Search for dark matter with Fermi gamma-ray space telescope

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Outline

- Introduction of dark matter indirect detection
- Search for dark matter signal with Fermi
- Summary

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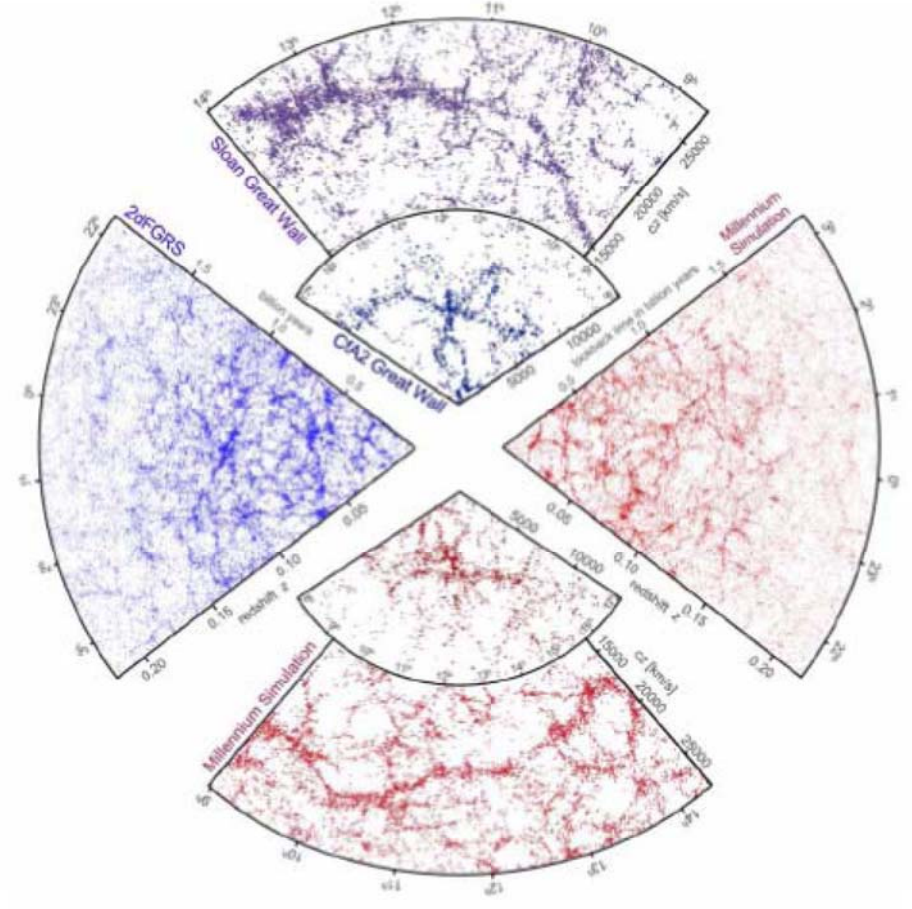
Structure evolution: cold/warm dark matter

Bottom-up structure formation pattern instead of top-down pattern (fragmentation): cold/warm dark matter



Springel et al. (2006) Nature

CDM simulation vs. galaxy survey

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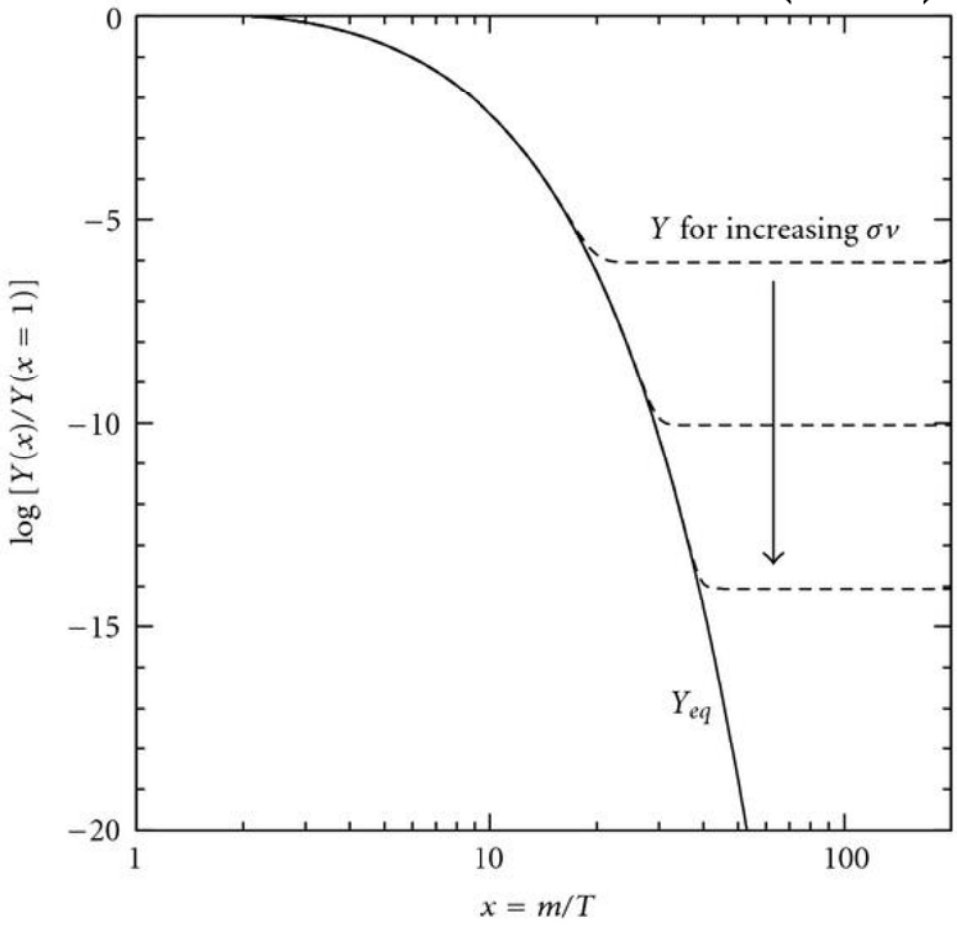
Thermal evolution of dark matter density

Garrett & Duta (2011)



$$\langle \sigma v \rangle \simeq \left(\frac{3 \times 10^{-27} \mathrm{cm}^3 \mathrm{s}^{-1}}{\Omega_\chi h^2} \right)$$

Weak scale interaction!

Weak Interacting Massive Particle (WIMP) is a natural candidate

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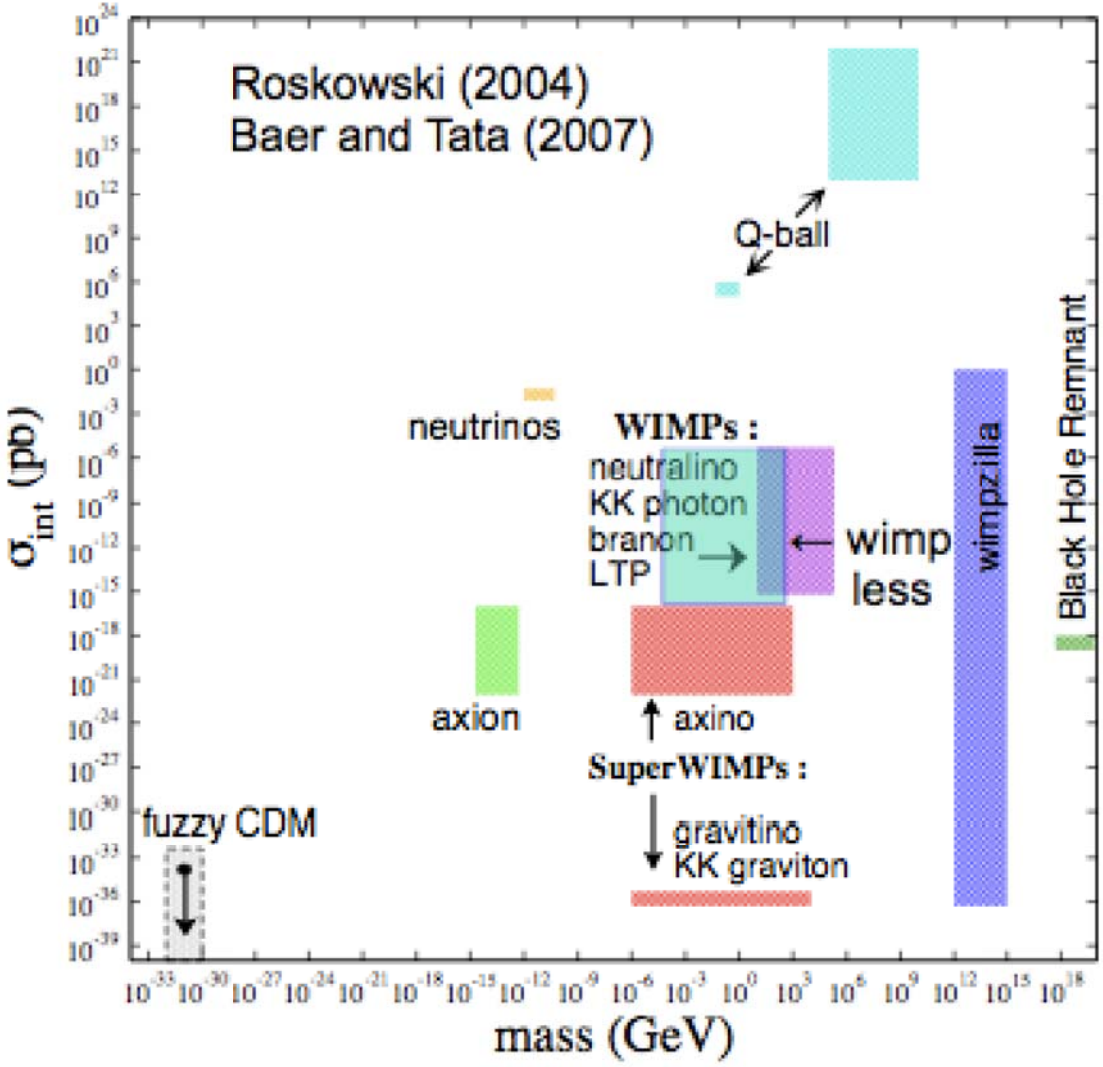
Particle candidate of dark matter



Many candidates with mass and cross section spanning many orders of magnitude

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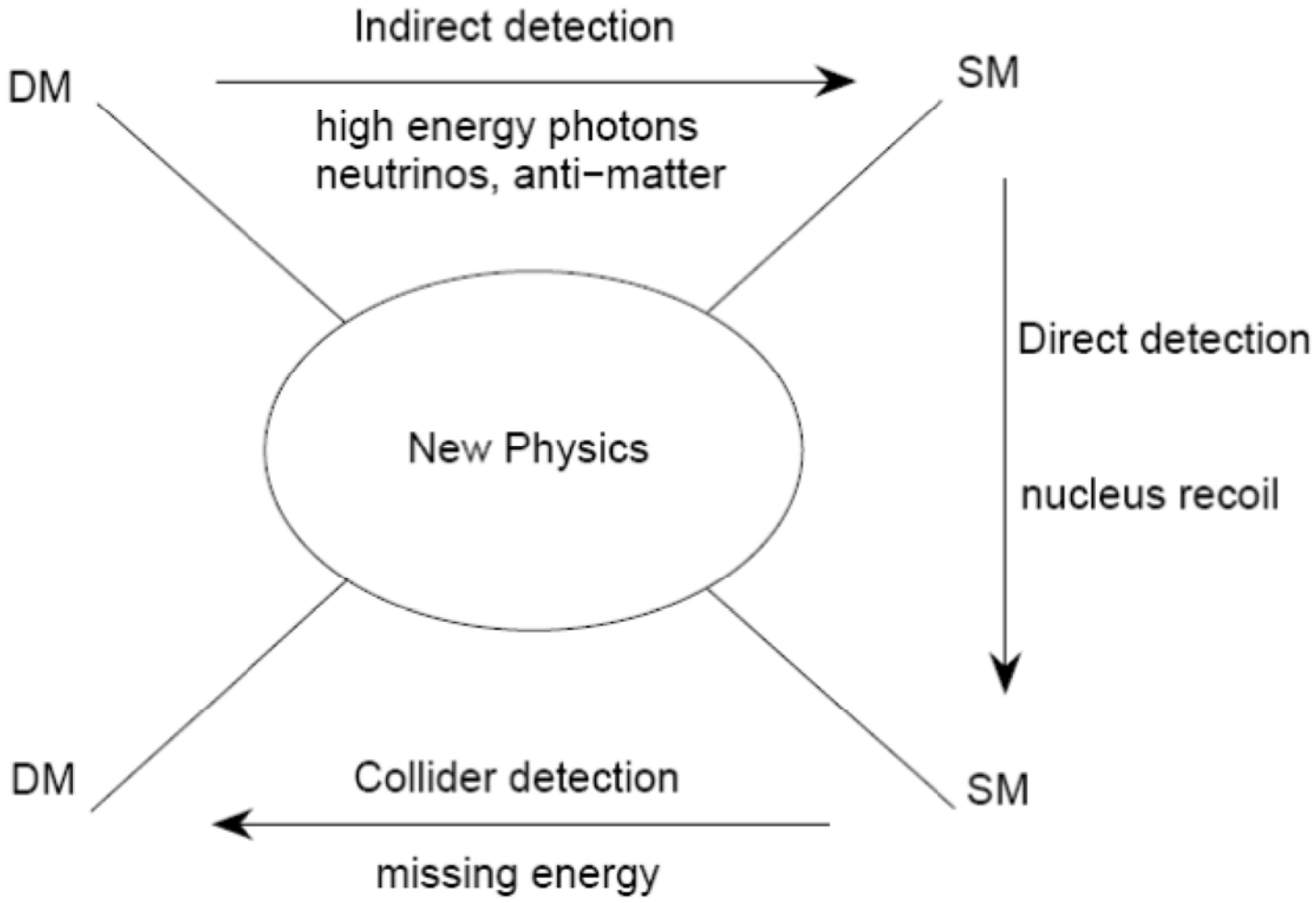
Detection of particle dark matter



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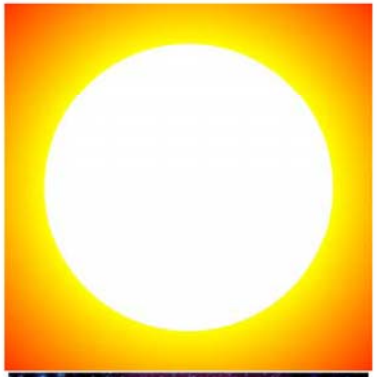
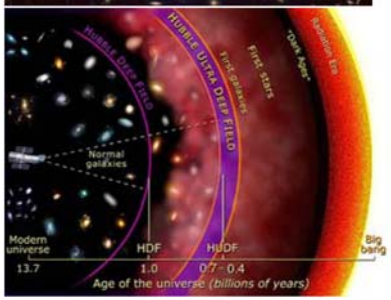
Indirect detection



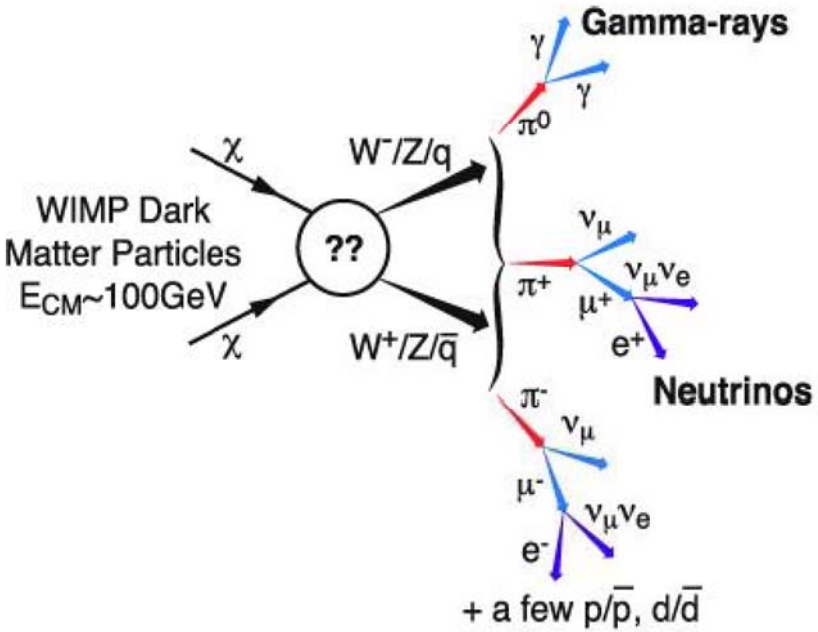
Sun

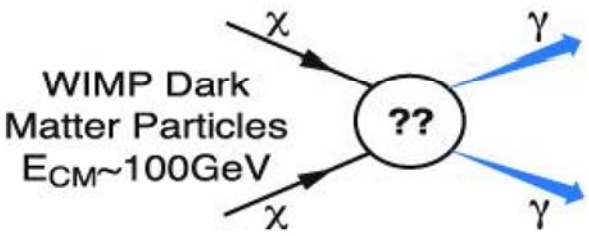
Galaxy

Cluster



Deep extragalactic space and early Universe





Baltz et al. 2008

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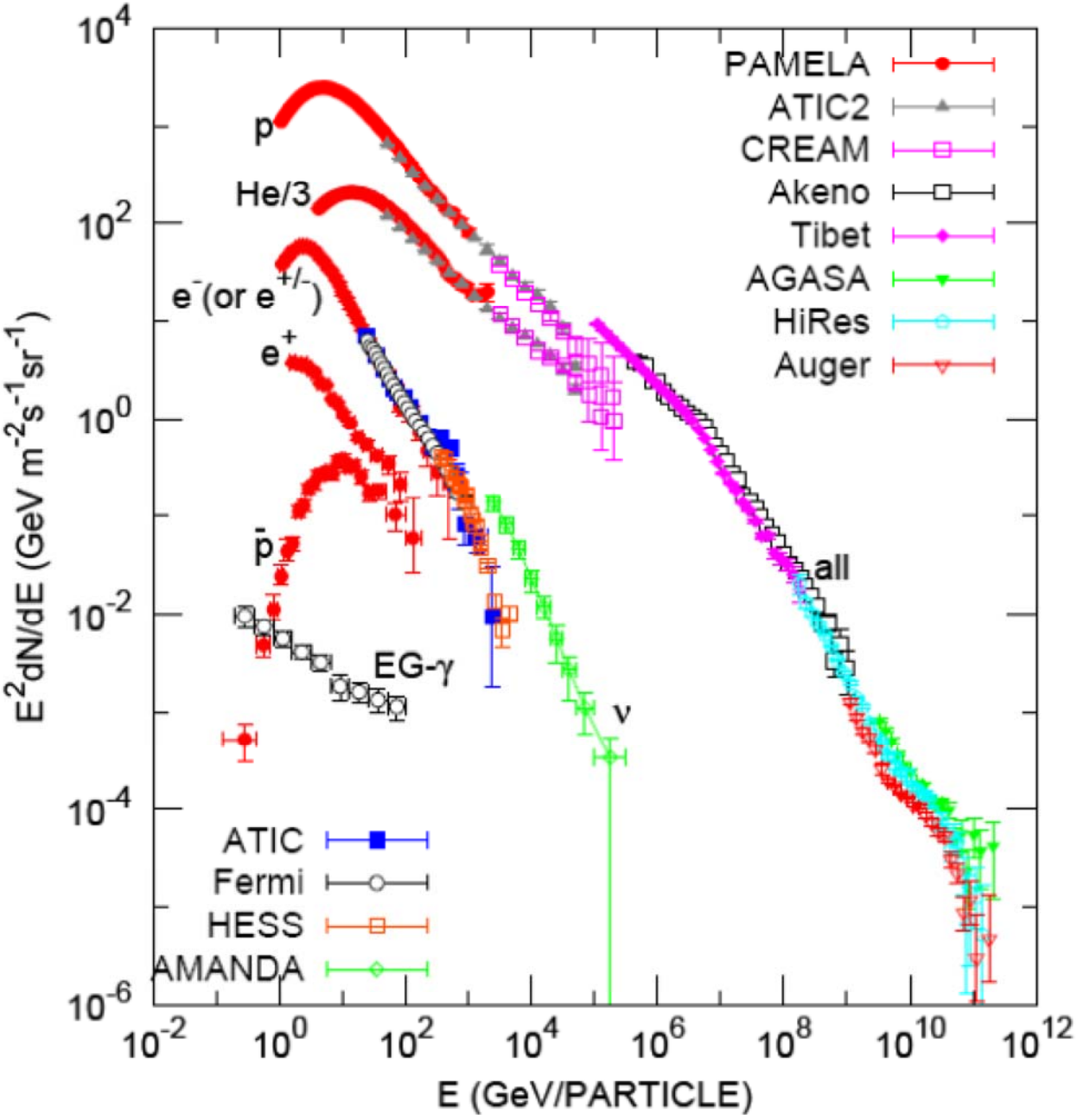
Search strategy



Better to search for DM signal in anti-particles due to lower background

gamma-rays and neutrinos are also good due to the simple propagation

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General method

Production $$q^j(\mathbf{r}, E) = \sum_i B_i \frac{\langle \sigma v \rangle}{2m_\chi^2} \left.\frac{\mathrm{d}N}{\mathrm{d}E}\right|_i^j \rho^2(\mathbf{r})$$

Propagation

diffusively for charged particles

$$-D\Delta N + V_c \frac{\partial N}{\partial z} + 2h\Gamma_{\mathrm{tot}}\delta(z)N + \frac{\partial}{\partial E}\left(\frac{\mathrm{d}E}{\mathrm{d}t}N\right) = q(\mathbf{x}, E)$$

straight line for photons and neutrinos

$$\begin{aligned}\phi(E, \psi) &= C \times W(E) \times J(\psi) \\ &= \rho_\odot^2 R_\odot \times \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_\chi^2} \frac{dN}{dE} \times \frac{1}{\rho_\odot^2 R_\odot} \int_{LOS} \rho^2(l) dl,\end{aligned}$$

Two key factors: particle physics parameters (from DM particle model) and density distribution (from gravitational observation and/or numerical simulation)

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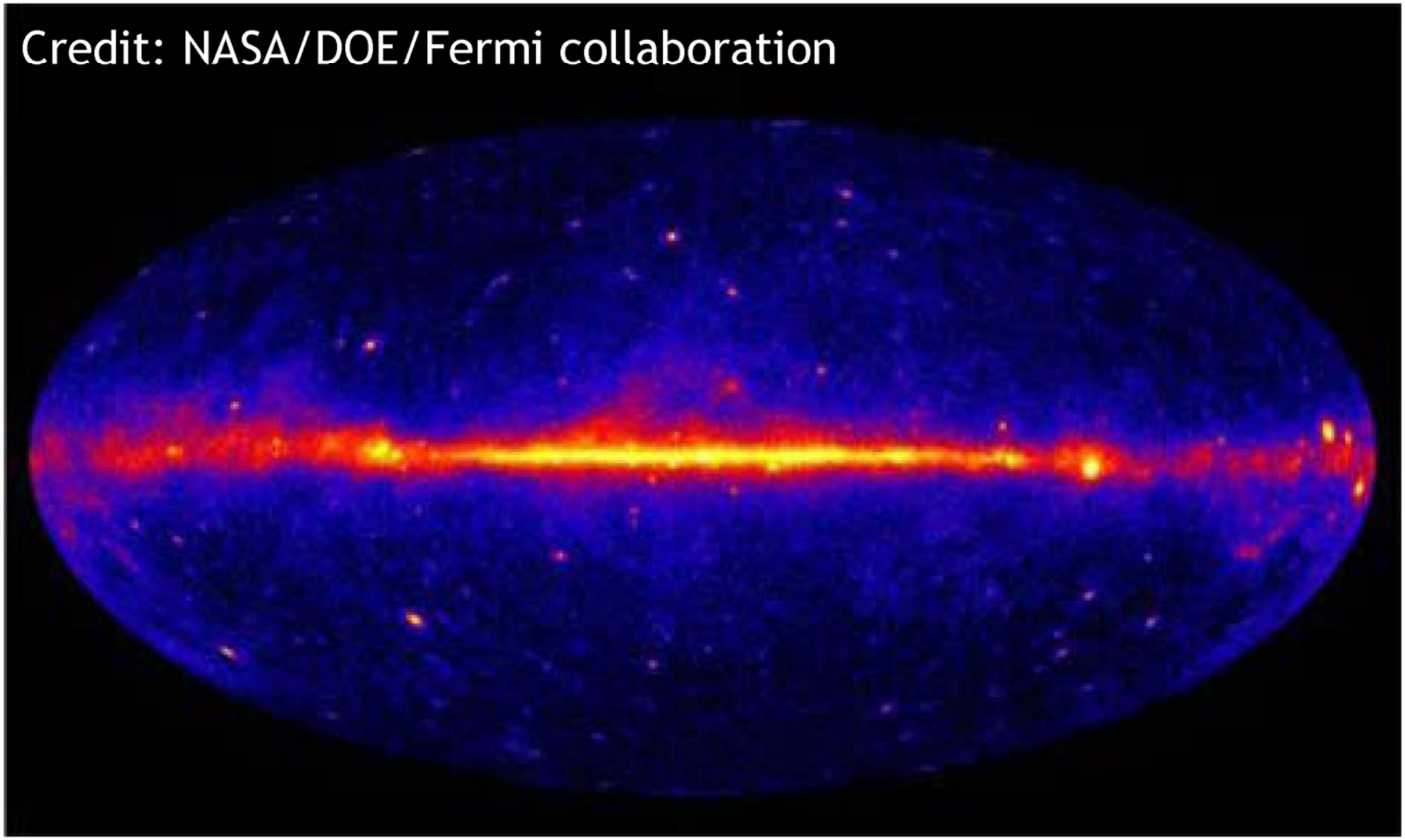
Fermi gamma-rays can provide good test of the DM models



- Galactic center
- Galactic halo
- Dwarf galaxies
- Clusters
- Extra-galactic diffuse
- Line search

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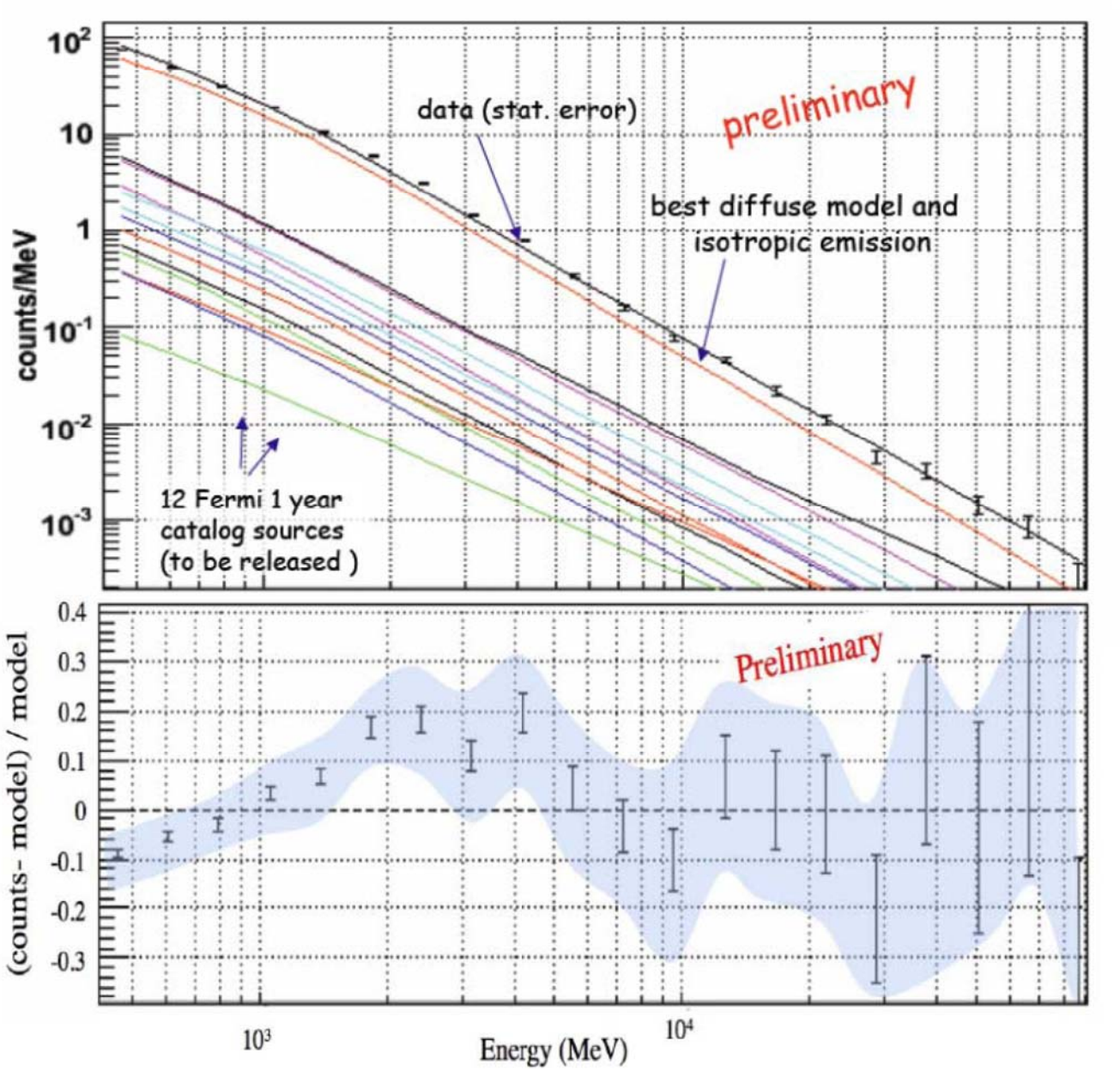
Galactic center



- 7°×7° region
- Basically consistent with model (diffuse background + point sources)
- No clear spectral feature of excess (somewhat under-prediction of ~GeV)

Vitale & Morselli (2009)
arXiv:0912.3828

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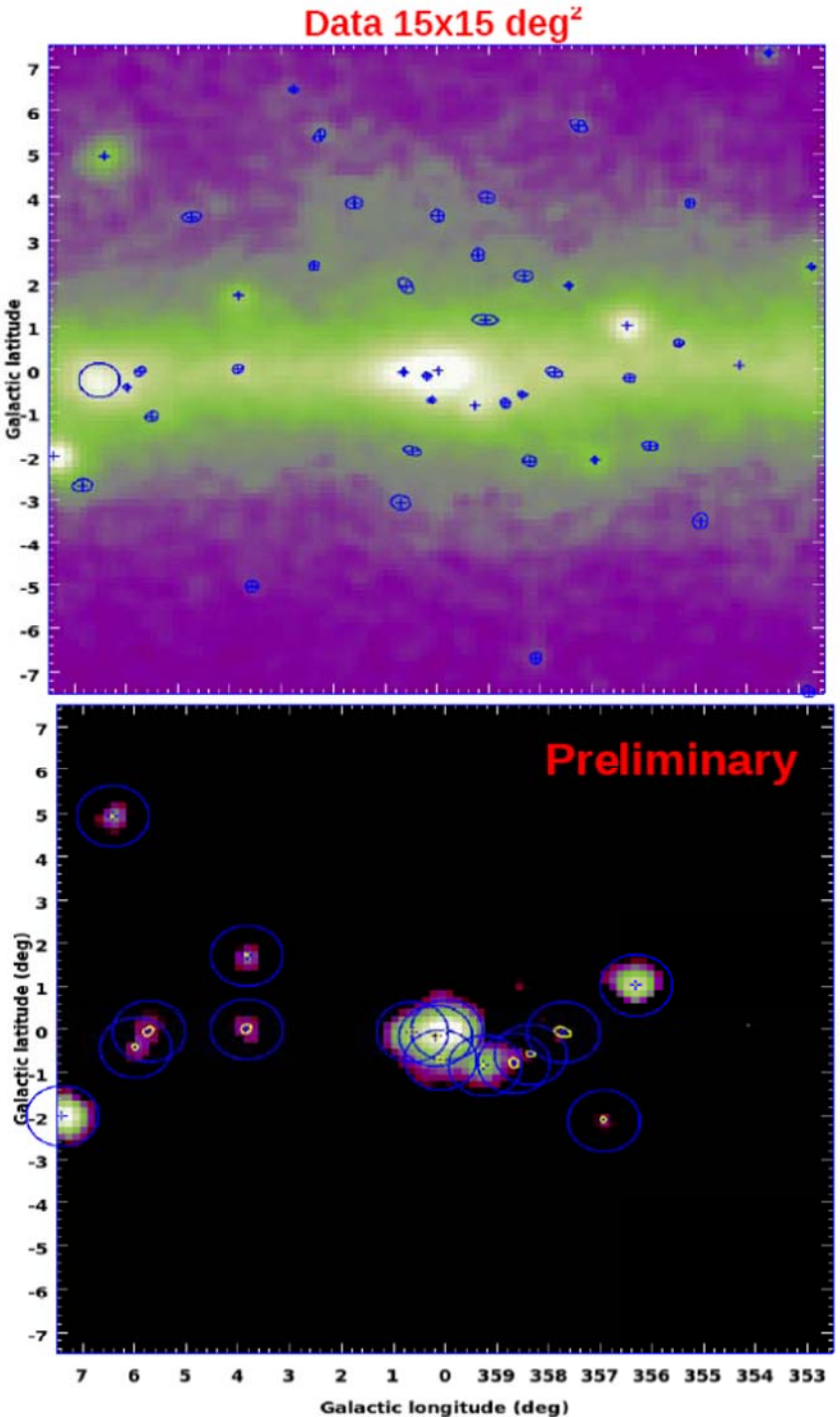
Galactic center



- 45°×45° region
- Majority of diffuse emission can be removed with a physically-motivated model based on GALPROP
- Residual is consistent with known point sources and small fluxtuations
- “Adding extra component like dark matter may improve the fit, but not necessary”

G. Vargas, DSU 2011

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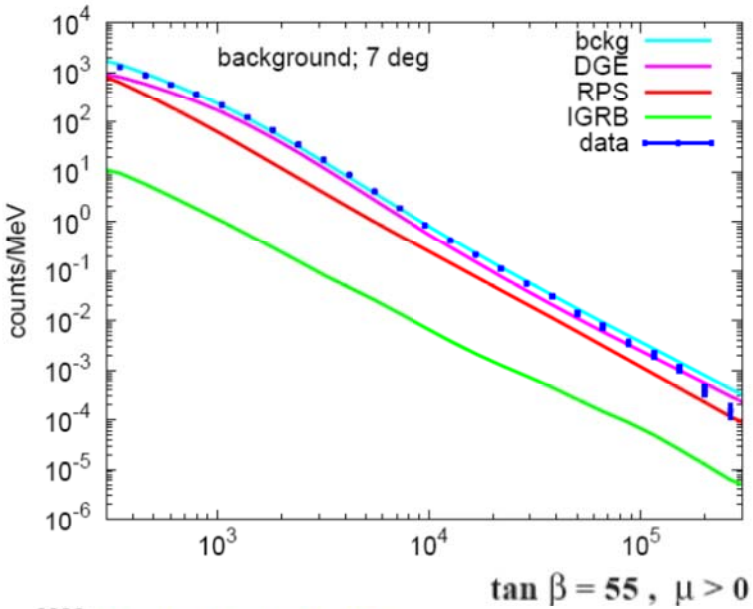
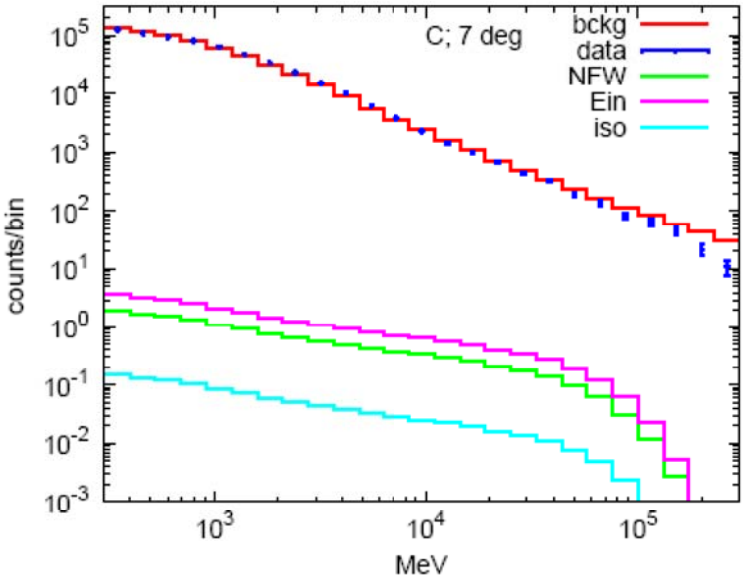
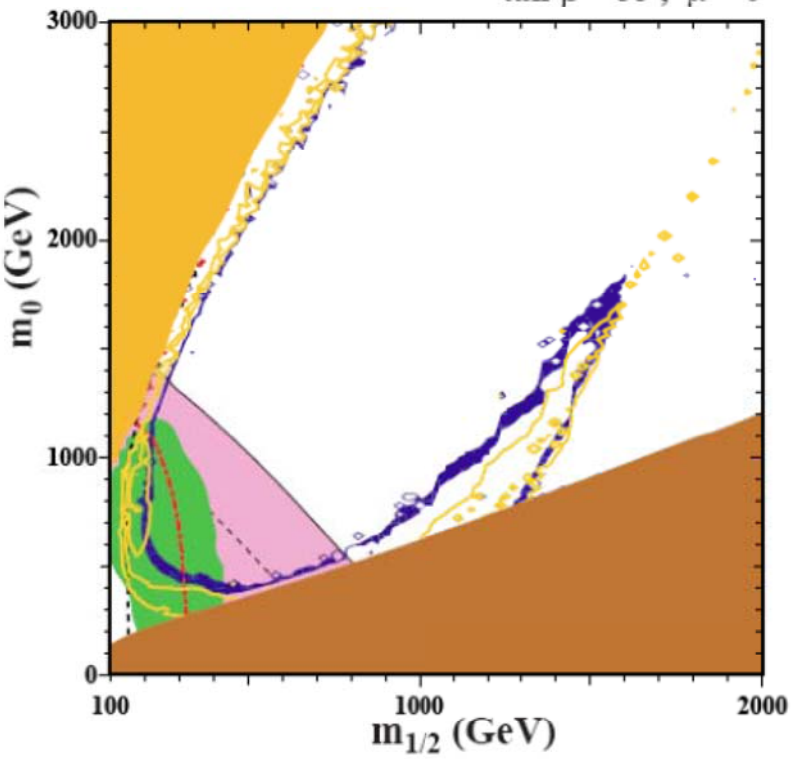
Galactic center







- Using Fermi GC data to study the CMSSM model
- Current Fermi data are not sensitive to the CMSSM model studied
- More data and better control of background uncertainties may probe the focus-point strip and rapid-annihilation funnel region

Ellis et al., arXiv:1106.0768

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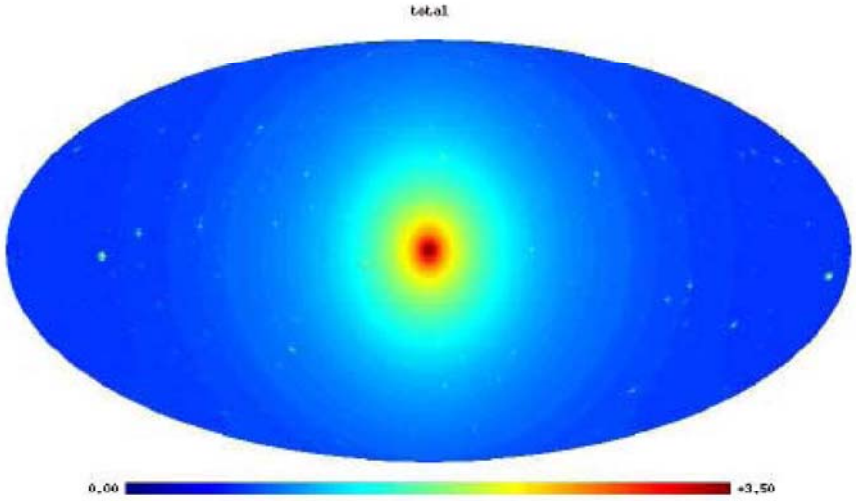
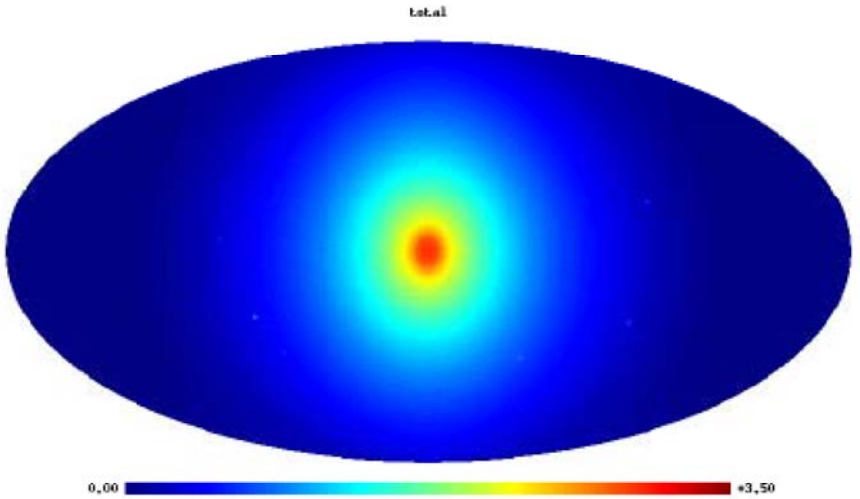
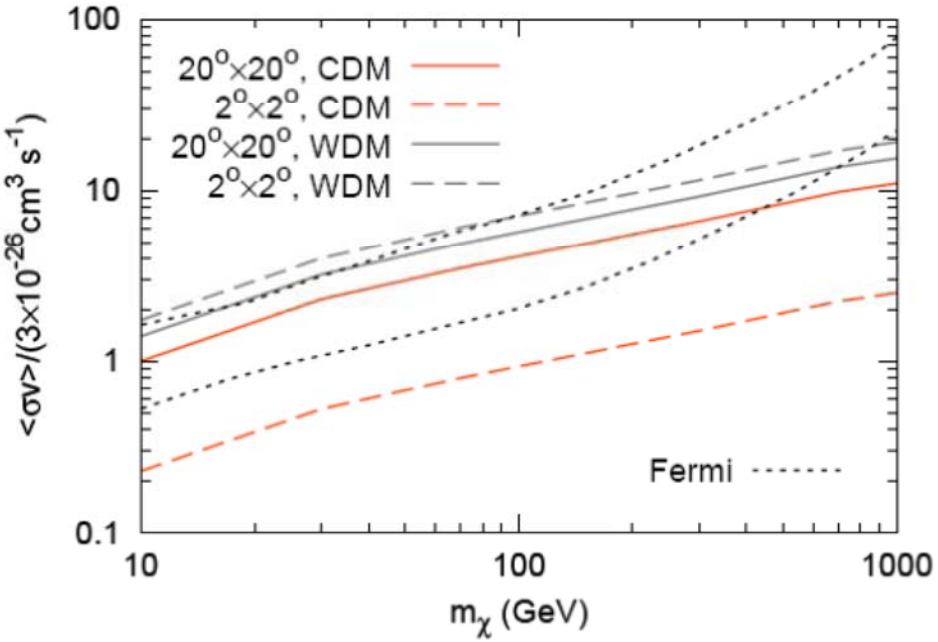
Galactic center







- Cold and warm WIMP scenario
- DM signal does not exceed the background
- The results are comparable with Fermi dwarf galaxy constraints
- Detailed comparison with Fermi data are on-going

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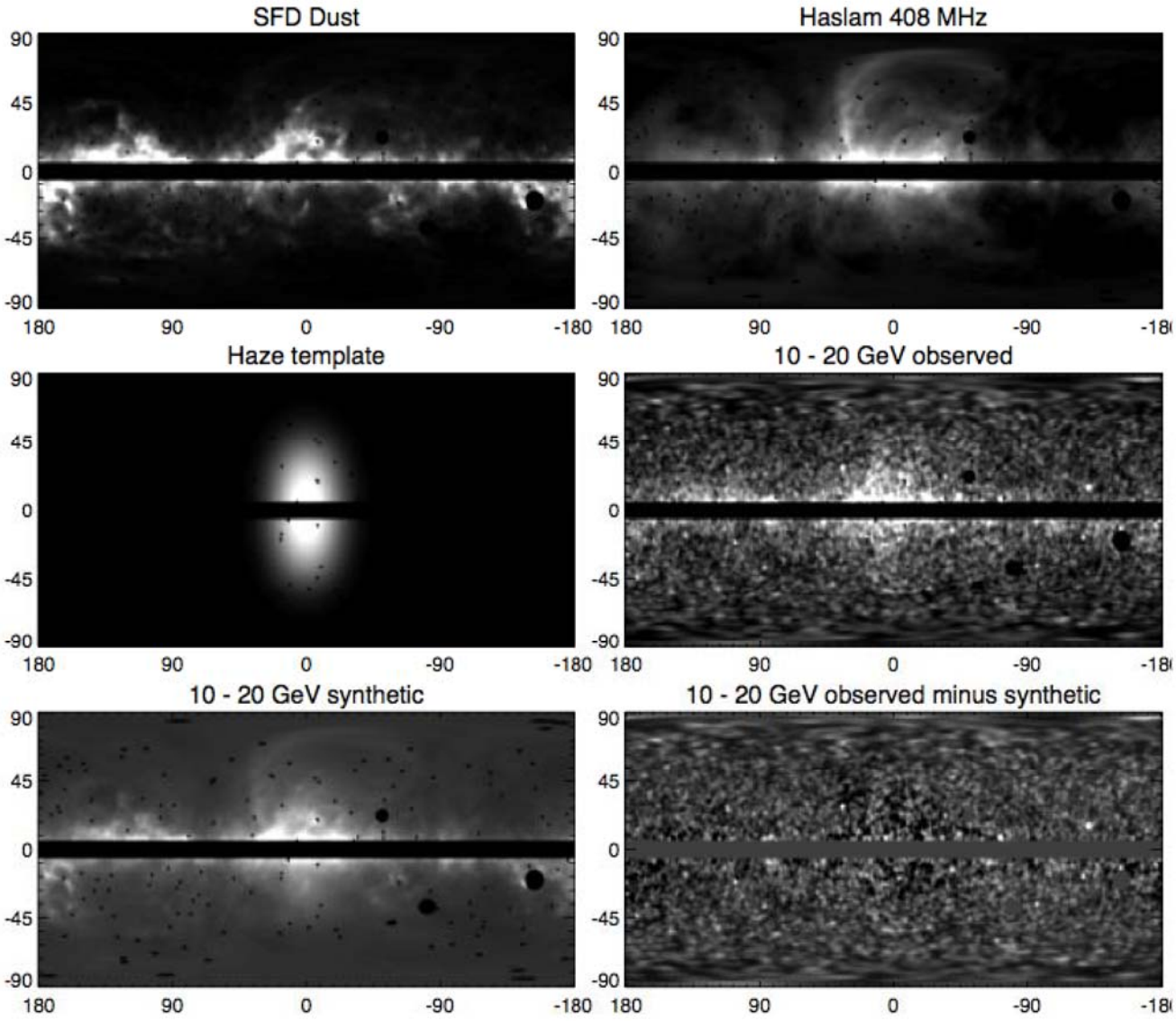
Galactic center



- Fermi haze (larger region 50°×90°)
- A hard spectrum
- Non-spherical
- Possibly coincides with WMAP microwave haze
- Generally not from DM (however, Dobler et al. 2011 proposed a DM scenario with anisotropic diffusion)

Dobler et al. (2009, ApJ)

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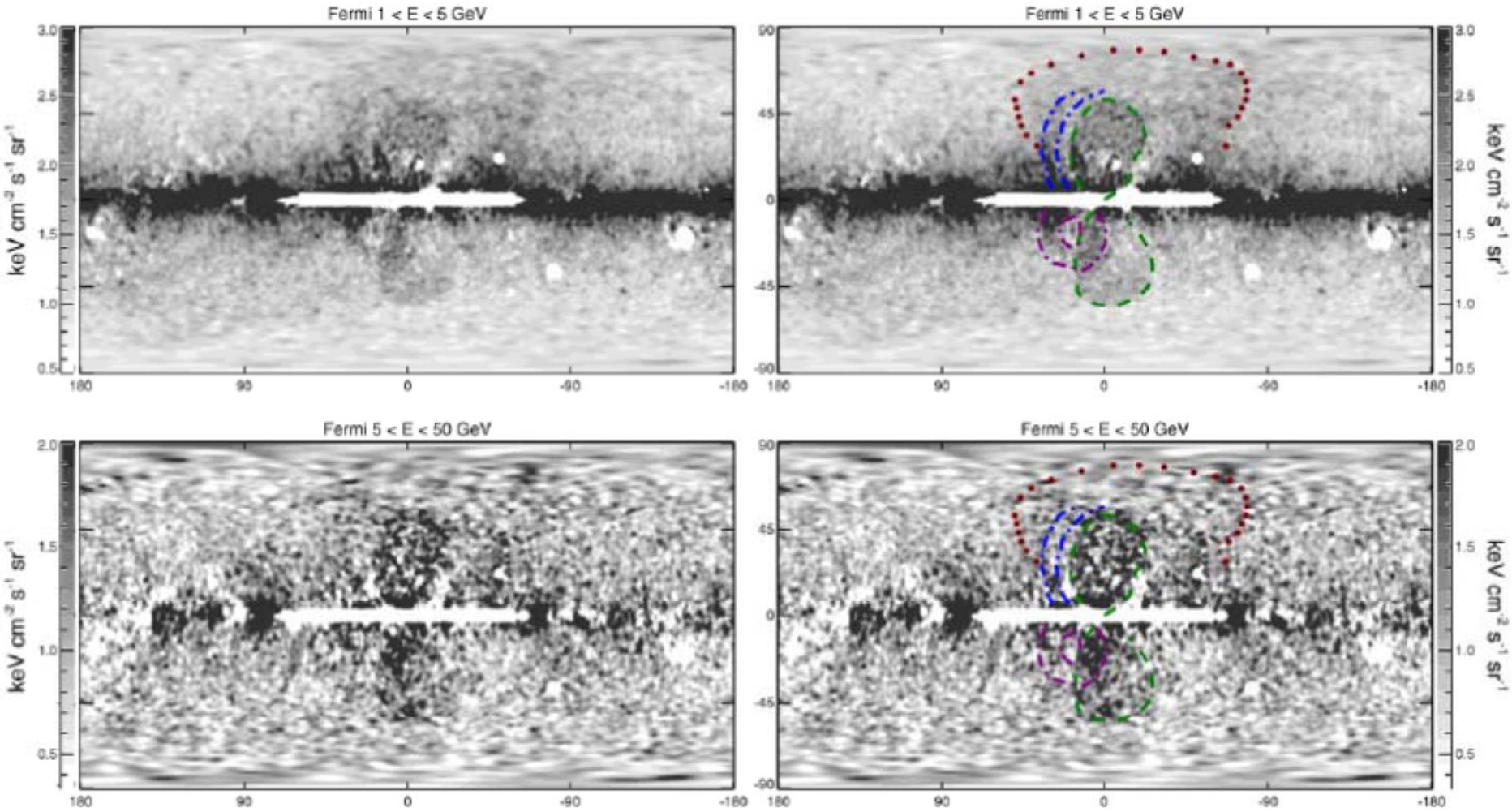
Galactic center



- Fermi bubble (larger region 40°×50°each)
- Roughly consistent with Fermi haze, with more detailed structure

Su et al. (2010, ApJ)

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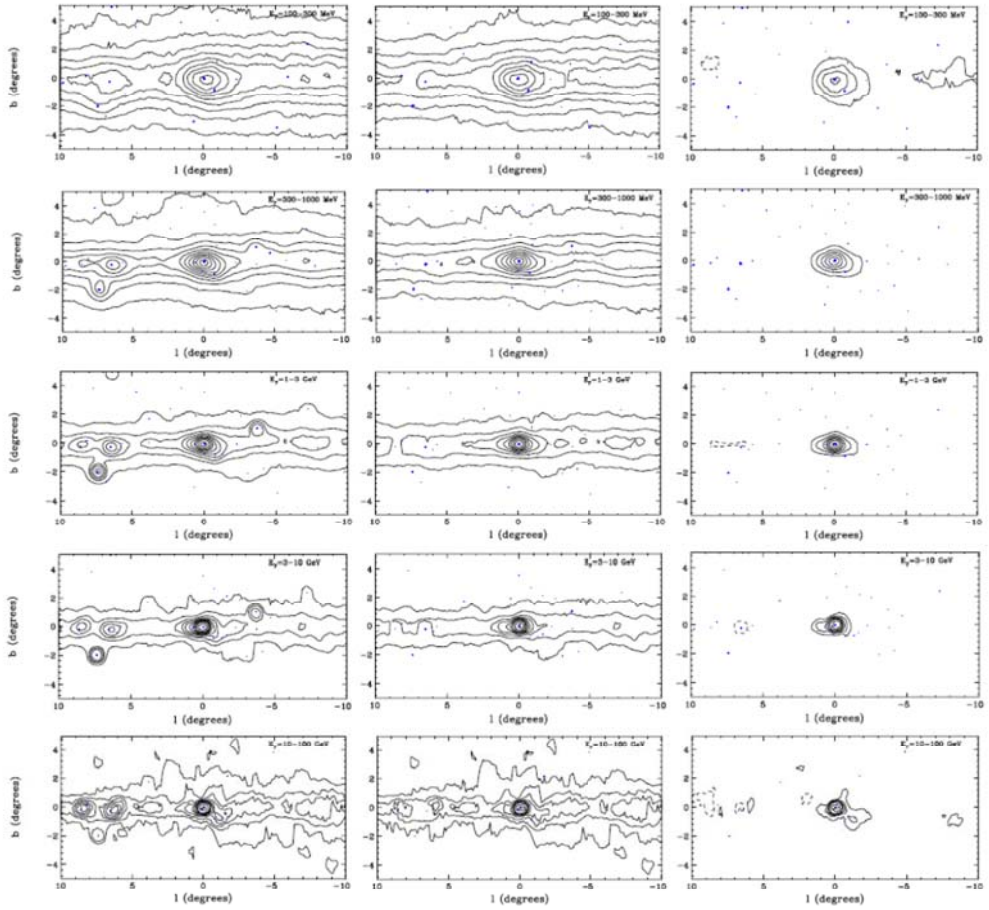
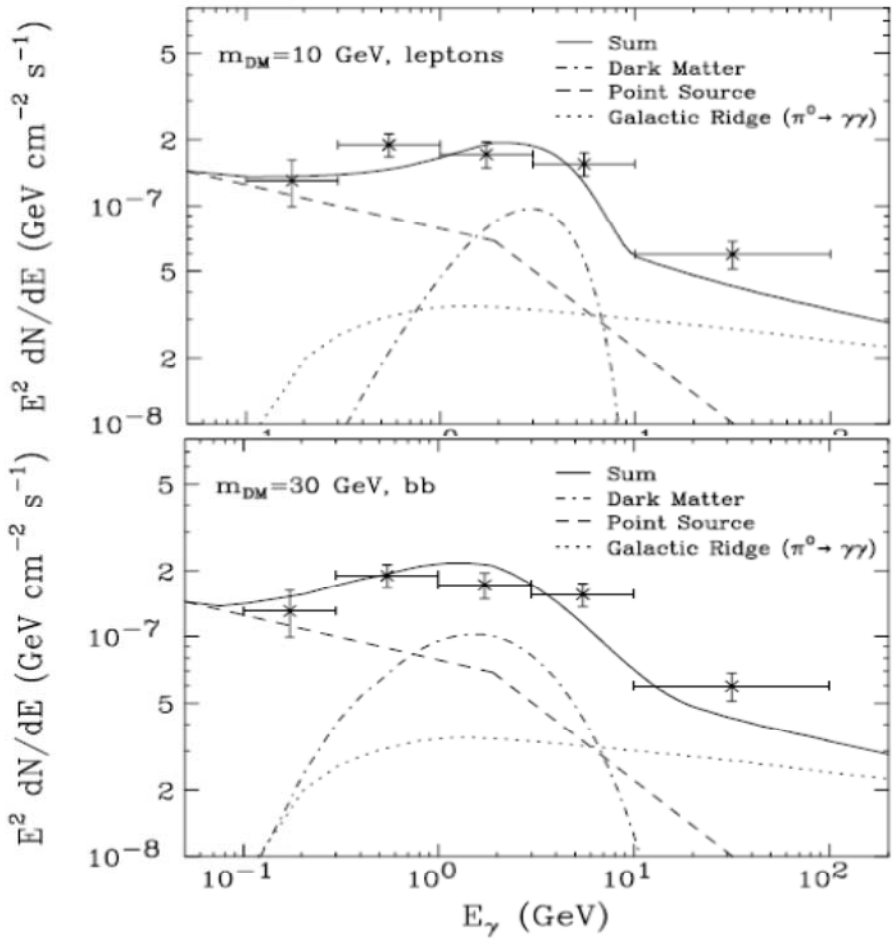
Galactic center





- Most inner region “excess” (<2°)
- Background template: a gas model
- Could be explained with 7-12 GeV (tau) or 25-45 GeV (bb) DM
- Density profile γ~1.3

Hooper & Linden, arXiv:1110.0006

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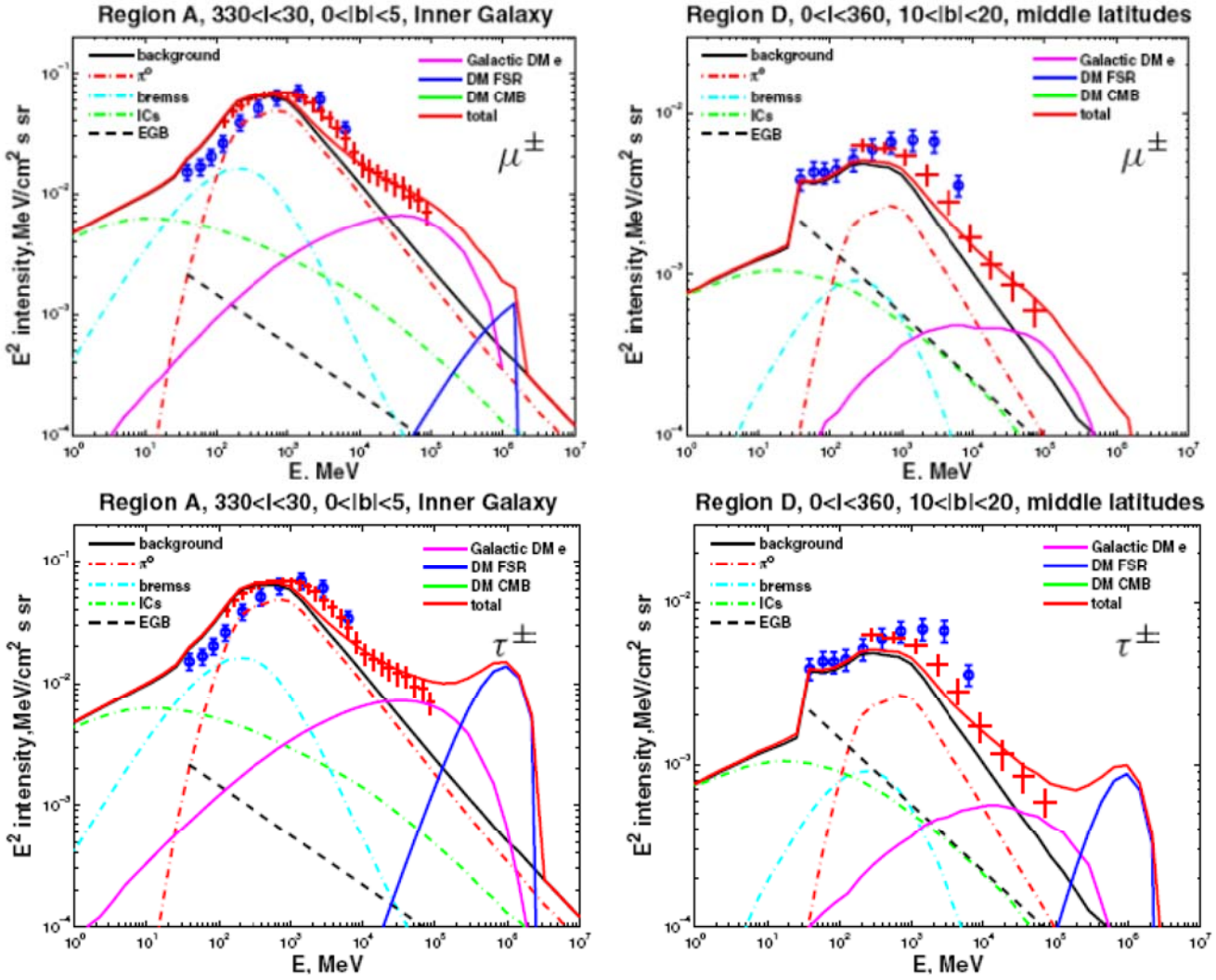
Galactic halo



- PAMELA/Fermi favored leptonic DM annihilation models with tau final states are constrained
- Decaying DM scenarios are less constrained

Zhang et al. (2010, ApJ)

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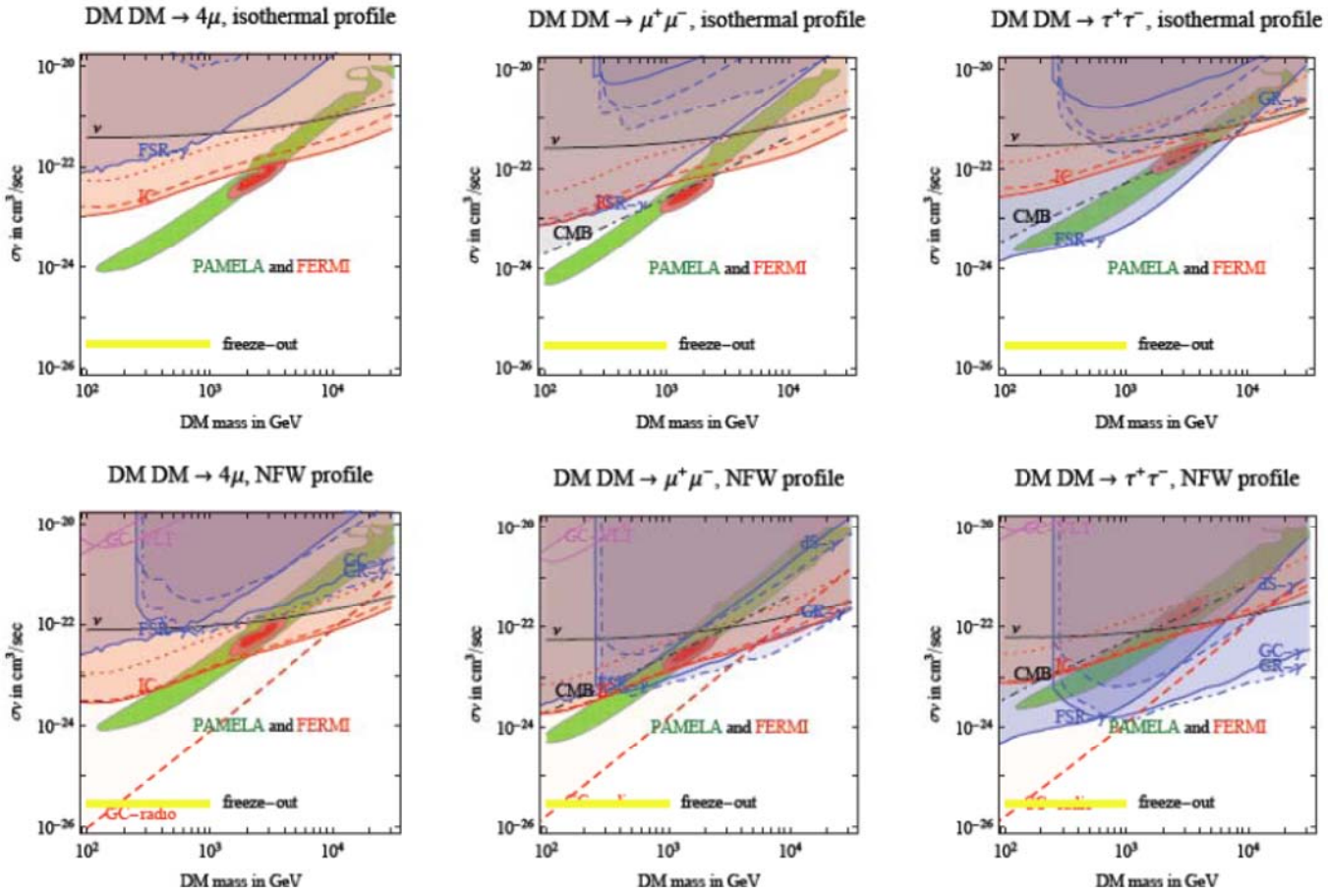
Galactic halo



- Using the all-sky Fermi gamma-rays as upper limits of DM contribution
- PAMELA/Fermi favored leptonic DM models are constrained
- Allowed annihilating final states $\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$ or $e^+e^-e^+e^-$
- Cuspy density profile is constrained

Papucci & Strumia (2010, JCAP)

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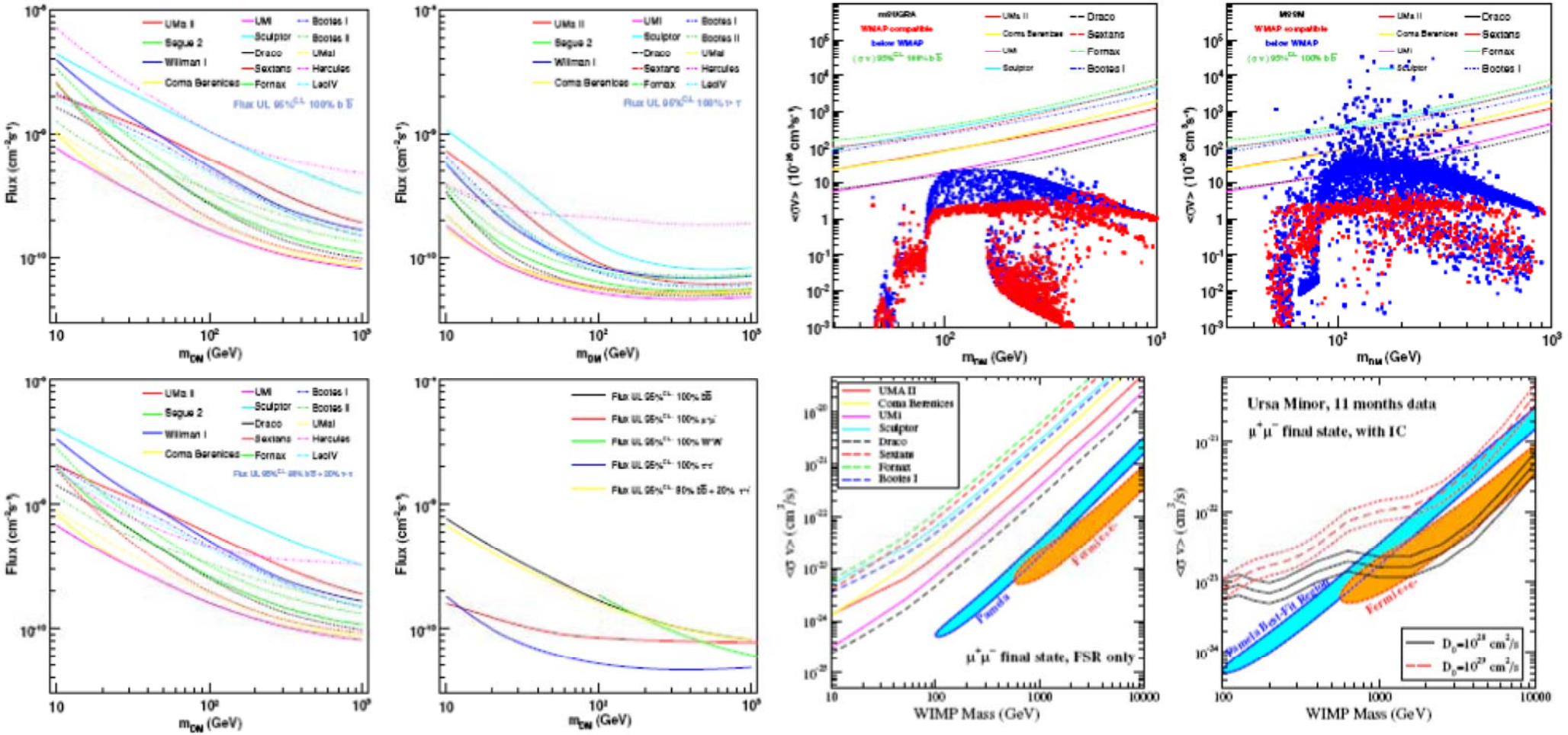
Dwarf galaxies



- Fermi search for a series of dwarf galaxies but with no signals
- Non-thermal super-symmetric model is constrained

Abdo et al. (2010, ApJ)

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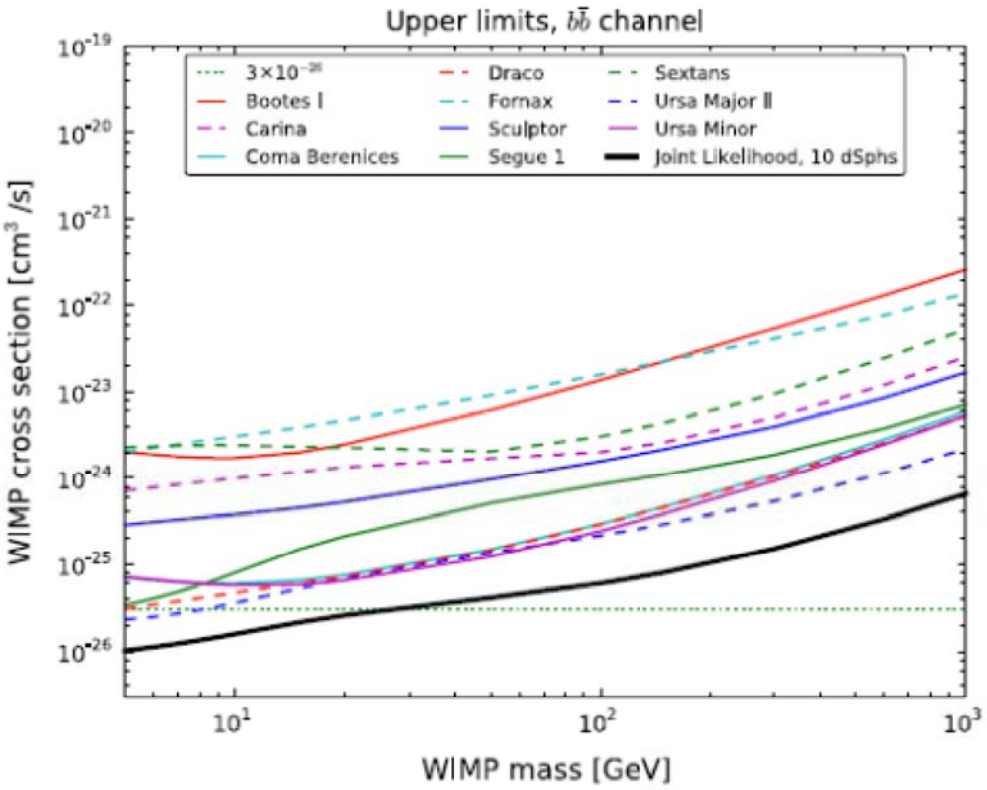
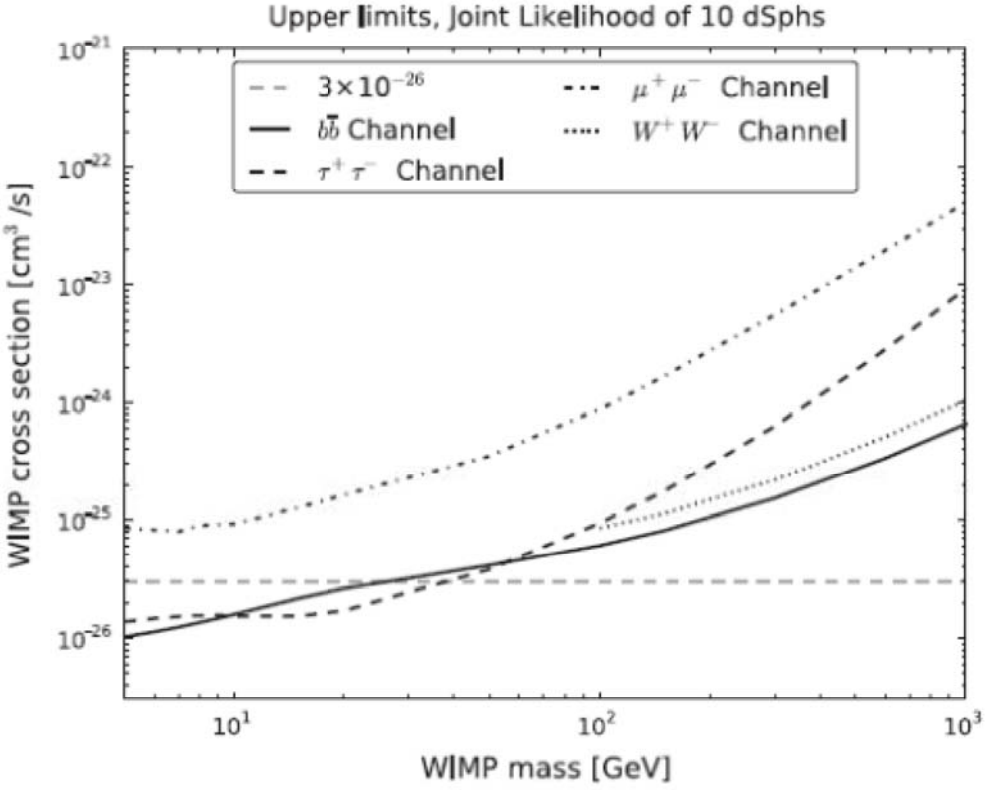
Dwarf galaxies





Joint analysis of a series of dwarf galaxies with 2-yr Fermi data can exclude low mass WIMPs with canonical cross section

Abdo et al. (2011, PRL)
Geringer-Sameth & Koushiappas (2011, PRL)

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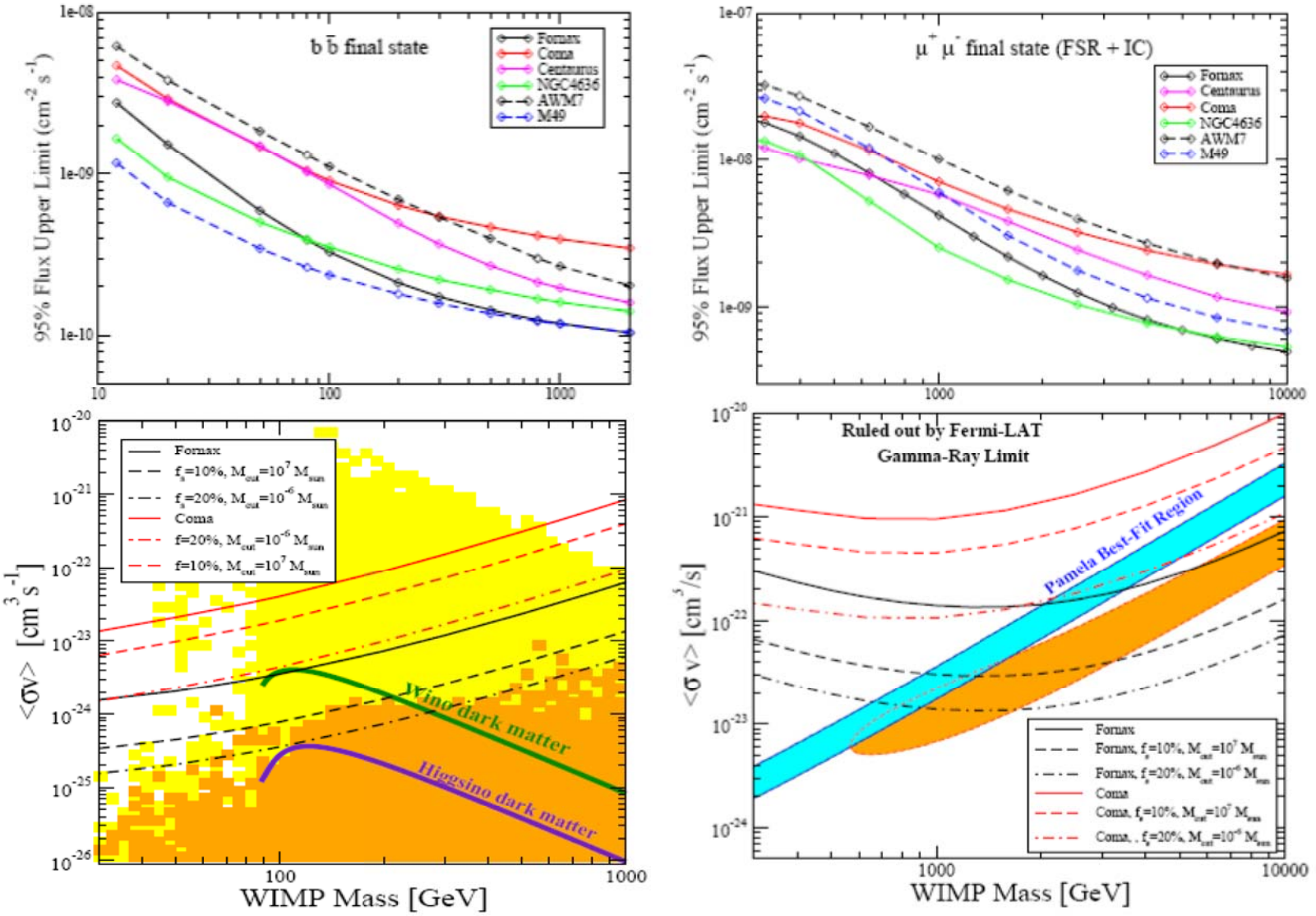
Galaxy clusters



Abdo et al. (2010a, JCAP)

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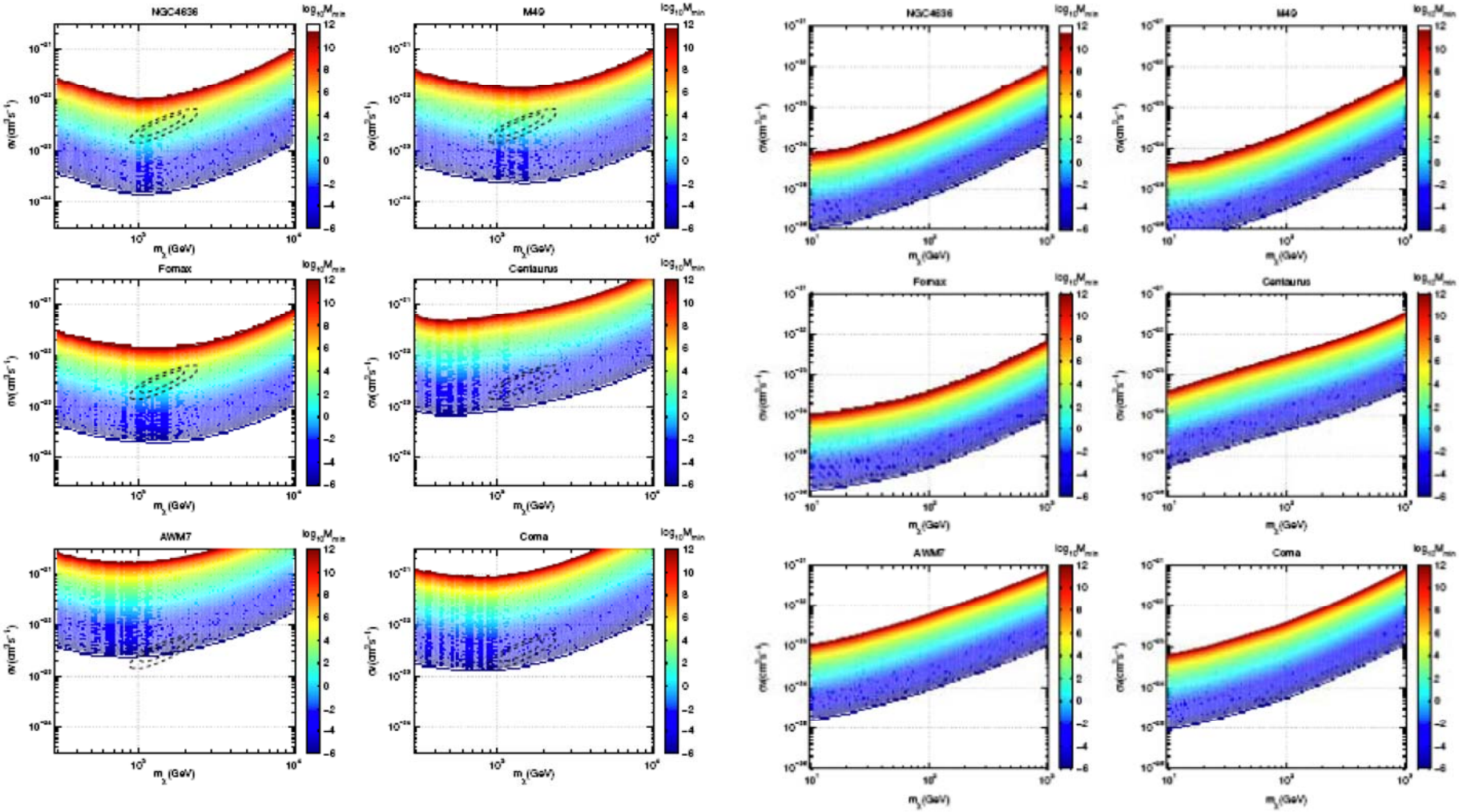
Galaxy clusters



- Use the same data of clusters by Fermi to constrain the substructure population of DM
- Scenario with standard extrapolation of CDM is constrained

Yuan et al. (2010, PRD)

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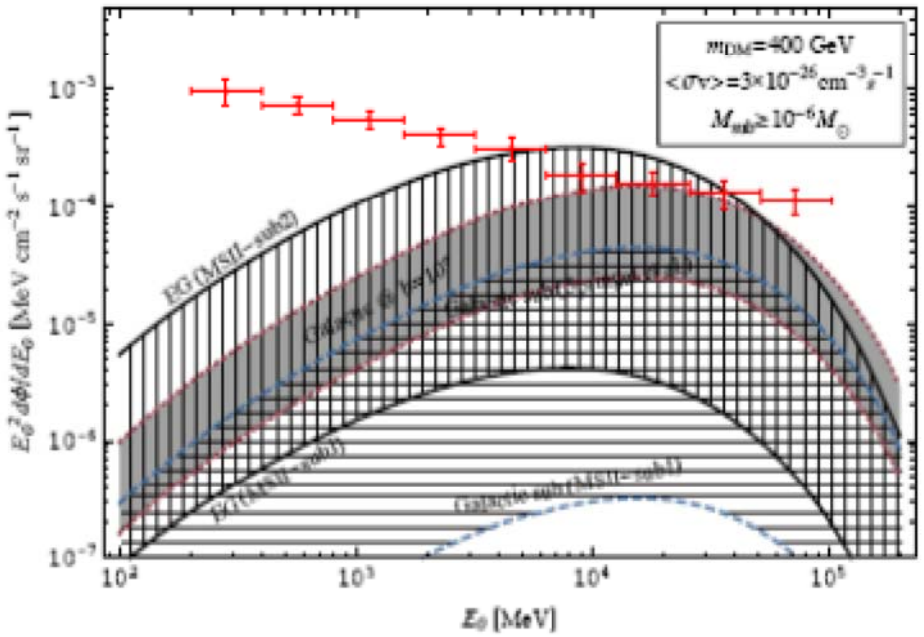
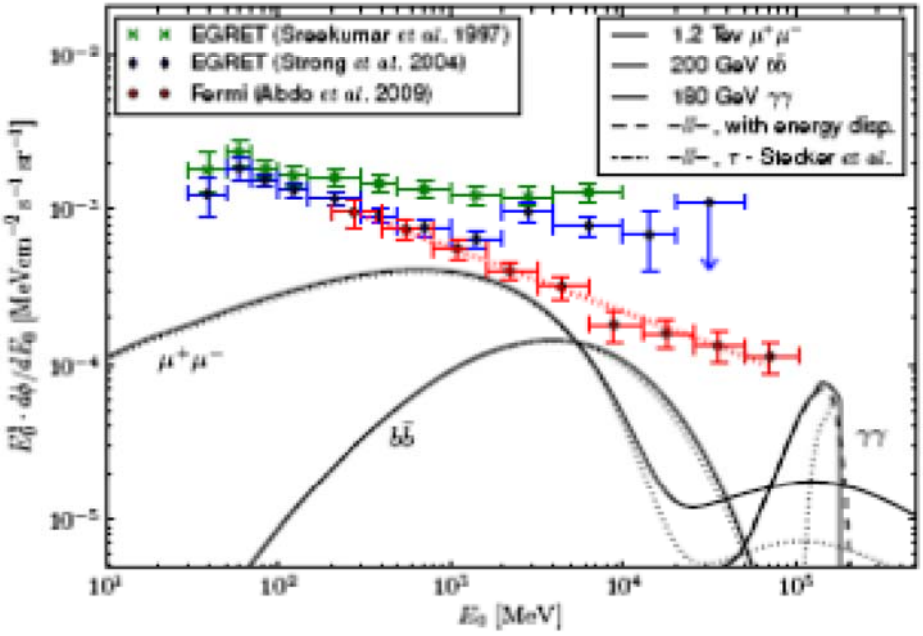
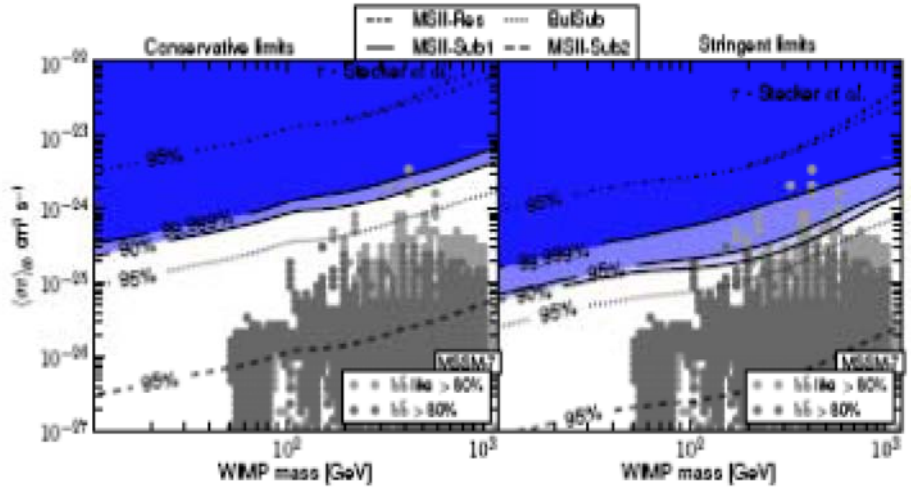
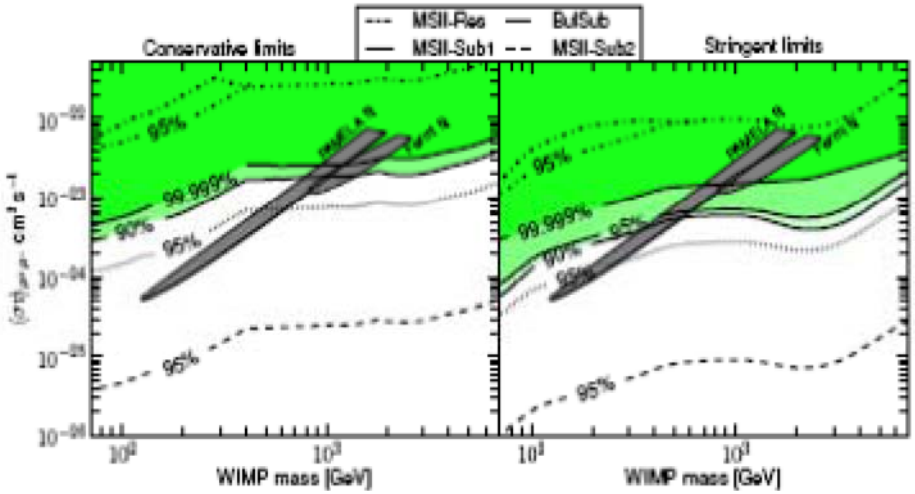
Extra-galactic diffuse background





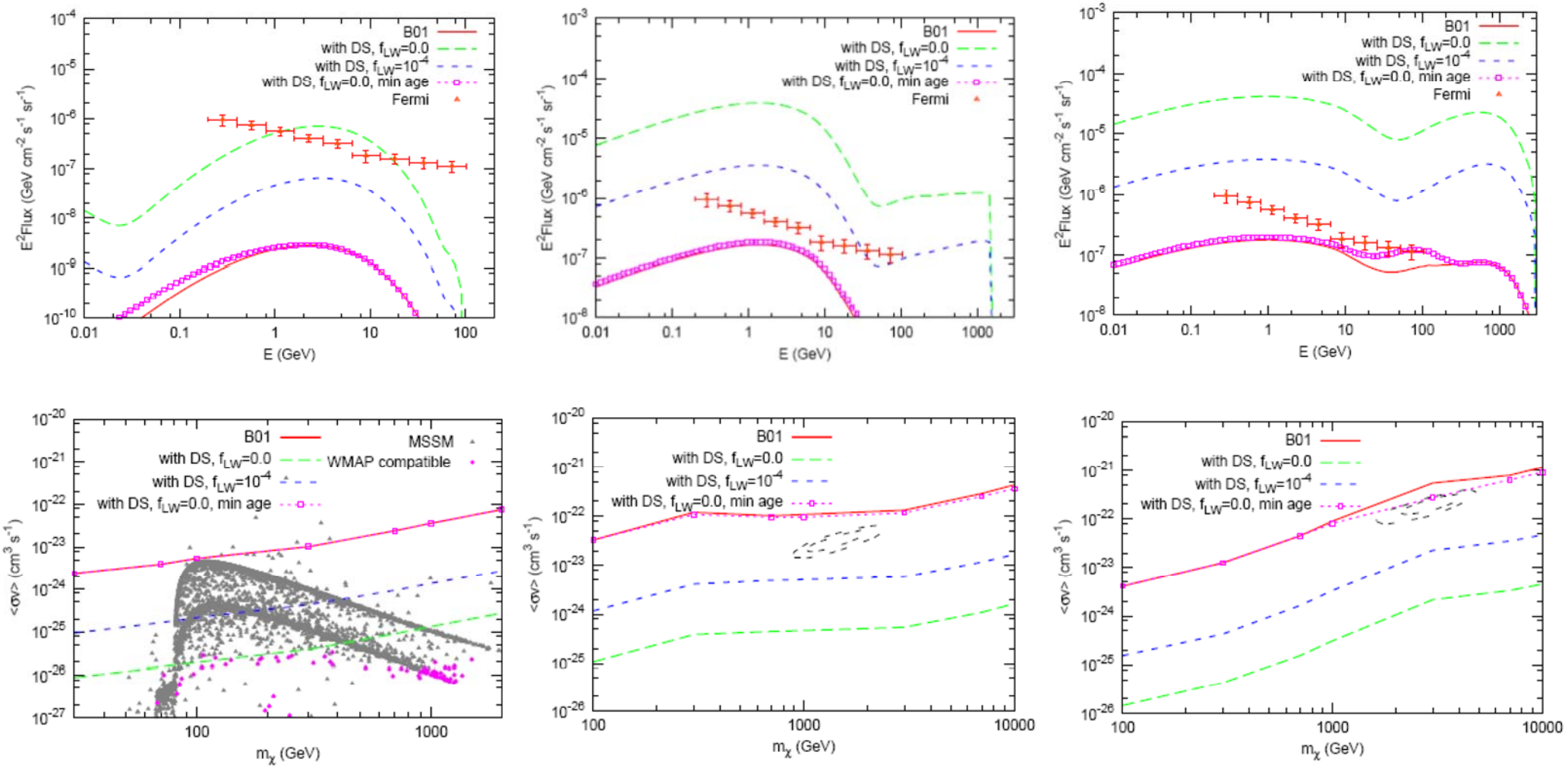




Abdo et al. (2010b, JCAP)

SNETP

Extra-galactic diffuse background



- Constrain the DM model parameters with dark star formation
- Tension with the PAMELA/Fermi favored models

Yuan et al. (2011, JCAP)

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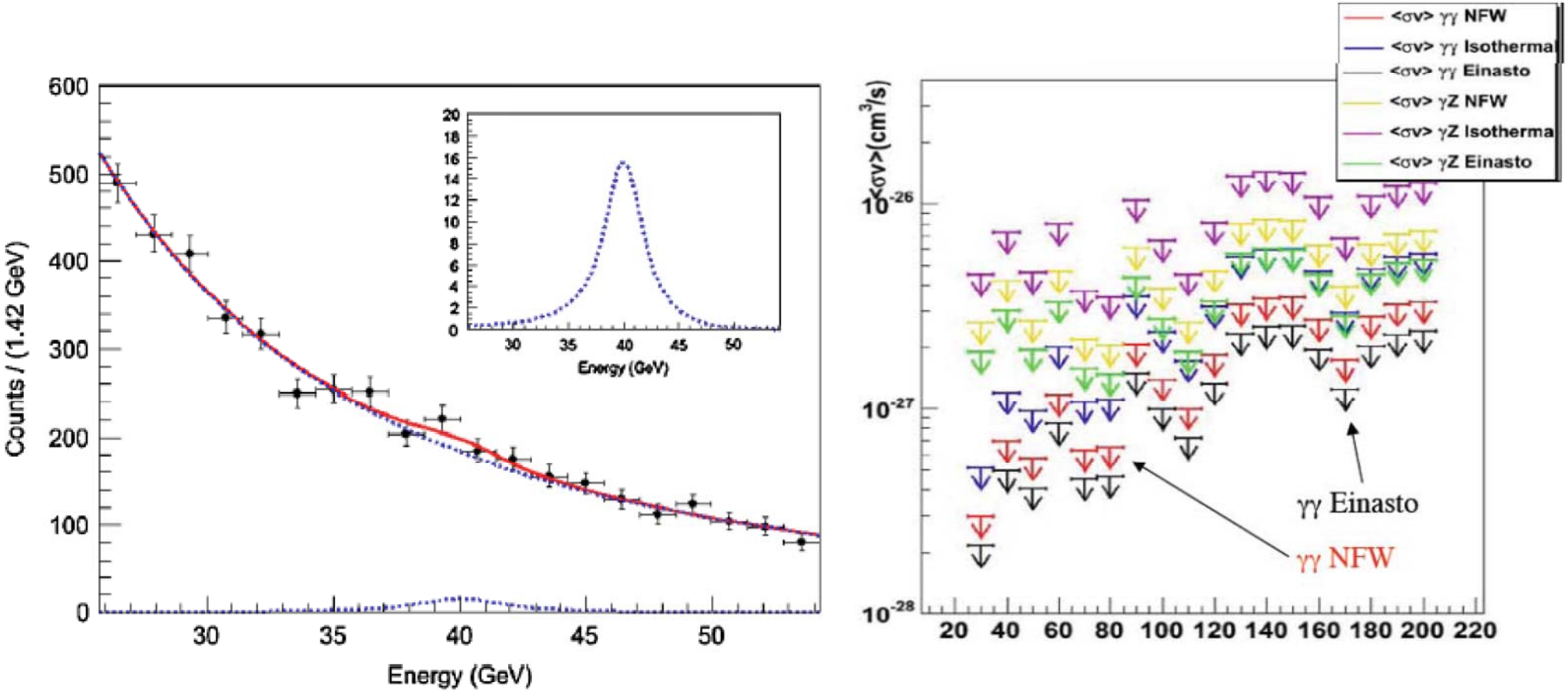
Line search



- 11%-13% energy resolution in 20-200 GeV
- No line signal is detected
- Upper limits are obtained through a likelihood fit

Abdo et al. (2010, PRL)

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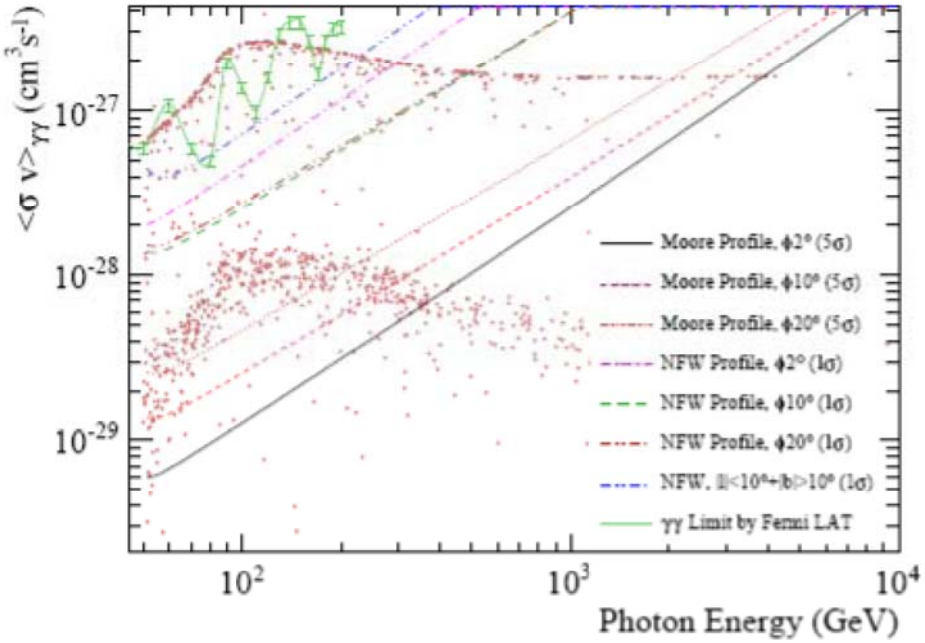
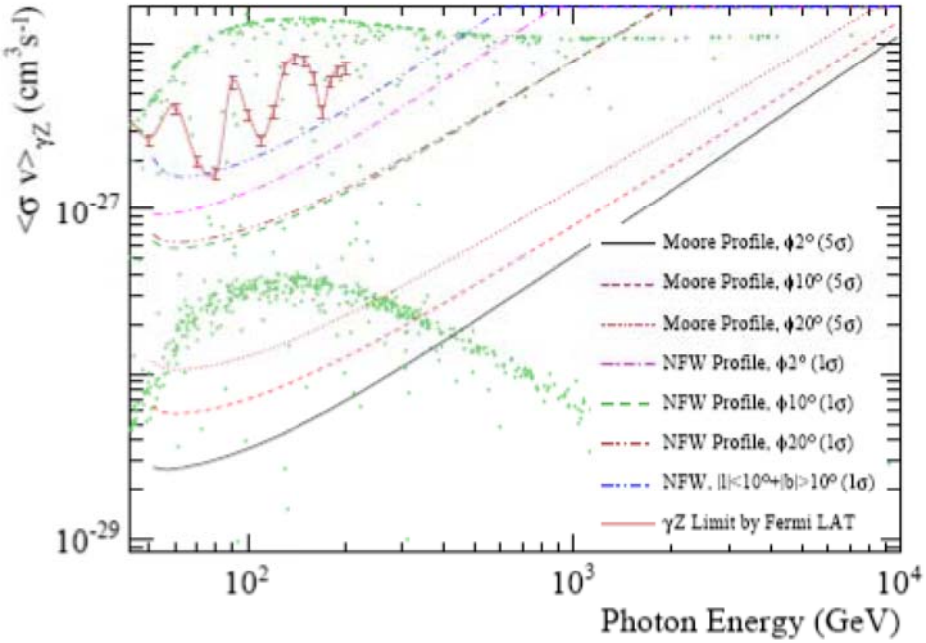
Line search





- A proposed detector with better energy resolution to search for DM line (HEGARD: 1%-2%)
- Better capability than Fermi

Tang et al. (2011, ChPhC)

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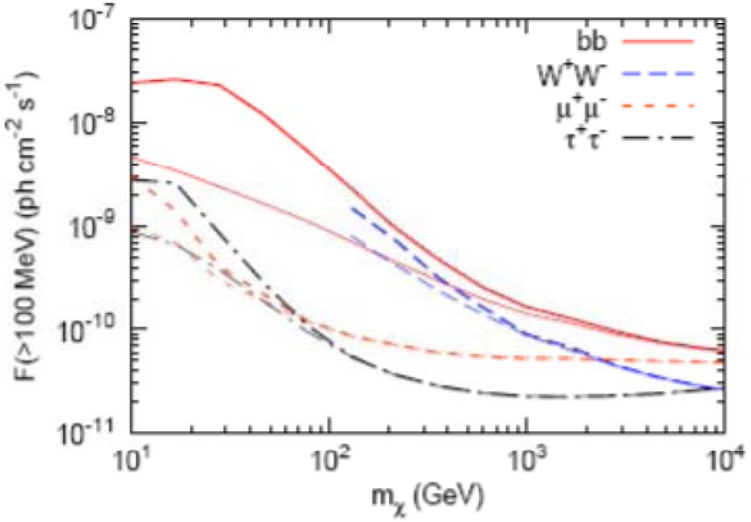
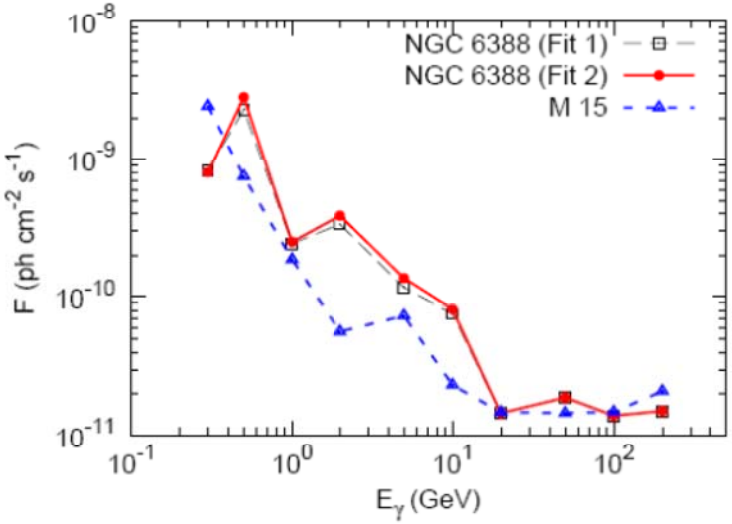
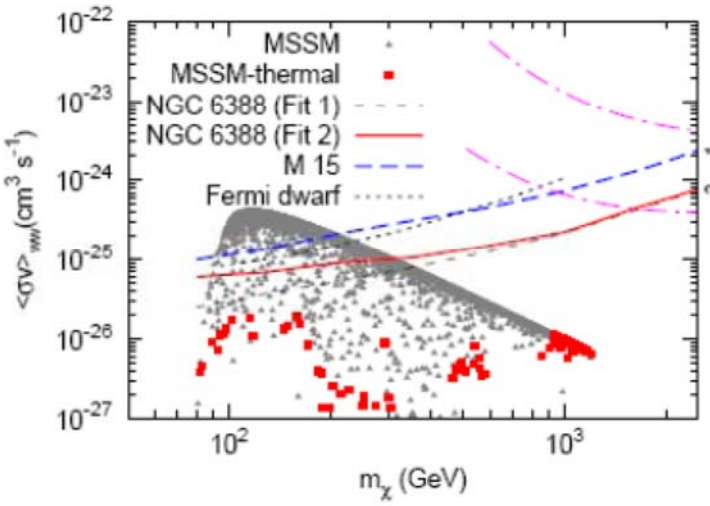
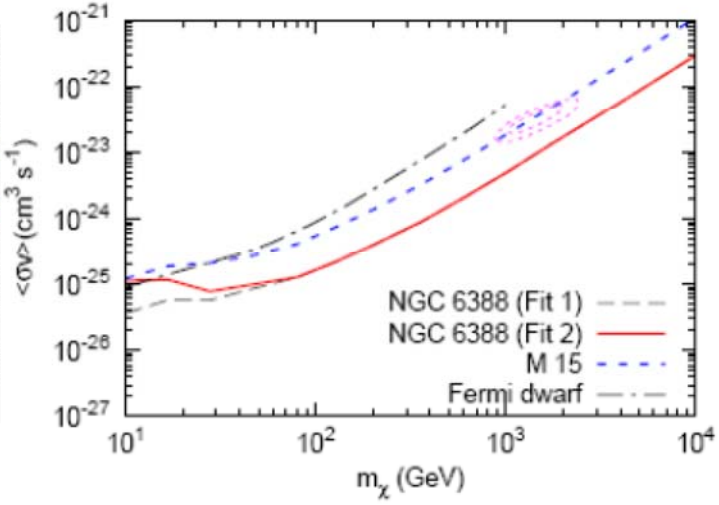
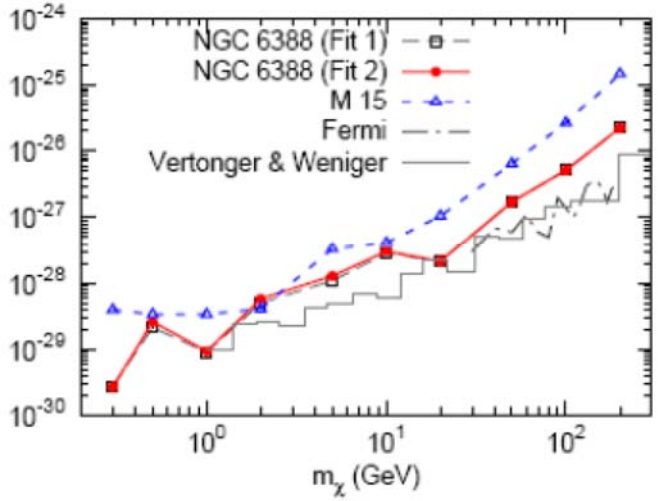
Globular cluster











Feng et al., arXiv:1112.2438

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Summary

- The sensitive Fermi detector is very powerful to probe the possible dark matter signals
- Up to now, no reliable indication of dark matter signal in Fermi data; stringent limits are placed
- Some possible candidate “excesses” are claimed, the DM connection with some of which are discussed, however, more careful studies of the data analysis and source contamination are needed

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