Constraints on Dark Matter with Fermi Observations of Clusters

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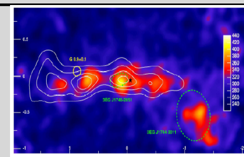
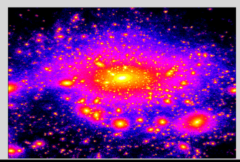
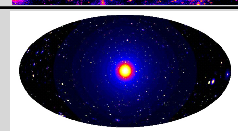
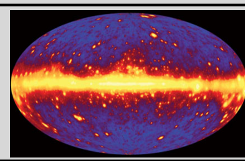
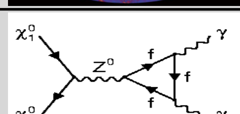
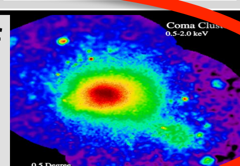
Fermi
Gamma-ray
Space Telescope

LICK
OBSERVATORY

Fermi Dark Matter Searches

Search Technique	advantages	challenges
Galactic center 	Good Statistics	Source confusion/Diffuse background
Satellites, Subhalos 	Low background, Good source id	Low statistics
Milky Way halo 	Large statistics	Galactic diffuse background
Extra-galactic 	Large Statistics	Astrophysics, galactic diffuse background
Spectral lines 	No astrophysical uncertainties, good source id	Low statistics
Clusters of Galaxies 	Low background, Good source id	Low statistics

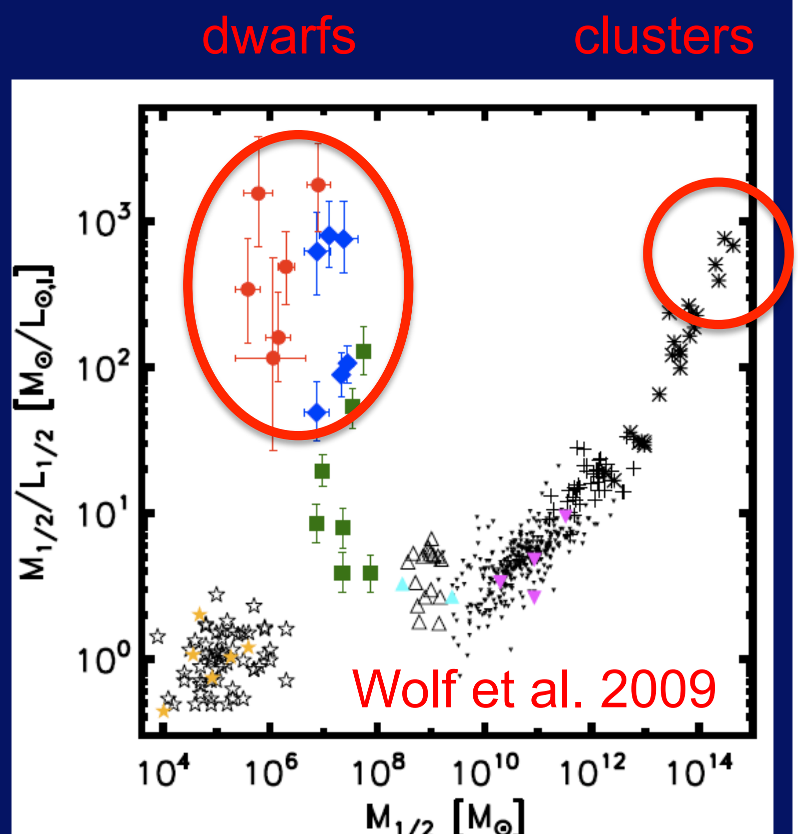
talks by Morselli and Bloom, Baltz et al. JCAP07 (2008) 013

Clusters for Dark Matter Searches

Clusters of galaxies are:

- ➢ The most massive collapsed objects and dark matter dominated
- ➢ Isolated and many lie in regions of low gamma-ray backgrounds

(similar to dwarf spheroidal galaxies)

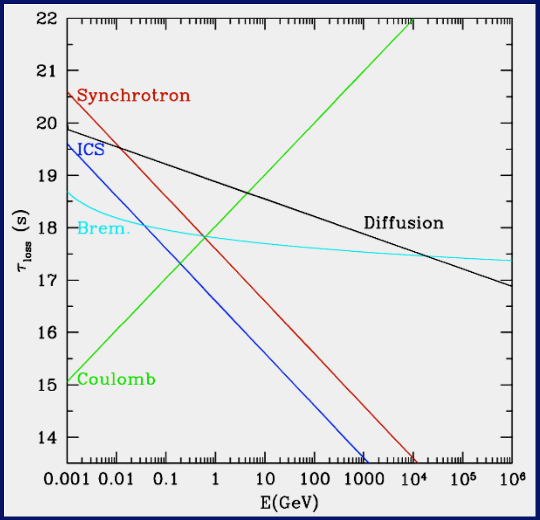


Clusters for Dark Matter Searches

Fermi observations of clusters are particularly powerful for constraining:

1. dark matter decay
2. leptophilic dark matter when IC emission dominates

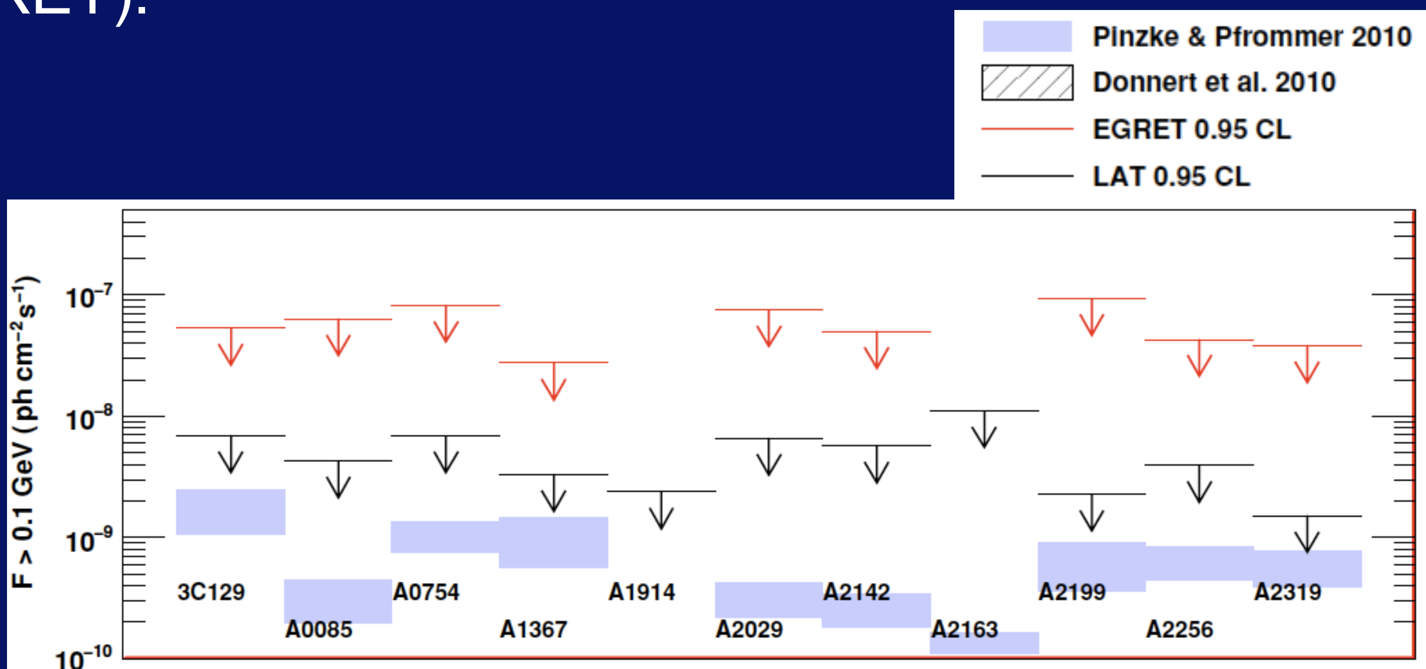
(Diffusion of e^+e^- not important, because the energy loss timescale via IC scattering is much shorter than the diffusion time)



Colafrancesco et al. 2006

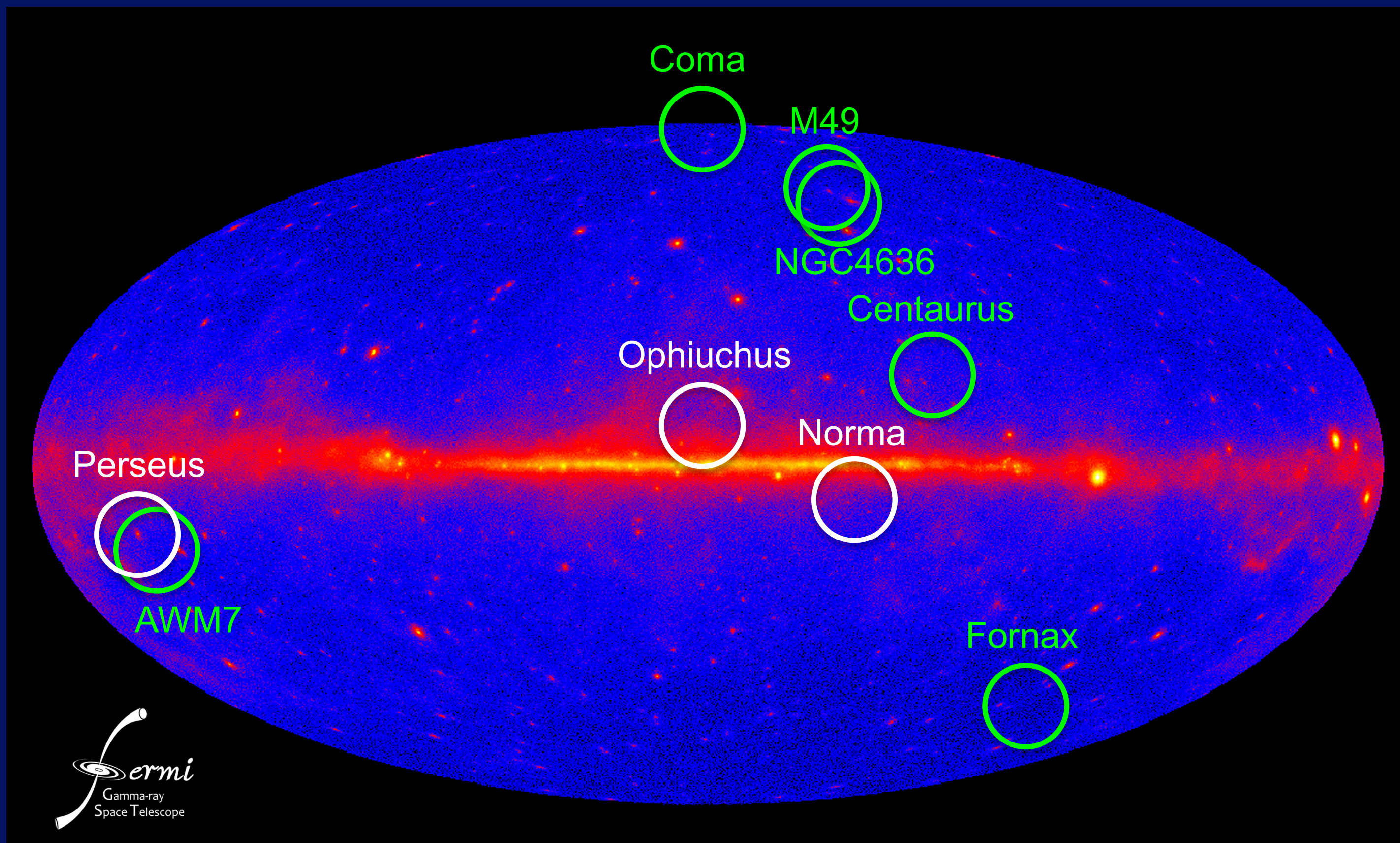
Gamma-Ray Emission – Fermi Limits

- Fermi-LAT does not detect gamma-ray emission from clusters (18 month limits a order of magnitude lower than EGRET).



Ackermann et al. 2010a

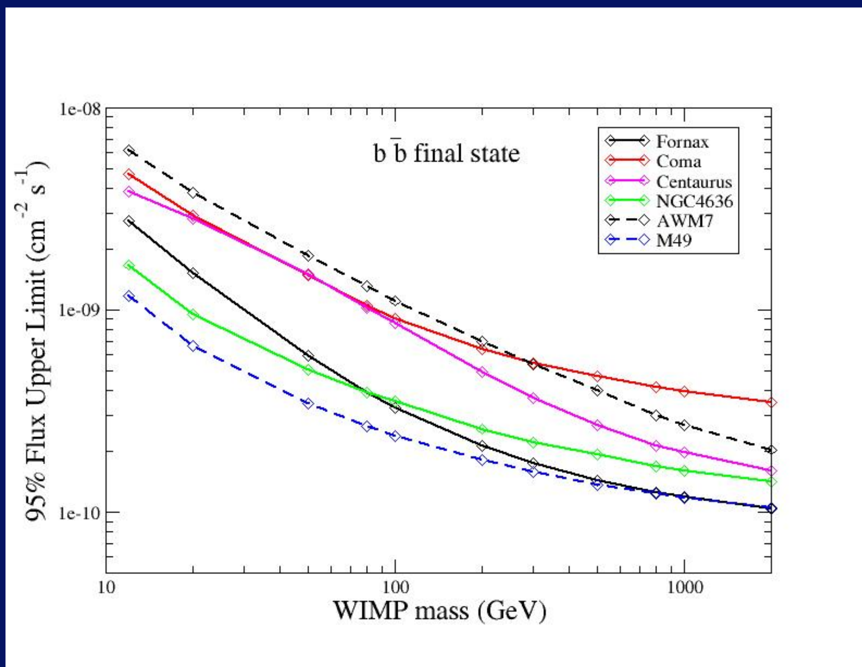
Cluster Sample

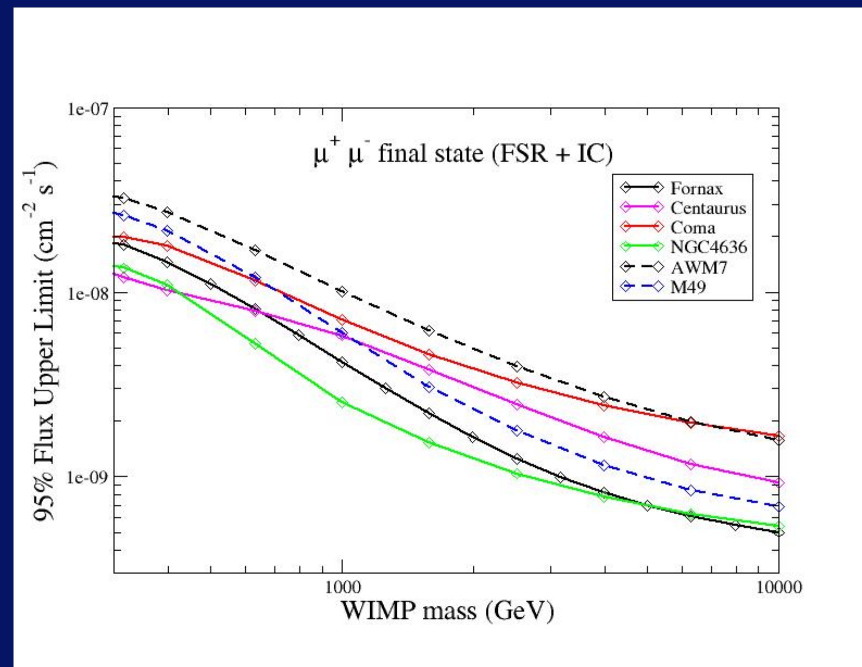


- Brightest Predicted clusters and groups of galaxies (Jeltema, Kehayias, & Profumo 2009)

Perseus (cluster and NGC1275) and Ophiuchus (near GC), and Norma (near Galactic plane)

Flux Upper Limits – DM Annihilation





- 95% confidence level limits assuming a $b\bar{b}$ or a $\mu^+\mu^-$ final state (100 MeV – 100 GeV).
- Flux limits depend on assumed spectrum.

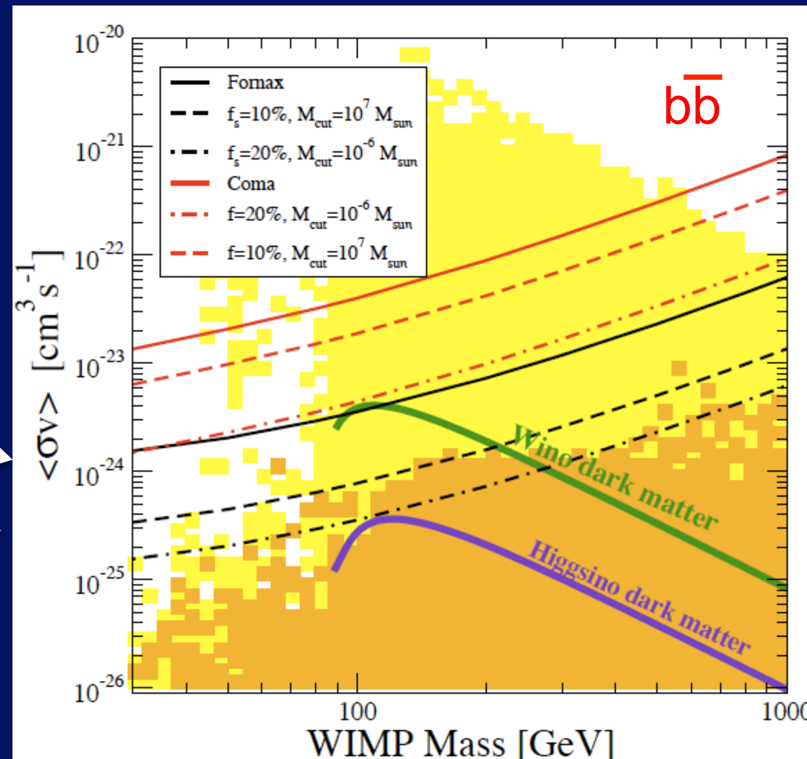
Dark Matter Annihilation - MSSM Models

---- Fornax
---- Coma
MSSM models
models matching WMAP

smooth NFW halo only

galaxies only

substructure with M > 10^{-6} M_{sun}

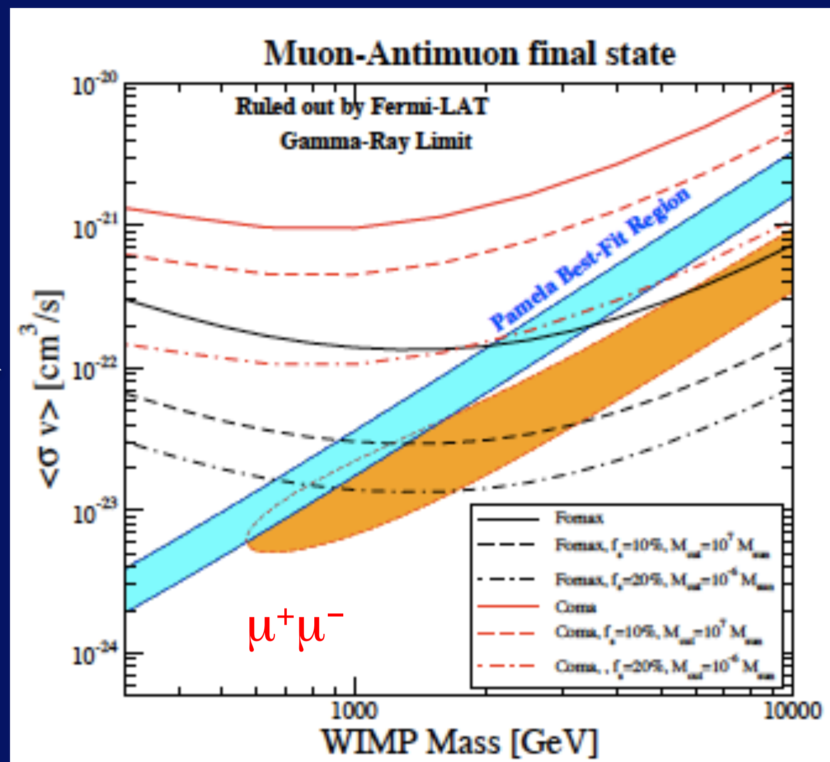


- Constraints are typically weaker than the Fermi dwarf and EGB limits on annihilation.

Ackemann et al. 2010b

Annihilation - “PAMELA” Models

galaxies only



- Exclude models fitting PAMELA data with mass > 1-2 TeV
- Dwarf constraints require assumptions on diffusion

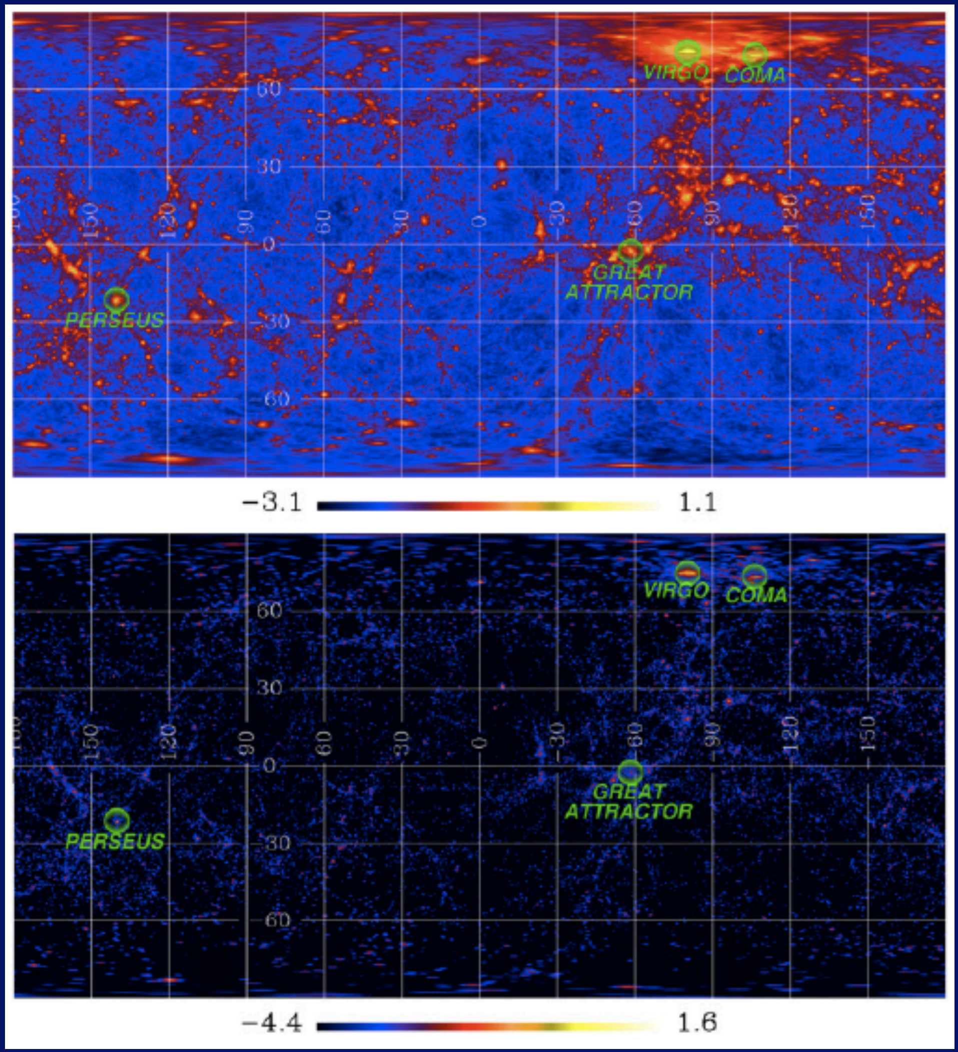
Ackemann et al. 2010b

Large-Scale Structure and Dark Matter

CLUES Project:
constrained simulations to generate sky maps that are consistent with the observed local universe in a ΛCDM cosmology

ρ

ρ^2

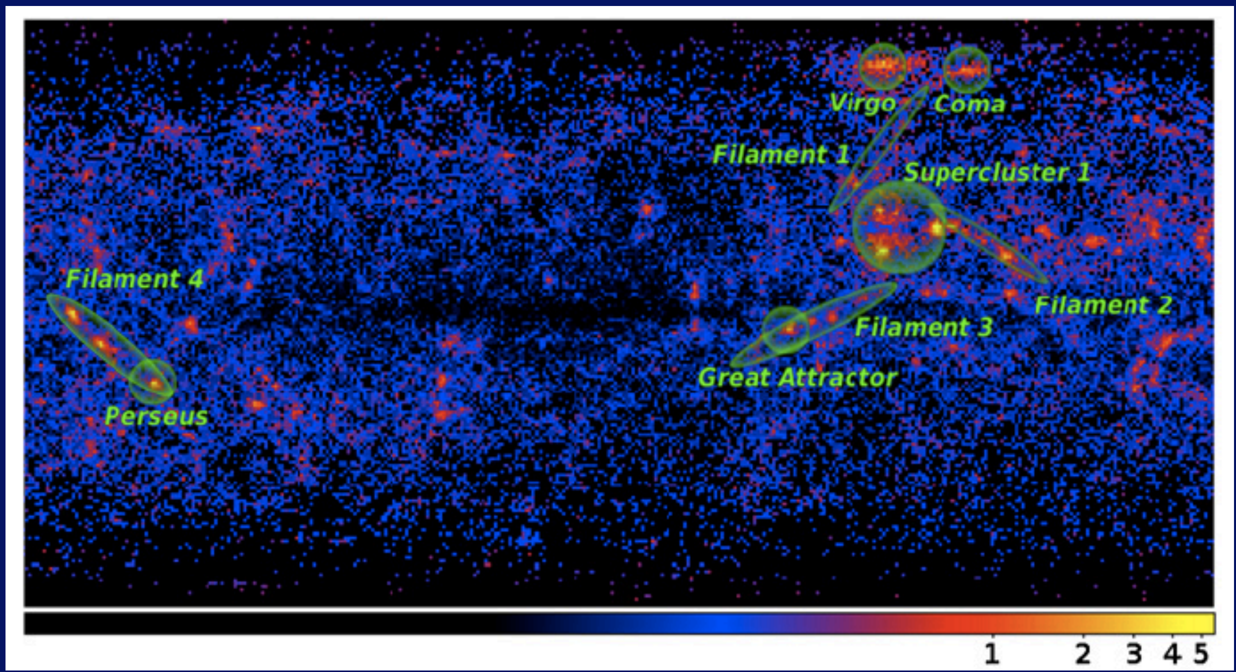


Cuesta et al. 2011

Dark Matter Decay

- Clusters and filaments/superclusters are particularly good targets for decay searches.

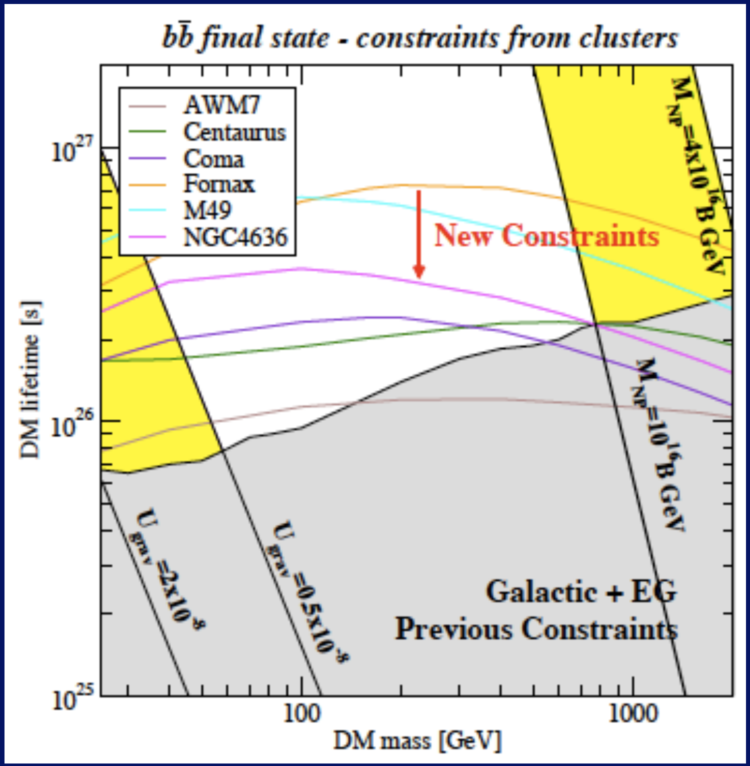
simulated Fermi S/N map



Cuesta et al. 2011

Cluster Constraints: Dark Matter Decay

$b\bar{b}$
final state

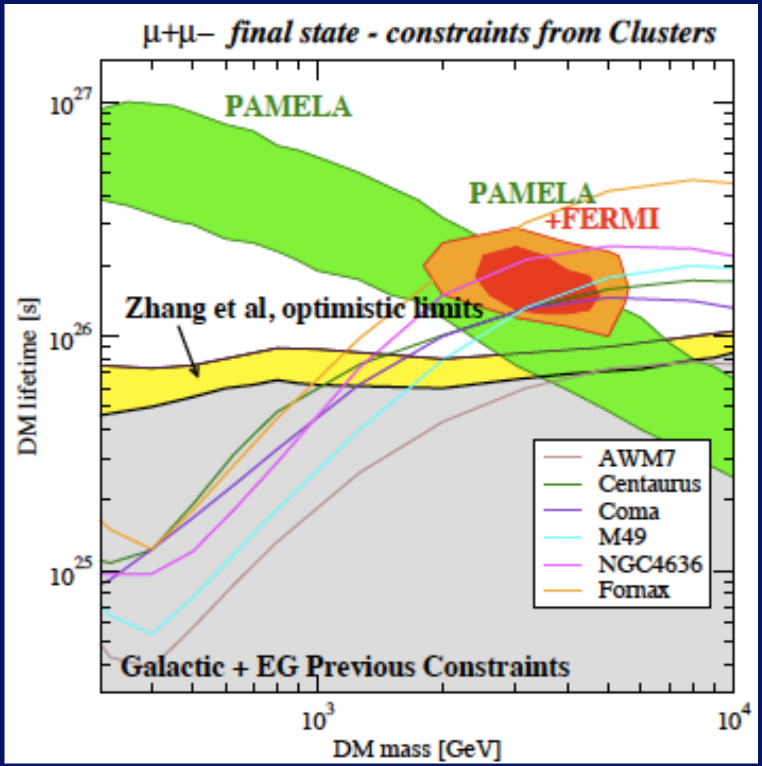


➢ The Fermi non-detection of clusters puts strong limits on the dark matter lifetime for a wide range of particle masses and decay final states.

Dugger, Jeltema, & Profumo 2010

Cluster Constraints: Dark Matter Decay

$\mu^+\mu^-$
final state

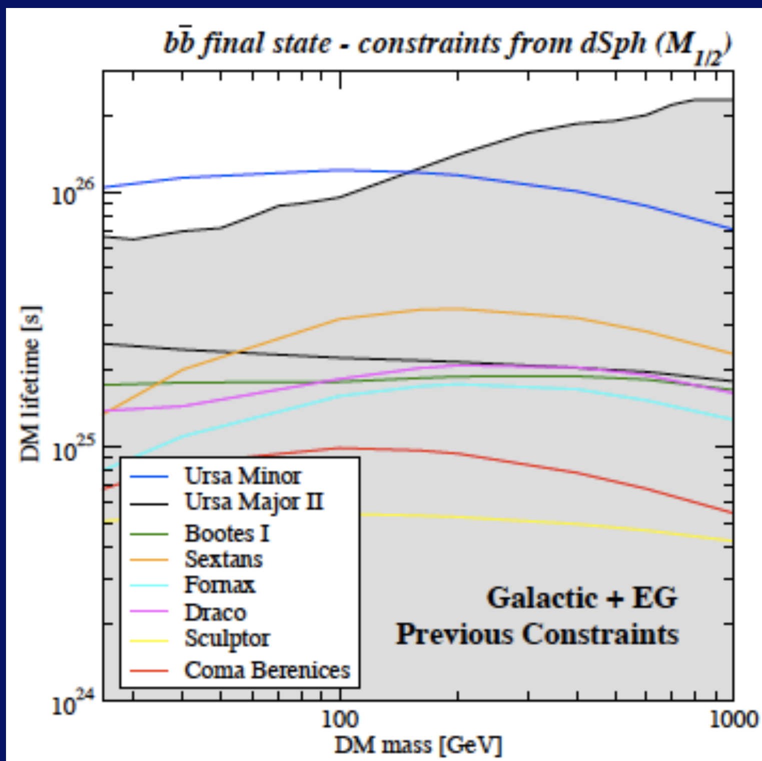


- Strong constraints on the production by dark matter decay of both the PAMELA e^+ fraction and the high-energy feature in the $e^- + e^+$ spectrum measured by Fermi.

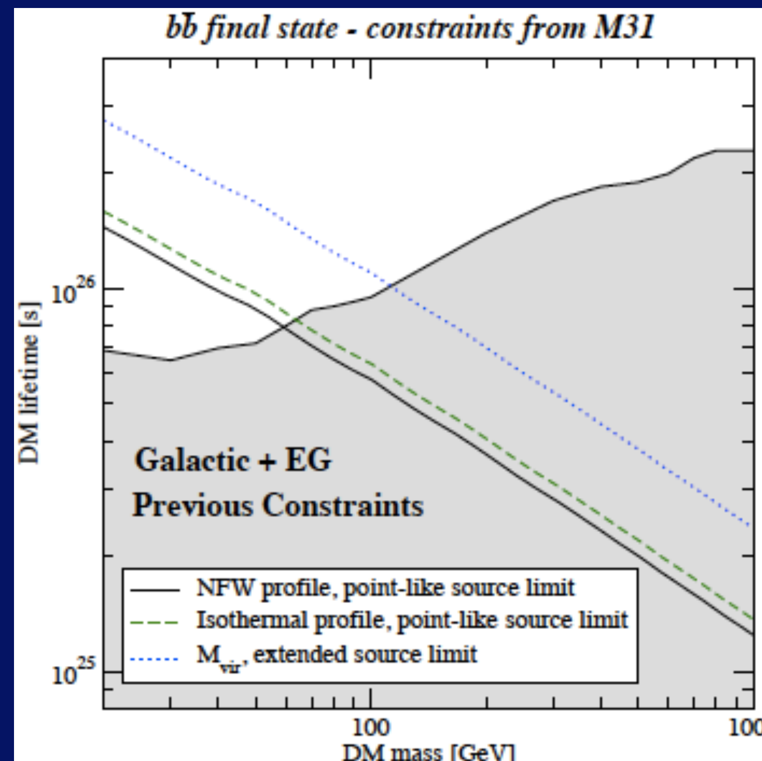
Dugger, Jeltema, & Profumo 2010

Comparison to Dwarfs and M31

Dwarfs



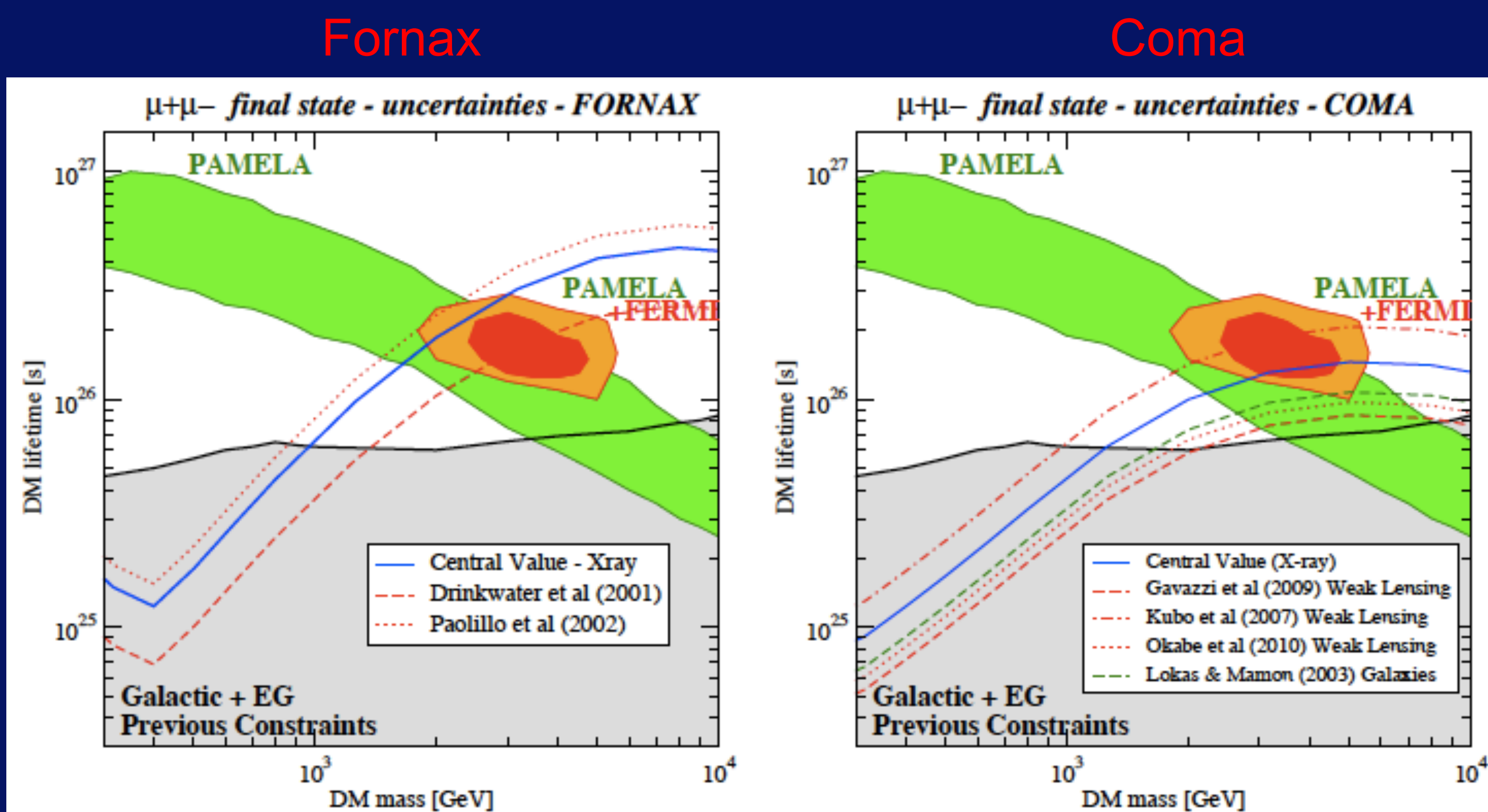
M31



➢ For DM decay clusters typically give stronger constraints than other isolated extragalactic objects.

Dugger, Jeltema, & Profumo 2010

Uncertainty in Decay Constraints



- Comparing independent estimates of the cluster masses the constraints change by less than a factor of two.

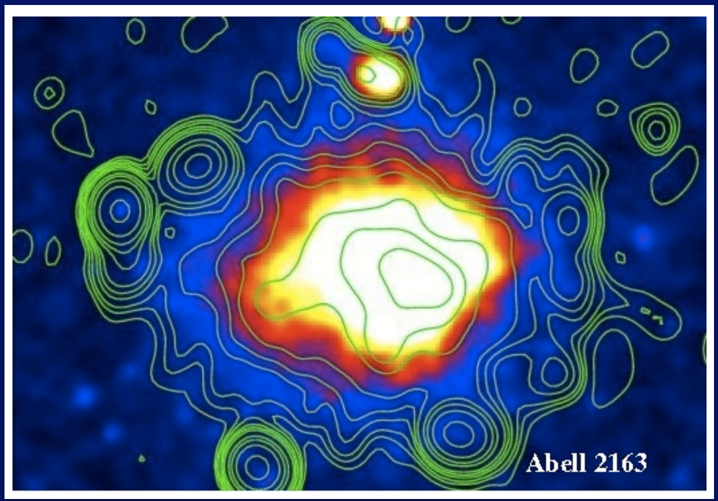
Dugger, Jeltema, & Profumo 2010

Cosmic Rays in Clusters

- Accelerated in accretion/merger shocks, AGN, and SNe
  - CR protons can survive for a long time and add pressure support to the cluster

- Radio synchrotron emission from CR electrons in the cluster magnetic field

  ➔ observed on Mpc scales!



Arnaud 2008, Feretti et al. 2001

- Gamma ray emission:
  - CR proton collisions with ICM
  - IC scattering by CR electrons (also hard X-ray)

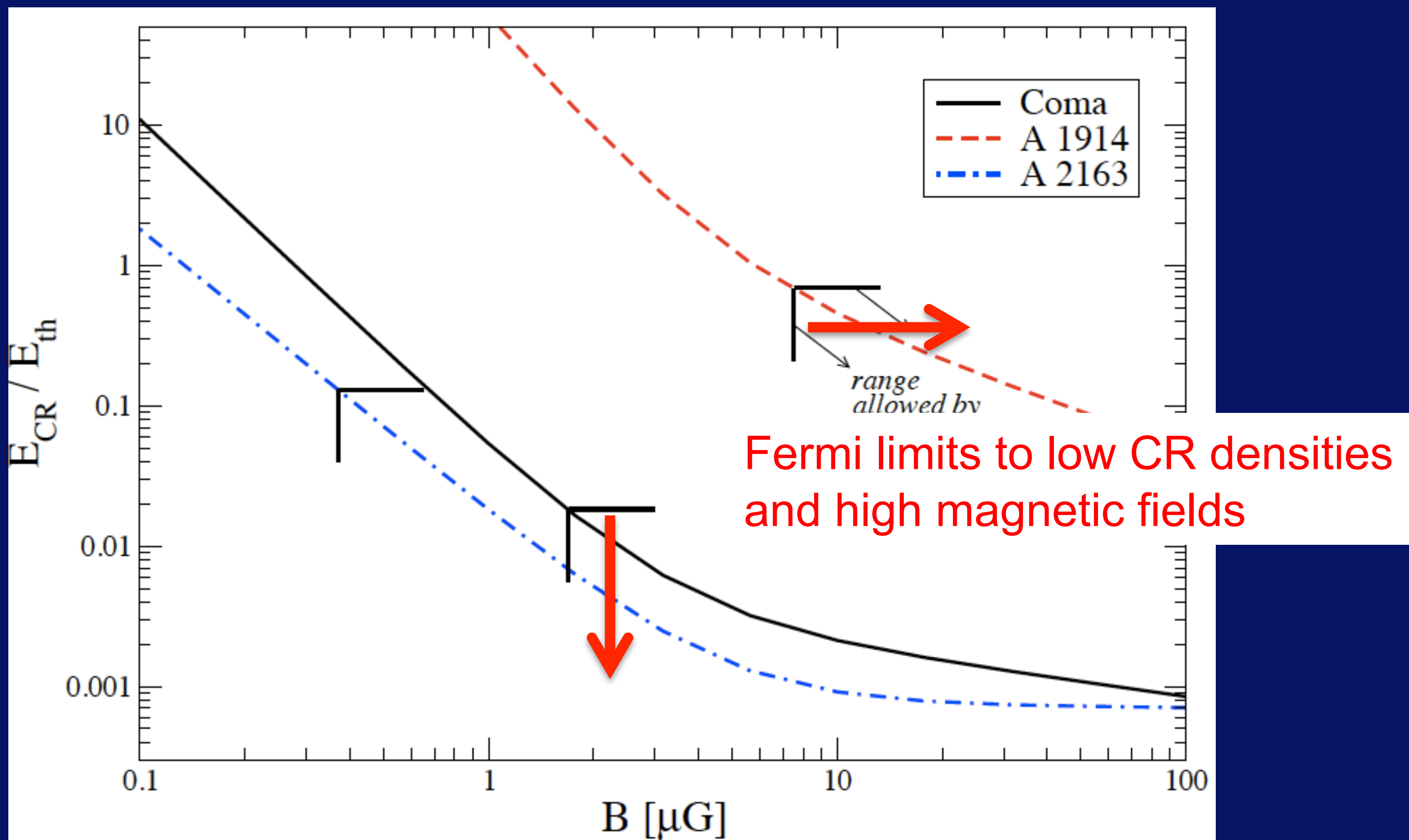
Cosmic Rays: Implications of Fermi Limits

- Low cosmic ray proton densities
  - at most ~ 1-10% of the thermal energy density in nearby clusters
  - little bias in cluster masses = good for cosmology

- Constrains hadronic origin of radio halos
  (i.e. secondary electrons from p-p collisions)
  - To produce the observed radio flux without overproducing gamma-ray emission implies a fairly high minimum average magnetic field in some cases.

Ackermann et al. 2010a, Jeltema & Profumo 2010

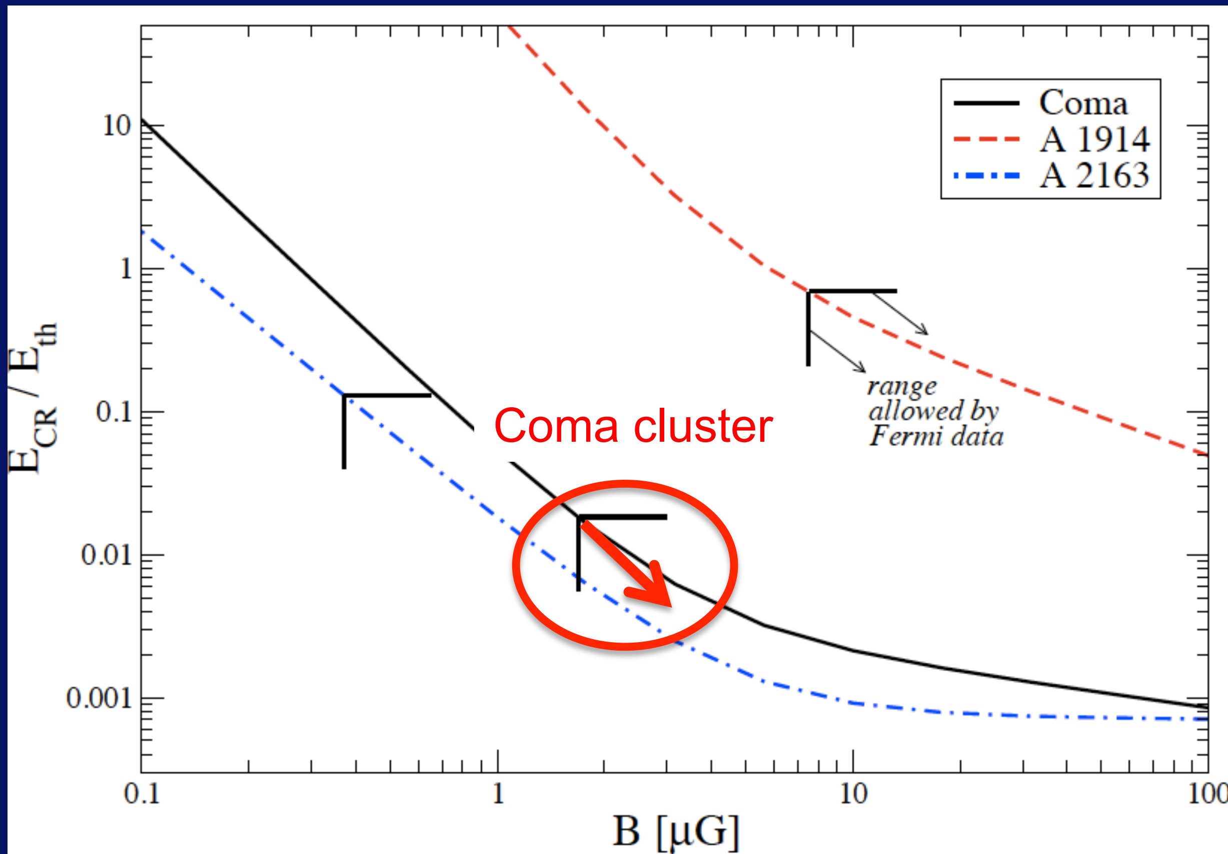
Example Constraints for Radio Halos



- Minimum average magnetic fields as high as ~ 7 μG for nearby radio halo clusters in the hadronic model.

Jeltema & Profumo 2010

Example Constraints for Radio Halos



- ➢ CR energy density < 2% and average B > 1.7 μG compared to RM average B ~ 2 μG (Bonafede et al. 2010)

Jeltema & Profumo 2010

Summary

- The non-detection of clusters by Fermi excludes many dark matter models (annihilation and decay) that could explain the PAMELA positron excess.

- Clusters (and filaments) are particularly powerful probes of dark matter decay.

- The Fermi limits also imply low cosmic ray energy densities in clusters and place constraints on a hadronic origin of radio halos.