Searching for *FERMI* γ-Ray Diffuse Extragalactic Signal via Cross-Correlations with LSS

Jun-Qing Xia (IHEP, Beijing)

collaboration with
A.Cuoco, M.Regis, N.Fornengo, E.Branchini, M.Viel
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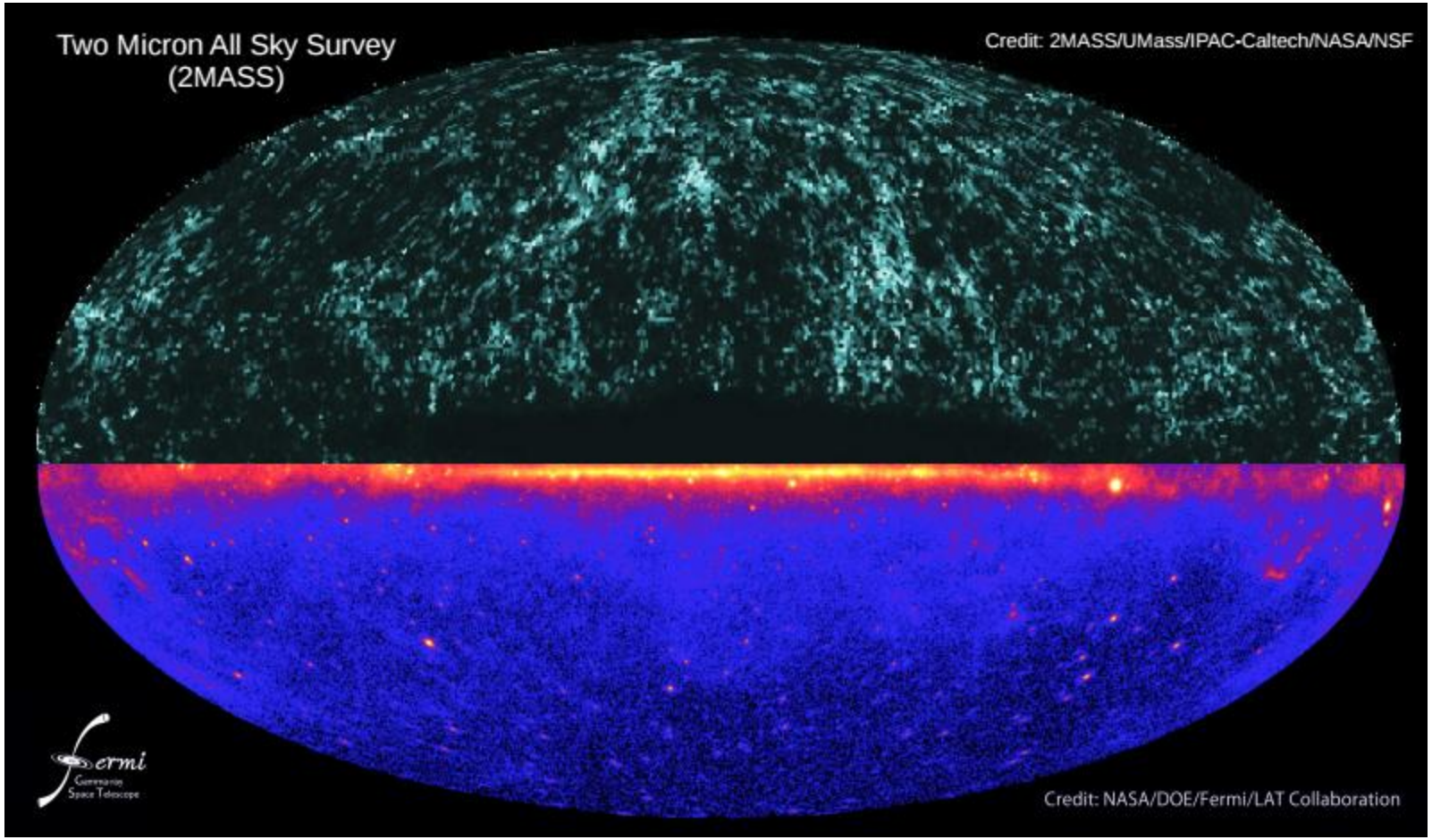
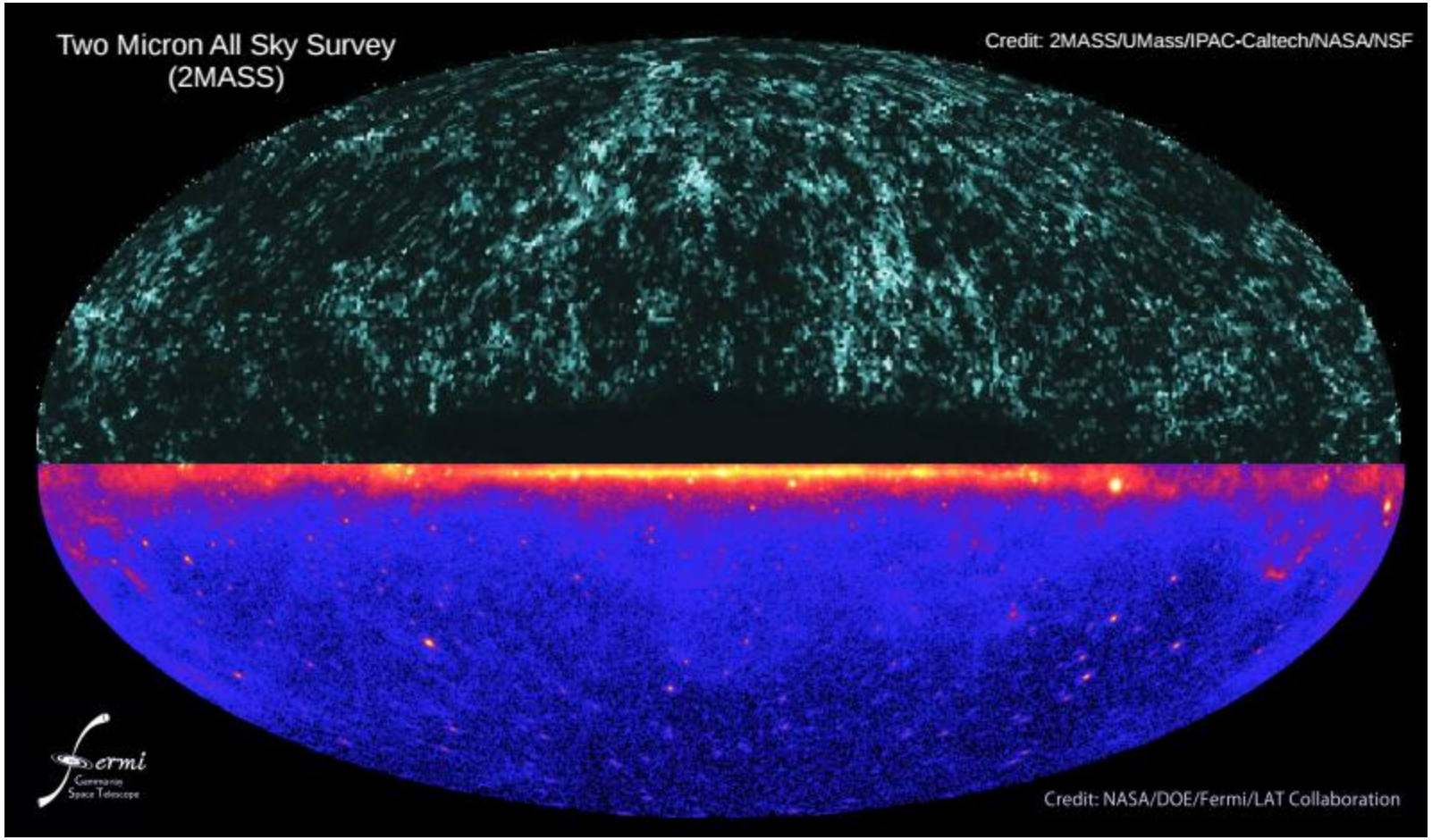
FERMI-LAT x LSS



- **Searching for isotropic γ-ray background signal**
- **Separating unresolved sources contributions**
- **Clarifying the origin of IGRB**

FERMI-LAT x LSS



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Theoretical Background

- **Cross-correlation between the extragalactic background and the fluctuation of discrete LSS sources**

$$C_l^{Ij} = \frac{2}{\pi}\int k^2 P(k)\left[G_l^I(k)\right]\left[G_l^j(k)\right]dk$$

$$G_l^I(k) = \int \rho_\gamma(z) b_\gamma(z) D(z) j_l[k\chi(z)]dz$$

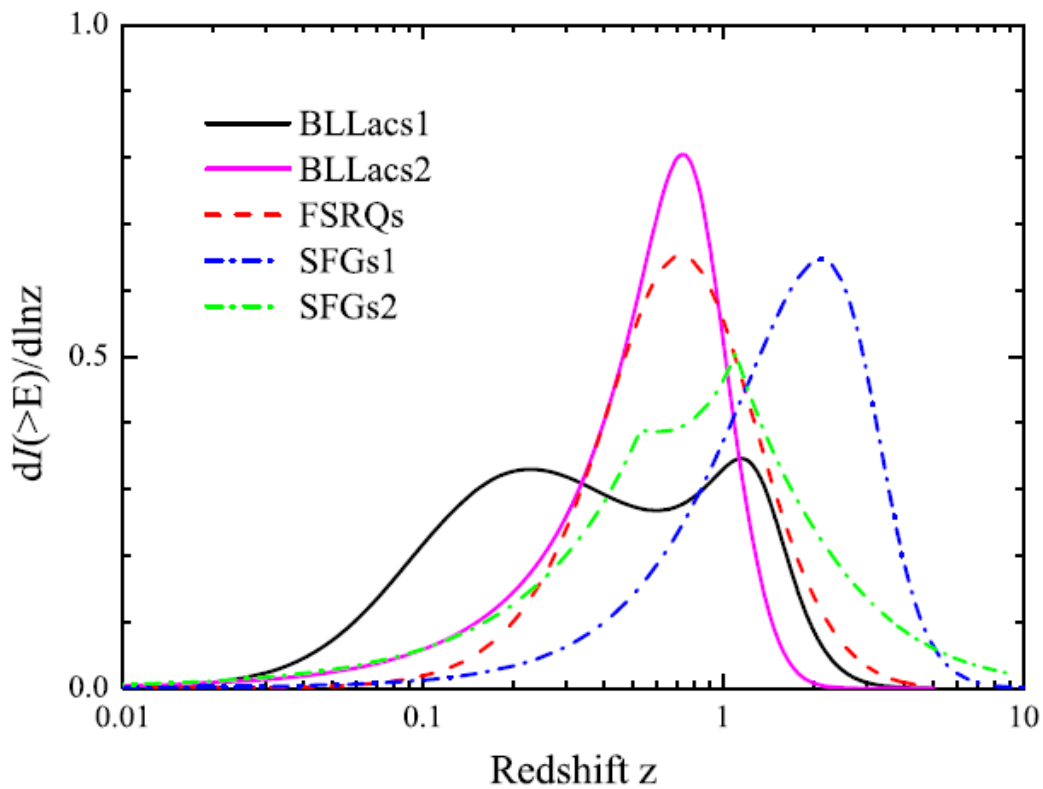
$$\rho_\gamma(z) \equiv \int_{L_{\mathrm{MIN}}}^{L_{\mathrm{MAX}}(z)} \Phi_j\left(L_\gamma, z\right) L_\gamma \frac{(1+z)^{-\mu_j\left(L_\gamma\right)}}{H(z)} dL_\gamma$$

$$\mu\left(L_\gamma\right) = \mu^* + \beta \times \left(\log_{10}\left(L_\gamma\right) - 46\right)$$

$$I_j(>E) \equiv \int_E^\infty \frac{dI_j}{dE} dE = \frac{cE^{2-\Gamma_j}}{4\pi}\int \rho_\gamma(z) dz$$

Unresolved Sources

- **Specific type of unresolved sources**
  - **Flat Spectrum Radio Quasars (FSRQs)**
  - **BL Lacertae objects (BL Lacs)**
  - **Star-Forming Galaxies (SFGs)**
  - **Misaligned AGNs (mAGNs)**



Bias & Luminosity Density

- **FSRQs:** $b_{\rm FSRQ}(z) = 0.42 + 0.04(1+z) + 0.25(1+z)^2$
- **BL Lacs:**
- **SFGs:** $b_{\rm SFG} = 1$ $\quad I(E) \propto E^{-\Gamma}$
- **mAGNs: the redshift distribution is similar with SFGs that peak at z ~ 2. The bias is high, however, the constraint is very poor now.**

Model	A^{a}	γ_1	L_*^{b}	γ_2	z_c^*	p_1^*
BLLacs1 LDDE	3.39×10^4	0.27	0.28	1.86	1.34	2.24
BLLacs2 LDDE	9.20×10^2	1.12	2.43	3.71	1.67	4.50
FSRQ LDDE	3.06×10^4	0.21	0.84	1.58	1.47	7.35

τ	p_2	α	μ^*	β	σ
4.92	−7.37	4.53×10^{-2}	2.10	6.46×10^{-2}	0.26
0.0	−12.88	4.46×10^{-2}	2.12	6.04×10^{-2}	0.26
0.0	−6.51	0.21	2.44	0.0	0.18

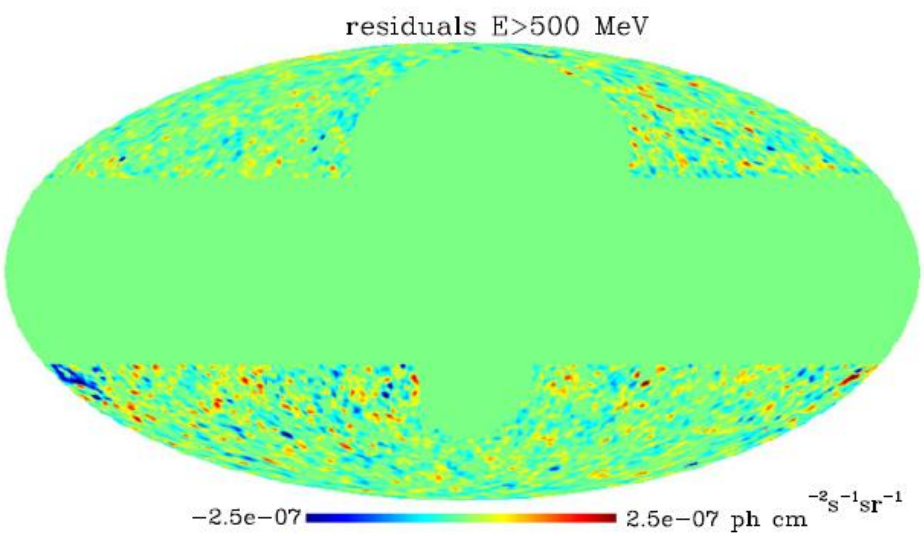
FERMI-LAT Flux Maps

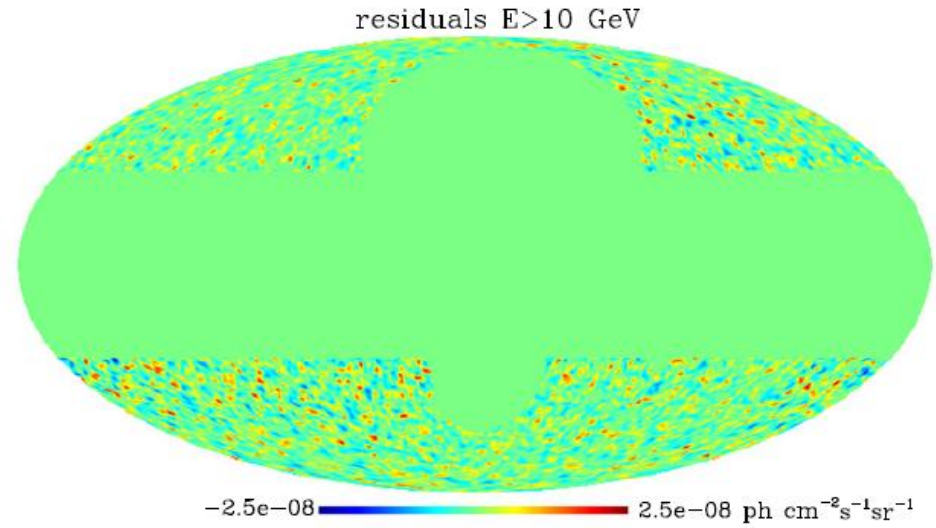
- **Best experiment to investigate nature of IGRB**
  - **Wide Energy Range: 20MeV ~ >300GeV**
  - **Excellent Angular Resolution: ~ 0.1° above 10GeV**
  - **Large Field of View: ~ 2.4 sr**
  - **Efficient rejection of background from charged particles**
- **Final Flux Maps:**
  - **60 months of data: 2008 ~ 2013**
  - **Using *P7REP_CLEAN* event selection: reduce cosmic-ray background contamination**
  - **Reducing the contamination from the bright Earth limb emission**
  - **Producing the corresponding exposure maps and dividing the count maps by exposure maps in three energy ranges: > 0.5GeV, > 1GeV, > 10GeV**
  - **Using both back-converting and front-converting events**

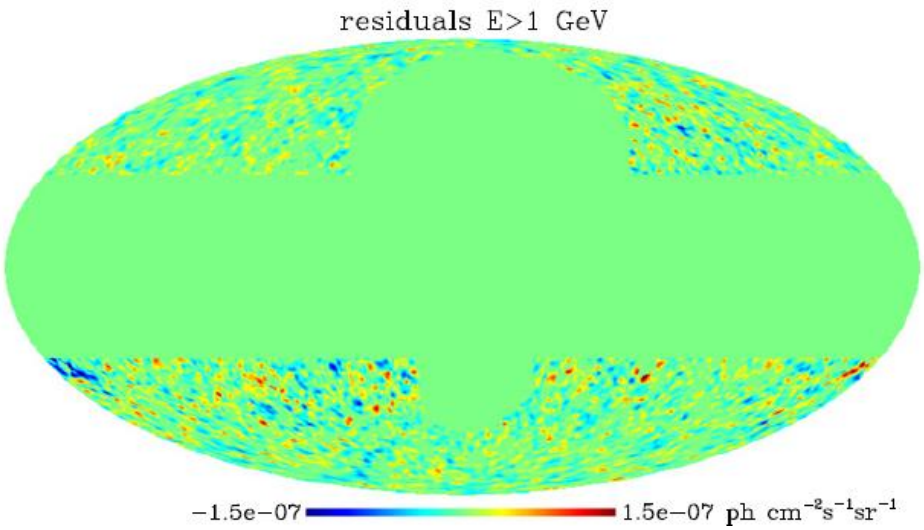
Masks used to subtract contaminations

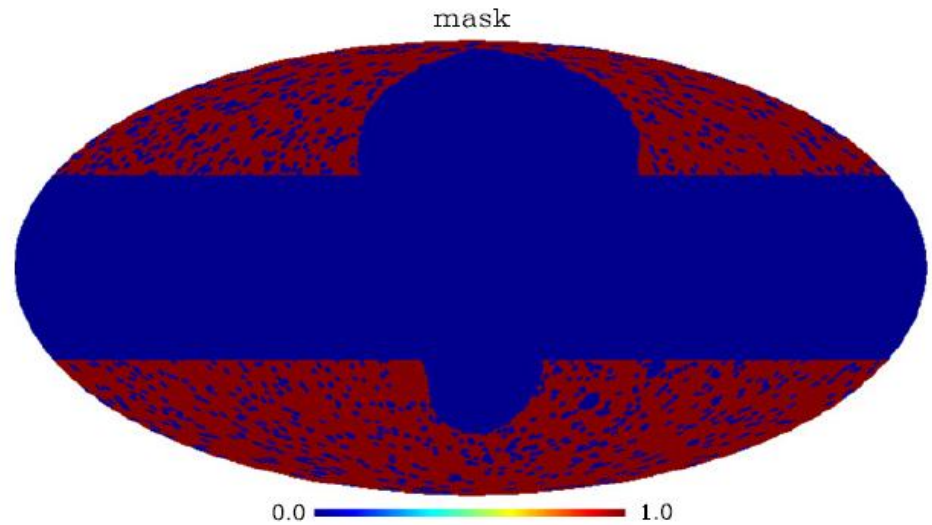
- Applying a Galactic latitude cut |b| > 30° to reduce the impact of the Galactic emission
- Excluding the region associated with the Fermi Bubbles and the Loop I structure located at high Galactic latitude
- Removing pixels placed at the positions of all resolved sources
- Using Galactic diffuse emission model to subtract from the observed emission to obtain the cleaned maps
- Subtracting the contributions from solar and lunar emission along the ecliptic
- Removing all contributions from multipoles up to \ell = 10 to reduce spurious signals at large scales

Maps and Masks





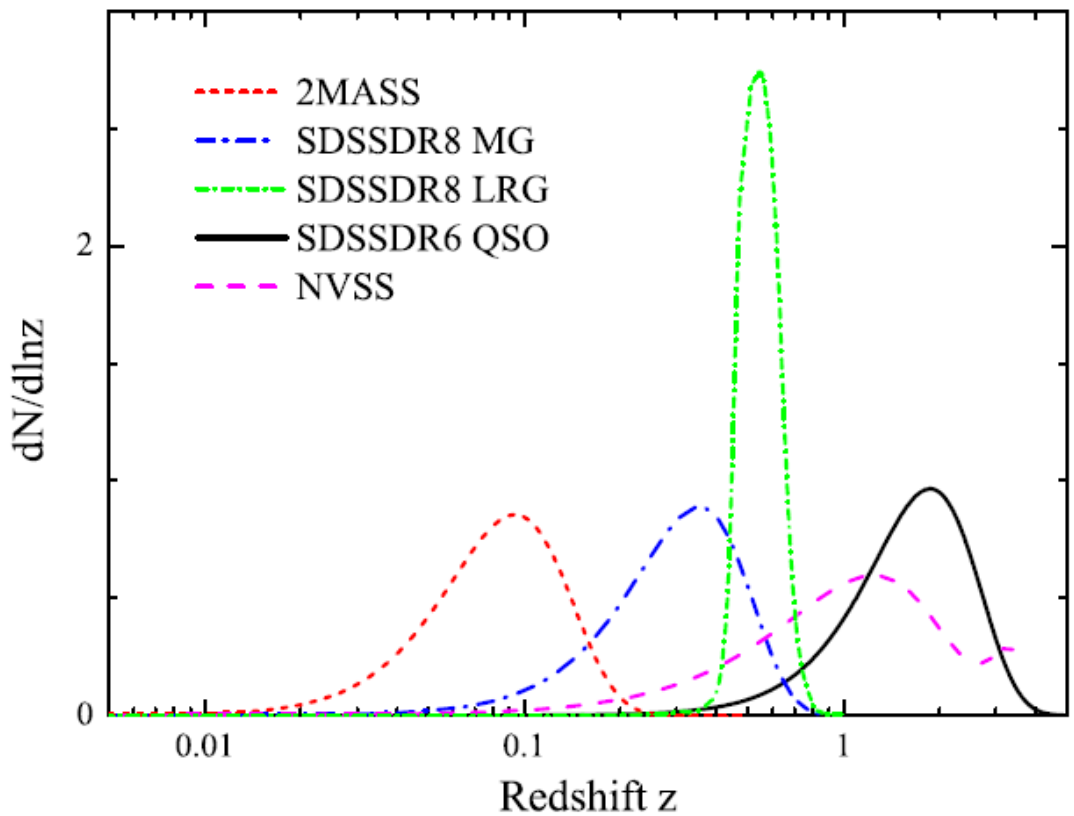




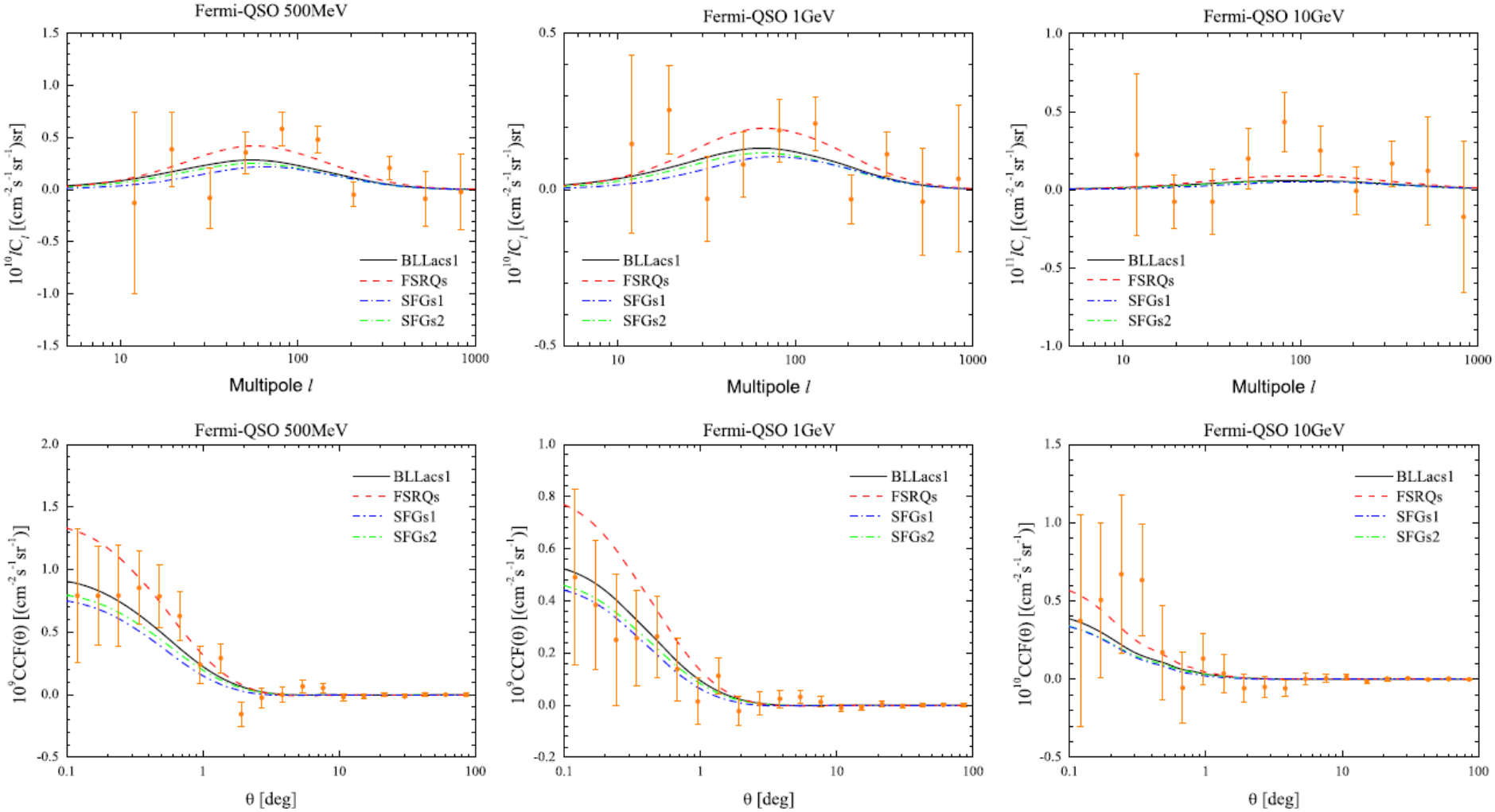
LSS Galaxies Sources

- **We consider five LSS catalogs:**
  - **Low z: 2MASS, SDSS DR8 Main galaxies, SDSS DR8 LRGs**
  - **High z: SDSS DR6 QSOs, NVSS**

$$G_l^j(k) = \int \frac{dN(z)}{dz} b_j(z) D(z) j_l[k\chi(z)] dz,$$



FERMI x QSO Result

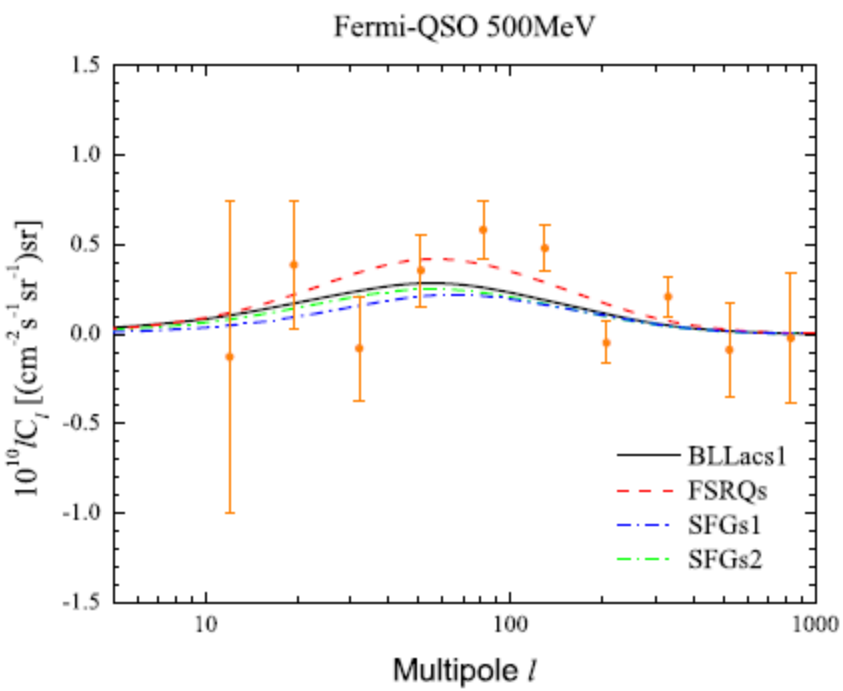


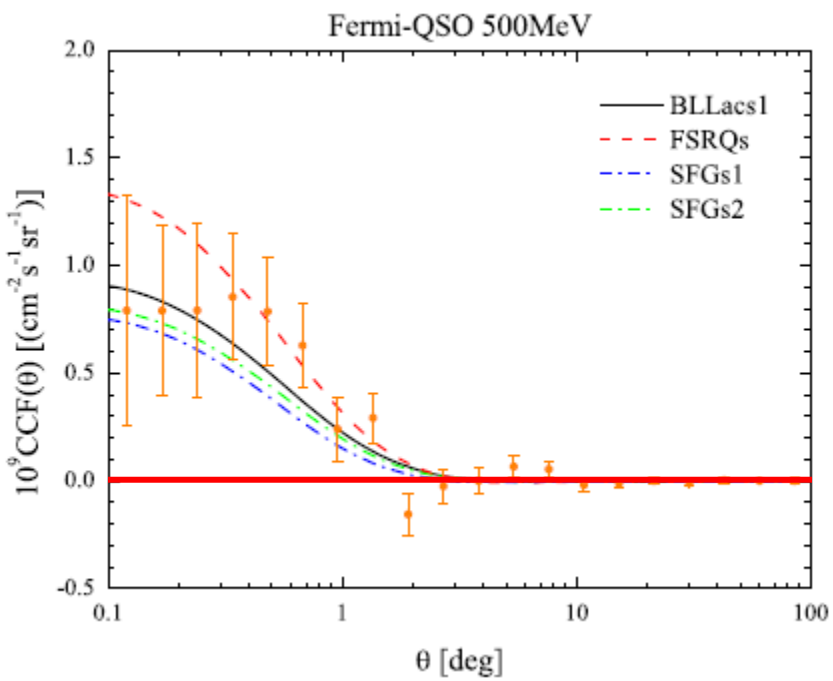
FERMI x QSO Result

- **At Θ<1°, observe a cross-correlation signal that is more significant in the low-energy band.**
- **Observations are consistent with theoretical predictions.**

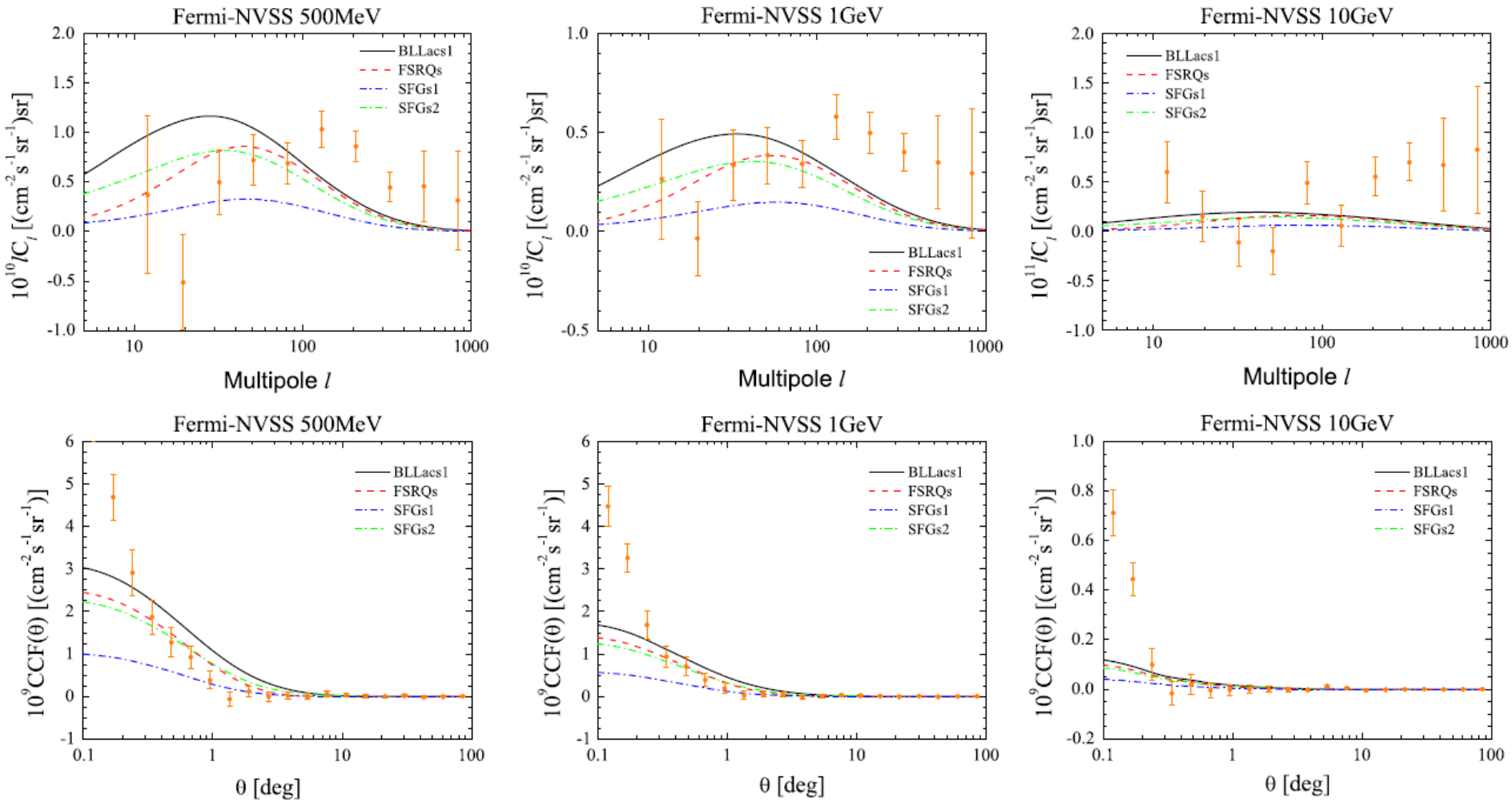
SDSS-QSO			SDSS-QSO		
χ^2_{bf}	σ	TS	χ^2_{bf}	σ	TS
9.7	5.3	28.6	9.0	4.5	21
7.6	3.3	10.9	3.5	2.3	5.1
4.6	2.7	7.3	4.8	1.6	2.6

$$TS = \chi_0^2 - \chi_{bf}^2$$





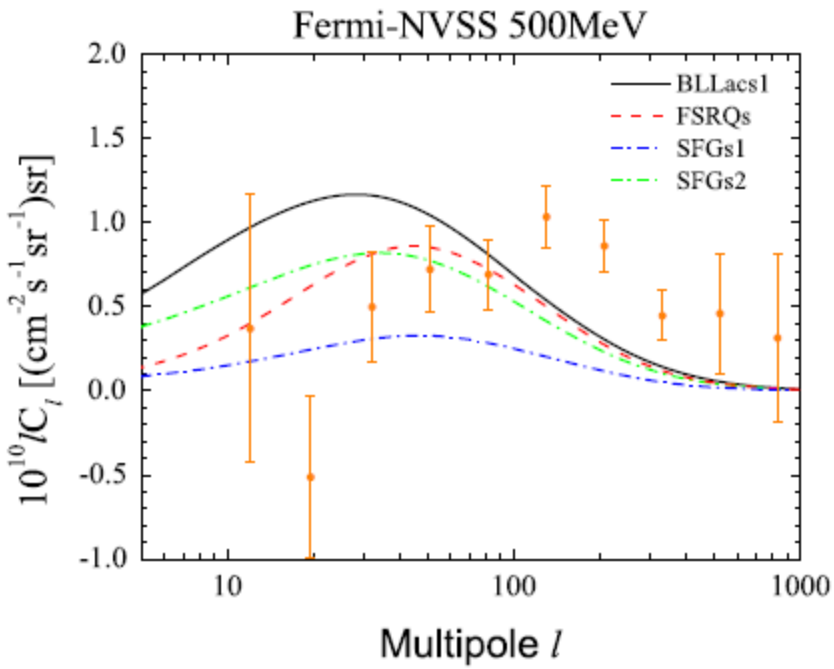
FERMI x NVSS Result

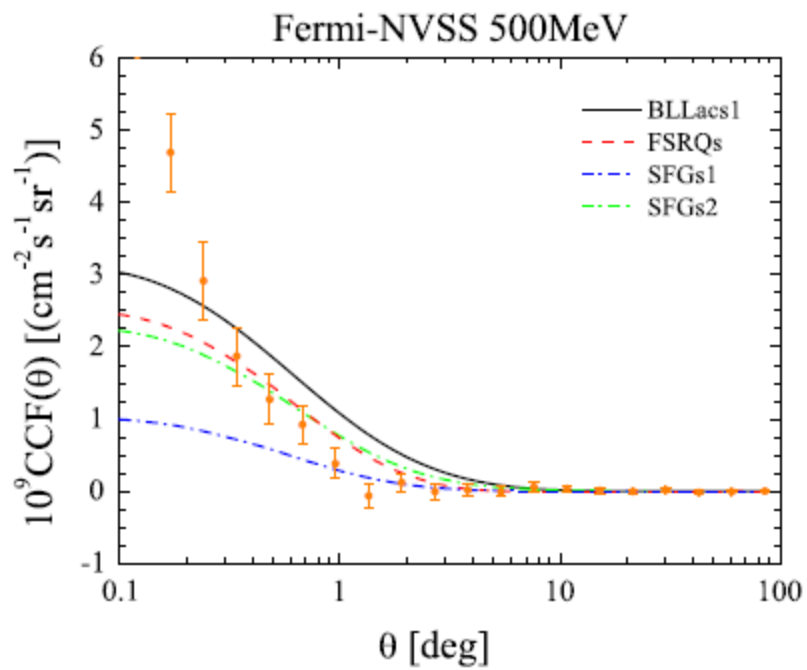


FERMI x NVSS Result

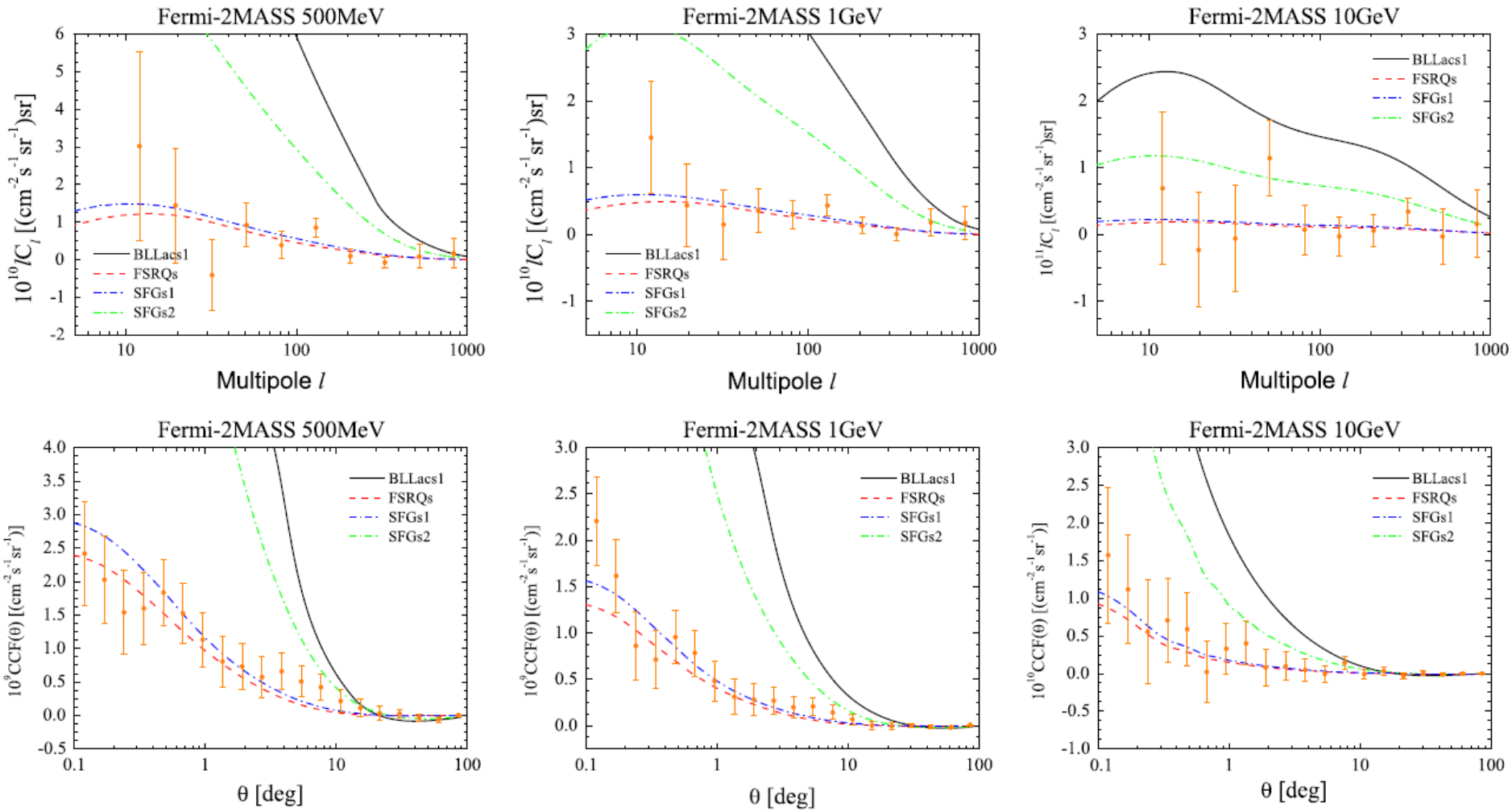
- **Detecting a strong signal at Θ<1° and \ell > 100**
- **Due to a one-halo term, or part of NVSS sources are also themselves γ-ray emitters.**
- **All models match to the data at Θ>1° well.**

NVSS (PSF)			NVSS (PSF)		
χ^2_{bf}	σ	TS	χ^2_{bf}	σ	TS
7.3	9.6	92.3	3.6	9.9	97.3
5.3	9.1	82.8	4.9	10.3	106.4
9.3	4.8	23.2	5.8	7.7	59.4





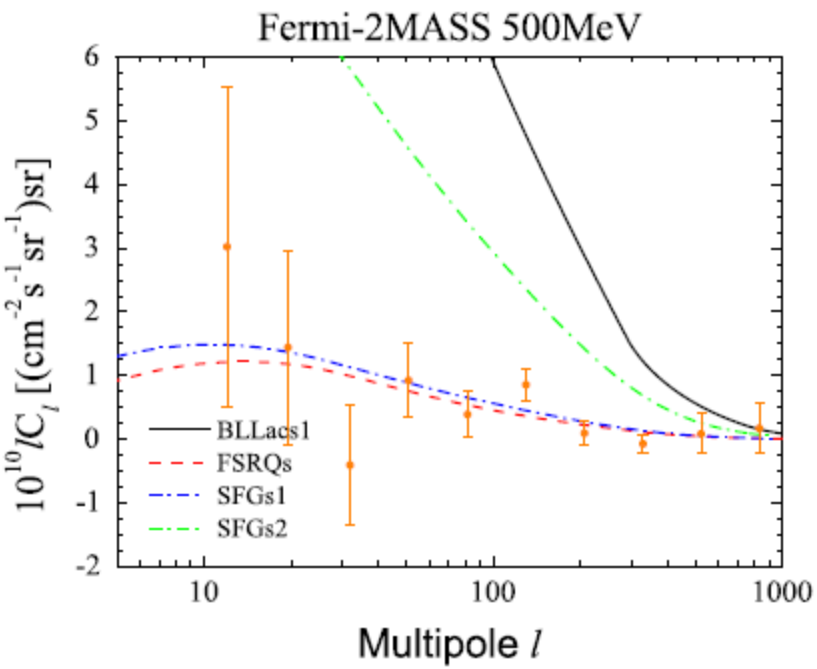
FERMI x 2MASS Result

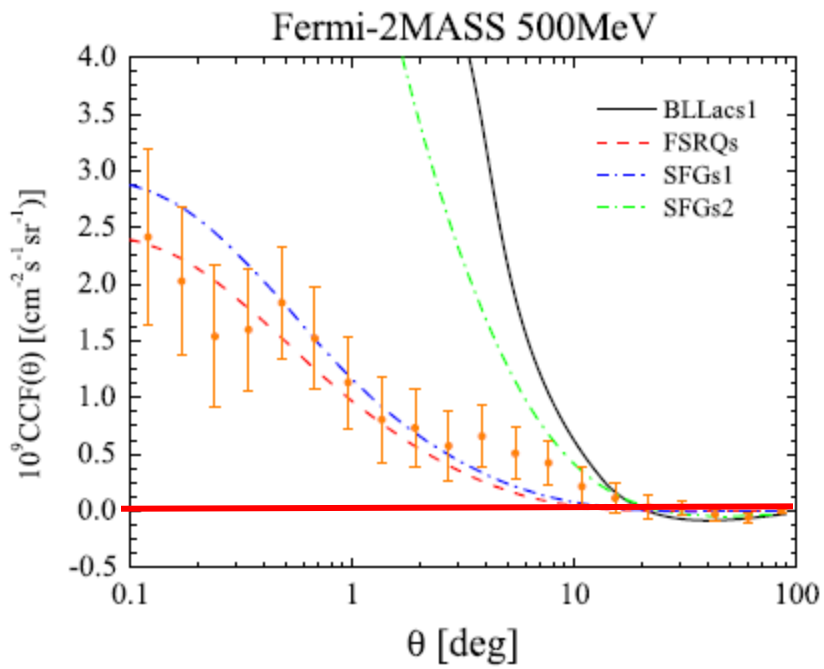


FERMI x 2MASS Result

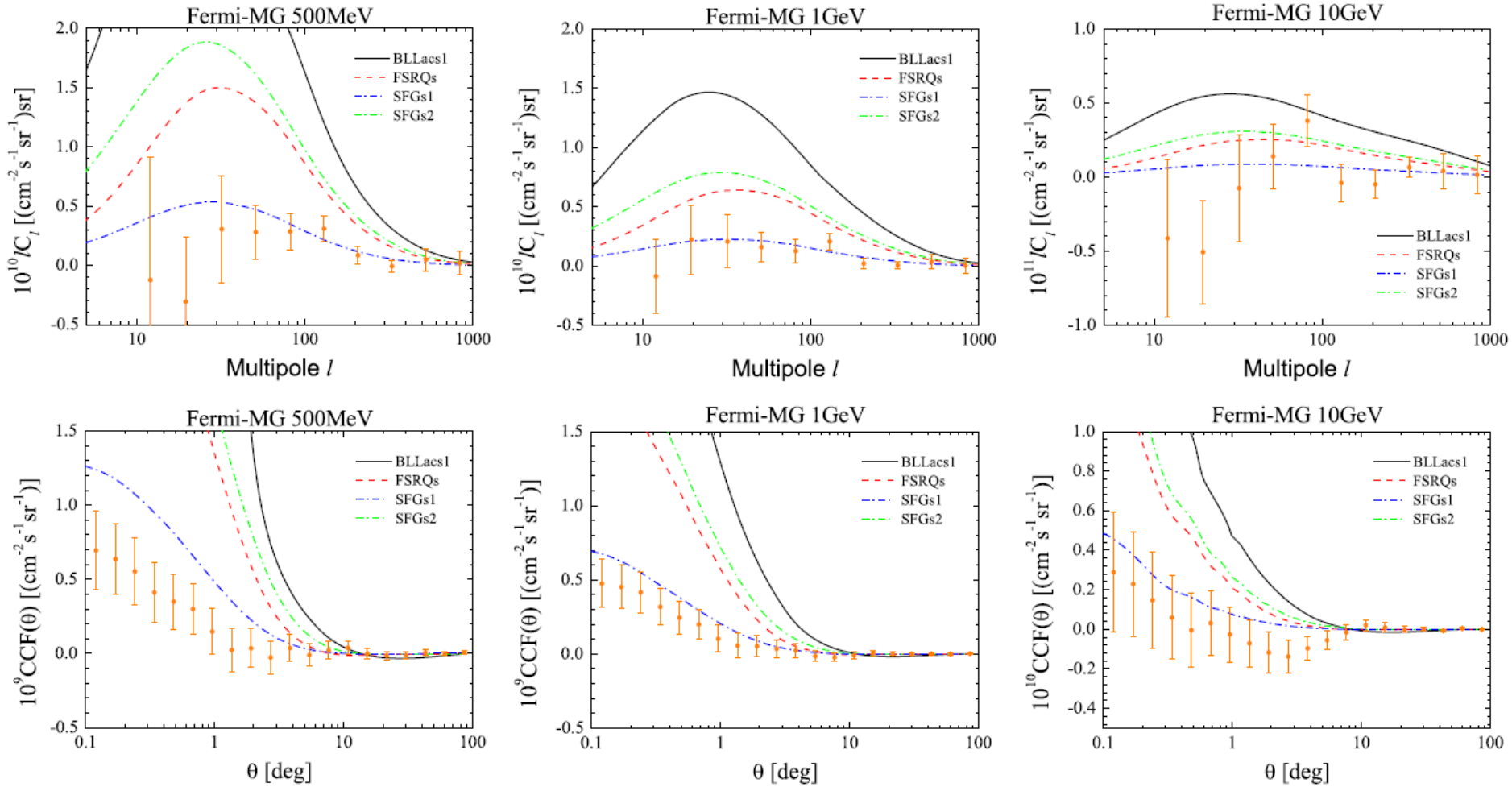
- **Observing the CCF and CAPS signal at Θ<10° and \ell < 200 at about 3.5\sigma**
- **Contribution from BL Lacs to IGRB diffuse emission is suppressed at low redshift.**

2MASS			2MASS		
χ^2_{bf}	σ	TS	χ^2_{bf}	σ	TS
8.3	3.4	11.5	6.2	3.6	12.9
3.7	3.6	12.8	10.6	4.4	19.4
5.1	1.6	2.7	2.0	2.1	4.5

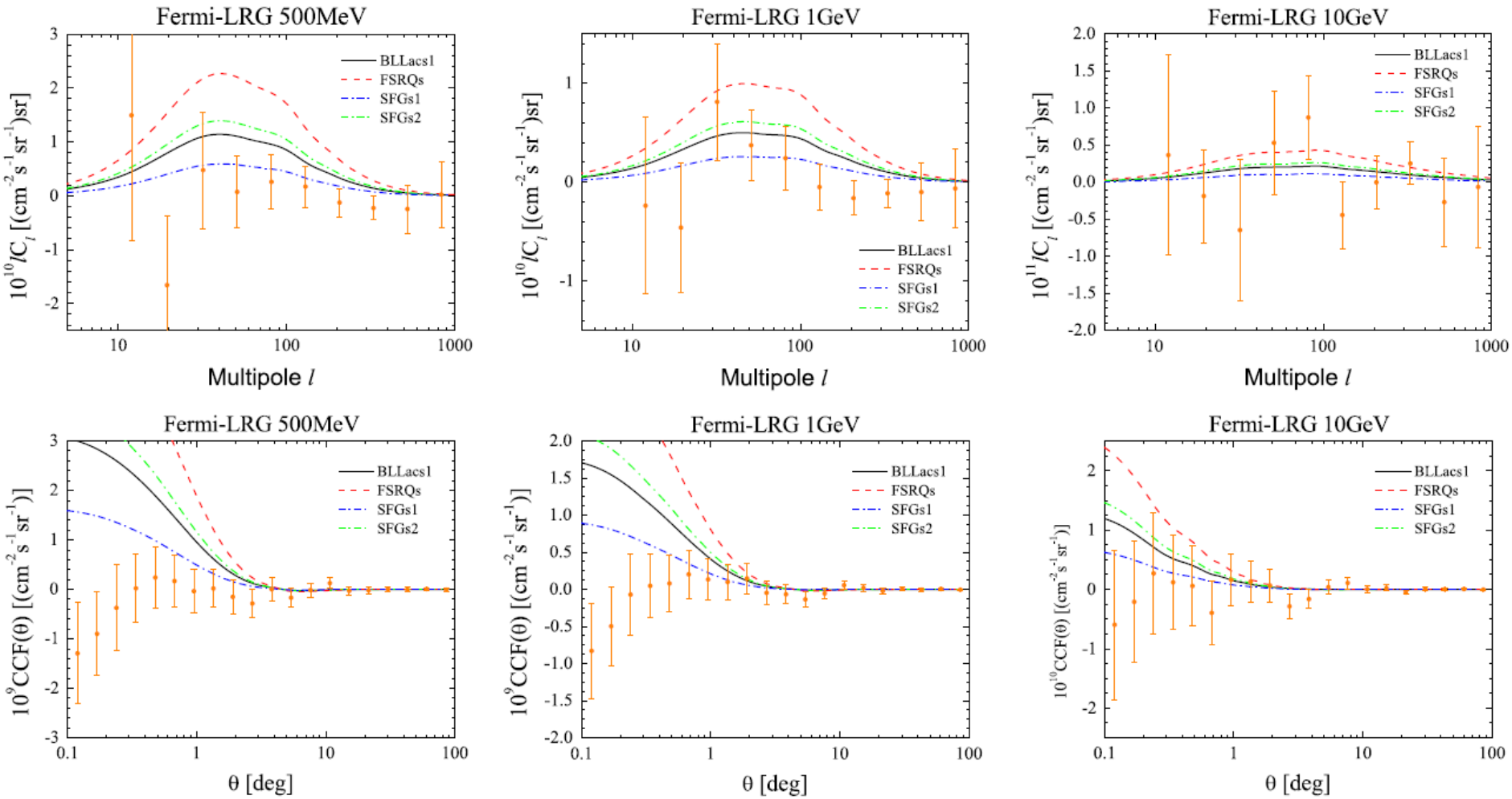




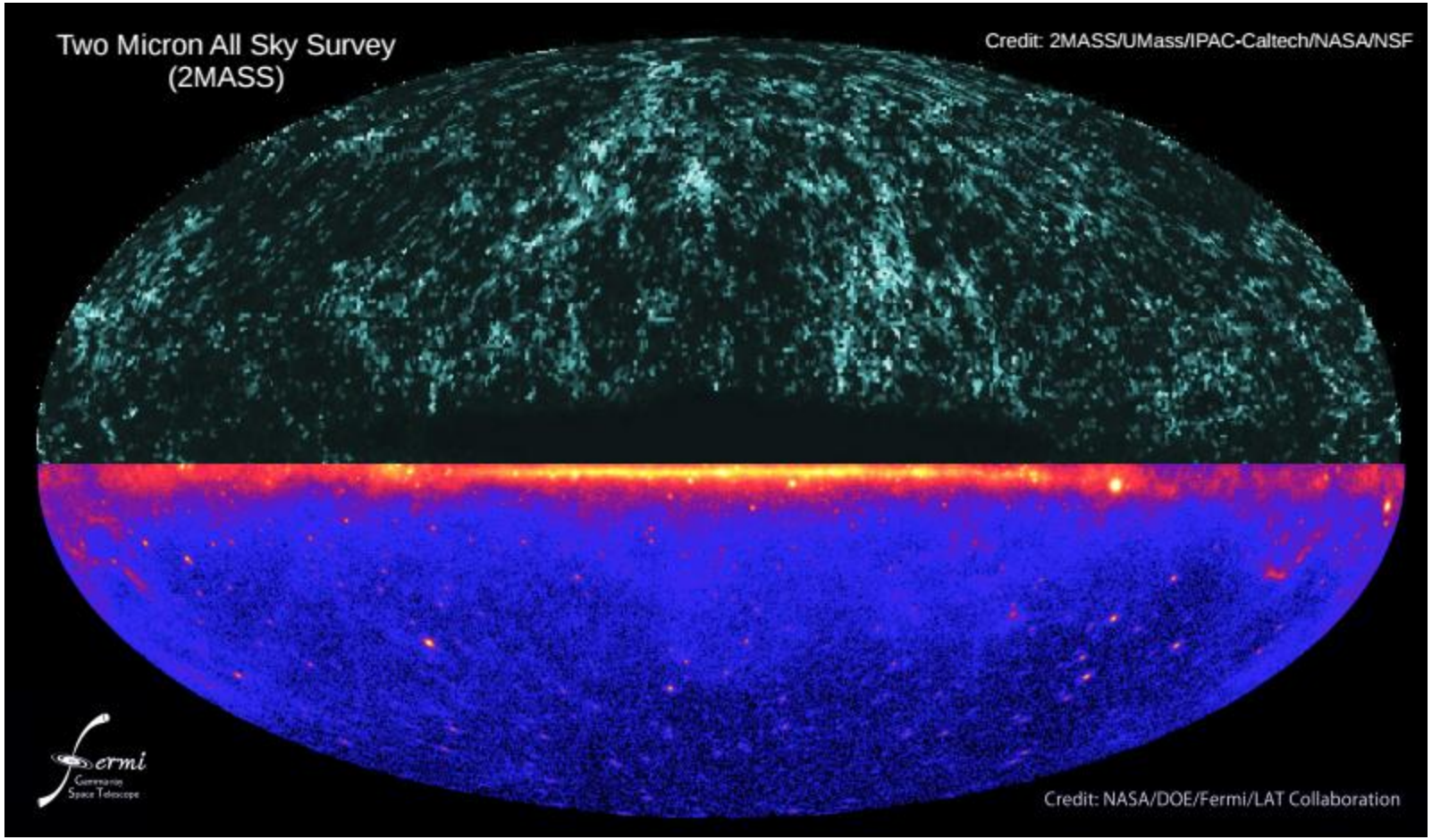
FERMI x MGs Result



FERMI x LRGs Result



FERMI-LAT x LSS



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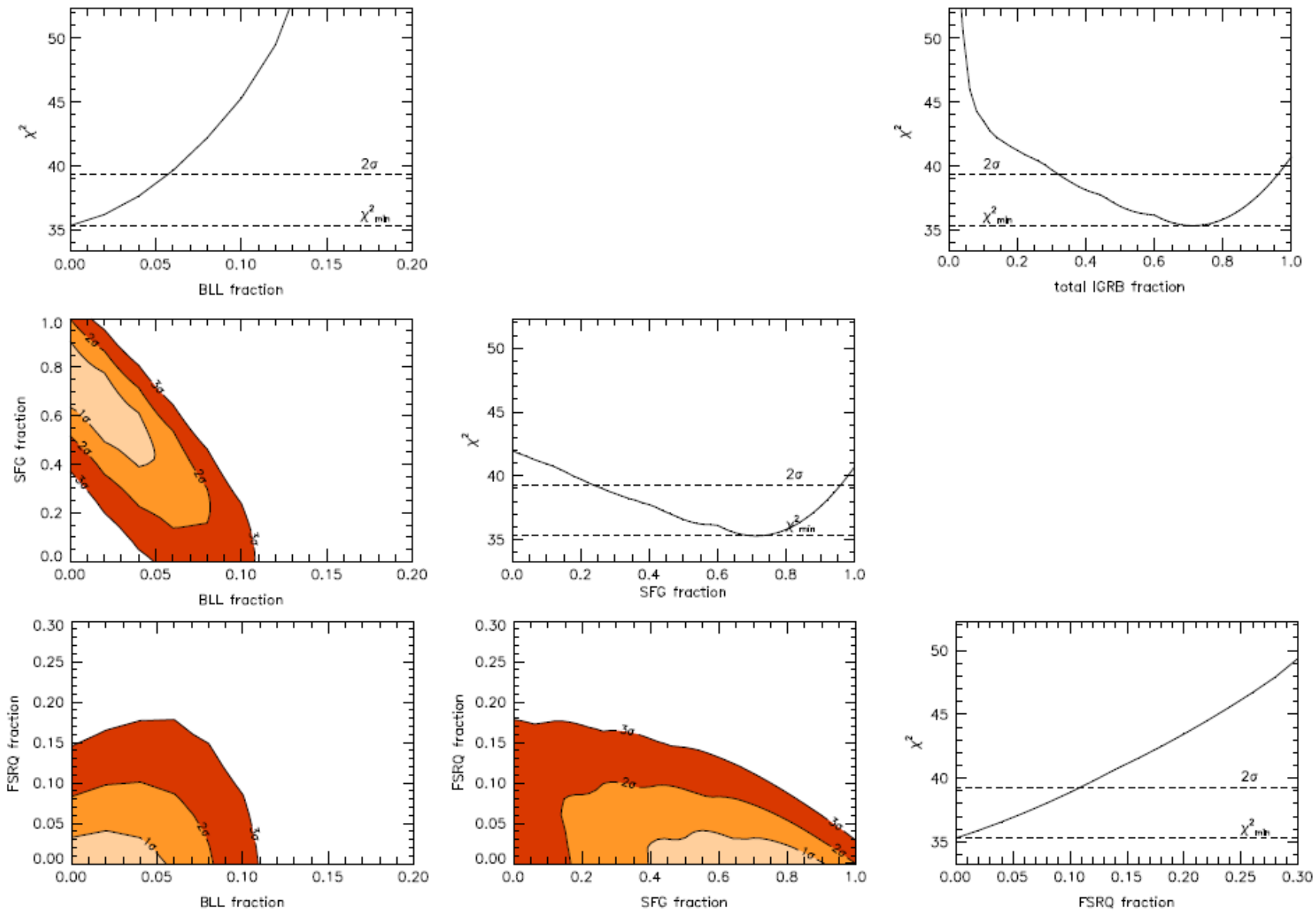
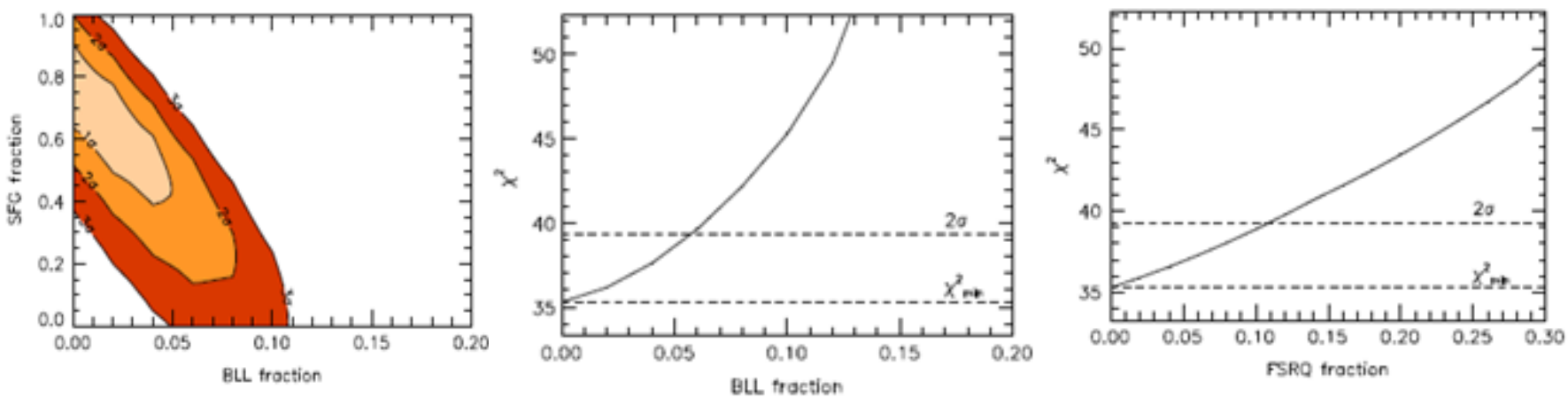
Chisq. Analysis

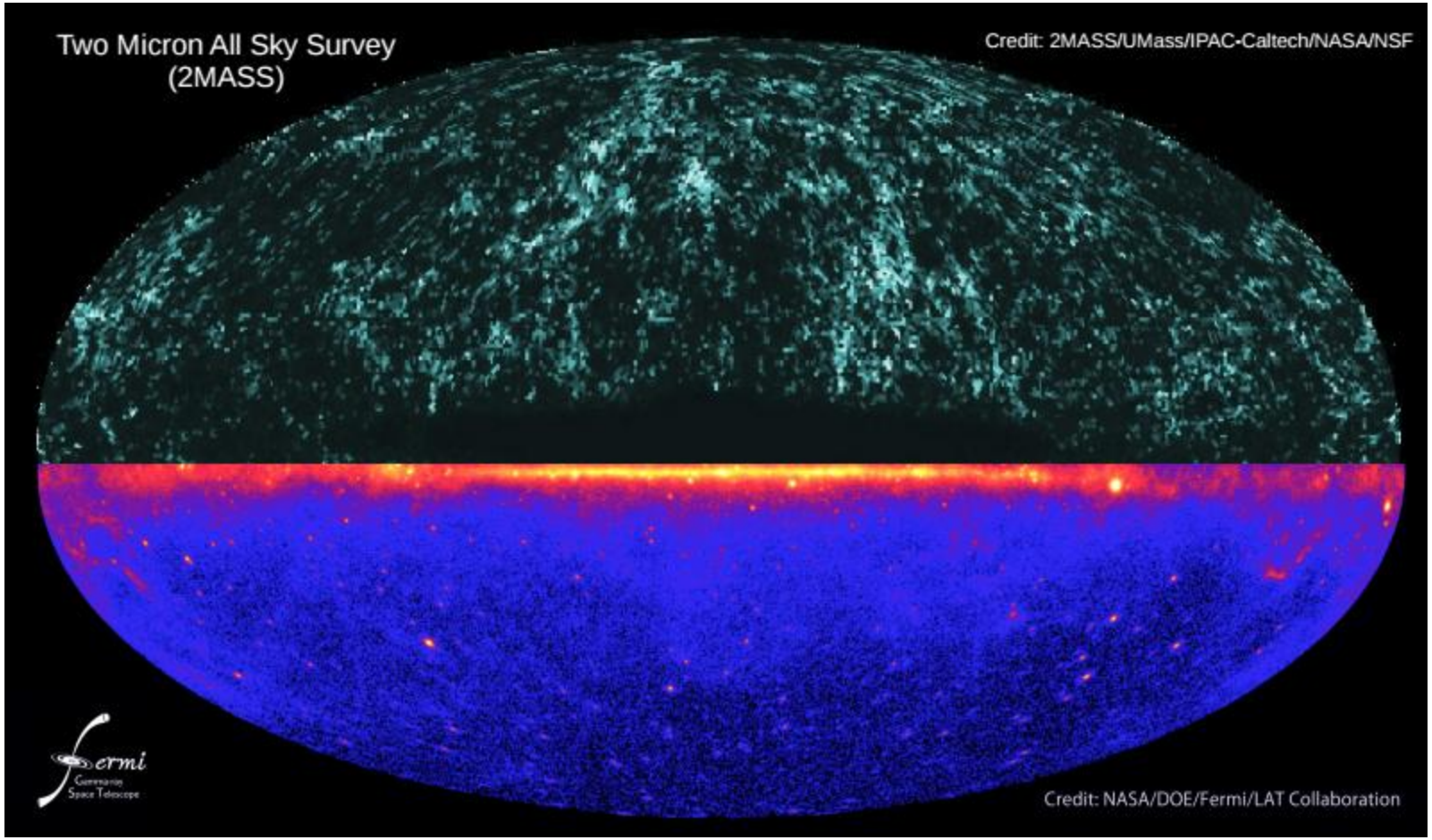


Summary

- **Constraints from objects at low redshifts, like 2MASS and SDSS galaxies, strongly suggest the SFGs dominates the IGRB.**
- **All models that include a contribution from SFGs provide a significantly better fit than those in which the IGRB is contributed to by AGNs only.**
- **In all models explored, the IGRB contribution from AGNs is subdominant. When SFGs are included among the IGRB sources, the AGN contribution is consistent with zero.**



FERMI-LAT x LSS



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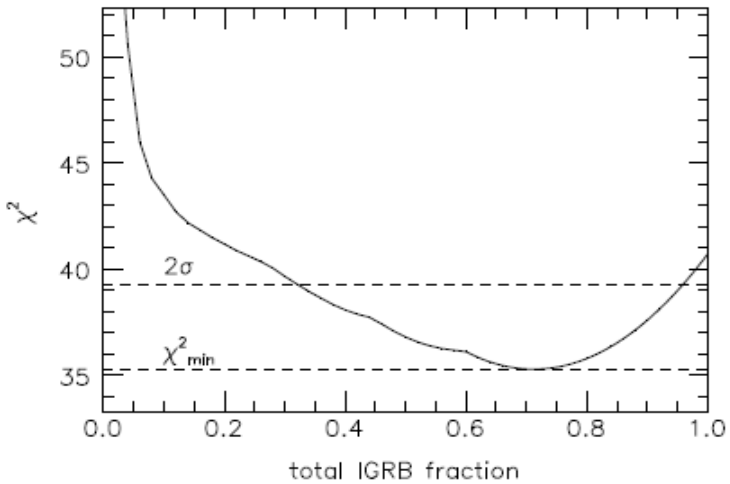
Dark Matter Interpretation

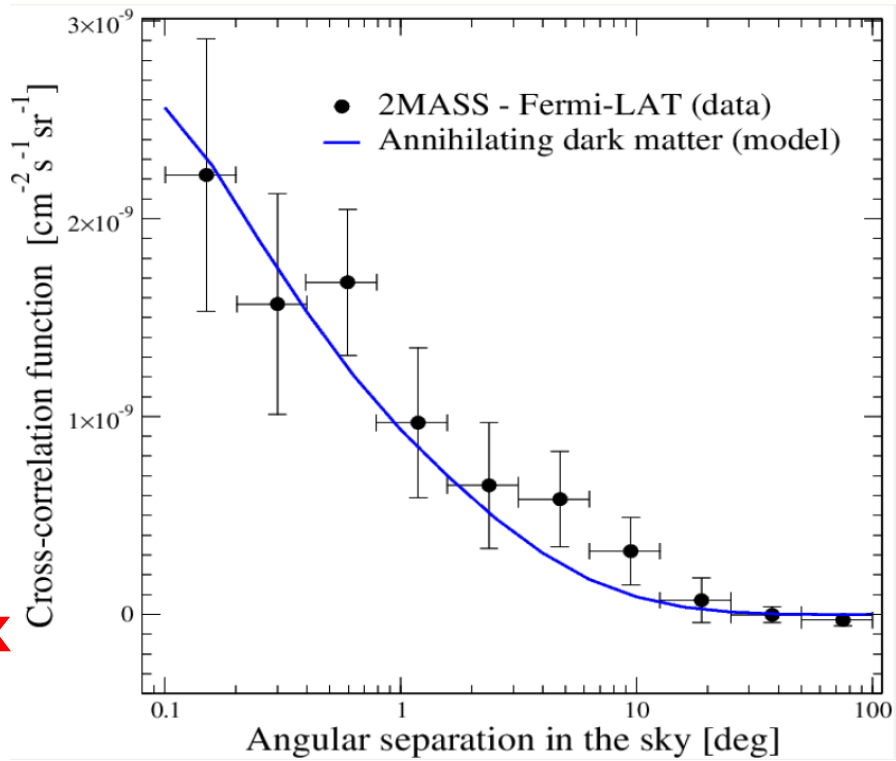
- **The combined emission from SFGs, BL Lacs, and FSRQs does not account for whole diffuse IGRB signal completely at low redshifts.**



- **A certain level of emitted radiation from dark matter annihilation or decay could also contribute the unresolved diffuse IGRB signal.**
- **We compared the predicted angular cross-correlation between the γ-ray emission induced by DM annihilation or decay in different channels and the distribution of 2MASS galaxies with the measured CCFs between these objects and the Fermi-LAT γ-ray maps (all energy bands together).**

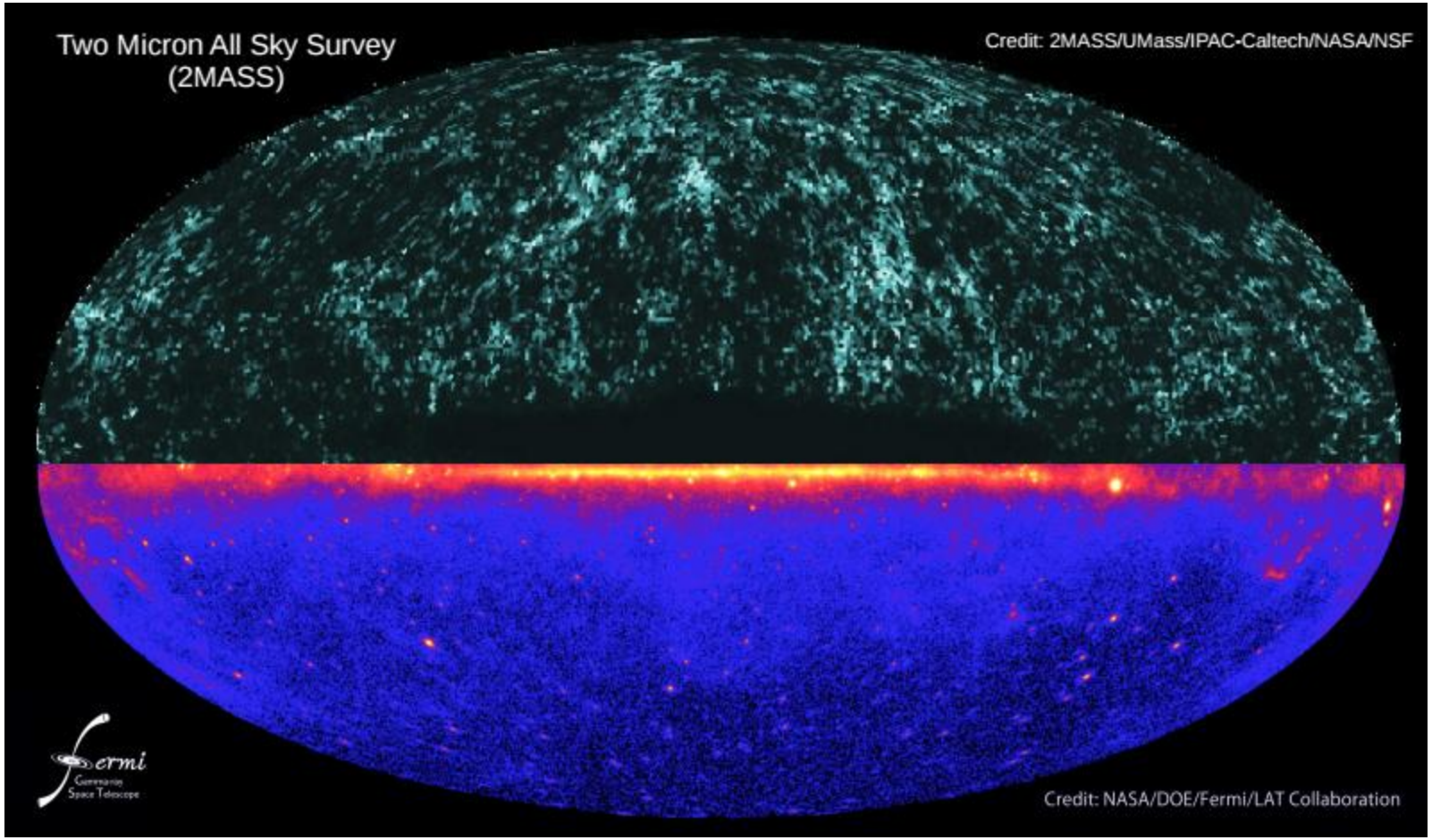
Conclusions

- **A WIMP DM contribution can fully explain the observed FERMI x 2MASS cross-correlation.**
- **A canonical WIMP with a mass in the 10–100 GeV range, an annihilation rate around the thermal value, and a realistic model for DM halo and sub-halo properties reproduce both the size and shape of the measured angular cross-correlation.**
- **The cross-correlation technique is more sensitive to a DM signal than other probes used so far.**



see Alessandro Cuoco's talk tomorrow in DM session

FERMI-LAT x LSS



- ✓ **Searching for isotropic γ-ray background signal**
- ✓ **Separating unresolved sources contributions**
- ? **Clarifying the origin of IGRB (Needs more data)**

Thanks!