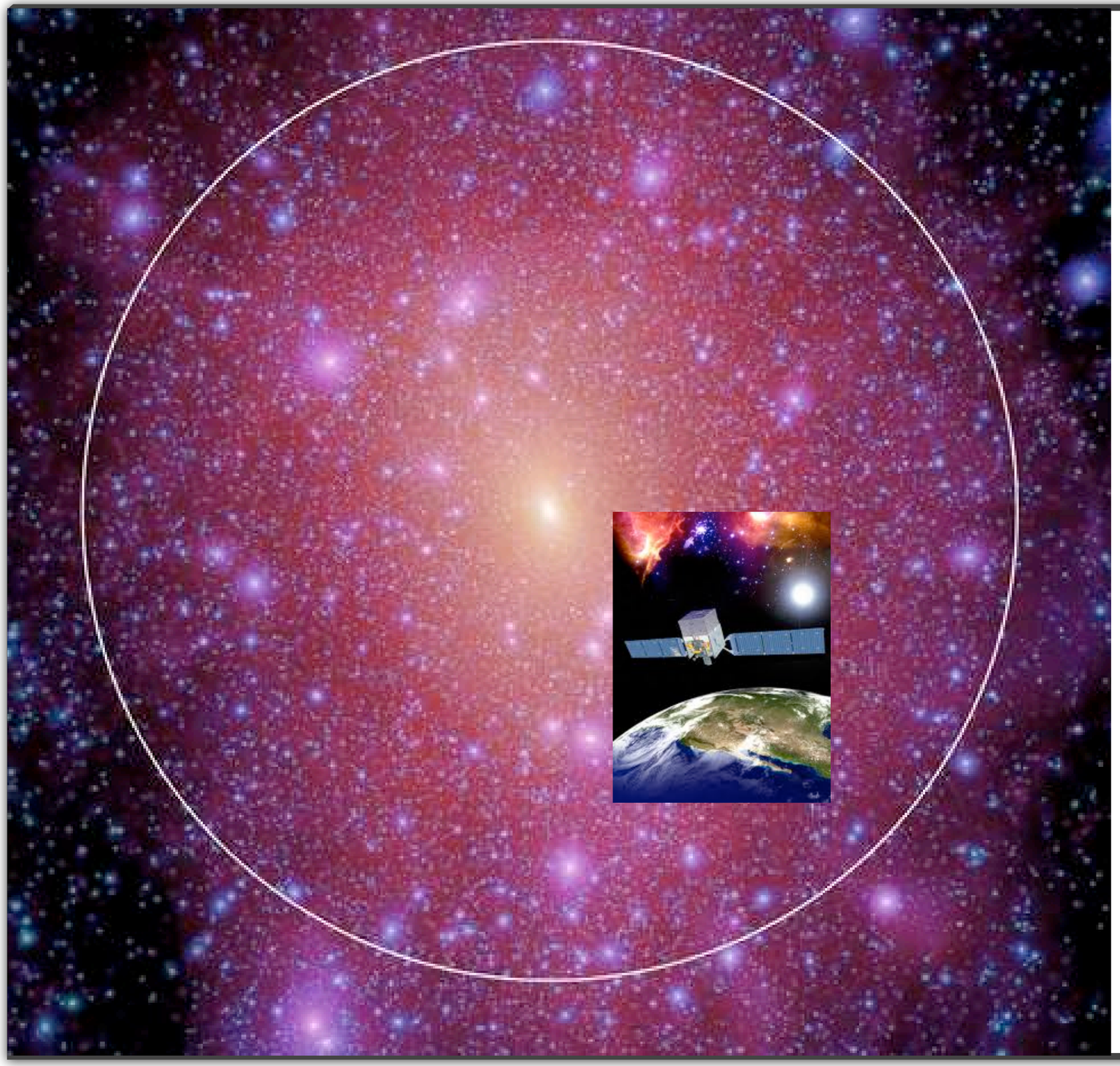
Indirect searches for dark matter



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rencontres de Blois

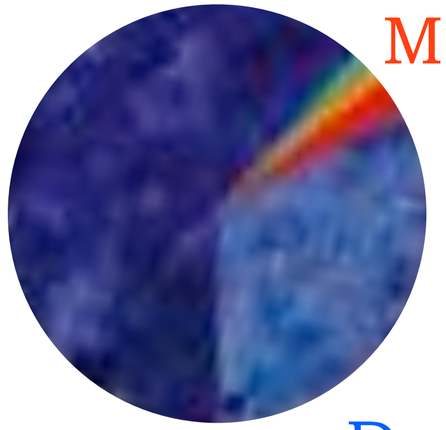
June 5, 2015

Dark matter/Cosmology

- Dark matter not contained within Standard Model of particle physics

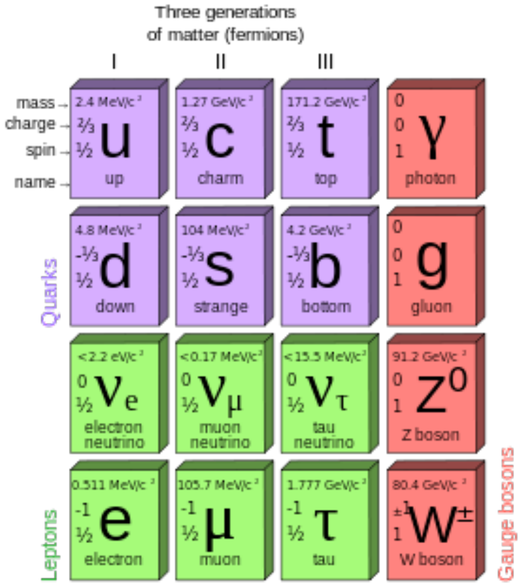
- Postulate a particle, solve for it's abundance

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



Standard Model

Dark Matter



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

"Thermal relic scale"

- Annihilation cross section characteristic of a weakly-interacting particle

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

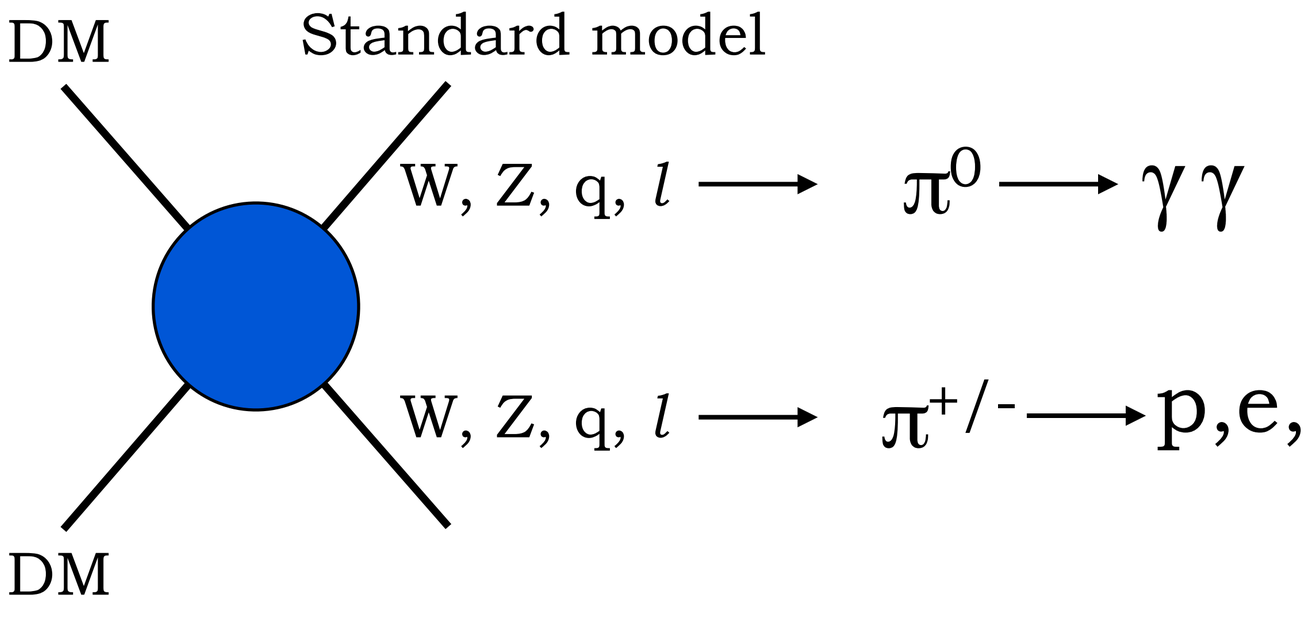
Macro-physics and microphysics of dark matter

$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma}_{\rm particle\ physics} \times \underbrace{\int_{\Delta\Omega}\int_{\rm l.o.s.}\rho^2_{\rm DM}(\boldsymbol{r}){\rm d}l{\rm d}\Omega'}_{\rm J-factor}$$

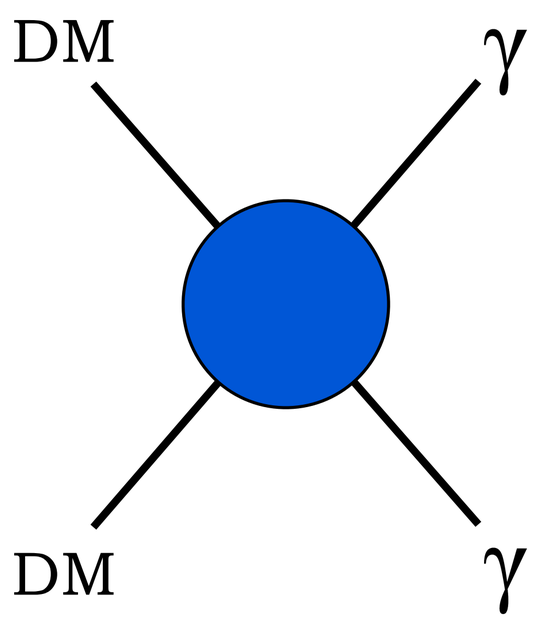
- LCDM N-body simulations predict NFW-like profile $\rho_{\rm DM}(r) = \dfrac{\rho_0 r_s^3}{r(r_s+r)^2}$
- Clumping and substructure predicted from N-body simulations
- Measurements of smooth dark matter distributions from astronomical observations
- Significant debate as to how NFW profile describes observations

Indirect dark matter detection: micro-physics

Continuum



Line



For continuum photon final states:

- Tens to hundreds of photons produced per WIMP annihilation
- 100 GeV mass WIMPs gives photons in the gamma-ray band, 10 MeV-10 GeV

Space and ground-based gamma-ray astronomy

Talk by B. Lott

Fermi gamma-ray space telescope
20 MeV-300 GeV

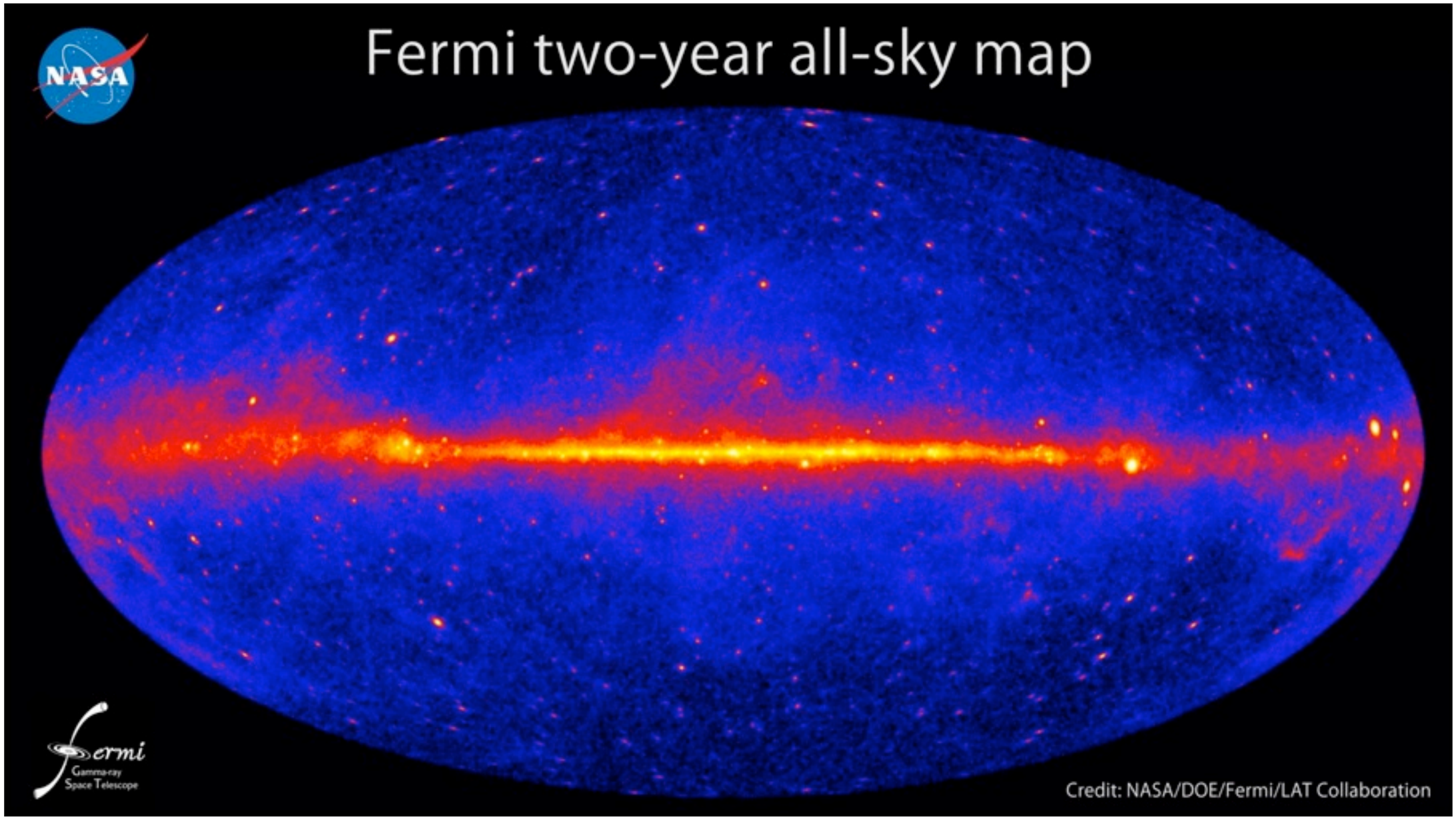
Talk by S. Funk

Talks by F. Brun, G. Maier, S. Einecke

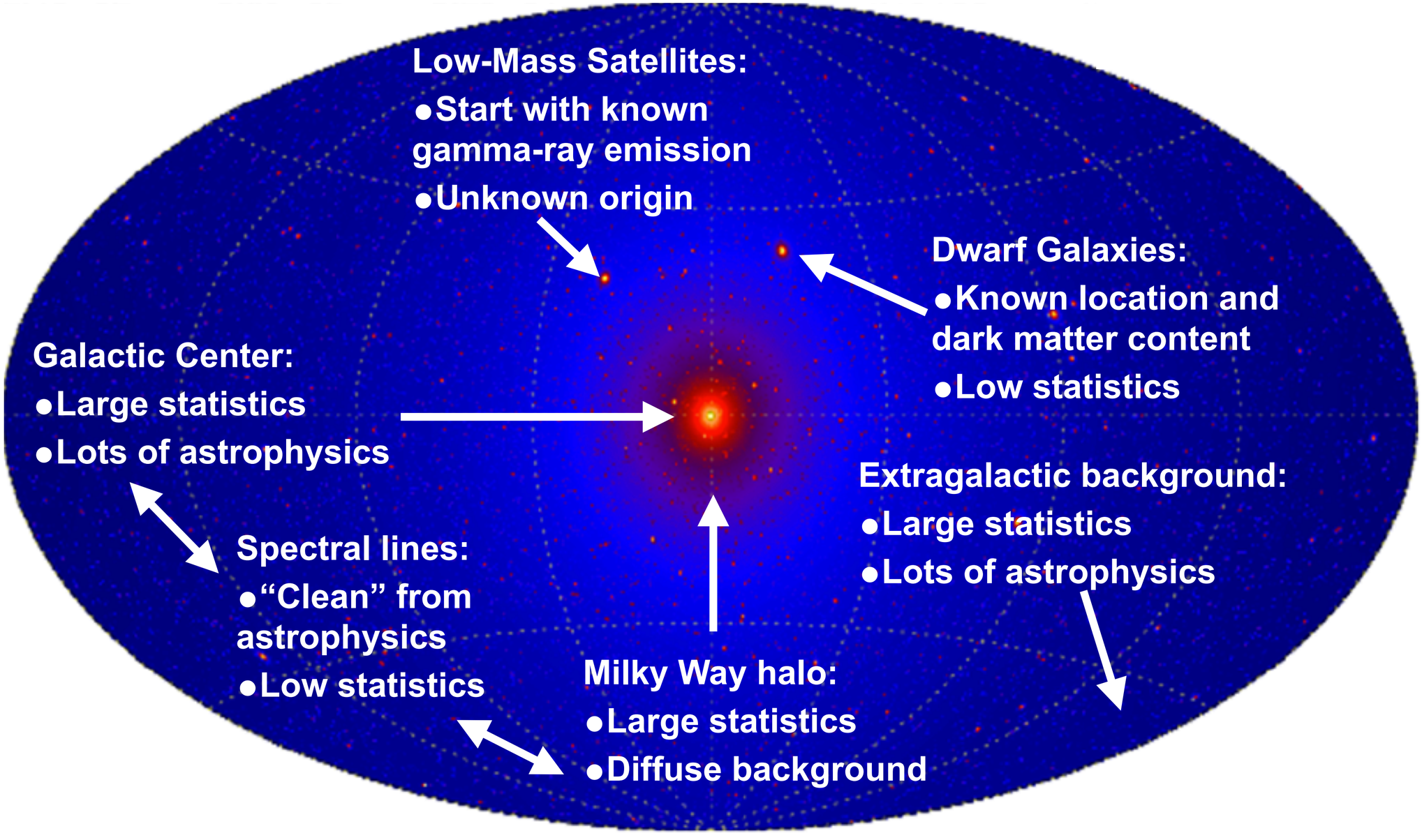
Air Cherenkov telescopes:
H.E.S.S., Magic, Veritas
30 GeV-100 TeV

Water Cherenkov telescopes: Talk by C. Riviere
HAWC
50 GeV-100 TeV

Fermi gamma-ray space telescope



Fermi-LAT all-sky search strategies



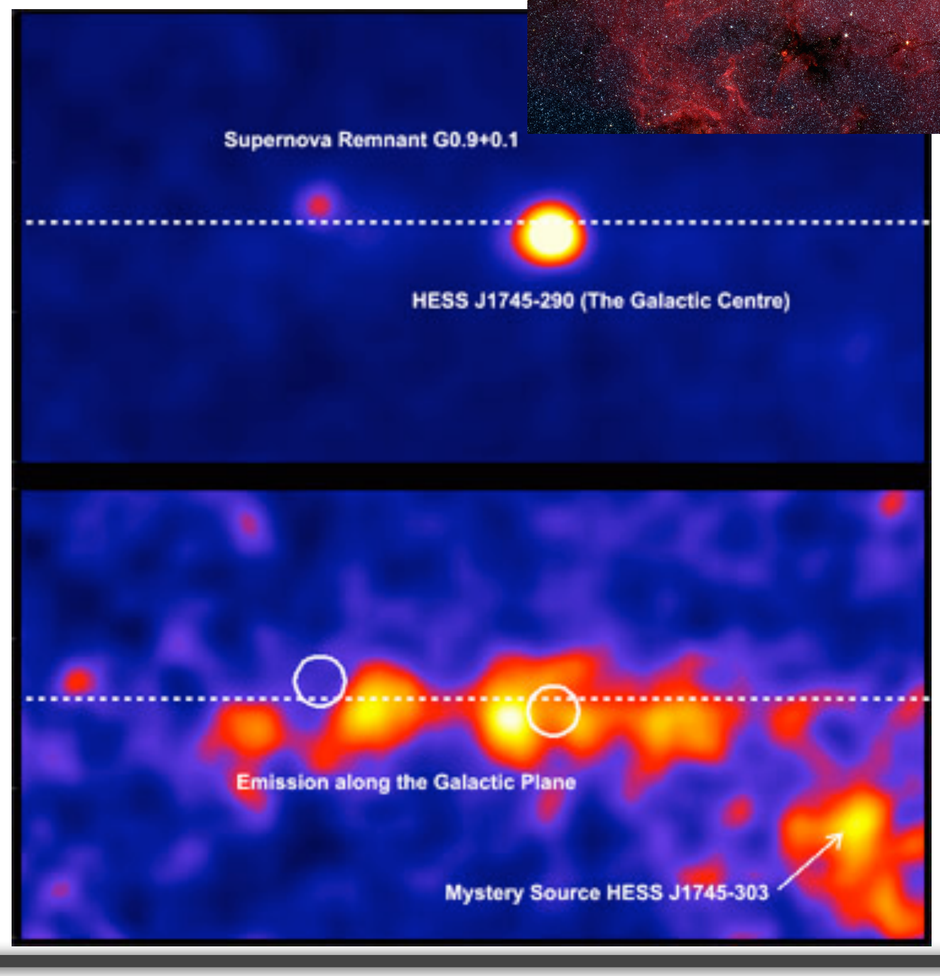
Galactic center (GC)

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

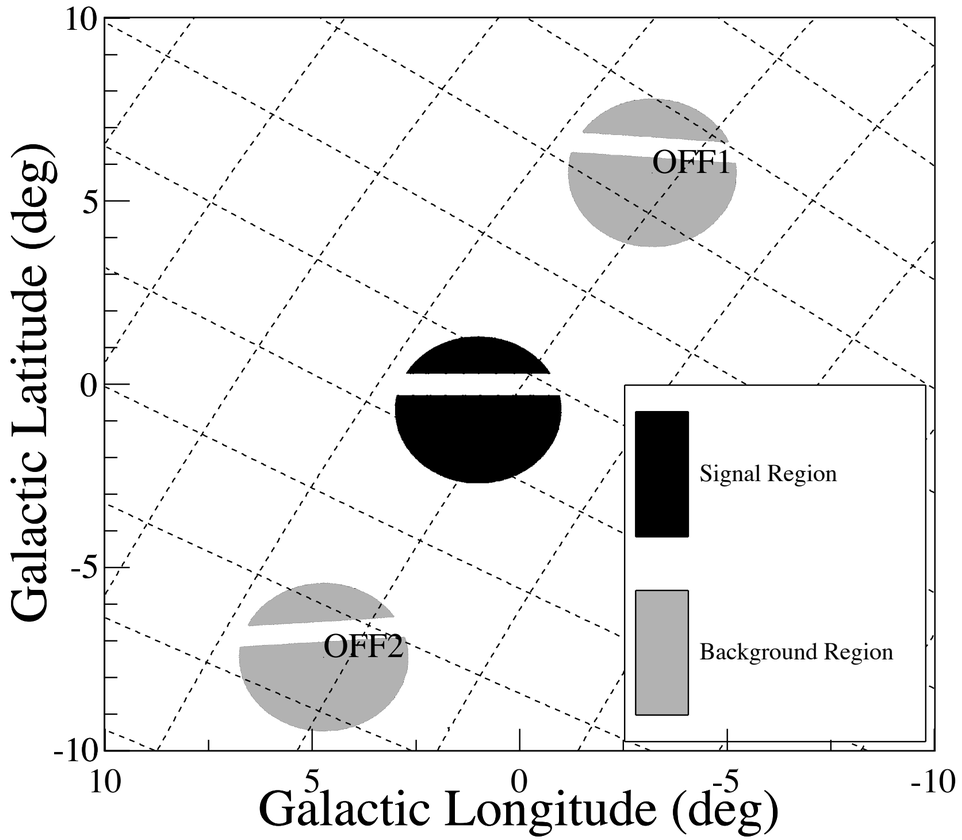
- Several Fermi-LAT point sources within 1 sq. deg. of Galactic center

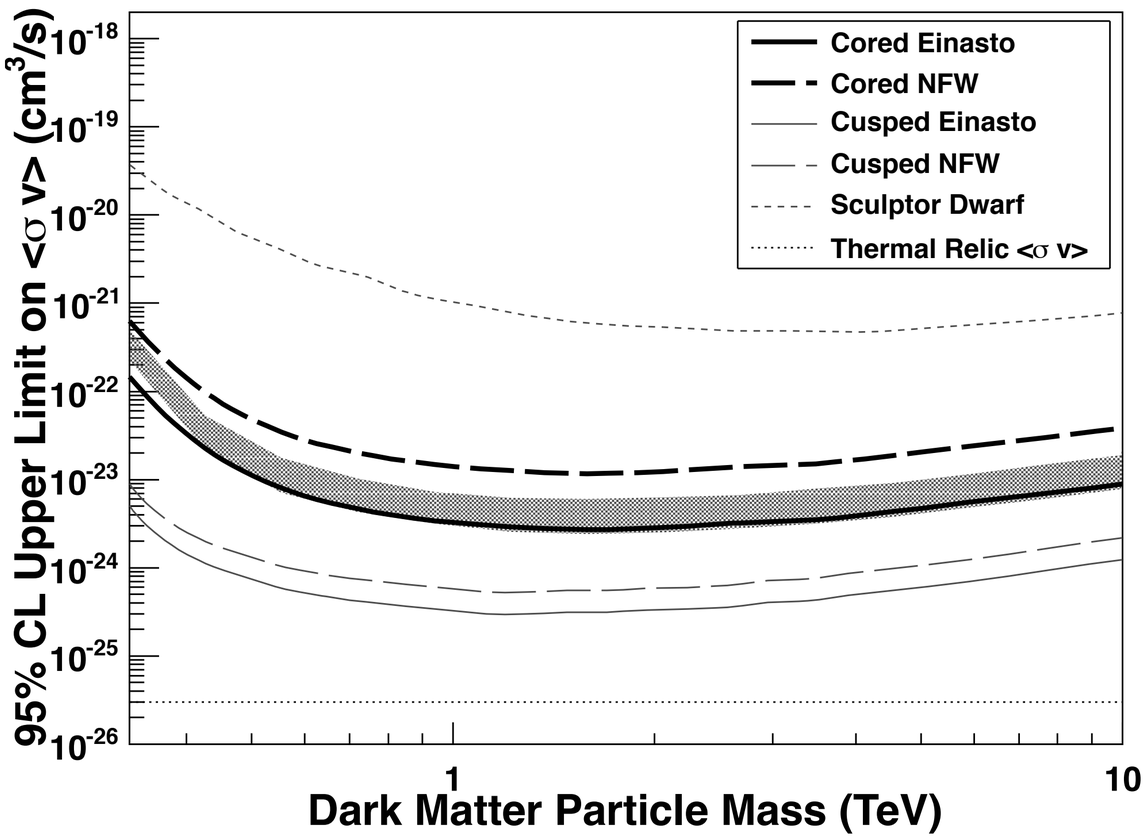
- At higher energies: H.E.S.S. and MAGIC source coincident with Sgr A* (HESS 1745-290)

- H.E.S.S. diffuse emission correlated with Giant Molecular Clouds



H.E.S.S. Gamma ray data from the *Galactic Center*





H.E.S.S. Collaboration 1502.03244

- No statistically-significant excess in gamma-rays
- DM cross section limits assume a core in density profile of constant density

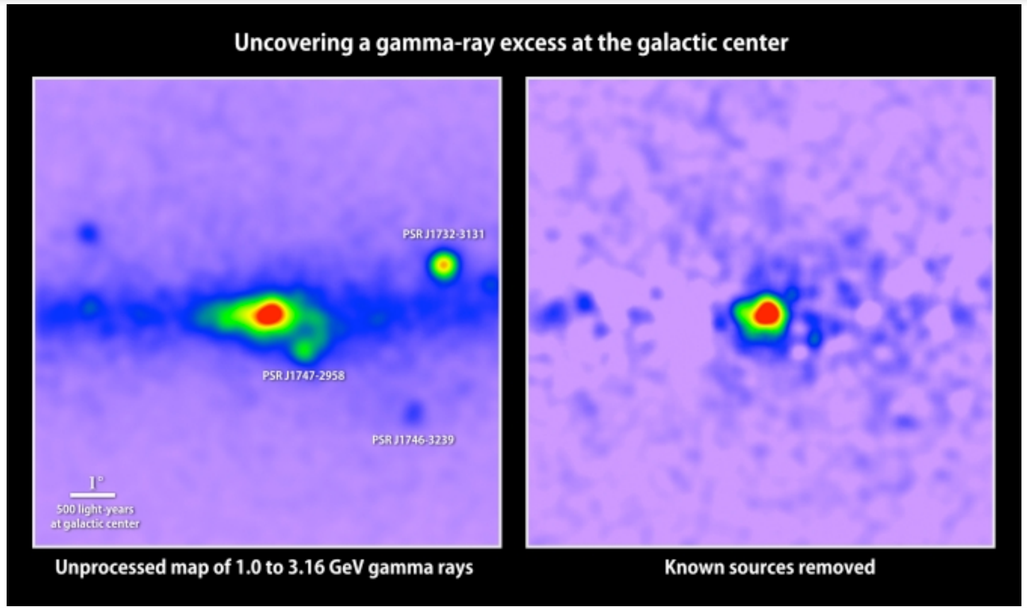
Gamma ray data from the *Inner Galaxy*

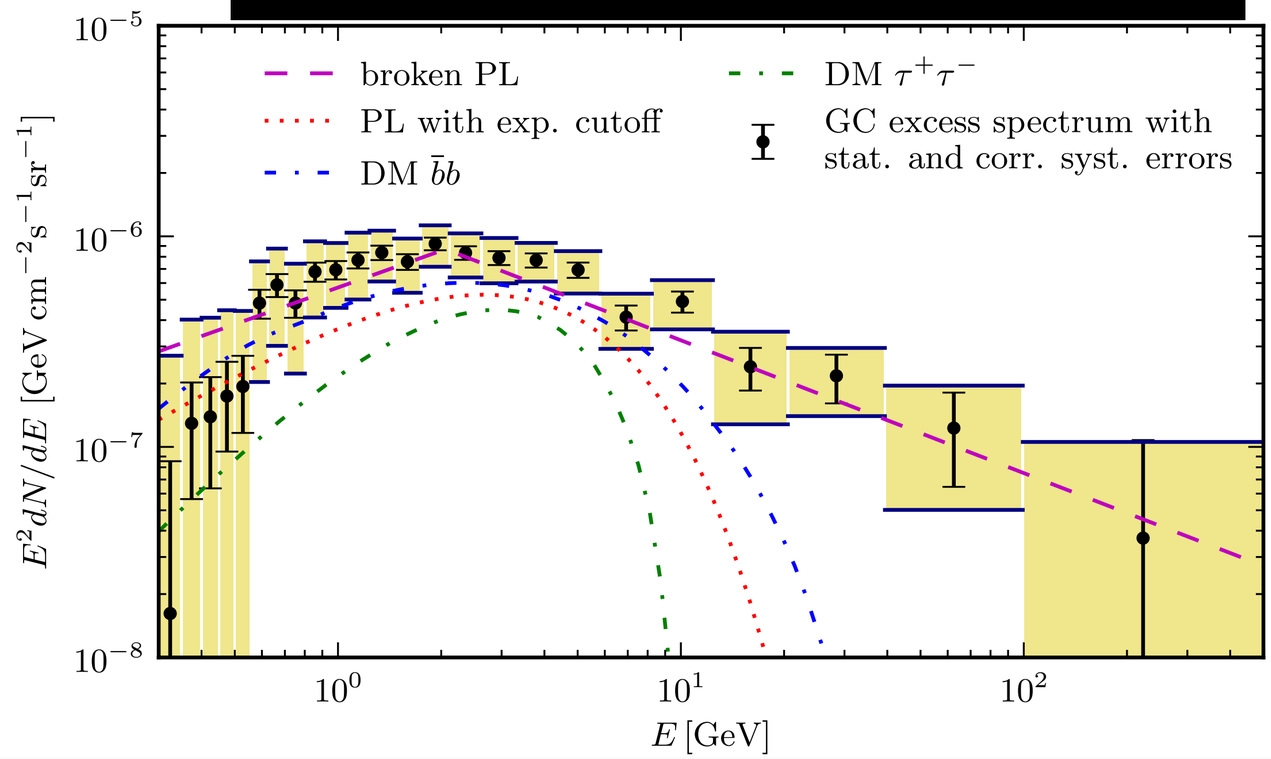
- Spherically-symmetric emission from the Galactic center not explained by standard cosmic ray propagation models

- Non-DM interpretations include pulsars, leptonic outbursts from GC

- DM interpretation: 50 GeV WIMP annihilation to b quarks

Hooper & Goodenough 0910.2998; Abazajian & Kaplinghat 1207.6047; Gordon & Macias 1306.5725; Dylan et al. 1402.6703; Calore et al 1409.0042, T. Linden talk

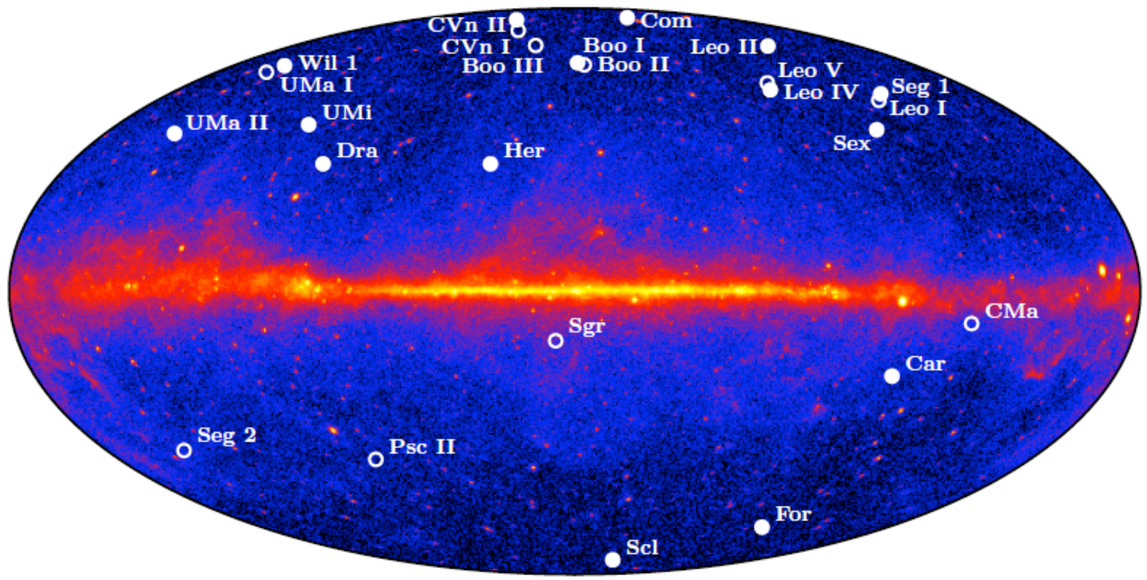




Milky Way satellite galaxies (dwarf spheroidals)

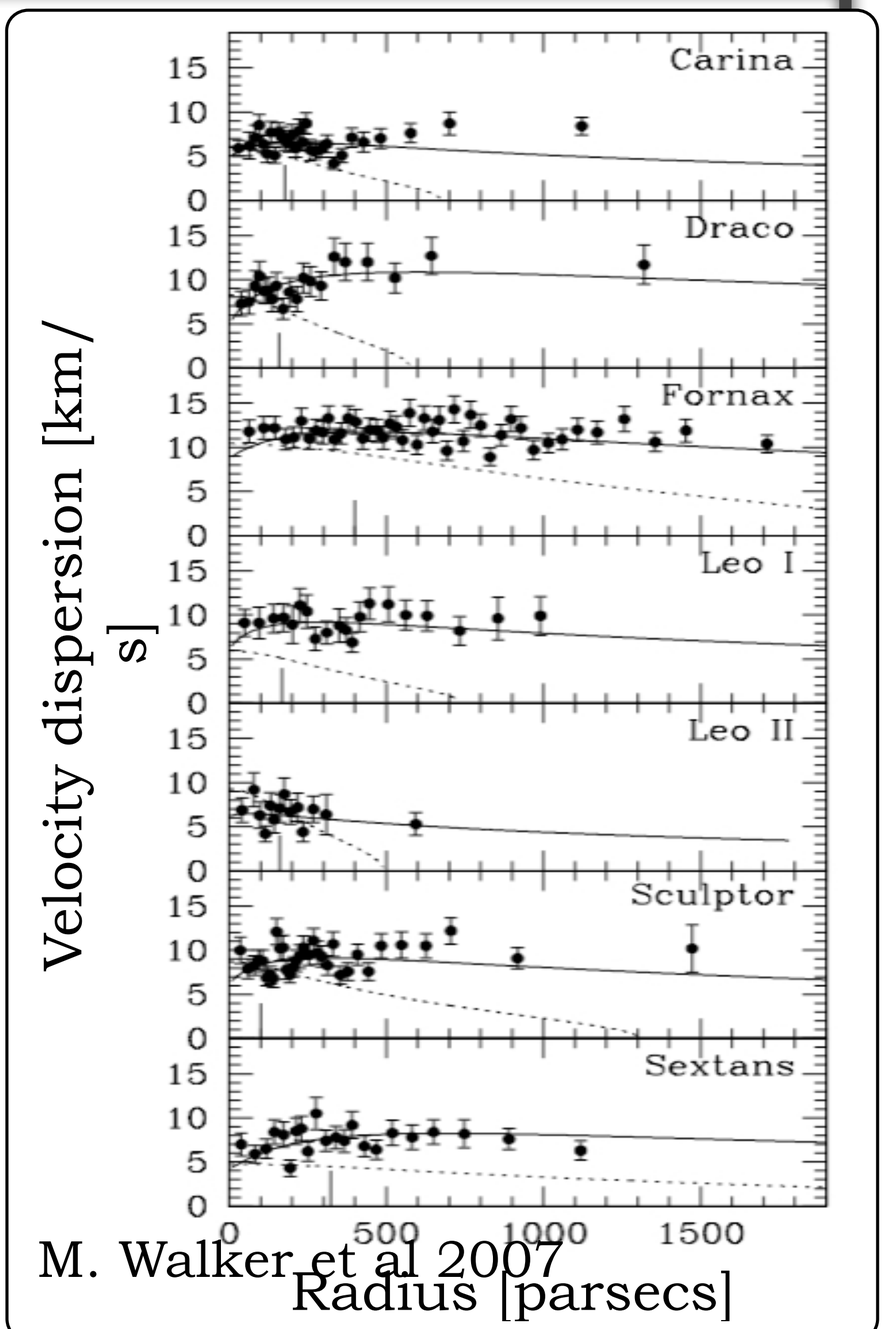
- Dark matter masses from motions of individual stars

- Most dark matter-dominated galaxies known



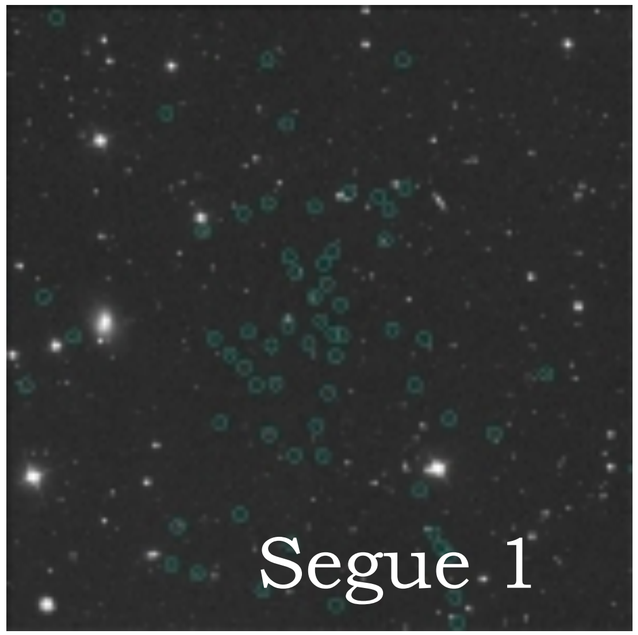
- Luminosities from hundreds to millions Solar luminosities

- No high energy gamma-rays from astrophysical sources

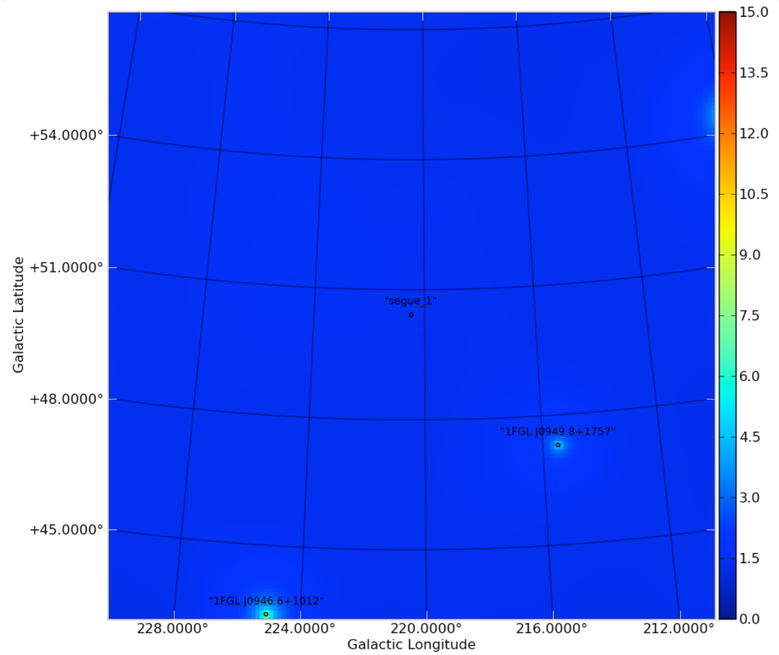


M. Walker et al 2007

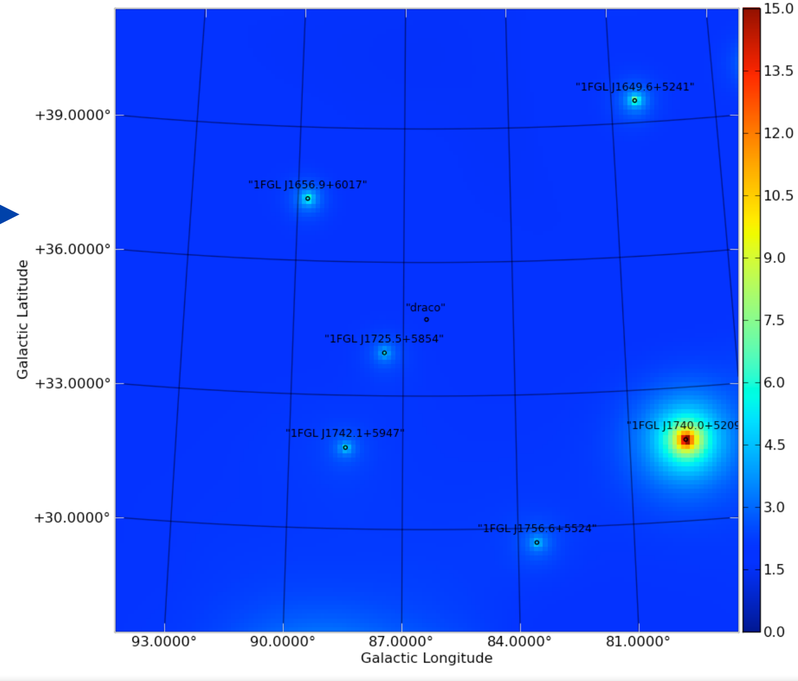
Satellite galaxies in visible light and gamma-rays



Visible Light



Gamma-rays

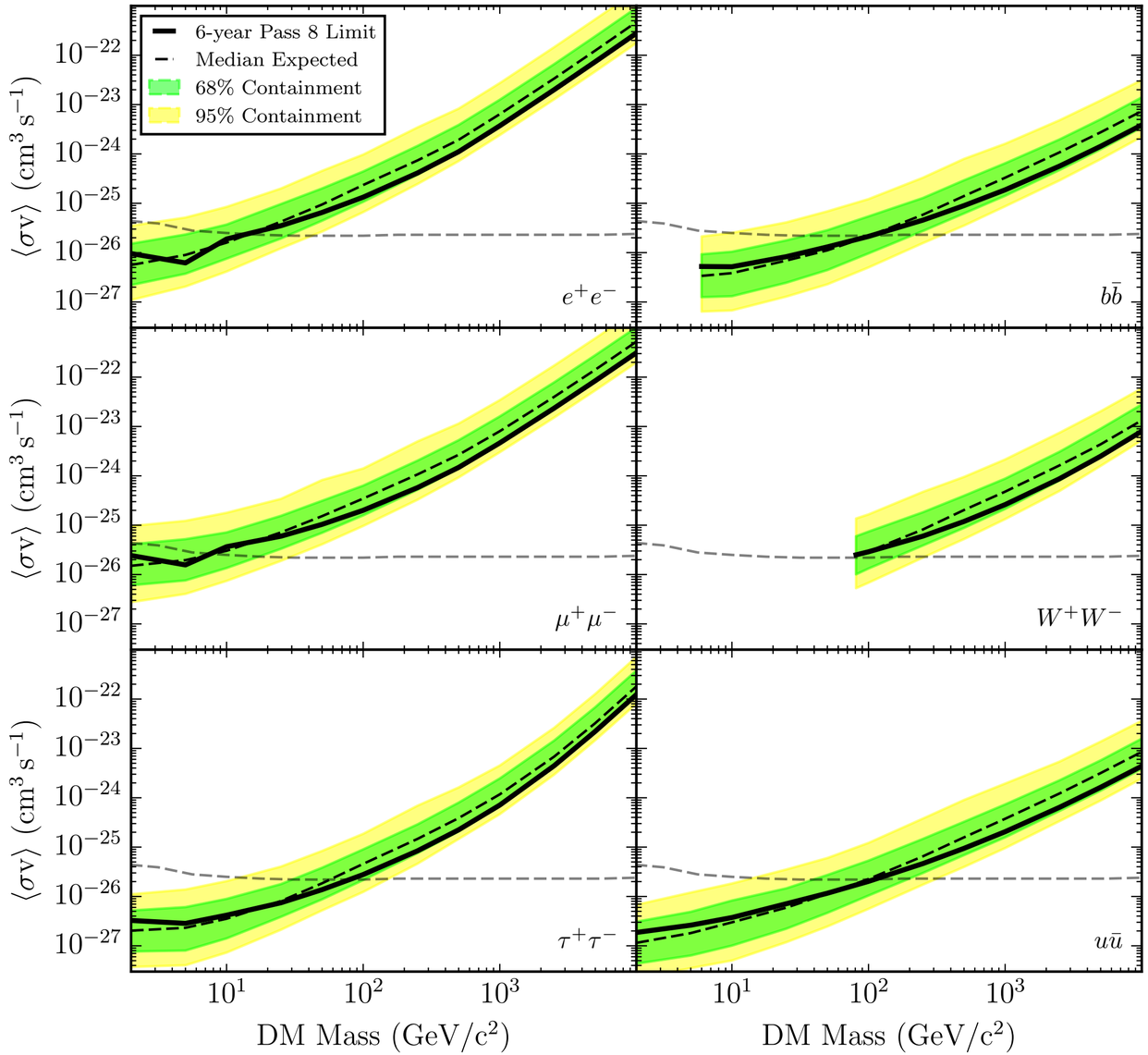


Fermi dwarf spheroidal analysis

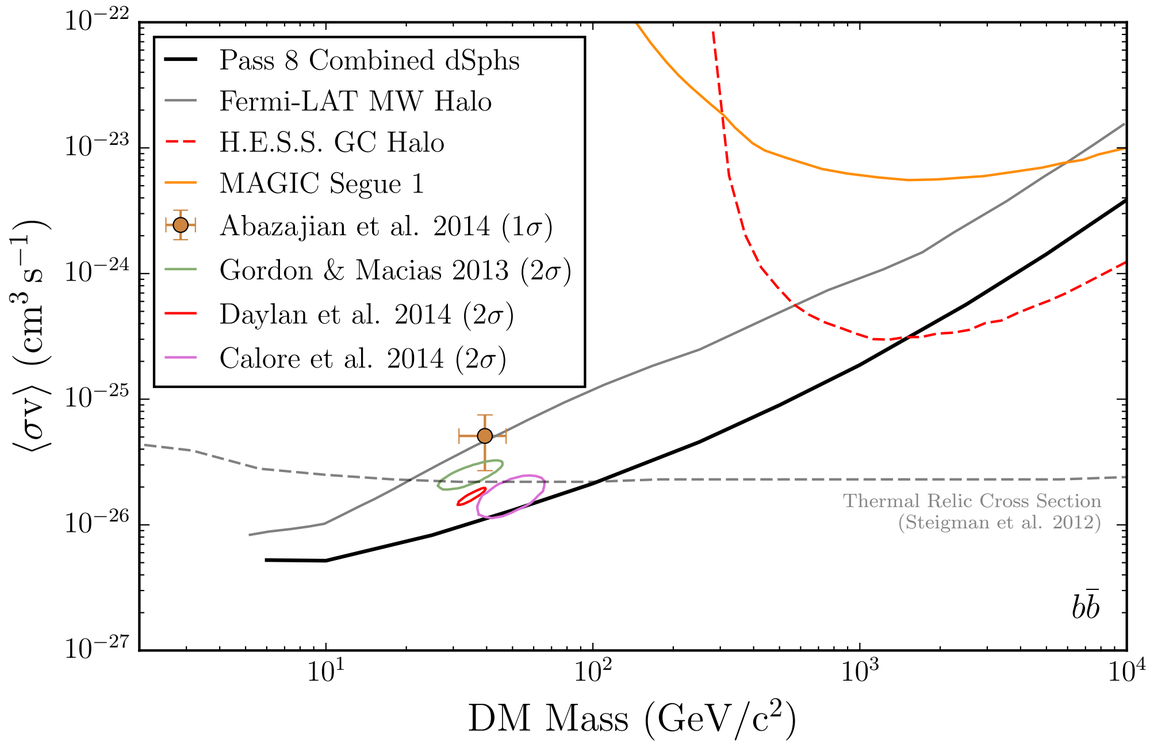
- Determine the total mass of dark matter from velocities of stars in each satellite

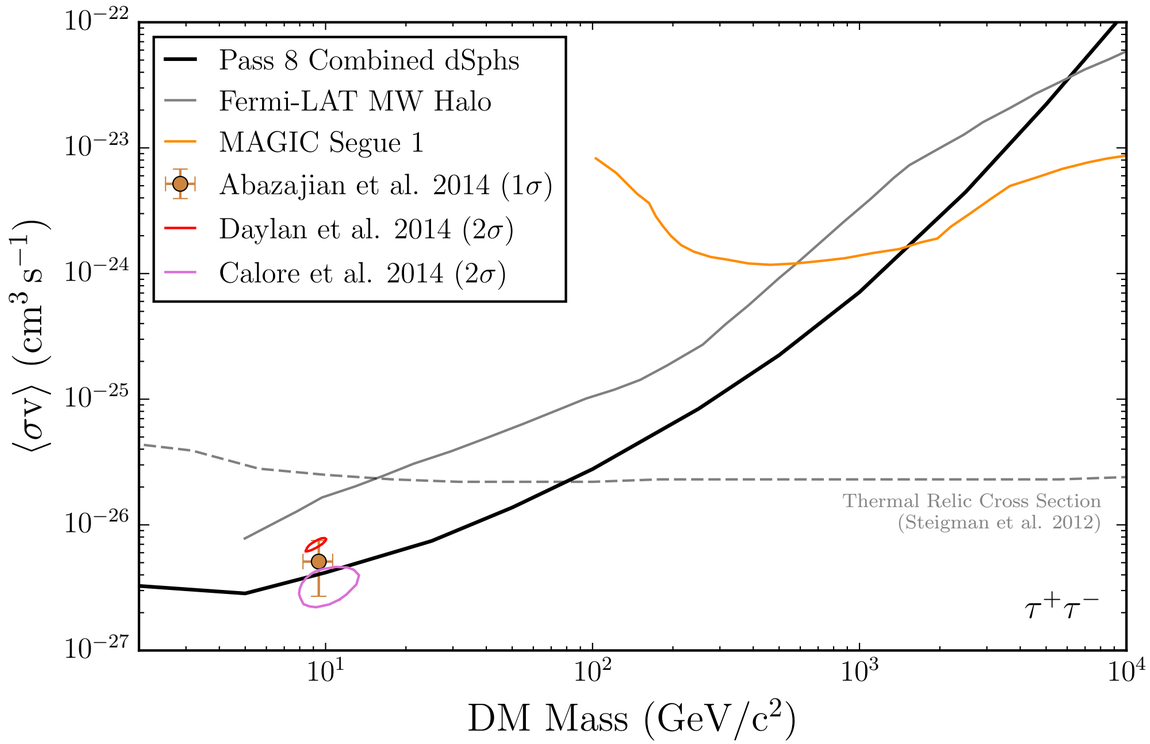
- Combine measured gamma-ray flux upper bound with total dark matter mass in each satellite to get upper bound on annihilation cross section

Fermi-LAT collaboration
PRL, 1108.3546
PRD, 1310.0828
PRL, 1503.02641



Implications for Galactic center searches





Fermi-LAT collaboration PRL, 1503.02641

- Some interpretations of Galactic center gamma-ray emission are constrained
- Uncertainty in Galactic center dark matter distribution prevents more definitive statement

New dwarf spheroidal discoveries

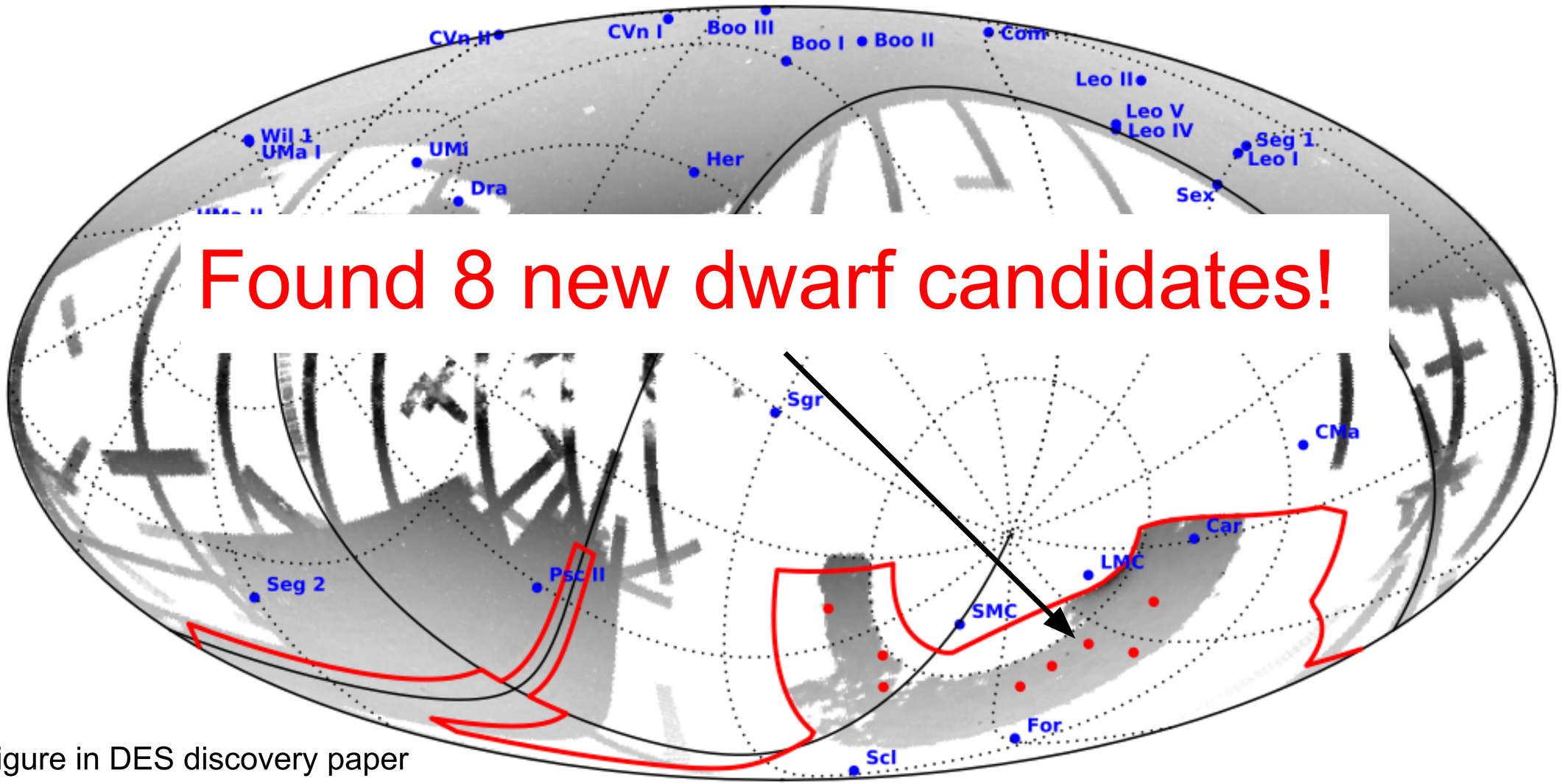
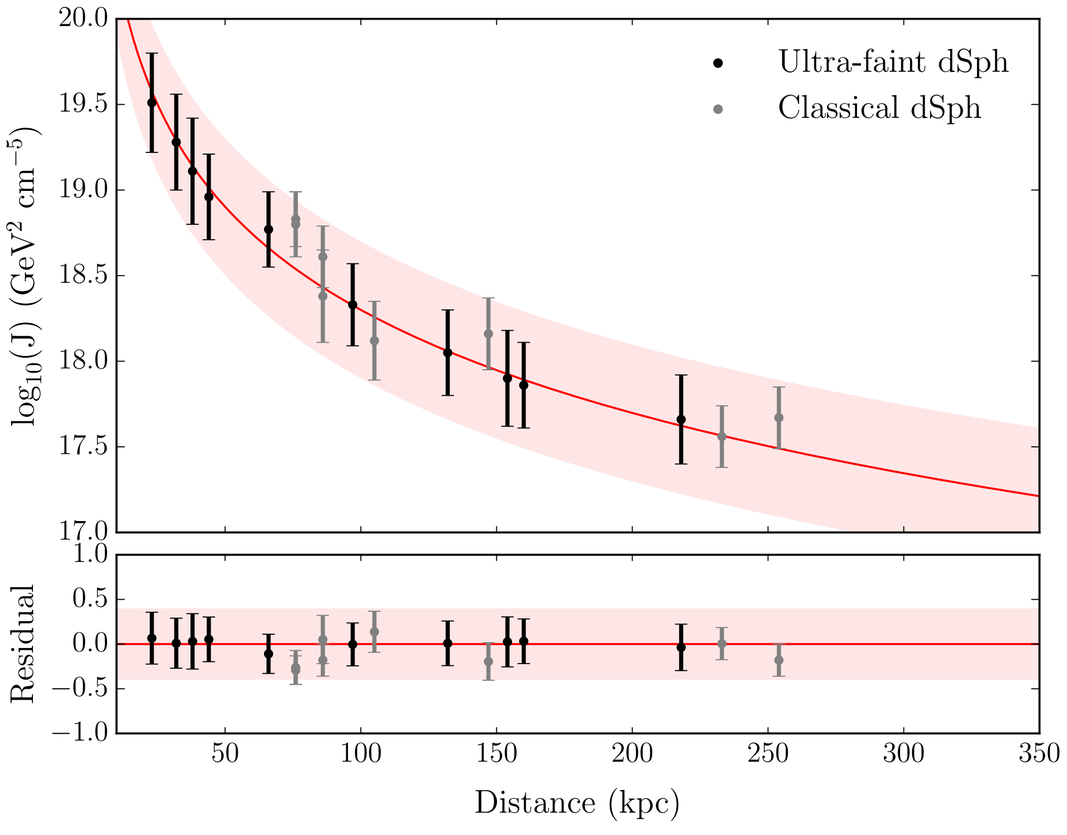
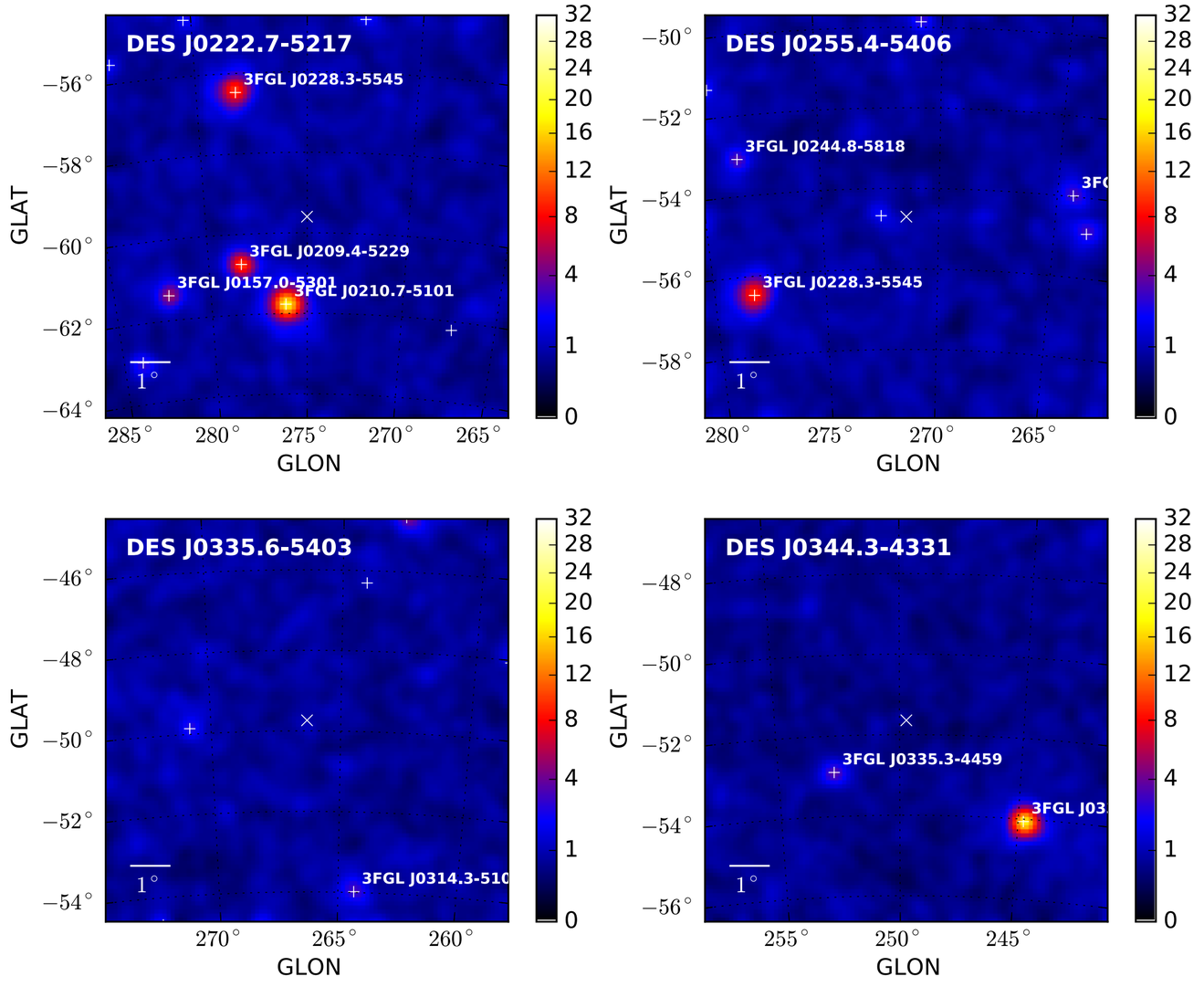


figure in DES discovery paper

Bechtol et al. DES Collaboration 1503.02584, Koposov et al. 1503.02079

Fermi/DES analysis of satellite candidates

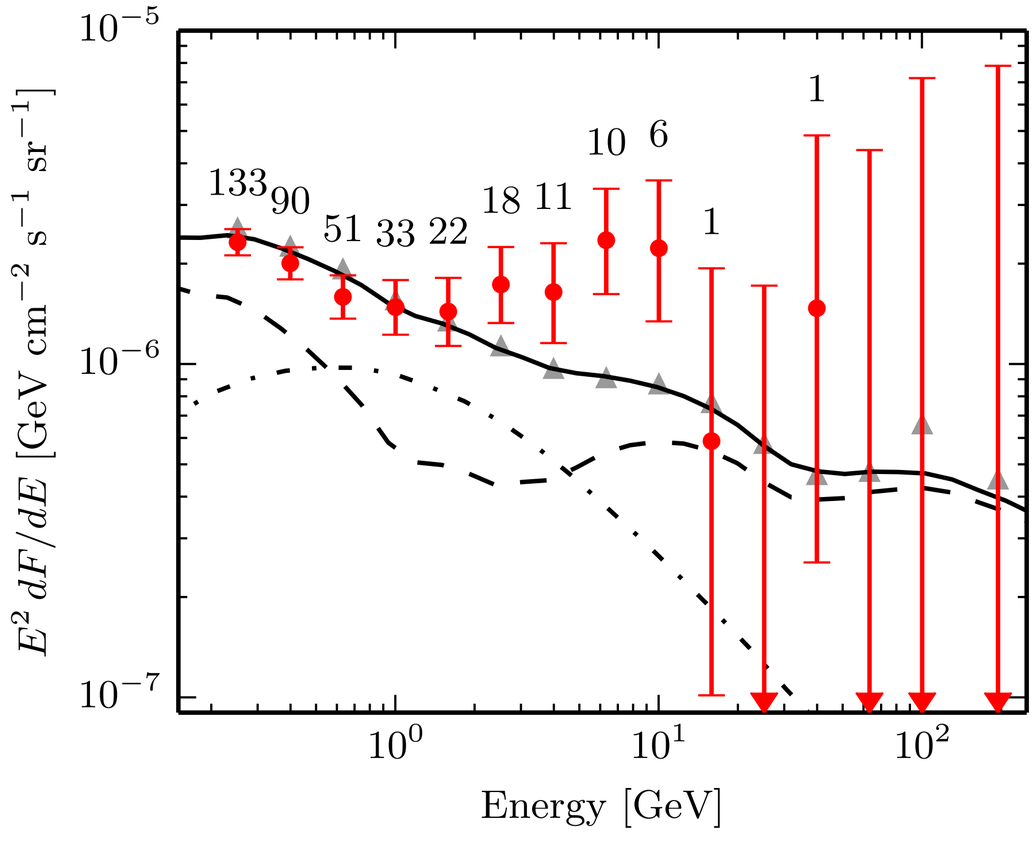




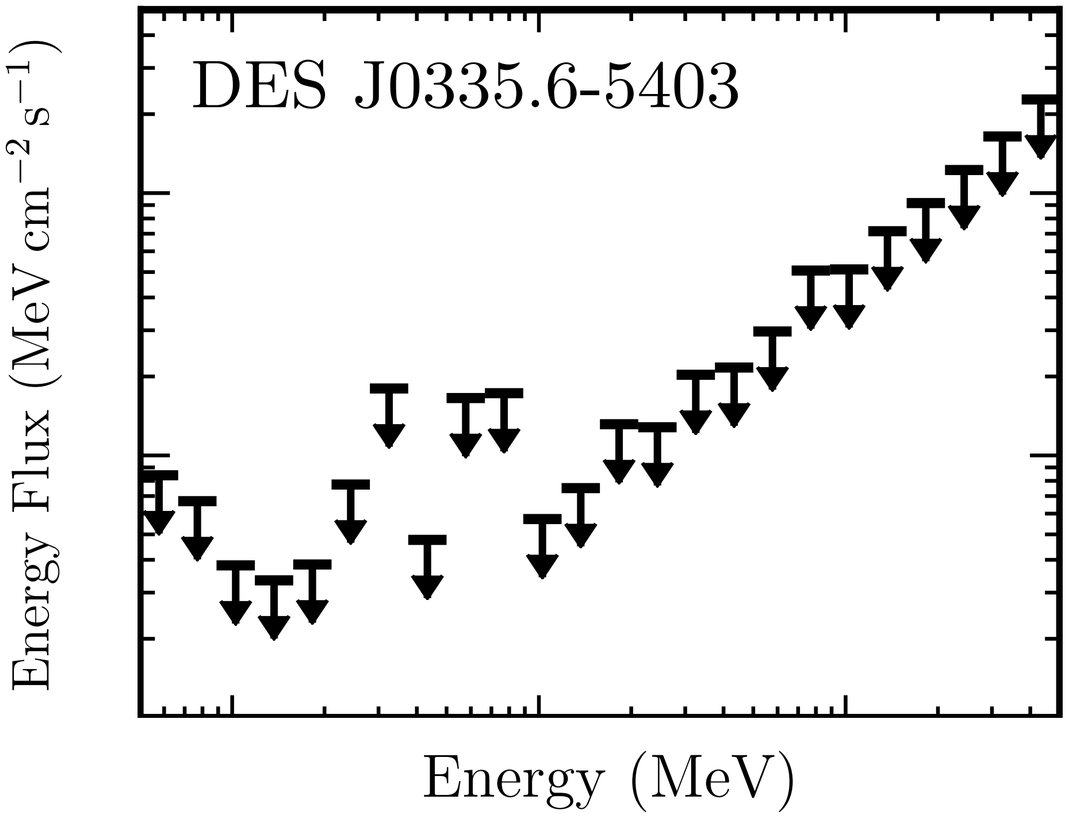
Drlica-Wagner et al. DES/Fermi-LAT collaborations 1503.02632

Evidence for Gamma-ray Emission from the Newly Discovered Dwarf Galaxy Reticulum 2 ??

- Geringer-Sameth et al. 1503.02320 identify 2-3 sigma excess from Reticulum II

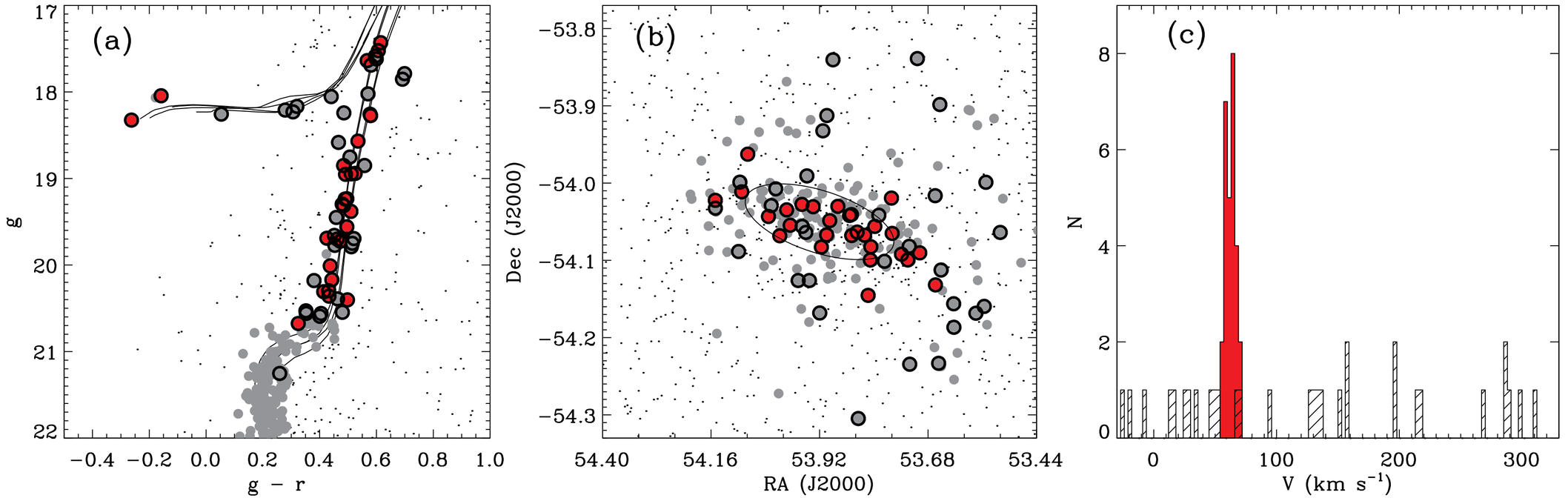


- No similar excess reported in DES/Fermi-LAT analysis 1503.02682



Measurements of DM distribution needed to shed further light.....

Reticulum II is a dark matter-dominated satellite galaxy



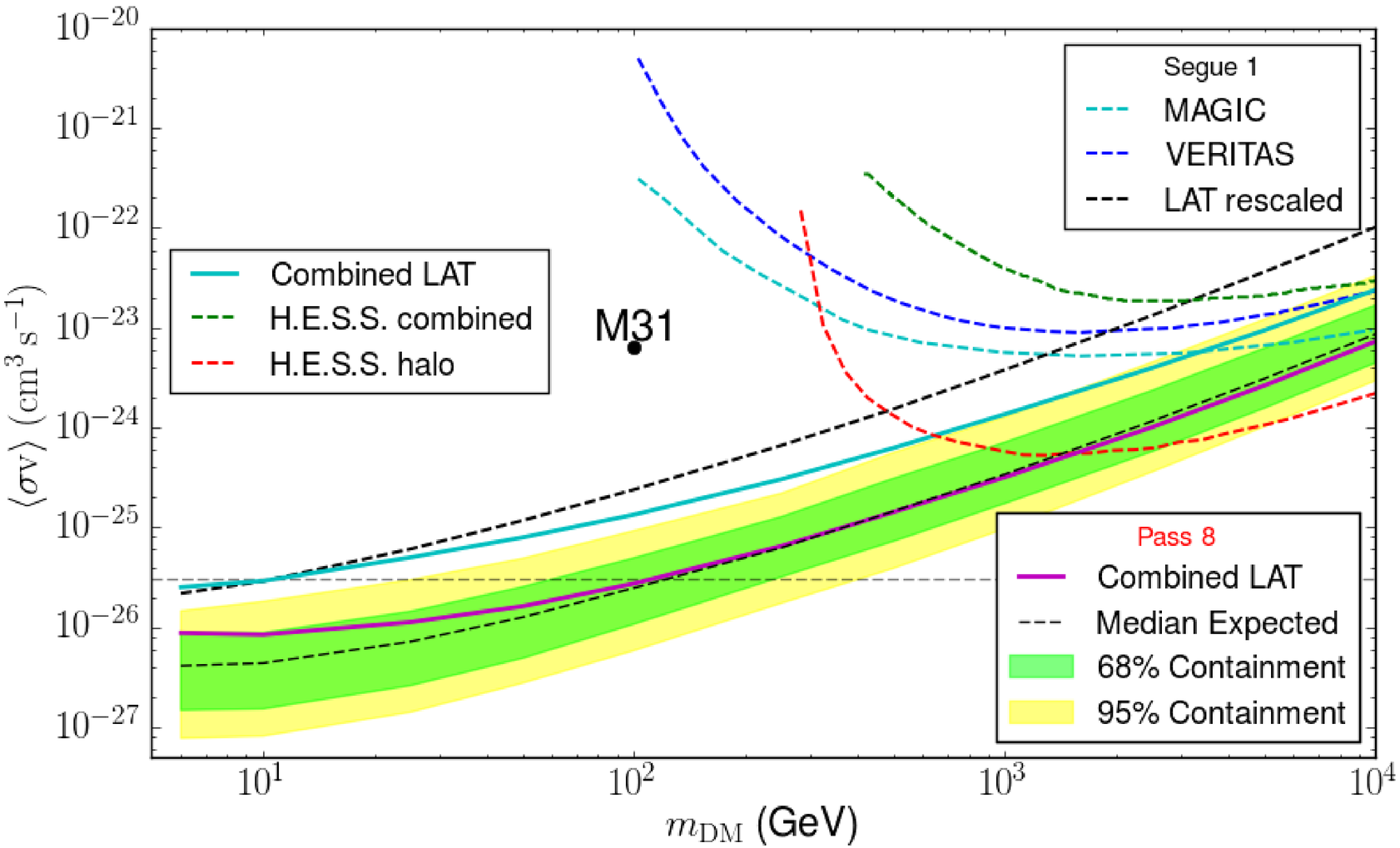
- Dark matter mass most likely too low to allow for a dark matter interpretation of the Reticulum II gamma ray observations

  Simon et al. DES collaboration 1504.02889

- Some parameter space available for DM interpretation of Ret II gamma-rays

  Walker et al. 1504.03060

Summary: Gamma-ray limits from dSphs



J. Conrad, J. Cohen-Tanugi, L. Strigari
1503.06348 JTEP

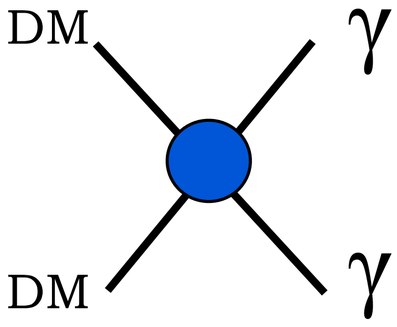
Also searches for subhalos with no associated stars that emit gamma-rays (Fermi-LAT collaboration 1201.2691, Bertoni et al. 1504.02087)

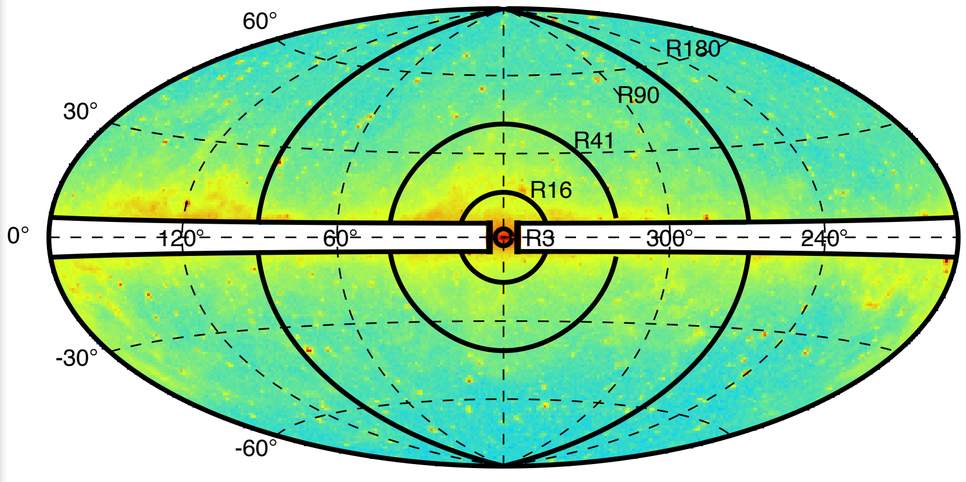
Gamma-ray Line searches

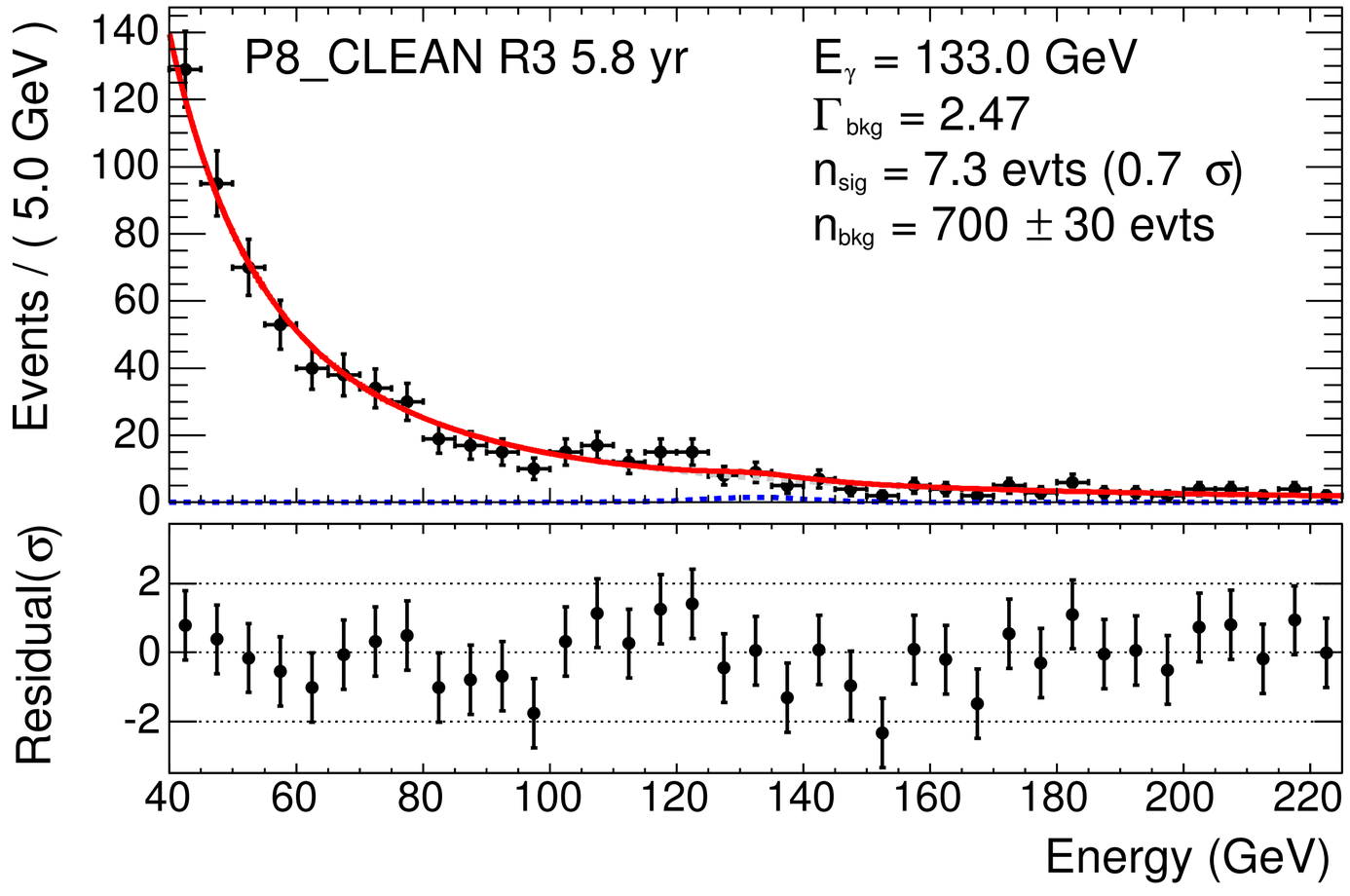
Weniger 1204.2797 identified a line-like feature ~ 130 GeV in global Fermi-LAT data at ~ 2-5sigma (also Su & Finkbeiner 1206.1616)

Systematic or DM annihilation signal?

Fermi-LAT analysis of 5.8 yrs of data find no significant detection of line-like feature:1506.00013







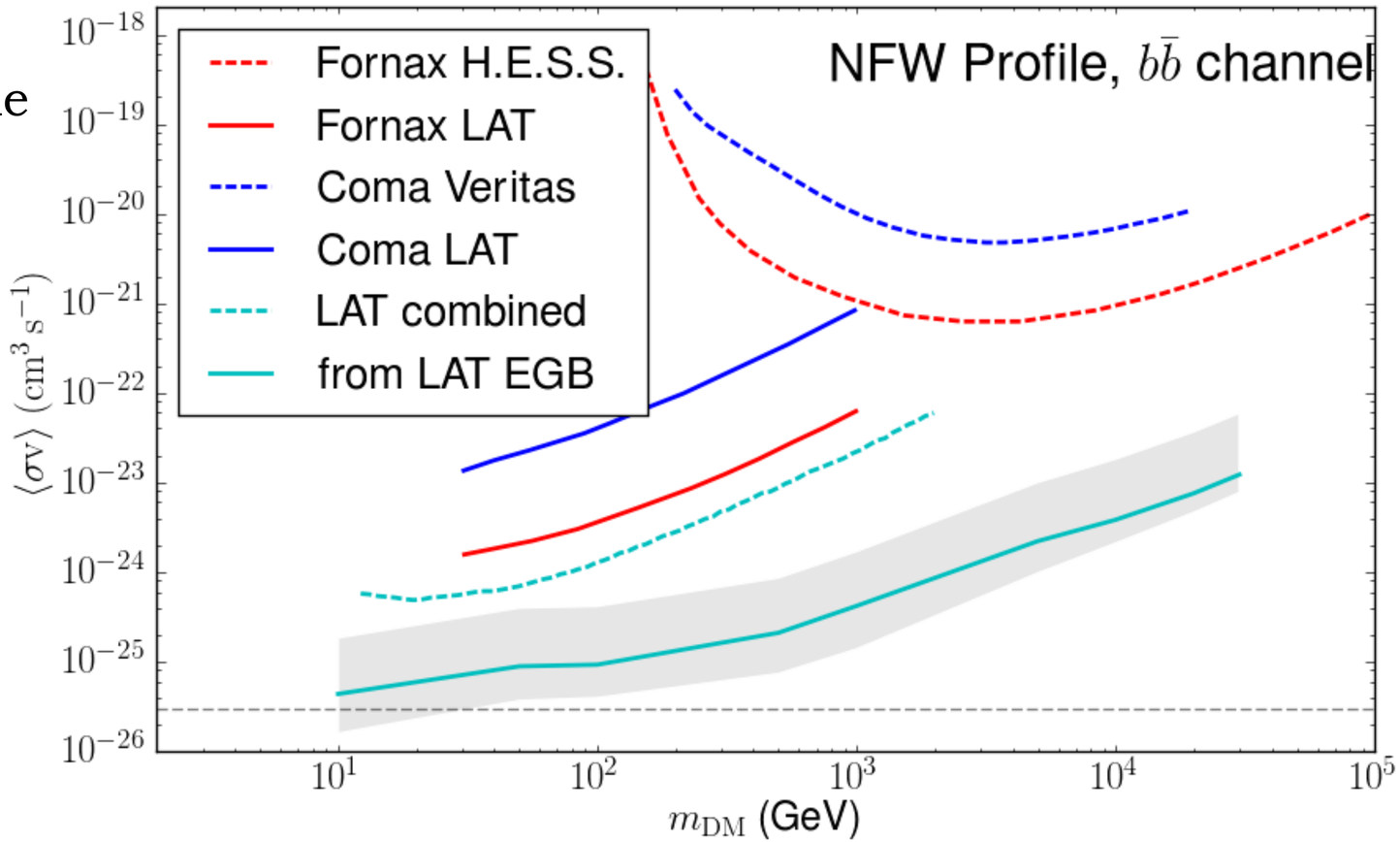
Galaxy clusters

- 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)

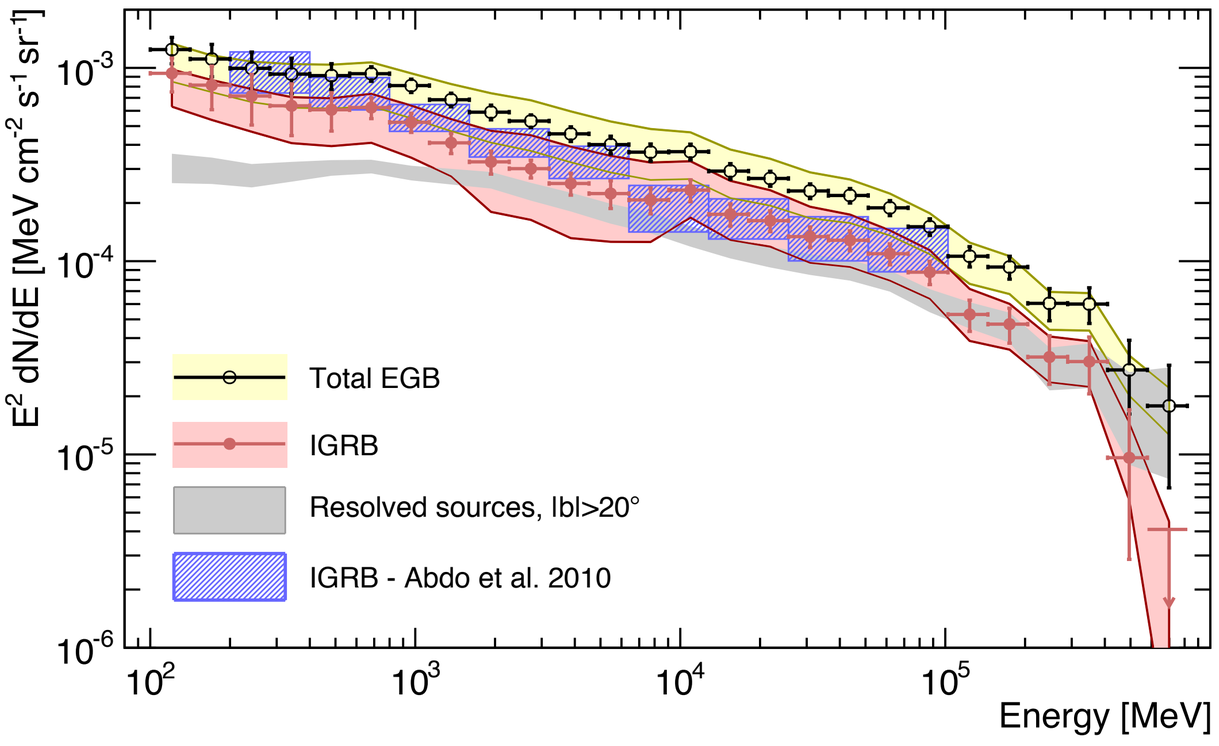
- Nearby clusters Fornax, Coma, and Virgo are some of the most interesting sources (Pinzke et al 1105.3240; Ando & Nagai 1201.0753)

- Significant contribution to the flux expected from substructure in the clusters (e.g. Gao et al. 1107.1916)

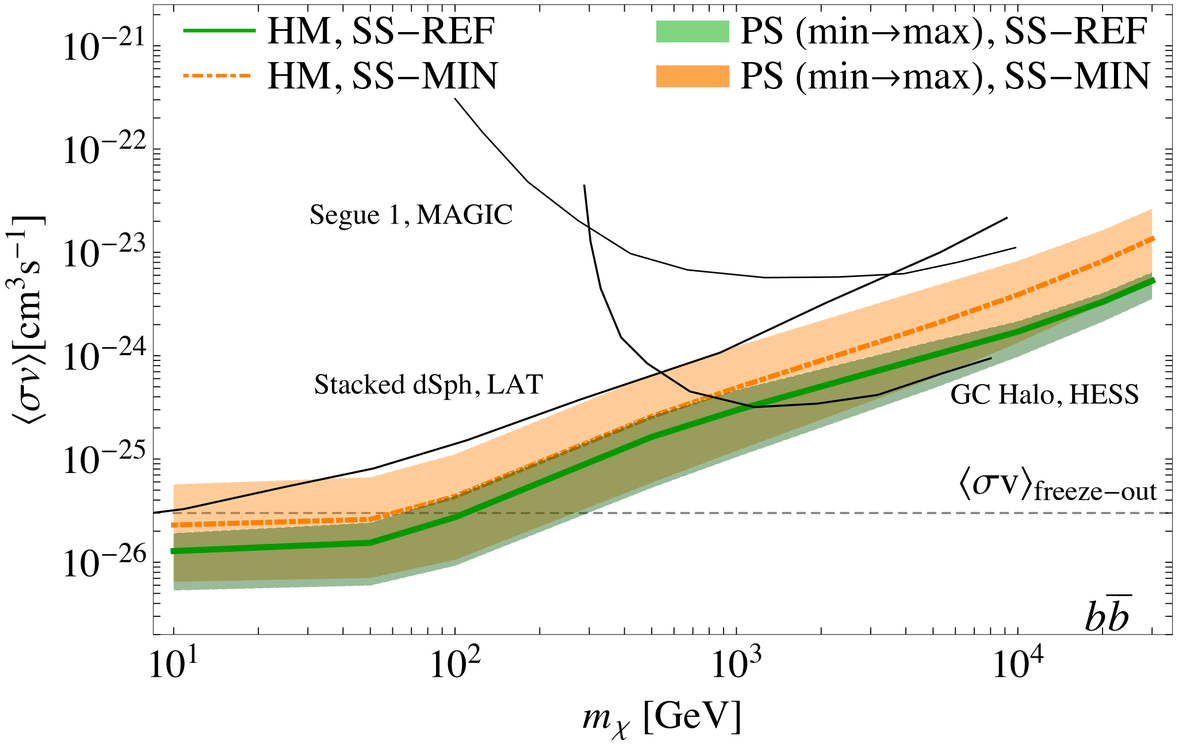


J. Conrad, J. Cohen-Tanugi, LS
1503.06348 JTEP

Extragalactic gamma-ray background



Fermi-LAT collaboration PRD 1410.3696



Fermi-LAT collaboration JCAP 1501.05464

- Extragalactic gamma-ray background = isotropic gamma-ray background + resolved sources
- Sources include Blazars, star-forming galaxies, radio galaxies

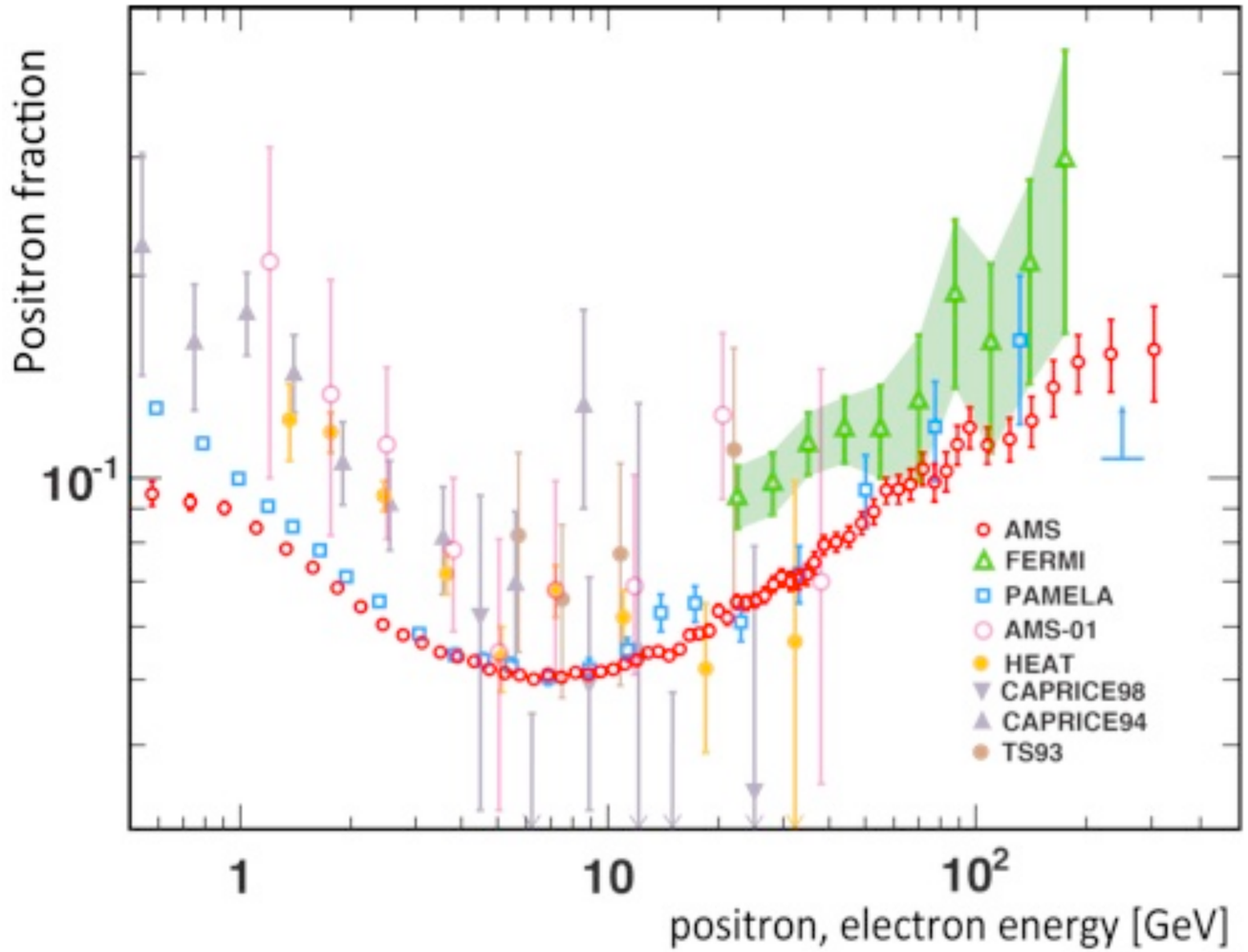
Anti-matter searches ($e^{+/-}$, $p^{+/-}$)

- AMS-02 confirmed and extended previous indications of rising positron fraction

- Diffuse flux falls steeply as a function of energy. Indicative of source term at high energies

- Source candidates are pulsars (DiMauro et al 1402.0321), SN remnants (Mertsch & Sarkar 1402.0855), or DM annihilation (e.g. Cirelli et al 0809.2409)

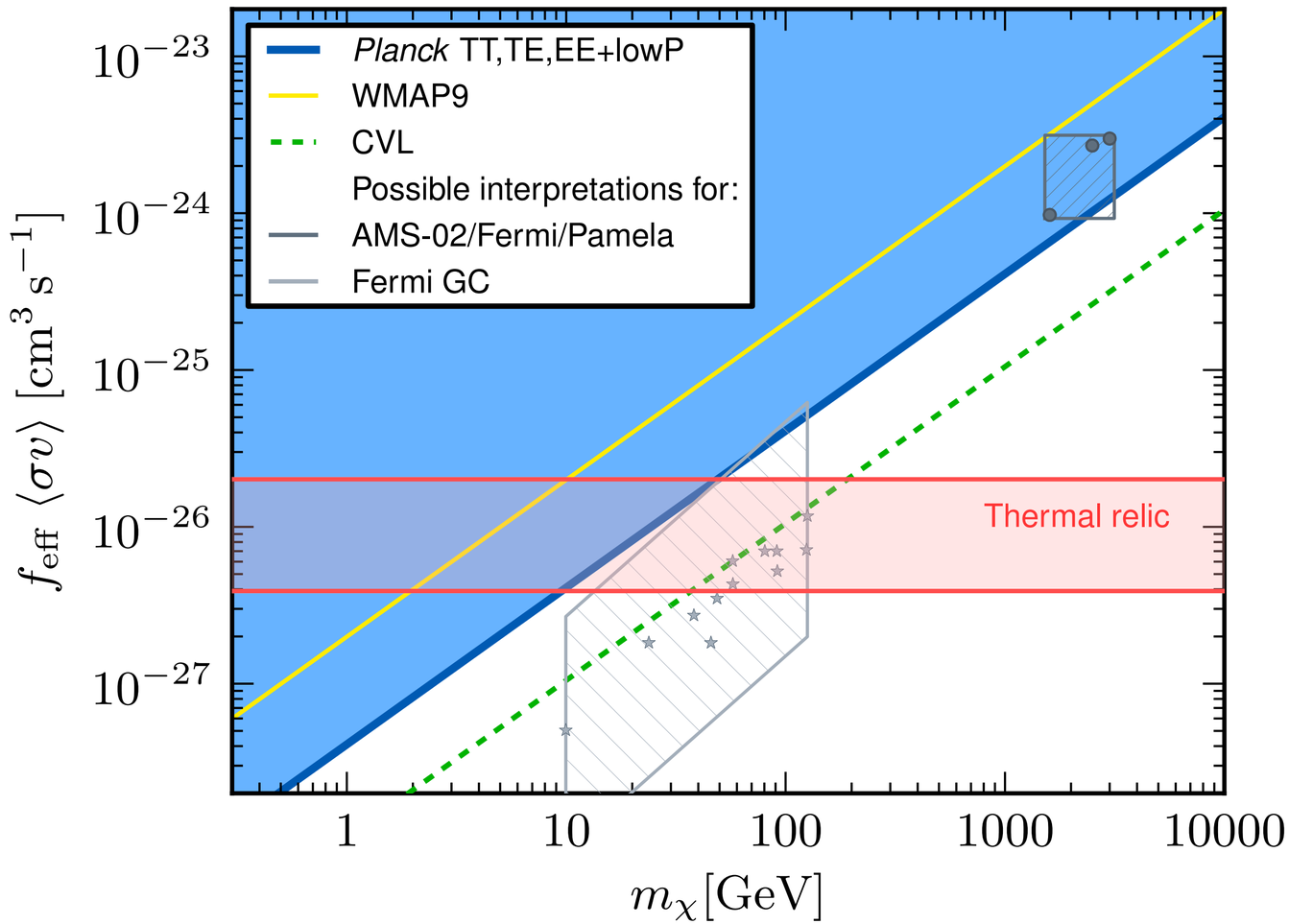
- Recent AMS-02 results for anti-protons



Talk by Derome

Constraints on DM annihilation from CMB

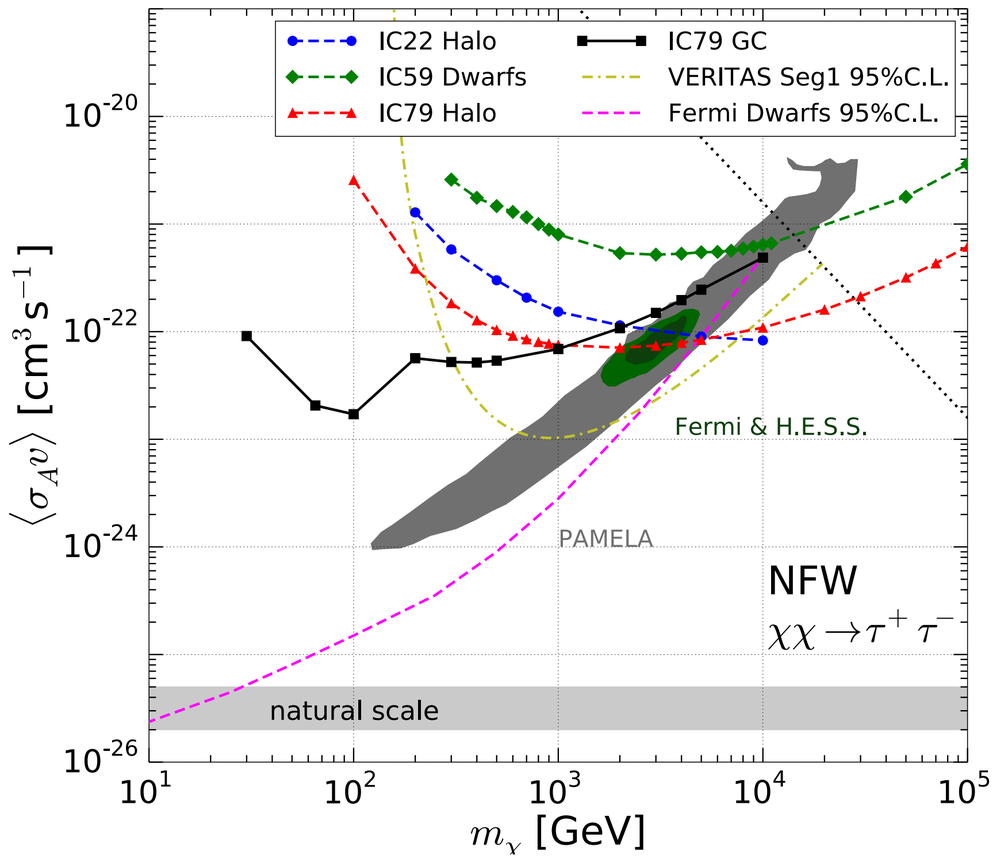
- DM annihilation injects energy into CMB at $z \sim 1000$.
- Annihilation products lose energy due to interactions with plasma
- Widens the surface of last scattering and alters CMB peaks
- Results are relatively insensitive to annihilation channels. Everything except directly annihilation to just neutrinos strongly constrained
- Also information from polarization

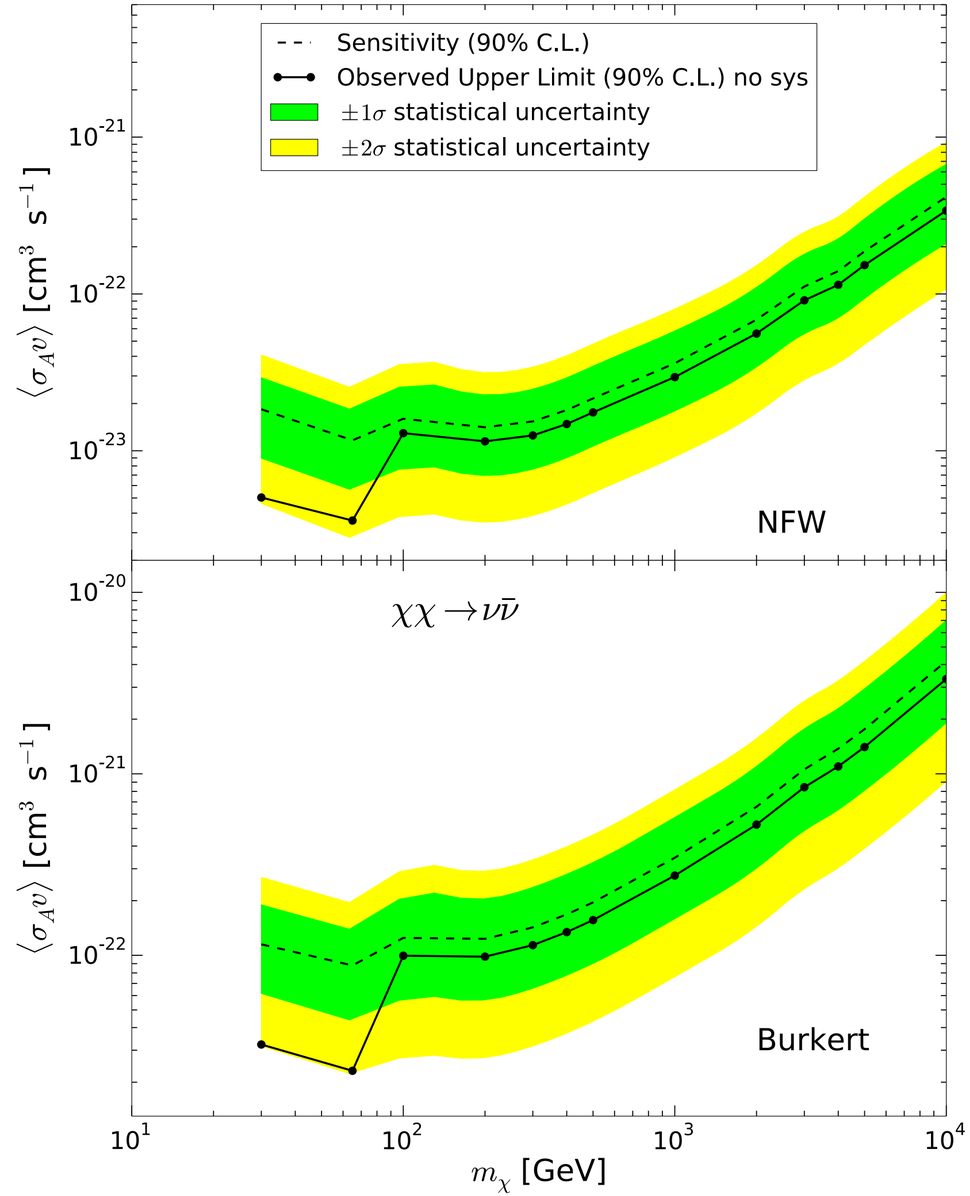


Planck collaboration 1502.01589

Indirect searches with neutrinos

- Ice cube observations of the Galactic center probe direct WIMP annihilation to neutrinos





IceCube Collaboration 1505.07259

Summary/interpretations

- Fermi-LAT gamma-ray searches have reached the thermal relic scale

- Planck constraints also reaching thermal relic scale. Strongly constrain AMS-02, Pamela DM interpretations

- Strongly constraining thermal relic WIMP dark matter with velocity independent annihilation cross sections

- Future progress:

    - More Fermi-LAT, Cherenkov telescope data
    - Discovery of more dSphs of the Milky Way
    - Neutrino constraints