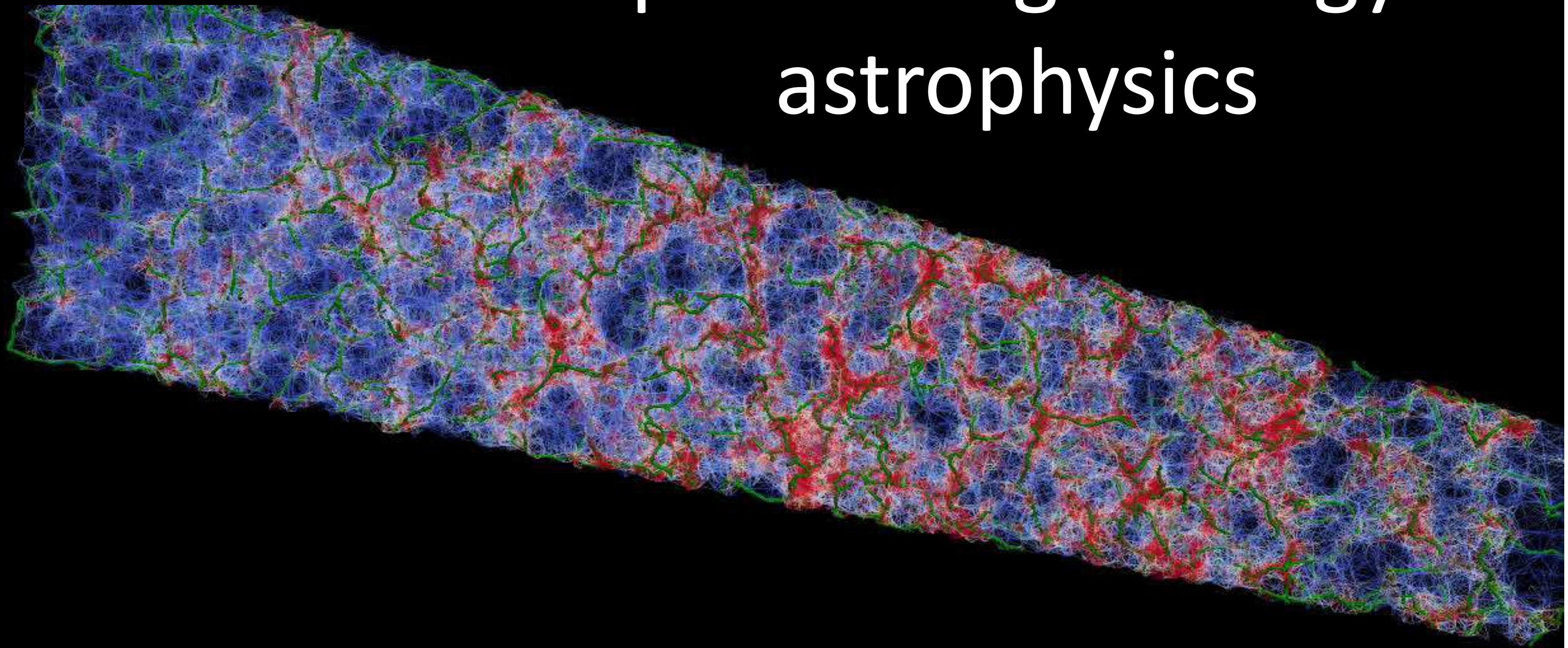
The Large Scale Structure path to high energy astrophysics



E. Branchini

ROMA TRE UNIVERSITÀ DEGLI STUDI

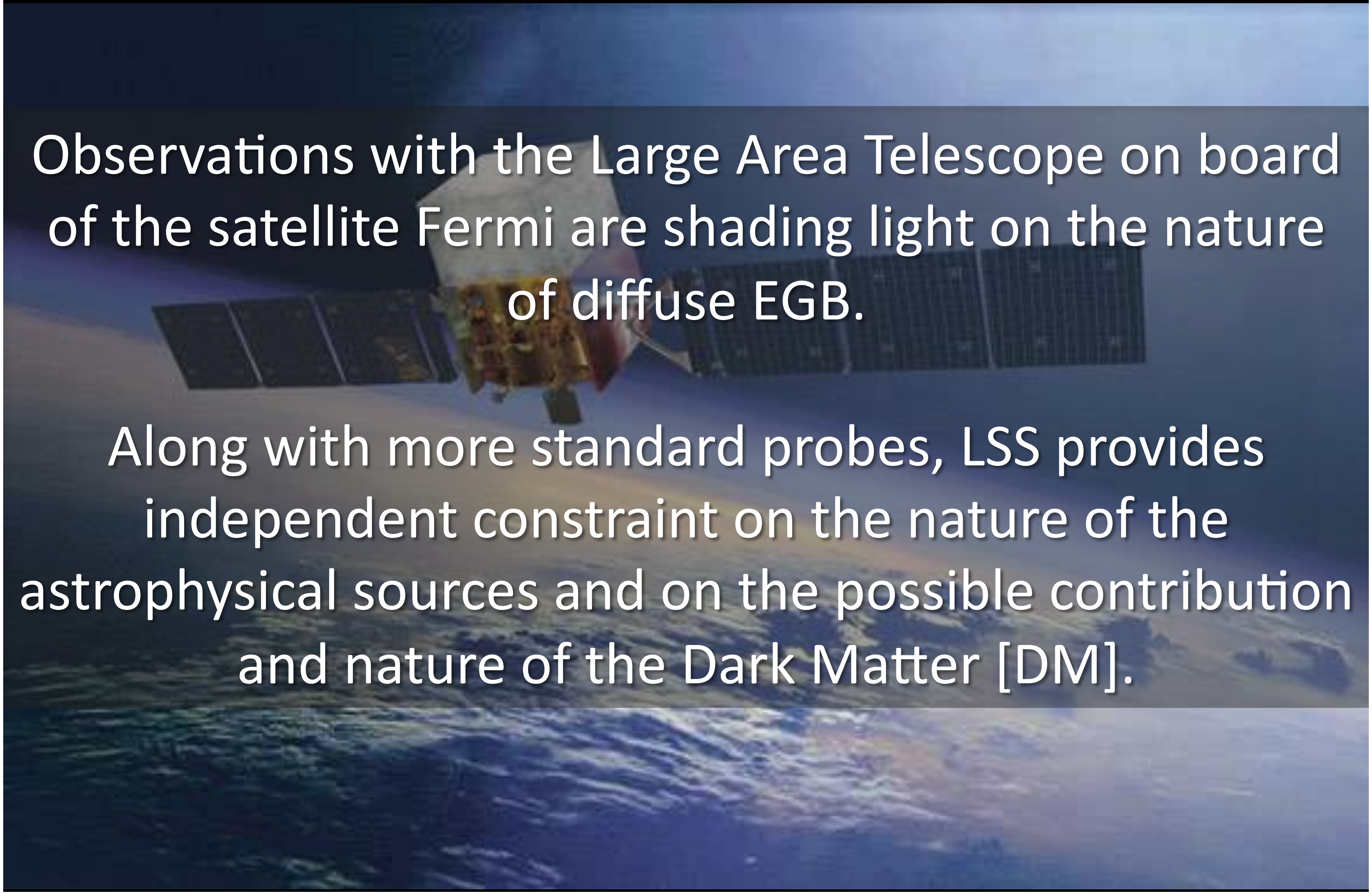
Vulcano Workshop 2016

Layout of the Talk

1. Nature of the diffuse extragalactic gamma-ray background [EGB] and Dark Matter contribution.
2. Detection and study of the Warm Hot Intergalactic Medium [WHIM].

Collaborators:
(2) Cuoco A., Fornengo N., Regis M., Xia J-Q., Viel M.
(3) Nevalainen J., Tempel E., Liivamagi L.,Roncarelli M.,Giocoli C., Heinamaki,P., Saar E., Tamm A., Finoguenov A., Nurmi., Bonamente M., VIPERS team

The nature of the diffuse gamma-ray background.

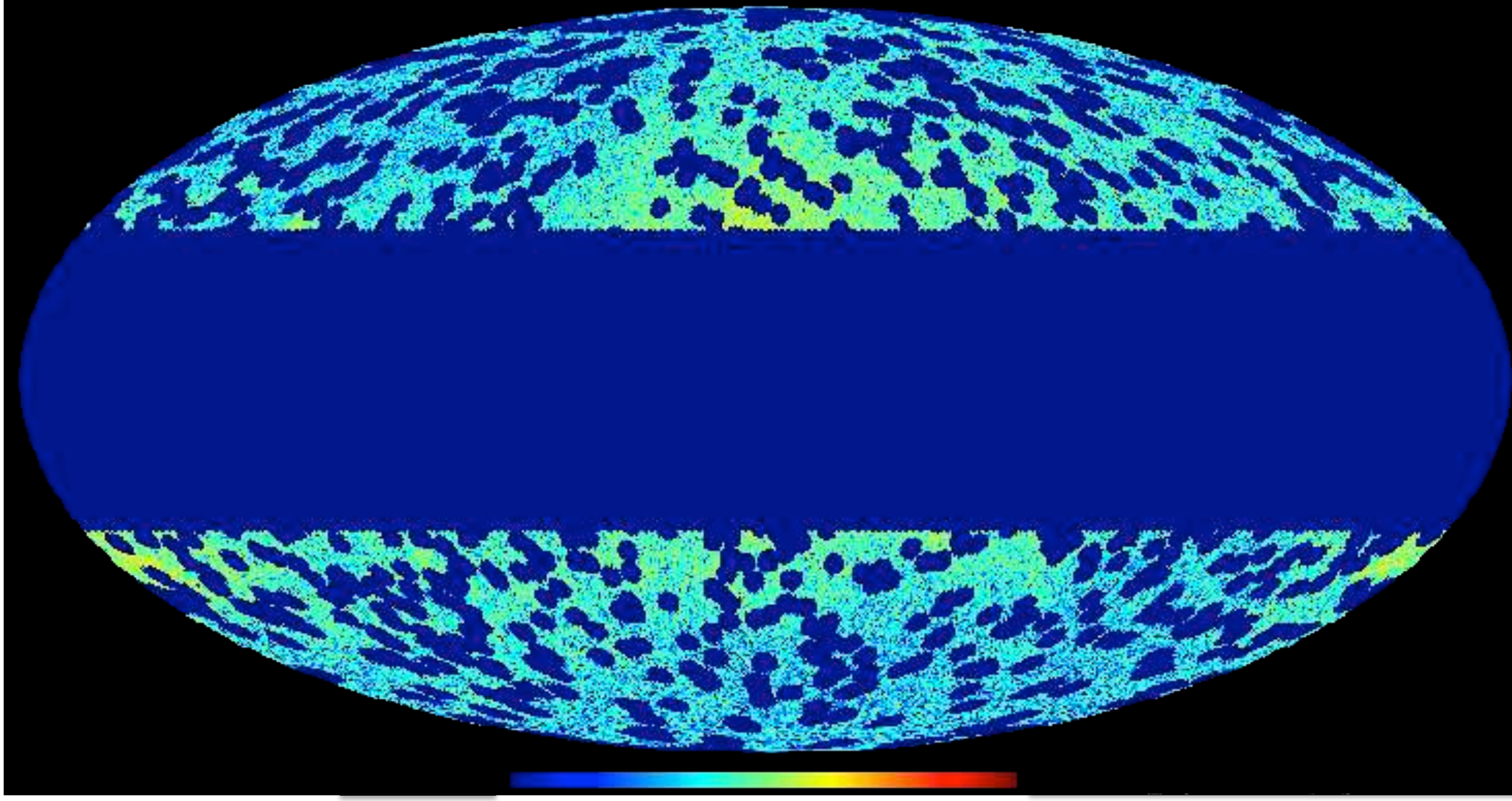


Observations with the Large Area Telescope on board of the satellite Fermi are shading light on the nature of diffuse EGB.

Along with more standard probes, LSS provides independent constraint on the nature of the astrophysical sources and on the possible contribution and nature of the Dark Matter [DM].

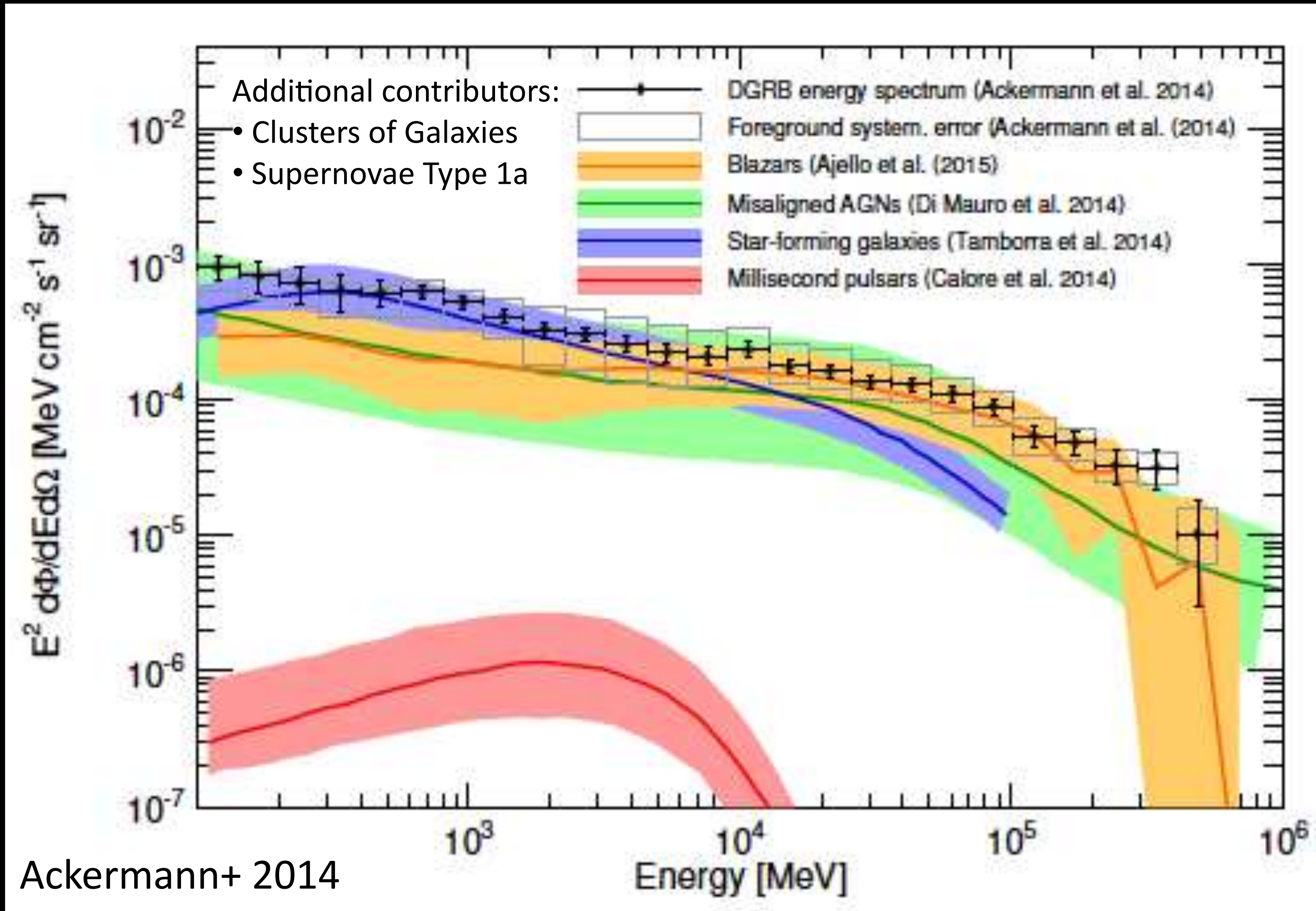
Fermi-LAT EGB

Diffuse γ-ray background. 80%
Galactic Foreground + *nearly isotropic* EGB



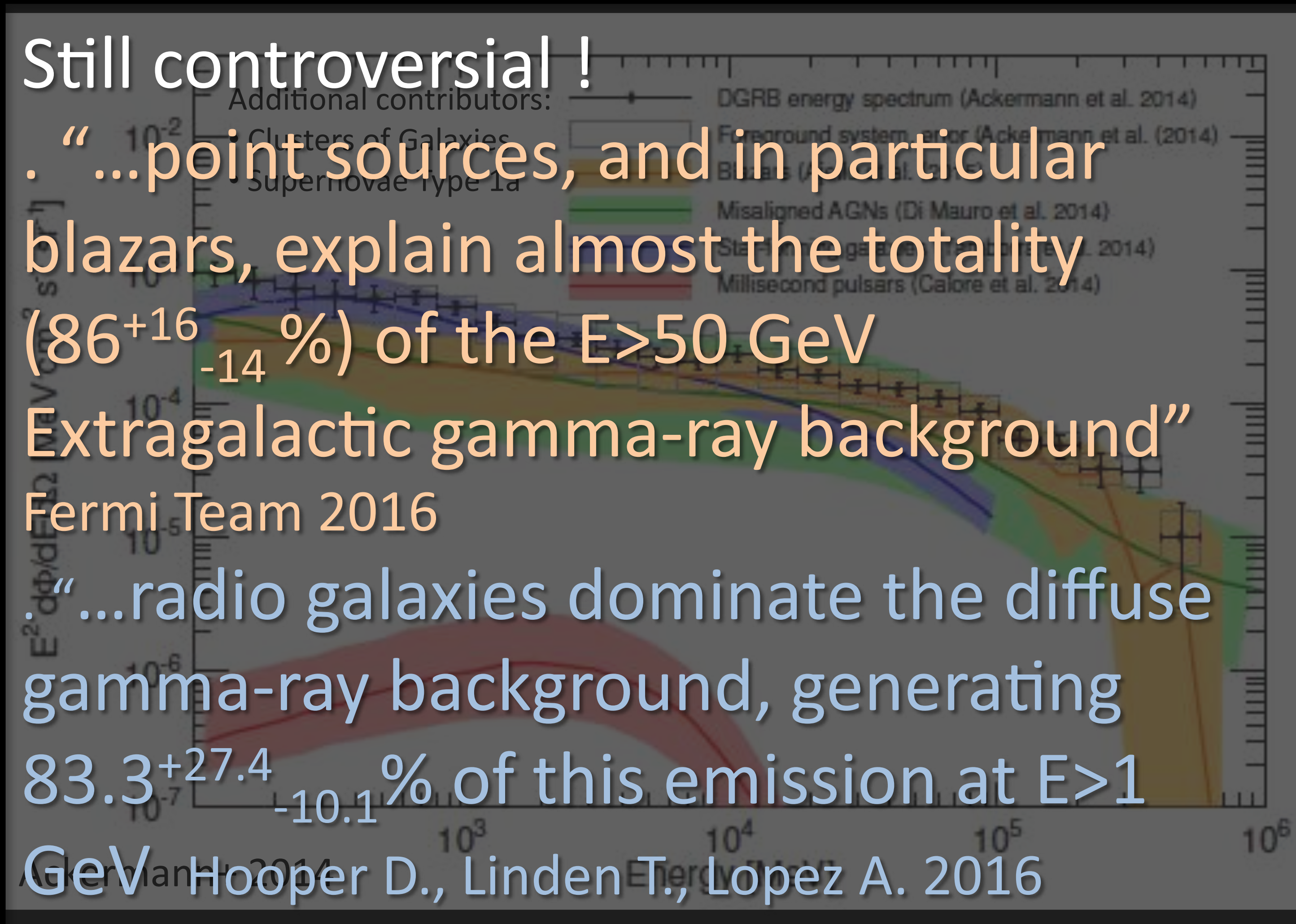
Energy Spectrum

Diffuse γ-ray background: astrophysical sources



Energy Spectrum

Diffuse γ-ray background: astrophysical sources



Still controversial !

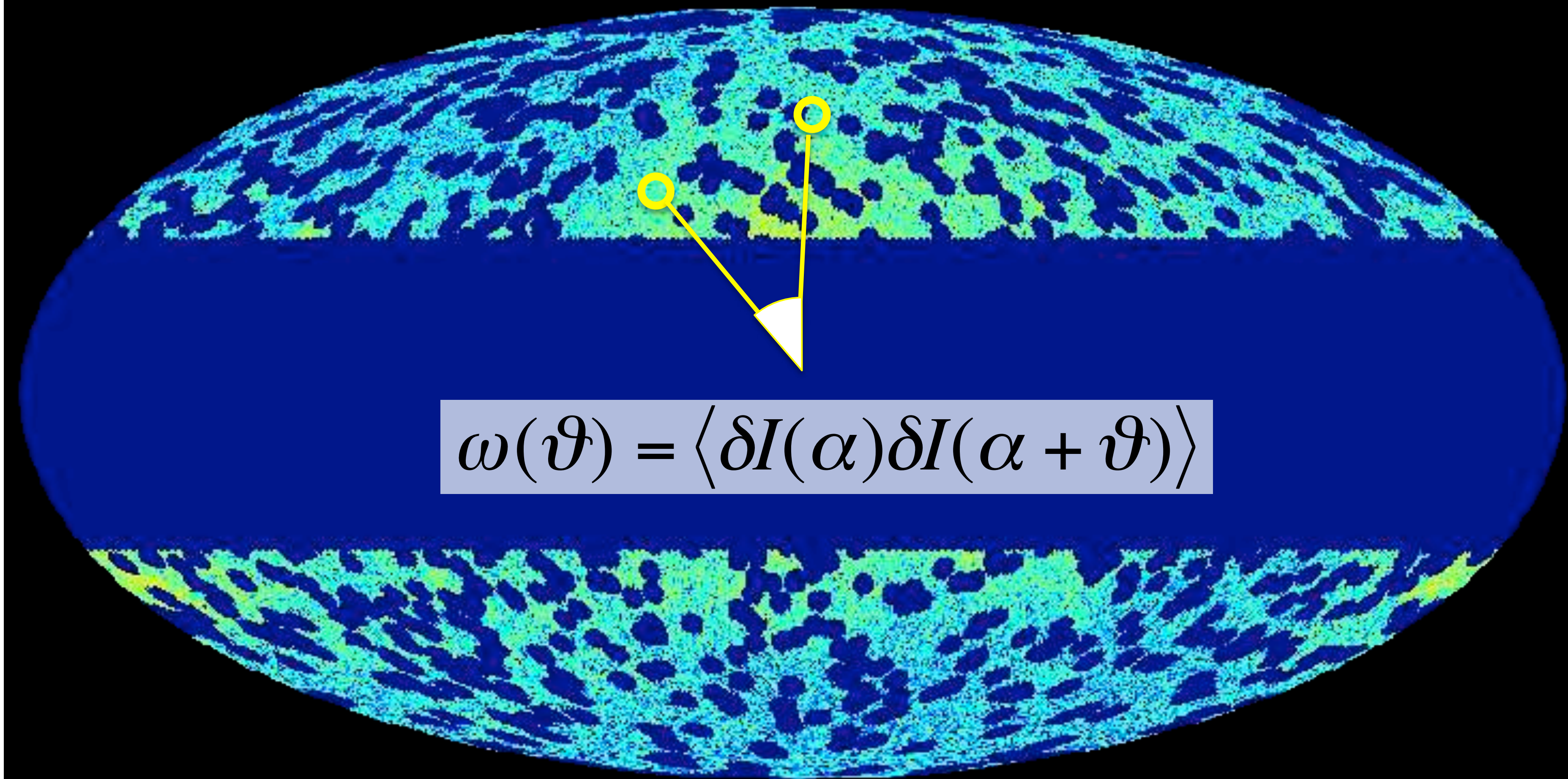
. "…point sources, and in particular blazars, explain almost the totality (86^{+16}_{-14} %) of the E>50 GeV Extragalactic gamma-ray background"

Fermi Team 2016

. "…radio galaxies dominate the diffuse gamma-ray background, generating $83.3^{+27.4}_{-10.1}$% of this emission at E>1 GeV

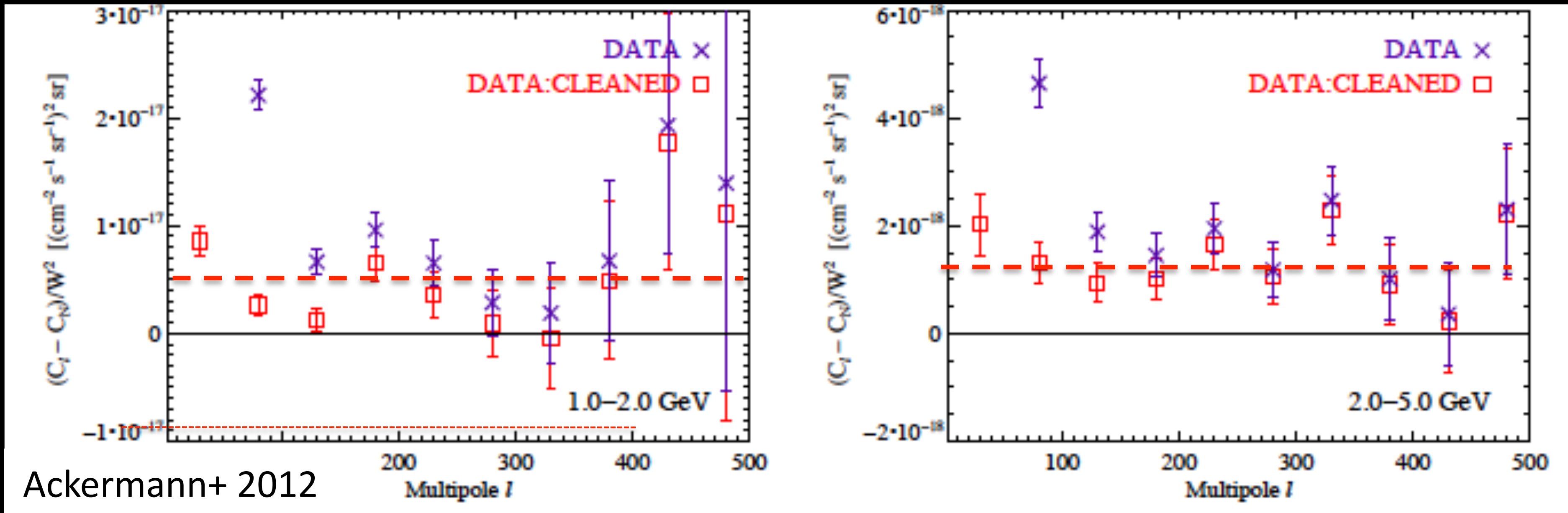
Hooper D., Linden T., Lopez A. 2016

Not quite isotropic !
EGB auto-correlation



$$\omega(\vartheta) = \langle \delta I(\alpha)\delta I(\alpha+\vartheta) \rangle$$

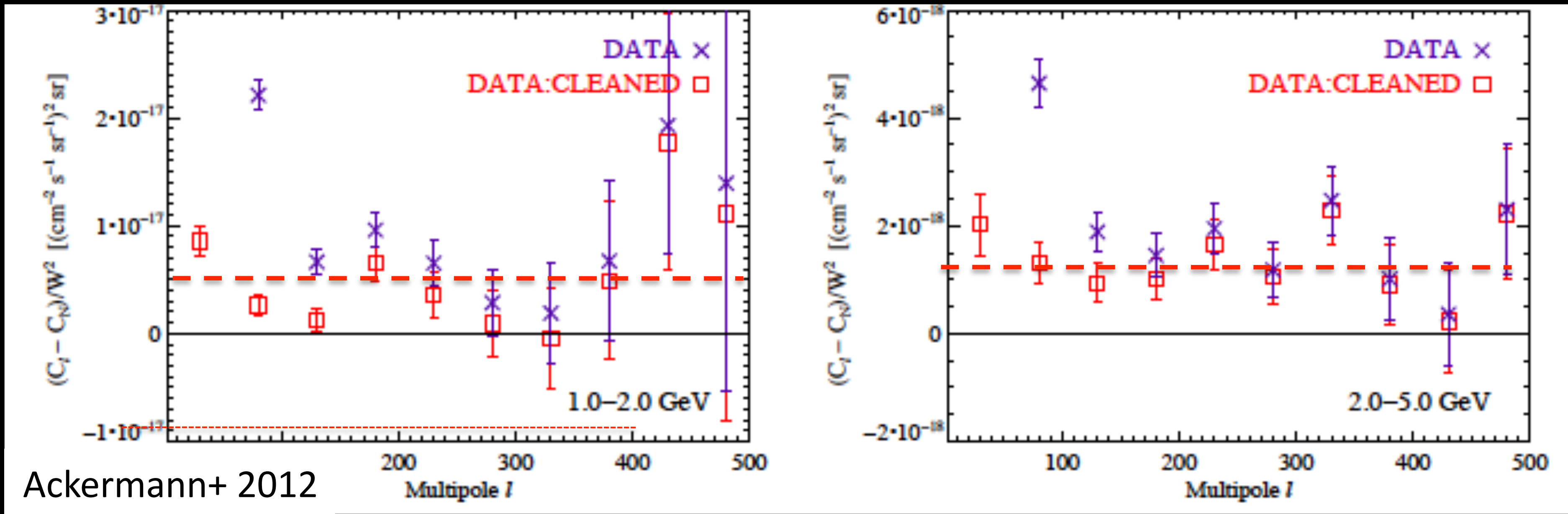
EGB auto-correlation



Ackermann+ 2012

Constant, shot-noise-like angular power.
Limited number of unresolved sources.
Blazars (35% @ 1GeV, 100 % @ 10 GeV) +
mAGN (10% @ 1GeV, 15 % @ 10 GeV)

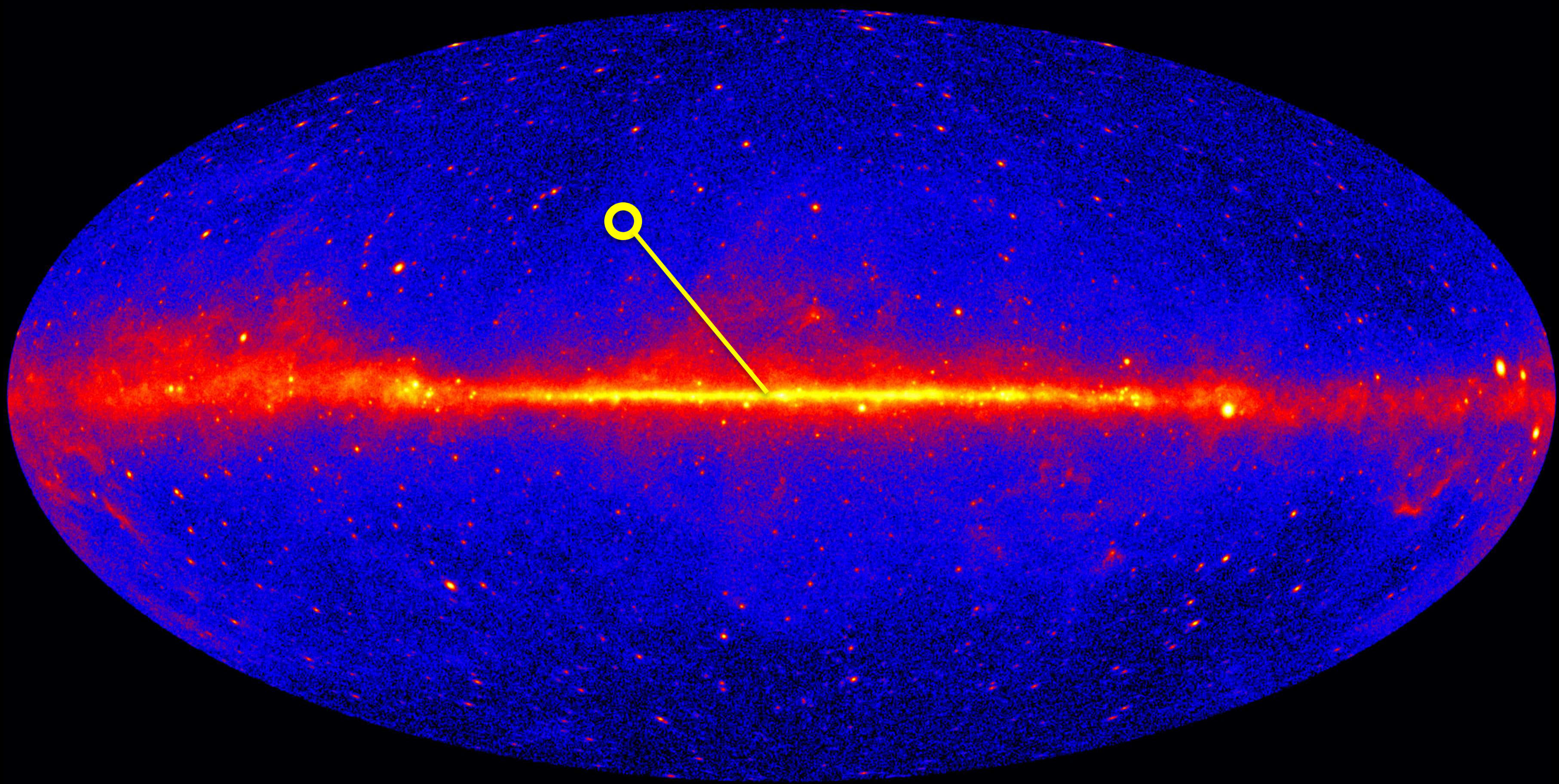
EGB auto-correlation



Observationally-driven errors, dominated by imperfect removal of the Galactic foreground, can be effectively reduced by **x-correlating γ-ray maps with catalogs of objects that trace the same cosmic structures hosting γ-ray sources** (Xia+ 2011, Ando+ 2014, Ando 2014).

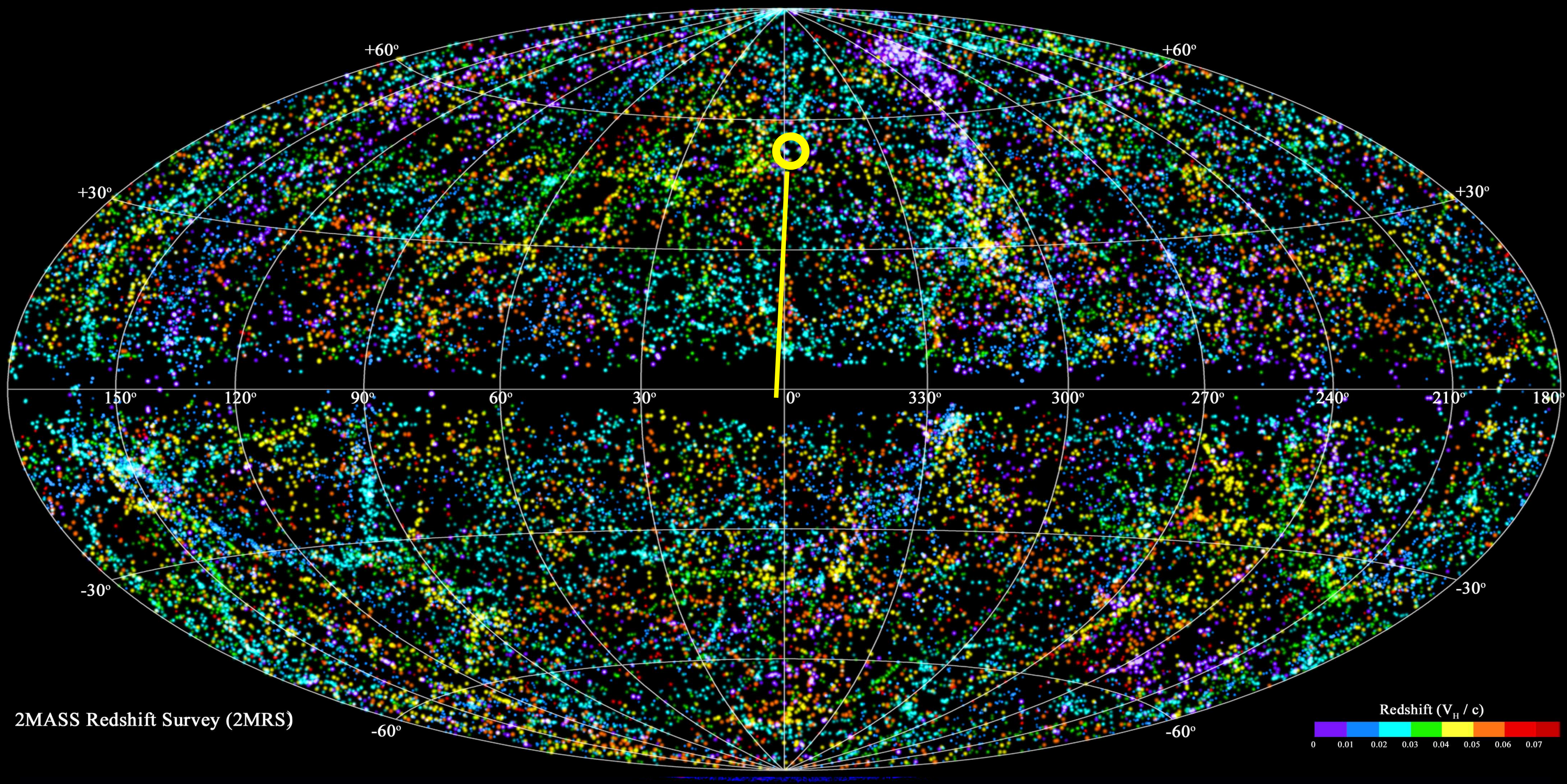
EGB cross-correlation

Cross-correlation with LSS



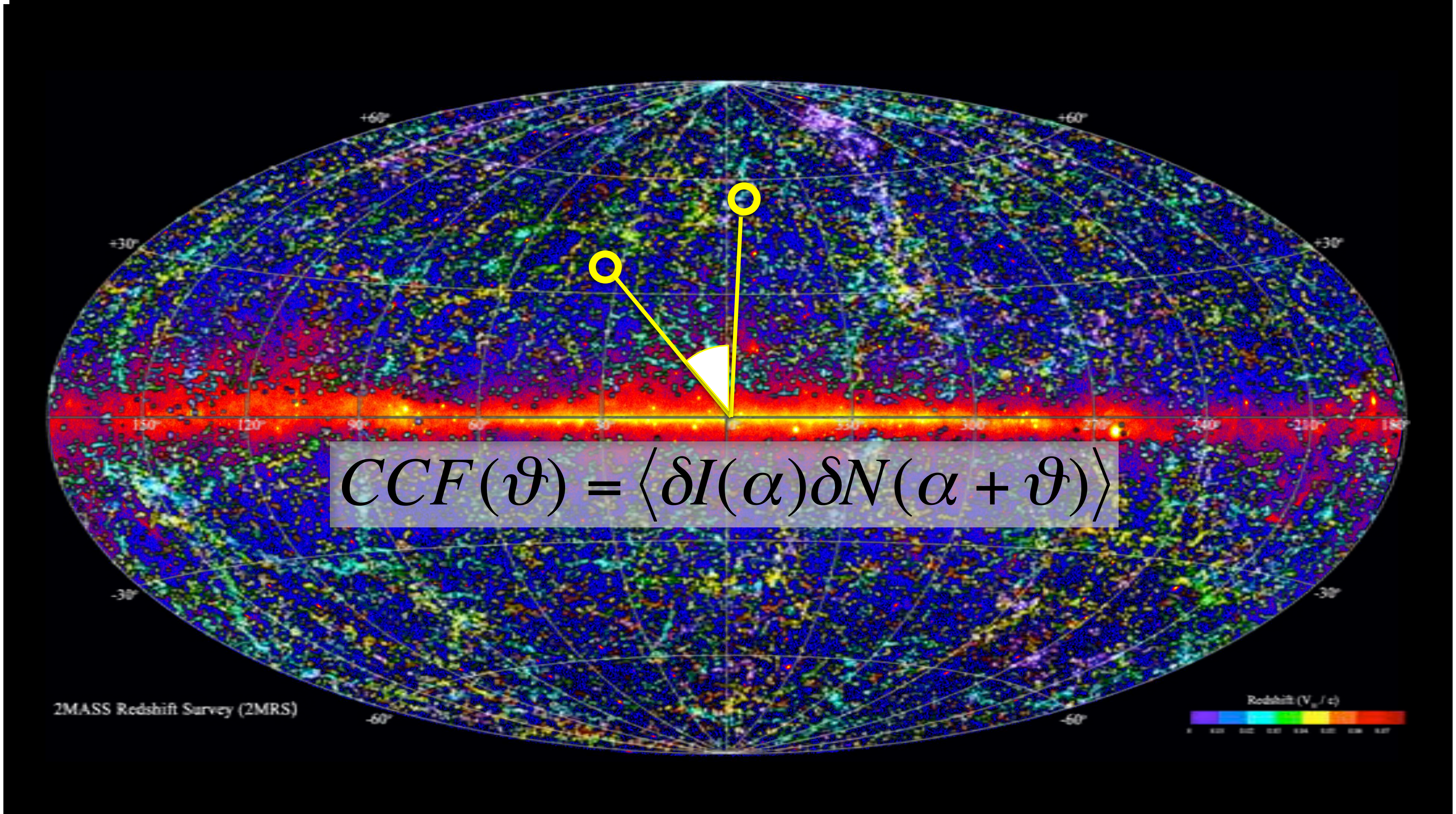
Fermi-LAT results

Cross-correlation with LSS



Fermi-LAT results

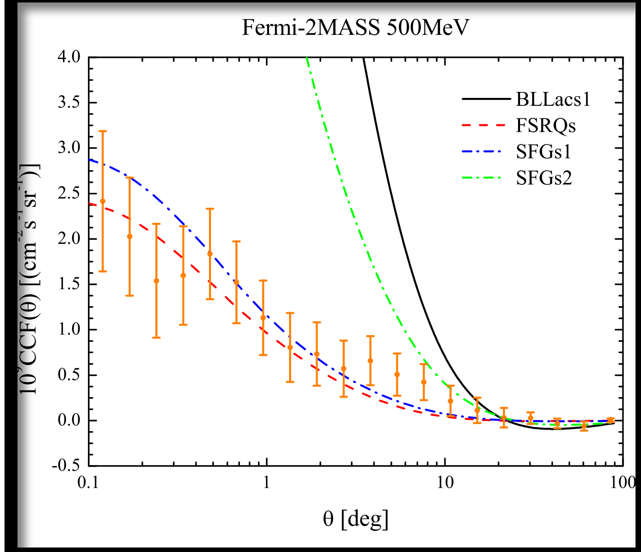
Cross-correlation with LSS



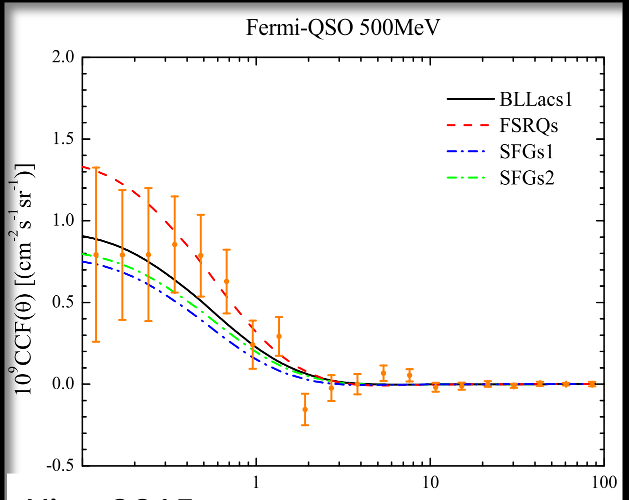
$$CCF(\vartheta) = \langle \delta I(\alpha)\,\delta N(\alpha + \vartheta) \rangle$$

EGB cross-correlation

X-correlations EGB Fermi 5-year

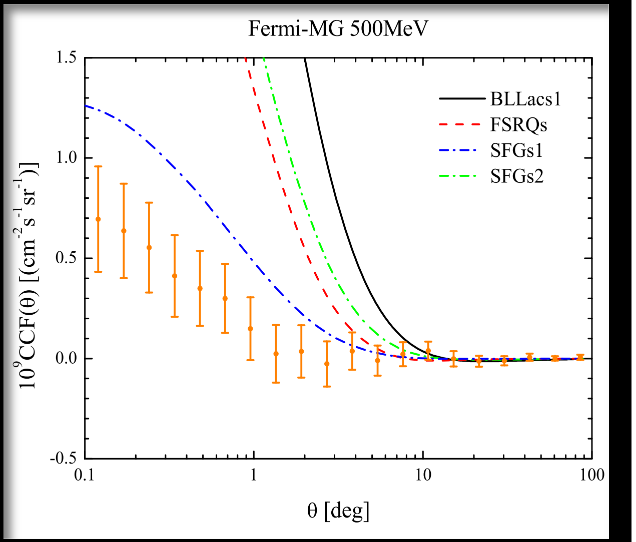


2MASS galaxies



Xia+ 2015

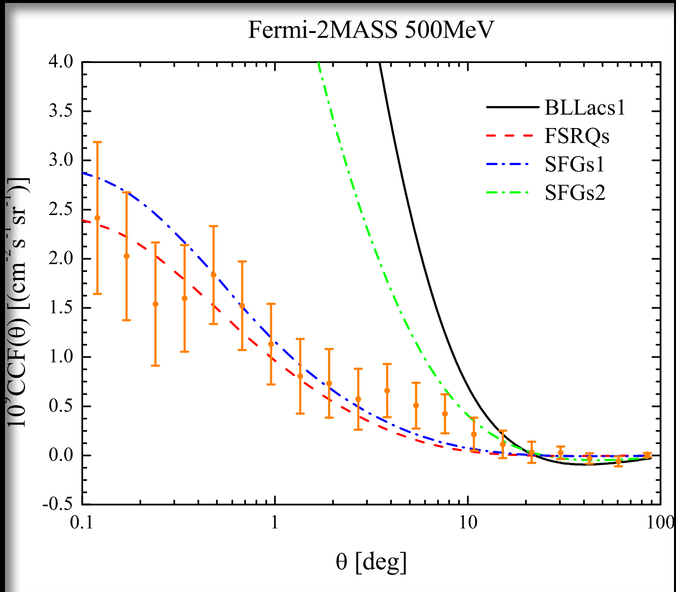
SDSS-QSOs



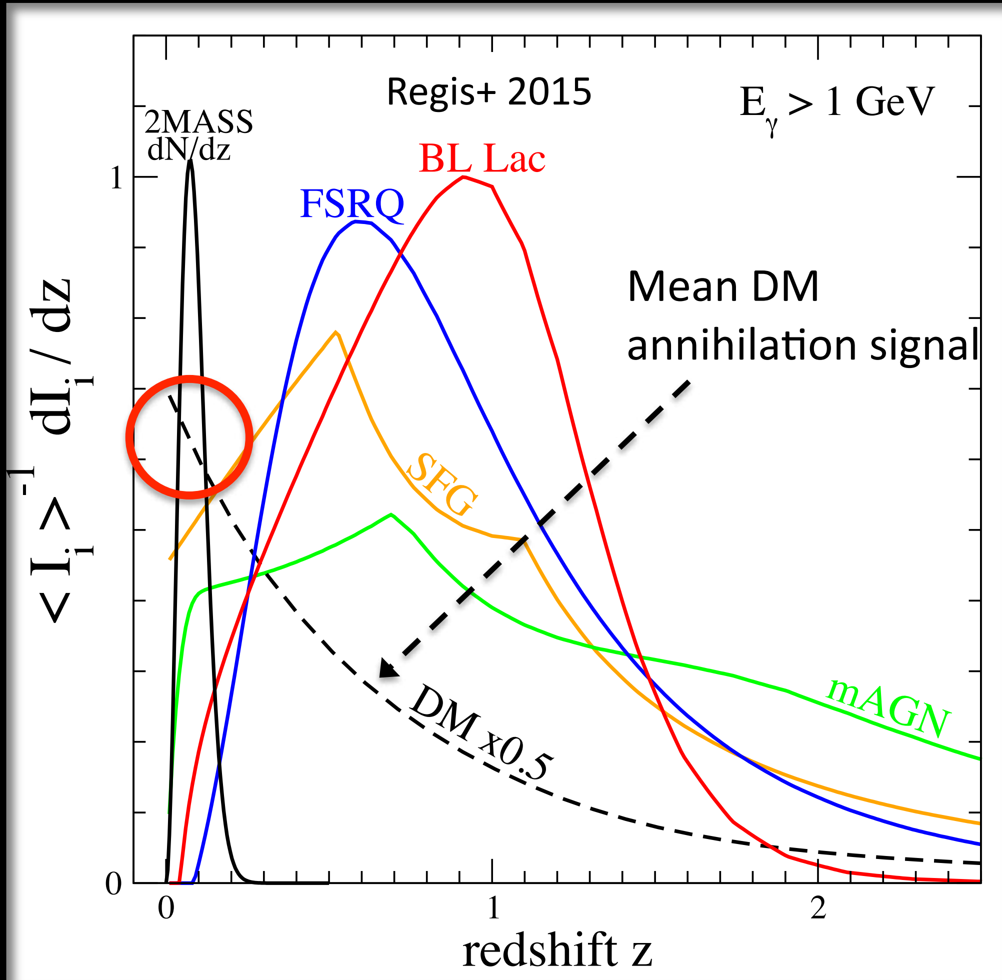
SDSS main galaxy sample

EGB cross-correlation

X-correlation 2MASS - EGB Fermi 5-year



Let us focus on 2MASS and assume that DM is the only (largely local) EGB source.



EGB cross-correlation

Model: DM – LSS cross-correlation (2-point stat)

$$C_l^{I,j} = \frac{2}{\pi}\int k^2 P_x(k)[G_l^I(k)][G_l^j(k)]dk$$

To model the x-power and the density along the LOS we use the halo model and consider the effect of sub-halos within their parent halos.

Given the theoretical uncertainties in the halo profile, sub-halo abundance, their profile etc… we consider two extreme scenarios: LOW and HIGH, corresponding to conservative and optimistic scenarios, respectively.

$$\propto \Omega_{DM}^2 \frac{\langle \sigma v \rangle}{2m_x^2}\int \rho^2(z)D(z)j_l[k\chi(z)]dz$$

$$\propto \Omega_{DM}\frac{\Gamma_D}{2m_x}$$

$$\int \frac{dN(z)}{dz} b_j(z) D(z) j_l[k\chi(z)]dz$$

bias of the discrete sources

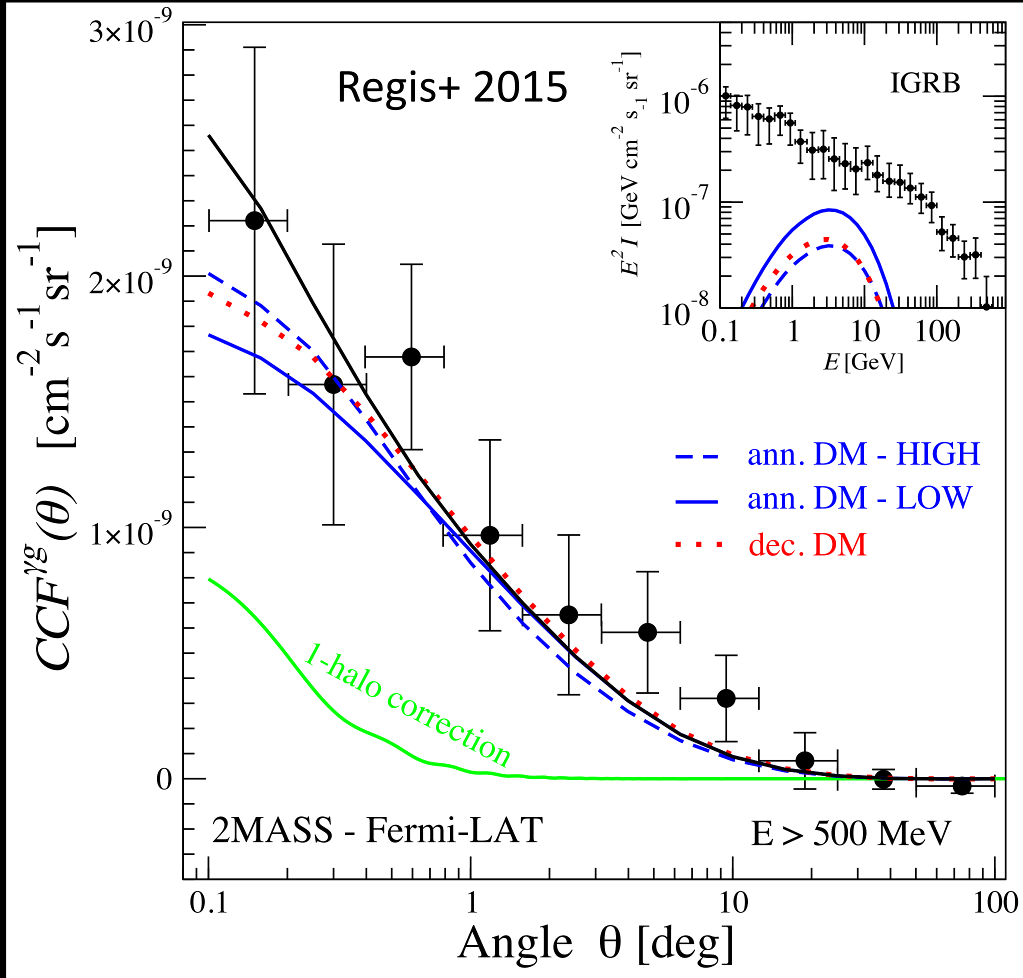
Redshift distribution of discrete sources

EGB cross-correlation

Model: DM only

DM-annihilation and decay models provide a good fit to the observed CCF without violating the EGB intensity constraint (small panel).

Forcing DM to be the only source of EGB allows one to obtain stringent UPPER limits to DM annihilation cross-section (or decay time).



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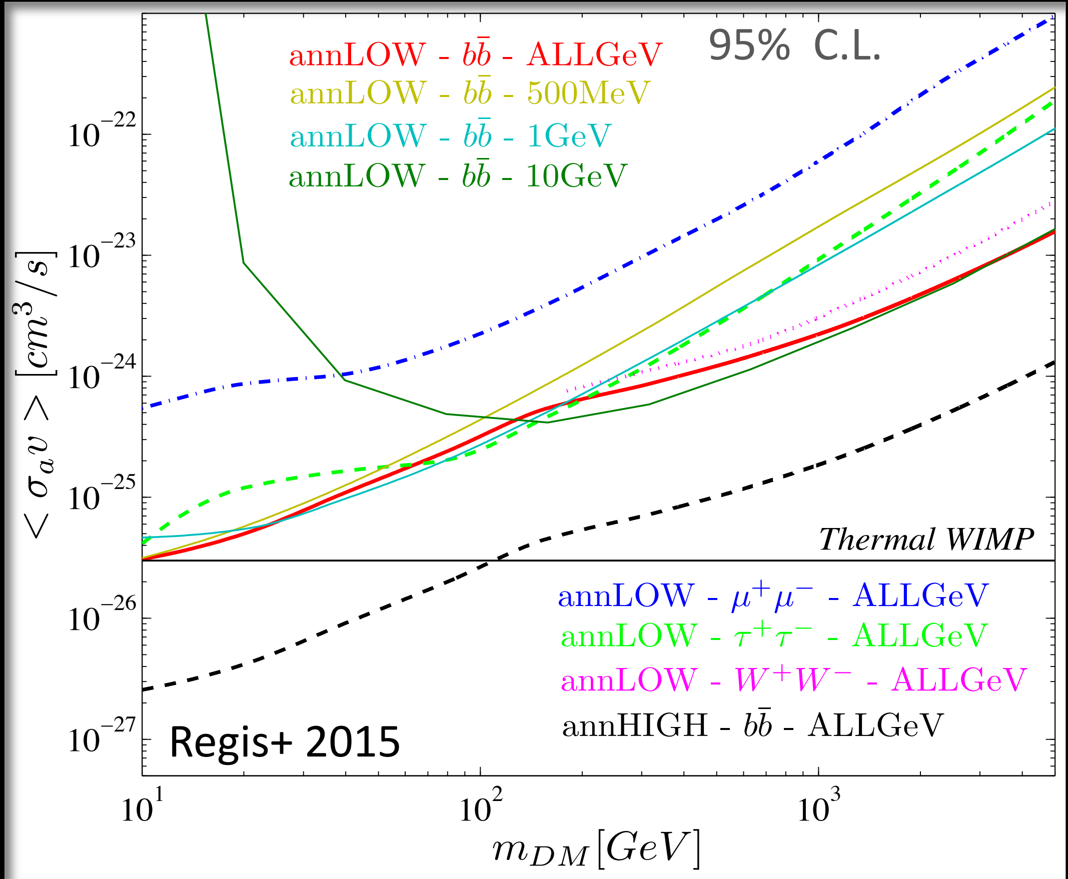


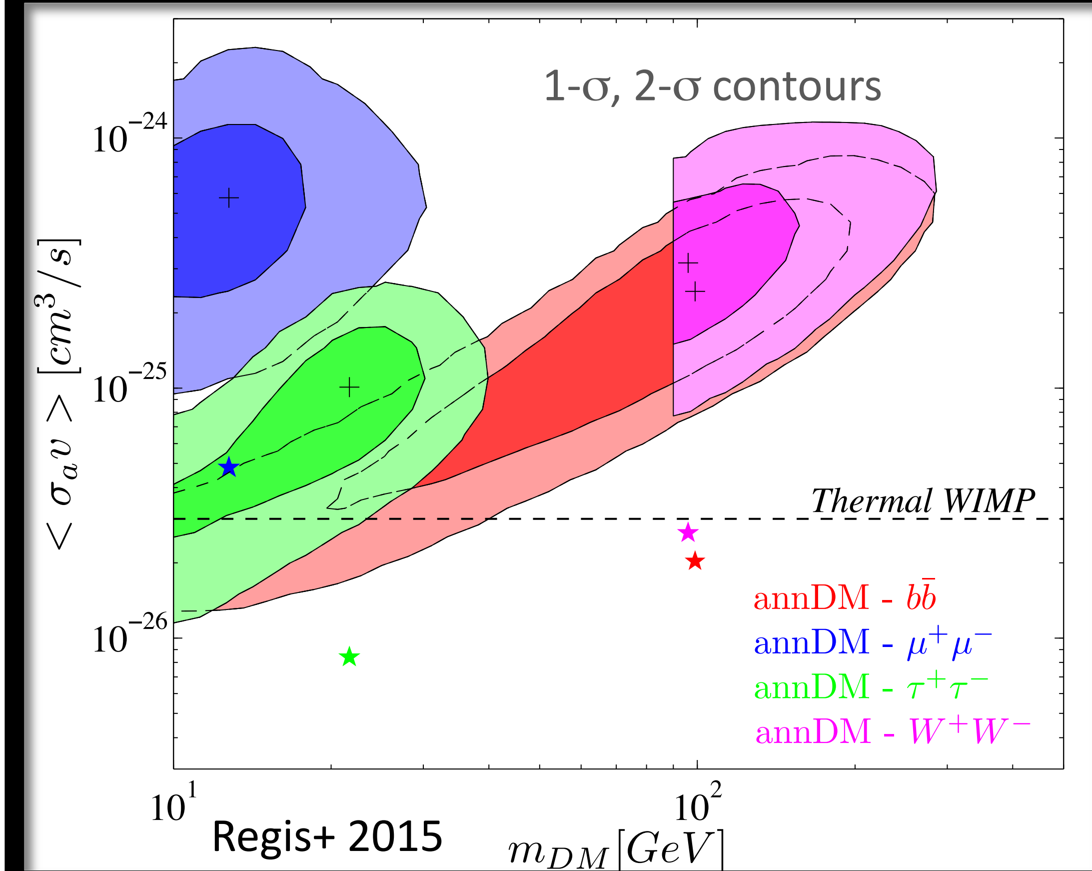
EGB cross-correlation

Model: DM only

Or to look for allowed regions for DM mass and annihilation cross-section.

The plot shows that 3 energy channels are sufficient to constrain DM mass.

This exercise is not too unrealistic since 2MASS is not expected to significantly correlate with standard astrophysical γ-ray sources.

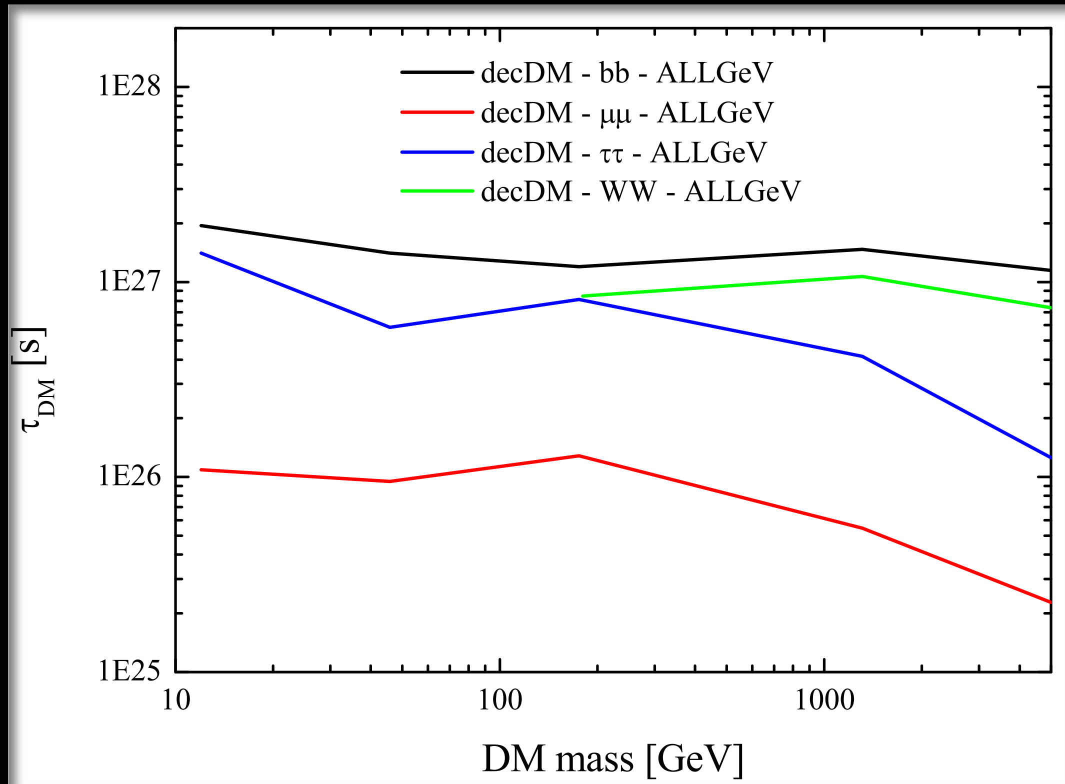


Regis+ 2015

EGB cross-correlation

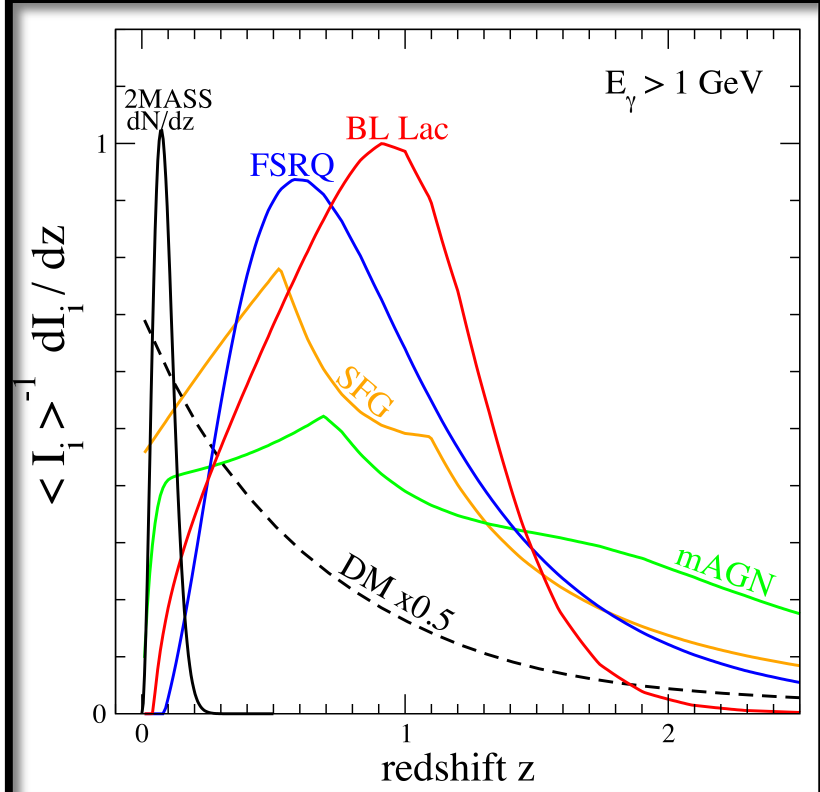
Model: DM only

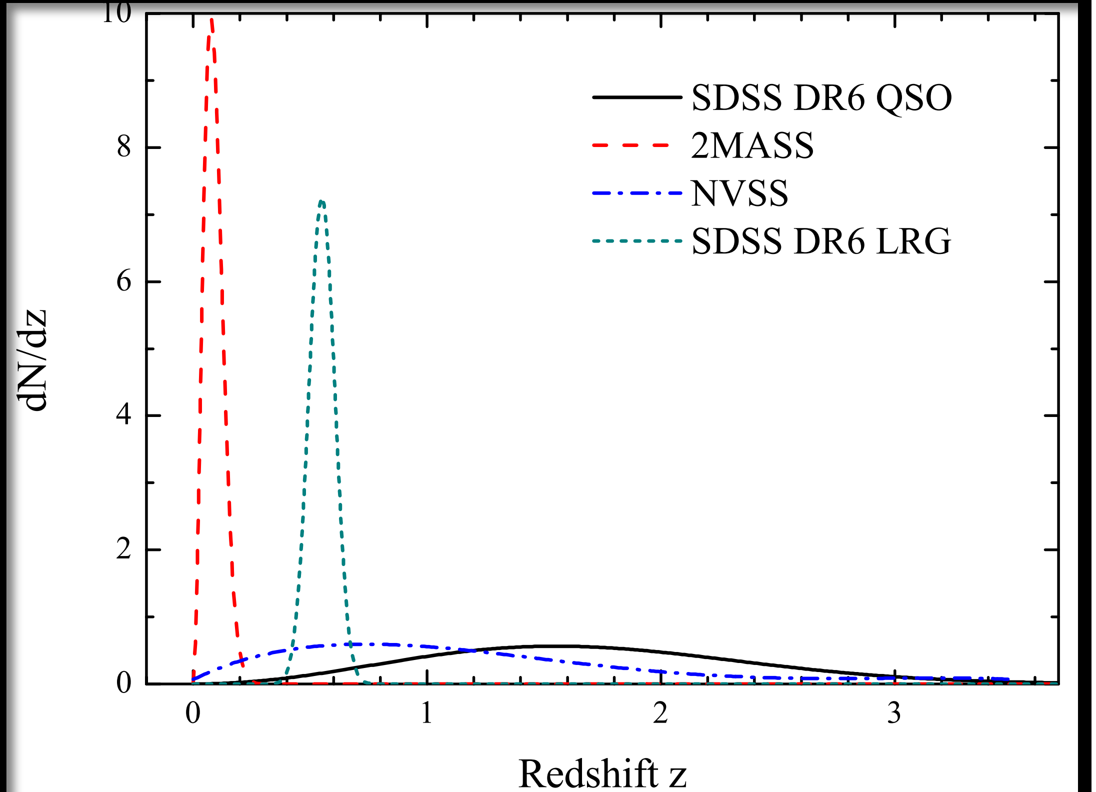
Similar constraints can be obtained also for decaying dark matter and decaying time.



EGB x-correlation

Model vs. data. X-correlation and tomography





Fermi-LAT results

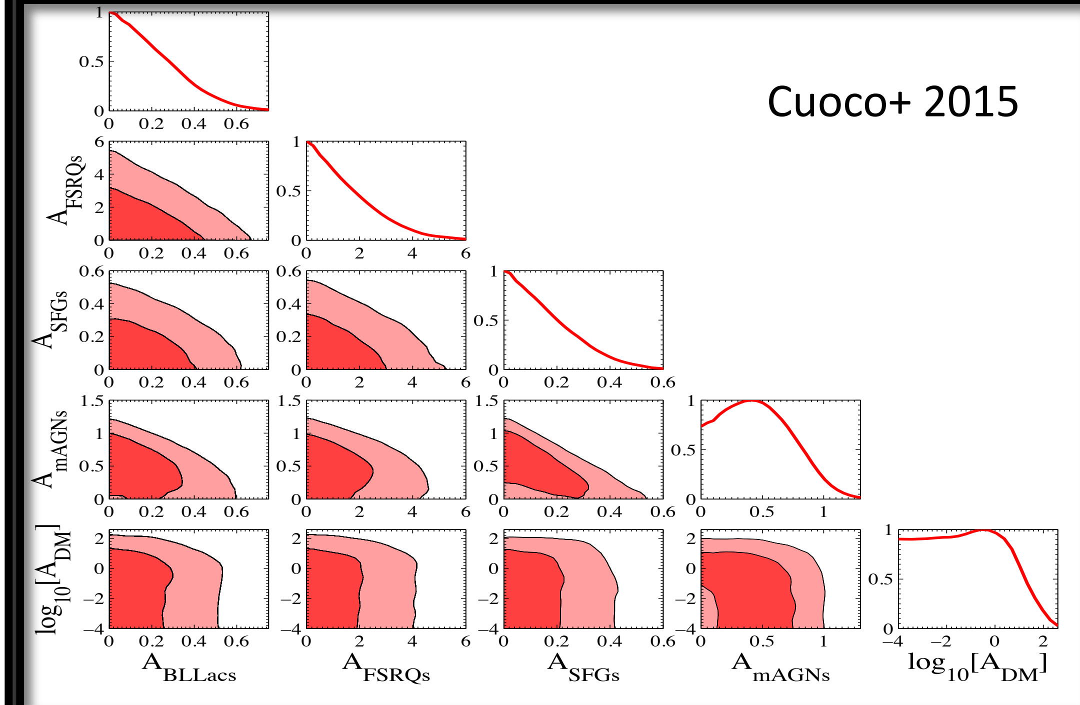
With this analysis one can estimate the contribution of the various sources to EGB.

The good news: the total EGB intensity constraint is not violated. DM constraints are somewhat improved

The bad news: degeneracy between mAGN and SFG contributions.

Degeneracy can be removed by *(i)* improving mAGN and SFG γ-ray LF models *(ii)* refining tomography *(iii)* better energy binning.

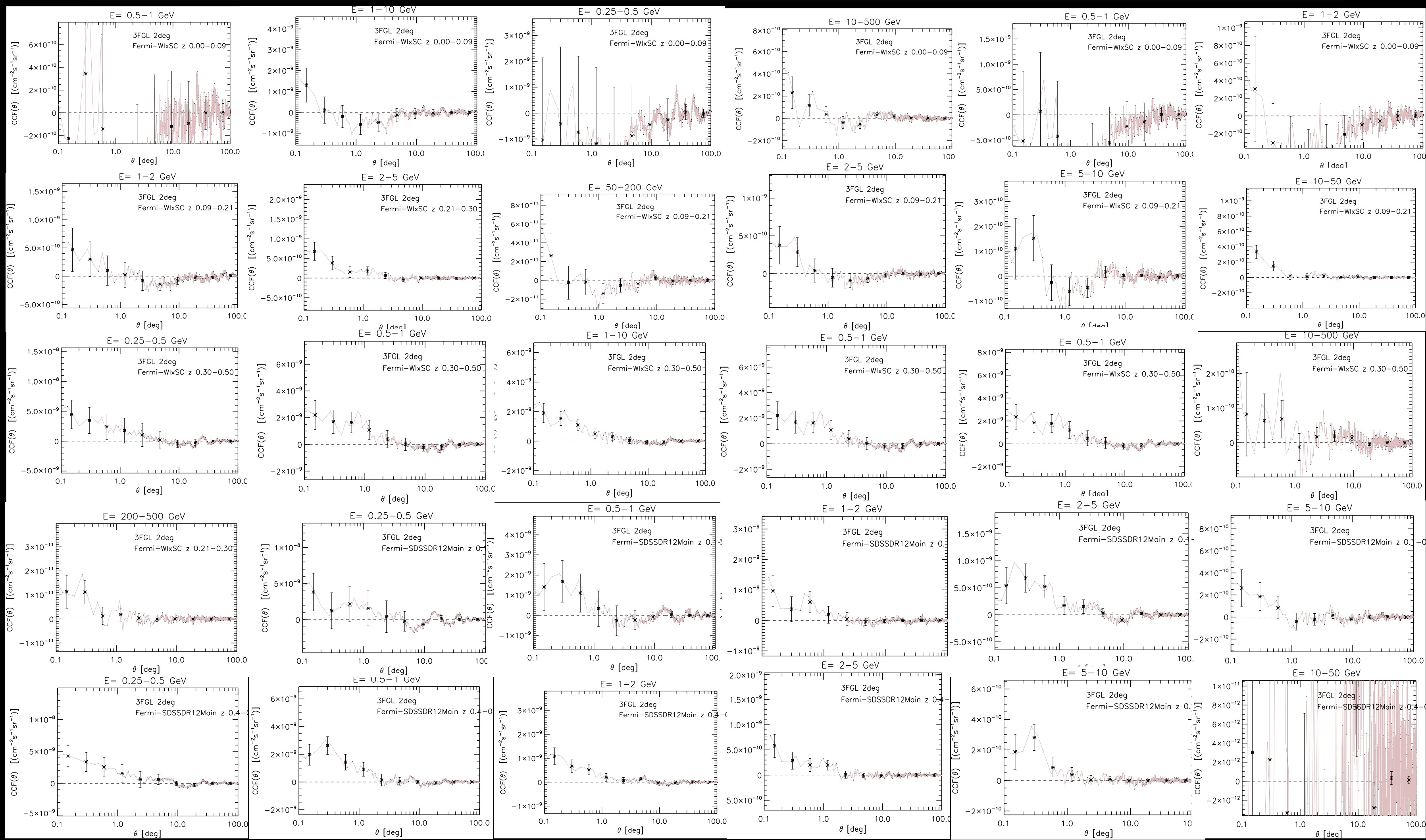
Model: All in



Fermi-LAT results

Ongoing analysis. Fermi Pass-8 for energy binning

MPz + WIxSC + BOSS for better z-slicing



Conclusions 1

- X-correlation with LSS is a powerful technique to investigate the nature of EGB *and* a competing probe for indirect DM searches. The availability of large (10^7-10^9 objects) galaxy catalogues probing a large (z=[0-2]) redshift range makes this strategy very promising

Detection and study of the WHIM

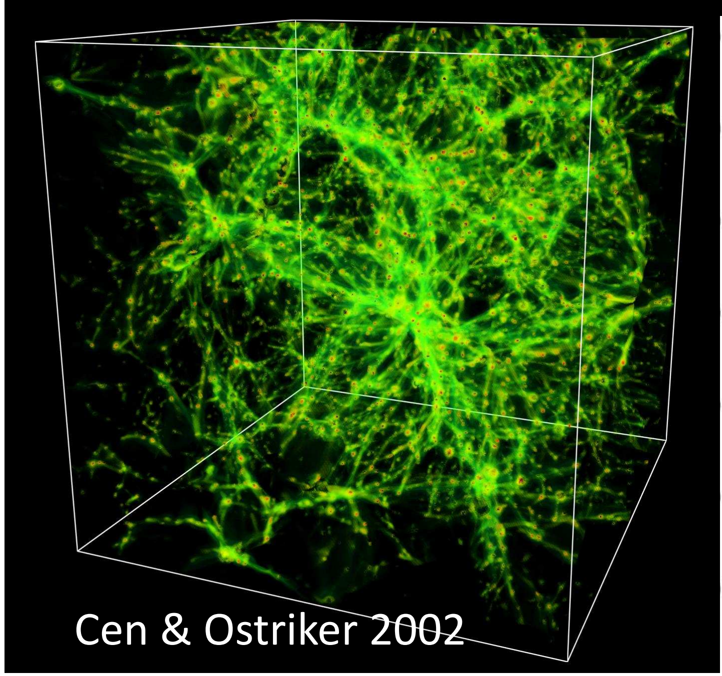
- A large (30-50%) fraction of baryons in the local Universe is missing from the luminous mass budget

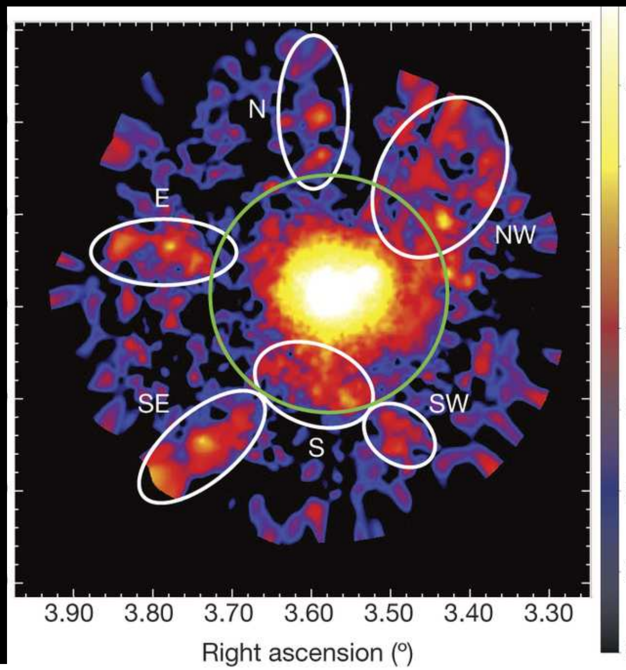
- Models, based on numerical experiments, predict that they preferentially reside in a diffuse, warm-hot gaseous (T=10^5-10^7 K^o) phase associated to mild overdensities in the LSS (e.g. filamentary structures).

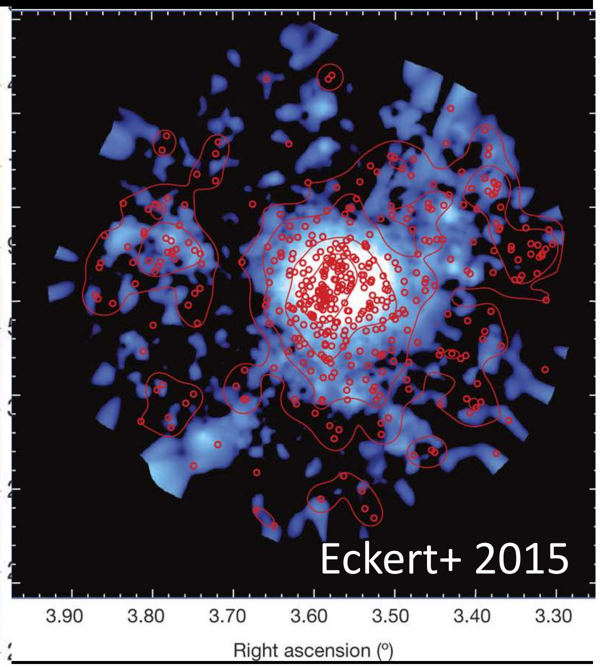
- These baryons are still largely undetected..

WHIM and LSS filaments

Hydrodynamical simulations: WHIM traces the filaments of cosmic web. *Observations*: hints of WHIM in filaments seen in X-rays. E.g. Weber+ 2009 and recent XMM-Newton observations of A2744. Excess emission in the 0.5-1.2 KeV band, outside the cluster's virial radius, associated to filaments of size ~ 4 Mpc. Gas temperature [1-2x10^7 KeV] marginally consistent with that of the WHIM. These structures are also associated to DM and galaxy overdensities (Eckert+ 2015).


Cen & Ostriker 2002

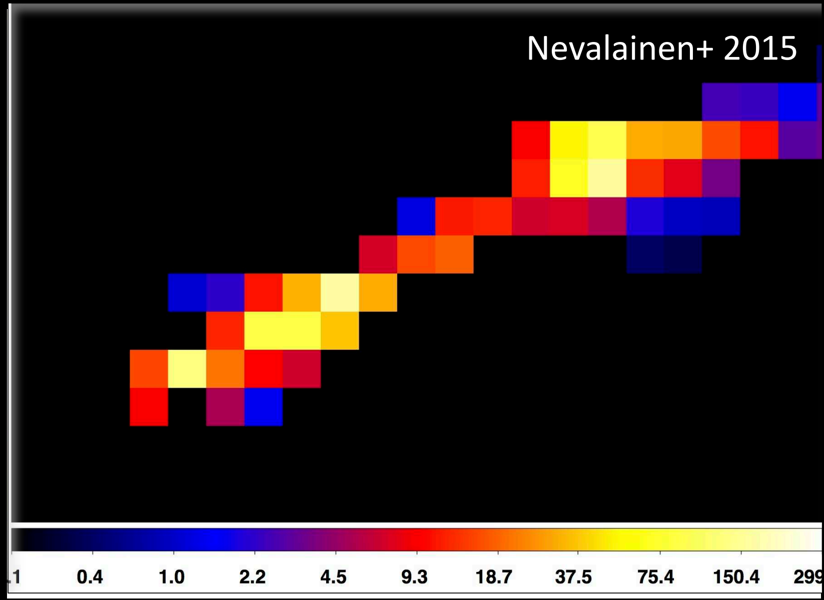




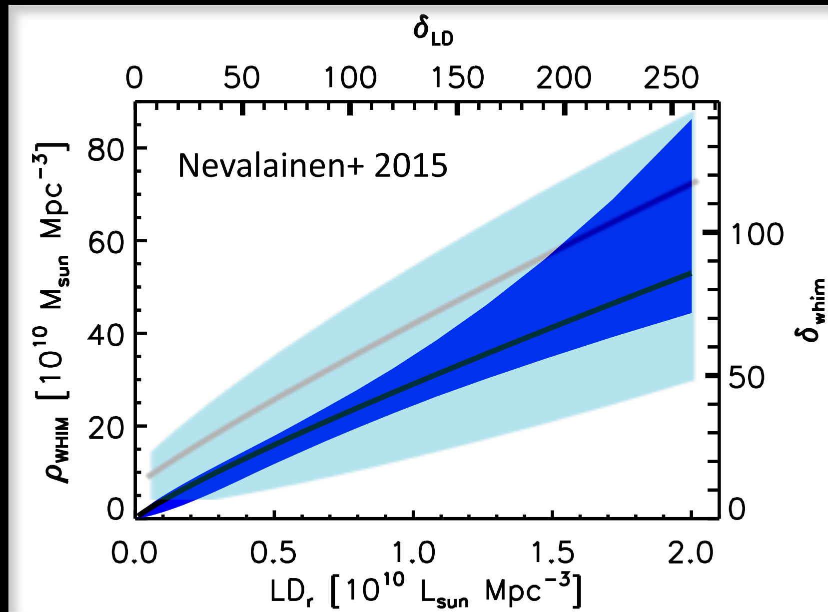
Eckert+ 2015

WHIM and LSS filaments

Possible strategy to detect and study he WHIM: (i) 3D galaxy distribution from galaxy surveys to trace filamentary structures (ii) theoretical input from hydrodynamical simulations (iii) estimate detection probability and characterize WHIM properties.



E.g. Nevalainen+ 2015 Galaxy Luminosity vs. WHIM gas density relation in filaments calibrated on simulations



Ingredients.

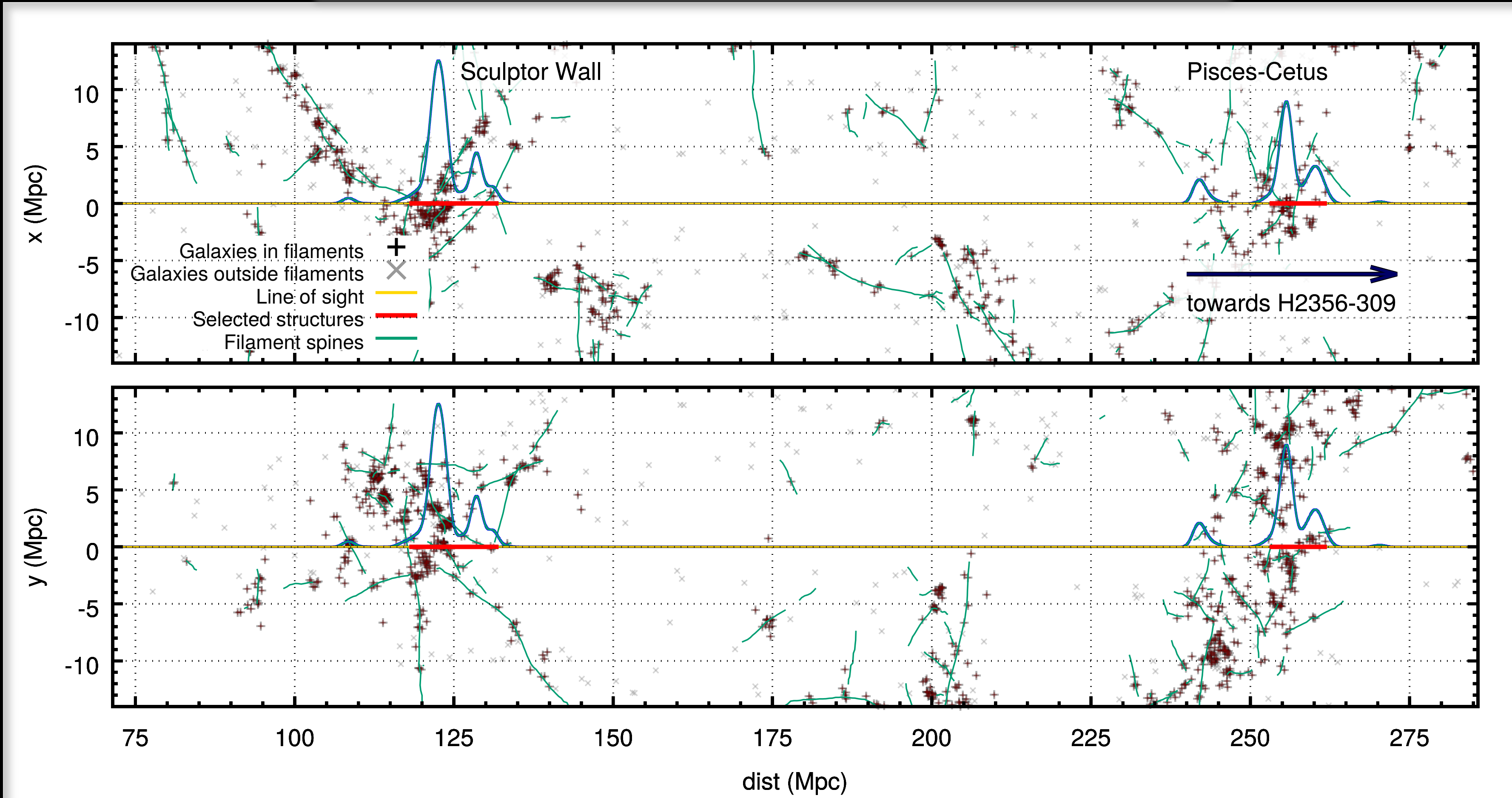
Hydro simulations: Cui+ 2012, Roncarelli+ 2012

HOD gal. model: Giocoli+ 2010, Zehavi+ 2011

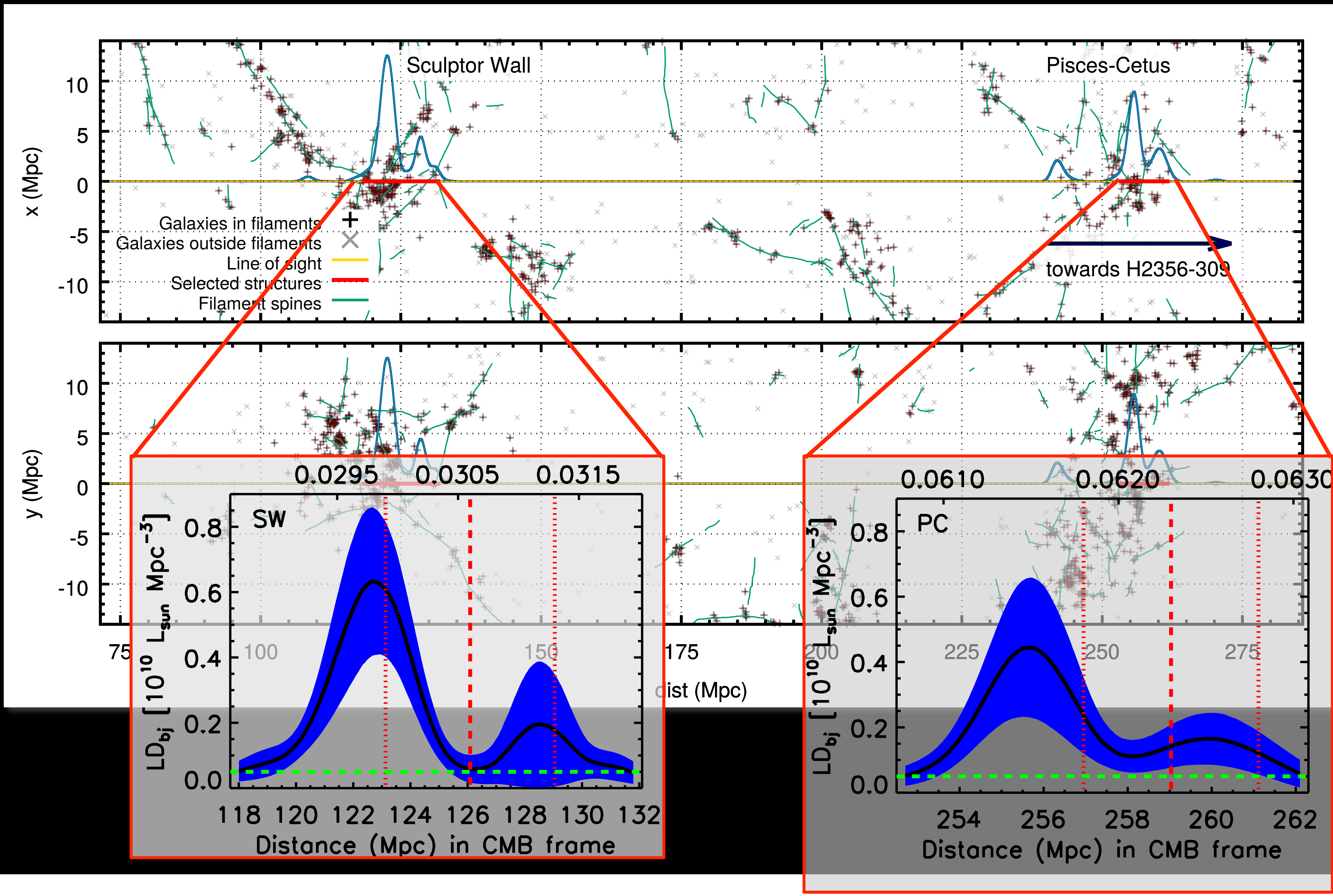
Real dataset: 2dF: Colless+ 2001

WHIM and filaments

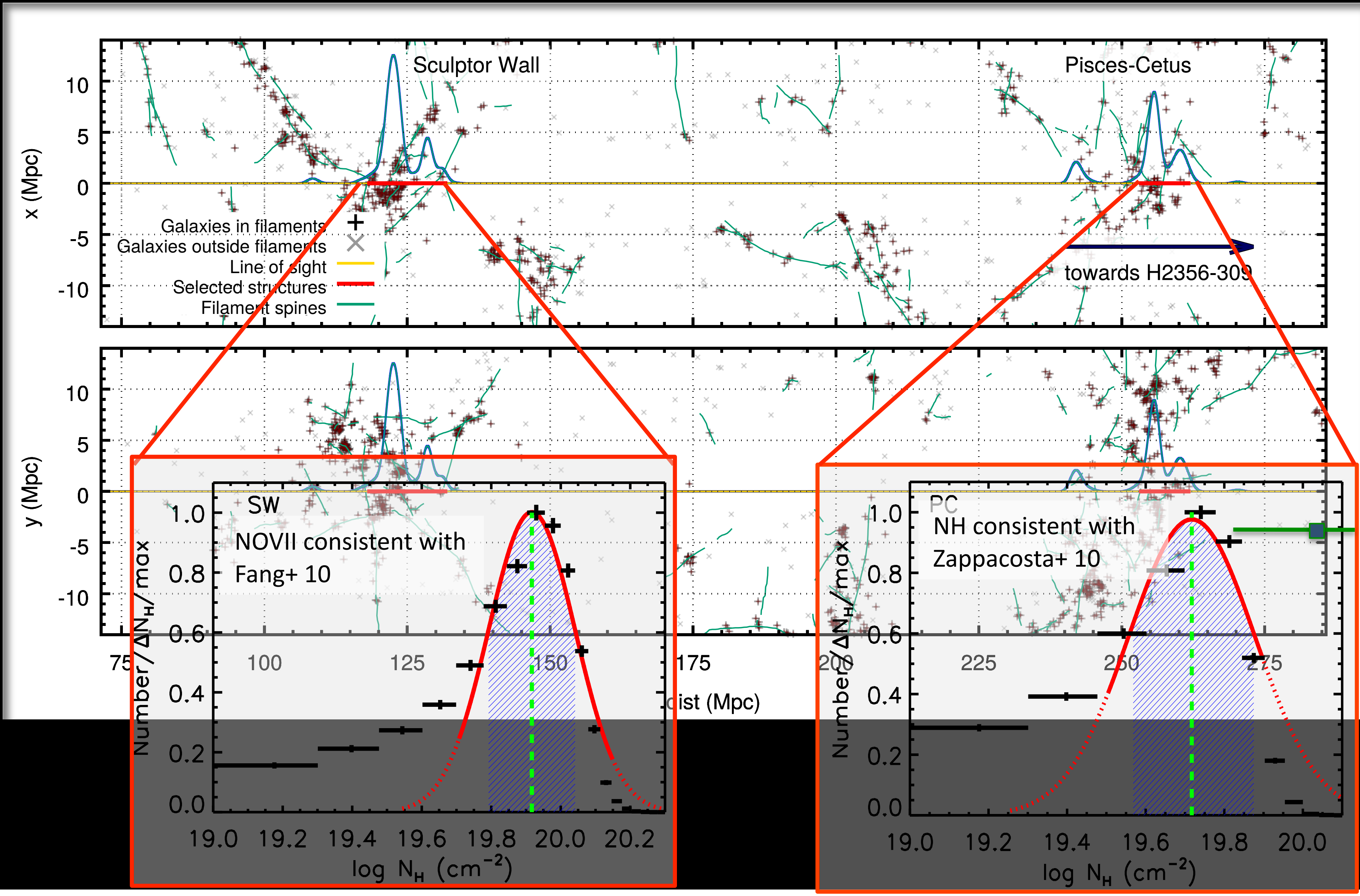
Application to line of sight to H2356 passing through Sculptor Wall and Pisces-Cetus in 2dF



WHIM and filaments



WHIM and filaments



Conclusions 2

- LSS is a good WHIM tracer. Future observational campaigns to study the WHIM *in emission* can effectively target filamentary structures in current and future galaxy redshift surveys (10^2-10^3 serendipitous detections expected with Athena).