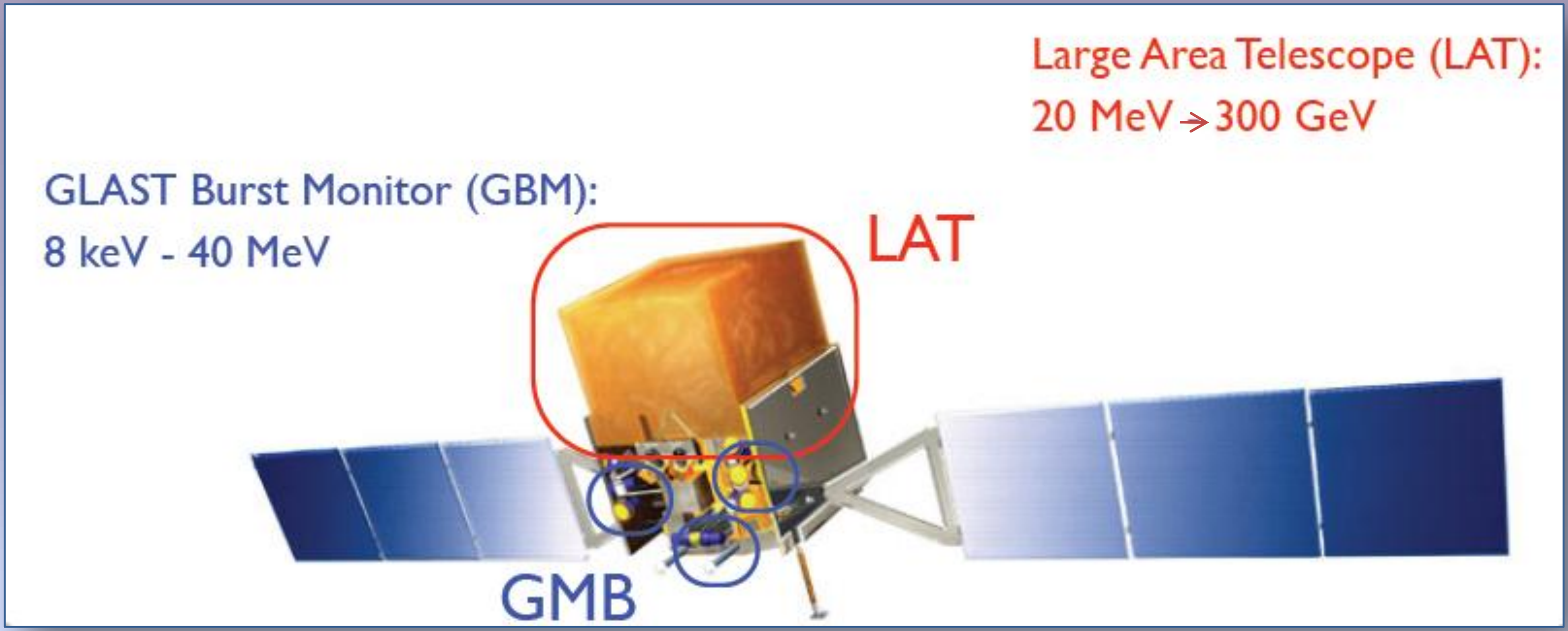
Indirect Dark Matter Searches with the LAT on board Fermi

Beatriz Cañadas
on behalf of the Fermi LAT Collaboration

Outline

- The Fermi Telescope
- Gamma rays from dark matter
- Dark matter searches with Fermi:
  - Line searches
  - Galactic Center
  - Dwarf Galaxies
  - Galactic Clusters
  - Extragalactic isotropic emission
- Conclusions and Outlook

The Fermi Telescope



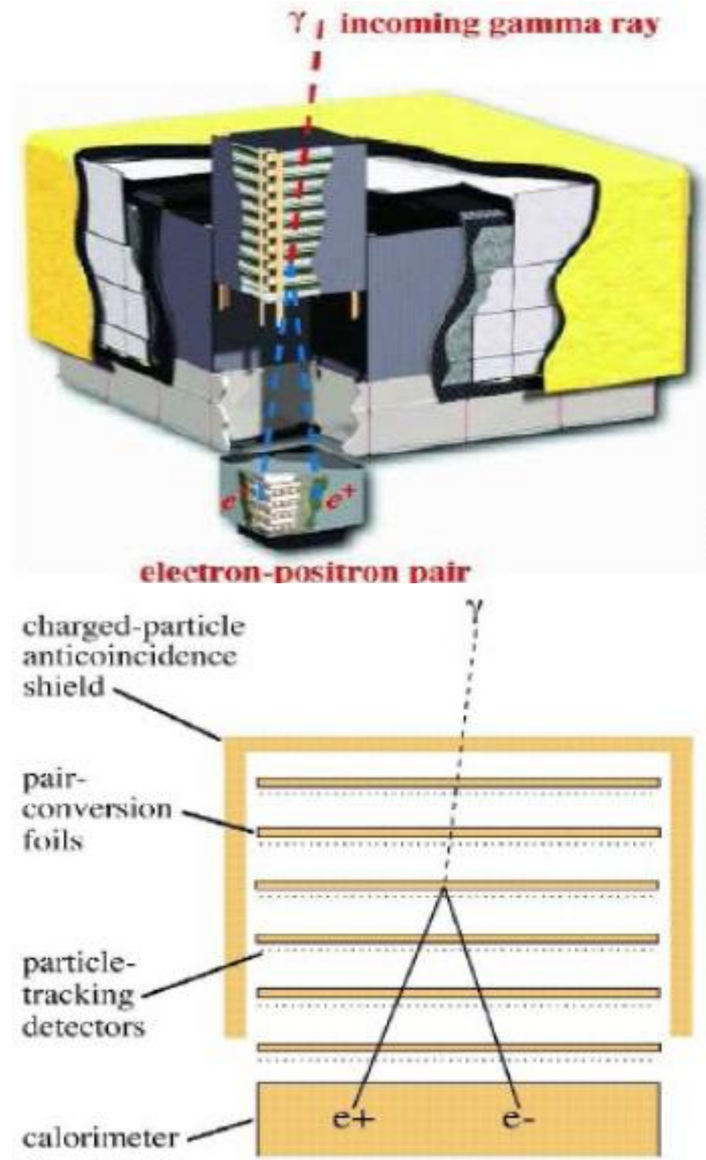
- Fermi was launched by NASA on June 11, 2008 from Cape Canaveral
- Designed to observe the gamma-ray sky in the 20 MeV - >300 GeV energy range
- Survey mode: observes the entire sky every 3 hours (2 orbits)

The Fermi Telescope

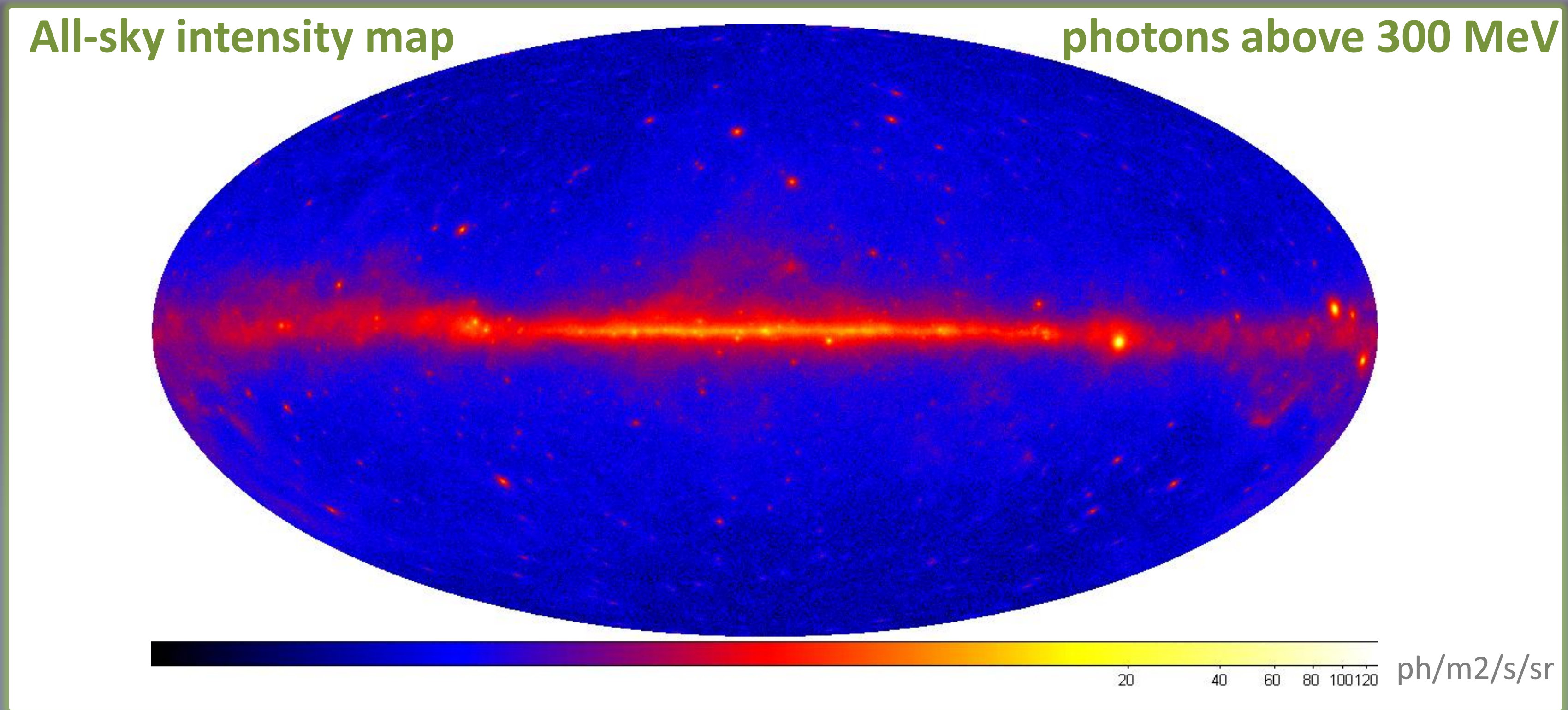
4 x 4 array of identical towers with:

• Precision Si-strip tracker (TKR) with converter foils made of tungsten
• Hodoscopic CsI calorimeter (CAL)
• DAQ and Power supply box

An anticoincidence detector around the telescope distinguishes gamma rays from charged particles



First year Fermi Catalog



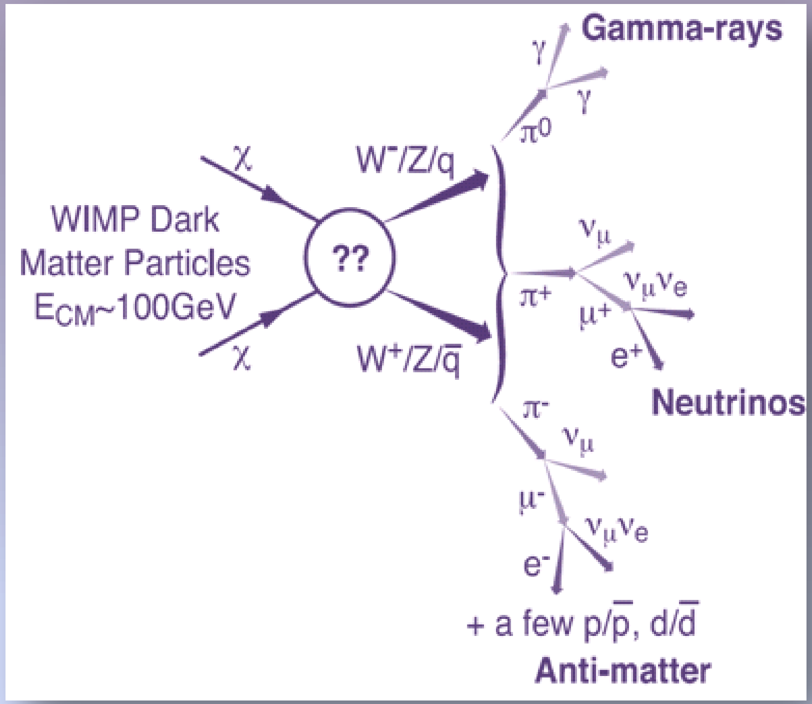
- Fermi 1st year Catalog (Astrophys.J.Suppl. 188:405-436,2010)
- 1451 sources in the 100 MeV to 100 GeV energy range, significance over 4σ

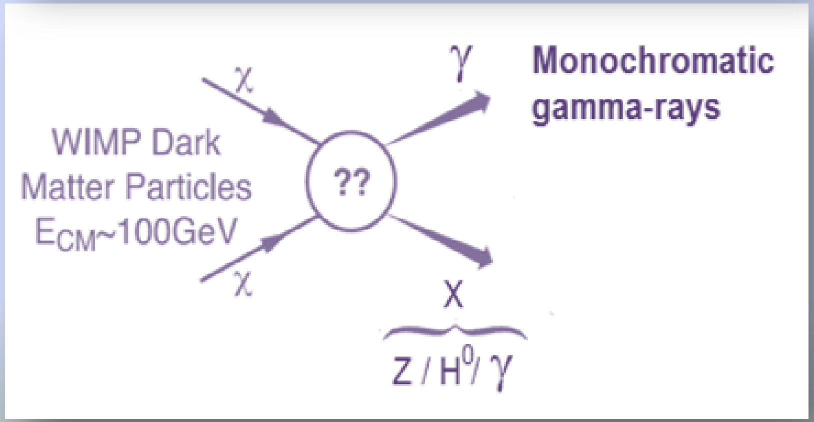
Gamma rays from dark matter

- Dark matter particles might produce gamma rays by **self-annihilation**.
- **Gamma-ray continuum** with cut-off at dark matter mass from hadronization
- Dark matter does not couple directly to photons

Monochromatic gamma ray production suppressed (10^{-1} -10^{-4})

$$E_\gamma = m_{DM}\left(1 - \frac{m_X^2}{4m_{DM}^2}\right)$$





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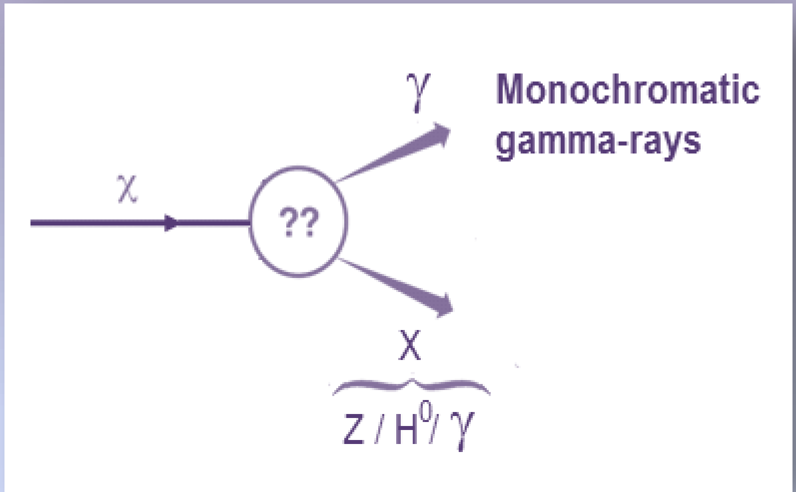
Gamma rays from dark matter

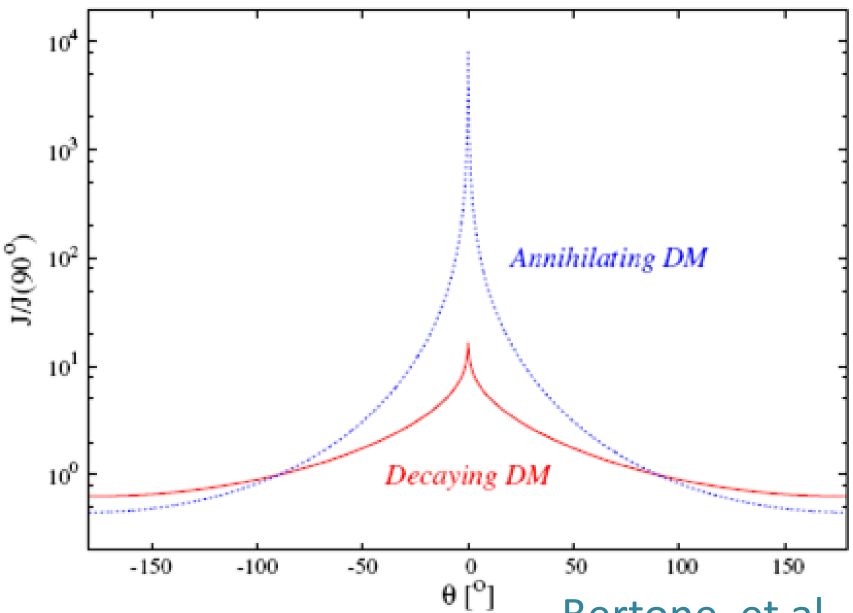
- Pseudo-stable dark matter particles might **decay in gamma rays**, producing monochromatic lines

$$E_\gamma = \frac{m_{DM}}{2}\left(1 - \frac{m_X^2}{m_{DM}^2}\right)$$

- Dark matter lifetime of the order of 10^{27} s is required



Gamma rays from dark matter



Bertone et al. ,2007

Decaying dark matter

$$\frac{d\phi}{dE} = \frac{N_\gamma}{4\pi}\frac{1}{\tau m_{DM}}\int_{l.o.s.} dl(\psi)\rho(l)$$

$$\frac{d\phi}{dE} = \frac{N_\gamma}{8\pi}\frac{<\sigma v>}{m_{DM}^2}\sum_f B_f \frac{dN_f}{dE}\int_{l.o.s.} dl(\psi)\rho(l)^2$$

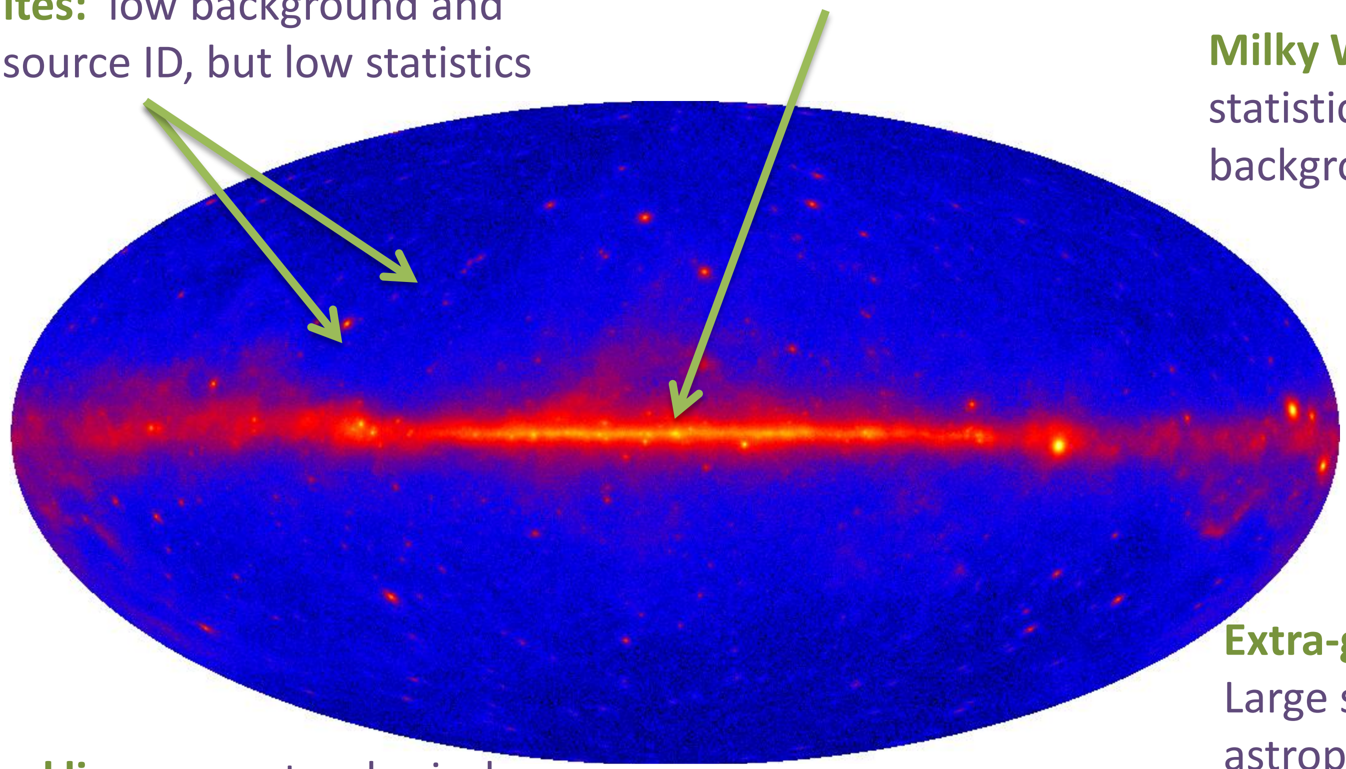
Annihilating dark matter

Where to look for dark matter?

Galactic center: good statistics, but source confusion/diffuse background

Satellites: low background and good source ID, but low statistics

Milky Way halo: large statistics, but diffuse background



Extra-galactic: Large statistics, but astrophysics,galactic diffuse background

Spectral lines: no astrophysical uncertainties, good source ID, but low statistics

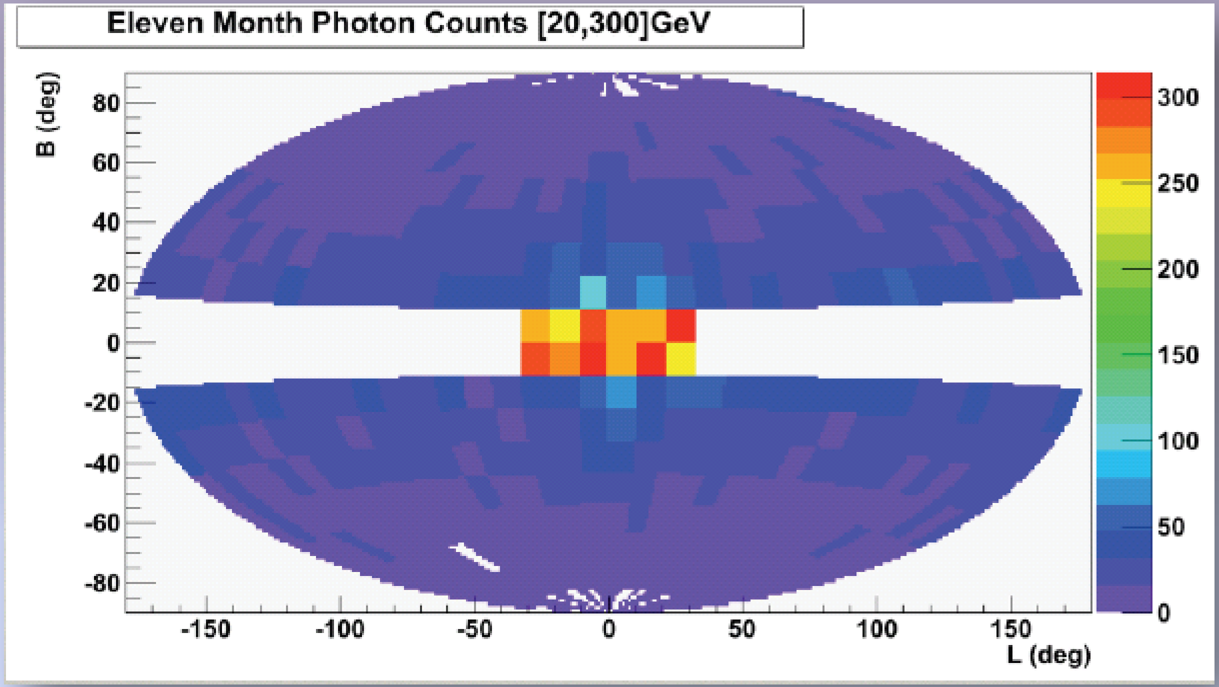
Galaxy clusters: Low background but low statistics

Search for dark matter lines

! Smoking gun signal of dark matter

- Search for lines in the first 11 months of Fermi data (30-200 GeV range)

- The data selection includes additional cuts to remove residual charged particle contamination

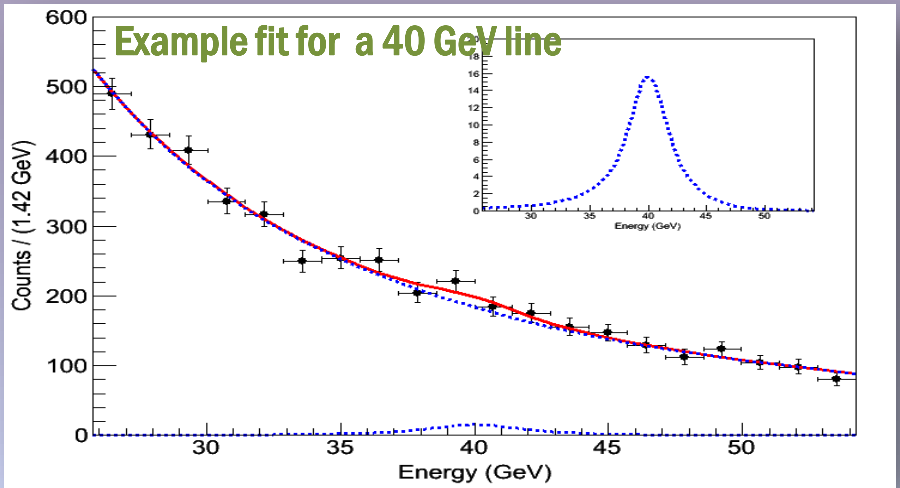


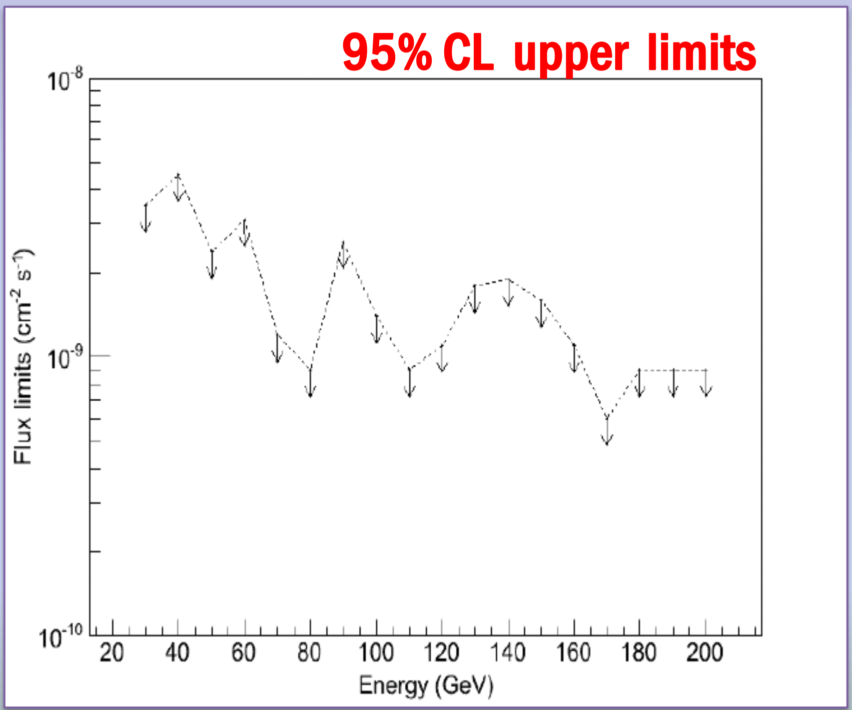
- Search region **|b|>10º** and **30º around galactic center**
- For the region within 1º of the GC, no point source removal was done as this would have removed the GC
- For the remaining part of the ROI, point sources were masked from the analysis using a circle of radius 0.2 deg

Fermi LAT Coll. PRL 104, 091302-08 (2010), arXiv:1001.4836

Search for dark matter lines

- The signal is LAT line response function
- The background is modeled by a power law function and determined by the fit -> no astrophysical uncertainties





No line detection

95% CL upper limits are evaluated

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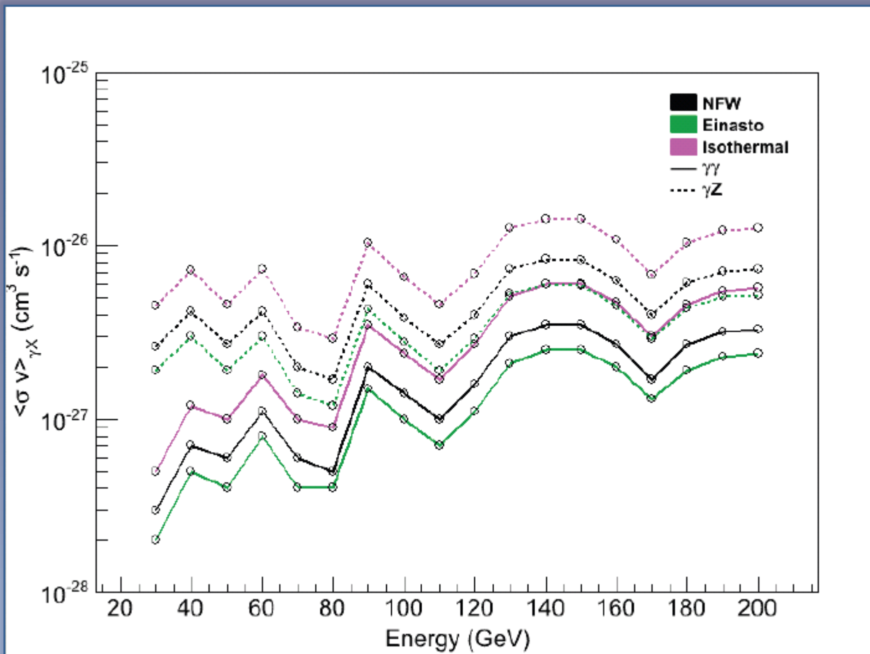
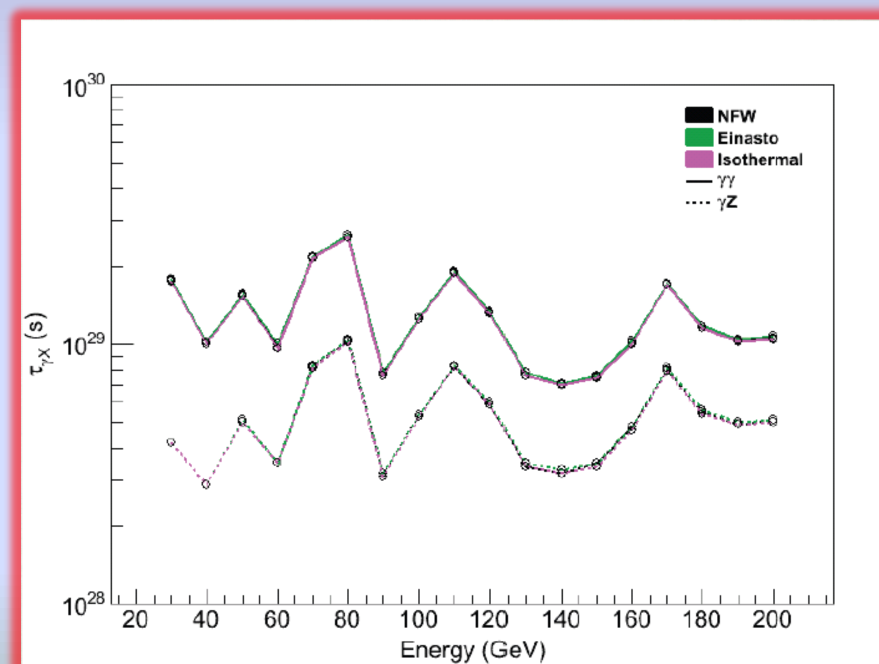
Search for dark matter lines



Upper limits on annihilation cross-section

Upper limits on lifetime for decaying dark matter



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Search for dark matter lines

- Limits on <σv> are too weak (by O(1) or more) to constrain a typical thermal WIMP

- However, theories with non-thermally produced WIMPs (consistent with the observed relic density) can predict large annihilation cross section and have been invoked to partially explain cosmic ray data as the by-product of dark matter annihilation

- Lifetime limits constrain some gravitino decay models with $\tau<10^{29}$s (expected lifetimes: $10^{23} - 10^{37}$ s for $m^{3/2} \sim 100$ GeV)

Fermi LAT Coll. PRL 104, 091302-08 (2010), arXiv:1001.4836

Search for dark matter in the Galactic Center

N-body simulations
+
Observations of galactic dynamics

} Steep dark matter profiles → We expect large dark matter annihilation/decay signal from the GC

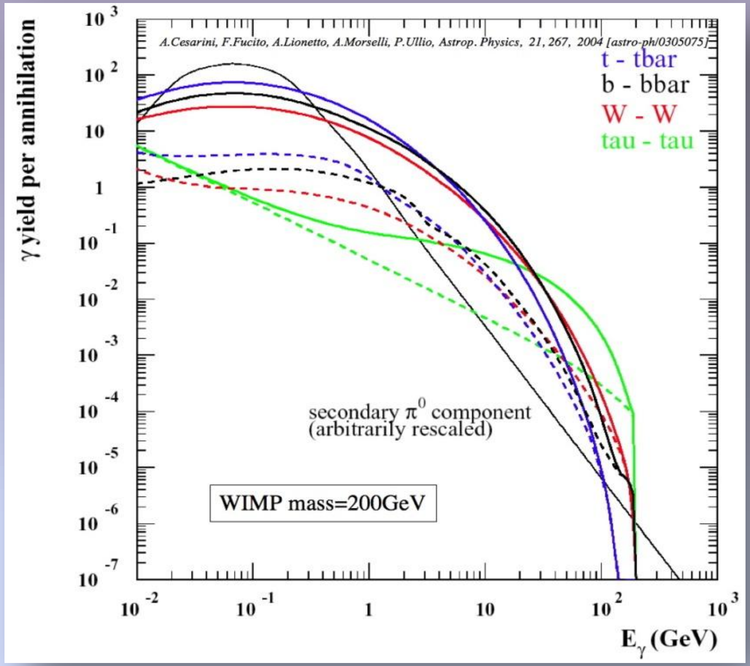
Good understanding of the astrophysical background is crucial to extract a potential DM signal from this complicated region of the sky:

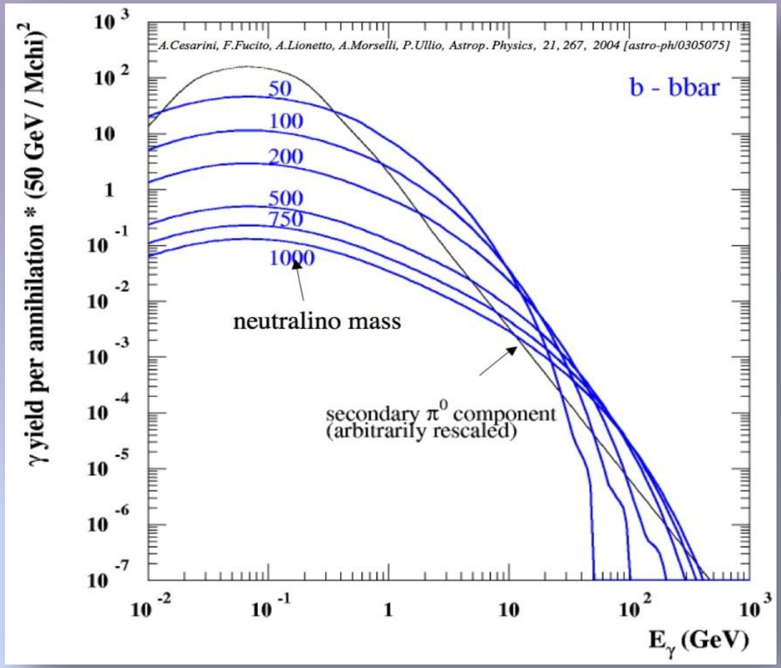
source confusion: energetic sources near to or in the line of sight of the GC

diffuse emission modeling: uncertainties on the intensity and spectra of the CRs and distribution of gas and radiation field targets along the line of sight

Fermi LAT Coll. in preparation, Fermi Symp.
arXiv:0912.3828

Search for dark matter in the Galactic Center
-Dark matter signature -





- Quite distinctive spectrum (no power-law)
- Dark Matter annihilation emission is not point-like.
- ... nor isotropic or Galactic-Ridge like (Dodelson et al 2007, arXiv0711:4621)
- Optimal Region of Interest from 0.5 to 10 deg

Fermi LAT Coll. in preparation, Fermi Symp. arXiv:0912.3828

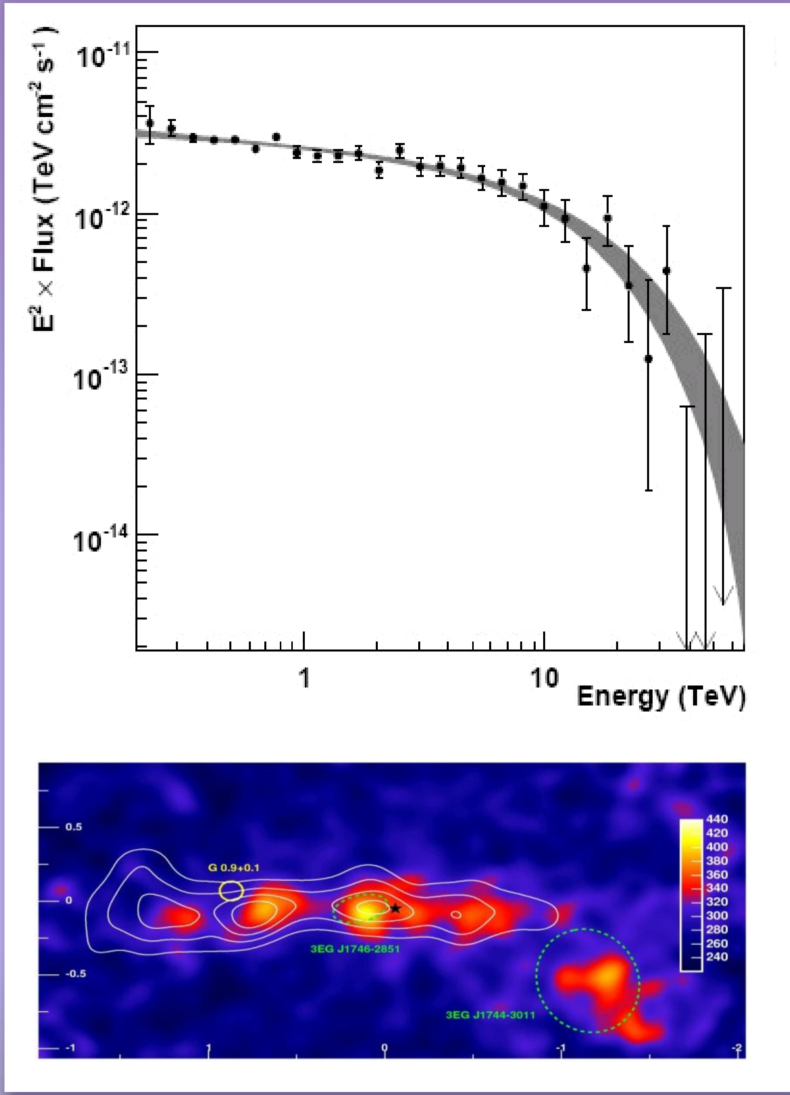
Search for dark matter in the Galactic Center
- Other wavelengths: TeV -

TeV Galactic Center Source:

- Detected by CANGAROO [Tsuchiya et al. 2004], VERITAS [Kosack et al. 2004], HESS [Aharonian et al. 2004] and MAGIC [Albert et al. 2006]

- Energy spectrum compatible with both a power law spectrum with an exponential cut-off and a broken power law spectrum. [Aharonian et al. 2009]

- Position of HESS J1745-290 agrees well with location of other two counterpart candidates, Sgr A∗ and G359.95-0.04 [van Eldik et al. 2007]



Diffuse TeV emission

appears spatially correlated with dense cores of molecular clouds

Fermi LAT Coll. in preparation, Fermi Symp. arXiv:0912.3828

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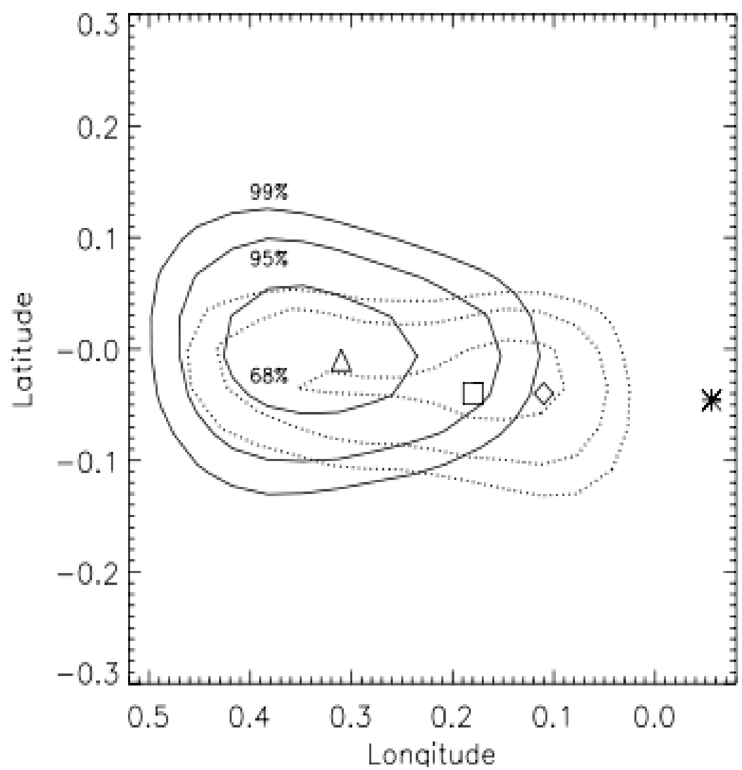
Search for dark matter in the Galactic Center
- Previous GeV Experiments: EGRET -

- 3EG J1746-2851 – GeV point source of detected by EGRET [Mayer-Hasselwander et al. 1998]
- No firm identification with sources in other frequency bands



[Pohl 2005, ApJ 626,174]

Search for dark matter in the Galactic Center
- Galactic and Extragalactic Backgrounds -

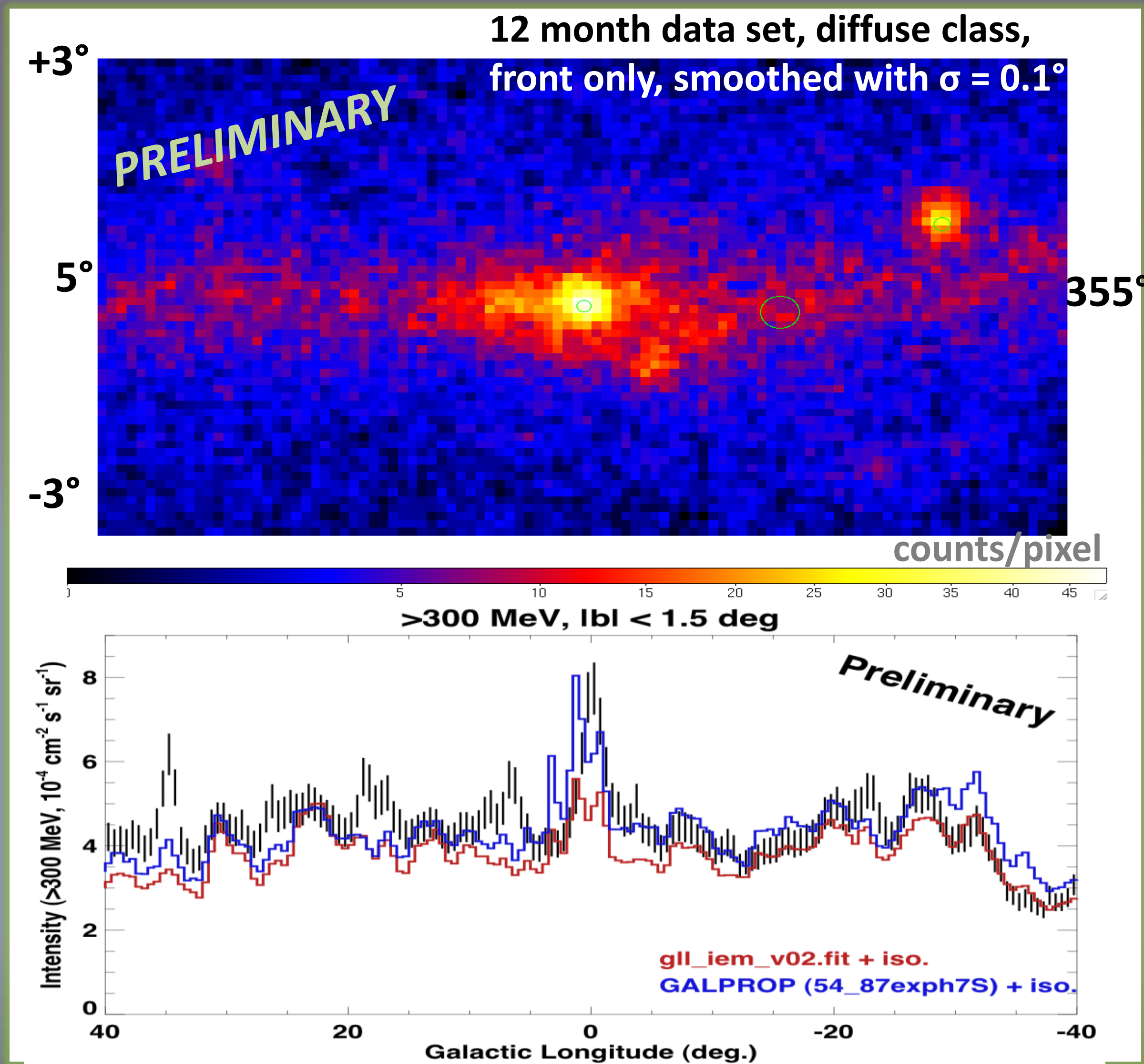
Galactic Diffuse Emission

•Modelled using the GALPROP code, the realization used was *gll−iem−54−87Xexph7S*.

• During the likelihood maximization only the normalization of the GALPROP model is varied, not its components

Extragalactic Diffuse

Modelled as an isotropic emission with a template spectrum.



Fermi LAT Coll. in preparation, Fermi Symp. arXiv:0912.3828

Search for dark matter in the Galactic Center
- Preliminary Analysis-

- 7˚ x 7˚ Region Of Interest centered at RA=266.46˚ Dec=-28.97˚
- 11 months of data
- events from 400 MeV to 100 GeV
- IRFs Pass6_v3
- Diffuse Class events, converting in the front part of the tracker
- Model of the Galactic Center includes:
  - 11 sources from Fermi 1st year Catalog (inside or very near the ROI)
  - Galactic and Extragalactic Diffuse Background
- Binned likelihood analysis using the GTLIKE tool, developed by the Fermi/LAT collaboration

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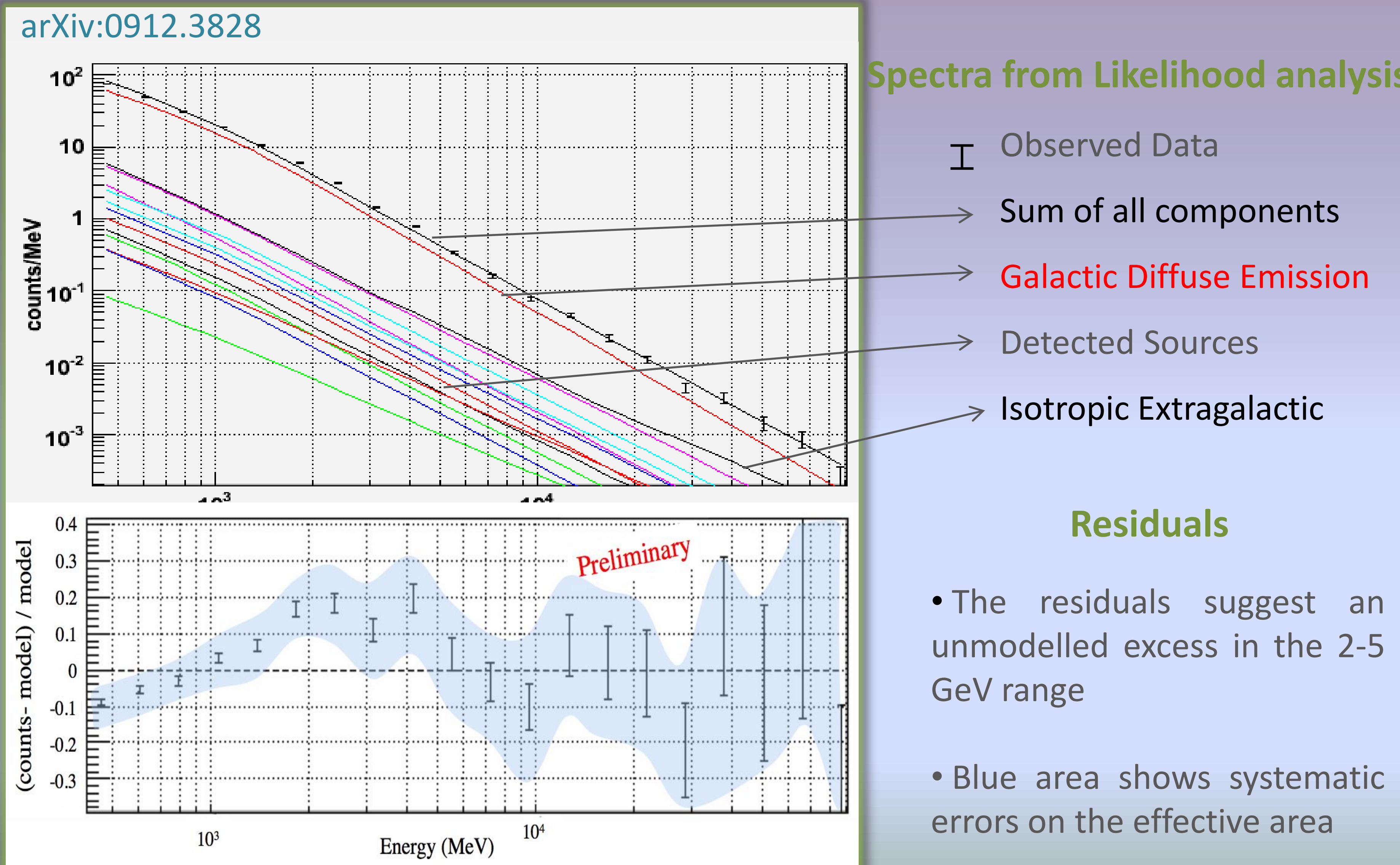
arXiv:0912.3828

Search for dark matter in the Galactic Center
- Results -



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Residuals

- The residuals suggest an unmodelled excess in the 2-5 GeV range
- Blue area shows systematic errors on the effective area

Search for dark matter in the Galactic Center

- Model generally reproduces data well within uncertainties. The model somewhat under-predicts the data in the few GeV range (spatial residuals under investigation)

- Any attempt to disentangle a potential DM signal from the GC region requires a detailed understanding of the conventional astrophysics and instrumental effects

- More prosaic explanations must be ruled out before invoking a contribution from dark matter if an excess is found (e.g. diffuse emission, unresolved sources…)

- Analysis in progress to updated constraints on annihilation cross section

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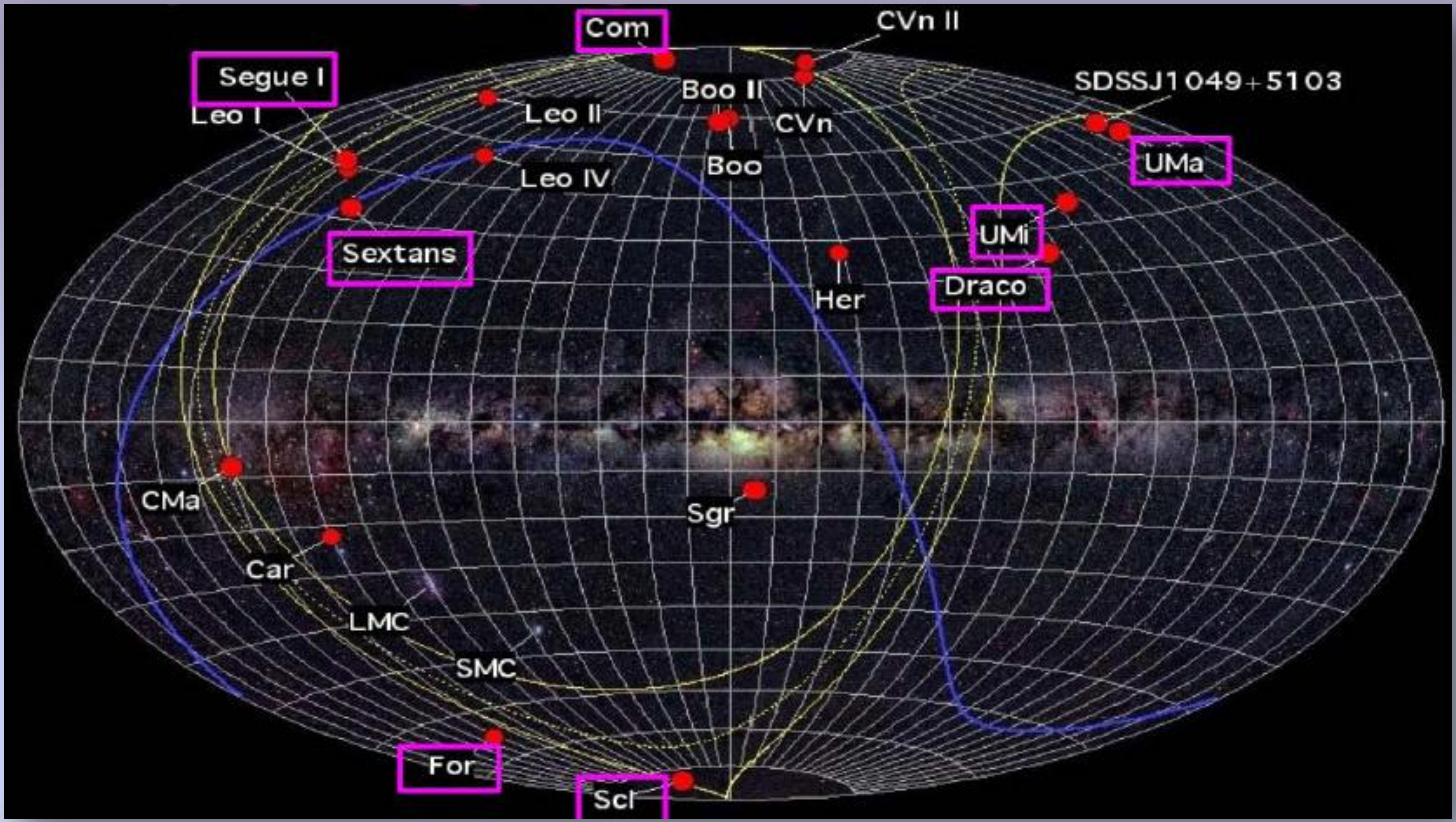
Search for dark matter in dwarf galaxies



Fermi LAT Coll. Astrophys.J. 712,147 (2010)
arXiv:1001.4531

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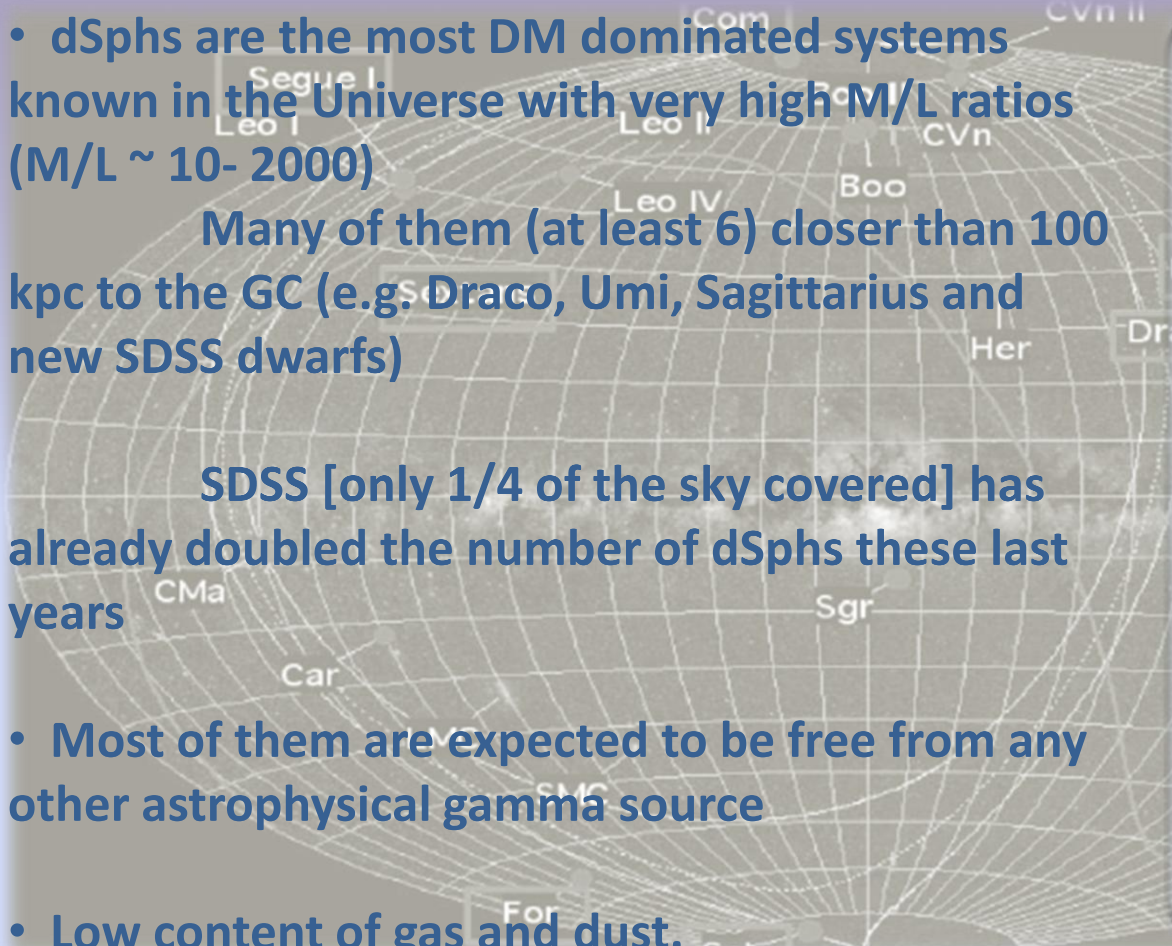

- dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000)

  Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs)

  SDSS [only 1/4 of the sky covered] has already doubled the number of dSphs these last years

- Most of them are expected to be free from any other astrophysical gamma source

- Low content of gas and dust.

Distance: ~30 to 160 kpc

Ursa Major II
Segue 2
Willman 1
Coma Berenices
Bootes II
Bootes I
Ursa Minor
Sculptor
Draco
Sextans
Ursa Major I
Hercules
Fornax
Leo IV

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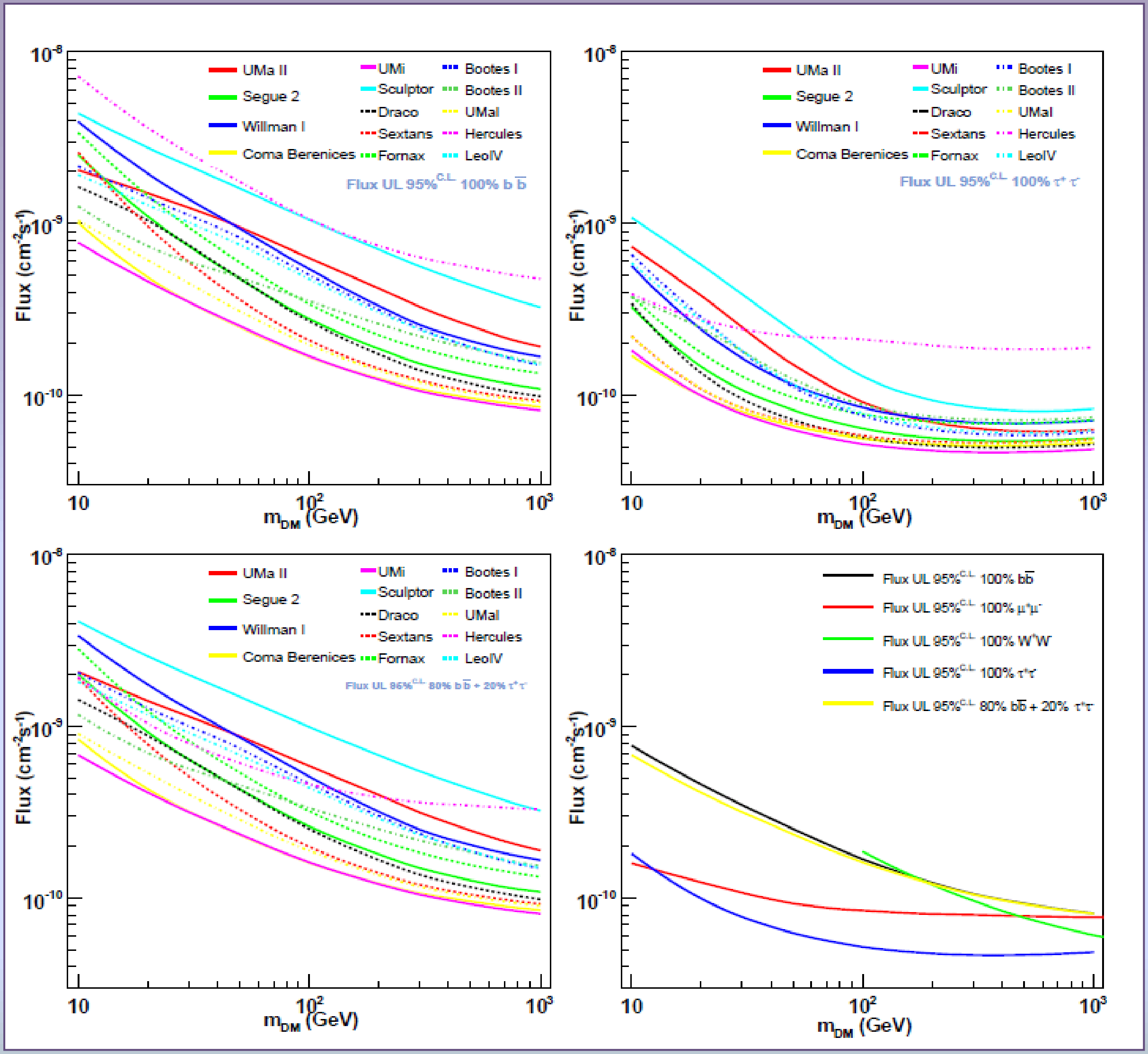
Search for dark matter in dwarf galaxies

No detection by Fermi with 11 months of data.

95% flux upper limits placed for several annihilation final states.

Flux upper limits are combined with the DM density inferred by stellar data for a subset of 8 dSph (based on quality of stellar data) to extract constraints on <σv> vs WIMP mass for specific DM models assuming NFW density profile



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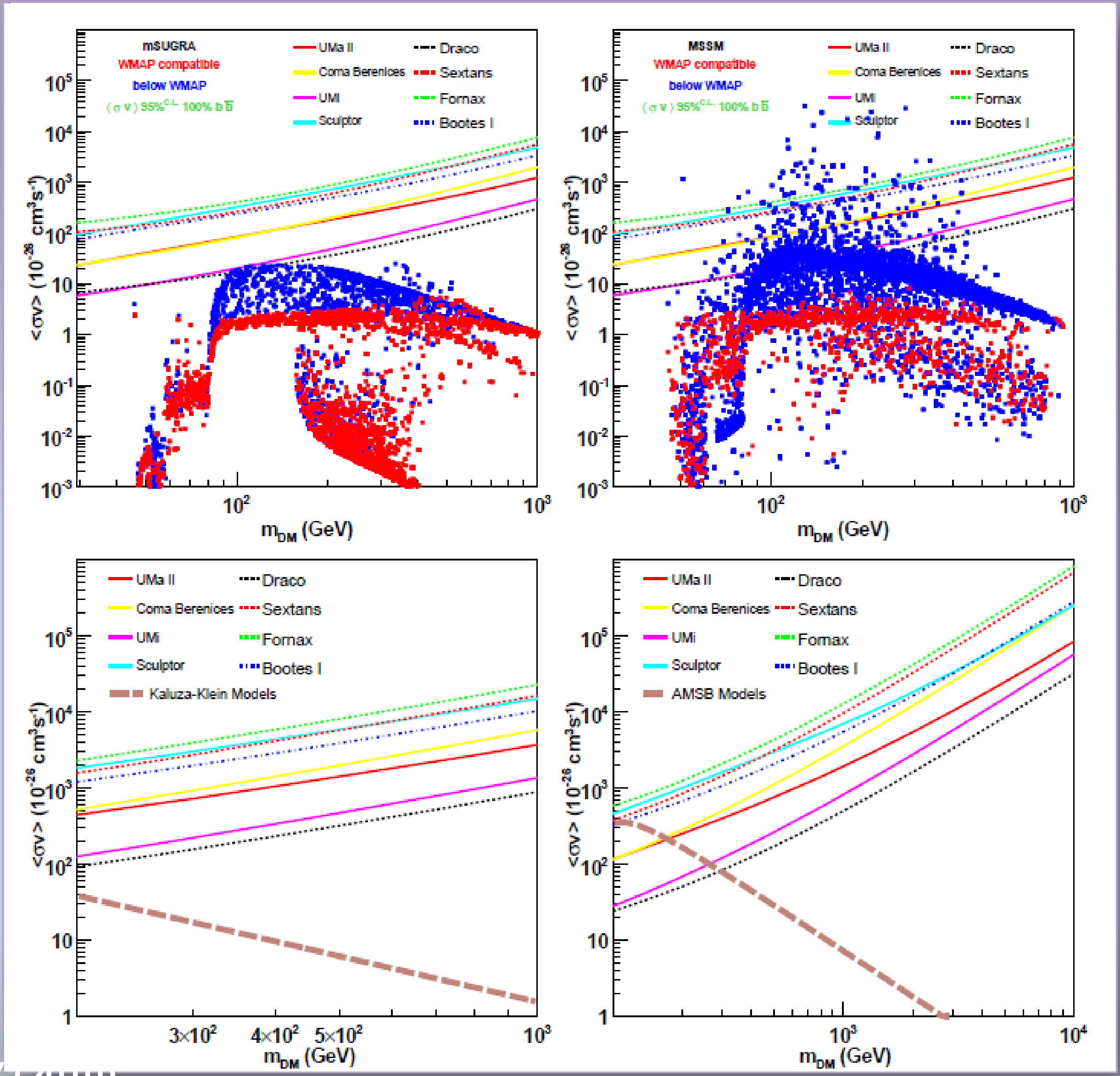

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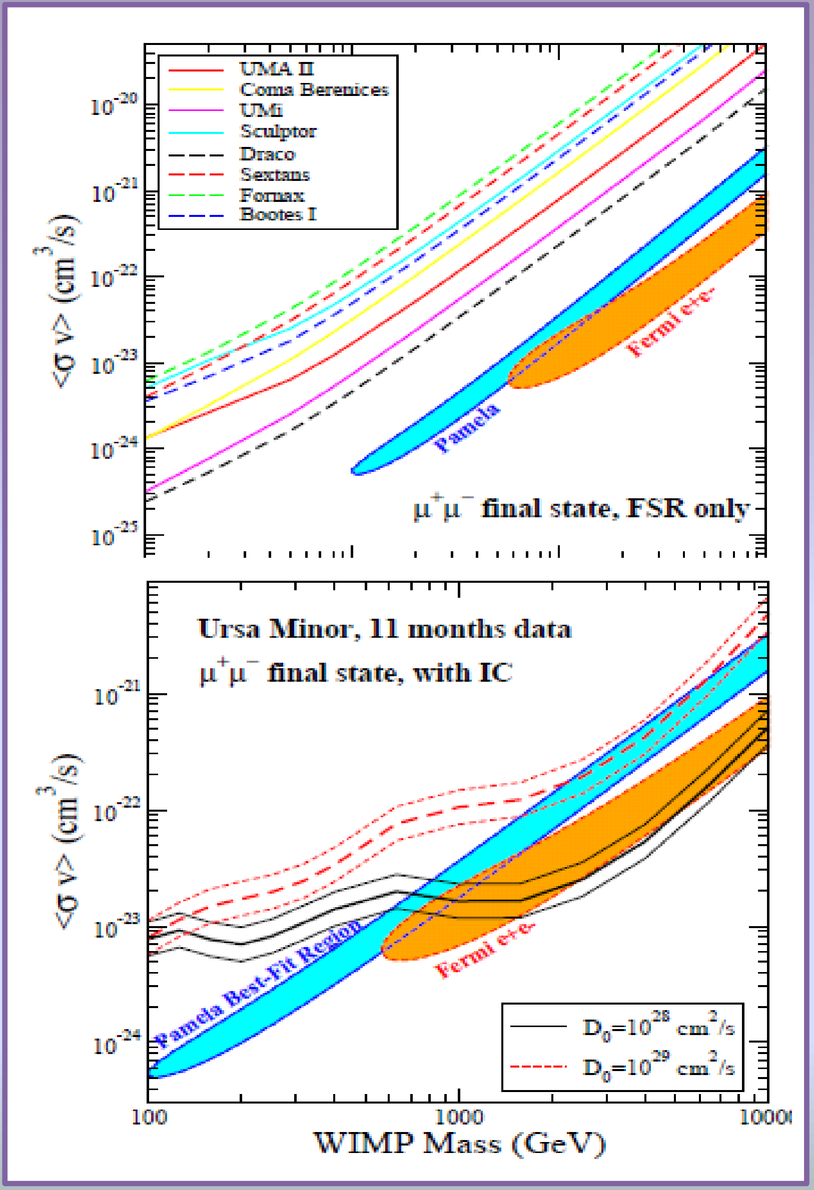
Comparison to models proposed to fit PAMELA and FERMI data on e^+/e^- data

These imply **leptonic final states** to avoid over-production of antiprotons

$\mu^+\mu^-$



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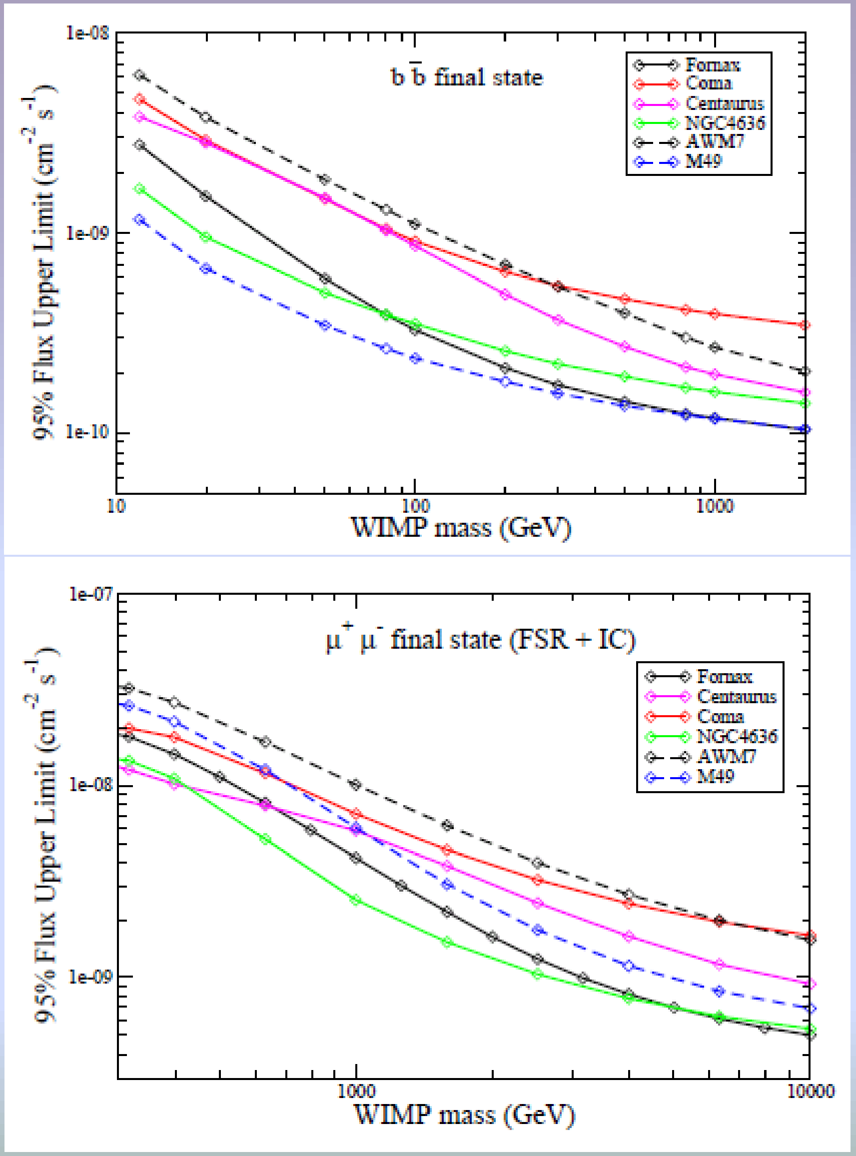
Search for dark matter in galaxy clusters

- Clusters are more distant but more massive than dSphs

- Gamma-ray emission from:
  - annihilating dm
  - cosmic ray population
  - IC of relativistic e^-

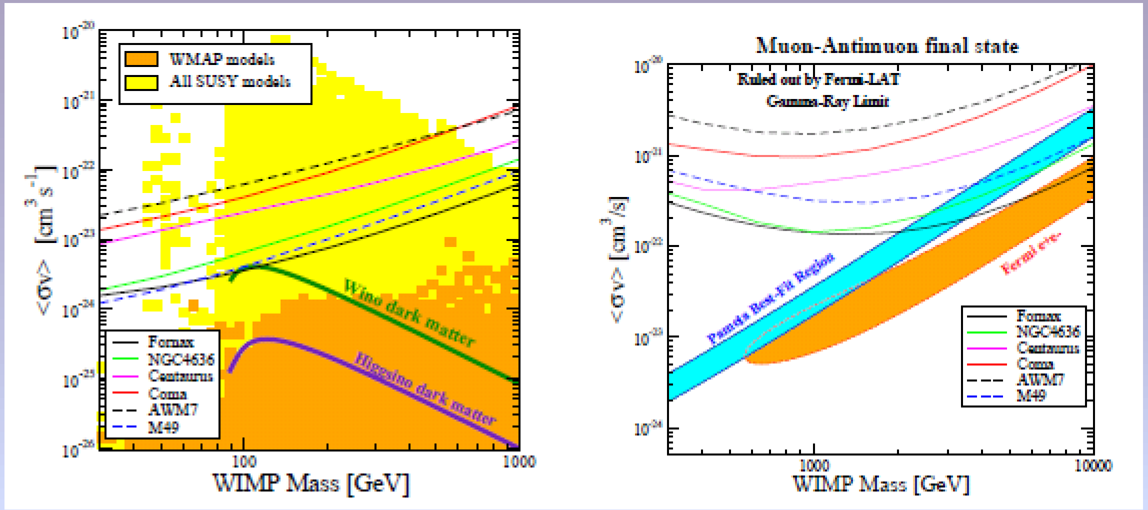
95% CL flux upper limits placed for several annihilation final states, including leptophilic models.

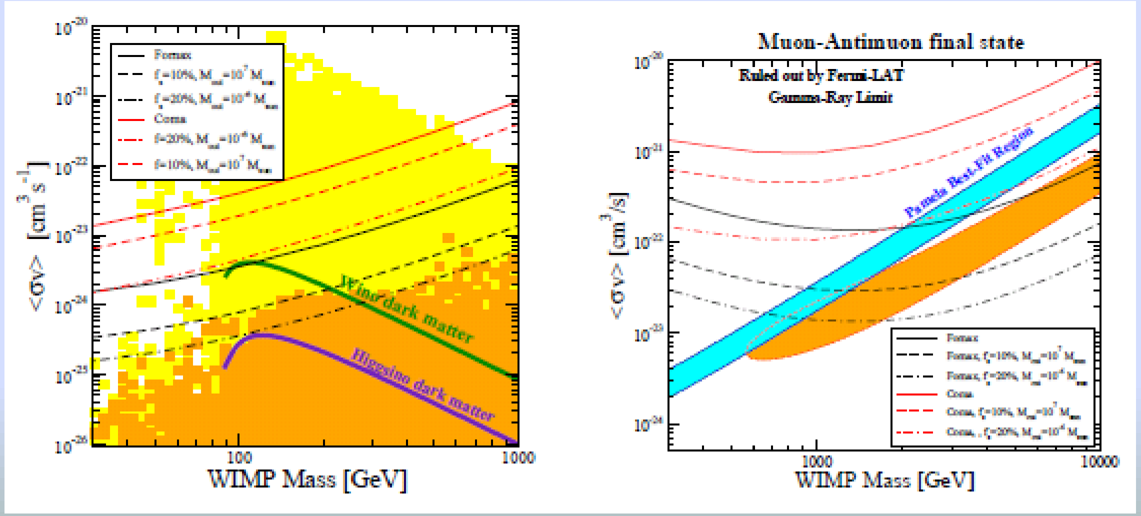


Fermi LAT Coll. JCAP 1005:025, 2010
arXiv:1002.2239

Search for dark matter in galaxy clusters

- Constraints on dark matter annihilation models assuming NFW density profile
    - Impact of substructures also considered
- MSSM, mSUGRA and LEPTOPHILIC models analysed.





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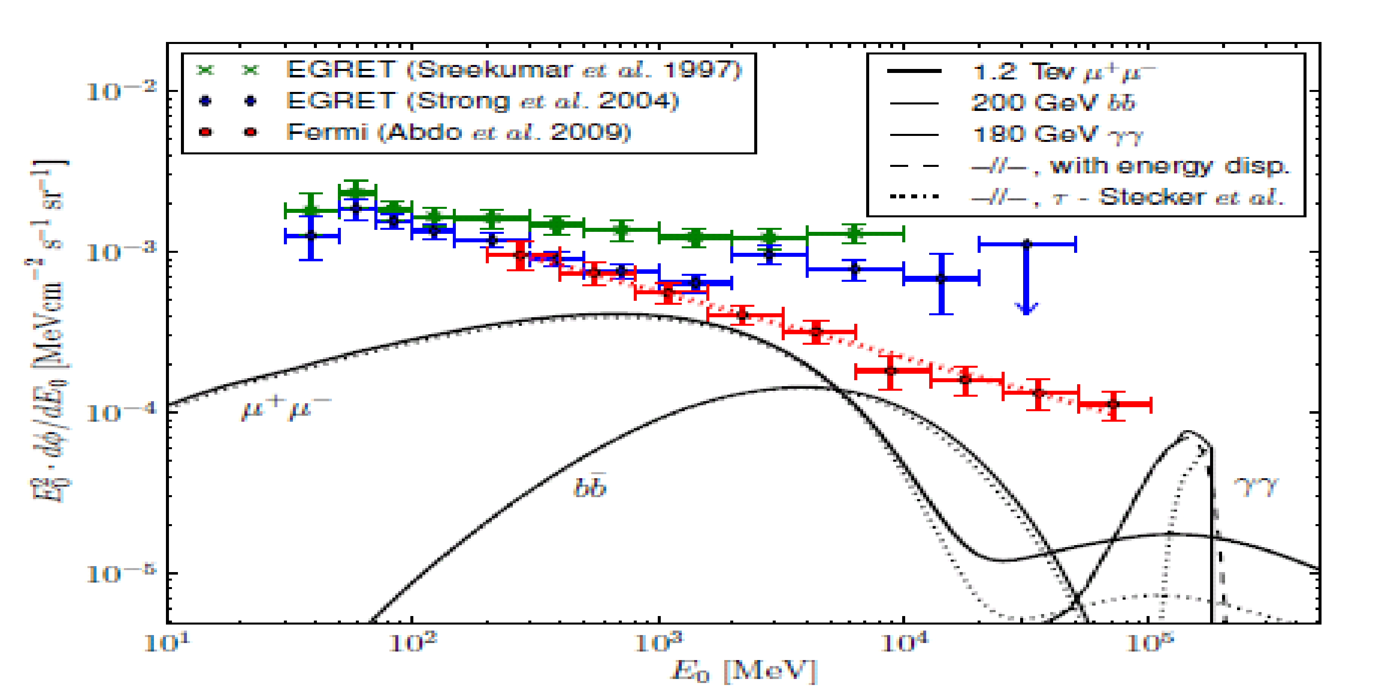
Search for dark matter in galaxy clusters

- Strong constraints on leptophilic DM models can be derived with Fermi non detection of galaxy clusters (when the IC contribution off the CMB of secondary electrons from DM annihilation is included in the signal)

- Constraints for a b-bbar final state are weaker than or comparable to (depending on the assumption on substructures) the ones obtained with dSph

Fermi LAT Coll. JCAP 1005:025, 2010
arXiv:1002.2239

Search for cosmological dark matter



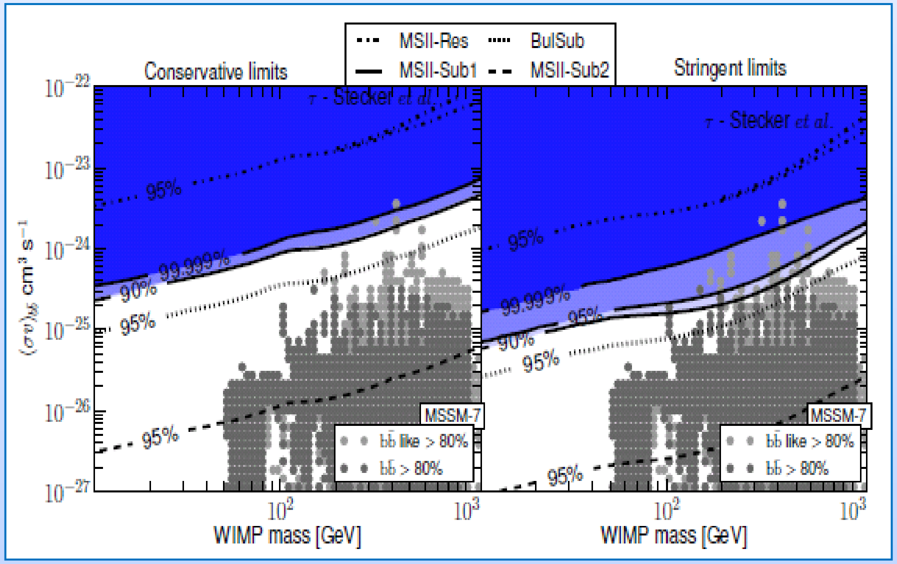
- Measurements of isotropic diffuse emission have been used to derive dark matter annihilation limits from all halos at all redshifts

- Contributions from extragalactic contributions

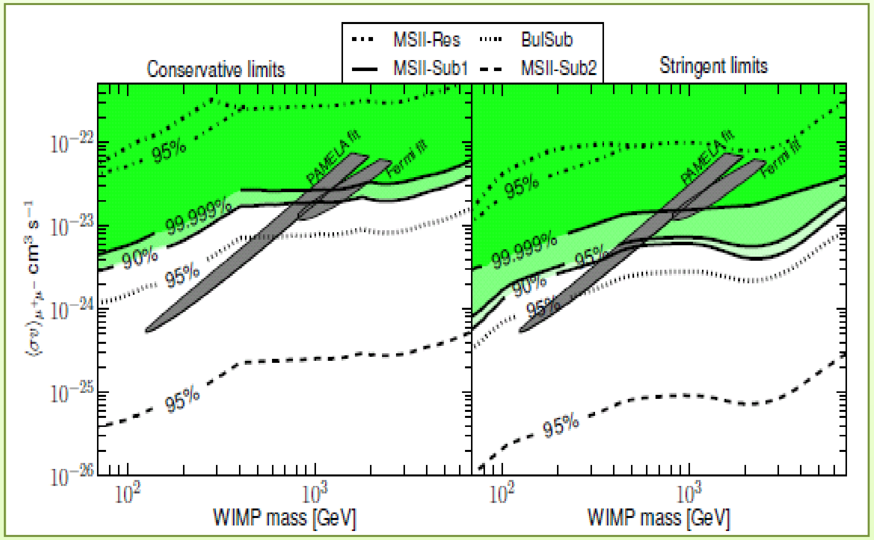
$$\frac{d\phi_\gamma}{dE_0} = \frac{\langle\sigma v\rangle}{8\pi}\frac{c}{H_0}\frac{\bar{\rho}_0^2}{m_{DM}^2}\int dz(1+z)^3\frac{\Delta^2(z)}{h(z)}\frac{dN_\gamma(E_0(1+z))}{dE}e^{-\tau(z,E_0)},$$

Fermi LAT Coll. JCAP 1004:014, 2010
arXiv:1002.4415

Search for cosmological dark matter



Limits for annihilation into b-bbar pairs



Limits for leptophilic models

Fermi LAT Coll. JCAP 1004:014, 2010
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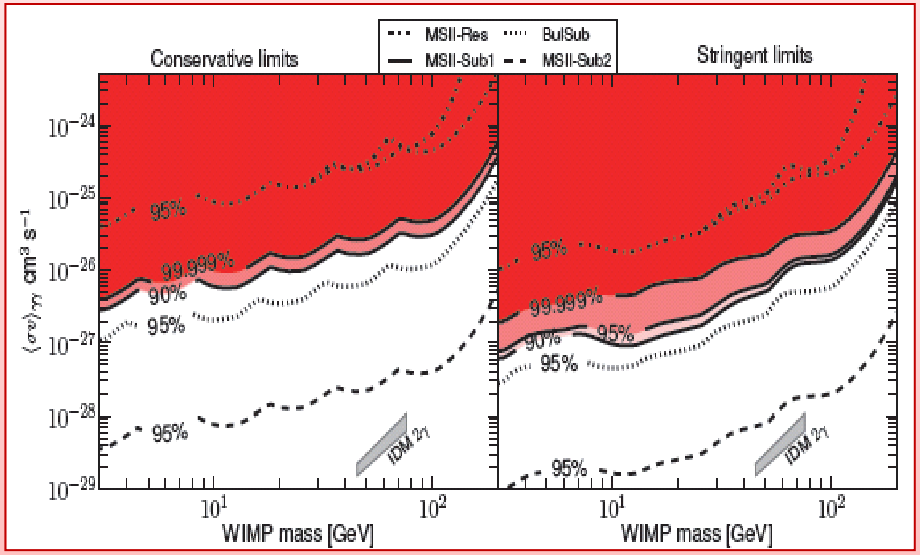
Search for cosmological dark matter



Limits for annihilation into photon pairs

✓ Limits can be very constraining for many interesting DM models, however the uncertainties on the evolution of the DM structure are large.

Fermi LAT Coll. JCAP 1004:014, 2010
arXiv:1002.4415

Conclusions and outlook

No discovery (yet)....

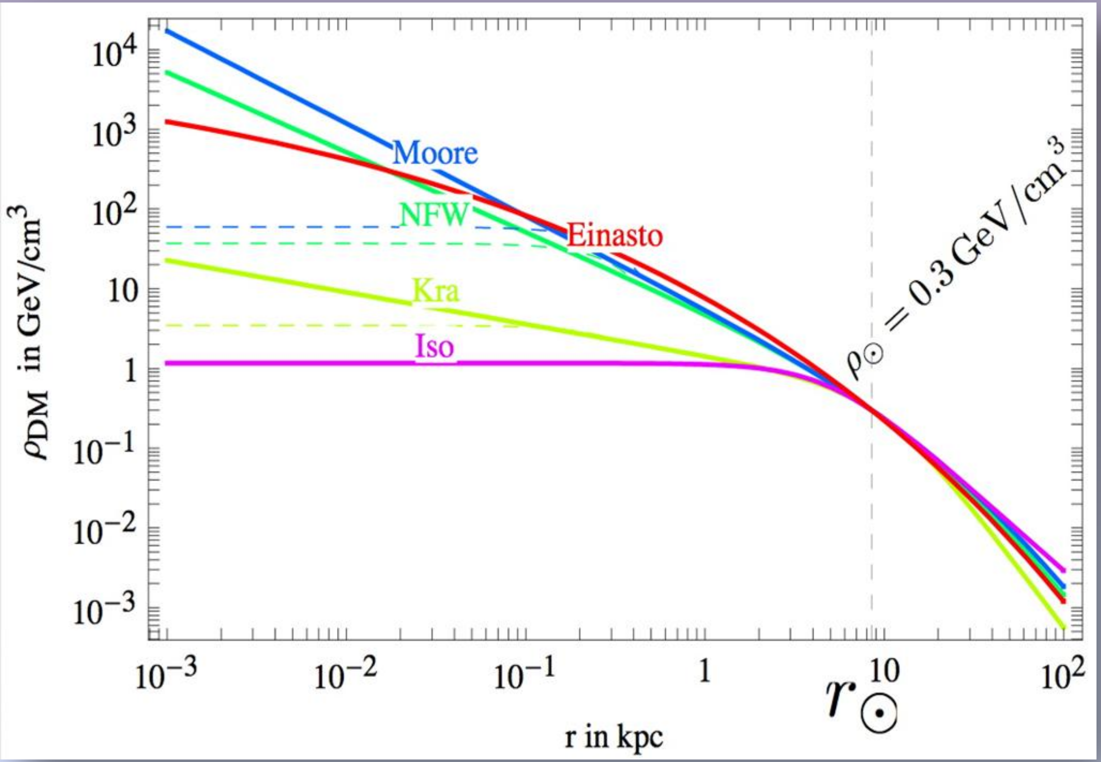
.... however promising constraints on the nature of DM have been placed (exclusion of a lot of DM models that explain the origin of the Fermi/Pamela lepton excess)

In addition to increased statistics, better understanding of the astrophysical and instrumental background will improve our ability to reliably extract a potential signal of new physics or set stronger constraints

Further improvements are anticipated for analysis that benefits from multi-wavelength observations (for example galactic center, dwarf spheroidal galaxies and DM satellites)

Dark matter density profile

- DM density profile fundamental for indirect gamma-ray detection
- DM distribution not experimentally known in the GC region
- Parametrization from N-Body Simulations



$$\rho(r) = \frac{\rho_s}{(r/r_s)^\gamma (1 + (r/r_s)^\alpha)^{(\beta-\gamma)/\alpha}}$$

$$\rho(r) = \frac{\rho_s}{2^{(\beta-\gamma)}} exp\left[-\frac{2}{\alpha}\left\{\left(\frac{r}{r_s}\right)^\alpha - 1\right\}\right]$$

α=1.5 β=3 γ=1.5 r_s = 30 kpc

α=1 β=3 γ=1 r_s = 20 kpc

α=2 β=2 γ=0 r_s = 5 kpc

α=0.17 r_s = 20 kpc

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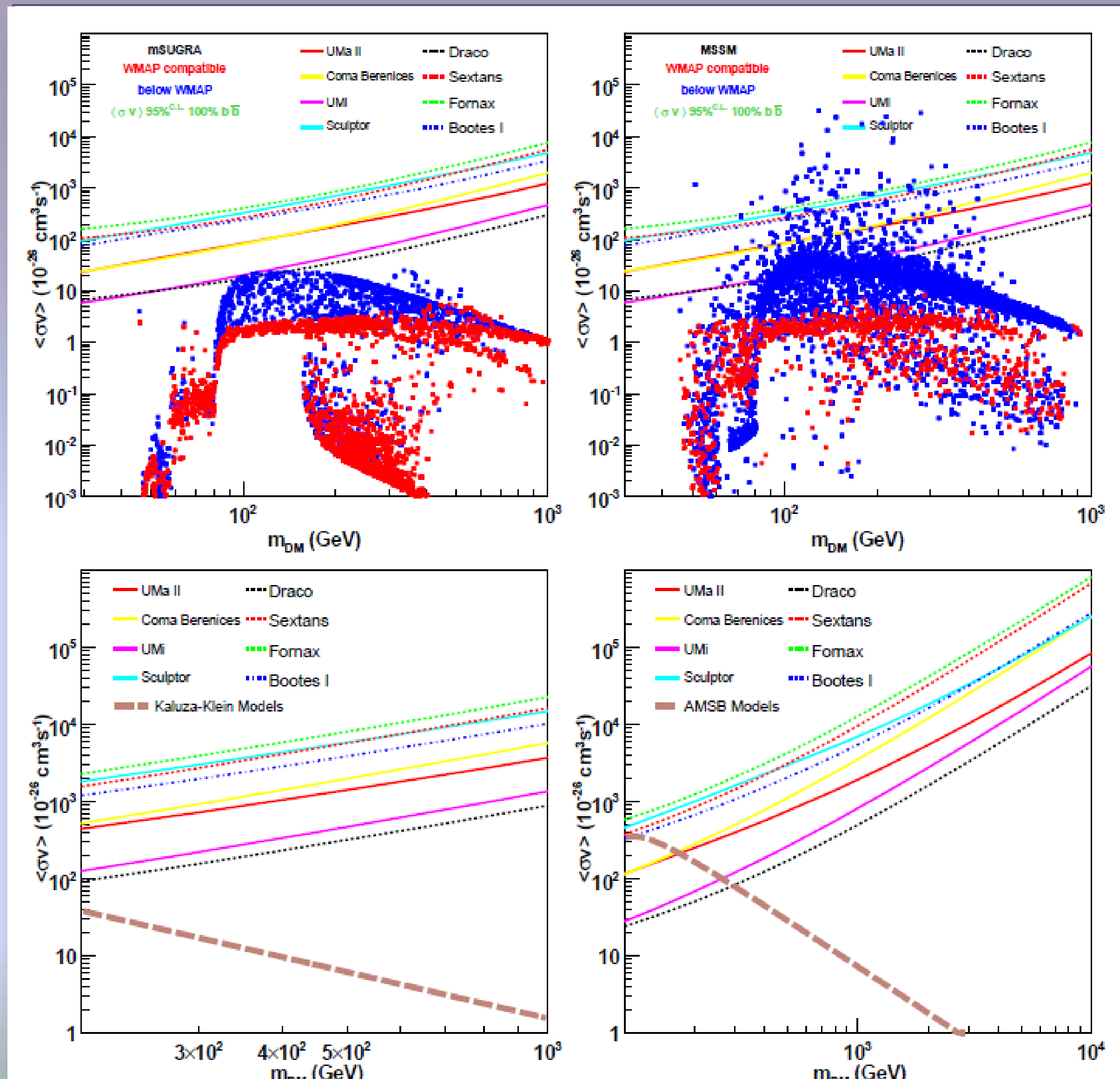

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