Correlations in the anisotropic dark-matter sky

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We look for a source which is:

- faint

I will focus on canonical WIMPs and on multi-wavelength extragalactic signals

Naively:

Go for a deep survey of most promising targets

We look for a source which is:

- faint
- very numerous

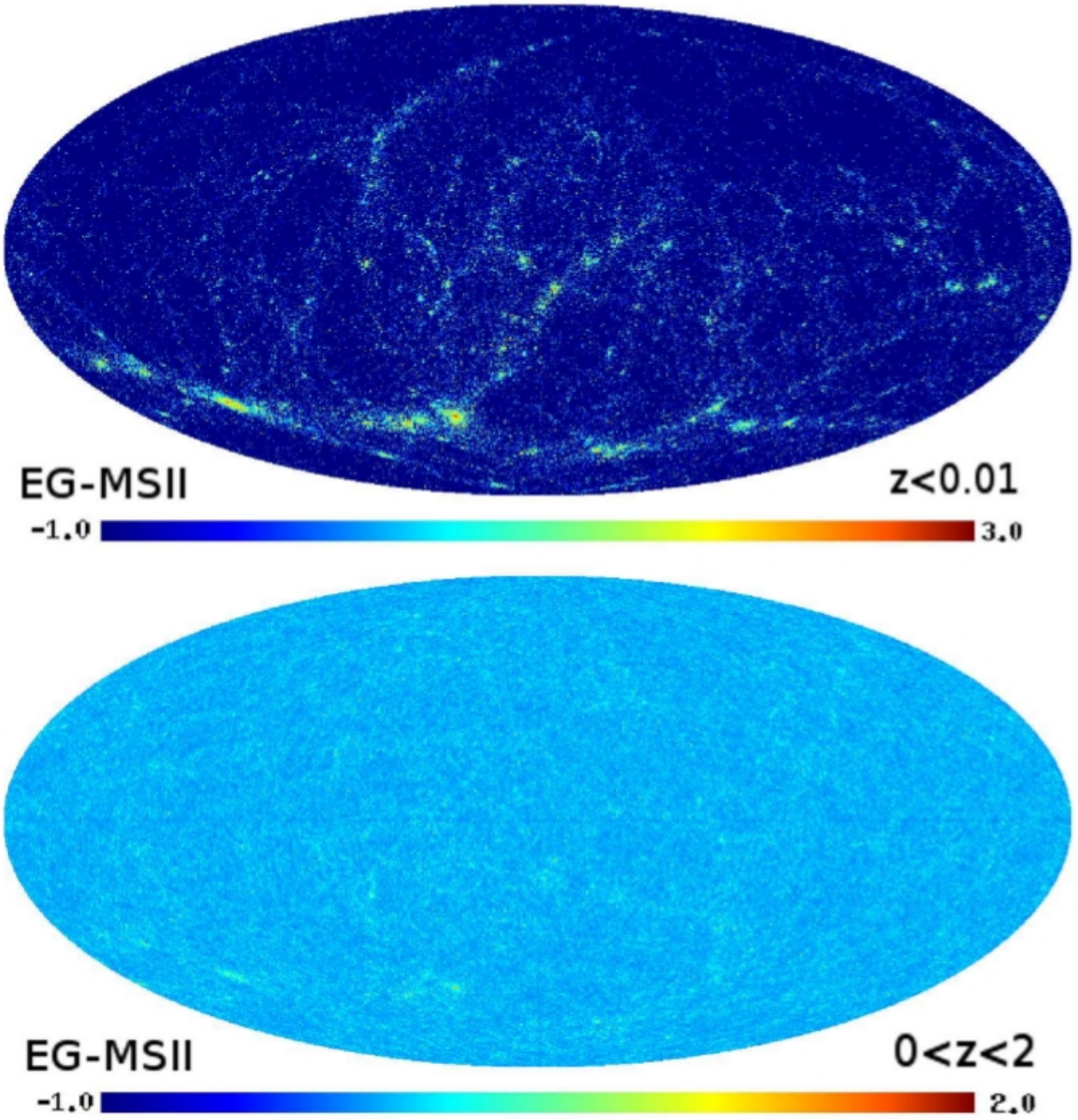
  (any luminous source is embedded in a DM halo)

I will focus on canonical WIMPs and on multi-wavelength extragalactic signals

DM sources can affect the statistics of photons across the sky (even in the case they are too dim to be individually detected)

→ Statistical correlations

Extragalactic γ-ray background



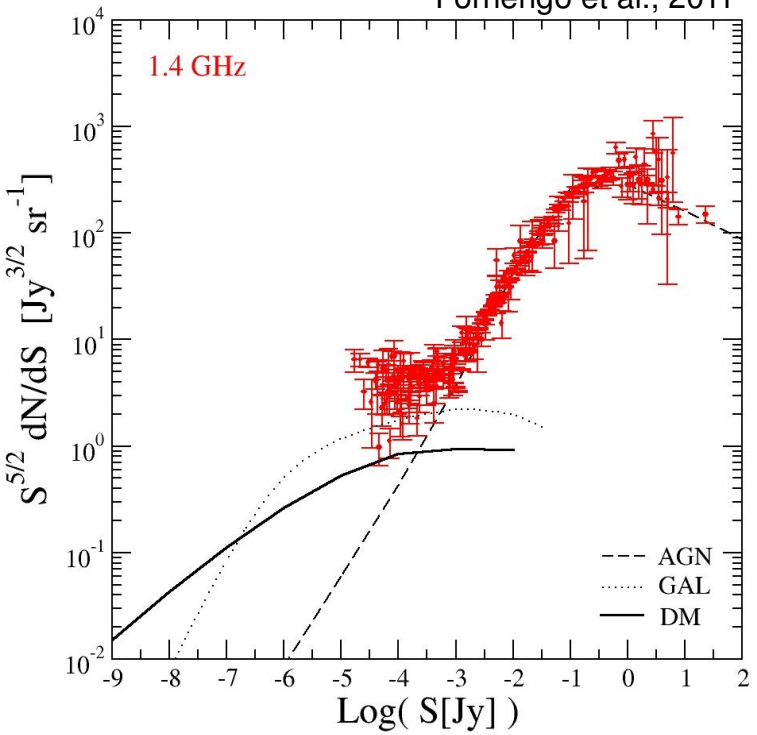
Fornasa et al., 2013

1-point correlation

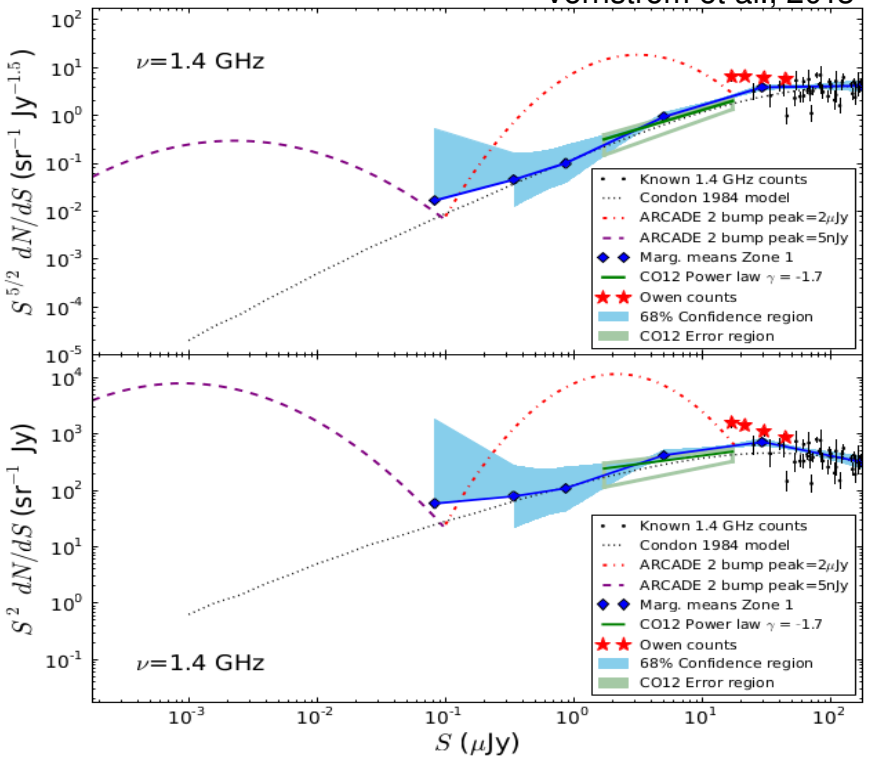
(also called P(D) distribution or photon/pixel counts)

It constrains the source number counts below the detection threshold.

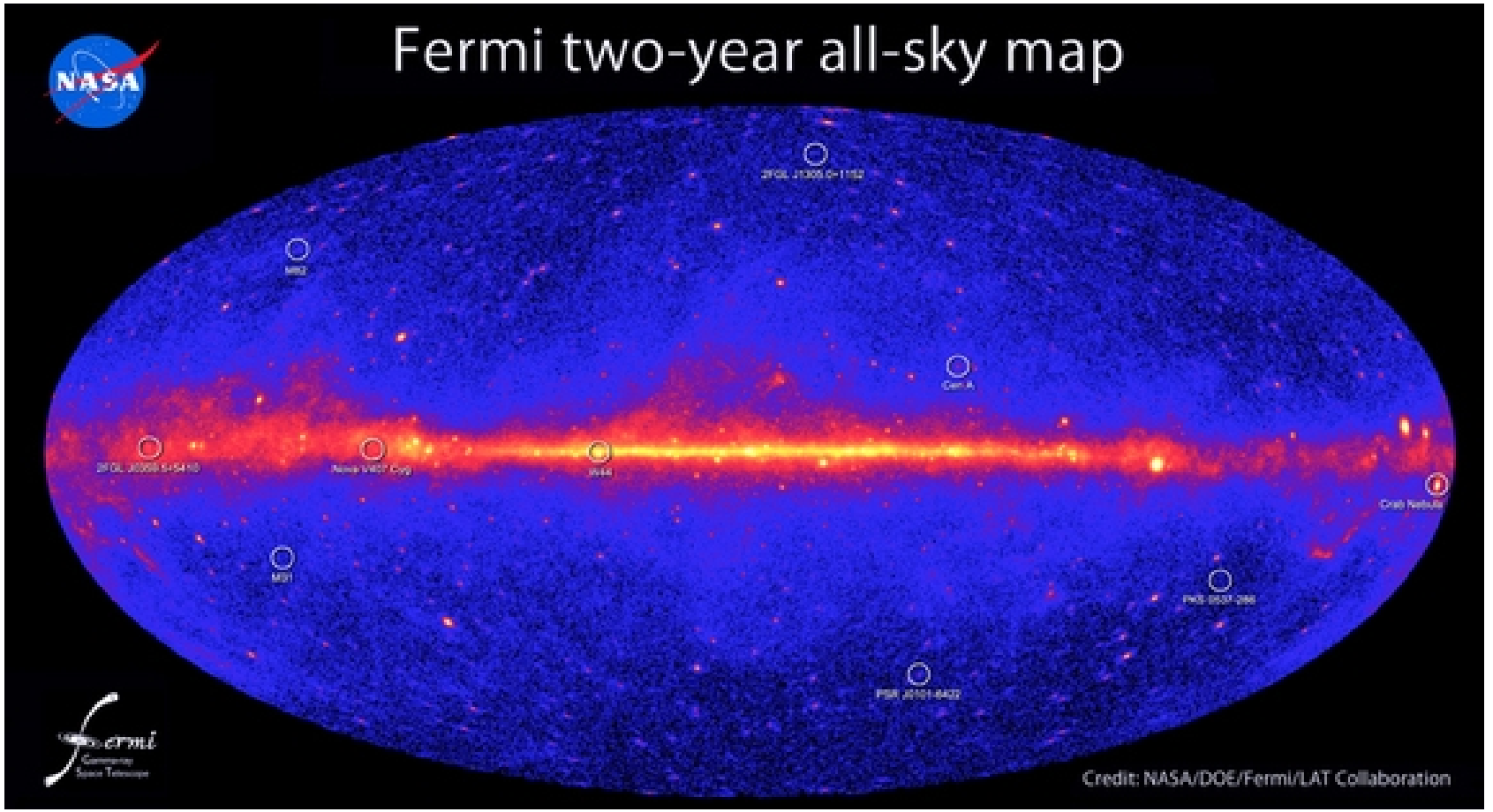
Fornengo et al., 2011



Vernstrom et al., 2013

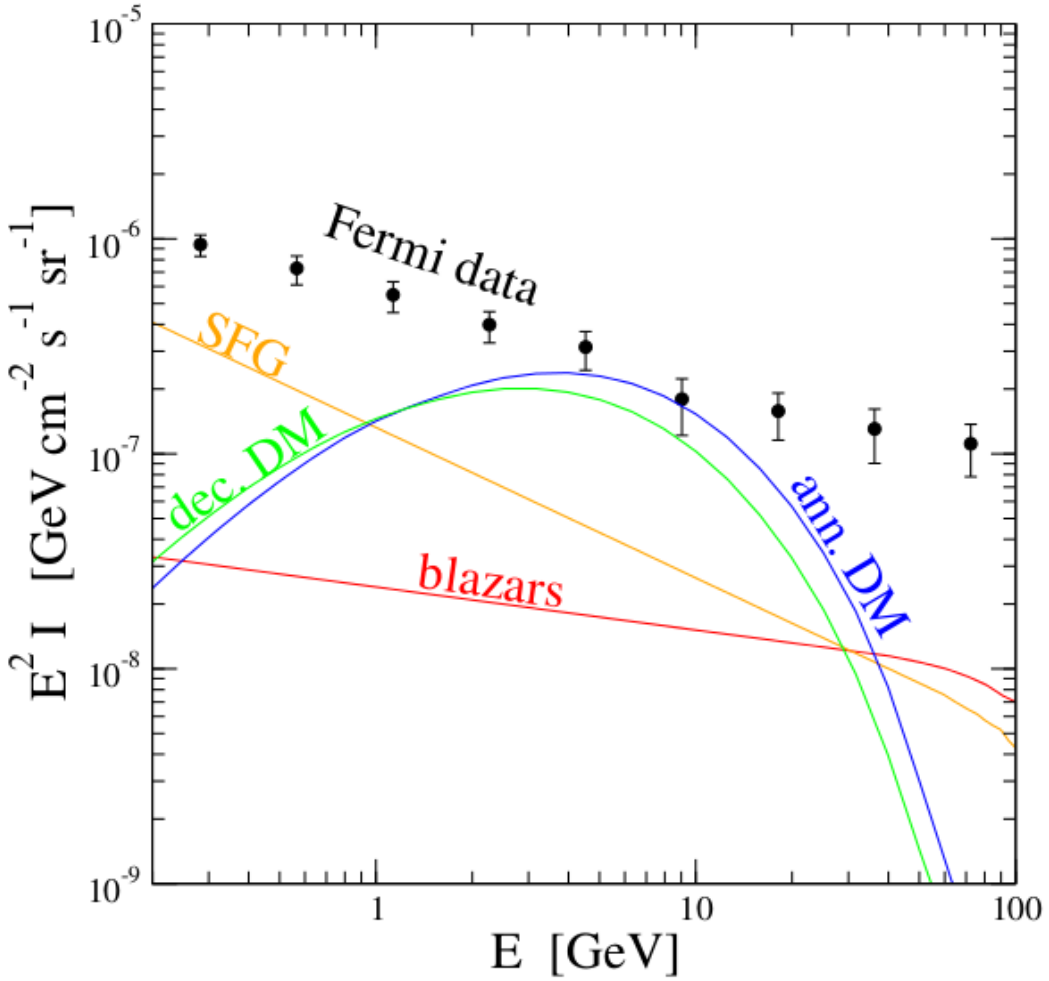


Extragalactic γ-ray background



What's "wrong" with γ-rays alone?

Example are shown for a typical WIMP model with an interaction rate such that the EGB is saturated in a given energy range.



$b\text{-}\bar{b}$ final state

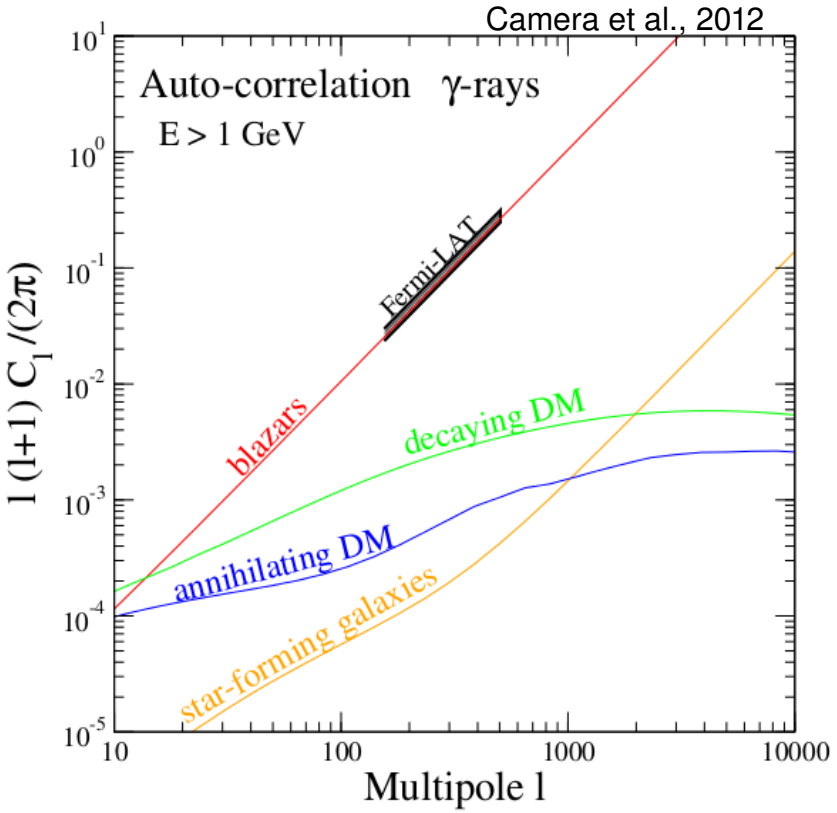
M_χ=100 GeV (annihilating)

M_χ=200 GeV (decaying)

Blazars model from (Harding & Abazajian, 2012)

SFG model from (Ackermann et al. 2012)

What's "wrong" with γ-rays alone?

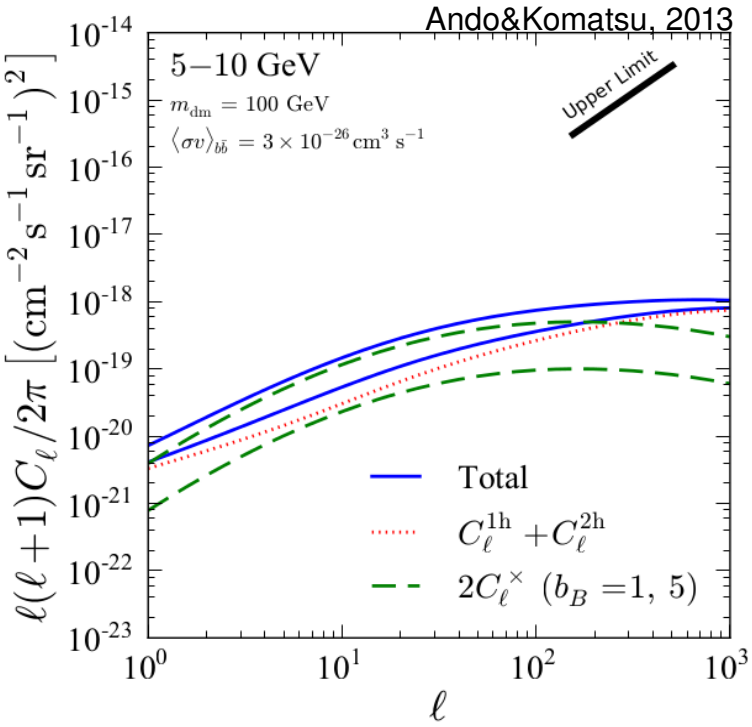


CURRENT PICTURE

Featureless EGB

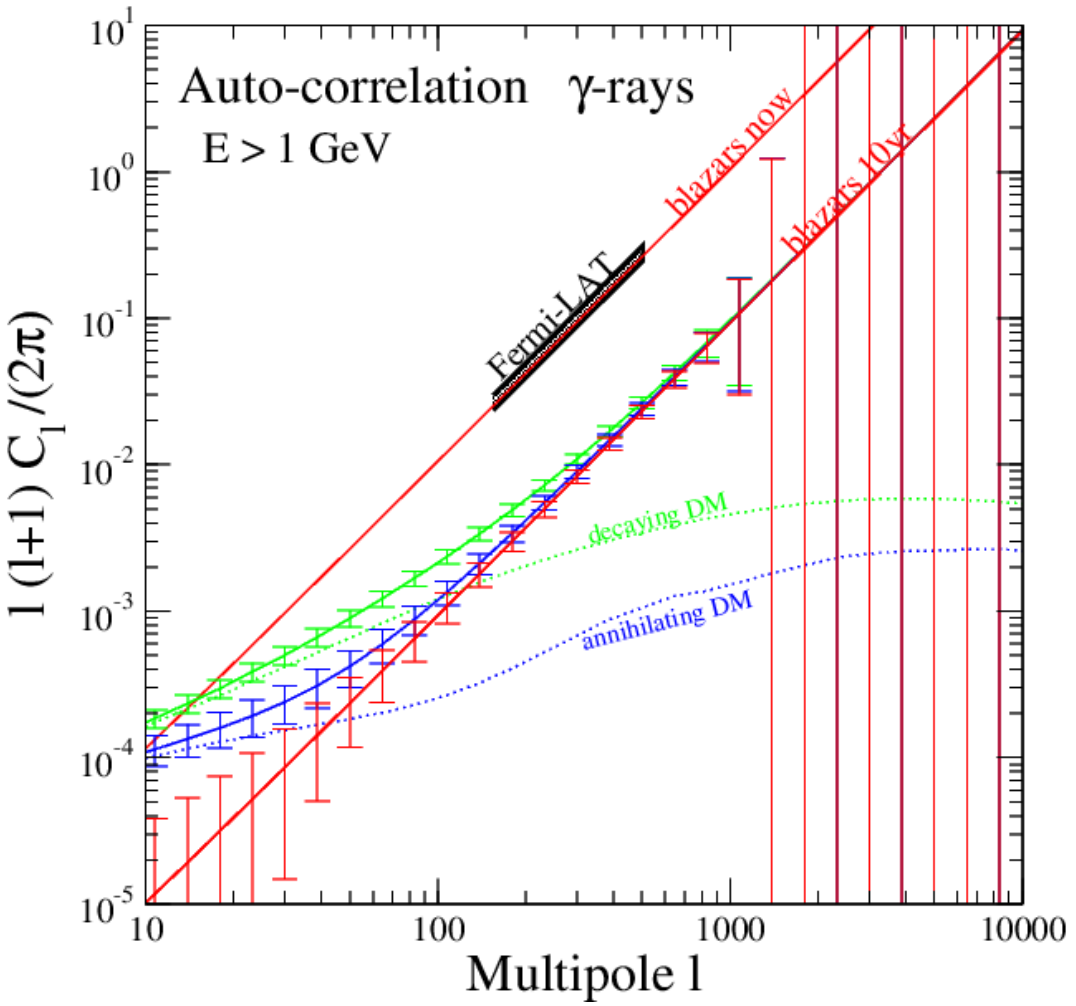
and

anisotropies dominated by blazars



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

What's "wrong" with γ-rays alone?



NEAR FUTURE

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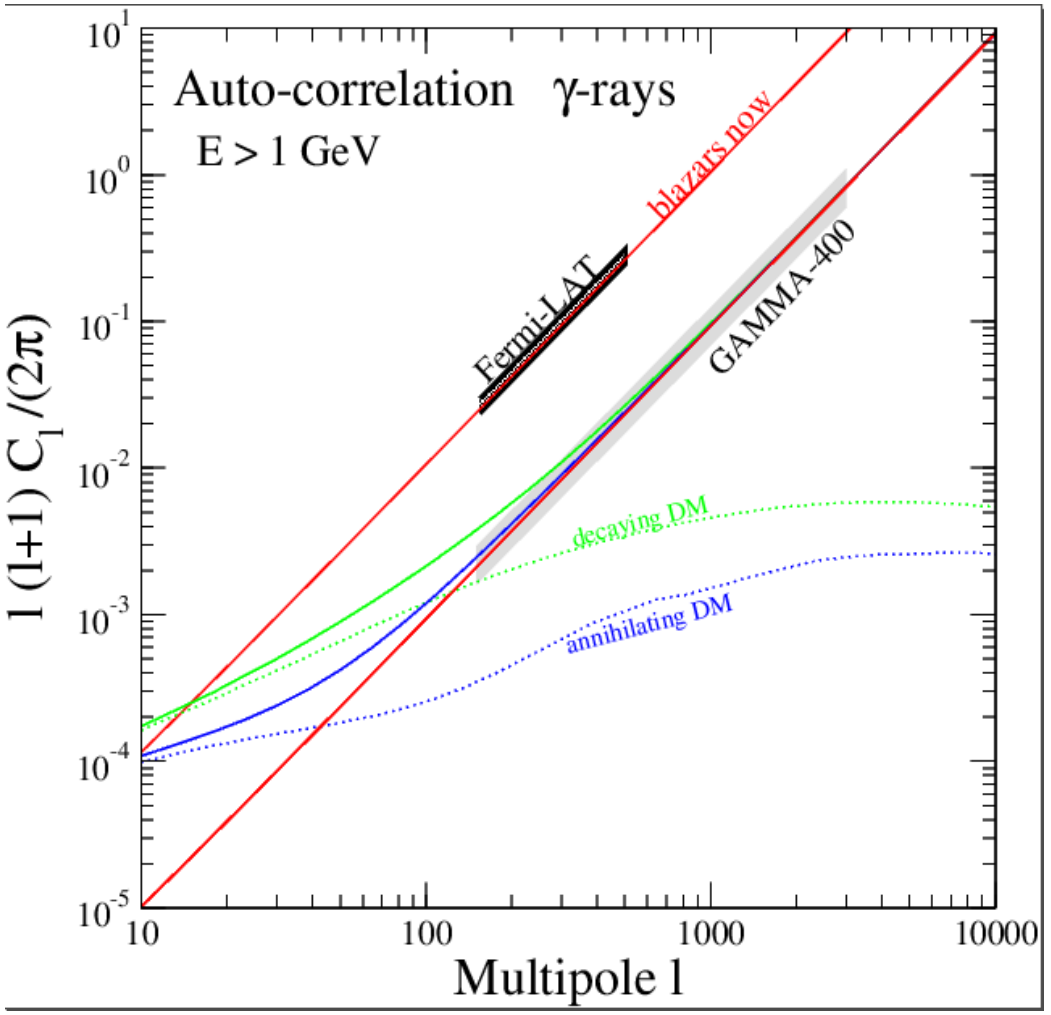
What's "wrong" with γ-rays alone?



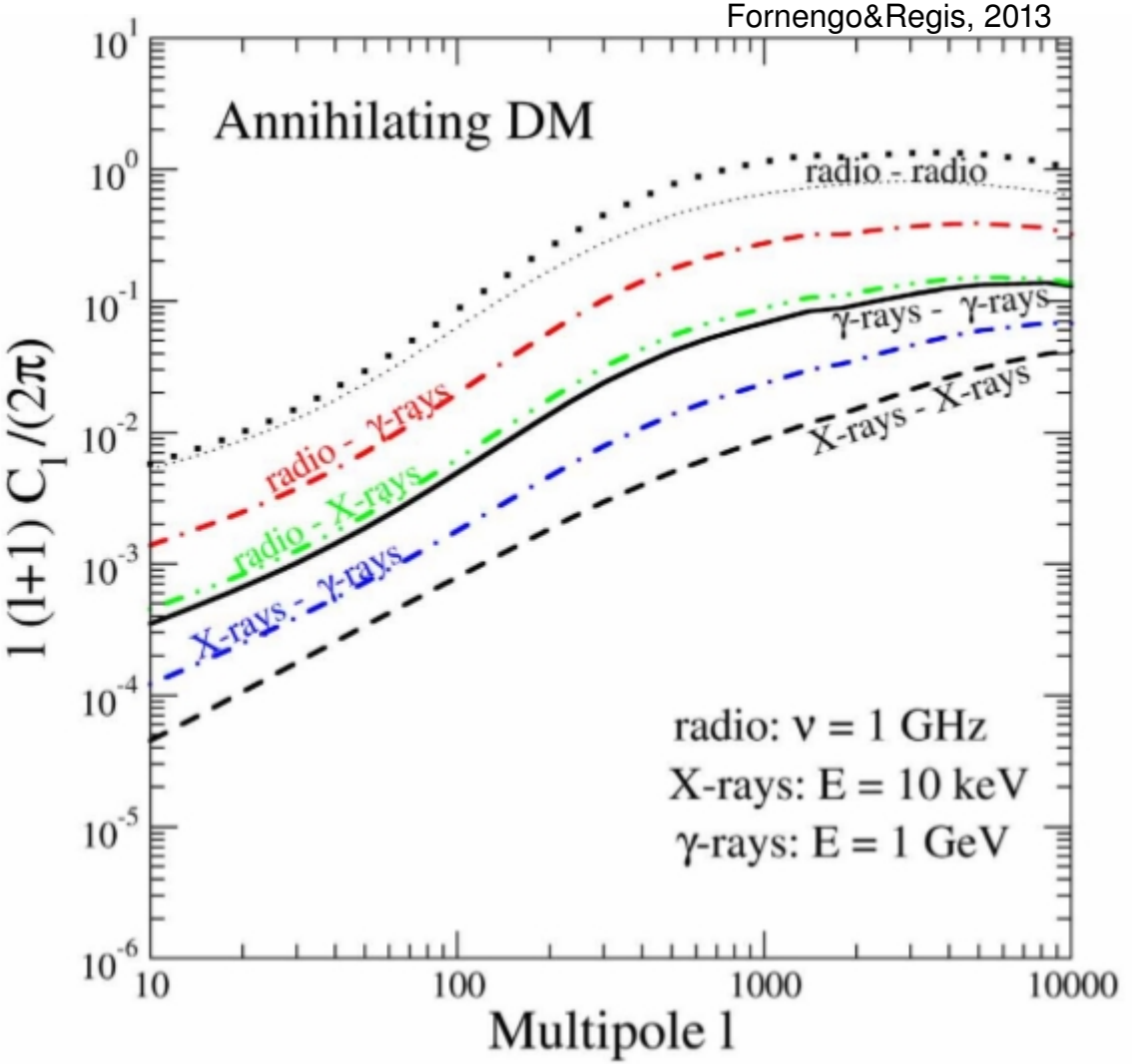
NEAR FUTURE

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

We probably need to go beyond and use something more than γ-rays alone

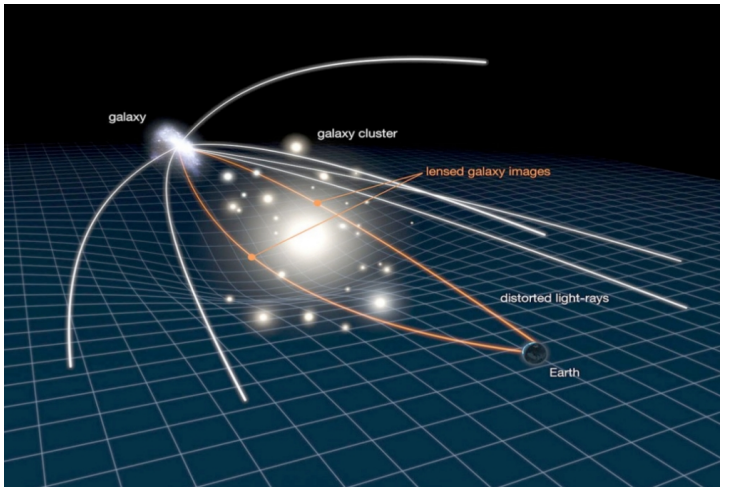
Multi-wavelength approach

Fornengo&Regis, 2013



Correlation with gravitational lensing

Both gamma-rays from DM and lensing signals are set by the (dark) matter density.



The lensing map could be the filter we need to isolate a **signal** which is there but is hidden by a large "noise".

Angular power spectrum

ISOTROPIC INTENSITY $\langle I_g \rangle = \int d\chi \; W(\chi)$

W = window function

χ = comoving distance

k = wavenumber, Limber ap$k = \ell/\chi$

f_g is (related to) the density field of emission

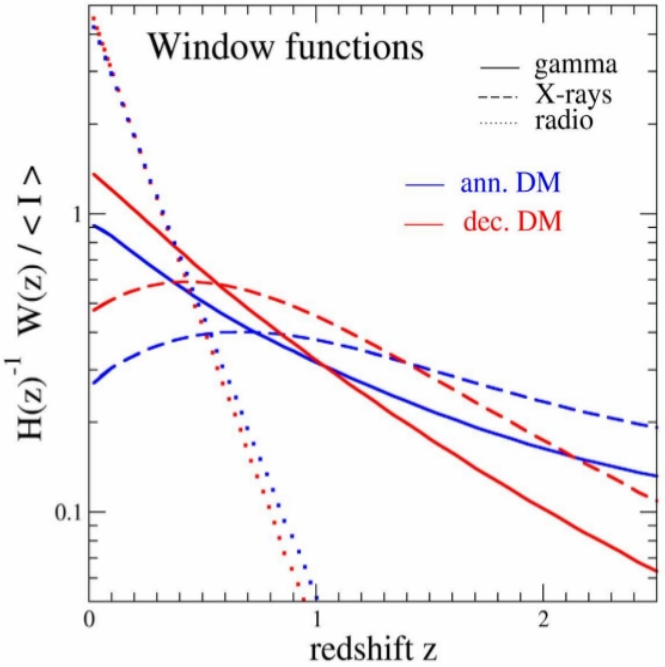
3D POWER SPECTRUM

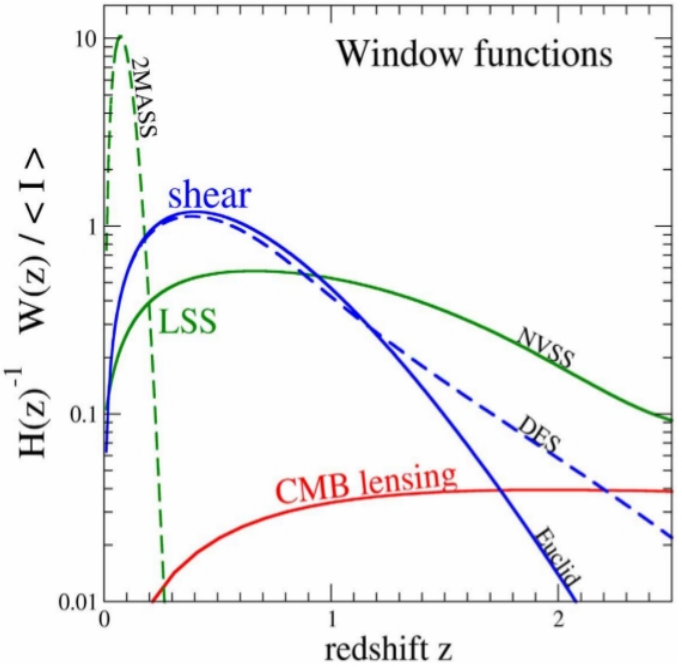
$$\langle \hat{f}_{g_i}(\chi, \boldsymbol{k}) \hat{f}^*_{g_j}(\chi', \boldsymbol{k}') \rangle = (2\pi)^3 \delta^3(\boldsymbol{k} - \boldsymbol{k}') P_{ij}(k, \chi, \chi')$$

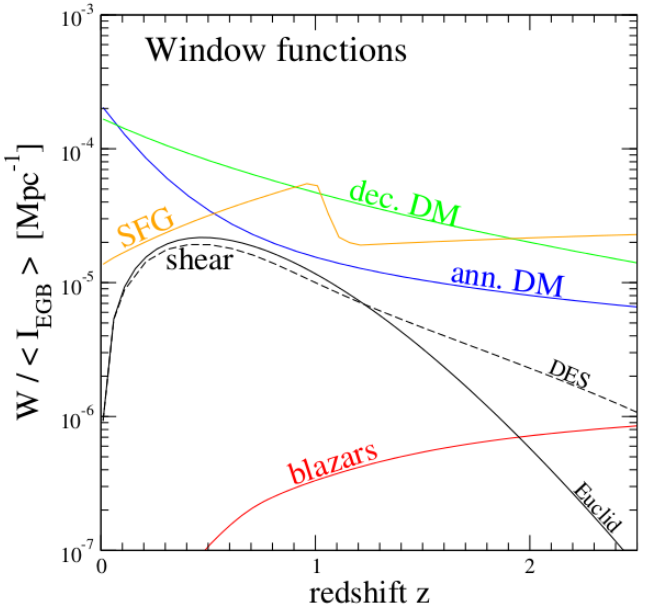
TWO-POINT ANGULAR POWER SPECTRUM

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

APS ingredients / window function

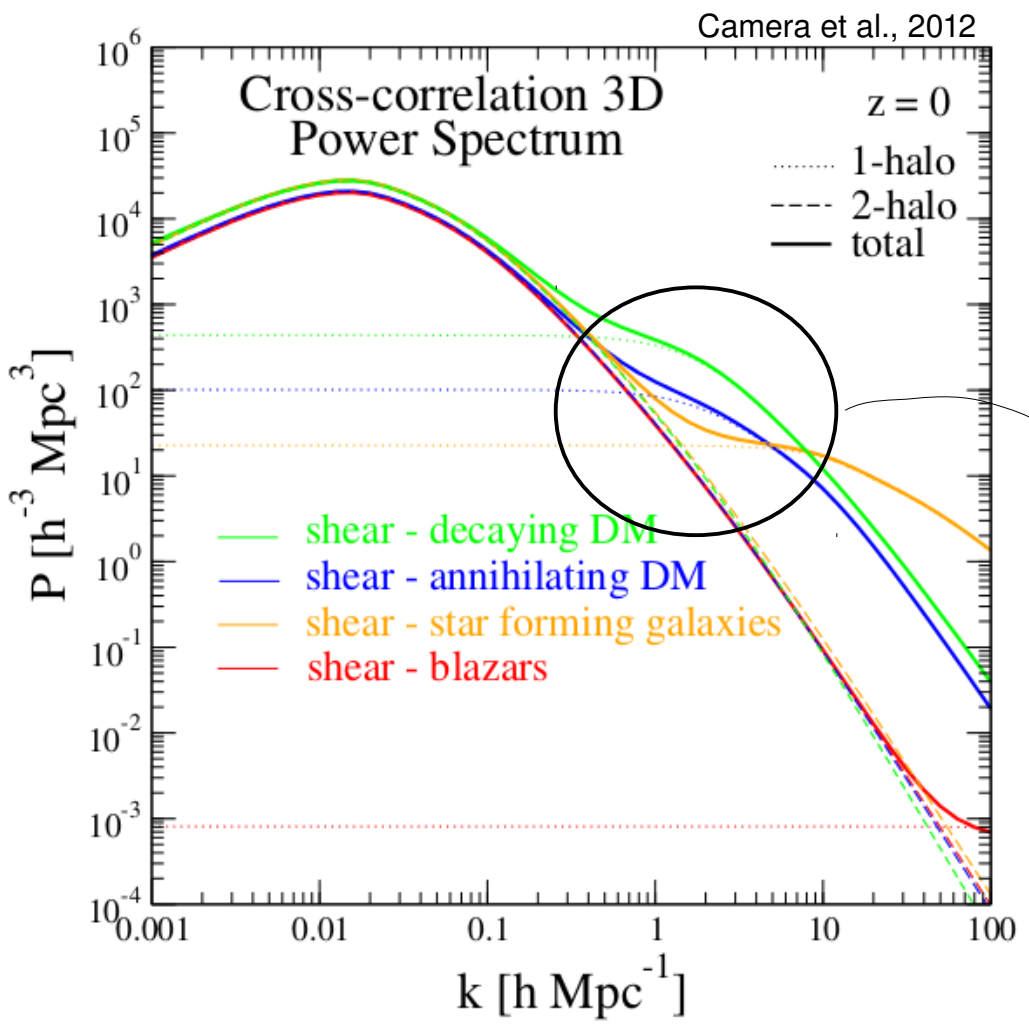


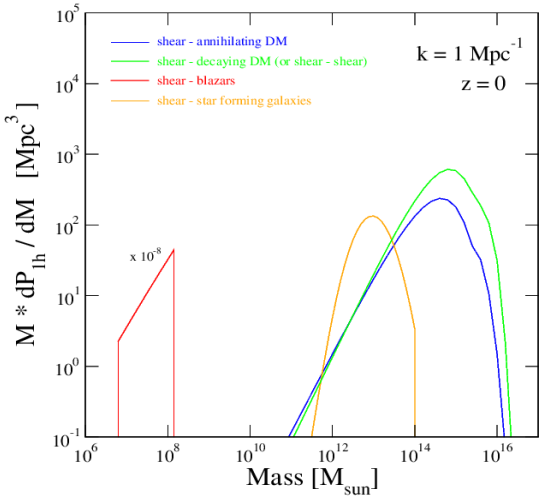




The peak of the WIMP **window function** is at lower z
than for astrophysical sources.
A tomographic approach looks promising.

APS ingredients / 3D power spectrum





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

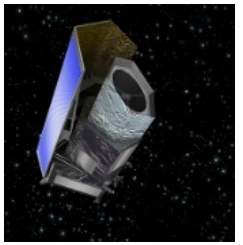
The WIMP **power spectrum** has more power at intermediate scales ($k \sim 1\text{-}10\ h\ Mpc^{-1}$).

We can use the angular information!

(not possible with the autocorrelation alone due to the blazars domination)

Experiments

Large sky coverage



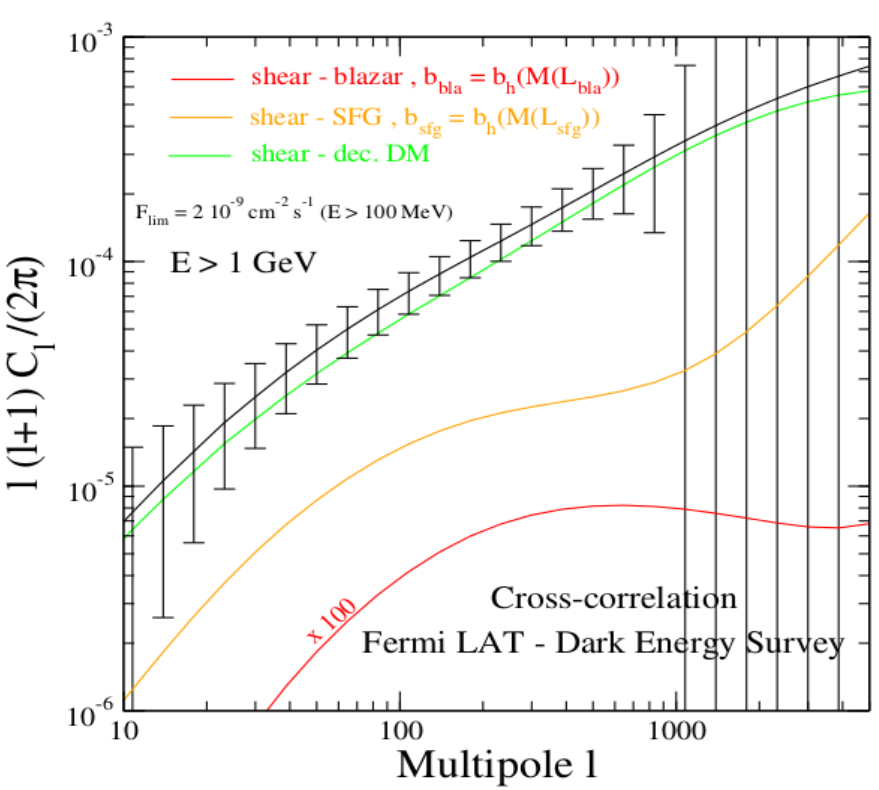
	FERMI-LAT	Dark Energy Survey	EUCLID
	Gamma-ray telescope	Photometric redshift survey	Photometric/spectroscopic survey
	0.3 < E/GeV < 300	0.3 < z < 1.5	0 < z < 2.5
Sensitivity and angular resolution	~10^{-9}cm^{-2}s^{-1} 0.1deg @ HE	13.3 gal / arcmin^2	30 gal / arcmin^2
Sky coverage	66%	5000 sq. degree	20000 sq. degree
Operational phase	2008-2018	2012-2017	2020-2026

Smaller sky coverage

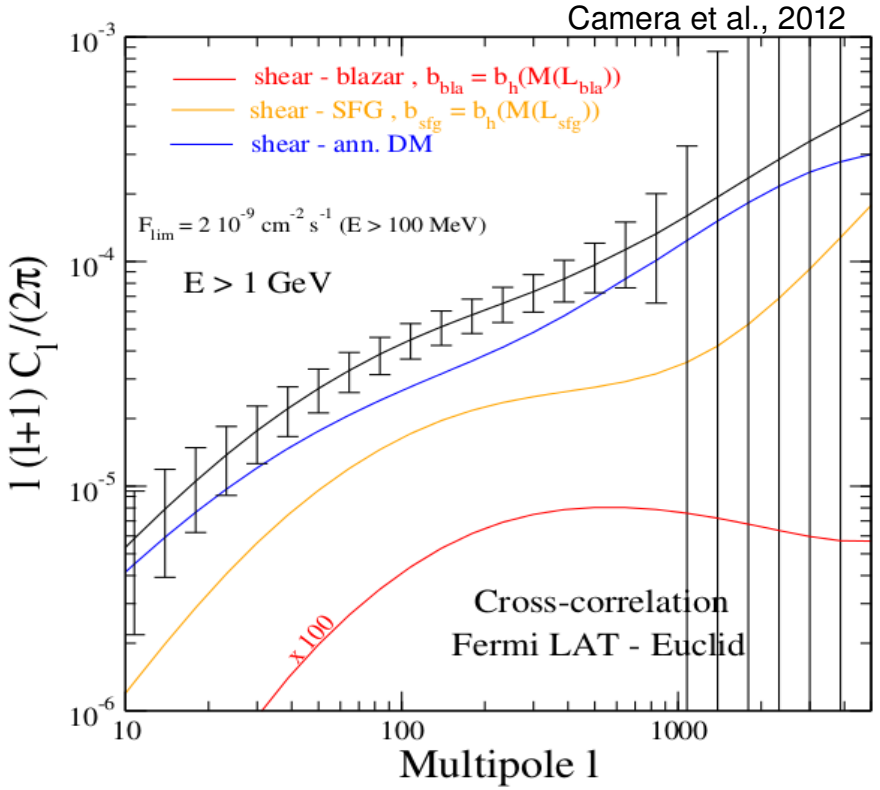
CFHTLenS (154 square degree), data available

CTA (few square degree): can allow to explore higher multipoles

Forecasts



Camera et al., 2012



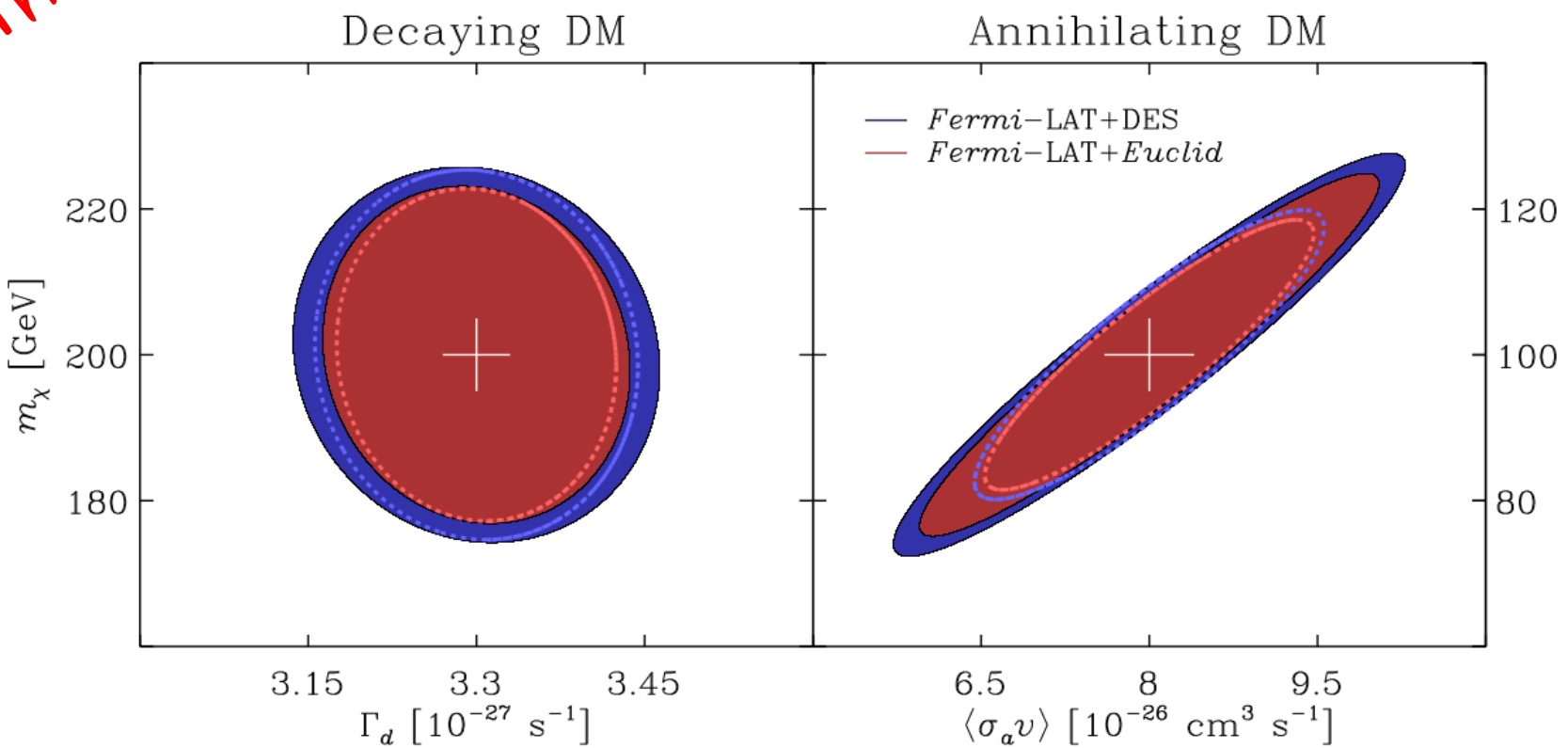
A WIMP model, which is undetectable with gamma-rays alone, can be instead clearly **detected** through the **correlation with cosmic shear**.

This test can be performed in the forthcoming future (DES + Fermi LAT).

Fisher Matrix forecasts

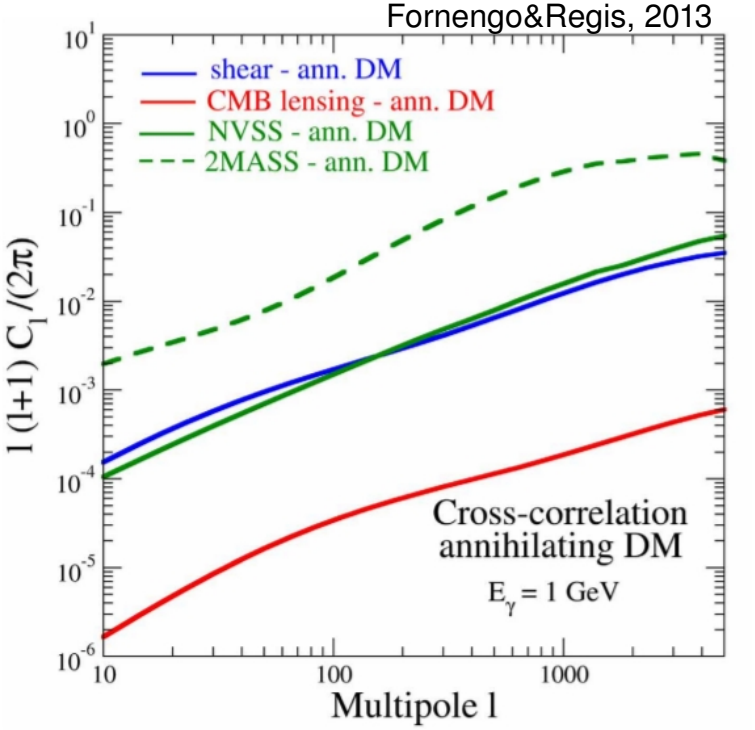
Tomographic approach (for cosmic shear observations) and **energy binning** (for γ-ray observations) make the method much more powerful

Preliminary



Cross-correlation with LSS

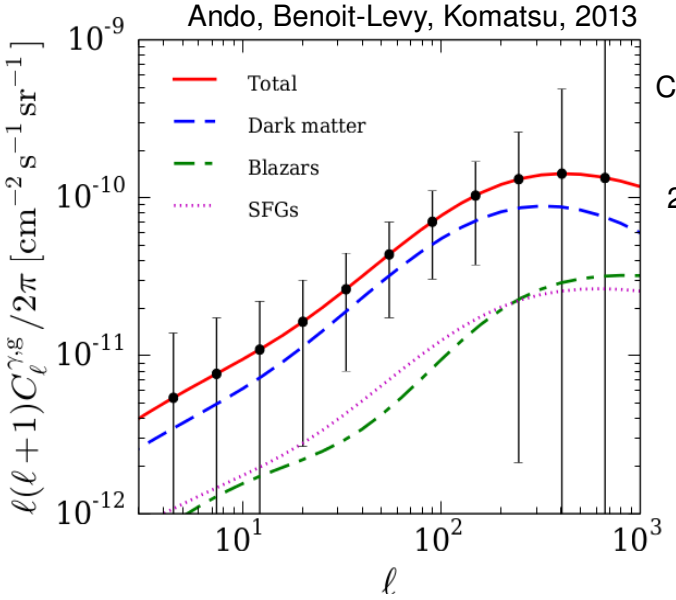
Fornengo&Regis, 2013



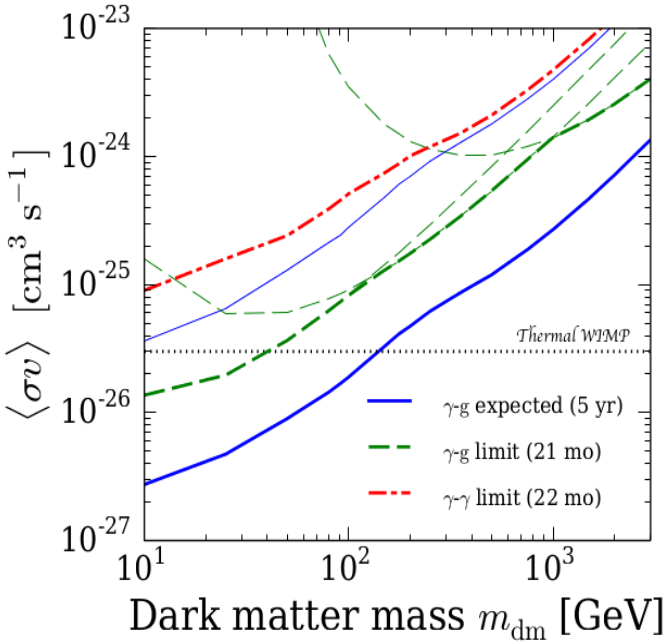
Possibility of **tomographic approach** using different galaxy surveys.

Part of the correlation (1-halo term) might be lost wrt the lensing case.

Ando, Benoit-Levy, Komatsu, 2013



Cross-correlations of gamma-rays from DM with 2MASS galaxies



Conclusions

DM halos are faint but they are a lot!

→ Look at statistical correlations

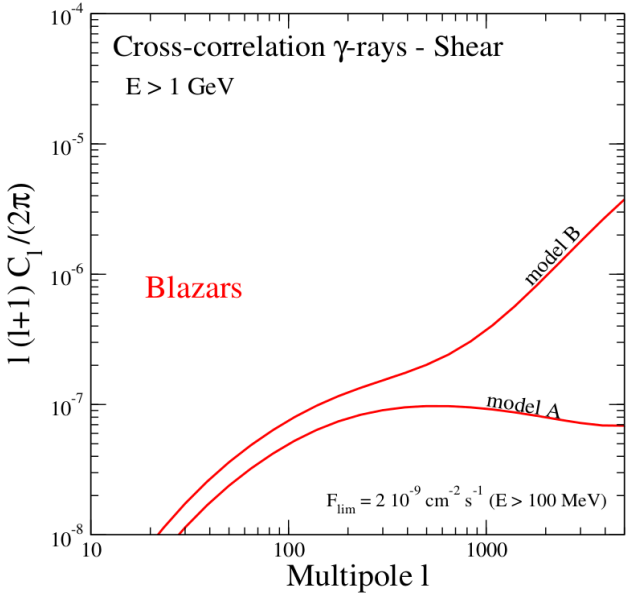
Detection prospects for the extragalactic gamma-ray angular power spectrum induced by WIMPs are not very bright if we look at gamma-rays alone.

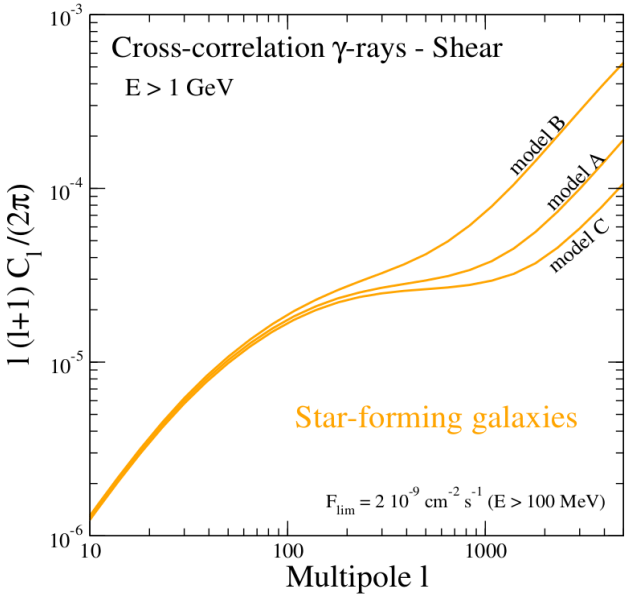
The cross-correlation of gamma-rays with gravitational probes and other wavelengths can act as a sort of filter and help to isolate a WIMP signature.

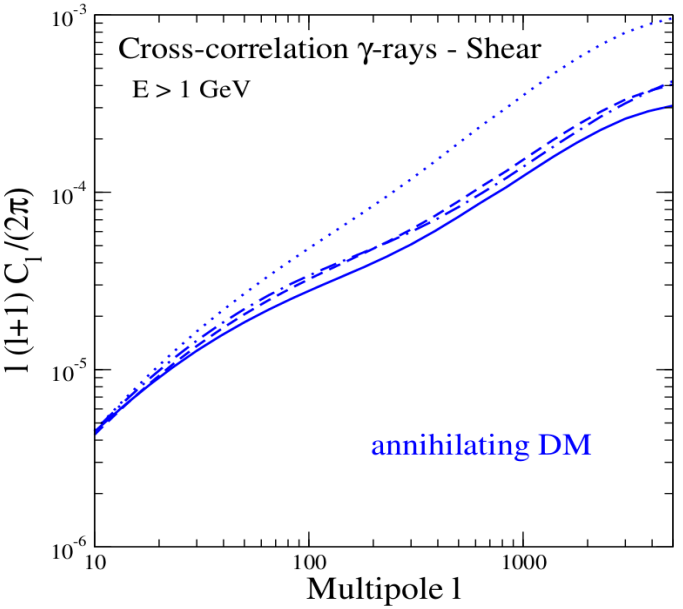
Interesting observational prospects in the near future

Backup slides

APS uncertainties



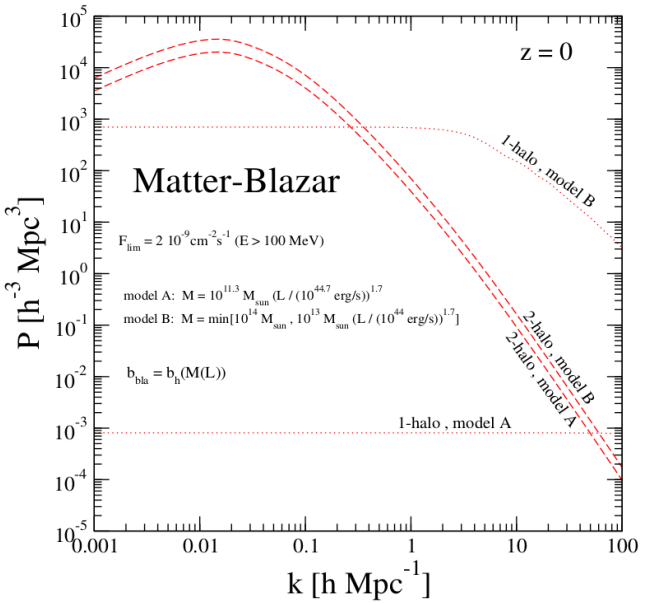


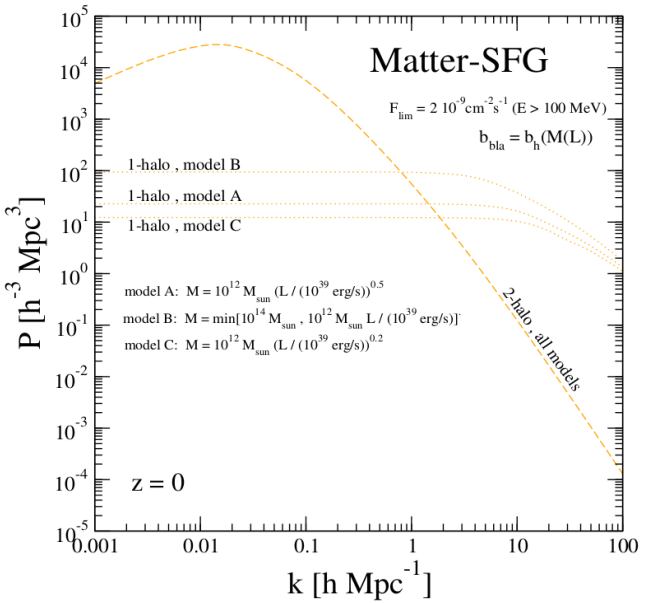


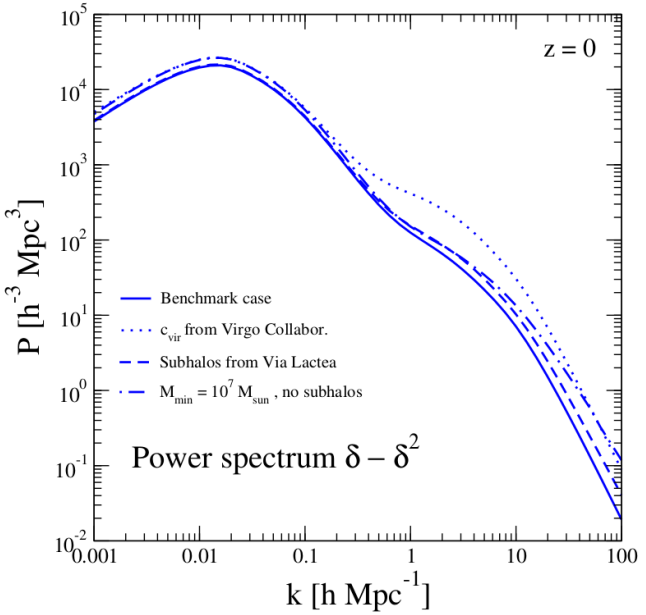
Uncertainties in the power spectrum estimate do not seem to significantly affect the possibility of detecting a WIMP signal

(provided the WIMP emission is a relevant component of the EGB)

3D PS uncertainties







The relation between **galaxy mass and gamma-ray luminosity** is the key ingredient of the 3D power spectrum of astrophysical sources.

Uncertainties are lower than in the autocorrelation case for annihilating DM.