Dark matter searches with Fermi-LAT

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Evidence for dark matter

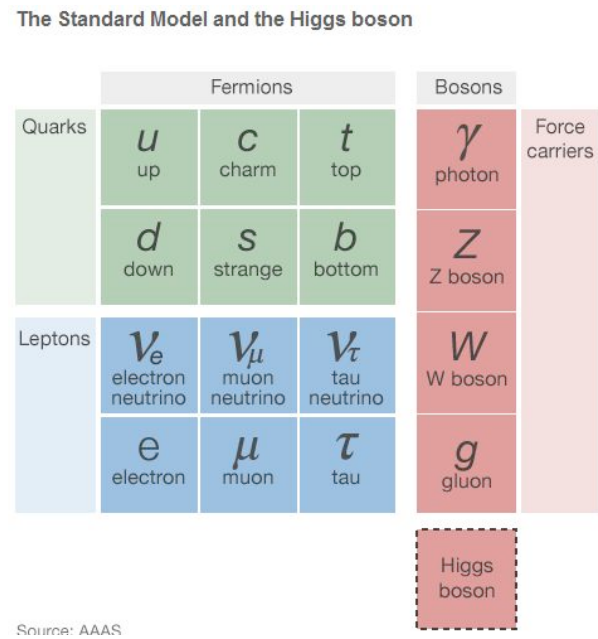
✦ Dark matter not contained within Standard Model of particle physics

✦ Postulate a particle, solve for it's abundance

✦ A particle's annihilation cross section and abundance are related:

$$\langle \sigma_{\rm ann} v \rangle \approx \frac{3\times 10^{-27}\,{\rm cm}^3{\rm s}^{-1}}{\Omega_{\rm DM} h^2} \longrightarrow \langle \sigma_{\rm ann} v \rangle \simeq 3\times 10^{-26}\,{\rm cm}^3\,{\rm s}^{-1}$$

"Thermal relic scale"



✦ Annihilation cross section characteristic of a weakly-interacting particle

✦ Weakly-interacting particles (WIMPs) a leading candidate for dark matter

Methods to detect particle dark matter

1) Indirect detection

- ✦ Standard model particles are produced in pair annihilation
- ✦ Most closely connected to cosmology

2) Direct detection

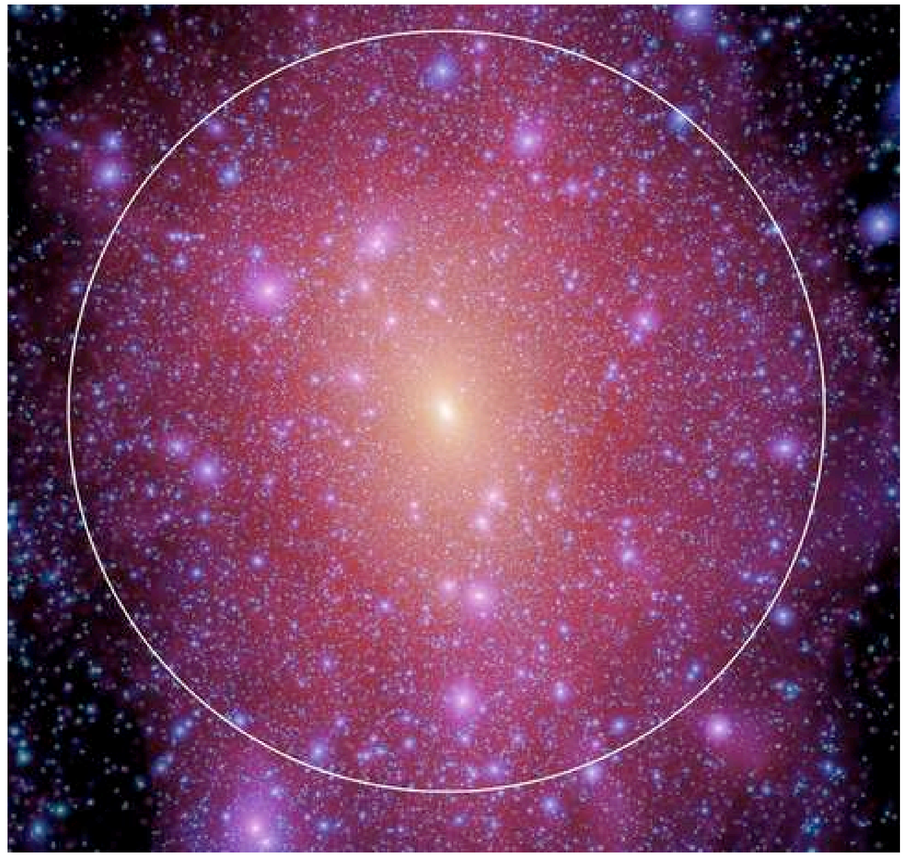
- ✦ Dark matter scatters off nucleons in underground detectors

3) Direct Production

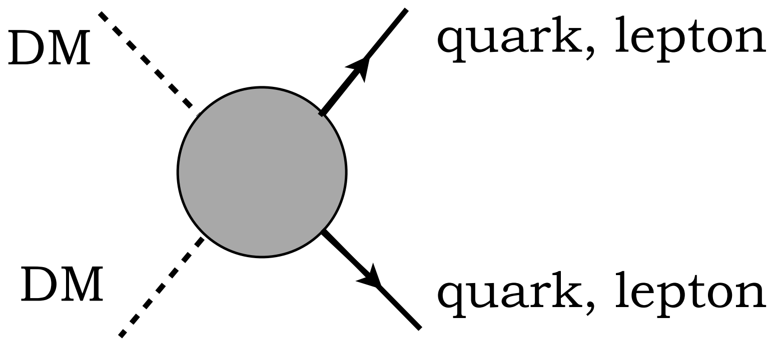
- ✦ Dark Matter produced in colliders during proton collisions

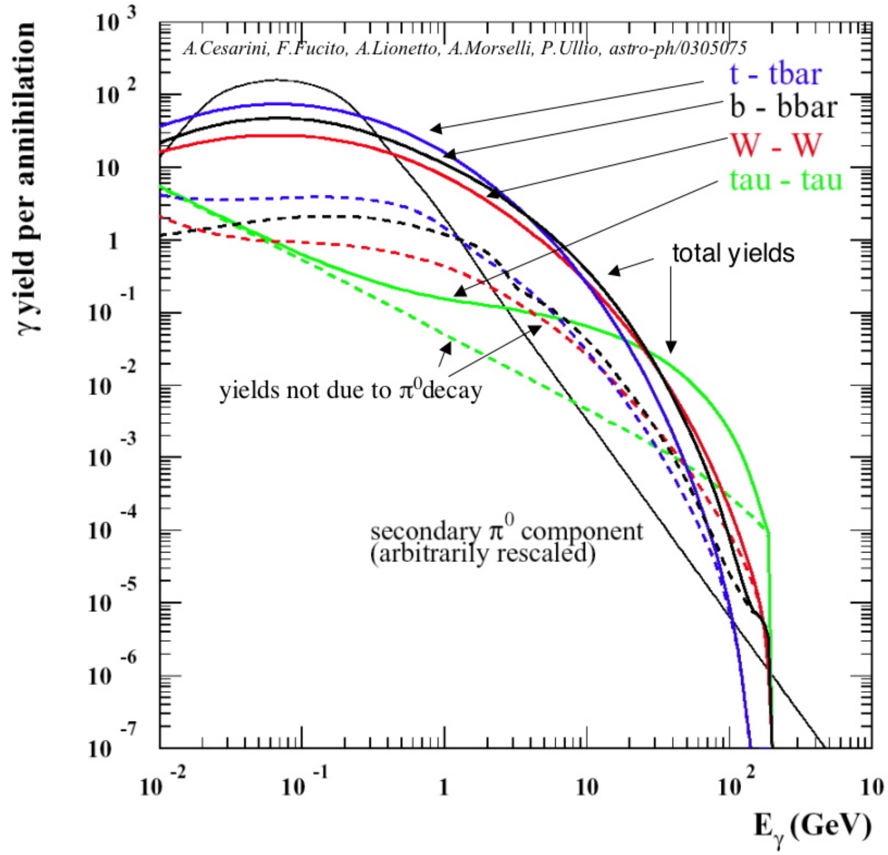
4) Astronomical methods

- ✦ Sensitive to self-interaction rate of dark matter, and its velocity at production



Indirect dark matter detection





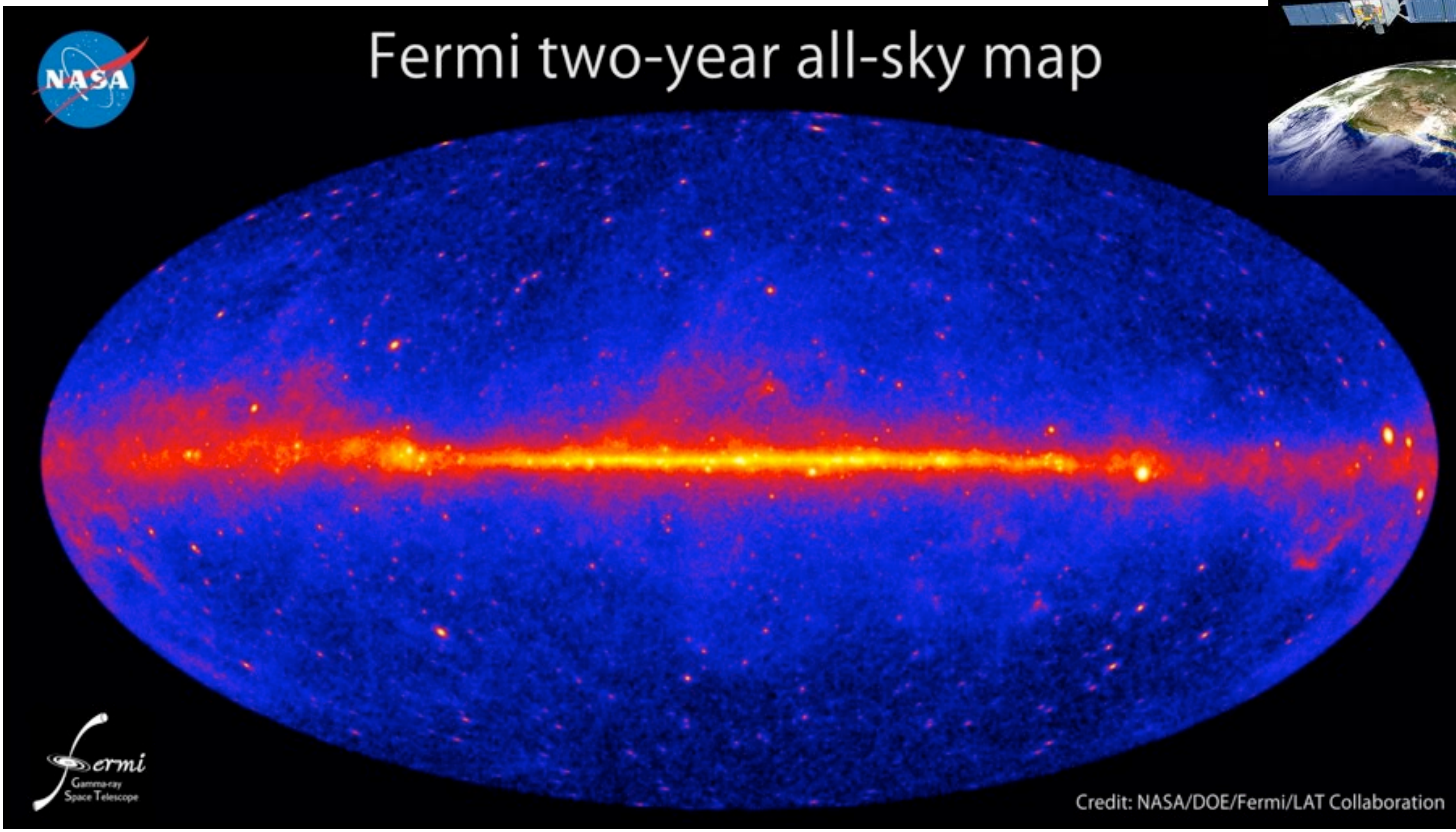
- Continuum gamma-ray spectra

- Tens to hundreds of photons produced per WIMP annihilation

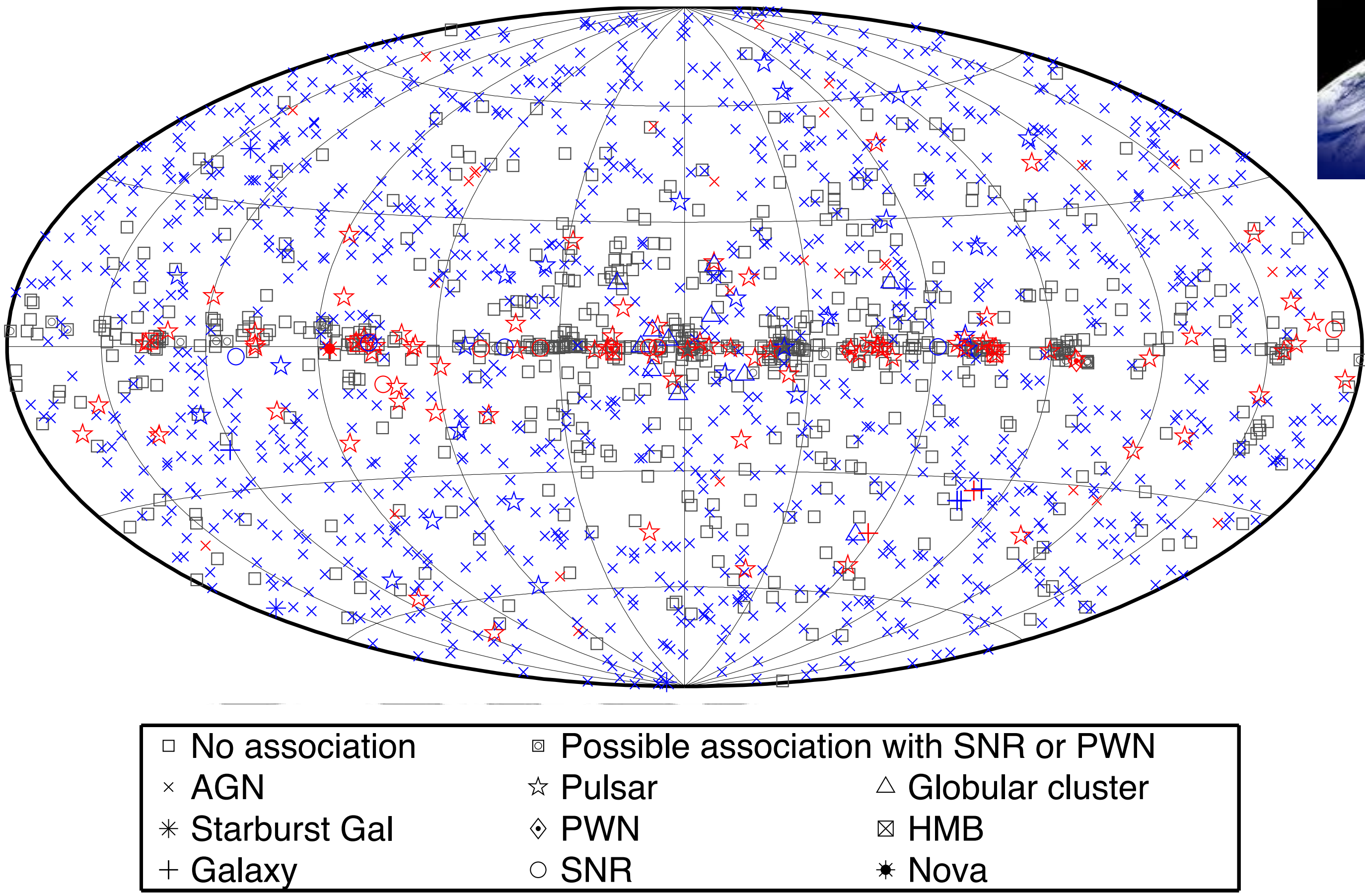
- 100 GeV mass WIMPs gives photons in the gamma-ray band, ~ 10 MeV - 10 GeV

- Gamma-ray line (Bern, Gondolo, Perelstein 1997; Ullio & Bergstrom 1998)

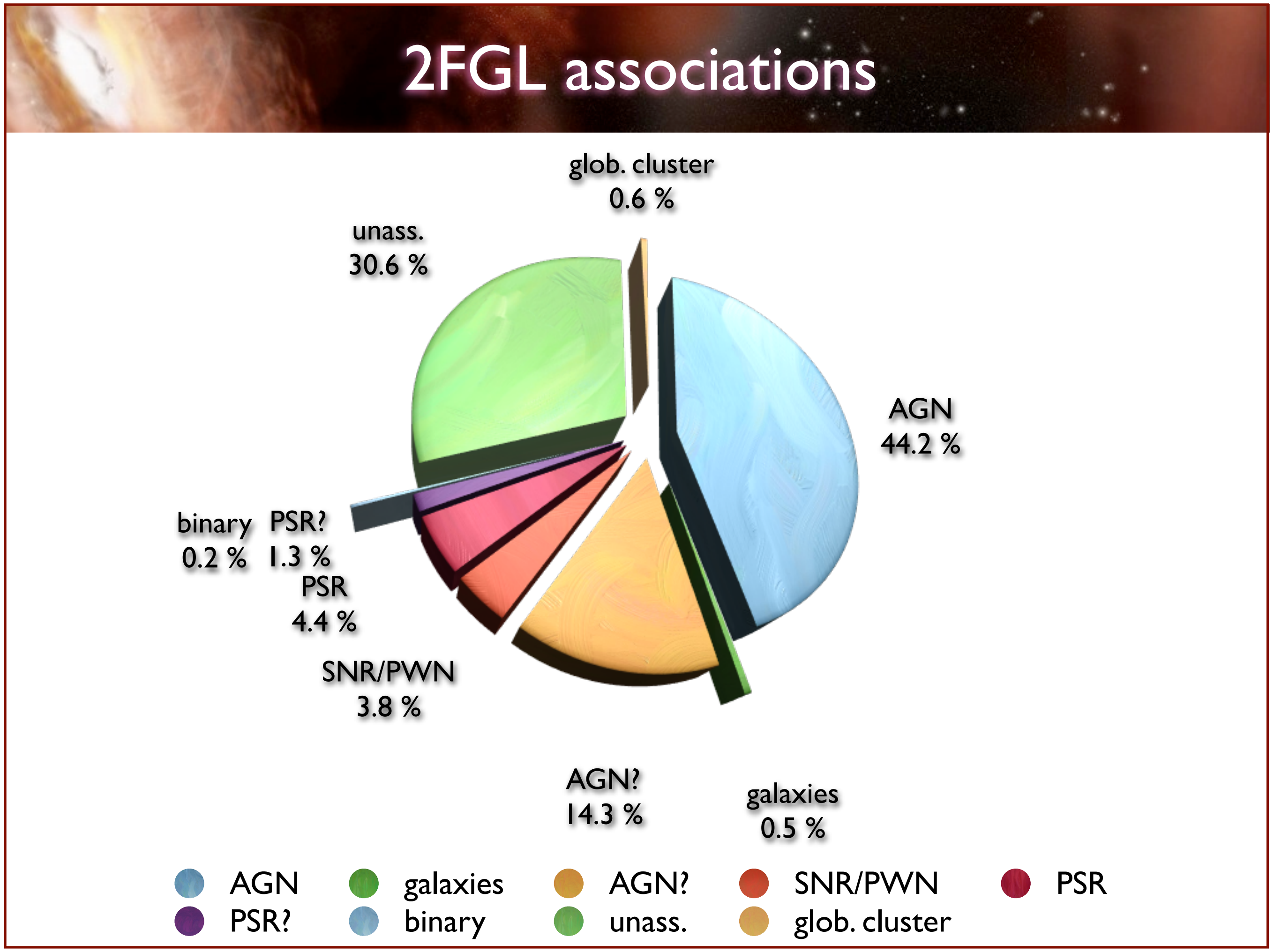
Fermi gamma-ray space telescope



Fermi-LAT two year source catalog



Fermi gamma-ray space telescope



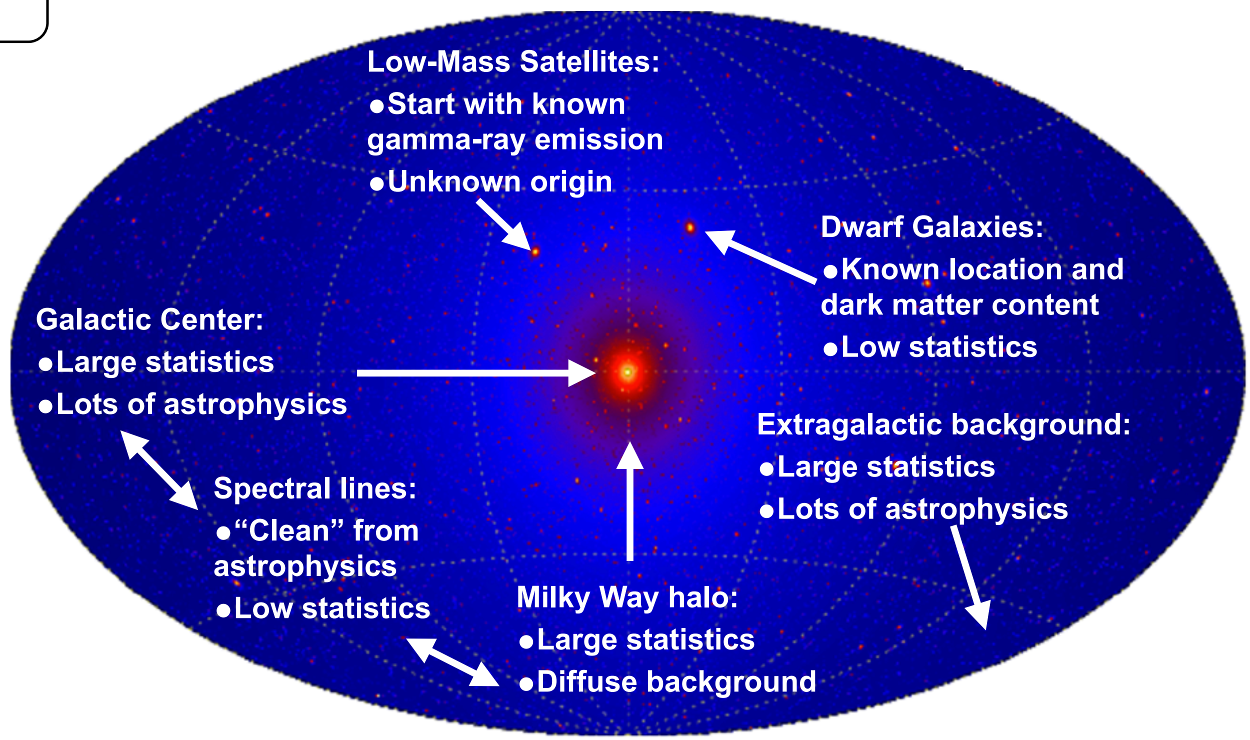
Fermi-LAT Collaboration 1108.1435

Fermi All-sky search strategies

Particle Dark Matter detectable from all astrophysical sources!

- **<u>Galactic center</u>**
- **<u>Satellite galaxies</u>** (also talk by S. Koushiappas)
- **<u>Galaxy clusters</u>**
- **<u>Diffuse sources</u>** (also talks by S. Campbell & J. Siegal-Gaskins)

Dark matter/gamma-ray map

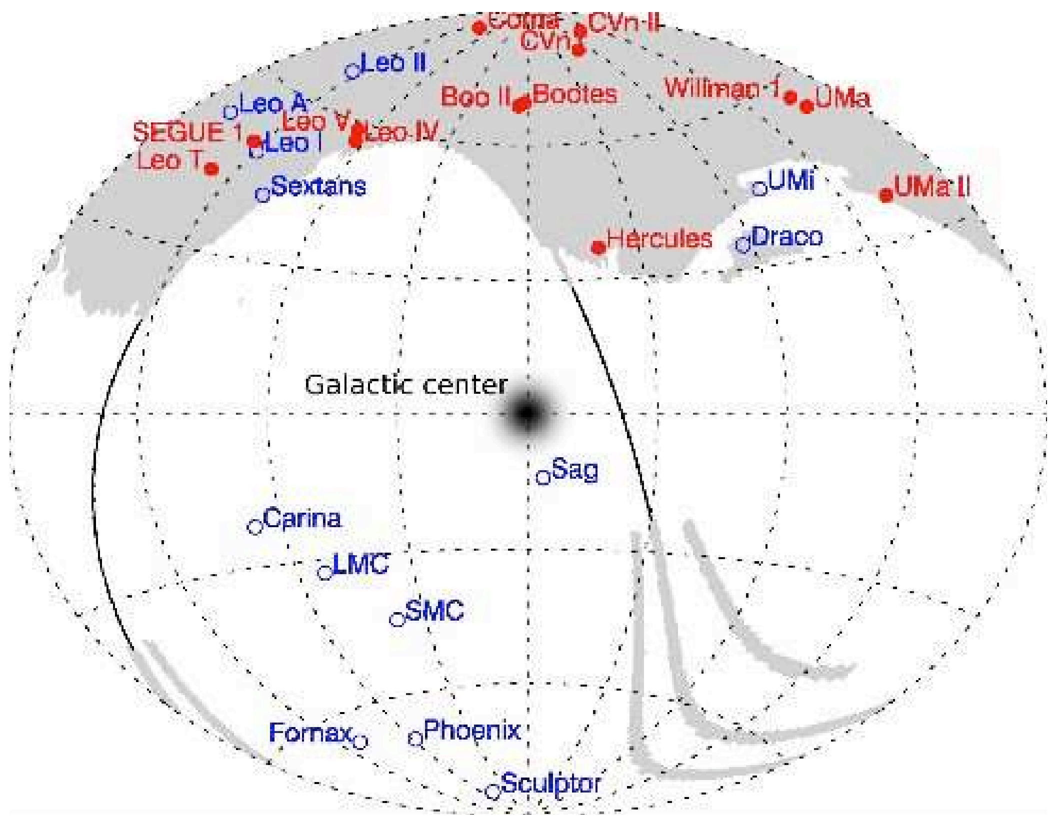


dwarf spheroidals (dSphs)

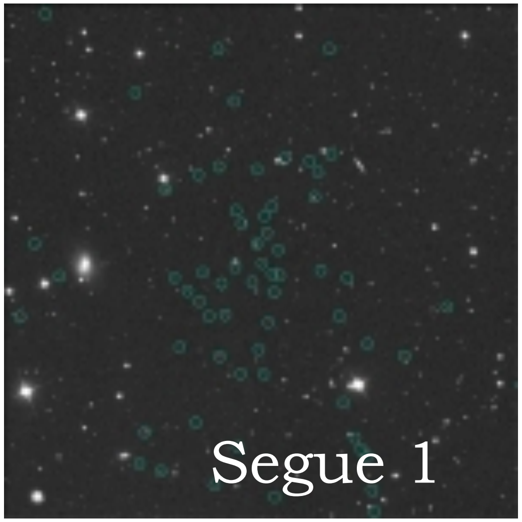
Milky Way satellite galaxies (dwarf spheroidals)

Properties

- Interesting astrophysical systems!
- Dark matter masses from motions of individual stars
- Most dark matter-dominated galaxies known
- Luminosities from hundreds to millions Solar luminosities
- No high energy gamma-rays from astrophysical sources

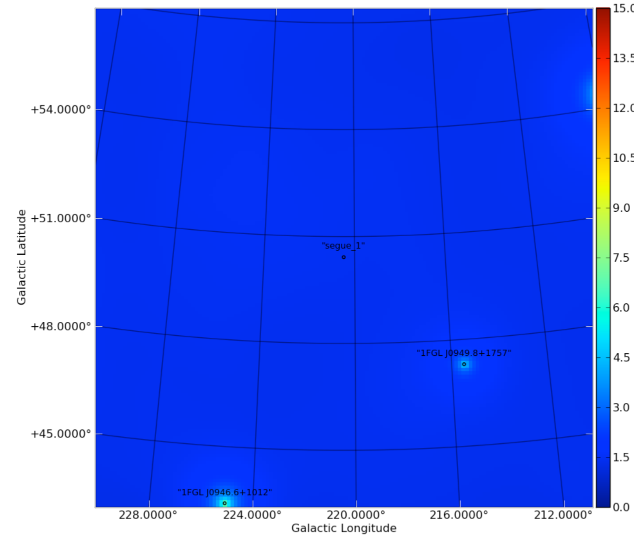


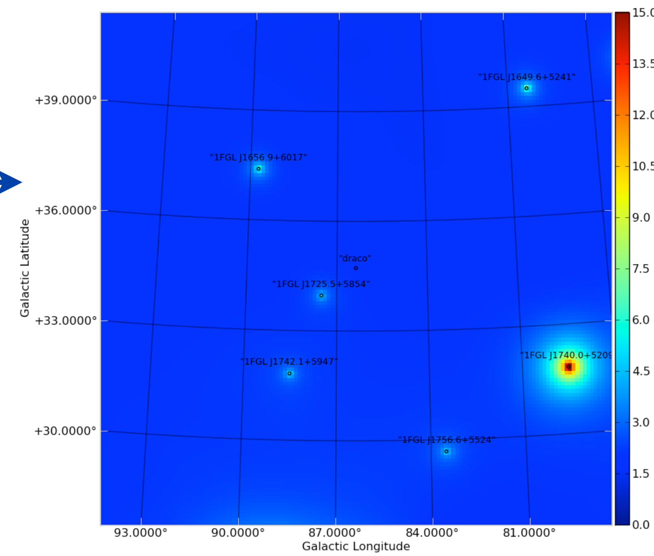
Satellite galaxies in visible light and gamma-rays



Visible Light

Gamma-rays



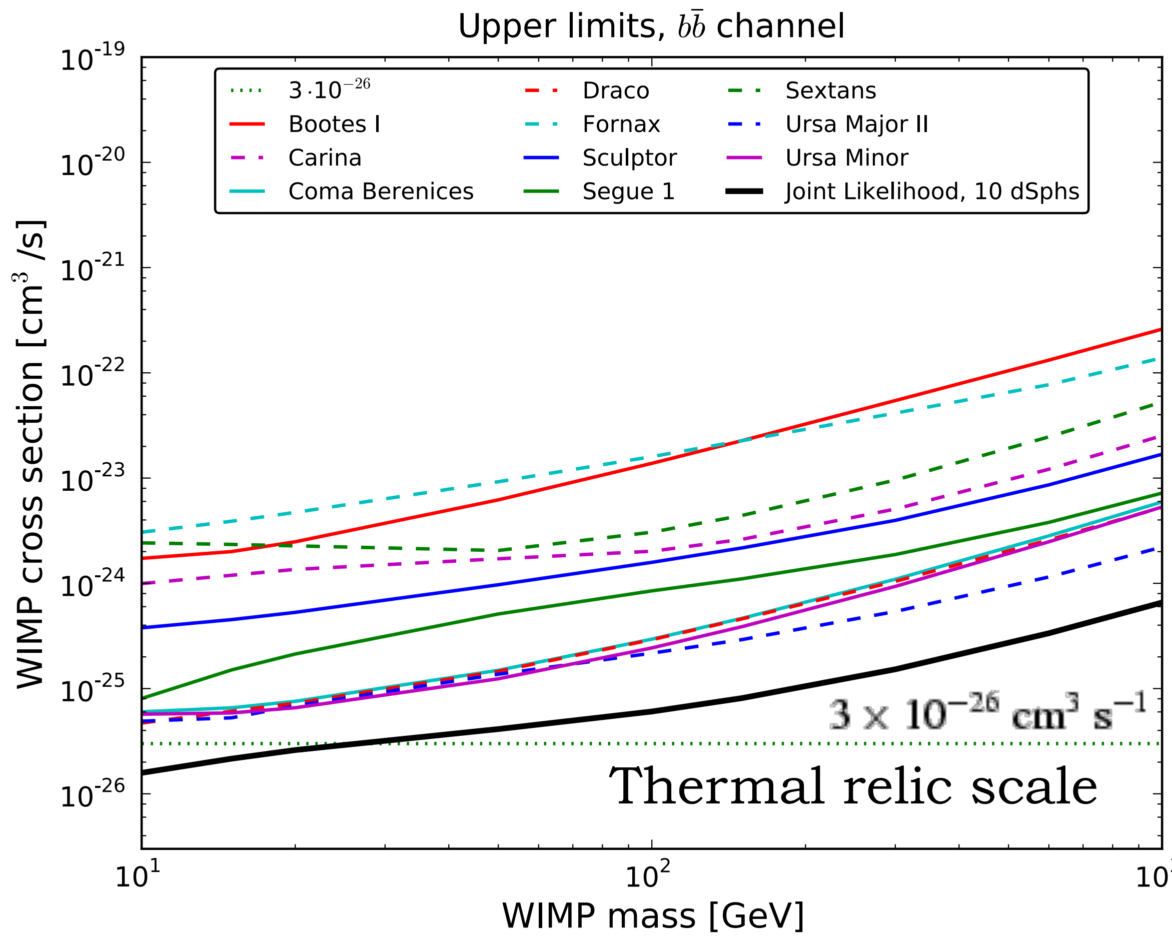


Dark matter bounds from Fermi-LAT

- Determine the total mass of dark matter from velocities of stars in each satellite [Strigari et al., PRD 2007, APJ 2008; Strigari, Phys. Reports 2013]

- Combine measured gamma-ray flux upper bound with total dark matter mass in each satellite to get upper bound on annihilation cross section

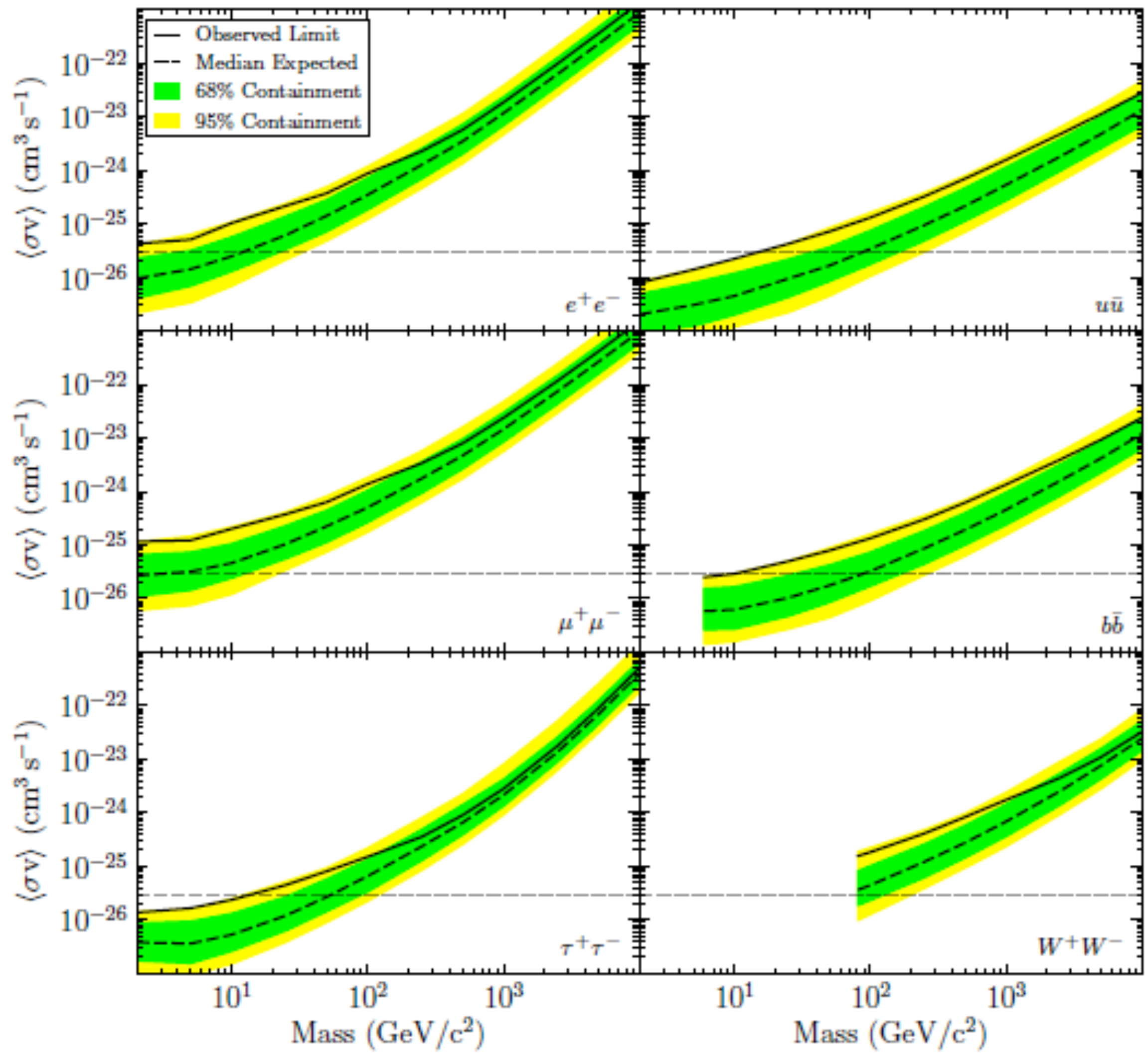
- See also Geringer-Sameth & Koushiappas PRL 2011; Next talk by S. Koushiappas, limits from ACTs at higher WIMP masses



Dark matter bounds from Fermi-LAT: New results

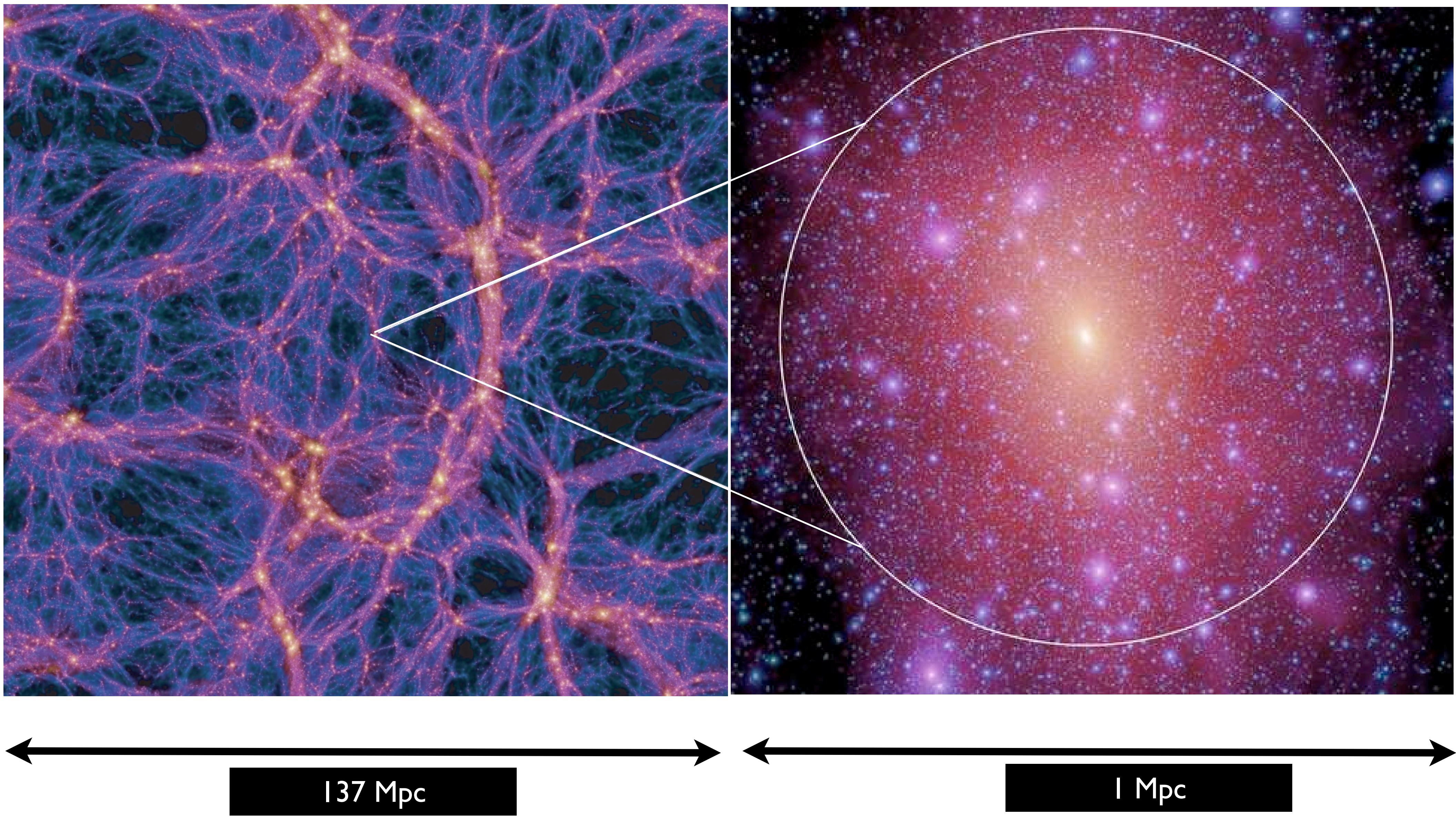
- ✦ Determine the total mass of dark matter from velocities of stars in each satellite [Strigari et al., PRD 2007, APJ 2008; Strigari, Phys. Reports 2013]

- ✦ Combine measured gamma-ray flux upper bound with total dark matter mass in each satellite to get upper bound on annihilation cross section



Fermi-LAT collaboration
arXiv:1310.0828 (PRD 2014)

Dark matter subhalos



Springel et al. 2008

Search for dark subhalos

- Search for subhalos that only shine because of dark matter annihilation
- Some satellite may be within 1 kpc of the Sun, and their extension may be resolvable by the LAT

- Search criteria:

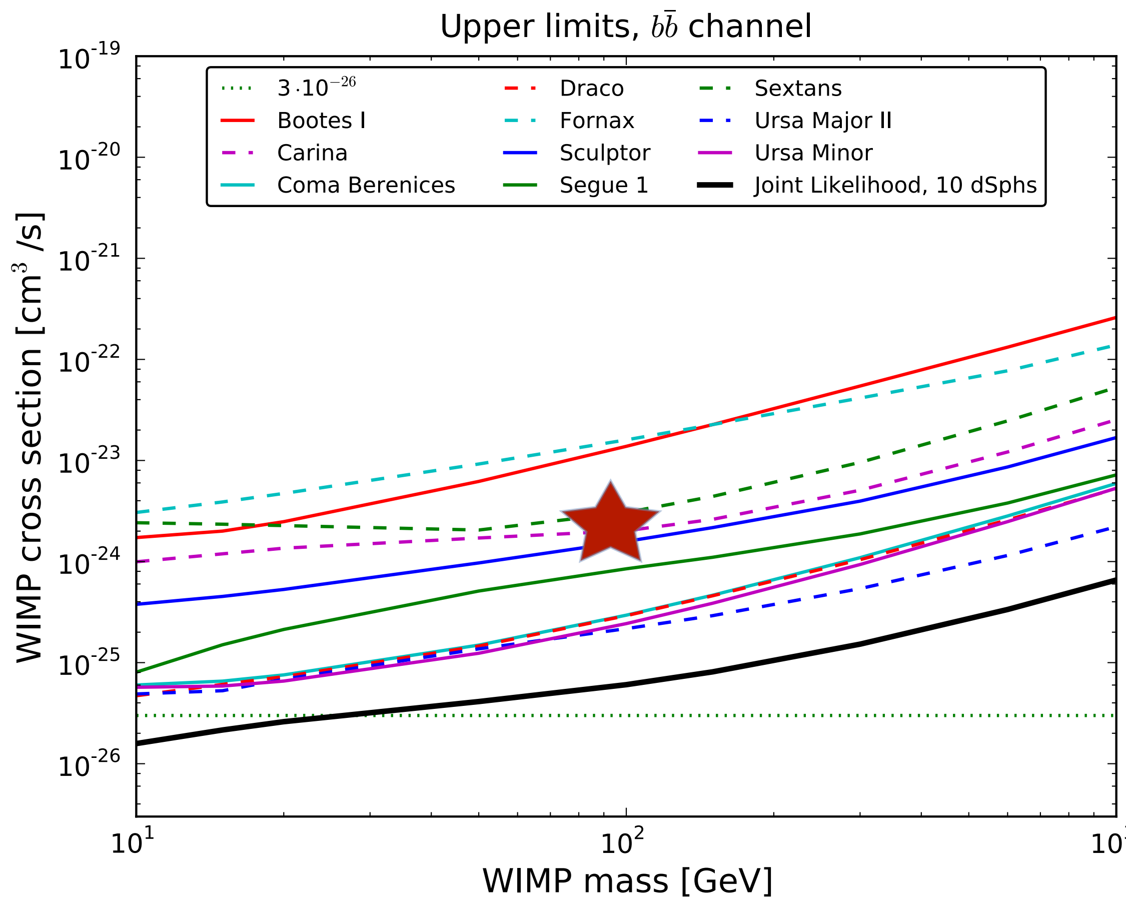
  1) Source > 20 degrees from Galactic plane
  2) No counterpart at other wavelengths
  3) Emission constant in time
  4) Spatially extended sources: ~ 1 degree radial extension

Search for dark subhalos

- Fermi LAT Results from ApJ 747 (2012) 121: No candidate subhalos in 1 year of data

- Membership classifications (Mirabal et al. MNRAS 2012): Majority of high latitude sources are AGN or pulsars

- Many subhalos match spectrum for DM annihilation into tau leptons (Buckley and Hooper PRD 2011)



Galaxy clusters

Galaxy clusters

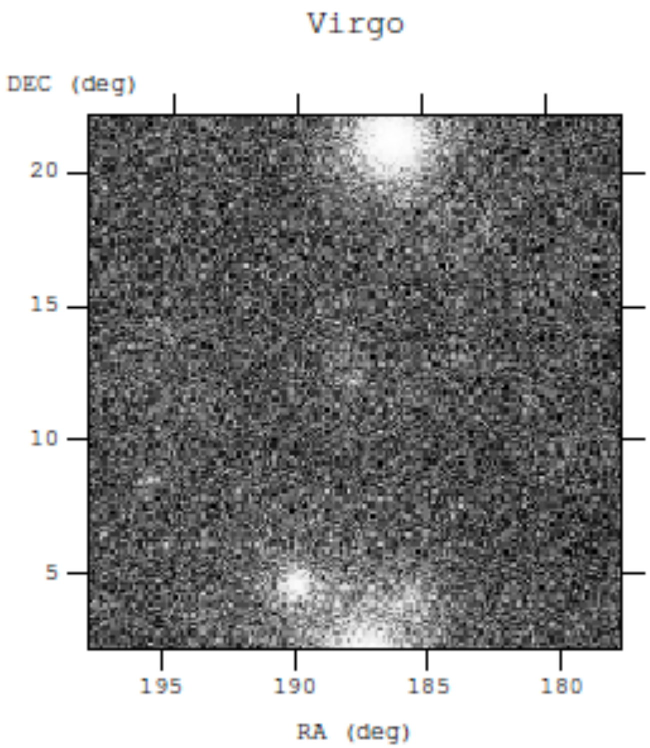
- Masses of galaxy clusters determined from temperature profile of x-ray spectra, and electron gas density profile from the X-ray luminosity

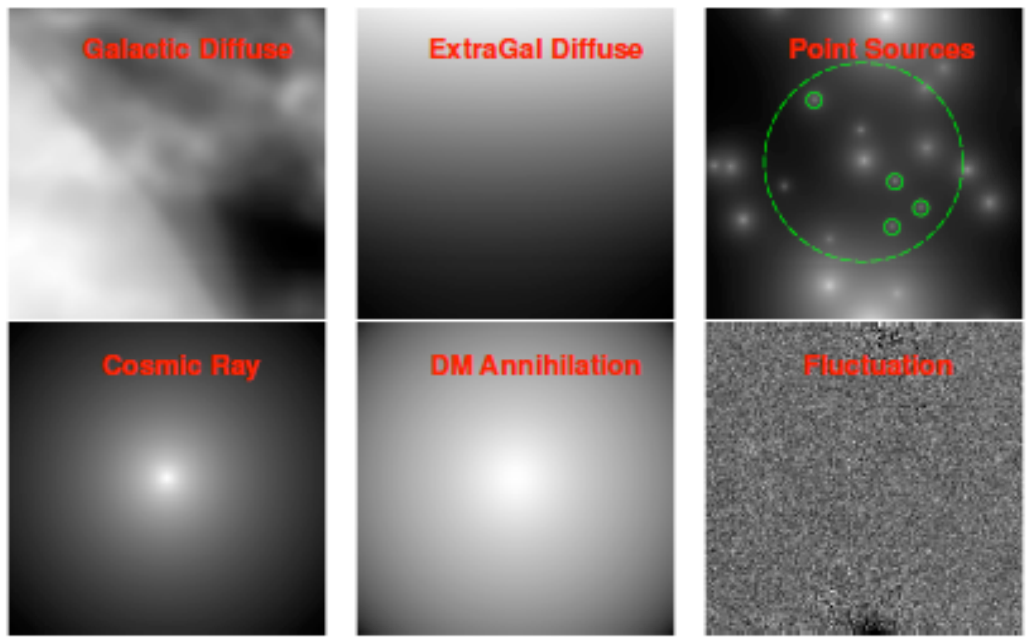
- Assumption of hydrostatic equilibrium gives the mass within a fixed physics radius, M(r)

- Nearby clusters Fornax, Coma, and Virgo are some of the most interesting sources (Pinzke et al PRD 2011; Ando & Komatsu JCAP 2012)

- Significant contribution to the flux expected from substructure in the clusters (e.g. Gao et al. MNRAS 2012)

Galaxy clusters





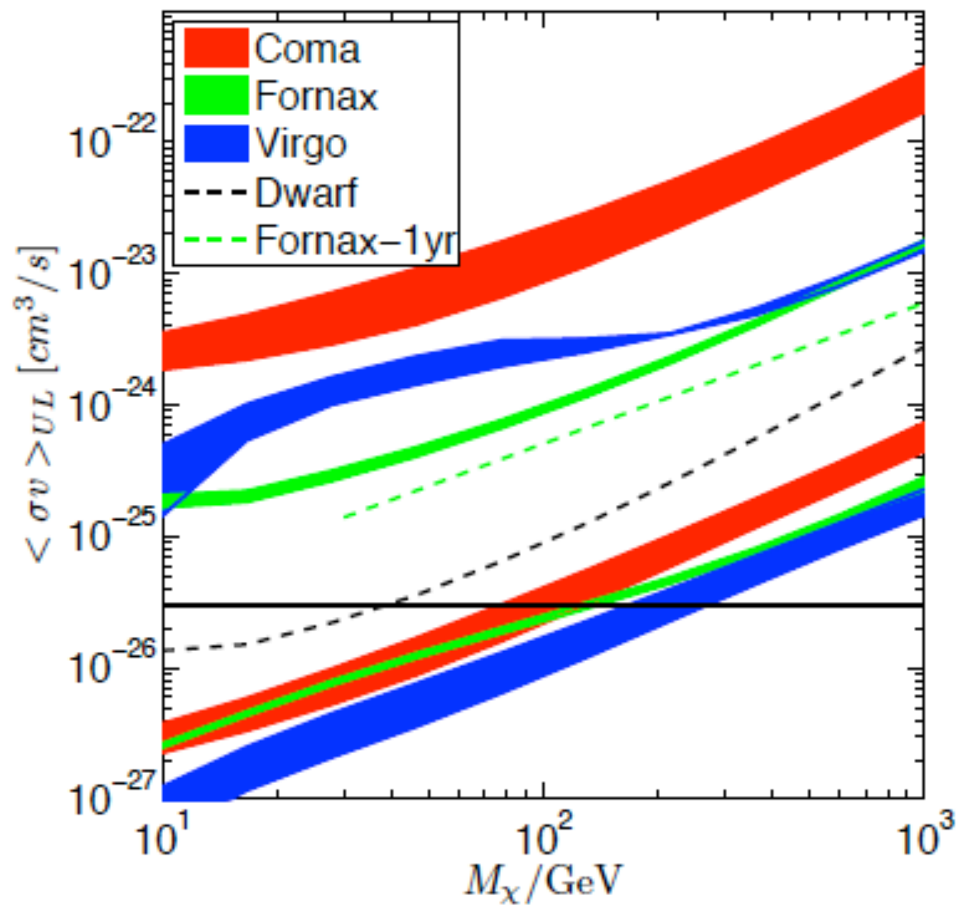
Han et al. MNRAS 427 2012

Galaxy clusters

No detection of any galaxy clusters by Fermi-LAT yet (Ackerman et al. JCAP 2012)

Limits on annihilation cross section strongly depend on assumption for cluster substructure (Han et al. MRNAS 2012, Ando & Nagai JCAP 2012)

HESS bounds from Fornax cluster above 1 TeV (Abramowski et al. ApJ 2012)



Han et al. MNRAS 427 2012

Galactic center

Galactic center (GC)

- Significant uncertainty in dark matter mass profile in Galactic center (bulge, nuclear star cluster dominate dynamics)

- Several Fermi-LAT point sources within 1 sq. deg. of Galactic center

- At higher energies: HESS and MAGIC source coincident with Sgr A* (HESS 1745-290)

- HESS diffuse emission correlated with Giant Molecular Clouds

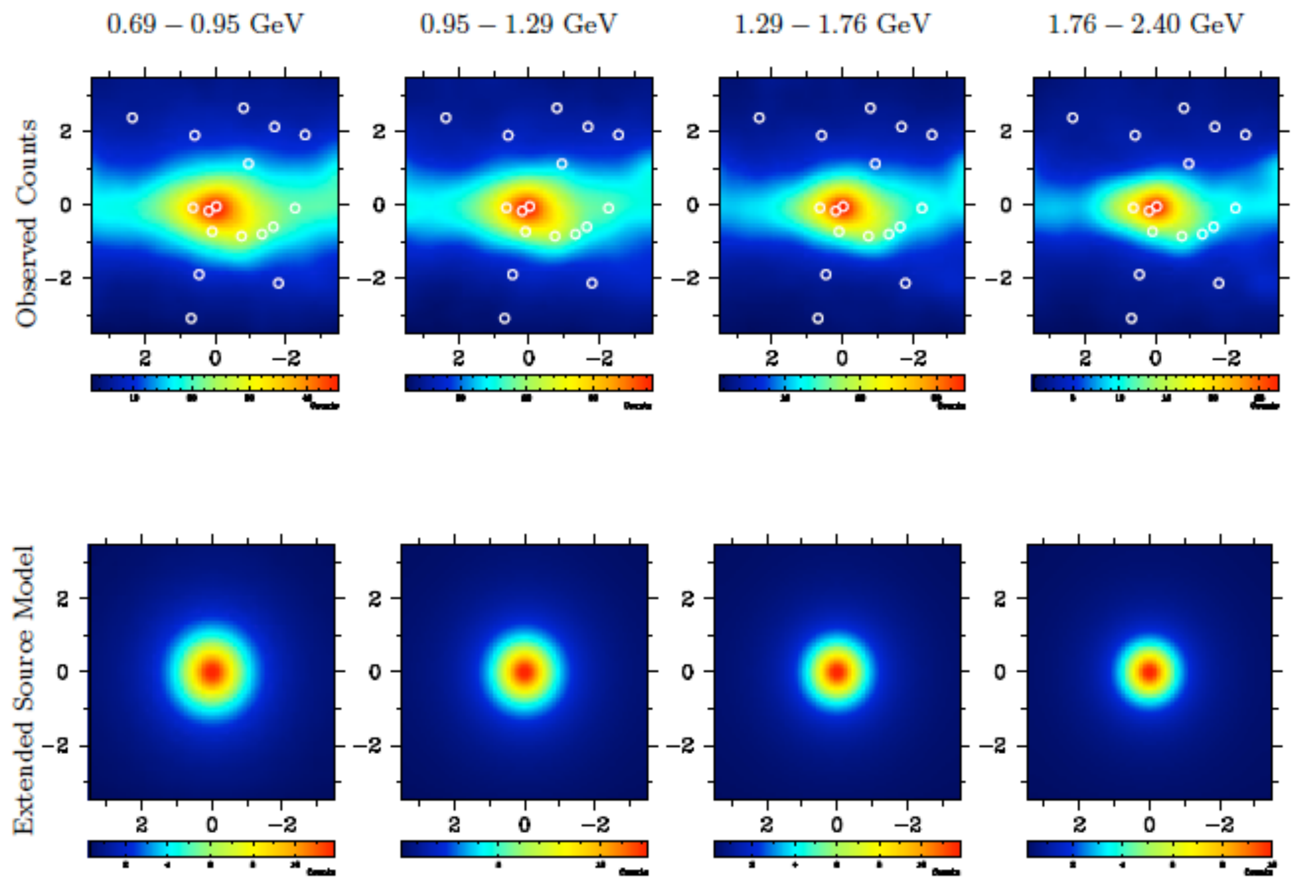
Galactic center (GC)

- Characterization of diffuse emission near GC challenging because of points sources (e.g. Boyarsky et al. PLB 2011)

- > 1 sq. deg. diffuse Fermi-LAT emission attributed to:

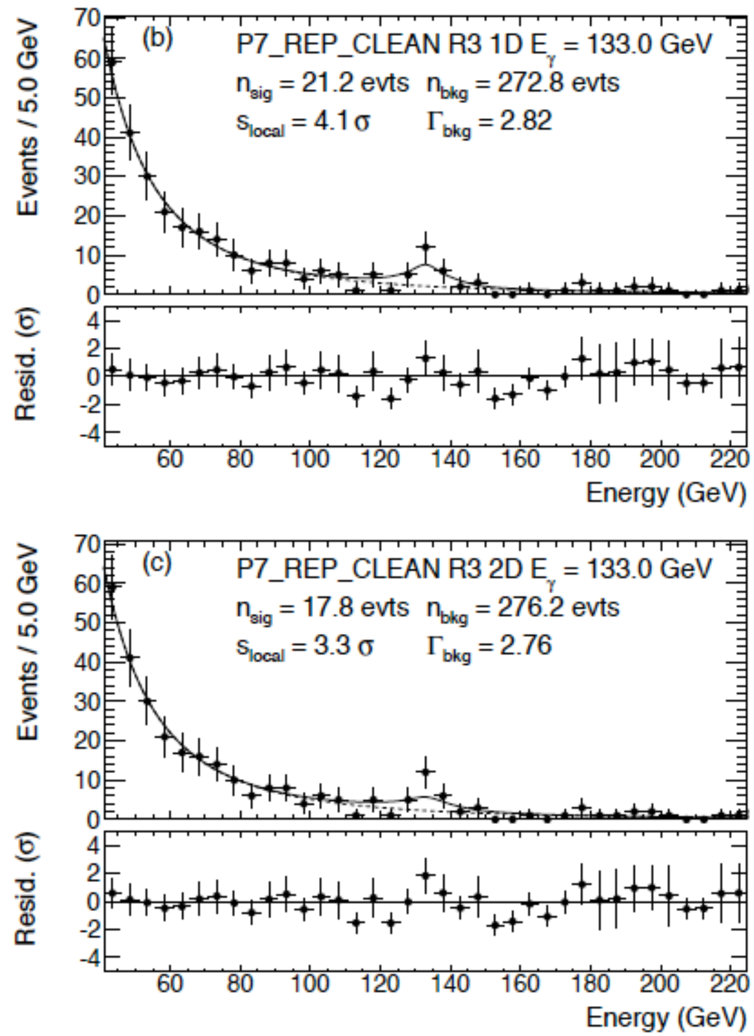
  - Cosmic rays from supermassive black hole in GC (Chernyakova et al. 2011 ApJ 2011) or cosmic rays + DM annihilation (Hooper & Linden PRD 2011)

  - Possible evidence for unresolved pulsars, diffuse emission from cosmic ray interactions, or a DM annihilation (Abazajian & Kaplinghat PRD 2012)



Galactic center line

- Weniger JCAP 2012 identified a line-like feature ~ 130 GeV in global Fermi-LAT data at ~ 2-5sigma (also Su & Finkbeiner 2012)
- However, Finkbeiner et al. 2012 also identify similar feature at > 3sigma in the ``Earth limb"
- Whiteson 2013 find 3sigma evidence of line feature in 5 sq deg circle around Sun
- Systematic or DM annihilation signal?
- Recent Fermi-LAT results of no significant excess: arXiv:1305.5597
- See Weniger et al. arXiv:1305.4710

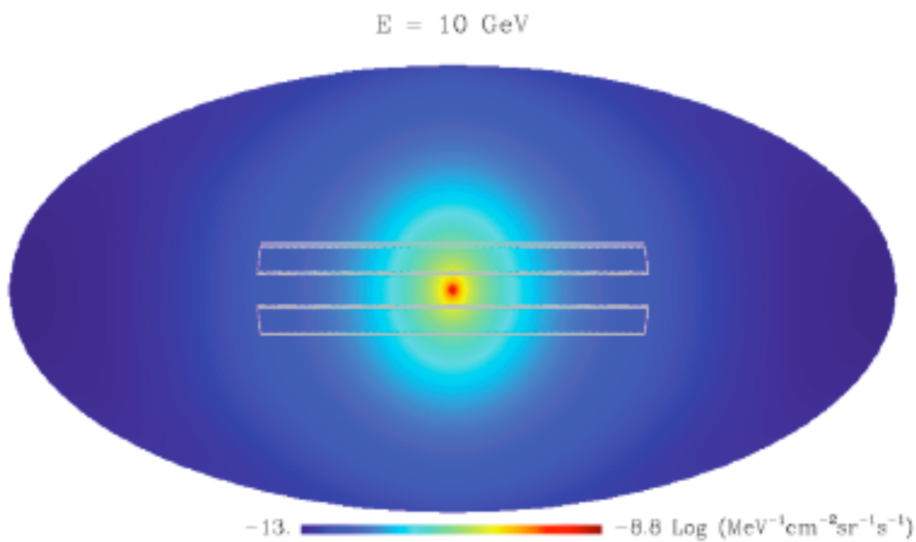


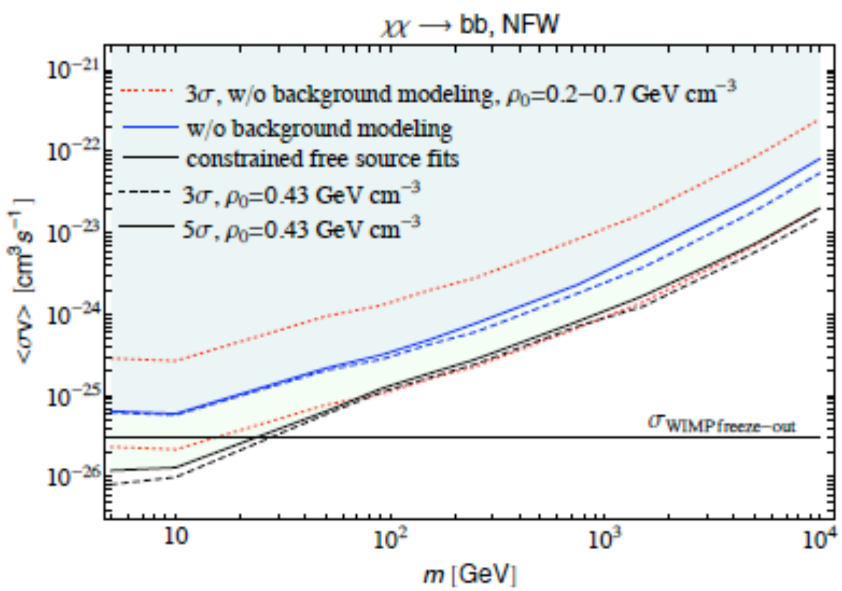
Diffuse backgrounds

Diffuse backgrounds: Galactic

• Residual annihilations throughout the Milky Way halo may produce a detectable DM annihilation signal

• Requires maximizing a 20 parameter model to describe cosmic ray source production and propagation in the Galaxy

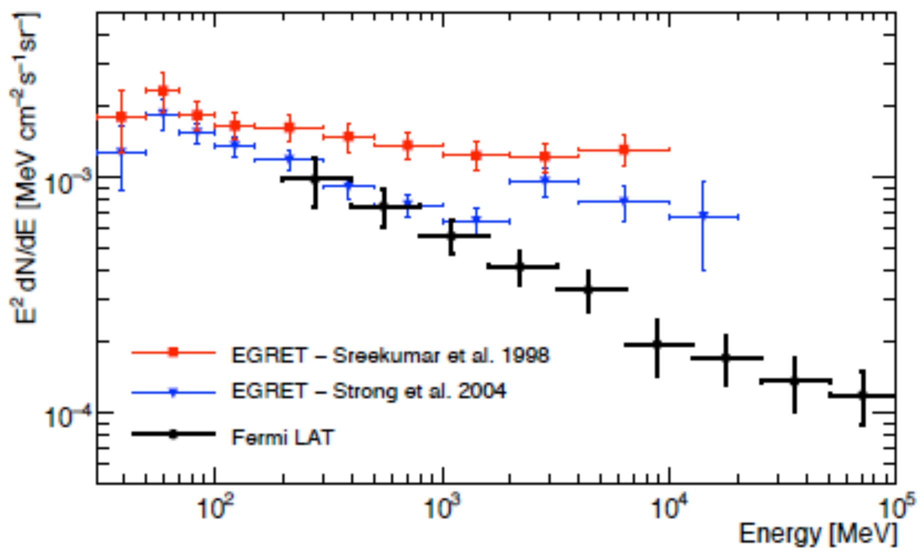




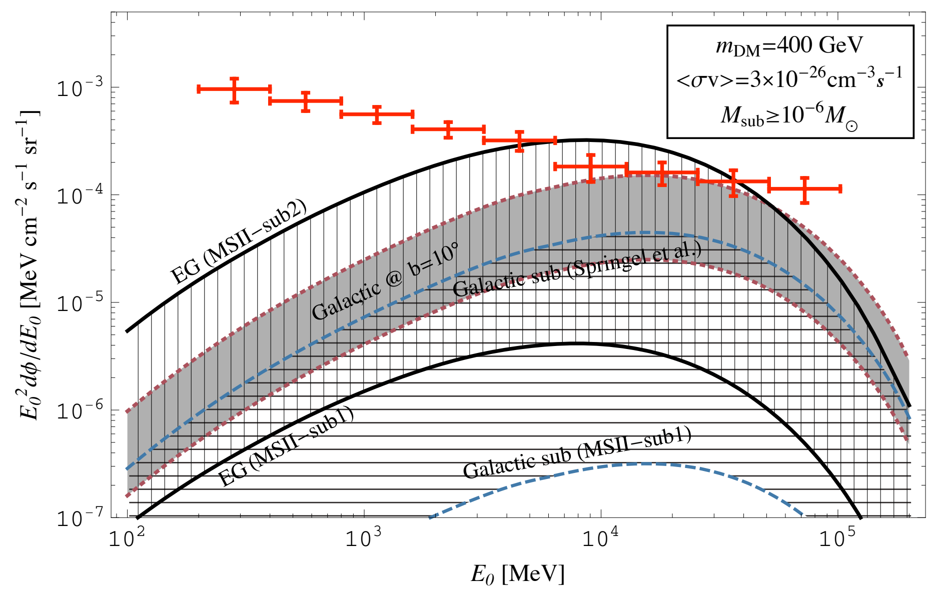
Ackerman et al. ApJ 761 2012

Diffuse backgrounds: Extragalactic

- Systematic uncertainties from dark matter distributions and substructure
- Possible to rule out DM interpretation of the Fermi electron spectrum and Pamela data



Abdo et al. PRL 104 2010



Abdo et al. JCAP 1004 2010

Summary of dark matter limits

Source	10 GeV		100 GeV		
	$b\bar{b}$	$\tau\bar{\tau}$	$b\bar{b}$	$\tau\bar{\tau}$	W^+W^-
Dwarf spheroidals [a]	1×10^{-26}	1×10^{-26}	7×10^{-26}	1×10^{-25}	1×10^{-25}
Diffuse Galactic halo [b]	1×10^{-26}	2×10^{-26}	1×10^{-25}	1×10^{-25}	–
Diffuse extragalactic [c]	2×10^{-25}	–	1×10^{-24}	–	–
Clusters [d]	1×10^{-25}	6×10^{-24}	1×10^{-25}	3×10^{-23}	1×10^{-23}

Thermal relic scale!

Strigari, Physics Reports 2013

- Interesting interplay with recent ATLAS/CMS results

Signals?

- Some unaccounted from diffuse emission from Galactic center
- Possible gamma-ray line from the Galactic center?

Conclusions

- Just in past few years, gamma ray searches for dark matter making great deal of progress

- Fermi-LAT has delivered very interesting limits, and produced many unexplained phenomena

- Still more years of Fermi-LAT data on the horizon, so expect improvements

- Future is bright at higher energies with CTA, HESS