Indirect Dark Matter Searches

(for DM masses in the range 10-1000 GeV
and with emphasis on gamma-rays)

Alejandro Ibarra
Technische Universität München

Sangam@HRI
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Introduction

Many pieces of evidence for particle dark matter. However, very little is known about the properties of the dark matter particle:

Spin: 0 or 1/2 or 1 or 3/2 (possibly higher if composite)

Parity: + or –

Mass: 10^{-15} GeV $\longrightarrow$ 10^{15} GeV
(axions) (WIMPzillas)

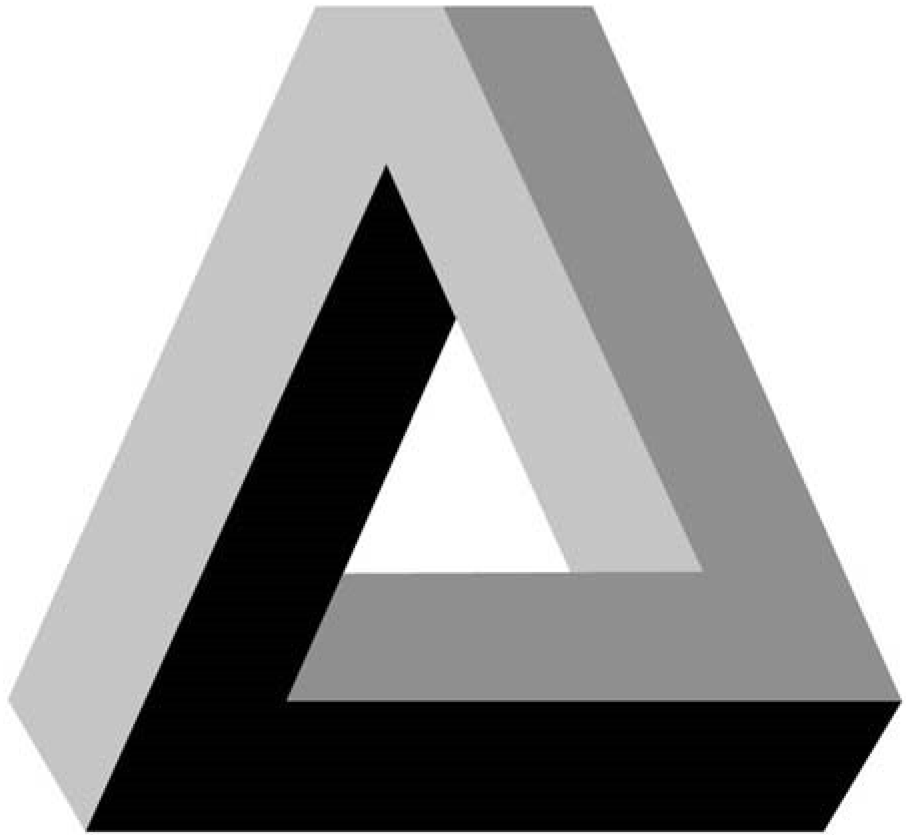
Interaction cross section with nucleons: 10^{-40} pb $\longrightarrow$ 10^{-5} pb
(gravitinos) (neutralinos)

Self-annihilation cross section: 10^{-40} pb $\longrightarrow$ 10^{-5} pb
(gravitinos) (neutralinos)

Lifetime: 10^{9} years $\longrightarrow$ infinity

Direct detection

DM nucleus $\to$ DM nucleus



Indirect detection

DM DM $\to \gamma$ X, e^+e^-... (annihilation)

DM $\to \gamma$ X, e^+X... (decay)

Collider searches

pp $\to$ DM X

Direct detection

DM nucleus → DM nucleus

Indirect detection

DM DM → γ X, e^+e^-... (annihilation)

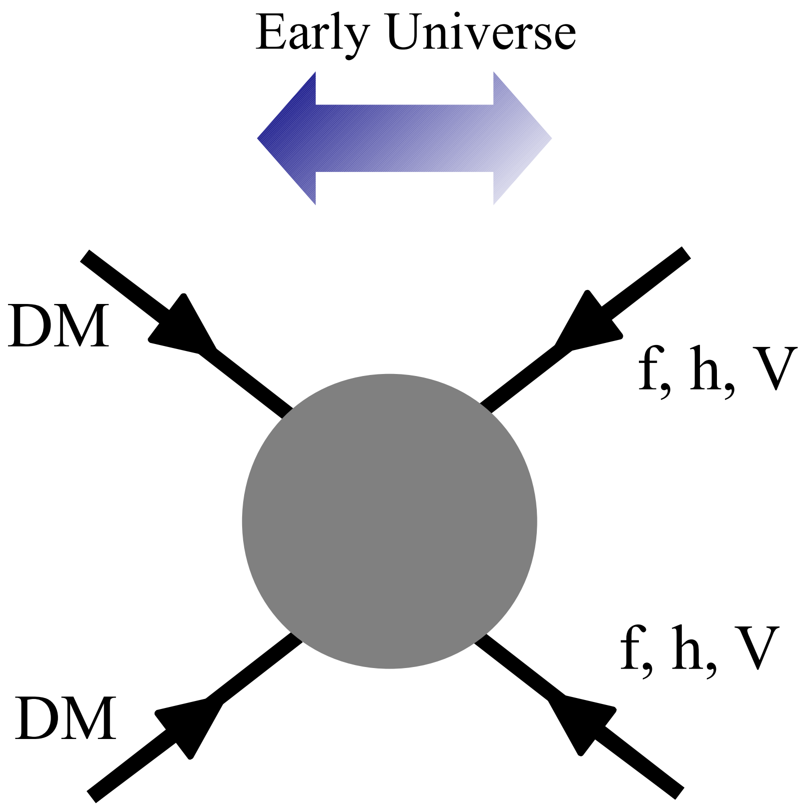
DM → γ X, e^+X... (decay)

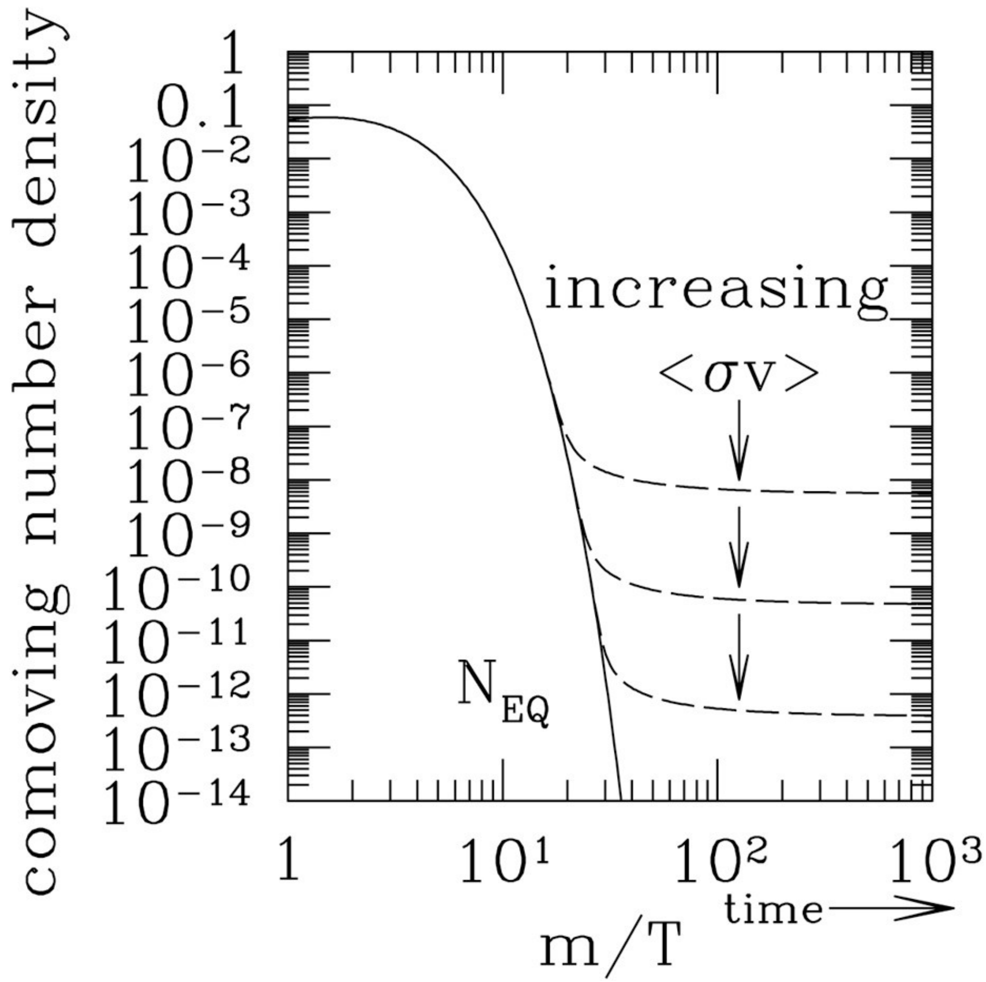
Collider searches

pp → DM X

Dark matter annihilations?

Guaranteed for thermal relics (WIMPs)

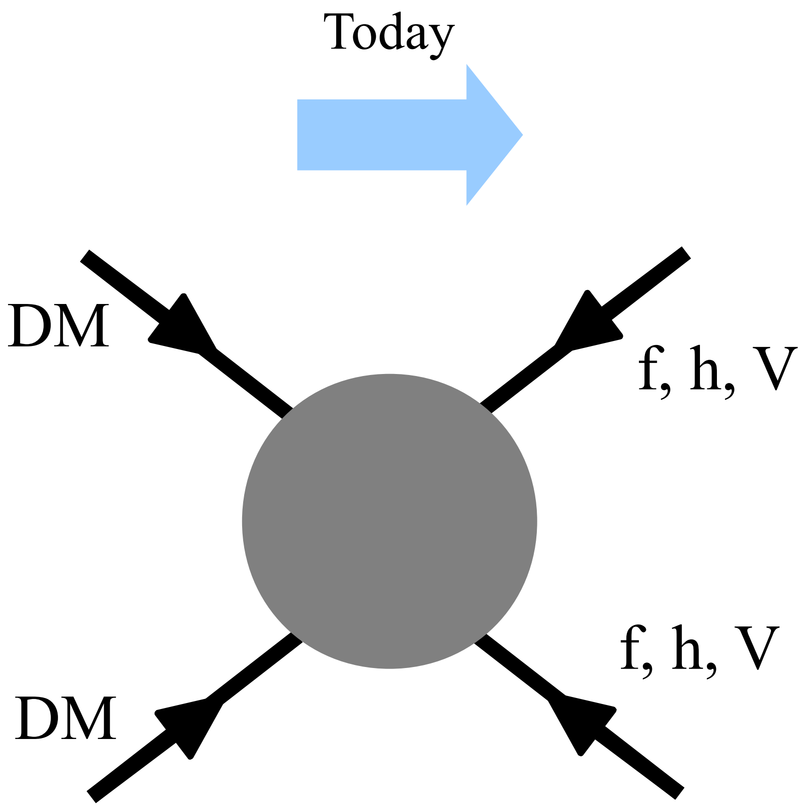




$$\Omega_{\rm DM} h^2 \simeq 0.11 \times \frac{3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}}{\langle \sigma_{\rm ann} v \rangle}$$

Dark matter annihilations?

Guaranteed for thermal relics (WIMPs)



Typical value of the velocity weighted annihilation cross-section

$$\langle \sigma_{\rm ann} v \rangle \simeq 3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

Target value for experiments

Note however that in some scenarios the annihilation cross section today can be very different to the annihilation cross section at the time of freeze-out.

Decompose the annihilation cross section as:

$$\langle \sigma v \rangle = a + b v^2$$

Assume now that $a = 0$. Then, the cross section strongly depends on the velocity of the dark matter particles

Freeze-out $\quad \langle v^2 \rangle \sim \frac{6T_{\rm f.o.}}{m_{\rm DM}} \sim 0.3 \quad \leftarrow \quad T_{\rm f.o.} \sim \frac{m_{\rm DM}}{20}$

Galactic center $\quad v \sim 10^{-3}$

$$\Rightarrow \quad \frac{\langle \sigma v \rangle_{\rm G.C.}}{\langle \sigma v \rangle_{\rm f.o.}} \sim 3 \times 10^{-6}$$

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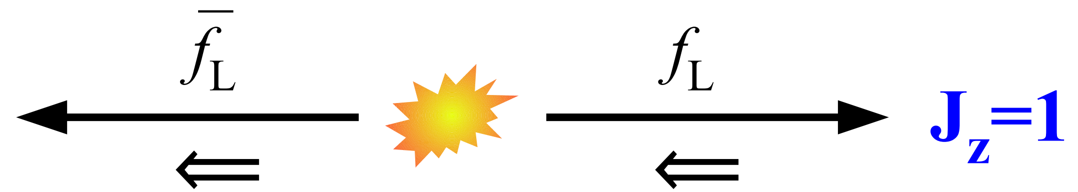
• Consider the annihilation DM DM → $f\bar{f}$, with DM a Majorana fermion or a scalar particle



In the limit $v \rightarrow 0$,
no preferred direction

J_z=0

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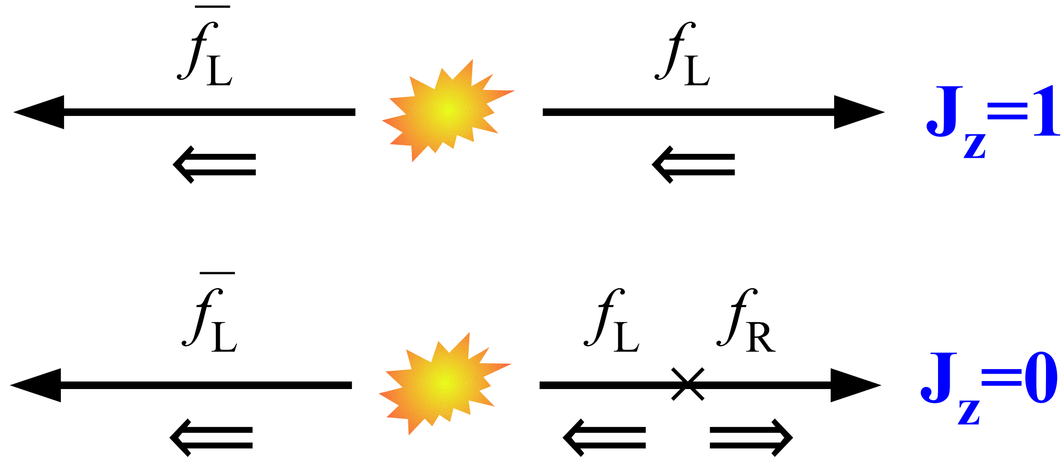

Rate of DM DM $\rightarrow f\bar{f}$ suppressed by $(m_f/m_{DM})^2$ if v=0. Otherwise by v^2.

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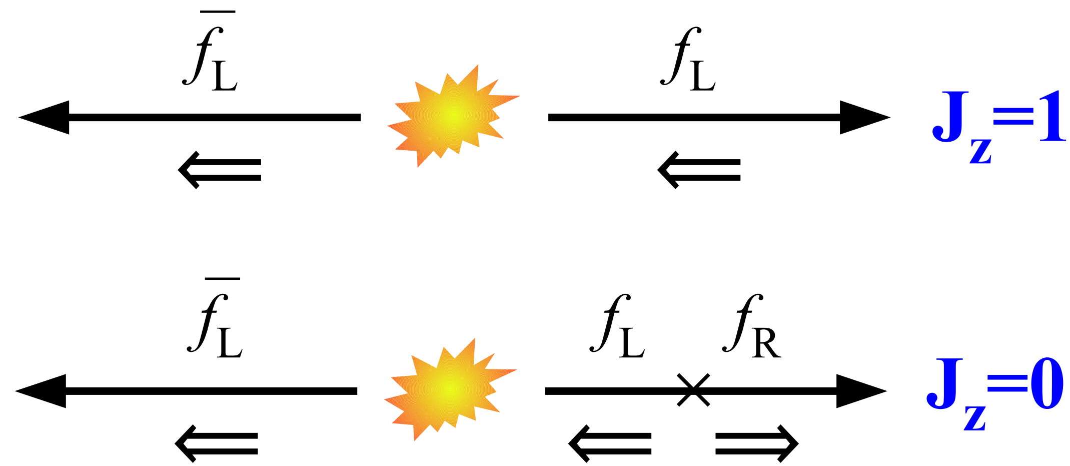


Rate of DM DM $\rightarrow f\bar{f}$ suppressed by $(m_f/m_{DM})^2$ if v=0. Otherwise by v^2.

• Relative contributions to the velocity weighted annihilation cross section $\langle\sigma v\rangle = a + bv^2$ for annihilations into light fermions:

For m=300 GeV, $$\frac{a}{bv^2} \sim \frac{m_f^2}{m_{\rm DM}^2 v^2} \sim \begin{cases} 10^{-6} & \text{for electrons} \\ 0.1 & \text{for muons} \\ 10^{-5} & \text{for up-type quarks} \end{cases}$$

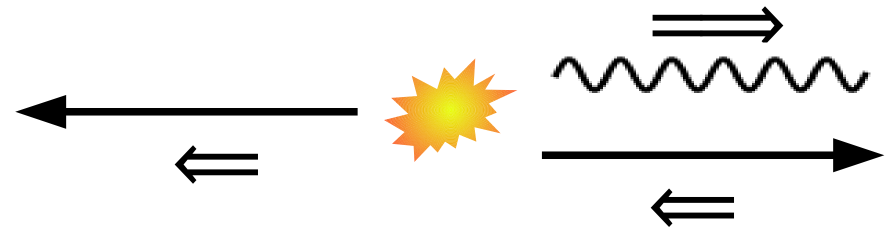
$$\Longrightarrow \langle\sigma v\rangle_{\rm G.C.} \sim 3\times 10^{-6}\langle\sigma v\rangle_{\rm f.o.} \sim 10^{-31}\,{\rm cm^3 s^{-1}}$$

Indirect detection hopeless?? Not really... higher order effects become important.

• Consider the annihilation DM DM $\rightarrow f\bar{f}V$, with DM a Majorana fermion or a scalar particle and V a vector

In the limit $v \rightarrow 0$,
no preferred direction

J_z=0



J_z=0

No suppression by mass insertion.
Suppressed, however, by the extra coupling constant and by the 3-body phase space.

Bergström
Flores, Olive, Rudaz

For annihilations into light fermions, the dominant annihilation channel *today* can be DM DM $\rightarrow f\bar{f}V$, while at the time of freeze-out, DM DM $\rightarrow f\bar{f}$

$$\langle\sigma v\rangle^{2\rightarrow 3}_{G.C.} \sim \frac{\alpha}{0.3\pi}\langle\sigma v\rangle^{2\rightarrow 2}_{f.o.} \sim 10^{-28}\mathrm{cm}^3\mathrm{s}^{-1}$$

Target cross section for this class of scenarios, instead of $3\times10^{-26}\,\mathrm{cm}^3\mathrm{s}^{-1}$.

Dark matter decays?

No matter particle is guaranteed to be stable

particle	Lifetime	Decay channel	Theoretical justification
proton	$\tau > 8.2 \times 10^{33}$ years	$p \to e^+ \pi^0$	Baryon number conservation
electron	$\tau > 4.6 \times 10^{26}$ years	$e \to \gamma \nu$	Electric charge conservation
neutrino	$\tau \gtrsim 10^{12}$ years	$\nu \to \gamma \gamma$	Lorentz symmetry conservation
neutron	$\tau = 885.7 \pm 0.8$ s	$n \to p \bar{\nu}_e e^-$	Isospin symmetry mildly broken.

} Accidental symmetry (proton)

} Local symmetry (electron, neutrino)

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dark matter	$\tau \gtrsim 10^{9}$ years	???	???

} Accidental symmetry (proton)

} Local symmetry (electron, neutrino)

It is conceivable that the dark matter particle is long lived due to an accidental symmetry of the renormalizable Lagrangian (as for the proton).

Higher dimensional operators may induce the dark matter decay (as for the proton). For a dimension six operator suppressed by a large scale M,

$$\tau_{\rm DM} \sim 10^{26}{\rm s} \left(\frac{\rm TeV}{m_{\rm DM}}\right)^5 \left(\frac{M}{10^{15}{\rm GeV}}\right)^4$$

Indirect dark matter searches

Production		Antimatter
Propagation	of	Gamma-rays
Detection		Neutrinos

Indirect dark matter searches

Production			Antimatter
Propagation	of		Gamma-rays ← This talk
Detection			Neutrinos

Production of gamma-rays

The gamma ray flux from dark matter annihilation/decay has two components:

- Prompt radiation of gamma rays produced in the annihilation/decay (final state radiation, pion decay...)
- May contain spectral features.

- Inverse Compton Scattering radiation of electrons/positrons produced in the annihilation/decay.
- Always smooth spectrum.

Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Halo component

Extragalactic component

Prompt radiation

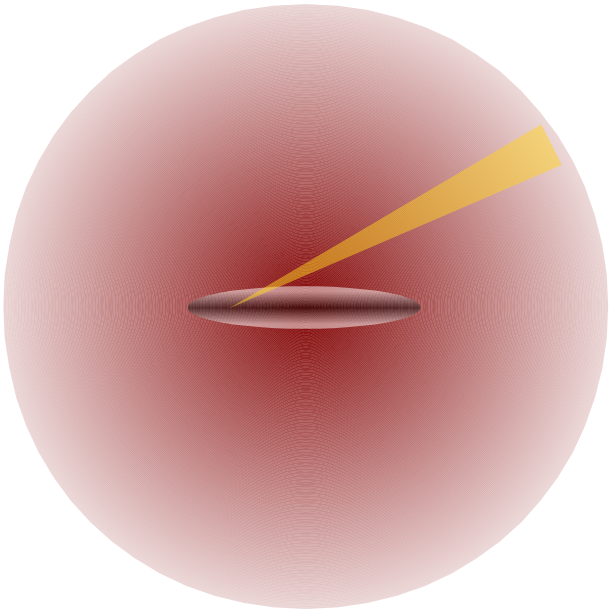
$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

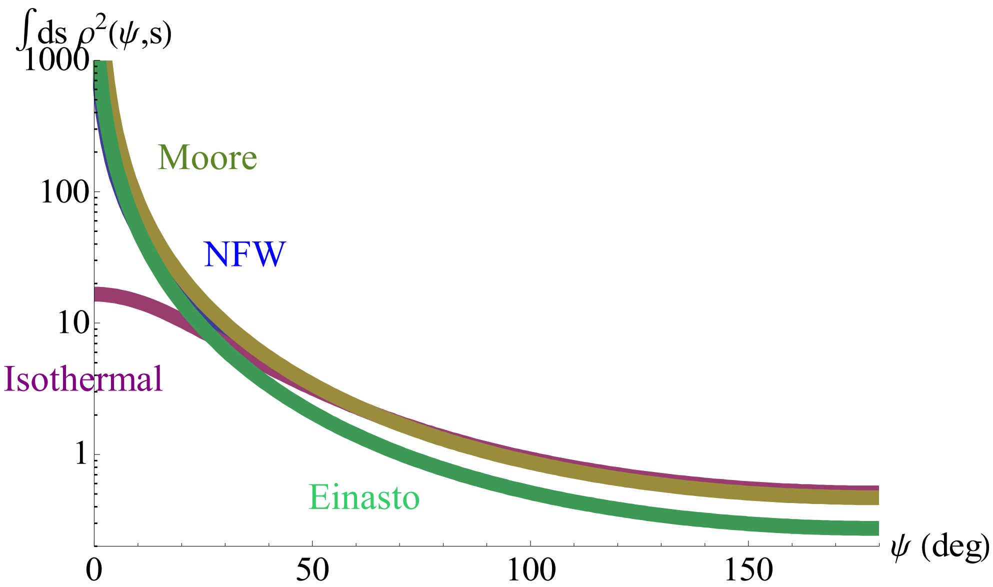
Halo component

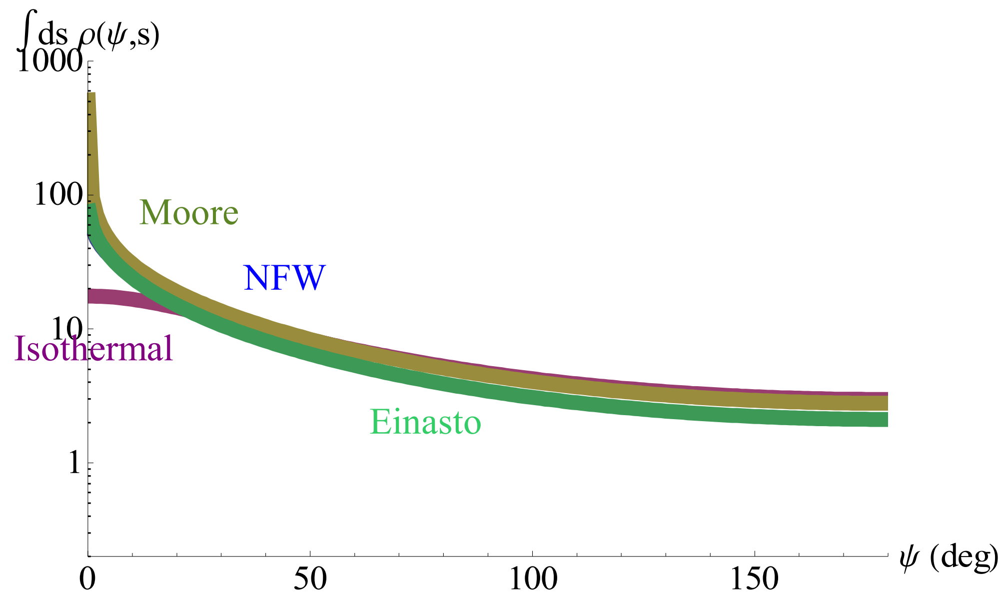
Annihilation $$\frac{dJ}{dE_\gamma} = \frac{1}{4\pi}\left[\frac{\langle\sigma_{\rm ann}v\rangle}{2m_{\rm DM}^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f\right] \times \int_{\rm l.o.s.} \rho^2(\vec{l})\, d\vec{l}$$

Source term (particle physics) — Line-of-sight integral (astrophysics)

Decay $$\frac{dJ}{dE_\gamma} = \frac{1}{4\pi}\left[\frac{1}{\tau_{\rm DM}\, m_{\rm DM}}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f\right] \times \int_{\rm l.o.s.} \rho(\vec{l})\, d\vec{l}$$




∫ds ρ²(ψ,s)
1000
100
10
1
0
50
100
150
ψ (deg)
Moore
NFW
Isothermal
Einasto


∫ds ρ(ψ,s)
1000
100
10
1
0
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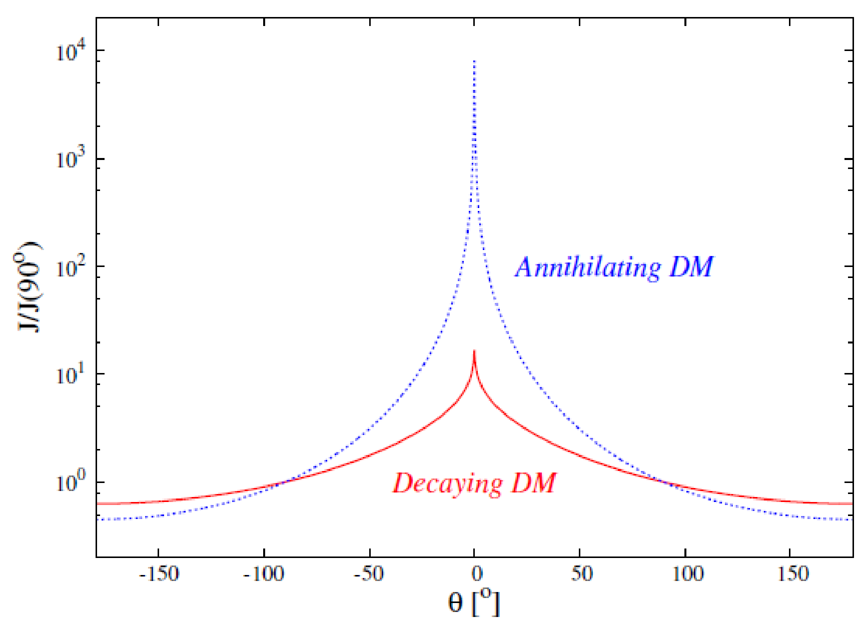
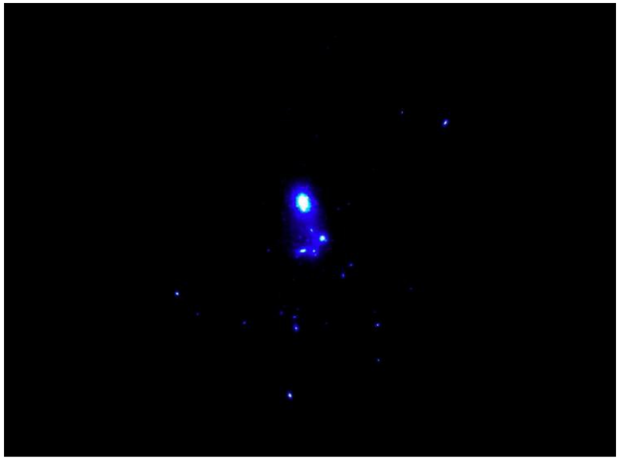

J/J(90°)
10^4
10^3
10^2
10^1
10^0
-150
-100
-50
0
50
100
150
θ [°]
Annihilating DM
Decaying DM

Prompt radiation: Effect of substructures

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

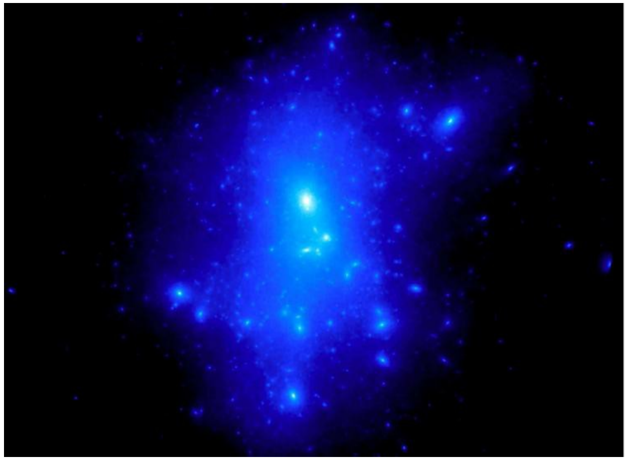
Halo component

Annihilation
$$\frac{dJ}{dE_\gamma} = \frac{1}{4\pi}\left[\frac{\langle\sigma_{\rm ann} v\rangle}{2m_{\rm DM}^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f\right] \times \int_{\rm l.o.s.} \rho^2(\vec{l})\, d\vec{l}$$



Source term (particle physics) — Line-of-sight integral (astrophysics)

Decay
$$\frac{dJ}{dE_\gamma} = \frac{1}{4\pi}\left[\frac{1}{\tau_{\rm DM}\, m_{\rm DM}}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f\right] \times \int_{\rm l.o.s.} \rho(\vec{l})\, d\vec{l}$$



Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Halo component

Summary:

- Depends on the dark matter profile. Strong dependence in the direction of the galactic center and mild at high latitudes (|b|>10°)
- Even if the profile is spherically symmetric, the flux at Earth depends on the direction of observation.

Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Extragalactic component

- Isotropic

Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Extragalactic component

- Isotropic
- Redshifted

Annihilation

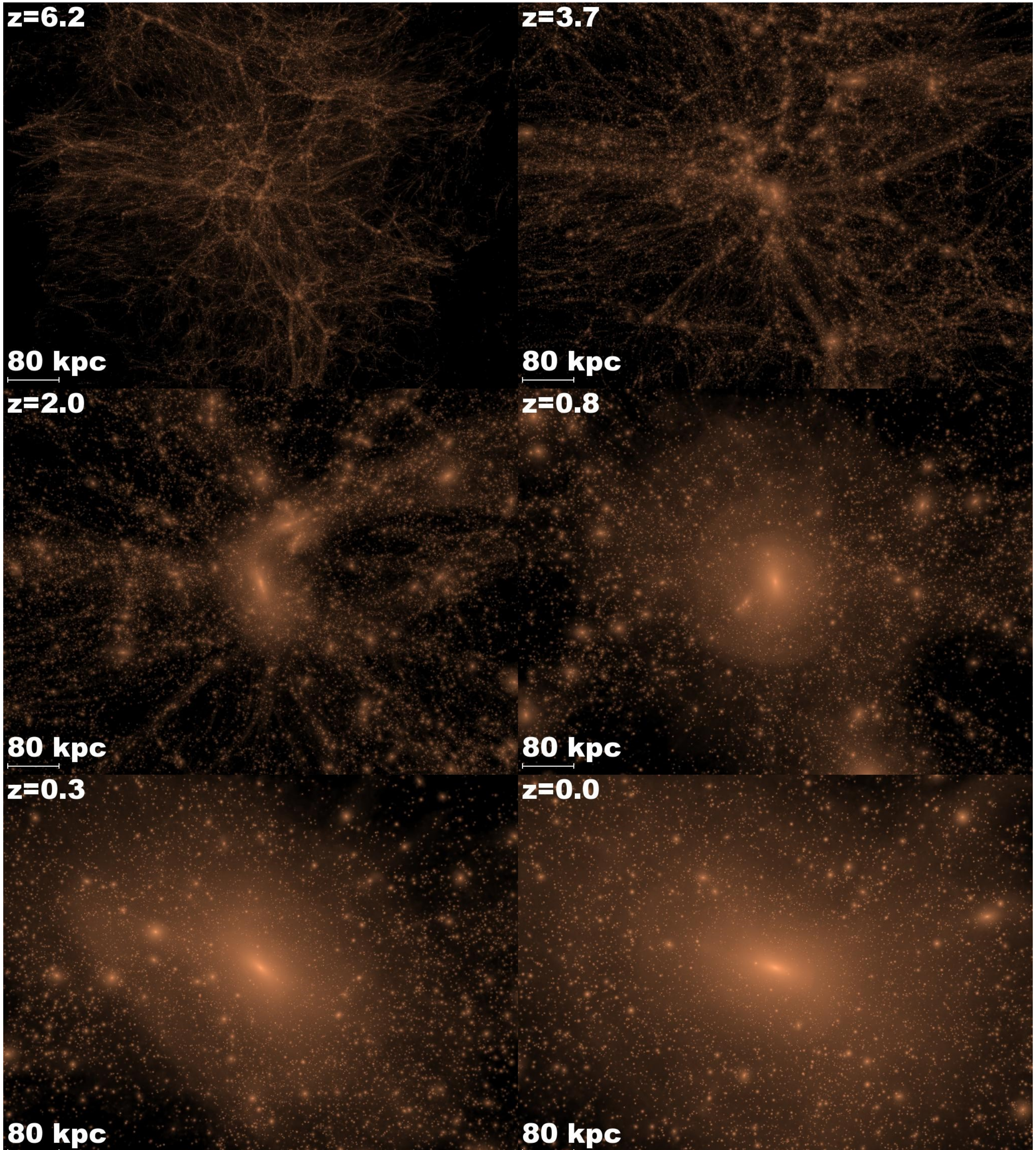
$$\frac{dJ_{\rm eg}}{dE_\gamma} = \frac{c}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2}\frac{\Omega^2_{\rm DM}\rho^2_{\rm c}}{m^2_{\rm DM}}\int_0^\infty dz \frac{1}{H(z)}\frac{dN_\gamma\left[(1+z)E_\gamma\right]}{dE_\gamma}\, e^{-\tau(E_\gamma,z)}$$

Decay

$$\frac{dJ_{\rm eg}}{dE_\gamma} = \frac{c}{4\pi}\frac{\Omega_{\rm DM}\rho_{\rm c}}{m_{\rm DM}\tau_{\rm DM}}\int_0^\infty dz \frac{1}{H(z)}\frac{dN_\gamma\left[(1+z)E_\gamma\right]}{dE_\gamma}\, e^{-\tau(E_\gamma,z)}$$

12.8 Gyr ago

12 Gyr ago



10.3 Gyr ago

6.8 Gyr ago

3.4 Gyr ago

Now

Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Extragalactic component

- Isotropic
- Redshifted

Enhancement

Annihilation $$\frac{dJ_{\rm eg}}{dE_\gamma} = \frac{c}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2}\frac{\Omega_{\rm DM}^2\rho_{\rm c}^2}{m_{\rm DM}^2}\int_0^\infty dz\frac{1}{H(z)}\frac{dN_\gamma\left[(1+z)E_\gamma\right]}{dE_\gamma}(1+z)^3\Delta^2(z)\, e^{-\tau(E_\gamma,z)}$$

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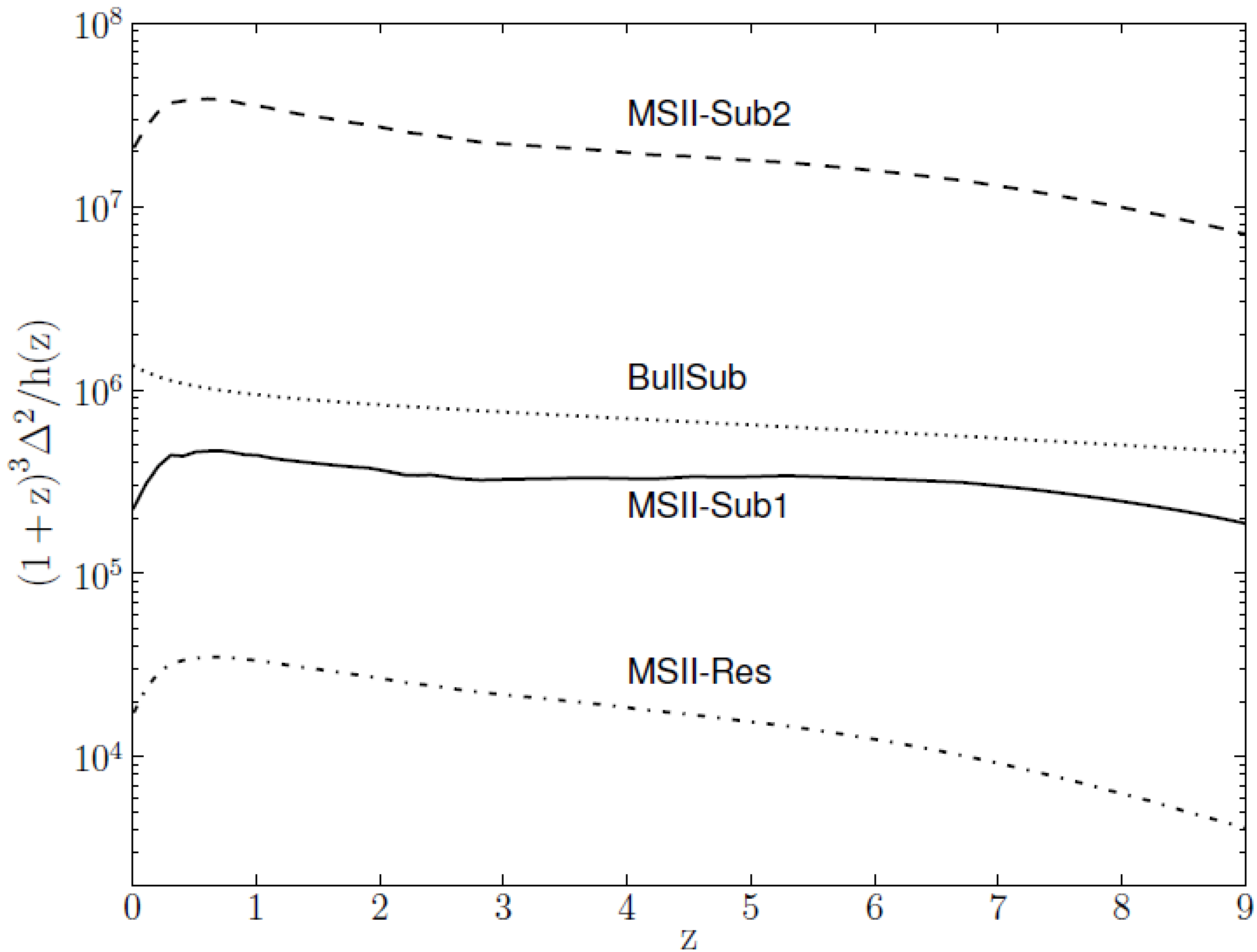

Fermi coll.
arXiv:1002.4415

Prompt radiation

$$\frac{dJ}{dE_\gamma}(\Omega) = \frac{dJ_{\rm halo}}{dE_\gamma}(\Omega) + \frac{dJ_{eg}}{dE_\gamma}$$

Extragalactic component

- Isotropic
- Redshifted
- Attenuated due to pair production $\gamma\gamma \rightarrow e^+e^-$

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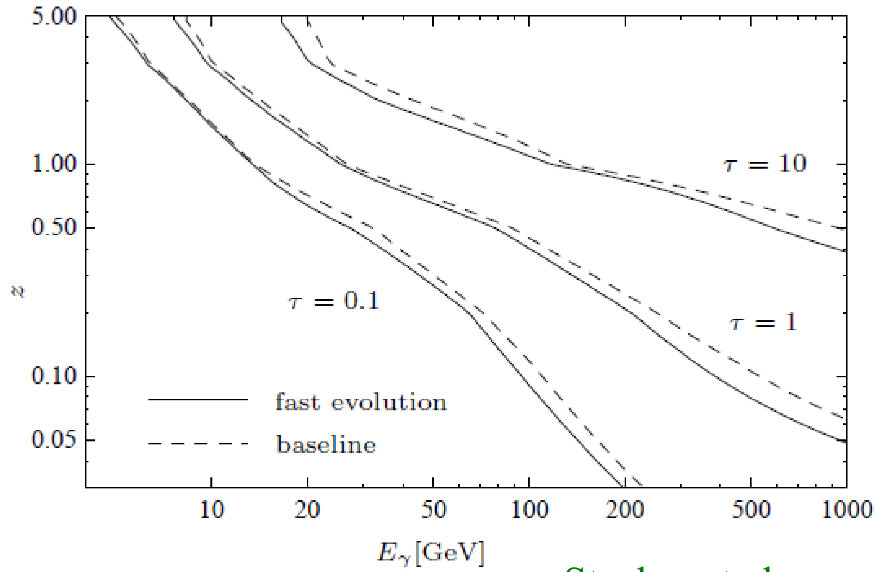
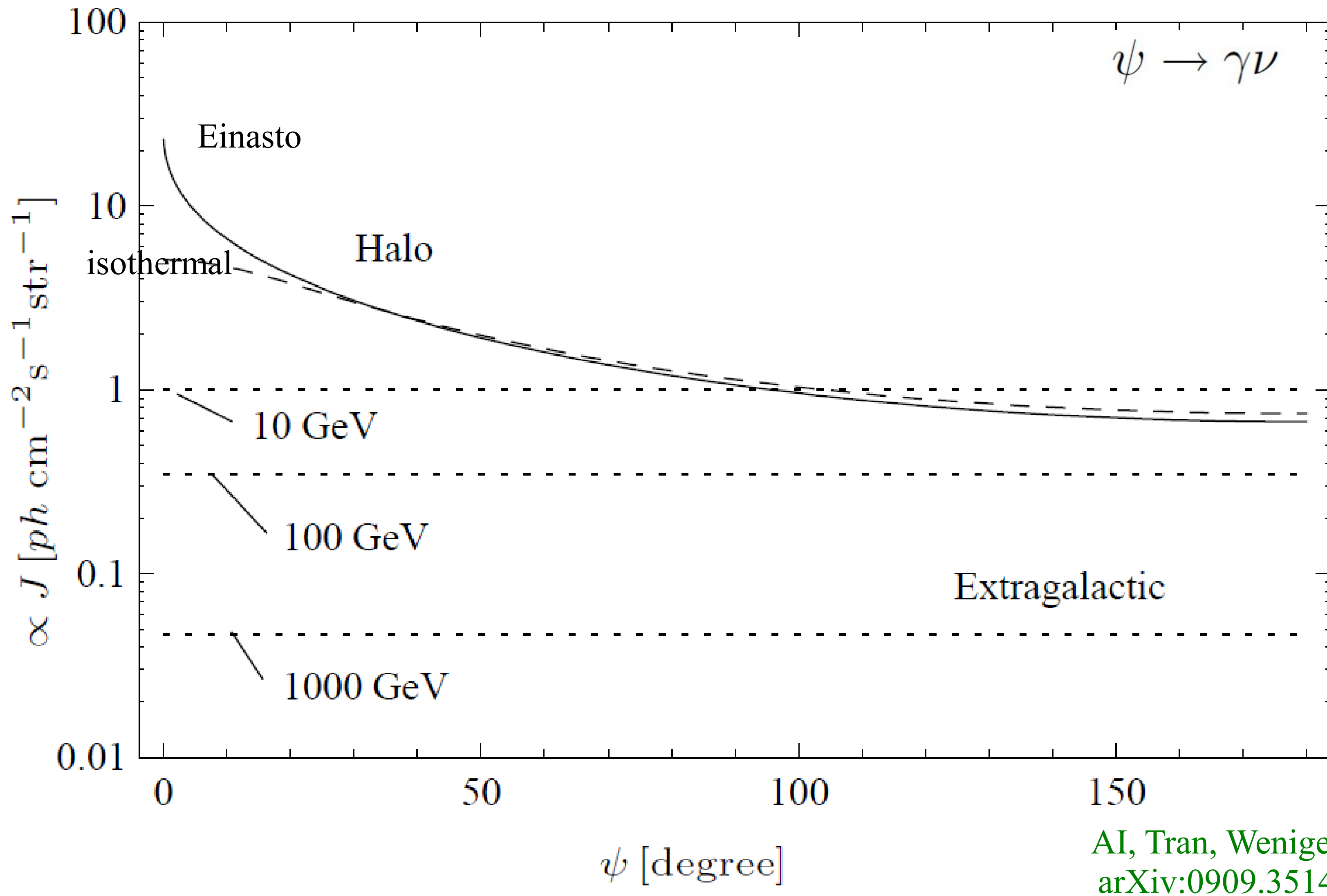


Stecker et al.

Impact of attenuation: decaying dark matter



AI, Tran, Weniger
arXiv:0909.3514

Inverse Compton Scattering radiation

The inverse Compton scattering of electrons/positrons from dark matter annihilation/decay with the interstellar and extragalactic radiation fields produces gamma rays.

$$e^{\pm} + \gamma \rightarrow e^{\pm} + \gamma^{*}$$

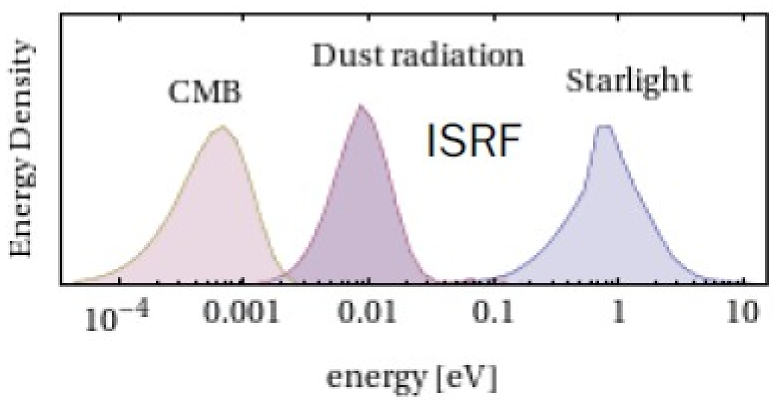
$e^{\pm}$ from dark matter annihilation/decay $E_e \lesssim 1$ TeV

Upscattered photon

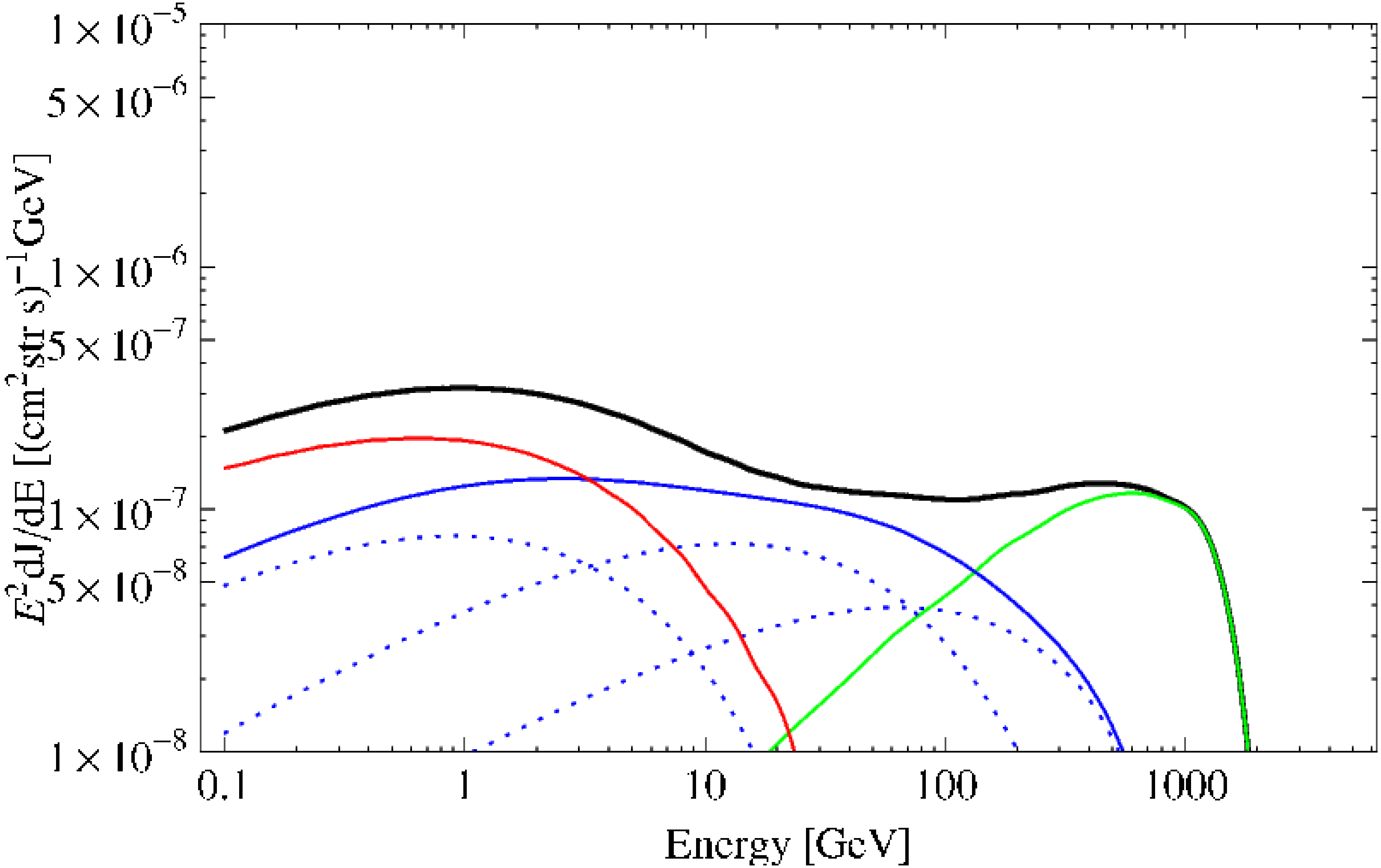
$$E_{\gamma^*} \leq 4 \left(\frac{E_e}{m_e}\right)^2 E_\gamma$$

This produces $E_{\gamma*} \lesssim 100$ GeV

Interstellar radiation field (starlight, thermal radiation of dust, CMB)



$\phi \to \mu^+\mu^-$, m_{DM}=2500 GeV, τ_{DM}=1.8×10^{26}s



AI, Tran, Weniger,
arXiv:0906.1571

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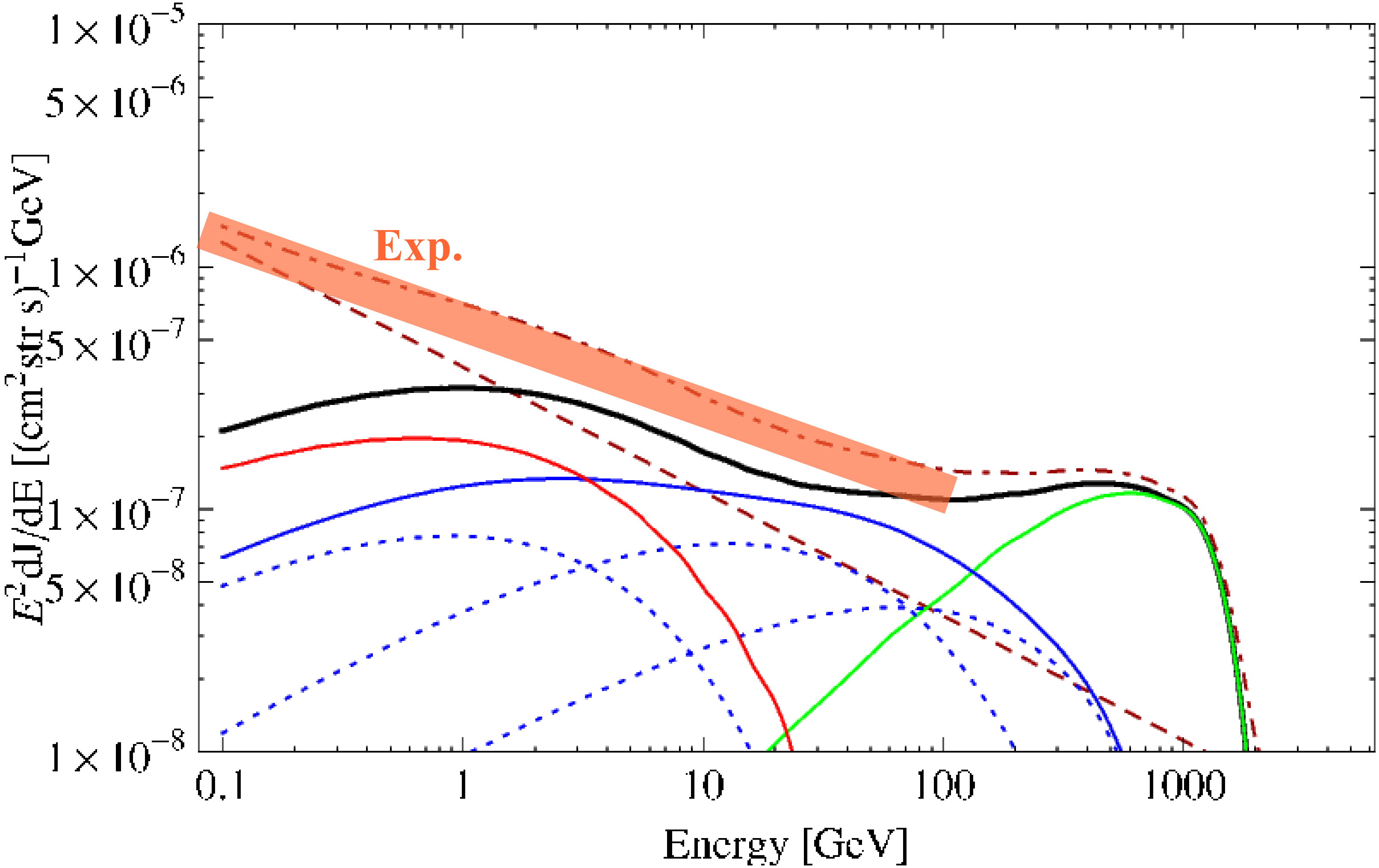
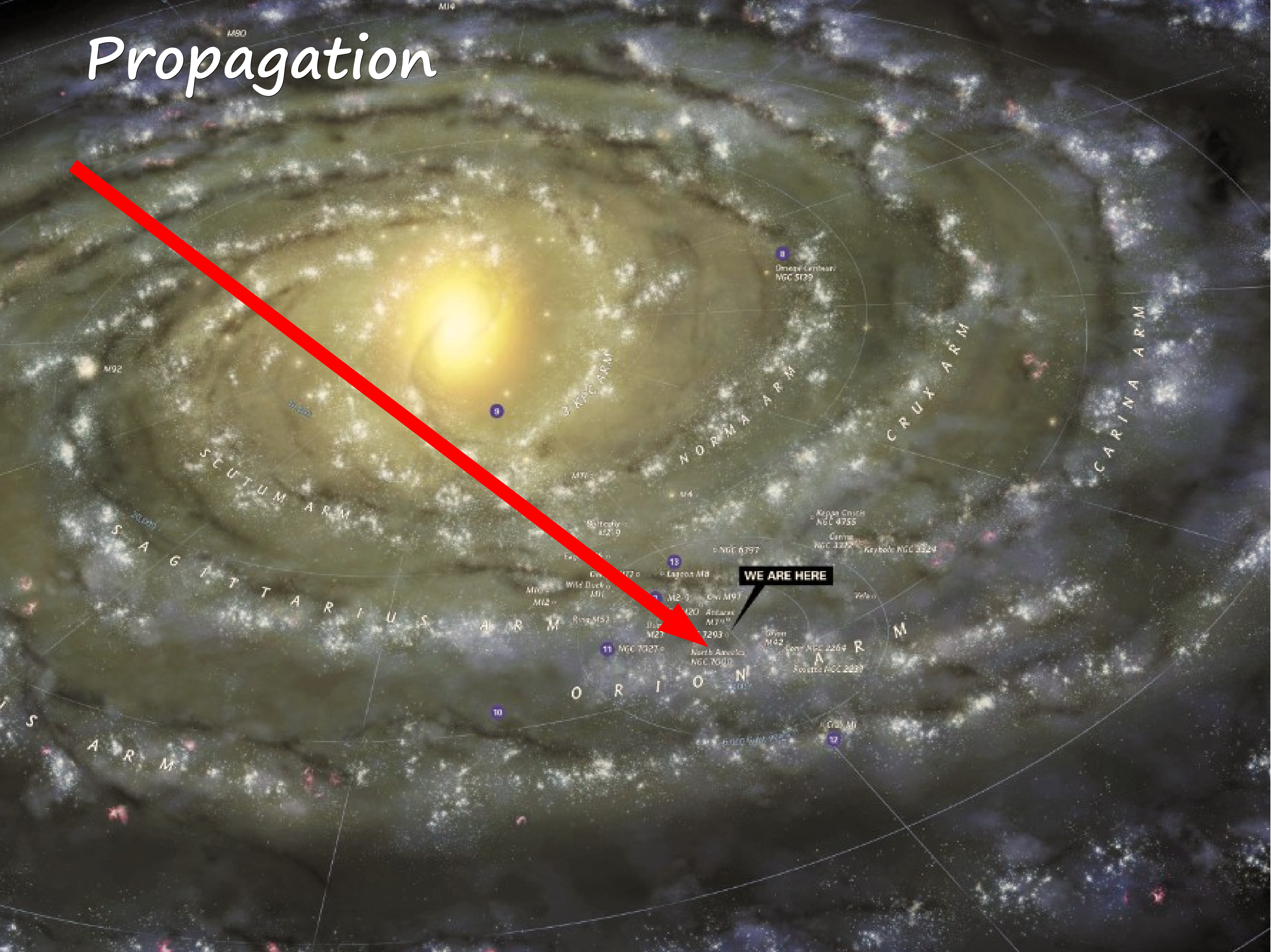


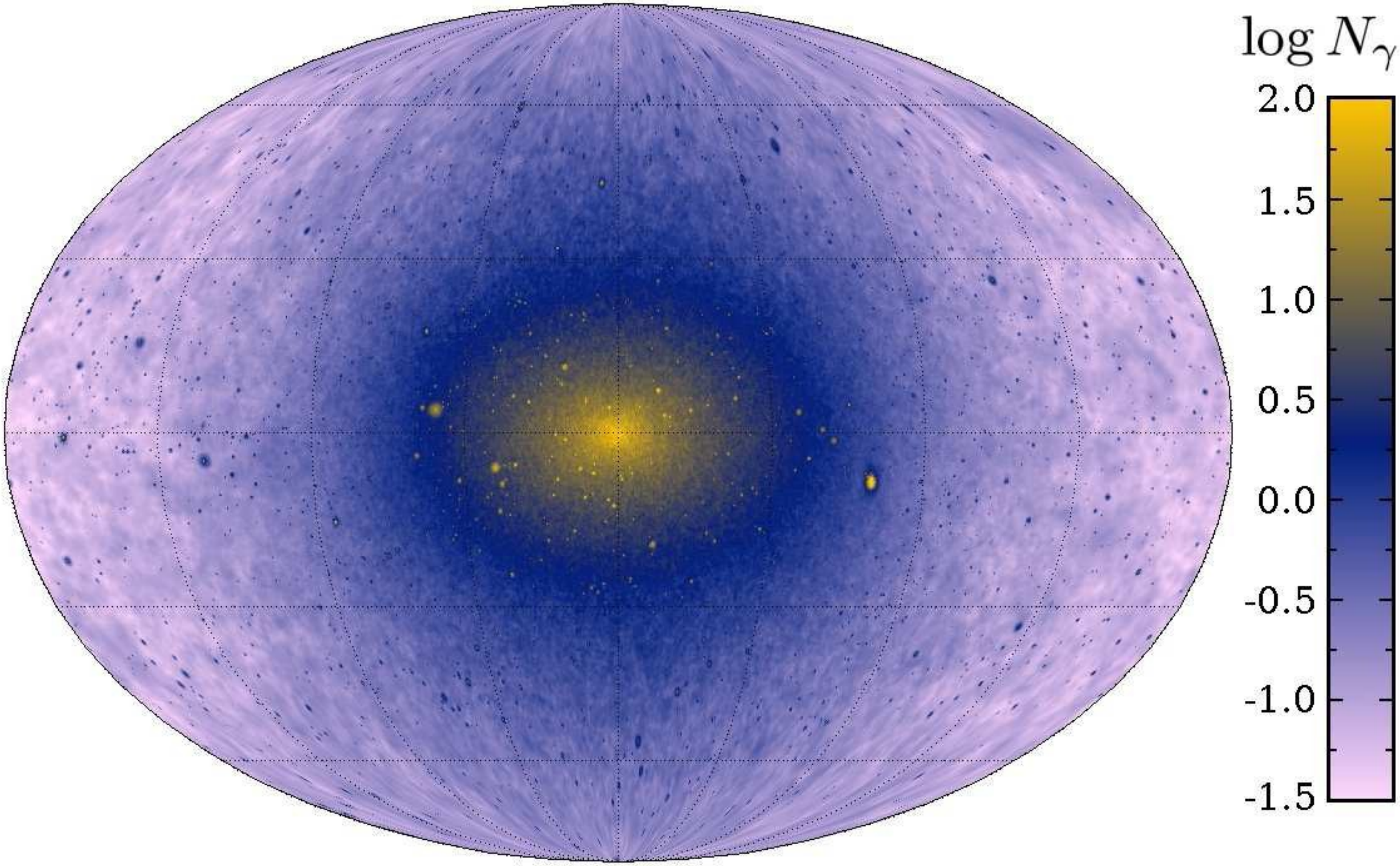
AI, Tran, Weniger,
arXiv:0906.1571

Propagation



Targets for indirect dark matter searches

Baltz et al. arXiv:0806.2911
Bertone et al. arXiv:0709.2299



Kuhlen, Diemand, Madau

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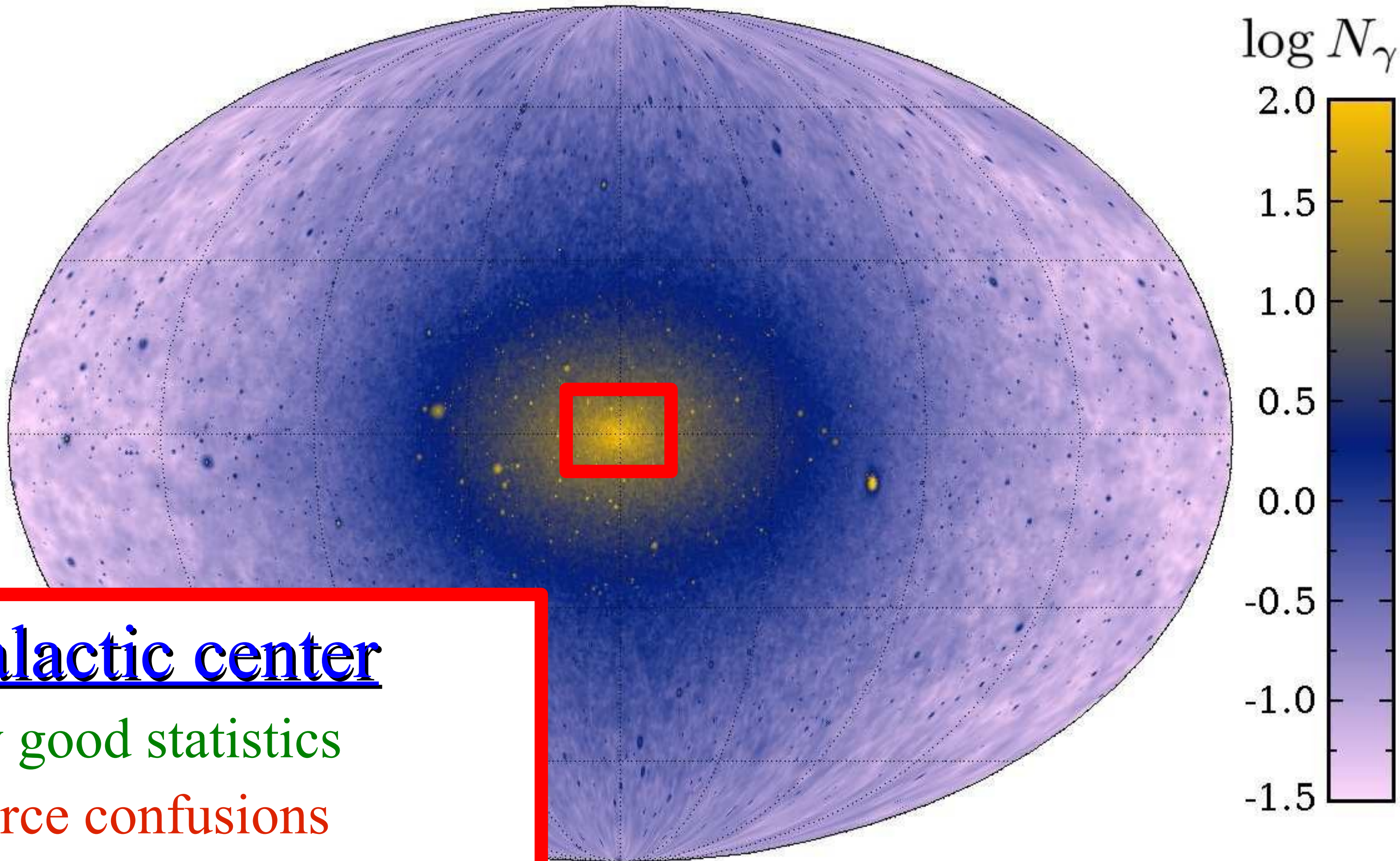


Kuhlen, Diemand, Madau

Galactic center

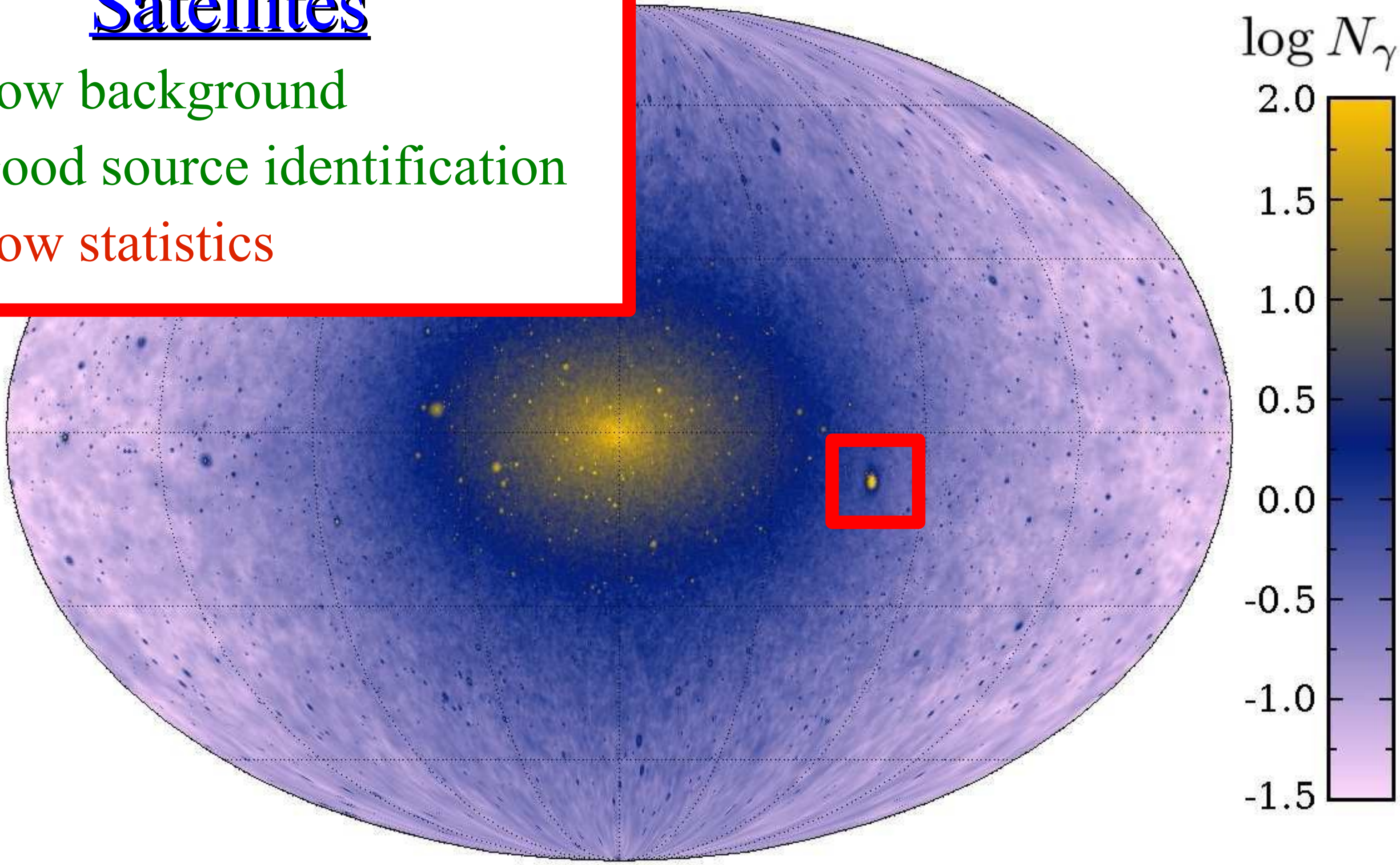
- 👍 Very good statistics
- 👎 Source confusions
- 👎 Uncertainties in diffuse background modelling

Targets for indirect dark matter searches

Baltz et al. arXiv:0806.2911
Bertone et al. arXiv:0709.2299

Satellites

- Low background
- Good source identification
- Low statistics



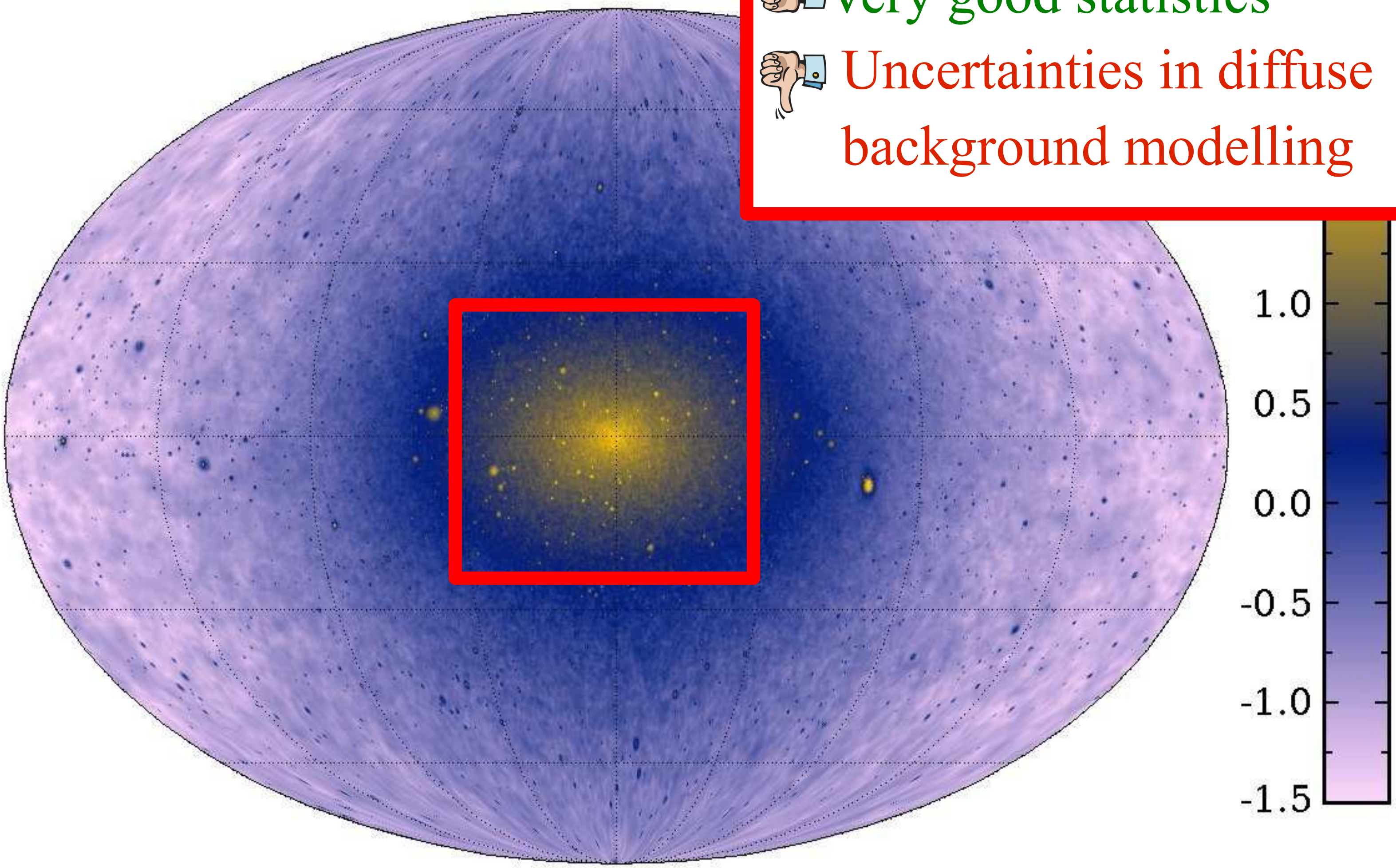
Kuhlen, Diemand, Madau

Targets for indirect dark matter searches

Baltz et al. arXiv:0806.2911
Bertone et al. arXiv:0709.2299

Galactic halo

- Very good statistics
- Uncertainties in diffuse background modelling



Kuhlen, Diemand, Madau

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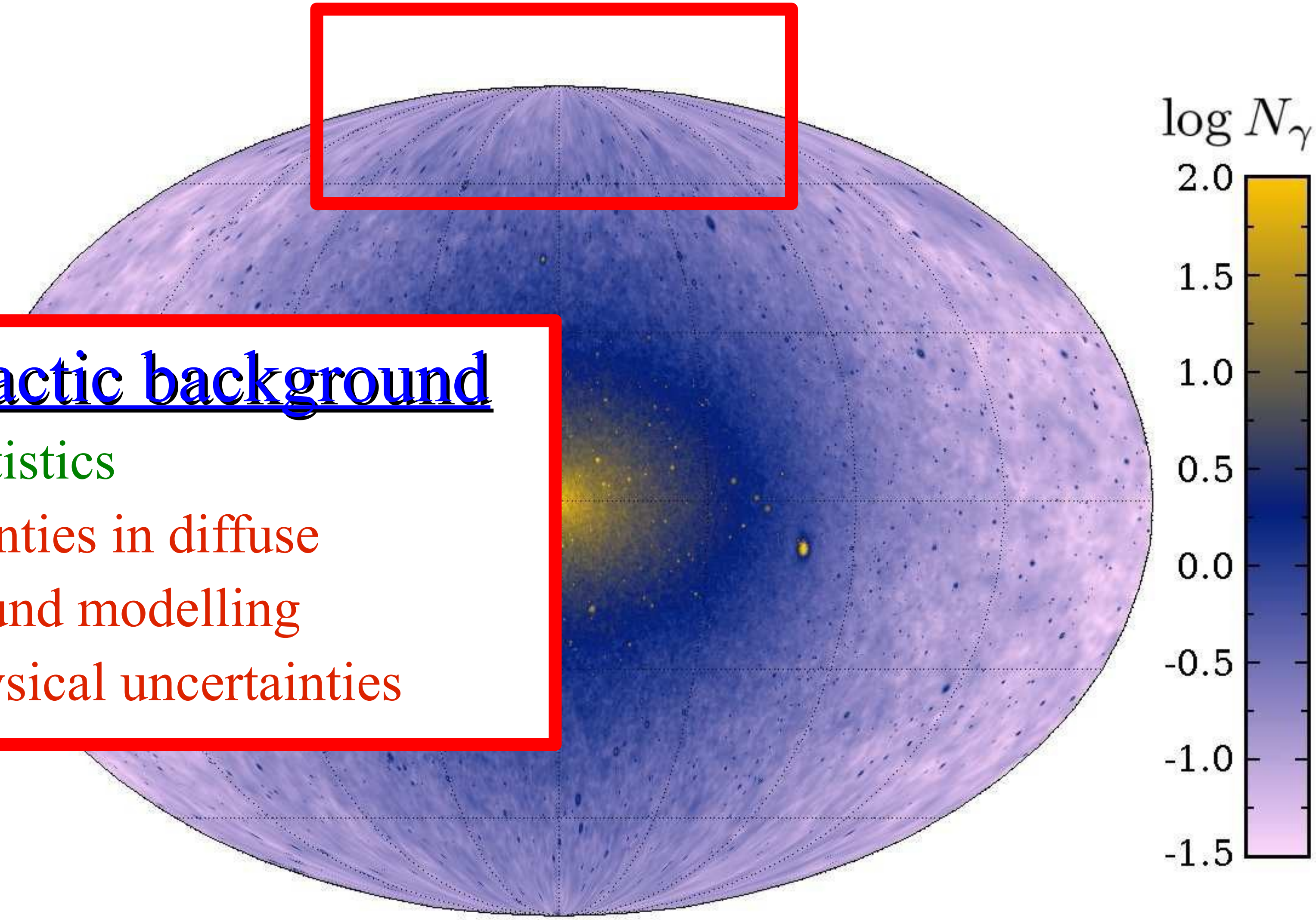

Extragalactic background

- 👍 Good statistics
- 👎 Uncertainties in diffuse background modelling
- 👎 Astrophysical uncertainties

Kuhlen, Diemand, Madau

Targets for indirect dark matter searches

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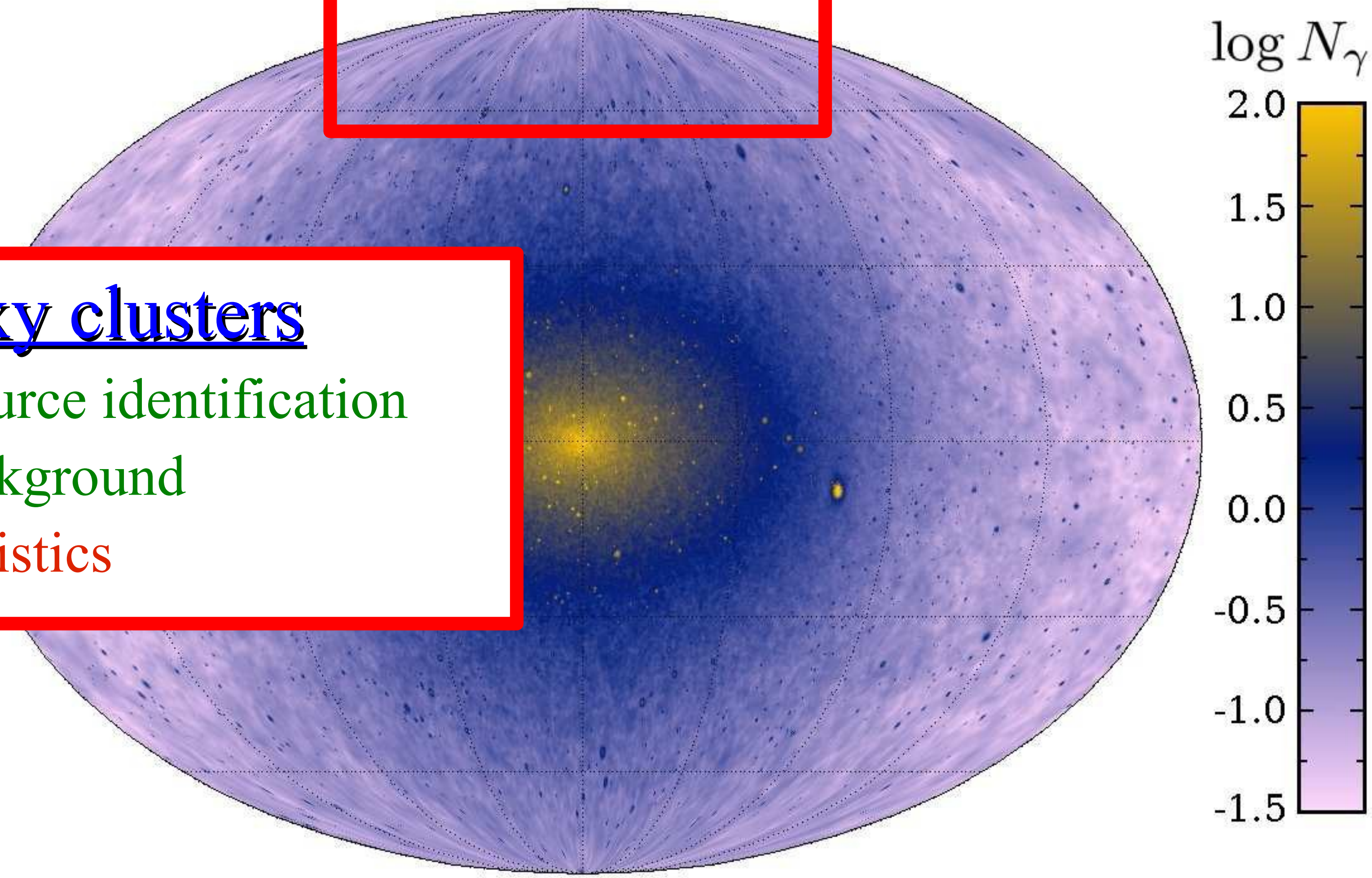


Kuhlen, Diemand, Madau

Galaxy clusters

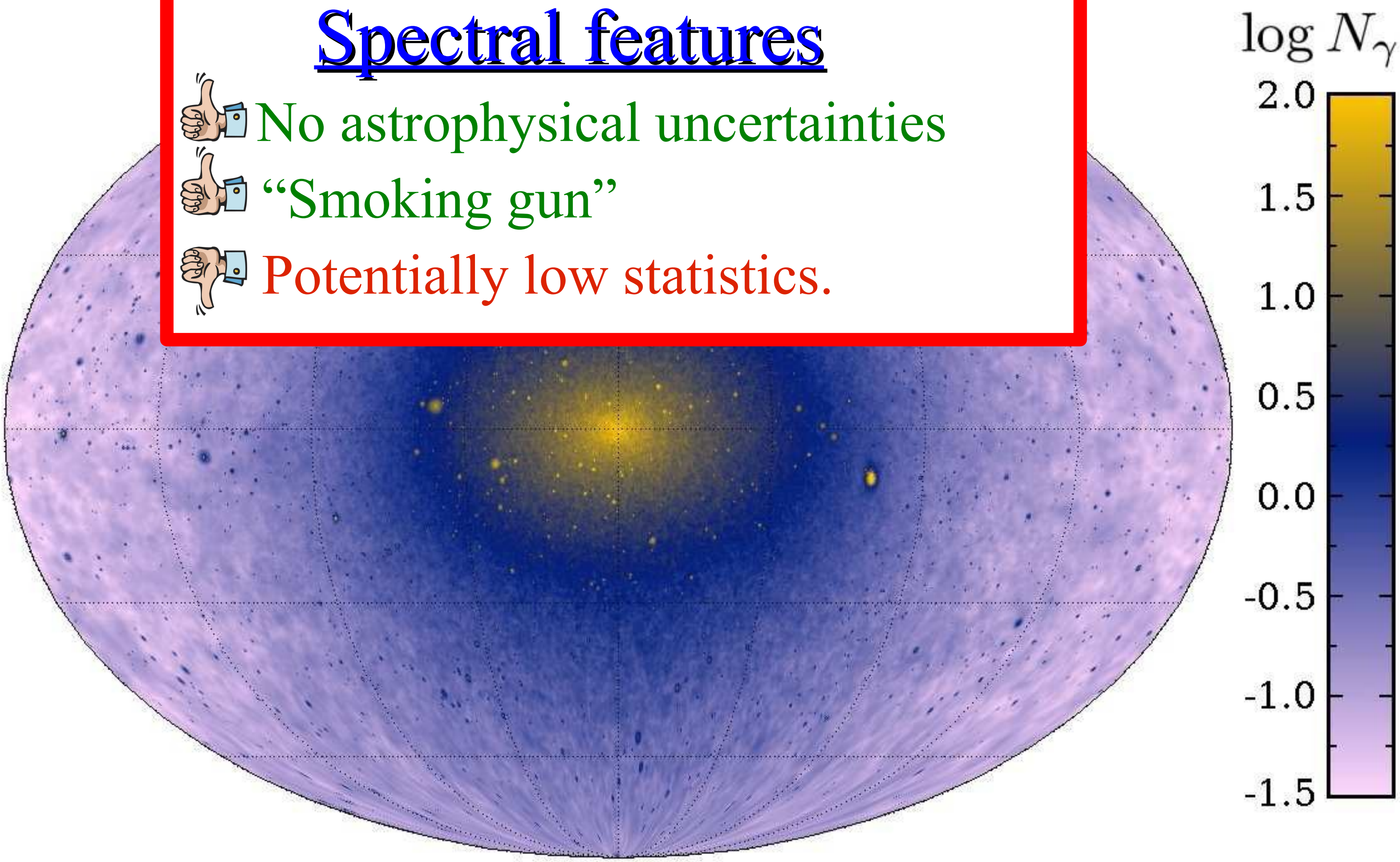
- 👍 Good source identification
- 👍 Low background
- 👎 Low statistics

Targets for indirect dark matter searches

Baltz et al. arXiv:0806.2911
Bertone et al. arXiv:0709.2299

Spectral features

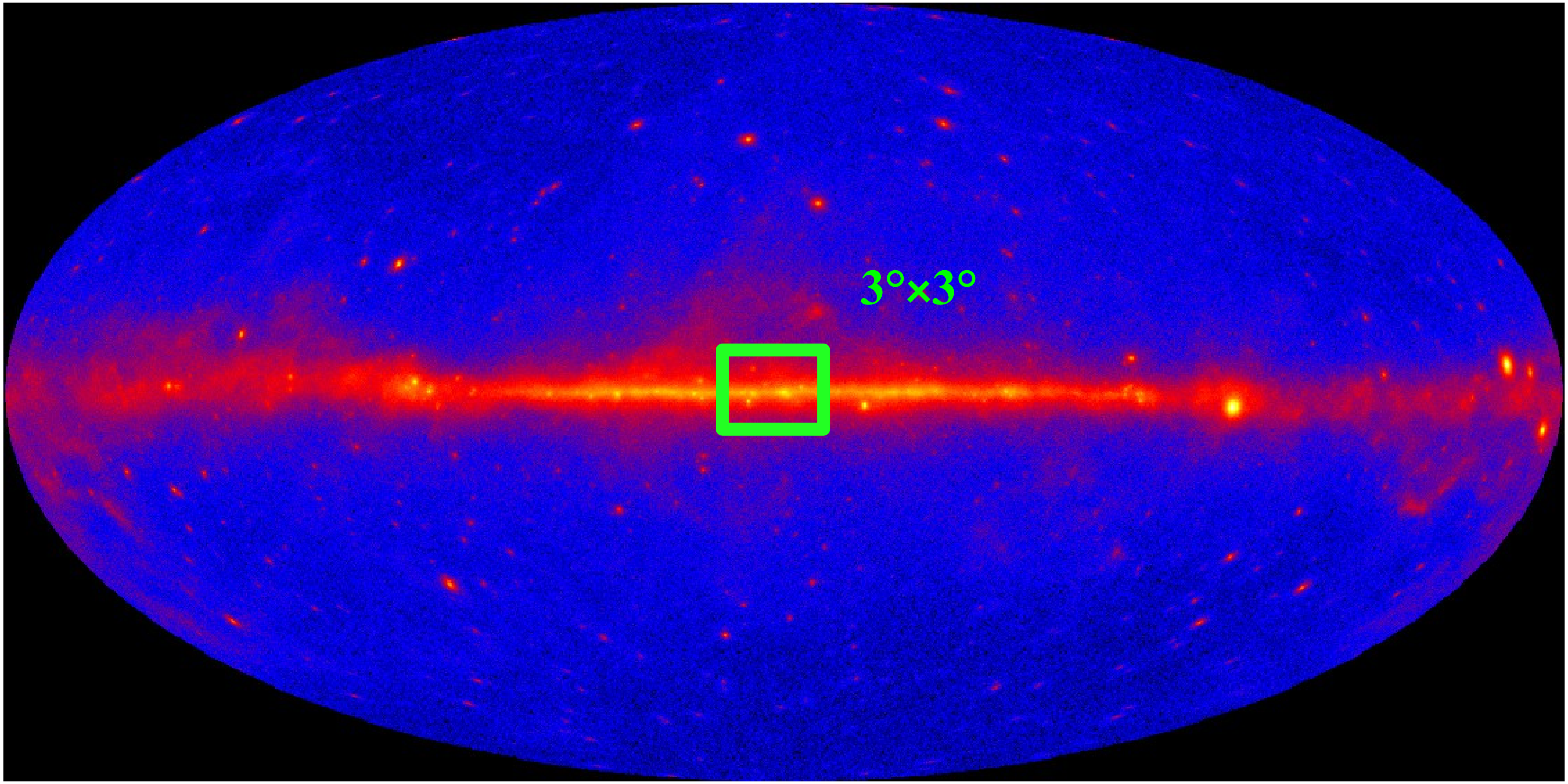
- 👍 No astrophysical uncertainties
- 👍 "Smoking gun"
- 👎 Potentially low statistics.



Kuhlen, Diemand, Madau

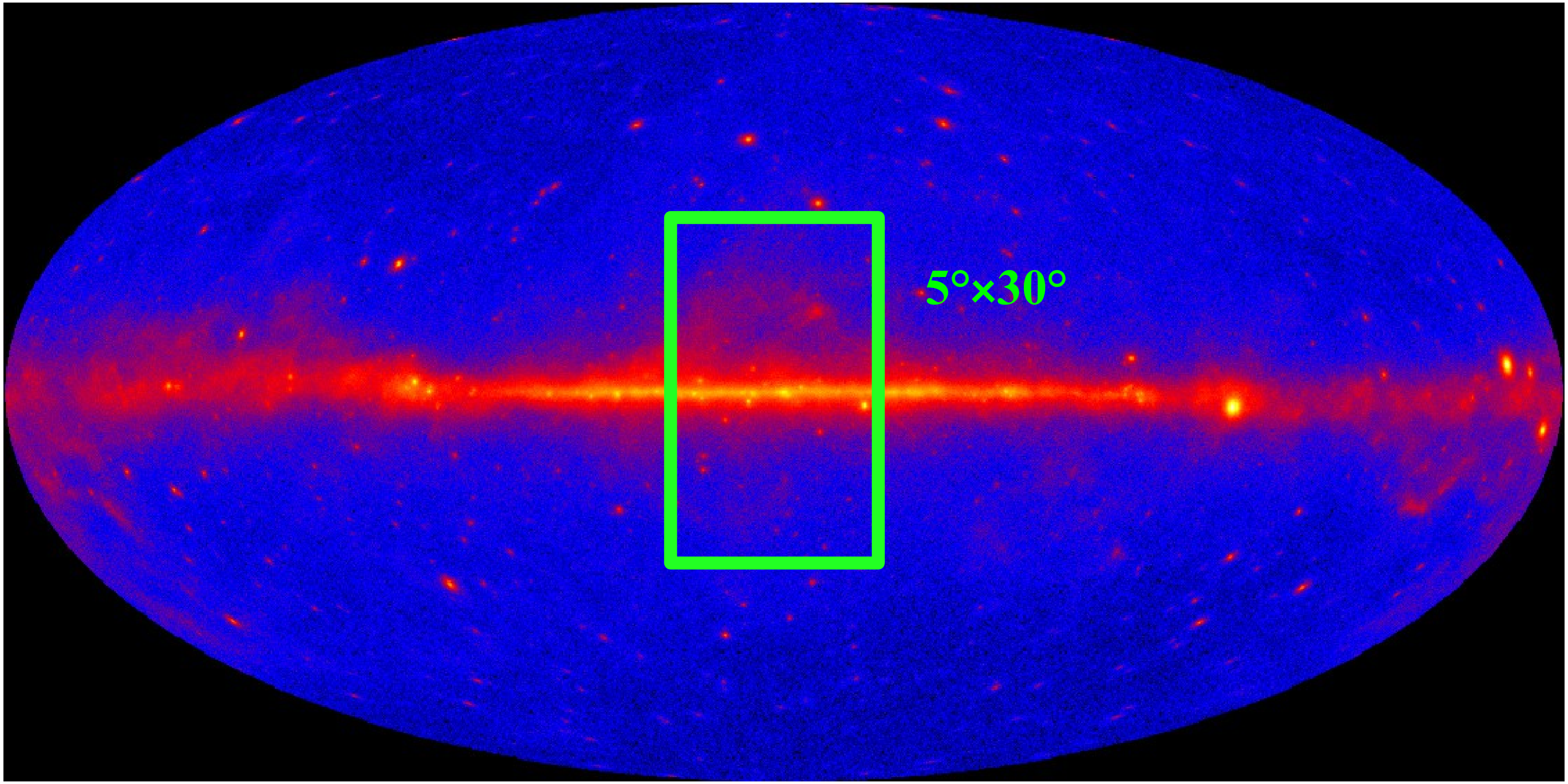
Diffuse Galactic emission

Divide the sky in different regions:



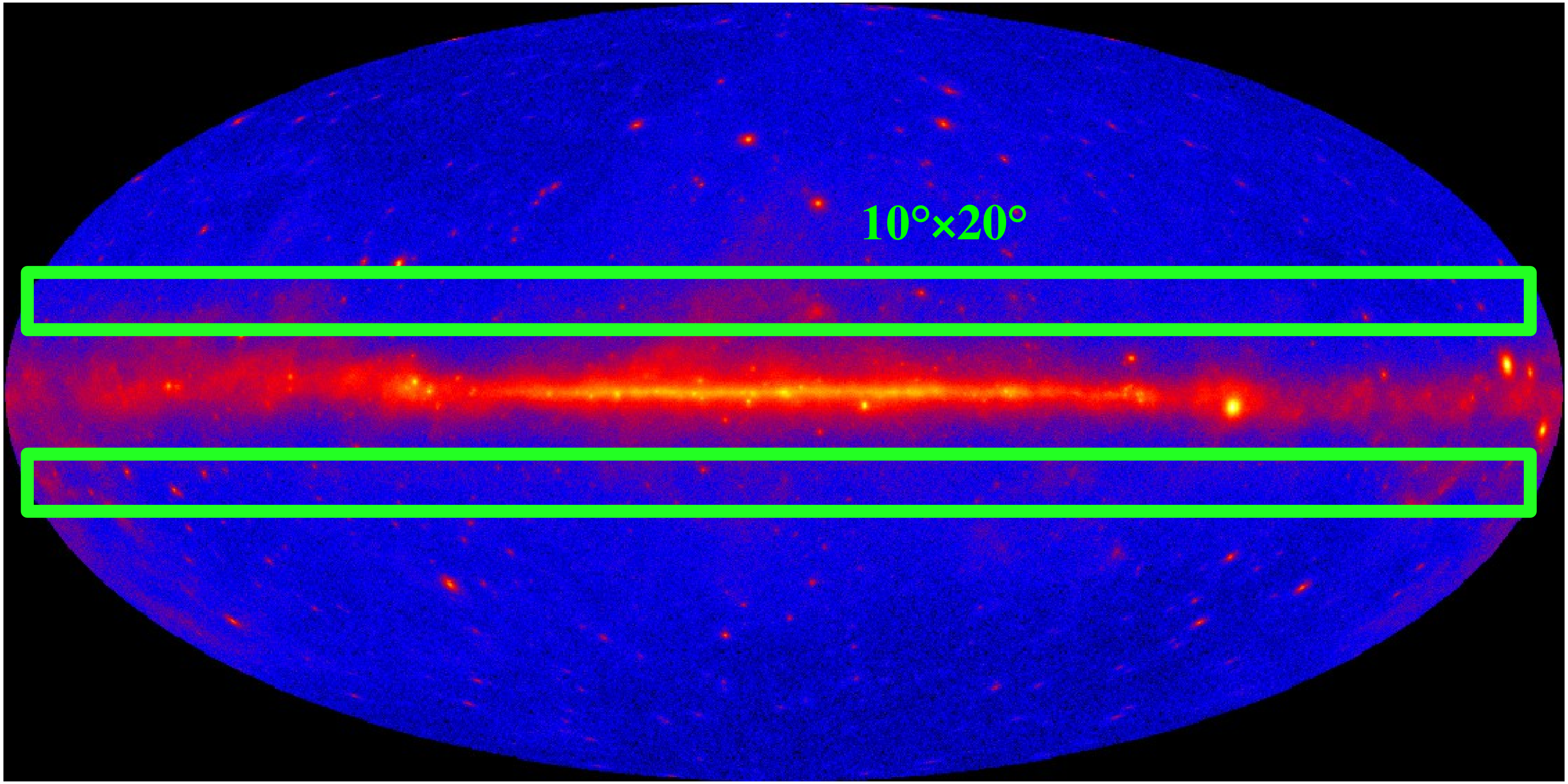
Diffuse Galactic emission

Divide the sky in different regions:



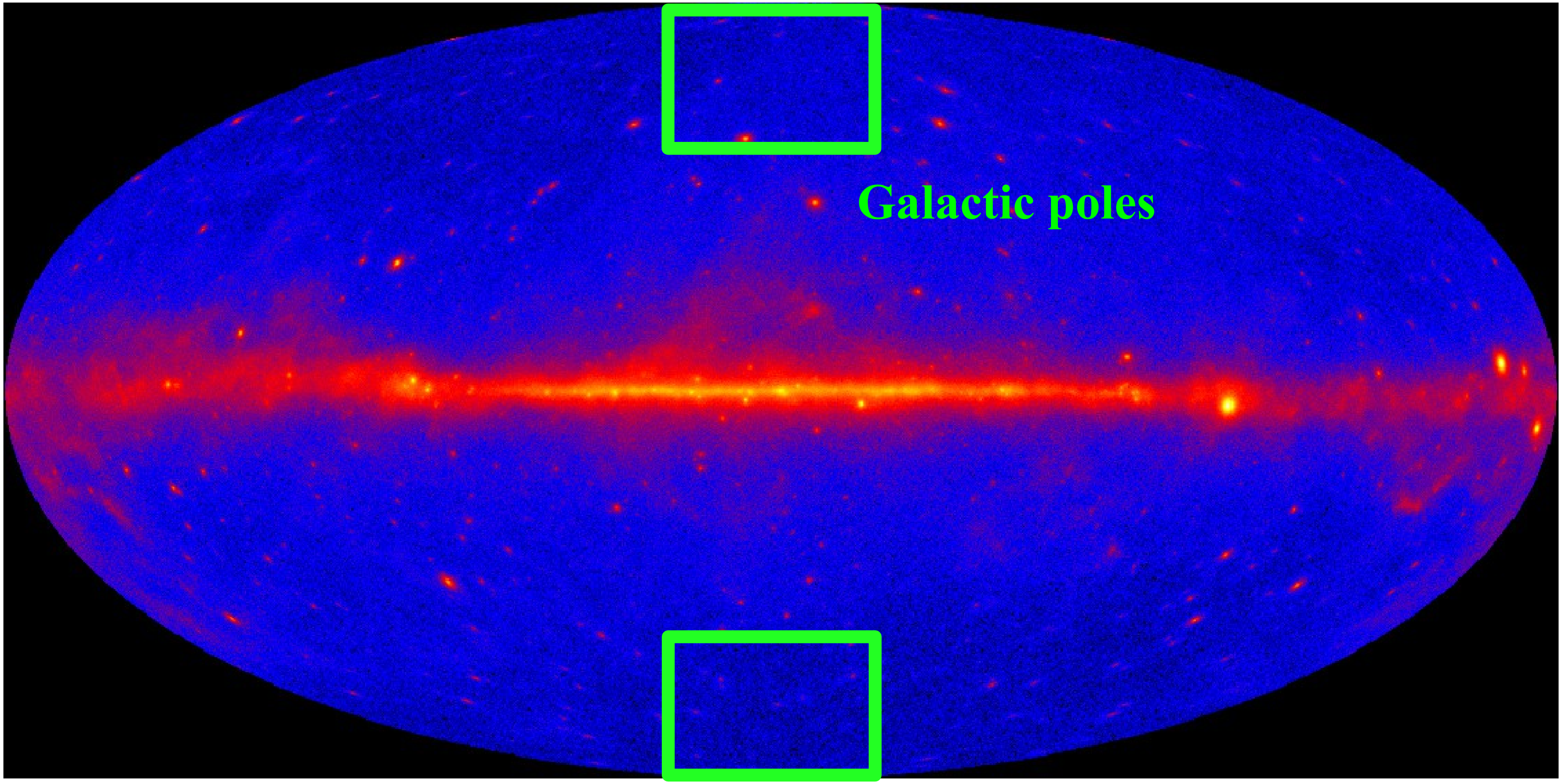
Diffuse Galactic emission

Divide the sky in different regions:



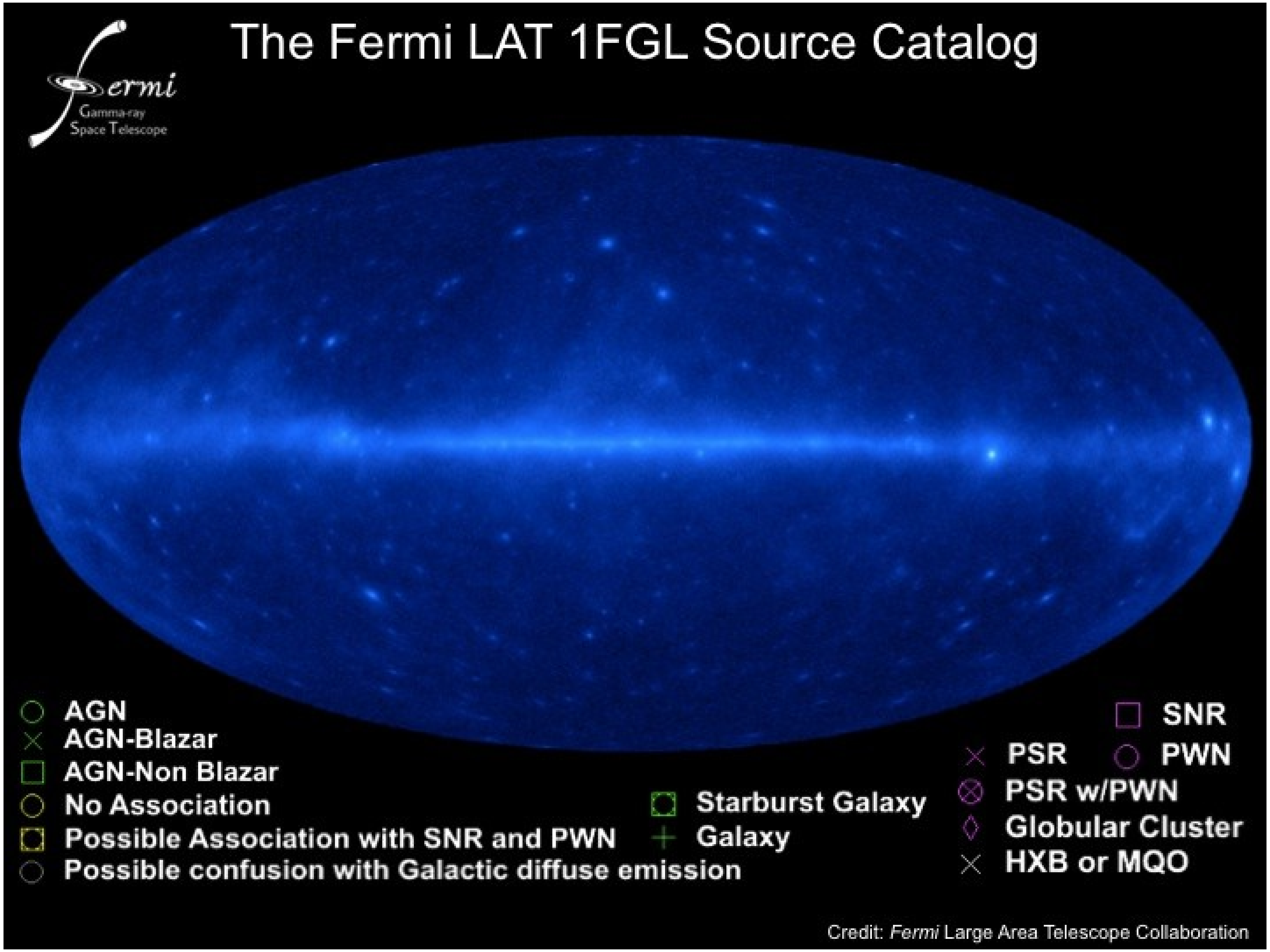
Diffuse Galactic emission

Divide the sky in different regions:

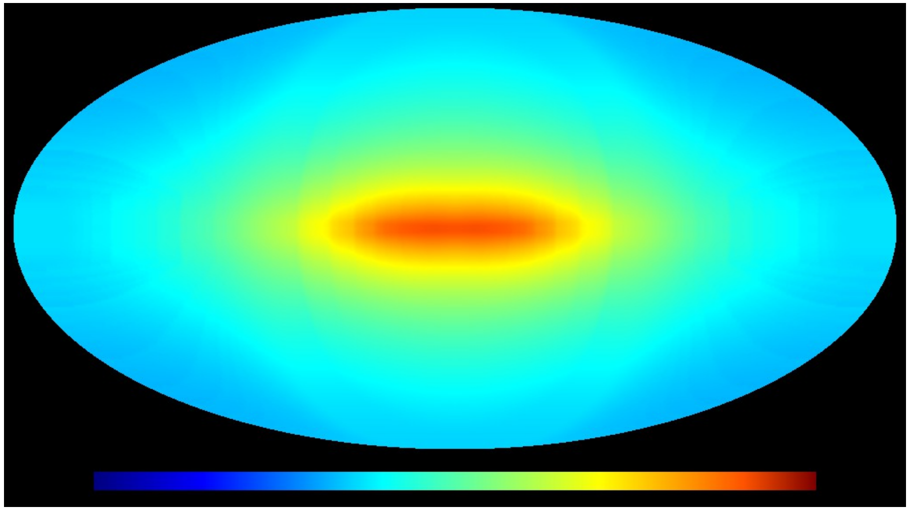


But beware of backgrounds when searching for dark matter...

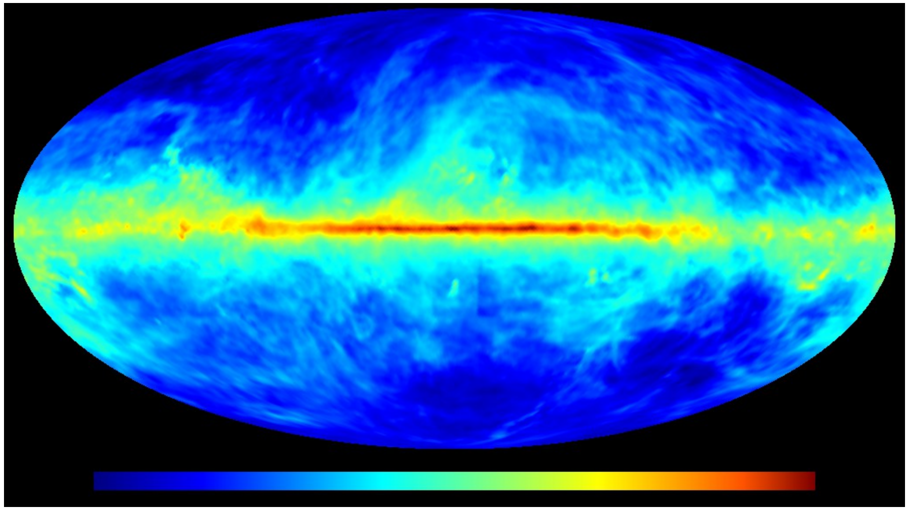
Background I: sources



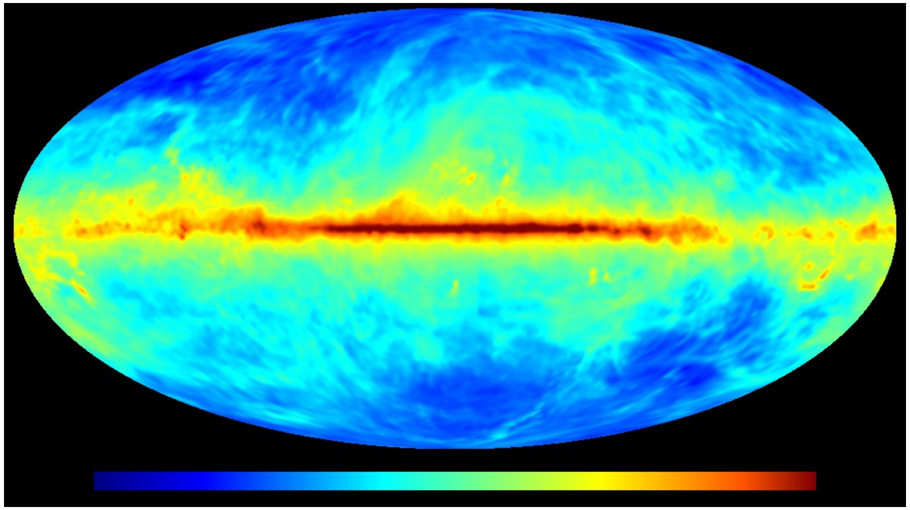
Background II: modelling of the diffuse emission



Inverse compton

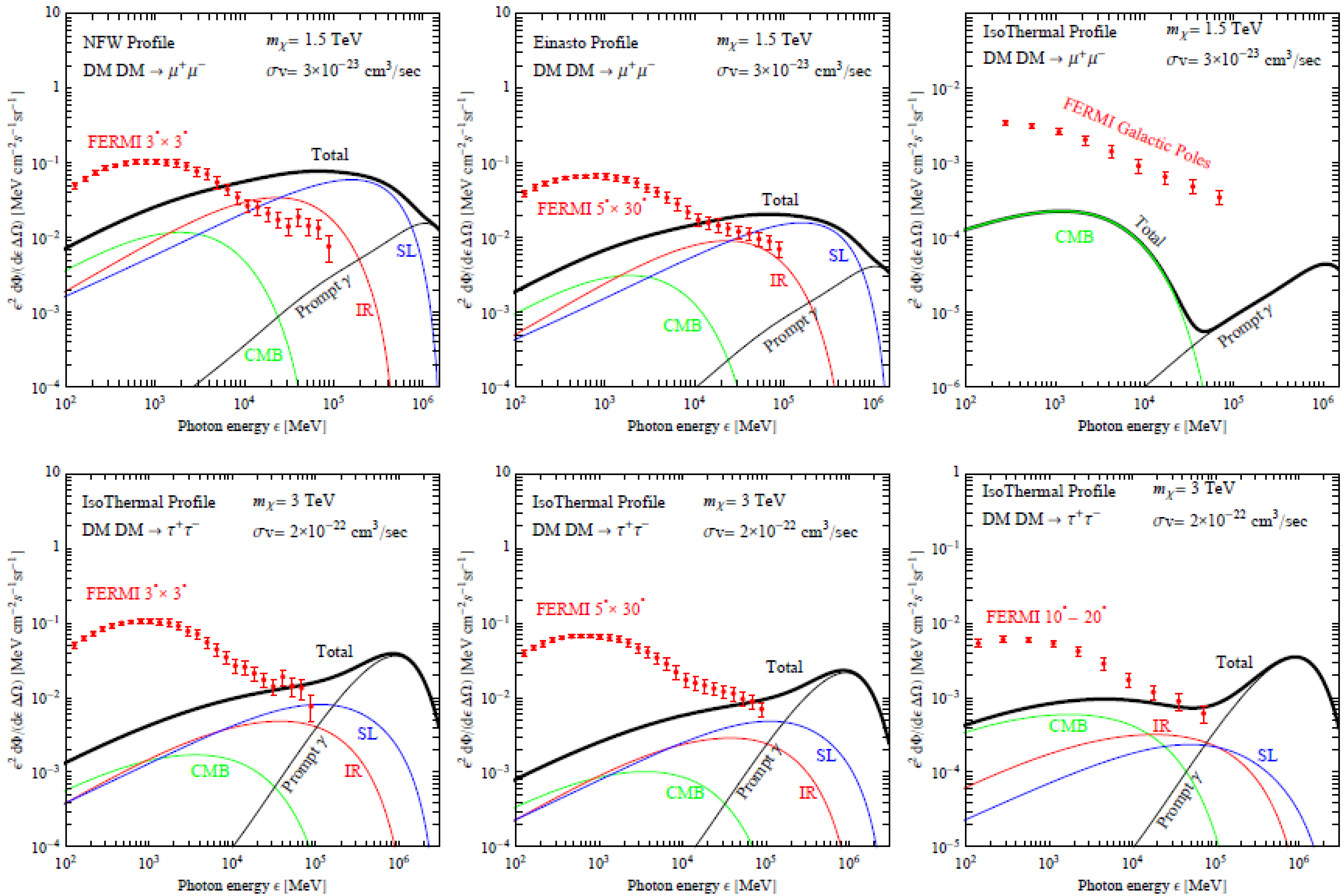


bremmstrahlung

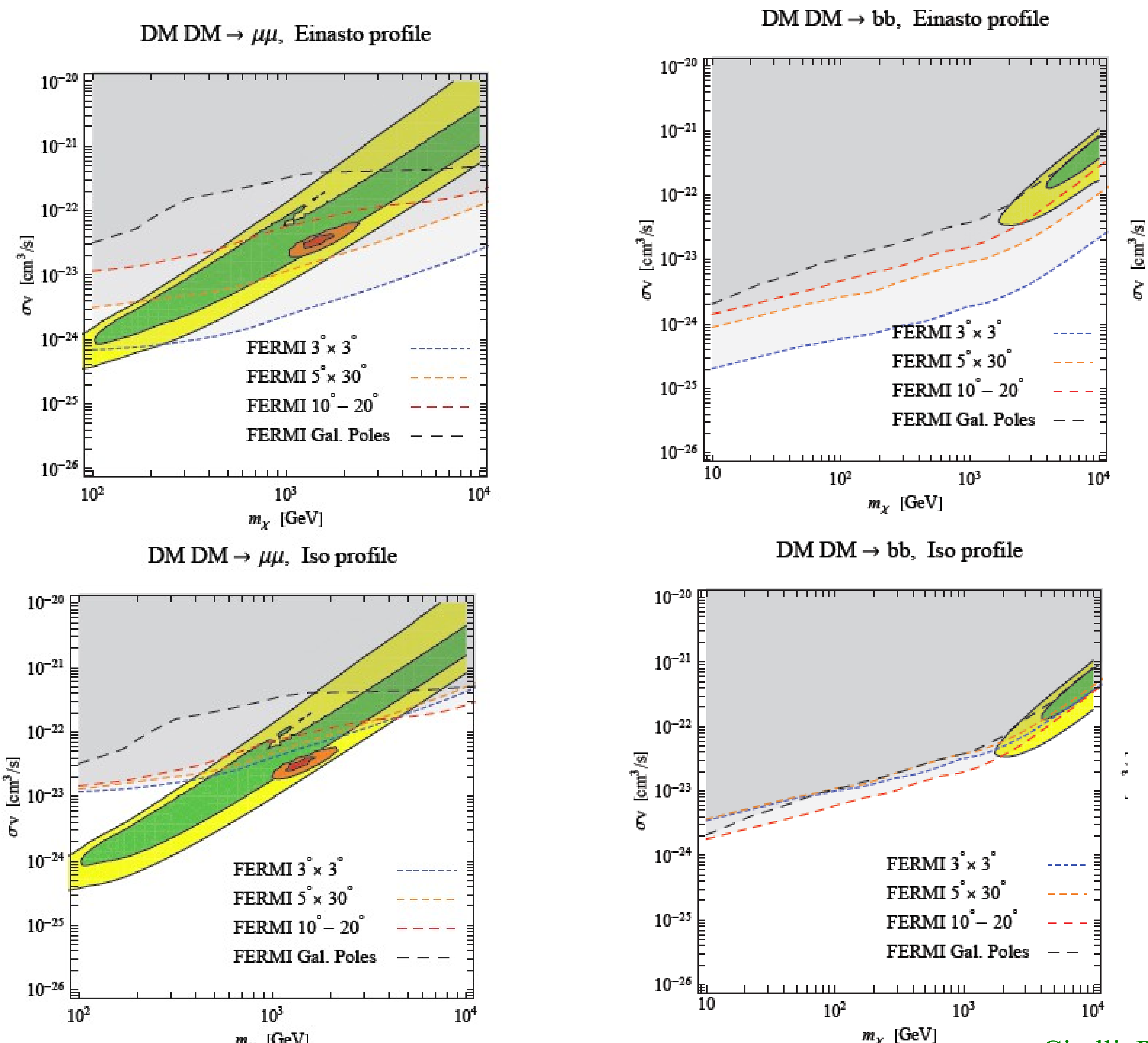


π^0-decay

Conservative approach: demand that the flux from dark matter annihilations does not exceed the measured flux

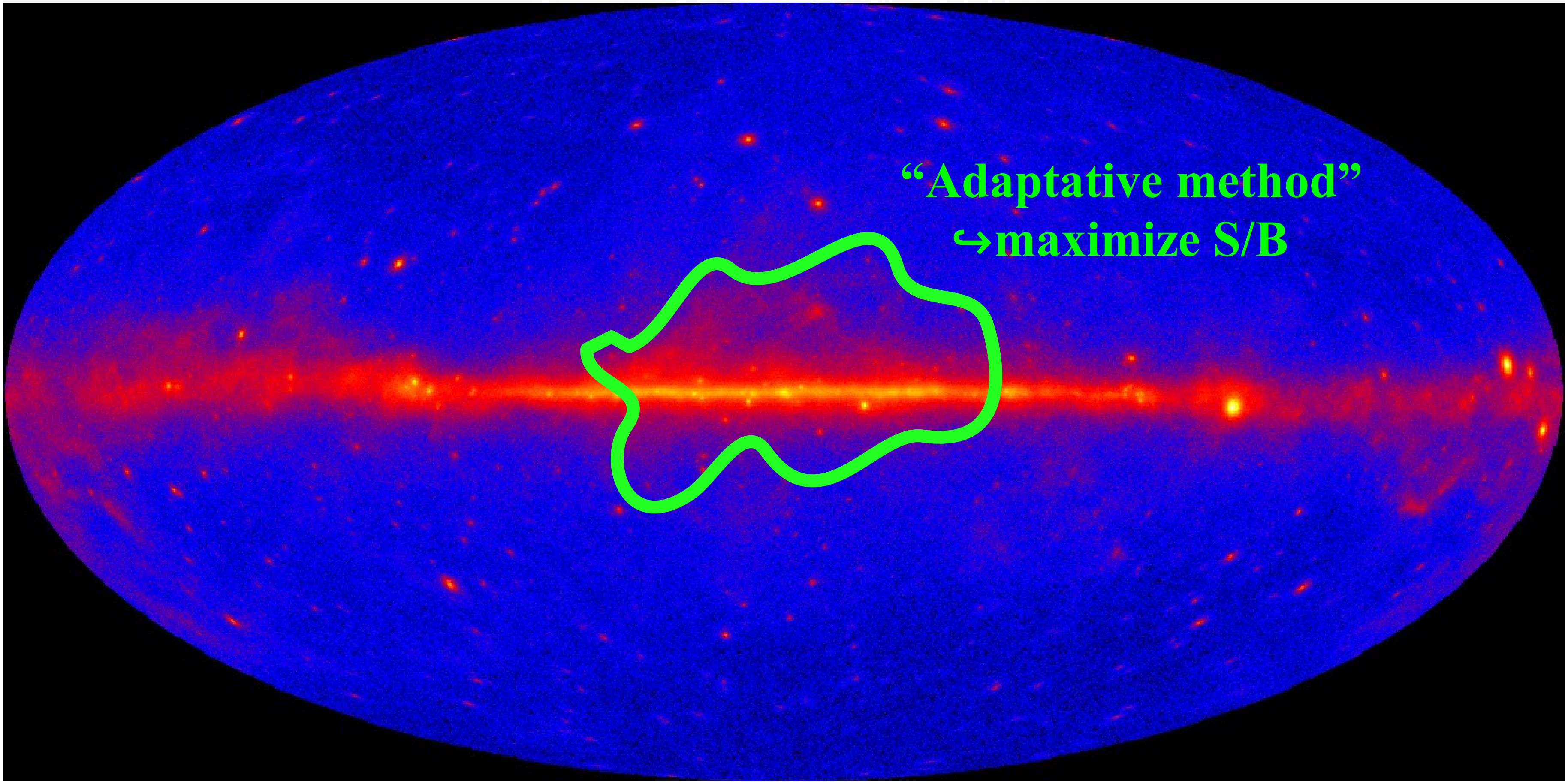


Cirelli, Panci, Serpico

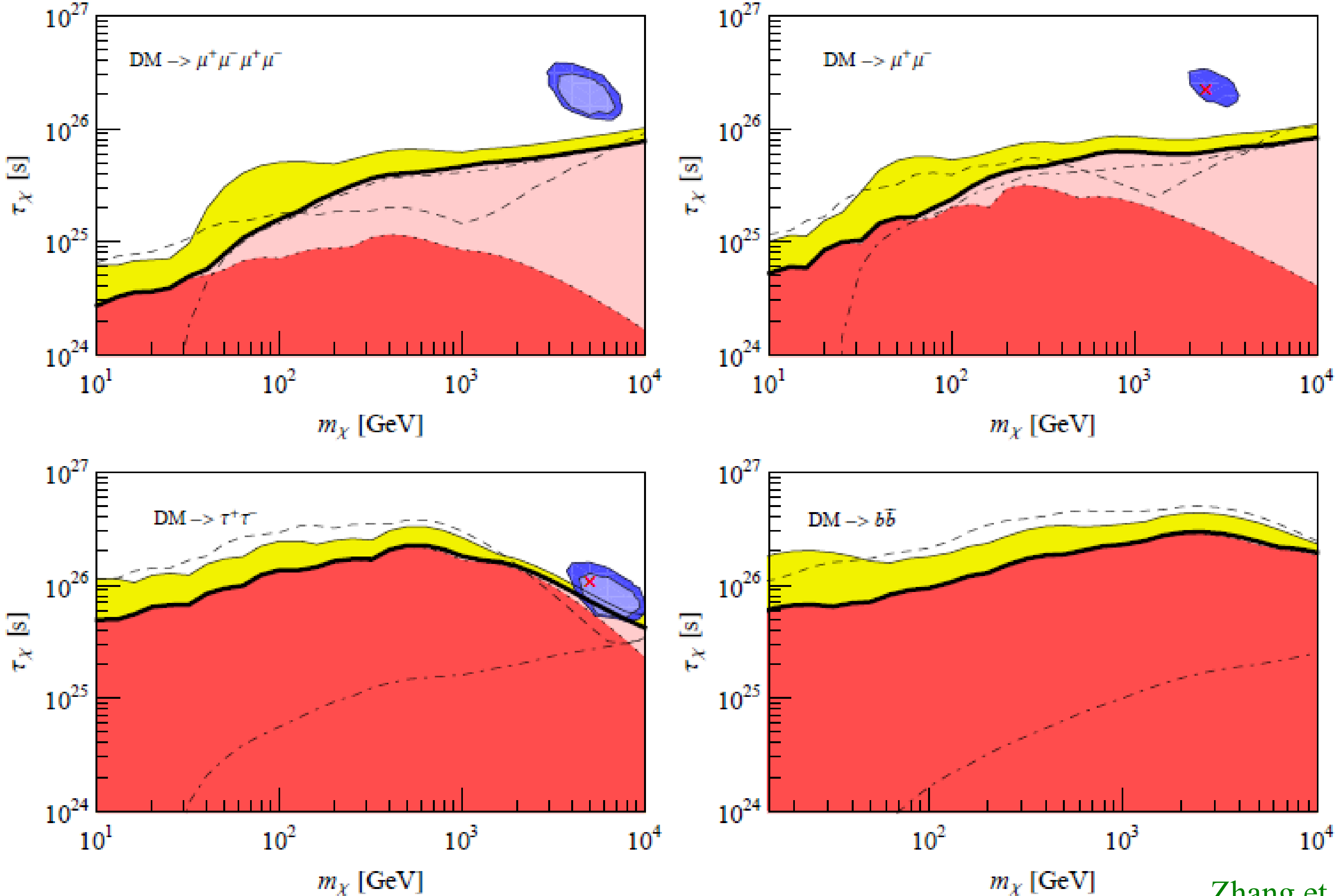


Cirelli, Panci, Serpico

Diffuse Galactic emission



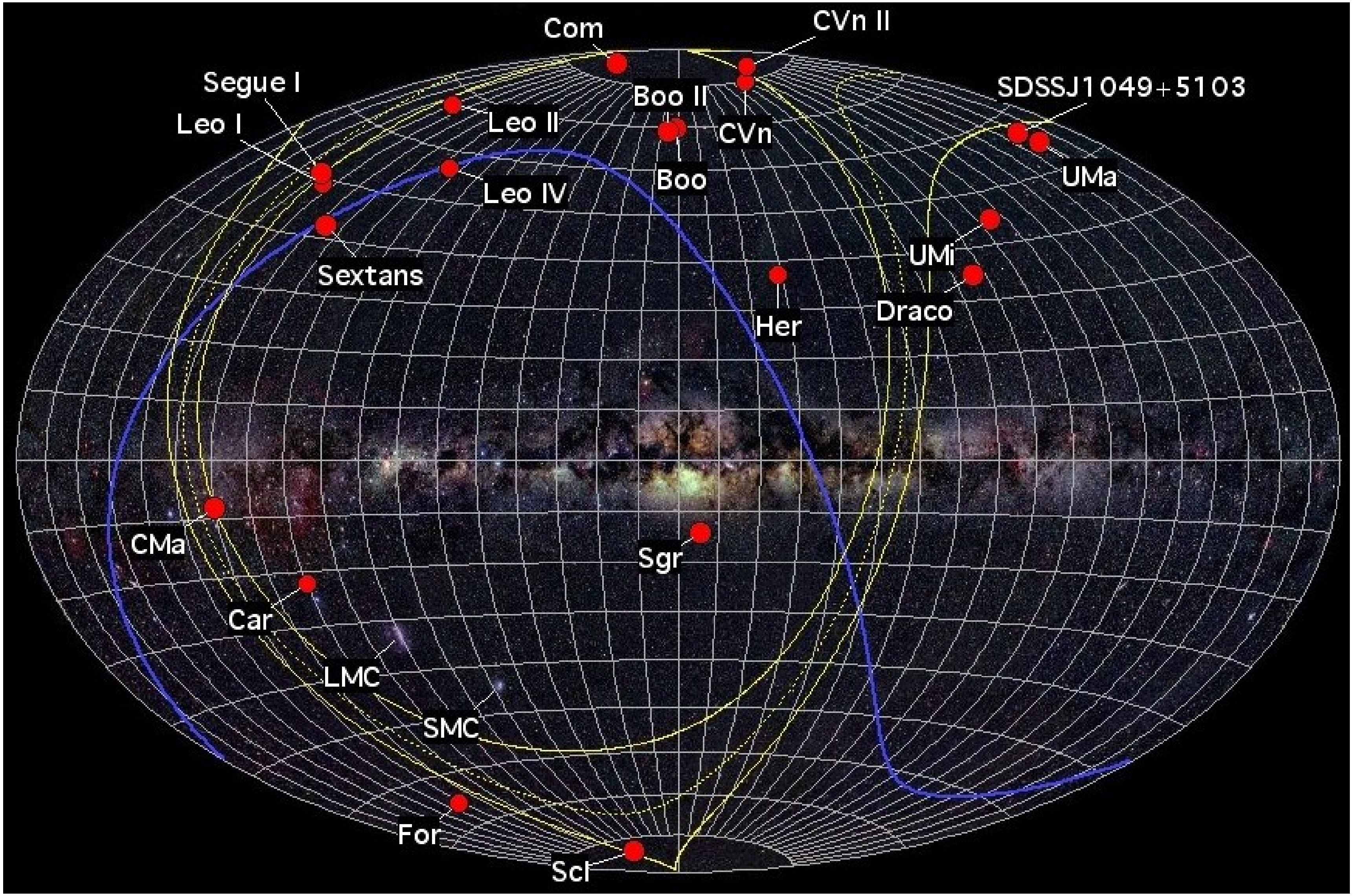
Limits on the dark matter lifetime from measurements of the diffuse gamma-ray background



Zhang et al.

Region: $|l| \leqslant 20°$, $-18° \leqslant b \leqslant -10°$, chosen to optimize S/B

Dwarf spheroidal galaxies



Name	Distance (kpc)	year of discovery	$M_{1/2}/L_{1/2}$ ref. 8	l	b	Ref.
Ursa Major II	30± 5	2006	4000^{+3700}_{-2100}	152.46	37.44	1,2
Segue 2	35	2009	650	149.4	-38.01	3
Willman 1	38± 7	2004	770^{+930}_{-440}	158.57	56.78	1
Coma Berenices	44± 4	2006	1100^{+800}_{-500}	241.9	83.6	1,2
Bootes II	46	2007	18000??	353.69	68.87	6,7
Bootes I	62±3	2006	1700^{+1400}_{-700}	358.08	69.62	6
Ursa Minor	66± 3	1954	290^{+140}_{-90}	104.95	44.80	4,5
Sculptor	79± 4	1937	18^{+6}_{-5}	287.15	-83.16	4,5
Draco	76± 5	1954	200^{+80}_{-60}	86.37	34.72	4,5,9
Sextans	86± 4	1990	120^{+40}_{-35}	243.4	42.2	4,5
Ursa Major I	97±4	2005	1800^{+1300}_{-700}	159.43	54.41	6
Hercules	132±12	2006	1400^{+1200}_{-700}	28.73	36.87	6
Fornax	138± 8	1938	$8.7^{+2.8}_{-2.3}$	237.1	-65.7	4,5
Leo IV	160±15	2006	260^{+1000}_{-200}	265.44	56.51	6

Relatively close

High mass-to-light ratio:
dwarf galaxies contain large
amounts of dark matter

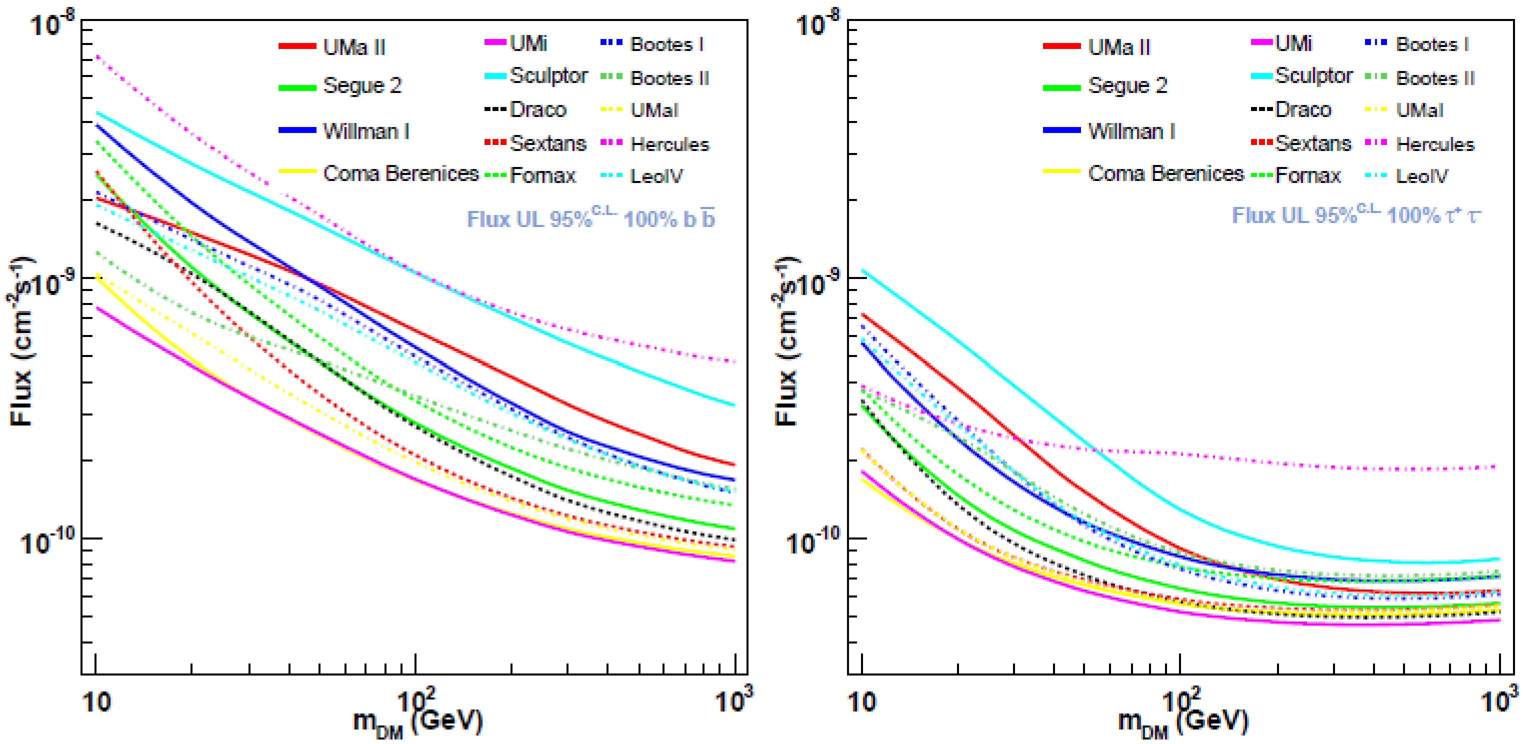
Assume a Navarro-Frenk-White dark matter halo profile inside the tidal radius:

$$\rho(r) = \begin{cases} \frac{\rho_s r_s^3}{r(r_s+r)^2} & \text{for} \quad r < r_t \\ 0 & \text{for} \quad r \geq r_t \end{cases}$$

Name	ρ_s $(M_\odot \; pc^{-3})$	r_s (kpc)	J^{NFW} $(10^{19} GeV^2 cm^{-5})$
Segue 1	1.65	0.05	0.97
Ursa Major II	0.17	0.25	0.57
Segue 2	0.61	0.06	0.1
Willman 1	0.417	0.17	0.84
Coma Berenices	0.232	0.22	0.42
Usra Minor	0.04	0.97	0.35
Sculptor	0.063	0.52	0.12
Draco	0.13	0.50	0.43
Sextans	0.079	0.36	0.05
Fornax	0.04	1.00	0.11

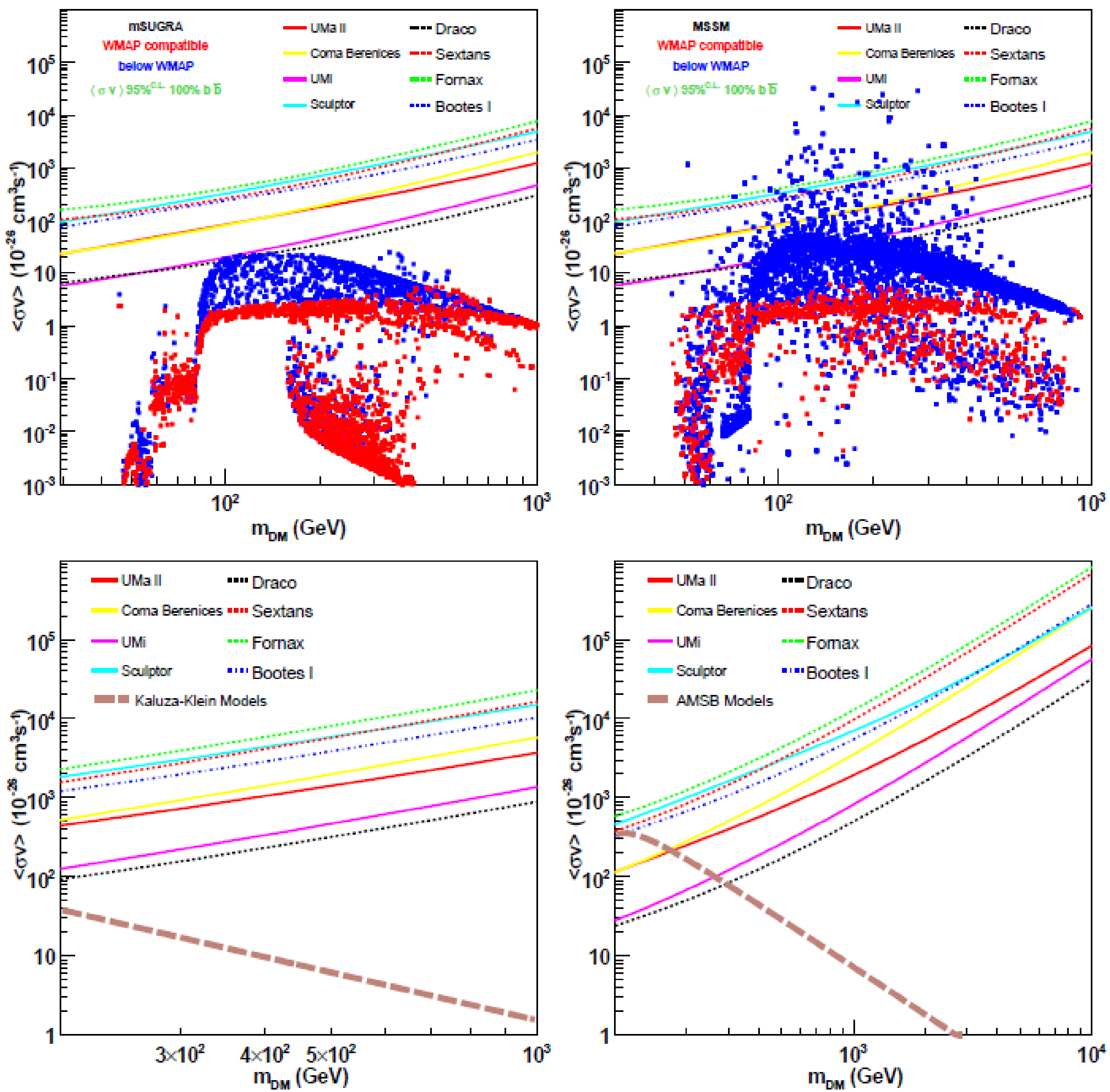
$$J(\psi) = \int_{l.o.s} dl(\psi)\rho^2(l(\psi))$$

Flux upper limits



Fermi coll.
arXiv:1001.4531

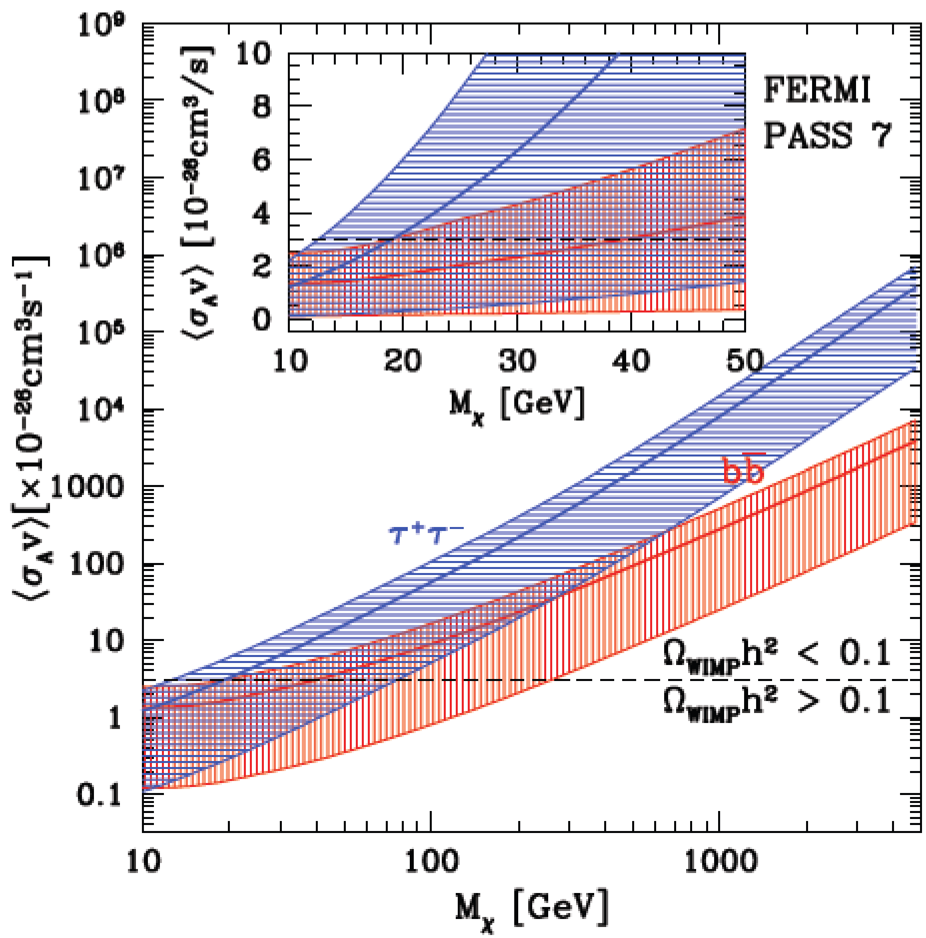
Constraints on annihilating WIMPs

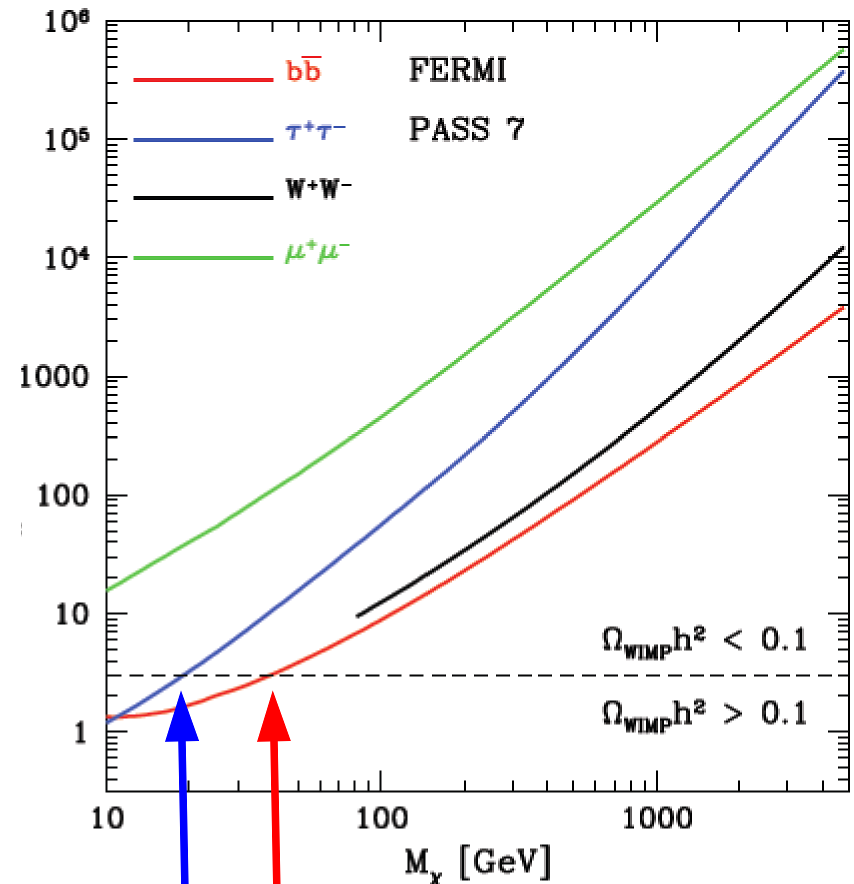


Fermi coll.
arXiv:1001.4531

Closing in on light WIMP scenarios from dwarf galaxy observations

Geringer-Sameth, Koushiappas '11

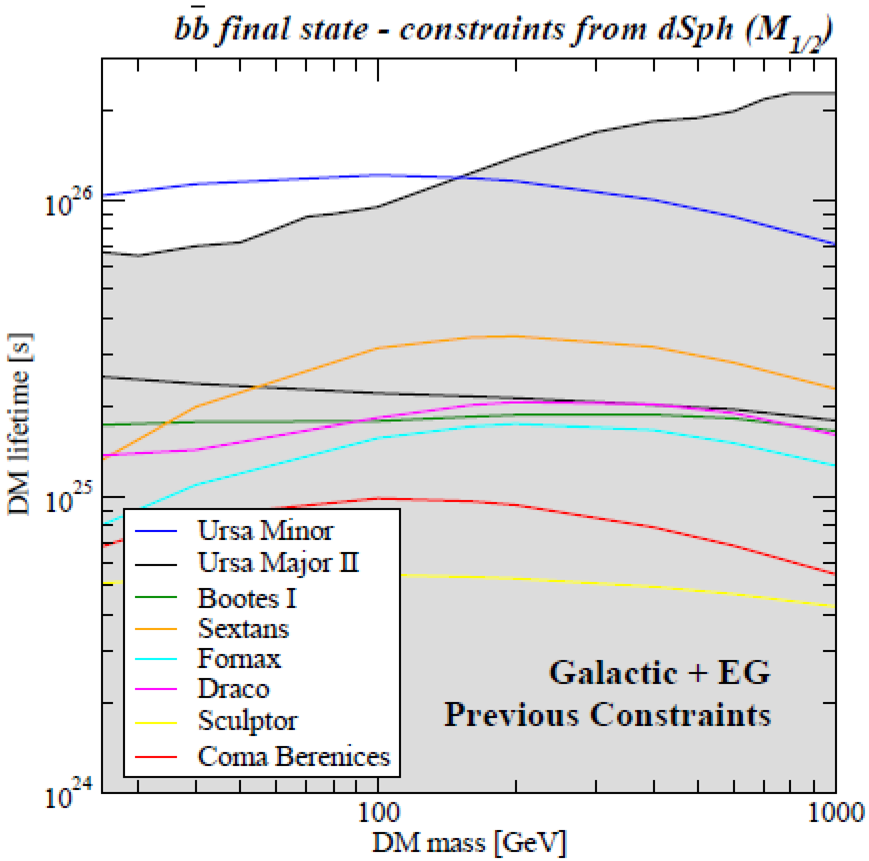


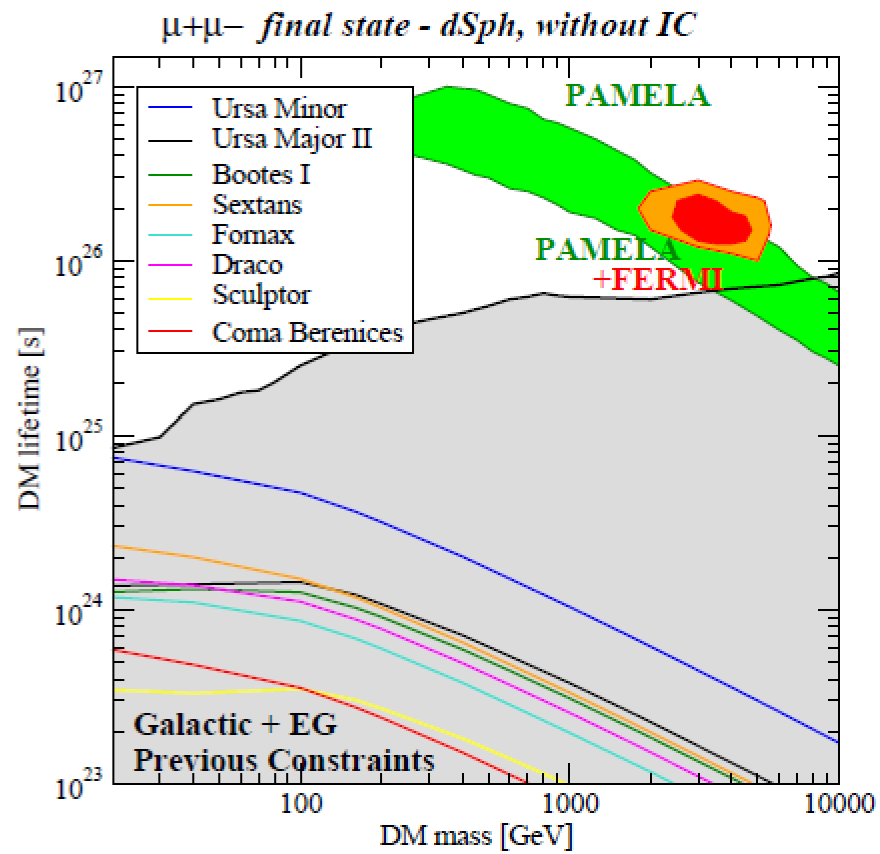


M_{DM}> 40 GeV for DM DM → b $\bar{b}$

M_{DM}> 19 GeV for DM DM → $\tau^+ \tau^-$

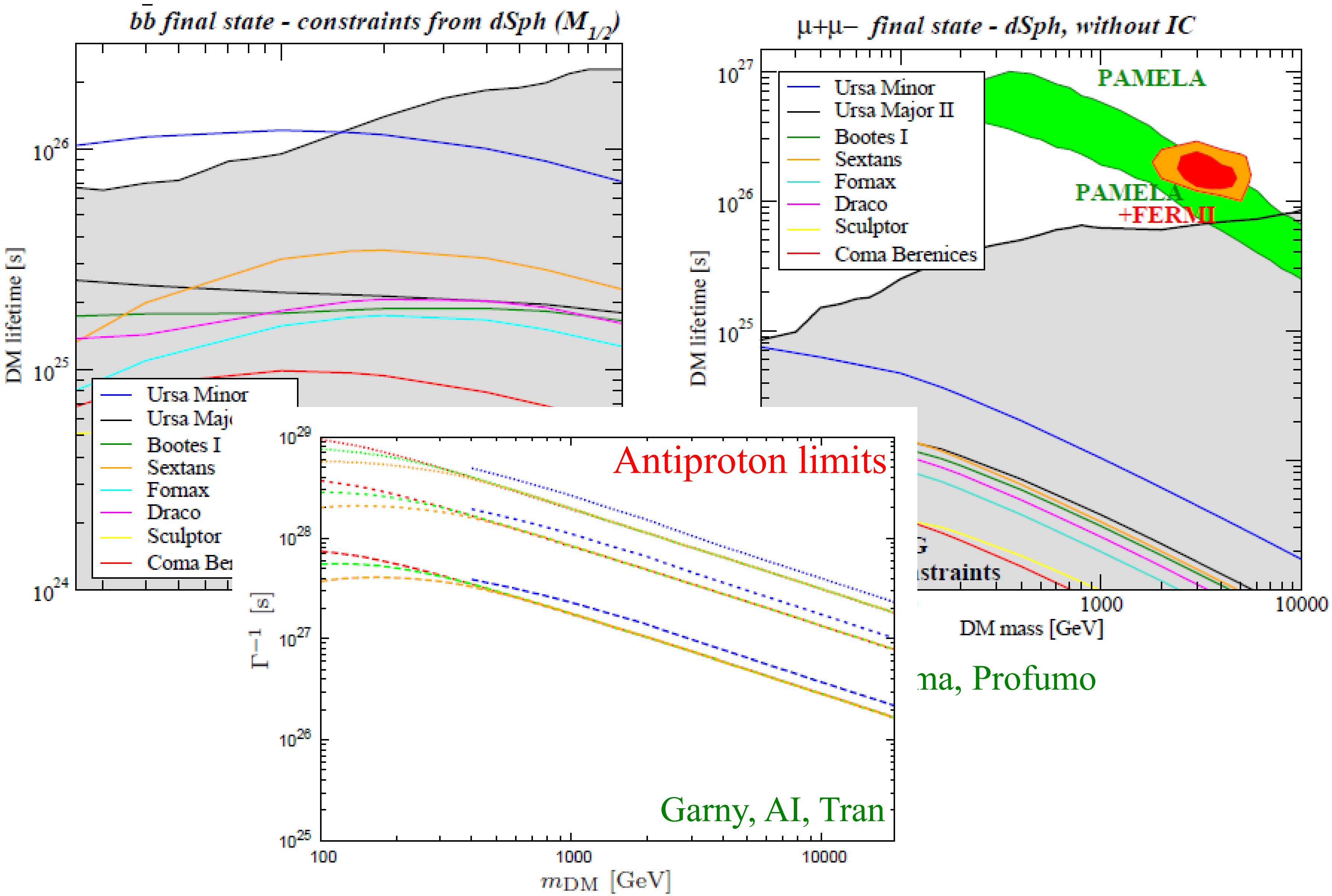
Limits on the dark matter lifetime from dwarf spheroidal observations





Dugger, Jeltema, Profumo

Limits on the dark matter lifetime from dwarf spheroidal observations

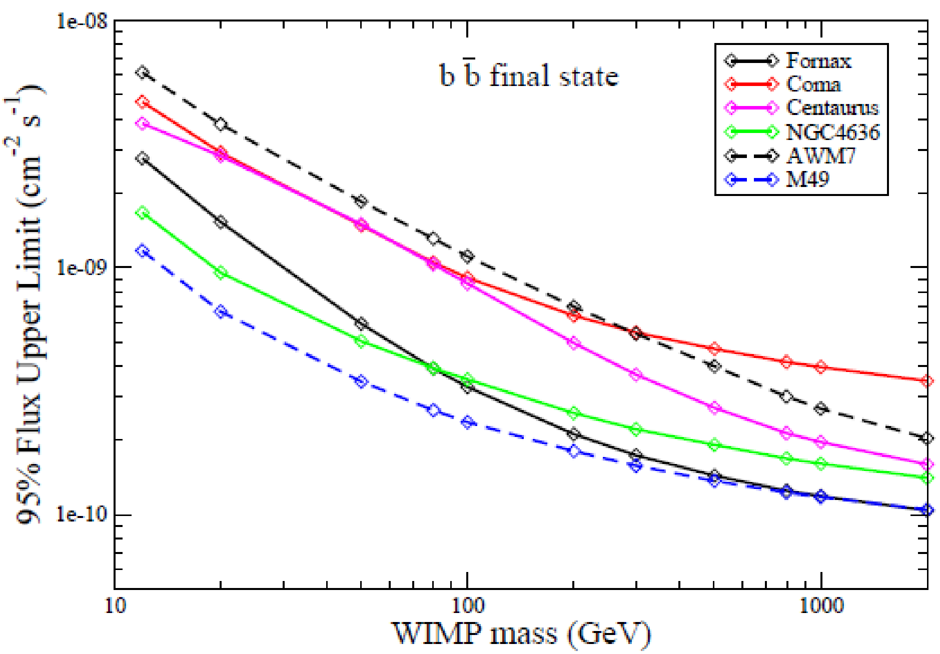


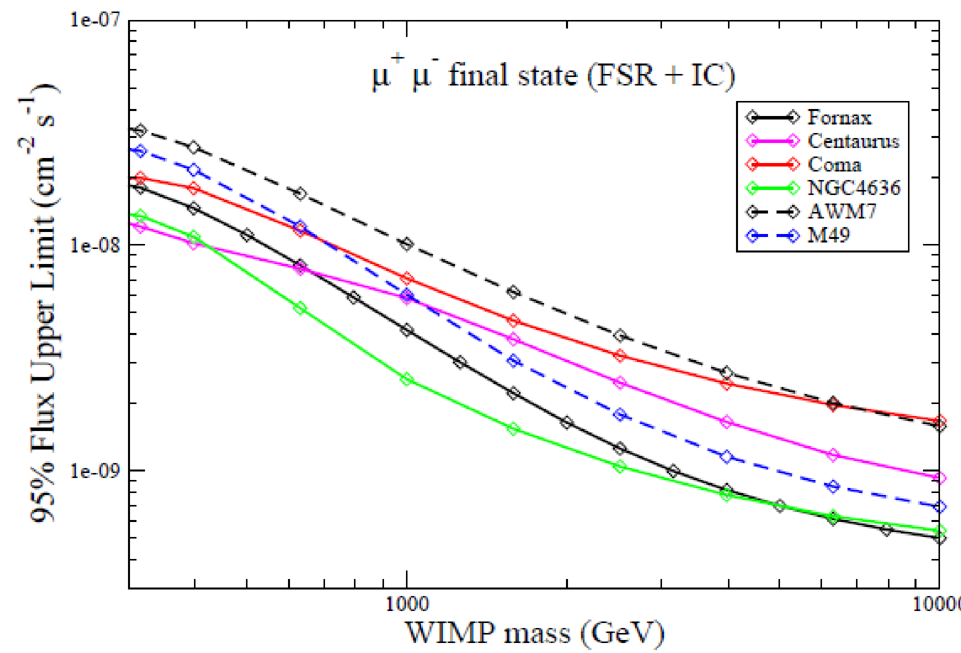
Dwarf limits weaker than other limits

Galaxy clusters

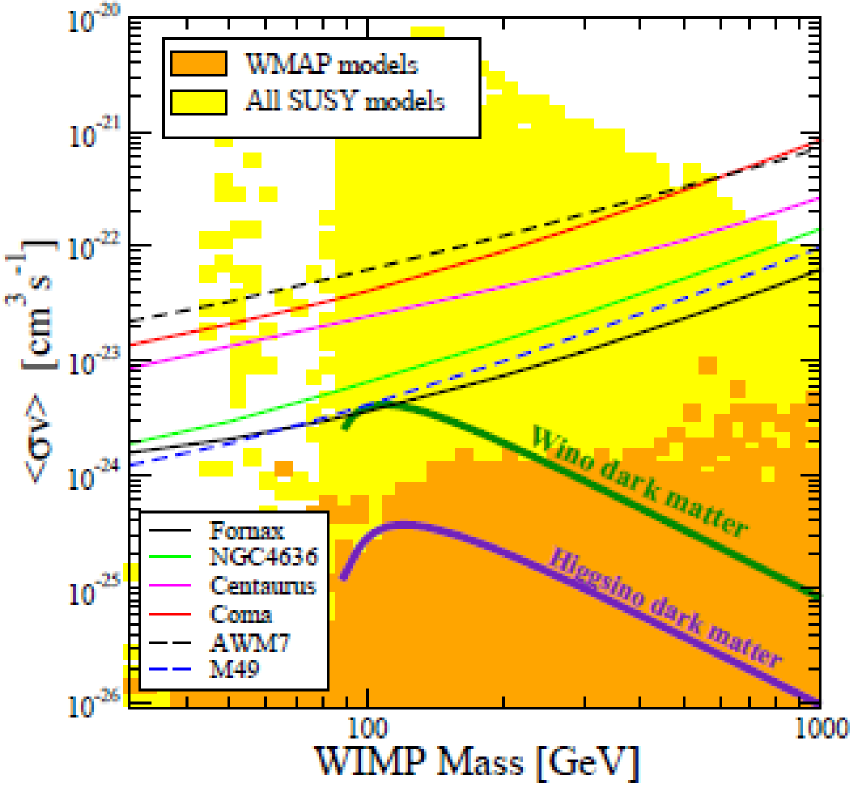
Cluster	RA	Dec.	z	J (10^{17} GeV^2 cm^{-5})
AWM 7	43.6229	41.5781	0.0172	$1.4^{+0.1}_{-0.1}$
Fornax	54.6686	-35.3103	0.0046	$6.8^{+1.0}_{-0.9}$
M49	187.4437	7.9956	0.0033	$4.4^{+0.2}_{-0.1}$
NGC 4636	190.7084	2.6880	0.0031	$4.1^{+0.3}_{-0.3}$
Centaurus (A3526)	192.1995	-41.3087	0.0114	$2.7^{+0.1}_{-0.1}$
Coma	194.9468	27.9388	0.0231	$1.7^{+0.1}_{-0.1}$

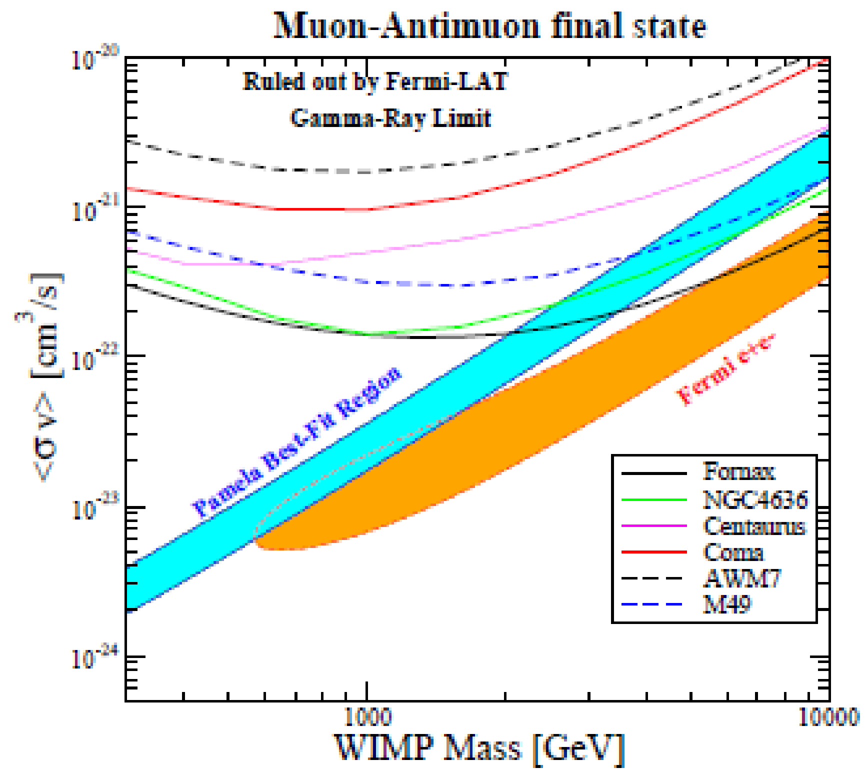
Flux upper limits





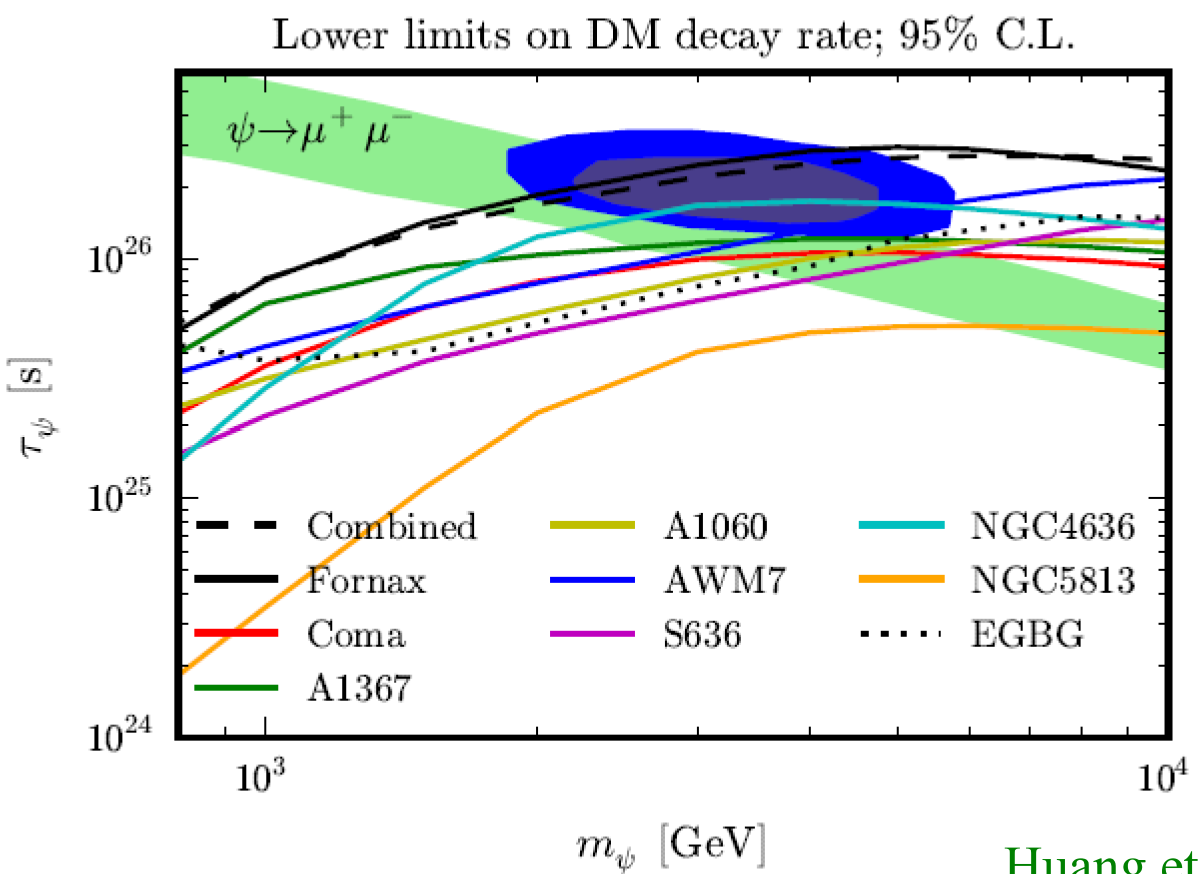
Constraints on the WIMP annihilation cross section





Fermi collaboration
arXiv:1002.2239

Constraints on the dark matter lifetime



Huang et al.

Gamma-ray features

Strategy: search for a feature in the gamma-ray spectrum which cannot be mimicked by any (known) astrophysical source:

- If not observed → strong limits on models
  (background substraction very efficient)
- If observed, unequivocal sign of dark matter

Gamma-ray lines

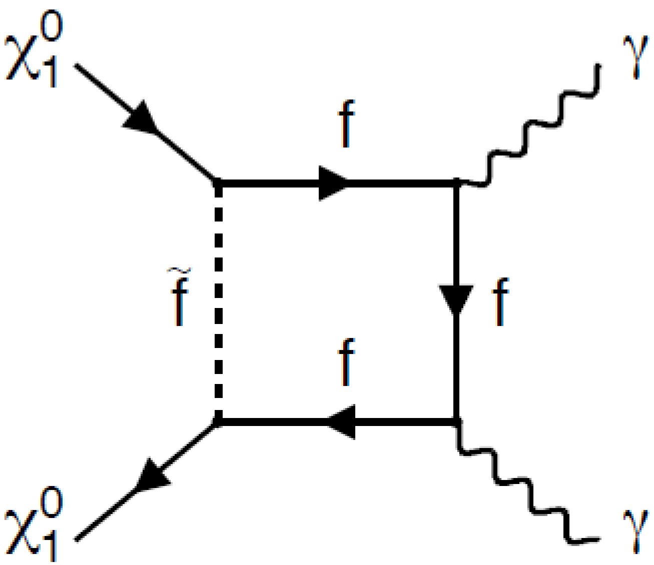
Gamma-ray boxes

Virtual Internal Bremsstrahlung

Gamma-ray lines

Produced in the annihilation DM DM $\rightarrow \gamma\, \gamma$

On general grounds, fairly suppressed in dark matter annihilations.



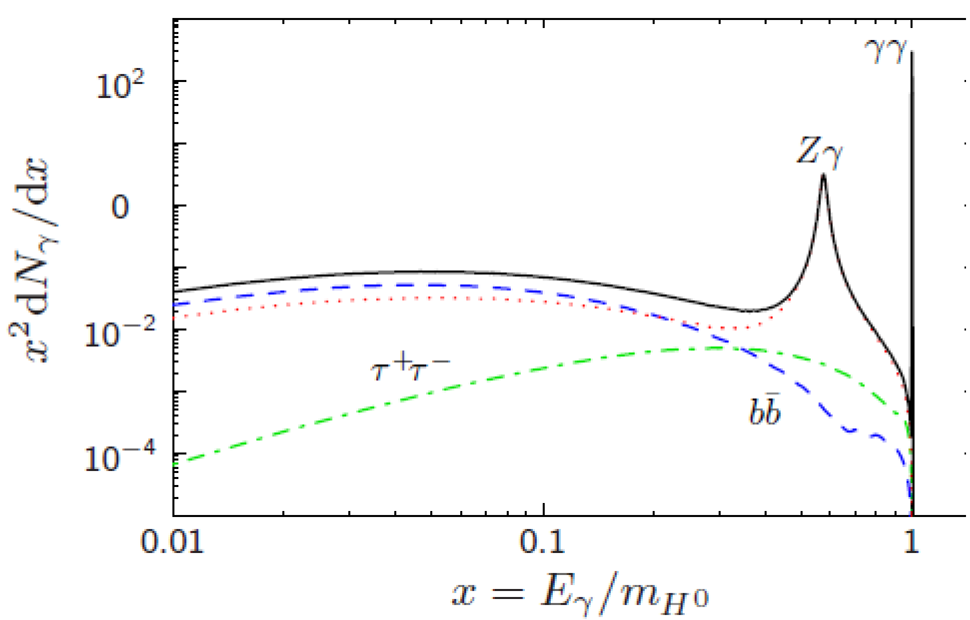
$$\langle \sigma v \rangle (\chi\chi \rightarrow \gamma\gamma) \sim \alpha_{\rm em}^2 \times \langle \sigma v \rangle_{f.o.} \sim 10^{-30}\, {\rm cm}^3 {\rm s}^{-1}$$

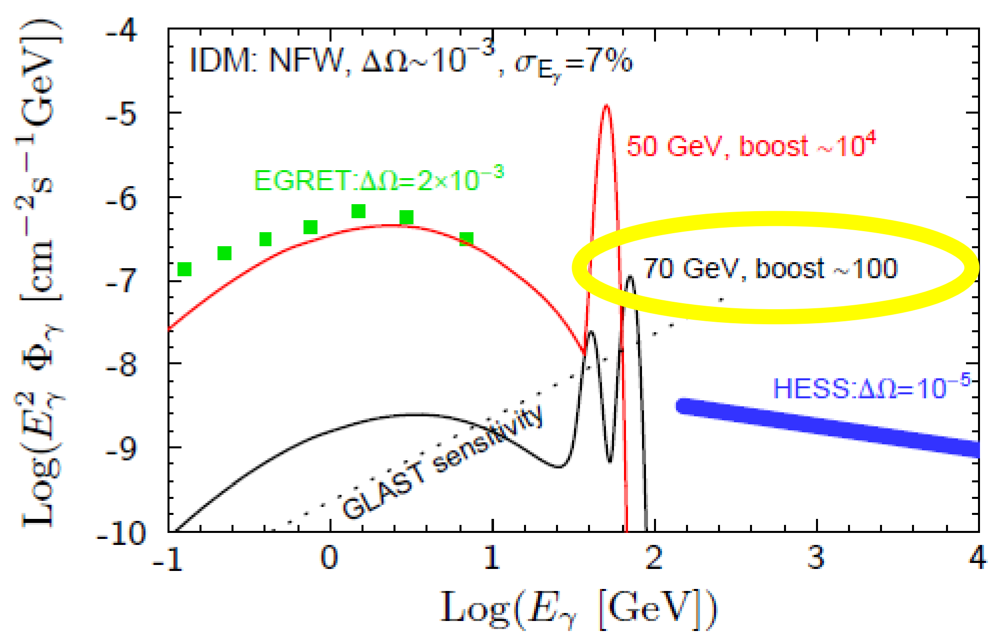
Gamma-ray lines

Produced in the annihilation DM DM $\rightarrow \gamma\,\gamma$

Predicted to be fairly intense in some concrete scenarios

- Inert Higgs





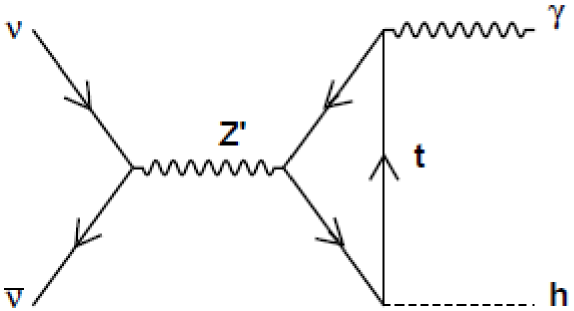
Gustafsson, Lundström, Bergström, Edsjö
astro-ph/0703512

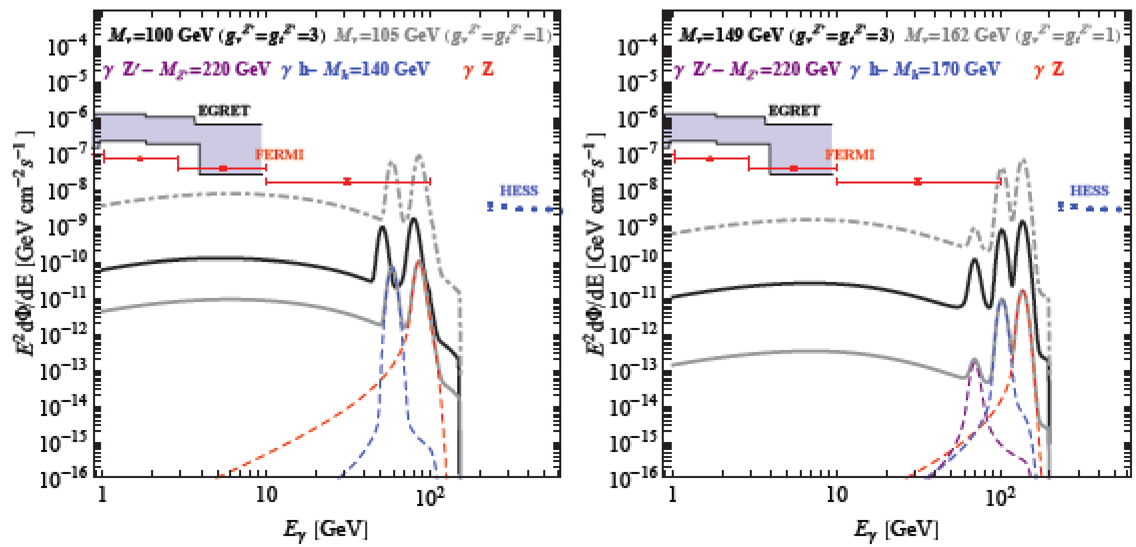
Gamma-ray lines

Produced in the annihilation DM DM $\rightarrow \gamma\,\gamma$

Predicted to be fairly intense in some concrete scenarios

- Dirac fermion coupled to a Z'





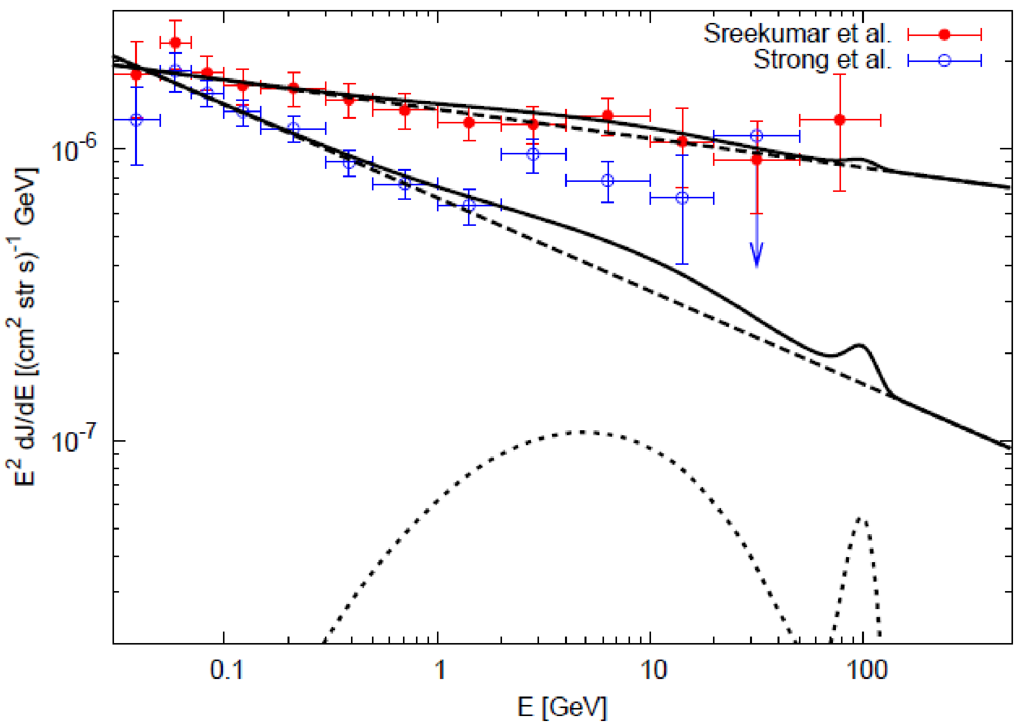
Jackson et al.
arXiv: 0912.0004

Gamma-ray lines

Produced also in the decay DM $\rightarrow \gamma\, \nu$

Predicted to be fairly intense in some concrete scenarios. No suppression.

• Gravitino in general SUSY models
(without imposing R-parity conservation)



m=200 GeV
$\tau = 7\times 10^{26}$ s

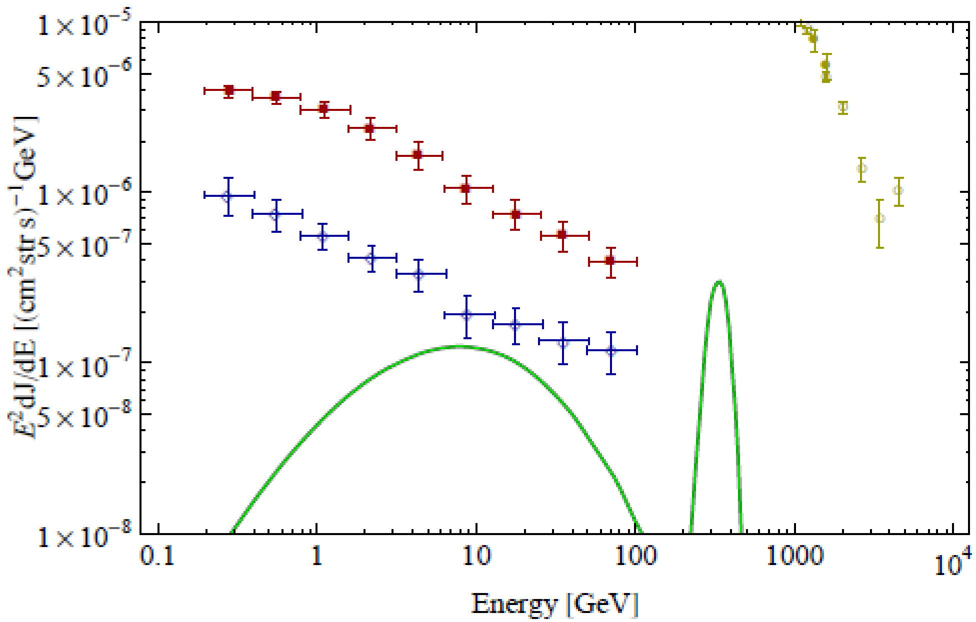
Buchmüller, AI, Shindou, Takayama, Tran
arXiv:0906.1187

Gamma-ray lines

Produced also in the decay DM $\rightarrow \gamma\,\nu$

Predicted to be fairly intense in some concrete scenarios. No suppression.

- Vector of a hidden SU(2)



m=600 GeV
τ=1.1×10^{27} s

Arina, Hambye, AI, Weniger arXiv:0912.4496

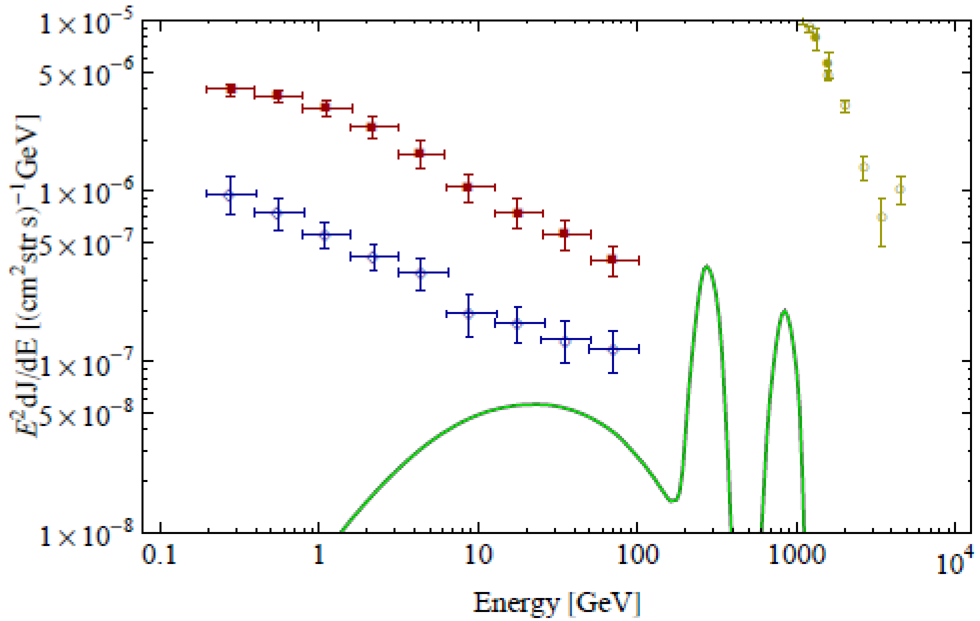
	$\eta\eta$	$h\eta$	hh	$\gamma\eta$	$Z\eta$	γh	Zh
Branching Ratios	-	0.04	0.62	0.002	0.003	0.15	0.18

Gamma-ray lines

Produced also in the decay DM $\to \gamma\, \nu$

Predicted to be fairly intense in some concrete scenarios. No suppression.

- Vector of a hidden SU(2)



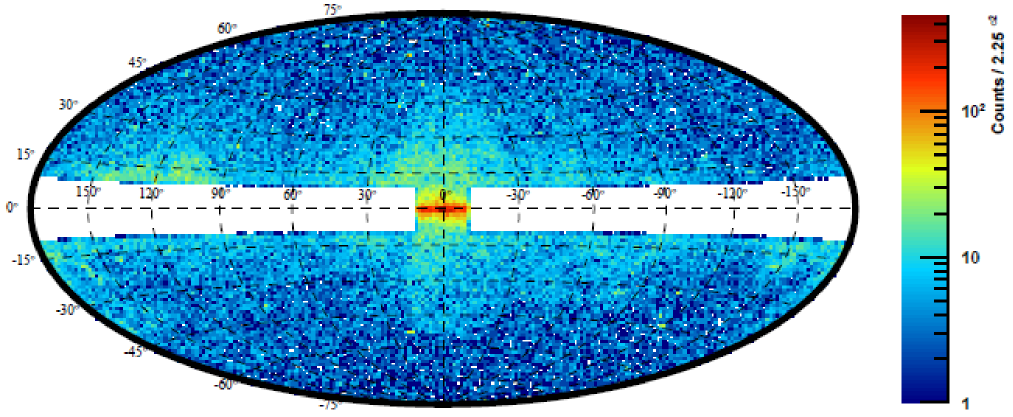
m=1550 GeV
τ=1.6×10^{27} s

Arina, Hambye, AI, Weniger arXiv:0912.4496

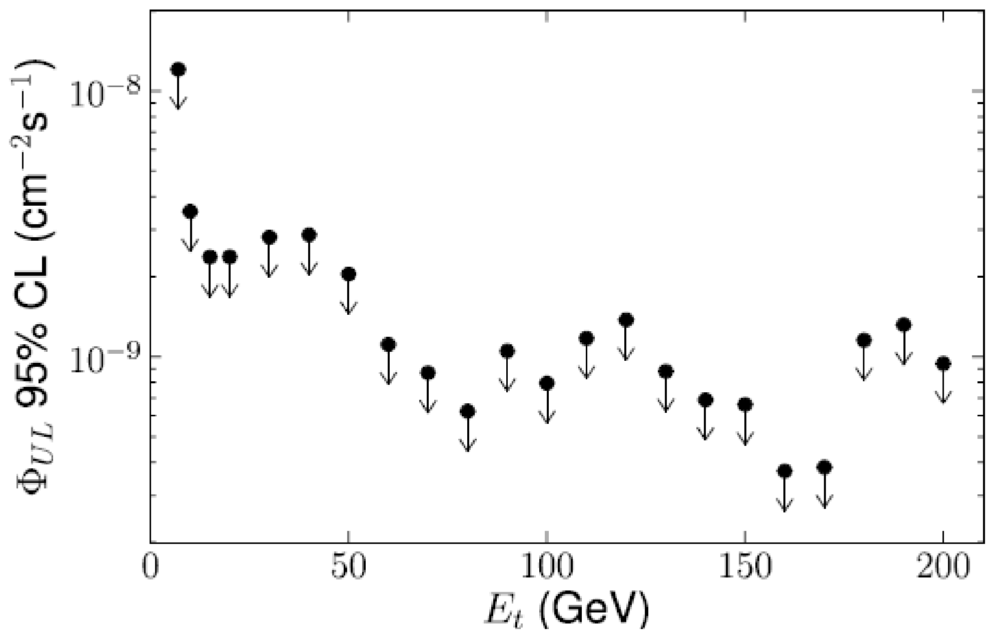
	$Z\eta$	$\gamma\eta$	Zh	γh
Branching Ratios	0.028	0.79	0.041	0.14

Gamma-ray lines

The Fermi collaboration has searched for lines in the region |b|>10° plus a 20°×20° square centered at the Galactic Center



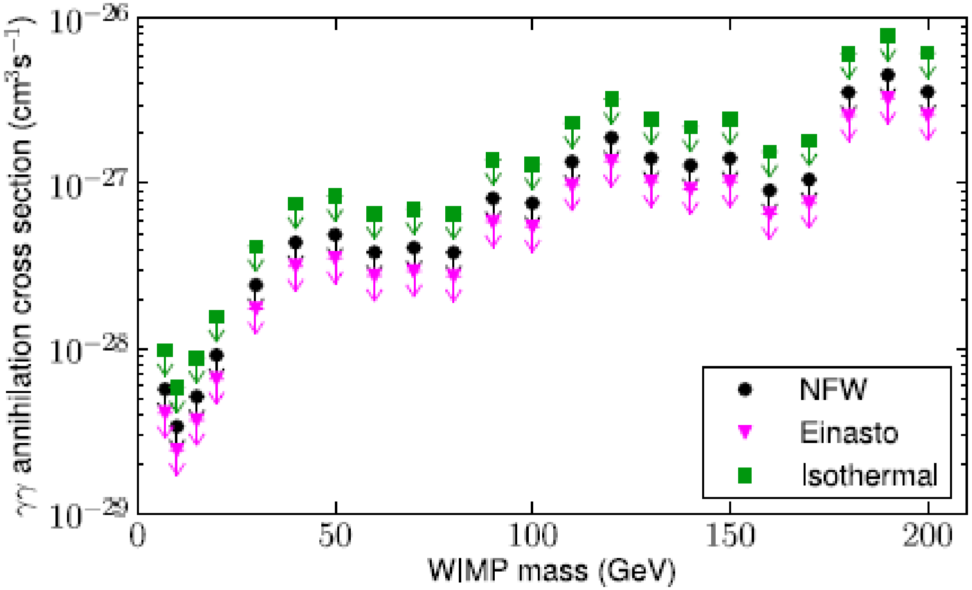
Flux upper limits from DM DM → $\gamma\,\gamma$

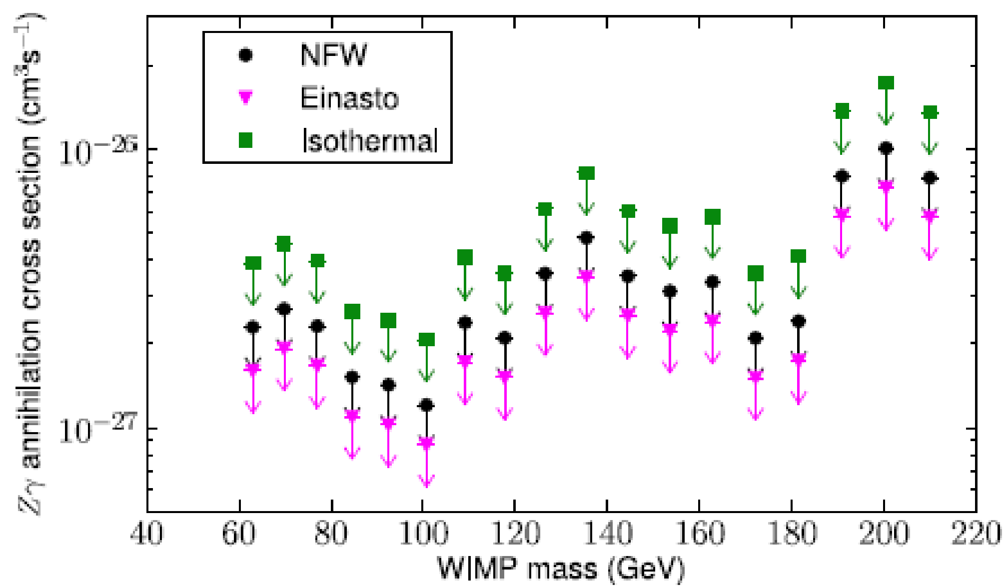


Fermi collaboration
arXiv:1205.2739

Gamma-ray lines

Limits on the annihilation cross section DM DM $\rightarrow \gamma\gamma, Z\gamma$

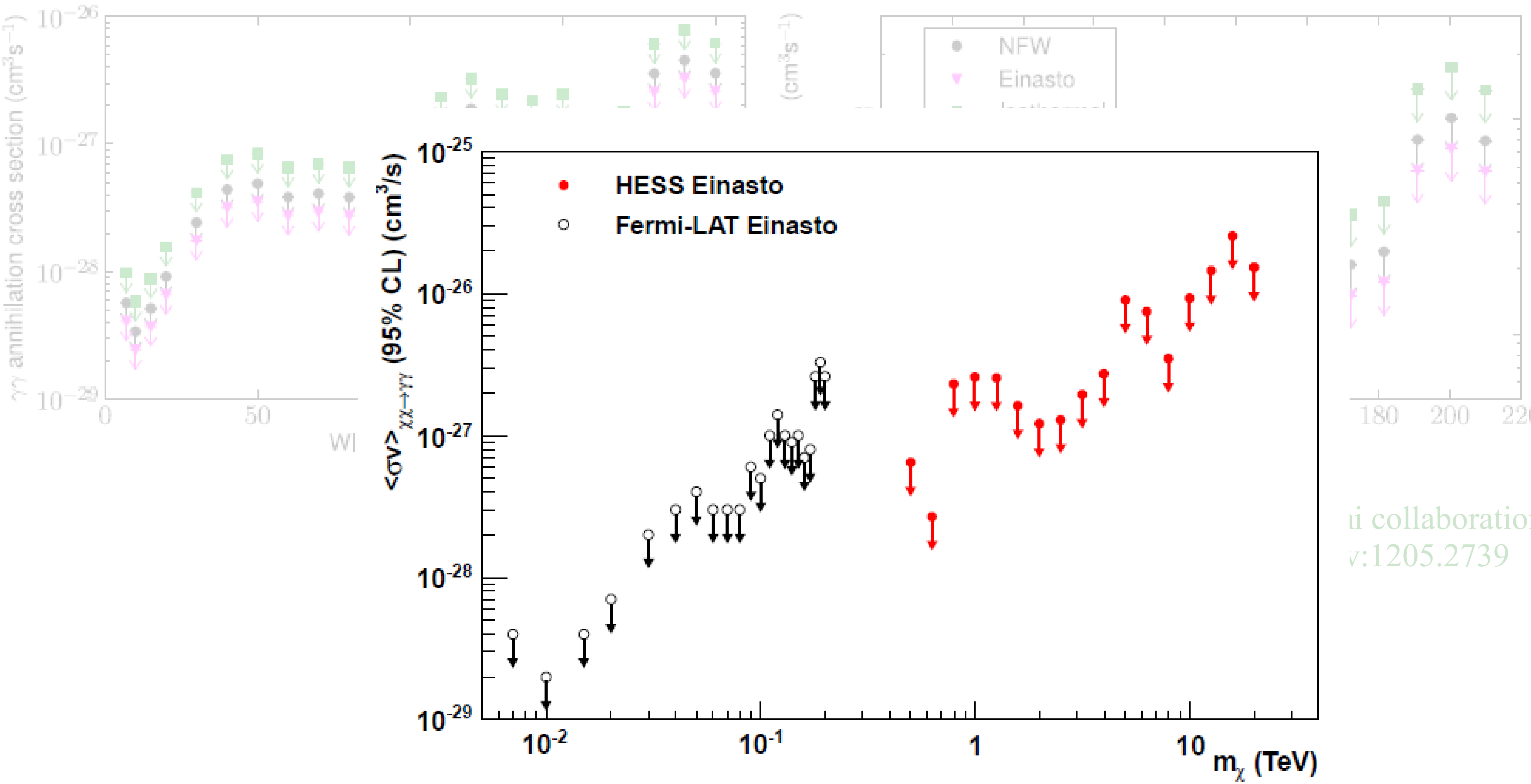




Fermi collaboration
arXiv:1205.2739

Gamma-ray lines

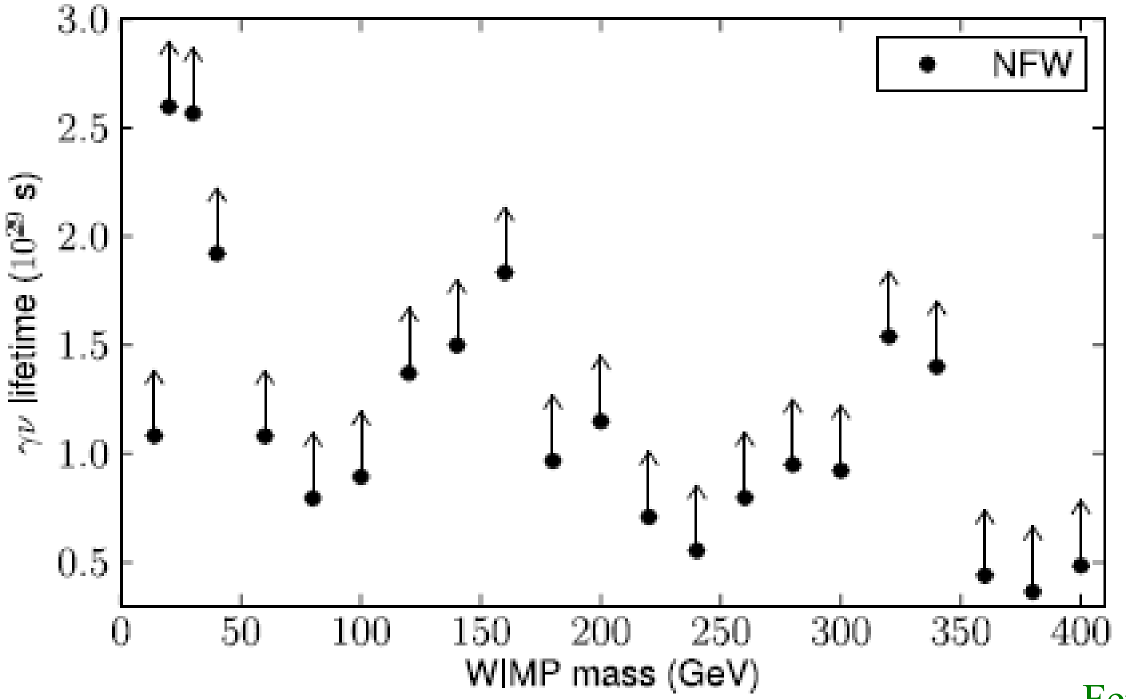
Limits on the annihilation cross section DM DM $\rightarrow \gamma\gamma, Z\gamma$



HESS collaboration
arXiv:1301.1173

Gamma-ray lines

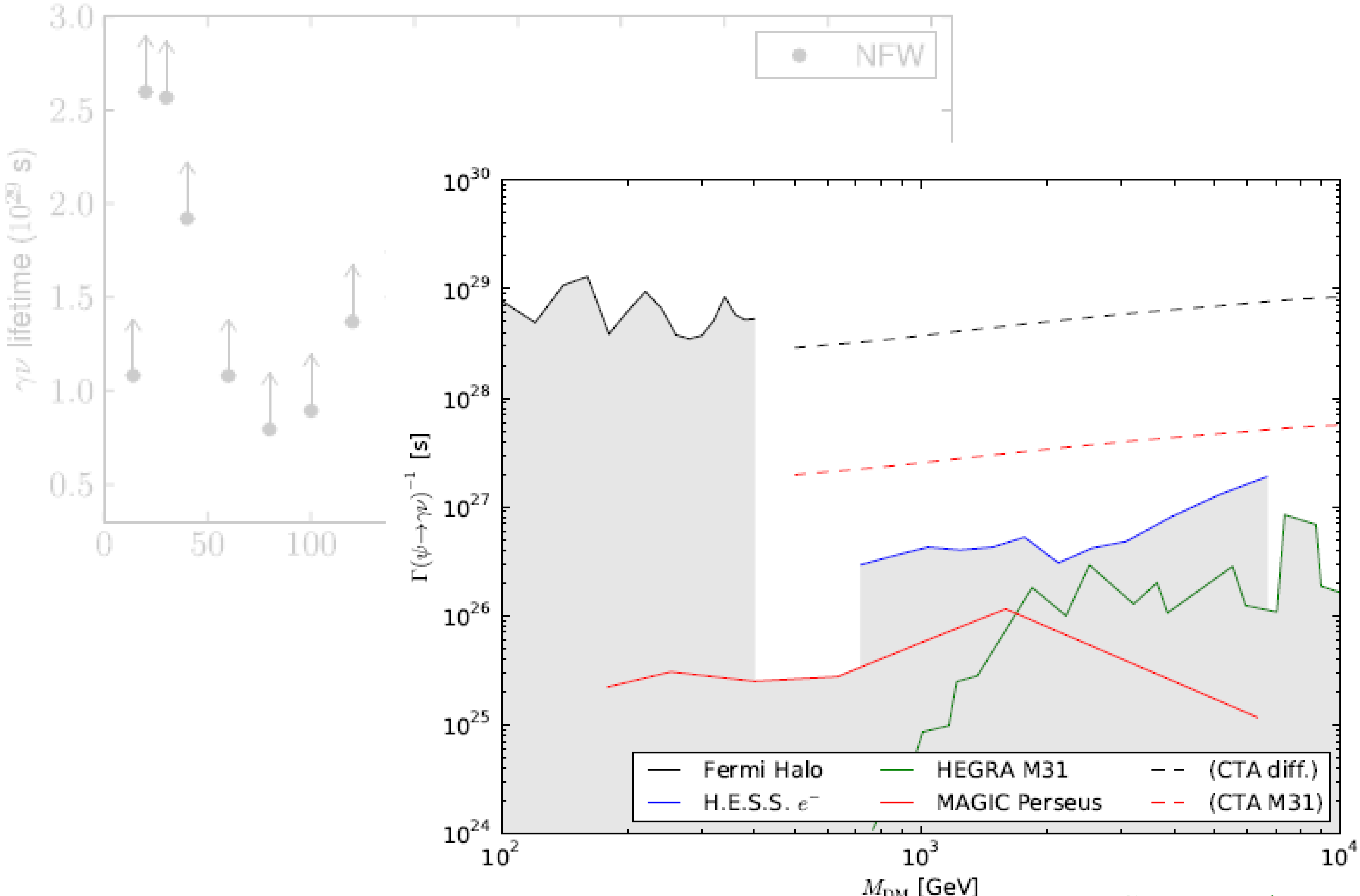
Limits on the lifetime DM → $\gamma\,\nu$



Fermi collaboration
arXiv:1205.2739

Gamma-ray lines

Limits on the lifetime DM $\rightarrow \gamma\,\nu$



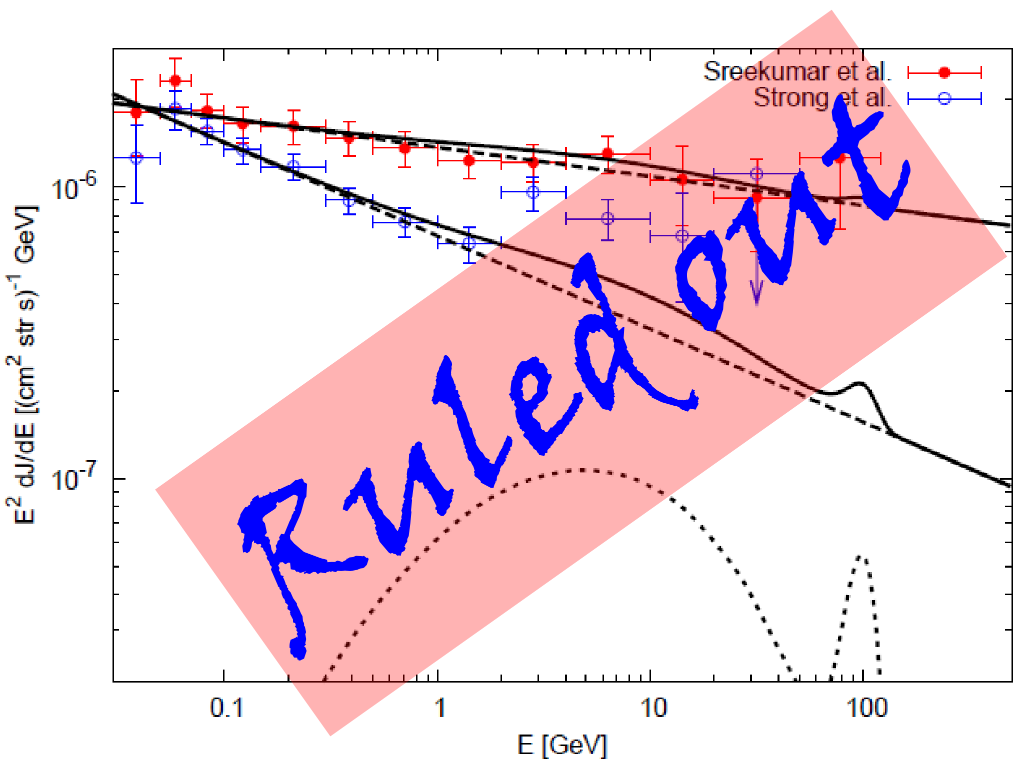
Garny et al.
1011.3786

Gamma-ray lines

Produced also in the decay DM $\rightarrow \gamma\, \nu$

Predicted to be fairly intense in some concrete scenarios

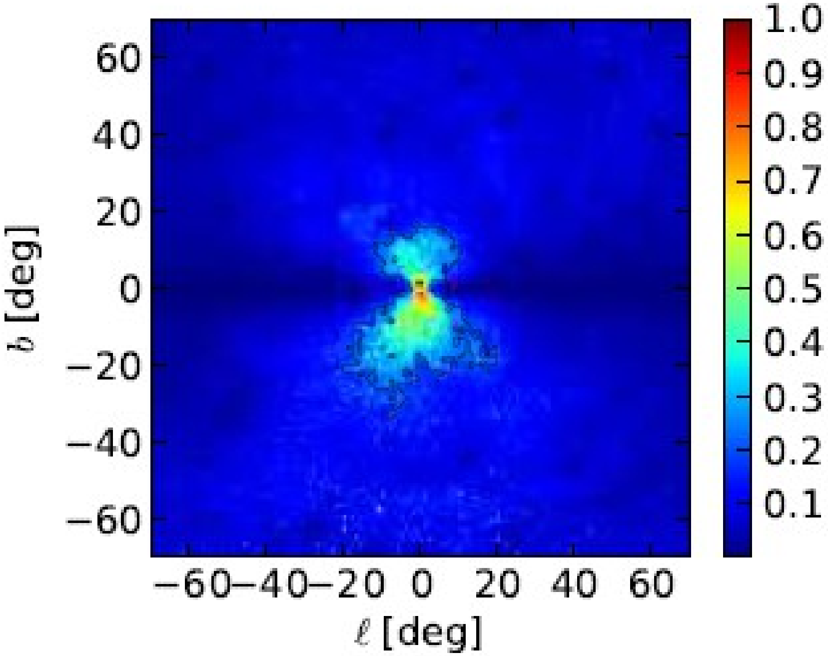
- Gravitino in general SUSY models
(without imposing R-parity conservation)

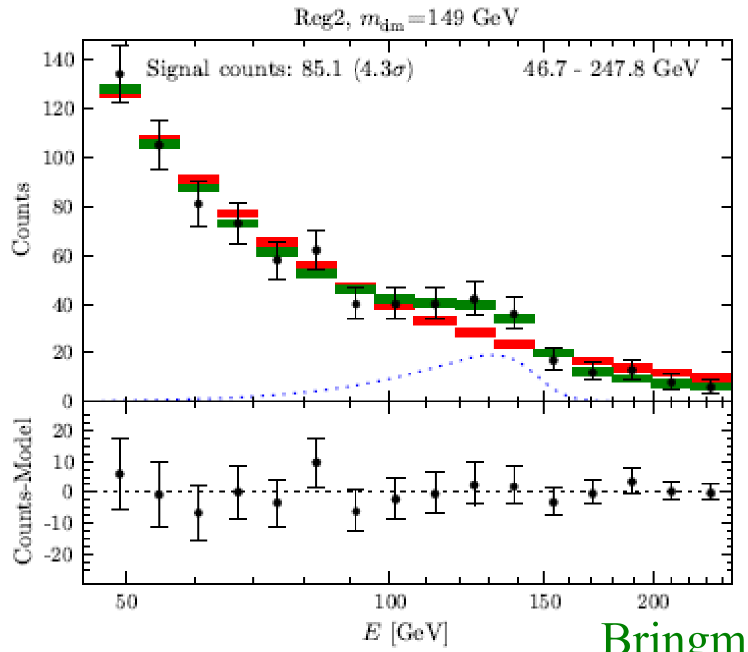


m=200 GeV
$\tau = 7\times10^{26}$ s

Buchmüller, AI, Shindou, Takayama, Tran arXiv:0906.1187

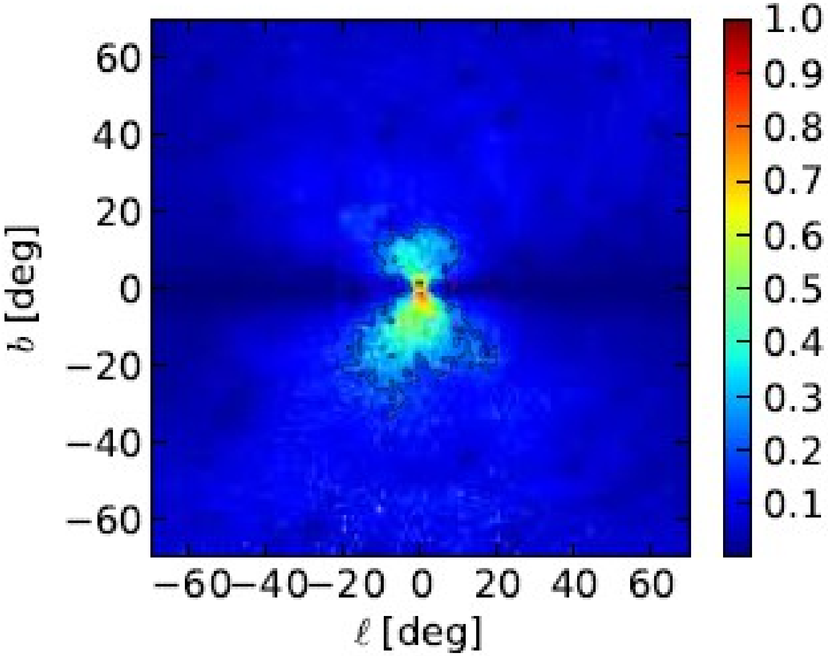
Gamma-ray lines. A hint for a signal?

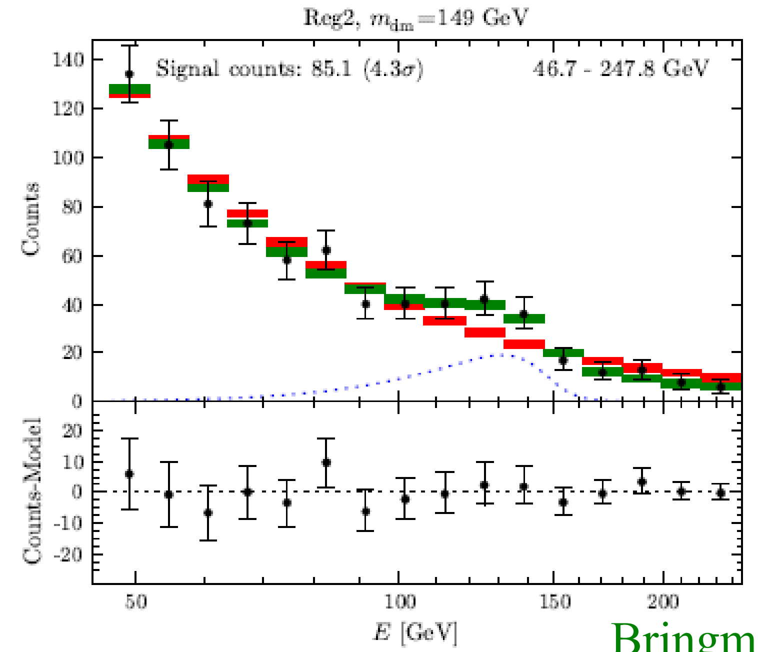




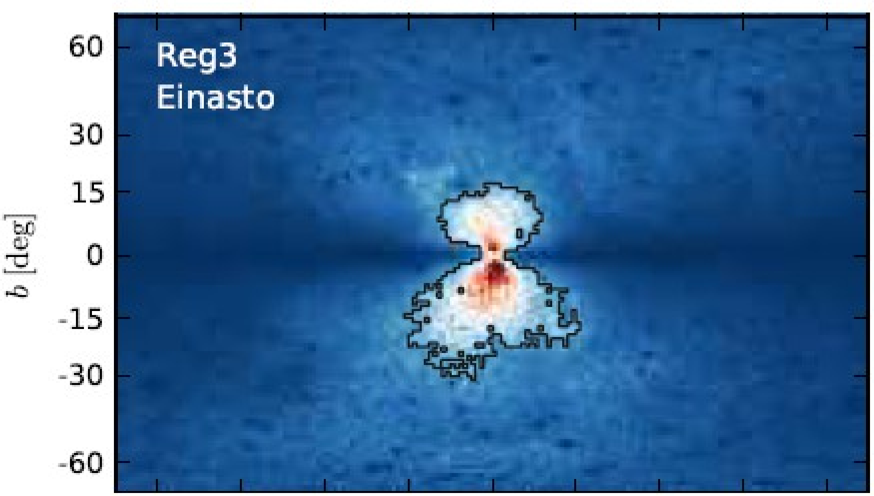
Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312

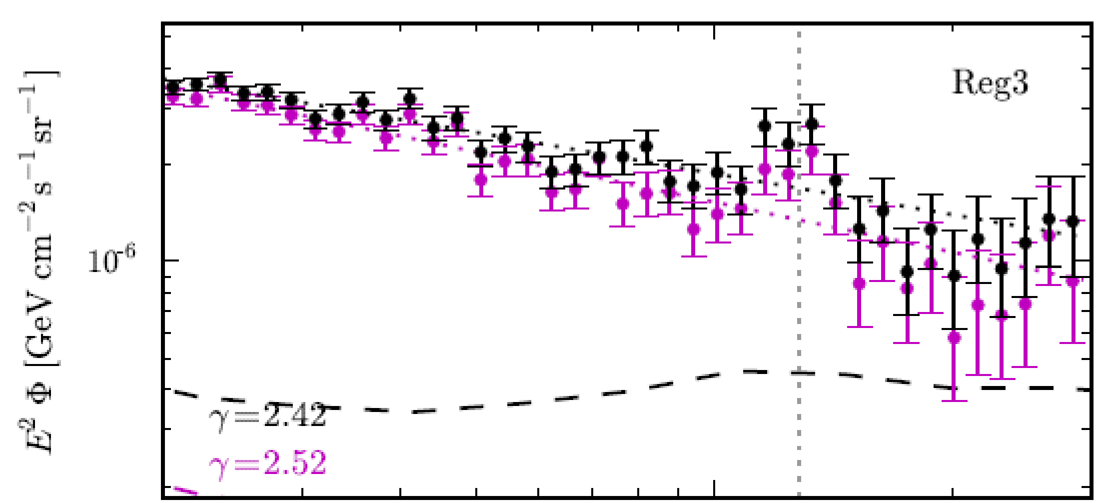
Gamma-ray lines. A hint for a signal?





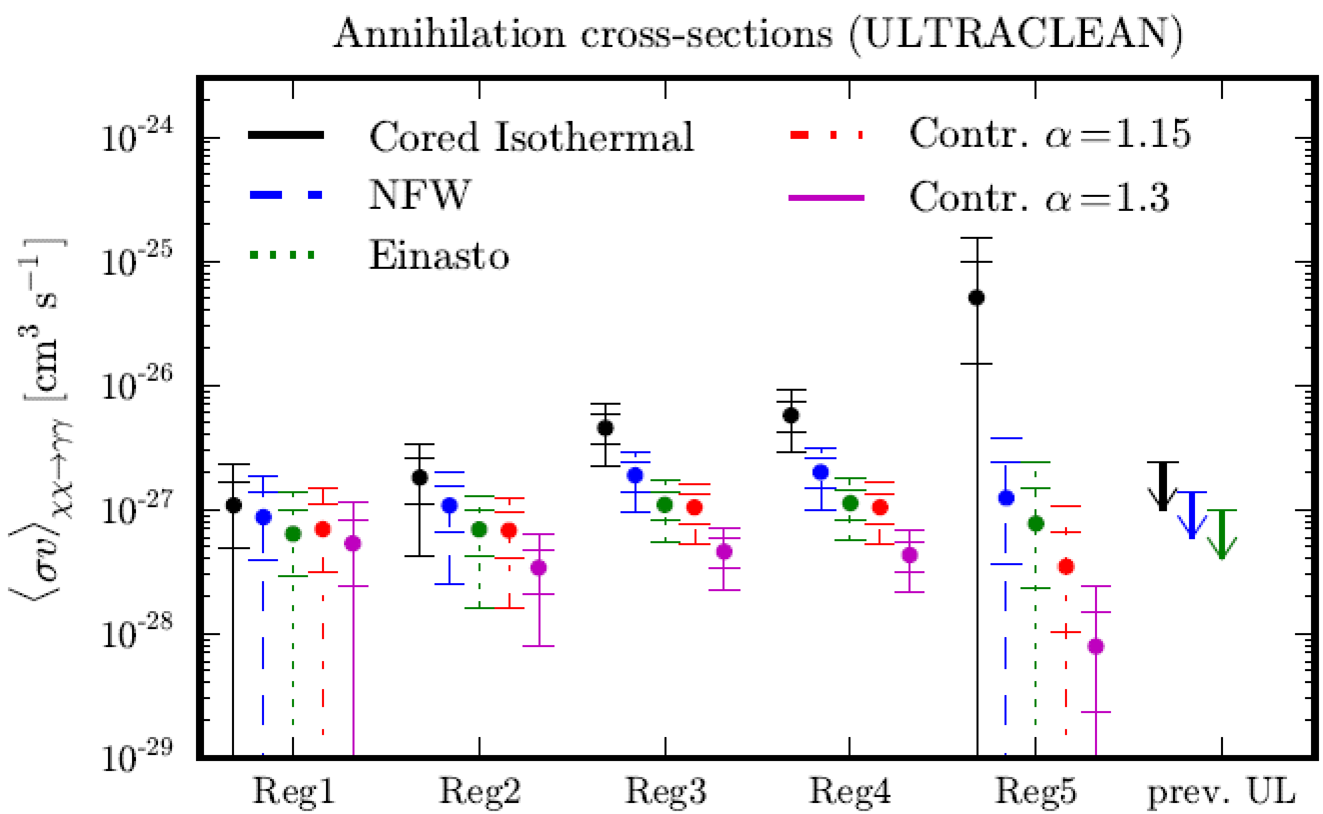
Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312





Weniger arXiv:1204.2797

Gamma-ray lines. A hint for a signal?



For Einasto halo profile,

$$m_\chi = 129.8 \pm 2.4\,^{+7}_{-13}\ \text{GeV}$$

$$\langle\sigma v\rangle_{\chi\chi\to\gamma\gamma} = \left(1.27 \pm 0.32\,^{+0.18}_{-0.28}\right) \times 10^{-27}\ \text{cm}^3\ \text{s}^{-1}$$

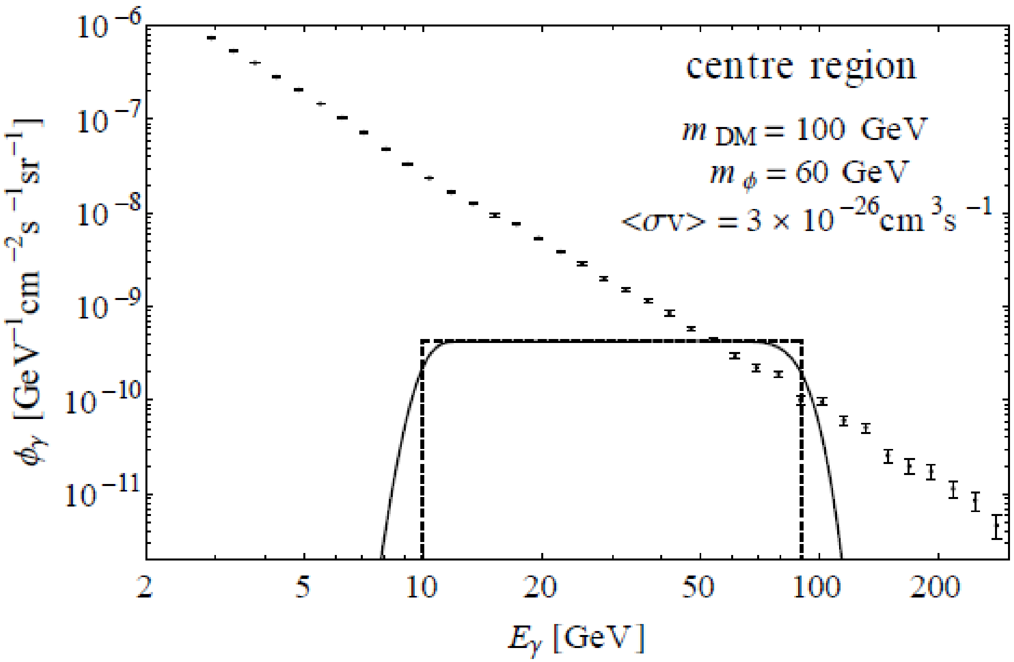
4.6 σ (3.3 σ including LEE)

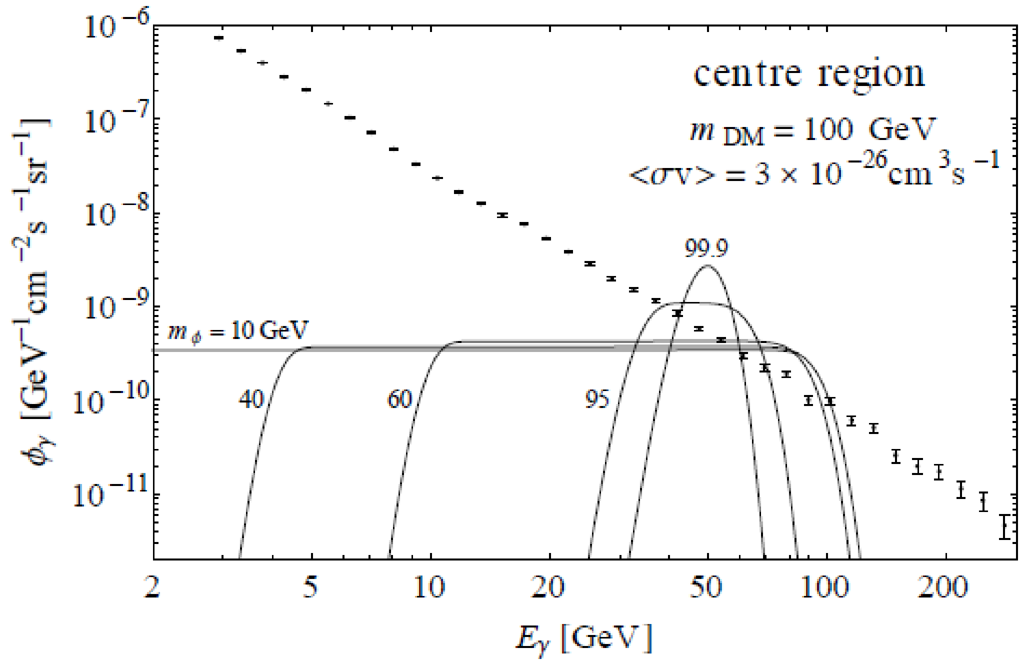
Weniger
arXiv:1204.2797

Gamma-ray "boxes"

Consider the cascade decay: DM DM $\rightarrow \phi\,\phi$

$\phi \rightarrow \gamma\,\gamma$



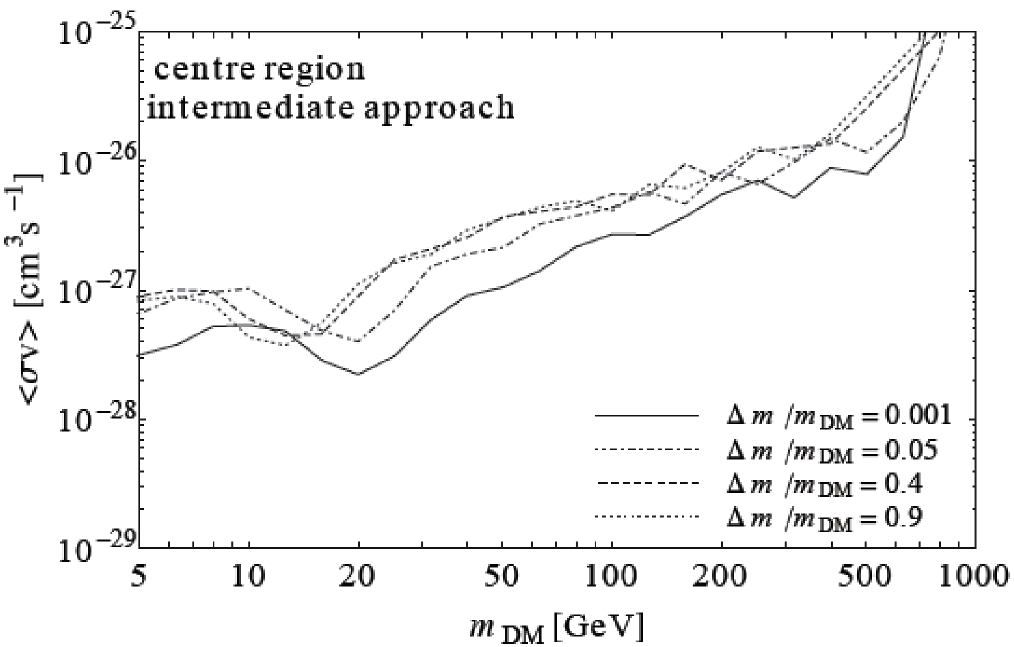


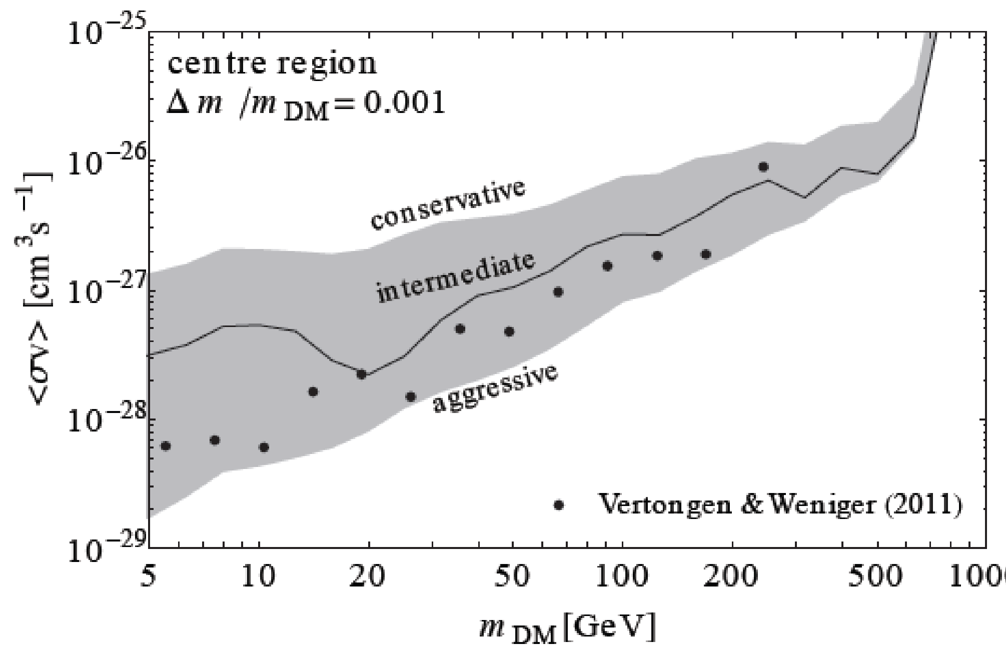
AI, Lopez-Gehler, Pato
arXiv:1205.0007

Gamma-ray “boxes”

Consider the cascade decay: DM DM $\rightarrow \phi\, \phi$

$\phi \rightarrow \gamma\, \gamma$



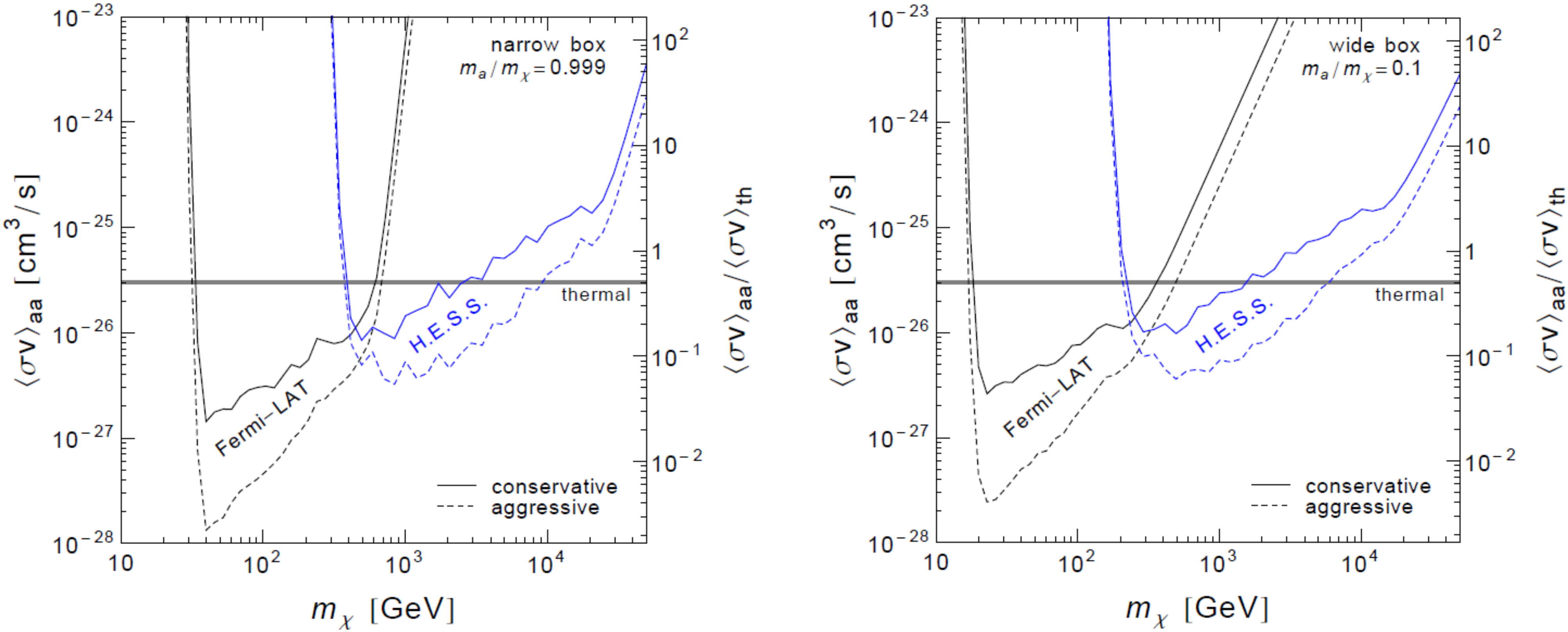


AI, Lopez-Gehler, Pato
arXiv:1205.0007

Gamma-ray "boxes"

Consider the cascade decay: DM DM $\rightarrow \phi\,\phi$

$\phi \rightarrow \gamma\,\gamma$

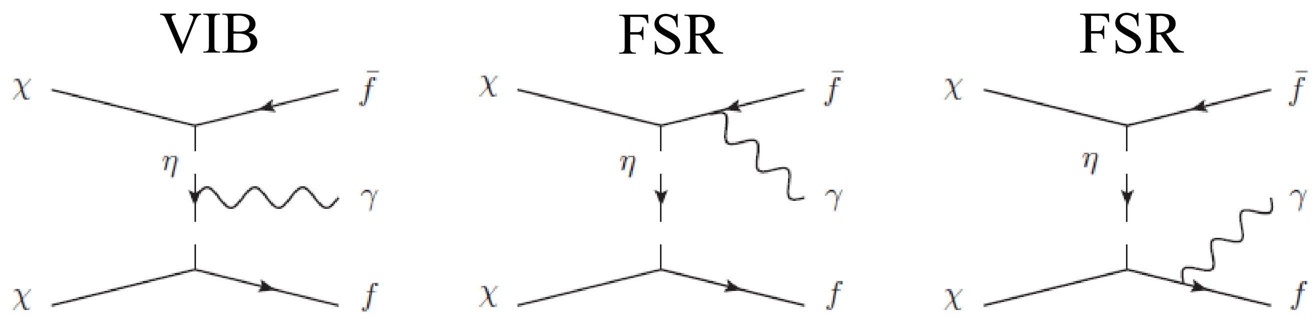


AI, Lee, Lopez-Gehler, Park, Pato

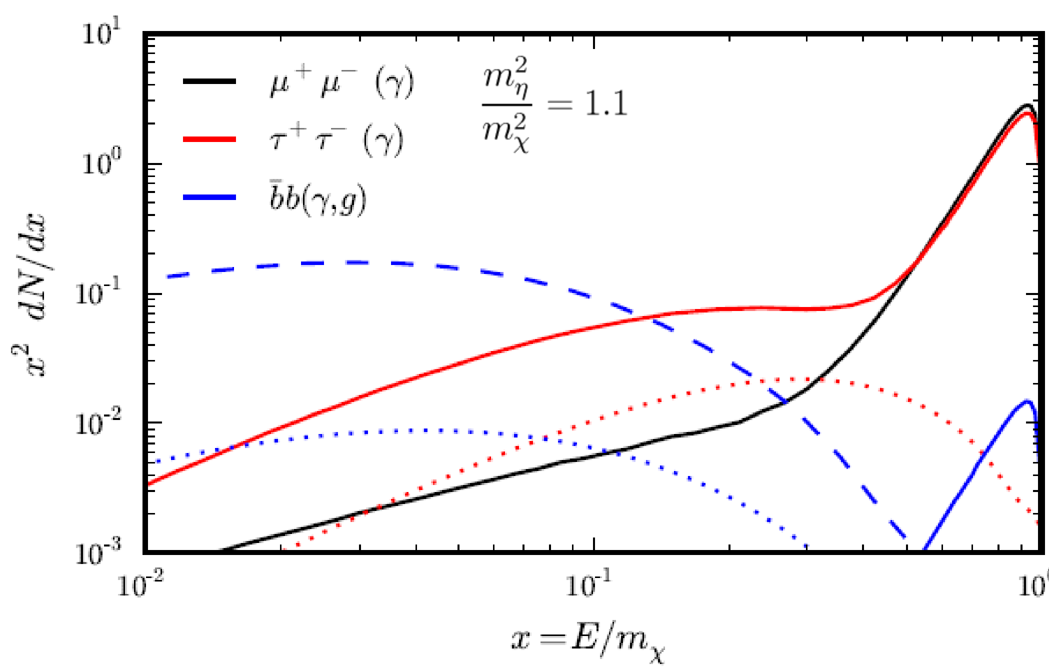
Virtual internal Bremsstrahlung

Bergström
Flores, Olive, Rudaz

In the case of Majorana dark matter annihilations into light fermions, the 2 → 3 process can have a larger cross section than the 2 → 2 one.

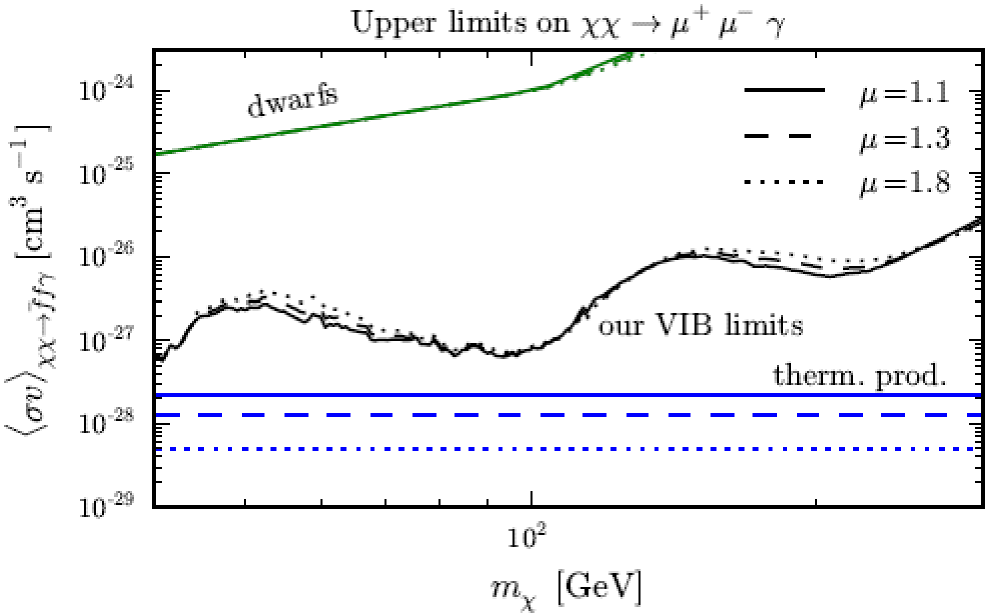


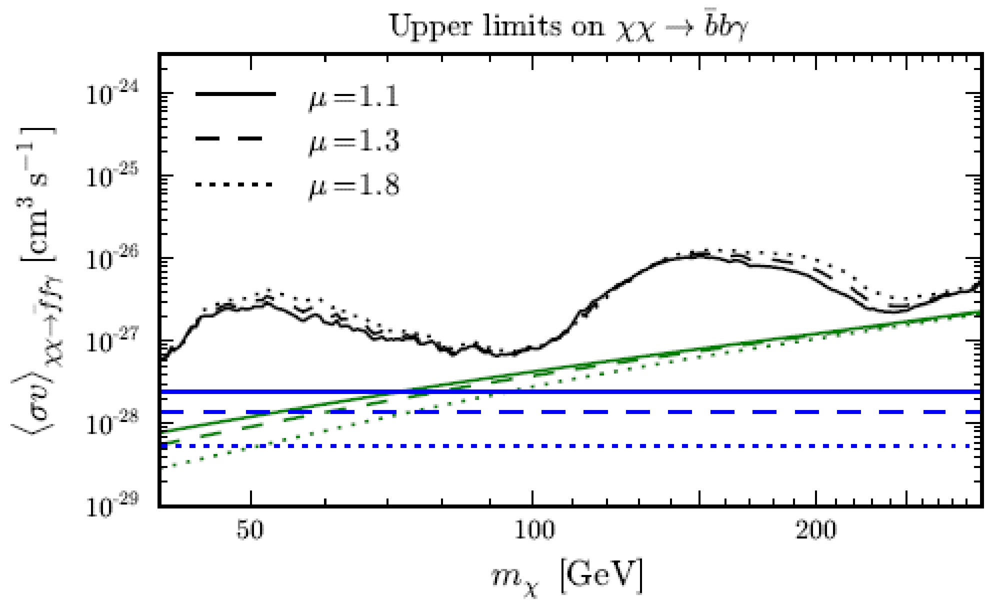
Bonus: if η is degenerate in mass with the dark matter particle, the Gamma-ray spectrum displays a characteristic feature



Bringmann, Huang, AI, Vogl, Weniger
arXiv:1203.1312

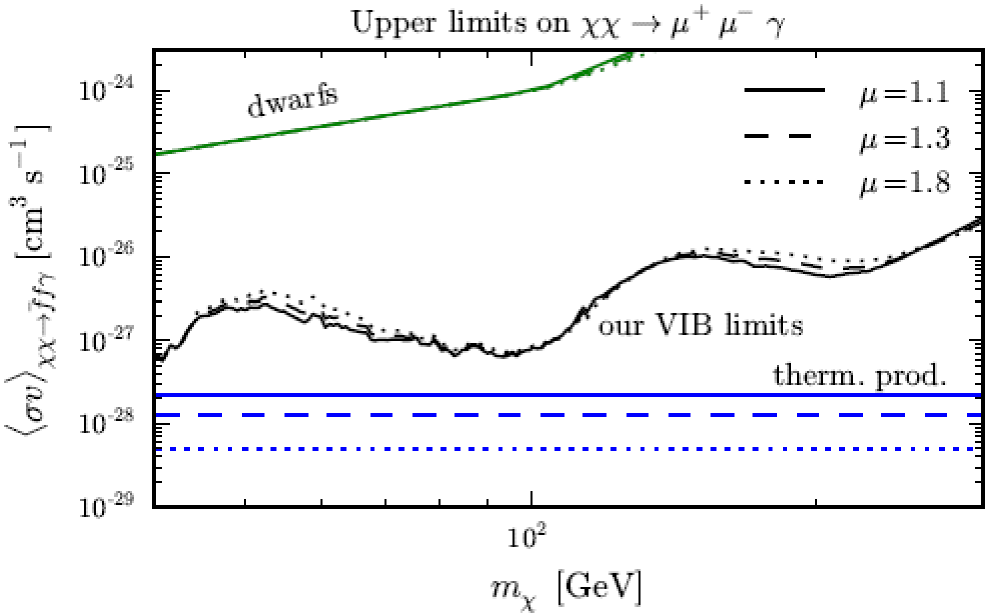
Virtual internal Bremsstrahlung

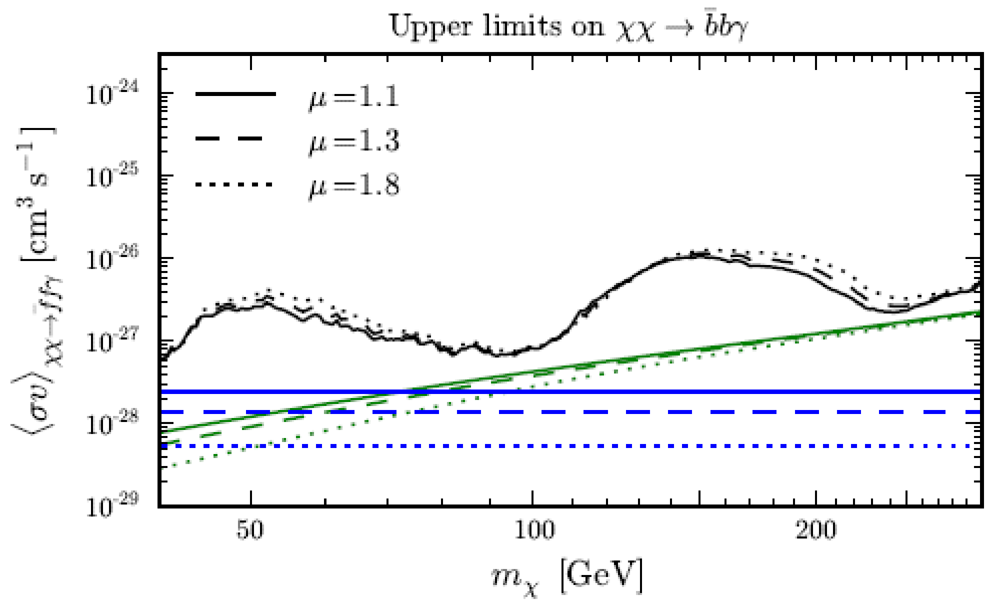


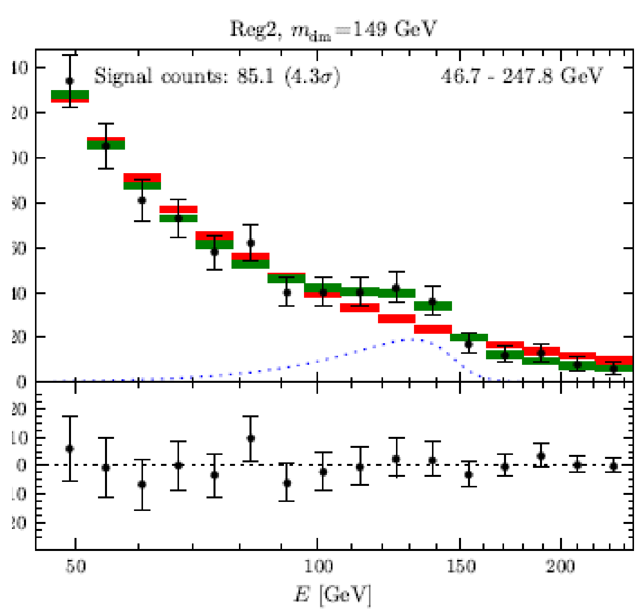


Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312

Virtual internal Bremsstrahlung







Bringmann, Huang, AI, Vogl, Weniger arXiv:1203.1312

$$m_\chi = (149 \pm 4) \text{ GeV}$$
$$\langle \sigma v \rangle = (5.7 \pm 1.4) \times 10^{-27} \text{ cm}^3 \text{ s}^{-1}$$

4.3 σ (3.1 σ with LEE)

Conclusions

■ We have entered an era where indirect searches provide strong constraints on the dark matter properties.

■ Experiments are starting to probe regions of the parameter space where a signal could be expected. Discovery potential?

■ Bright future in indirect dark matter searches: AMS-02, IceCube, CTA... New surprises (and new challenges) are surely awaiting us.