Complementary Gamma-Ray Signatures in Indirect Dark Matter Searches

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Multi3 Workshop,
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Stockholm University

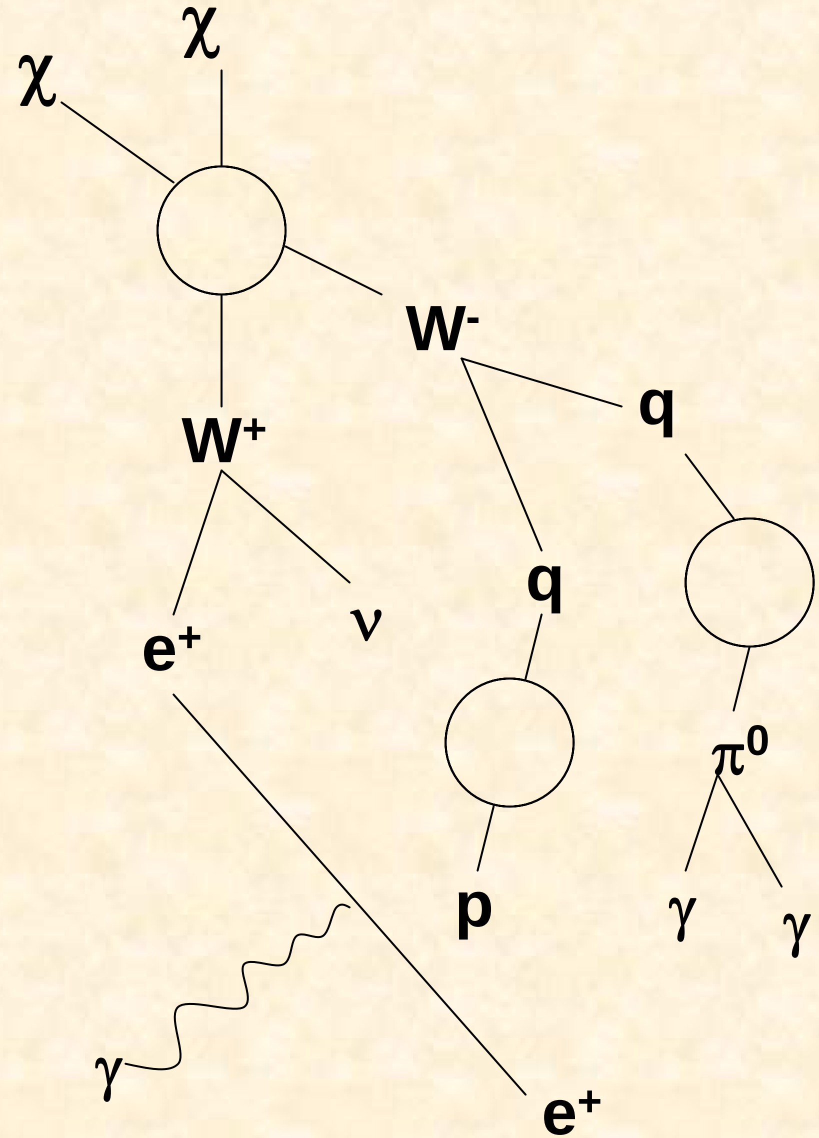
Oskar Klein centre

Indirect Detection of Dark Matter: the General Framework

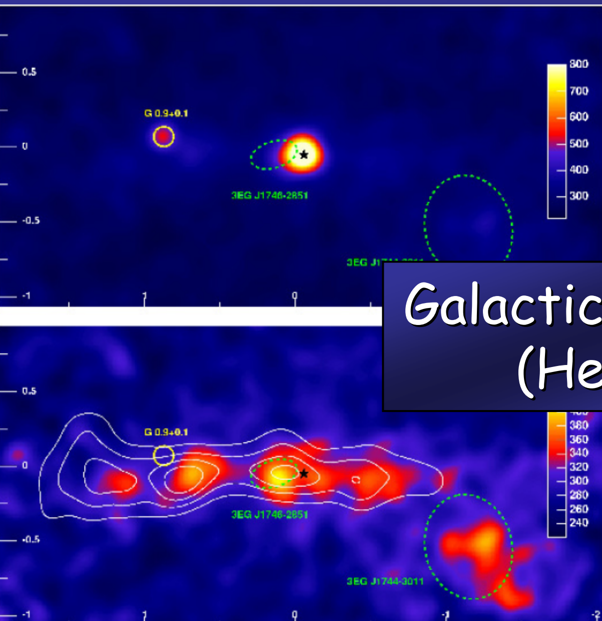
1) **WIMP Annihilation**
Typical final states include heavy fermions, gauge or Higgs bosons

2) **Fragmentation/Decay**
Annihilation products decay and/or fragment into some combination of electrons, protons, deuterium, neutrinos and gamma rays

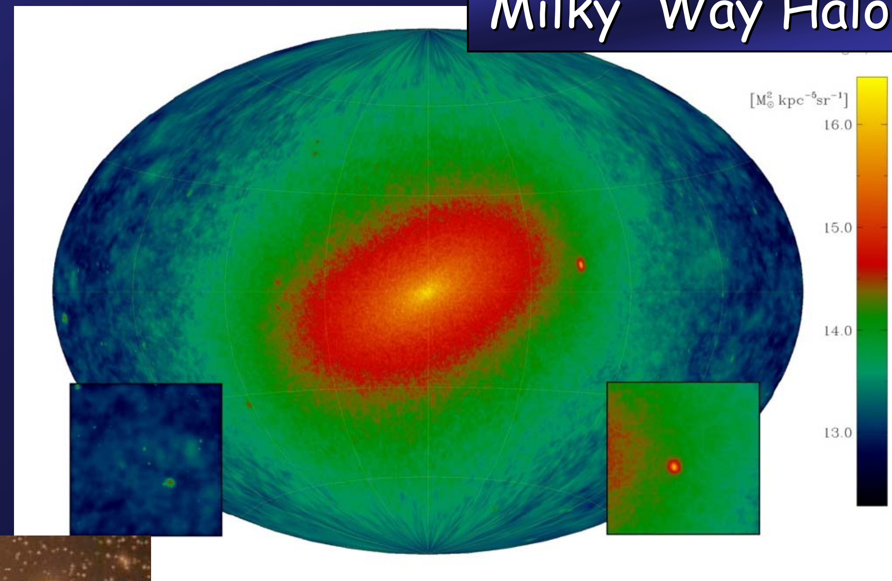
3) **Synchrotron and Inverse Compton**
Relativistic electrons up-scatter starlight to MeV-GeV energies, and emit synchrotron photons via interactions with magnetic fields



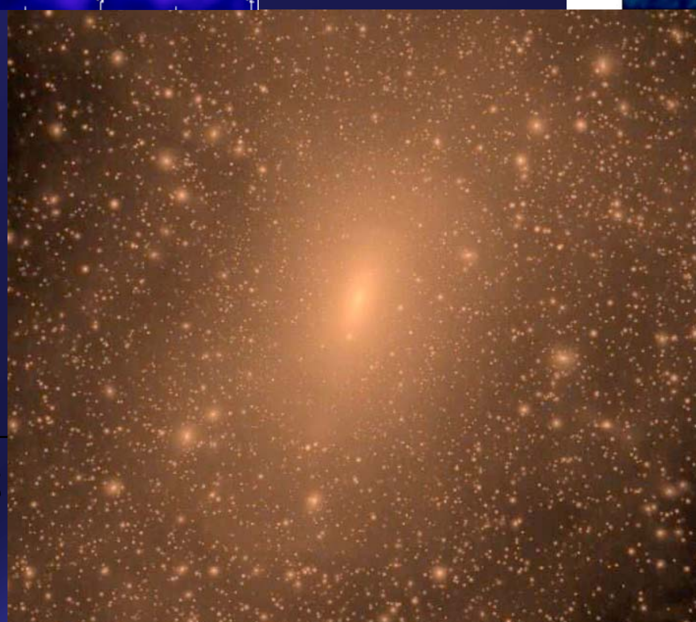
Where to look



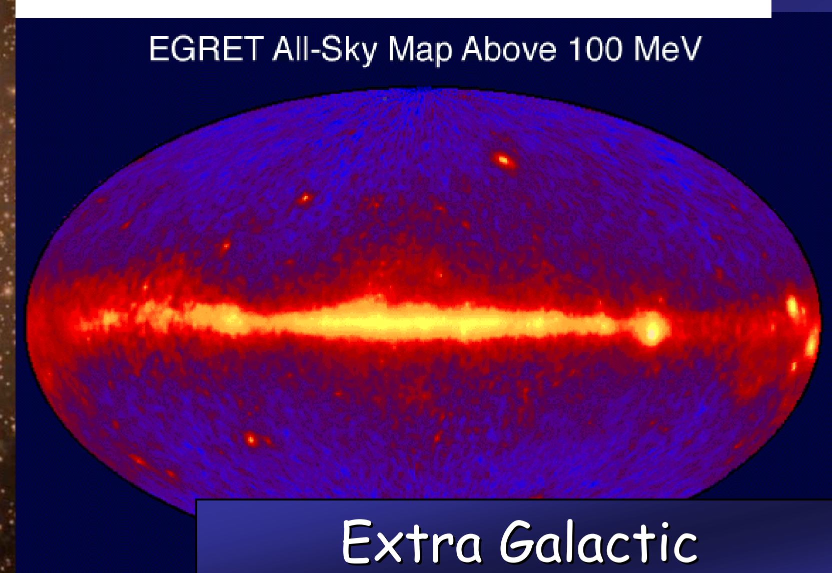
Galactic Center (Hess)



Milky Way Halo



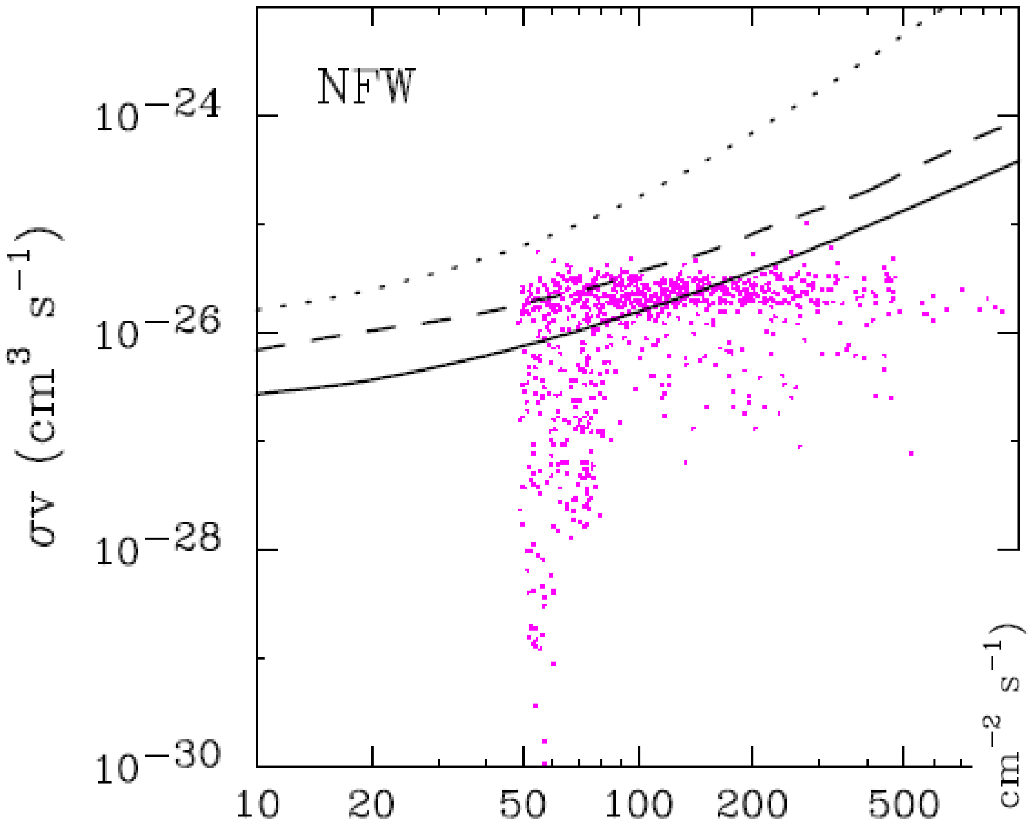
DM Clumps: Via Lactea Simulation Diemand et al.



Extra Galactic Background

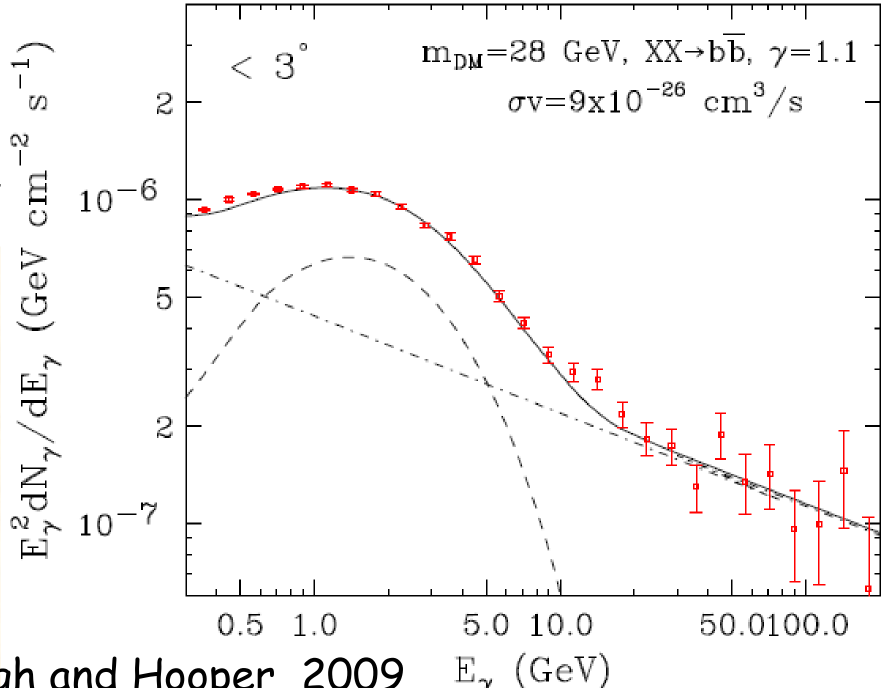
Galactic Center

Good Sensitivity to the DM Signal



Hooper and Serpico 2009
Dodelson et al. 2009

Difficult Background from astrophysical pions decay, can be easily mistaken as DM annihilation

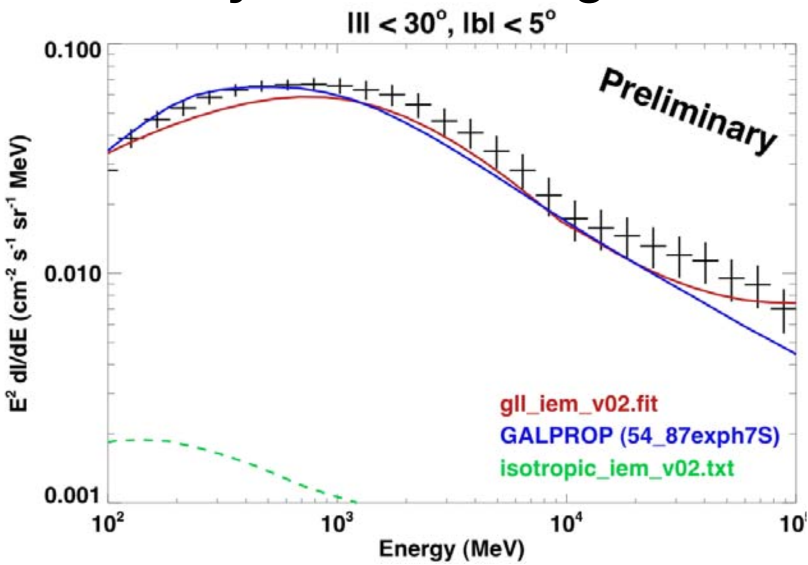


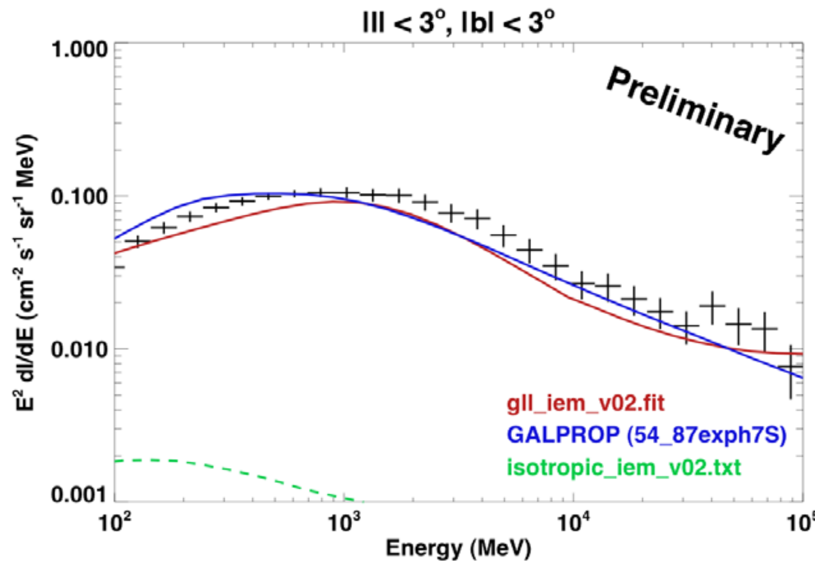
Goodenough and Hooper 2009

Spectral Residuals

Seth Digel @ Fermi Symposium

- The all-sky Galactic diffuse emission model released by the LAT team (red curve) somewhat under-predicts the sky intensity in the GC region

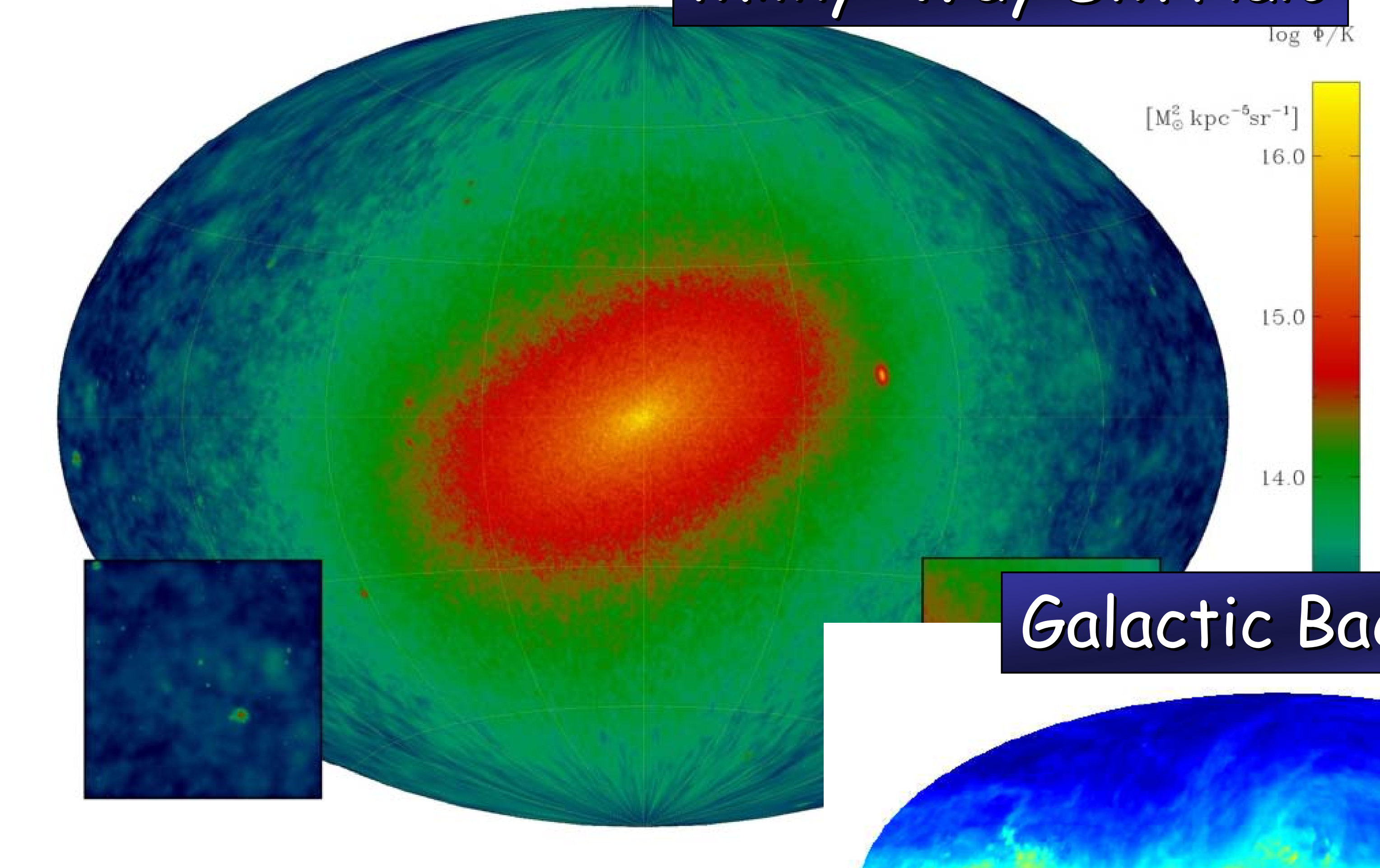




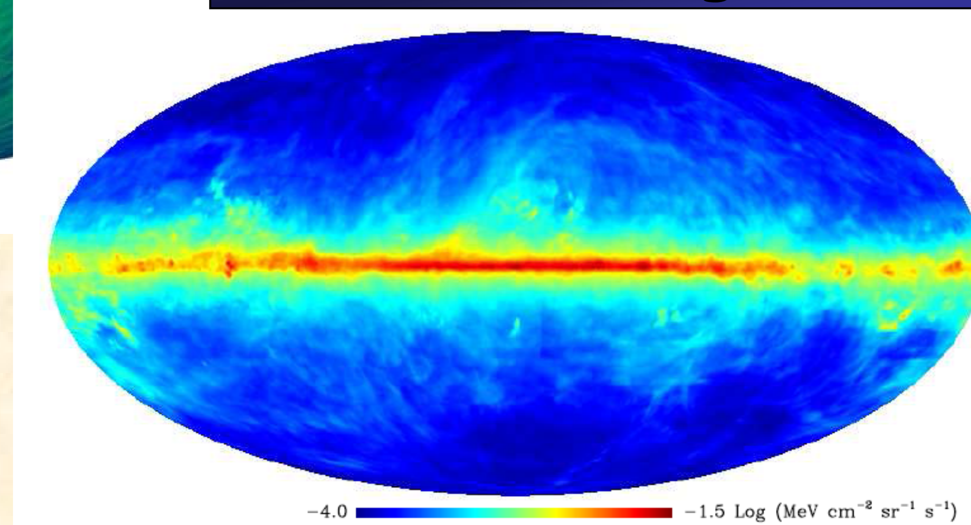
- Similar deviations are present in a GALPROP model calculation (blue) for the same region;
- Models are clearly in the right ballpark, although clearly deviations are greater than the systematic uncertainty
- N.B.: No point sources are included

Milky Way Halo and Secondary Radiation

Milky Way DM Halo



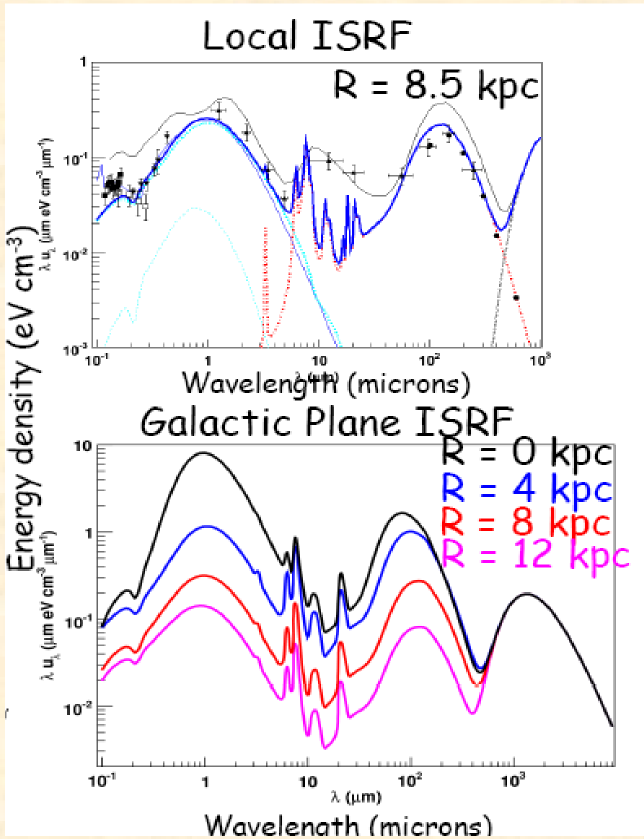
Galactic Backgrounds



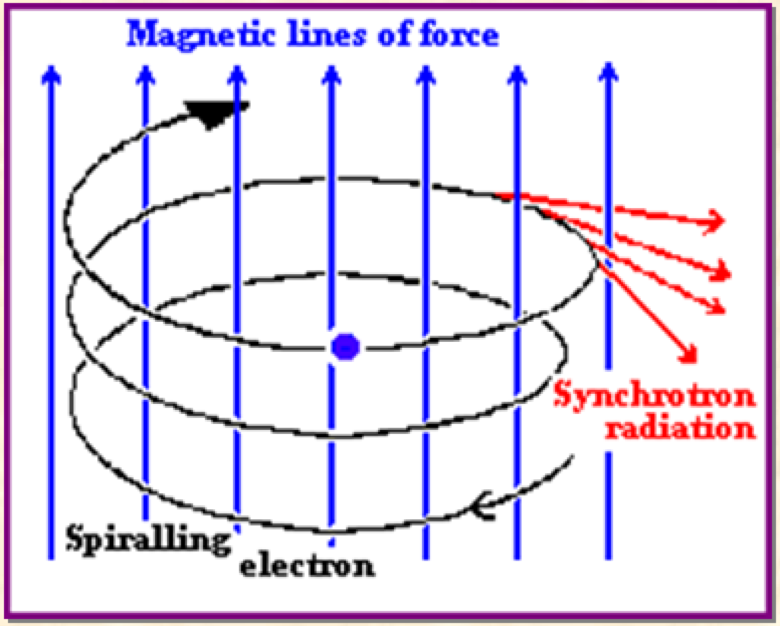
Different morphologies can be exploited to disentangle the DM signal from astrophysics

Indirect Detection With Synchrotron and Inverse Compton Radiation

ICS on the Galactic ISRF



Synchrotron on the GMF

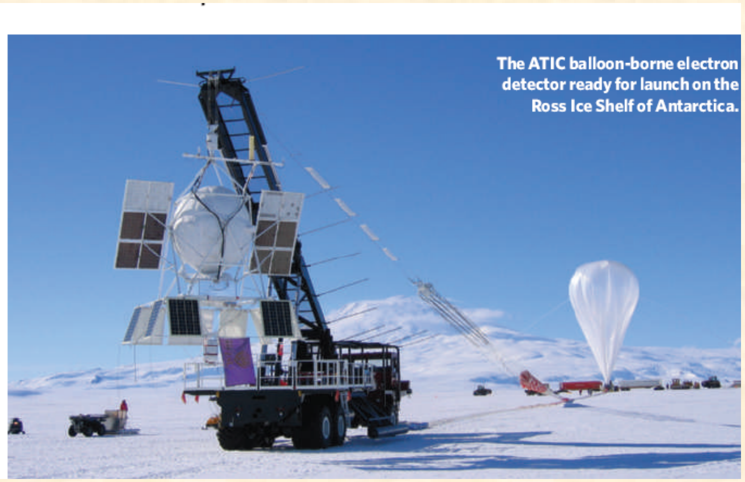


- Charged leptons and nuclei strongly interact with gas, Interstellar Radiation and Galactic Magnetic Field.
- During the process of thermalization HE e+e− release secondary low energy radiation, in particular in the radio and X-ray/soft Gamma band.

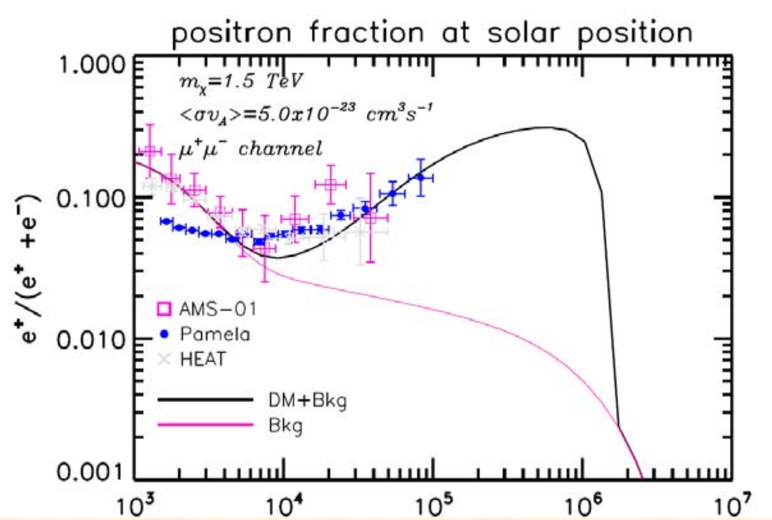
the Pamela/ATIC Anomalies: e+e- excesses w.r.t. the background

Both the signals seems to have the same origin:

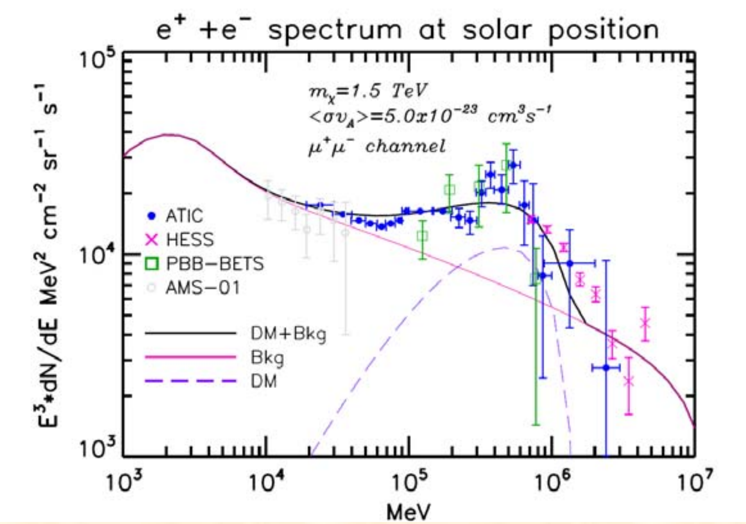
- Astrophysical explanation?
- DM explanation?



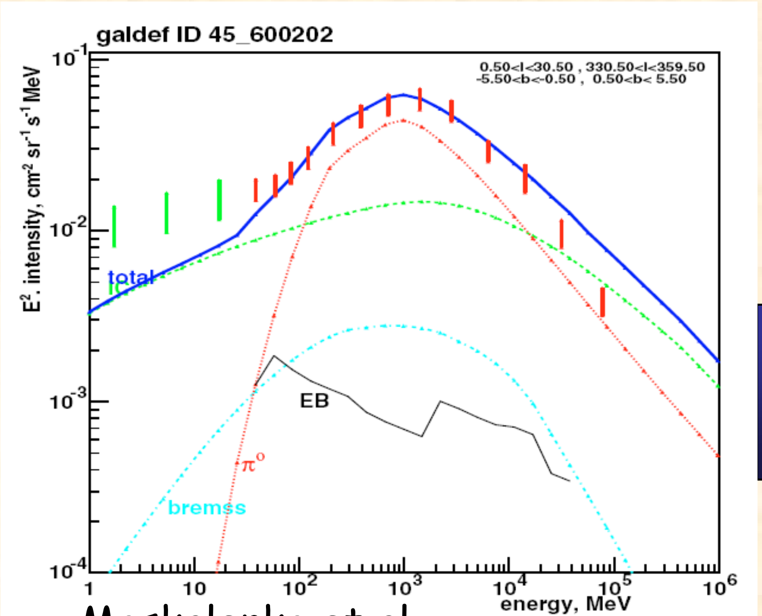
positron fraction



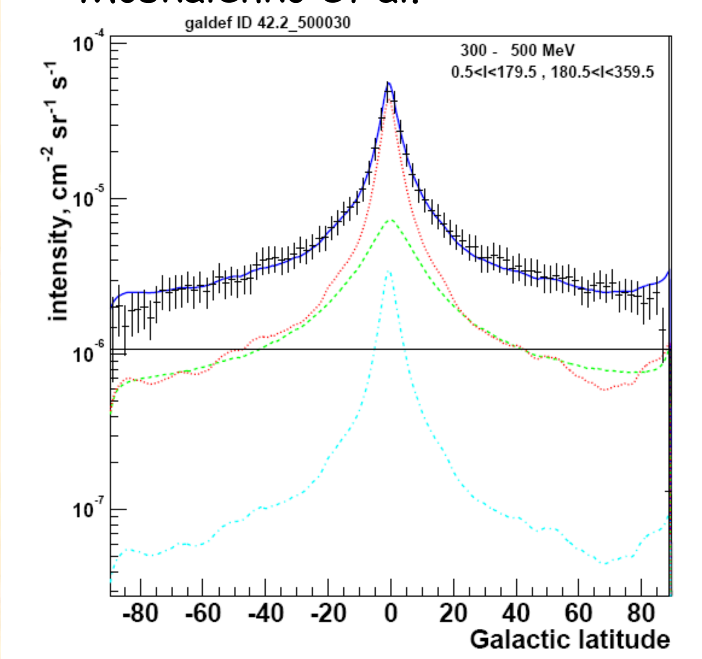
e^++e^- flux



The Gamma Sky



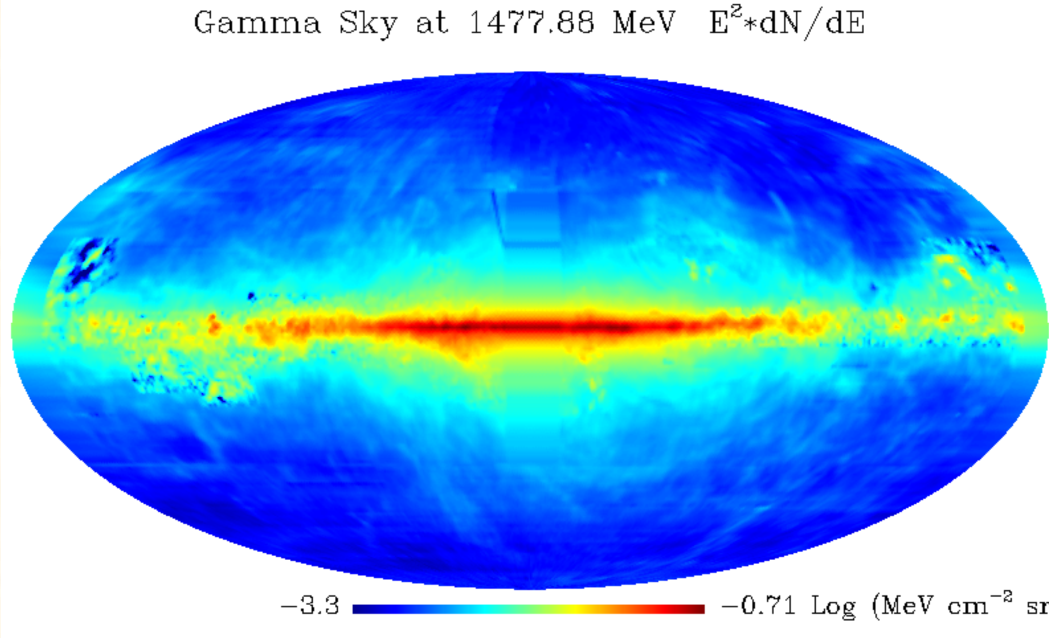
Moskalenko et al.



Galactic Contribution from:

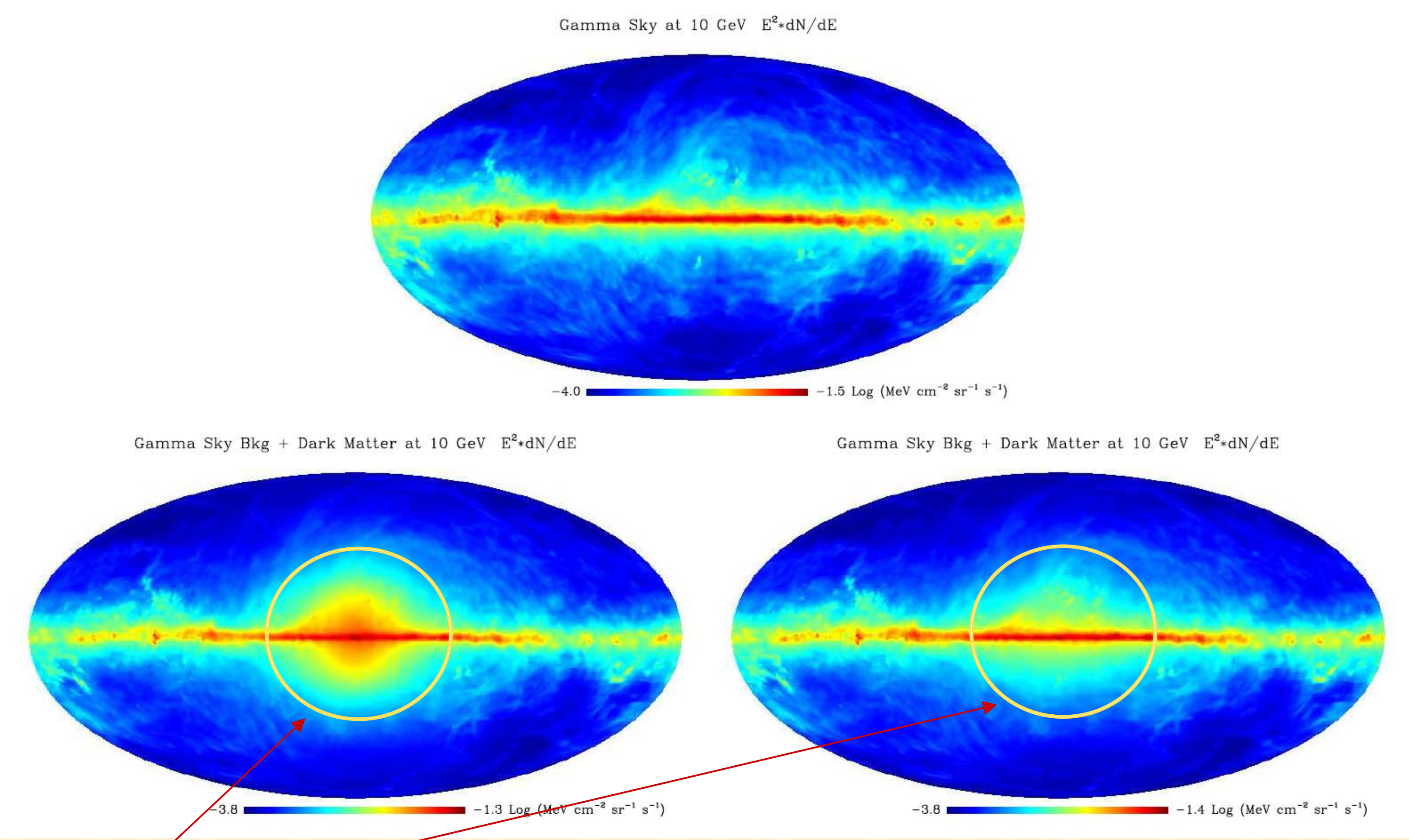
1. Pion Decay
2. Inverse Compton
3. Electron Bremsstrahlung

Galprop Foregrounds Model:



Also, detector resolution, charged particle background…

The "ICS Haze"

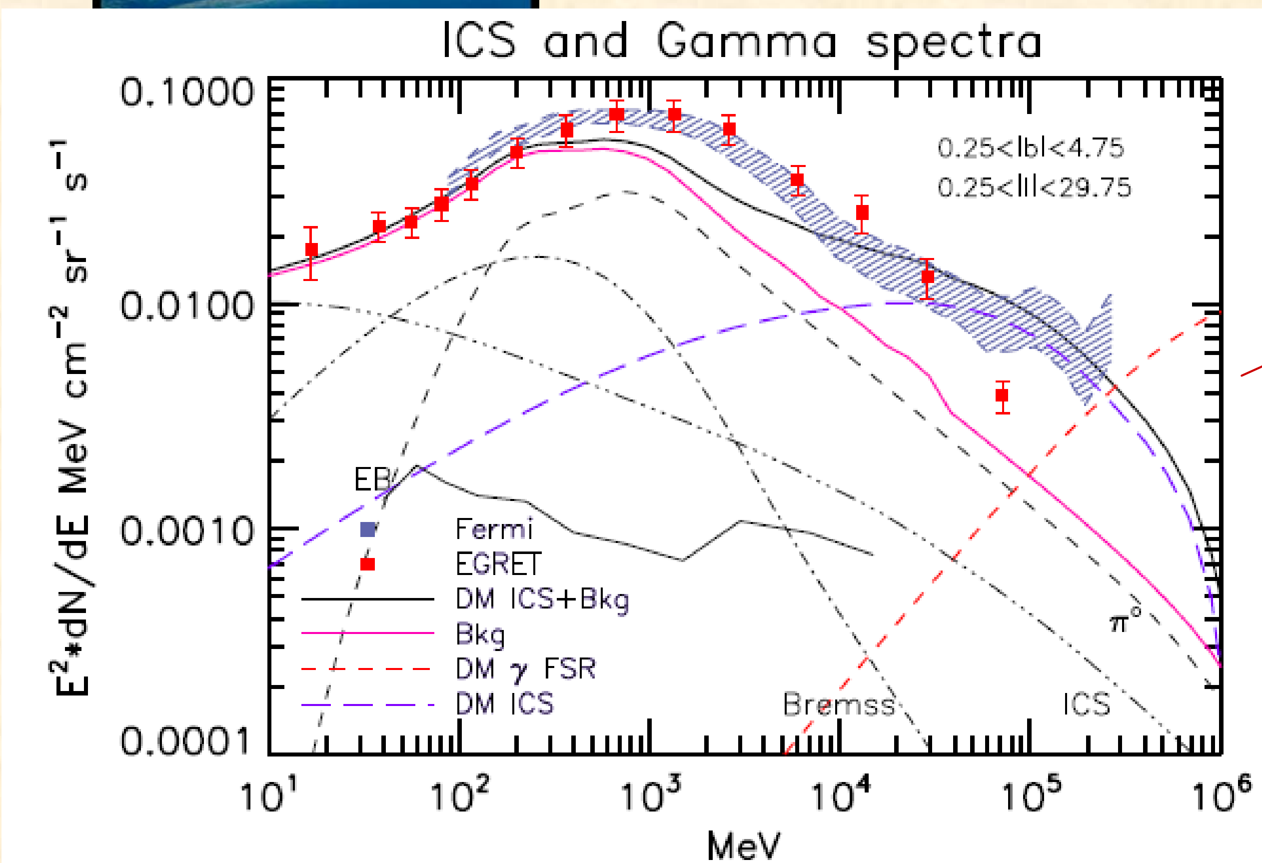


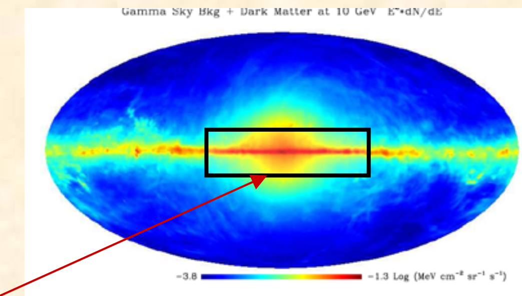
Similarly to the synchrotron case, IC signal produces an extremely peculiar "ICS Haze" peaking around 10-100 GeV which provides a further mean to discriminate the DM signal from the astrophysical backgrounds and/or to check for possible systematics.

ICS and background Spectra from Pamela/ATIC and forecast for Fermi

•The Pamela/Atic electrons produce a large excess of Inverse Compton Radiation w.r.t to the galactic backgrounds

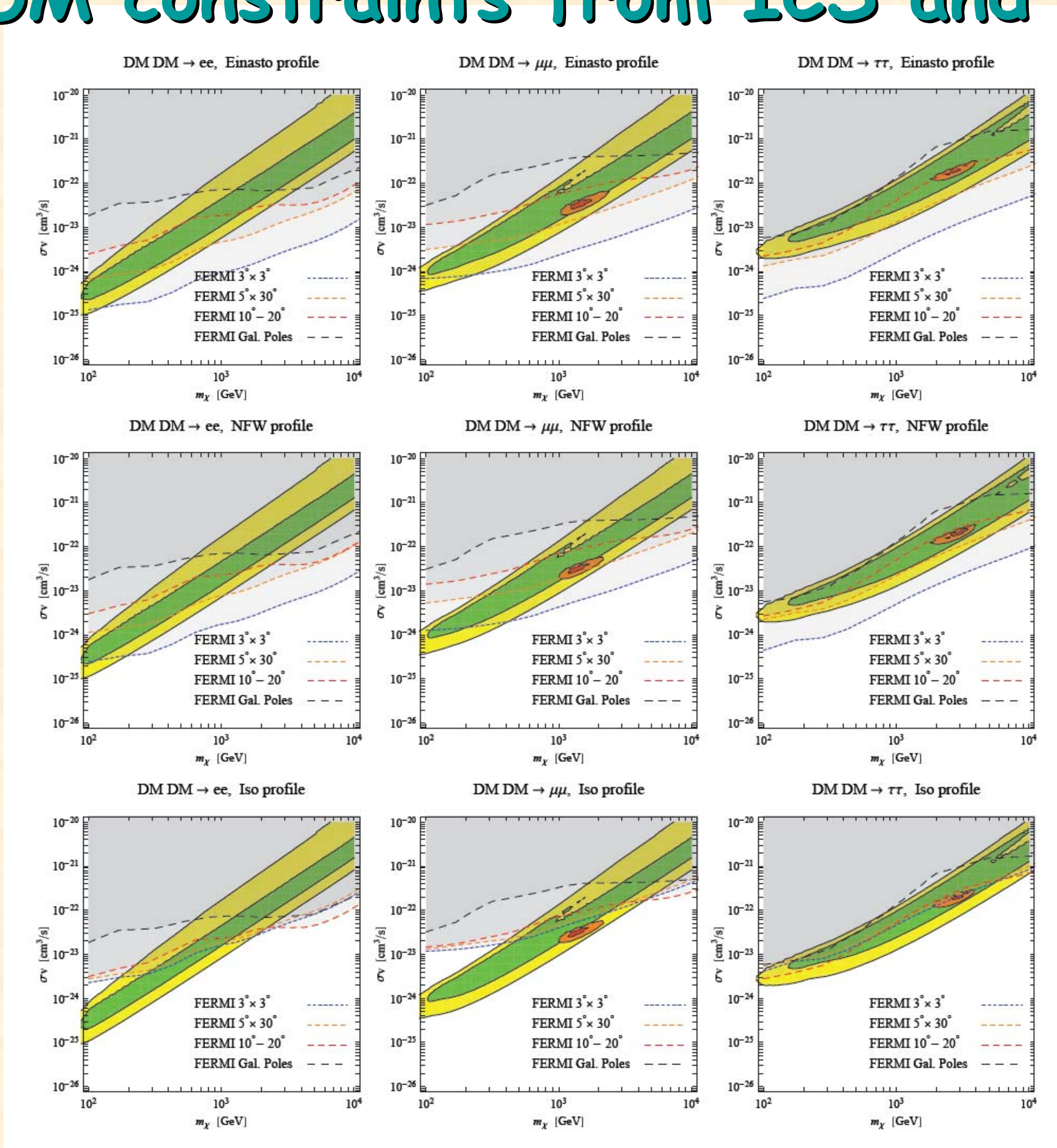
•EGRET somewhat disfavors the excess. Fermi can say more, but care is needed with the systematics





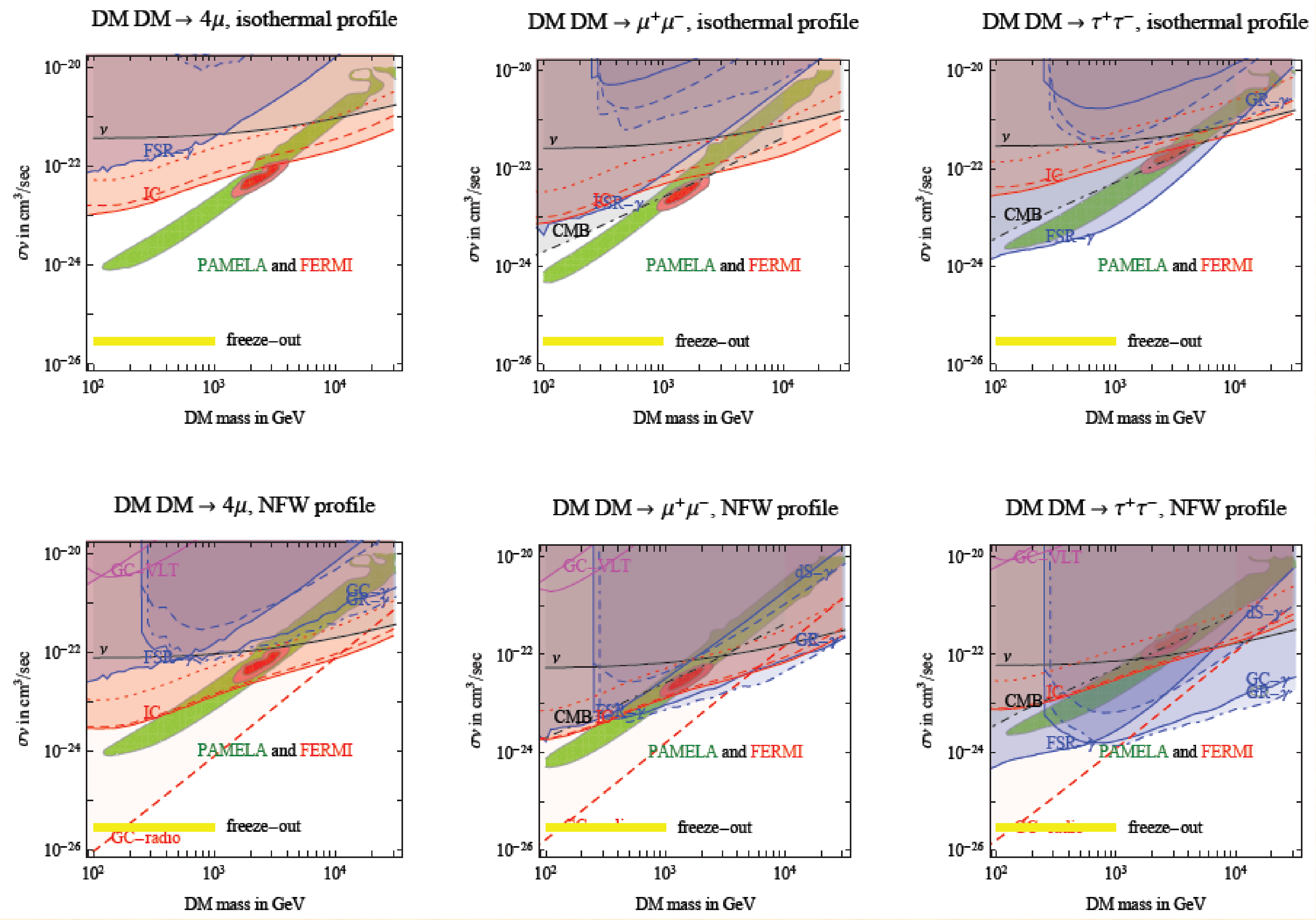
E.Borriello, A.Cuoco, G.Miele
Ap.J.699:L59-L63,2009

DM constraints from ICS and Fermi data



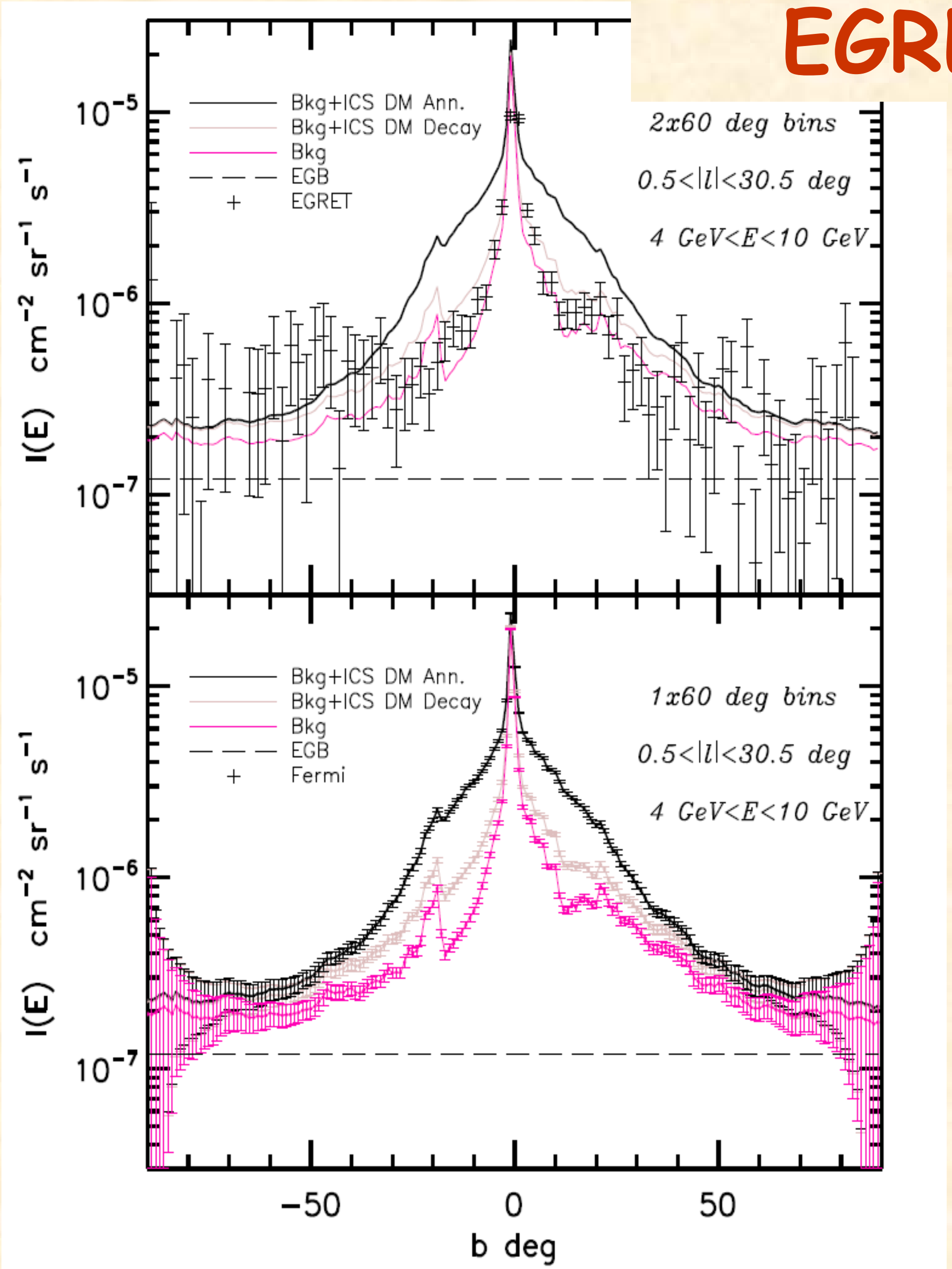
M. Cirelli, P. Panci, P. D. Serpico, arXiv:0912.0663

DM constraints from ICS and Fermi data



M. Papucci, A. Strumia, arXiv:0912.0742

Profiles and Comparison of EGRET/Fermi Statistic



- Upper panel: EGRET data compared the annihilation model and the decaying model. Annihilating DM produces a too much broad peak to fit the data, beside producing an excessively high normalization.

- Lower Panel: forecast of the Fermi ability to discriminate among the astrophysical and annihilating DM scenario. Also shown is the Decaying DM scenario.

Sytematics:

- Uncertainties in the exposure
- Residual charged particle contamination.
- Foreground modeling

A Fermi Haze?

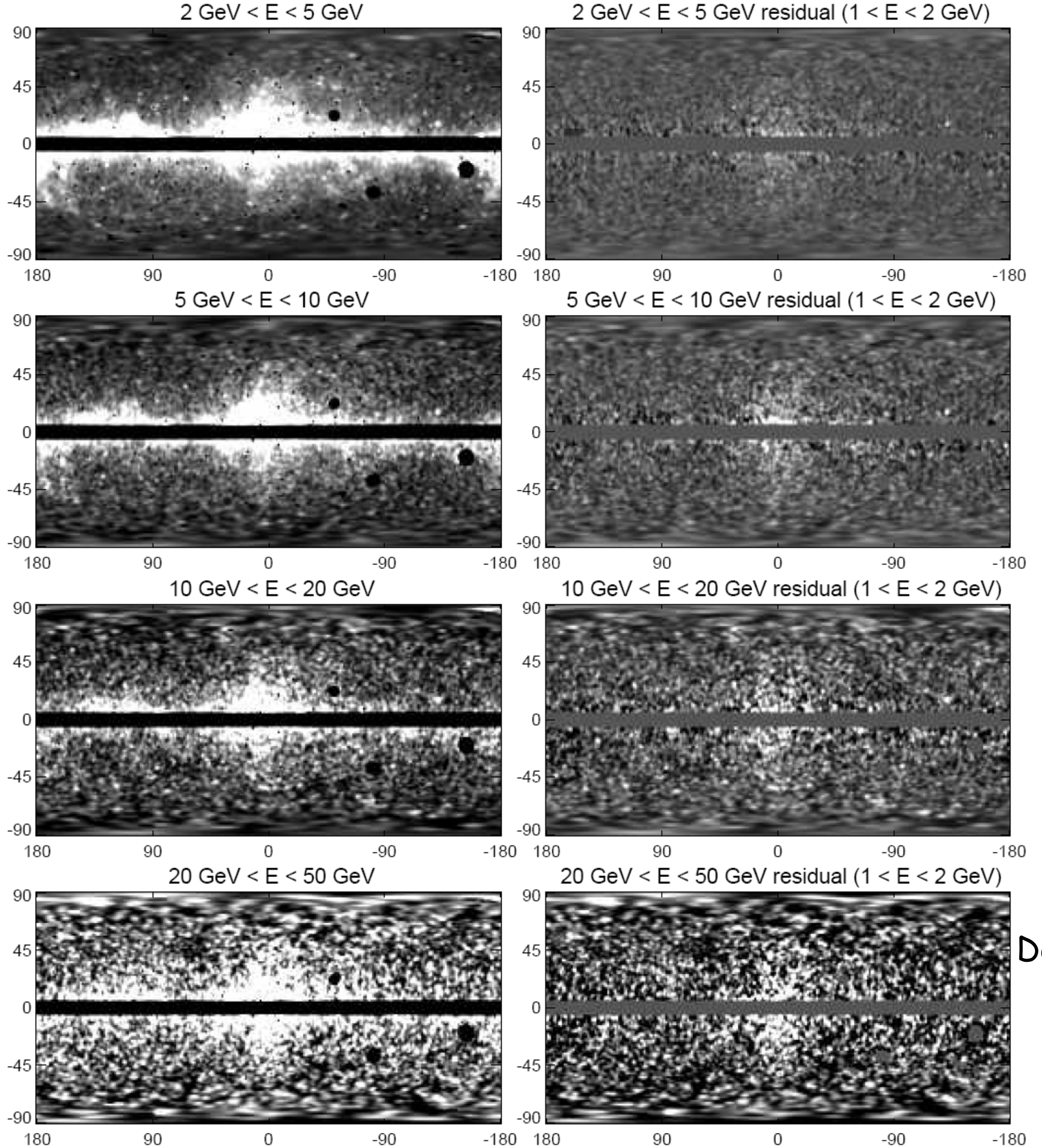
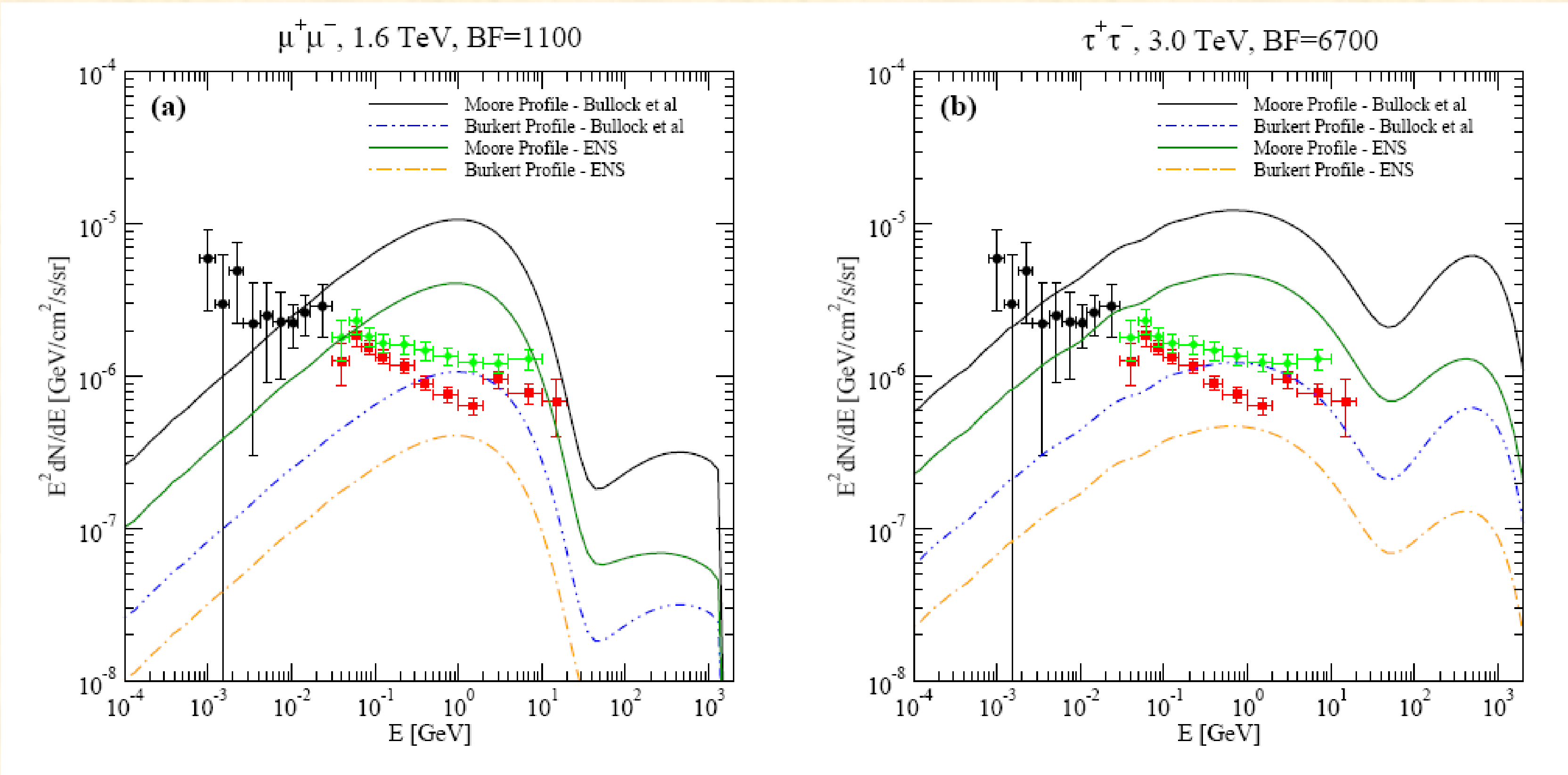


FIG. 5.— The same as Figure 3 but using the *Fermi* 1-2 GeV map for cross-correlations instead. Unlike the SFD dust map which should trace π^0 emission only, the low energy *Fermi* map includes the soft ICS and bremsstrahlung associated with lower energy electrons. In fact comparing the residuals in this figure with those in Figure 3, it is clear that the disky component has been subtracted leaving only the ICS haze. Furthermore, the ICS haze is more prominent in the high energy maps indicating a harder spectrum than π^0 emission which is the dominant emission mechanism at ~1 GeV energies.

Dobler, Finkbeiner et al. 2009

Comparison with the Extra-Galactic Inverse Compton



Jeltema & Profumo 2009

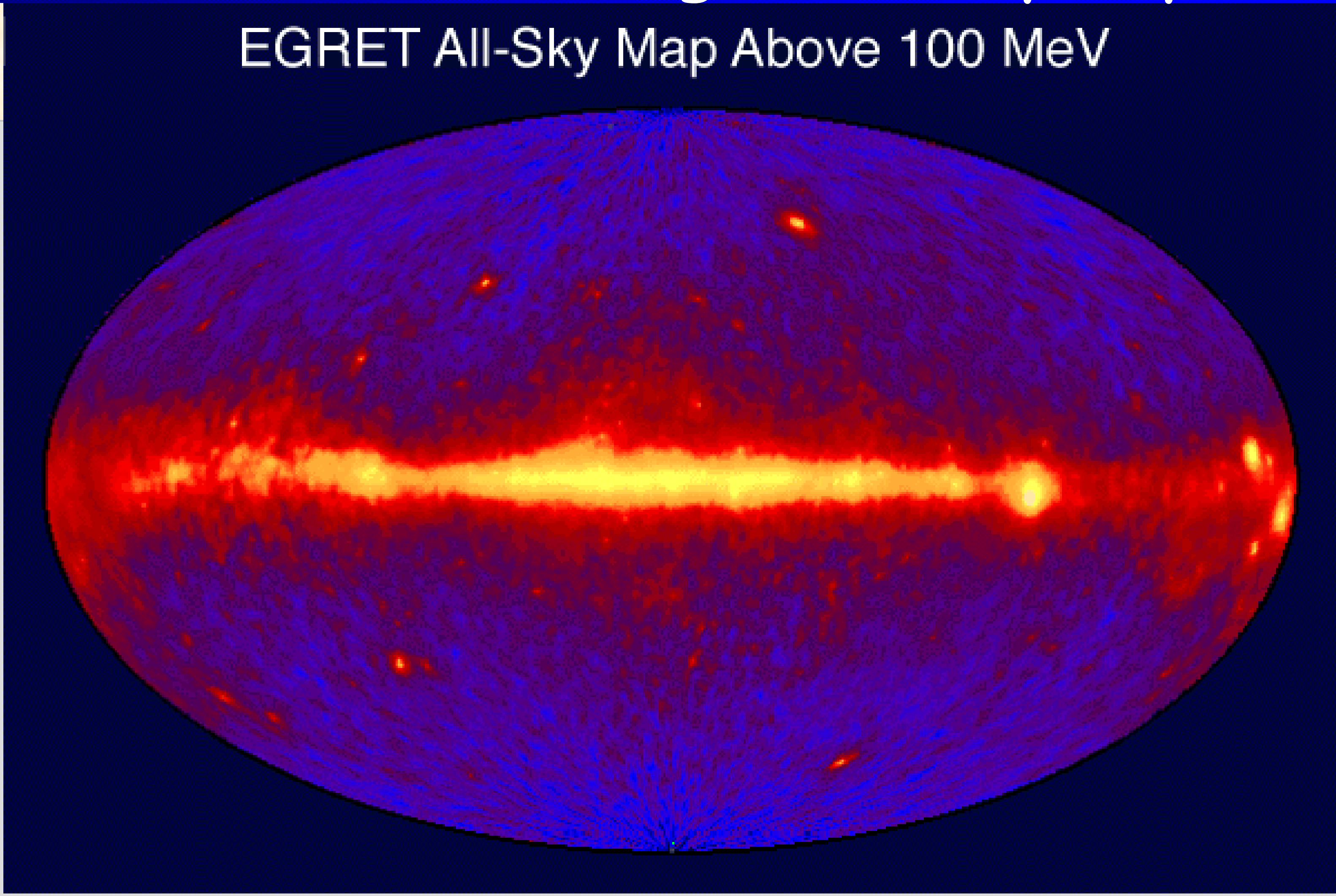
- Constraints from the Extra-Galactic Inverse Compton can be in principle stronger than the galactic ones but are generally more model dependent.

Belikov & Hooper 2009

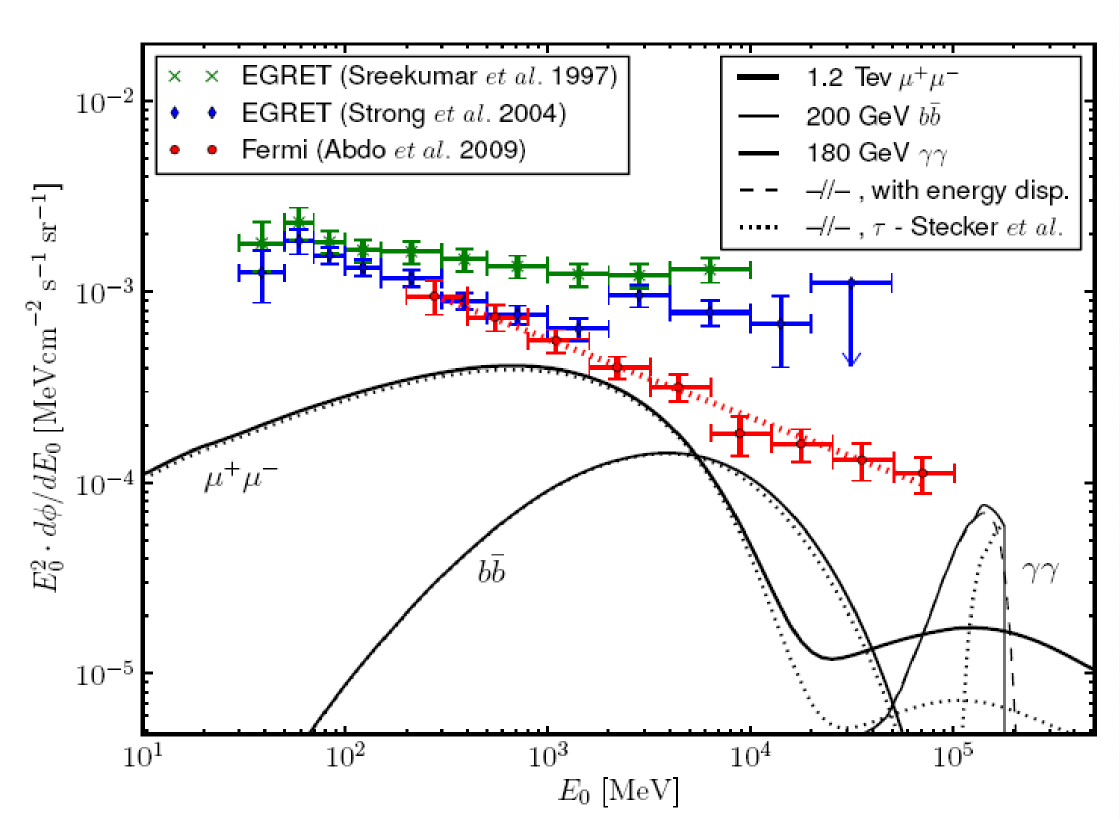
Hütsi, Hektor, Raidal 2009

Isotropic Gamma Background and Anisotropies

A further probe: Anisotropies in the diffuse cosmic gamma ray sky



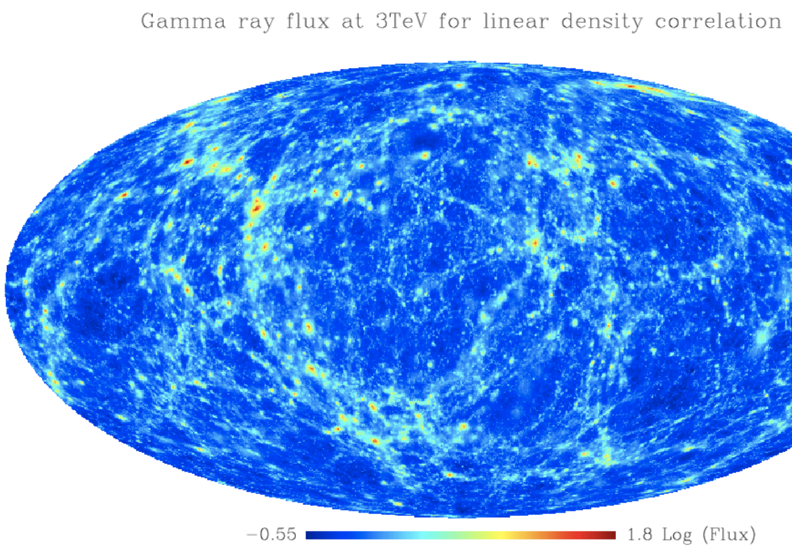
IGRB Energy Spectrum

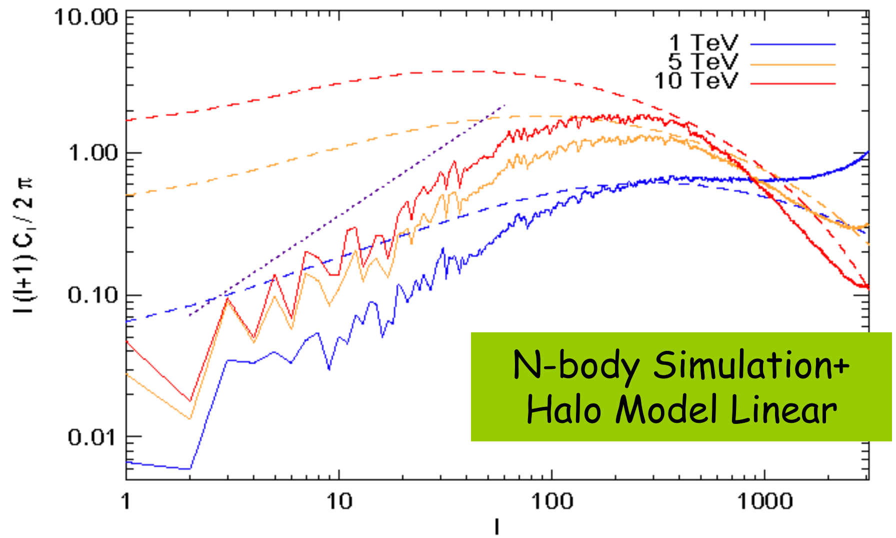


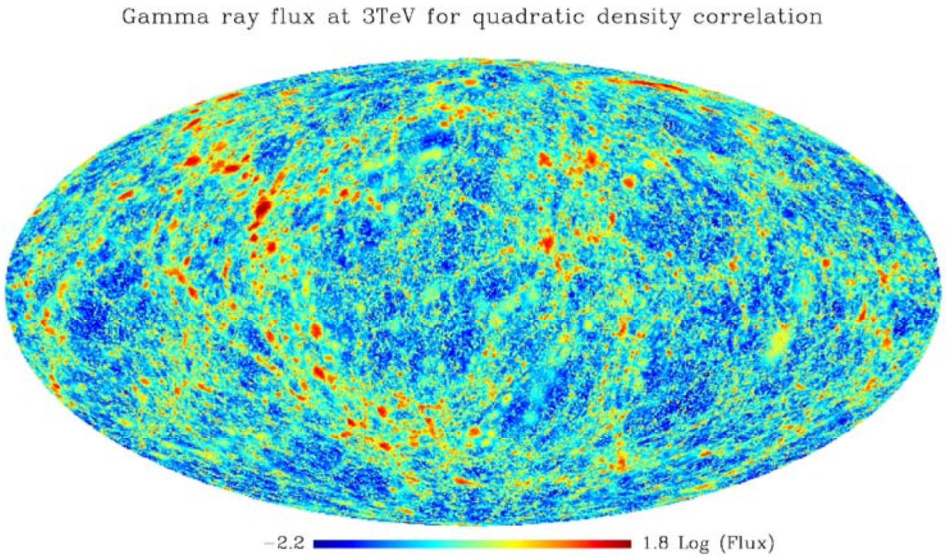
Abdo et al. 2009

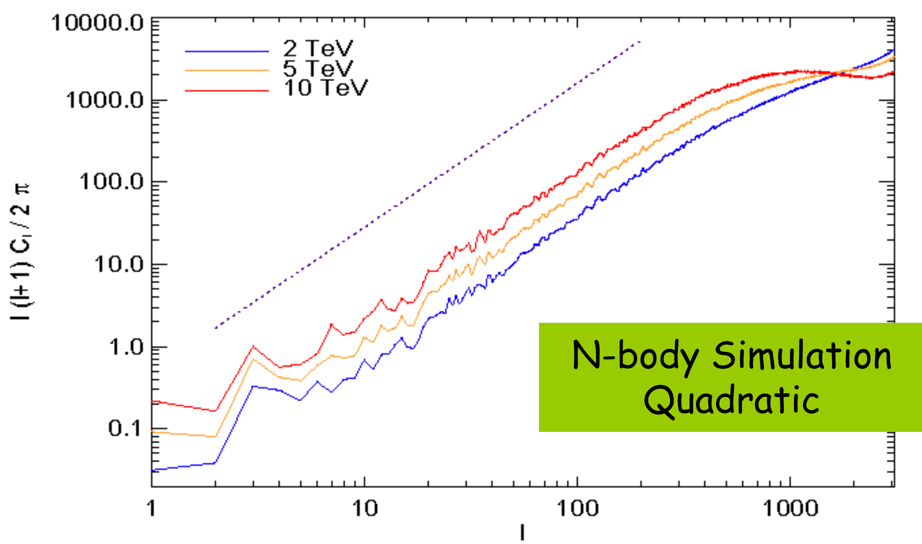
Features in the energy spectrum from DM can be complemented by the presence of angular features

The CBG angular power spectrum from N-body Simulations of LSS



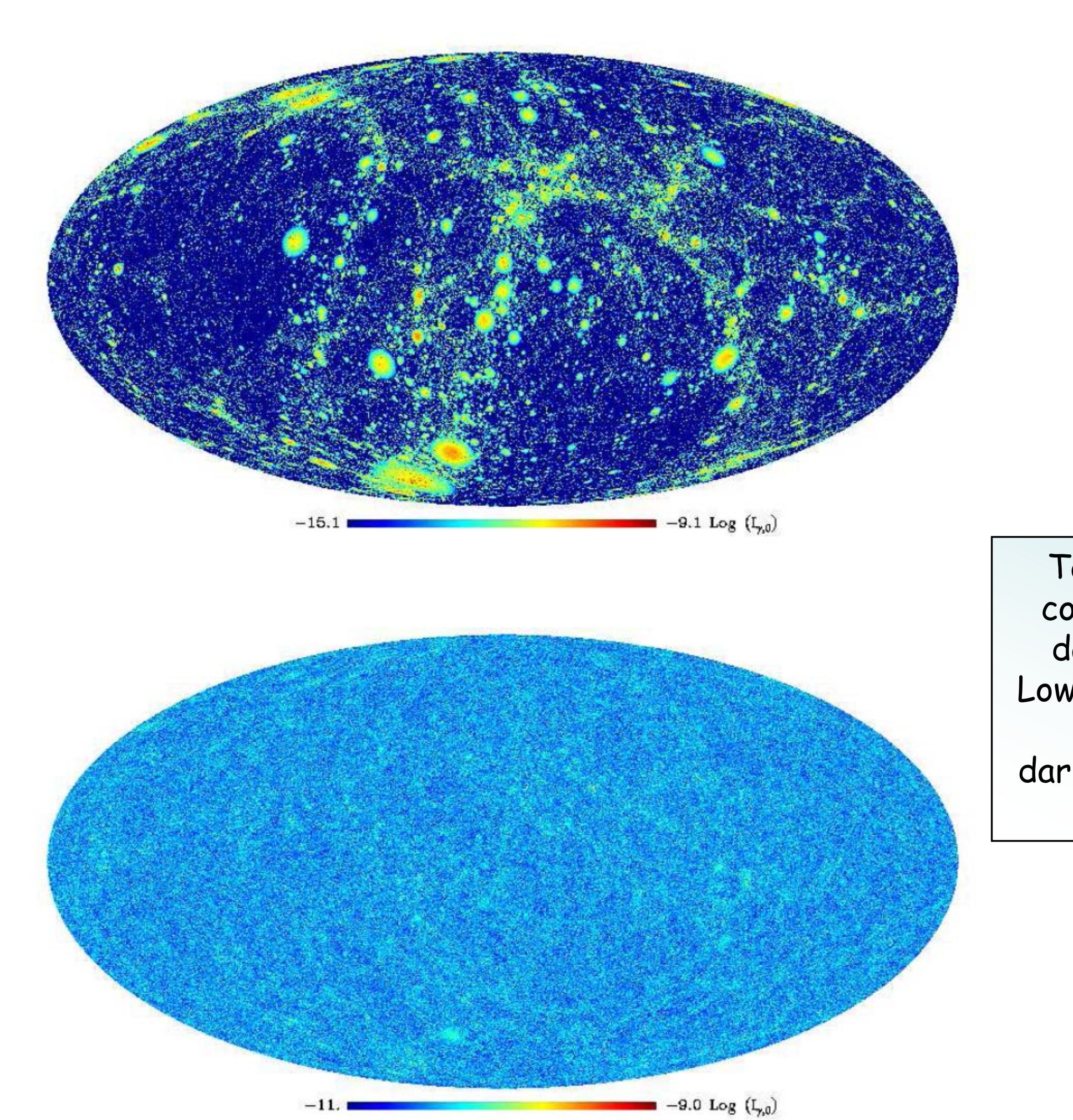






A.Cuoco, S.Hannestad, T.Haugbolle, G.Miele, P.D.Serpico, JCAP 0704:013,2007

MilleniumII simulation

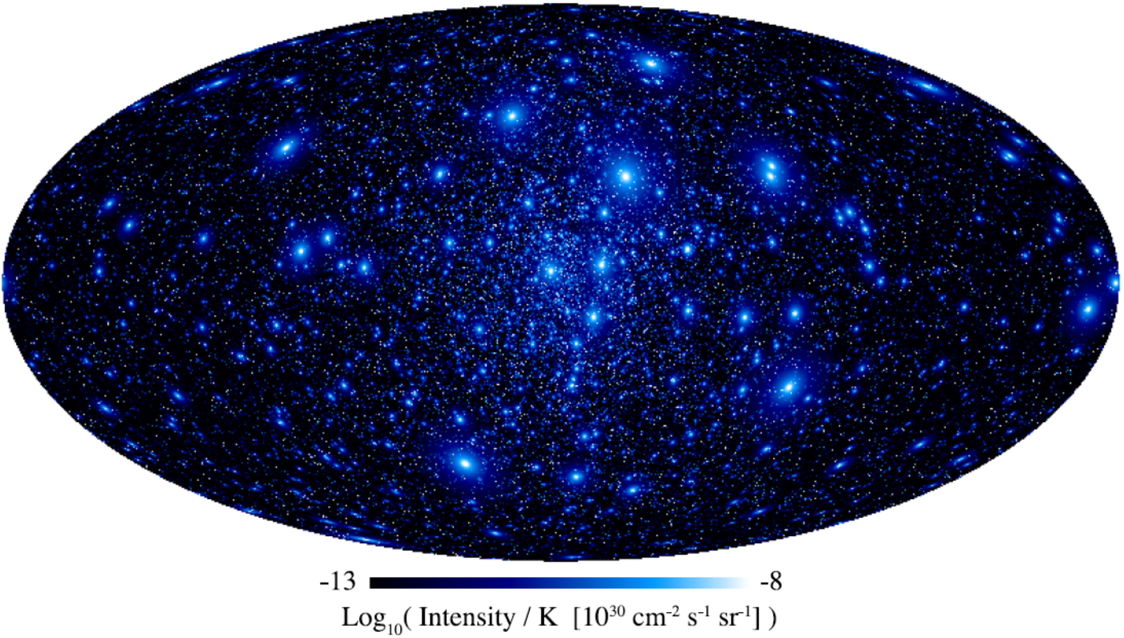


DM Skymaps from the MilleniumII simulation

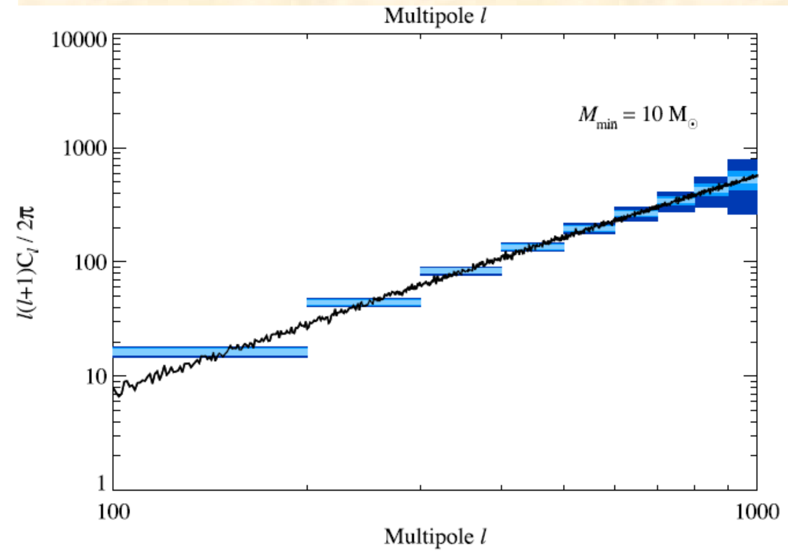
J. Zavala, V. Springel, M. Boylan-Kolchin, .arXiv:0908.2428

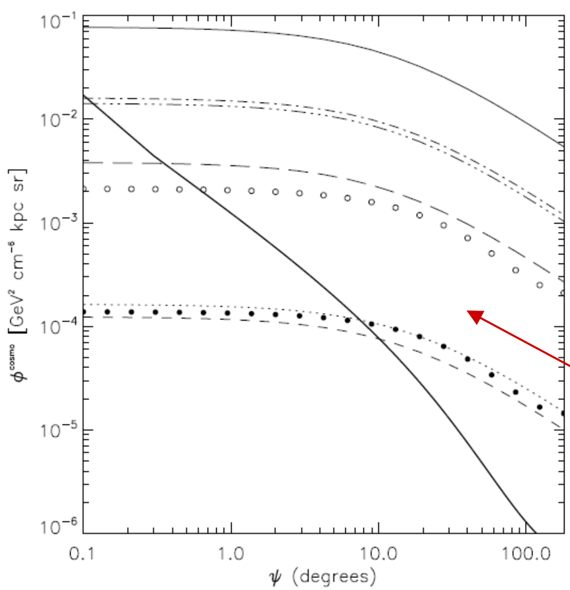
Top: partial map (z = 0) showing the cosmic -ray background produced by dark matter annihilation at 10 GeV, Lower panel: Co-added map showing the full -ray sky map from dark matter annihilation integrated out to z = 10.

Anisotropies: The Galactic Case



J. Siegal-Gaskins, JCAP 0810:040,2008.
M.Fornasa, L.Pieri, G.Bertone, E.Branchini, Phys.Rev.D80:023518,2009.
L.Pieri, G.Bertone, E.Branchini, Mon.Not.Roy.Astron.Soc.384:1627,2008.

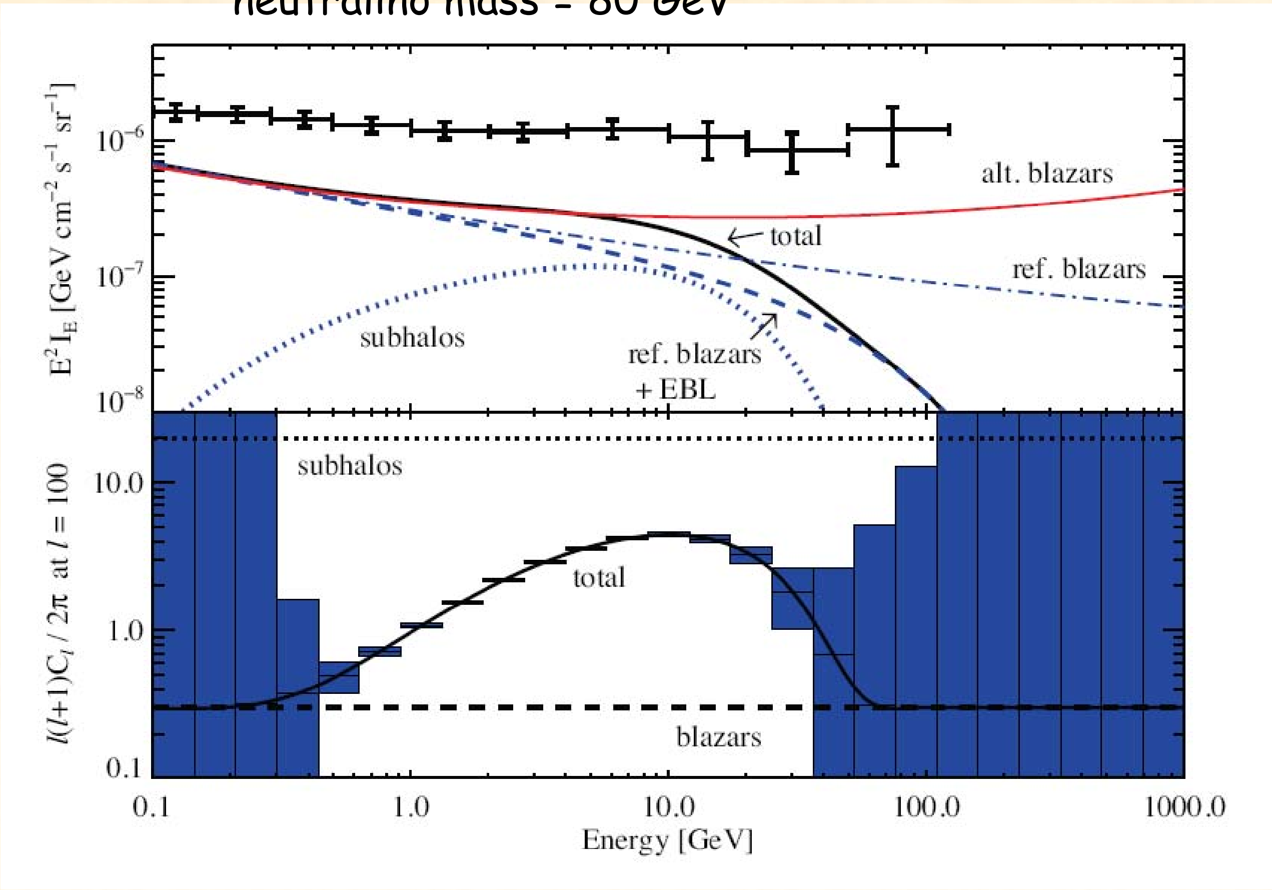




But… huge uncertainties in the normalization of the signal:
sub-halo concentration?
Minimum sub-halo mass?

Dark Matter signature in the anisotropy energy spectrum

neutralino mass = 80 GeV

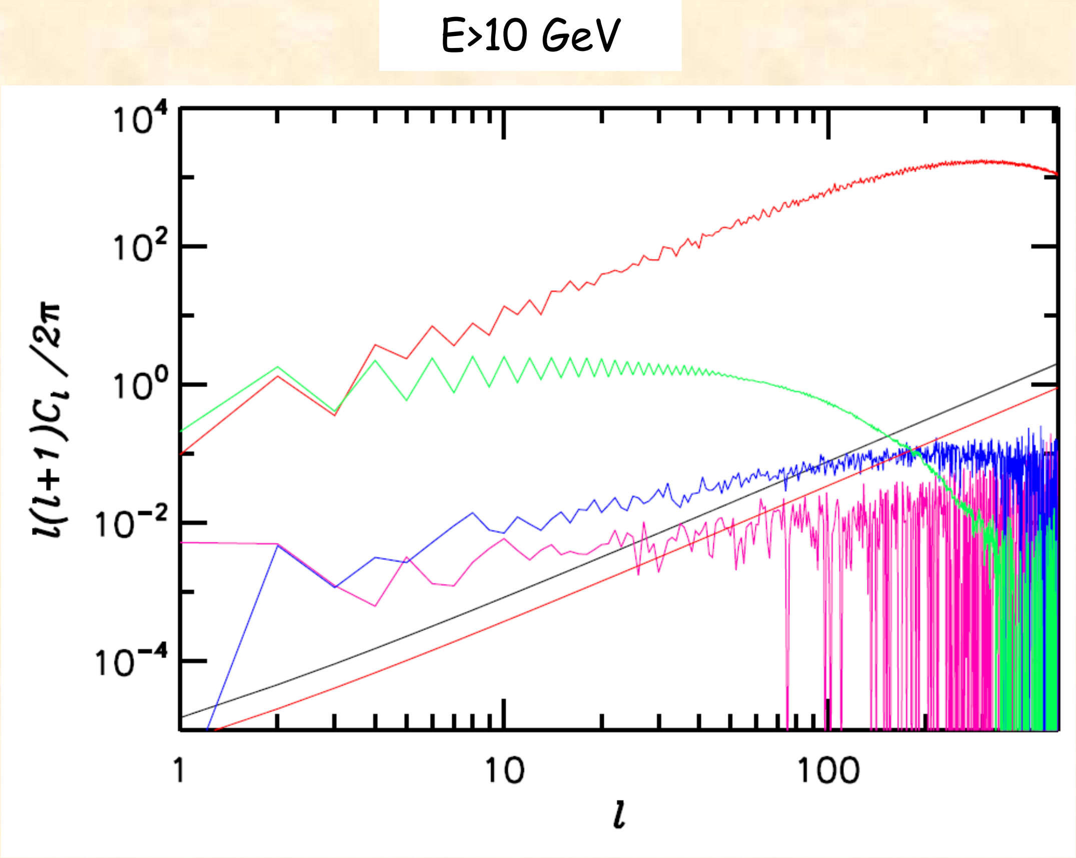


the anisotropy energy spectrum characterizes intensity fluctuations at a *fixed* angular scale as a function of energy

C_ℓ vs. E
(at a fixed ℓ)

J. Siegal-Gaskins, V. Pavlidou, Phys.Rev.Lett.102:241301,2009.

Some preliminary results with simulations



Angular Power Spectra of the various component:

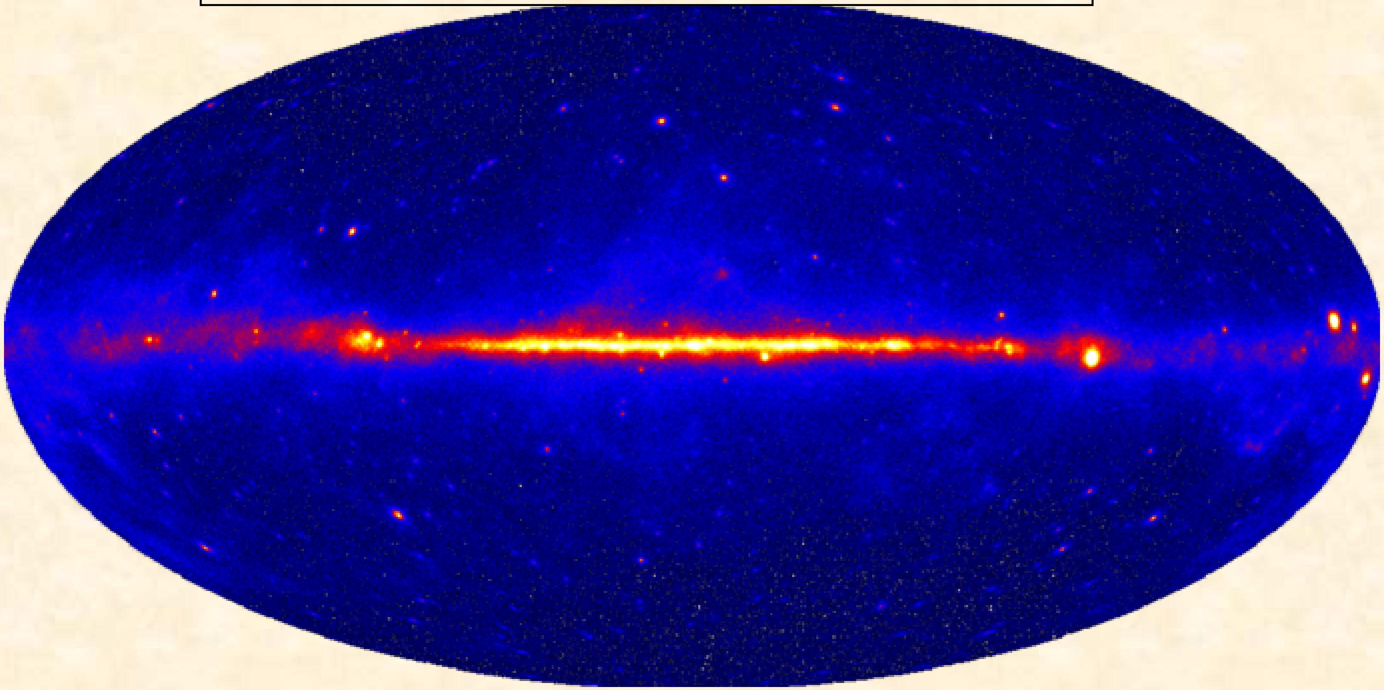
point sources (red),
galactic foregrounds (green),
CGB (pink)
WIMP (blue)

Point Sources dominates at all scales: efficient masking is required

Cuoco et al. 2010, in preparation

What can we achieve with the Fermi data?

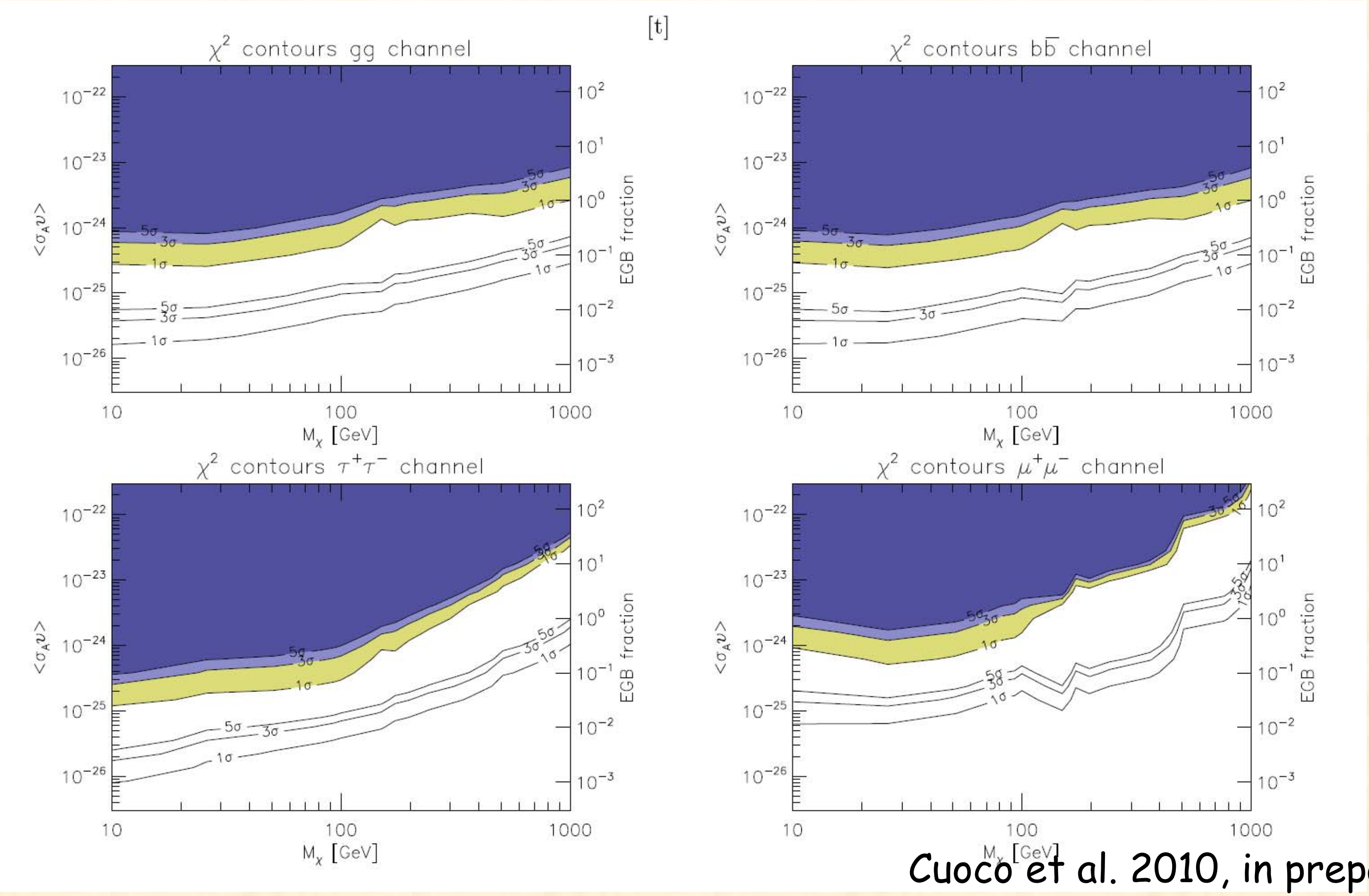
Fermi Gamma-Sky 30 MeV-300 GeV



Good angular resolution:
better than 0.6° above 1 GeV
better than 0.1° above 10 GeV

Effective Area:
Fermi: ~10000 cm2
EGRET: ~1000 cm2
→ ~one order of magnitude better statistic

Anisotropy and sensitivity to Dark Matter



Cuoco et al. 2010, in preparation

Sensitivity curves in the m_χ - $\langle\sigma_A v\rangle$ plane for various annihilation channels. Each panel shows the sensitivity curves at the 1 σ, 3 σ and 5 σ levels. Two possible normalizations for the DM signal have been employed, galactic haloes with substructures (lower curves) and no-substructures (higher curves).

Summary and Conclusions

•Seconadary radiation and gamma-ray anisotropies provides complentary mean to test/find possible DM signatures.

•Secondary Radiation and Final State Radiation in particular provides a fairly model independent test of the origin of the PAMELA/ATIC/FERMI electrons.

•Constraints achievable from anisotropies studies are comparable to the ones using energy spectrum information alone

•Fermi data provide already interesting constraints on DM . More statistics and a study of the foregrounds can further pin down the limits.