29 October 2013
GDR TeraScale Annecy - Dark Universe session

DM indirect detection with γ-rays:

status and some recent developments

Marco Cirelli

(CNRS IPhT Saclay)

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How does DM produce γ-rays?

1. prompt emission

1a. continuum **1b.** line(s) **1c.** sharp features

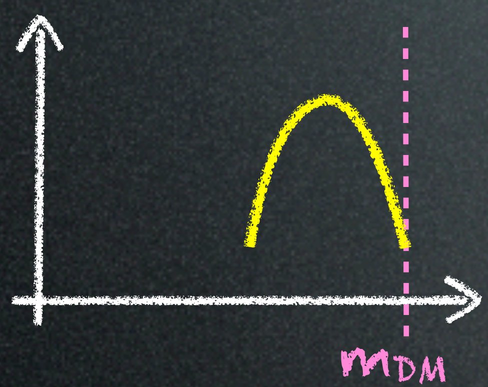
2. secondary emission

2a. ICS **2b.** bremsstrahlung **2c.** synchrotron

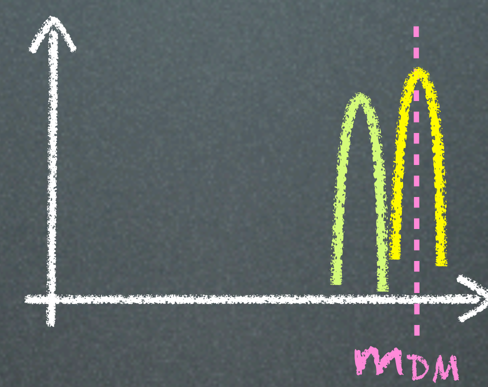
How does DM produce γ-rays?

1. prompt emission

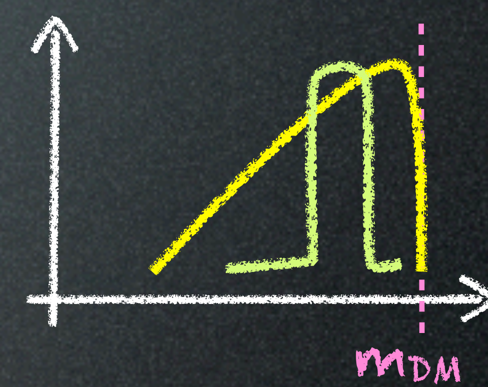
1a. continuum



1b. line(s)

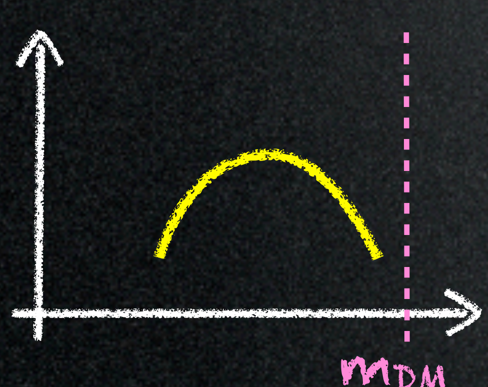


1c. sharp features

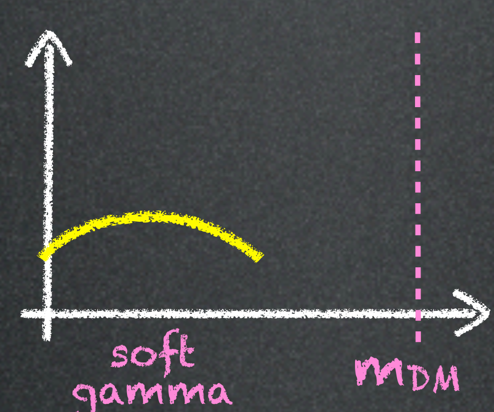


2. secondary emission

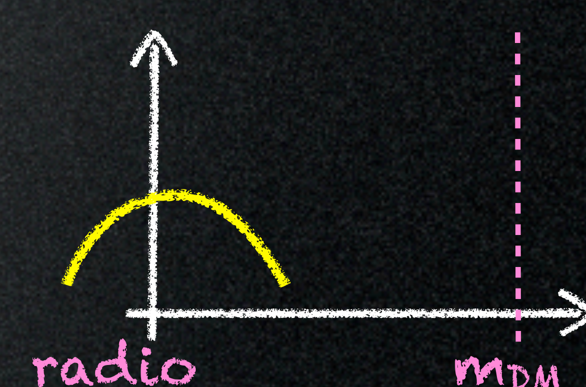
2a. ICS



2b. bremsstrahlung



2c. synchrotron

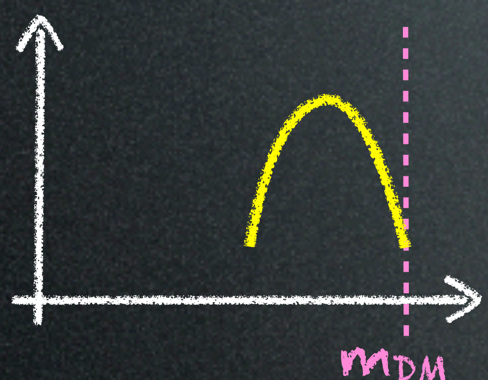


How does DM produce γ-rays?

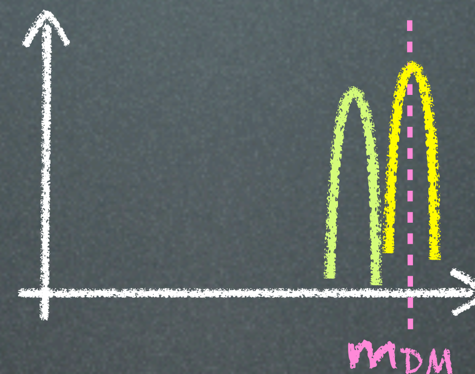
environment-independent

1. prompt emission

1a. continuum



1b. line(s)

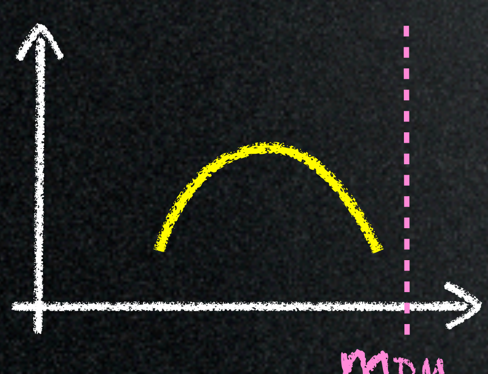


1c. sharp features

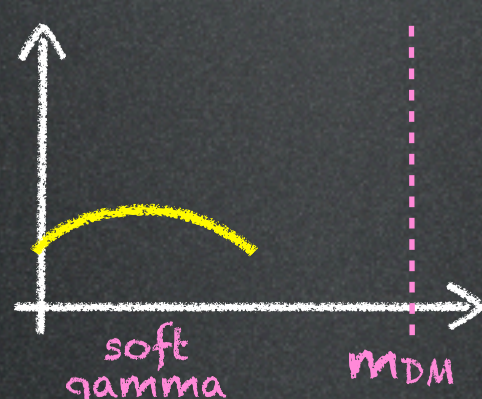
environment-dependent

2. secondary emission

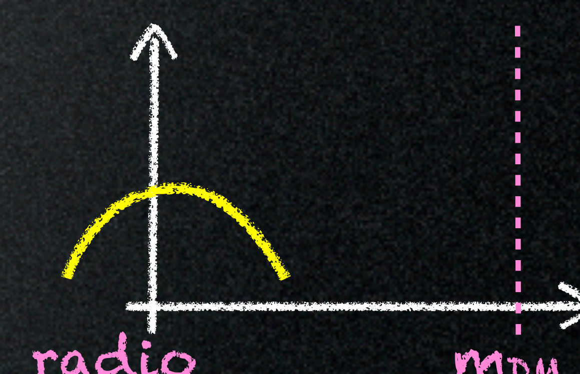
2a. ICS



2b. bremsstrahlung



2c. synchrotron



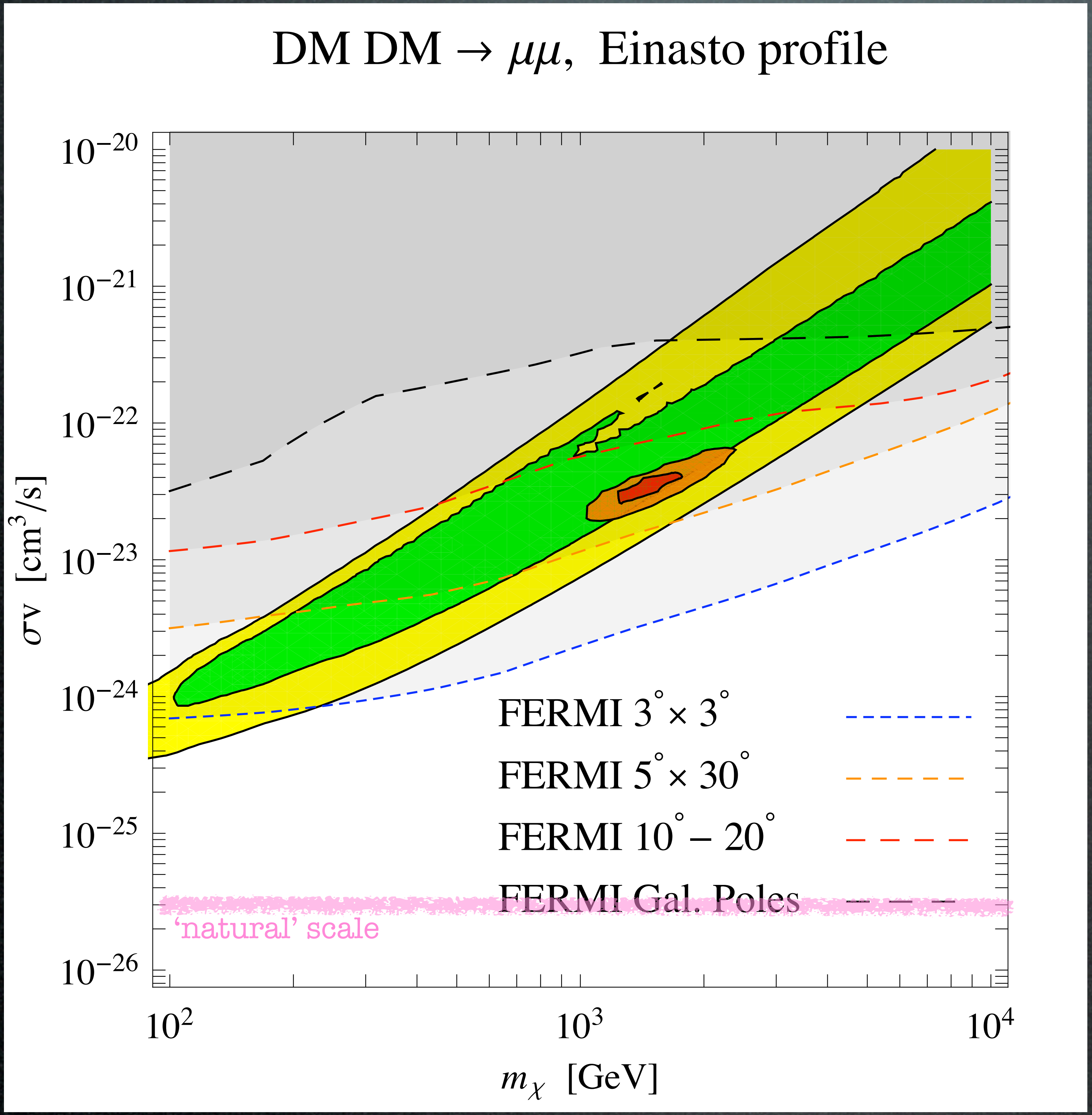
Status of the constraints

Status of the constraints

(a selection)

Gamma constraints

γ from Inverse Compton on $e^{\pm}$ in halo

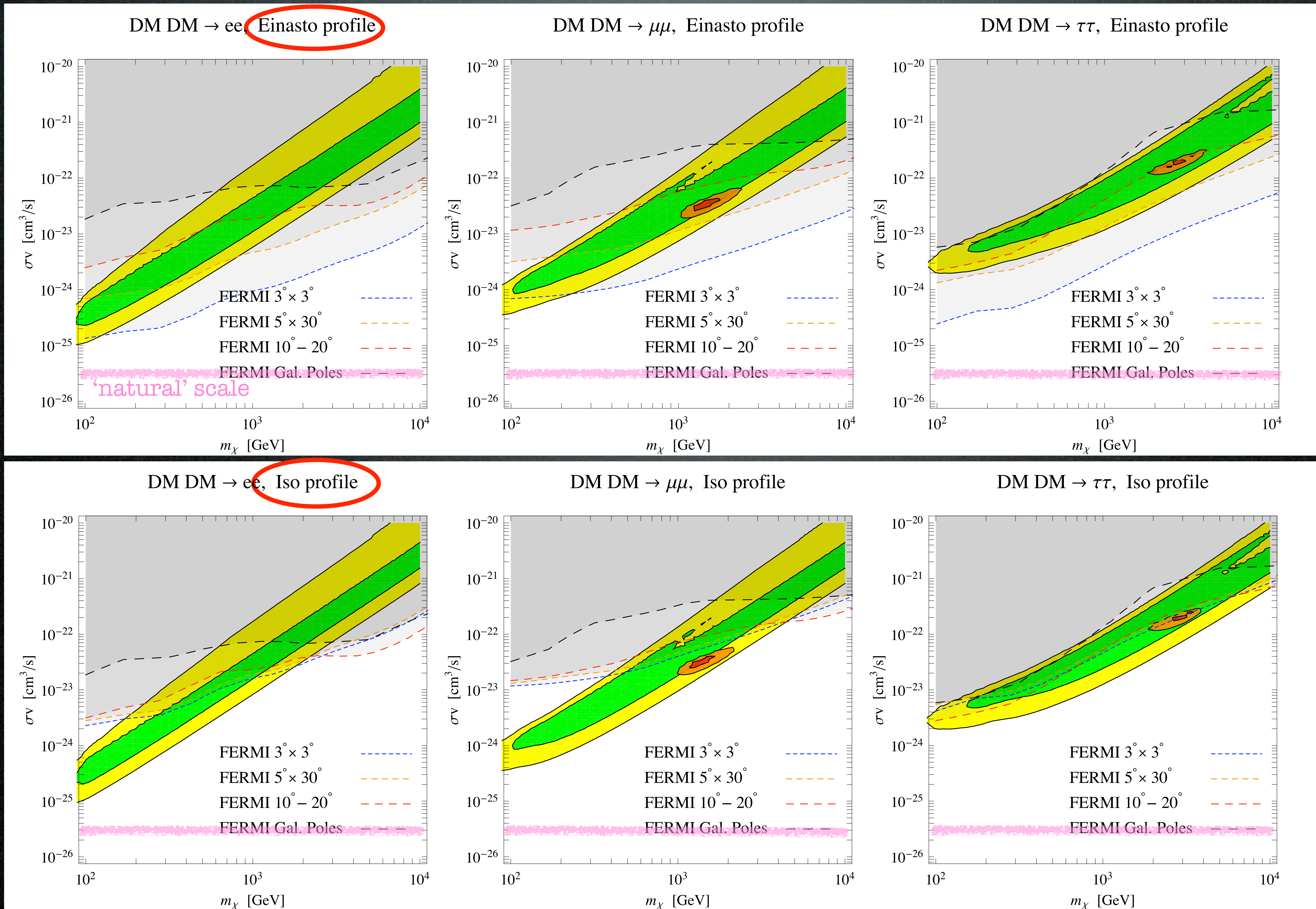


Cirelli, Panci, Serpico 0912.0663

Gamma ray constraints on the charged CR excesses

Gamma constraints

γ from Inverse Compton on $e^{\pm}$ in halo

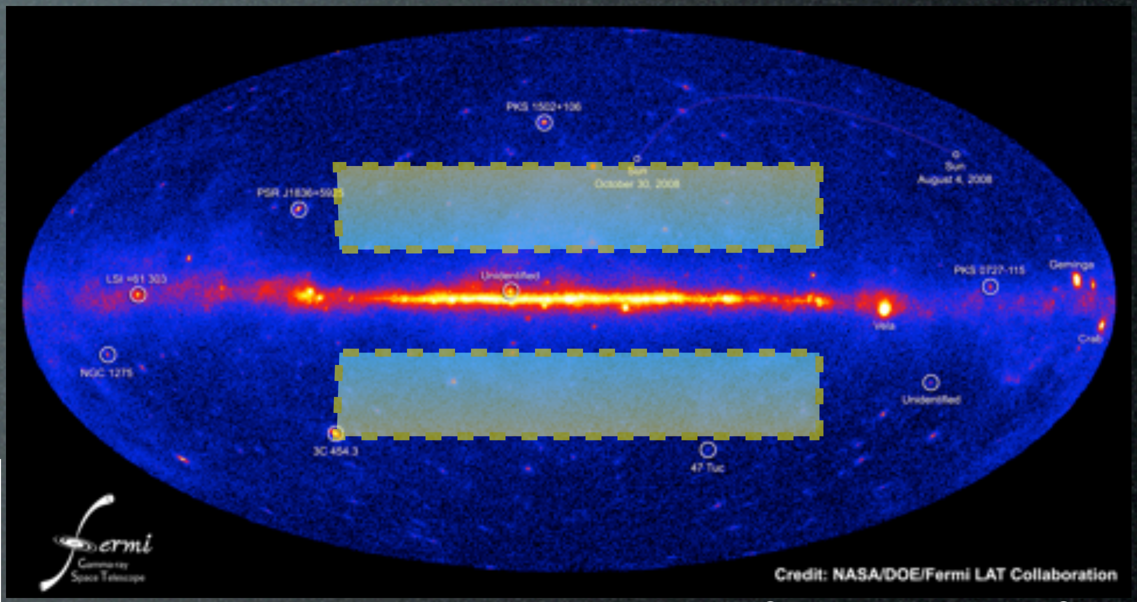


Cirelli, Panci, Serpico 0912.0663

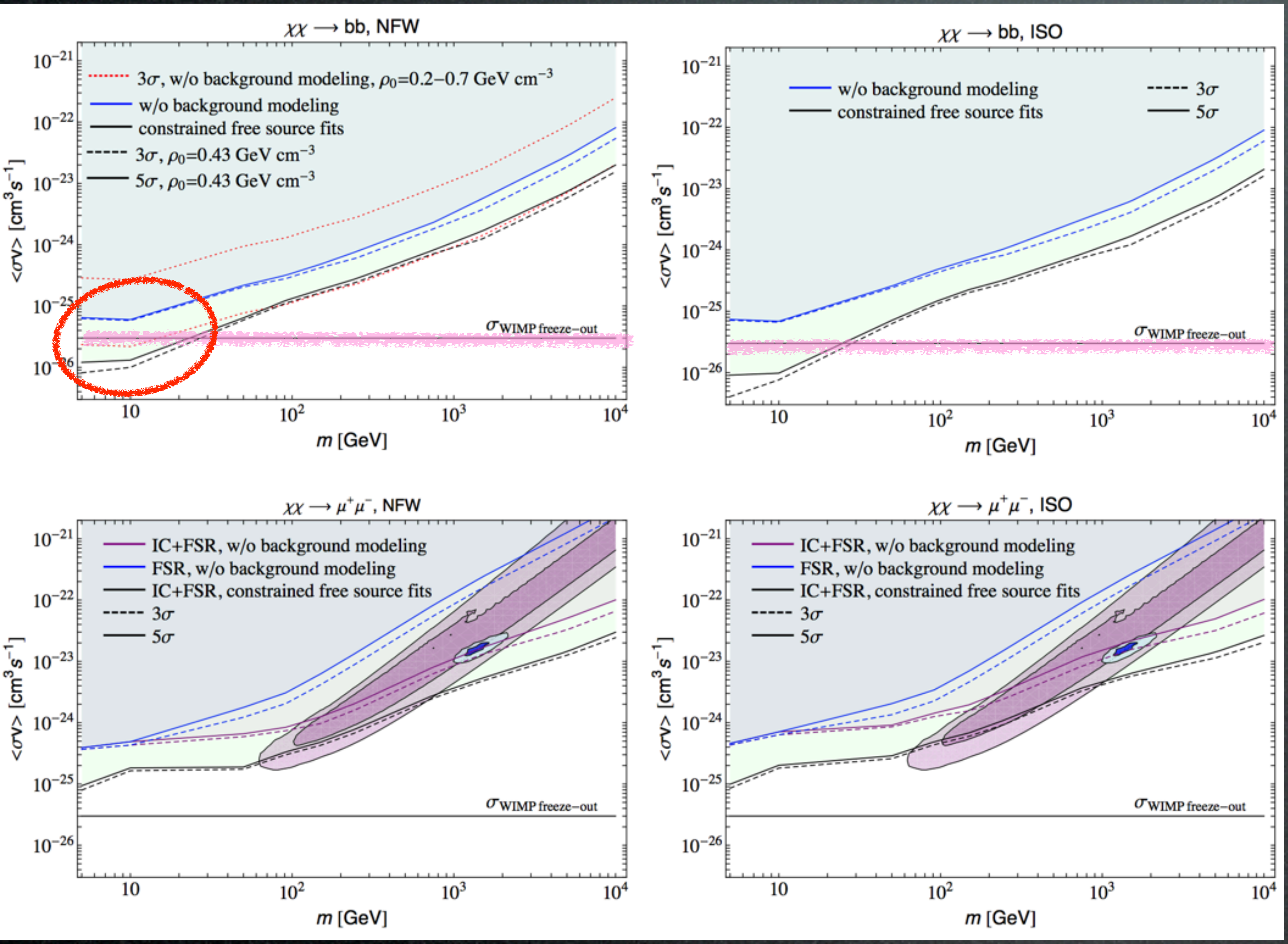
Gamma constraints

γ from Inverse Compton on $e^{\pm}$ in halo

Updated results from the **FERMI** coll. itself



$5^\circ < b < 15^\circ$
$-80^\circ < \ell < +80^\circ$



FERMI coll., Cuoco - Zaharijas, 1205.6474

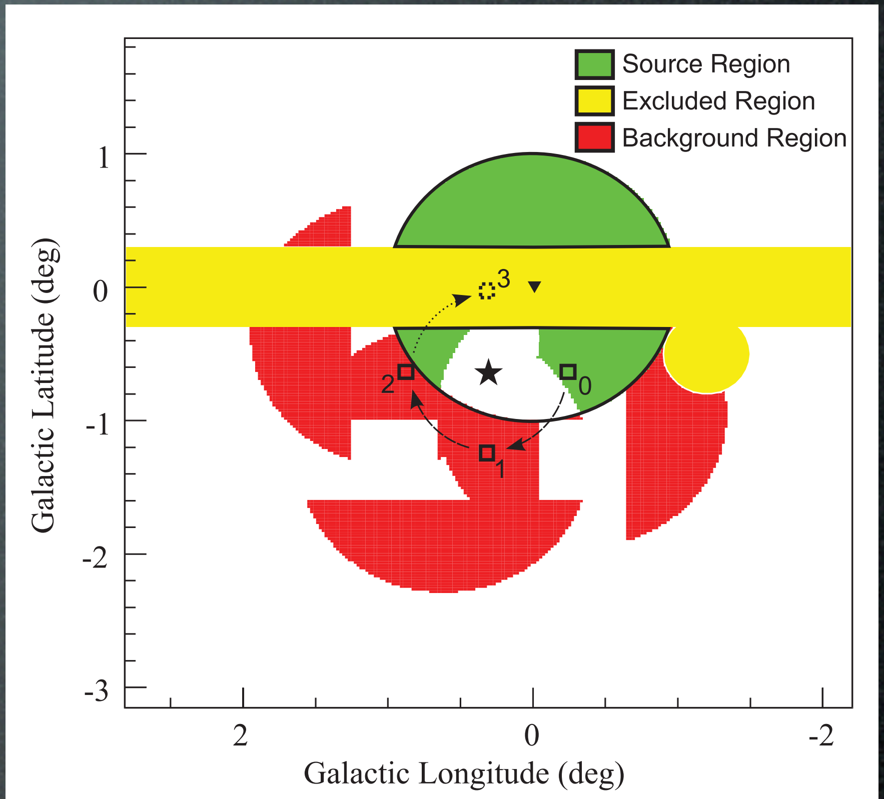
See also:
Papucci, Strumia,
0912.0742

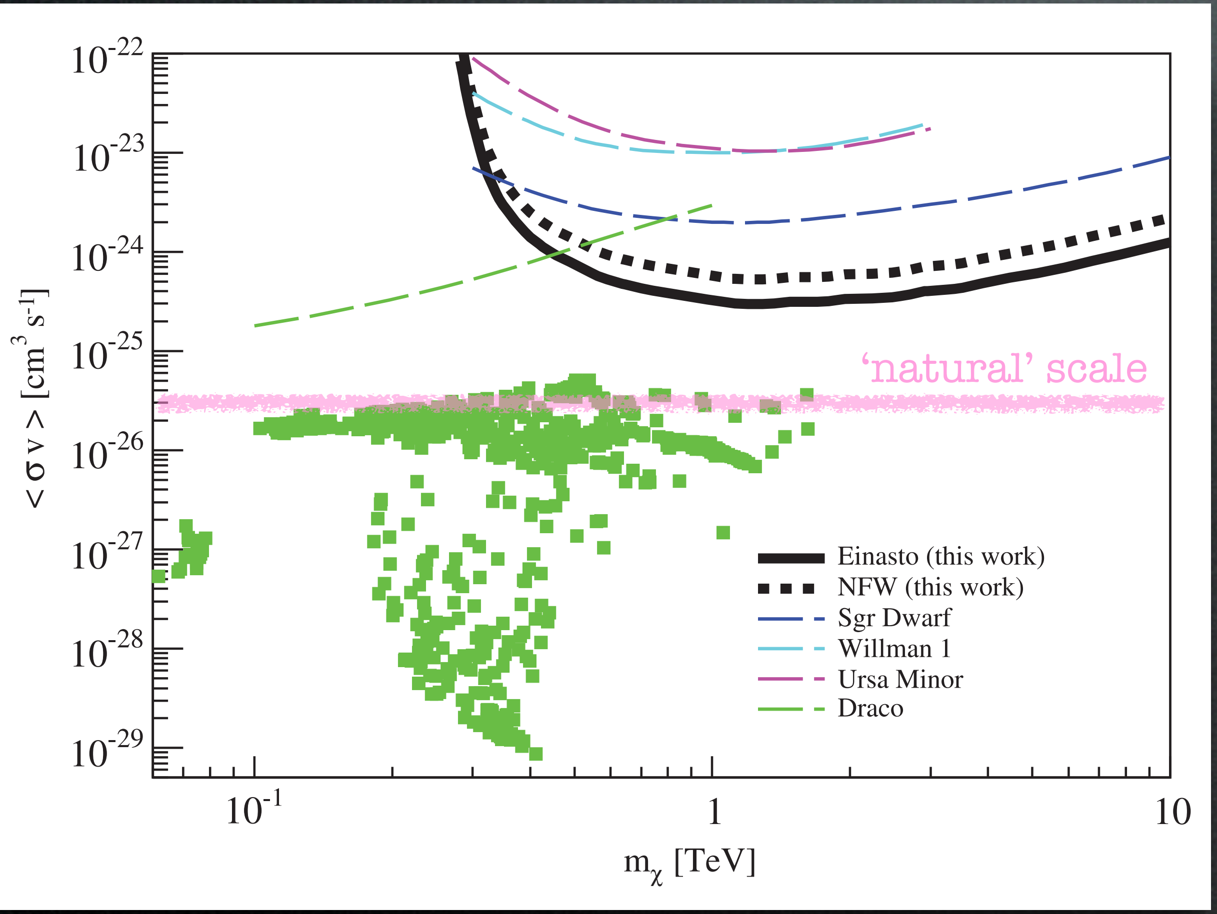
Gamma constraints

a. γ from DM annihilations in the Galactic Center

HESS has detected γ-ray emission from annulus around GC.

Derive bounds from on/off comparison.





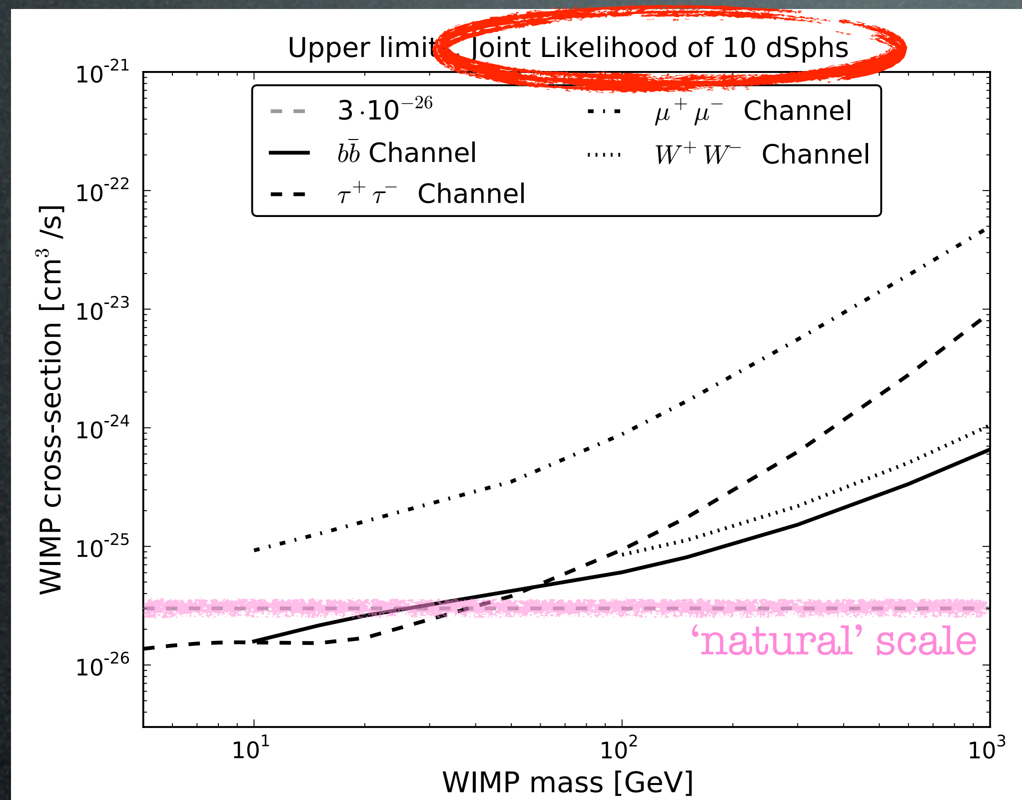
HESS coll., PRL 106, 2011

Gamma constraints

γ from DM annihilations in Satellite Galaxies

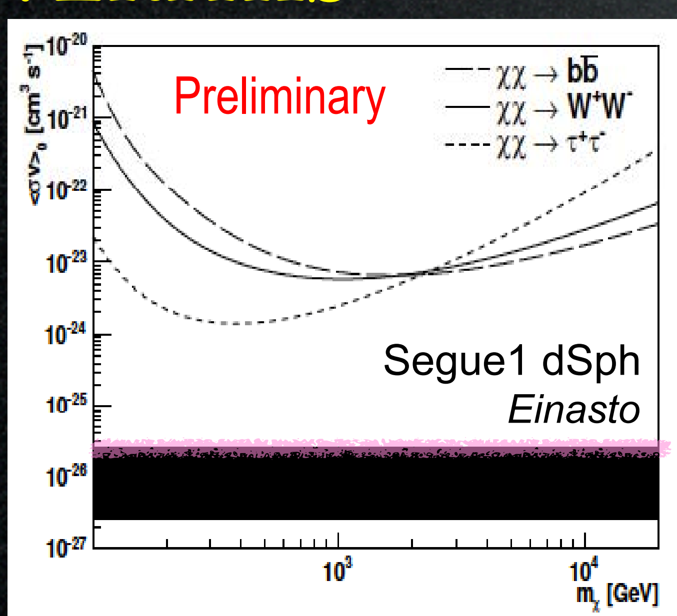
FERMI

FERMI coll., 1108.3546



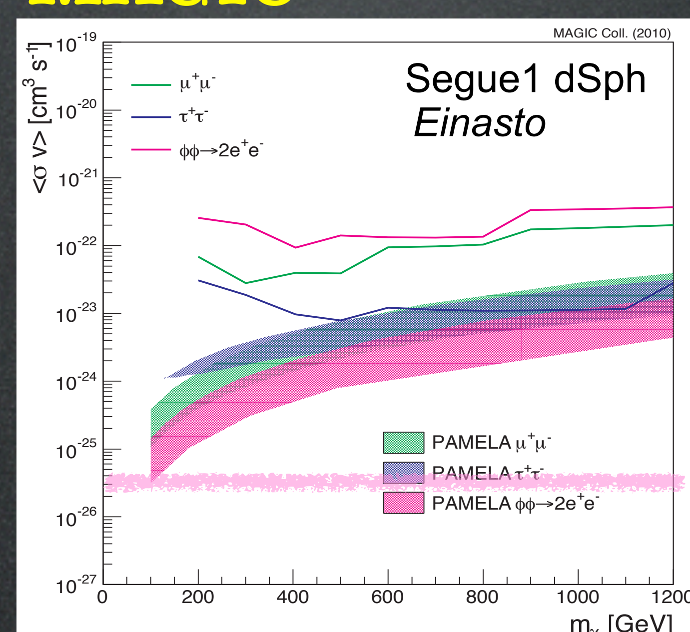
And the winner is...

VERITAS



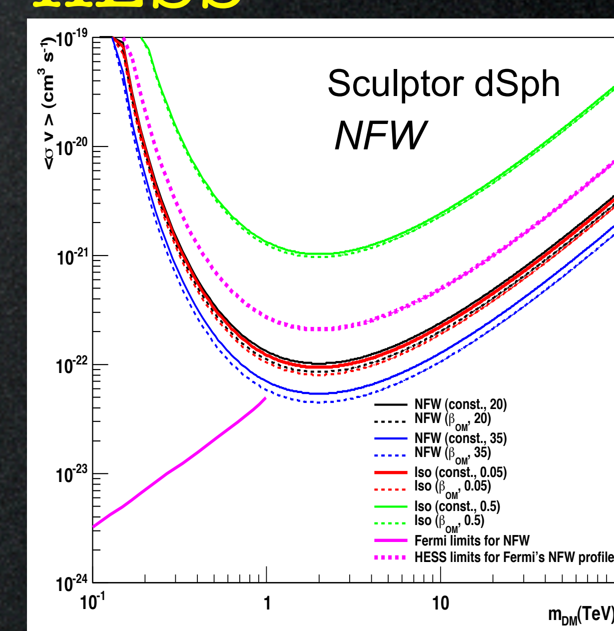
Veritas coll., courtesy of R.Ong

MAGIC



Magic coll., 1103.0477

HESS



HESS coll., 1012.5602

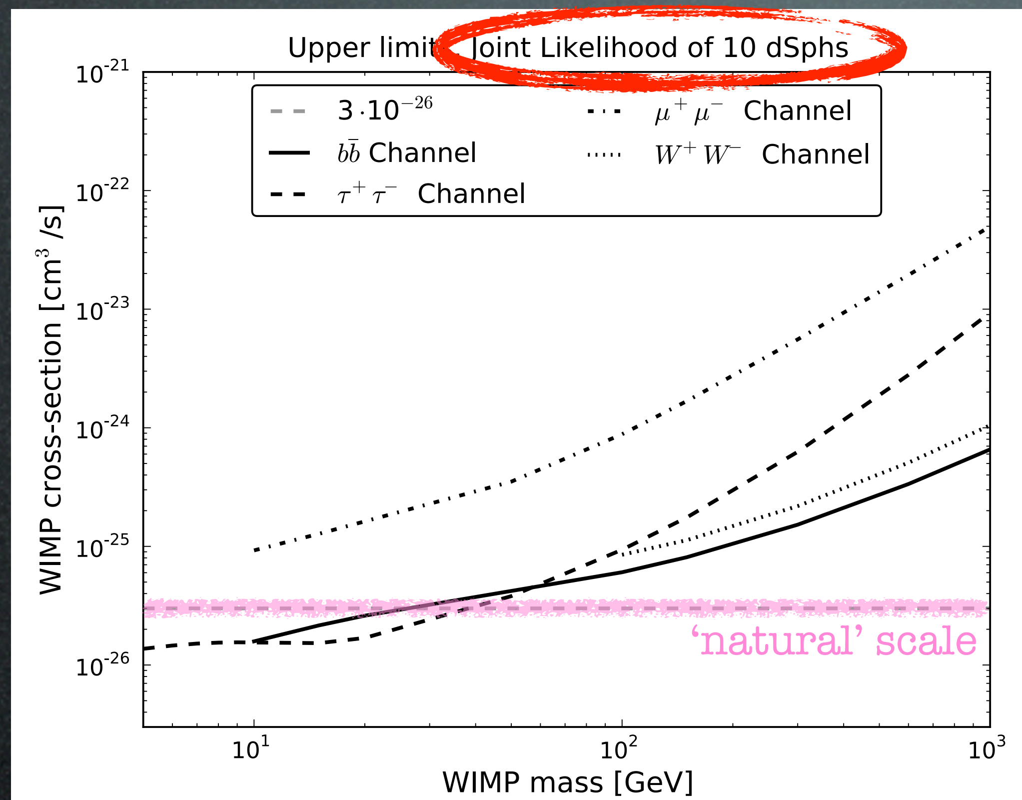
(HESS: Globular Clusters analysis too)

Gamma constraints

γ from DM annihilations in Satellite Galaxies

FERMI

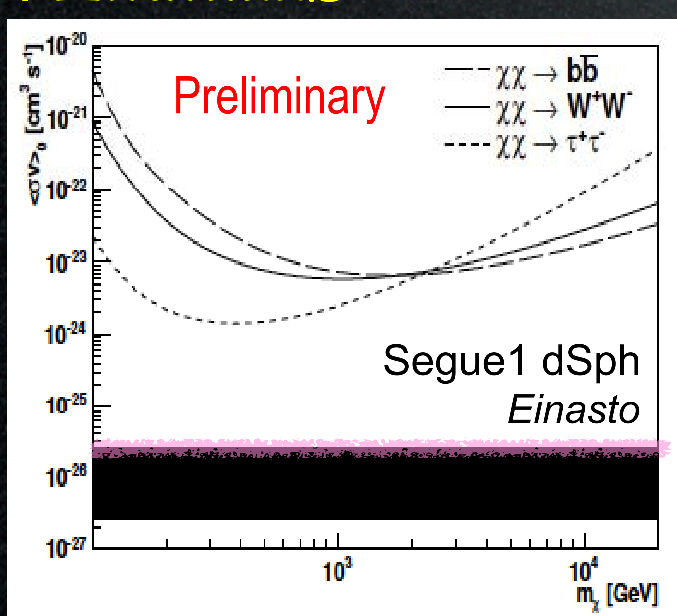
FERMI coll., 1108.3546



And the winner is... FERMI.
But beware of different profiles, techniques...

see also:
Geringer-Sameth, Koushiappas, 1108.2914
Strigari et al. (0902.4750, 1007.4199...)
Baxter, Dodelson et al.

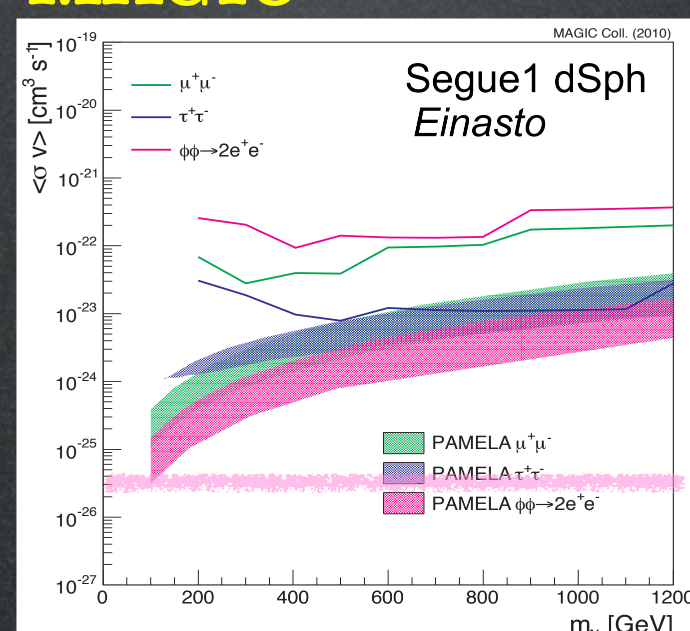
VERITAS



Veritas coll., courtesy of R.Ong

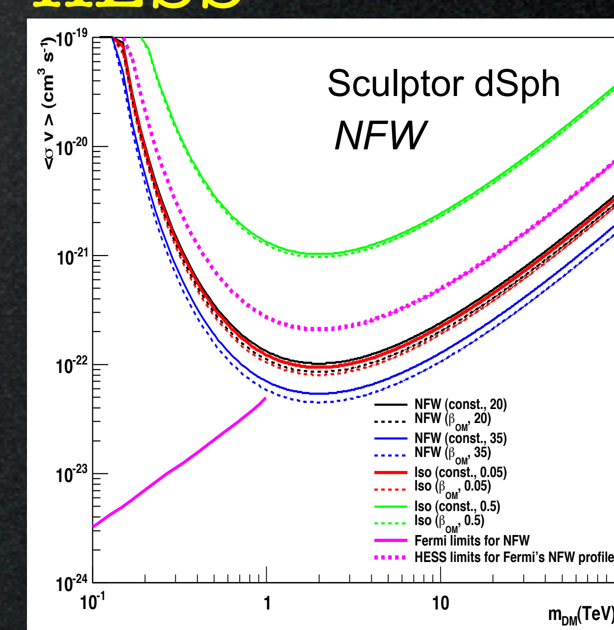
(currently the winner in the '1 dSph' category)

MAGIC



Magic coll., 1103.0477

HESS



HESS coll., 1012.5602

(HESS: Globular Clusters analysis too)

Gamma constraints

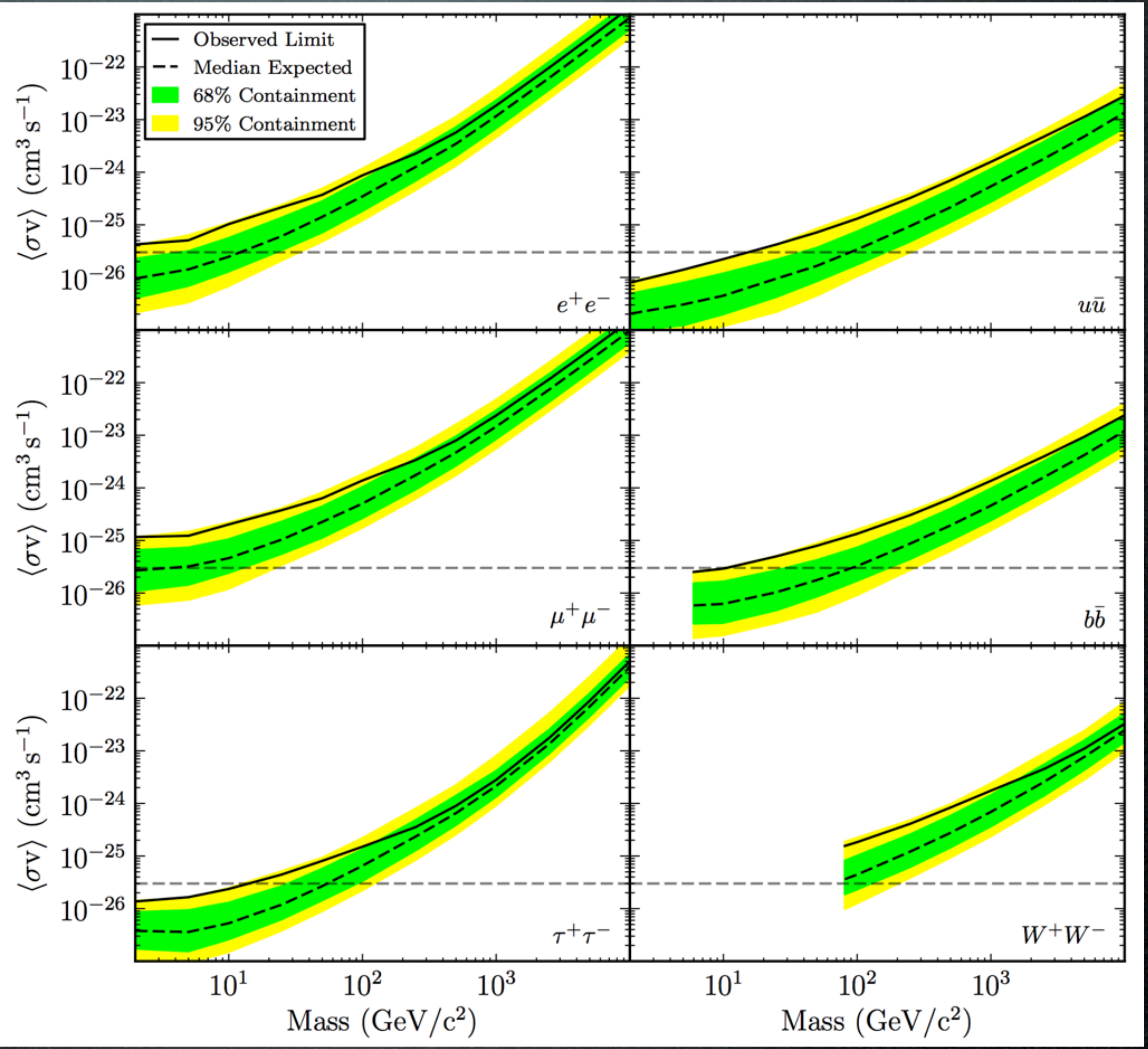
γ from DM annihilations in Satellite Galaxies

FERMI

1310.0828 Fermi coll., Alex Drlica-Wagner

4 years data: weaker bound

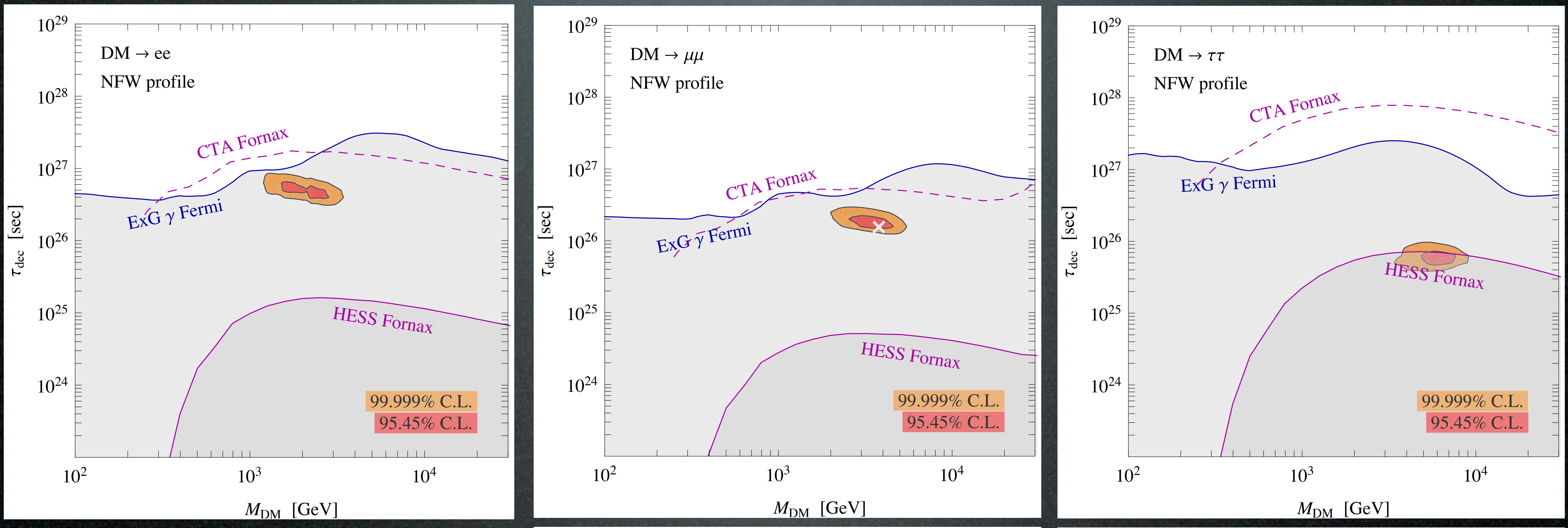
(or 10 GeV DM peeping out?)



Decaying DM

But, again: gamma ray constraints

(although: no radio, neutrino constraints)



Cirelli, Moulin, Panci, Serpico, Viana 1205.5283

The PAMELA and FERMI regions are in conflict with these gamma constraints.

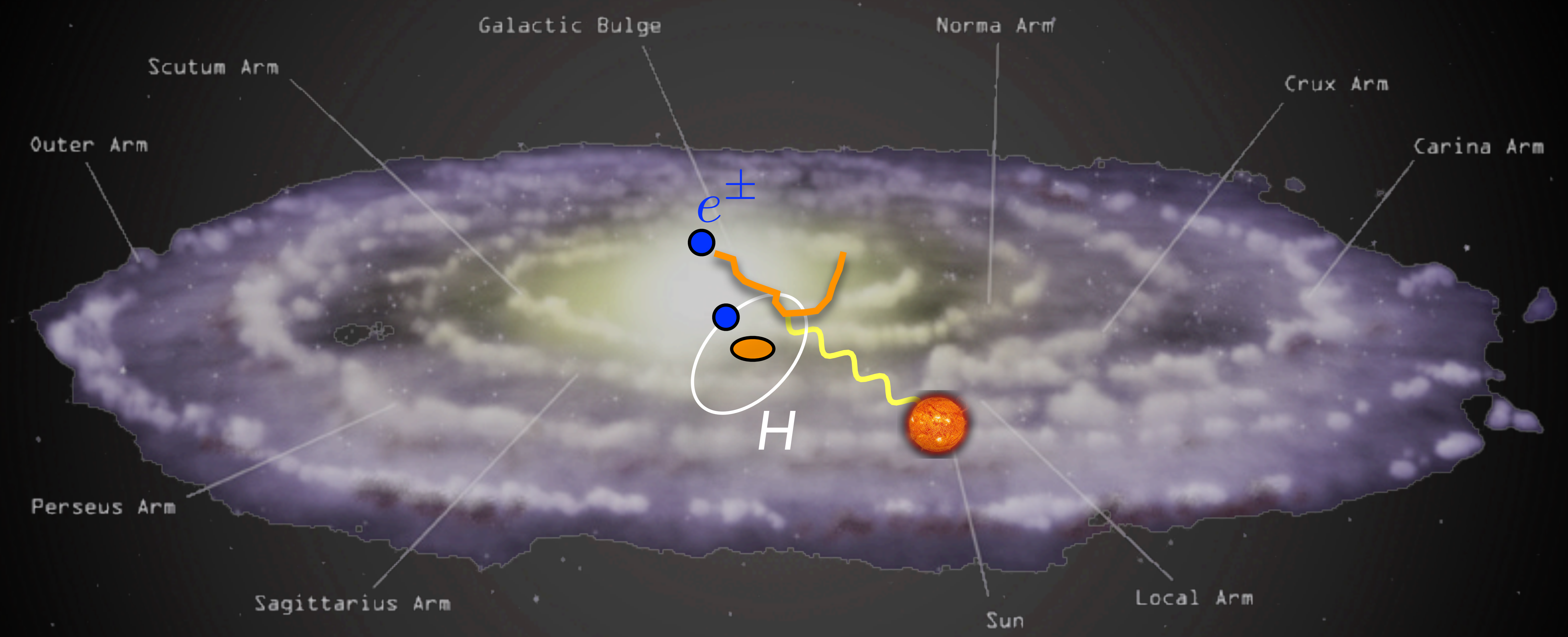
Some recent developments

Some recent developments:

- bremsstrahlung γ-rays from light DM
- FERMI 130 GeV line
- excesses near the Galactic Center

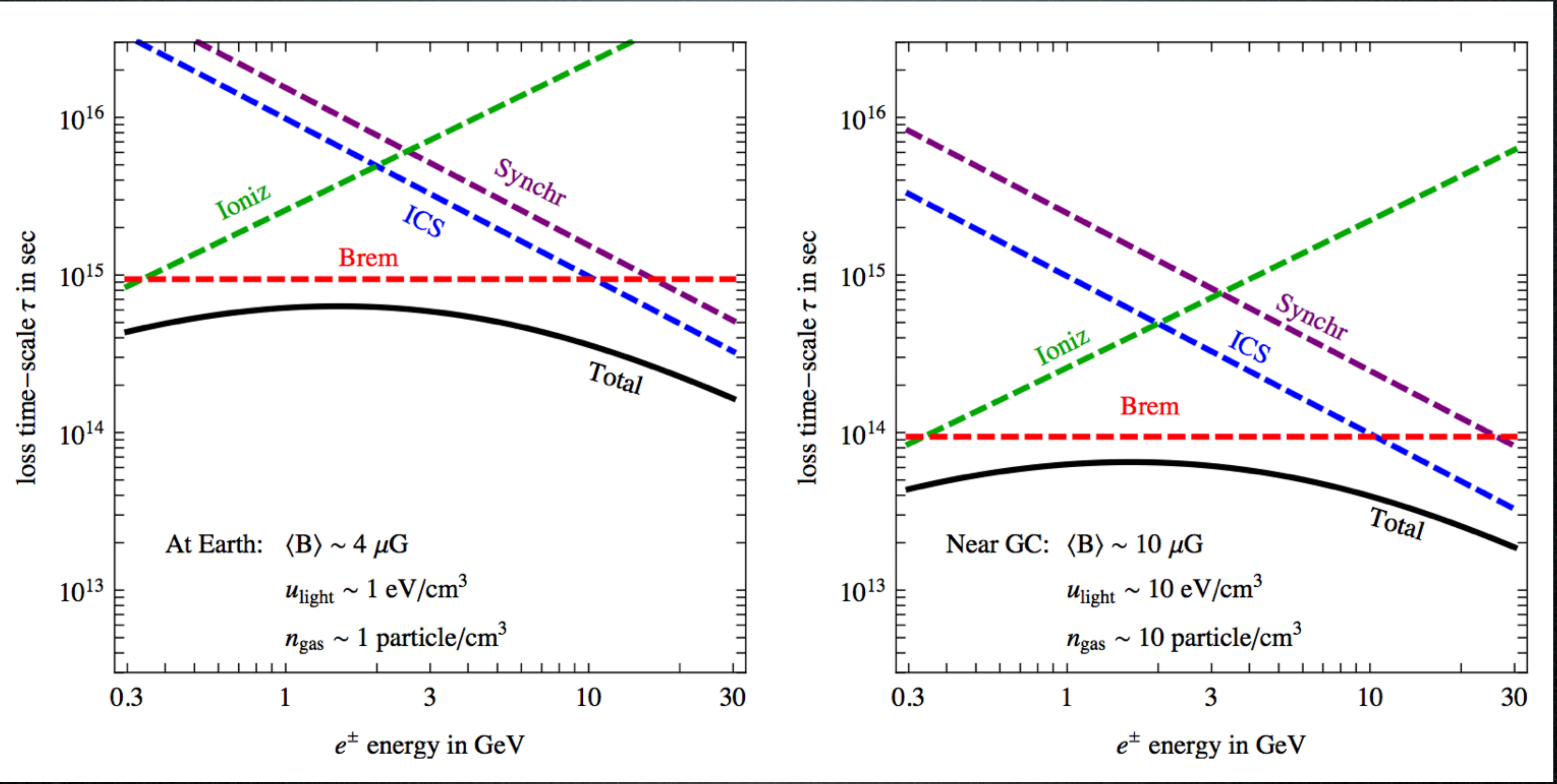
Secondary emission

b. soft gammas from bremsstrahlung of $e^{\pm}$ on ISM



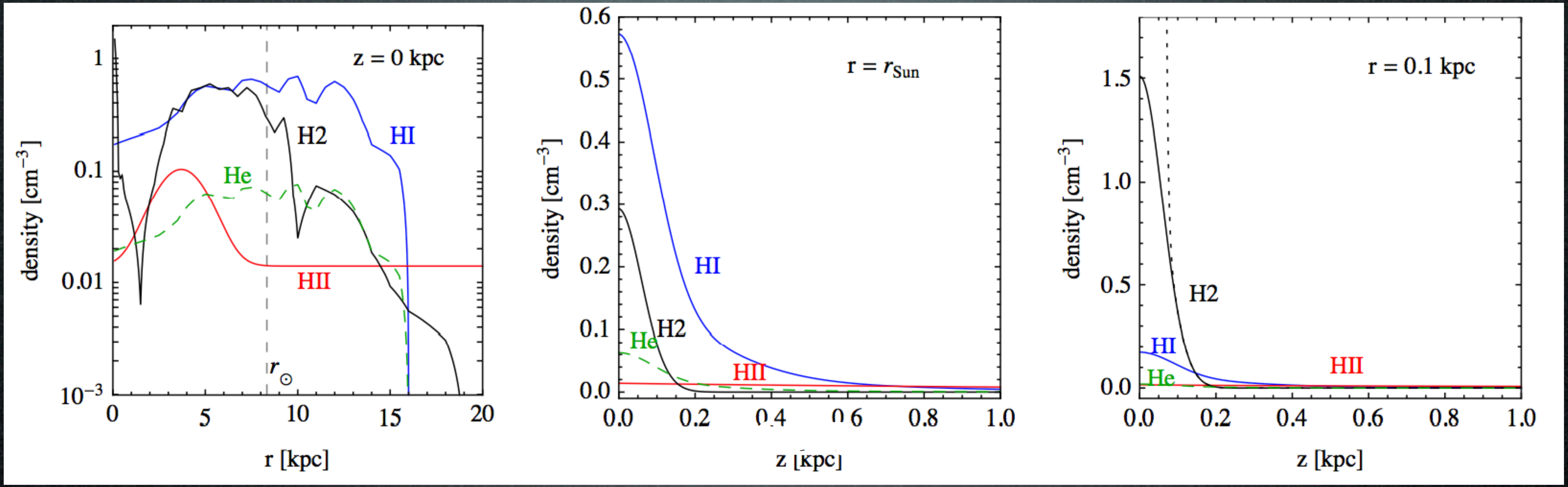
- (very) relevant at low energy, in the disk and at the GC

Relative importance of secondary emissions



=> brem is the dominant energy loss for low energy $e^{\pm}$!

Gas maps



But: inner kpc of the Galaxy is denser
(and more uncertain)

SNB	CMZ	CNR
Stellar Nuclear Bulge	Central Molecular Zone	Circum-Nuclear Ring
< 1 kpc	< 200 pc	< 3 pc
?	10^2-10^3 /cm^3	10^5/cm^3

Formalism

Formalism

Bremsstrahlung gamma emission:

$$\frac{\mathrm{d}\mathcal{E}_{\gamma,\mathrm{brem}}(\vec{x})}{\mathrm{d}E_\gamma} = \sum_i n_i(\vec{x}) \int_{E_L} \mathrm{d}E_{e^\pm}\ 2\frac{\mathrm{d}\Phi_{e^\pm}(\vec{x})}{\mathrm{d}E_{e^\pm}} \cdot \frac{\mathrm{d}\sigma_i}{\mathrm{d}E_\gamma}$$

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bremsstrahlung differential cross section

$$\frac{\mathrm{d}\sigma_i(E_{e^\pm}, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{3\,\alpha_{\mathrm{em}}\sigma_T}{8\pi\, E_\gamma}\left\{\left[1+\left(1-\frac{E_\gamma}{E_{e^\pm}}\right)^2\right]\phi_1^i - \frac{2}{3}\left(1-\frac{E_\gamma}{E_{e^\pm}}\right)\phi_2^i\right\}$$

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$e^\pm$ population

bremsstrahlung differential cross section

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gas density

$e^\pm$ population

bremsstrahlung differential cross section

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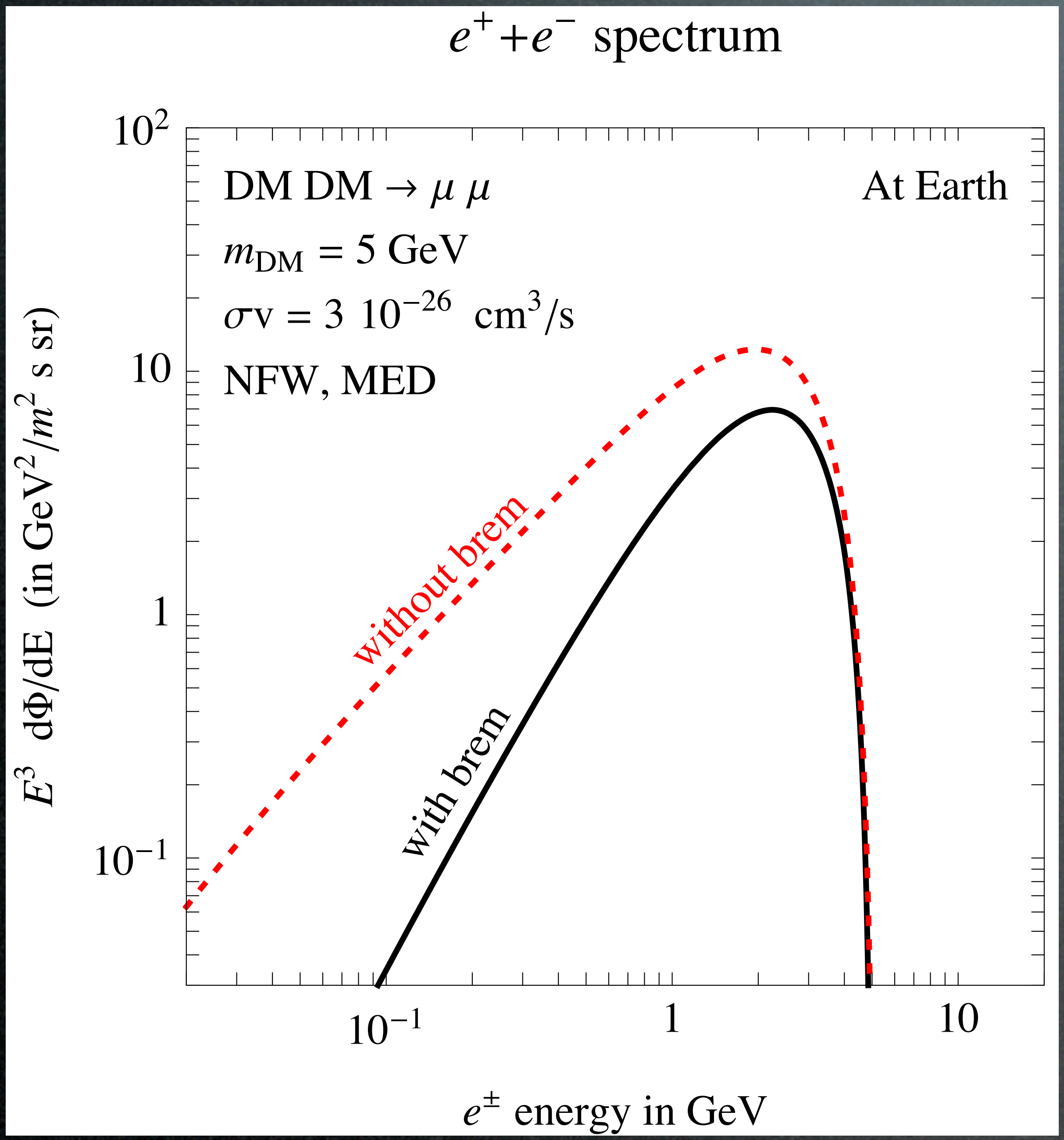
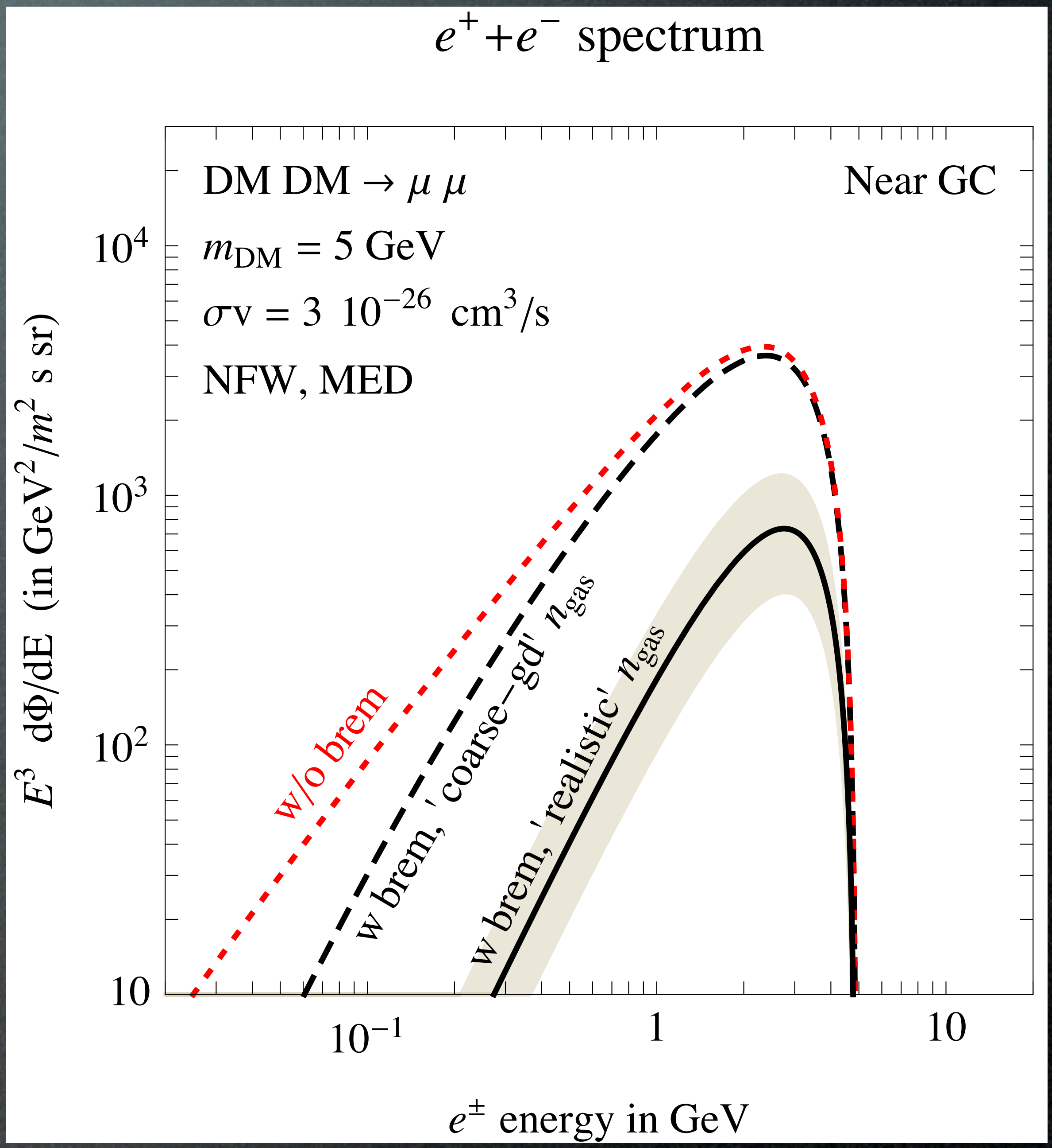
$$\phi_1^{\mathrm{H}}(\Delta=0) \equiv \phi_{1,\mathrm{ss}}^{\mathrm{H}} = 45.79,$$
$$\phi_2^{\mathrm{H}}(\Delta=0) \equiv \phi_{2,\mathrm{ss}}^{\mathrm{H}} = 44.46,$$
$$\phi_1^{\mathrm{He}}(\Delta=0) \equiv \phi_{1,\mathrm{ss}}^{\mathrm{He}} = 134.60,$$
$$\phi_2^{\mathrm{He}}(\Delta=0) \equiv \phi_{2,\mathrm{ss}}^{\mathrm{He}} = 131.40,$$
$$\phi_{(1,2)}^{\mathrm{H}_2}(\Delta=0) \simeq 2\,\phi_{(1,2),\mathrm{ss}}^{\mathrm{H}},$$

$$\phi_1^{\mathrm{ion}}(E_{e^\pm}, E_\gamma) = \phi_2^{\mathrm{ion}}(E_{e^\pm}, E_\gamma) = 4(Z^2+Z)\left\{\log\left[\frac{2E_{e^\pm}}{m\,c^2}\left(\frac{E_{e^\pm}-E_\gamma}{E_\gamma}\right)\right] - \frac{1}{2}\right\}$$

Results

The e± population is affected by bremsstrahlung





= factor 2 uncertainty in n_{gas}

Results

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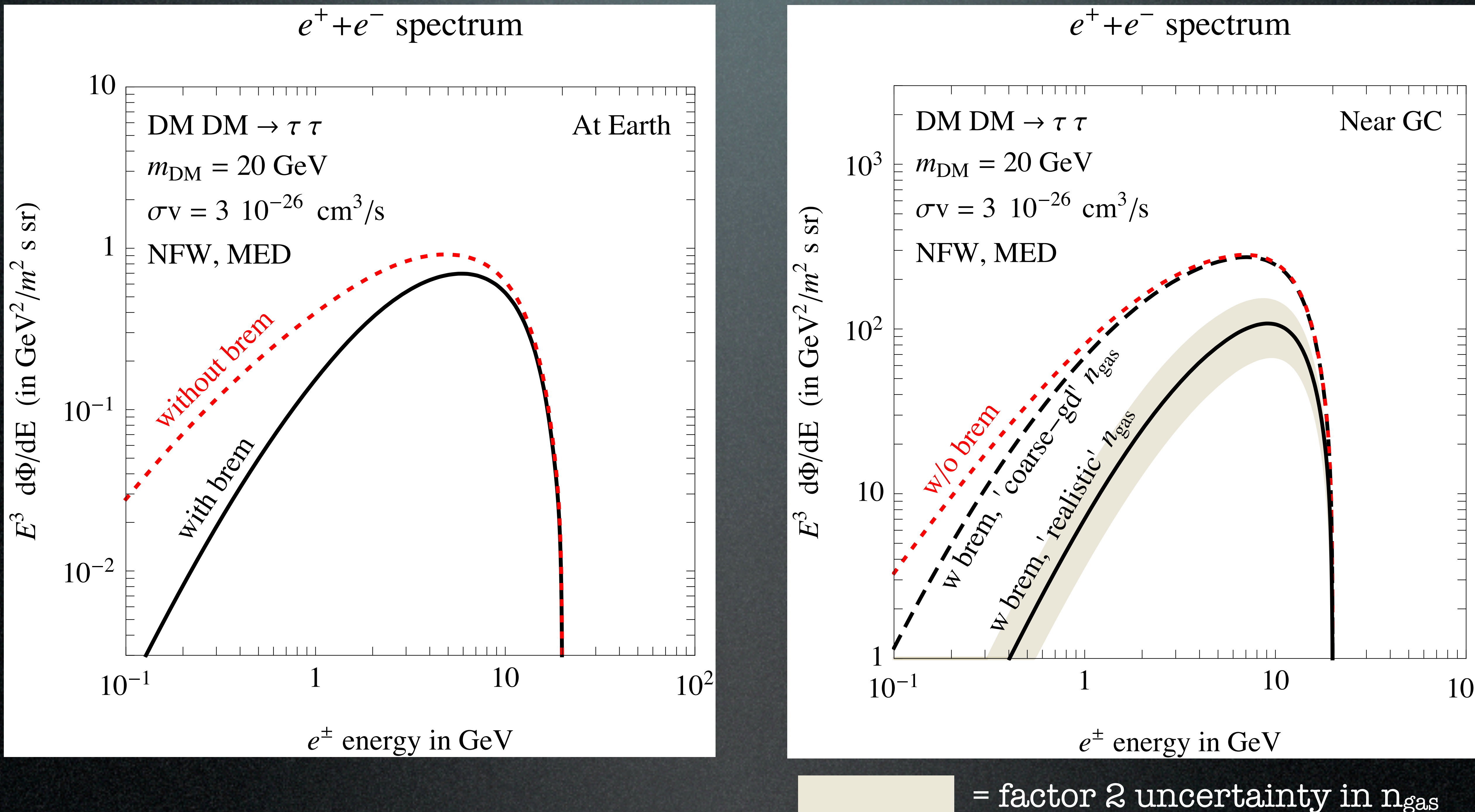

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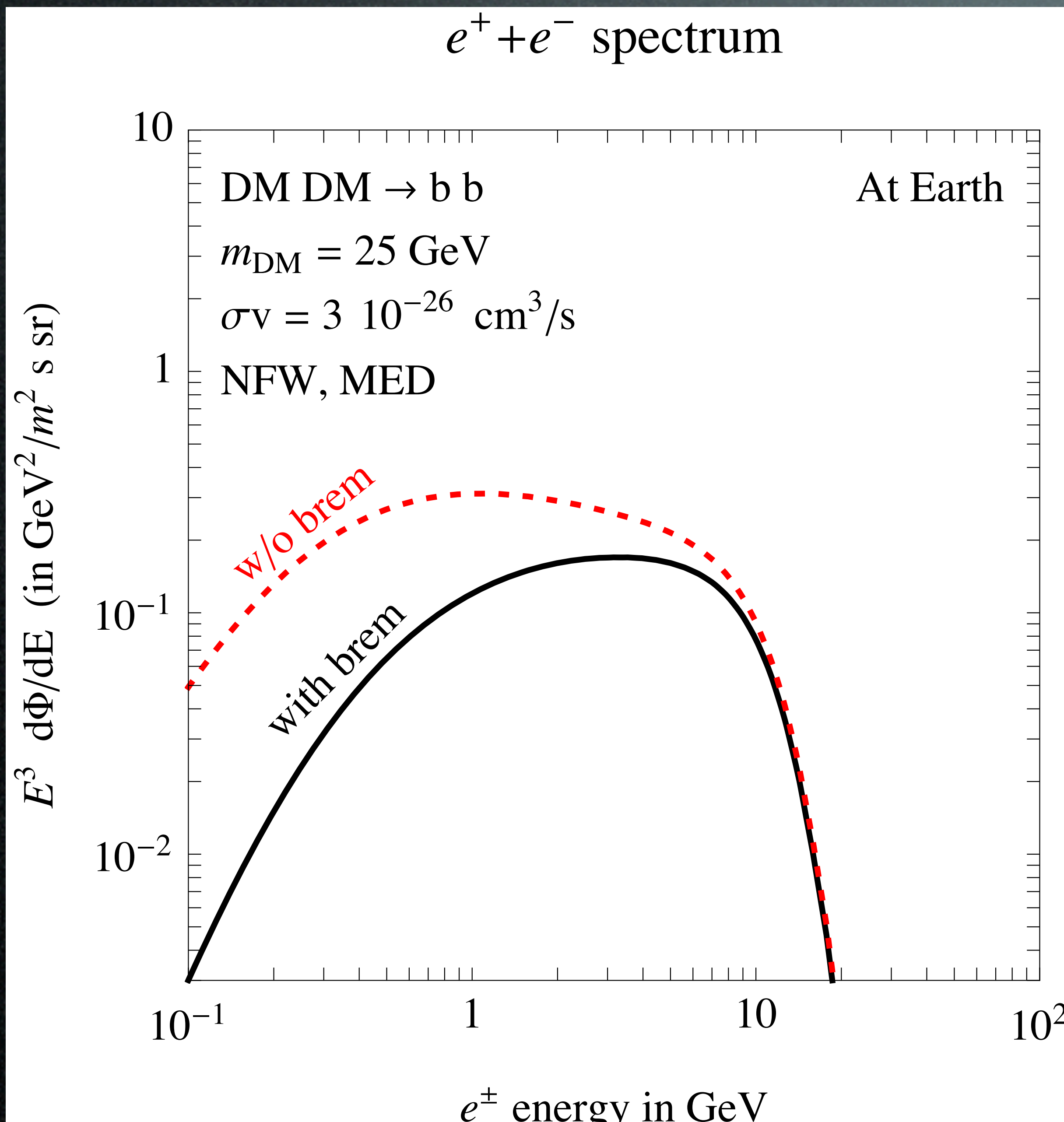
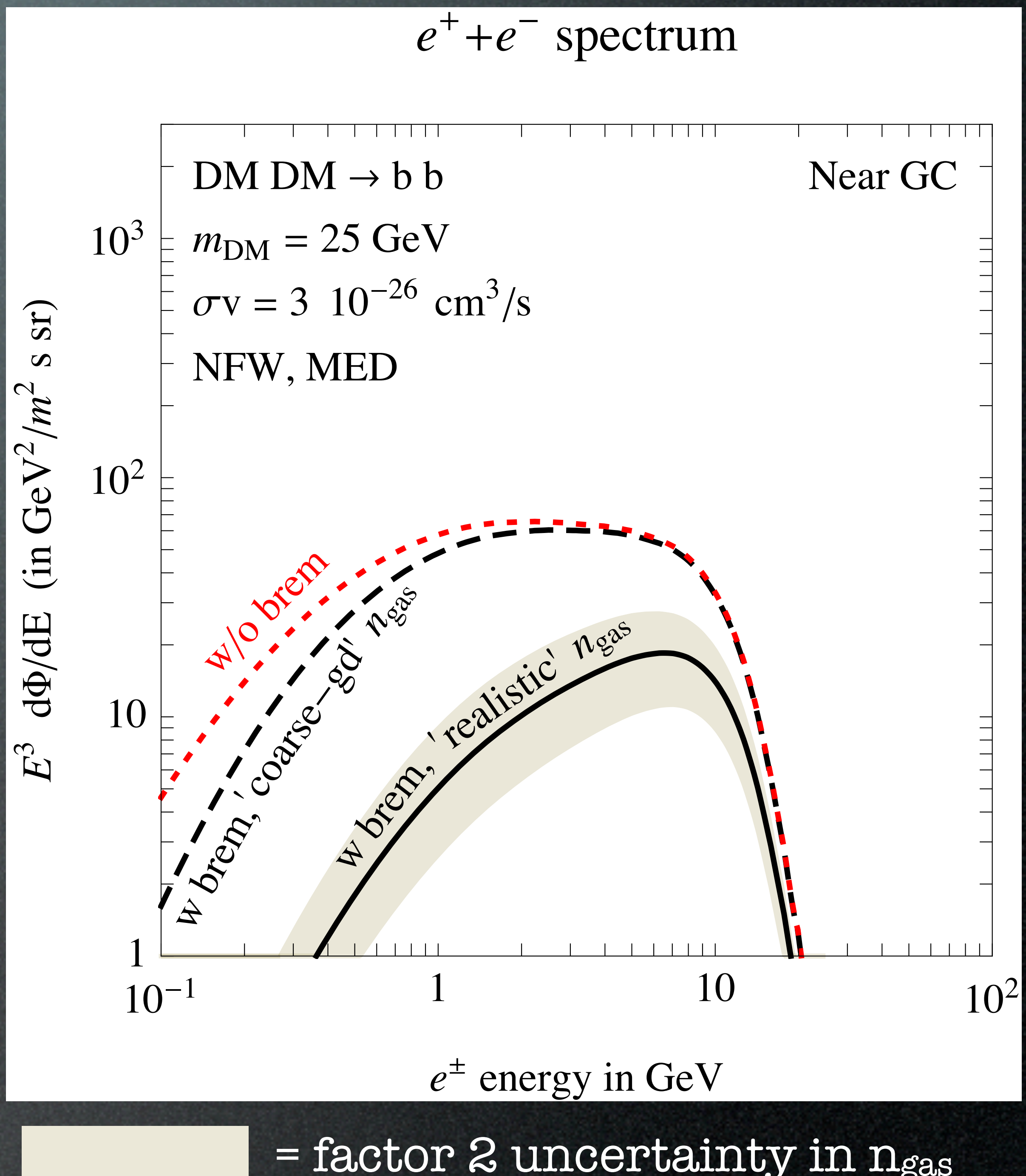
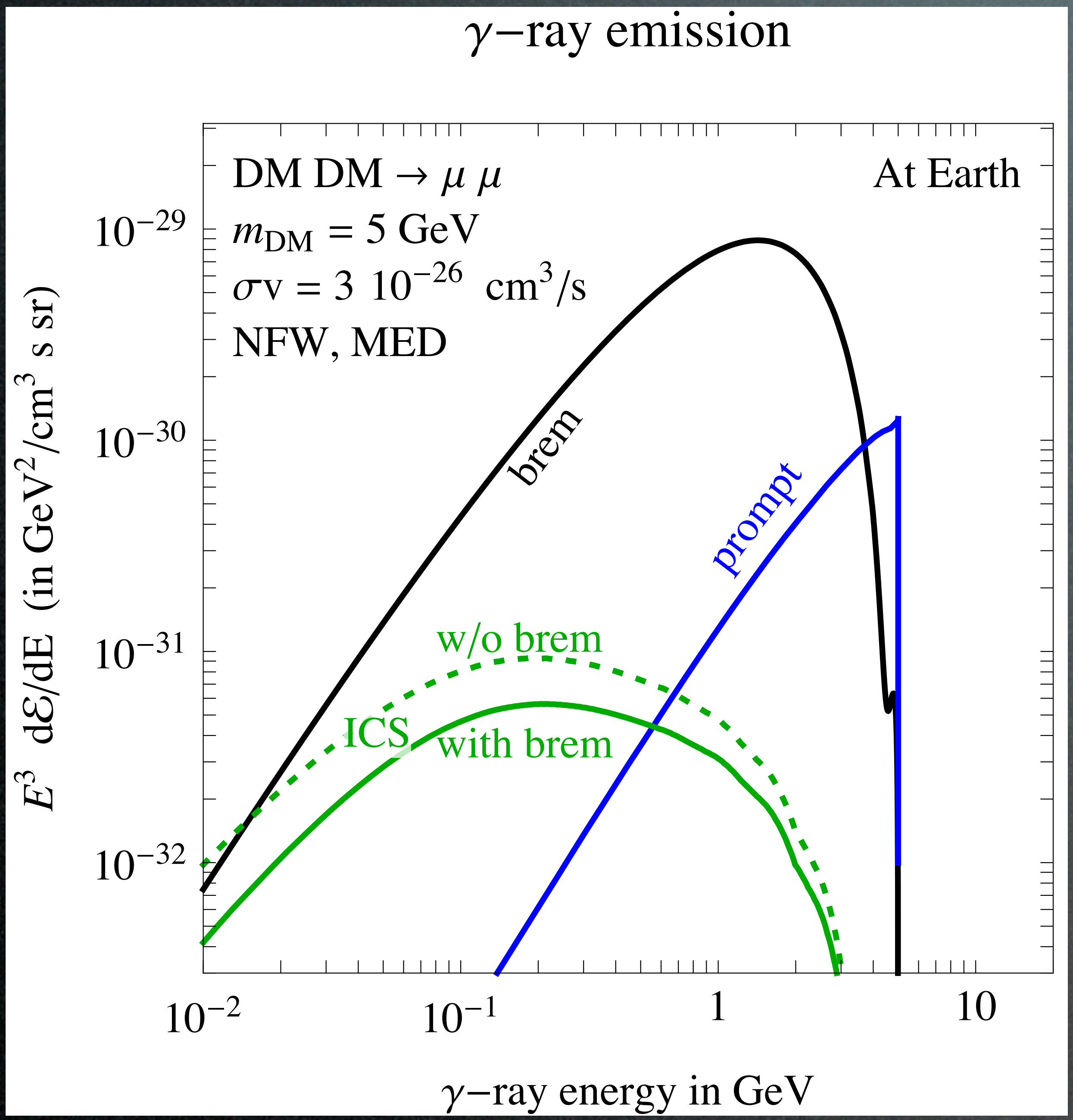


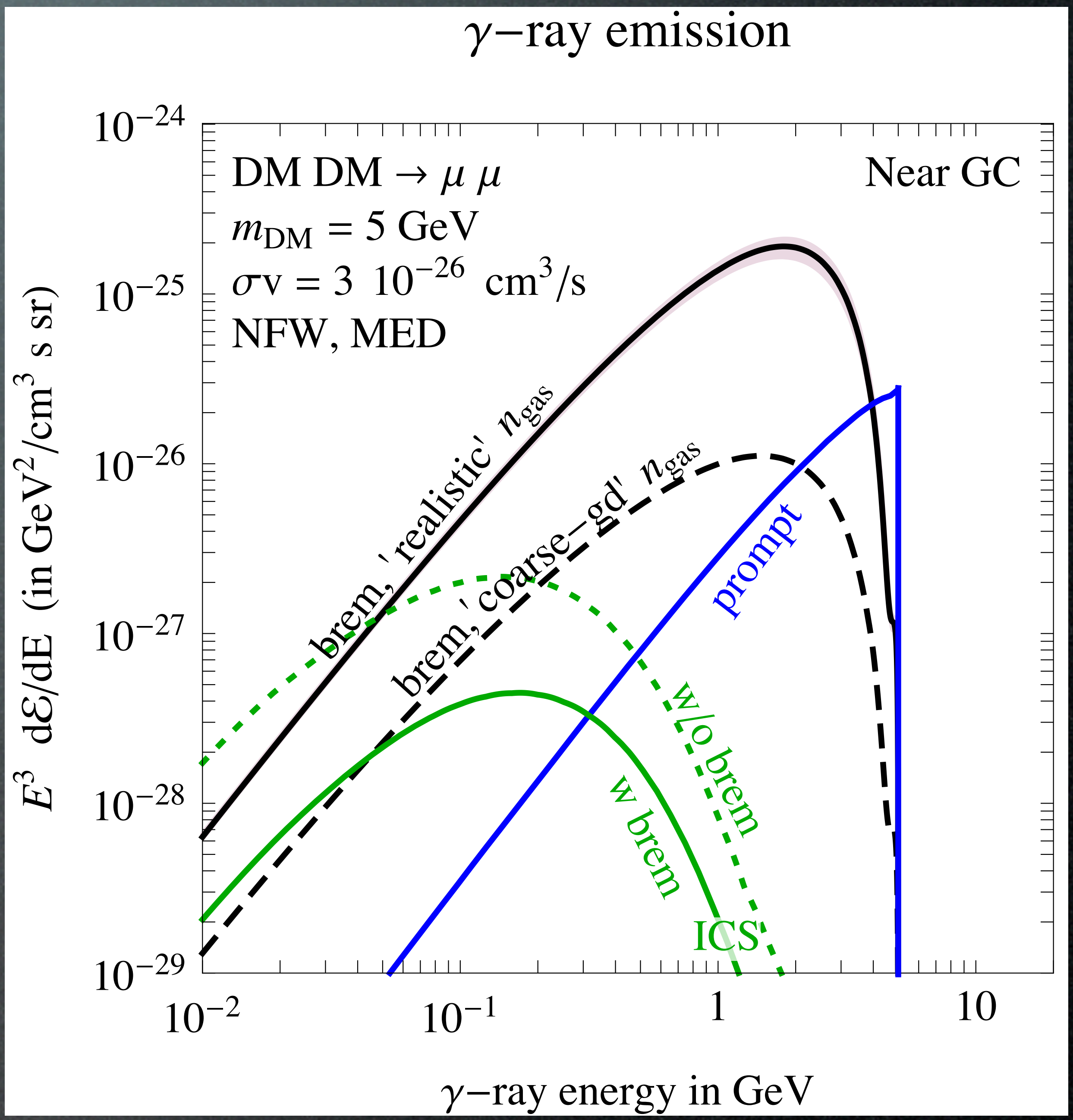


= factor 2 uncertainty in n_{gas}

Results

The total γ ray spectrum





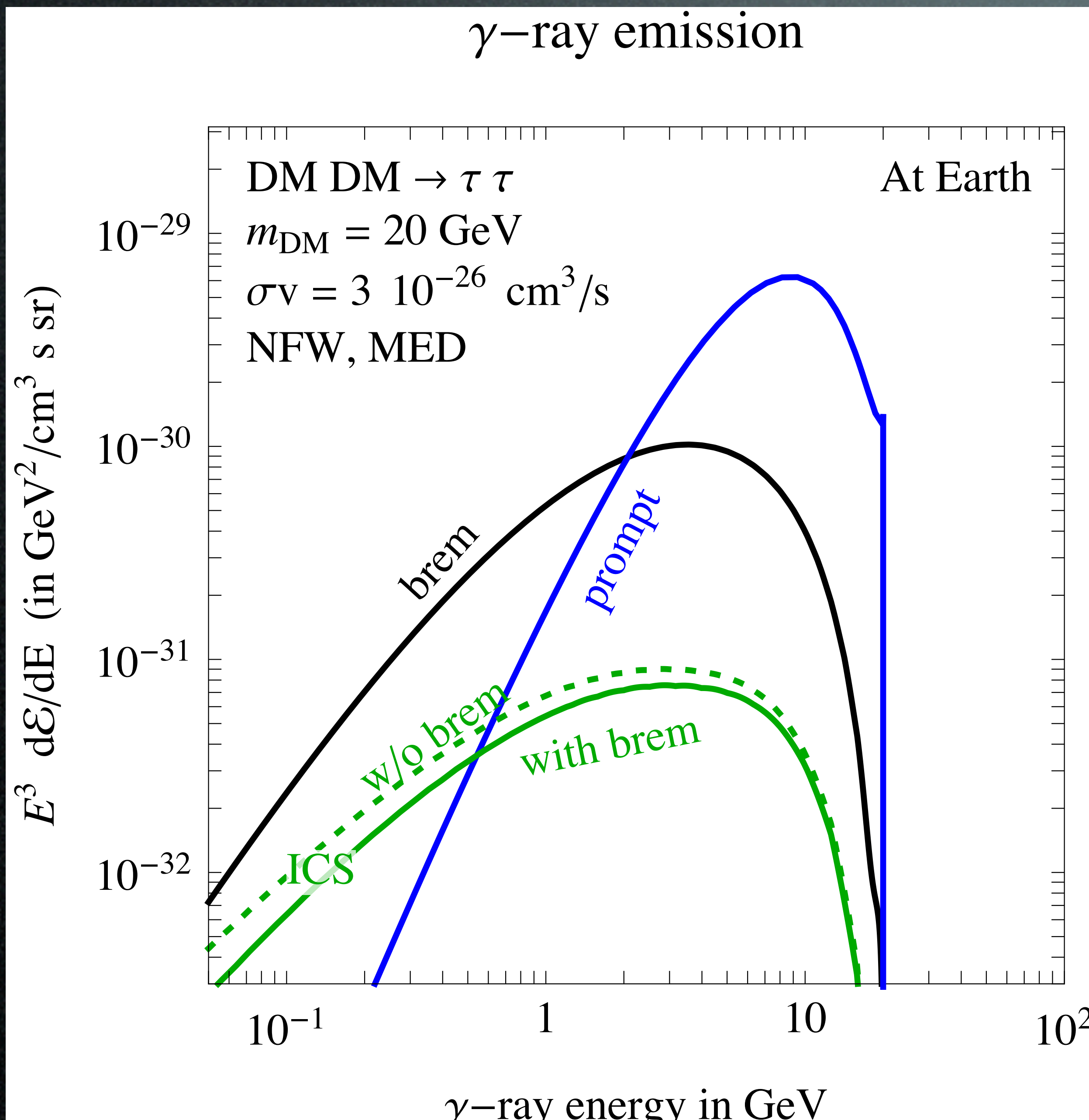
- brem is dominant
- ICS is affected

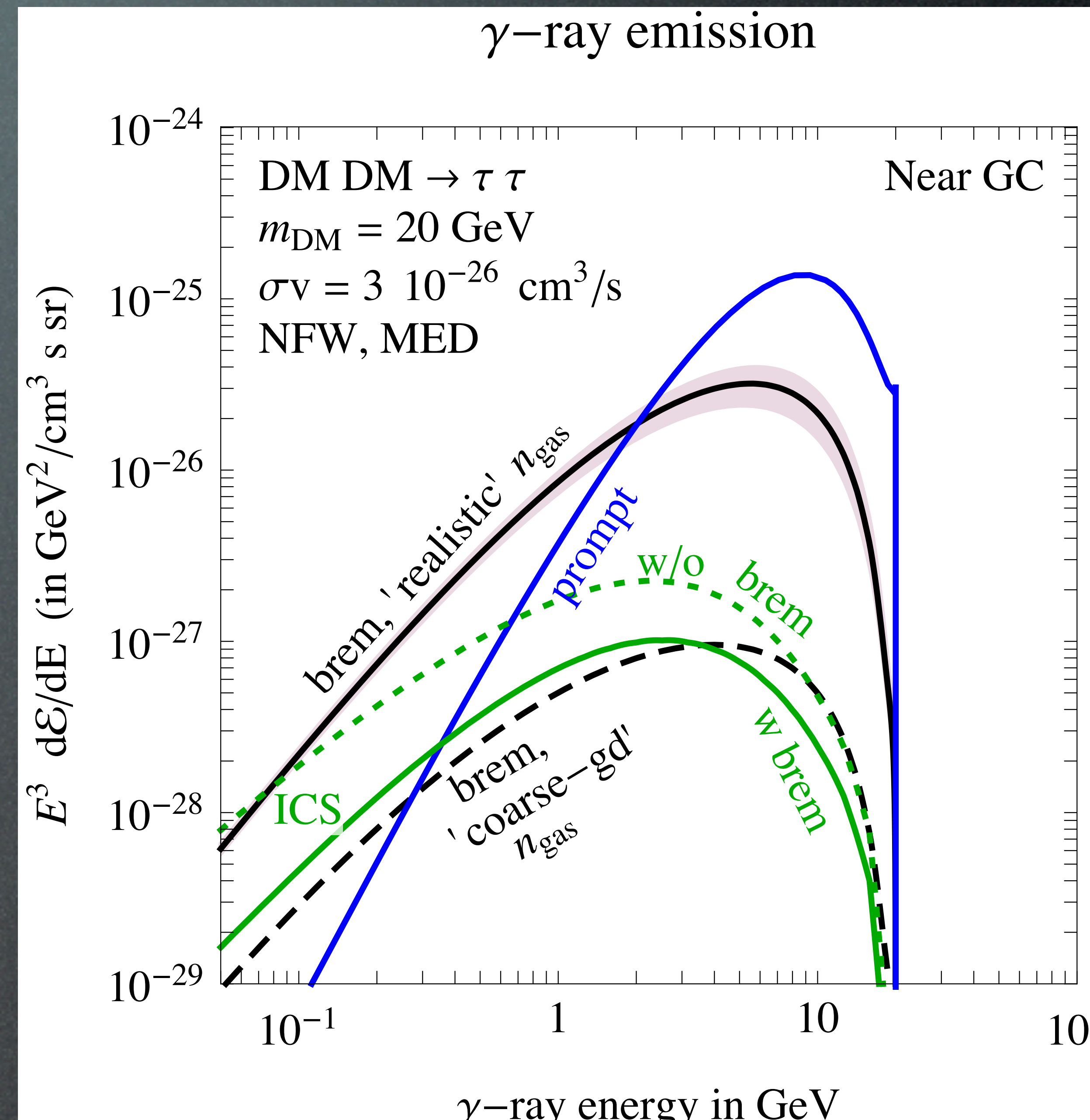
- uncertainty ▭ is somewhat reabsorbed:

large n_{gas} ⇨ more loss **and** more emission

Results

The total γ ray spectrum





- brem is important
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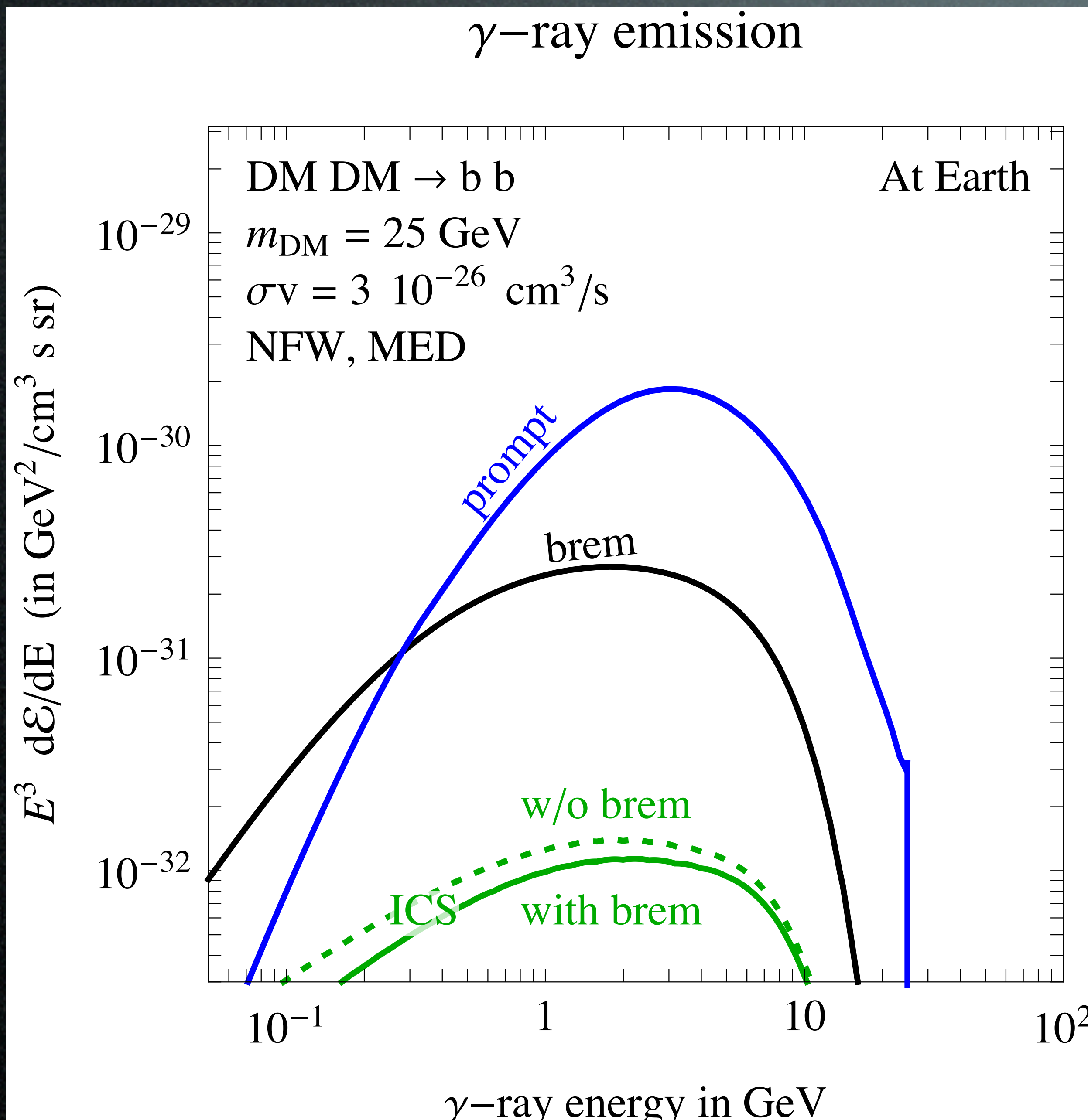
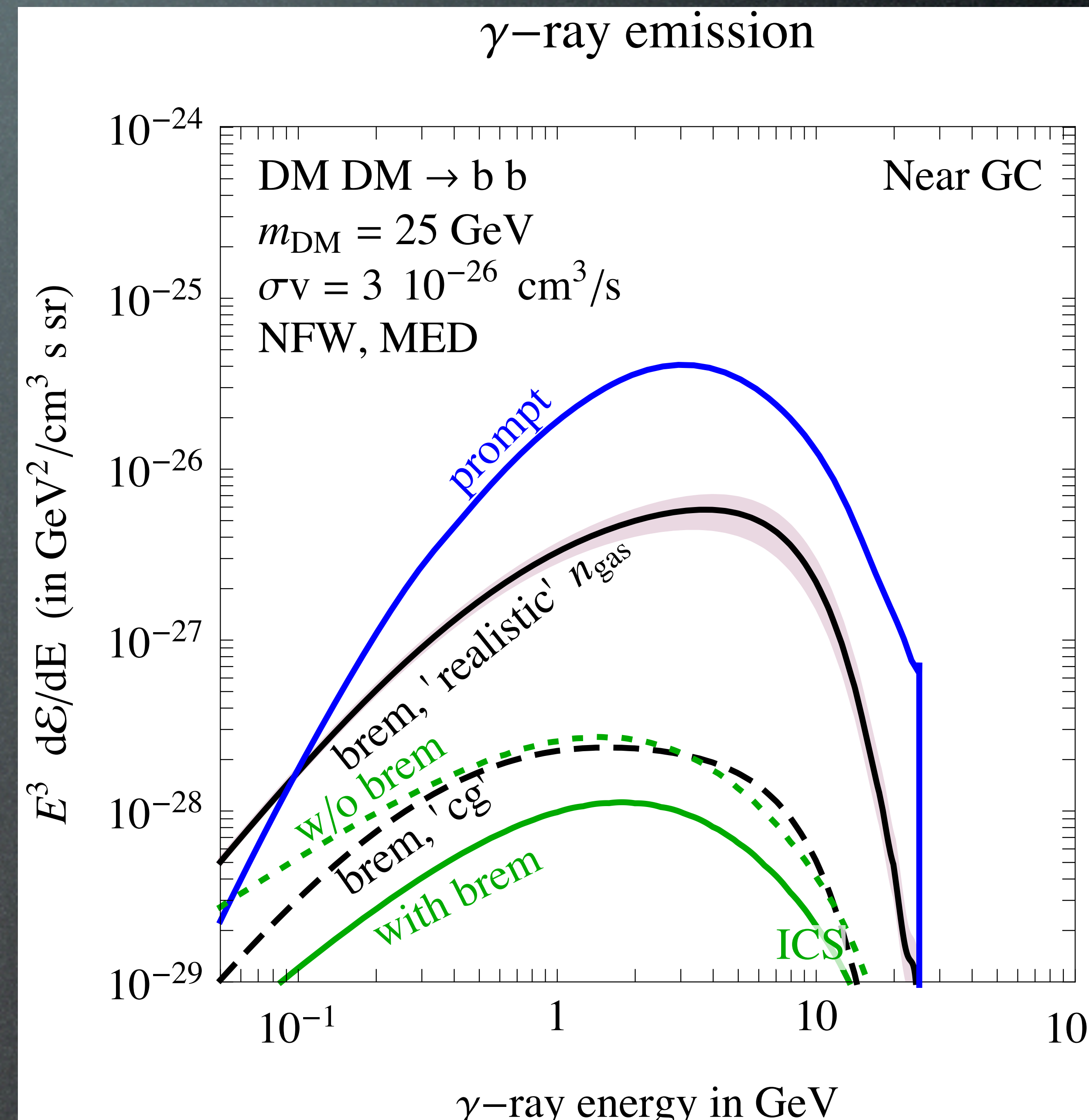
Results

The total γ ray spectrum





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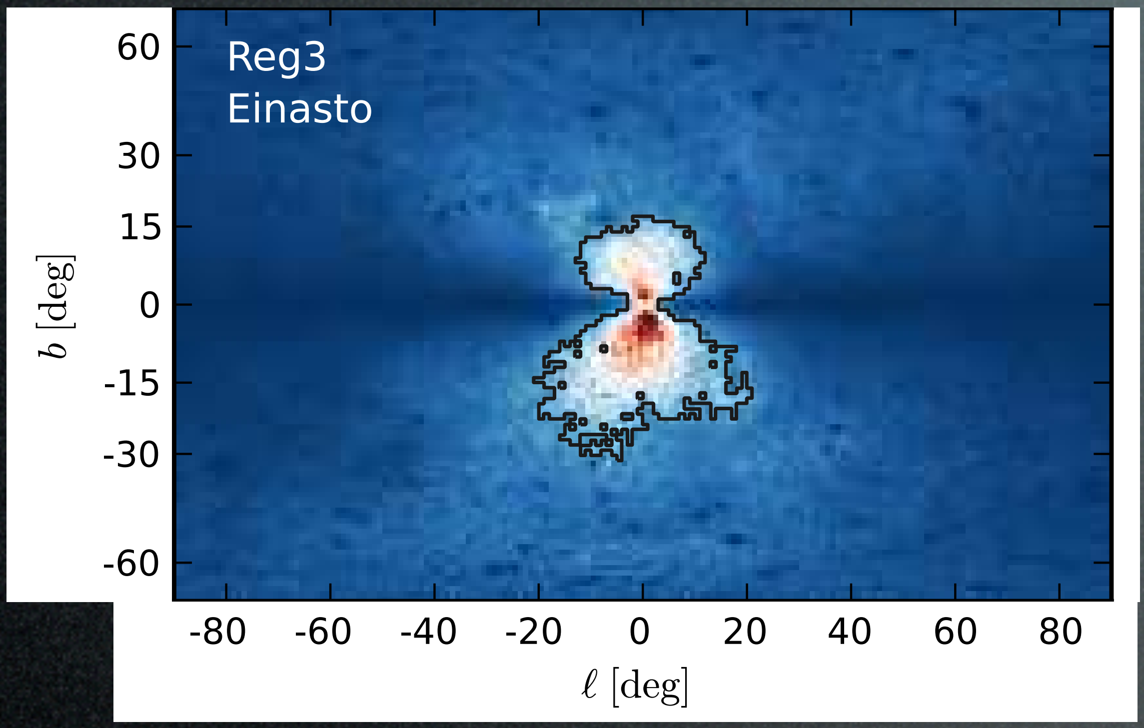
large n_{gas} ⇨ more loss **and** more emission

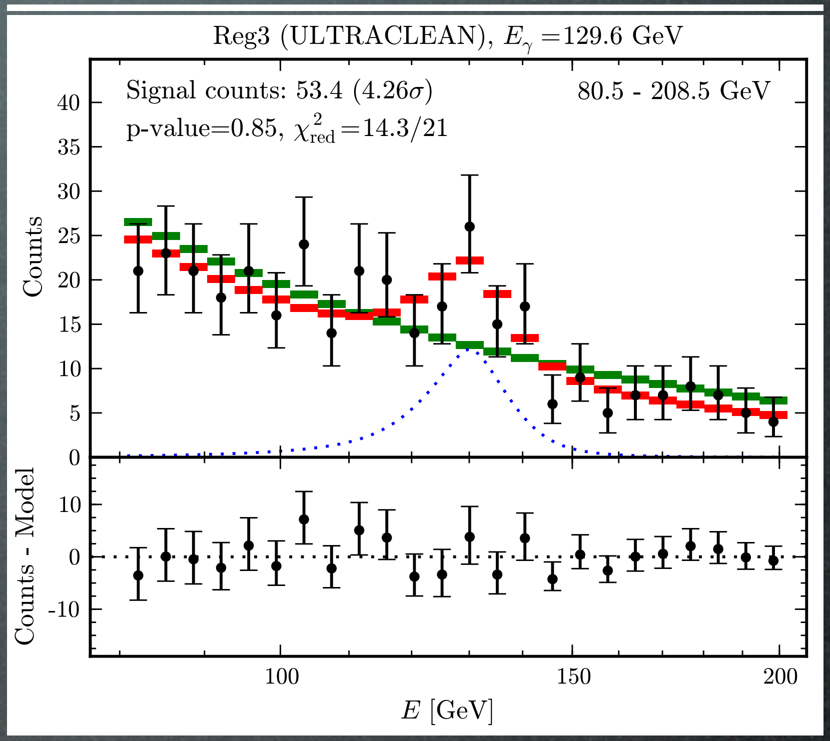
Some recent developments:

- bremsstrahlung γ-rays from light DM
- FERMI 130 GeV line
- excesses near the Galactic Center

Fermi 130 GeV line

What if a signal of DM is *already* hidden in Fermi diffuse γ data?





Ch. Weniger, 1204.2797

4.6σ (3.3σ with LEE)

$\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} \simeq 1.3 \cdot 10^{-27} \text{cm}^3/\text{s}$ (large!)

Fermi 130 GeV line

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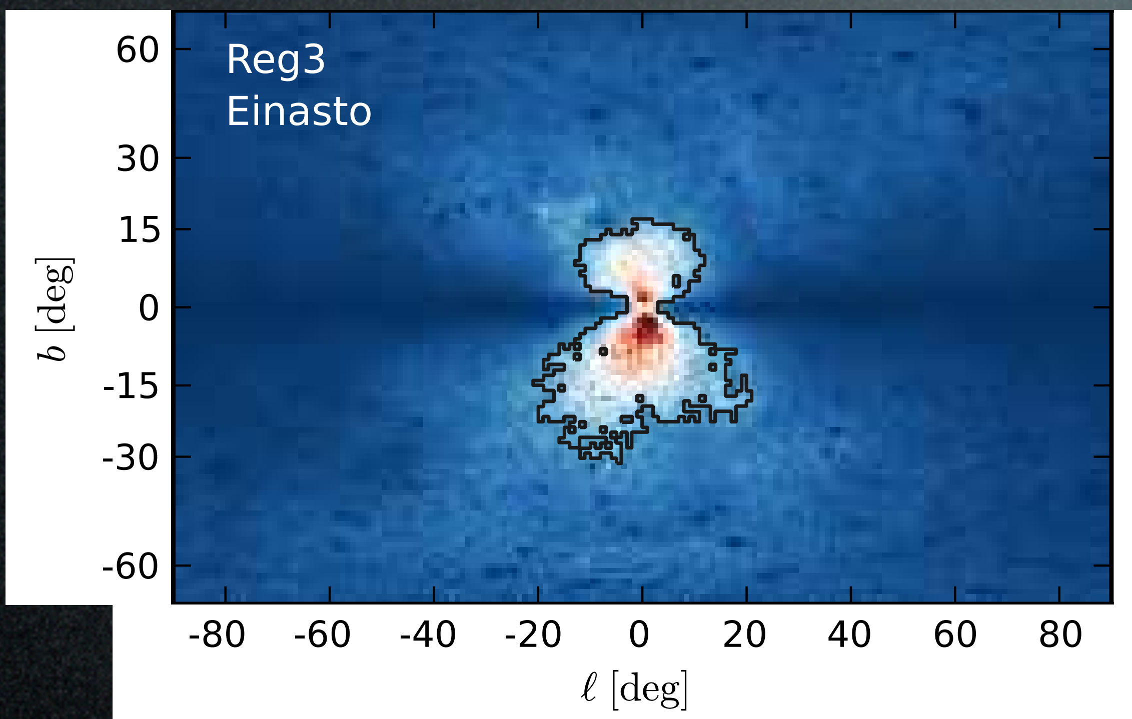

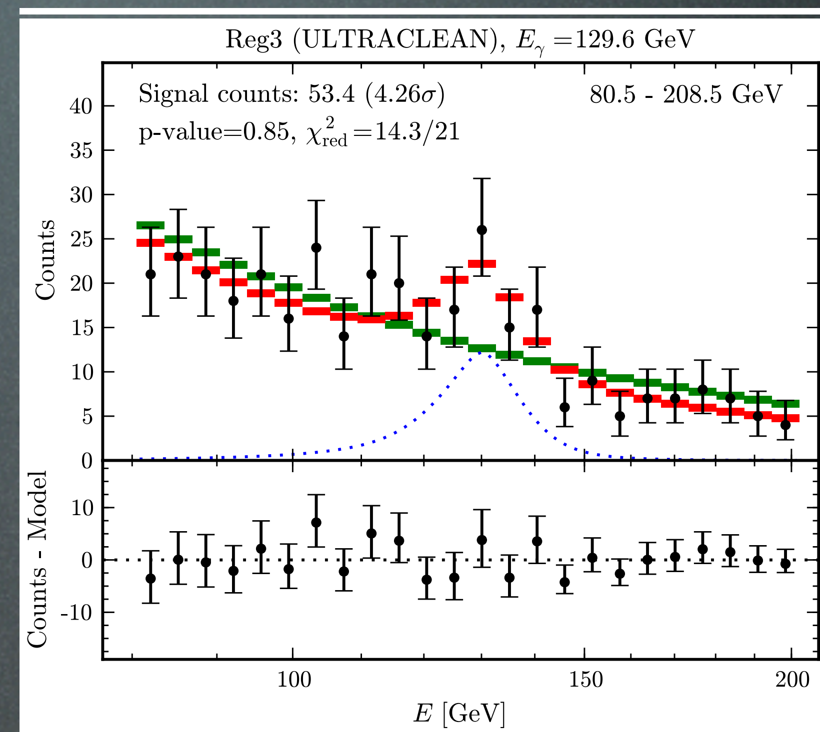

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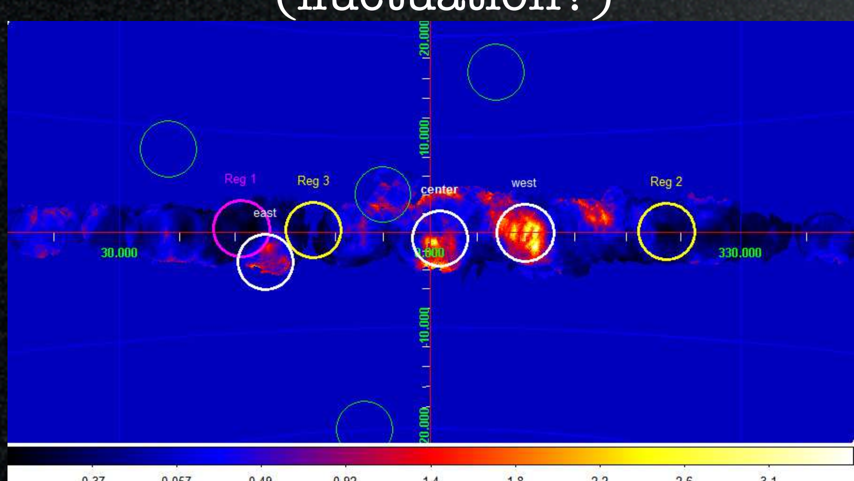
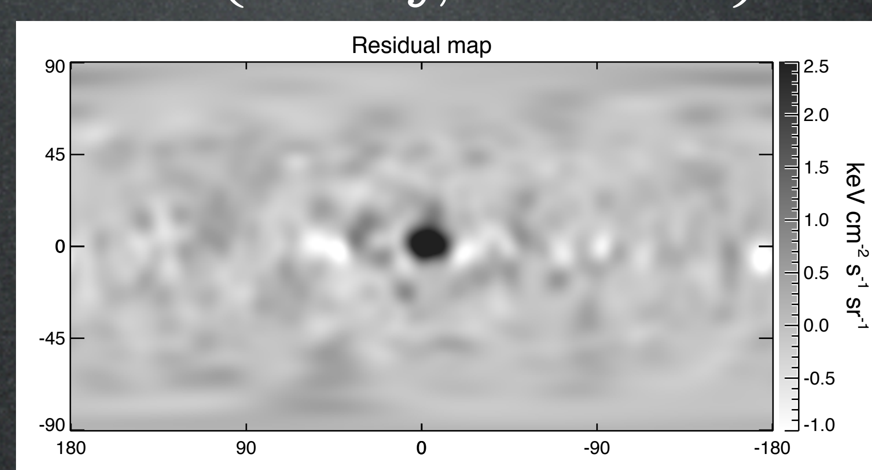
$\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} \simeq 1.3 \cdot 10^{-27} \text{cm}^3/\text{s}$ (large!)

Similar excesses found elsewhere (fluctuation?)



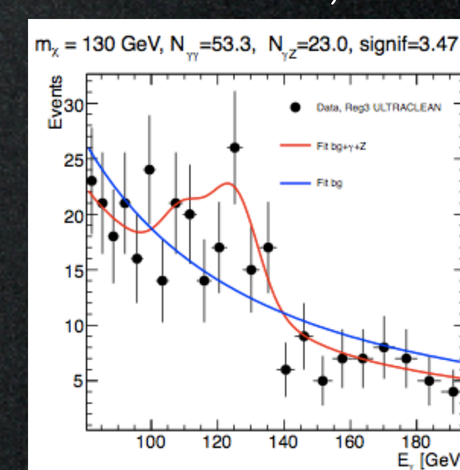
Boyarsky, Malyshev, Ruchayskyi, 1205.4700

The excess is only in the GC (actually, a bit off-set)



Su, Finkbeiner, 1206.1616

And there might be 2 lines: 111 GeV, 129 GeV



Rajaraman, Tait, Whiteson 1205.4723

Su, Finkbeiner 1206.1616

Su Finkbeiner 1207.7060

Fermi 130 GeV line

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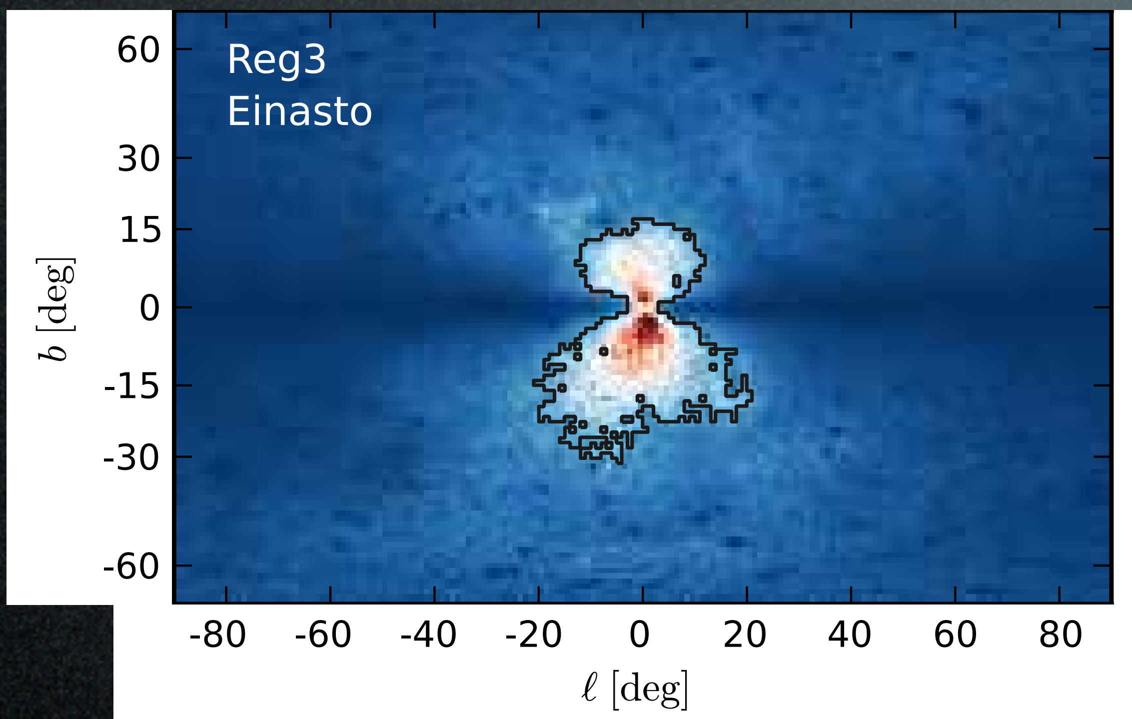
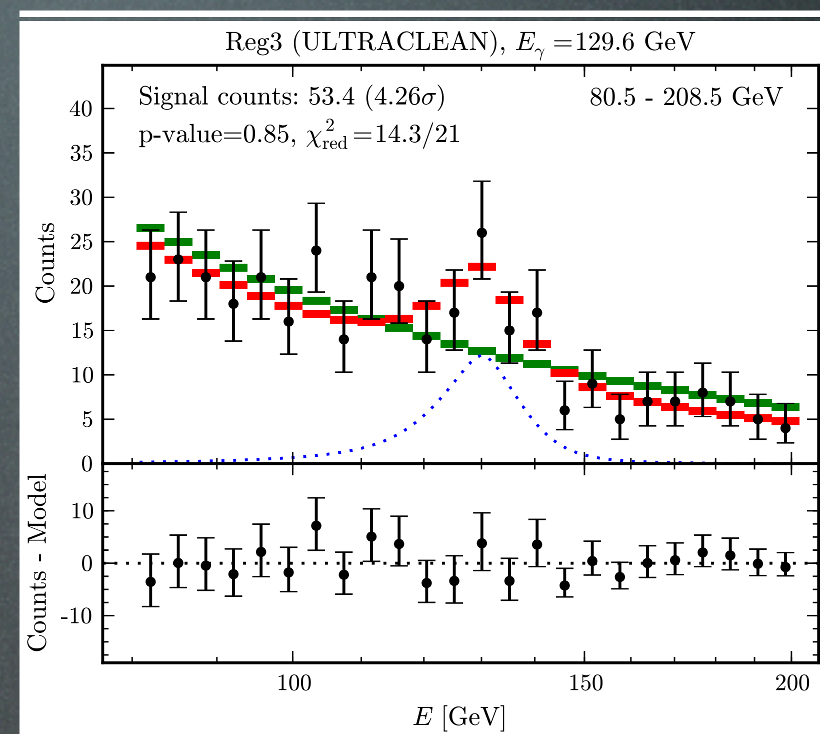


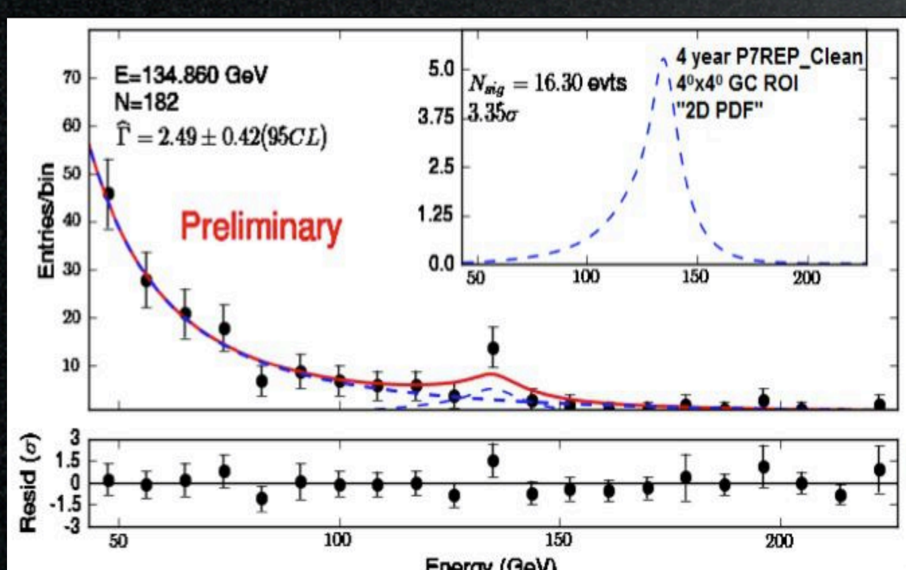


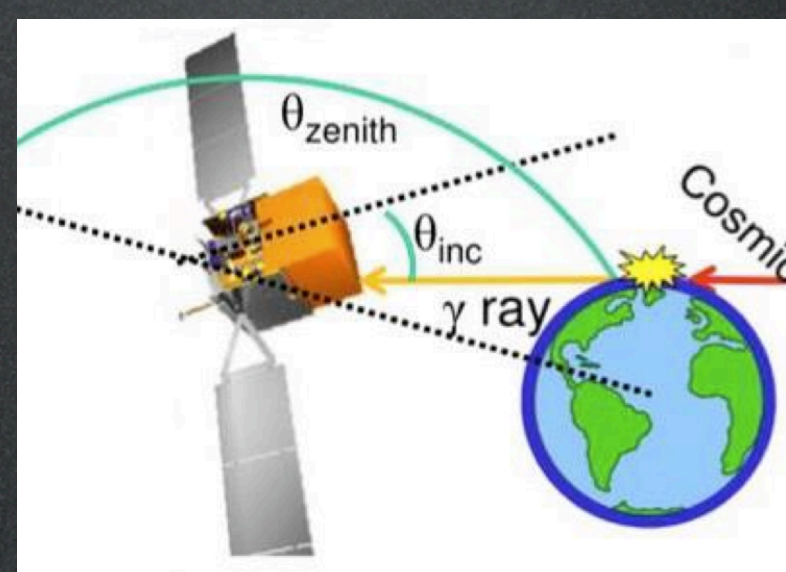
Ch. Weniger, 1204.2797

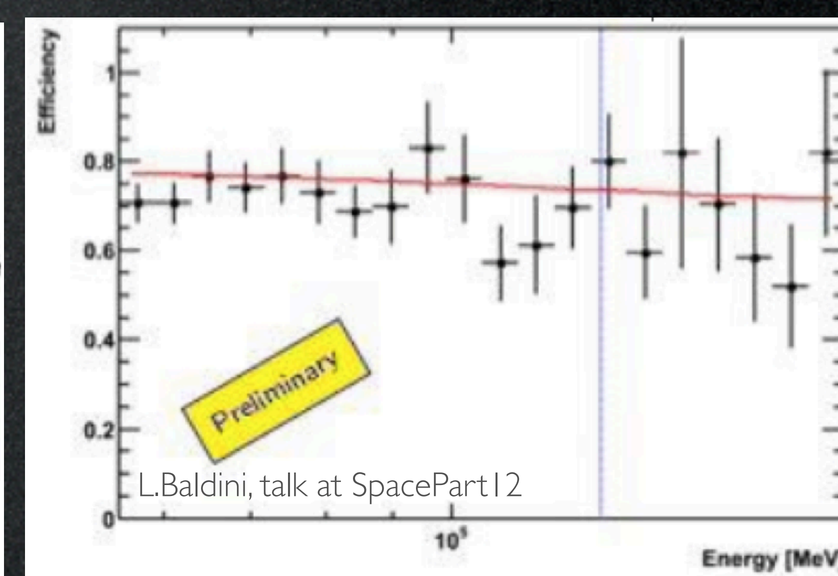
4.6σ (3.3σ with LEE)

$\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} \simeq$ $1.3 \cdot 10^{-27} \mathrm{cm}^3/\mathrm{s}$ (large!)

The Fermi coll's cold shower. An instrumental effect?







Some recent developments:

- bremsstrahlung γ-rays from light DM
- FERMI 130 GeV line
- excesses near the Galactic Center

Gamma hints?

What if a signal of DM is *already* hidden in Fermi diffuse γ data?

A diffuse GeV excess from around the GC

Dan Hooper

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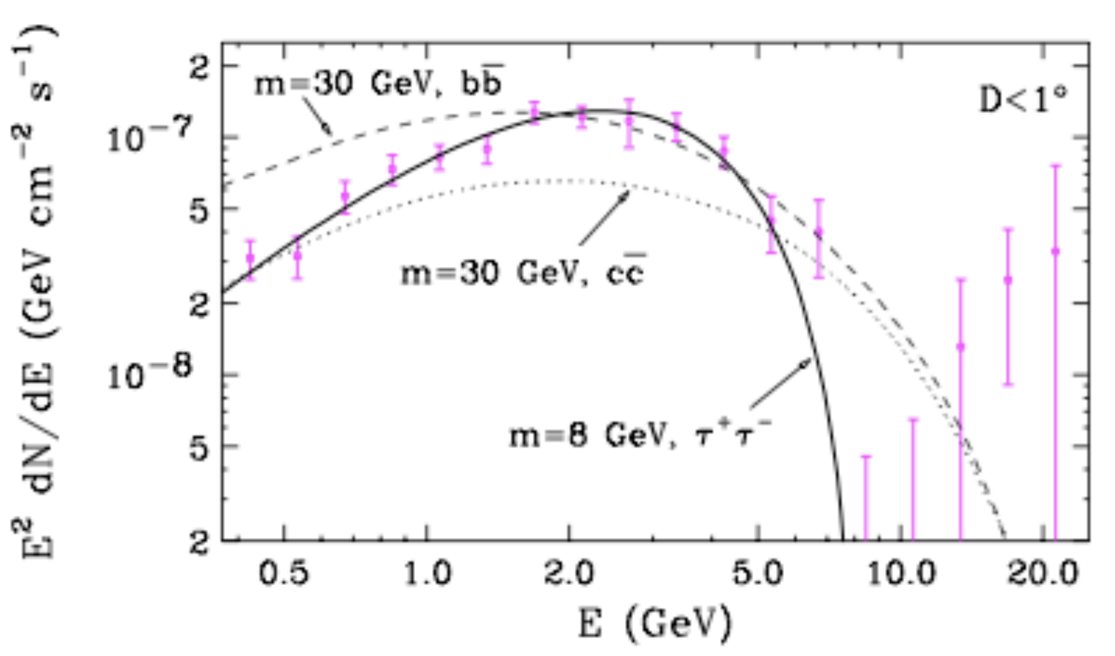

Hooper, Goodenough 1010.2752

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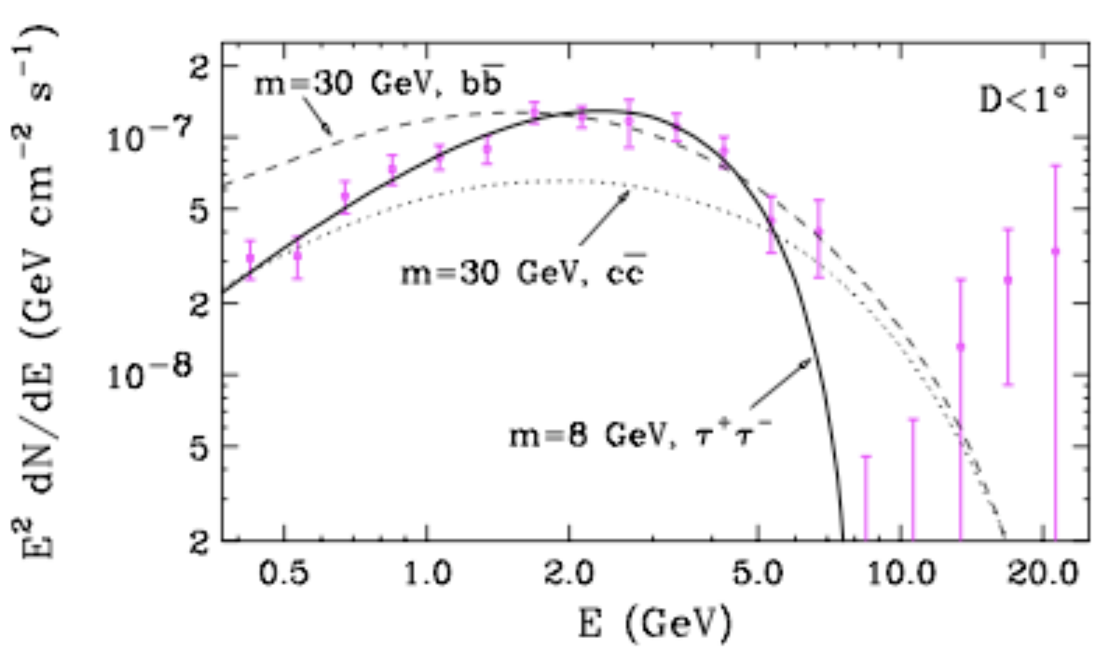
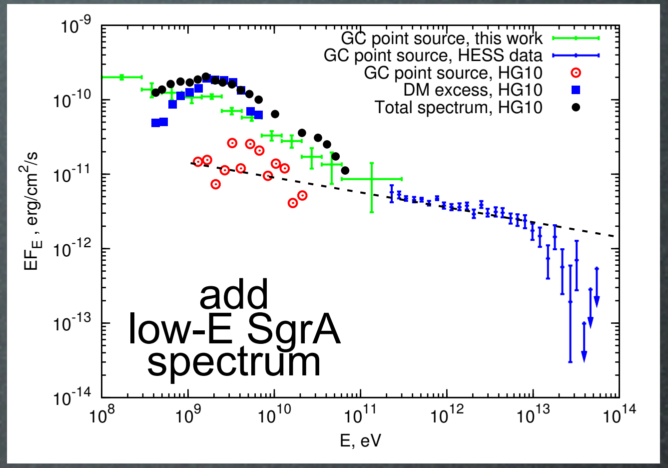
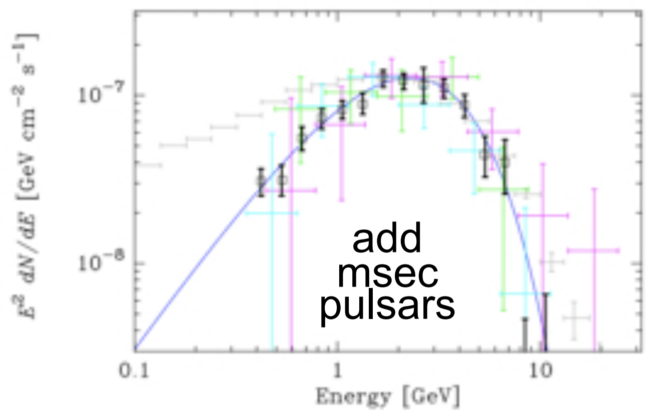


Hooper, Goodenough 1010.2752

Objection: know your backgrounds!



Boyarsky et al., 1012.5839



Abazajian 1011.4275

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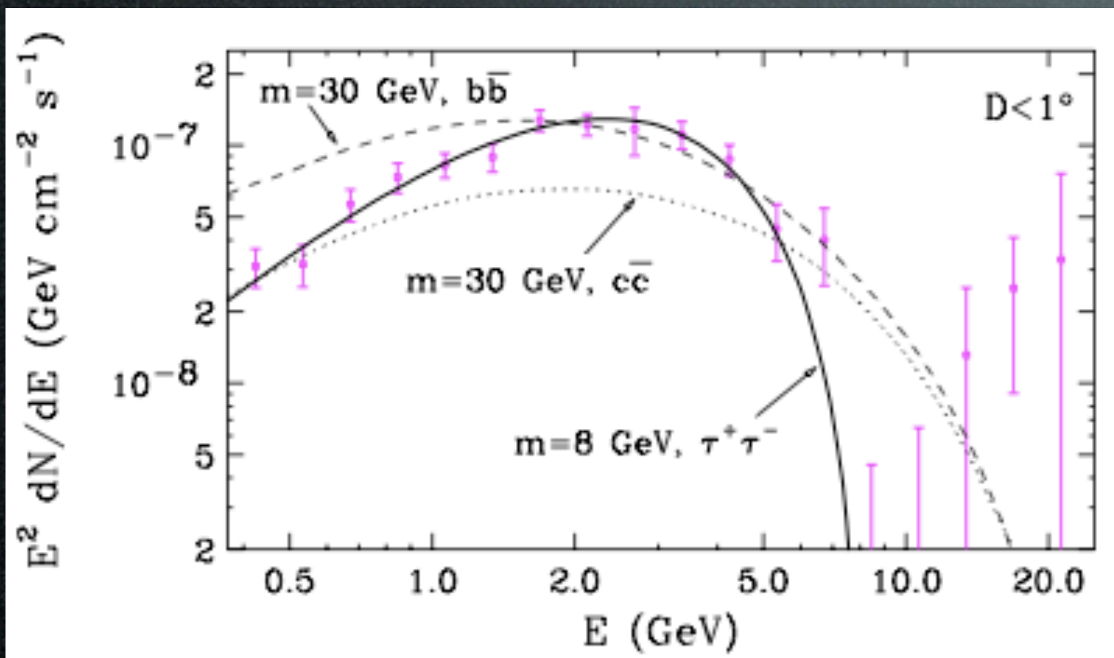

Hooper, Goodenough 1010.2752

Best fit: 8 GeV, $\tau^+ \tau^-$, ~thermal σv

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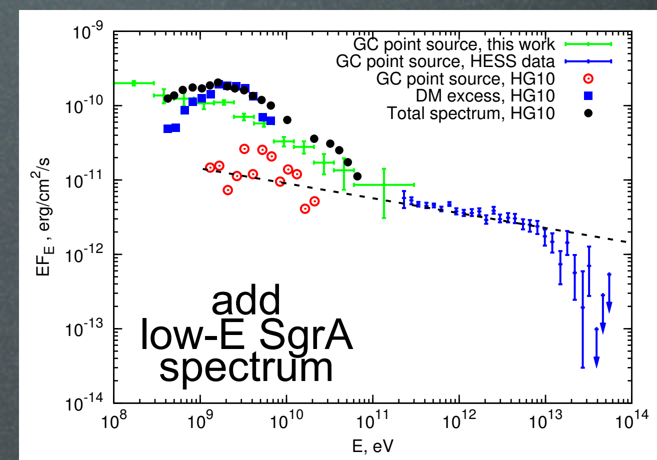

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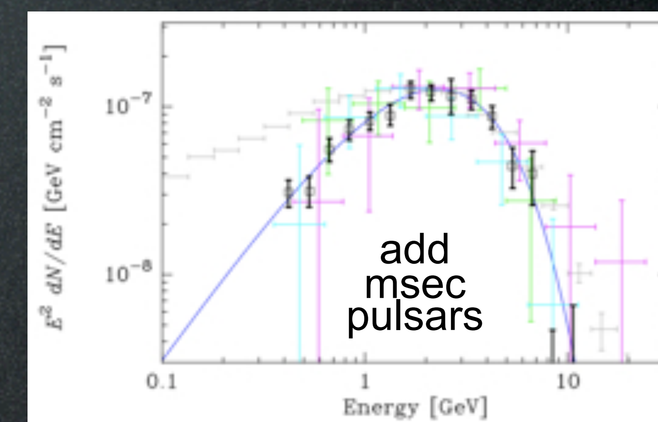


Abazajian 1011.4275

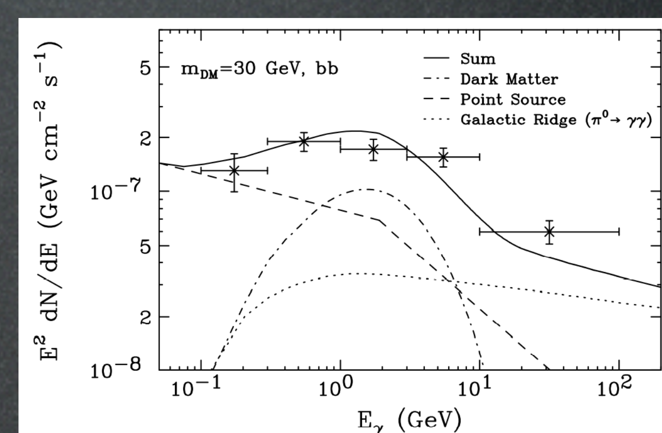
No, too few

(and we should have seen them elsewhere)

and wrong spectra

Hooper et al. 1305.0830

Still works...



Hooper, Linden 1110.0006

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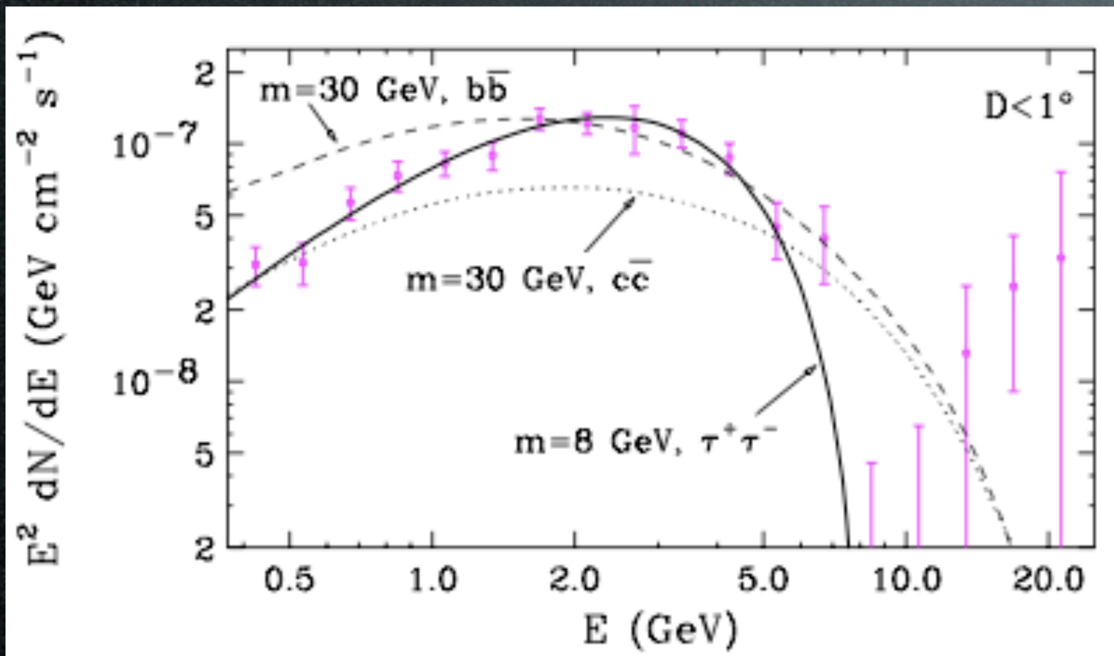

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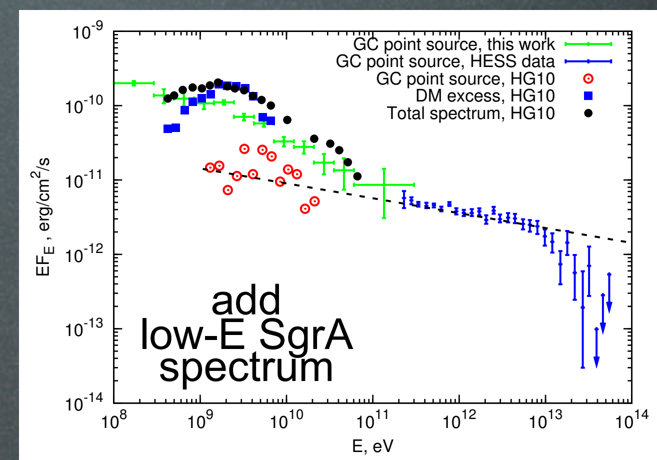
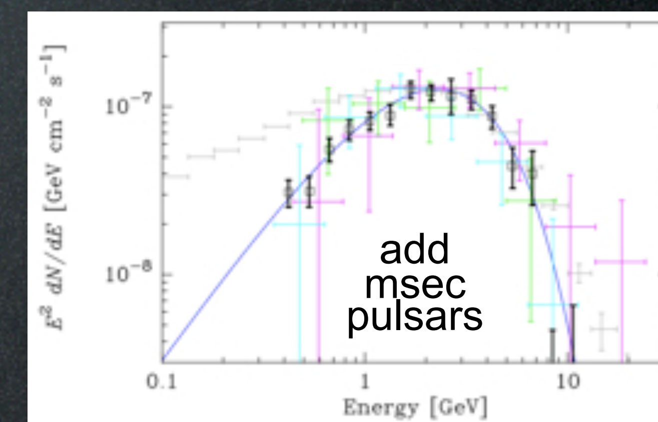


Boyarsky et al., 1012.5839



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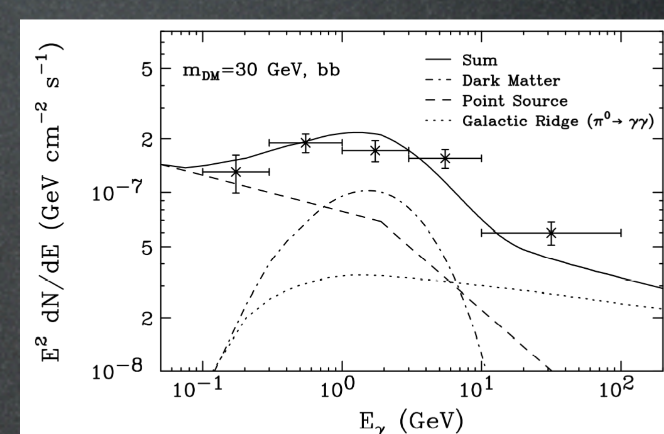

Hooper, Linden 1110.0006

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+ synchr from radio filaments
+ WMAP/Planck haze
+ Direct Detection... Hooper, 1201.1303

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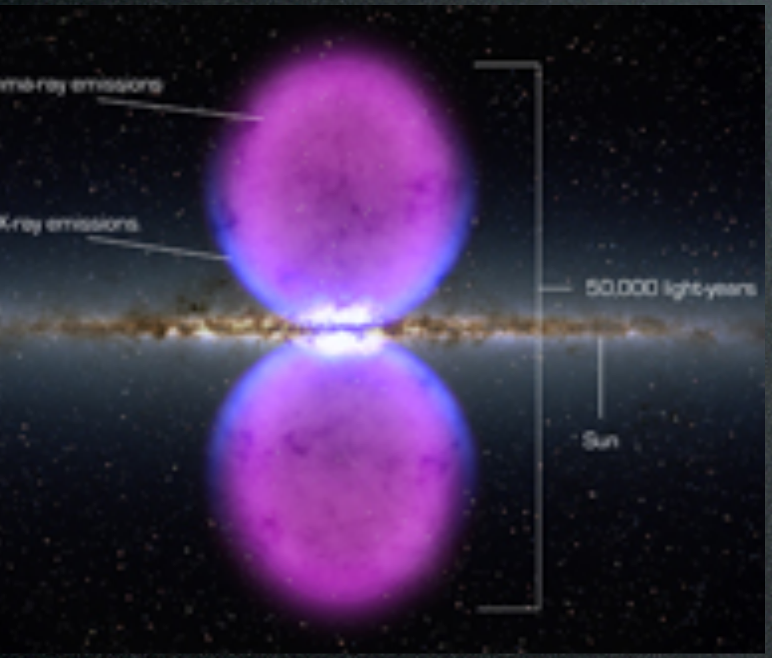

Fermi bubbles

Dan Hooper

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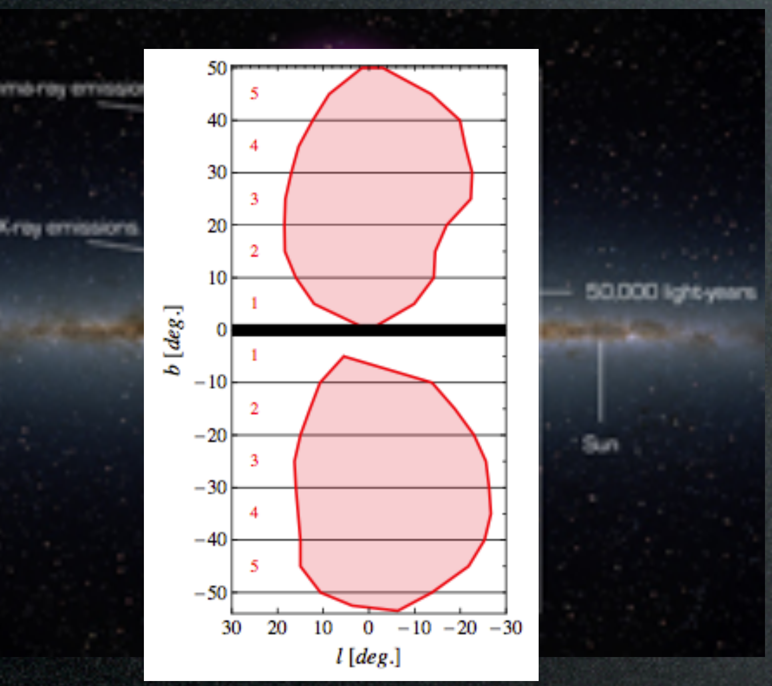

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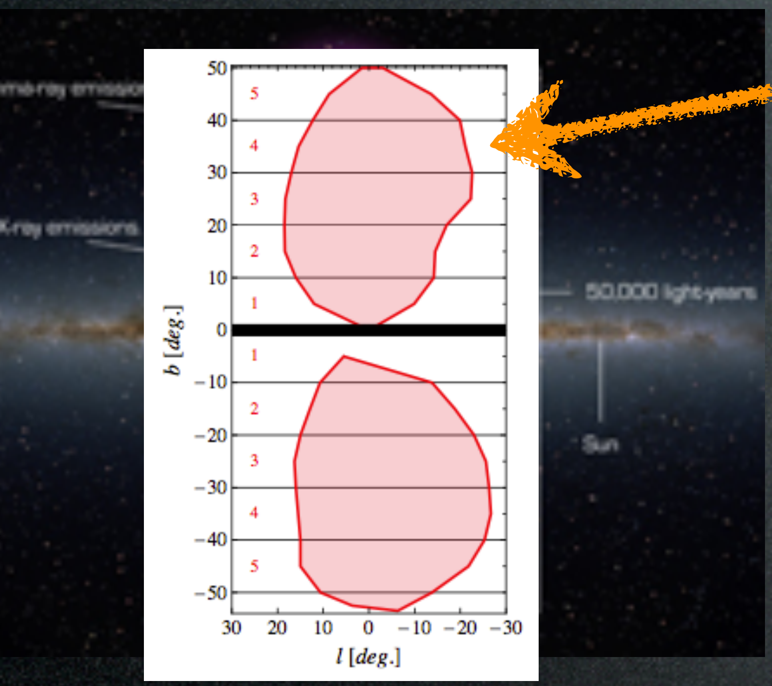

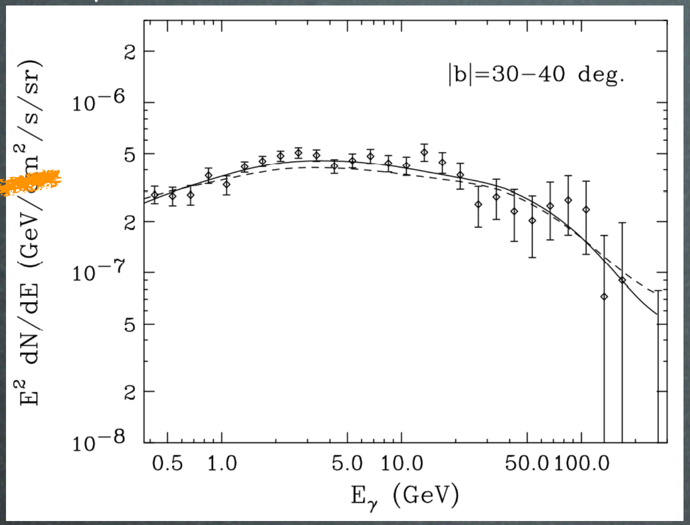

Here there's no excess which cannot be explained in terms of ordinary ICS.

Fermi bubbles

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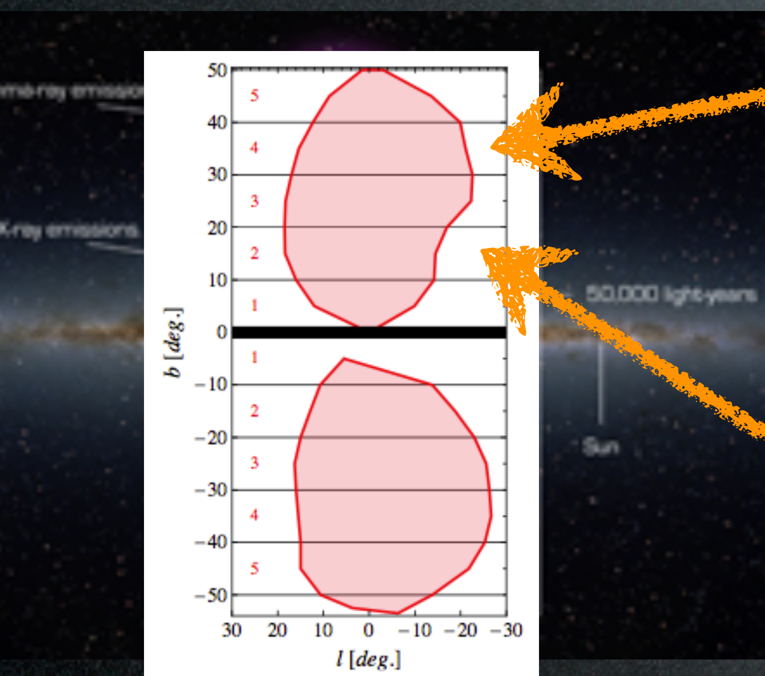

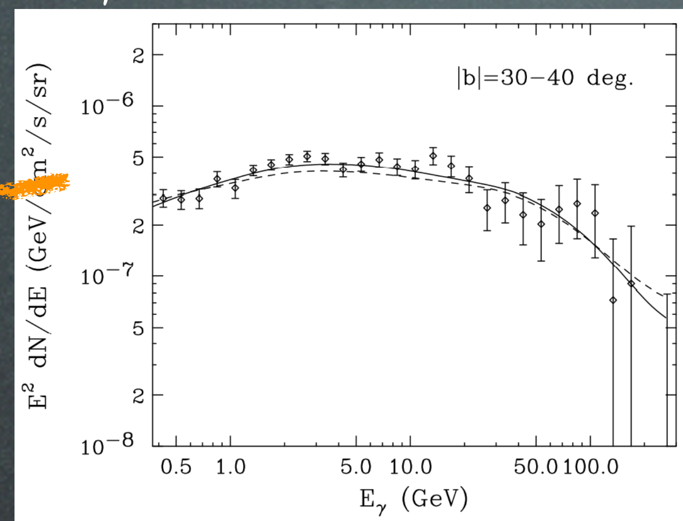

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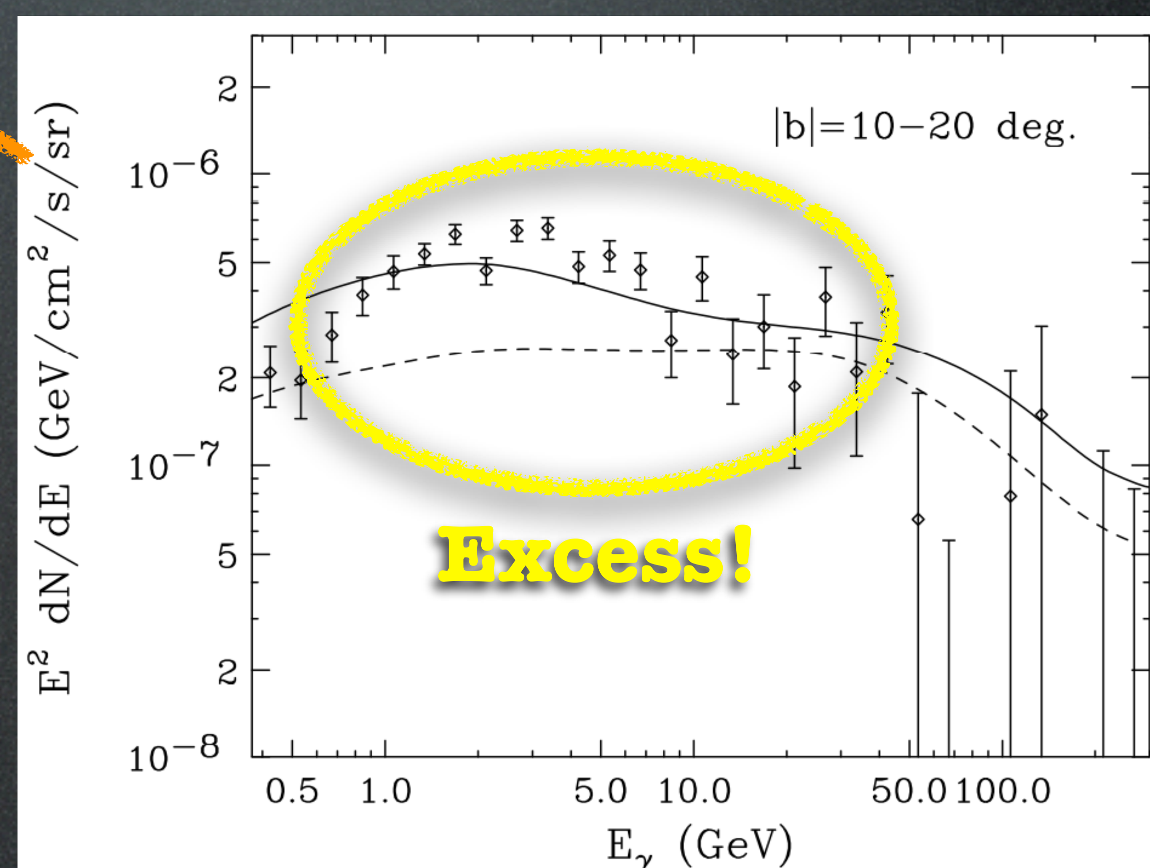

Best fit:
~10 GeV, leptons, ~thermal σv

Fermi bubbles

Dan Hooper

Hooper, Slatyer 1302.6589

Essentially confirmed by: Huang, Urbano, Xue 1307.6862

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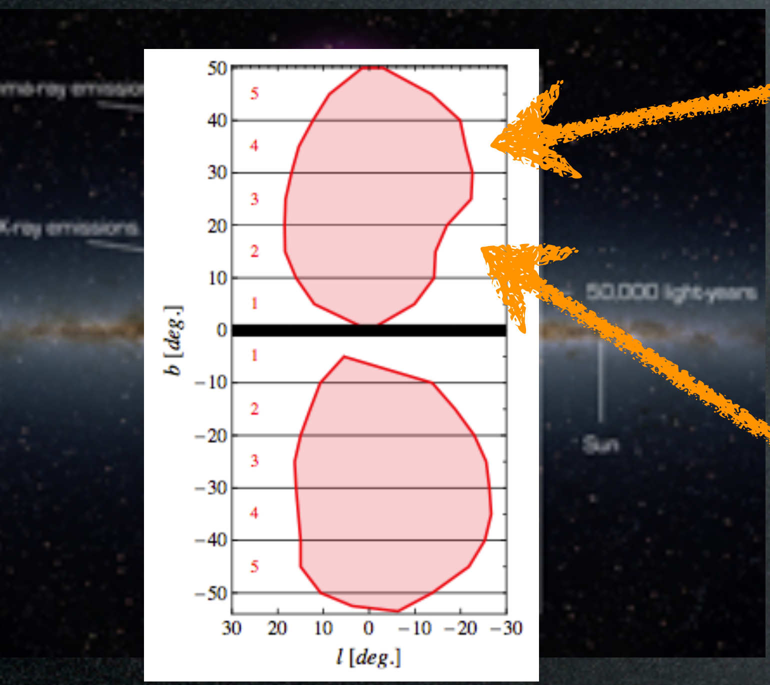

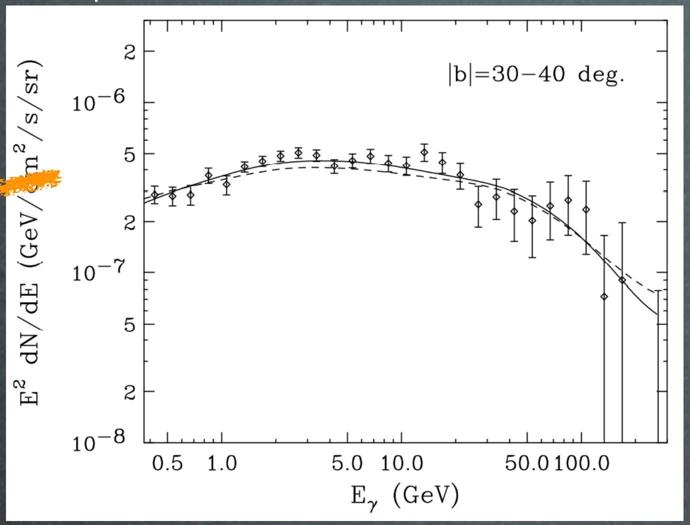

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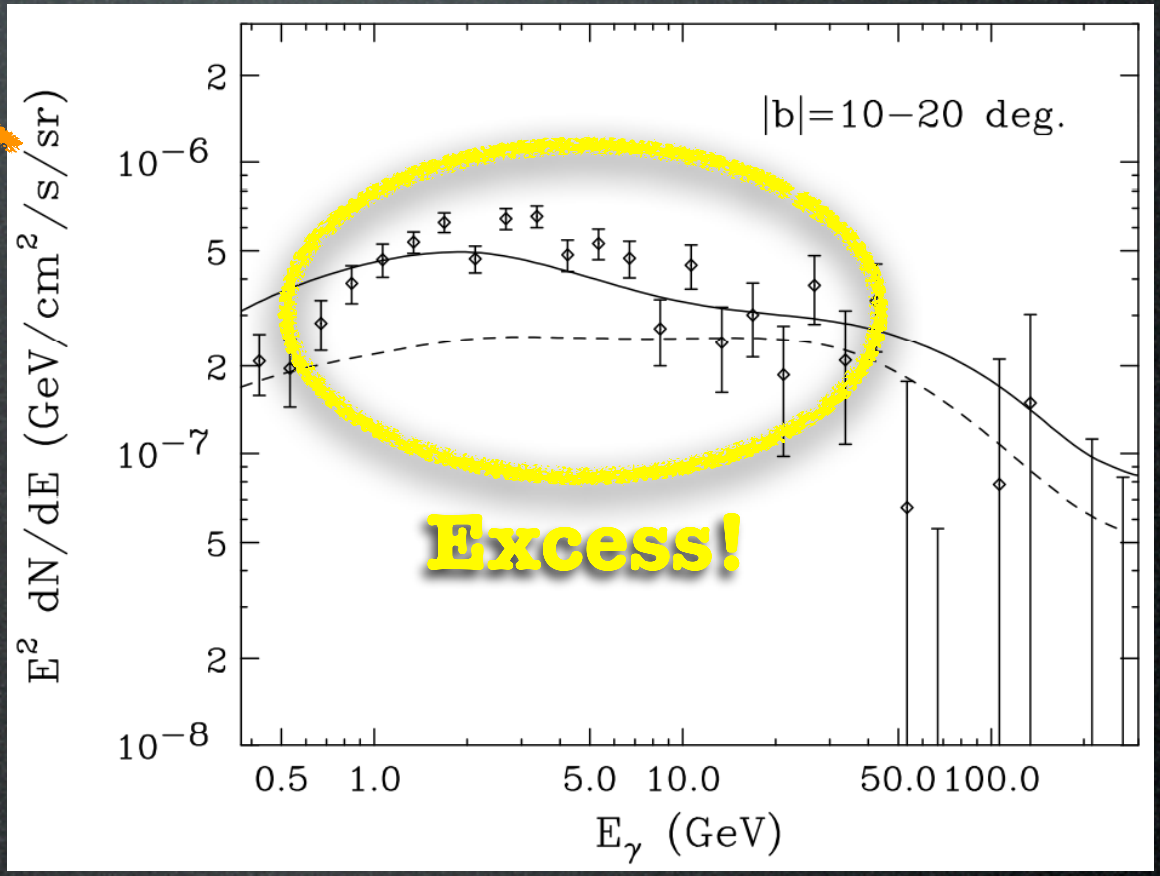

Objection:
nothing tells you that the input $e^\pm$ spectrum stays the same at high and low latitudes
(the ISRF too, but one can better model that)

Hooper, Slatyer 1302.6589
Essentially confirmed by: Huang, Urbano, Xue 1307.6862

Conclusions

Conclusions

Huang, Urbano, Xue 1307.6862

Since the dawn of civilization, the desire to gaze, study and understand the mysteries hedged in the astonishing beauty of the sky has been an unavoidable and innate prerogative of human nature. In March 1610 Galileo Galilei published the *Sidereus Nuncius*, the first scientific work based on telescope observations. Through the eye of this revolutionary instrument Galileo was able to take the first steps in the exploration of a completely unknown world, describing the results of his studies about the mountainous surface of the Moon, a myriad of stars never seen before with the naked eye, and the discovery of four Erratic Stars that appeared to be orbiting around the planet Jupiter.

After more than four hundred years, telescopes are becoming the most important scientific instrument in astronomy and astrophysics, reaching a degree of technical perfection that enables us to study in great detail the Universe. Among them, the Fermi Large Area Telescope (LAT) [1] is devoted to the study of photons in the high energy region of gamma-rays, and one of the most challenging goals of the mission is to shed light on the elusive nature of Dark Matter (DM).

Many efforts have been made, for instance, to study and understand the nature of a spatially extended excess, peaked at few GeV, found in the gamma-ray emission from the Galactic center [2, 3, 4, 5, 6]. The signal can be explained by $\mathcal{O}(10)$ GeV DM annihilating into $\tau^+\tau^-$, $b\bar{b}$, or by model with dark forces [7].

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Huang, Urbano, Xue 1307.6862

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Gamma rays are promising for DM searches, but they are difficult.

environmental dependence, backgrounds...

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Huang, Urbano, Xue 1307.6862

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So far only solid constraints and maybe some hint.

(Even the best smoking guns have proven to be a bit wet...)