PARTICLE DARK MATTER

NICOLAO FORNENGO

Department of Physics (Theory Division) – University of Torino
and Istituto Nazionale di Fisica Nucleare (INFN) – Torino
Italy

UNIVERSITA' DEGLI STUDI DI TORINO
ALMA UNIVERSITAS TAURINENSIS

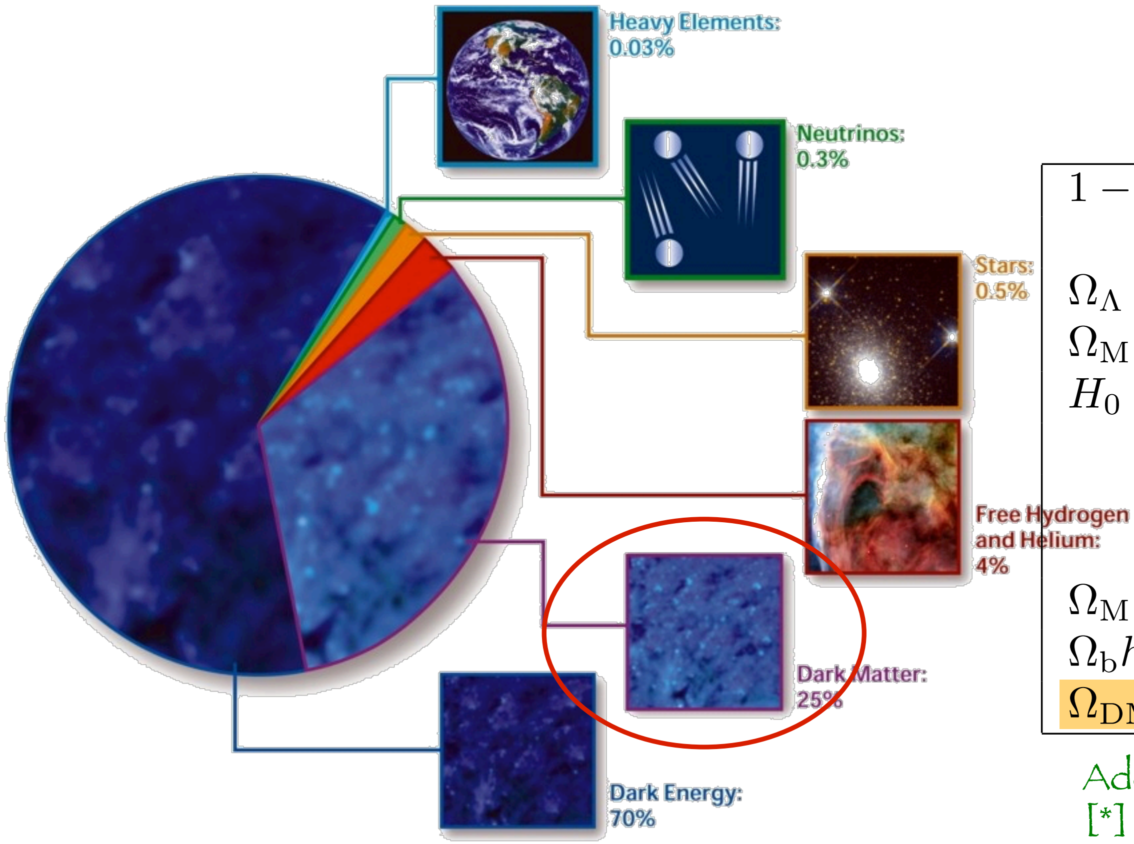
fornengo@to.infn.it
nicolao.fornengo@unito.it

www.to.infn.it/~fornengo
www.astroparticle.to.infn.it

INFN Torino

Dipartimento di Fisica – Università di Pavia – 11.06.2015

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

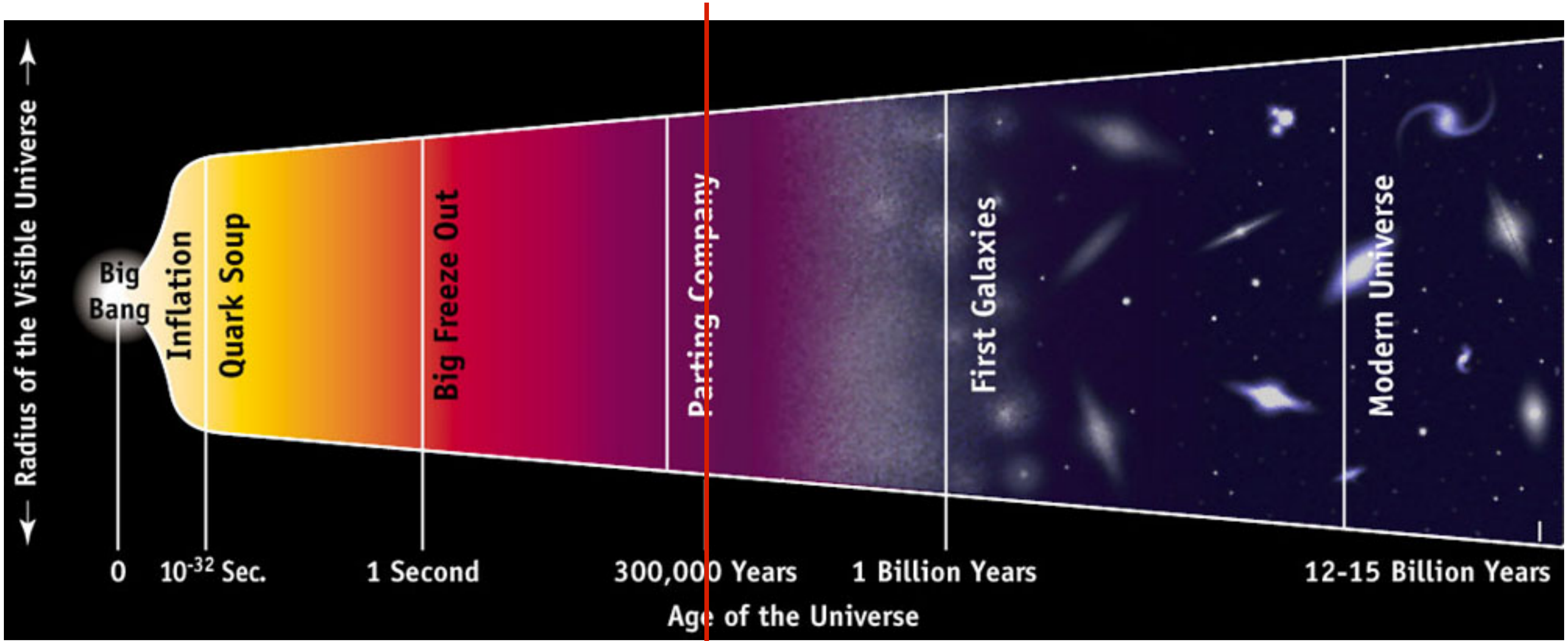
Overwhelming evidence:

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

Dark Matter

- Only "seen" gravitationally
- Can be ascribed to:
  - Modification of the theory of Gravity
  - Elementary particle, relic from the early Universe
    - No viable candidate in the Standard Model (standard, almost massless, neutrinos do not work)
    - New fundamental physics beyond the SM
    - To demonstrate that it's a new particle, a non-gravitational signal (due to it's particle phsyics nature) is needed

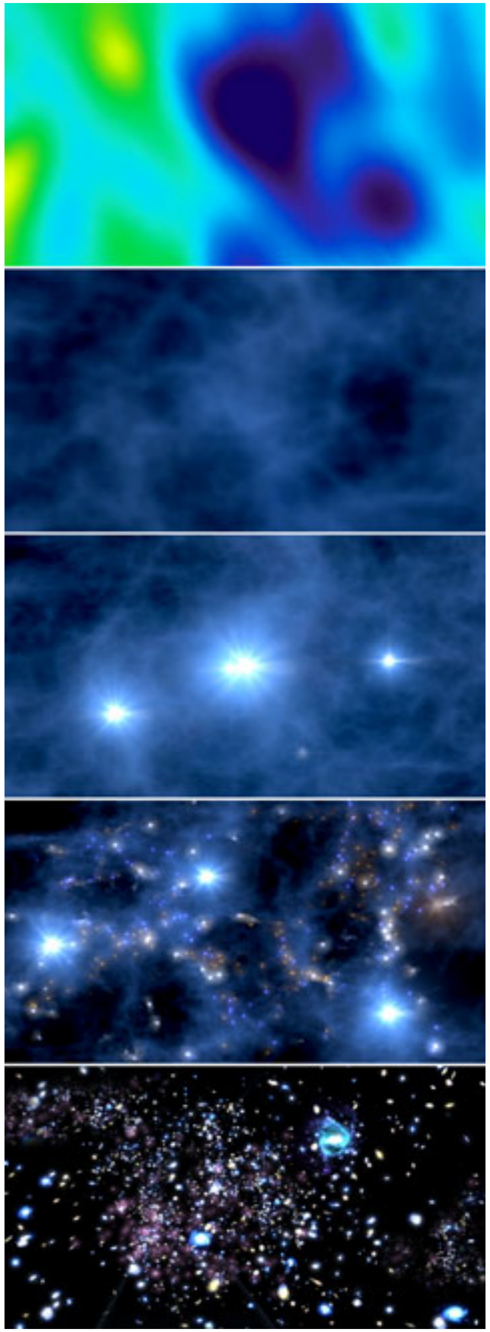
How comes a particle physics interpretation?



Plasma phase

In this primordial phase, U. evolution is determined by particle interactions

In this phase, U. evolution is determined only by gravity



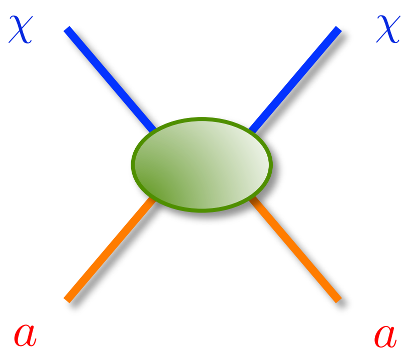
Primordial fluctuations

Growth of perturbation by
Gravitational instabilities

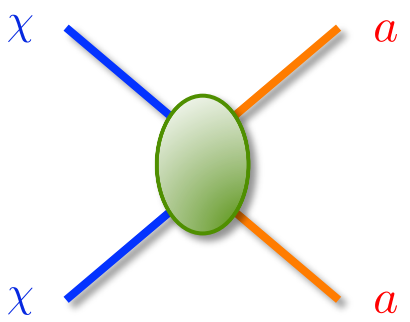
Dark matter acts ac
Key element (and is
required to be
effectively cold [-ish])

Structure formation
(galaxies, clusters)

Collisions in the primordial plasma



Elastic process — kinetic equilibrium



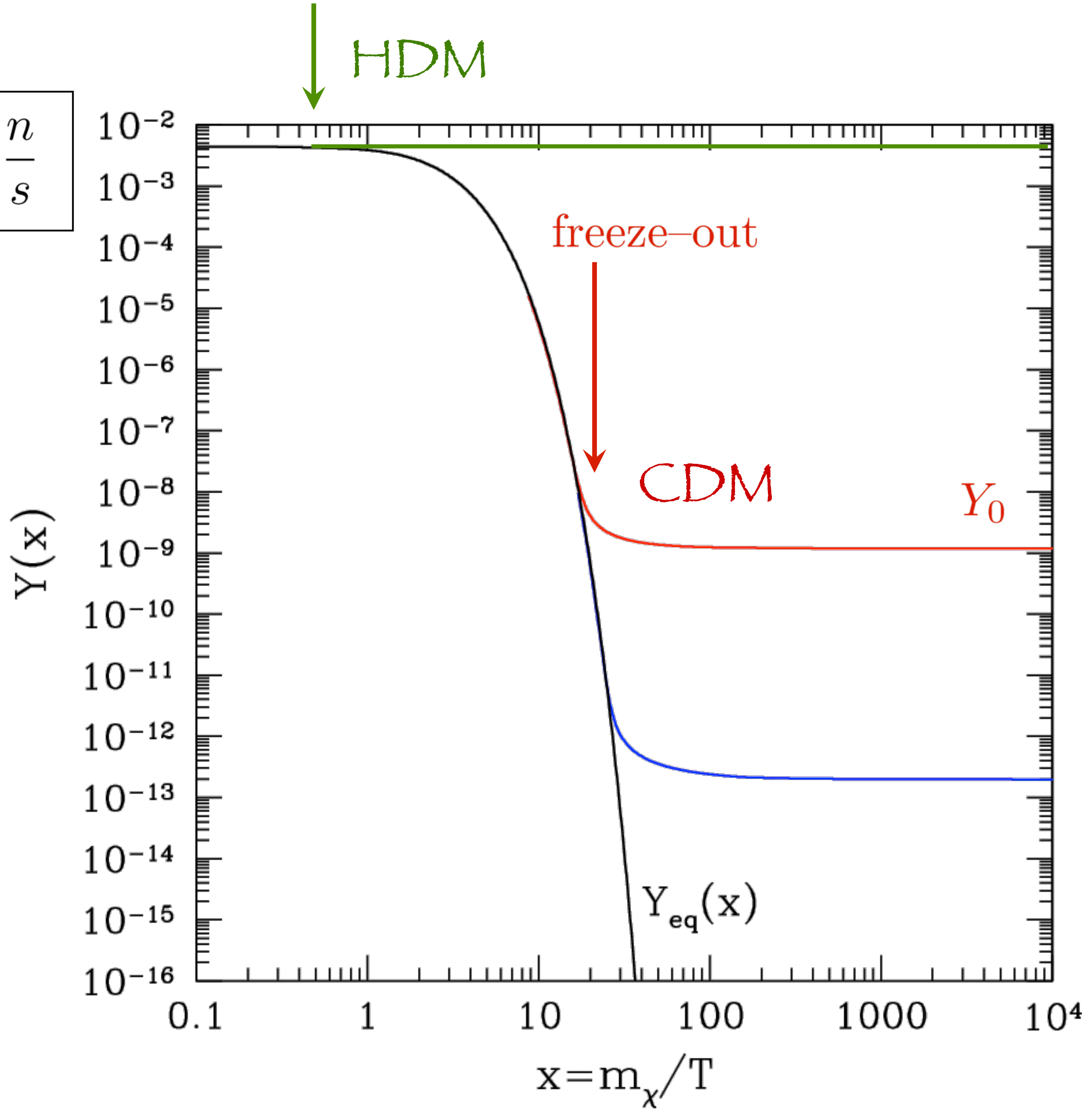
Inelastic process — chemical equilibrium

Both processes are able to modify the phase-space distribution $f_i(p,T)$

Elastic processes: do not modify the number density $n_i(T)$

Inelastic processes: do modify the number density $n_i(T)$

$$\boxed{Y = \frac{n}{s}}$$



$$Y_0 = Y(x_f)$$

$$\boxed{\Omega_{\rm CDM} h^2 = \frac{m\, s_0\, Y_0}{\rho_C^0}}$$

$$\boxed{\Omega h^2 \sim \frac{1}{\langle \sigma v \rangle}}$$

$$s = \frac{2\pi^2}{45} g_{\star S} T^3$$

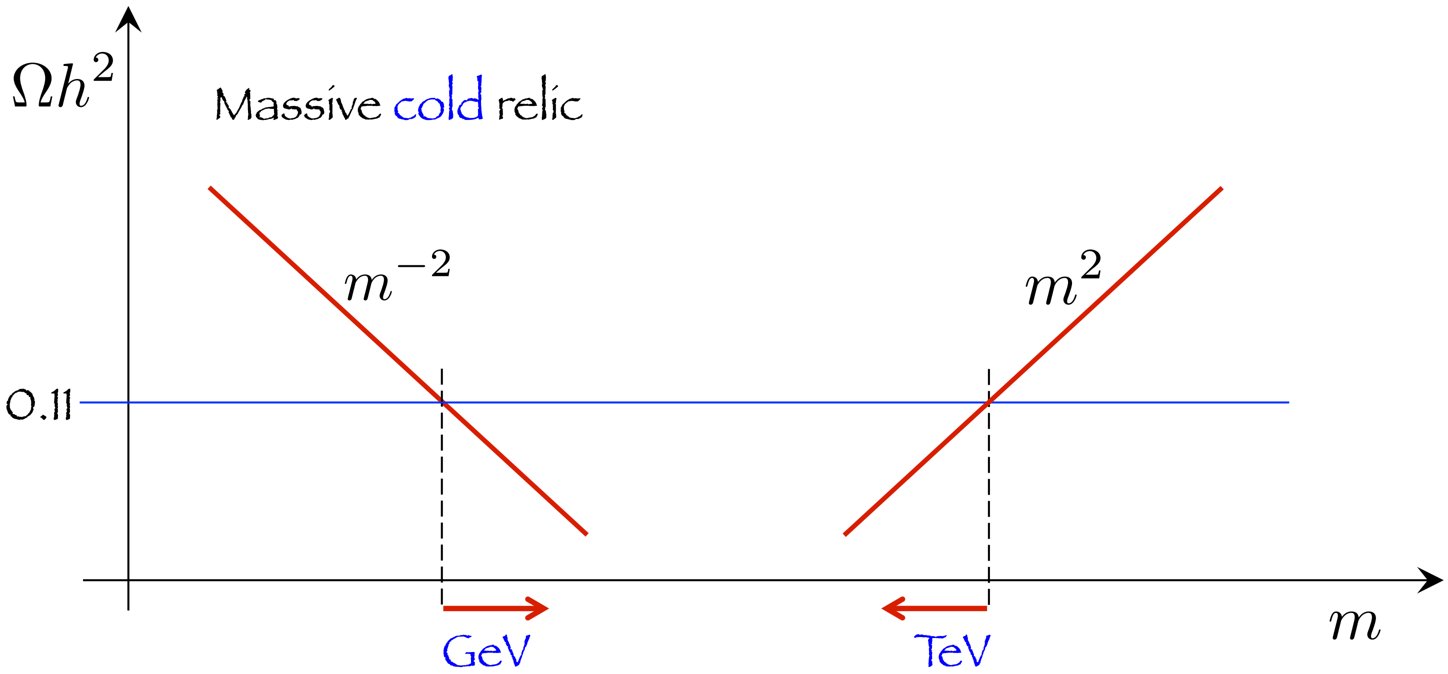
The "WIMP" miracle

WIMP: Weakly Interacting Massive Particle

$$m_\chi \sim (\mathrm{GeV} \div \mathrm{TeV})$$

$$\langle \sigma v \rangle = G_F^2 m_\chi^2 \qquad\qquad \langle \sigma v \rangle = \frac{\alpha}{m^2}$$

$$\langle \sigma v \rangle = G_F^2 m_\chi^2 \xrightarrow{\text{naturally}} \Omega_\chi h^2 \sim 0.1 \xleftarrow{\text{naturally}} \langle \sigma v \rangle = \frac{\alpha}{m^2}$$



Succesfull DM candidate

- Needs to be produced in the early Universe

- Needs to be "cold" (or, at least, "warm" enough)
  - For thermal production: weakly interacting and massive (WIMP)

    $$\Omega h^2 \sim \langle\sigma v\rangle_{\rm ann}^{-1} \longrightarrow \langle\sigma v\rangle_{\rm ann} = 3\cdot 10^{-26}{\rm cm}^3{\rm s}^{-1}$$

    unless coannihilation occurs

  - If light, it nevertheless needs to act as "cold" (see the axion)

- Needs to be neutral

- Needs to be stable (or, if it decays, it needs a lifetime larger than the age of the Universe)

Alternatives

The standard paradigm for CDM is a thermal symmetric relic (i.e. particle and antiparticles have the same number density)

Asymmetry between particle/antiparticle is an alternative

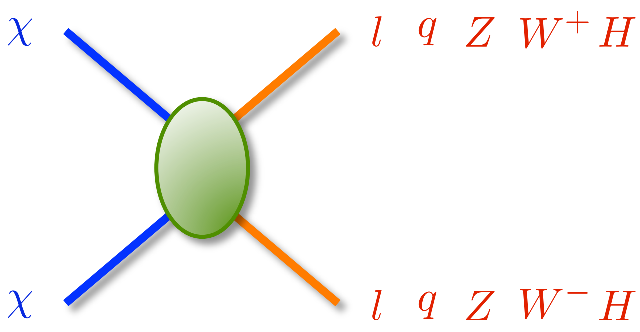
- Boltzmann eq.s are modified
- This may link DM abundance to baryon asymmetry

Non-thermal production may also be possible

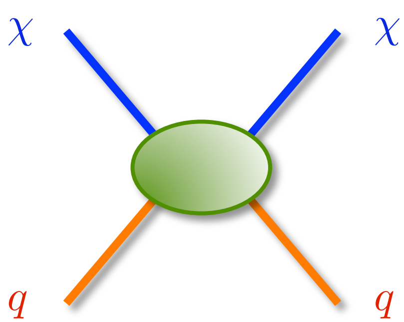
- e.g. : particle not fully excited in the plasma
- e.g. : DM produced by the decay of a heavier particle

Non – gravitational signals of particle DM

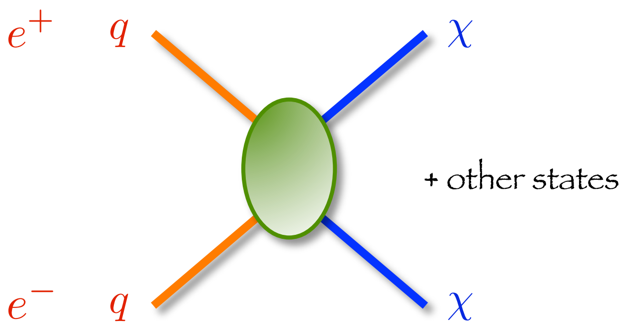
Mechanisms of DM signal production



Annihilation (or decay)

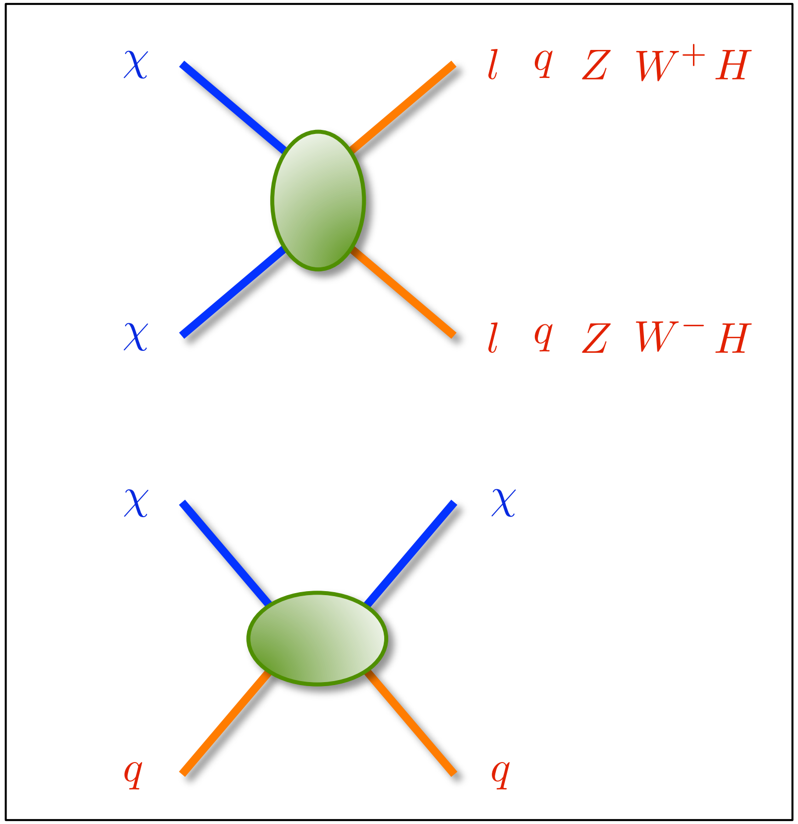


Scattering with ordinary matter



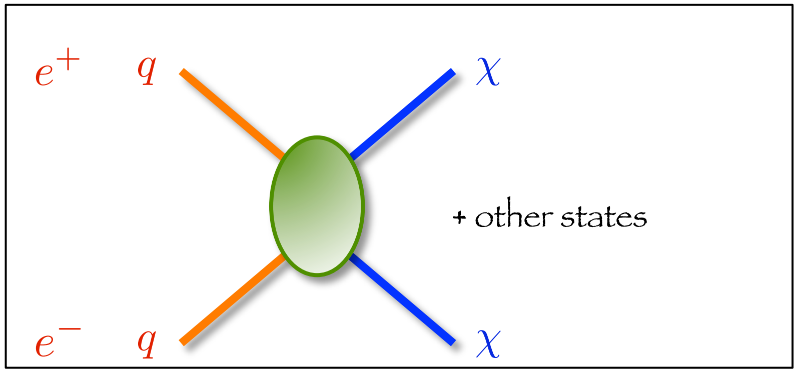
Production at accelerators

Mechanisms of DM signal production



Signals occur in astrophysical context

Directly test the particle-physics nature of DM



Signal produced in accelerators

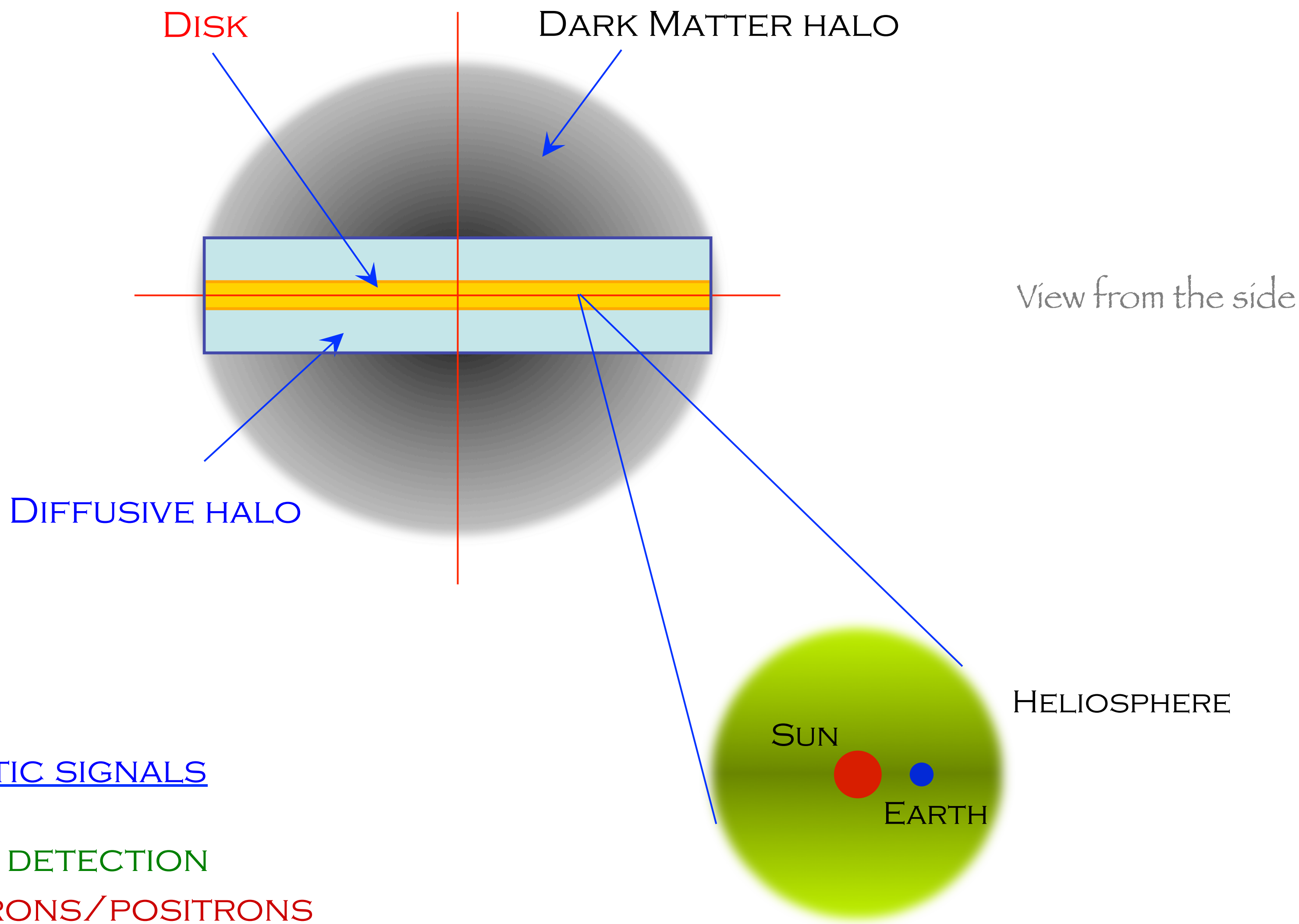
Directly tests New Physics: compatibility with DM needs to be cross-checked with cosmology adn astrophysics

Where to search for a signal

DM is present in:

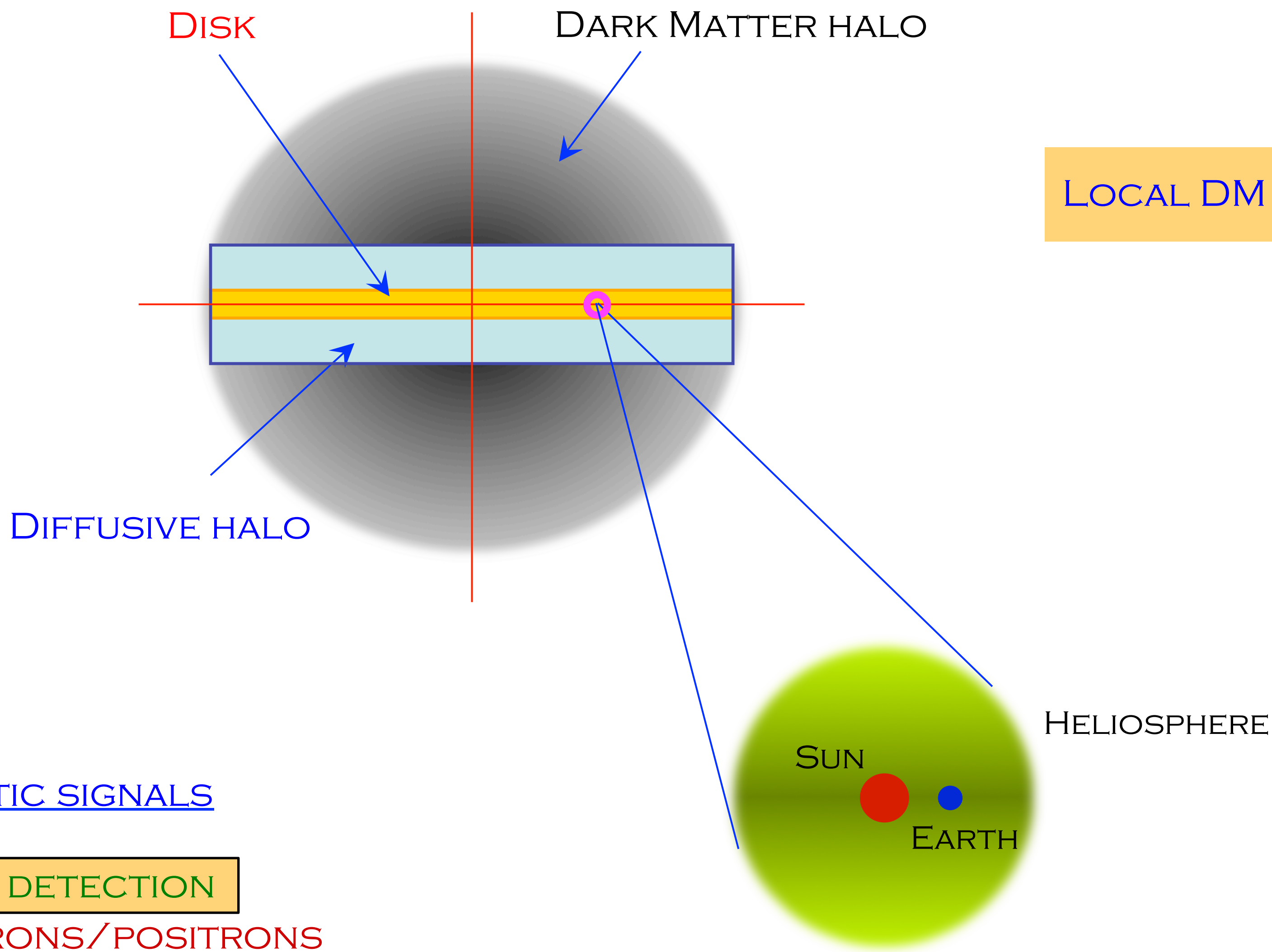
- Our Galaxy
  - smooth component
  - subhalos
- Satellite galaxies (dwarfs)
- Galaxy clusters
  - smooth component
  - individual galaxies
  - galaxies subhalos
- "Cosmic web"

Signals in the local environment



Galactic signals

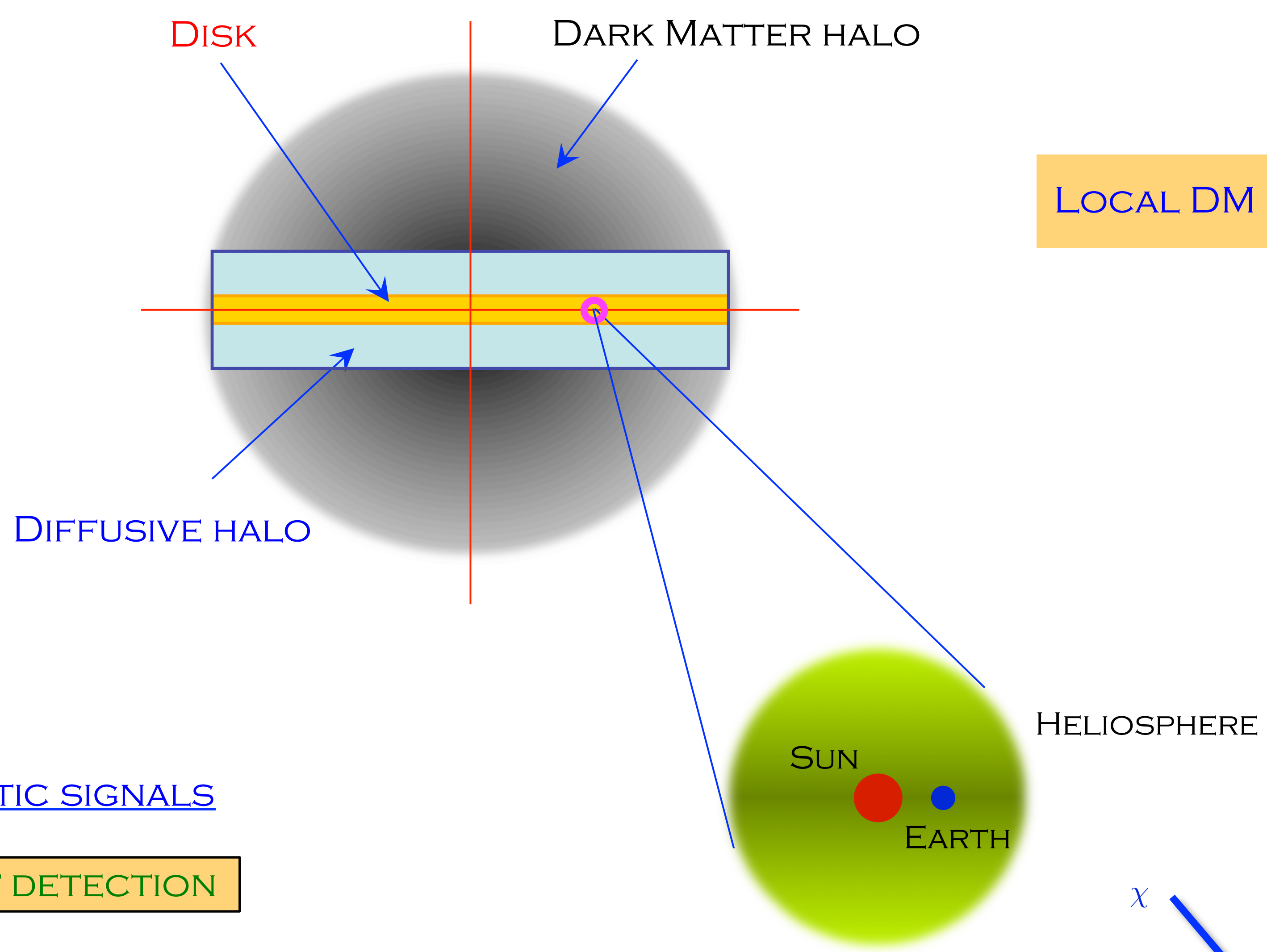
Direct detection
Electrons/positrons
Antiprotons
Antideuterons
Photons (from radio to gamma rays)
neutrinos



Local DM halo

Galactic signals

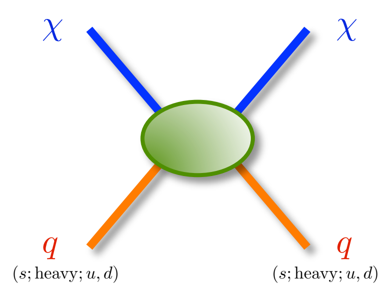
Direct detection
Electrons/positrons
Antiprotons
Antideuterons
Photons (from radio to gamma rays)
Neutrinos from Earth and Sun



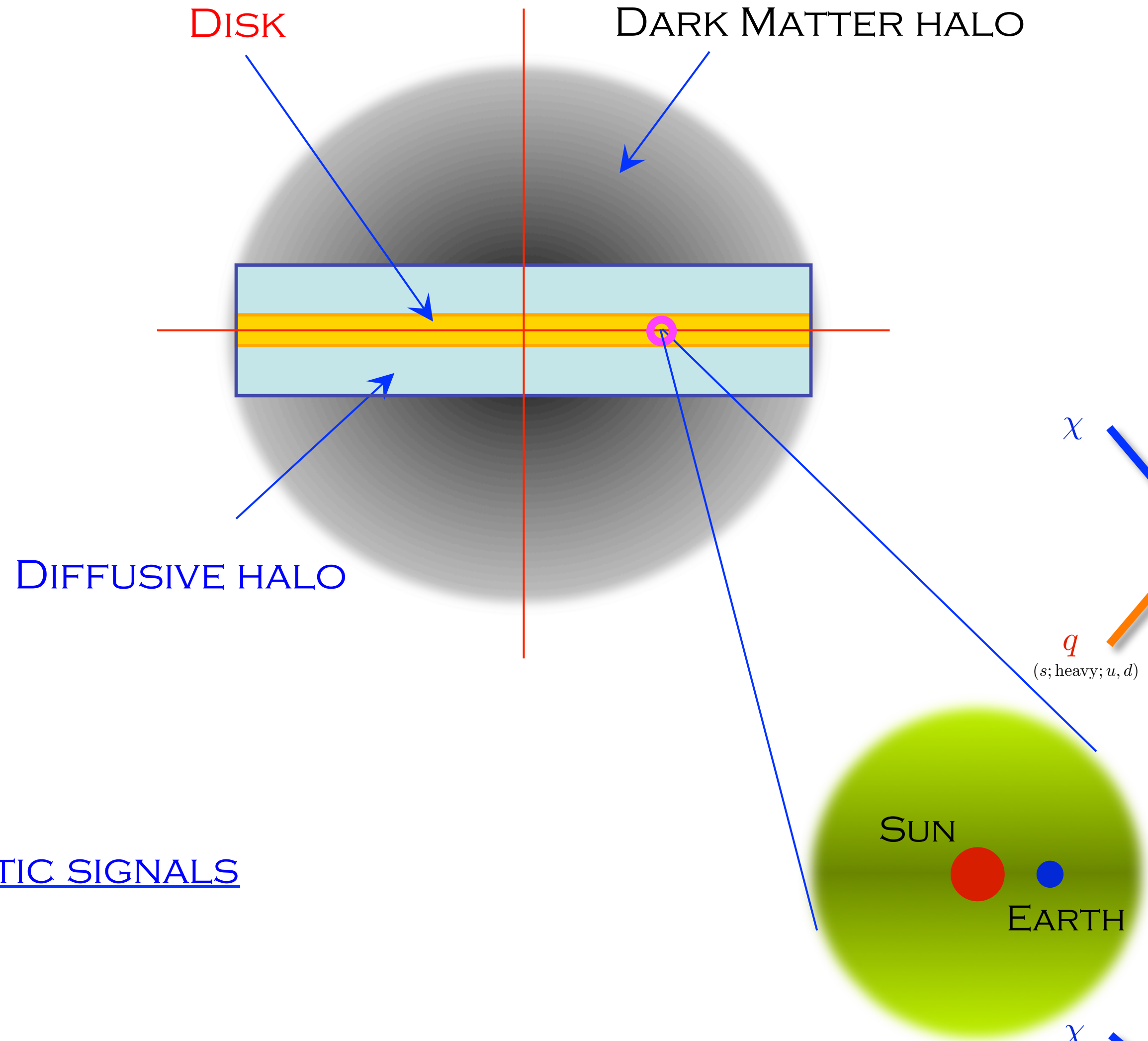
Local DM halo

Galactic signals

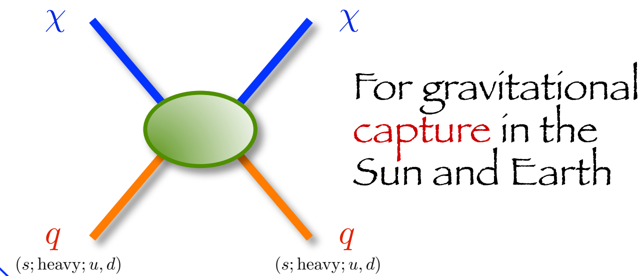
Direct detection



Feels ony the local DM density (not space distribution)
Feels how DM is locally distributed in velocity space



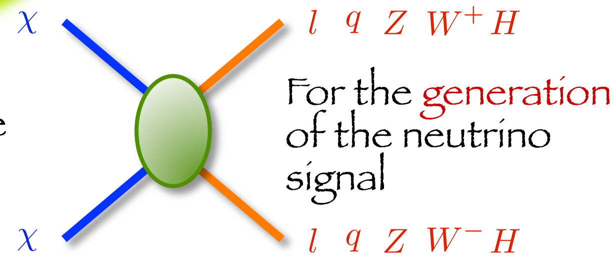
Local DM halo



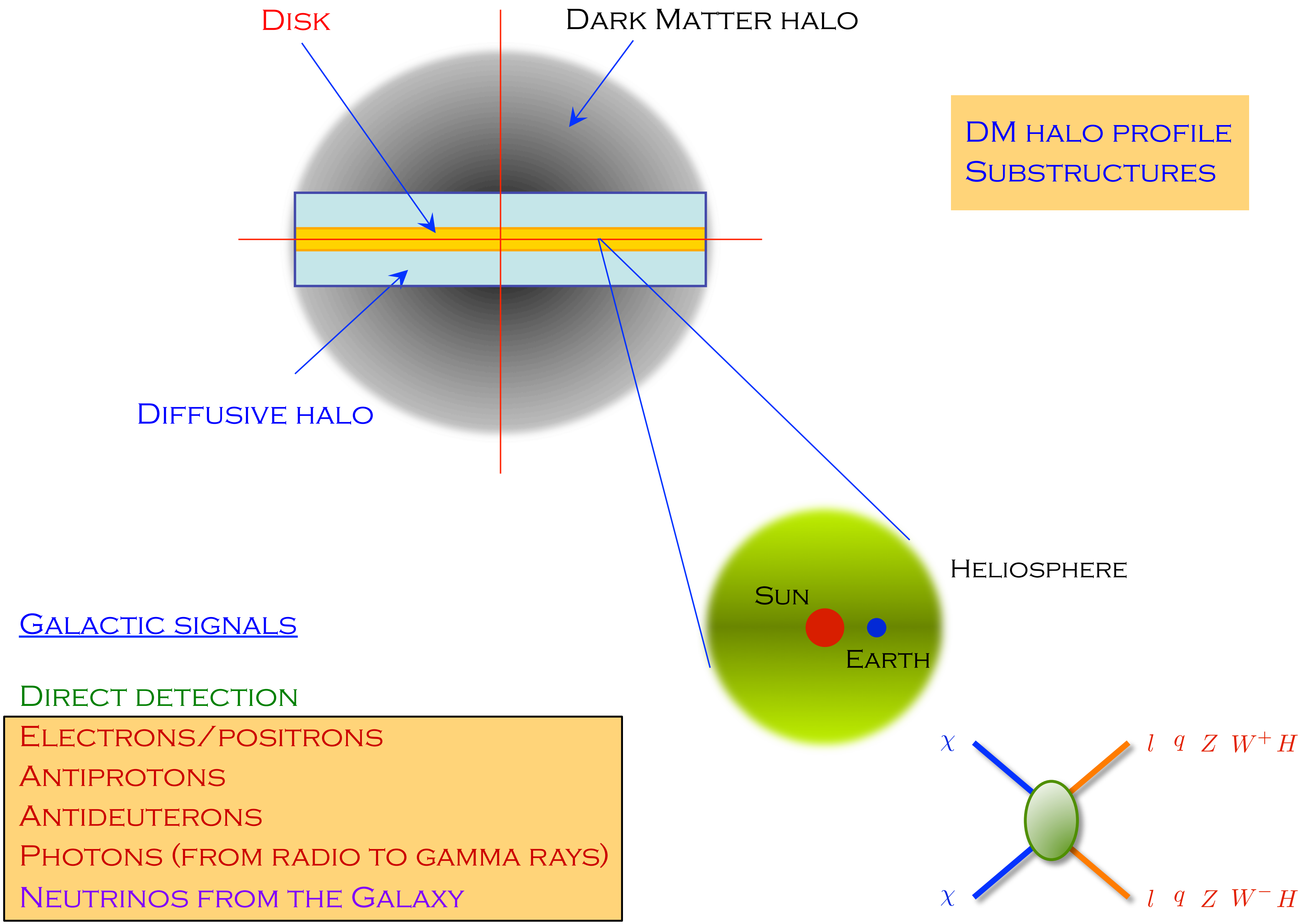
Galactic signals

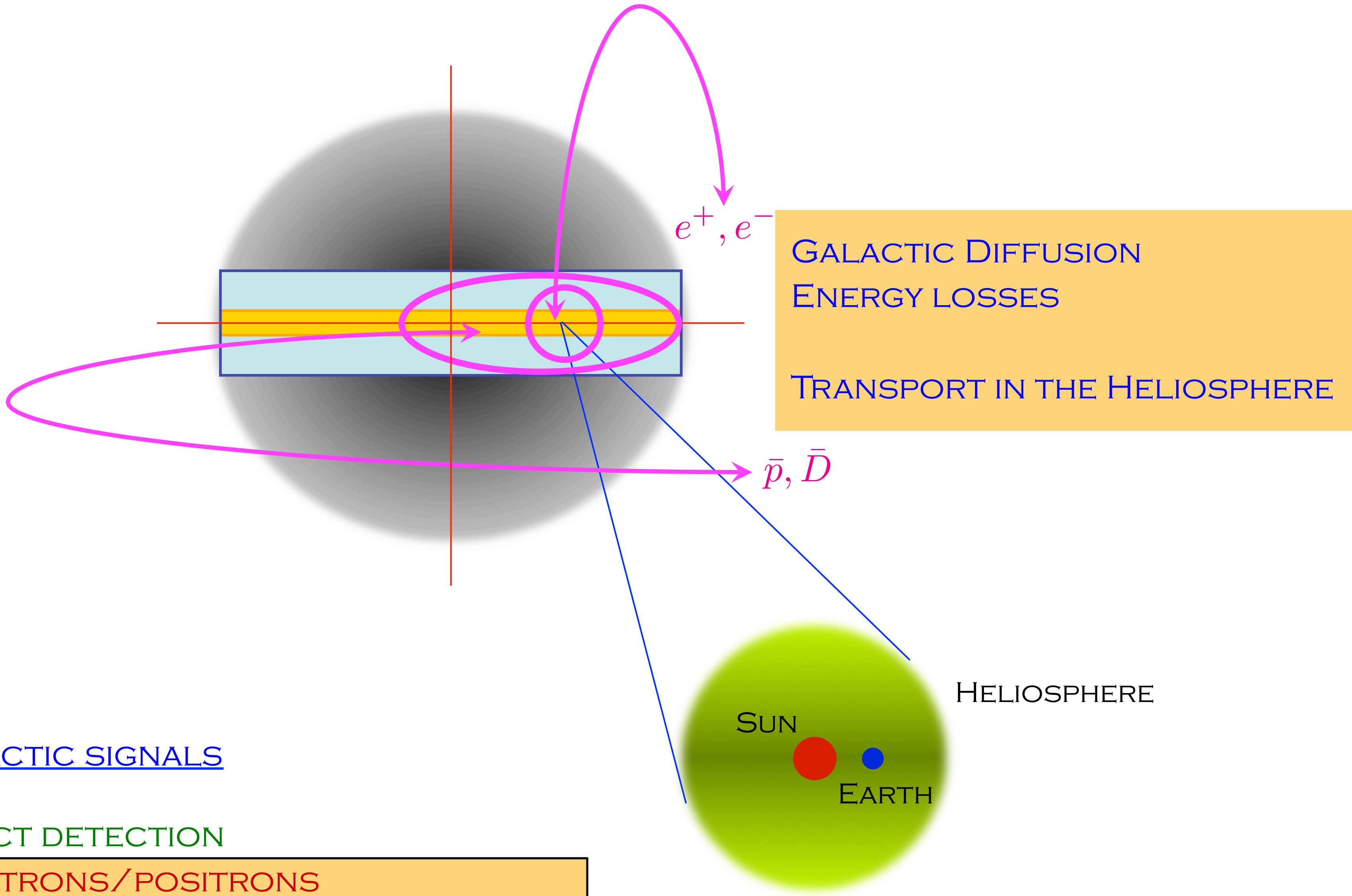
Feels ony the local DM density (not space distribution)

Feels (somehow) how DM is locally distributed in velocity space



Neutrinos from Earth and Sun


Disk
Dark Matter halo
DM halo profile
Substructures
Diffusive halo
Heliosphere
Sun
Earth
Galactic signals
Direct detection
Electrons/positrons
Antiprotons
Antideuterons
Photons (from radio to gamma rays)
Neutrinos from the Galaxy
χ
χ
$l \quad q \quad Z \quad W^+ \, H$
$l \quad q \quad Z \quad W^- \, H$



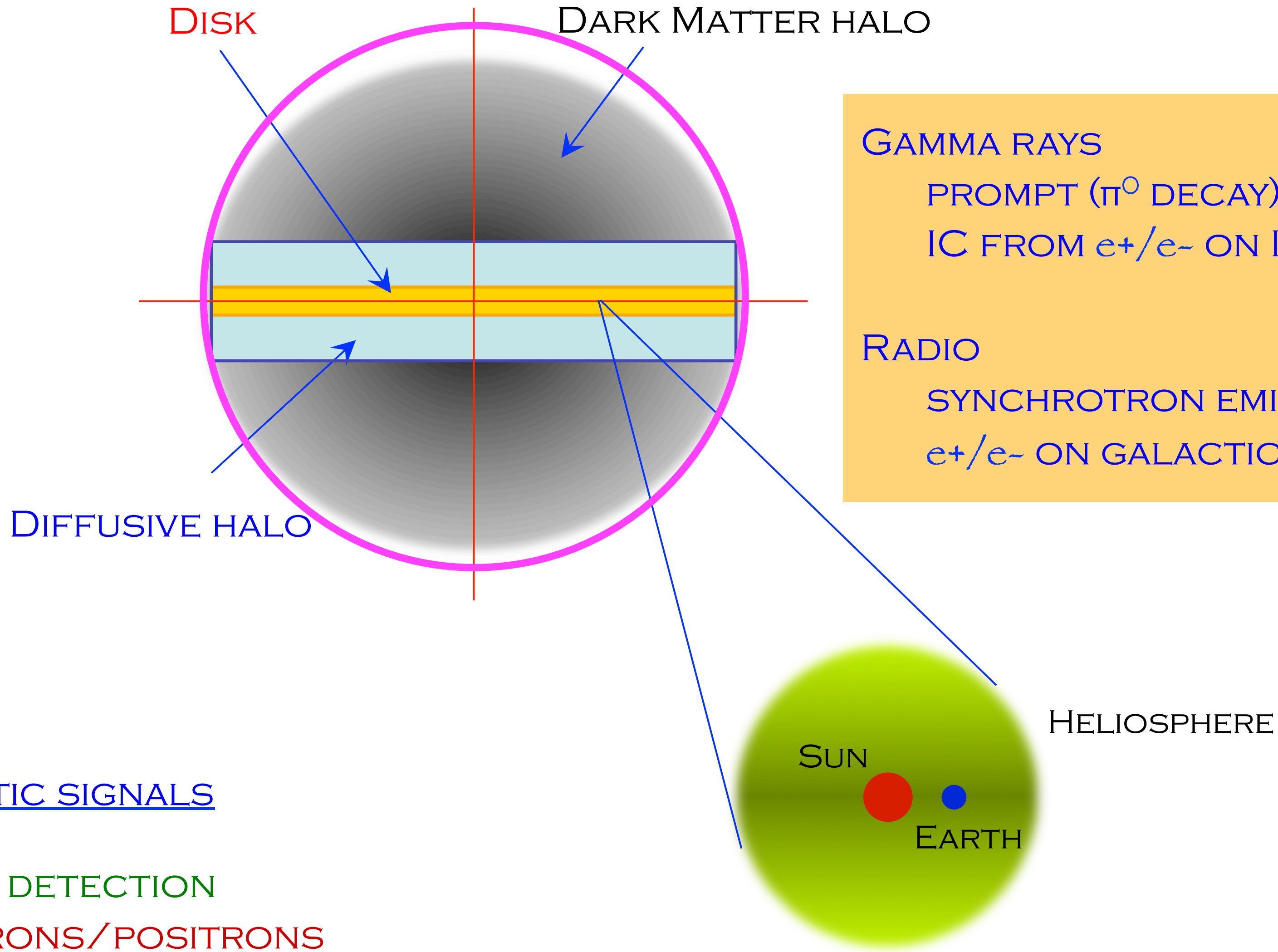
Galactic signals

Direct detection

Electrons/positrons
Antiprotons
Antideuterons

Photons (from radio to gamma rays)

Neutrinos from the Galaxy



Gamma rays

prompt (π^0 decay)

IC from $e+/e-$ on ISRF

Radio

synchrotron emission from $e+/e-$ on galactic B

Galactic signals

Direct detection

Electrons/positrons

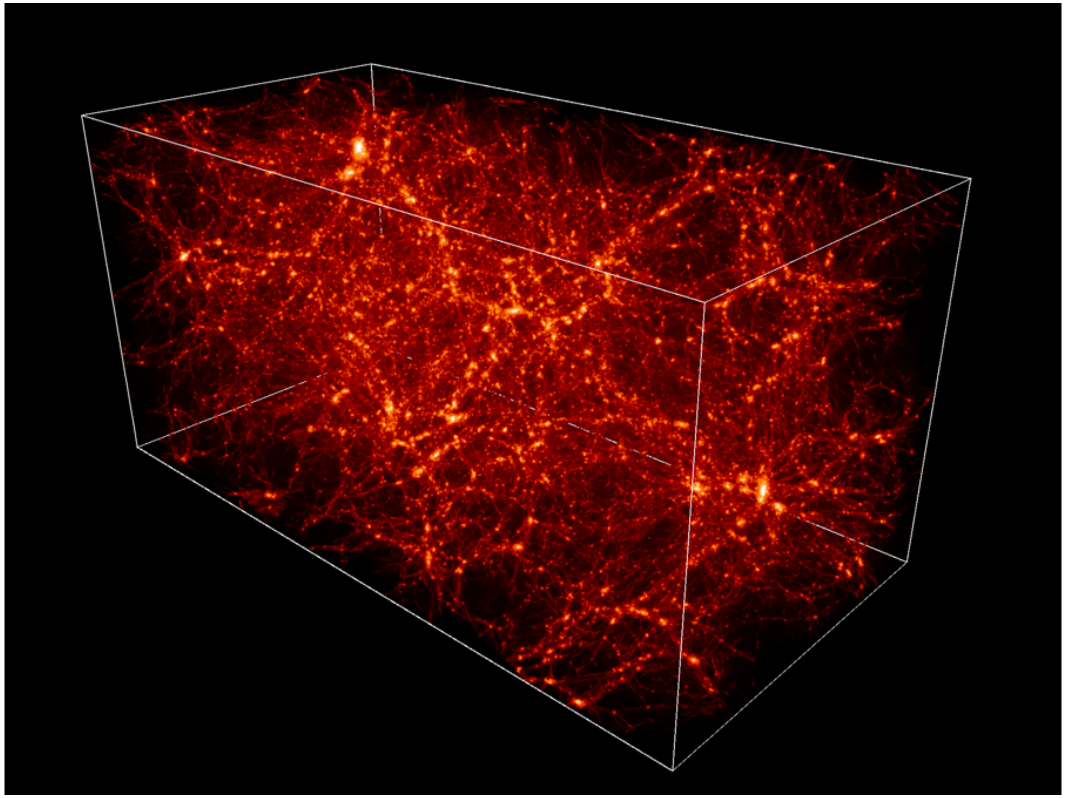
Antiprotons

Antideuterons

Photons (from radio to gamma rays)

Neutrinos from the Galaxy

Extragalactic/cosmological signals



Extragalactic signals

Photons: gamma, X, radio

Neutrinos

Sunyaev-Zeldovich effect on CMB

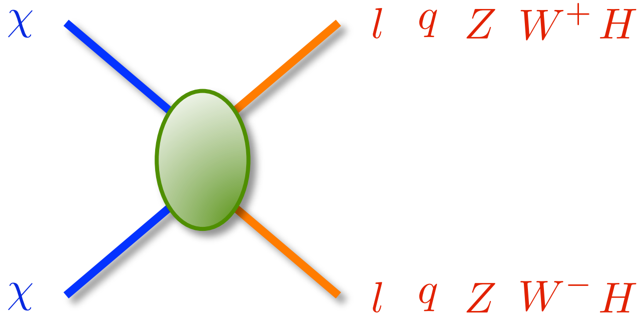
Optical depth of the Universe

Stellar physics

Effects on stellar physics

Neutron stars

Indirect astrophysical signals

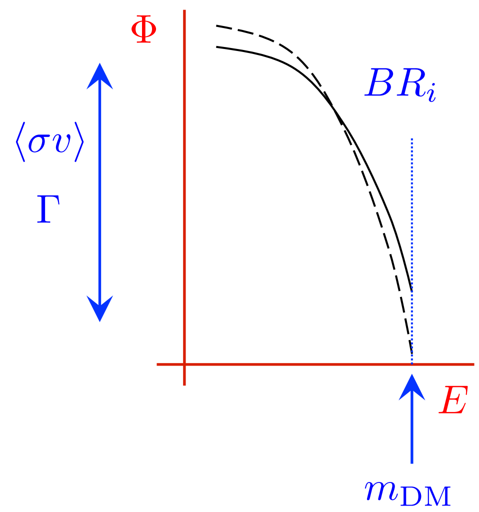


Annihilation (or decay)

Relevant particle physics properties:

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

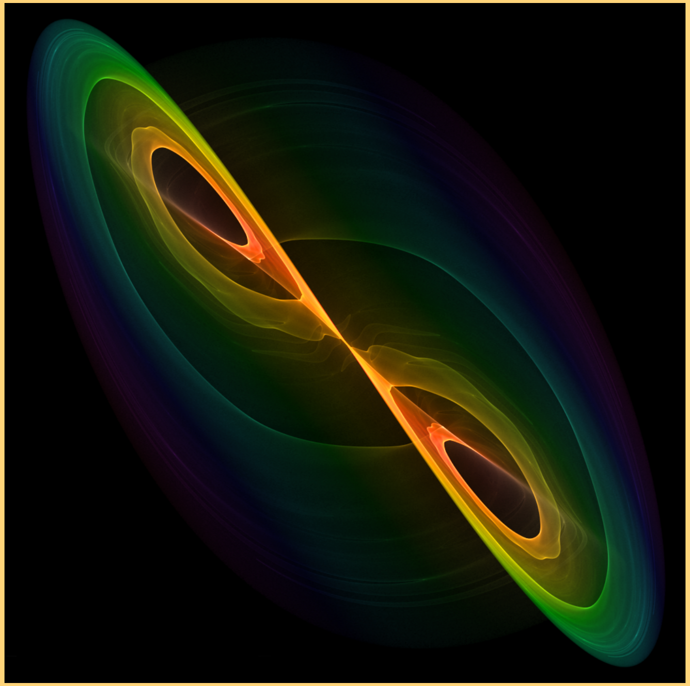
1 + 2 : Size of the signal
2 + 3 : Spectral features



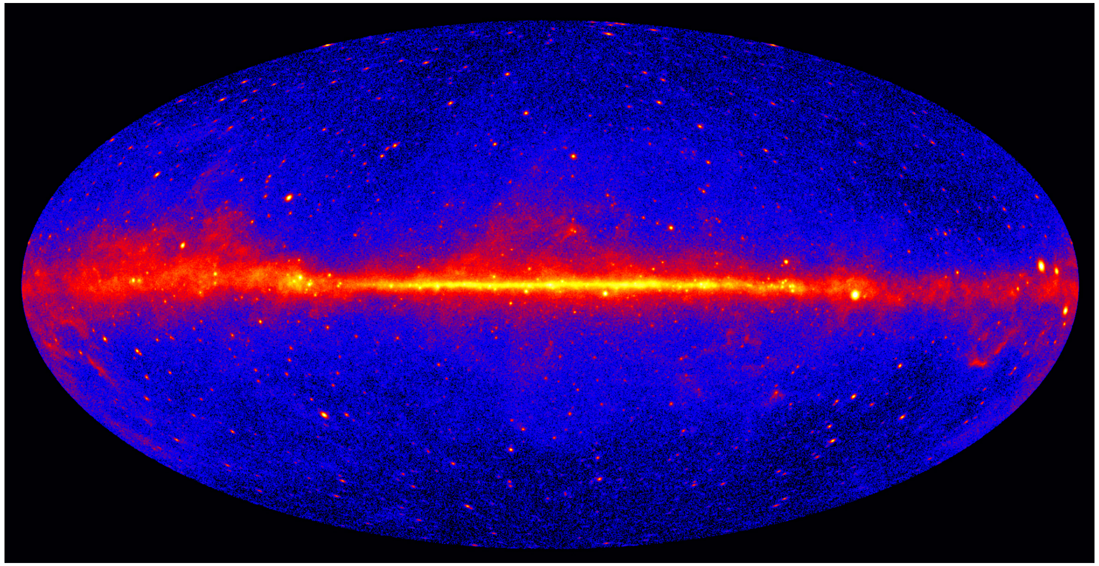
(*) Determines also the cosmological relic abundance (for a thermal DM)

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

Flux/Intensity searches

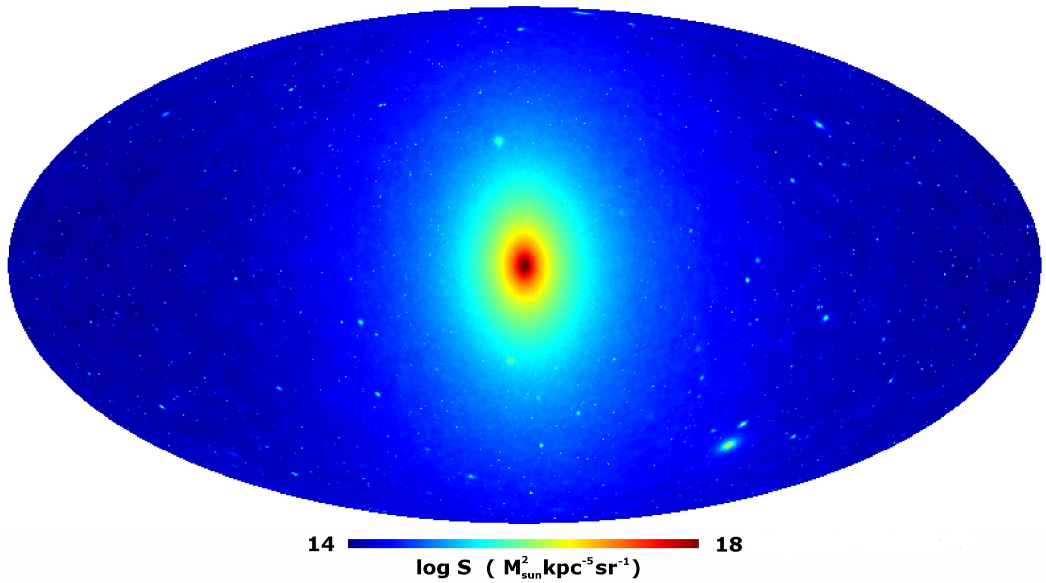


Gamma-rays sky

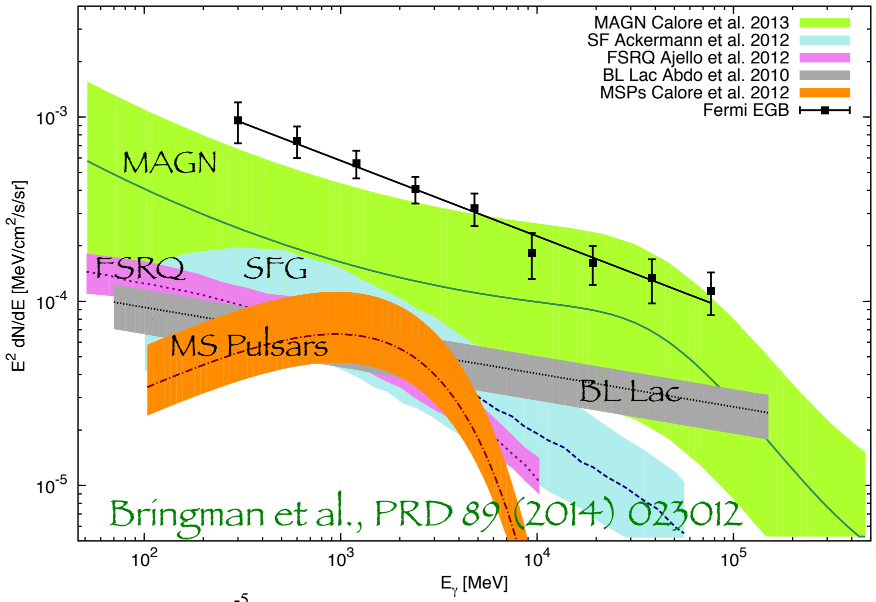


Fermi/LAT
Photon energies: E > 1 GeV
Observation time: 5 yrs

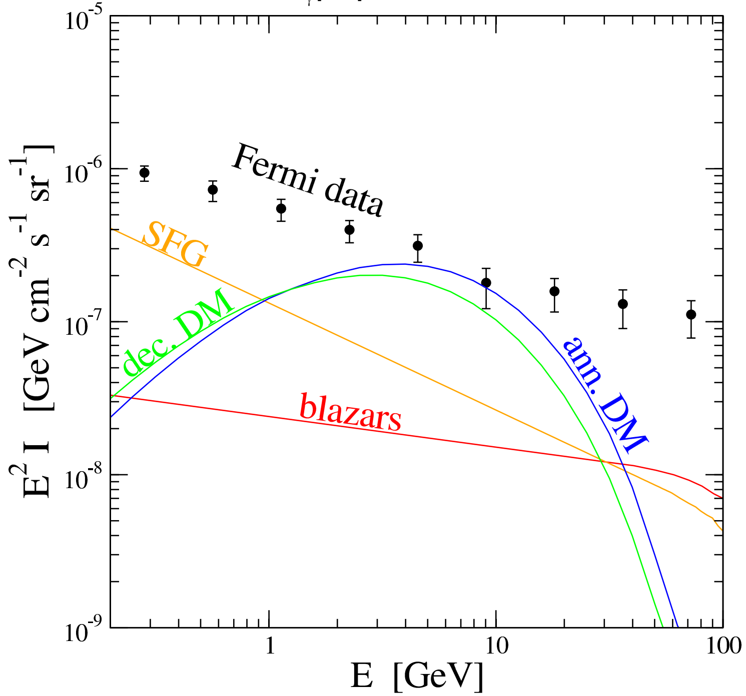
N-body Aquarius simulation



Gamma-rays intensity



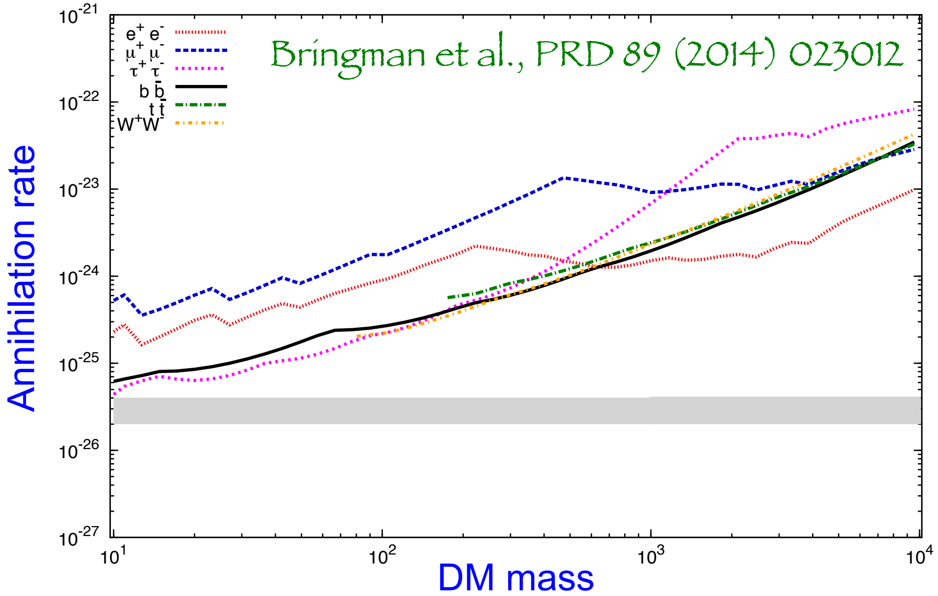
Astrophysical contributions



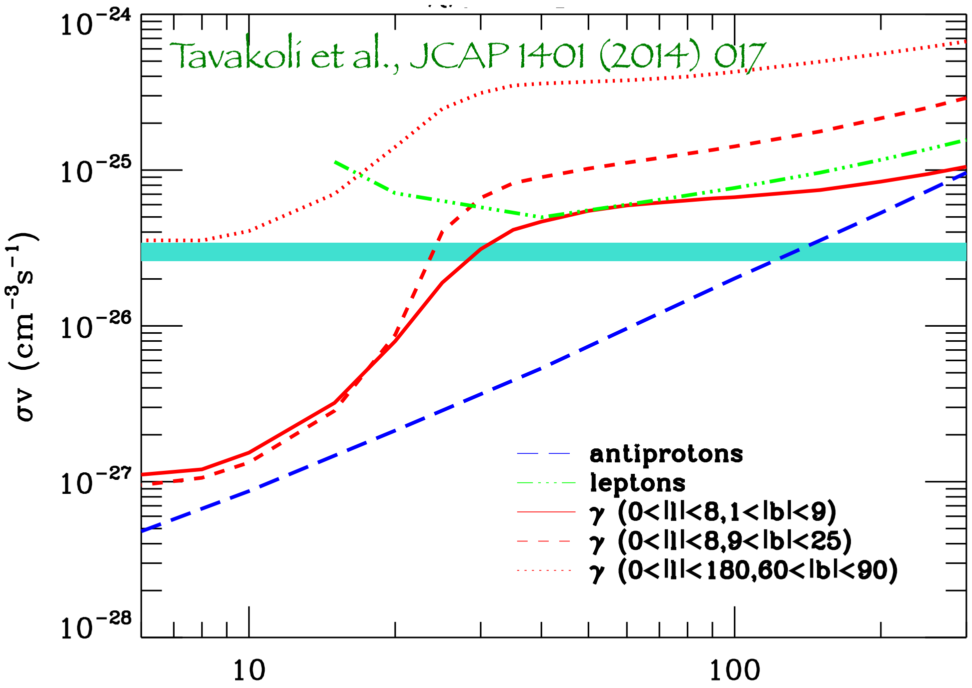
Example of DM signal

Gamma-rays: Bounds on DM annihilation

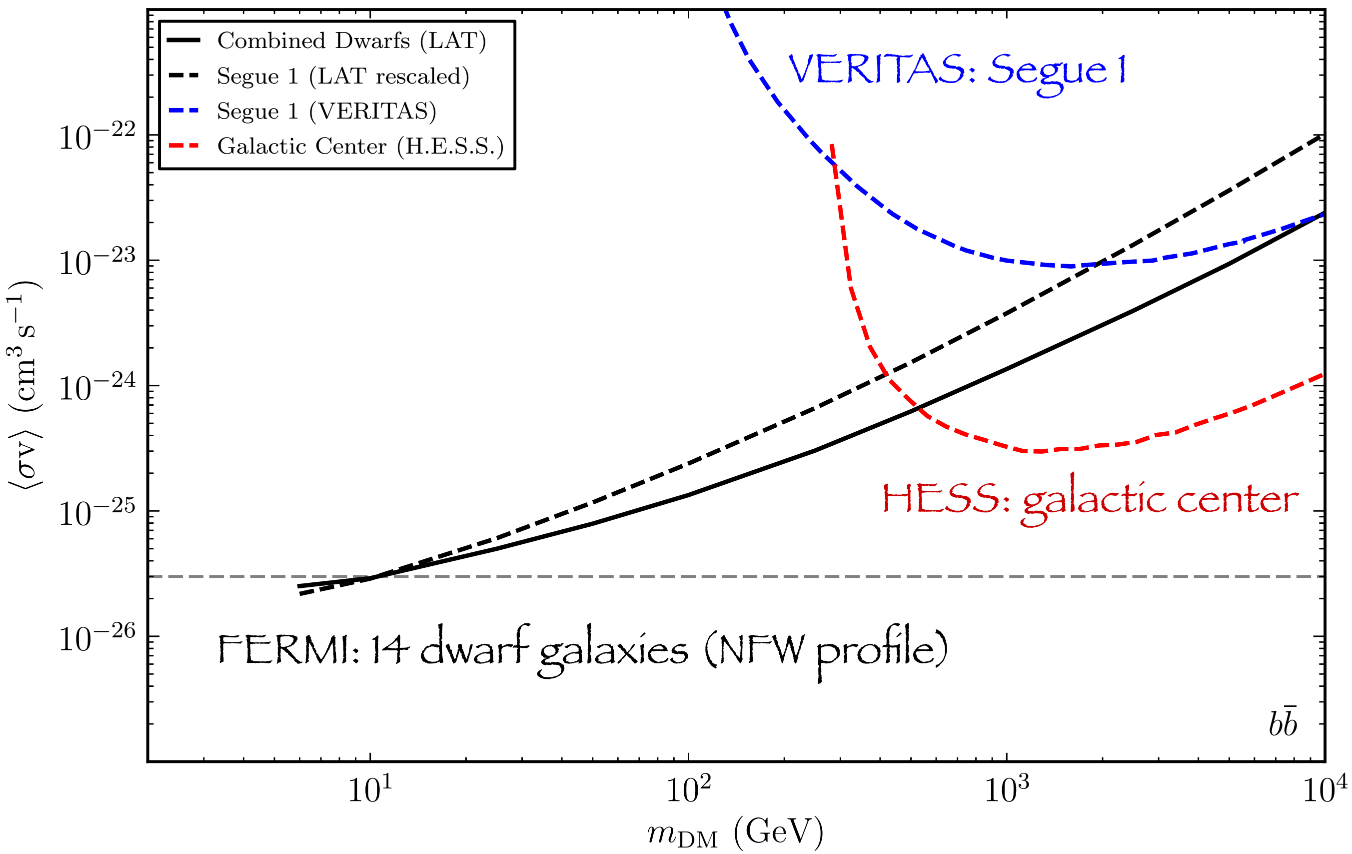
Bounds from extragalactic emission



Bounds from galactic emission

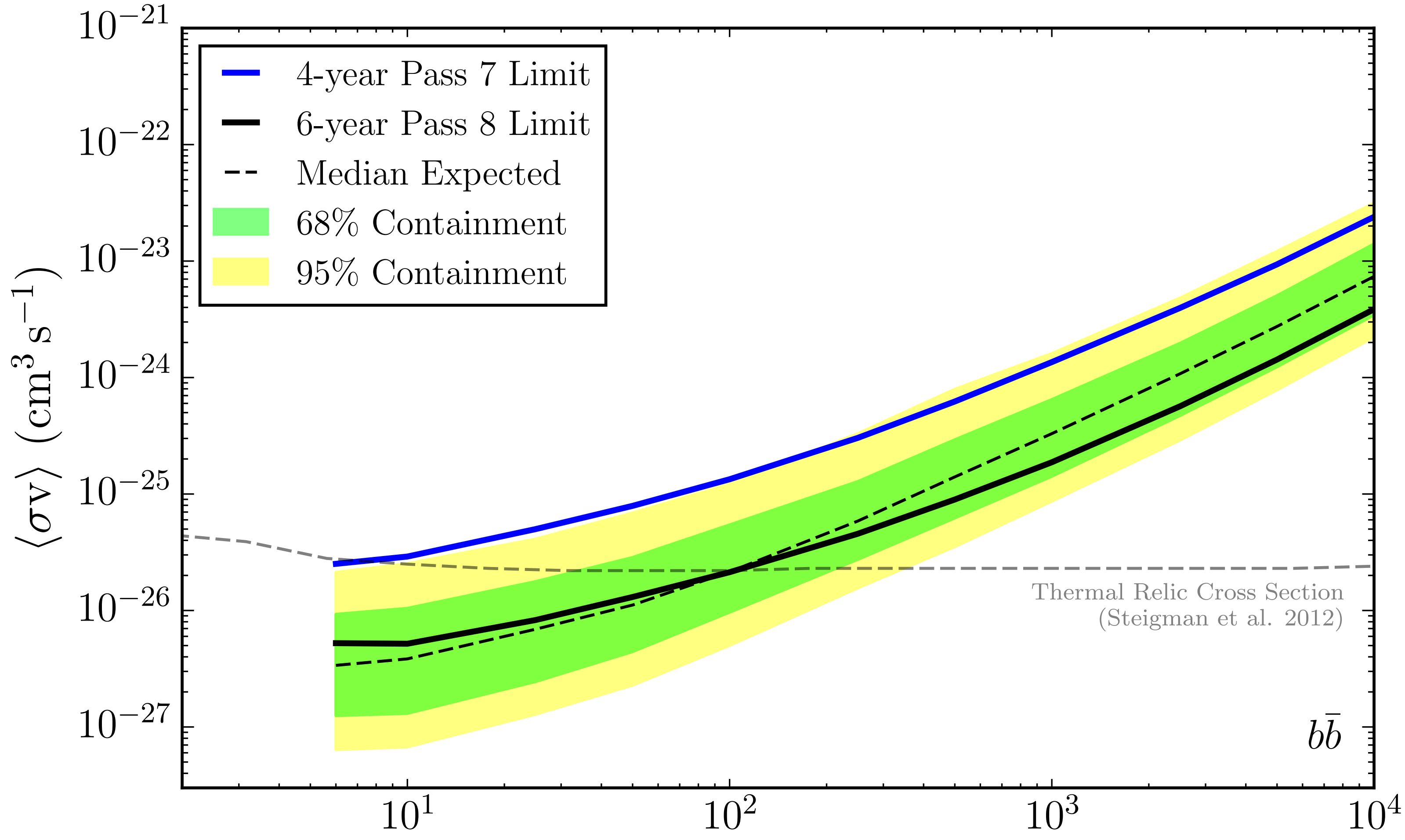


Gamma-rays: Bounds from specific targets



Ackermann et al. (FERMI), PRD 89 (2014) 042001
Alu et al. (VERITAS), PRD 85 (2012) 062001
Abramovski et al. (HESS), PRL 106 (2011) 161301

Dwarf galaxies

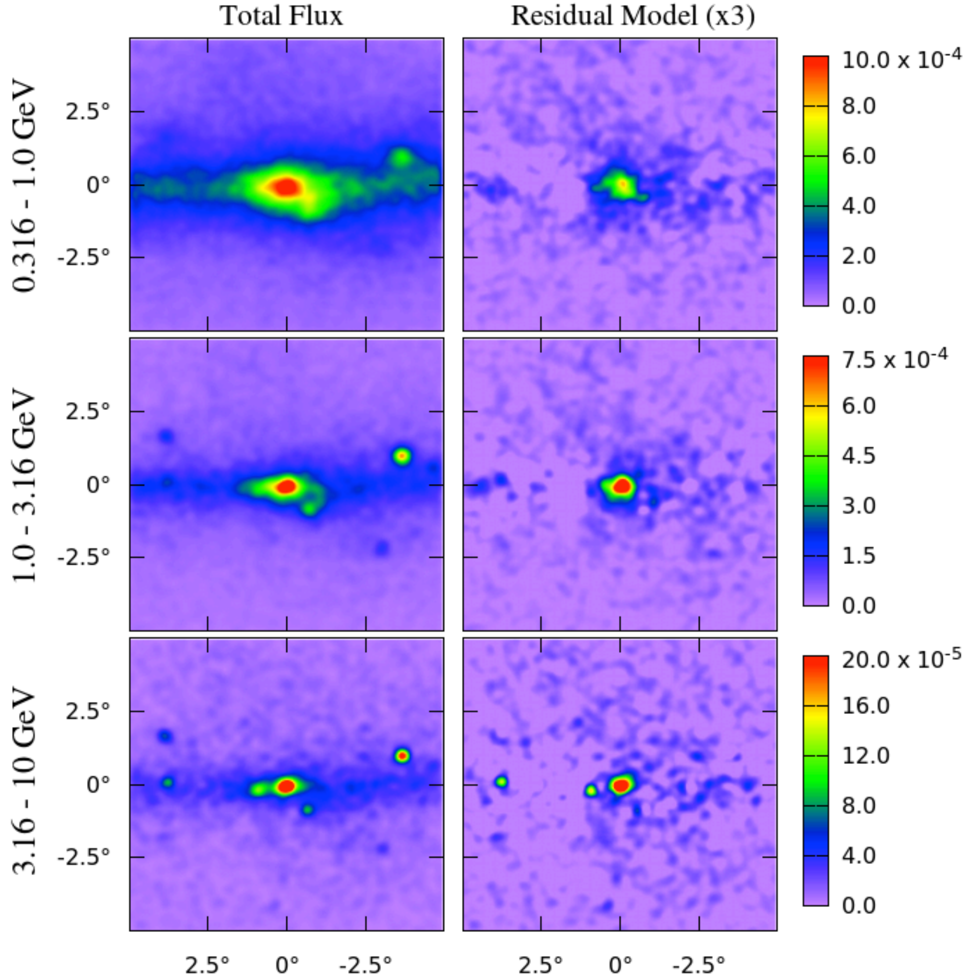


Ackermann et al. (Fermi Collab.), arXiv:1503.02641

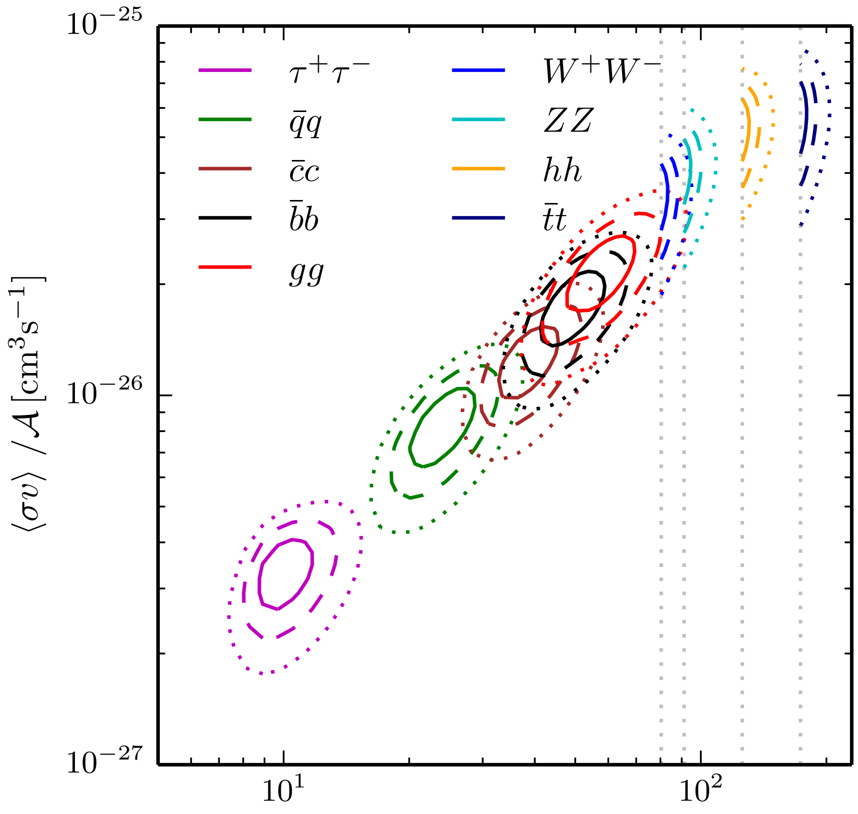
Some potential hints in gamma-rays

Hooper, Goodenough, PLB (2011) 697 (2011)
Hooper, Linden, PRD 84 (2011) 123005
Boyarsky et al., PLB (2011) 705
Daylan et al., arXiv:1402.6703
Abazajian et al., arXiv 1402.4090
Lacroix, Boehm, Silk, arXiv: 1403.1987

- Fermi/LAT excess(es) at the galactic center
  - Compatible to "10 GeV" DM



Daylan et al., arXiv:1402.6703



Calore et al. PRD 91 (2015) 063003

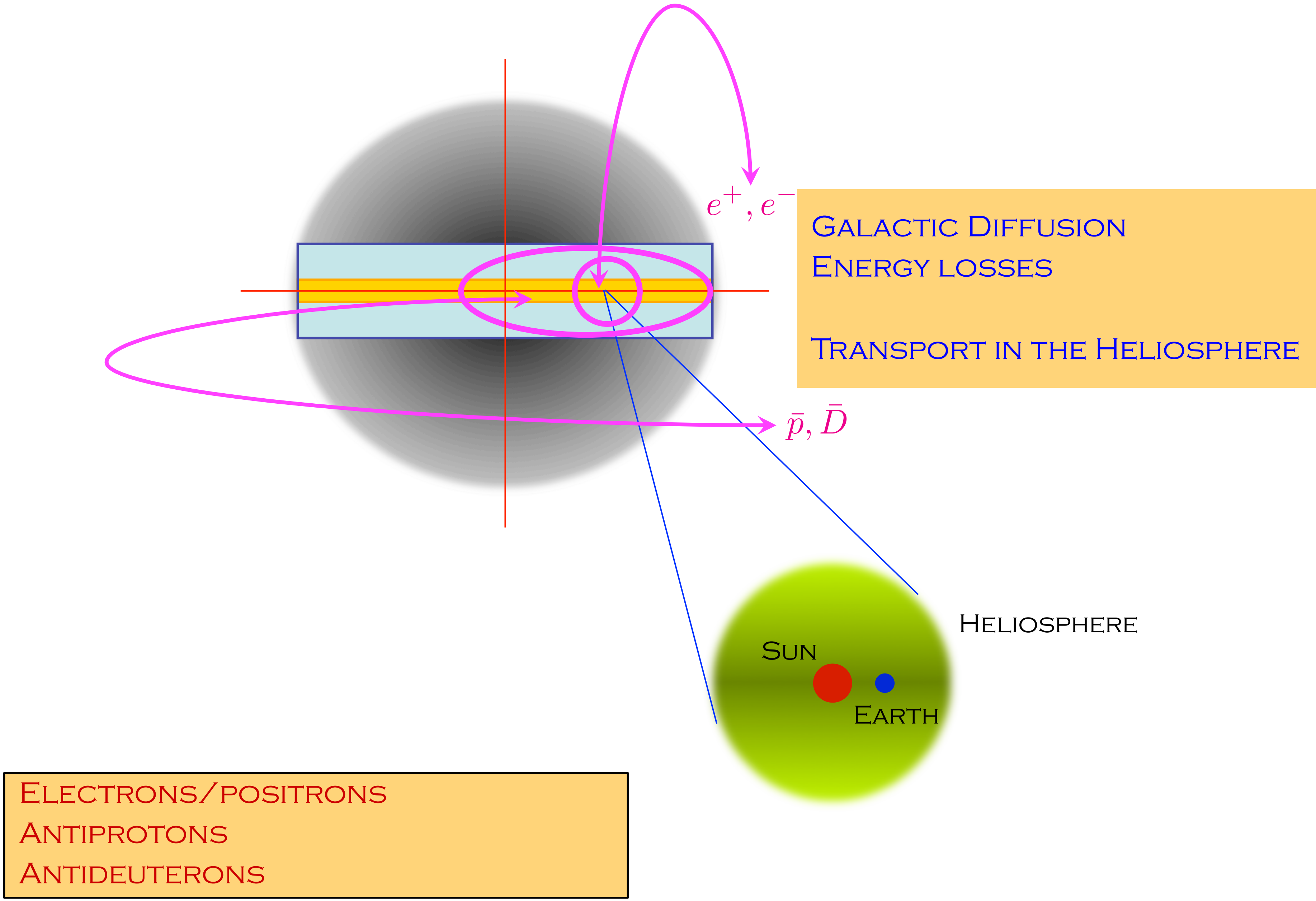
Some potential hints in gamma-rays

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

- Extended gamma-ray emission from the Virgo, Fornax and Coma
  - Weak hint, cosmic rays can account for it although with lower significance than DM

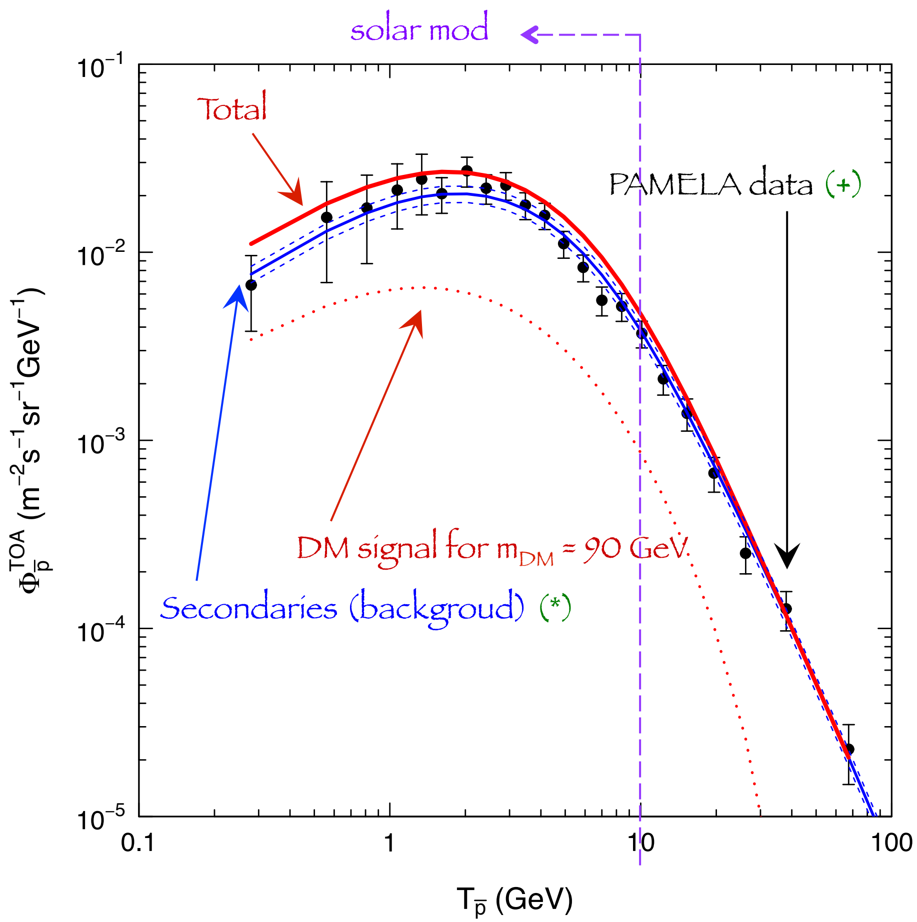
Zechlin, Horns, JCAP 2011(2012) 050
Berlin, Hooper, PRD 89 (2014) 016014

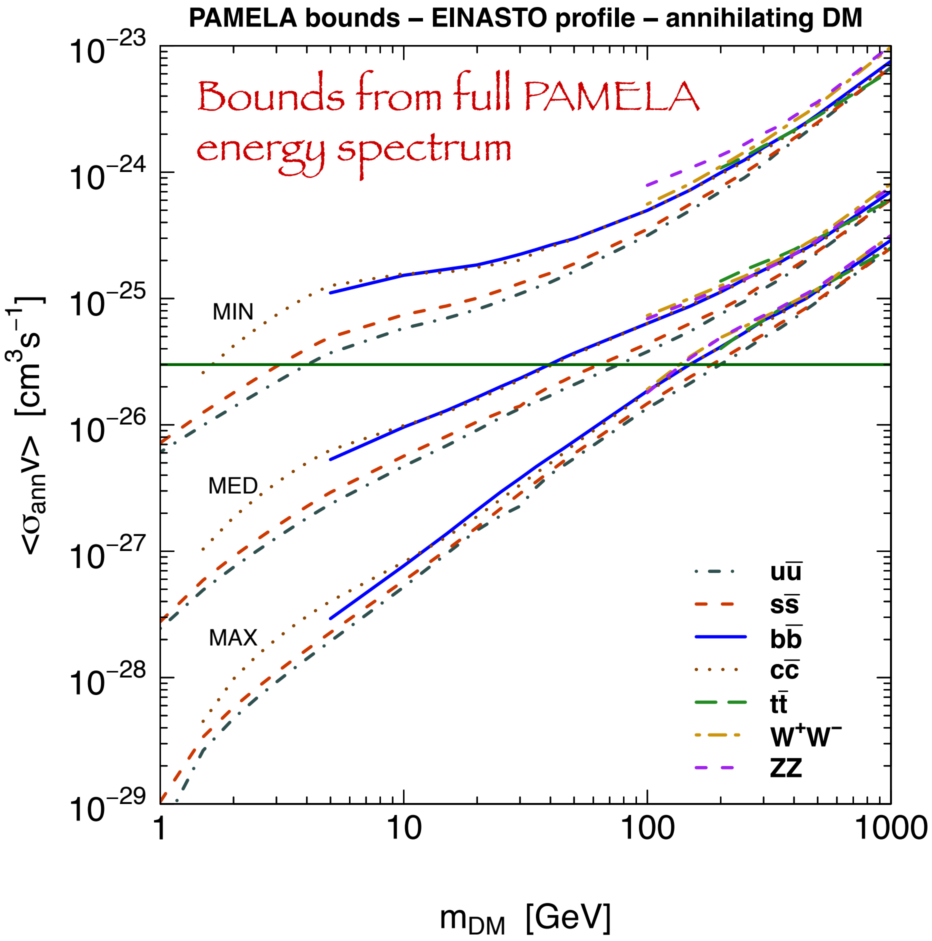
- Unidentified Fermi Objects
  - 30% of detected gamma-rays sources in Fermi catalog are unidentified: DM clumps?
  - Some potential candidates, although possible association at other wavelengths



e^+, e^-
Galactic Diffusion
Energy losses
Transport in the Heliosphere
$\bar{p}, \bar{D}$
Heliosphere
Sun
Earth
Electrons/positrons
Antiprotons
Antideuterons

Antiprotons: (currently) a channel for bounds

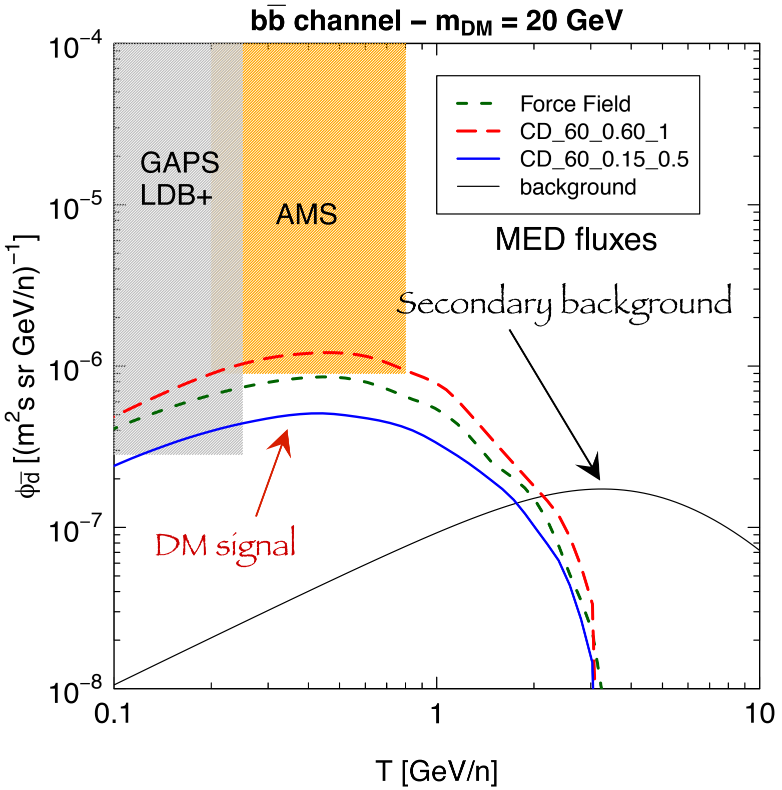


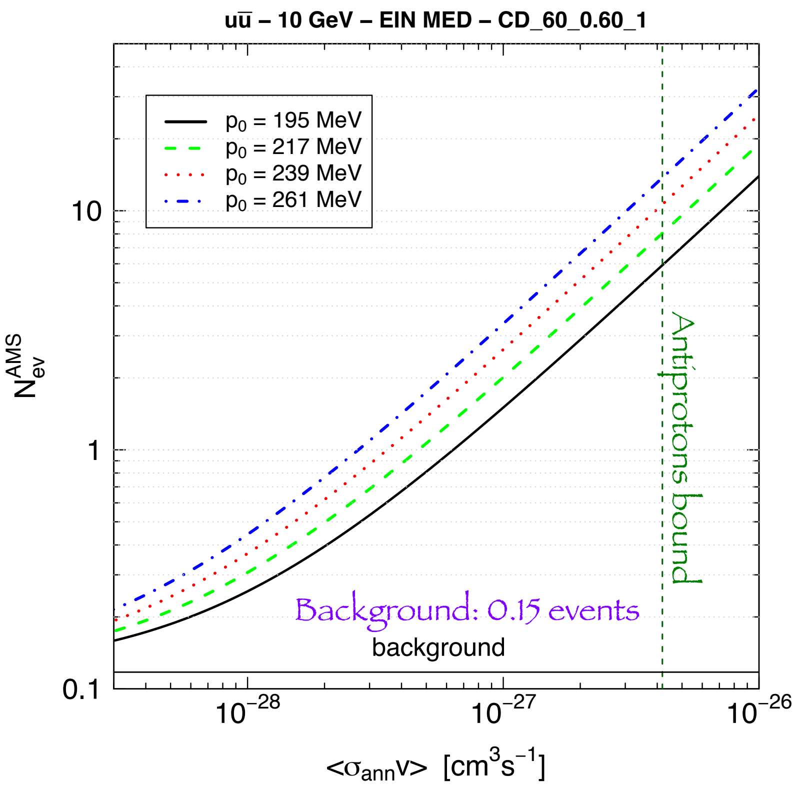


(*) Donato et al, PRL 102 (2009) 071301
(+) Adriani et al. (PAMELA Collab.), PRL 105 (2010) 121101

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

Antideuterons: a channel for signal discovery





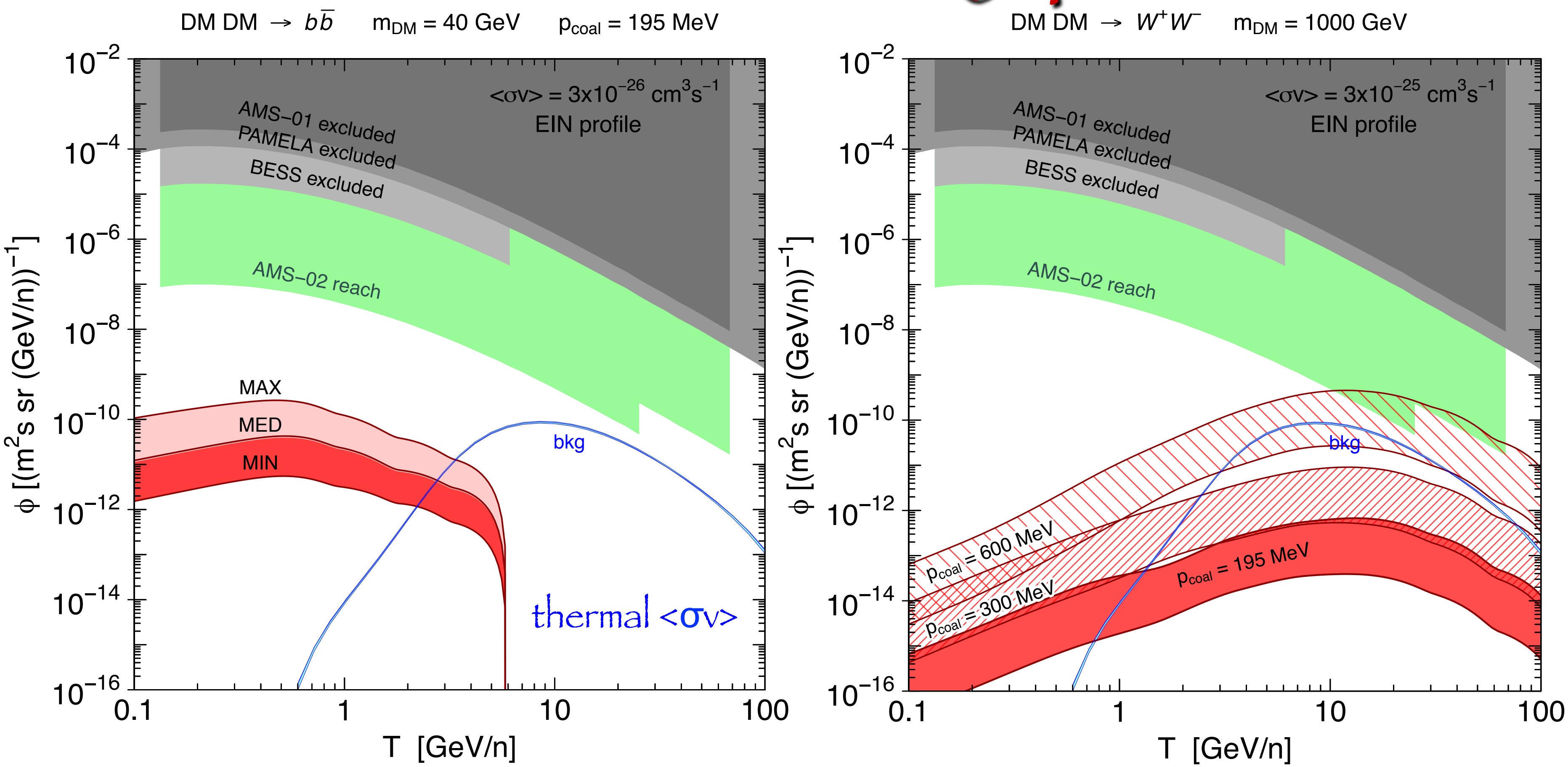
DM configurations allowed by antiproton bounds

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

Expected number of events for AMS nominal sensitivity

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

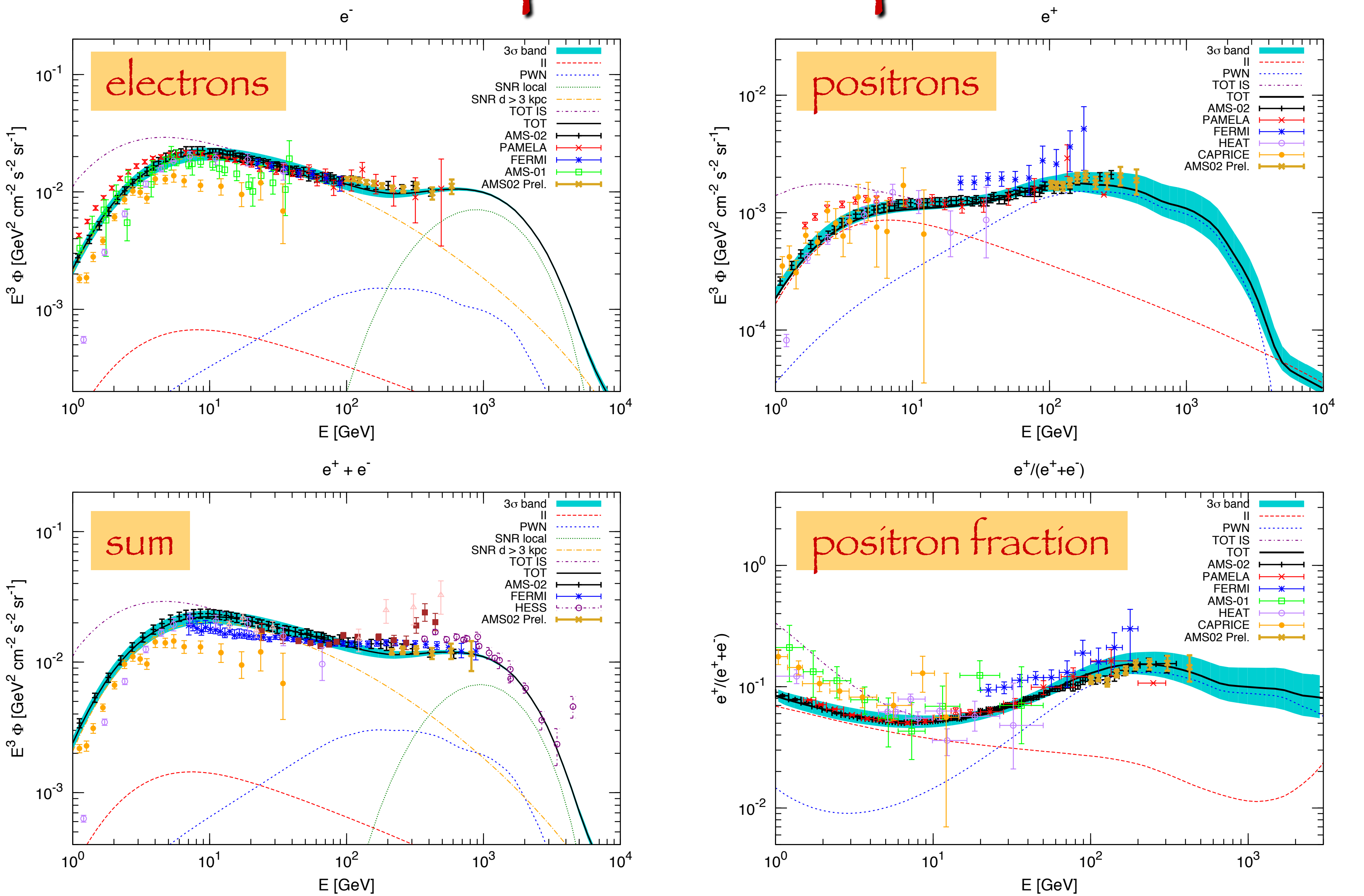
Anti ^{3}Helium: currently quite far



Light red: DM configurations disfavoured by antiproton bounds

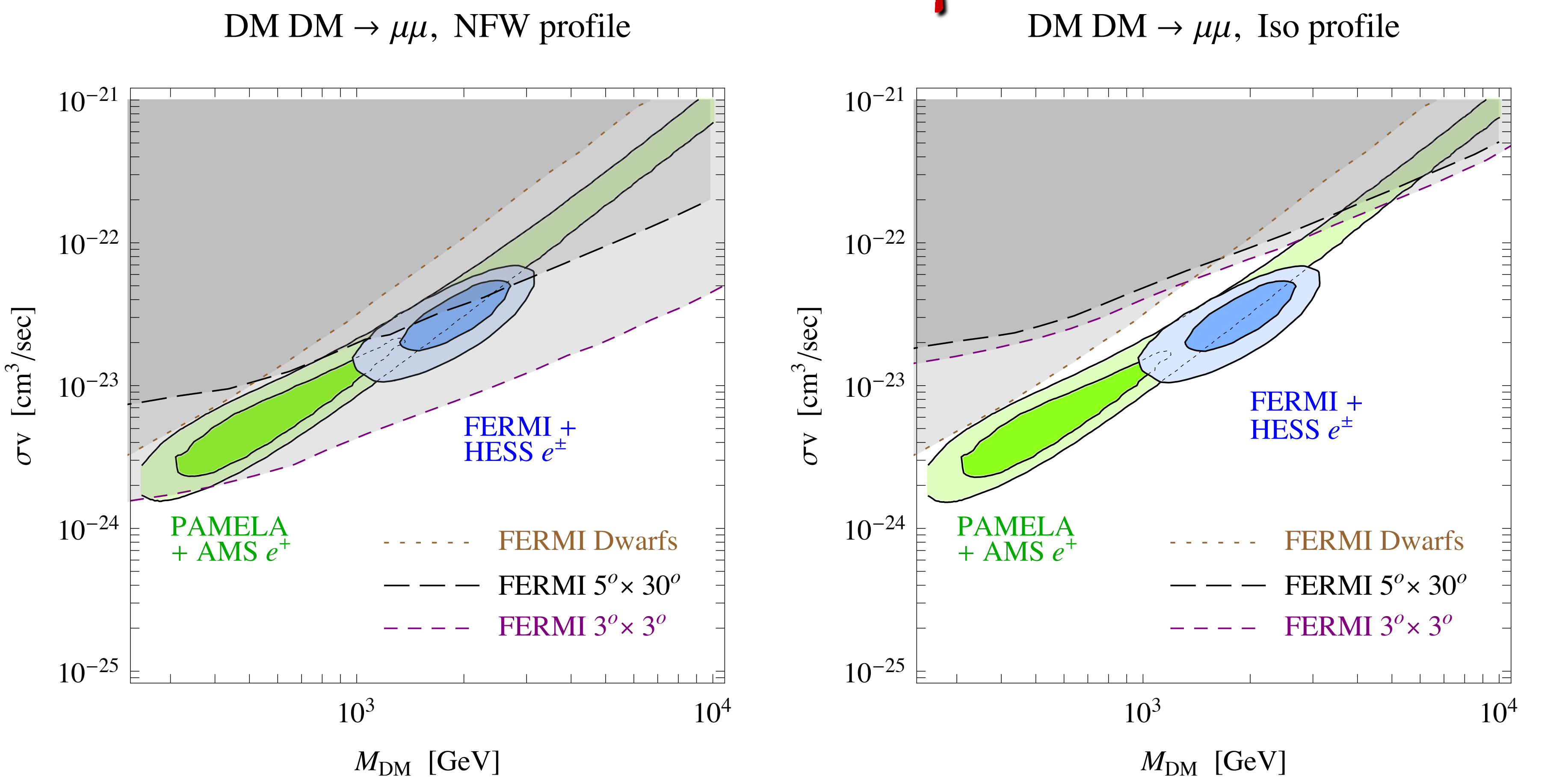
Cirelli, NF, Taoso, Vittino, JHEP 1408 (2014) 009
See also: Carlson, Coogan, Linden, Profumo, Ibarra, Wild, PRD 89 (2014) 076005

Positrons: pulsars interpretation



Di Mauro, Donato, NF, Lineros, Vittino, JCAP 1404 (2014) 006

Positrons: DM interpretation



Bounds from IC gamma-rays on "positive" interpretation

Cirelli, Kadastik, Raidal, Strumia, NPB813 (2009) 1
as updated in arXiv:0809.2409v5

Radio signals from dark matter

- DM annihilation into e+/e- produces radio signals by synchrotron emission in galactic/extragalactic magnetic fields

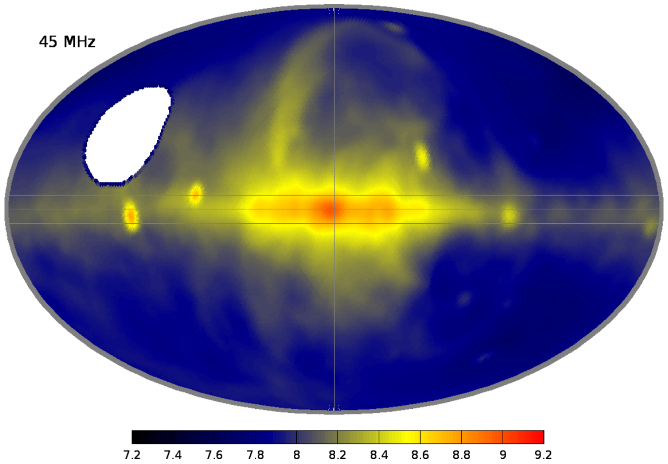
- Emission in the MHz-GHz frequency range occurs for:
  - Electrons/positrons energies in the GeV-TeV range (*)
  - Magnetic fields of the order of microG

$$\nu_{\rm GHz} \sim B_{\mu {\rm G}} \left(\frac{E}{15\,{\rm GeV}} \right)^2$$

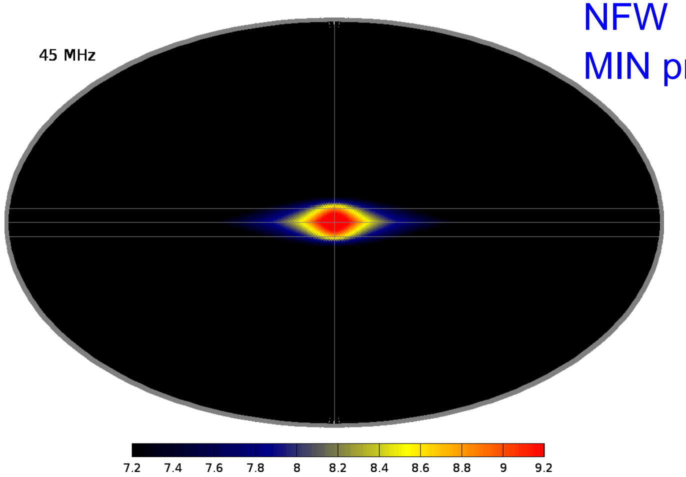
(*) Relevant interval for WIMP DM in the GeV-TeV mass range

Morphology of radio sky at 45 MHz

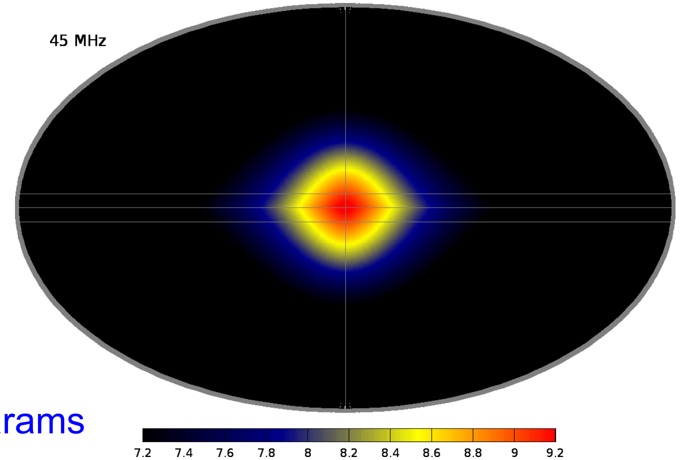
observed



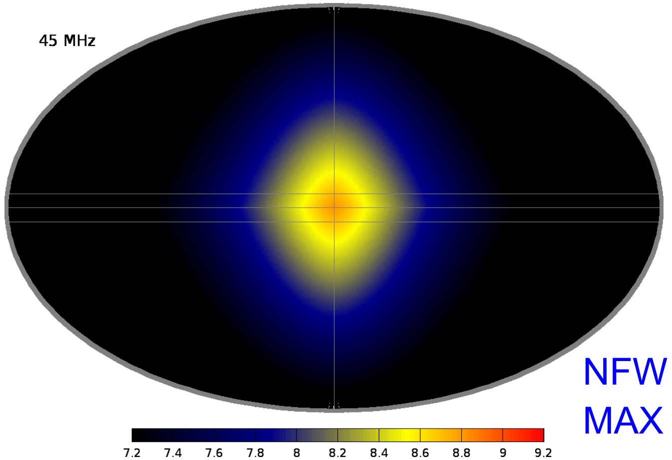
NFW
MIN propag params



NF, Lineros, Regís, Taoso, JCAP 01 (2012) 005 [arXiv:pa]



NFW
MED propag params

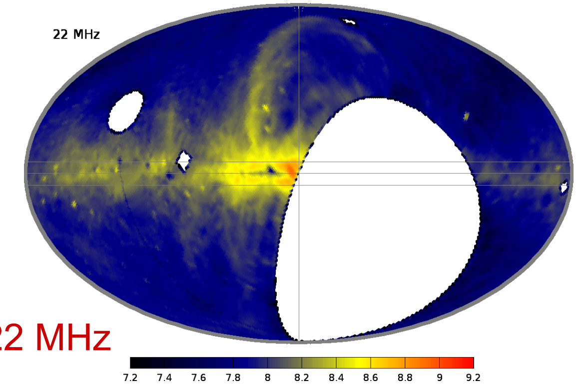


NFW
MAX propag params

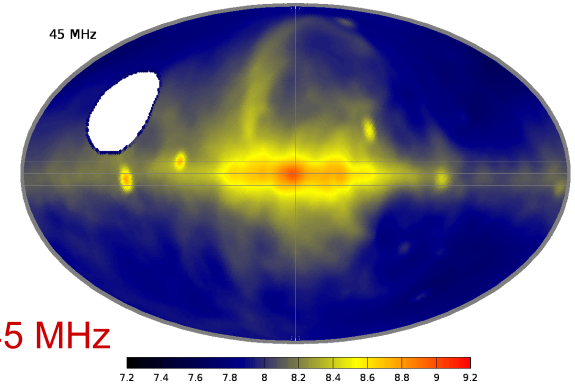
10 GeV DM
Annihilation into muon with thermal cross section
Exp decaying B(r,z) with B_{TOT} = 6 microG (GMF I)

NFW tuned to Via Lactea II
No substructures included

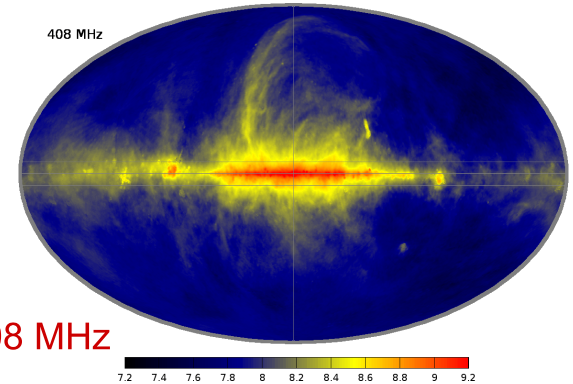
Skymaps



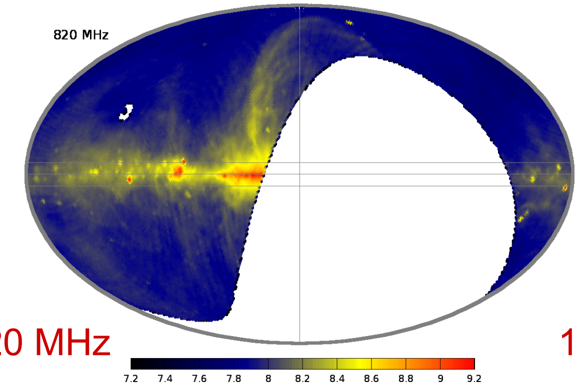
22 MHz



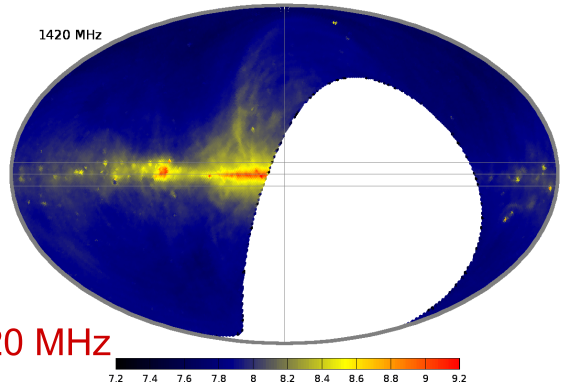
45 MHz



408 MHz

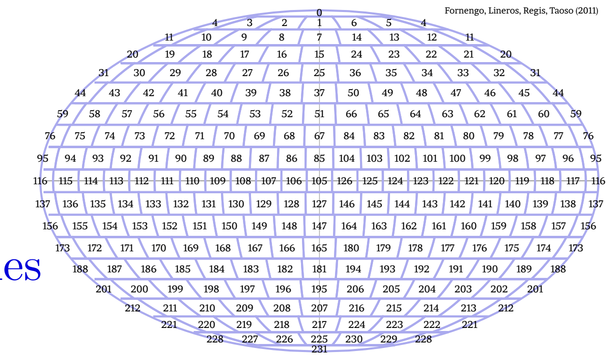


820 MHz



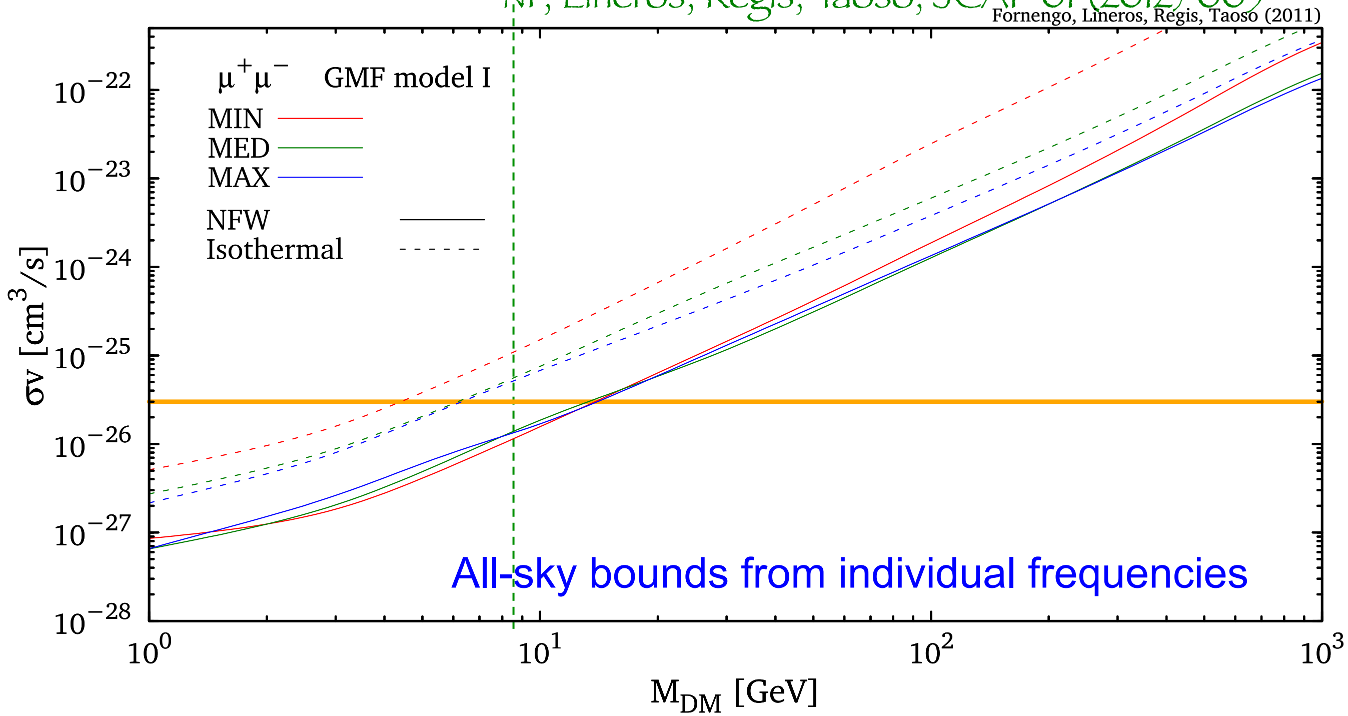
1420 MHz

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



Galactic radio signal: bounds

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



Lower frequencies better for lighter DM

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

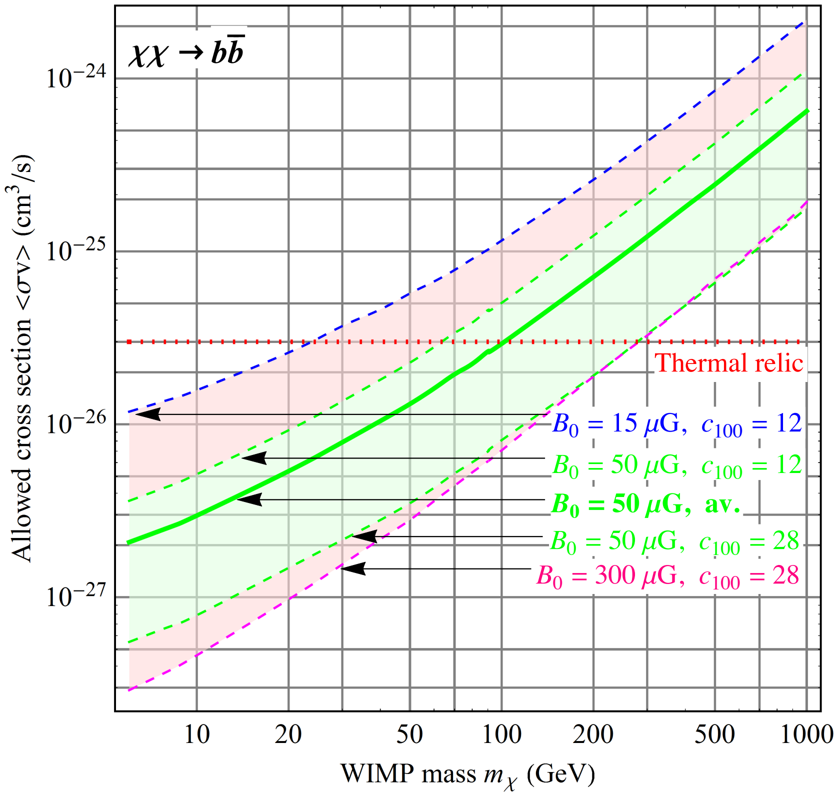
NF, Lineros, Regis, Taoso, JCAP 03 (2012) 033

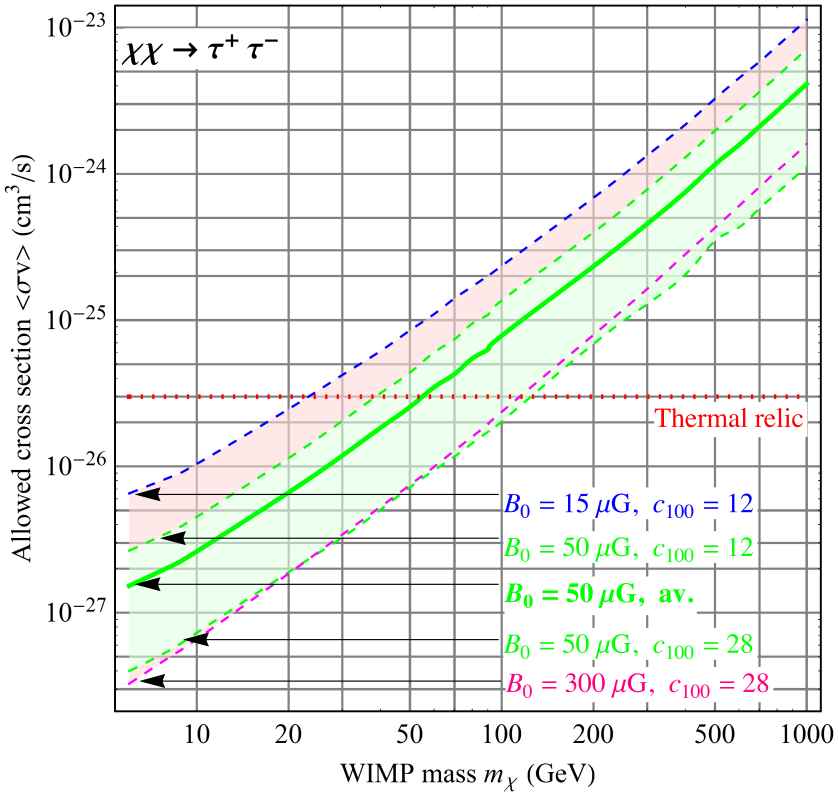
Extragalactic radio has a similar (slightly worse) constraining power (but different uncertainties in modeling)

Egorov, Pierpaoli, PRD 88 (2013) 023504

Bounds from specific target start to be competitive (dwarf galaxies; Andromeda)

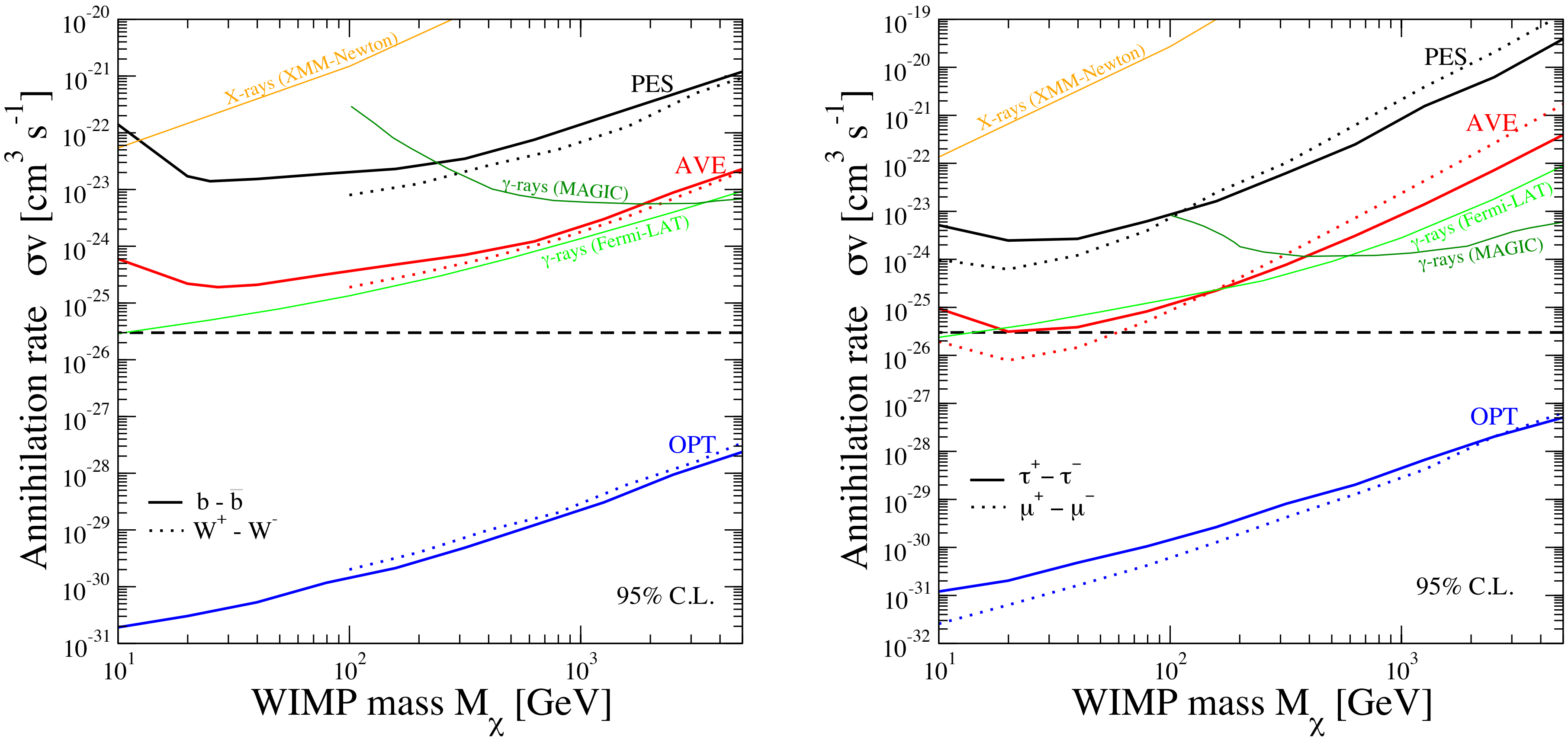
Specific target: Andromeda





Egorov and Pierpaoli, arXiv:1304.0517

Specific target: local group dSph



6 dSPh of the local group

ATCA 16 cm dedicated observation

No evidence for an extened emission

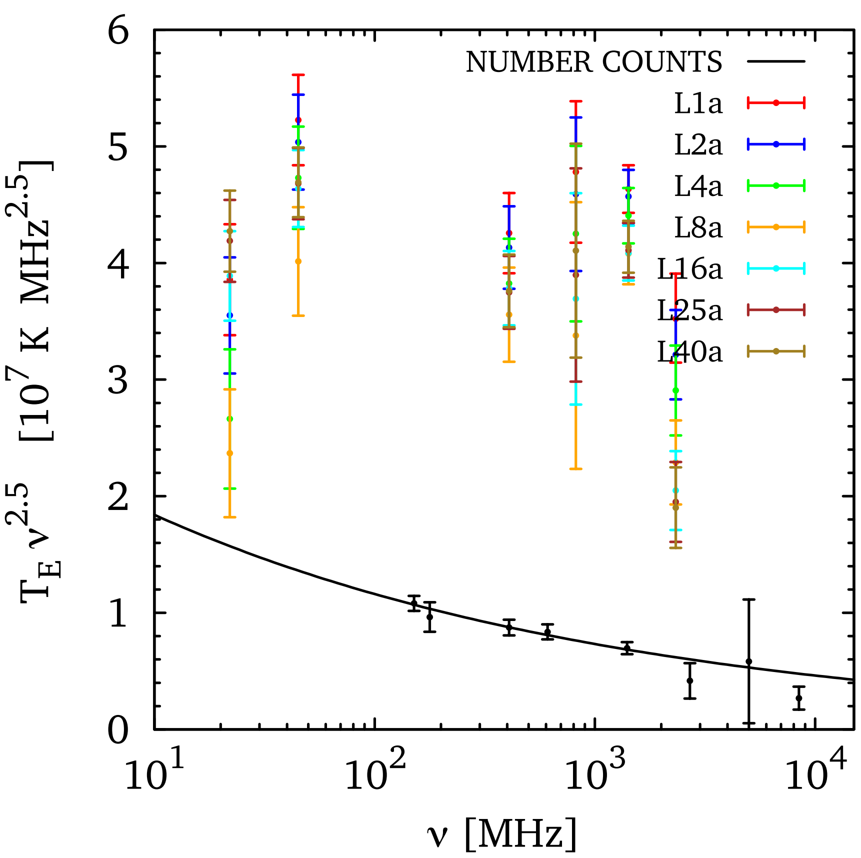
Regis, Colafrancesco, Profumo, De Blokl, Massardi, Righter, JCAP 1410 (2014) 016

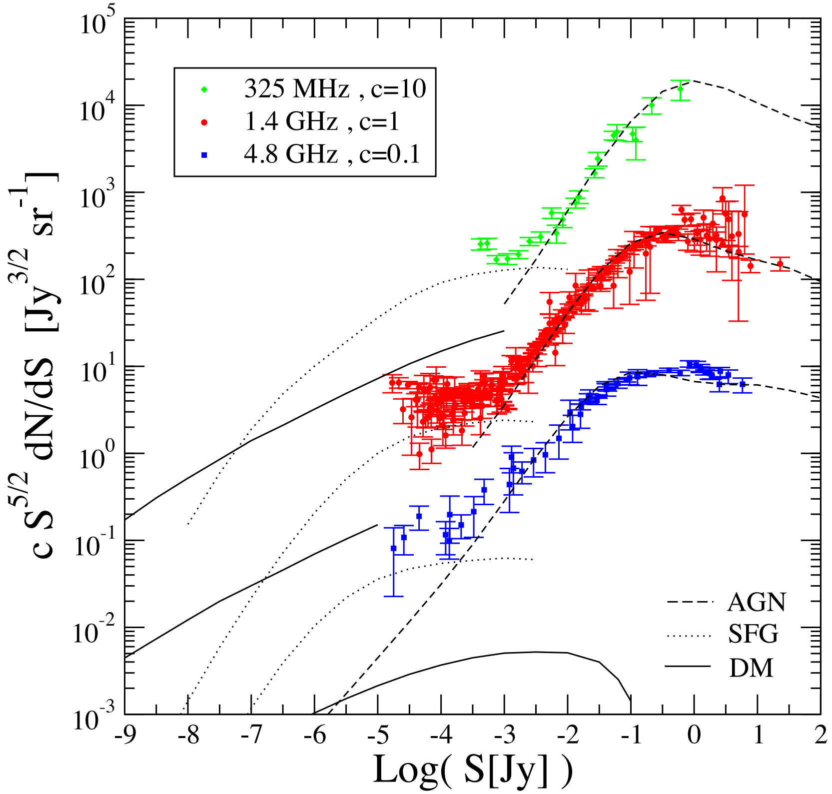
“ARCADE” excess

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

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

NF, Lineros, Regis, Taoso, JCAP 1404 (2014) 008





NF, Lineros, Regis, Taoso, PRL 107 (2011) 2727

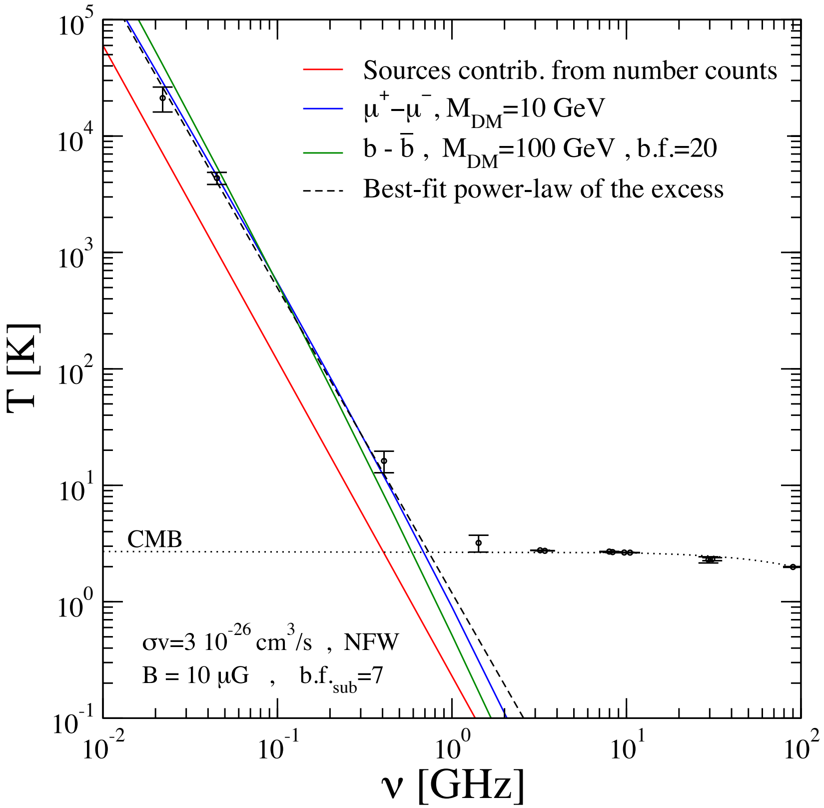
A new population of numerous and faint radio sources (able to dominate source counts around μ Jy flux) has to be introduced

“ARCADE” excess

DM can easily explain the excess without special fine tunings (currently: only viable and consistent interpretation)

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

Anistropies at high-l (*) might put the DM interpretation under deep scrutiny



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

(*) Holder, ApJ 780 (2014) 112

Beyond intensity: the anisotropic sky

Features of the multiwavelength DM signals

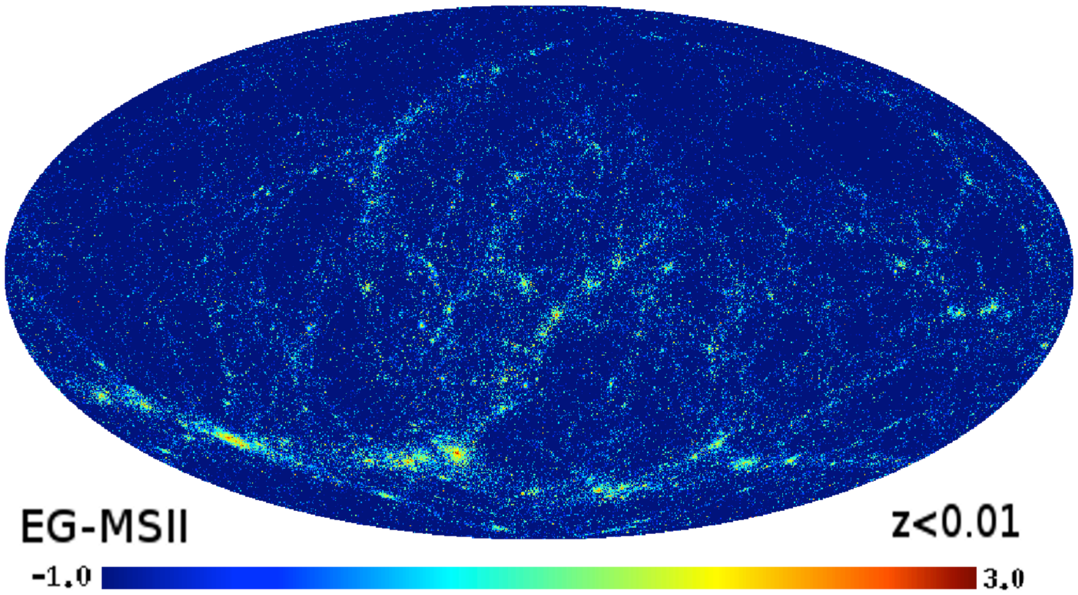
- Sources of DM signals are:
  - Faint
  - Very numerous

- The cumulative emission from these unresolved sources produces a nearly "isotropic" component, but …

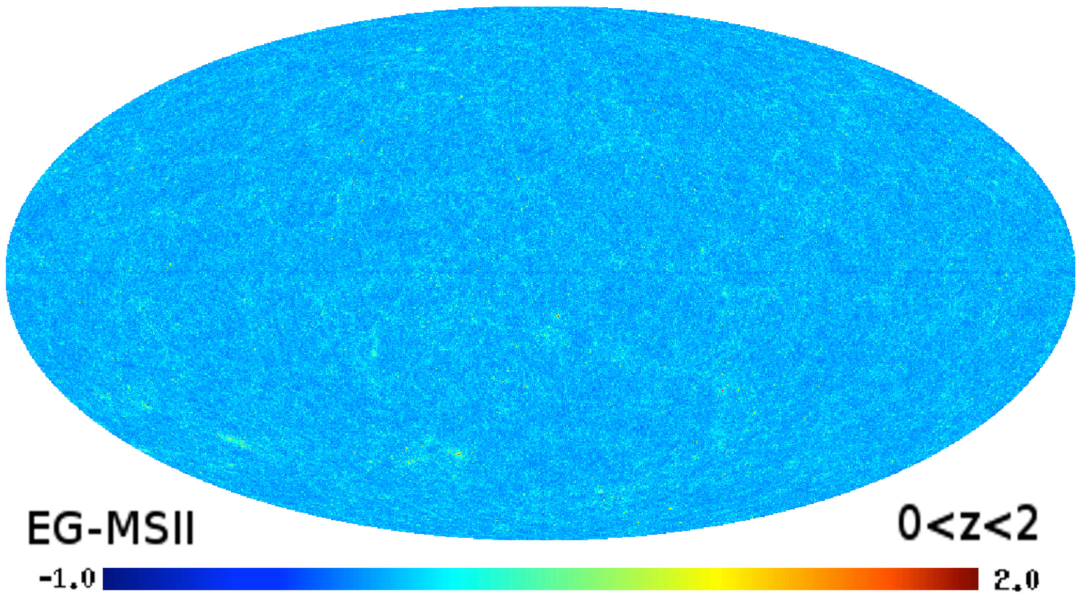
- DM sources can affect the statistics of photons across the sky, even though they are too dim to be individually detected

statistical correlations

Simulation of extraG gamma-ray emission



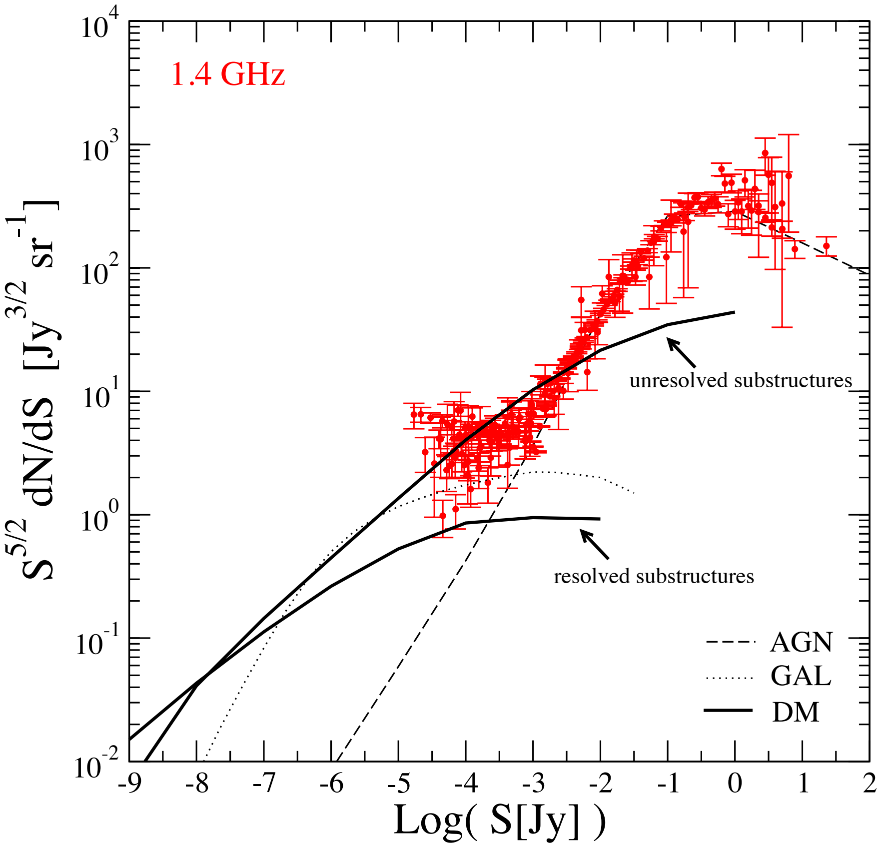
intensity at 4 GeV
m_{DM} = 200 GeV
<σv> thermal
bb channel

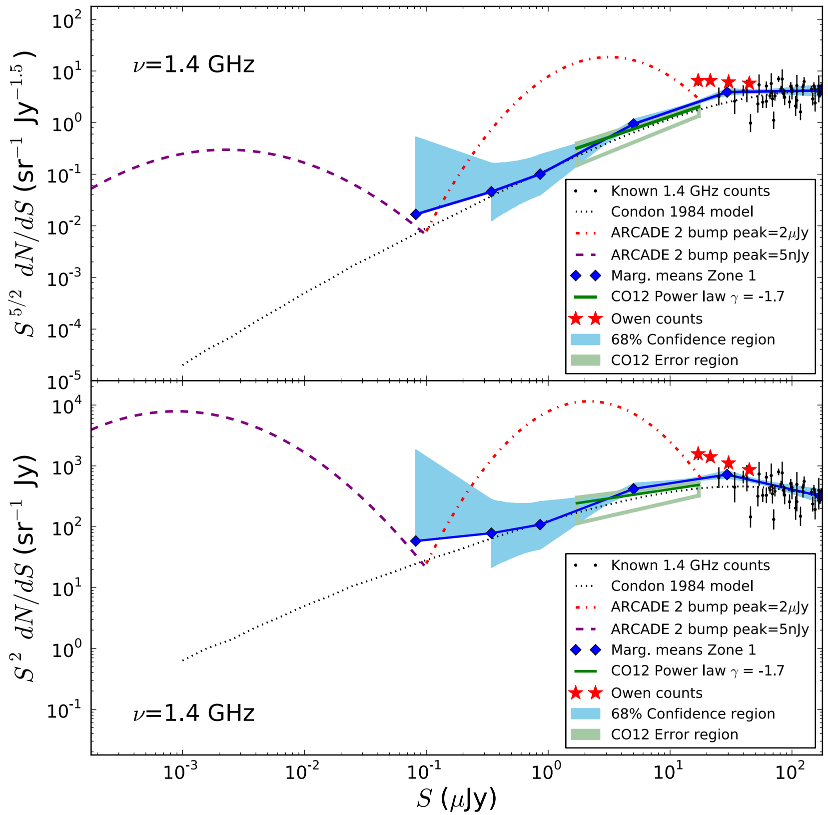


Fornasa et al., MNRAS 329 (2013) 1529

Pixel counts ("1-point" correlation function)

It can constrain the source number counts below detection threshold





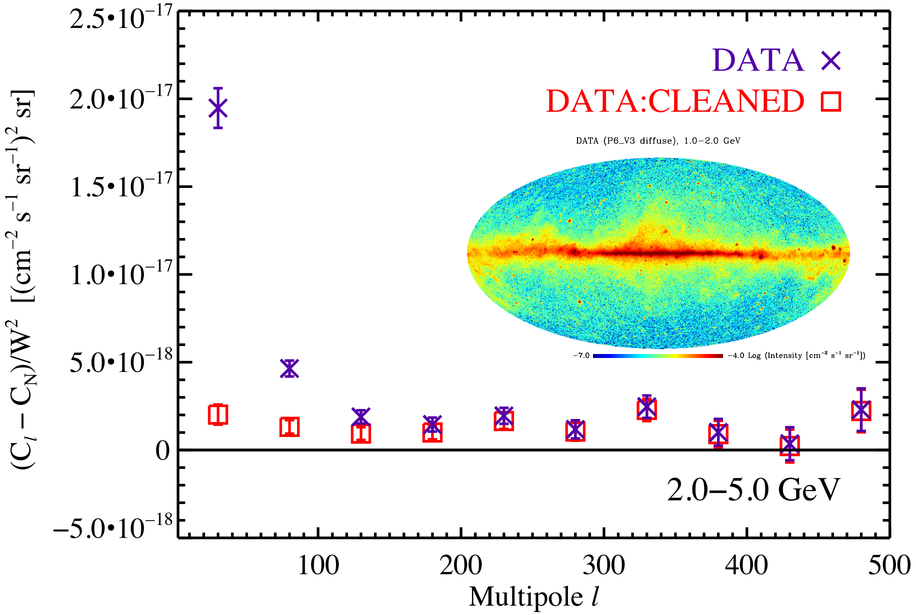
Vernstrom et al, MNRAS 440 (2014) 2791

example taken from radio emission

For gamma-rays, see : Malyshev, Hogg, ApJ 738 (2011) 181 (and wait a couple of months for news ...)

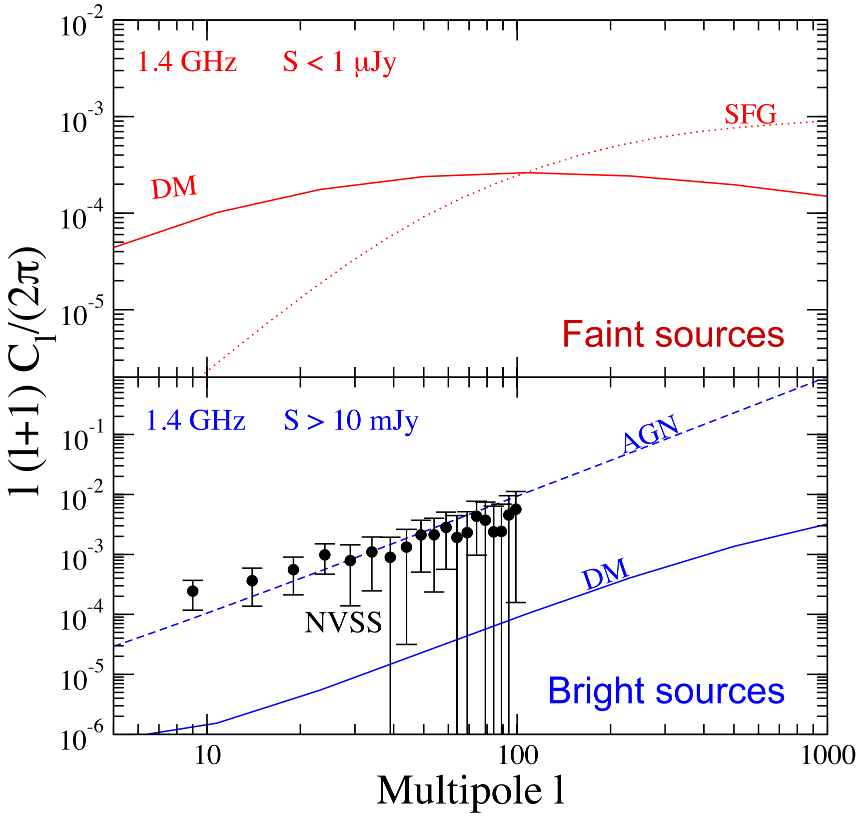
2-point auto-correlation function

Gamma-rays



Gamma-rays auto-correlation observed by Fermi

Radio



Ackerman et al. (Fermi) PRD 85 (2012) 083007

NF, Lineros, Regis, Taoso, JCAP 03 (2012) 033
See also: Zhang, Sigl, JCAP 0809 (2008) 027

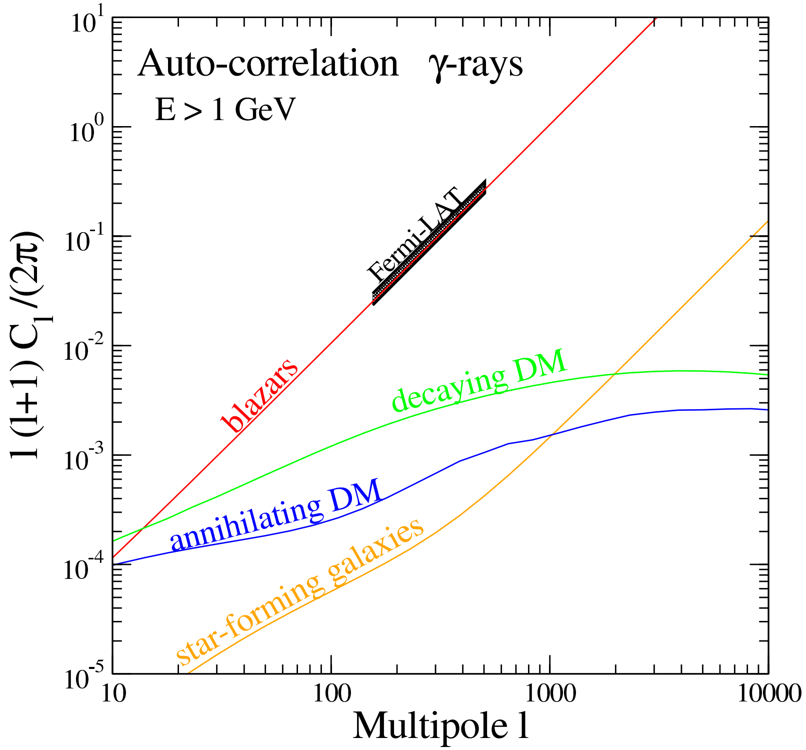
Gamma-rays auto-correlation

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

Features of the signal point toward interpretation in terms of blazars

DM likely plays a subdominant role
(as for total intensity)

Difficult to extract a clear WIMP signature from the EGB alone



For the gamma autocorrelation signal:

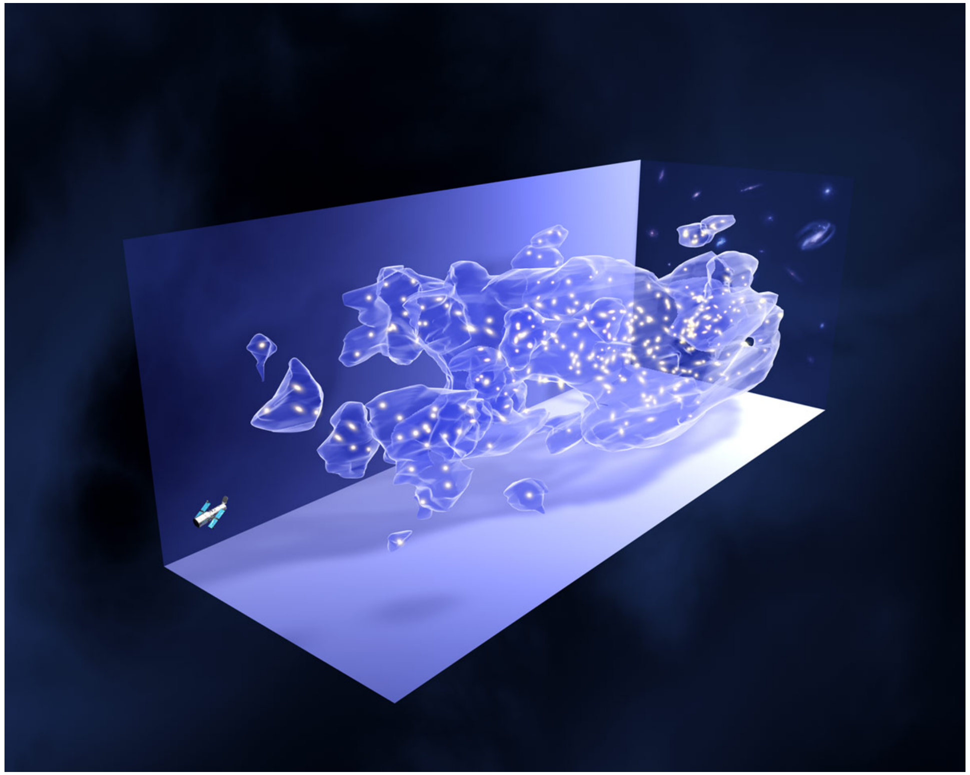
Ando, Komatsu, PRD 73 (2006) 023521
Ando, Komatsu, Narumoto, Totani, PRD D75 (2007) 063519
Miniati, Koushiappas, Di Matteo, ApJ 667 (2007) L1
Siegal-Gaskins, JCAP 0810 (2008) 040
Cuoco, Brandbyge, Hannestad, Haugboelle, Miele, PRD 77 (2008) 123518
Zhang, Sigl, JCAP 0809 (2008) 027 (2008)
Fornasa, Pieri, Bertone, Branchini, PRD 80 (2009) 023518
Taoso, Ando, Bertone, Profumo, PRD 79 (2009) 043521
Ibarra, Tran, Weniger, PRD 81 (2010) 023529
Cuoco, Sellerholm, JConrad, Hannestad, MNRAS 414 (2011) 2040
Cuoco, Komatsu, Siegal-Gaskins, PRD 86 (2012) 063004
Harding, Habazajian, JCAP 11 (2012) 26

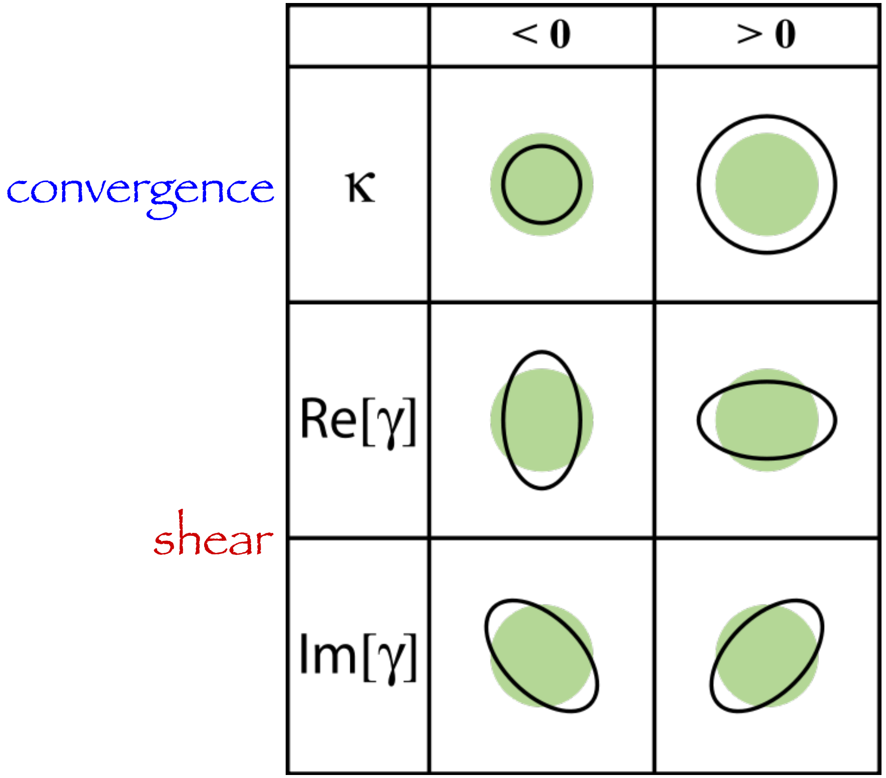
Going further beyond:

gamma rays/cosmic shear cross correlations

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

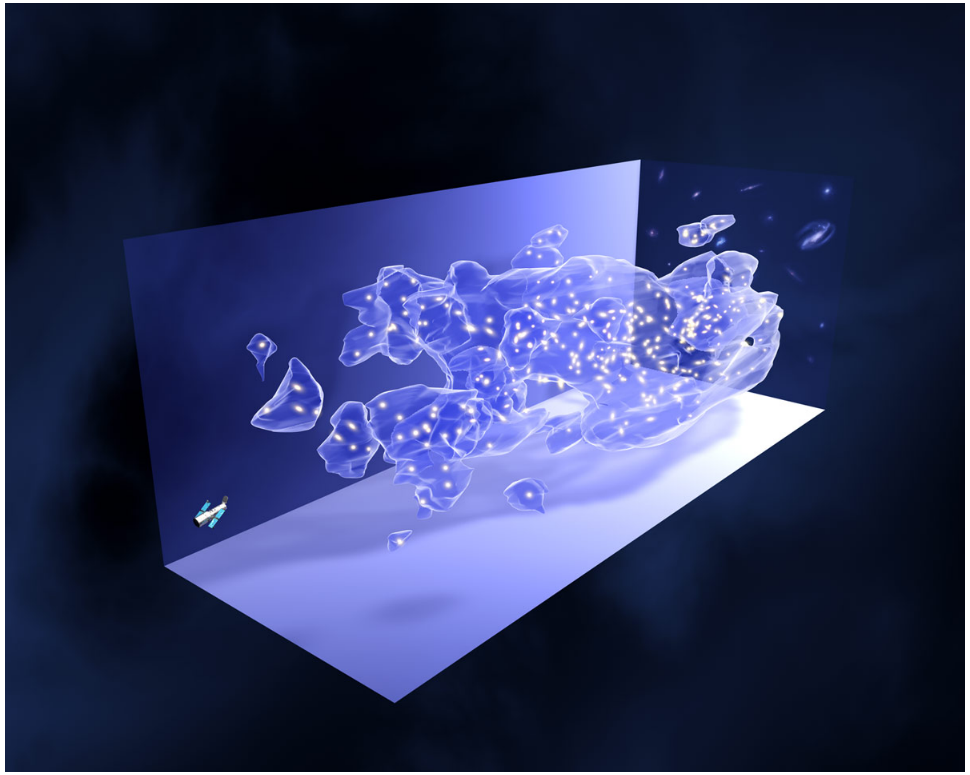




Cosmic structures and gamma-rays

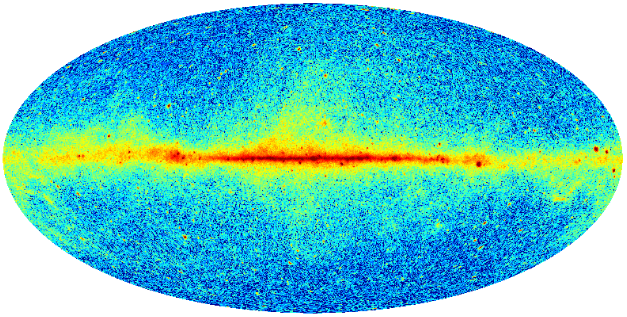
The same Dark Matter structures that act as lenses can themselves emit light at various wavelengths, including the gamma-rays range

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

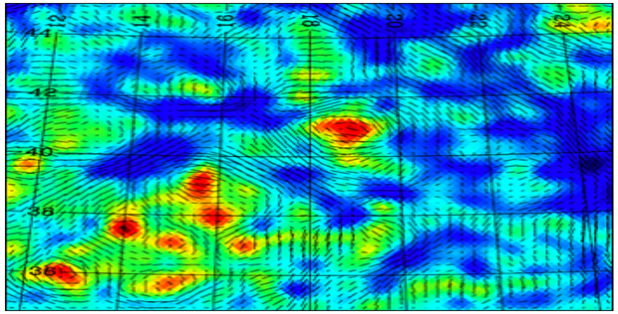


Gamma-rays emitted by DM may exhibit strong correlation with lensing signal

The lensing map can act as a filter to isolate the signal hidden in a large "noise"



The signal



Cross-correlation of:

- Gravitational shear with
- Extragalactic gamma-ray background (the residual radiation contributed by the cumulative emission of *unresolved* gamma-ray sources)

Looked through the statistical correlations encoded in its cross angular power spectrum

$$C_l^{\gamma\phi}$$

Camera, Fornasa, NF, Regis, Ap. J. Lett. 771 (2013) L5
Camera, Fornasa, NF, Regis, arXiv:1411.4651, to appear in JCAP
NF, Regis, Front. Physics 2 (2014) 6

Correlation functions

Source Intensity

$$I_g(\vec{n}) = \int d\chi \, g(\chi, \vec{n}) \, \tilde{W}(\chi)$$

Window function

depends on: source redshift-distribution for lensing
DM photon emissivity for gamma-rays

Cross-correlation angular power spectrum

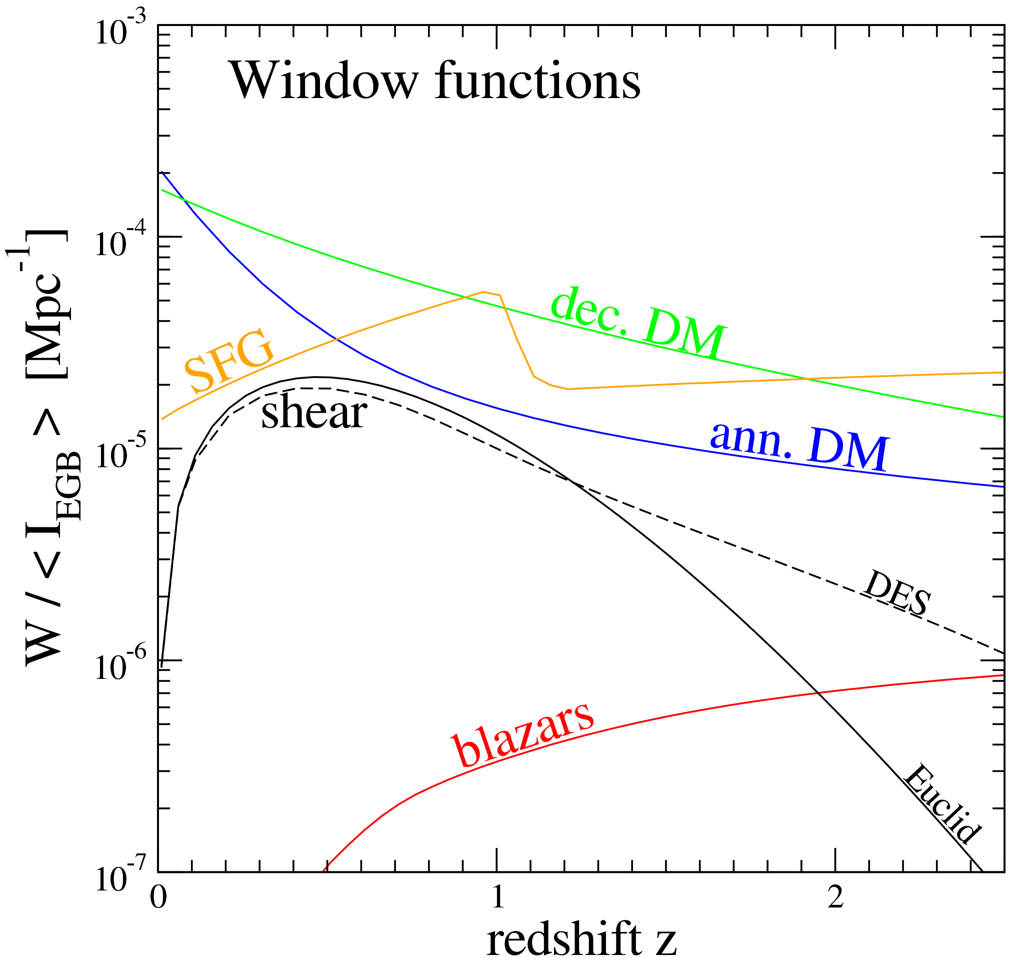
$$C_\ell^{(ij)} = \frac{1}{\langle I_i \rangle \langle I_j \rangle} \int \frac{d\chi}{\chi^2} W_i(\chi) \, W_j(\chi) P_{ij}(k = \ell/\chi, \chi)$$

3D Power spectrum

$$\langle \hat{f}_{g_i}(\chi, \boldsymbol{k}) \hat{f}^*_{g_j}(\chi', \boldsymbol{k}') \rangle = (2\pi)^3 \delta^3(\boldsymbol{k} - \boldsymbol{k}') P_{ij}(k, \chi, \chi')$$

$$f_g \equiv [g(\boldsymbol{x}|m, z)/\bar{g}(z) - 1]$$

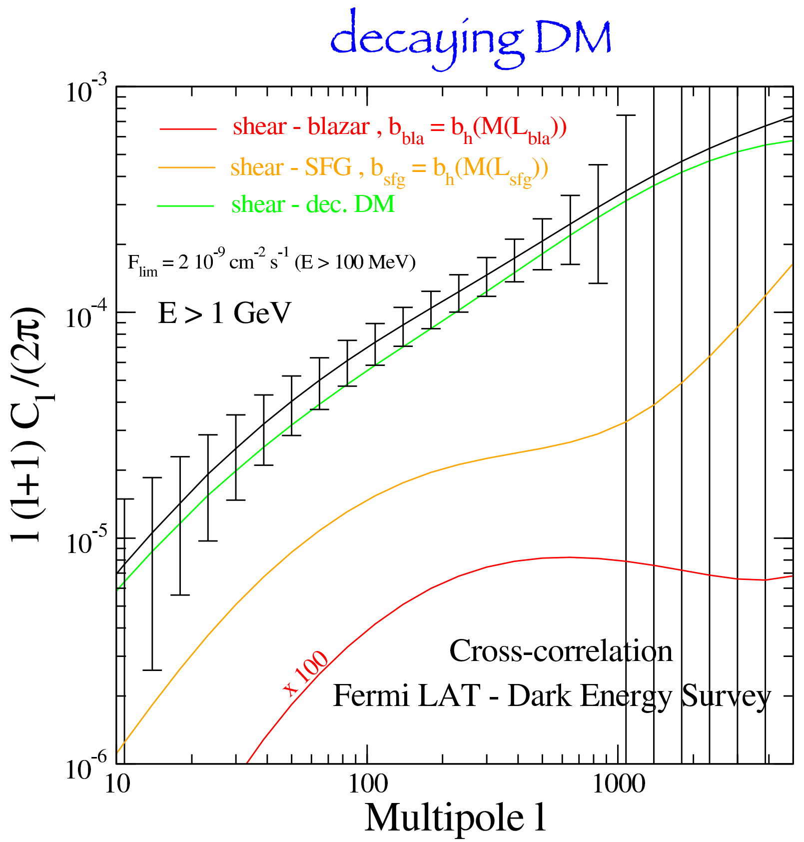
Window functions

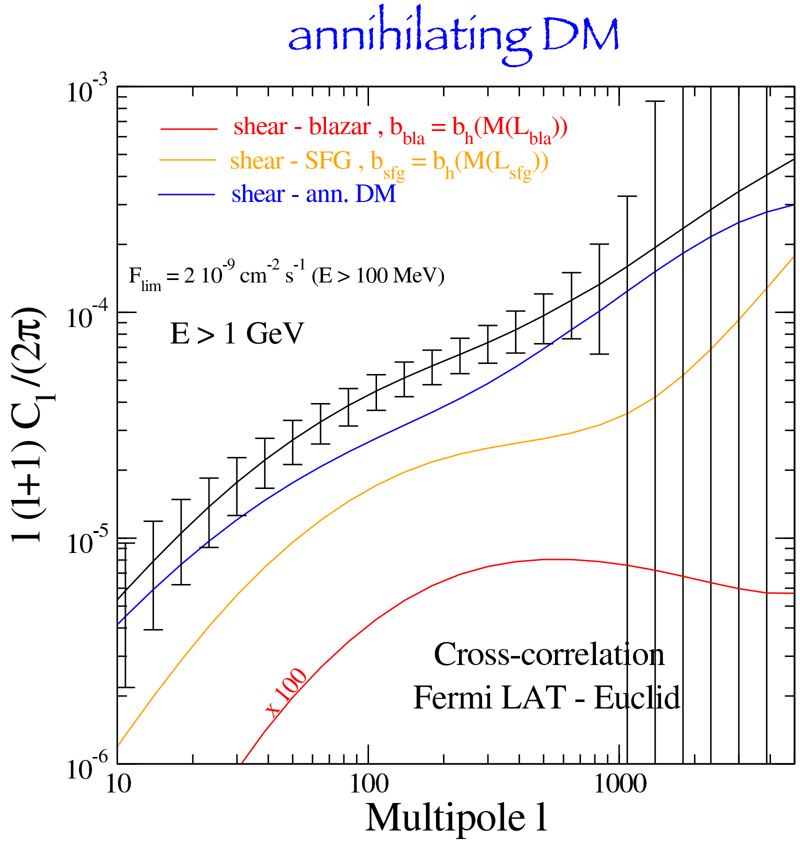


DM peaks at lower z

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

Cross-correlation predictions



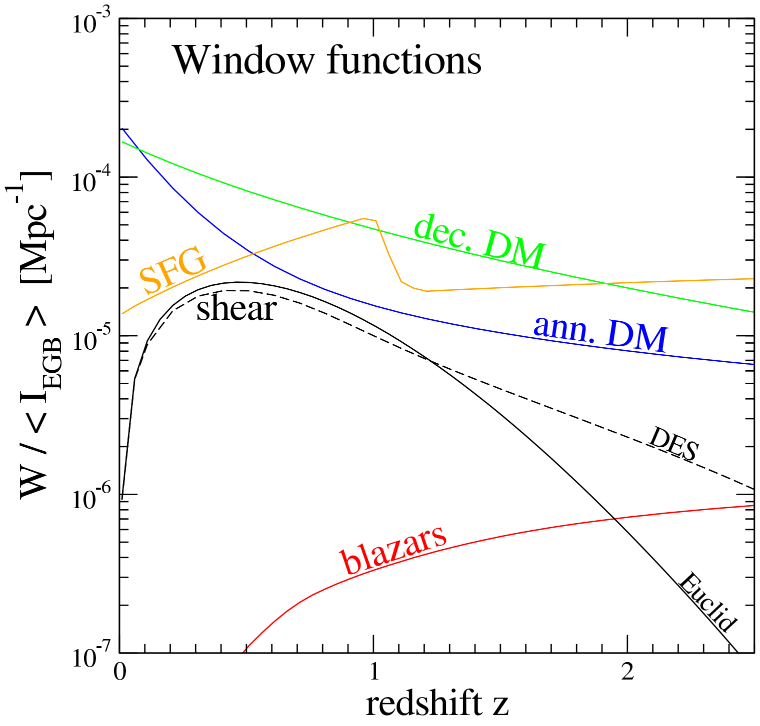


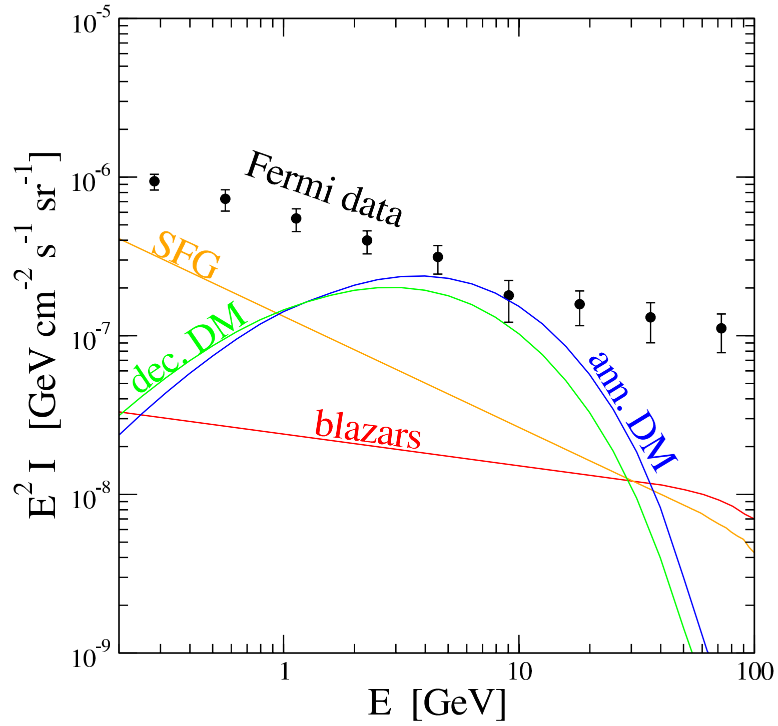
Fermi-LAT/5-yr with DES

Fermi-LAT/5-yr with Euclid

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

Energy slicing and redshift tomography





Reshift information in shear: can help in "filtering" signal sources

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

Forecasts for conceivable configurations

Parameter	Description	DES	Euclid
$f_{\rm sky}$	Surveyed sky fraction	0.12	0.36
$\bar{N}_g$ [arcmin^{-2}]	Galaxy density	13.3	30
$z_{\rm min} - z_{\rm max}$	Redshift range	0.3 – 1.5	0 – 2.5
N_z	Number of bins	3	10
Δ_z	Bin width	0.4	0.25
$\sigma_z/(1+z)$	Redshift uncertainty	–	0.03
σ_ϵ	Intrinsic ellipticity	0.3	0.3

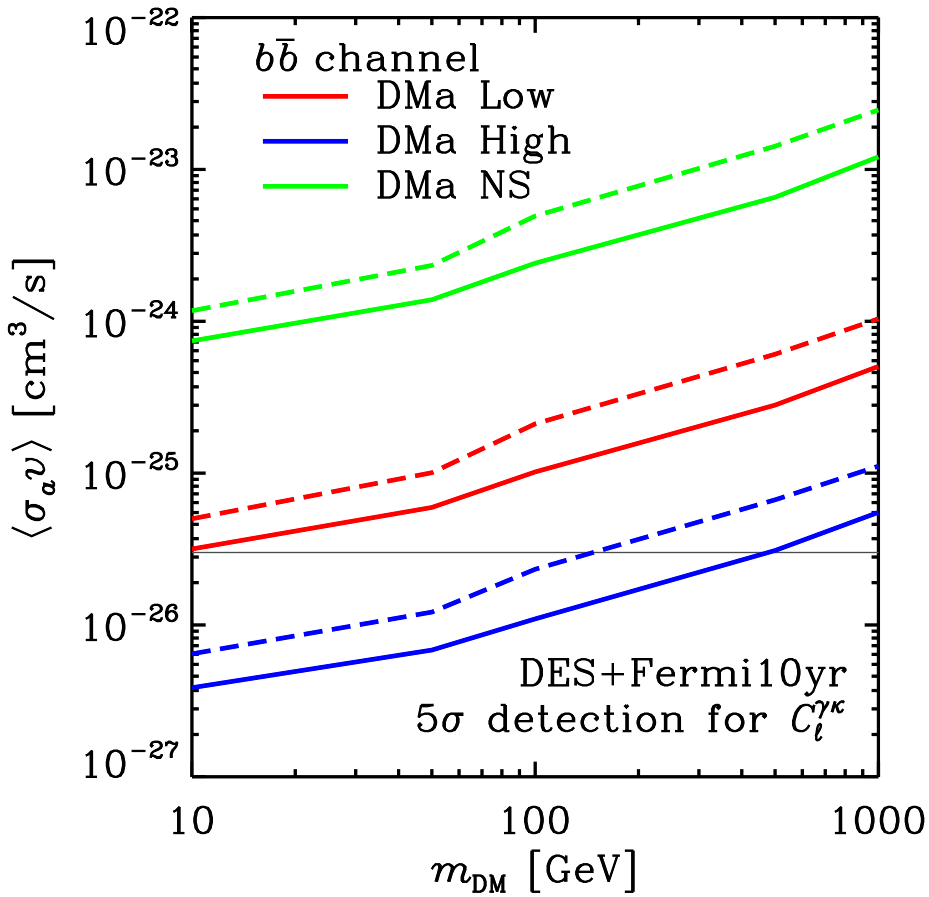
Parameter	Description	Fermi-10yr	Fermissimo
$f_{\rm sky}$	Surveyed sky fraction	1	1
$E_{\rm min} - E_{\rm max}$ [GeV]	Energy range	1 – 300	0.3 – 1000
N_E	Number of bins	6	8
ε [cm^2 s]	Exposure	3.2×10^{12}	4.2×10^{12}
$\langle \sigma_b \rangle$ [deg]	Average beam size	0.18	0.027

Combinations:

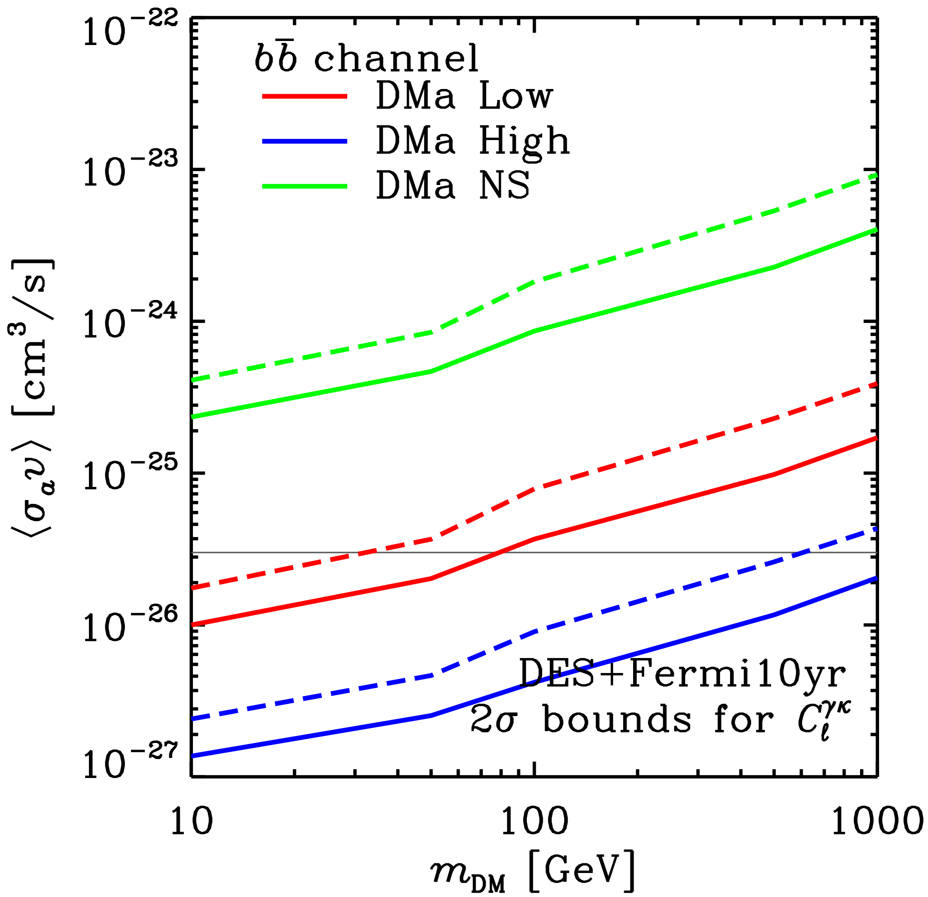
DES + Fermi 10 yr

Euclid + "Fermissimo"

Forecasts



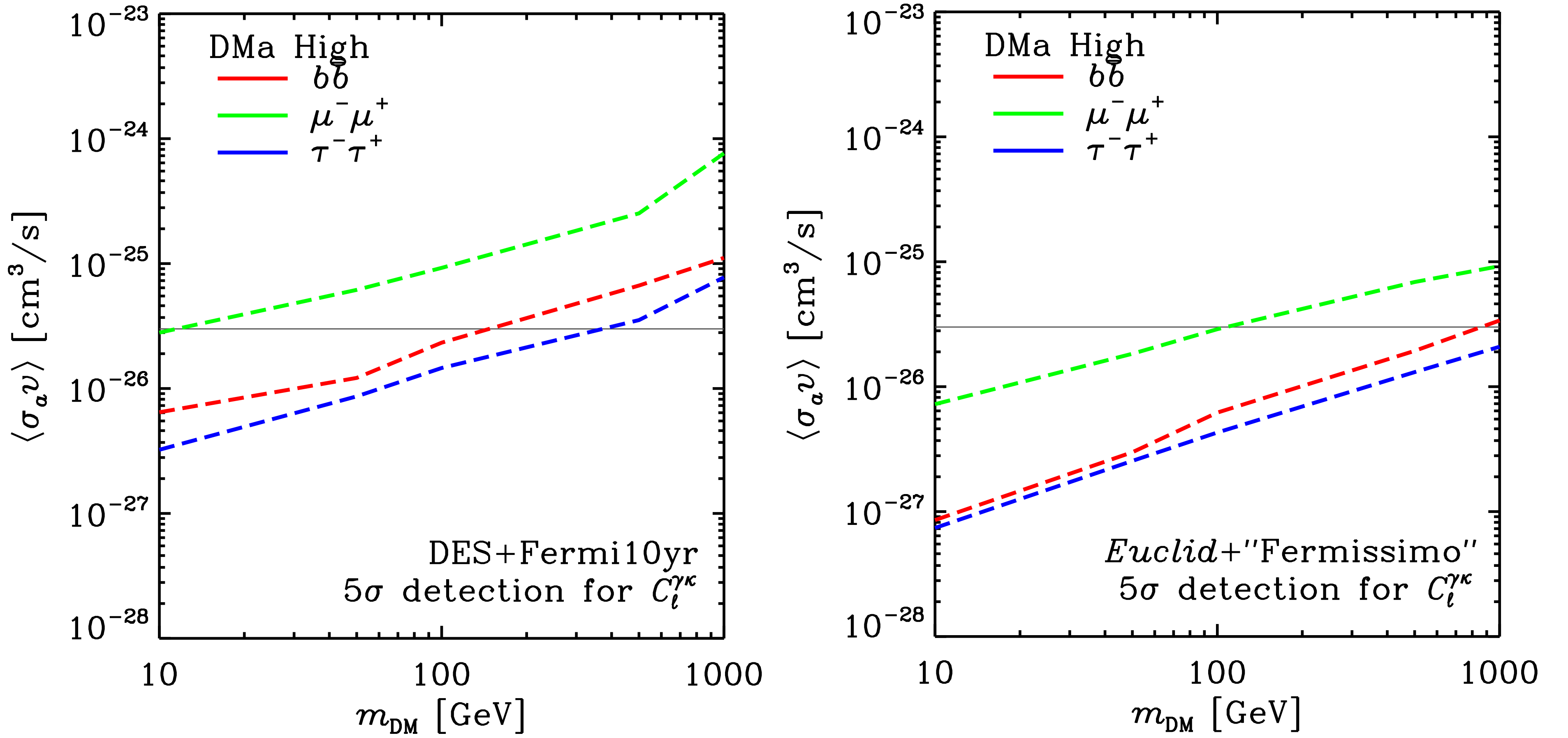
5σ detection



sensitivity limit

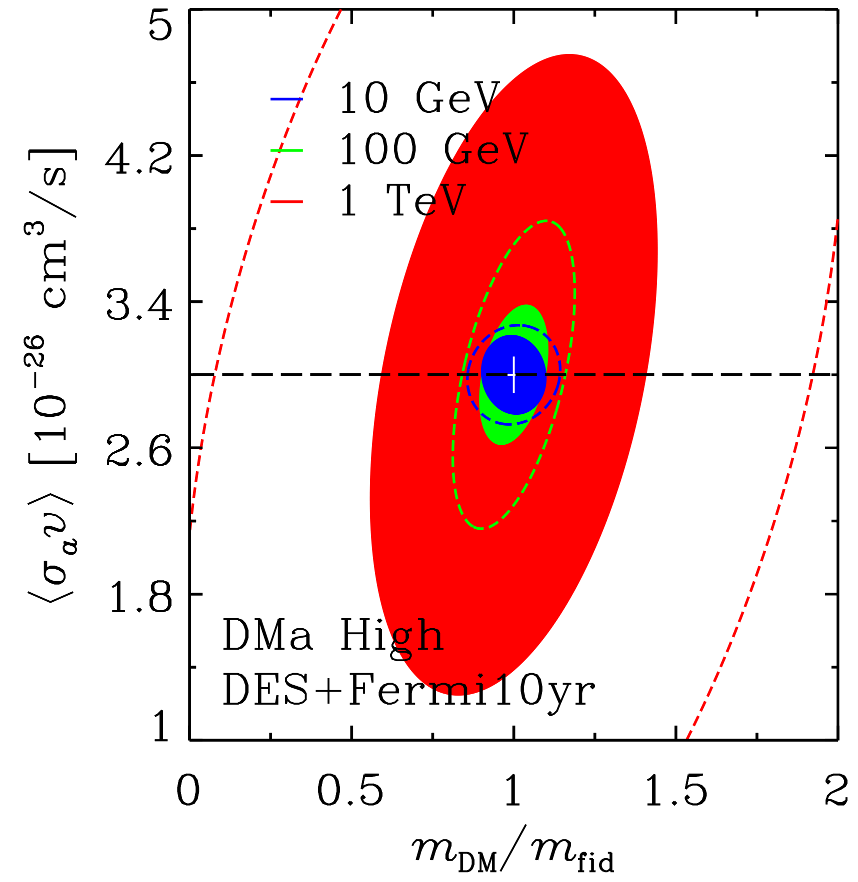
Camera, Fornasa, NF, Regis, arXiv:1411.4651, to appear in JCAP

Forecasts: detection reach



Camera, Fornasa, NF, Regis, arXiv:1411.4651, to appear in JCAP

Forecasts: reconstruction capabilities



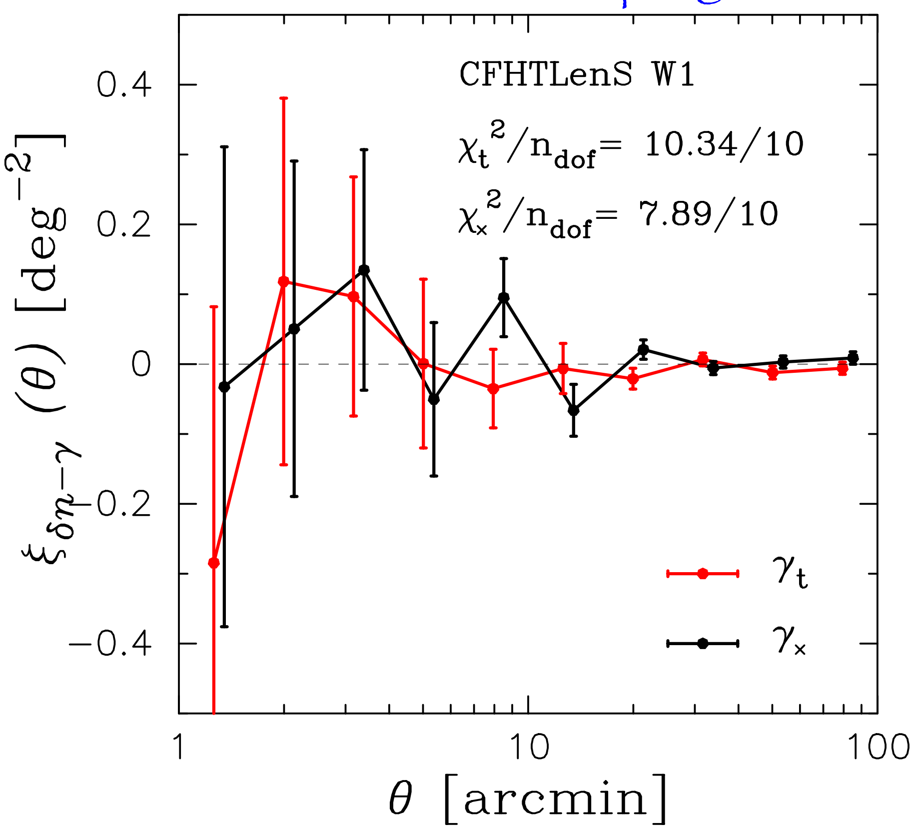
Camera, Fornasa, NF, Regis, arXiv:1411.4651, to appear in JCAP

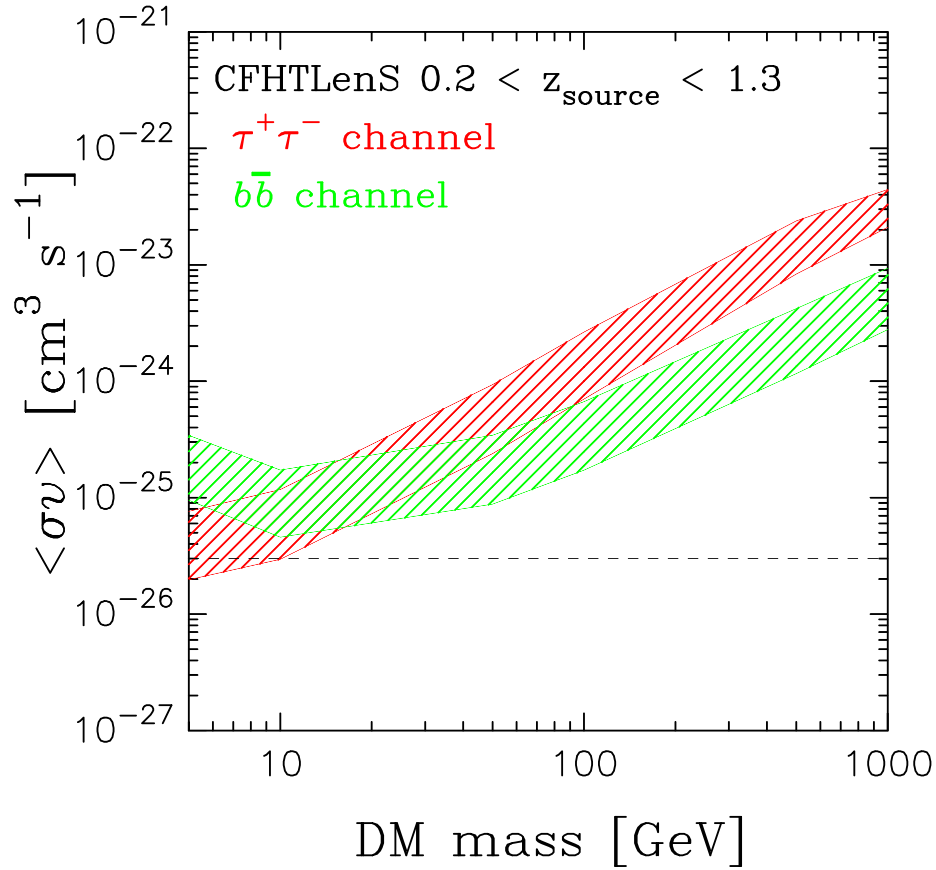
Comments

- The cross-correlation between gamma-rays + cosmic-shear looks promising
- Fermi has alreasy accumulated 6+ yr of data
- DES will likely release its first data in a few years
- For the future:
  - Fermi will likely double its statistics
  - Successors of Fermi are under discussion/preparation
  - Euclid will largely improve over DES

Attempt on data with a small survey

Patch W1: 72 sq. deg





CFHTLens + Fermi/5yr

Shirasaki, Horiuchi, Yoshida, PRD 90 (2014) 063502

CROSS CORRELATIONS
EXTENSION OF THE APPROACH

Extension of the cross-correlation approach

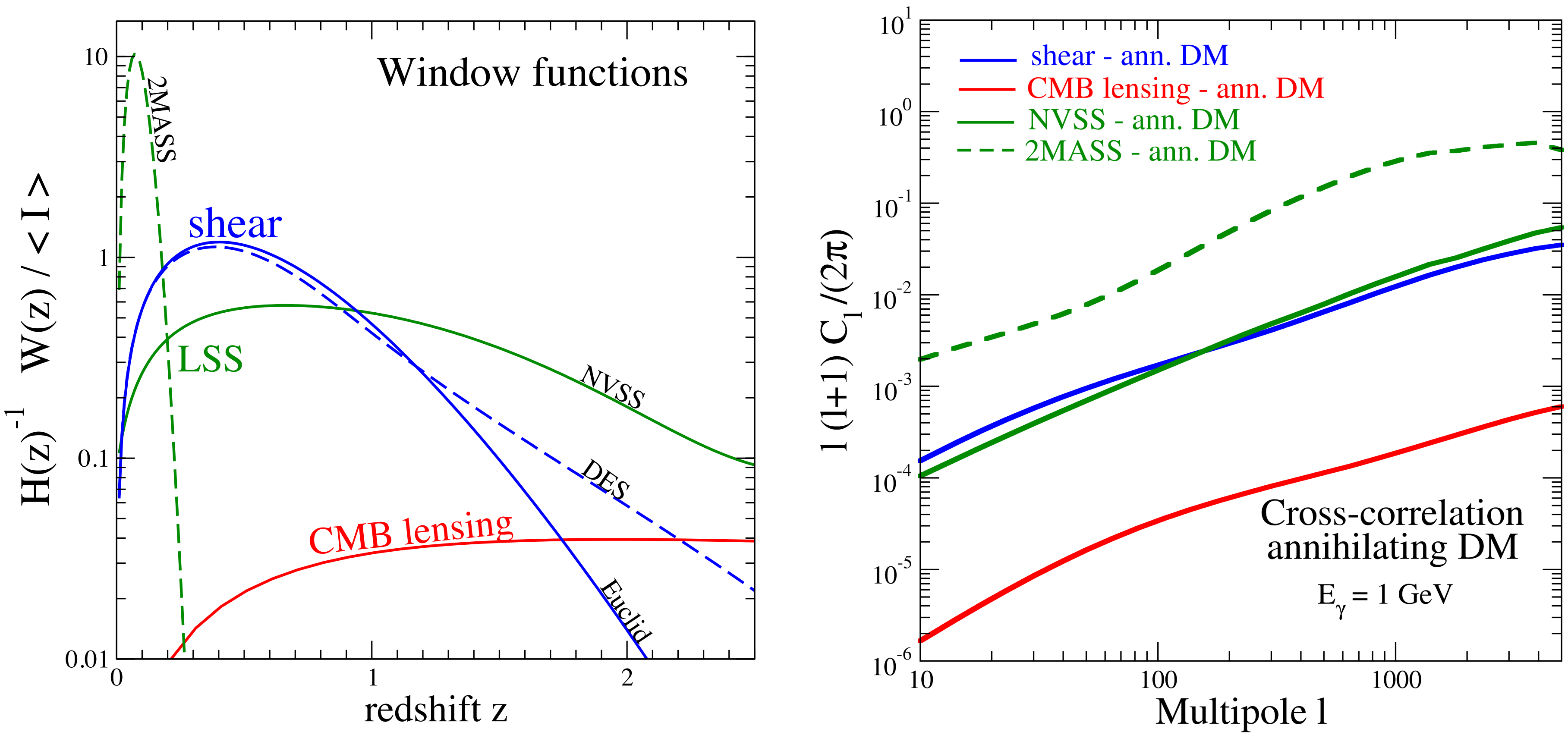
- Gravitational tracers: G_i
  - Weak lensing surveys (cosmic shear) — traces the whole DM
  - CMB lensing
  - LSS surveys — traces light -> bias

- Electromagnetic signals: E_a
  - Radio
  - X
  - Gamma

$$\langle G_i \times E_b \rangle \qquad \langle E_a \times E_b \rangle$$

NF, Regis, Front. Physics 2 (2014) 6

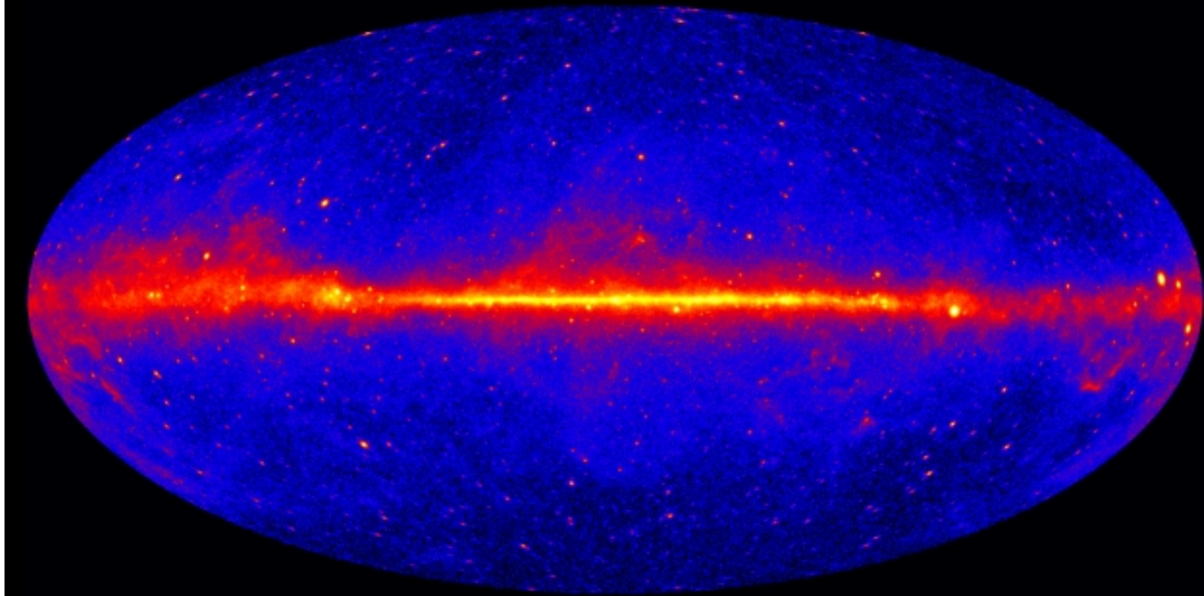
Additional cross correlations channels

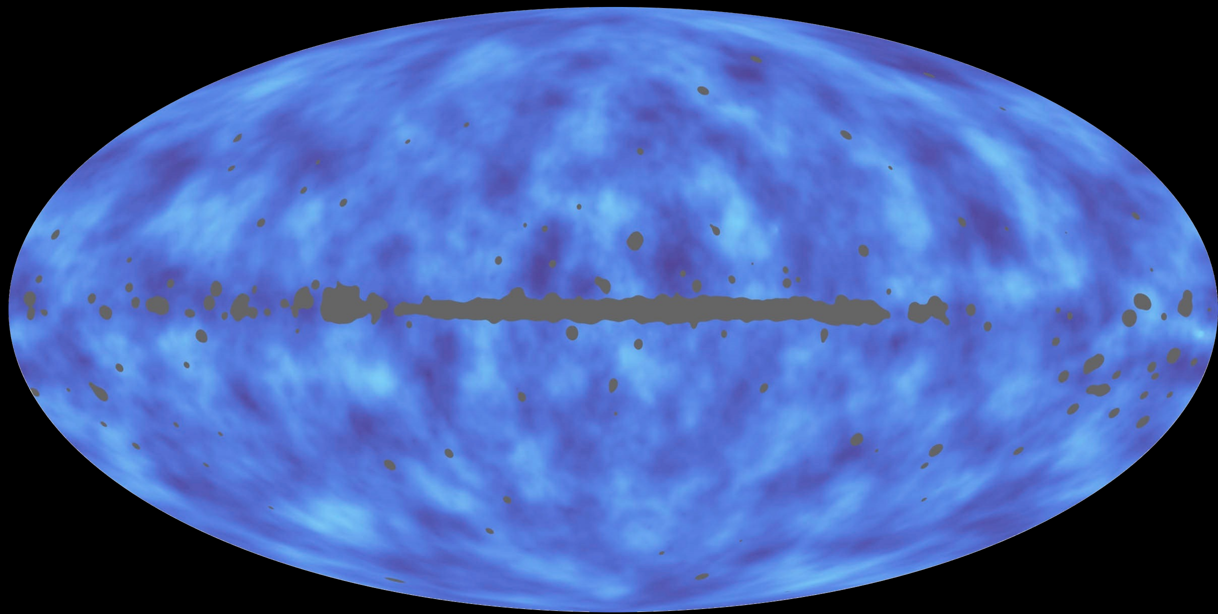


Multiwavelength signals with
LSS tracers and gravitational probes

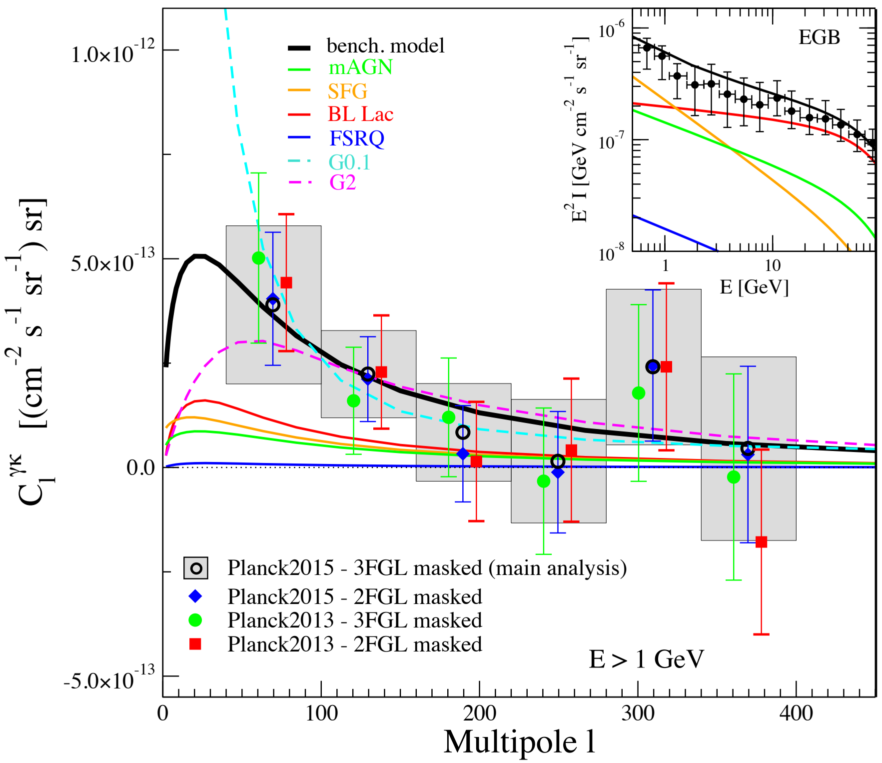
NF, Regis, Front. Physics 2 (2014) 6

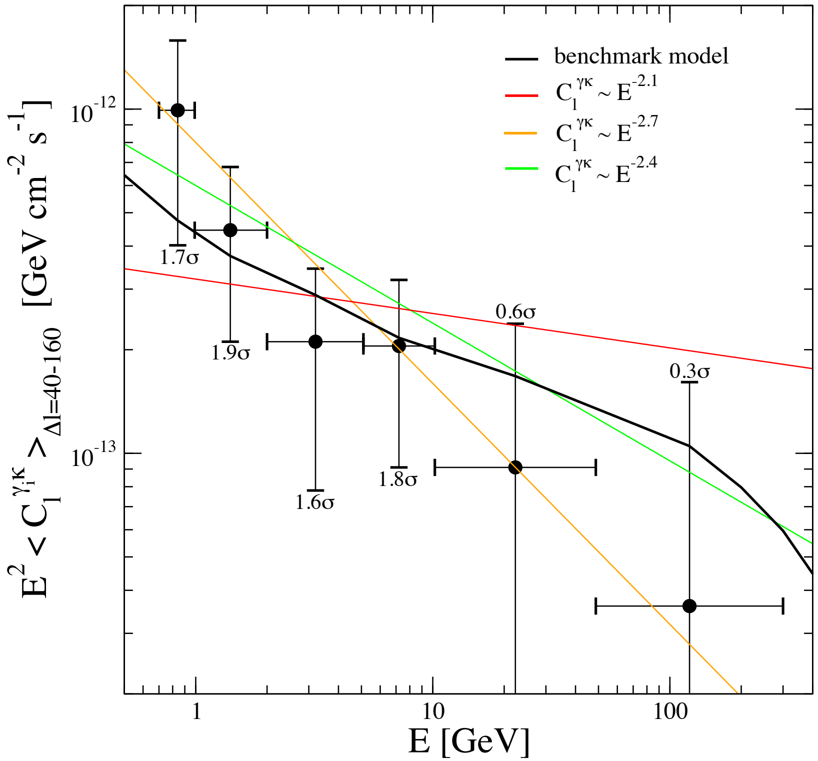
Fermi/gamma + Planck/CMB lensing





Fermi/gamma + Planck/CMB lensing





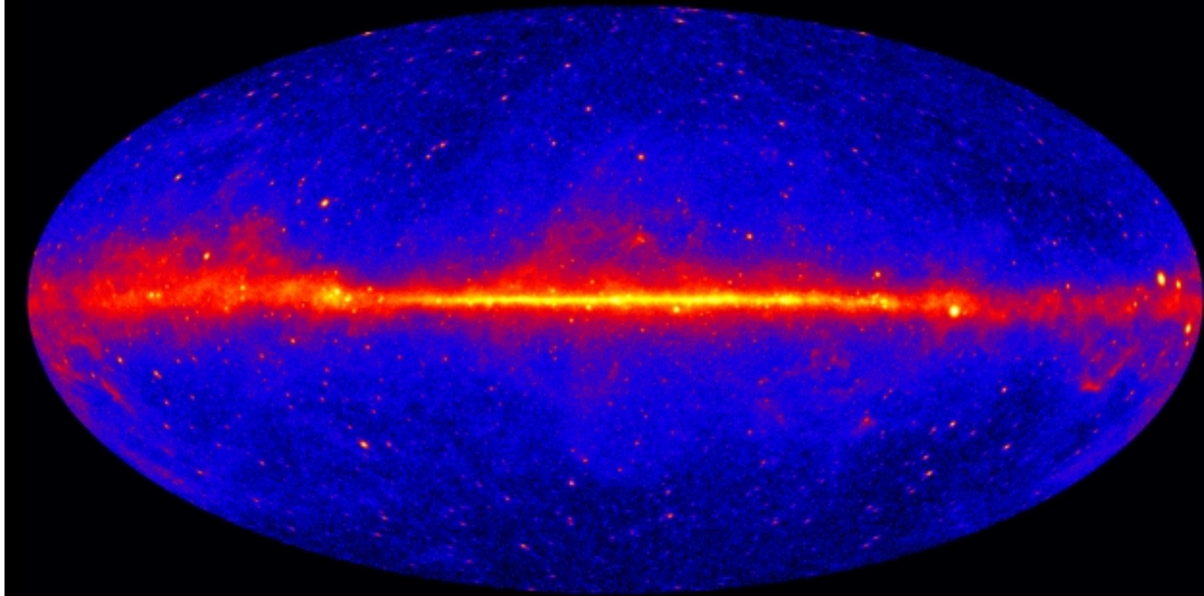
Cross-correlation: 3.0σ evidence

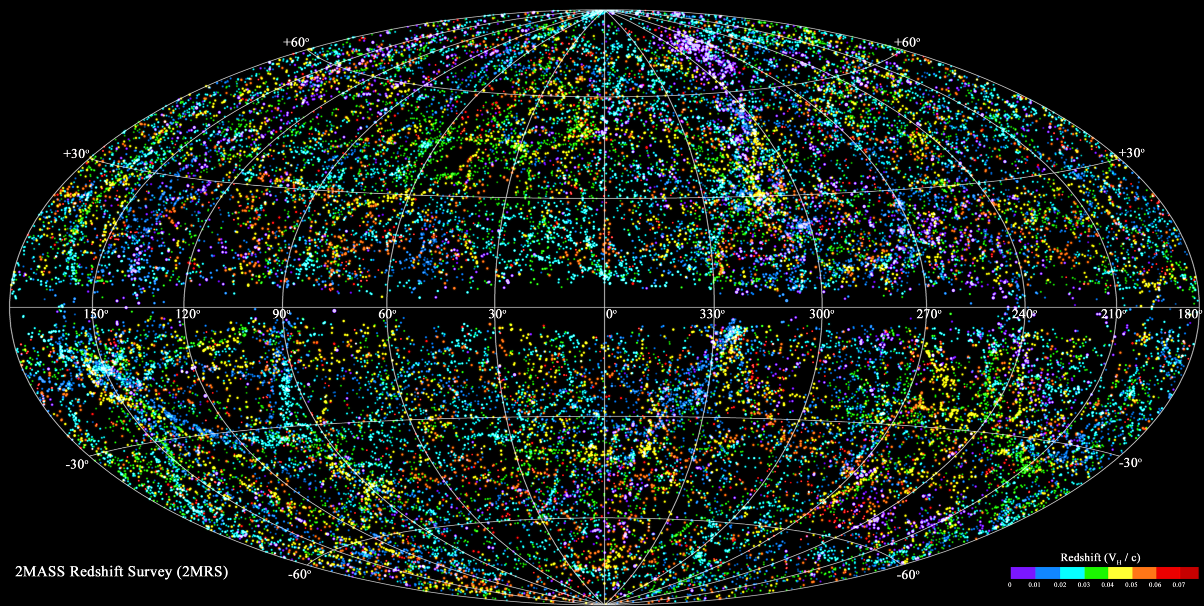
Compatible with AGN + SFG + BLA gamma-rays emission

Points toward a direct evidence of extragalactic origin of the IGRB

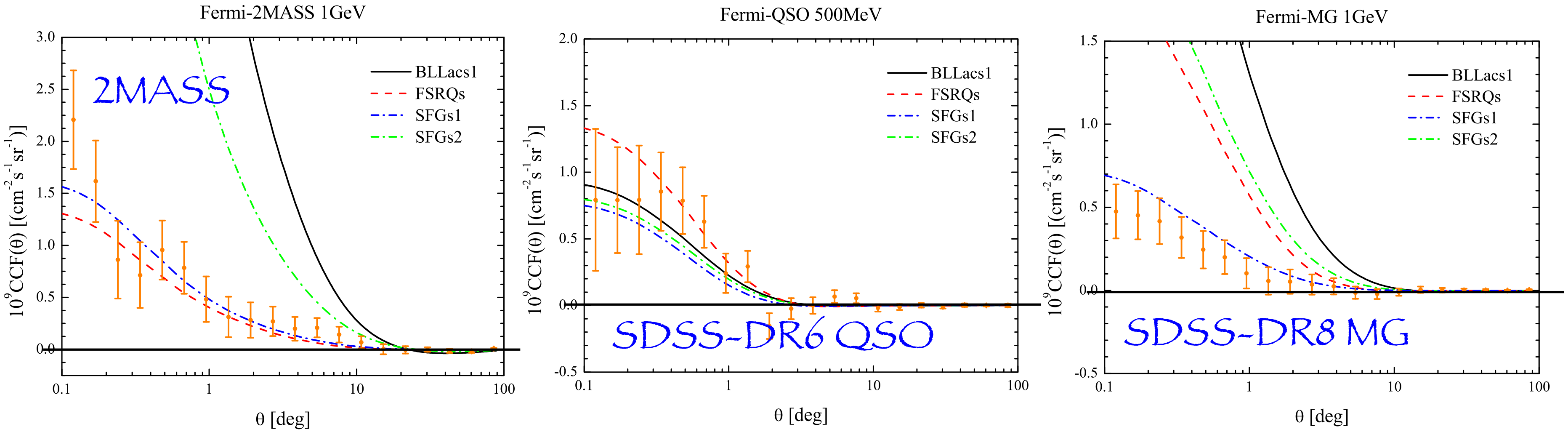
NF, Perotto, Regis, Camera, ApJ 802 (2015) L1

Fermi/gamma + Galaxy catalogs





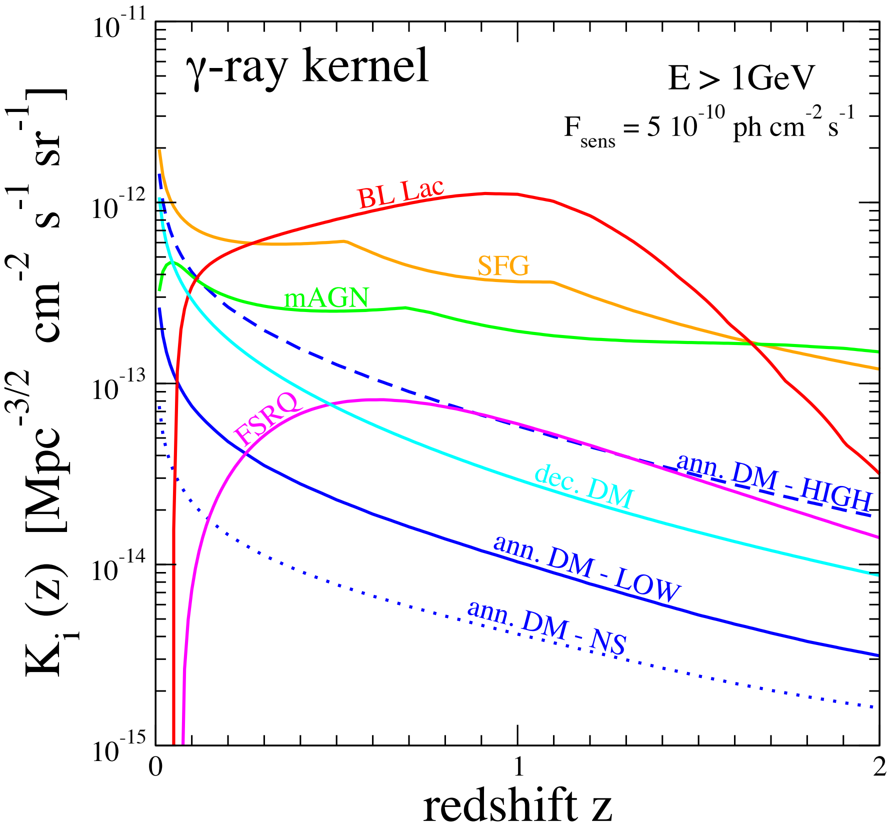
Fermi/gamma + LSS: correlation observed

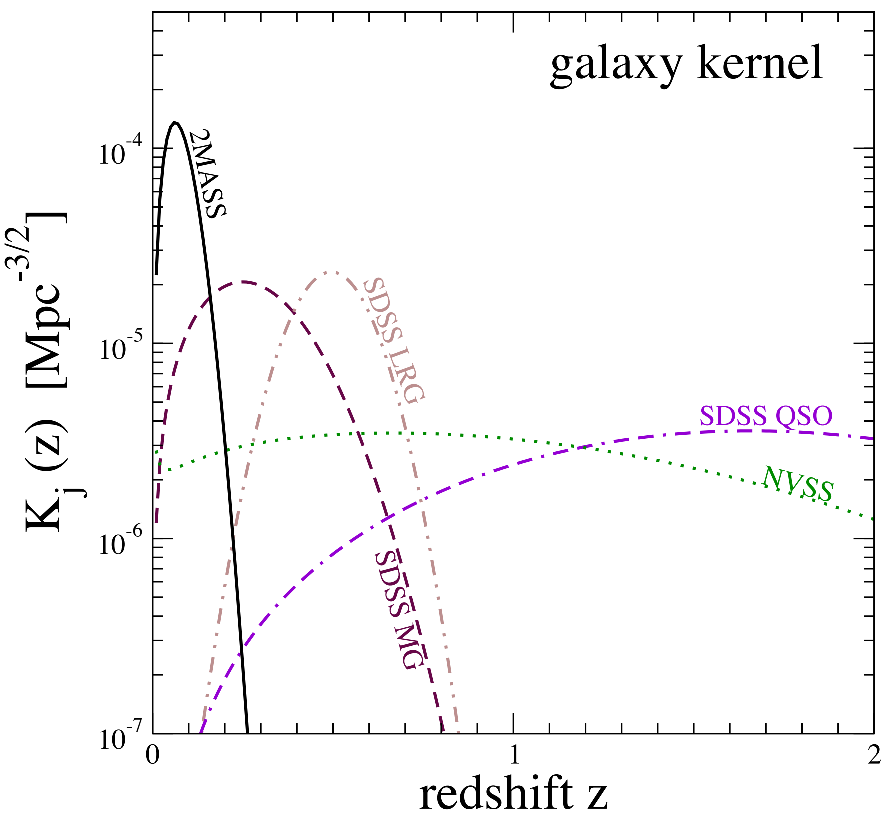


- 2MASS, SDSS-QSO and NVSS: >3.5 σ
- SDSS galaxies: 3.0 σ
- Signal is stronger in two energy bands: E > 0.5 GeV and E > 1 GeV
- Also seen at E > 10 GeV
- Results robust against the choice of statistical estimator, estimate of errors, map cleaning procedure and instrumental effects

Xia, Cuoco, Branchini, Viel, ApJS 217 (2015) 1

Fermi + 2MASS: DM interpretation





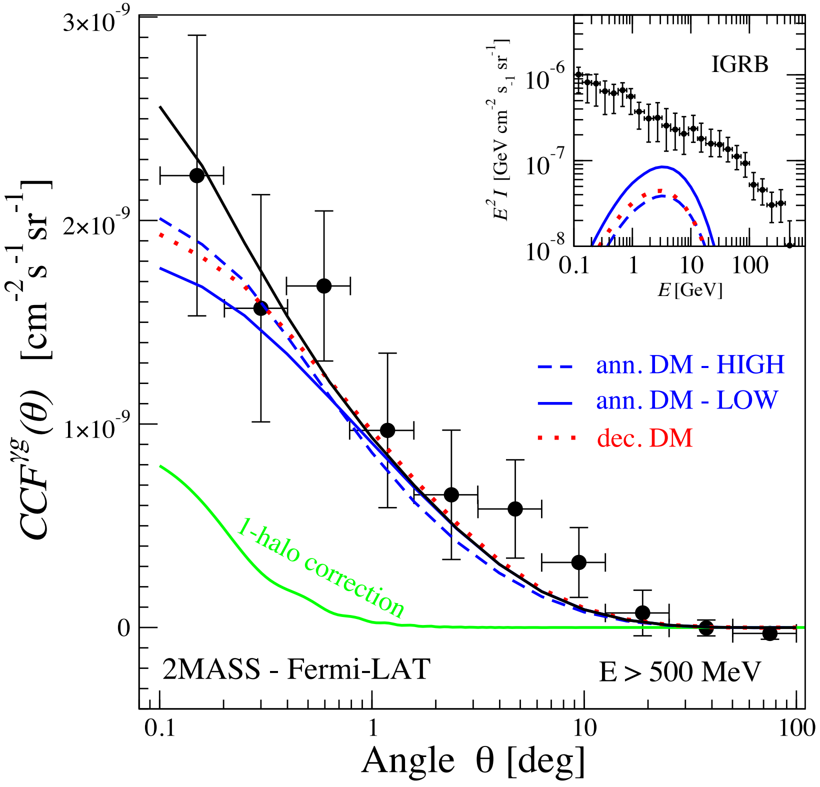
The DM kernel peaks at low redshift, as well as the 2MASS one

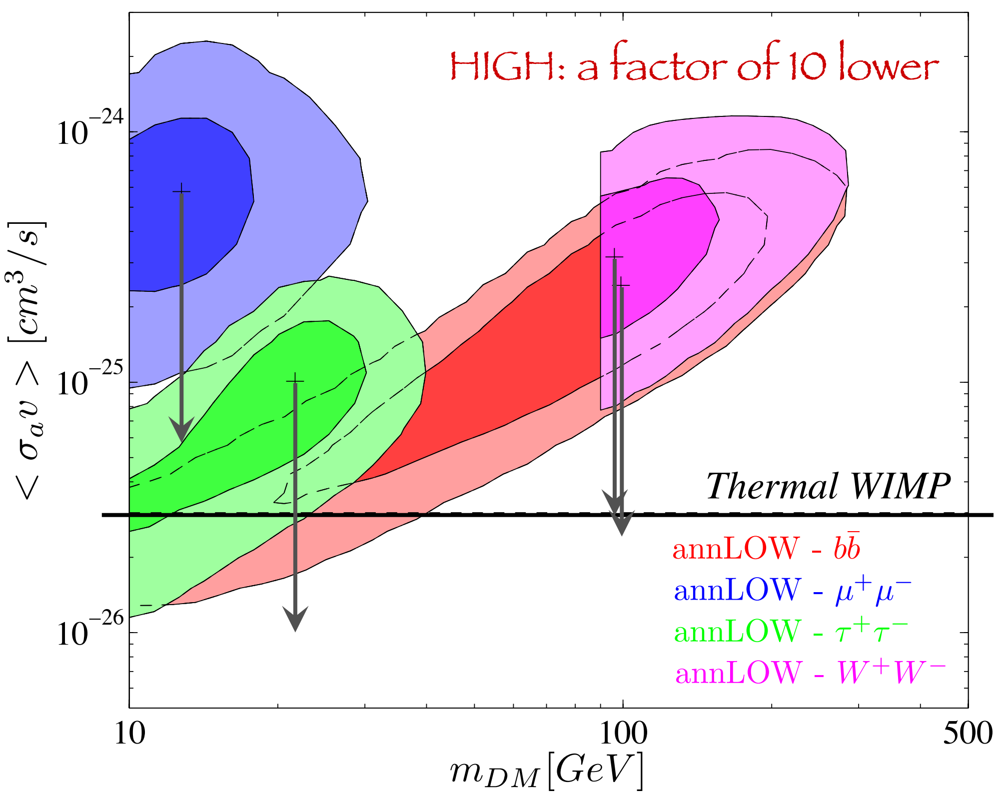
Best option for DM studies: cross-correlate with 2MASS

The different behaviour of kernels can help to discriminate the sources

Regis, Xia, Cuoco, Branchini, NF, Viel, arXiv:1503.05922, to appear in PRL

Fermi + 2MASS: DM analysis





The observed cross-correlation is perfectly reproduced (both in shape and size) by a DM contribution

While the DM emission is largely subdominant in the total intensity

Analysis includes spectral information (3 energy bins)

Regis, Xia, Cuoco, Branchini, NF, Viel, arXiv:1503.05922, to appear in PRL

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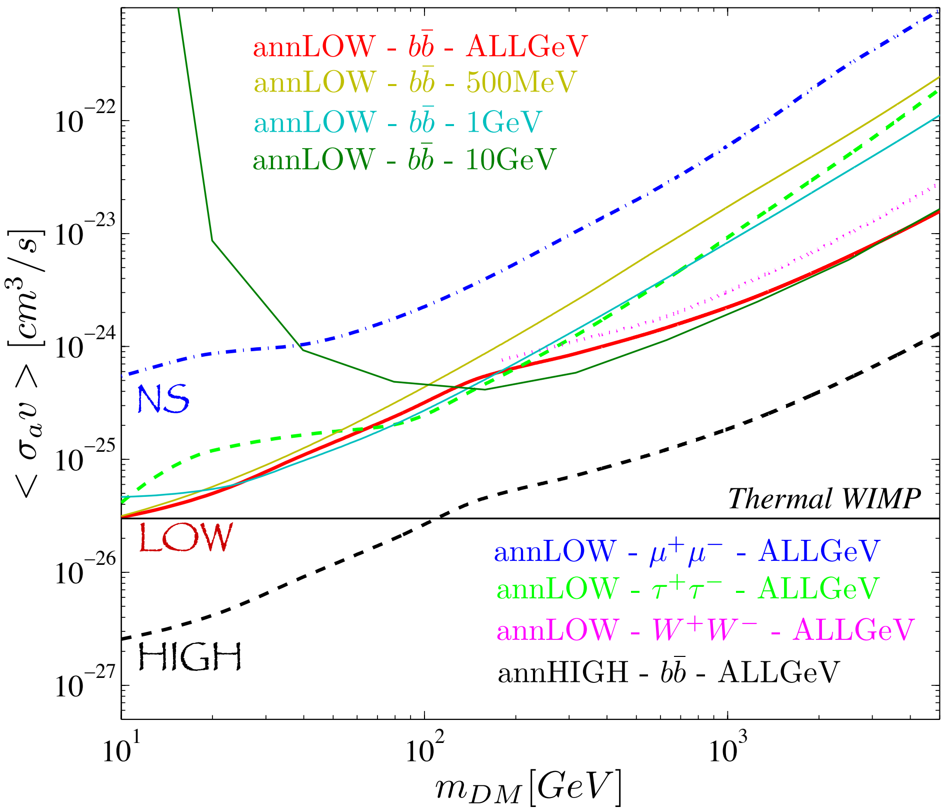
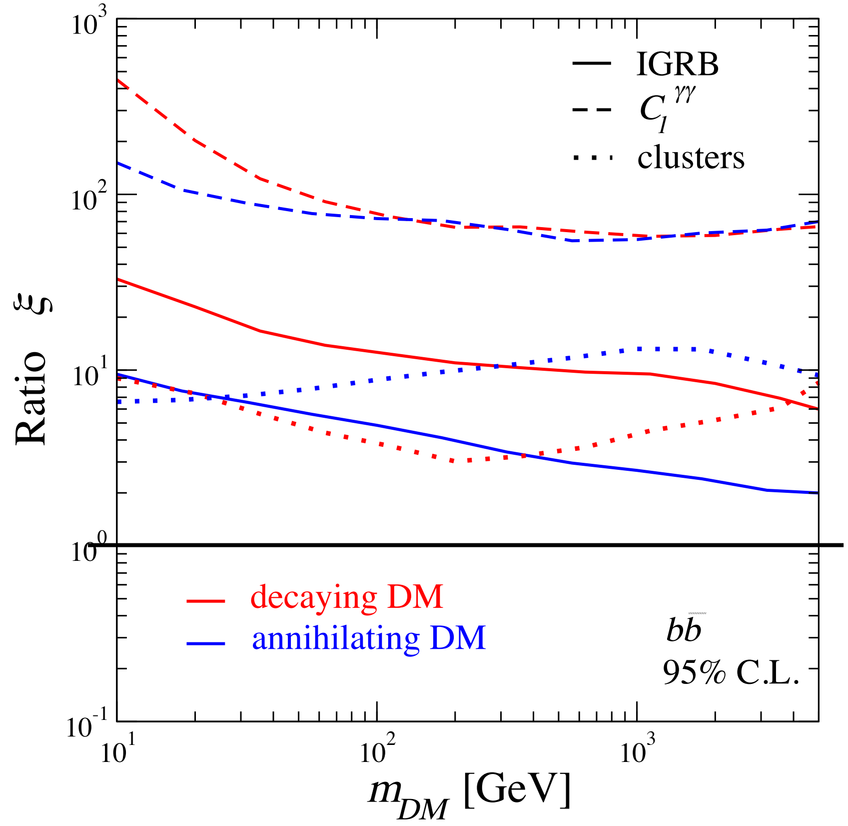


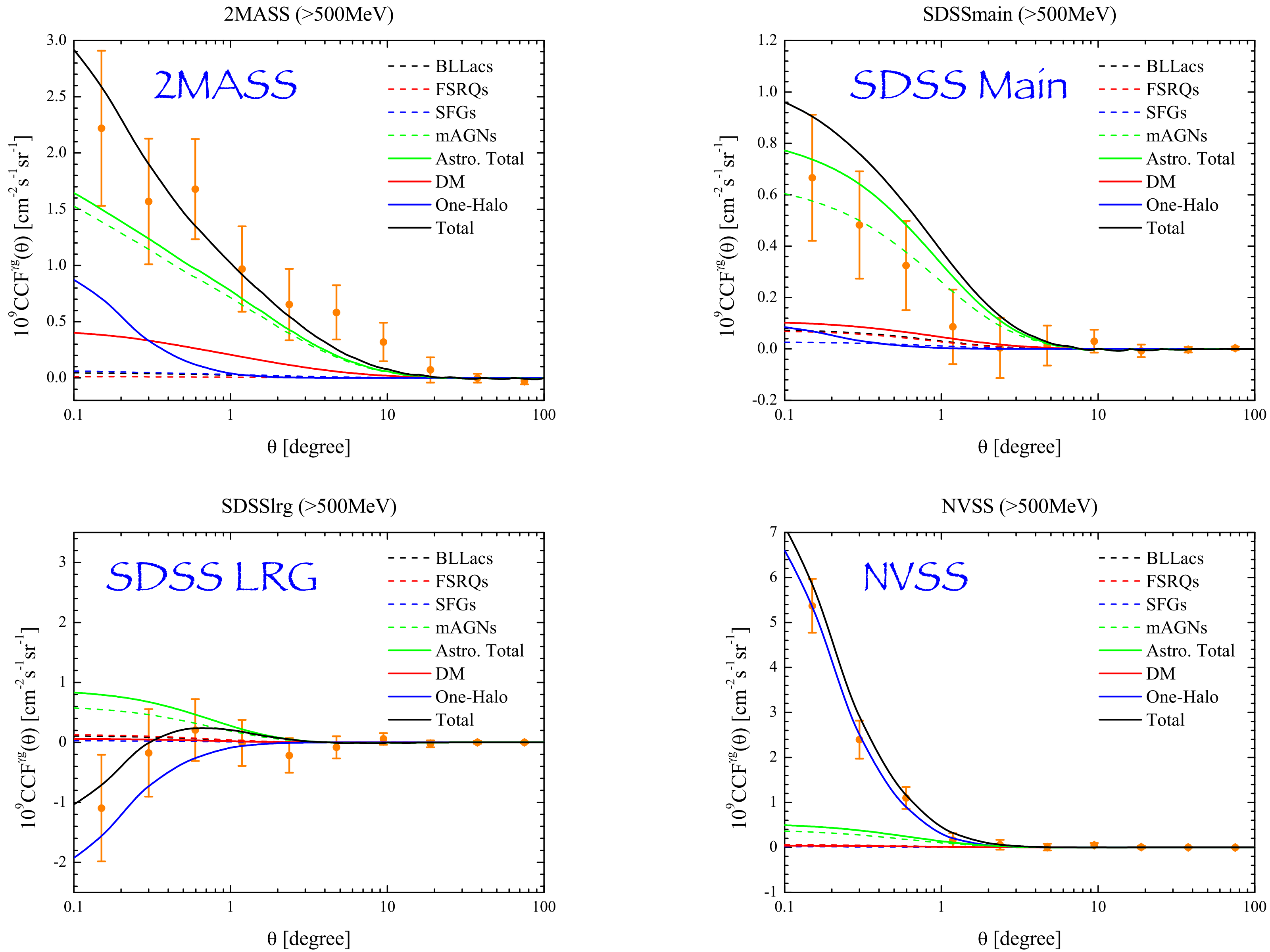
Bound from cross correlation



Bounds ratios
Correlation technique stronger

Regis, Xia, Cuoco, Branchini, NF, Viel, arXiv:1503.05922, to appear in PRL

Fermi + all LSS catalogs: DM + astro sources

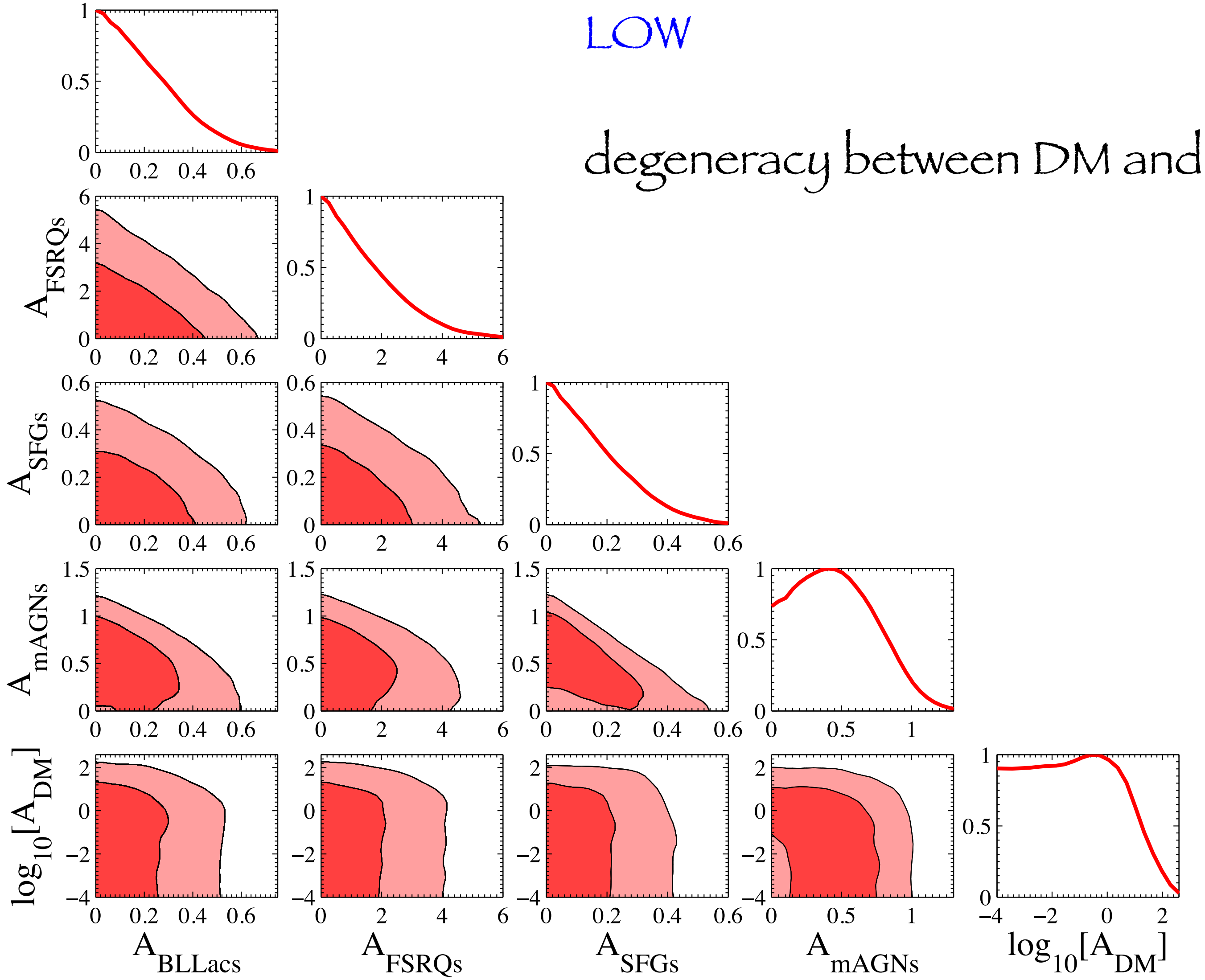


Cuoco, Xia, Regis, Branchini, NF, Viel, arXiv:1506.01030

Fermi + LSS catalogs: DM + astro sources

LOW

degeneracy between DM and mAGN

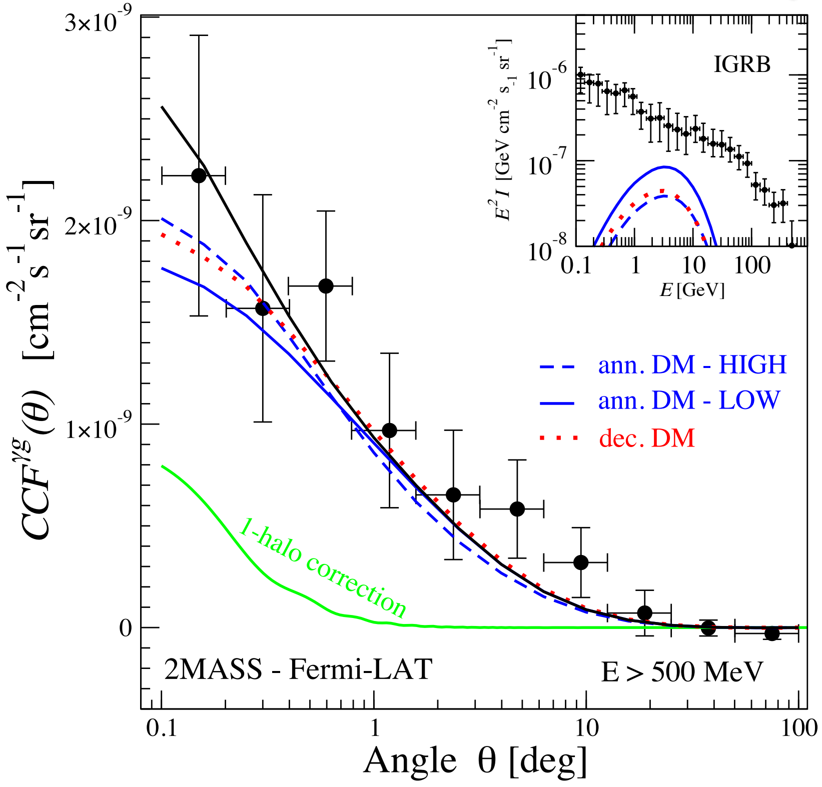


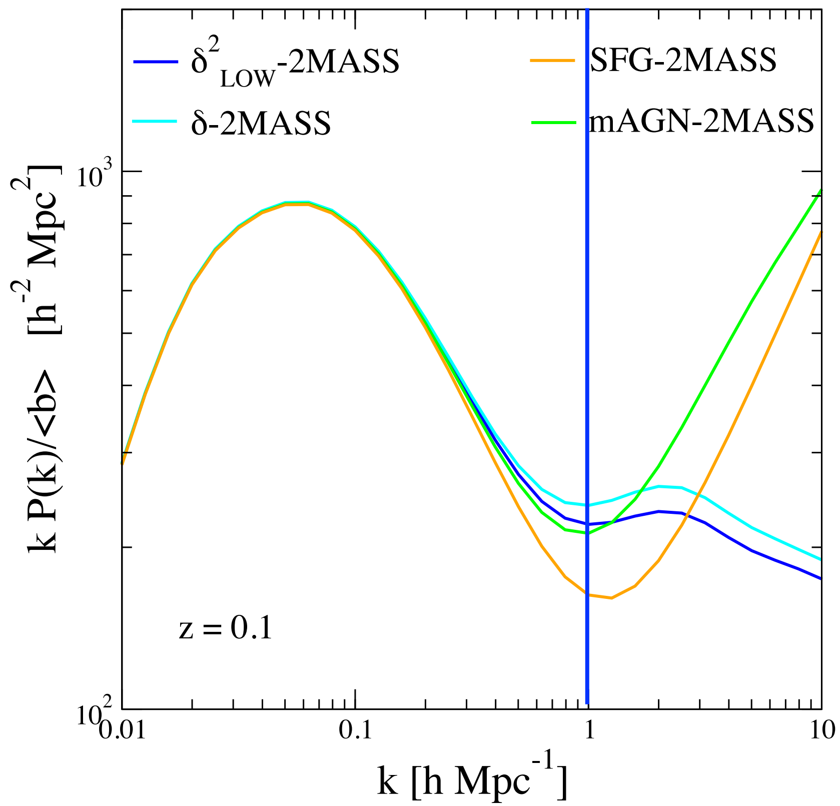
Cuoco, Xia, Regis, Branchini, NF, Viel, , arXiv:1506.01030

- DM signal:
  - peaks at low redshift
  - mostly contributed by massive halos

- To mimic this, an astrophysical source must be hosted in large halos at low z:
  - mAGN likely hosted in large halos
  - SFG typically populate galaxy-size halos

Measured power and scales





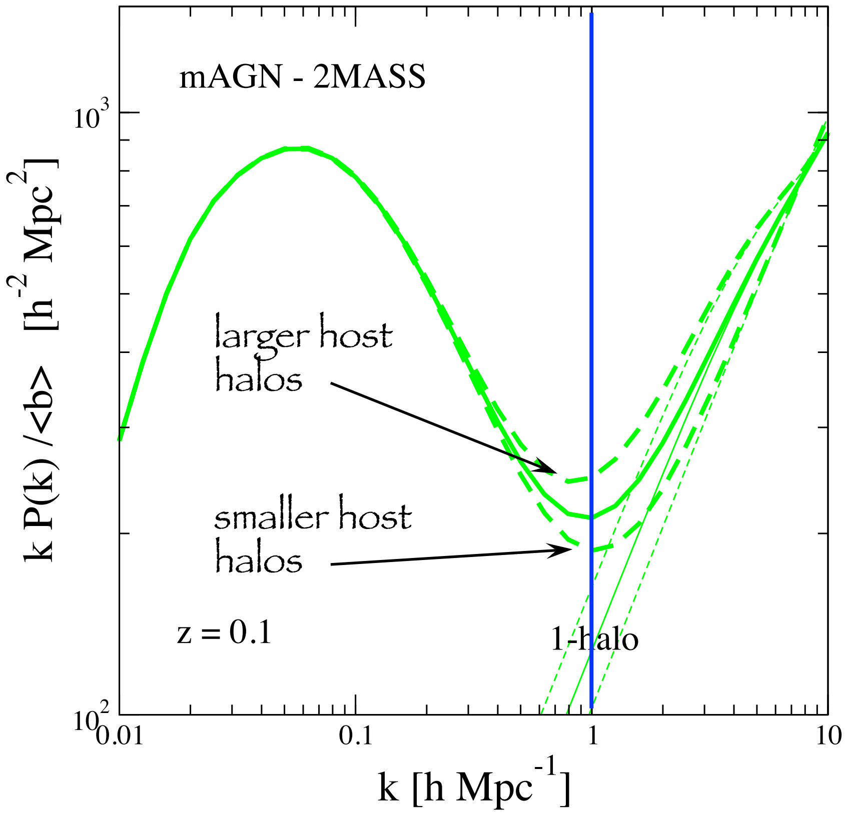
Data show power at the sub-degree scale

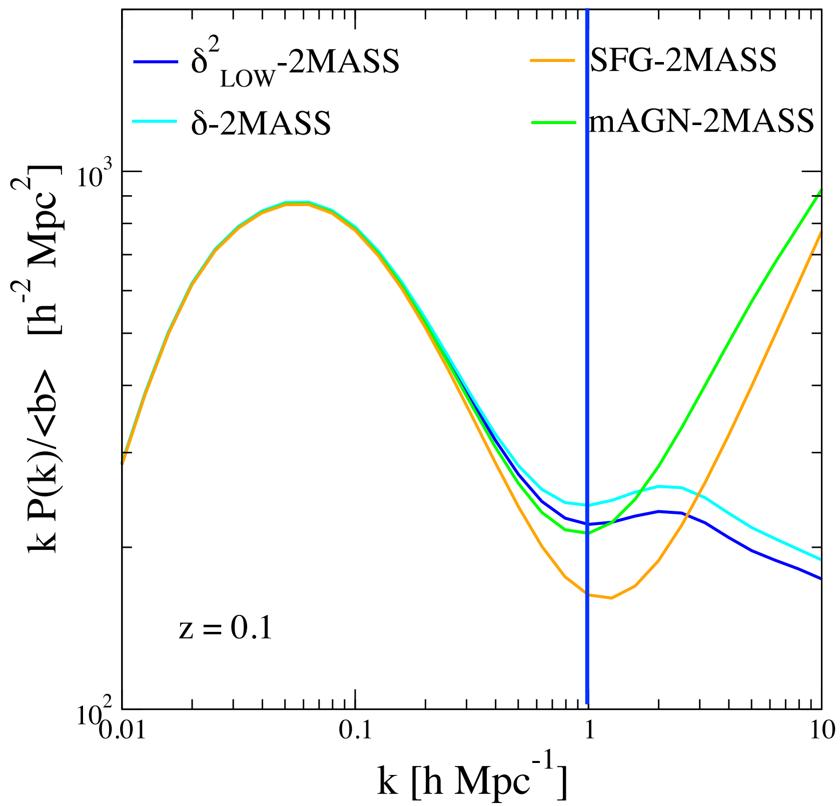
At the 2MASS redshift, sub-deg corresponds to Mpc scales, which are more compatible with DM or mAGN, rahter than SFG

Clear separation requires improved γ rays angular resolution

Cuoco, Xia, Regis, Branchini, NF, Viel, , arXiv:1506.01030

Model uncertainty for mAGN

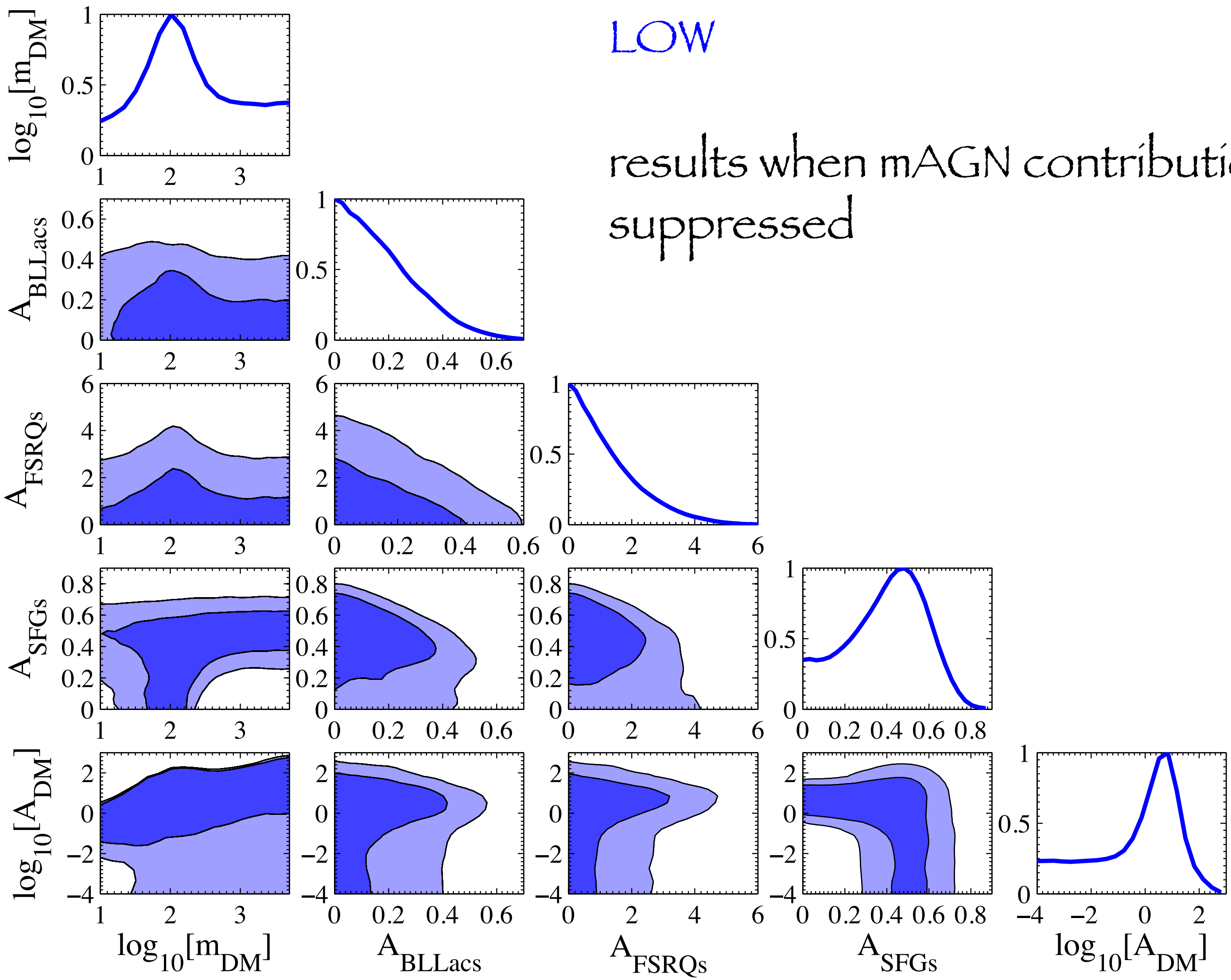




Model uncertainty on mAGN is large (only few detected in γ rays so far)

Key quantity: γ-rays -luminosity vs host-halo-mass relation

Fermi + LSS catalogs: DM + astro sources

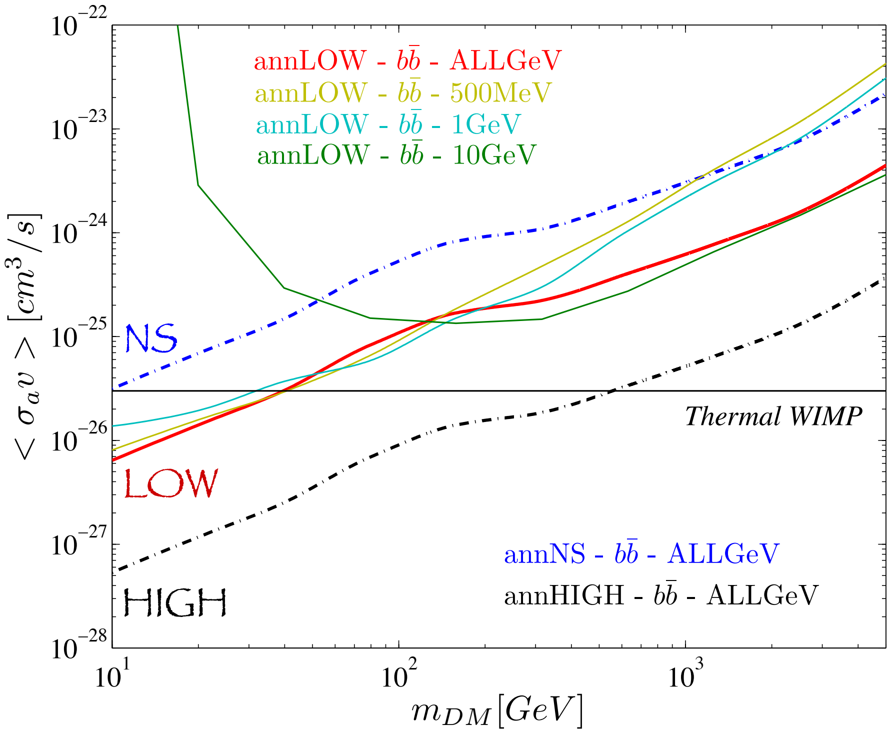


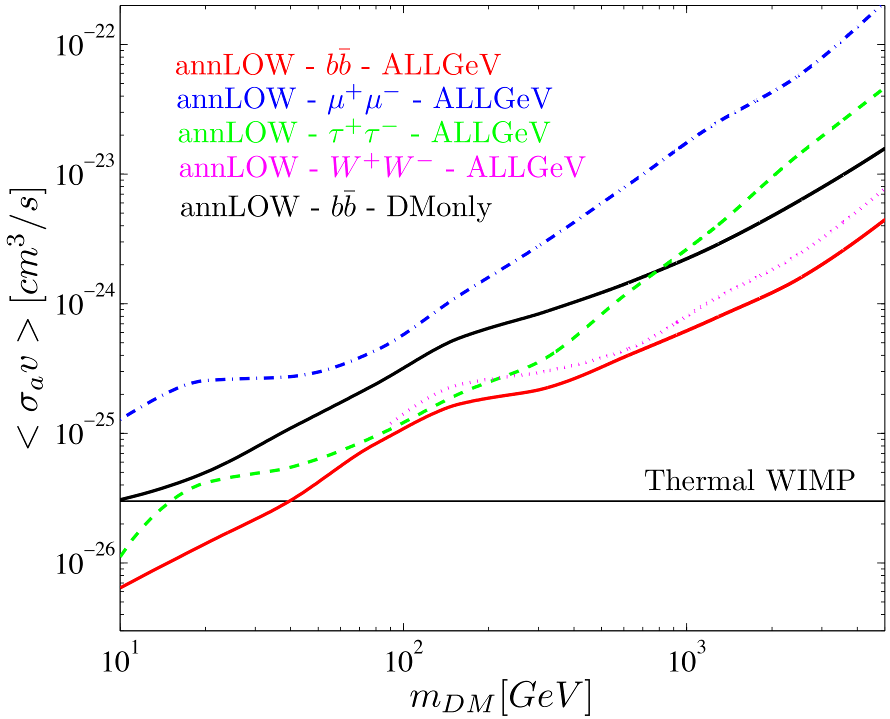
LOW

results when mAGN contribution is suppressed

Cuoco, Xia, Regis, Branchini, NF, Viel, , arXiv:1506.01030

Fermi + all LSS catalogs: DM bounds





Cuoco, Xia, Regis, Branchini, NF, Viel, , arXiv:1506.01030

Conclusions

- Multi-messenger and multi-wavelength signals offer a large network of opportunities for DM searches
- Galactic antiprotons and gamma-rays are currently setting the strongest and most robust bounds among the indirect detection searches
- Low-energy antideuterons persist among the best opportunities for indirect-detection signal discovery (option of "background free" signal for AMS and GAPS for a large portion of DM parameter space)
- Radio signals, notably at low frequencies, represent a promising channel, especially in view of the large sensitivities expected in future surveys (e.g. Lofar, SKA)
- Cross-correlations offer an emerging opportunity: especially correlations of gamma-rays with gravitational tracers, like cosmic-shear appear to be a potential channel of discovery with the future weak-lensing survey (DES, Euclid)

Conclusions

- In the meanwhile, two gamma-rays/gravity-tracers correlations have been measured:
  - Cross-correlation with galaxy catalogues and LSS objects (3.5σ)
  - Cross-correlation with CMB-lensing (3.0σ)

- Implications for DM starts to be intriguing

- Cross-correlations represent the strongest technique to investigate DM and its clustering properties outside the local neighbourhood, setting a critical bridge between the CMB and the local enviromnent (galactic center, dwarf galaxies) scales