26 january 2009
Max Planck Kernphysik Heidelberg

Seeing Dark Matter in cosmic rays?!?

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(CNRS, IPhT-CEA/Saclay)

in collaboration with:
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N.Fornengo (Torino)
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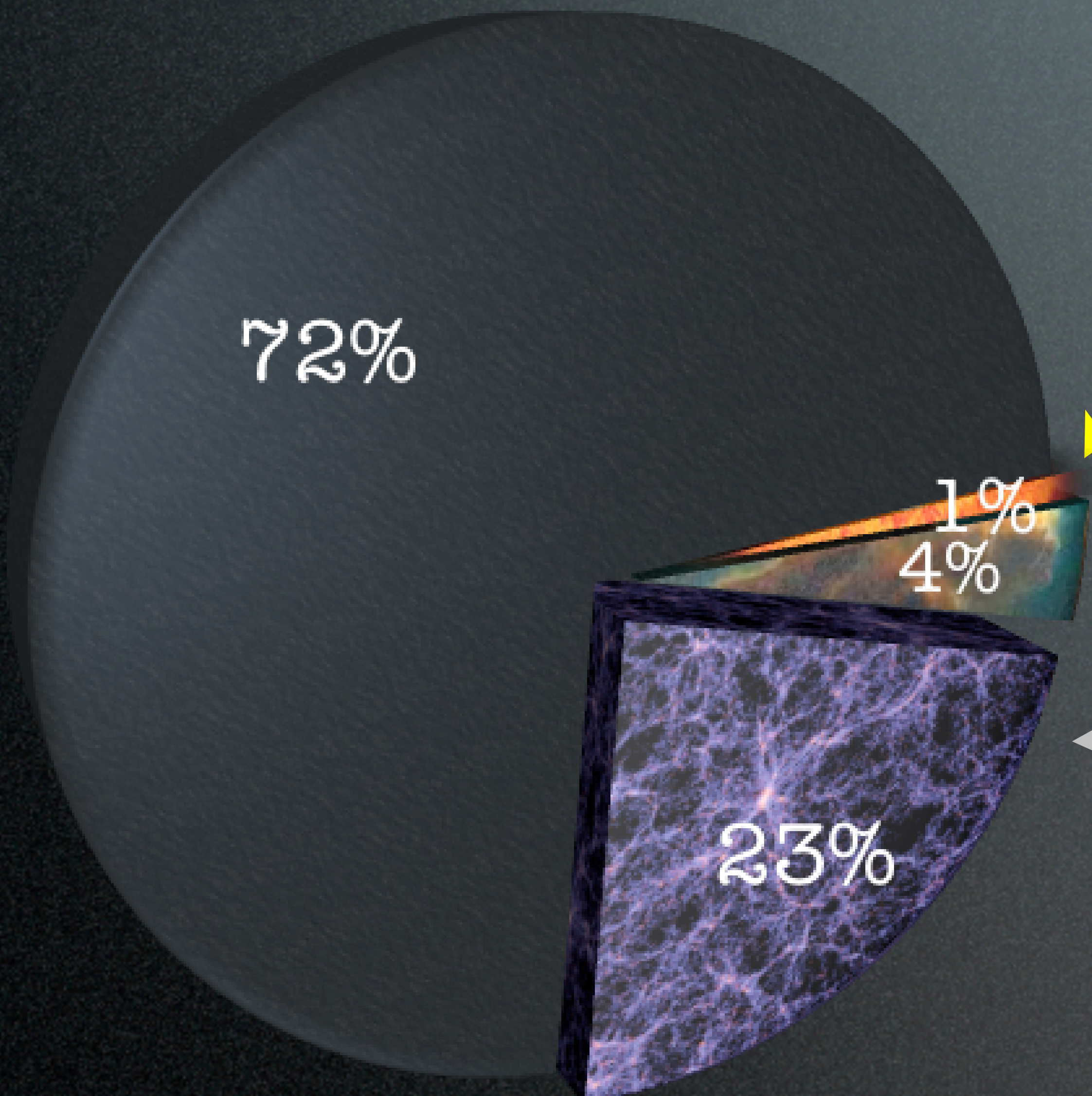
R.Franceschini (Pisa)
M.Raidal (Tallin)
M.Kadastik (Tallin)
Gf.Bertone (IAP Paris)
M.Taoso (Padova)
C.Bräuninger (Saclay)

Nuclear Physics B 753 (2006)
Nuclear Physics B 787 (2007)
Nuclear Physics B 800 (2008)
0808.3867 [astro-ph]
0809.2409 [hep-ph]
0811.3744 [astro-ph]
and work in progress

The cosmic inventory

Most of the Universe is Dark



$\Omega_{\rm lum} \sim 0.01$

$\Omega_{\rm b} \simeq 0.040 \pm 0.005$

-BBN
-CMB

$\Omega_{\rm DM} \sim 0.23$

$\Omega_{\rm de} \sim 0.72$

- CMB + SNIa
- CMB - DM
- acoustic peak in baryons

$\left(\Omega_x = \frac{\rho_x}{\rho_c};\ \text{CMB first peak} \Rightarrow \Omega_{\rm tot} = 1\ \text{(flat)};\ \text{HST}\ h = 0.71 \pm 0.07\right)$

what's the difference between DM and DE?

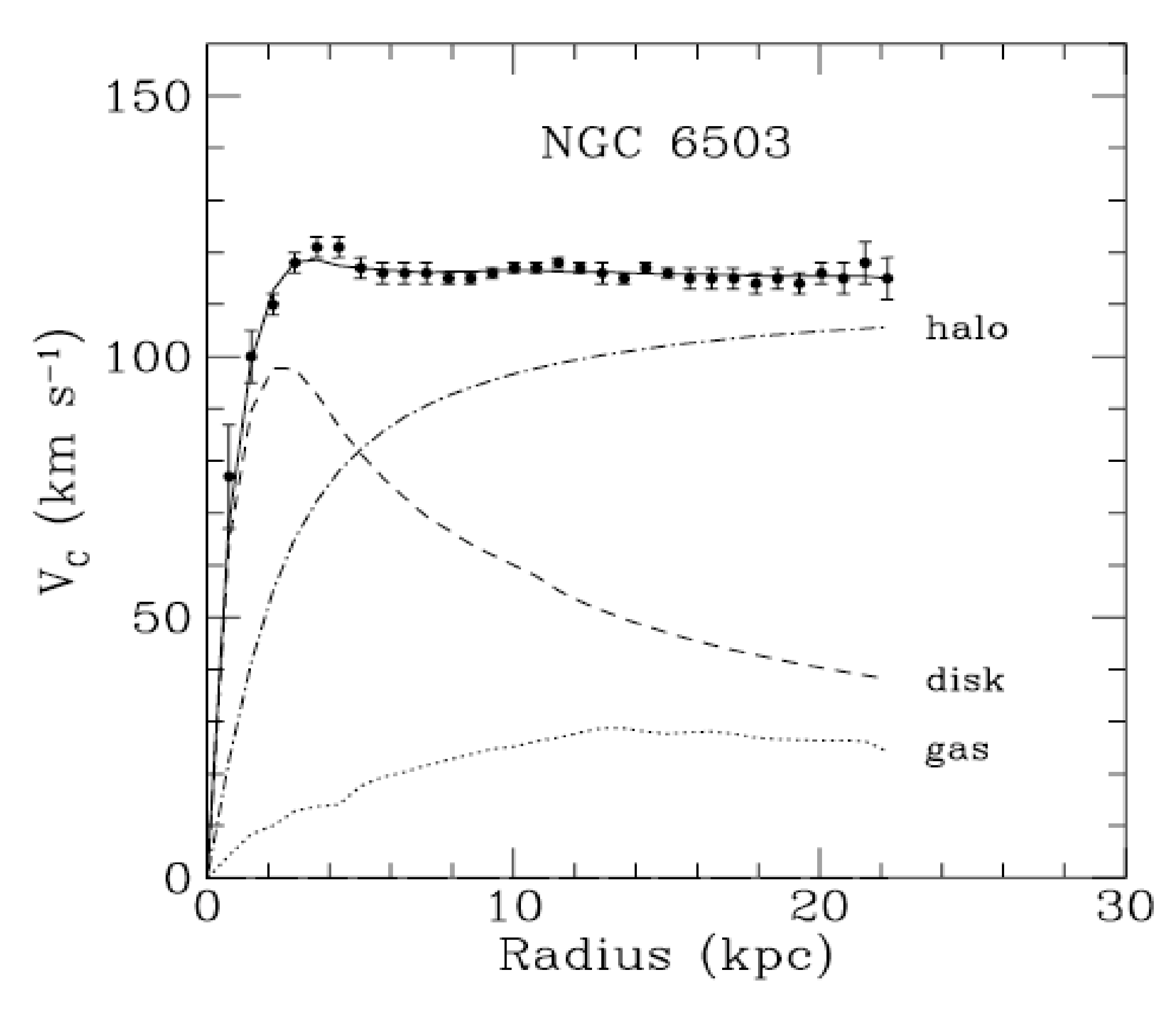
The Evidence for DM

1) galaxy rotation curves

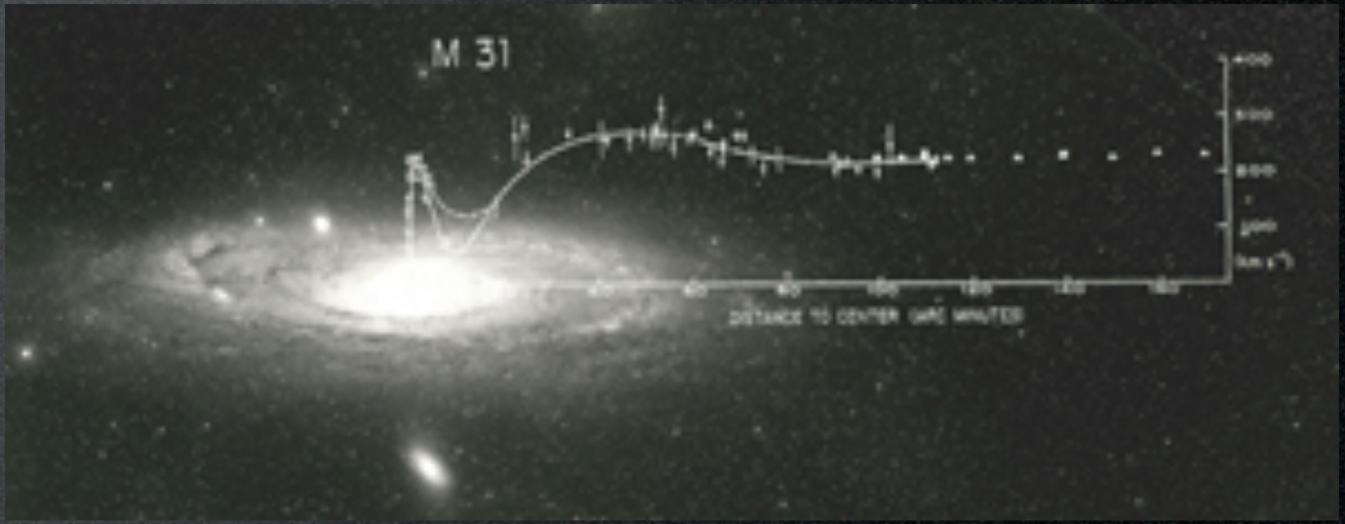
$$v_c(r) = \sqrt{\frac{2G_N M(r)}{r}}$$

$$v_c(r) \sim \text{const} \Rightarrow \rho_M(r) \sim \frac{1}{r^2}$$

$$\Omega_\mathrm{M} \gtrsim 0.1$$

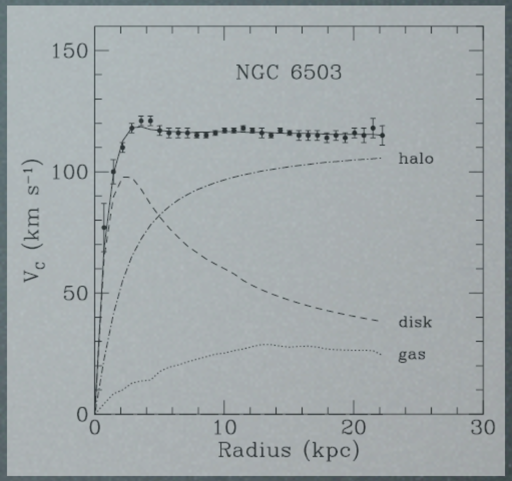


Begeman et al., MNRAS 249 (1991)



The Evidence for DM

1) galaxy rotation curves



$\Omega_M \gtrsim 0.1$

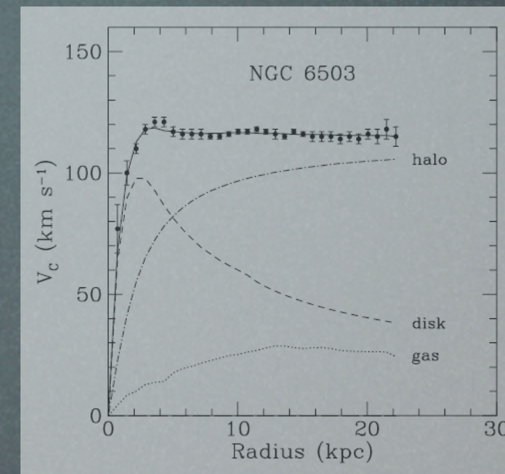
2) clusters of galaxies
- "rotation curves"
- gravitation lensing

$$\Omega_M \sim 0.2 \div 0.4$$

"bullet cluster" - NASA
astro-ph/0608247

The Evidence for DM

1) galaxy rotation curves



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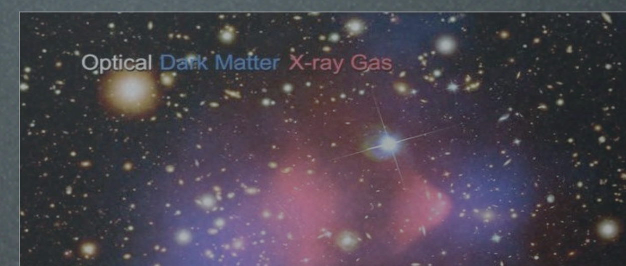
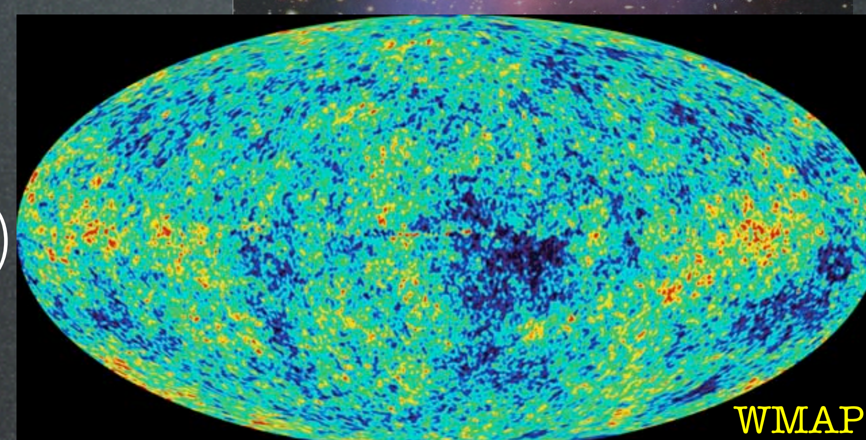
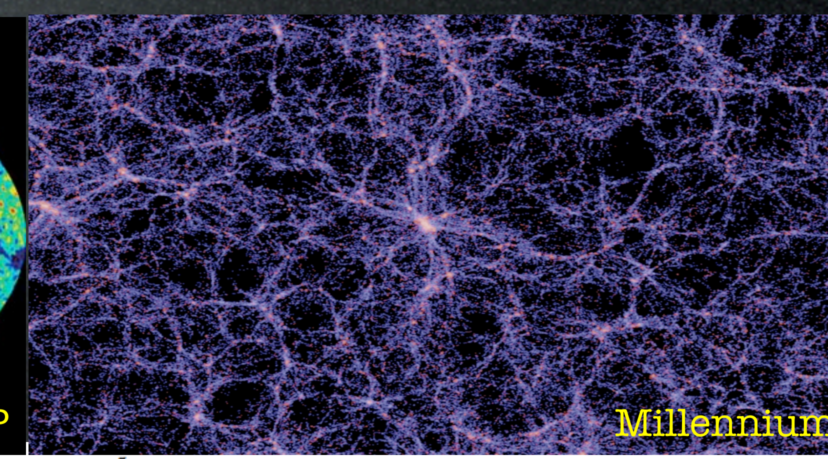


$\Omega_M \sim 0.2 \div 0.4$

3) CMB+LSS(+SNIa:)

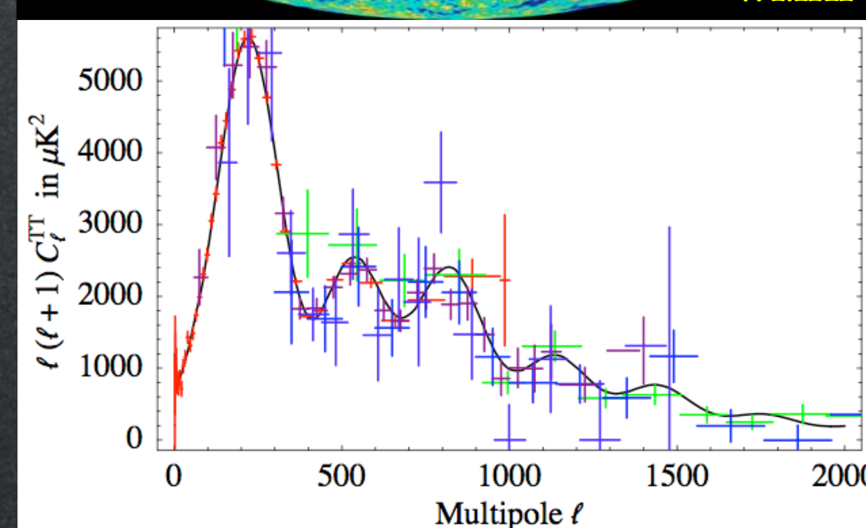


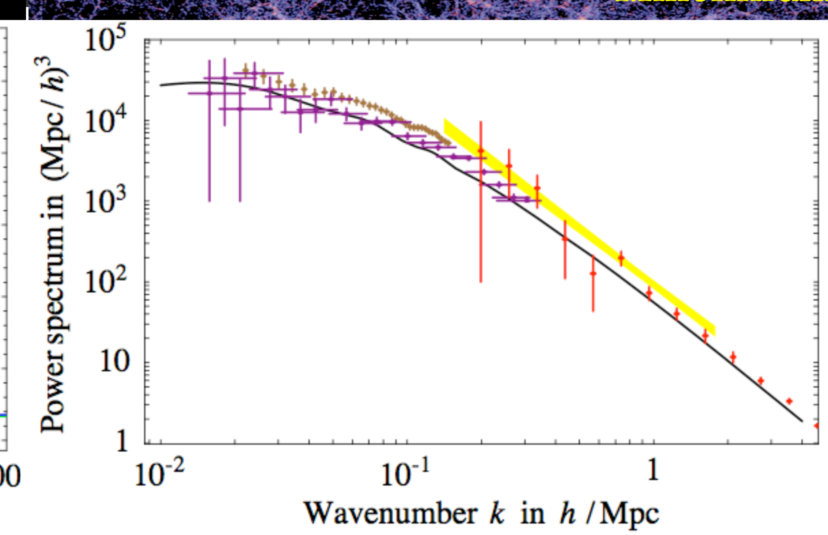


WMAP-3yr
ACbar
CBI

Boomerang
DASI
VSA

SDSS, 2dFRGS
LyA Forest Croft
LyA Forest SDSS





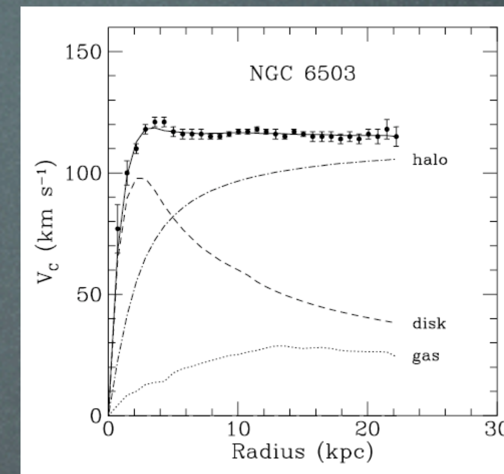
$\Omega_M \approx 0.26 \pm 0.05$

(spectra w/o DM)

M.Cirelli and A.Strumia, astro-ph/0607086

The Evidence for DM

1) galaxy rotation curves



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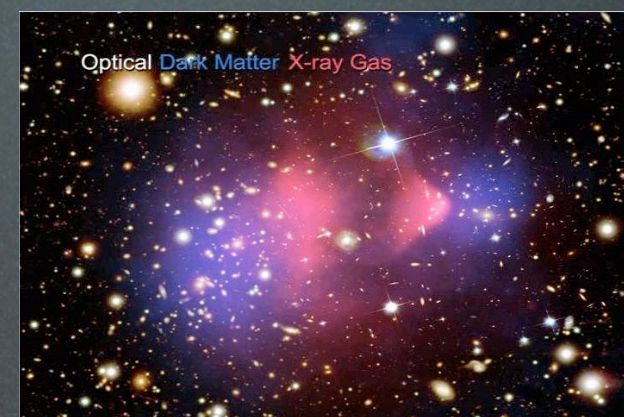
2) clusters of galaxies



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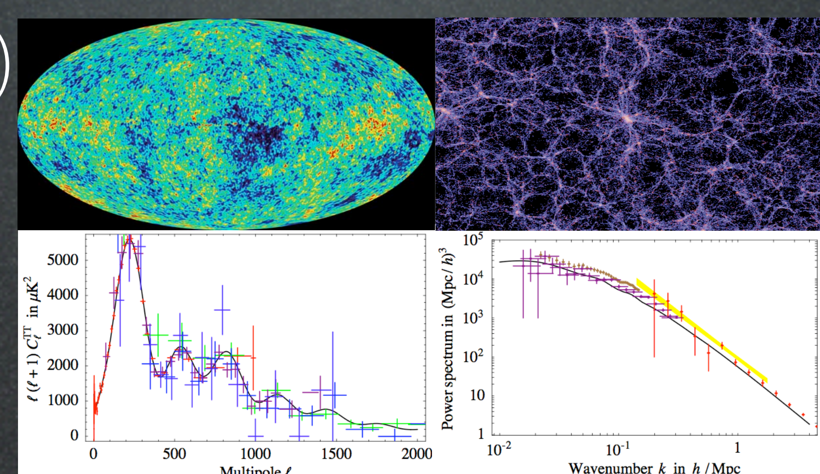


$\Omega_M \approx 0.26 \pm 0.05$

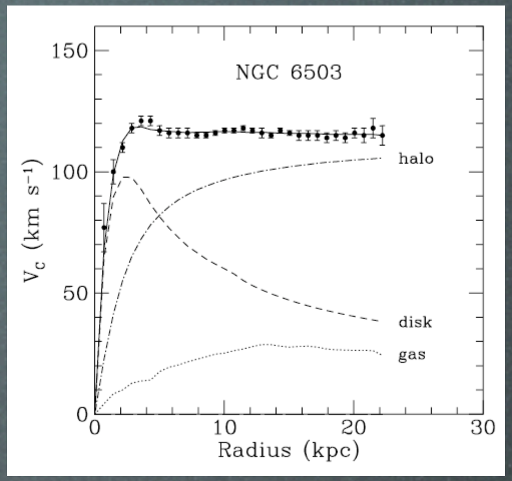
DM exists.

It consists of a particle.

Permeates galactic haloes.

The Evidence for DM

1) galaxy rotation curves



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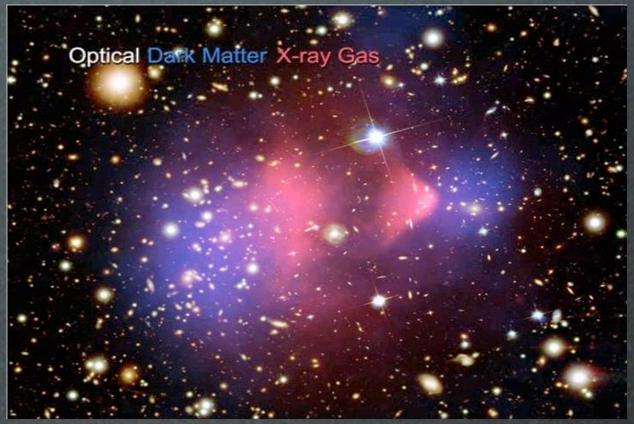

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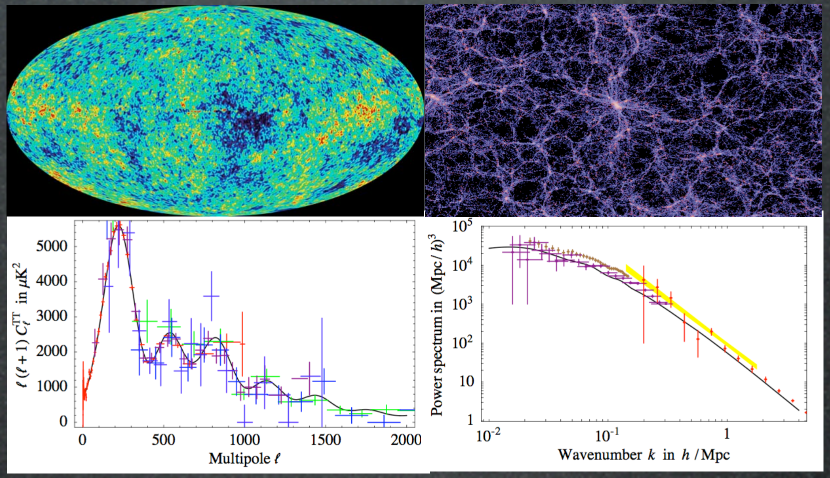

$\Omega_M \approx 0.26 \pm 0.05$

What is the DM??

It consists of a particle.

Permeates galactic haloes.

DM detection

direct detection

Xenon, CDMS (Dama/Libra?)

production at colliders

LHC

indirect

γ from annihil in galactic halo or center
(line + continuum)

Fermi/GLAST

e^+ from annihil in galactic halo or center

PAMELA, AMS02, **balloons**

$\bar{p}$ from annihil in galactic halo or center

$\bar{D}$ from annihil in galactic halo or center

GAPS

$\nu, \bar{\nu}$ from annihil in massive bodies

Icecube, Km3Net

DM detection

direct detection

production at colliders

indirect

γ from annihil in galactic halo or center
(line + continuum)

e^+ from annihil in galactic halo or center

PAMELA, AMS02, balloons

$\bar{p}$ from annihil in galactic halo or center

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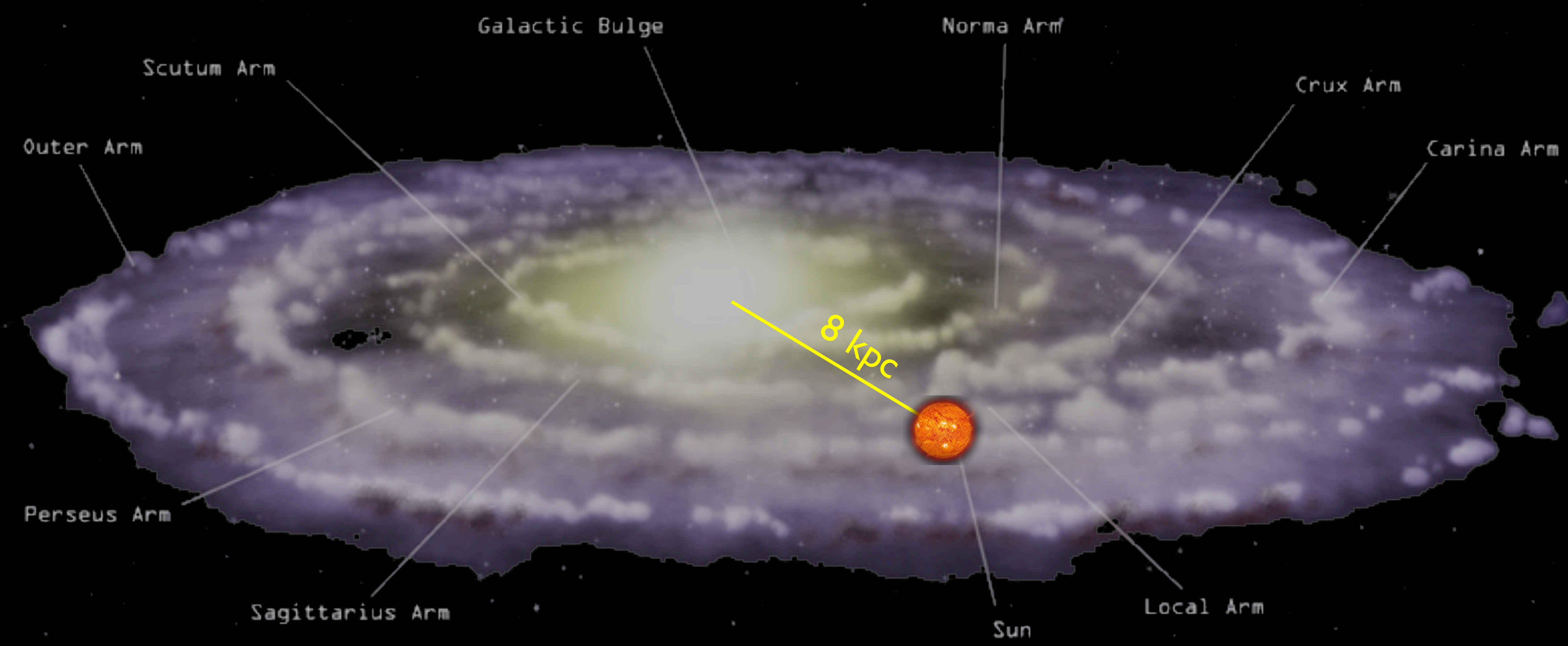
Indirect Detection

$\bar{p}$ and e^+ from DM annihilations in halo



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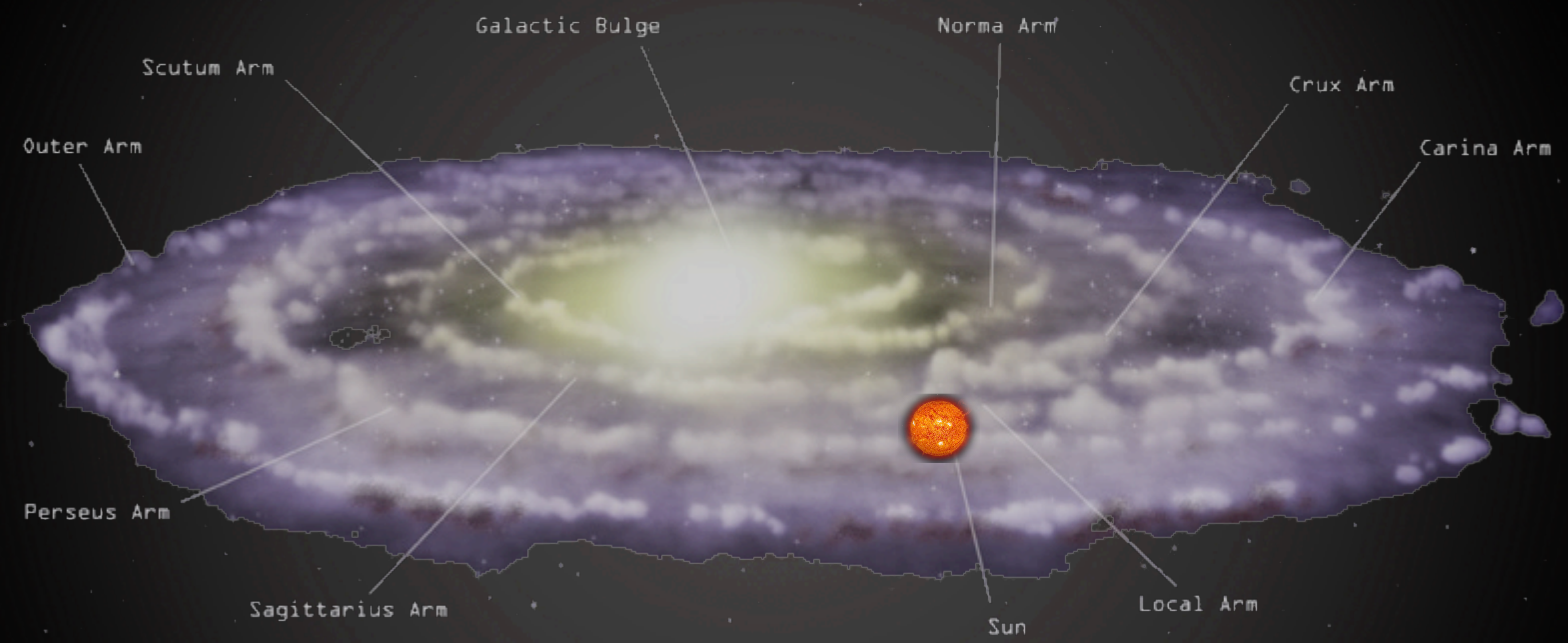

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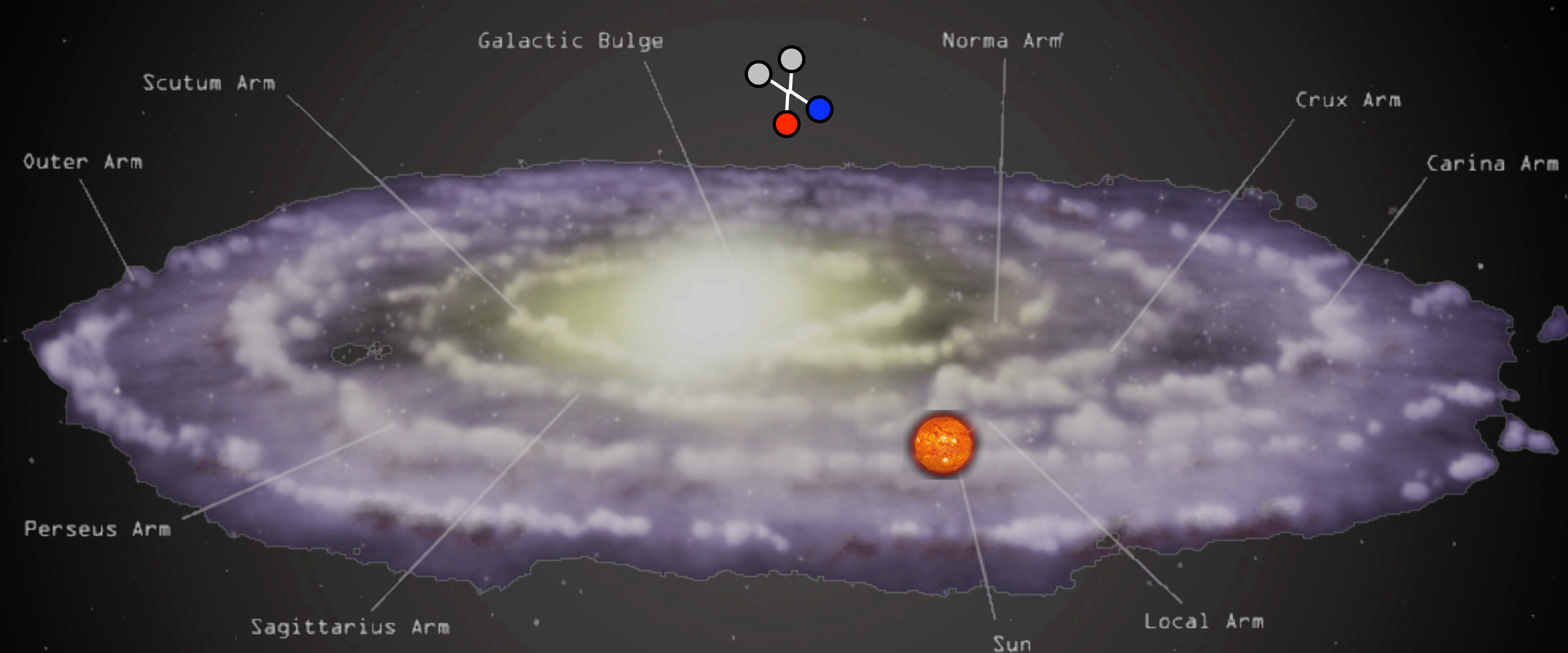

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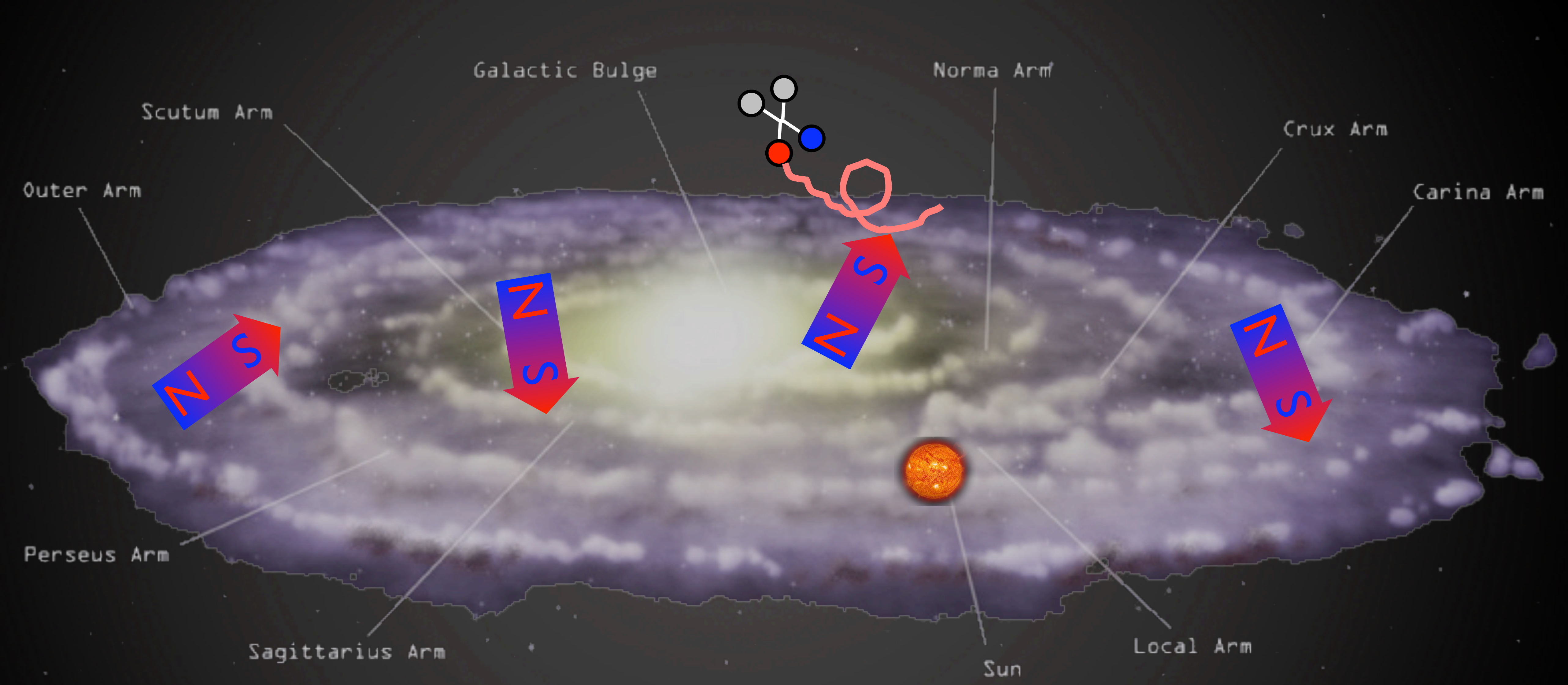

Indirect Detection

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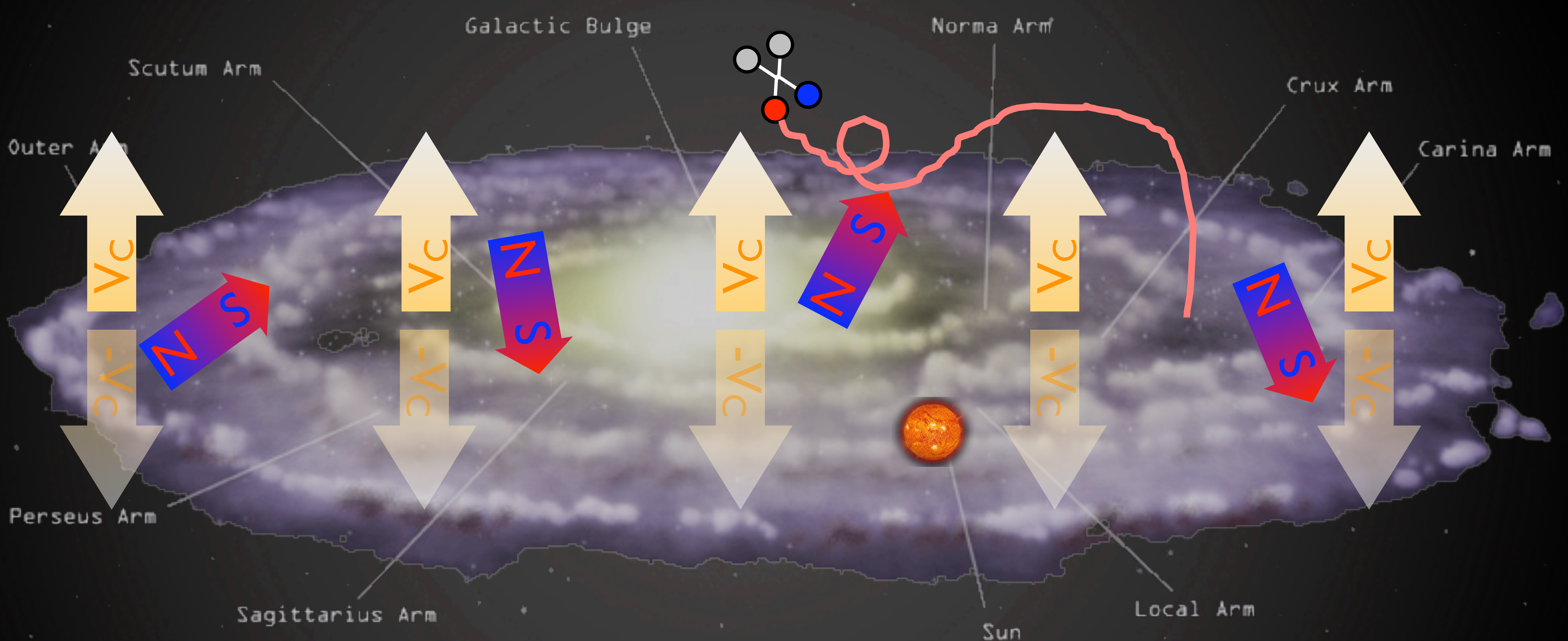

Indirect Detection

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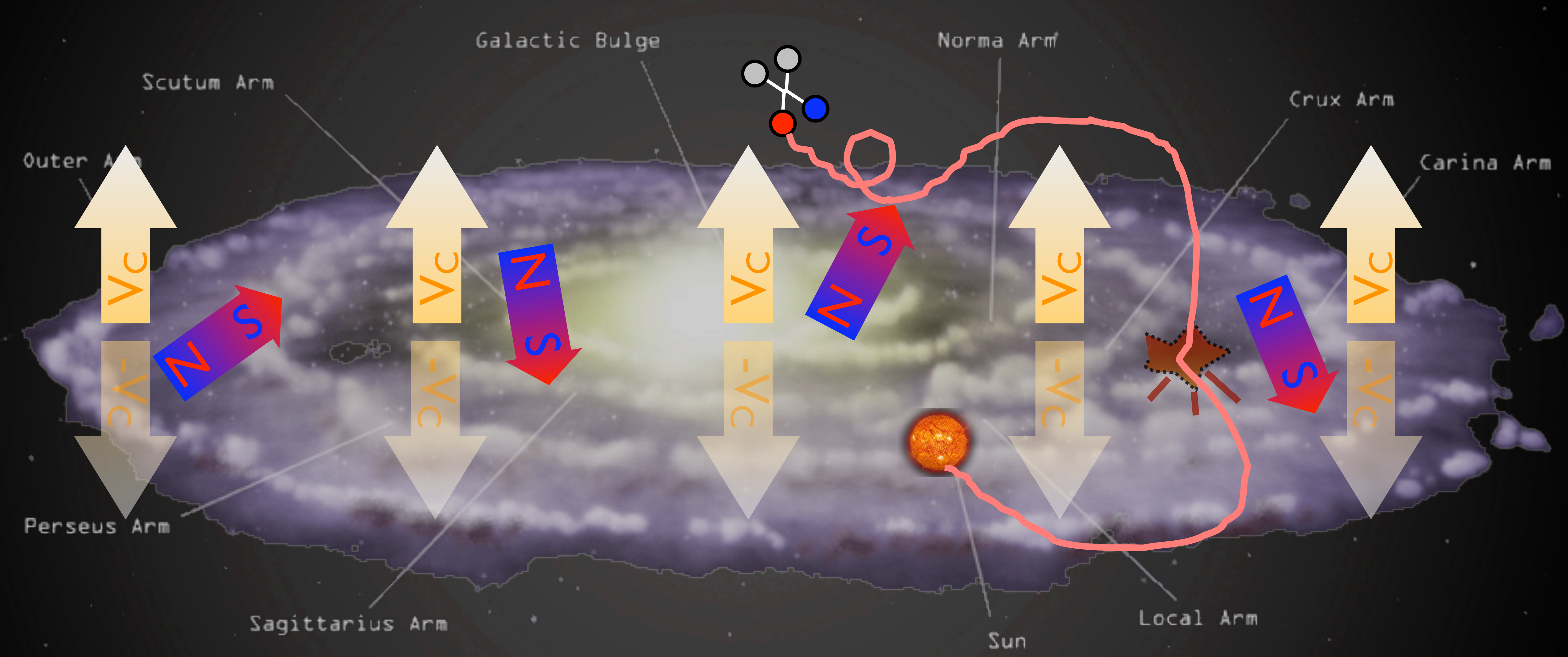

Indirect Detection

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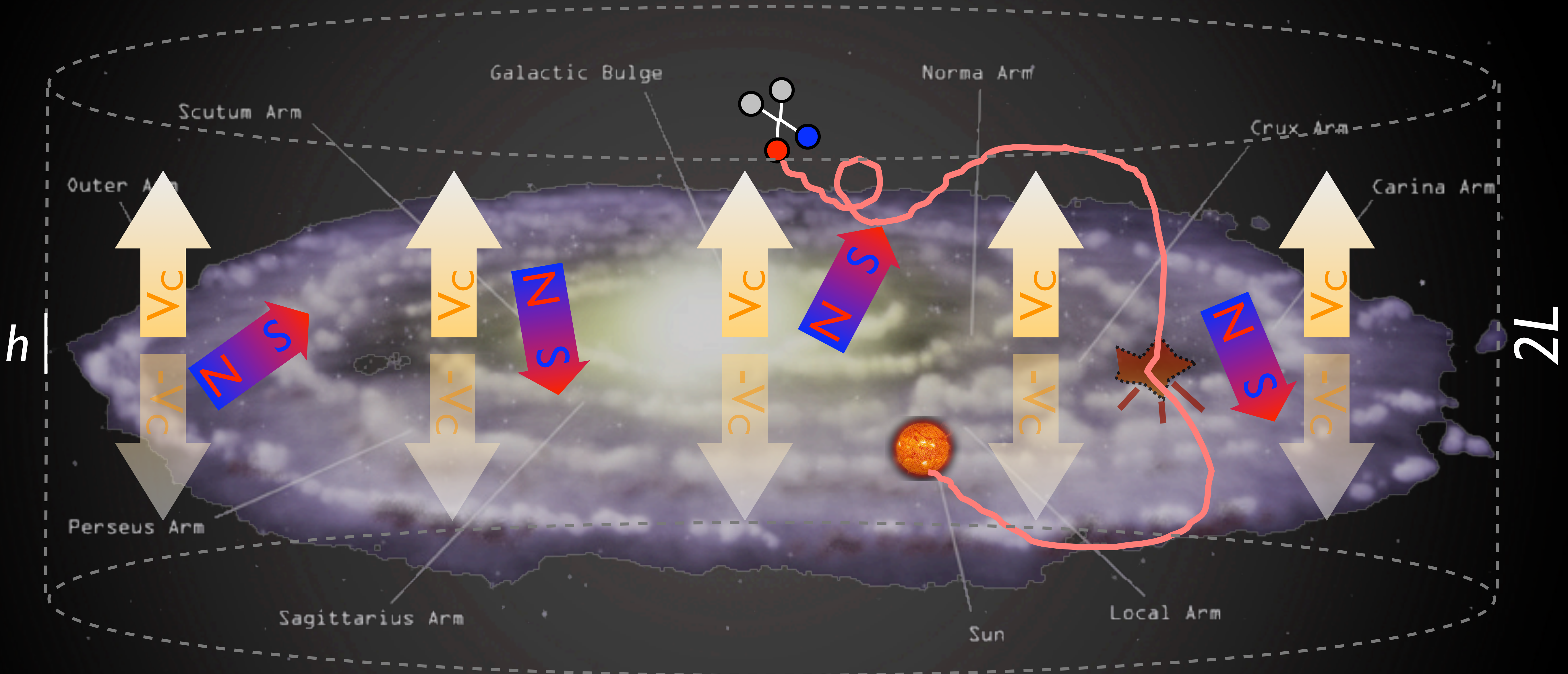


Salati, Chardonnay, Barrau, Donato, Taillet, Fornengo, Maurin, Brun... '90s, '00s

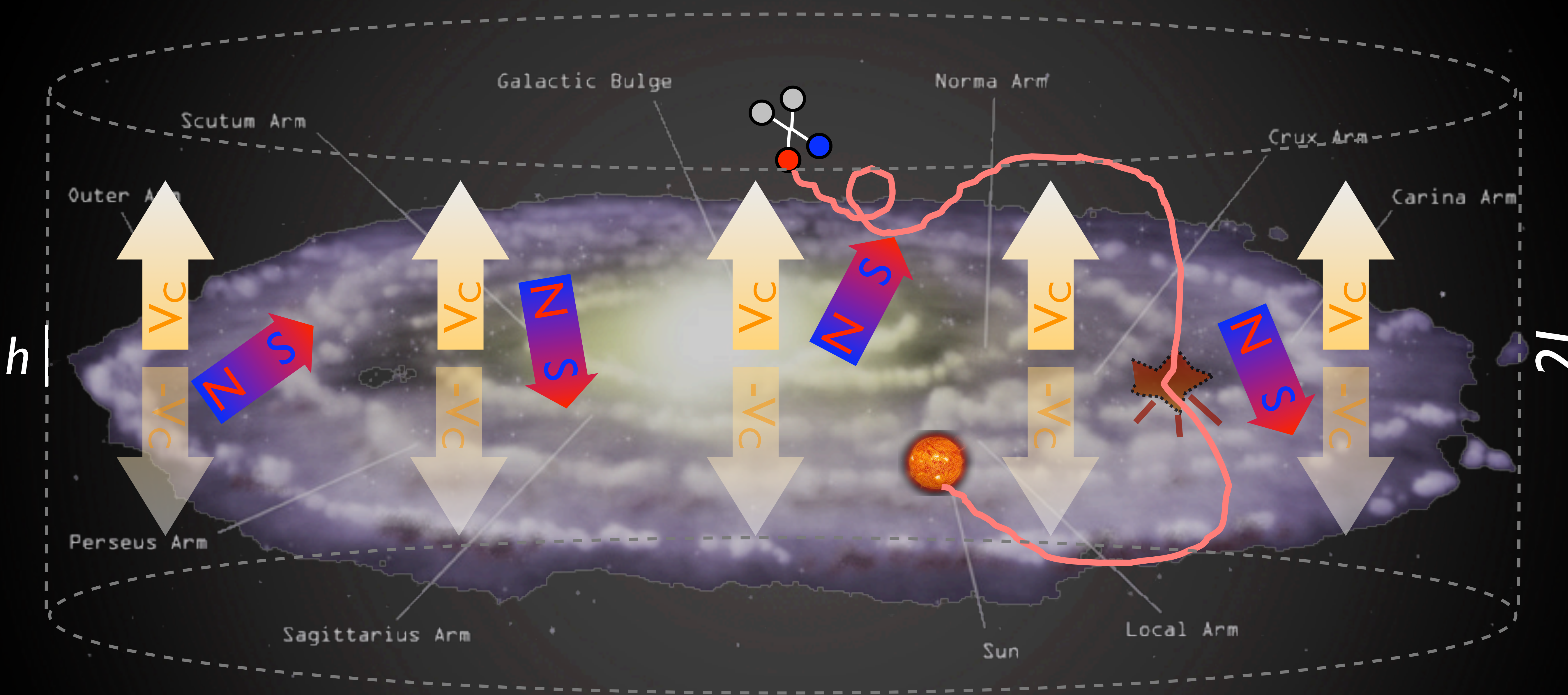
spectrum

$$\frac{\partial f}{\partial t} - K(E)\cdot\nabla^2 f - \frac{\partial}{\partial E}\left(b(E)f\right) + \frac{\partial}{\partial z}(V_c f) = Q_{\rm inj} - 2h\delta(z)\Gamma_{\rm spall} f$$

diffusion energy loss convective wind source spallations

Indirect Detection

$\bar{p}$ and e^+ from DM annihilations in halo

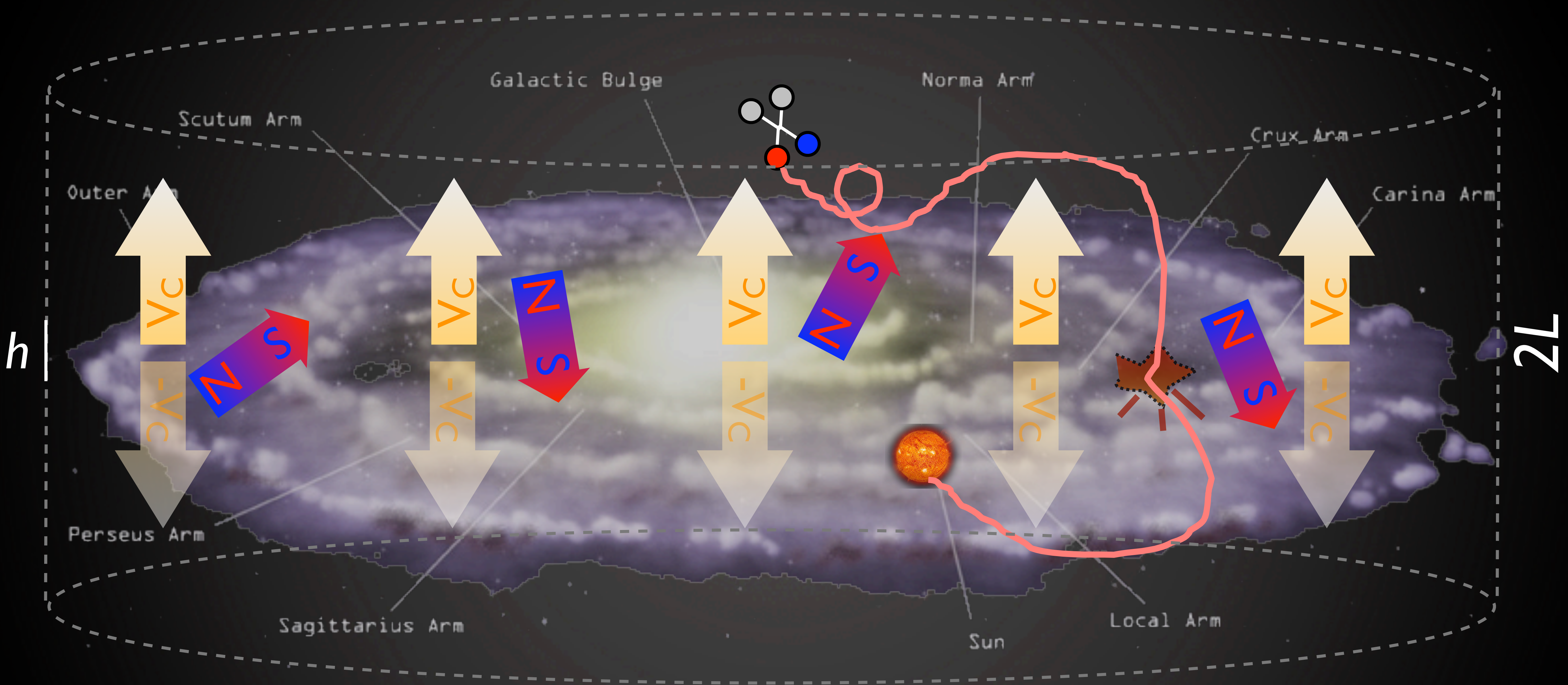


What sets the overall expected flux?

$$\text{flux} \propto n^2\,\sigma_{\text{annihilation}}$$

Indirect Detection

$\bar{p}$ and e^+ from DM annihilations in halo



What sets the overall expected flux?

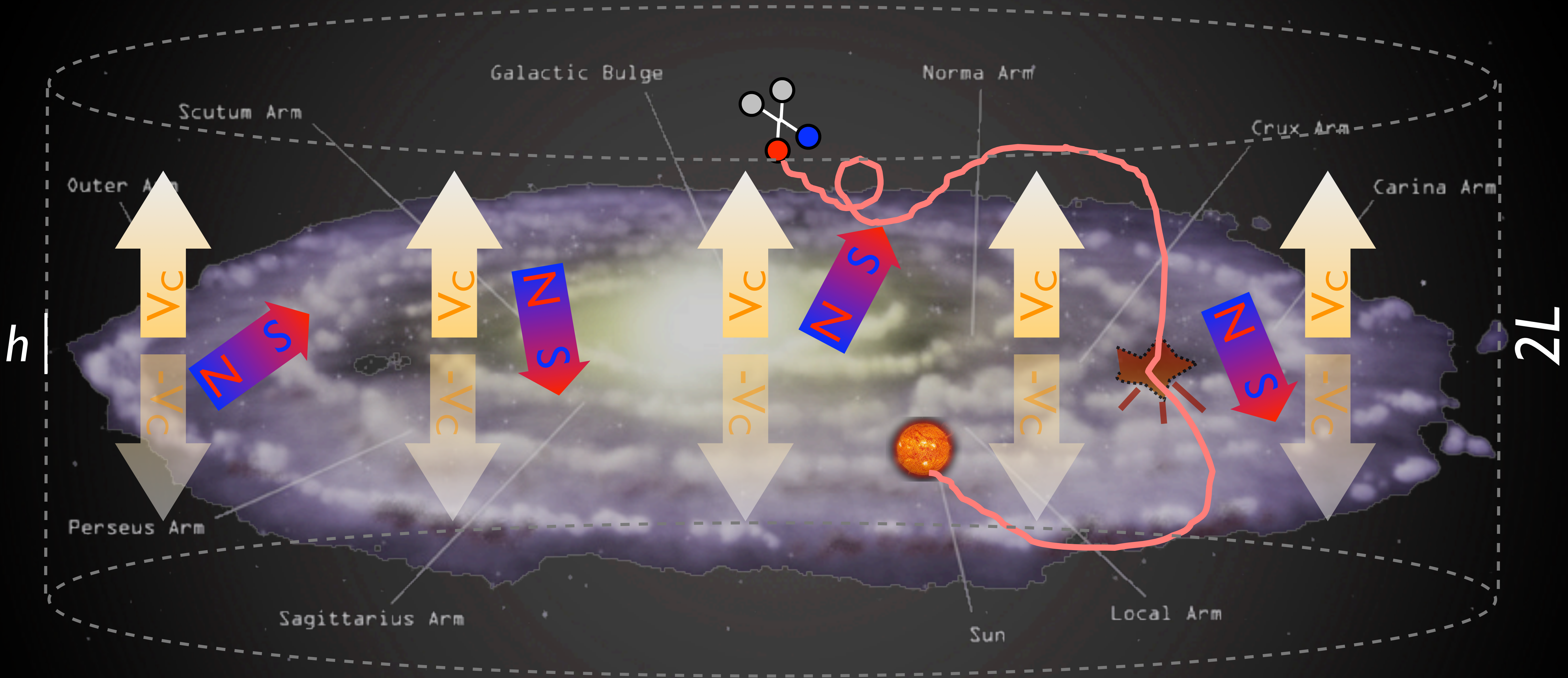
$$\text{flux} \propto n^2 \sigma_{\text{annihilation}}$$

astro& cosmo

particle

Indirect Detection

$\bar{p}$ and e^+ from DM annihilations in halo



What sets the overall expected flux?

$$\text{flux} \propto n^2 \, \sigma_{\text{annihilation}}$$

astro& cosmo

particle

reference cross section:

$\sigma = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$

DM halo profiles

From N-body numerical simulations:

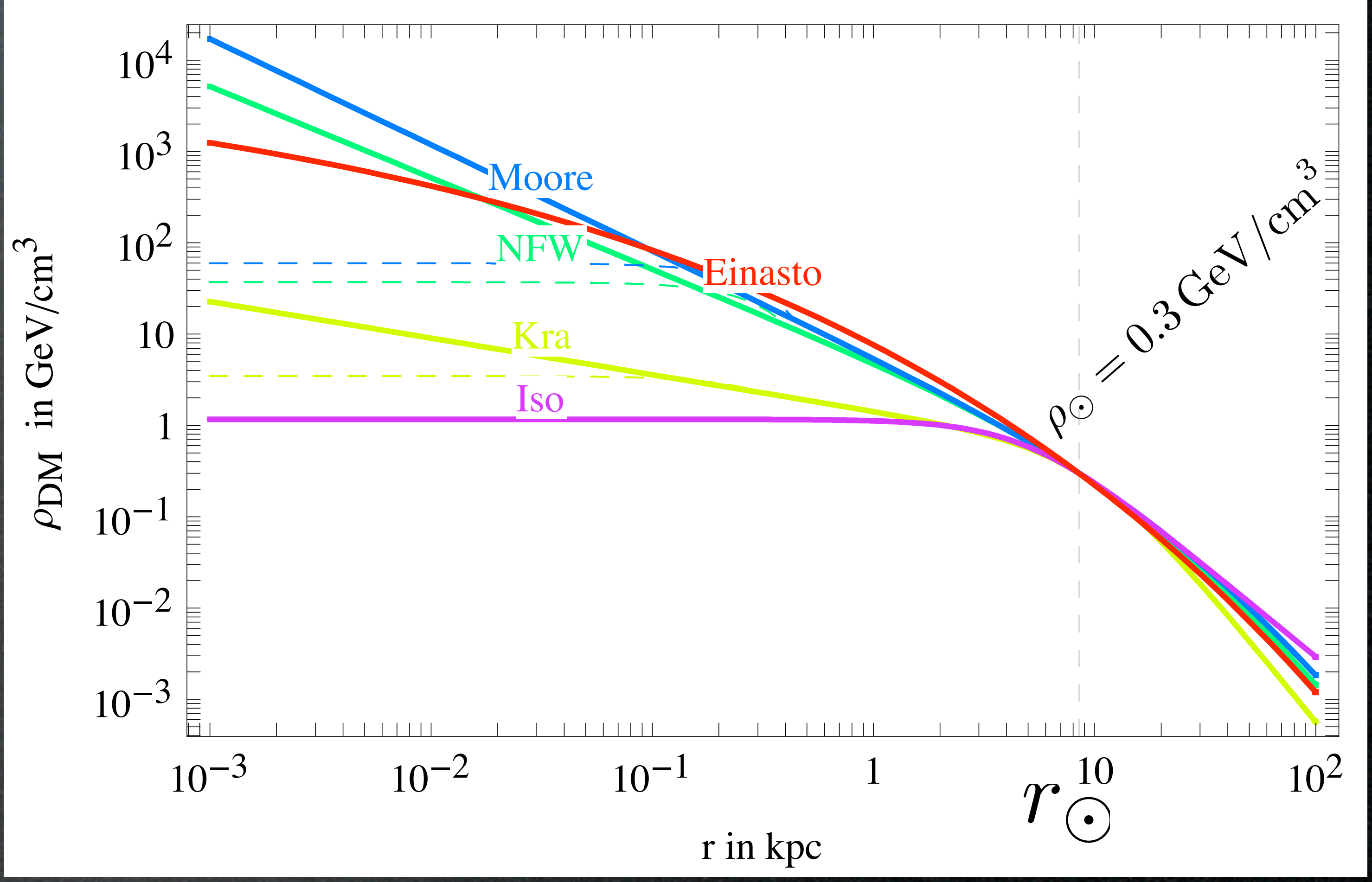
$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/r_s)^\alpha}{1+(r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

At small r: $\rho(r) \propto 1/r^\gamma$

$$\rho(r) = \rho_s \cdot \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^\alpha - 1\right)\right]$$

Einasto | $\alpha = 0.17$ $r_s = 20\,\text{kpc}$ $\rho_s = 0.06\,\text{GeV/cm}^3$

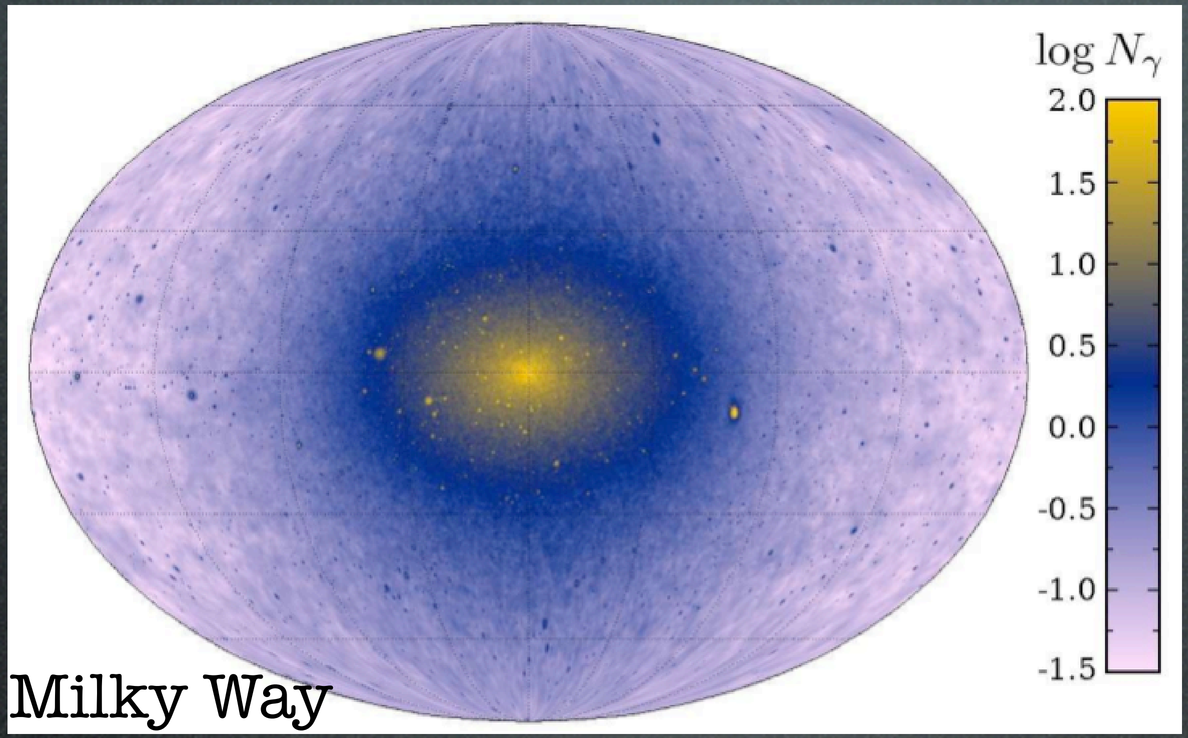


cuspy: NFW, Moore
mild: Einasto
smooth: isothermal

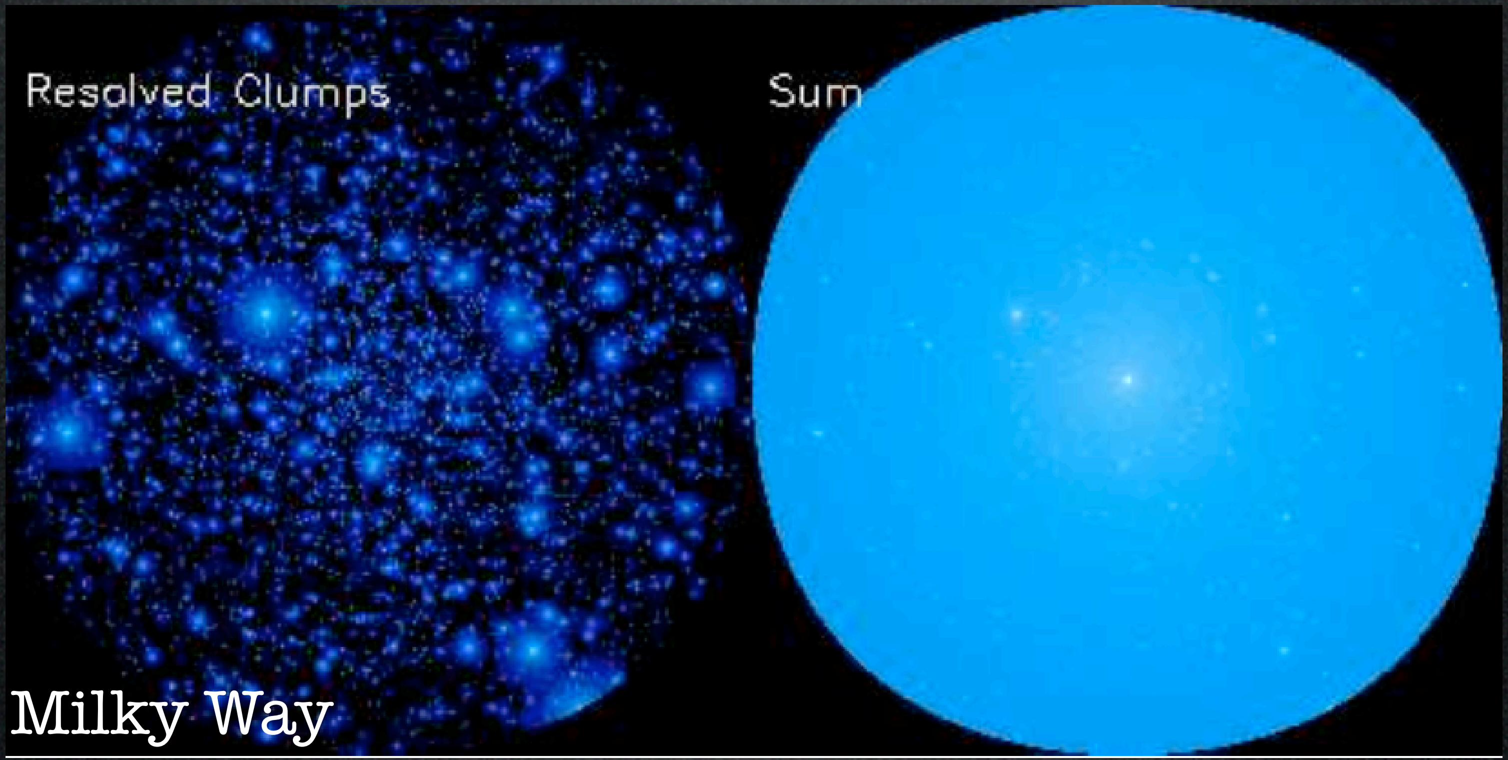
Indirect Detection

Boost Factor: local clumps in the DM halo enhance the density, boost the flux from annihilations. Typically: $B \simeq 1 \to 20 \quad (10^4)$

For illustration:



Kuhlen, Diemand, Madau 2007



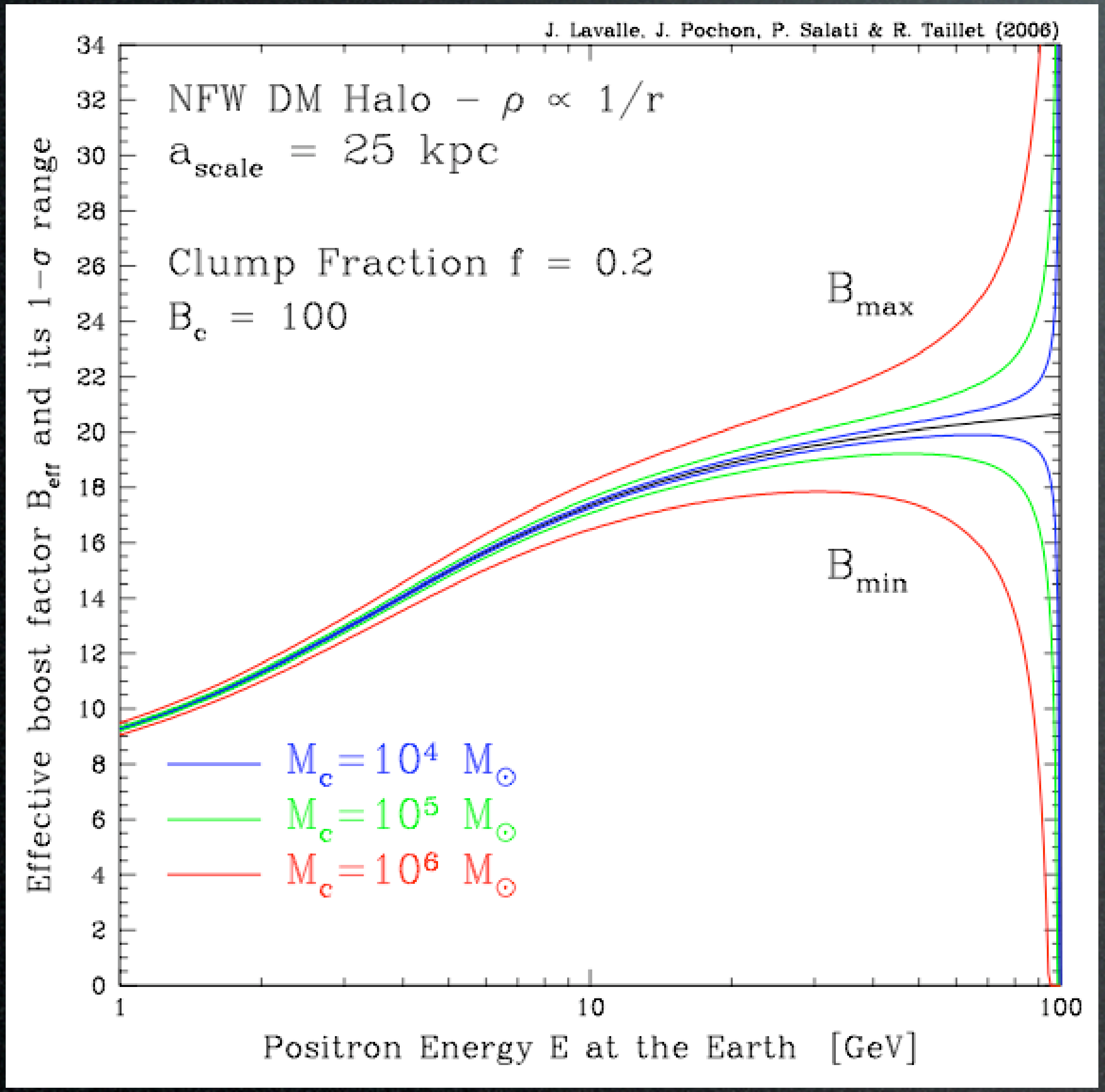
Bertone, Branchini, Pieri 2007

Indirect Detection

Boost Factor: local clumps in the DM halo enhance the density, boost the flux from annihilations. Typically: $B \simeq 1 \rightarrow 20 \quad (10^4)$

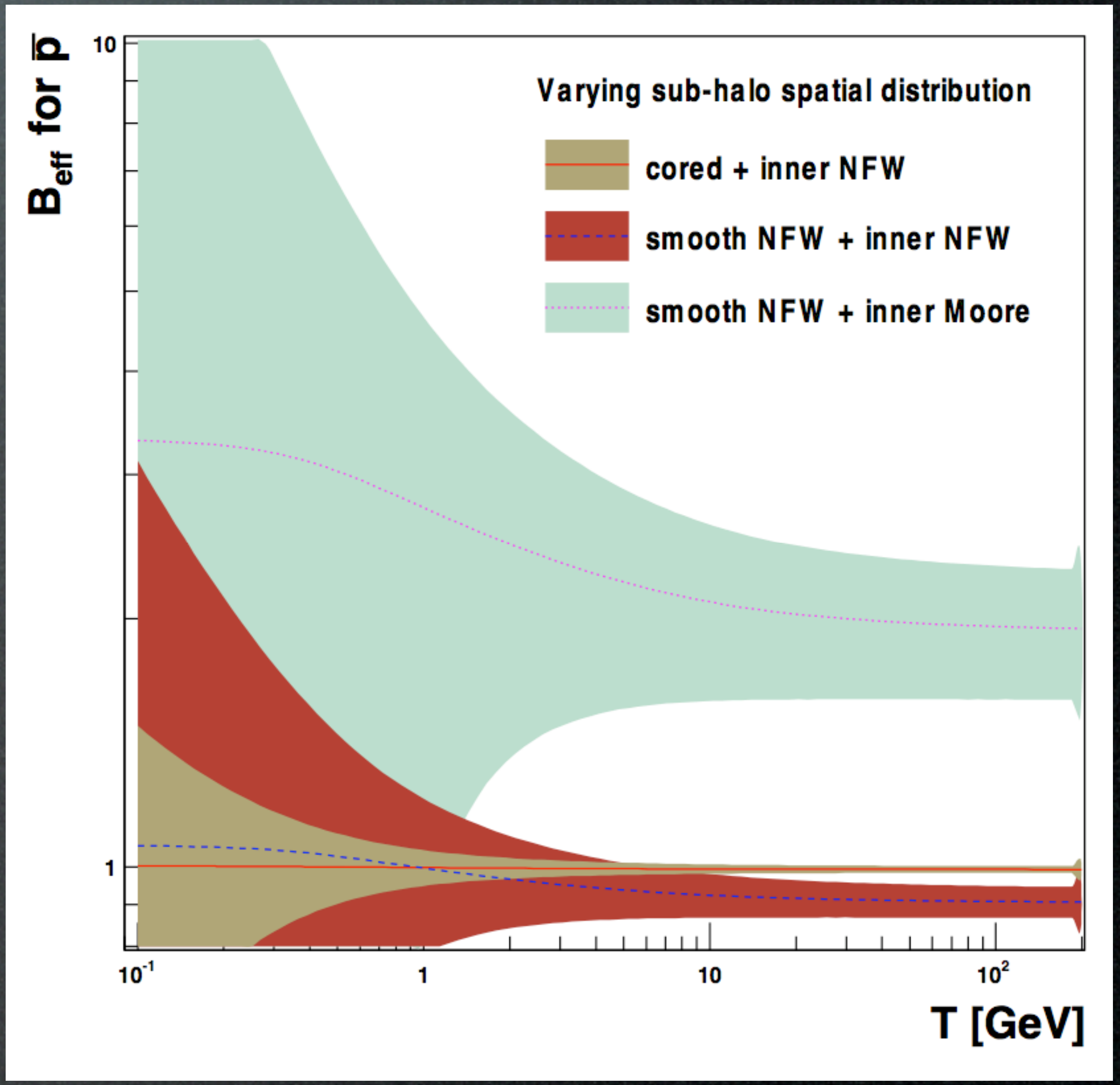
In principle, B is different for e^+, anti-p and gammas,
energy dependent,
dependent on many astro assumptions,
with an energy dependent variance, at high energy for e^+, at low energy for anti-p.

positrons



Lavalle et al. 2006

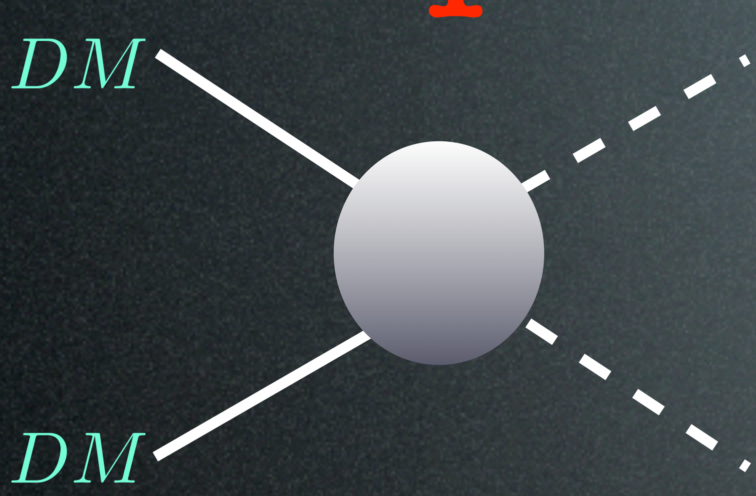
antiprotons



Lavalle et al. 2007

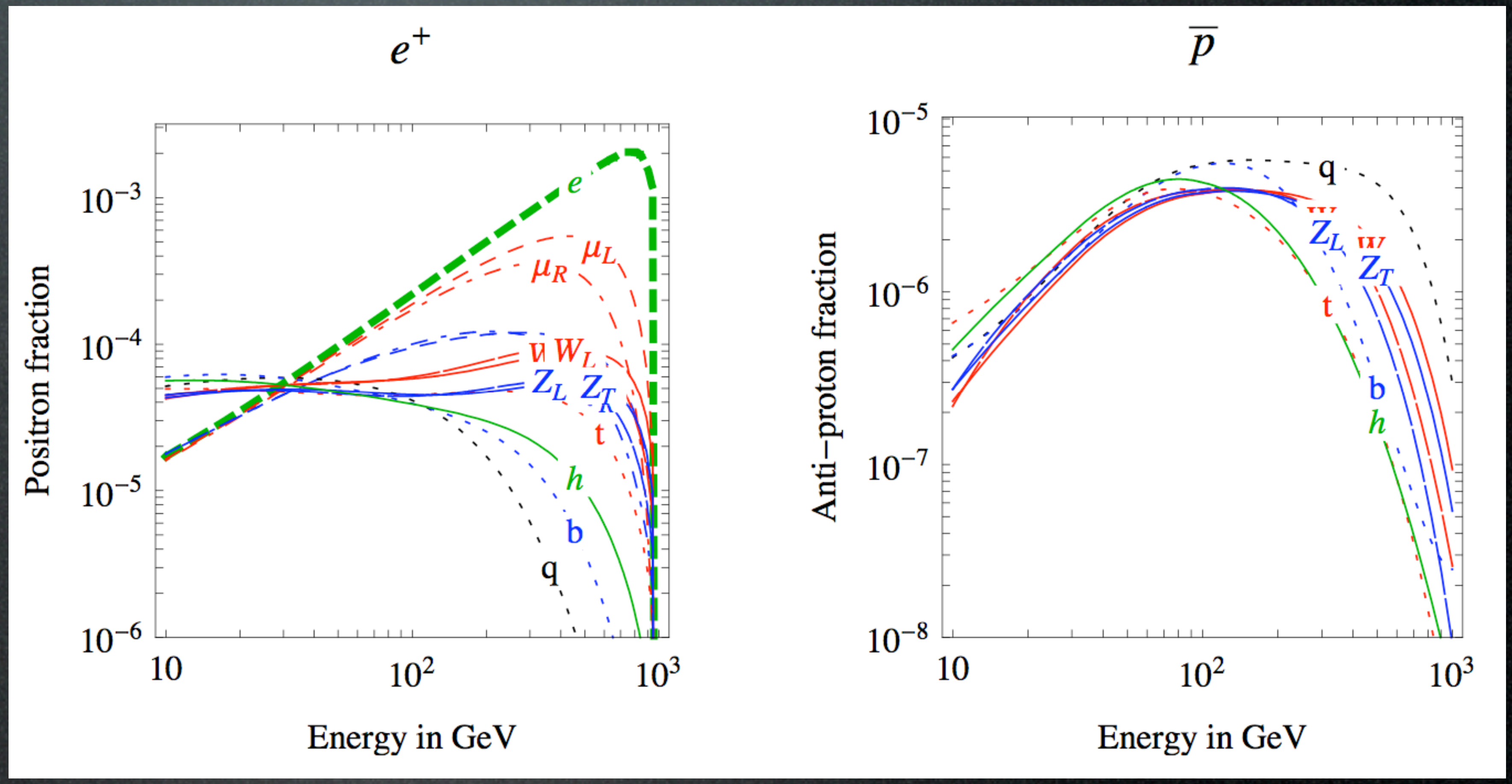
Computing the theory predictions

Spectra at production

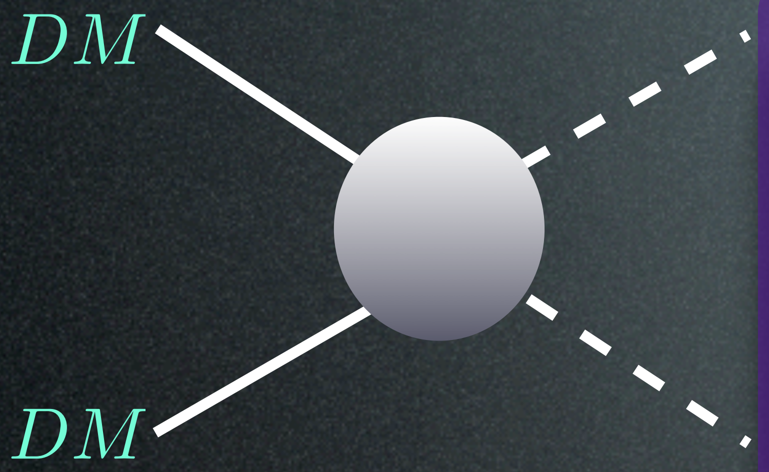


$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$



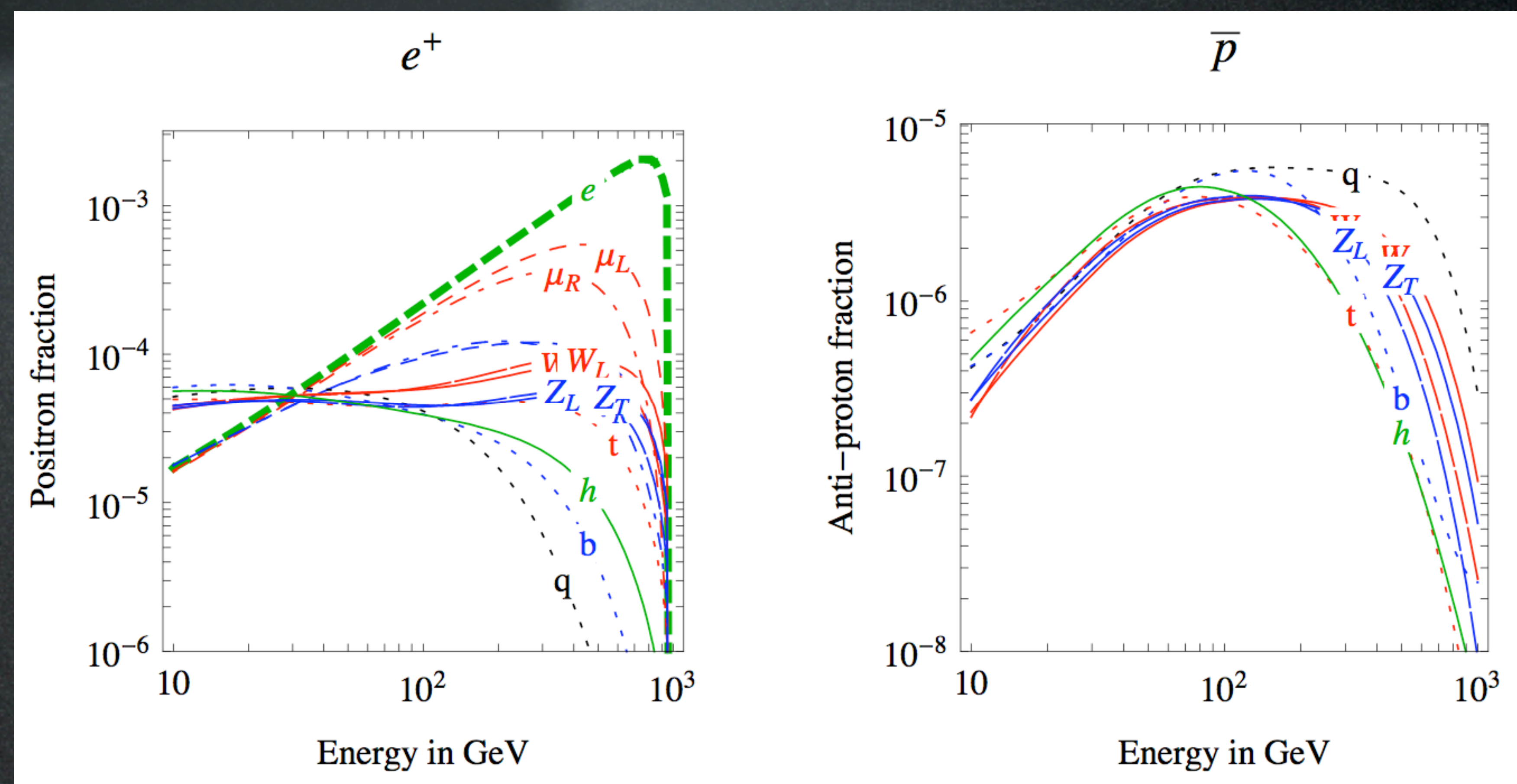
Spectra at production



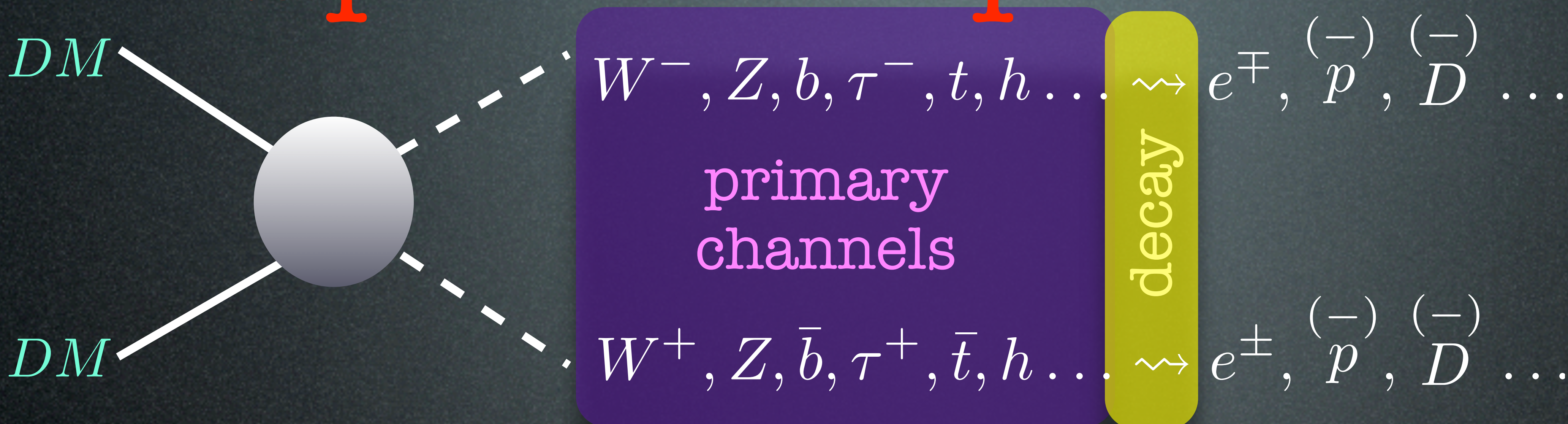
$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$

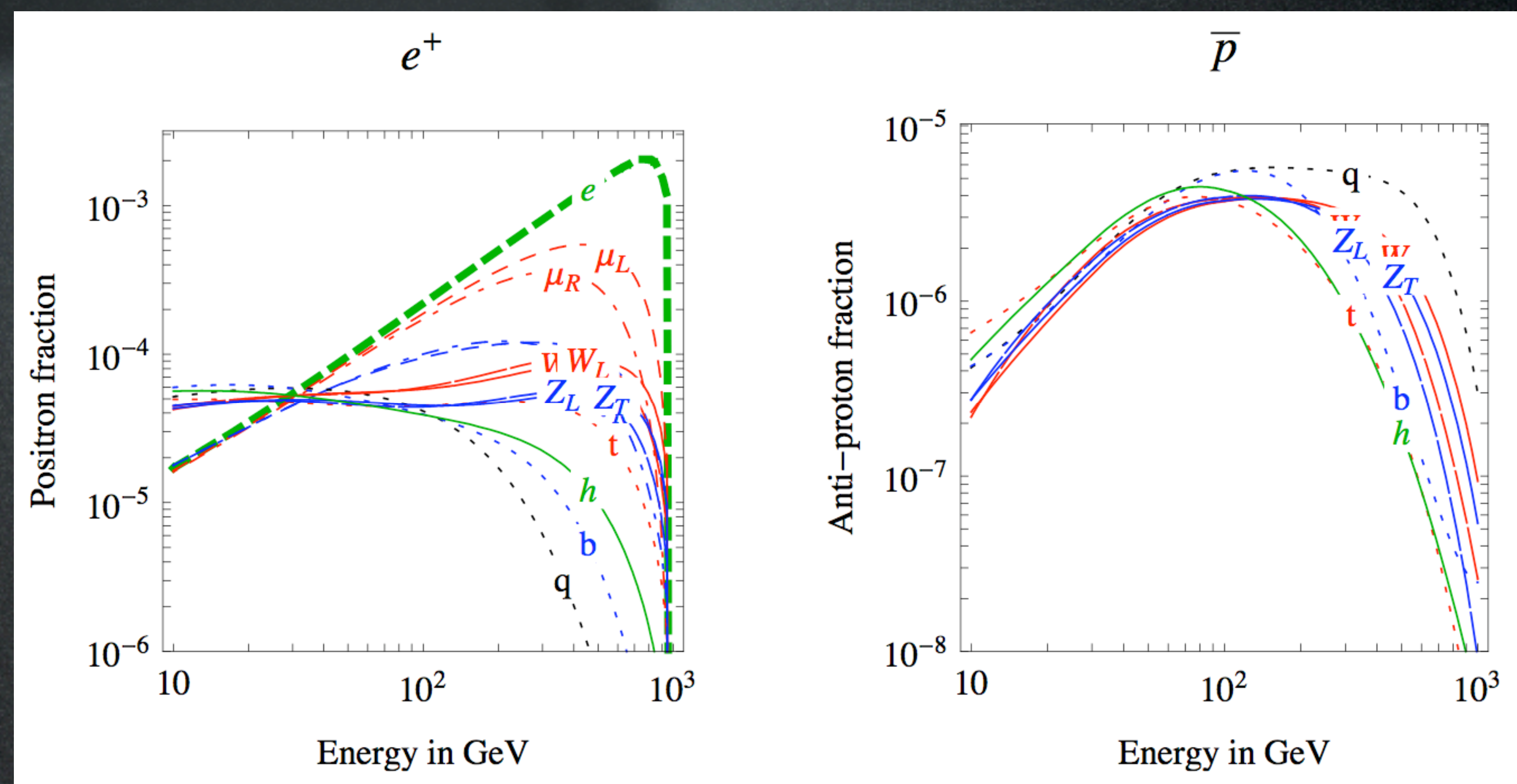
primary channels

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots$$



Spectra at production





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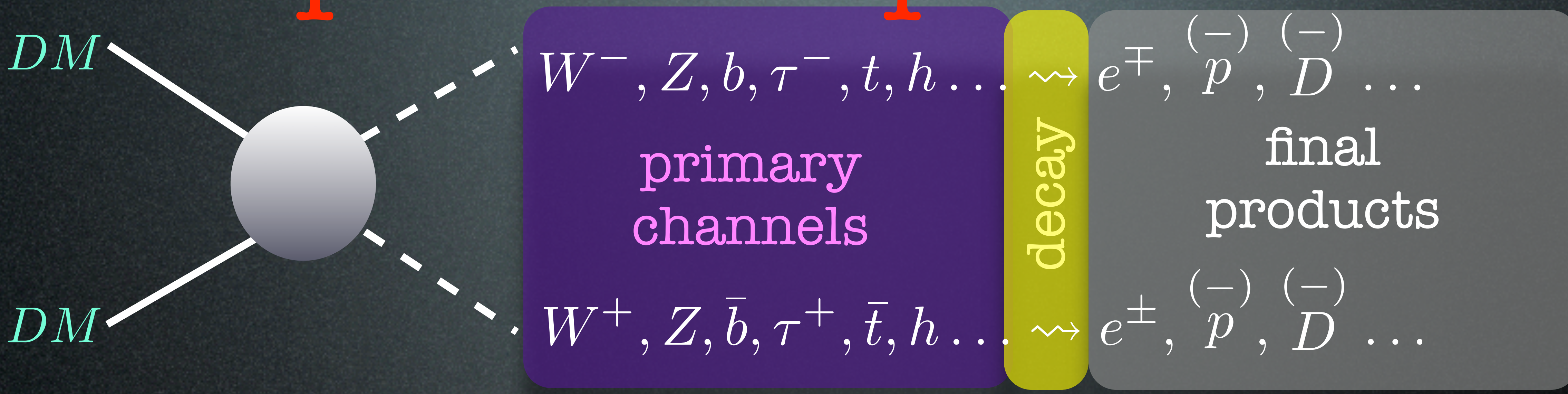

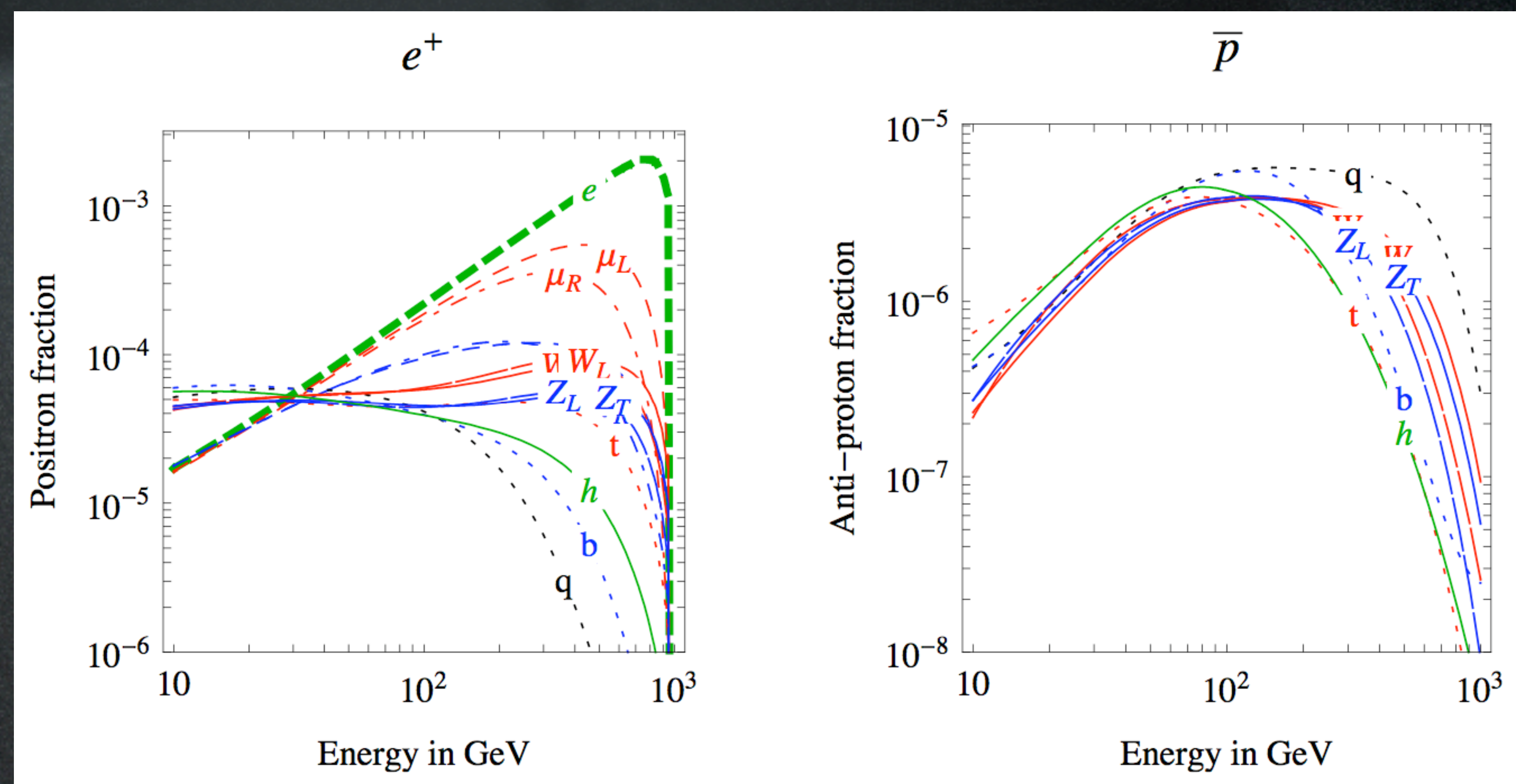

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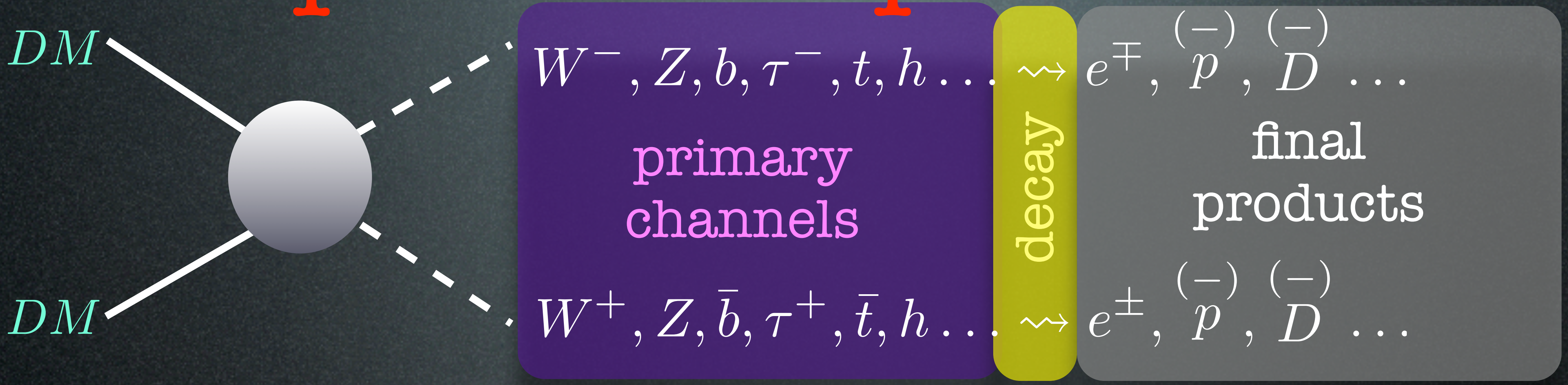
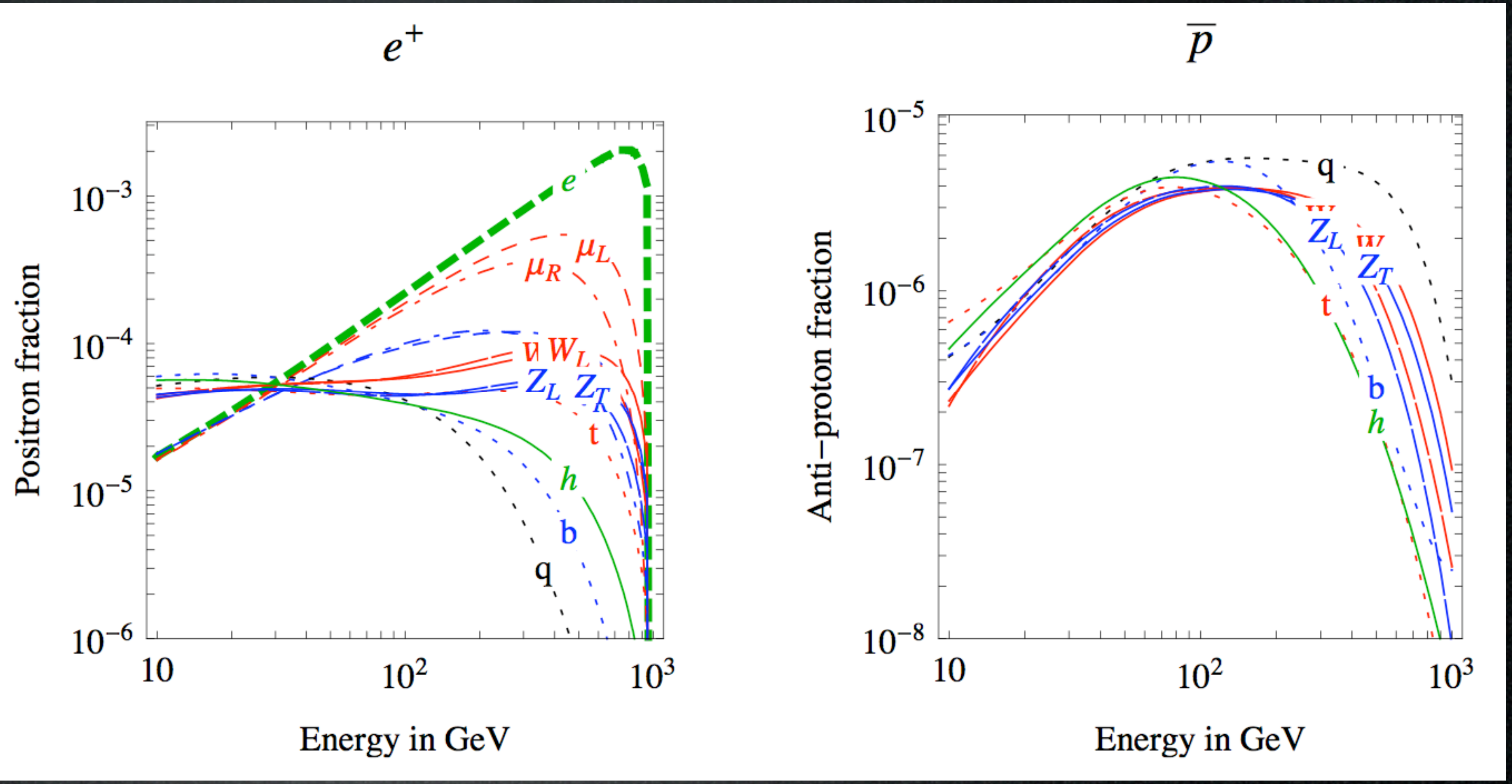




So what are the particle physics parameters?

1. Dark Matter mass
2. primary channel(s)

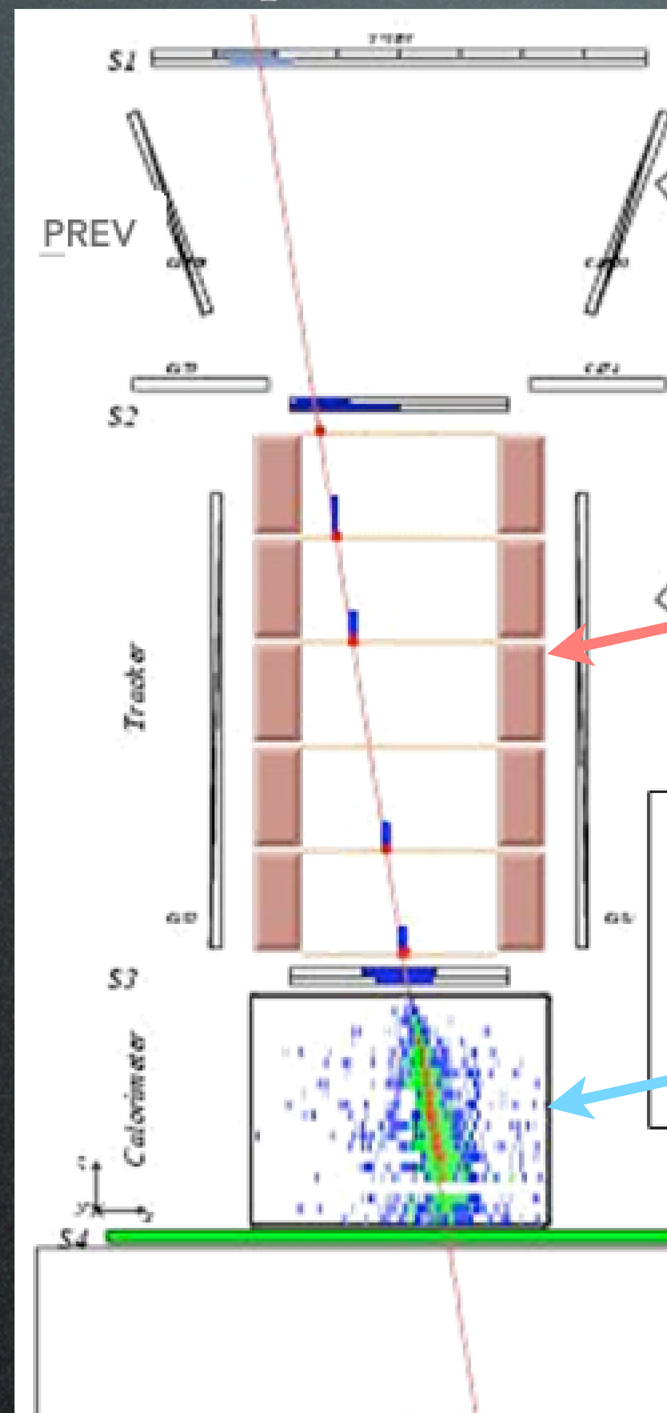
Comparing with data

Data sets

Positrons from PAMELA:

Payload for
Anti-
Matter
Exploration and
Light-nuclei
Astrophysics

92 GeV positron event



calibrated on accelerator fluxes

magnetic spectrometer:
charge and energy

calorimeter: $e^{\pm}$ vs $p/\bar{p}$

(make showers) (swipe thru)

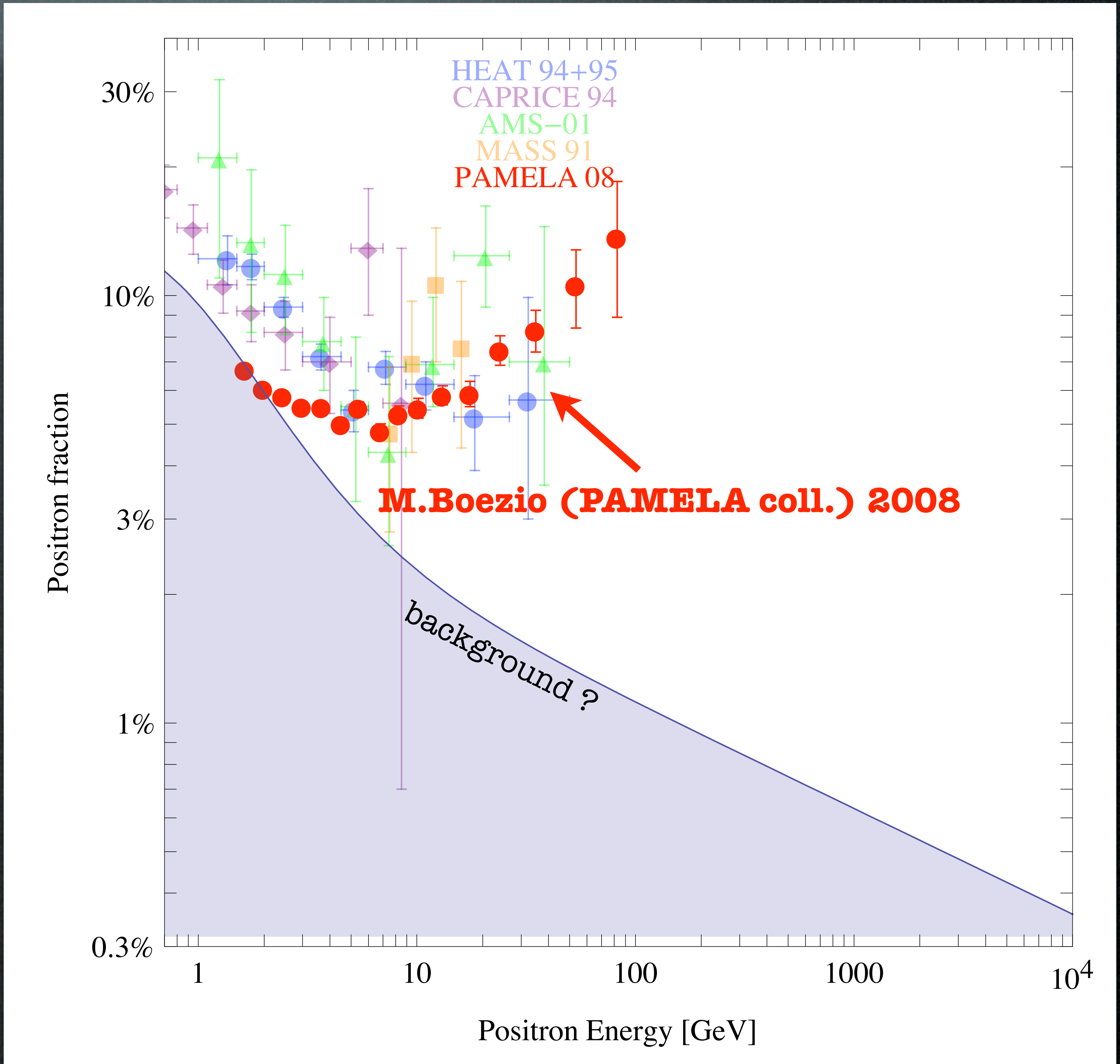
Big challenge: backgnd contamination
from p (10^4 more numerous at 100 GeV)

Data sets

Positrons from PAMELA:

- steep e^+ excess above 10 GeV!
- very large flux!

(9430 e⁺ collected)



[backgnd]

Data sets

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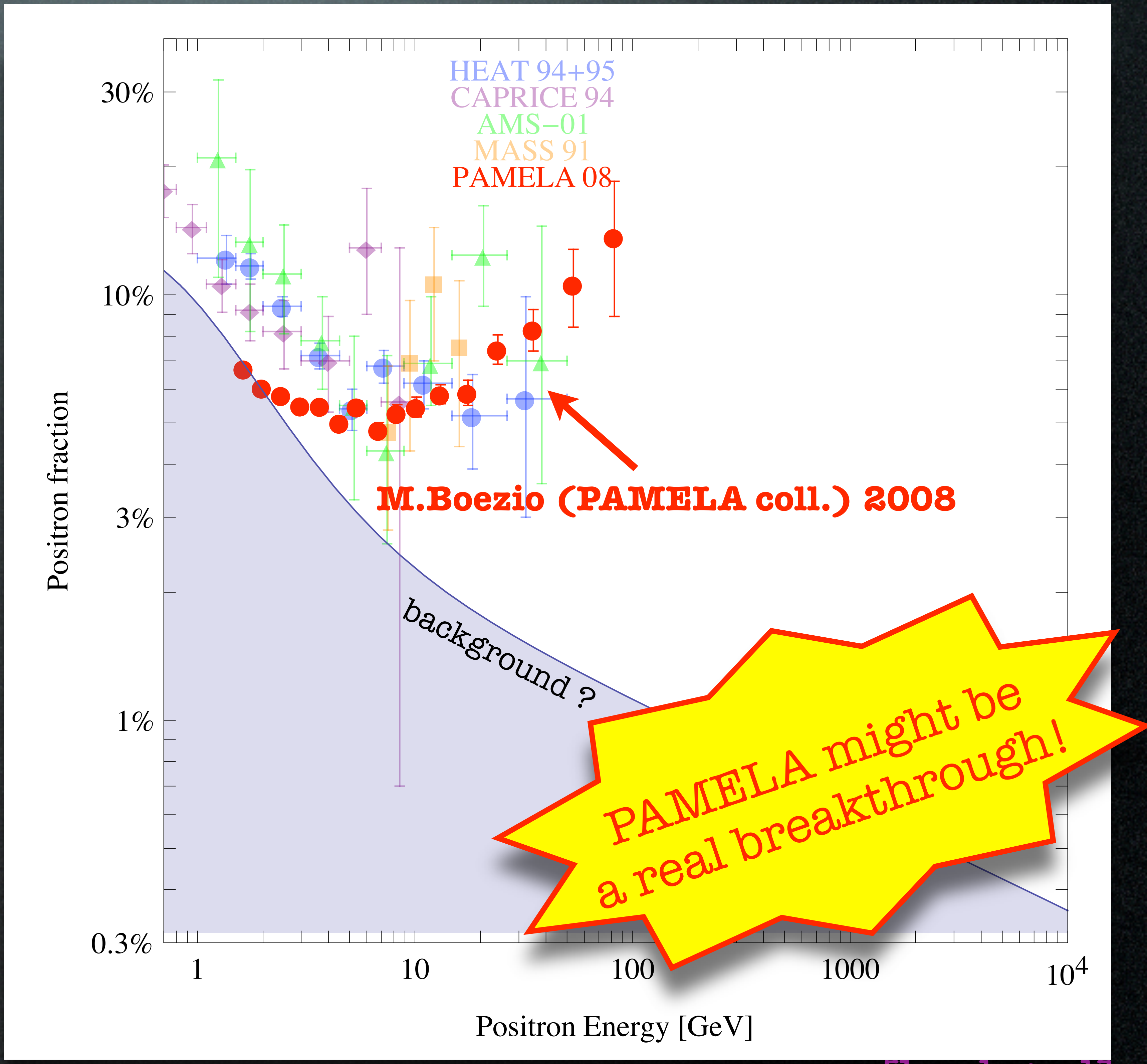
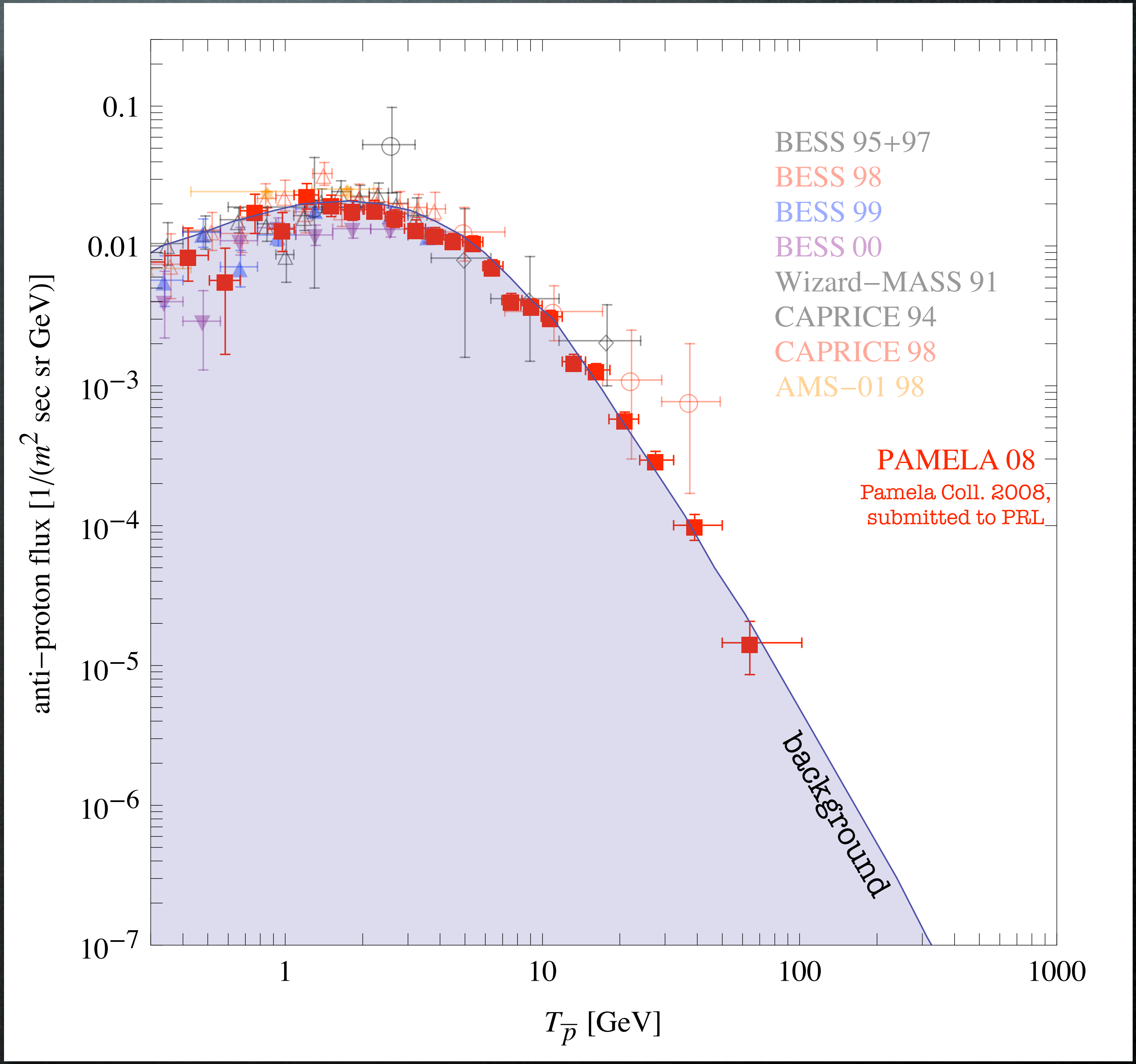


[backgnd]

Data sets

Antiprotons from PAMELA:

- consistent with the background



(about 1000 $\bar{p}$ collected)

Results

Which DM spectra can fit the data?

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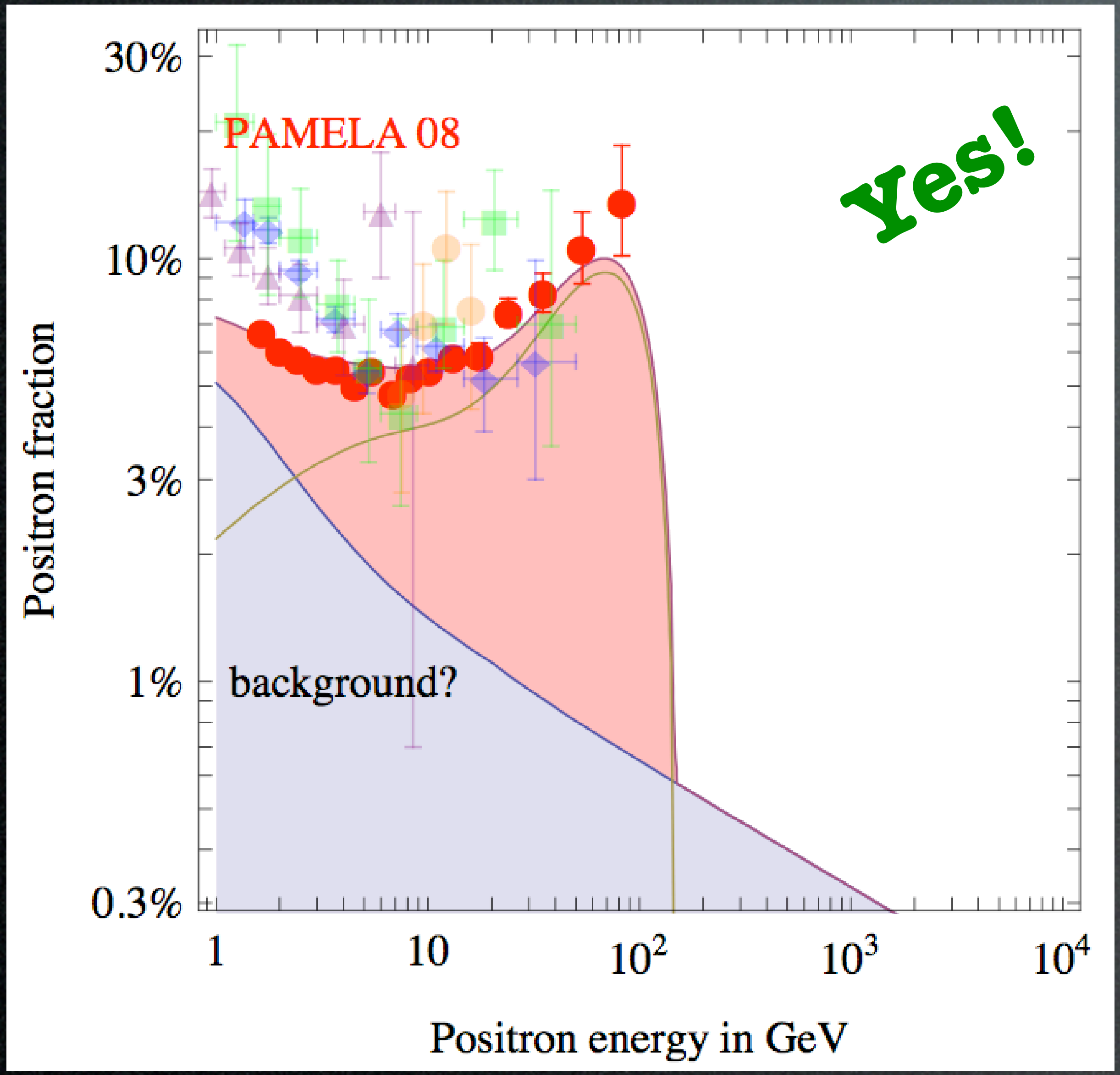
Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 150\,{\rm GeV}$

-annihilation $\rm DM\ DM \to W^+W^-$

(a possible SuperSymmetric candidate: wino)

Positrons:



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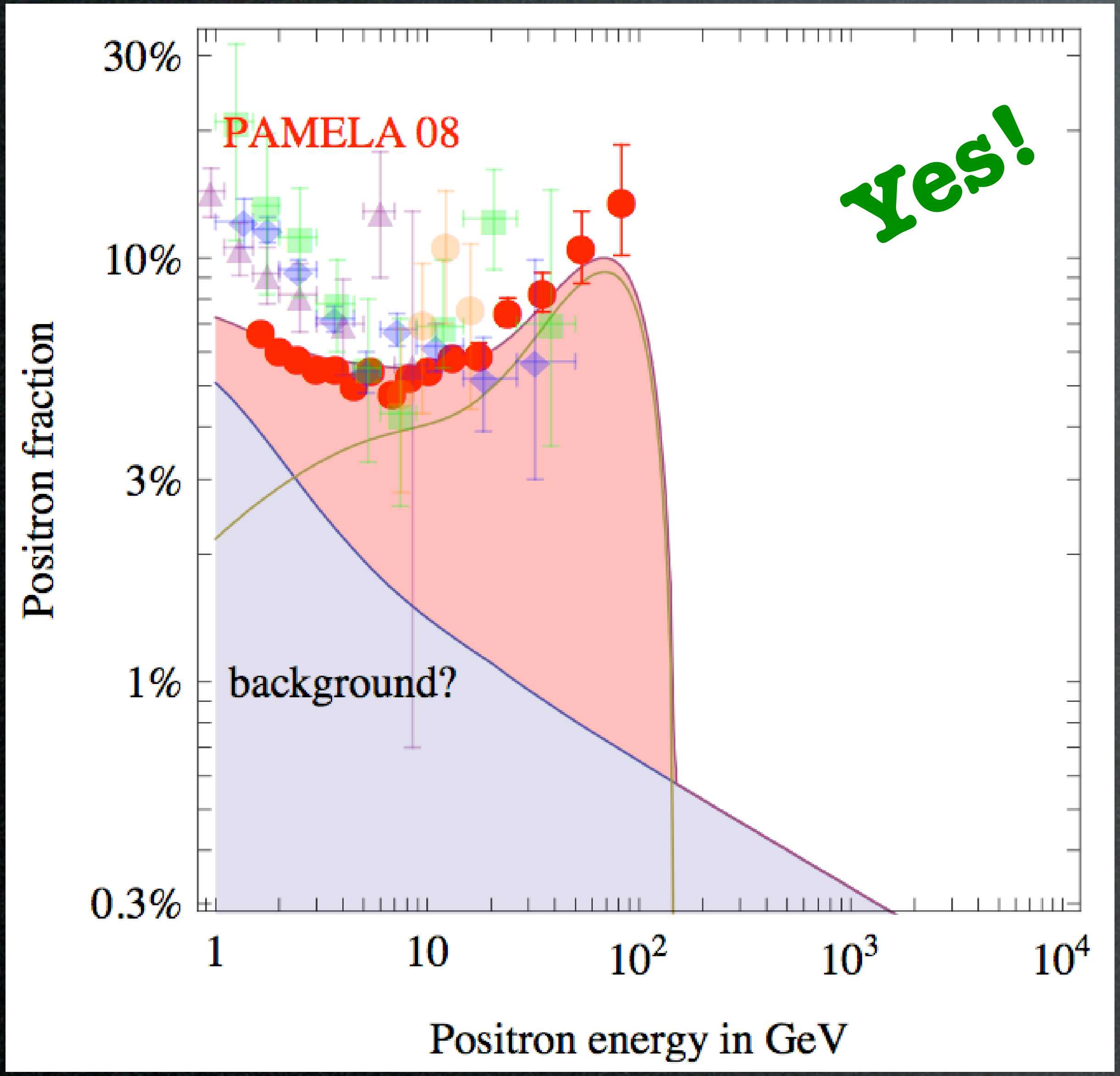
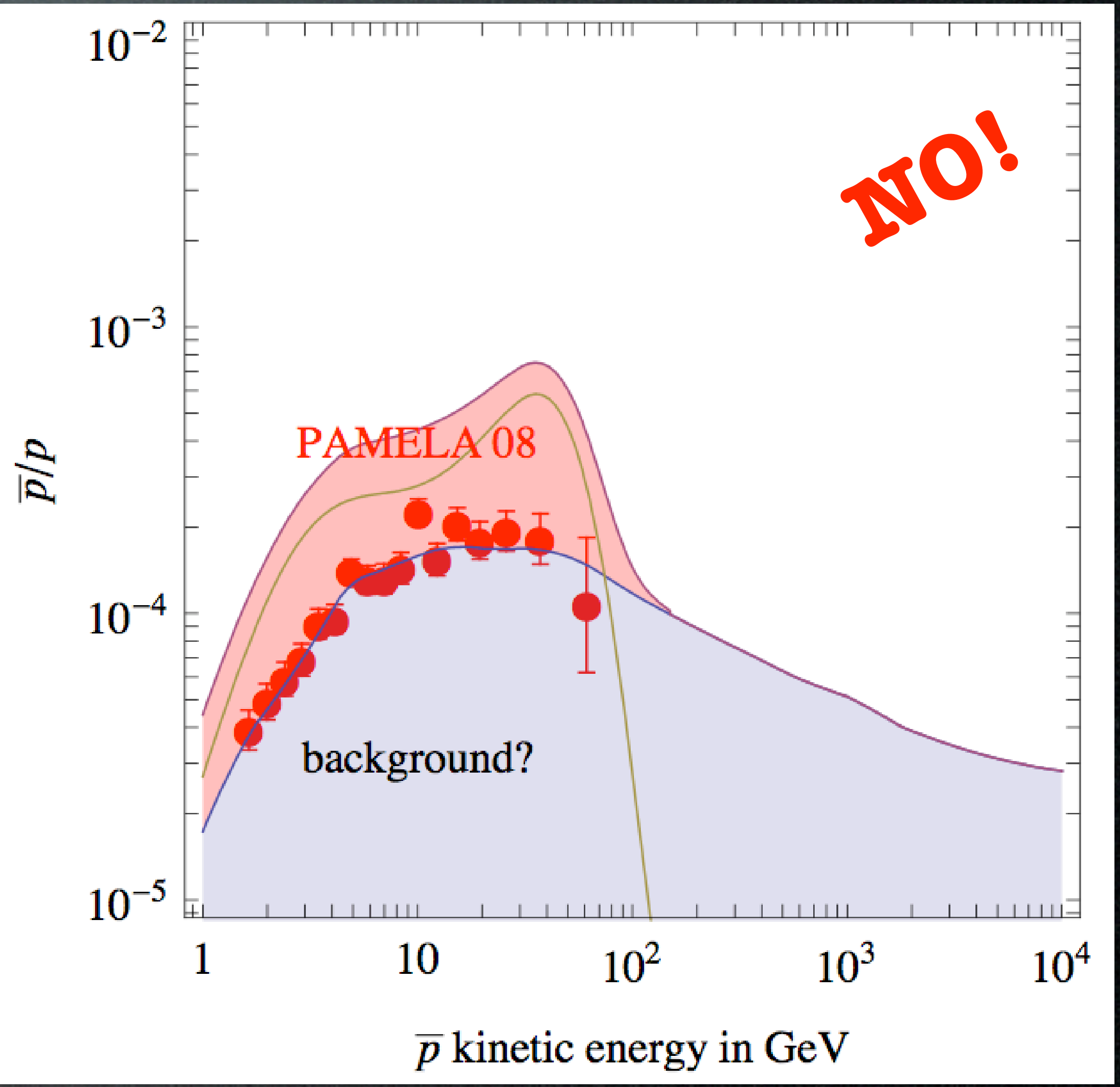


Anti-protons:



[insisting on Winos]

Results

Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 10\,{\rm TeV}$

-annihilation $\rm DM\ DM \to W^+W^-$

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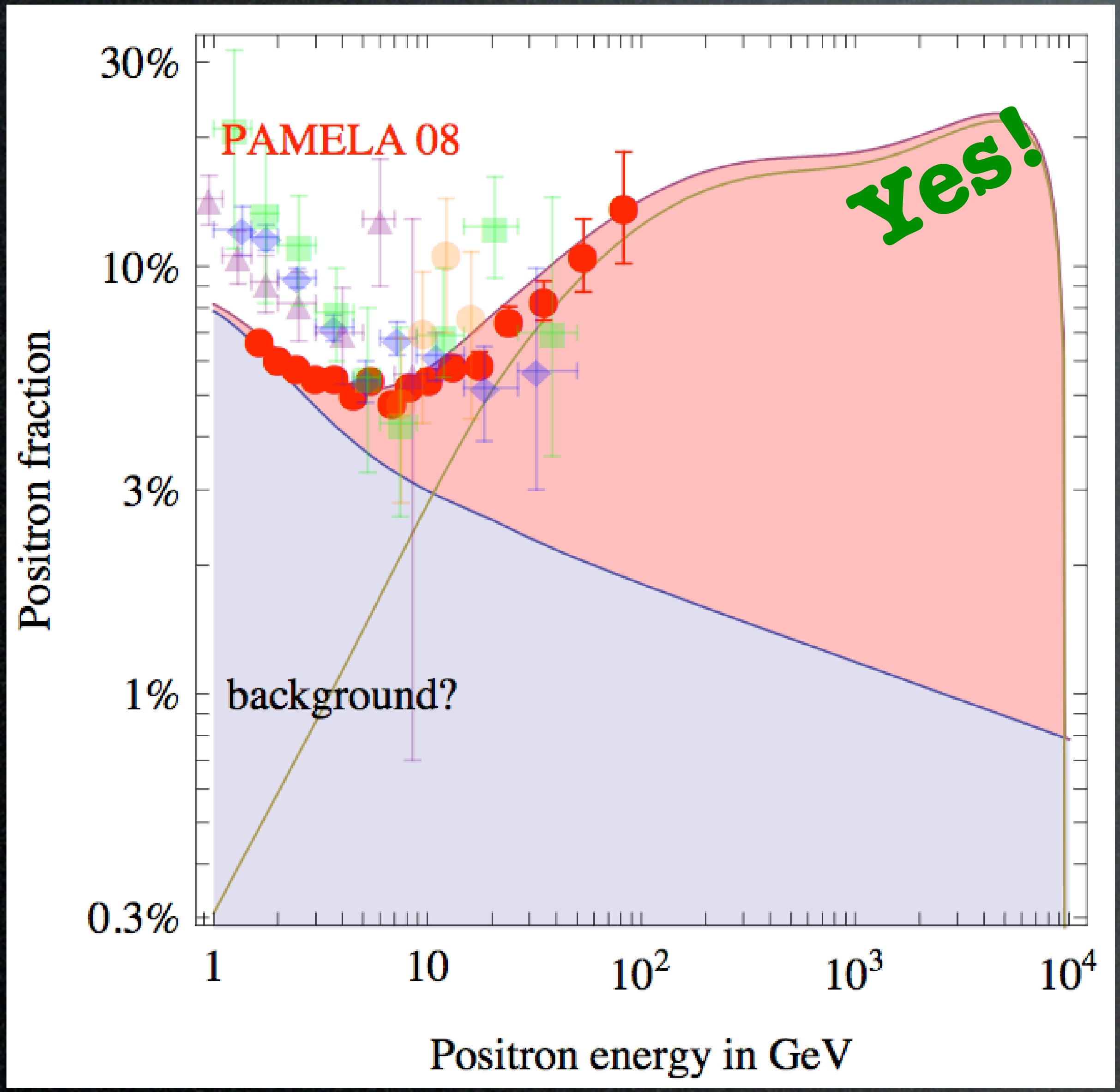
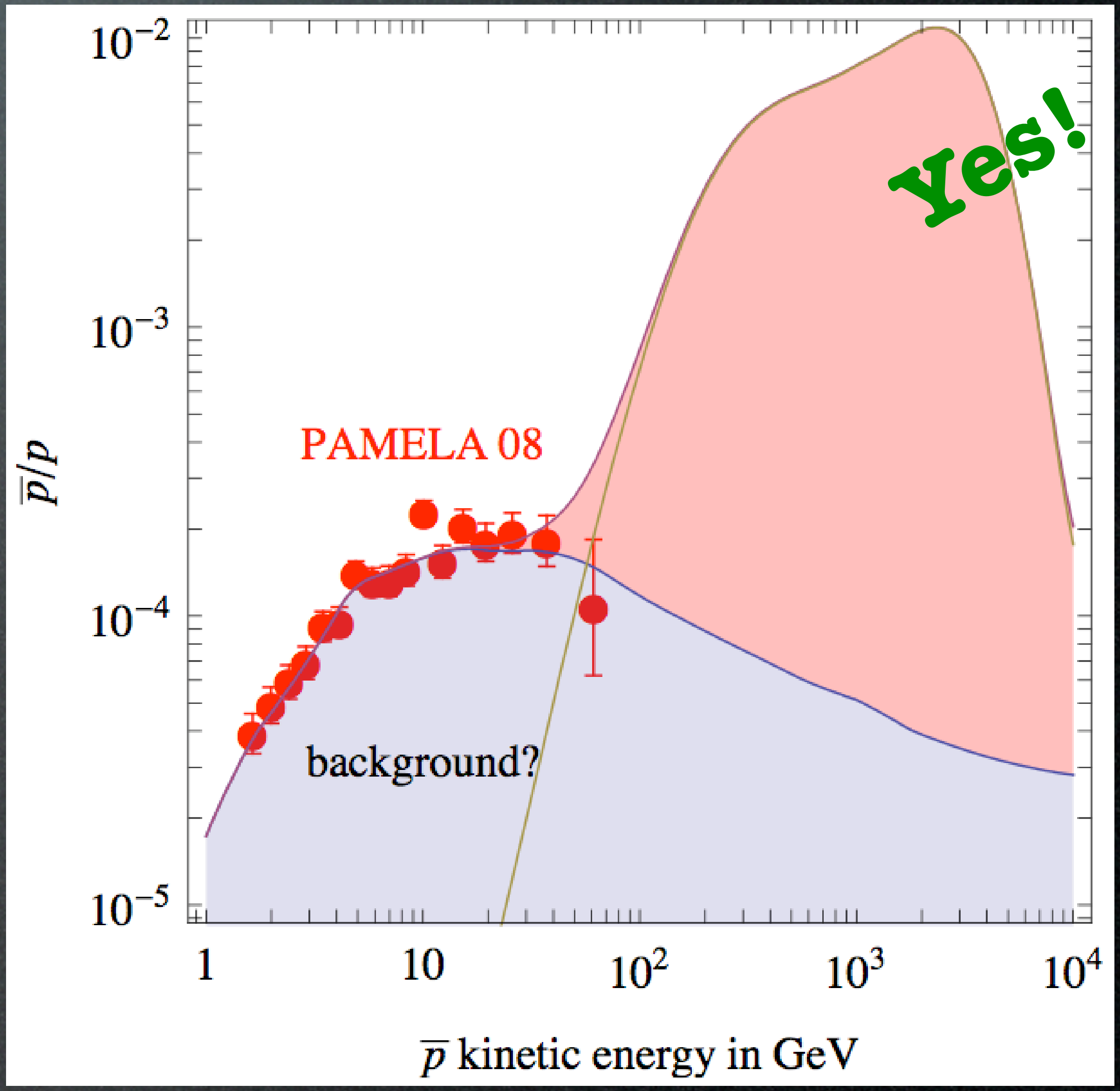


Anti-protons:



Results

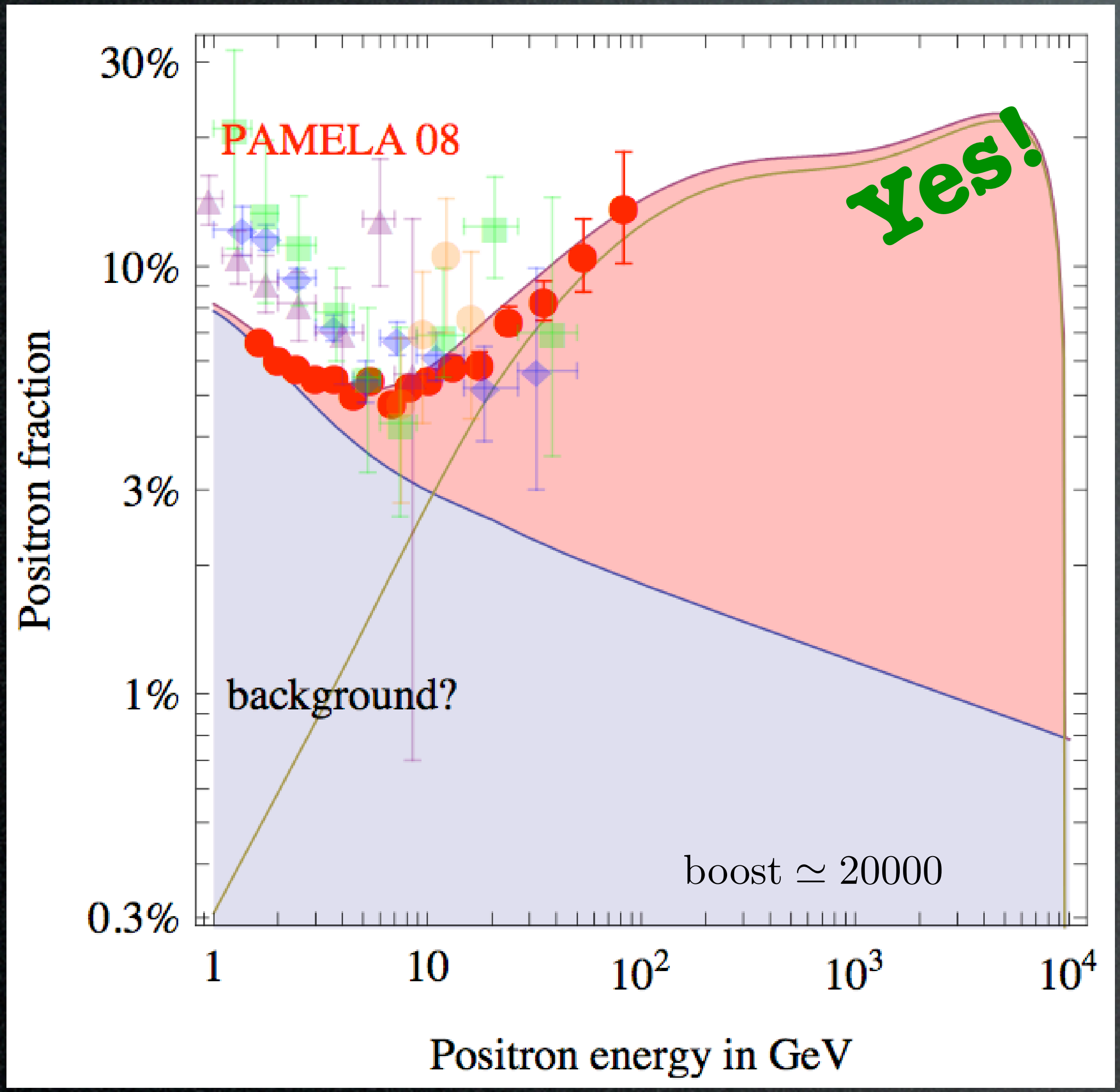
Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 10\,{\rm TeV}$

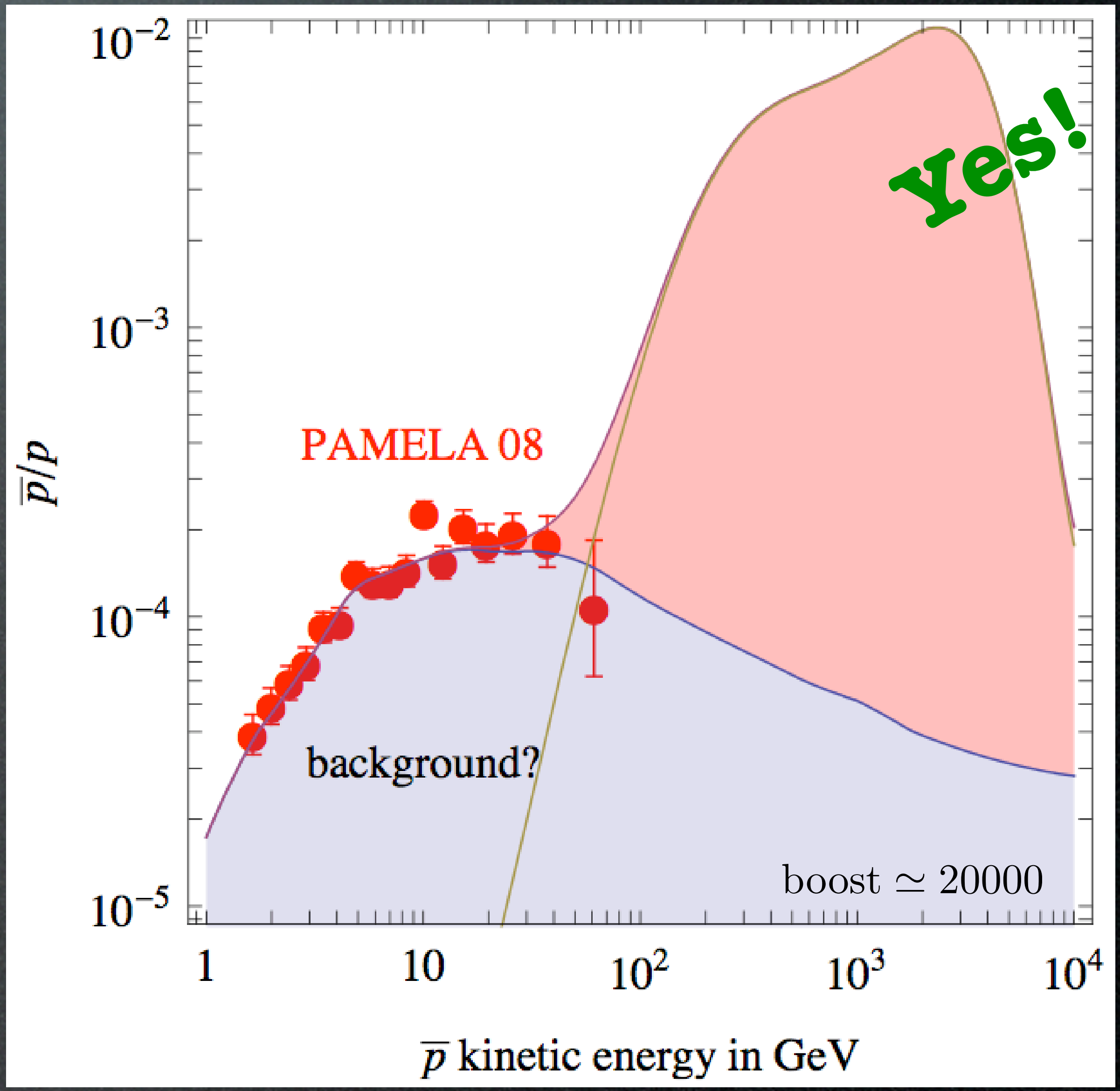
-annihilation $\rm DM\ DM \to W^+W^-$

but...: -boost $B = 2\cdot 10^4$ No...

Positrons:



Anti-protons:



Results

Which DM spectra can fit the data?

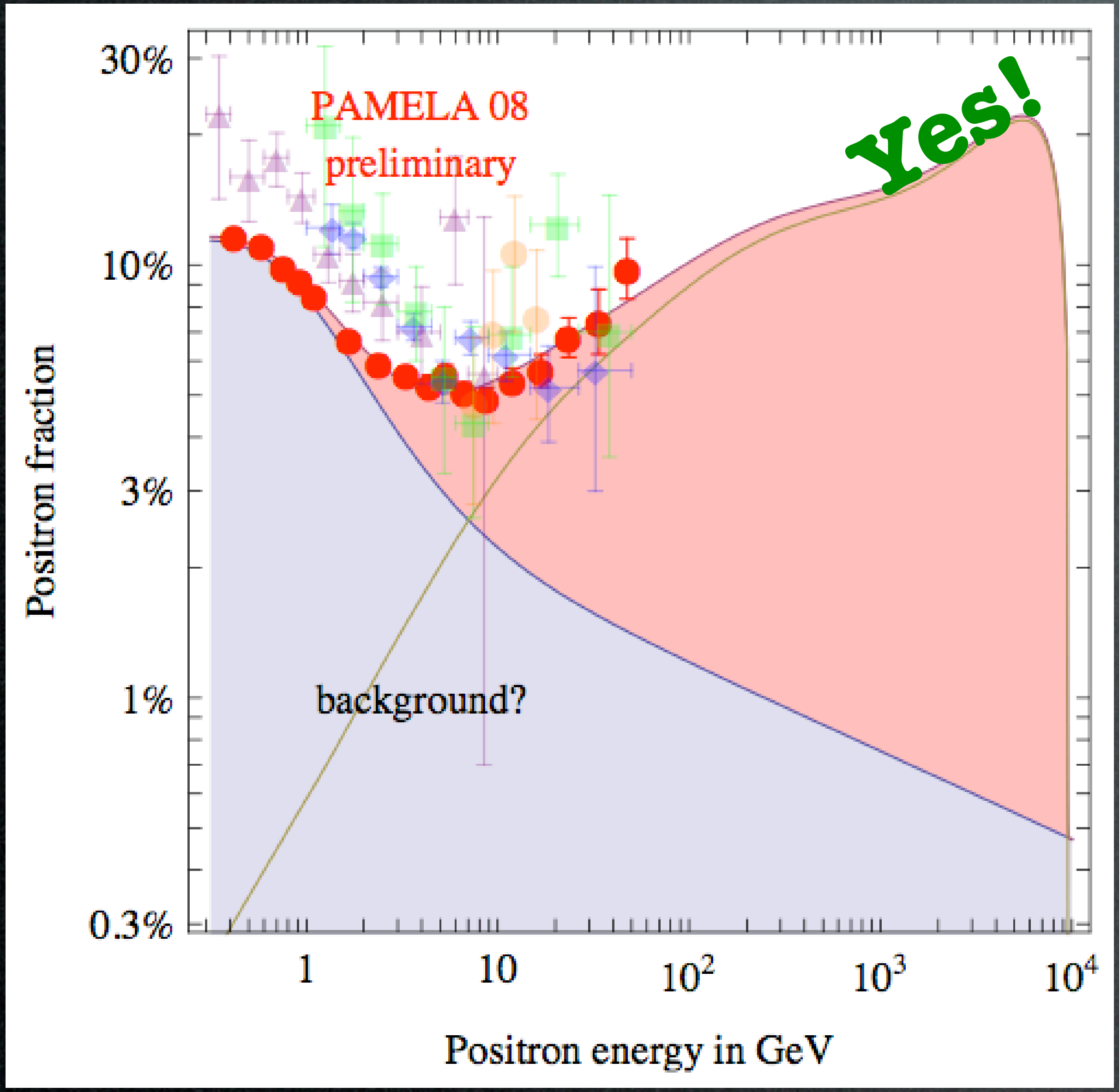
E.g. Minimal DM: -mass $M_{\rm DM} = 9.7\,\rm TeV$

[Cirelli, Strumia et al. 2006]

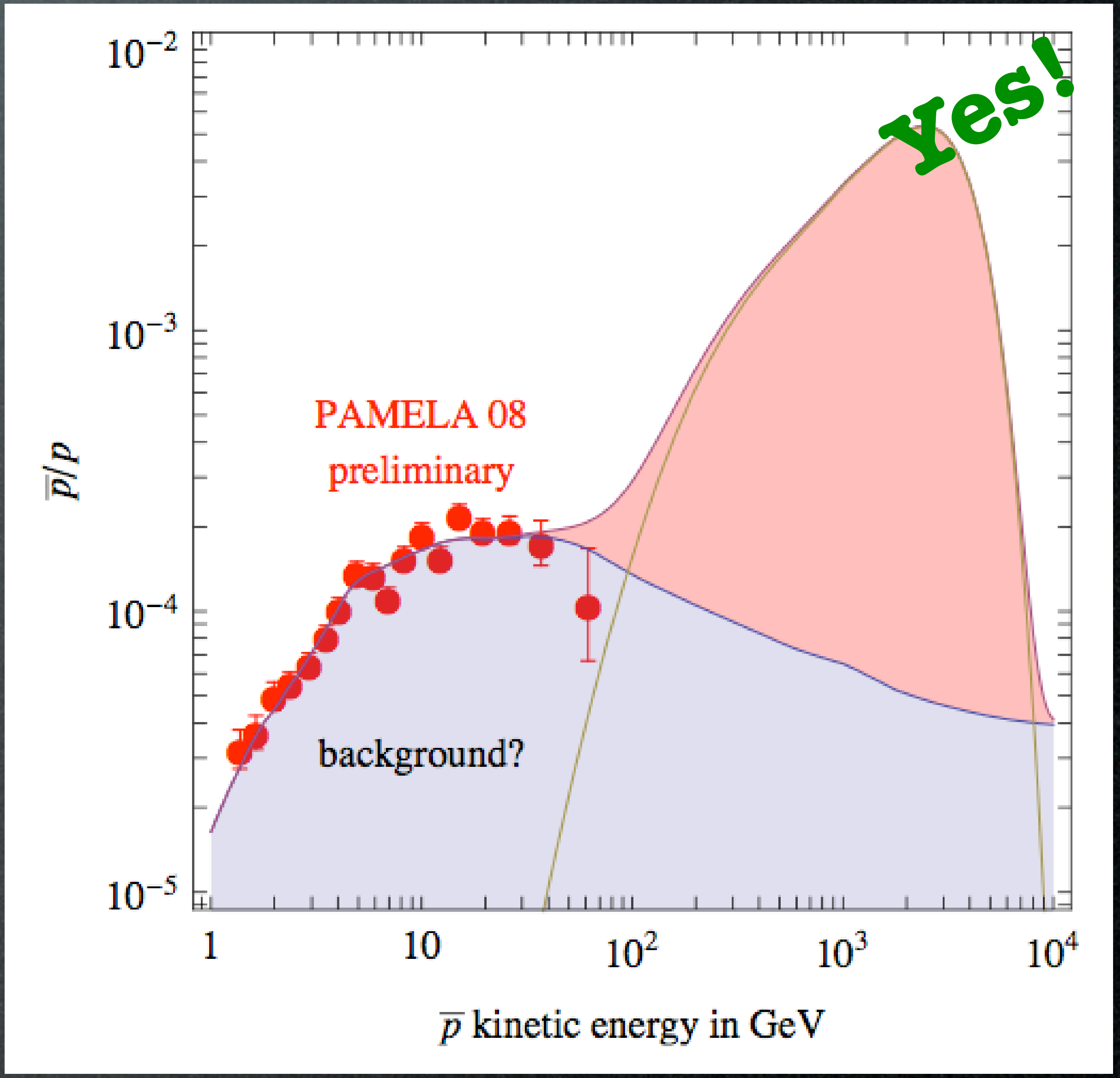
-annihilation $\rm DM\ DM \to W^+W^-$

-boost $B \simeq 30$ Yes!

Positrons:



Anti-protons:

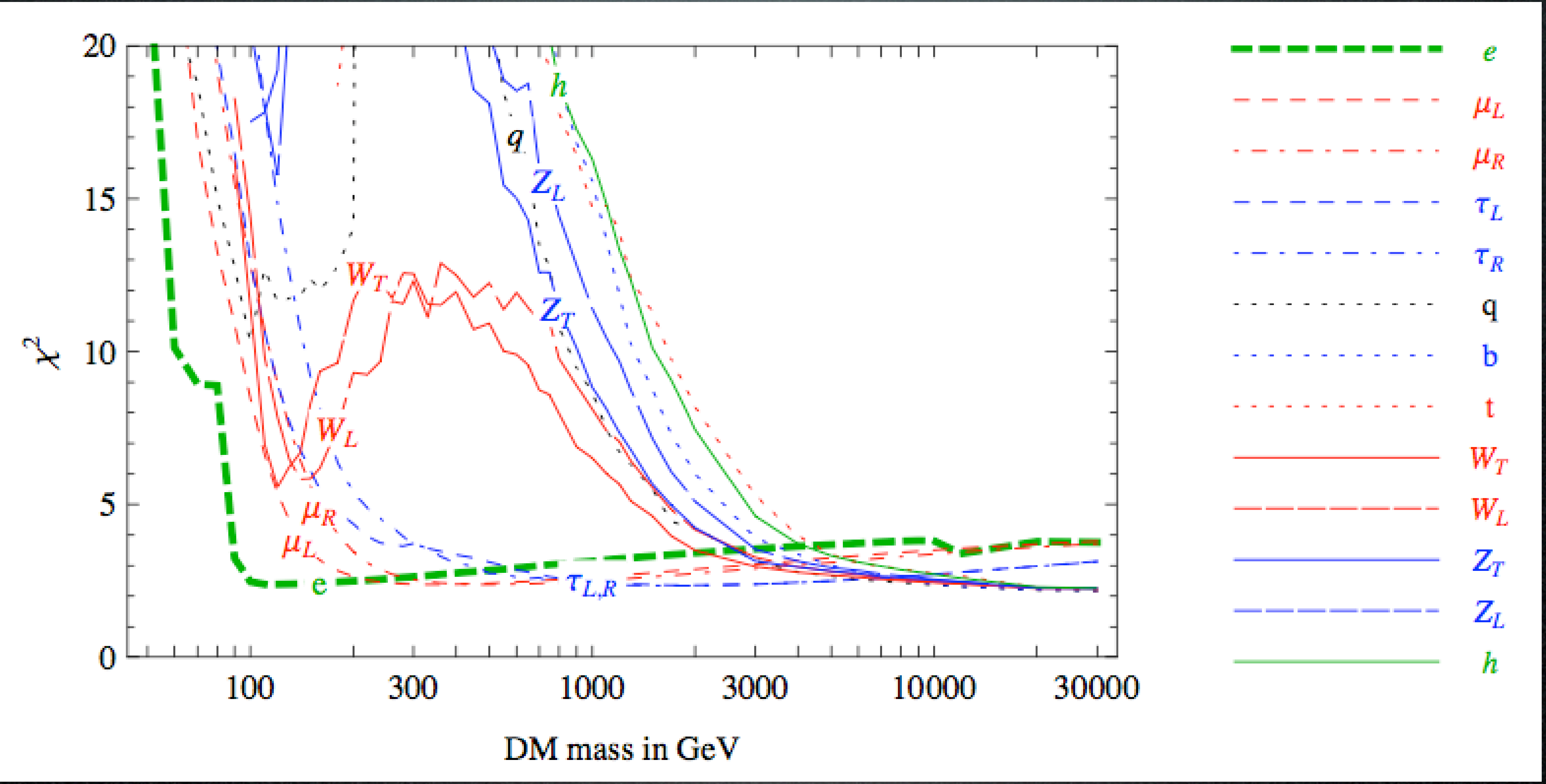


Results

Which DM spectra can fit the data?

Model-independent results:

fit to PAMELA positrons only

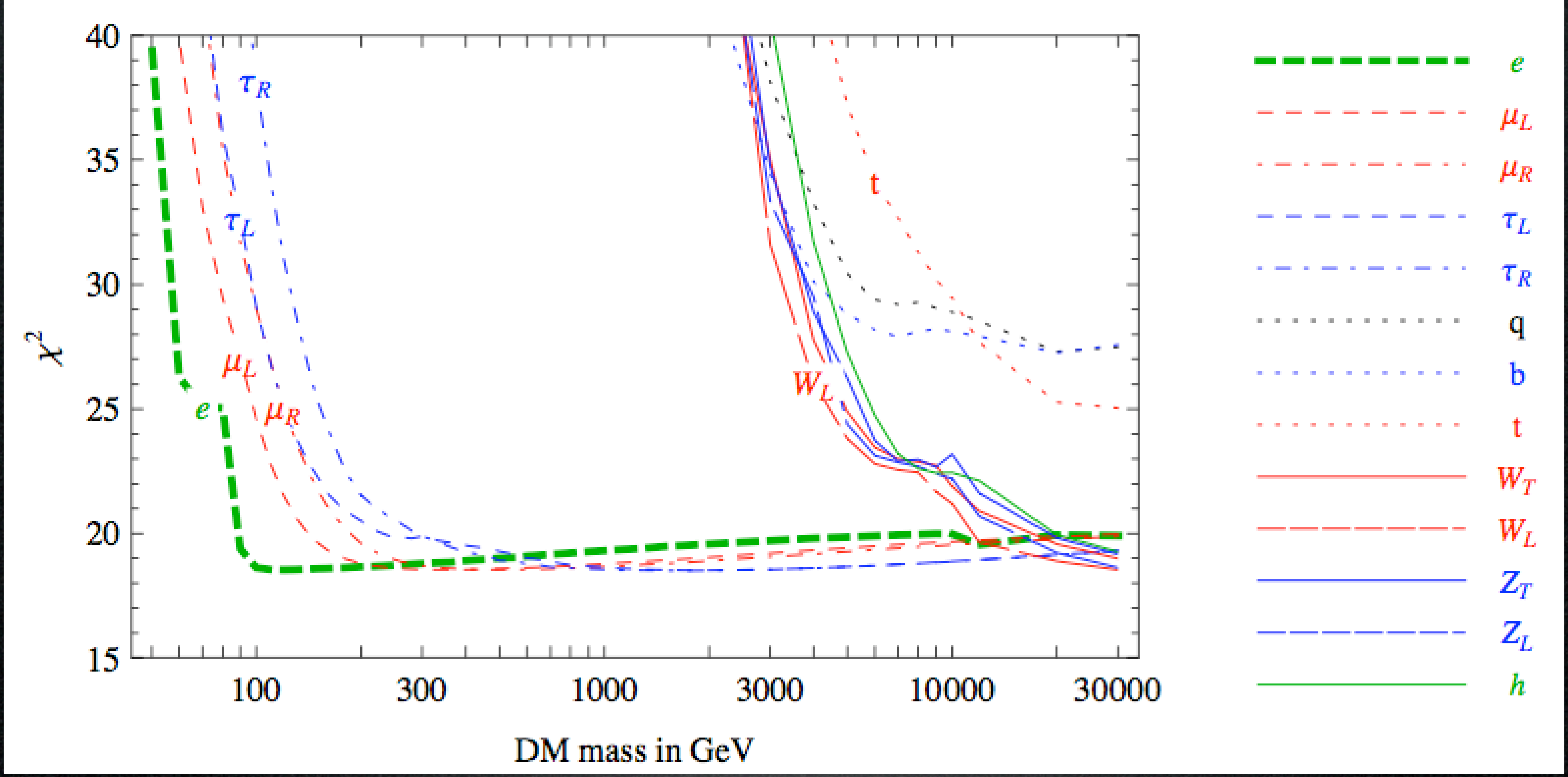


Results

Which DM spectra can fit the data?

Model-independent results:

fit to PAMELA positrons + anti-protons

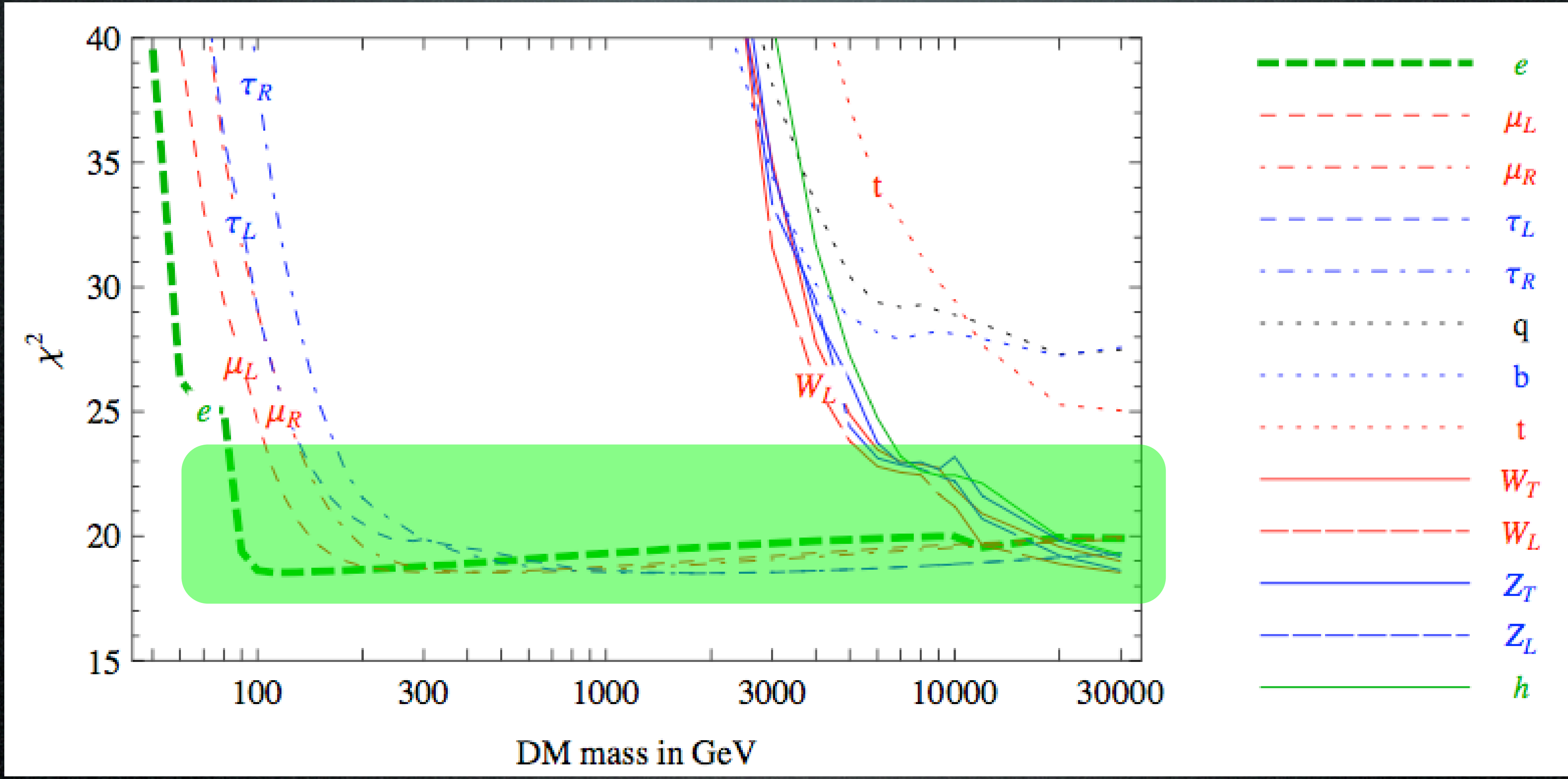


Results

Which DM spectra can fit the data?

Model-independent results:

fit to PAMELA positrons + anti-protons



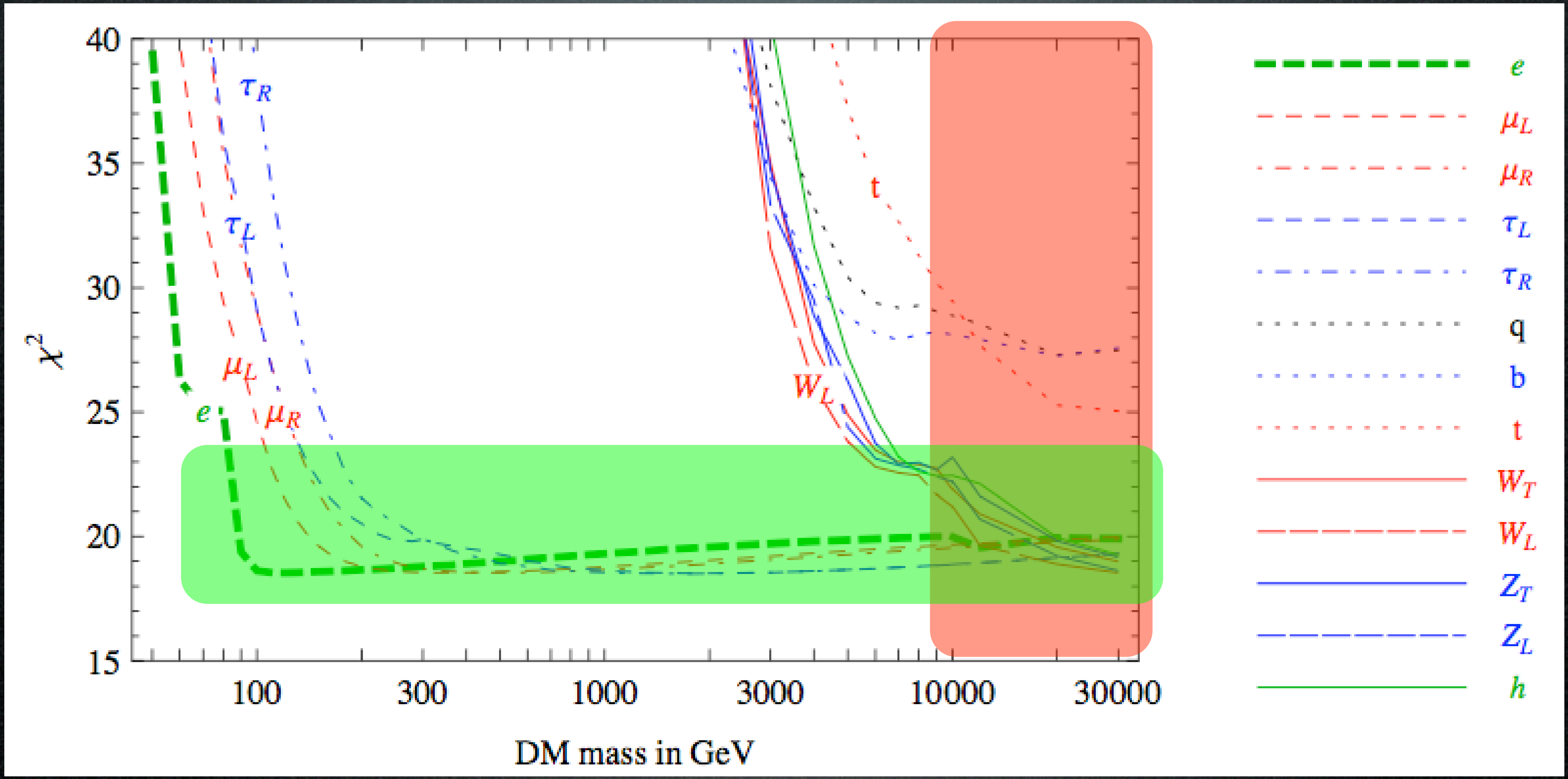
(1) annihilate into leptons (e.g. $\mu^+\mu^-$)

Results

Which DM spectra can fit the data?

Model-independent results:

fit to PAMELA positrons + anti-protons



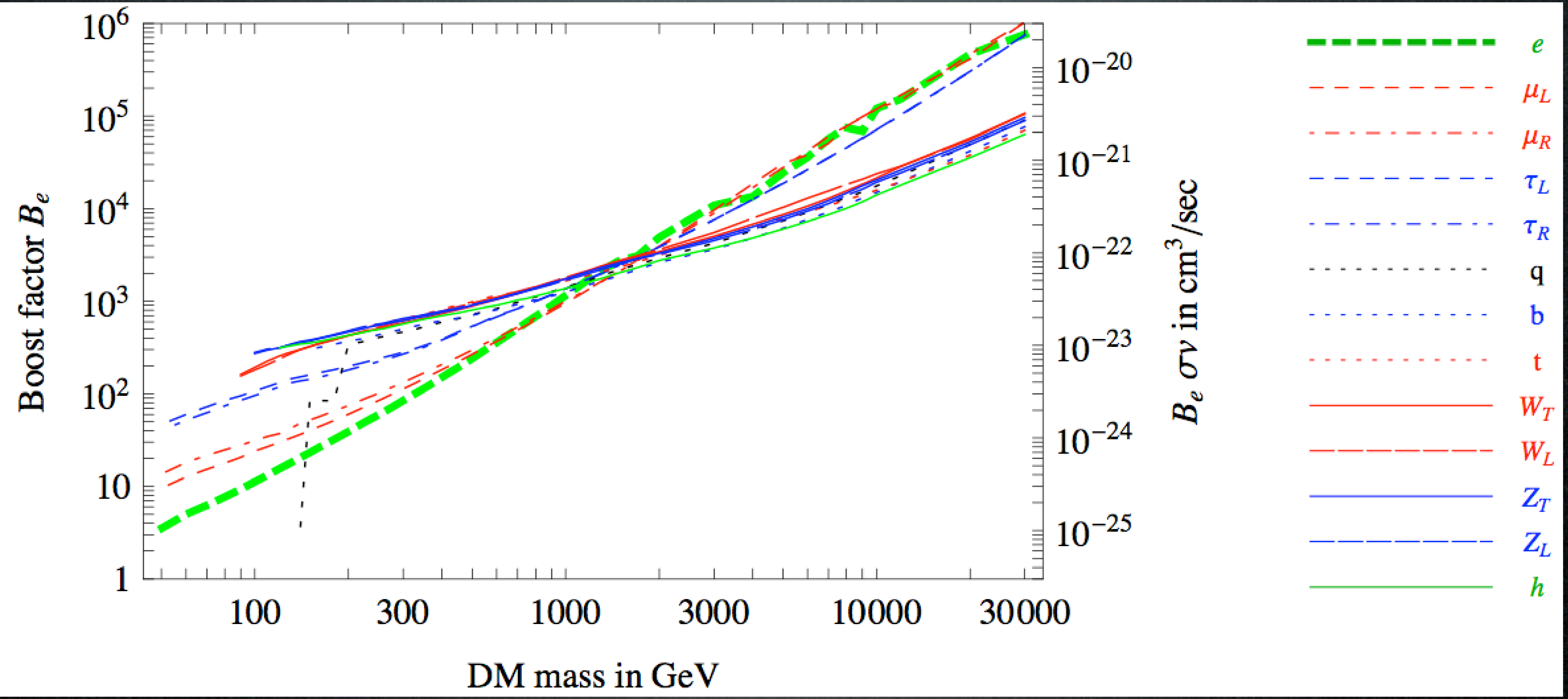
(1) annihilate into leptons (e.g. $\mu^+\mu^-$) or
(2) annihilate into W^+W^- with mass $\gtrsim$ 10 TeV

Results

Which DM spectra can fit the data?

Model-independent results:

Boost required by PAMELA



Data sets

Electrons + positrons from ATIC, PPB-BETS:

PPB-BETS (Japan)

Polar
Patrol
Balloon
of the
Balloon-borne
Electron
Telescope with
Scintillating
fibers

ATIC (Usa + Germany, Russia, China)

Advanced
Thin
Ionization
Calorimeter

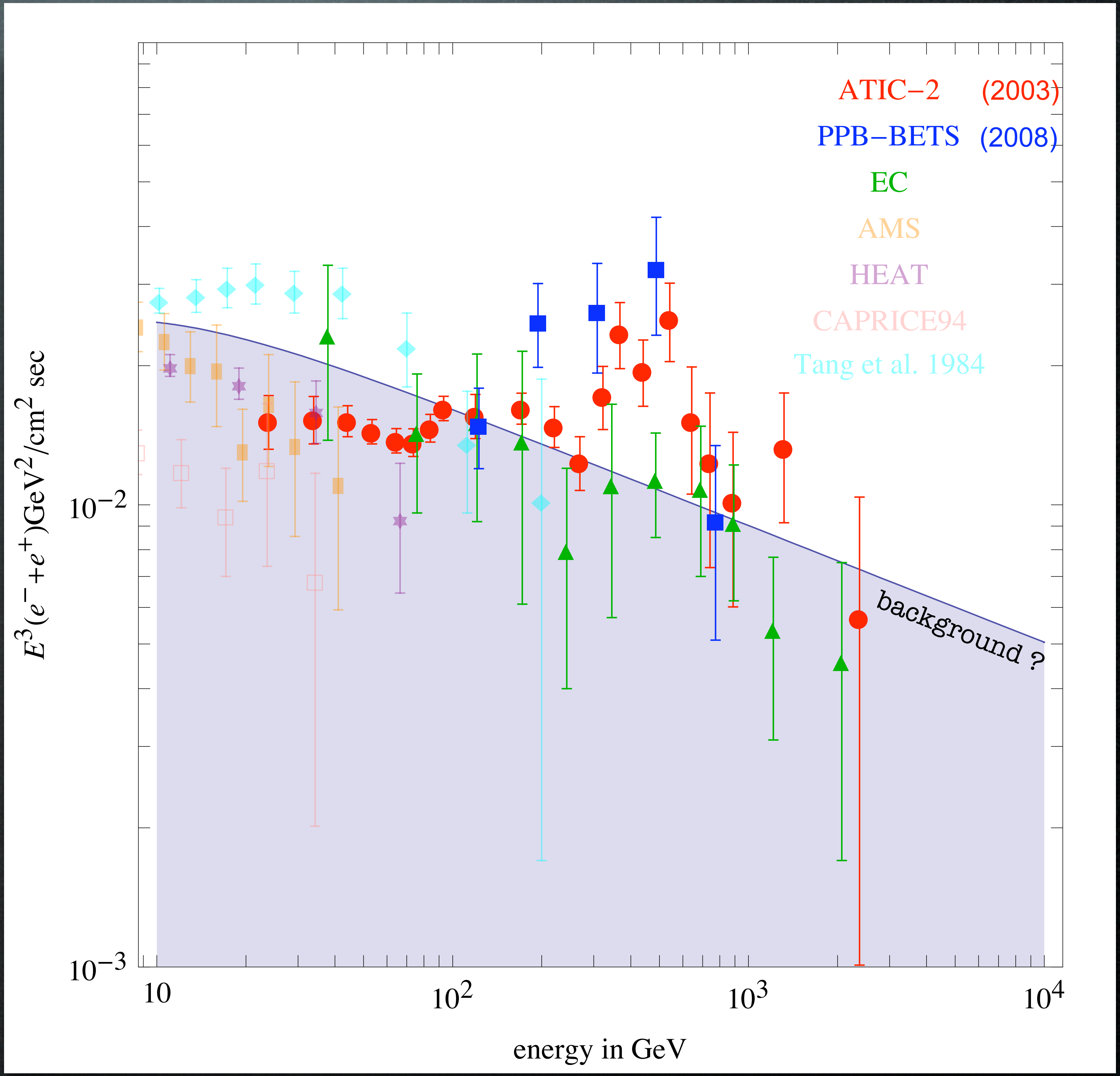
- bigger/denser: higher energy

- calorimeter only, no magnet:
  no charge discrimination

Data sets

Electrons + positrons from ATIC, PPB-BETS:

- an $e^+ + e^-$ excess at $\sim$700 GeV??

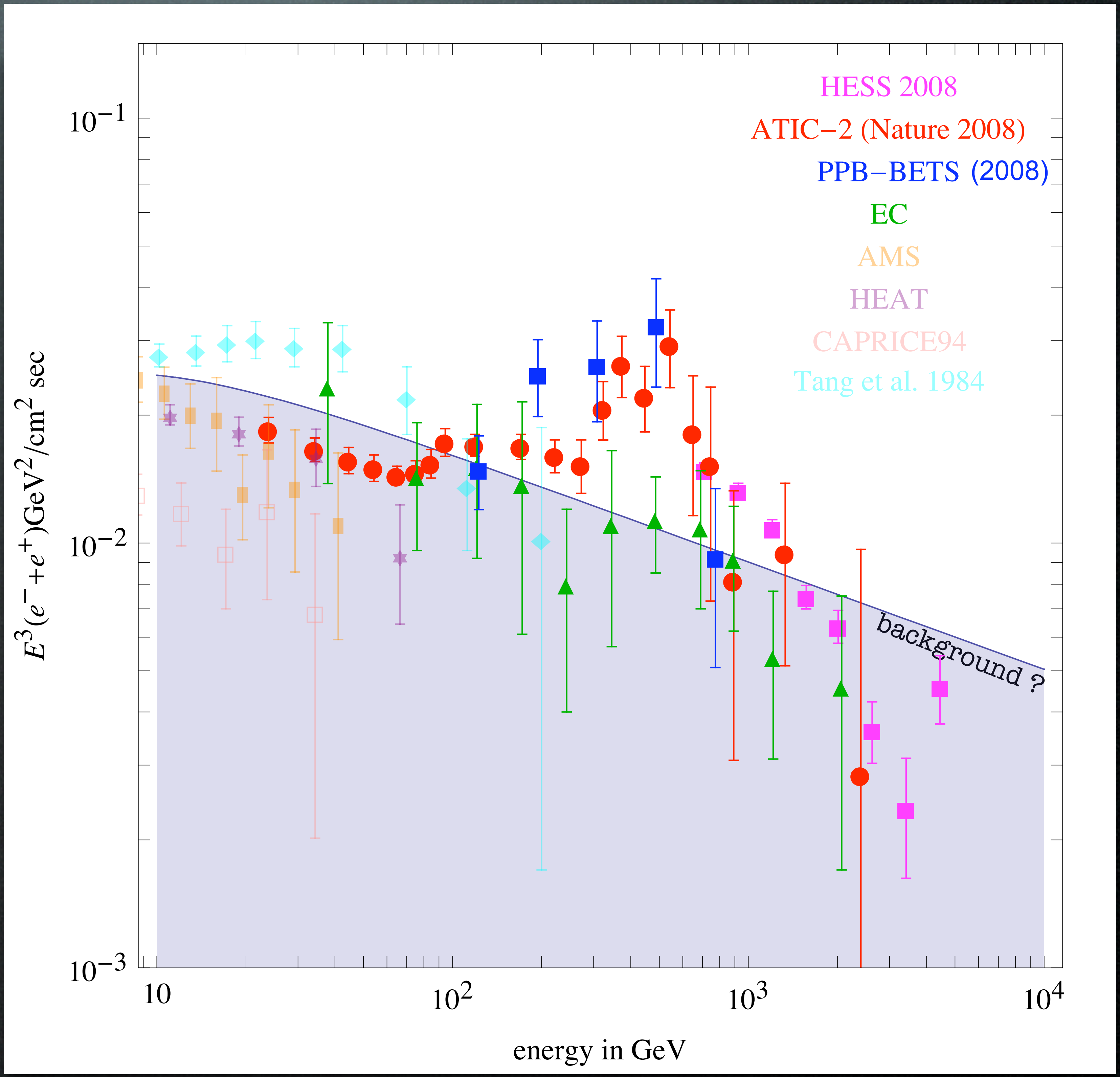


(ATIC: 1724 $e^+ + e^-$ collected at >100 GeV; 4σ above bkgnd)

Data sets

Electrons + positrons from ATIC, PPB-BETS and HESS!:

- an $e^+ + e^-$ excess at $\sim$700 GeV??



HESS:
very interesting (independent!)
but difficult analysis
(particle ID: contamination
from gamma & hadronic showers):
are these upper limits?

[future data from GLAST]

Results

Which DM spectra can fit the data?

A DM with: -mass $M_{\rm DM} = 1\,{\rm TeV}$

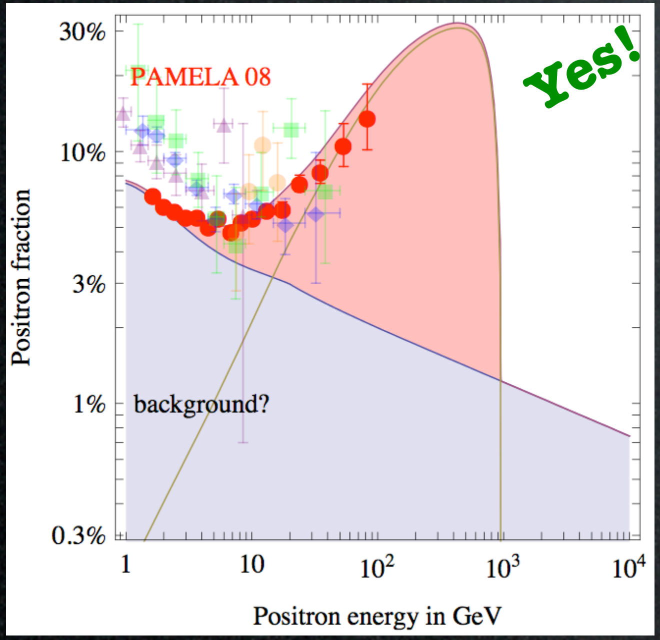
-annihilation ${\rm DM\ DM} \to \mu^+\mu^-$

Results

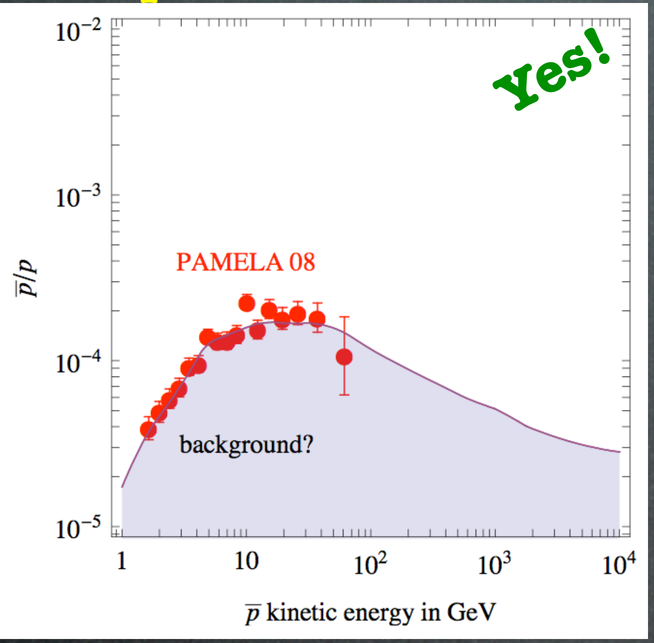
Which DM spectra can fit the data?

A DM with: -mass $M_{\rm DM} = 1\,{\rm TeV}$
-annihilation ${\rm DM\ DM} \to \mu^+\mu^-$

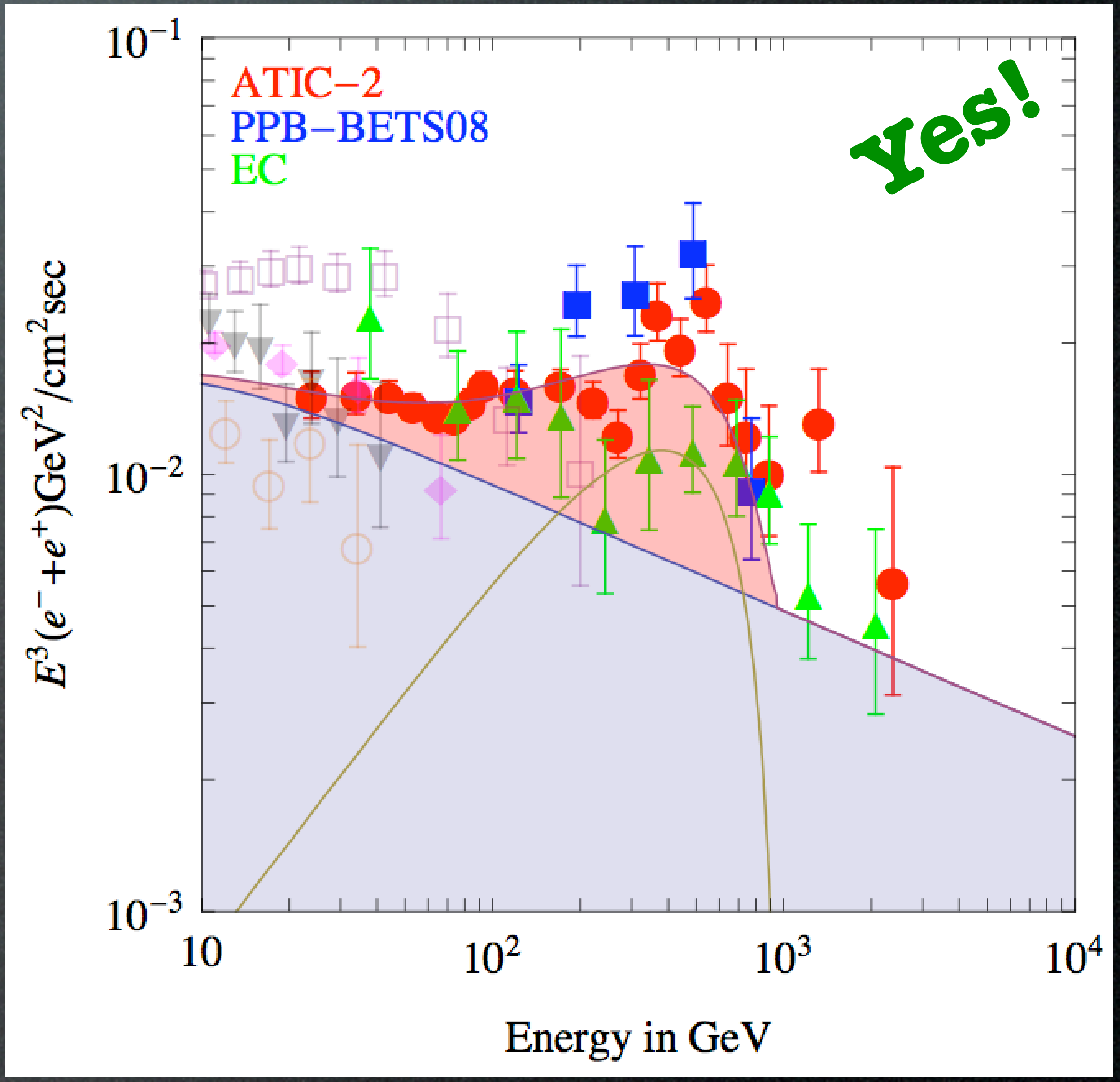
Positrons:



Anti-protons:



Electrons + Positrons:



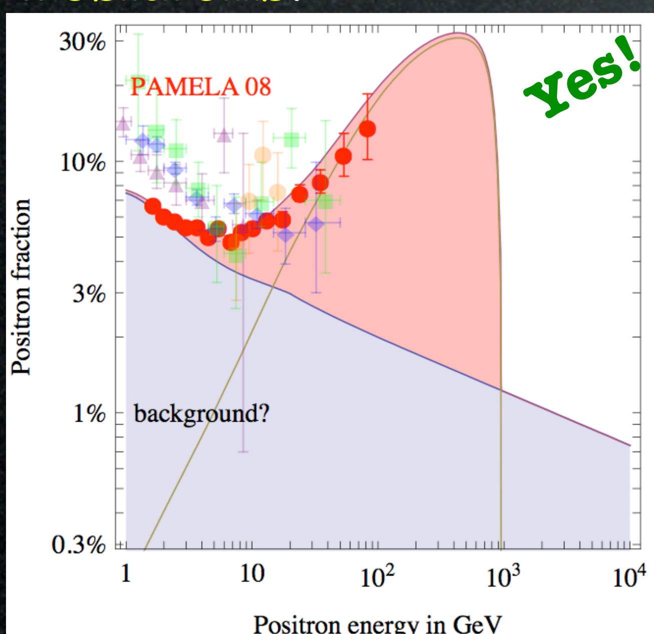
Results

Which DM spectra can fit the data?

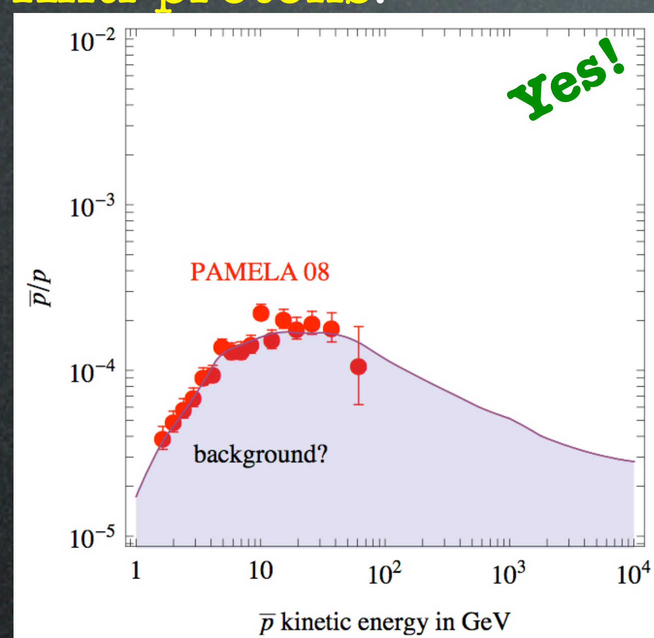
A DM with: -mass $M_{\rm DM} = 1\,\mathrm{TeV}$

-annihilation $\mathrm{DM\,DM} \to \mu^+\mu^-$

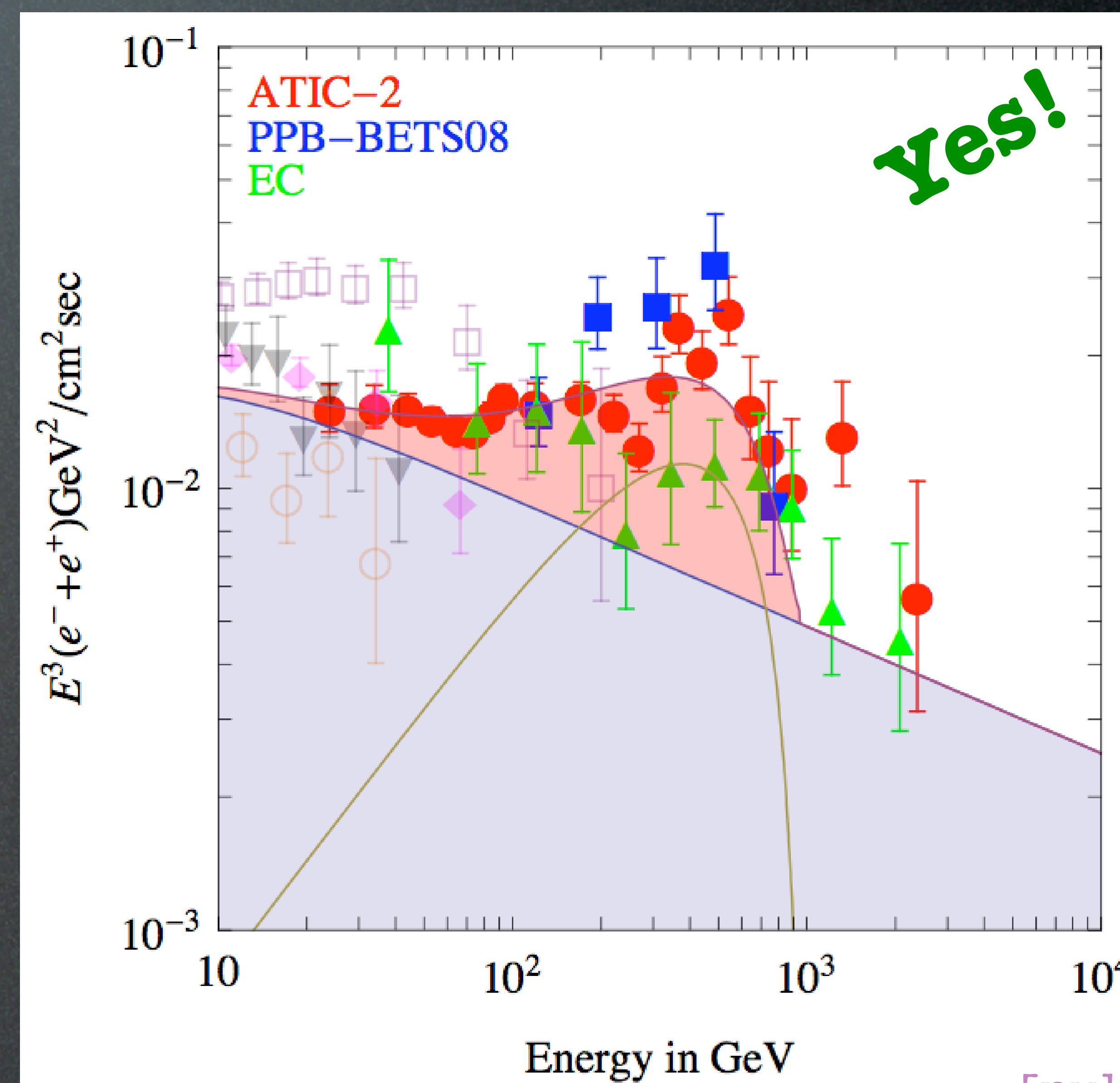
Positrons:



Anti-protons:



Electrons + Positrons:



[pulsar]

Have we identified the DM for the first time???

Arkani-Hamed, Weiner et al. 0810: Yes!
+ a ton of others

Results

Which DM can fit the data?

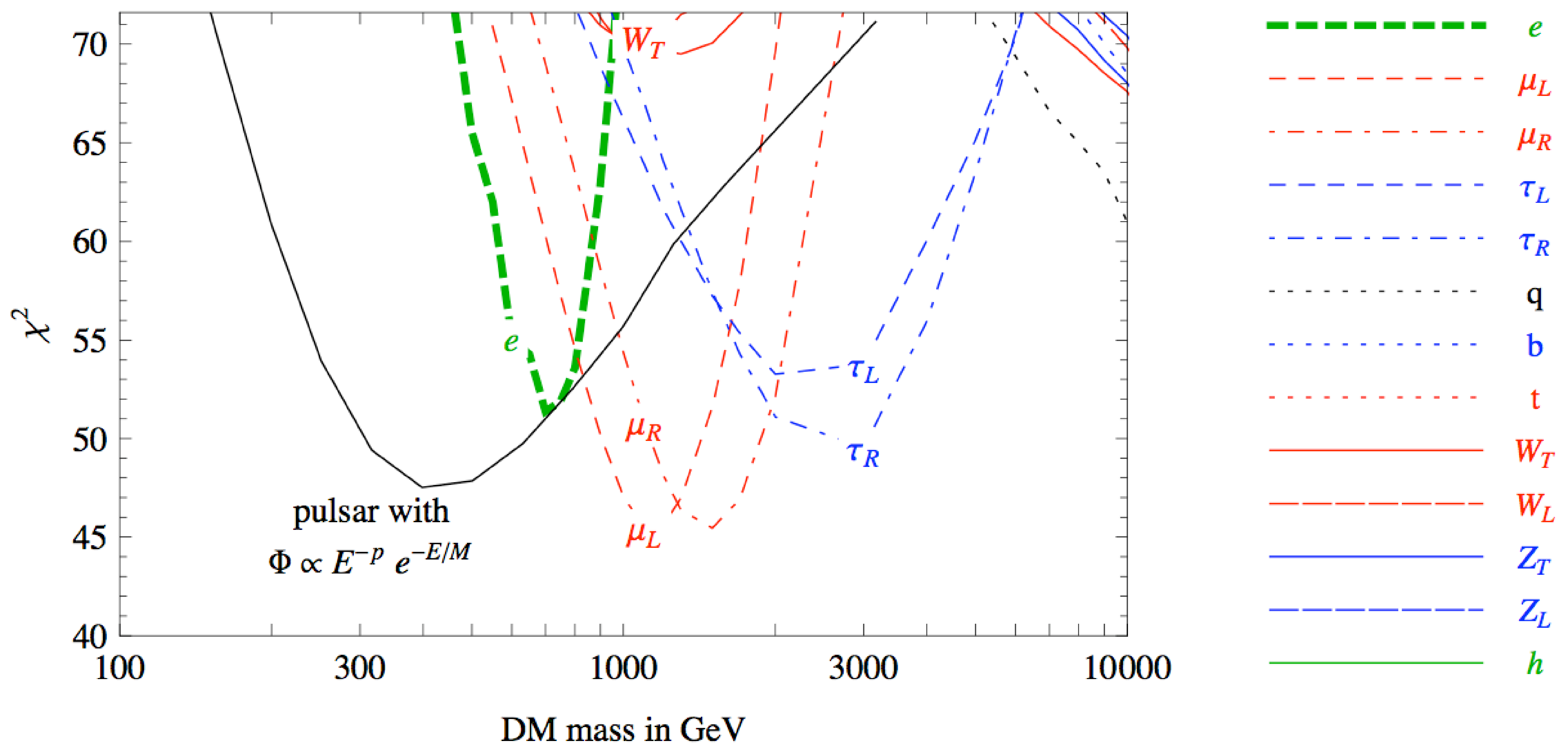
M.Pospelov and A.Ritz, 0810.1502: Secluded DM - A.Nelson and C.Spitzer, 0810.5167: Slightly Non-Minimal DM - Y.Nomura and J.Thaler, 0810.5397: DM through the Axion Portal - R.Harnik and G.Kribs, 0810.5557: Dirac DM - D.Feldman, Z.Liu, P.Nath, 0810.5762: Hidden Sector - T.Hambye, 0811.0172: Hidden Vector - Yin, Yuan, Liu, Zhang, Bi, Zhu, 0811.0176: Leptonically decaying DM - K.Ishiwata, S.Matsumoto, T.Moroi, 0811.0250: Superparticle DM - Y.Bai and Z.Han, 0811.0387: sUED DM - P.Fox, E.Poppitz, 0811.0399: Leptophilic DM - C.Chen, F.Takahashi, T.T.Yanagida, 0811.0477: Hidden-Gauge-Boson DM - K.Hamaguchi, E.Nakamura, S.Shirai, T.T.Yanagida, 0811.0737: Decaying DM in Composite Messenger - E.Ponton, L.Randall, 0811.1029: Singlet DM - A.Ibarra, D.Tran, 0811.1555: Decaying DM - S.Baek, P.Ko, 0811.1646: U(1) Lmu-Ltau DM - C.Chen, F.Takahashi, T.T.Yanagida, 0811.3357: Decaying Hidden-Gauge-Boson DM - I.Cholis, G.Dobler, D.Finkbeiner, L.Goodenough, N.Weiner, 0811.3641: 700+ GeV WIMP - E.Nardi, F.Sannino, A.Strumia, 0811.4153: Decaying DM in TechniColor - K.Zurek, 0811.4429: Multicomponent DM - M.Ibe, H.Murayama, T.T.Yanagida, 0812.0072: Breit-Wigner enhancement of DM annihilation - E.Chun, J.-C.Park, 0812.0308: sub-GeV hidden U(1) in GMSB - M.Lattanzi, J.Silk, 0812.0360: Sommerfeld enhancement in cold substructures - M.Pospelov, M.Trott, 0812.0432: super-WIMPs decays DM - Zhang, Bi, Liu, Liu, Yin, Yuan, Zhu, 0812.0522: Discrimination with SR and IC - Liu, Yin, Zhu, 0812.0964: DMnu from GC - M.Pohl, 0812.1174: electrons from DM - J.Hisano, M.Kawasaki, K.Kohri, K.Nakayama, 0812.0219: DMnu from GC - A.Arvanitaki, S.Dimopoulos, S.Dubovsky, P.Graham, R.Harnik, S.Rajendran, 0812.2075: Decaying DM in GUTs - R.Allahverdi, B.Dutta, K.Richardson-McDaniel, Y.Santoso, 0812.2196: SuSy B-L DM- S.Hamaguchi, K.Shirai, T.T.Yanagida, 0812.2374: Hidden-Fermion DM decays - D.Hooper, A.Stebbins, K.Zurek, 0812.3202: Nearby DM clump - C.Delaunay, P.Fox, G.Perez, 0812.3331: DMnu from Earth - Park, Shu, 0901.0720: Split-UED DM - .Gogoladze, R.Khalid, Q.Shafi, H.Yuksel, 0901.0923: cMSSM DM with additions - Q.H.Cao, E.Ma, G.Shaughnessy, 0901.1334: Dark Matter: the leptonic connection - E.Nezri, M.Tytgat, G.Vertongen, 0901.2556: Inert Doublet DM - C.-H.Chen, C.-Q.Geng, D.Zhuridov, 0901.2681: Fermionic decaying DM - J.Mardon, Y.Nomura, D.Stolarski, J.Thaler, 0901.2926: Cascade annihilations (light non-abelian new bosons) - P.Meade, M.Papucci, T.Volansky, 0901.2925: DM sees the light - D.Phalen, A.Pierce, N.Weiner, 0901.3165: New Heavy Lepton - T.Banks, J.-F.Fortin, 0901.3578: Pyrma baryons - K.Bae, J.-H. Huh, J.Kim, B.Kyae, R.Viollier, 0812.3511: electrophilic axion from flipped-SU(5) with extra spontaneously broken symmetries and a two component DM with Z_2 parity - ...

Results

Which DM spectra can fit the data?

Model-independent results:

fit to PAMELA positrons* + balloon experiments

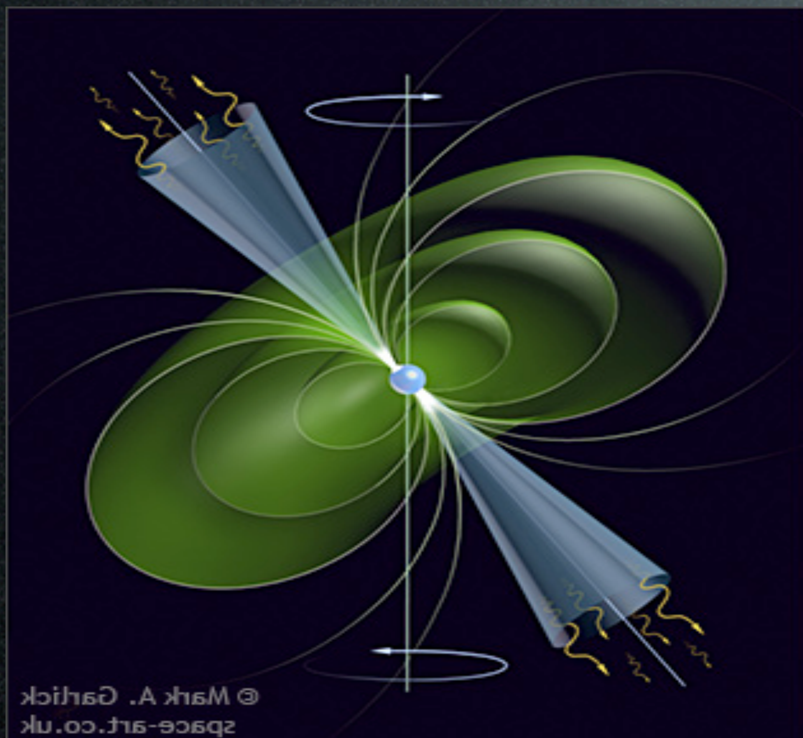


*adding anti-protons does not change much, non-leptonic channels give too smooth spectrum for balloons

Astrophysical explanation?

[others?]

Or perhaps it's just a young, nearby pulsar...



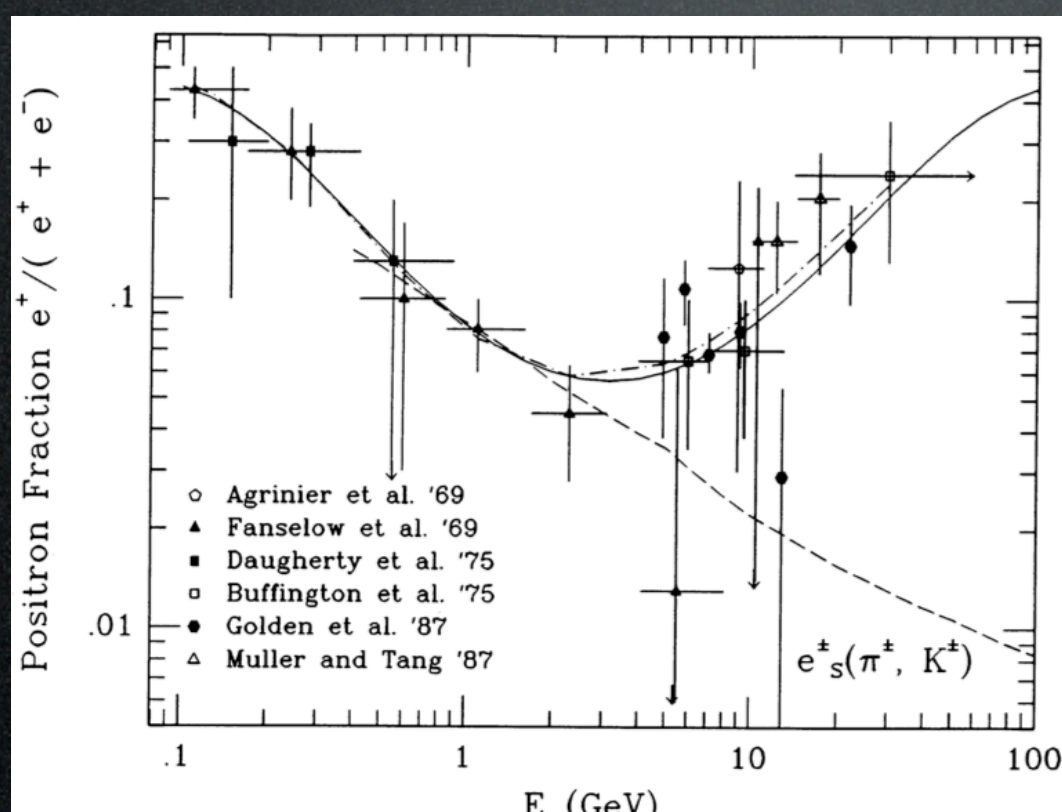
'Mechanism': the spinning $\vec{B}$ of the pulsar strips e^- that emit γ that make production of $e^\pm$ pairs that are trapped in the cloud, further accelerated and later released at $\tau \sim 0 \to 10^5$ yr (typical total energy output: 10^{46} erg).

Must be young (T < 10^5 yr) and nearby (< 1 kpc);
if not: too much diffusion, low energy, too low flux.

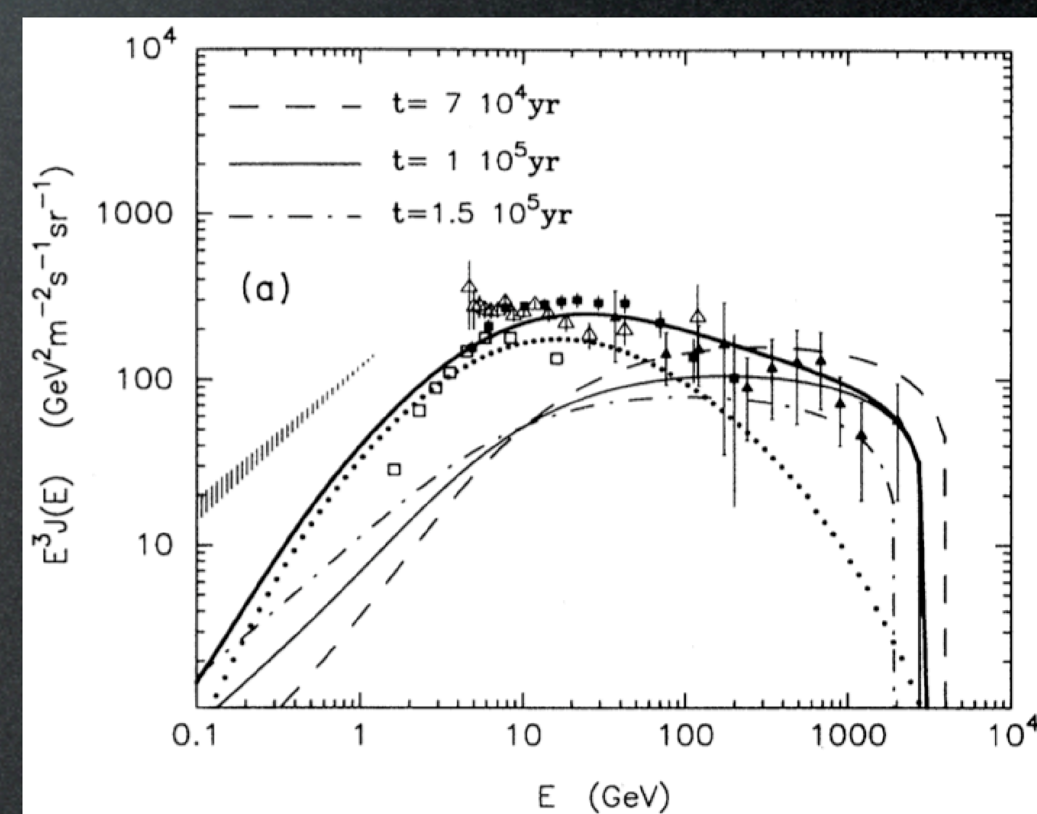
Predicted flux: $\Phi_{e^\pm} \approx E^{-p} \exp(E/E_c)$ with $p \approx 2$ and $E_c \sim$ many TeV

$(1.4 < p < 2.4,$ Profumo 2008)

Not a new idea:



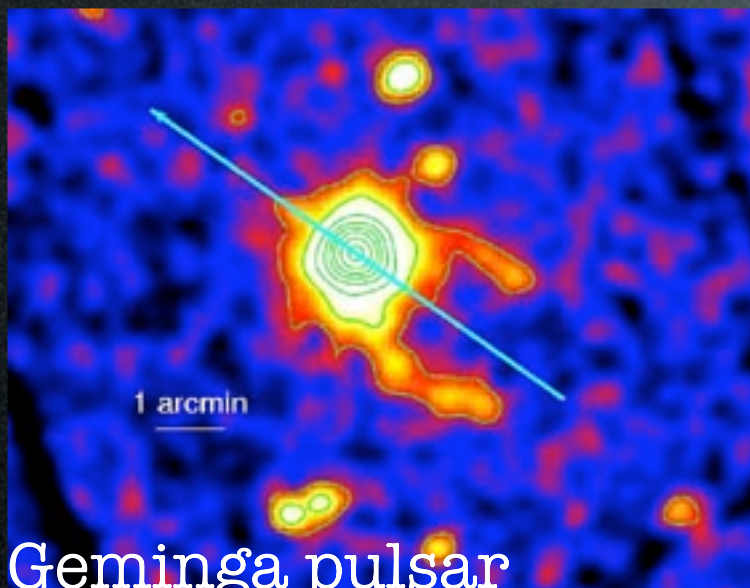
A.Boulares, APJ 342 (**1989**)



Atoyan, Aharonian, Volk (**1995**)

Astrophysical explanation?

Or perhaps it's just a young, nearby pulsar...



Geminga pulsar
(funny that it means:
"it is not there" in milanese)

'Mechanism': the spinning $\vec{B}$ of the pulsar strips e^- that emit γ that make production of $e^\pm$ pairs that are trapped in the cloud, further accelerated and later released at $\tau \sim 0 \to 10^5$ yr.

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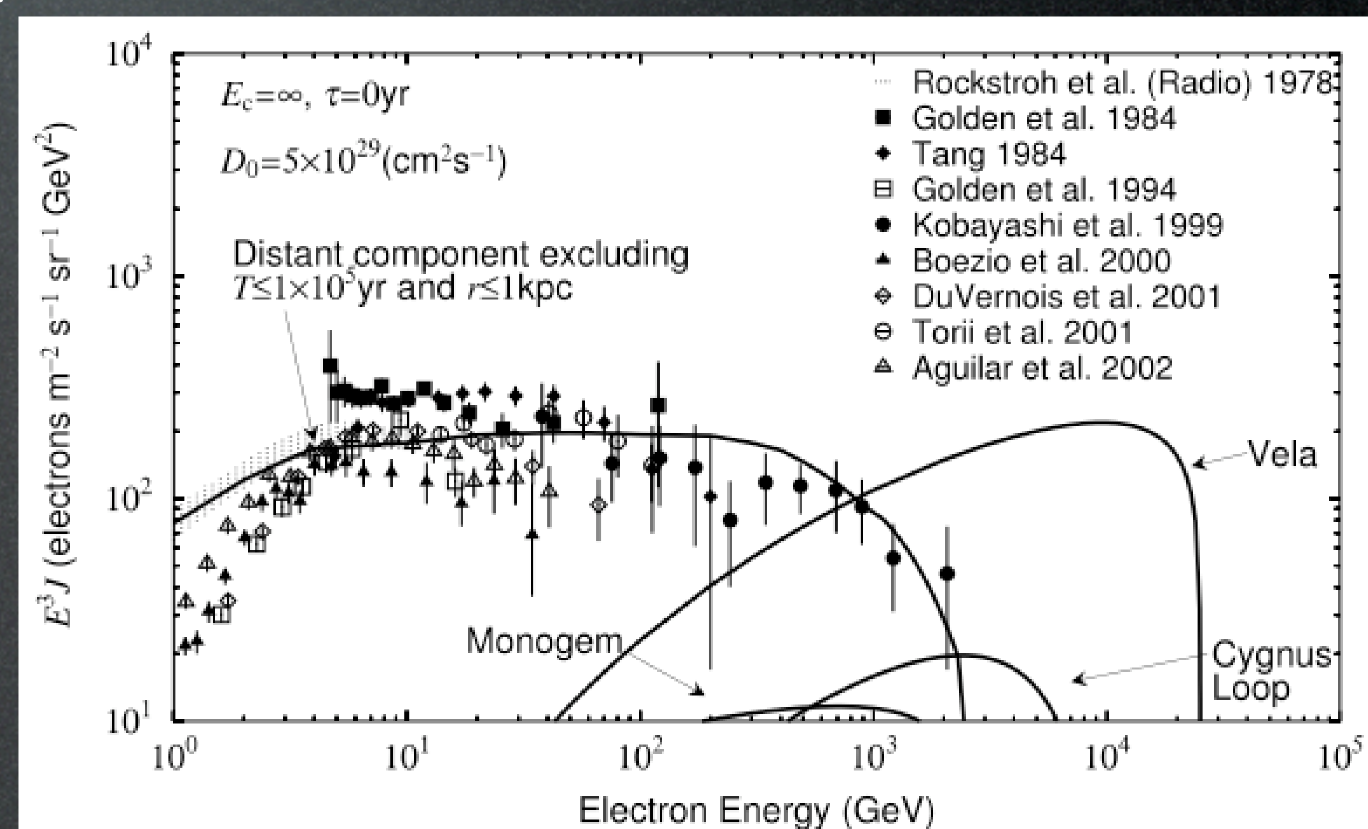
Predicted flux: $\Phi_{e^\pm} \approx E^{-p} \exp(E/E_c)$ with $p \approx 2$ and
$E_c \sim$ many TeV

Try the fit with known nearby pulsars:

TABLE 1
List of Nearby SNRs

SNR	Distance (kpc)	Age (yr)	E_{max} [a] (TeV)
SN 185	0.95	1.8×10^3	1.7×10^2
S147	0.80	4.6×10^3	63
HB 21	0.80	1.9×10^4	14
G65.3+5.7	0.80	2.0×10^4	13
Cygnus Loop	0.44	2.0×10^4	13
Vela	0.30	1.1×10^4	25
Monogem	0.30	8.6×10^4	2.8
Loop1	0.17	2.0×10^5	1.2
Geminga	0.4	3.4×10^5	0.67

Kobayashi, Komori et al. 2004



Kobayashi, Komori et al. 2004

Astrophysical explanation?

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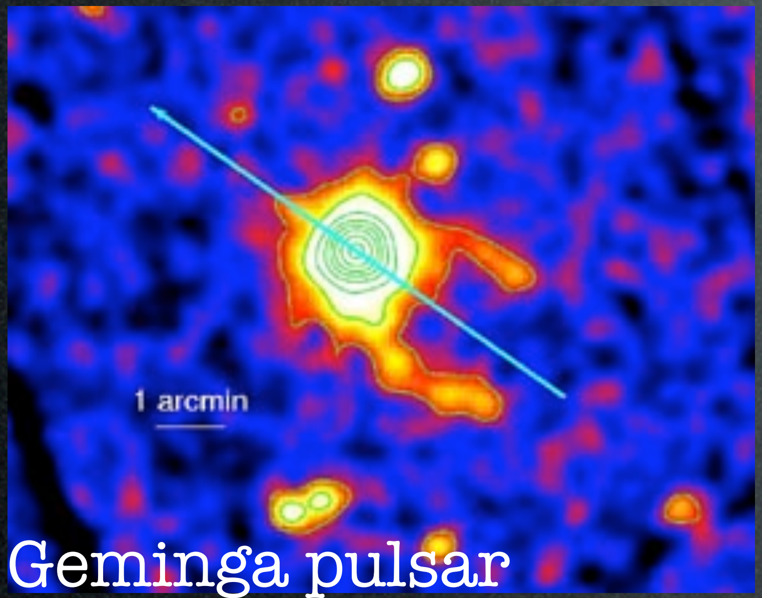

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Predicted flux: $\Phi_{e^\pm} \approx E^{-p}\exp(E/E_c)$ with $p \approx 2$ and $E_c \sim$ many TeV

Try the fit with known nearby pulsars:

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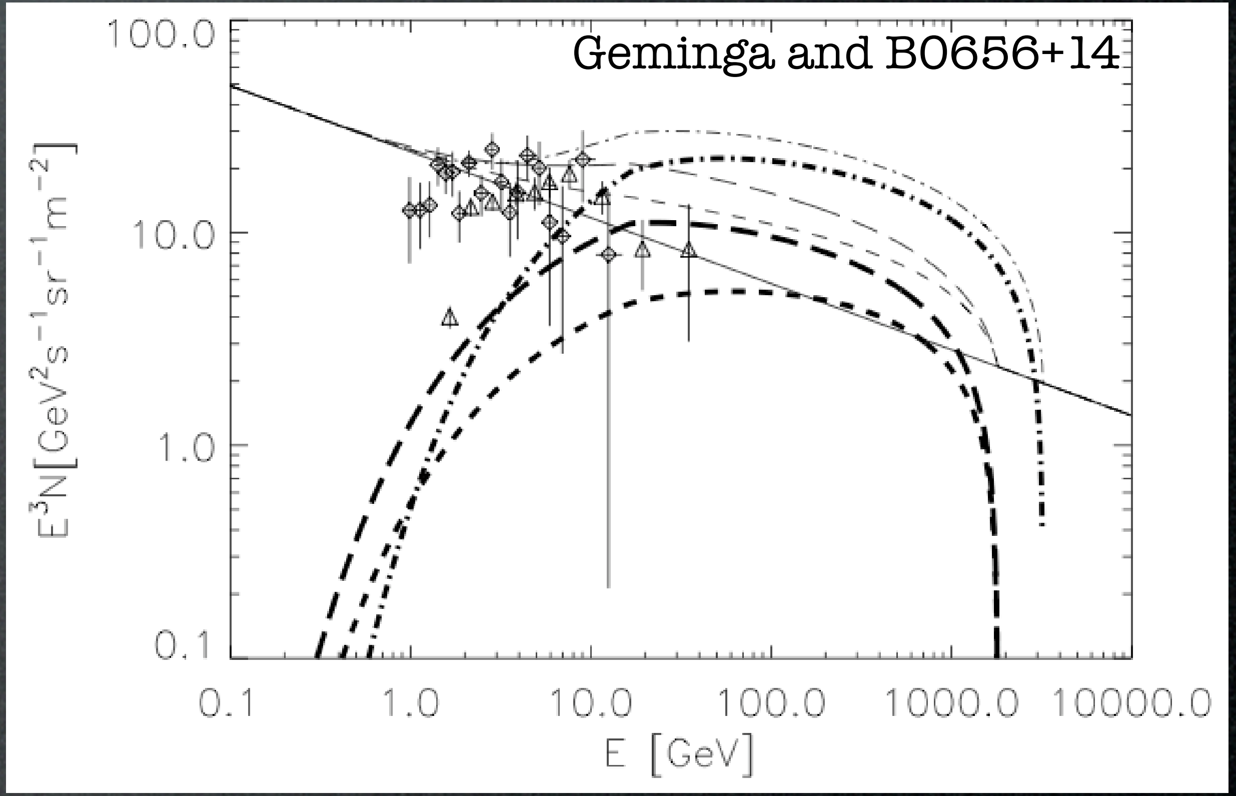
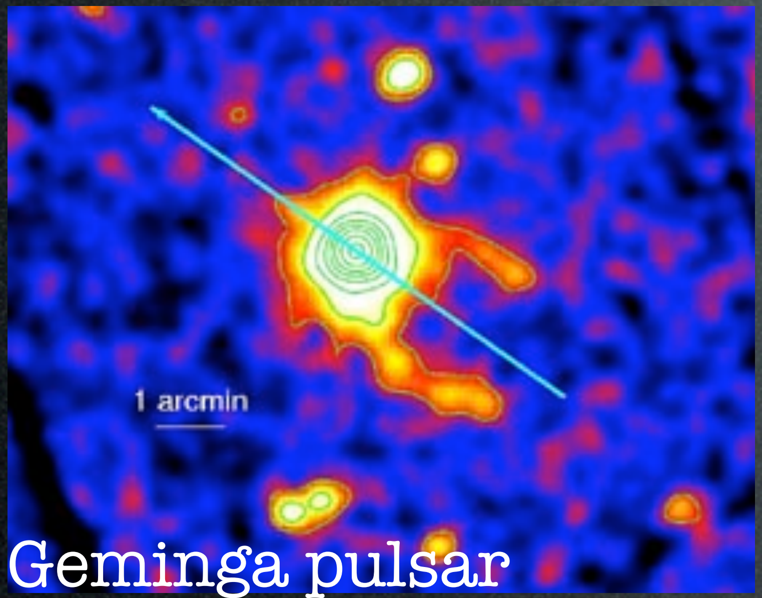
Geminga	0.4	3.4×10^5	0.67



Büshing, de Jager et al. 0804.0220

Astrophysical explanation?

Or perhaps it's just a young, nearby pulsar...

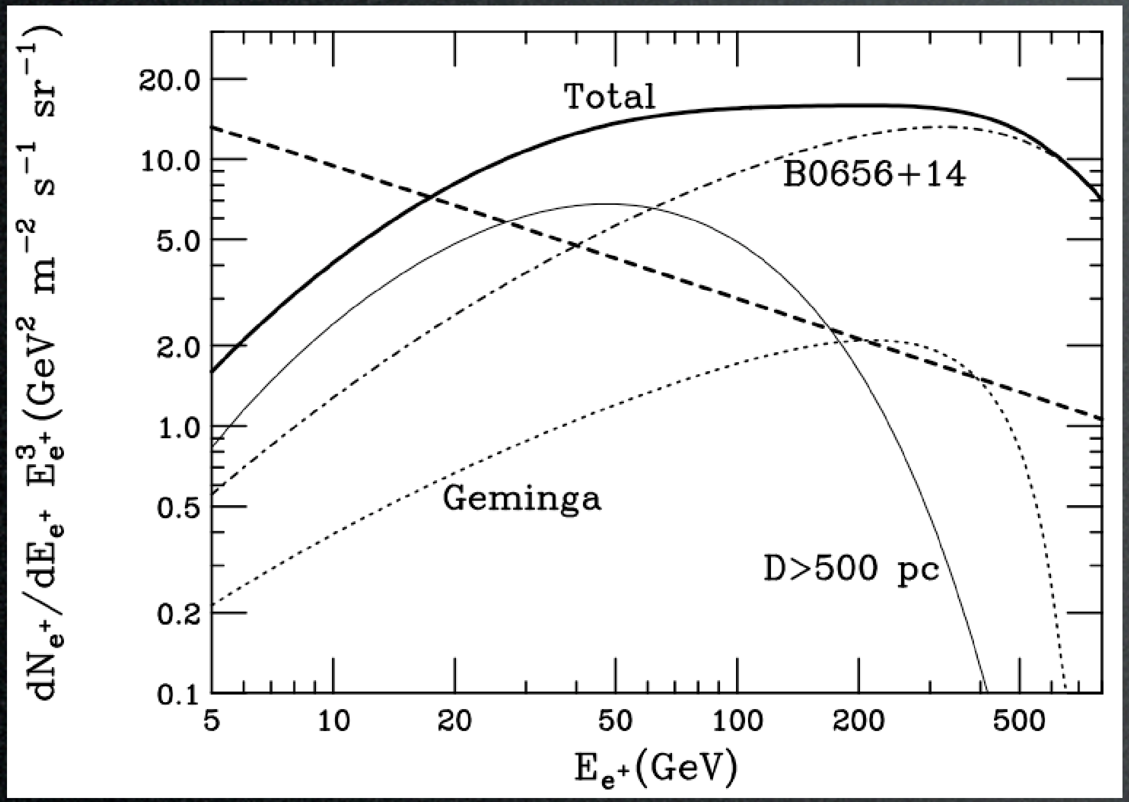


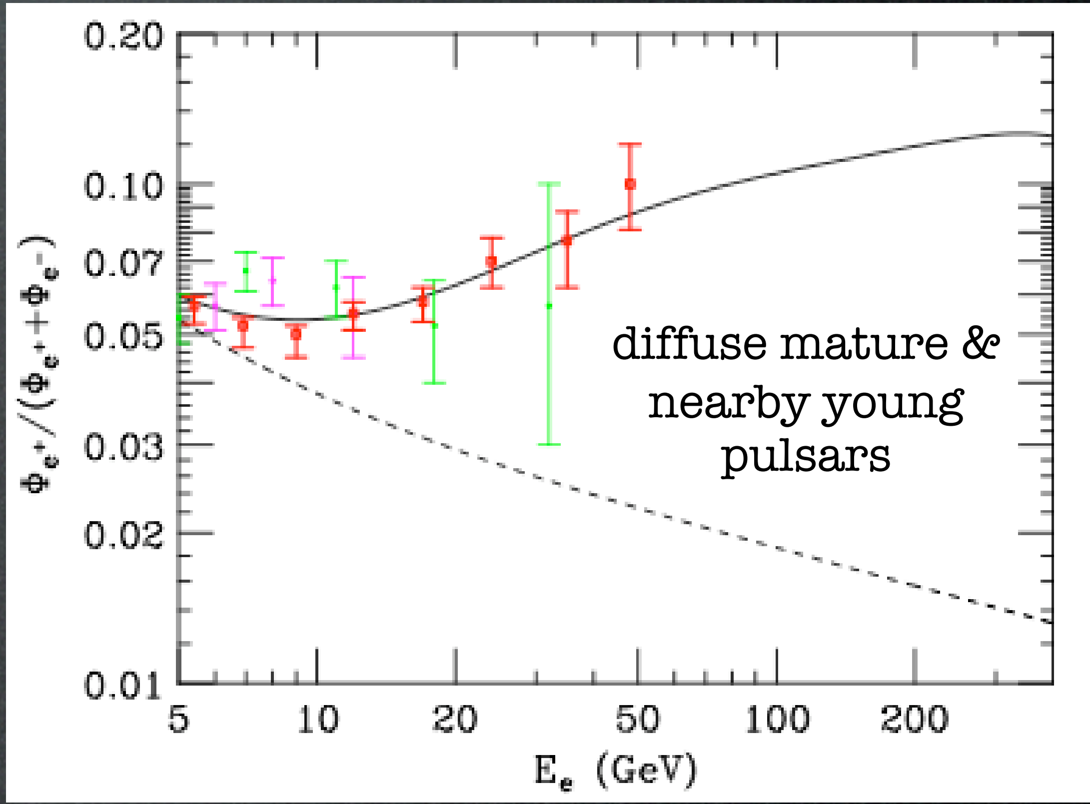
'Mechanism': the spinning $\vec{B}$ of the pulsar strips e^- that emit γ that make production of $e^\pm$ pairs that are trapped in the cloud, further accelerated and later released at $\tau \sim 0 \to 10^5$ yr.

Must be young (T < 10^5 yr) and nearby (< 1 kpc);
if not: too much diffusion, low energy, too low flux.

Predicted flux: $\Phi_{e^\pm} \approx E^{-p} \exp(E/E_c)$ with $p \approx 2$ and $E_c \sim$ many TeV

Try the fit with known nearby pulsars and diffuse mature pulsars:

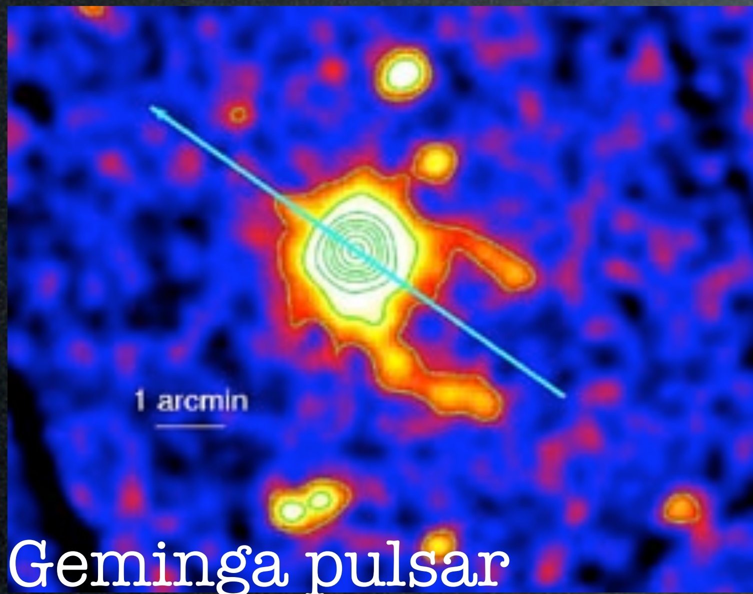




Hooper, Blasi, Serpico 2008

Astrophysical explanation?

Or perhaps it's just a young, nearby pulsar...



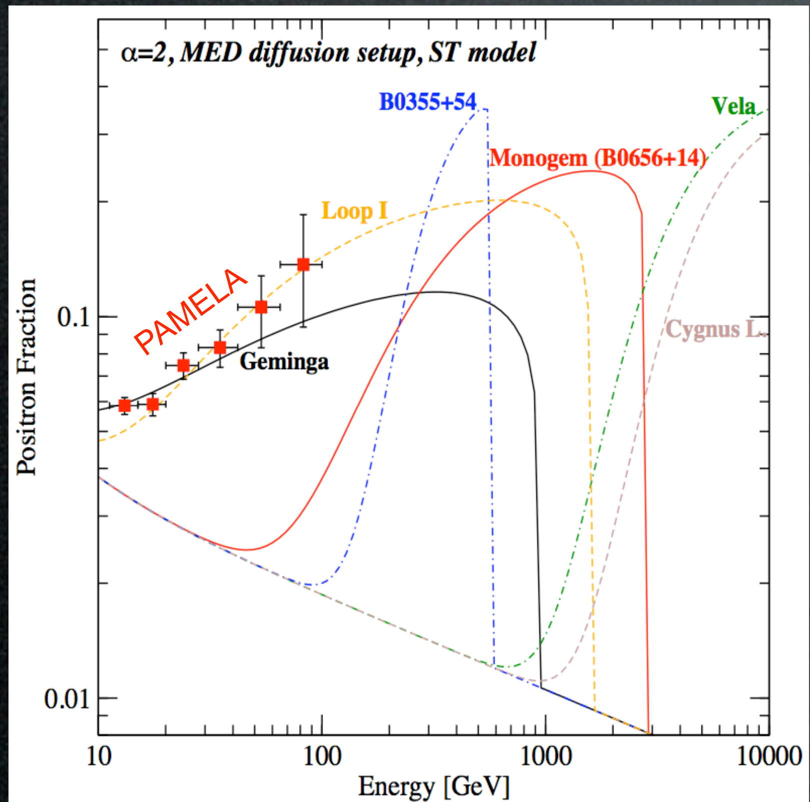
Geminga pulsar

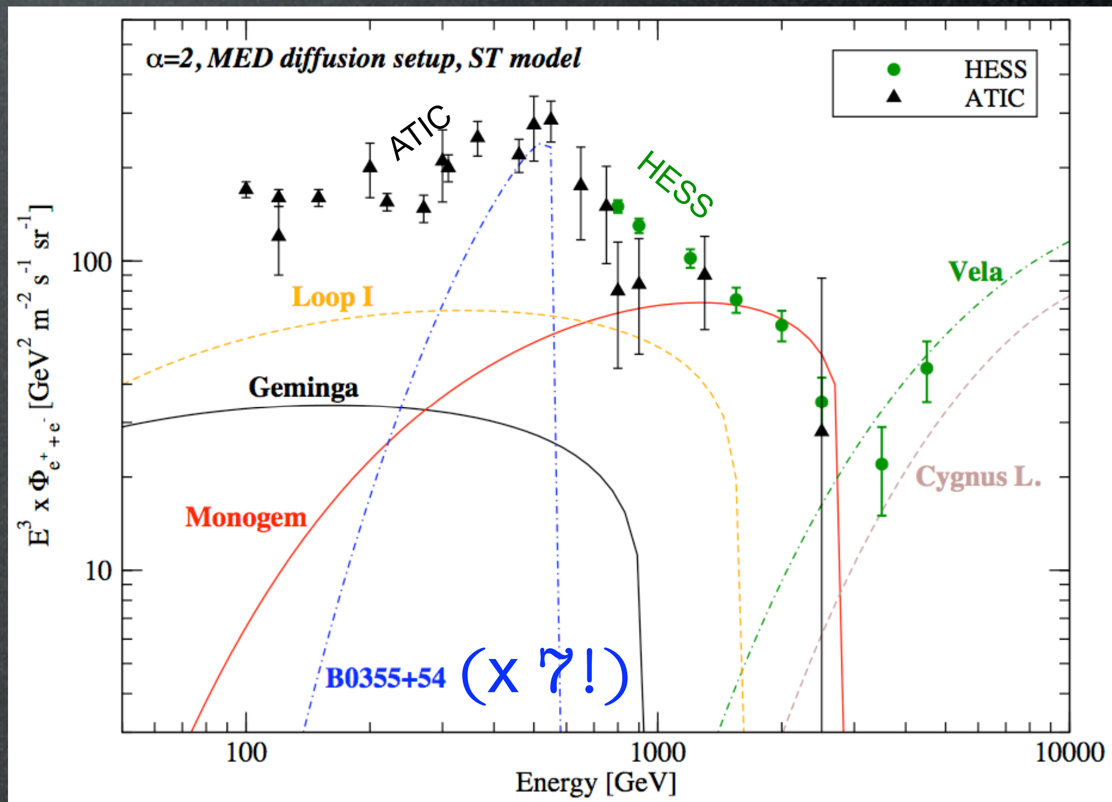
'Mechanism': the spinning $\vec{B}$ of the pulsar strips e^- that emit γ that make production of $e^\pm$ pairs that are trapped in the cloud, further accelerated and later released at $\tau \sim 0 \to 10^5$ yr.

Must be young (T < 10^5 yr) and nearby (< 1 kpc);
if not: too much diffusion, low energy, too low flux.

Predicted flux: $\Phi_{e^\pm} \approx E^{-p} \exp(E/E_c)$ with $p \approx 2$ and $E_c \sim$ many TeV

But ATIC needs a different (and very powerful) source:

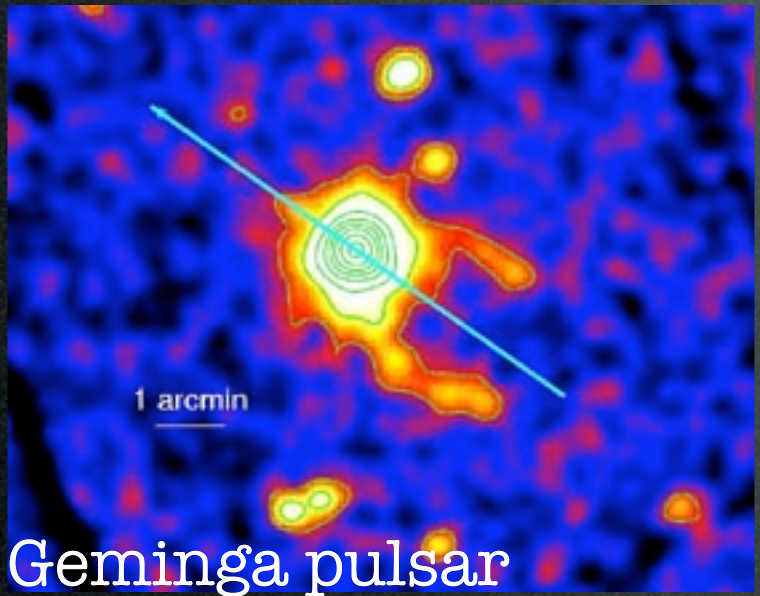




Profumo 0812.4457

Astrophysical explanation?

Or perhaps it's just a young, nearby pulsar...



Geminga pulsar

'Mechanism': the spinning $\vec{B}$ of the pulsar strips e^- that emit γ that make production of $e^\pm$ pairs that are trapped in the cloud, further accelerated and later released at $\tau \sim 0 \to 10^5\,\mathrm{yr}$.

Must be young (T < 10^5 yr) and nearby (< 1 kpc);
if not: too much diffusion, low energy, too low flux.

Predicted flux: $\Phi_{e^\pm} \approx E^{-p} \exp(E/E_c)$ with $p \approx 2$ and $E_c \sim$ many TeV

Open issue.

(look for anisotropies,
(both for single source and collection in disk)
antiprotons, gammas...
(Fermi is discovering a pulsar a week)
or shape of the spectrum...)

e.g. Yuksel, Kistler, Stanev 0810.2784
Hall, Hooper 0811.3362

[back]

DM detection

direct detection

production at colliders

indirect

γ from annihil in galactic center and from synchrotron emission

HESS, radio telescopes

e^+ from annihil in galactic halo or center

PAMELA, AMS02, **balloons**

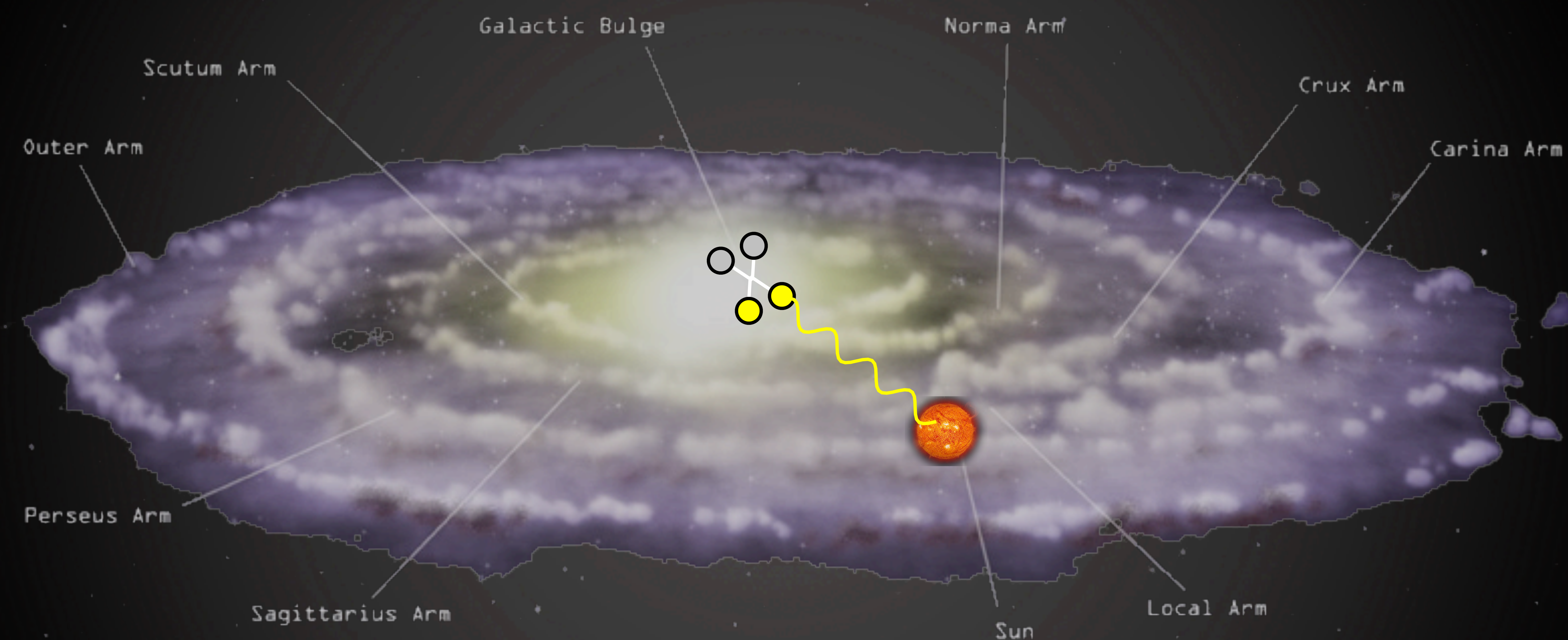
$\bar{p}$ from annihil in galactic halo or center

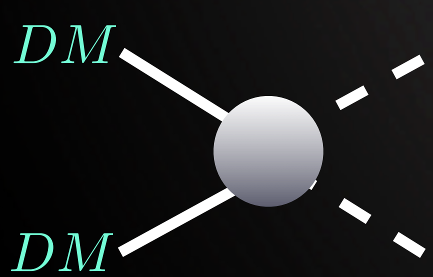
$\bar{D}$ from annihil in galactic halo or center

$\nu, \bar{\nu}$ from annihil in massive bodies

Indirect Detection

γ from DM annihilations in galactic center



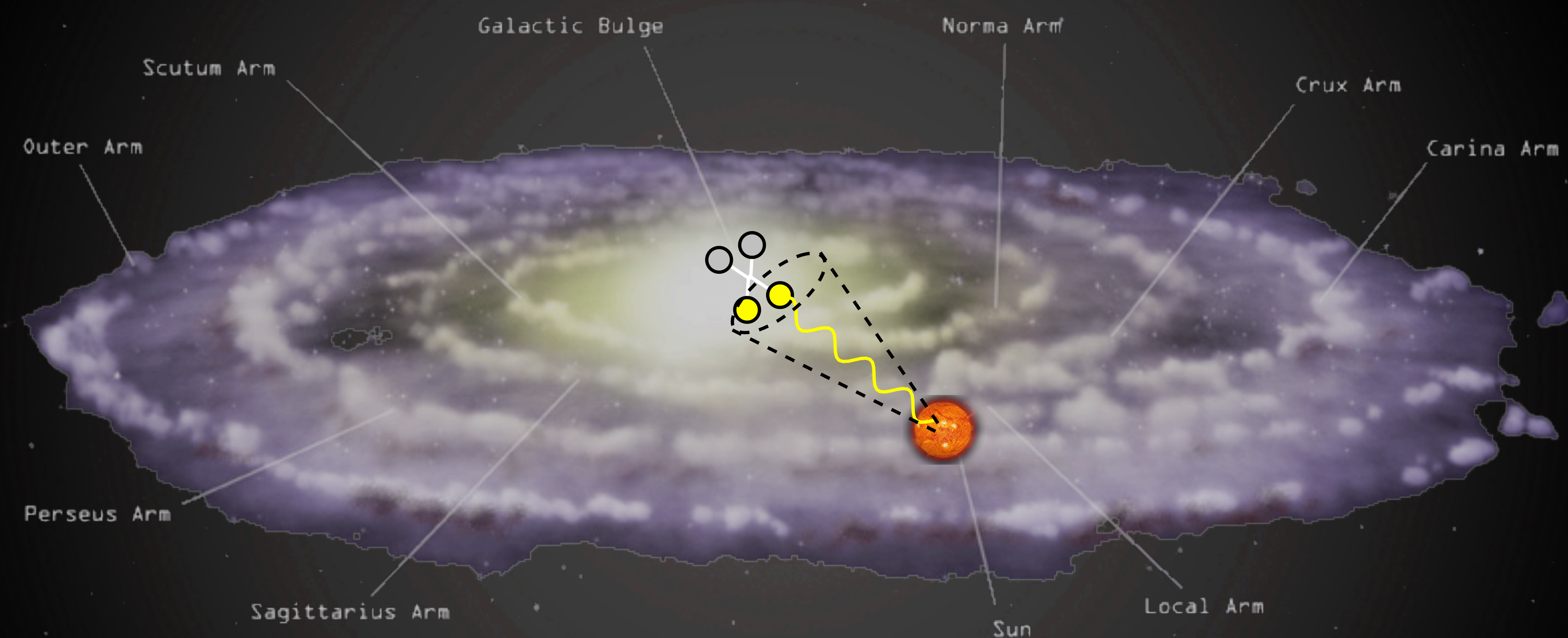


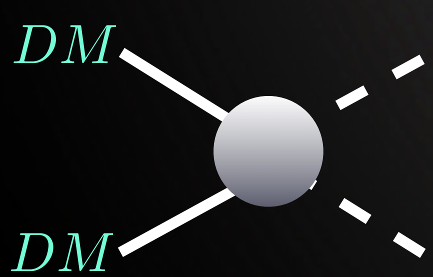
$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots$ and γ

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots$ and γ

Indirect Detection

γ from DM annihilations in galactic center



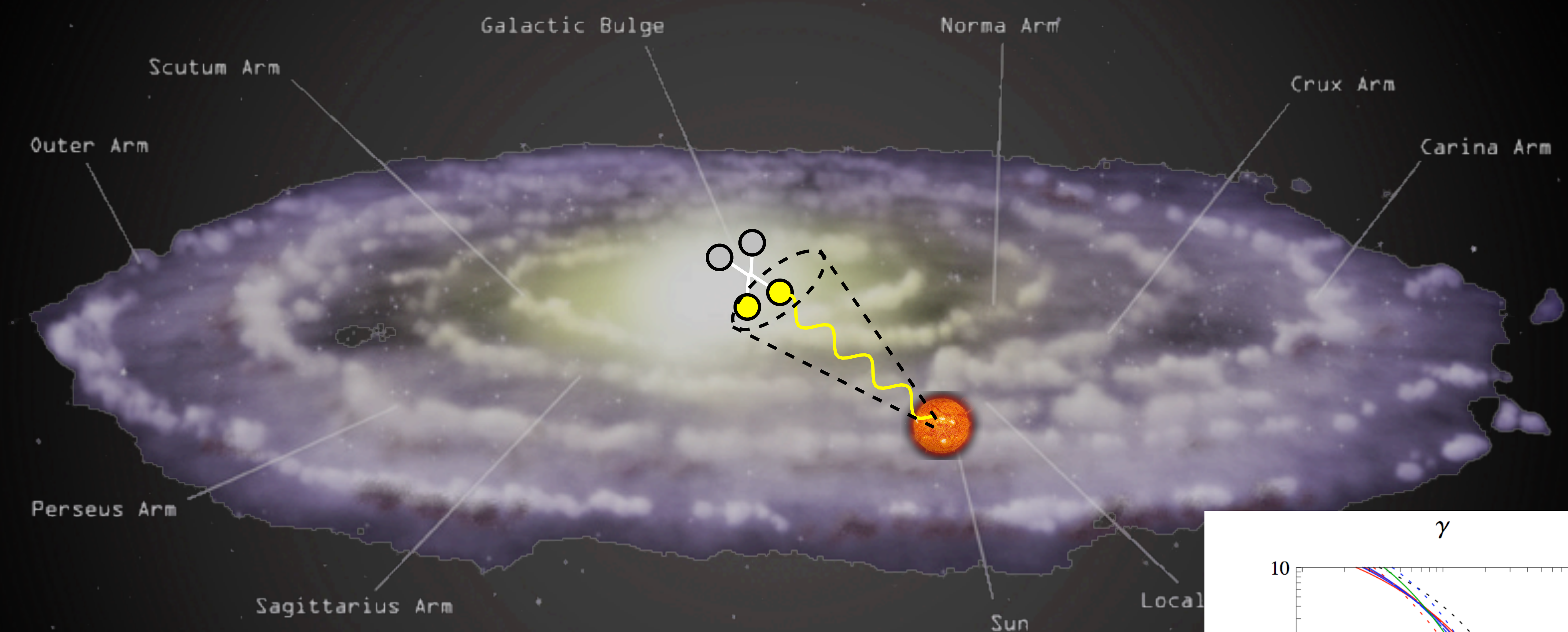


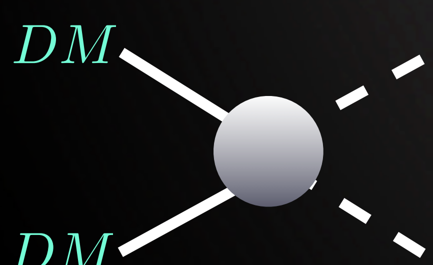
$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots$ and γ

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots$ and γ

Indirect Detection

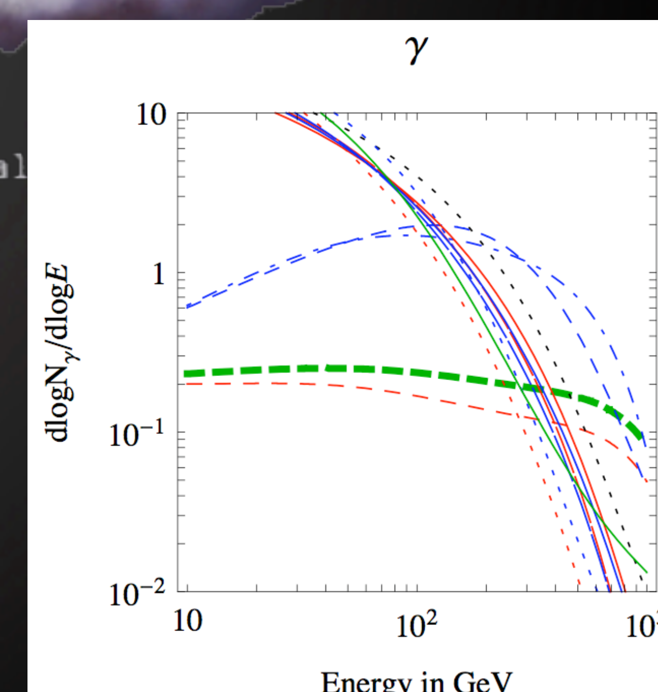
γ from DM annihilations in galactic center





$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^\mp, \overset{(-)}{p}, \overset{(-)}{D} \ldots$ and γ

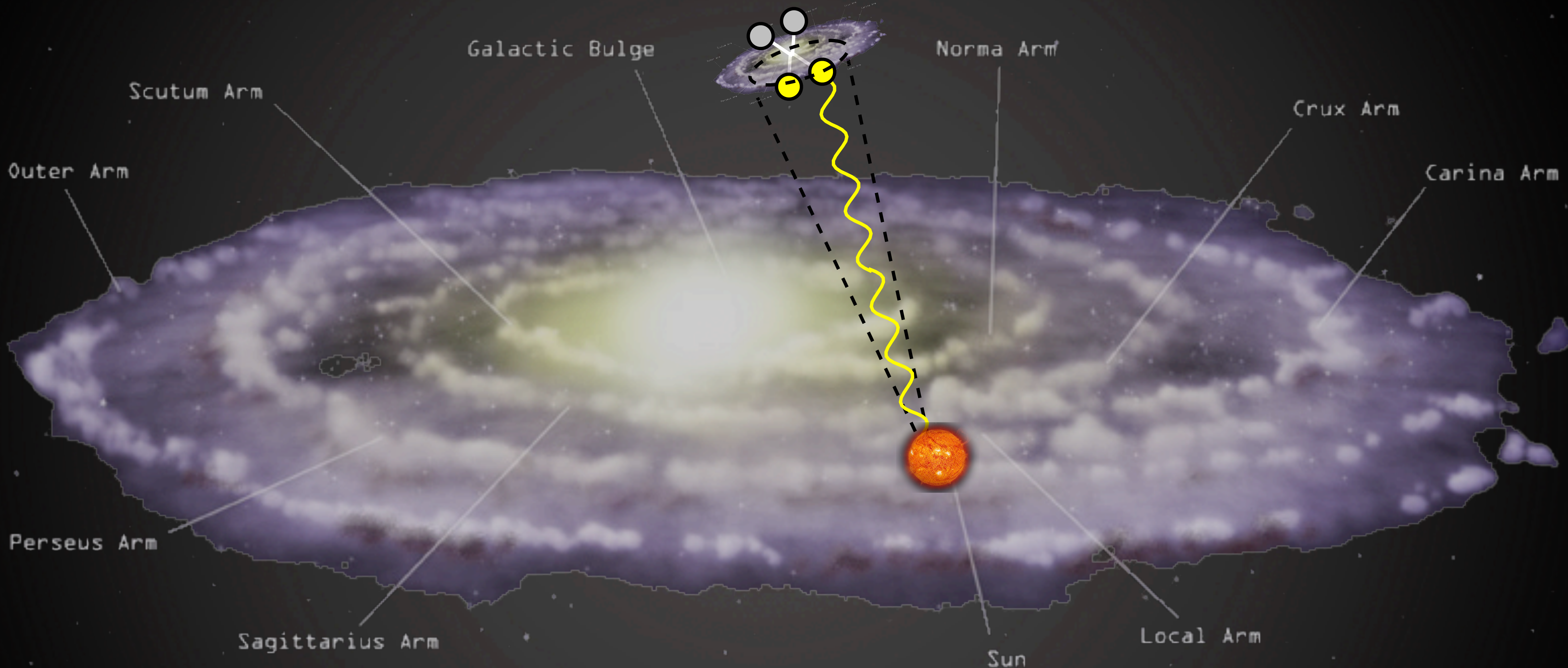
$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^\pm, \overset{(-)}{p}, \overset{(-)}{D} \ldots$ and γ



typically sub-TeV energies

Indirect Detection

γ from DM annihilations in Sagittarius Dwarf

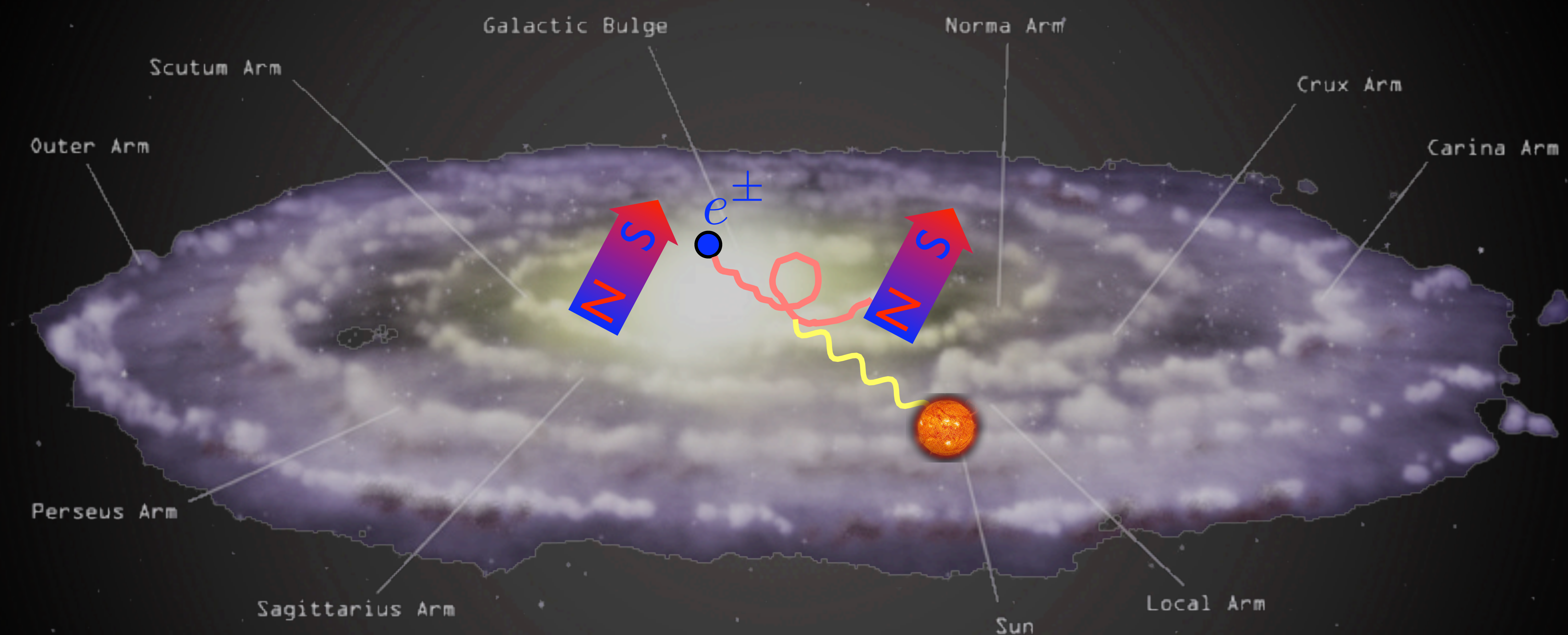


$$DM\, DM \to W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp}, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \gamma$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^{\pm}, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \gamma$$

Indirect Detection

radio-waves from synchrotron radiation of $e^{\pm}$ in GC



Indirect Detection

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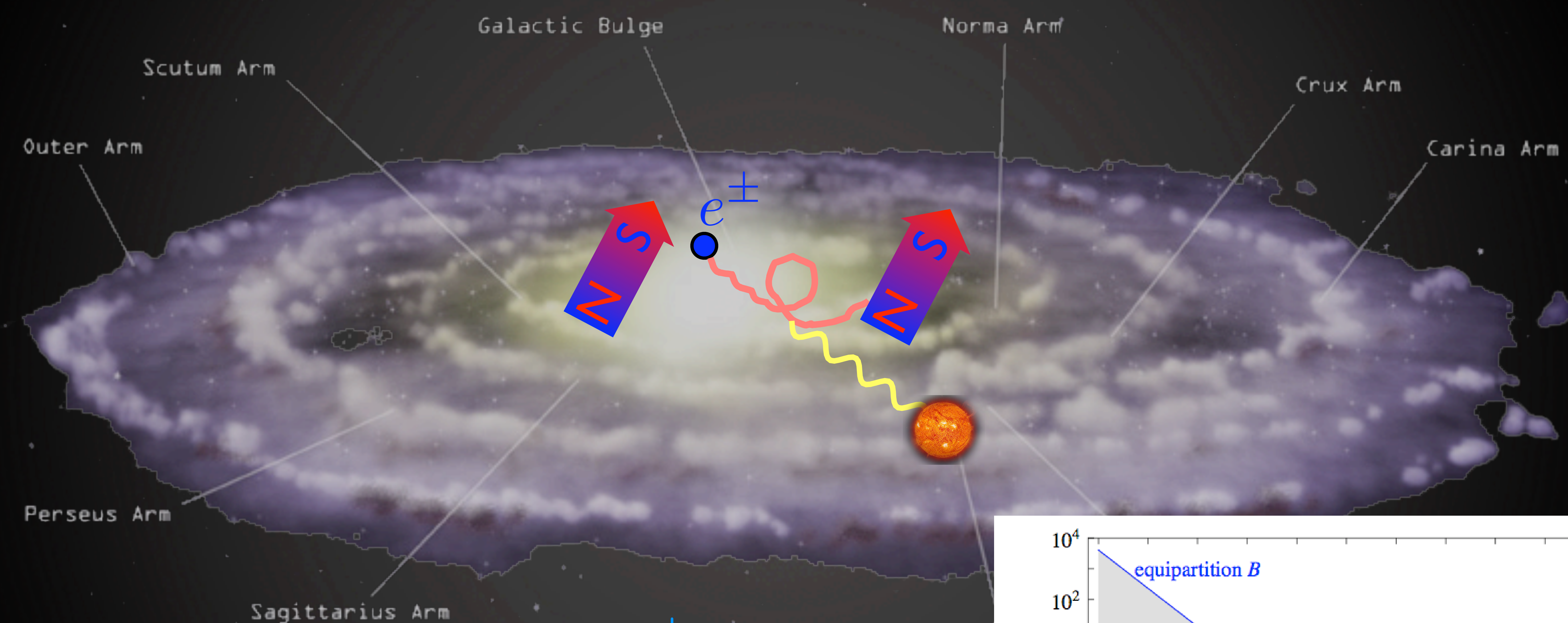
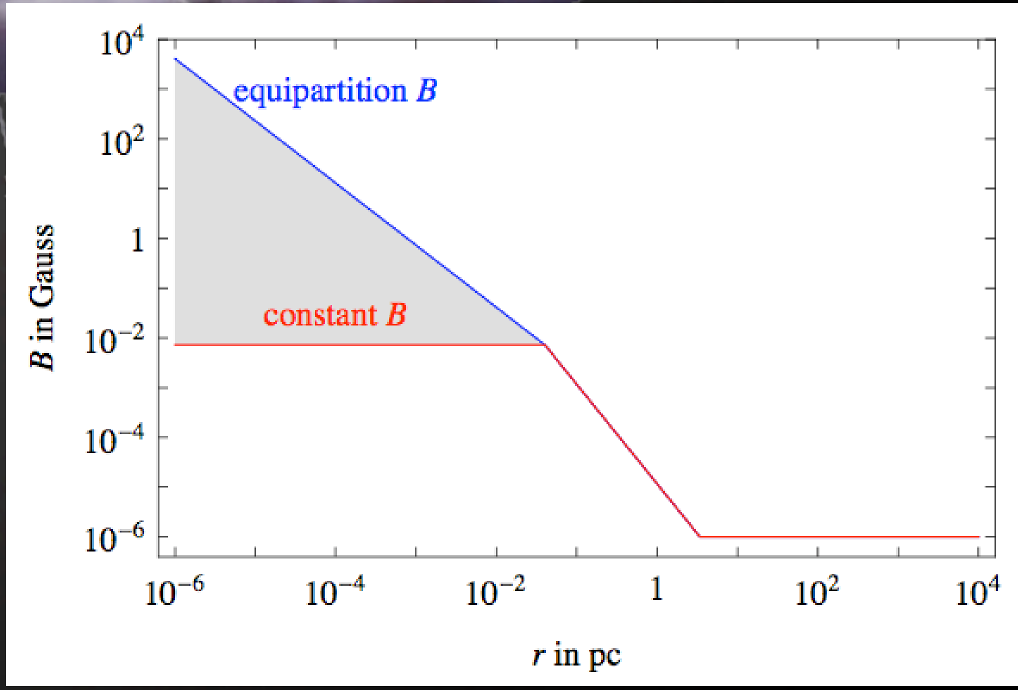


- compute the population of $e^{\pm}$ from DM annihilations in the GC
- compute the synchrotron emitted power for different configurations of galactic $\vec{B}$

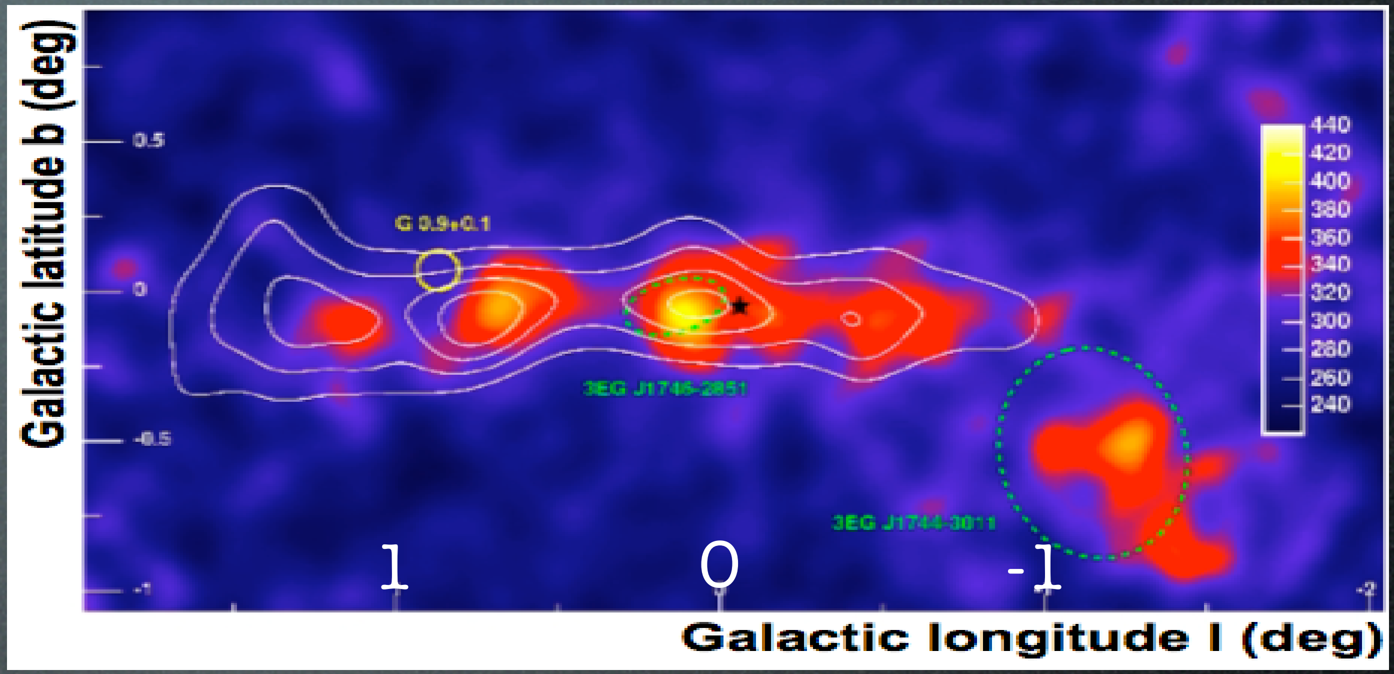
(assuming 'scrambled' B; in principle, directionality could focus emission, lift bounds by O(some))



Comparing with data

Gamma constraints

HESS has detected γ-ray emission from Gal Center and Gal Ridge. The DM signal must not excede that.



HESS coll.

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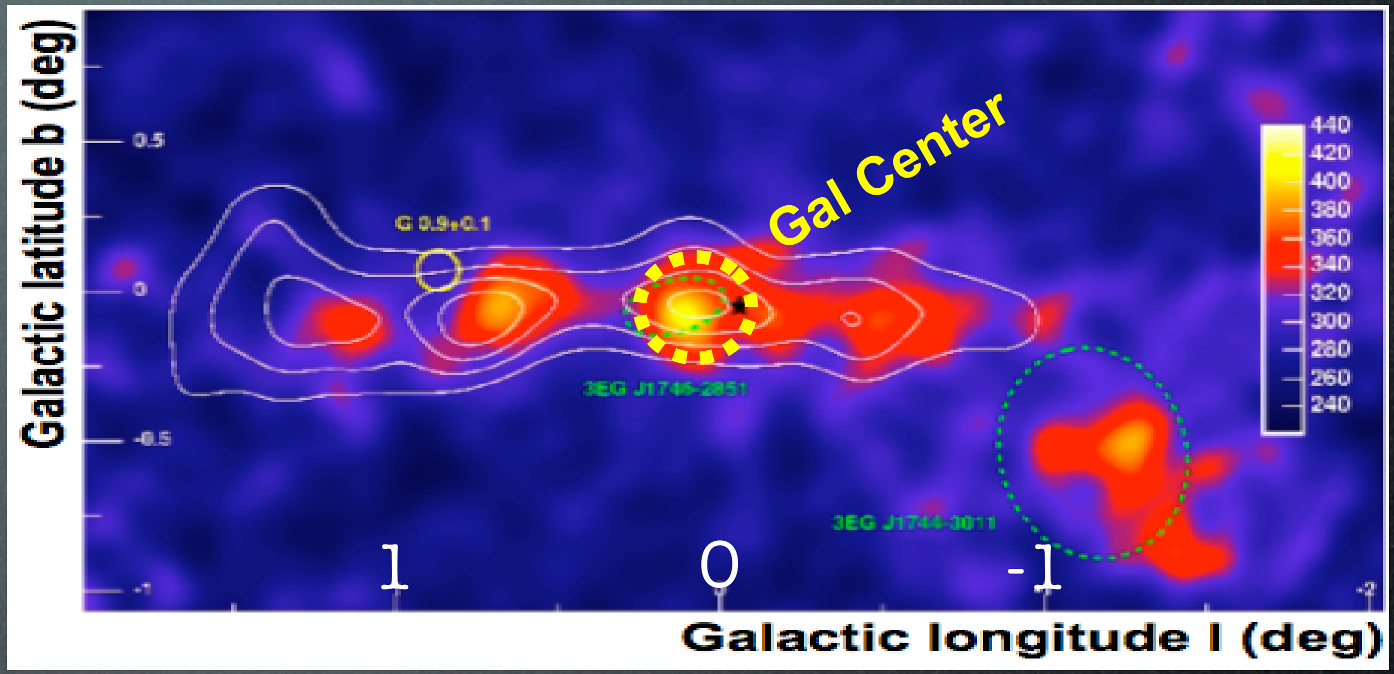

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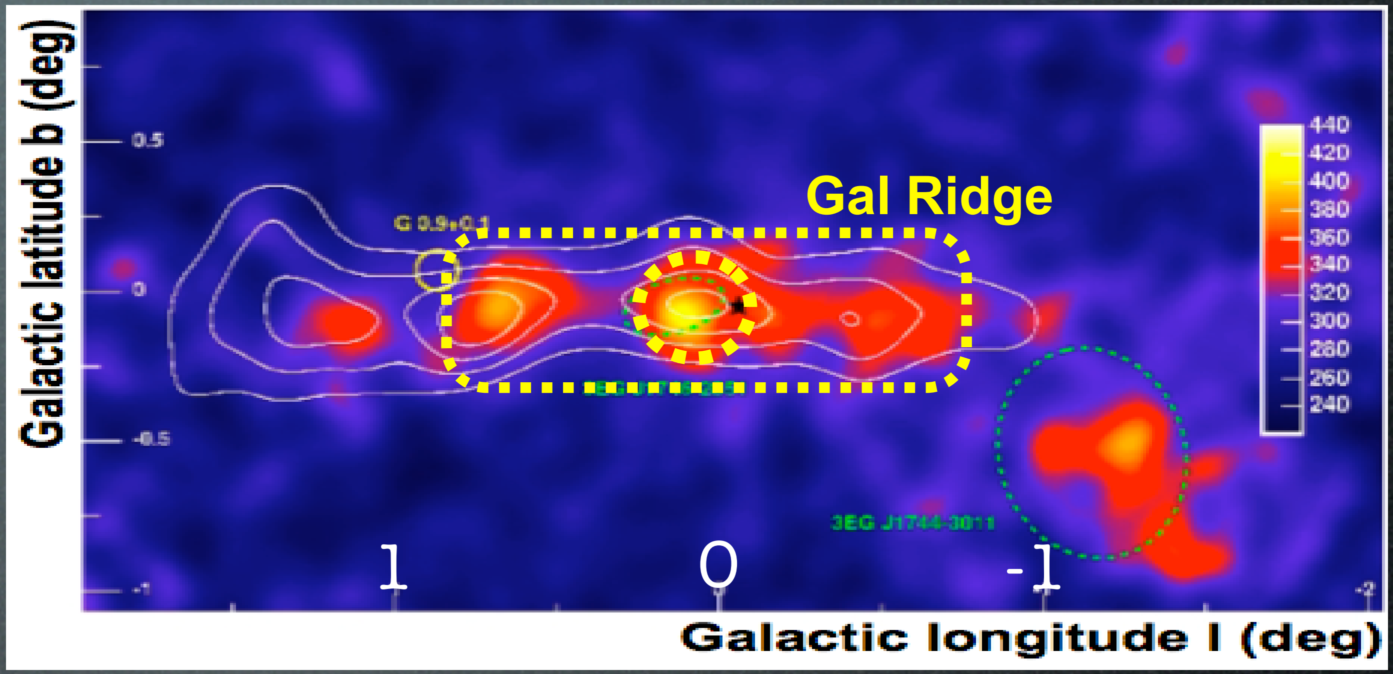

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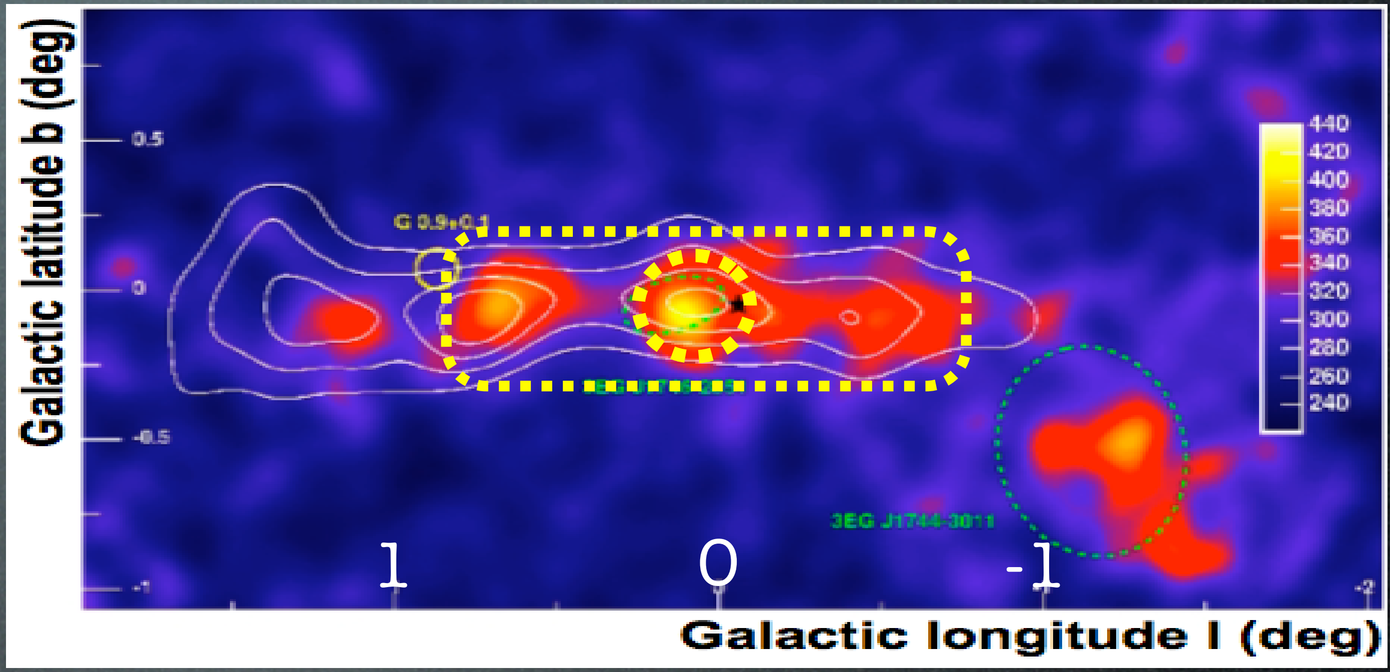
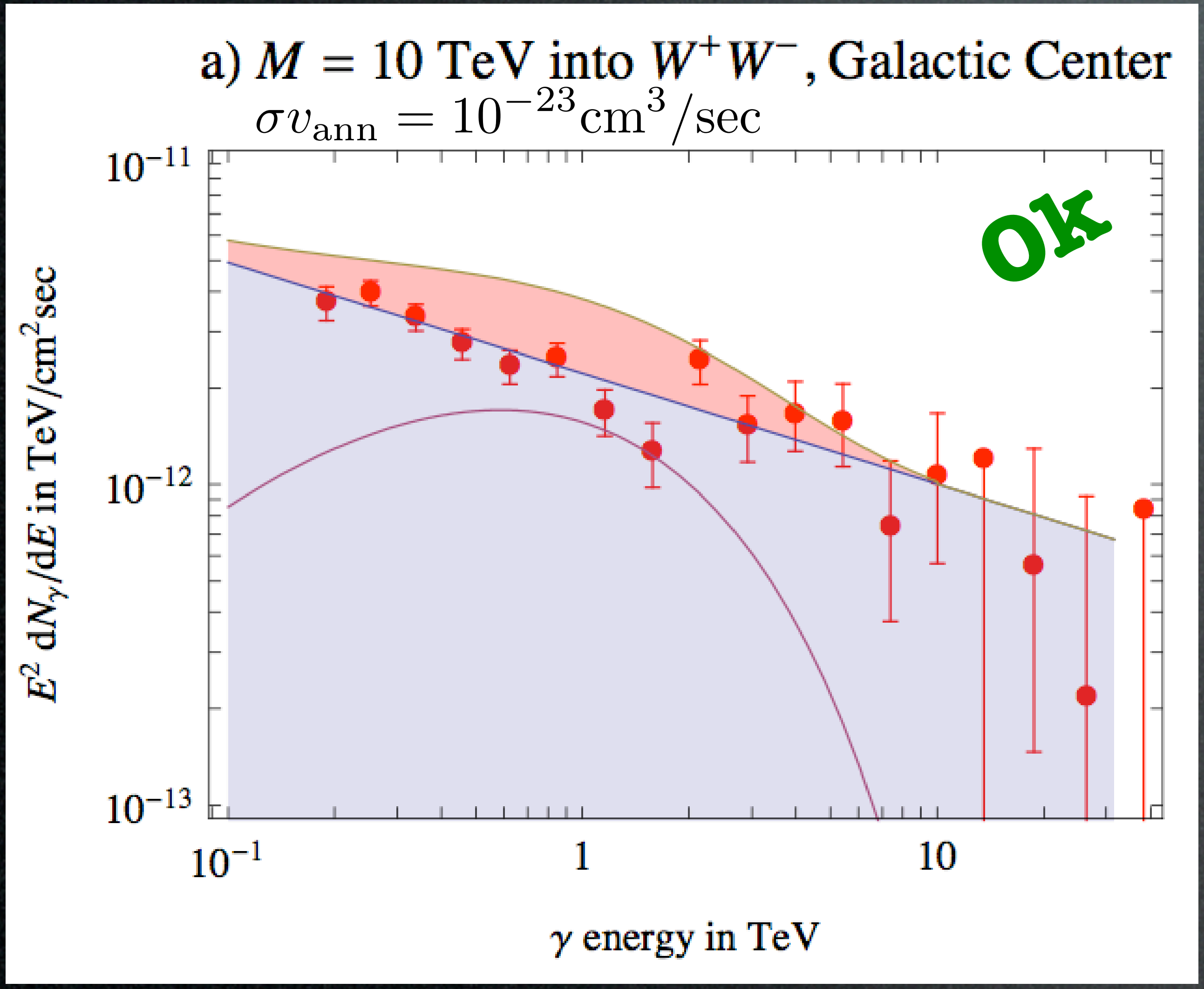


HESS coll.



Data: HESS coll., astro-ph/0408145 and astro-ph/0610509

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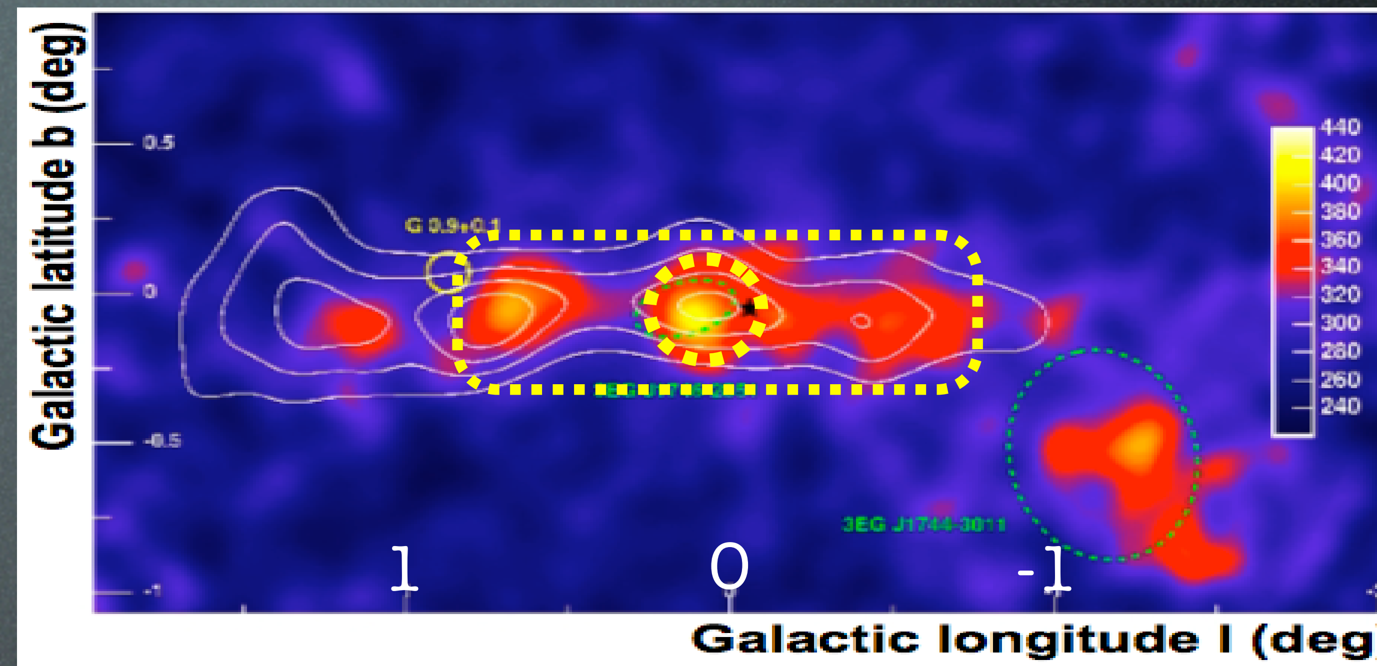

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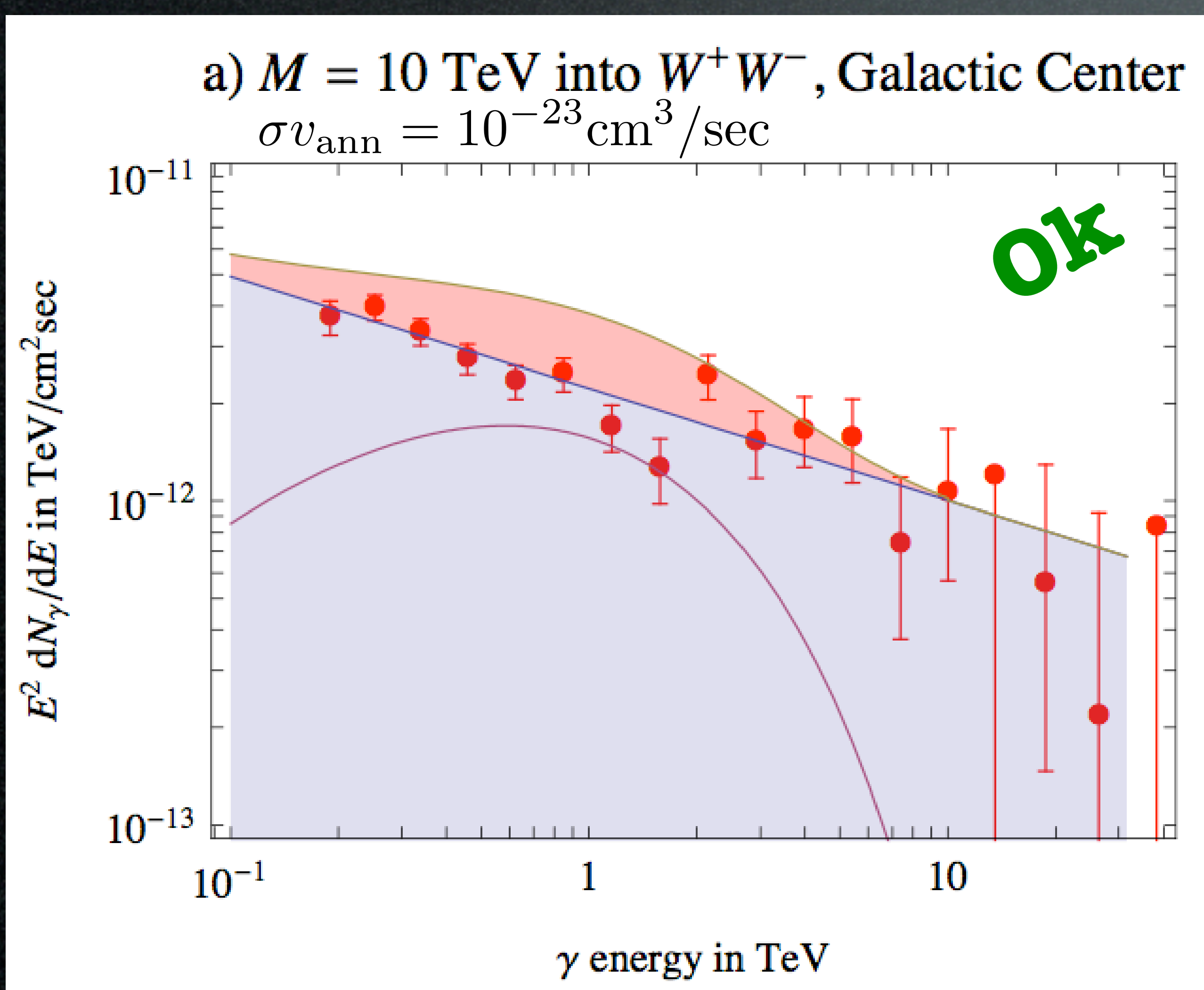

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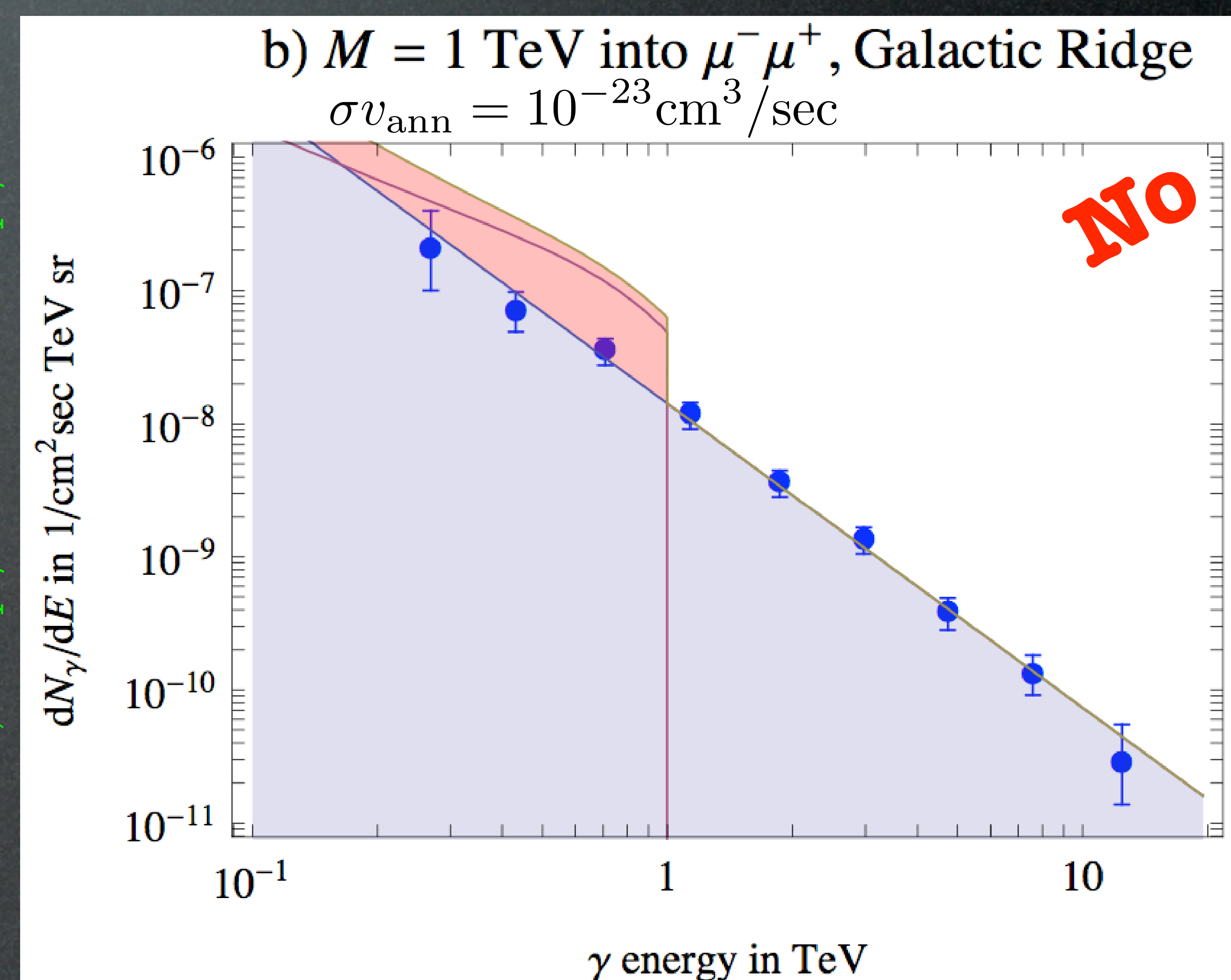
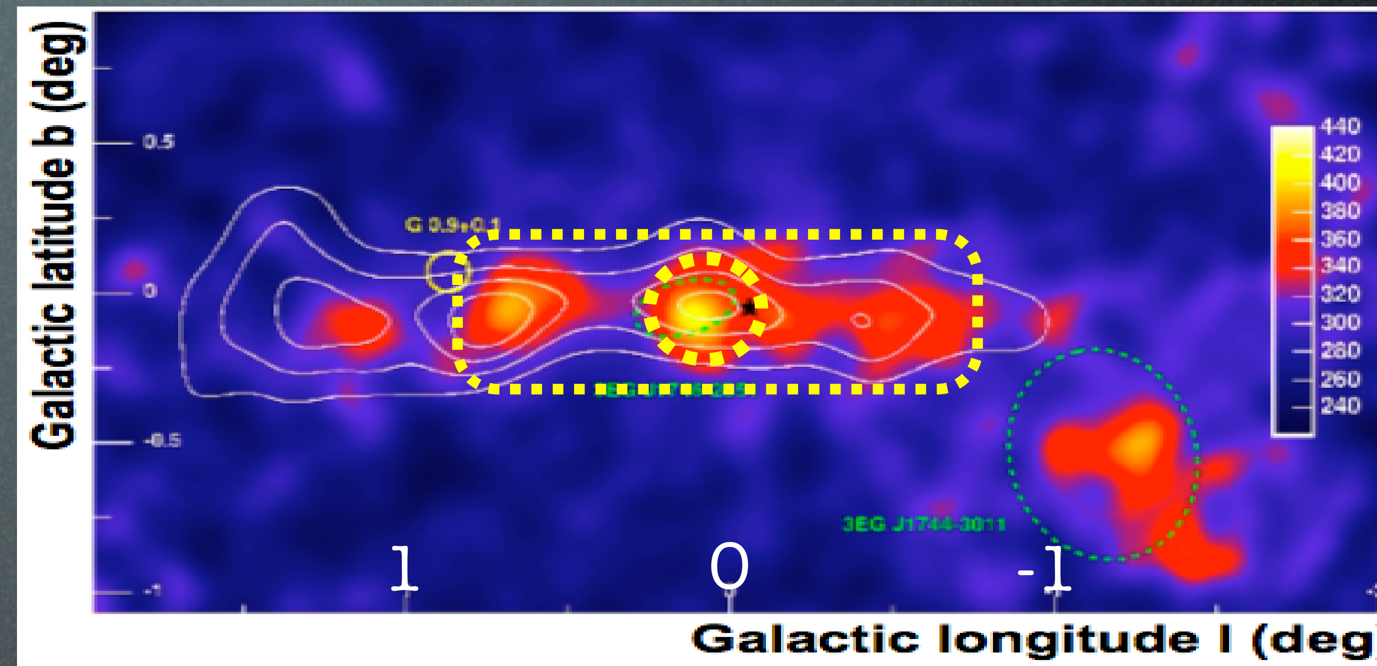


Data: HESS coll., astro-ph/0603021

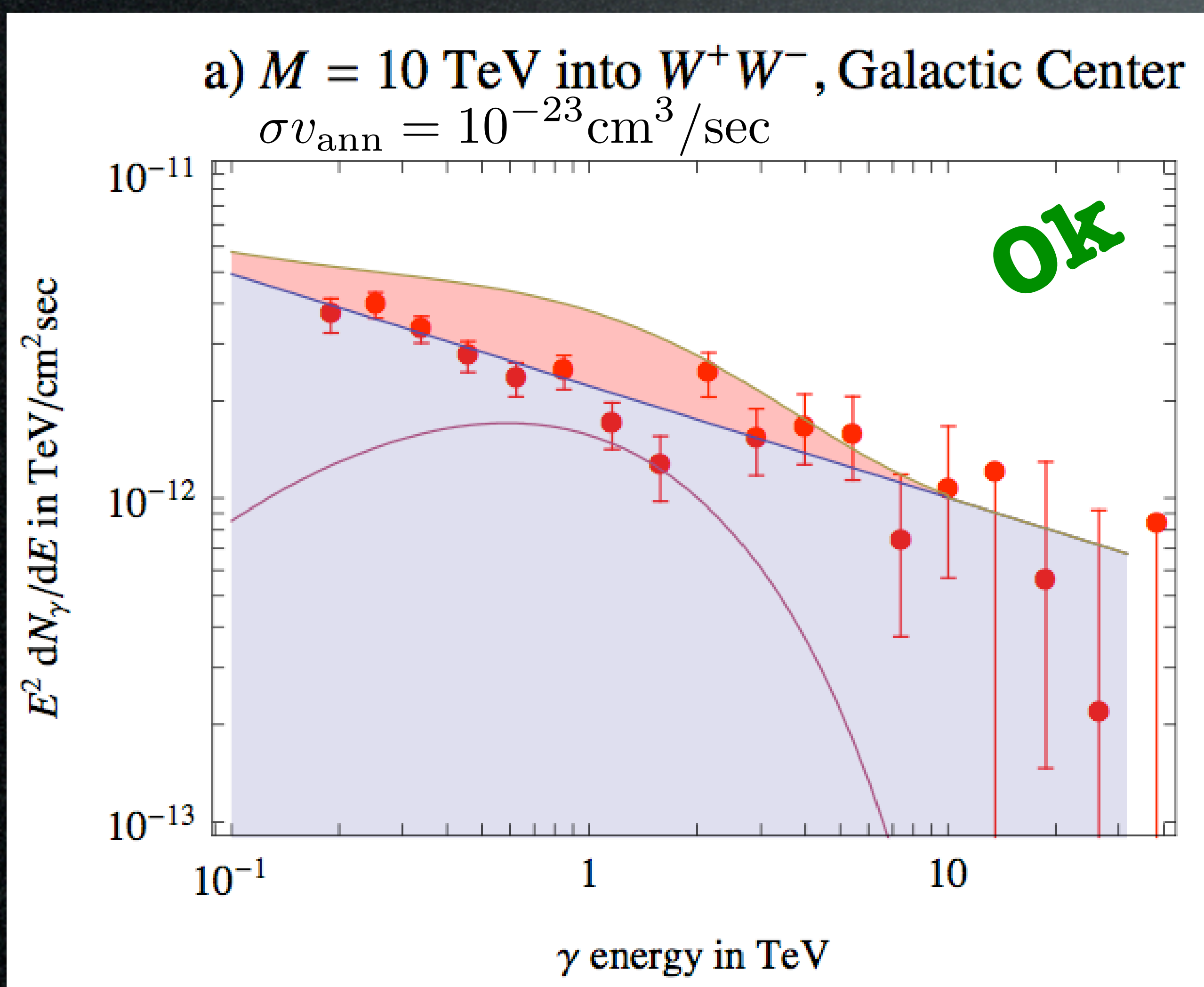
Gamma constraints

HESS has detected γ-ray emission from Gal Center and Gal Ridge. The DM signal must not excede that.

Moreover: no detection from Sgr dSph => upper bound.



HESS coll.



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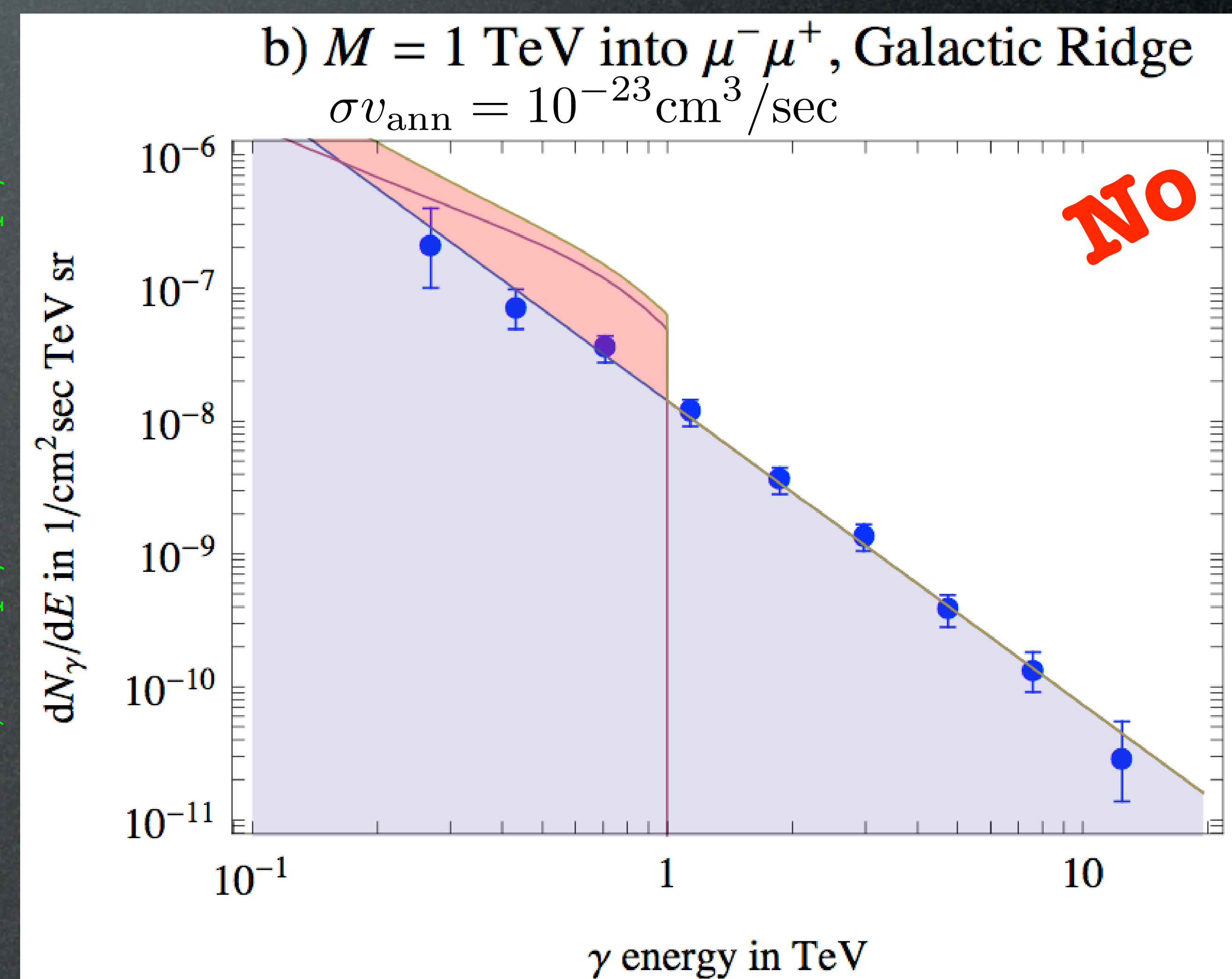

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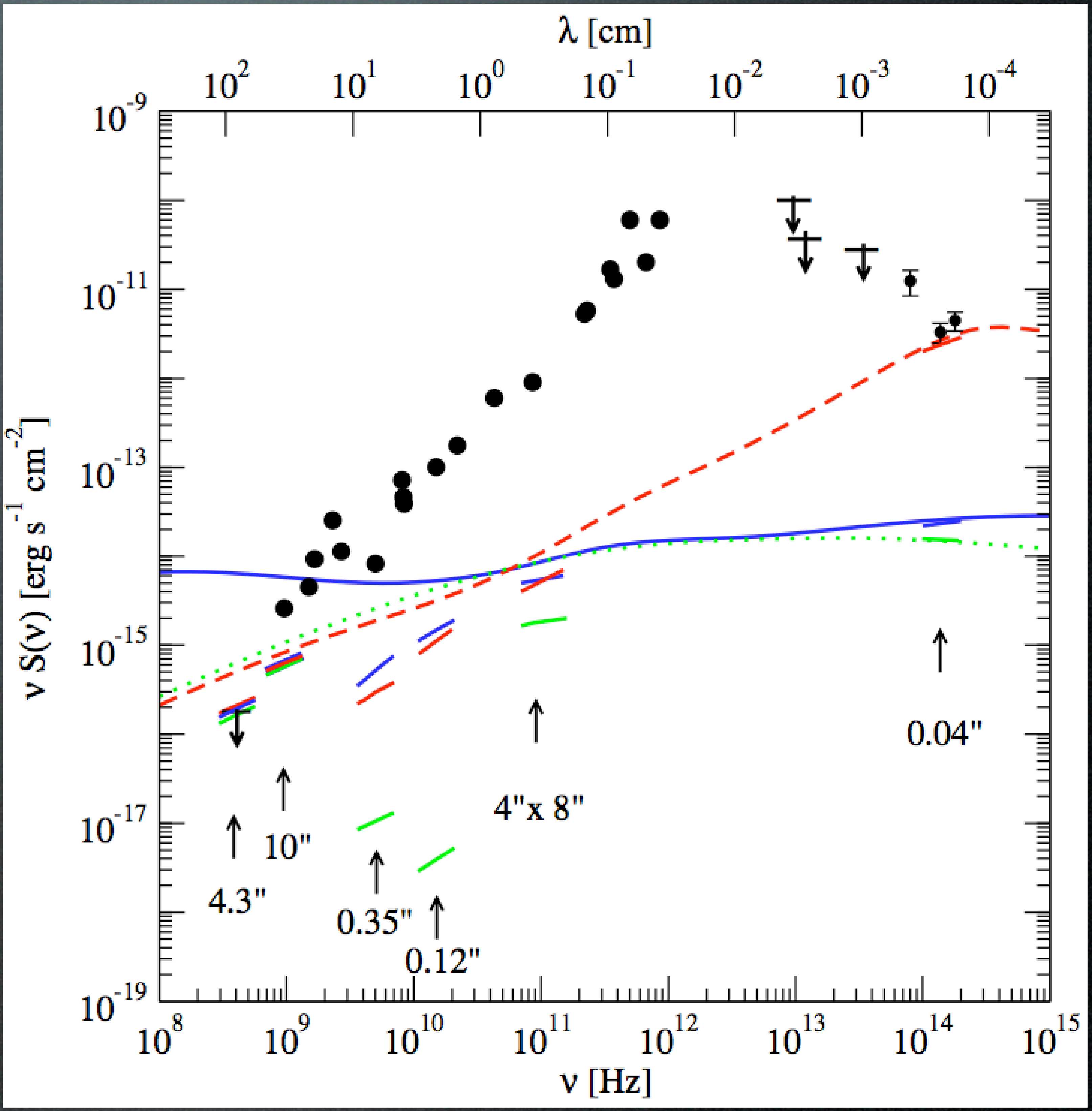
Gamma constraints

Several observations detected radio to IR emission from the Gal Center. The DM signal must not excede that.

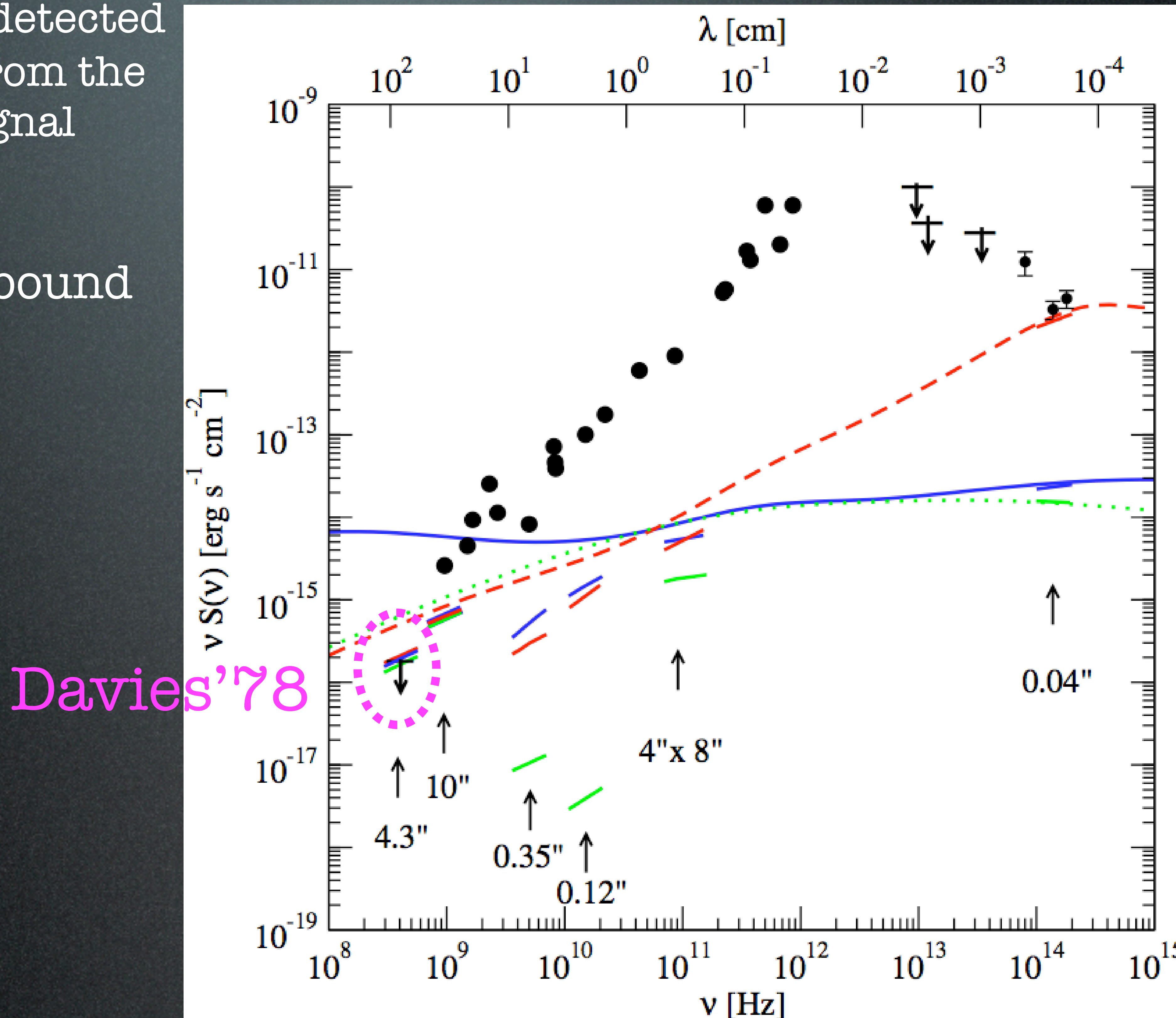


Regis, Ullio PRD 78 (2008)

Gamma constraints

Several observations detected radio to IR emission from the Gal Center. The DM signal must not excede that.

Davies 1978 upper bound at 408 MHz.



Regis, Ullio PRD 78 (2008)

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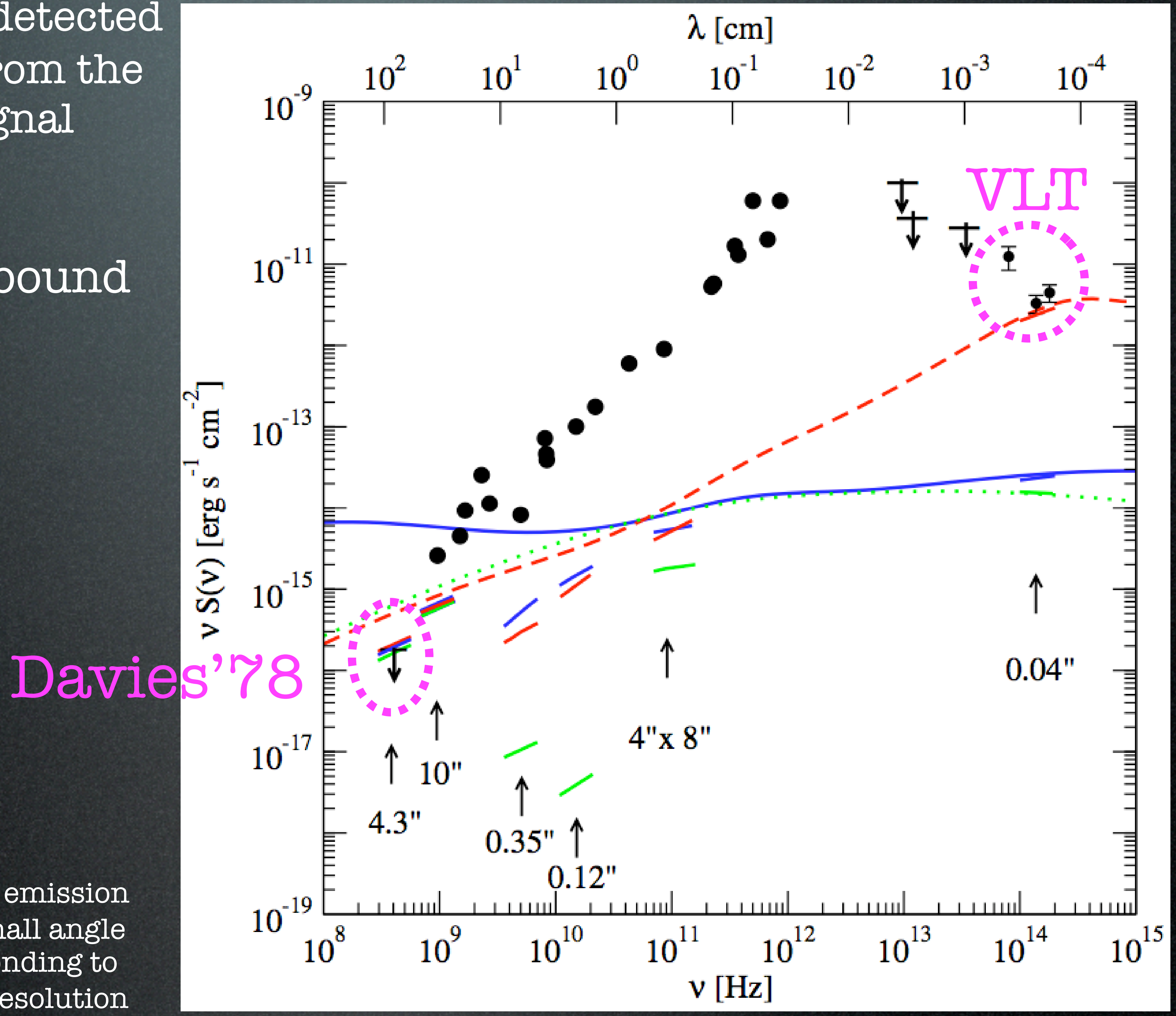
Davies 1978 upper bound at 408 MHz.

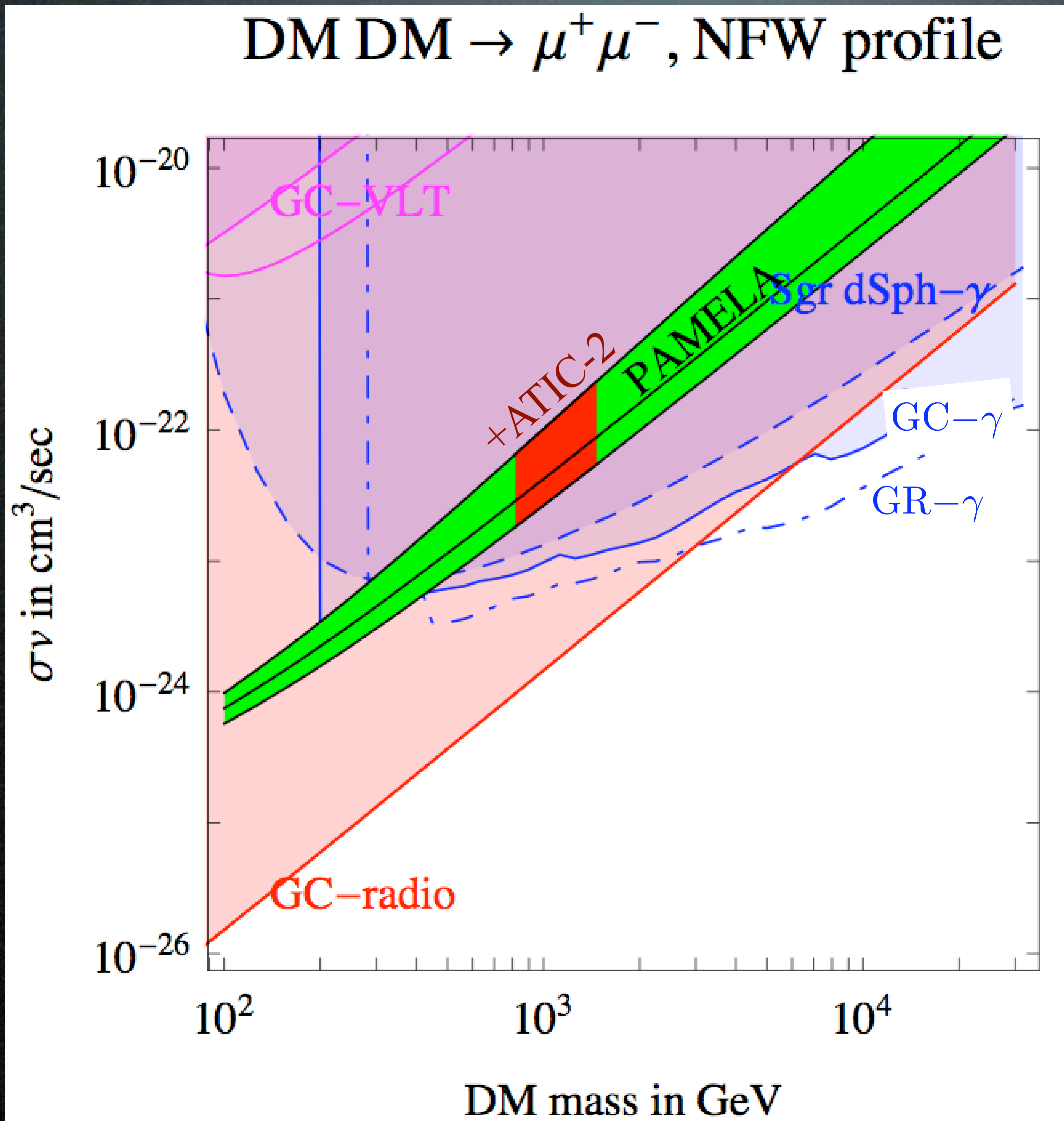
VLT 2003 emission at 10^{14} Hz.



integrate emission over a small angle corresponding to angular resolution of instrument

Regis, Ullio PRD '78 (2008)

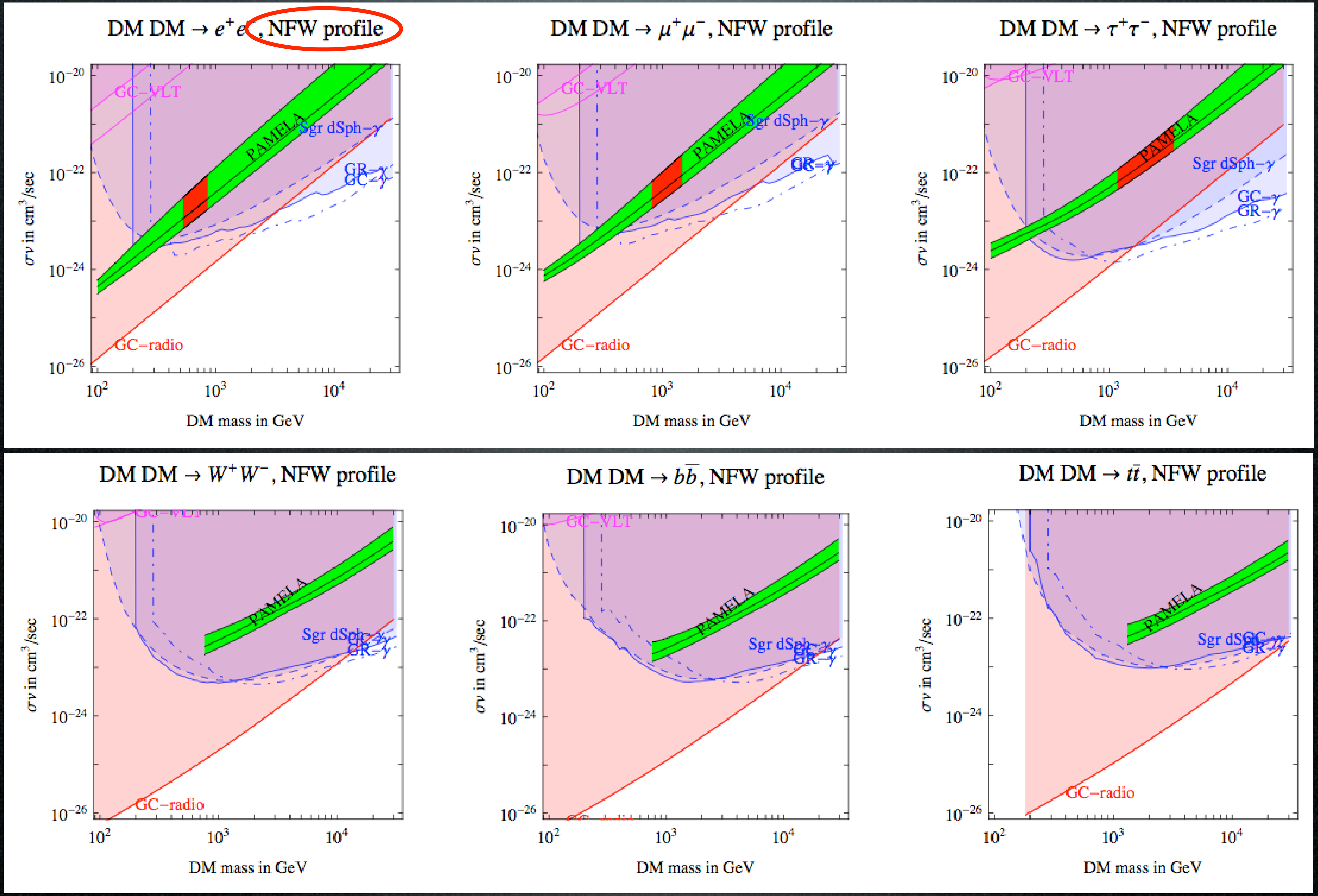
Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

The PAMELA and ATIC regions are in conflict with gamma constraints.

Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

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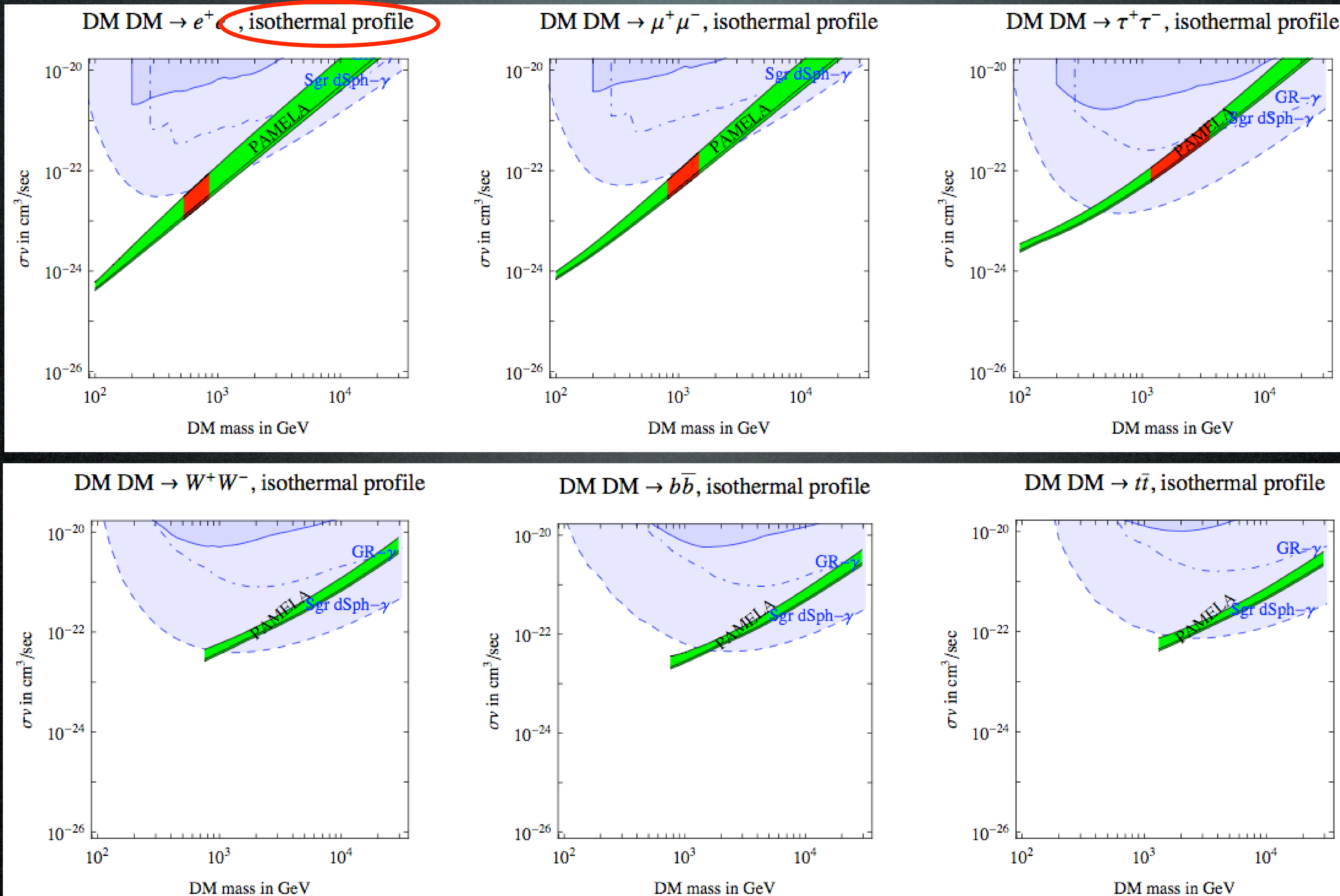

Bertone, Cirelli, Strumia, Taoso 0811.3744

Conclusions

Indirect DM searches are powerful and promising.

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Would anything go with PAMELA? Not at all!
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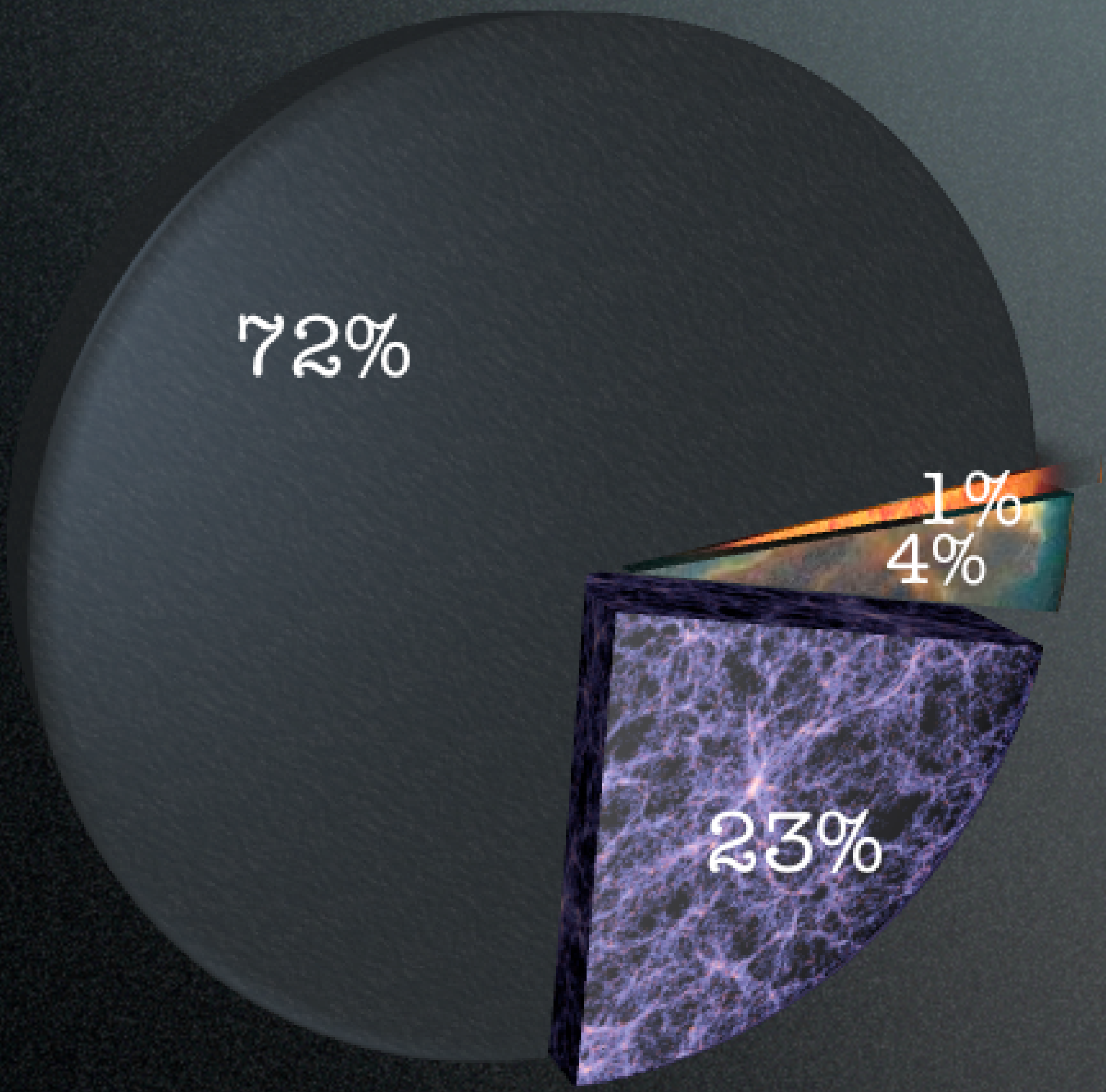
Need a not-too-steep DM profile.

Future data (PAMELA, ATIC, GLAST/Fermi) will be crucial.
Will it be just some young, nearby pulsar?

Back up slides

The cosmic inventory

Most of the Universe is Dark.



FAvgQ: what's the difference between DM and DE?

DM behaves like matter

- overall it dilutes as volume expands
- clusters gravitationally on small scales
- $w = P/\rho = 0$ (NR matter)
  (radiation has $w = -1/3$)

DE behaves like a constant

- it does not dilute
- does not cluster, it is prob homogeneous
- $w = P/\rho \simeq -1$
- pulls the acceleration, FRW eq. $\frac{\ddot{a}}{a} = -\frac{4\pi G_N}{3}(1-3w)\rho$

[back]

DM N-body simulations

$2\ 10^6$ CDM particles, 43 Mpc cubic box

DM N-body simulations

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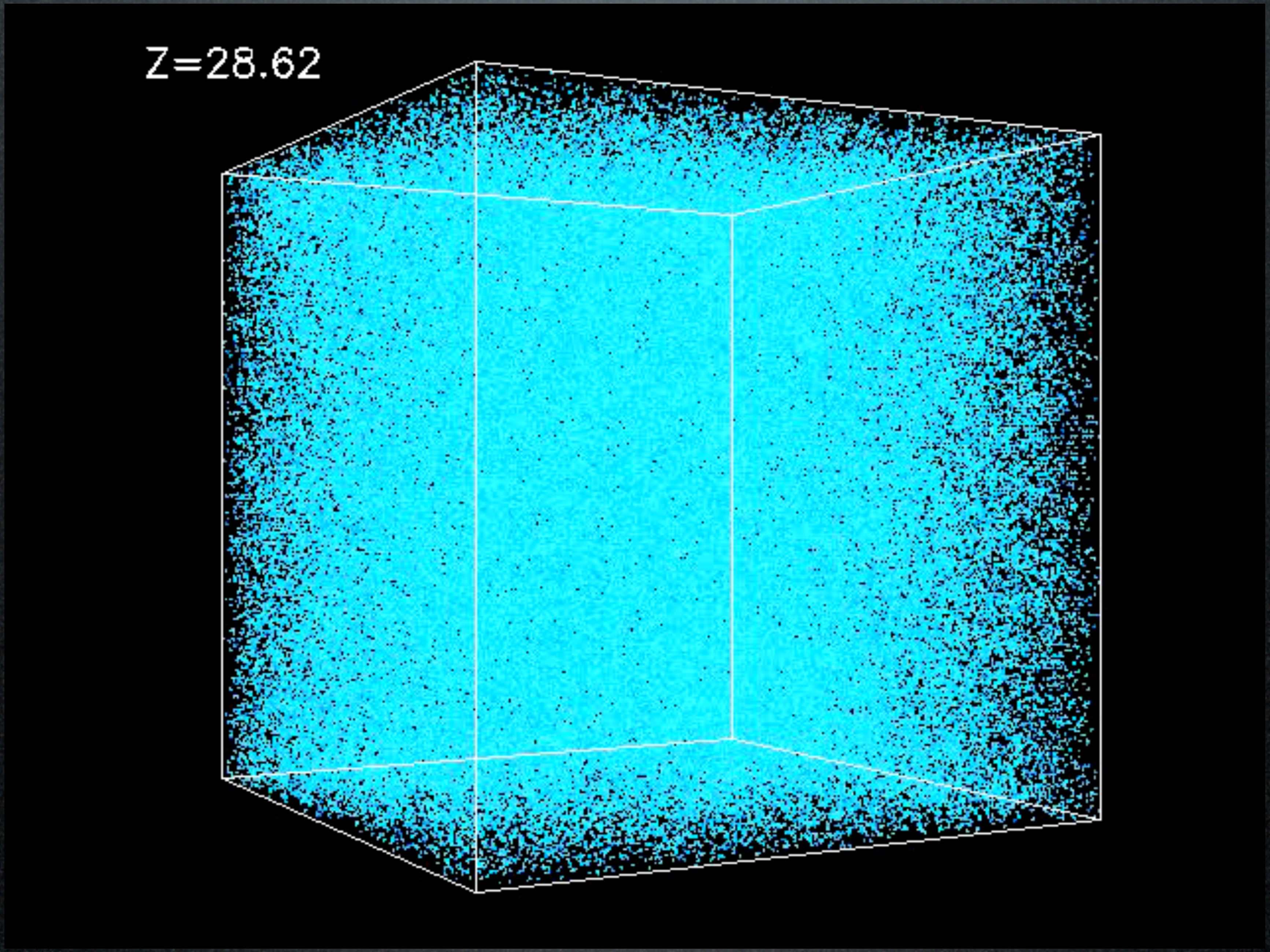


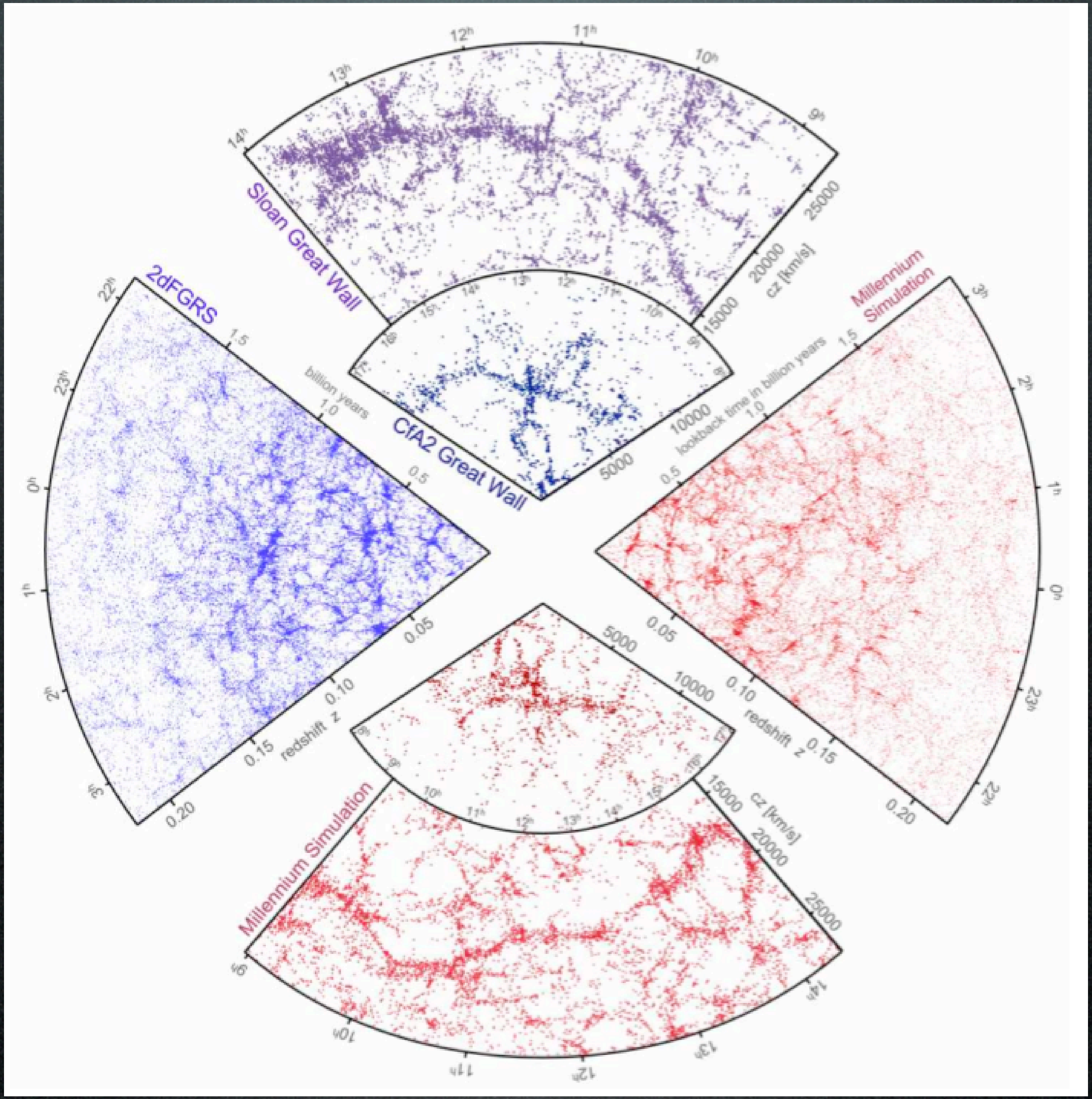
Andrey Kravtsov, cosmicweb.uchicago.edu

[back]

DM N-body simulations

2dF: 2.2 10^5 galaxies

SDSS: 10^6 galaxies,
2 billion lyr



Springel, Frenk, White, Nature 440 (2006)

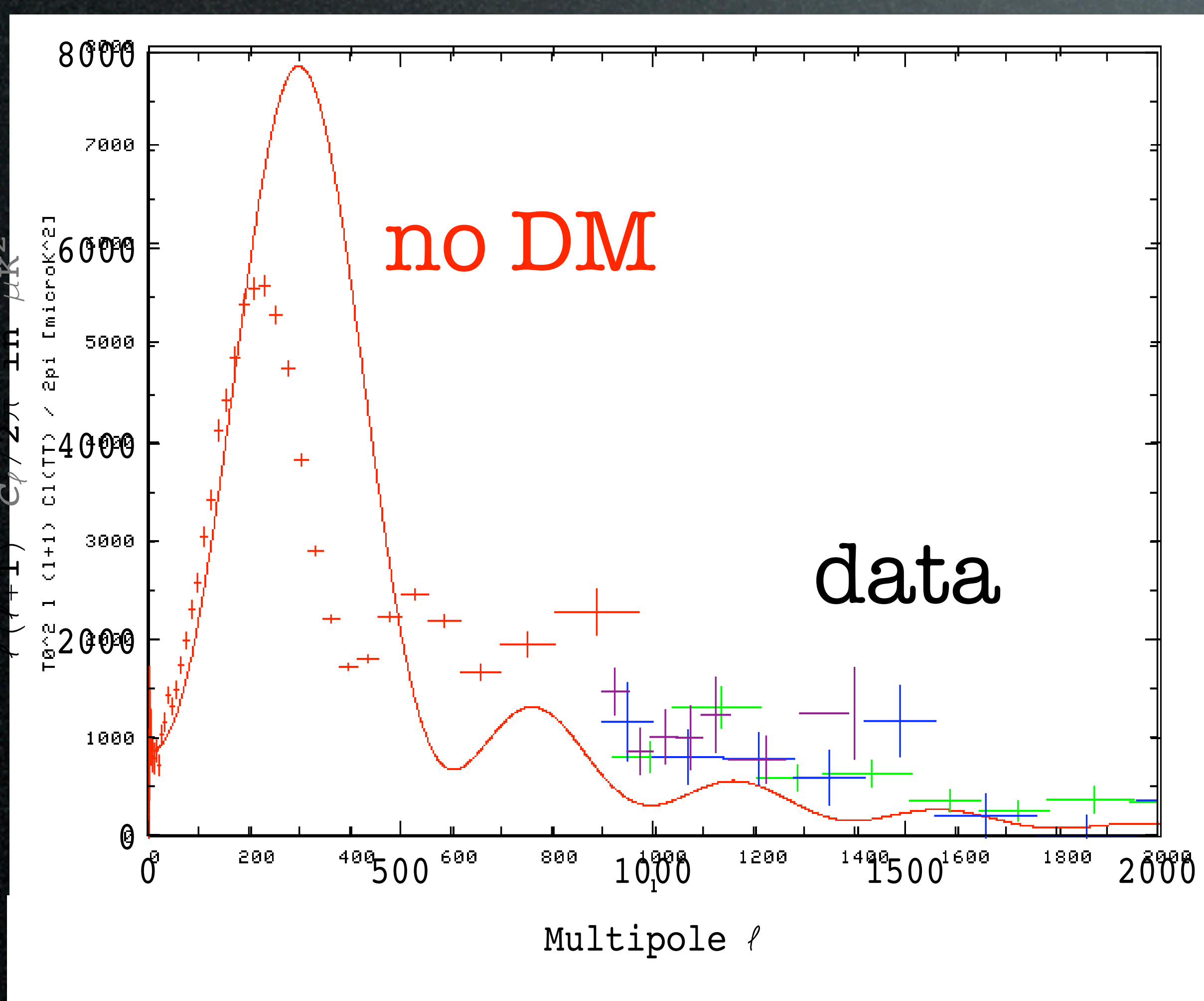
Millennium:
10^{10} particles,
500 h^{-1} Mpc

[back]

The Evidence for DM

How would the power spectra be without DM?
(and no other extra ingredient)

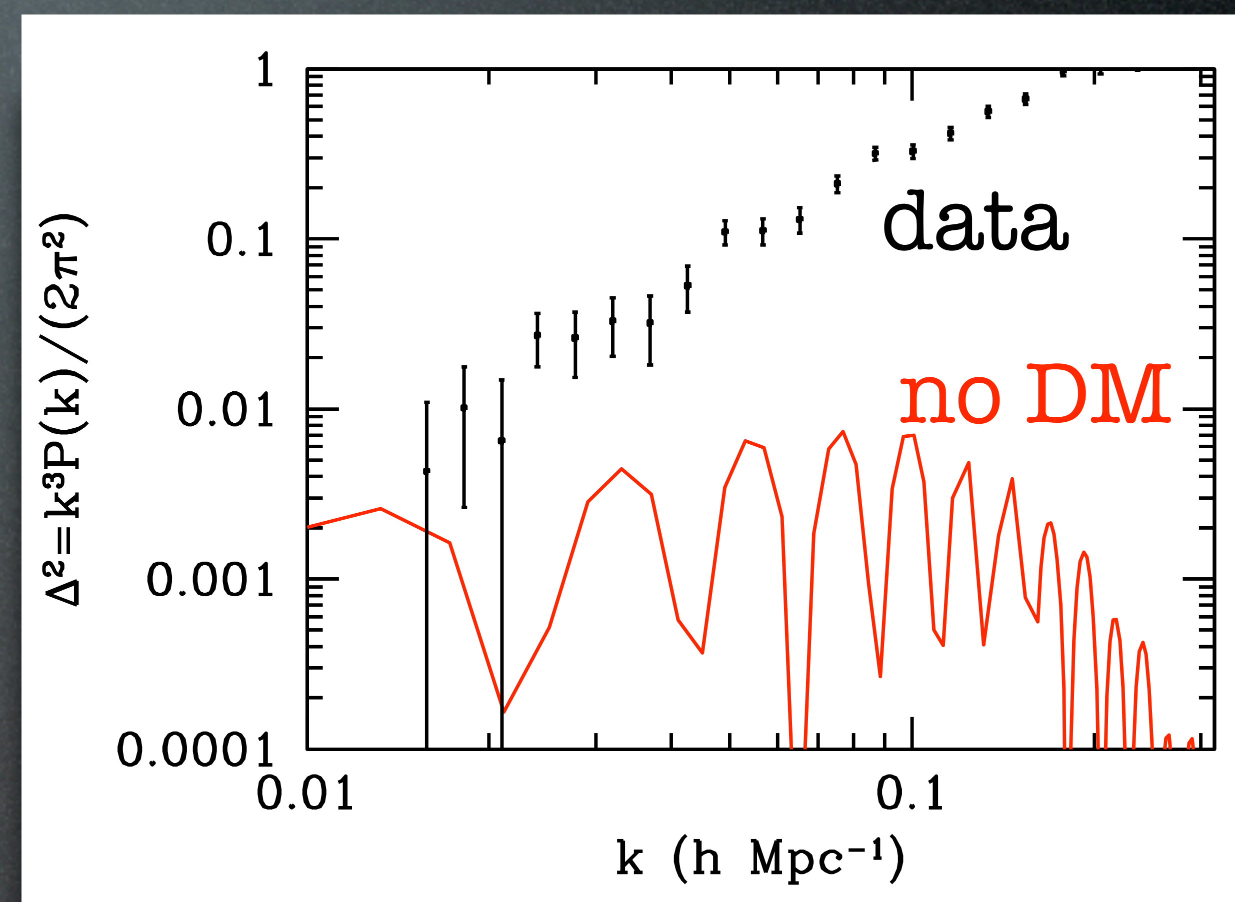
CMB



CAMB online

(in particular: no DM => no 3rd peak!)

LSS



Dodelson, Liguori 2006

(you need DM to gravitationally "catalyse" structure formation)

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Indirect Detection

Propagation for positrons:

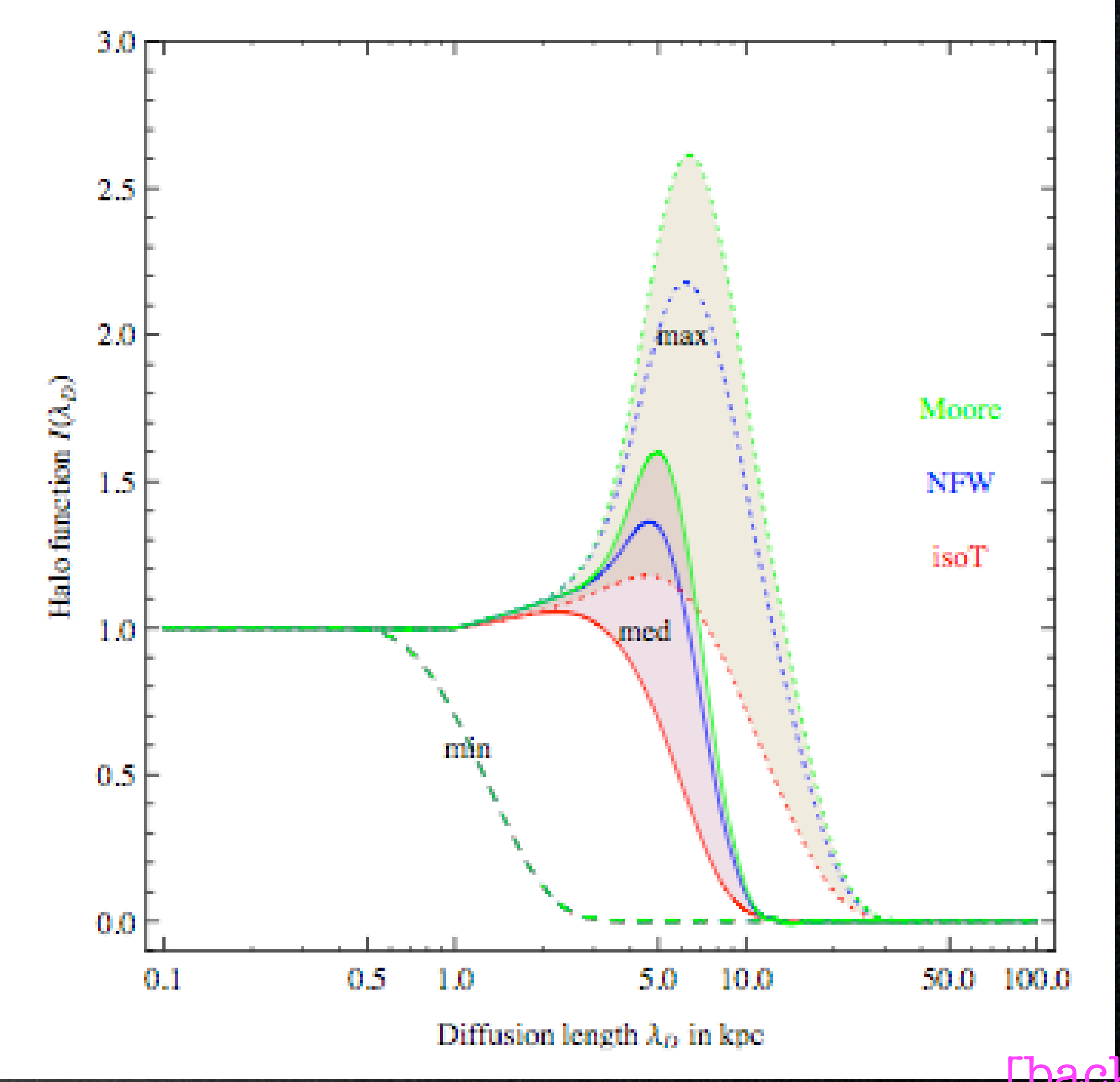
$$\frac{\partial f}{\partial t} - K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E}\left(b(E) f\right) = Q$$

diffusion
(in turbulent $\bar{B} \approx \mu$G, assumed space indep.)
$K(E) = K_0 (E/\text{GeV})^\delta$

energy loss
$b(E) = (E/\text{GeV})^2/\tau_E$
$\tau_E = 10^{16}$ s

$$Q = \frac{1}{2}\left(\frac{\rho}{M_{\rm DM}}\right)^2 f_{\rm inj}, \qquad f_{\rm inj} = \sum_k \langle \sigma v \rangle_k \frac{dN^k_{e^+}}{dE}$$

Model	δ	K_0 in kpc^2/Myr	L in kpc
min (M2)	0.55	0.00595	1
med	0.70	0.0112	4
max (M1)	0.46	0.0765	15



Solution:

$$\Phi_{e^+}(E, \vec{r}_\odot) = B \frac{v_{e^+}}{4\pi} \frac{\tau_E}{E^2} \int_E^{M_{\rm DM}} dE'\, Q(E') \cdot I\left(\lambda_D(E, E')\right)$$

$$\lambda_D^2 = 4 K_0 \tau_E \left[\frac{(E/\text{GeV})^{\delta-1} - (E'/\text{GeV})^{\delta-1}}{\delta - 1}\right]$$

[back]

Indirect Detection

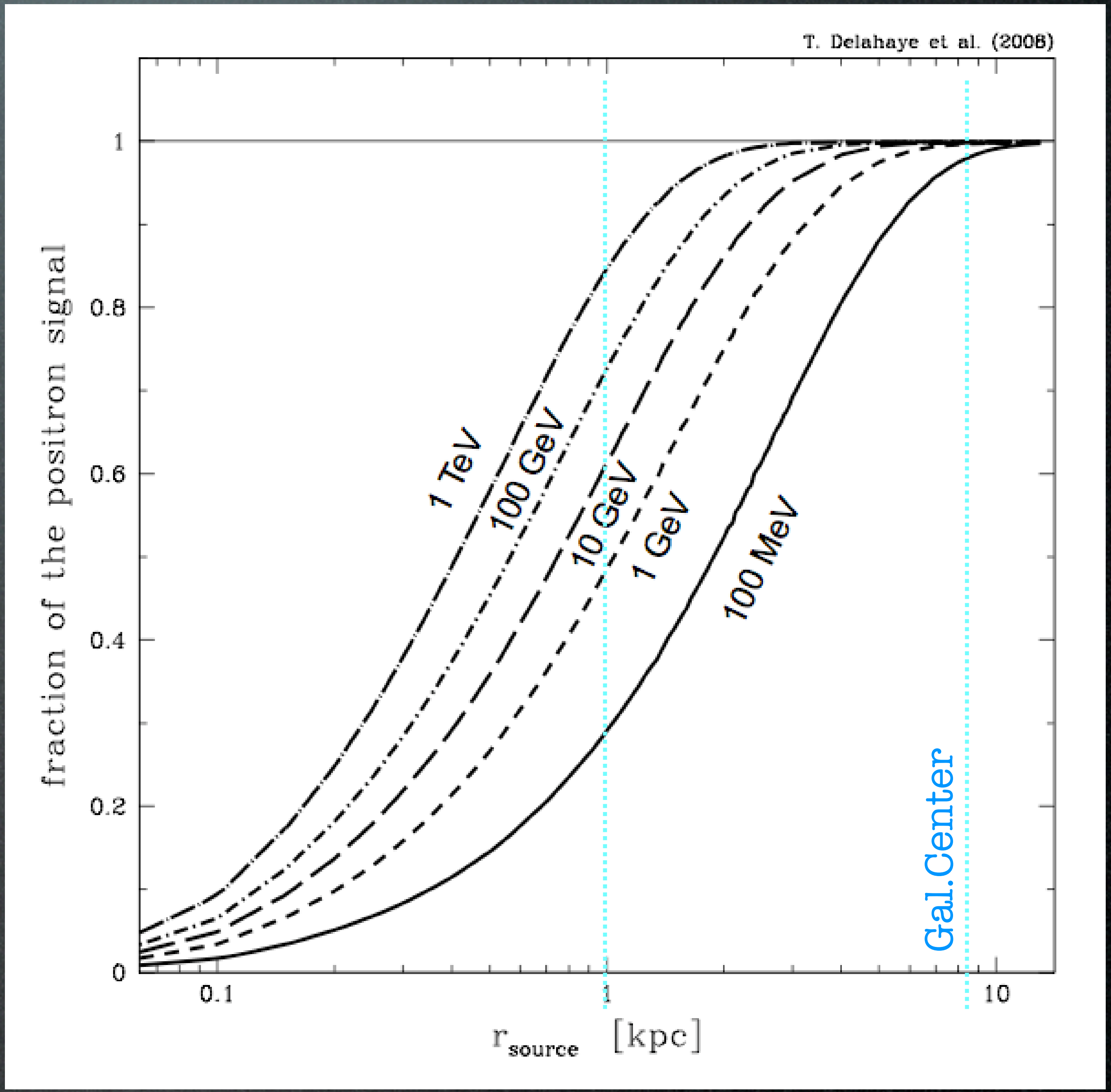
Where do positrons come from?

Mostly locally, within 1 kpc (more so at higher energy).

Typical lifetime (due to syn rad & IC):

$$\tau \approx 5 \cdot 10^5 \mathrm{yr} \frac{\mathrm{TeV}}{E} \frac{1}{\left(\frac{B}{5\mu\mathrm{G}}\right)^2 + 1.6 \frac{w}{\mathrm{eV/cm^3}}}$$

(w = density of IS photons)



T.Delahaye et al., 2008

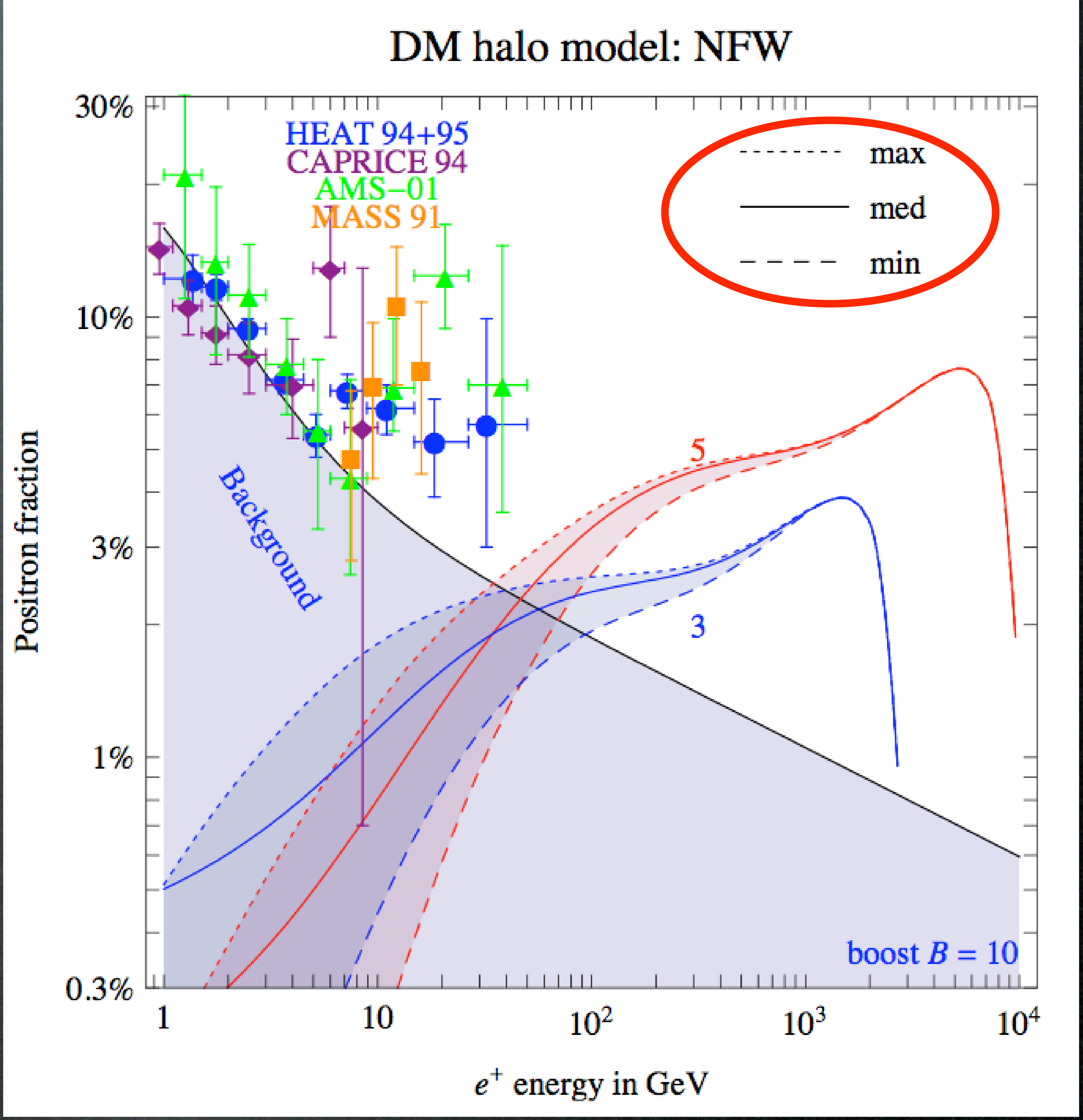
[back]

3. Indirect Detection

Results for positrons:

Astro uncertainties:

- propagation model
- DM halo profile
- boost factor B



[back]

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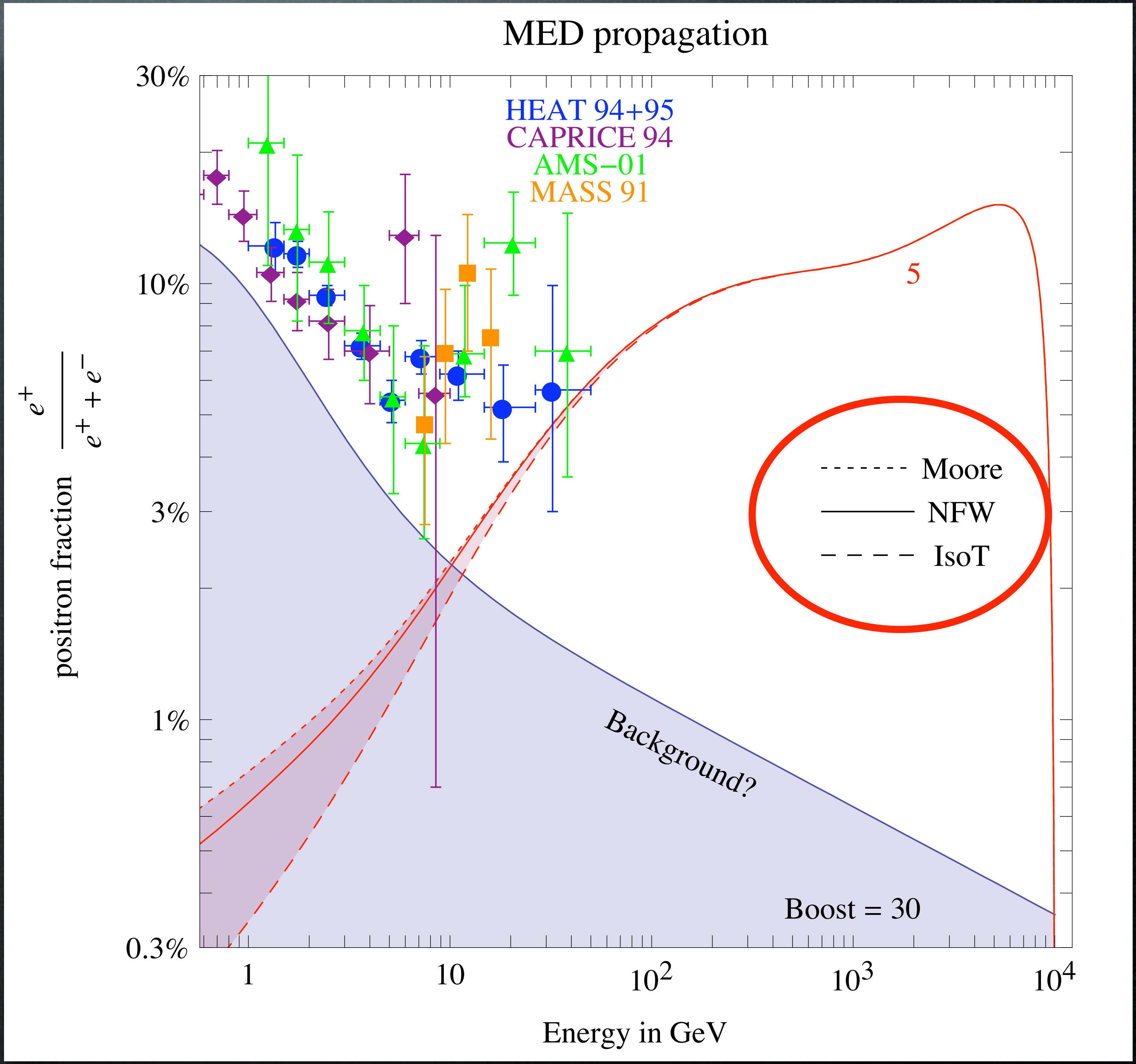


Distinctive signal,
quite robust vs astro.

[back]

3. Indirect Detection

Propagation for antiprotons:

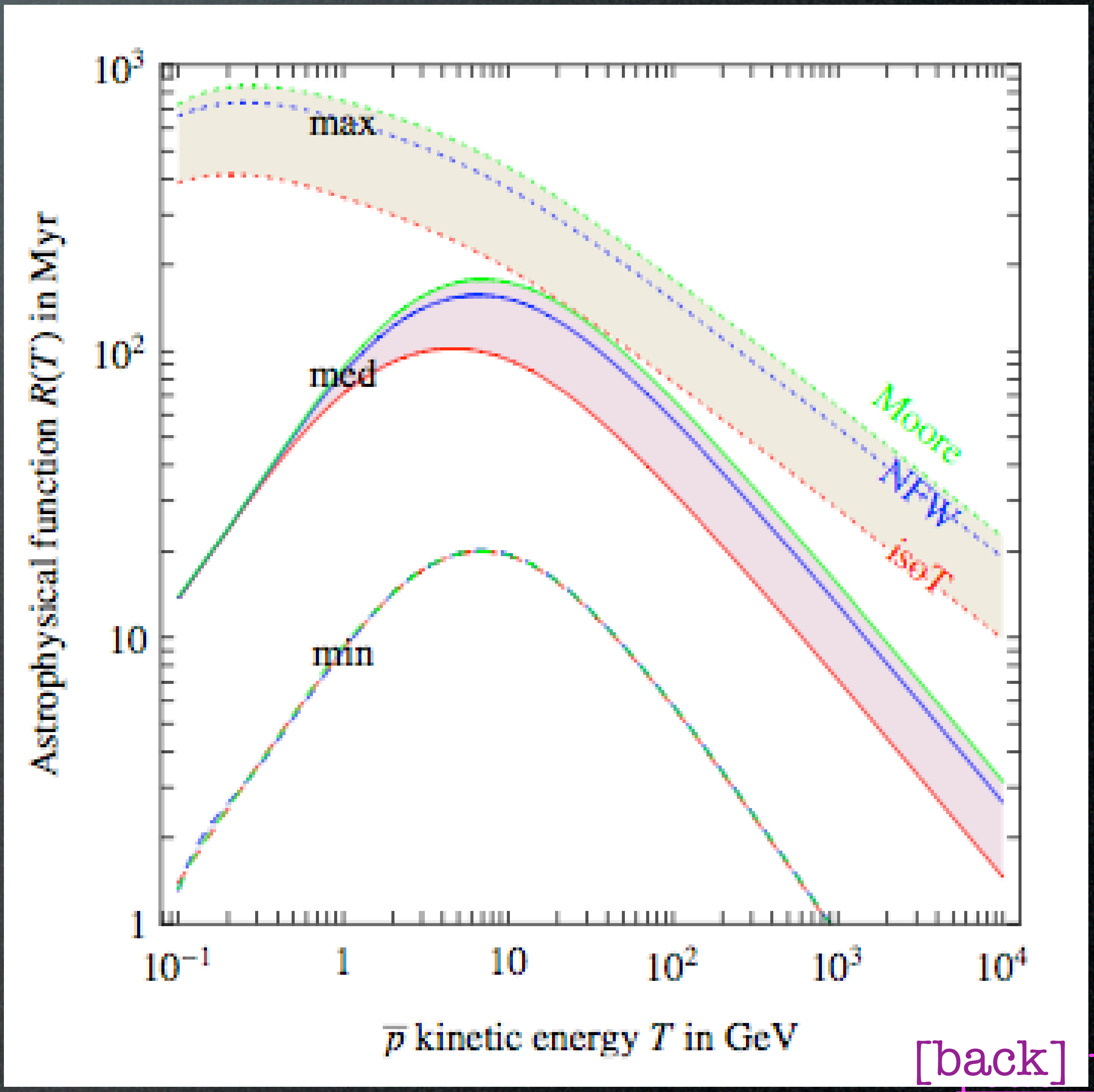
$$\frac{\partial f}{\partial t} - K(T)\cdot\nabla^2 f + \frac{\partial}{\partial z}\left(\mathrm{sign}(z)\, f\, V_{\mathrm{conv}}\right) = Q - 2h\,\delta(z)\,\Gamma_{\mathrm{ann}} f$$

diffusion — convective wind — spallations

$K(T) = K_0 \beta\,(p/\mathrm{GeV})^{\delta}$

T kinetic energy

Model	δ	K_0 in kpc^2/Myr	L in kpc	V_{conv} in km/s
min	0.85	0.0016	1	13.5
med	0.70	0.0112	4	12
max	0.46	0.0765	15	5



Solution:

$$\Phi_{\bar{p}}(T,\vec{r}_{\odot}) = B\frac{v_{\bar{p}}}{4\pi}\left(\frac{\rho_{\odot}}{M_{\mathrm{DM}}}\right)^2 R(T)\sum_k \frac{1}{2}\langle\sigma v\rangle_k \frac{dN^k_{\bar{p}}}{dT}$$

[back]

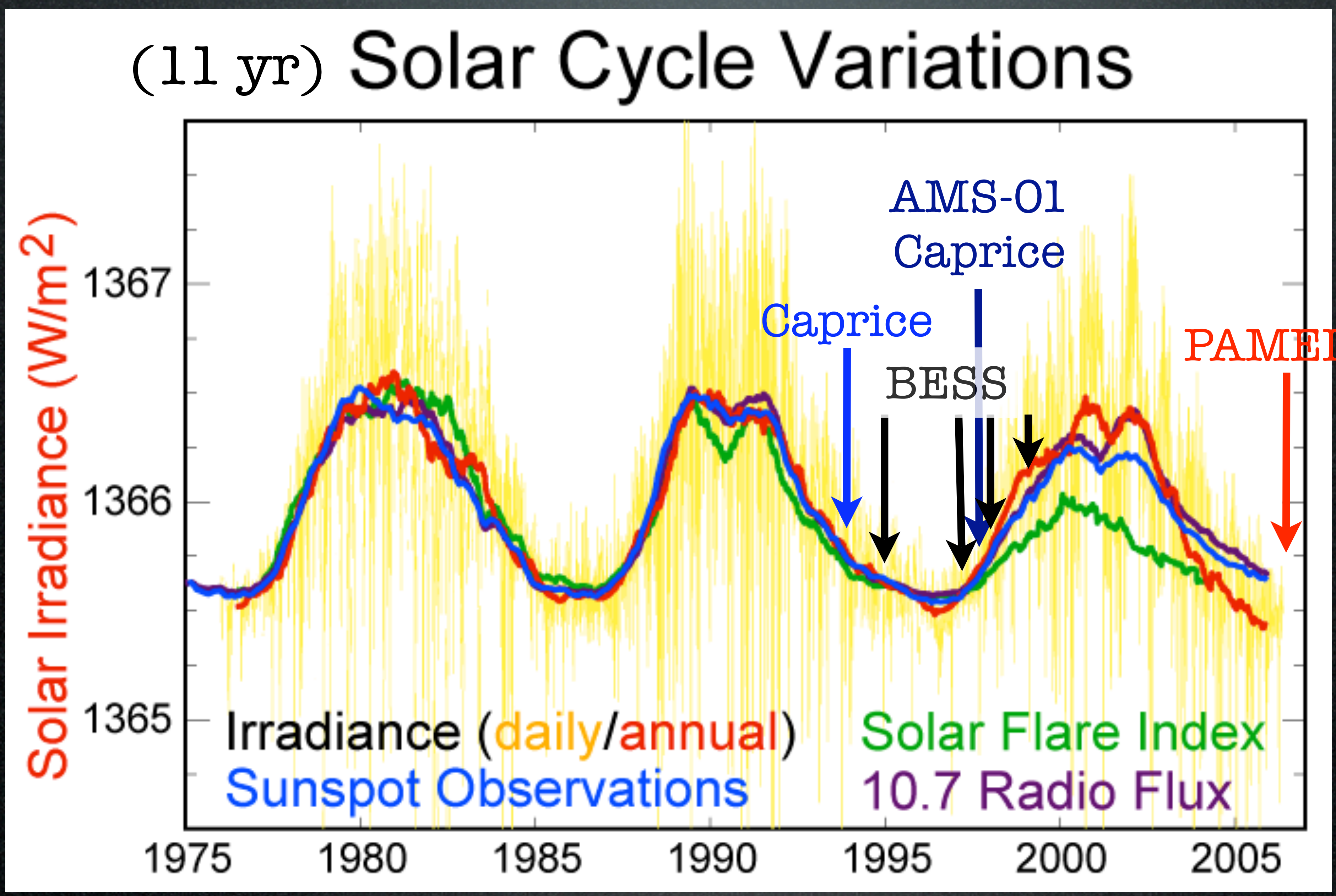
Indirect Detection

Solar wind Modulation of cosmic rays:

$$\frac{d\Phi_{\bar{p}\oplus}}{dT_\oplus} = \frac{p_\oplus^2}{p^2}\frac{d\Phi_{\bar{p}}}{dT}, \qquad T = T_\oplus + |Ze|\phi_F$$

spectrum at Earth — spectrum far from Earth

Fisk potential $\phi_F \simeq 500$ MV

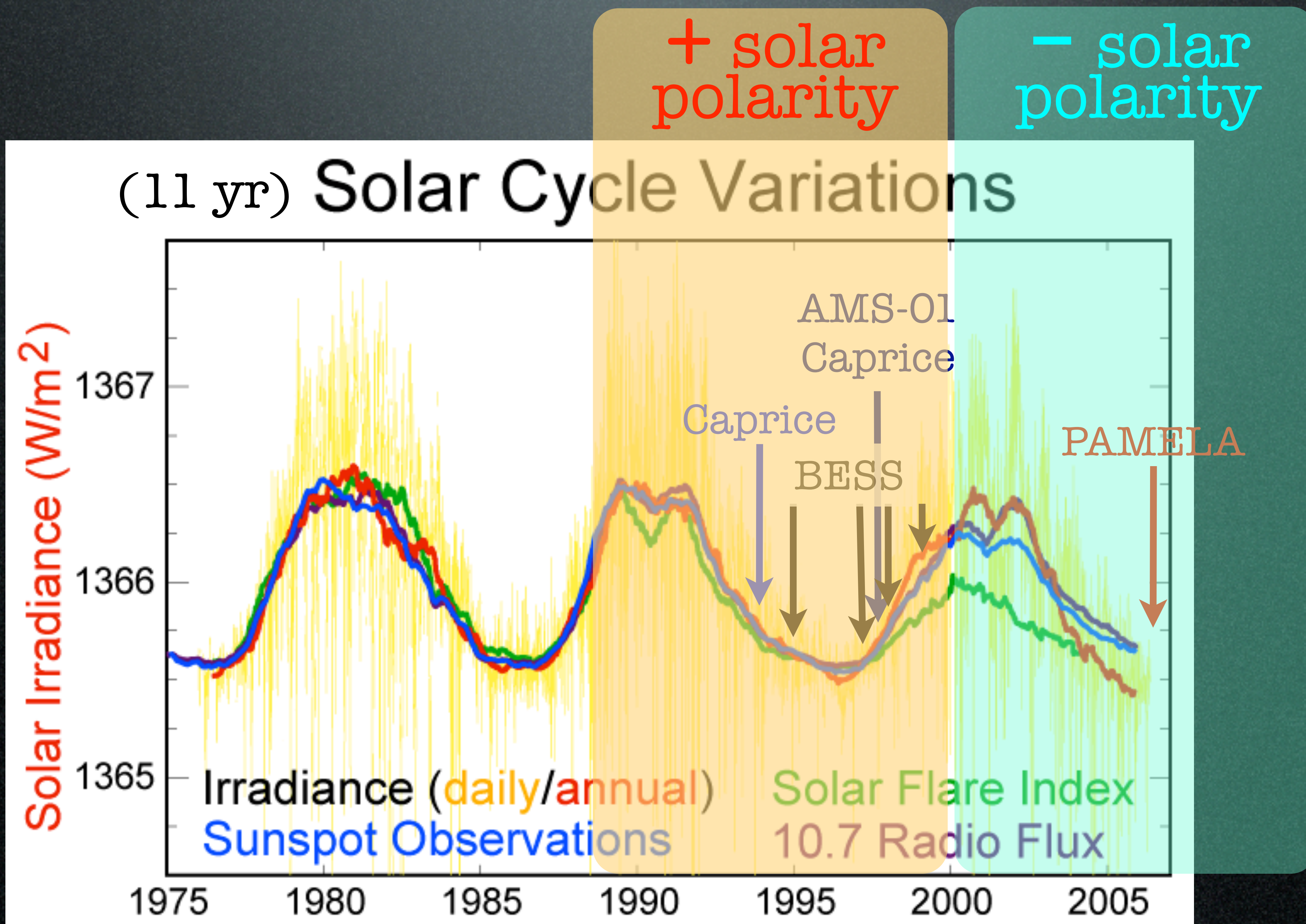


Indirect Detection

Solar polarity Modulation of cosmic rays:

solar magnetic polarity reverses at (the max of) each cycle;
during '– polarity' state, positive particles are more deflected away

+ = rotation parallel to magnetic field;
- = antiparallel



Indirect Detection

Background computations for positrons:

main source: CR nuclei spallating on IS gas

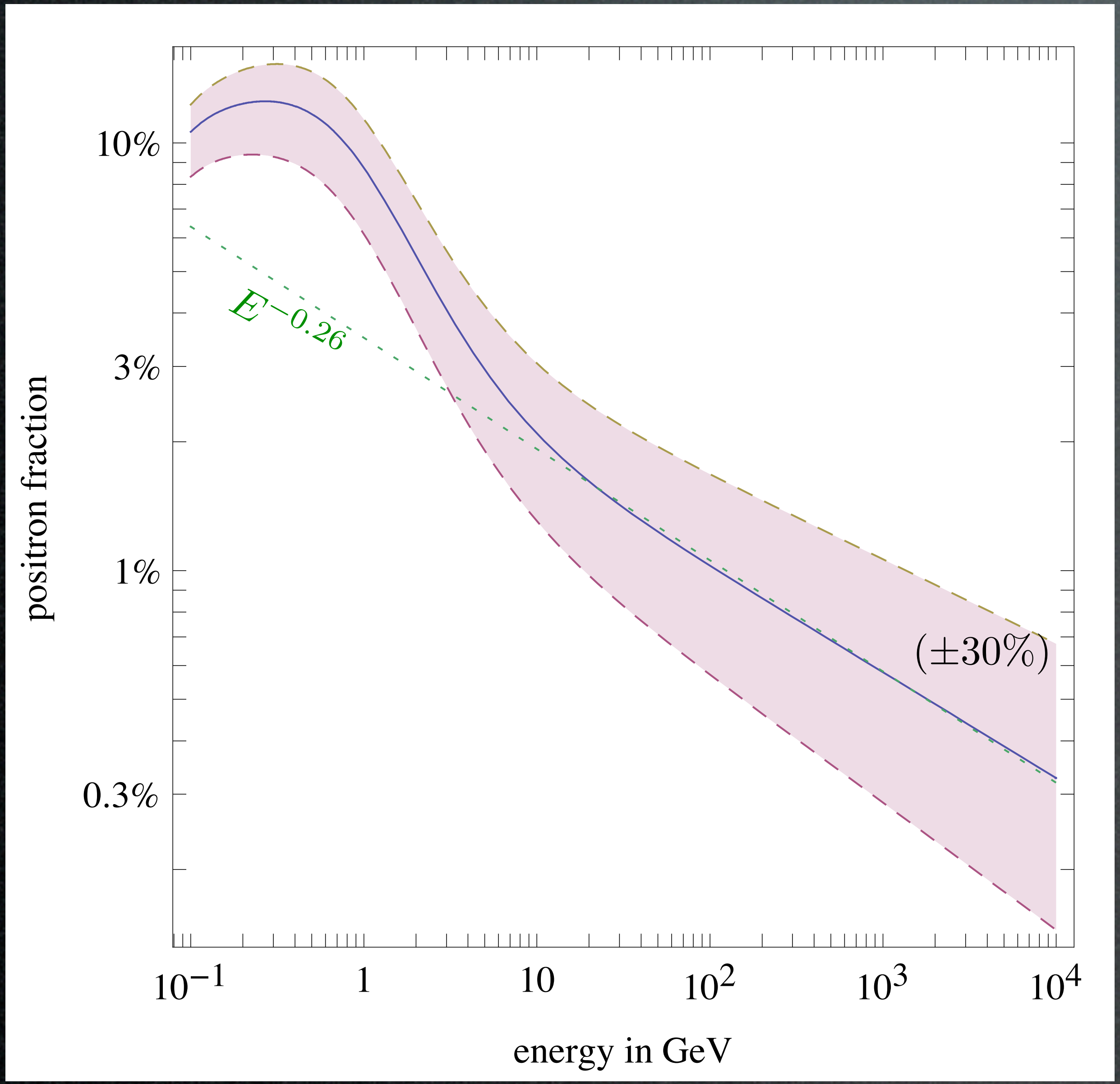
$$\Phi^{\rm bkg}_{e^+} = \frac{4.5\, E^{0.7}}{1 + 650\, E^{2.3} + 1500\, E^{4.2}}$$

$$\Phi^{\rm bkg}_{e^-} = \Phi^{\rm bkg,\,prim}_{e^-} + \Phi^{\rm bkg,\,sec}_{e^-} = \frac{0.16\, E^{-1.1}}{1 + 11\, E^{0.9} + 3.2\, E^{2.15}} + \frac{0.70\, E^{0.7}}{1 + 110\, E^{1.5} + 580\, E^{4.2}}$$

Baltz, Edsjo 1999

On the basis of CR simulations of Moskalenko, Strong 1998

More recently:
Delahaye et al., 0809.5268
P.Salati, Cargese 2007

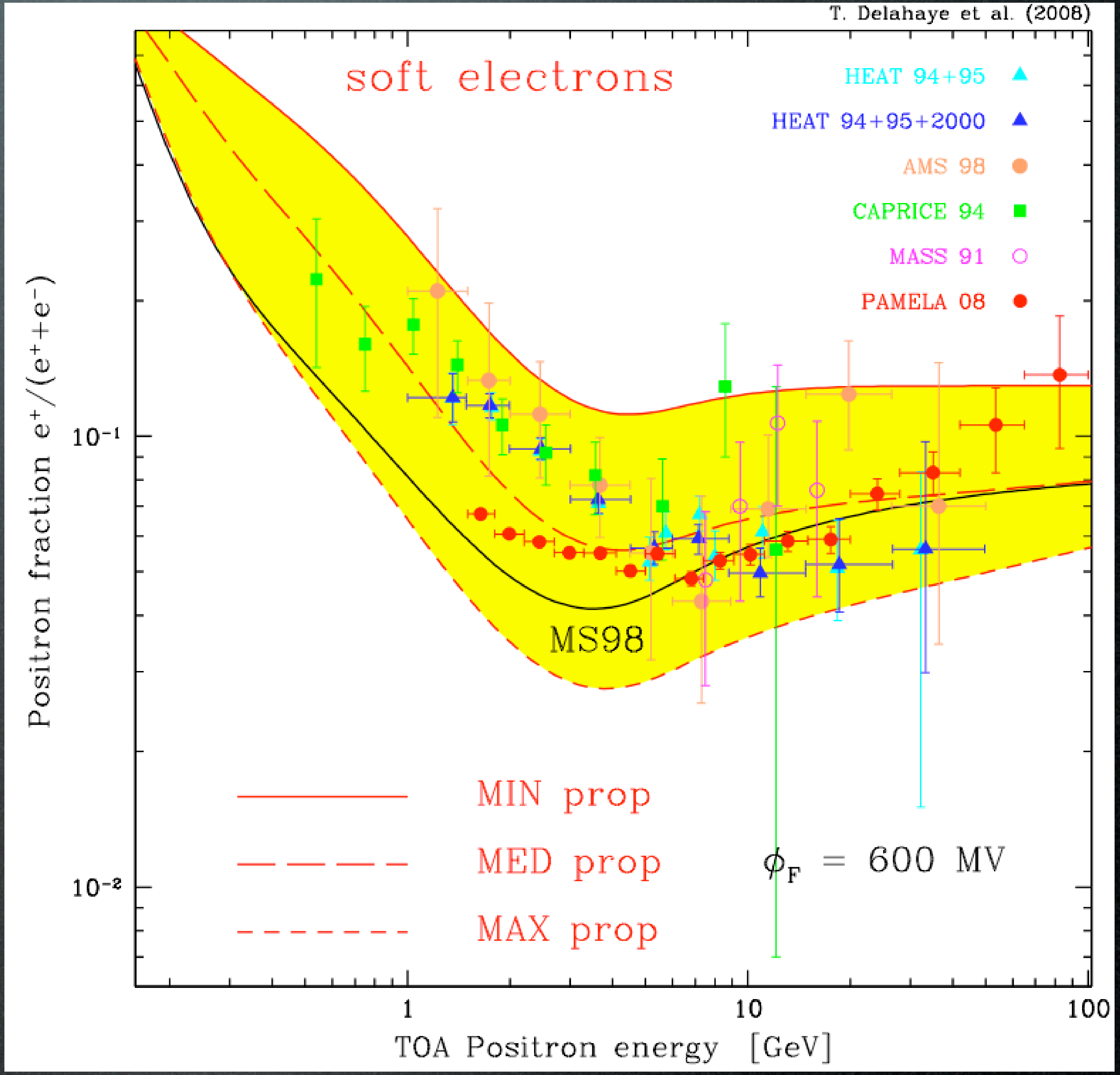


We marginalize w.r.t. the slope E^p, $\quad p = \pm 0.05$ and let normalization free.

[back]

Indirect Detection

Background estimation for positrons:



using new measuremens of electron fluxes

Casadei, Bindi 2008

T.Delahaye et al., 09.2008

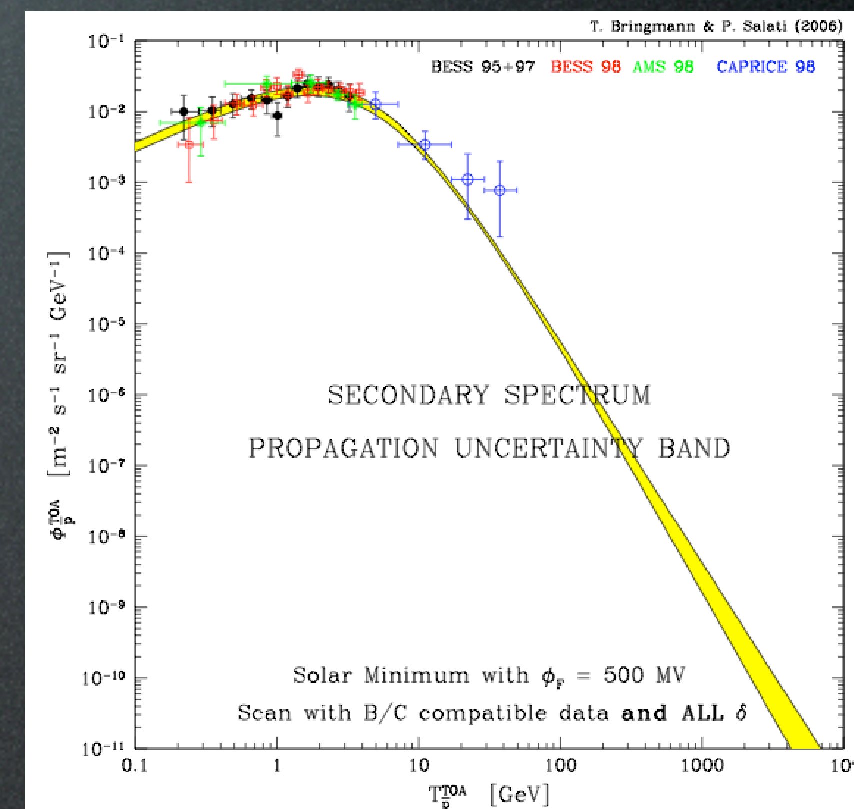
[back]

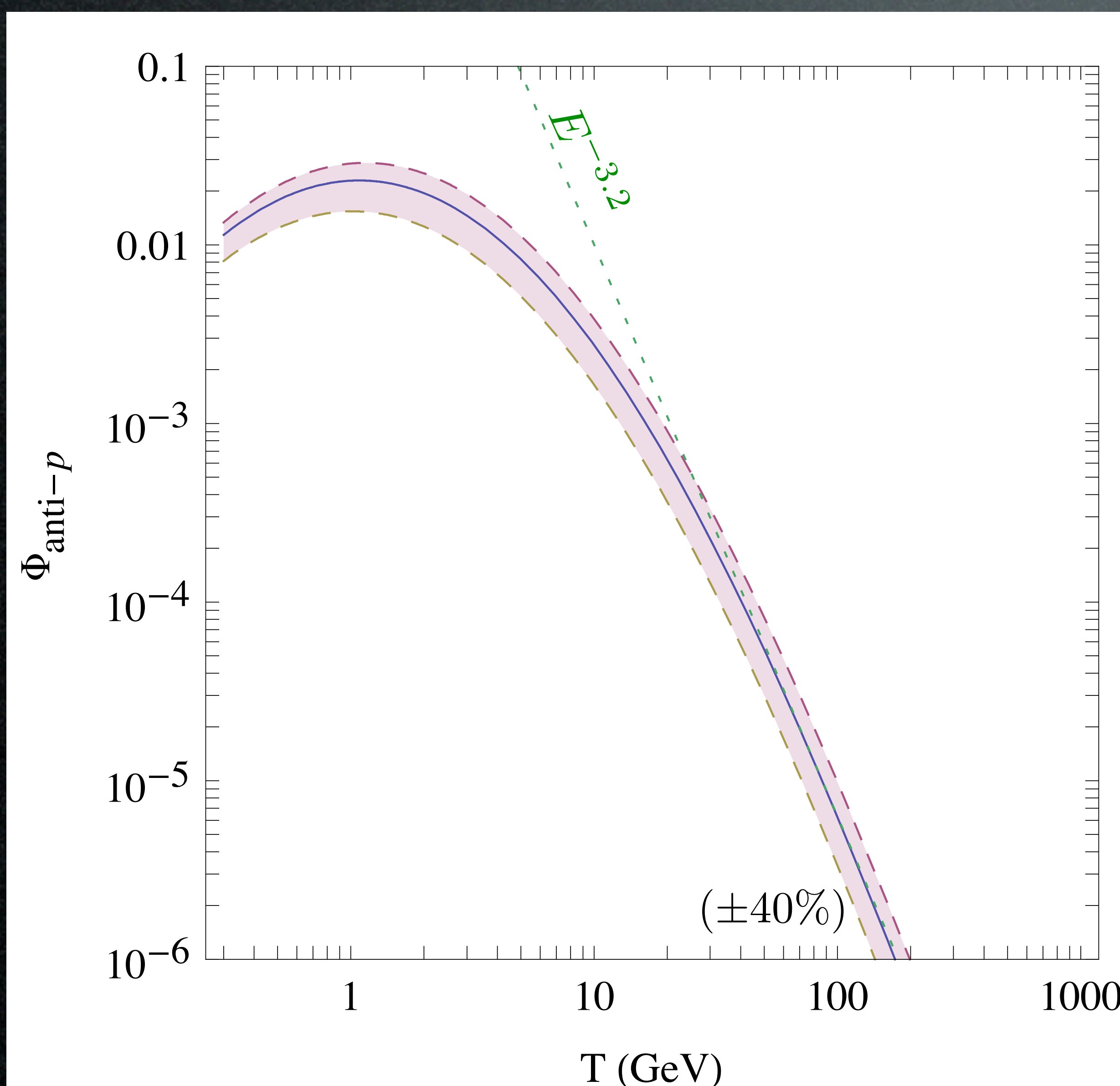
Indirect Detection

Background computations for antiprotons:

$$\log_{10}\Phi_{\bar{p}}^{\rm bkg} = -1.64 + 0.07\,\tau - \tau^2 - 0.02\,\tau^3 + 0.028\,\tau^4 \qquad \tau = \log_{10} T/\mathrm{GeV}$$

Bringmann, Salati 2006





We marginalize w.r.t. the slope
$E^p, \quad p = \pm 0.05$
and let normalization free.

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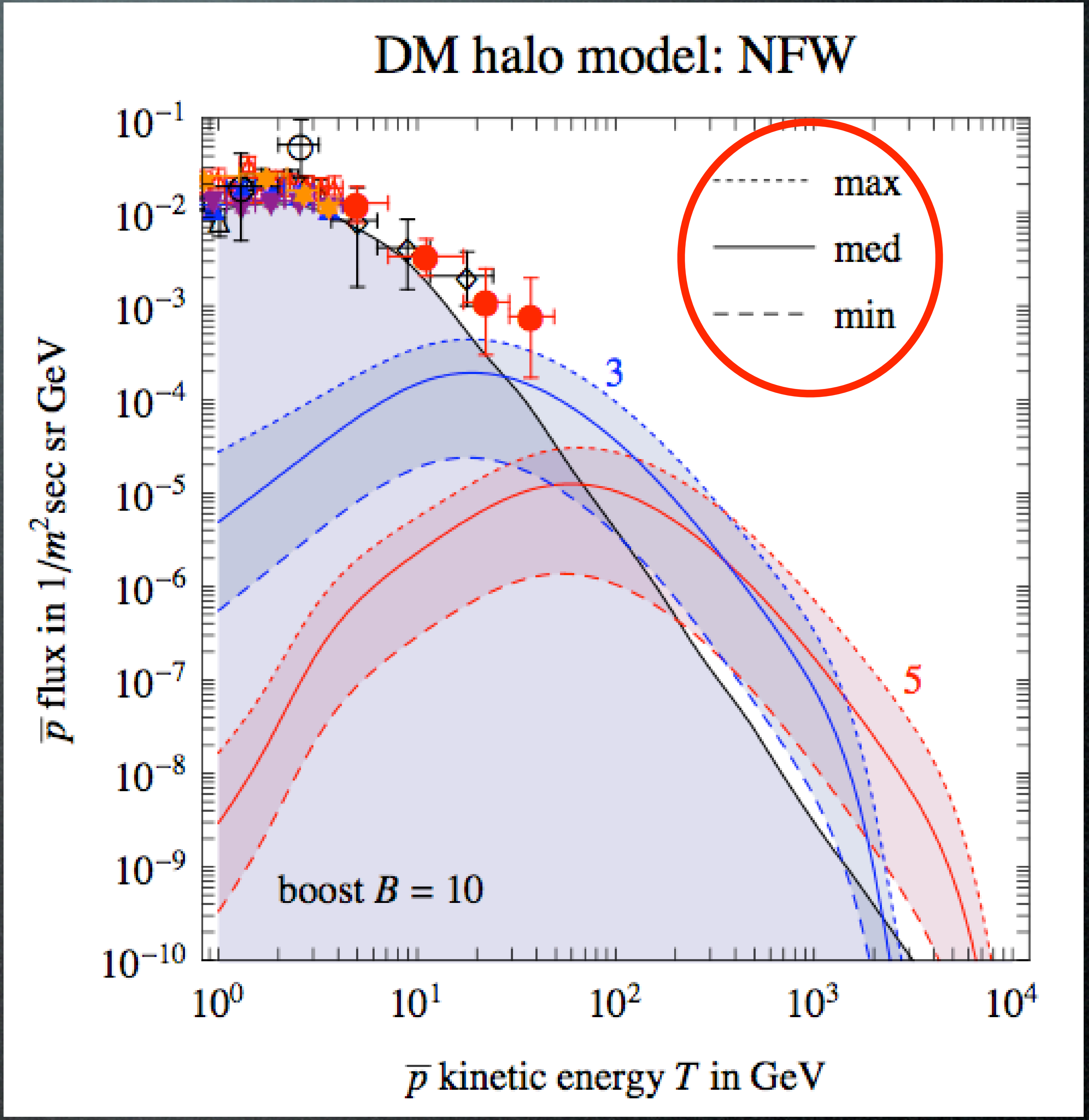
Indirect Detection

Results for anti-protons:

Astro uncertainties:

- propagation model
- DM halo profile
- boost factor B



Indirect Detection

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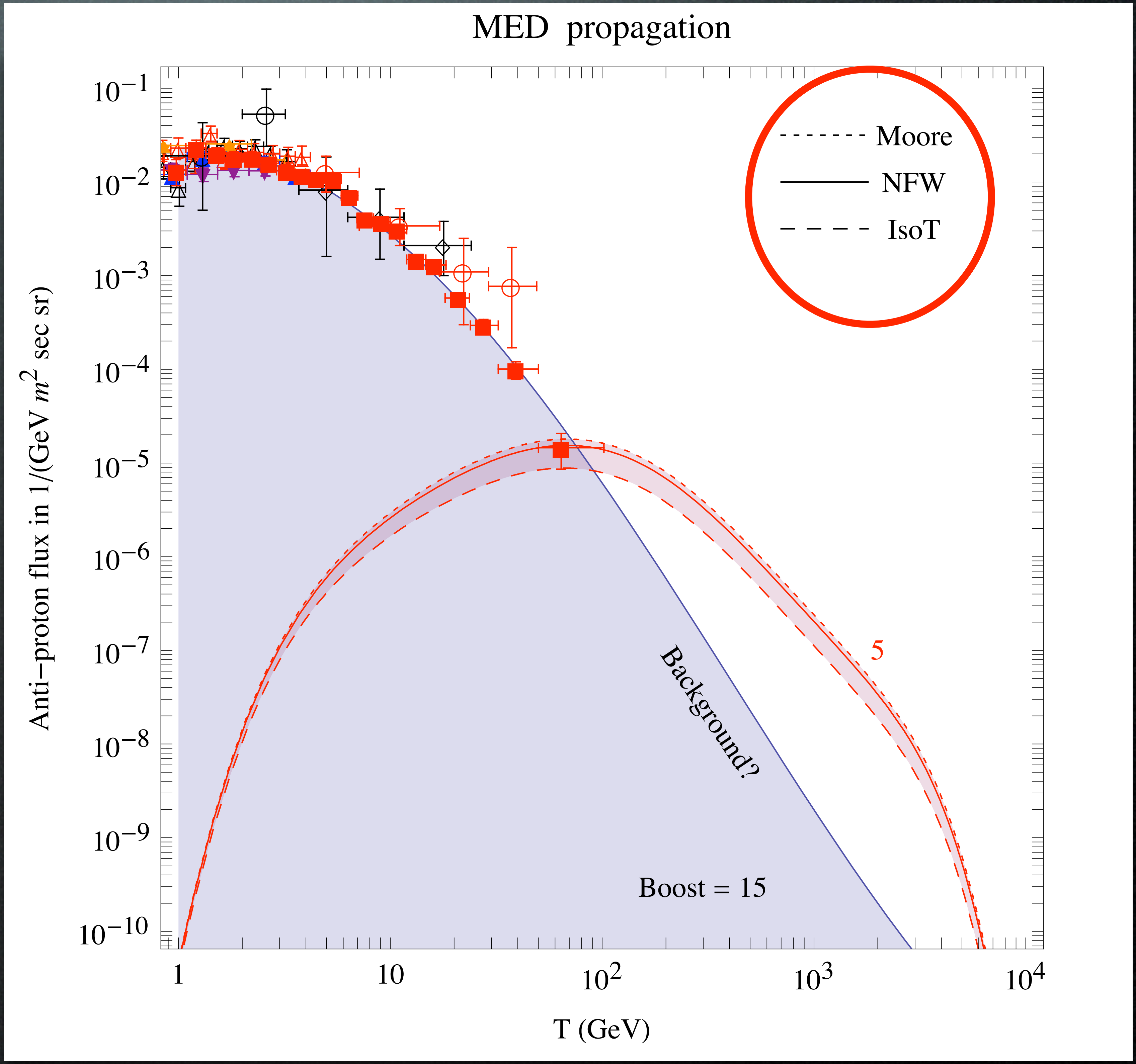


Results

Which DM spectra can fit the data?

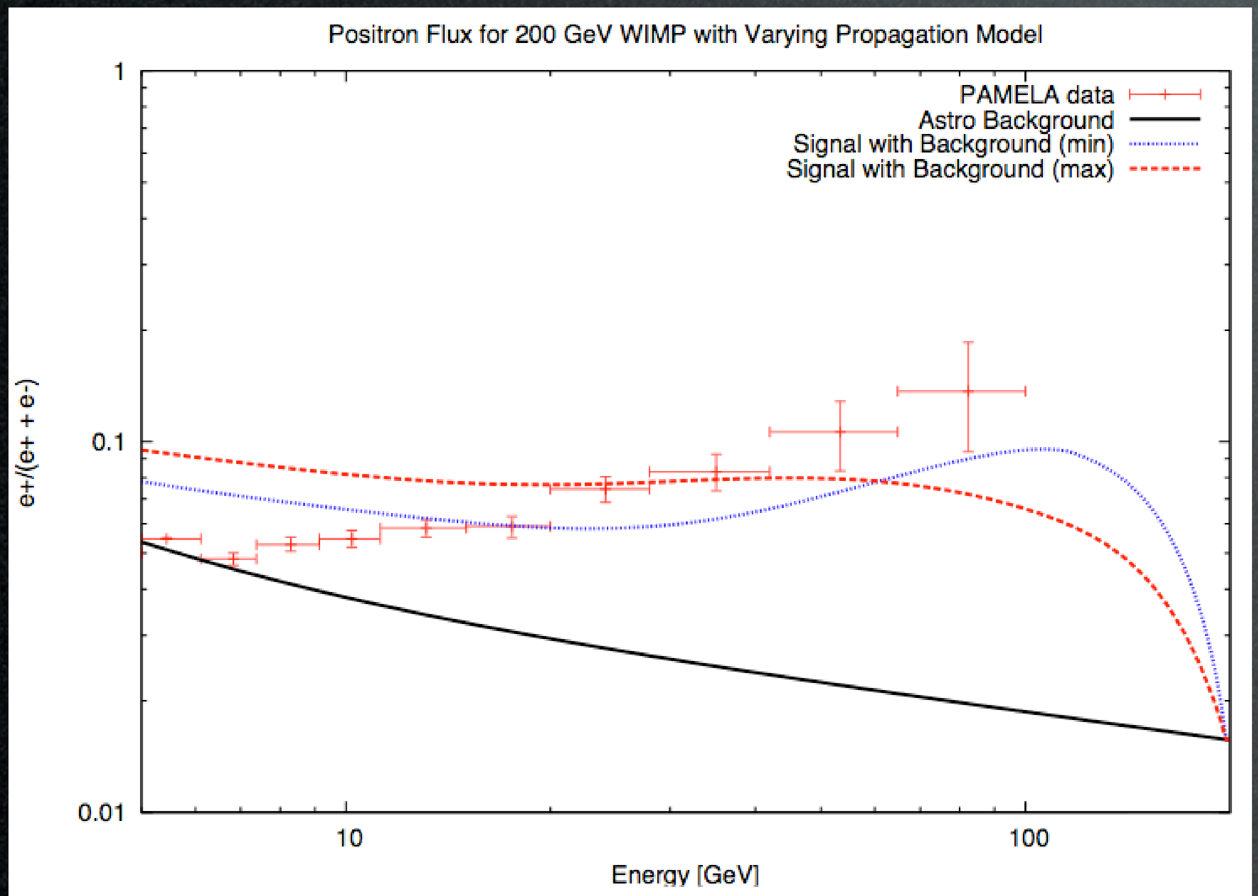
Ok, let's ***insist*** on Wino with: -mass $M_{\rm DM} = 200\,{\rm GeV}$

-annihilation ${\rm DM\ DM} \to W^+W^-$

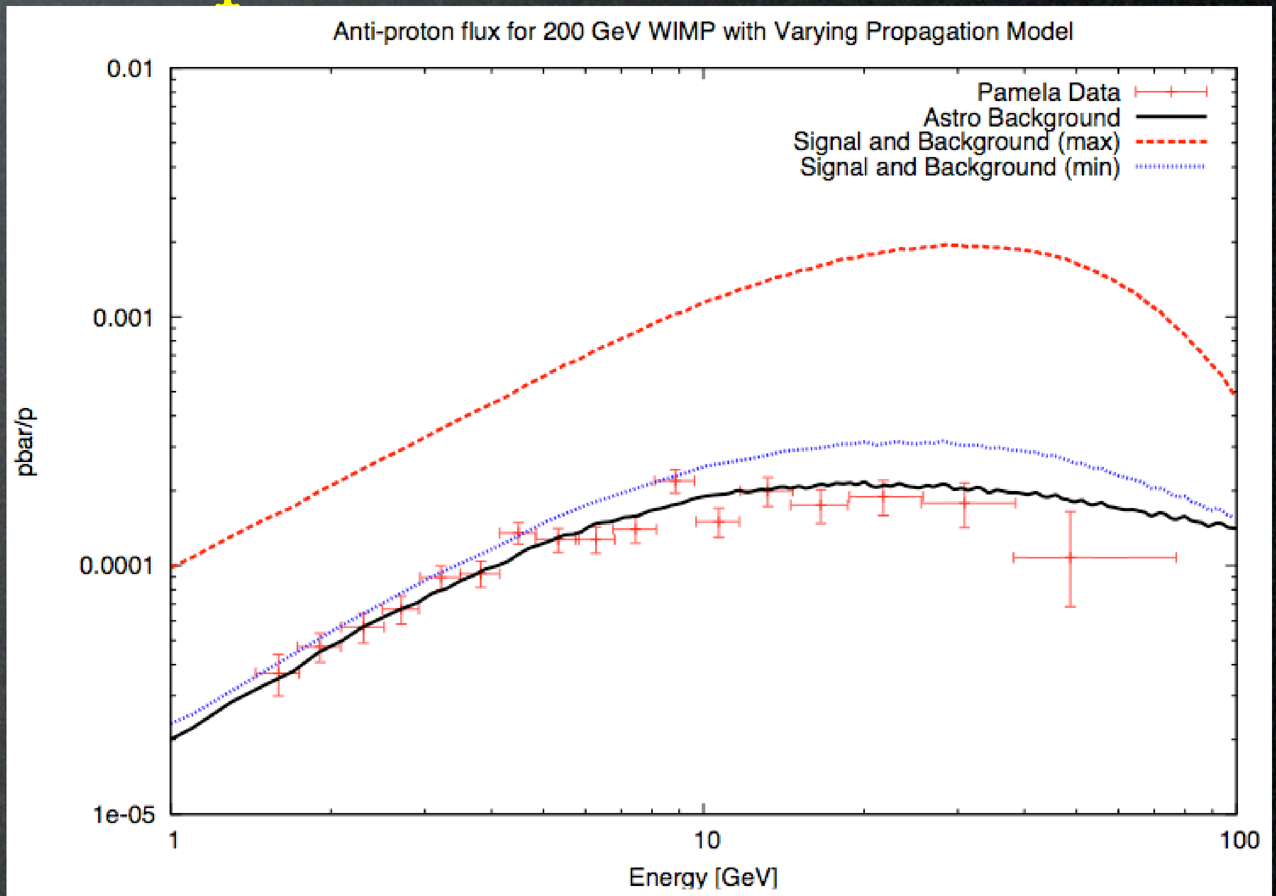
If one: - assumes non-thermal production of DM
- takes positron energy loss 5 times larger than usual
- takes "min" propagation only
- gives up ATIC
- neglects conflict with EGRET bound (4 times too many gammas)

then:

Positrons:



Anti-protons:

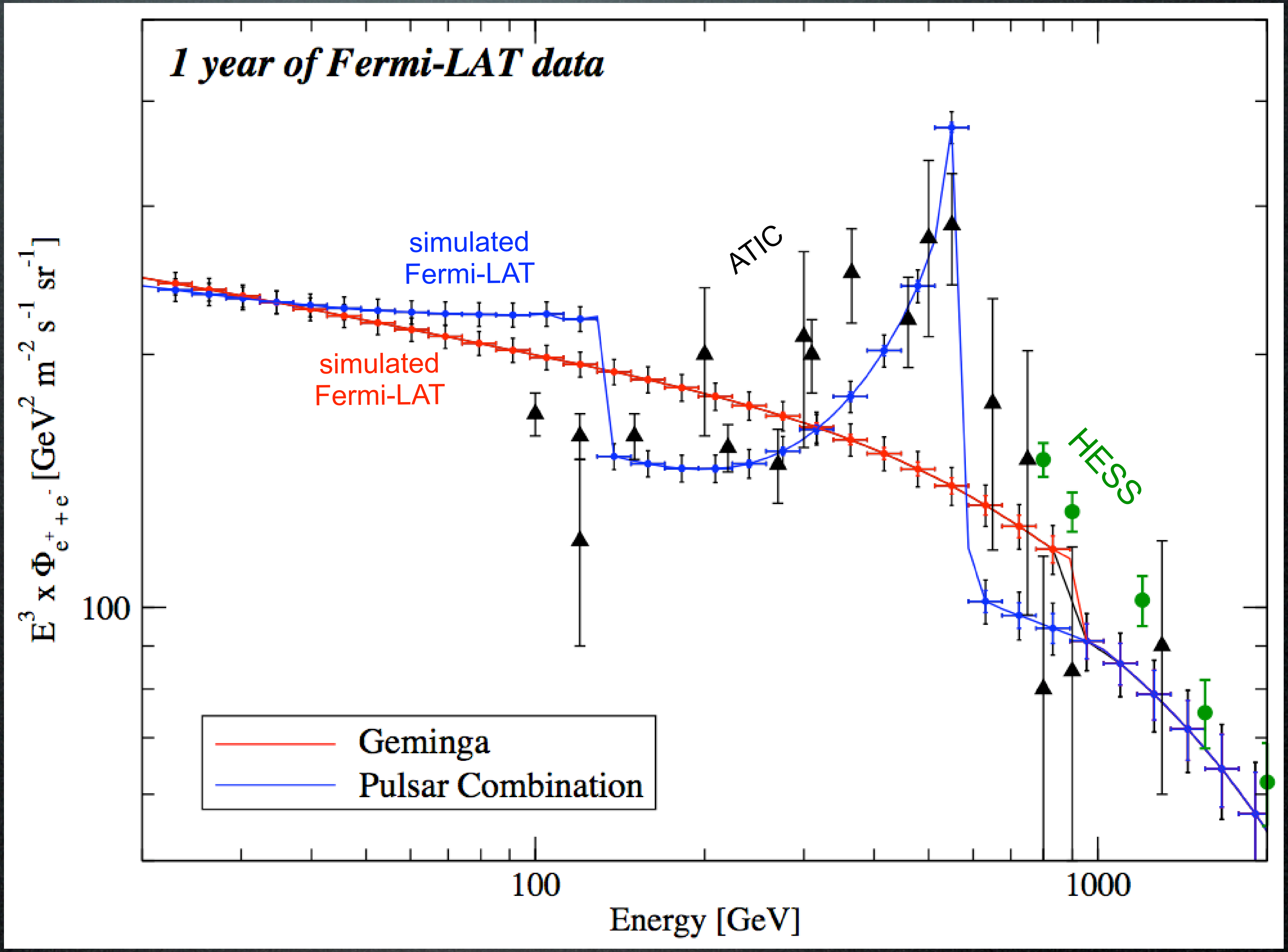


G.Kane, A.Pierce, P.Grajek, D.Phalen, S.Watson 0812.4555 [back]

Data sets

Electrons + positrons from Fermi-LAT:

Fermi detects gammas by pair production: it's inherently an e^+e^- detector



Profumo 0812.4457

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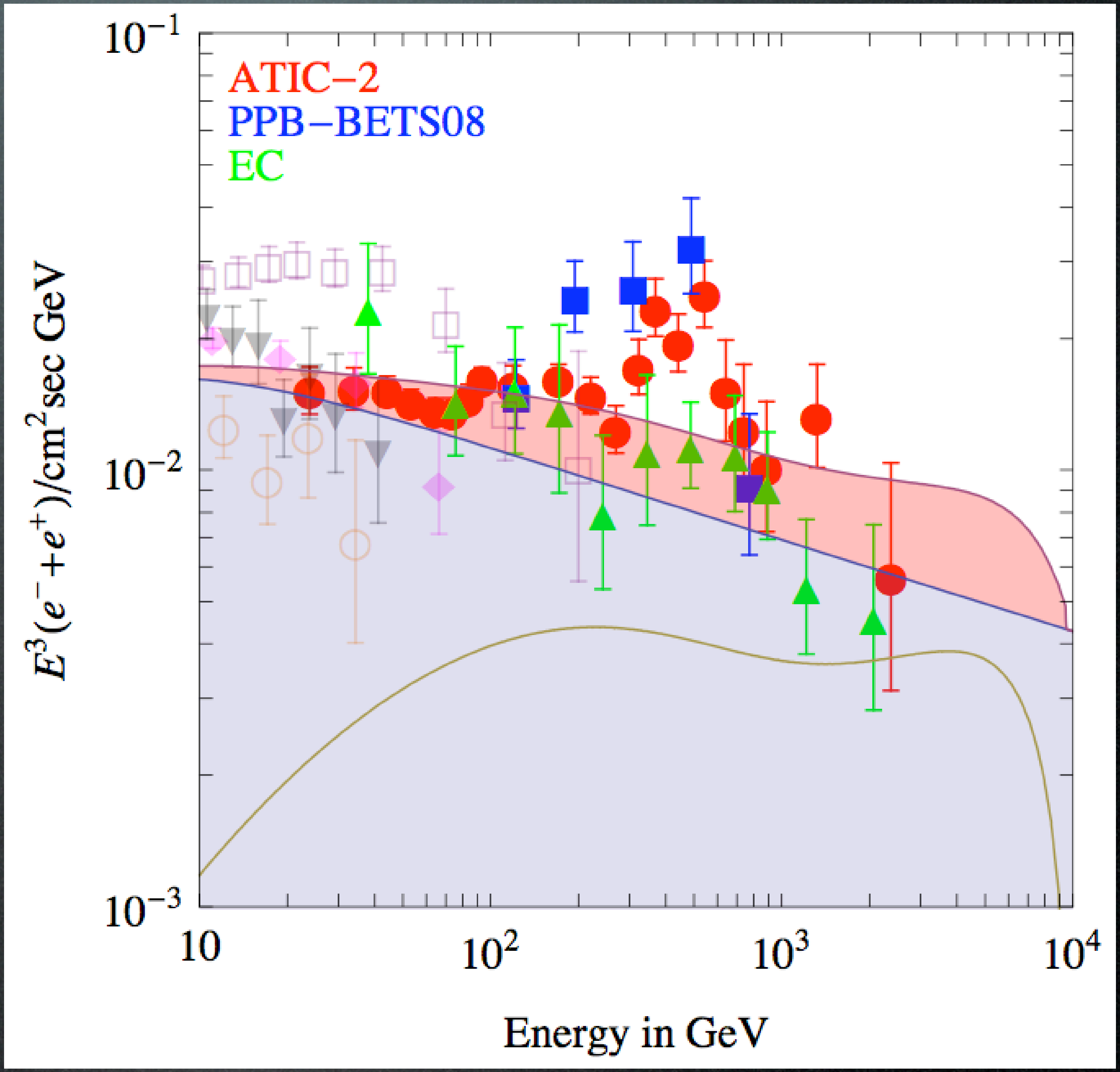
Results

Which DM spectra can fit the data?



Astrophysical explanation?

see S.Profumo, 0812.4457

the electron spectrum has a steep deepening!

T.Delahaye et al., 09.2008
Casadei, Bindi 2008

- difficult to get PAMELA slope
- does not explain ATIC or HESS

CR proton collisions on giant molecular clouds produce e^+e^-!

Dogiel, Sharov 1990

- does not work at E > 30 GeV

Coutu et al (HEAT), 1990

Gamma Ray Bursts produce e^+e^-!

Ioka 0812.4851

- maybe, constrained by gammas

β^+ decays of ^{56}Co in SN produce e^+!

ICRC 1990

- low energy and low flux

...

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