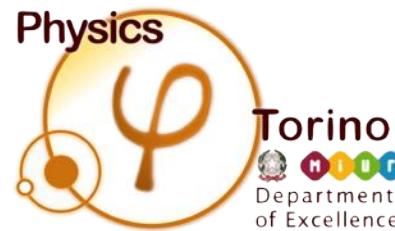


INDIRECT DARK MATTER SEARCHES

NICOLAO FORNENGO

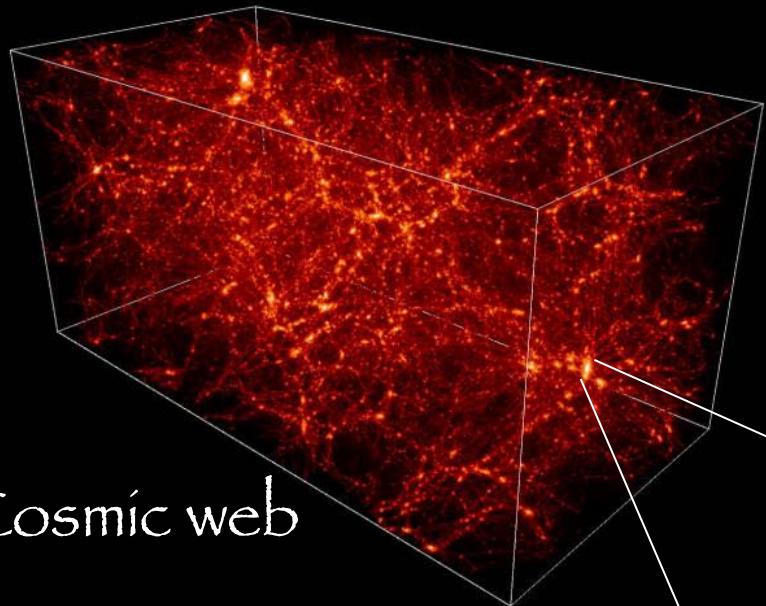
Department of Physics – University of Torino
and Istituto Nazionale di Fisica Nucleare (INFN) – Torino
Italy



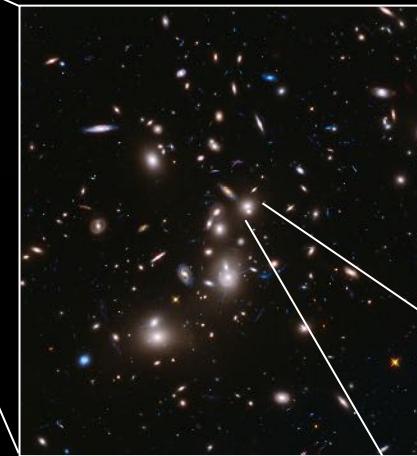
Istituto Nazionale di Fisica Nucleare

Supersymmetry and Unification of Fundamental Interactions (SUSY 2018)
Barcelona – 26.07.2018

Dark matter is present at any scale



Cosmic web



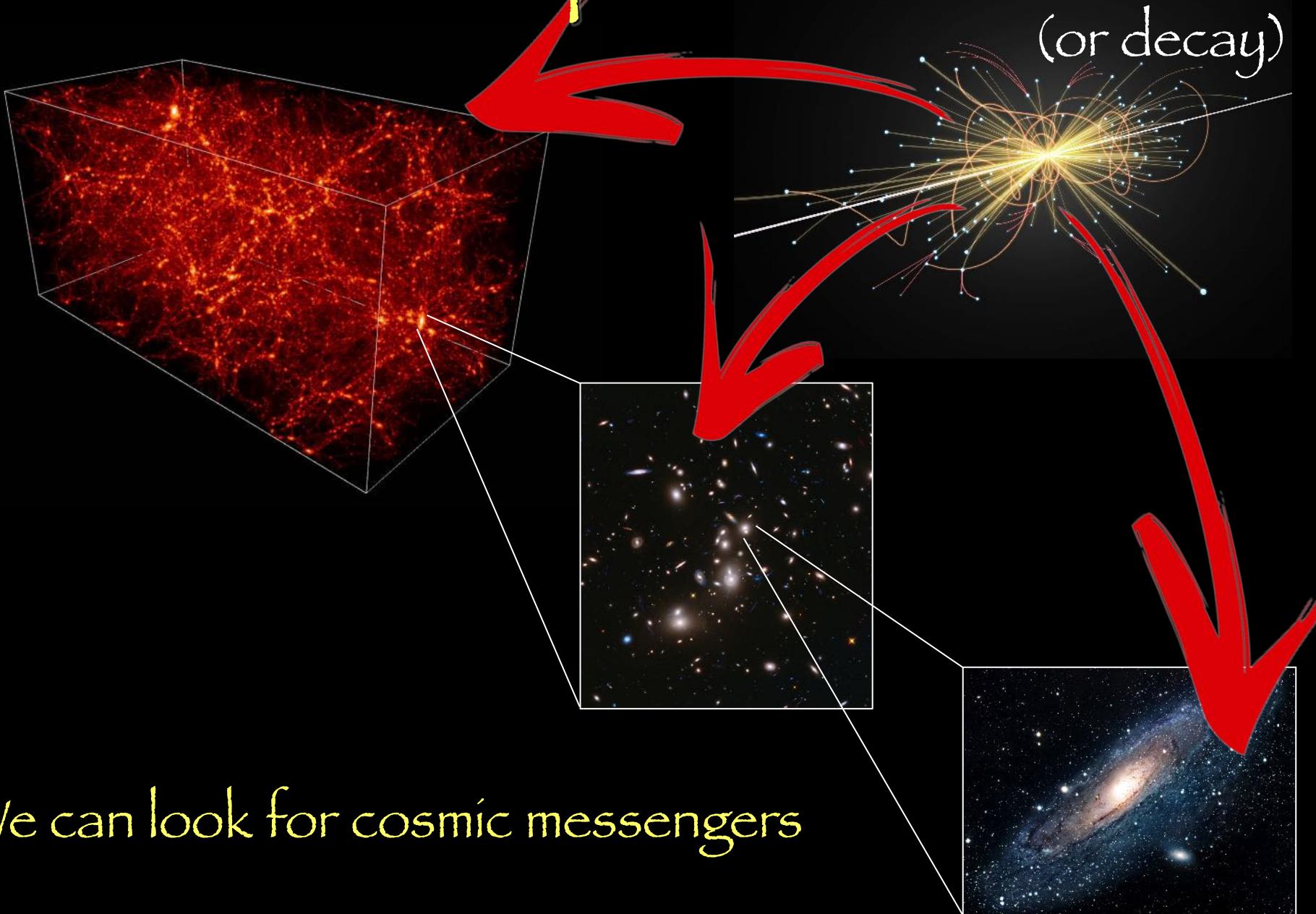
Clusters of galaxies



Galaxies

If dark matter is a particle ...

annihilation
(or decay)



We can look for cosmic messengers

Multimessengers scenario

radio IR X gamma

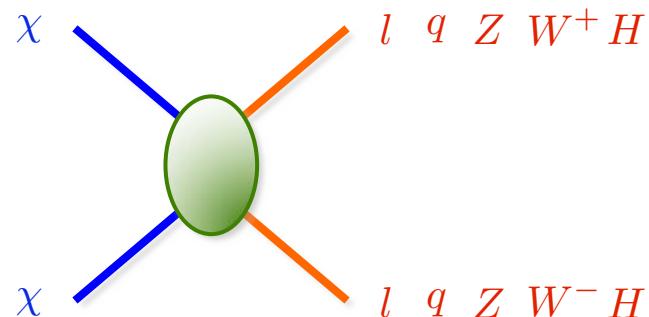
Photons

Cosmic rays electrons/positrons
 antiprotons, antideuterium, antinuclei

Neutrinos



Features of the astrophysical signals



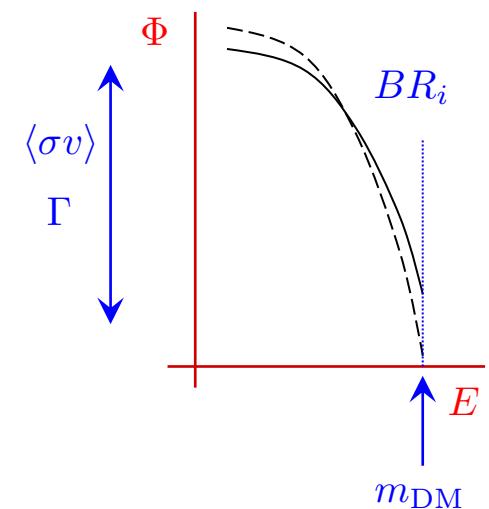
Non-relativistic
annihilation (or decay)

$$S \sim \left(\frac{\rho_{\text{DM}}}{m_{\text{DM}}} \right)^{2,1} \times \{ \langle \sigma v \rangle, \Gamma \} \times [\text{energy spectrum}]$$

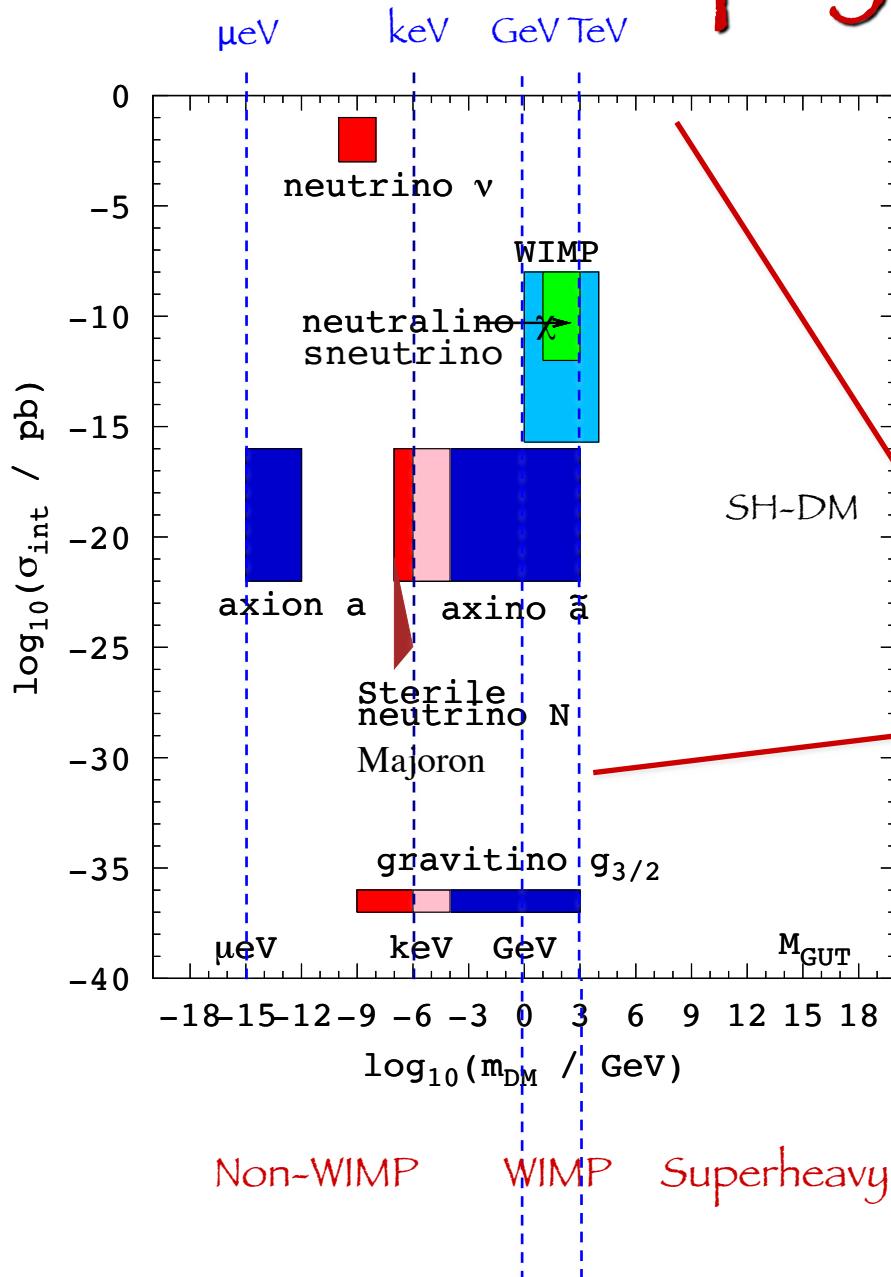
Relevant particle physics properties:

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



Particle physics scales



“Strong (-ish)”

Self-interacting
Technicolor DM

...

“EM (-ish)”

Millicharged DM
Electric/magnetic dipole

...

Weak

WIMP

Gravitational

Relic from the early Universe

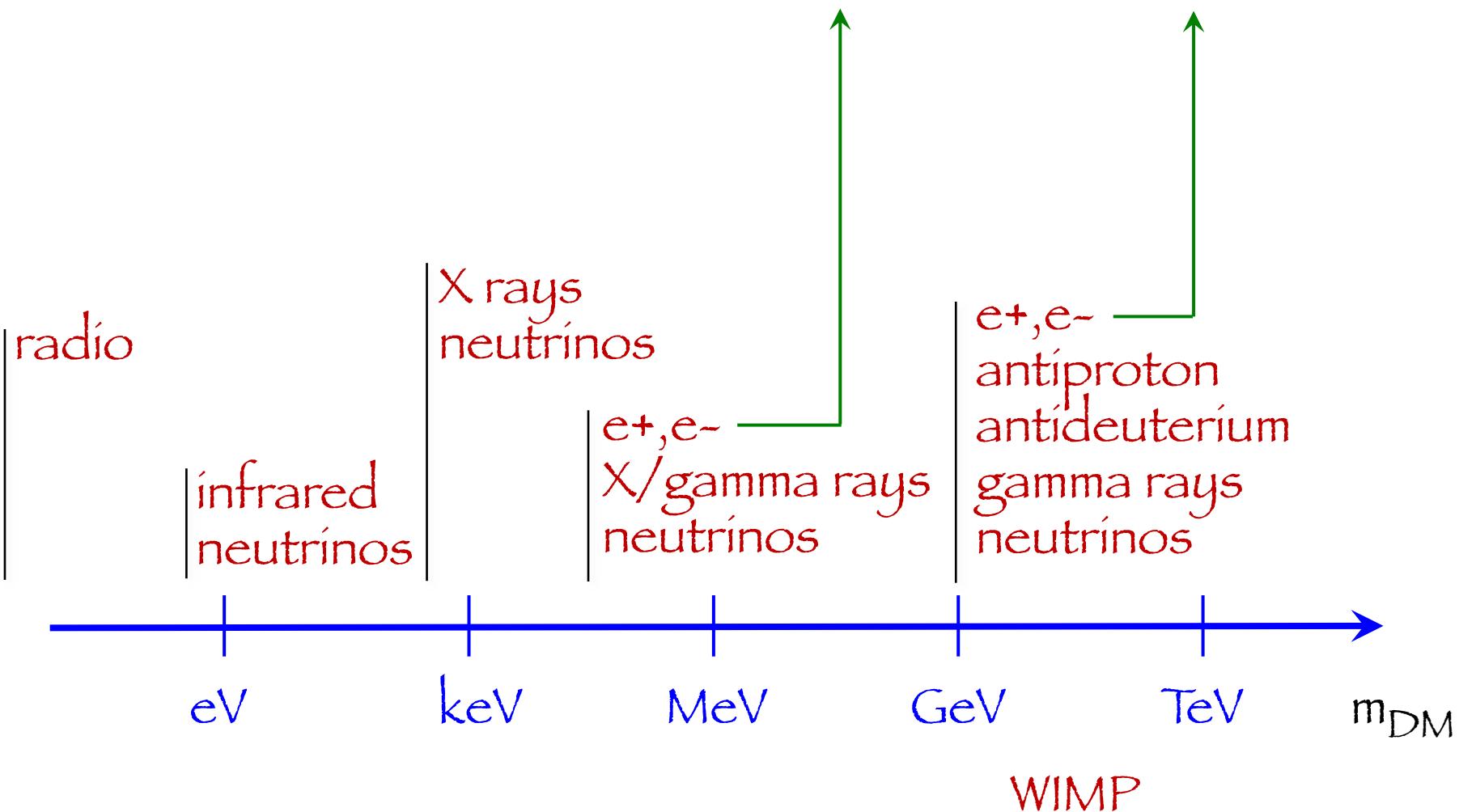
Thermal

Non thermal

Dynamically: non relativistic (cold)
collisionless

The MultiMessenger Landscape

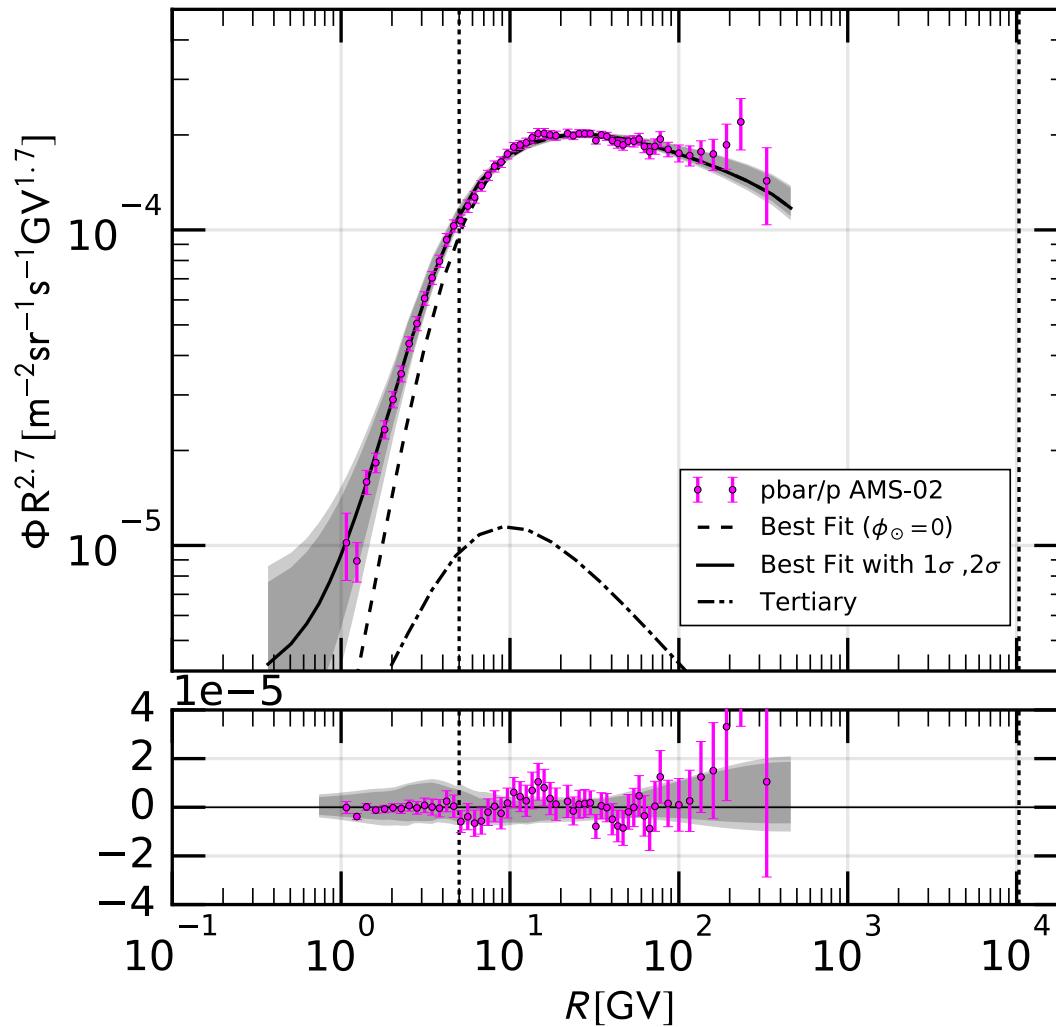
X/gamma rays: IC on radiation fields
radio: synchro on ambient mag fields



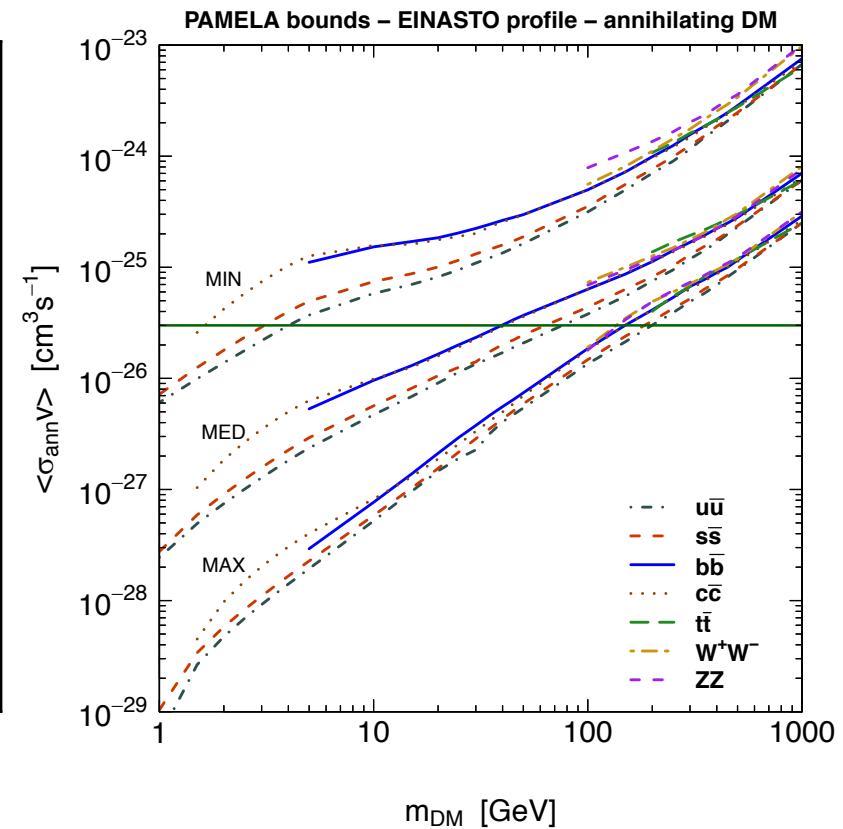
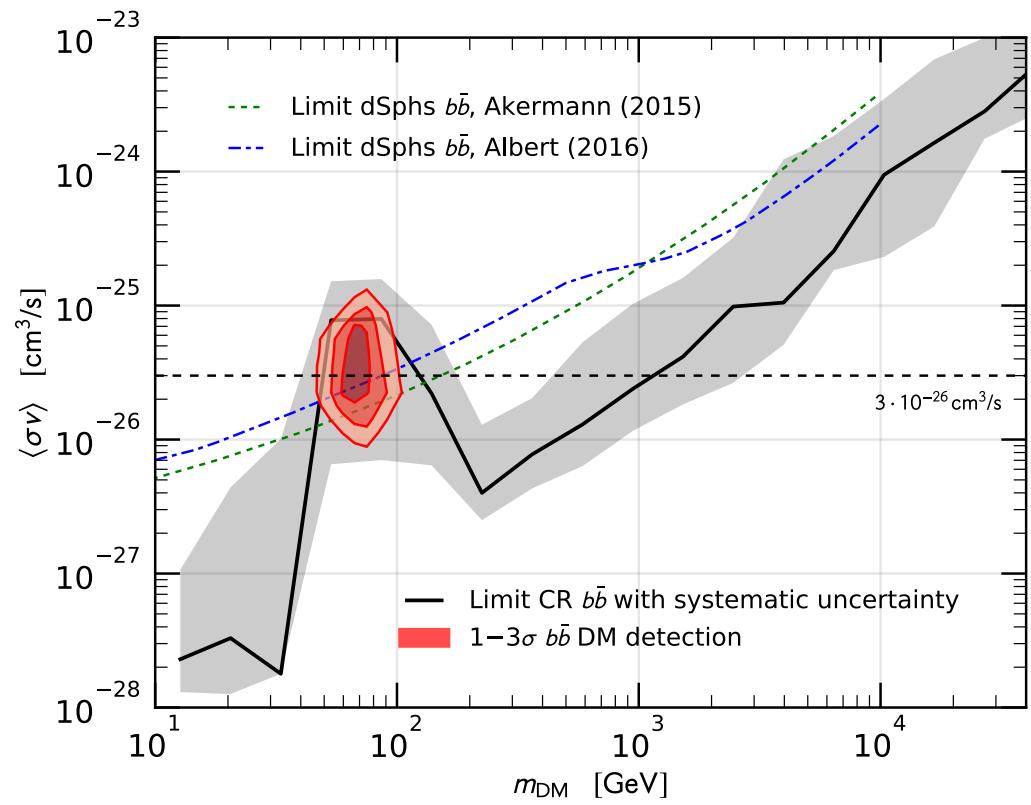
Cosmic messengers and Dark Matter

	WIMP non WIMP radio	IR	X	WIMP gamma
Photons				
Cosmic rays	electrons/positrons antiprotons, antideuterium, antinuclei			WIMP, non WIMP WIMP
Neutrinos				WIMP, non WIMP

Antiprotons



Bounds from antiprotons

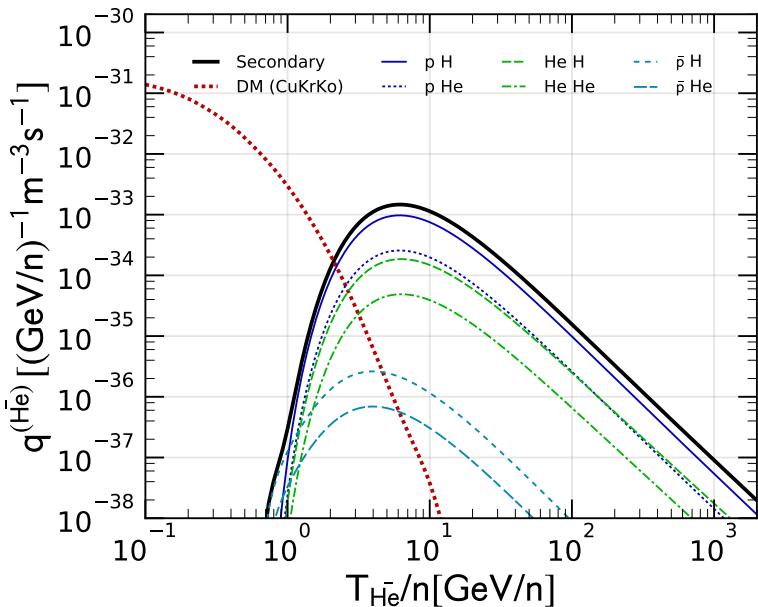
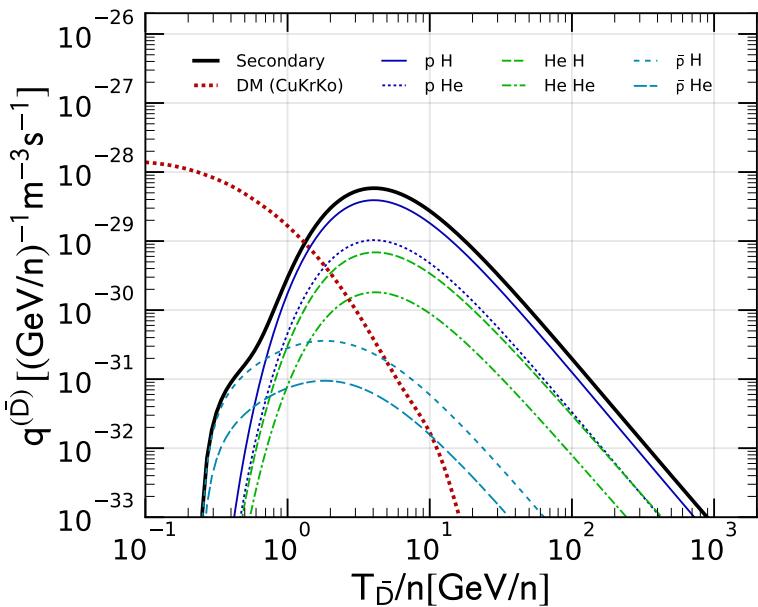


Cuoco, Kraemer, Korsmeier, PRL 118 (2017) 191102

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

Antinuclei

Korsmeier, Donato, NF, PRD 97 (2018) 103011



Anti Deuterium

Originally from:
Donato, NF, Salati, PRD 62 (2000) 043003

$$E_{p_{\text{CR}}}^{\text{th}} = 17 m_p$$

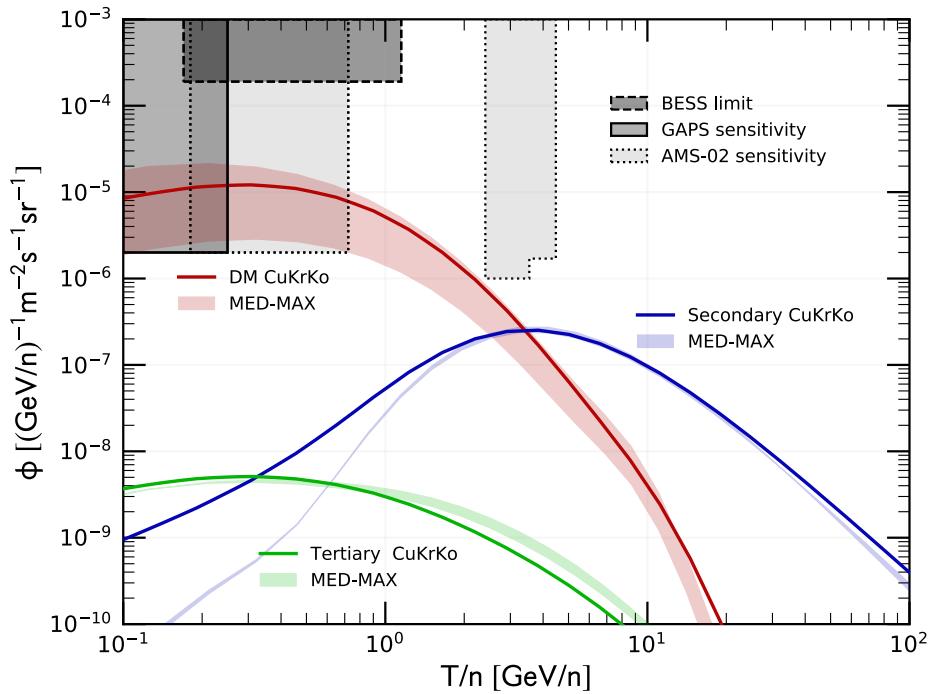
Anti Helium

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

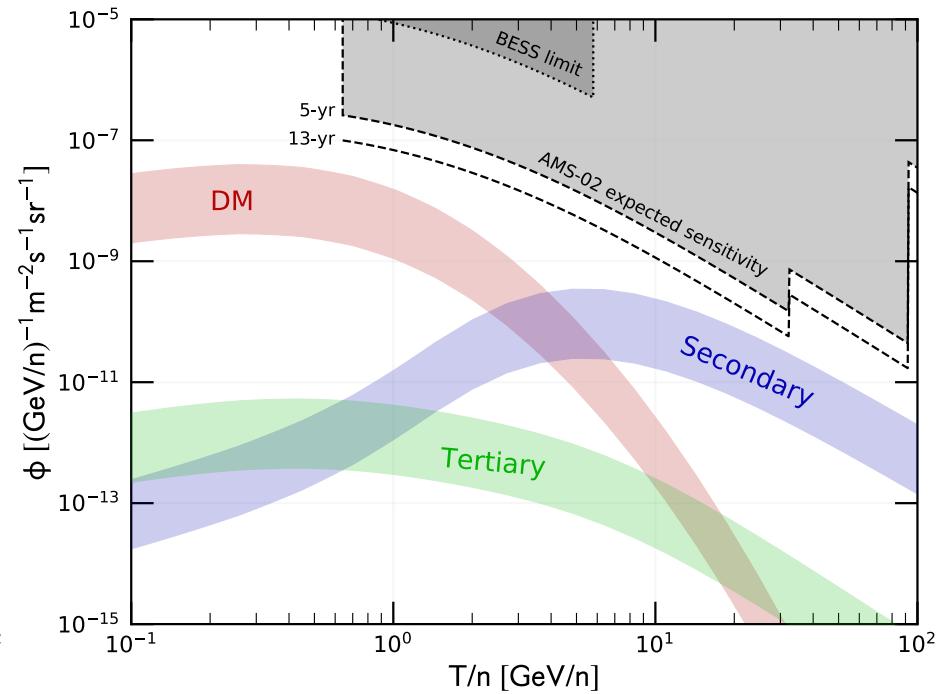
$$E_{p_{\text{CR}}}^{\text{th}} = 31 m_p$$

Prospects for Antinuclei

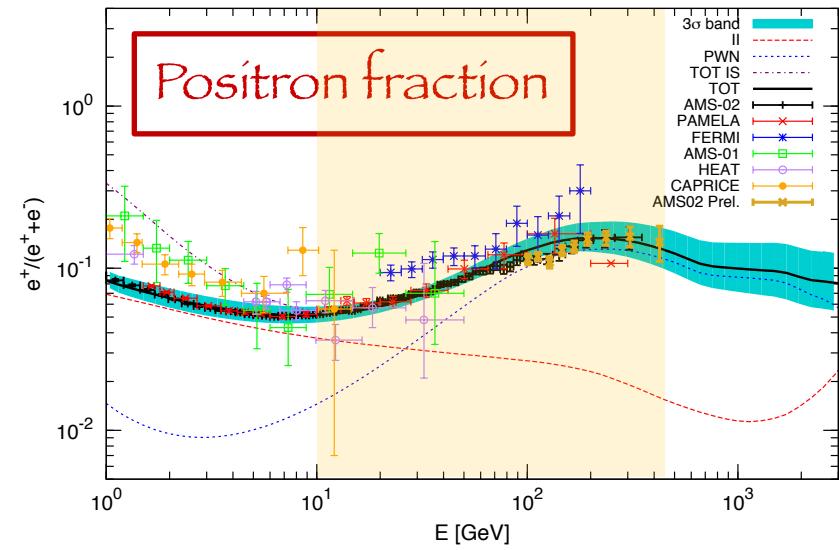
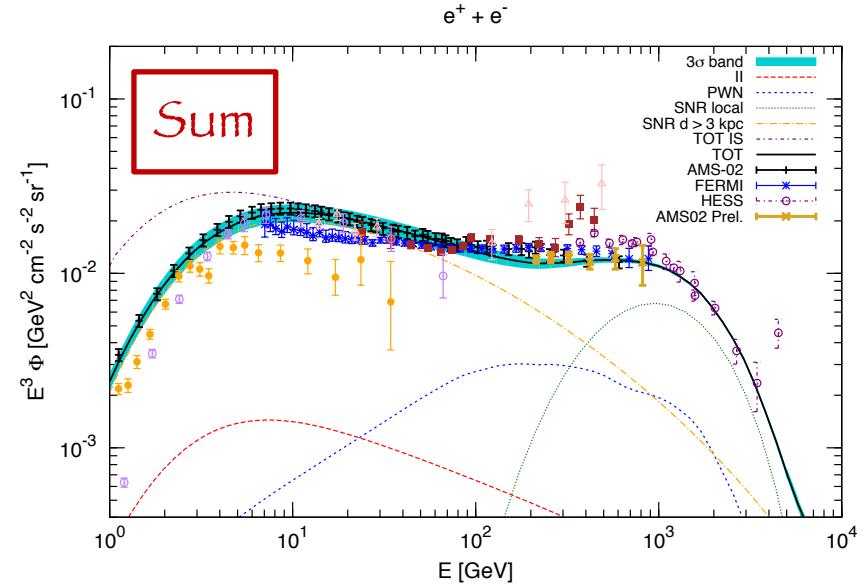
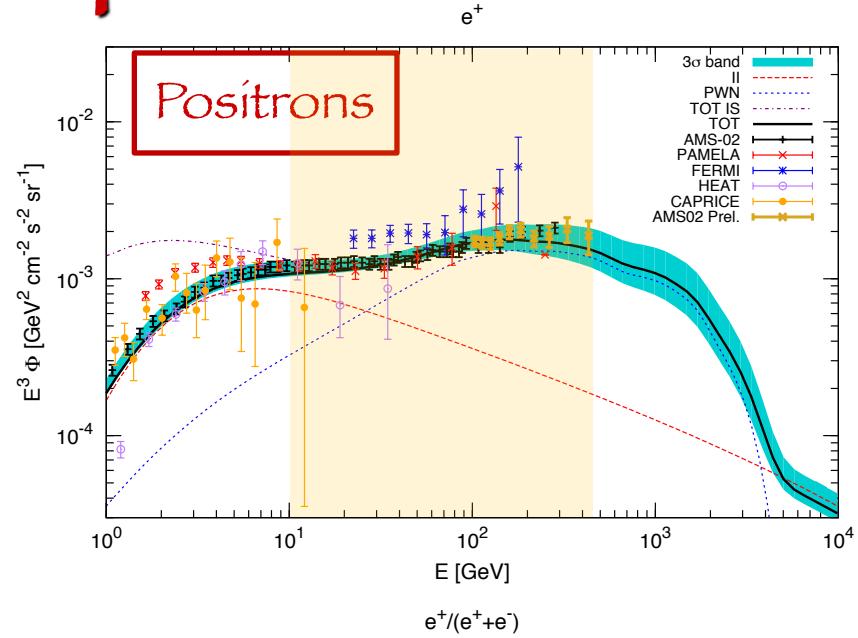
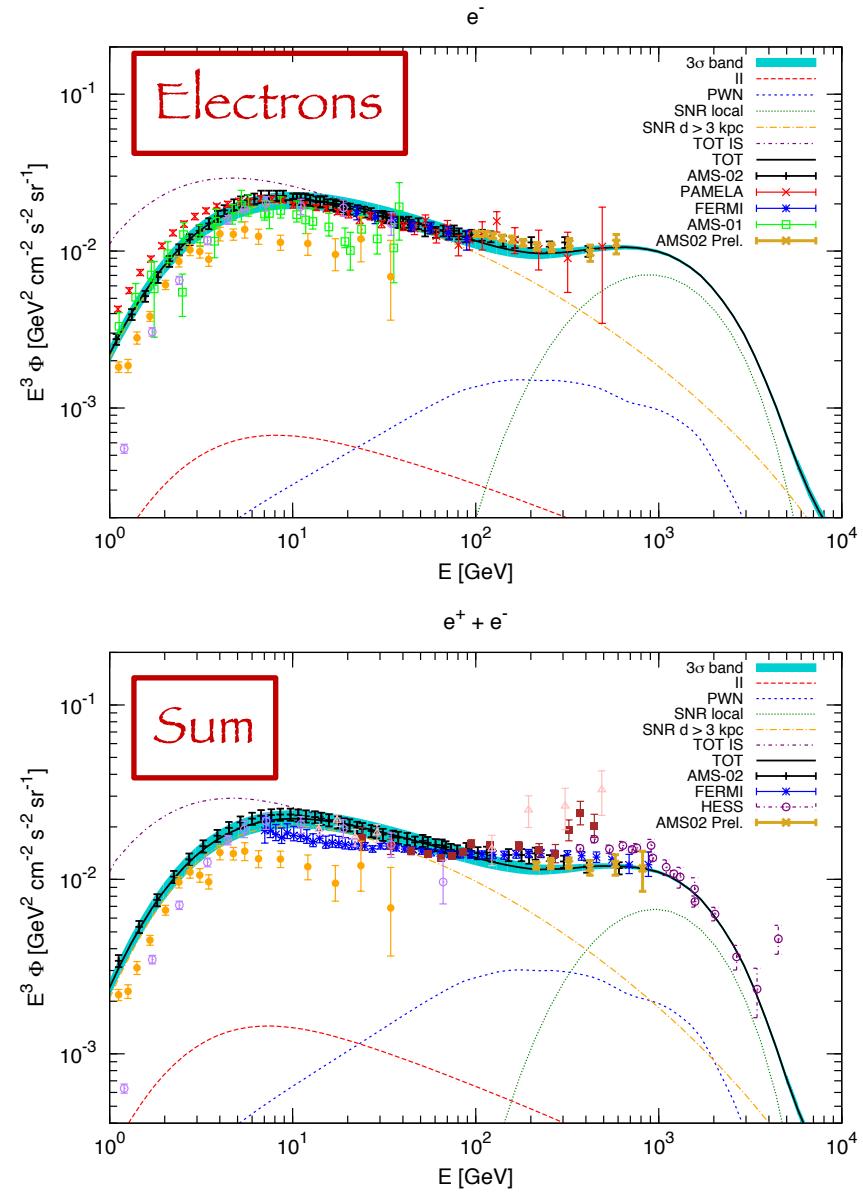
Anti Deuterium



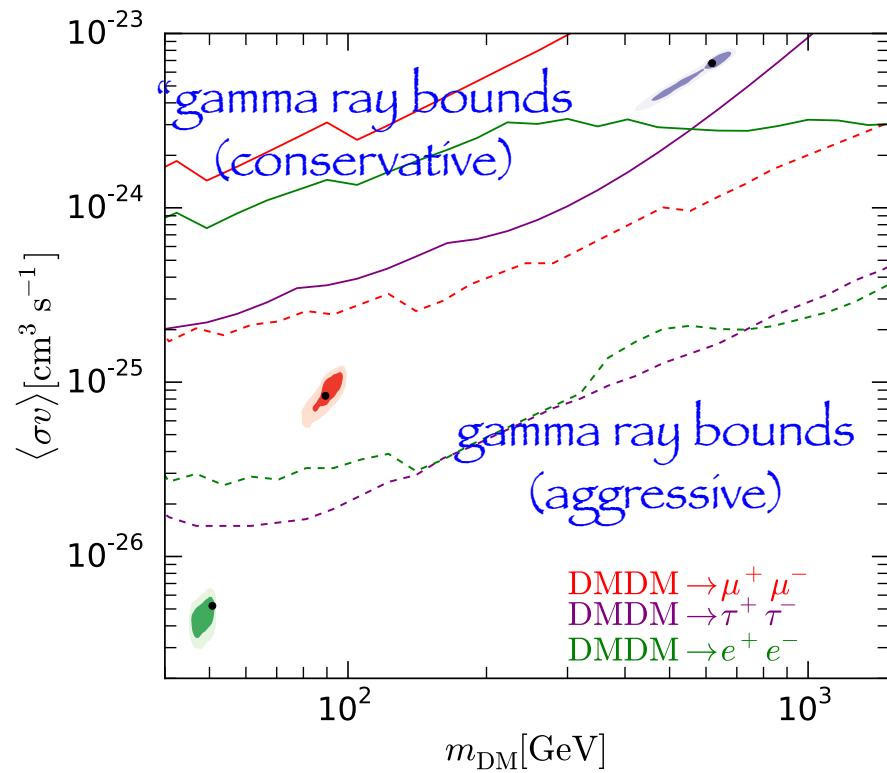
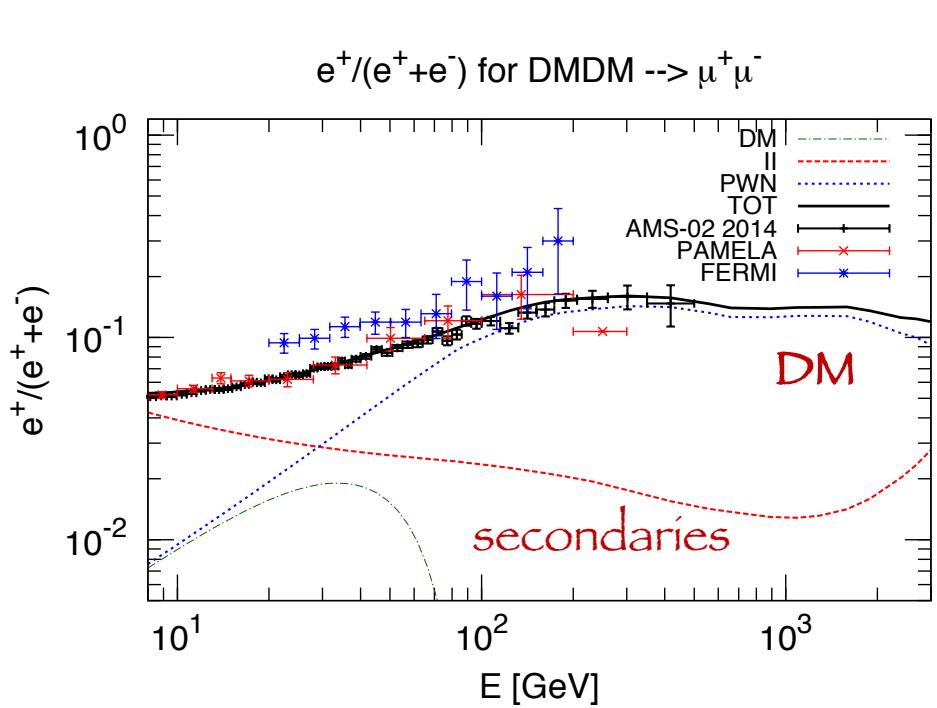
Anti Helium



Electrons and positrons



DM as dominant contributor

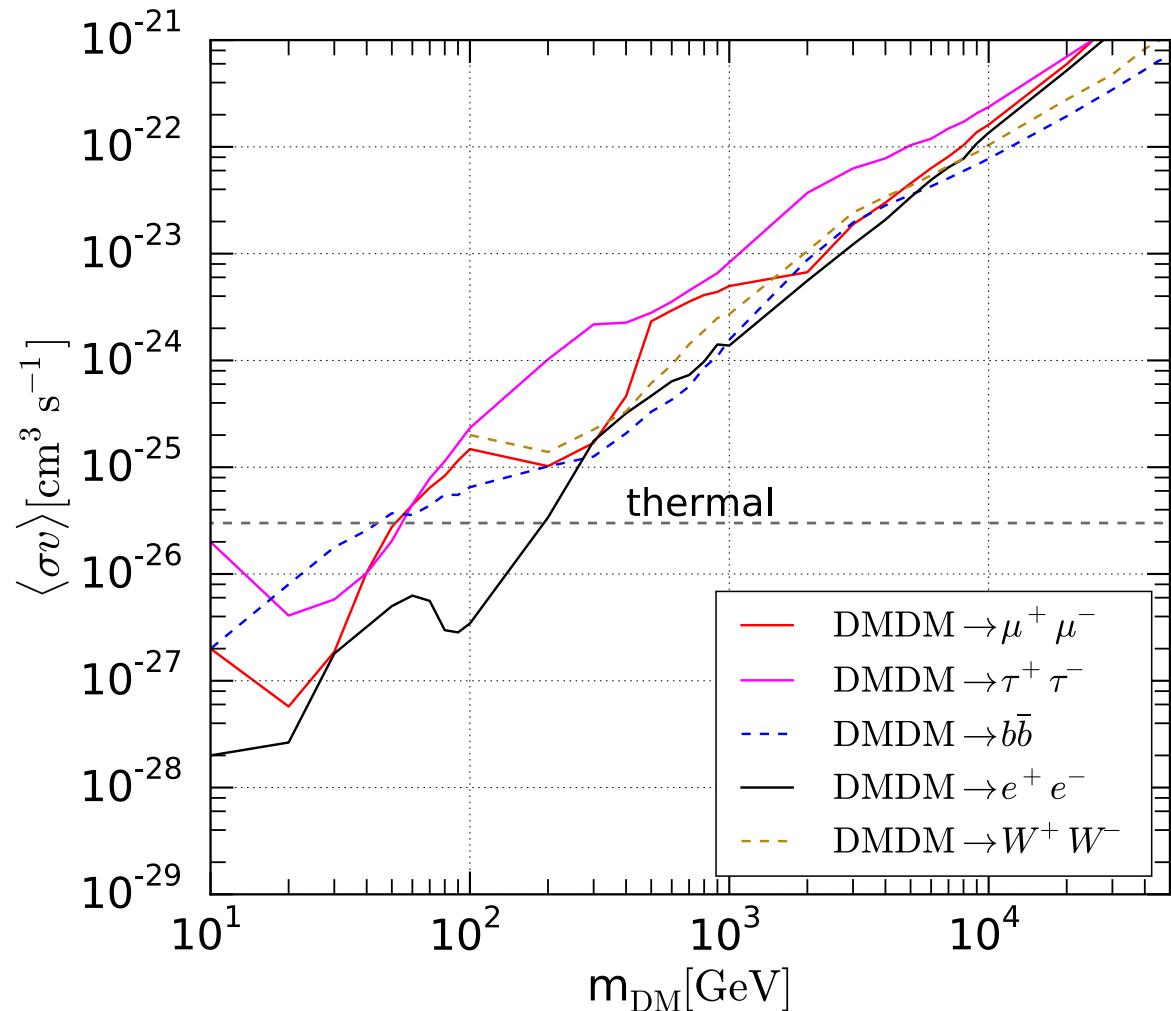


Large “boosts” are required

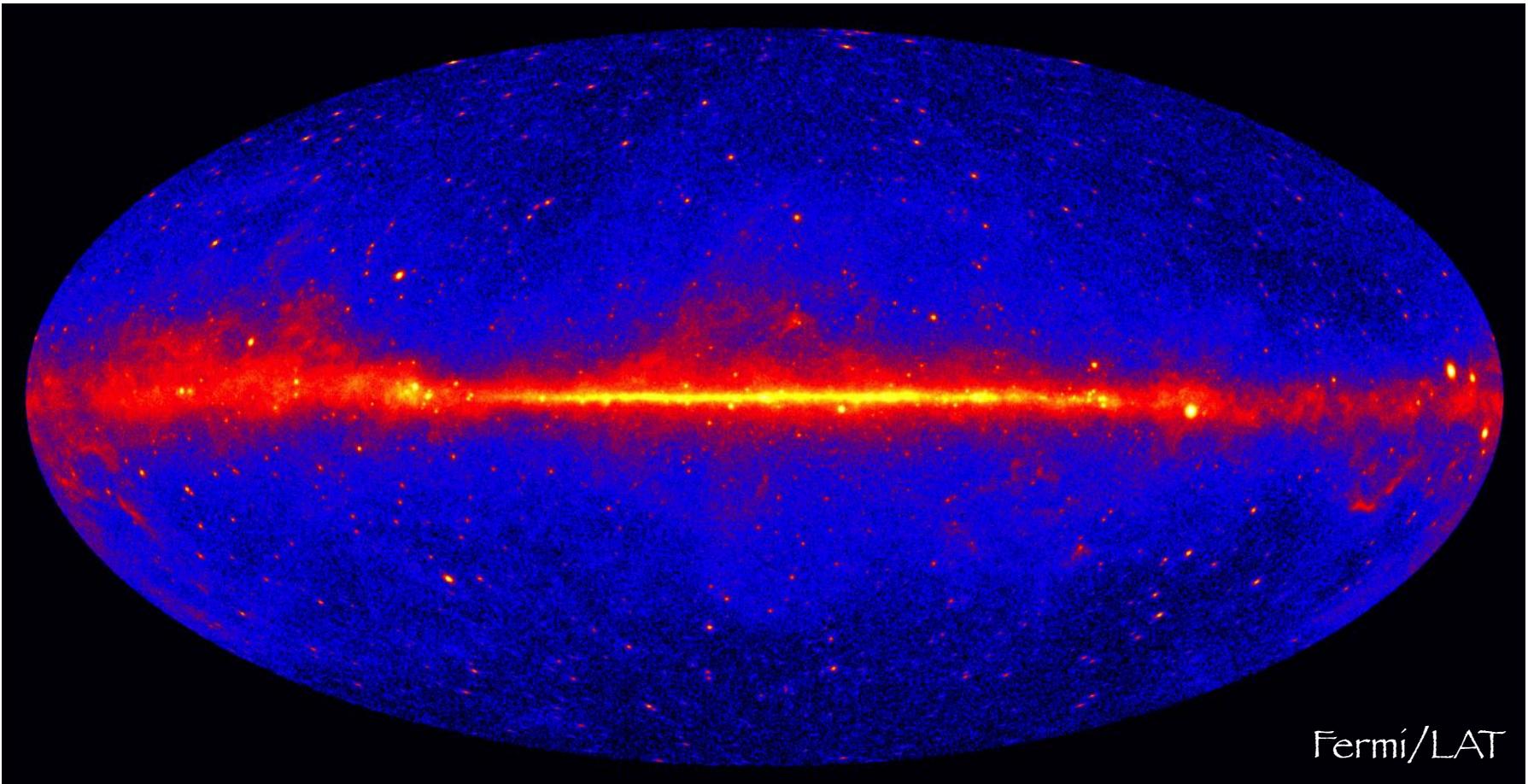
Leptonic production required (otherwise accompanied by too-many antiprotons and gamma rays, unless DM is very heavy)

DM as subdominant contributor

Bounds on DM



Gamma rays



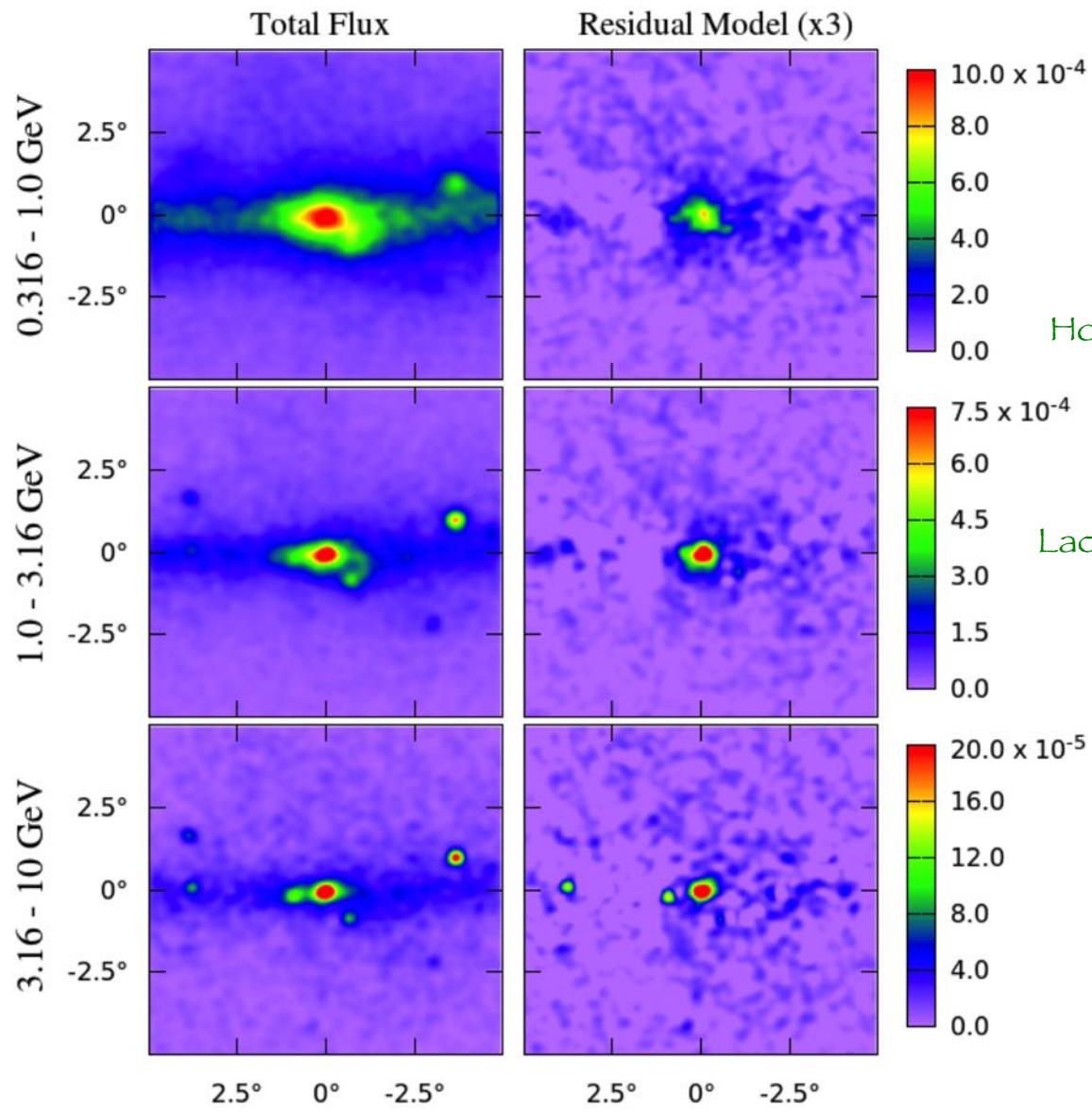
Fermi/LAT

Galactic center

Diffuse gamma ray background

Dwarf galaxies

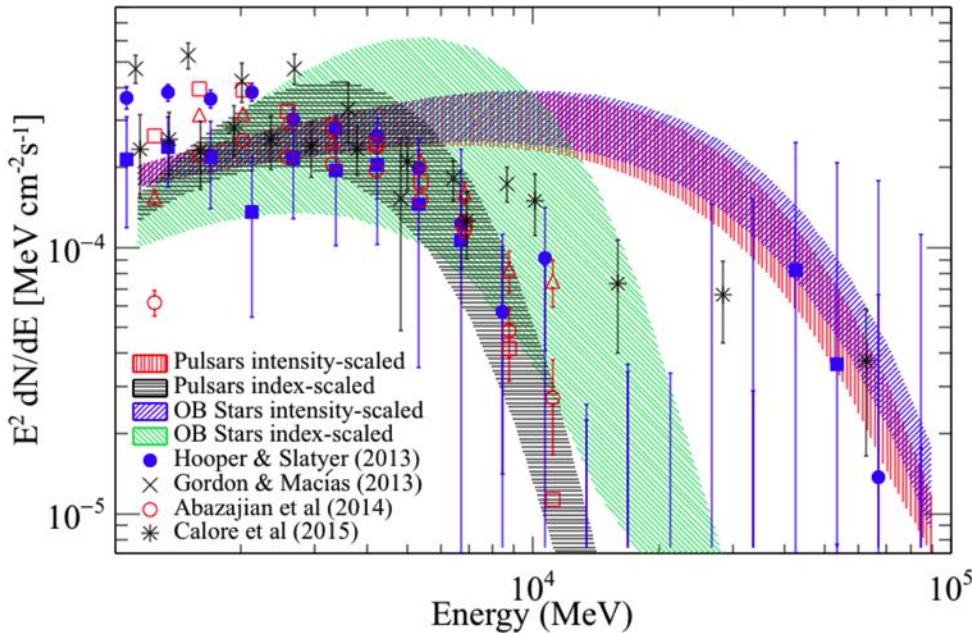
Galactic center: an “excess” ?



Hooper, Goodenough, PLB (2011) 697 (2011)
Hooper, Linden, PRD 84 (2011) 123005
Boyarsky et al., PLB (2011) 705
Daylan et al., Phy Dark Univ 12 (2016) 1
Abazajian et al, PRD 90 (2014) 023526
Lacroix, Boehm, Silk, PRD 90 (2014) 043508

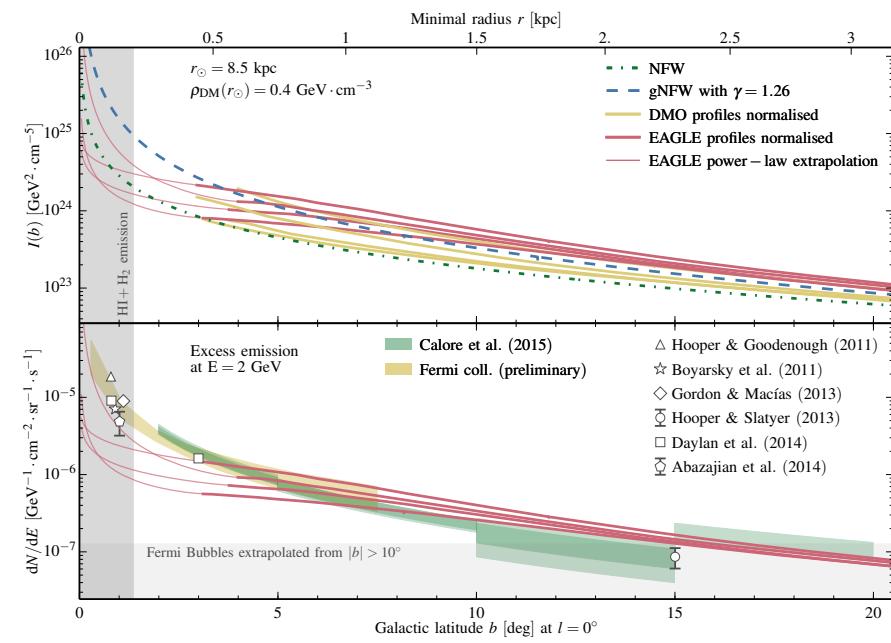
Features of the excess

Energy spectrum



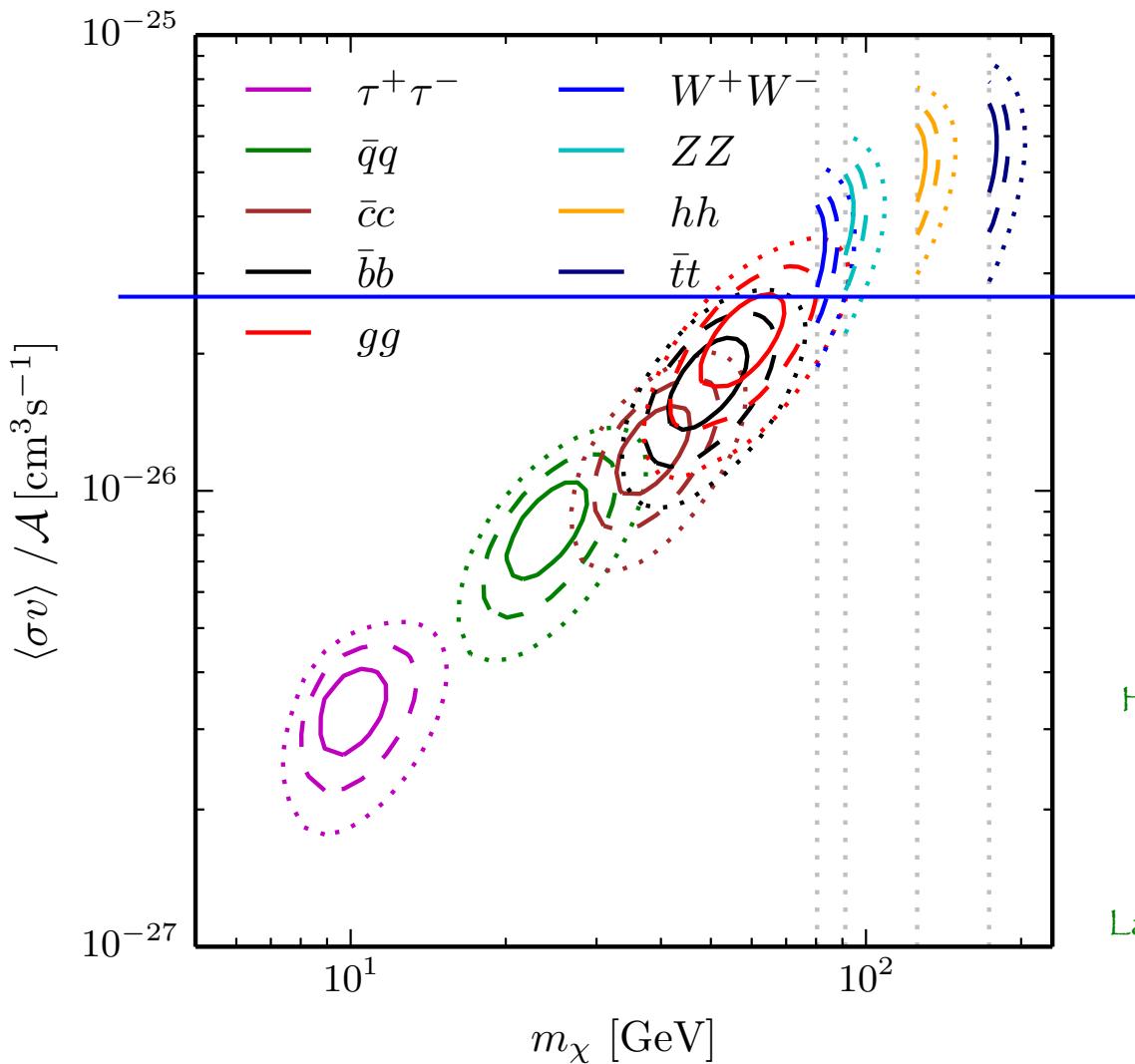
Ajello et al, ApJ 819 (2016) 44

Radial profile



Schaller et al, MNRAS 455 (2016) 4442

DM interpretation



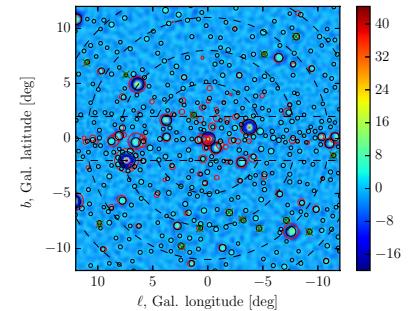
Calore et al, PRD 91 (2015) 063003

Hooper, Goodenough, PLB (2011) 697 (2011)
Hooper, Linden, PRD 84 (2011) 123005
Boyarsky et al., PLB (2011) 705
Daylan et al., Phy Dark Univ 12 (2016) 1
Abazajian et al, PRD 90 (2014) 023526
Lacroix, Boehm, Silk, PRD 90 (2014) 043508

Point sources interpretation ?

Wavelet analysis

Bartels, Krishnawirthy, Weniger, PRL 116 (2016) 051102

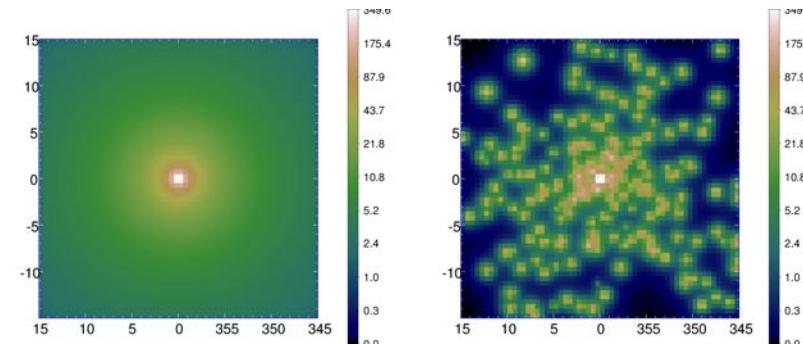


Non-poissonian template fit

Lee, Lisanti, Safdi, Slatyer, PRL 116 (2016) 051102

Machine learning

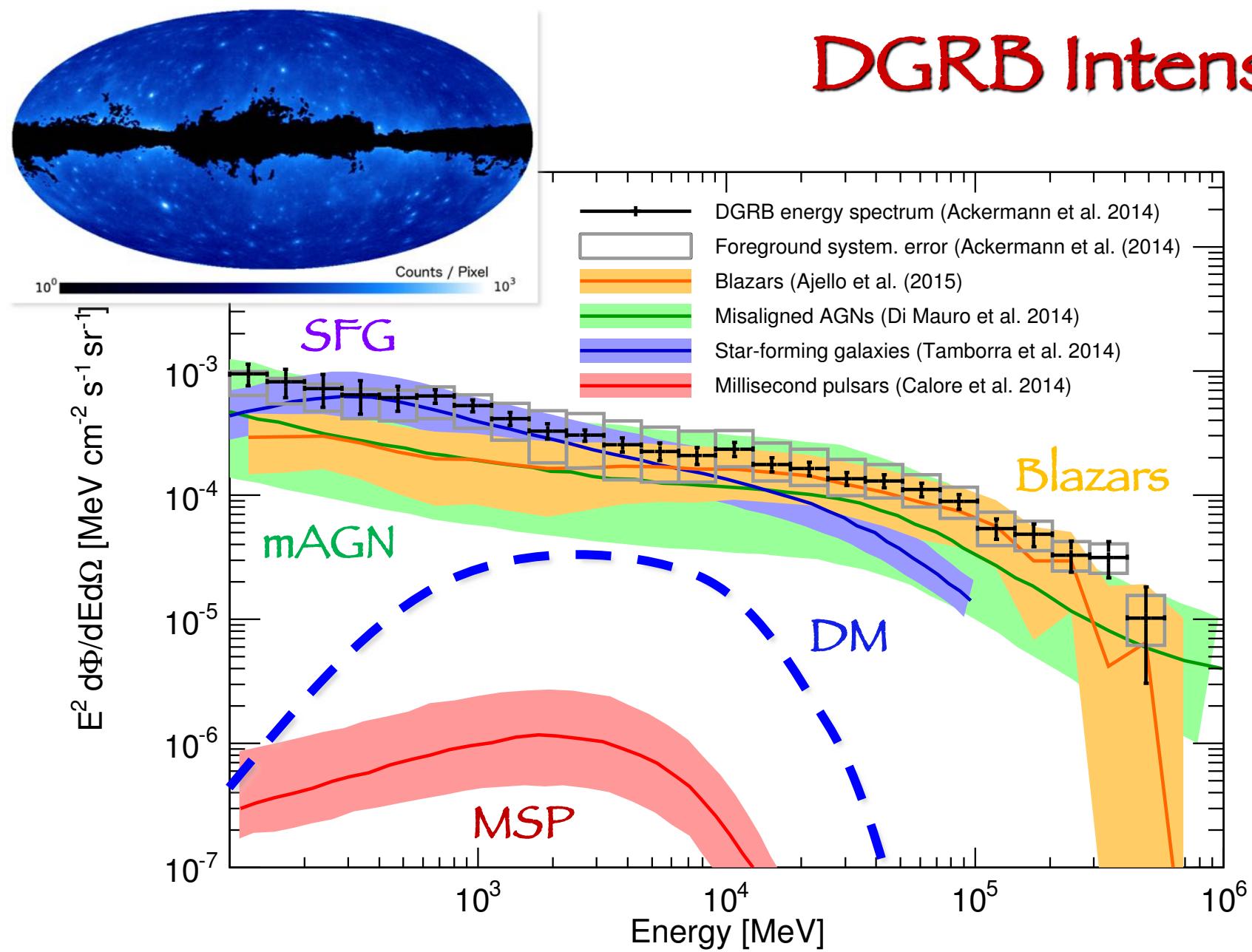
Caron, Gomez-Vargas, Hendriks, Ruiz de Austri,
JCAP 1805 (2018) 058



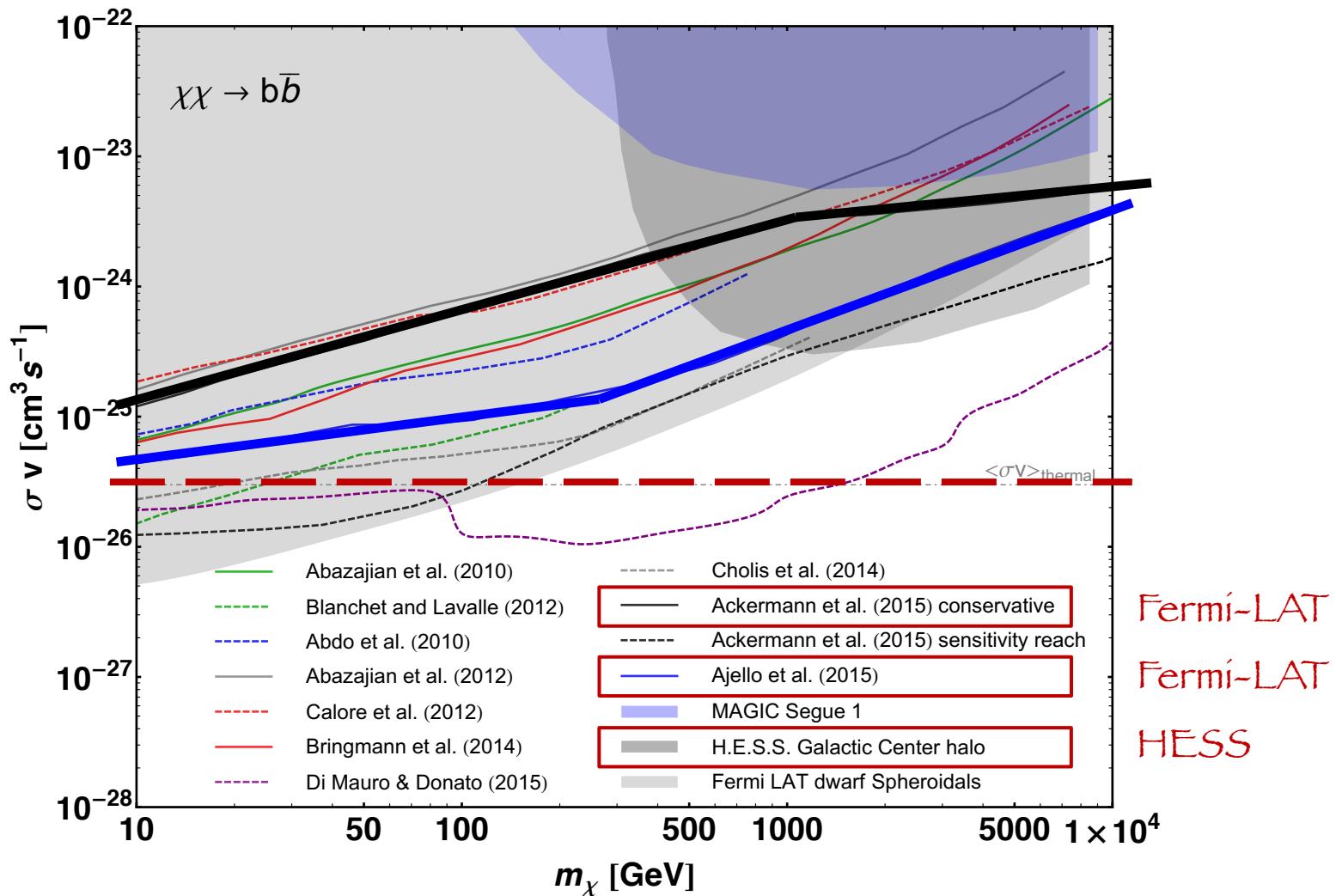
Different techniques devised to distinguish between point sources and true diffuse emission report a preference for point sources

This suggests emission from unresolved pulsars

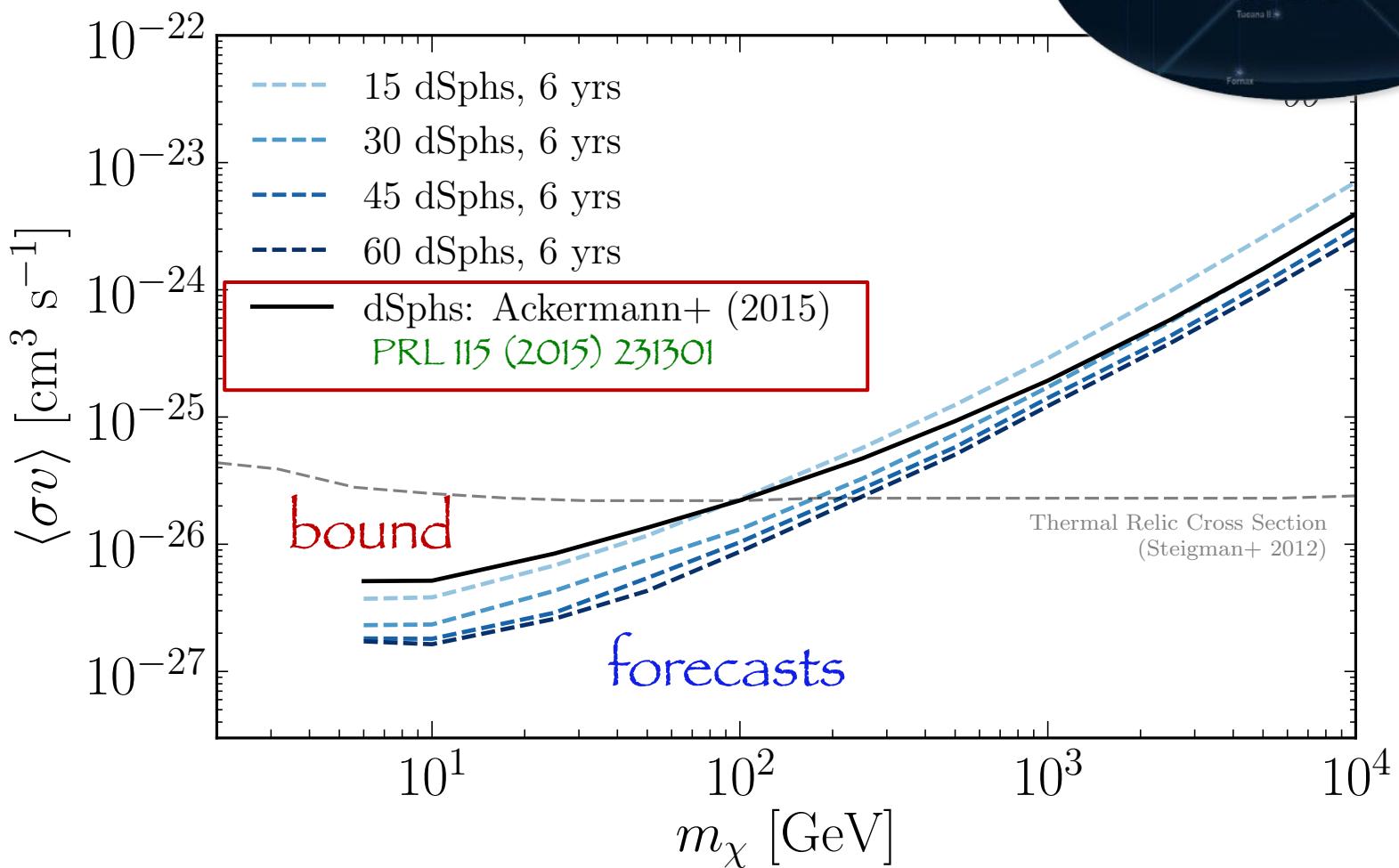
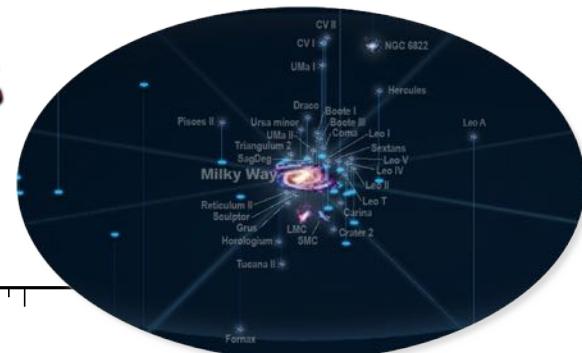
DGRB Intensity



DGRB intensity bounds on DM



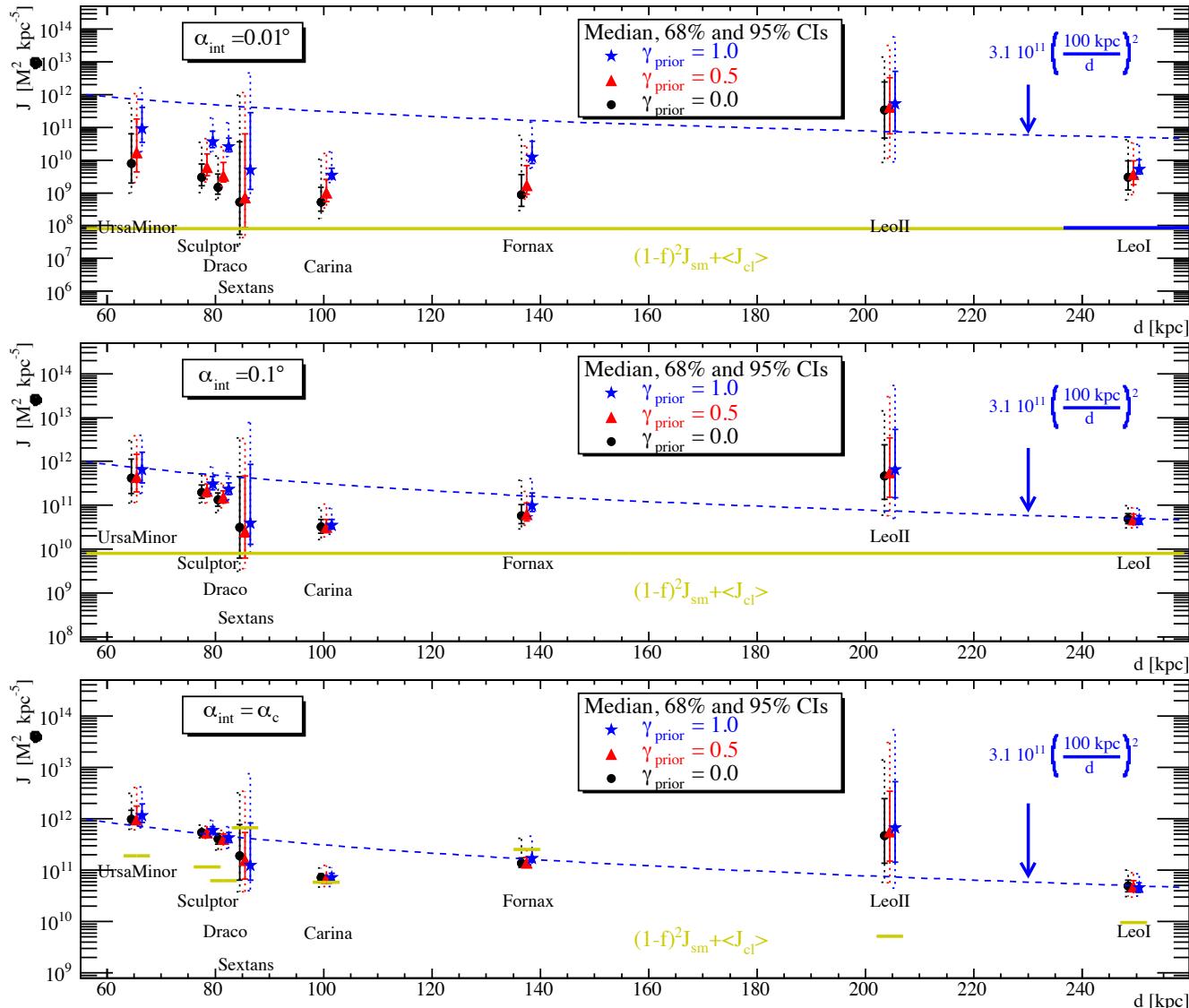
Dwarf galaxies



J factor

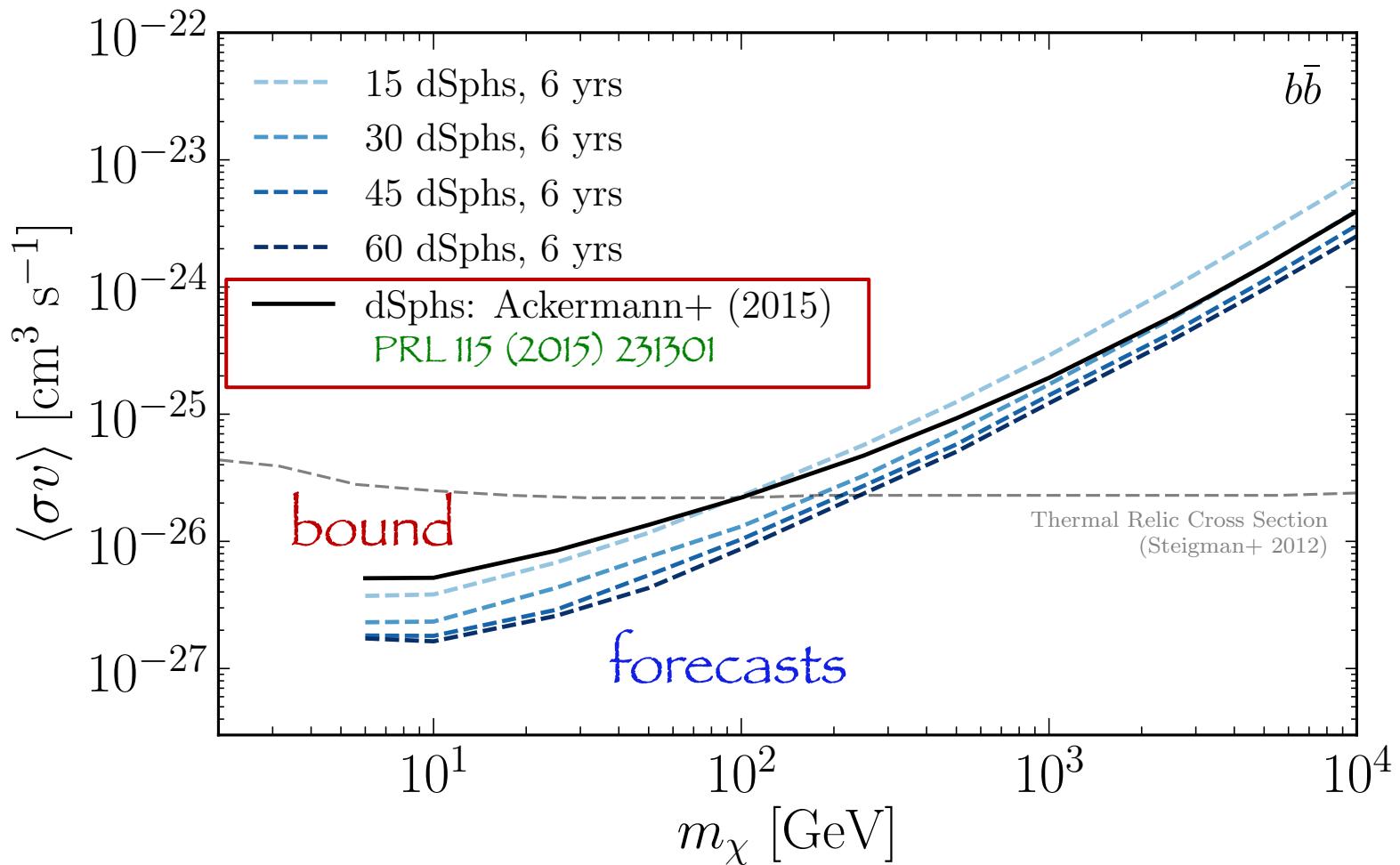
galactic

Charbonnier et al, MNRAS 418 (2011) 1526



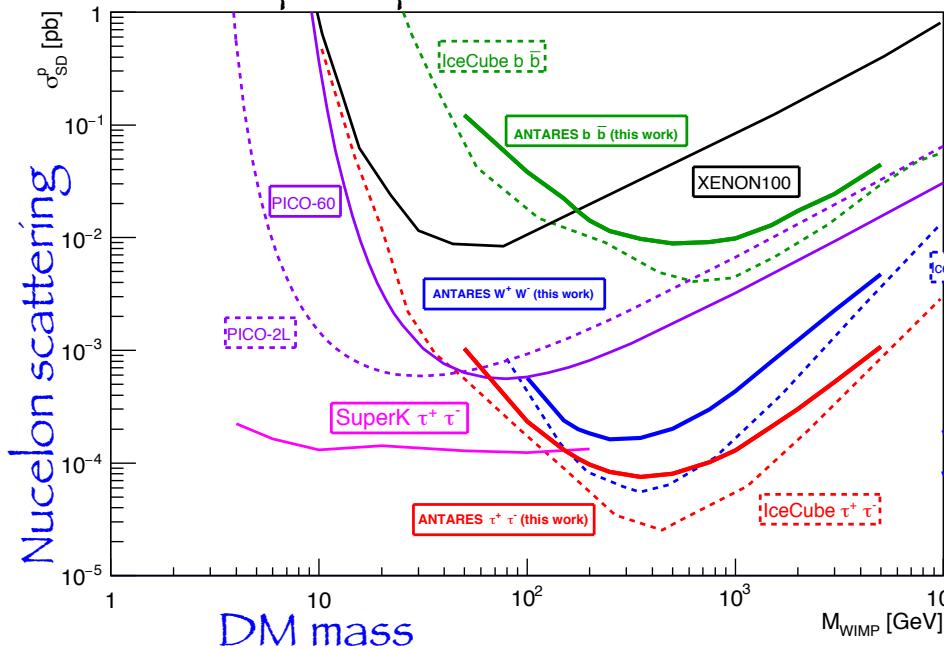
$$J = \int \rho_{\text{DM}}^2(l, \Omega) dl d\Omega$$

Dwarf galaxies



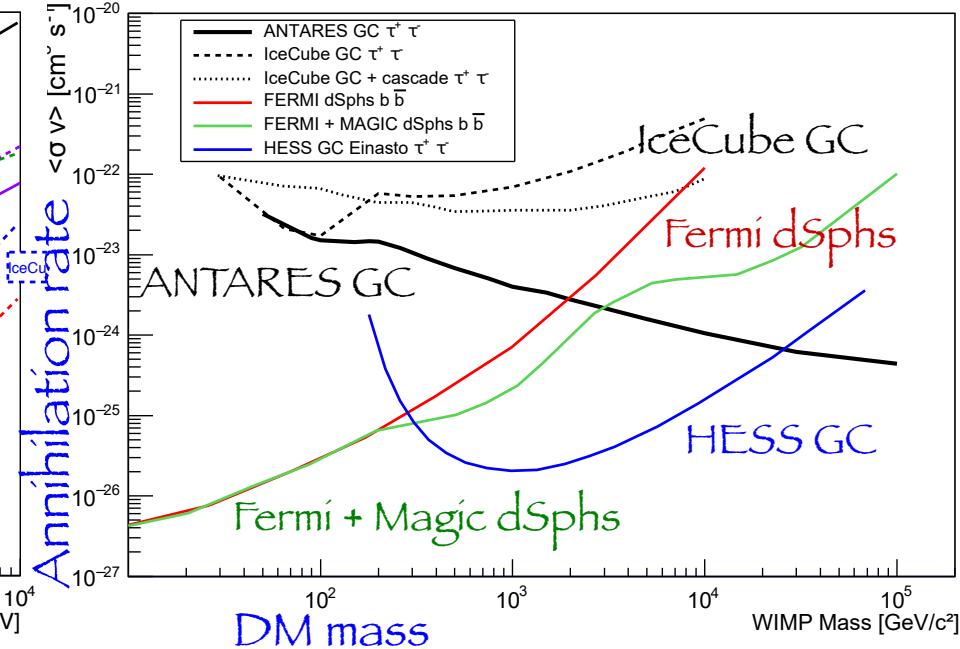
Neutrinos

From the Sun
Spin dependent interaction



ANTARES Collab, PLB 759 (2016) 69

Other targets



ANTARES Collab, PLB 769 (2017) 249

DM gets captured inside the Sun,
then accumulates and finally
annihilates

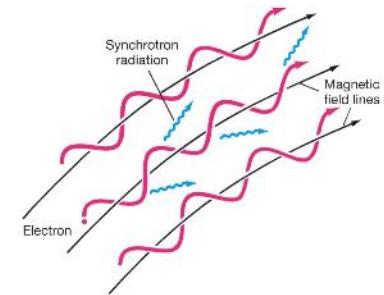
Radio signals from dark matter

DM annihilation/decay into e^+/e^- produce 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

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

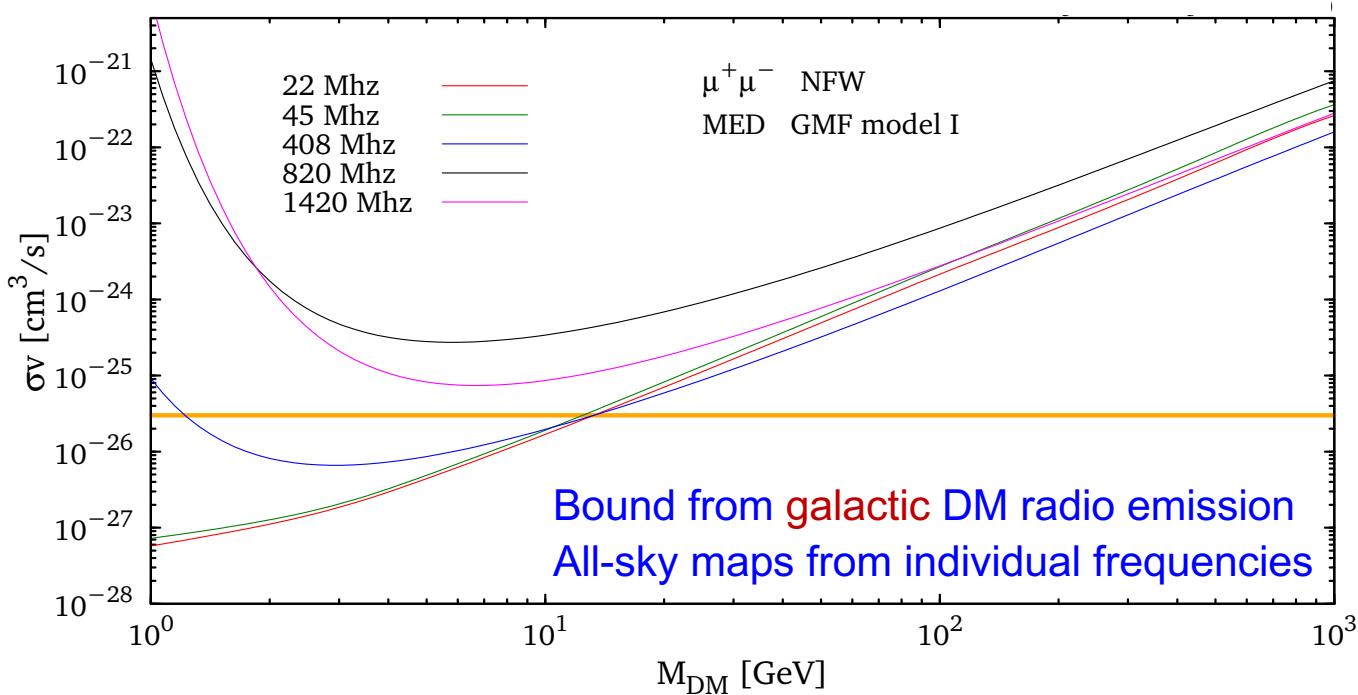


(*) Relevant interval for WIMP DM in the GeV-TeV mass range

More specifically: electron energies < 10 GeV produce signals at frequencies < GHz

Bounds from radio frequencies

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



Lower frequencies better for lighter DM

Strong prospects: SKA and precursors

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

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

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

Egorov, Pierpaoli, PRD 88 (2013) 023504
Regis et al, JCAP 1410 (2014) 016

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

ARCADE excess

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

Singal et al, *Astrophys. J.* 730 (2011) 138

Kogut et al., *Astrophys. J.* 734 (2011) 4

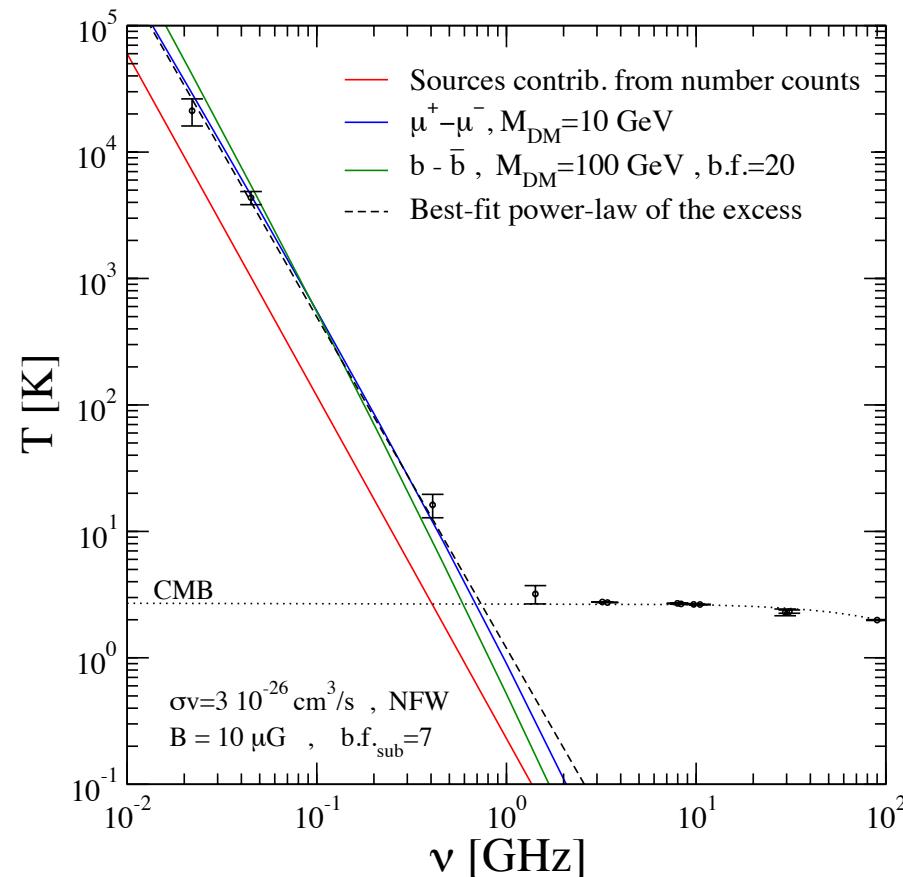
NF, Lineros, Regis, Taoso, JCAP1404 (2014) 008

Singal et al, arXiv:1711.09979

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

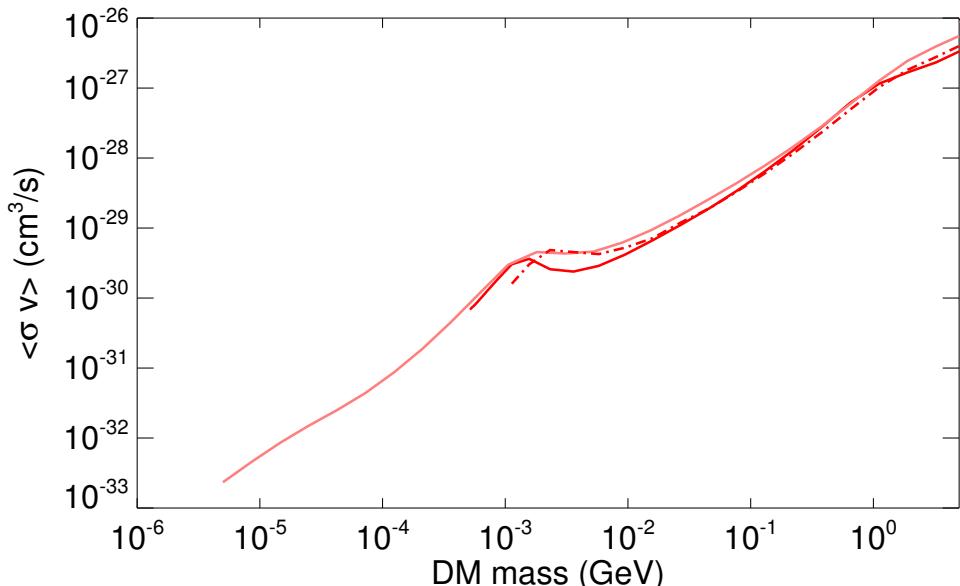
Systematics effects and galactic sources seems excluded

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

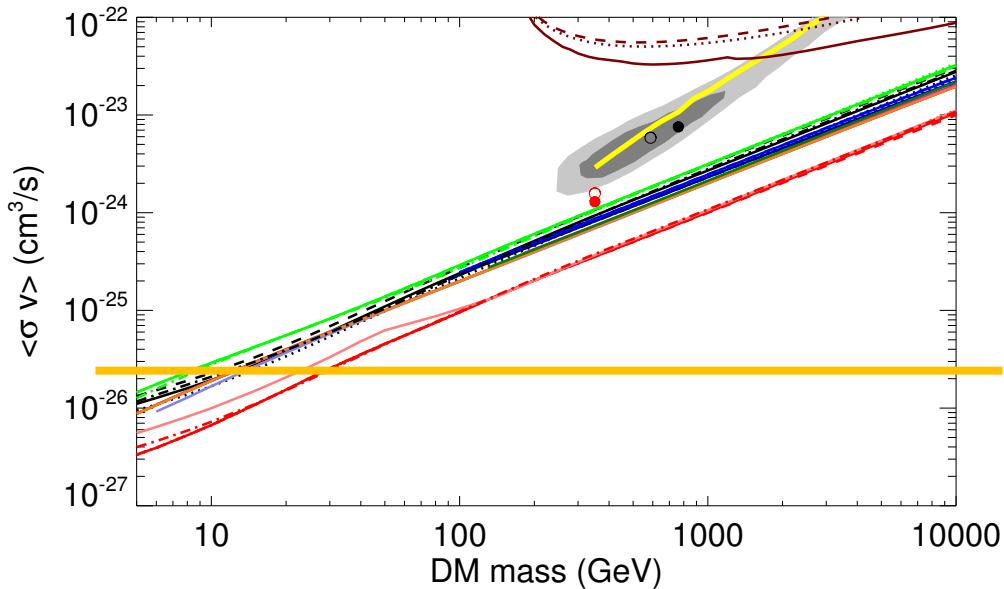


NF, Líneros, Regis, Taoso, PRL 107 (2011) 27 27

CMB



Slatyer, PRD 93 (2016) 023527



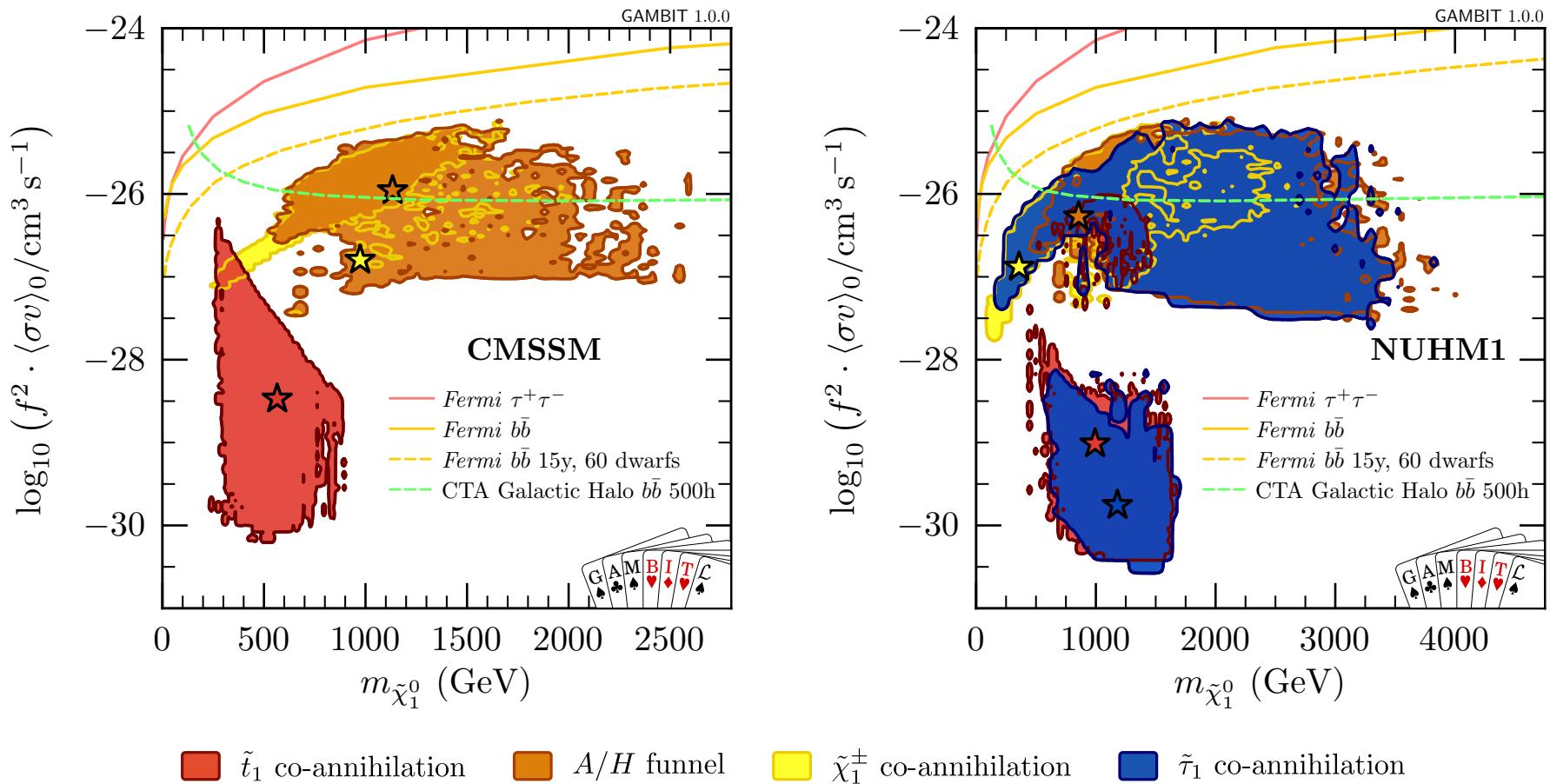
Injection of ionizing particles
during the cosmic dark ages

Increase in the residual ionization
fraction and affect CMB

See also:

- Zhang et al, PRD 76 (2007) 061301
- Galli et al, PRD 80 (2009) 023505
- Slatyer et al, PRD 80 (2009) 043526
- Kanzakiet et al, Prog. Theor. Phys. 123 (2010) 853
- Hisano et al, PRD 83 (2011) 123511
- Hutsí et al., A&A 535 (2011) A26
- Galli et al, PRD 84 (2011) 023502
- Finkbeiner et al, PRD 85 (2012) 043522
- Slatyer et al, PRD 87 (2013) 123513 (2013)
- Galli et al, PRD 88 (2012) 063502
- Lopez-Honorez et al, JCAP 1307 (2013) 046
- Madhavacheril et al, PRD 89 (2014) 103508

Impact on Supersymmetry

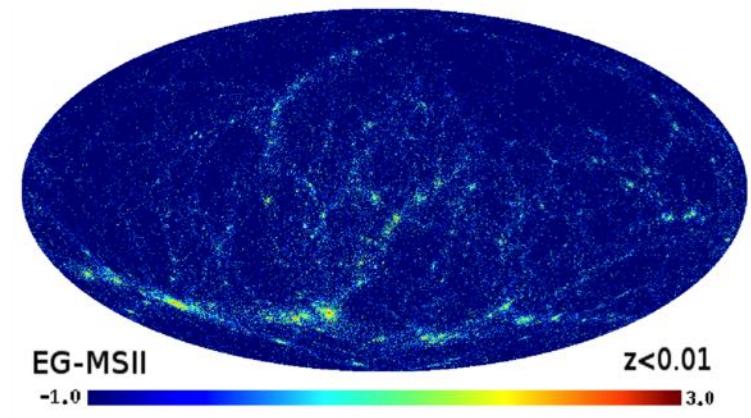
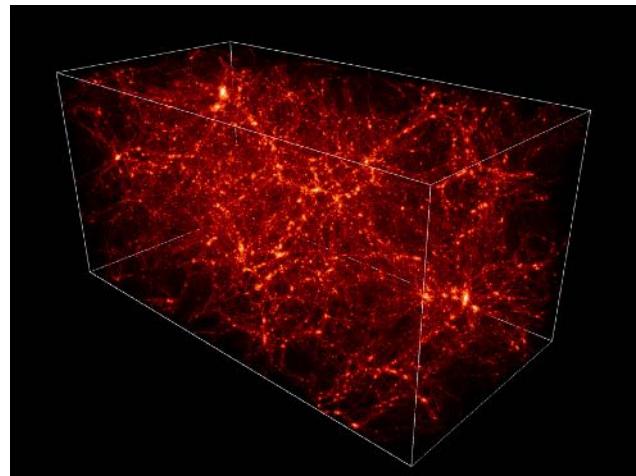


Diffuse signals: faint & not isotropic ...

Being the cumulative sum of independent sources (astro/DM)

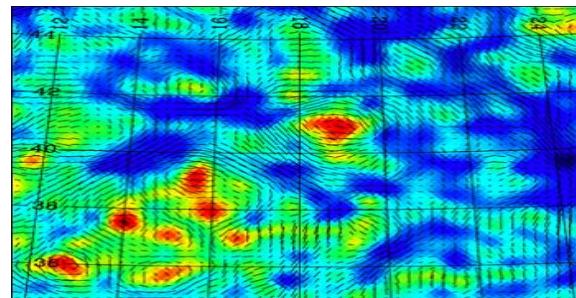
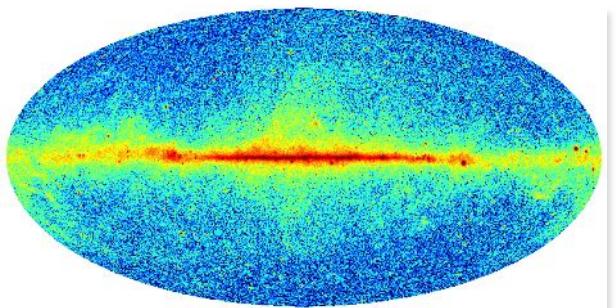
To first approximation: isotropic

At a deeper level: anisotropies are present



Even though sources are too dim to be individually resolved, they can affect the statistics of photons across the sky

Fold two pieces of information



Cross-correlation of EM signal with gravitational tracer of DM

It exploits two distinctive features of particle DM:

Electromagnetic signal: manifestation of particle nature of DM

Gravitational tracer: probe of the existence of DM

It can offer a direct evidence that what is measured by means of gravity is indeed due to DM as a particle

Cross Correlations

Gamma rays x Galaxy catalogs (LSS)

Xia, Cuoco, Branchini, Viel, APJS 217 (2015) 15

Regis, Xia, Cuoco, Branchini, NF, Viel, PRL 114 (2015) 241301

Cuoco, Xia, Regis, Branchini, NF, Viel, ApJS 221 (2015) 29

Shirasaki, Horiuchi, Yoshida, PRD 92 (2015) 123540

X-CORR DETECTED

Fermi x (SDSS + 2MASS + NVSS)

"

"

Fermi x SDSS LRG

Gamma rays x Cosmic shear

X-CORR NOT DETECTED (YET ...)

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

Shirasaki, Macias, Horiuchi, Shirai, Yoshida, 1607.02187

Troester et al, MNRAS 467 (2017) 2706

Shirasaki et al, PRD 97 (2018) 123015

Fermi x CFTHLenS

Fermi x (CFTHLenS + RCSLenS)

Fermi x (CFTHLenS + RCSLenS + KiDS)

Fermi x Subary HSC

Gamma rays x CMB lensing

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

X-CORR DETECTED

Fermi x Planck

Gamma rays x Galaxy clusters

Branchini, Camera, Cuoco, NF, Regis, Viel, Xia, ApJS 228 (2017) 8

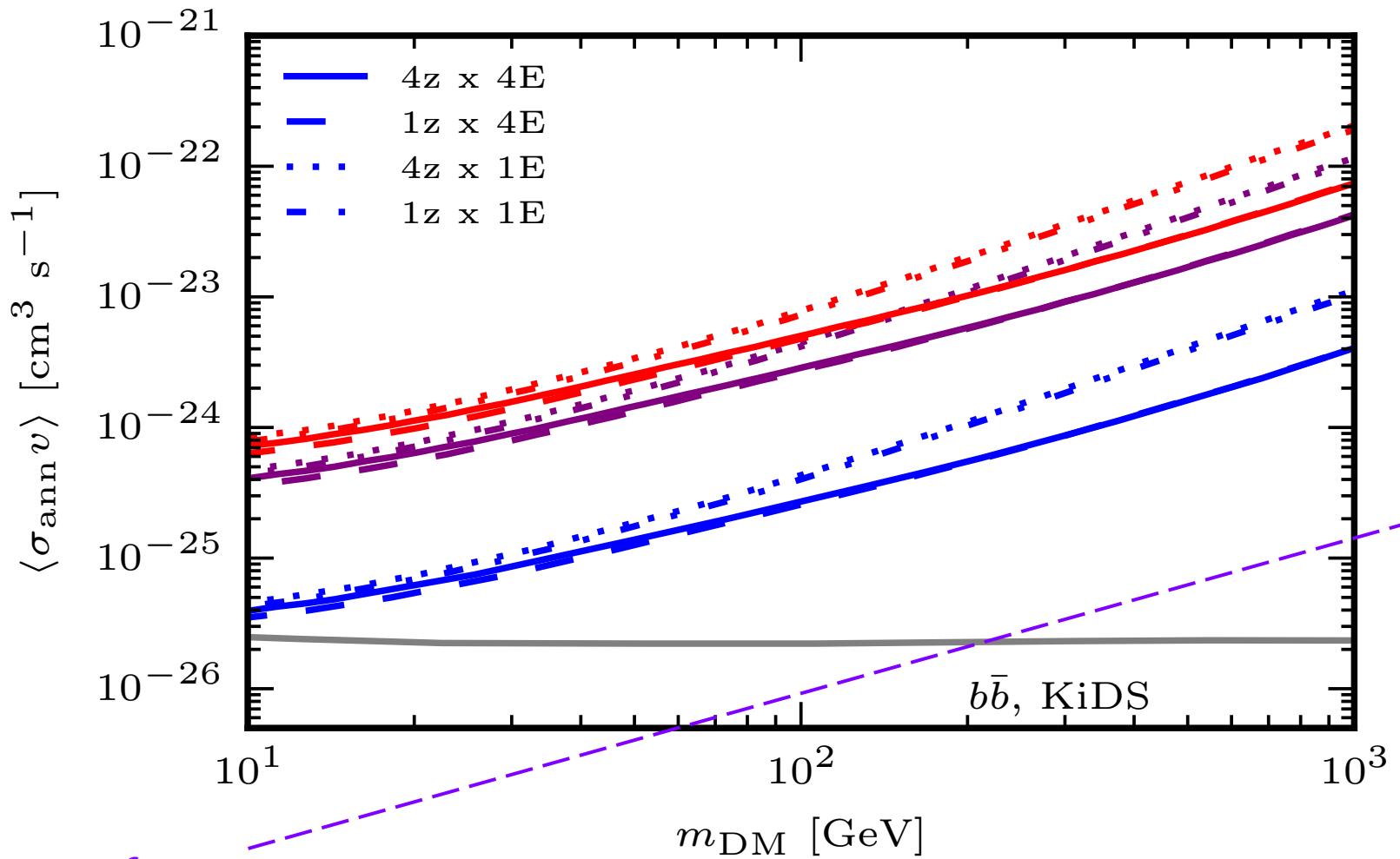
Hashimoto et al, 1805.08139

X-CORR DETECTED

Fermi x (redMaPPer + WHL12 + PlanckSZ)

Fermi x Subary HSC

Fermi x KiDS+RCSLens+CFTHLens



Forecast for DES

Troester et al, MNRAS 467 (2017) 2706

Conclusions

- The solution to the DM problem requires to identify (or disprove) its particle physics nature: either way, New Physics is there
- This can be done only through a coordinated and multifaceted effort which gets input both from:
 - Accelerator physics
 - Astrophysical and cosmological probes
- WIMP Current techniques have started probing the region of interest
It is the right moment to push forward
- Non WIMP Substantial window of opportunity complementary to WIMPs

A signal of DM is clearly faint, but the opportunities are rich:
Multimessenger, Multiwavelength, Multitechnique