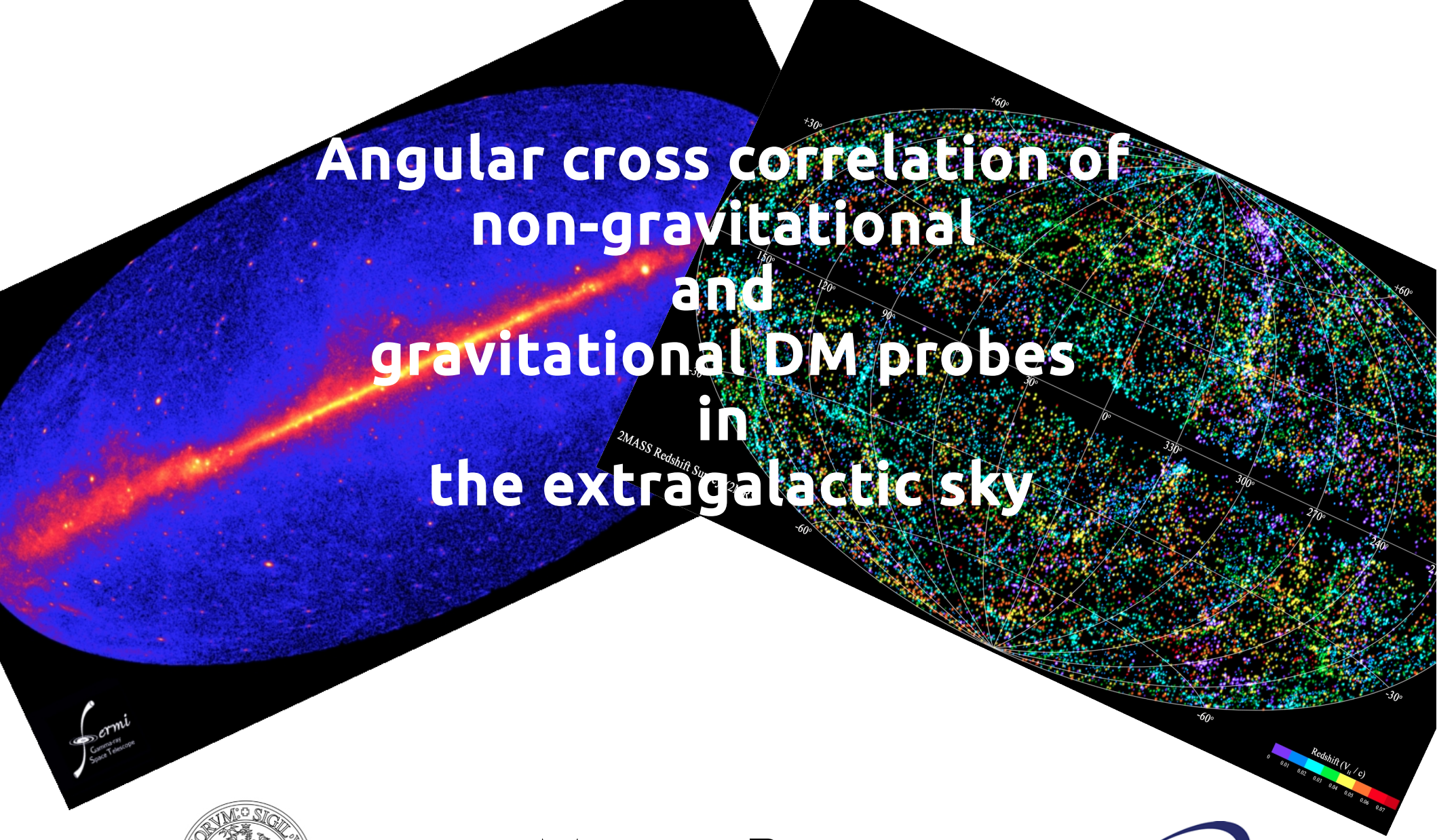
Angular cross correlation of non-gravitational and gravitational DM probes in the extragalactic sky



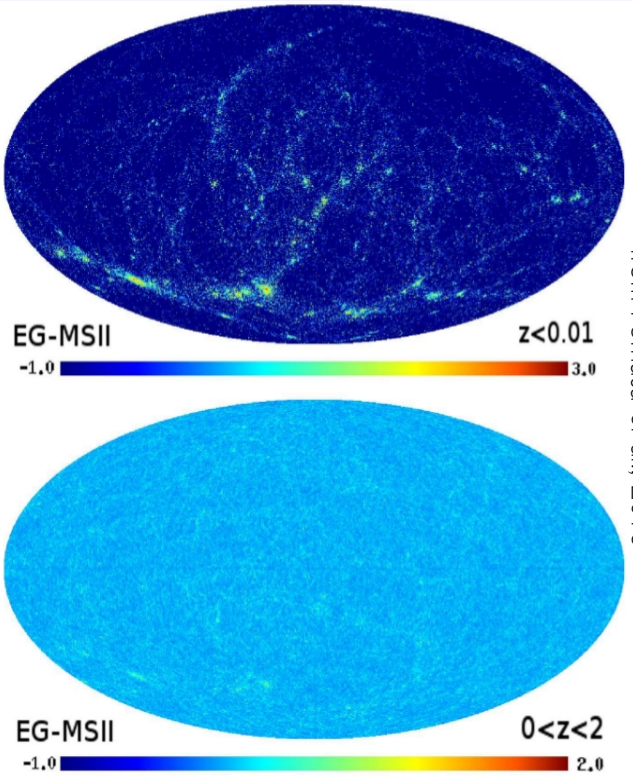
Marco Regis
(Torino)

UNIVERSITÀ DEGLI STUDI
DI TORINO

INFN
Istituto Nazionale
di Fisica Nucleare

General Point

Even if DM halos are too faint to be individually detected in gamma-rays, they form the most numerous population in the Universe.
The **DM "cumulative" signal** or its **spatial coherence** might be observable.



from Fornasa et al., 2013

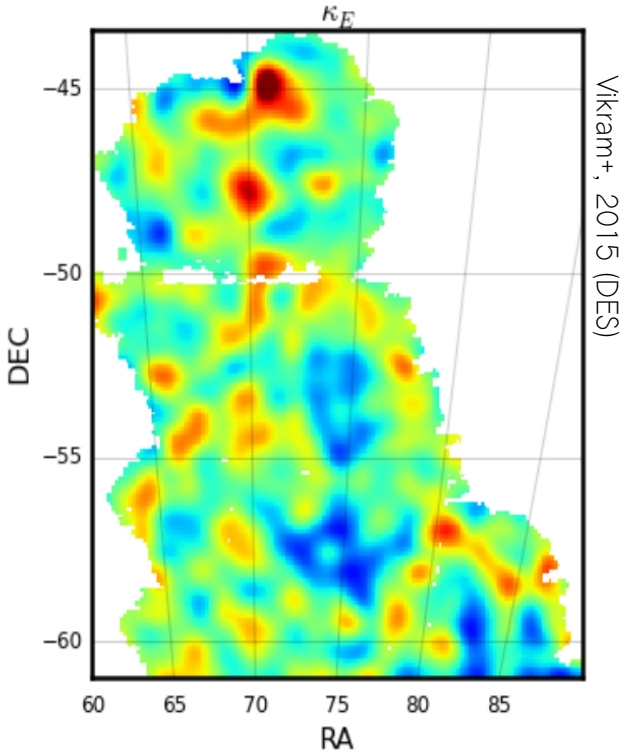
→ Dig into the unresolved extragalactic sky

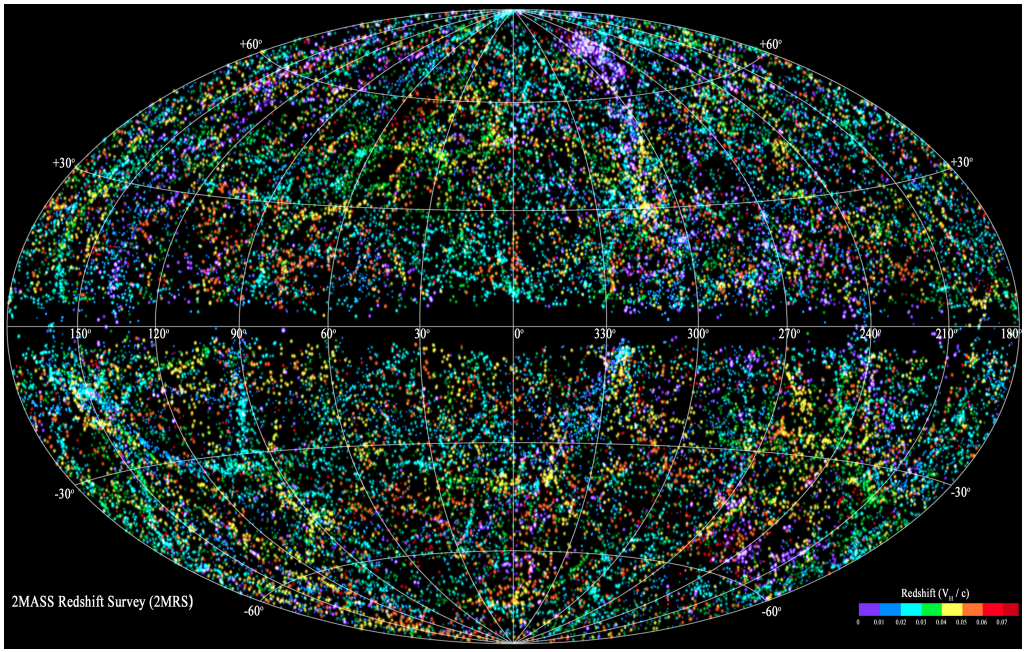
Stacking

Statistical correlations of fluctuations

In order to separate the DM non-gravitational signal from other γ-ray astrophysical emissions, we can use a filter based on the DM gravitational potential

- Weak lensing surveys → gravitational potential
- Galaxy surveys → number counts of galaxies trace DM density





Two-point statistics

Angular power spectrum of fluctuations

$$C_\ell^{(ij)} = \frac{1}{2\ell+1}\left\langle \sum_{m=-\ell}^{\ell} a_{\ell m}^{(i)} a_{\ell m}^{(j)*} \right\rangle$$

Gravitational tracer ("filter")

Gamma-ray sky (or X-ray, radio, ... sky)

Correlation function

$$\omega(\theta) = \frac{1}{4\pi}\sum_{\ell=1}^{\infty}(2\,\ell+1)\,C_\ell\,P_\ell(\cos\theta)$$

(Stacking profile: $\langle\rho\rangle(\theta) = \int \frac{\ell\, d\ell}{2\pi} J_0(\ell\theta) C_\ell$)

Angular power spectrum

$$C_\ell^{XY} = \int \mathrm{d}\chi \, \frac{W^X(\chi) W^Y(\chi)}{\chi^2} P^{XY}\left(k = \frac{\ell}{\chi}, \chi\right)$$

$$\langle \mathcal{I}^X \rangle = \int \mathrm{d}\chi \, W^X(\chi)$$

Window function

$$\langle \tilde{f}_X(\chi, \mathbf{k}) \tilde{f}_Y(\chi, \mathbf{k}') \rangle = (2\pi)^3 \delta^3(\mathbf{k}+\mathbf{k}') P^{XY}(k, \chi)$$

3D power spectrum

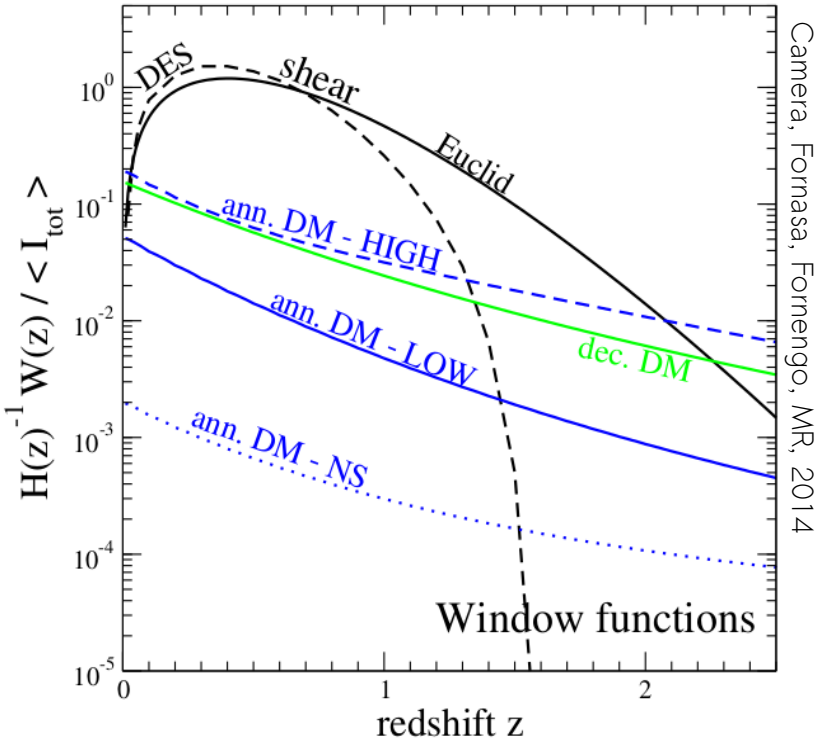
FT of density field of the source

Window function

It **weights** the contribution at different redshifts.

$$\langle \mathcal{I}^X \rangle = \int \mathrm{d}\chi \, W^X(\chi)$$

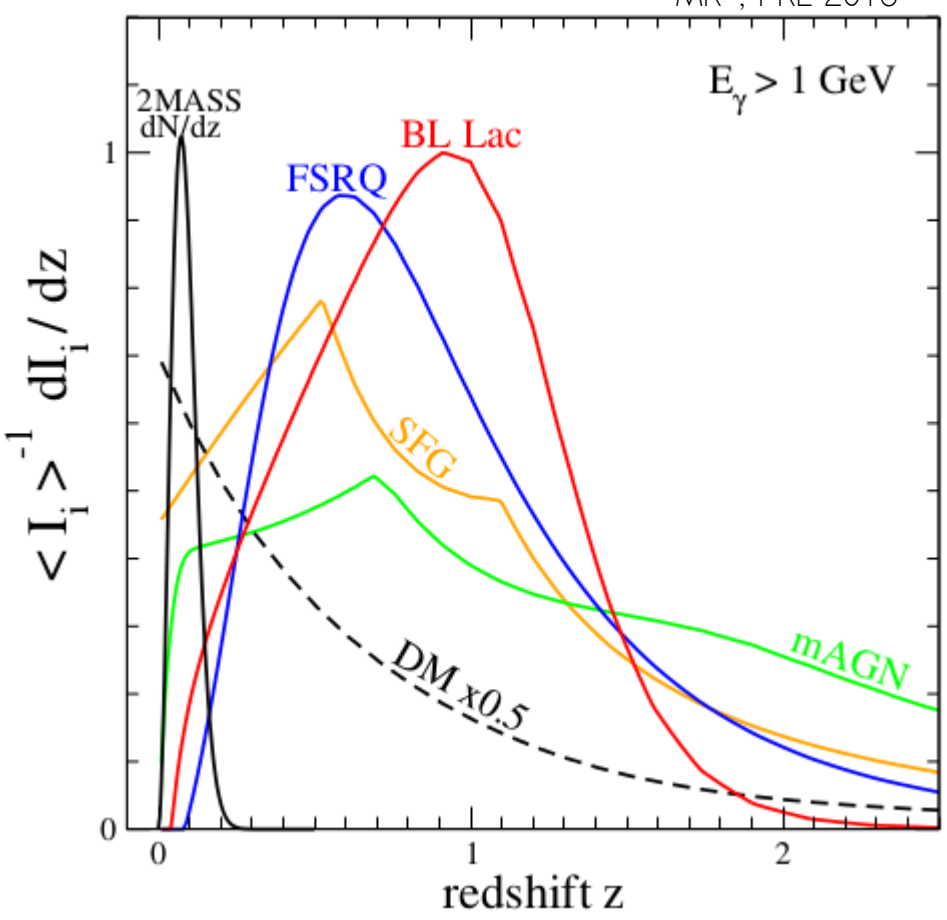
Gravitational		Non-gravitational (γ-rays, X-rays, radio)	
W_κ	lensing	W_{ann}	annihilating DM
W_g	# of galaxies	W_{dec}	decaying DM
		W_{astro}	astrophysical non-thermal sources



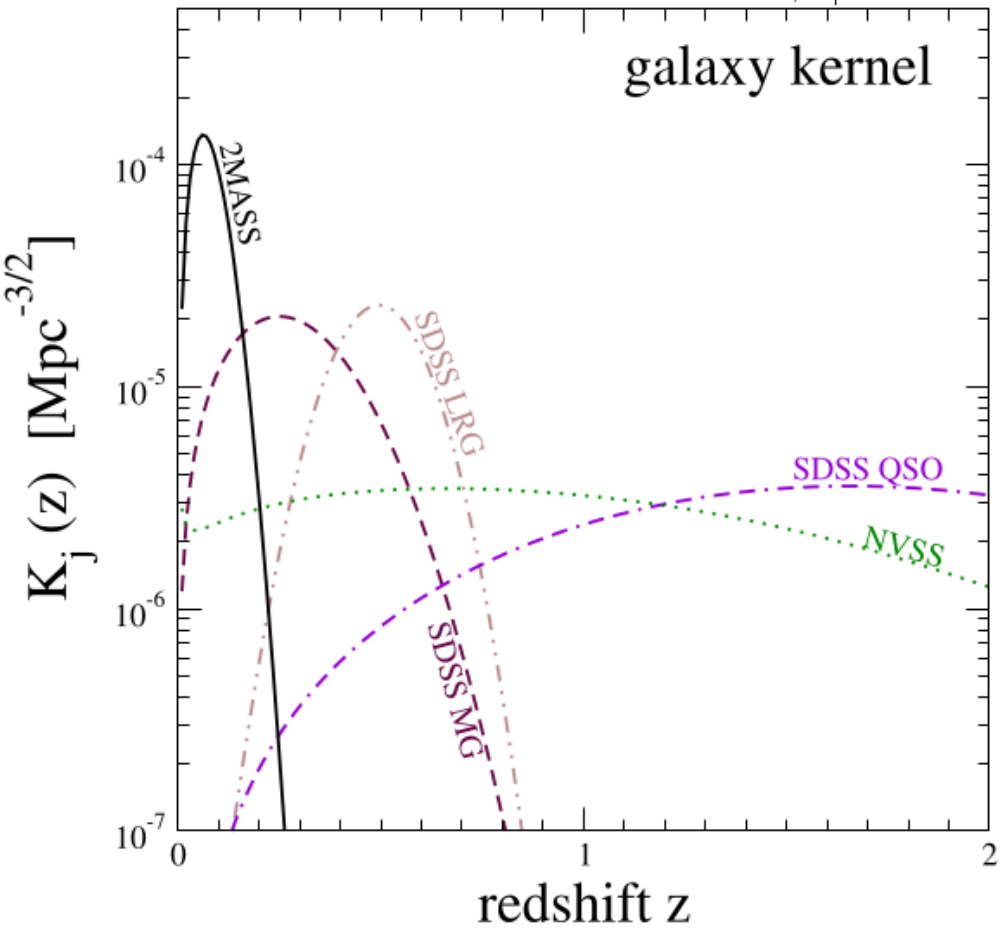
DM and lensing probes peak at low z

Window function

MR+, PRL 2015



Cuoco+, ApJS 2015



Astrophysical sources peak at z > 0.5

TOMOGRAPHIC APPROACH

3D power spectrum

Typically obtained from **Simulations or Halo model**

Halo model $\quad P_{ij}(k) = P_{ij}^{1h}(k) + P_{ij}^{2h}(k)$

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

f = FT of density field

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

Required ingredients:

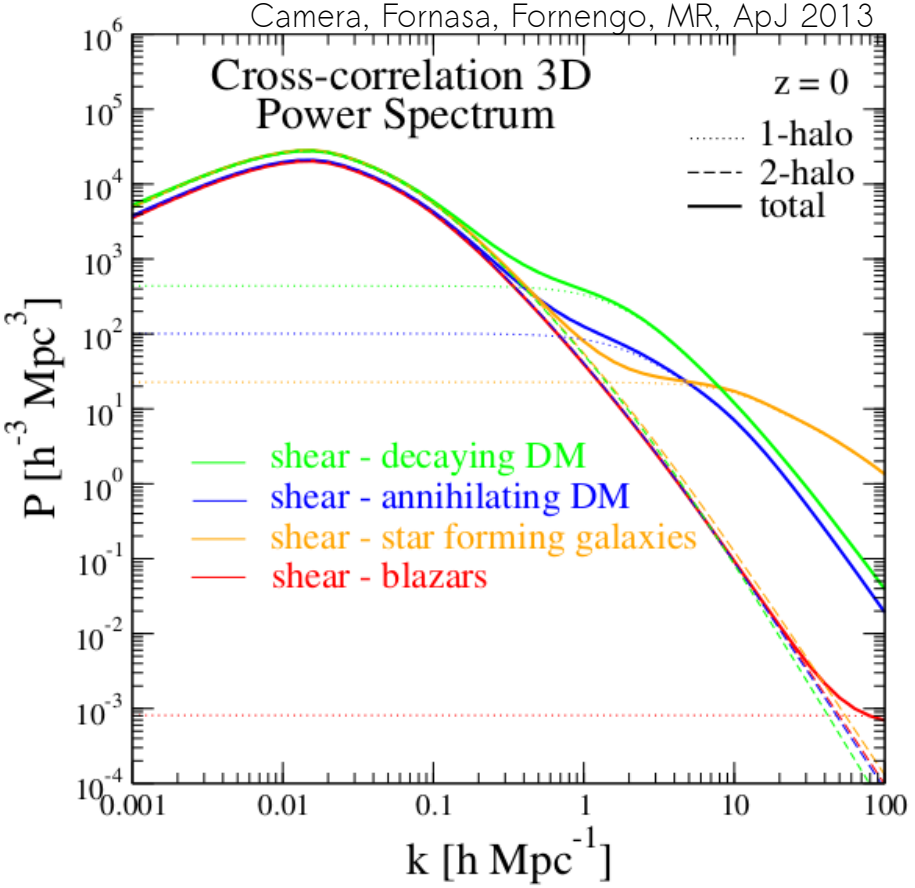
- Halo mass function dn/dm
- Concentration of halos c(m),
- DM distribution in halos (NFW, Einasto, Burkert, ...)

and the same for subhalos, or B(**x**,m,z)

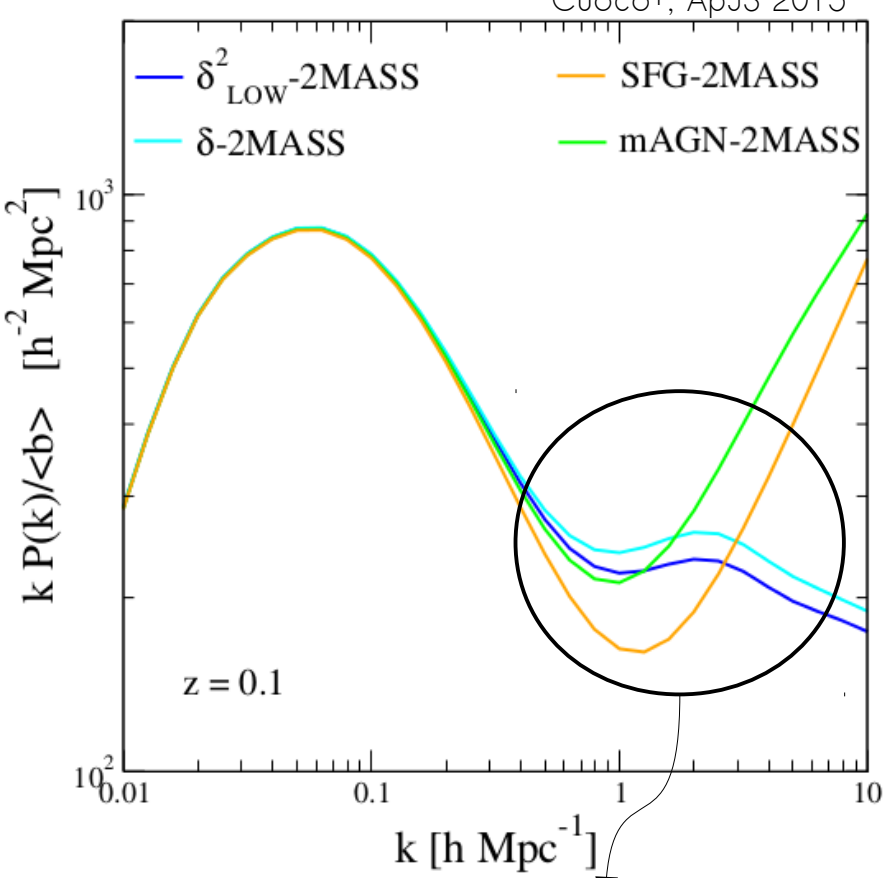
Critical point: **extrapolation** from the resolution of numerical simulations down to $\mathbf{m}_{\rm min}$

3D power spectrum

Camera, Fornasa, Fornengo, MR, ApJ 2013



Cuoco+, ApJS 2015

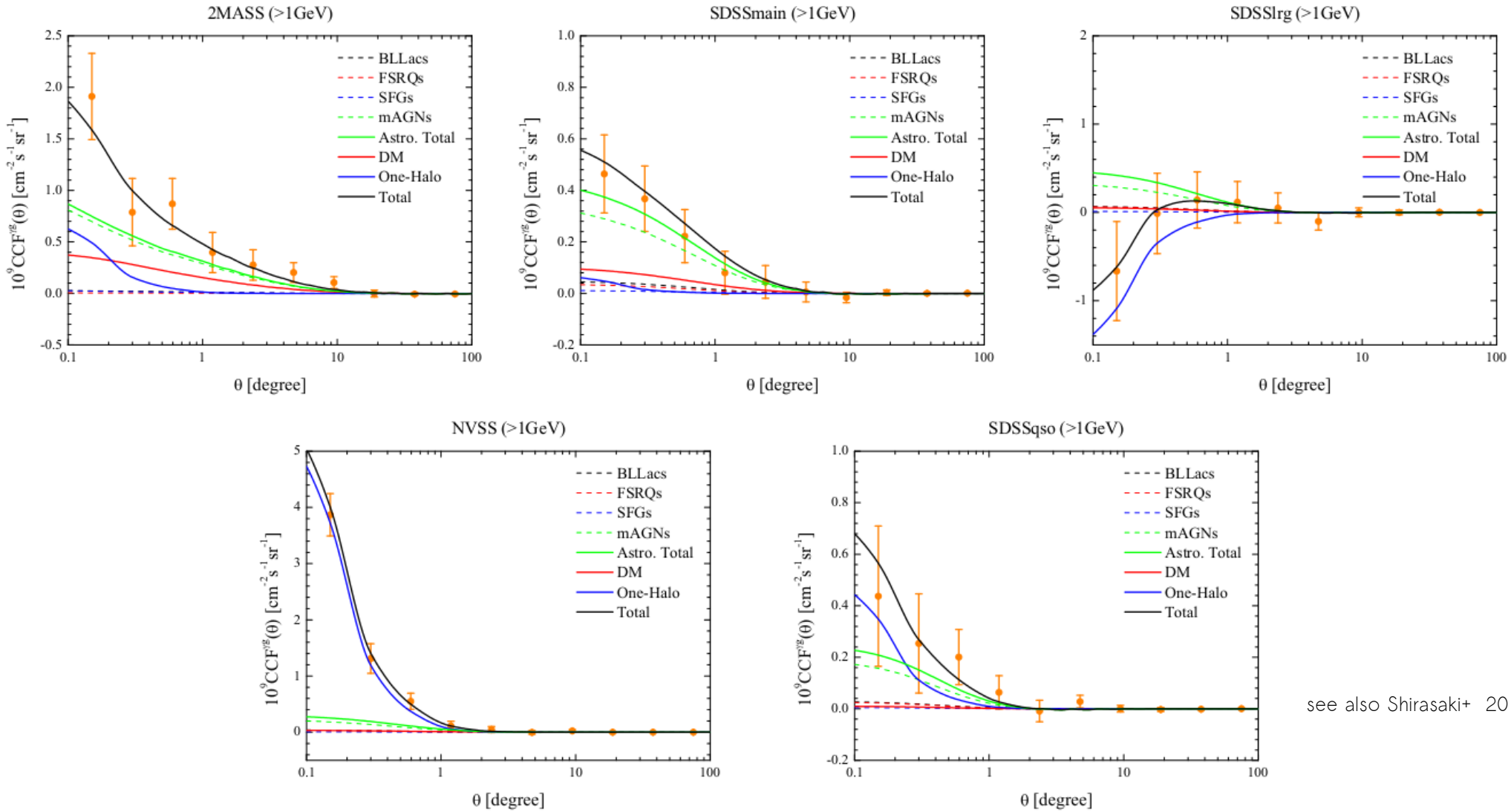


It is (roughly speaking) mapped in the multipole range $100 < l < 1000$

Measurements, interpretations and forecasts

Observations of cross correlations between Fermi-LAT maps and galaxy catalogues

Xia, Cuoco, Branchini, Viel, ApJS 2015



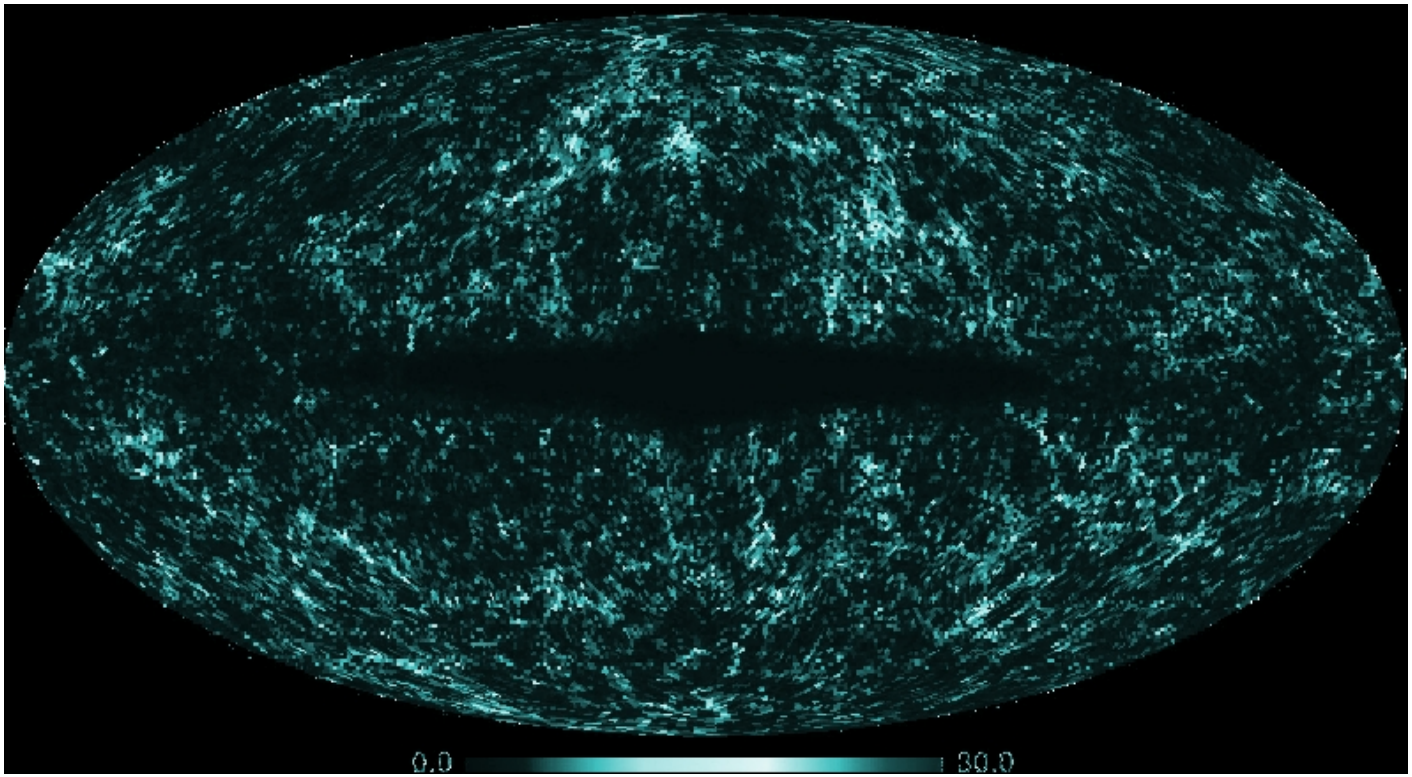
see also Shirasaki+ 2015

Cross correlation of Fermi-LAT with the 2MASS catalogue

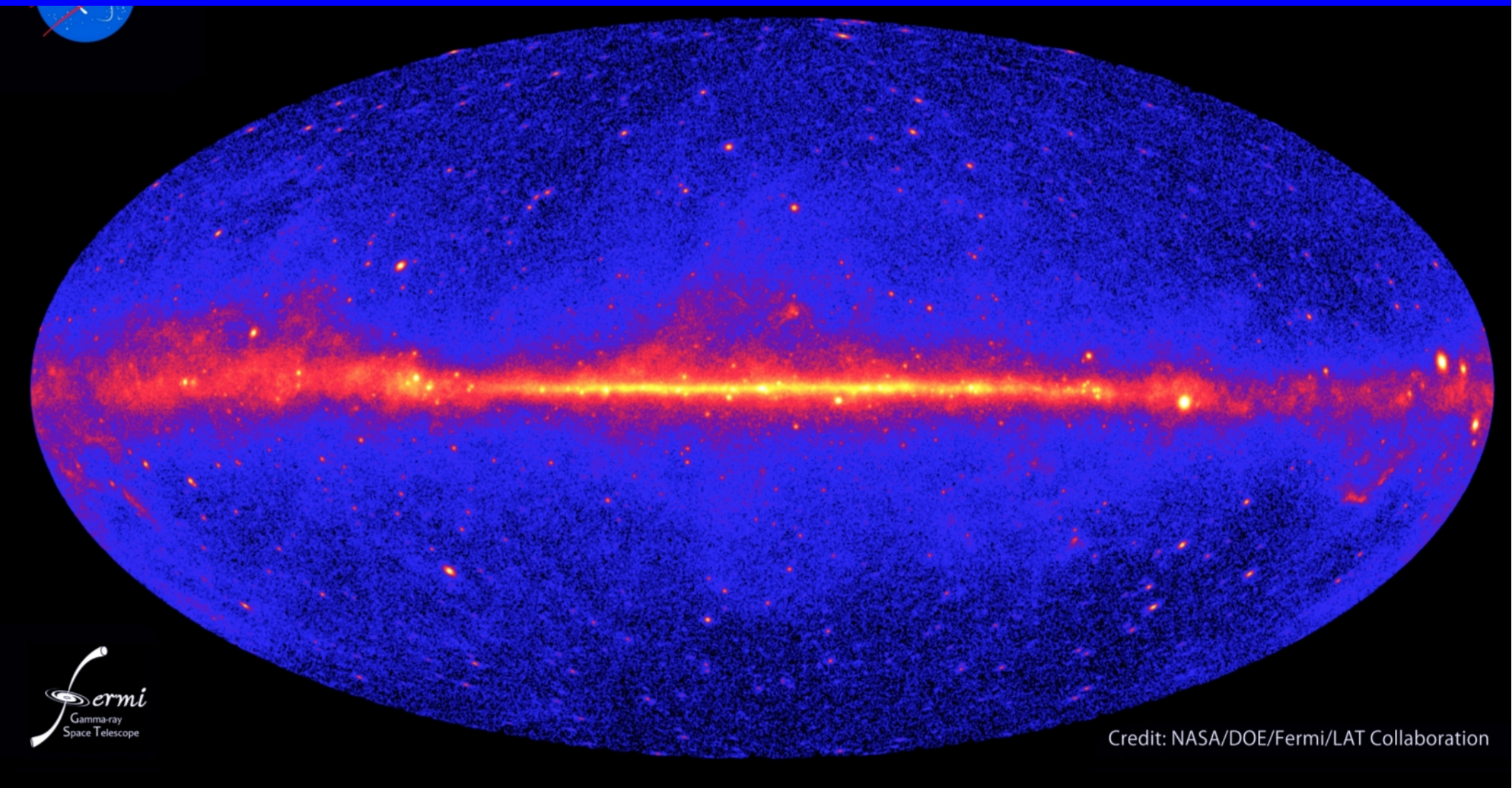
2MASS

770000 galaxies with mean redshift z ~ 0.072

2MASS Redshift Survey
"only" 43500 galaxies
but spectroscopic redshift
(for prospects, see Ando JCAP 2014, Ando+ PRD 2014)

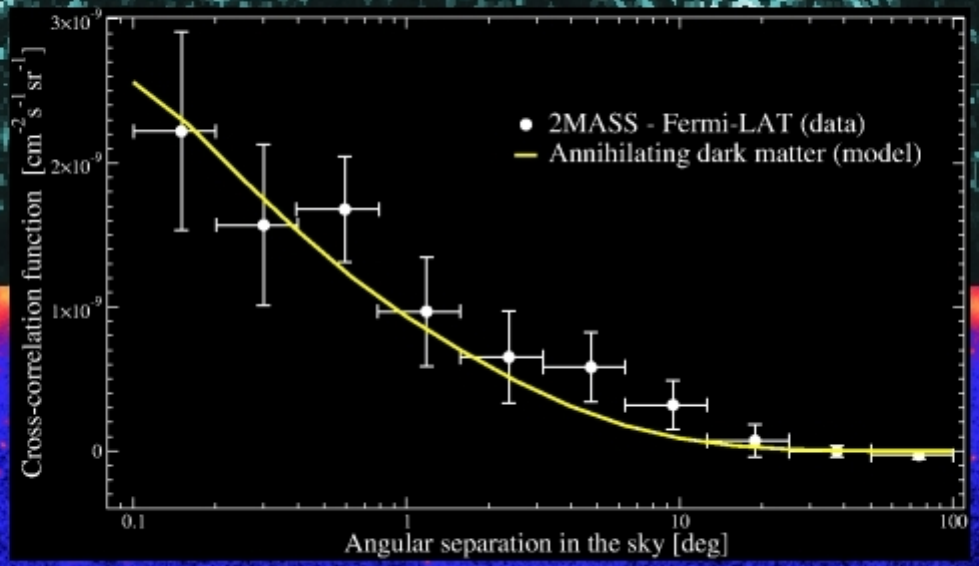


Cross correlation of Fermi-LAT with the 2MASS catalogue



Two Micron All Sky Survey
(2MASS)

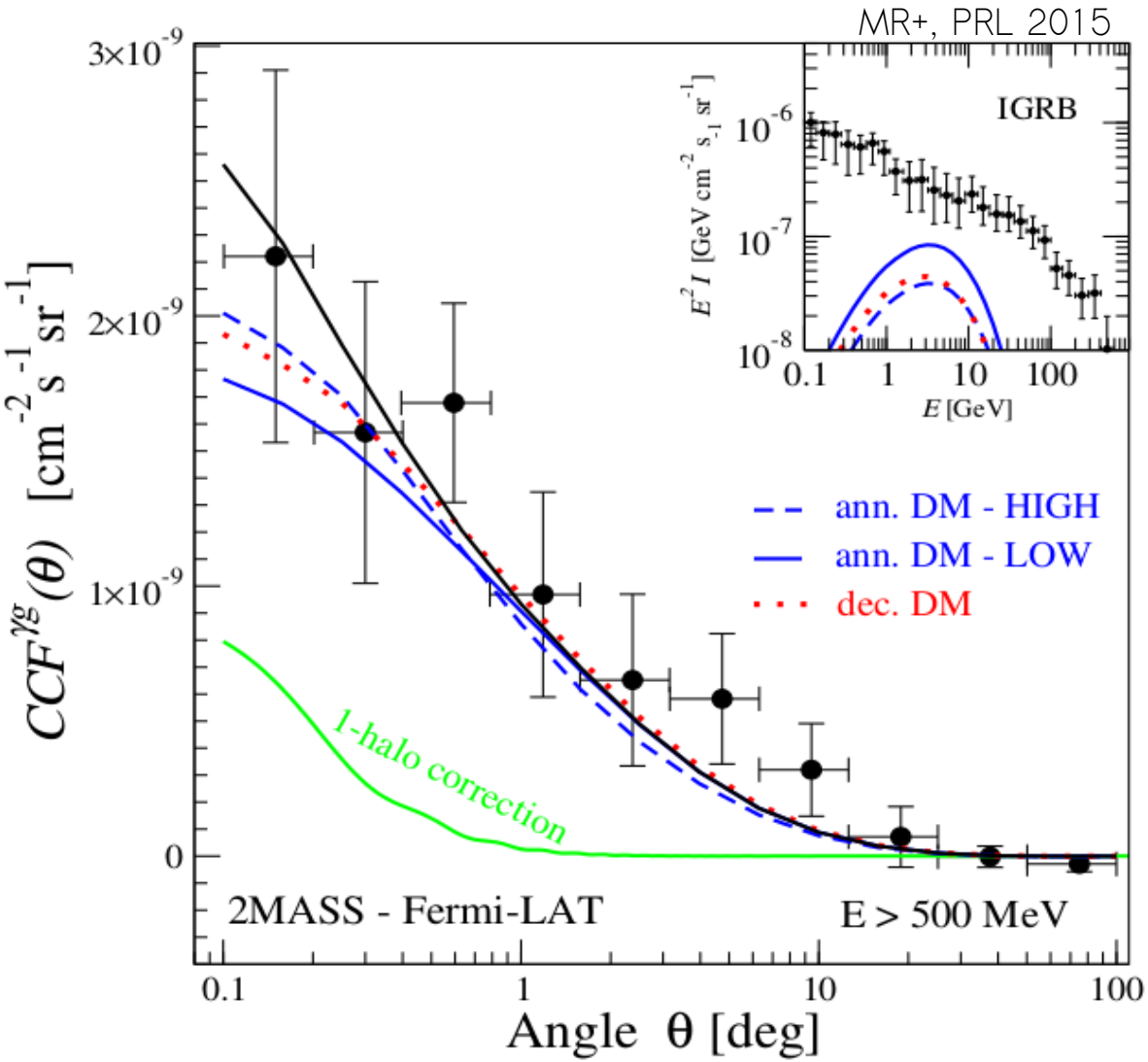
Credit: 2MASS/UMass/IPAC-Caltech/NASA/NSF



Fermi Gamma-ray Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

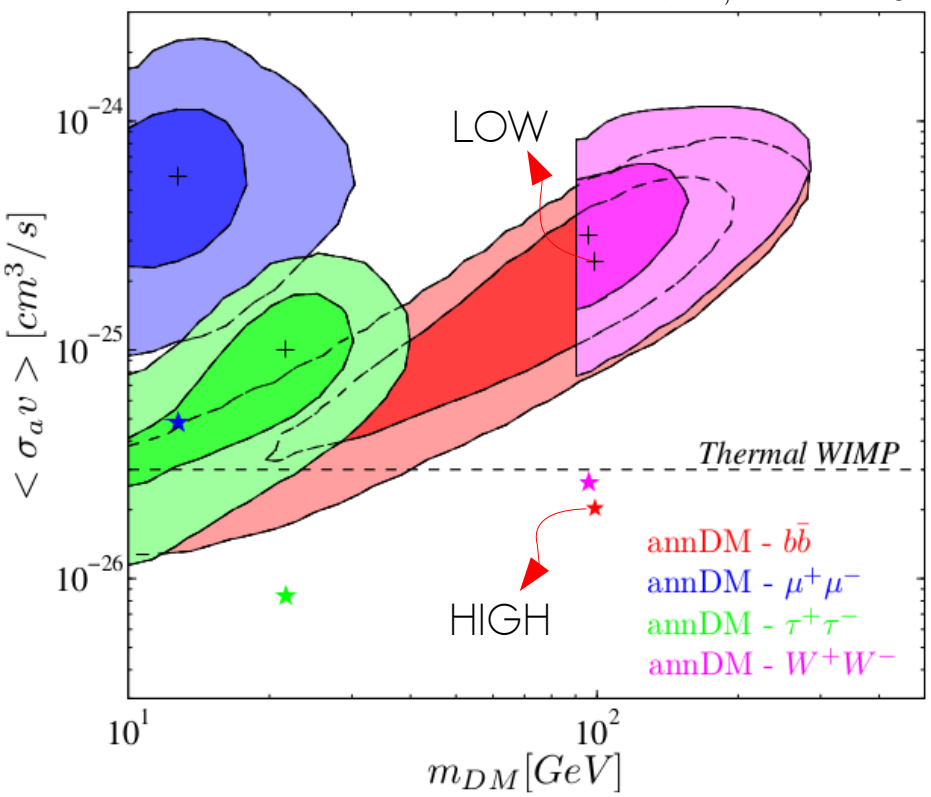
DM interpretation



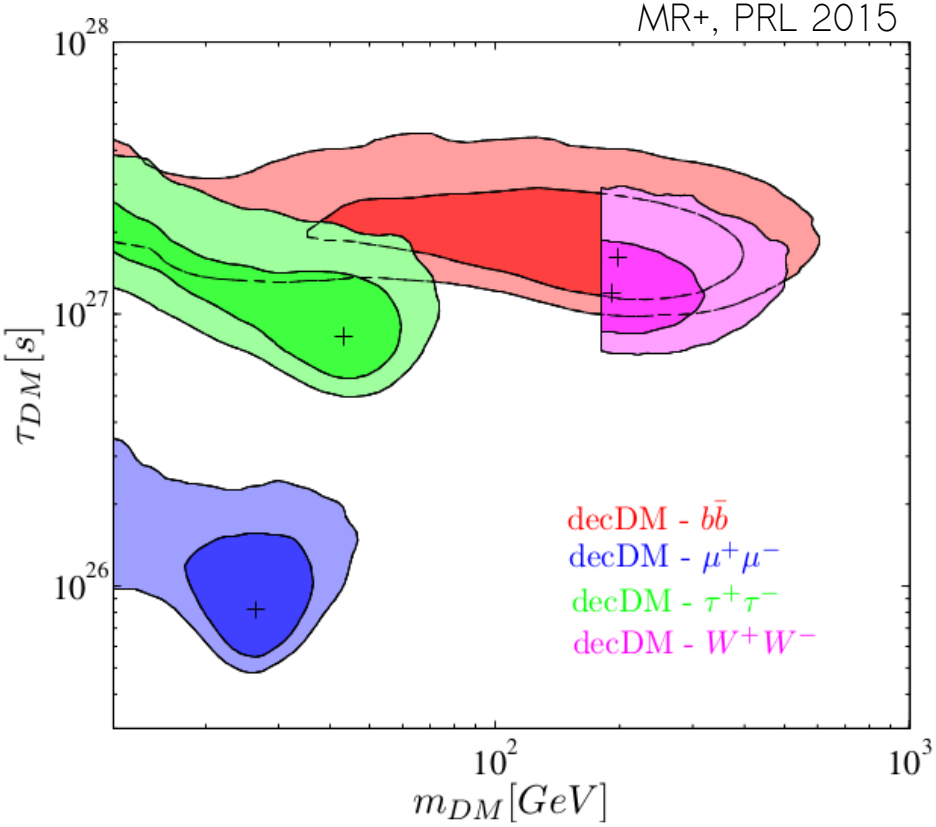
The particle DM signal **can fit** the measured cross correlation between Fermi-LAT and 2MASS

DM interpretation

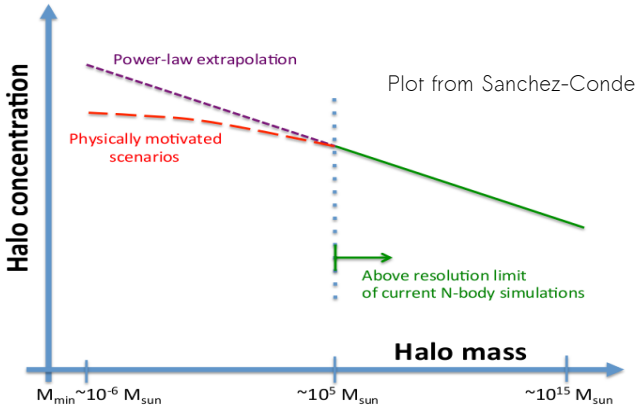
MR+, PRL 2015



MR+, PRL 2015



(about subhalos model)

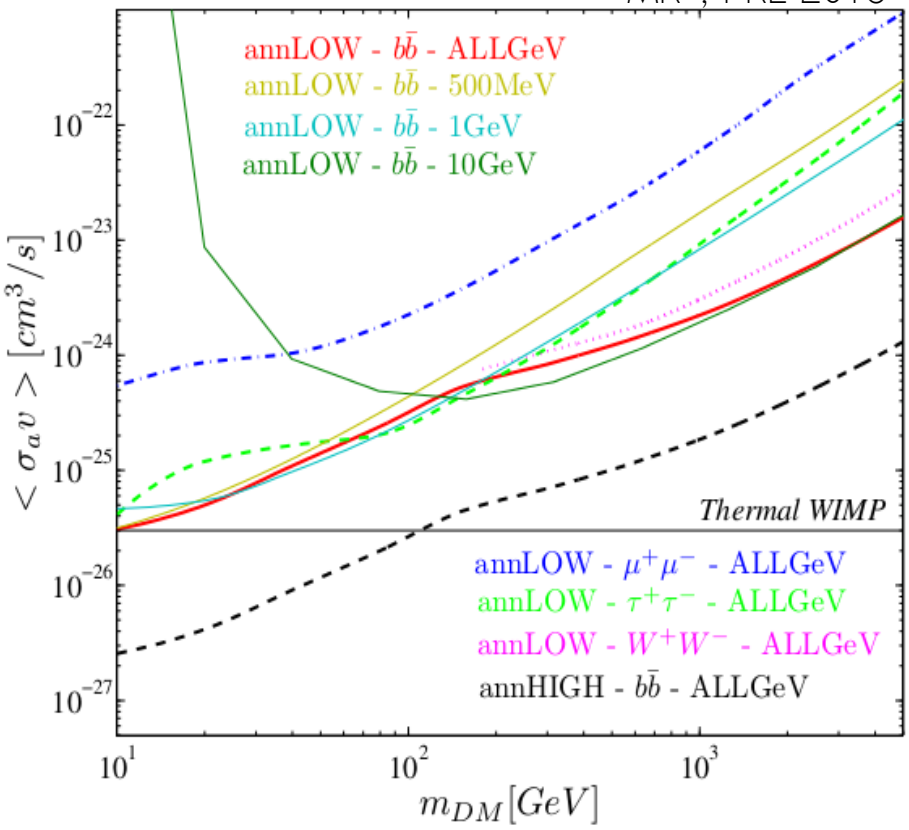


Plot from Sanchez-Conde talk, 2014

Bounds on WIMP DM

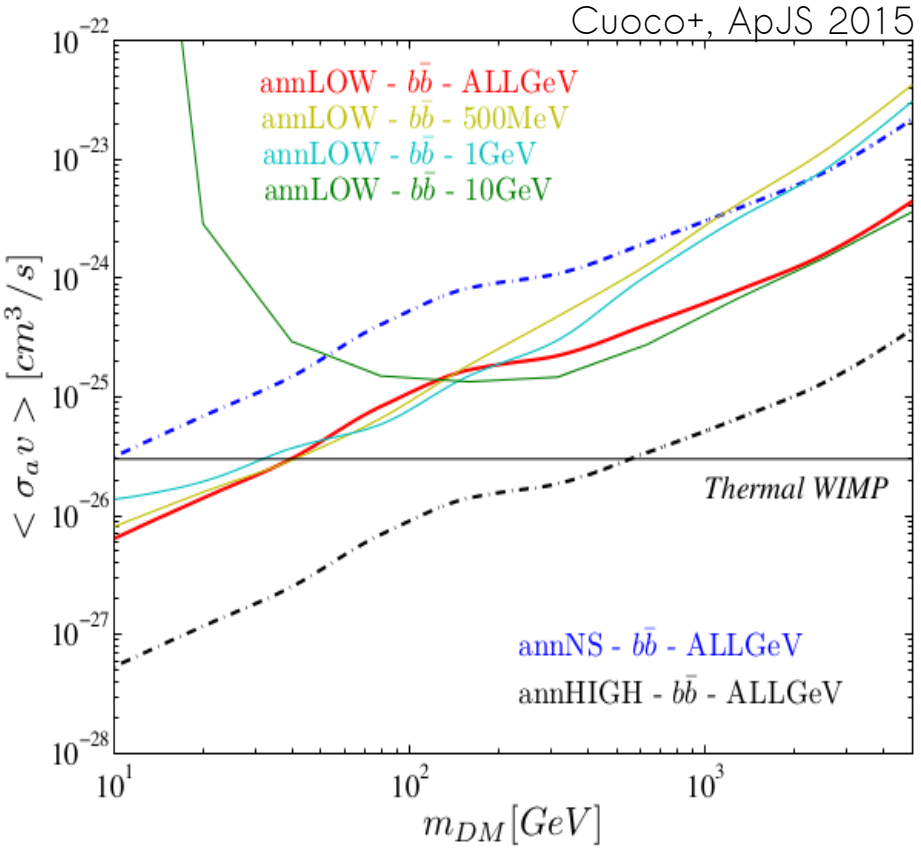
DM-only

MR+, PRL 2015

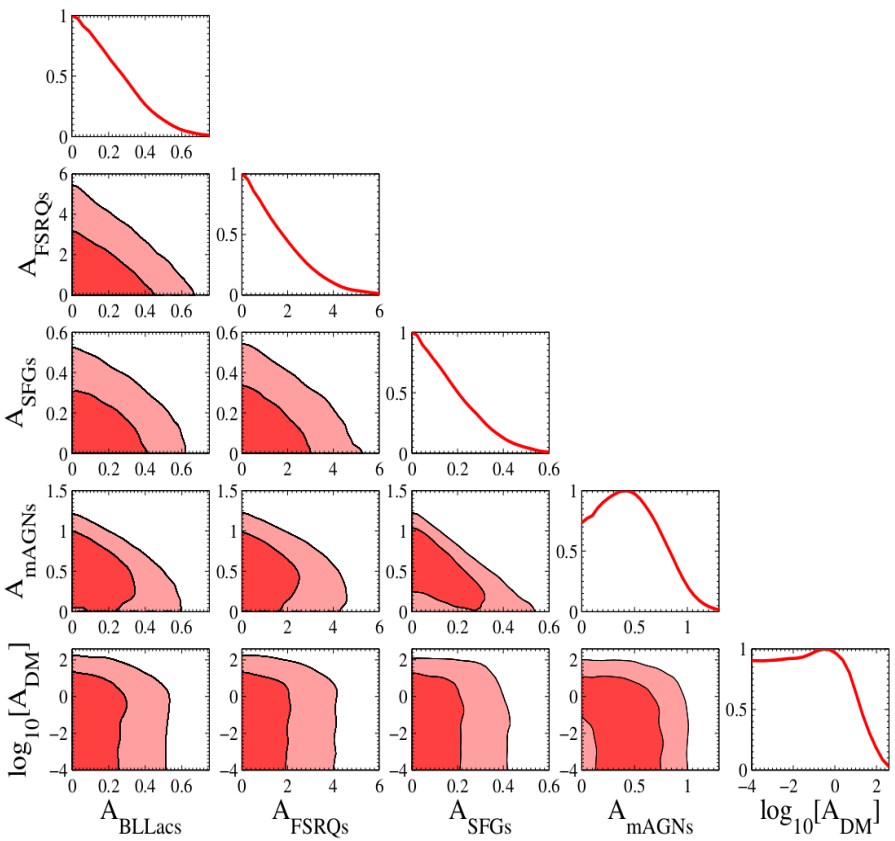


including astro sources

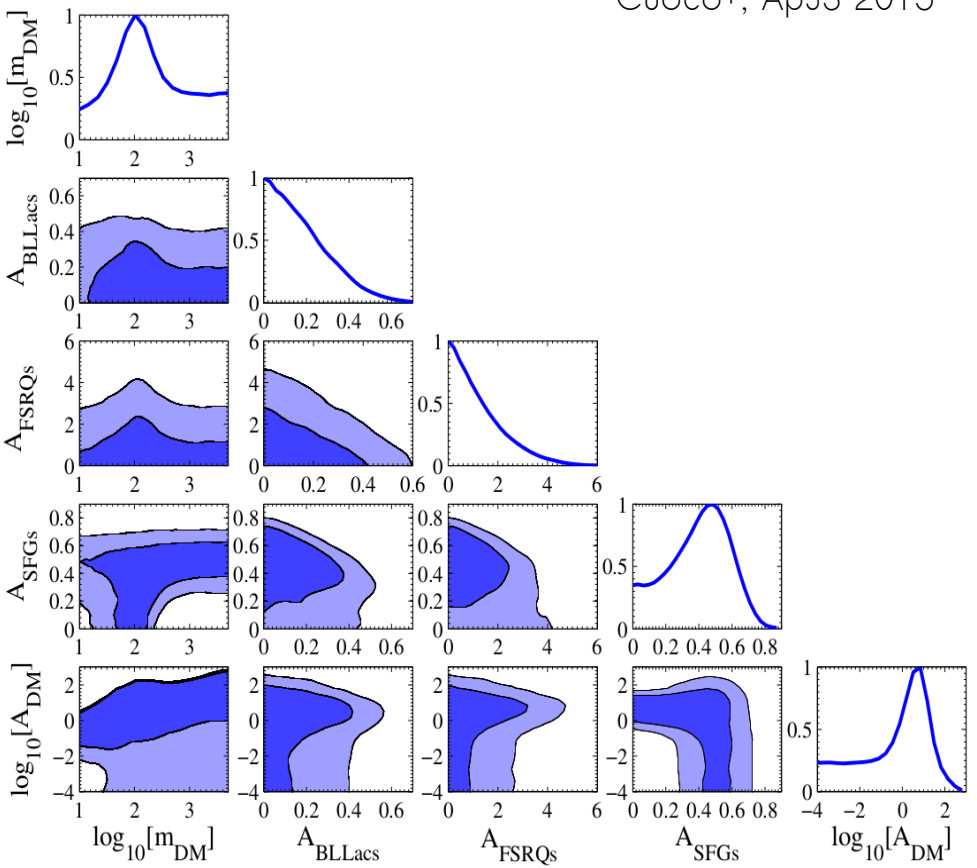
Cuoco+, ApJS 2015



Astrophysical backgrounds

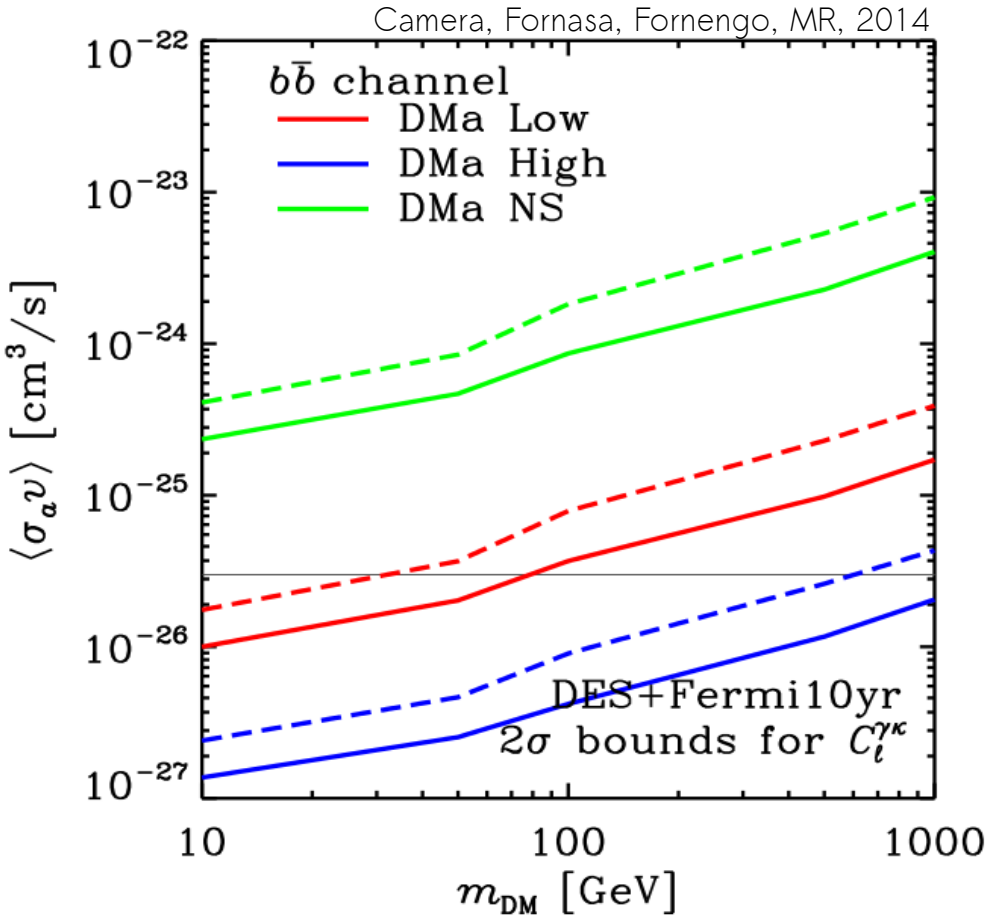


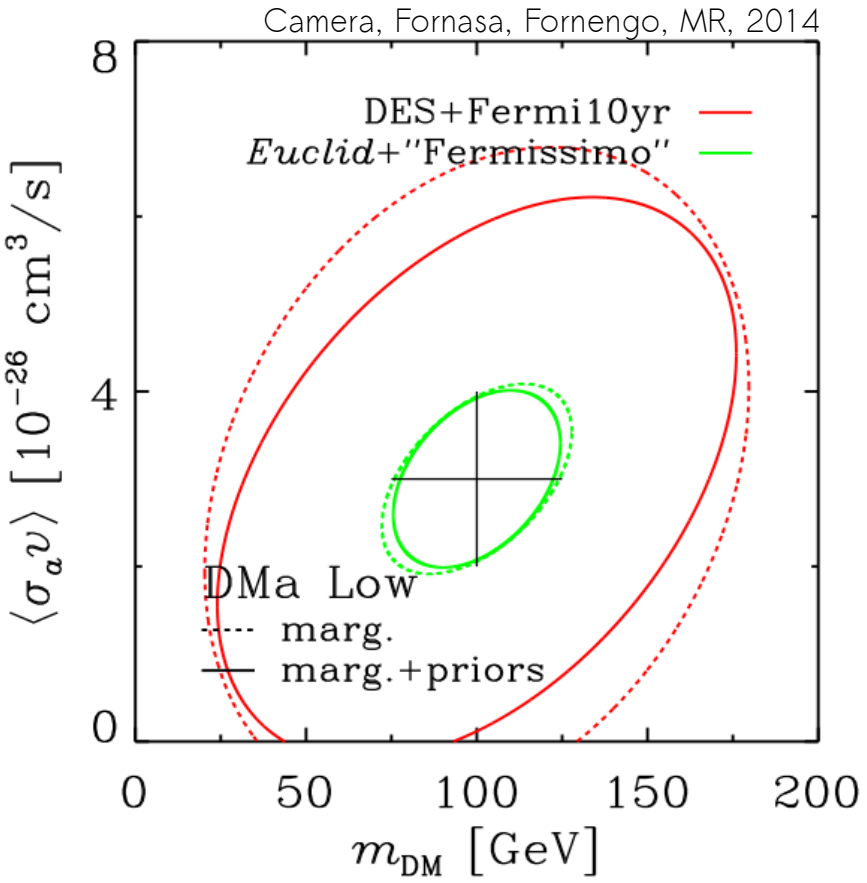
Cuoco+, ApJS 2015



Degeneracy between DM interpretation and AGN hosted in big halos (groups or clusters)

Prospects for DM detection/bounds using cross correlation with shear





First attempt of measurement

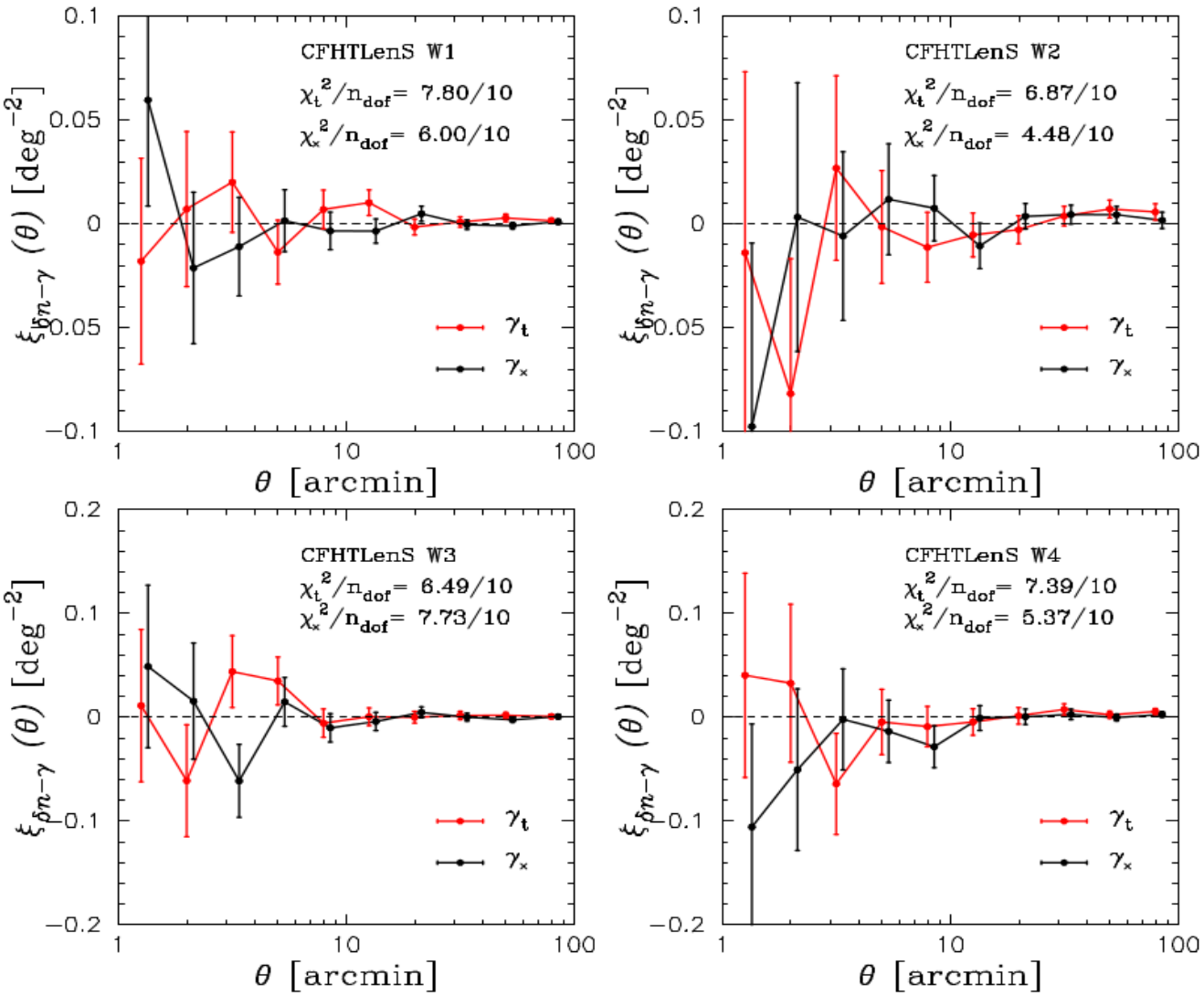
(of the cross correlation between cosmic shear and the EGB)

Canada-France-Hawaii Lensing Survey (CFHTLenS) + 5yr Fermi LAT data

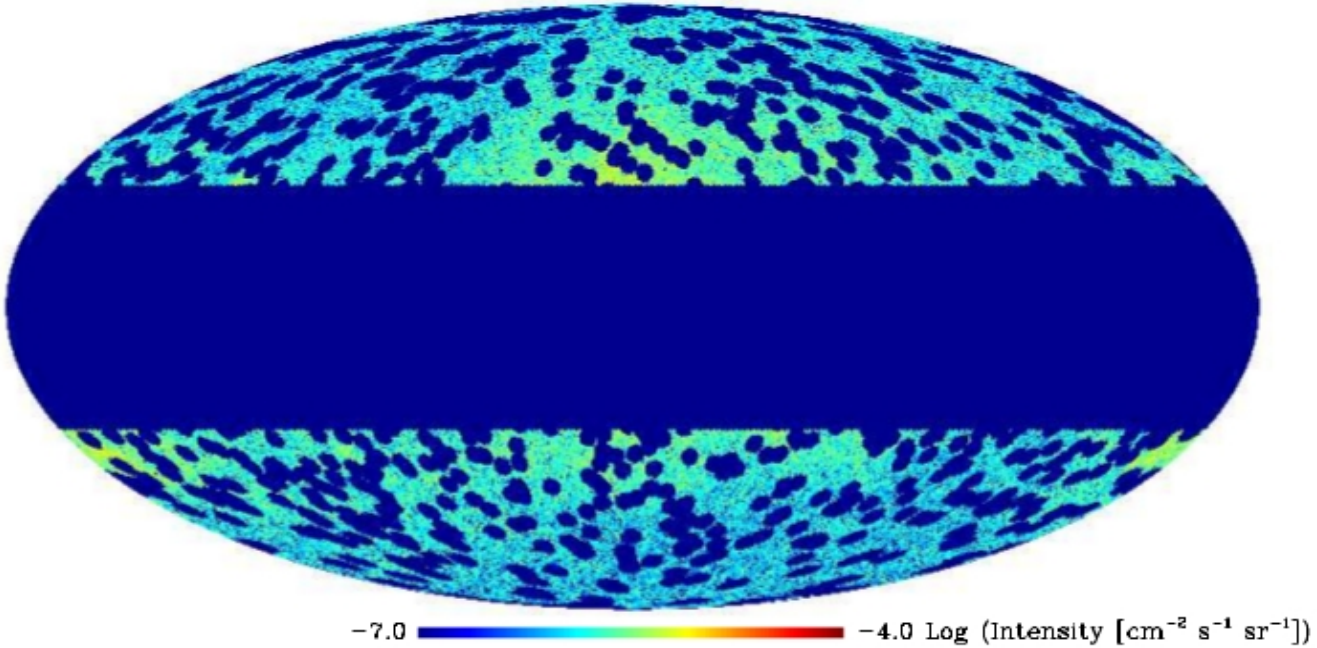
(Shirasaki, Horiuchi, Yoshida, PRD 2014)

CFHTLenS surveyed four separated fields for a total of ~150 sq. deg. with 11 gal/arcmin^2

(DES → 5000 sq.deg.)

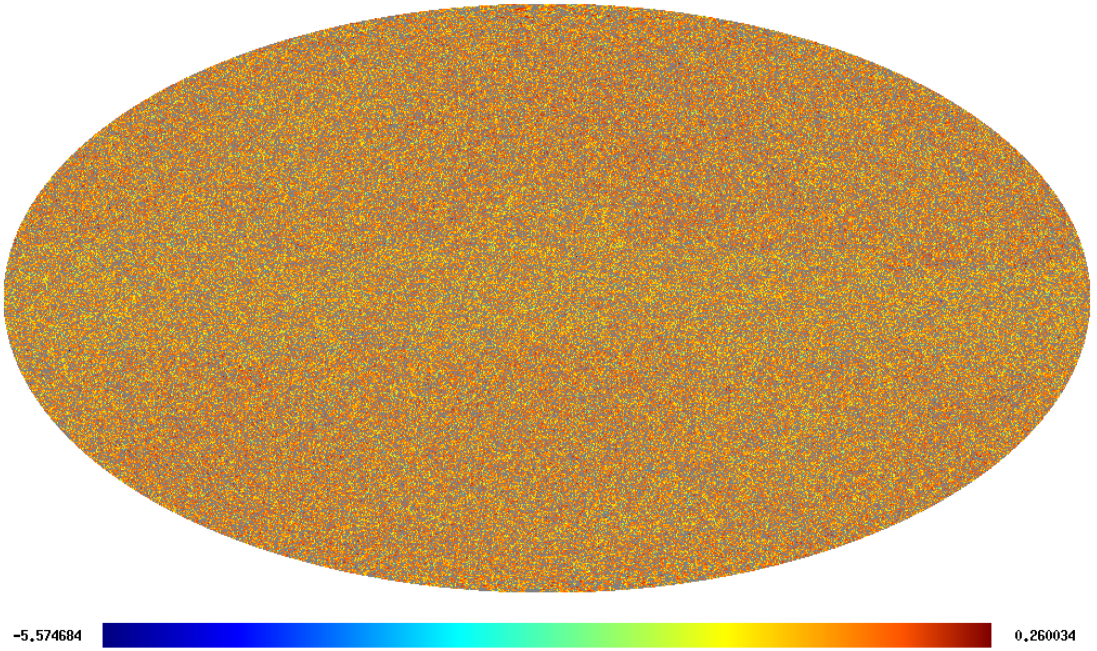


Cross correlation with CMB lensing

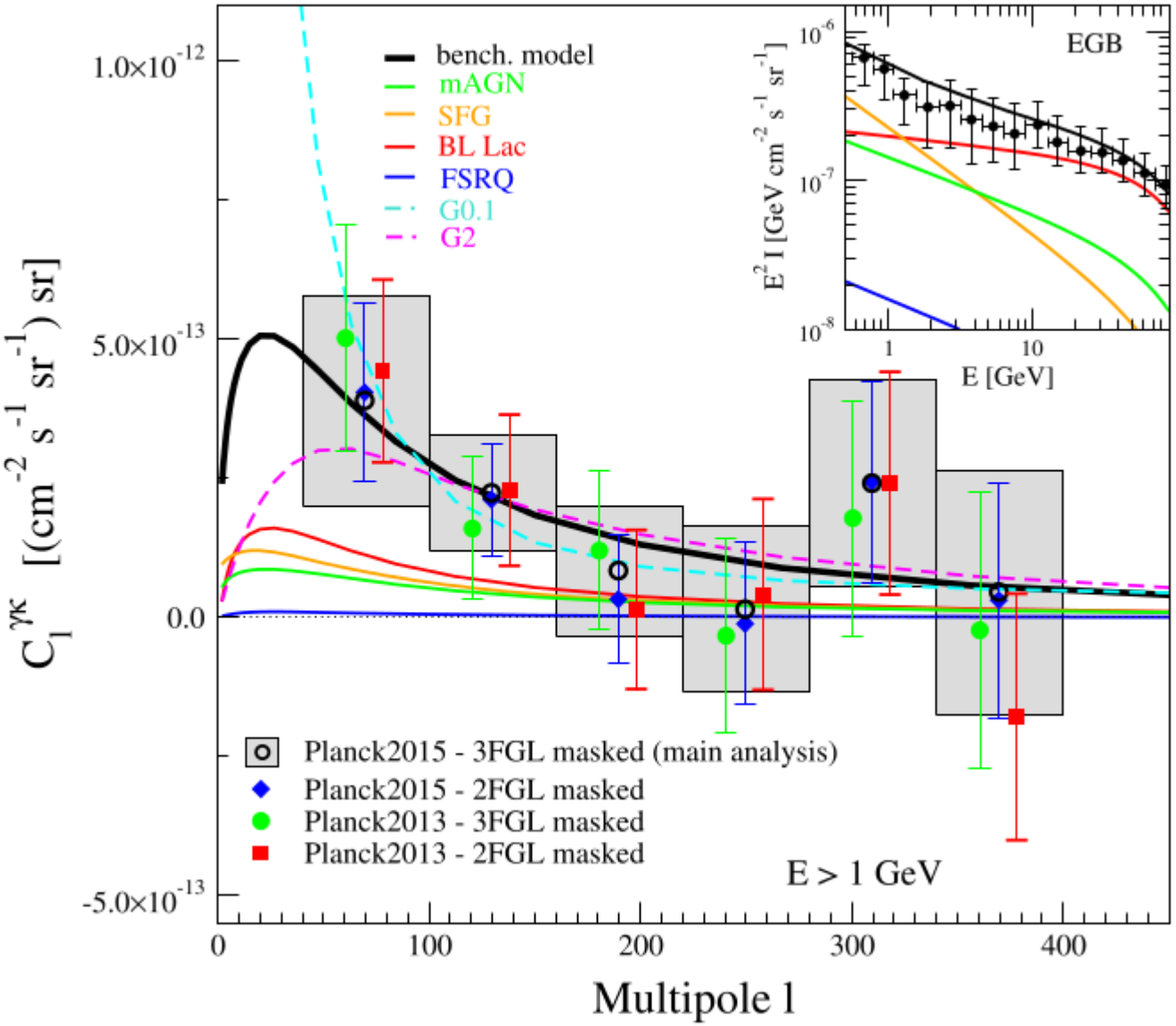


Fermi-LAT 6yr data

Planck 2015 data release



Cross correlation with CMB lensing



3σ evidence

Fornengo, Perotto, Regis, Camera

ApJ 2015

Direct evidence of the extragalactic origin of the diffuse γ-ray background

Future directions

Gamma: Fermi-LAT Pass-8, GAMMA-400, HERD, DAMPE, PANGU, ..

Radio: SKA and its precursors (LOFAR, ASKAP)

X-rays: eROSITA, ATHENA, ASTRO-H, .. (also in the context of keV DM, see Zandanel, Weniger, Ando JCAP 2015)

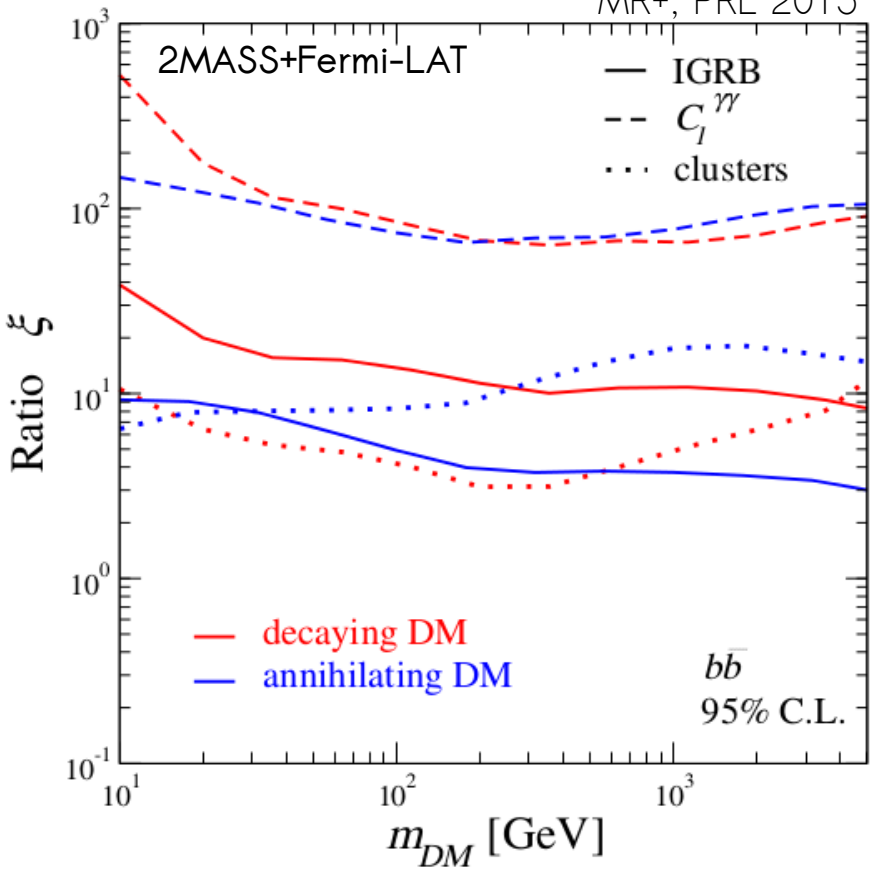
Lensing and galaxy surveys: HSC, DES, eBOSS, DESI, LSST, Euclid, ..

Backup

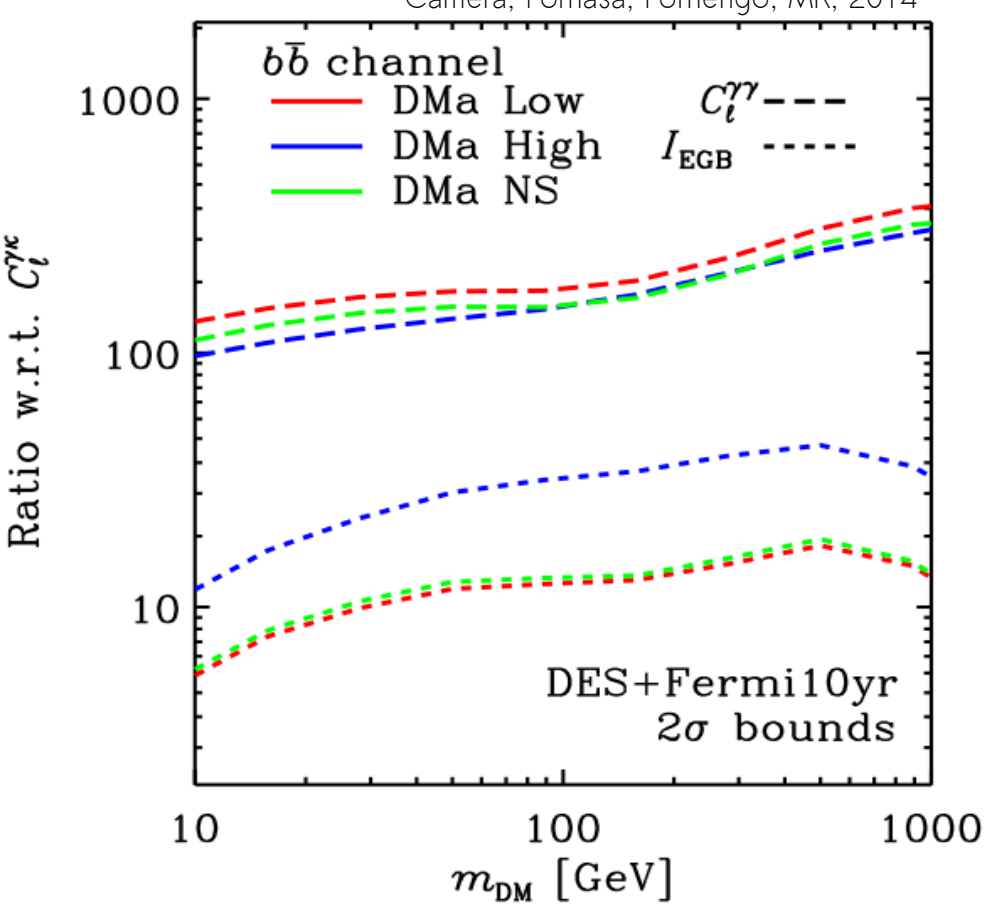
WTF?

(Where To Find dark matter?)

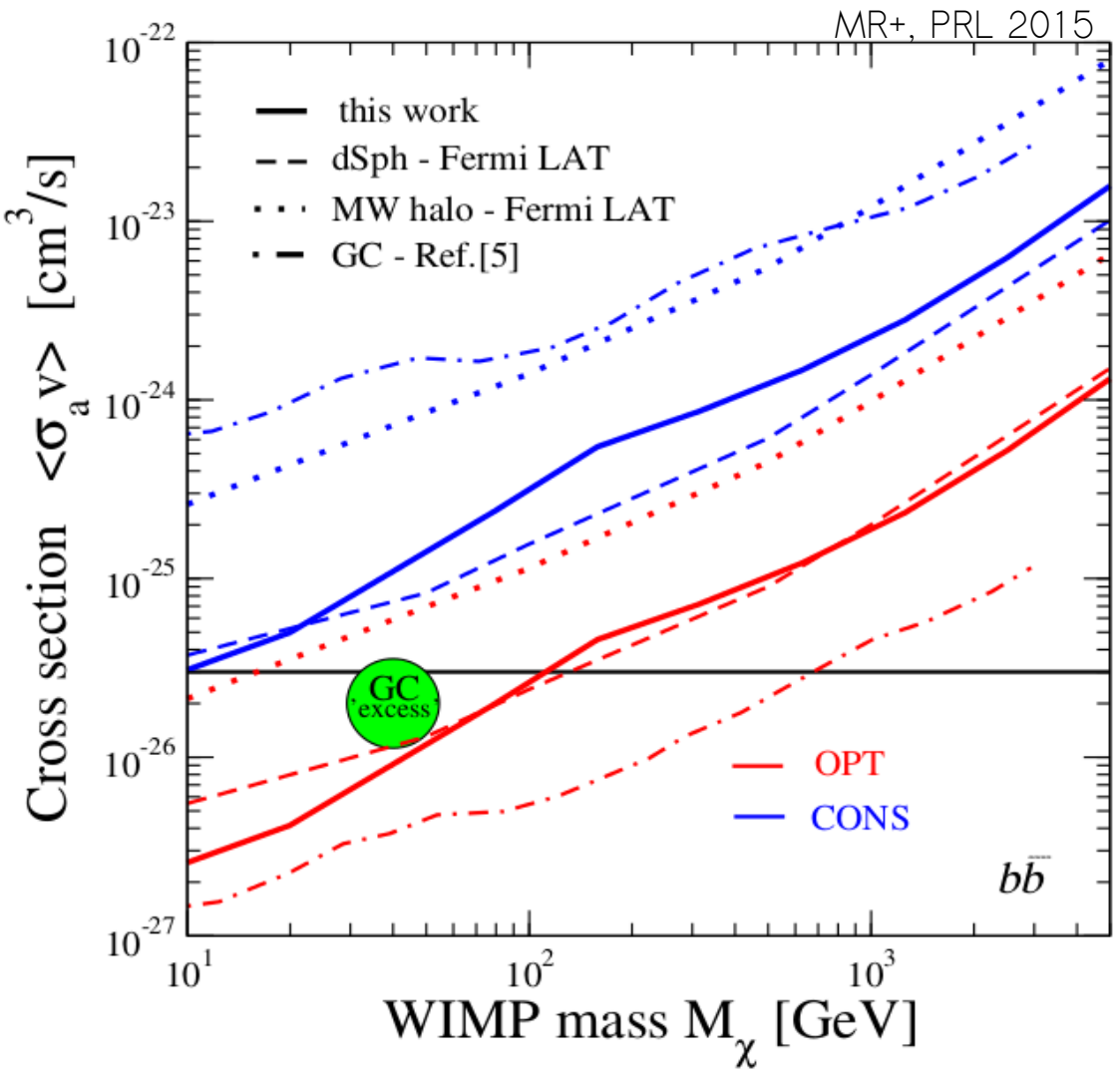
MR+, PRL 2015

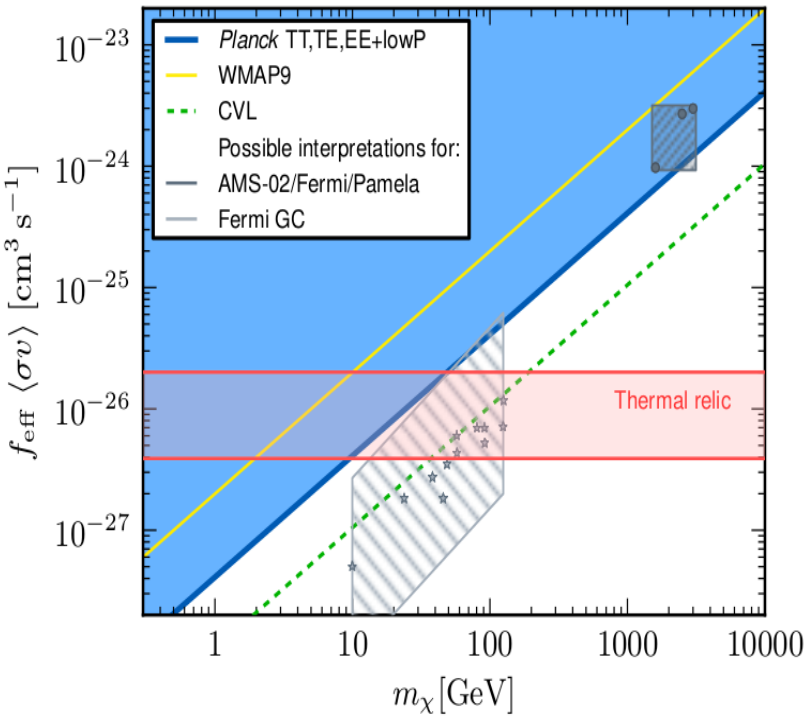


Camera, Fornasa, Fornengo, MR, 2014



Comparison with other methods



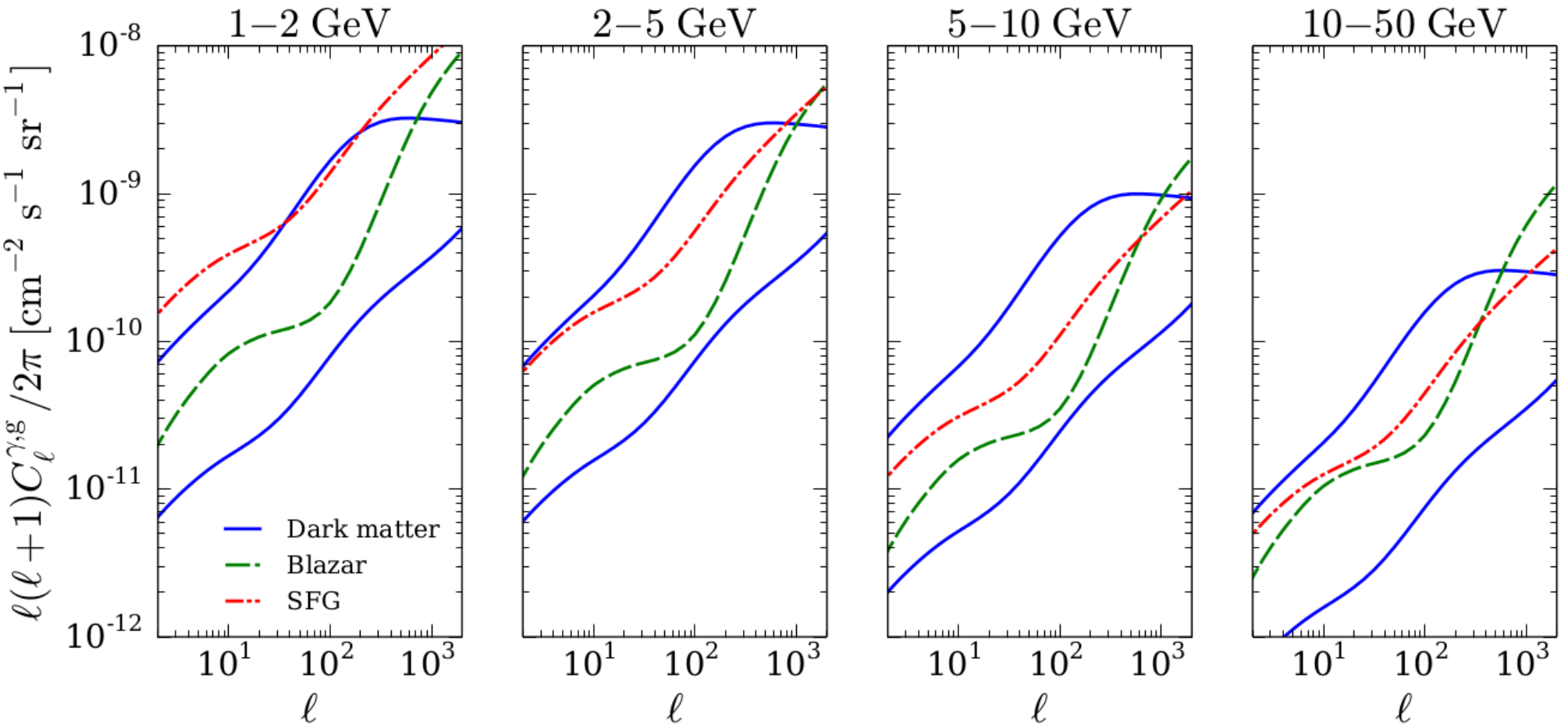


Cross correlation with 2MASS: predictions

$m_{\rm dm} = 100$ GeV, $\langle \sigma v \rangle = 3 \times 10^{-26}$ cm^3 s^{-1}

$b\bar{b}$ annihilation channel

Ando, JCAP 2014



Window function

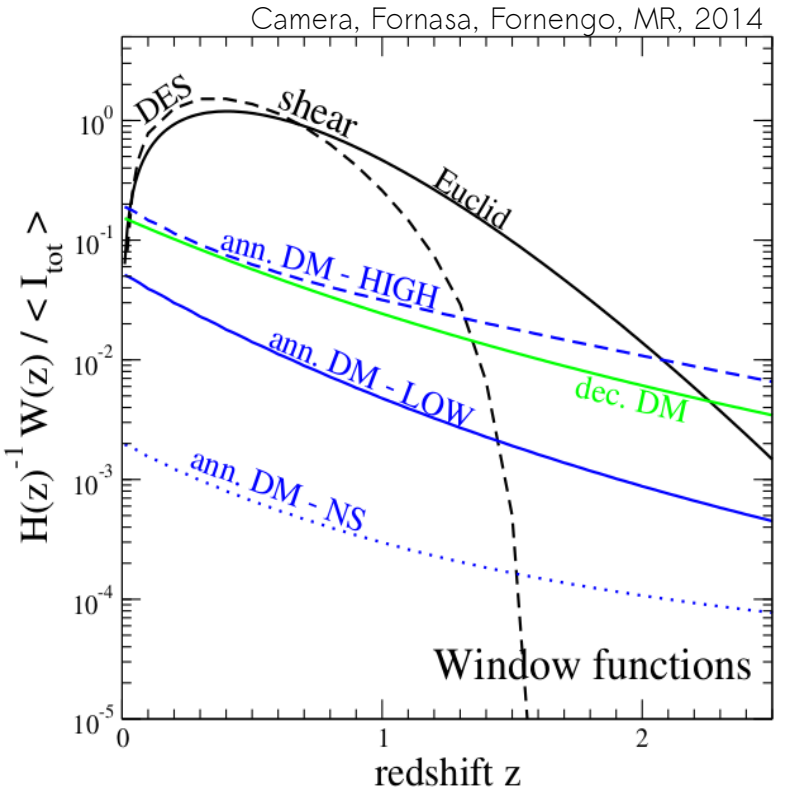
Annihilating DM

$$W(E,z) = \frac{(\Omega_{DM}\rho_c)^2}{4\pi}\frac{\langle\sigma_a v\rangle}{2m_\chi^2}(1+z)^3\,\Delta^2(z)\,\frac{dN_a[E(1+z)]}{dE}\,e^{-\tau[E(1+z),z]}$$

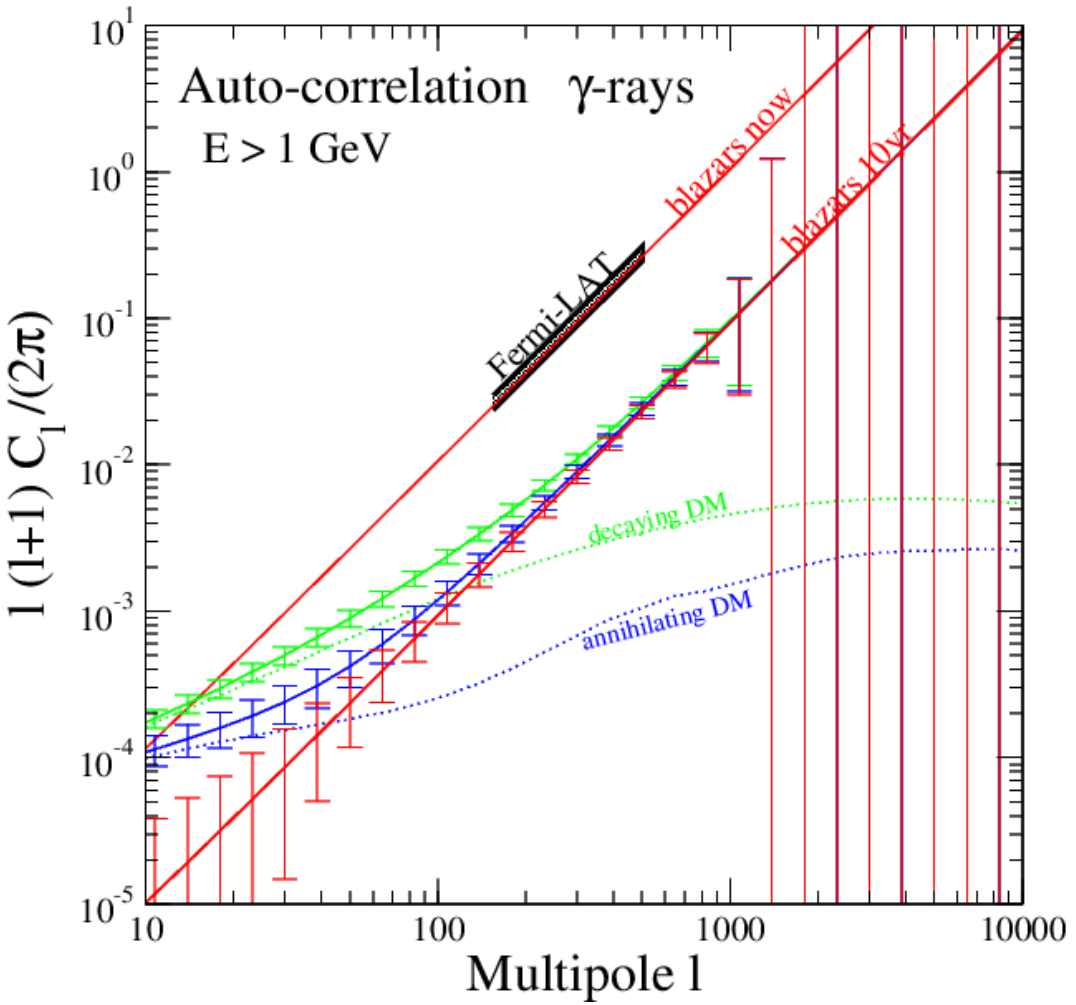
Clumping factor (or flux multiplier):

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

Camera, Fornasa, Fornengo, MR, 2014



What's "wrong" with γ-rays alone?



NEAR FUTURE

Very difficult to extract a clear WIMP signature from the extragalactic gamma-ray background alone.

Example

WIMP model with m_{DM}=100 GeV and $\langle \sigma_a v \rangle = 8 \times 10^{-26}$ cm^3/s in $b\bar{b}$

(such that the EGB is saturated at few GeV)