

# Cosmological and astrophysical synergies for indirect dark matter detection

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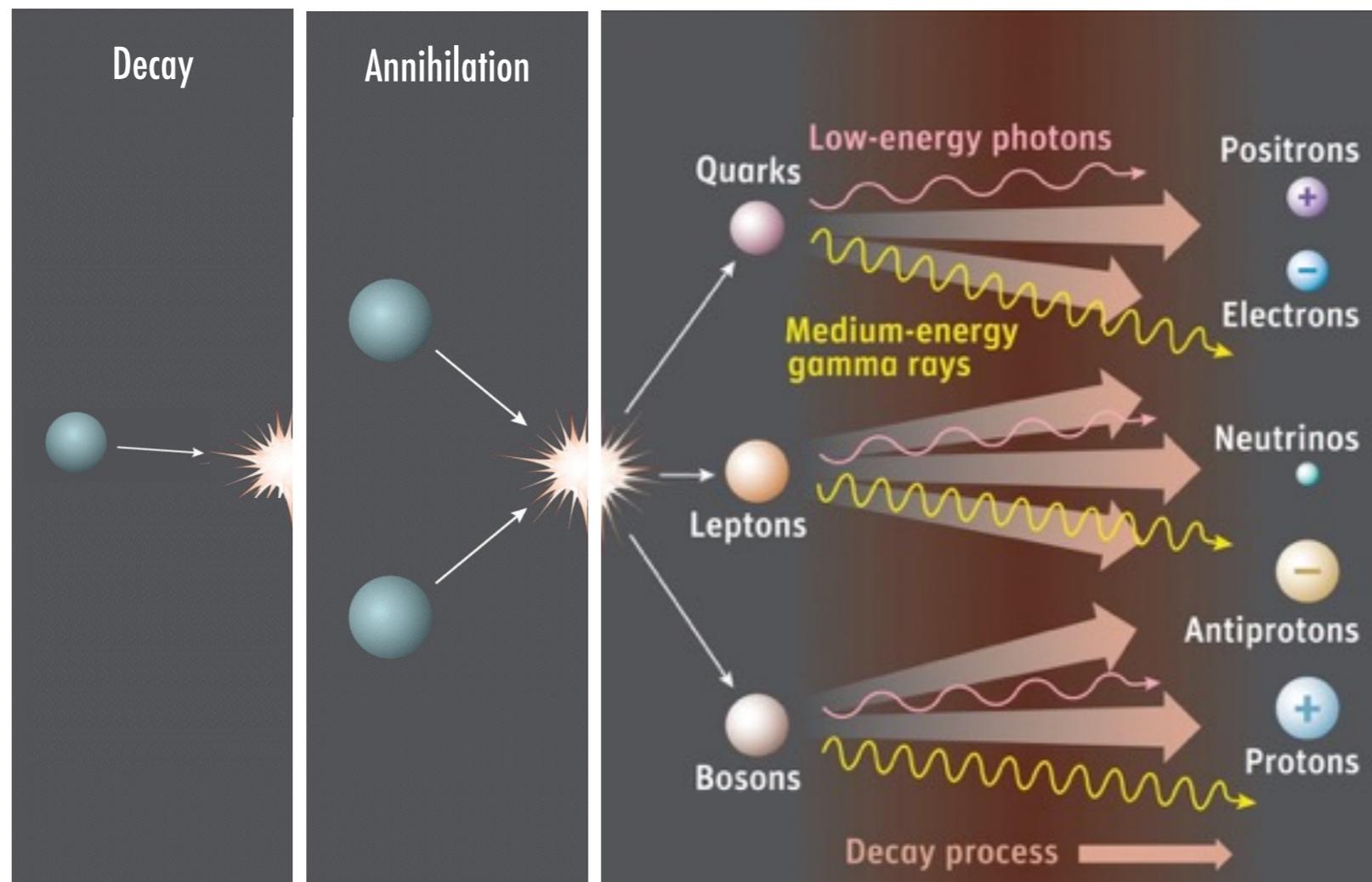


Programma per Giovani Ricercatori  
"Rita Levi Montalcini"



# Particle dark matter

- Dark matter (**DM**) is an established ingredient of  $\Lambda$ CDM
- Weakly interacting massive particles (**WIMPs**)
  - Indirect detection experiments: **WIMP-sourced cosmic and  $\gamma$  rays**

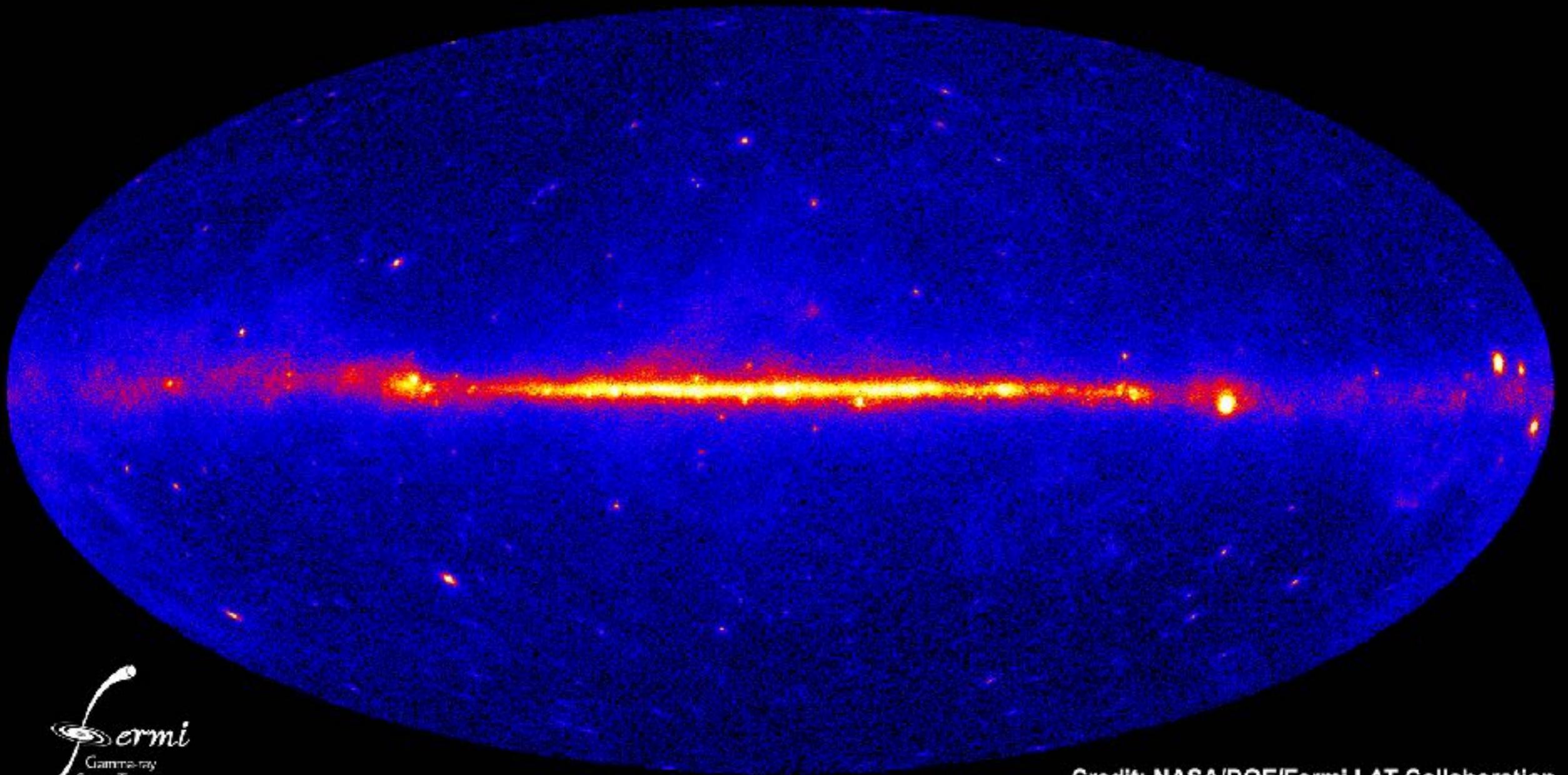


# DM-sourced $\gamma$ rays



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NASA's Fermi telescope reveals best-ever view of the gamma-ray sky

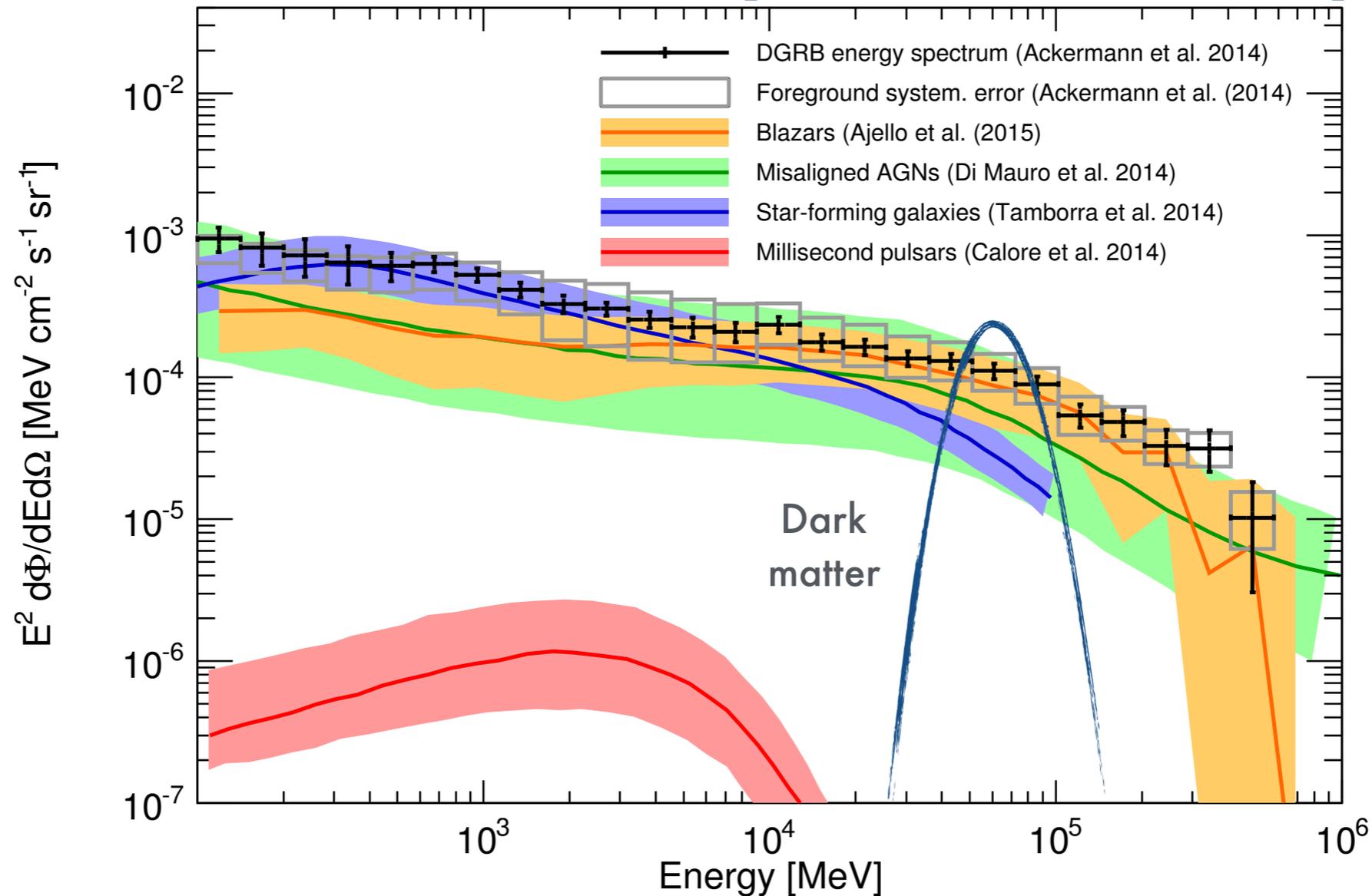


Credit: NASA/DOE/Fermi LAT Collaboration

# DM-sourced $\gamma$ rays

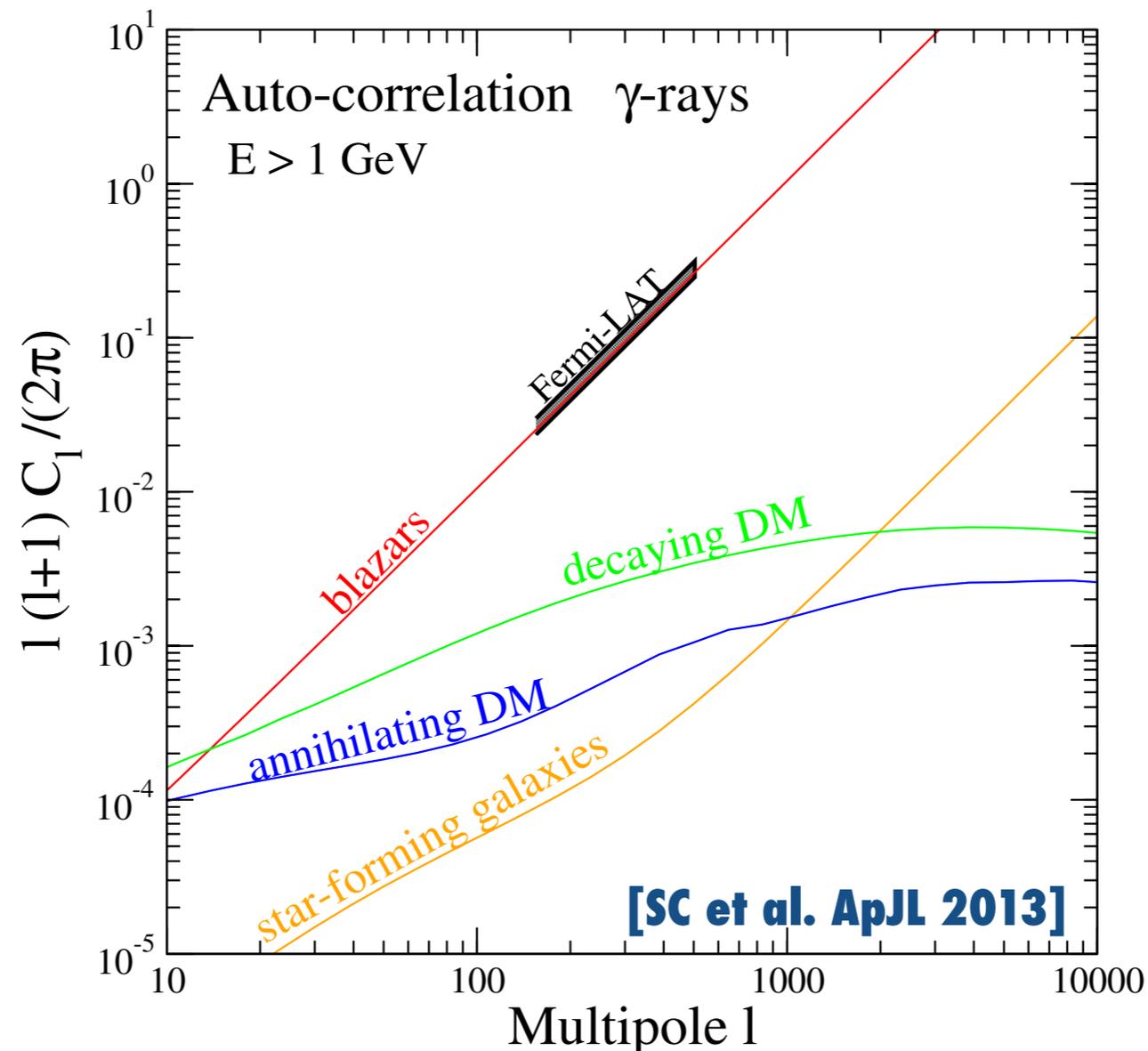
- WIMP annihilations/decays in unresolved  $\gamma$ -ray bkgd (UGRB)
  - $\gamma$ -ray energy spectrum

[Fornasa & Sánchez-Conde 2015]



# DM-sourced $\gamma$ rays

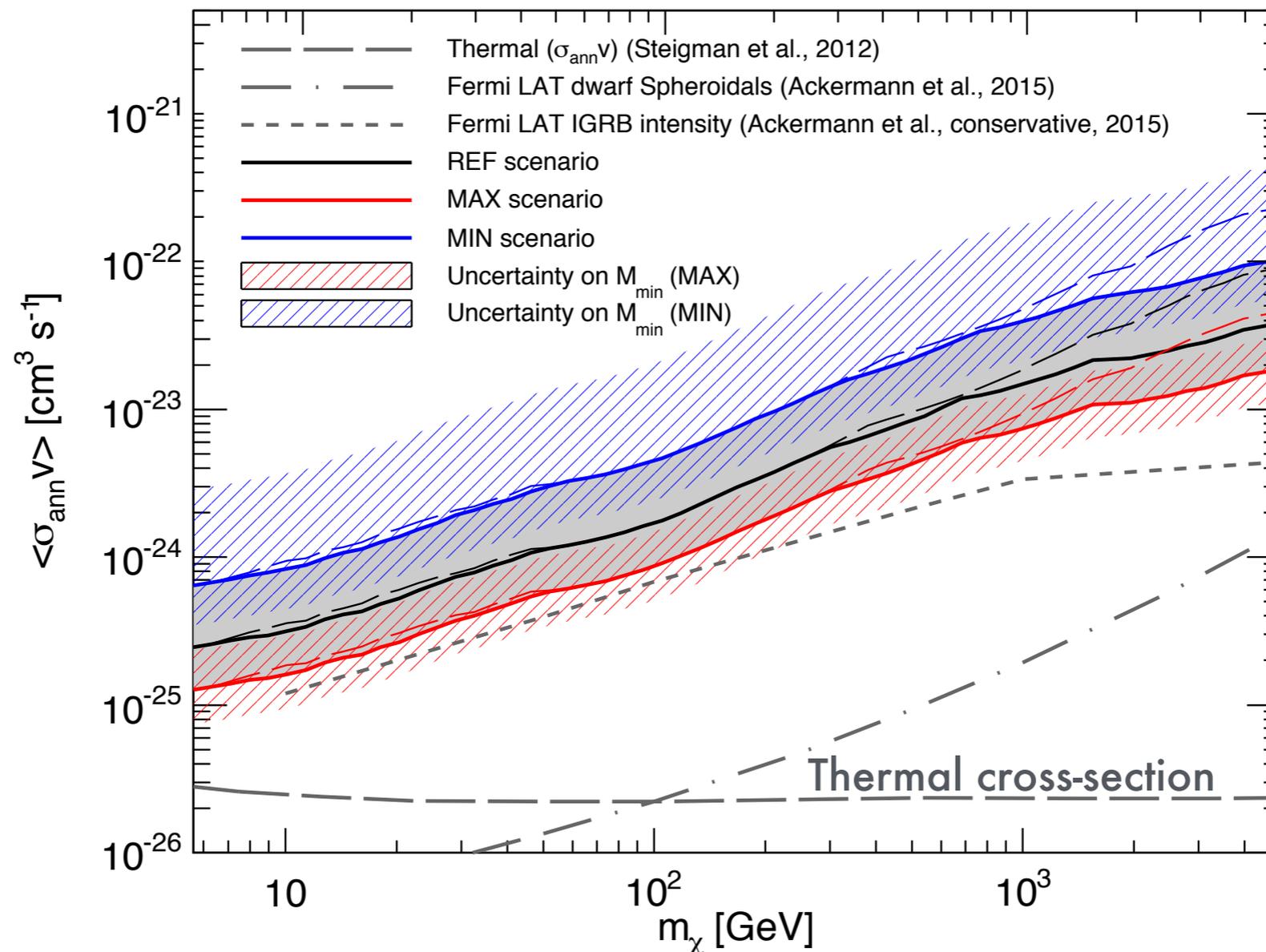
- WIMP annihilations/decays in unresolved  $\gamma$ -ray bkgd (UGRB)
  - $\gamma$ -ray anisotropy angular power spectrum



# DM-sourced $\gamma$ rays

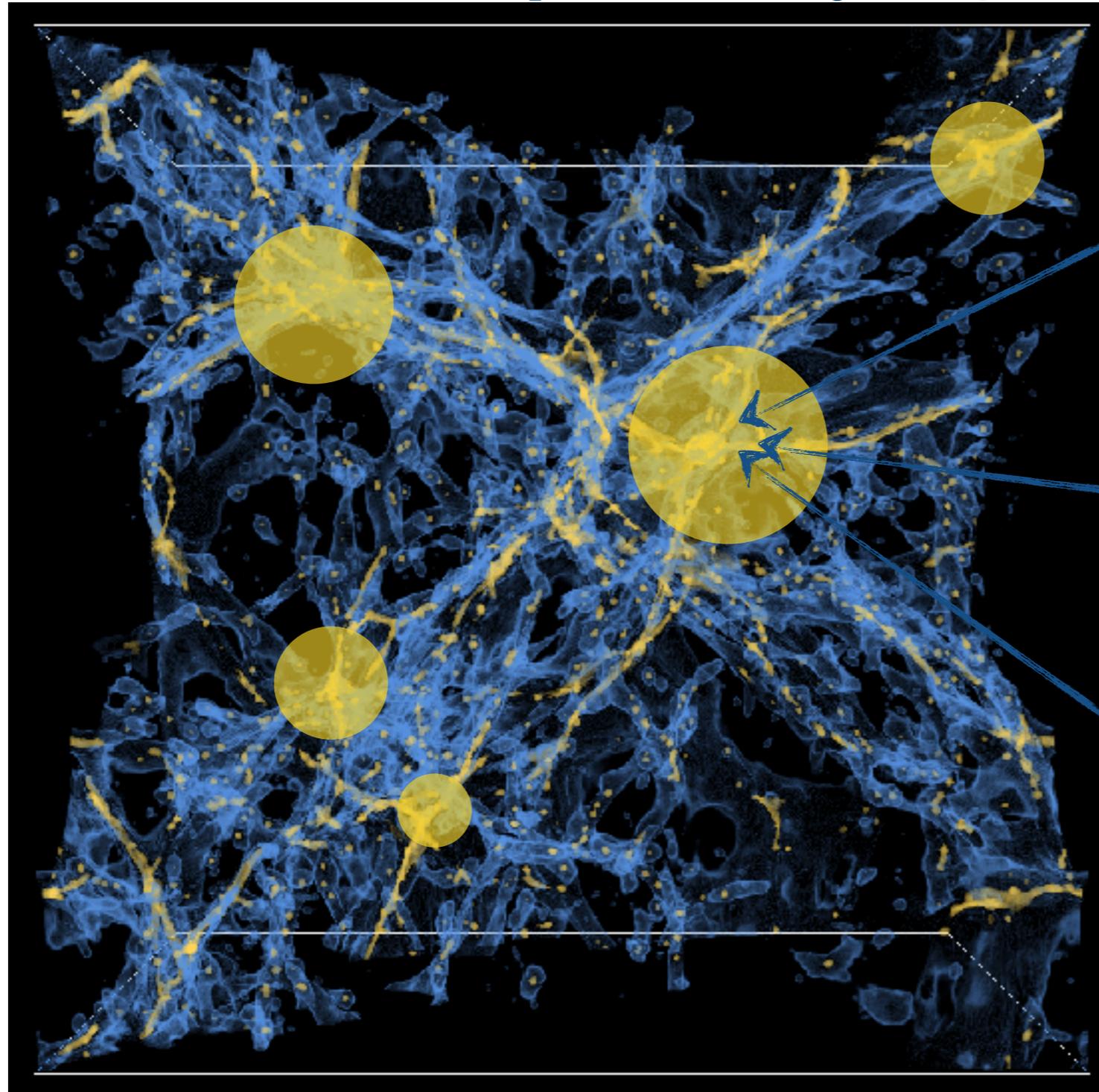
- WIMP annihilations/decays in unresolved  $\gamma$ -ray bkgd (UGRB)

[Fornasa et al. 2016]



# Gravitational probes of DM

[Lukic et al.; Image: Casey Stark]



Galaxies,  
galaxy clusters,  
gravitational lensing

$\gamma$  rays from  
astrophysical sources  
hosted within the  
dark matter halo

$\gamma$  rays from  
annihilations/decays of  
dark matter particles  
forming the halo

# Gravitational probes of DM



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Many tracers of large-scale structure:

- Weak lensing (cosmic shear, CMB lensing...)  
[SC et al. 2013; Fornengo, SC et al. 2015;  
Shirasaki et al. 2014, 2016, 2018; Tröster, SC et al. 2017;  
Ammazzalorso, SC et al. in prep.]
- Clustering (galaxies, galaxy clusters...)  
[Fornengo & Regis 2014; Ando et al. 2014; Xia et al. 2015;  
Regis et al. 2015; Shirasaki et al. 2015;  
Branchini, SC et al. 2017; Colavincenzo, SC et al. in prep.]
- ...

Find an optimal tracer of the large-scale cosmic DM distribution to filter out astrophysical non-thermal emission from the DM  $\gamma$ -ray signal

# Observational synergies

## Large-scale structure surveys

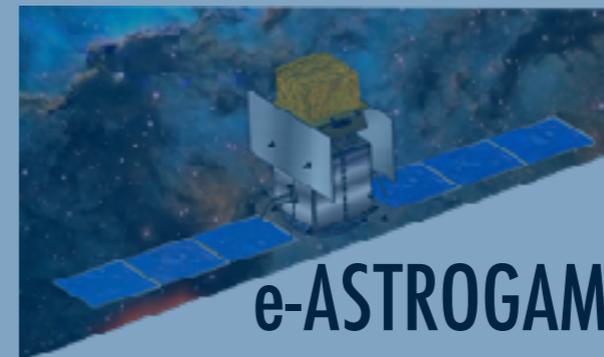
- Weak gravitational lensing



- Clustering of structures



## $\gamma$ -ray experiments



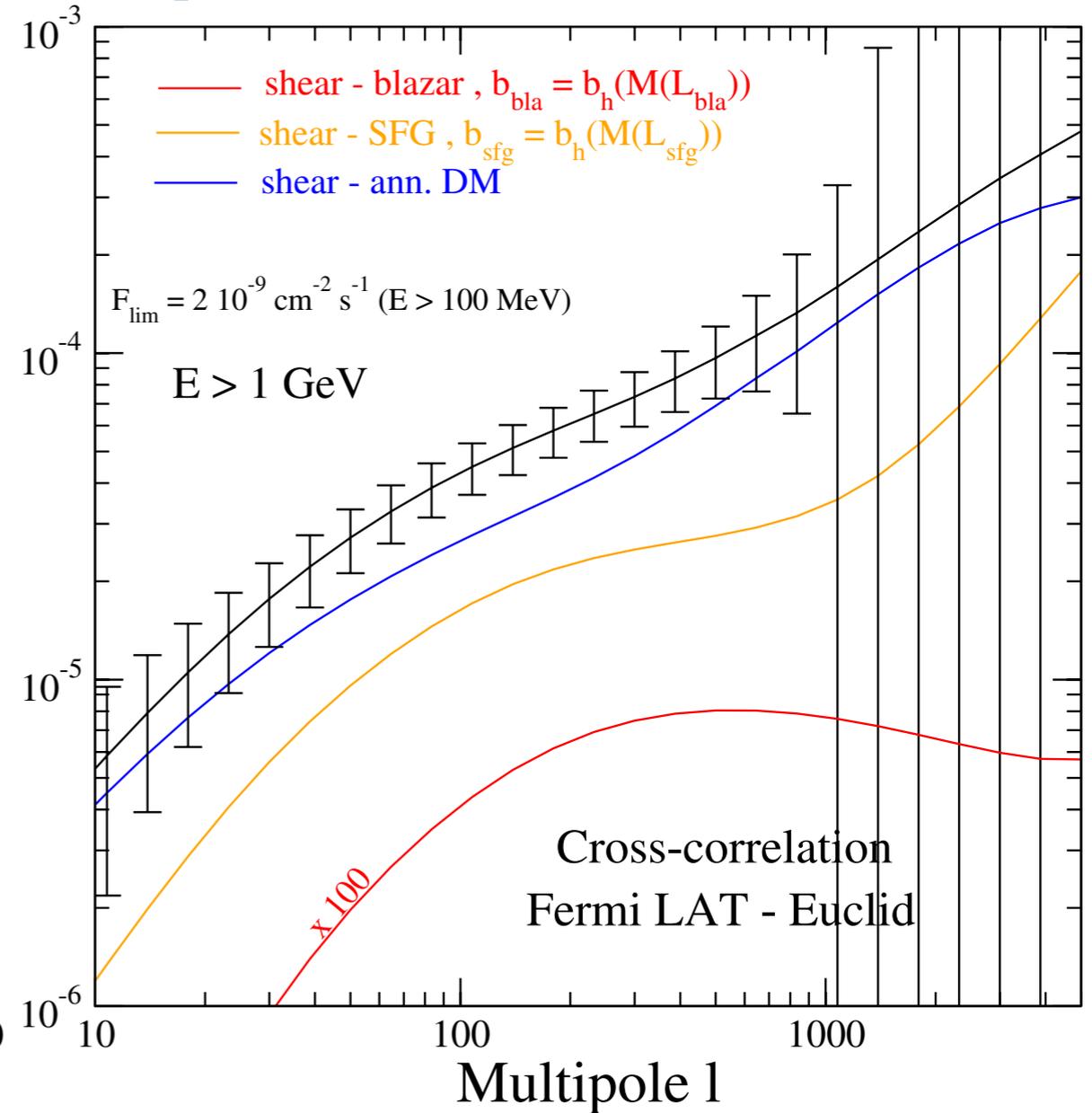
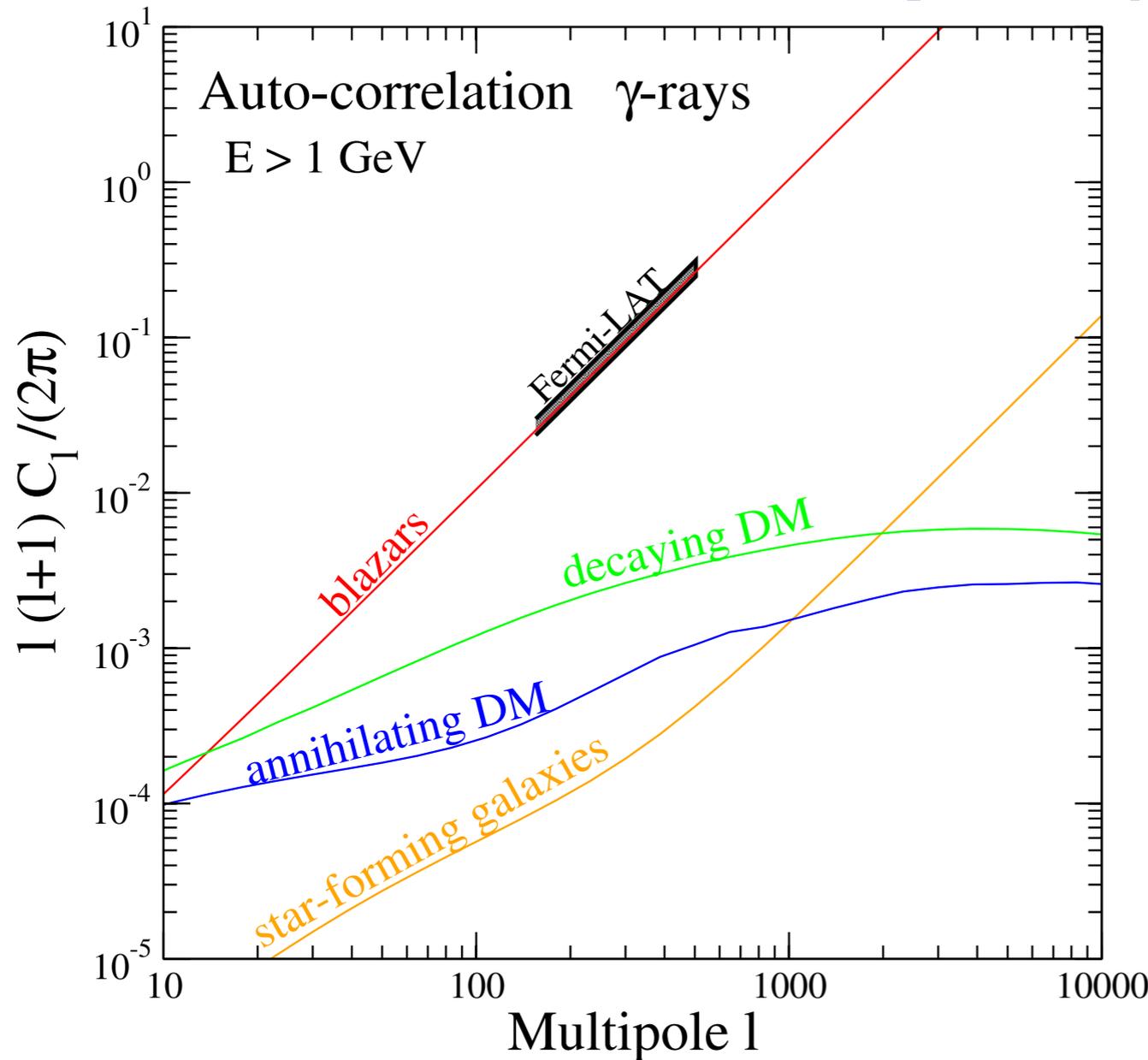
# Observational synergies



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[SC et al. ApJL 2013]



# Observational synergies

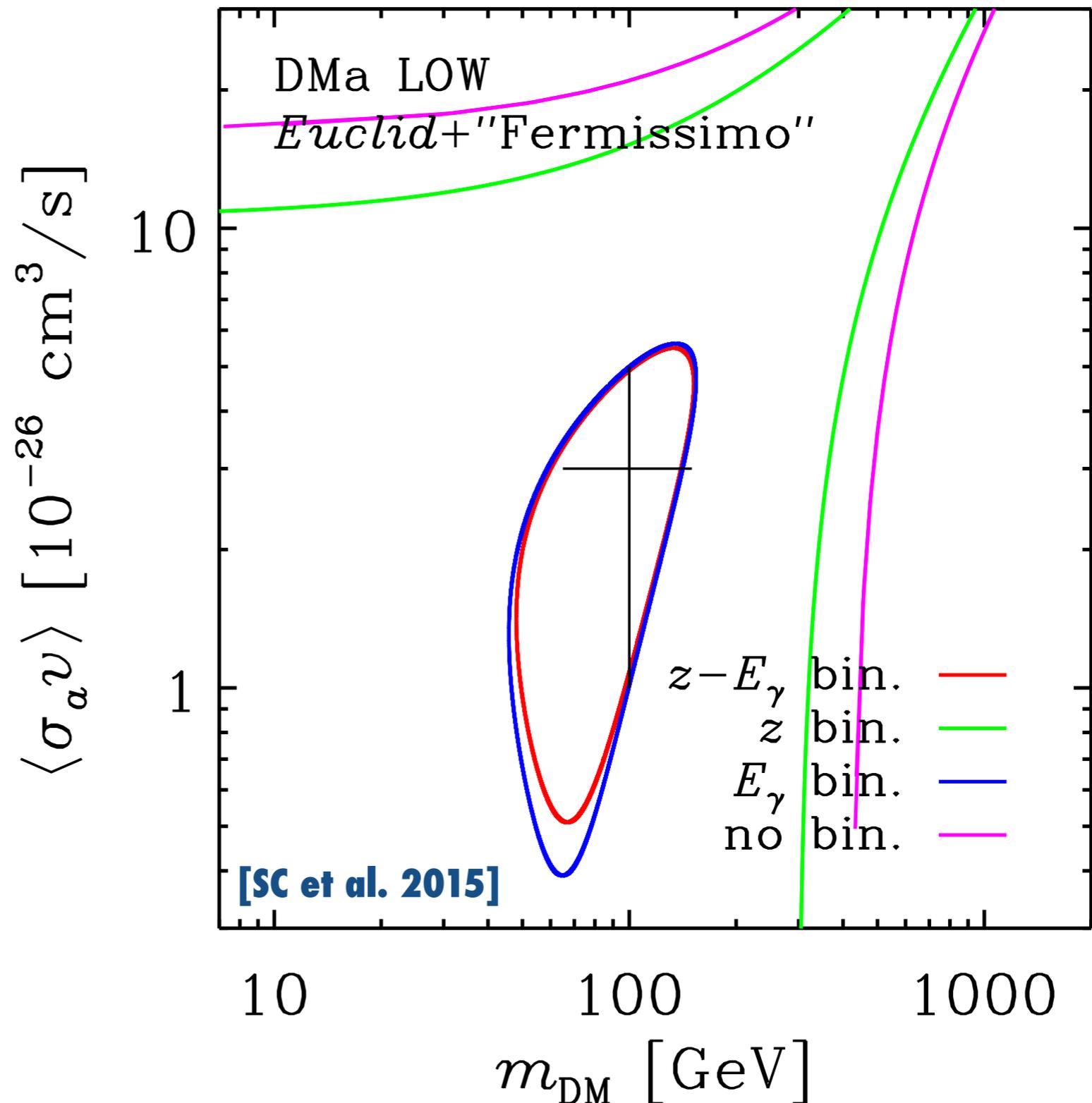
- Tomographic-spectral approach

[SC et al. 2015]

- $N_z$  redshift bins
- $N_E$  energy bins

$$C_l^{\gamma\kappa} \longrightarrow \mathbf{C}_l^{\gamma\kappa} = \begin{pmatrix} C_l^{\gamma_1\kappa_1} & C_l^{\gamma_1\kappa_2} & \dots & C_l^{\gamma_1\kappa_{N_E}} \\ C_l^{\gamma_2\kappa_1} & C_l^{\gamma_2\kappa_2} & \dots & C_l^{\gamma_2\kappa_{N_E}} \\ \vdots & \vdots & \ddots & \vdots \\ C_l^{\gamma_{N_z}\kappa_1} & C_l^{\gamma_{N_z}\kappa_2} & \dots & C_l^{\gamma_{N_z}\kappa_{N_E}} \end{pmatrix}$$

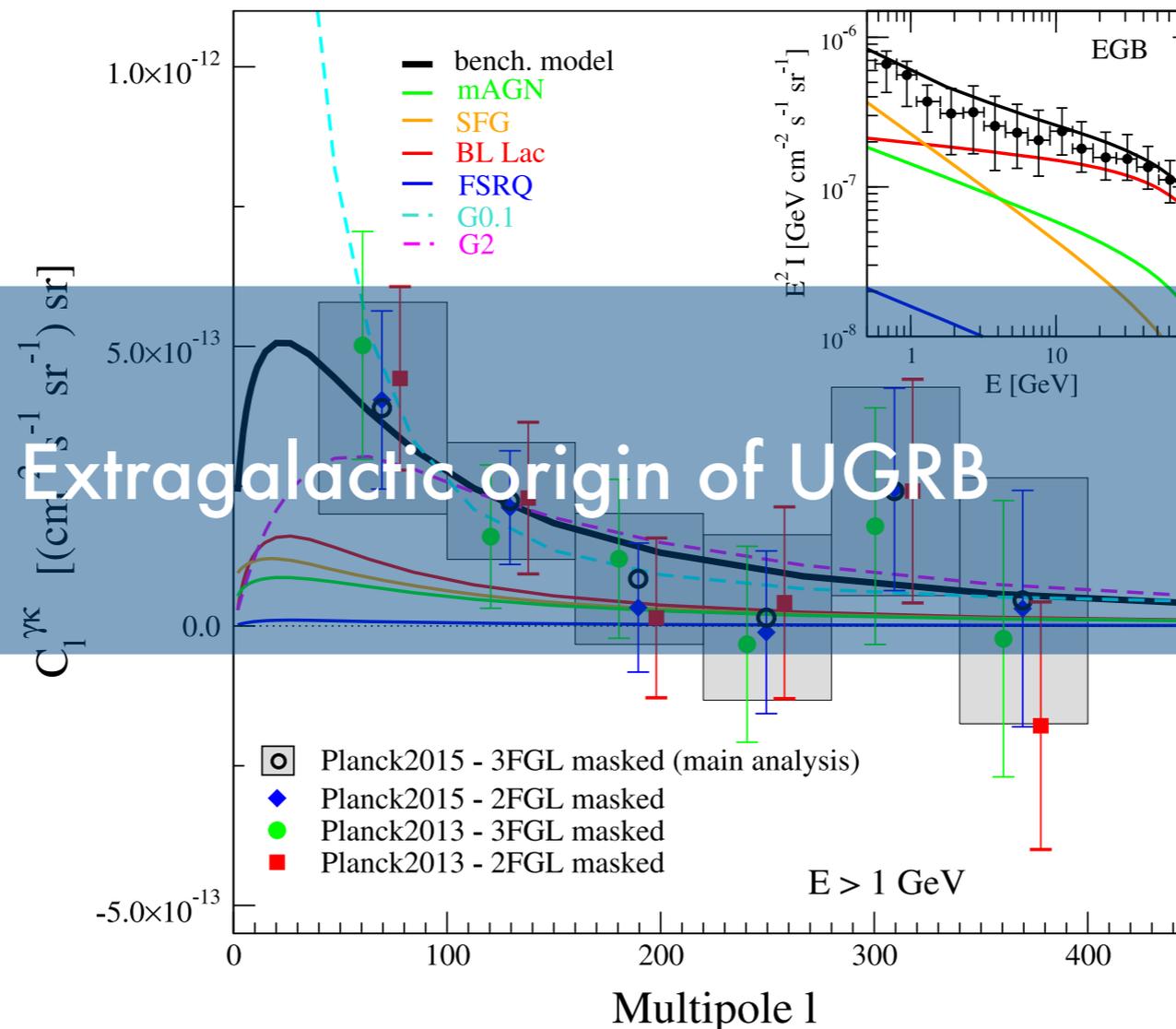
# Observational synergies



# Measurements



- Detections:
  - $>3\sigma$  evidence **[Fornengo, SC et al. ApJL 2015]**  
CMB lensing [Planck 2013 & 2015]  $\times$  UGRB [Fermi Pass7-reprocessed (68 months)]



# Measurements

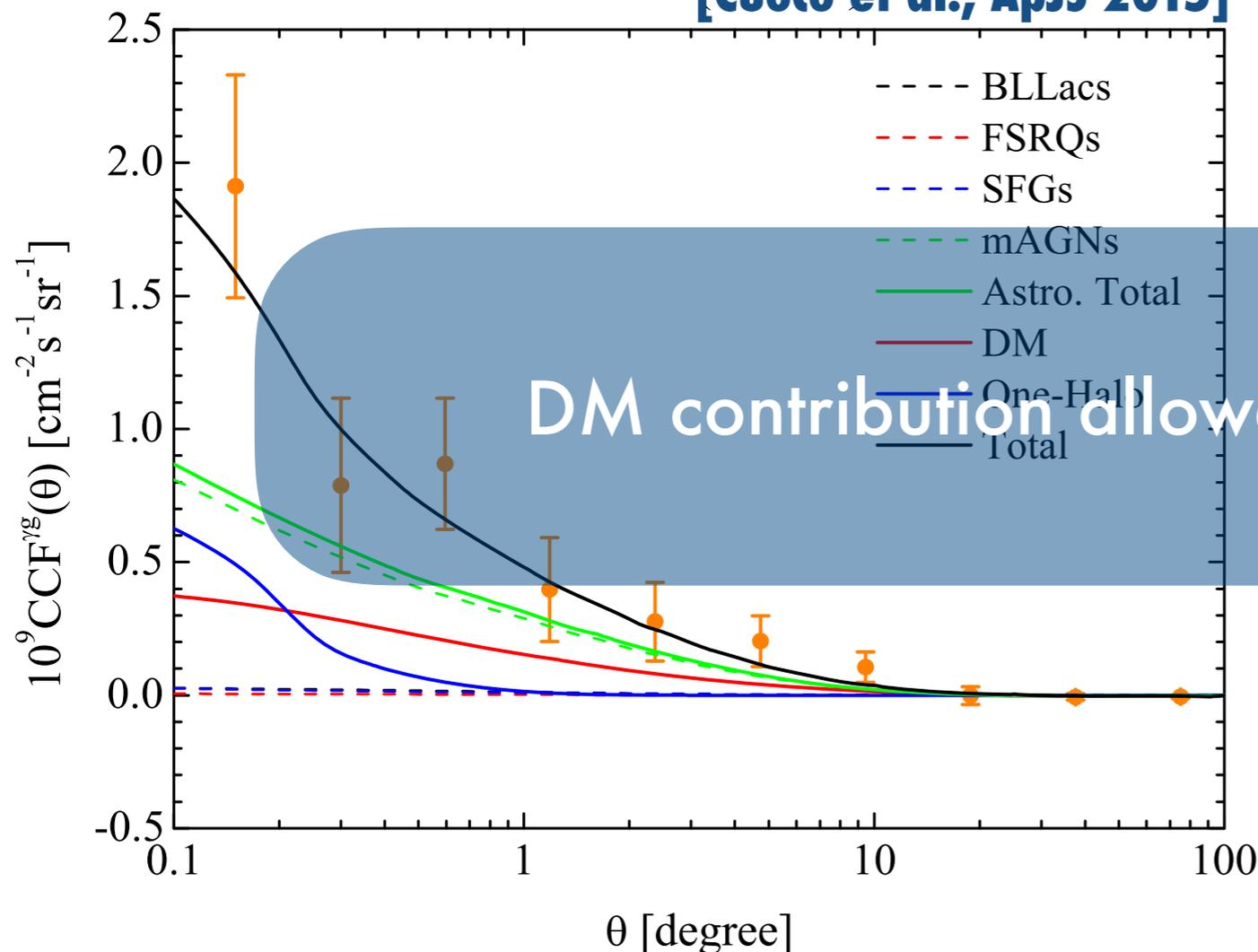


- Detections:

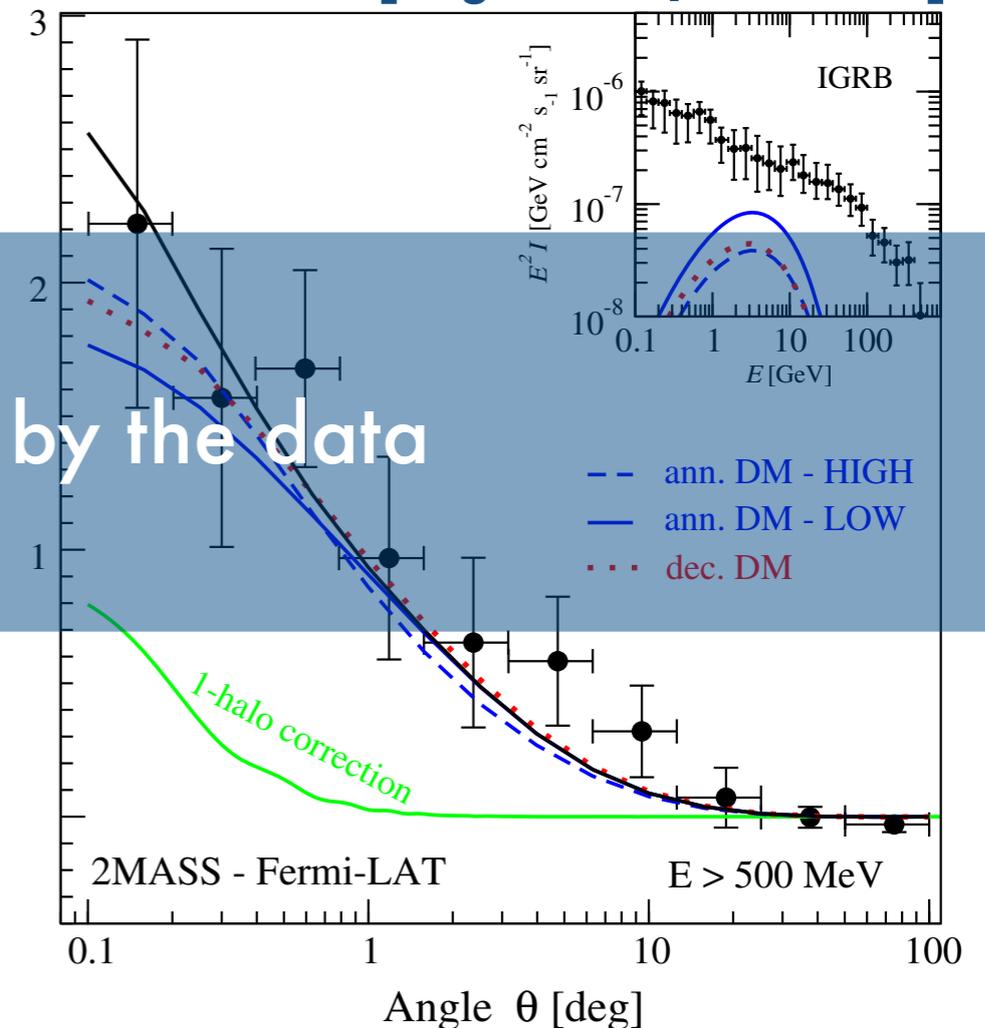
- $>3.5\sigma$  evidence [Xia et al. ApJS 2015]

Clustering of galaxies [2MASS, NVSS, QSOs, SDSS] x UGRB [Fermi Pass7 (60 months)]

[Cuoco et al., ApJS 2015]



[Regis et al., PRL 2015]



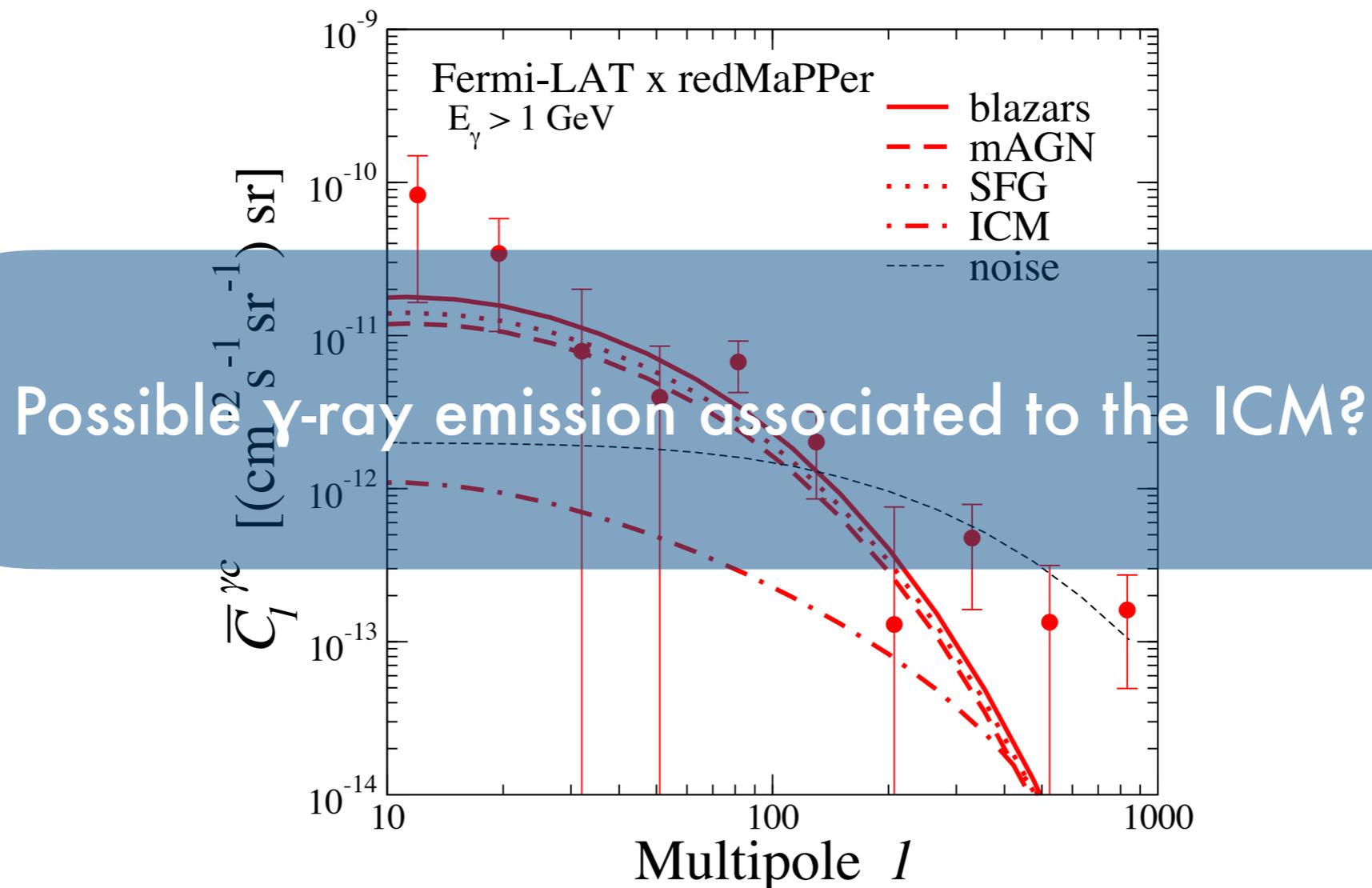
DM contribution allowed by the data

# Measurements

- Detections:

- $>5\sigma$  evidence [**Branchini, SC et al. ApJS 2017**]

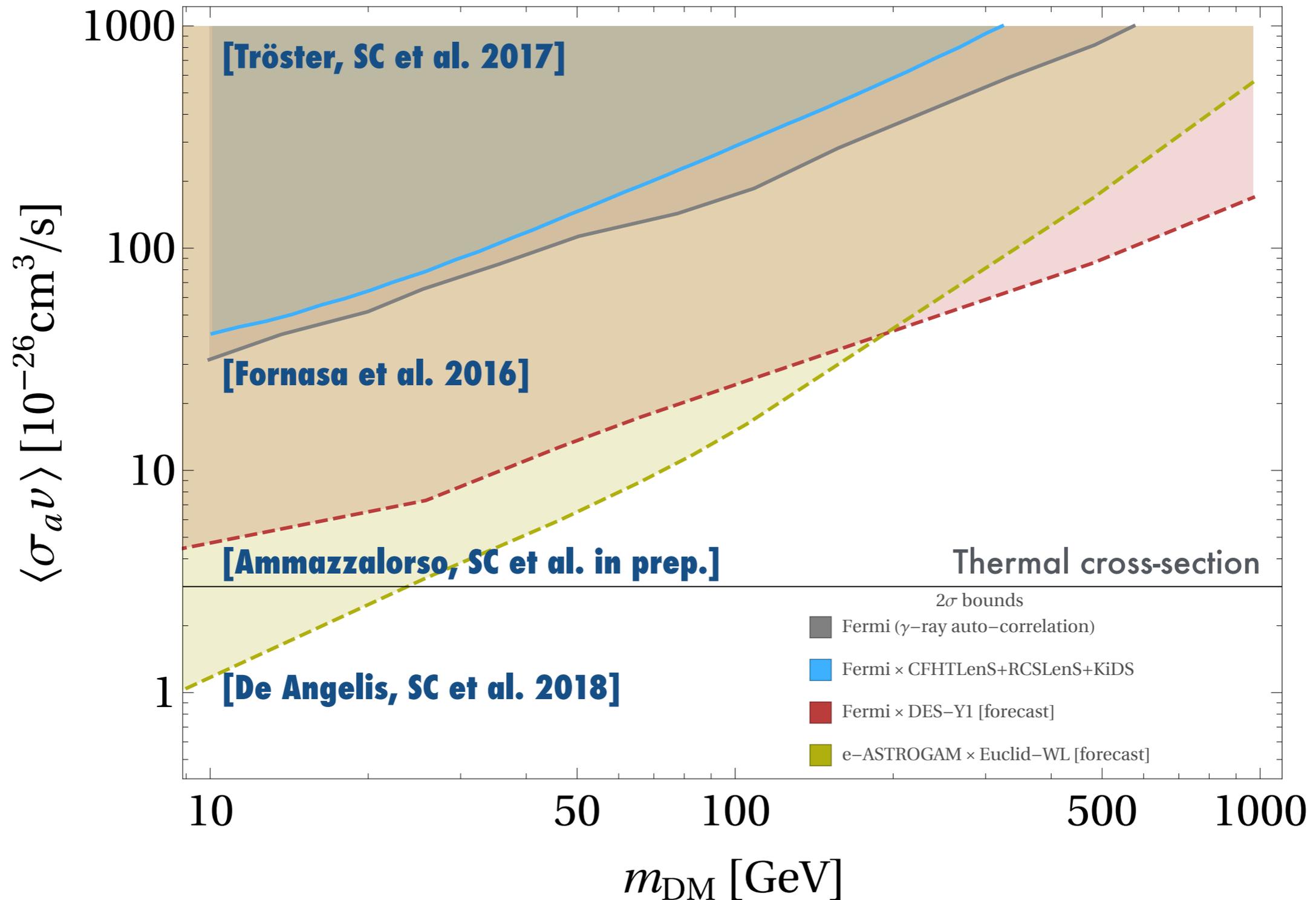
Clustering of clusters [Planck-SZ 2015, redMaPPer, WH12] x UGRB [Fermi Pass8 (78 mths)]



# Bounds

- Non-detections:
  - Clustering of galaxies [SDSS LRGs]  $\times$  UGRB [Fermi Pass7-reprocessed (76 mths)]  
[Shirasaki et al. 2015]
  - Cosmic shear [CFHTLenS+RCSLenS]  $\times$  UGRB [Fermi Pass7-repr. (76 mths), Pass8 (85 mths)]  
[Shirasaki et al. 2014, 2016]
  - Cosmic shear [Subaru HSC]  $\times$  UGRB [Pass8 (85 mths)]  
[Shirasaki et al. 2018]
  - Cosmic shear [CFHTLenS+RCSLenS+KiDS]  $\times$  UGRB [Fermi Pass8 (84 mths)]  
[Tröster, SC et al. 2017]
  - Cosmic shear [DES Y1]  $\times$  UGRB [Fermi Pass8 (108 mths)]  
[Ammazzalorso, SC et al. in prep.]

# Bounds



# Take-home message



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- Unique added value of synergies at various wavelengths
- Cross-correlations valuable for accessing signal buried in noise
- Multi-wavelength synergies between direct gravitational probes of DM and the  $\gamma$ -ray sky have the real power to find signatures of the particle nature of DM
- Apart from DM studies, these cross-correlations can lift degeneracies among the various astrophysical source populations and shed new light on the UGRB