26 August 2014
PANIC 2014 - Hamburg

Dark Matter:

experimental results & theory

Marco Cirelli

(CNRS IPhT Saclay)

26 August 2014
PANIC 2014 - Hamburg

Dark Matter:
experimental results & theory

Marco Cirelli
(CNRS IPhT Saclay)

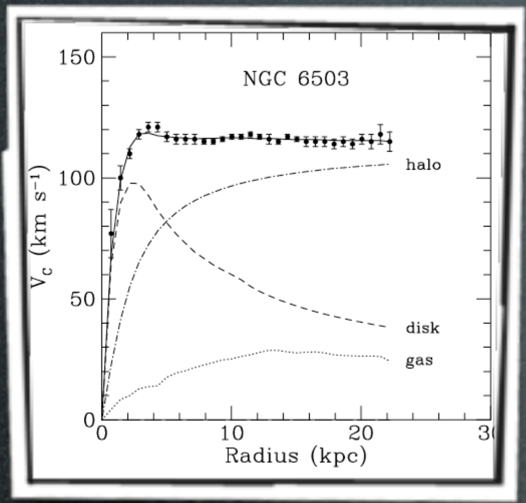
Introduction

Introduction

DM exists

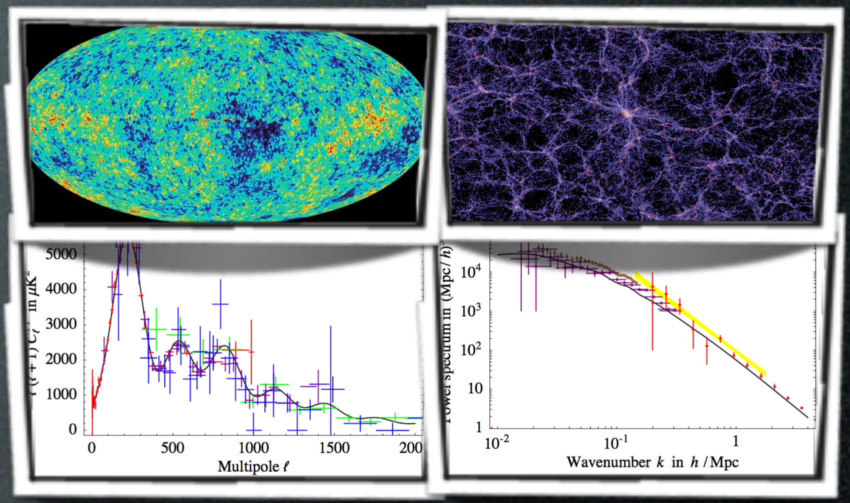
Introduction

DM exists



galactic rotation curves

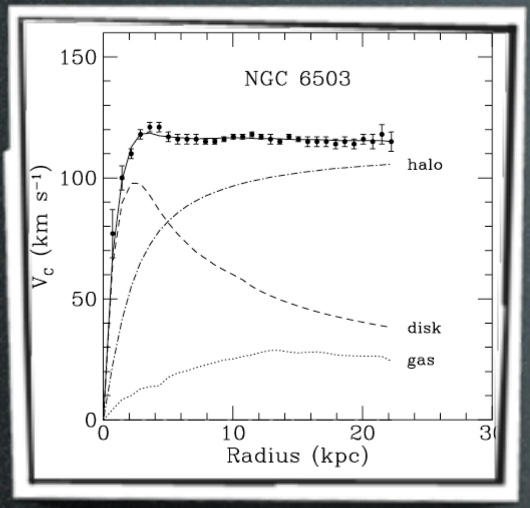
weak lensing (e.g. in clusters)



‘precision cosmology’ (CMB, LSS)

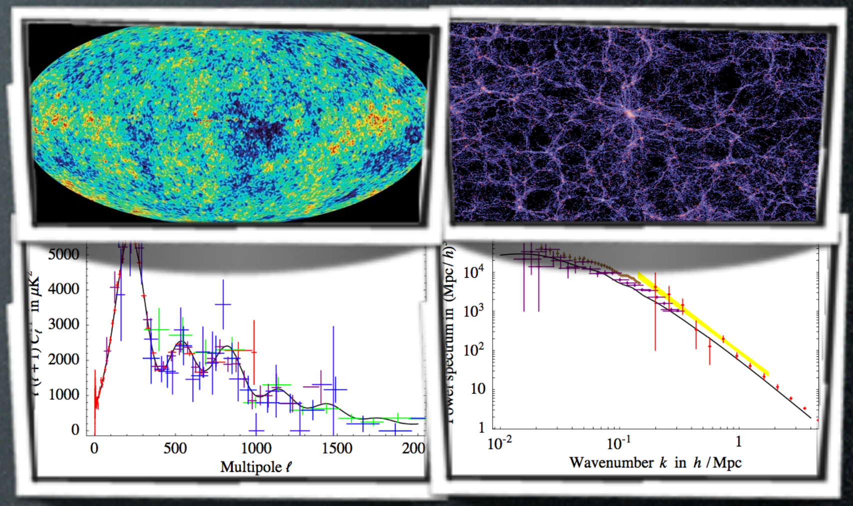
Introduction

DM exists



galactic rotation curves

weak lensing (e.g. in clusters)

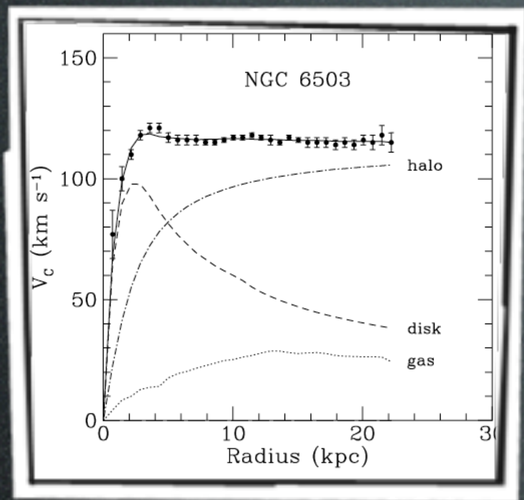


‘precision cosmology’ (CMB, LSS)

DM is a neutral, very long lived, feebly- interacting corpuscle.

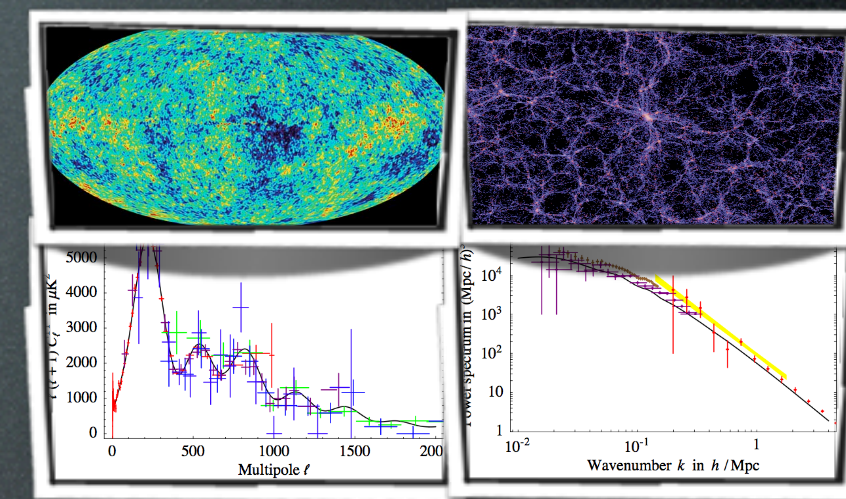
Introduction

DM exists



galactic rotation curves

weak lensing (e.g. in clusters)

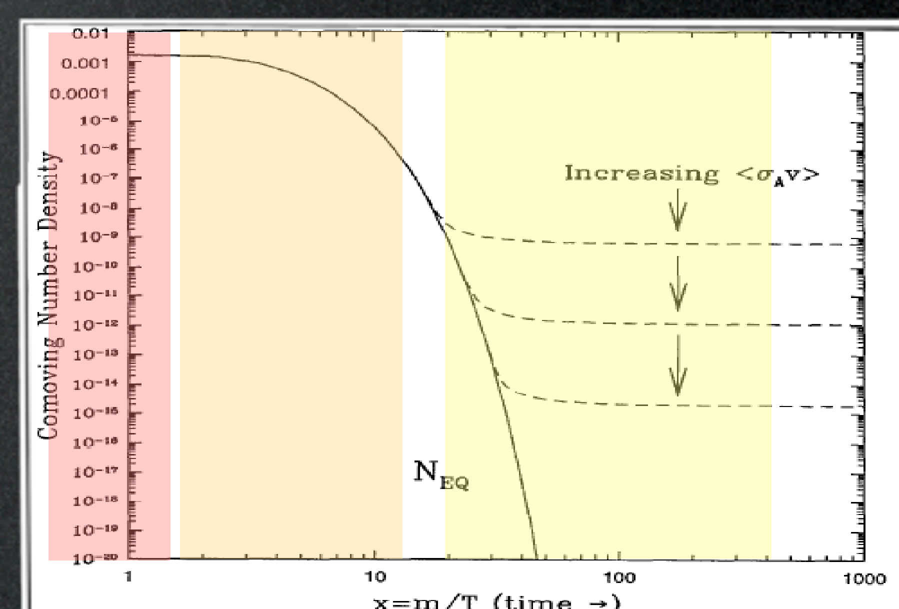


'precision cosmology' (CMB, LSS)

DM is a neutral, very long lived, weakly interacting particle.

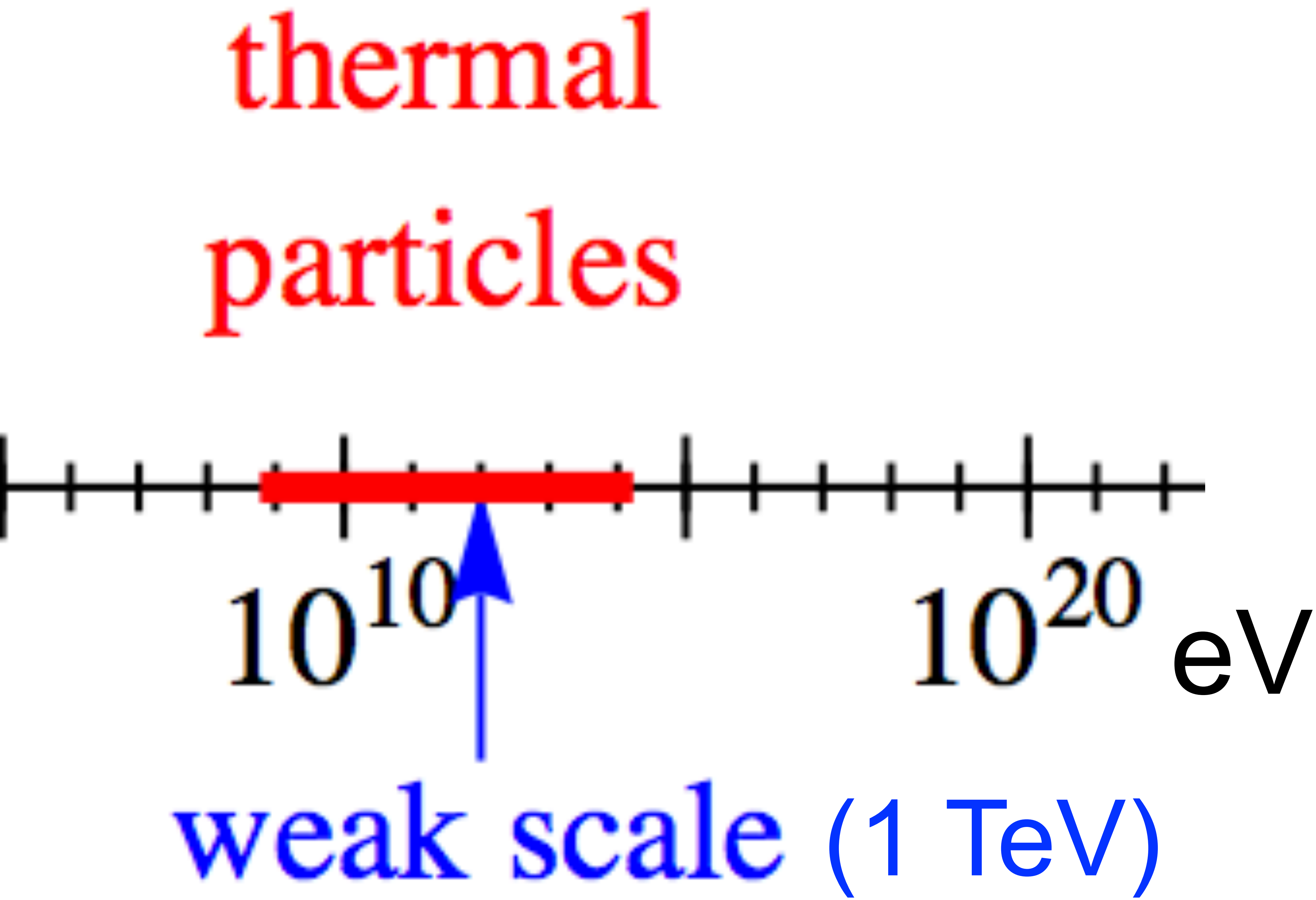
Some of us believe in the WIMP miracle.

- *weak*-scale mass (10 GeV - 1 TeV)
- *weak* interactions $\sigma v = 3 \cdot 10^{-26} \mathrm{cm}^3/\mathrm{sec}$
- give automatically correct abundance



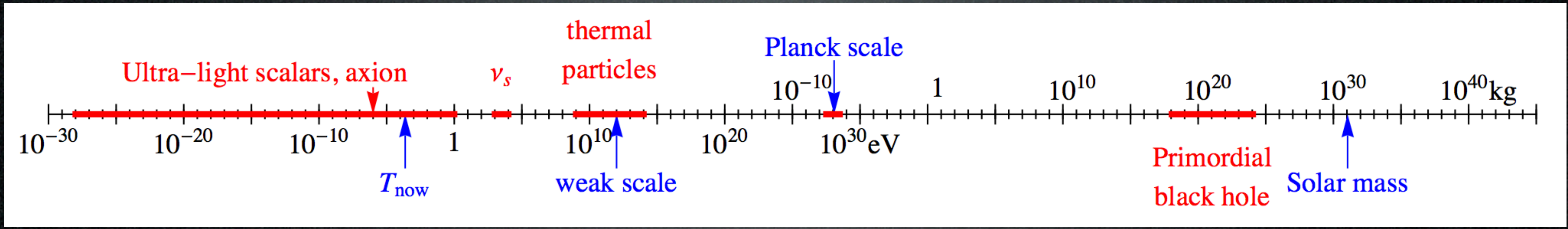
DM Candidates

A matter of perspective: plausible mass ranges



DM Candidates

A matter of perspective: plausible mass ranges



'only' 90 orders of magnitude!

DM Candidates

A matter of perspective: plausible mass ranges

Color code: ID, DD

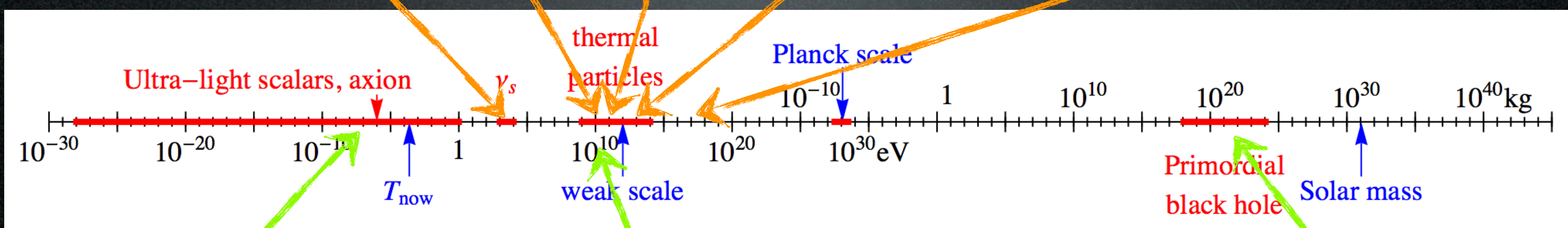
Fermi 135 GeV line

GeV gamma excess at GC

3.5 KeV line

PAMELA, Fermi, HESS excesses

PeV neutrinos Icecube



some activity recently

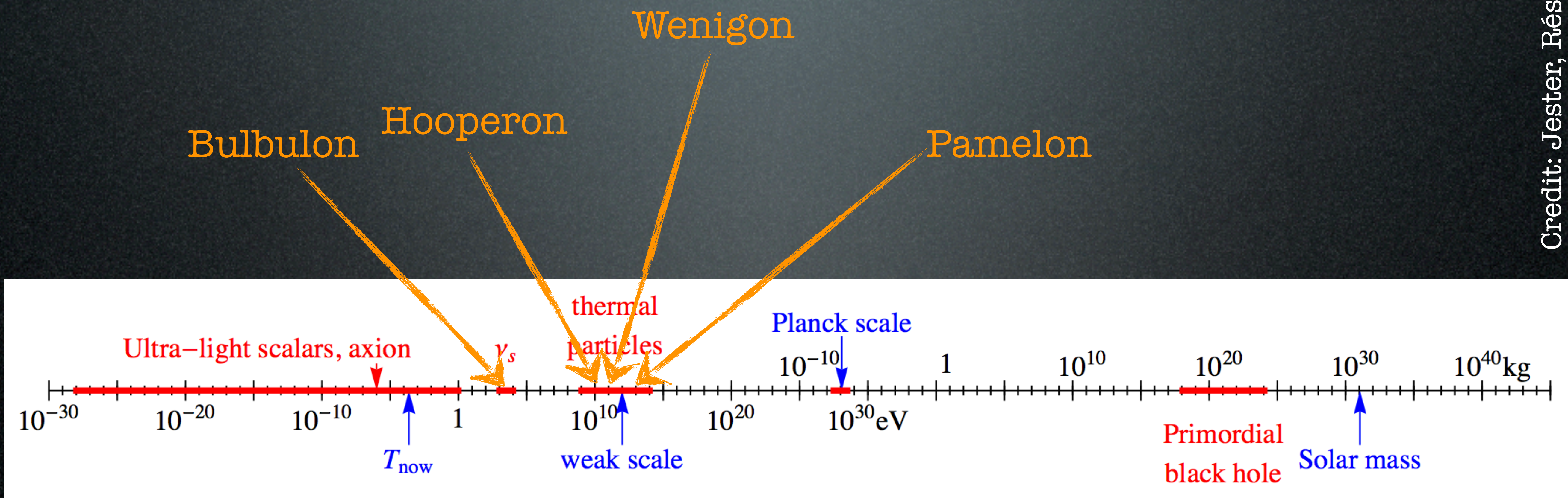
Light DM ('Dama') anomaly

lots of activity recently

'only' 90 orders of magnitude!

DM Candidates

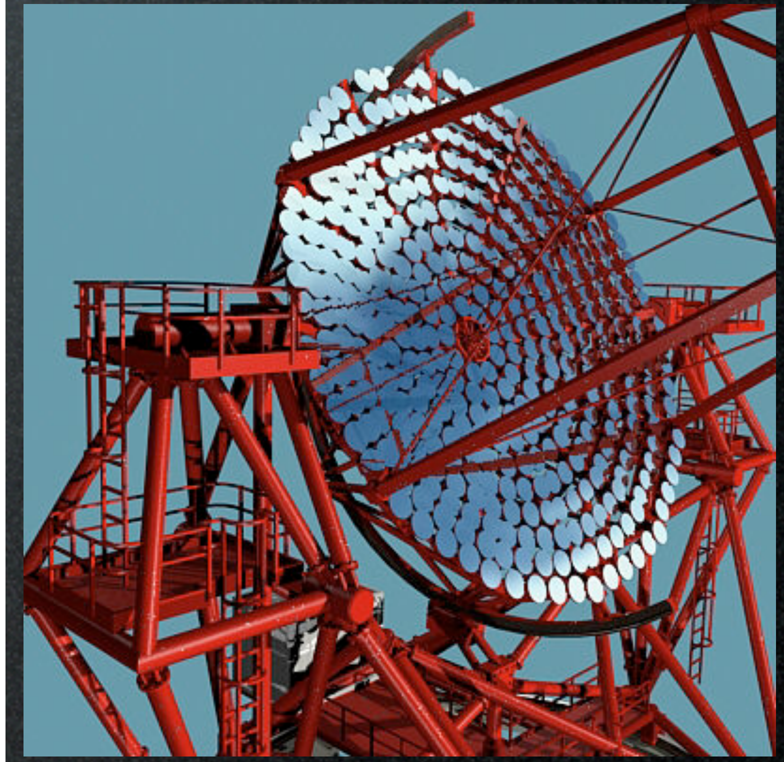
A matter of perspective: plausible mass ranges



Credit: Jester, Résonaances

‘only’ 90 orders of magnitude!

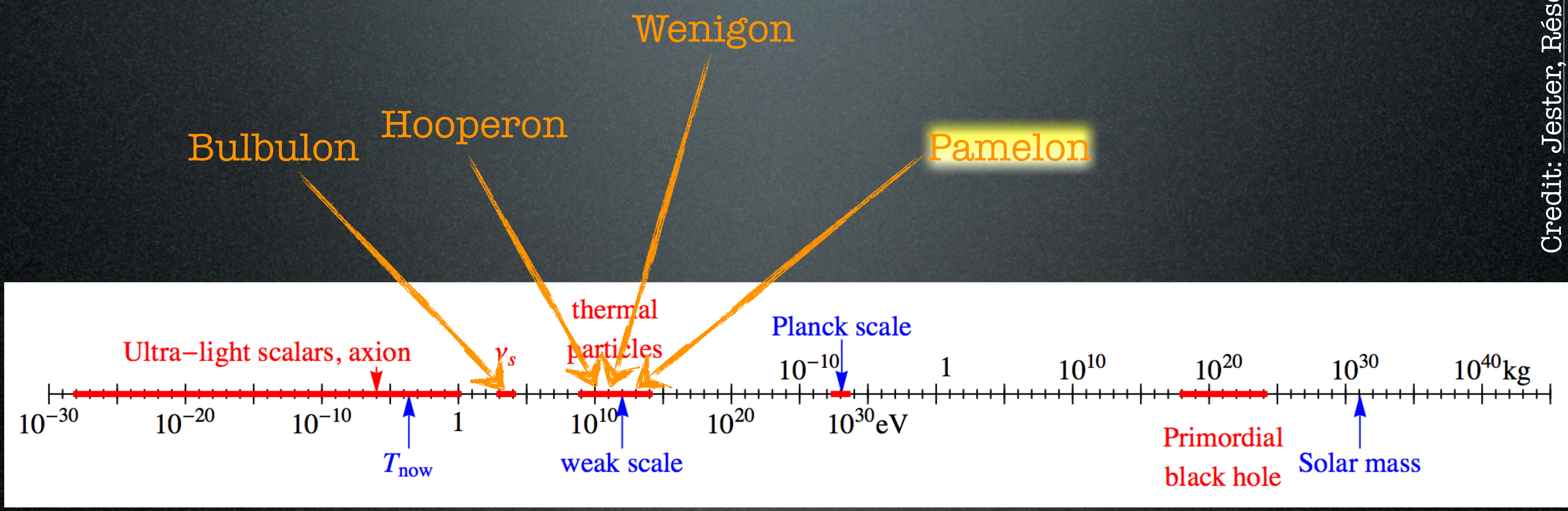
Charged CRs



1. the PAMELA/Fermi/HESS ‘excesses’

DM Candidates

A matter of perspective: plausible mass ranges

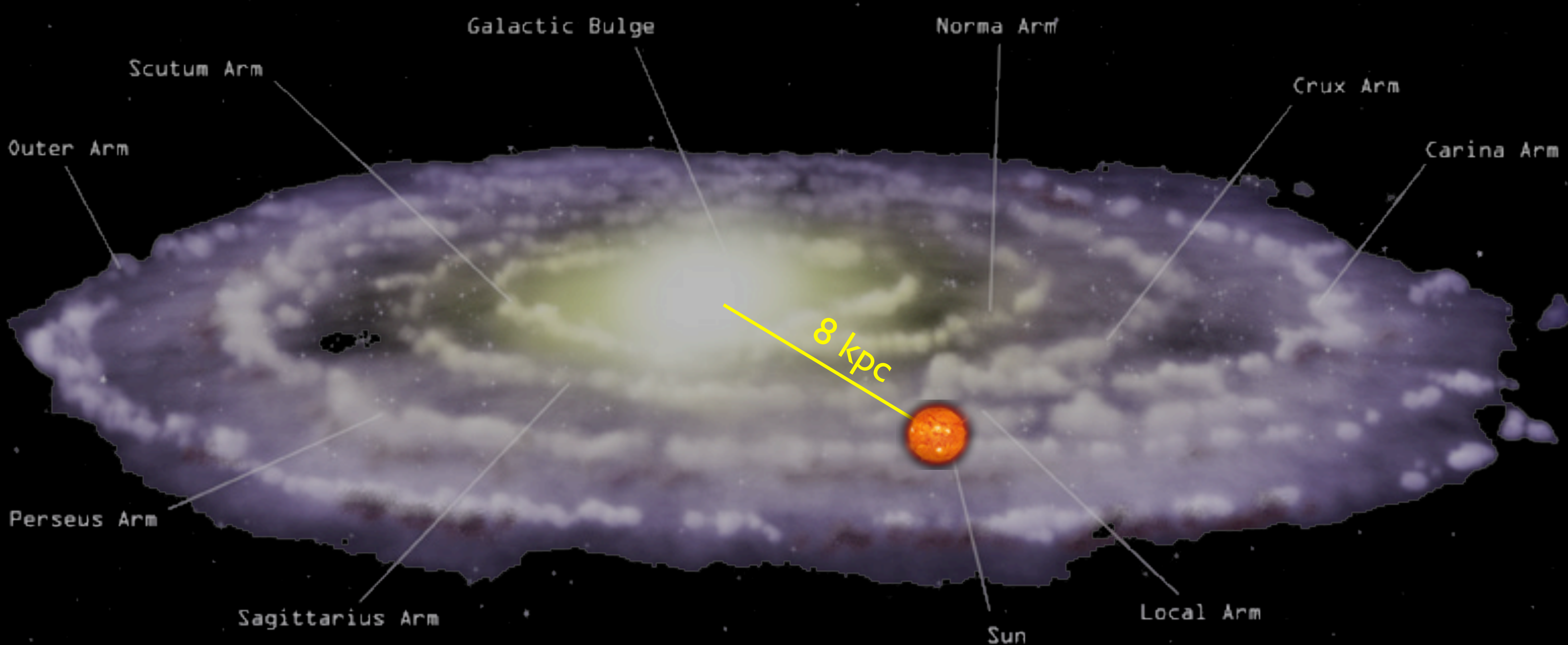


Credit: Jester, Résonaances

'only' 90 orders of magnitude!

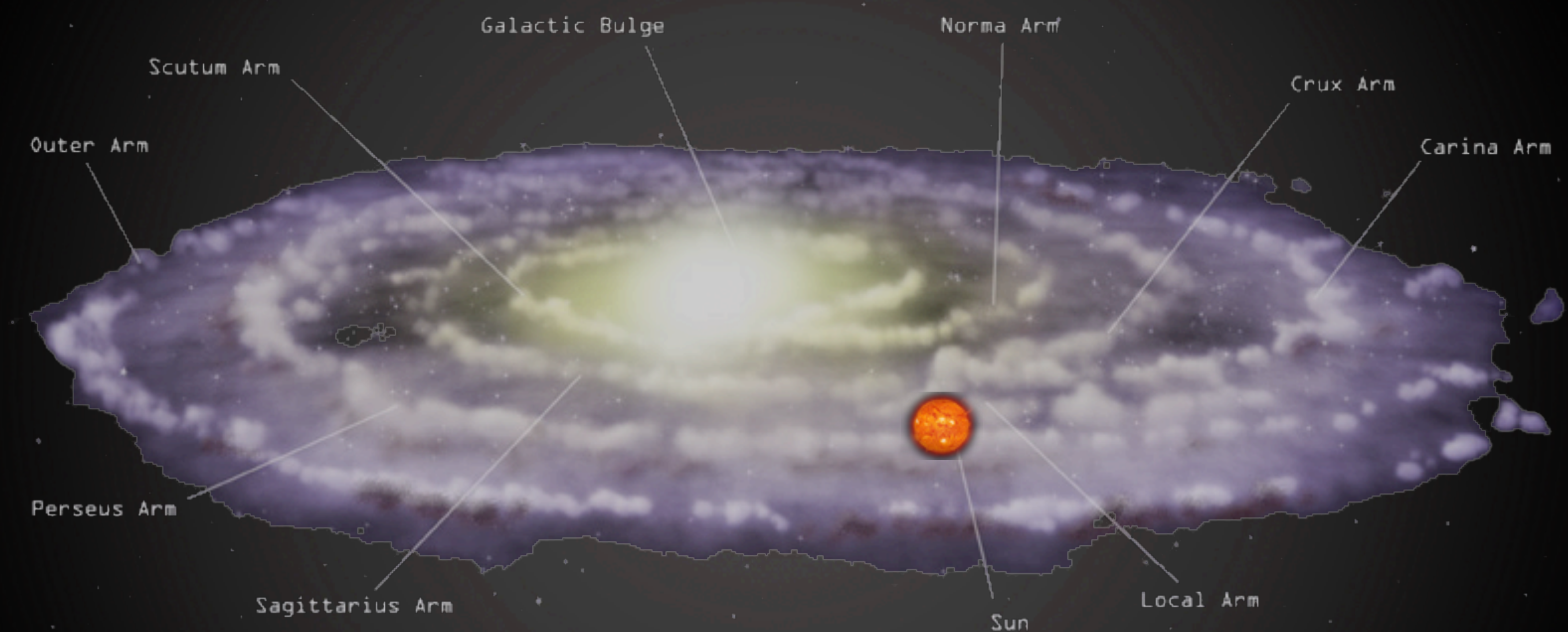
Indirect Detection: basics

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



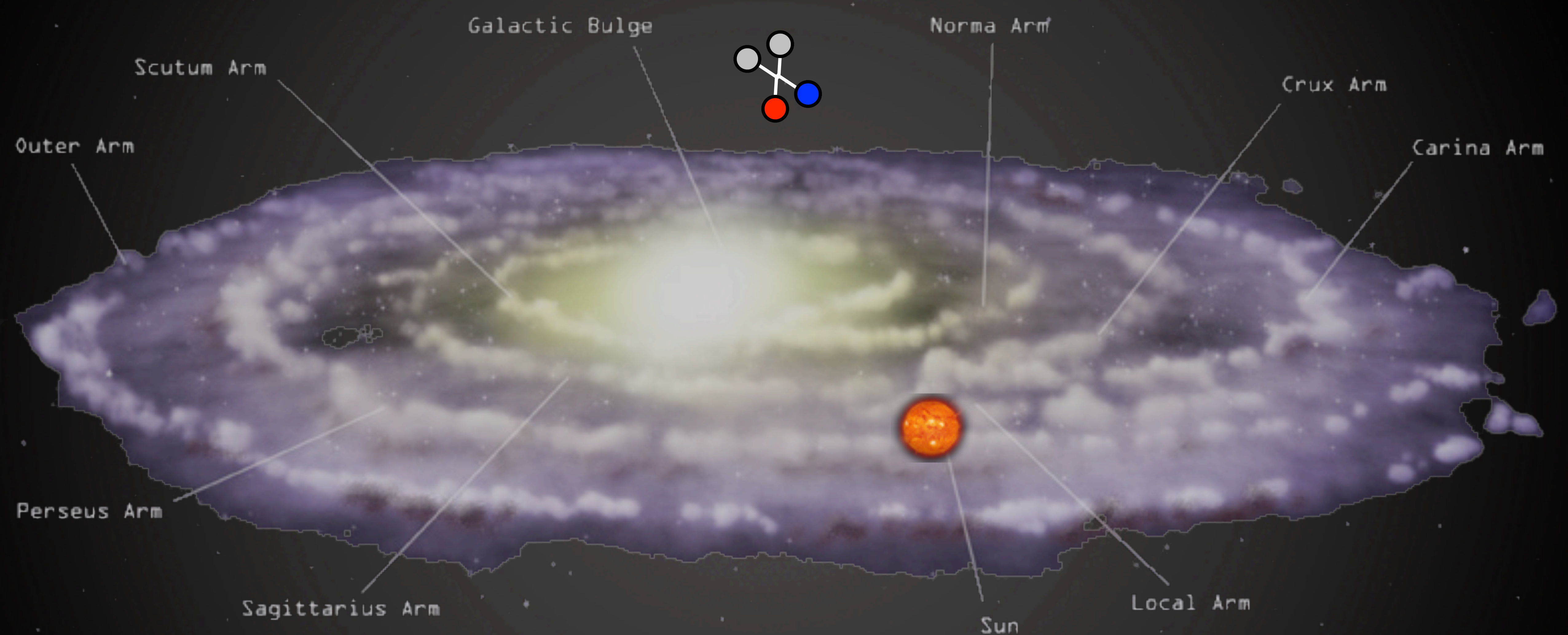
Indirect Detection: basics

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



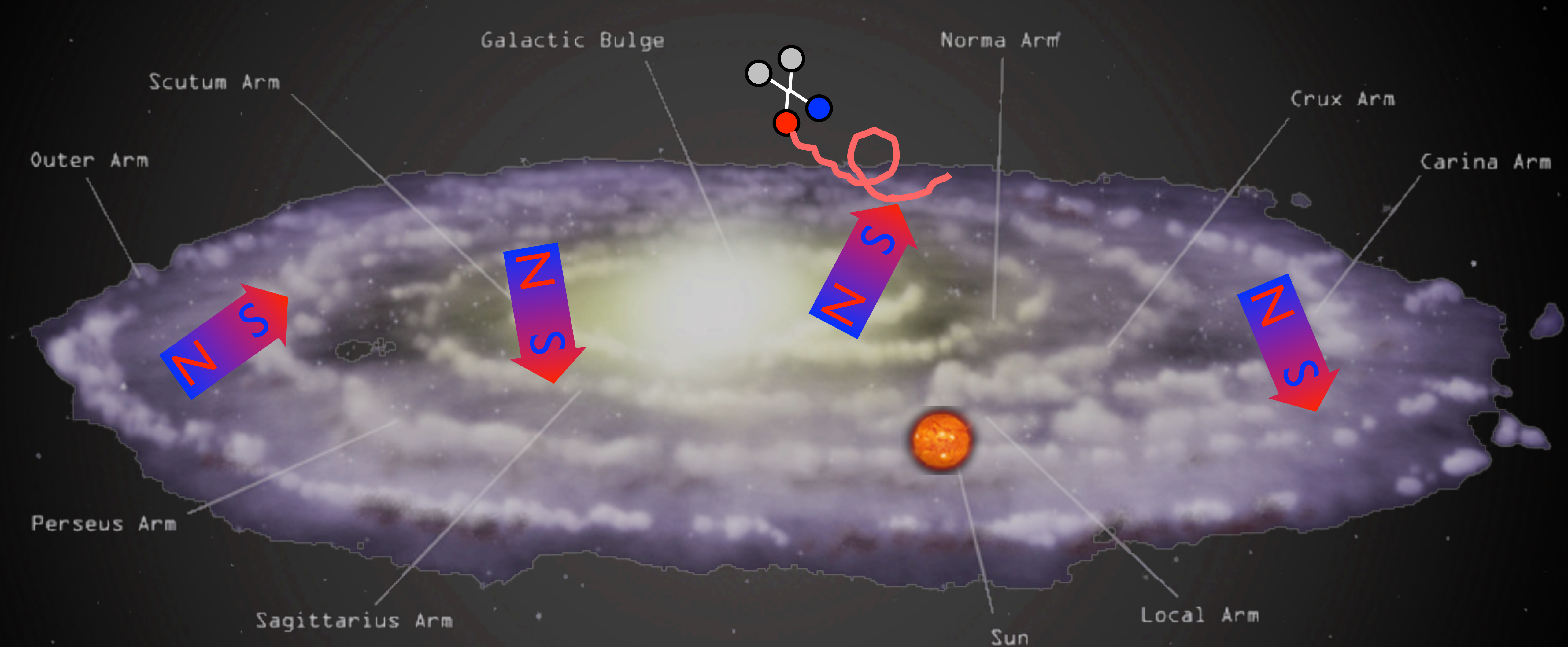
Indirect Detection: basics

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



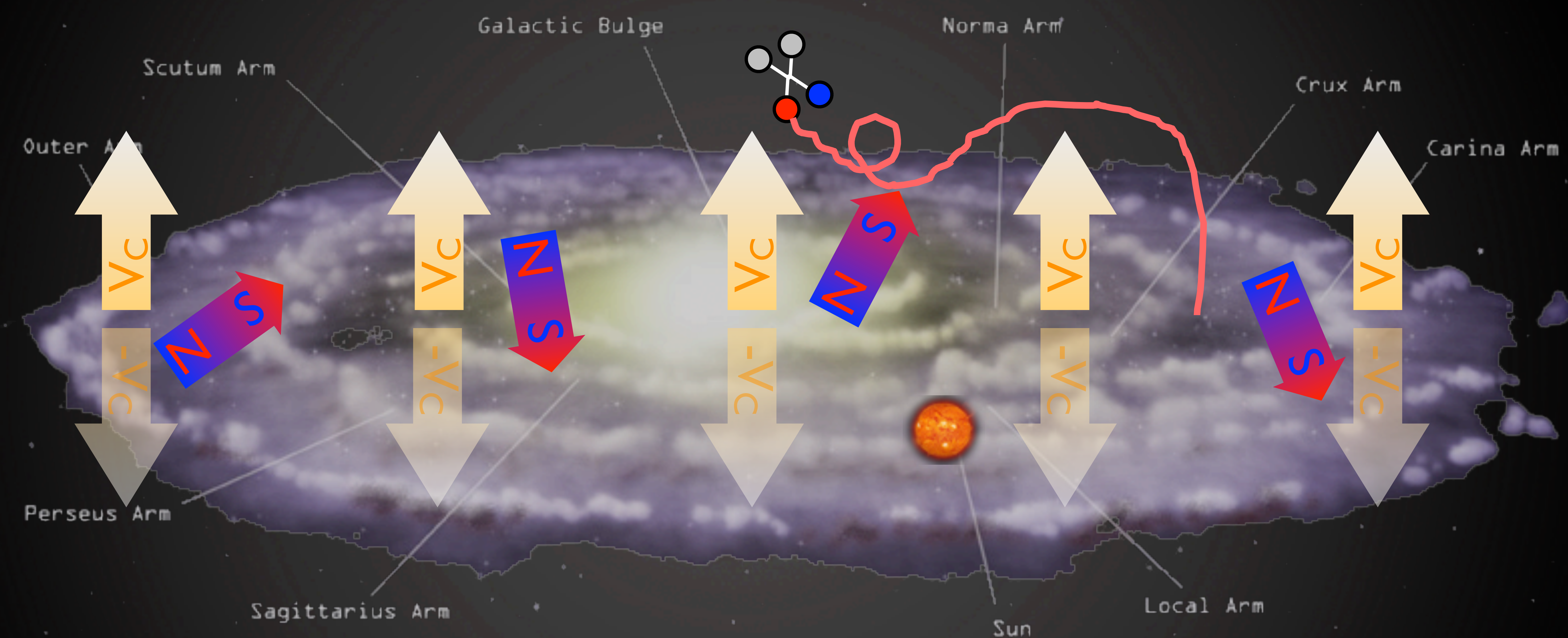
Indirect Detection: basics

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



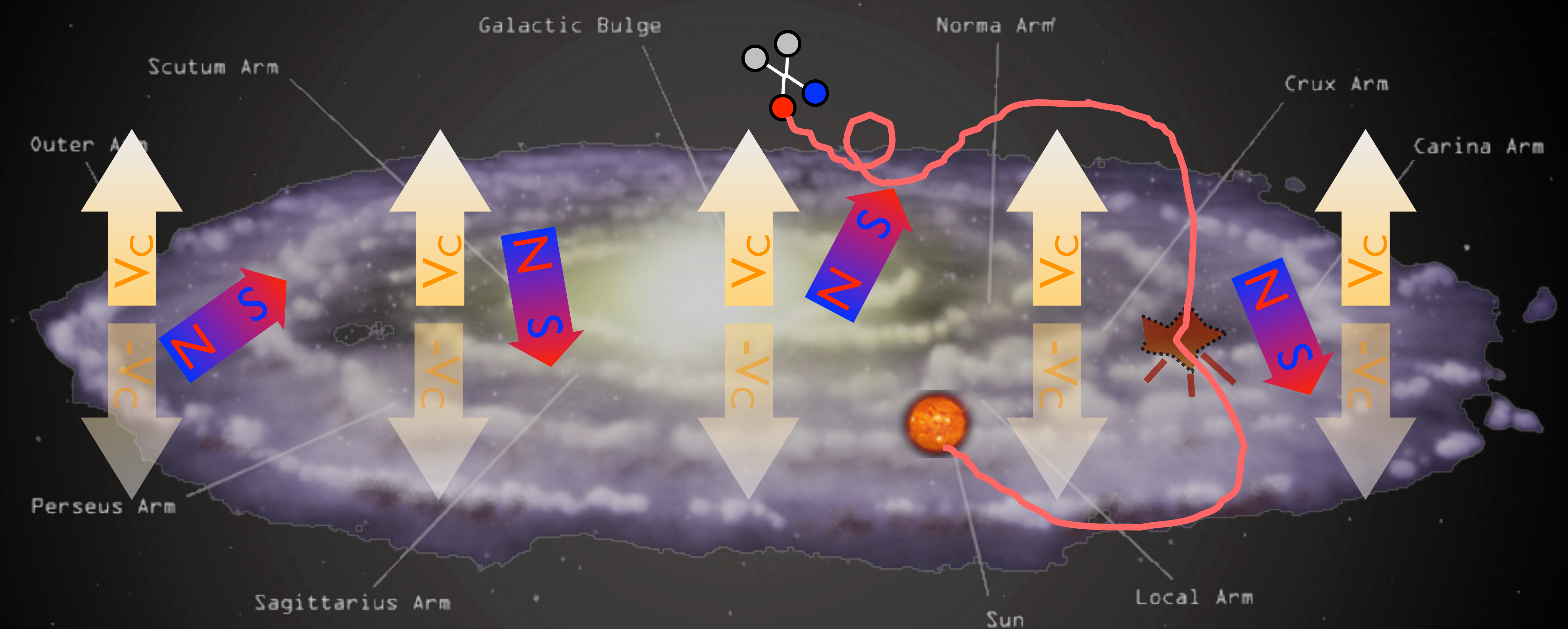
Indirect Detection: basics

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



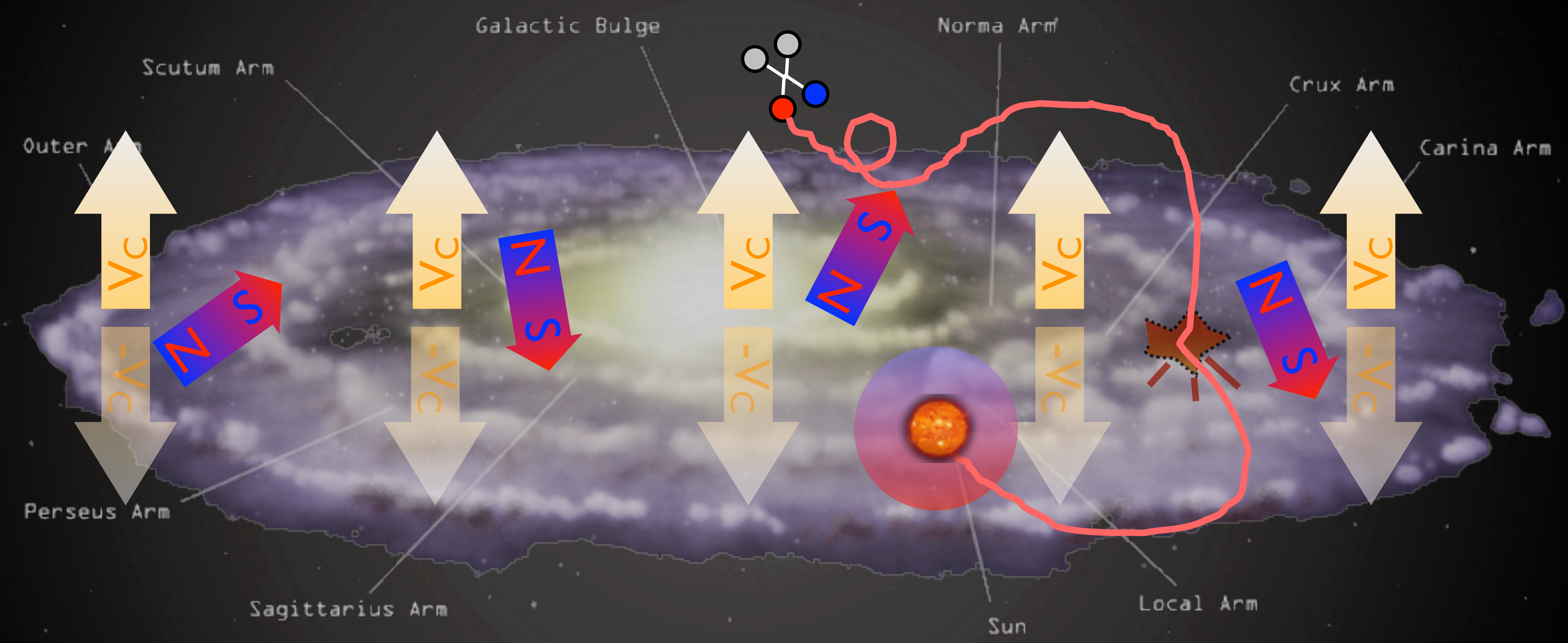
Indirect Detection: basics

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



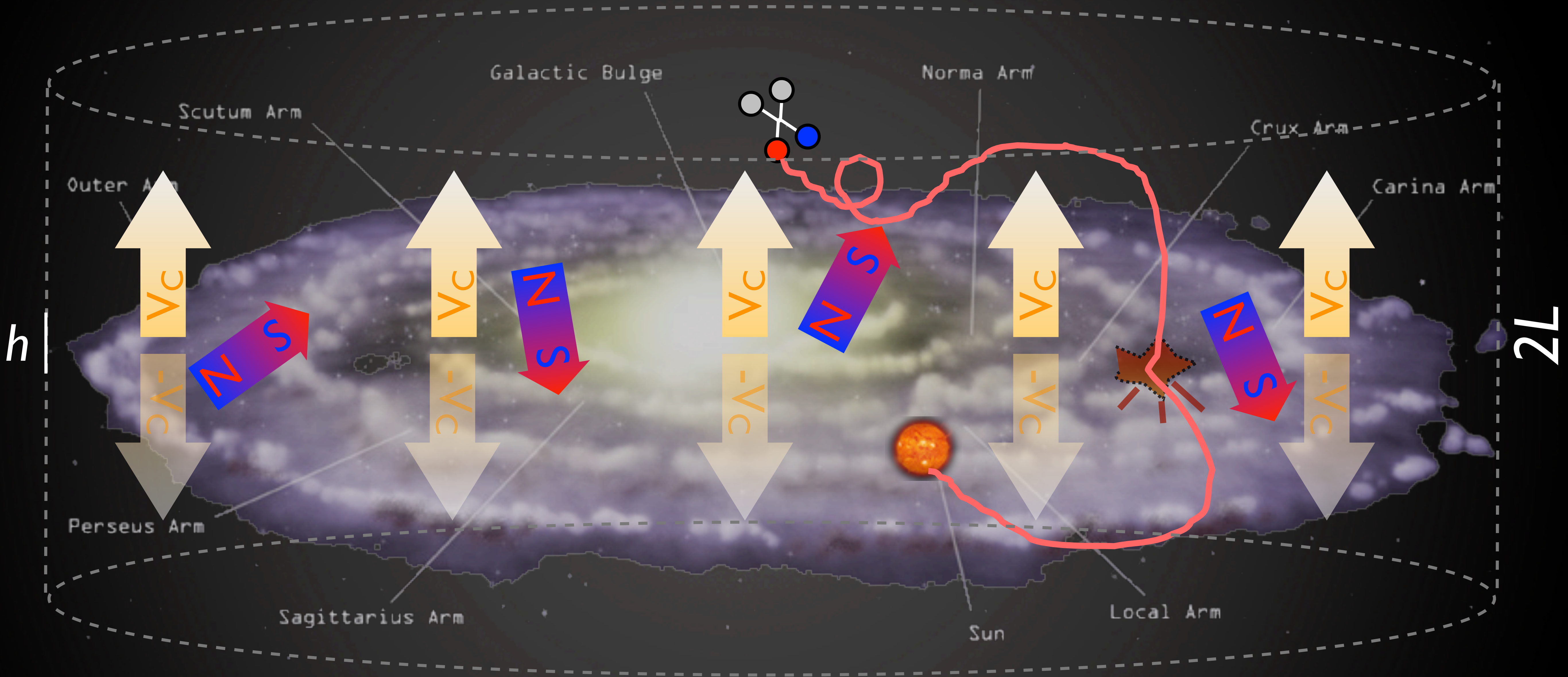
Indirect Detection: basics

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



Indirect Detection: basics

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



spectrum

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

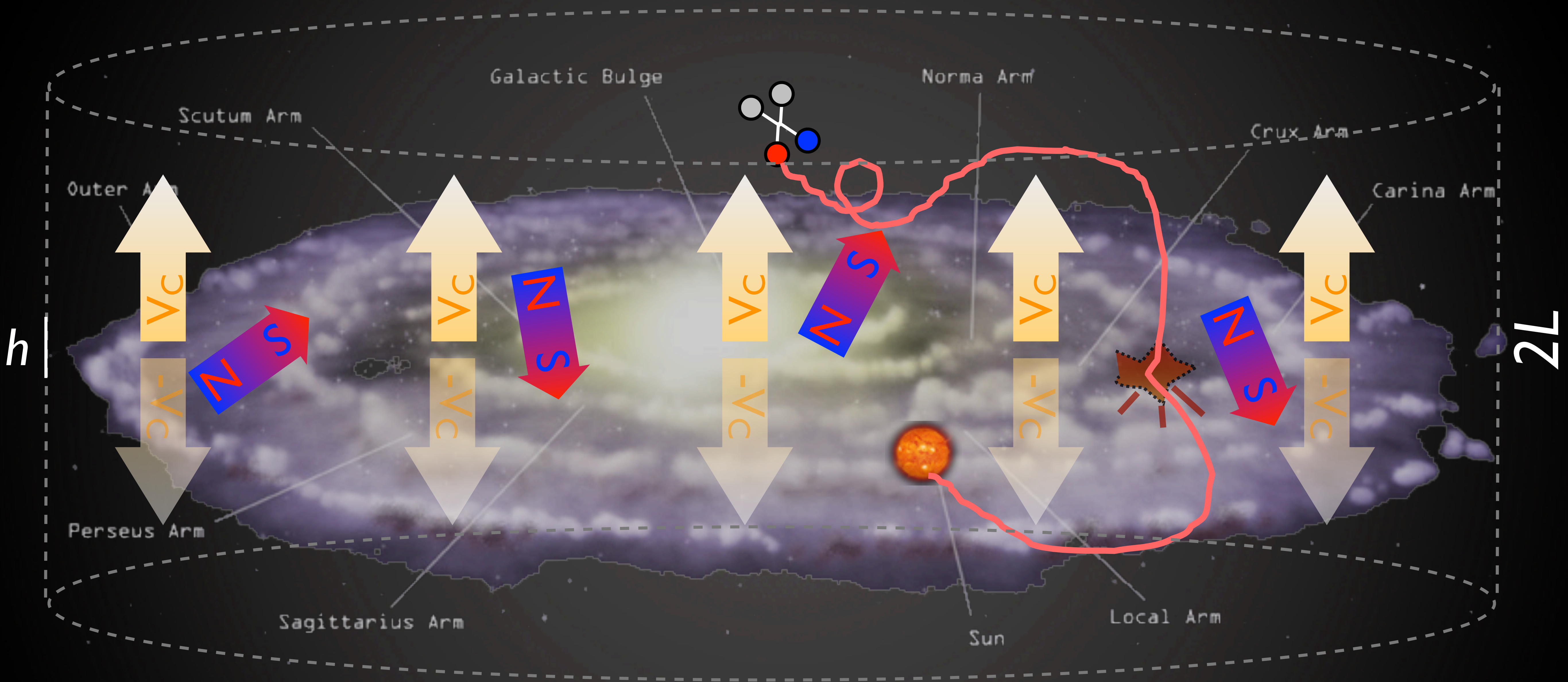
diffusion   energy loss   convective wind   source   spallations

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

[uncert]

Indirect Detection: basics

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

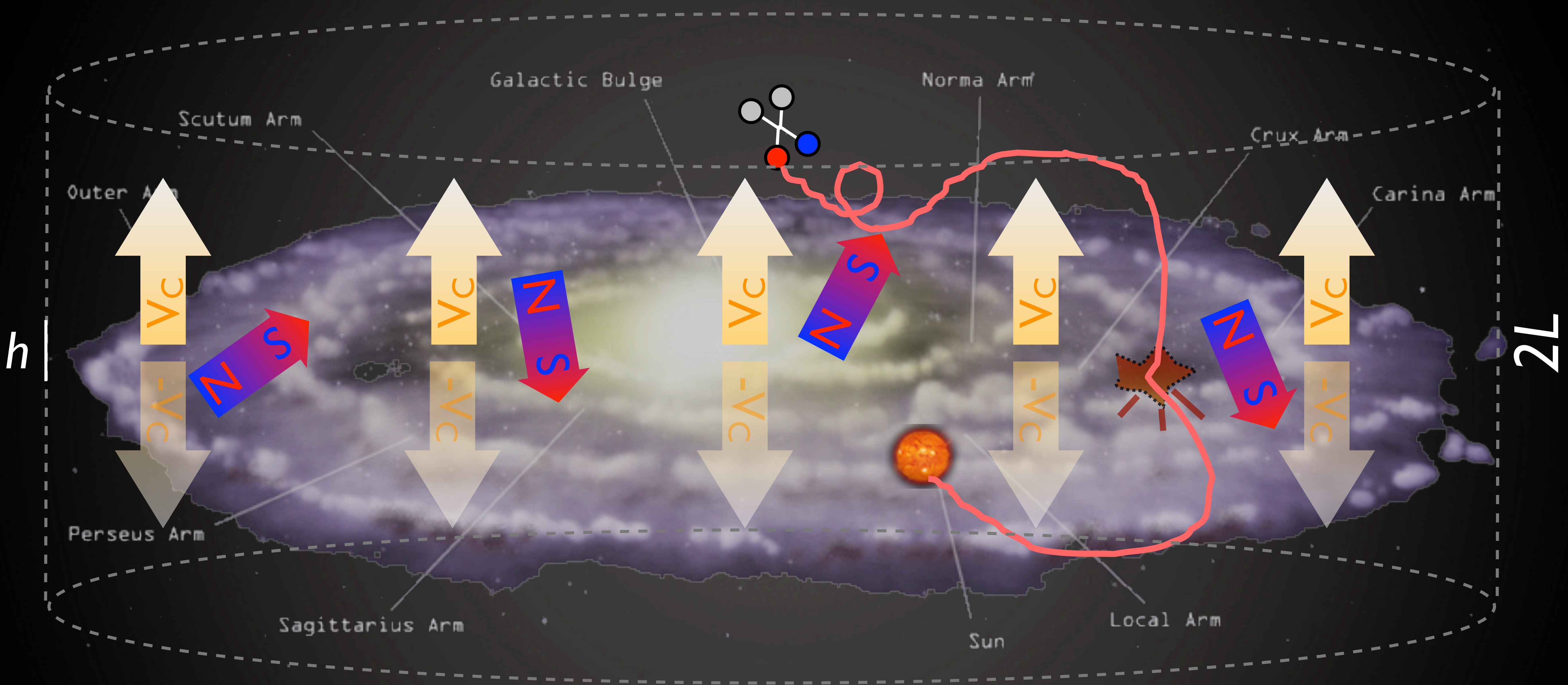


What sets the overall expected flux?

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

Indirect Detection: basics

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



What sets the overall expected flux?

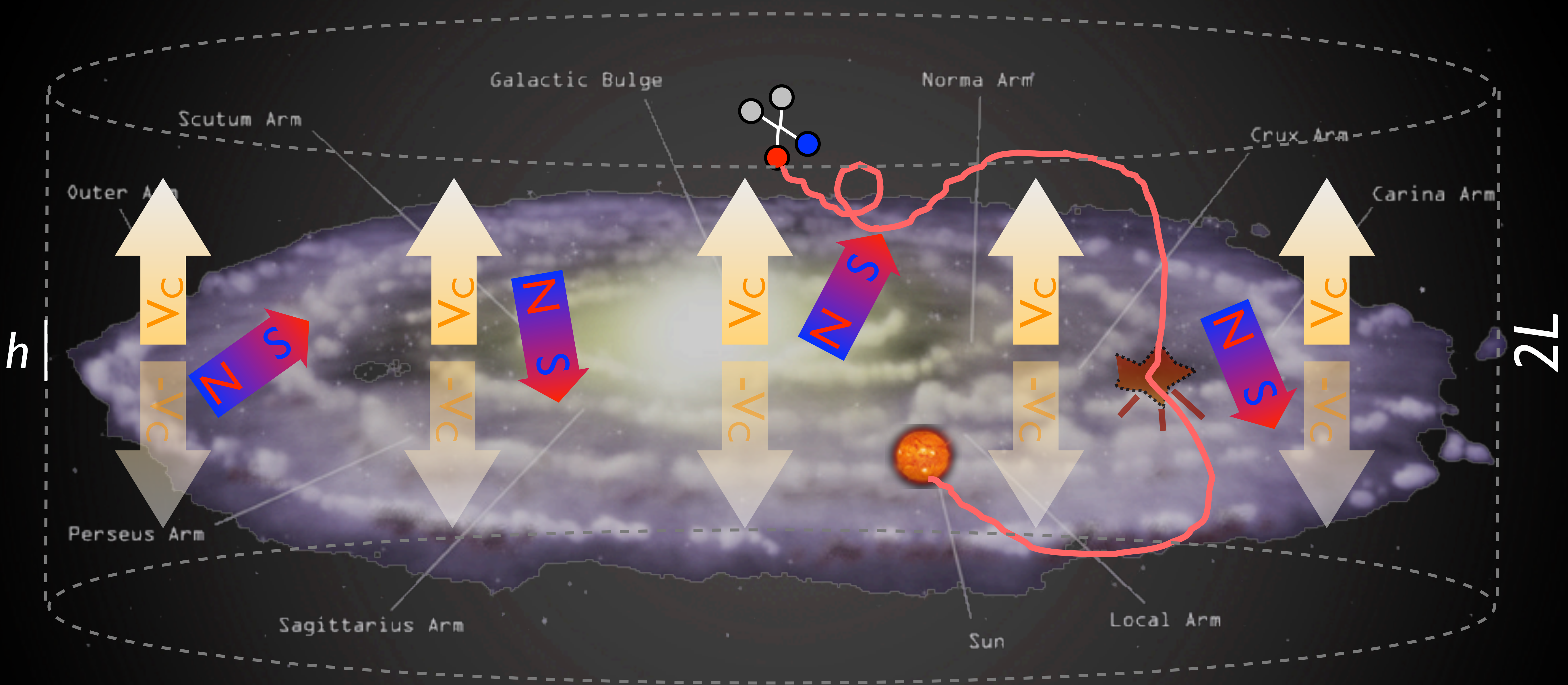
$$\text{flux} \propto n^2 \, \sigma_{\text{annihilation}}$$

astro& cosmo (n^2)

particle ($\sigma_{\text{annihilation}}$)

Indirect Detection: basics

$\bar{p}$ 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:

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

DM halo profiles

From N-body numerical simulations:

$$\text{NFW}: \quad \rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\rm Ein}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

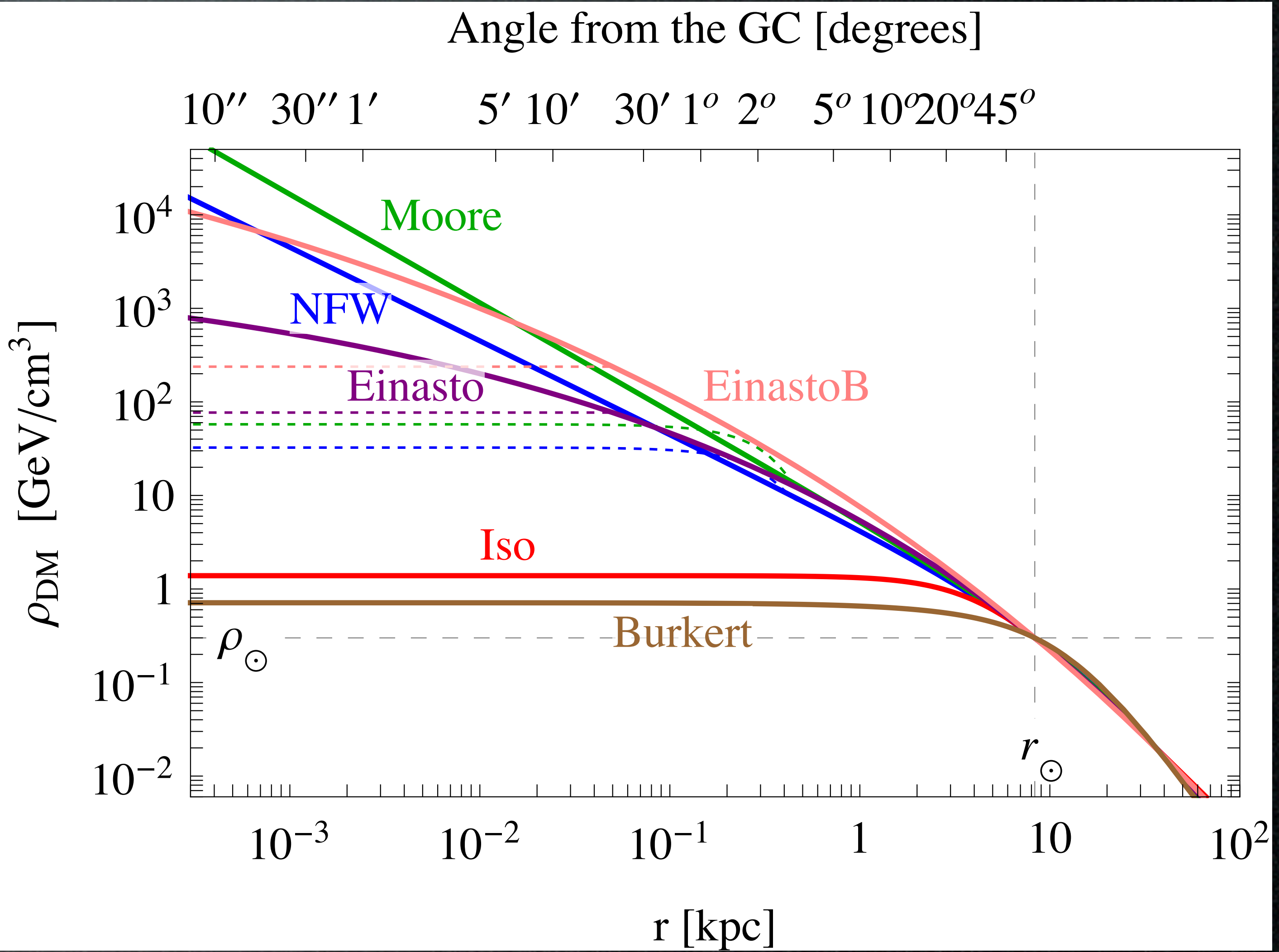
$$\text{Isothermal}: \quad \rho_{\rm Iso}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\text{Burkert}: \quad \rho_{\rm Bur}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\rm Moo}(r) = \rho_s \left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$

DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	–	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	–	4.38	1.387
Burkert	–	12.67	0.712
Moore	–	30.28	0.105

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



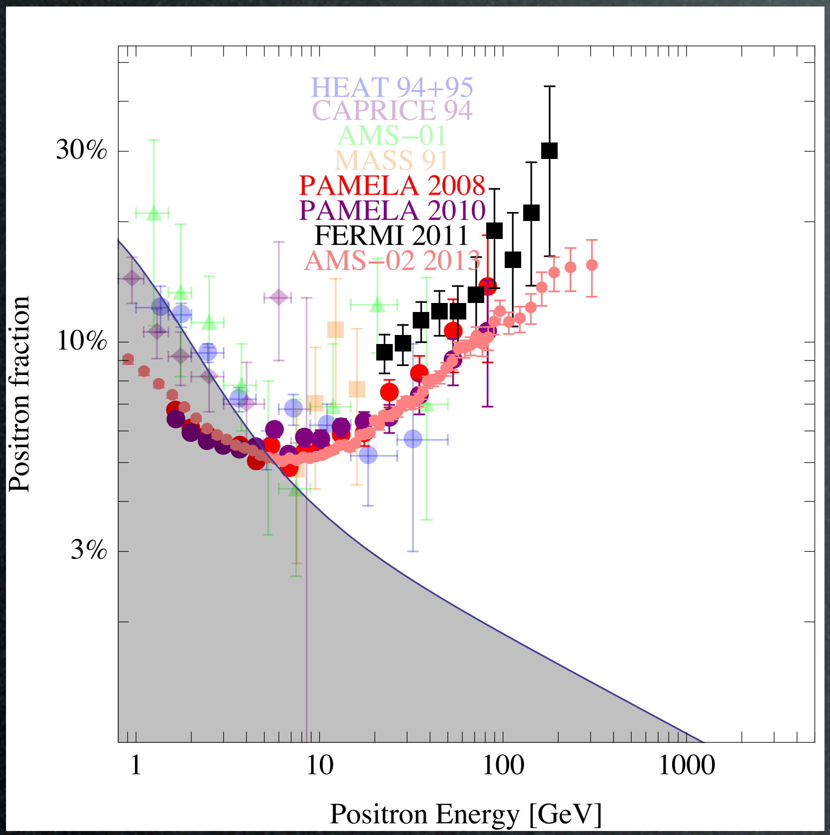
6 profiles:

- cuspy: NFW, Moore
- mild: Einasto
- smooth: isothermal, Burkert

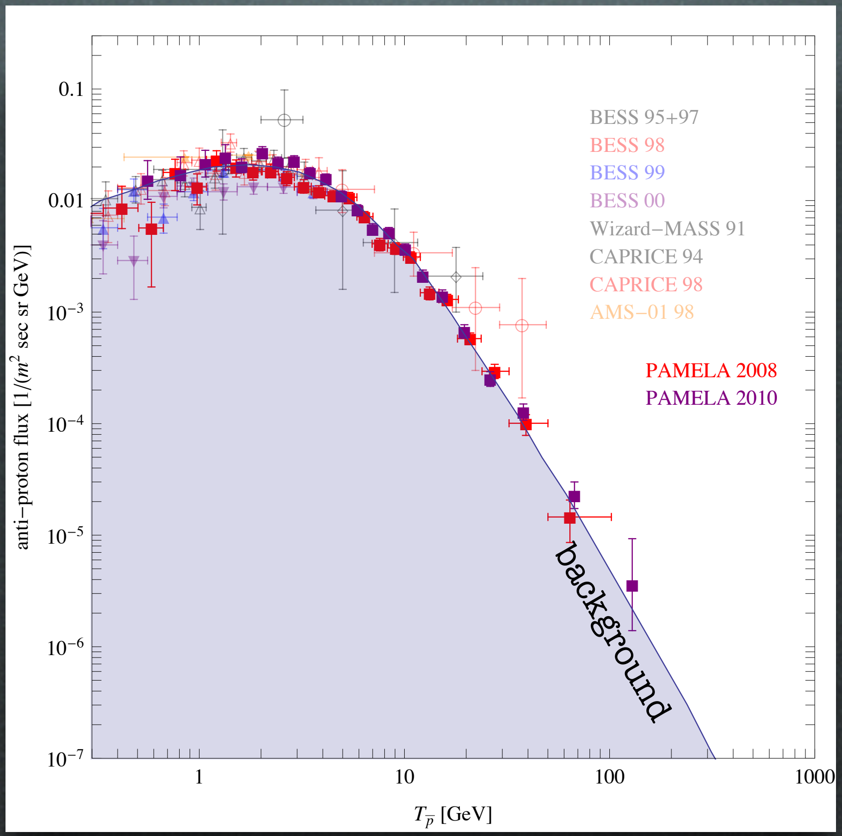
EinastoB = steepened Einasto (effect of baryons?)

Indirect Detection: **hints**

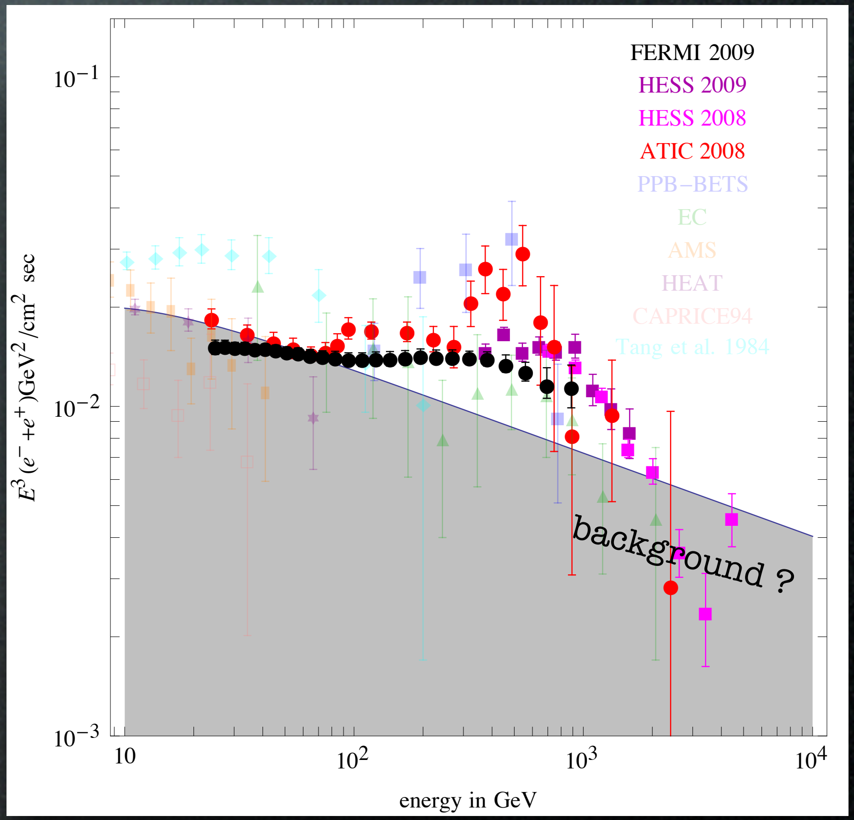
positron fraction



antiprotons

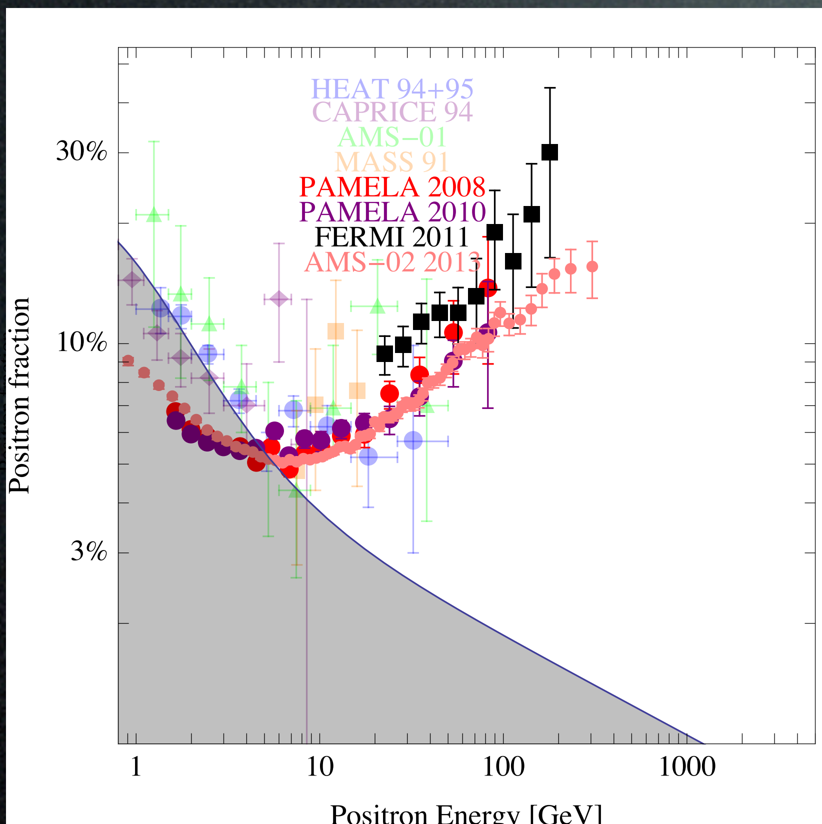


electrons + positrons

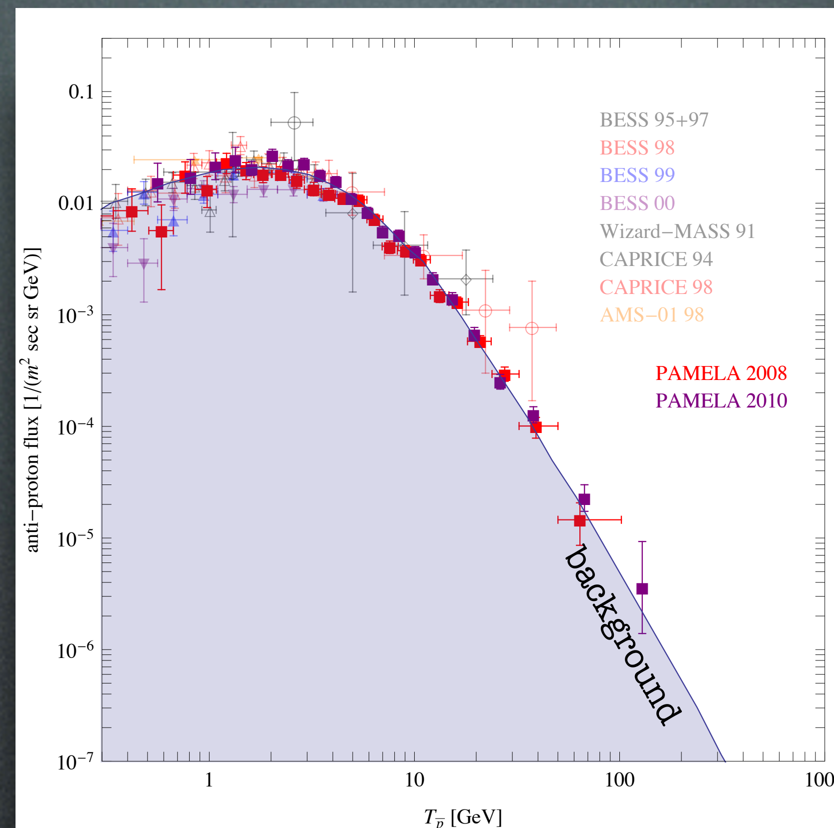


Positrons & Electrons

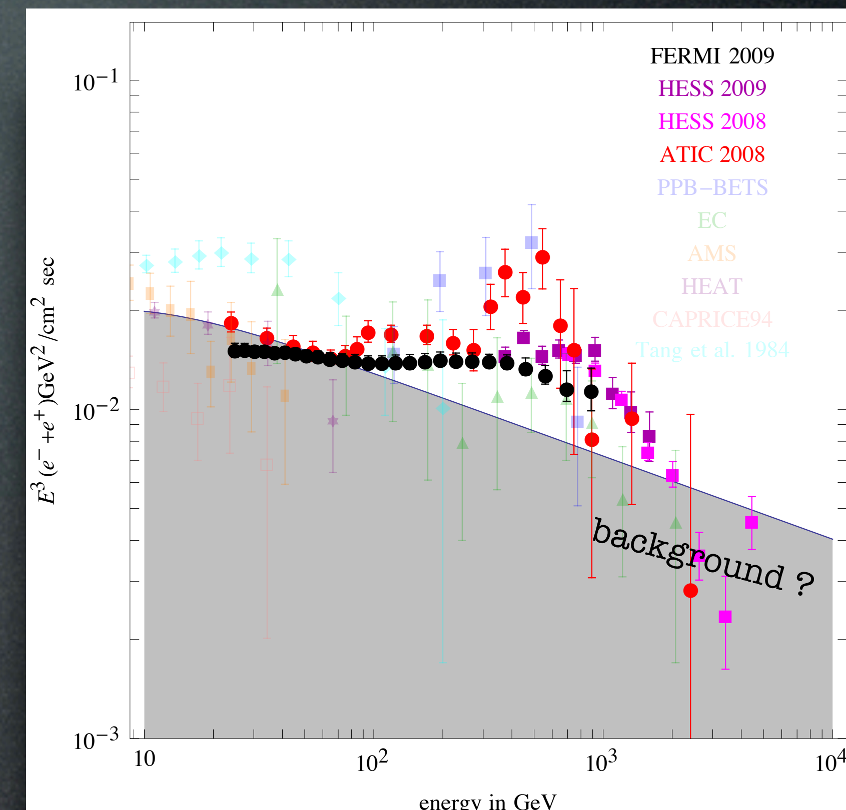
positron fraction



antiprotons



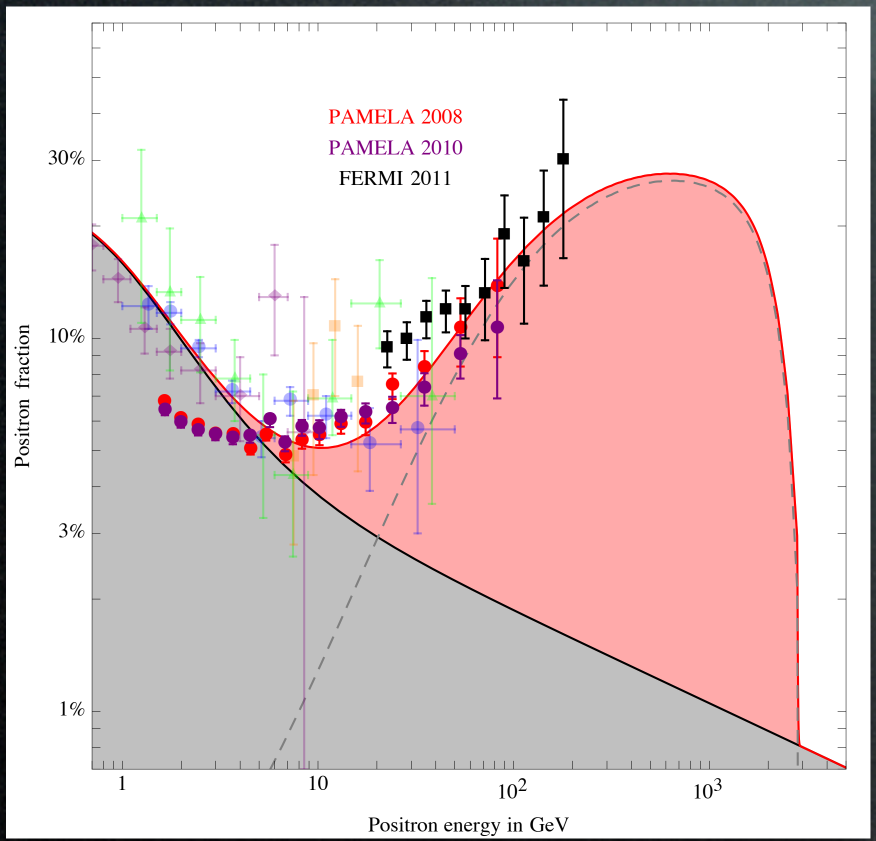
electrons + positrons



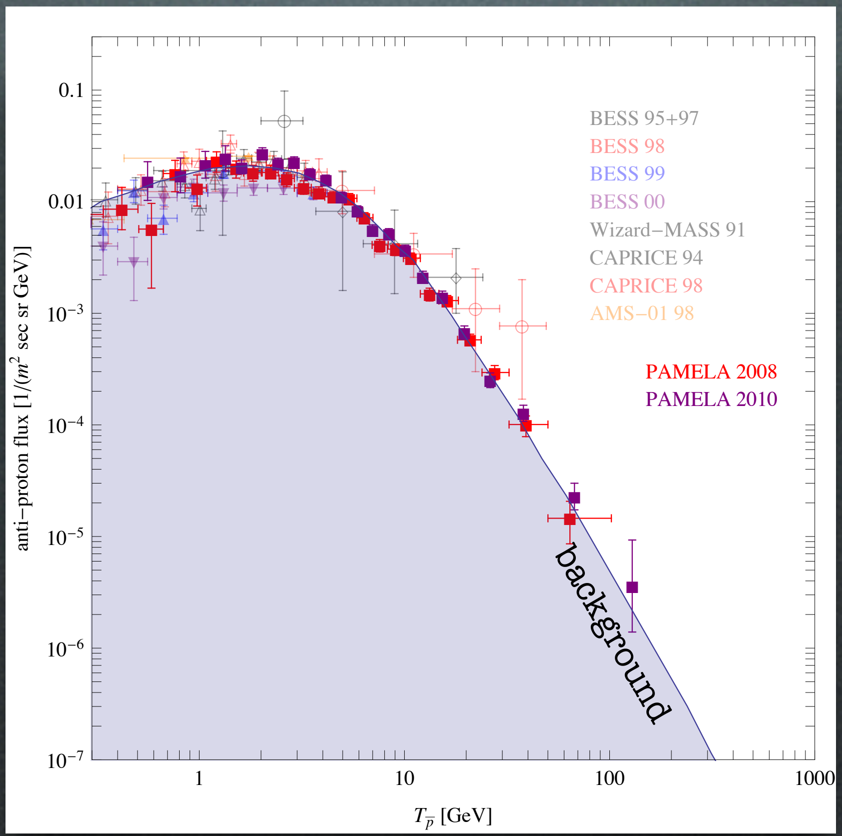
Are these signals of Dark Matter?

Positrons & Electrons

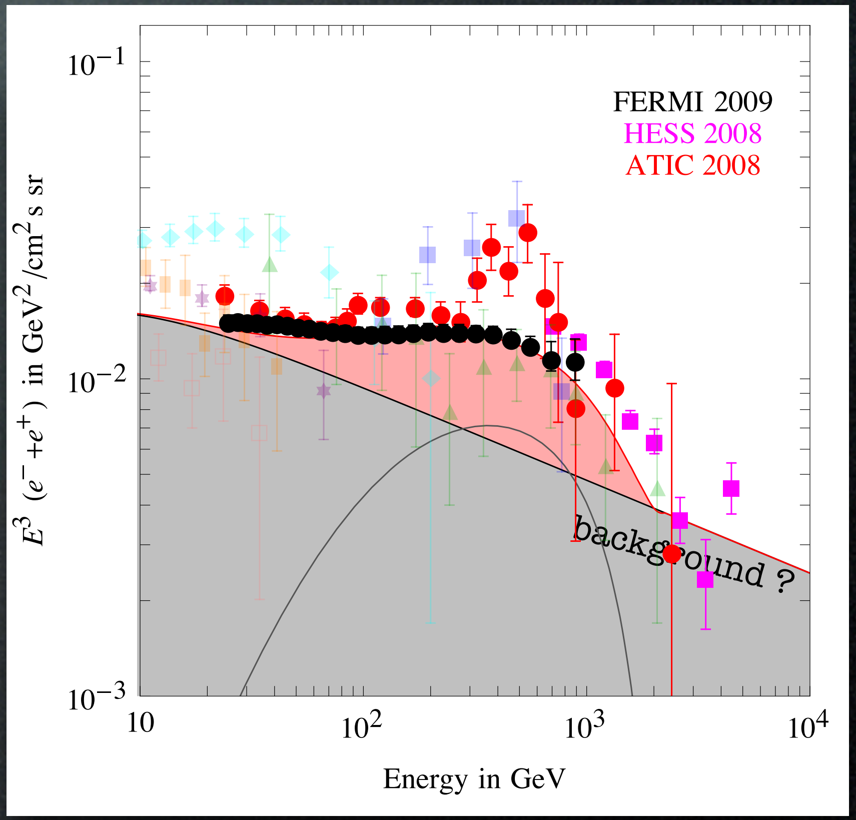
positron fraction



antiprotons



electrons + positrons

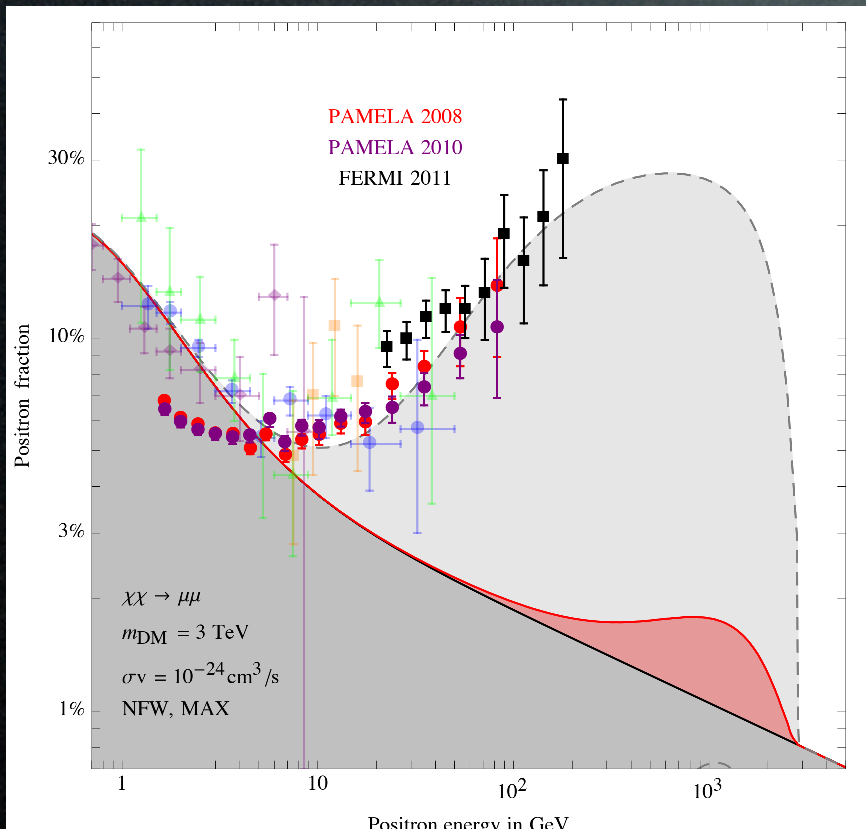


Are these signals of Dark Matter?

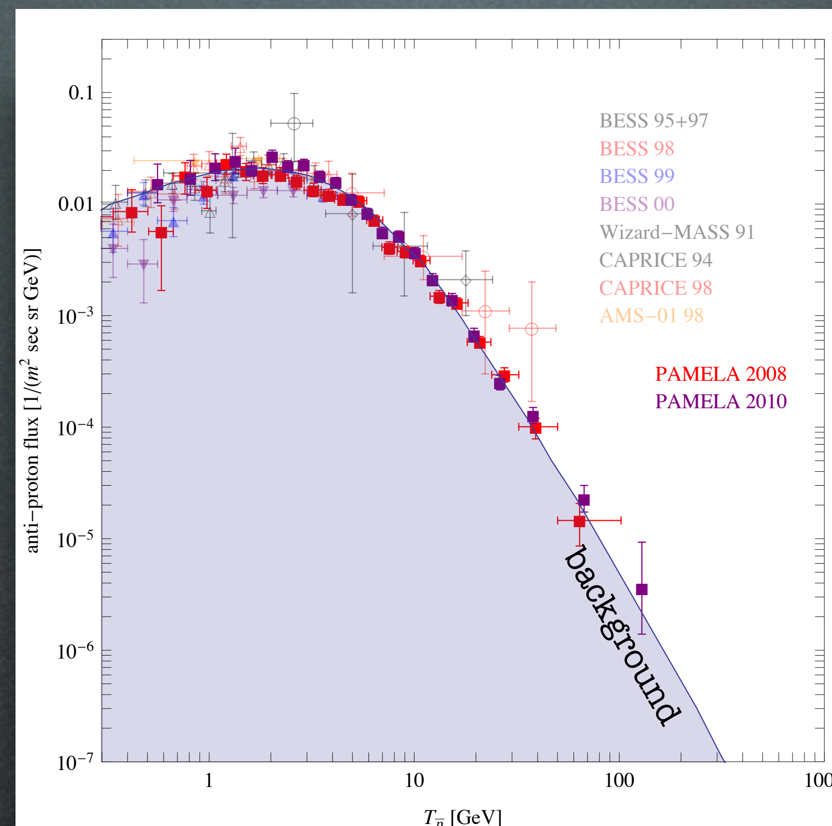
YES: few TeV, leptophilic DM
with huge $\langle \sigma v \rangle \approx 10^{-23}\,\mathrm{cm}^3/\mathrm{sec}$

Positrons & Electrons

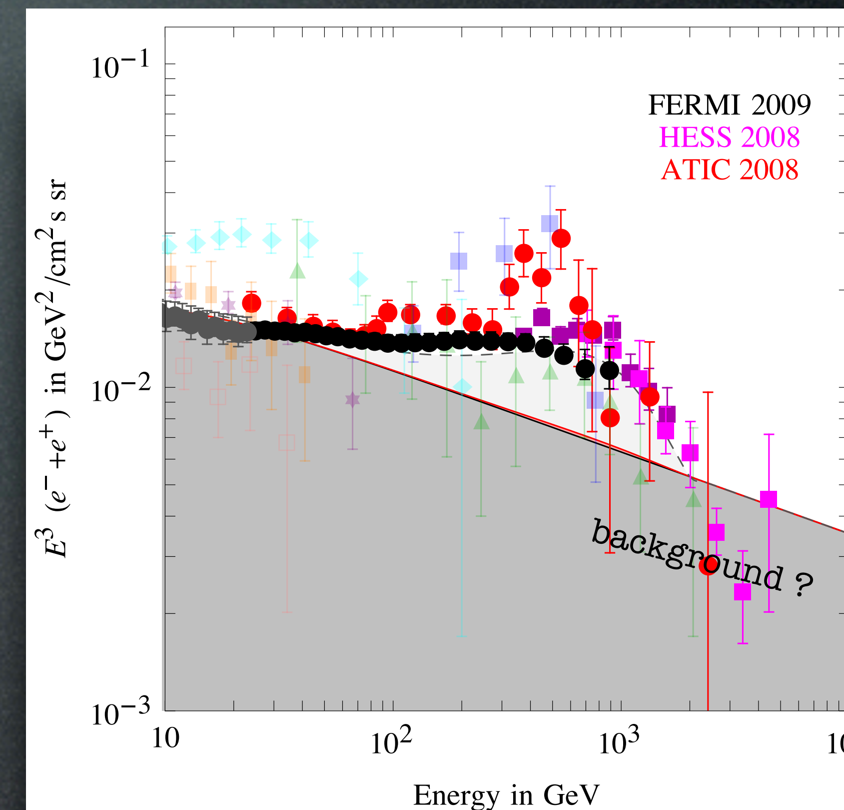
positron fraction



antiprotons



electrons + positrons

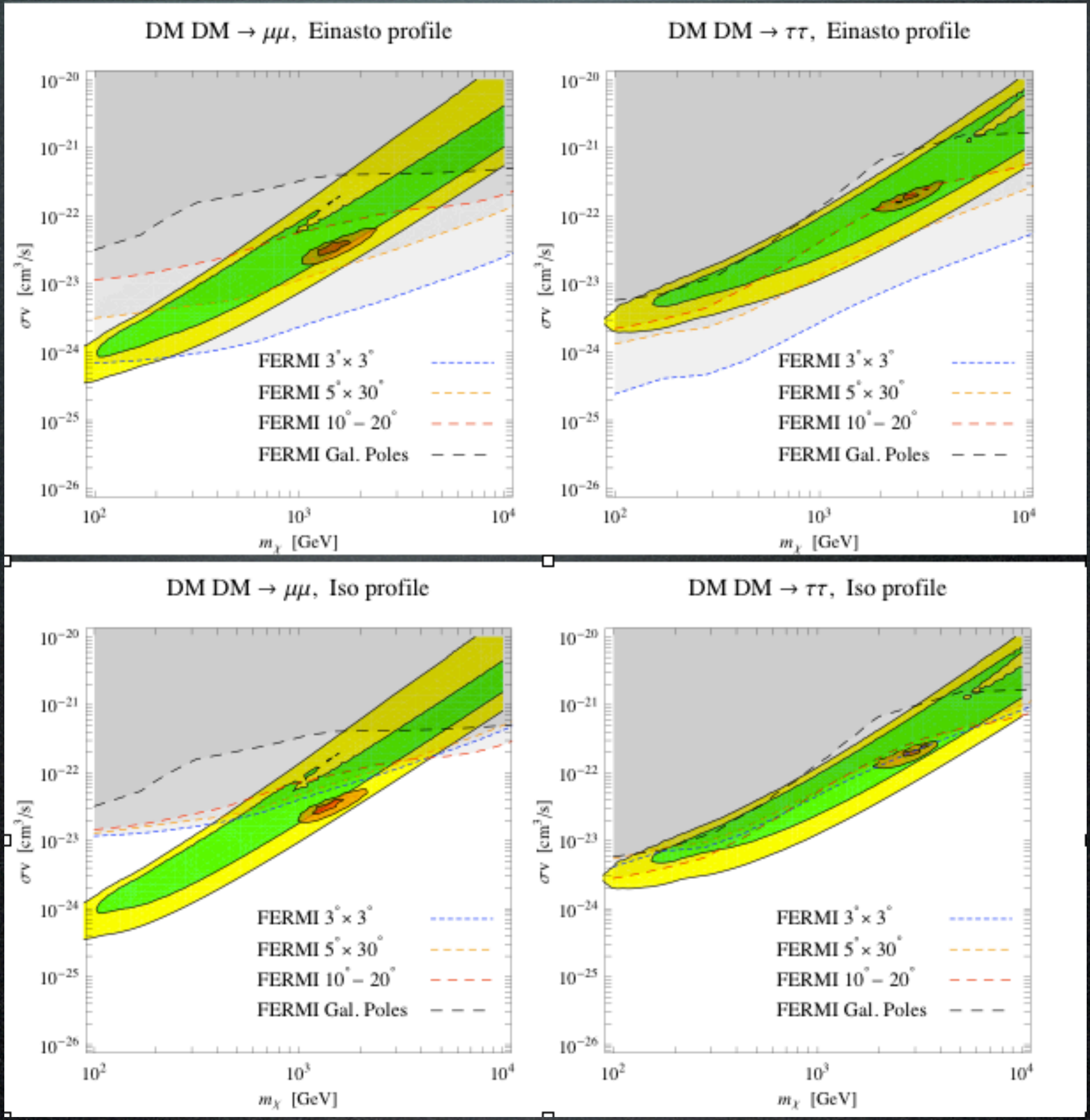


Are these signals of Dark Matter?

YES: few TeV, leptophilic DM
with huge $\langle \sigma v \rangle \approx 10^{-23}\ \text{cm}^3/\text{sec}$

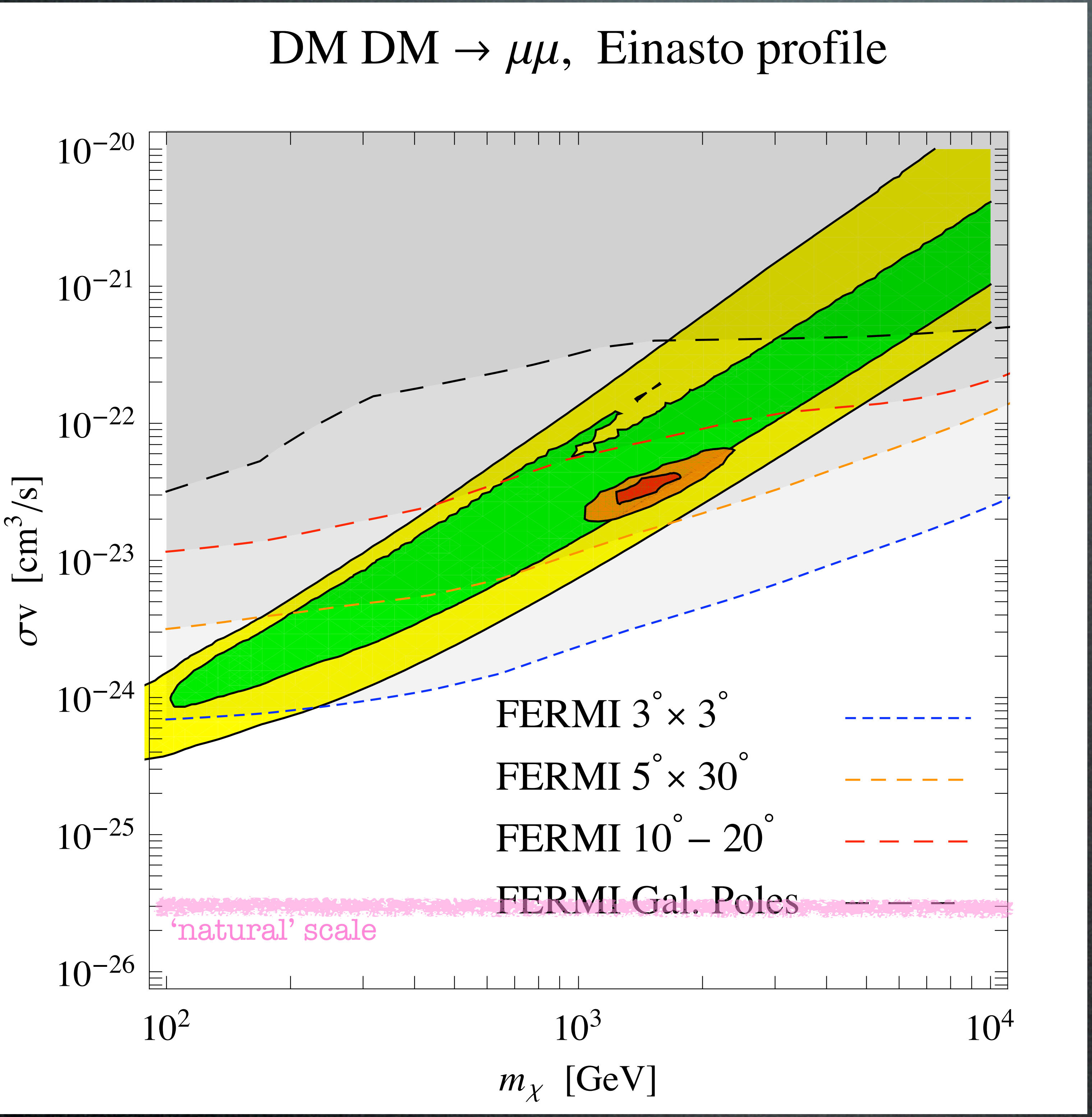
NO: a formidable ‘background’ for future searches

Positrons & Electrons



Gamma constraints

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

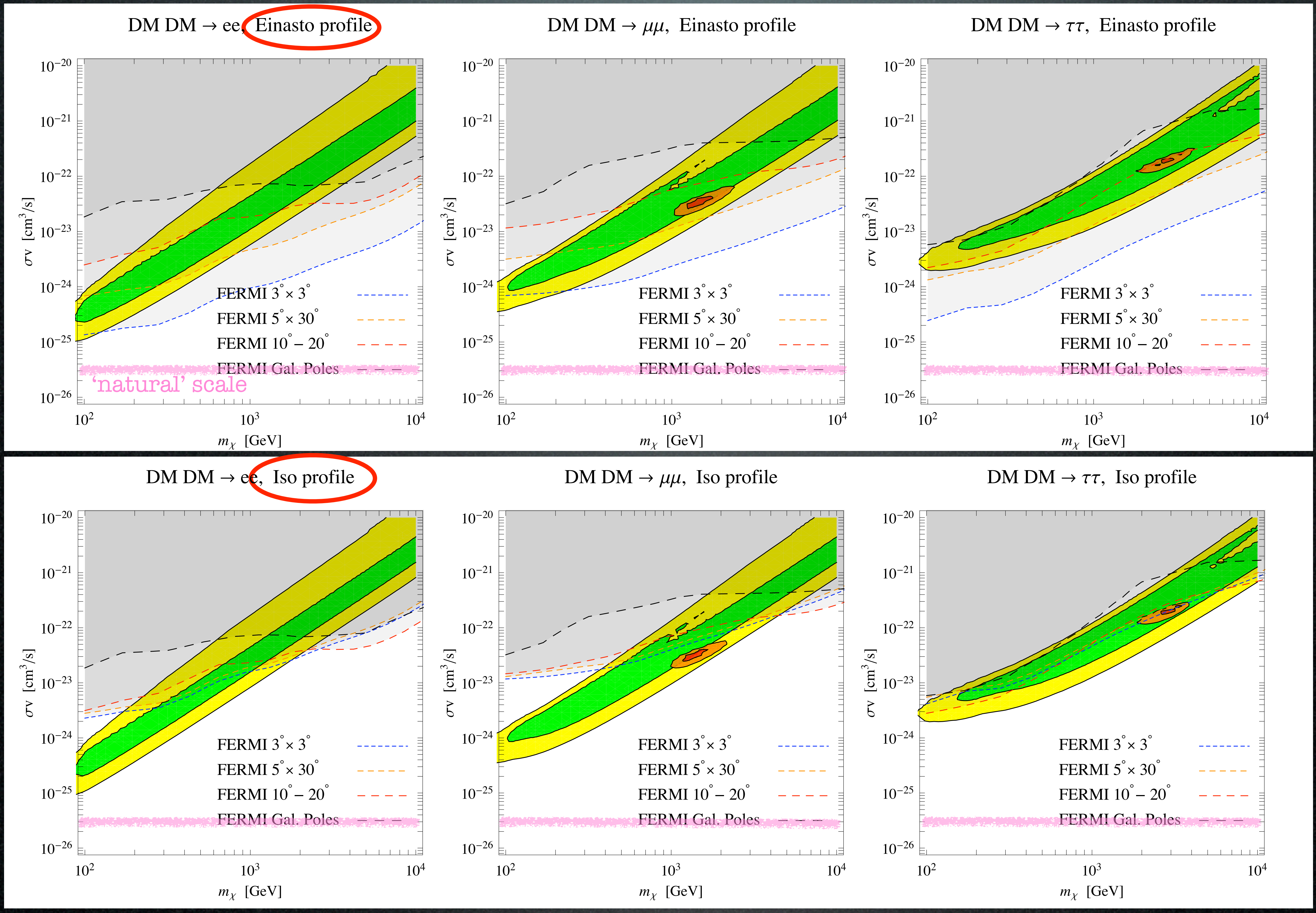


Cirelli, Panci, Serpico 0912.0663

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

Gamma constraints

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

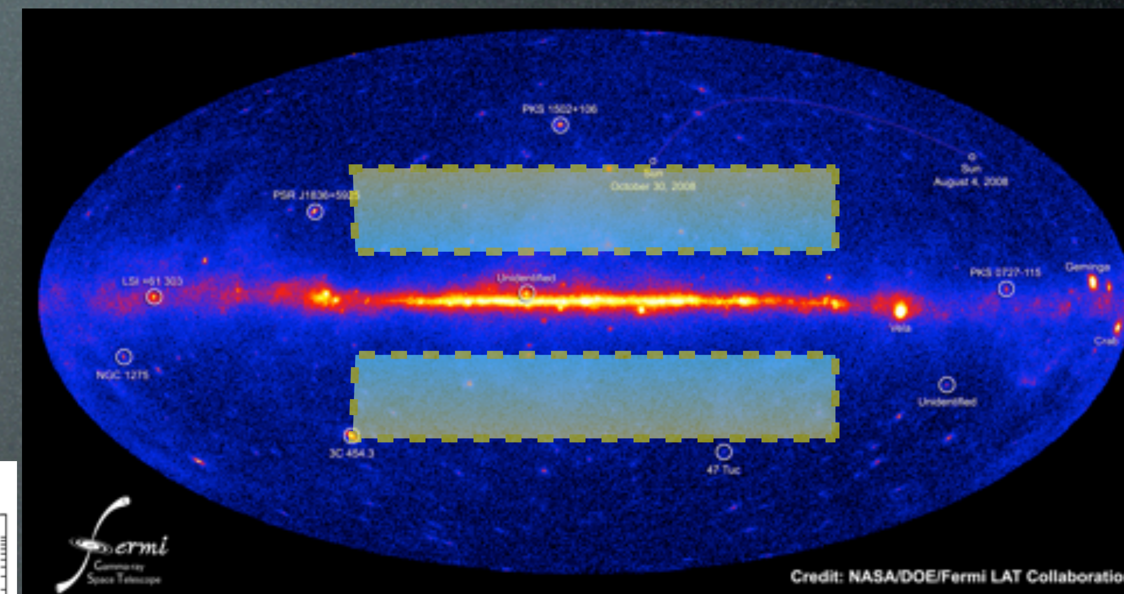


Cirelli, Panci, Serpico 0912.0663

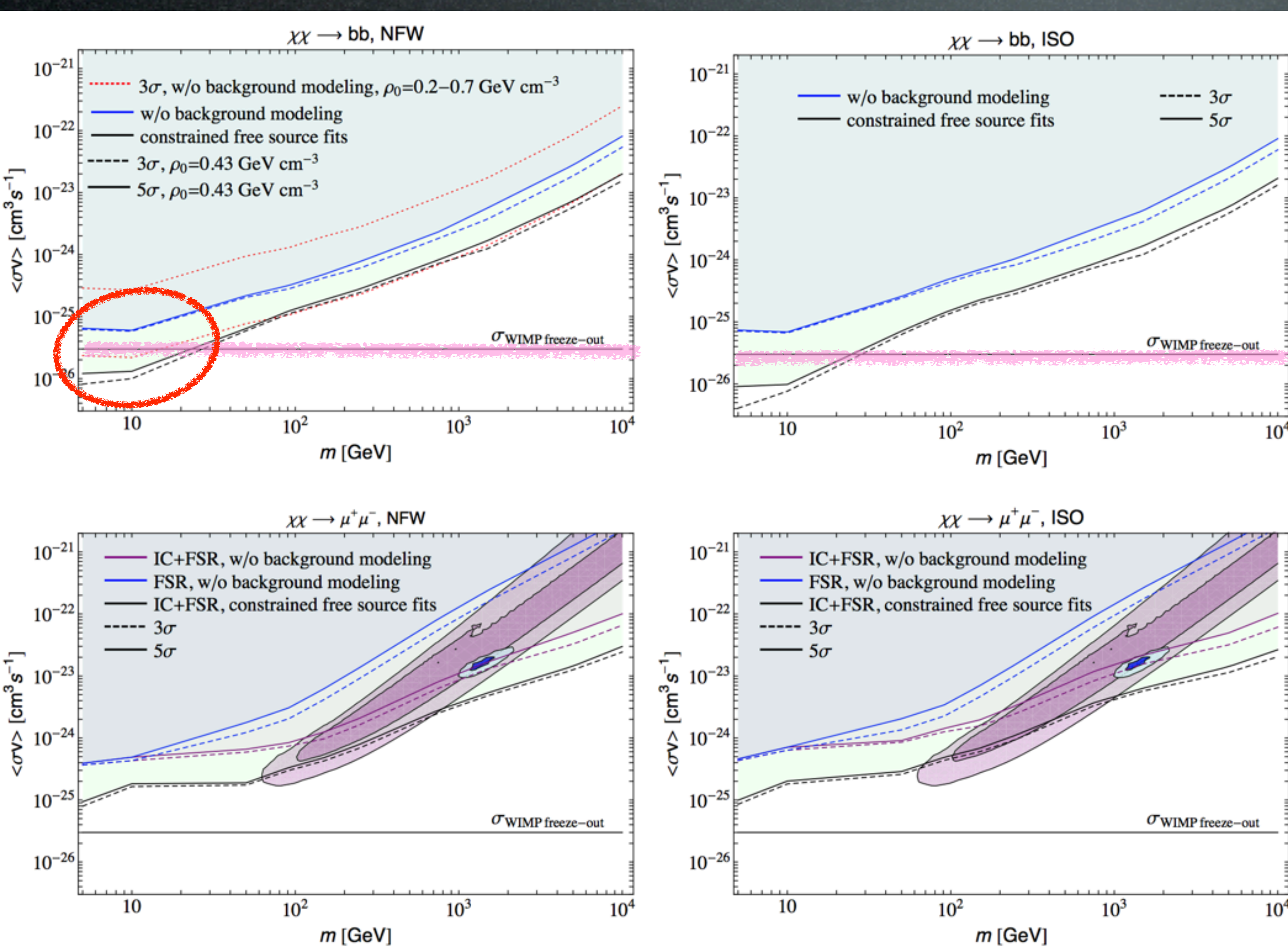
Gamma constraints

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

Theorist's reaction

Theorist's reaction

1. the 'PAMELA frenzy'

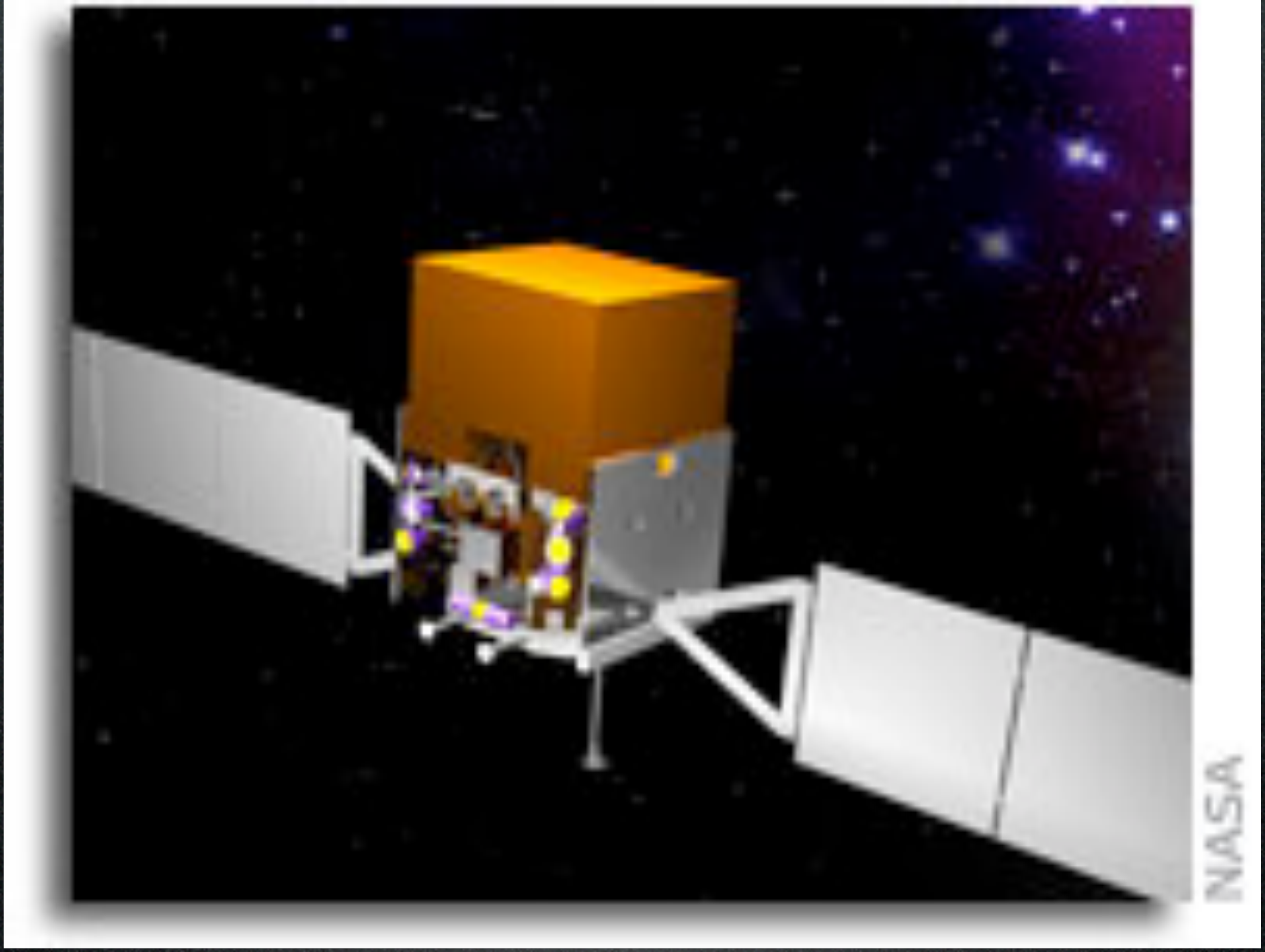
Challenges for the 'conventional' DM candidates

Needs:	**SuSy DM**	**KK DM**
- TeV or multi-TeV masses	difficult	ok
- no hadronic channels	difficult	difficult
- very large flux	no	ok

for any Majorana DM,
s-wave annihilation cross section

$$\sigma_{\rm ann}(\mathrm{DM}\,\bar{\mathrm{DM}} \to f\bar{f}) \propto \left(\frac{m_f}{M_{\rm DM}}\right)^2$$

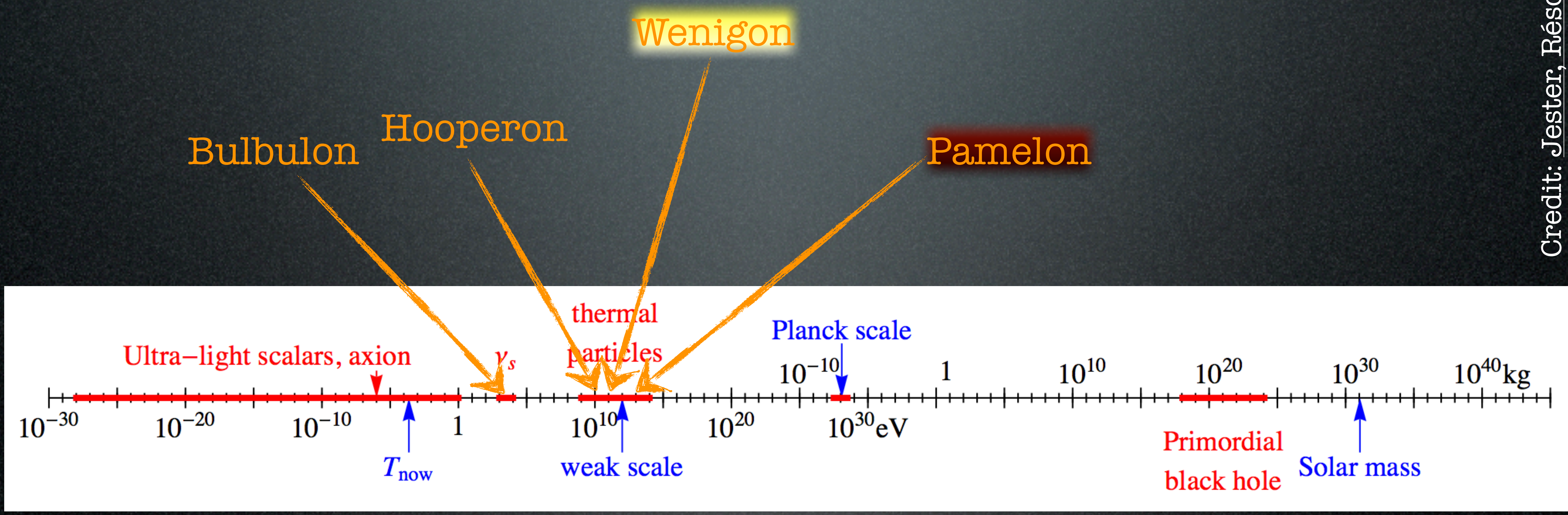
Gamma rays



2. the '130 GeV line'

DM Candidates

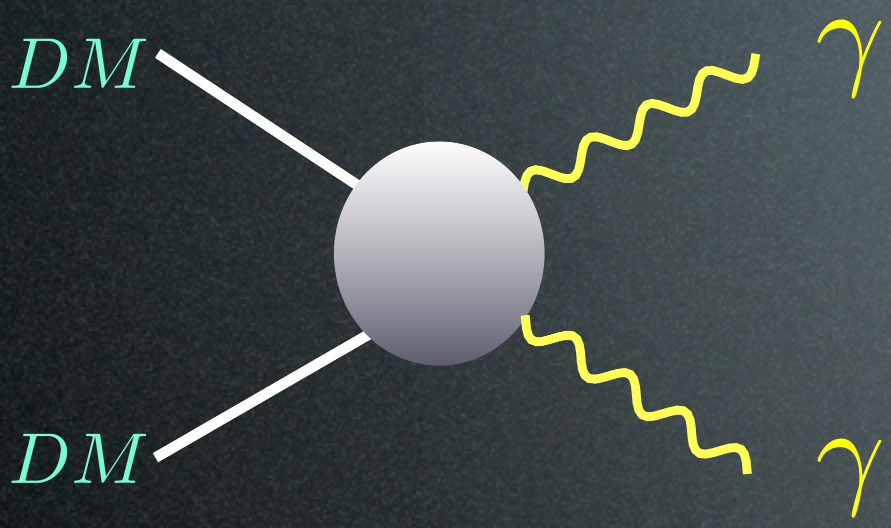
A matter of perspective: plausible mass ranges



Credit: Jester, Résonaances

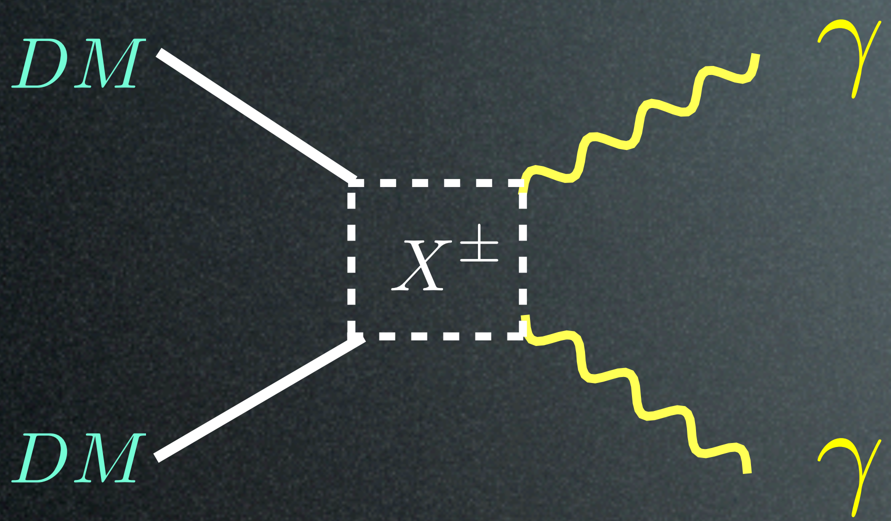
'only' 90 orders of magnitude!

Prompt emission: line(s)



primary
channels

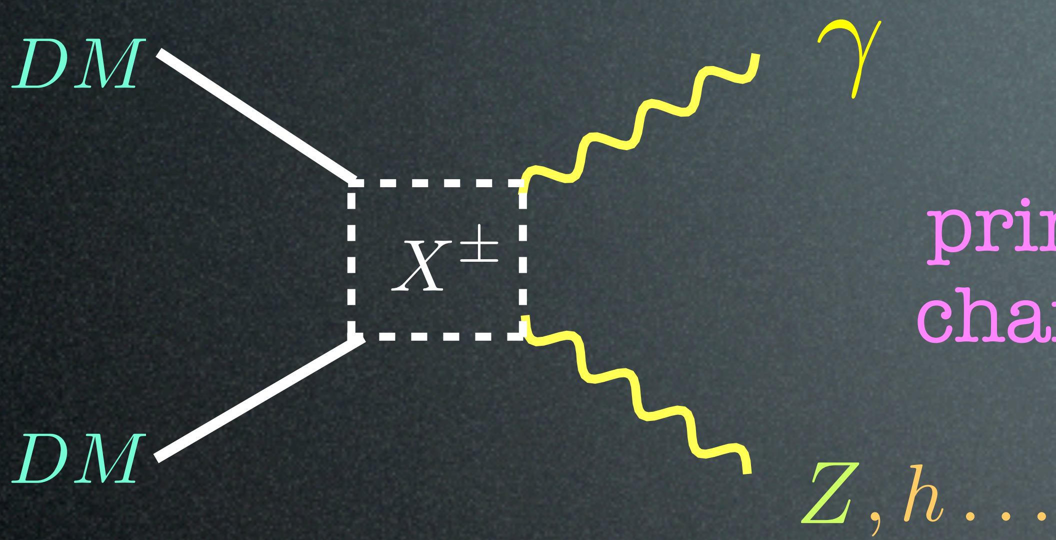
Prompt emission: line(s)



primary channels

$$E_\gamma = m_{\rm DM}$$

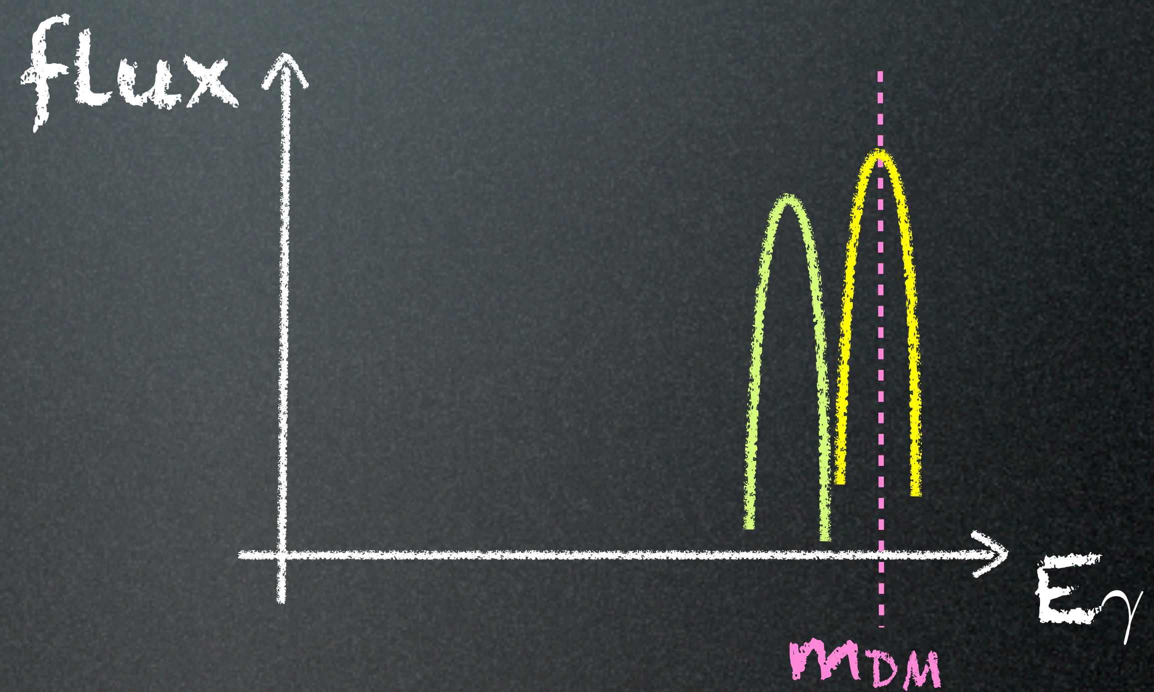
Prompt emission: line(s)



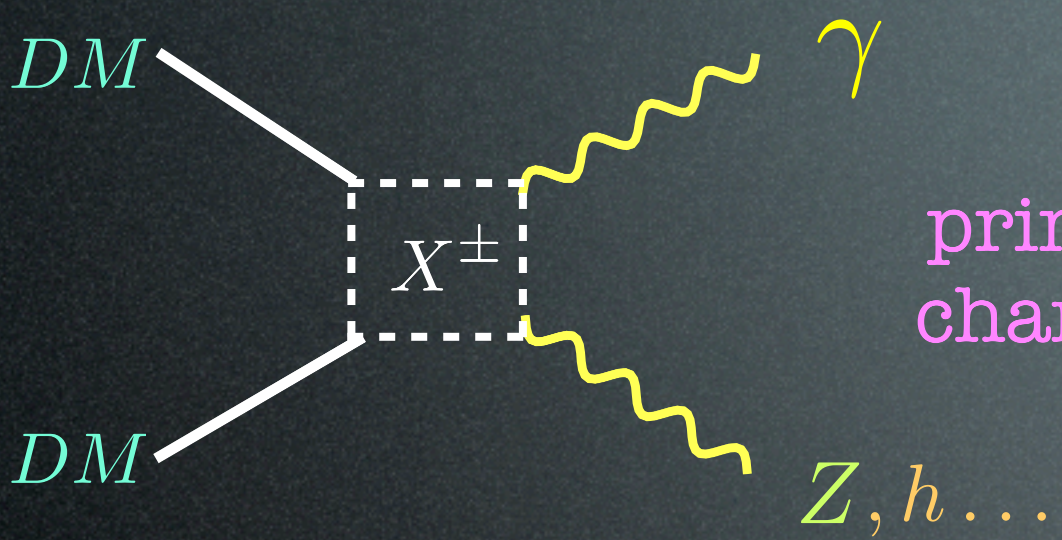
primary channels

$$E_\gamma = m_{\rm DM}$$

$$E_\gamma = m_{\rm DM}\left(1 - \frac{m_Z^2}{4\,m_{\rm DM}^2}\right)$$



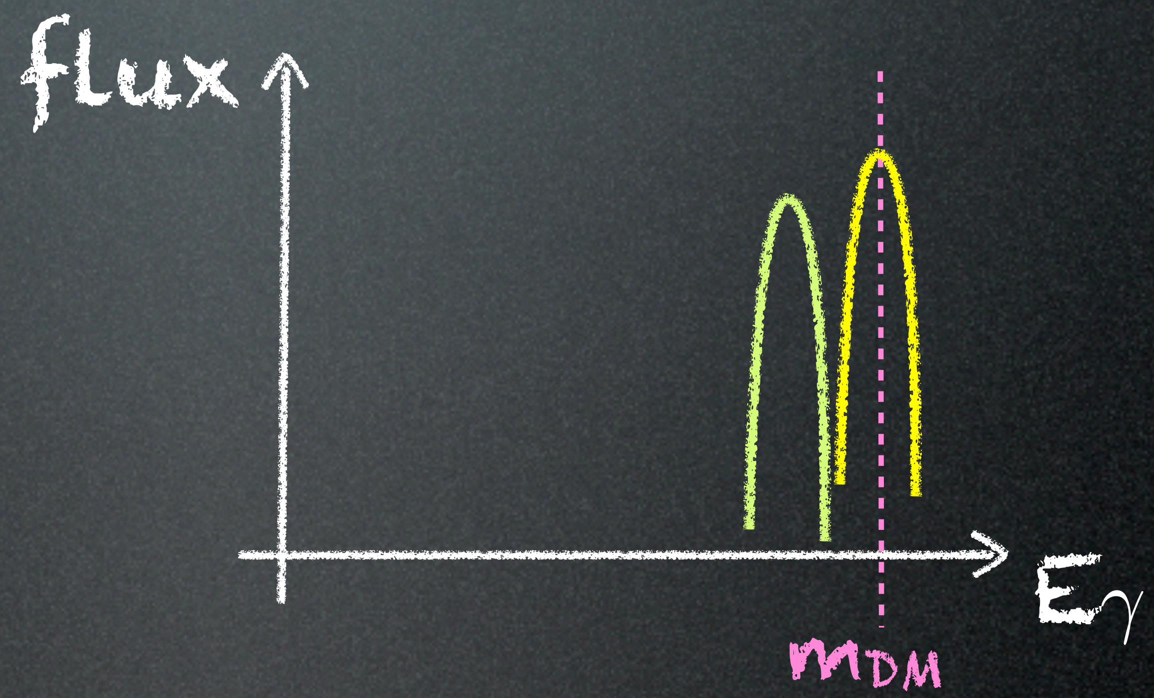
Prompt emission: line(s)



primary channels

$$E_\gamma = m_{\rm DM}$$

$$E_\gamma = m_{\rm DM}\left(1 - \frac{m_Z^2}{4\,m_{\rm DM}^2}\right)$$



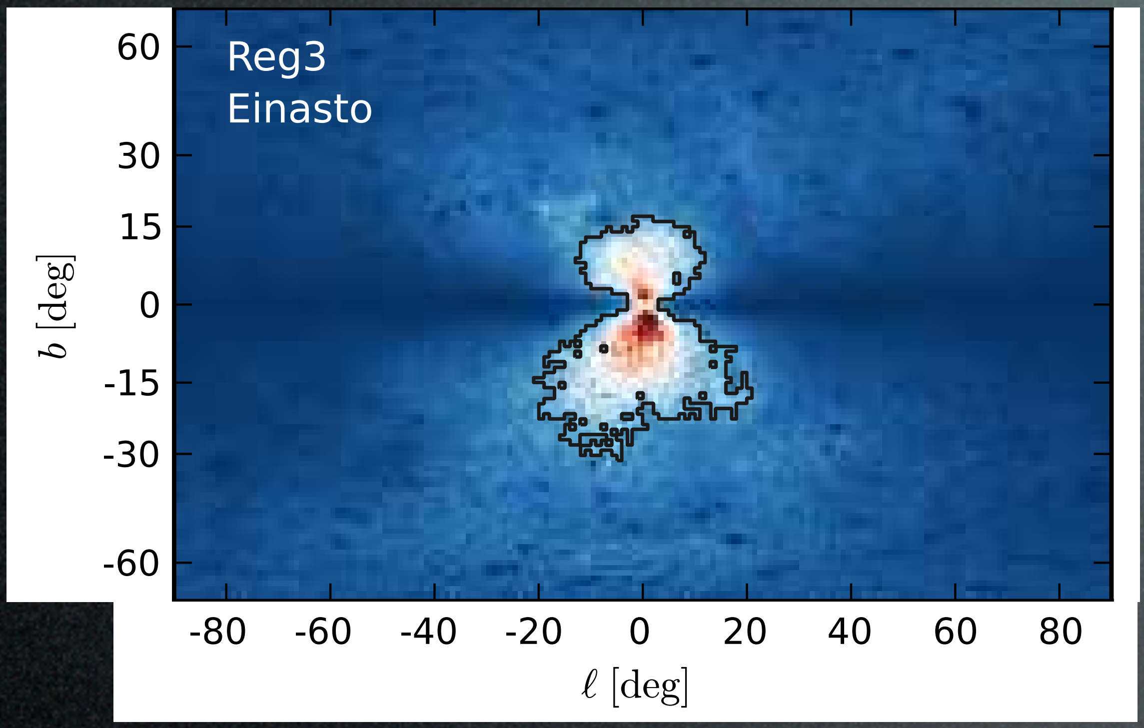
So what are the particle physics parameters?

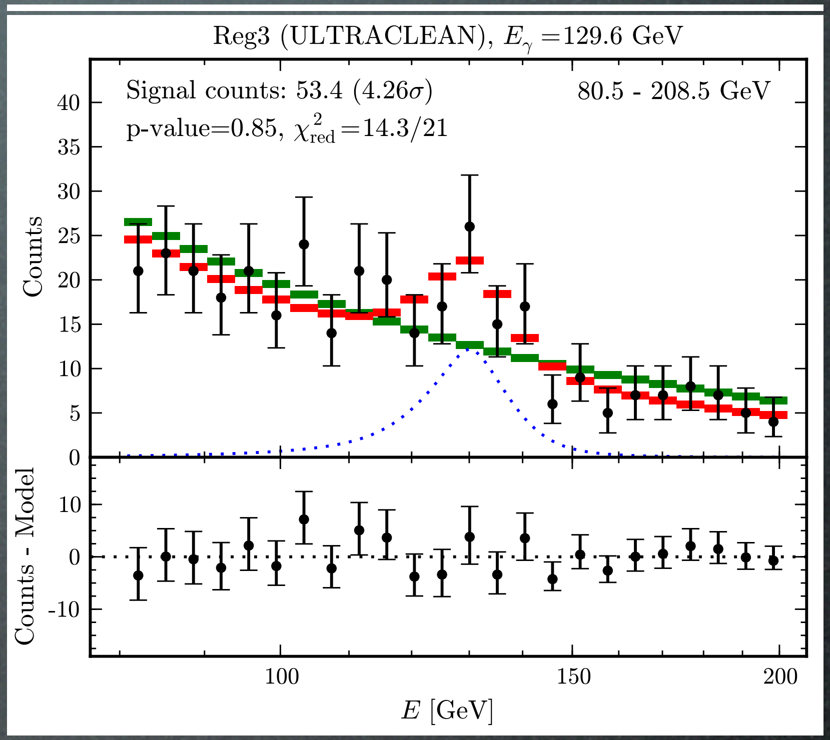
1. Dark Matter mass

2. annihilation cross section $\sigma_{\rm ann}$

Fermi 130 GeV line

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





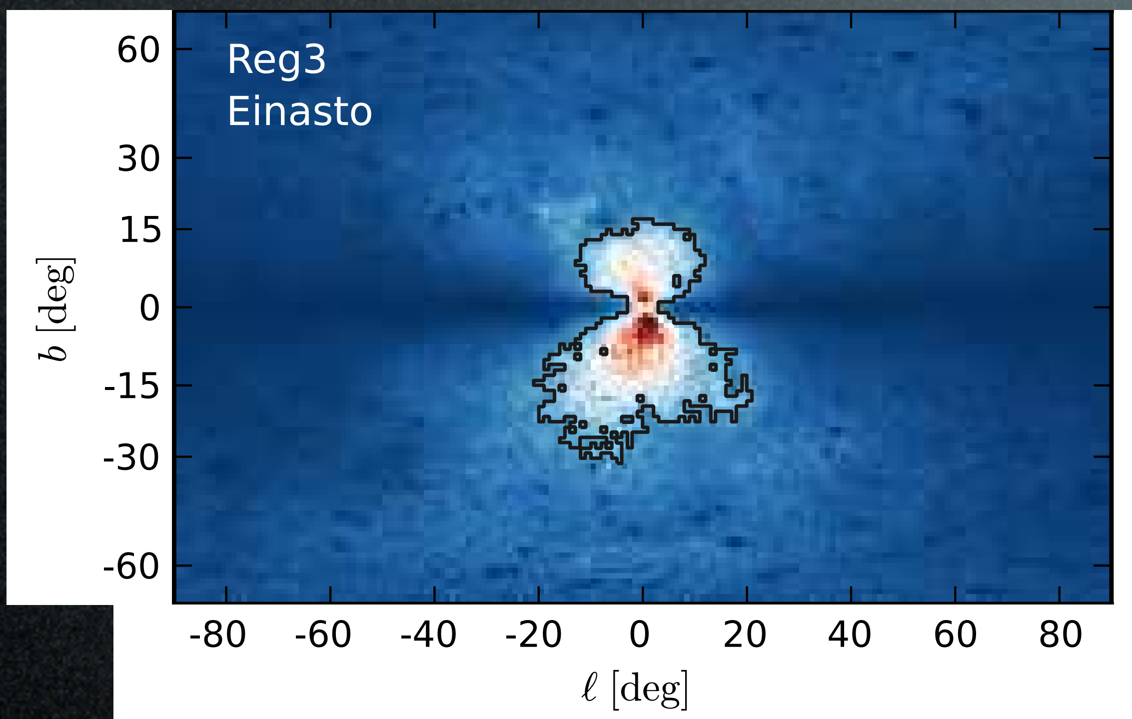
Ch. Weniger, 1204.2797

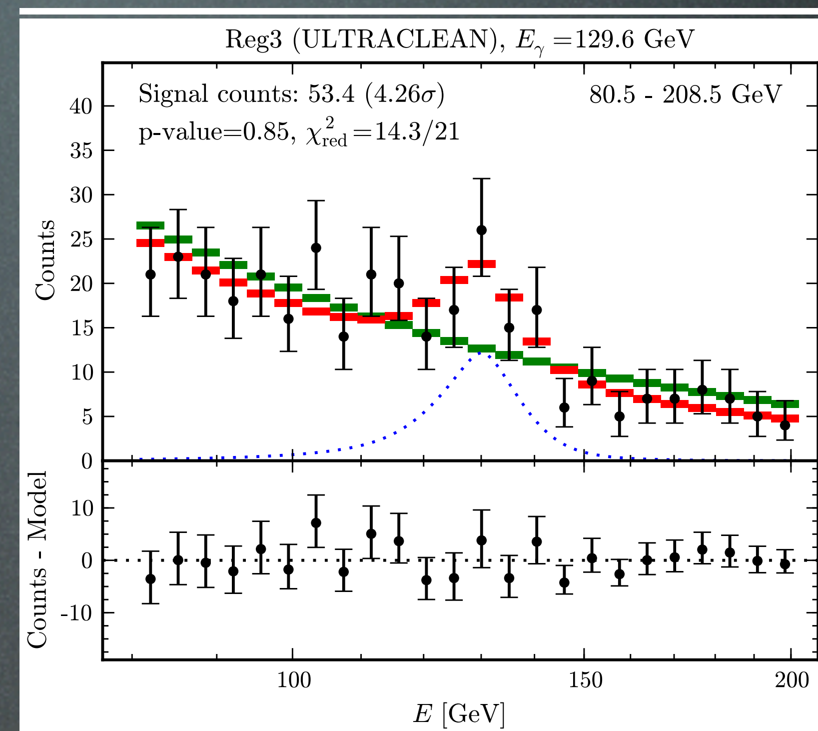
4.6σ (3.3σ with LEE)

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

Fermi 130 GeV line

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



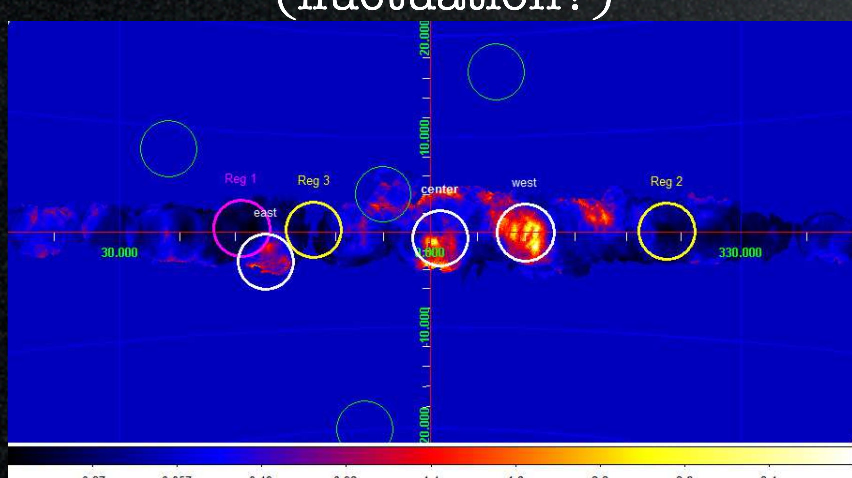


Ch. Weniger, 1204.2797

4.6σ (3.3σ with LEE)

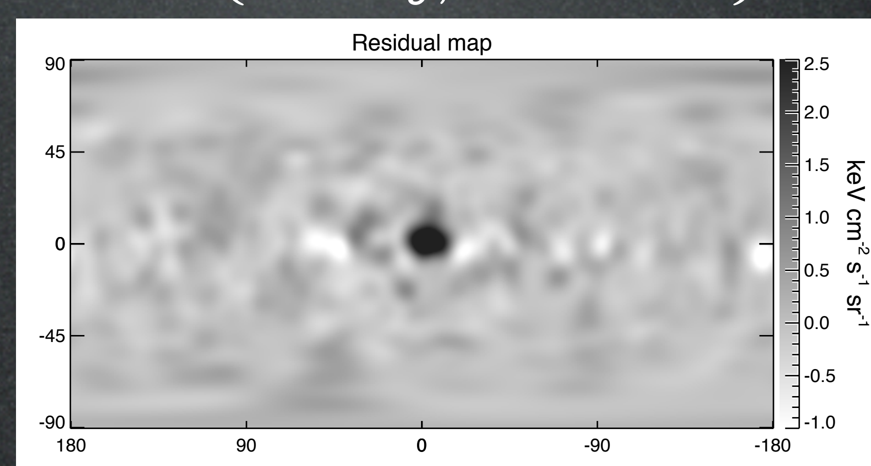
$\langle \sigma v \rangle_{\chi\chi \to \gamma\gamma} \simeq 1.3 \cdot 10^{-27} \mathrm{cm}^3/\mathrm{s}$ (large!)

Similar excesses found elsewhere (fluctuation?)



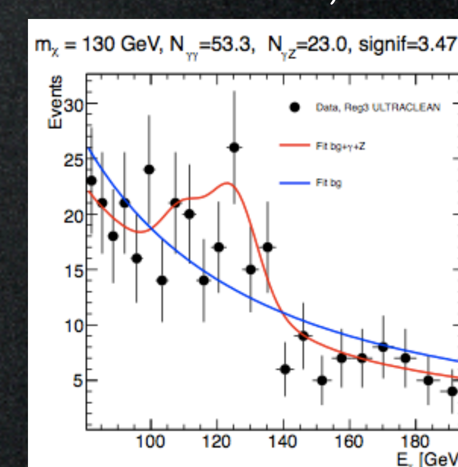
Boyarsky, Malyshev, Ruchayskyi, 1205.4700

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



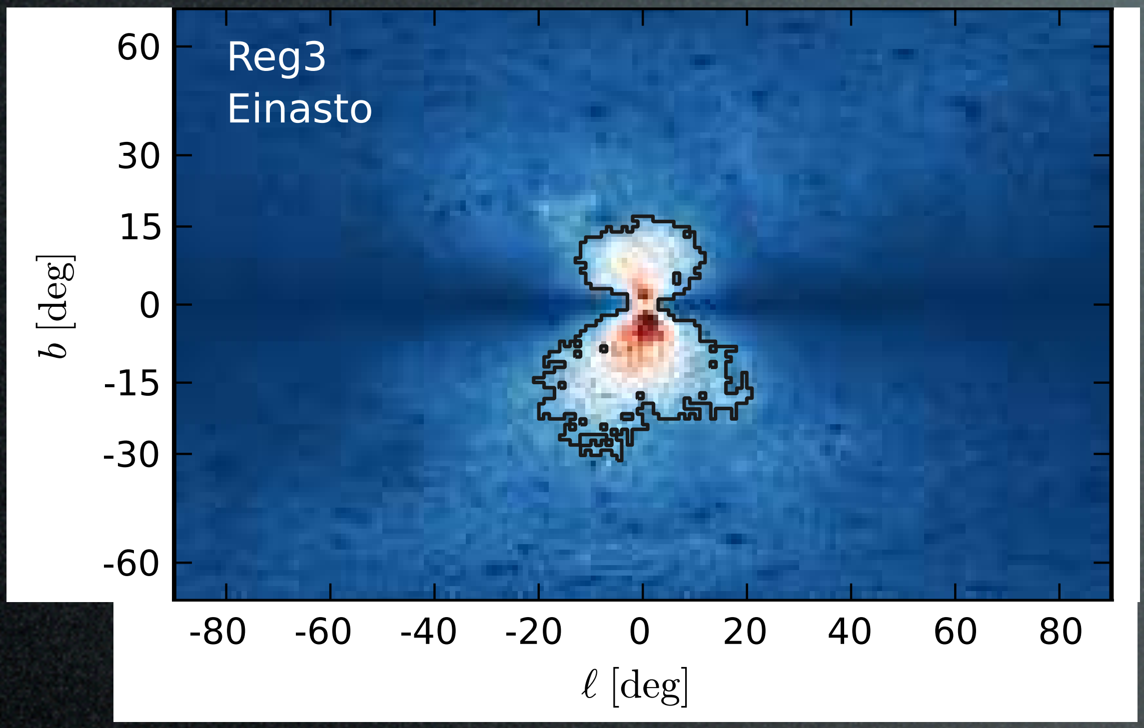
Rajaraman, Tait, Whiteson 1205.4723

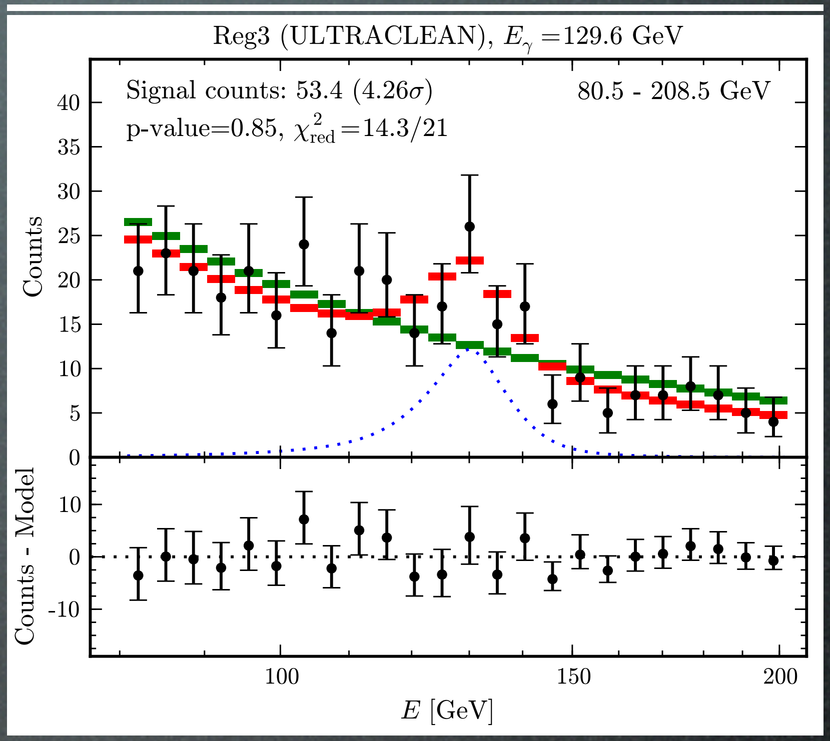
Su, Finkbeiner 1206.1616

Su Finkbeiner 1207.7060

Fermi 130 GeV line

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



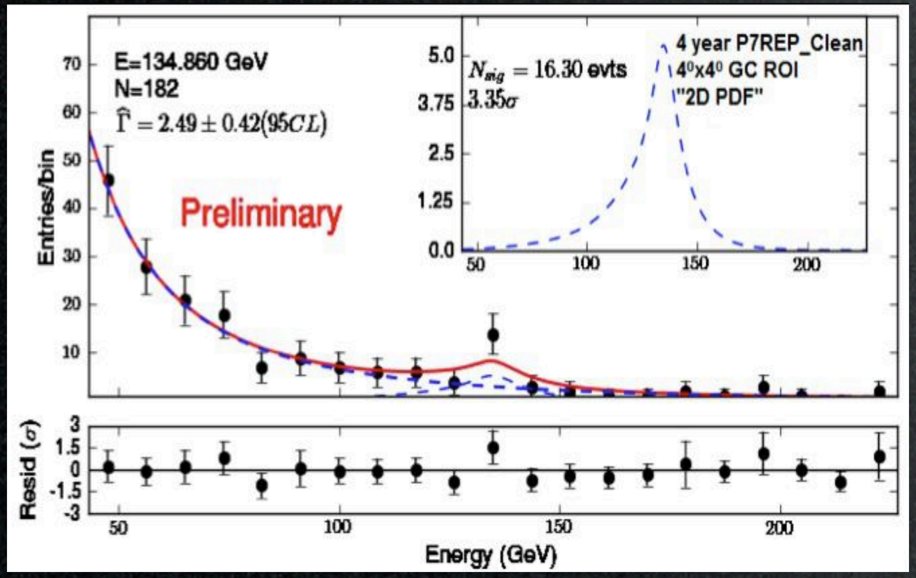


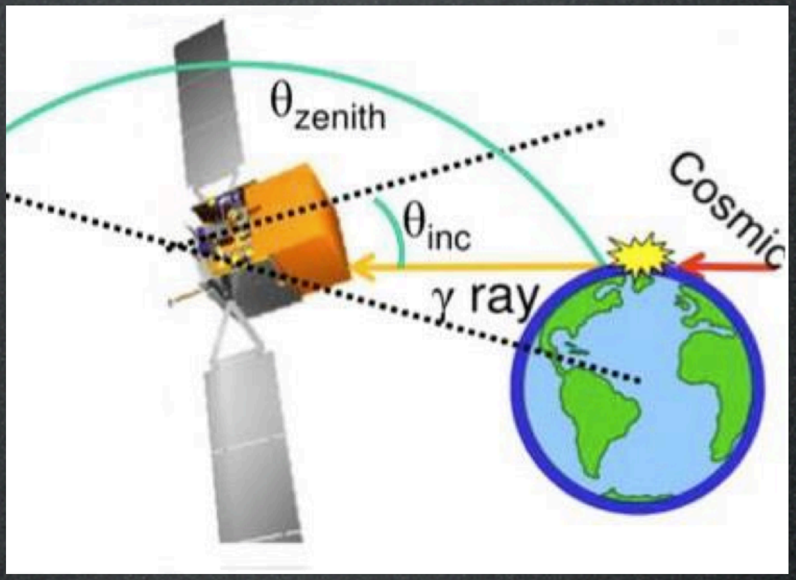
Ch. Weniger, 1204.2797

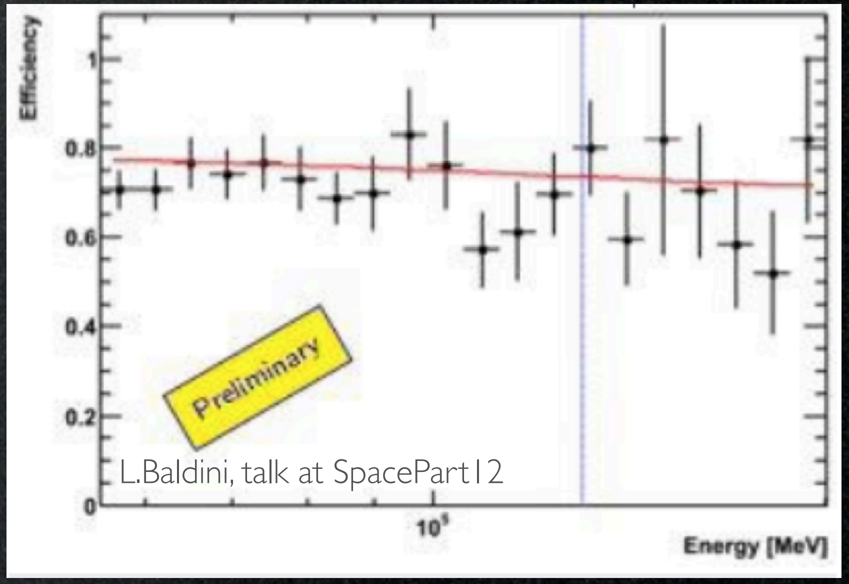
4.6σ (3.3σ with LEE)

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

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

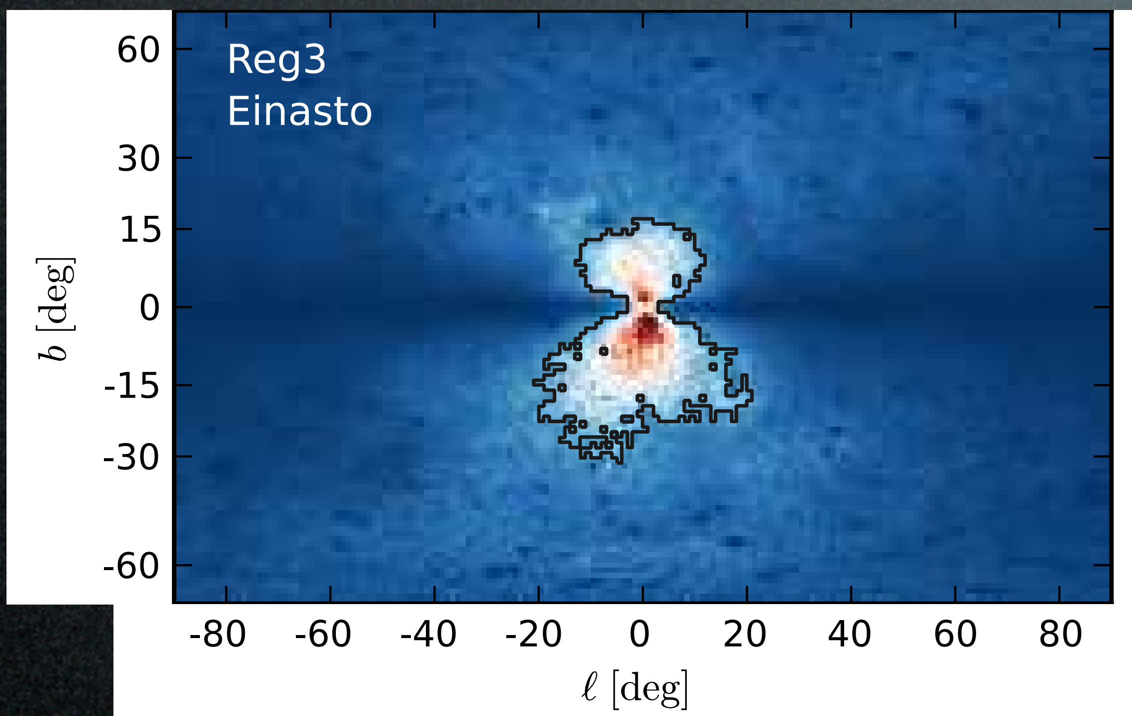


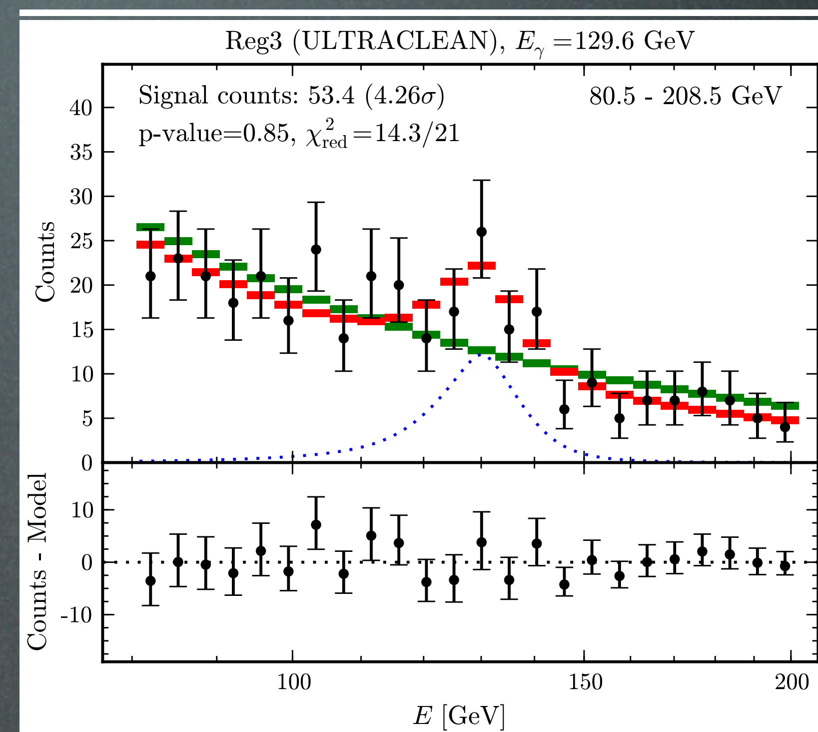




Fermi 130 GeV line

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



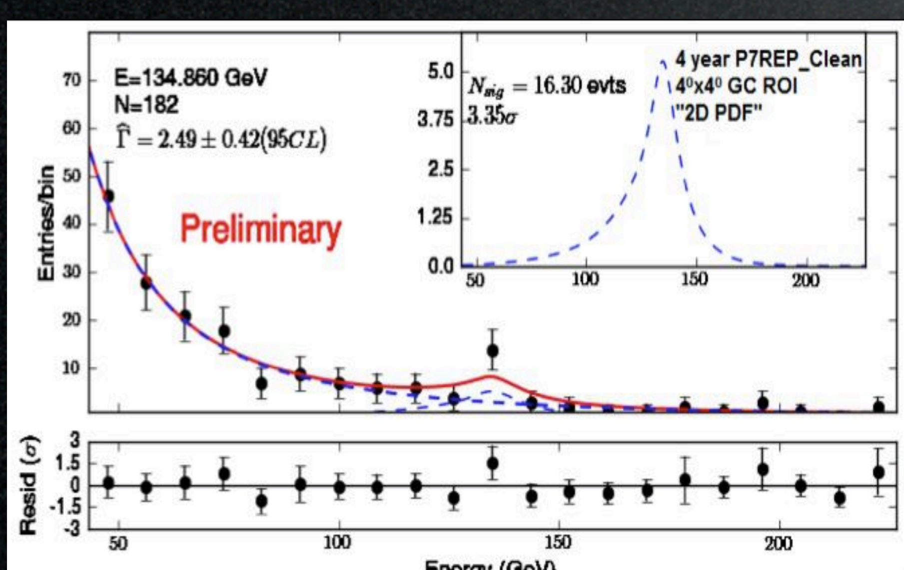


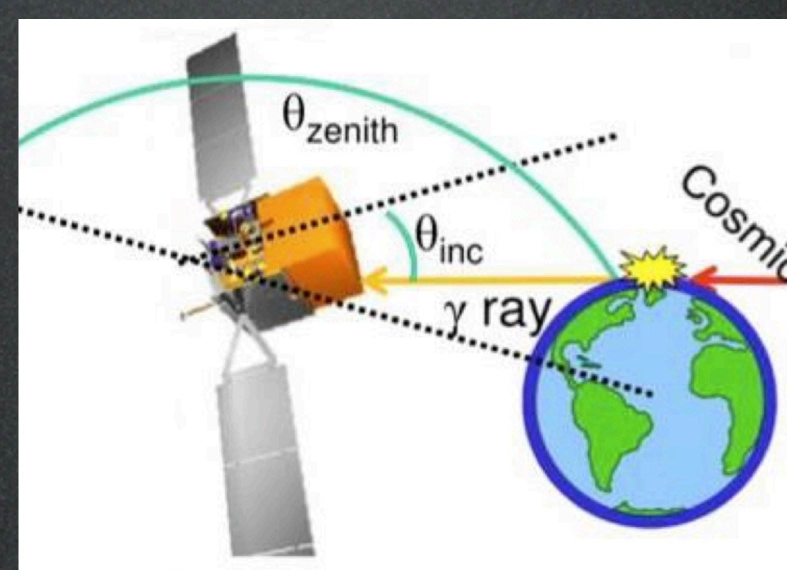
Ch. Weniger, 1204.2797

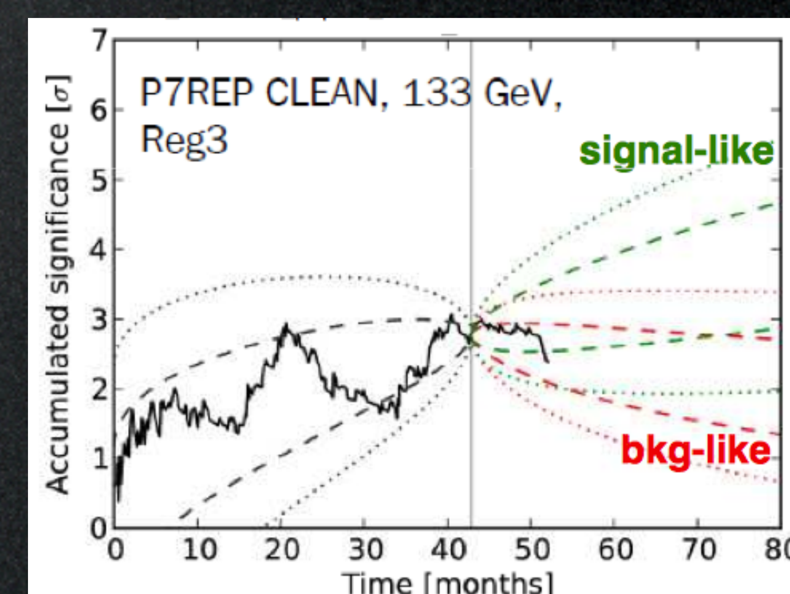
4.6σ (3.3σ with LEE)

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

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







Theorist's reaction

2. the '130 GeV line' frenzy

It's 'easy' to make a line:
any 2-body final state
with at least one γ. But:

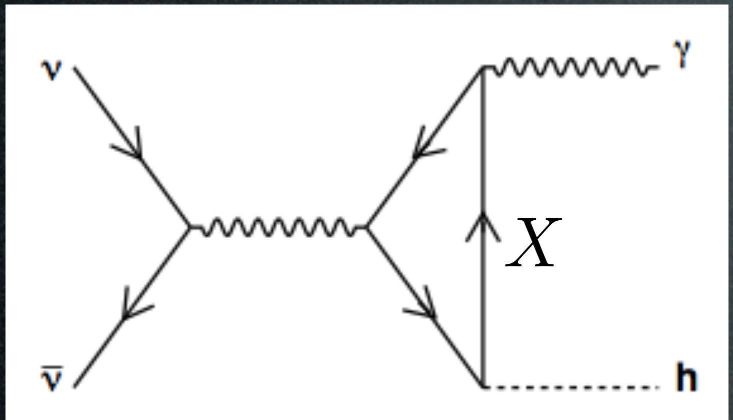
Challenges

DM is neutral: need '*something*' to couple to γ

Challenges

DM is neutral: need 'something' to couple to γ

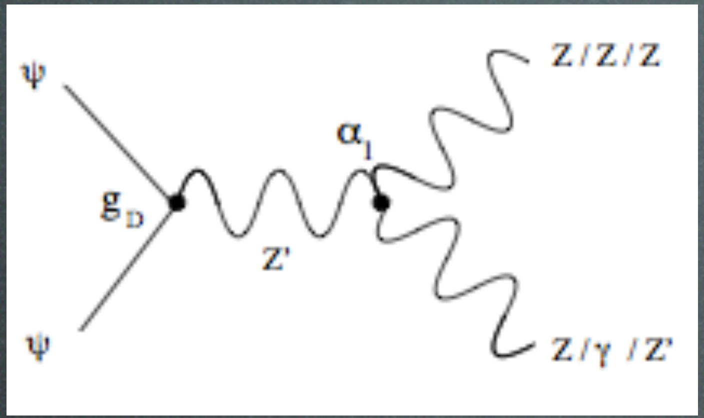
a loop



'Higgs in space!' 0912.0004
Kyae, Park 1205.4151
Cline 1205.2688

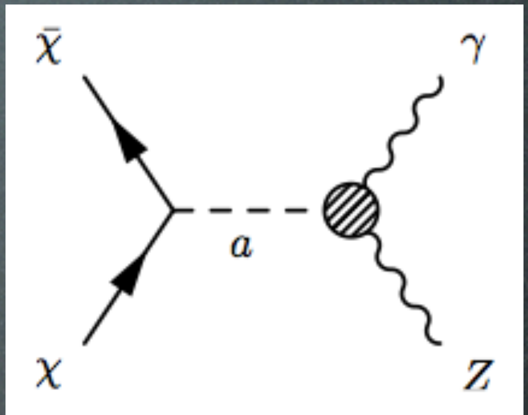
$X \in$ SM
MSSM
dark sector...

Chern-Simons



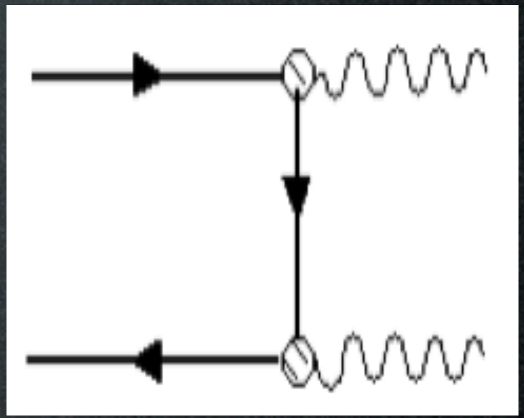
Dudas et al., 1205.1520

axions



Lee & Park[2] 1205.4675

magn dipole

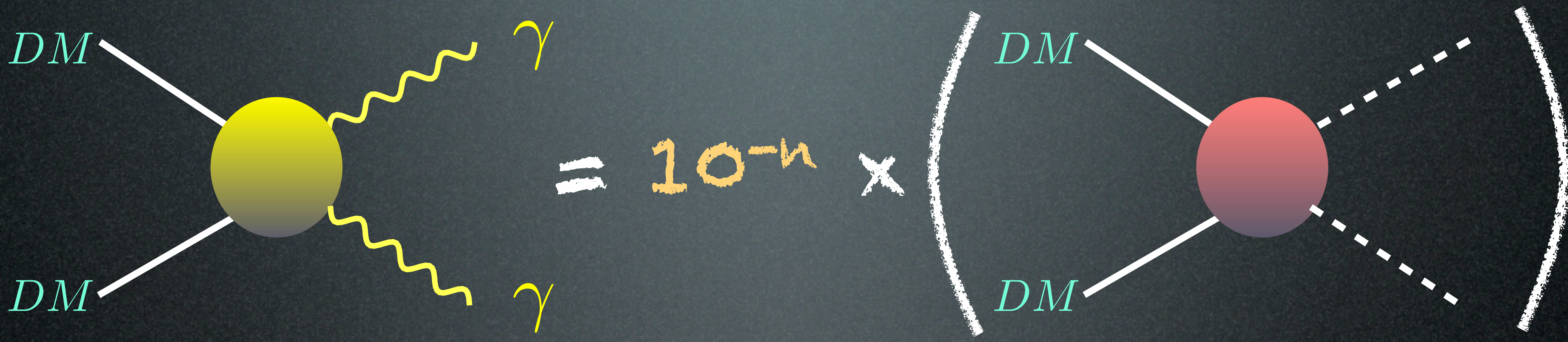


Heo, Kim 1207.1341

...

Challenges

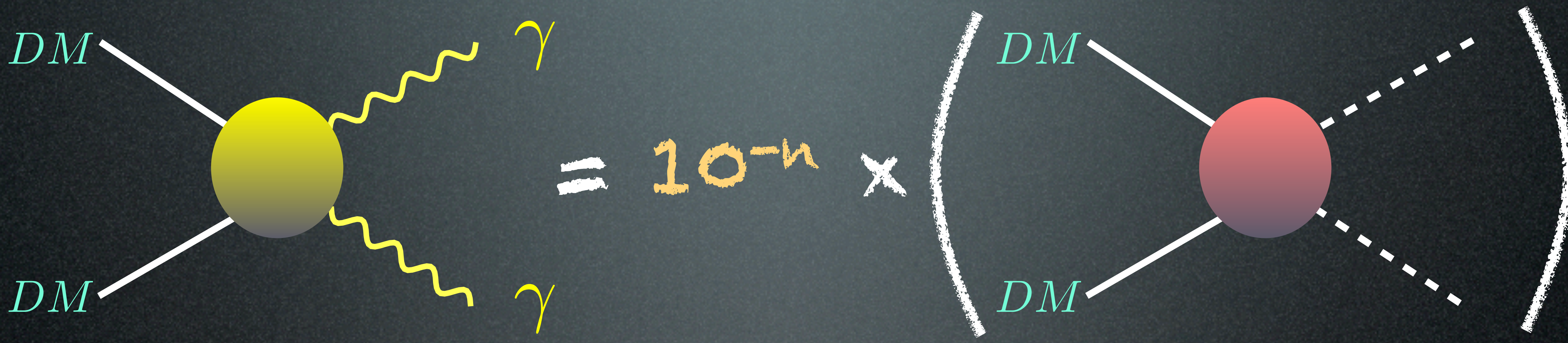
DM is neutral: need 'something' to couple to γ



The 'something' implies usually a suppression,

Challenges

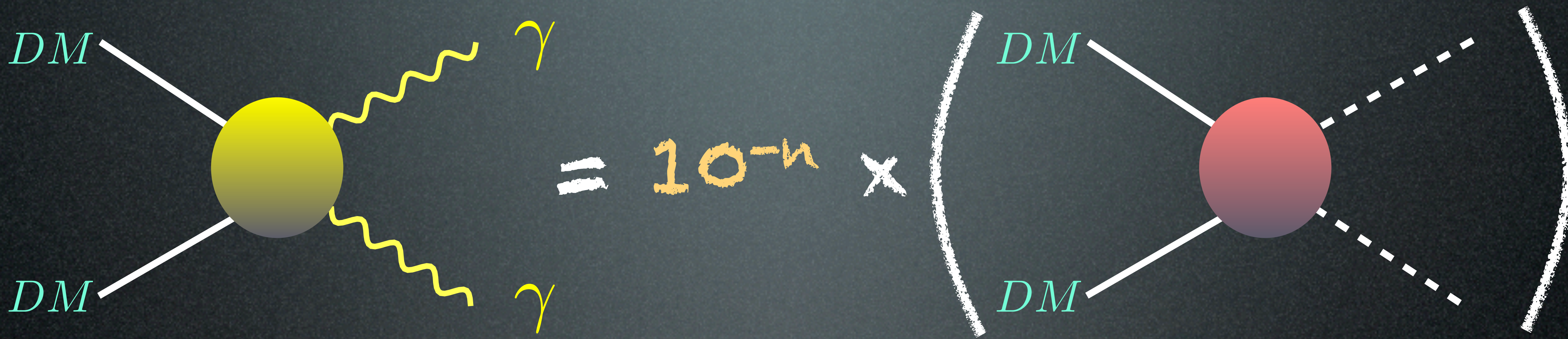
DM is <u>neutral</u>: need ‘something’ to couple to γ



The ‘something’ implies usually a suppression,
but one needs a large $\gamma\gamma$ cross section (o(10^{-27} cm^3/s))

Challenges

DM is neutral: need 'something' to couple to γ



The 'something' implies usually a suppression, but one needs a large $\gamma\gamma$ cross section (o(10^{-27} cm^3/s))

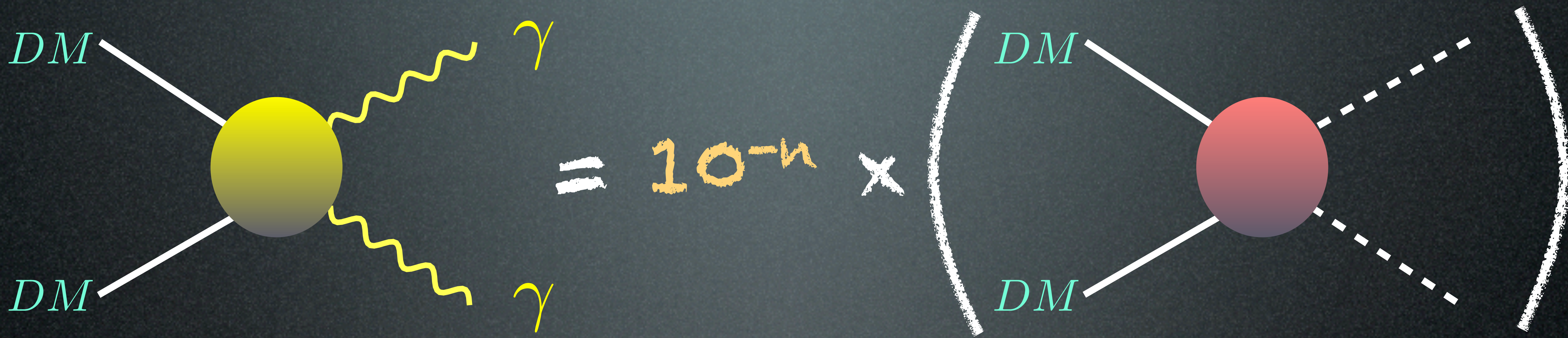
so the corresponding unsuppressed processes are **too** large:

- may overshoot other observations
- too large annihilation in the EU

Buchmuller, Garny 1206.7056
Cohen et al. 1207.0800
Cholis, Tavakoli, Ullio 1207.1468
Huang et al. 1208.0267

Challenges

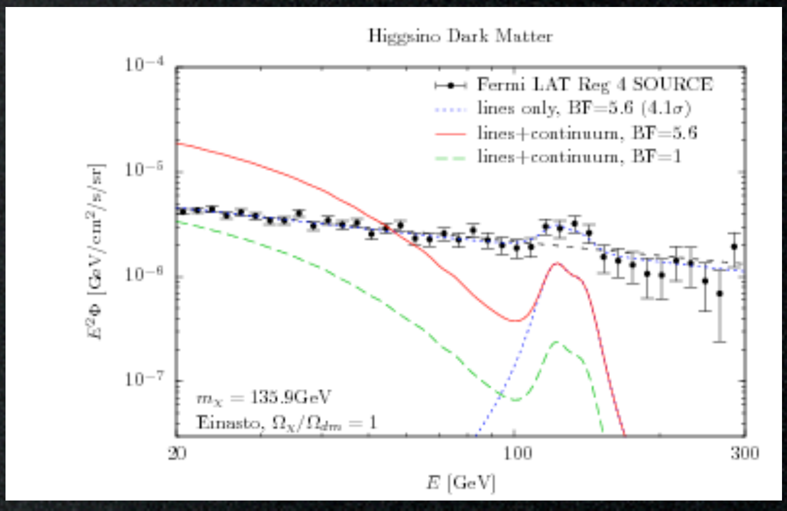
DM is neutral: need 'something' to couple to γ



The 'something' implies usually a suppression,
but one needs a large $\gamma\gamma$ cross section (o(10^{-27} cm^3/s))

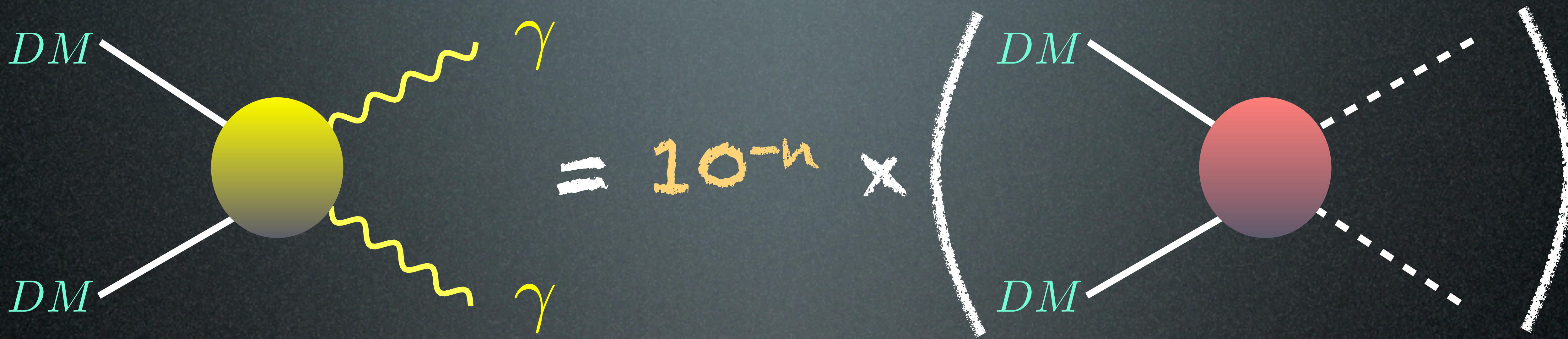
so the corresponding unsuppressed processes are **too** large:

- may overshoot other observations
- too large annihilation in the EU



Challenges

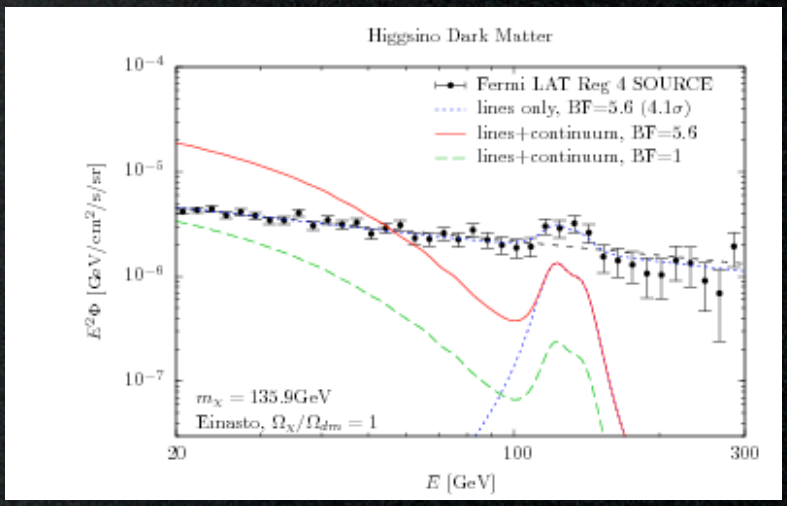
DM is neutral: need ‘something’ to couple to γ



The ‘something’ implies usually a suppression,
but one needs a large $\gamma\gamma$ cross section (o(10^{-27} cm^3/s))

so the corresponding unsuppressed processes
are **too** large:

- may overshoot other observations
- too large annihilation in the EU



But solutions exist

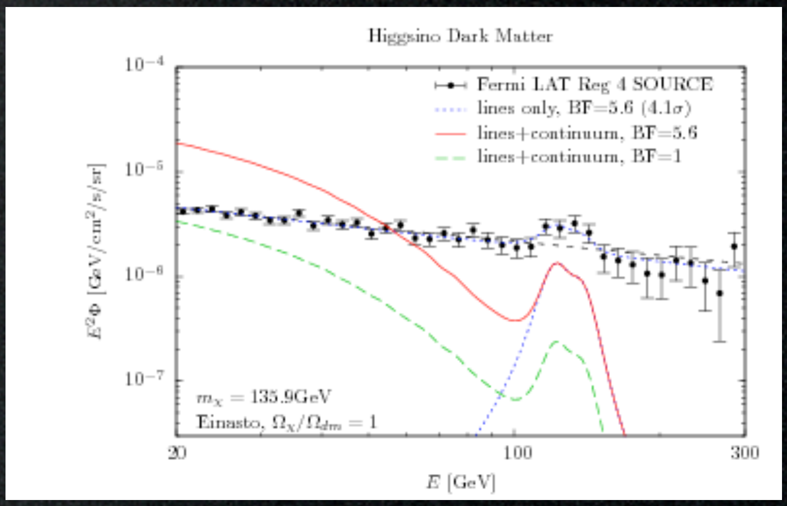
Challenges

DM is neutral: need 'something' to couple to γ

The 'something' implies usually a suppression,
but one needs a large $\gamma\gamma$ cross section (o(10^{-27} cm^3/s))

so the corresponding unsuppressed processes
are **too** large:

- may overshoot other observations
- too large annihilation in the EU



But solutions exist

Model building

- may overshoot other observations
- too large annihilation in the EU

But solutions exist

Model building

- may overshoot other observations
- too large annihilation in the EU

But solutions exist

In summary:

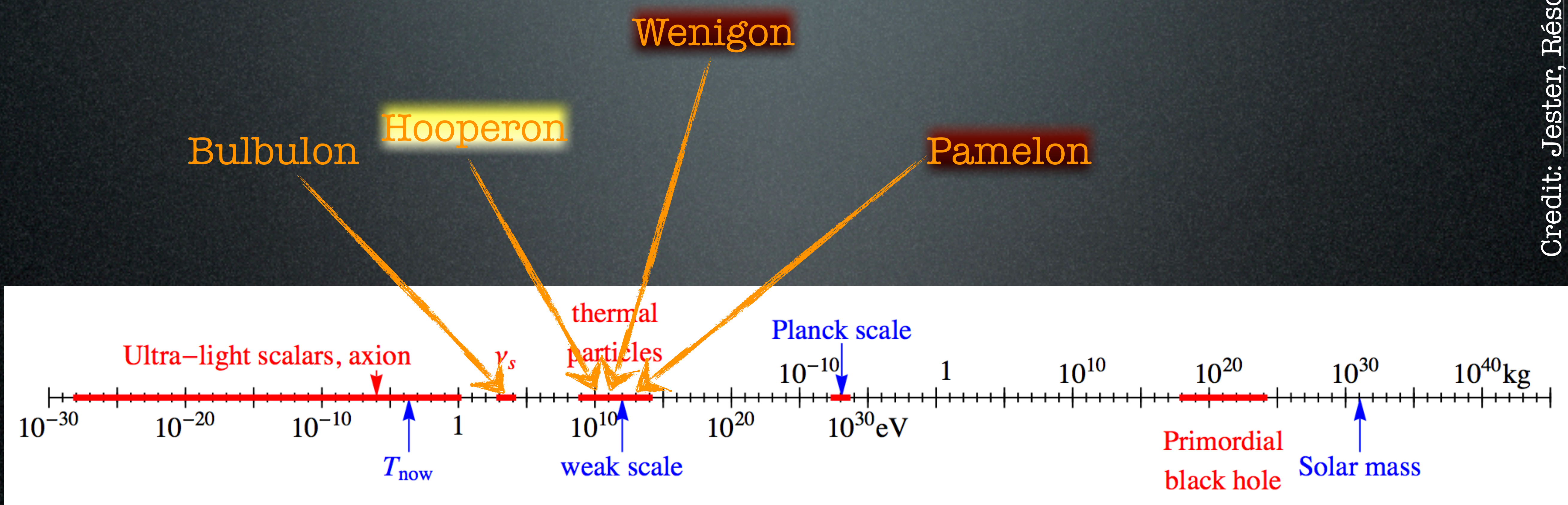
- kinematically forbidden channel
- different diagrams
- s-wave vs p-wave
- coannihilations and splitting
- DM production is decoupled from annihilations
- ...

Gamma rays

3. the 'Hooperon'

DM Candidates

A matter of perspective: plausible mass ranges



Credit: Jester, Résonaances

'only' 90 orders of magnitude!

GeV gamma excess?

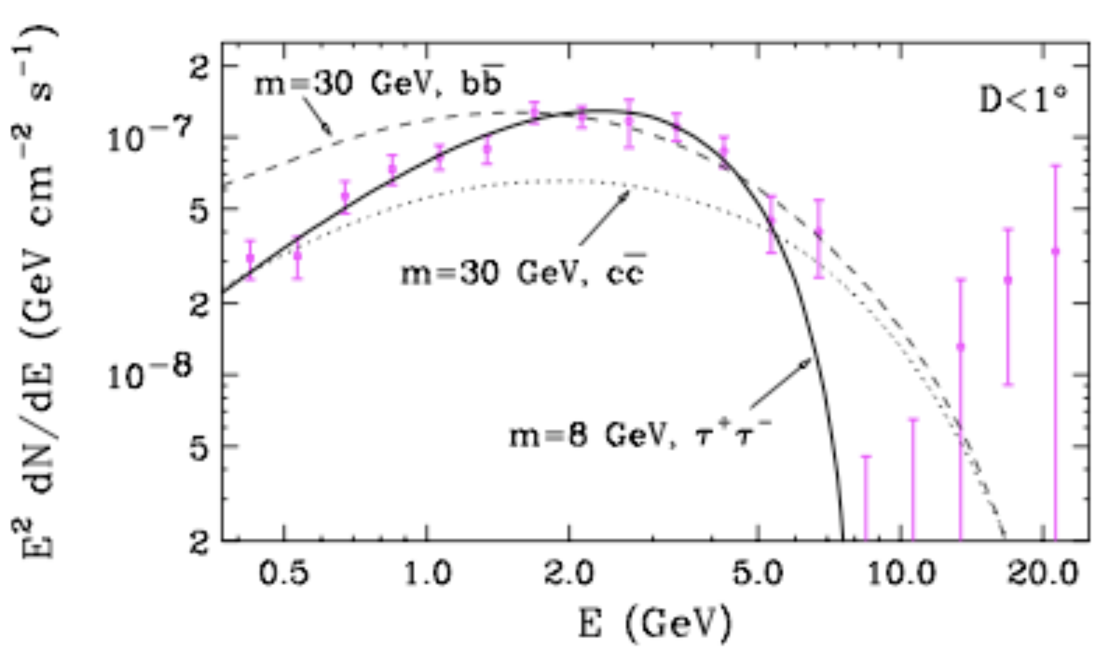
What if a signal of DM is *already* hidden in Fermi diffuse γ data from the GC?

A diffuse GeV excess from around the GC

Dan Hooper

GeV gamma excess?

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



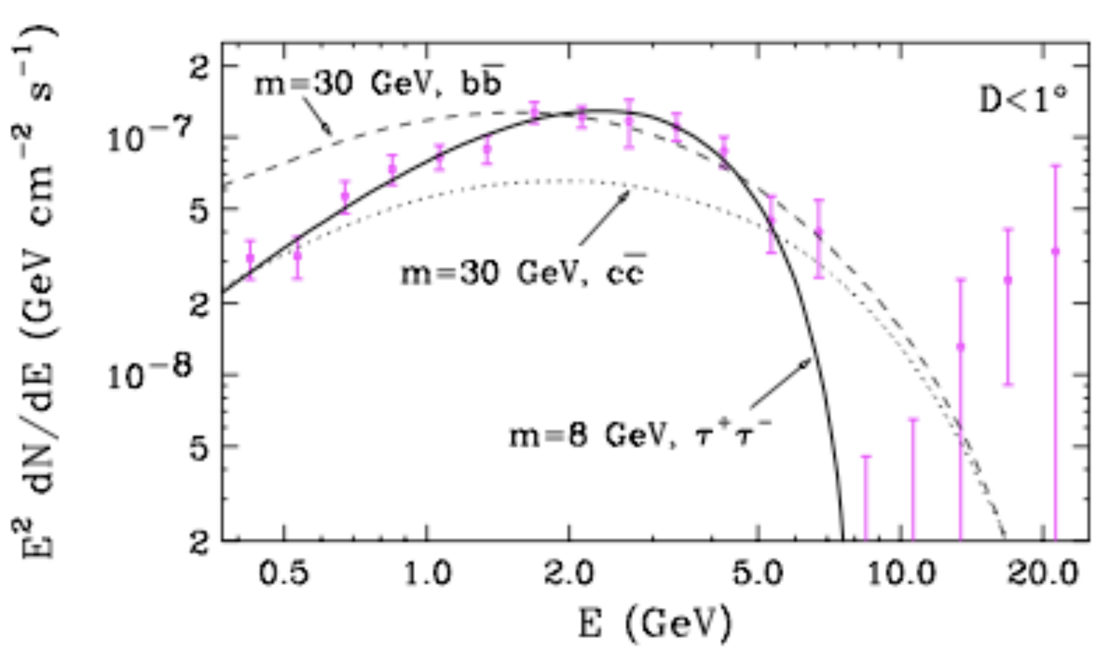
Hooper, Goodenough 1010.2752

A diffuse GeV excess from around the GC

Dan Hooper

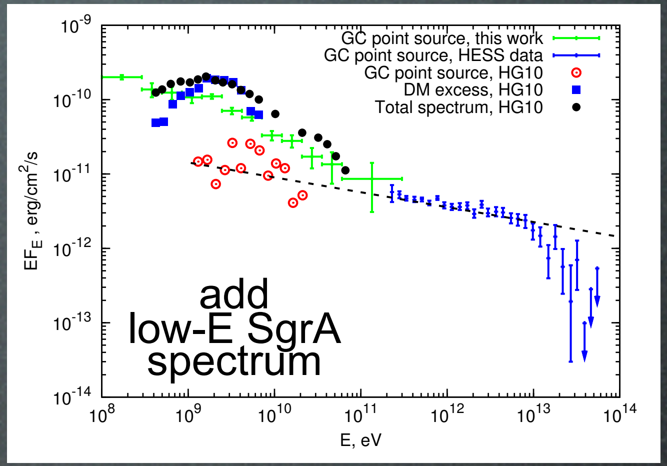
GeV gamma excess?

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

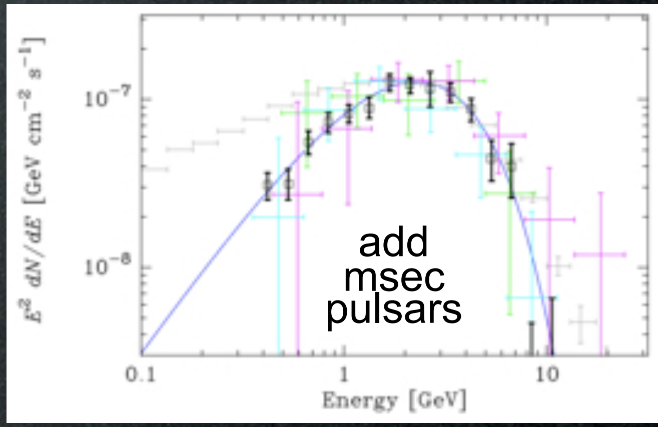


Hooper, Goodenough 1010.2752

Objection: know your backgrounds!



Boyarsky et al., 1012.5839



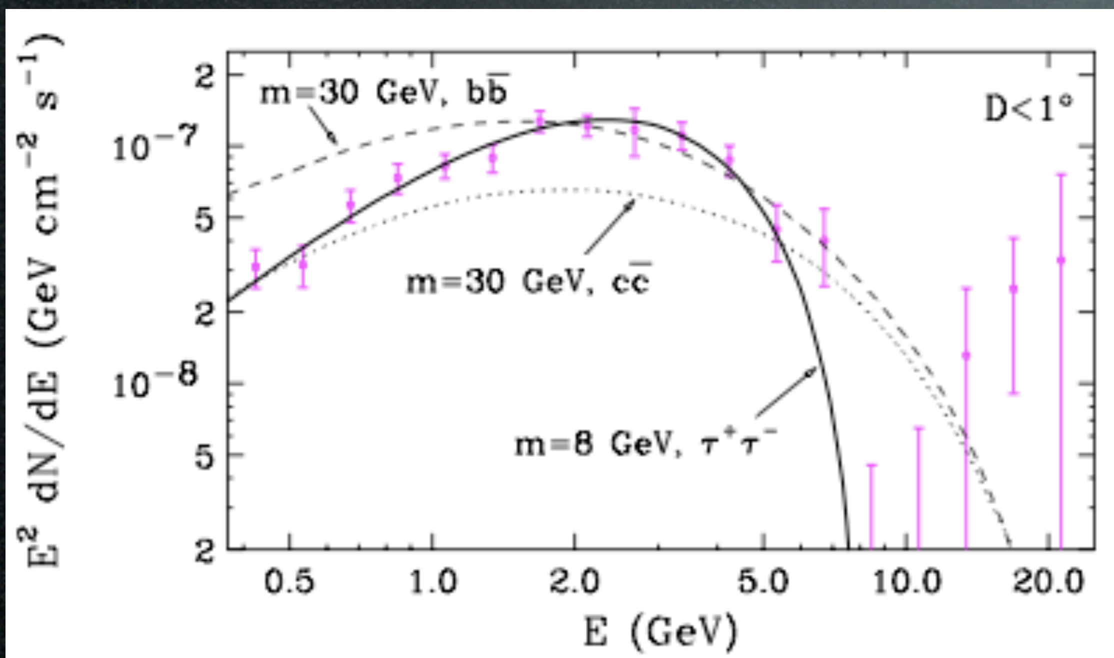
Abazajian 1011.4275

A diffuse GeV excess from around the GC

Dan Hooper

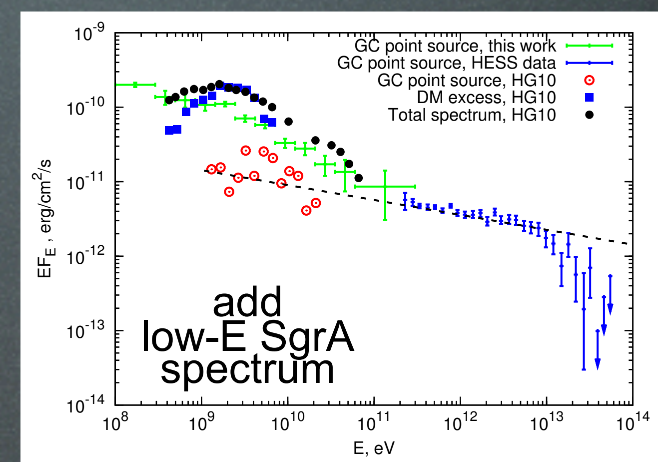
GeV gamma excess?

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

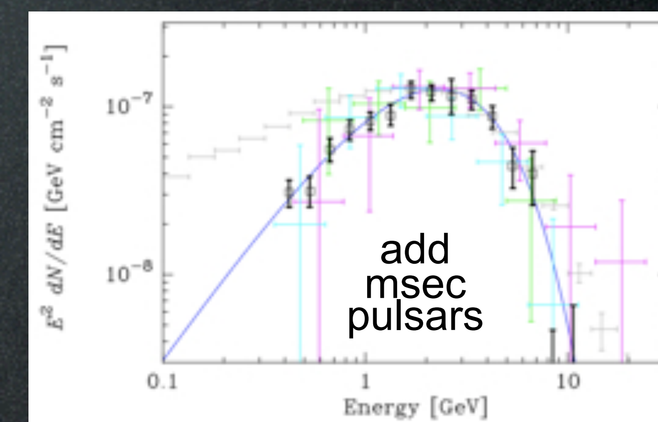


Hooper, Goodenough 1010.2752

Objection: know your backgrounds!



Boyarsky et al., 1012.5839



Abazajian 1011.4275

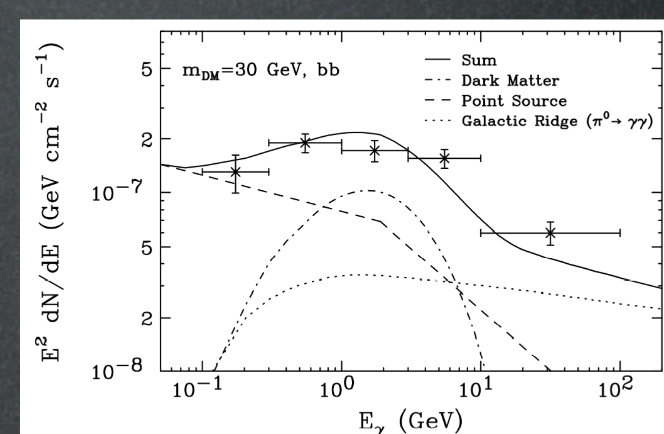
No, too few

(and we should have seen them elsewhere)

and wrong spectra

Hooper et al. 1305.0830

Still works...



Hooper, Linden 1110.0006

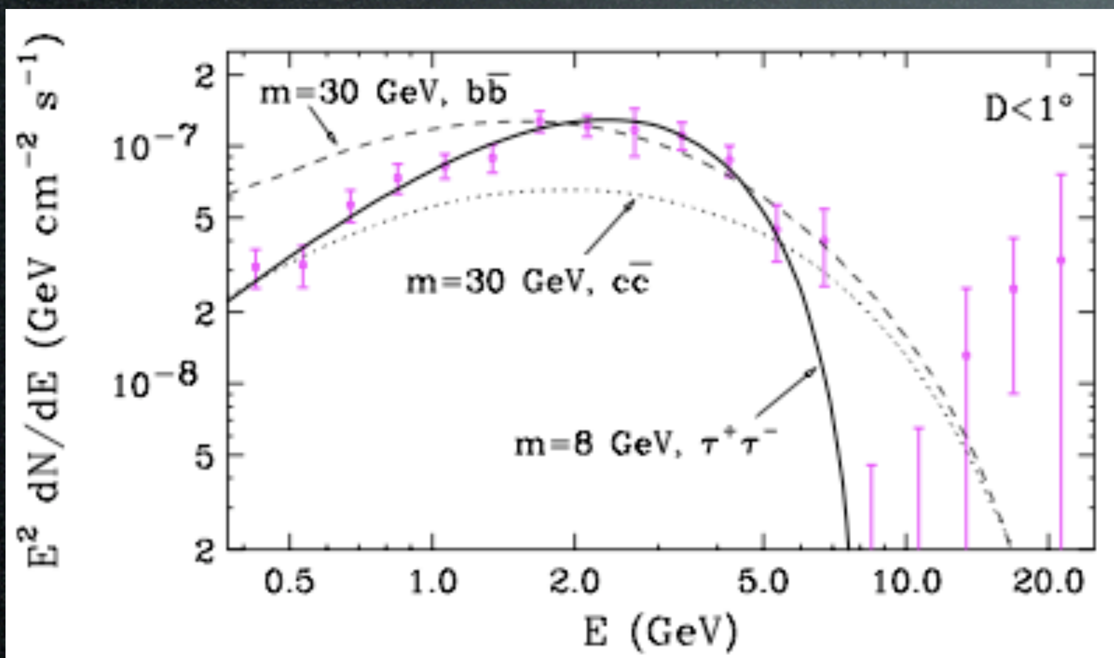
Best fit: 8 GeV, $\tau^+ \tau^-$, ~thermal σv

A diffuse GeV excess from around the GC

Dan Hooper

GeV gamma excess?

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



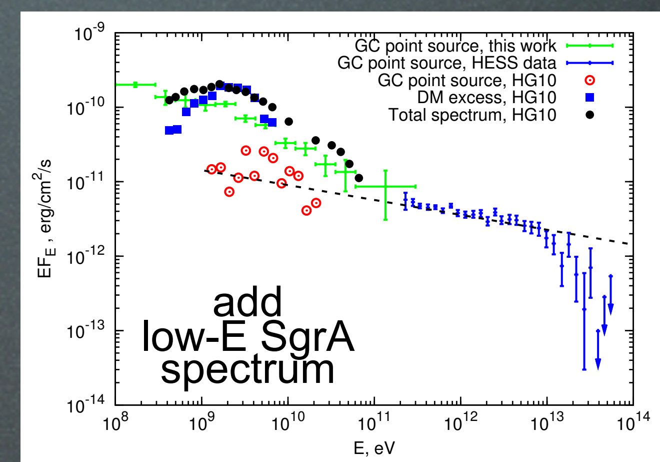
Hooper, Goodenough 1010.2752

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

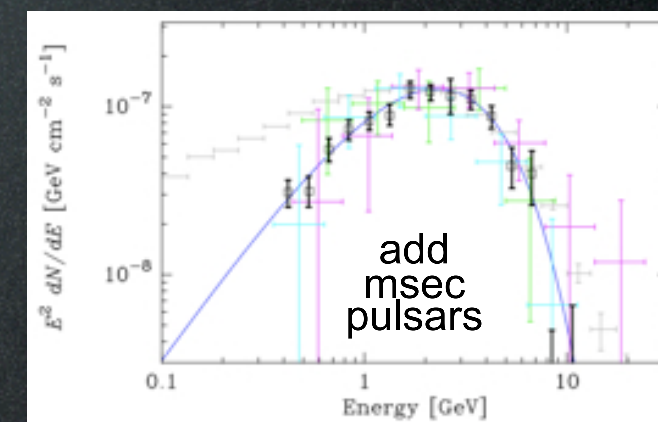
A diffuse GeV excess from around the GC

Dan Hooper

Objection: know your backgrounds!



Boyarsky et al., 1012.5839



Abazajian 1011.4275

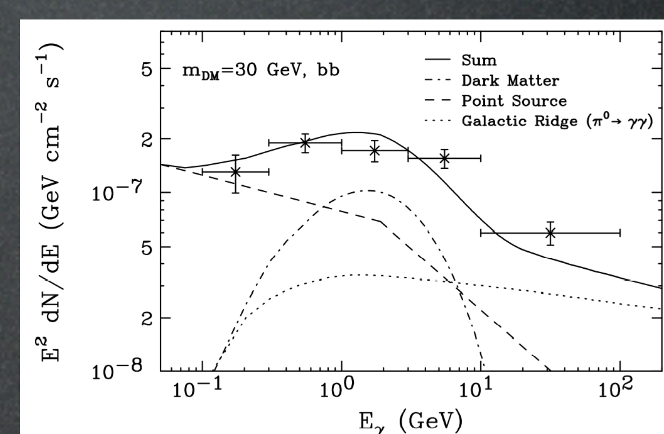
No, too few

(and we should have seen them elsewhere)

and wrong spectra

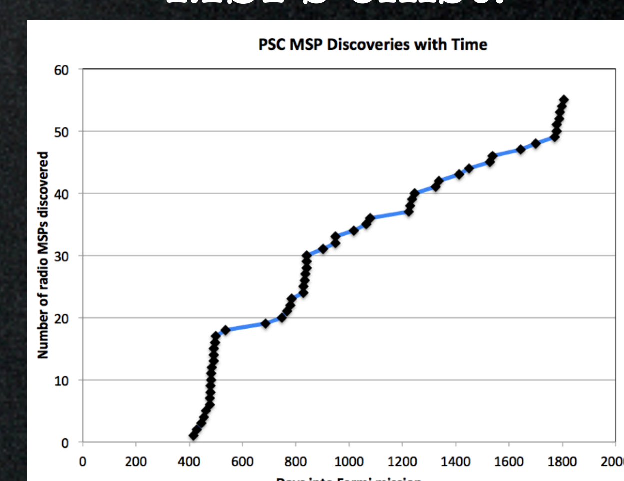
Hooper et al. 1305.0830

Still works...



Hooper, Linden 1110.0006

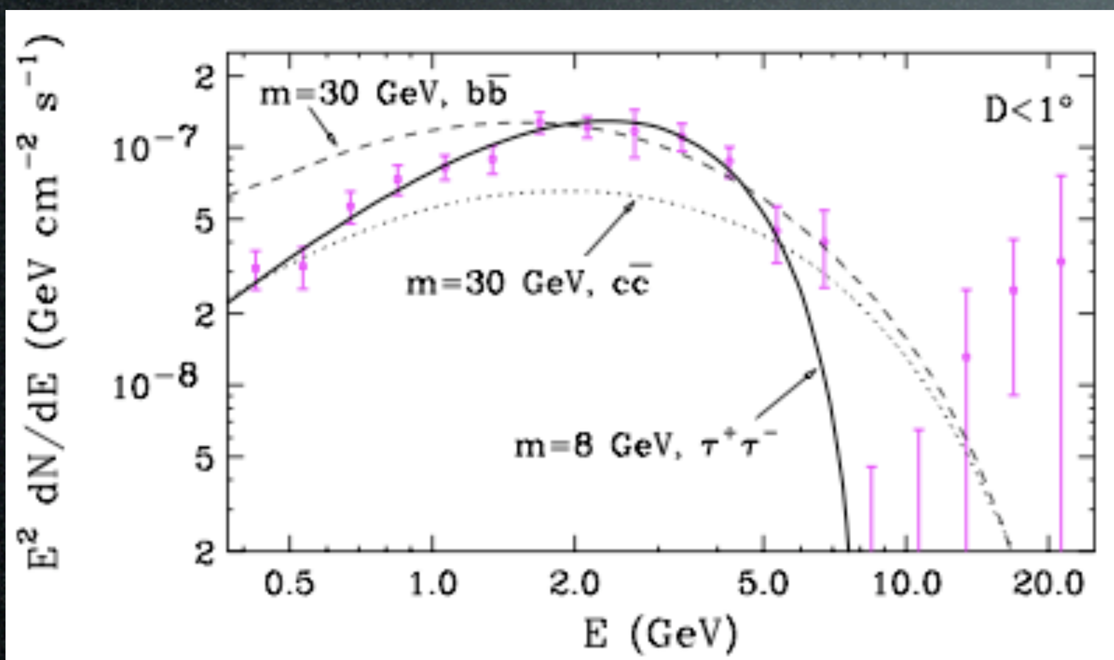
MSPs exist.



Caraveo 1312.2913

GeV gamma excess?

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



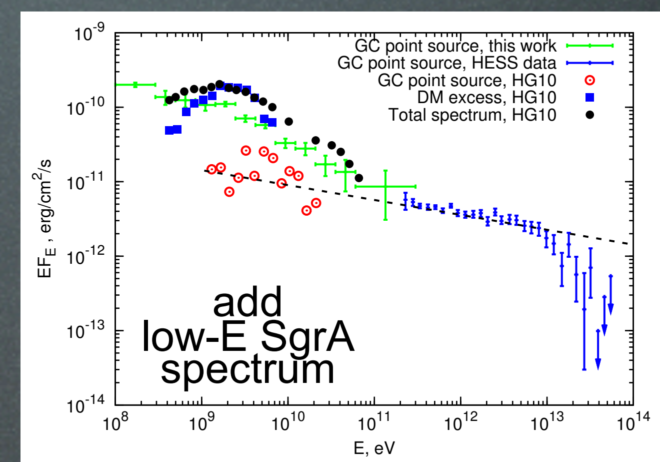
Hooper, Goodenough 1010.2752

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

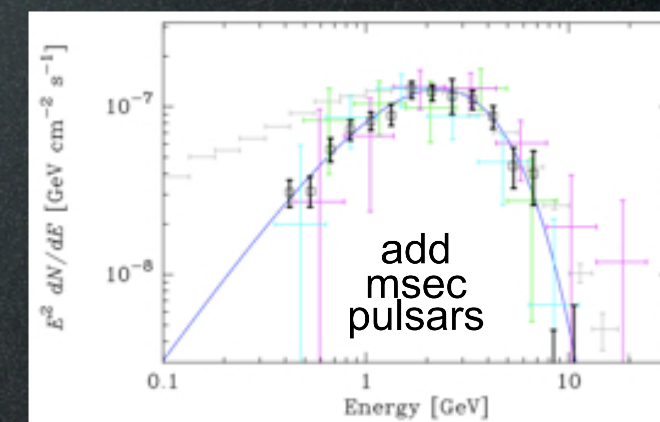
A diffuse GeV excess from around the GC

Dan Hooper

Objection: know your backgrounds!

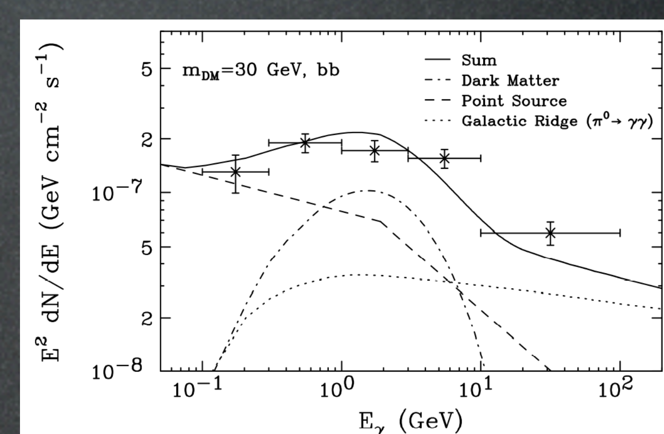


Boyarsky et al., 1012.5839



Abazajian 1011.4275

Still works...



Hooper, Linden 1110.0006

No, too few

(and we should have seen them elsewhere)

and wrong spectra

Hooper et al. 1305.0830

No no, MSPs can do.

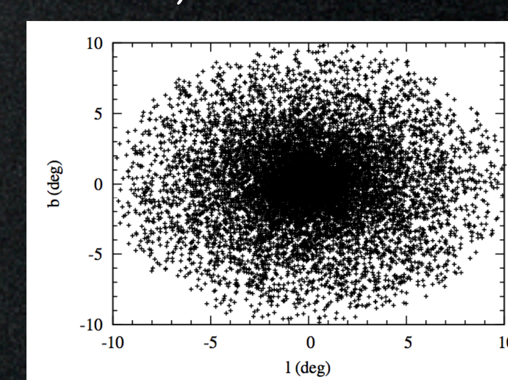


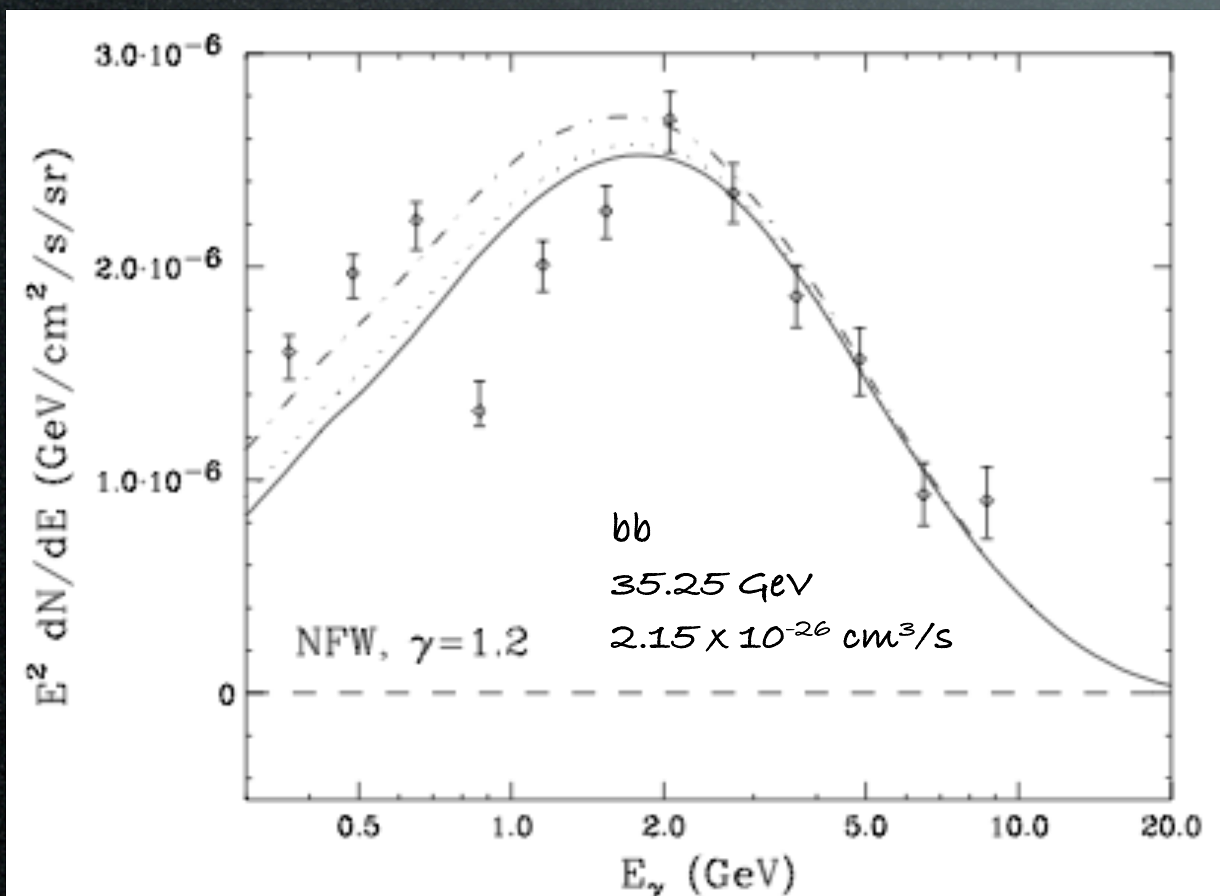
Figure 5: Simulated spatial distribution of the bulge MSPs.

Yuan, Zhang 1404.2318

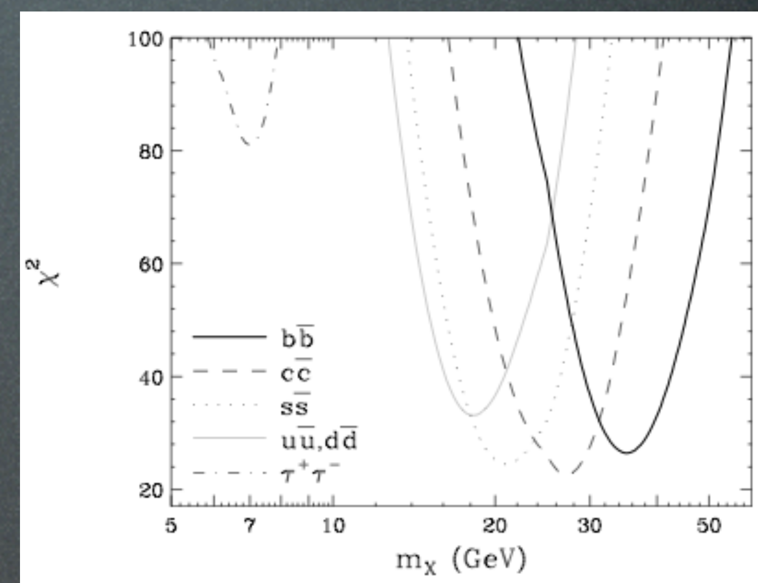
(LMXB (tracers of MSP?) seen in M31 with this distribution)

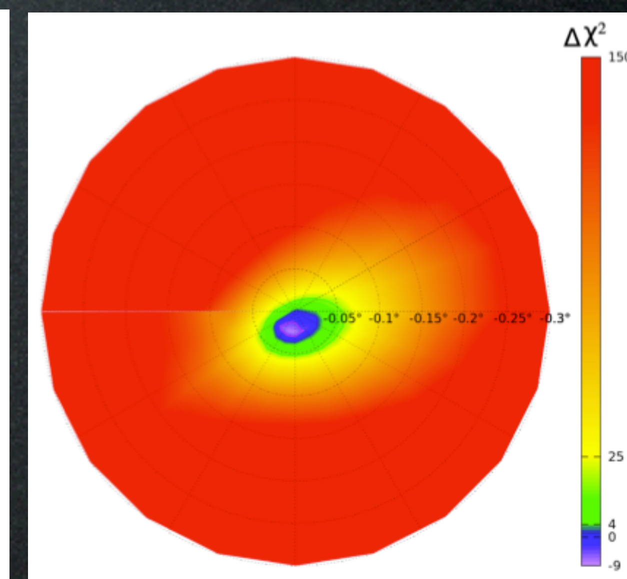
GeV gamma excess?

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



Using events with accurate directional reconstruction





Best fit:
~35 GeV, quarks, ~thermal σv

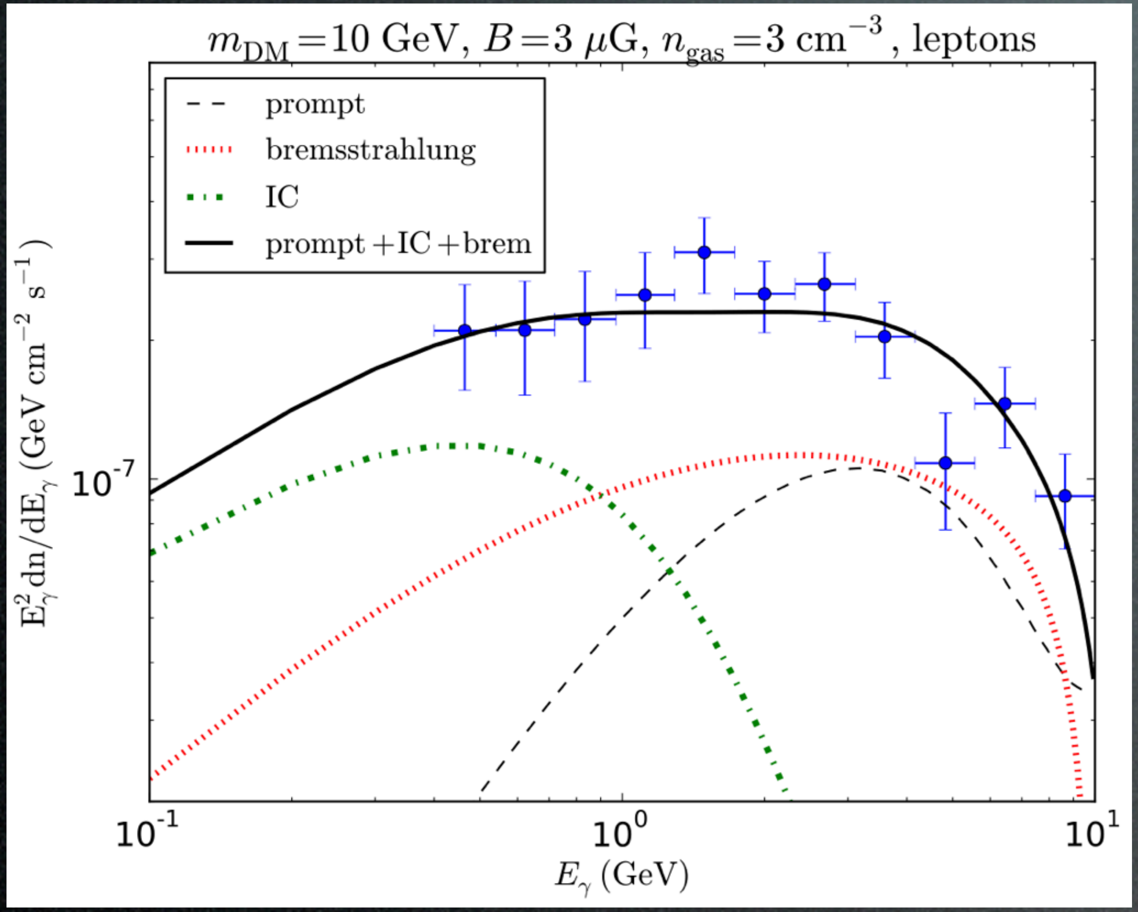
A compelling case for annihilating DM

Daylan, Finkbeiner, Hooper, Linden, Portillo, Rodd, Slatyer 1402.6703

As found in previous studies [8, 9], the inclusion of the dark matter template dramatically improves the quality of the fit to the *Fermi* data. For the best-fit spectrum and halo profile, we find that the inclusion of the dark matter template improves the formal fit by $\Delta\chi^2 \simeq 1672$, corresponding to a statistical preference greater than 40σ.

GeV gamma excess?

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



Lacroix, Bœhm, Silk 1403.1987

Including secondary emission changes the conclusions

But: propagation is approximate

Best fit:

~10 GeV, leptons, ~thermal σv

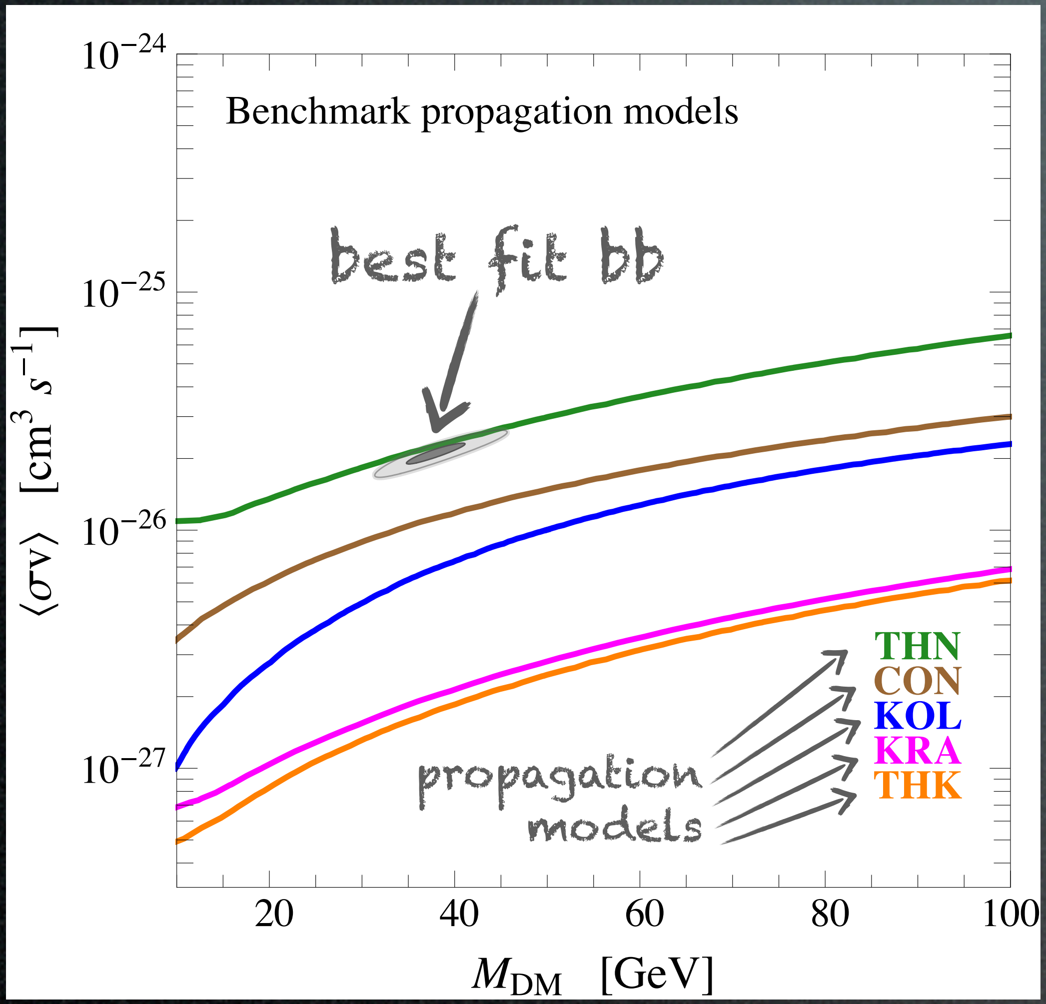
Fermi-LAT excess

Lacroix, Bœhm, Silk 1403.1987

GeV gamma excess?

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

Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

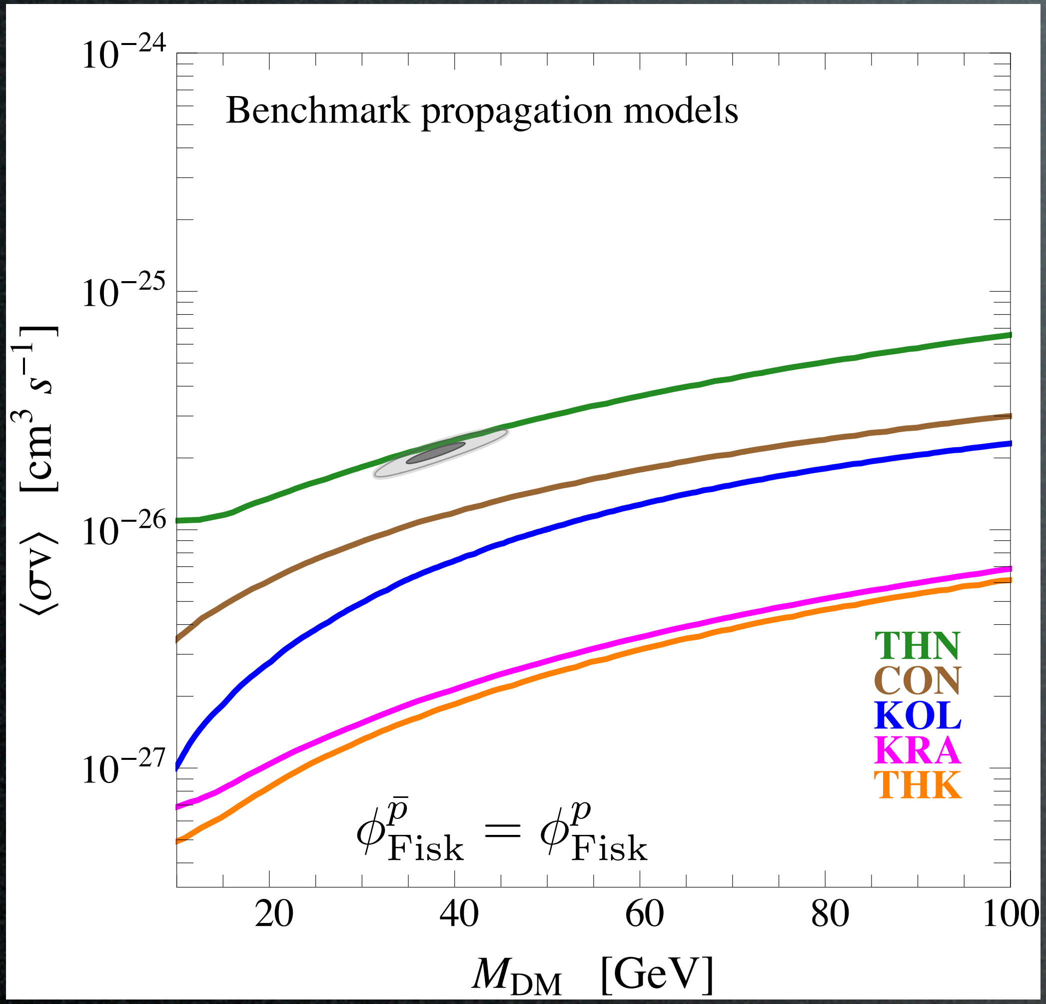


Fermi-LAT excess

Antiproton constraints may be very relevant! But not robust.

GeV gamma excess?

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



Fermi-LAT excess

Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

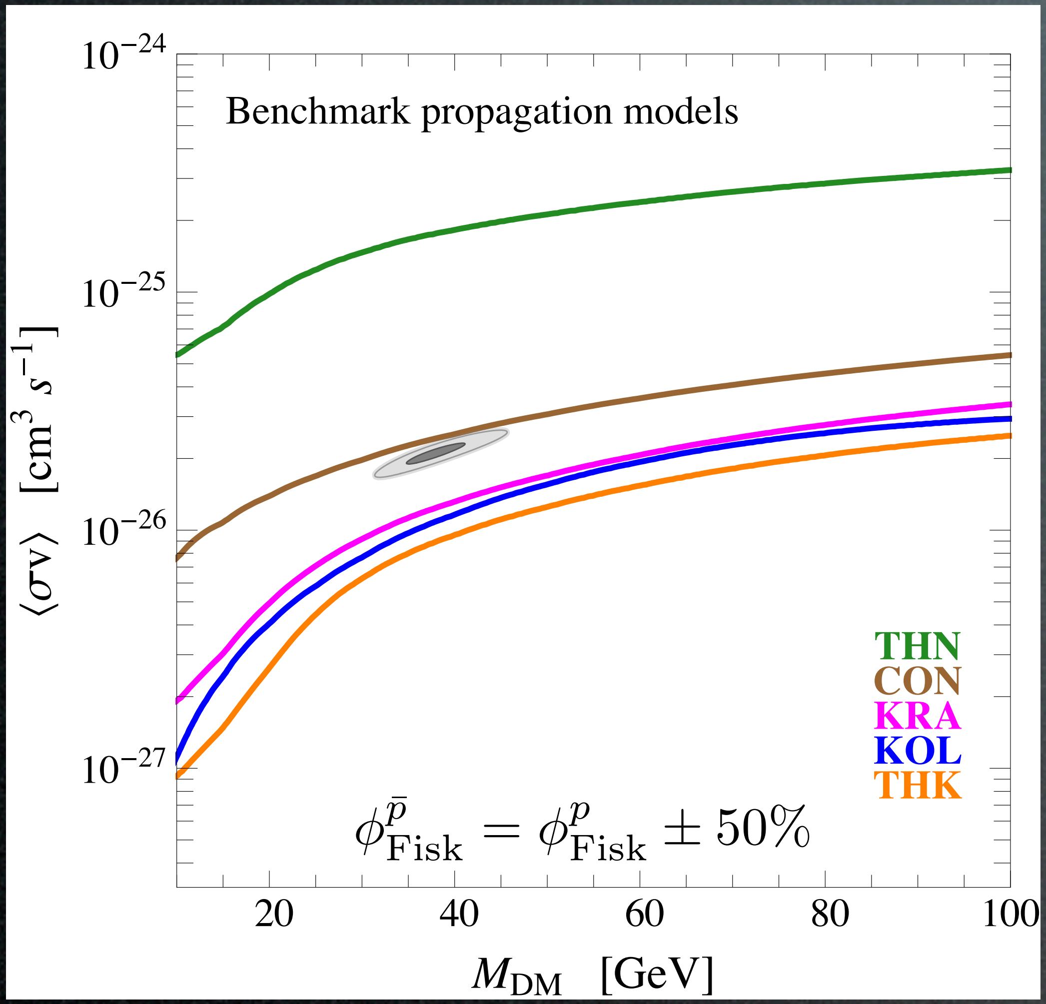
Antiproton constraints may be very relevant! But not robust.

Assumption: fixed solar modulation

Result: hooperon excluded
(except unrealistic THN)

GeV gamma excess?

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



Fermi-LAT excess

Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

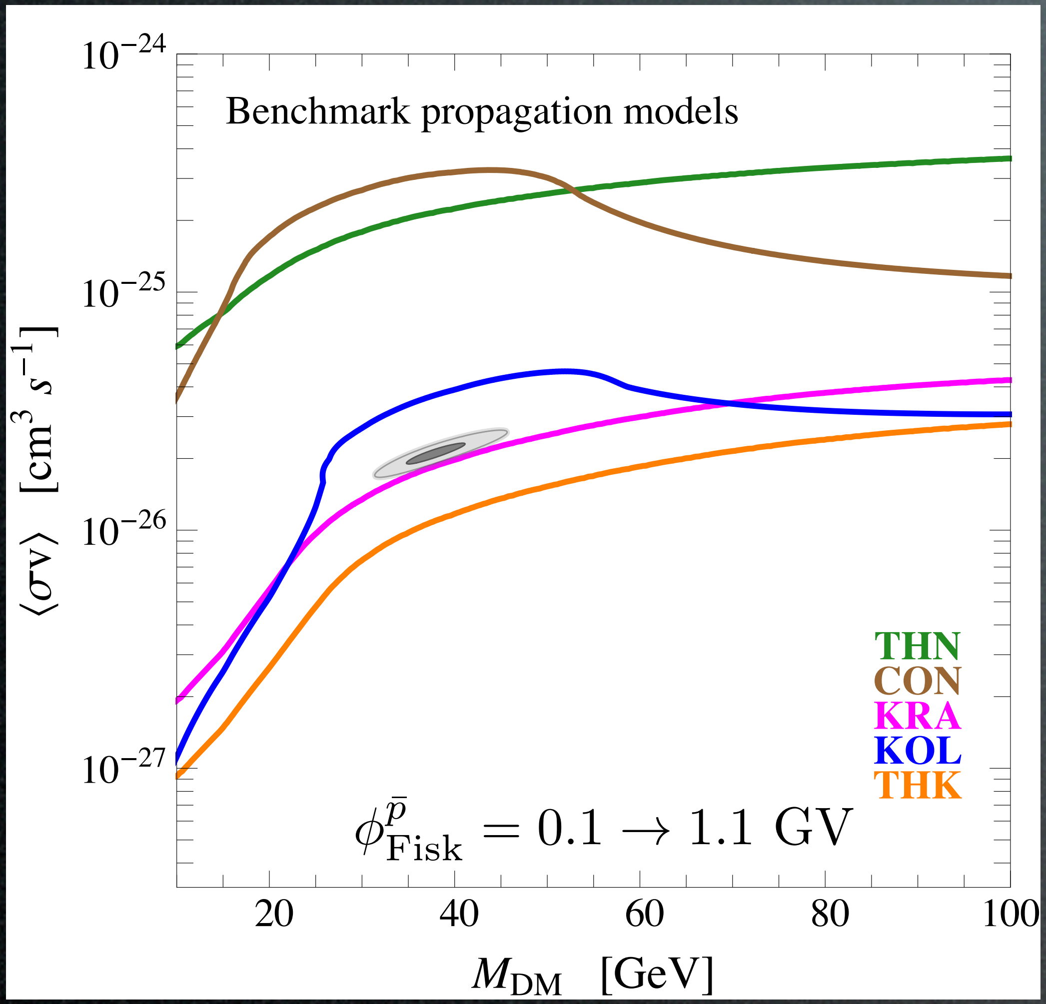
Antiproton constraints may be very relevant! But <u>not</u> robust.

<u>Assumption</u>: flexible solar modulation

<u>Result</u>: hooperon may be excluded or not

GeV gamma excess?

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



Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

Fermi-LAT excess

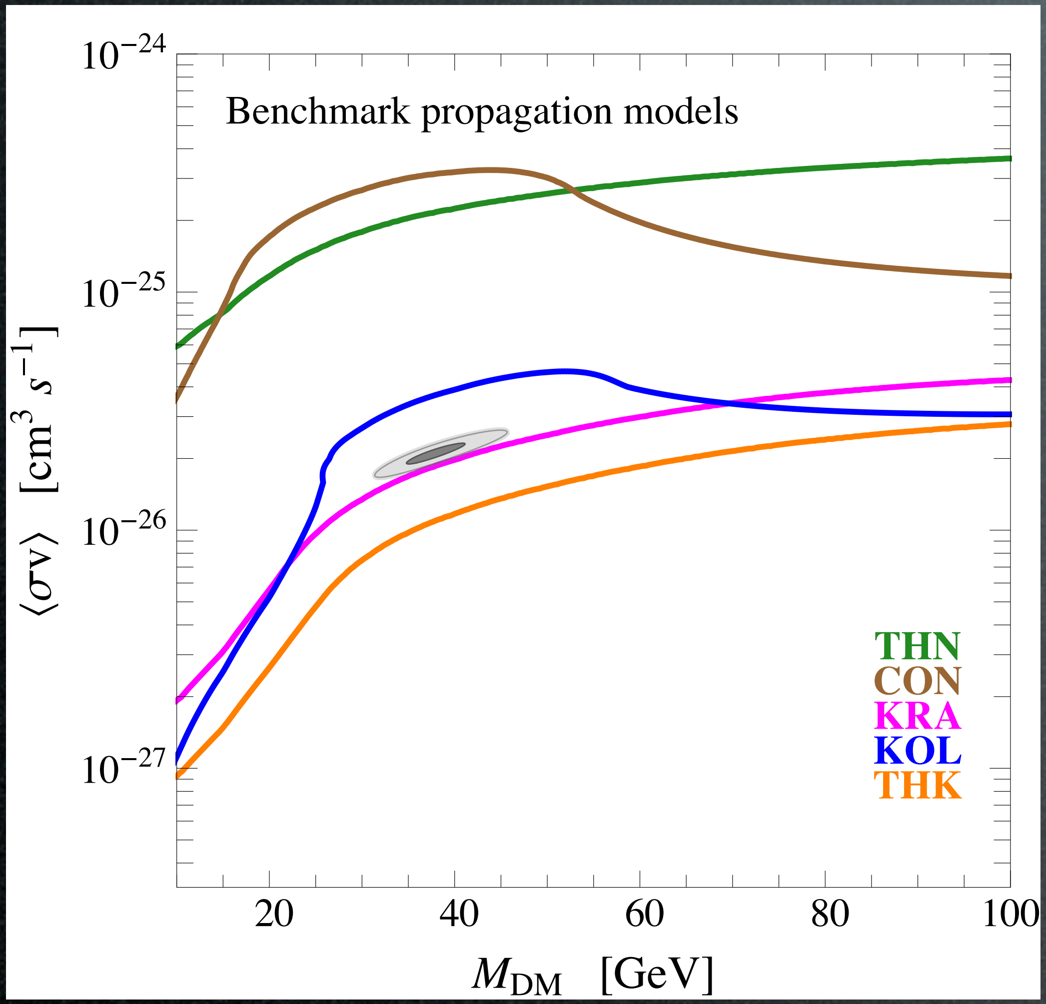
Antiproton constraints may be very relevant! But not robust.

Assumption: conservative solar modulation

Result: hooperon probably reallowed (except THK models)

GeV gamma excess?

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



Fermi-LAT excess

Cirelli, Gaggero, Giesen, Taoso, Urbano 1407.2173

Antiproton constraints may be very relevant! But not robust.

Assumption: conservative solar modulation

Result: hooperon probably reallowed (except THK models)

NB Conclusion differs from Bringmann, Vollmann, Weniger 1406.6027 which finds exclusion / strong tension

GeV gamma excess?

An excess with respect to **what**?
Extracting 'data points' is not trivial:

i. choose a ROI (shape, extension, masking...) and harvest Fermi-LAT data
ii. impose sensible cuts (Pass N, angles, CTBCORE...)
iii. in each energy bin, fit to a sum of spatial templates:

1. Fermi Coll. diffuse
2. isotropic
3. unresolved point sources
4. features (bubbles...)
5. AOB (molecular gas...)

iv. repeat the same, adding a template for:

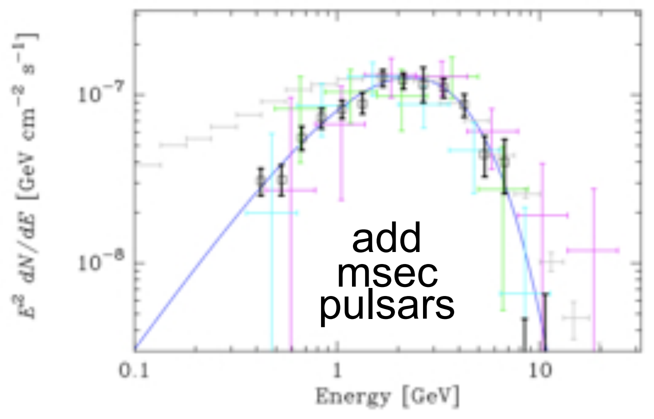
6. Dark Matter, having chosen a certain profile!

v. if iii. → iv. improves χ^2, there's evidence for DM
vi. the component fitted by 6 is the residual excess to be explained

Note:
Adding 6 will in general change the recipe of 1...5 (you'll need a bit more of x here, a bit less of y there...).
Changing the profile of 6 too.

Astrophysical interpretation

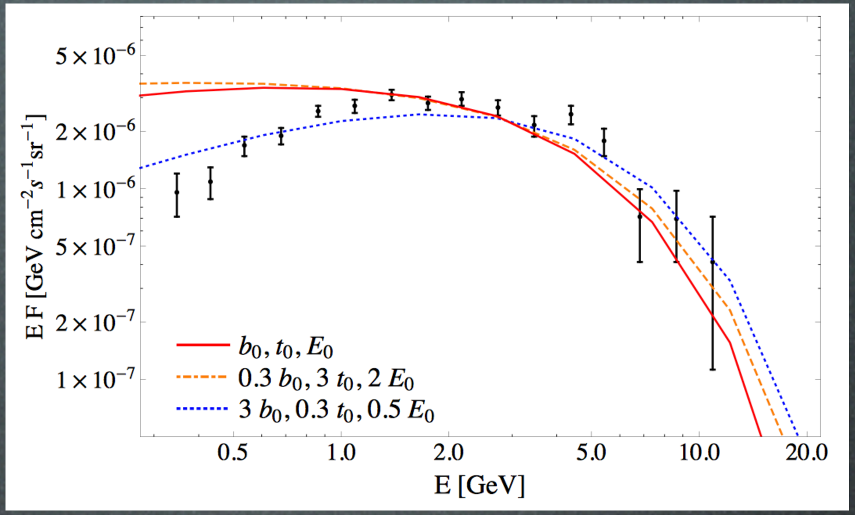
Millisec pulsars

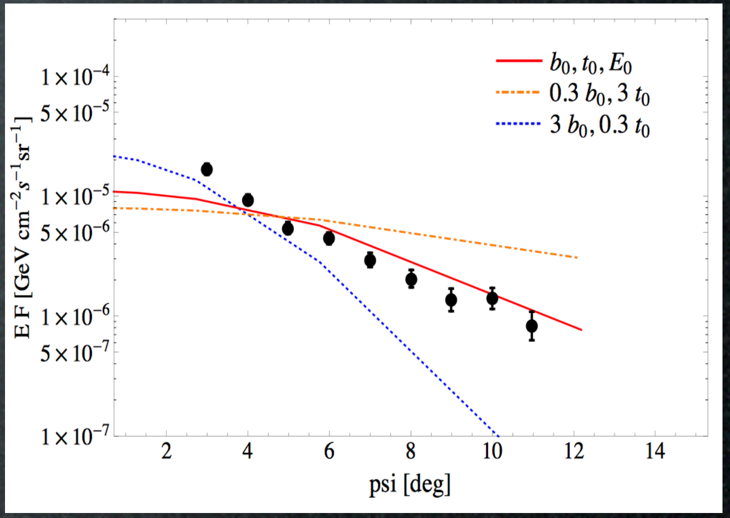


Abazajian 1011.4275
Hooper et al. 1305.0830
Yuan, Zhang 1404.2318

A transient phenomenon:

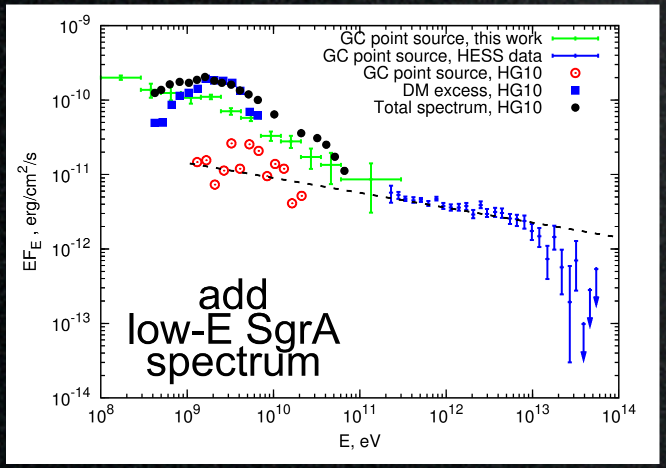
the GC spit 10^{52} ergs in $e^{\pm}$ 1 mln yrs ago and they do ICS on ambient light, 'fits' both spectrum and morphology Petrović, Serpico, Zaharijas 1405.7928





but: can one really get everything right?

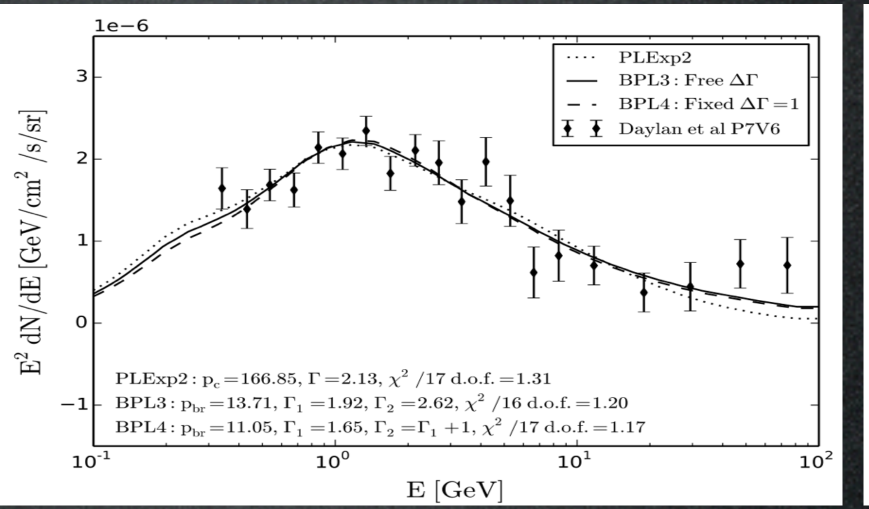
Non-trivial SgrA spectrum

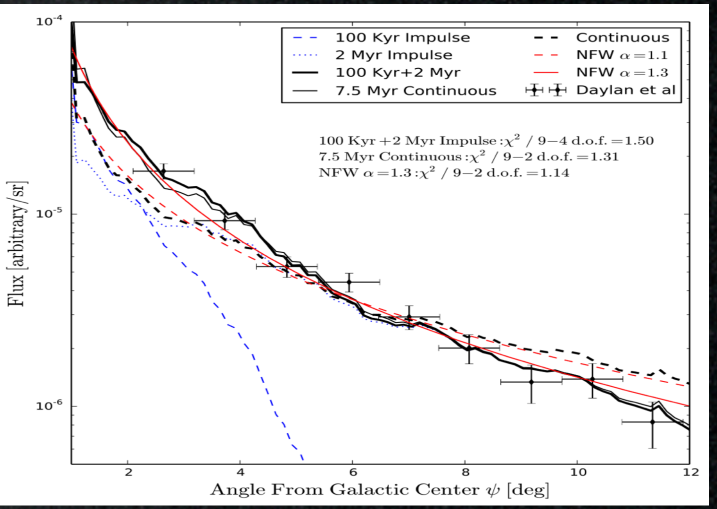


Boyarsky et al., 1012.5839

a SN explosion spits protons 5000 yrs ago and they do spallations + bremsstrahlung as well as $e^{\pm}$ which do ICS... fits spectrum & morphology

Carlson, Profumo 1405.7685



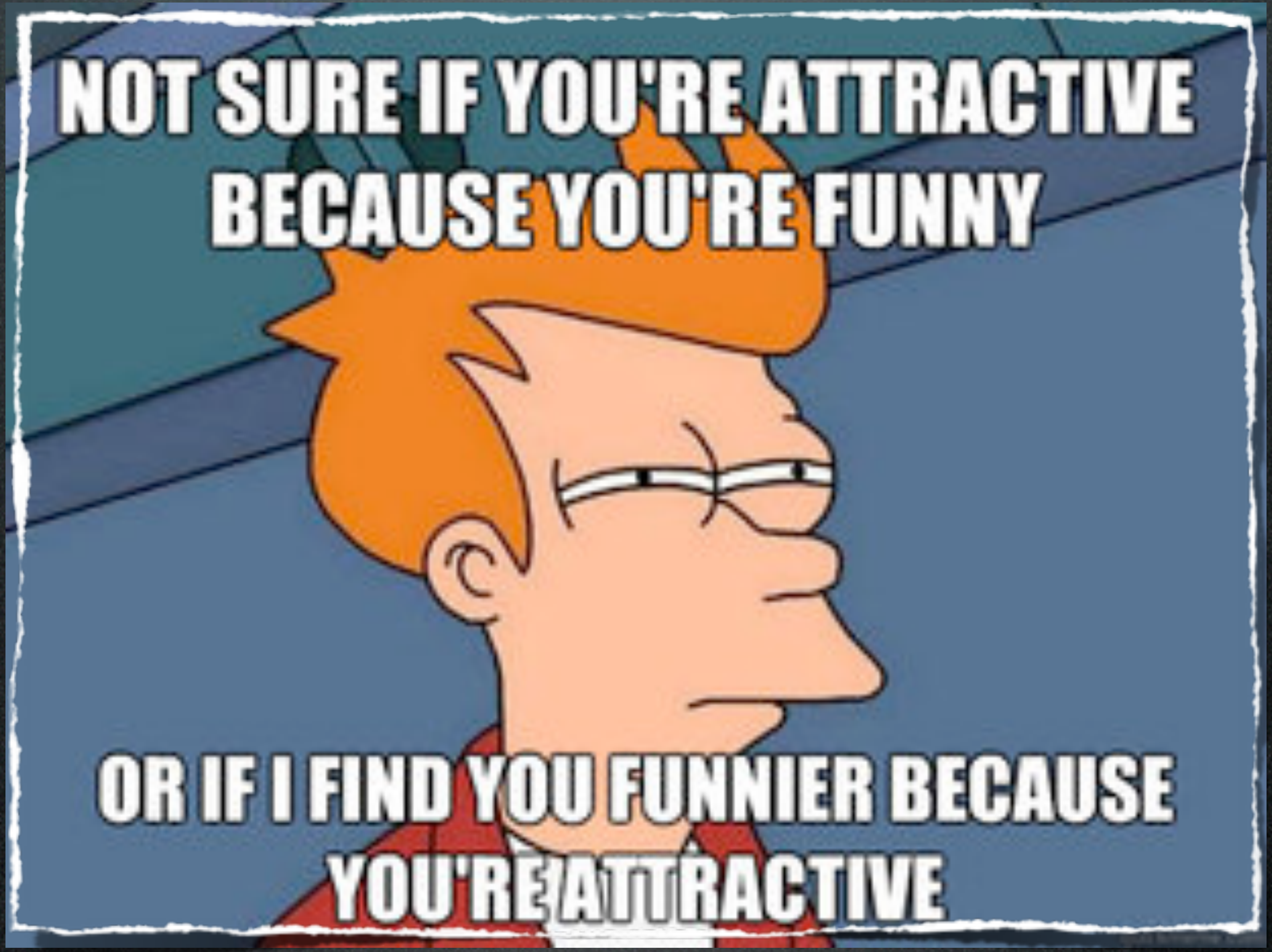


but: why correlation with gas density not seen?

Theorist's reaction

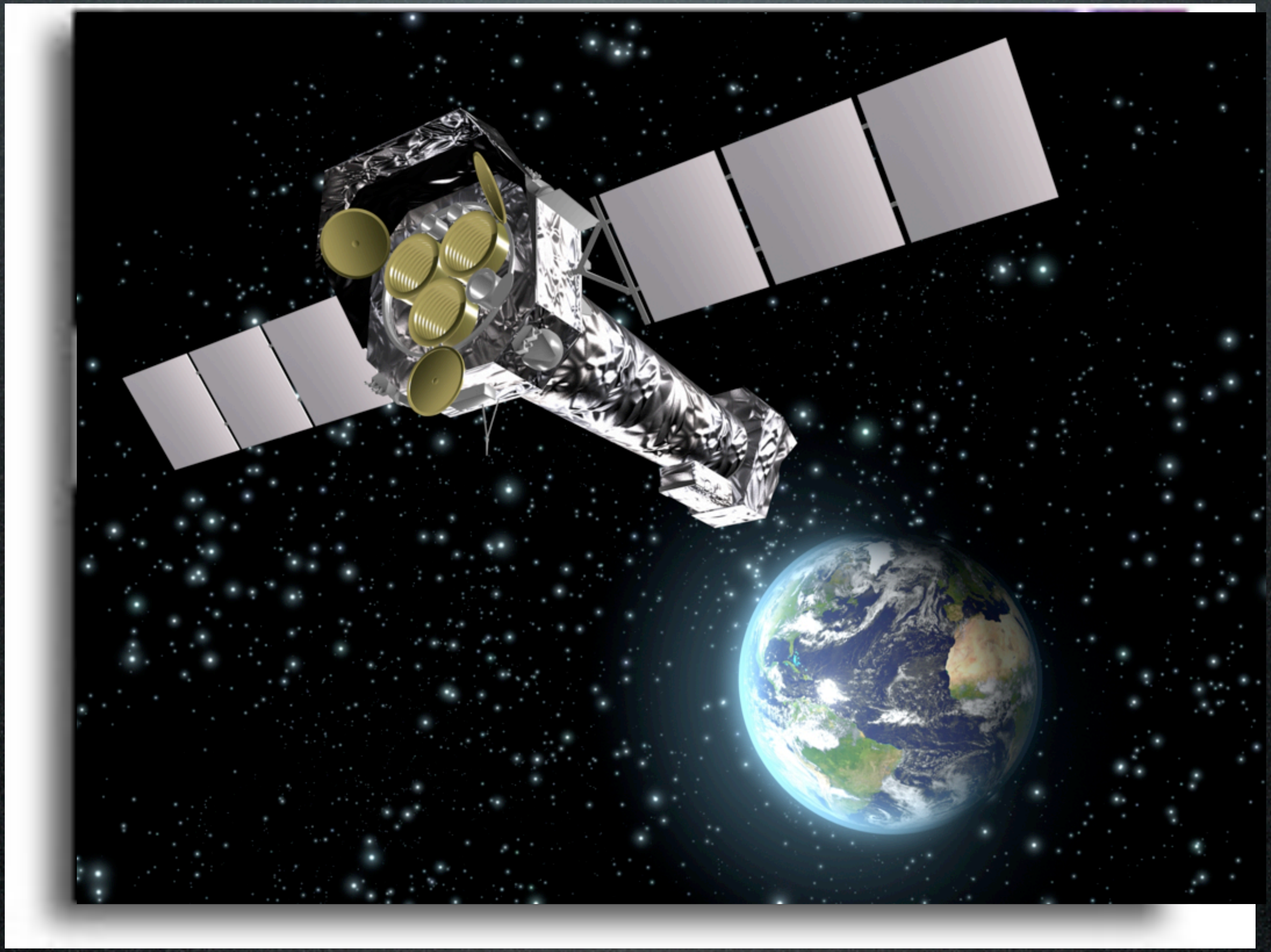
3. the 'Hooperon'

Theorist's reaction



3. the 'Hooperon'

X-rays

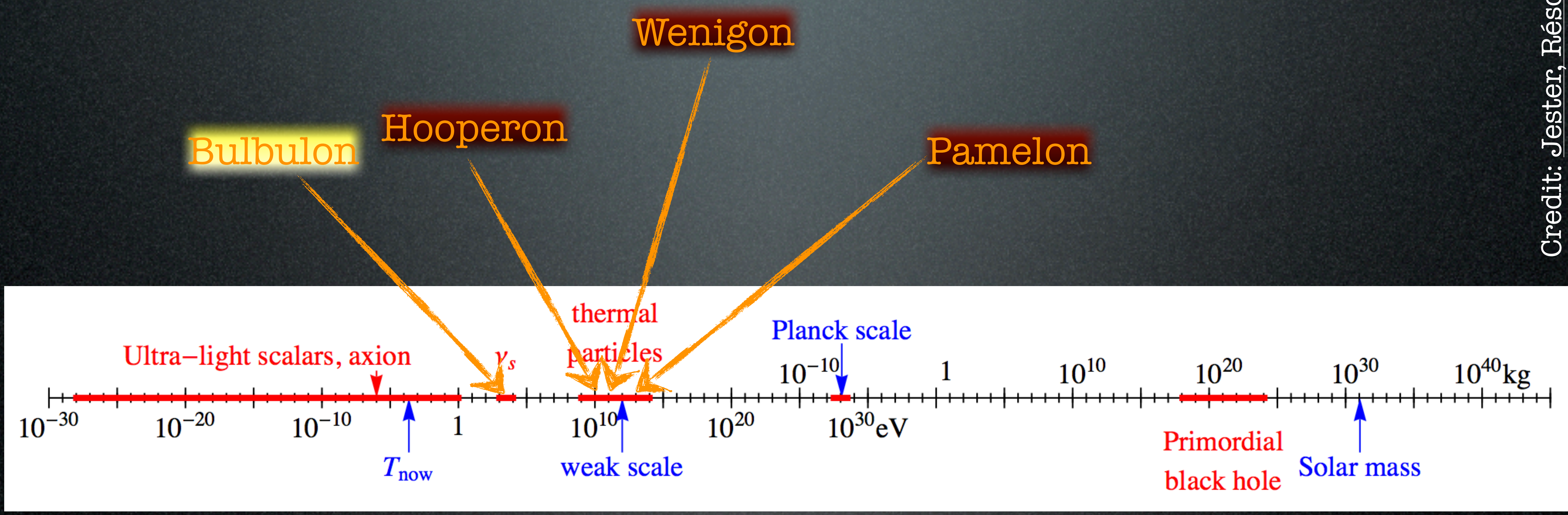


4. the ‘3.5 KeV line’

DM Candidates

A matter of perspective: plausible mass ranges

Credit: Jester, Résonaances



'only' 90 orders of magnitude!

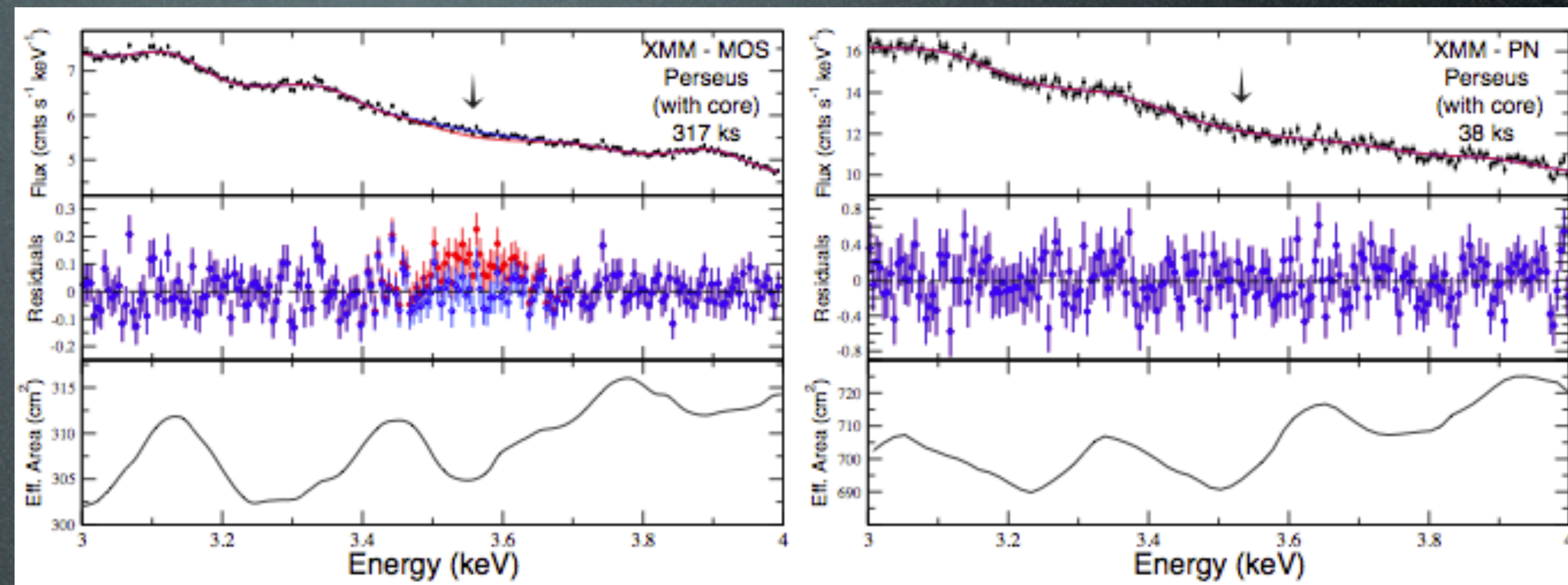
X-ray line

Bulbul et al., 1402.2301

3.55 - 3.57 ± 0.03 KeV

73 clusters

z = 0.01 - 0.35

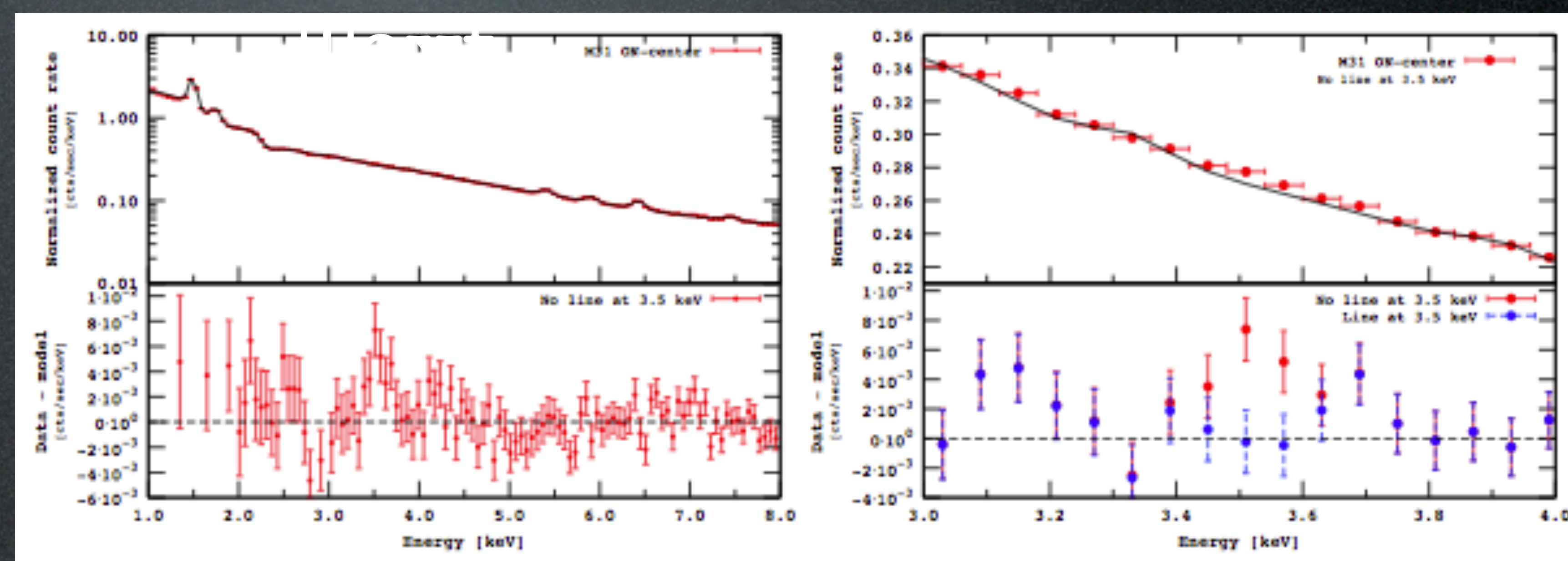


Boyarsky, Ruchayskiy, 1402.4119

3.5 KeV

Andromeda galaxy
+ Perseus cluster

z = 0 and 0.0179

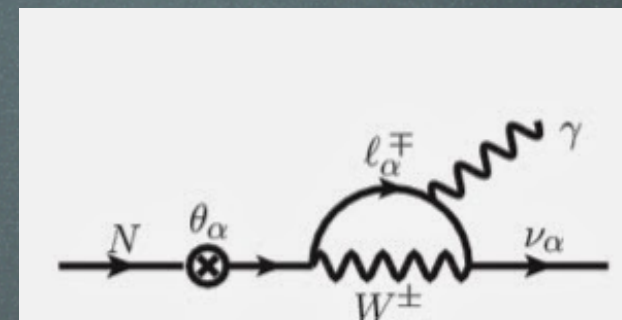


Theorist’s reaction

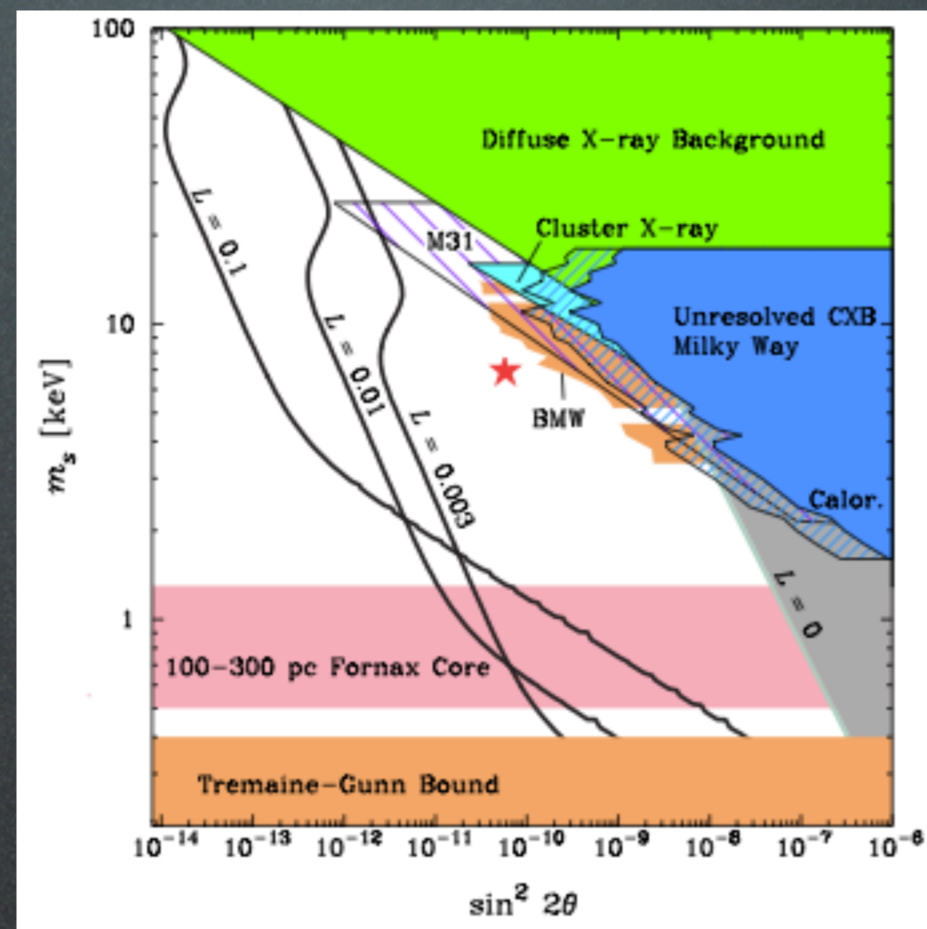
4. the ‘3.5 KeV’ line

X-ray line

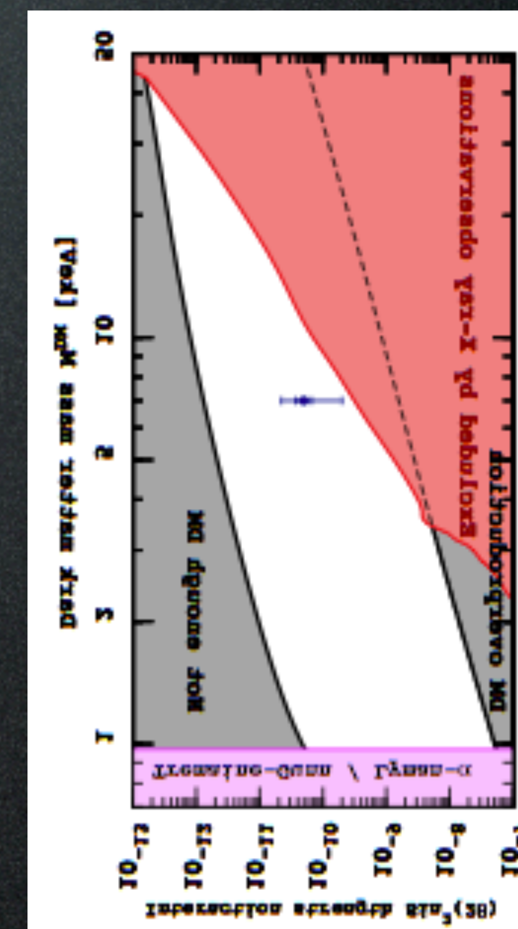
Sterile neutrino decay



$m_\nu = 7.1$ KeV
$\tau \simeq 10^{29}$ sec
$\sin^2 2\theta \sim$ few 10^{-11}



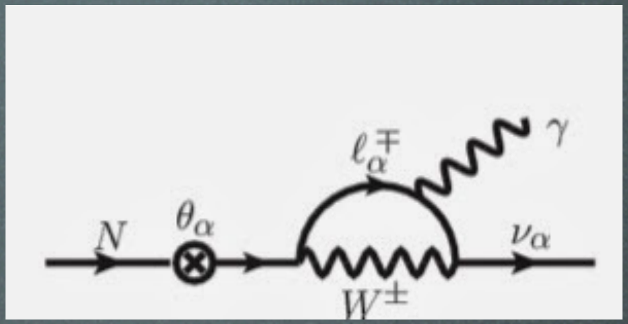
Bulbul et al., 1402.2301



Boyarsky, Ruchayskiy et al., 1402.4119

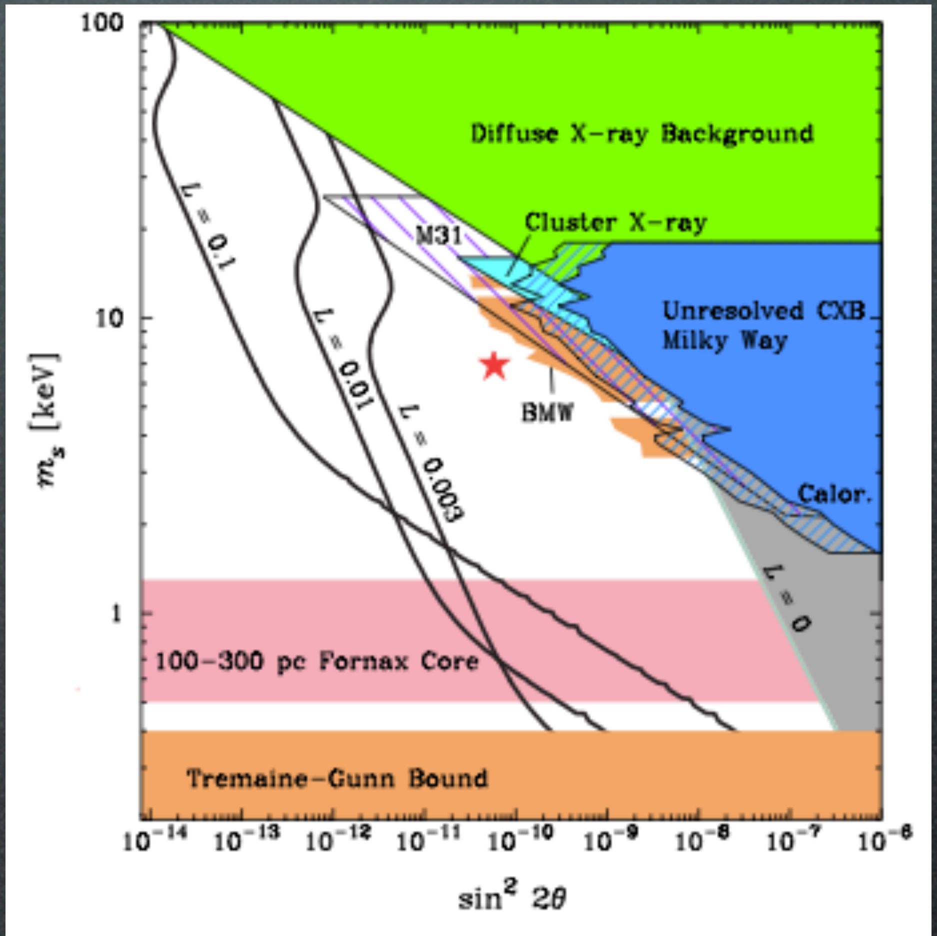
X-ray line

Sterile neutrino decay

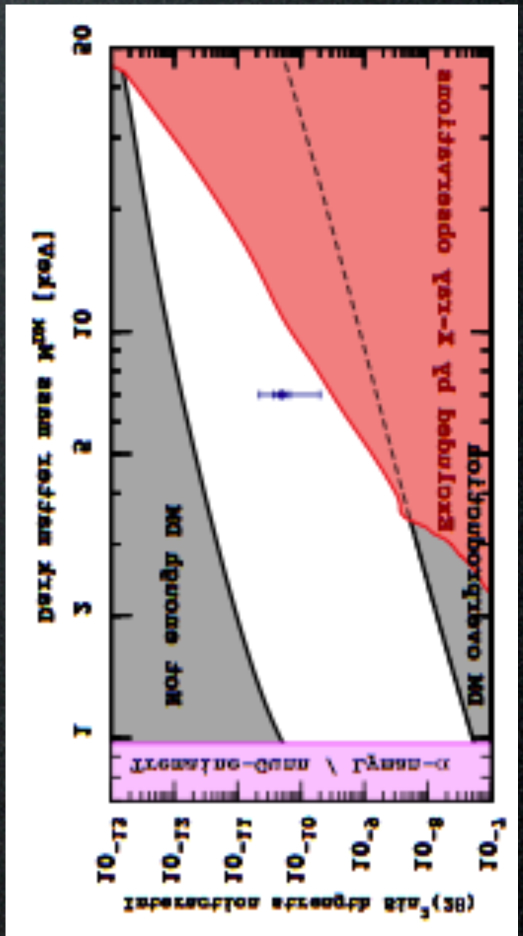


$m_\nu = 7.1$ KeV
$\tau \simeq 10^{29}$ sec
$\sin^2 2\theta \sim$ few 10^{-11}

Possible challenges:
- EU production?
- Perseus flux too large?



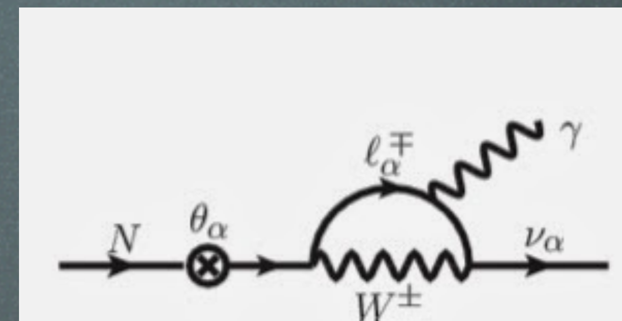
Bulbul et al., 1402.2301



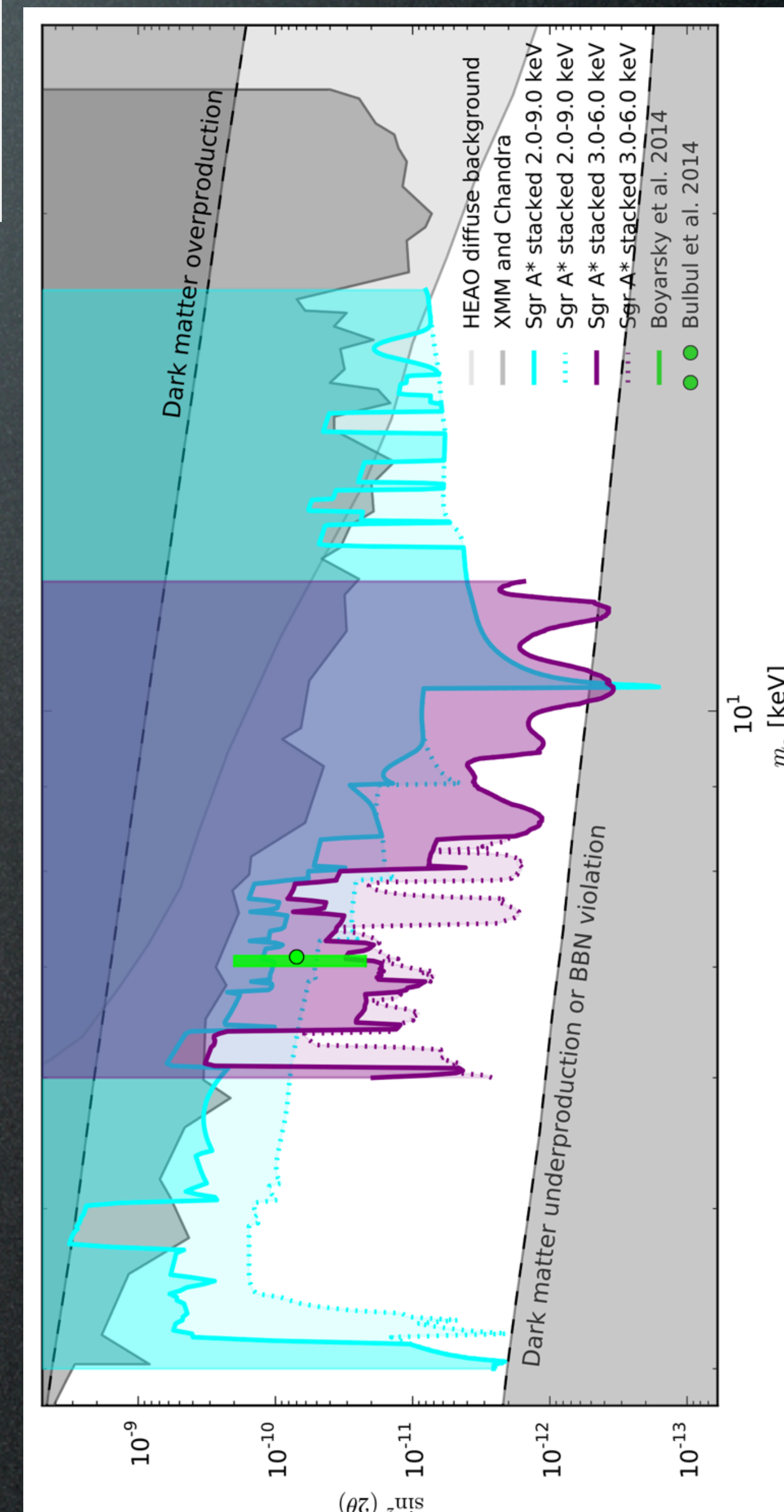
Boyarsky, Ruchayskiy et al., 1402.4119

X-ray line

Sterile neutrino decay



$$m_\nu = 7.1 \text{ KeV}$$
$$\tau \simeq 10^{29} \text{ sec}$$
$$\sin^2 2\theta \sim \text{few } 10^{-11}$$



Possible challenges:
- EU production?
- Perseus flux too large?

Caveat:

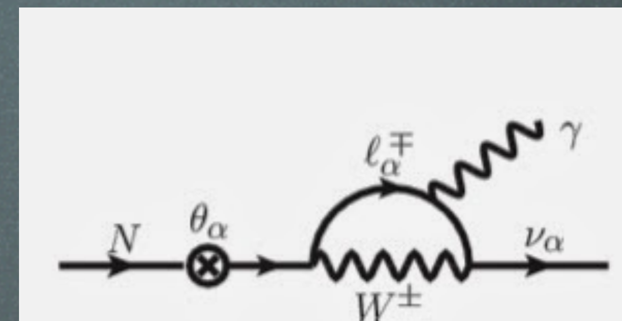
Riemer-Sørensen, 1405.7943

- no line seen with Chandra in the Galactic Center

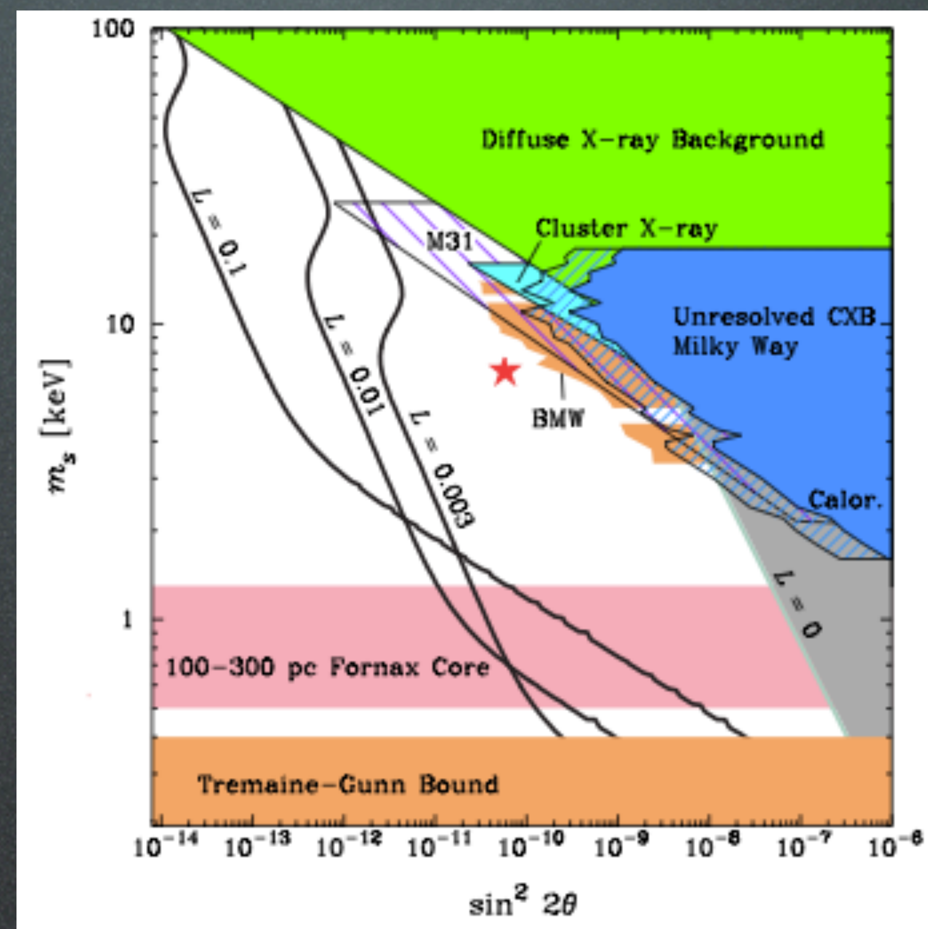
(but conclusion depends on how one models the local background)

X-ray line

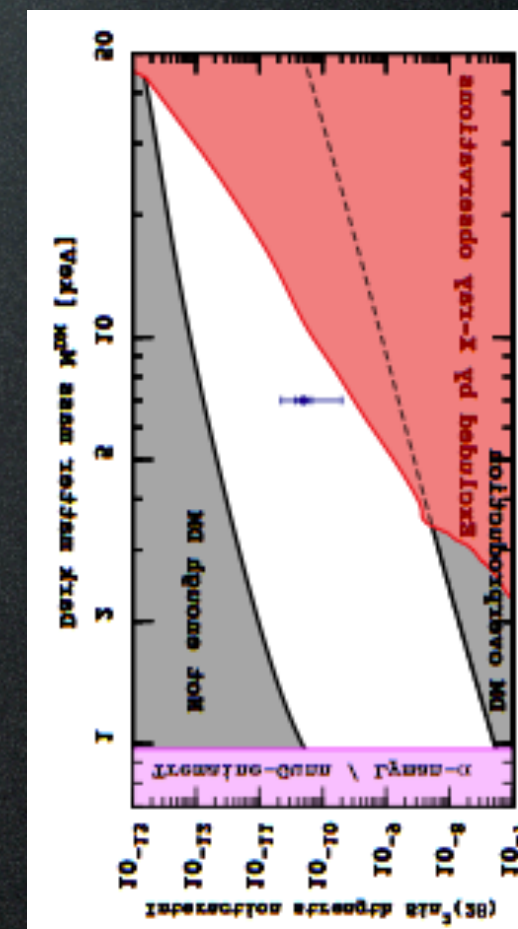
Sterile neutrino decay



$$m_\nu = 7.1 \text{ KeV}$$
$$\tau \simeq 10^{29} \text{ sec}$$
$$\sin^2 2\theta \sim \text{few } 10^{-11}$$



Bulbul et al., 1402.2301



Boyarsky, Ruchayskiy et al., 1402.4119

Possible challenges:
- EU production?
- Perseus flux too large?

Other possibilities:

axion (1402.7335), axino (1403.1536, 1403.1782, 1403.6621), modulus (1403.1733), ALP (1403.2370), gravitino (1403.6503), excited DM (1404.4795), the good the bad and the unlikely (1403.1570), sgoldstino (1404.1339), magnetic DM (1404.5446), majoron (1404.1400), annihilating effective DM (1404.1927), 7KeV scalar DM (1404.2220)...

Conclusions & Outlook

Hints

Constraints

Hopes

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA
FERMI
HESS

γ FERMI

X XMM-Newton

Constraints

Hopes

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA
FERMI
HESS

γ FERMI

X XMM-Newton

Constraints

γ FERMI, HESS, VERITAS etc

$\bar{p}$ PAMELA

ν SK, ICECUBE

Cosmology

Hopes

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA
FERMI
HESS

γ FERMI

X XMM-Newton

Constraints

γ FERMI, HESS,
VERITAS etc

$\bar{p}$ PAMELA

ν SK, ICECUBE

Cosmology

Hopes

$\bar{d}$ GAPS, AMS-02

γ ν

$\bar{p}$

AMS-02

- ‘enhancements’

- new theory directions

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA
FERMI
HESS

γ FERMI

X XMM-Newton

Constraints

γ FERMI, HESS, VERITAS etc

$\bar{p}$ PAMELA

ν SK, ICECUBE

Cosmology

Hopes

$\bar{d}$ GAPS, AMS-02

γ ν

$\bar{p}$

AMS-02

- ‘enhancements’

- new theory directions

Old wise remarks:

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA
FERMI
HESS

γ FERMI

X XMM-Newton

Constraints

γ FERMI, HESS, VERITAS etc

$\bar{p}$ PAMELA

ν SK, ICECUBE

Cosmology

Hopes

$\bar{d}$ GAPS, AMS-02

γ ν

$\bar{p}$

AMS-02

- 'enhancements'

- new theory directions

Old wise remarks:

- any convincing result must be multimessenger

Conclusions & Outlook

Hints

$e^{\pm}$ PAMELA, FERMI, HESS

γ FERMI

X XMM-Newton

Constraints

γ FERMI, HESS, VERITAS etc

$\bar{p}$ PAMELA

ν SK, ICECUBE

Cosmology

Hopes

$\bar{d}$ GAPS, AMS-02

γ ν

$\bar{p}$

AMS-02

- ‘enhancements’

- new theory directions

Old wise remarks:

- any convincing result must be multimessenger
- beware of uncertainties, beware of astrophysics