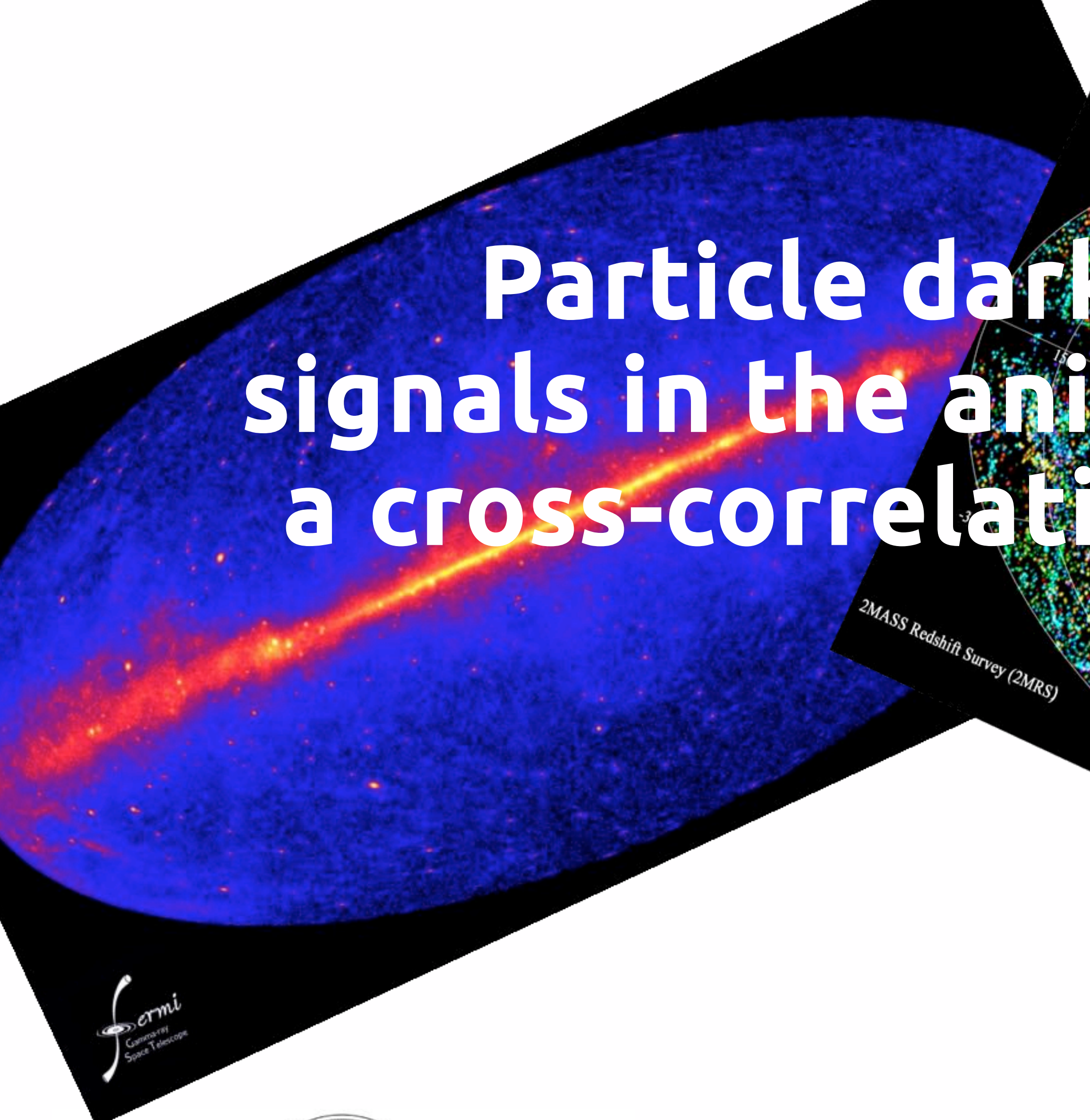
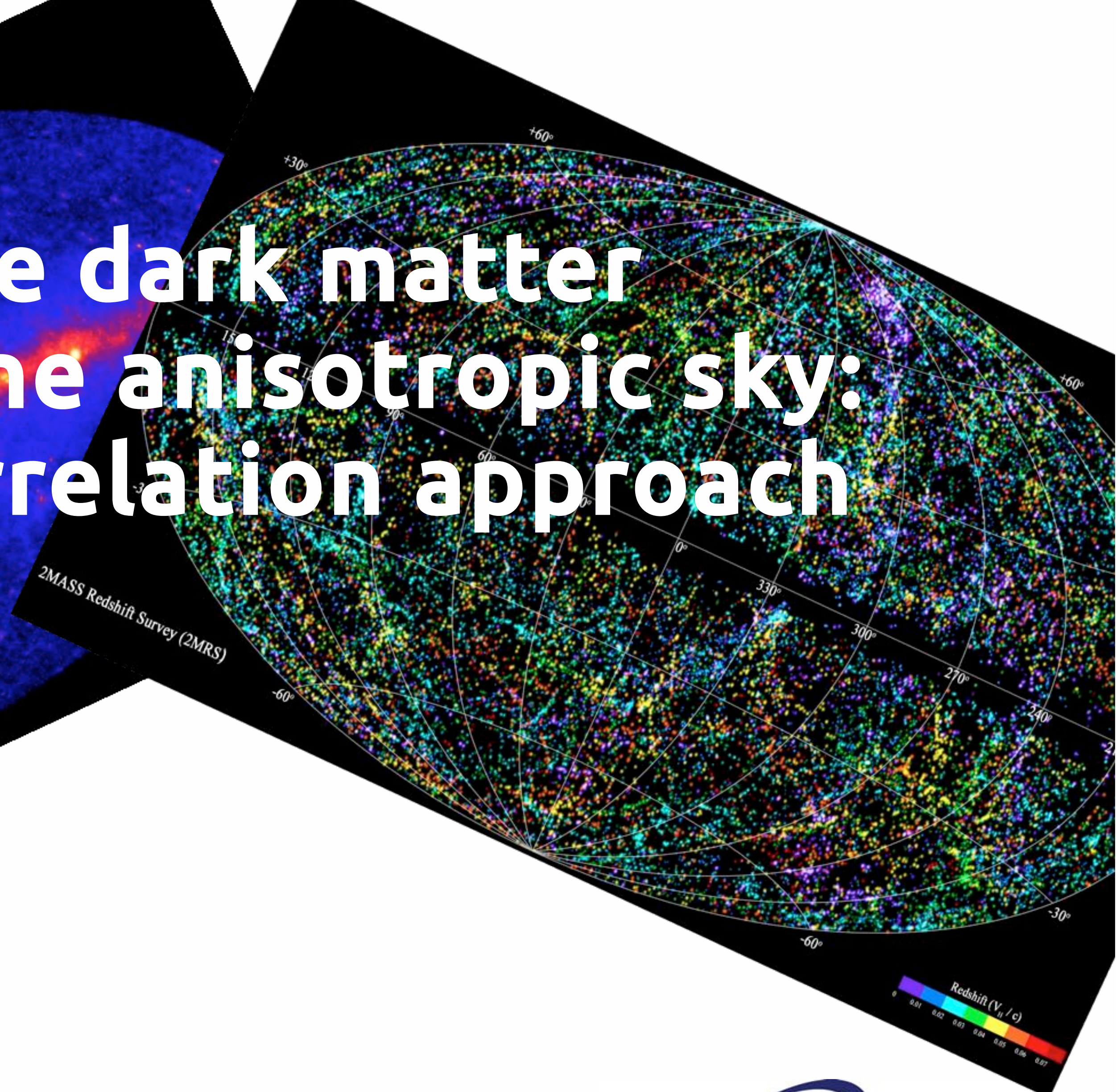
Particle dark matter signals in the anisotropic sky: a cross-correlation approach





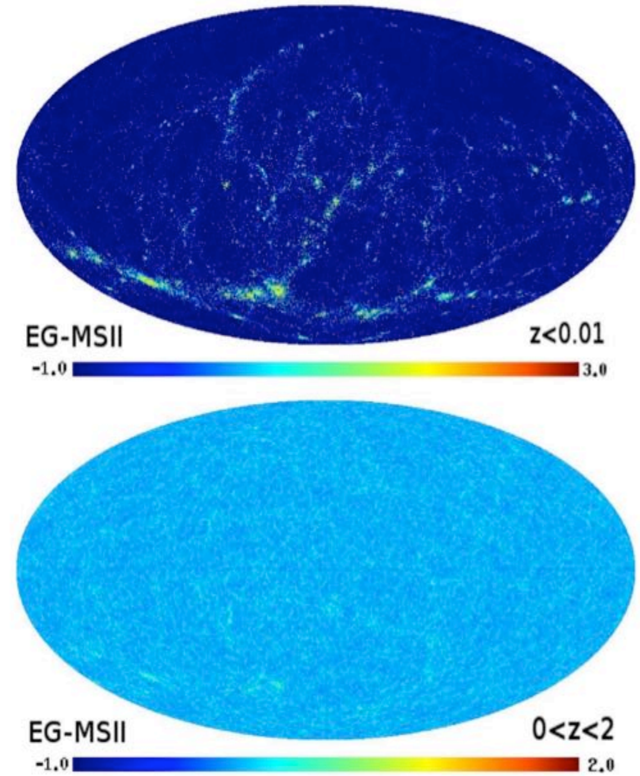
Marco Regis
(Torino)

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.



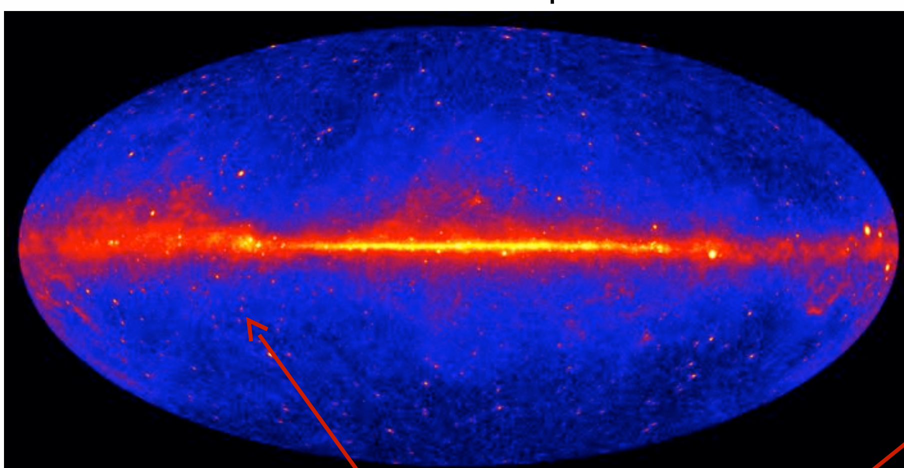
from Fornasa et al., 2013

Dig into the unresolved extragalactic sky

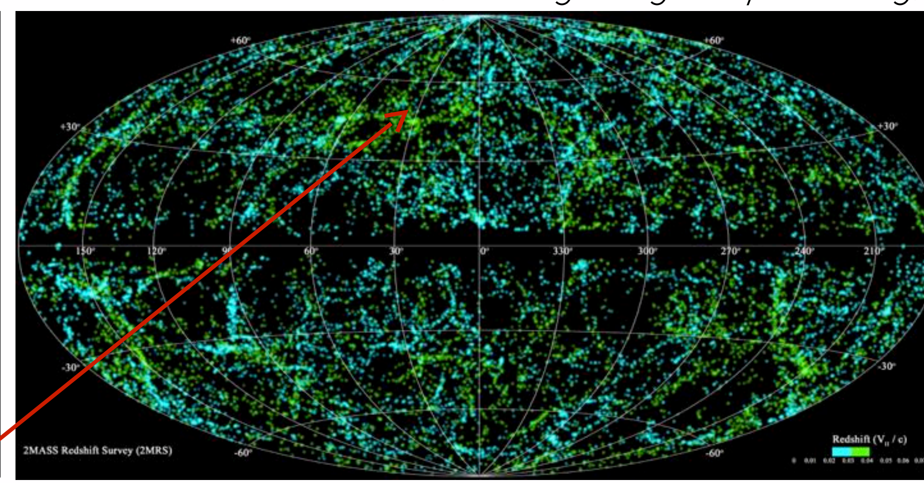
WIMP angular correlations

The idea is to have an **accurate tracer of the DM distribution** (gravitational potential) in the Universe, to be used as a filter in order to separate the DM non-gravitational signal from other astrophysical non-thermal emissions.

Fermi-LAT map



Gravitational tracer (lensing or galaxy catalog)



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

$C^{ij}(\theta)$: correlation in physical space

C_l^{ij}: correlation in harmonic space

Two-point statistics

Angular power spectrum

of fluctuations

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

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

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

In the limit of low angles: $<\rho> \sim \omega$

Angular power spectrum

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

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

Window function

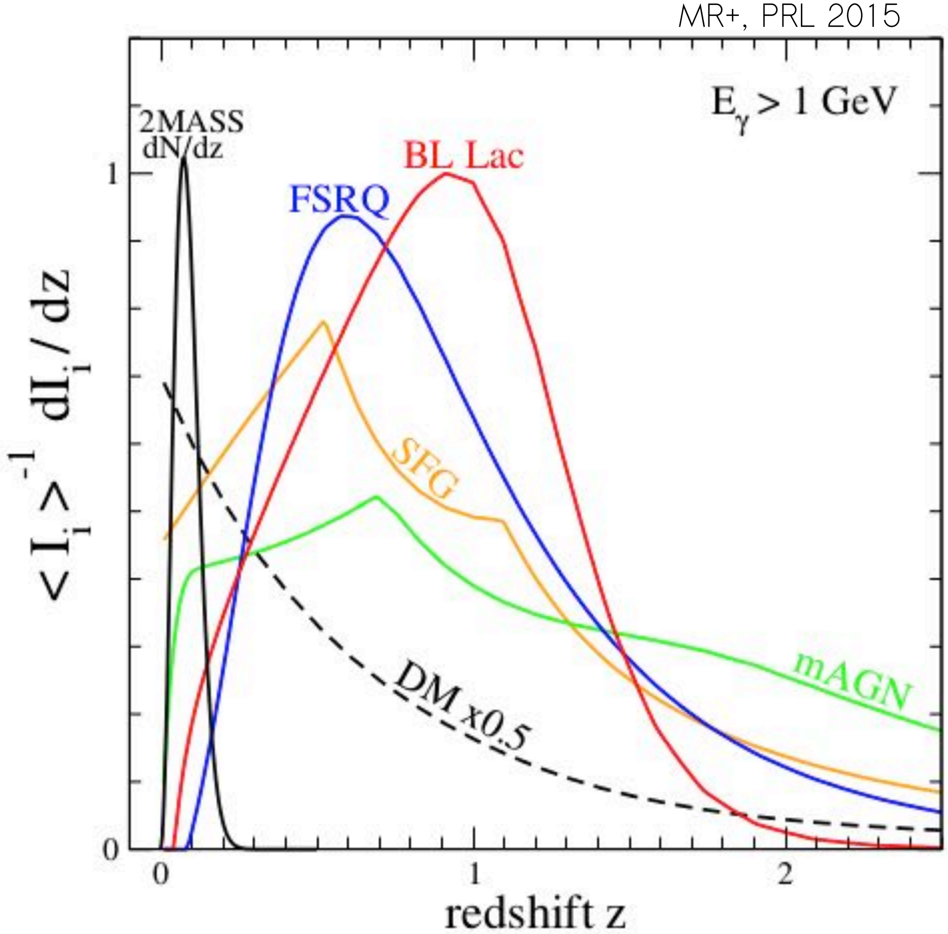
$$\langle \tilde{f}_X(\chi, \mathbf{k}) \tilde{f}_Y(\chi, \mathbf{k}') \rangle = (2\pi)^3 \delta^3(\mathbf{k} + \mathbf{k}') P^{XY}(k, \chi)$$

3D power spectrum

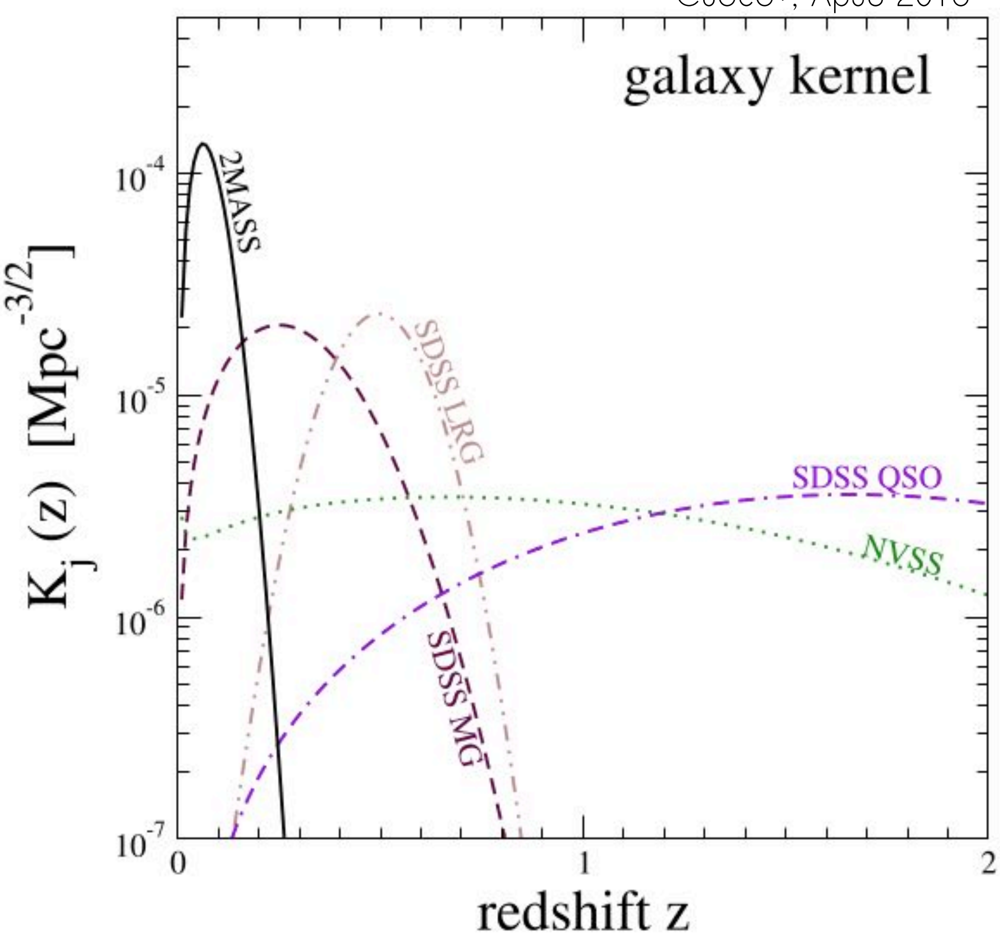
FT of density field of the source

window function

MR+, PRL 2015



Cuoco+, ApJS 2015



DM peaks at low z, whilst
astrophysical sources peak at z > 0.5

TOMOGRAPHIC APPROACH

3D power spectrum

Typically obtained from **Simulations or Halo model**

Halo model

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

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

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:

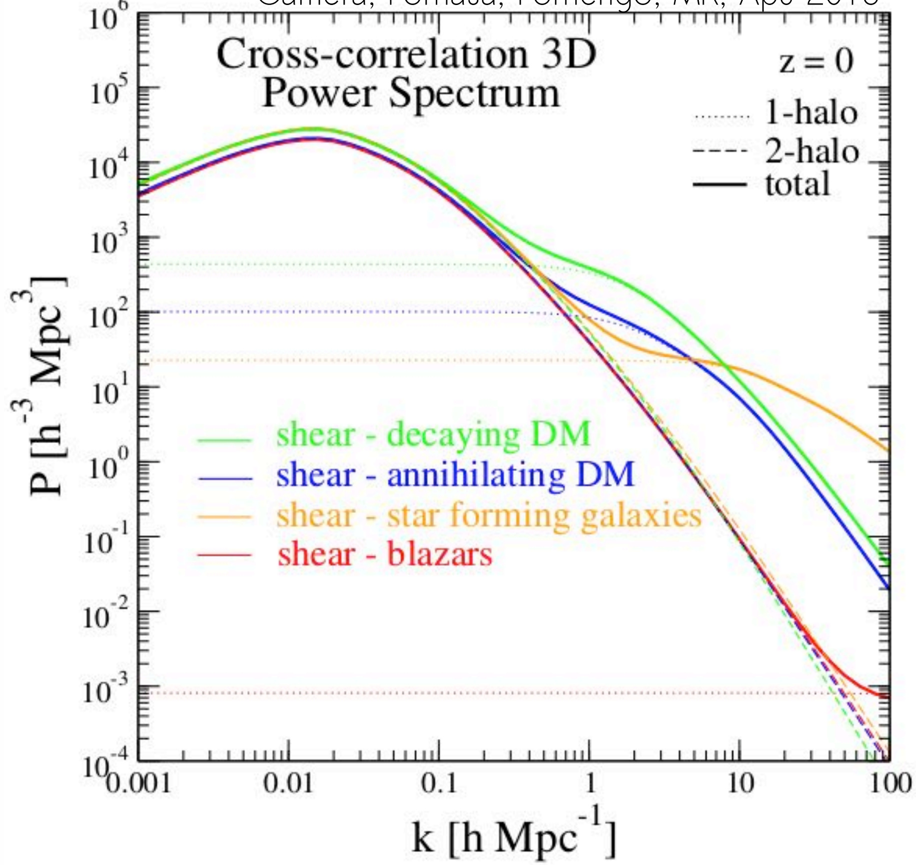
- Halo mass function dn/dm
- Concentration of halos c(m),
- DM distribution in halos (NFW, Einasto, Burkert, ...)

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

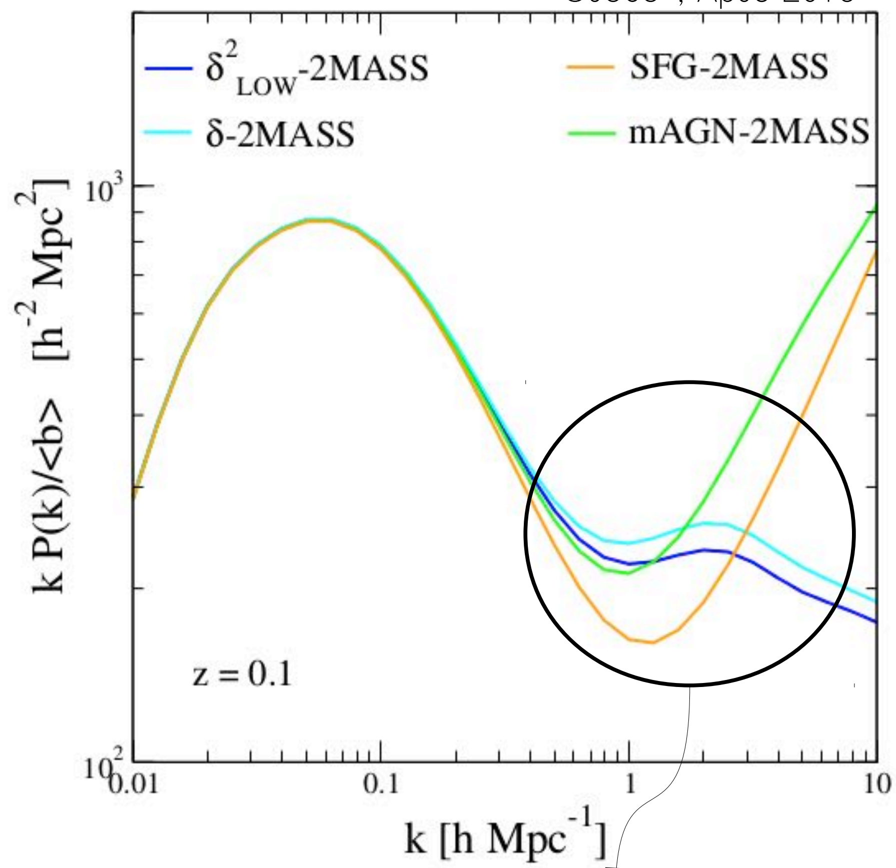
Critical point: **extrapolation** from the resolution of numerical simulations down to $\mathbf{m}_{\rm min}$

3D power spectrum

Camera, Fornasa, Fornengo, MR, ApJ 2013



Cuoco+, ApJS 2015

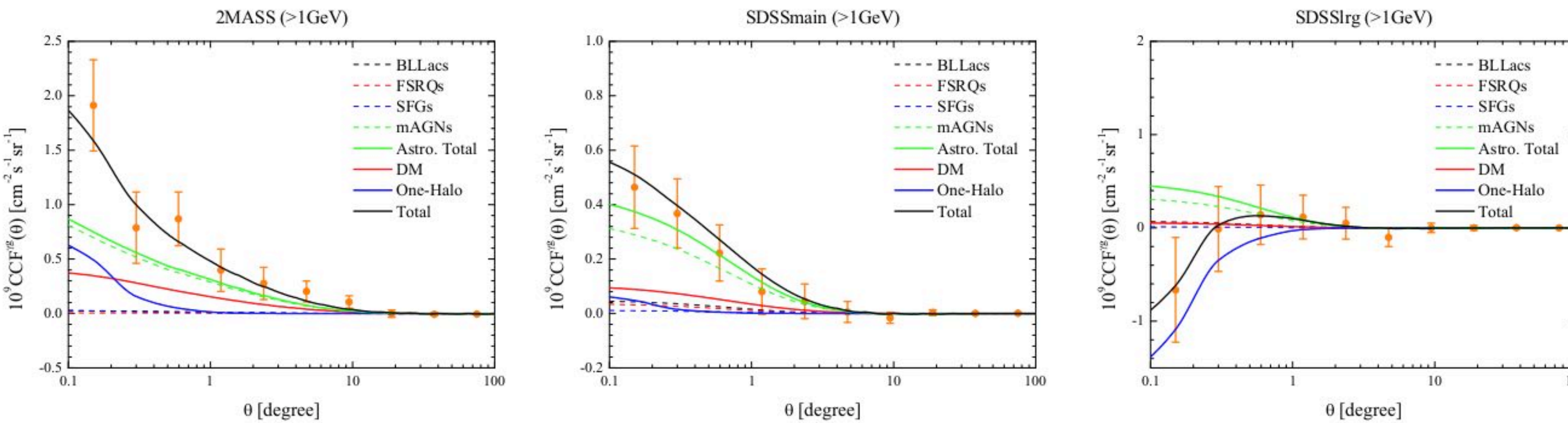


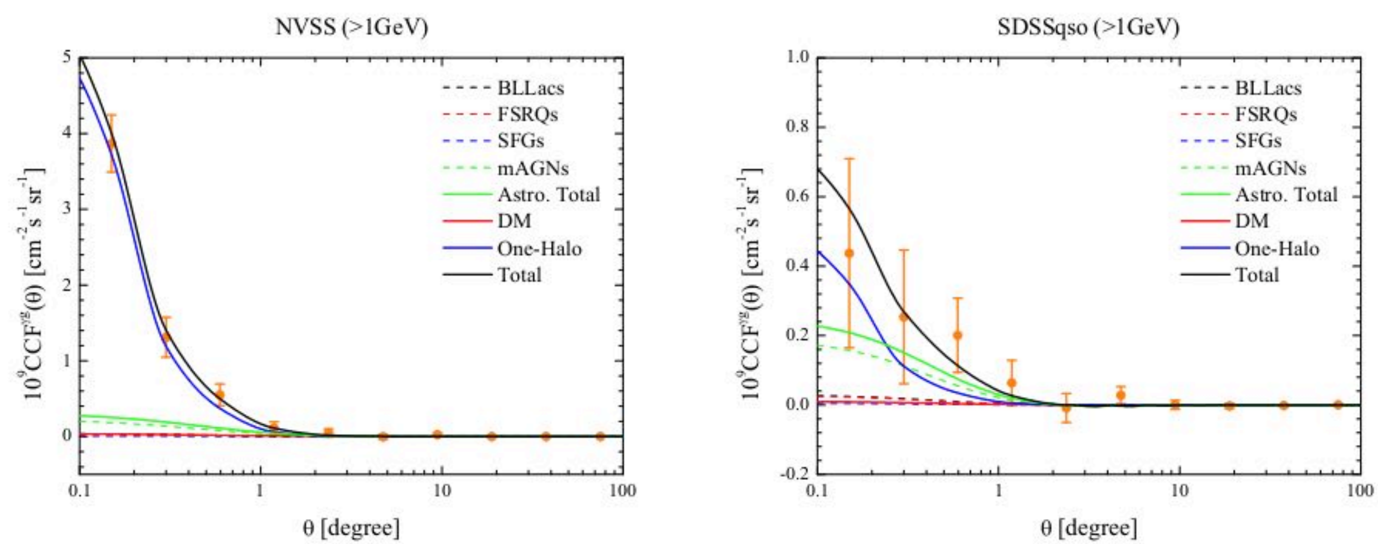
It is (roughly speaking) mapped in the multipole range 100 < l < 1000

Measurements, interpretations and forecasts

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

Xia, Cuoco, Branchini, Viel, ApJS 2015



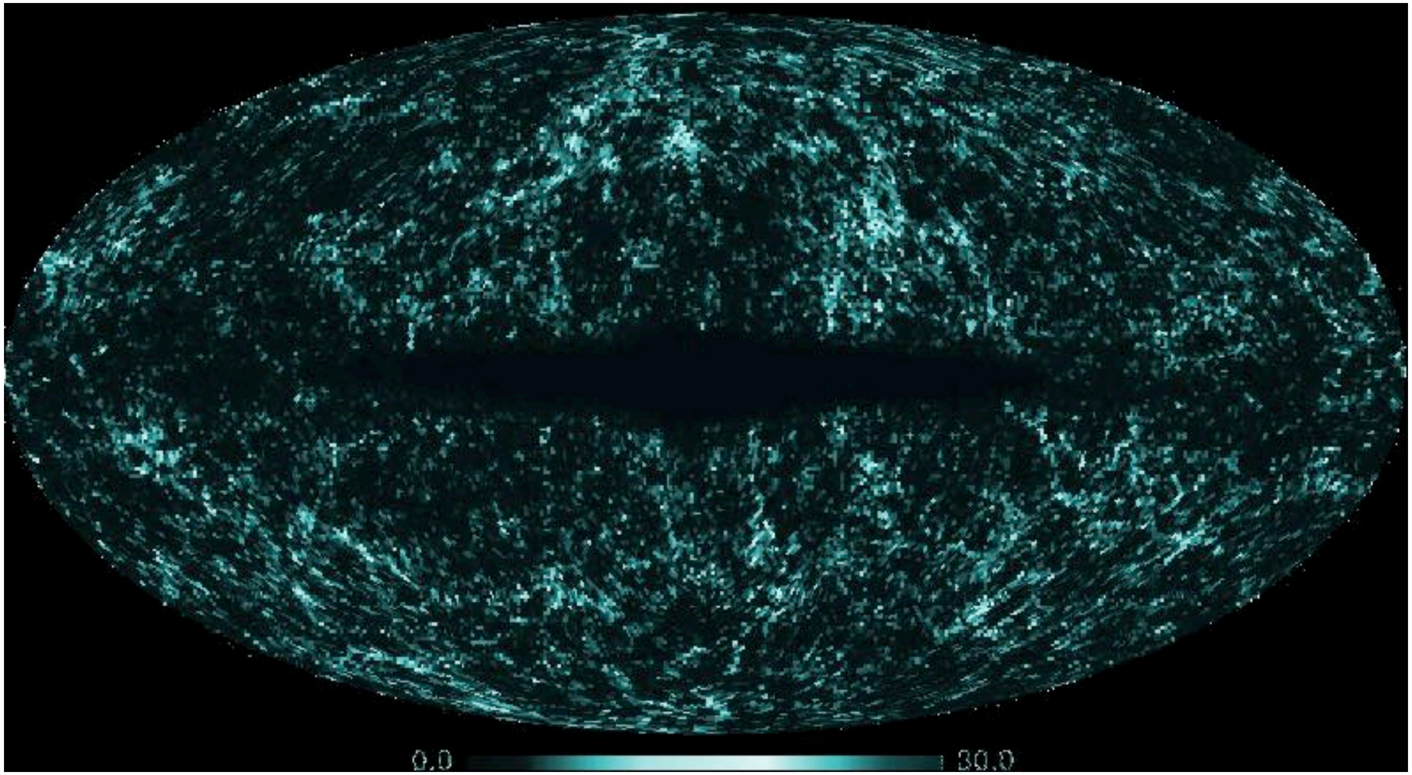


see also Shirasaki+ 2015

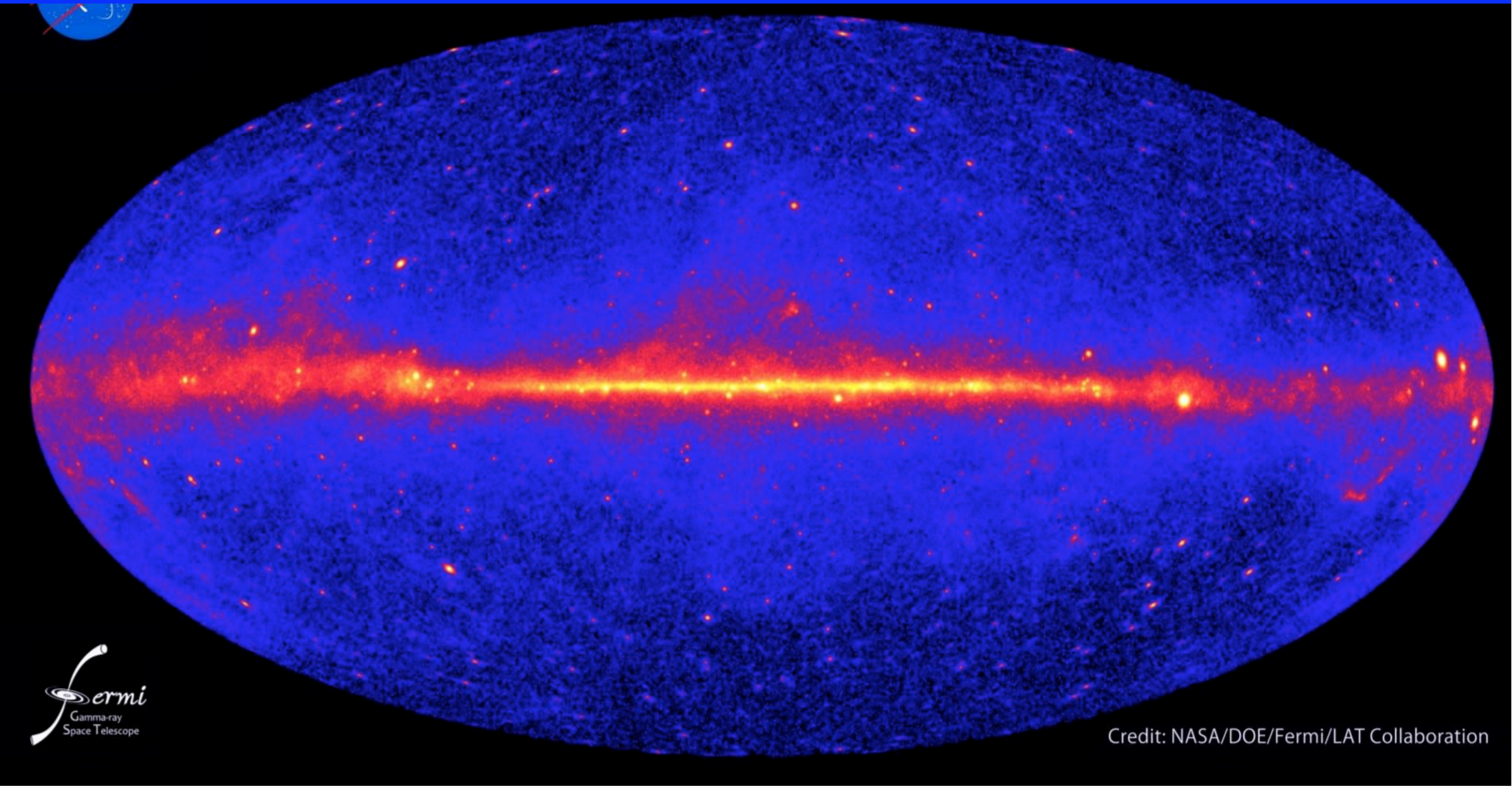
Cross correlation of Fermi-LAT with the 2MASS catalog

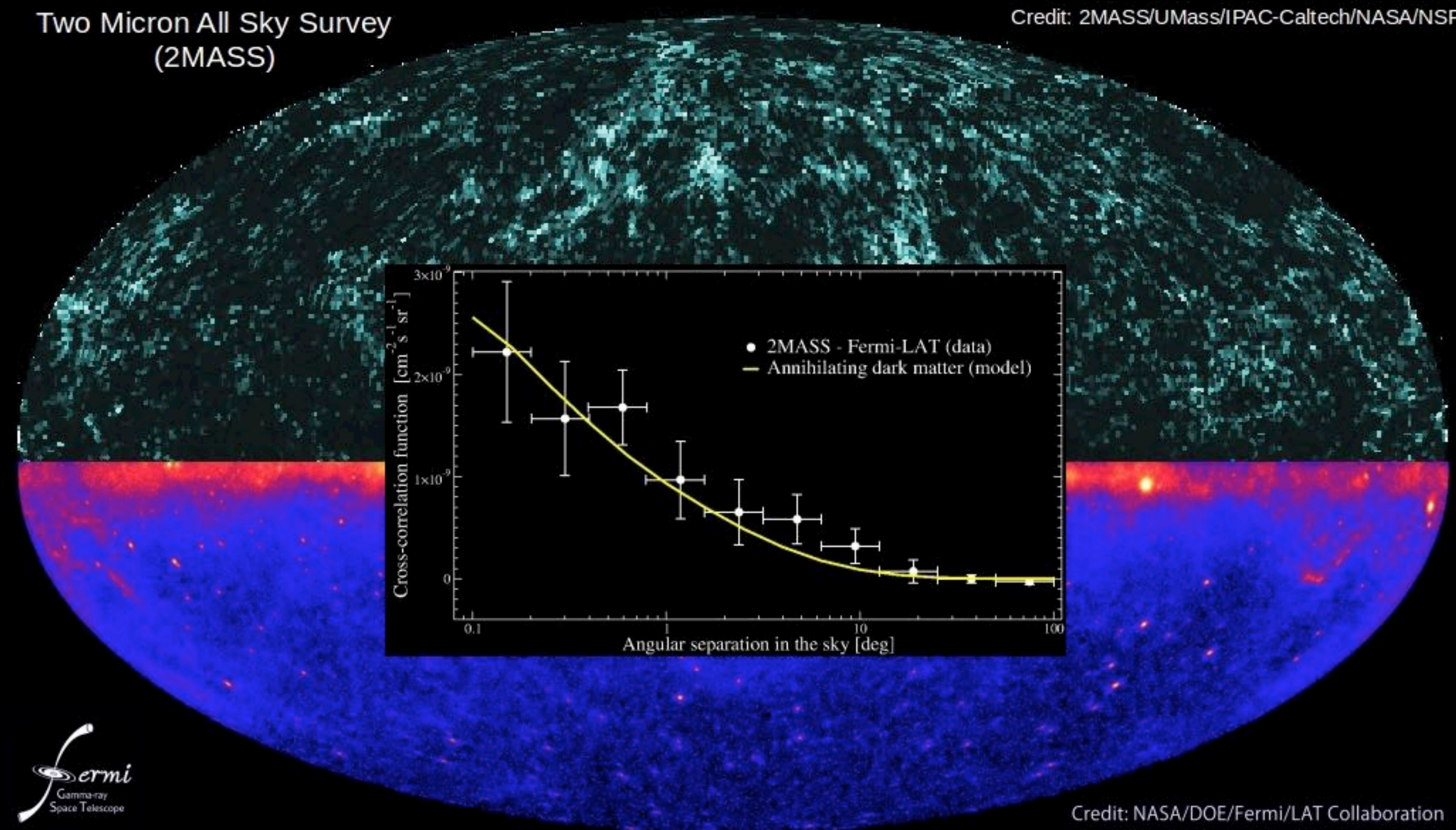
2MASS

770000 galaxies with mean redshift z ~ 0.072



Cross correlation of Fermi-LAT with the 2MASS catalogue

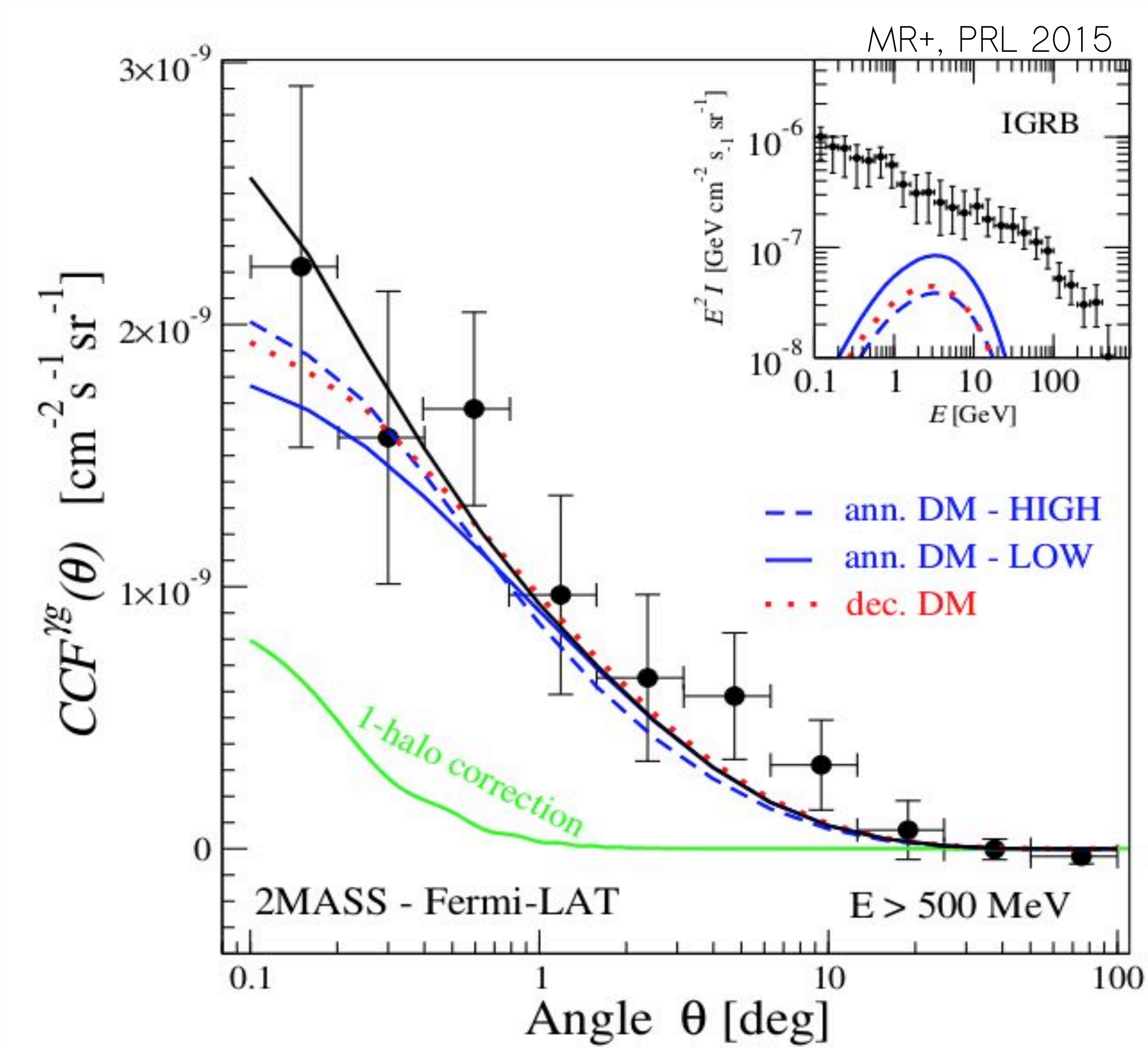




Two Micron All Sky Survey
(2MASS)
Credit: 2MASS/UMass/IPAC-Caltech/NASA/NSF
3×10⁻⁹
2×10⁻⁹
1×10⁻⁹
0
Cross-correlation function [cm⁻² s⁻¹ sr⁻¹]
2MASS - Fermi-LAT (data)
Annihilating dark matter (model)
0.1
1
10
100
Angular separation in the sky [deg]
Fermi
Gamma-ray Space Telescope
Credit: NASA/DOE/Fermi/LAT Collaboration

DM interpretation

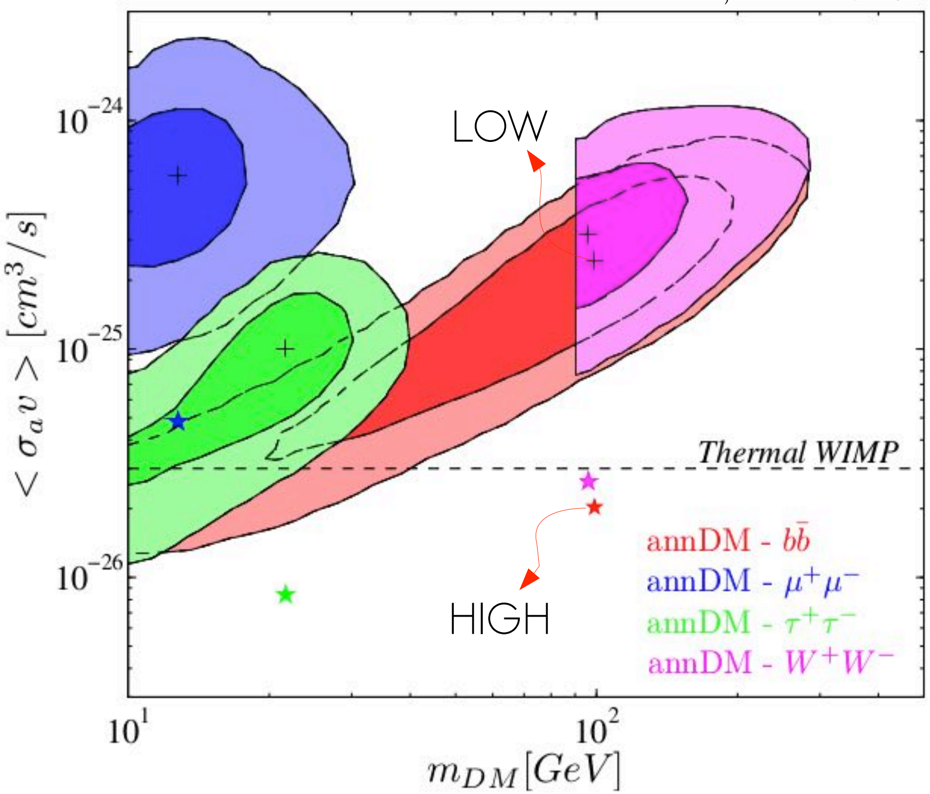
MR+, PRL 2015



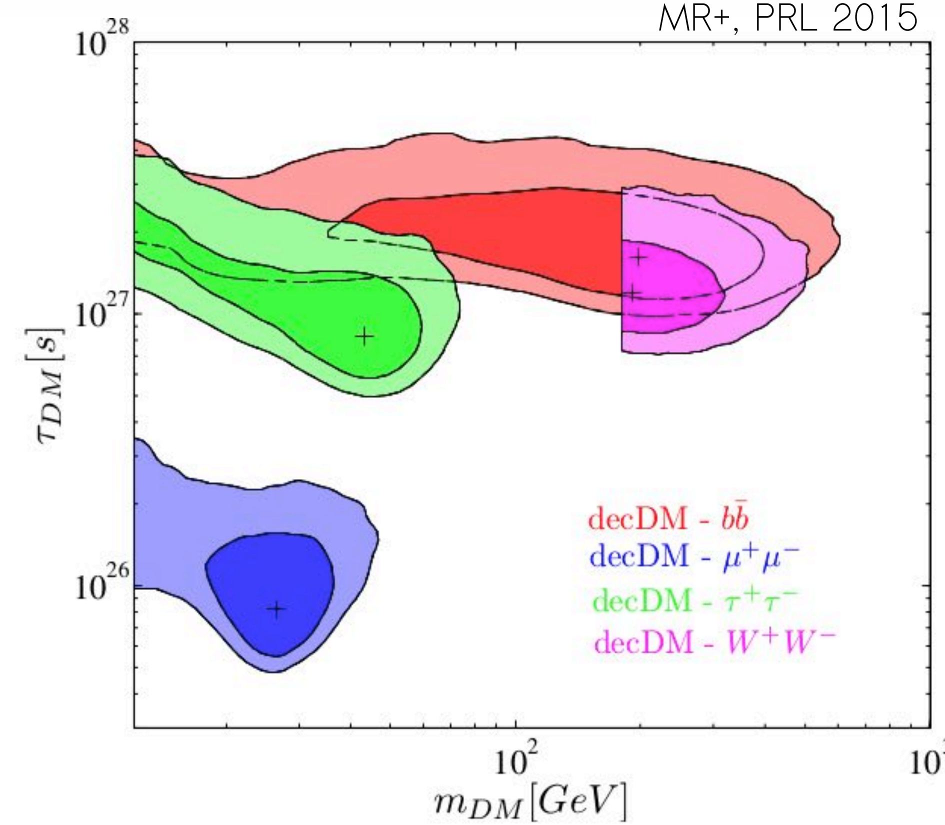
The particle DM signal **can fit** the measured cross correlation between Fermi-LAT and 2MASS

DM interpretation

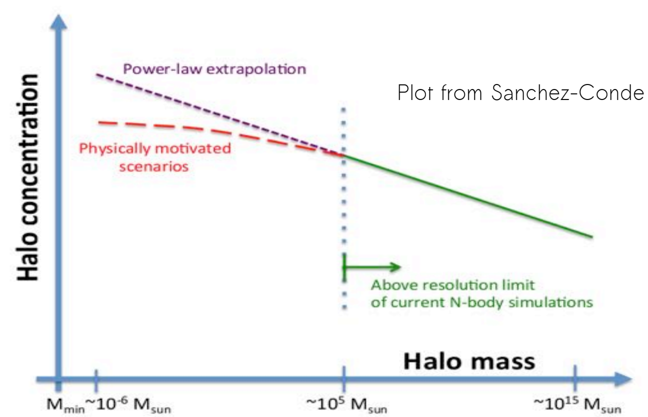
MR+, PRL 2015



MR+, PRL 2015



(about subhalos model

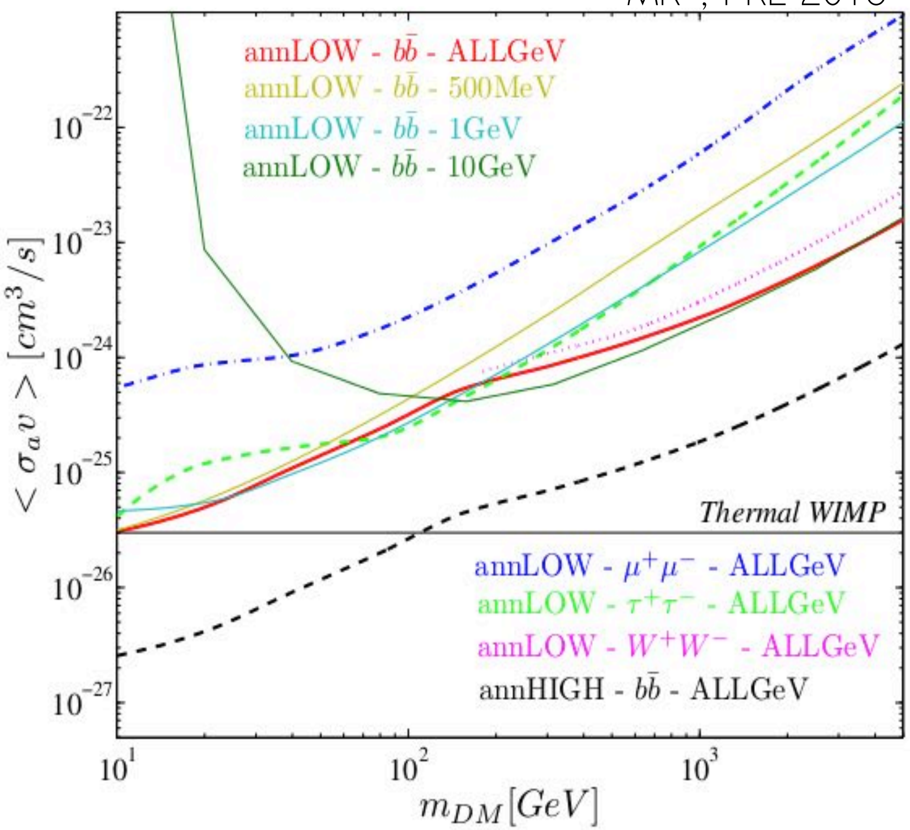


)

Bounds on WIMP DM

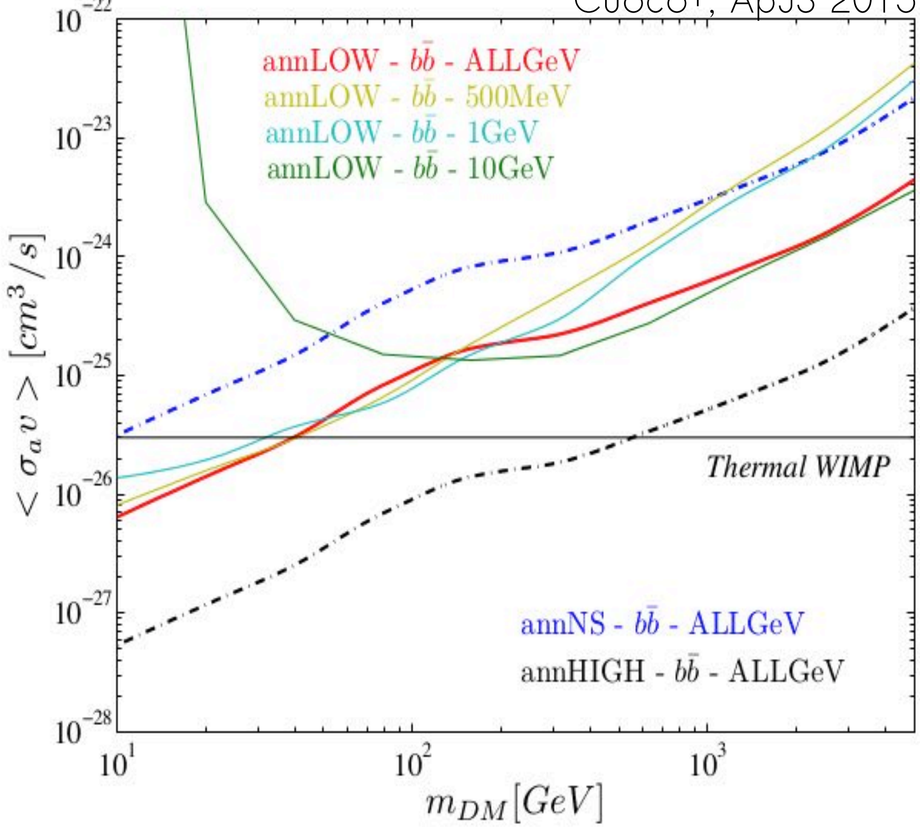
DM-only

MR+, PRL 2015



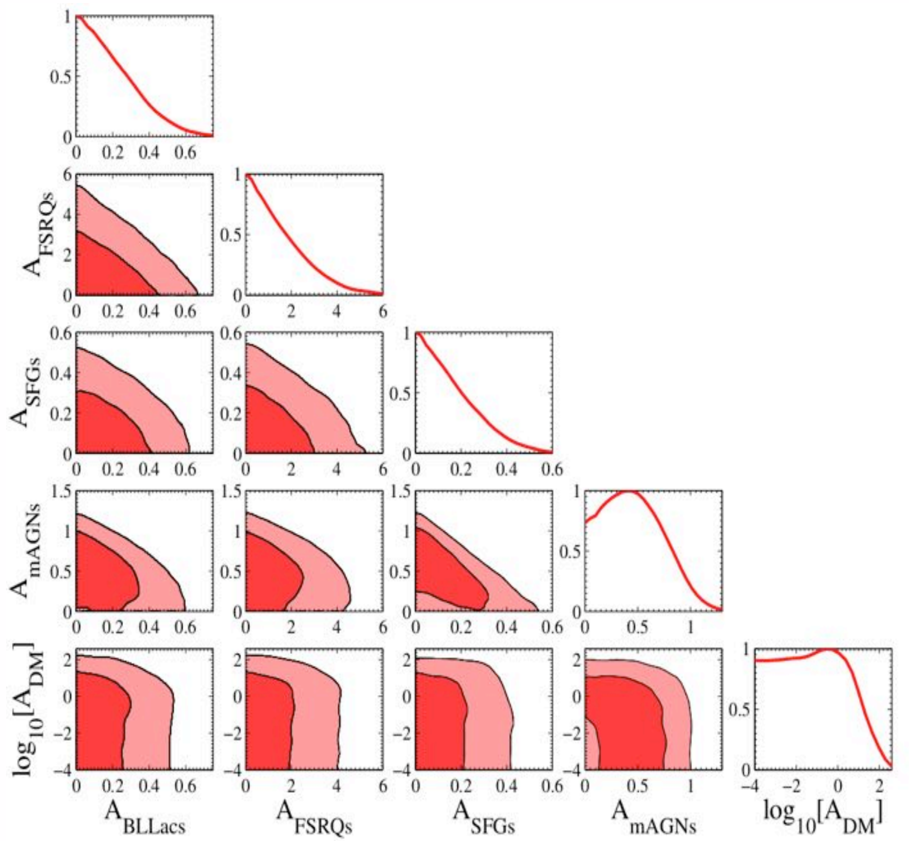
including astro sources

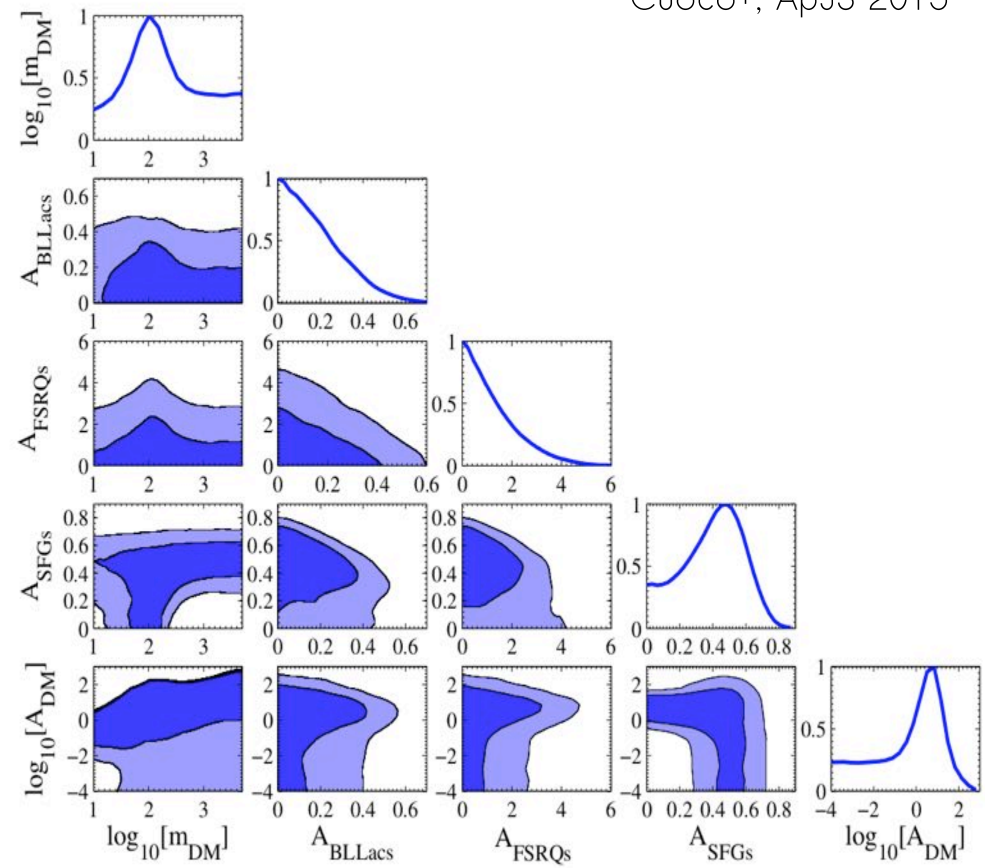
Cuoco+, ApJS 2015



Astrophysical backgrounds

Cuoco+, ApJS 2015





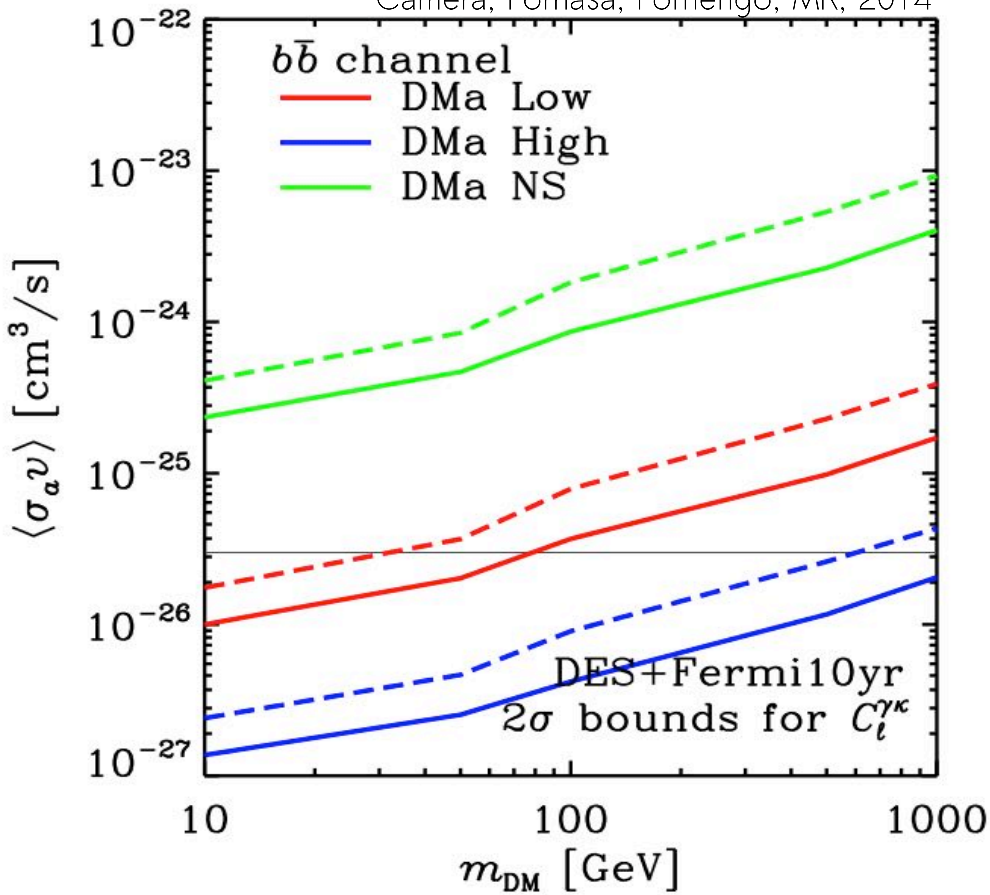
Degeneracy between DM interpretation and AGN hosted in big halos (groups or clusters)

Prospects for DM detection/bounds using cross correlation with shear

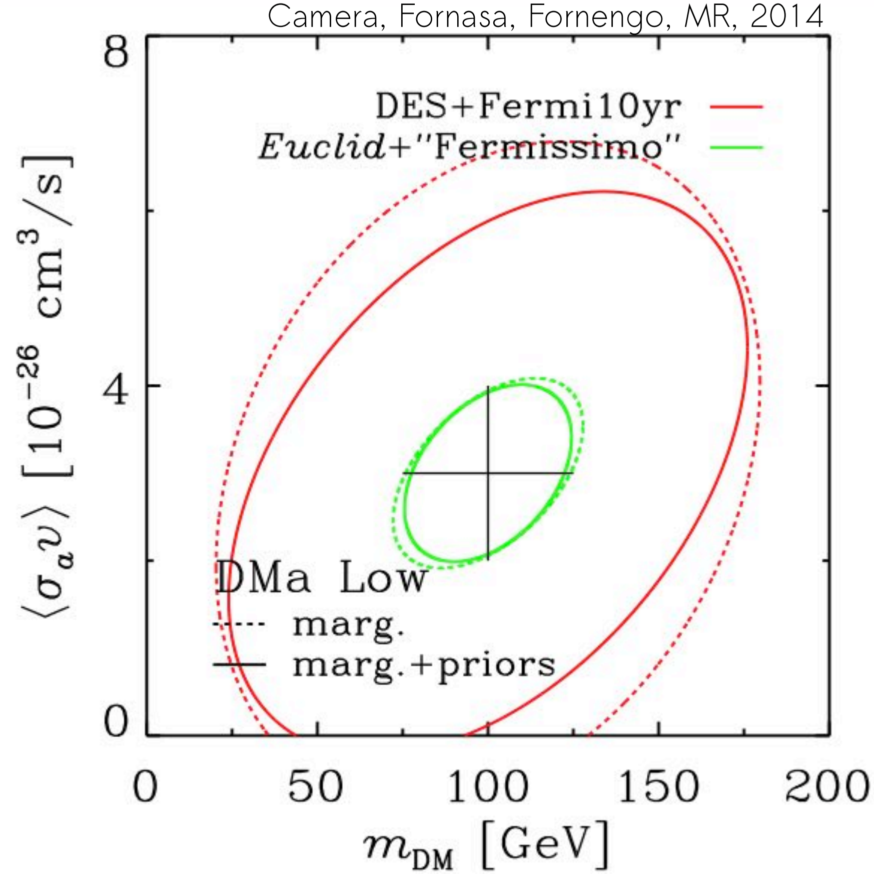
Cross-correlation with lensing surveys:

cleaner test and larger non-linear term

Camera, Fornasa, Fornengo, MR, 2014



Camera, Fornasa, Fornengo, MR, 2014



First attempt of measurement

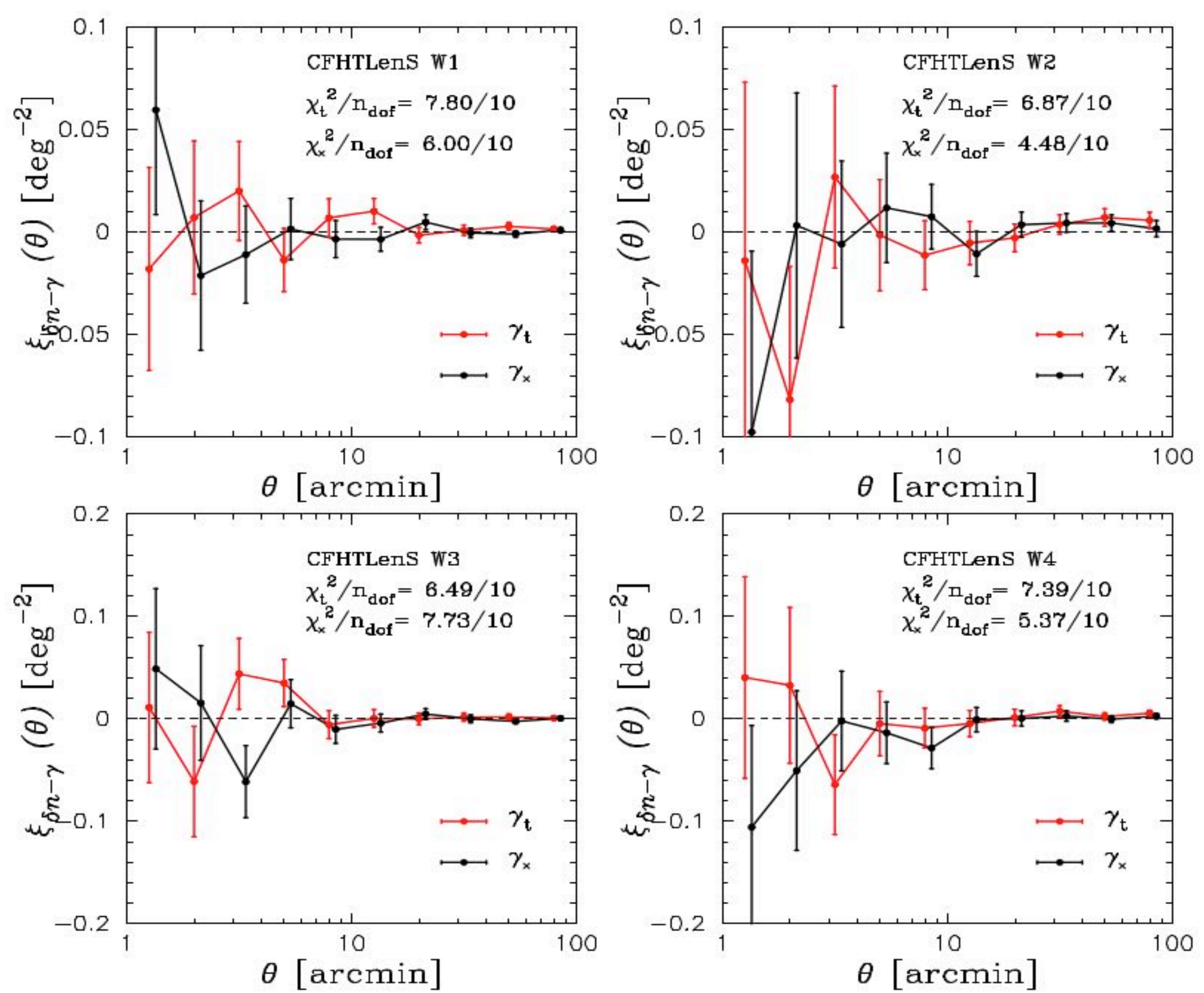
(of the cross correlation between cosmic shear and the EGB)

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

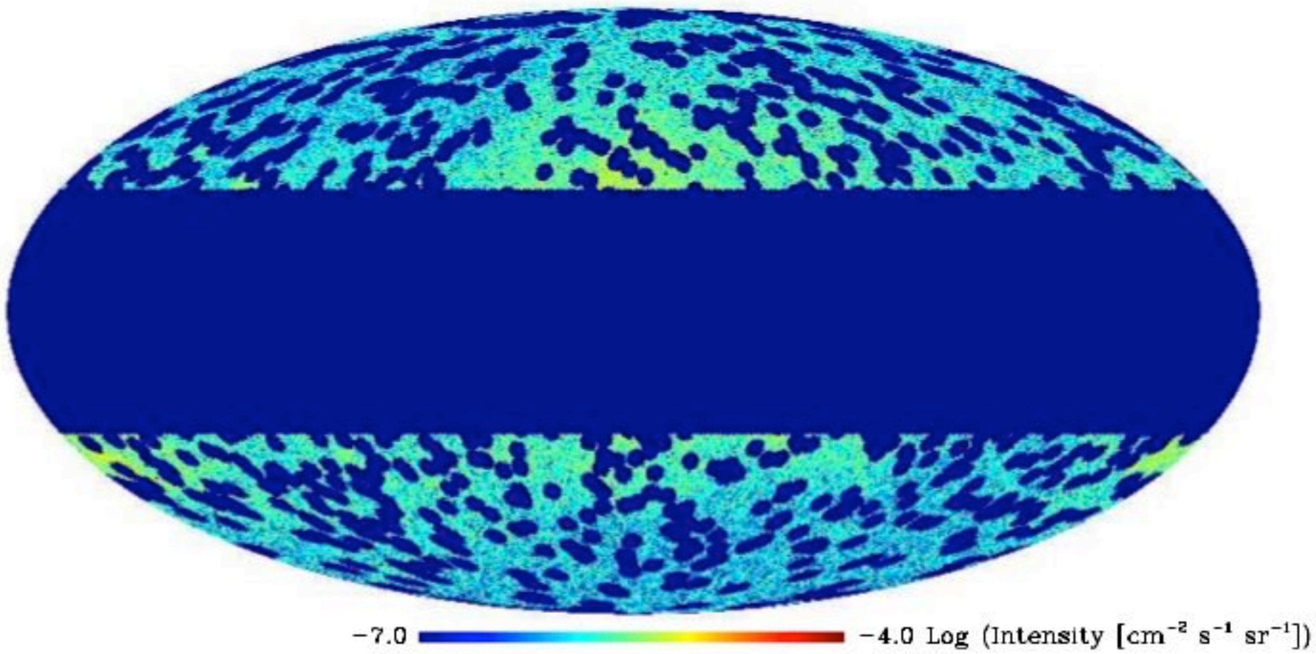
(Shirasaki, Horiuchi, Yoshida, PRD 2014)

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

(DES → 5000 sq.deg.)

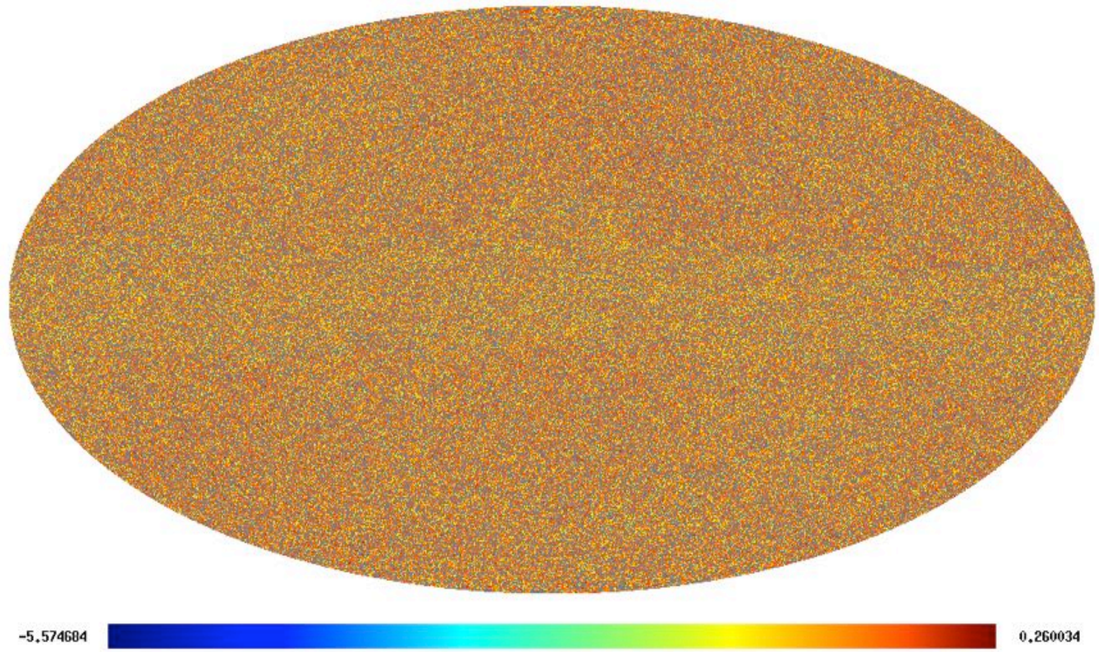


Cross correlation with CMB lensing

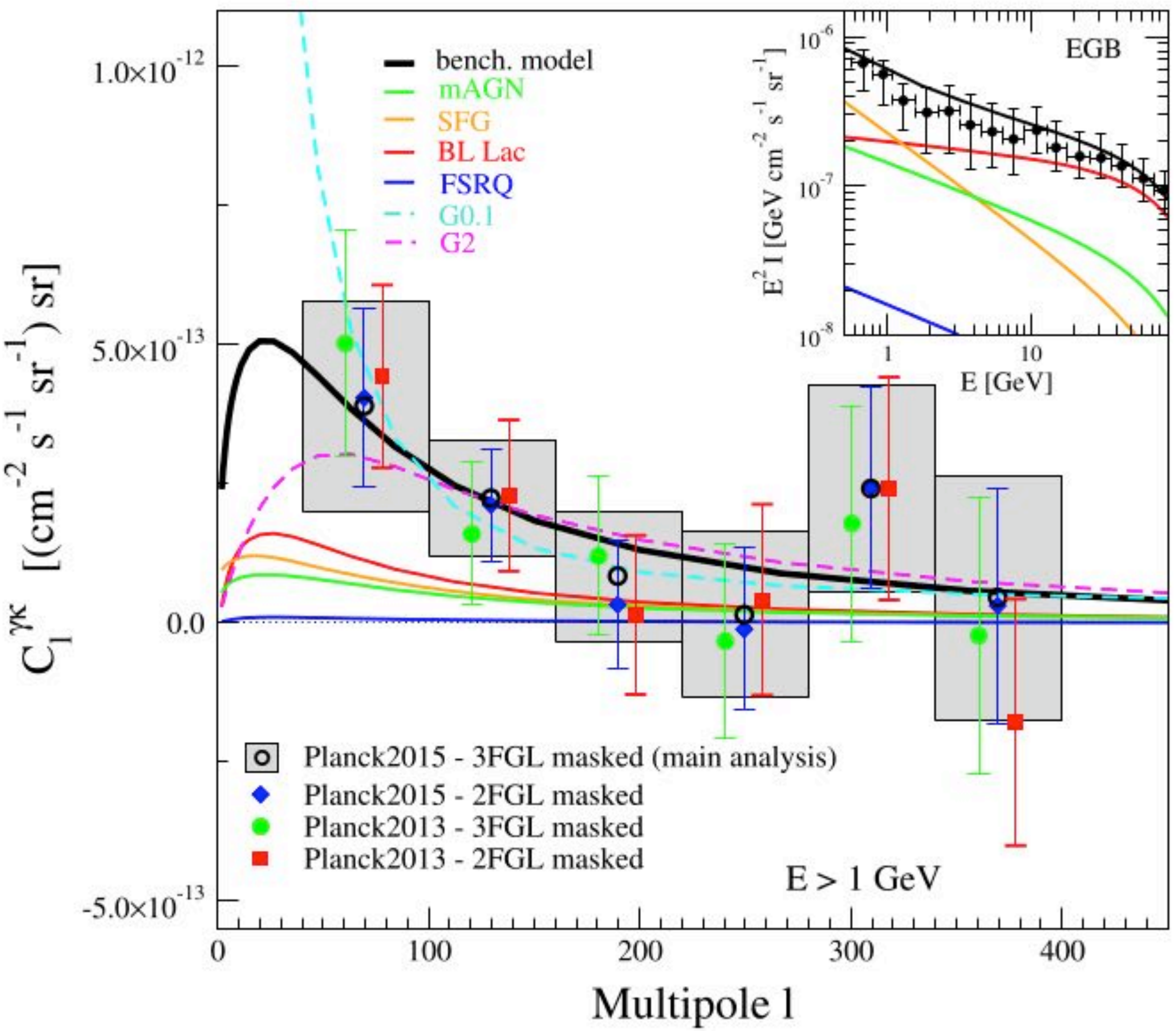


Fermi-LAT 6yr data

Planck 2015 data release



Cross correlation with CMB lensing



3σ evidence

Fornengo, Perotto, MR, Camera
ApJ 2015

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

Near-future directions

Energy spectrum

Low-z tomography

Better understanding of astro GLF at low z

Smaller scales

NEW DATA

Lensing surveys: cleaner test, larger non-linear term
(Camera+ 2012, 2014)

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

Radio: SKA and its precursors (LOFAR, ASKAP)

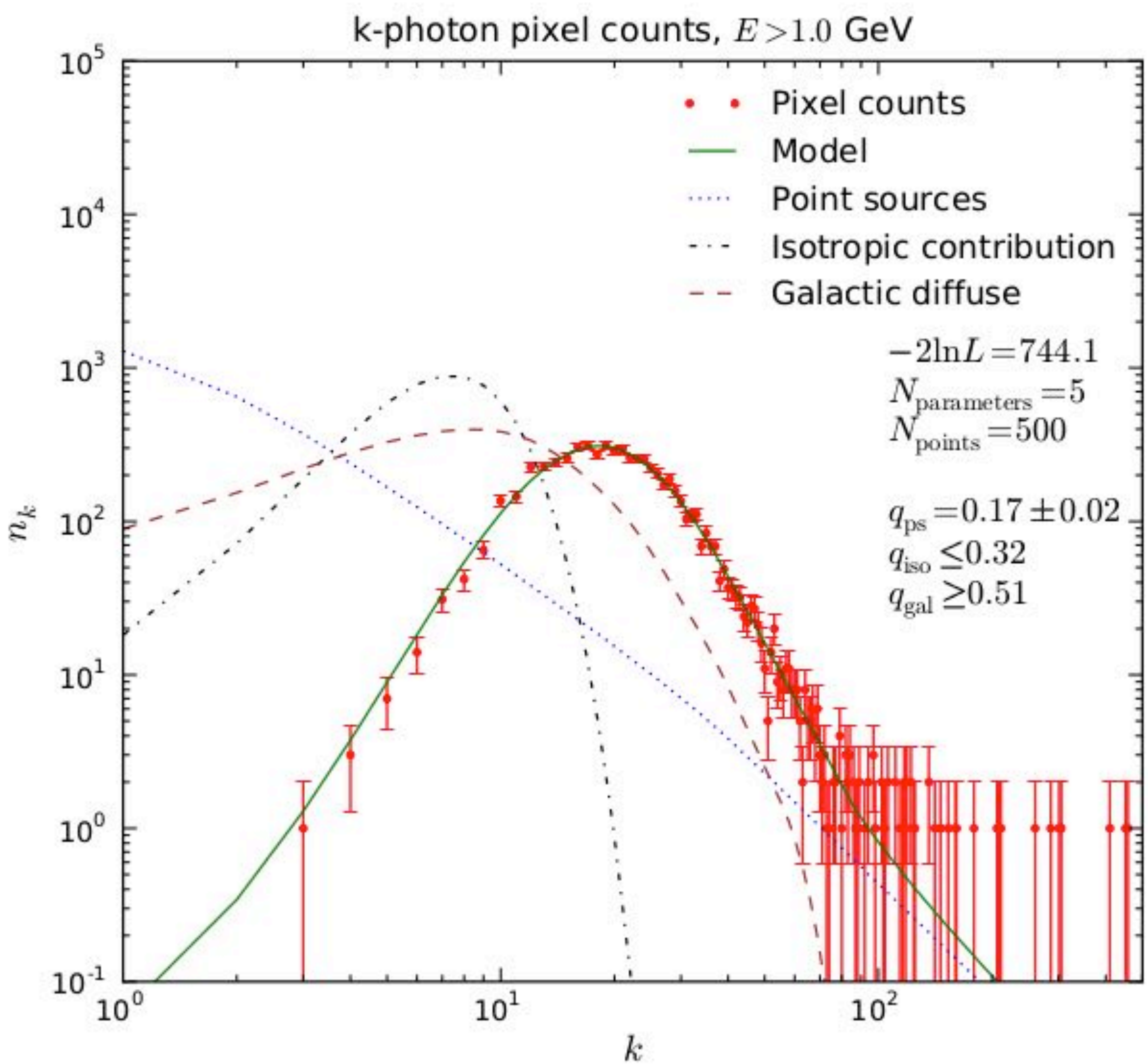
X-rays: eROSITA, ATHENA, .. (also in the context of keV DM, see Zandanel, Weniger, Ando JCAP 2015)

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

1-point statistics

1-point statistics

in γ-ray context: number of pixels versus number of photons in the pixel



Malyshev and Hogg 2011

NEWS

NEWS

UNVEILING THE GAMMA-RAY SOURCE COUNT DISTRIBUTION BELOW THE FERMI DETECTION LIMIT WITH PHOTON STATISTICS

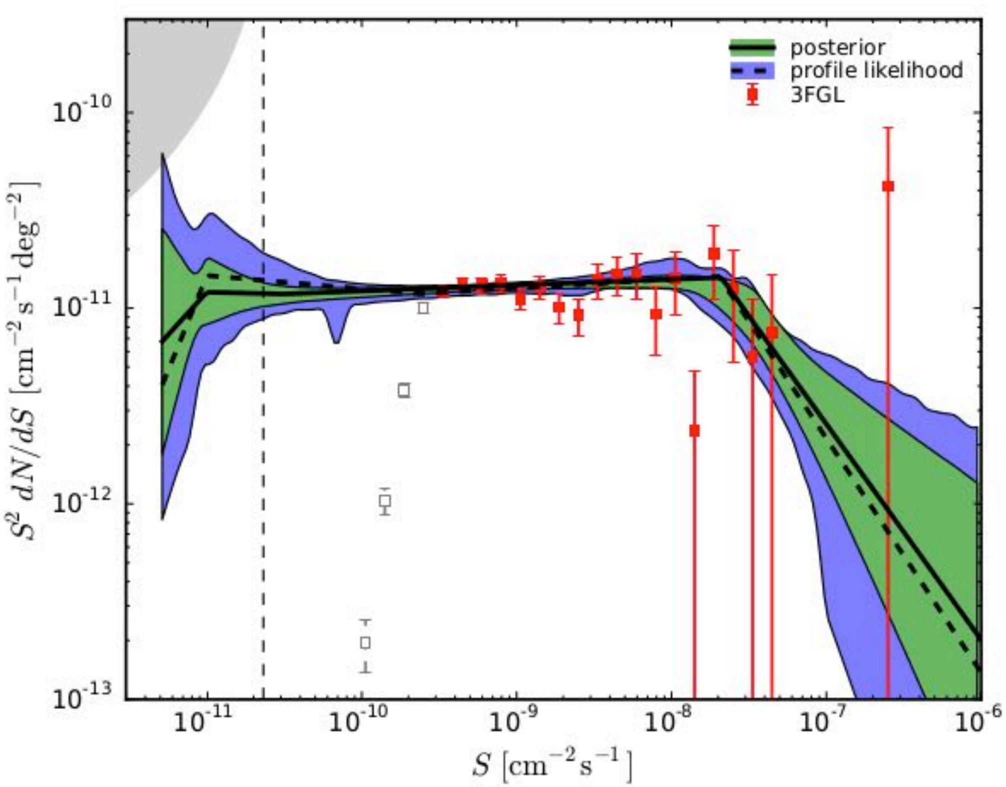
HANNES-S. ZECHLIN[1,2], ALESSANDRO CUOCO[2,3],
FIORENZA DONATO[1,2], NICOLAO FORNENGO[1,2], AND ANDREA VITTINO[4]

Preprint December 22, 2015

ABSTRACT

The source-count distribution as a function of their flux, $\mathrm{d}N/\mathrm{d}S$, is one of the main quantities characterizing gamma-ray source populations. We employ statistical properties of the *Fermi*-LAT photon counts map to measure the composition of the extragalactic gamma-ray sky at high latitudes ($|b| \geq 30°$) between 1 GeV and 10 GeV. We present a new method, generalizing the use of standard pixel-count statistics, to decompose the total observed gamma-ray emission into: (a) point-source contributions, (b) the Galactic foreground contribution, and (c) a truly diffuse isotropic background

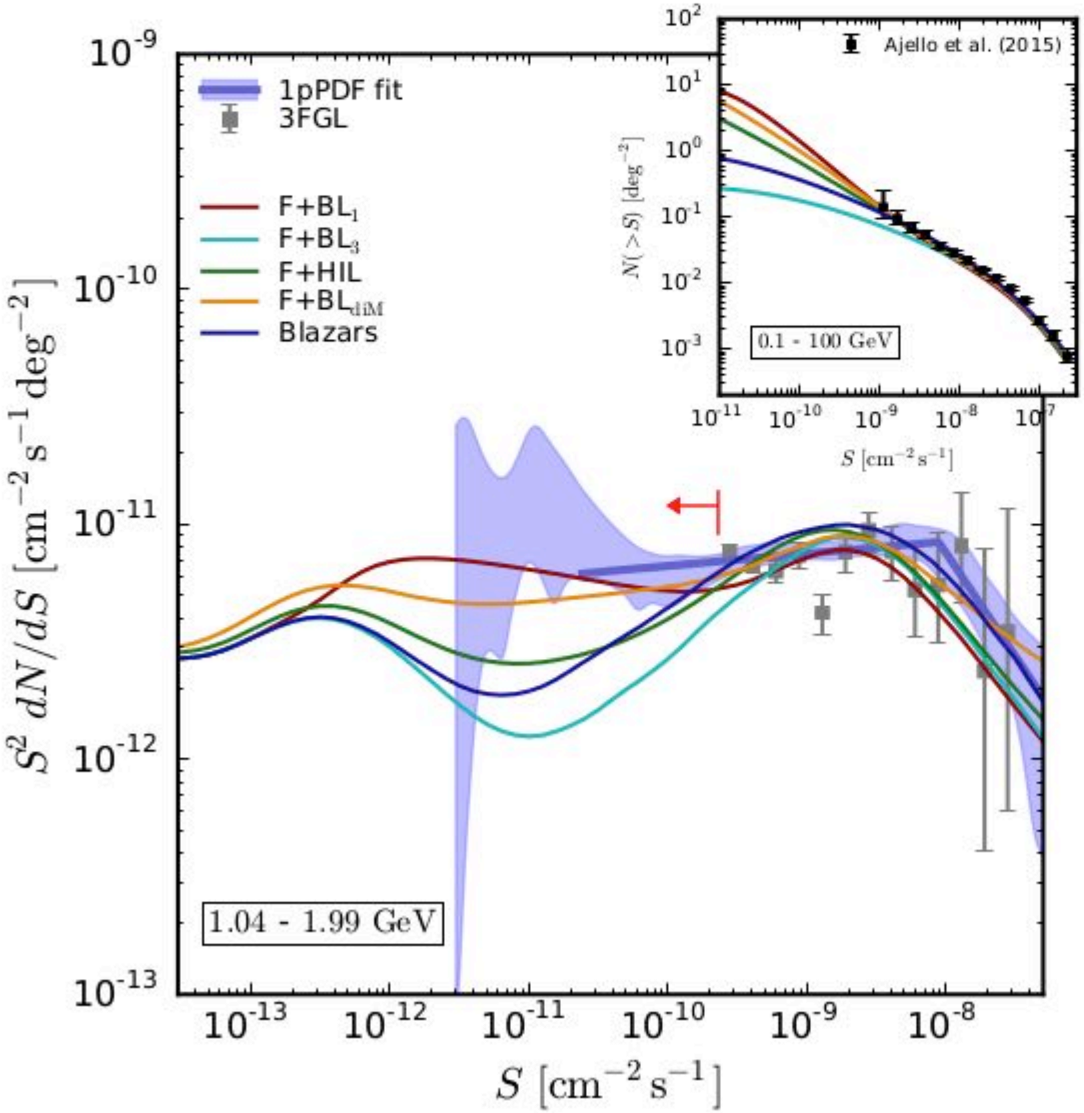
that the $\mathrm{d}N/\mathrm{d}S$ distribution
escribed with a power-law of
flux of $\sim 2 \times 10^{-11}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$,
er of magnitude. The overall
k at $2.1^{+1.0}_{-1.3} \times 10^{-8}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.
ardens to $n_2 = 1.97 \pm 0.03$ for
S distribution is constrained
high-latitude gamma-ray sky
urces, $\sim$69% diffuse Galactic



$$N = 4\pi \int_{S_{sens}}^{S_{thr}} dS\, \frac{dN}{dS} \simeq 20,000$$

What can we learn from 1pPDF?

Zechlin, Cuoco, Donato, Fornengo, MR, arXiv:1605.04256



The study of the **1-point** and **2-point statistics** of Fermi-LAT maps (combined with gravitational tracers) can provide important insights on the **unresolved γ-ray sky**.

Thank you!