Dark Matter Review

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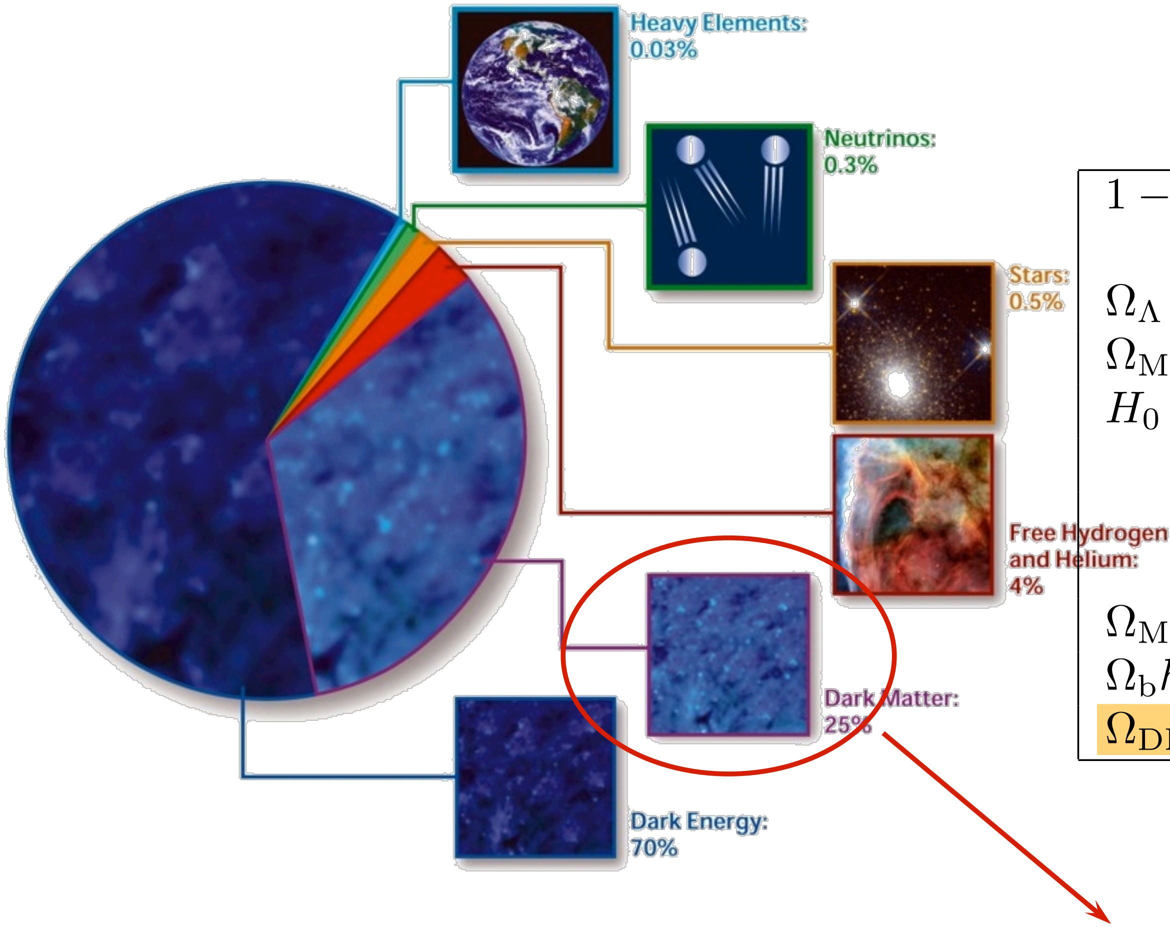
INFN Torino

IAP Belgian Meeting "Fundamental Interactions"
UCL (Louvain-la-Neuve) – 19.12.2013

Dark Matter



$1-\Omega_{\rm TOT}$	-0.0105 ± 0.061	[95% C.L.]
Ω_Λ	0.693 ± 0.019	[68% C.L.]
$\Omega_{\rm M}$	0.307 ± 0.019	[68% C.L.]
H_0	67.9 ± 1.5	[95% C.L.]
	73.8 ± 2.4	[*]
	74.3 ± 2.6	[+]
$\Omega_{\rm M} h^2$	0.1414 ± 0.0029	[68% C.L.]
$\Omega_{\rm b} h^2$	0.02217 ± 0.00033	[68% C.L.]
$\Omega_{\rm DM} h^2$	0.1186 ± 0.0031	[68% C.L.]

Ade et al. (Planck Collab.), arXiv: 1303.5076
[*] Riess et al., Ap. J. 730 (2011) 119
[+] Freedmann et al., Ap. J. 758 (2012) 24

Overwhelming evidence:

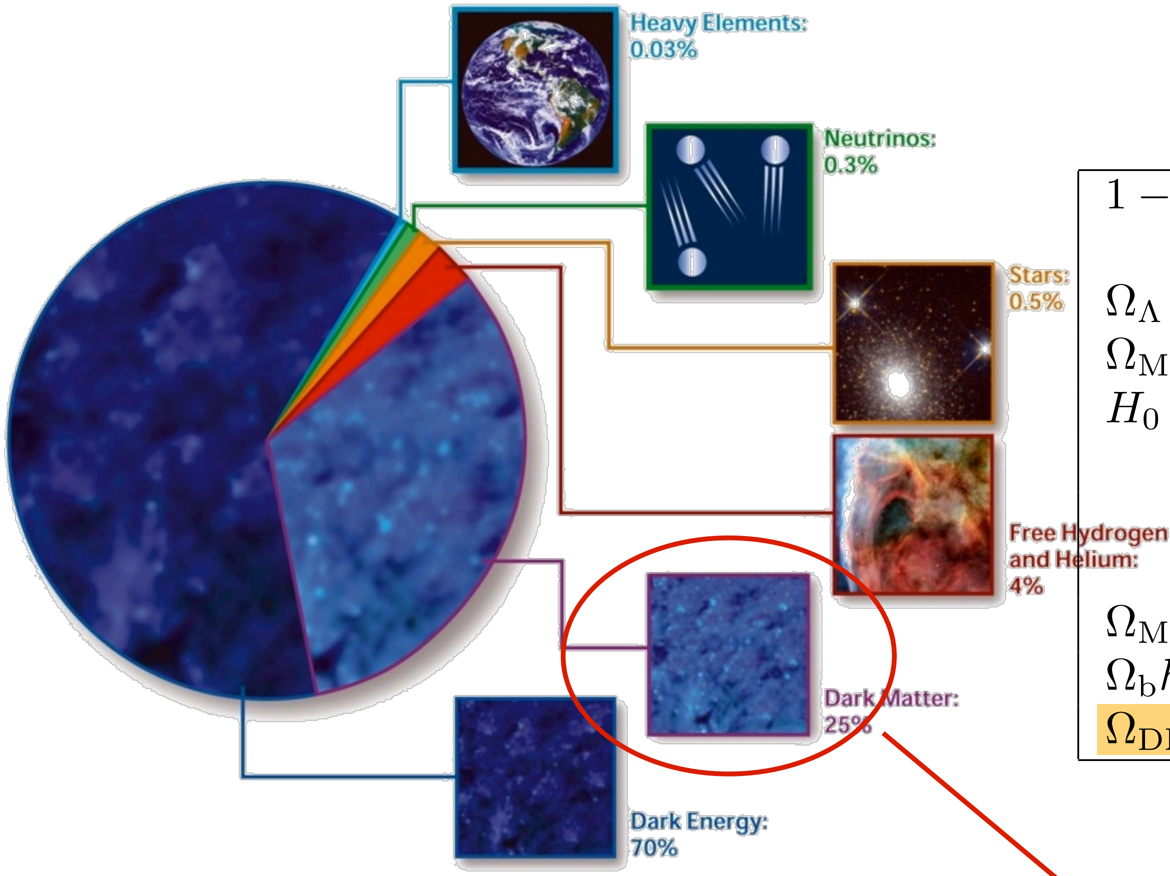
Dynamics of galaxy clusters
Rotational curves of galaxies
Gravitational lensing
Structure formation from primordial density fluctuations
Energy density budget

Points toward New Physics

i) Non-baryonic (cold) dark matter

- No candidate in the Standard Model
- New elementary particle

ii) Theory of Gravity is not purely GR



Dark Matter

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Non-baryonic (cold) dark matter

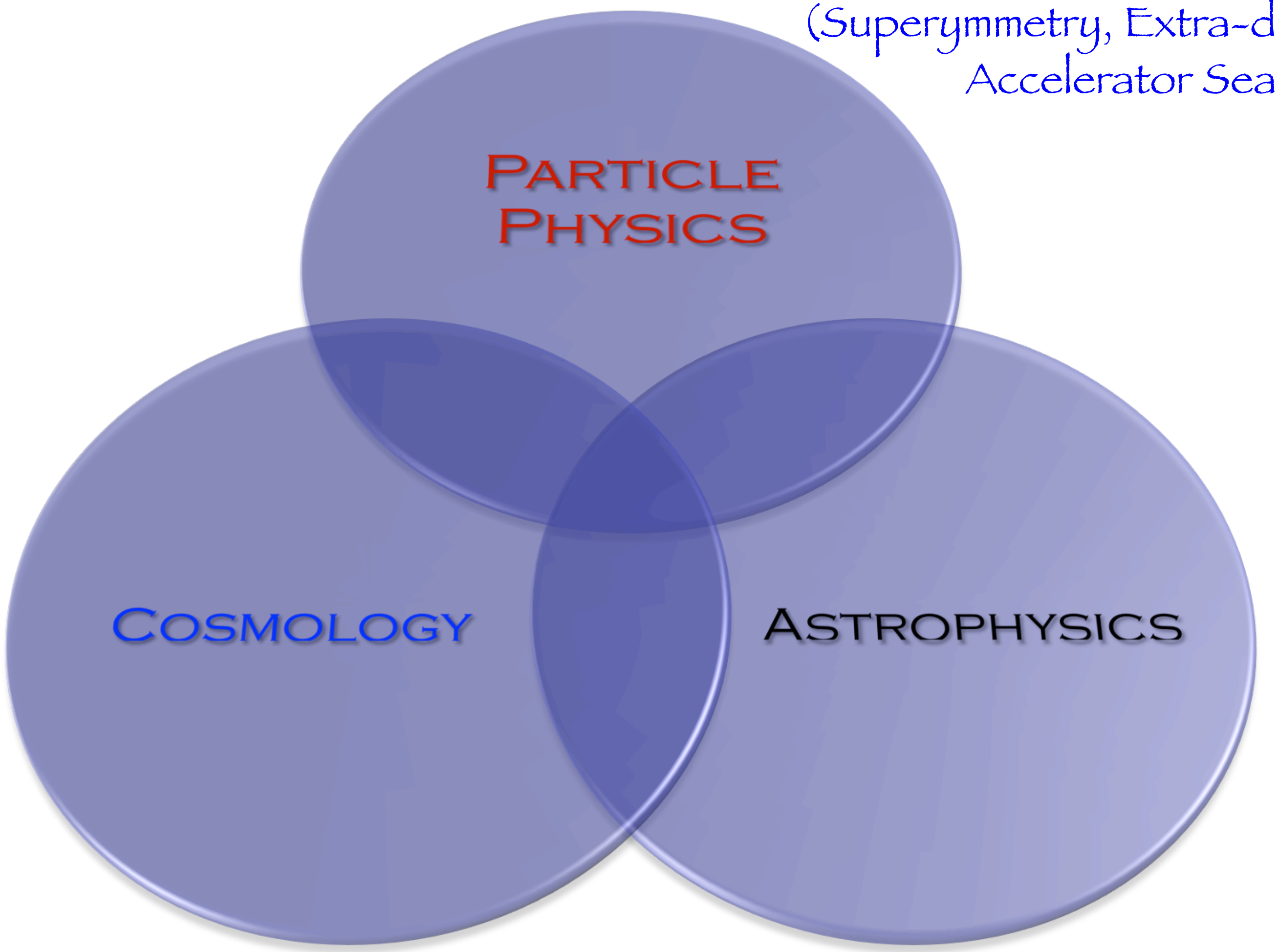
- No candidate in the Standard Model
- New elementary particle

Two fundamental questions

- Identify the particle candidate
- Identify a non-gravitational signal

The Particle Dark Matter Crossroad

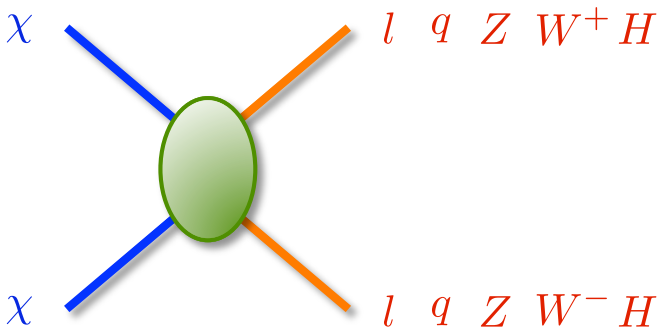
Particle Candidate: Models of New Physics
(Superymmetry, Extra-dimensions, ...)
Accelerator Searches



Cosmology of the
Dark Matter Particle

Astrophysical Signals of the
Dark Matter Particle

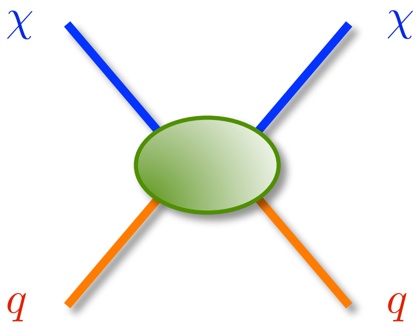
Mechanisms of DM signal production



Annihilation

Responsible for:

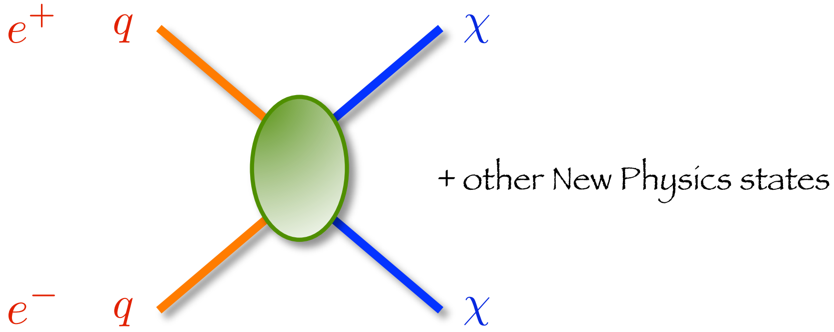
- cosmological abundance (if DM is thermal relic)
- indirect astrophysical signals



Scattering with ordinary matter

Responsible for:

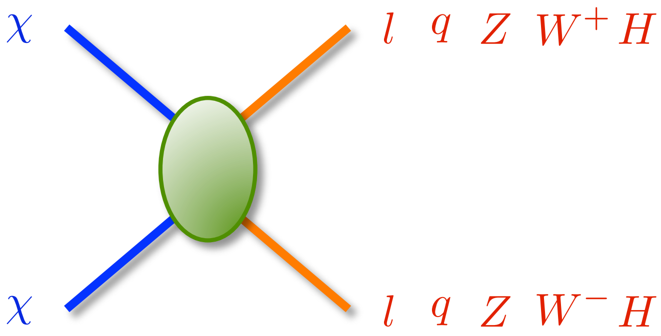
- direct detection
- neutrinos from Earth and Sun



Direct production

Relevant for accelerator searches

Mechanisms of DM signal production



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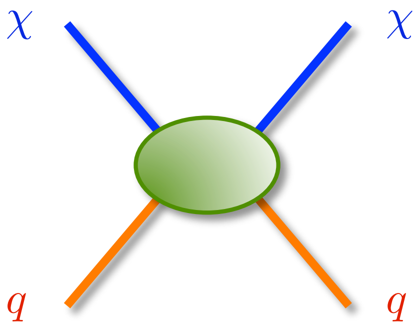

* See talk by Sumner

Scattering with ordinary matter

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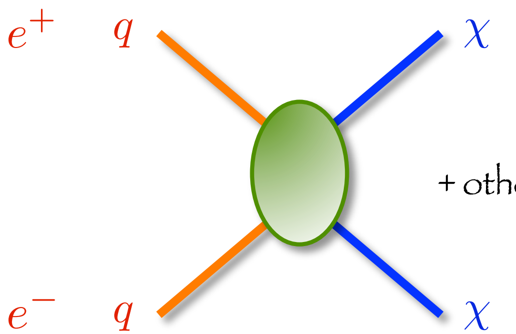


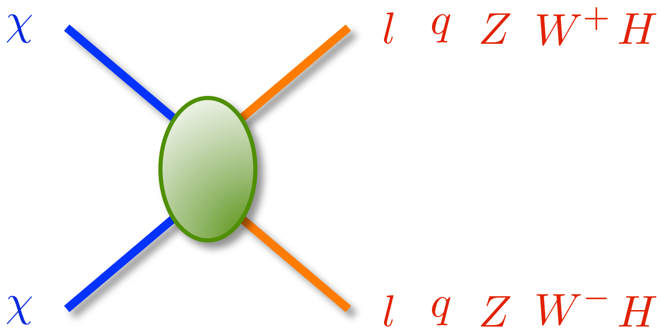
+ other New Physics states

* See talk by Lowette

Direct production

Relevant for accelerator searches

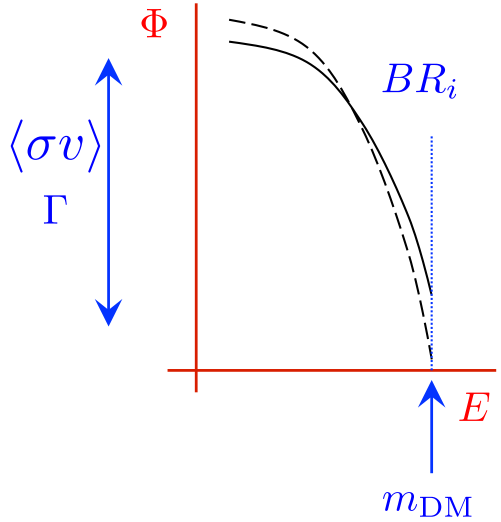
Indirect astrophysical signals



Annihilation (or decay)

Relevant particle physics properties:

1. Annihilation cross section (*) (or decay rate)
2. Mass of the DM particle
3. BR in the different final states

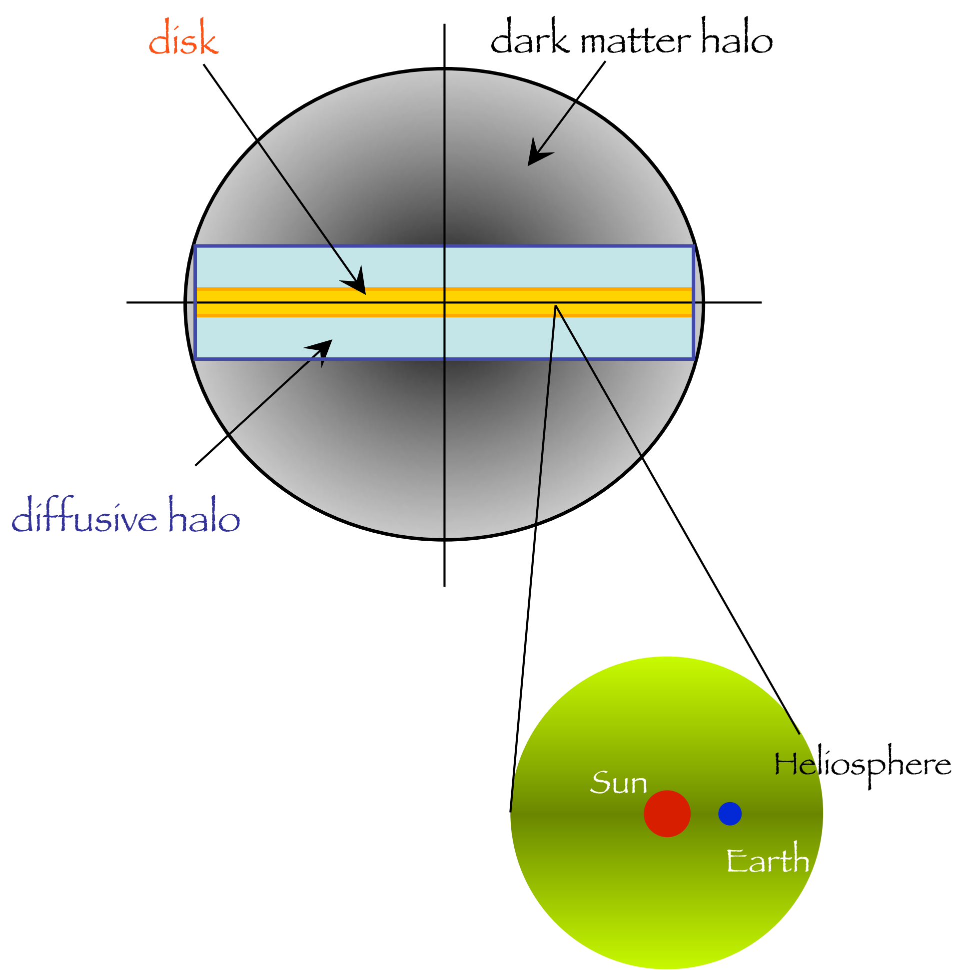


1 + 2 : Size of the signal
2 + 3 : Spectral features

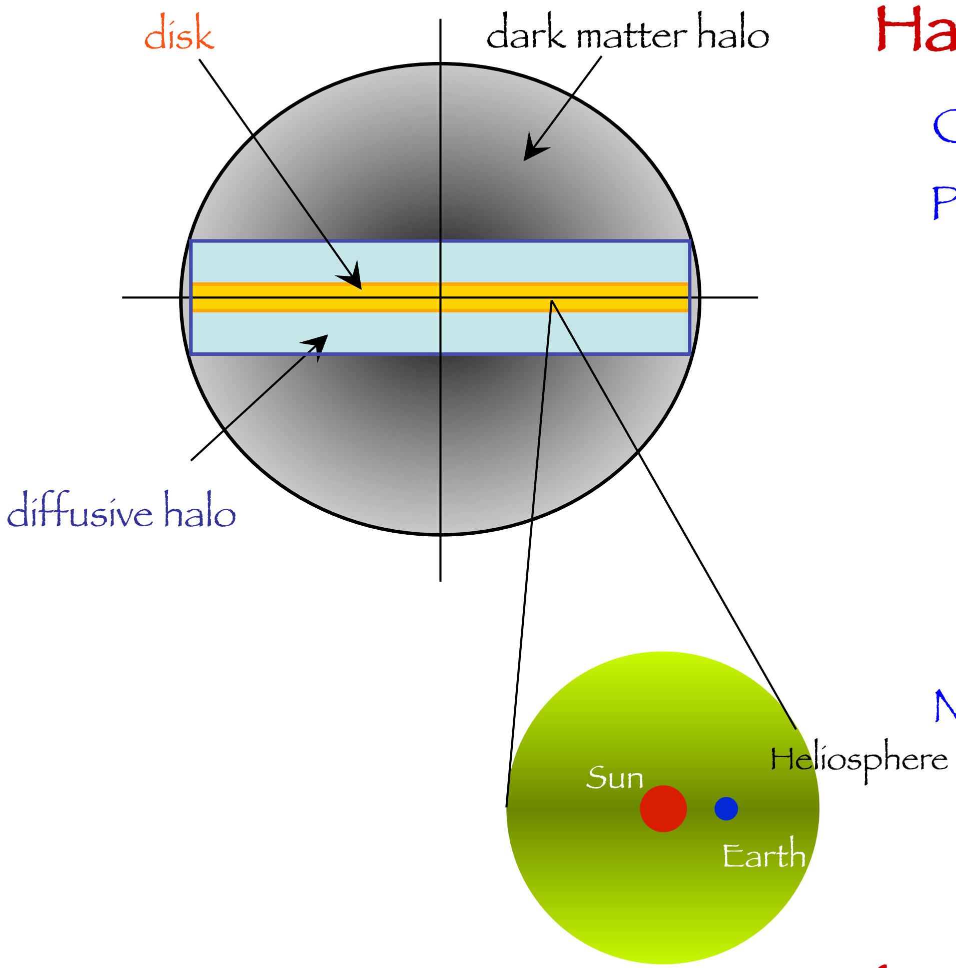
(*) Determines also the cosmological relic abundance (for a thermal DM)

$$\Omega h^2 = 0.11 \quad \longleftrightarrow \quad \langle \sigma_{\rm ann} v \rangle = 2.3 \times 10^{-26} \ {\rm cm}^3 \ {\rm s}^{-1}$$

Galactic environment



Particle dark matter signals



Halo signals

Charged CR ($e^{\pm}$, antip, antiD)

Photons

- Gamma-rays
  - Prompt production
  - IC from $e^{\pm}$ on ISRF and CMB
- X-rays
  - IC from $e^{\pm}$ on ISRF and CMB
- Radio
  - Synchro from $e^{\pm}$ on mag. field

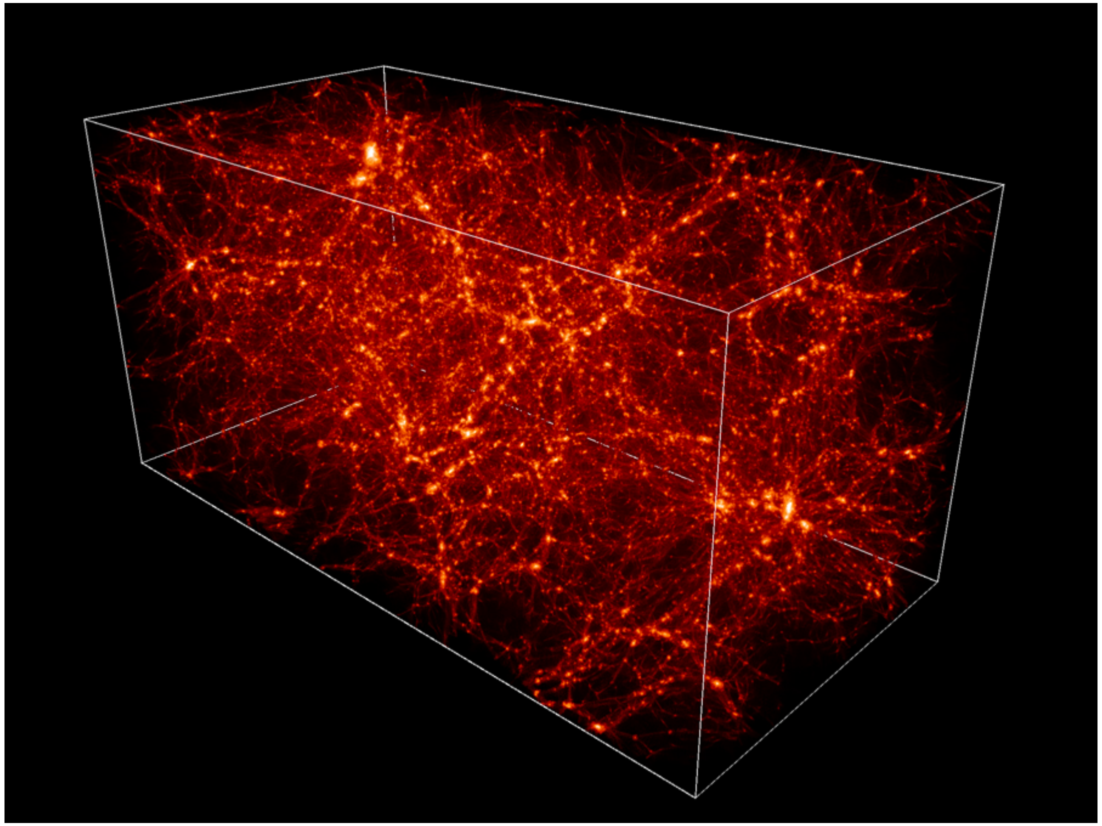
Neutrinos

Local signals

Direct detection

Neutrinos from Earth and Sun

Extra-galactic environment



Extragalactic signals

Photons: gamma, X, radio

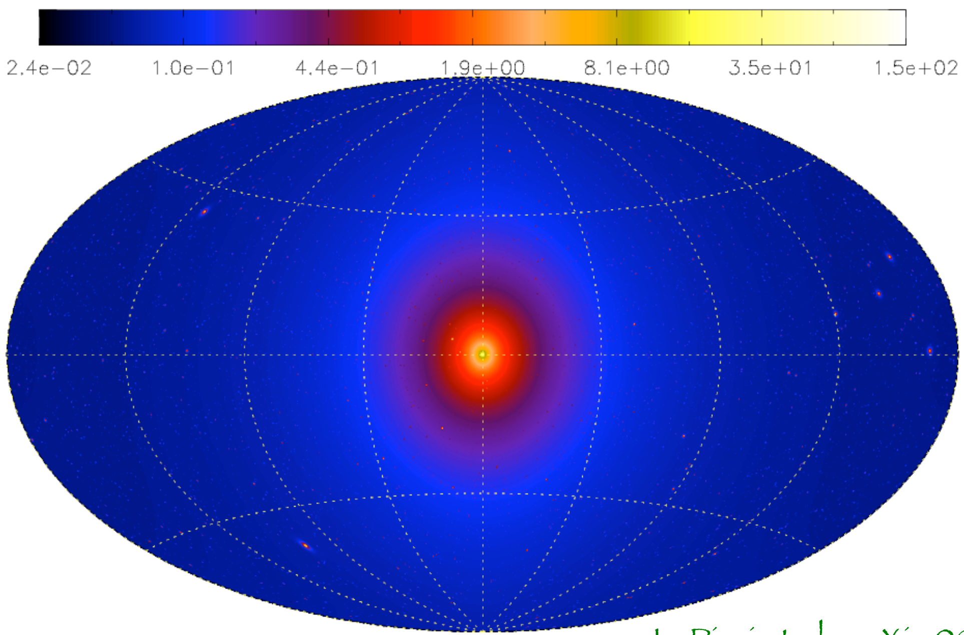
Neutrinos

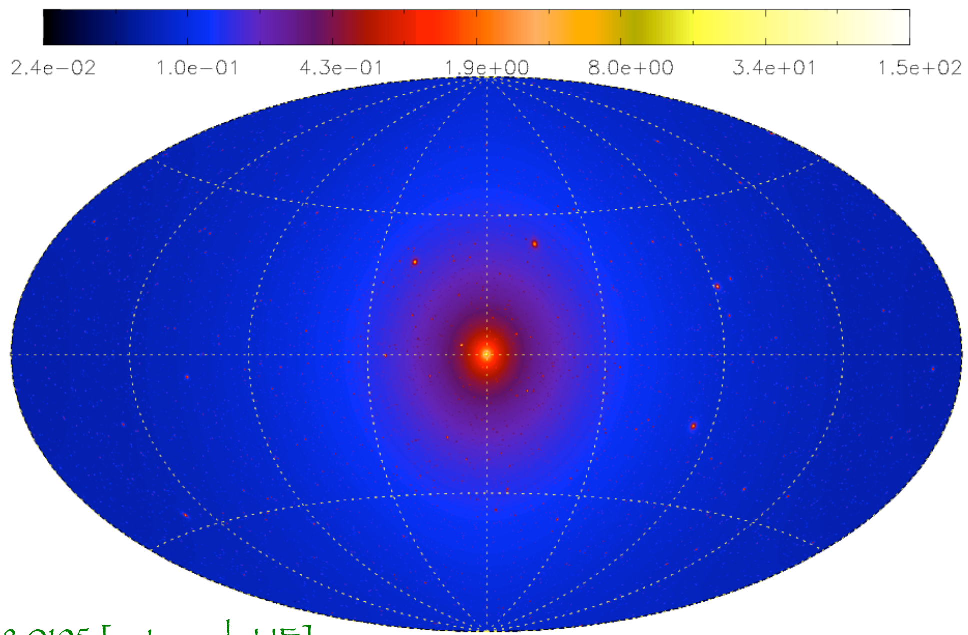
Sunyaev-Zeldovich effect on CMB

Optical depth of the Universe

Gamma rays

DM gamma-ray sky





L. Pieri et al., arXiv:0908.0195 [astro-ph.HE]

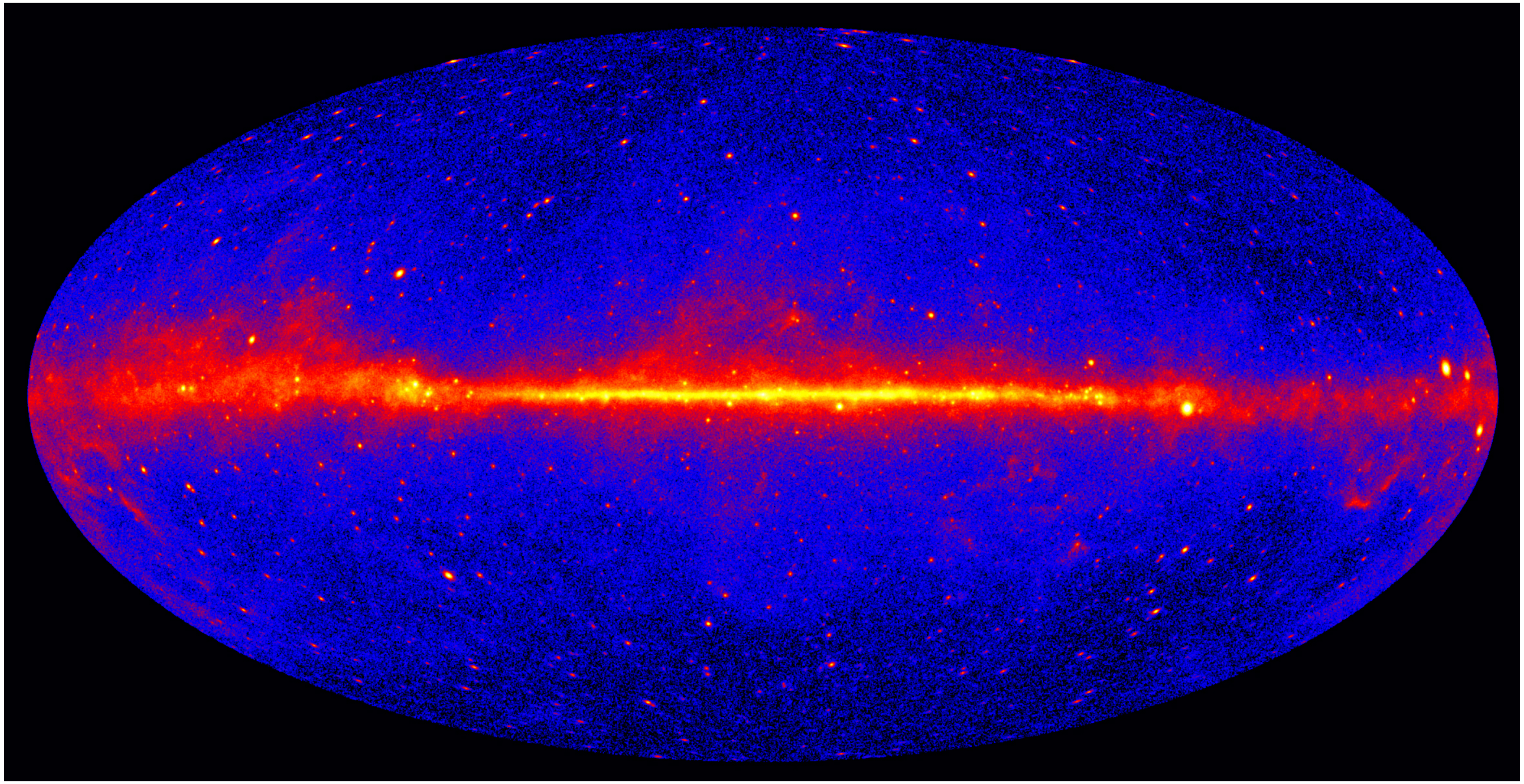
Aquarius simulation

Via Lactea II simulation

Gamma-rays contributions come from:

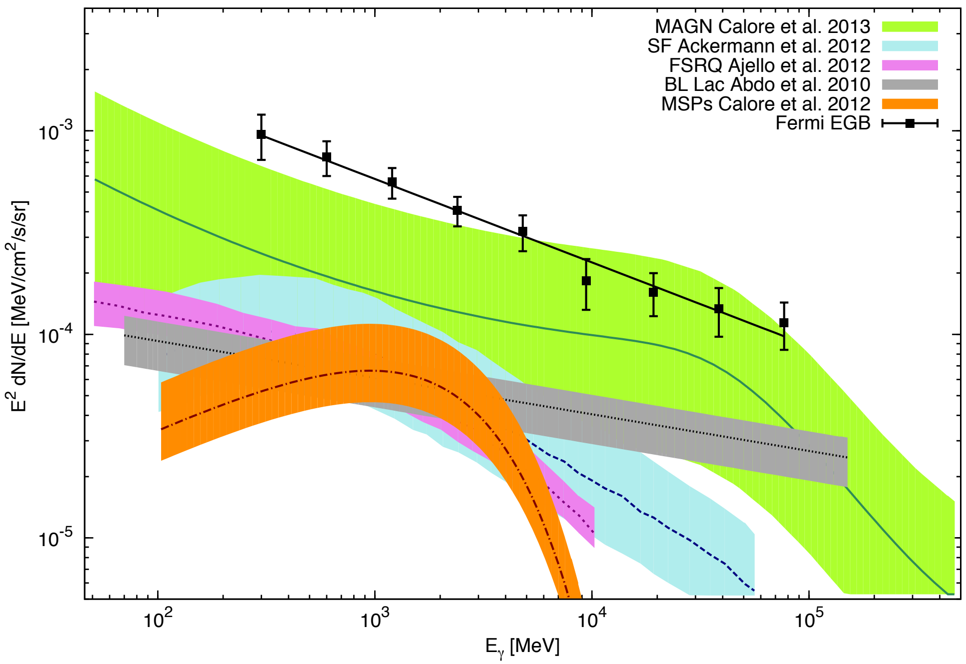
- smooth halo
- halo substructures
- extra-galactic environment

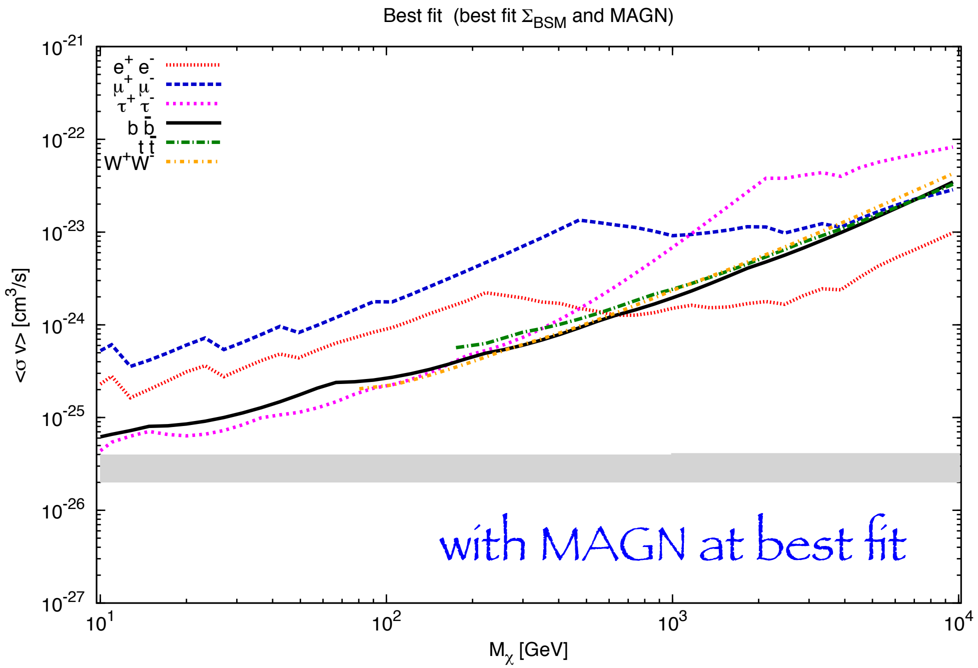
Fermi/LAT gamma-rays sky

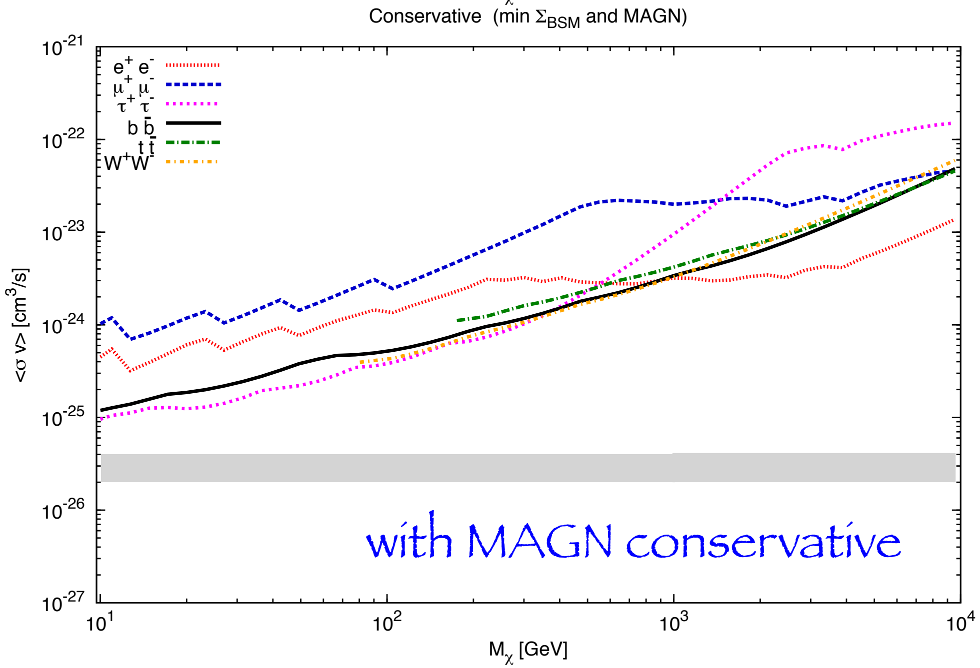


Photon energies: E > 1 GeV
Observation time: 5 yrs

Bounds on DM annihilation





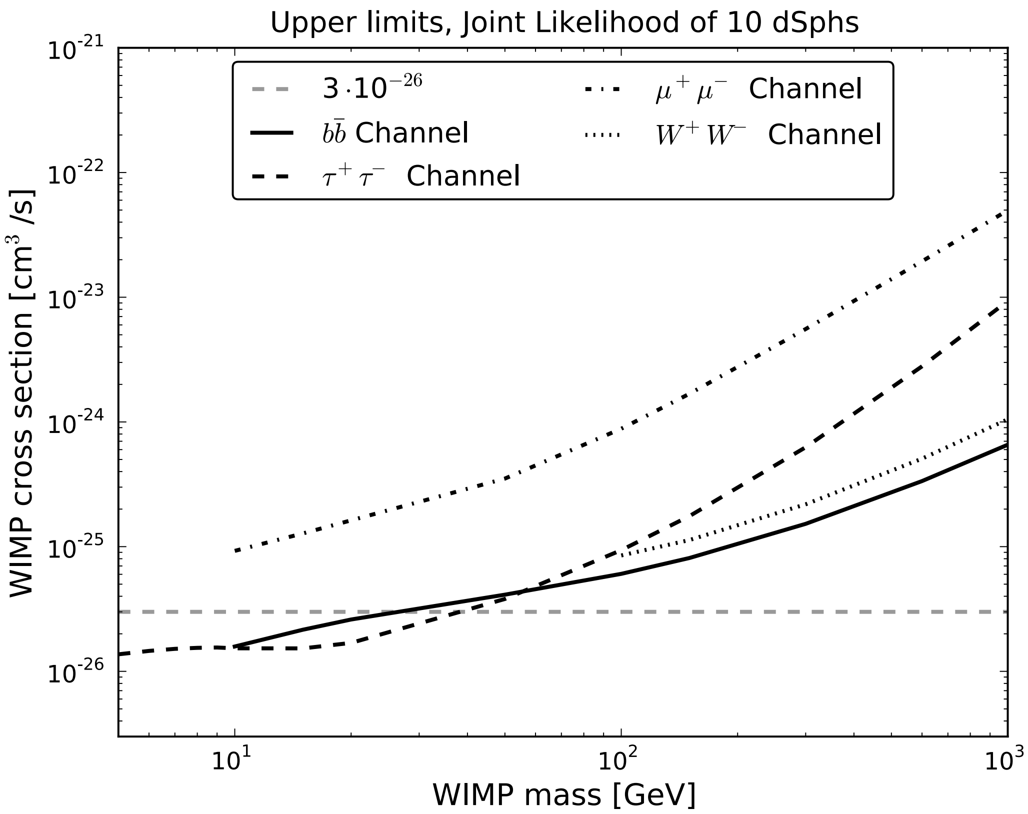


Bringman, Calore, Di Mauro, Donato, arXiv:1303.3284
Di Mauro, Calore, Donato, Ajello, Latronico, arXiv:1304.0908

FERMI analysis on Milky-Way satellites

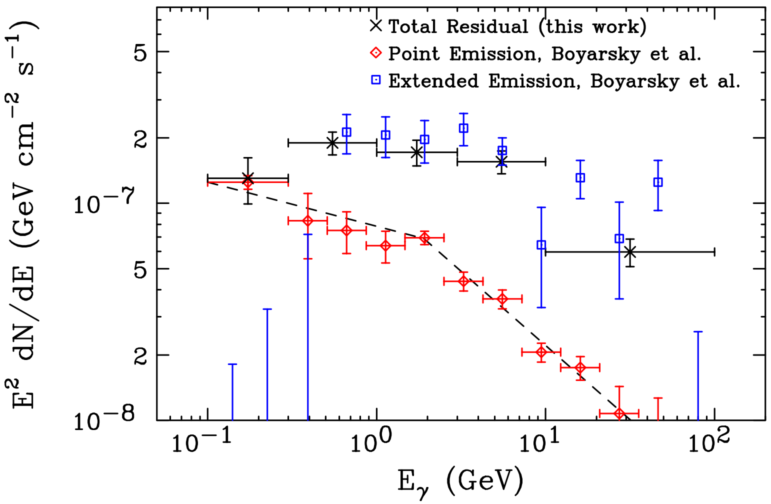
Name	l	b	d	$\overline{\log_{10}(J)}$	σ
	deg.	deg.	kpc	$\log_{10}[\mathrm{GeV}^2\mathrm{cm}^{-5}]$	
Bootes I	358.08	69.62	60	17.7	0.34
Carina	260.11	−22.22	101	18.0	0.13
Coma Berenices	241.9	83.6	44	19.0	0.37
Draco	86.37	34.72	80	18.8	0.13
Fornax	237.1	−65.7	138	17.7	0.23
Sculptor	287.15	−83.16	80	18.4	0.13
Segue 1	220.48	50.42	23	19.6	0.53
Sextans	243.4	42.2	86	17.8	0.23
Ursa Major II	152.46	37.44	32	19.6	0.40
Ursa Minor	104.95	44.80	66	18.5	0.18

joint likelihood analysis of
10 satellite galaxies



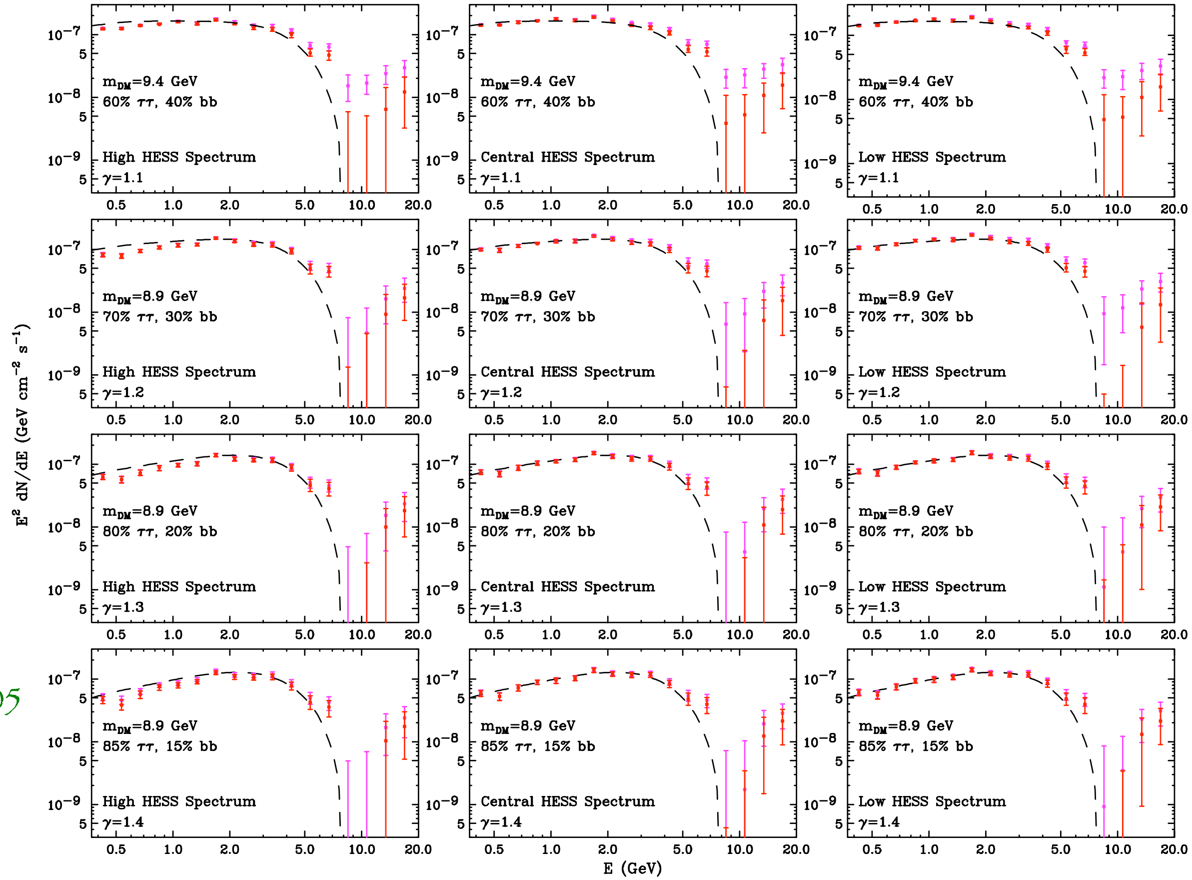
Ackermann et al., arXiv:1108.3546
See also: Geringer-Sameth, Koushappas, arXiv:1108.2914

FERMI-LAT excess toward the GC ?



[1] Hooper, Goodenough, PLB (2011) 697 (2011)
[1] Hooper, Linden, PRD 84 (2011) 123005

[2] Boyarsky, Malyshev, Ruchayskiy, PLB (2011) 705



[1] Spatially extended emission toward the GC
Compatible with 7-12 GeV DM (annihilation into leptons)
25-45 GeV DM (annihilation into hadrons)

[1] Compatible also with collisions of high-E protons accerated by the SMBH with gas

[2] Consistent with diffuse emission from point sources (with different spectrum from [1])

Gamma-rays structure in clusters?

- Extended gamma-ray emission from the Virgo, Fornax and Coma

- Excess emission within 3 deg of the center, peaking at the GeV scale
- Not accounted for by known Fermi sources or by the galactic and extragalactic backgrounds

- Compatible with: 2-10 GeV or > 1 TeV DM (annihilating to leptons)
  20-60 GeV DM (annihilating to hadrons)

- Potentially compatible with the GC-extended emission

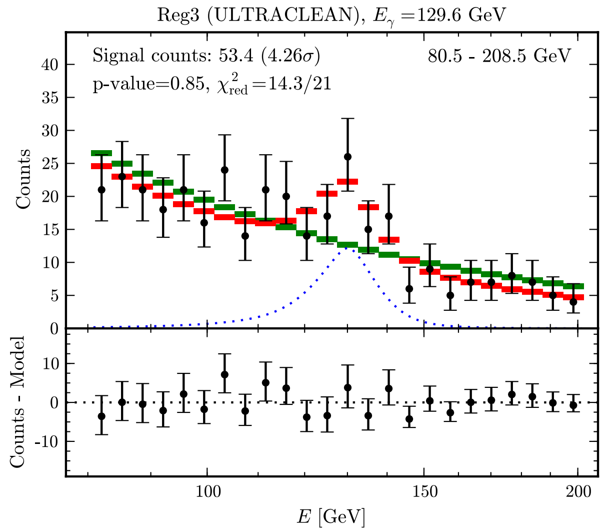
- CR induced gamma-rays can account for it, with a lower significance than for DM

- In any case, very weak hint

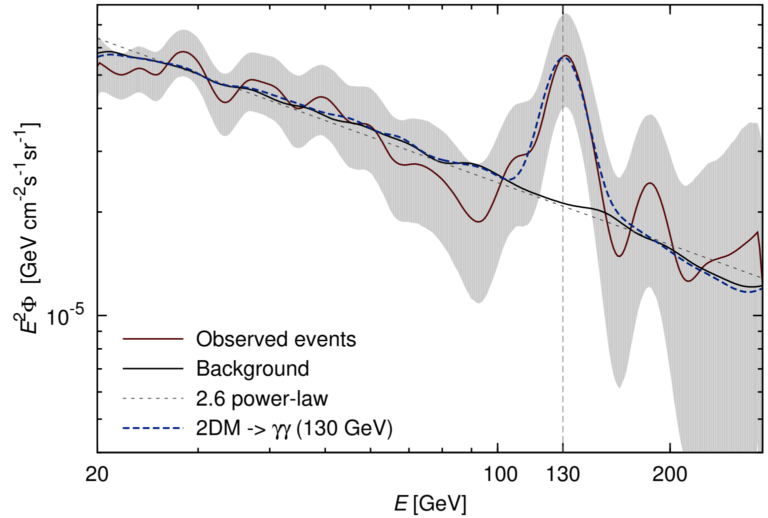
Han, Frenk, Eke, Gao, White, arXiv:1201.1003

Gamma-ray line ?

Weniger, arXiv:1204.2797



Tempel, Hektor, Raidal, arXiv:1205.1045



Spatial target regions optimize S/N for specific DM profiles

Best evidence for Einasto profile

For annihilating DM implies:

m_{DM} = 130 GeV

<sigma v> = 1.27×10^{-27} cm^3 s^{-1}

Data-driven spatial target regions

The excess originates from relatively small disconnected regions, the most important relevant being the GC

Target regions may indicate DM clumps

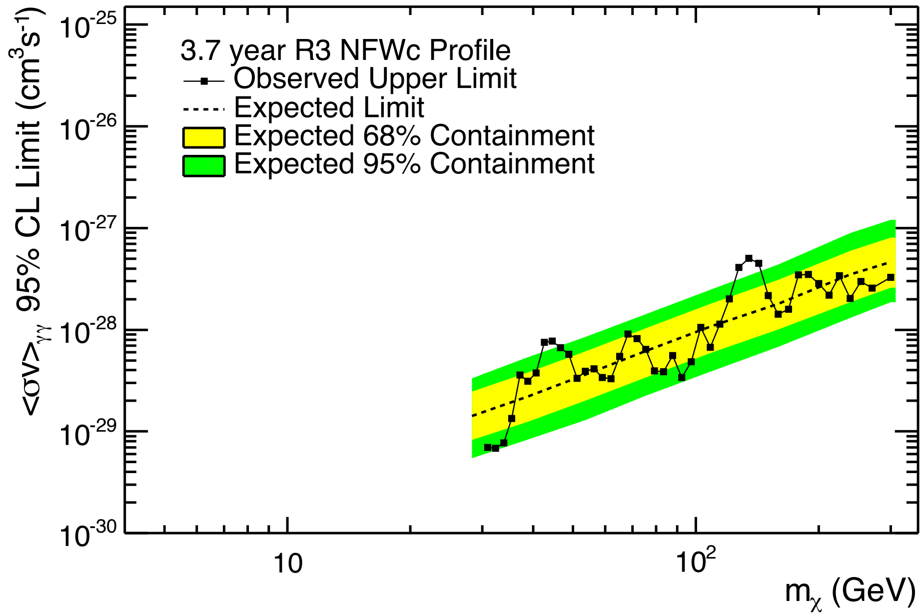
Very sharp spectral feature: “true” line, excludes internal bremsstrahlung

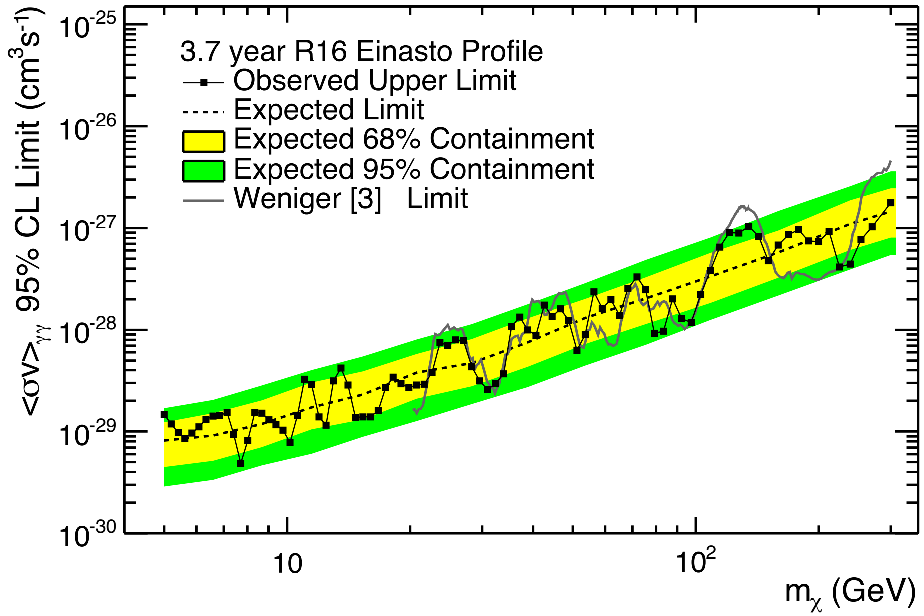
Gamma-ray line

Fermi Collab. analysis (2013)

no statistically significant evidence of a line signal

global significance for a 133 GeV feature: < 1σ





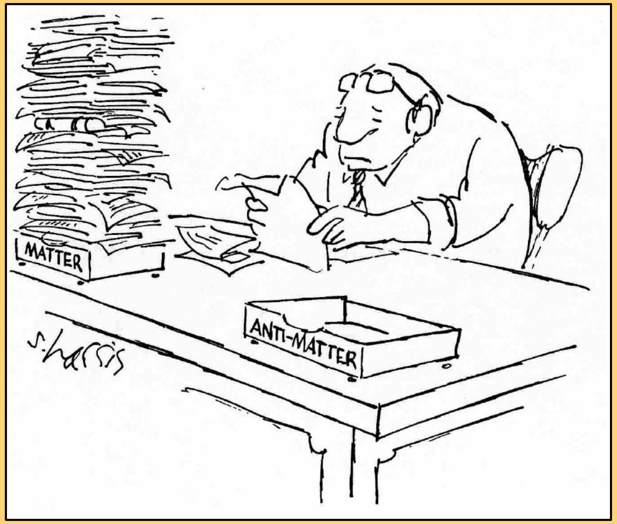
Gustafsson et al (Fermi Collab.) arXiv:1310.2953

Unidentified Fermi objects

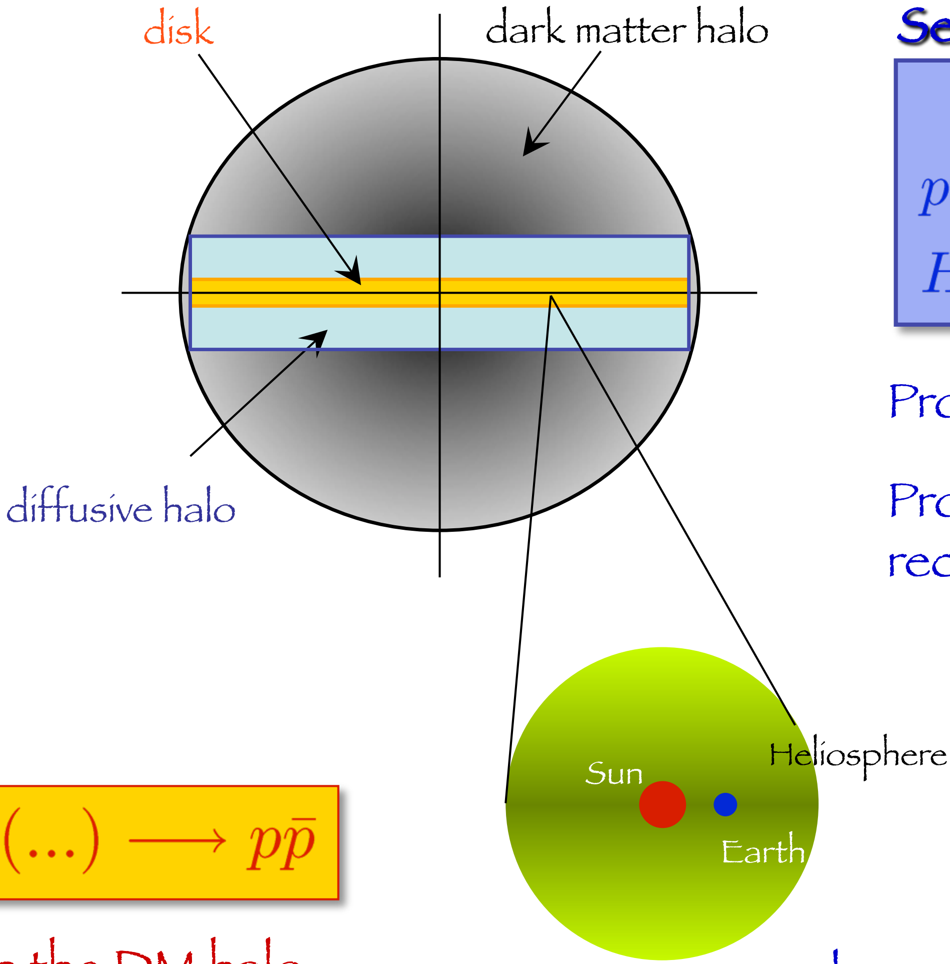
- About 30% of detected gamma-rays sources in Fermi catalog are unidentified: DM clumps?
- Selection criteria for DM sources:
  - High latitudes (to avoid confusion with galactic sources and cleaner environment)
  - Temporal stability of the flux
  - Hard spectra
- Four candidates found, potentially compatible with DM emission
- But:
  - For 3 candidates, clear association detected in radio, IR, optical and X-rays
  - For 1 candidate, indication for association with a faint X-ray source
- Currently: no unassociated gamma-rays source found to originate from DM annihilation, with m_{DM} > 100 GeV

Zechlin, Horns, JCAP 1211 (2012) 050

Antiprotons
Antideuterons



Cosmic antiprotons



Secondaries (background)

$$p_{\text{CR}} + p_{\text{ISM}} \longrightarrow \bar{p}$$
$$p_{\text{CR}} + He_{\text{ISM}} \longrightarrow \bar{p}$$
$$He_{\text{CR}} + p_{\text{ISM}} \longrightarrow \bar{p}$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

solar modulation

DM signal

$$\chi\chi \longrightarrow (\ldots) \longrightarrow p\bar{p}$$

Produced in the DM halo

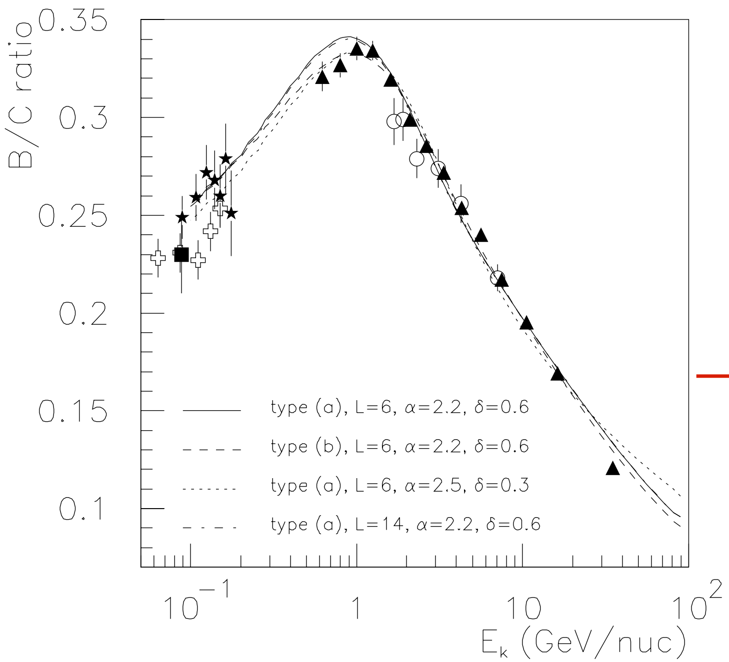
Propagation and energy redistribution in the diffusive halo

Transport in the galactic medium

$$q_{\bar{p}}^{\text{source}}(r, z, T_{\bar{p}}) \xrightarrow{\text{Propagation in the Galaxy}} \Phi_{\bar{p}}(r, z, T_{\bar{p}})$$

LIS

Propagation model constrained by secondary/primary ratios, mainly B/C



diffusion — reacceleration

case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{\mathrm{B/C}}$
max	0.46	0.0765	15	5	117.6	39.98
med	0.70	0.0112	4	12	52.9	25.68
min	0.85	0.0016	1	13.5	22.4	39.02

convection

+ energy losses, scattering, annihilation

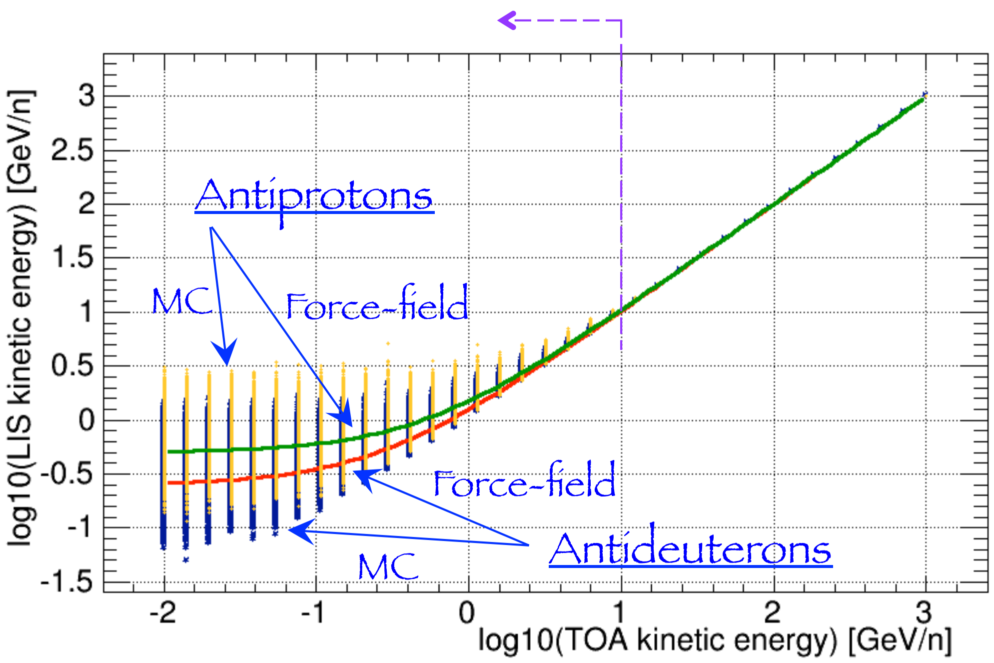
D. Maurin et al. Astron. Astrophys. 394 (2002) 1039

See J. Lavalle's talk for a detailed and critical discussion

Transport in the heliosphere

$$\Phi_{\bar{p}}(r, z, T_{\bar{p}}) \xrightarrow{\text{Propagation in the heliosphere}} \Phi_{\bar{p}}(\hat{T}_{\bar{p}})|_{\text{EARTH}}$$

LIS → TOA



CR transport in the heliosphere treated with a "stochastic equation" technique:

- phase space density sampled and evolved according to a random walk set by the diffusion properties of the heliosphere

Model parameters and geometry:

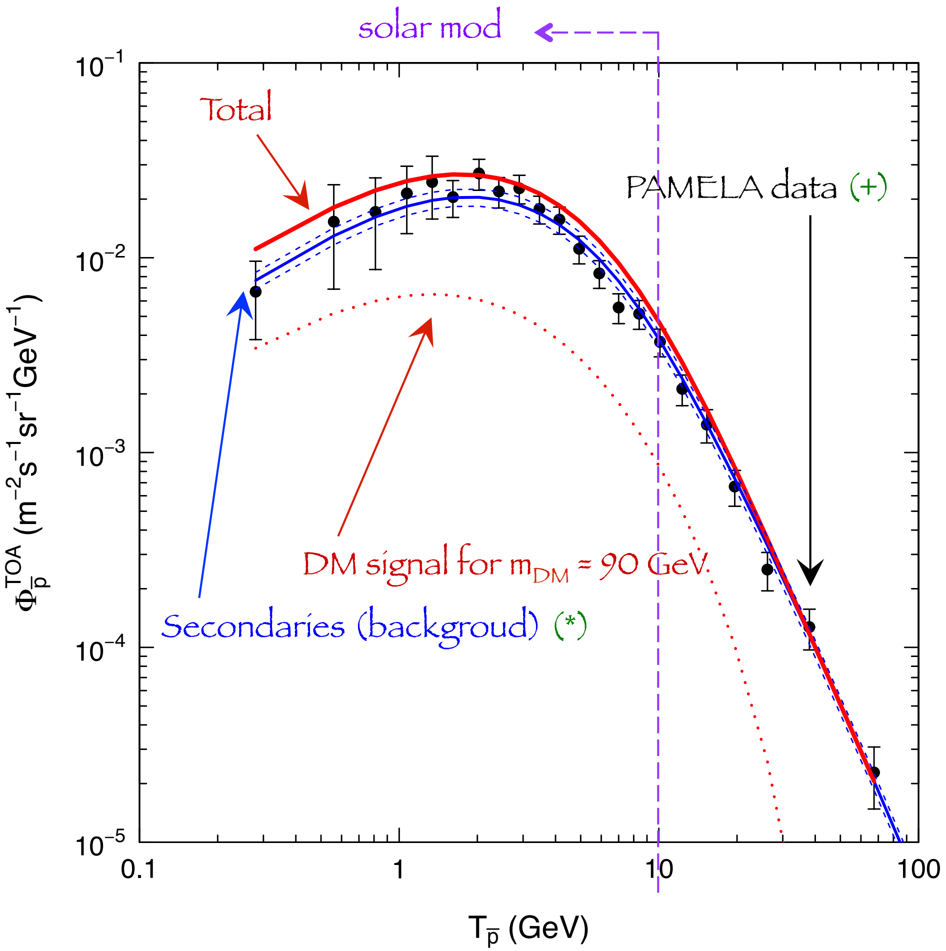
Solar magnetic field: Parker spiral

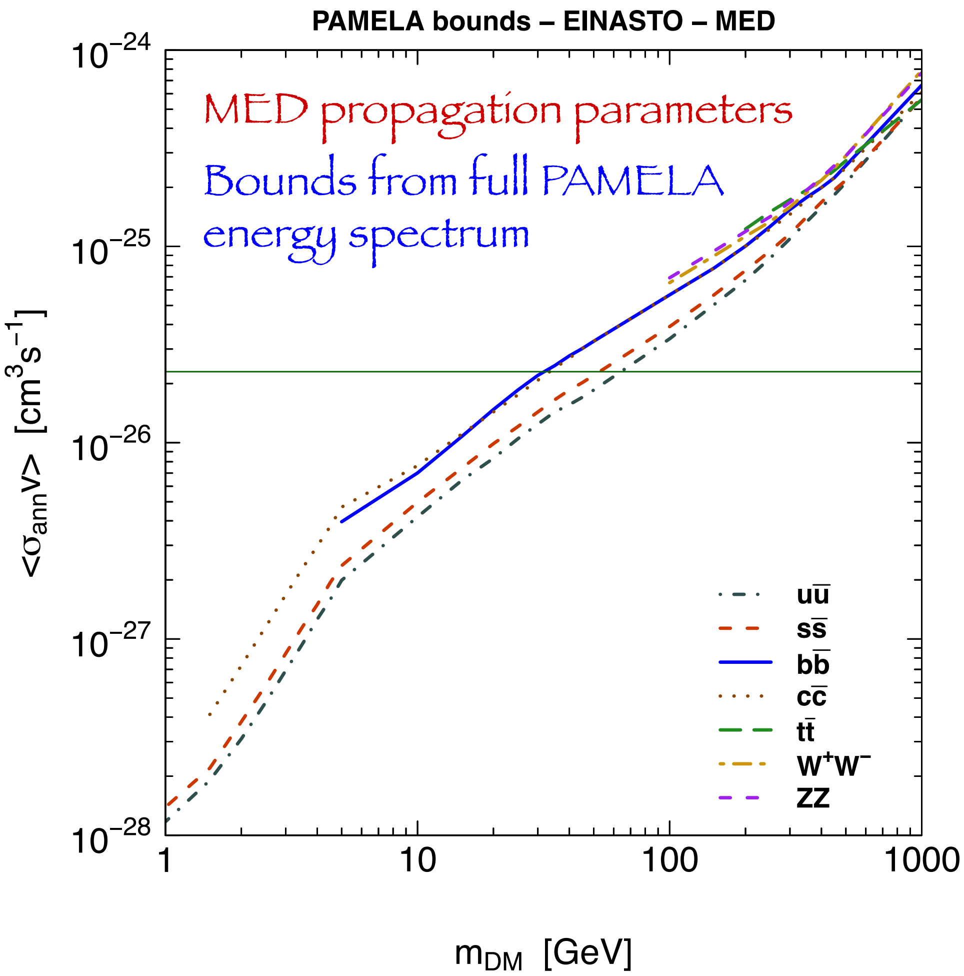
Tilt angle of the current-sheet α

Mean free path $\lambda_{\|} = \lambda_0 (\rho / 1 \text{ GeV})^{\gamma} (B_{\oplus} / B)$

Polarity (changes every 11 yr)

Antiproton bounds on DM properties



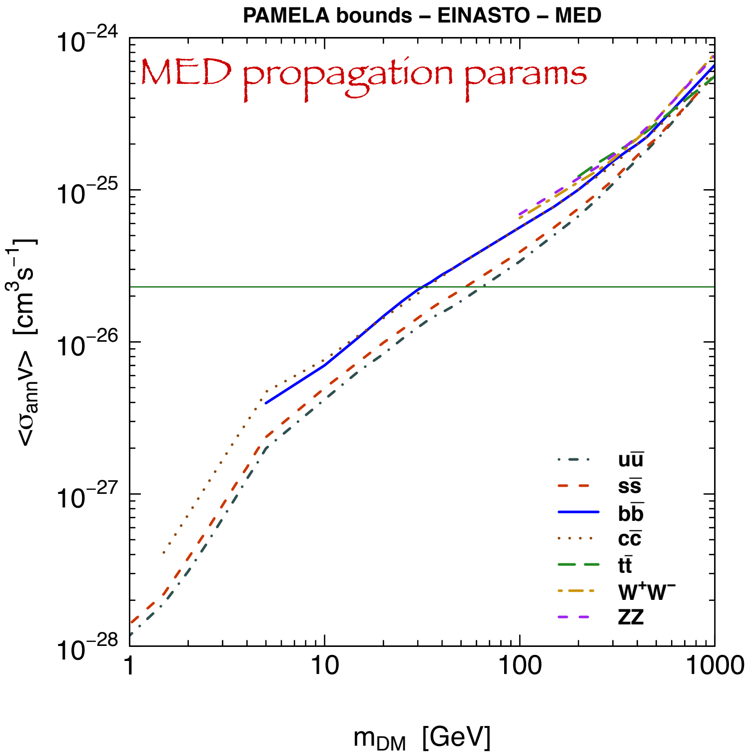


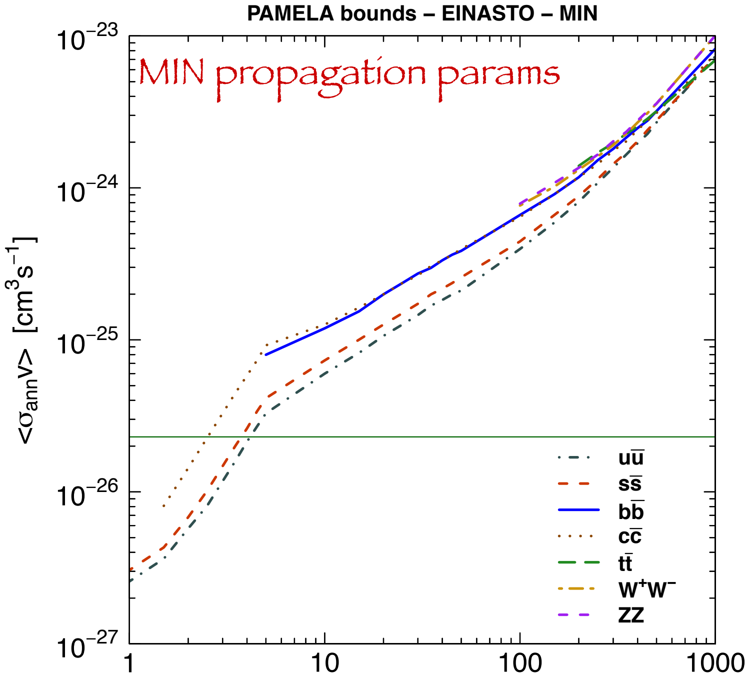
(*) Donato, Maurin, Brun, Delahaye, Salati, PRL 102 (2009) 071301
(+) Adriani et al. (PAMELA Collab.), PRL 105 (2010) 121101

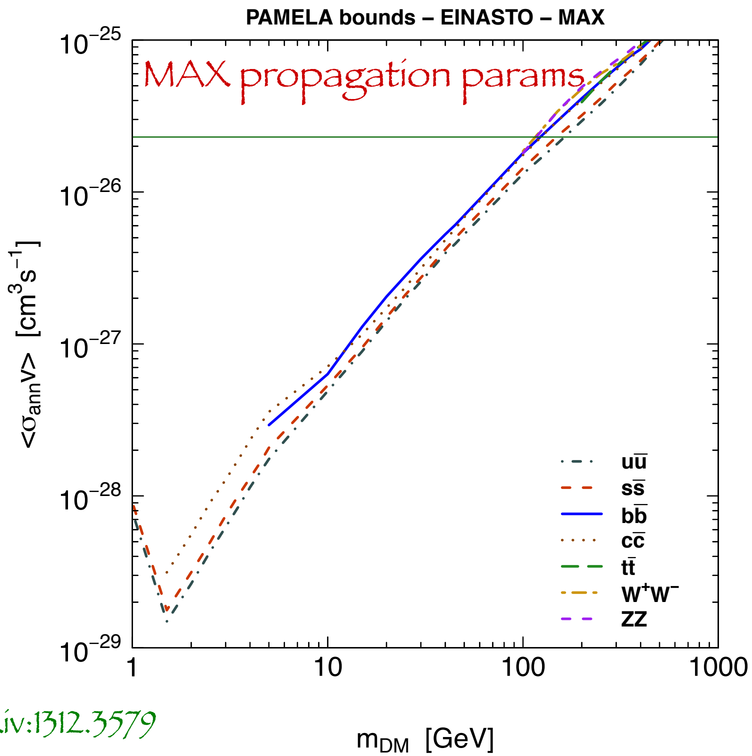
Fornengo, Maccione, Vittino, arXiv:1312.3579

Caveat: the bounds are reported (as is usual) under the hypothesis that the DM candidate Is the dominant DM component, regardless of its thermal properties in the early Universe

Antiproton bounds







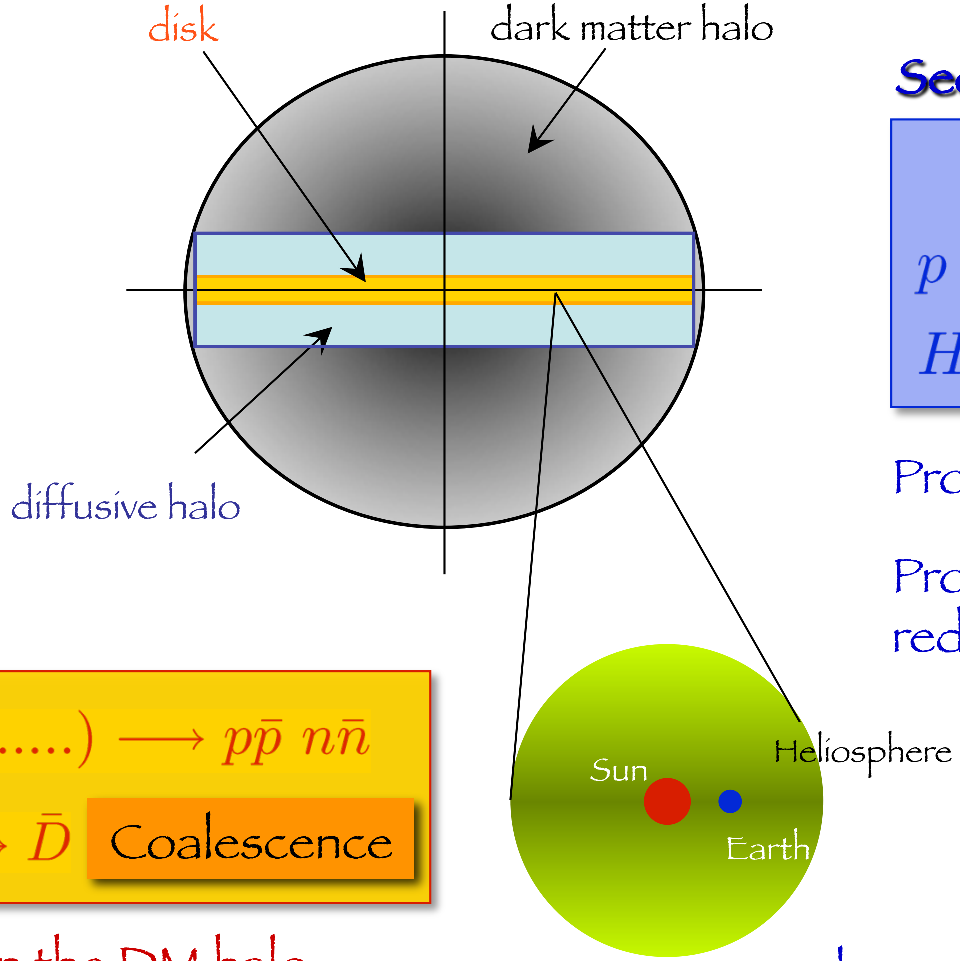
Dependence on modeling of
CR transport in the Galaxy

Fornengo, Maccione, Vittino, arXiv:1312.3579

- For recent antiproton signal and bounds, see also:
  - Cirelli, Franceschini, Strumia, Nucl. Phy B800 (2008) 204
  - Ibarra, Tran, JCAP 0807 (2008) 002
  - Donato, Maurin, Brun, Delahaye, Salati, Phys. Rev. Lett. 102 (2009) 071301
  - Buchmuller, Ibarra, Shindou, Takayama, Tran, JCAP 0909 (2009) 021
  - Hooper, Zurek, Phys. Rev. D79 (2009) 103529
  - Lavalle, Phys. Rev. D82 (2010) 081302
  - Cerdeno Delahaye, Lavalle, Nucl. Phys B854 (2011) 738-779
  - Garny, Ibarra, Vogl, JCAP 1107 (2011) 028
  - Evoli, Cholis, Grasso, Maccione, Ullio, Phys. Rev. D 85 (2012) 123511
  - Chu, Hambye, Scarna, Tytgat, Phys. Rev. D86 (2012) 083521
  - Ibarra, Lopez Gehler, Pato, JCAP 1207 (2012) 043
  - Delahaye, Grefe, arXiv:1305.7183
  - Cirelli, Giesen, JCAP 1304 (2013) 015

Cosmic antideuterons

Donato, Fornengo, Salati, PRD 62 (2000) 043003



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$$He_{\,\mathrm{CR}} + p_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

DM signal

$$\chi\chi \longrightarrow (.....) \longrightarrow p\bar{p}\; n\bar{n}$$
$$\bar{p} + \bar{n} \longrightarrow \bar{D}$$ Coalescence

Produced in the DM halo

Propagation and energy redistribution in the diffusive halo

solar modulation

Coalescence process

$$\frac{dN_{\bar d}}{dT_{\bar d}} = (4\pi E_{\bar d}\, k_{\bar d})\, F^{\rm MC}_{\bar d}(\sqrt{s}, \vec{k}_{\bar d})$$

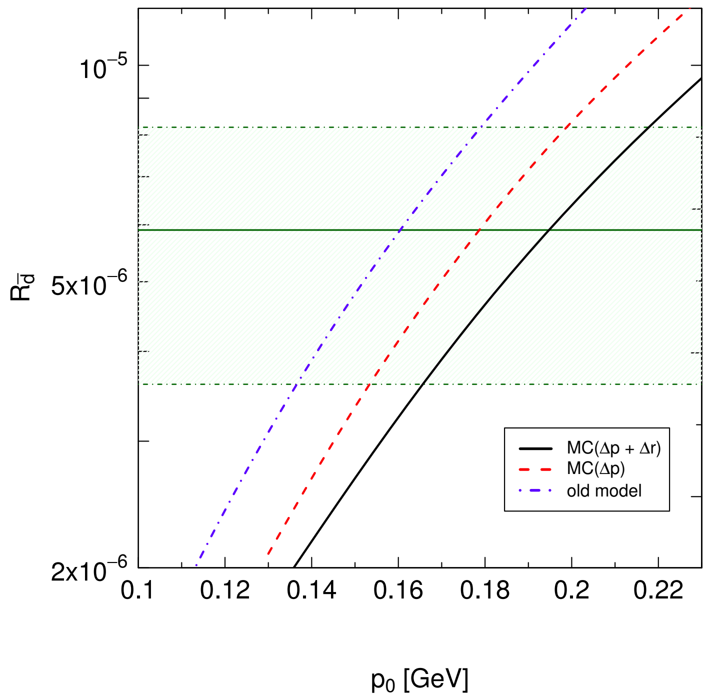
$$F^{\rm MC}_{\bar d}(\sqrt{s}, \vec{k}_{\bar d}) = \int F^{\rm MC}_{(\bar p \bar n)}(\sqrt{s}, \vec{k}_{\bar p}, \vec{k}_{\bar n})\; C(\Delta)\; \delta^3(\vec{k}_{\bar d} - \vec{k}_{\bar p} - \vec{k}_{\bar n})\; d^3\vec{k}_{\bar n}\; d^3\vec{k}_{\bar n}$$

coalescence function

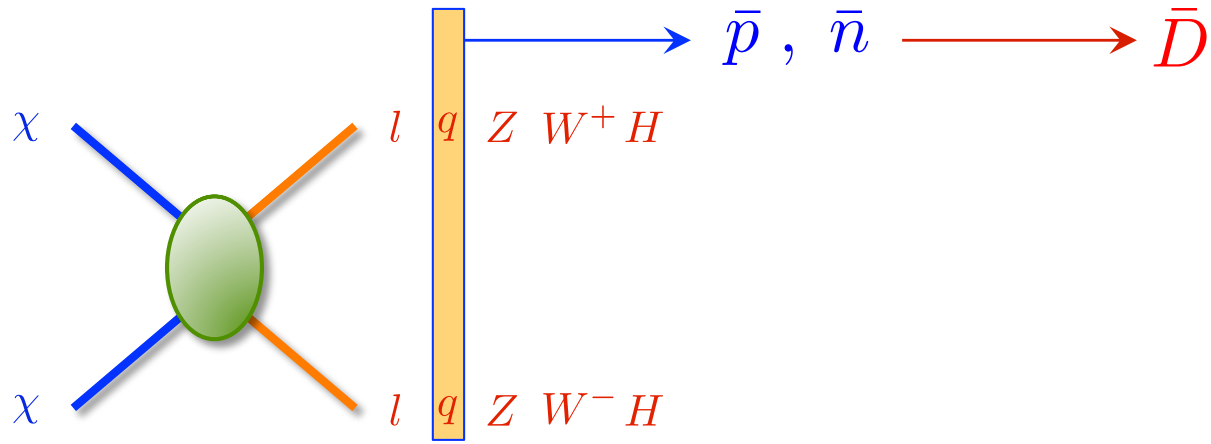
$\Delta p \leq p_0$ coalescence momentum
Fixed on ALEPH data on antiD production

$\Delta r \leq R_\star$ antideuteron radius

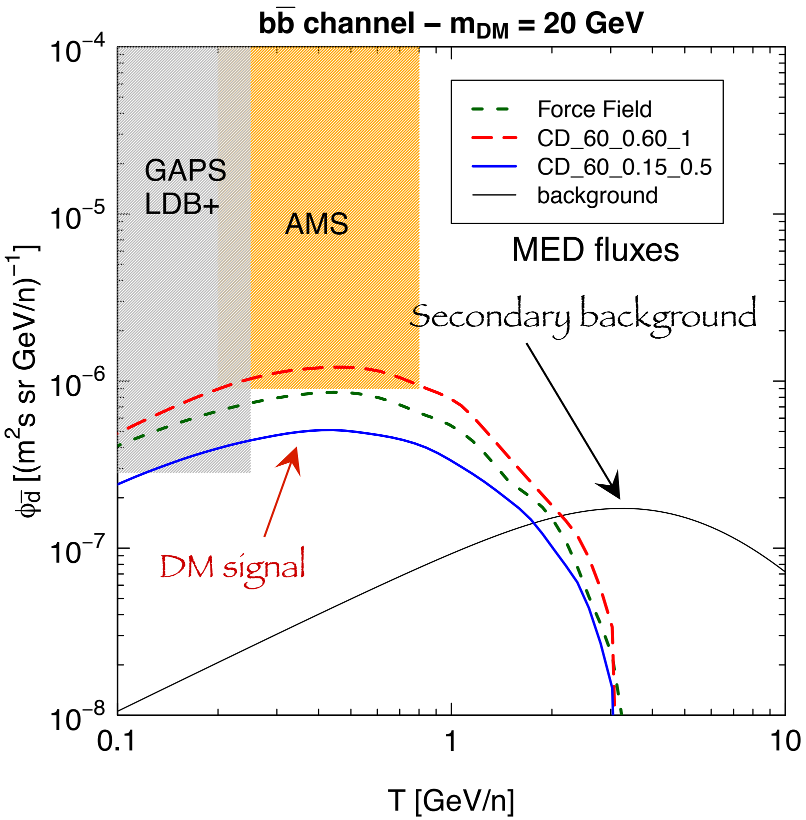
$p_0 = (195 \pm 22)$ MeV

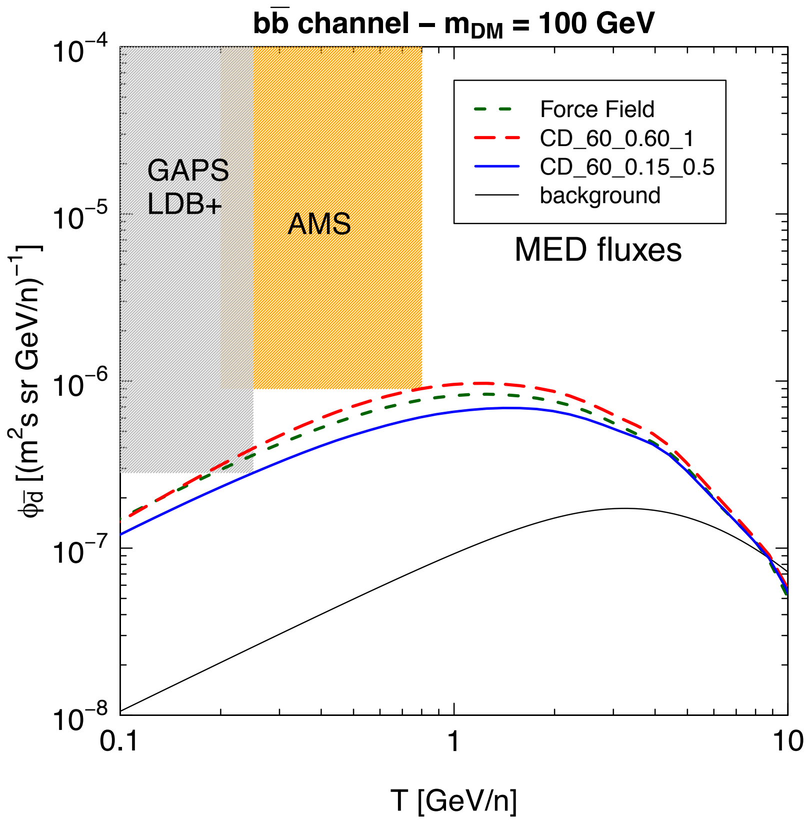


Donato, Fornengo, Salati, PRD 62 (2000) 043003
Kadastik, Raidal, Strumia, Phys. Lett. B 683 (2010) 248-254
Dal, Kachelriess, Phys. Rev. D 86 (2012) 103536
Fornengo, Maccione, Vittino, JCAP 09 (2013) 031



Detection prospects





DM configurations allowed by antiproton bounds

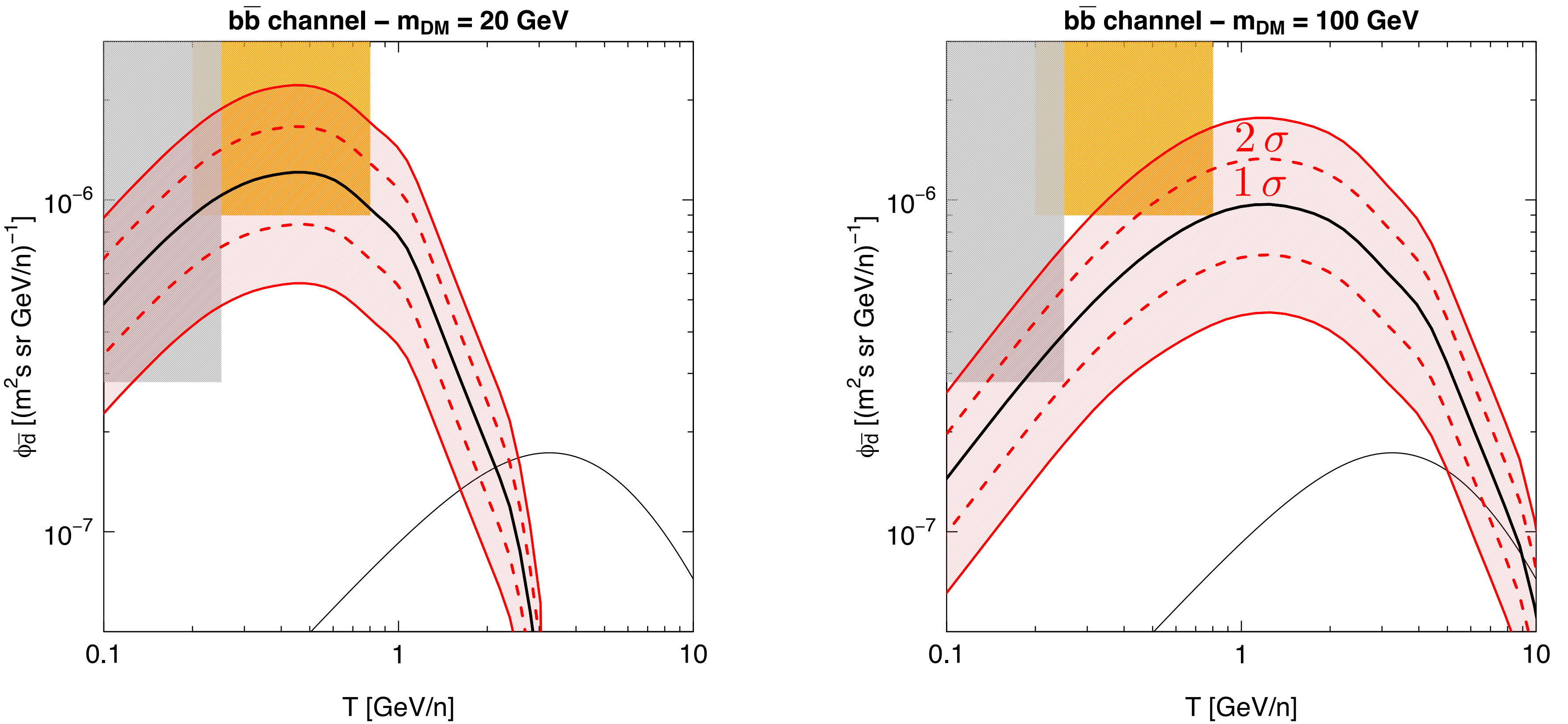
Relevant detection prospects for Dbar energies below few Gev/n, where dependence on solar modulation modeling can have an impact on the DM signal up to a factor of 2

Experimental expected sensitivities : 3 σ C.L.

GAPS LDB+ : 1 detected event
AMS : 2 detected events

Fornengo, Maccione, Vittino, JCAP 09 (2013) 031

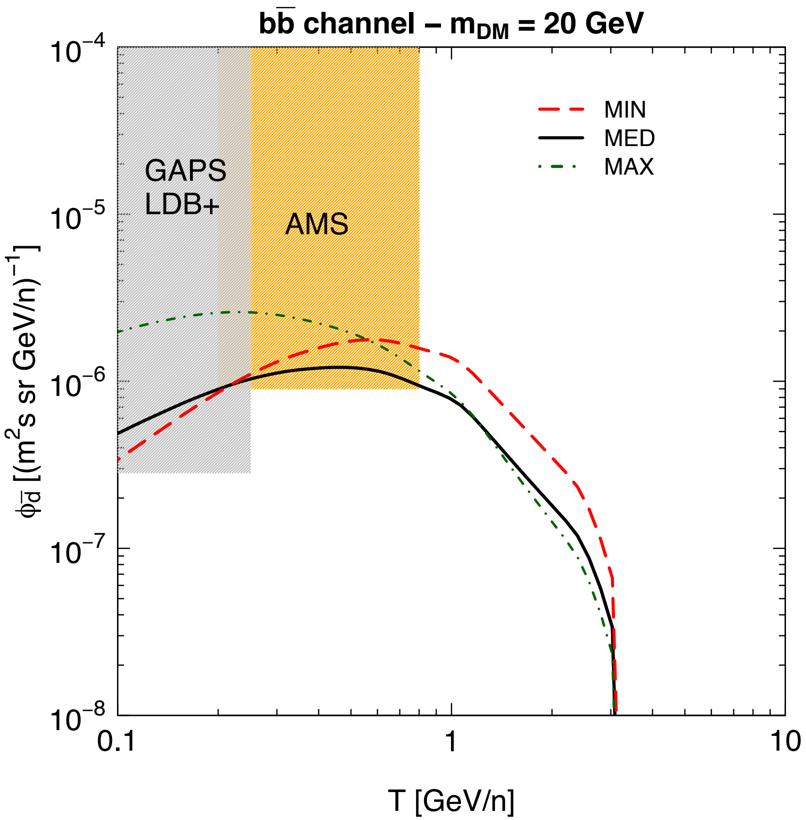
Dependence on coalescence momentum

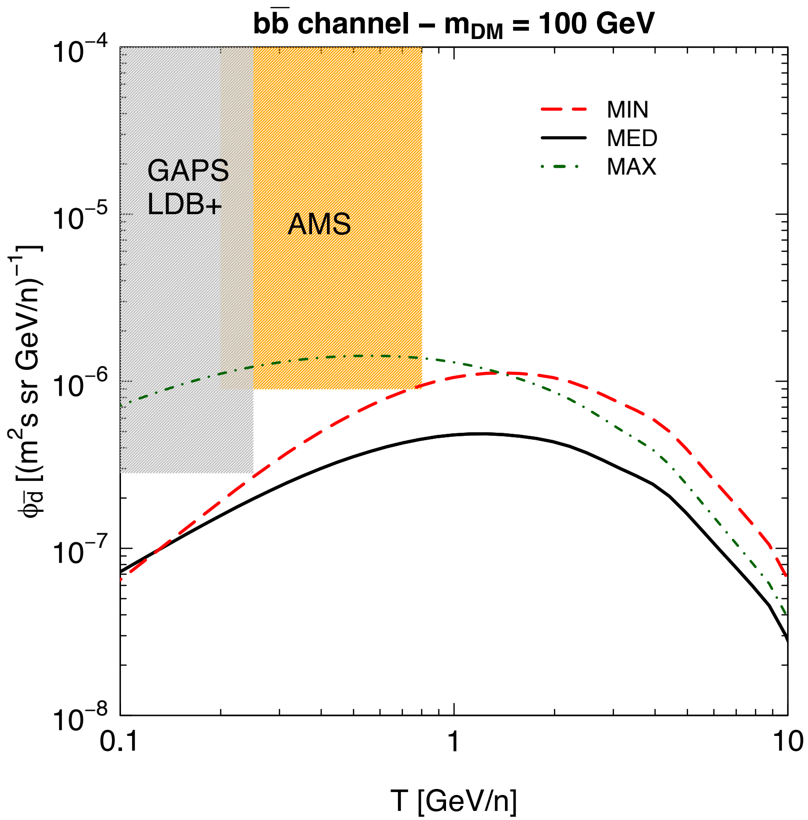


$$p_0 = (195 \pm 22)\ \mathrm{MeV}$$

Fornengo, Maccione, Vittino, JCAP 09 (2013) 031

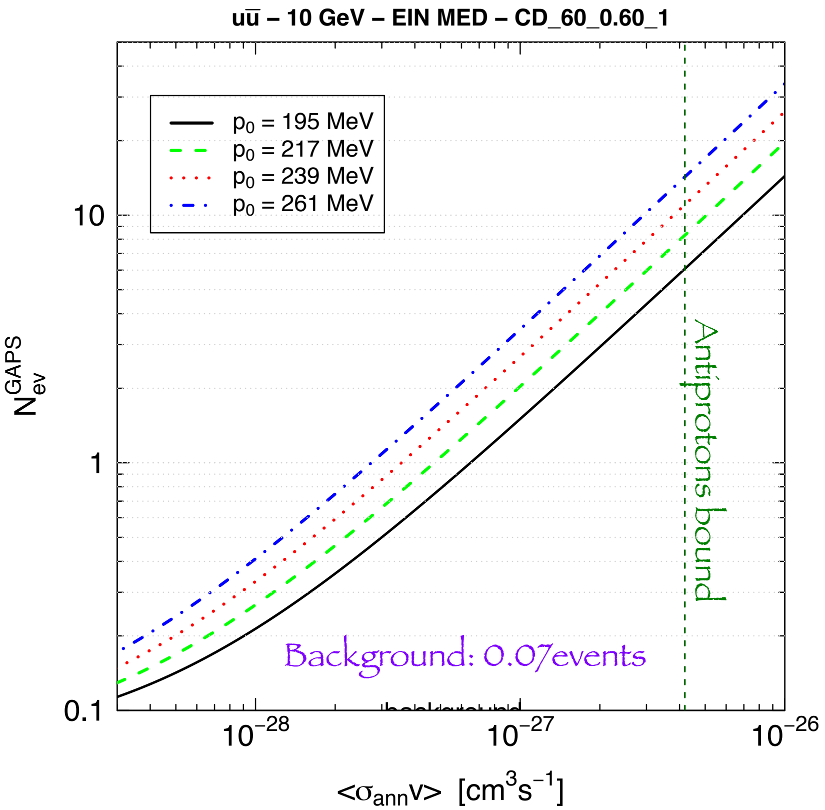
Dependence on galactic transport



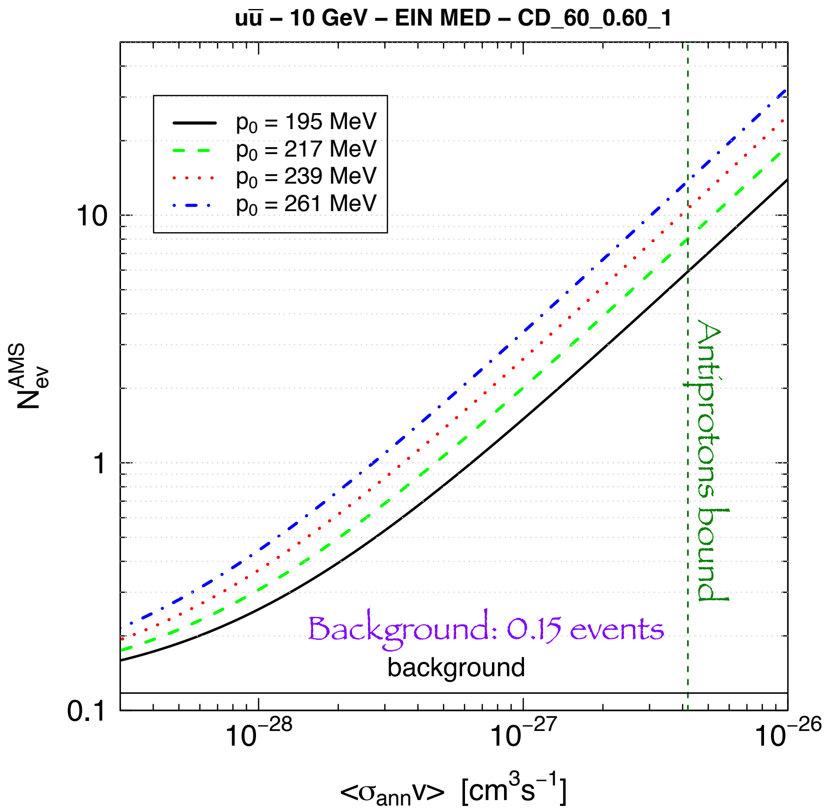


Fornengo, Maccione, Vittino, JCAP 09 (2013) 031

Events expected in GAPS and AMS



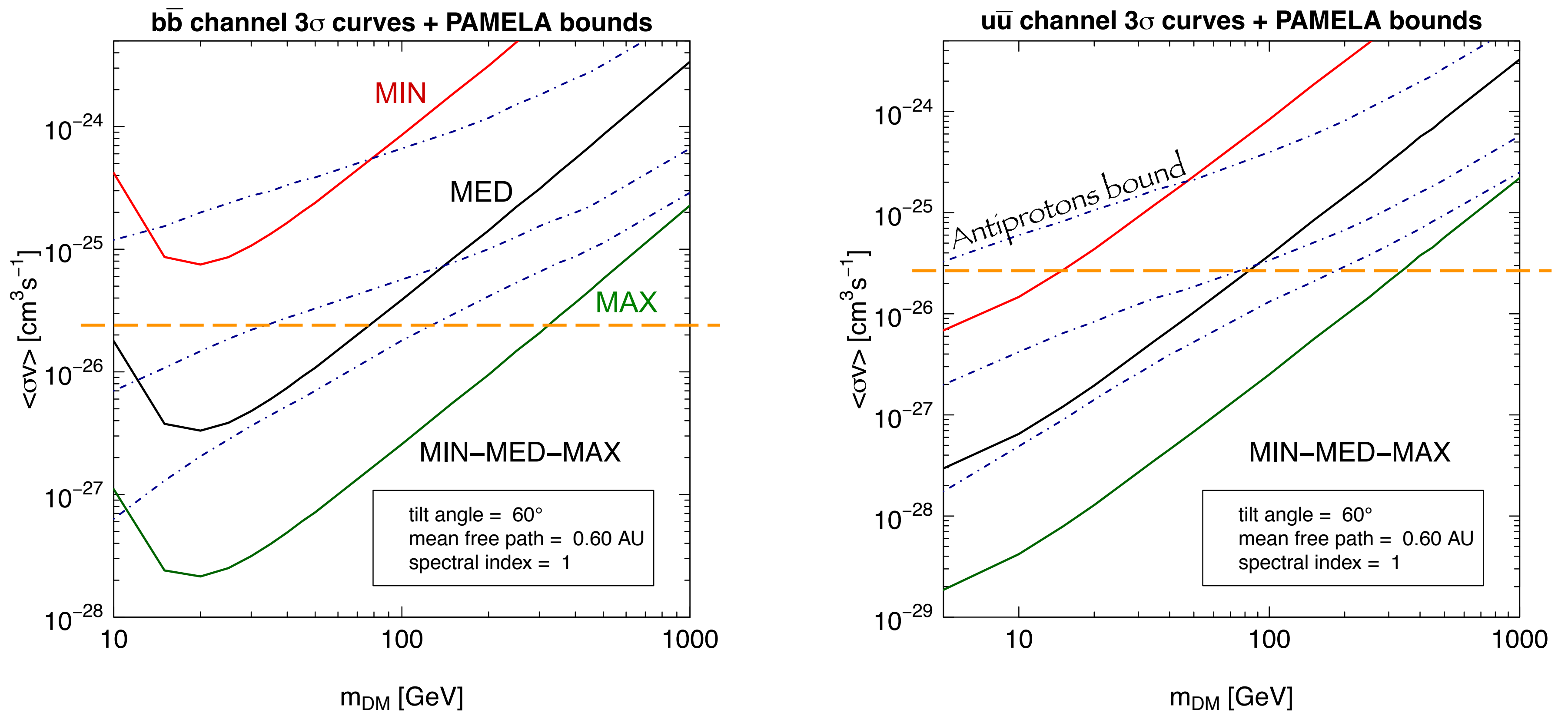
For GAPS LDB+ setup



For AMS nominal sensitivity

Fornengo, Maccione, Vittino, JCAP 09 (2013) 031

Detection reachability at 3 σ C.L.



Example for GAPS LDB+ setup

3σ detection : $N_{crit} \approx 1$ events

Fornengo, Maccione, Vittino, JCAP 09 (2013) 031

- For antideuteron analyses, see also:
  - Donato, Fornengo, Salati, Phys. Rev. D 62 (2000) 043003
  - Donato, Fornengo, Maurin, Phys. Rev. D 78 (2008) 043506
  - Baer, Profumo, JCAP 0512 (2005) 008
  - Ibarra, Tran, JCAP 0906 (2009) 004
  - Braeuninger, Cirelli, Phys. Lett. B 678 (2009) 20
  - Kadastik, Raidal, Strumia, Phys. Lett. B 683 (2010) 248-254
  - Cui, Mason, Randall, JHEP 1011 (2010) 017
  - Dal, Kachelriess, Phys. Rev. D 86 (2012) 103536
  - Ibarra, Wild, JCAP 1302 (2013) 021
  - Ibarra, Wild, arXiv:1301.3820 [hep-ph]

Multiwavelength signals

Multiwavelength emission

From the interaction of electrons/positrons with the (extra)galactic environment:

Synchrotron emission on magnetic fields: from radio to X-ray band

Inverse Compton on radiation fields (CMB, stellar): X-rays, gamma-rays

For:

magnetic field intensity of O(microG) (like in the case of our galaxy)
electrons/positrons of GeV-TeV energies (like those produced by WIMP DM)

the synchrotron emission falls in the MHz-GHz range (radio band)

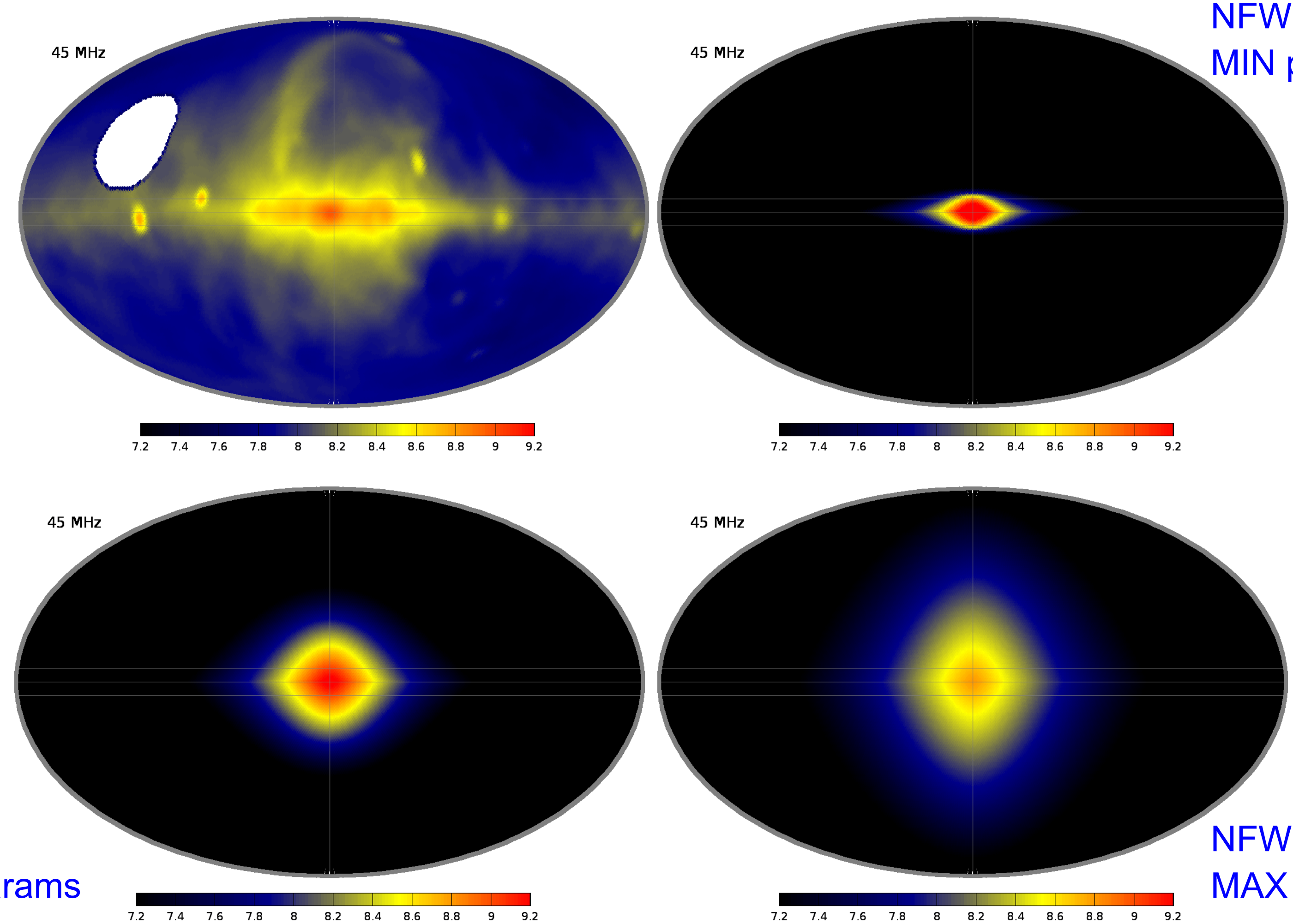
Targets for the radio signal

- Galactic Center
  - Good target for spiky DM profiles
  - On the scale of the bulge: "WMAP haze" ?
  - GC is an active region: disentanglement of a signal rather complicated
- Galactic Halo
  - Mid/high latitudes may be cleaner
  - Low radio frequences for soft e+/e- spectra, microwave range otherwise
- Extragalactic diffuse emission
  - ARCADE 2: isotropic radio emission significantly brighter than expected: requires a "new" population of unresolved sources which become the most numerous at very low (observationally unreached) brightness [maybe DM ?]
  - Anisotropies studies may be a goal for the future
- Extragalactic objects
  - Non-thermal emission with spherical morphology correlated with the DM halo profile inferred from kinematic measurements in the external part of extragalactic objects can be a strong indication for WIMP-induced emission
  - Promising targets: dwarf spheroidal galaxies and galaxy clusters

Galactic DM: morphology of radio sky at 45 MHz

observed

NFW
MIN propag params



NFW
MED propag params

NFW
MAX propag params

Fornengo, Lineros, Regis, Taoso, JCAP 01 (2012) 005

10 GeV DM
Annihilation into muon with thermal cross section
Exp decaying B(r,z) with B_{TOT} = 6 microG (GMF I)

NFW tuned to Via Lactea II
No substructures included (checked that are not relevant at |b| < 30 deg because of antibiased clump distribution)

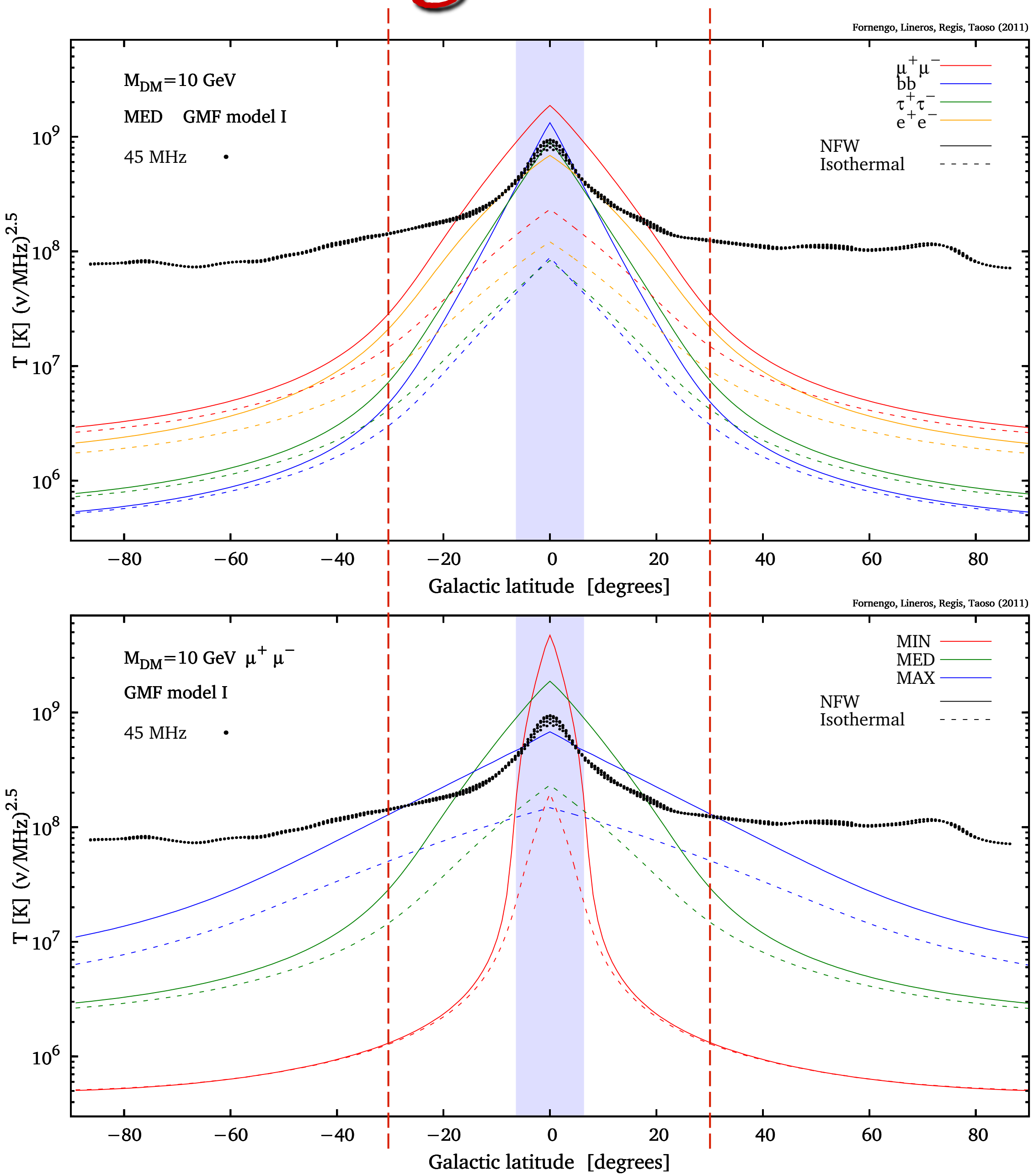
Galactic radio signal

45 MHz

Data: |l| < 3°
DM models: l = 0°

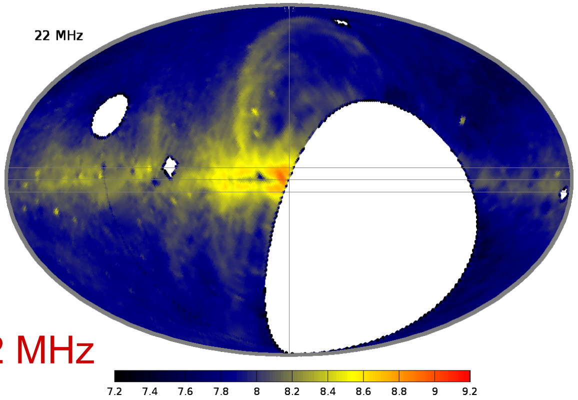
DM could substantially contribute to the radio flux

MED, MAX: allow to search for DM outside the GC region (while form MIN is too concentrated)

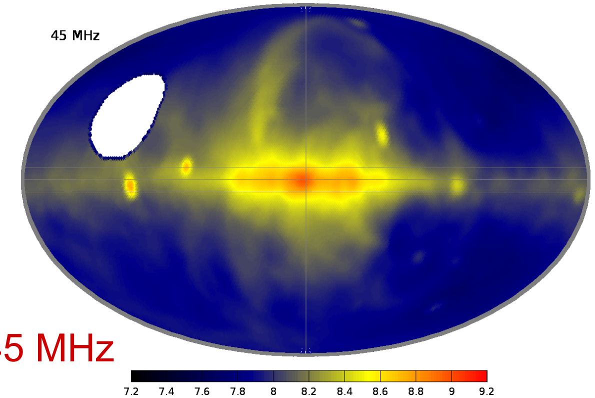


Fornengo, Lineros, Regis, Taoso, JCAP 01 (2012) 005 [arXiv:1110.4337]

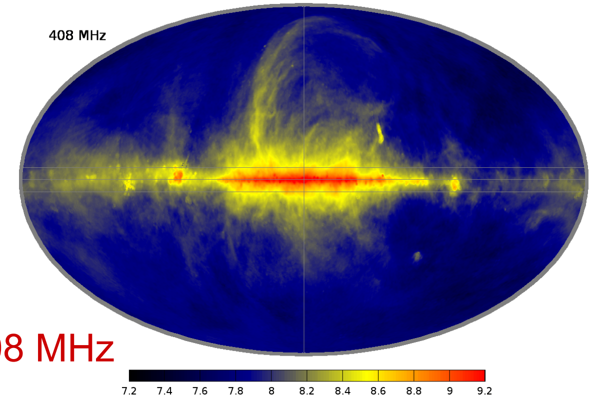
Skymaps



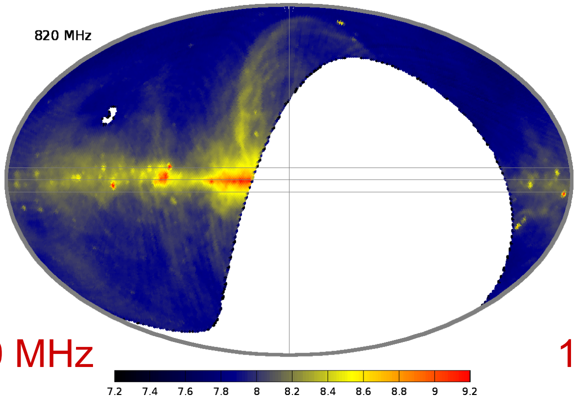
22 MHz



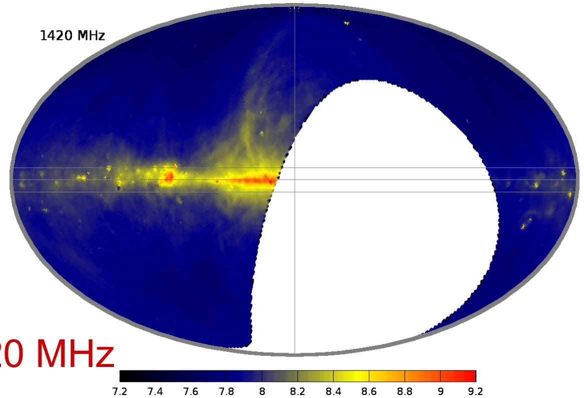
45 MHz



408 MHz

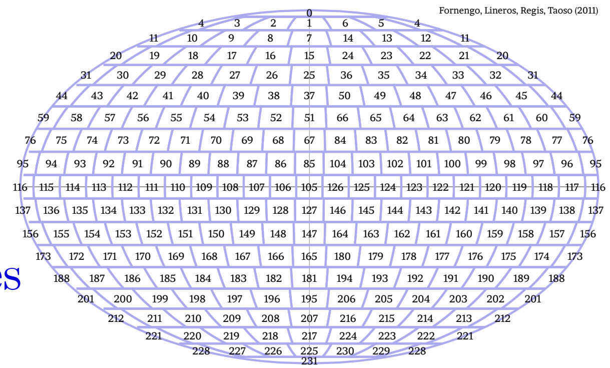


820 MHz



1420 MHz

$(T_{\rm obs})^i$ $\qquad$ $i =$ patches



Fornengo, Lineros, Regis, Taoso, JCAP 01 (2012) 005 [arXiv:1110.4337]

Galactic radio signal: bounds

Bounds from combination of all frequency skymaps

$$(T_{\rm DM})^i \leq (T_{\rm obs})^i + 3\sigma$$

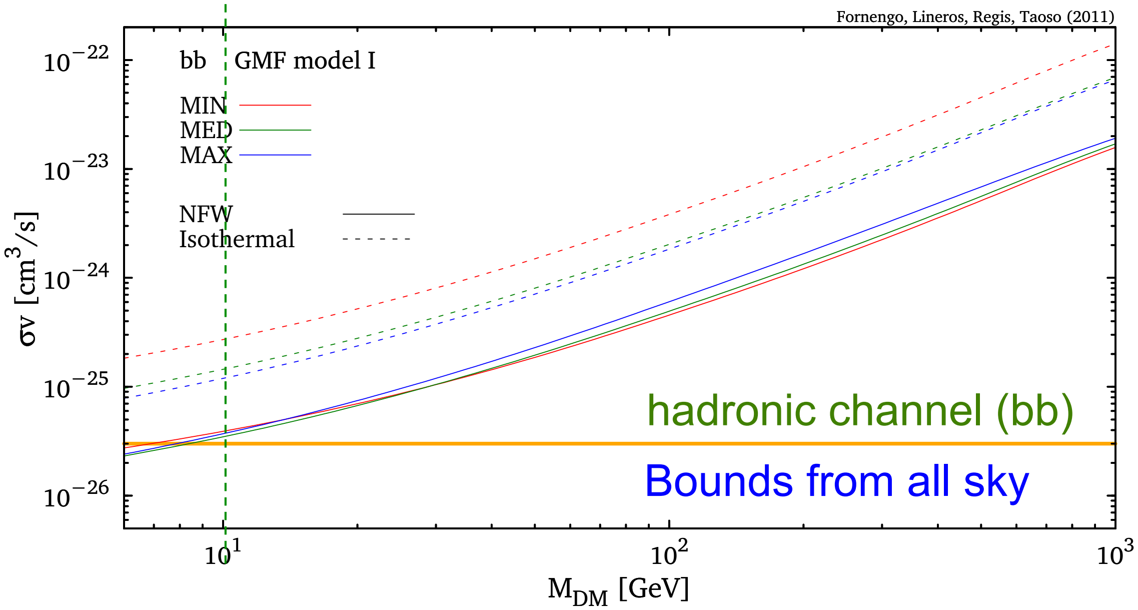
$$[\langle \sigma v \rangle, M_{\rm DM}] \longleftrightarrow \min_i \{(T_{\rm DM})^i\}$$

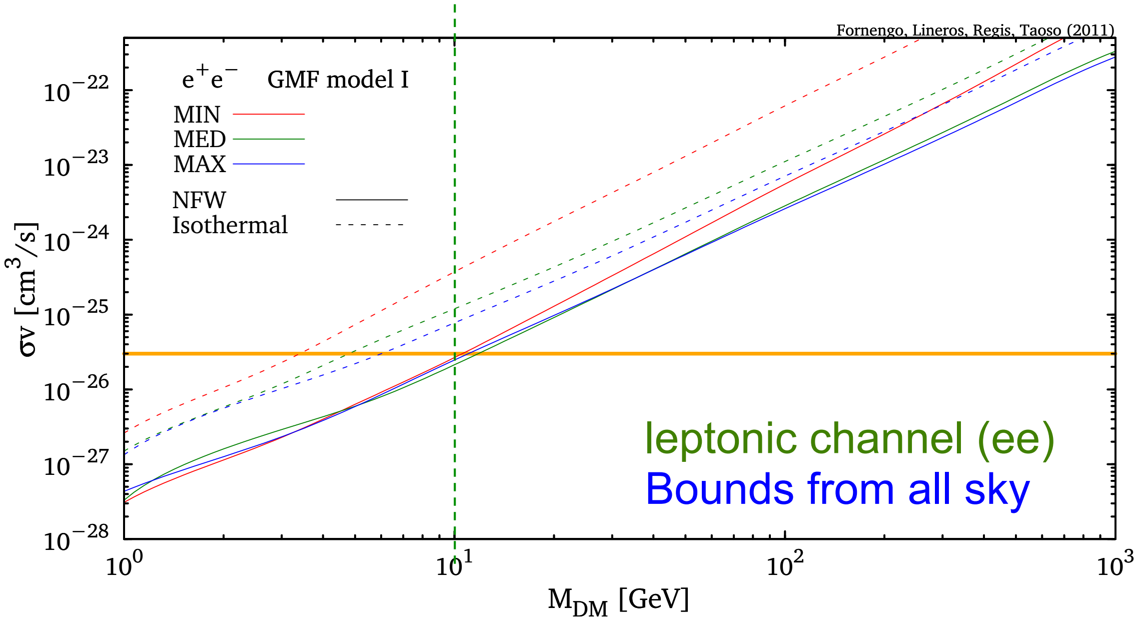
Conservative bounds:

- no astrophysical background subtraction
- no DM substructures included (*)

No strong dependence of bound on magnetic field because most constraining patches are those at low latitude, where various B(r,z) do not sizeably differ

ν [MHz]	Survey	rms noise [K]
22	DRAO	5000
45	Guzman et al.	3500
408	Haslam et al.	0.8
820	Dwingeloo	1.4
1420	Stockert	0.02





Fornengo, Lineros, Regis, Taoso, JCAP 01 (2012) 005 [arXiv:1110.4337]
(*) See: Borriello, Cuoco, Miele, PRD 79 (2009) 023518

Galactic radio signal: bounds

ν [MHz]	Survey	rms noise [K]
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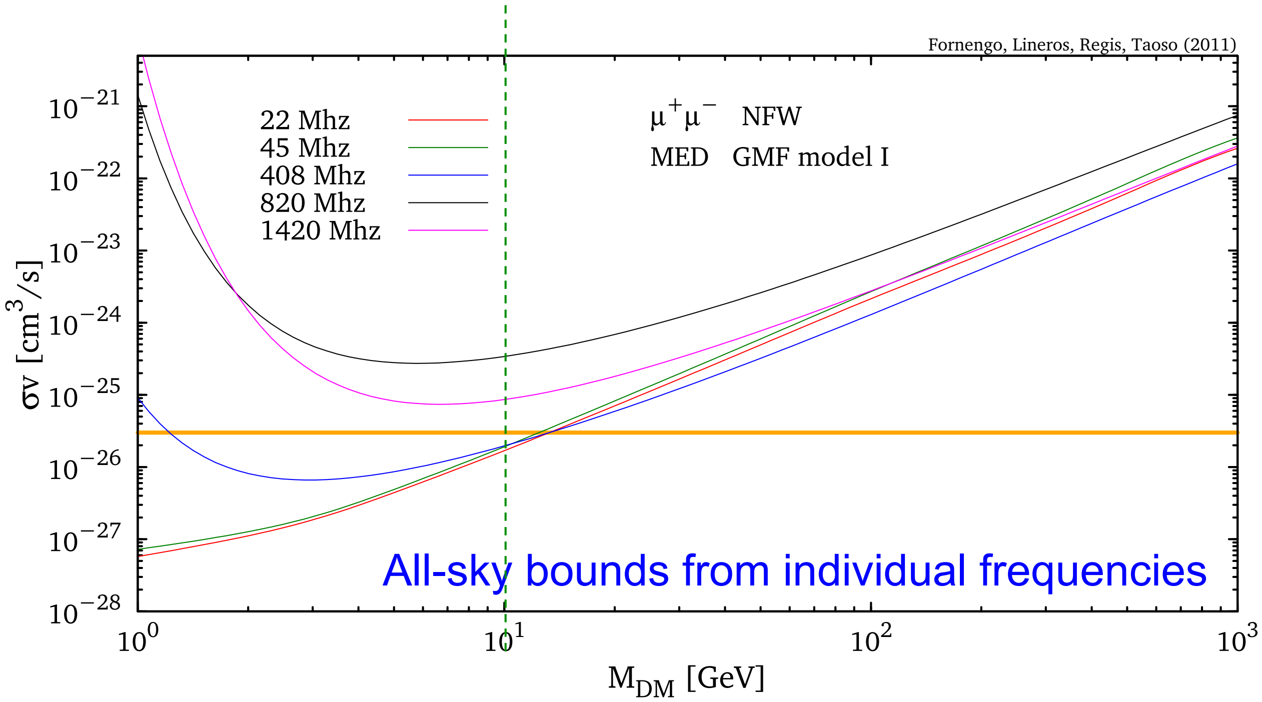


Lower frequencies better for lighter DM

Constraining power also depends on sky-coverage and sensitivity of the survey

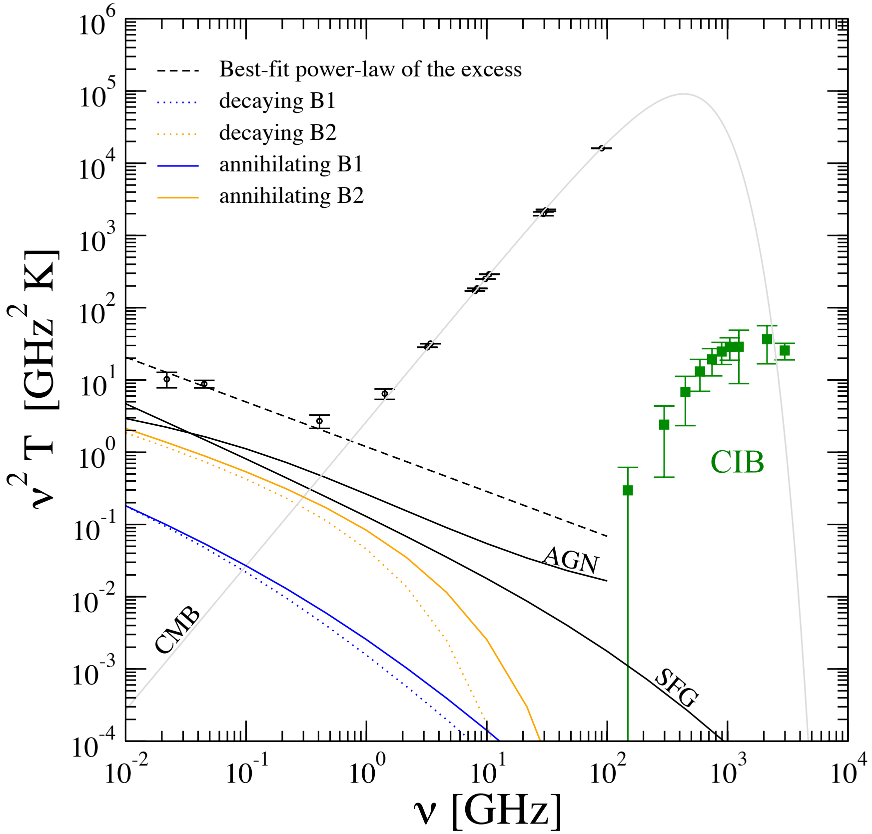
Fornengo, Lineros, Regis, Taoso, JCAP 01 (2012) 005 [arXiv:1110.4337]

Extragalactic signal

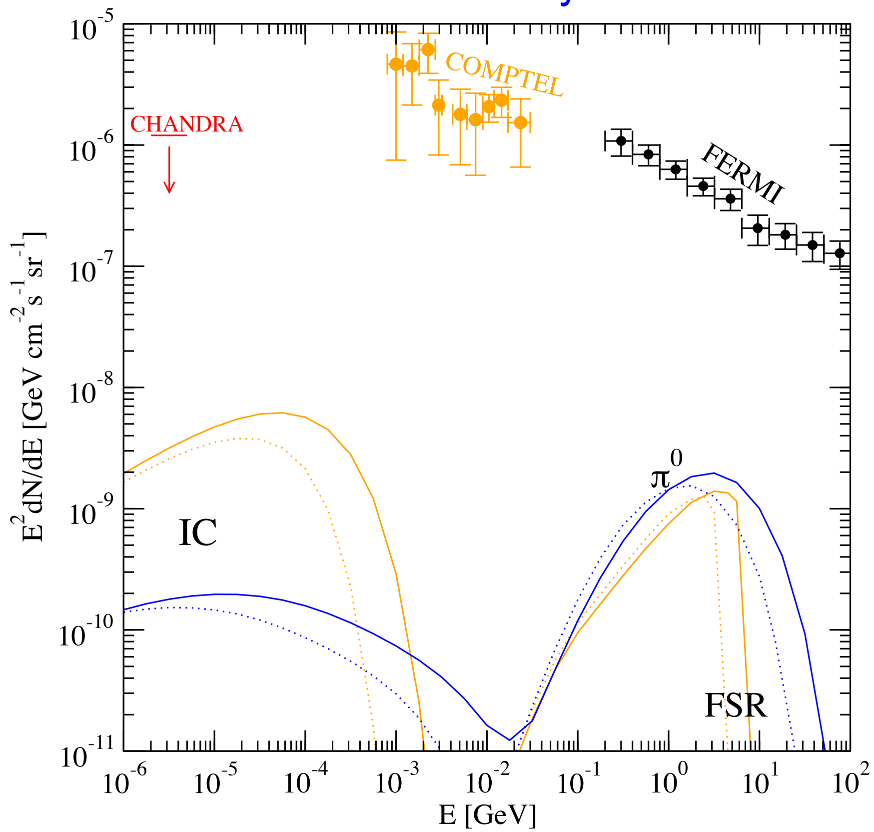
- Radio emission may occurr also in extragalactic halos
- Three relevant observables:
  - Intensity of the emission
    - High frequency: CMB largely dominates
    - Close and below 1 GHz: CMB may be efficiently subtracted
    - Low frequencies: extra-galactic sources dominate
  - Differential number counts of sources
    - Quite useful to study different radio populations
    - Dominated by radio-loud AGNs down to the mJy level
    - Star-forming galaxies and radio-quiet AGN take over at fainter fluxes
  - Angular correlations
    - Angular distribution of sources is a powerful probe of LS clustering
    - Wide-area radio surveys allow to test large scales
    - 2-point correlation function and angular power spectrum

Total intensity

Radio



Gamma-rays



Radio is quite constraining for DM producing leptons

For DM producing hadrons, constraining power is "similar" to gamma-rays

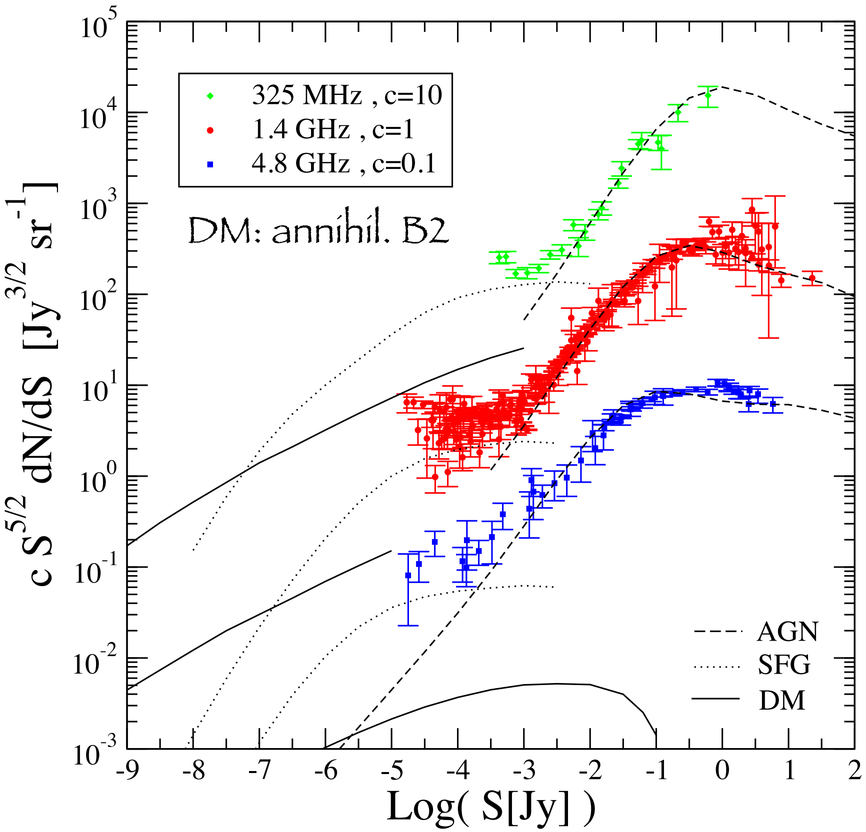
Illustrative benchmarks

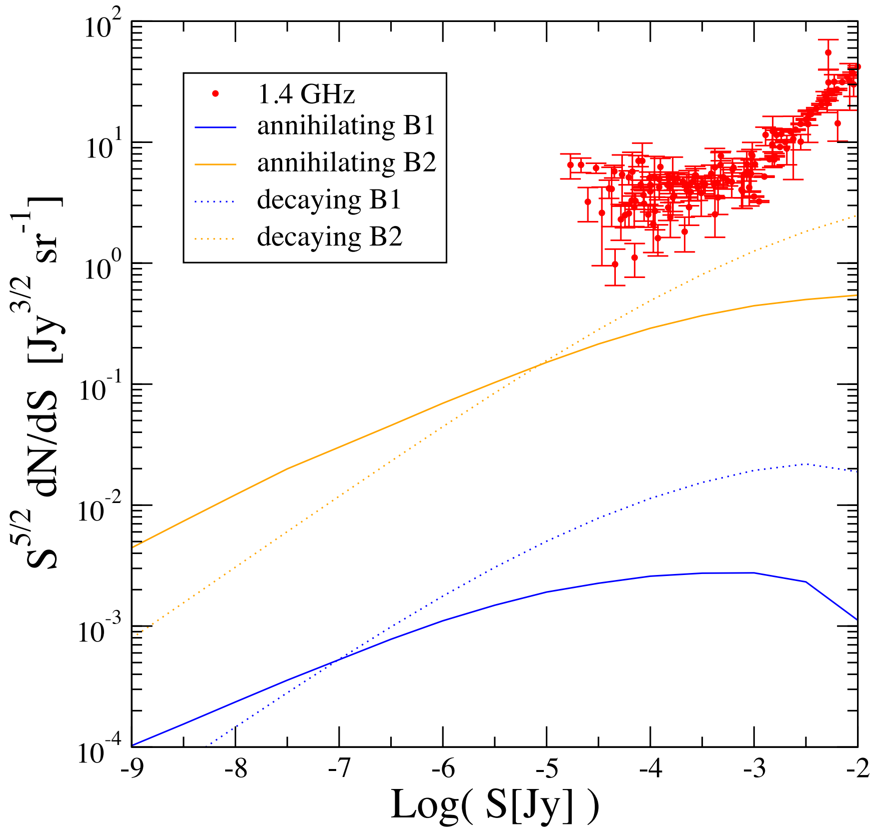
Name	Mass [GeV]	$(\sigma_a v)$ [cm^{3}s^{-1}] annihilating case	τ [s] decaying case	Dominant final state
B1	100	$3 \cdot 10^{-26}$	$4 \cdot 10^{28}$	$b - \bar{b}$
B2	10	$3 \cdot 10^{-26}$	$5 \cdot 10^{27}$	$\mu^+ - \mu^-$

Fornengo, Lineros, Regis, Taoso, JCAP 03 (2012) 033 [arXiv:1112.4517]

Source number counts

Benchmark B2





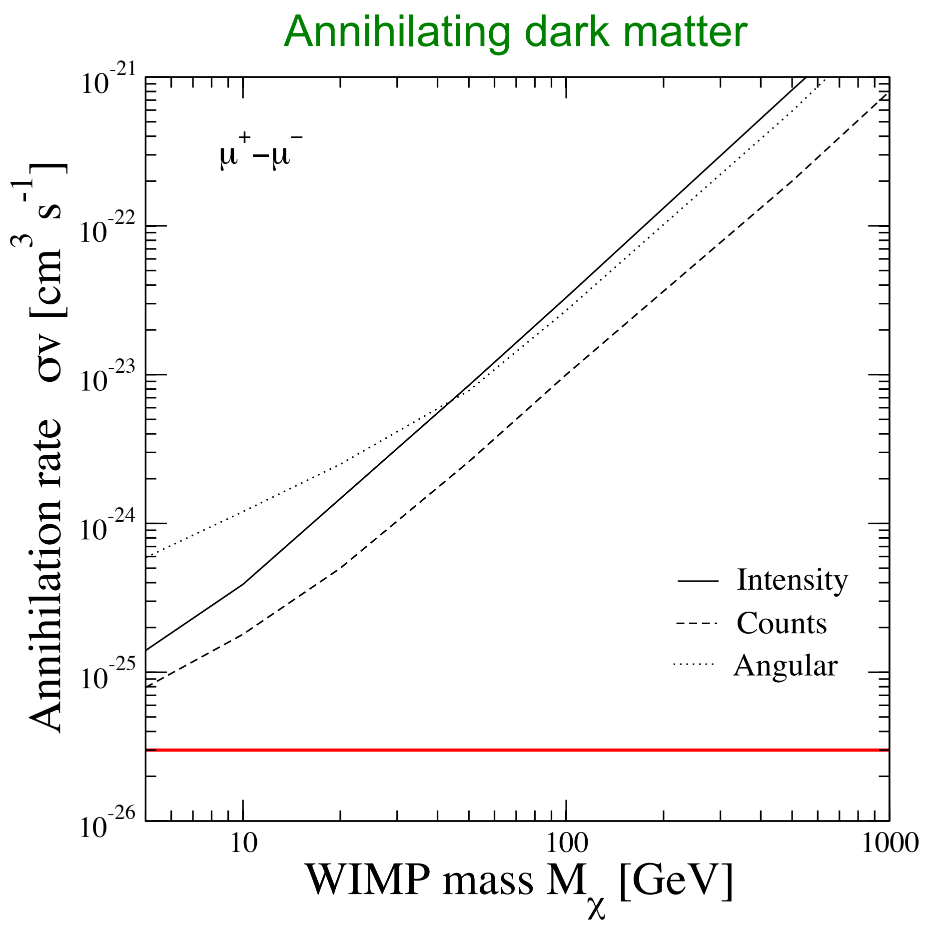
DM constribution becomes more dominant at sub-microJy levels

Decaying-DM spectrum steeper -> takes over at even smaller fluxes

Annihilating DM (density)^2 + (growing of concentration at small halo masses): makes the smaller and fainter structures more important than brighter halos

Fornengo, Lineros, Regis, Taoso, JCAP 03 (2012) 033 [arXiv:1112.4517]

Extragalactic radio signal: bounds



Intensity bound: subdominant (but see ARCADE discussion)
becomes more effective if low-brightness objects are included
(smaller M_{cut} / resolved substructures)

Future survey: are expected to improve considerably the bounds from number counts and anisotropies

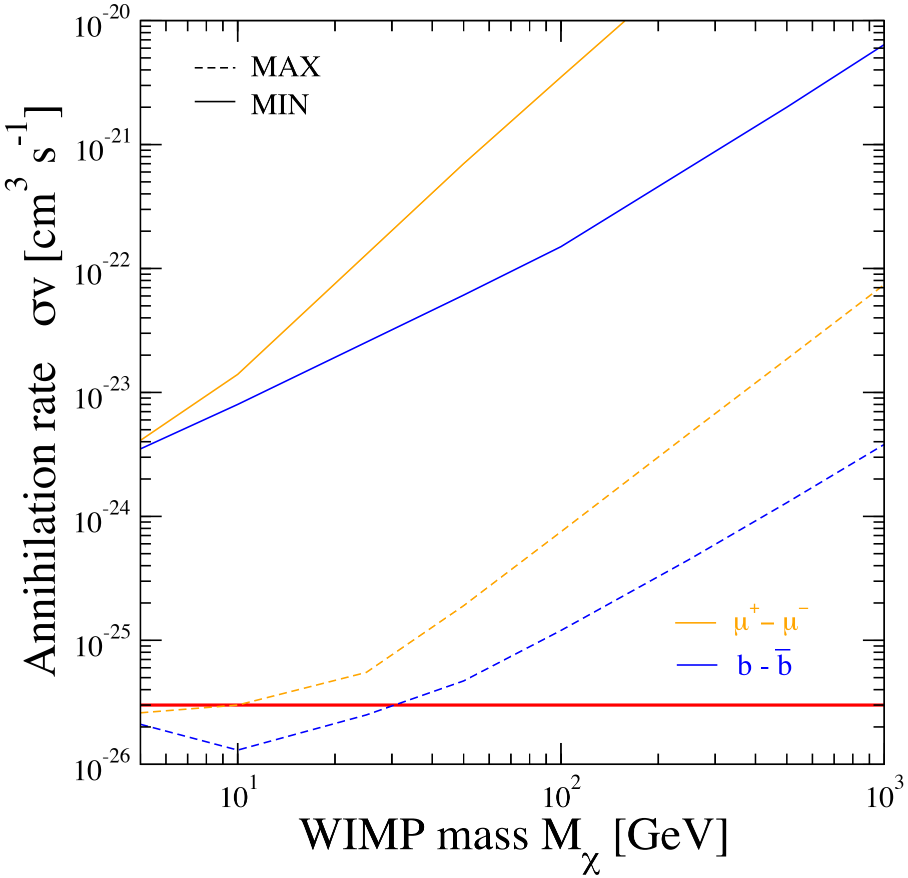
Fornengo, Lineros, Regis, Taoso, JCAP 03 (2012) 033 [arXiv:1112.4517]

Constraints on DM properties

MIN: $M_{cut} = 10^6\, M_{sun}$
$B = B_0 (M/M_{cut})^{0.1} \exp(-r/(R_{vir}/50))$
$B_0 = 10$ microG
electron escape
no substructures

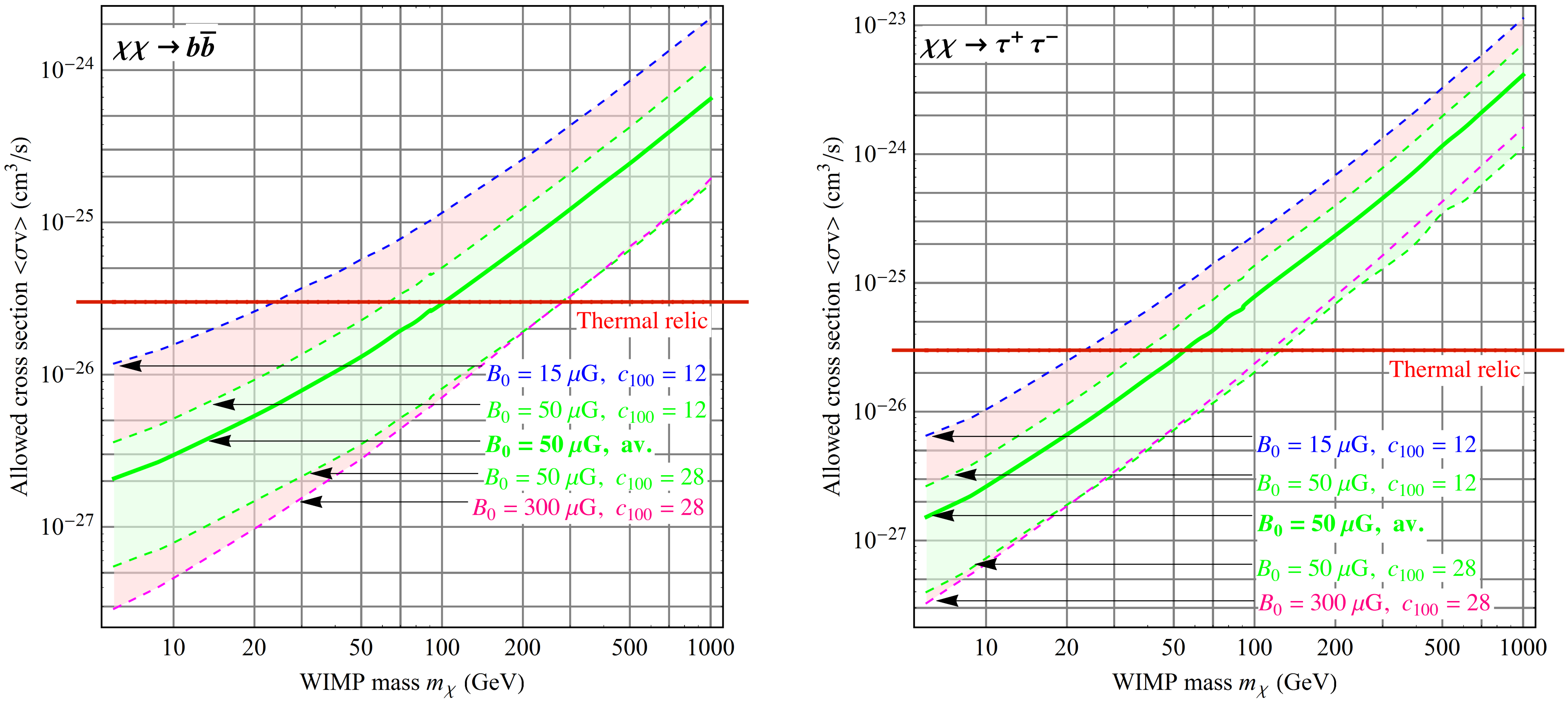
MAX: $M_{cut} = 10^{-6}\, M_{sun}$
$B = B_0 = 10$ microG
electron radiate at injection point
substructures not relevant with these params

Annihilating dark matter



Fornengo, Lineros, Regis, Taoso, JCAP 03 (2012) 033 [arXiv:1112.4517]

Specific target: Andromeda



Egorov and Pierpaoli, arXiv:1304.0517

ARCADE excess

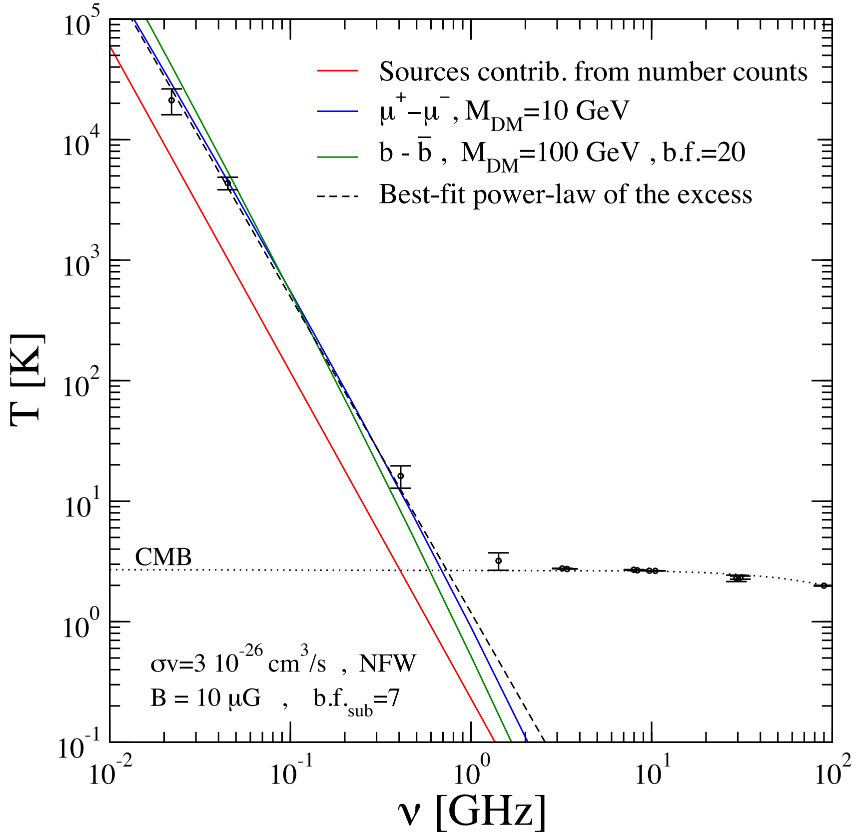
- After subtraction of an isotropic component, ARCADE reports a remaining flux (interpreted as extragalactic) 5-6 times larger than the total contribution from detected extragalactic radio sources

ARCADE:
Singal et al., Astrophys. J. 730 (2011) 138
A. Kogut et al., Astrophys. J. 734 (2011) 4

- Extrapolating the source number counts to lower (unreached) brightness, the excess remains

- Systematics effects and galactic sources seems excluded

- Such a level of radio extragactic emission does not appear to have an immediate explanation in terms of standard astrophysical scenarios,, expecially when multiwavelength constraints are applied



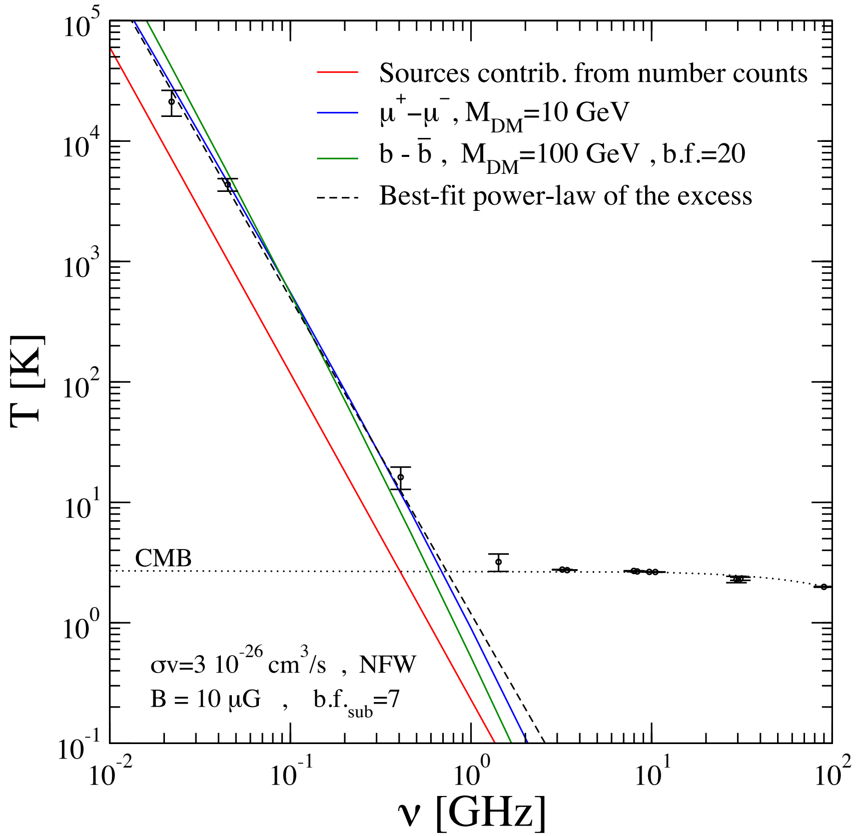
- A new population of numerous and faint radio sources (able to dominate source counts around μJy flux) has to be introduced

Fornengo, Lineros, Regis, Taoso, PRL 107 (2011) 27 27

ARCADE excess

DM can easily explain the excess without special fine tunings

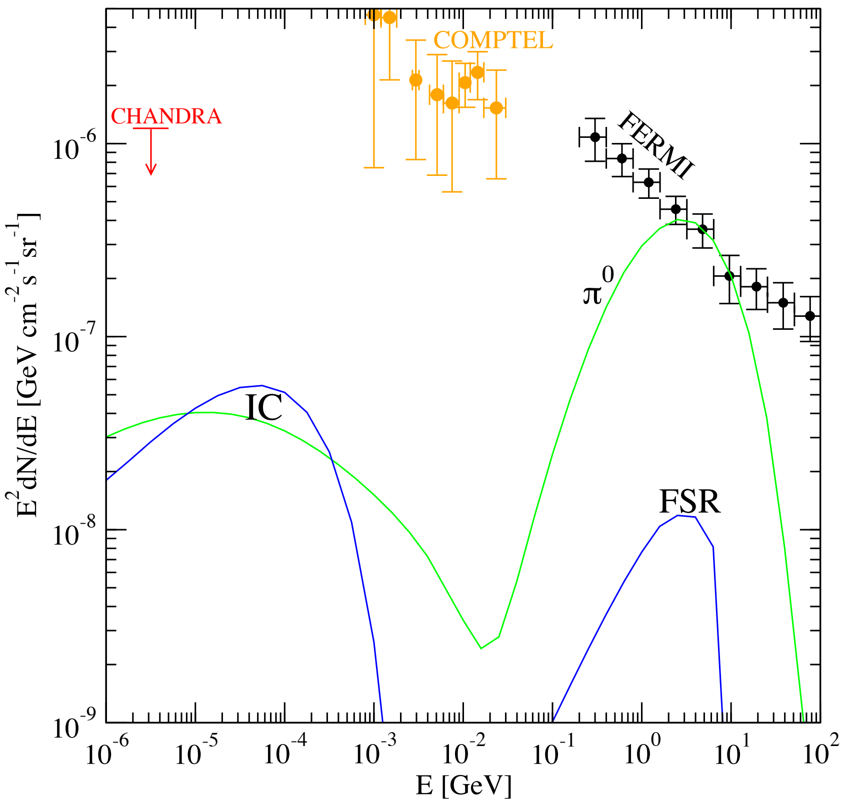
(Slight) preference for light (around 10 GeV) and leptophilic DM



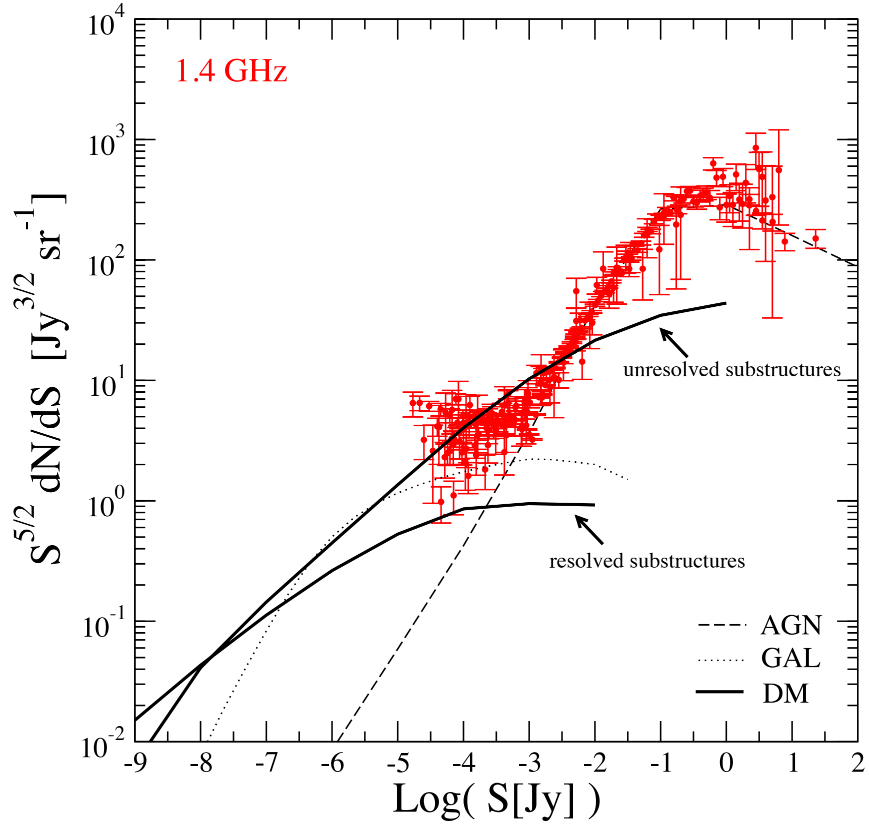
Fornengo, Lineros, Regis, Taoso, PRL 107 (2011) 27 27

ARCADE excess

corresponding multiwavelength signals



differential number counts



Fornengo, Lineros, Regis, Taoso, PRL 107 (2011) 27 [arXiv:1108.0569]
See also: Hooper et al., arXiv:1203.3547

- For radio DM searches, see also:

  - Bertone, Sigl, Silk, MNRAS 337 (2002) 98
  - Hooper, Finkbeiner, Dobler, PRD 76 (2007) 083012
  - Regis, Ullio, PRD 78 (2008) 043505
  - Zhang, Sigl, JCAP 0809 (2008) 027
  - Dobler, Finkbeiner, ApJ 680 (2008) 1222
  - Borriello, Cuoco, Miele, PRD 79 (2009) 023518
  - Bergstrom, Bertone, Bringmann, Edsjo, Taoso, PRD 79 (2009) 081303
  - Bertone, Cirelli, Strumia, Taoso, JCAP 0903 (2009) 009
  - Cumberbatch, Zuntz, Eriksen, Silk, arXiv:0902.0039
  - Boehm, Delahaye, Silk, PRD 105 (2010) 221301
  - Boehm, Silk, Ensslin,arXiv:1008.5175
  - Crocker, Bell, Balazs, Jones, PRD 81 (2010) 063516
  - Linden, Profumo, Anderson, PRD 82 (2010) 063529
  - Mambrini, Tytgat, Zaharijas, Zaldivar, JCAP 1211 (2012) 038
  - Hooper, Belikov, Jeltema, Linden, Profumo, Slatyer, Phys. Rev. D86 (2012) 103003
  - Asano, Bringmann, Sigl, Vollmann, arXiv:1211.6739
  - Wechakama, Ascasibar, arXiv:1212.2583
  - Egorov, Pierpaoli, arXiv:1304.0517
  - Cline, Vincent, JCAP 1302 (2013) 011
  - Spekkens, Mason, Aguirre, Nhan, arXiv:1301.5306
  - Storm, Jeltema, Profumo, Rudnick, Ap.J. 768 (2013) 106

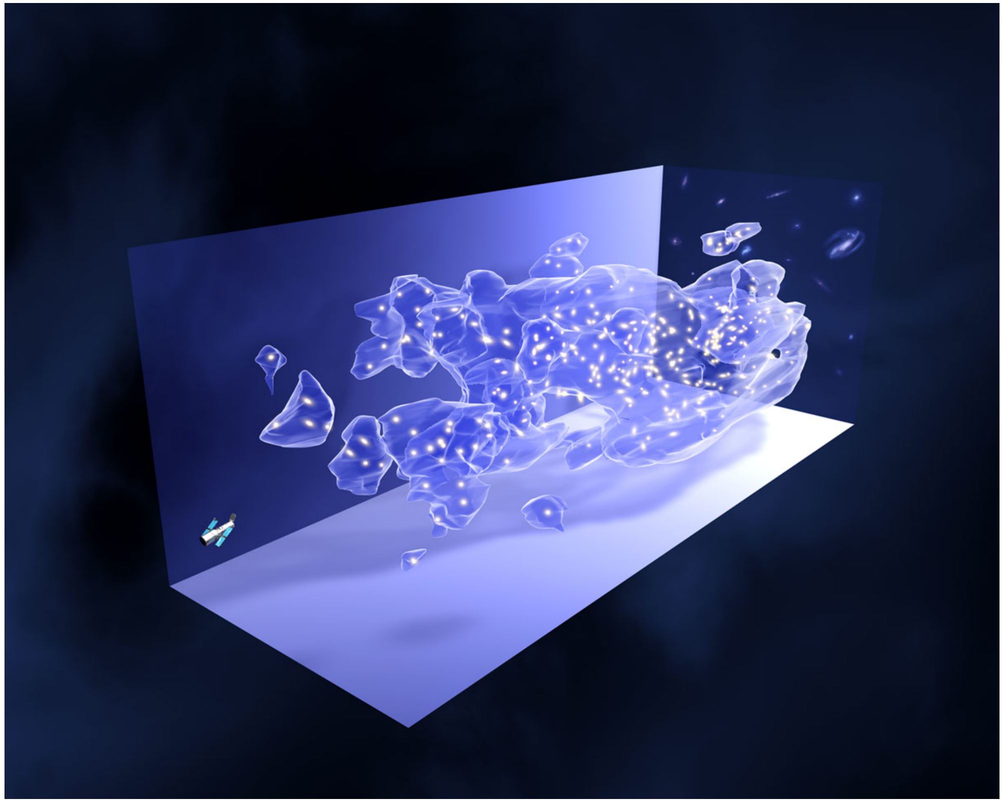
  - Spekkens, Mason, Aguirre, Nhan, arXiv:1301.5306

A new proposal:

gamma rays/cosmic shear cross correlation

Weak gravitational lensing

- Weak lensing: small distortions of images of distant galaxies, produced by the distribution of matter located between background galaxies and the observer

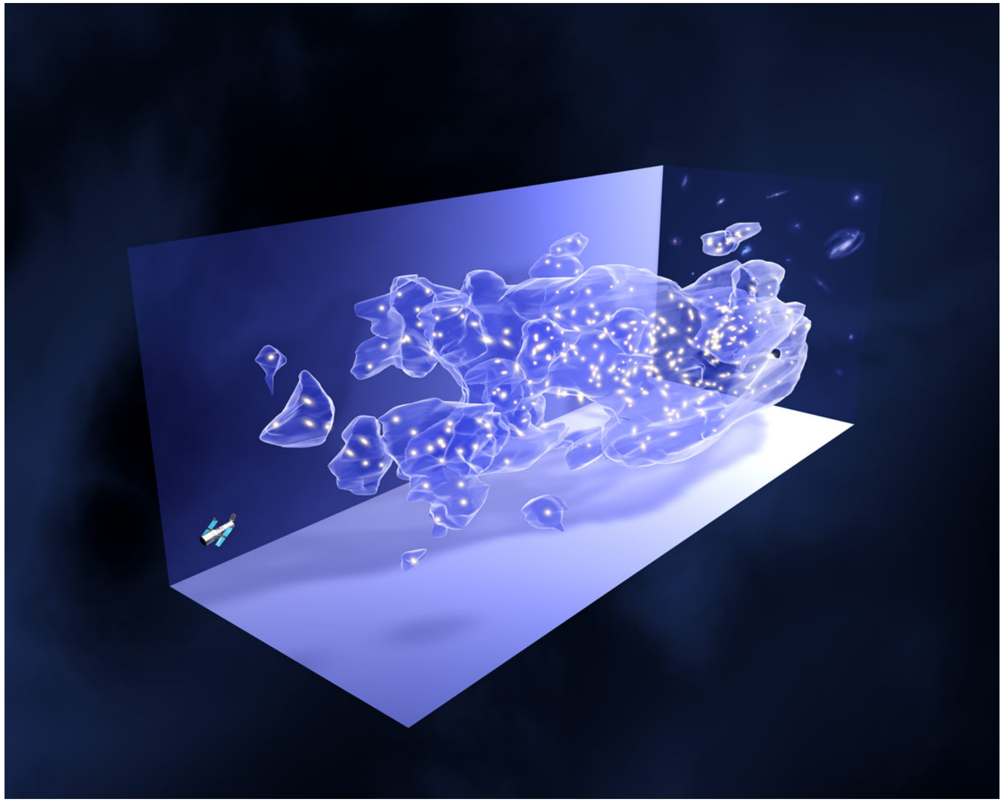


Powerful probe of dark matter distribution in the Universe

Cosmic structures and gamma-rays

The same Dark Matter structures that act as lenses can themselves emit light at various wavelengths, including the gamma-ray range

- ✓ From astrophysical sources hosted by DM halos (SFG, AGN)
- ✓ From DM itself (annihilation/decay)

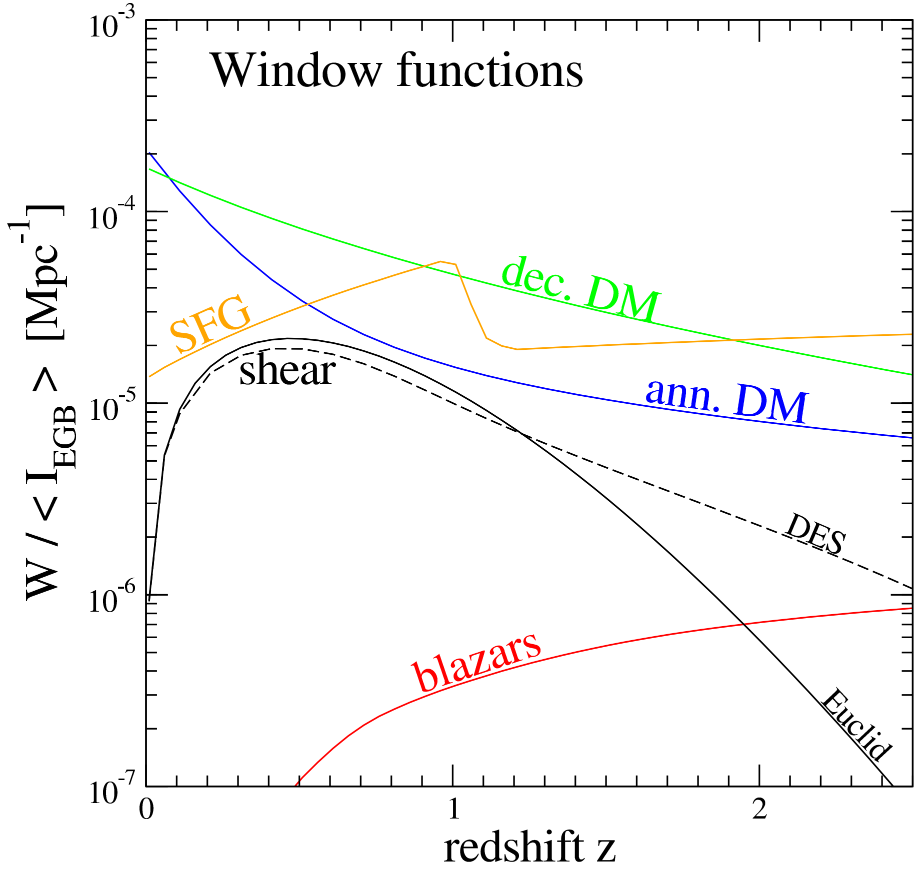


Gamma-rays emitted by DM may exhibit strong correlation with lensing signal

Cross-correlation gamma/shear — Proposed in:

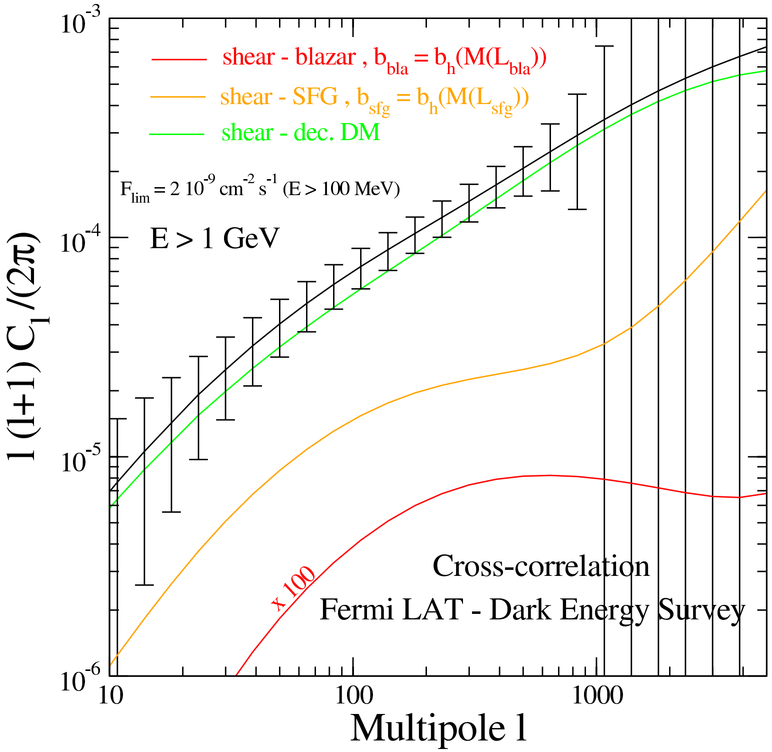
Camera, Fornasa, Fornengo, Regis
Ap. J. Lett. 771 (2013) L5 [arXiv:1212.5018]

Window functions

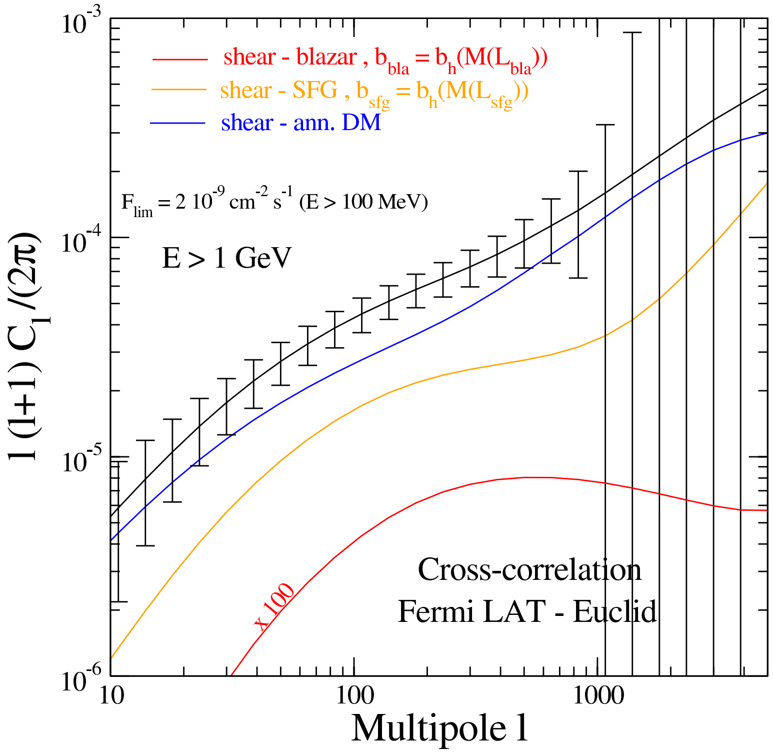


Camera, Fornasa, Fornengo, Regis, Ap. J. Lett. 771 (2013) L5 [arXiv:1212.5018]

Cross-correlation predictions



Fermi-LAT/5-yr with DES



Fermi-LAT/5-yr with Euclid

Camera, Fornasa, Fornengo, Regis, Ap. J. Lett. 771 (2013) L5 [arXiv:1212.5018]

Gamma-rays auto-correlation

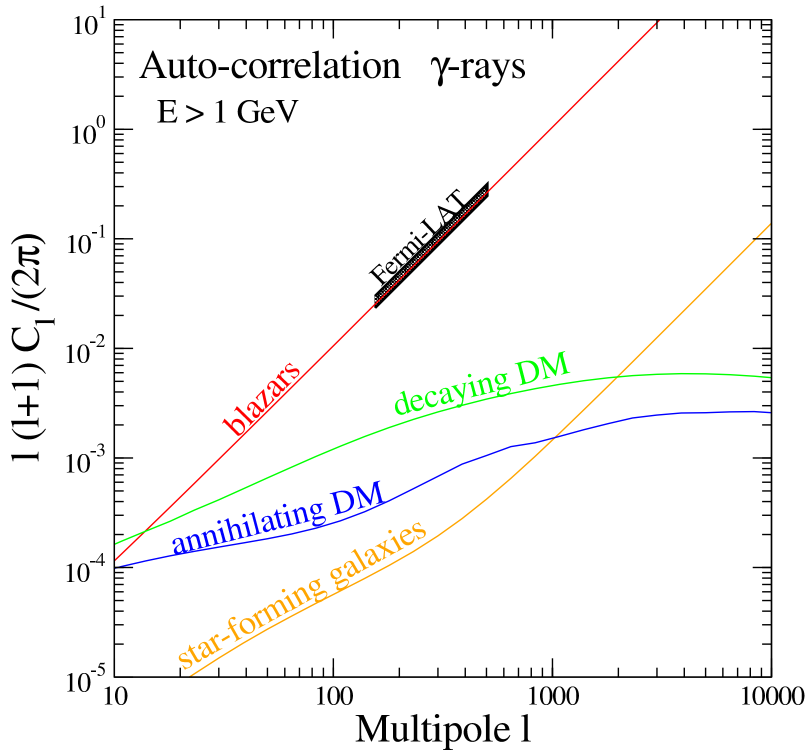
Ackerman et al. (Fermi), Phys. Rev. 85 (2012) 083007

Auto-correlation in the gamma-rays emission has been reported

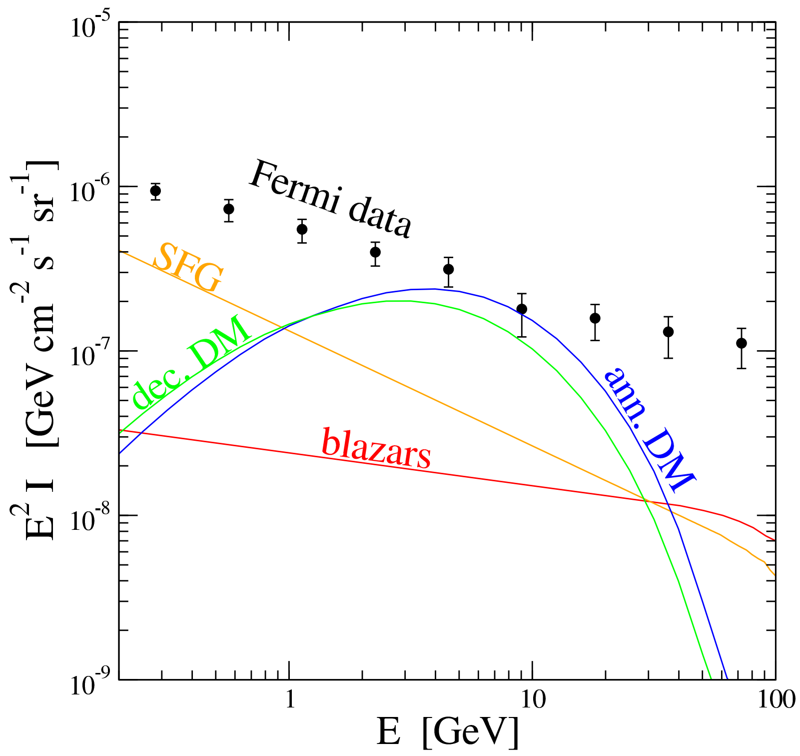
For l > 100 galactic foreground can be negleted: EGB contribution

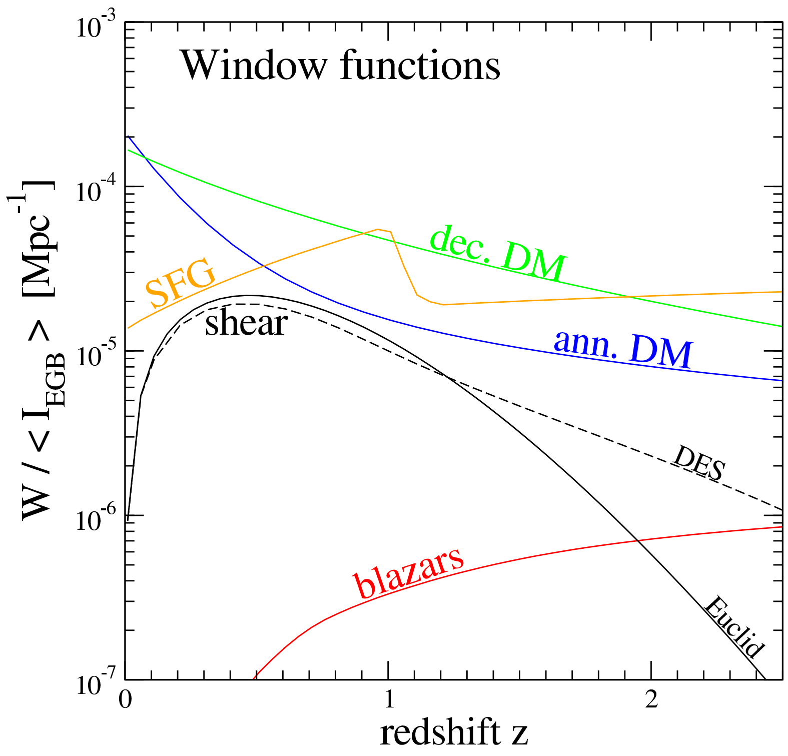
Features of the signal (energy and multipole independent) point toward interpretation in therms of blazars

DM plays here a subdominant role



Energy-slicing and redshift-tomography



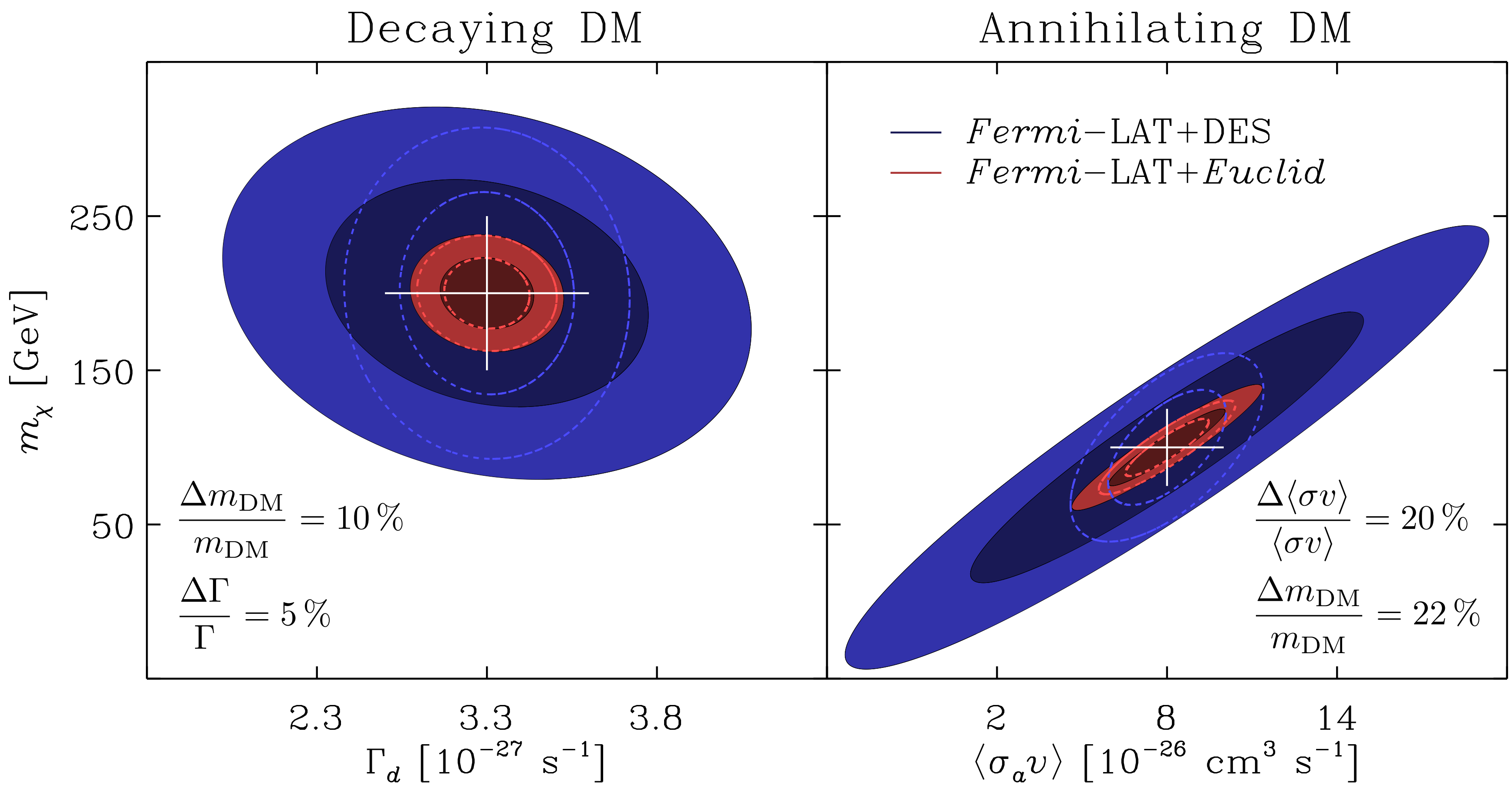


Reshift information in shear: can be used to "separate" lensing sources

Energy spectrum of gamma-rays: can help in DM-mass reconstruction

Camera, Fornasa, Fornengo, Regis, in preparation

Bayesian forecasts



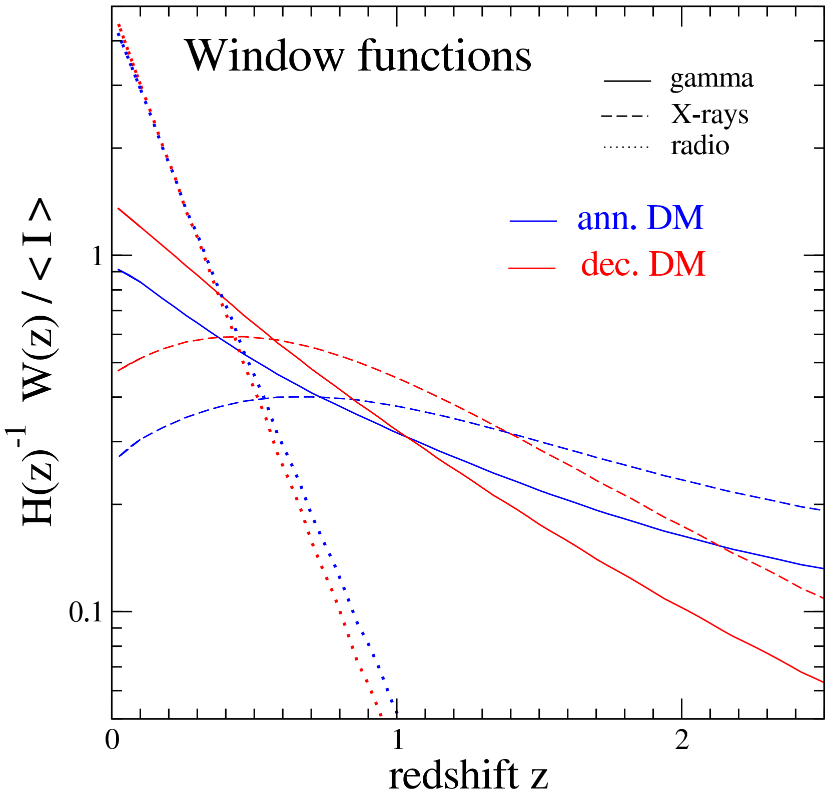
Joint 68% 2-parameter error contours

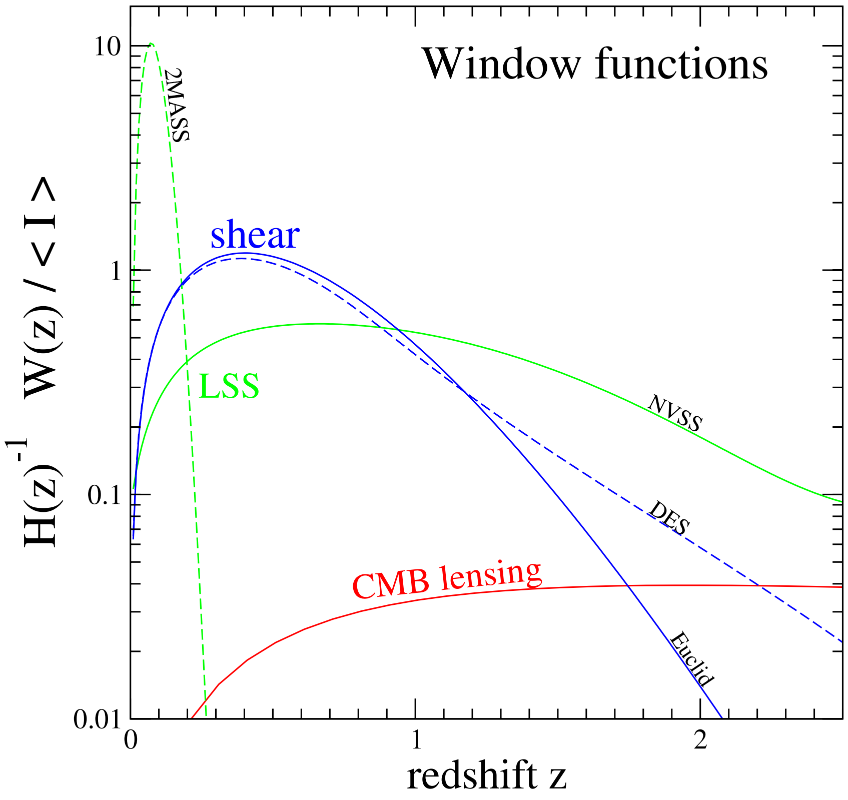
Solid: gamma/shear cross-correlation

Dashed: includes also gamma auto-correlation

Camera, Fornasa, Fornengo, Regis, in preparation [preliminary plot]

DM searches in the anisotropic sky





- Auto-correlation of electromagnetic signals
- Cross-correlation between electromagnetic signals
- Cross-correlation between electromagnetic signals and gravitational tracers

Fornengo, Regis, arXiv:1312.4835

- Gamma-rays auto-correlation

  - Ando, Komatsu, Phys. Rev. D73 (2006) 023521
  - Ando et al., Phys. Rev. D 75 (2007) 063519
  - Fornasa, Pieri, Bertone, Branchini, Phys. Rev. D 80 (2009) 023518
  - Ibarra, Tran, Weniger, Phys. Rev. D 81 (2010)
  - Cuoco, Sellerholm, Conrad, Hannestad, MNRAS 414 (2011) 2040
  - Fornasa, Zavala, Sanchez-Conde, Siegal-Gaskins, Delahaye et al., MNRAS 429 (2013) 1529
  - Ripken, Cuoco, Zechlin, Conrad, Horns, arXiv:1211.6922
  - Hensley, Pavlidou, Siegal-Gaskins, MNRAS, 433 (2013) 591
  - Ando and E. Komatsu, Phys. Rev. D 87 (2013) 123539
  - Ackermann et al. (Fermi Collab.), Phys. Rev. D 85 (2012) 083007

- Radio auto-correlation

  - Zhang, Sigl, JCAP 0809 (2008) 027
  - Fornengo, Lineros, Regis, Taoso, JCAP 1203 (2012) 033

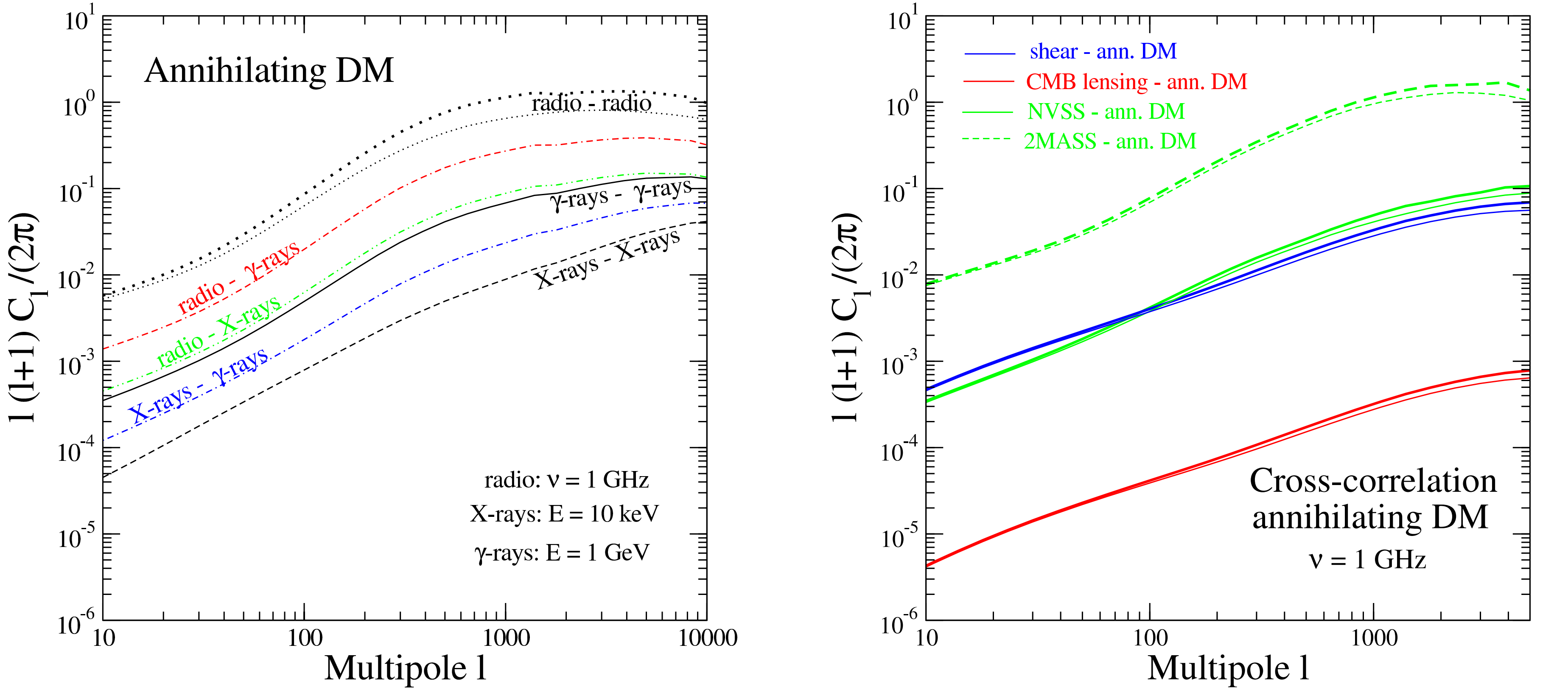
- X-rays auto-correlation

  - Inoue, Murase, Madejski, Y. Uchiyama, Astrophys. J. 776 (2013) 33

- Gamma-rays/cosmic-shear cross correlation

  - Camera, Fornasa, Fornengo, Regis, Ap. J. Lett. 771 (2013) L5

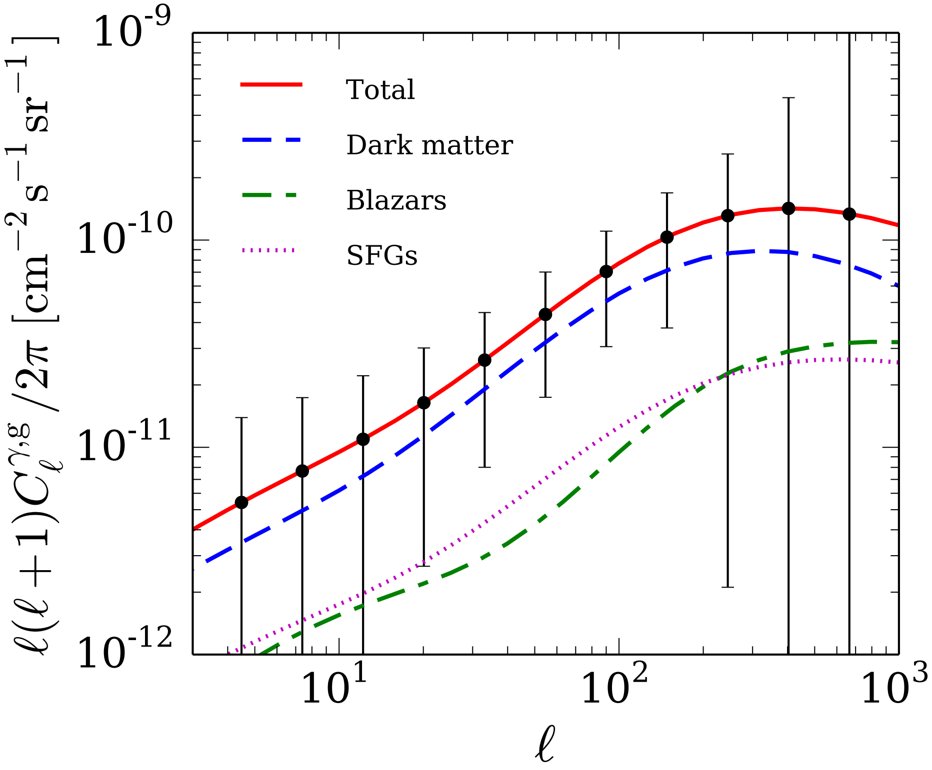
Angular power spectra of anisotropies

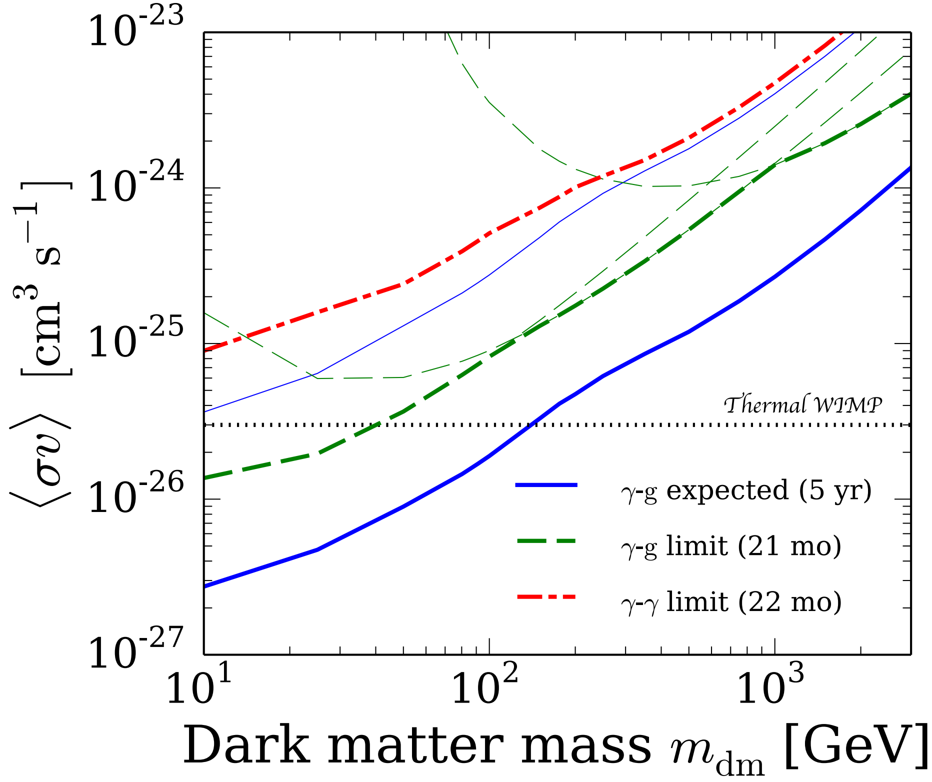


Fornengo, Regis, arXiv:1312.4835

LSS/gamma-rays

Cross-correlation: Fermi-LAT with 2MASS galaxy survey





Ando, Levy, Komatsu, arXiv:1312.4403

Conclusions

- Antiprotons and Gamma-rays: provide relevant bounds
  - Galactic antiprotons (PAMELA, AMS to come soon)
  - Extra-galactic gamma-rays (Fermi)
  - Gamma-rays from dwarf galaxies (Fermi)
  - Few hints in gamma-rays, but weak
- Antideuterons: prospect for signal detection in GAPS or AMS
- Radio: already setting interesting bounds
  - Good prospects both for galactic and extragalactic emission
  - "ARCADE" excess?
- Anisotropic sky: recent field, with quite promising prospects
  - Gamma/Gamma and Radio/Radio already providing mild bounds
  - EM / gravitational probes: could allow to directly test particle-DM hypothesis