Looking to Dark Matter through Gamma-Ray Anisotropies

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Department of Physics, University of Oslo − 31.05.2017

Dark Matter

The presence of DM is supported by copious and consistent astrophysical and cosmological probes

- Large scales: Average DM density about 6 times baryon density
- Smaller scales: DM distribution is quite anisotropic and hierarchical clusters – galaxies – subhalos

Observations are compatible with a theoretical understanding of cosmic structure formation through gravitational instability

Dark Matter

DM evidence purely gravitational

- Galaxy clusters dynamics
- Rotational curves of spiral galaxies
- Gravitational lensing
- Hydrodynamical equilibrium of hot gas in galaxy clusters
- Energy budget of the Universe
- The same theory of structure formation

Dark Matter as a particle?

DM evidence purely gravitational

- Galaxy clusters dynamics
- Rotational curves of spiral galaxies
- Gravitational lensing
- Hydrodynamical equilibrium of hot gas in galaxy clusters
- Energy budget of the Universe
- The same theory of structure formation

A natural solution is that DM is a new particle, relic from the early Universe

Dark Matter as a particle

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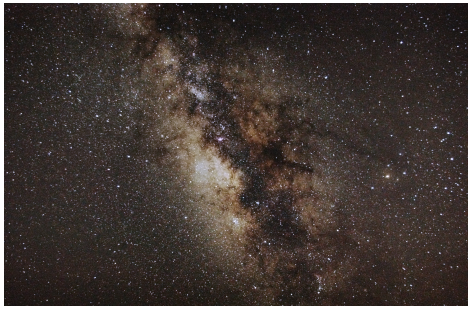
- The same theory of structure formation

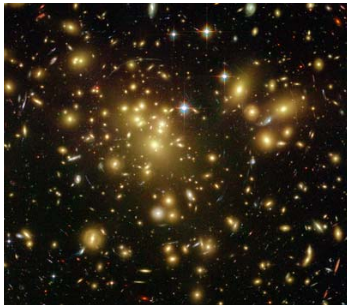
If DM is a new particle, a non-gravitational signal (due to it's particle physics nature) is expected

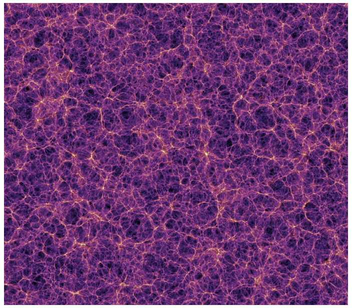
Where to search for a signal ...

We can exploit every structure where DM is present ...

- Our Galaxy
  - Smooth component
  - Subhalos
- Satellite galaxies (dwarfs)
- Galaxy clusters
  - Smooth component
  - Individual galaxies
  - Galaxies subhalos
- "Cosmic web"







... and what

...and we have a large number of messengers at disposal

- Our Galaxy
  - Smooth component
  - Subhalos
- Satellite galaxies (dwarfs)
- Galaxy clusters
  - Smooth component
  - Individual galaxies
  - Galaxies subhalos
- "Cosmic web"

A

- Charged CR ($e^\pm$, antip, antiD) [G]
- Neutrinos [G,E]
- Photons [G,E]
  - 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

B

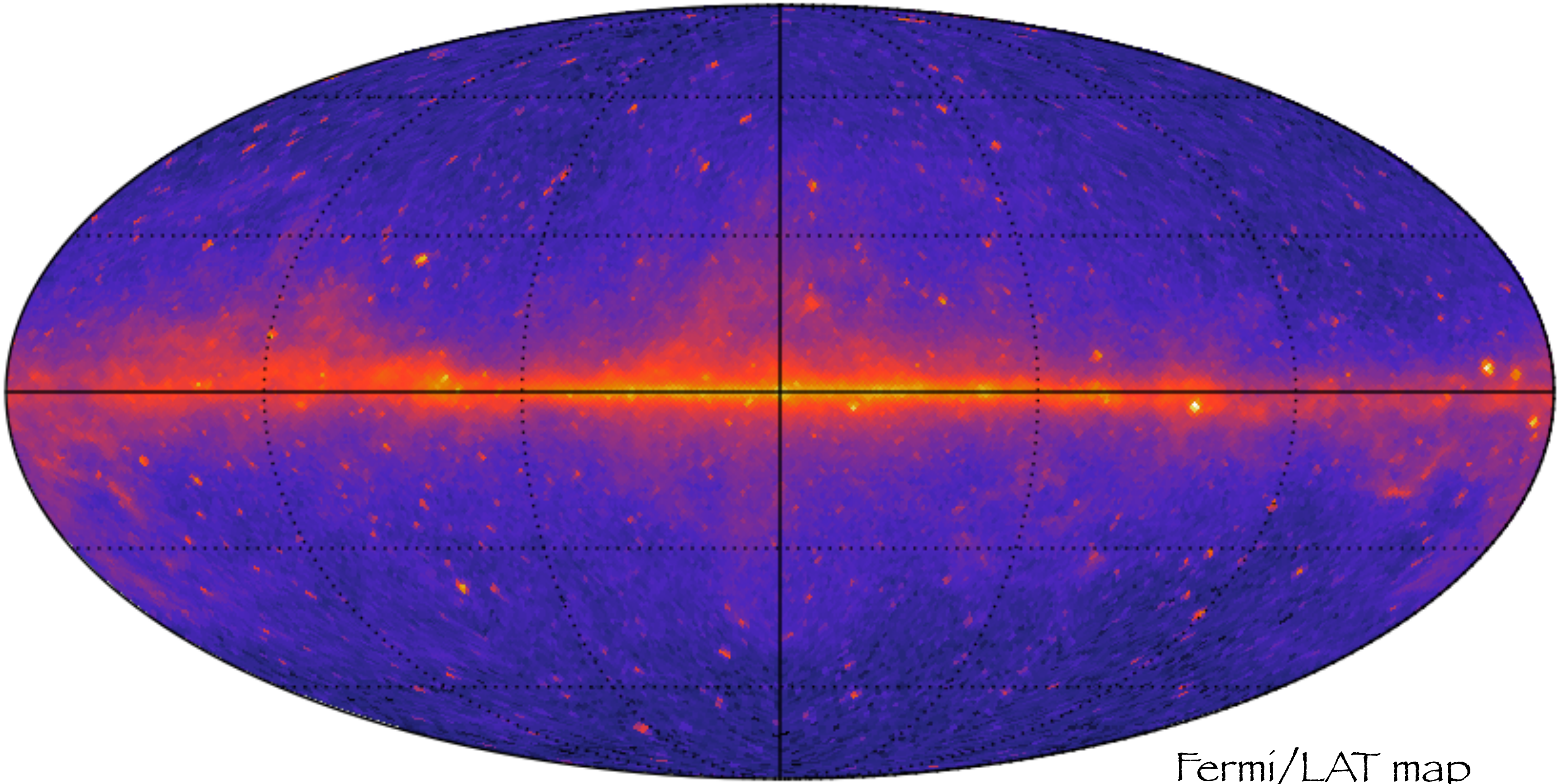
- Direct detection [L]

A: $\mathrm{DM} + \mathrm{DM} \longrightarrow (\ldots) \longrightarrow \mathrm{signal}$

B: $\mathrm{DM} + \mathcal{N} \longrightarrow \mathrm{DM} + \mathcal{N}$

Local [L] - Galactic [G] - Extragalactic [E]

Gamma ray sky



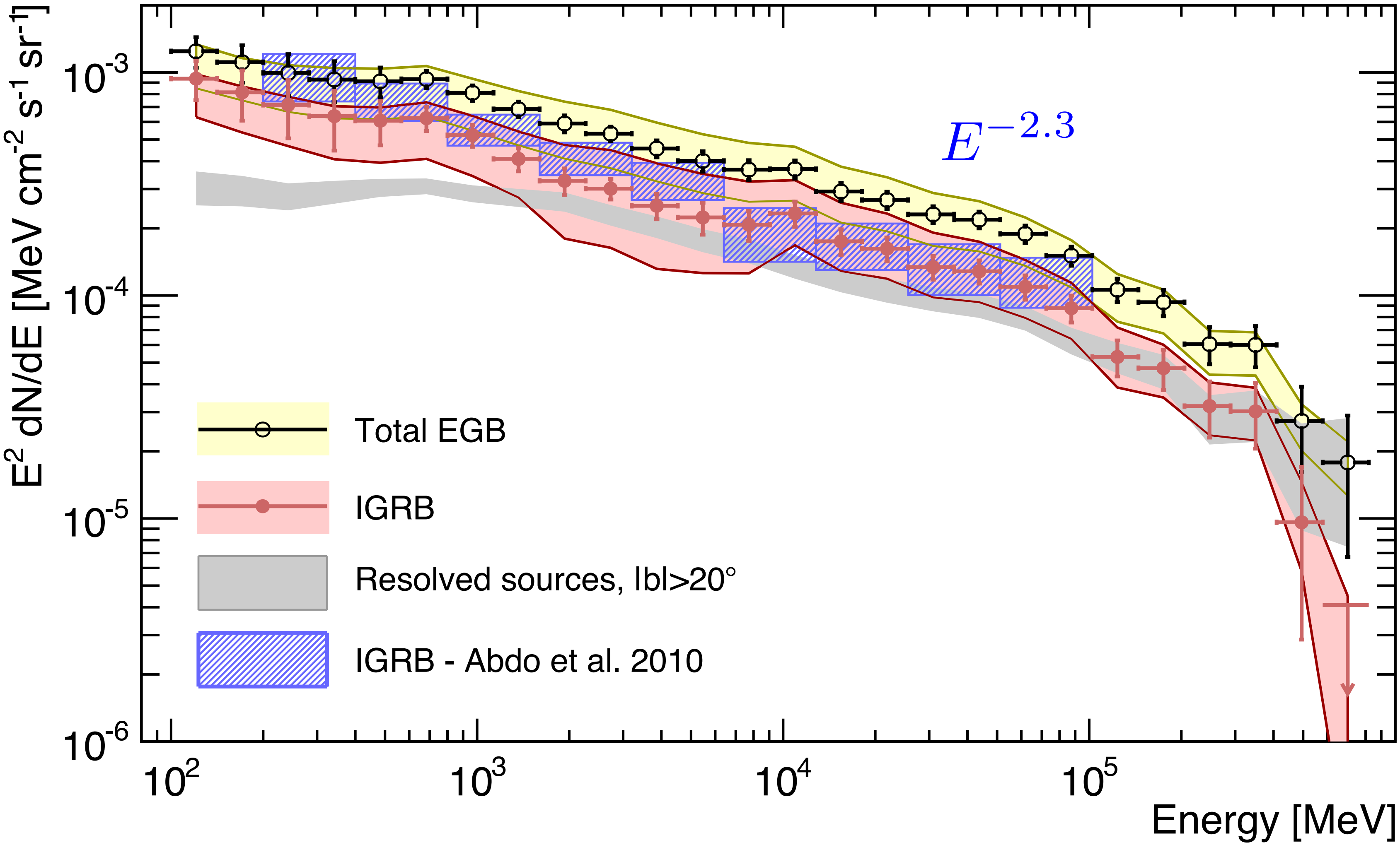
Fermi/LAT map

Galactic foreground emission

Resolved sources

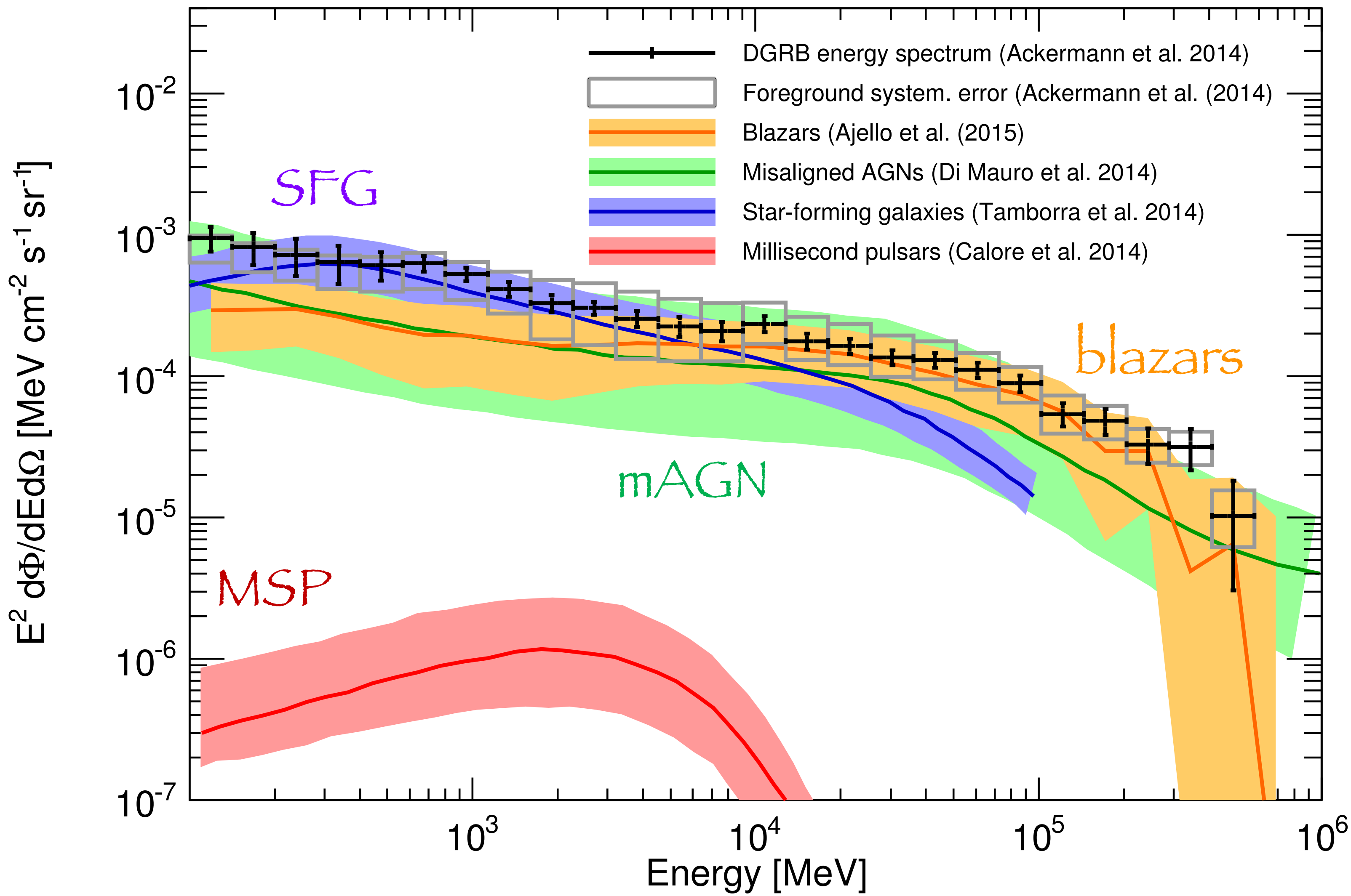
Diffuse Gamma Rays Backgound (DGRB)

DGRB Intensity



Ackerman et al. (Fermi Collab.) Ap. J. *799* (2015) 86

DGRB Intensity

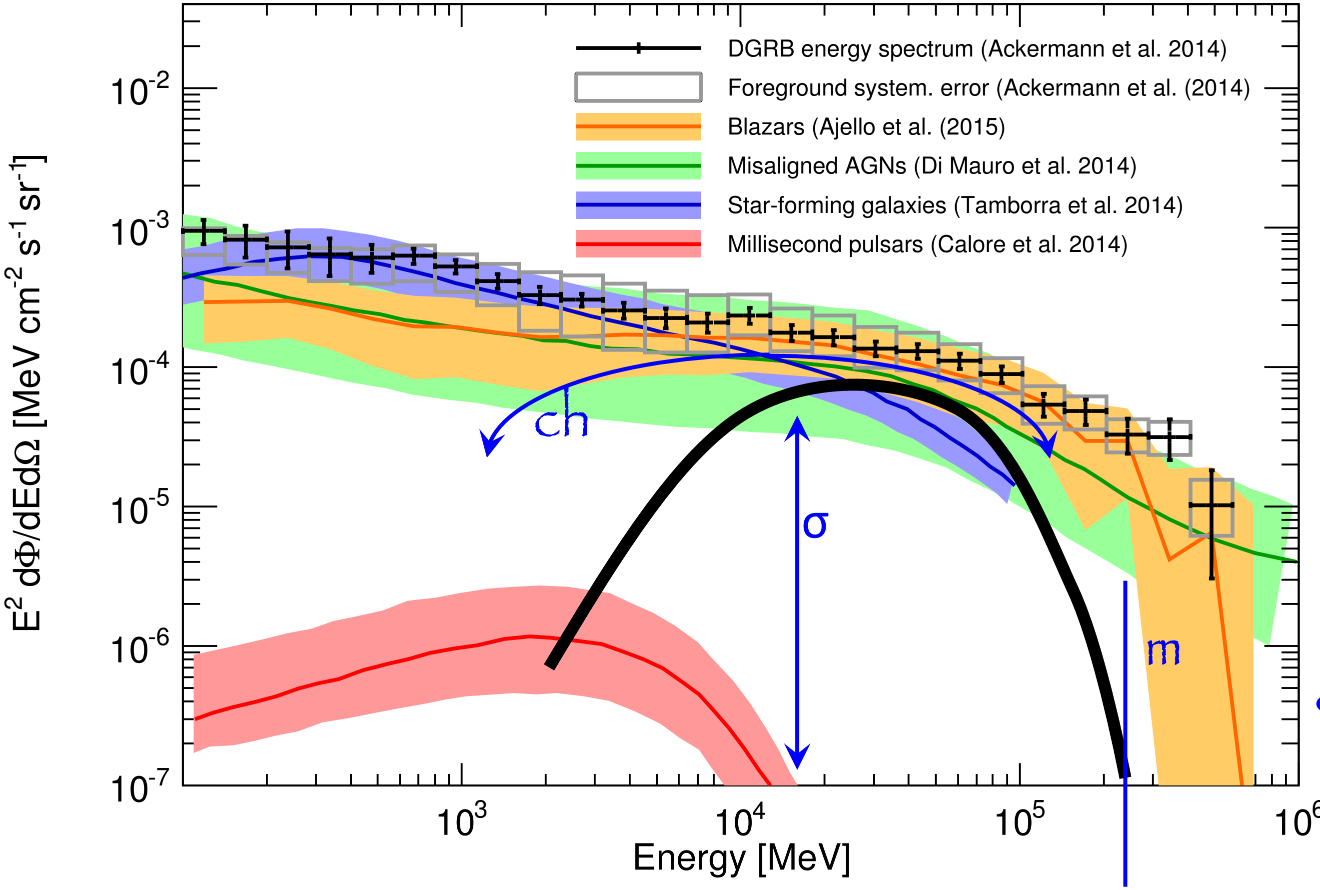


Fornasa, Sanchez-Conde, Phys. Rep. 598 (2015) 1

DGRB and Dark Matter

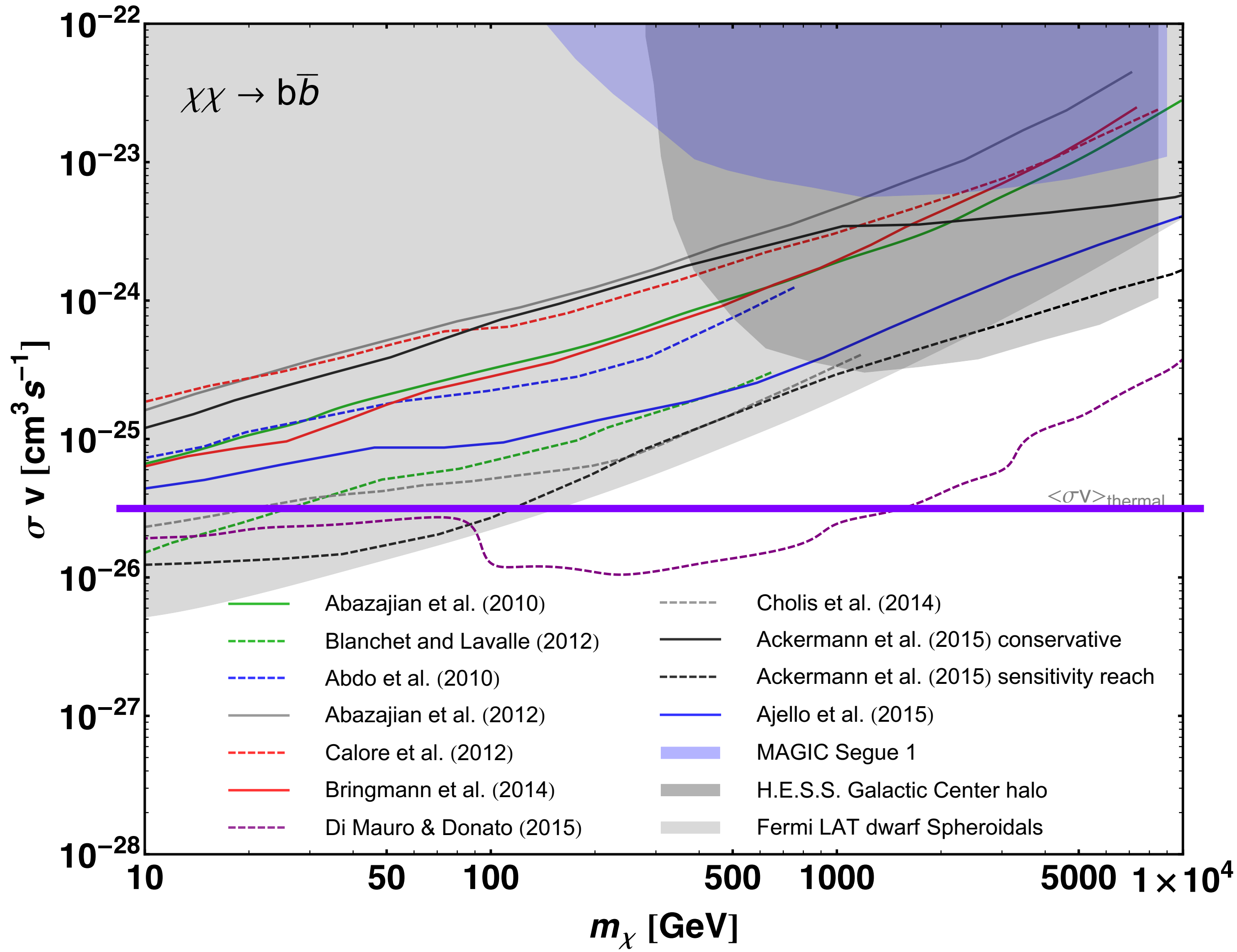
The Good: Spectral behaviour different from astro sources:
(σ,m, channel)

The Bad: Can be quite subdominant in intensity



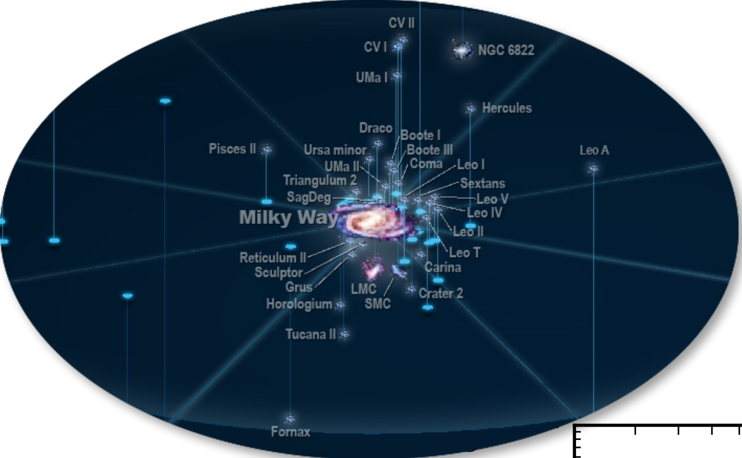
$$\Phi(E) \sim \langle \sigma v \rangle \left(\frac{\rho_{\rm DM}}{m_{\rm DM}} \right)^2 F(E)$$

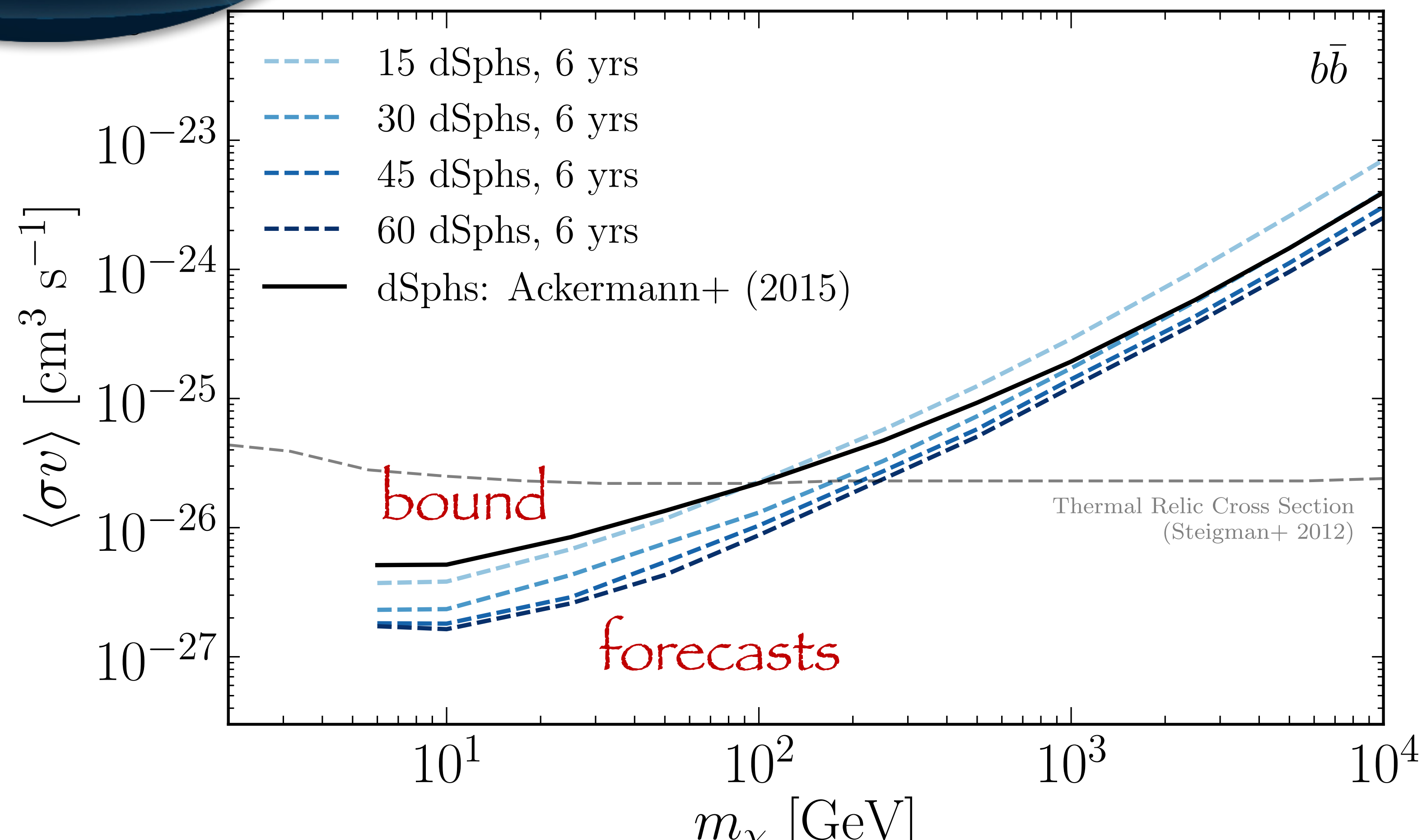
DGRB intensity bounds on DM



Fornasa, Sanchez-Conde, Phys. Rep. 598 (2015) 1

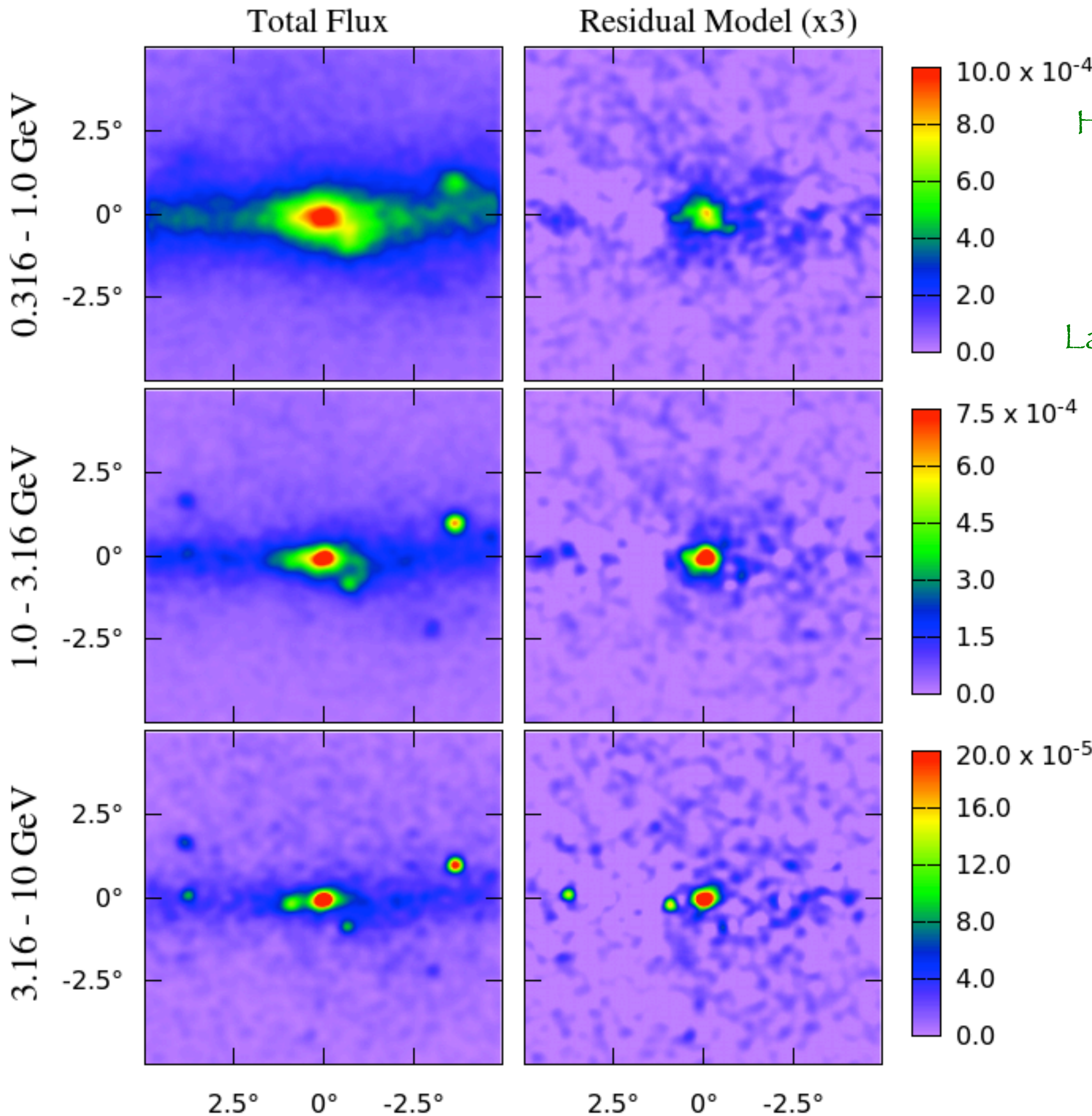
Dwarf galaxies



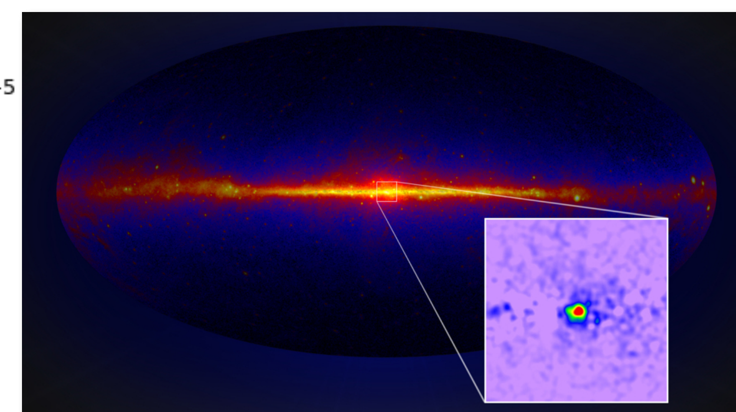


Charles et al (Fermi Collab) Phys Rep 636 (2016) 1

Galactic center: an "excess" ?

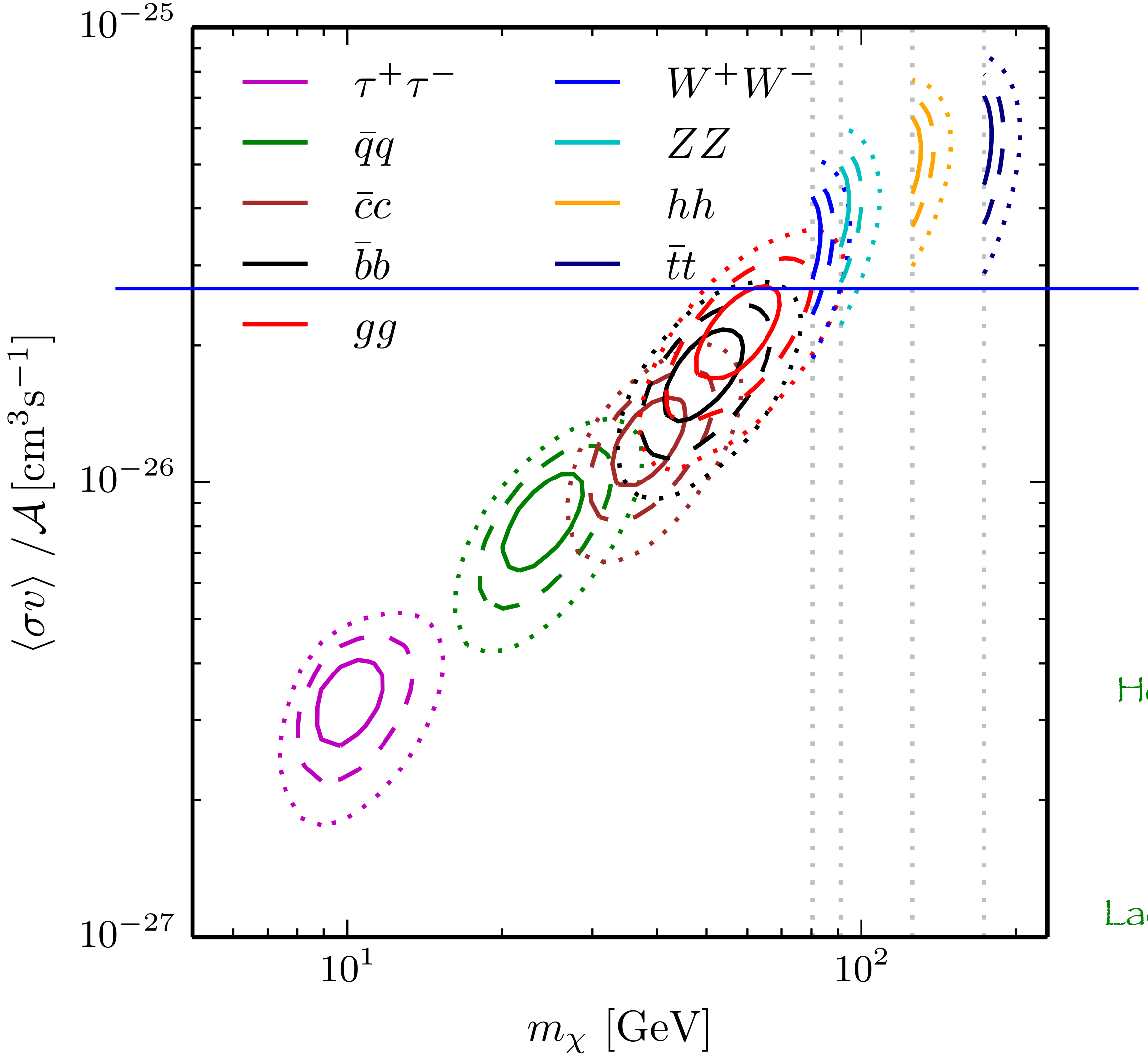


Hooper, Goodenough, PLB (2011) 697 (2011)
Hooper, Linden, PRD 84 (2011) 123005
Boyarsky et al., PLB (2011) 705
Daylan et al., Phy Dark Univ 12 (2016) 1
Abazajian et al, PRD 90 (2014) 023526
Lacroix, Boehm, Silk, PRD 90 (2014) 043508
Calore et al, PRD 91 (2015) 063003



Daylan et al, Phys Dark Univ 12 (2016) 1

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

Alternative approaches?

- Indirect detection signals are intrinsically anisotropic

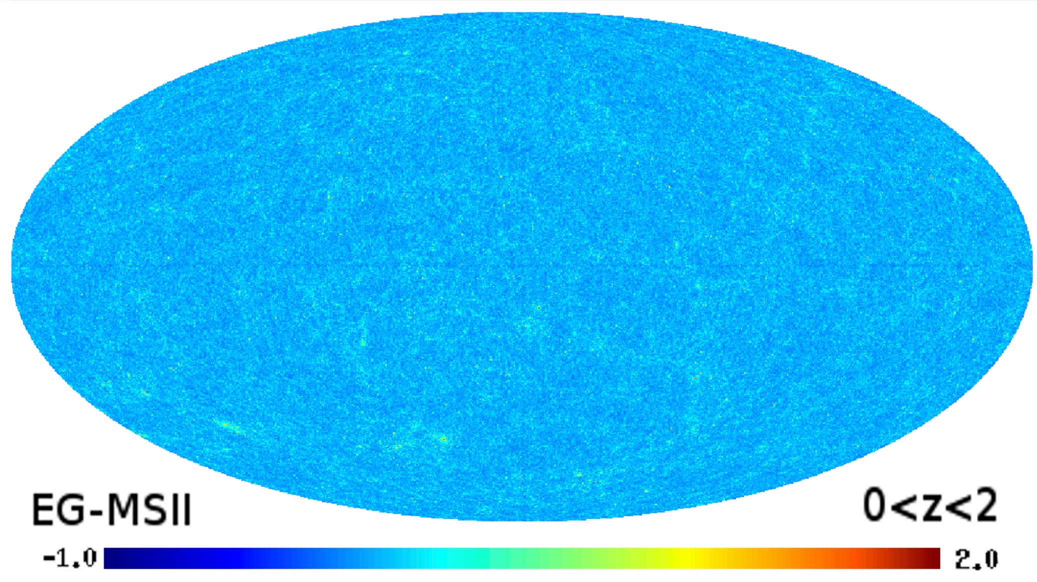
  (being produced by DM structures, present at any scale)

- EM signals (and neutrinos) more directly trace the underlying DM distribution: they need to exhibit some level of anisotropy

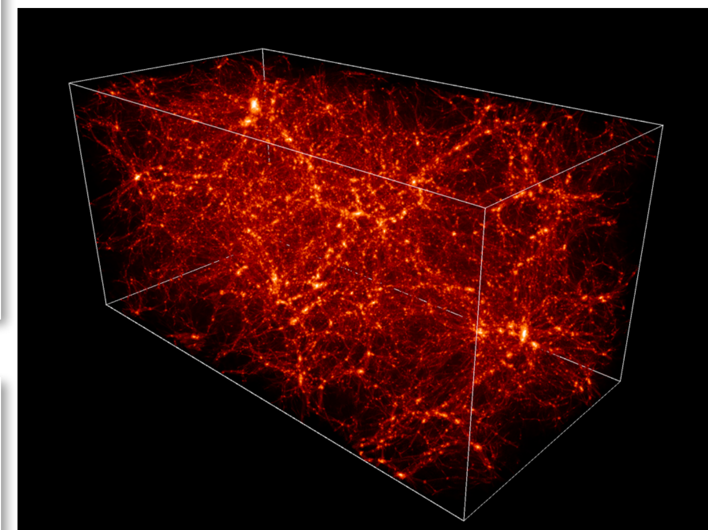
  - "Bright" DM objects: would appear as *resolved* sources
    - e.g: gamma or radio halo around clusters, dwarf galaxies or even subhalos

  - Faint DM objects: would be *unresolved* (i.e. below detector sensitivity)
    - Diffuse flux: at first level isotropic
      at a deeper level anisotropic

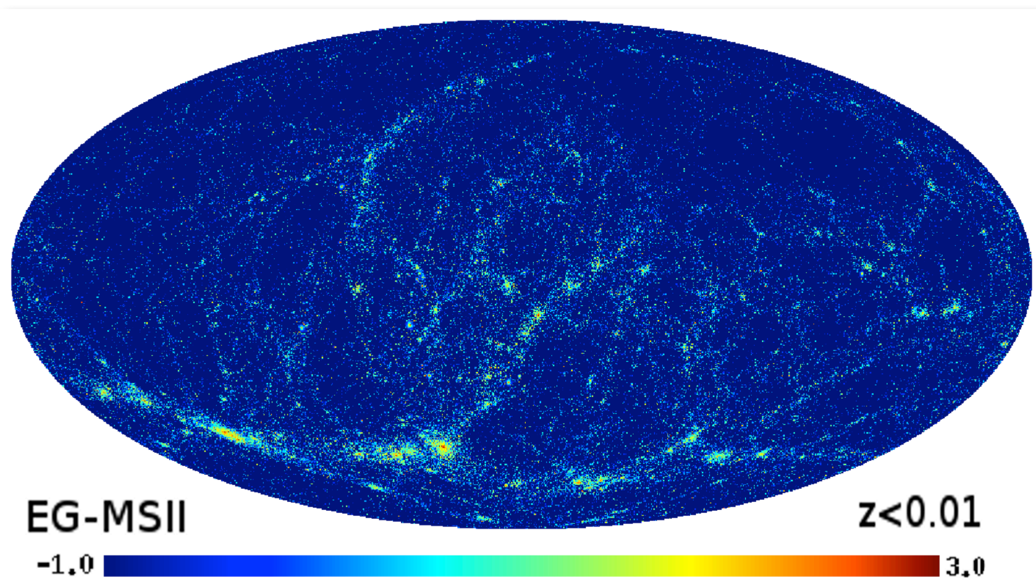
Gamma rays and Dark Matter



Extra galactic emission
Higher redshift



(simulated maps)



Extra galactic emission
Lower redshift

Anisotropic emission

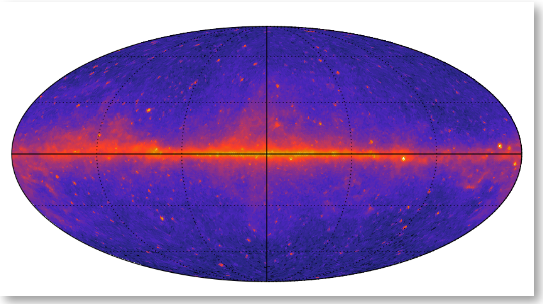
Even though sources are too dim to be individually resolved, they can affect the <u>statistics of photons</u> across the sky

Anisotropic emission - Photon statistics

This can be help in characterizing the gamma-ray sky:

- Astrophysical sources (AGN, SFG, ...)
- Dark matter

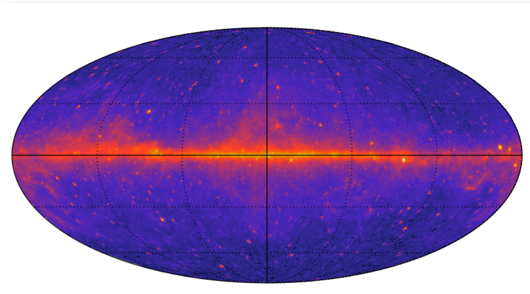
Photon statistics



Photon pixel counts (1-point PDF)

Source count number dN/dS below detection threshold

Photon statistics



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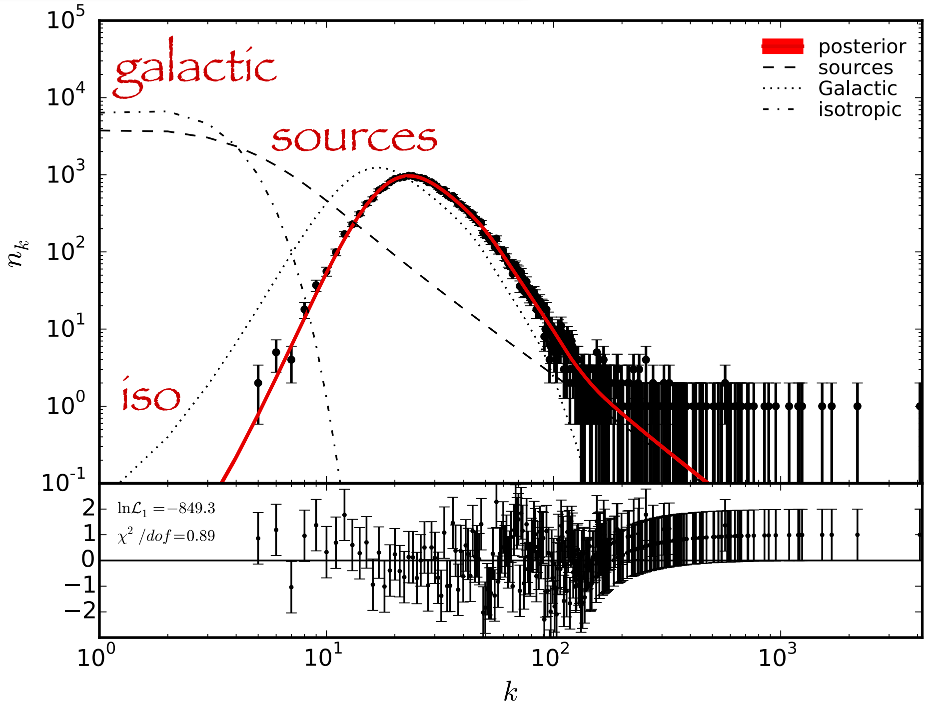
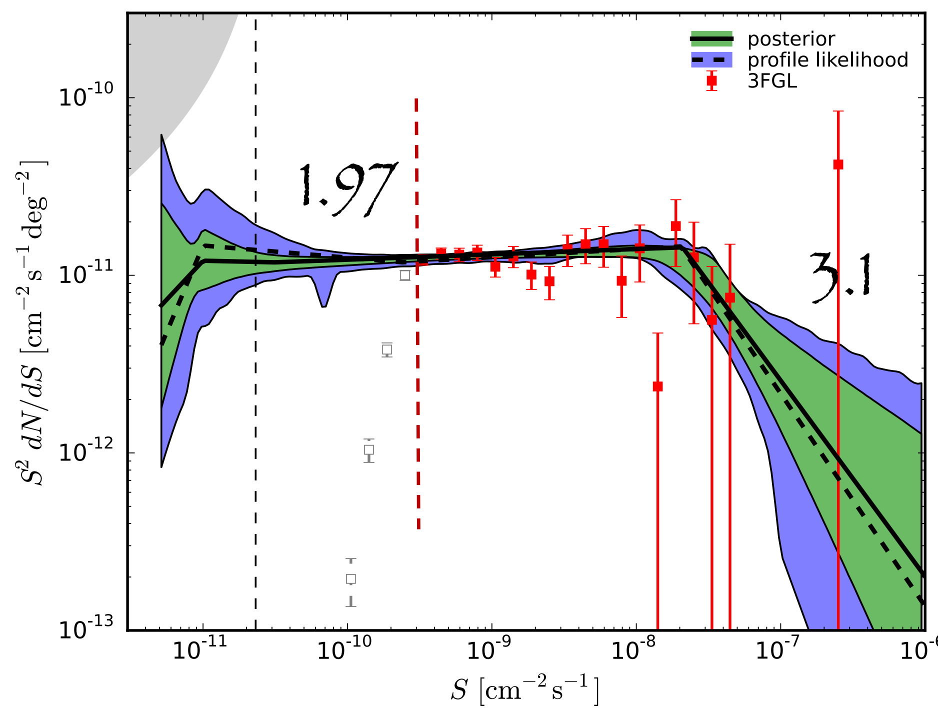
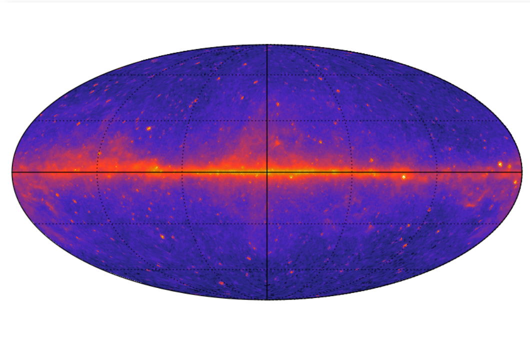




Zechlin, Cuoco, Donato, NF, Vittino, ApJS 225 (2015) 039
Zechlin, Cuoco, Donato, NF, Regis, ApJL 826 (2016) 831

See also: Malyshev, Hogg, Astrophys. J. 738 (2011) 181
Lisanti et al, 1606.0401

Photon statistics



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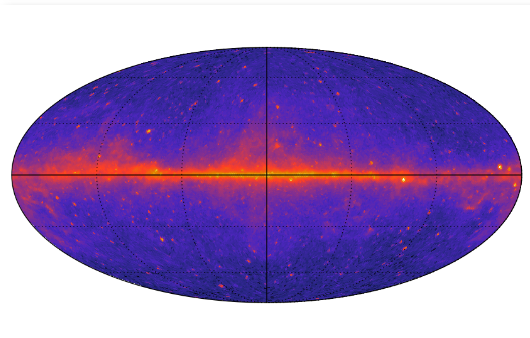

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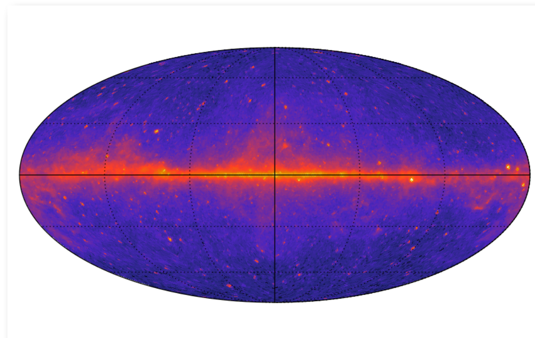


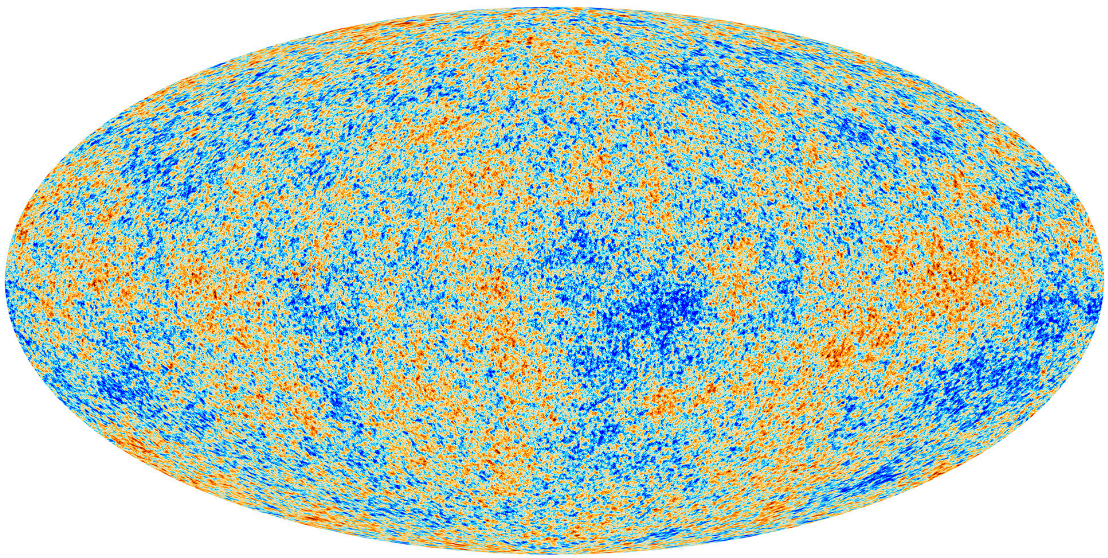
2-point correlator

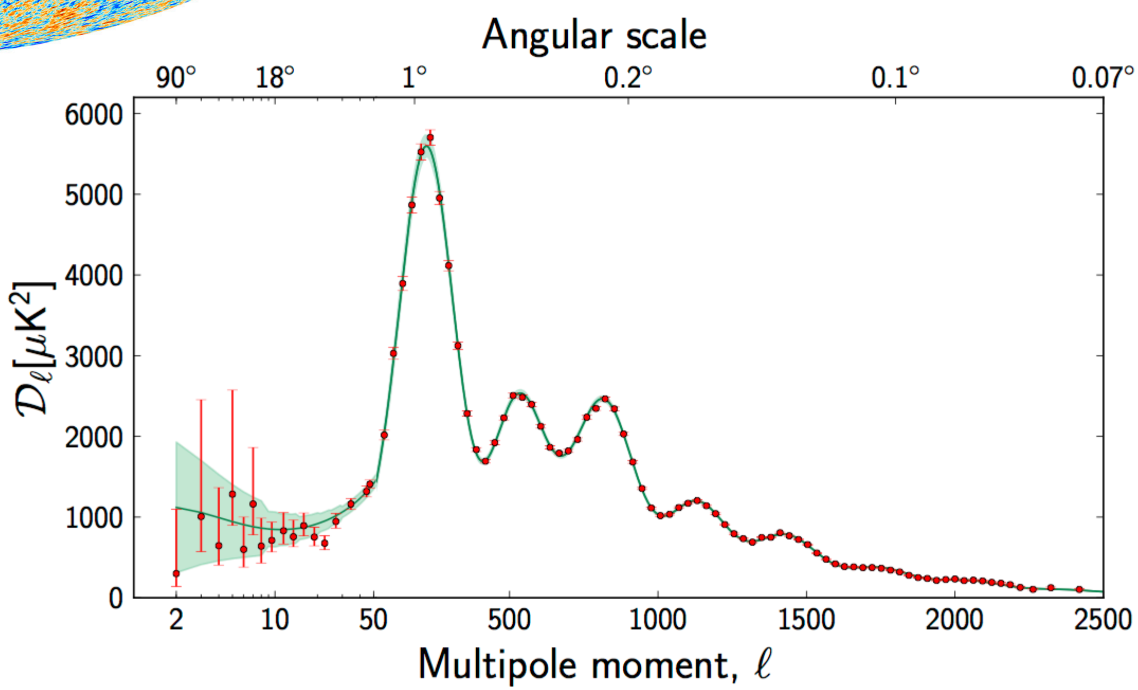
Correlation function

Angular power spectrum

$$\langle\, I(\vec{n}_1) I(\vec{n}_2)\, \rangle \;\longrightarrow\; C(\theta) \;\longrightarrow\; C_l$$

Like for CMB temperature anisotropies





Correlation functions

Source Intensity

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

Window function

Density field of the source

W(z): does not depend on direction
depends on redishift
depends on energy

g(z,**n**): describes how the "field" changes from point to point
contains the dependence on abundance +
distribution of sources

$$I_g(\vec{n}) \longrightarrow a^g_{lm} \longrightarrow C^{gg}_l = \frac{1}{2l+1} \sum_{l=-m}^{m} |a^g_{lm}|^2$$

Correlation functions

Source Intensity

Window function

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

Density field of the source

Angular power spectrum

3D Power spectrum (e.g. from the halo model)

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

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

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

$\hat{f}_g$: *Fourier tranform*

$$I_g(\vec{n}) \longrightarrow a^g_{lm} \longrightarrow C^{gg}_l = \frac{1}{2l+1}\sum_{l=-m}^{m} |a^g_{lm}|^2$$

Ingredient # 1: Window functions

Clumping factor : a measure of the clustering

$$W^g(\chi) = \frac{(\Omega_{\rm DM}\rho_c)^2}{4\pi}\frac{\langle\sigma_a v\rangle}{2{m_{\rm DM}}^2}[1+z(\chi)]^3\,\Delta^2(\chi)J_a(E,\chi)$$

DM photon "emissivity"

Halo mass function Halo profile

$$\Delta^2(\chi) \equiv \frac{\langle\rho^2_{\rm DM}\rangle}{\bar\rho^2_{\rm DM}} = \int_{M_{\rm min}}^{M_{\rm max}} {\rm d}M\,\frac{{\rm d}n}{{\rm d}M}\int {\rm d}^3\mathbf{x}\,\frac{\rho_h^2(\mathbf{x}|M,\chi)}{\bar\rho^2_{\rm DM}}[1+B(M,\chi)]$$

Subhalo boost (measure of the amount of subhalos hosted by main halos)

$$J_a(E,\chi) = \int_{\Delta E_\gamma} {\rm d}E_\gamma\,\frac{{\rm d}N_{a/d}}{{\rm d}E_\gamma}[E_\gamma(\chi)]\,e^{-\tau[\chi,E_\gamma(\chi)]}$$

Uncertainties from:

- Minimal halo mass M_{min}
- Halo concentration c(M)

Alternative approach to the Halo Model:
Serpico et al. MNRAS 421 (2012) L87
Sefusatti et al.MNRAS 441 (2014) 1861

Gamma-rays are also emitted by astrophysical sources, each of which has a specific window function

Ingredient # 2: Power spectrum

Source Intensity

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

Window function

Density field of the source

Angular power spectrum

3D Power spectrum (e.g. from the halo model)

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

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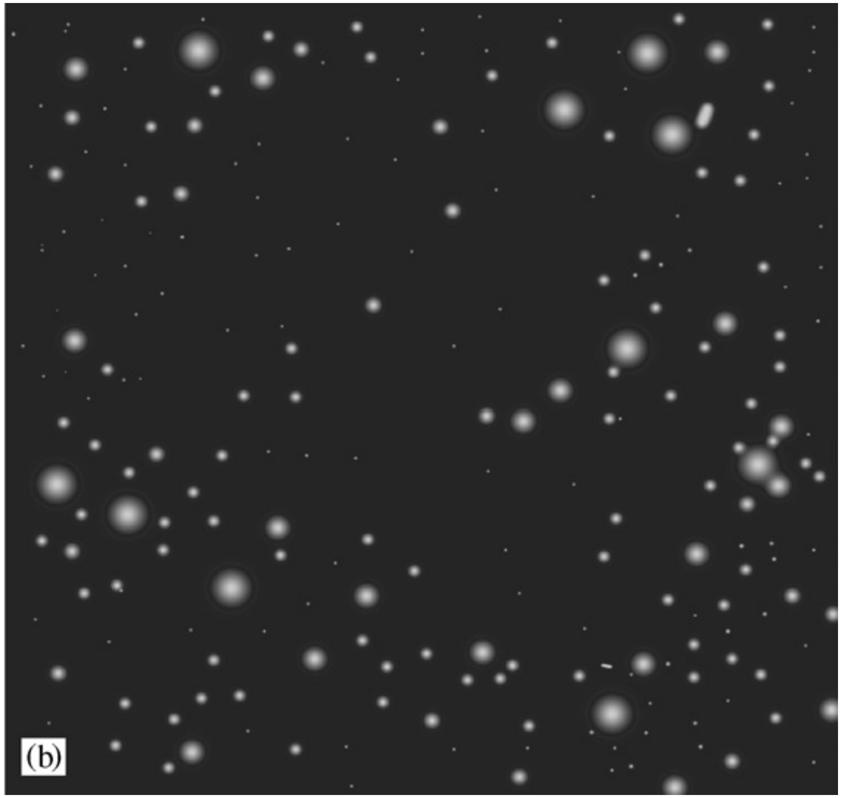
$$f_g \equiv [g(\boldsymbol{x}|m, z)/\bar{g}(z) - 1]$$

$\hat{f}_g$: *Fourier tranform*

Halo Model

DM is distributed in halos

- With a given mass function dN/dM
- With a DM profile within halos



Sheth & Tormen, Phys Rep 372 (2002) 1

Power spectrum decomposition

$$P_{ij}(k) = P_{ij}^{1h}(k) + P_{ij}^{2h}(k)$$

1-halo term $$P_{ij}^{1h}(k) = \int dm \, \frac{dn}{dm} \hat{f}_i^*(k|m) \, \hat{f}_j(k|m)$$

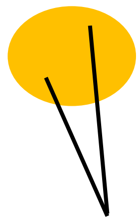
Linear matter PS

2-halo term $$P_{ij}^{2h}(k) = \left[\int dm_1 \, \frac{dn}{dm_1} b_i(m_1) \hat{f}_i^*(k|m_1)\right] \left[\int dm_2 \, \frac{dn}{dm_2} b_j(m_2) \hat{f}_j(k|m_2)\right] P^{\rm lin}(k)$$

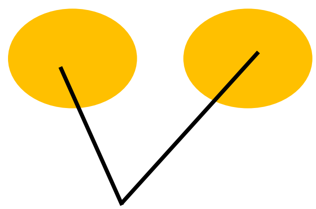
Linear bias

Correlations

1 halo



2 halo



depens on spatial clustering

Astro sources: typically considered as point-like

Dark matter: extended

Correlations

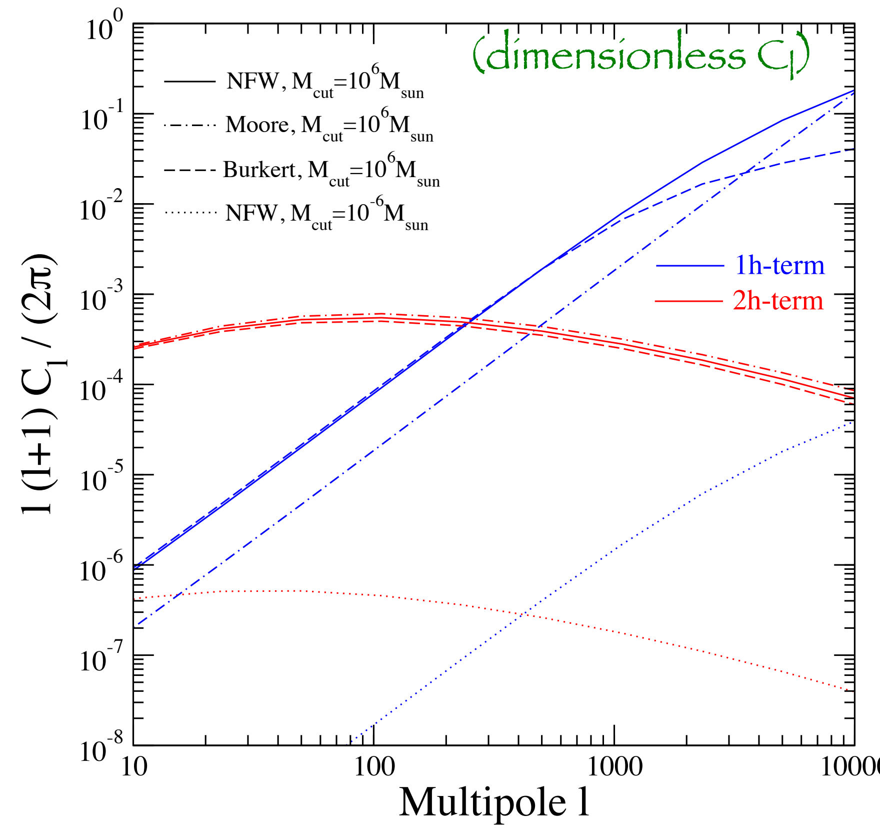
Point-like sources:

1h flat

2h may emerge and give info on clustering

Extended sources:

1h no longer flat, suppressed at scale > size of sources



Main uncertainties for DM:

M_{min}

subhalo boost

Some dependencies

Amount of subhalos (boost) affects mainly 1-halo

e.g.: larger subhalo boost = increases contribution of most massive halos = increase of the 1-halo term

Mmin affects mainly 1-halo

Clustering affects overall norm

Recap on dependencies

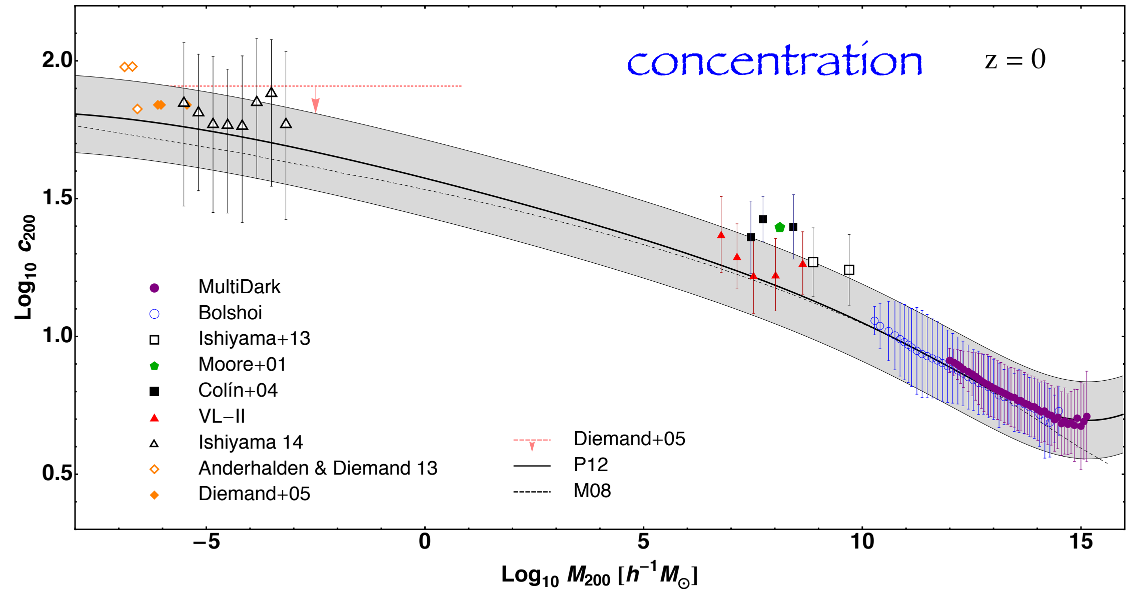
Halo mass function dN/dM

Concentration

Halo density profile (NFW, Burkert, etc)

Minimum halo mass $(10^{-6}, 10^{6})\ M_{Sun}$

Subhalo abundance



Auto Correlation

$$C_l^{\gamma\gamma} \longleftarrow W_\gamma^2(z) P(k,z)$$

window function

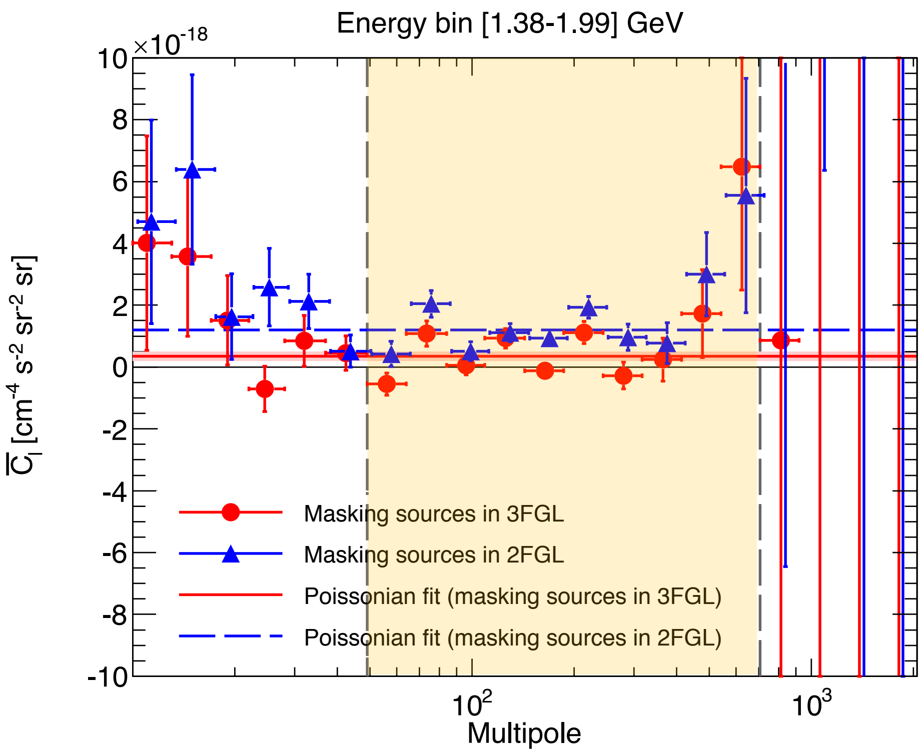
power spectrum

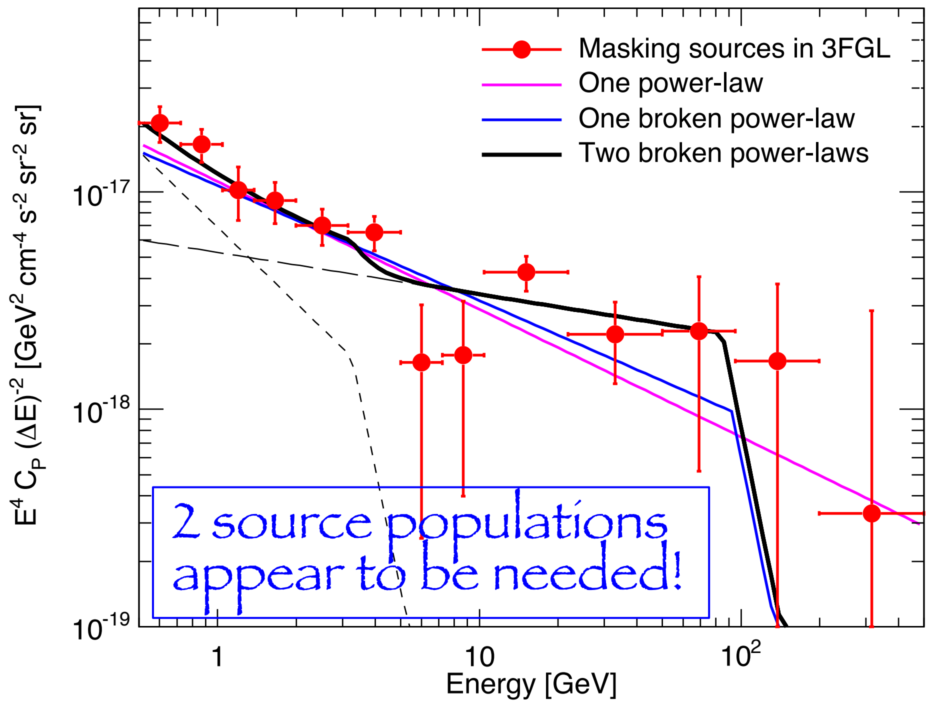
Observationally:

Energy dependence is available

Redshift dependence is not available

Gamma rays auto-correlation





Fornasa, Cuoco et al, PRD 94 (2016) 123005

Ando, Fornasa, NF, Regis, Zechlin, 1701.06988 (interpretation)

See also: Ackerman et al (Fermi Collab) PRD 85 (2012) 083007 (first detection)

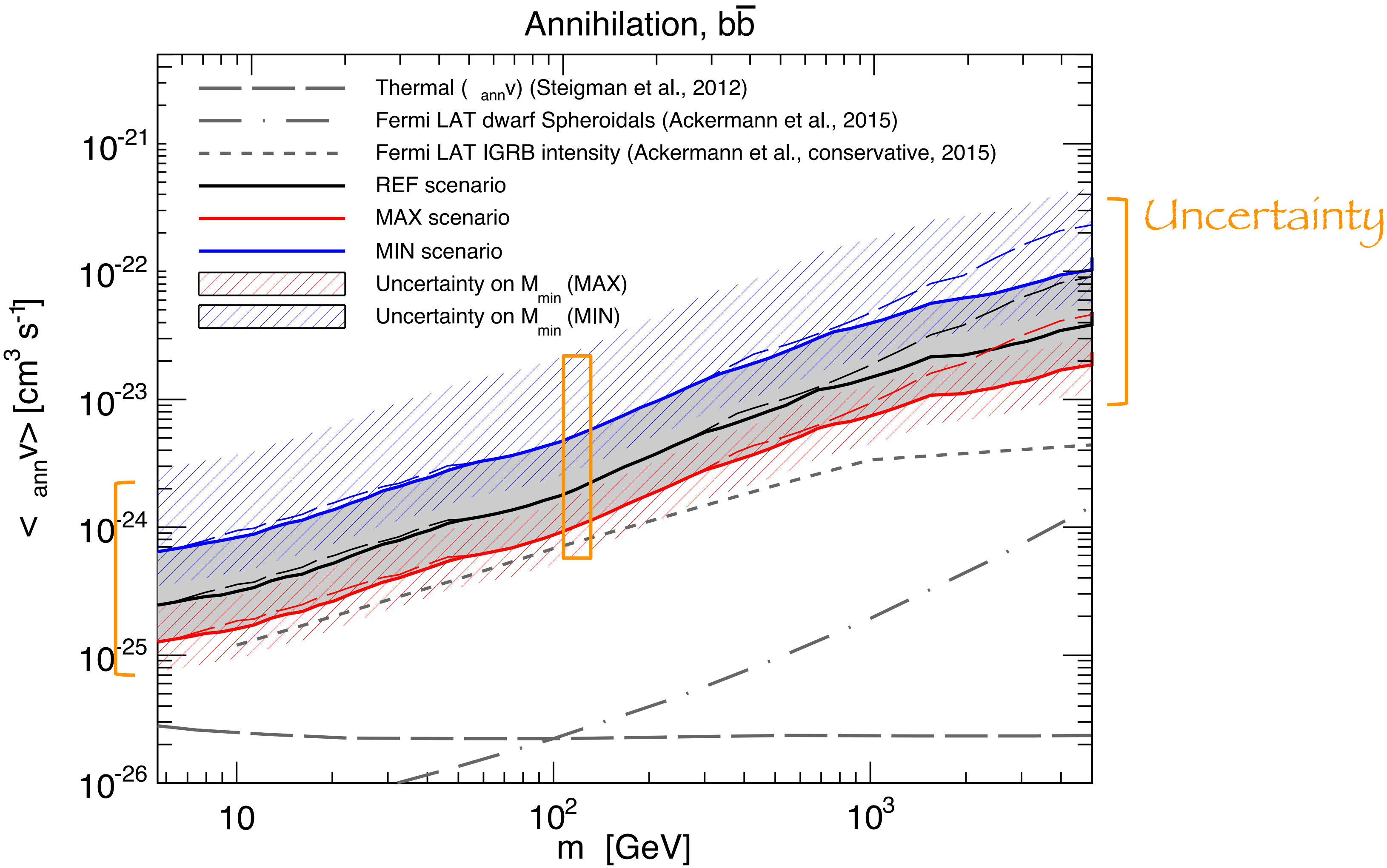
Gamma-ray auto-correlation

Features of the signal point toward interpretation in terms of blazars

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

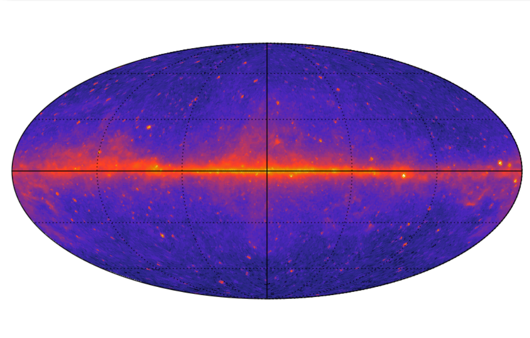
Difficult to extract a clear DM signature from the EGB alone, while relevant to constrain the level of astro sources

Bounds from Auto Correlation

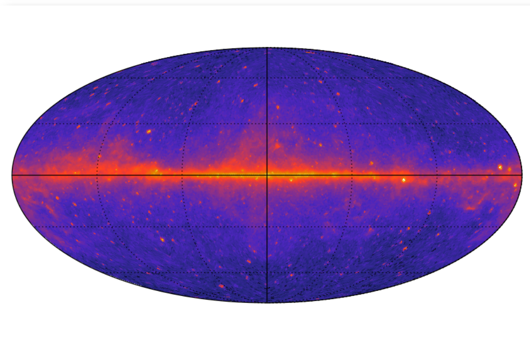


Fornasa, Cuoco et al, 1608.07289

Photon statistics



Photon pixel counts (1 point PDF)



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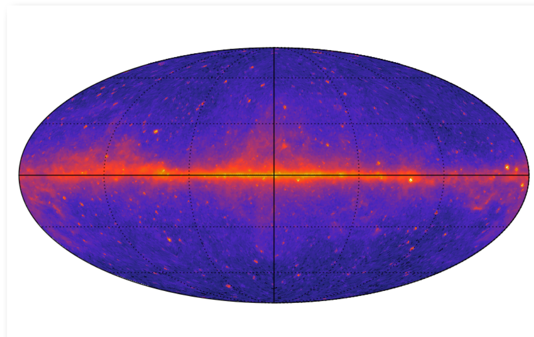
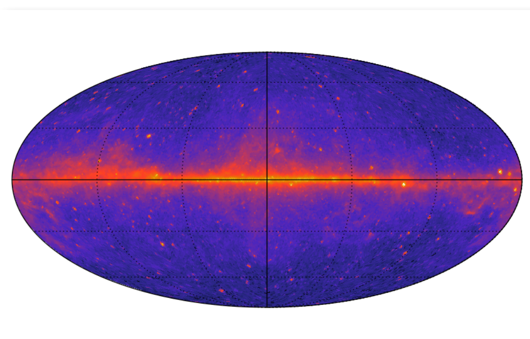


2 point correlator
angular power spectrum



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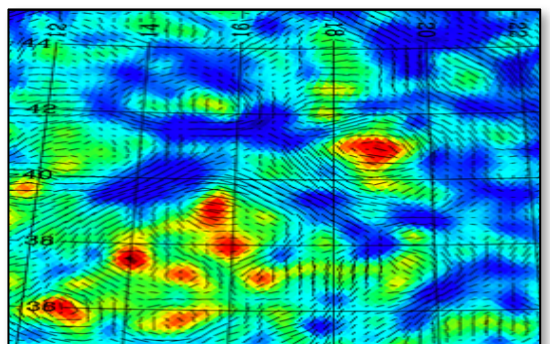
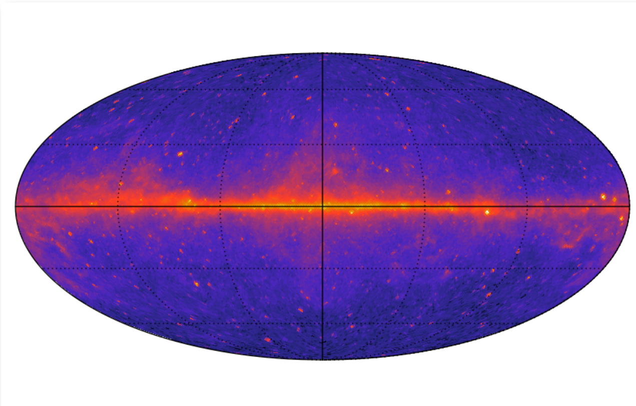


2 point correlator
angular power spectrum

$$\langle I_i(\vec{n}_1) I_j(\vec{n}_2) \rangle \longrightarrow C_{ij}(\theta) \longrightarrow C_l^{ij}$$

Cross Correlations



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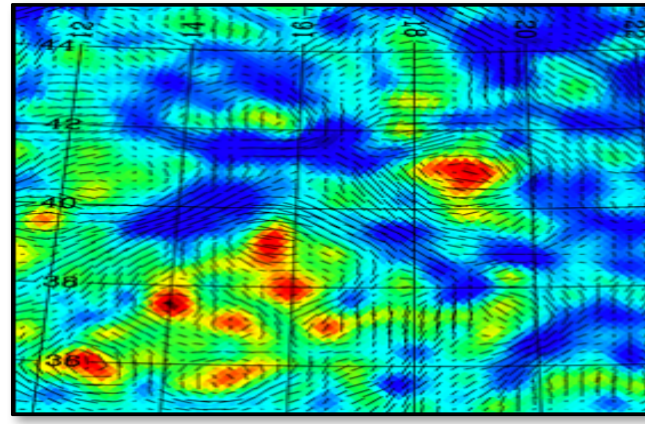


Cross-correlation of EM signal with gravitational tracer of DM

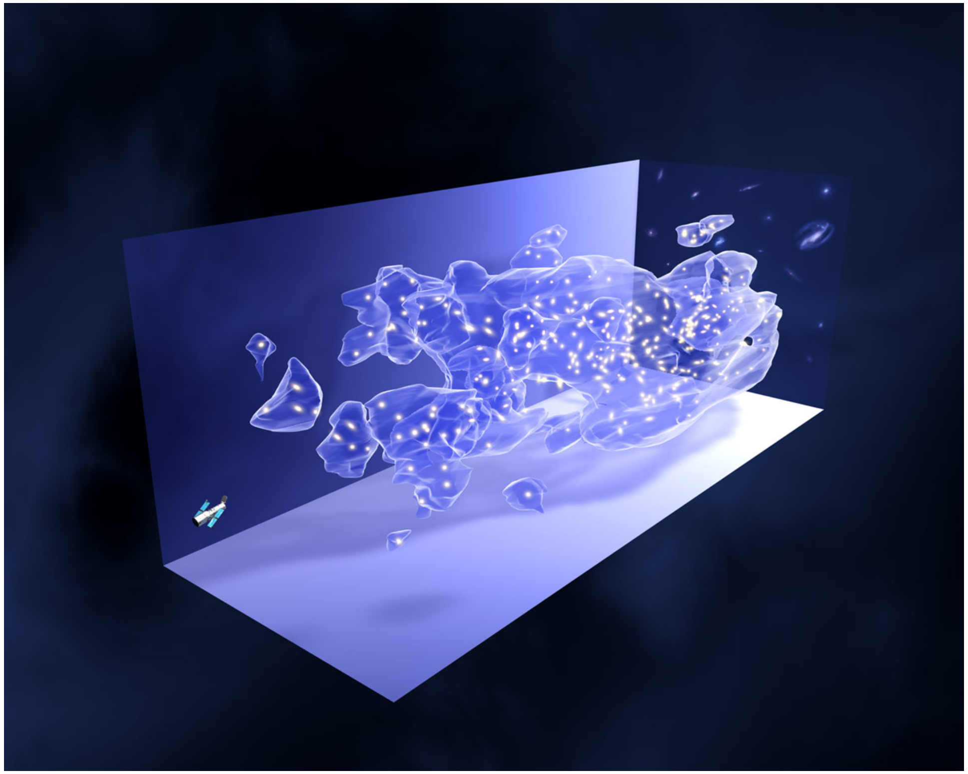
It exploits two distinctive features of particle DM:

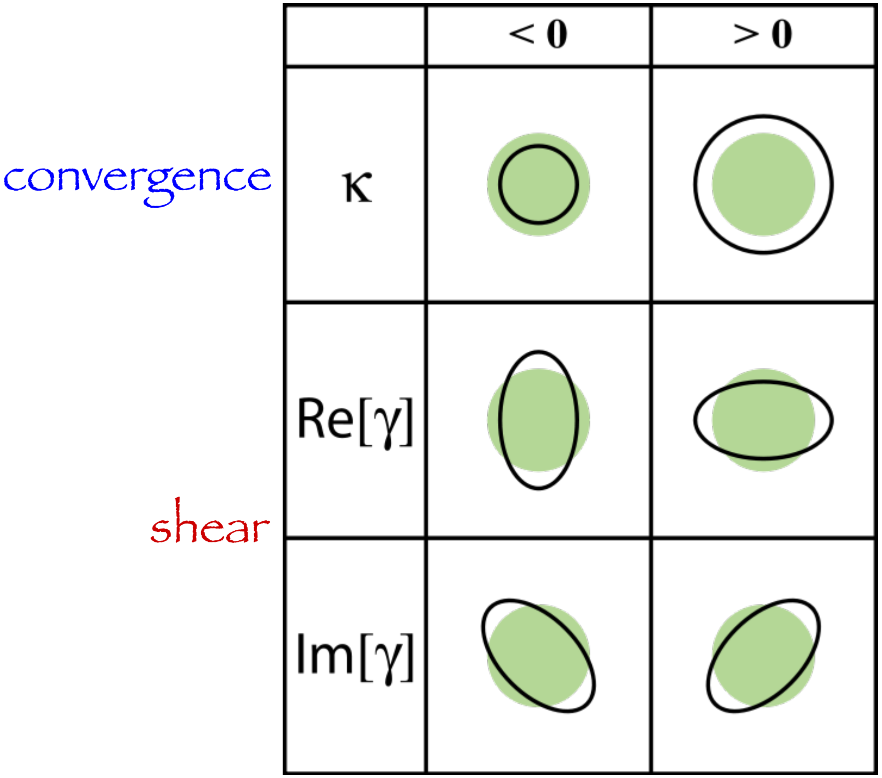
- An electromagnetic signal, manifestation of the particle nature of DM
- A gravitational probe of the existence of DM

It can offer a direct evidence that what is measured by means of gravity is indeed due to DM in terms of an elementary particle

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

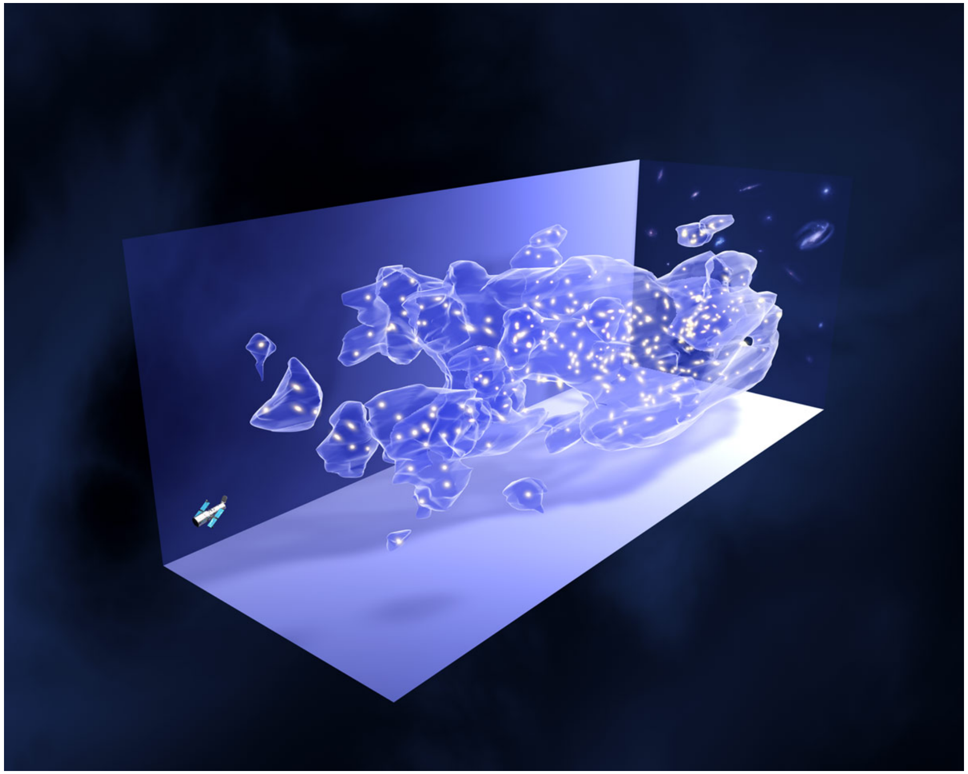




Cosmic structures and gamma-rays

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

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



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

The lensing map can act as the filter needed to isolate the signal (DM) hidden in a large "noise" (astro)

Cross Correlations

- Lensing observables
  - Cosmic shear: directly traces the whole DM distribution
  - CMB lensing: traces DM imprints on CMB anisotropies
- Large scale structure
  - Galaxy catalogs: trace DM by tracing light
  - Cluster catalog

Furhter advantages

Observationally:

- Auto correlation feels:
  - Detector noise (auto correlates with itself)
  - Galactic foregound (auto correlates with itself: typically GF is subtracted, but residuals may be present)

- Cross correlation "automatically" removes:
  - Detector noises (2 different detectors, noises do not correlate)
  - Galactic foreground (gravitational tracers signals do not correlate with galactic gamma ray emission)

Life is more complex than that, but these can offer a good help

Correlation functions

Source Intensity

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

Window function

Density field of the source

W(z): does not depend on direction
depends on redishift
depends on energy

g(z,n): describes how the "field" changes from point to point
contains the dependence on abundance of sources distribution

$$I_g(\vec{n}) \longrightarrow a^g_{lm}$$

$$I_k(\vec{n}) \longrightarrow a^k_{lm}$$

$$\longrightarrow C^{gk}_l = \frac{1}{2l+1}\sum_{m=-l}^{l} a^{g*}_{lm} a^k_{lm}$$

Cross angular power spectrum

$$\langle I_\gamma(\vec{n}_1) I_\phi(\vec{n}_2) \rangle \longrightarrow C_l^{\gamma\phi}$$

$$C_l^{\gamma\phi} \longleftarrow W_\gamma(z) W_\phi(z) P(k,z)$$

window functions

power spectrum

Redshift dependence

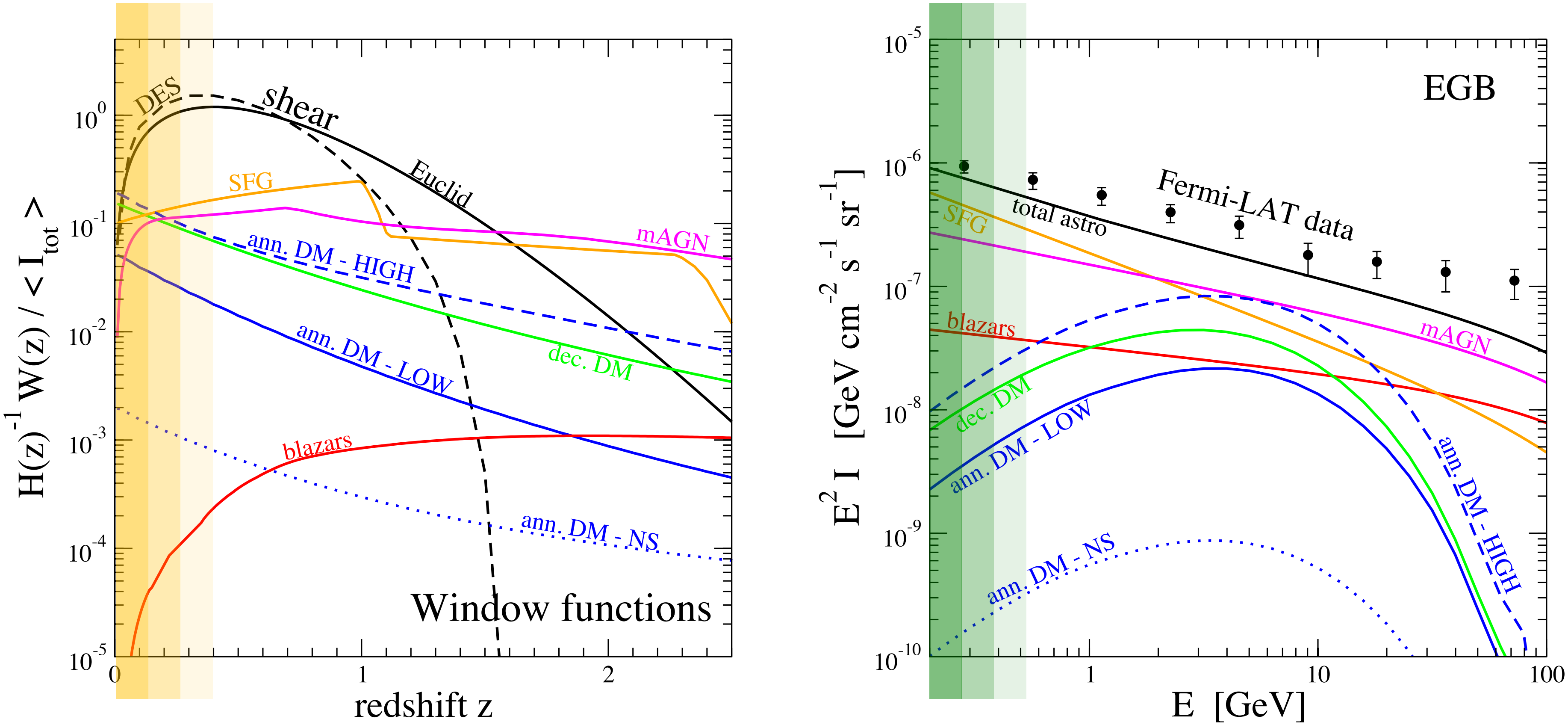
Energy dependence

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

Camera, Fornasa, NF, Regis, JCAP 1506 (2015) 029

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

Tomographic-spectral approach



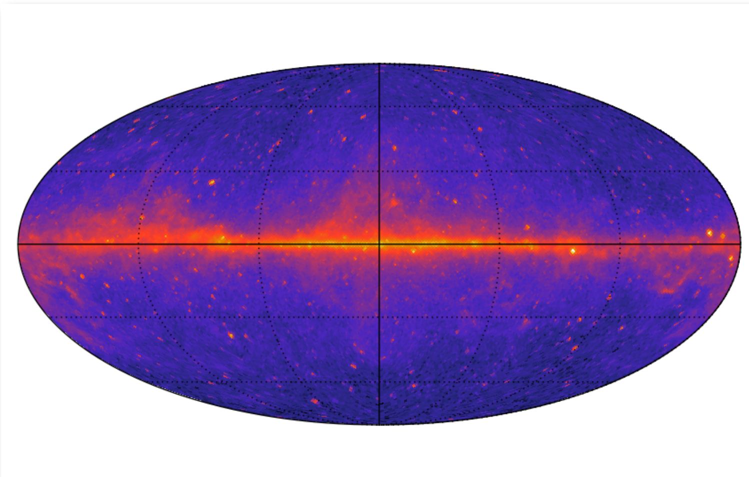
Reshift information in shear can help in "filtering" signal sources

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

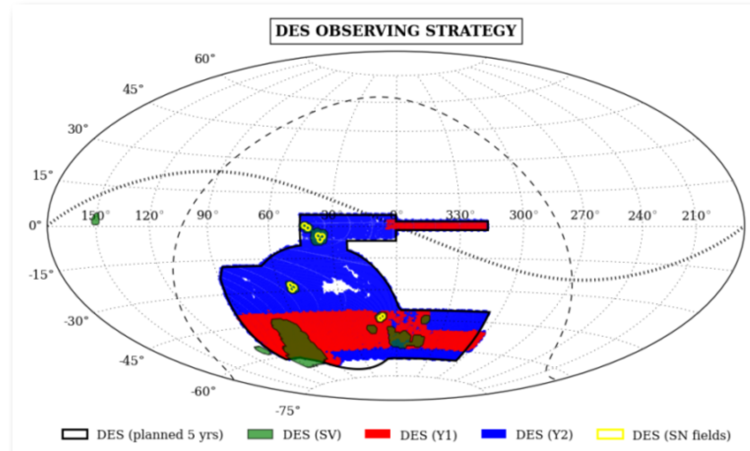
Camera, Fornasa, NF, Regis, JCAP 1506 (2015) 029

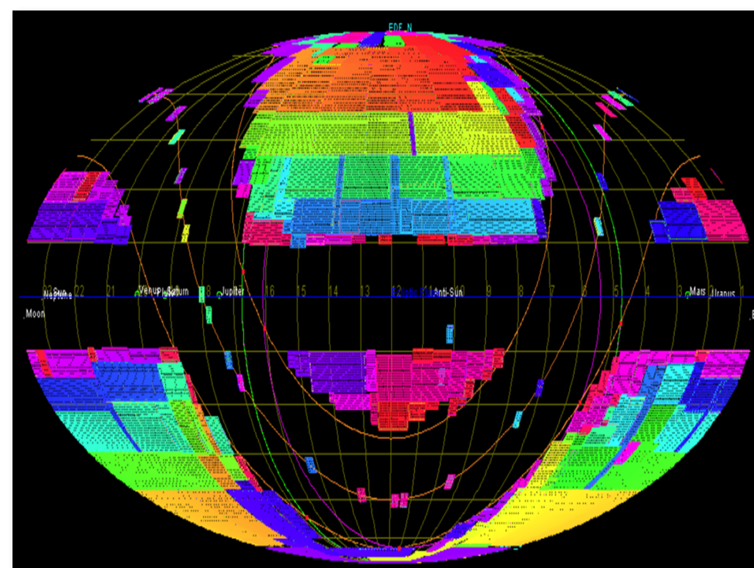
Opportunities

DES – 5000 sq deg



Fermi-LAT

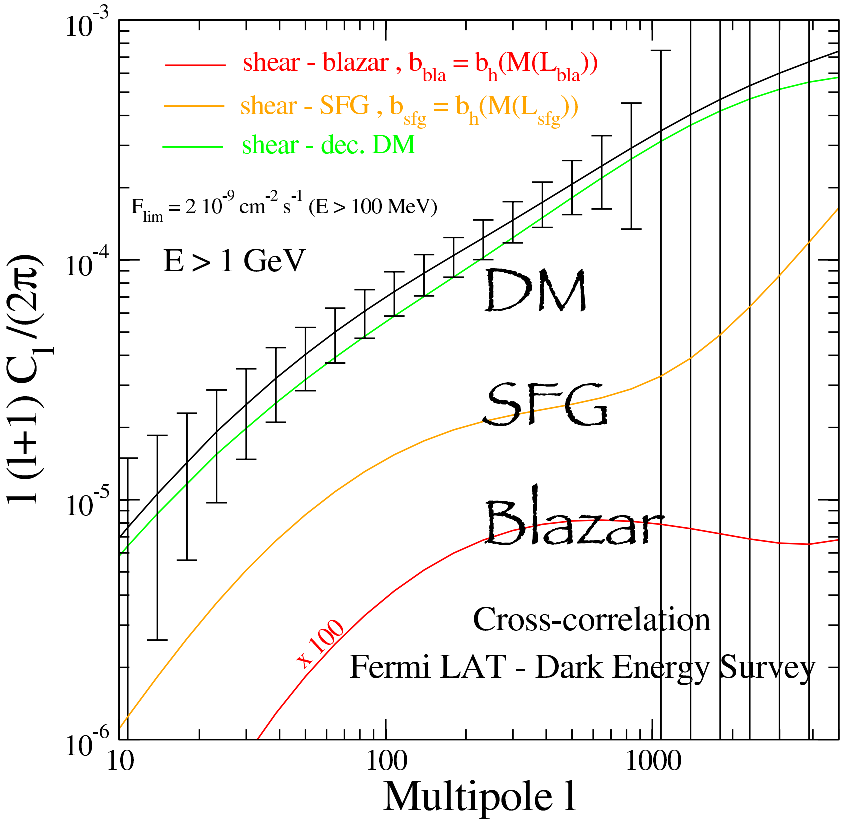




Euclid – 15000 sq deg
LSST – 30000 sq deg

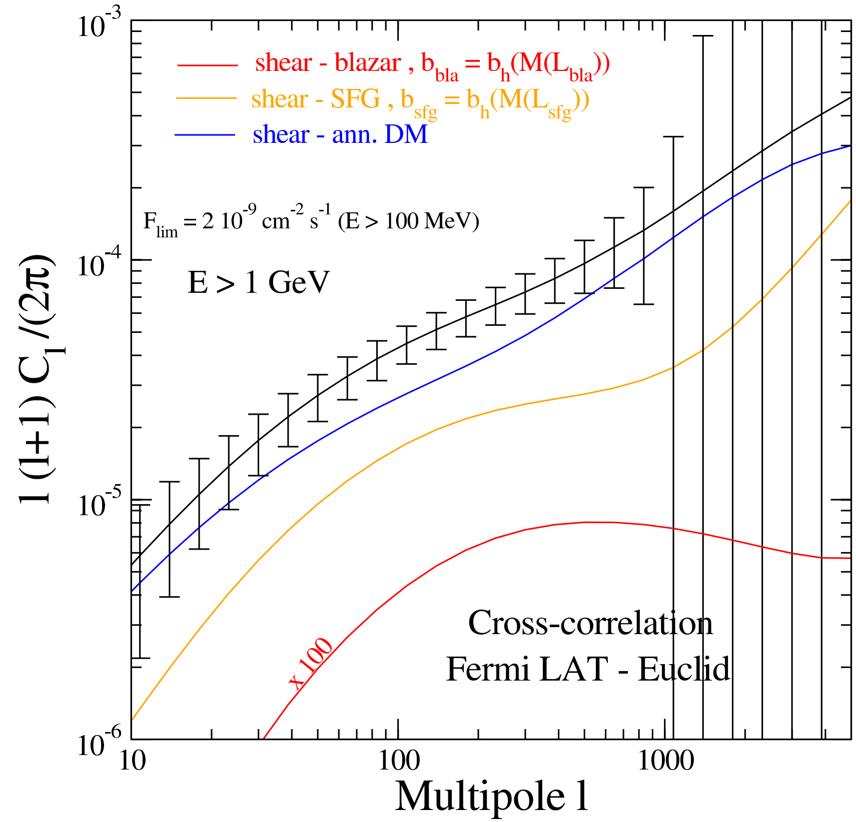
Proof of concept

Decaying DM



Fermi-LAT/5-yr with DES

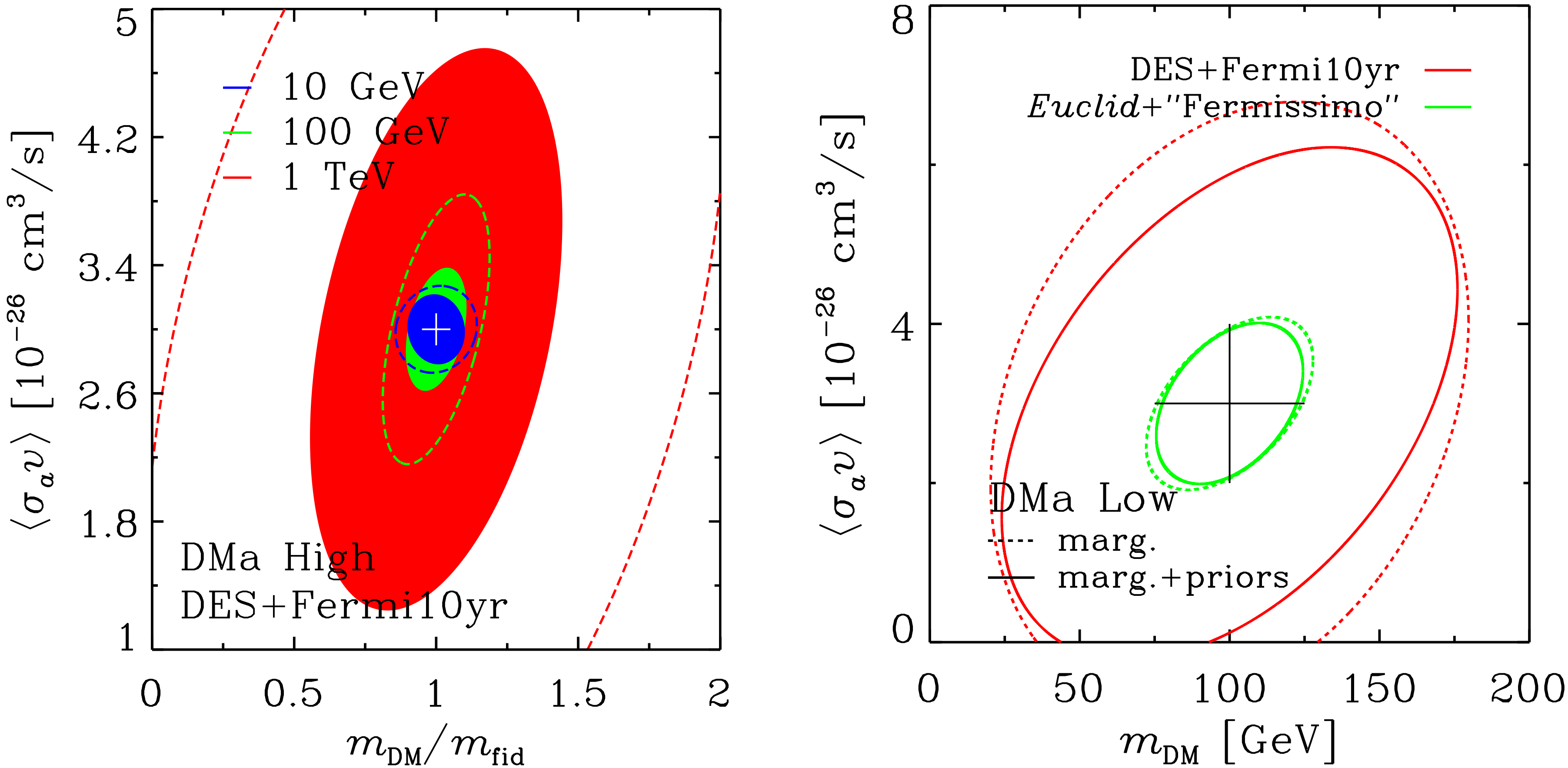
Annihilating DM



Fermi-LAT/5-yr with Euclid

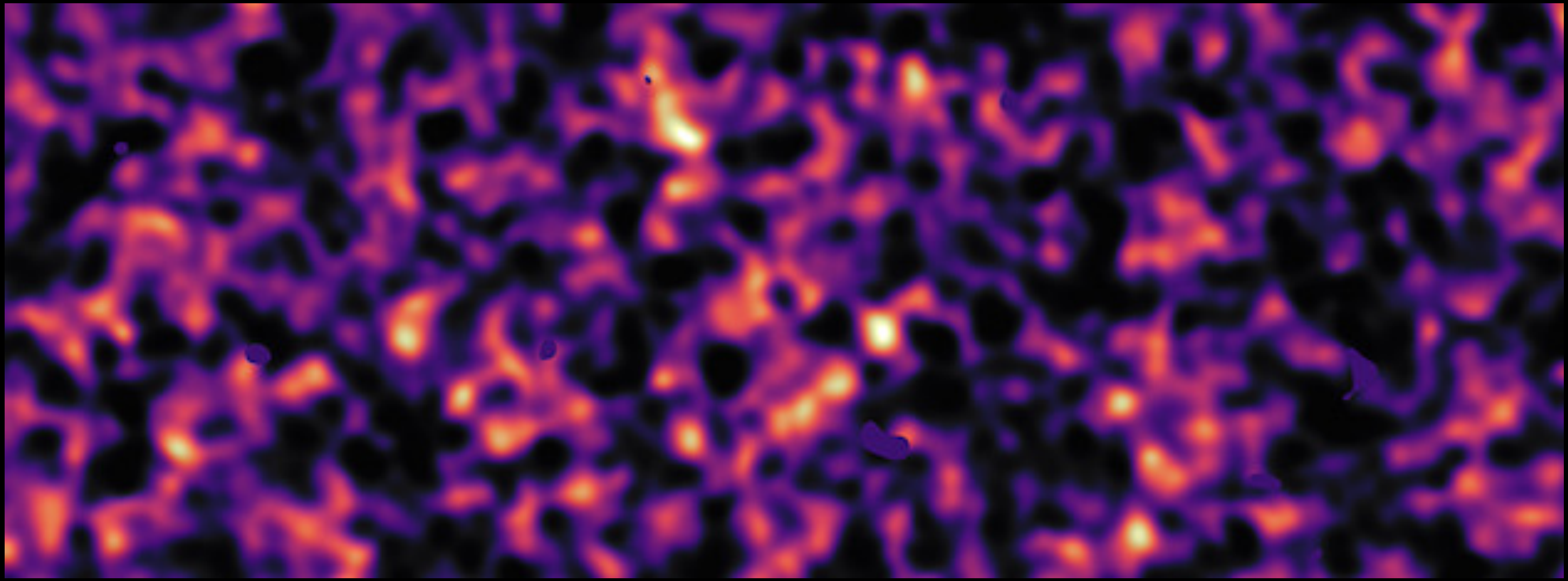
Camera, Fornasa, NF, Regis, Ap. J. Lett. 771 (2013) L5

Sensitivity on DM parameters



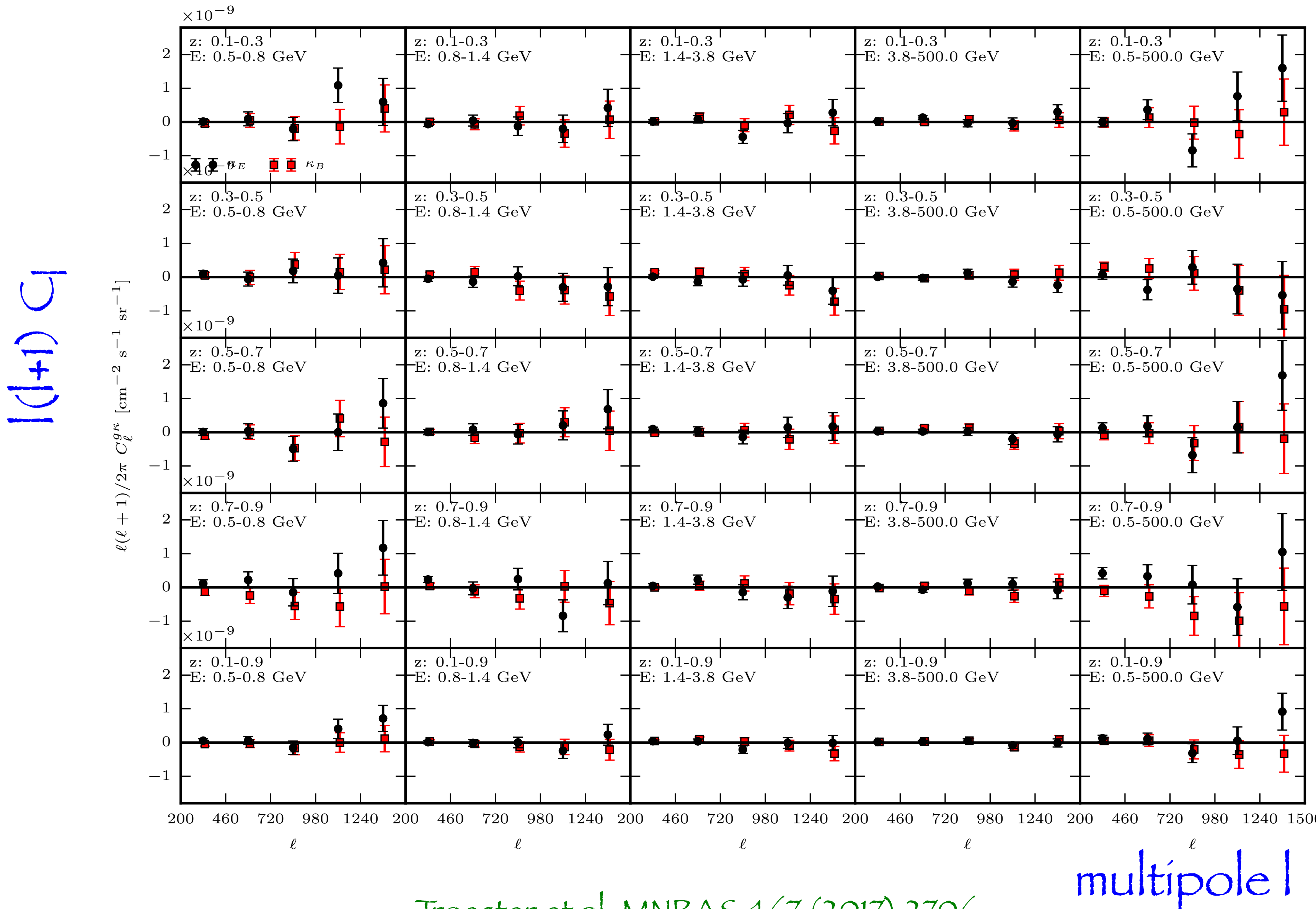
Camera, Fornasa, NF, Regis, JCAP 06 (2015) 029

We start having data



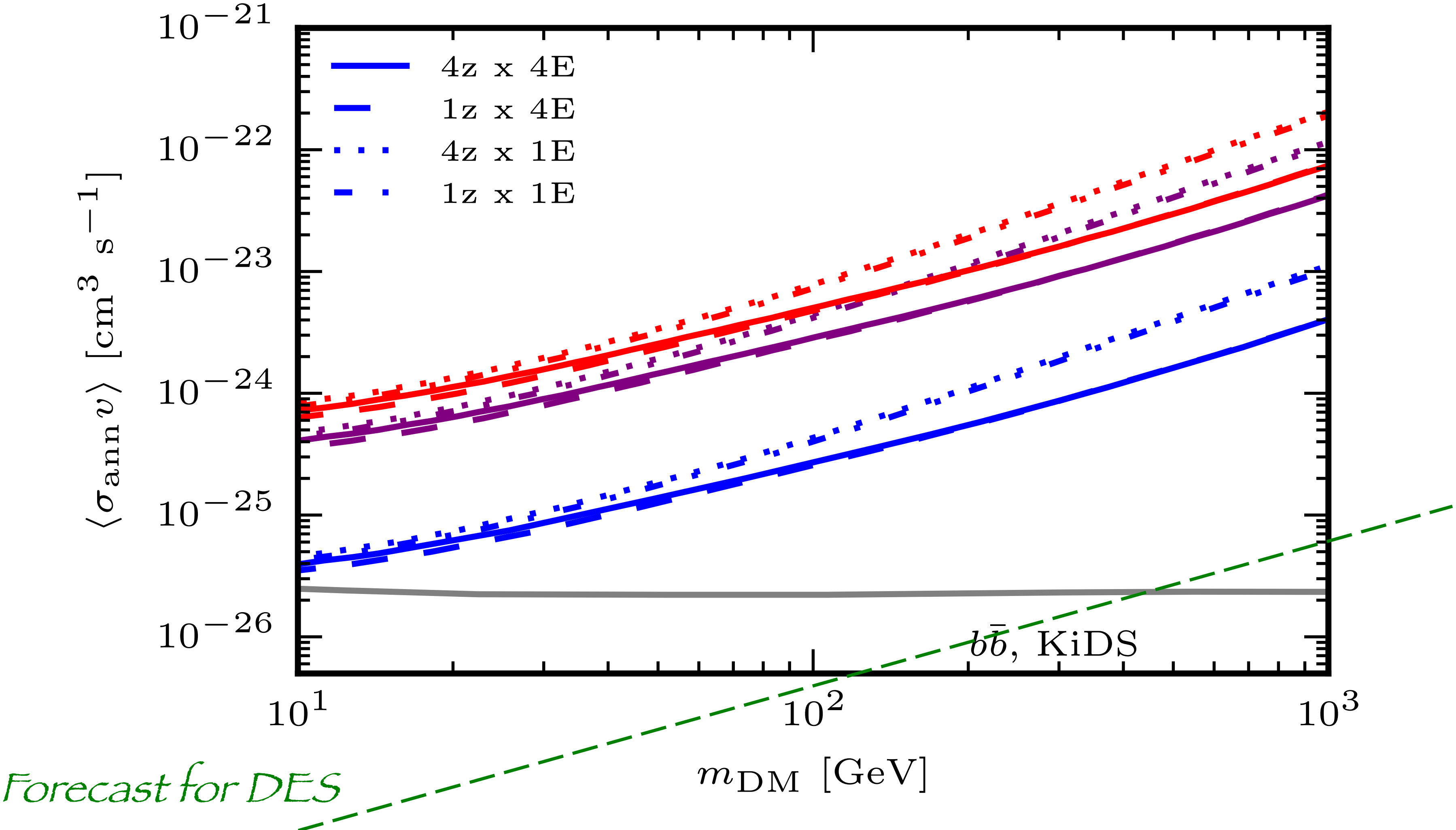
DM maps from KiDS analysis on weak lensing

Fermi x KiDS+RCSLens+CFTHLens



Troester et al, MNRAS 467 (2017) 2706

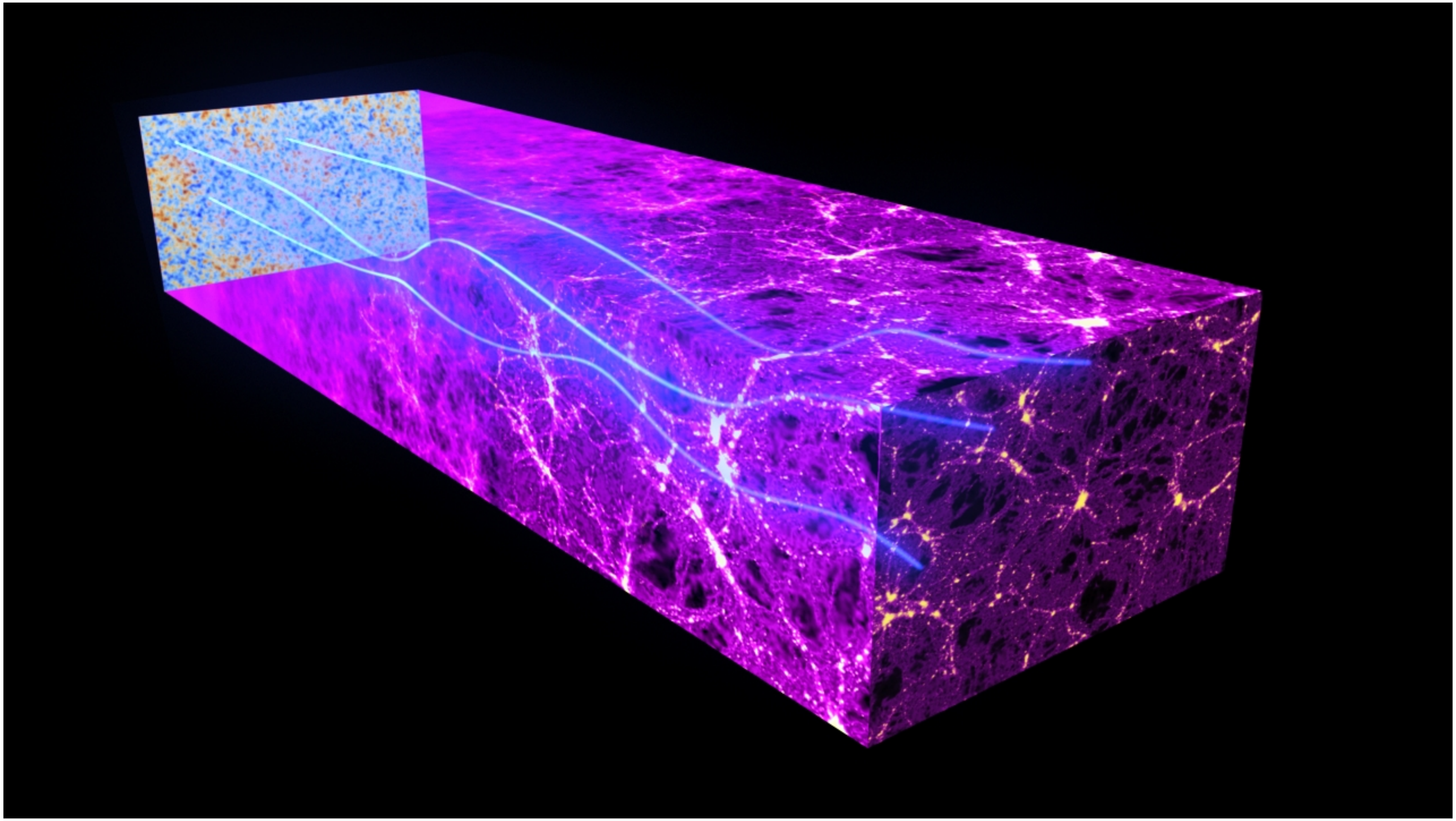
Fermi x KiDS+RCSLens+CFTHLens



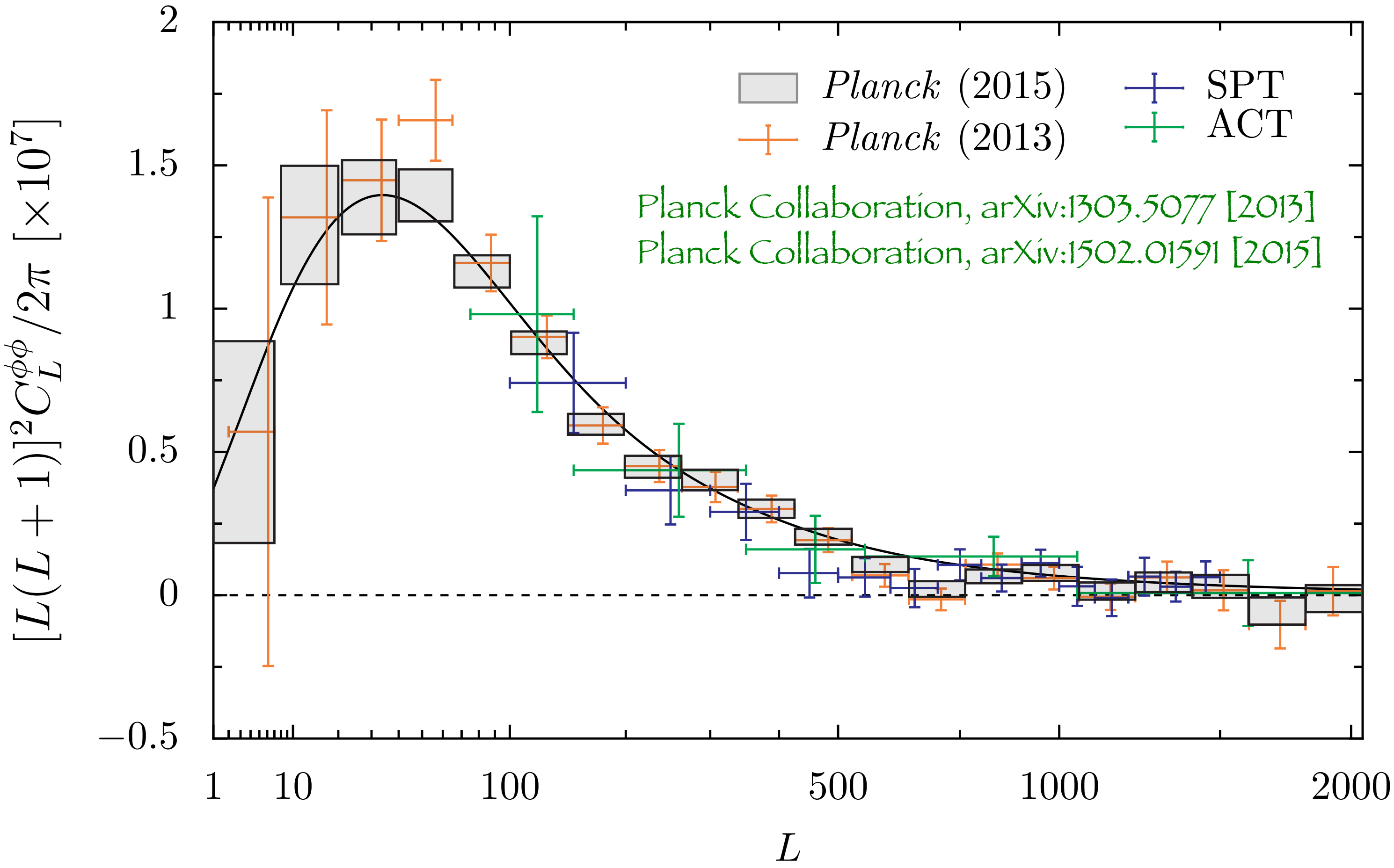
Troester et al, MNRAS 467 (2017) 2706

See also: Shirasaki, Horiuchi, Yoshida, PRD 90 (2014) 063502
Shirasaki, Marcias, Horiuchi, Shirai, Yoshida, PRD 94(2016) 063522

CMB Lensing

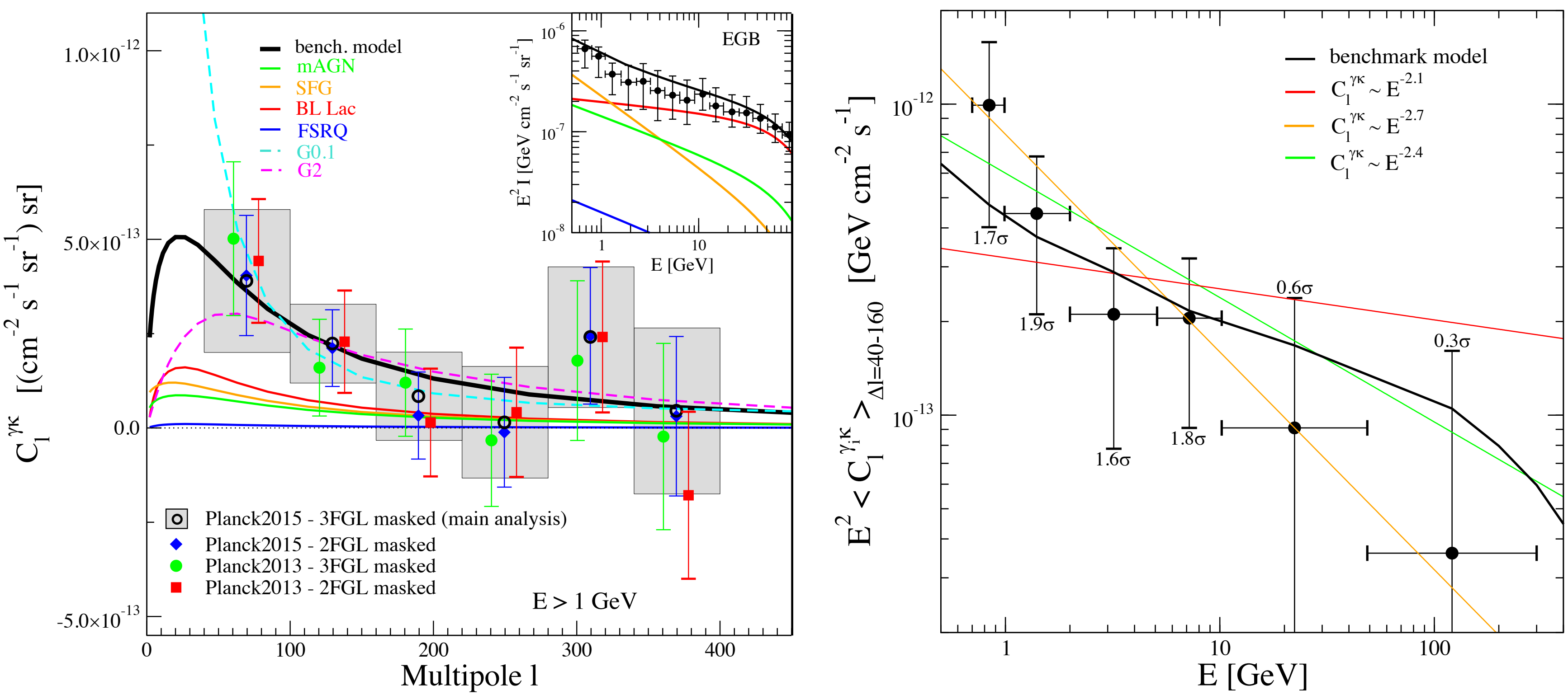


Planck CMB lensing



- CMB-lensing autocorrelation is measured: 40σ significance
- CMB-lensing: integrated measure of DM distribution up to last scattering
- It might exhibit correlation with gamma-rays emitted in DM structures

Fermi/gamma + Planck/CMB lensing



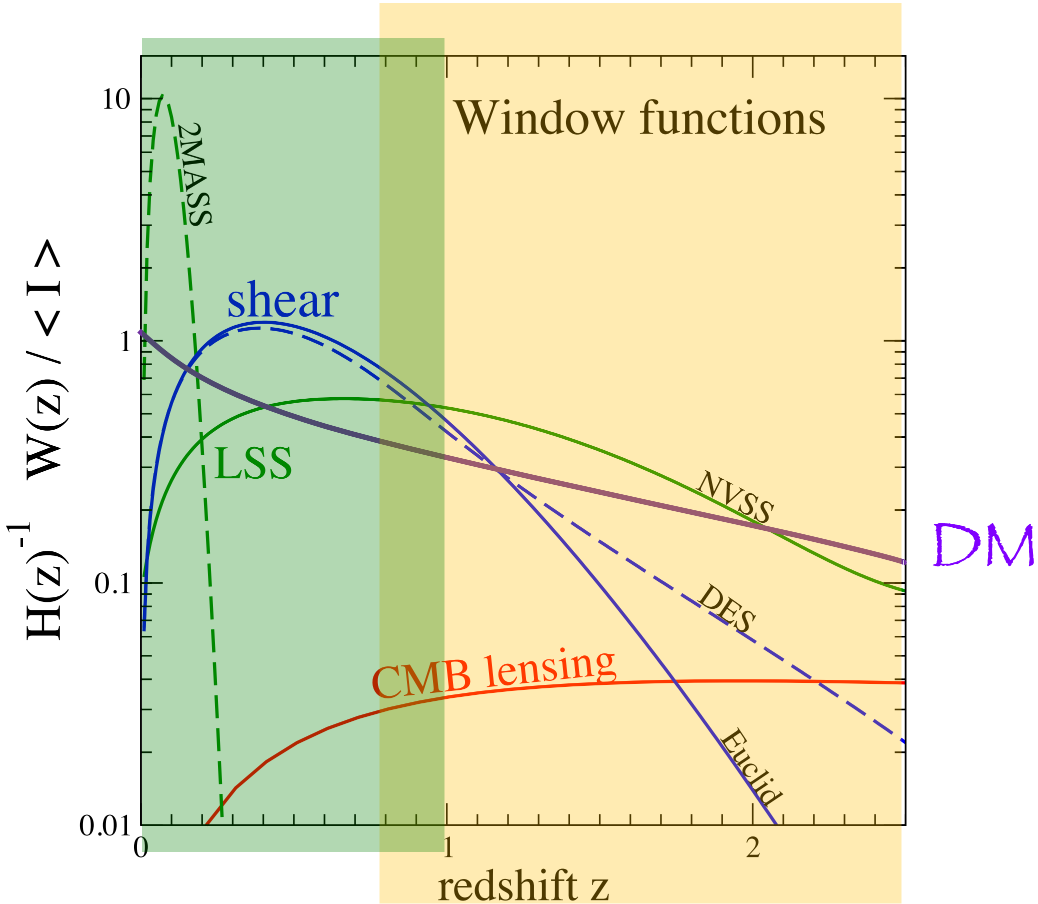
Cross-correlation: deviates 3.0σ from null signal

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

Window functions: DM x CMB lensing

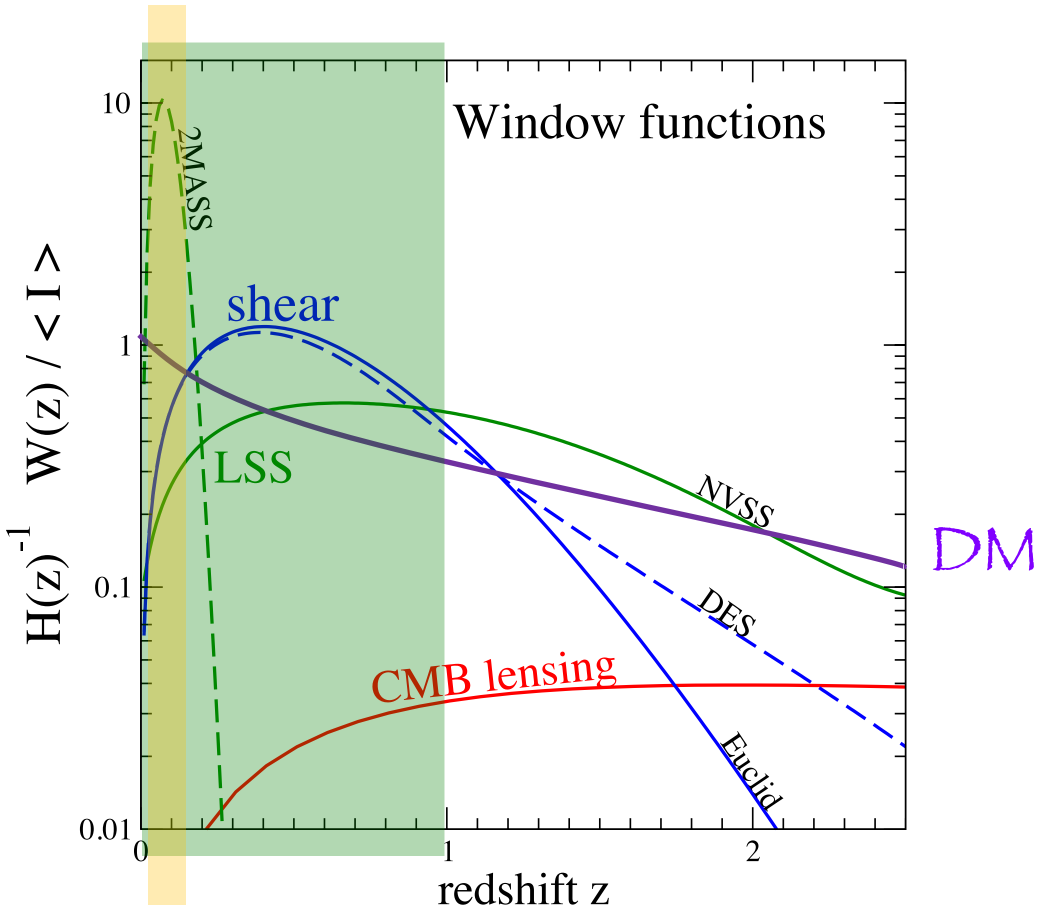


CMB lensing is likely not the best observable for DM

Instead it can hopefully help in constraining astrophysical sources

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

Window functions: DM x LSS

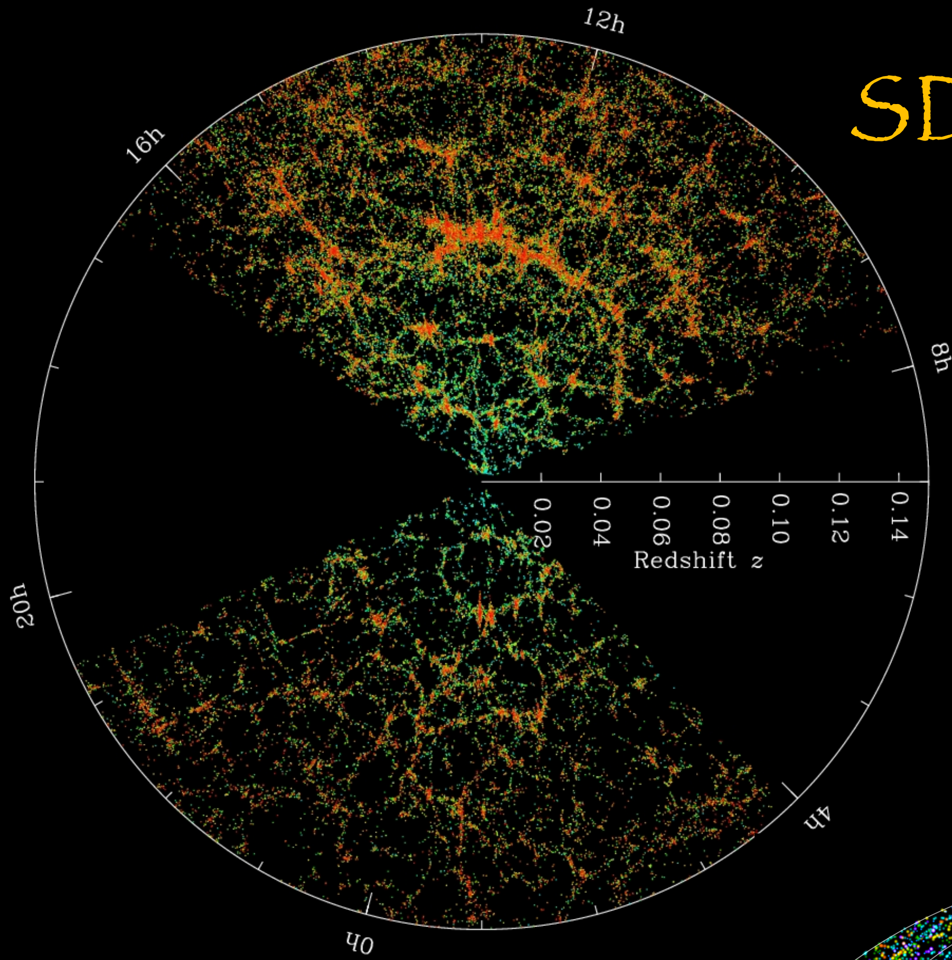


Galaxy catalogs (expecially low-z ones) can have good overlap with DM

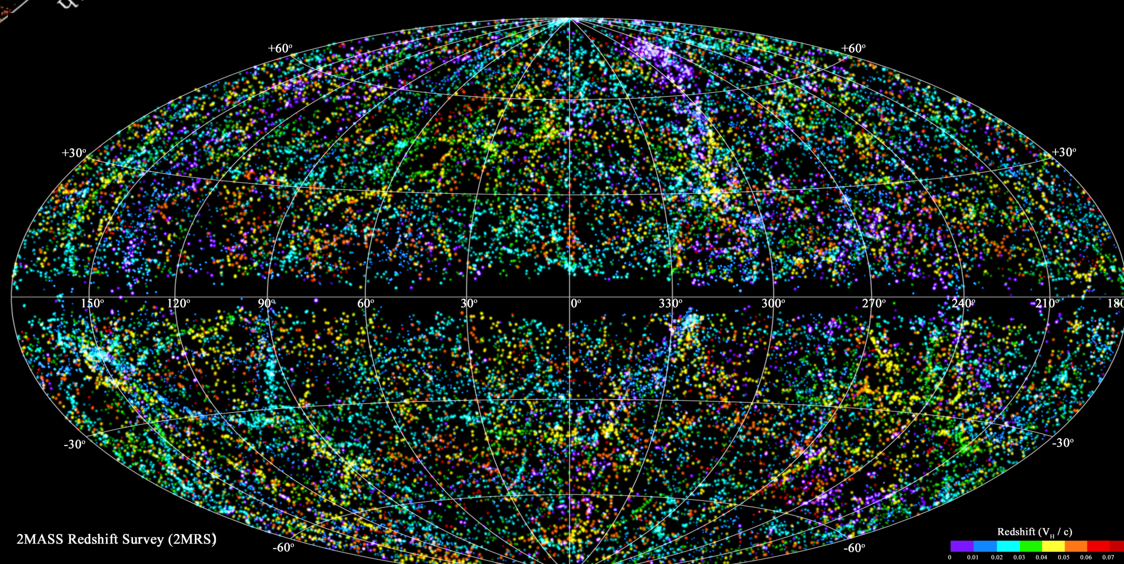
They trace light (while shear directly traces DM), but great potential

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

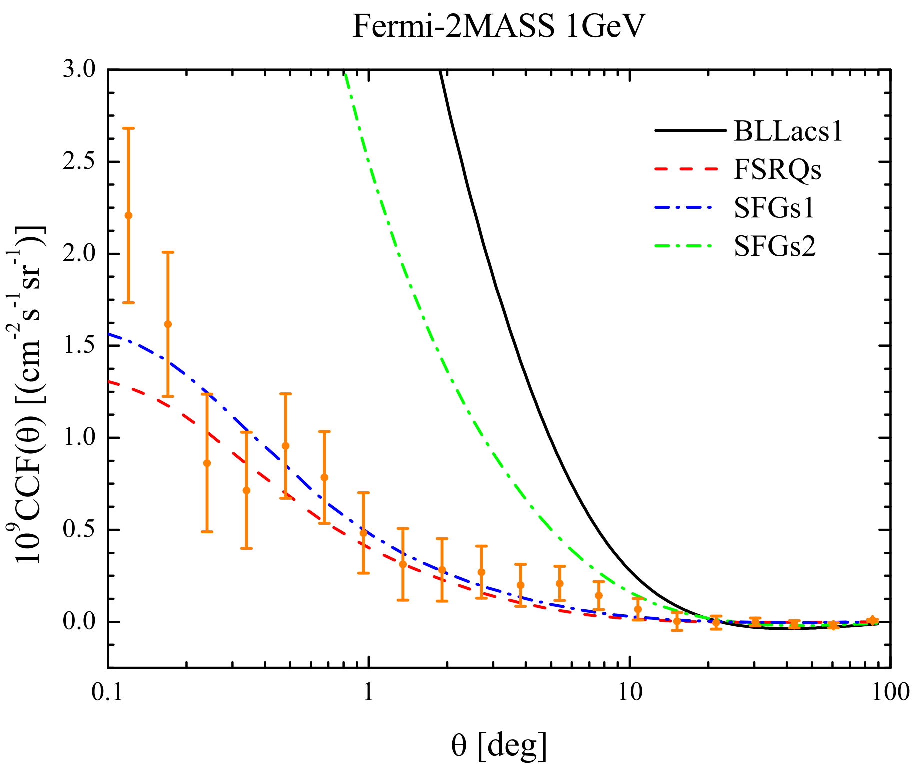
SDSS

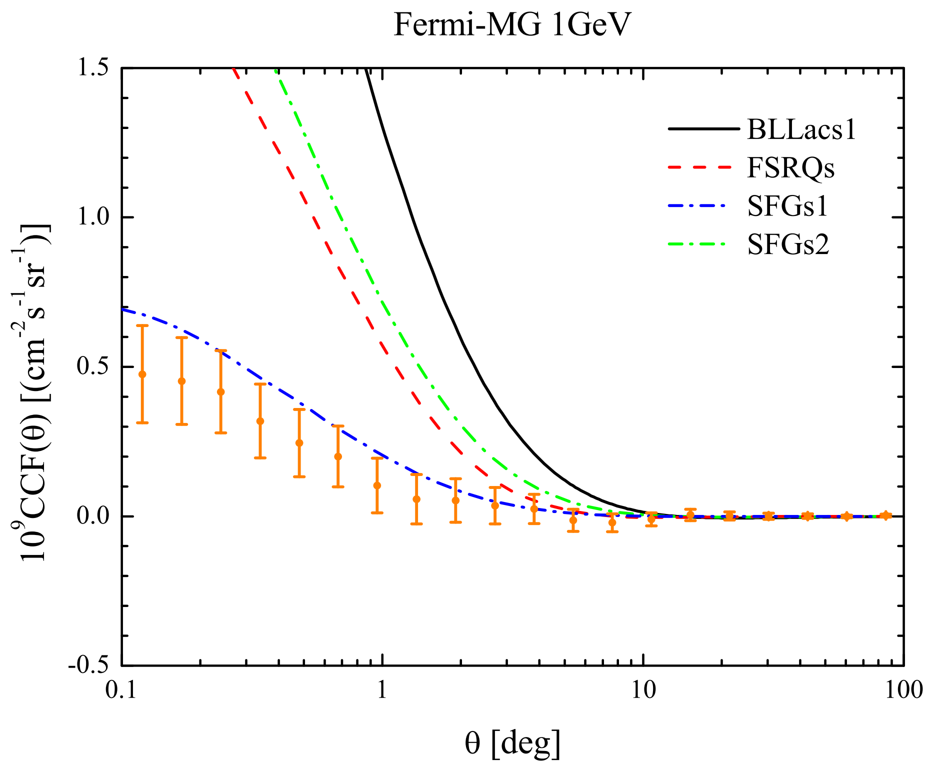

12h
16h
8h
20h
4h
0h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z

2MASS


+60°
+60°
+30°
+30°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
180°
-30°
-30°
-60°
-60°
2MASS Redshift Survey (2MRS)
Redshift (V_H / c)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07

Cross correlation with galaxy catalogs





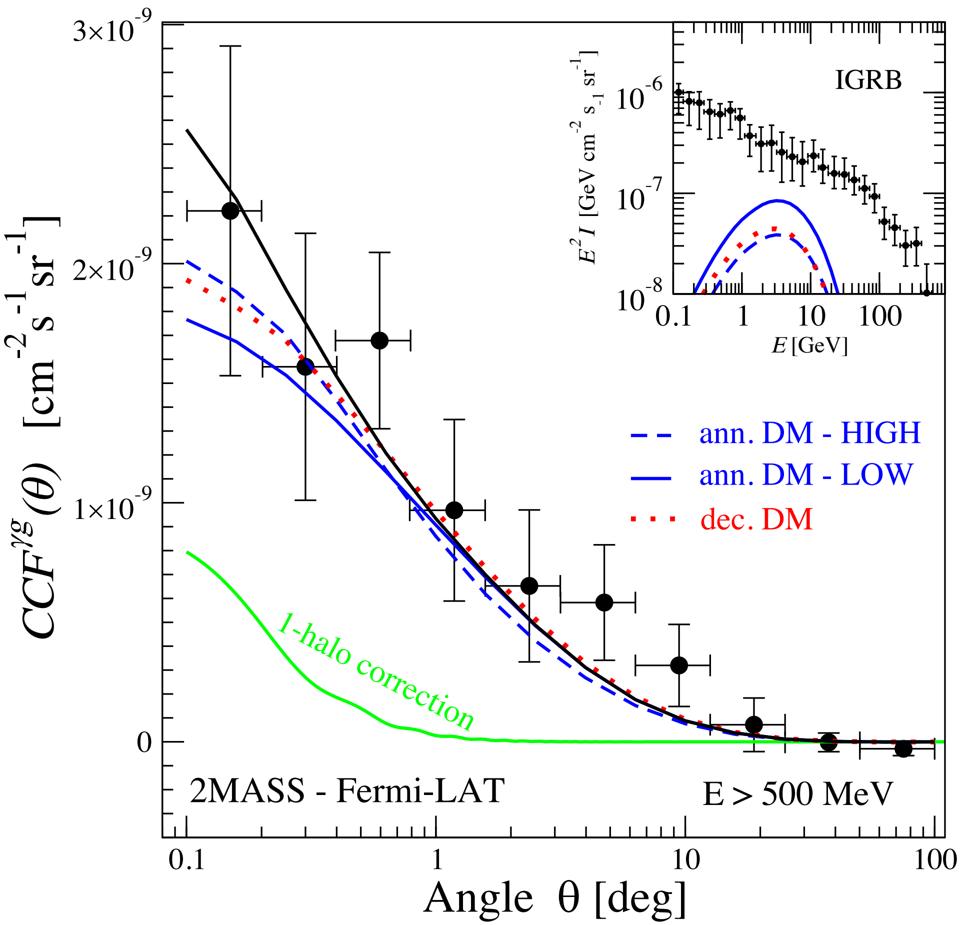
Fermi x 2MASS

Fermi x SDSS-DR8 MG

correlation at the degree scale

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

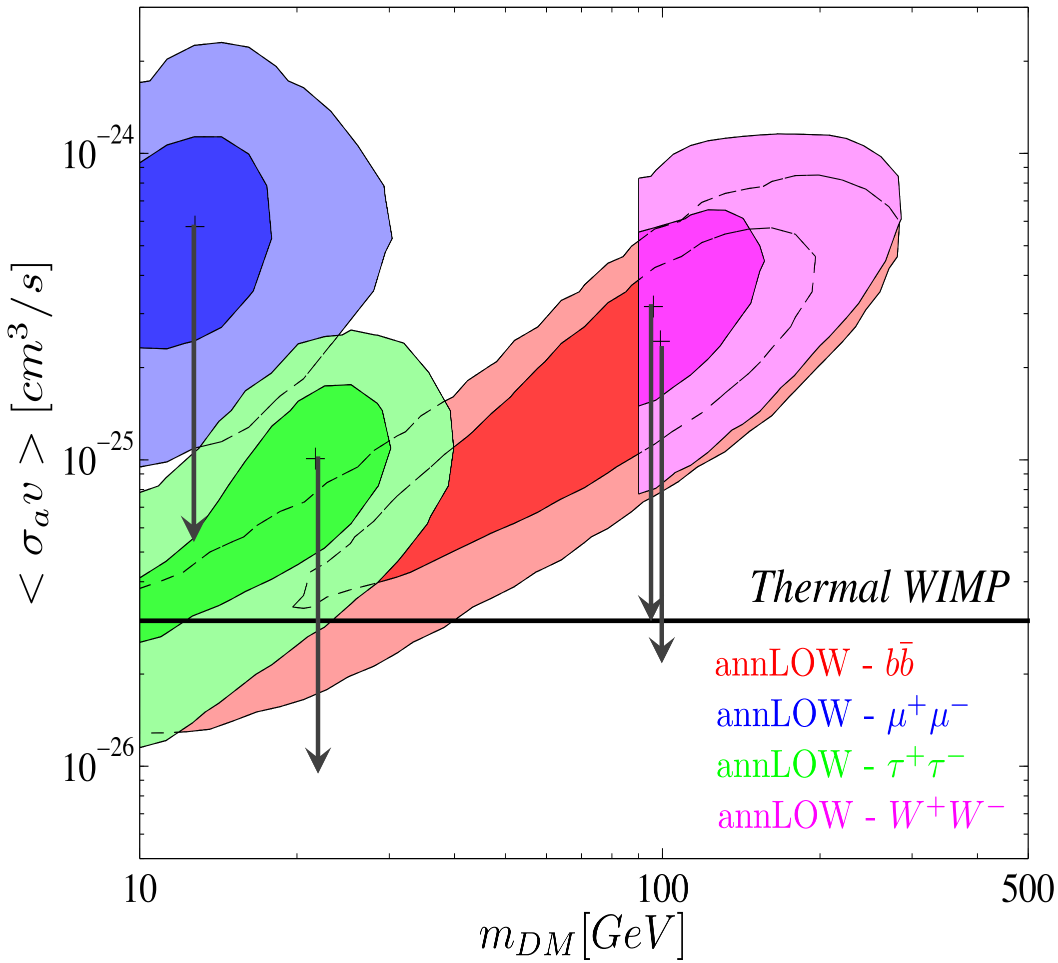
Fermi x 2MASS



The observed cross-correlation can be reproduced (both in shape and size) by a DM contribution that is largely subdominant in the total intensity

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

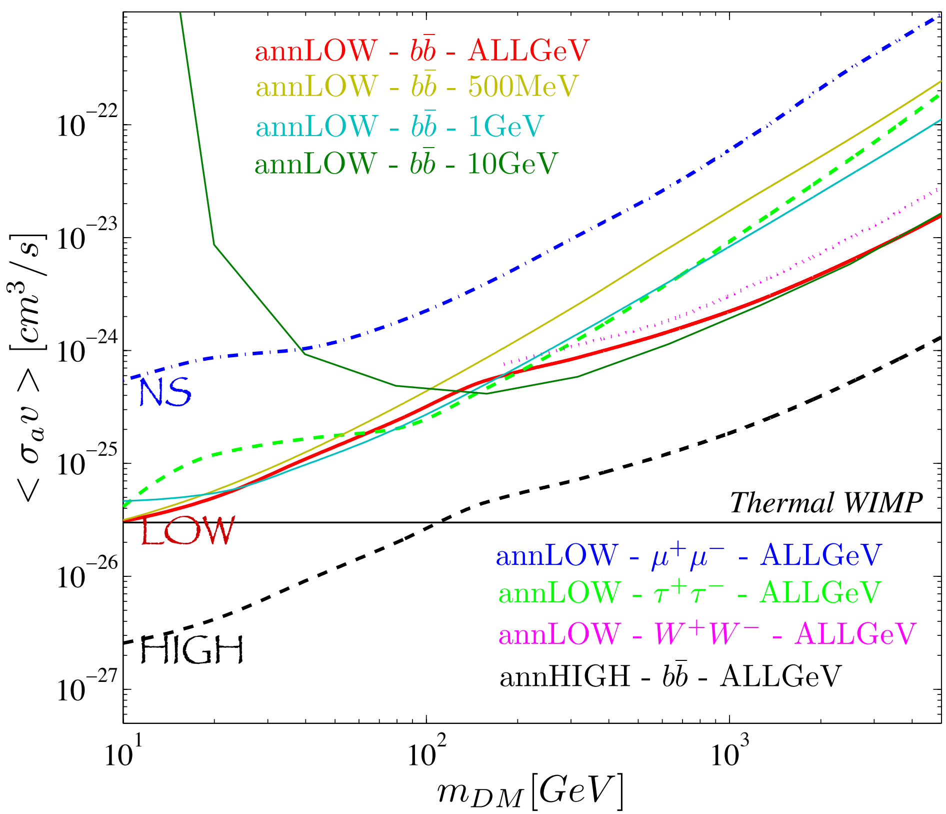
Fermi x 2MASS

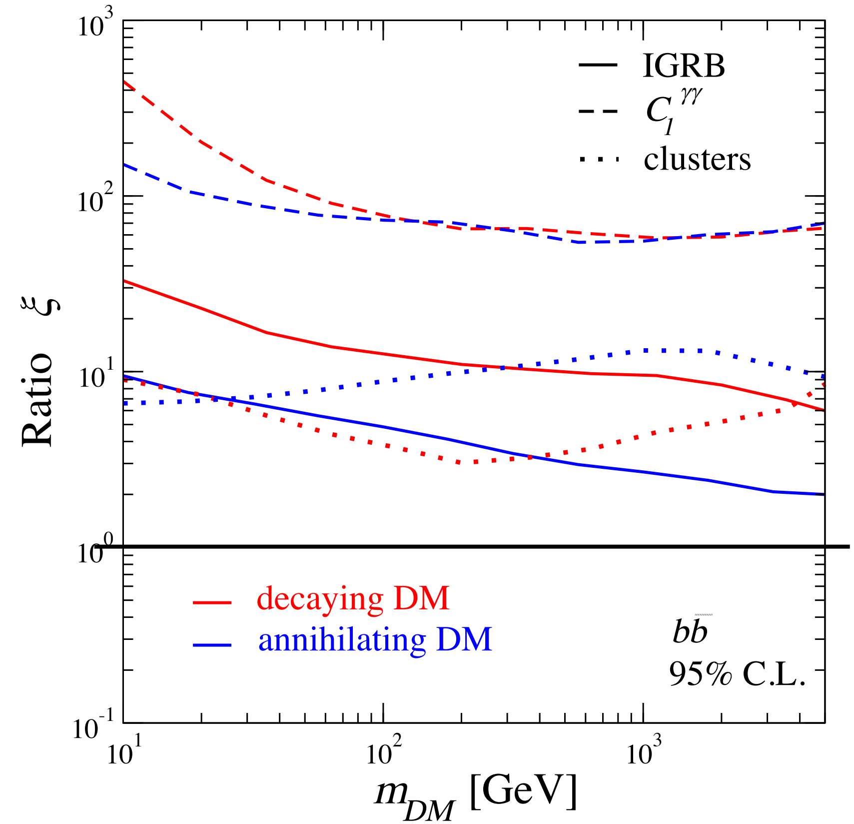


Just in case it's a DM signal ...

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

Fermi x 2MASS





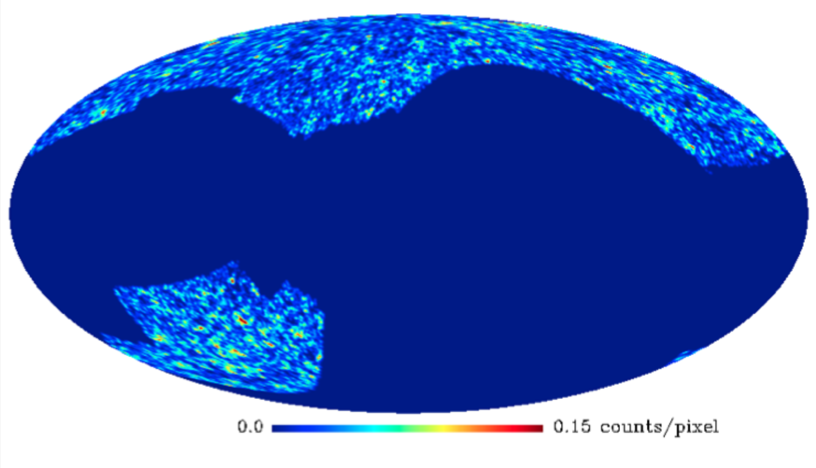
Bound from cross correlation

Bounds ratios
Correlation technique stronger

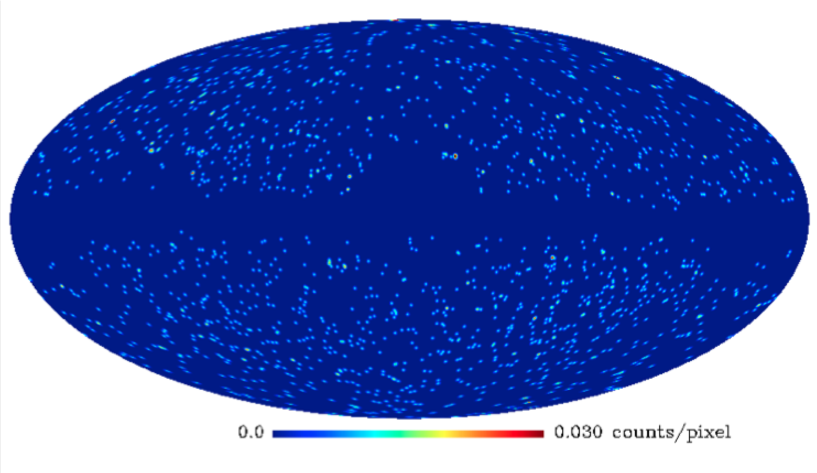
Regis, Xia, Cuoco, Branchini, NF, Viel, ApJS 221 (2015) 29
See also: Shirasaki, Horiuchi, Yoshida, PRD 90 (2014) 063502
Shirasaki, Horiuchi , Yoshida, PRD 92 (2015) 123540

Galaxy clusters

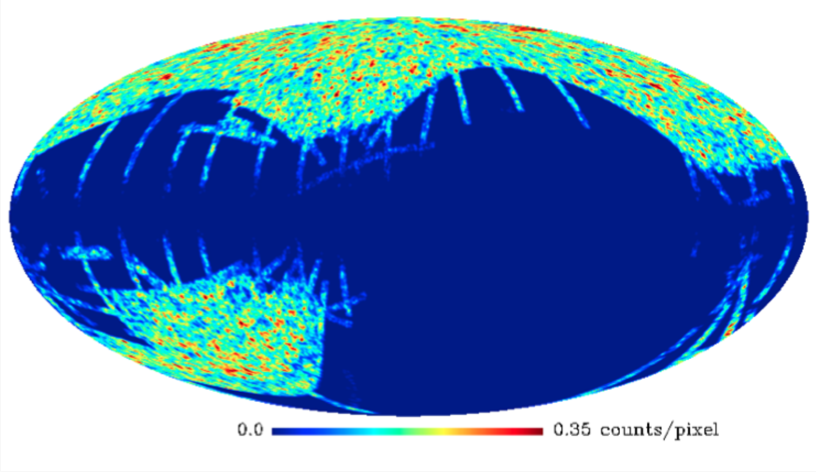
redMaPPer



Planck SZ

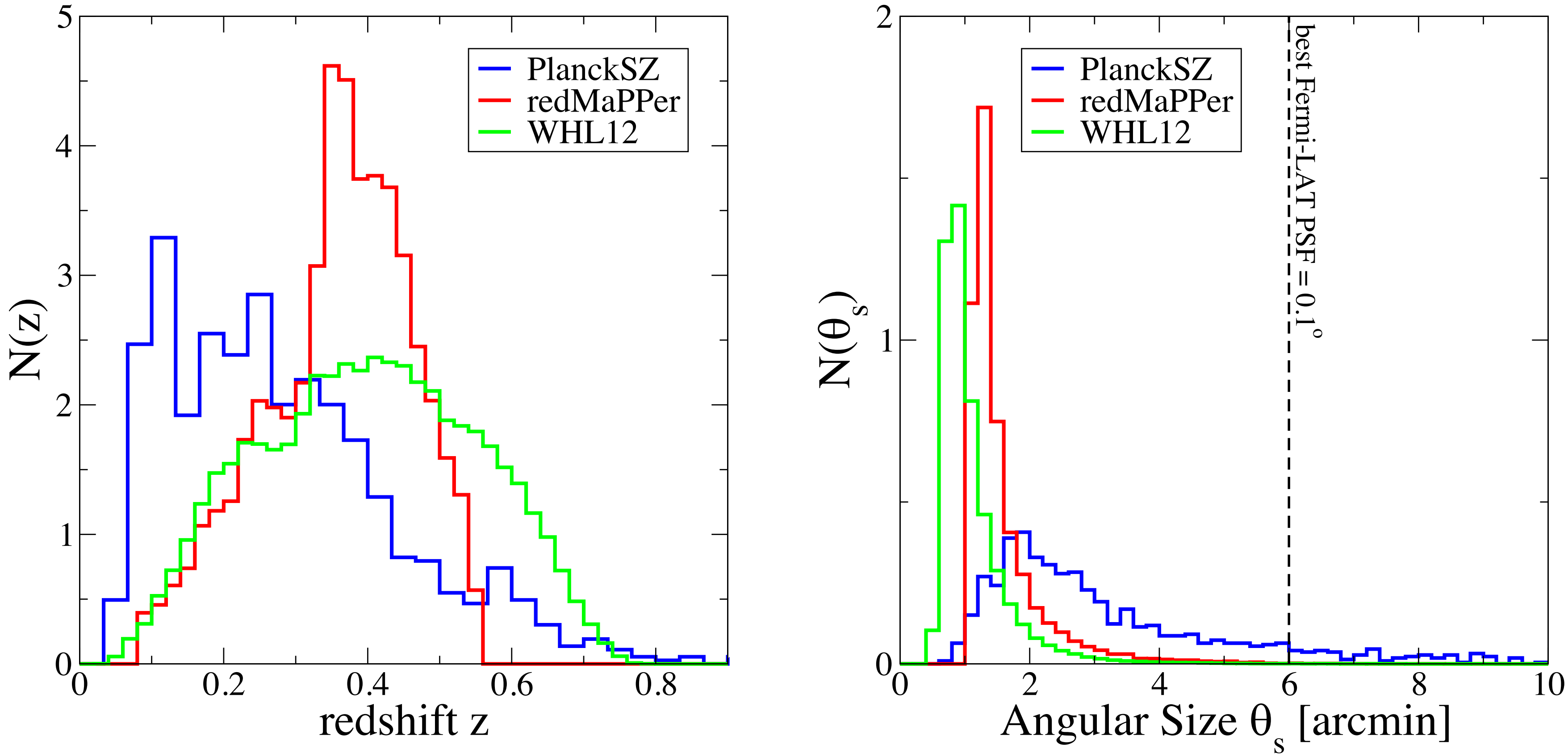


WHL12



Catalog	Objects
redMaPPer	26 350
WHL12	39 668
Planck SZ	1 653

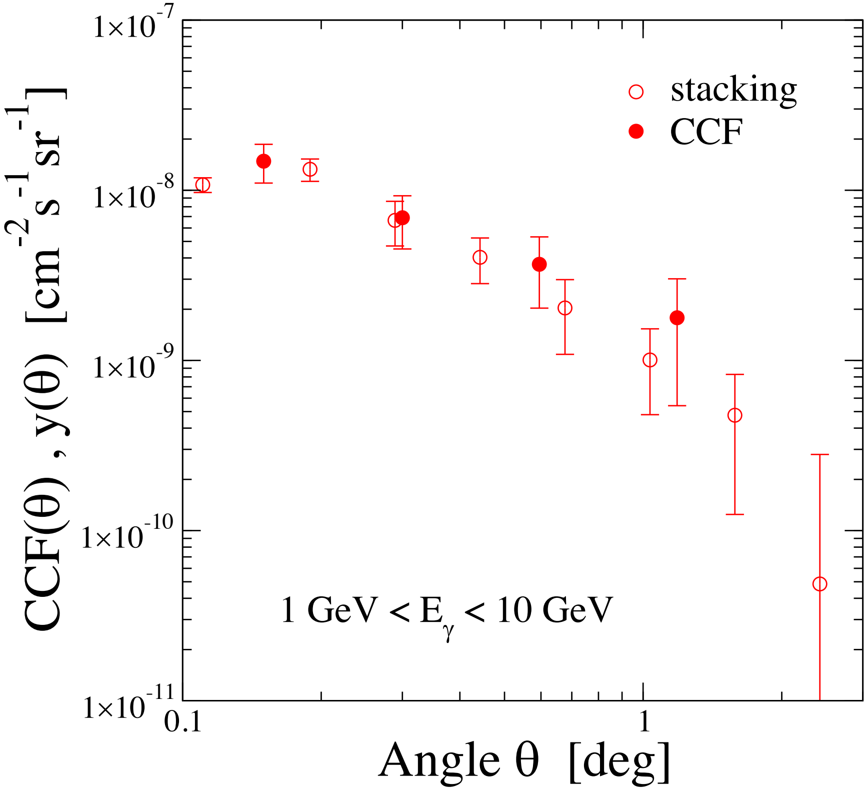
Catalogs

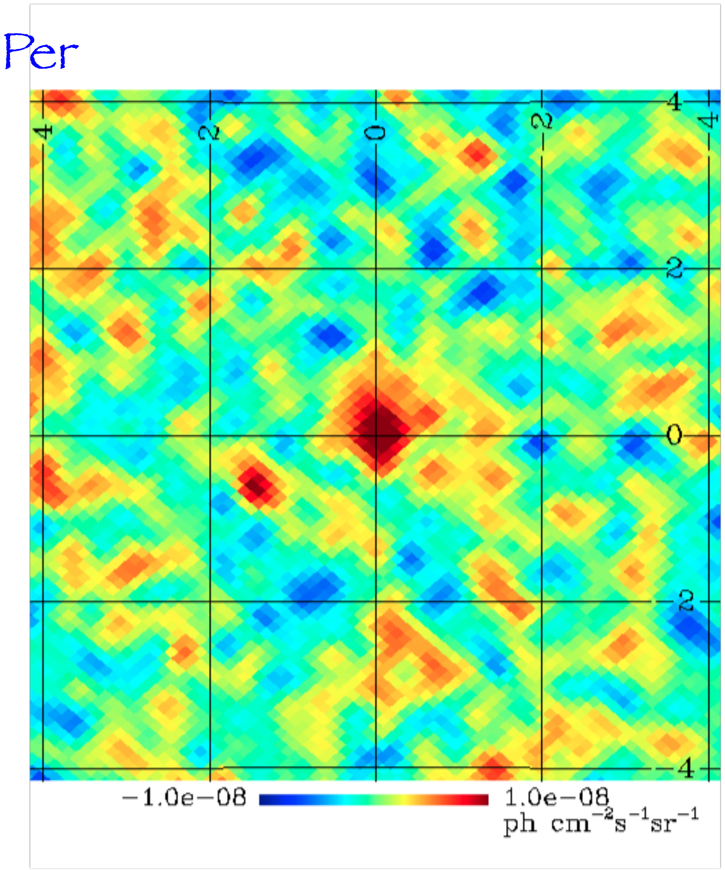


N(z)
redshift z
0
0.2
0.4
0.6
0.8
1
2
3
4
5
PlanckSZ
redMaPPer
WHL12
N(θs)
Angular Size θs [arcmin]
0
2
4
6
8
10
1
2
PlanckSZ
redMaPPer
WHL12
best Fermi-LAT PSF = 0.1°

Cross correlation with gamma rays

redMaPPer





Correlation function and stacking profile

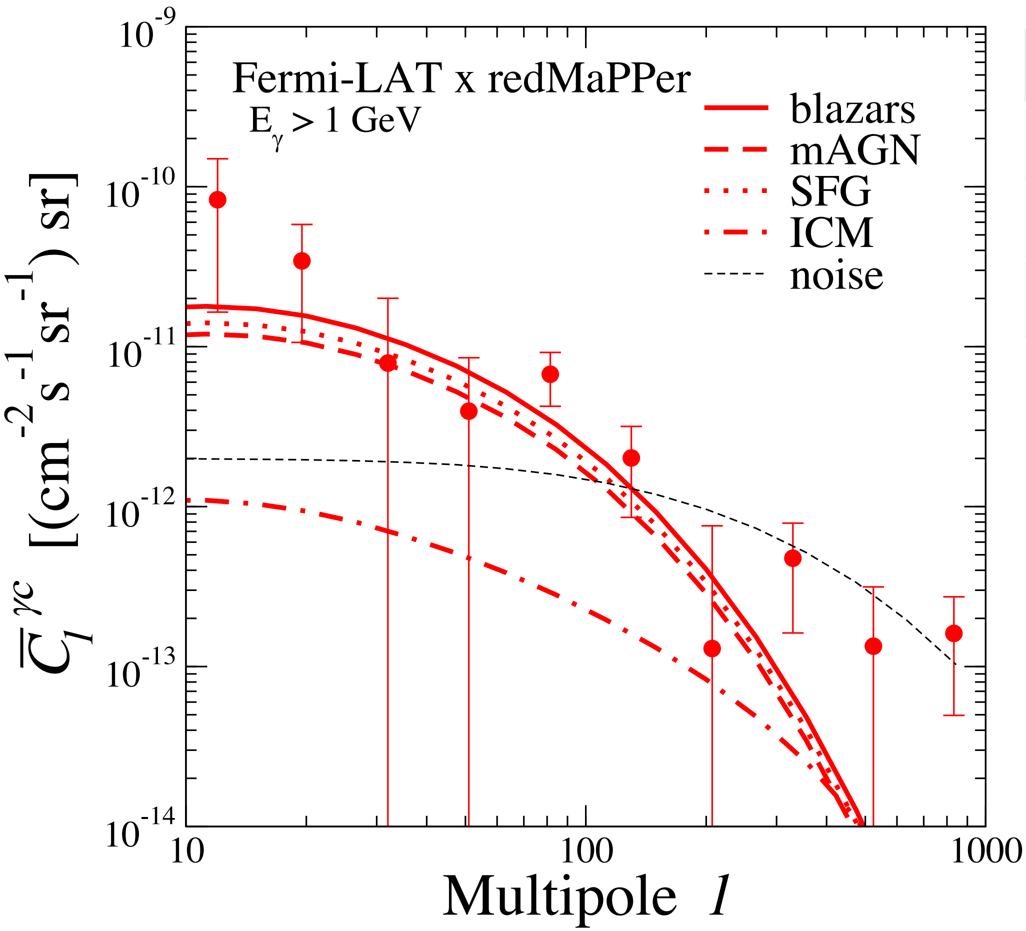
Gamma ray stacking

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

Galaxy clusters

- A cross correlation signal is significantly detected out to 1 degree (beyond the Fermi PSF extension)
- The cross-correlation measurement confirms that the unresolved EGB observed by Fermi correlates with the large scale clustering of matter in the Universe (here traced by clusters)
- At the typical redshifts of the clusters in these catalogs, one degree corresponds to a linear scale of 10 Mpc
- This means that a (large?) fraction of the correlation signal seems to be not physically associated to the clusters
- Instead, it can be produced by AGNs or SFGs residing in the larger scale structures that surround the high density peaks where clusters reside

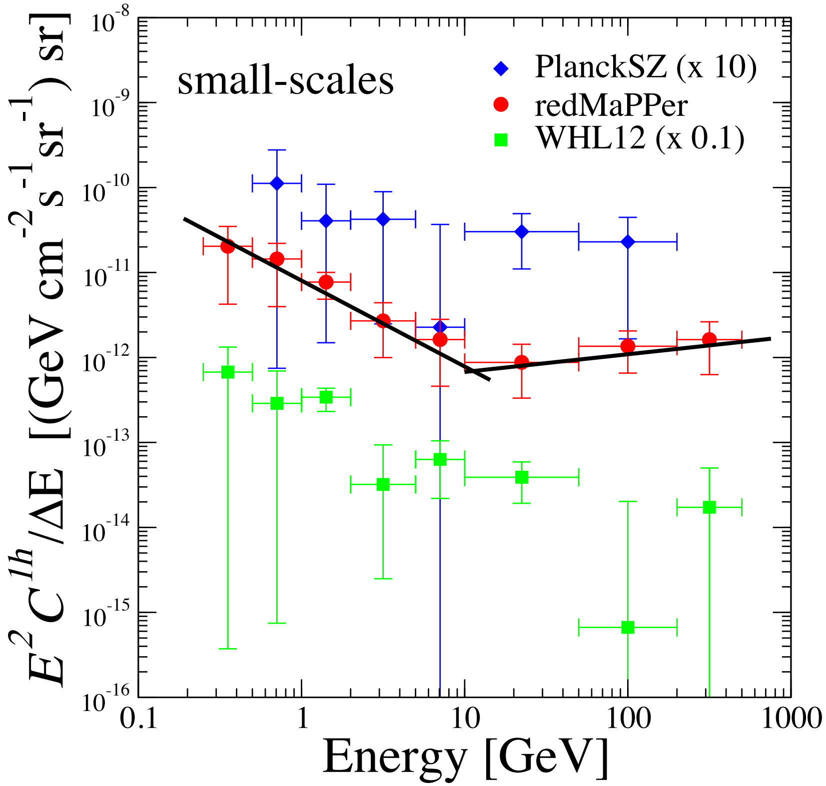
Angular power spectrum

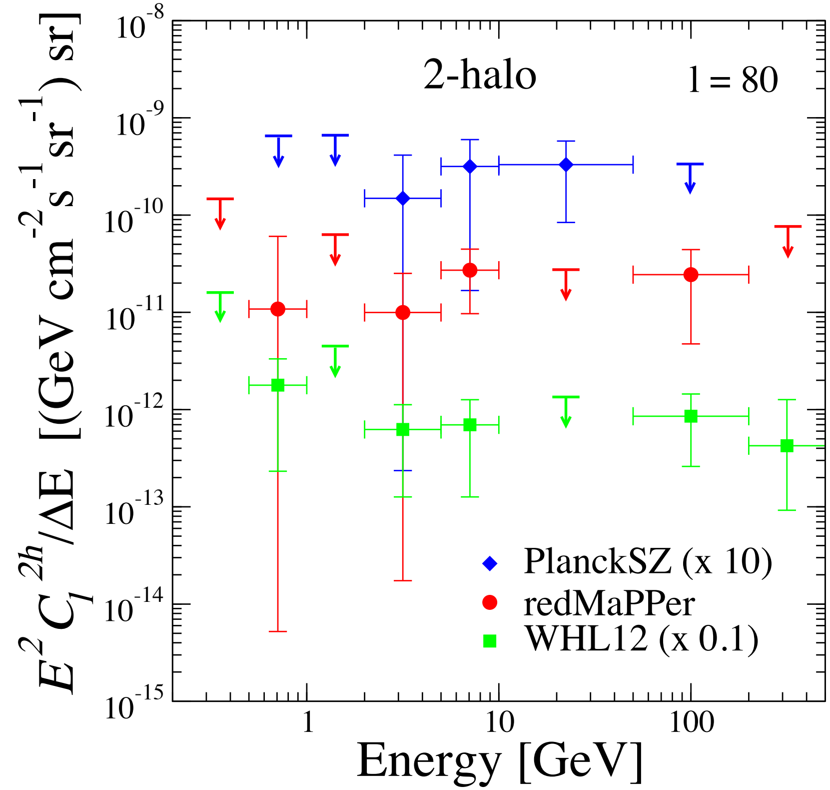


	1 halo	2 halo
redMaPPer	4.7 σ	2.1 σ
WHL12	3.9 σ	2.6 σ
Planck SZ	2.3 σ	1.8 σ

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

Energy dependence





Constant 1 halo term

2 halo term at l = 80

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

Energy dependence

- Large scales (2-halo dominates): the signal is contributed by sources with hard energy spectra, consistent with that of the BL Lacs

- Small scales (1-halo dominates): signal could be contributed by different types of sources
  - At high (E > 10 GeV) energies the dominant sources have hard spectra (probably the same BL Lac population)
  - At smaller energies, the correlation signal shows a hint of contribution by sources with softer spectra. These can be non-BL LacAGNs, SFGs and/or the ICM (or DM)

Conclusions

- In order to separate a DM non-gravitational signal from other astrophysical emissions, a filter based on the DM properties (i.e. the associated gravitational potential) appears to be very promising

- Cross-correlations offer an emerging opportunity:
  - DM particle signal: multiwavelenght emission
  - DM gravitational tracers: cosmic-shear, LSS surveys

- Gamma rays x cosmic shear is the cleanest possibility and it appears to be powerful

Conclusions

- Gamma-rays/gravity-tracers correlations start to emerge:
  - Cross-correlation with galaxy catalogs (3.5σ)
  - Cross-correlation with CMB-lensing (3.0σ)
  - Cross-correlation with cluster catalogs (4.7σ)
- For cosmic shear, first relevant observational opportunity soon with DES
- High-sensitivity will require Euclid/LSST, coupled with the total accumulated Fermi statistics (opportunity for CTA?)

Talk based on:

Camera, Fornasa, NF, Regis, *ApJ 771 (2013) L5*	gamma + cosmic shear
Camera, Fornasa, NF, Regis, *JCAP 1506 (2015) 029*	gamma + cosmic shear
Troester et al., *MNRAS* 467 (2016) 2706	gamma + cosmic shear
NF, Regis, *Front. Physics 2 (2014) 6*	general theory
NF, Regis, Perotto, Camera, *ApJ 802 (2015) L1*	gamma + CMB lensing
Regis, Xia, Cuoco, NF, Branchini, Viel, *PRL 114 (2015) 241301*	gamma + LSS
Cuoco, Xia, Regis, NF, Branchini, Viel, *ApJS 221 (2015) 29*	gamma + LSS
Zechlin, Cuoco, Donato, NF, Vittino, *ApJS 225 (2016) 18*	gamma 1pPDF
Zechlin, Cuoco, Donato, NF, Regis, *ApJL 826 (2016) L31*	gamma 1pPDF
Ando, Fornasa, NF, Regis, Zechlin, *arXiv:0701.06988*	gamma autocorrelation
Branchini, Camera, Cuoco, NF, Regis, Viel, Xia, *ApJS 228 (2017) 8*	gamma + clusters