Cross-correlations between non-gravitational and gravitational probes of particle dark-matter

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We look for a non-gravitational signal of Dark Matter.

The source we want to discover is:

- faint

Naively:

Go for a deep observations of single objects

We look for a non-gravitational signal of Dark Matter.

The source we want to discover is:

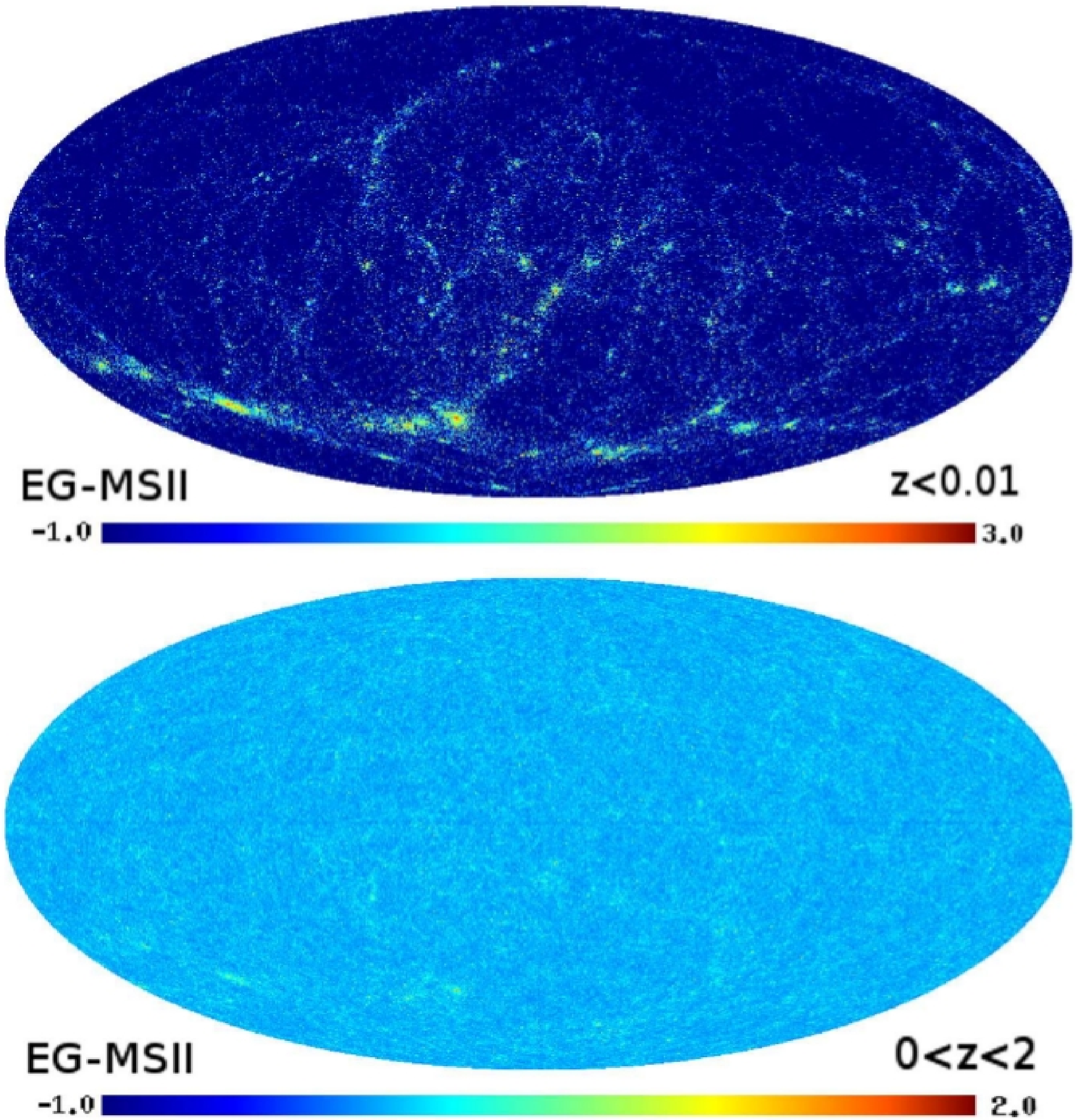
- faint
- **very numerous**

  (any luminous source is embedded in a DM halo)

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

$\longrightarrow$ Statistical correlations

Extragalactic DM background



Fornasa et al., 2013

γ-ray background from annihilating DM

The two-point angular correlation can contain a wealth of information on particle DM.

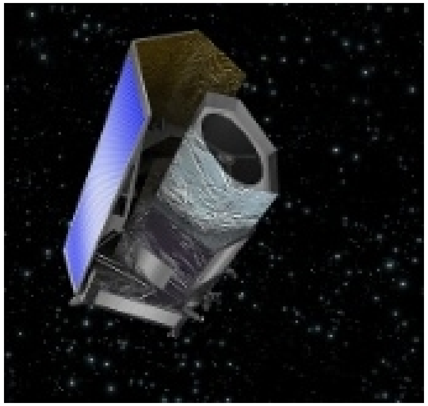
In order to separate the DM non-gravitational signal from other astrophysical emissions, a filter based on the DM properties we know (i.e. the associated **gravitational potential**) can be very helpful.

Correlation with gravitational lensing

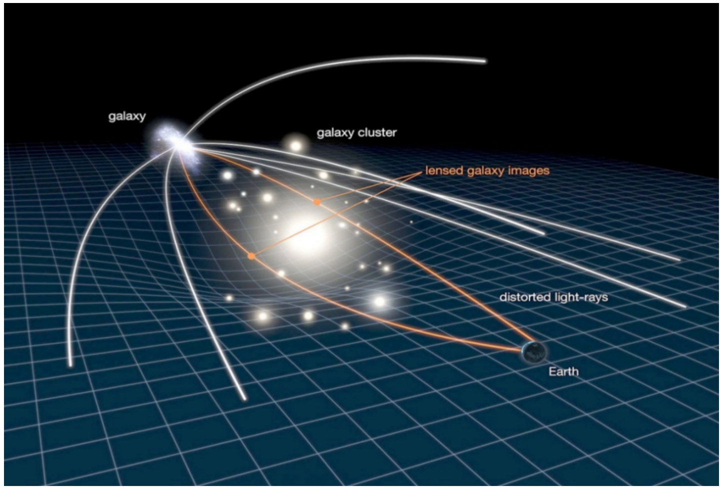
EUCLID

Photometric/spectroscopic survey

Sensitivity 30 gal / $arcmin^2$
Sky coverage 20000 sq. degree
Operational phase 2020-2026
Approximately 10 z-bins in the range $0 < z < 2.5$ with photometric scatter $\sigma_z = 0.05(1 + z)$



An astrophysical experiment but can have interesting things to say about particle physics.



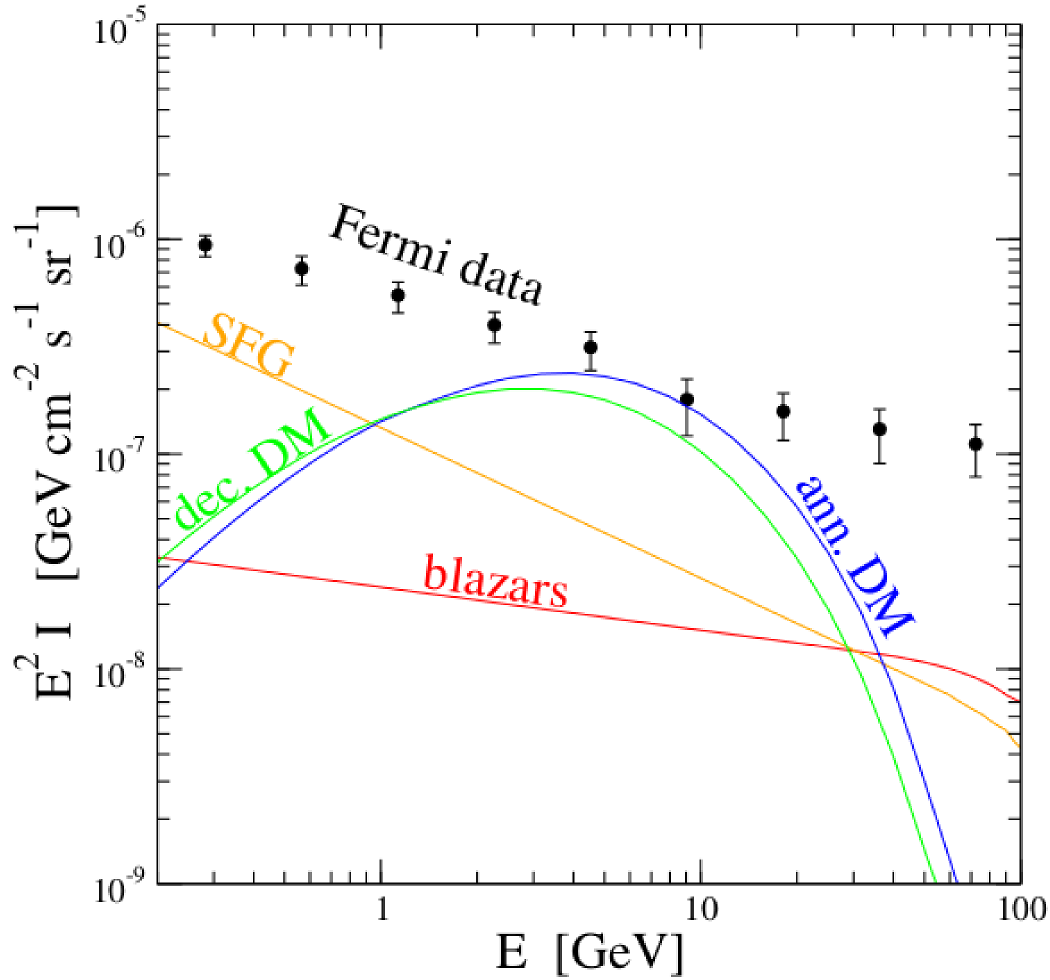
Both **electromagnetic signals from DM and lensing signals are set by the (dark) matter density**.

↓

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

What's "wrong" with γ-rays alone?

Examples are shown for a typical WIMP model with an interaction rate such that the EGB is saturated at few GeV.



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

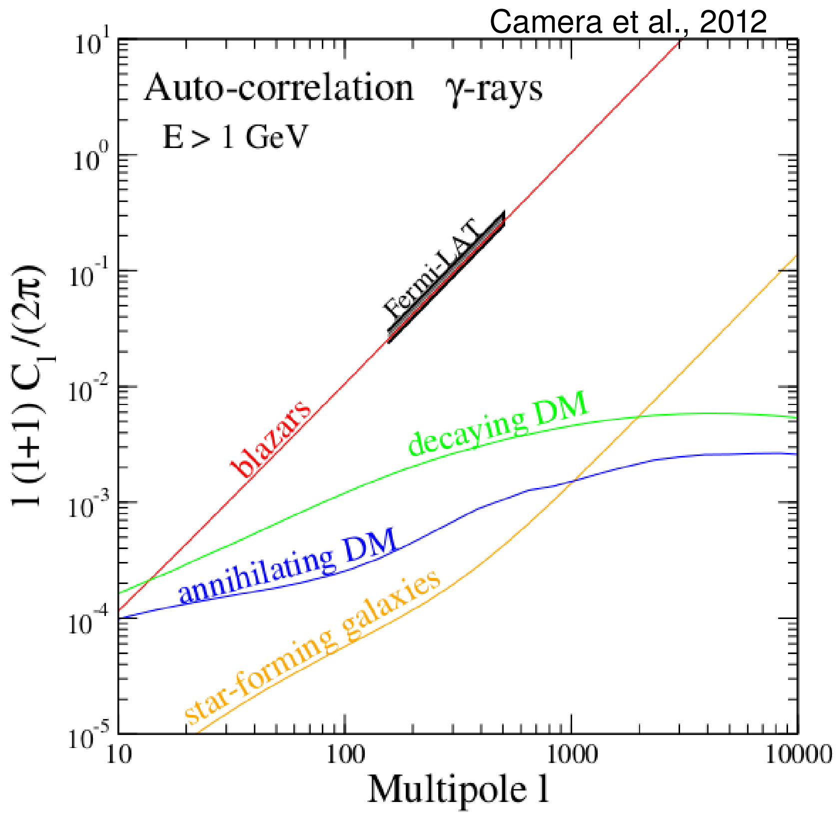
M_χ=100 GeV (annihilating)

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?

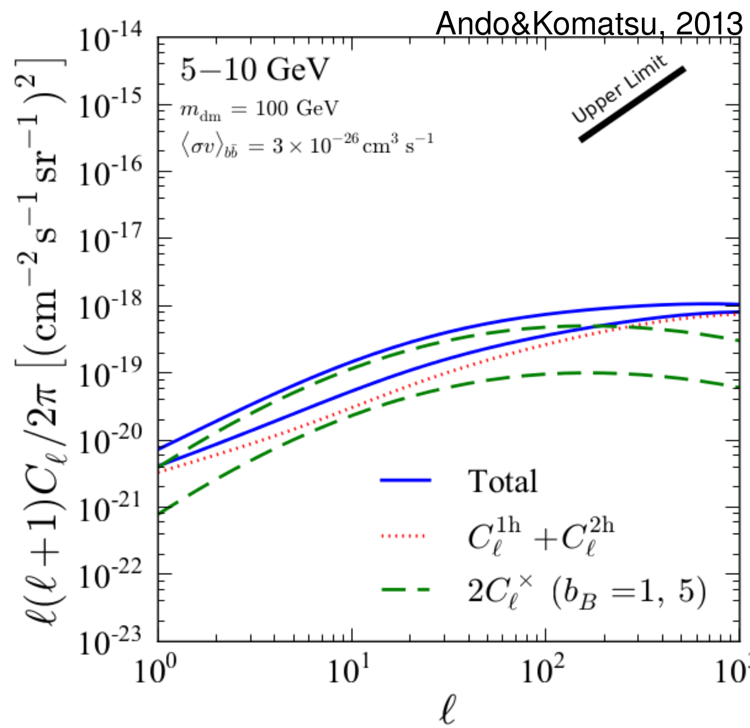


CURRENT PICTURE

Featureless EGB

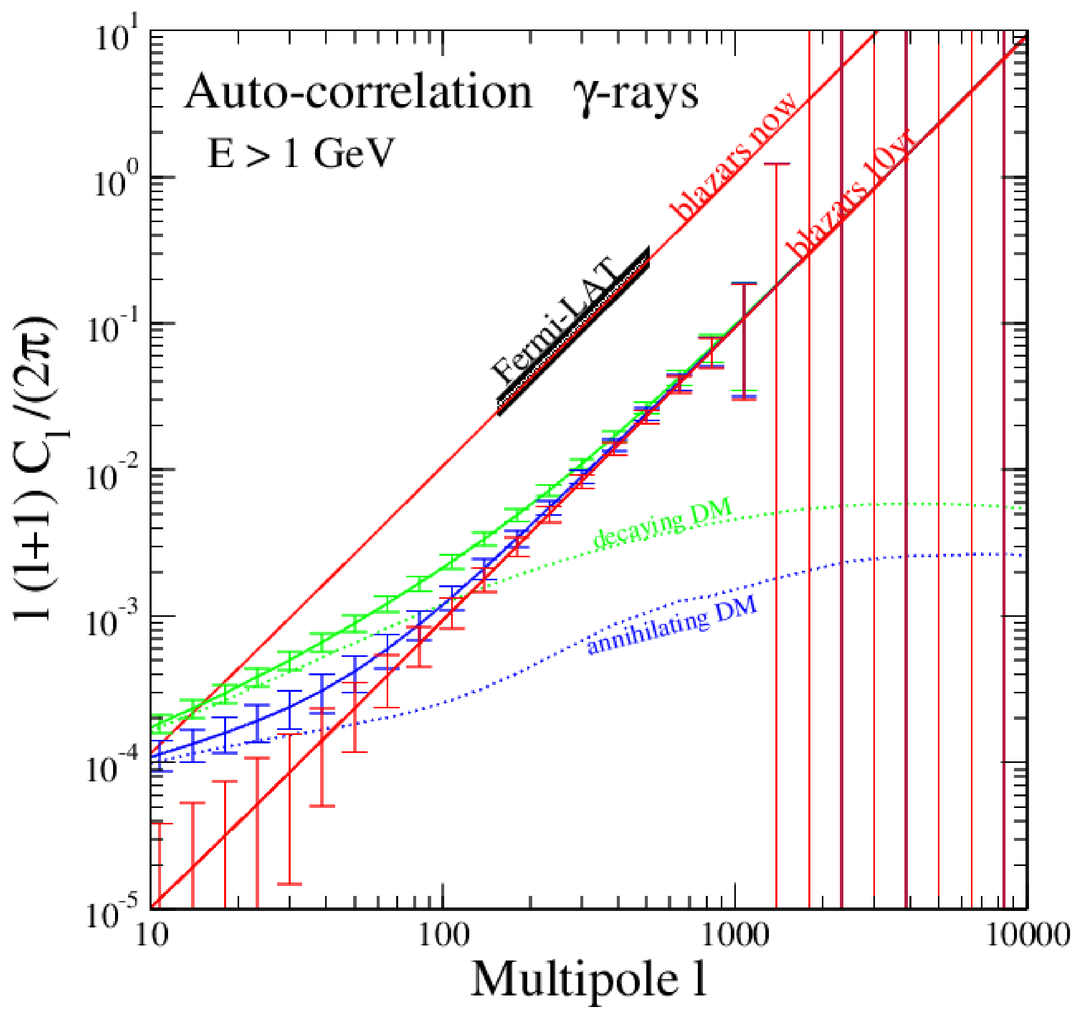
and

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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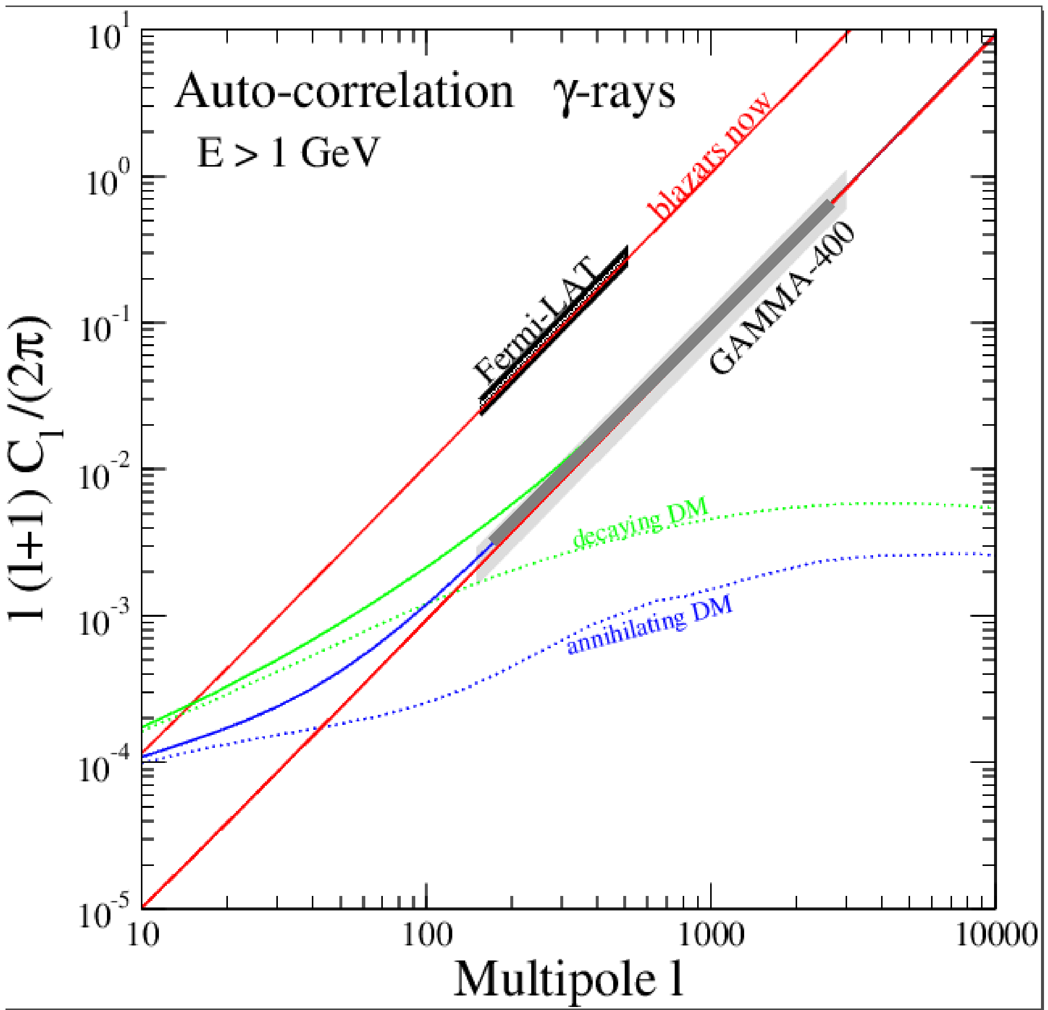
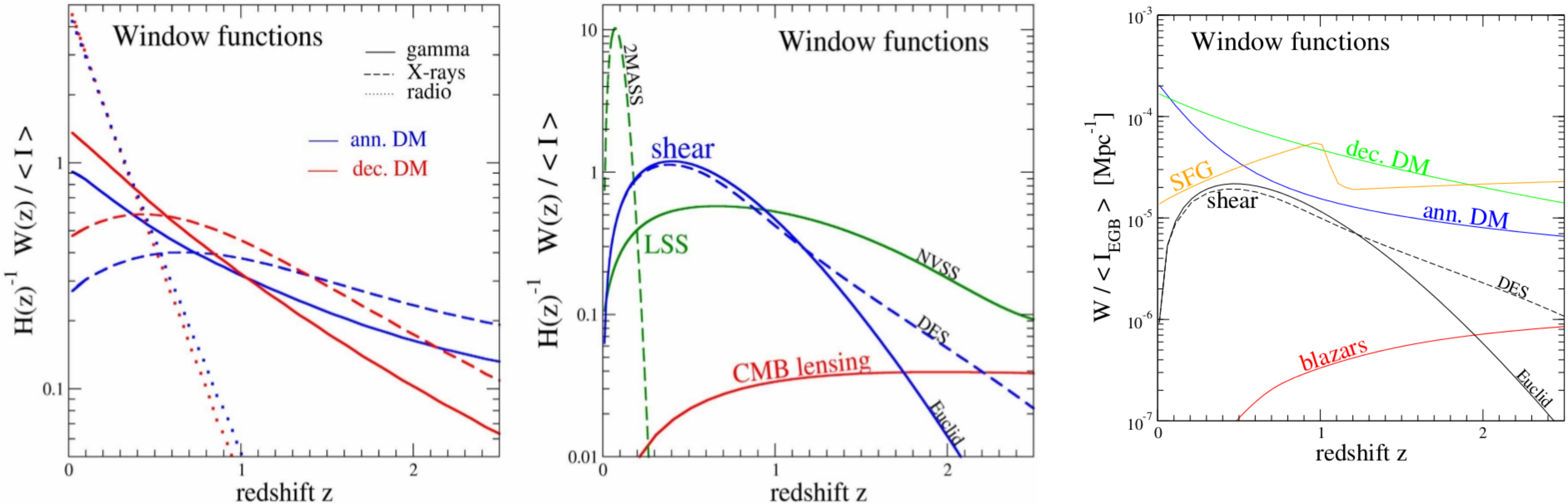


NEAR FUTURE

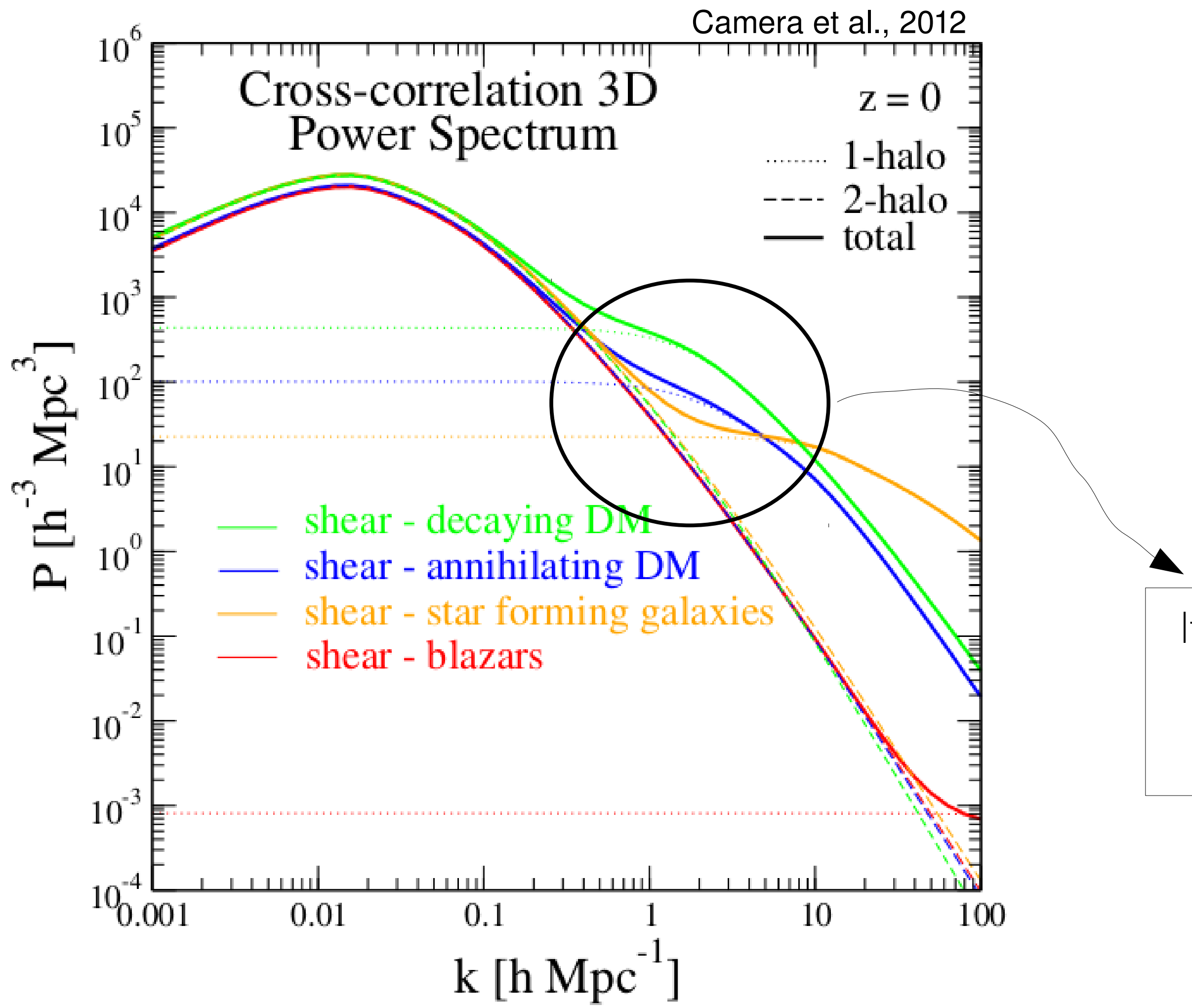
Very difficult to extract a clear WIMP signature from the extragalactic gamma-ray background alone.

APS ingredients / window function



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

APS ingredients / 3D power spectrum



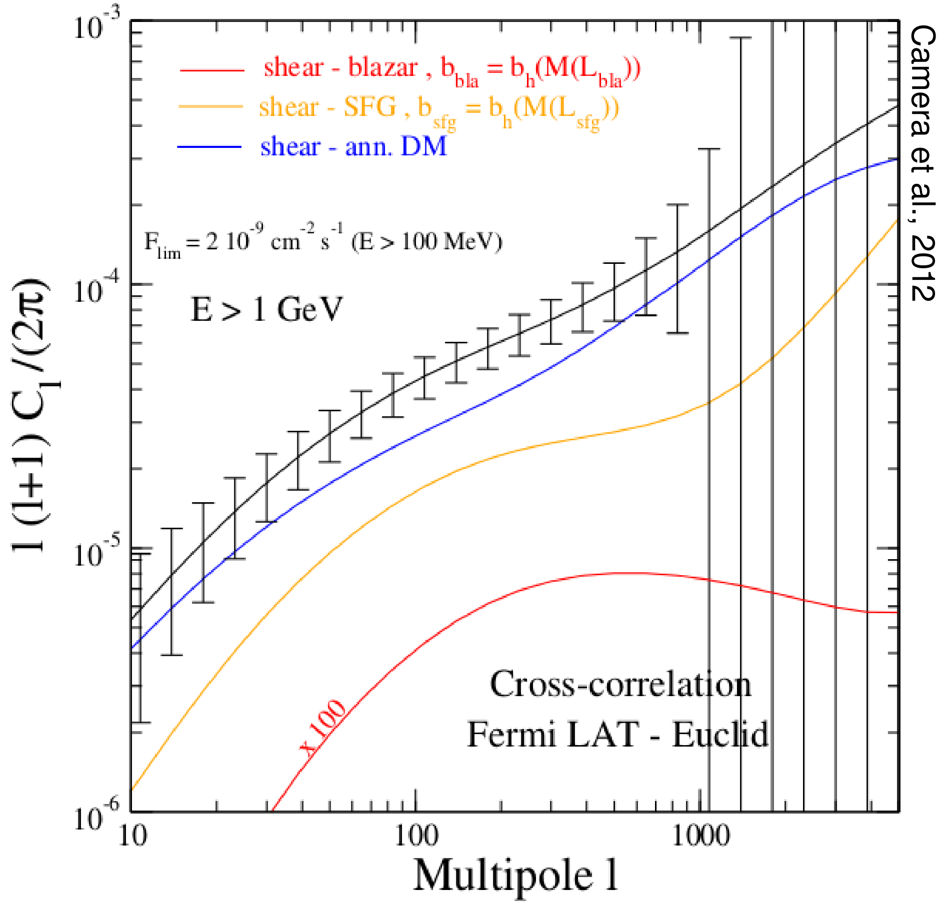
It is (roughly speaking) mapped in the multipole range 100 < l < 1000

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

We can use the angular information!

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

Forecasts



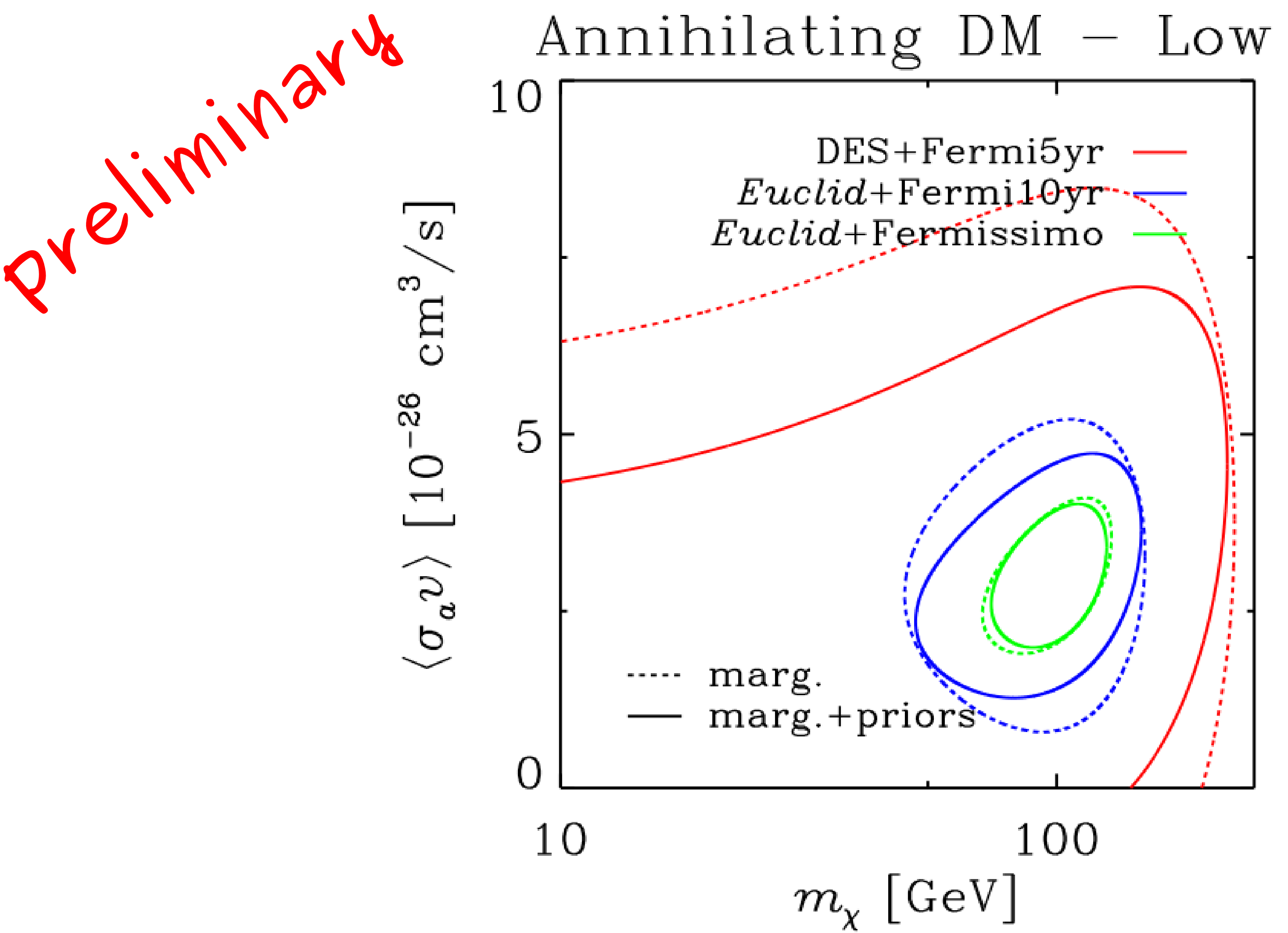
A WIMP model, which is undetectable with gamma-rays alone, can be instead clearly **detected** through the **correlation with cosmic shear**.

First tests can be performed in the forthcoming future (DES + Fermi LAT).

Fisher Matrix forecasts

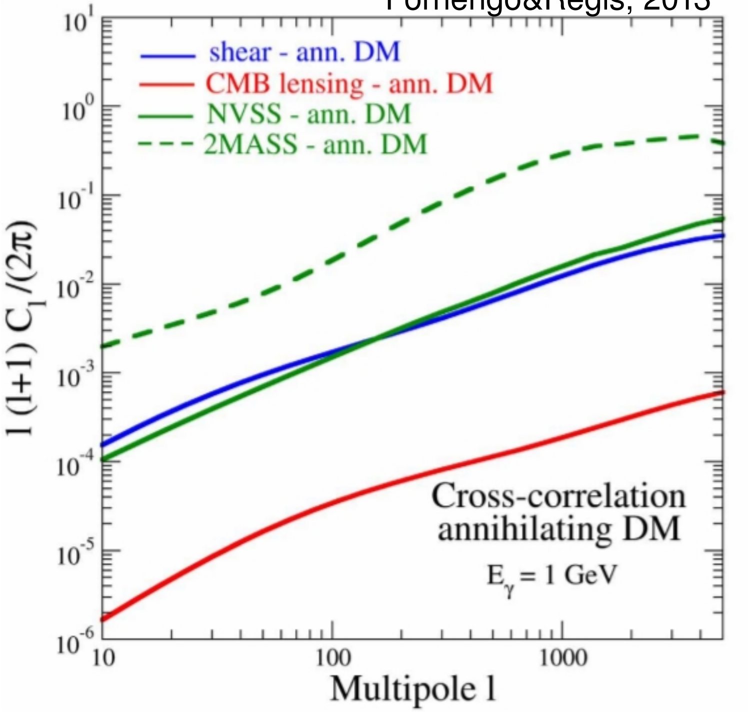
Tomographic approach (for cosmic shear observations) and

energy binning (for γ-ray observations) make the method much more powerful

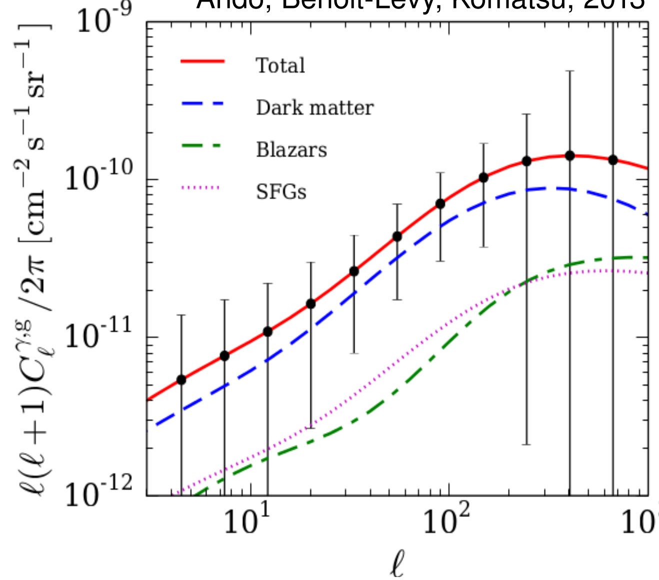


Cross-correlation with LSS

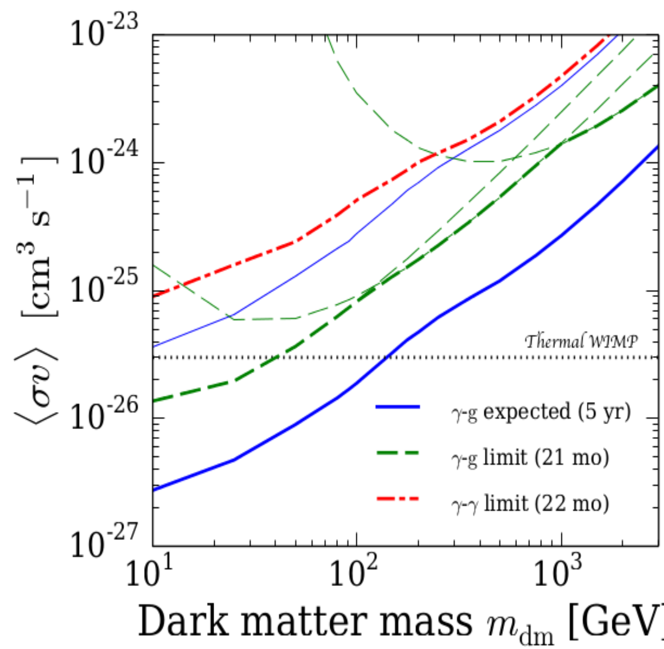
Fornengo&Regis, 2013



Ando, Benoit-Levy, Komatsu, 2013



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



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

wrt the lensing case: part of the correlation (1-halo term) might be lost and galaxy bias is needed.

Conclusions

DM halos are faint but they are a lot!

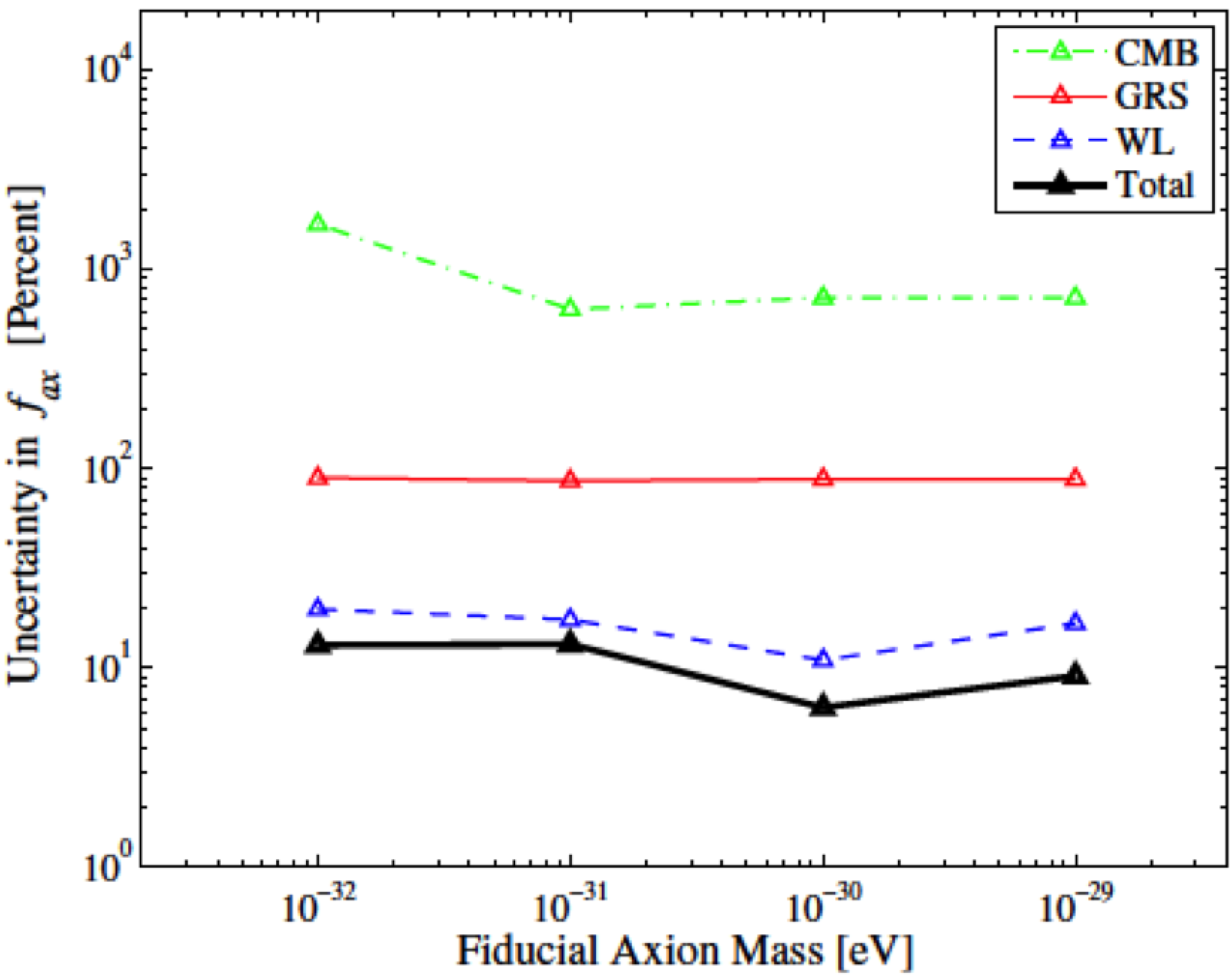
→ Look at statistical correlations

If a particle DM model (WIMP, sterile neutrinos, axions, etc..) induces an electromagnetic emission, such non-gravitational signal is correlated with the gravitational potential.

Gravitational probes can act as a filter and help to **isolate a WIMP signature** (in particular by exploiting a tomographic approach).

Very promising prospects for the Euclid weak-lensing survey!

Particle Cosmology
with
Euclid


CMB
GRS
WL
Total
Uncertainty in f_{ax} [Percent]
10^4
10^3
10^2
10^1
10^0
10^{-32}
10^{-31}
10^{-30}
10^{-29}
Fiducial Axion Mass [eV]

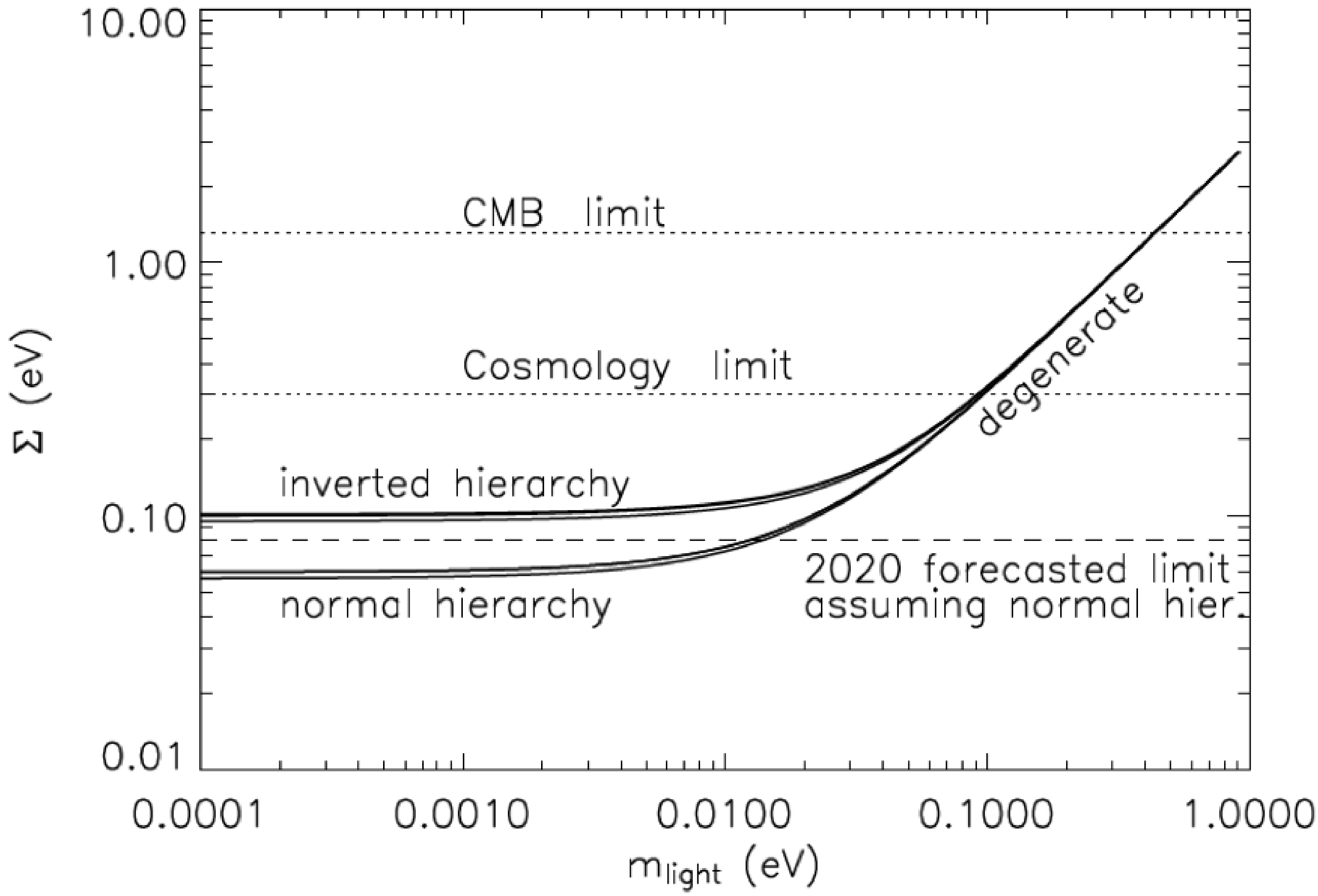


Table 18: $\sigma(M_\nu)$ and $\sigma(N_{\rm eff})$ marginalized errors from LSS+CMB

			General cosmology			
fiducial →	$\Sigma = 0.3\,\mathrm{eV}^a$	$\Sigma = 0.2\,\mathrm{eV}^a$	$\Sigma = 0.125\,\mathrm{eV}^b$	$\Sigma = 0.125\,\mathrm{eV}^c$	$\Sigma = 0.05\,\mathrm{eV}^b$	$N_{\rm eff} = 3.04^d$
EUCLID+Planck	0.0361	0.0458	0.0322	0.0466	0.0563	0.0862
			ΛCDM cosmology			
EUCLID+Planck	0.0176	0.0198	0.0173	0.0218	0.0217	0.0224

[a] for degenerate spectrum: $m_1 \approx m_2 \approx m_3$; [b] for normal hierarchy: $m_3 \neq 0$, $m_1 \approx m_2 \approx 0$
[c] for inverted hierarchy: $m_1 \approx m_2$, $m_3 \approx 0$; [d] fiducial cosmology with massless neutrinos

Backup slides

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

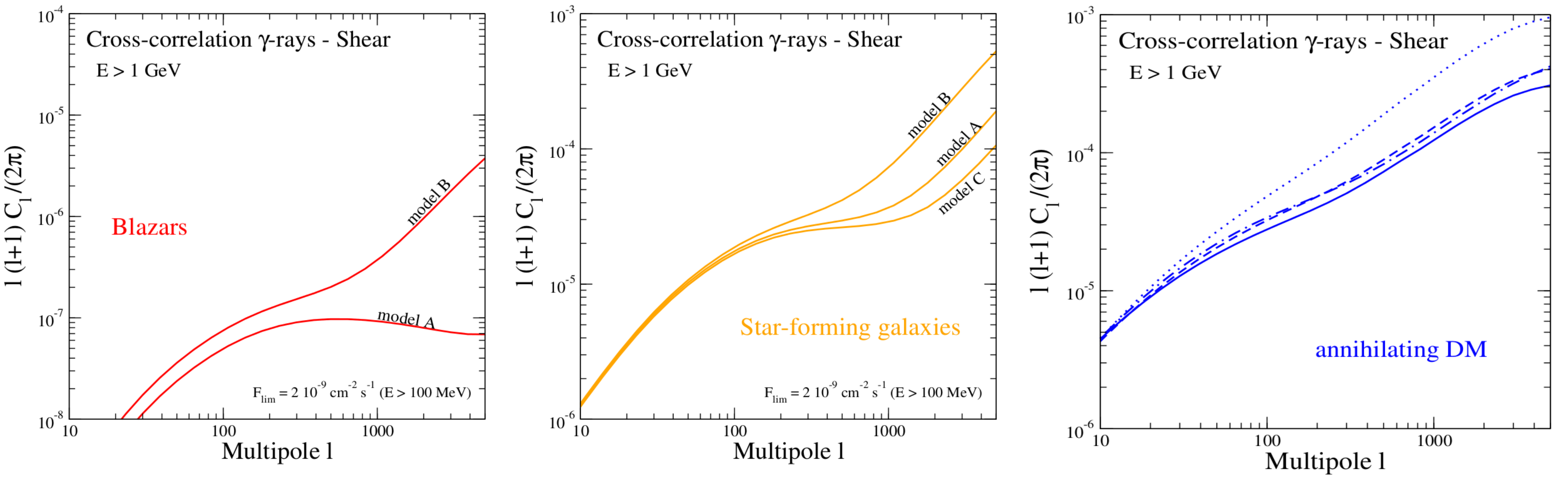
3D POWER SPECTRUM

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

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 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)