Dark Matter Searches via cross-correlations with Large Scale Structures

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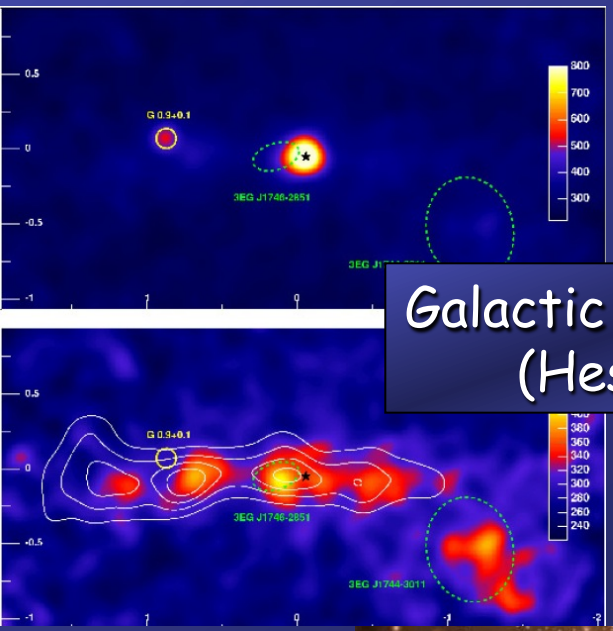
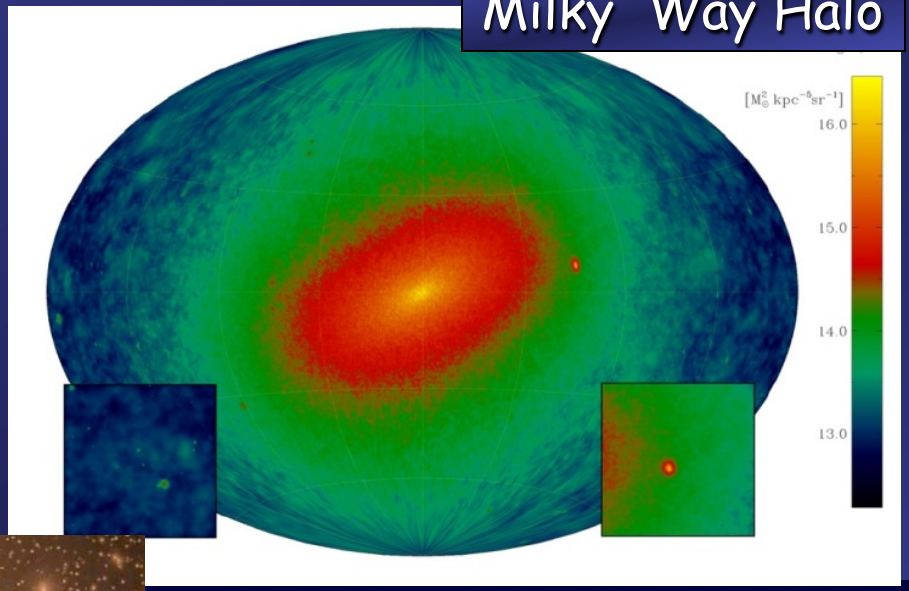
Where to look

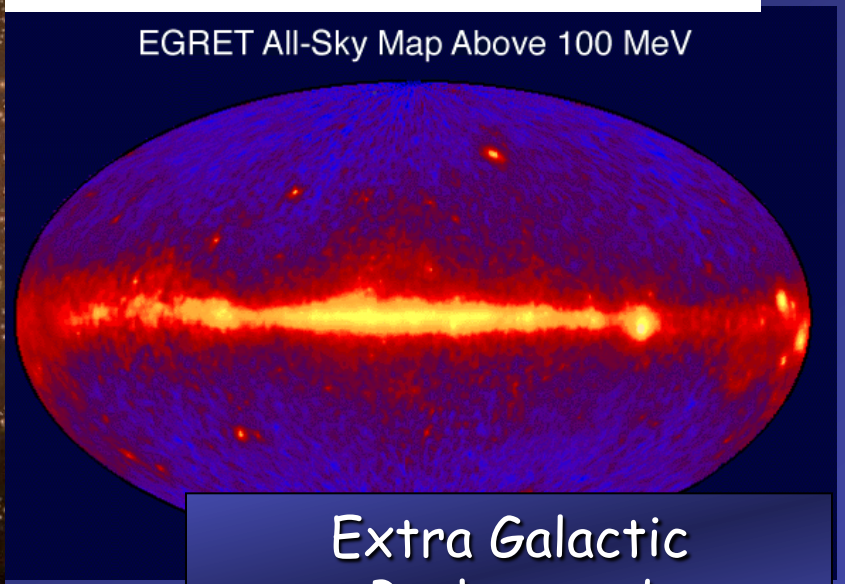


Galactic Center (Hess)

Milky Way Halo



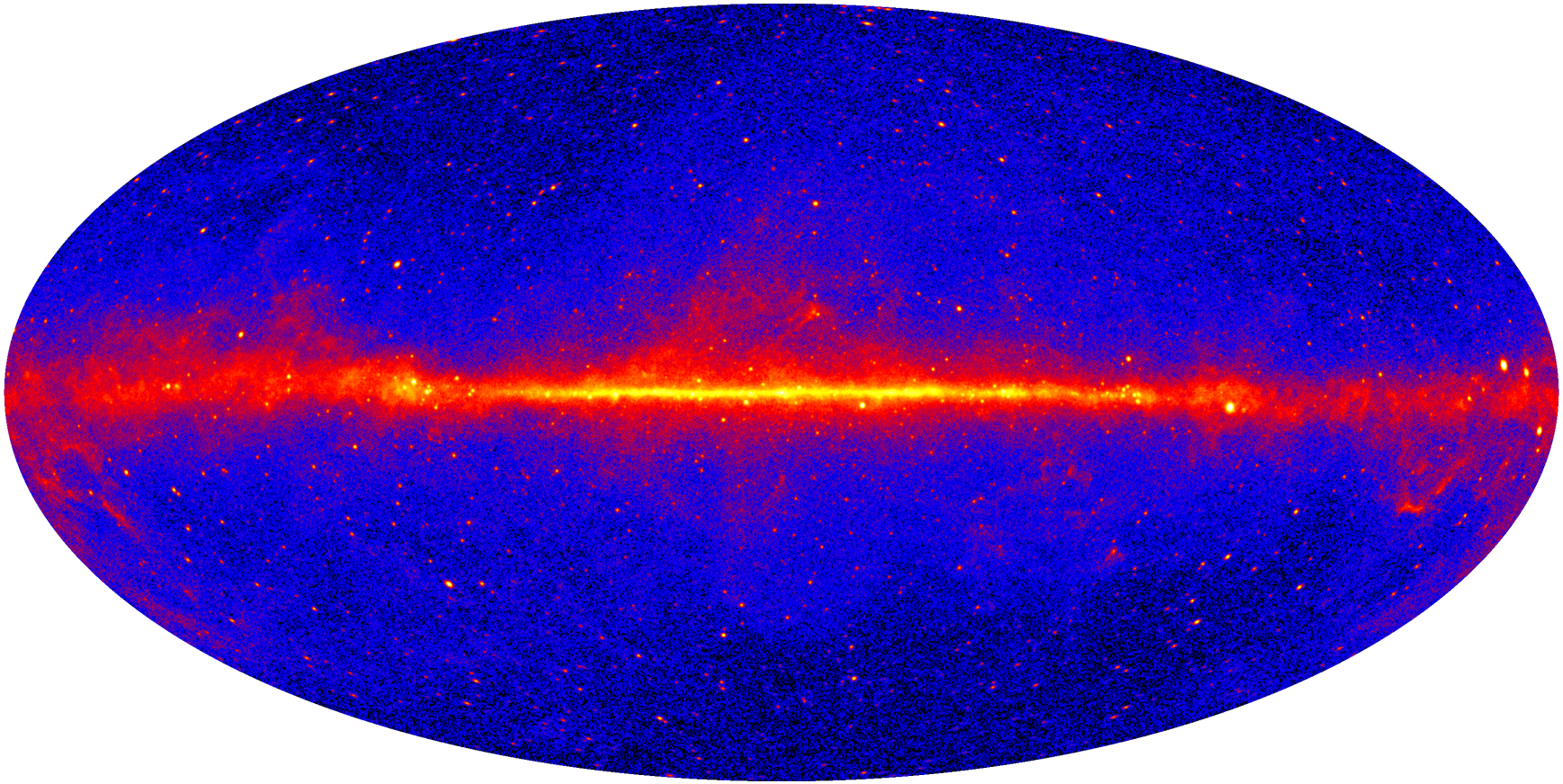
DM Clumps: Via Lactea Simulation Diemand et al.



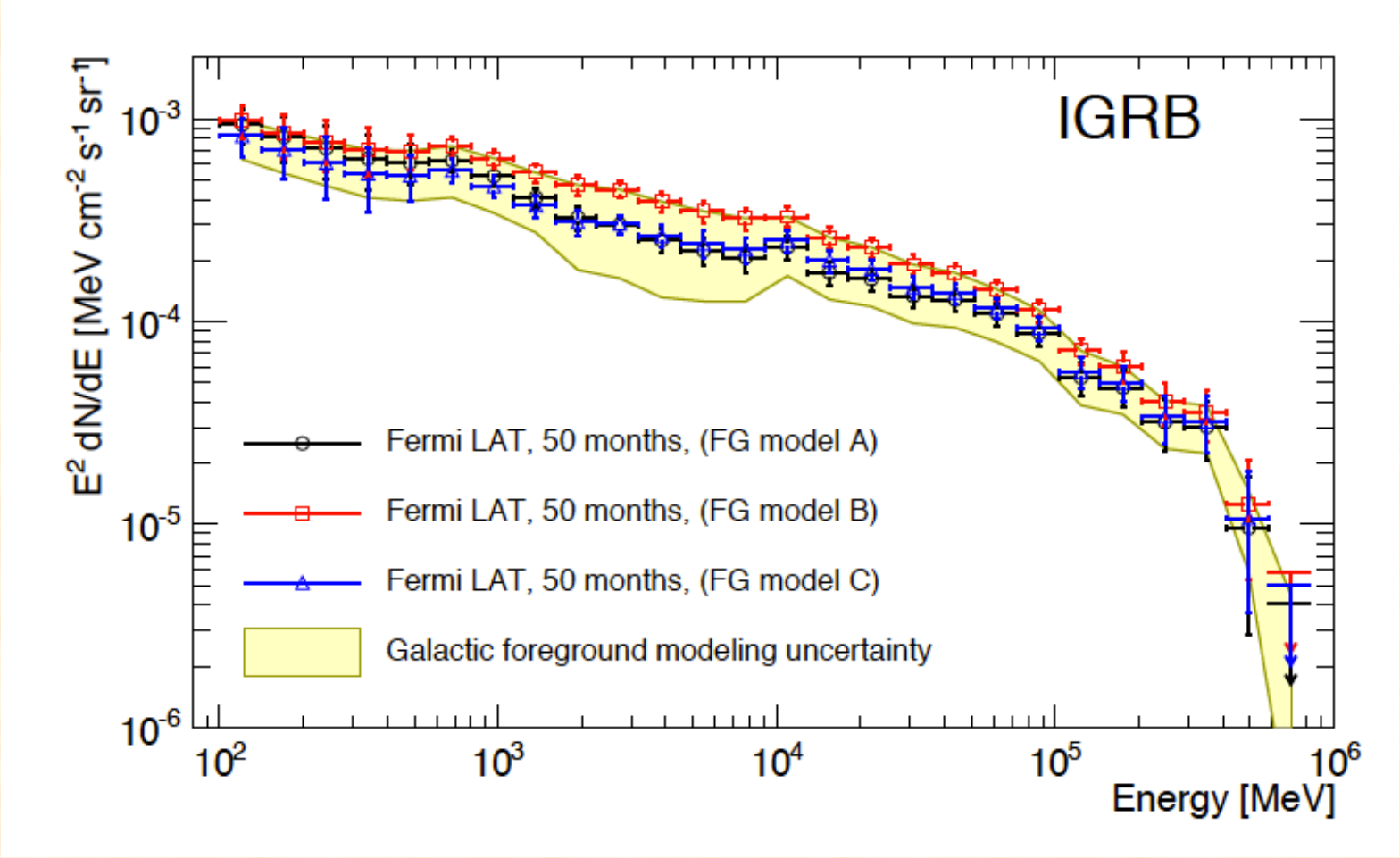
Extra Galactic Background

The Gamma Sky

Fermi Gamma-Sky, P8, PSF3-only, >1 GeV
(72 months(6 yrs), ~3.4M events)



The Extra-Galactic Gamma-ray Background (EGB)



Fermi LAT collaboration, Astrophys.J. 799 (2015) 1, 86

- Power Law for E < 100 GeV
- Spectral softening at high energies

The origin of the EGB

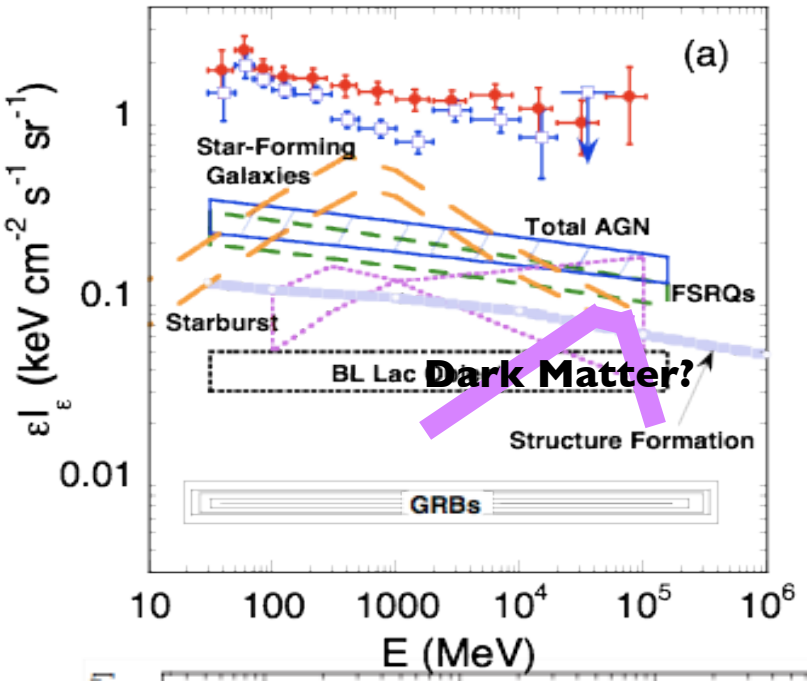
- many astrophysical sources are *guaranteed* to contribute, e.g.:
- blazars
- star-forming galaxies
- millisecond pulsars
- AGNs
- clusters of Galaxies
- clusters Shocks
- cascades from UHECRs

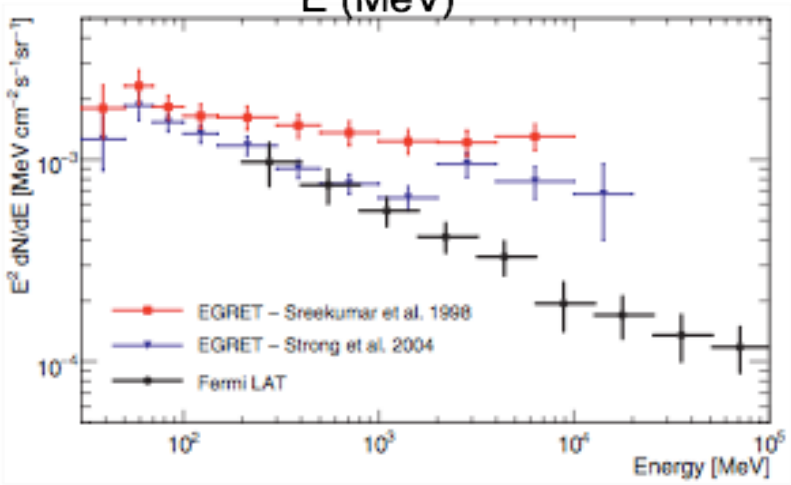
and…

- Dark matter(?)

- relatively featureless total EGB intensity spectrum → lack of spectral handles to ID individual components

Dermer 2007

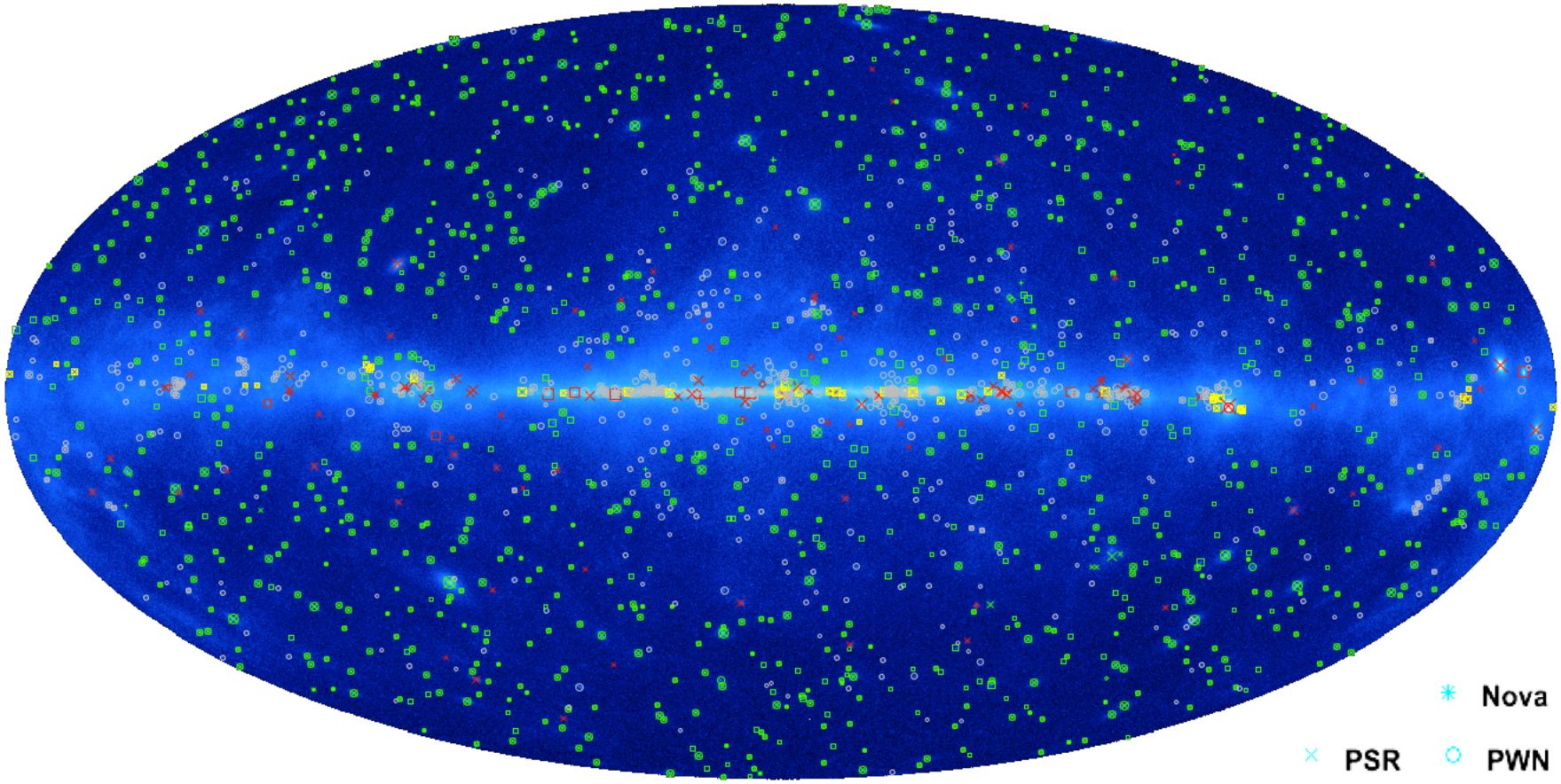




Abdo et al., PRL 104 (2010) 101101

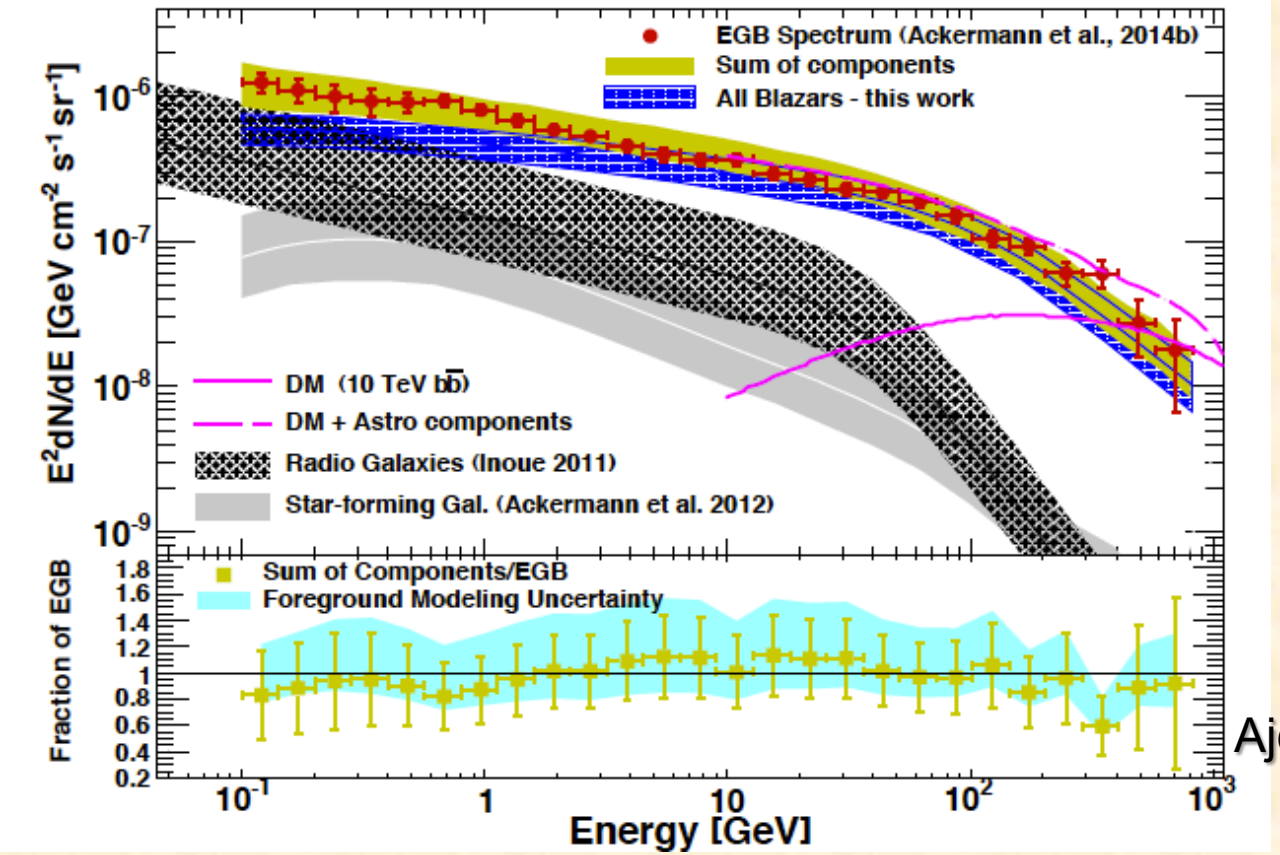
Resolved Sources - 2FGL catalogue

~2000 sources



Credit: Fermi Large Area Telescope Collaboration

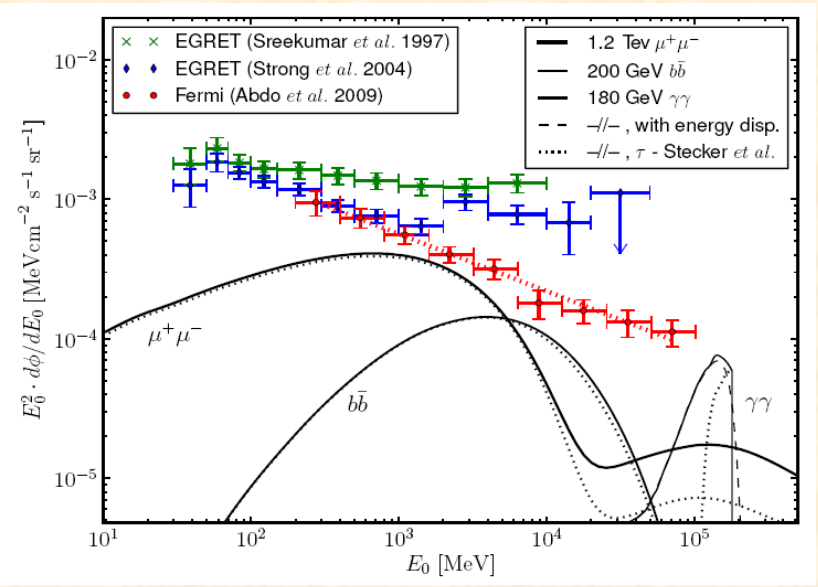
IGRB Energy Sprectrum



Ajello et al. ApjL 2015

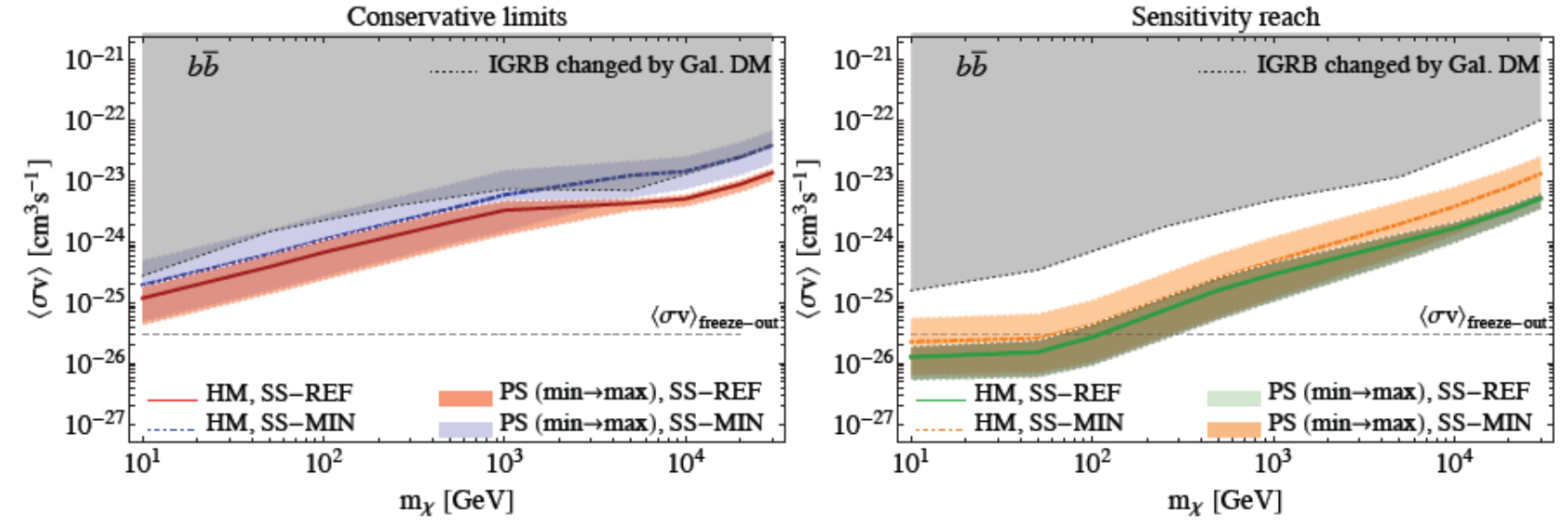
- The IGRB energy spectrum can be well fitted by a sum of different astro-physical components.
- No obvious need of Dark Matter

Constraints from the Extra-Galactic Gamma-ray Background



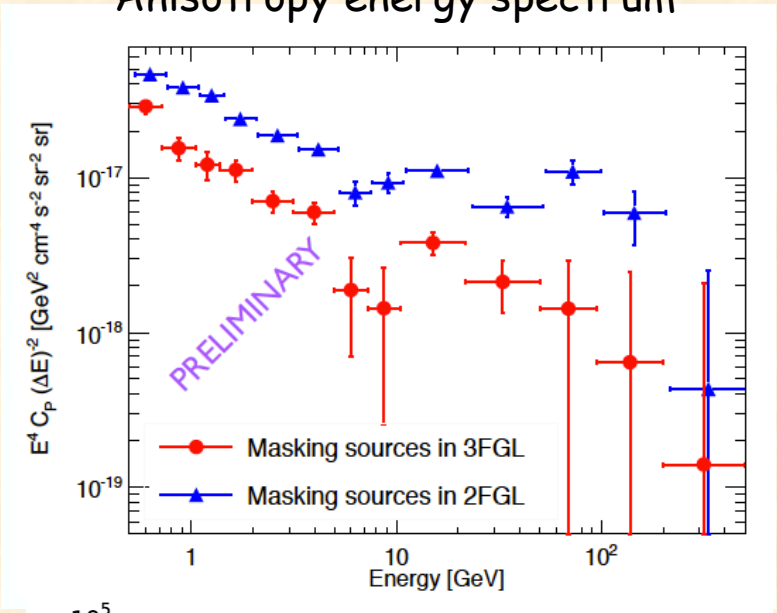
- Potentially very constraining, but gives very model dependent limits due to large uncertainties in the predicted DM signal
- Better understanding of the DM clustering at small scales can help tight the uncertainties. (see e.g. Serpico et al. arXiv:1109.0095)

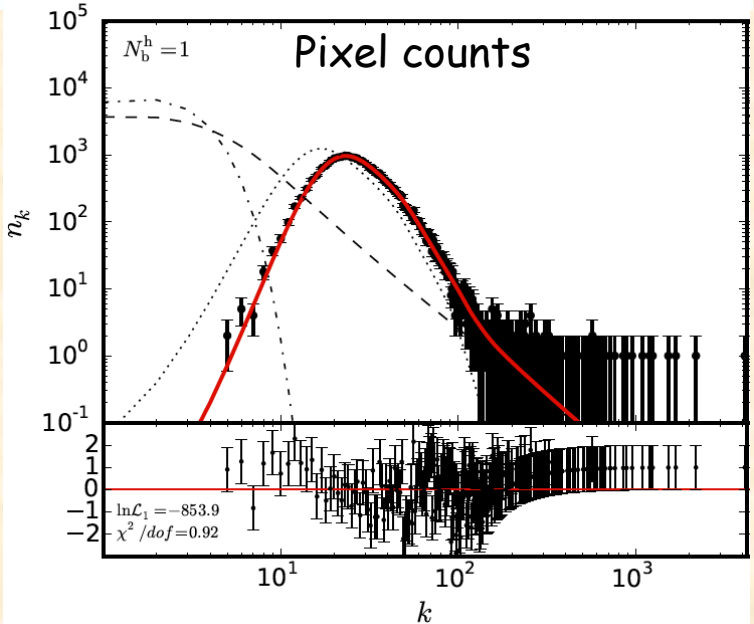
Abdo et al. (Fermi-LAT) JCAP 1004 (2010) 014,
Ackermann et al. JCAP 1509 (2015) 09, 008



Anisotropy Features of the EGB-IGRB

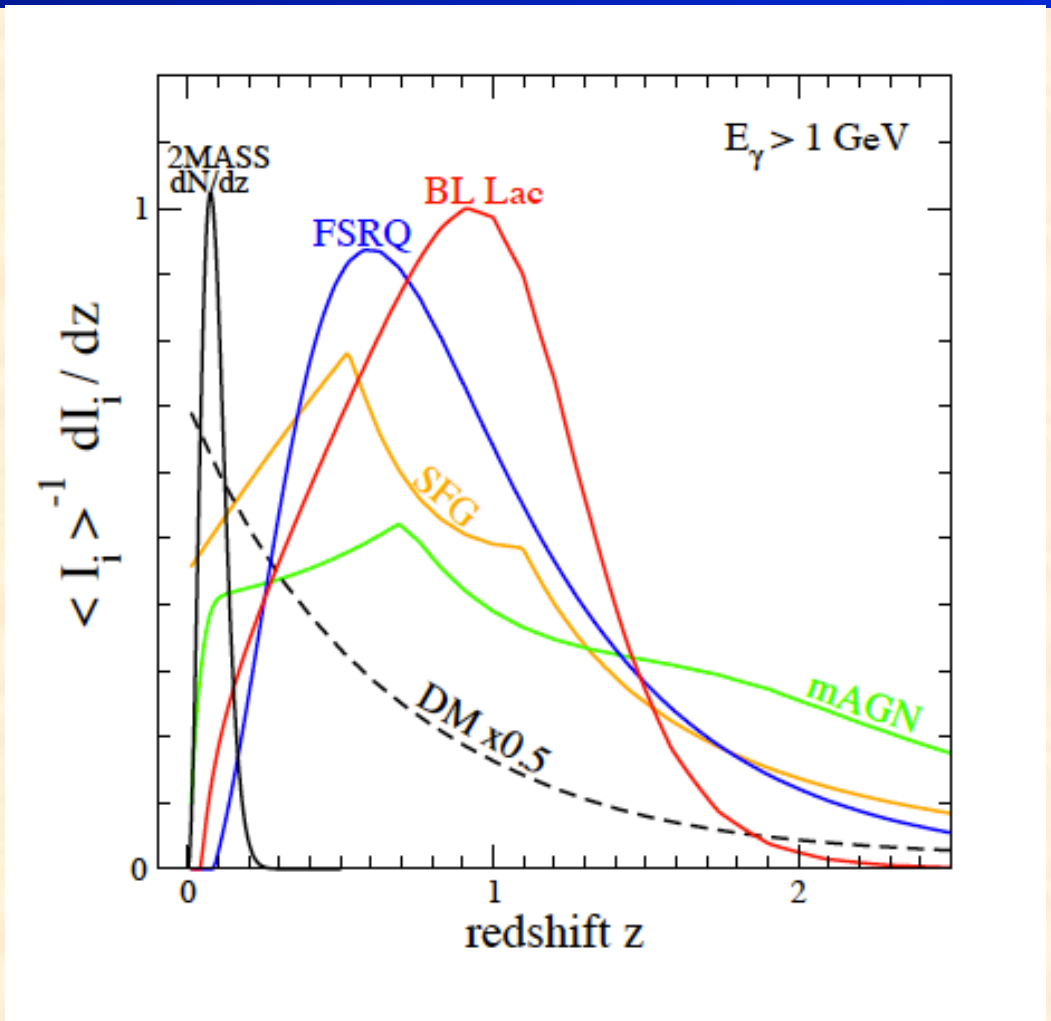
Anisotropy energy spectrum





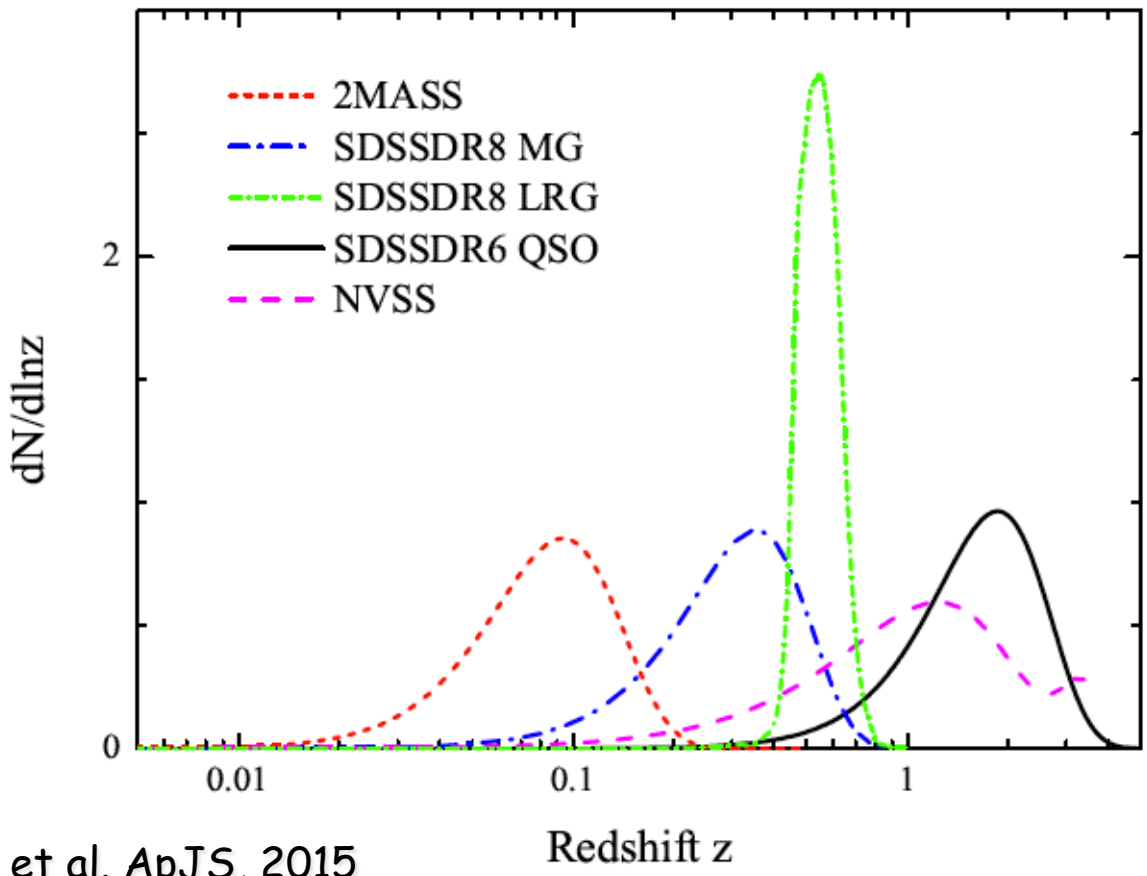
- Besides the energy spectrum there is much more information to explore!
- In the last years a lot of work on this:
- Anisotropy energy spectrum (IGRB auto-correlation) (see Mattia' talk)
- Pixel count fluctuations (1pPDF) (see Safdi's talk and Zechlin+2015, Feyereisen+ JCAP 2015)
- Cross-correlations (next slides)

IGRB redshift distribution



- Besides the energy spectrum, the various components differ also by their distribution in z. In particular DM is expected to peak at low redshift.
- Need to isolate the IGRB emission coming from different redshifts!

Tomography of the IGRB via x-correlation with LSS

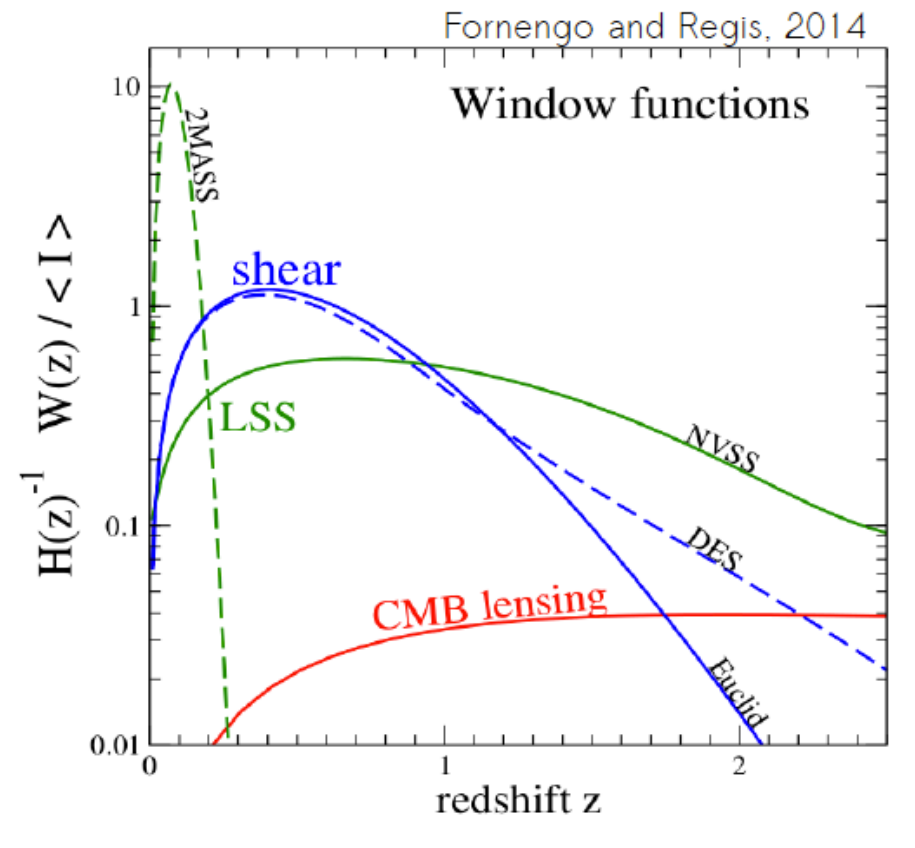


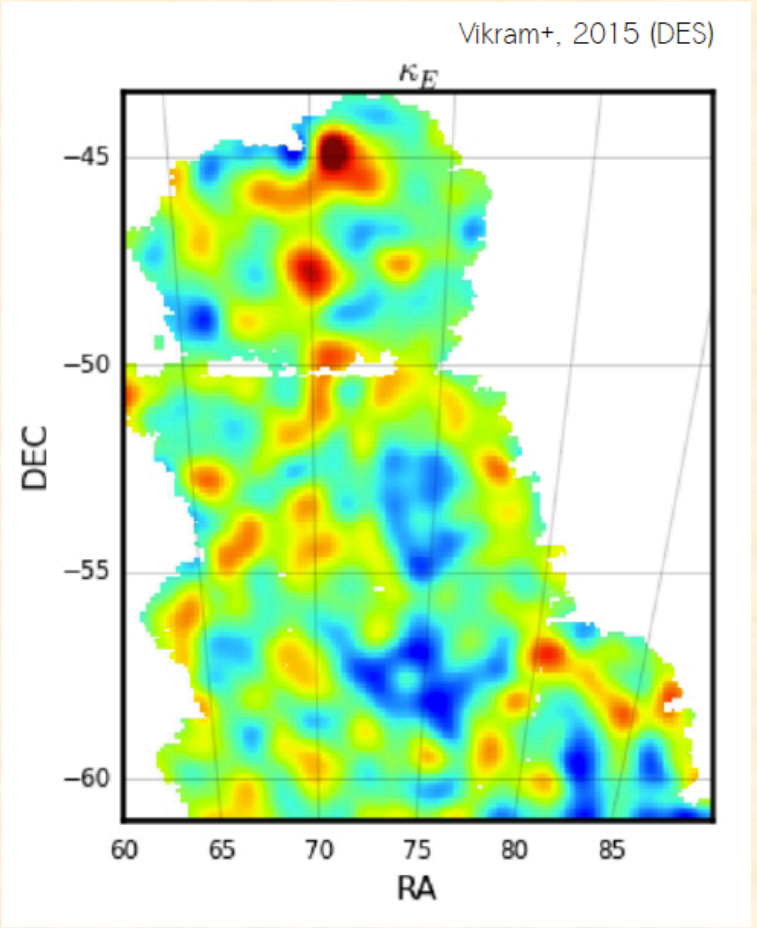
Xia et al. ApJS, 2015

See also:
Xia et al. MNRAS 2011,
Ando, JCAP 2014,
Ando, Benoit-Levy,
Komatsu PRD 2014

- The different z-coverage of each catalogue allows to isolate the IGRB at different z effectively performing a Tomography of the IGRB
- This provides a strong handle to better separate components and eventually DM

x-correlation with Lensing Shear

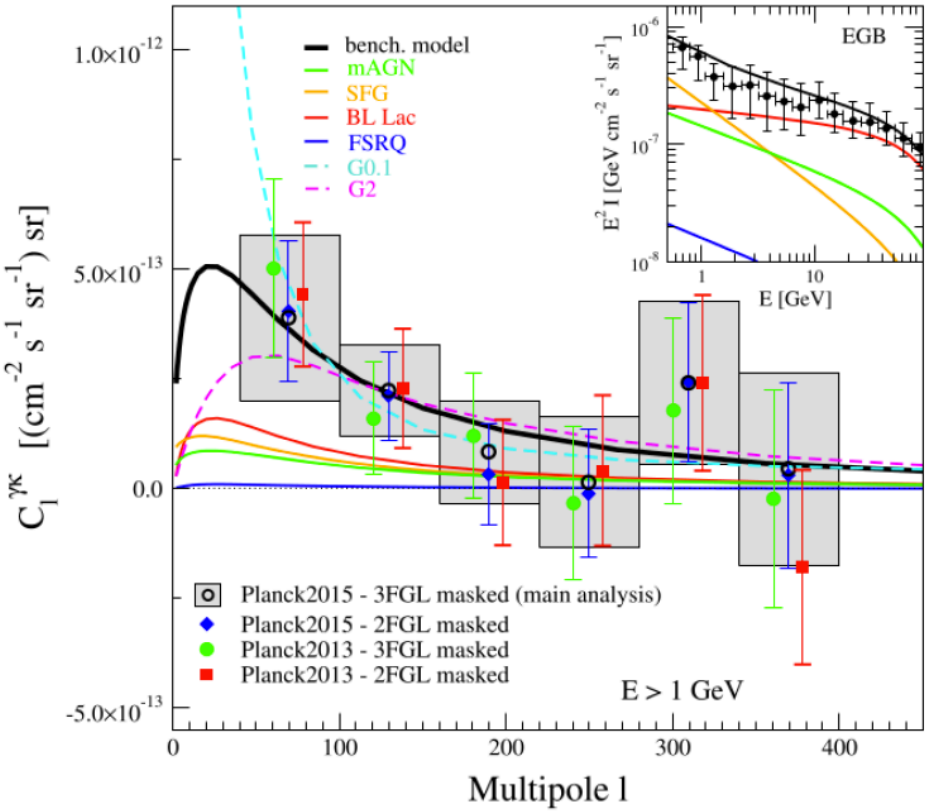




- Advantage: traces directly the total matter. No bias modeling required.
- Disadvantage: not ready yet. Best result at the moment a small patch of the sky from DES. But interesting results to come with full DES maps and in the future Euclid.

x-correlation with CMB Lensing

Fornengo, Perotto, Regis, Camera, ApJ 2015



Planck Collaboration 2015, arXiv:1502.01591

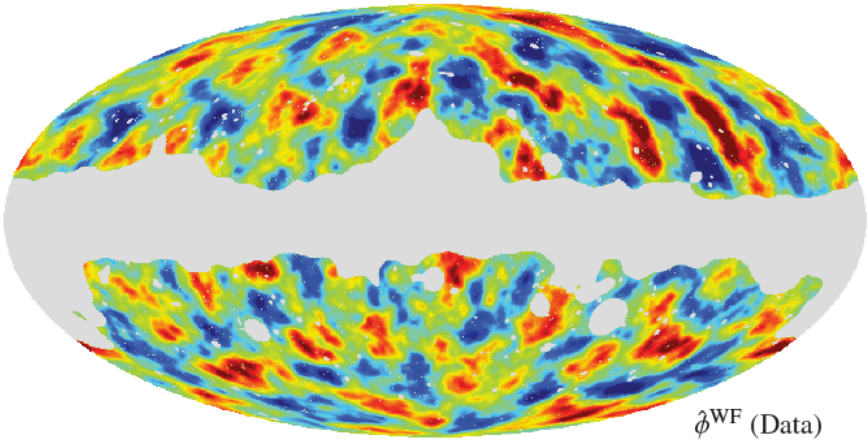
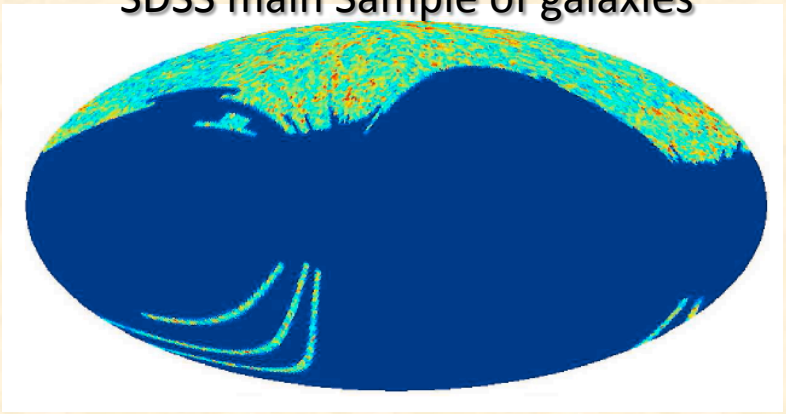


Fig. 2 Lensing potential estimated from the SMICA full-mission CMB maps using the MV estimator. The power spectrum of this map forms the basis of our lensing likelihood. The estimate has been Wiener filtered following Eq. (5), and band-limited to $8 \leq L \leq 2048$.

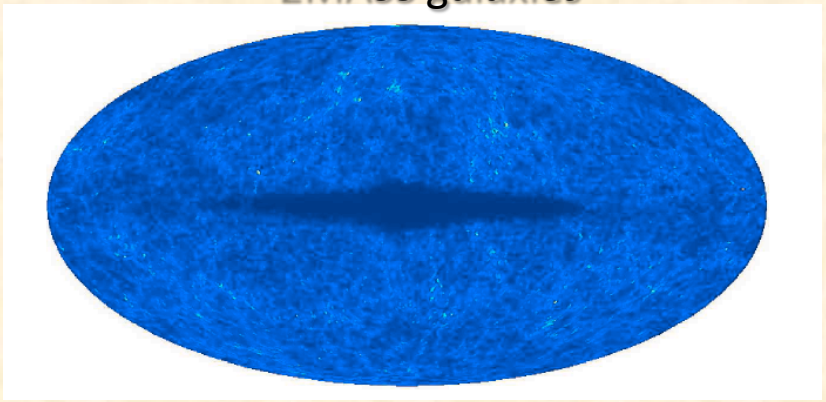
- A further possibility is to cross-correlate with the LSS gravitational potential estimated through its lensing effect on the CMB.
- Indeed, a ~3 sigma correlation is present (Fornengo+ ApJ, 2015). Interesting for the future if lensing maps will improve.

cross-correlation with LSS: catalogues

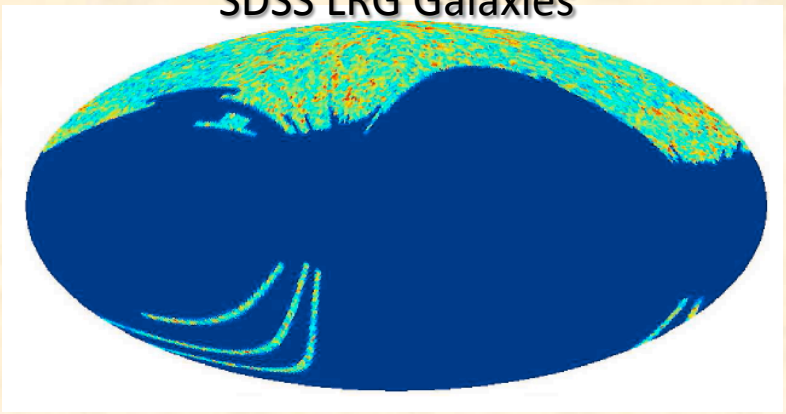
SDSS main Sample of galaxies



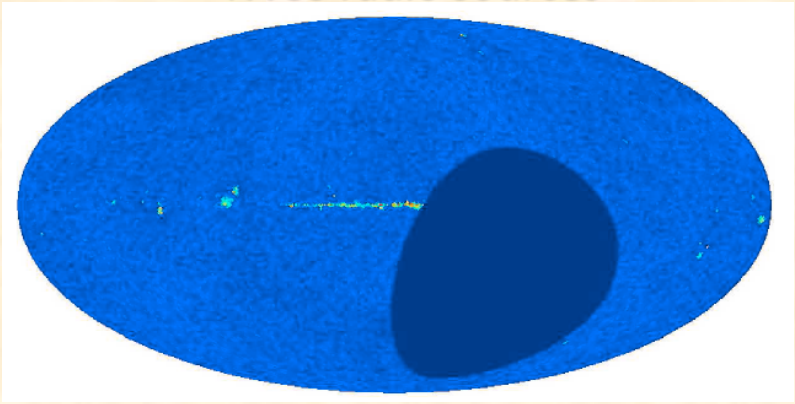
2MASS galaxies



SDSS LRG Galaxies



NVSS radio sources

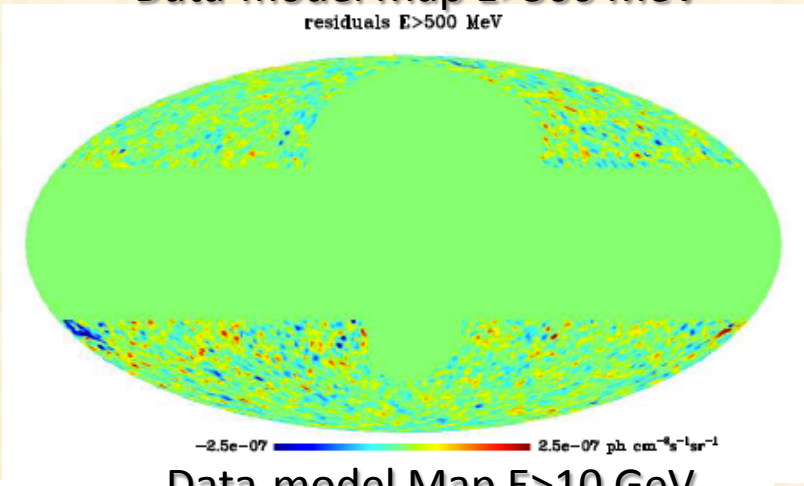


- DM emission in the IGRB should trace the Large Scale Structures of the Universe.
- Galaxy Catalogues can be used as LSS template to cross-correlate with

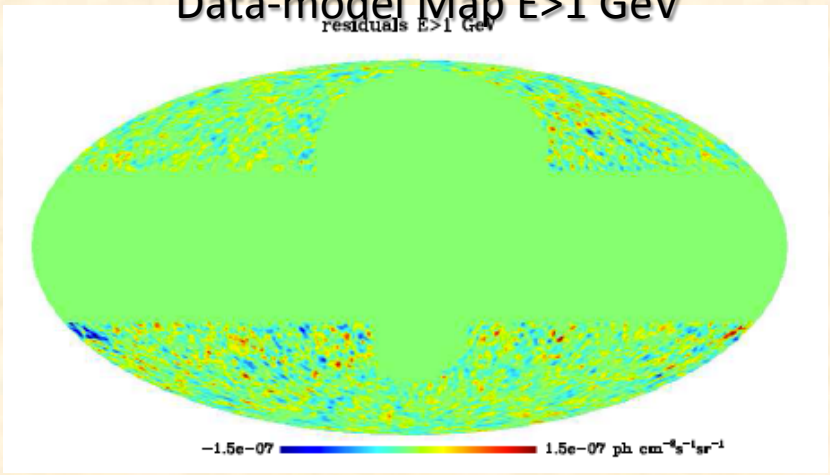
Xia, Cuoco, Branchini, Viel, ApJS, 2015
Regis, Xia, Cuoco+ PRL 2015
Cuoco, Xia, Regis,+ ApJS, 2015

Fermi Maps

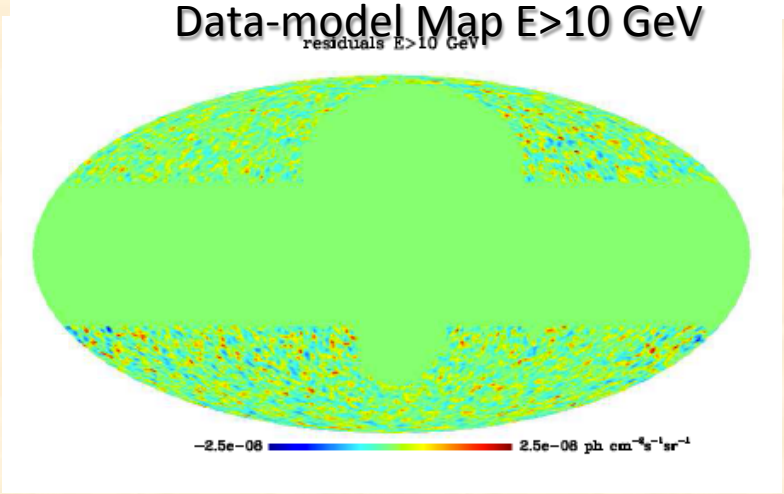
Data-model Map E>500 MeV

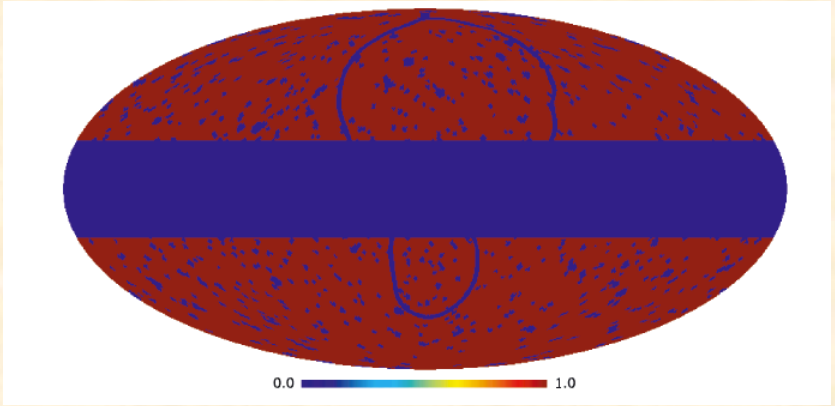


Data-model Map E>1 GeV



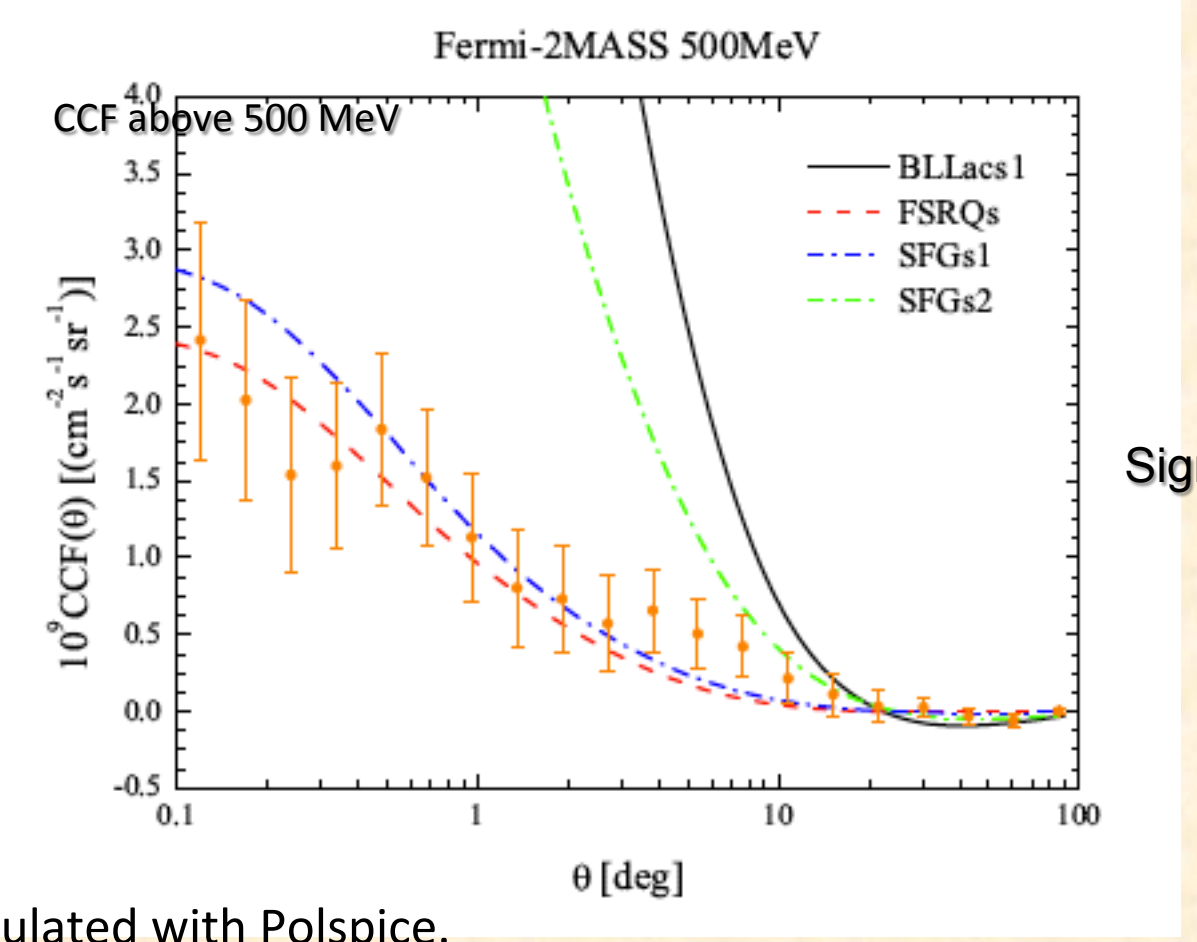
Data-model Map E>10 GeV





- 60 months P7REP_clean_v15 data
- galactic diffuse model subtracted: ring_2year_P76_v0.fits
- Galactic latitude mask (>30 deg), point sources mask (2FGL and 3FGL catalog) and Lobes-LoopI mask
- Mostly flat residuals apart a small deficit in Taurus region. Region is masked anyway by the catalogues mask

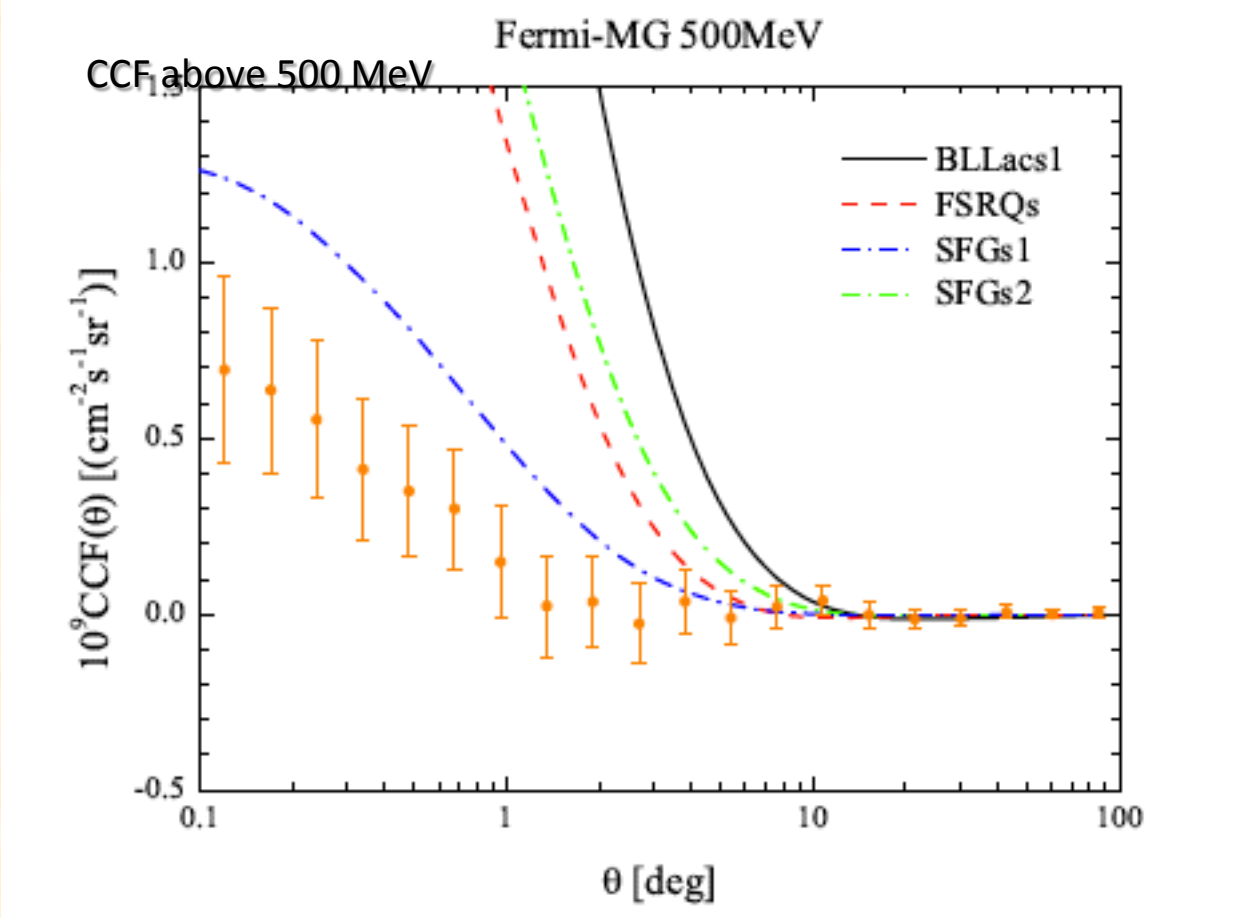
Fermi-2 MASS X-Correlation



Significance ~4 sigma

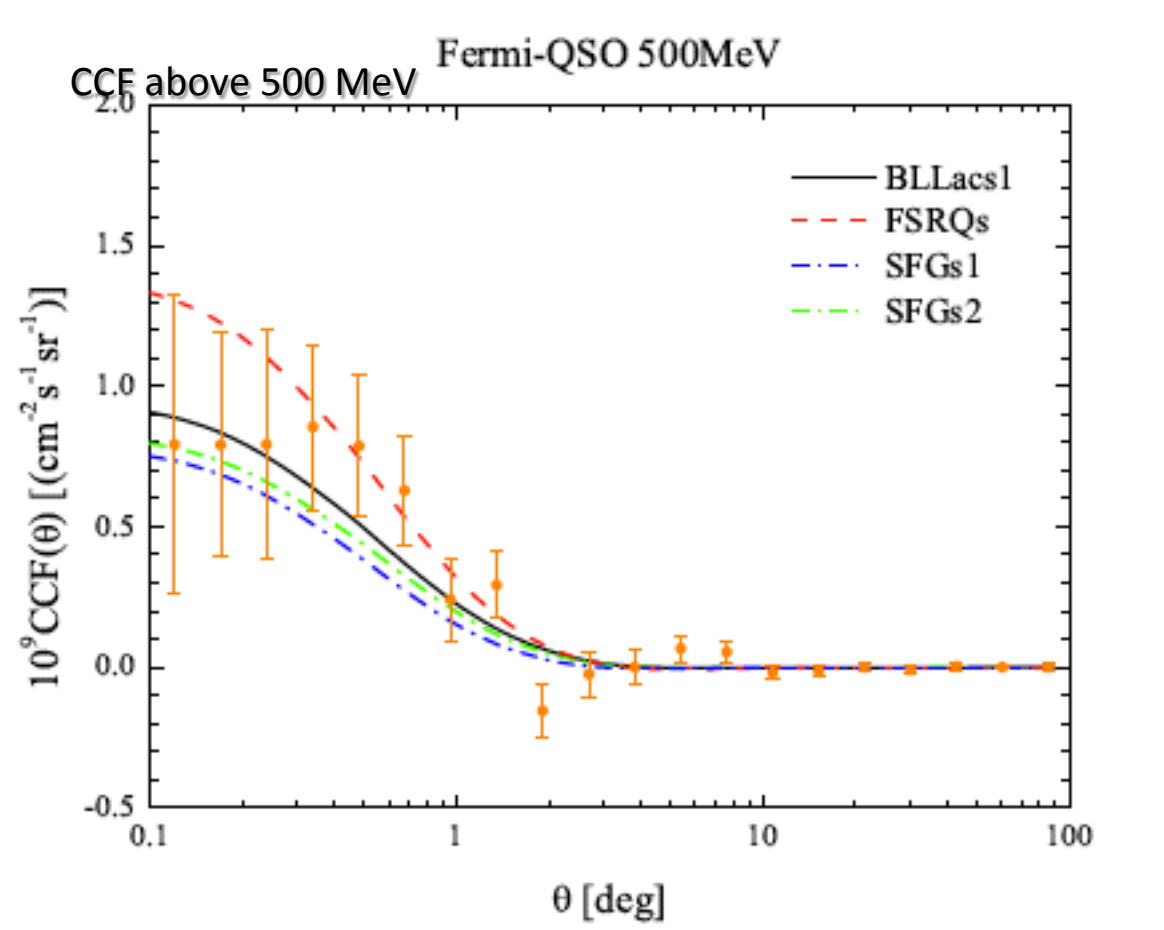
- CCF calculated with Polspice.
- PSF correction taken into account in the models, rather than the data.
- Errors calculated from Polspice. Checked that they agree with Jack-Knife estimate.
- In the plot each model is normalized as predicting 100% of the IGRB
- Models are simple implementation of the assumption that IGRB sources follow LSS with some bias

Fermi-2 SDSS-MG X-Correlation

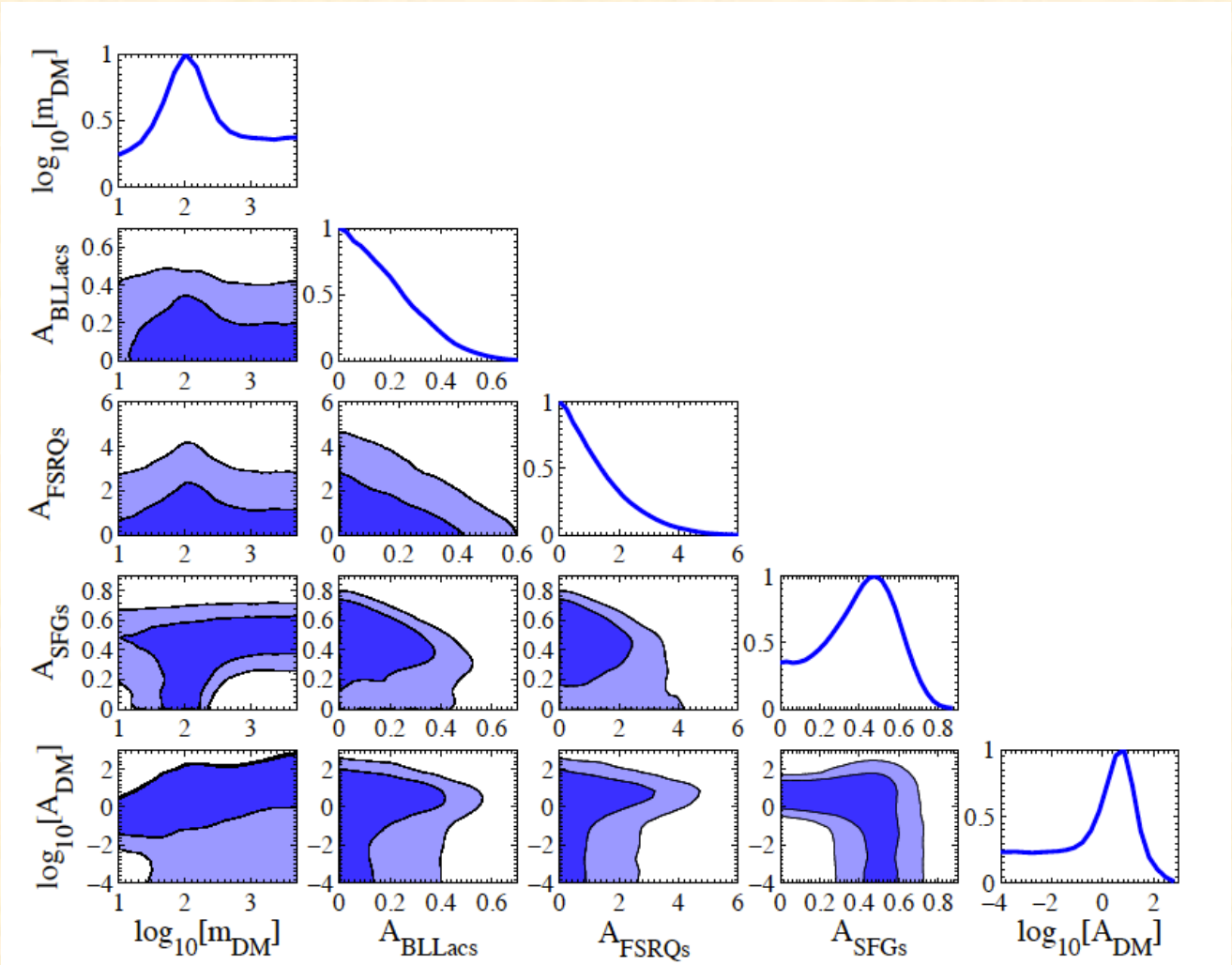


- Exploiting the correlations with other catalogues, degeneracies can be removed.

Fermi-2 SDSS-QSO X-Correlation

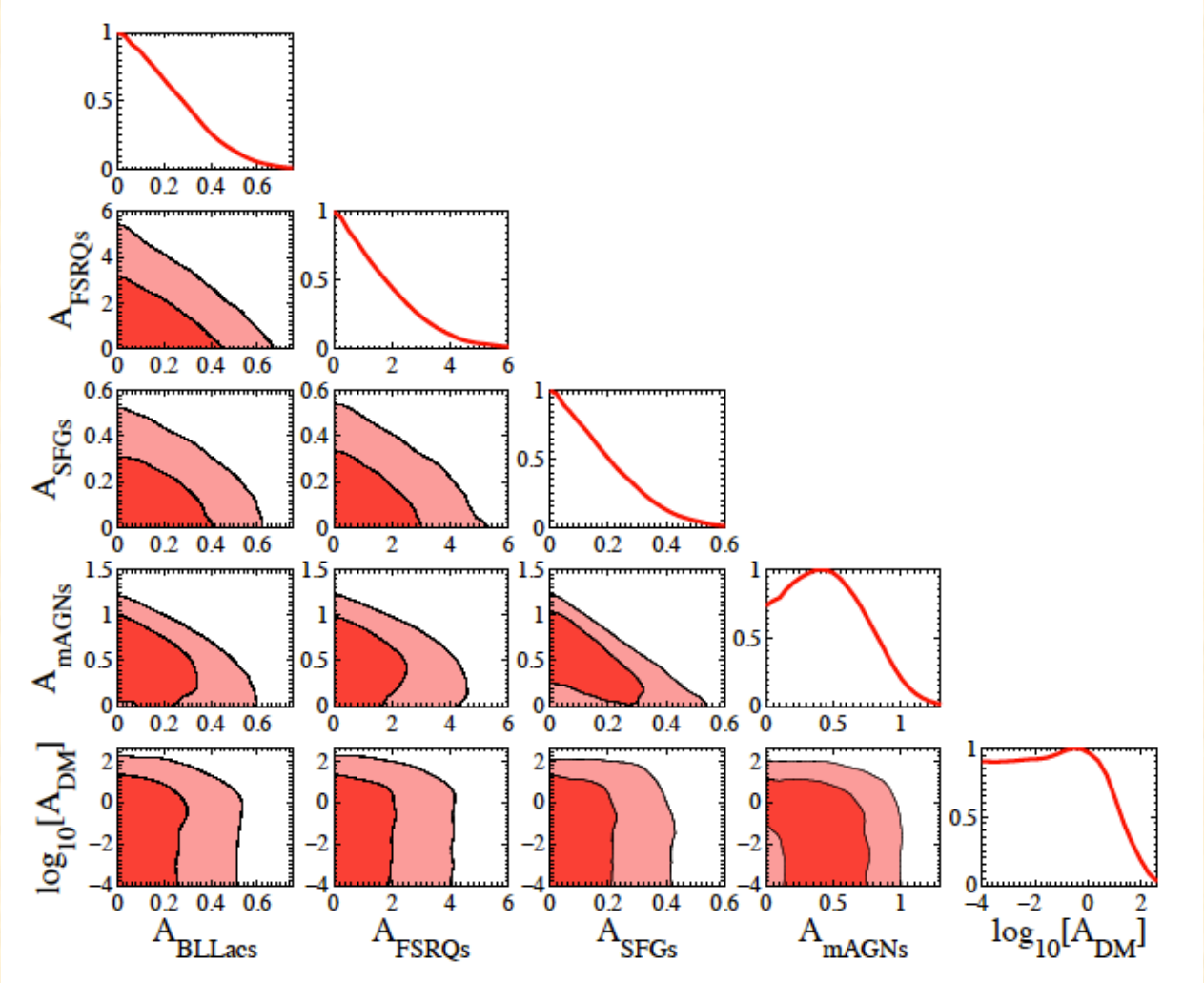


Global multi-component fit



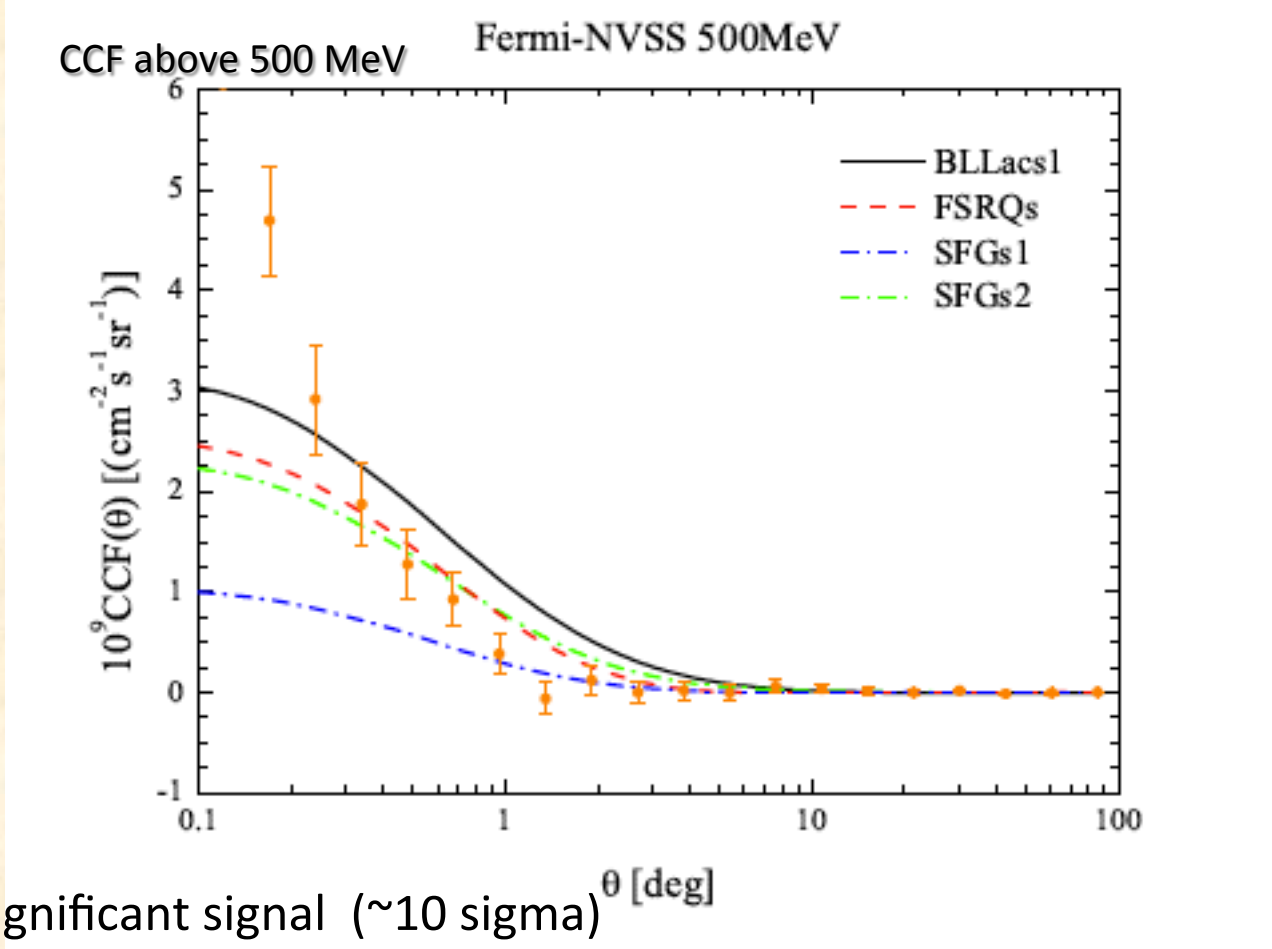
- DM can be included in the fit as a further component. There is some weak hint for DM (< 2 sigma), but not very significant.
- SFGs seem to give the main contribution to the IGRB, while blazars are subdominant

Global multi-component fit (II)



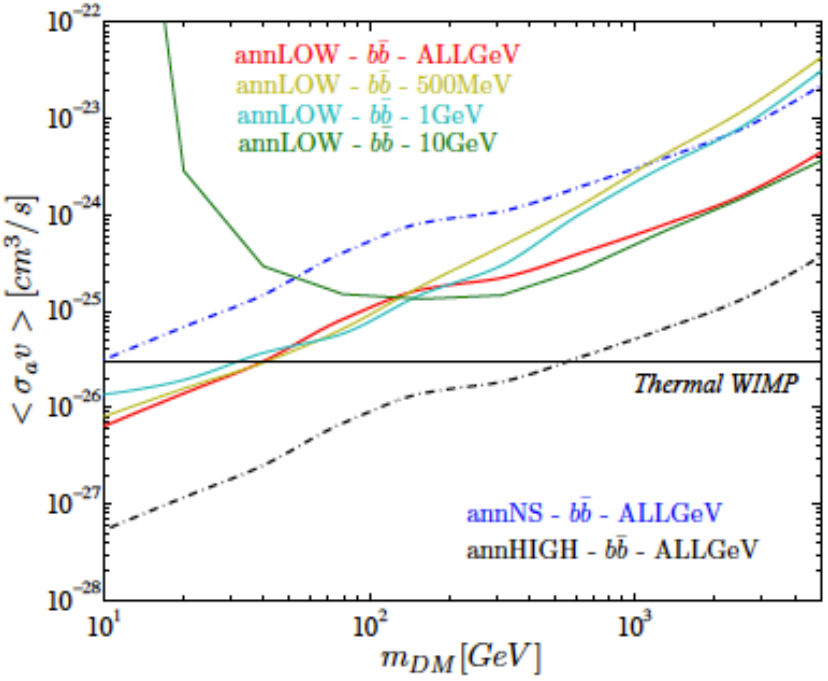
- mAGN can be further added to the fit. In this case several degeneracies appear. mAGN and SFGs give the main contribution, while DM cannot be distinguished anymore from the other components.

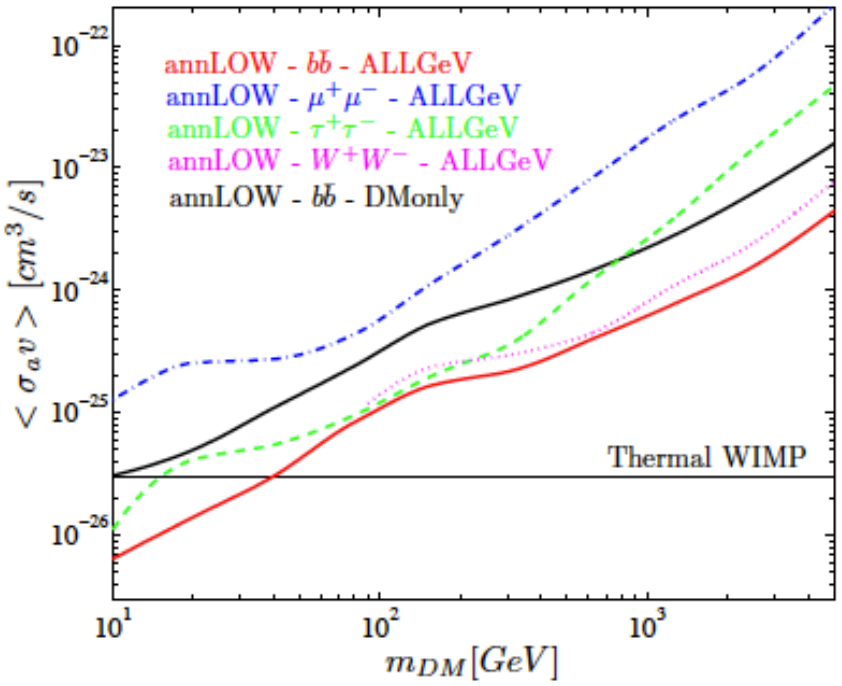
Fermi-2 NVSS X-Correlation



- Highly significant signal (~10 sigma)
- Do not fit with "naïve" models.
- Related to very small-scale clustering (1-halo term vs 2-halo term) being dominant
- Dominant 1-halo term difficult to model, i.e. becomes quite model dependent.
- Conclusion: interesting signal although probably less useful for the IGRB characterization

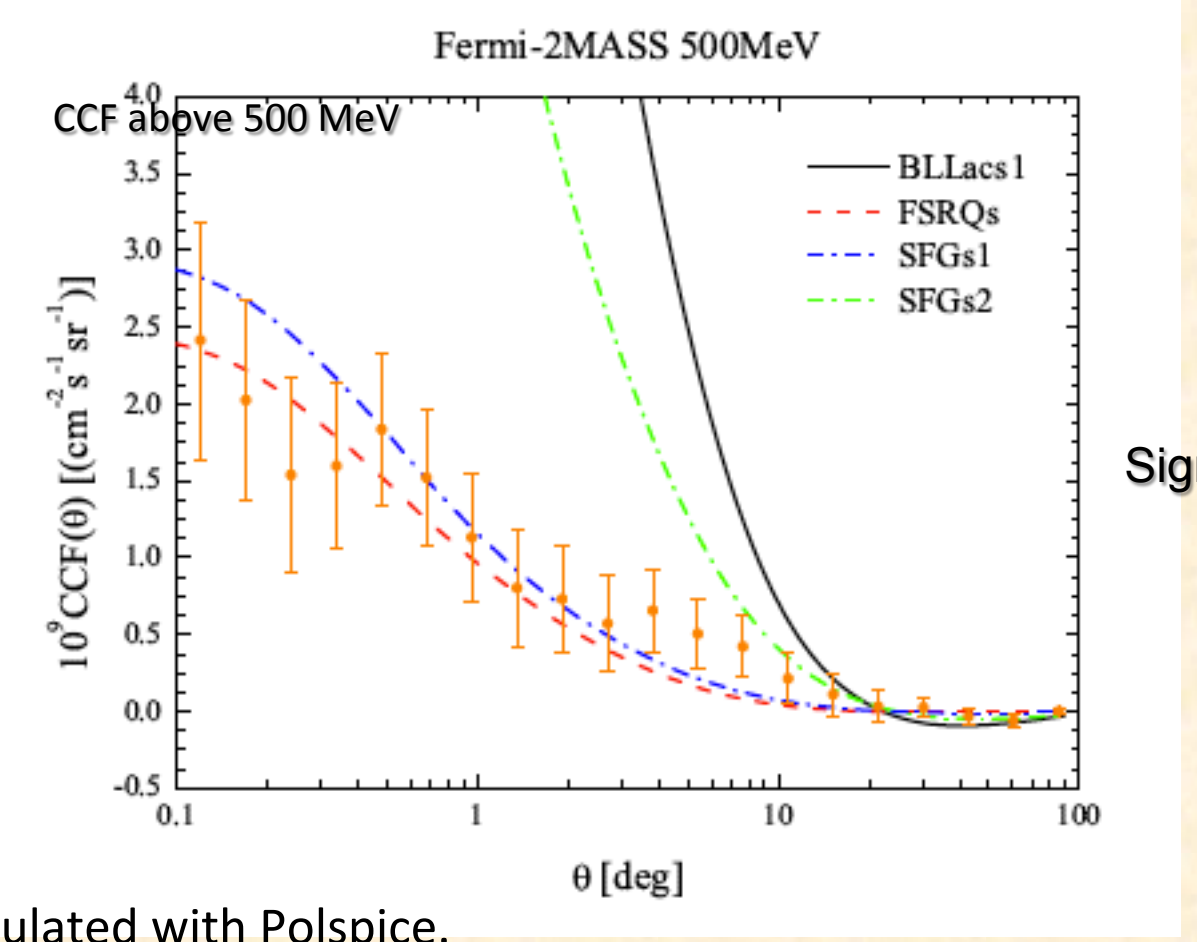
Dark Matter Constraints





- Limits on the DM contribution can be placed, although they depend on the DM Halo substructure modeling.
- They are, however, competitive even in the most conservative substructure boost scenario (i.e. no boost)

Fermi-2 MASS X-Correlation



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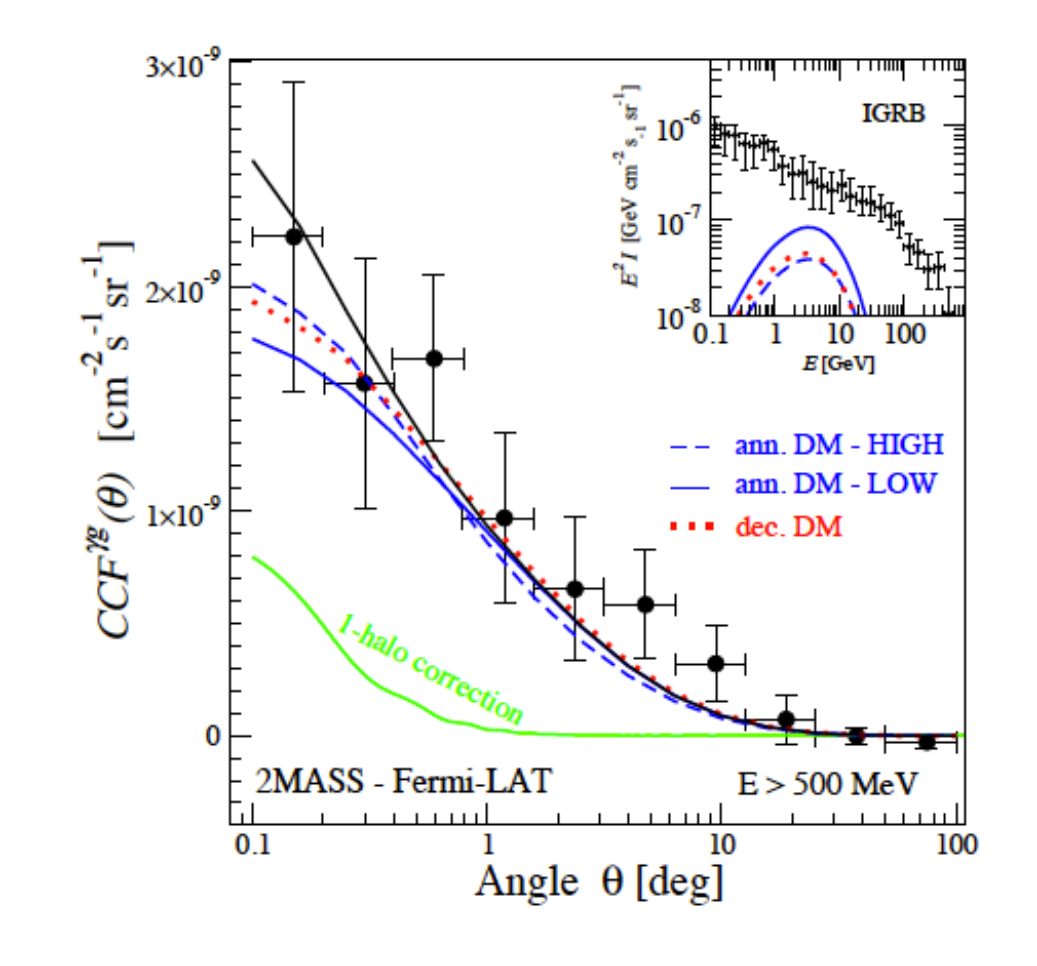
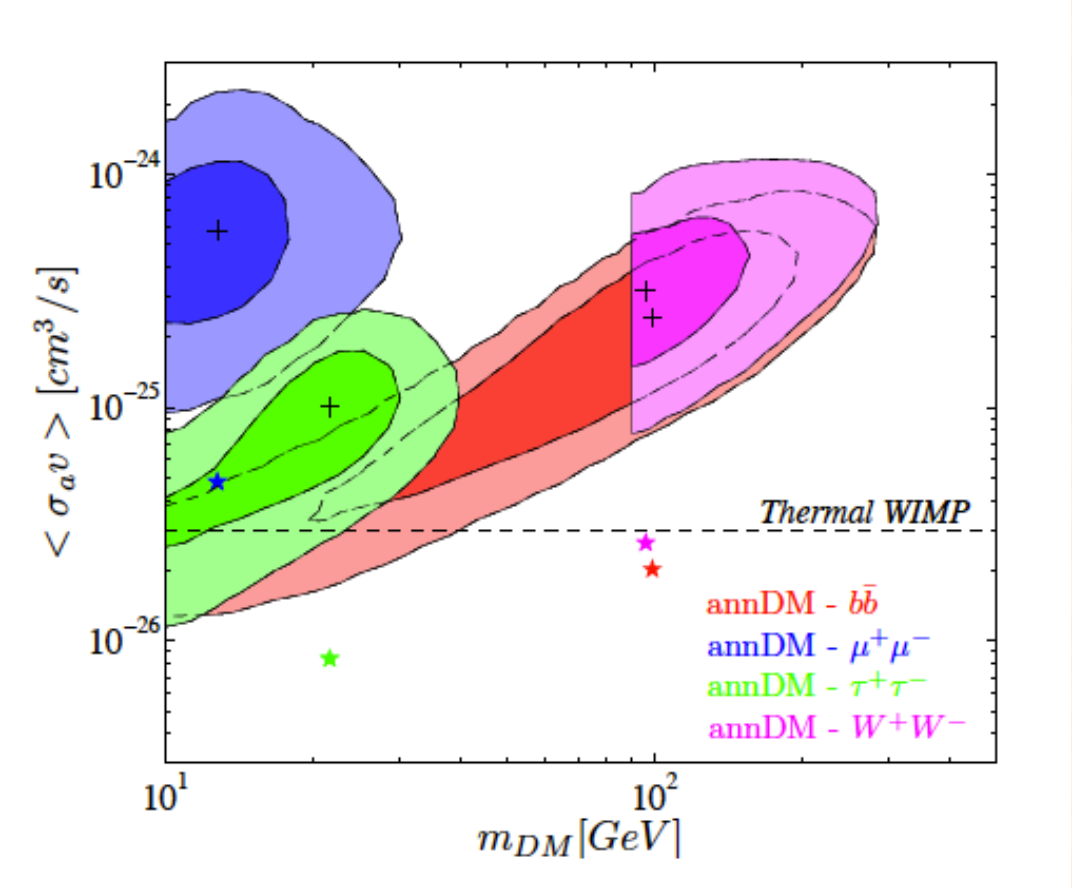
Fermi-2 MASS X-Correlation



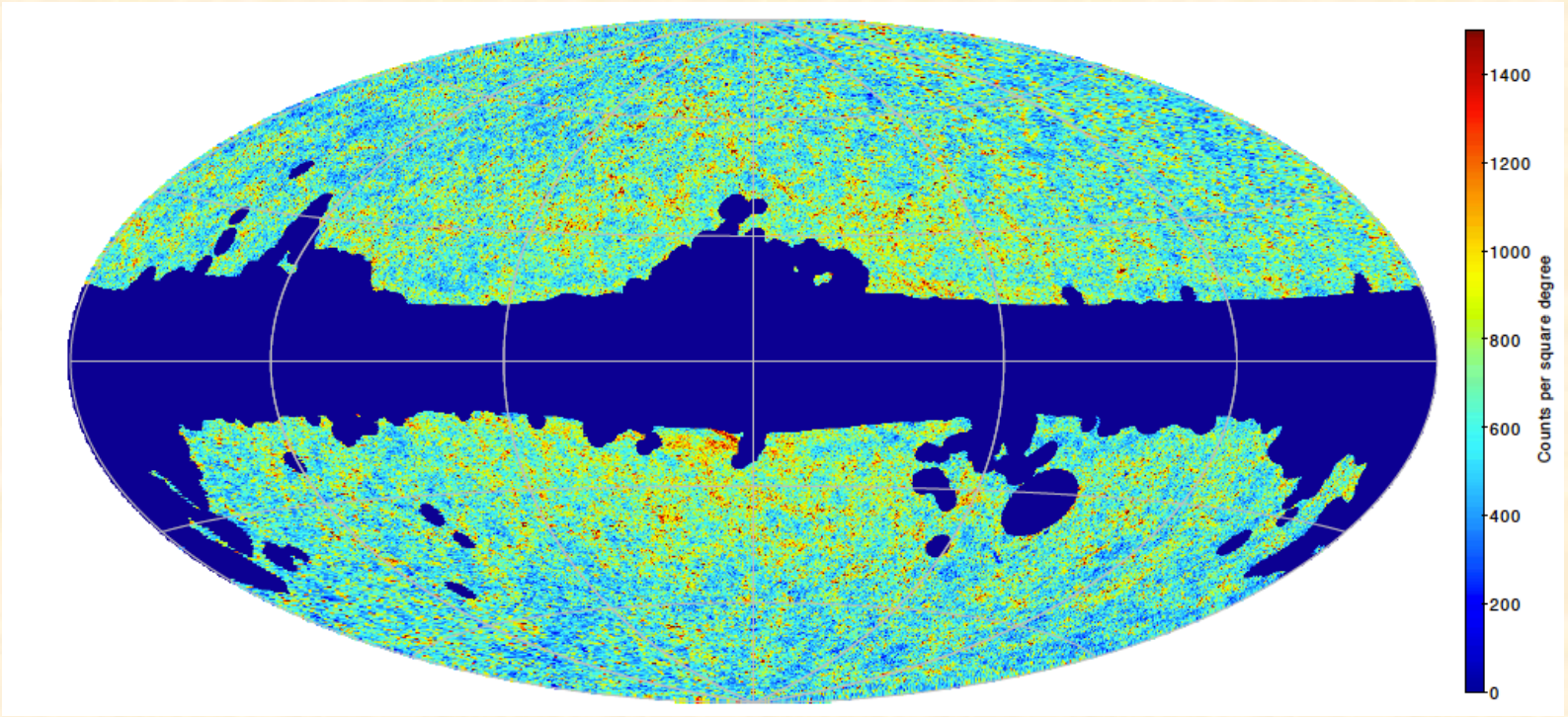
- A fit with DM only is equally good as the multi-component fit. Degeneracy prevents from distinguishing the two scenario. The DM only scenario (cor the 2MASS correlation) is thus viable in principle.
- In this scenario, also, DM gives a subdominant contribution to the IGRB (inset plot), as generically expected.

Dark Matter Interpretation



- A large DM contribution to the 2MASS correlation cannot be excluded, since, due to the peaking at low z, an high 2MASS correlation does not affect the correlations at higher z.
- Further analyses with more statistics will help to clarify this picture

Outlook



Wise x SuperCosmos photoz catalog, Bilicki et al. 2016

- New Pass 8 data from Fermi-LAT provide more statistics and less cosmic-ray contamination
- More statistics --- > more bins, better spectrum
- New, almost all-sky, catalogue to use besides 2MASS: WixSC

Summary and Conclusions

- Cross correlation of the IGRB with LSSs provides a way to isolate the IGRB contribution in different redshift, i.e. to perform **Tomography**
- The methods provides strong constraints on the DM contribution to the IGRB
- In principle 2MASS correlation can be explained and fitted with DM without violating other constraints
- The picture is evolving rapidly and soon more gamma-ray data, better LSS catalogues and precise lensing shear maps will provide further insights and stronger sensitivities