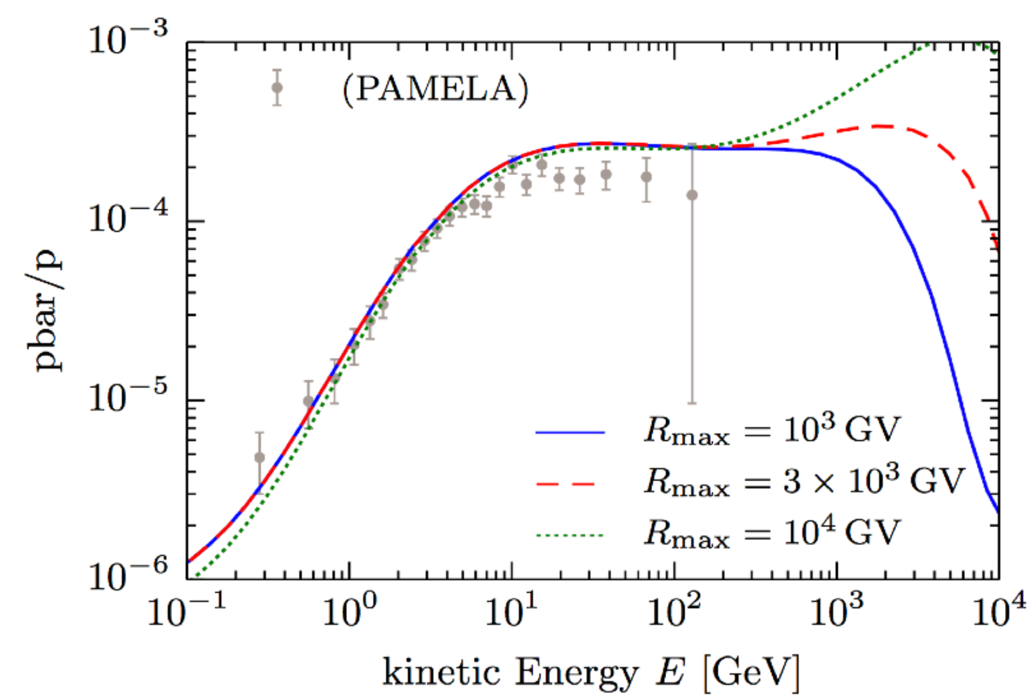
Primary positrons



Mertsch & Sarkar (2014)

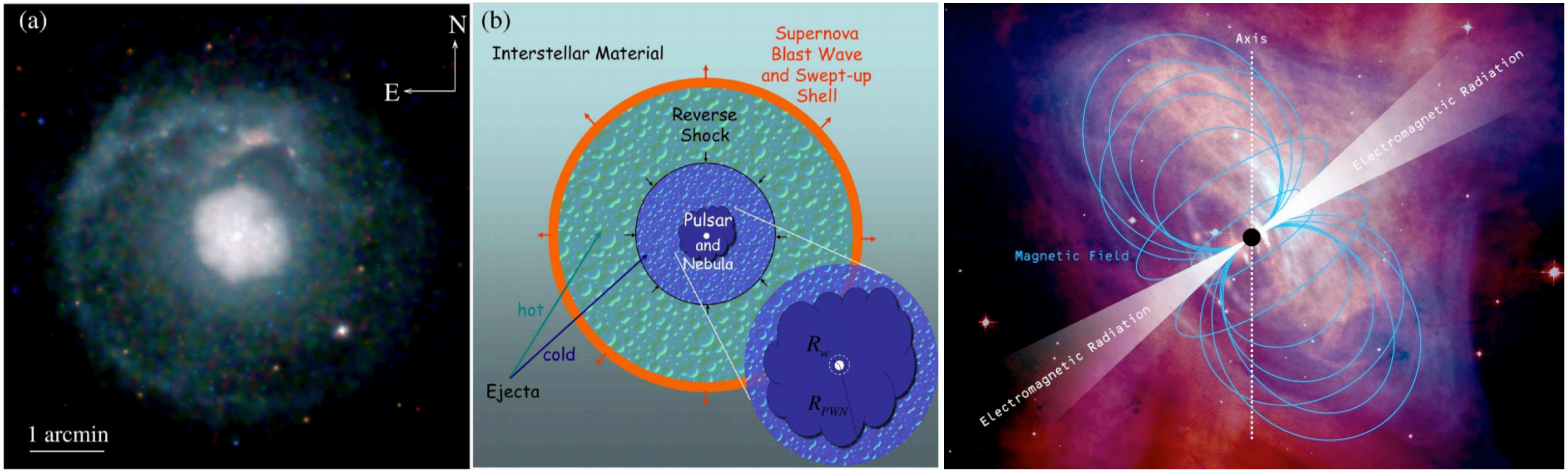
Nevertheless, if positrons are produced in SNRs, all secondary CRs too! (Li, Be, B, $\bar{p}$, etc.)





In serious tension with B/C and antiprotons measured by AMS-02!

Pulsar wind nebulae (PWNe)



A pulsar is a rotative neutron star which the magnetic dipole is not aligned with the rotation axis.

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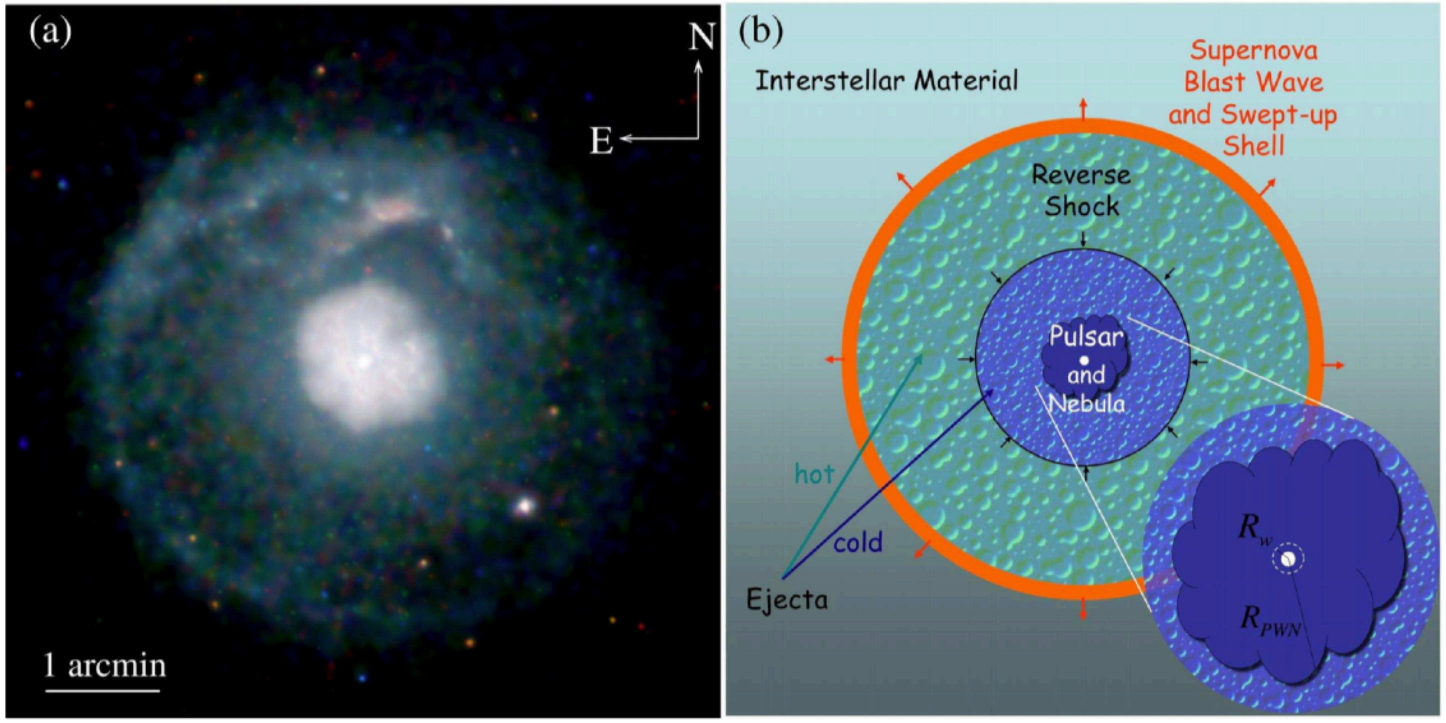
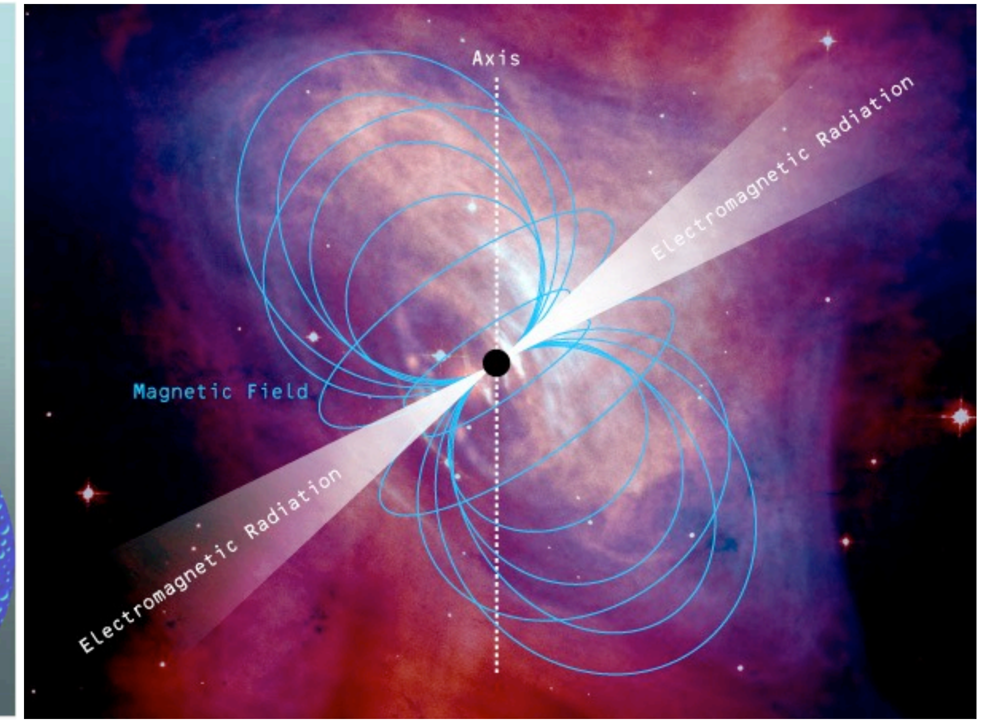
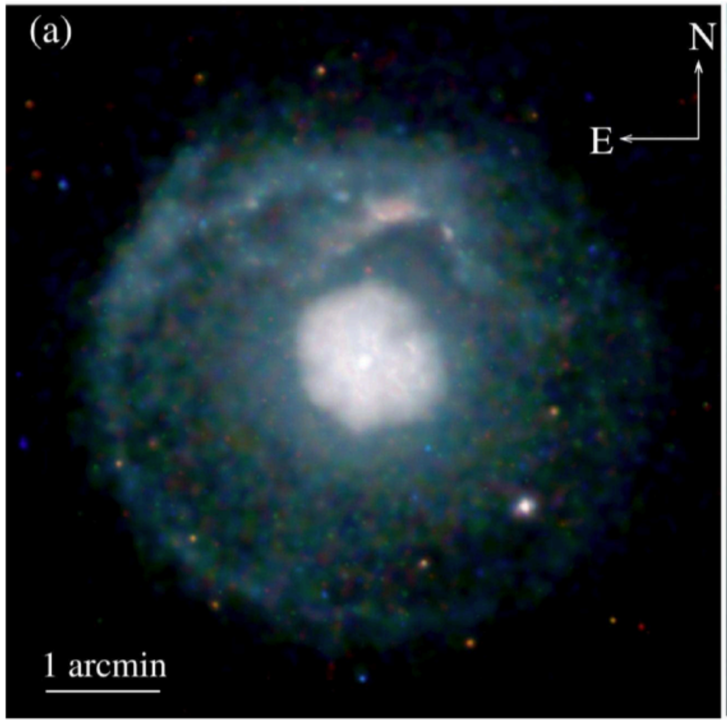


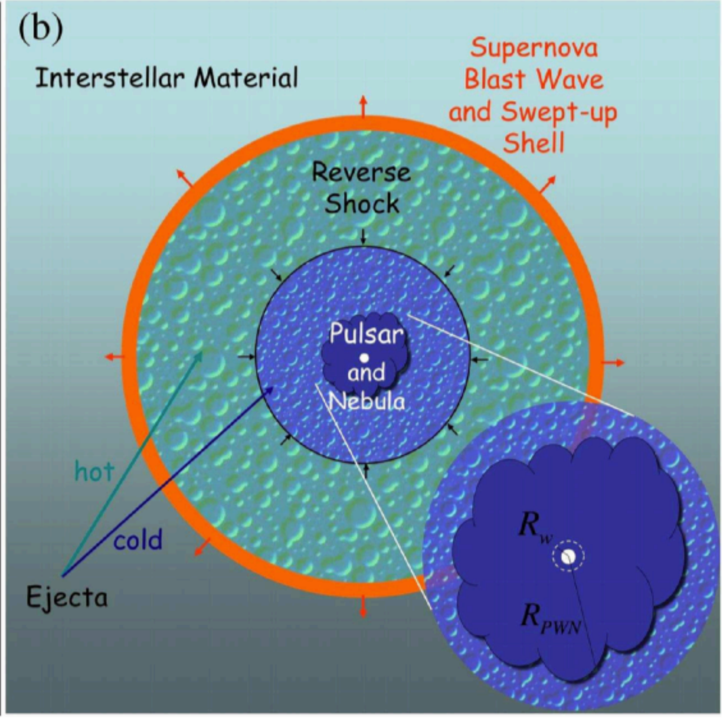


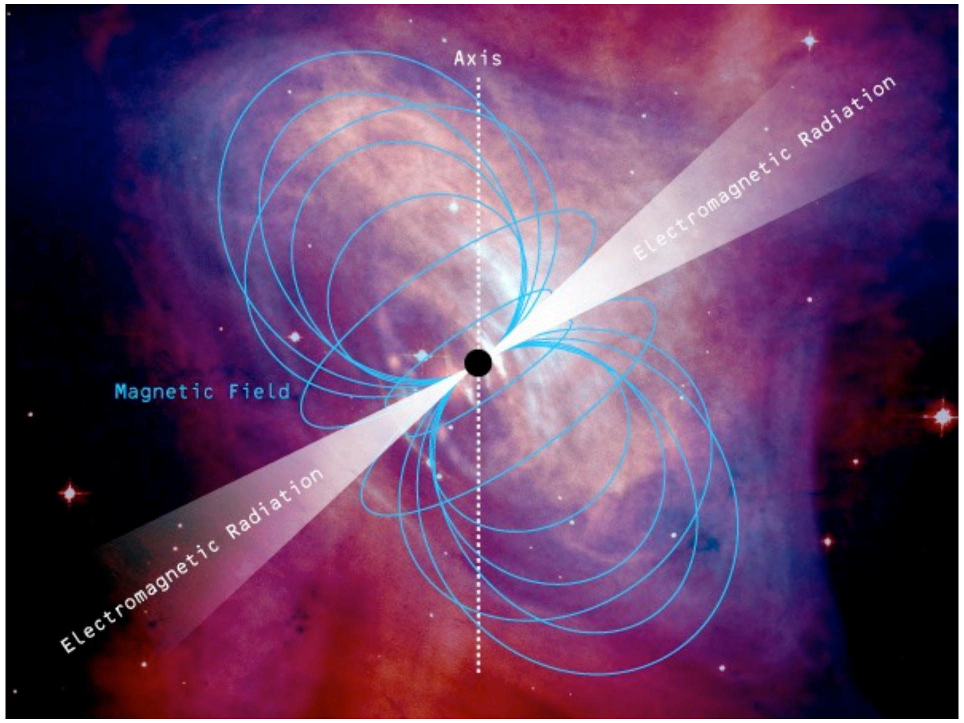
A pulsar is a rotative neutron star which the magnetic dipole is not aligned with the rotation axis.

⇒ a strong electric field is created by induction.

Pulsar wind nebulae (PWNe)







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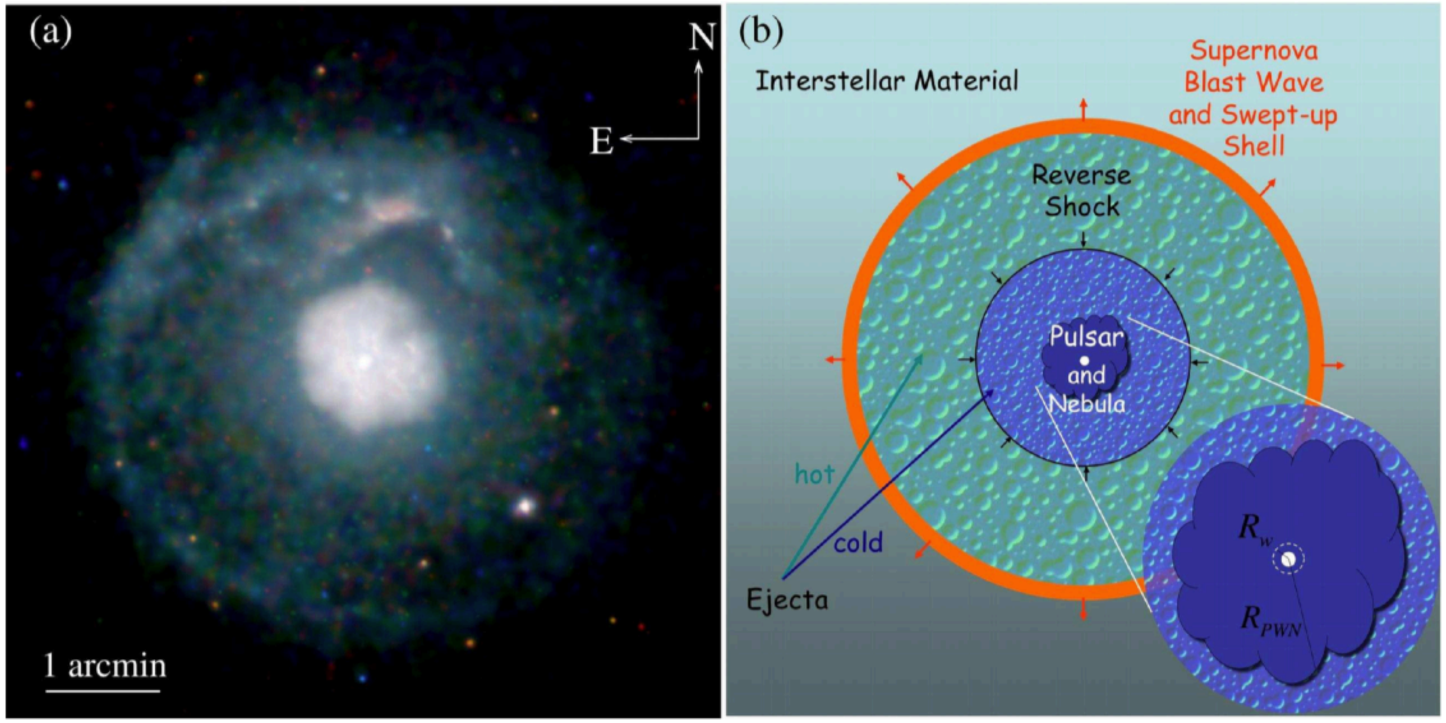

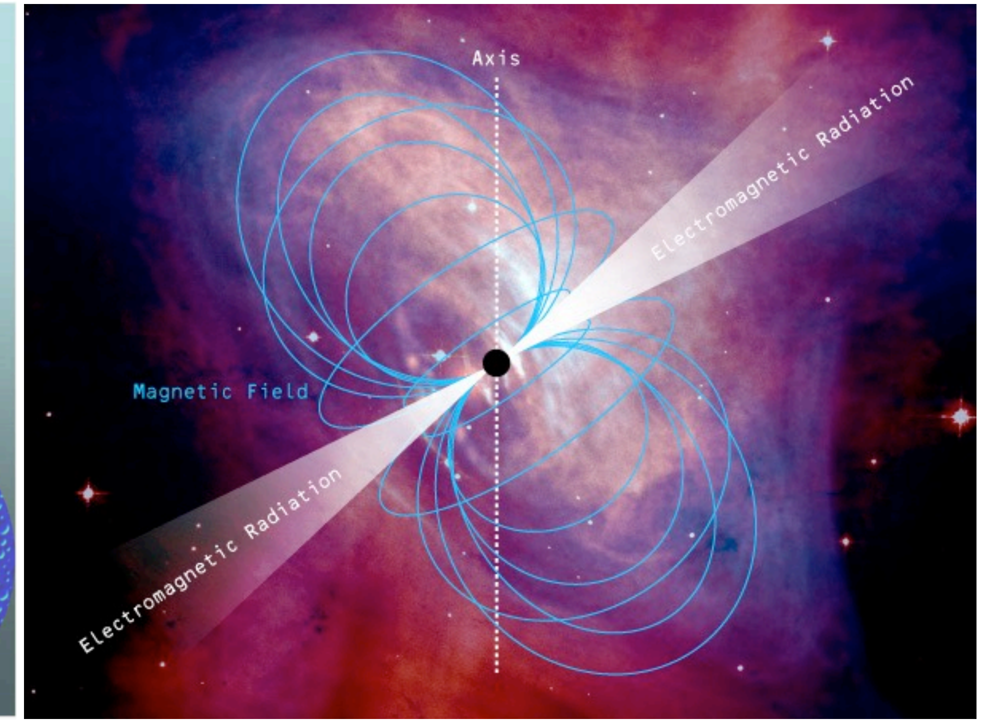

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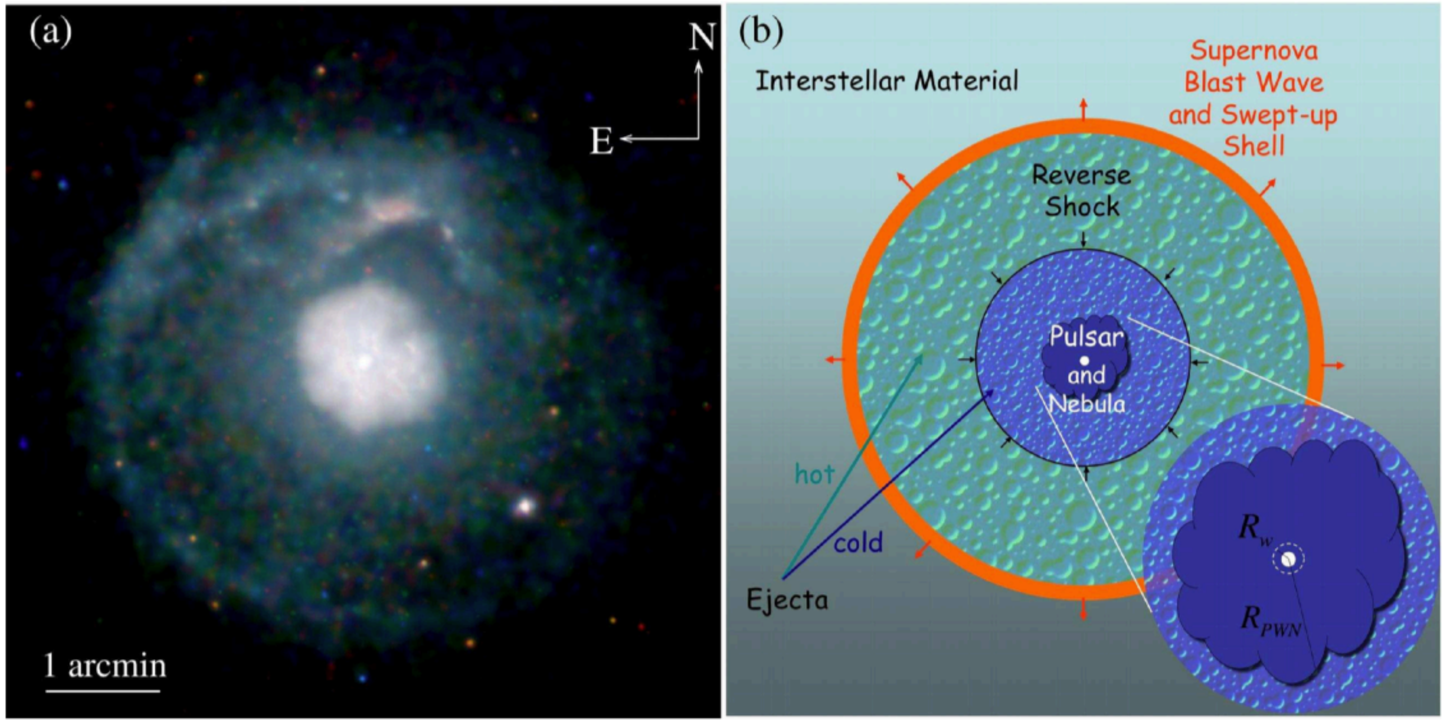
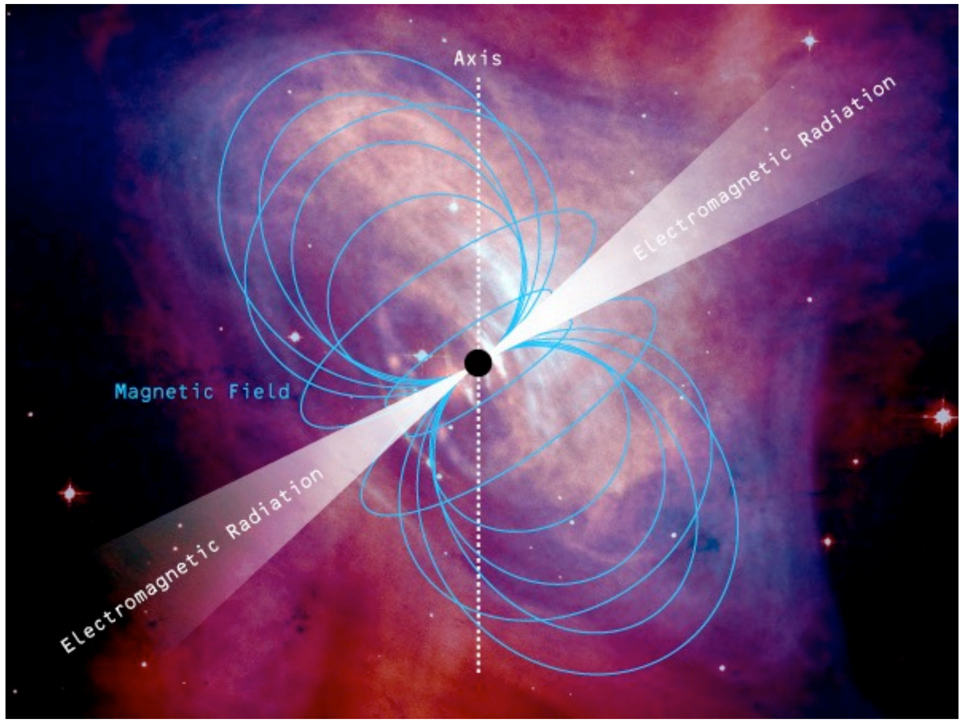
⇒ a strong electric field is created by induction.

⇒ electrons are extracted from the surface of the pulsar.

⇒ electrons + strong B ⇒ electromagnetic cascade ⇒ creation of e^+e^- pairs.
1 e^- extracted can produce up to 10^5 e^+e^- pairs.

Pulsar wind nebulae (PWNe)





A pulsar is a rotative neutron star which the magnetic dipole is not aligned with the rotation axis.

⇒ a strong electric field is created by induction.

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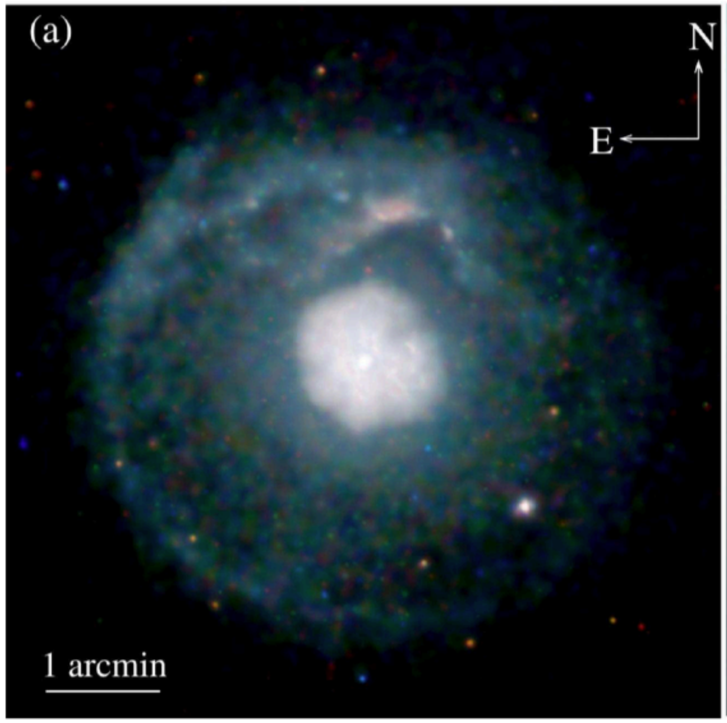

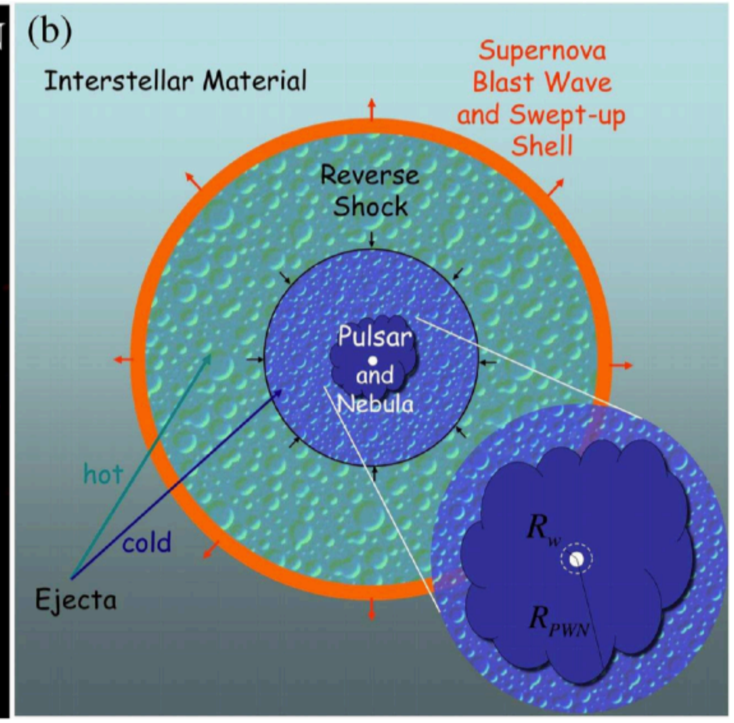

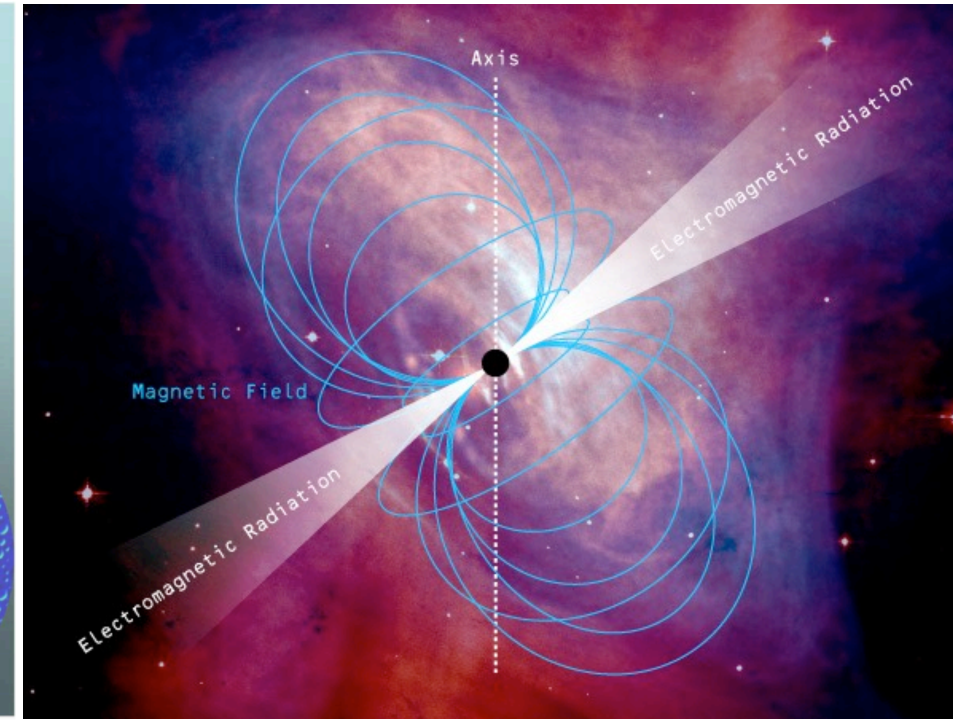

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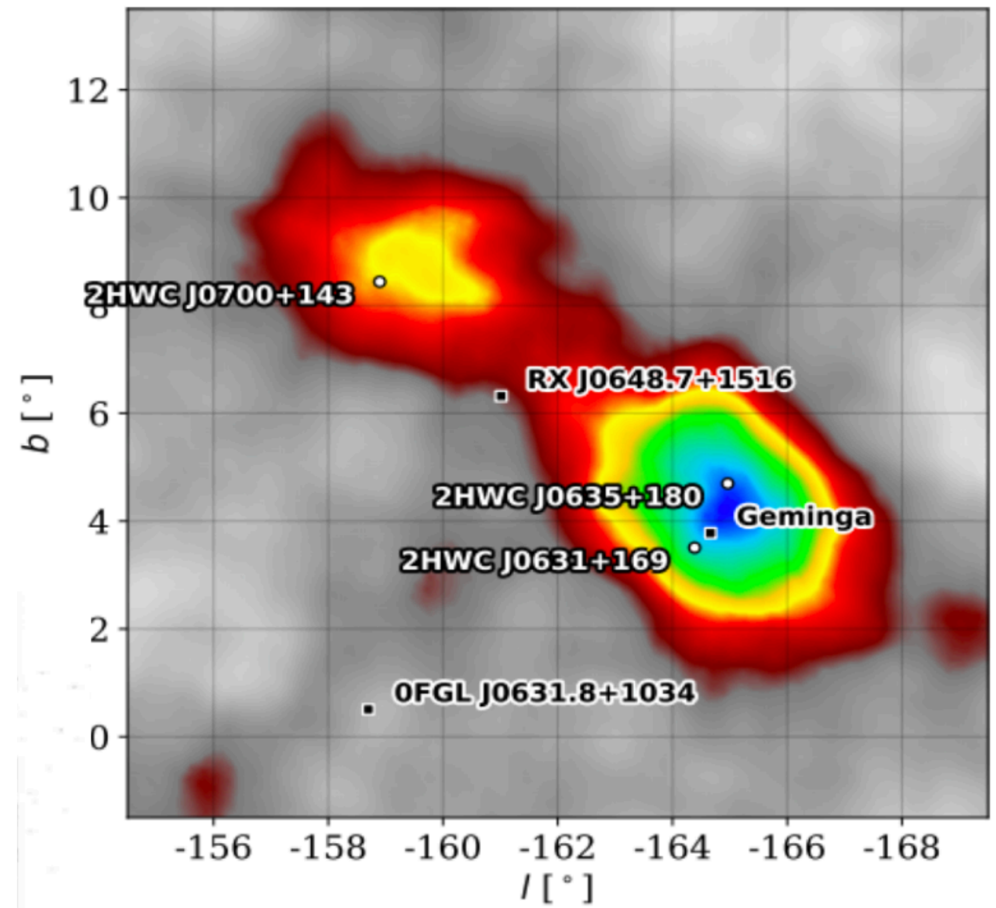
When the pulsar wind reaches the reverse shock, e^- and e^+ are accelerated and ejected in the ISM.

Pulsars: very unknown objects

- Age $t_\star$

The period *P* is very well measured and observations show that $P\dot{P} = Cst$.

$$t_\star = \frac{P}{2\dot{P}} + \frac{d}{c}$$



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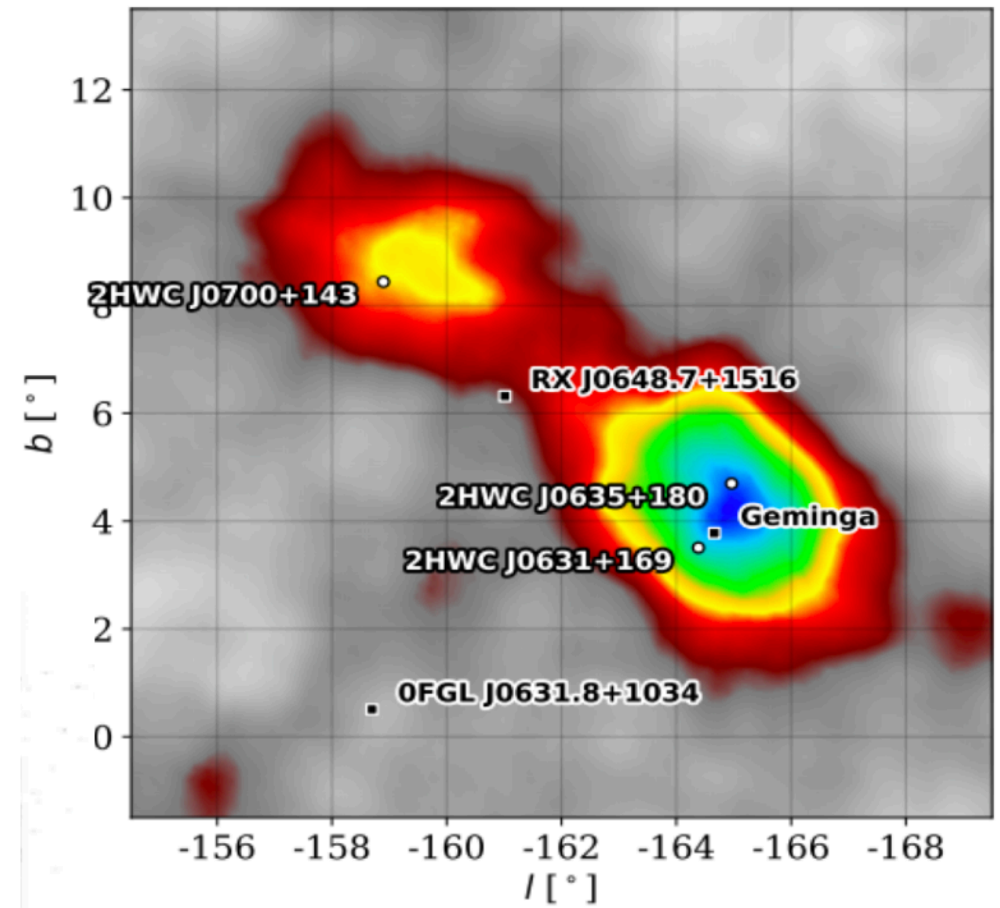

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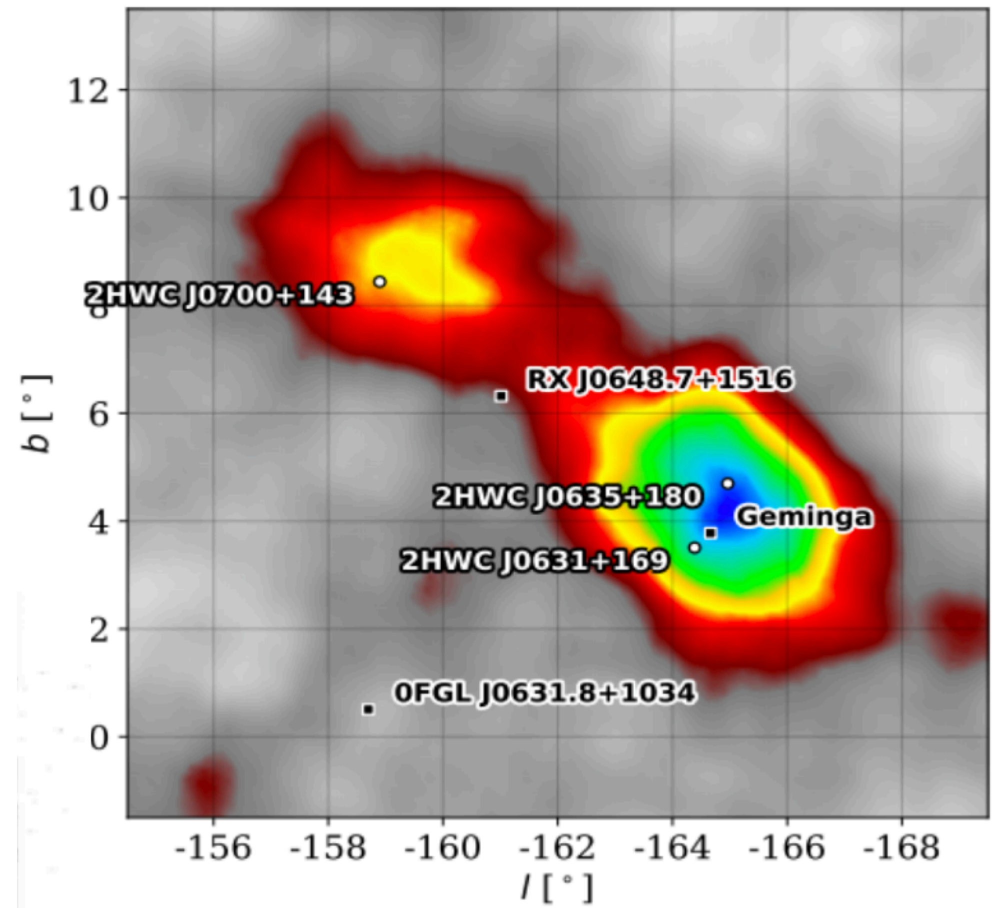

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$$Q(E) = Q_0\, E^{-\gamma} \exp\left(-\frac{E}{E_C}\right)$$

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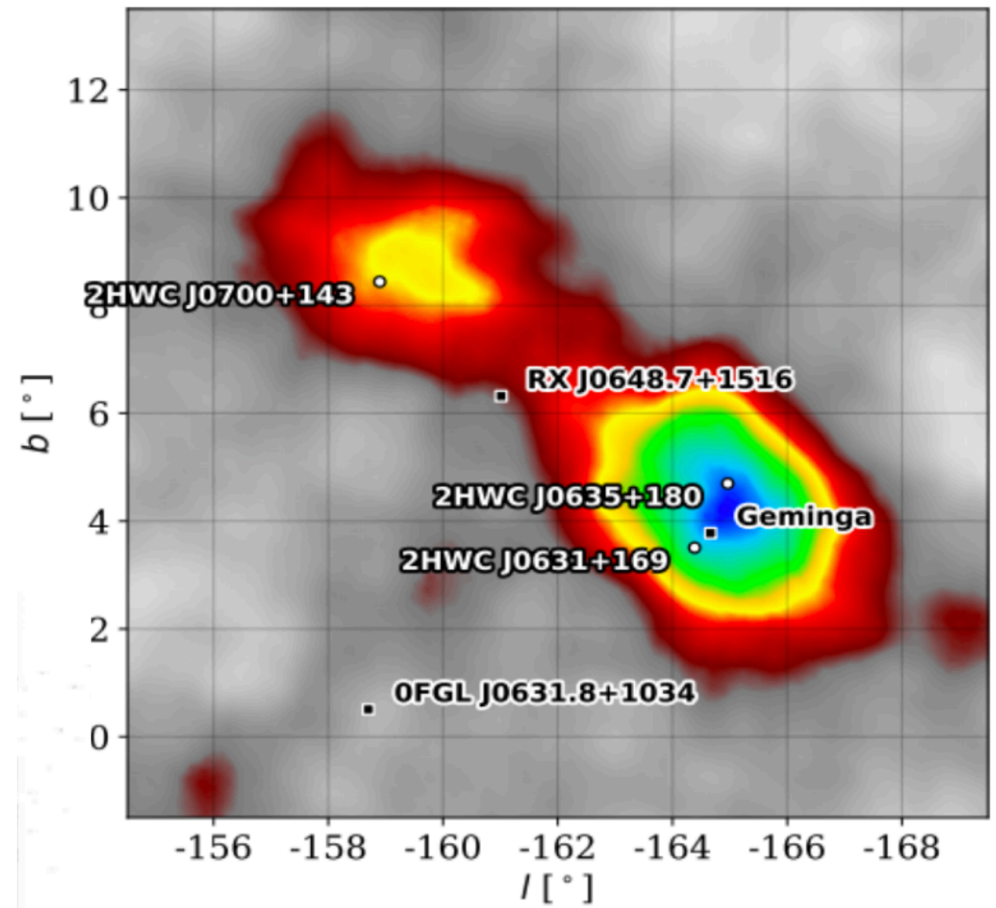

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$1.5 \leq \gamma \leq 2.5$ from gamma rays observations.

- Total energy released by a pulsar through e+ fW_0

$$W_0 \simeq \frac{1}{2}\, I\, \Omega_0^2 \simeq 2.2 \times 10^{49} \left(\frac{M}{1.4\, M_\odot}\right) \left(\frac{R}{10\,\mathrm{km}}\right)^2 \left(\frac{\Omega_0}{2\pi\,\mathrm{Hz}}\right)^2 \ \mathrm{erg}$$

$$P_0 \geq 1\,\mathrm{ms} \;\Rightarrow\; \mathrm{fW}_0 \leq 10^{54}\ \mathrm{erg}\,(10^{57}\mathrm{GeV})$$

Positrons flux from PWNe

Activity time (acceleration)

$$t_a \sim 1 - 10 \text{ kyr}$$

Propagation time

$$t_d = \left(\frac{d}{1 \text{ kpc}}\right)^2 \left(\frac{K_0}{10^{-2} \text{ kpc}^2 \text{ Myr}^{-1}}\right)^{-1} \left(\frac{E}{1 \text{ GeV}}\right)^{-\delta} \text{Myr.}$$

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PWNe are modelled by a point source in time and space.

$$Q^{PSR}(E, t, \vec{x}) = \delta(t - t_*)\delta(\vec{x} - \vec{x}_*)Q_0 \left(\frac{E}{E_0}\right)^{-\gamma} \exp\left(-\frac{E}{E_C}\right)$$

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age

position

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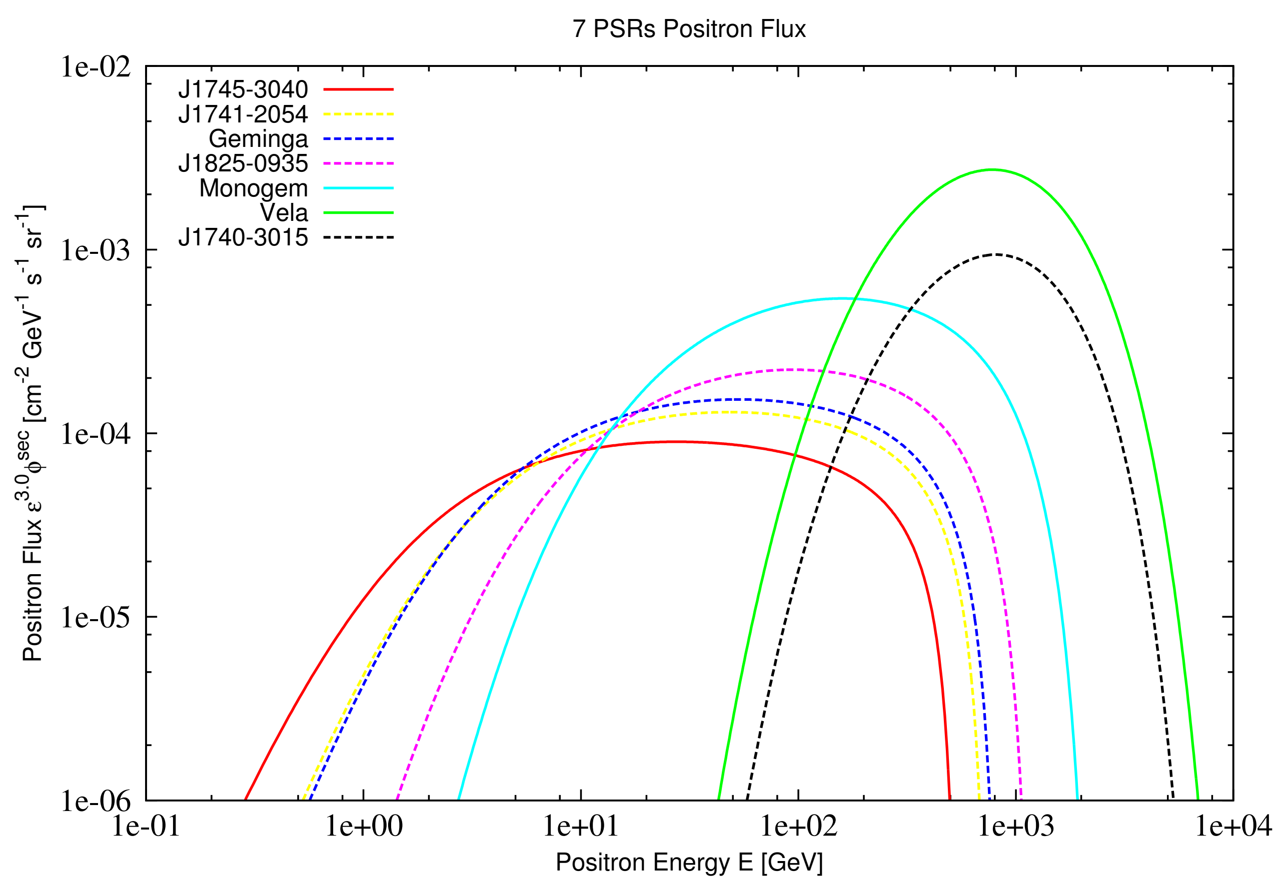
age

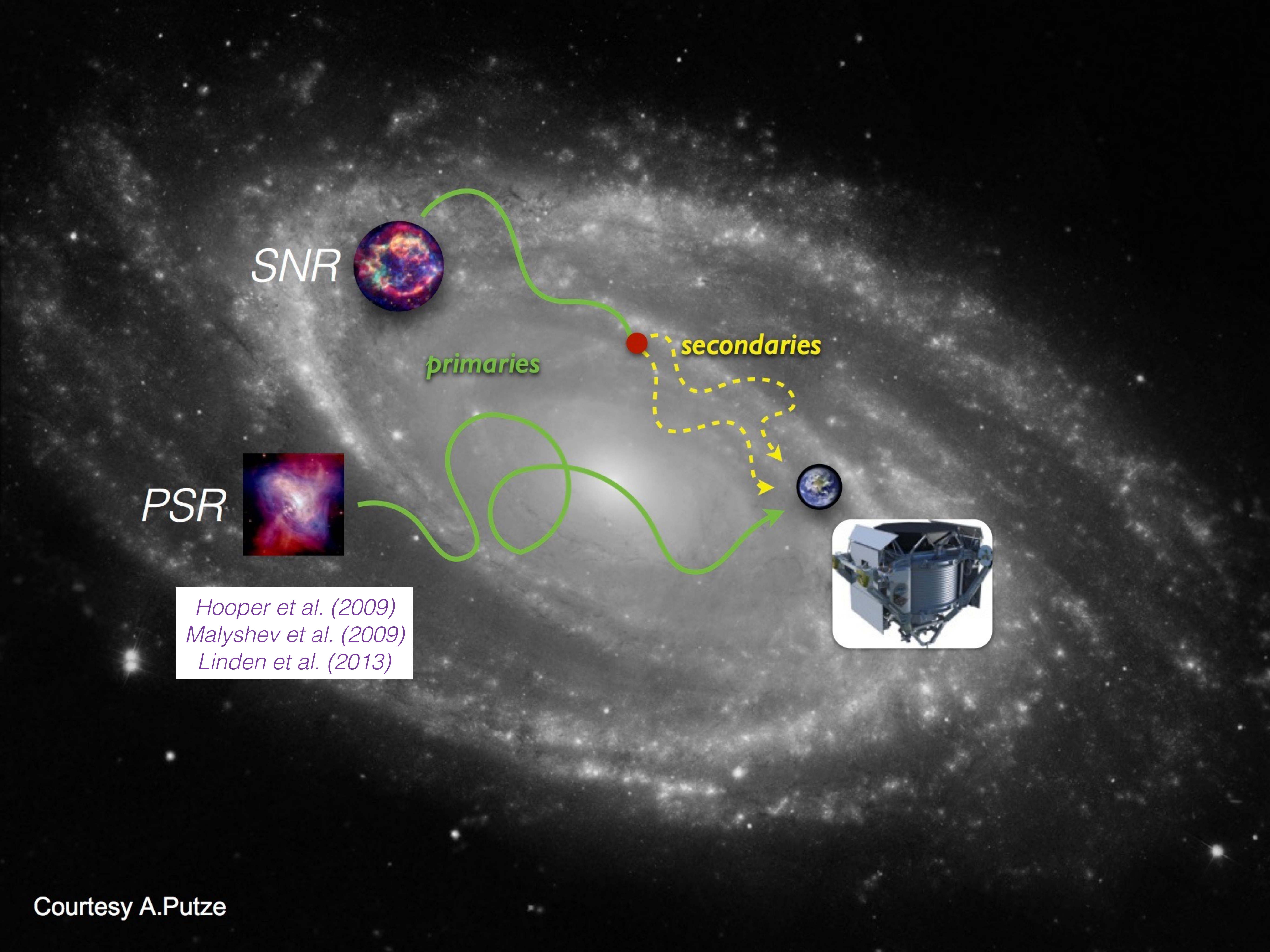
position

The positron flux is restricted between E_{min} and E_{max} where

$$E_{min} = \left(\frac{d^2}{4K_0 t_\star}\right)^{1/\delta}$$

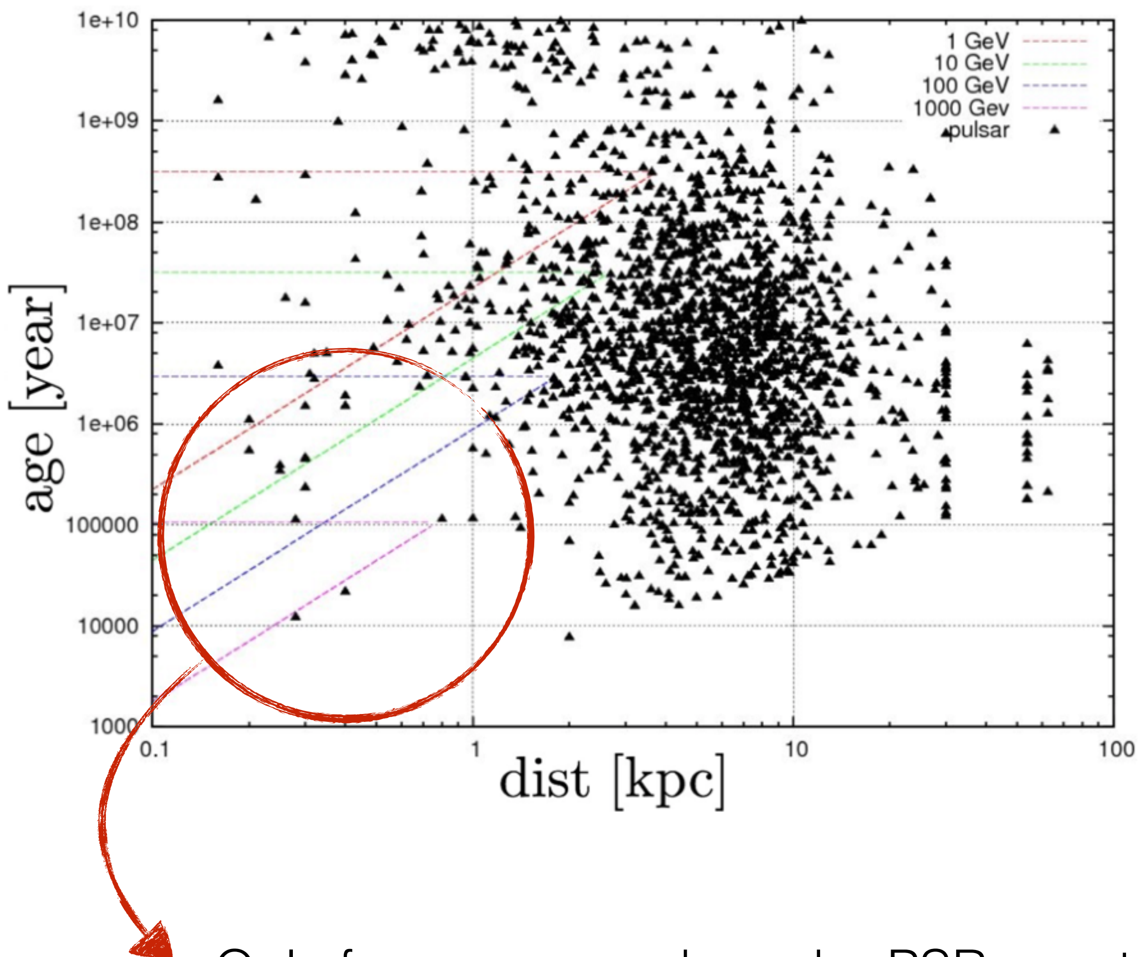
$$E_{max} = \frac{E_C}{1 + \frac{E_C}{1 \text{ GeV}} \frac{t_\star}{\tau_l}} \quad \text{(Thomson regime)}$$




SNR
primaries
secondaries
PSR
Hooper et al. (2009)
Malyshev et al. (2009)
Linden et al. (2013)
Courtesy A.Putze

The single pulsar scenario

Reported pulsars from the **A**ustralian **T**elescope **N**ational **F**acility catalogue



$$\int_0^{+\infty} dE\, E\, Q_0 \left(\frac{E}{E_0}\right)^{-\gamma} \exp\left(-\frac{E}{E_C}\right) = f W_0$$

Fixed parameter

- $E_C = 1\,\mathrm{TeV}$

Free parameters

- $1.5 < \gamma < 2.5$
- $fW_0 < 10^{54}$ erg

Only few young and nearby PSRs contribute to the positron flux for $E \gtrsim$ 10 GeV.

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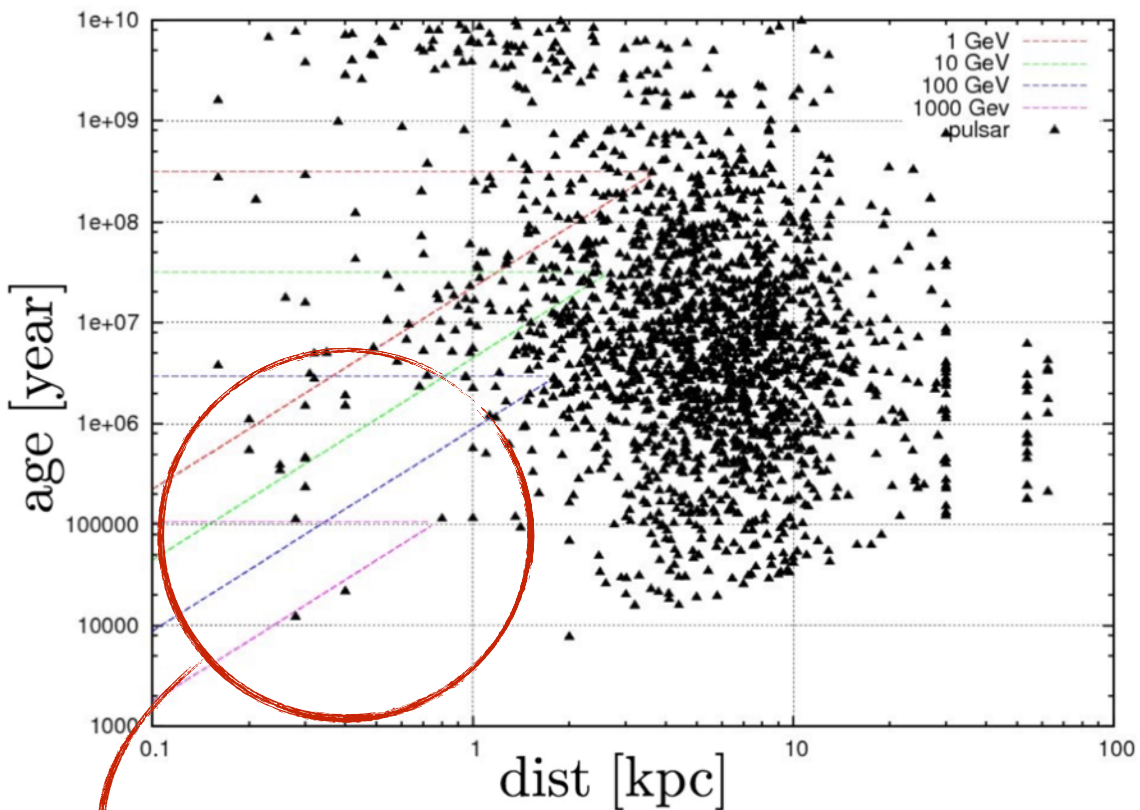

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Only few young and nearby PSRs contribute to the positron flux for $E \gtrsim$ 10 GeV.

- There is only an **upper limit** on the injection normalisation fW_0.
- fW_0 is expected to be different for each PSR.

⇒ if **one single pulsar** can explain the AMS-02 data, **a collection of pulsars** can also.

The single pulsar scenario

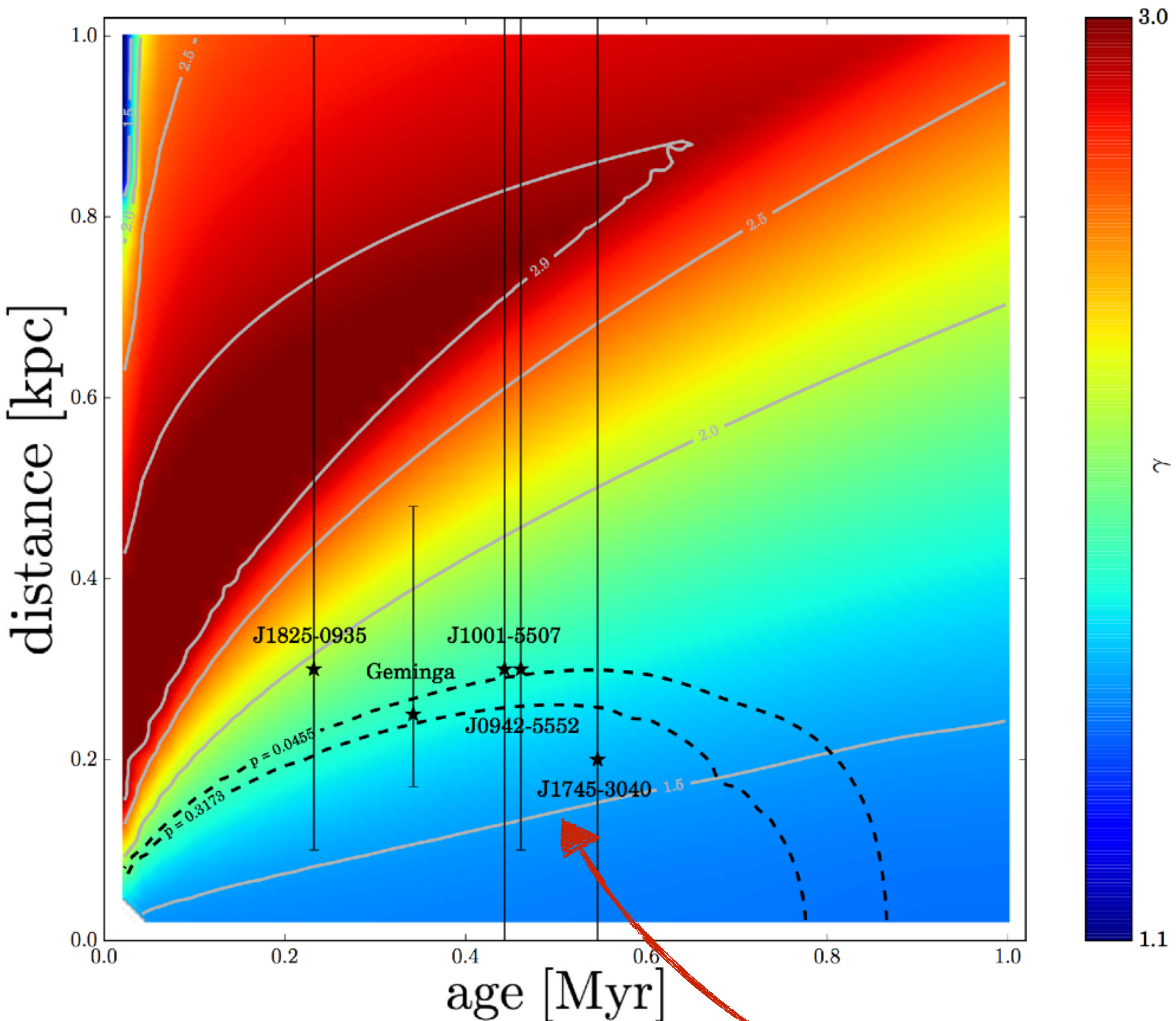
Is it possible to explain the AMS-02 Positron Fraction data with **one single** pulsar?

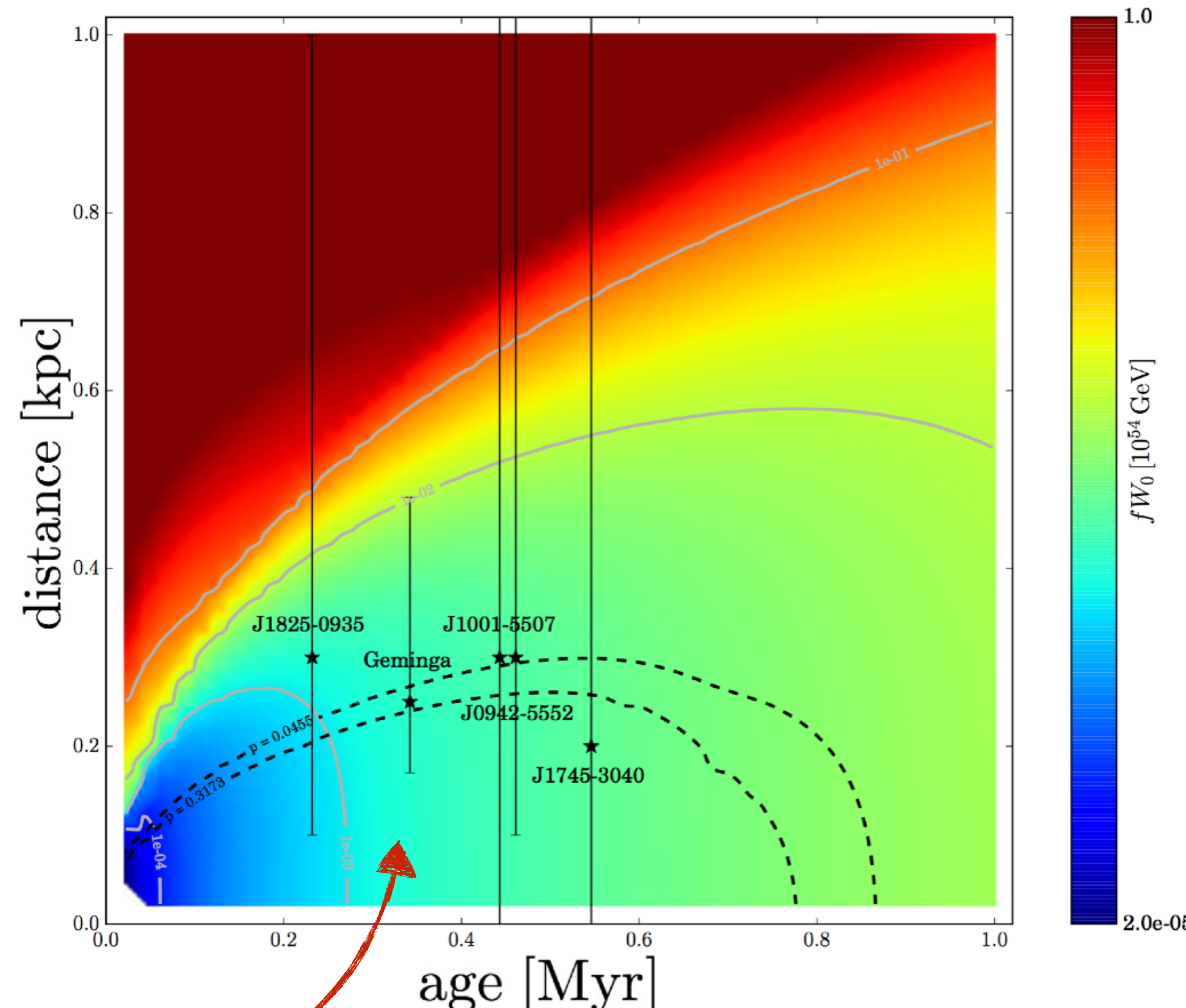
The single pulsar scenario

Is it possible to explain the AMS-02 Positron Fraction data with **one single** pulsar?

YES !

MB+(2014a)





Good fit to the AMS-02 data (p > 30%)

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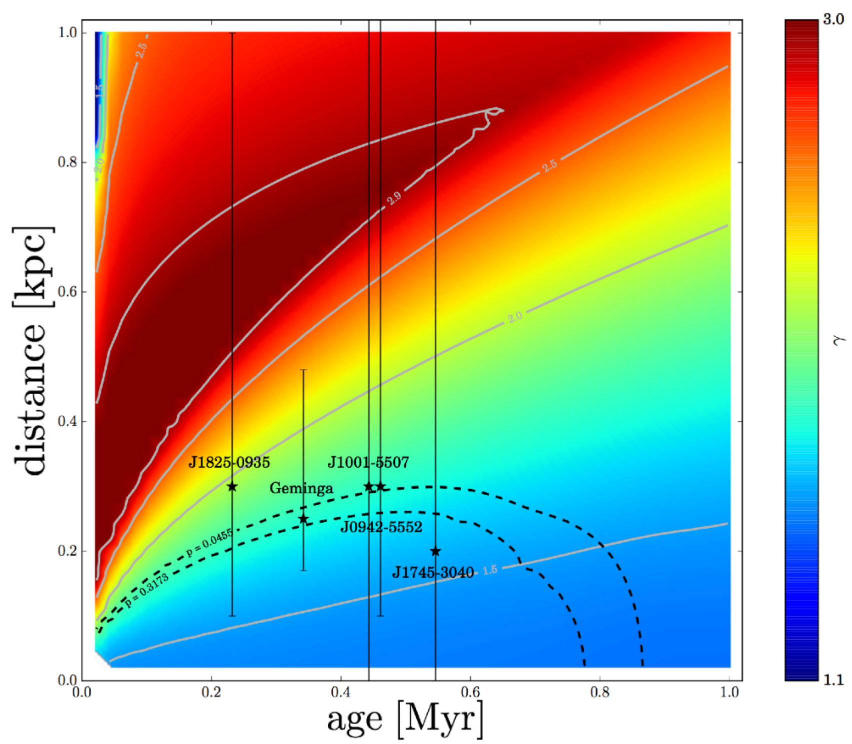

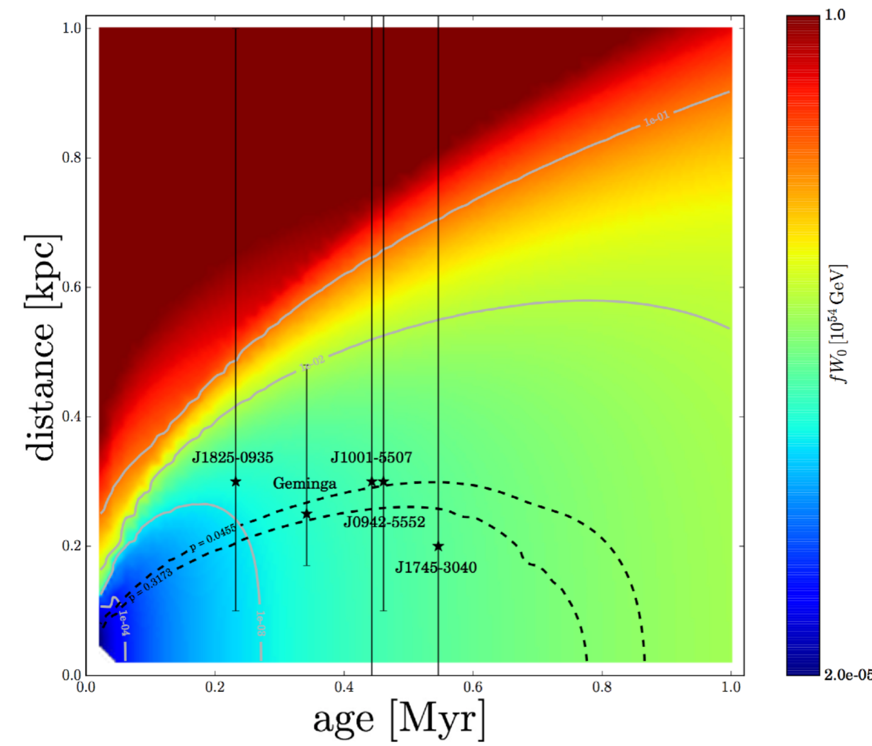

Name	Age [kyr]	Distance [kpc]	fW_0 [10^{54} GeV]	γ	χ^2	χ^2_{dof}	p
J1745−3040	546	0	$(2.95 \pm 0.07) \cdot 10^{-3}$	1.45 ± 0.02	23.4	0.57	0.99
		0.20	$\mathbf{(3.03 \pm 0.06) \cdot 10^{-3}}$	$\mathbf{1.54 \pm 0.02}$	**33.6**	**0.82**	**0.79**
		1.3	1	2.54	9902	241	0
J0633+1746 *Geminga*	342	0.17	$(1.48 \pm 0.03) \cdot 10^{-3}$	1.56 ± 0.02	26.8	0.65	0.96
		0.25	$\mathbf{(1.63 \pm 0.02) \cdot 10^{-3}}$	$\mathbf{1.68 \pm 0.02}$	**49.6**	**1.21**	**0.17**
		0.48	$(1.01 \pm 0.06) \cdot 10^{-2}$	2.29 ± 0.02	332	8.10	0
J0942−5552	461	0.10	$(2.28 \pm 0.05) \cdot 10^{-3}$	1.48 ± 0.02	21.7	0.53	0.99
		0.30	$\mathbf{(2.61 \pm 0.04) \cdot 10^{-3}}$	$\mathbf{1.69 \pm 0.02}$	**61.0**	**1.49**	**0.02**
		1.1	1	2.65	7747	189	0
J1001−5507	443	0	$(2.13 \pm 0.05) \cdot 10^{-3}$	1.46 ± 0.02	19.8	0.48	0.99
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J1825−0935	232	0.1	$(0.80 \pm 0.02) \cdot 10^{-3}$	1.52 ± 0.02	21.0	0.51	0.99
		0.30	$\mathbf{(1.45 \pm 0.03) \cdot 10^{-3}}$	$\mathbf{1.94 \pm 0.02}$	**126**	**3.07**	**0**
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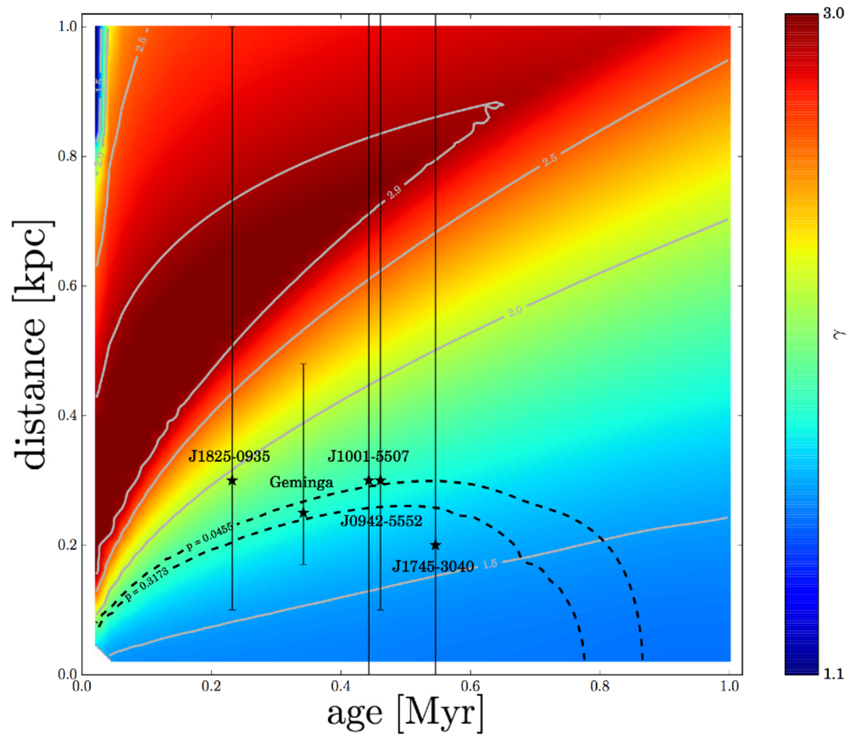

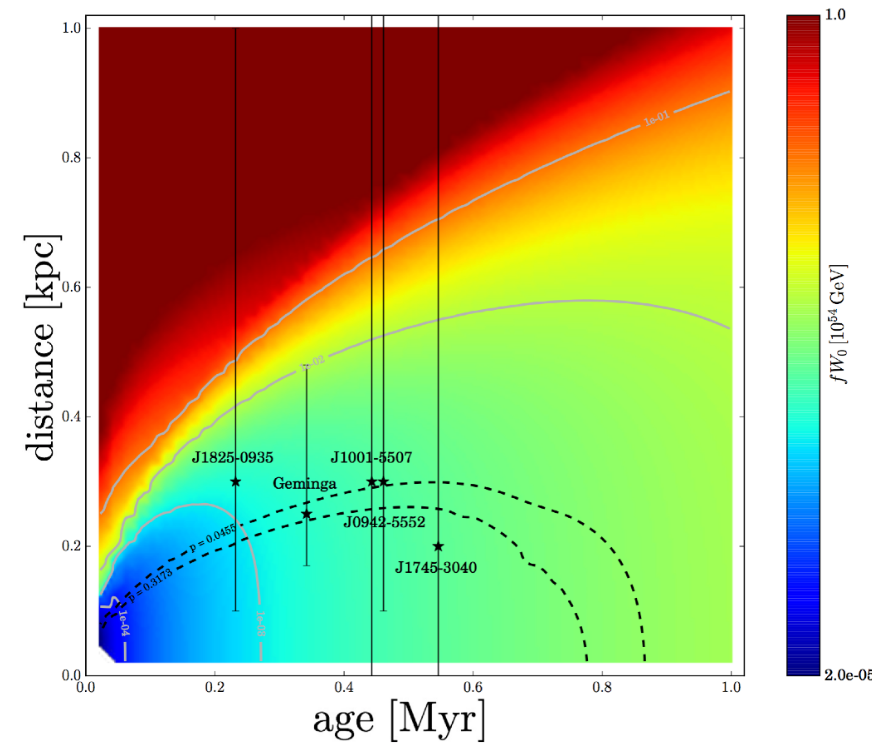

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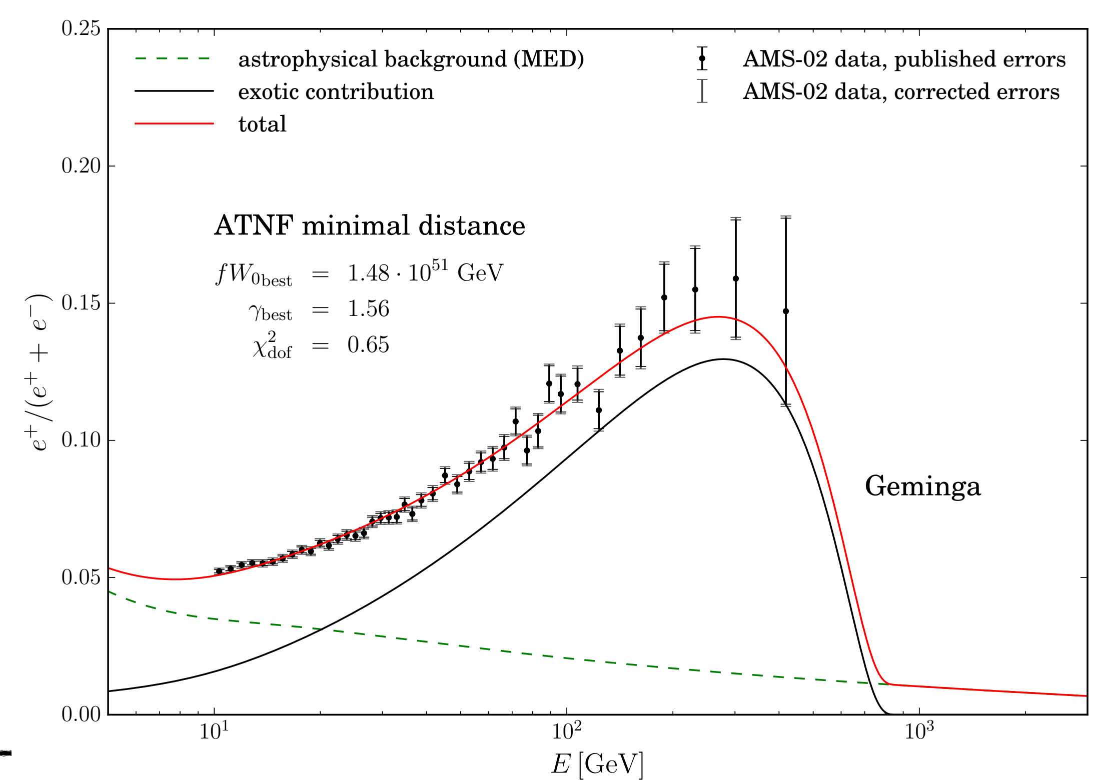
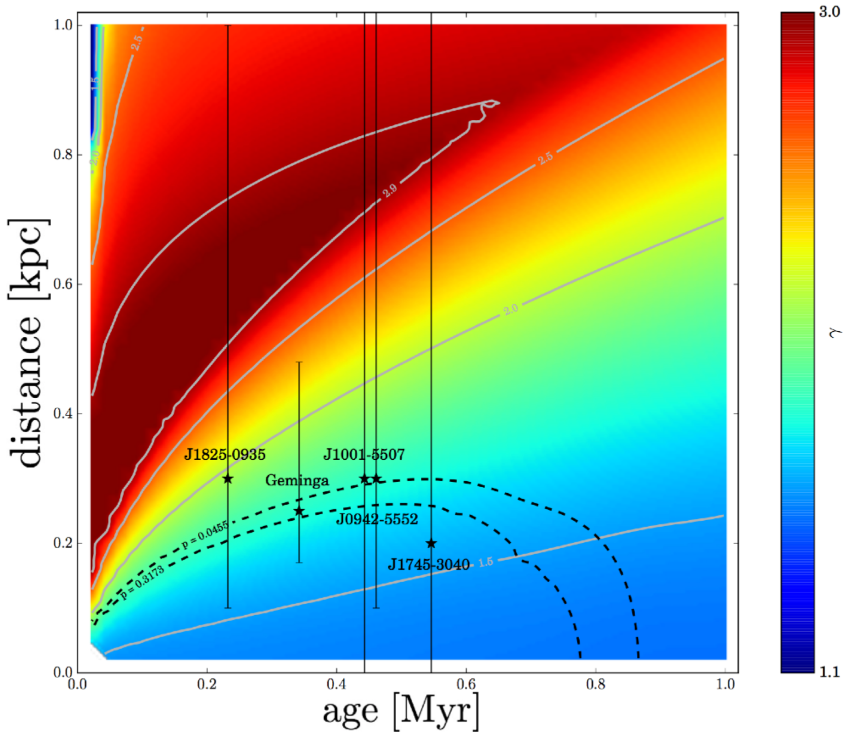


The single pulsar scenario



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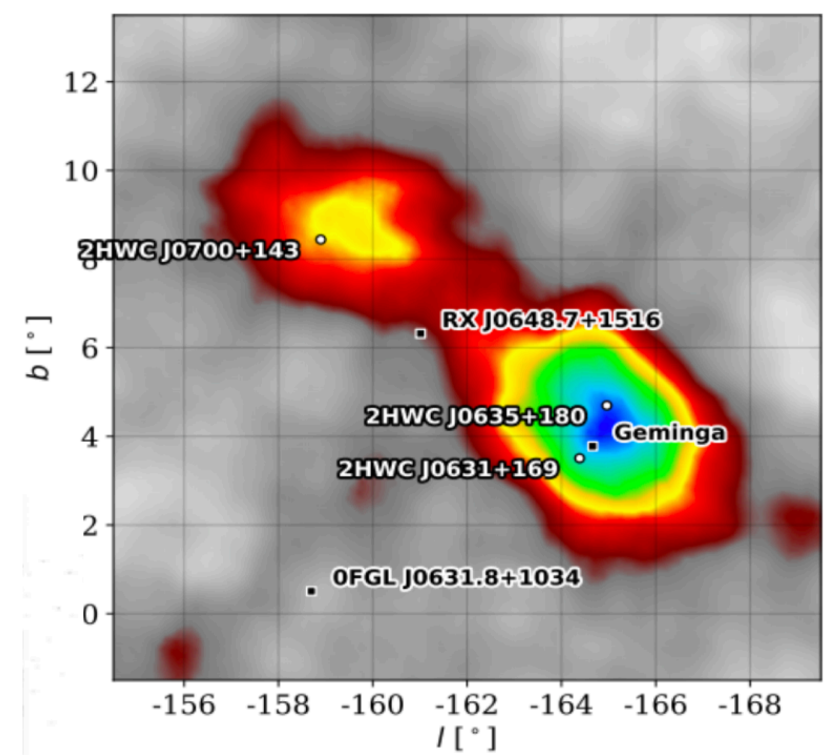
HAWC Observations Strongly Favor Pulsar Interpretations of the Cosmic-Ray Positron Excess

Dan Hooper,[a,b,c] **Ilias Cholis,**[d] **Tim Linden**[e] **and Ke Fang**[f,g]

[a]Fermi National Accelerator Laboratory, Center for Particle Astrophysics, Batavia, IL 60510
[b]University of Chicago, Department of Astronomy and Astrophysics, Chicago, IL 60637



Geminga

$$\gamma \simeq 1.5 - 1.9 \qquad f \simeq 7.2 - 29\%$$

27 Feb 2017

The dark matter scenario

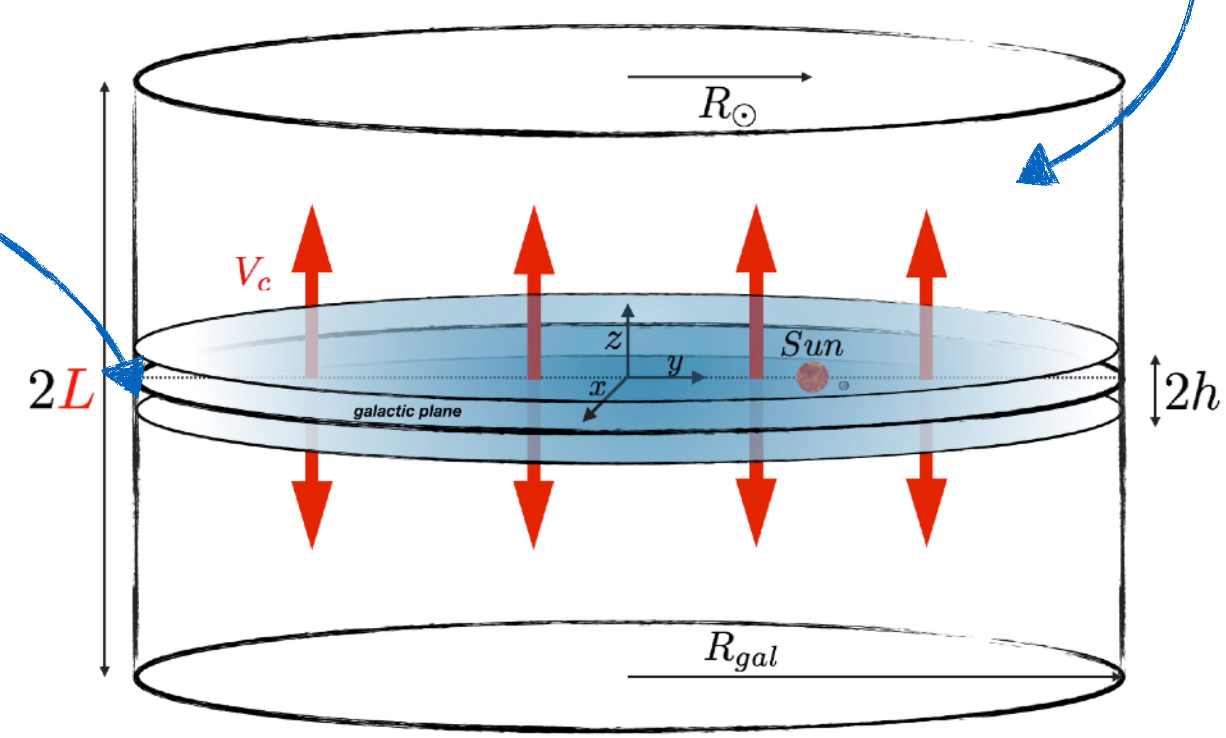
Electrons and positrons: the high-energy approximation

Cosmic rays transport equation (steady state)

$$\partial_z[V_C\,\mathrm{sign(z)}\,\psi] - K(E)\,\Delta\,\psi + 2h\,\delta(z)\,\partial_E\,[b_{\mathrm{disc}}(E)\,\psi] - D(E)\,\partial_E\,\psi] + \partial_E[b_{\mathrm{halo}}(E)\,\psi] = Q(E,\vec{x})$$

$$b_{\mathrm{disc}} = b_{\mathrm{adia}} + b_{\mathrm{ioni}} + b_{\mathrm{brem}} + b_{\mathrm{coul}}$$

$$b_{\mathrm{halo}} = b_{\mathrm{IC}} + b_{\mathrm{sync}}$$



We cannot solve analytically the transport equation when energy losses processes take place in different places in the Galaxy.

We need a **numerical** algorithm to solve the transport equation (GALPROP, DRAGON, PICARD, etc.)

The pinching method

Cosmic rays transport equation (steady state)

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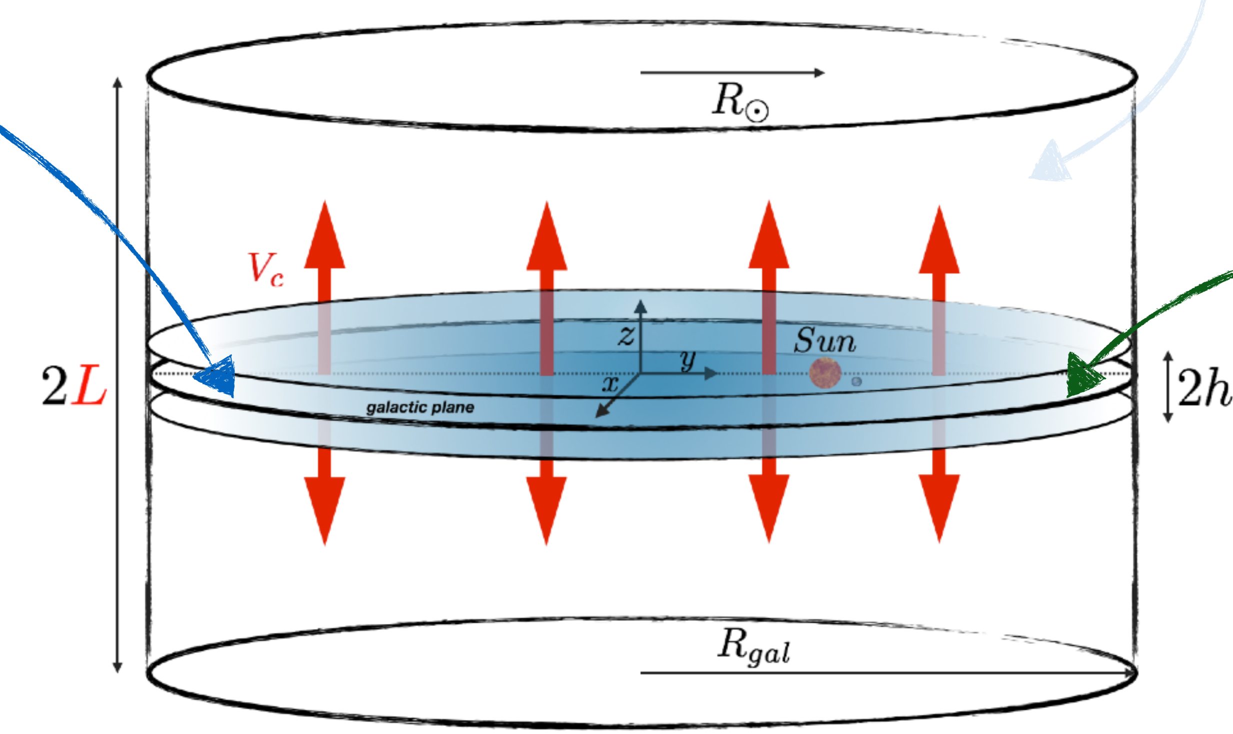
b^{eff}_{halo}



MB+(2016a)

The pinching method

$$\partial_z[V_C\,\mathrm{sign(z)}\,\psi] - K(E)\,\Delta\psi + 2h\,\delta(z)\,\partial_E\left\{\left[b_{\mathrm{disc}}(E) + b^{eff}_{\mathrm{halo}}(E)\right]\,\psi - D(E)\,\partial_E\,\psi\right\} = Q(E,\vec{x})$$

The pinching method

MB+(2016a)

$$\partial_z [V_C \, \mathrm{sign(z)} \, \psi] - K(E) \, \Delta \, \psi + 2h \, \delta(z) \, \partial_E \left\{ \left[b_{\mathrm{disc}}(E) + b^{eff}_{\mathrm{halo}}(E) \right] \psi - D(E) \, \partial_E \, \psi \right\} = Q(E, \vec{x})$$

$$b_{\mathrm{halo}} = b_{\mathrm{IC}} + b_{\mathrm{sync}} \longrightarrow b^{eff}_{\mathrm{halo}}(E, r) = \bar{\xi}(E, r) \, b_{\mathrm{halo}}(E)$$

pinching factor

$$\bar{\xi}(E, r) = \frac{1}{\psi(E, r, 0)} \sum_{i=1}^{+\infty} J_0(\alpha_i \frac{r}{R}) \, \bar{\xi}_i(E) \, P_i(E, 0)$$

$$\bar{\xi}_i(E) = \frac{\int_E^{+\infty} dE_S \left[J_i(E_S) + 4k_i^2 \int_E^{E_S} dE' \, \frac{K(E')}{b(E')} \, B_i(E', E_S) \right]}{\int_E^{+\infty} dE_S \, B_i(E, E_S)}$$

$$J_i(E_S) = \frac{1}{h} \int_0^L dz_S \, \mathcal{F}_i(z_S) \, Q_i(E_S, z_S) \qquad Q_i(E, z) = \frac{2}{R^2 J_1^2(\alpha_i)} \int_0^R dr \, r \, J_0(\xi_i) \, Q(E, r, z)$$

$$B_i(E, E_S) = \sum_{n=2m+1}^{+\infty} Q_{i,n}(E_S) \exp\left[-C_{i,n} \lambda_D^2\right] \qquad C_{i,n} = \frac{1}{4} \left[\left(\frac{\alpha_i}{R} \right)^2 + (n k_0)^2 \right]$$

$$Q_{i,n}(E) = \frac{1}{L} \int_{-L}^{L} dz \, \varphi_n(z) \, \frac{2}{R^2 J_1^2(\alpha_i)} \int_0^R dr \, r \, J_0 \left(\alpha_i \frac{r}{R} \right) \, Q(E, r, z)$$

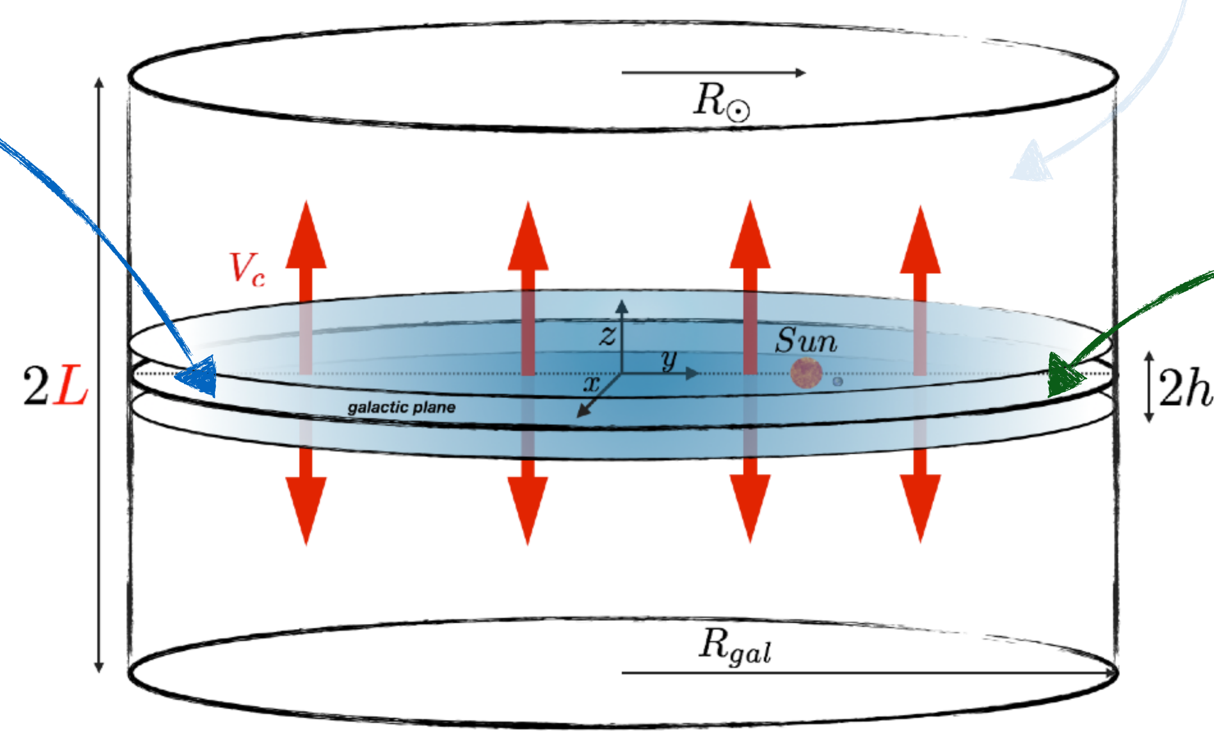
The pinching method

Cosmic rays transport equation (steady state)

$$\partial_z[V_C\,\mathrm{sign(z)}\,\psi] - K(E)\,\Delta\,\psi + 2h\,\delta(z)\,\partial_E\,[b_{\mathrm{disc}}(E)\,\psi] - D(E)\,\partial_E\,\psi] + \partial_E[b_{\mathrm{halo}}(E)\,\psi] = Q(E,\vec{x})$$

$$b_{\mathrm{disc}} = b_{\mathrm{adia}} + b_{\mathrm{ioni}} + b_{\mathrm{brem}} + b_{\mathrm{coul}}$$

$$b_{\mathrm{halo}} = b_{\mathrm{IC}} + b_{\mathrm{sync}}$$



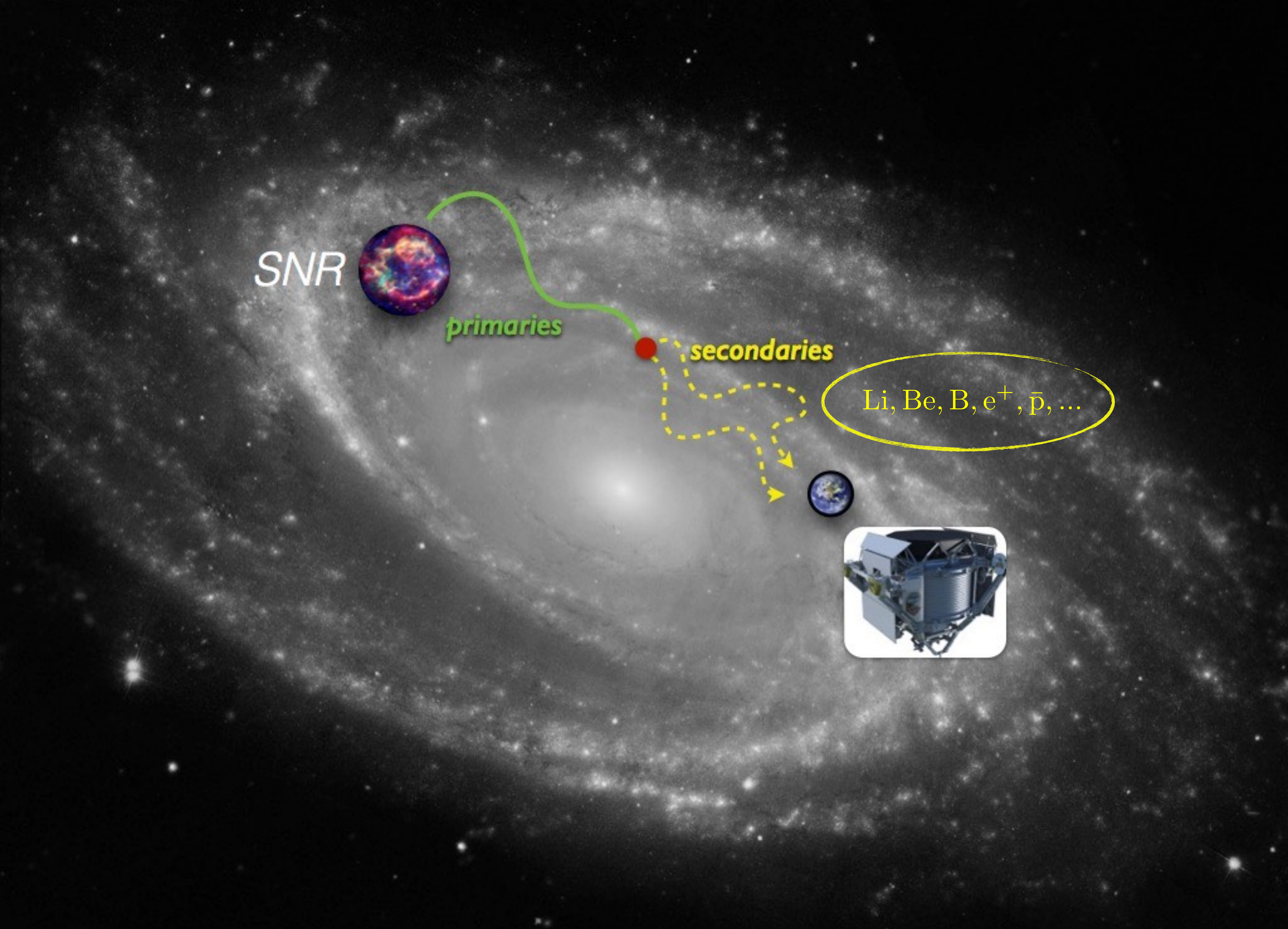
b^{eff}_{halo}

The pinching method

MB+(2016a)

$$\partial_z[V_C\,\mathrm{sign(z)}\,\psi] - K(E)\,\Delta\,\psi + 2h\,\delta(z)\,\partial_E\left\{\left[b_{\mathrm{disc}}(E) + b^{eff}_{\mathrm{halo}}(E)\right]\,\psi - D(E)\,\partial_E\,\psi\right\} = Q(E,\vec{x})$$

From now we are able to compute the positron flux analytically, **including all propagation effects**!



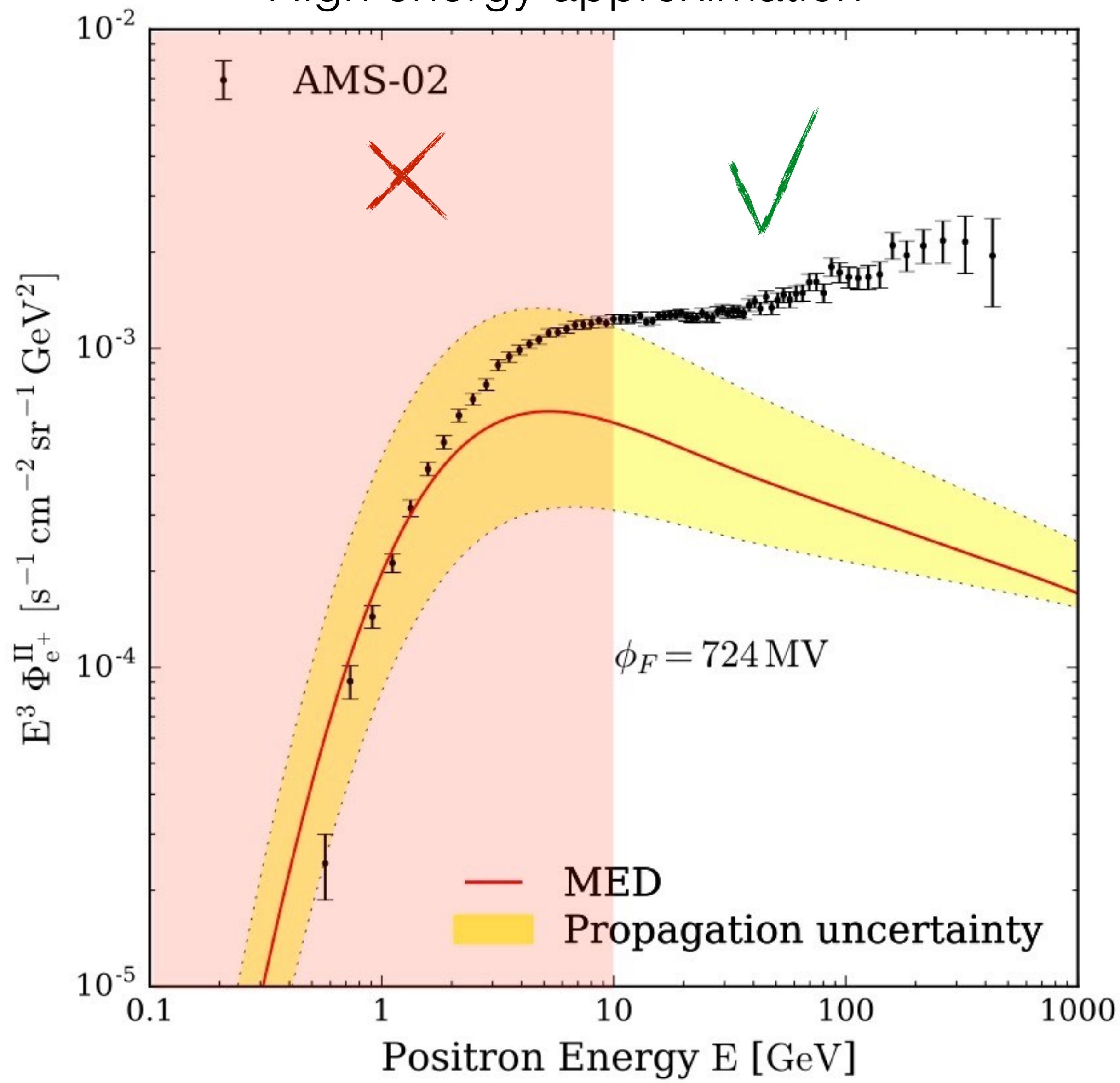
Courtesy A. Putze

Astrophysical secondary positrons

$$Q^{\mathrm{II}}(E,\vec{x}) = 4\pi \sum_{i=p,\alpha} \sum_{j=H,He} n_j \int_{E_0}^{+\infty} dE_i\, \phi_i(E_i,\vec{x})\, \frac{d\sigma}{dE_i}(E_j \to E) \qquad \begin{cases} i = projectile \\ j = target \end{cases}$$

$$p + p \longrightarrow \begin{cases} p + \Delta^+ \\ \quad \Delta^+ \longrightarrow n + \pi^+ \\ \quad\quad \pi^+ \longrightarrow \nu_\mu + \mu^+ \\ \quad\quad\quad \mu^+ \longrightarrow \bar{\nu}_\mu + \nu_e + e^+ \\ X + \pi^+ \\ \quad \pi^+ \longrightarrow \nu_\mu + \mu^+ \\ \quad\quad \mu^+ \longrightarrow \bar{\nu}_\mu + \nu_e + e^+ \\ X + K^+ \\ \quad K^+ \longrightarrow \begin{cases} \nu_\mu + \mu^+ \\ \quad \mu^+ \longrightarrow \bar{\nu}_\mu + \nu_e + e^+ \\ \pi^0 + \pi^+ \\ \quad \pi^+ \longrightarrow \nu_\mu + \mu^+ \\ \quad\quad \mu^+ \longrightarrow \bar{\nu}_\mu + \nu_e + e^+ \end{cases} \end{cases}$$

High energy approximation



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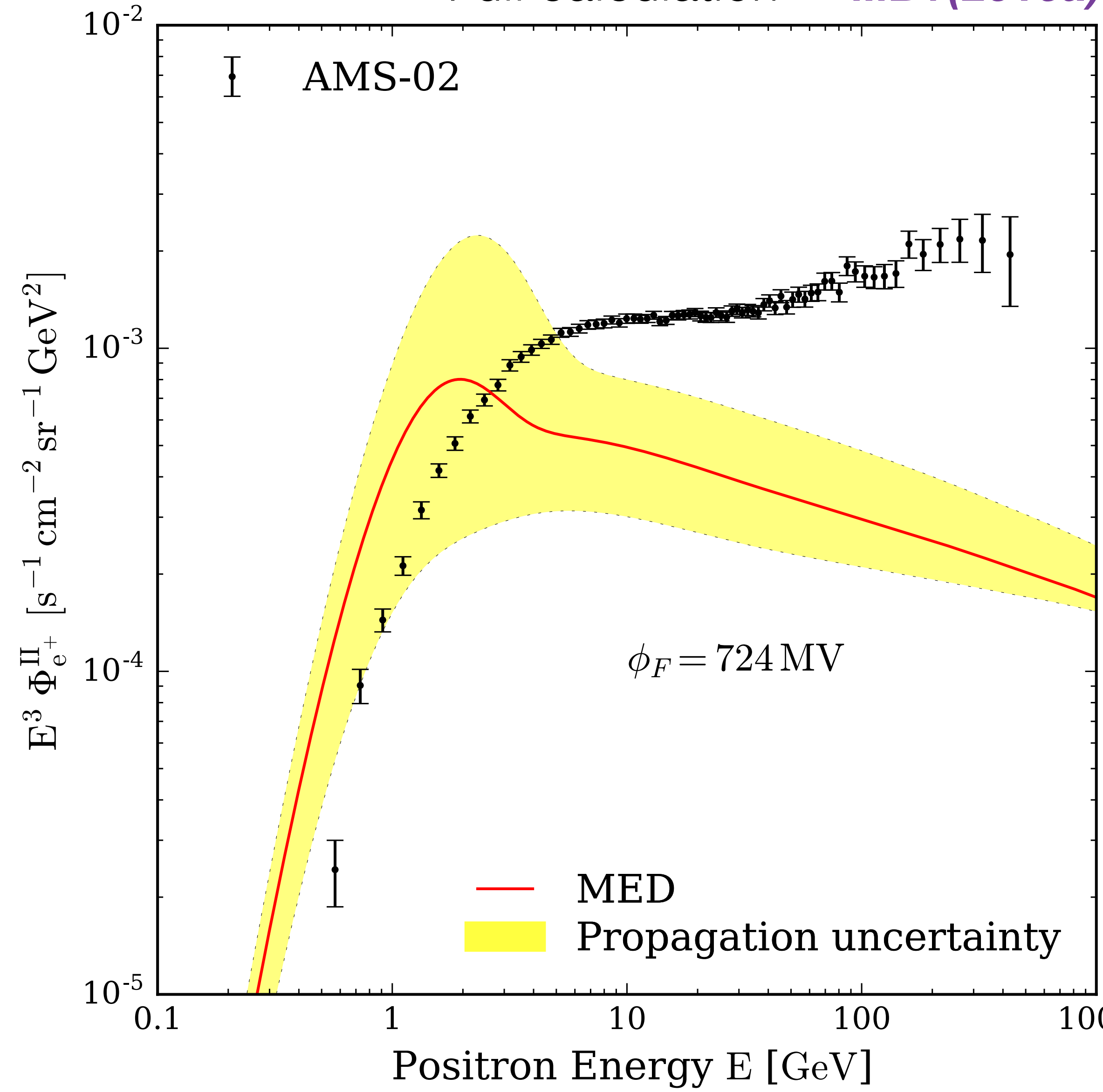
Full calculation ***MB+(2016a)***



The HE approximation ⇒ error up to 50% at 10 GeV!

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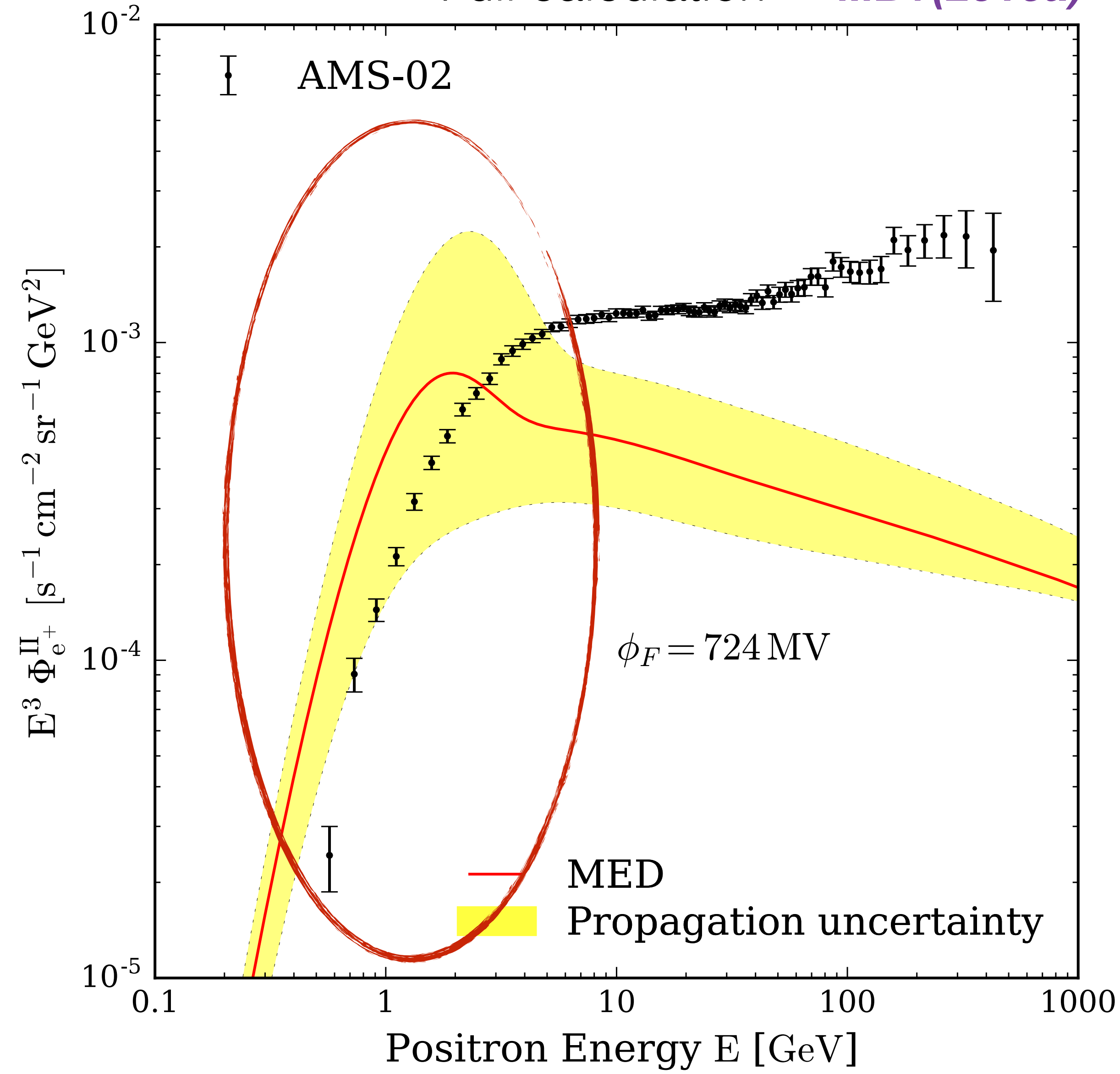

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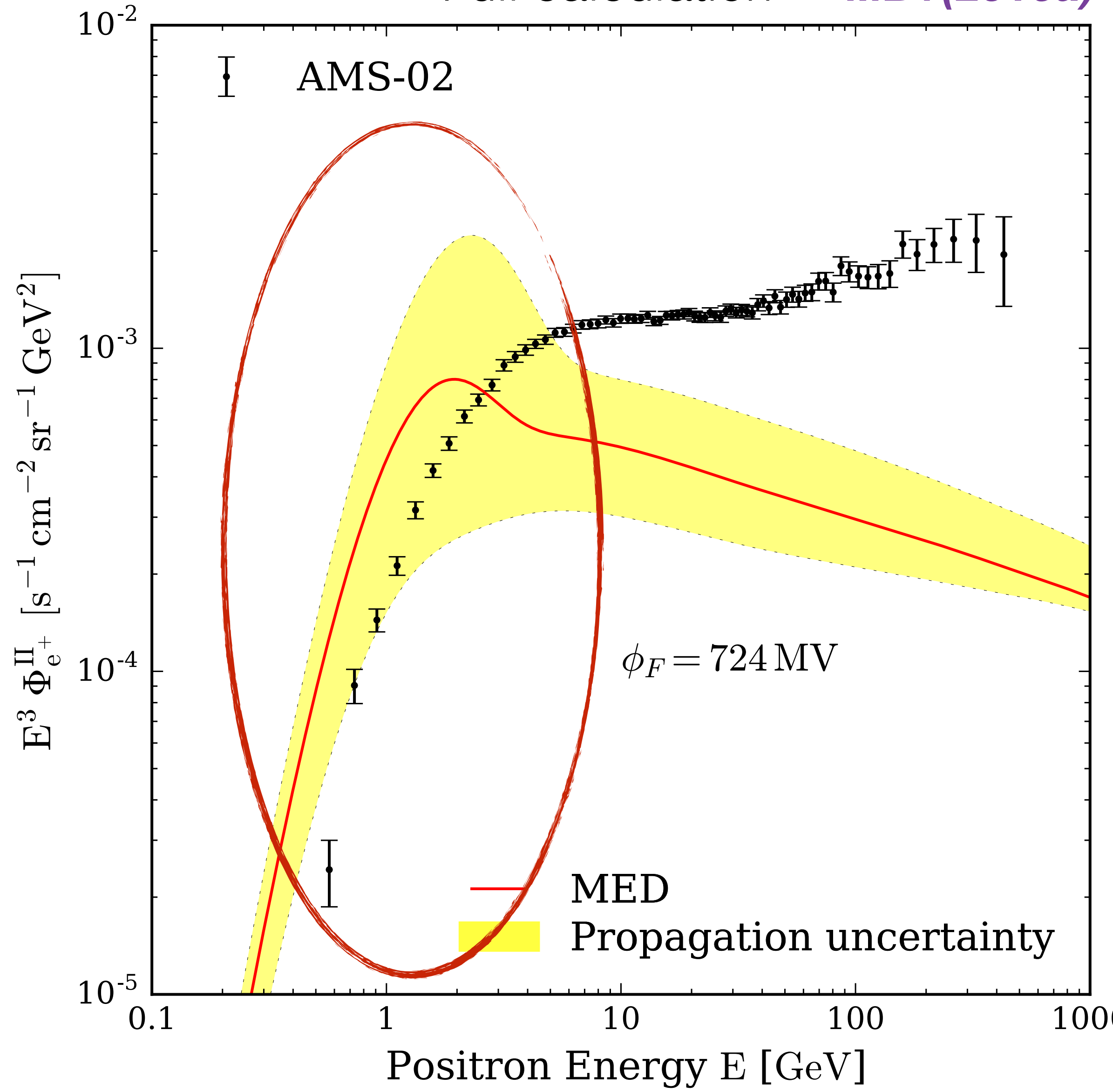
Positrons can be used as an independent probe for the propagation parameters.

The degeneracy between K_0 and L can be lifted!

Lavalle+(2014)

Full calculation **MB+(2016a)**



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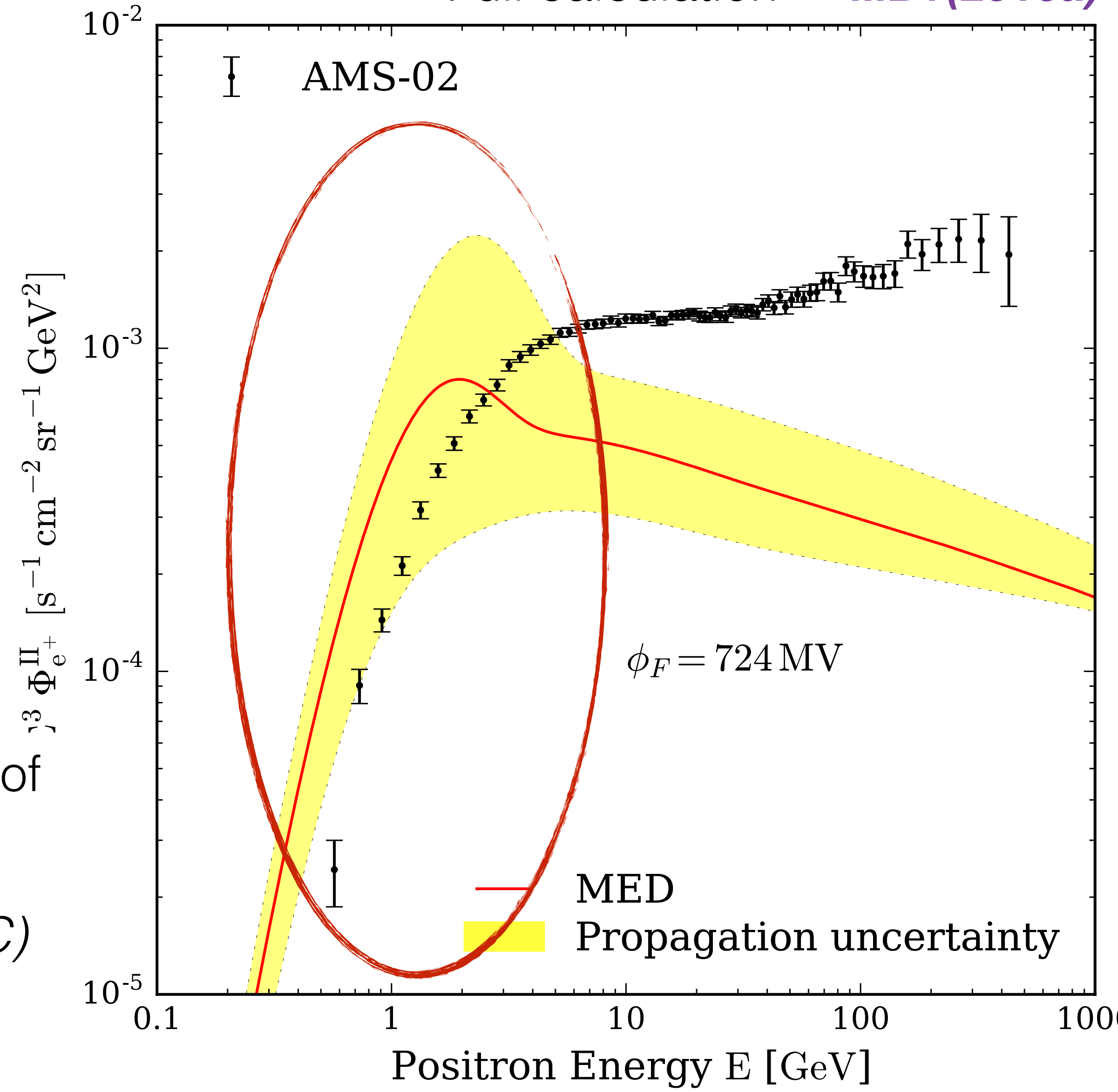
Lavalle+(2014)

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

Ruled out!

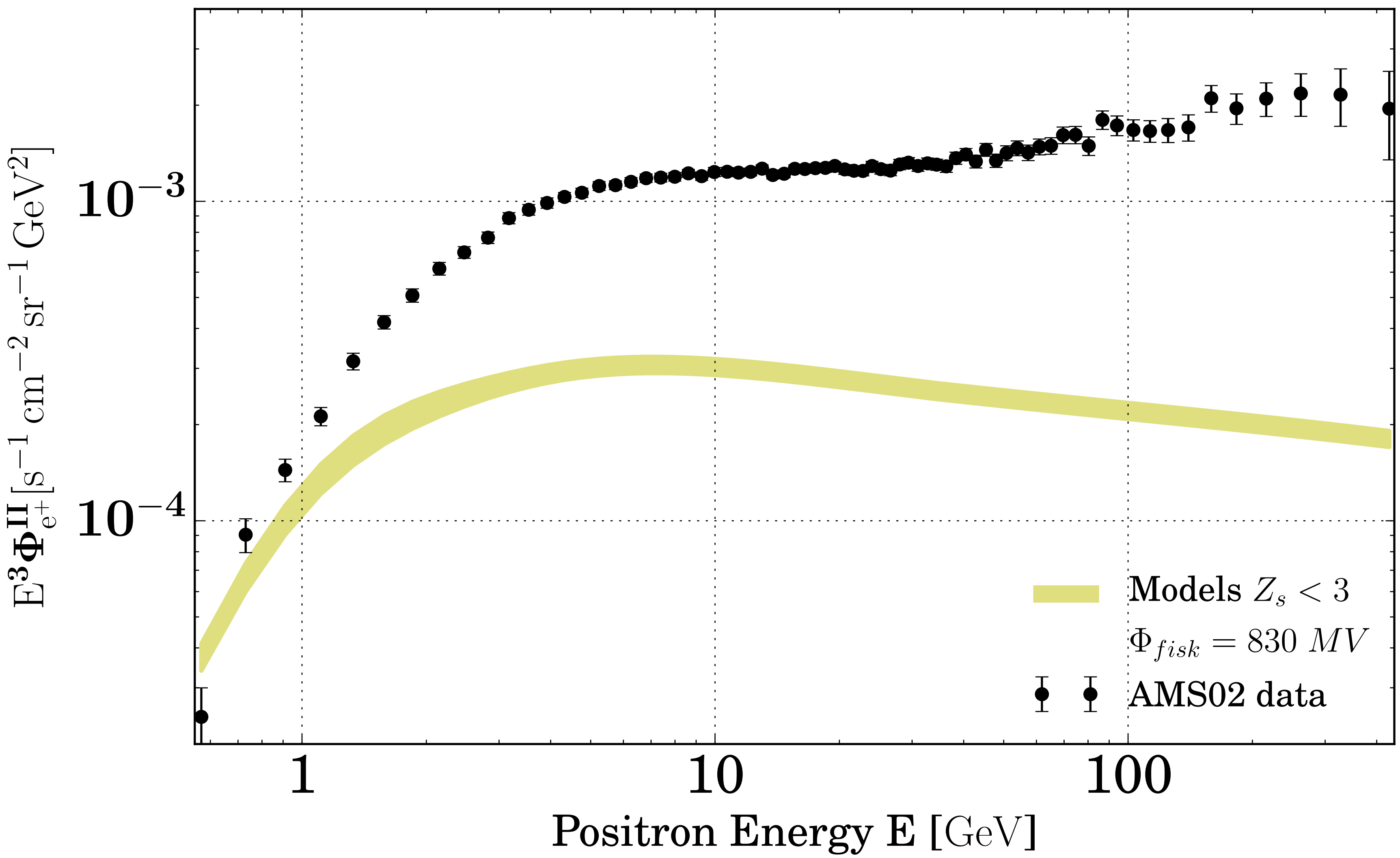
Full calculation *MB+(2016a)*



The AMS-02 positrons data favour the **MAX-type** sets of propagation parameters.

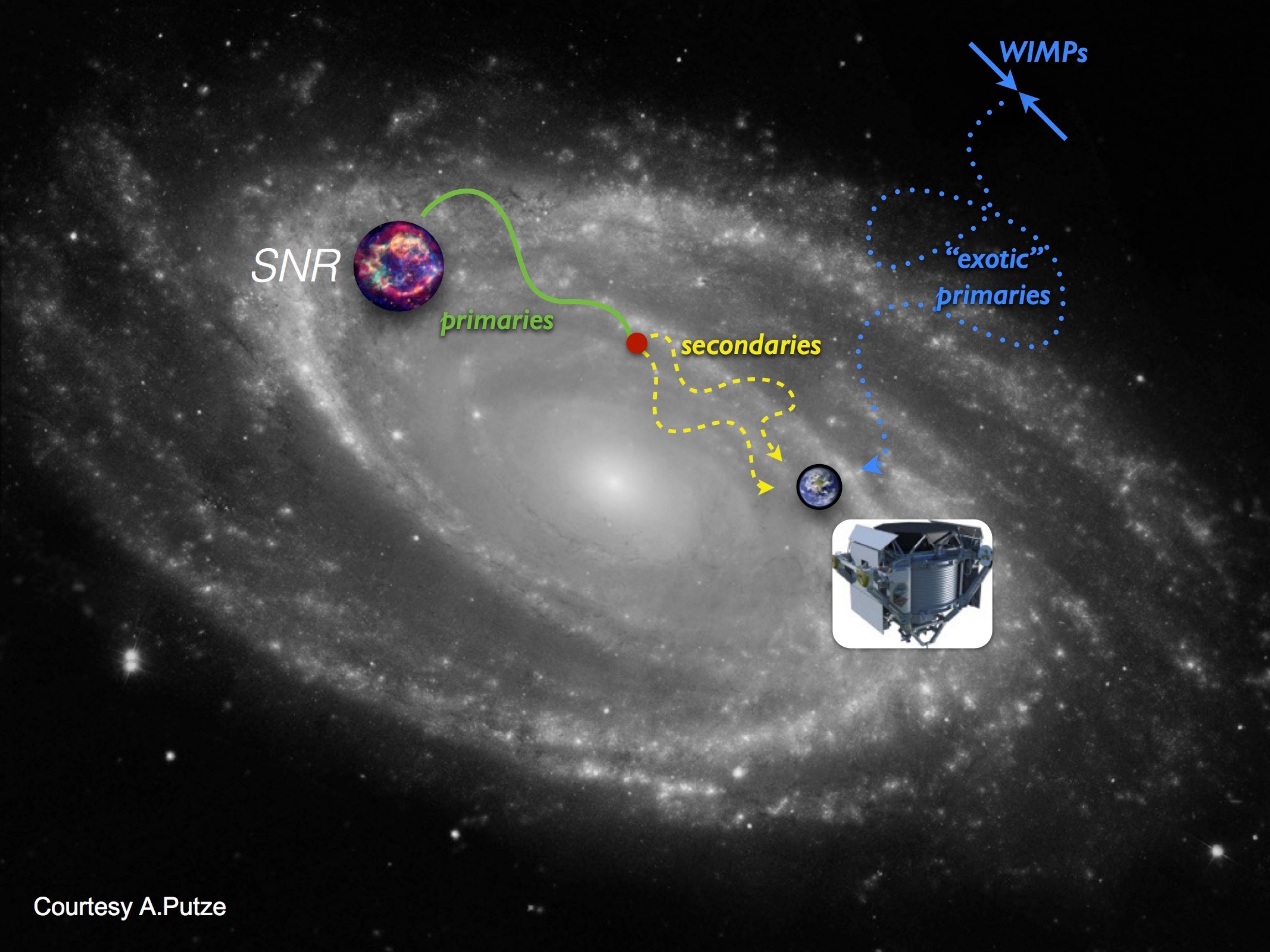
(result confirmed by AMS-02 antiprotons and recent B/C)

Astrophysical secondary positrons

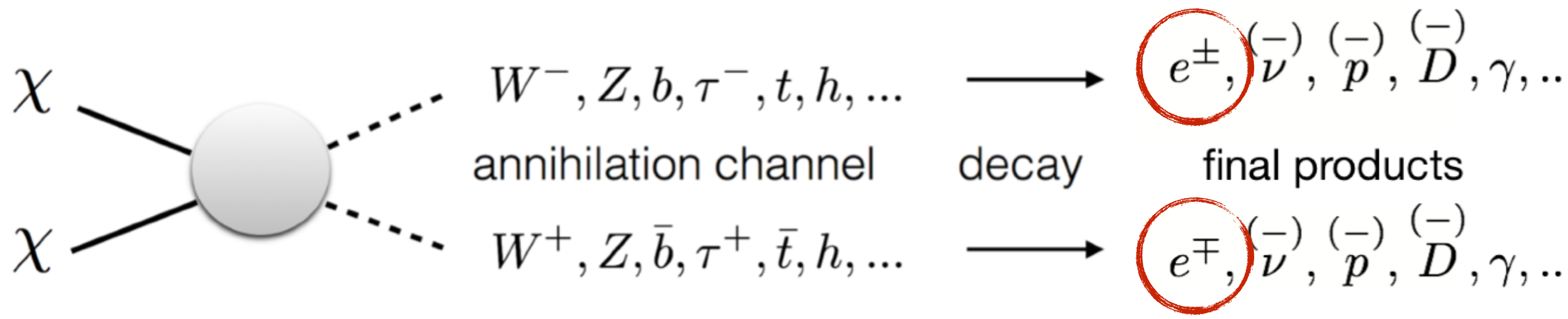


MB+(2016a)

- The uncertainty band for the e⁺ is now very narrow.
- The positron excess appears now from ~1 GeV.
- Where do come from the remained positrons?
- We need another component(s) to explain the positron data **from ~1 GeV to ~500 GeV**.


WIMPs
SNR
"exotic"
primaries
primaries
secondaries
Courtesy A.Putze

The Dark Matter scenario



A very generic class of models

$$\chi\chi \longrightarrow B_b\, \bar{b}b + B_W\, W^+W^- + B_\tau\, \tau^+\tau^- + B_\mu\, \mu^+\mu^- + B_e\, e^+e^-$$

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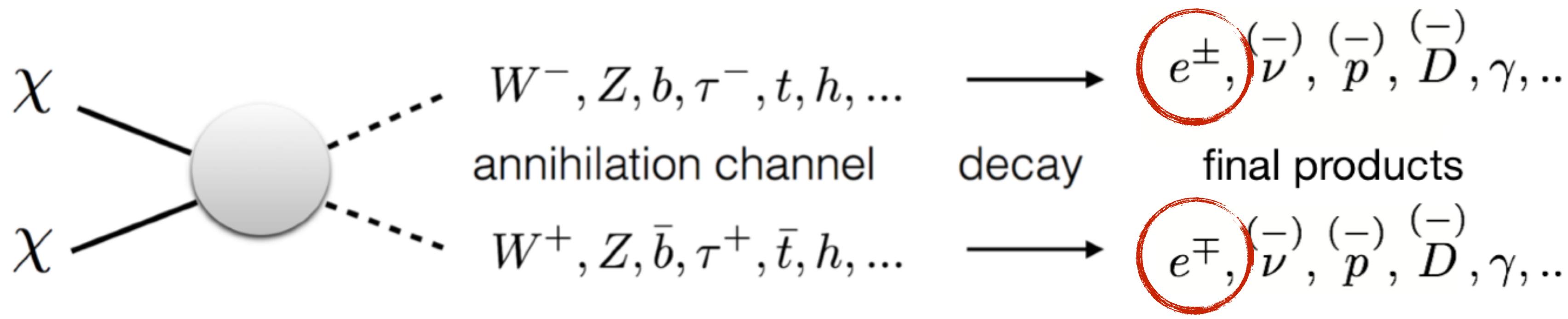

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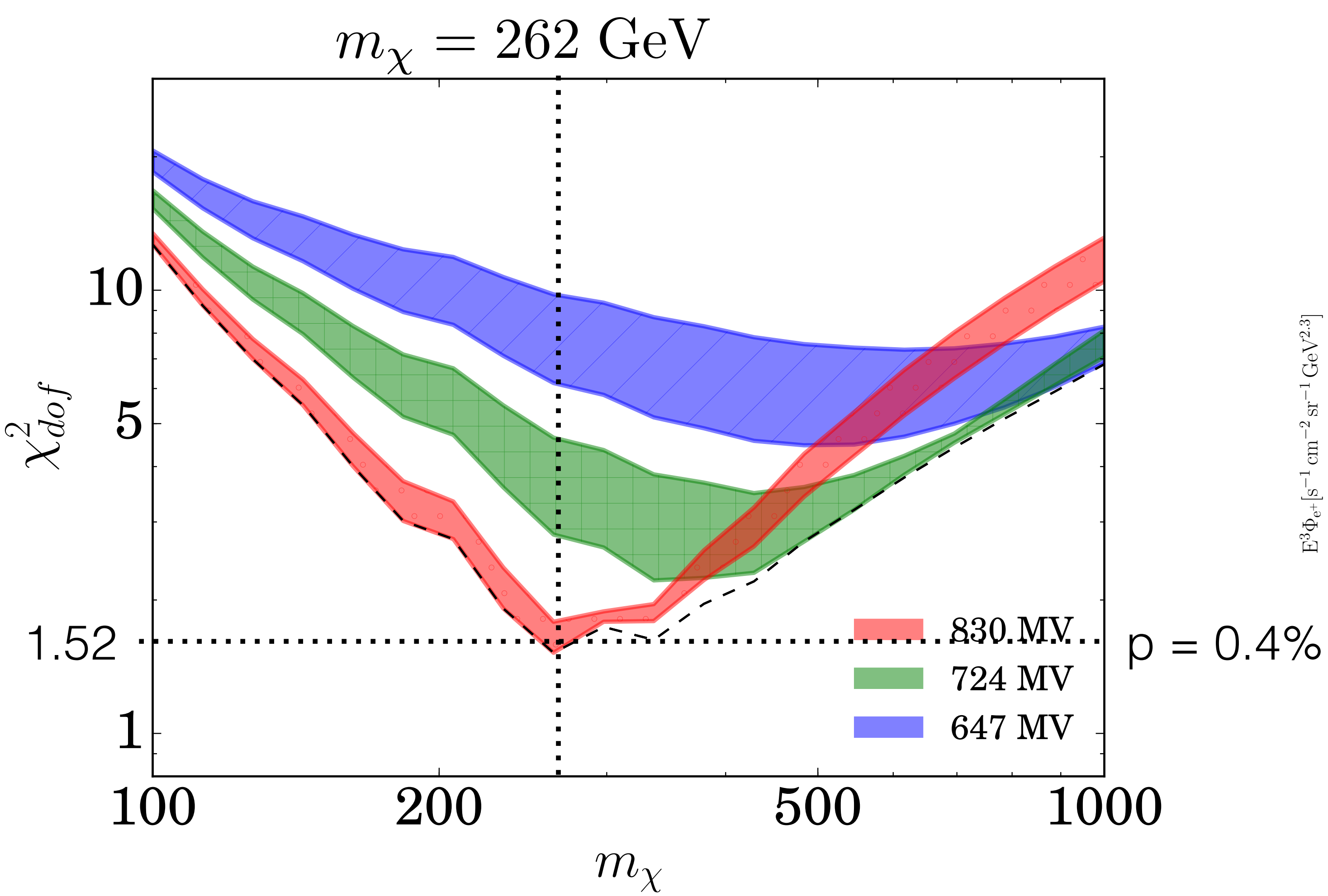
We scan over:

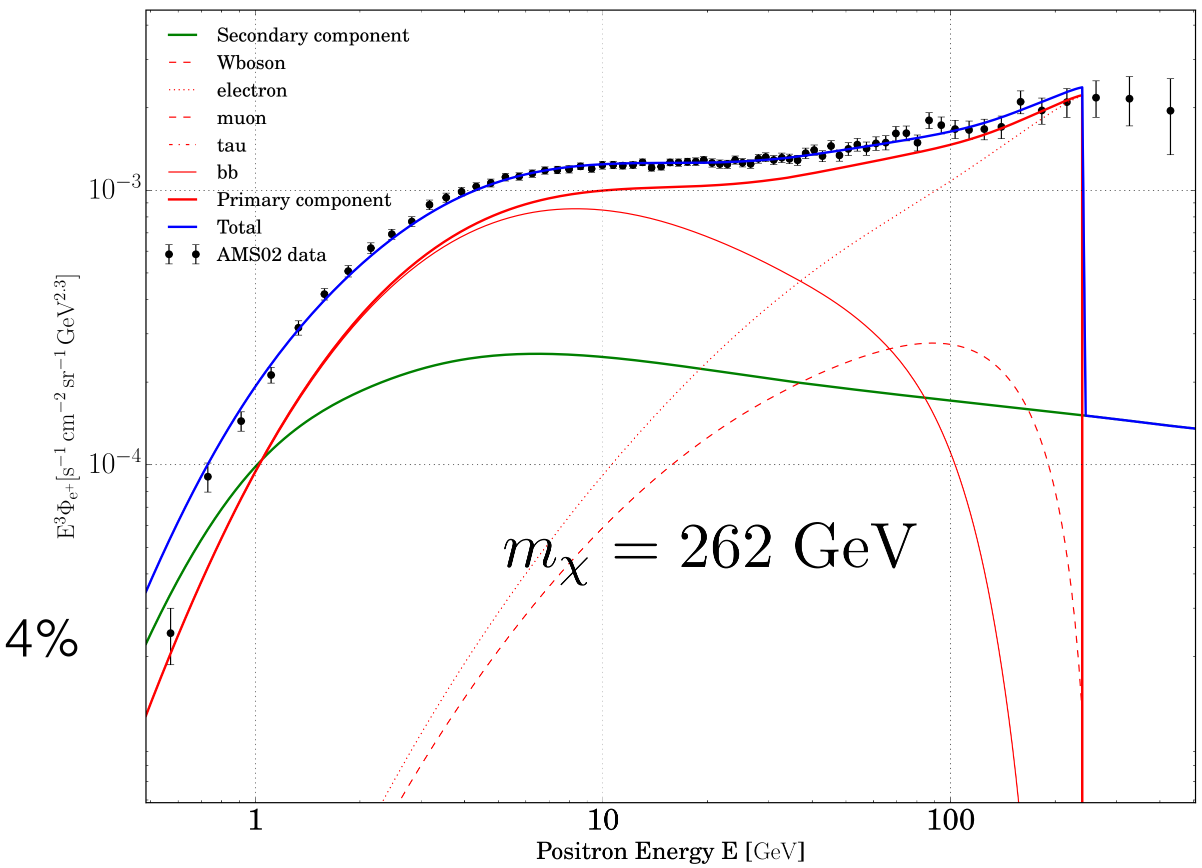
- the DM mass range $m_\chi \in [100\,\mathrm{GeV}, 1\,\mathrm{TeV}]$
- all the sets of propagation parameters left (3 σ CL)
- the Fisk potential range $\phi_F \in [647, 830]\,\mathrm{MV}$ (3 σ CL) *Ghelfi+(2015)*

We fit the dark matter parameters ($\langle\sigma v\rangle,\ B_b,\ B_W,\ B_\tau,\ B_\mu,\ B_e$) on the AMS-02 data.

The Dark Matter scenario

MB+(2016a)





The spectrum of e^+ from DM annihilations **cannot** account for the **shape** of the spectrum measured by AMS-02.

The positron flux produced by DM is restricted « around » the DM mass.

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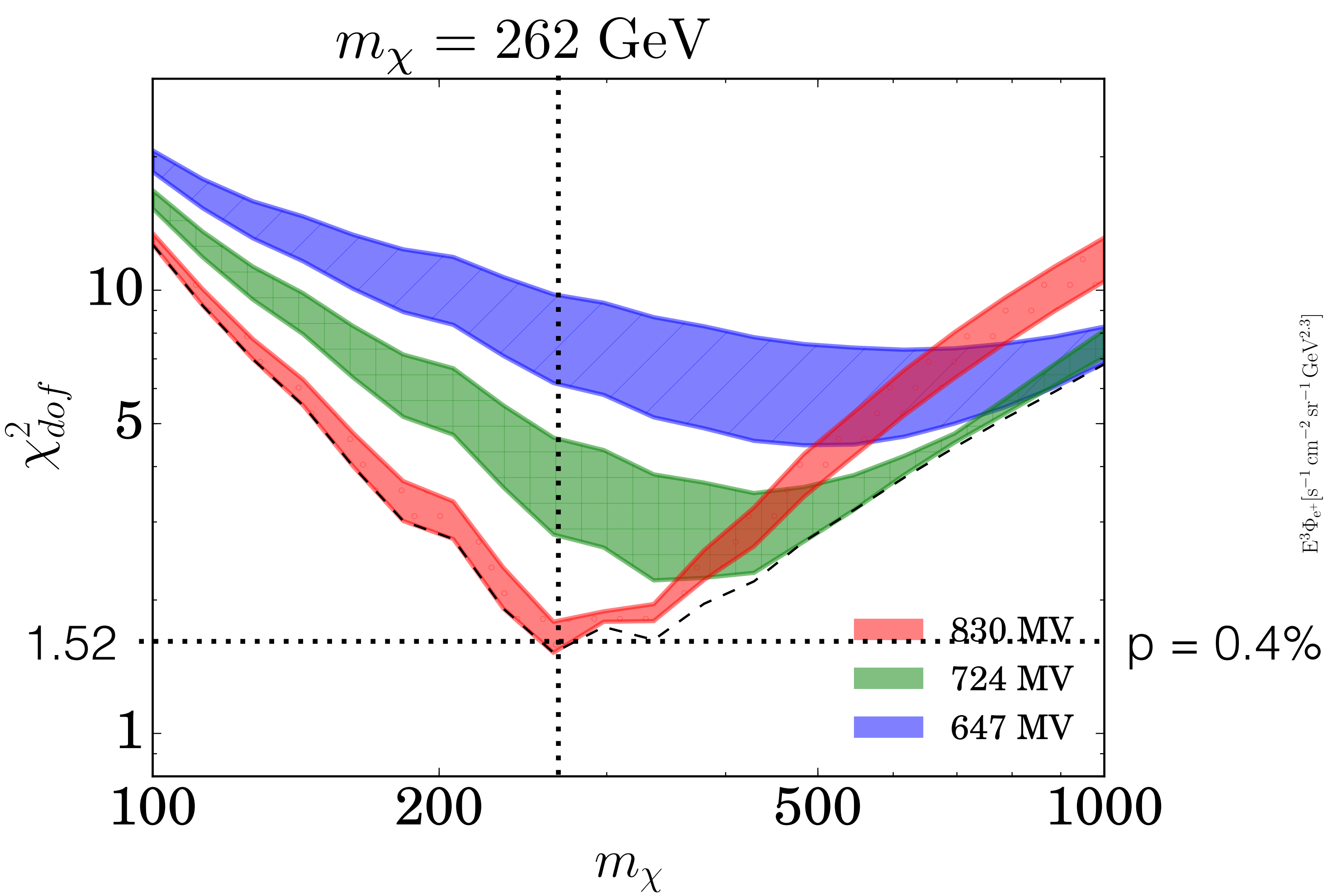
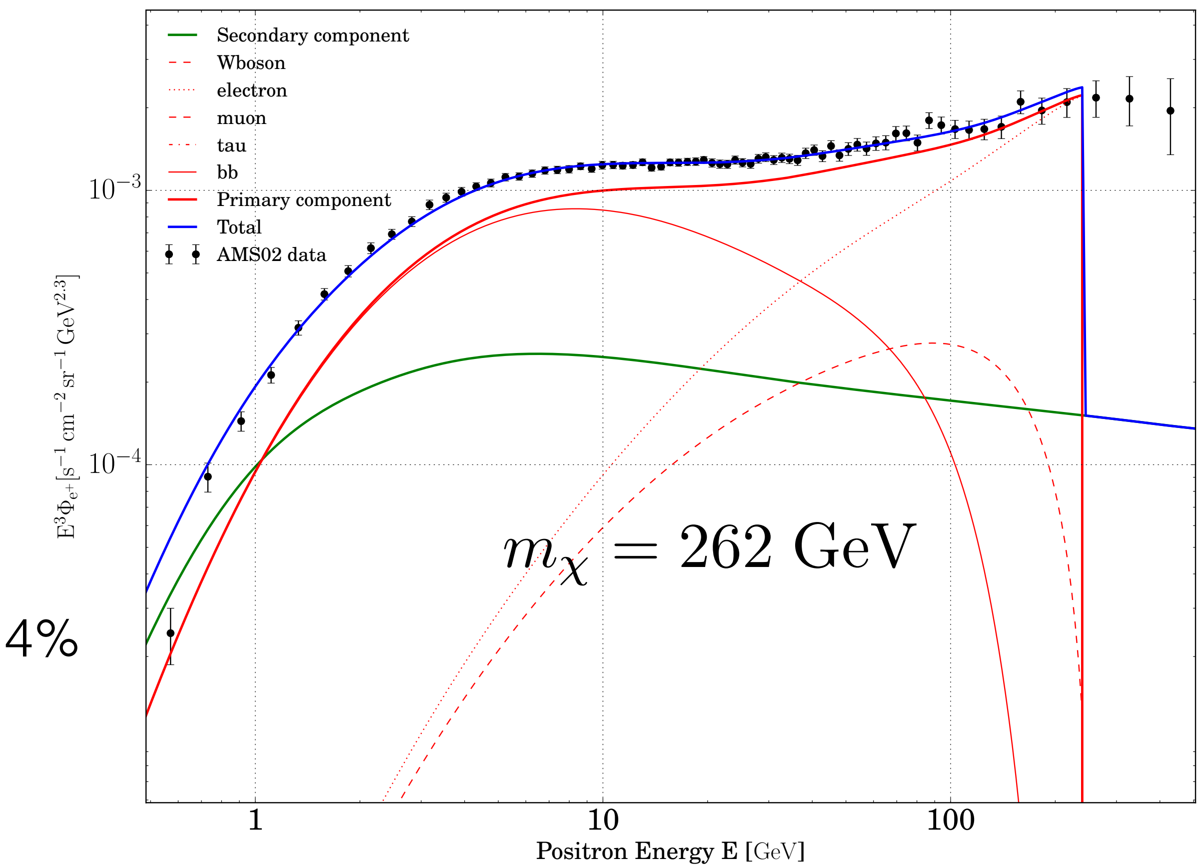
MB+(2016a)





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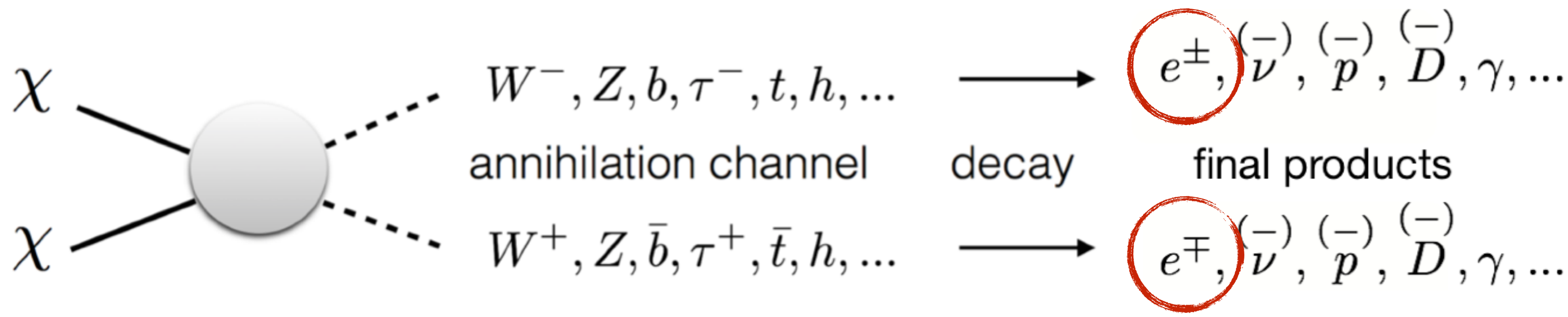

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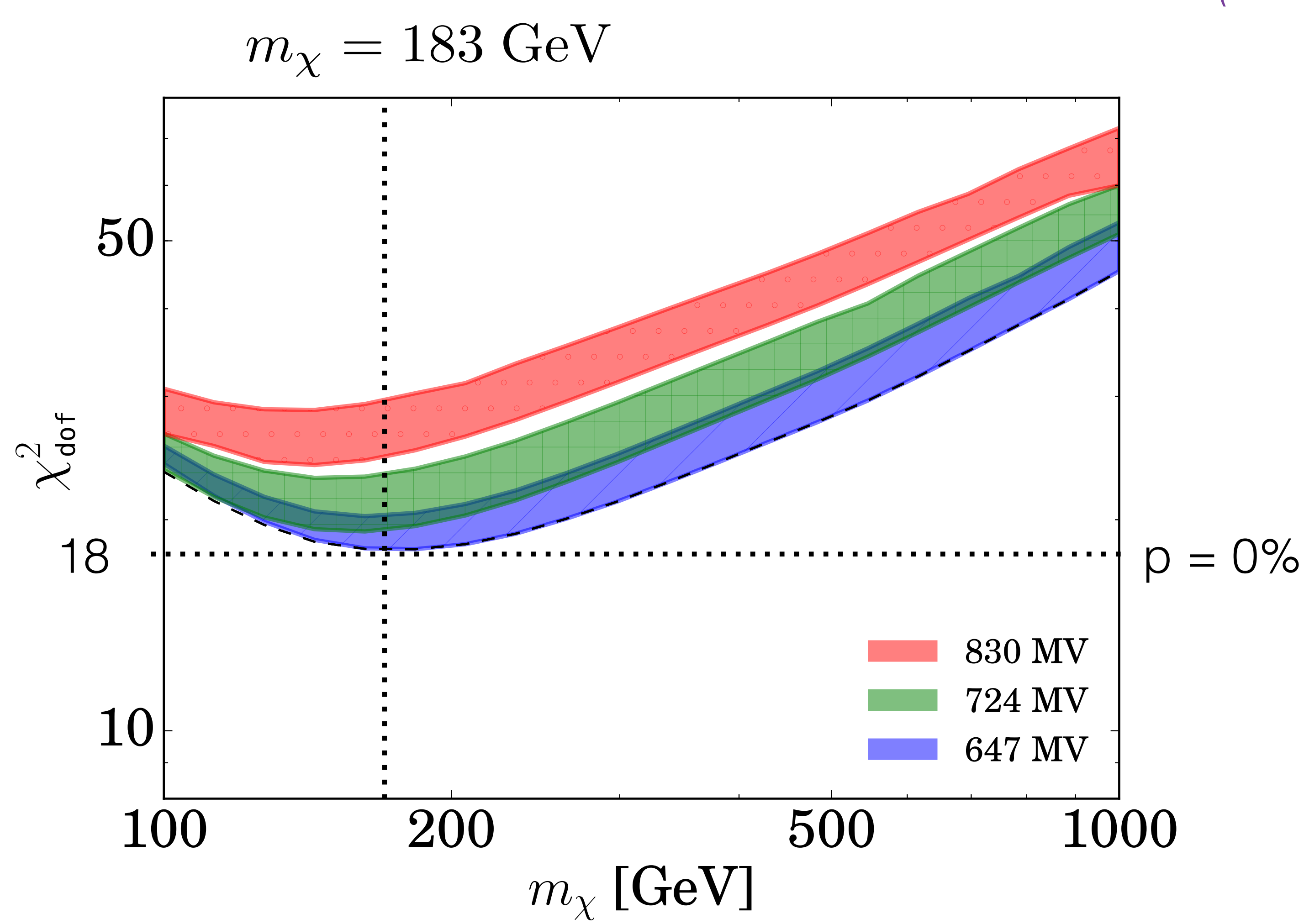

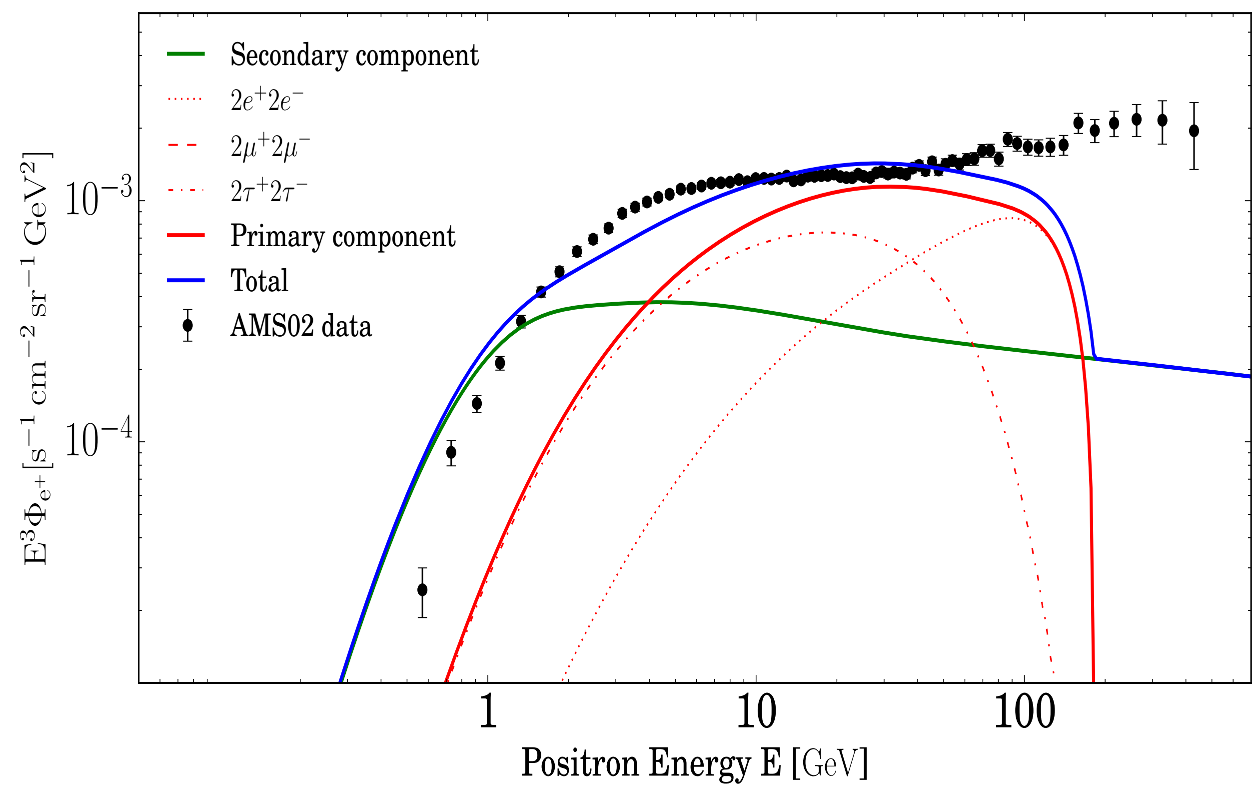

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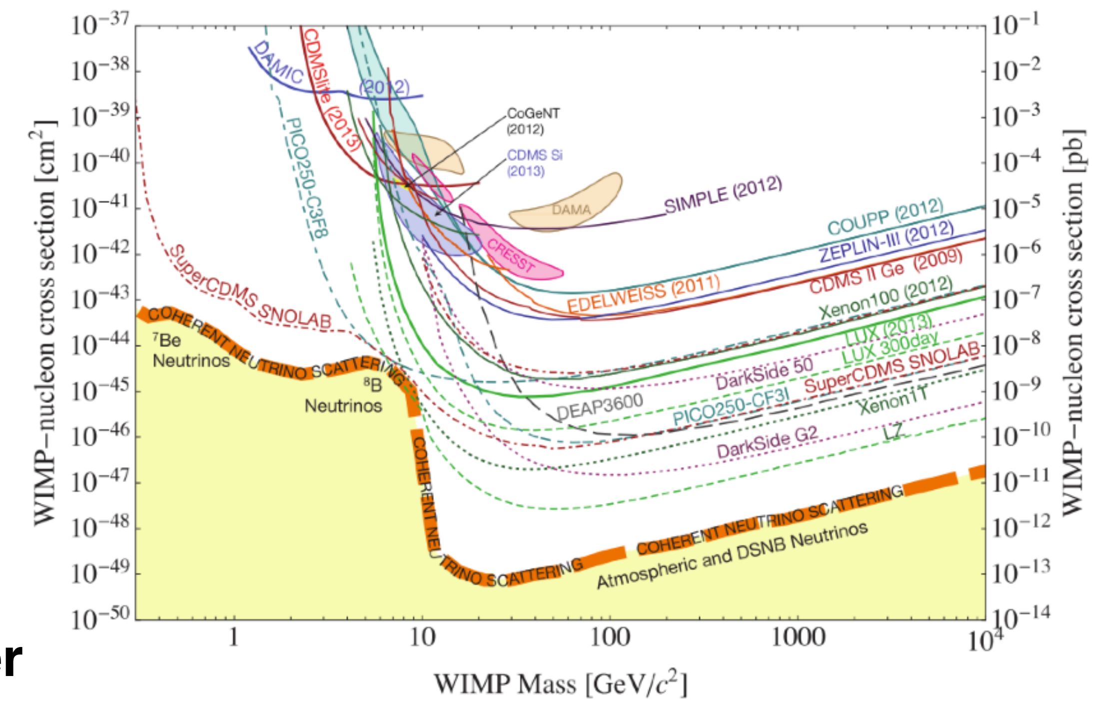
Novel constraints on MeV dark matter

Why MeV dark matter?

GeV-TeV dark matter

Motivated by SUSY theories.

- Gamma rays: No (clear) signal in the Galactic center. No signal in dSphs galaxies.
- Antiprotons: No (clear) signal.
- Direct detection: No (clear) signal.



MeV dark matter

- Not many channels kinematically available:
  - Pions (> 140 MeV)
  - Muons (> 105 MeV)
  - Electrons
  - Neutrinos
  - Photons
- Difficult to detect in direct detection experiments.

Why there is no constraints on MeV dark matter from CR e^- and e^+?

- So far, we needed numerical codes to solve the transport equation in the sub-GeV energy range. Important CPU time to derive bounds on the DM particle annihilation cross-section (decay life-time).

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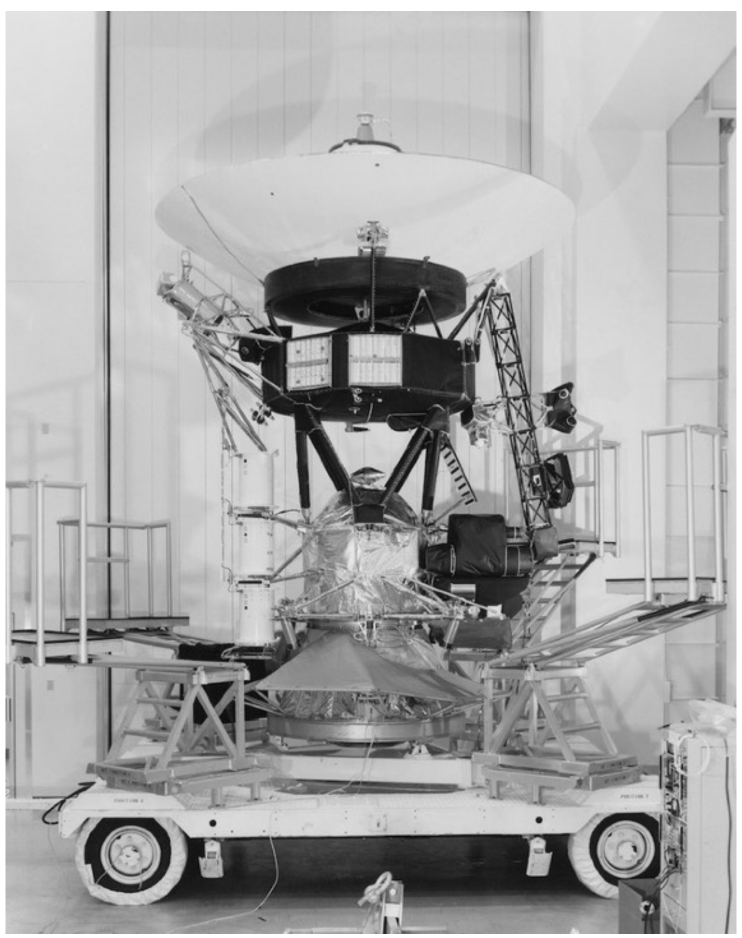
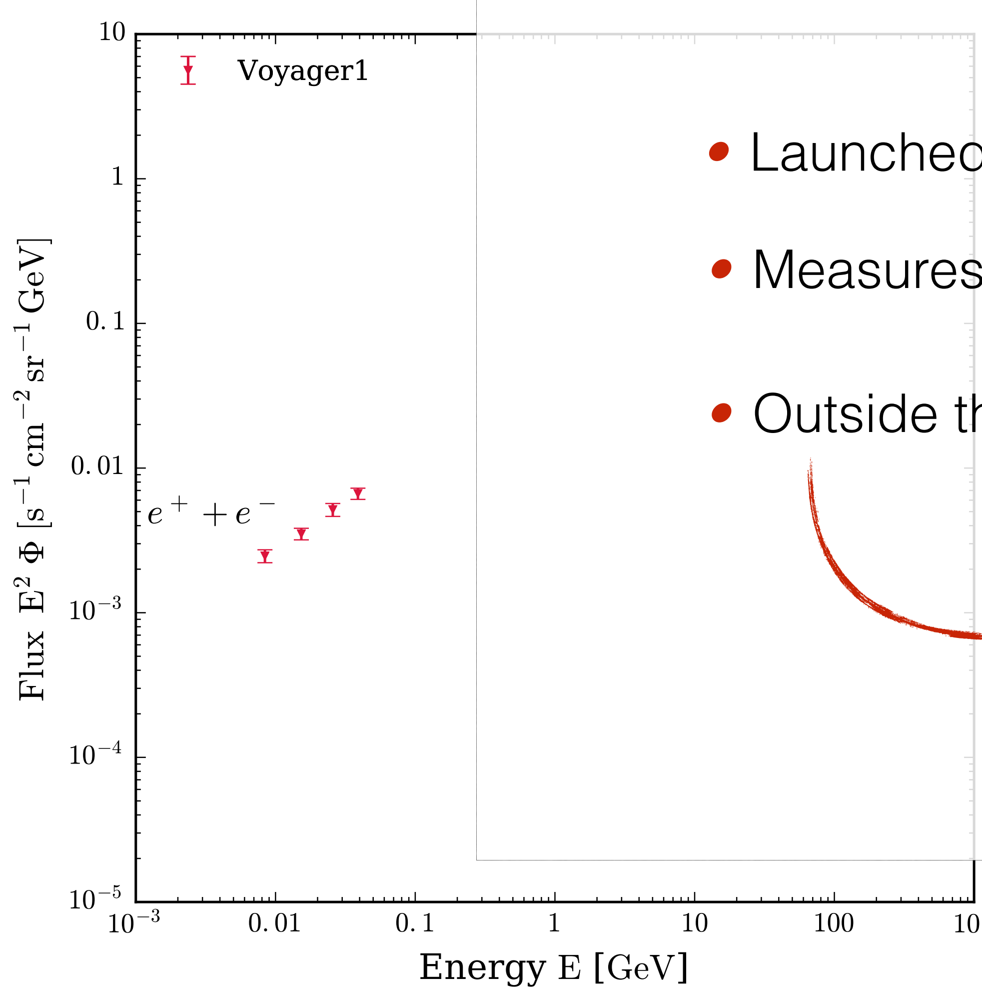
✓ **Voyager-I spacecraft has crossed the heliopause during summer 2012.**



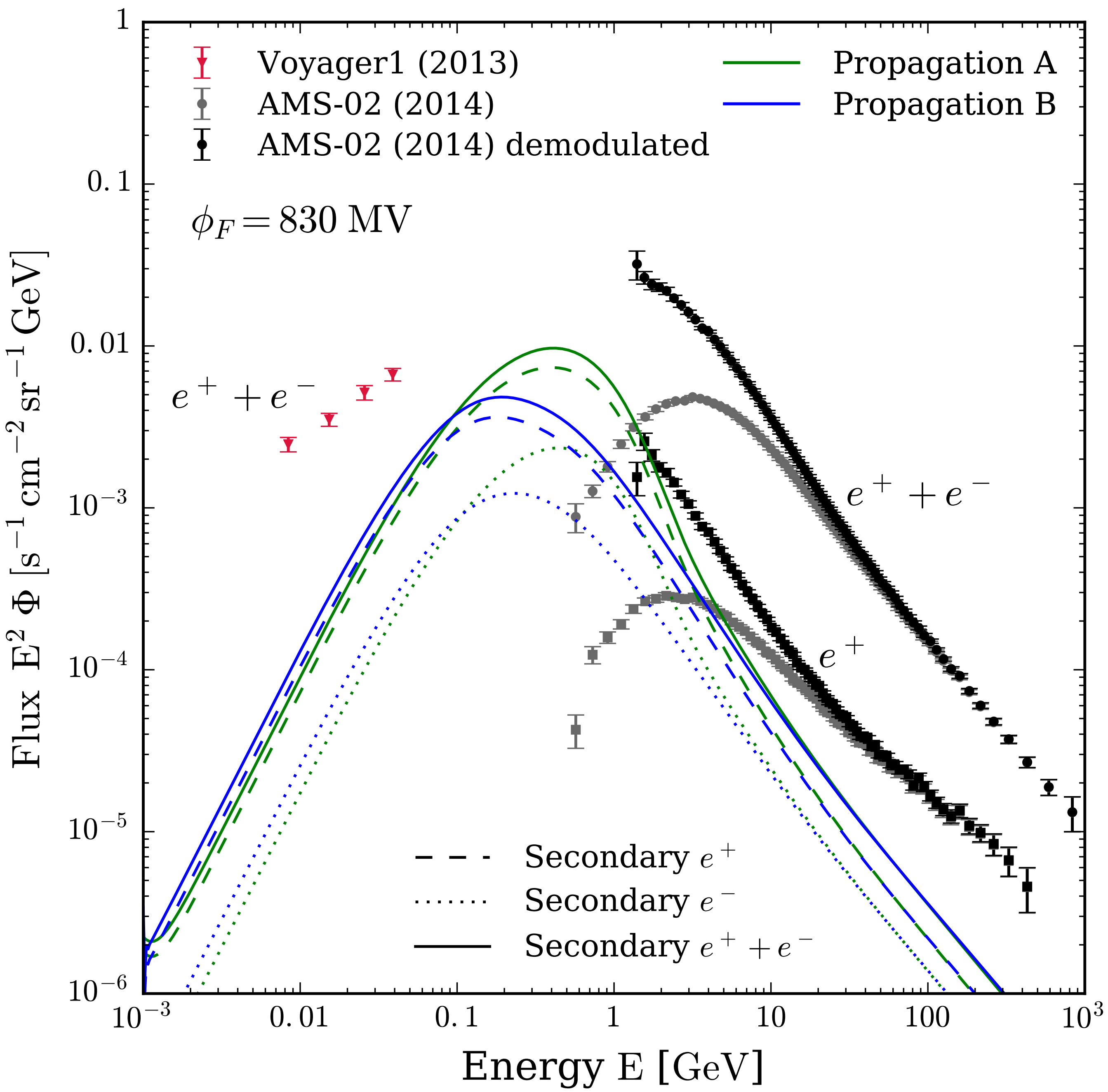


- Launched in 1977
- Measures the flux of **electrons + positrons**
  Stone et al. (2013)
- Outside the heliosphere since august 2012

  independent of solar effects

Constraints on DM

We require the DM induced fluxes of e^-+e^+ and e^+ do not exceed the Voyager-I and AMS-02 data more than 2 σ.



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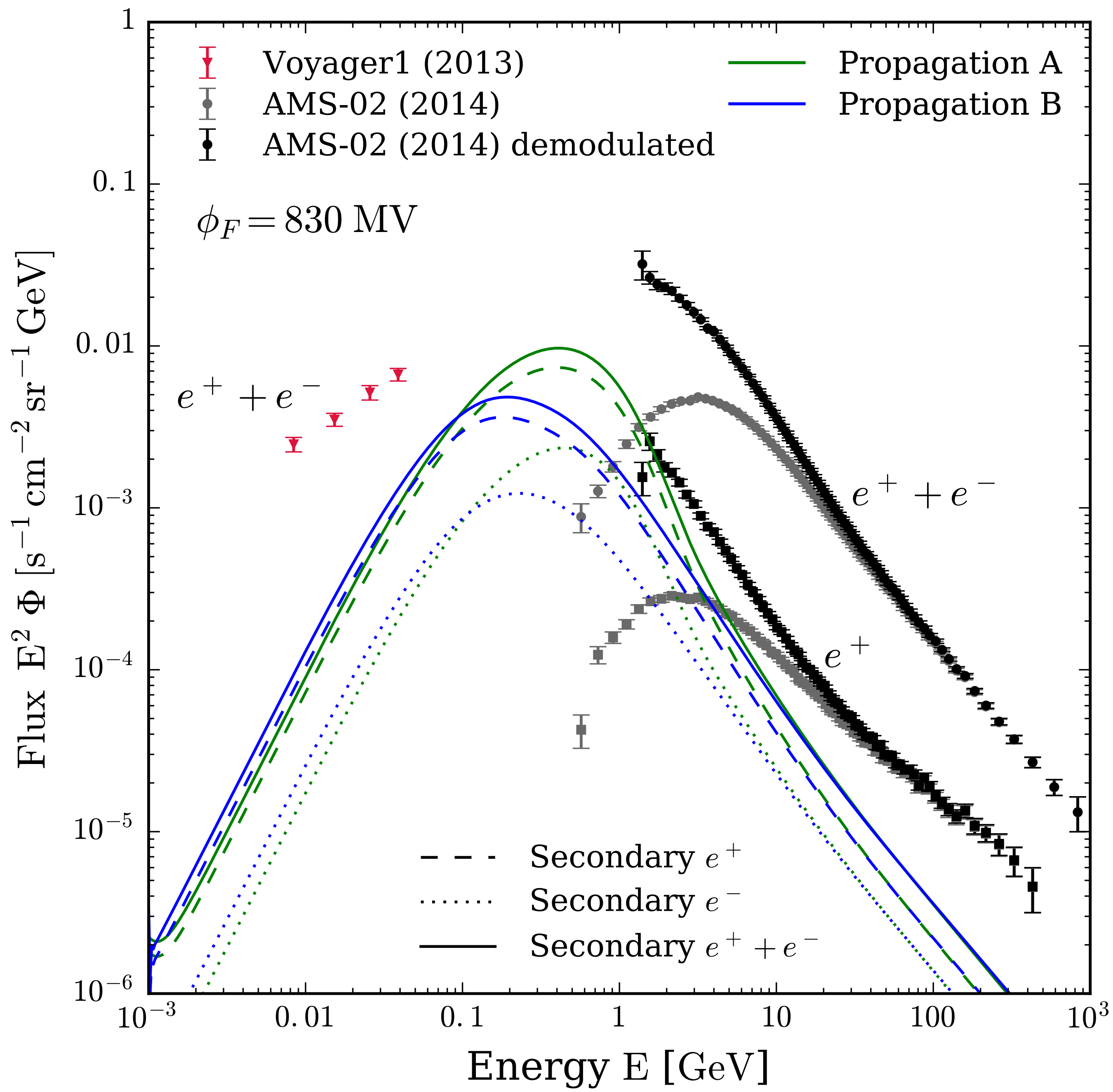

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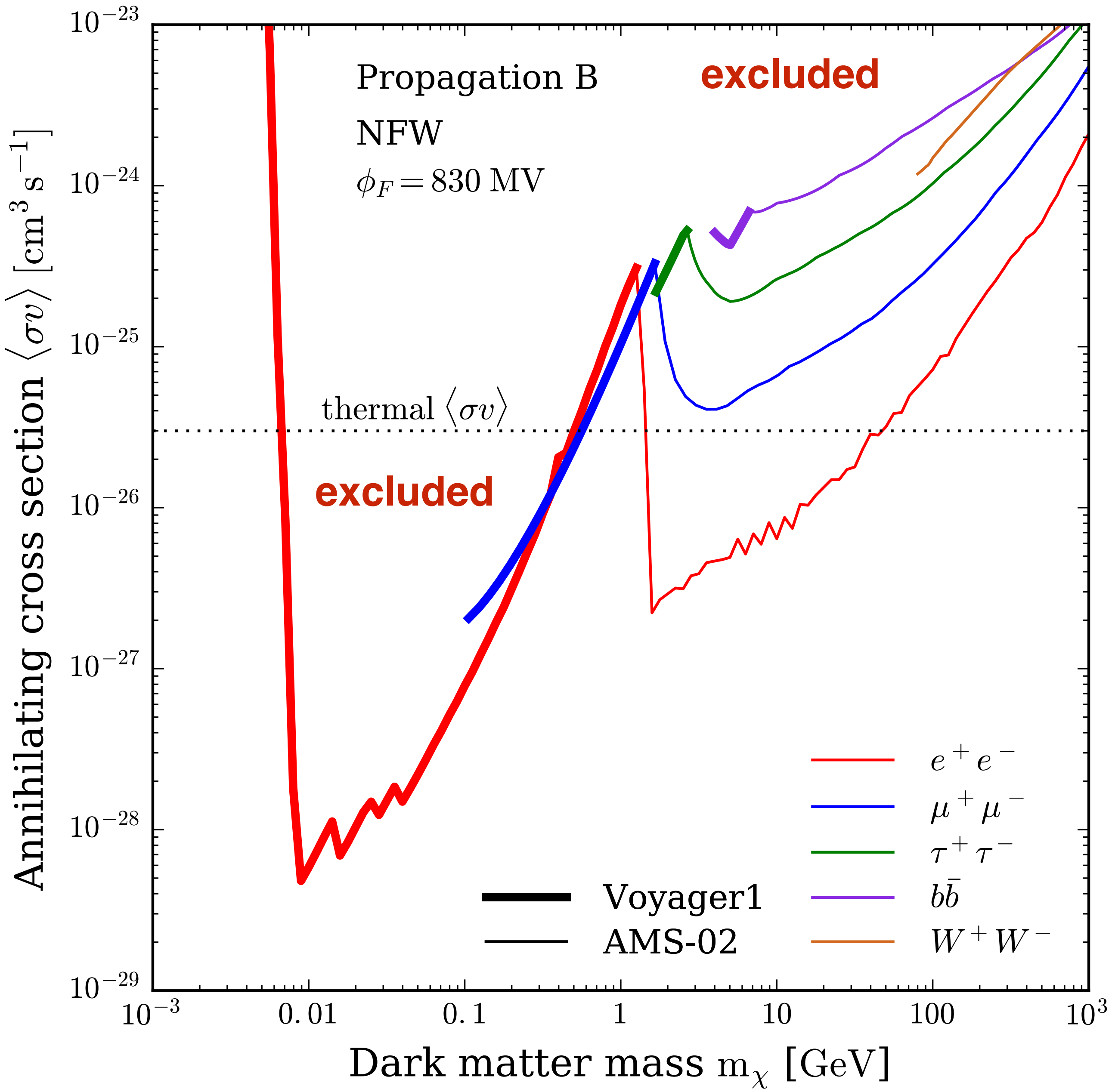
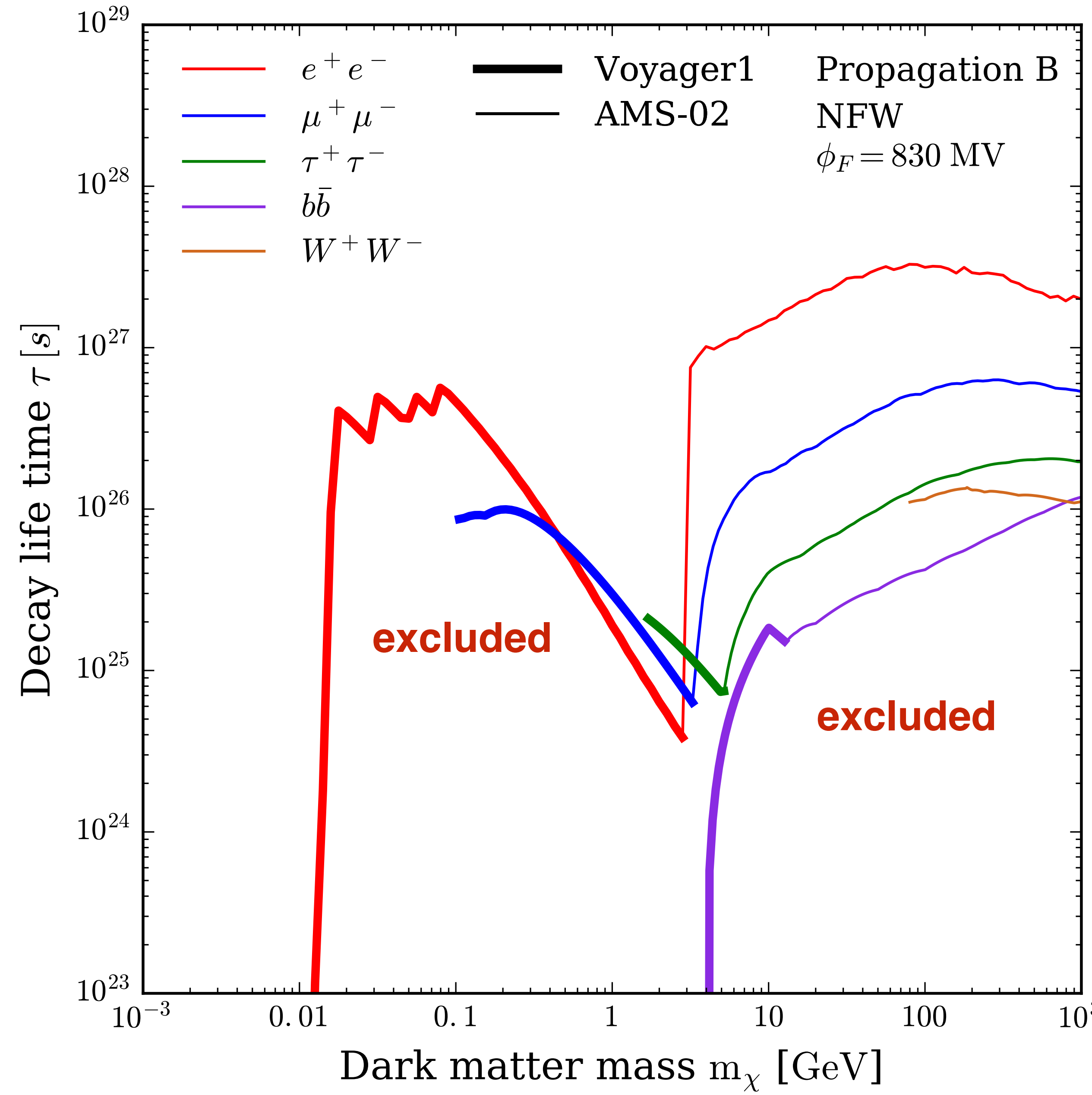
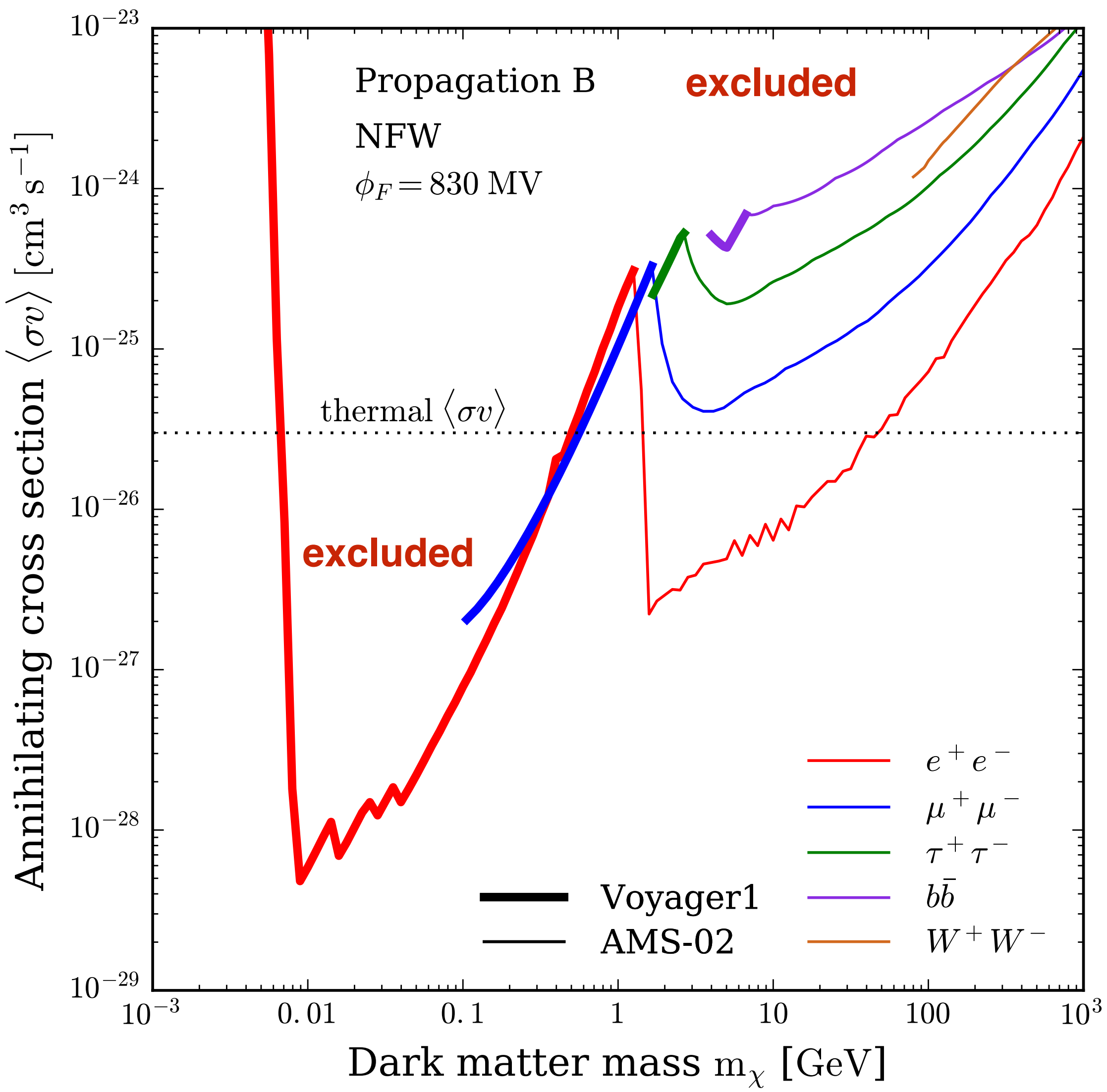
Annihilating Dark Matter



Decaying Dark Matter

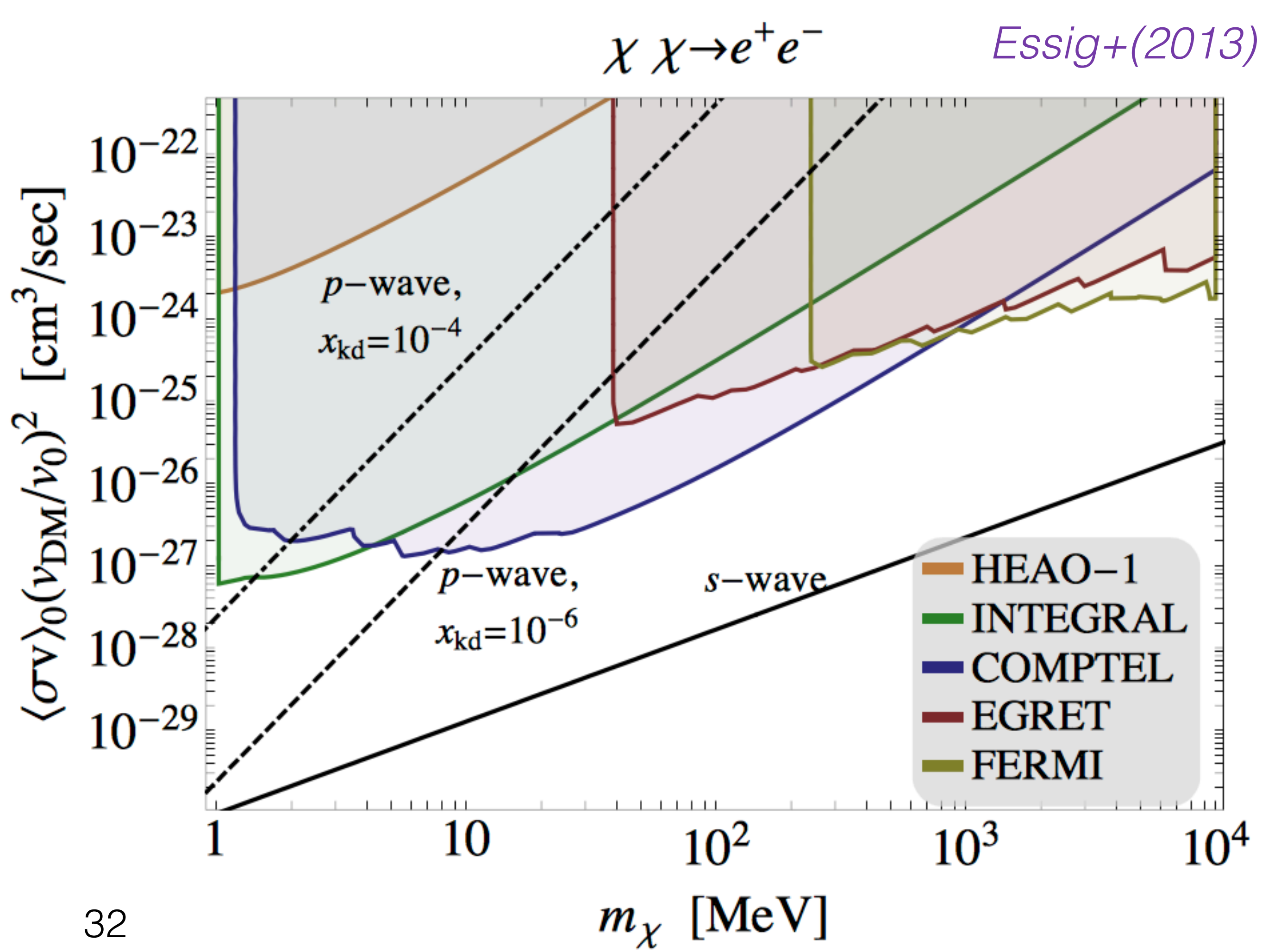


Comparison with other constraints



X-rays and ɣ-rays

- **More** stringent by almost 2 orders of magnitude.
- **Less** sensitive to the DM halo shape.



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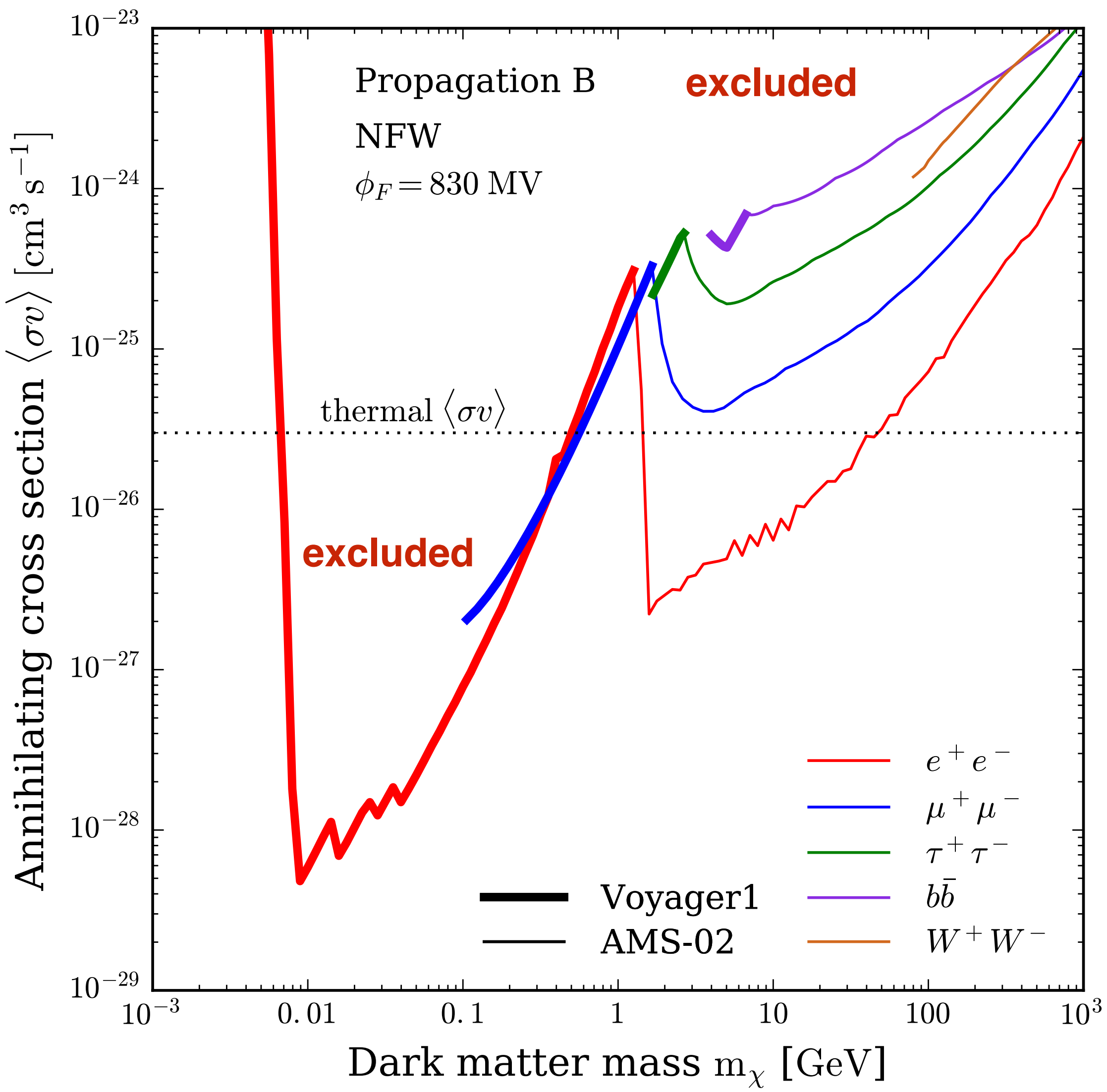
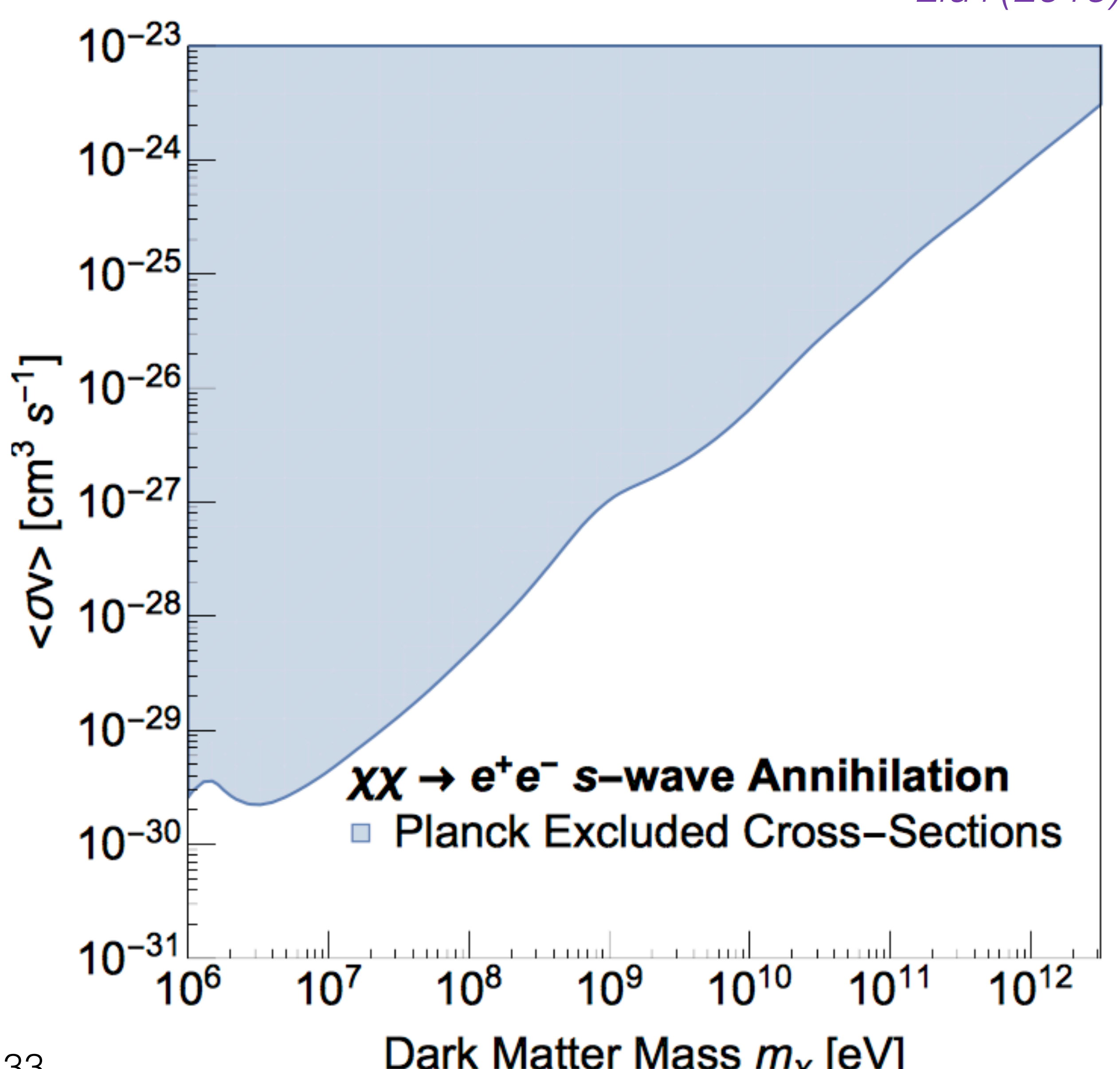


CMB

- Slightly less stringent for s-wave <σv>.

Liu+(2016)



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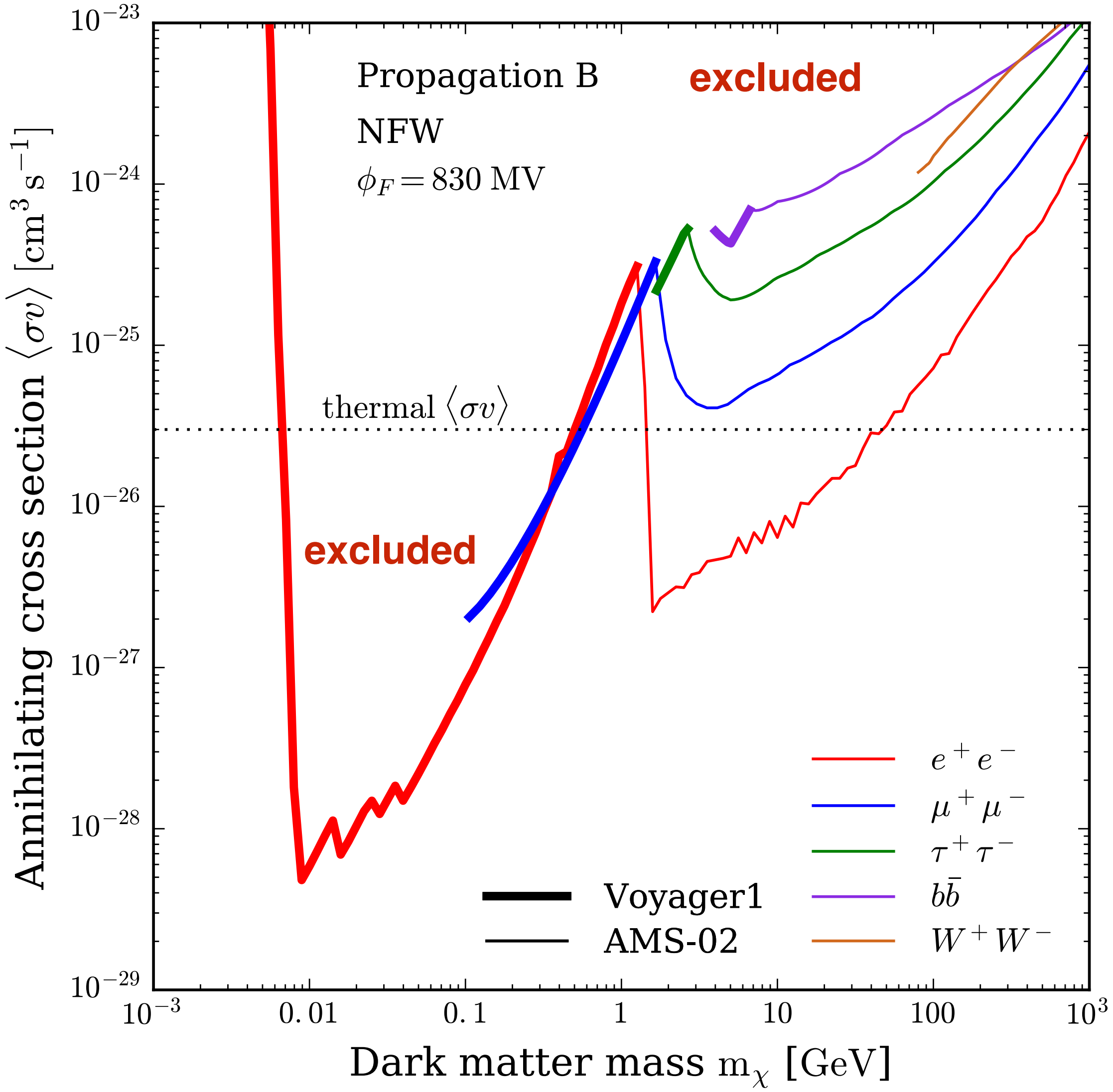
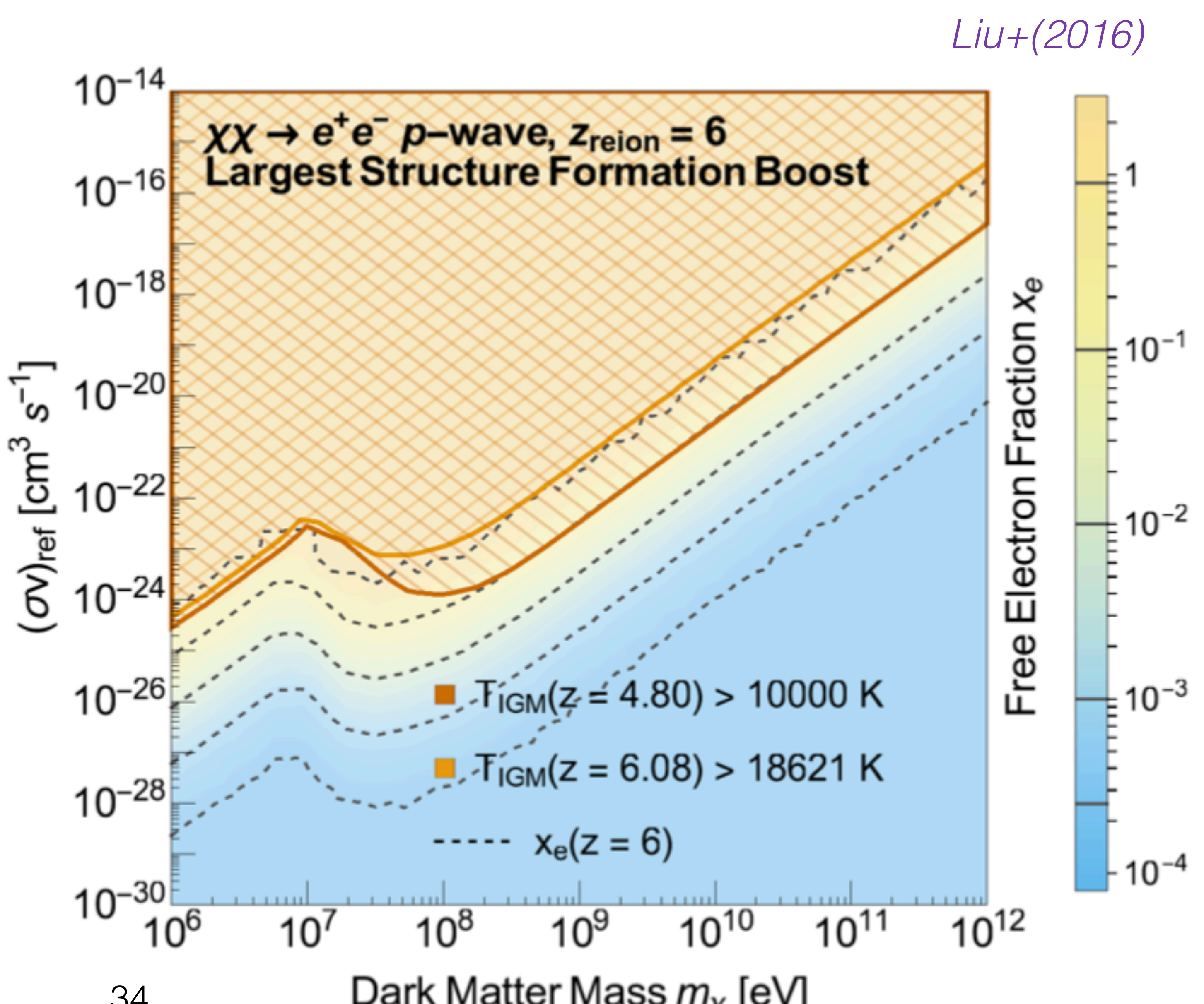


CMB

- Slightly less stringent for s-wave <σv>.
- **More** stringent by 5 orders of magnitude for p-wave <σv>.



Conclusions and prospects

- The **single PSR** scenario **succeeds** to explain the positron data.

  The free parameters obtained to fit the positron data are consistent with recent TeV gamma observations by HAWC.

  Since there is no known lower limit for the positron injection, if one single pulsar can explains the data therefore a collection of pulsars do.

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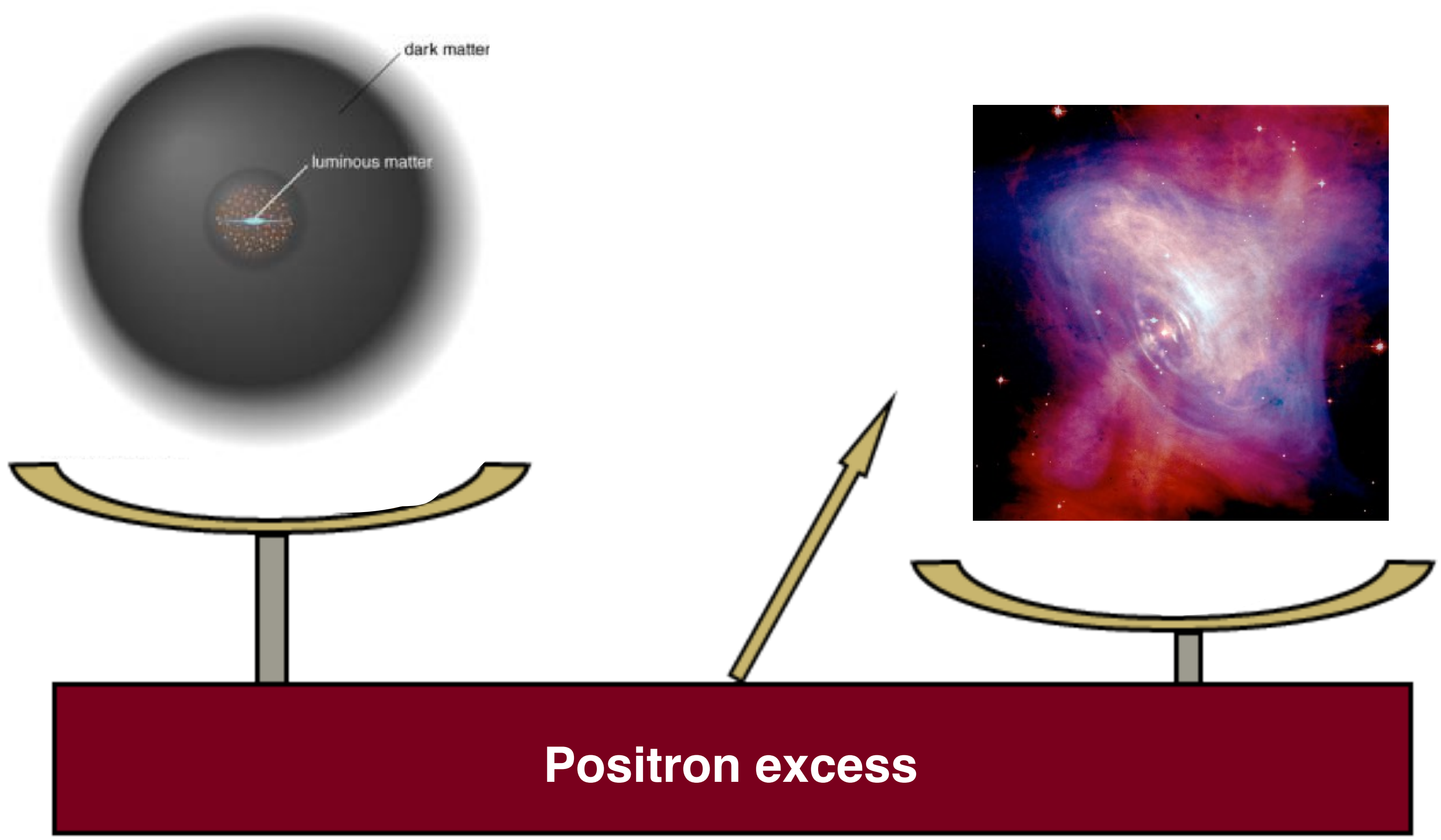


Thank you for your attention!

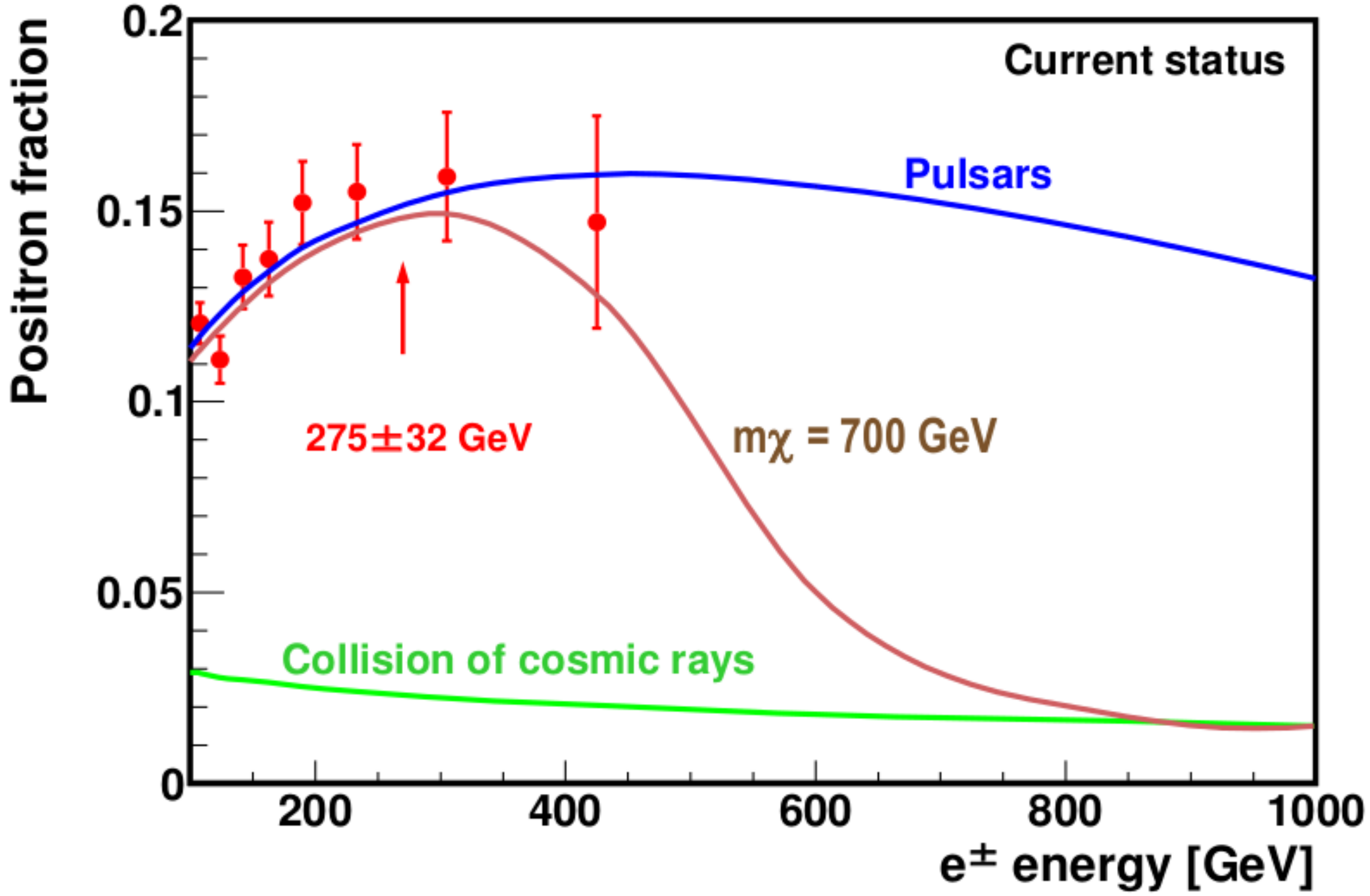
Questions?

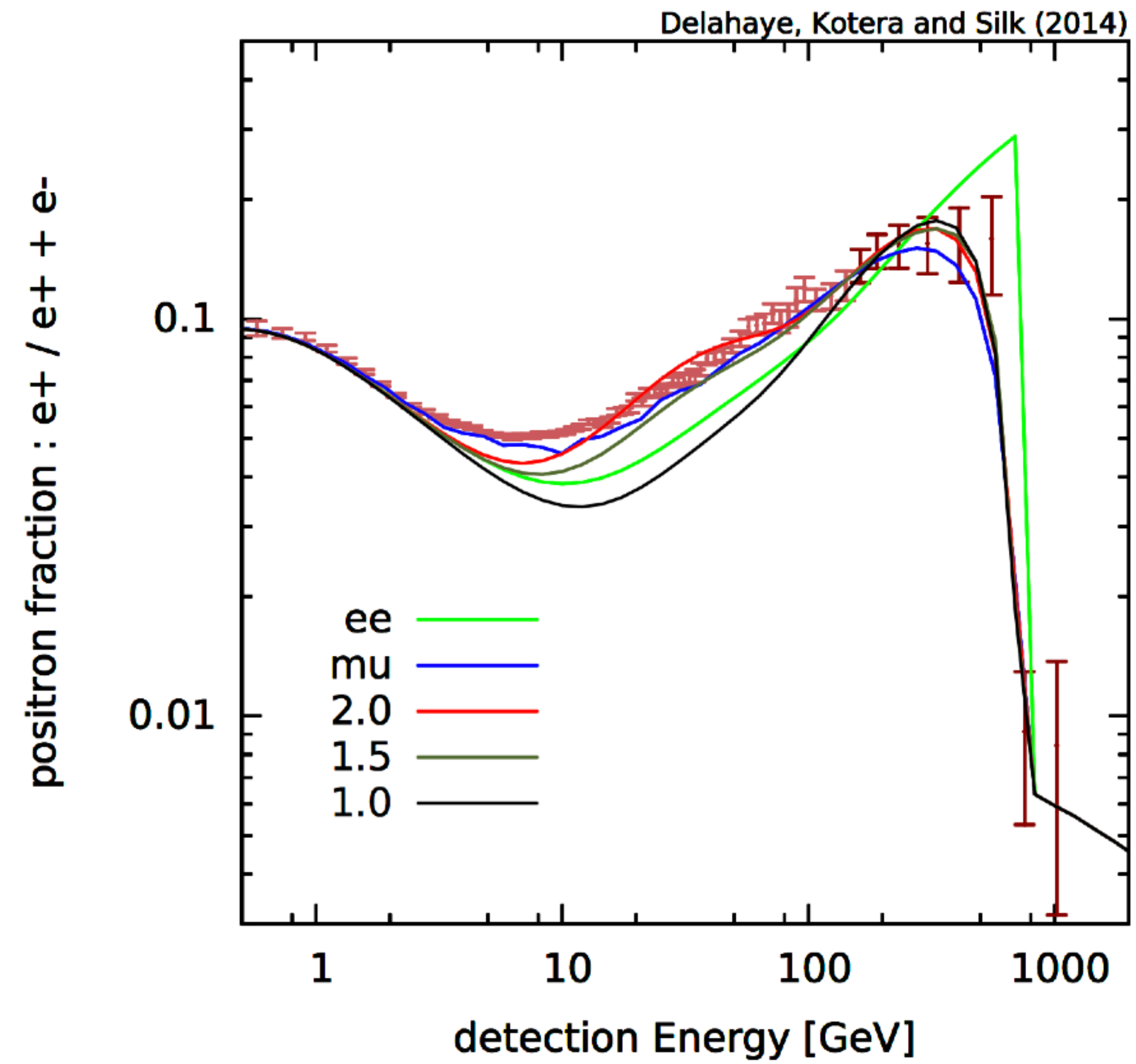
Back up

How to distinguish PSR scenario from DM scenario?

- Spectral shape?

Delahaye, Kotera and Silk (2014)





Both scenarios predict a sharp cut-off at high energy.

Dark matter

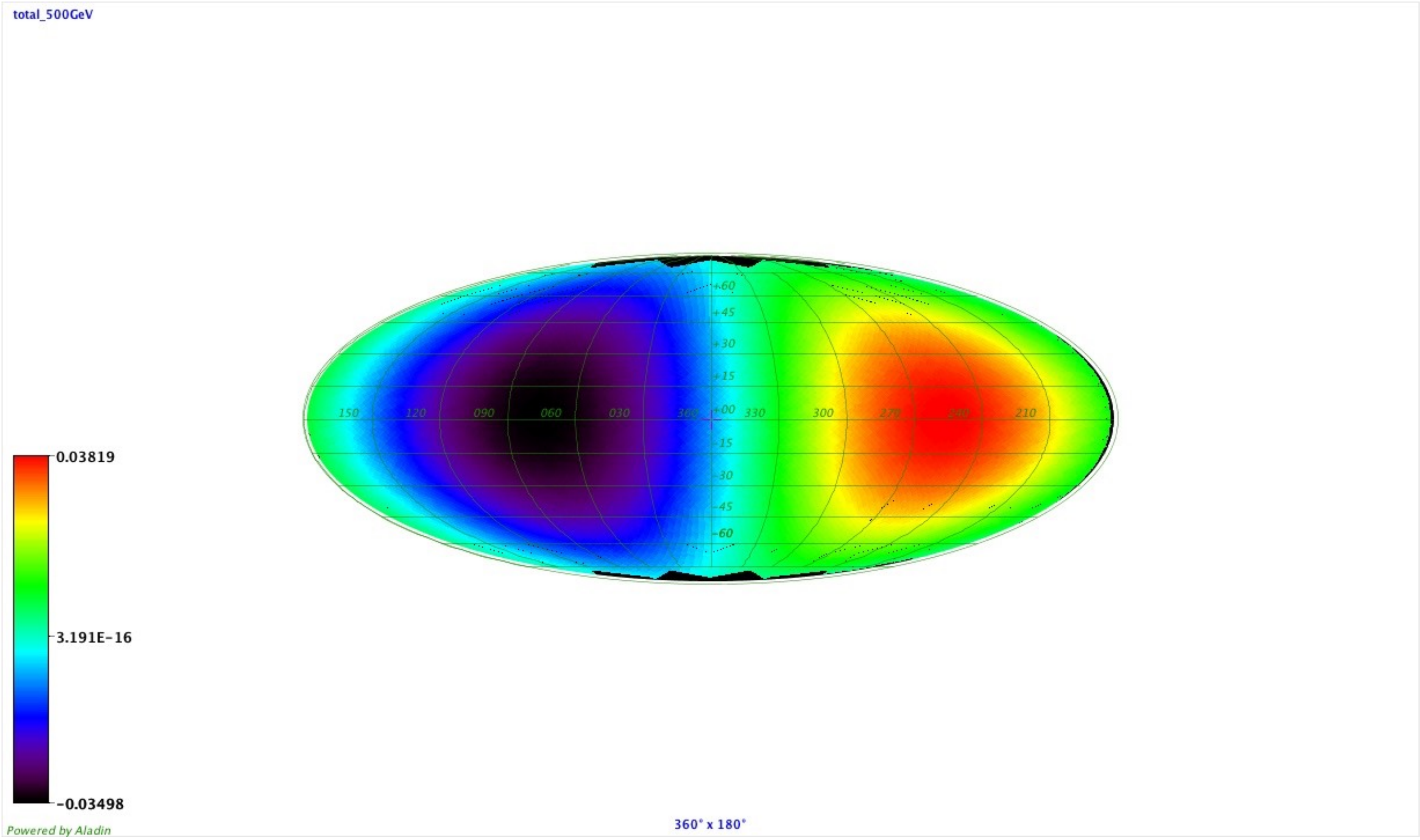
$$E_{max} = m_\chi$$

Pulsars

$$E_{max} = \frac{E_C}{1 + \frac{E_C}{1\,\mathrm{GeV}} \frac{t_\star}{\tau_l}}$$

How to distinguish PSR scenario from DM scenario?

- Anisotropy?

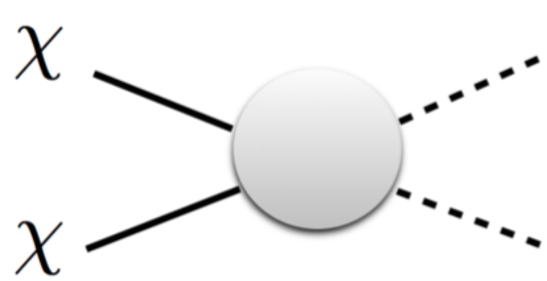


- May only reflect the direction of the local magnetic field.
- May be affected by the Solar magnetic field.

Ahlers & Mertsch (2015)

Let's see and stay tuned!

e⁻ and e⁺ from the annihilation of DM particles



$W^-, Z, b, \tau^-, t, h, \ldots \longrightarrow e^\pm, \overset{(-)}{\nu}, \overset{(-)}{p}, \overset{(-)}{D}, \gamma, \ldots$

annihilation channel — decay — final products

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h, \ldots \longrightarrow e^\mp, \overset{(-)}{\nu}, \overset{(-)}{p}, \overset{(-)}{D}, \gamma, \ldots$

$$Q^{\mathrm{DM}}_{\mathrm{e}^+}(E, \vec{x}) = \underbrace{\left(\frac{\rho(\vec{x})}{m_\chi}\right)^2}_{astrophysics} \times \underbrace{\frac{1}{2} \sum_i \langle \sigma v \rangle \, B_i \, \frac{dN_i(E)}{dE}}_{particle\ physics}$$

$\rho(\vec{x})$: DM density profile

NFW *McMillan(2016)*

Cored *McMillan(2016)*

$\frac{dN_i}{dE}$: e⁻ and e⁺ spectrum at source

MicrOmegas

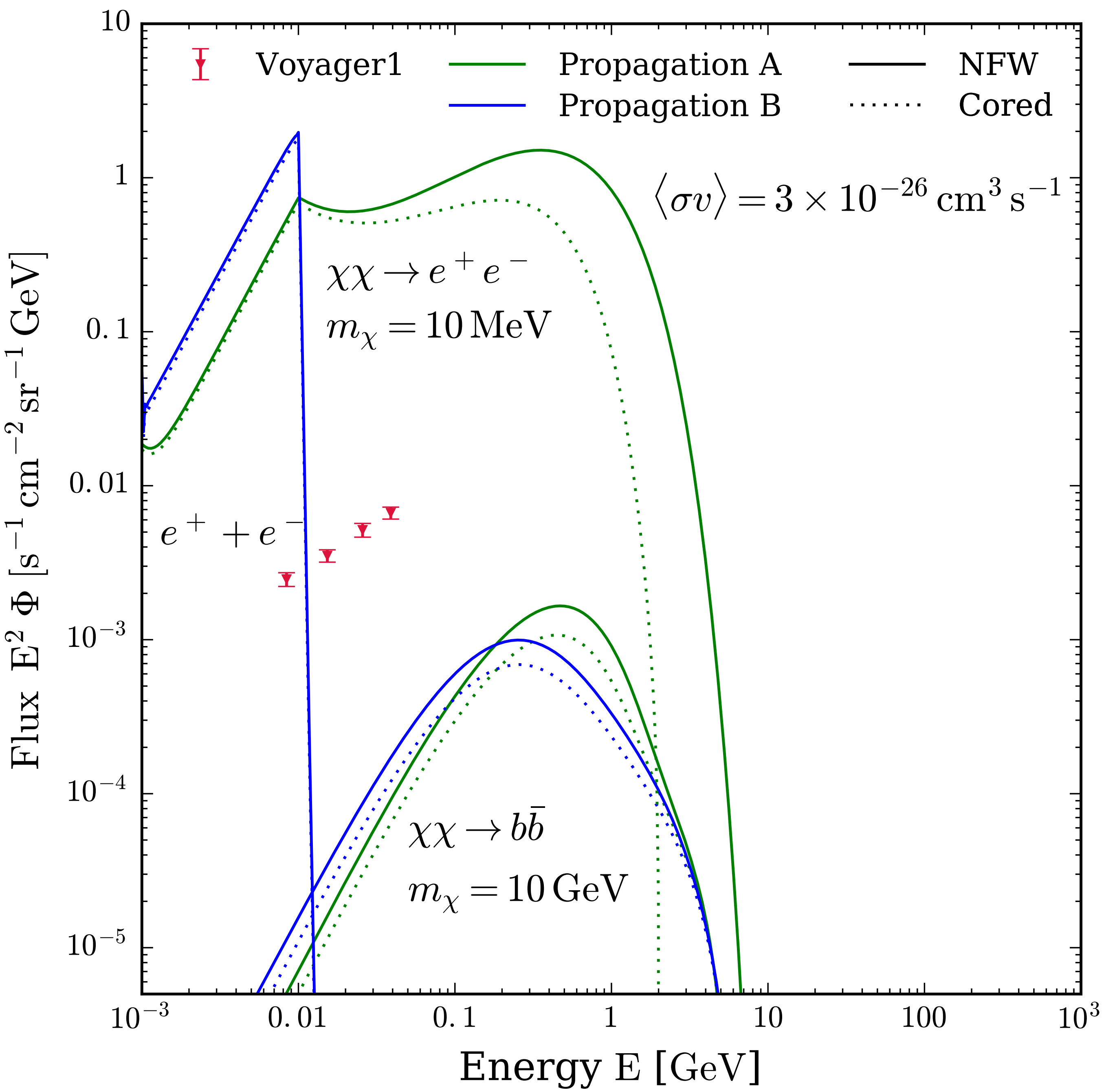
Cosmic rays propagation paramaters

- **Model A**: MAX from B/C analysis of *Maurin+(2001)* consistent with AMS-02 positrons and antiprotons data.
- **Model B**: best fit model of *Kappl+(2015)* on preliminary AMS-02 B/C data.

$V_A = 117.6\,\mathrm{km/s}$

$V_A = 31.9\,\mathrm{km/s}$

Constraints on DM annihilating cross section



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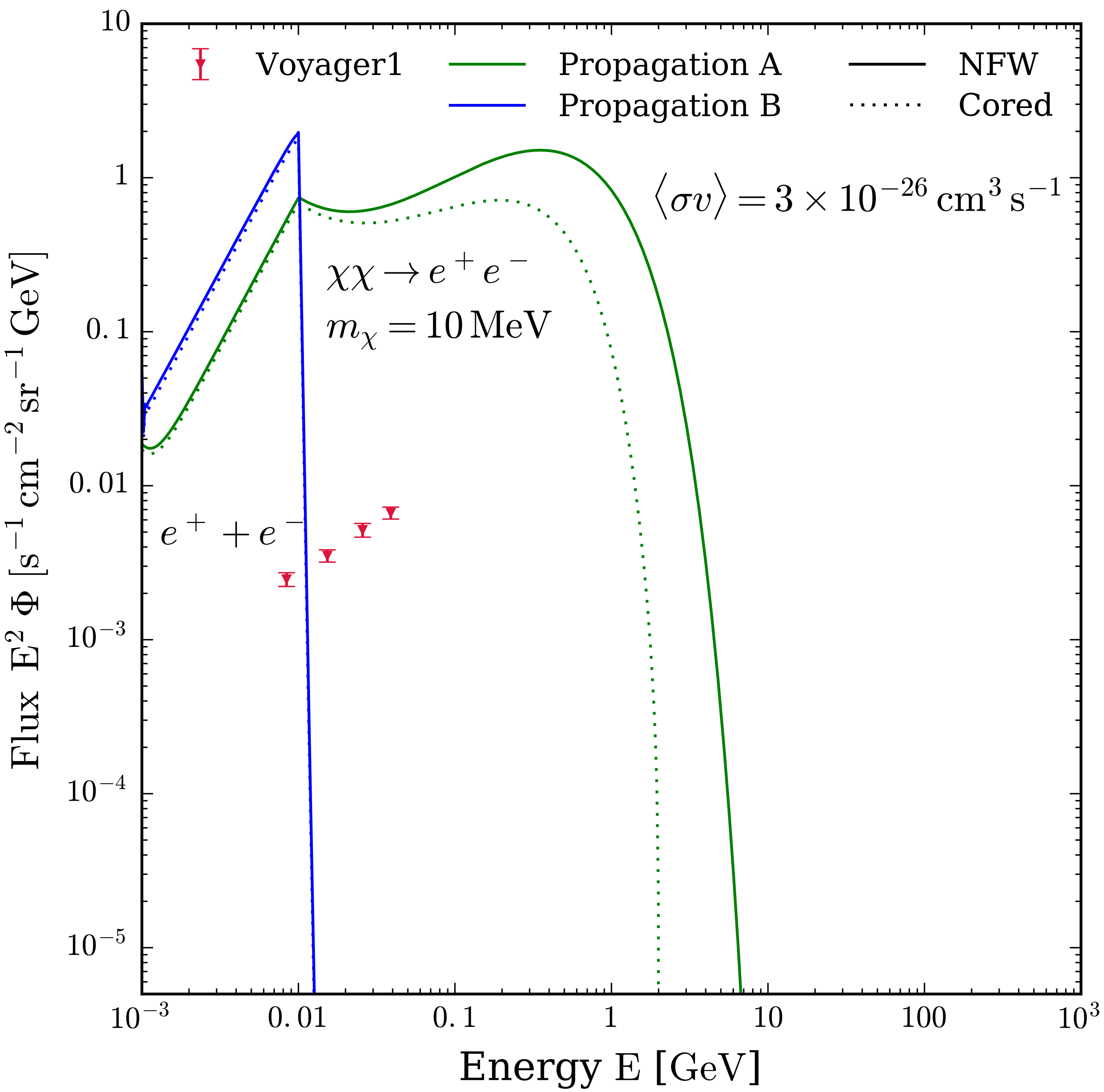

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$$\chi\chi \longrightarrow e^+e^-$$

Conservative constraints (without background):

$$\Phi^{\mathrm{DM}}_{e^+ + e^-}(E_i) \leq \Phi^{\mathrm{exp}}_{e^+ + e^-}(E_i) + 2\sigma_i$$

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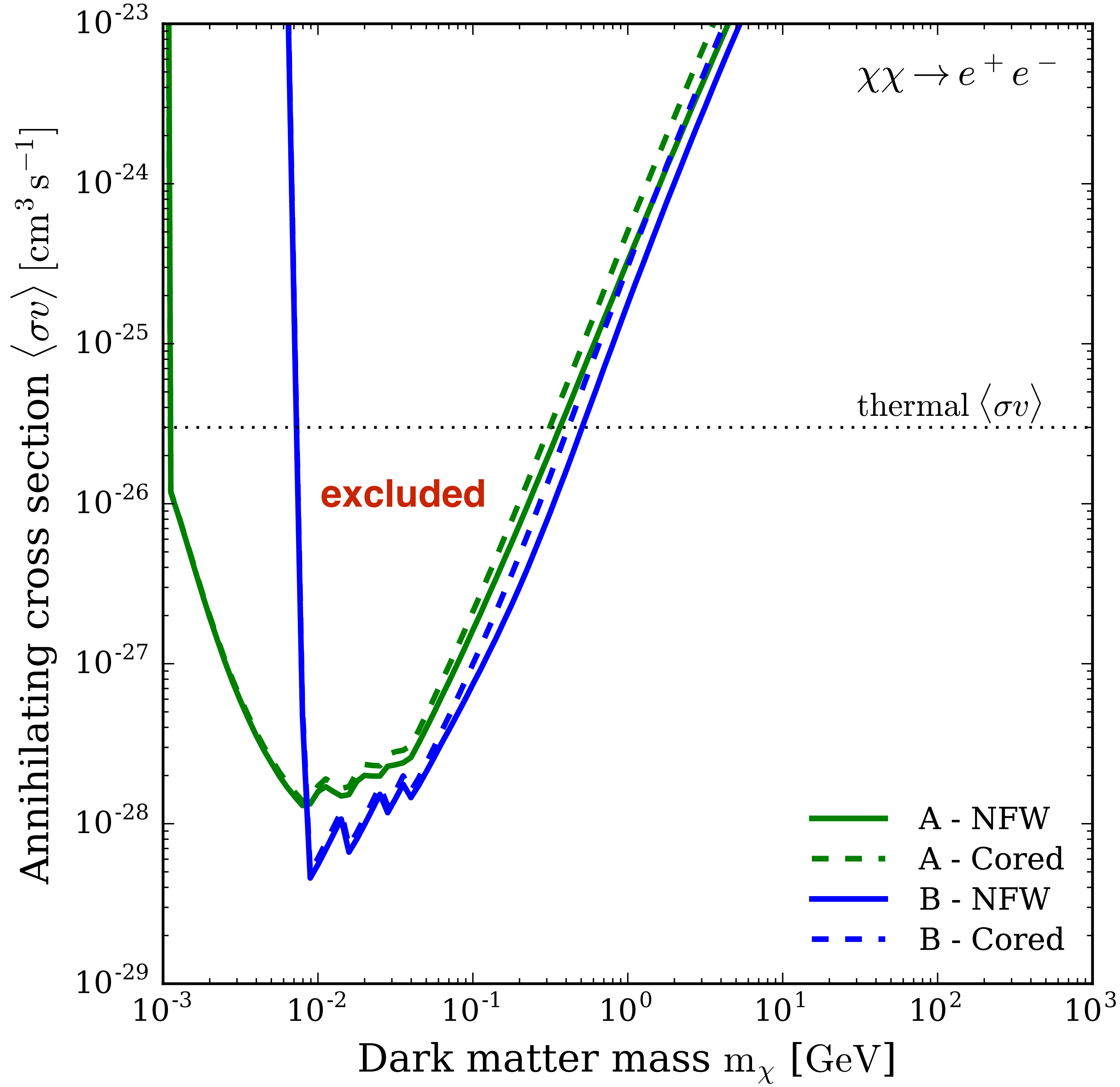

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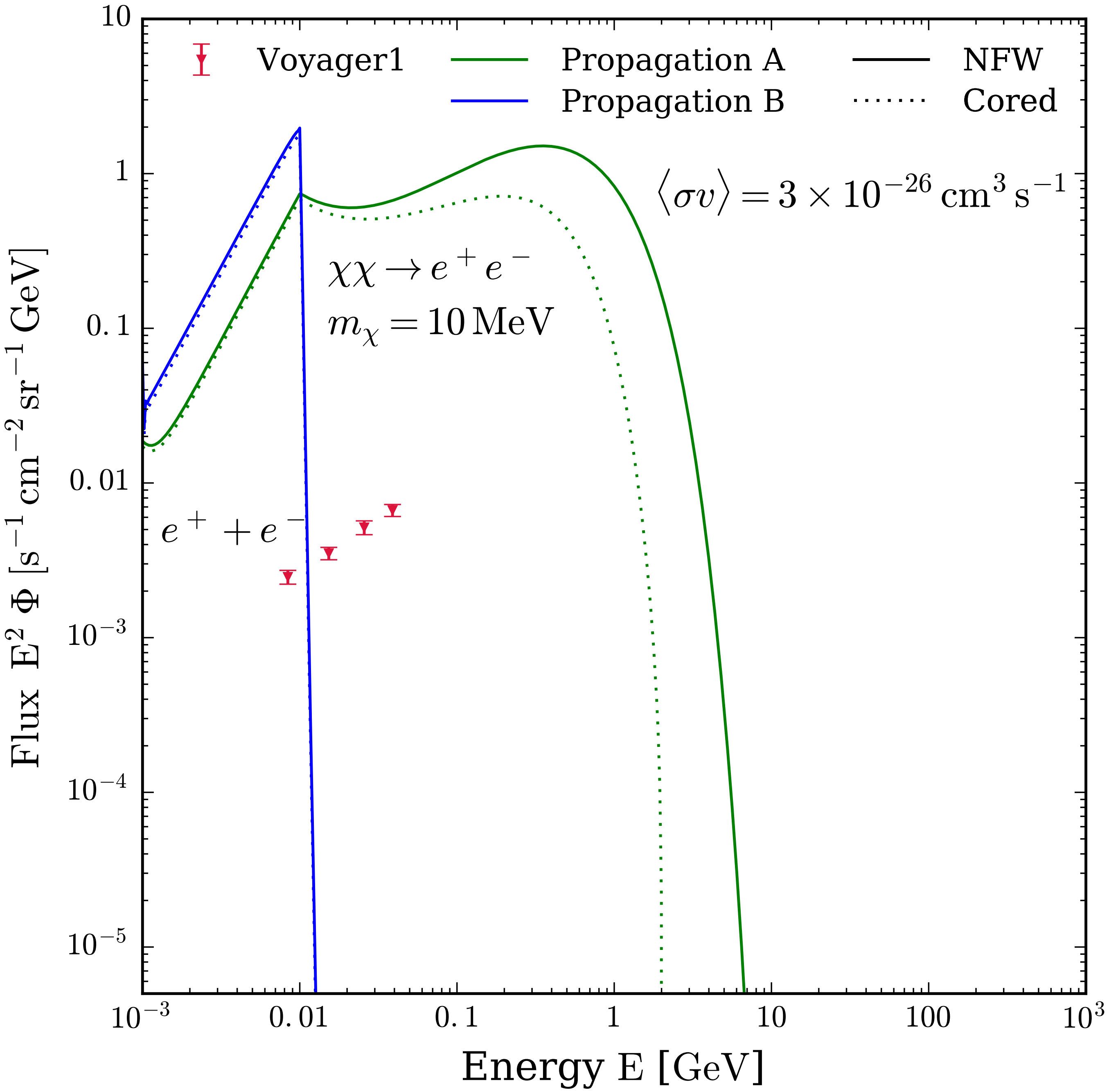

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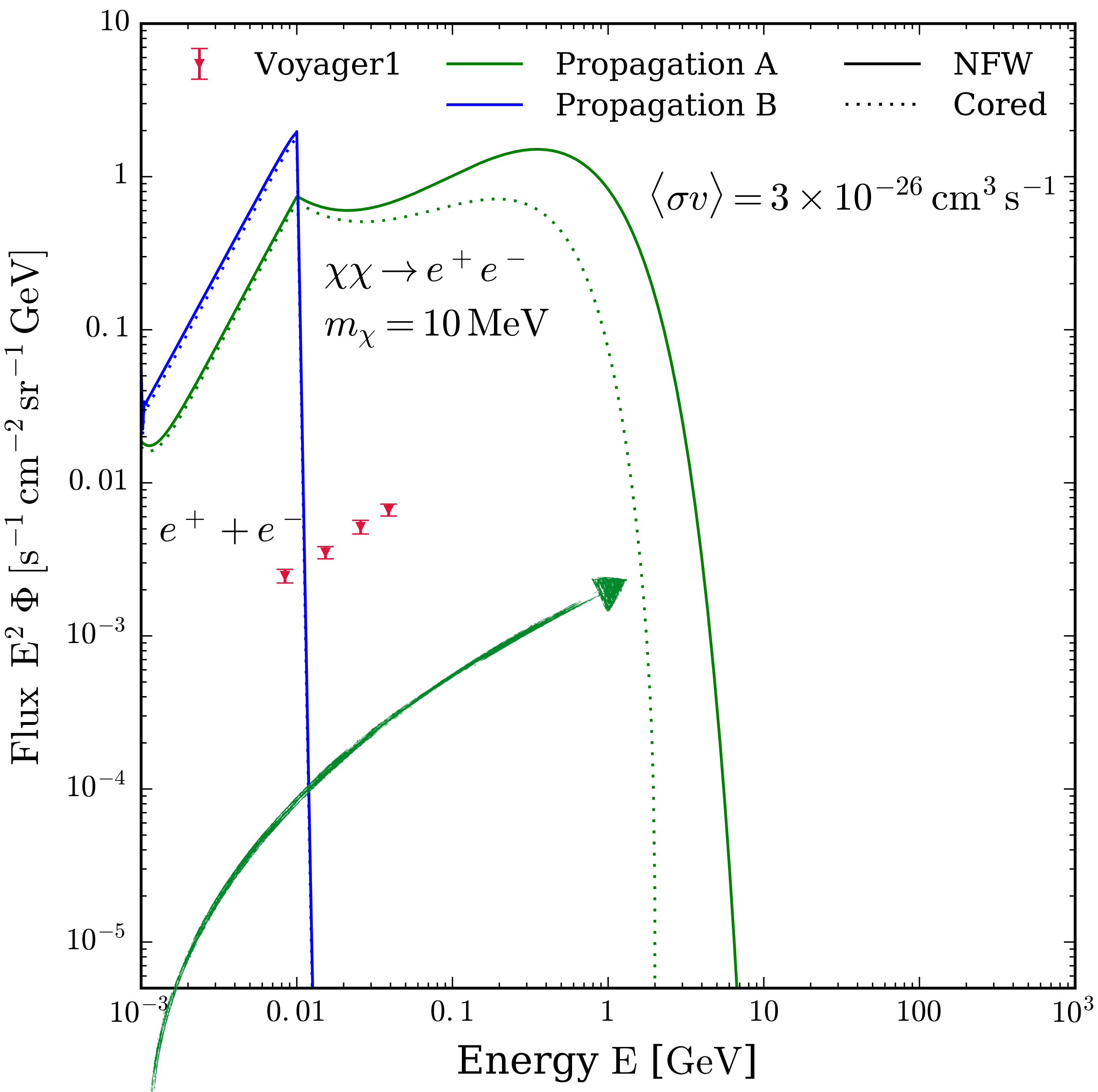

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Models with strong diffusive reacceleration enable to detect positrons **above** the DM mass!

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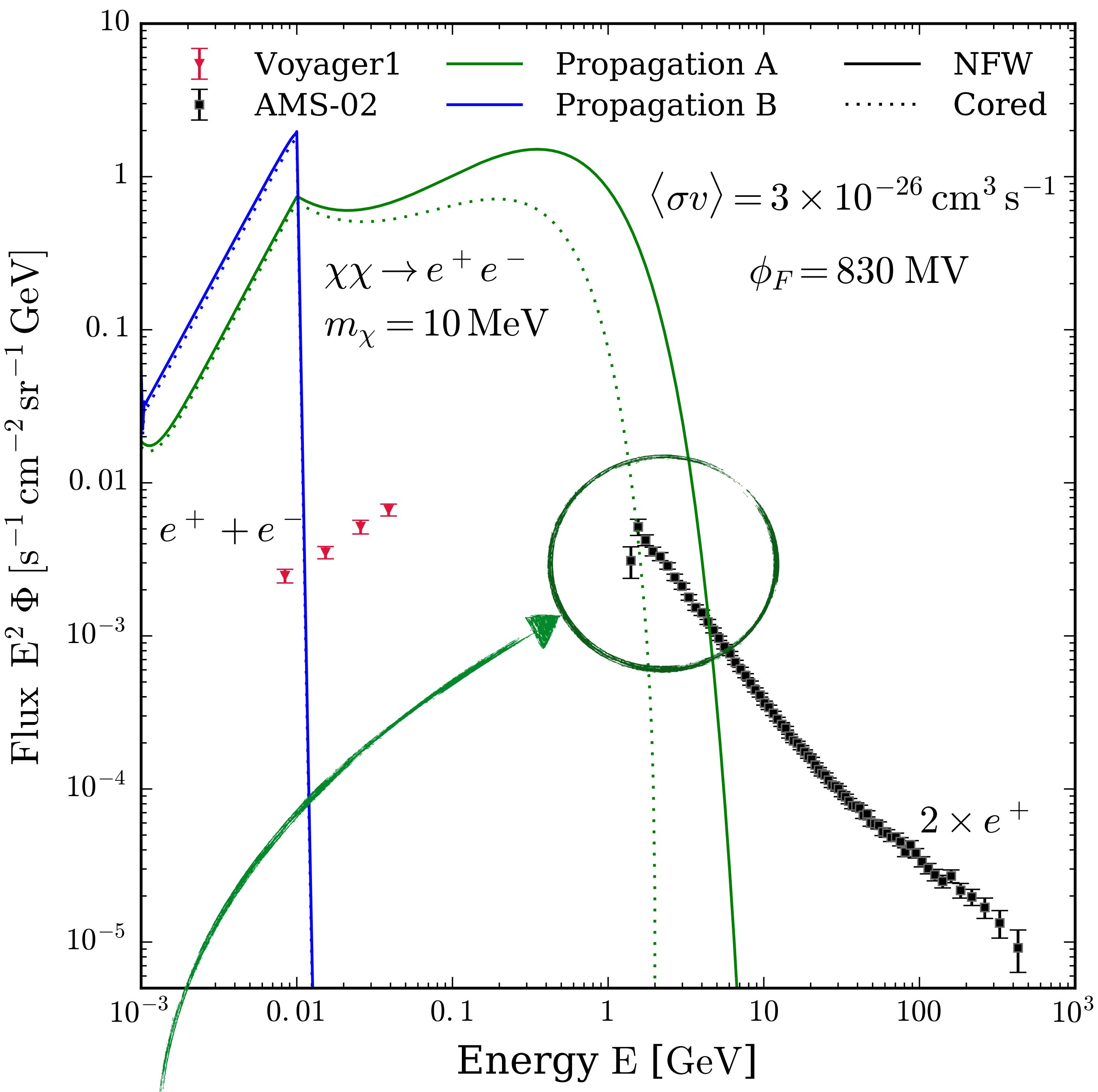

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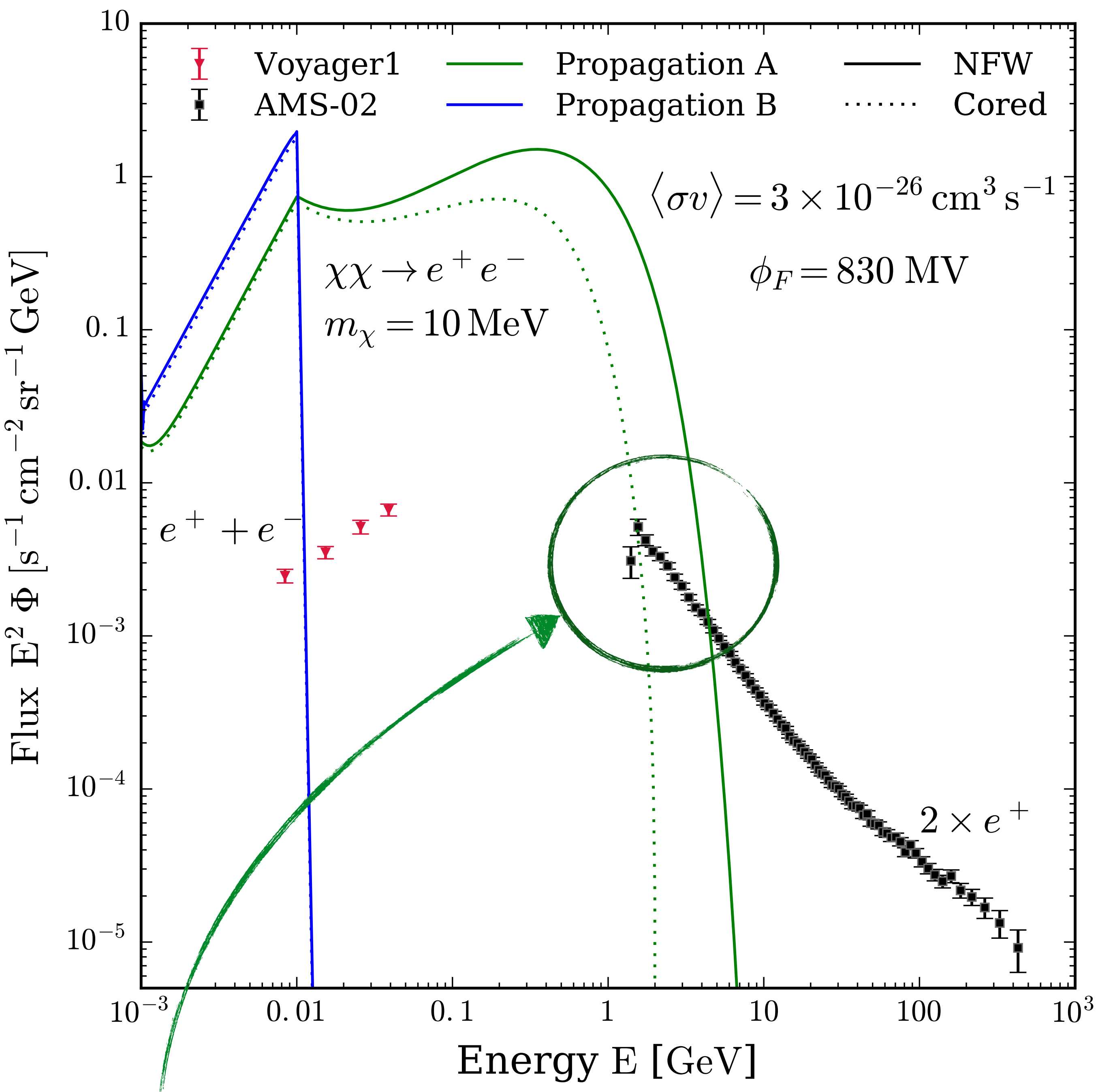

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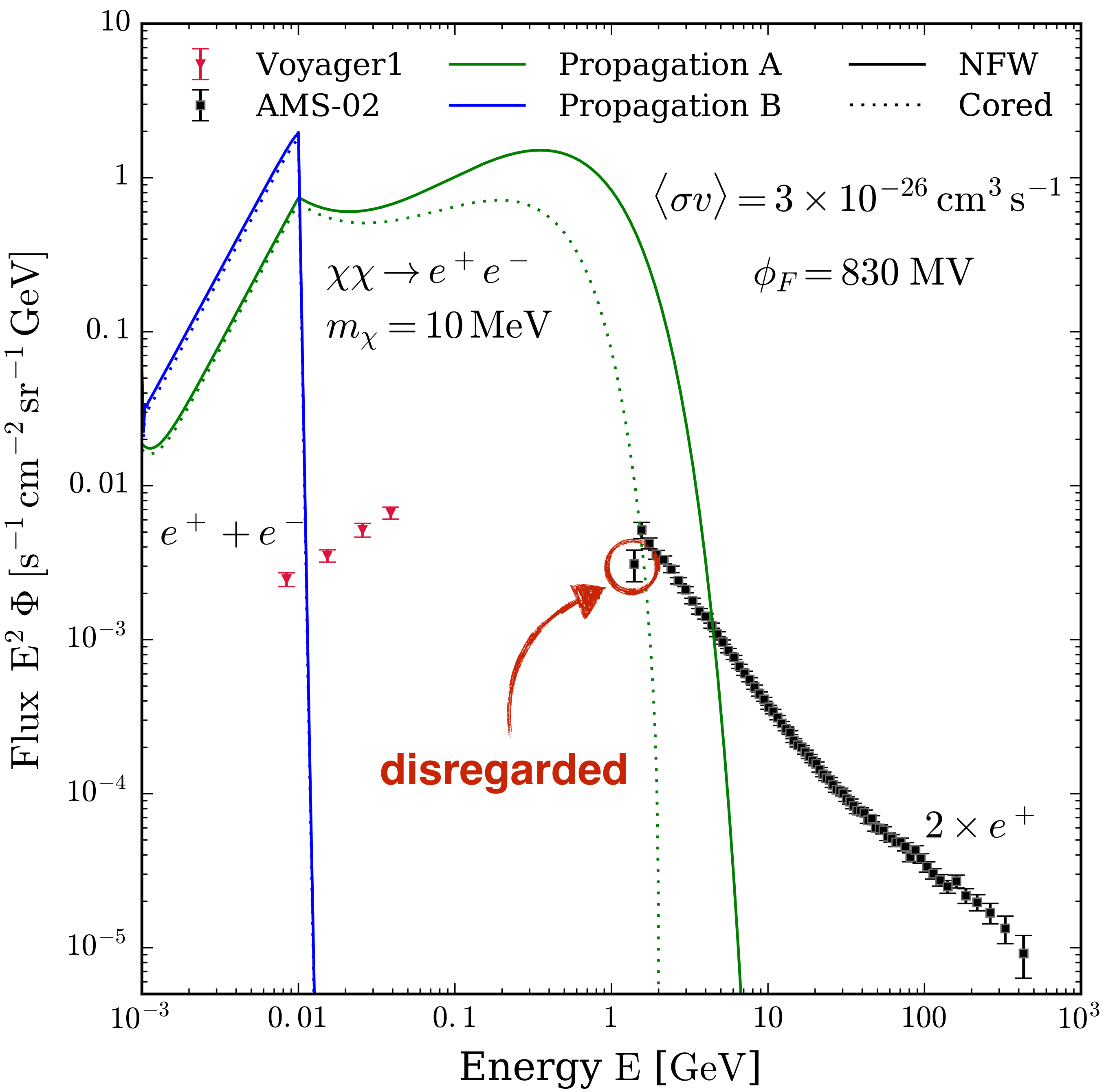

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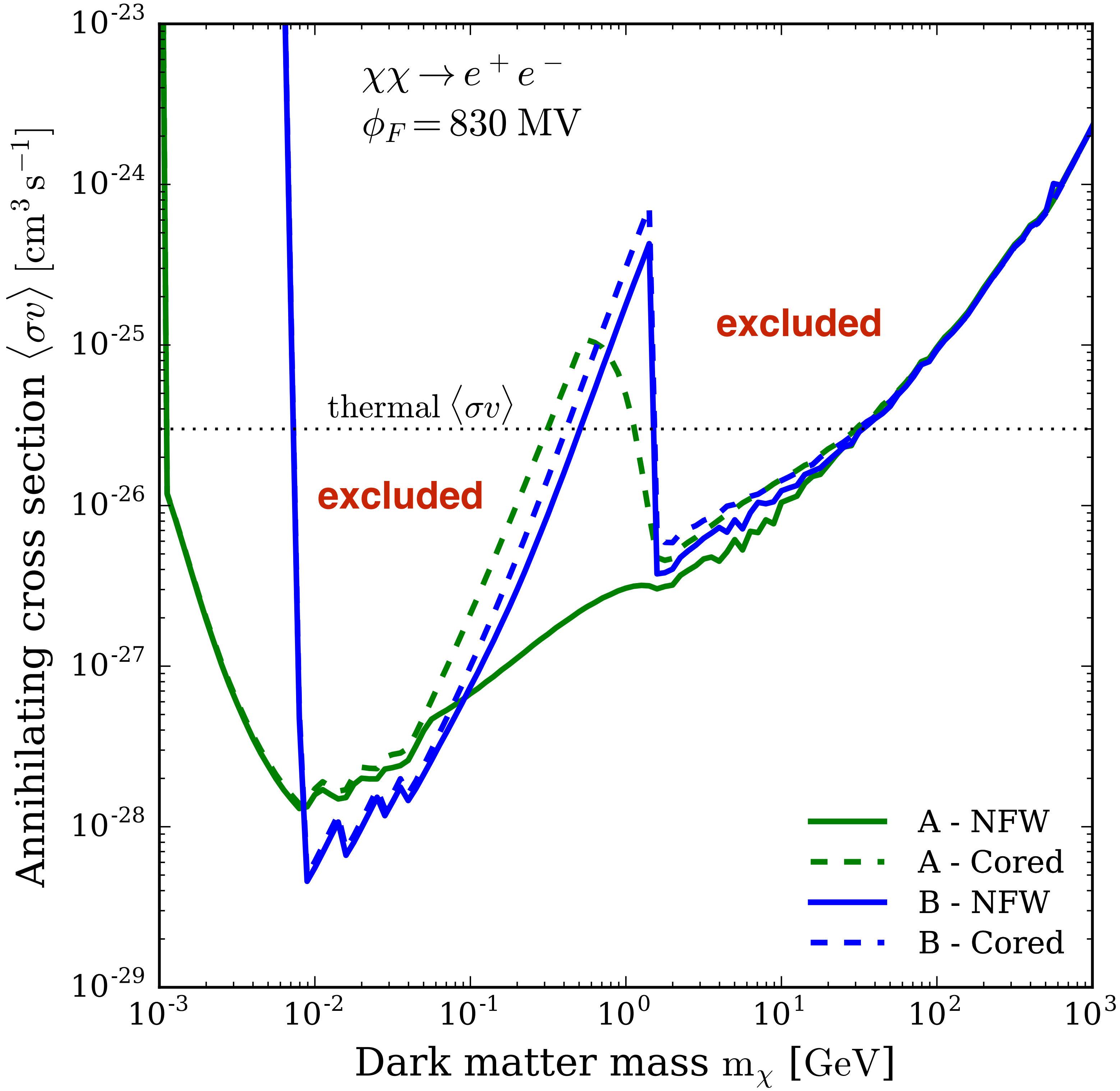

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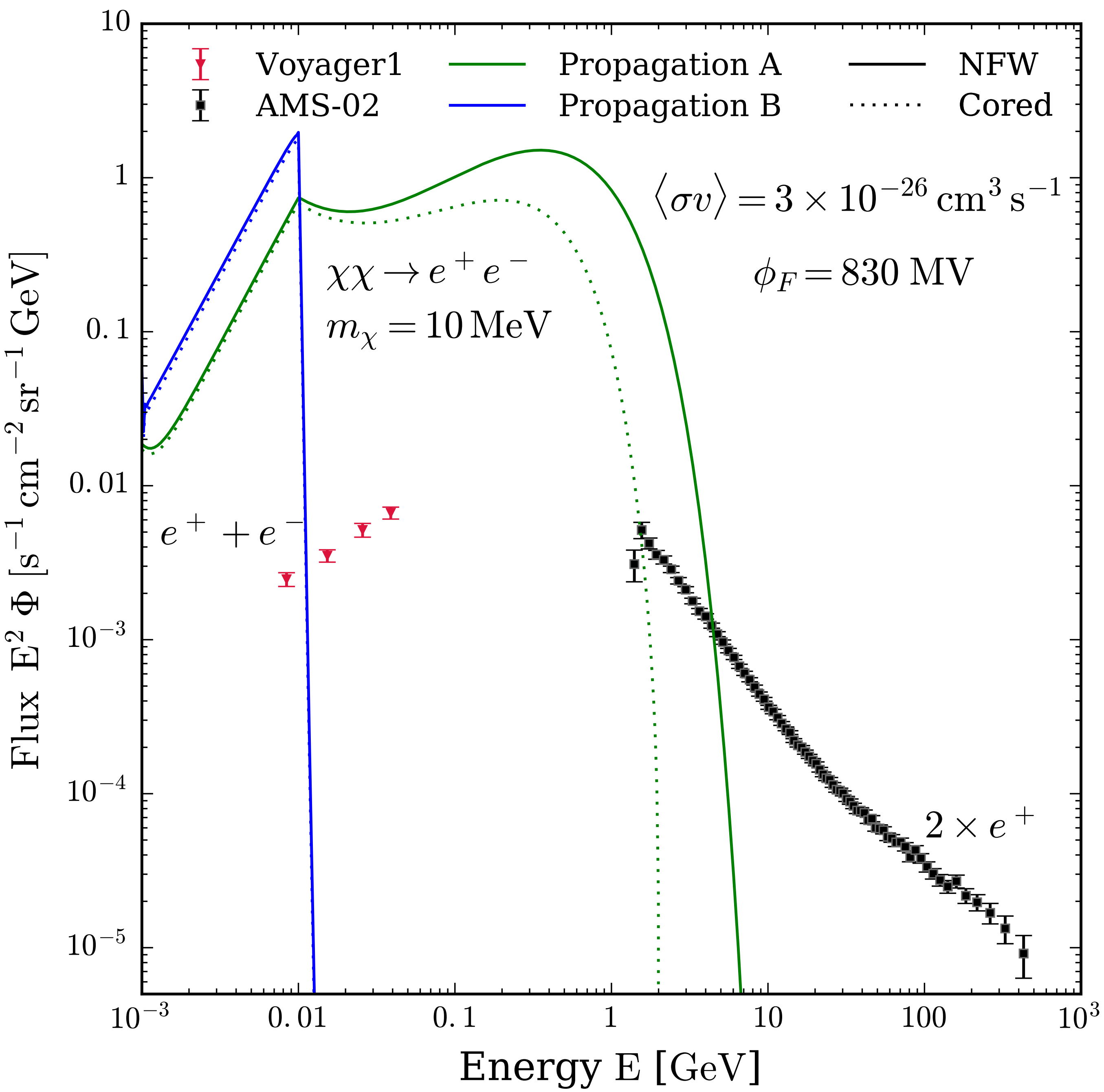

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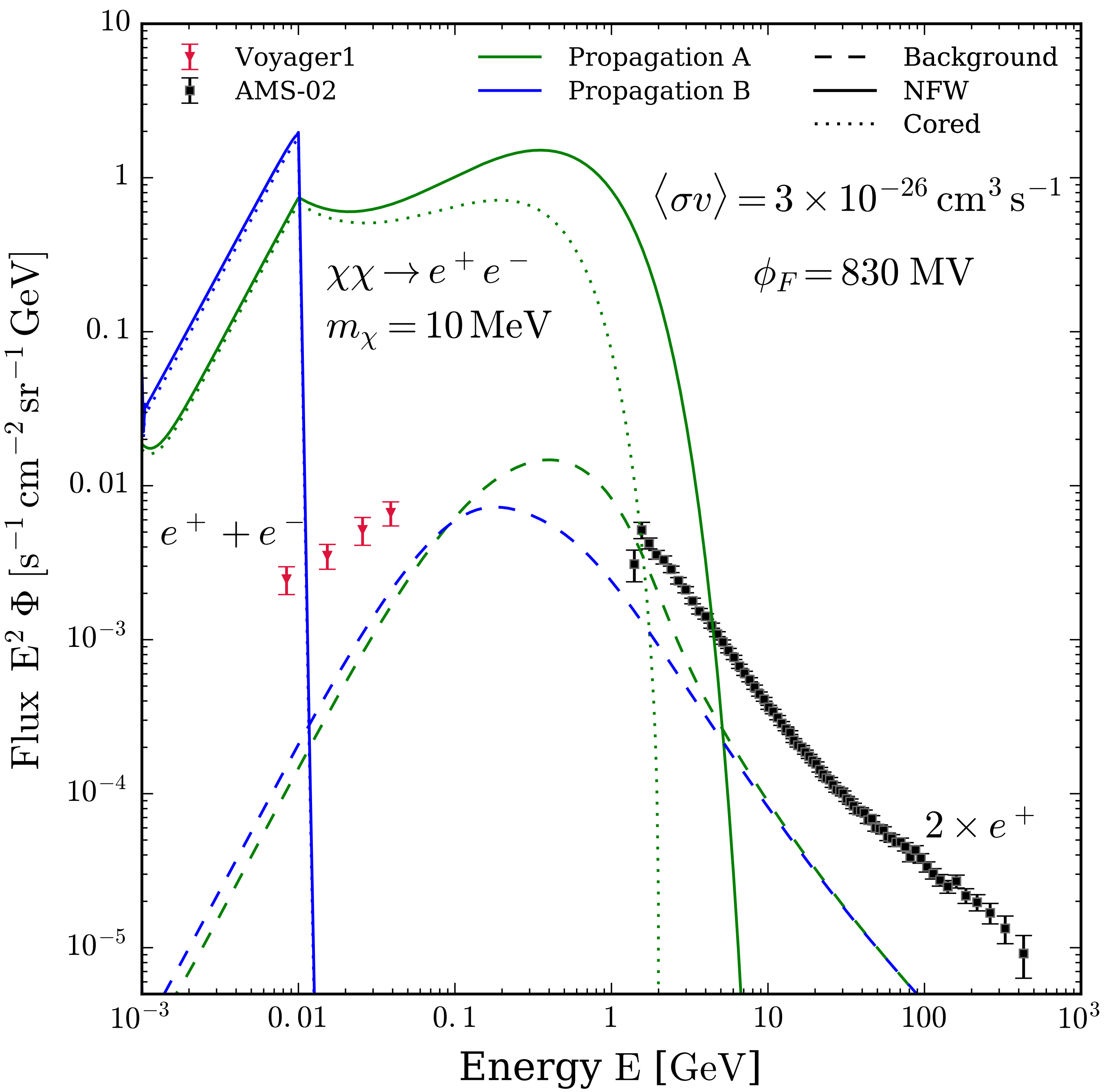

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With astrophysical background of secondary e+:

$$\Phi^{\mathrm{DM}}_{e^+ + e^-}(E_i) \leq \Phi^{\mathrm{exp}}_{e^+ + e^-}(E_i) + 2\sigma_i$$

and

$$\Phi^{\mathrm{DM}}_{e^+}(E_i) + \Phi^{\mathrm{II}}_{e^+}(E_i) \leq \Phi^{\mathrm{exp}}_{e^+}(E_i) + 2\sigma_i$$

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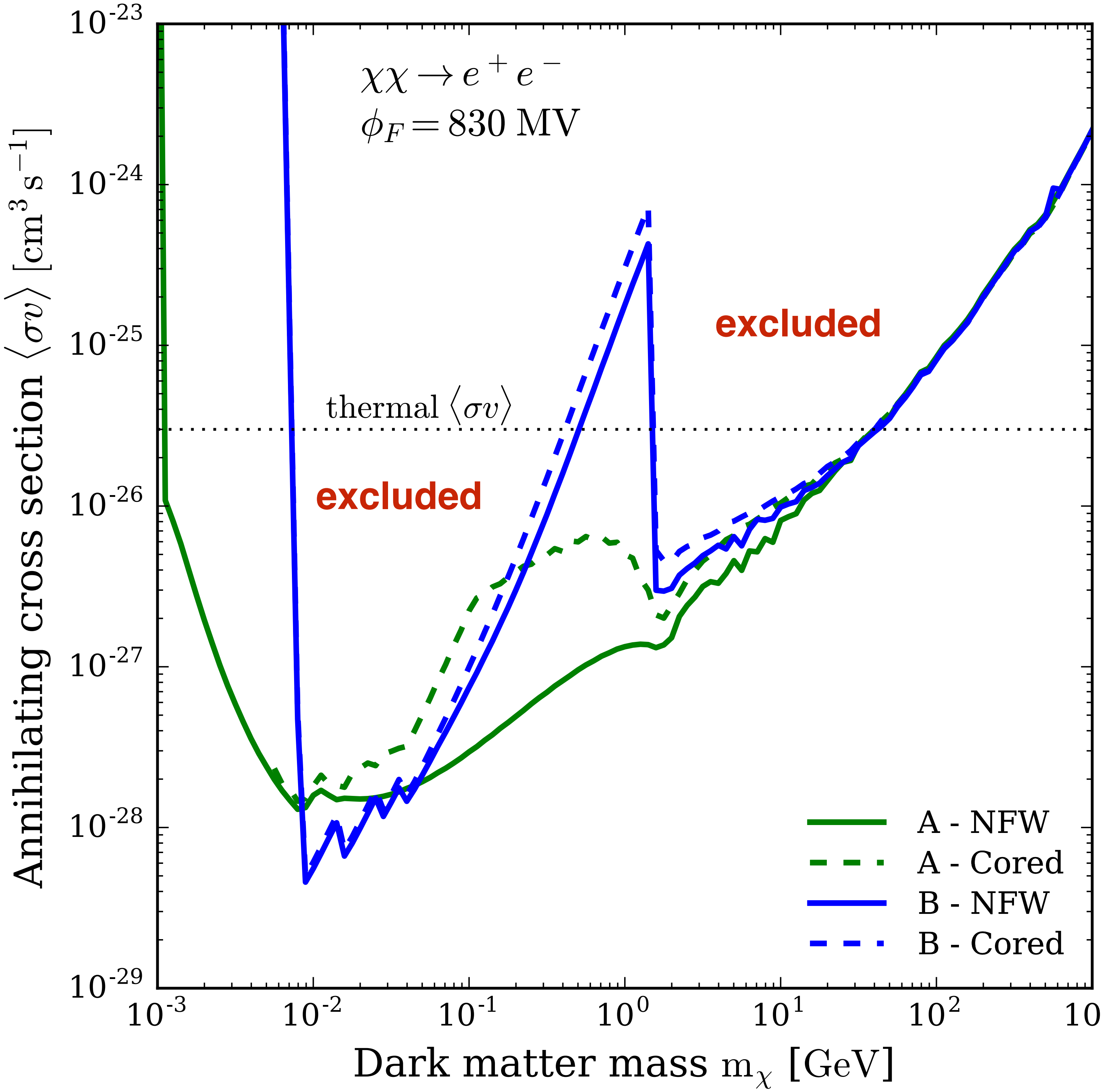

Astrophysical background of secondary antiprotons

$$q^{\mathrm{II}}(E,r) = 4\pi \sum_{i=p,\alpha} \sum_{j=\mathrm{H,He}} \int_{E^0}^{+\infty} dE_i \frac{d\sigma_{ij\to\bar{p}X}}{dE}(E_i \to E)\, \phi_i(E_i,r)\, n_j$$

- Production XS of antiprotons

$$p\,(\mathrm{CR}) \; + \mathrm{H}\,(\mathrm{ISM}) \;\longrightarrow\; \bar{p} \;+\; X \;\; (\simeq 70\%)$$
$$\alpha\,(\mathrm{CR}) \; + \mathrm{H}\,(\mathrm{ISM}) \;\longrightarrow\; \bar{p} \;+\; X \;\; (\simeq 25\%)$$
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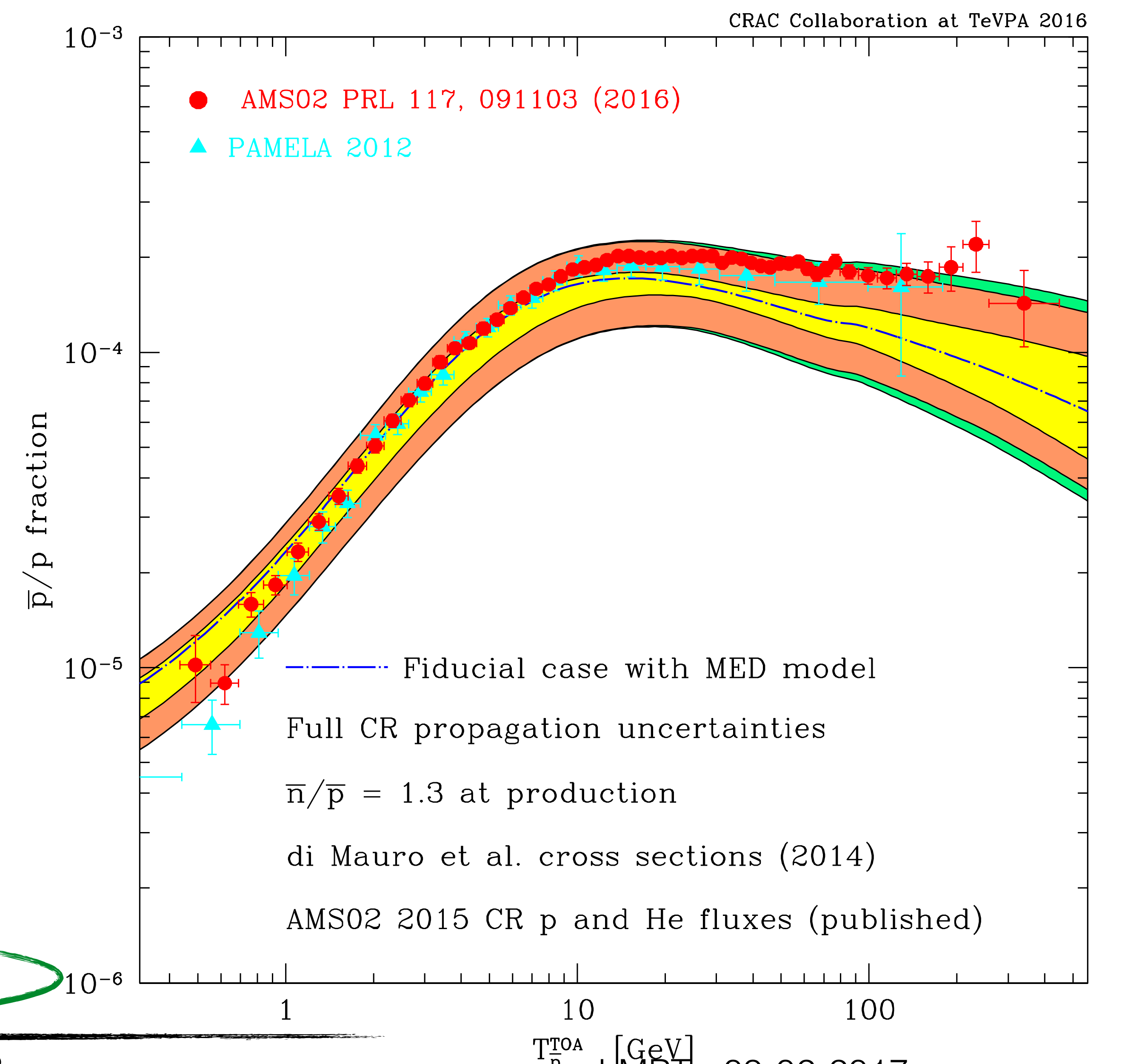
- Energy and space distribution of primary CRs (H, He)

- **AMS-02 data are consistent with the antiproton astrophysical background.**
- **The data prefer a MAX-type set of propagation parameters.**

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



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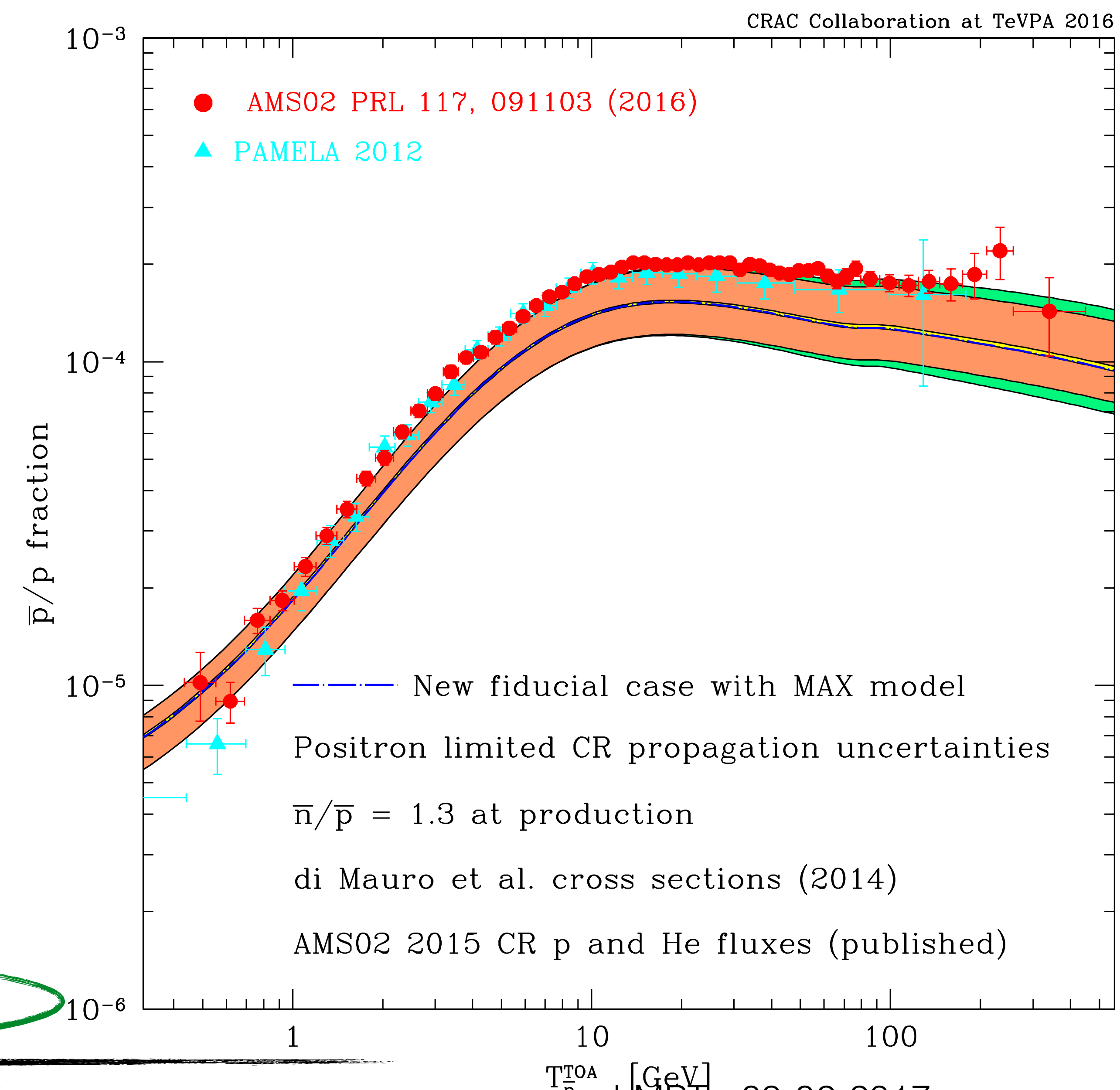
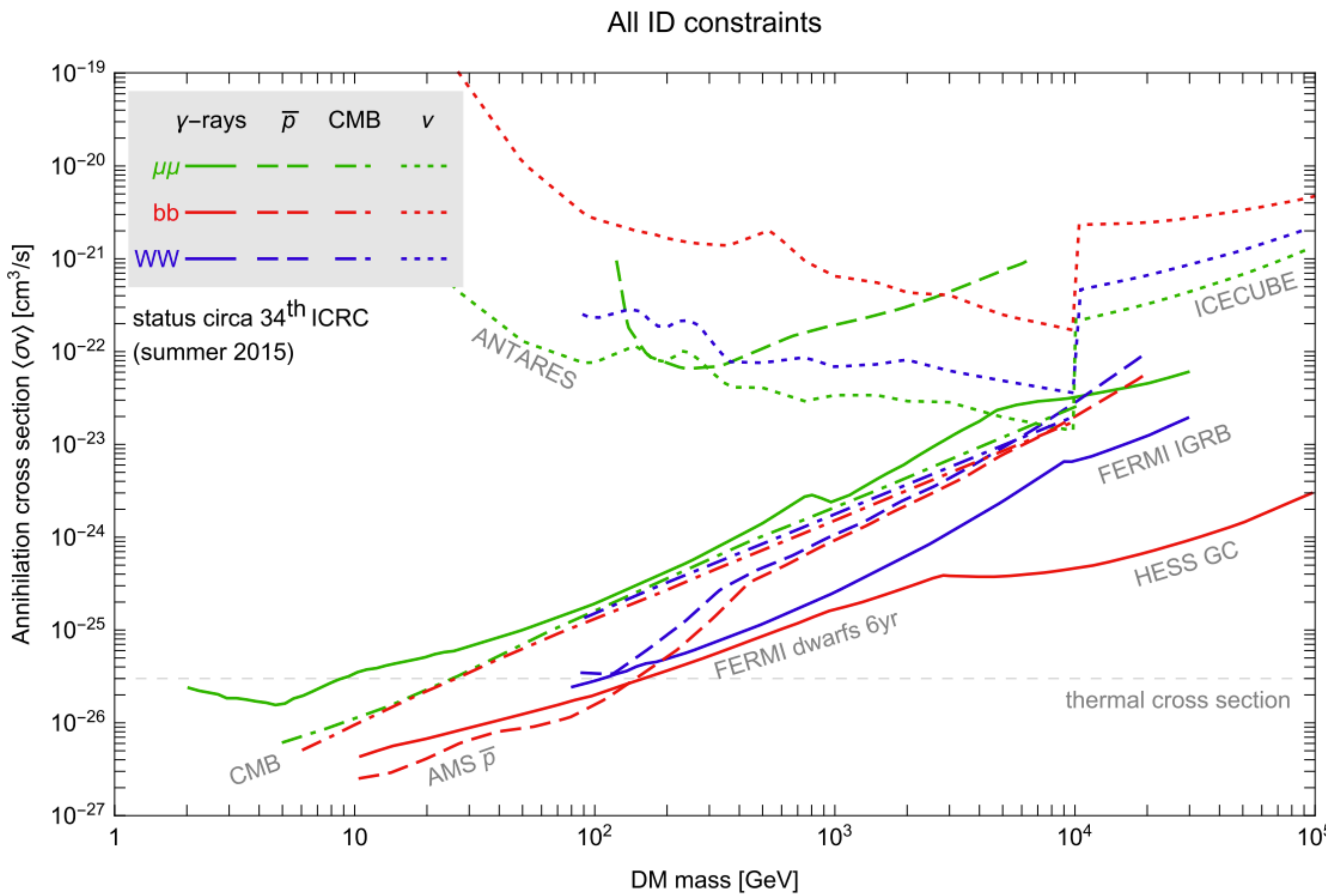


Dark matter indirect detection

Measure an excess of cosmic rays with respect to the astrophysical background.



Thermal cross section