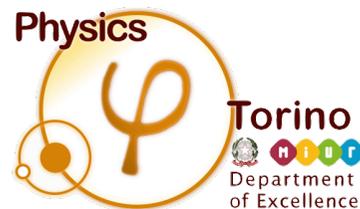


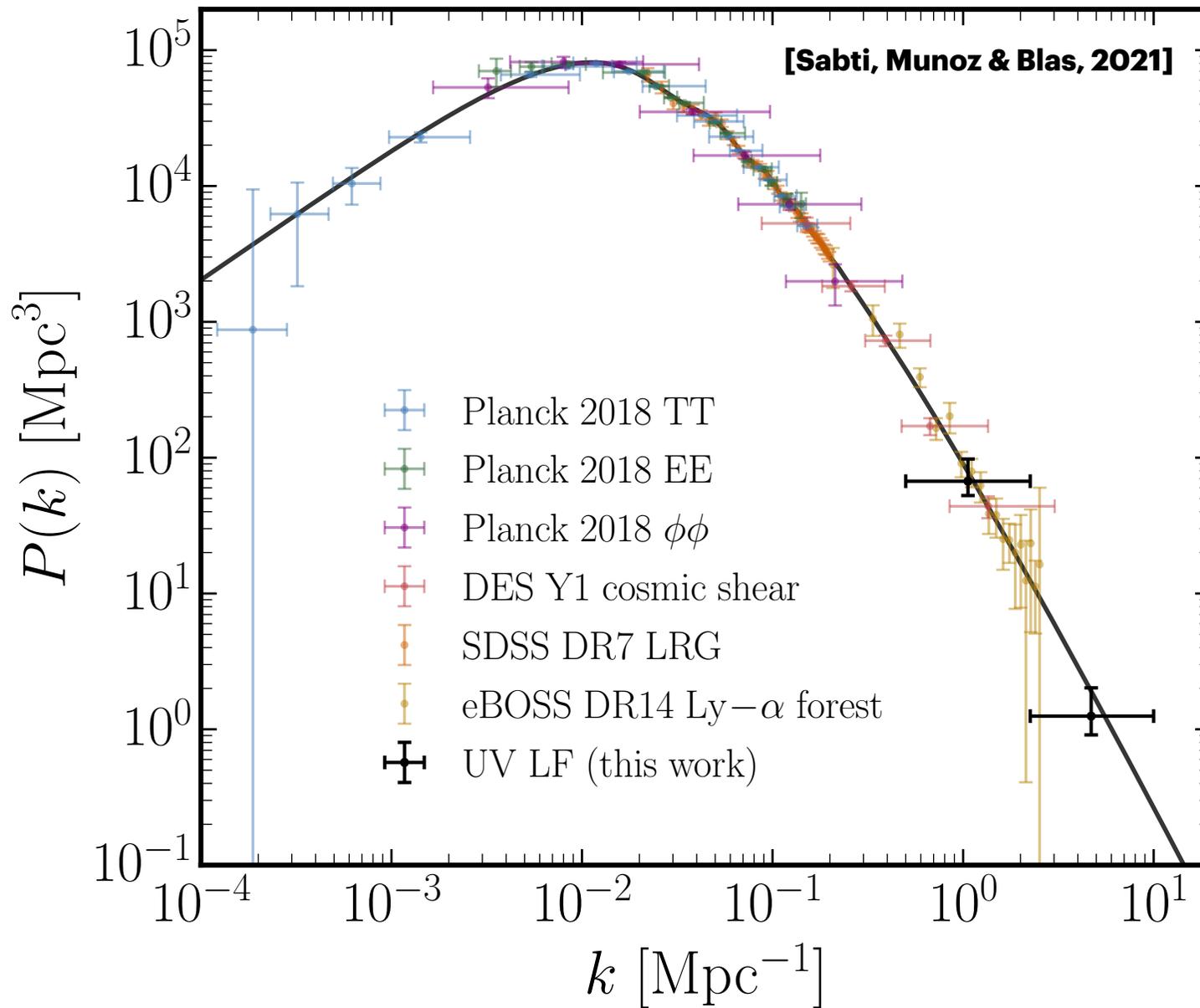
Synergies across the spectrum for astrophysics and cosmology

Stefano **Camera**

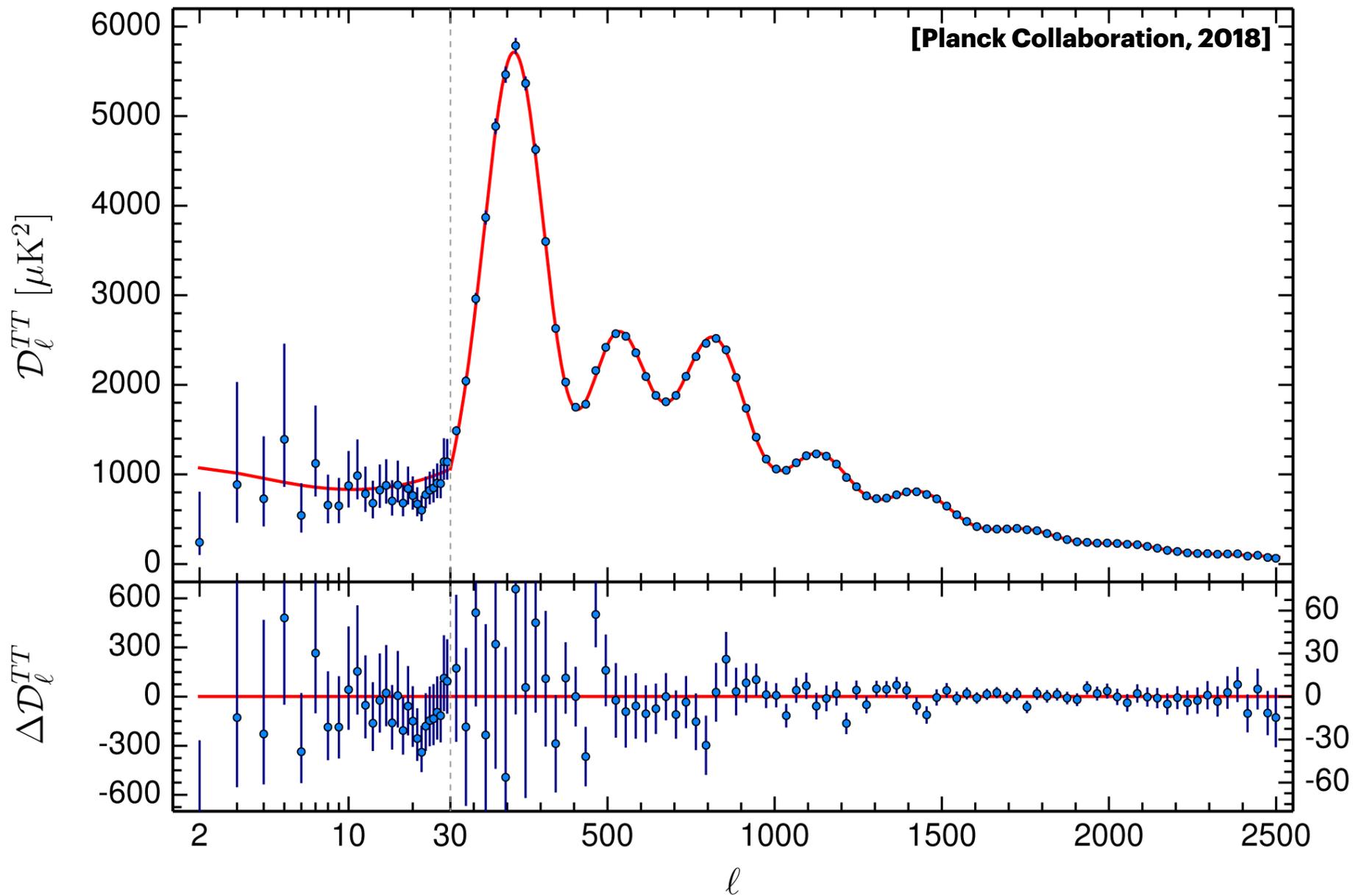
Department of Physics, University of Turin, Italy



- Cosmological (scalar) perturbations $f(t, \mathbf{x})$
[density fluctuations, gravitational potential(s), ...]
- Observable sourced by perturbation(s) $\mathcal{O}_f(t, \mathbf{x})$
[galaxy number density fluctuations, weak gravitational lensing, ...]
- Correlation function $\langle \mathcal{O}_f(t, \mathbf{x}) \mathcal{O}_f(t, \mathbf{y}) \rangle = \xi_{\mathcal{O}_f \mathcal{O}_f}(t, \mathbf{x} - \mathbf{y})$
- Fourier-space power spectrum $\langle \hat{\mathcal{O}}_f(t, \mathbf{k}) \hat{\mathcal{O}}_f^*(t, \mathbf{k}') \rangle = \delta^{(D)}(\mathbf{k} - \mathbf{k}') P_{\mathcal{O}_f \mathcal{O}_f}(t, \mathbf{k})$



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- Fourier-space power spectrum $\langle \hat{\mathcal{O}}_f(t, \mathbf{k}) \hat{\mathcal{O}}_f^*(t, \mathbf{k}') \rangle = \delta^{(D)}(\mathbf{k} - \mathbf{k}') P_{\mathcal{O}_f \mathcal{O}_f}(t, \mathbf{k})$
- Harmonic-space power spectrum $\langle \widetilde{\mathcal{O}}_{f \ell m}(z) \widetilde{\mathcal{O}}_{f \ell' m'}^*(z') \rangle = \delta_{\ell \ell'}^{(K)} \delta_{mm'}^{(K)} C_{\ell}^{\mathcal{O}_f \mathcal{O}_f}(z, z')$



- Cosmological (scalar) perturbations $f(t, \mathbf{x}), g(t, \mathbf{x})$
[density fluctuations, gravitational potential(s), ...]
- Observable sourced by perturbation(s) $\mathcal{O}_f(t, \mathbf{x}), \mathcal{O}_g(t, \mathbf{x})$
[galaxy number density fluctuations, weak gravitational lensing, ...]
- Correlation function $\langle \mathcal{O}_g(t, \mathbf{x}) \mathcal{O}_f(t, \mathbf{y}) \rangle = \xi_{\mathcal{O}_f \mathcal{O}_g}(t, \mathbf{x} - \mathbf{y})$
- Fourier-space power spectrum $\langle \hat{\mathcal{O}}_f(t, \mathbf{k}) \hat{\mathcal{O}}_g^*(t, \mathbf{k}') \rangle = \delta^{(D)}(\mathbf{k} - \mathbf{k}') P_{\mathcal{O}_f \mathcal{O}_g}(t, \mathbf{k})$
- Harmonic-space power spectrum $\langle \widetilde{\mathcal{O}}_{f \ell m}(z) \widetilde{\mathcal{O}}_{g \ell' m'}^*(z') \rangle = \delta_{\ell \ell'}^{(K)} \delta_{mm'}^{(K)} C_{\ell}^{\mathcal{O}_f \mathcal{O}_g}(z, z')$

- Observed signal

$$f^{\text{obs}} = f^{\text{cosmo}} + f^{\text{noise}} + f^{\text{cont}} + f^{\text{sys}}$$

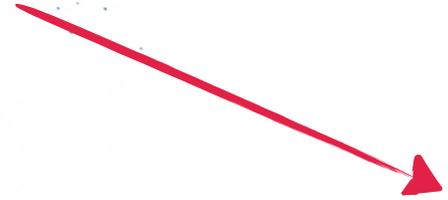
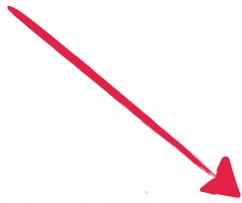
- Auto-correlation power spectrum

$$\langle f^{\text{obs}} f^{\text{obs}} \rangle = \langle f^{\text{cosmo}} f^{\text{cosmo}} \rangle + \langle f^{\text{noise}} f^{\text{noise}} \rangle + \langle f^{\text{cont}} f^{\text{cont}} \rangle + \langle f^{\text{sys}} f^{\text{sys}} \rangle + 2\langle f^{\text{cosmo}} f^{\text{cont}} \rangle$$

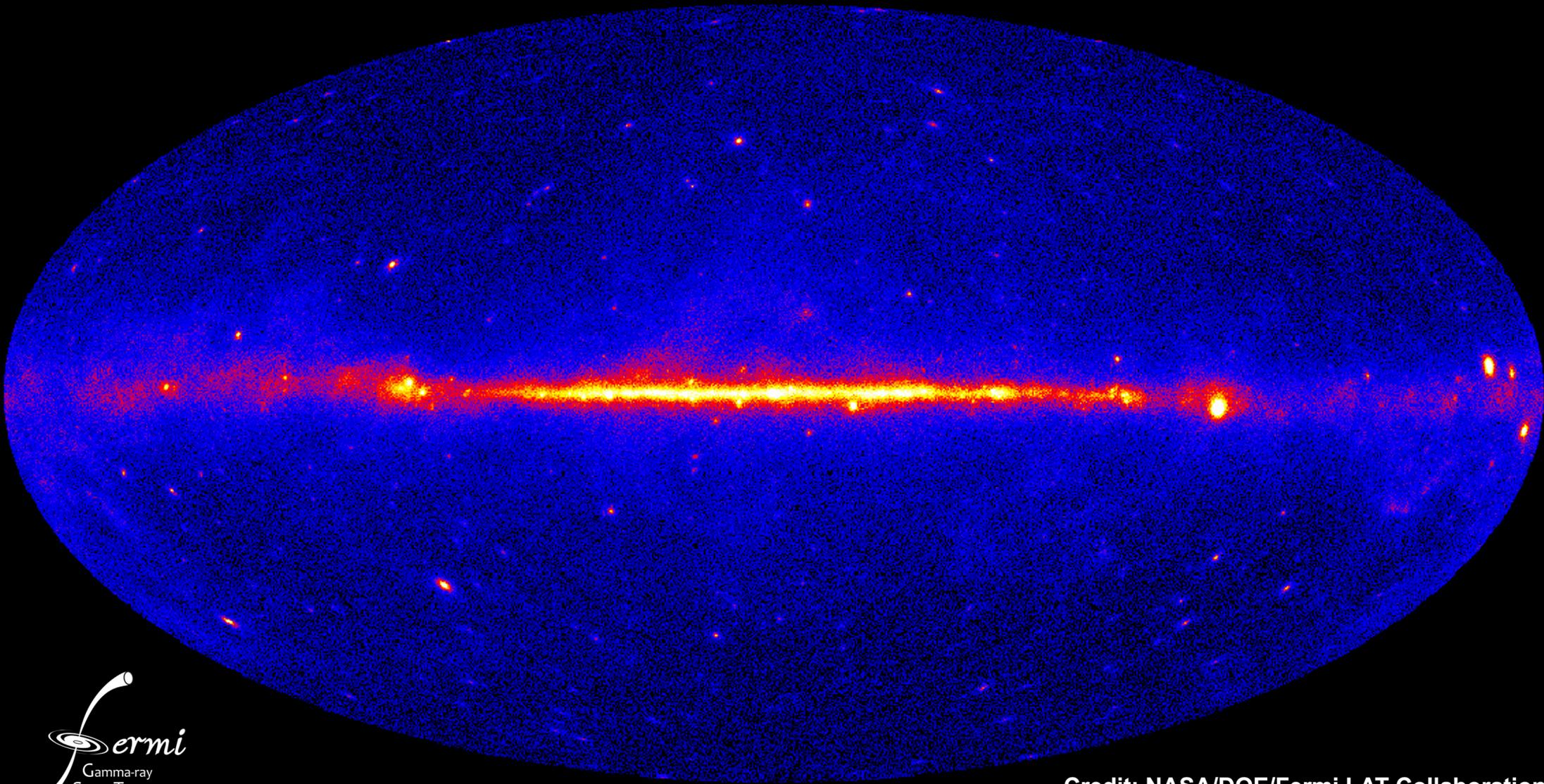
- Cross-correlation power spectrum

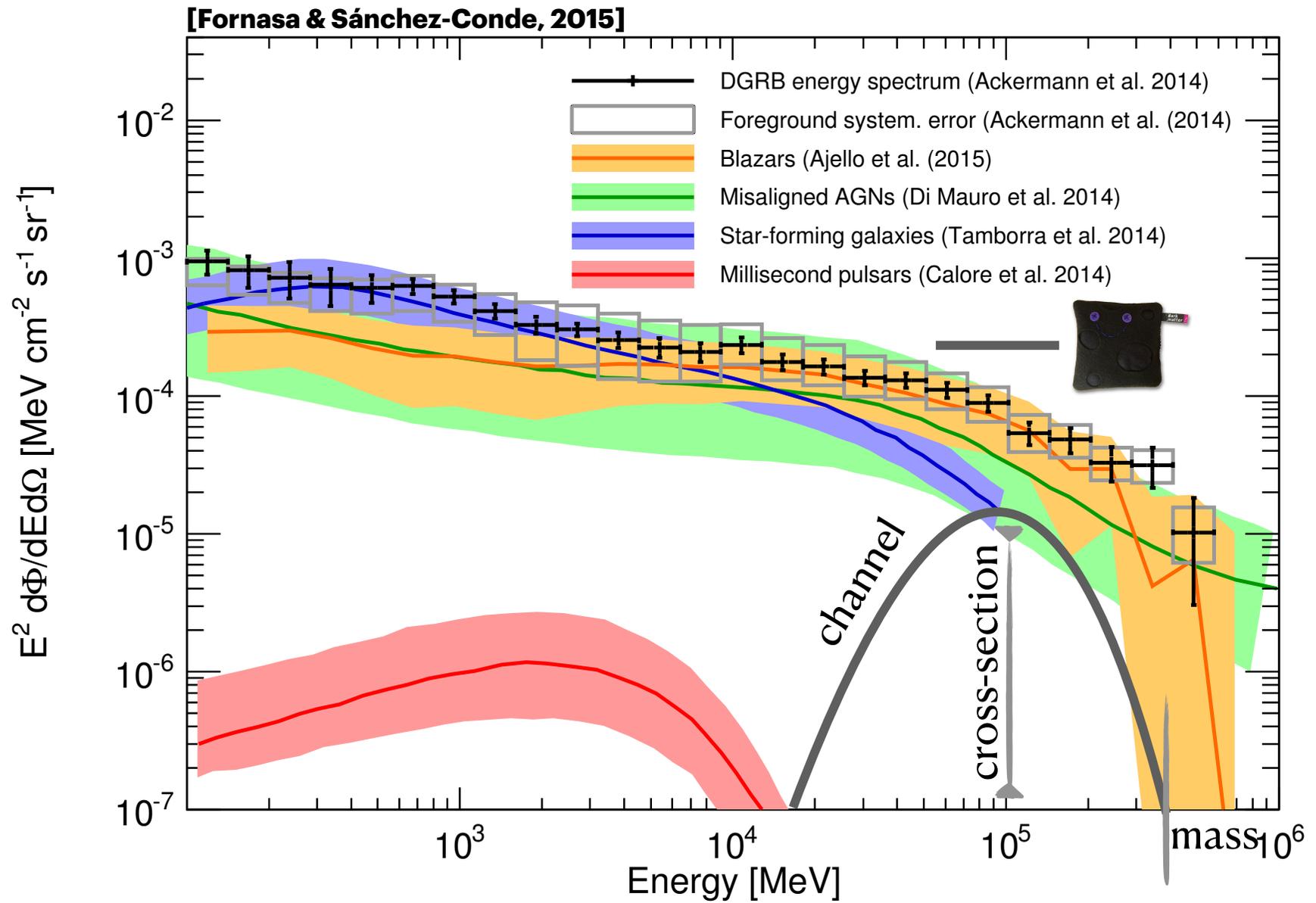
$$\langle f^{\text{obs}} g^{\text{obs}} \rangle = \langle f^{\text{cosmo}} g^{\text{cosmo}} \rangle + \langle f^{\text{cont}} g^{\text{cont}} \rangle + \langle f^{\text{cosmo}} g^{\text{cont}} \rangle + \langle g^{\text{cosmo}} f^{\text{cont}} \rangle$$

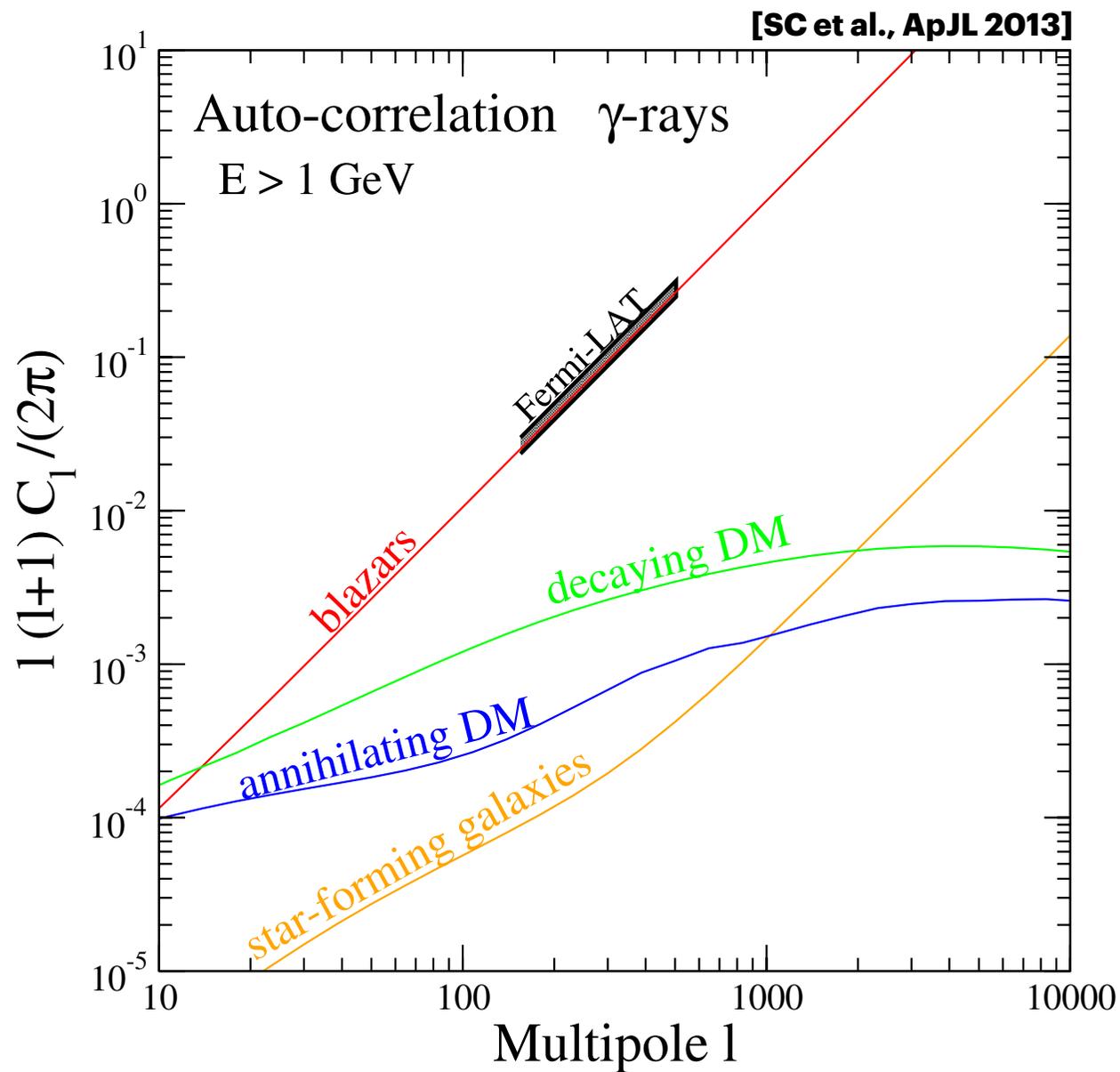
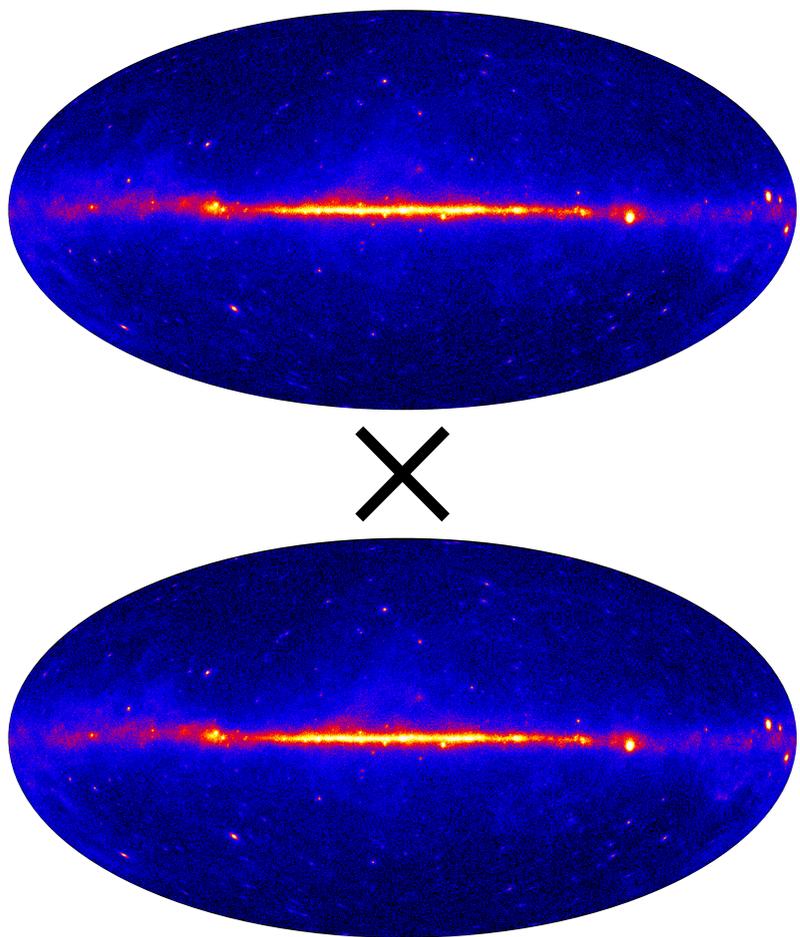
Synergies for Astro(particle)physics

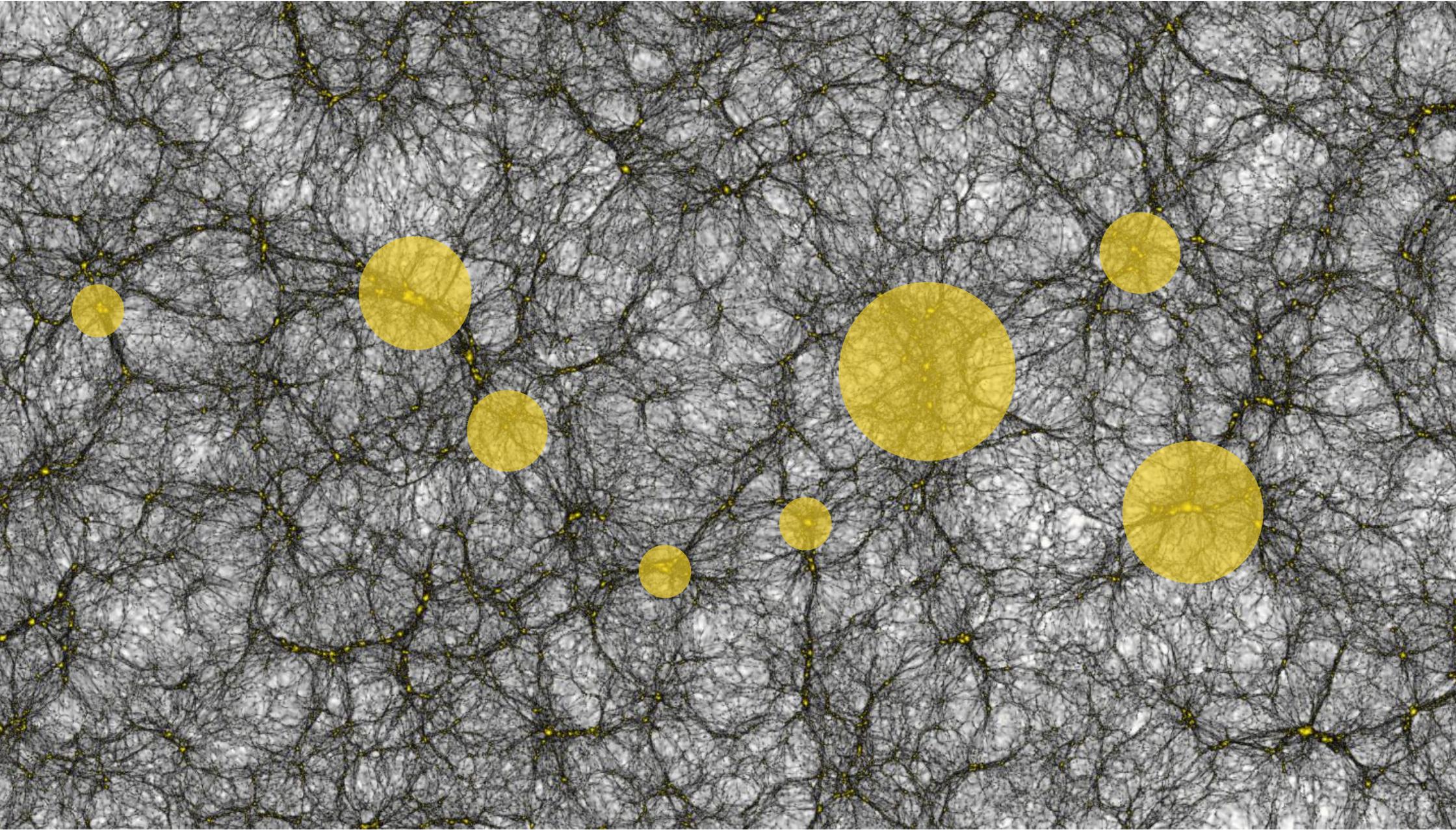


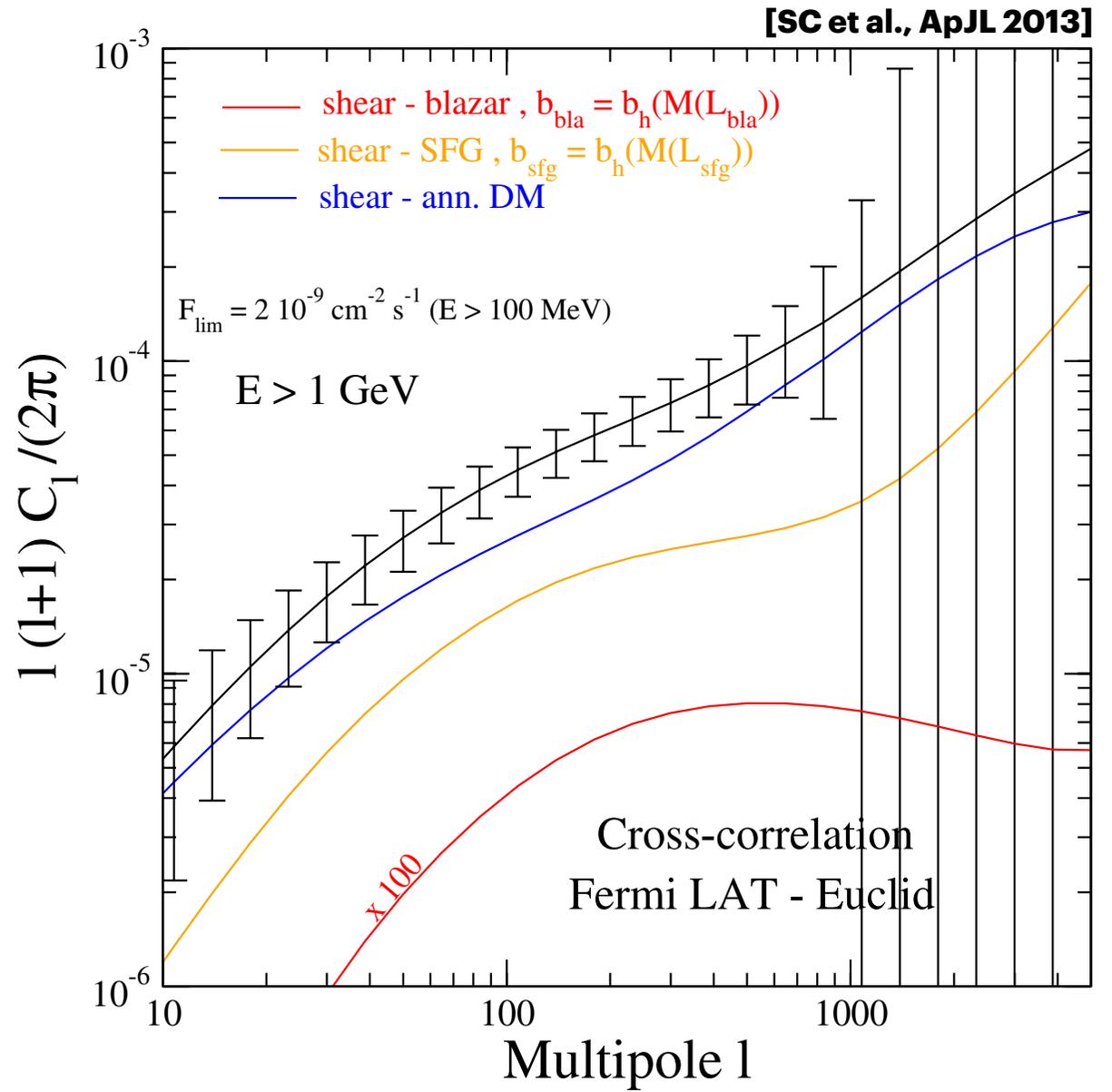
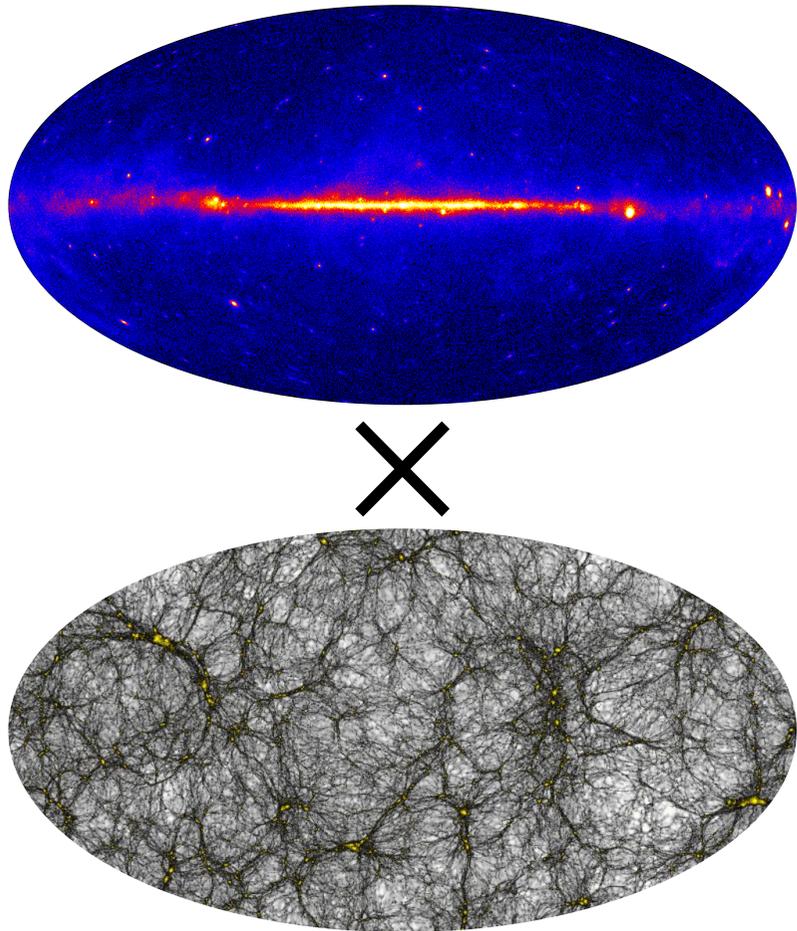
NASA's Fermi telescope reveals best-ever view of the gamma-ray sky



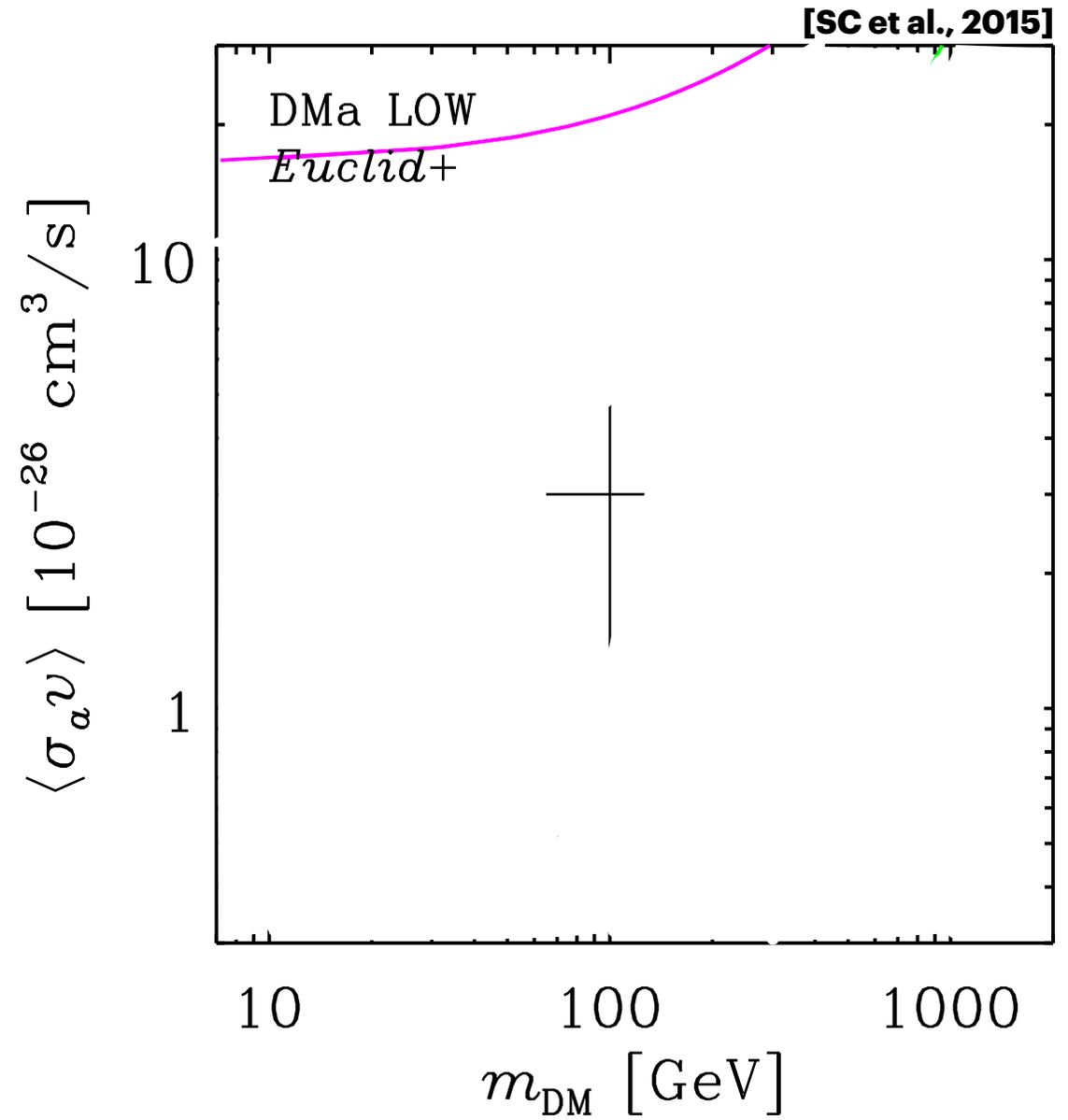






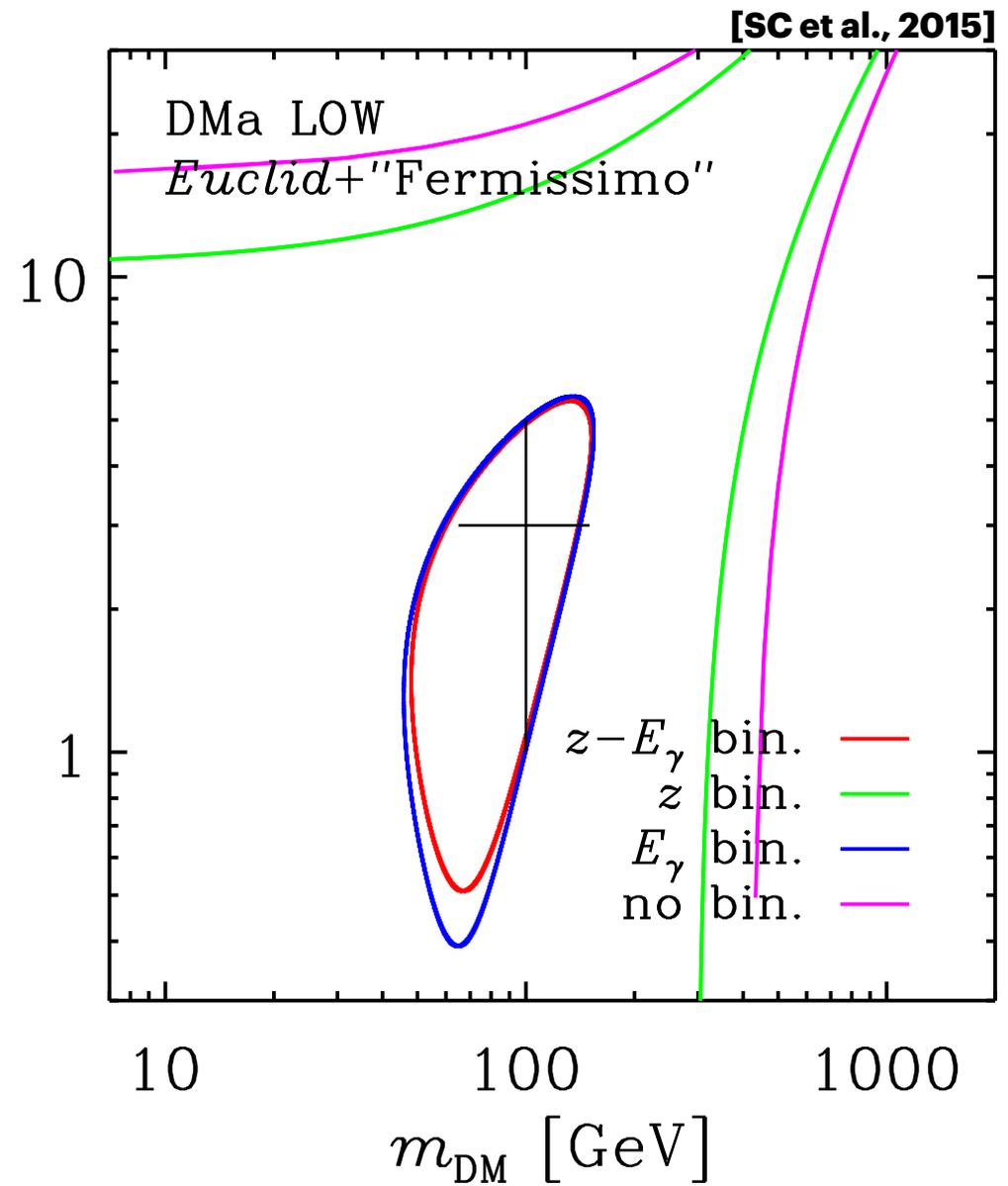


$C_{\ell}^{\gamma K}$



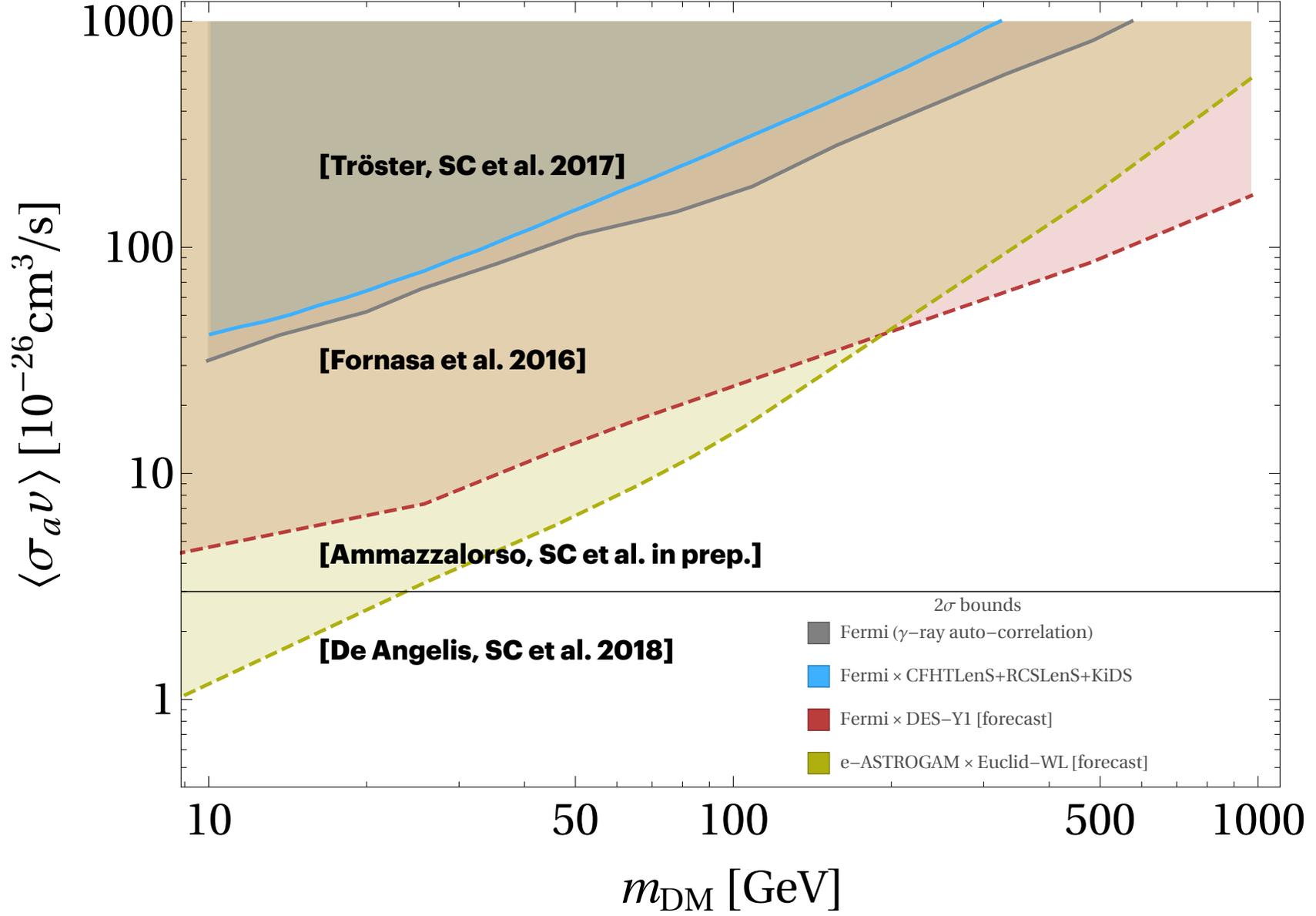
$$\begin{bmatrix}
 C_{\ell}^{\gamma_1 k_1} & C_{\ell}^{\gamma_1 k_2} & \dots & C_{\ell}^{\gamma_1 k_{N_z}} \\
 C_{\ell}^{\gamma_2 k_1} & C_{\ell}^{\gamma_2 k_2} & \dots & C_{\ell}^{\gamma_2 k_{N_z}} \\
 \vdots & \ddots & & \vdots \\
 C_{\ell}^{\gamma_1 k_1} & C_{\ell}^{\gamma_1 k_2} & \dots & C_{\ell}^{\gamma_1 k_{N_z}}
 \end{bmatrix}$$

$\langle \sigma_{\alpha\nu} \rangle [10^{-26} \text{ cm}^3/\text{s}]$

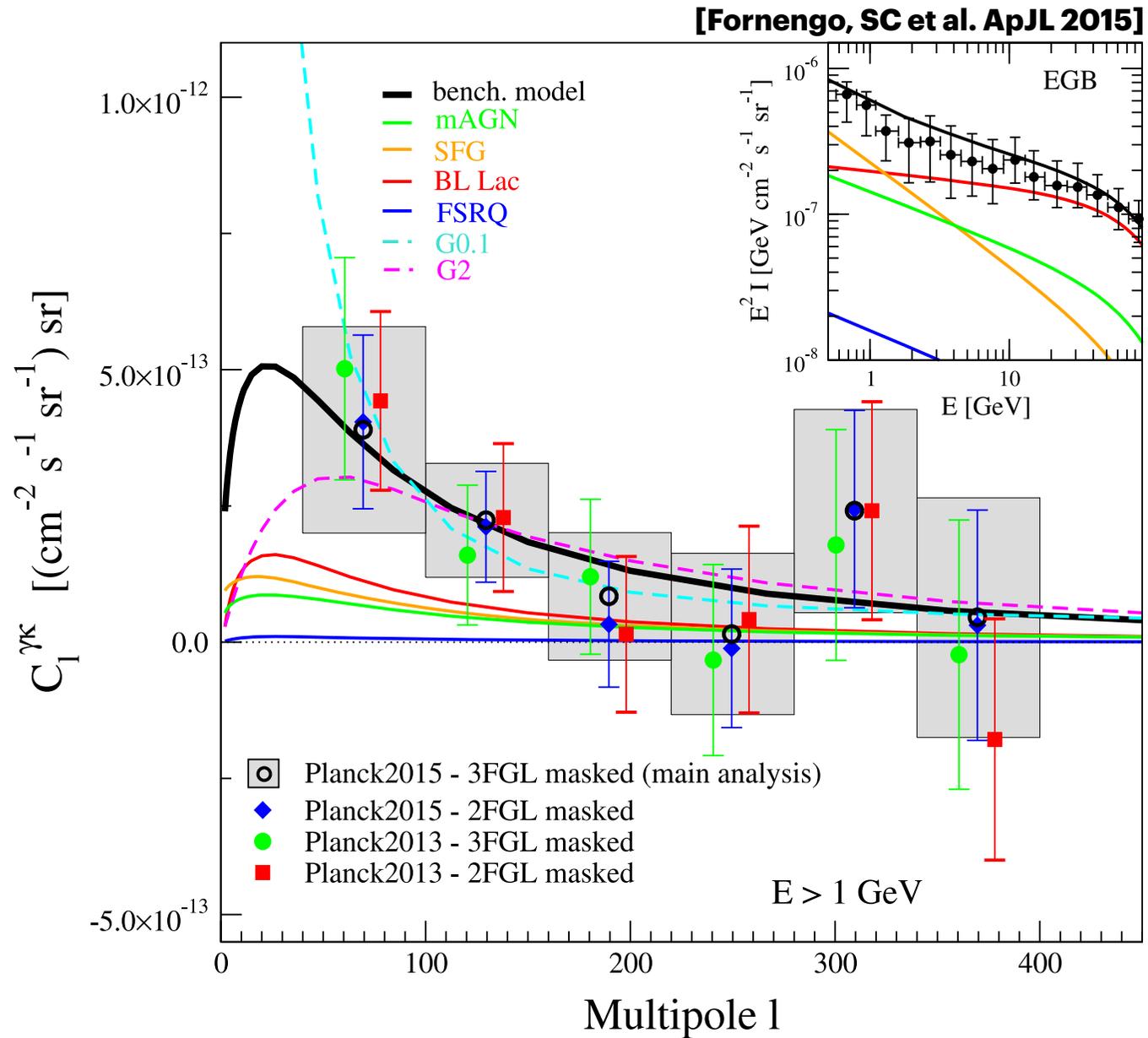


- Non-detections:

- Clustering of galaxies [*SDSS LRGs*] x UGRB [*Fermi Pass7-reprocessed (76 mths)*]
[Shirasaki et al. 2015]
- Cosmic shear [*CFHTLenS+RCSLenS*] x UGRB [*Fermi Pass7-r (76 mths), Pass8 (85 mths)*]
[Shirasaki et al. 2014, 2016]
- Cosmic shear [*Subaru HSC*] x UGRB [*Pass8 (85 mths)*]
[Shirasaki et al. 2018]
- Cosmic shear [*CFHTLenS+RCSLenS+KiDS*] x UGRB [*Fermi Pass8 (84 mths)*]
[Tröster, SC et al. 2017]

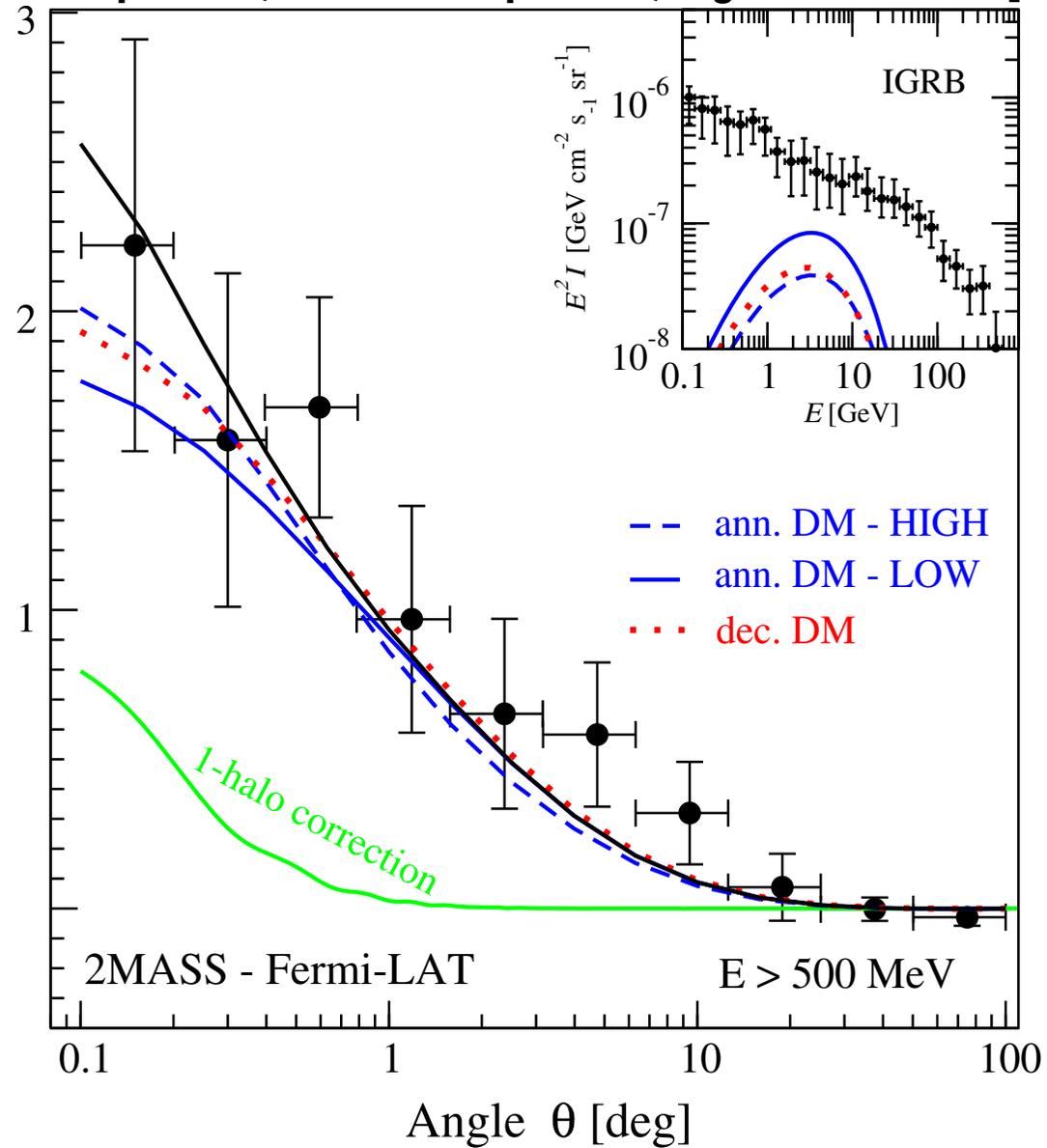


- $>3\sigma$ evidence
- CMB lensing
[Planck 2013 & 2015]
- UGRB
[Fermi Pass7-r (68 months)]

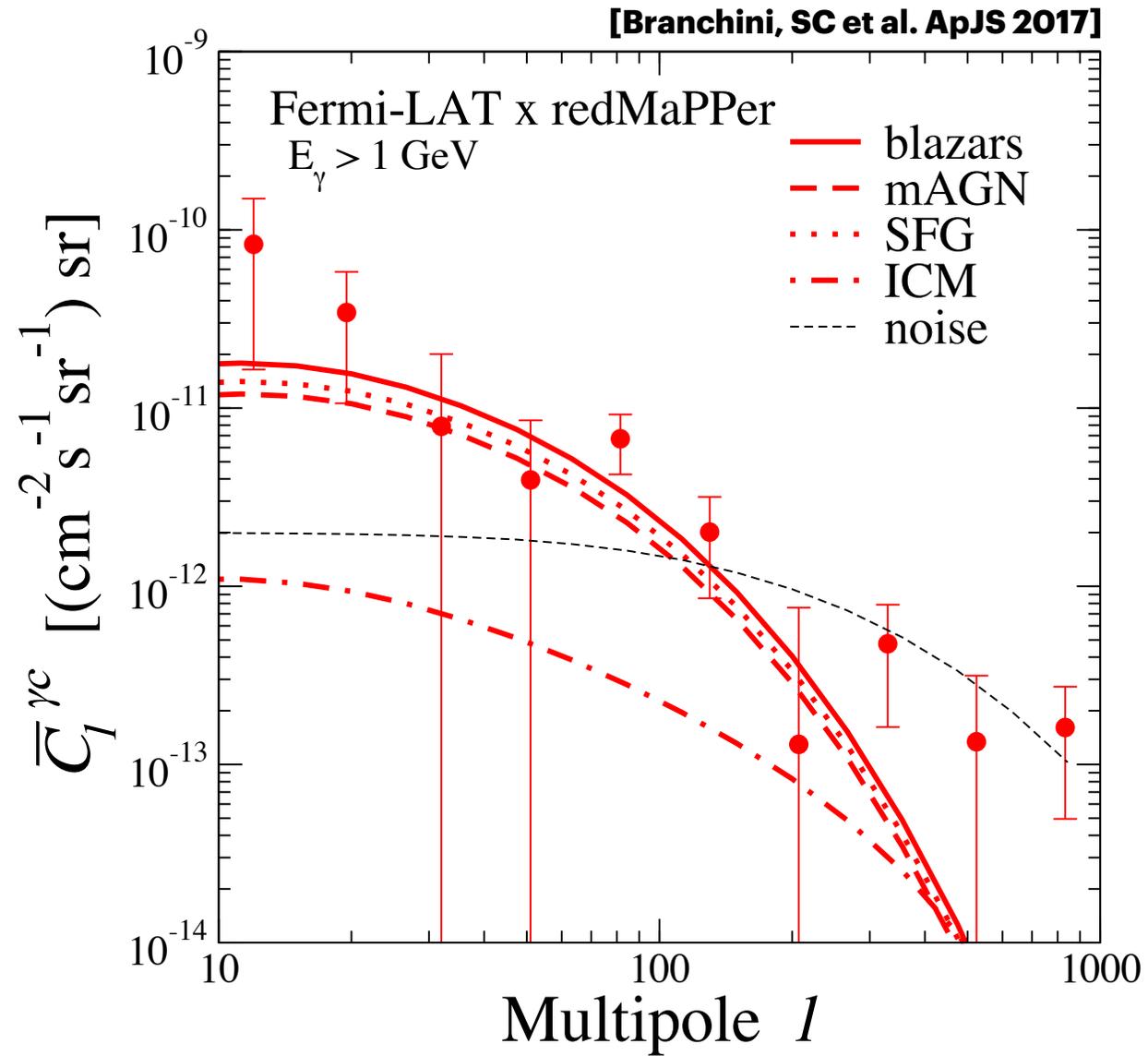


[Xia et al. ApJL 2015, Cuoco et al. ApJS 2015, Regis et al. PRL 2015]

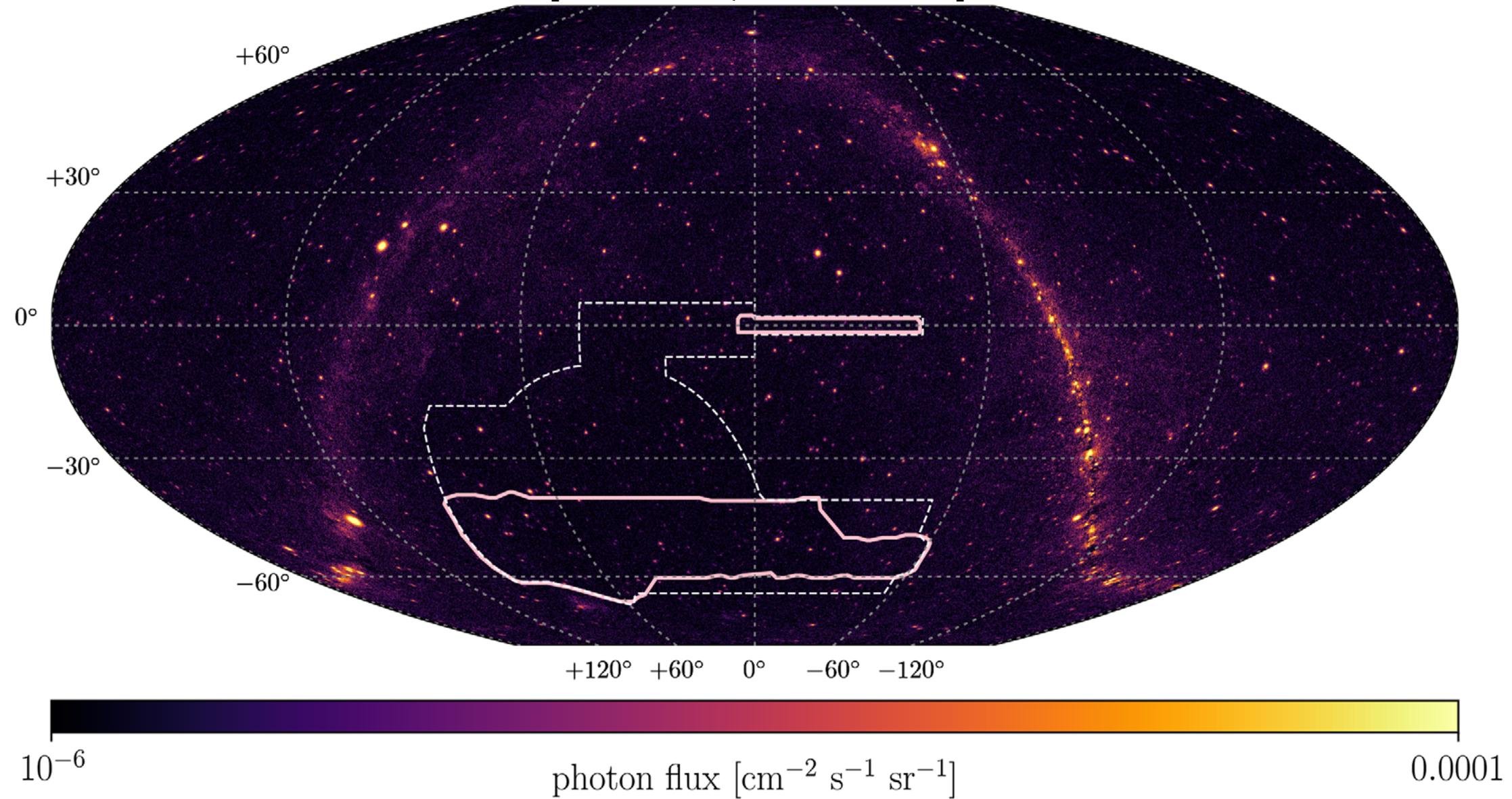
- $>3.5\sigma$ evidence
- Clustering of galaxies
[2MASS, NVSS, QSOs, SDSS]
- UGRB
[Fermi Pass7 (60 months)]



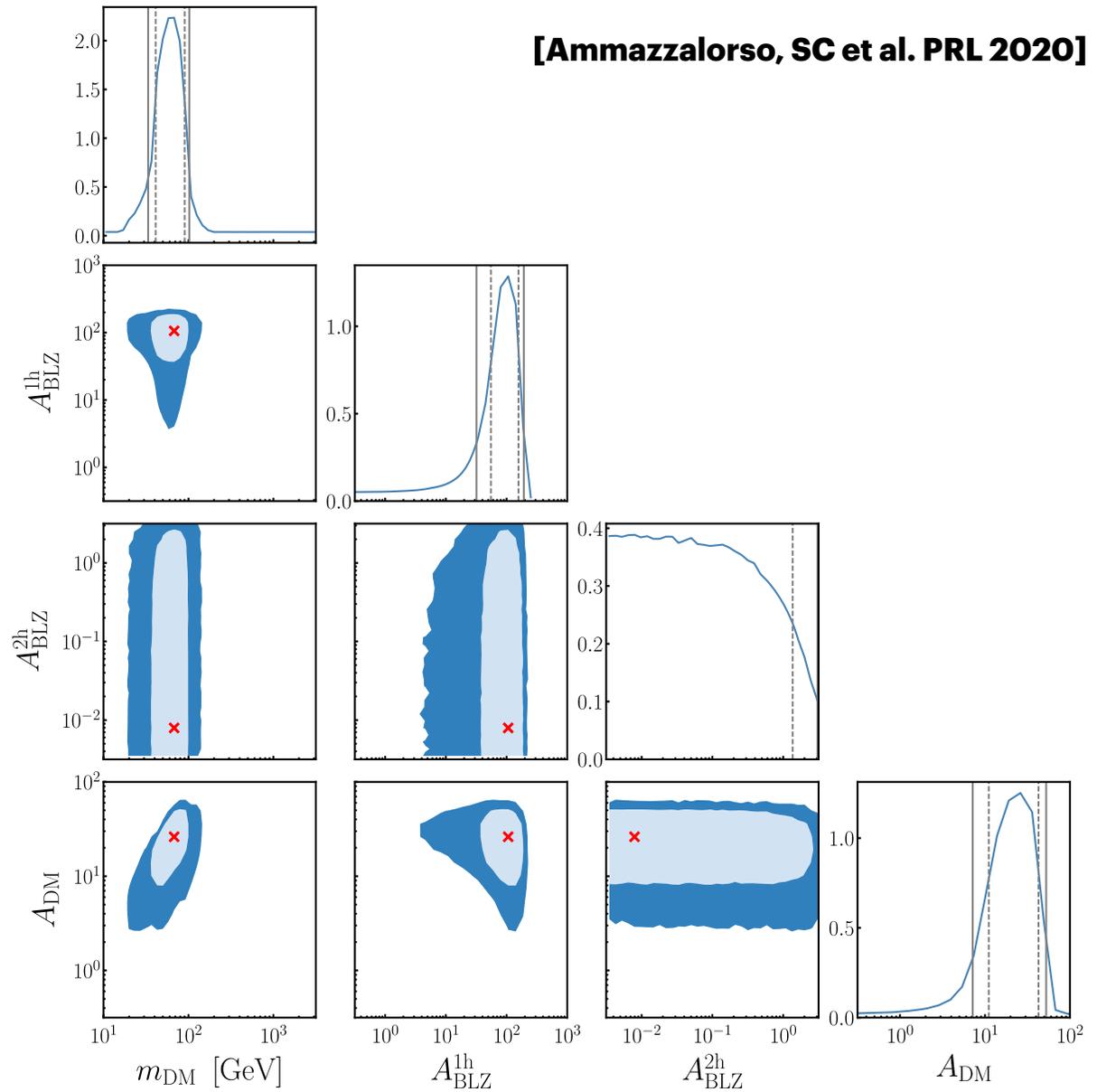
- $>5\sigma$ evidence
- Clustering of clusters
[Planck-SZ 2015, redMaPPer, WH12]
- UGRB
[Fermi Pass8 (78 mths)]



[Ammazzalorso, SC et al. PRL 2020]



- 5.3σ evidence
- Cosmic shear
[DES Y1]
- UGRB
[Fermi (108 mths)]



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**Astronomy
&
Astrophysics**

Detecting ultra-high-energy cosmic ray anisotropies through harmonic cross-correlations

Federico R. Urban¹, Stefano Camera^{2,3}, and David Alonso⁴

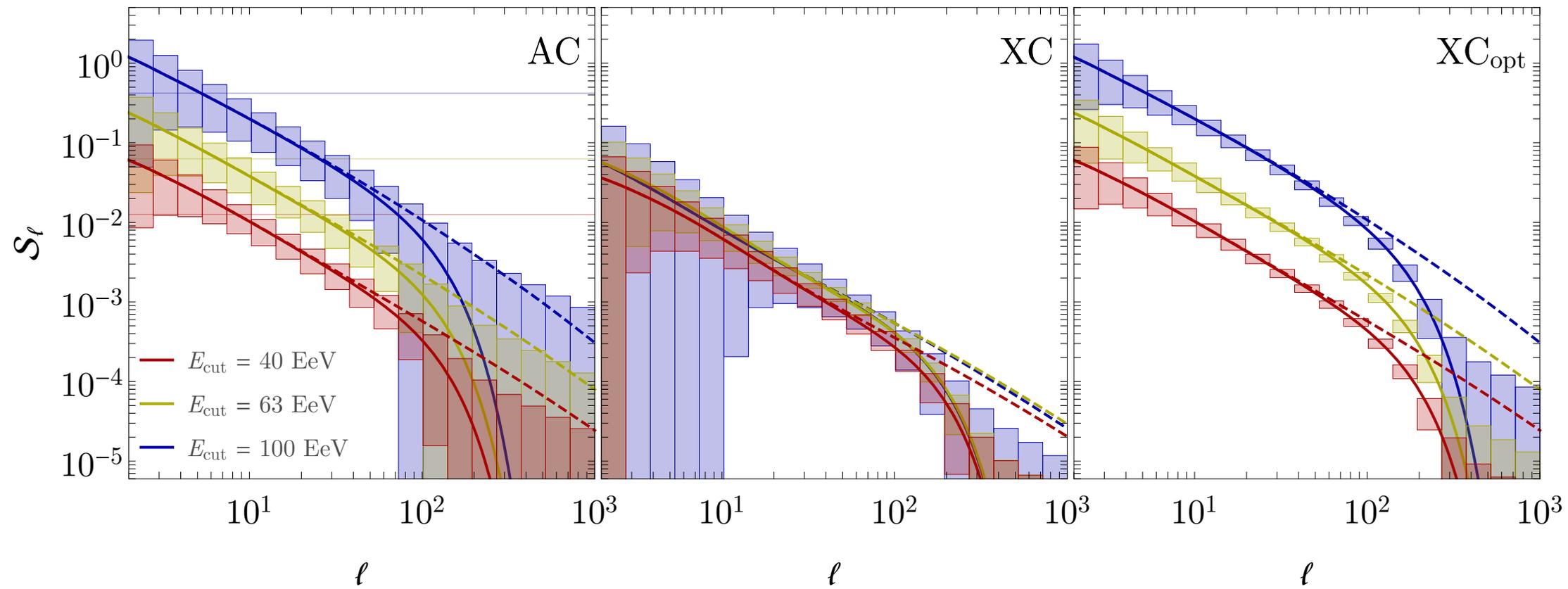
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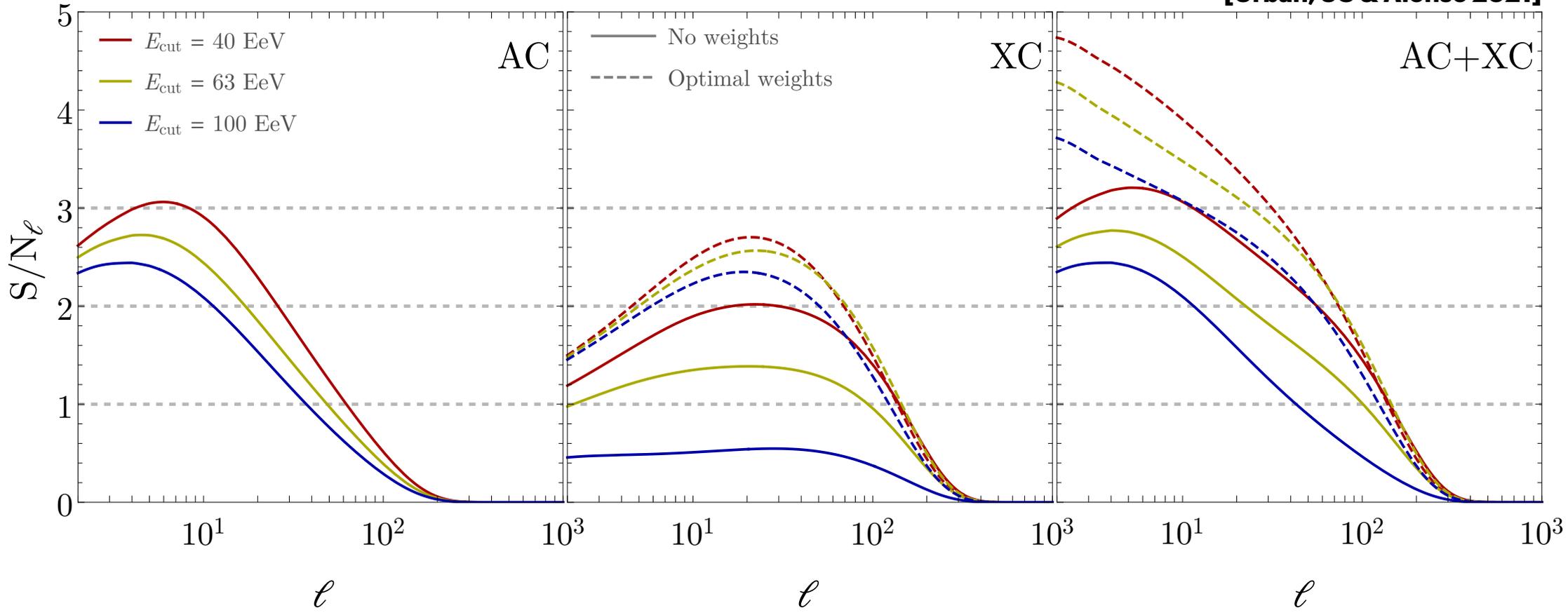
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Take-home message

- Great time for cosmological synergies at various wavelengths
- Cross-correlations crucial for:
 - Cross-checking validity of cosmological results
 - Accessing signal buried in noise or cosmic variance
[e.g. particle dark matter, UHECRs]
 - Removing/alleviating contamination from systematic effects
[e.g. radio-optical cosmic shear, galaxy and HI intensity mapping]