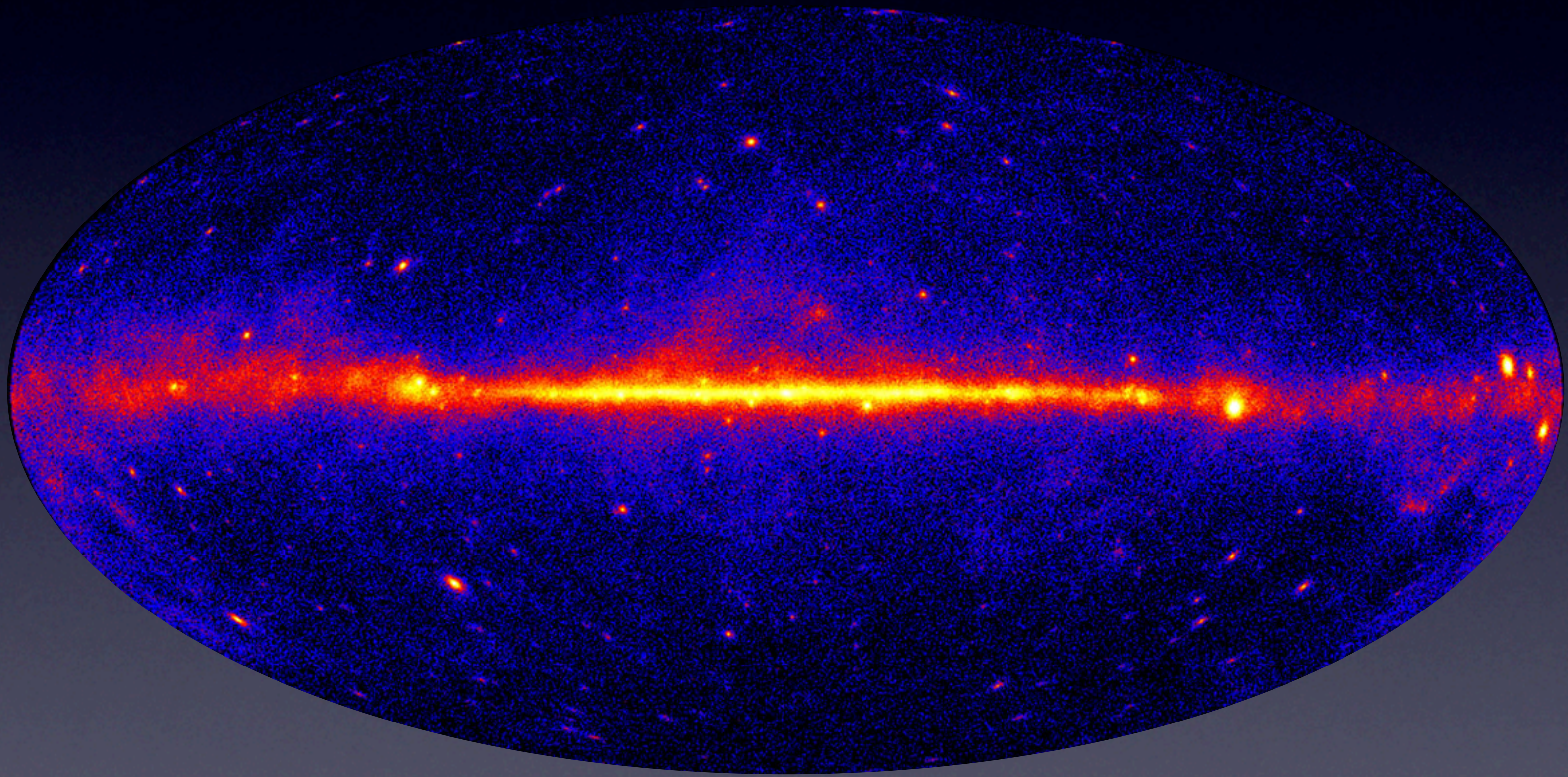
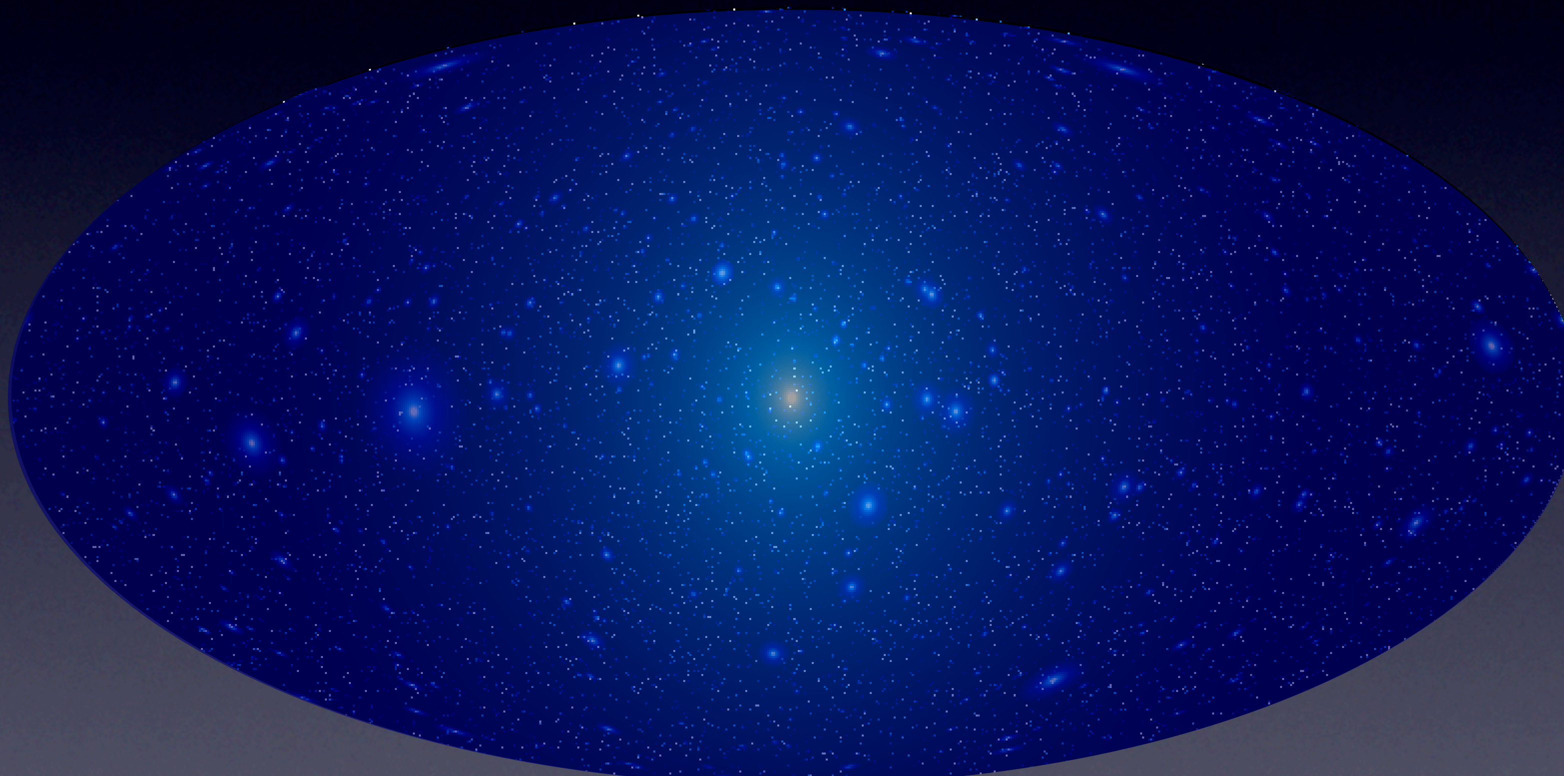
Image Credit: NASA/DOE/International LAT Team

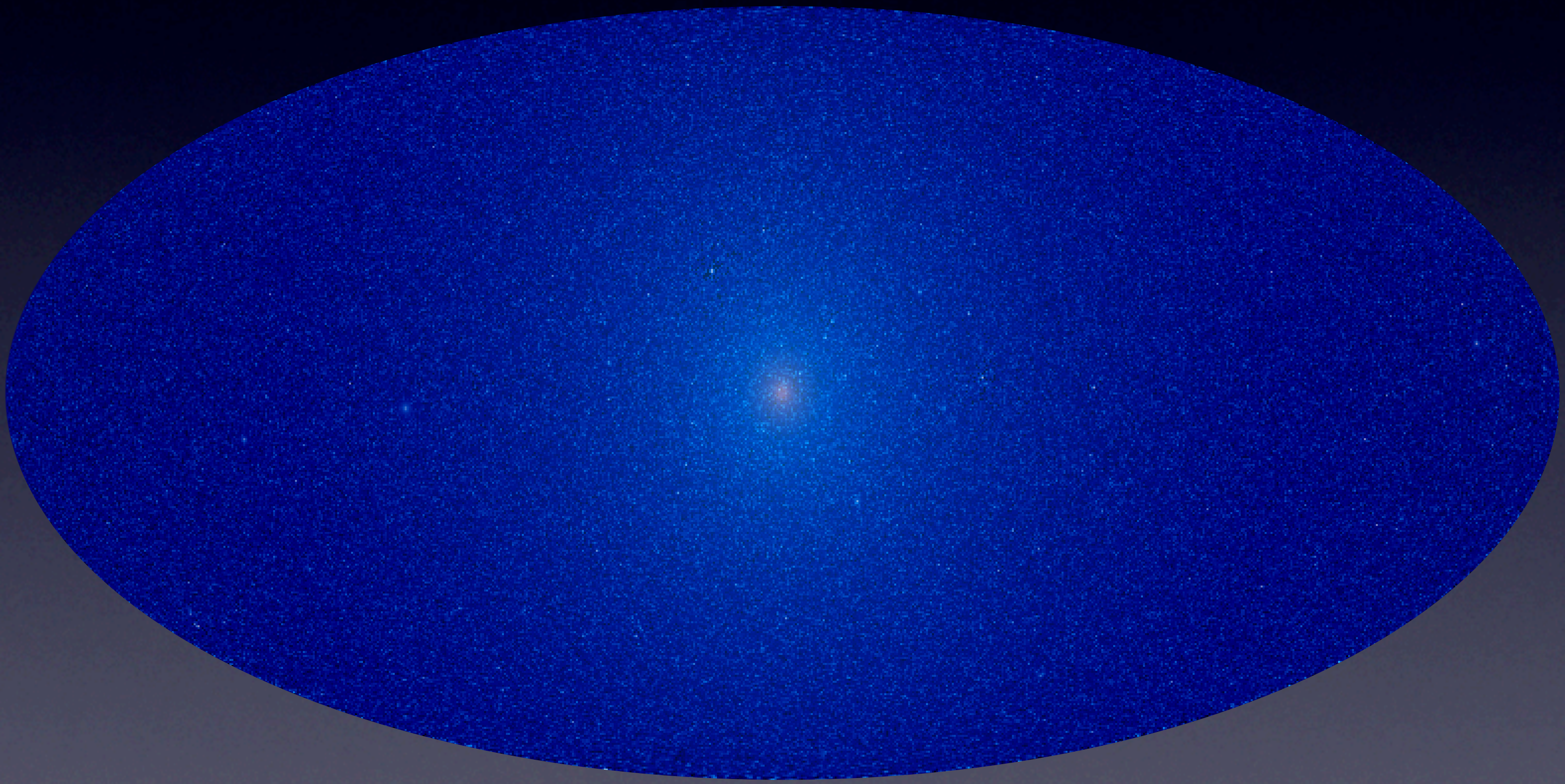
Discussion: dark matter searches with Fermi



Discussion: dark matter searches with Fermi



Discussion: dark matter searches with Fermi

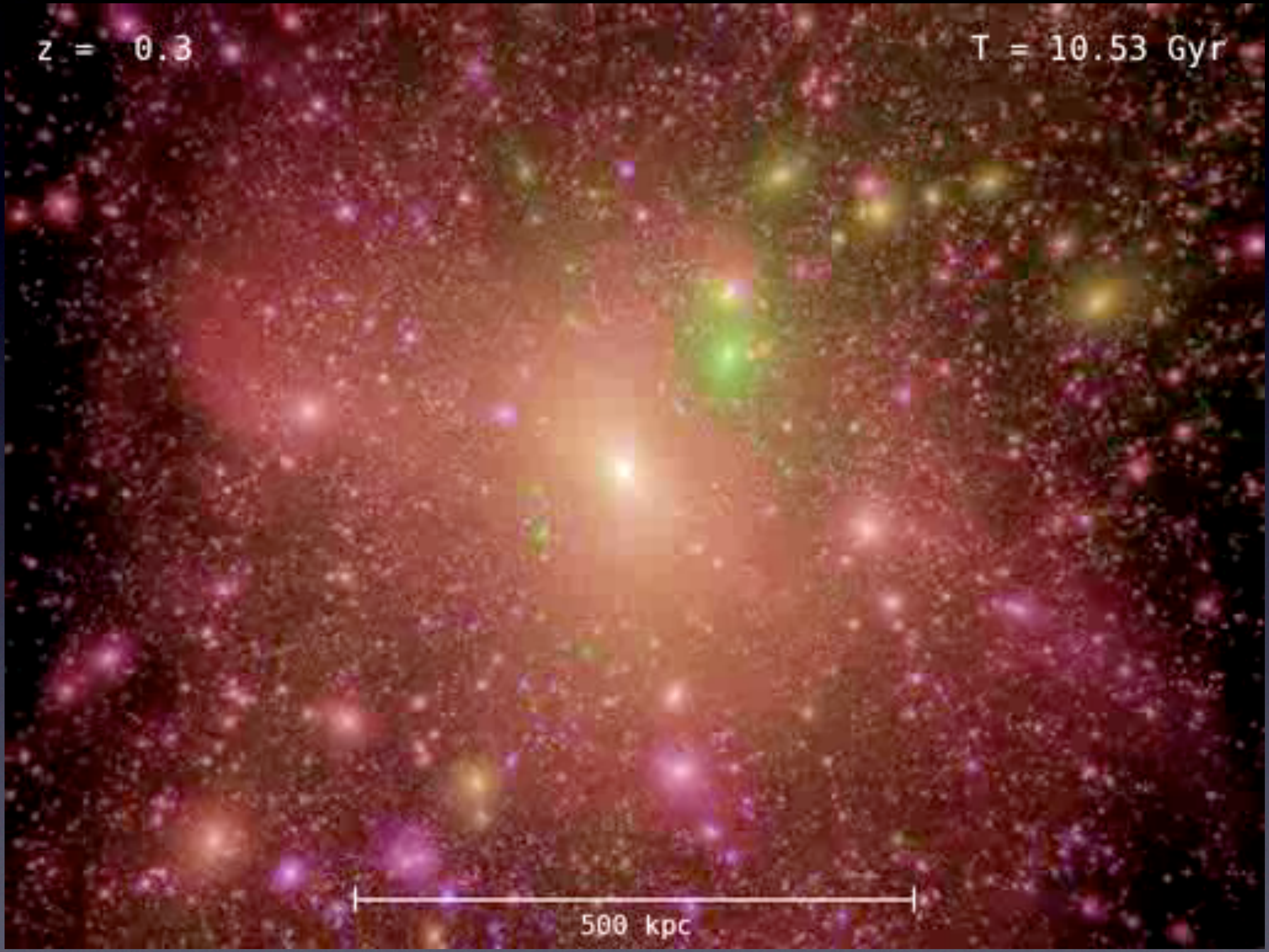


The Fermi Gamma-ray Space Telescope

- energy range: 100 MeV to a few hundred GeV
- effective area ~ 10^4 cm^2 (size-limited detector!)
- angular resolution ~ 0.1 deg above 10 GeV
- FOV ~ 2.4 sr
- primarily observes in sky-scanning mode; ~24 hr per day livetime
- excellent charged particle background rejection
- also detects cosmic-rays (including electrons and positrons)

Credit: NASA/General Dynamics

The dark matter distribution

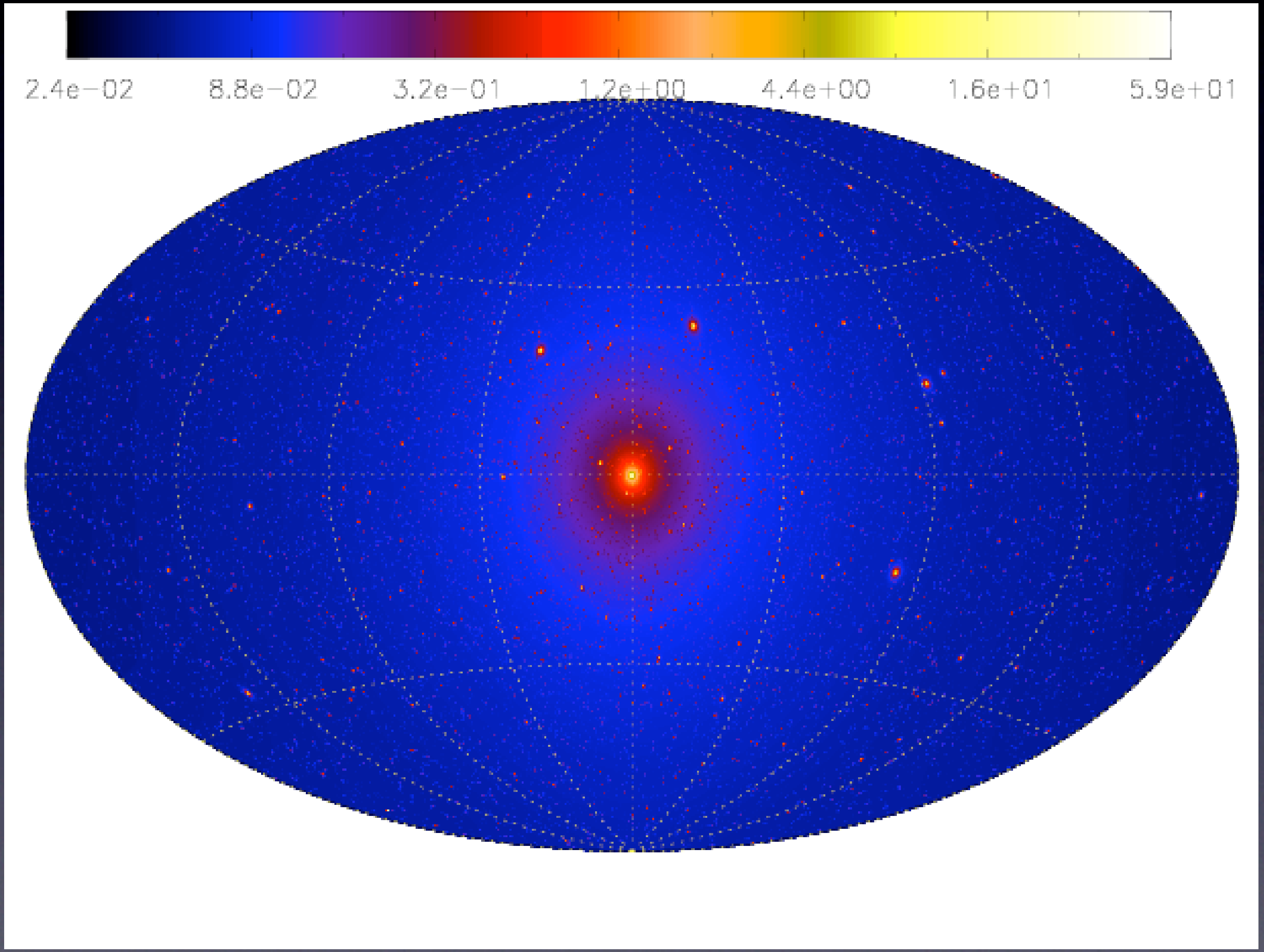


Credit: Springel et al. (Virgo Consortium)

Where to look for indirect signals?

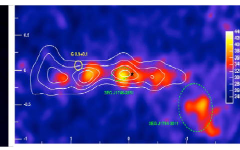
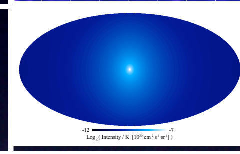
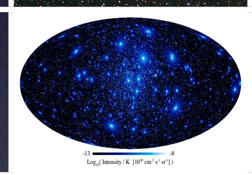
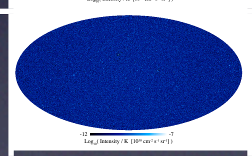
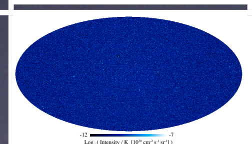
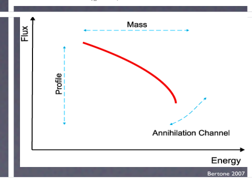
- Galactic Center
- Milky Way halo
- dwarf galaxies and known satellites
- Milky Way subhalos
  - point sources
  - diffuse emission from unresolved subhalos
- extragalactic dark matter structures

Gamma-rays from dark matter annihilation



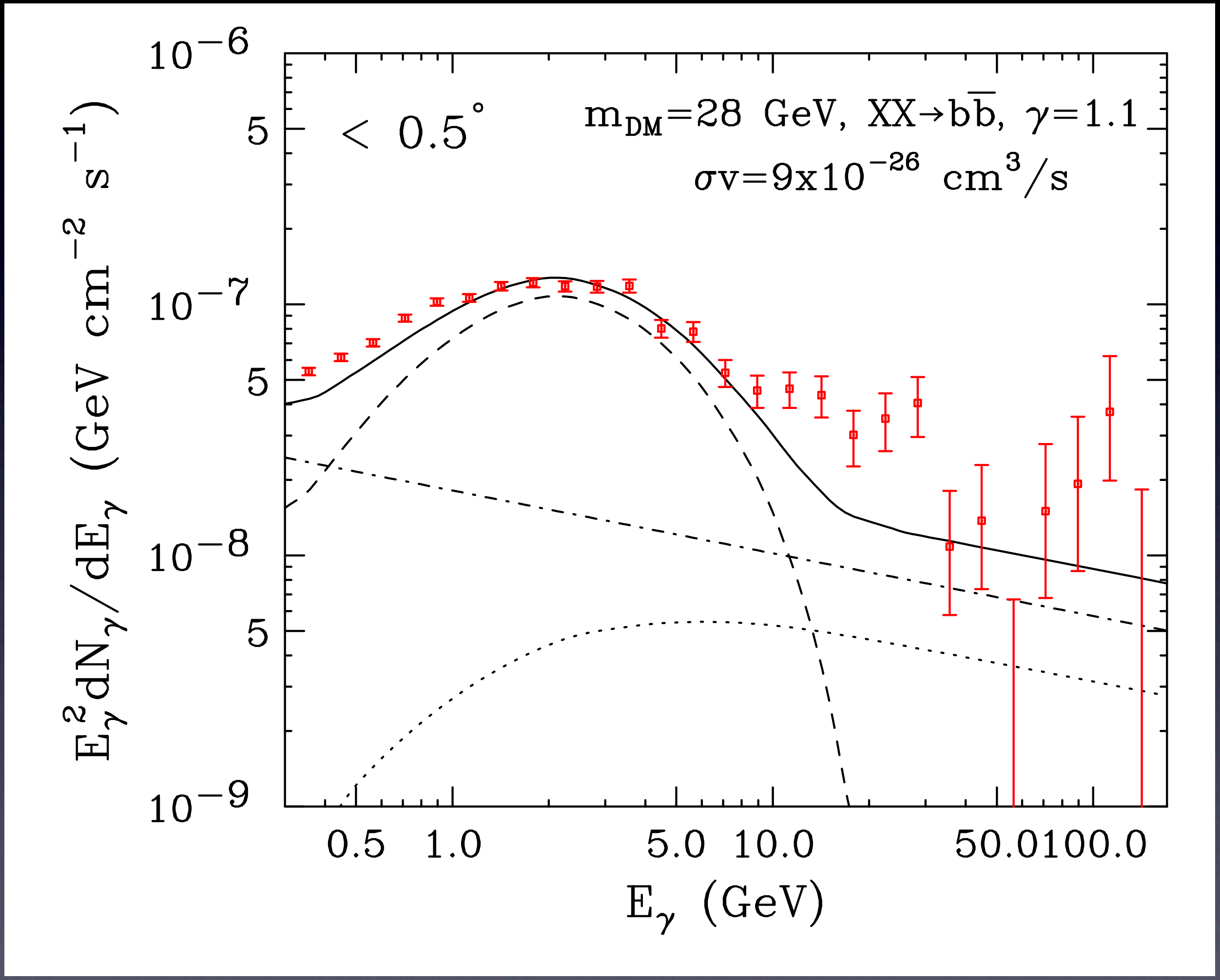
Pieri et al. 2009

Search strategies

Where?		How?
GC		look hard
halo		large scale angular dependence
dwarfs, Galaxy clusters		look hard
subhalos (point sources)		non-variable point sources with identical spectra
subhalos (diffuse)		anisotropies
extragalactic (diffuse)		anisotropies
ALL		spectral information, line emission

The Galactic Center

- claim that Fermi data in the GC region is consistent with a 28 GeV WIMP annihilation to b quarks

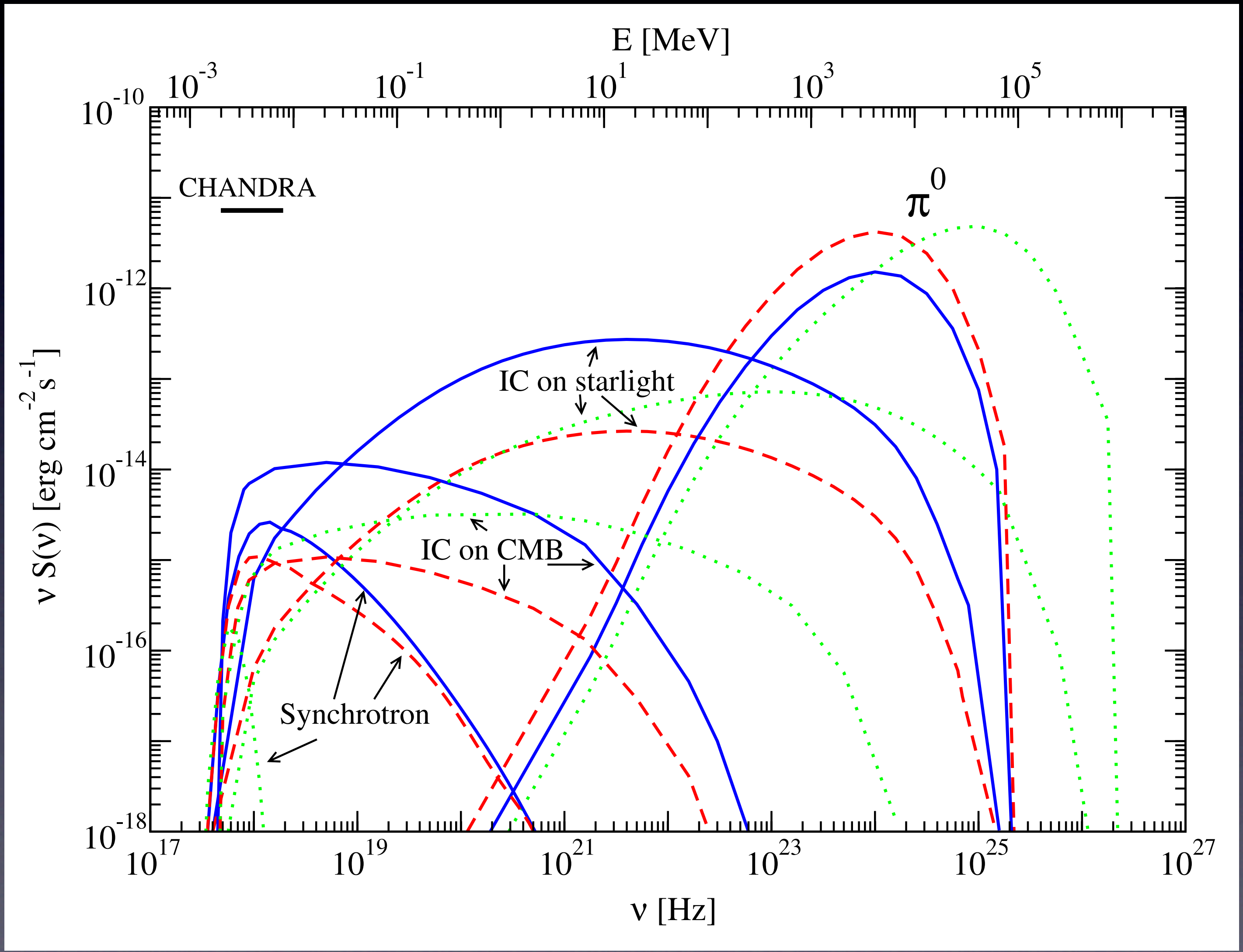


Goodenough & Hooper 2009

Multiwavelength dark matter photon spectra

- secondary photon emission associated with charged particle final states:
    - inverse Compton scattering of starlight, CMB
    - synchrotron due to propagation in magnetic fields

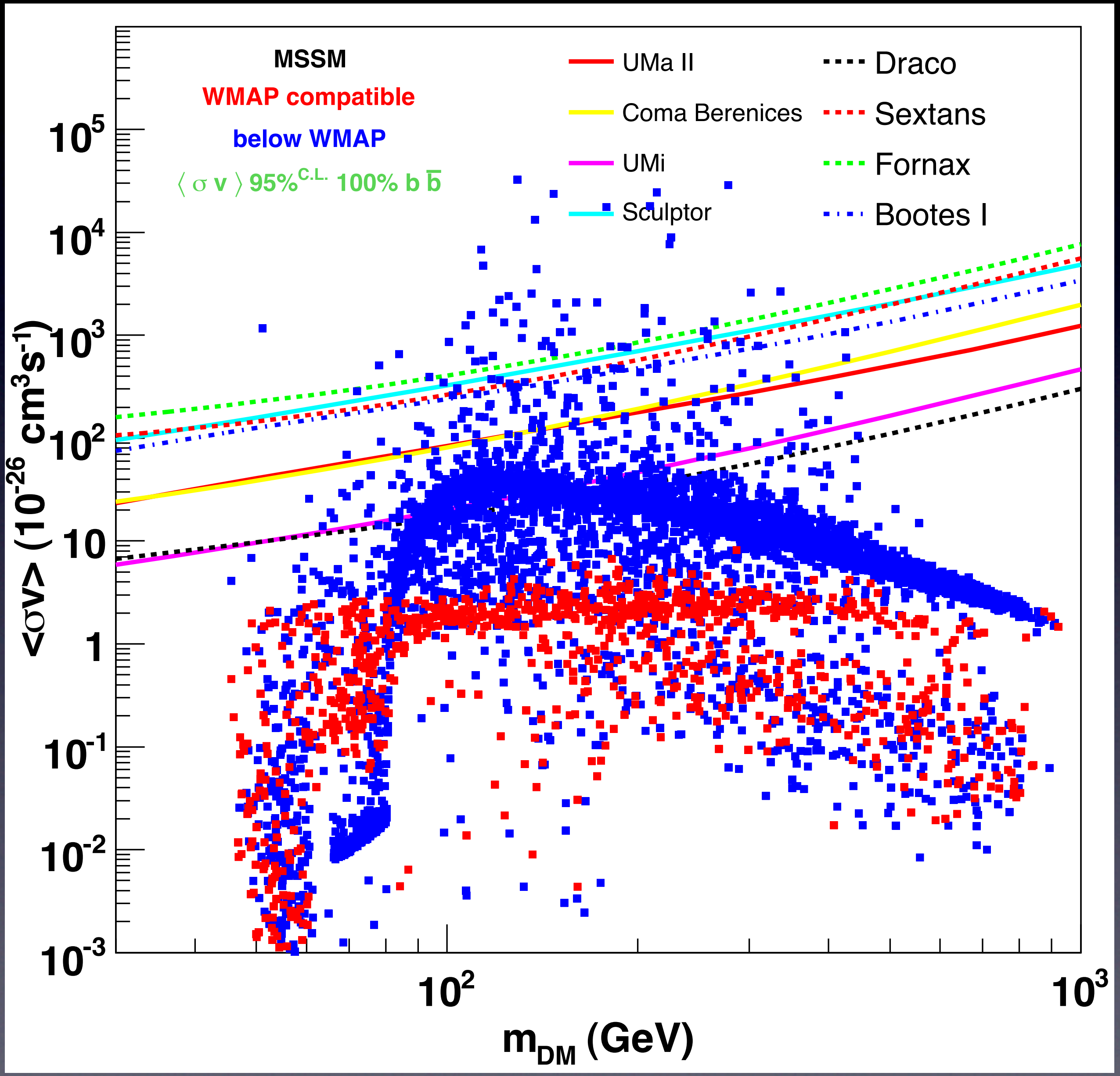
DM spectrum from the Galactic Center



Regis & Ullio 2008

Constraints from Fermi observations of dwarf spheroidals

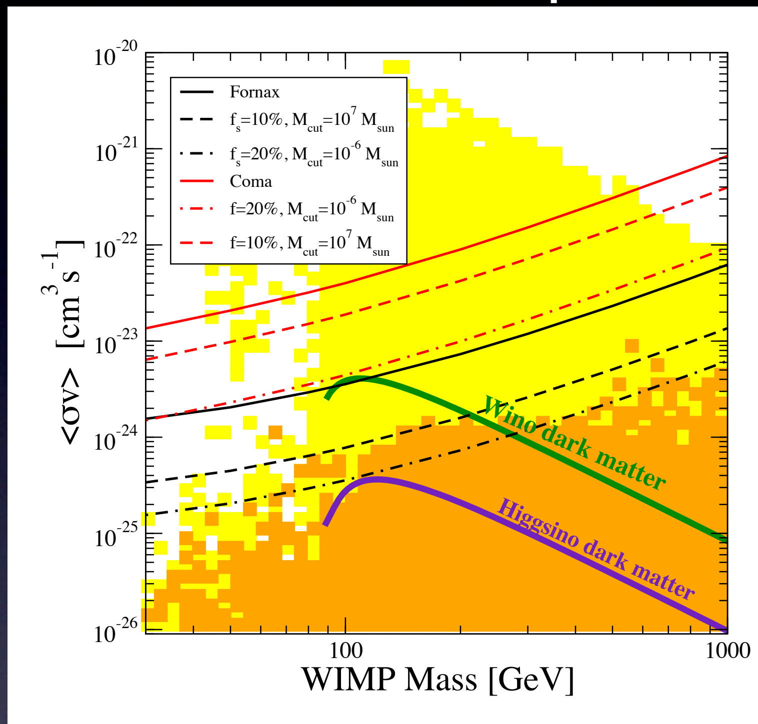
- annihilation to b quarks
- NFW density profile
- red points represent models which generate the correct relic dark matter density



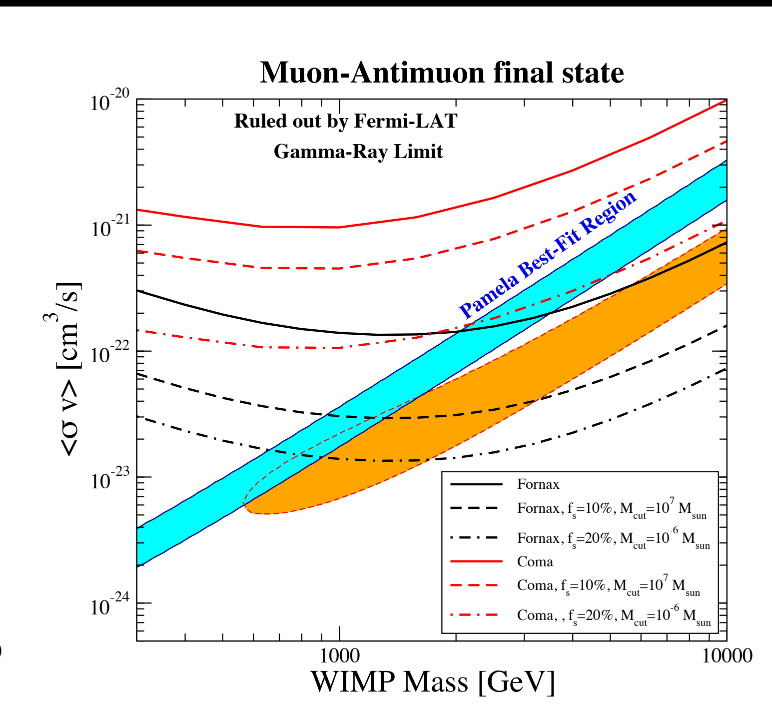
Abdo et al (Fermi LAT Collaboration) 2010

Constraints from Fermi observations of galaxy clusters

annihilation to b quarks



annihilation to muons



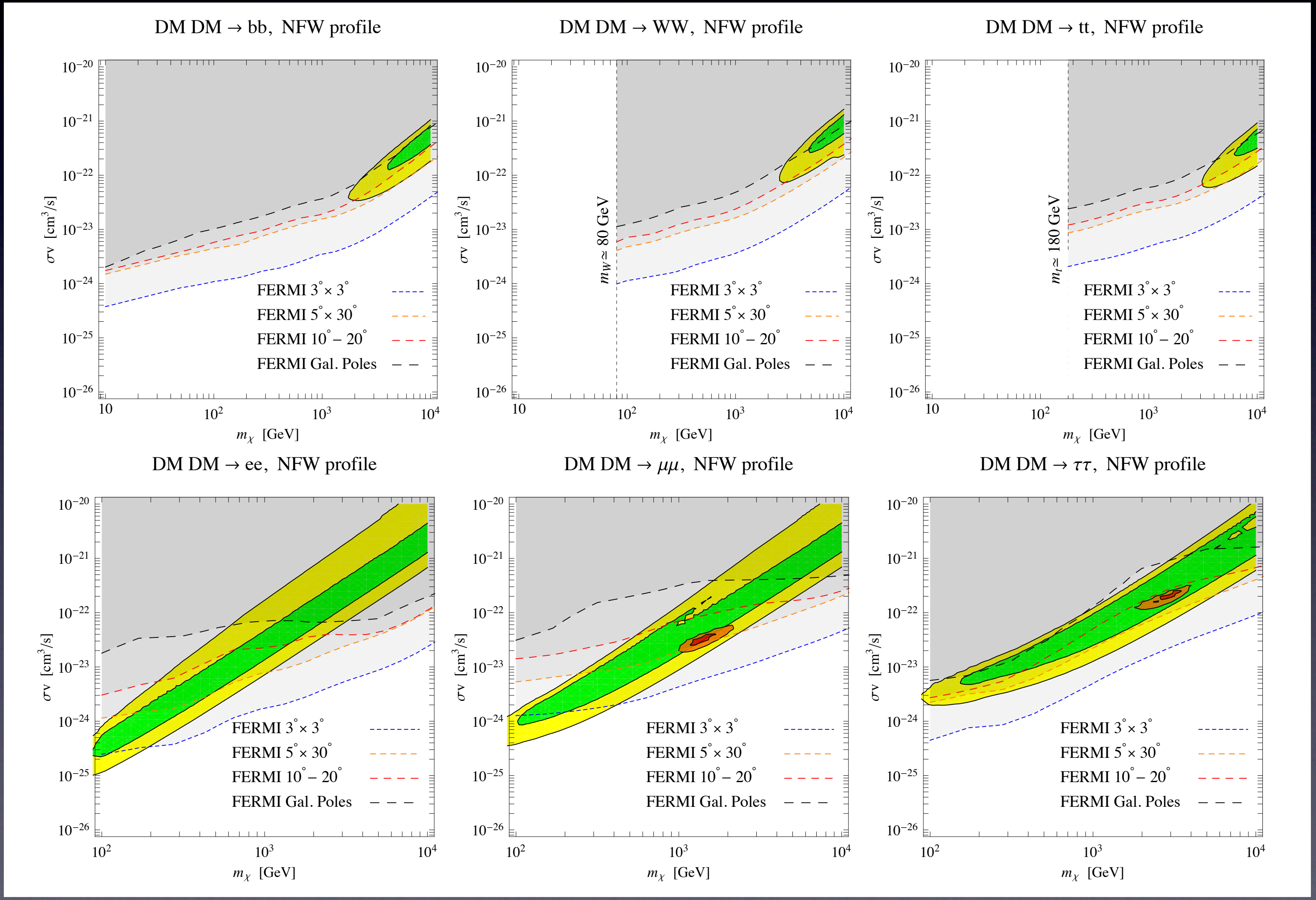
Abdo et al (Fermi LAT Collaboration) 2010

- constraints shown for various substructure models
- for muon channel, IC is included --> strong constraint on annihilation to muon pairs

Constraints from Fermi diffuse data

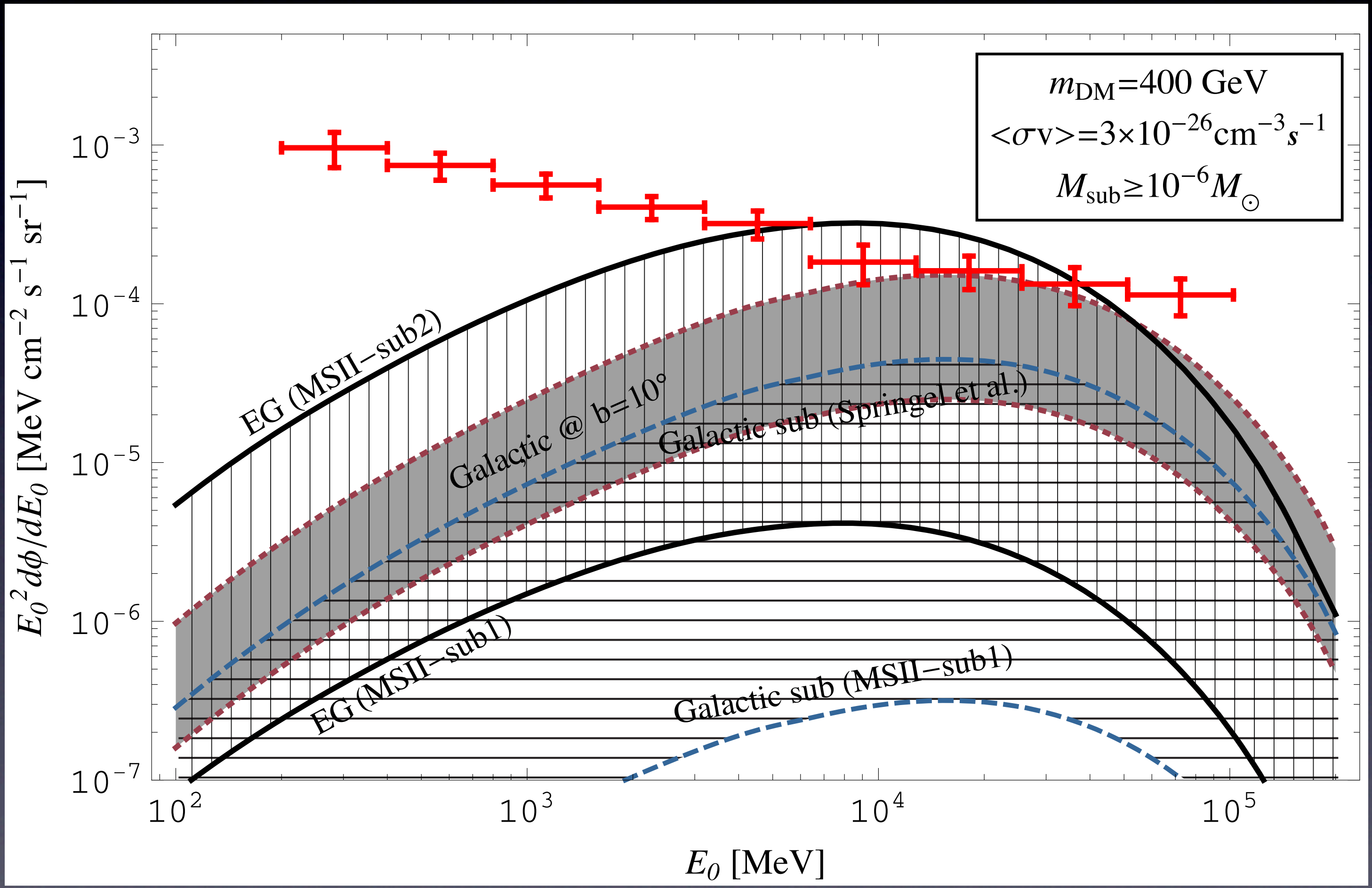
total measured signal in different sky regions constrains prompt and IC gamma-rays from annihilation in the smooth Milky Way halo and extragalactic structures (no Galactic subhalos)

- largre regions of parameters space preferred for explanations of the Fermi/PAMELA cosmic ray data excluded
- including the IC signal in the inner galaxy tends to produce stronger constraints, but is subject to additional uncertainties



Cirelli, Panci, & Serpico 2009

An extragalactic DM signal in the Fermi large-scale isotropic diffuse



Abdo et al. 2010

Constraints from the Fermi large-scale isotropic diffuse

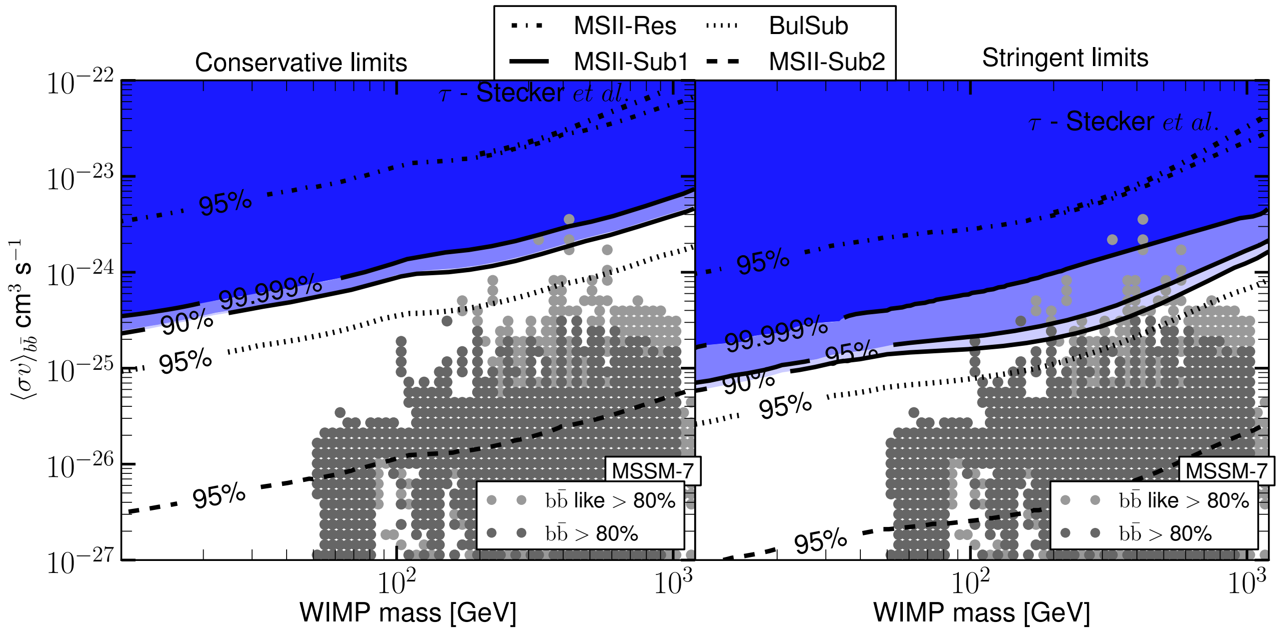


Figure 5: Cross section $\langle\sigma v\rangle$ limits on dark matter annihilation into $b\bar{b}$ final states. The blue regions mark the (90, 95, 99.999)% exclusion regions in the MSII-Sub1 $\Delta^2(z)$ DM structure scenario (and for the other structure scenarios only 95% upper limit lines). The absorption model in Gilmore *et al.* [68] is used, and the relative effect if instead using the Stecker *et al.* [69] model is illustrated by the upper branching of the dash-dotted line in the MSII-Res case. Our *conservative* limits are shown on the left and the *stringent* limits on the right panel. The grey regions show a portions of the MSSM7 parameter space where the annihilation branching ratio into final states of $b\bar{b}$ (or $b\bar{b}$ like states) is > 80%. See main text for more details.

Abdo et al. 2010

annihilation to b quarks

- large-scale isotropic diffuse spectrum measurement constrains gamma-rays from annihilation in extragalactic dark matter
- no ICS included
- depends on EBL model
- strong dependence on structural properties of DM

Constraints from the Fermi large-scale isotropic diffuse

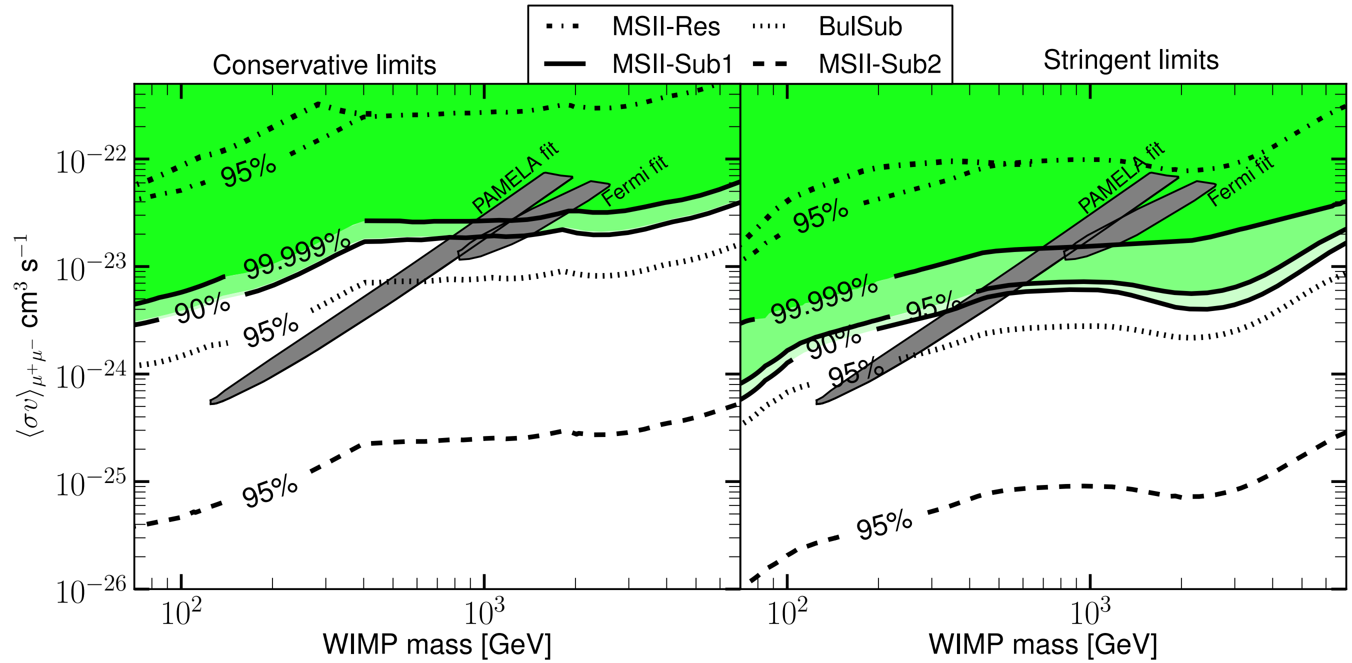


Figure 6: Cross section $\langle\sigma v\rangle$ limits on dark matter annihilation into $\mu^+\mu^-$ final states. The green regions mark the (90, 95, 99.999)% exclusion regions in the MSII-Sub1 $\Delta^2(z)$ DM structure scenario (and for the other structure scenarios only 95% upper limit lines). The layout of the figure is otherwise the same as in figure 5. Note that the Stecker *et al.* [69] absorption model affects the lower DM mass limits since they are set by the high energy FSR part of the DM spectrum. The two gray contours show the best fit regions for a WIMP explanation to the local electron and positron spectra measured by Fermi-LAT and PAMELA.

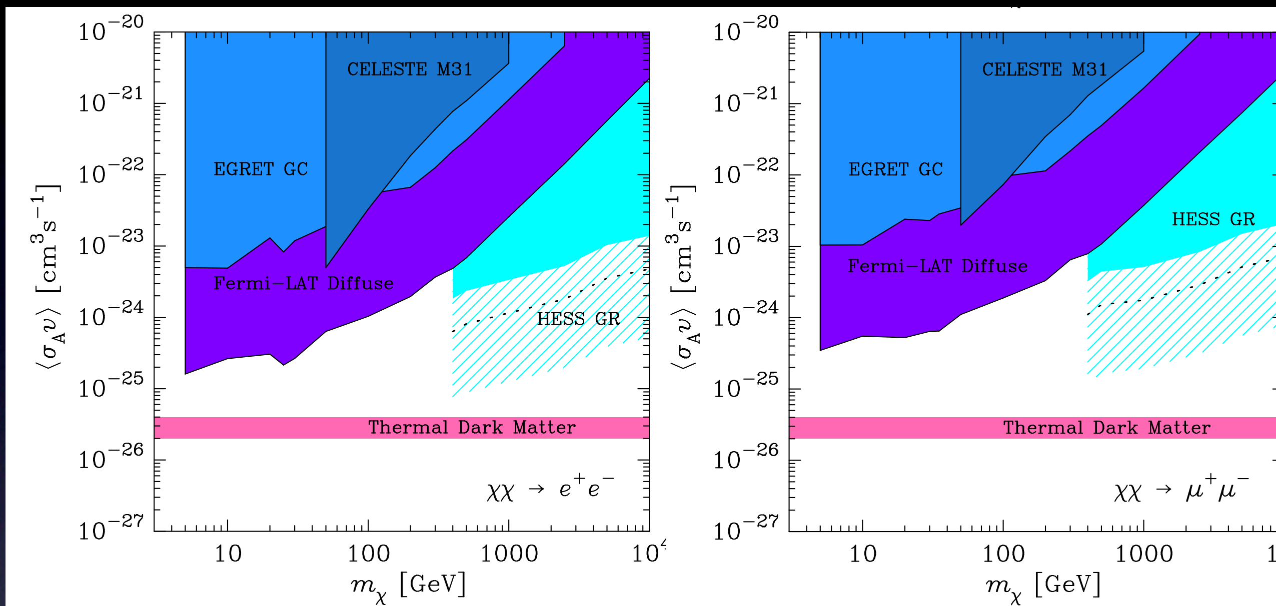
Abdo et al. 2010

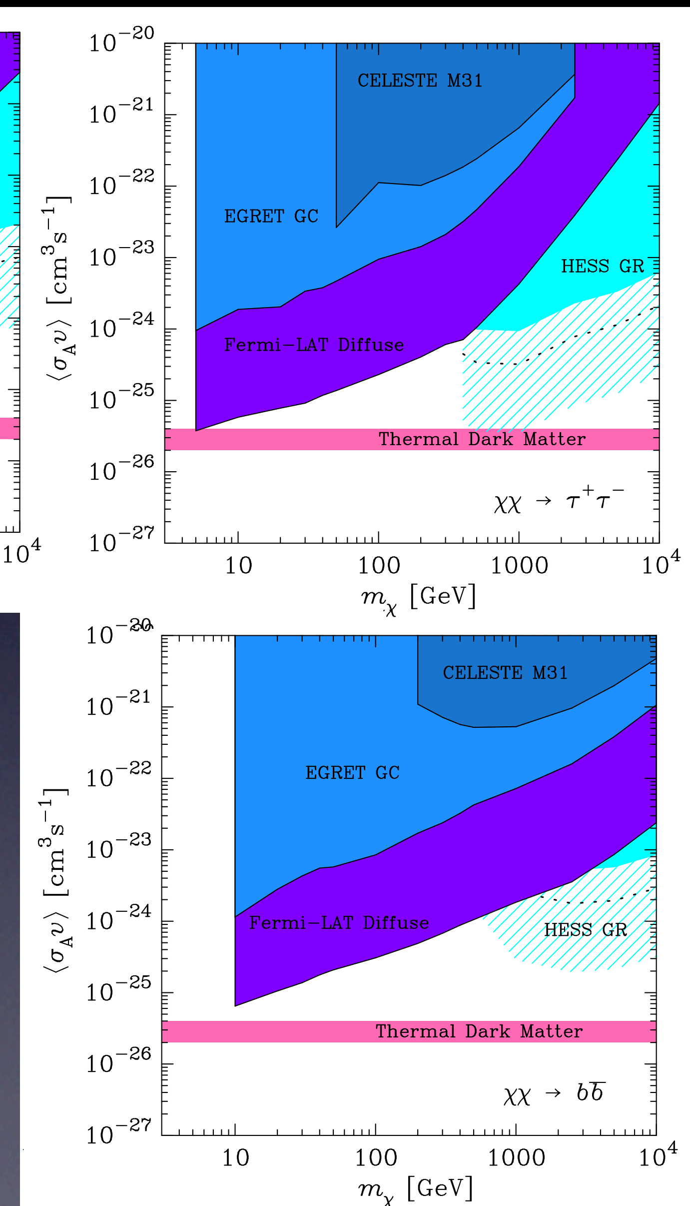
annihilation to muon pairs

- large-scale isotropic diffuse spectrum measurement constrains gamma-rays from annihilation in extragalactic dark matter
- includes ICS
- depends on EBL model
- strong dependence on structural properties of DM

Constraints from the Fermi large-scale isotropic diffuse

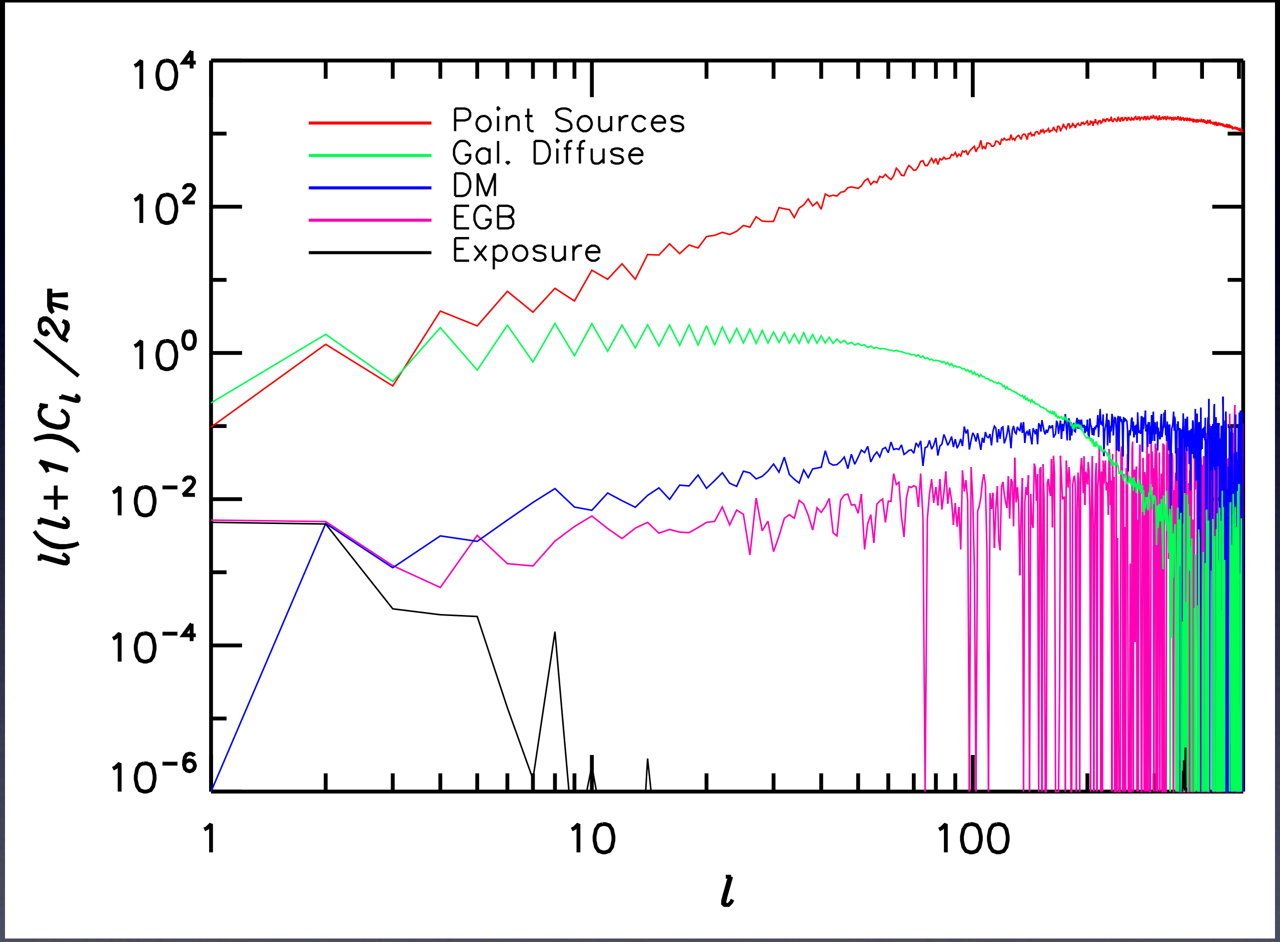
Abazajian, Agrawal, Chacko, & Kilic 2010





- large-scale isotropic diffuse spectrum measurement constrains gamma-rays from annihilation in the smooth Milky Way halo and extragalactic dark matter (no Galactic subhalos)

Fermi sensitivity to anisotropies from DM

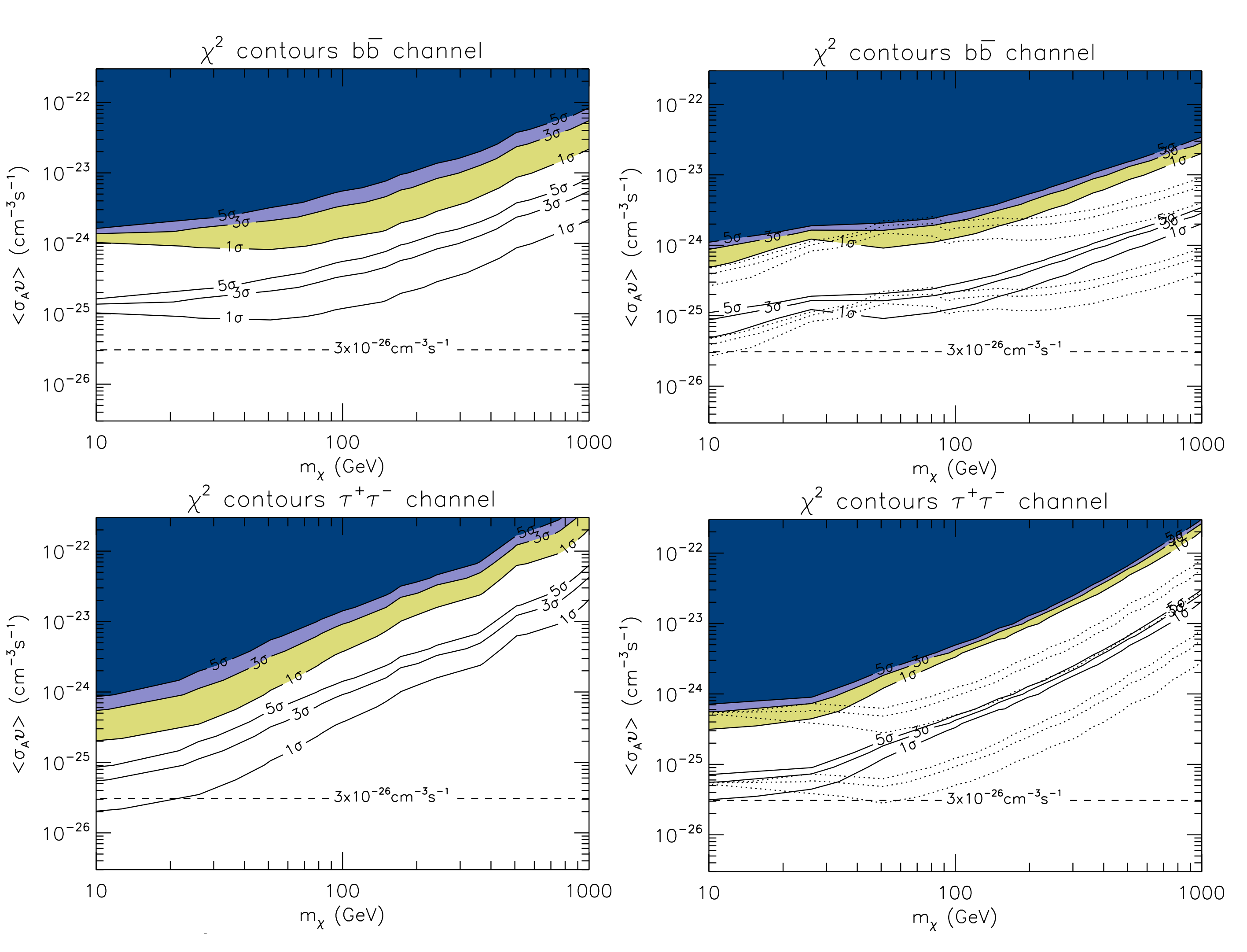


Cuoco et al. 2010

- expected anisotropies in the large-scale diffuse from DM and astrophysical components

Fermi sensitivity to anisotropies from DM

extragalactic DM | Galactic DM



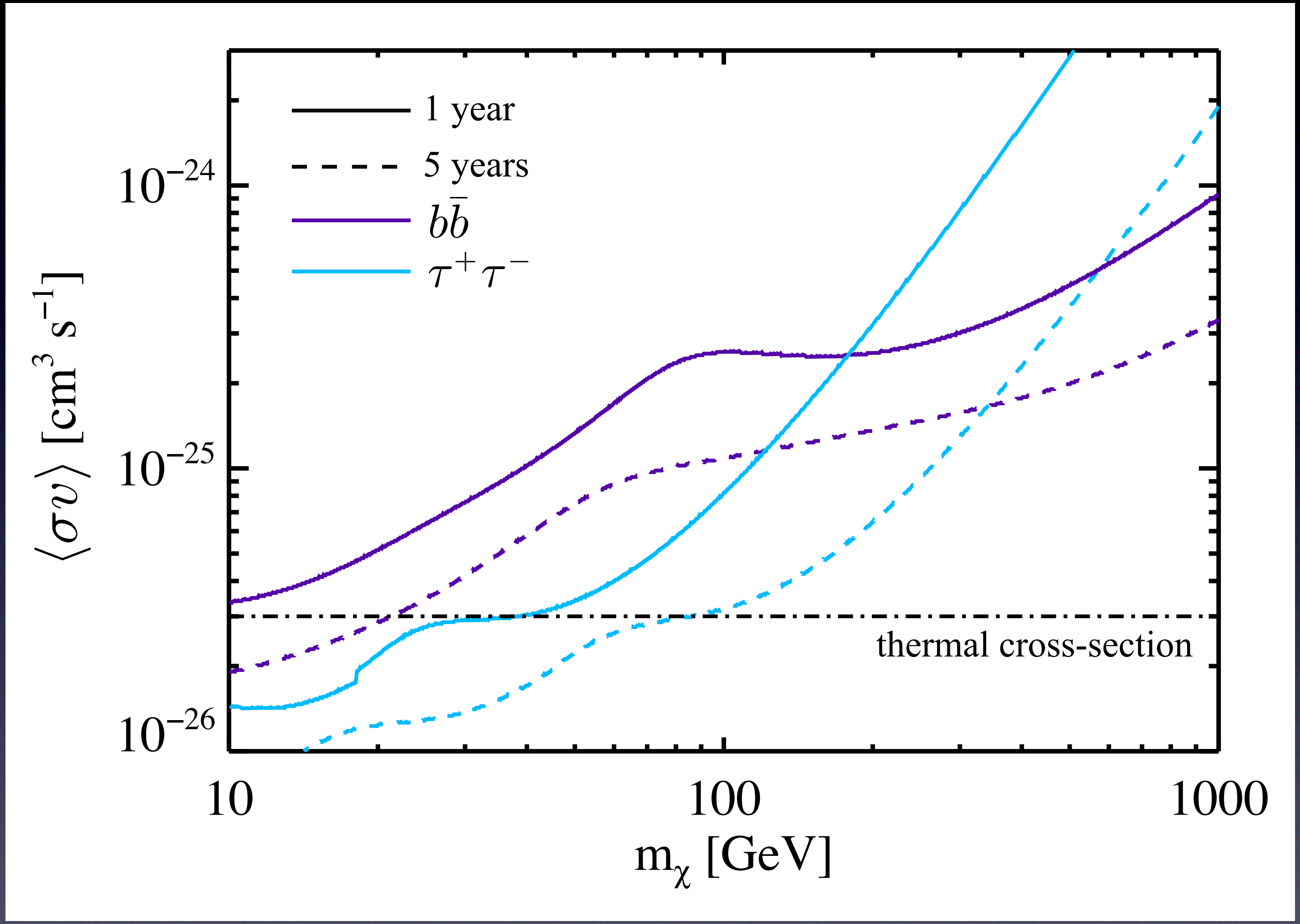
Cuoco et al. 2010

- sensitivity to measure excess power from DM over the anisotropy expected without DM with 5 years of observation

Fermi sensitivity to DM-induced modulations in the anisotropy energy spectrum

- combining anisotropy and energy information allows for the detection of multiple contributors to the diffuse emission without requiring a priori knowledge of anisotropy or spectral properties of any component

- annihilation in Galactic DM substructure produces a detectable feature in the anisotropy energy spectrum for a substantial region of parameter space



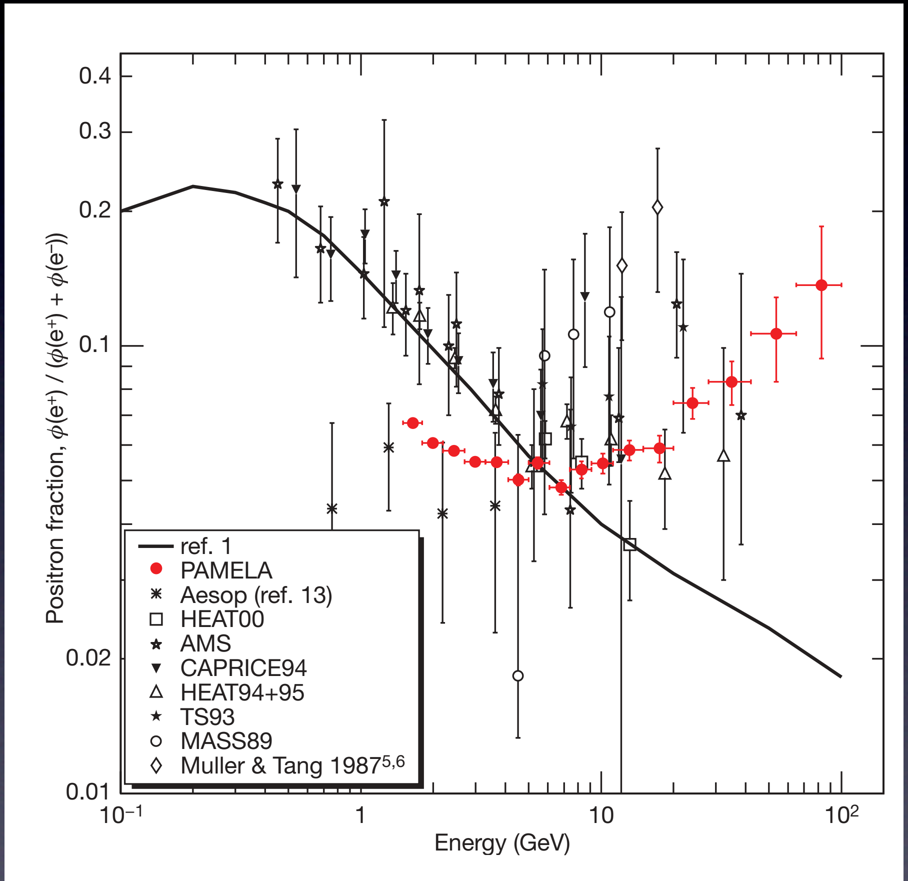
Hensley, JSG, & Pavlidou (2009)

dark matter models above the curves are detectable by this test!

Hints of a dark matter signal in the $e^{\pm}$ spectrum?

- rise in local positron fraction above ~10 GeV disagrees with conventional model for cosmic rays

PAMELA positron fraction



Adriani et al. 2009

Hints of a dark matter signal in the e$^{\pm}$ spectrum?

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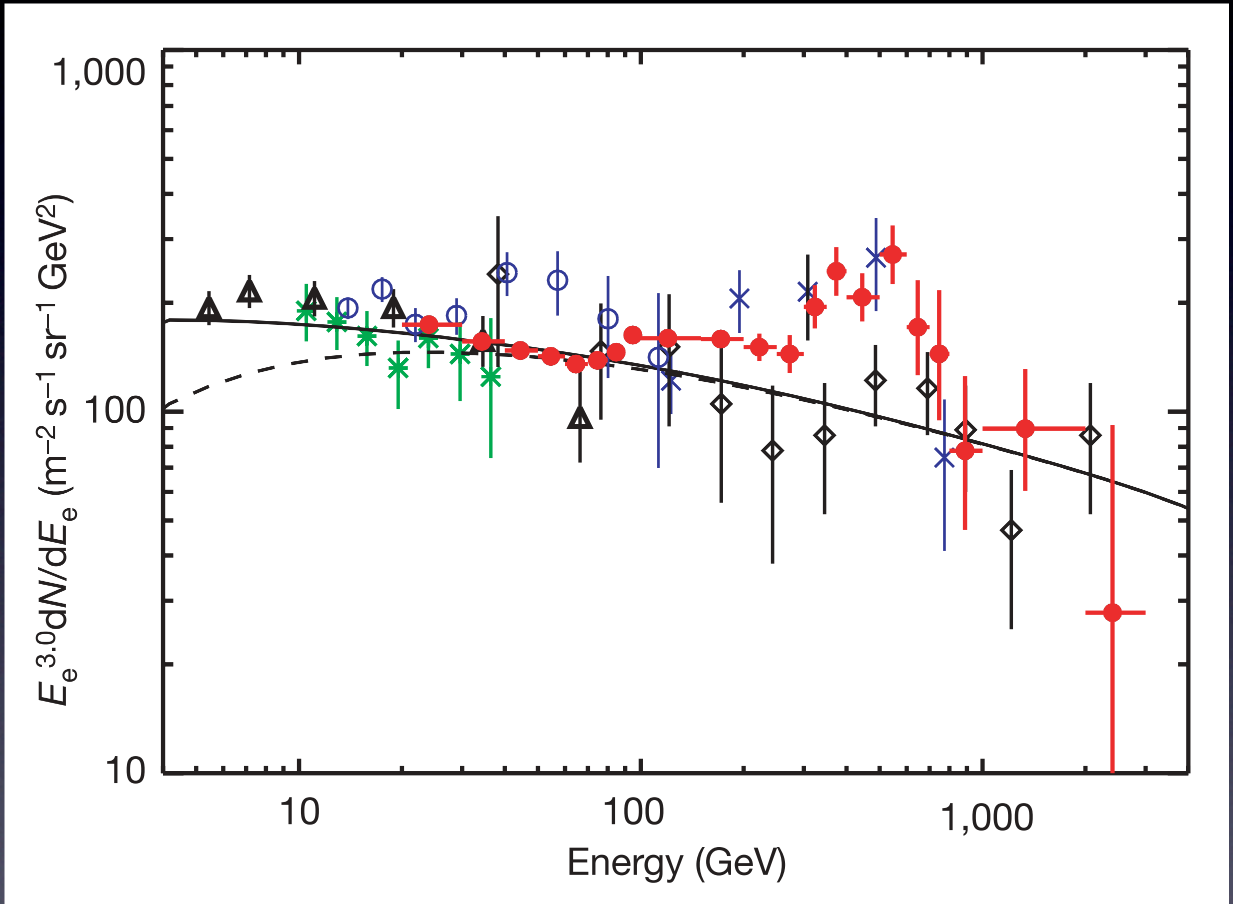
- unexpected bump in total electron + positron spectrum measured by ATIC

ATIC electron + positron



Chang et al. 2008

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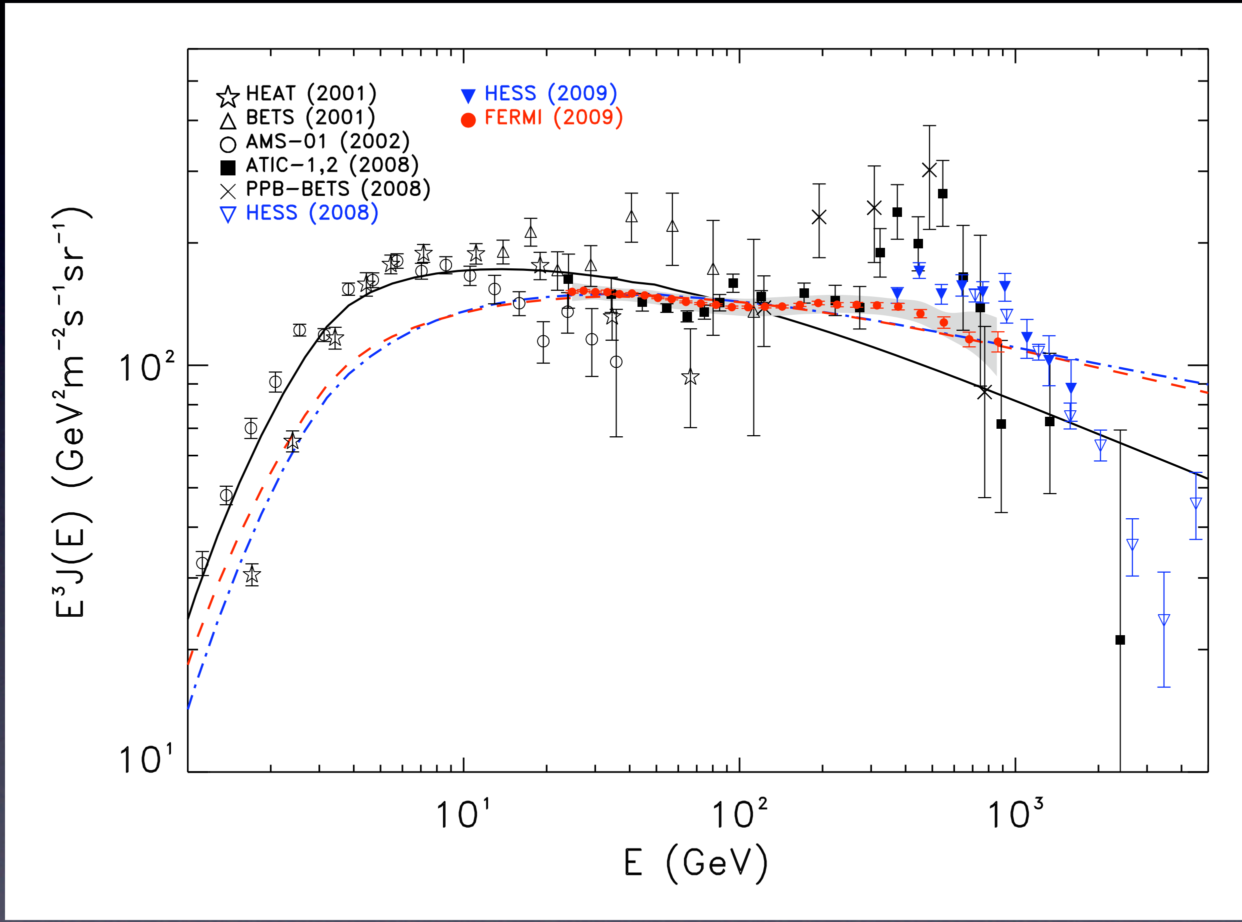
- less prominent bump seen in Fermi cosmic ray electron/positron spectrum

Fermi electron + positron



Grasso et al. 2009

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- sparked interest in DM explanations (e.g., Arkani-Hamed et al. 2009; Lattanzi & Silk 2009; Cirelli et al. 2009; Cholis et al. 2008; Grasso et al. 2009;...)
  - leptophilic models
  - large annihilation cross-sections (e.g., via Sommerfeld)

The Case for a 700+ GeV WIMP: Cosmic Ray Spectra from ATIC and PAMELA

Ilias Cholis,[1] Gregory Dobler,[2] Douglas P. Finkbeiner,[2] Lisa Goodenough,[1] and Neal Weiner[1]

Hints of a dark matter signal in the $e^{\pm}$ spectrum?

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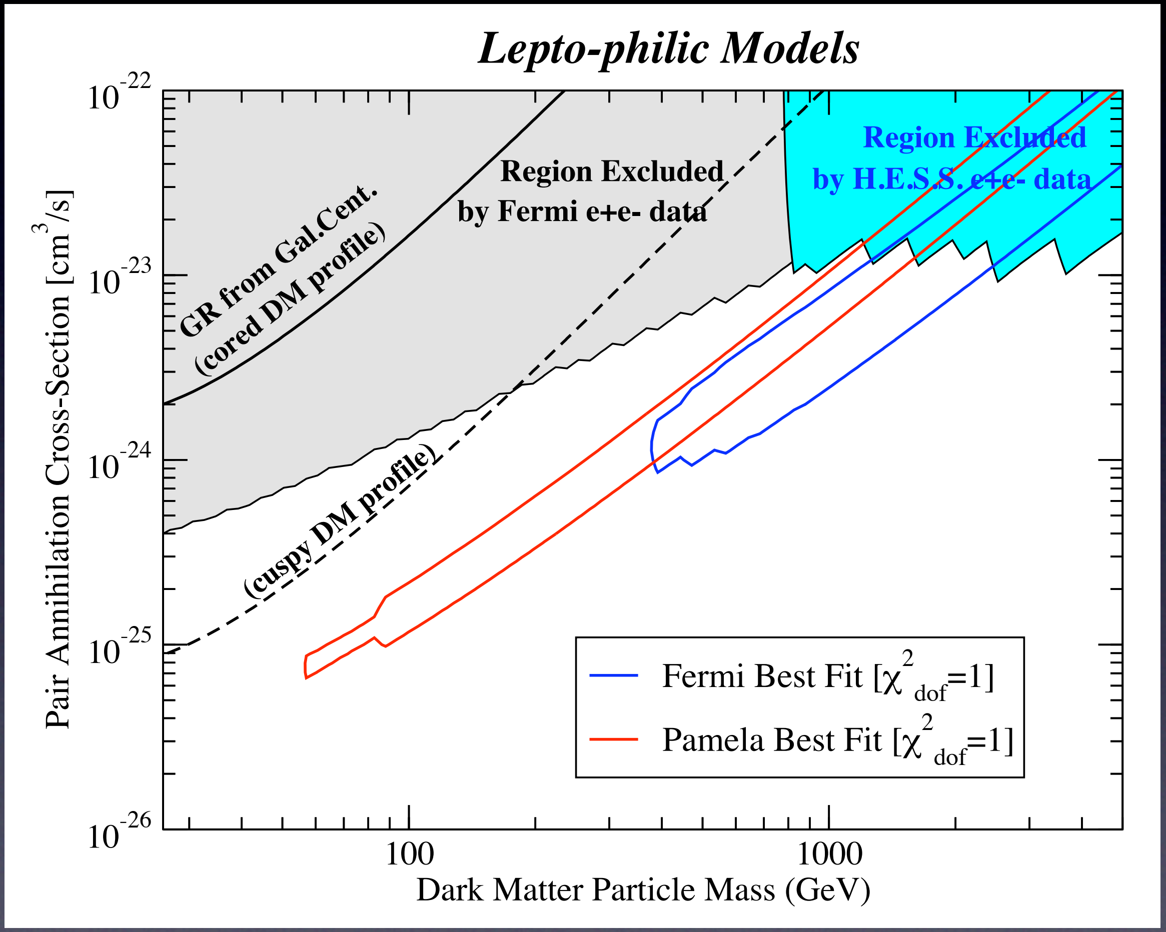
  - leptophilic models
  - large annihilation cross-sections (e.g., via Sommerfeld)
- astrophysical explanations: pulsars (e.g., Yuksel, Kistler, & Stanev 2009; Hooper, Blasi, & Serpico 2009; Profumo 2008; Grasso et al. 2009;...), SNR (e.g., Blasi & Serpico 2009), etc.

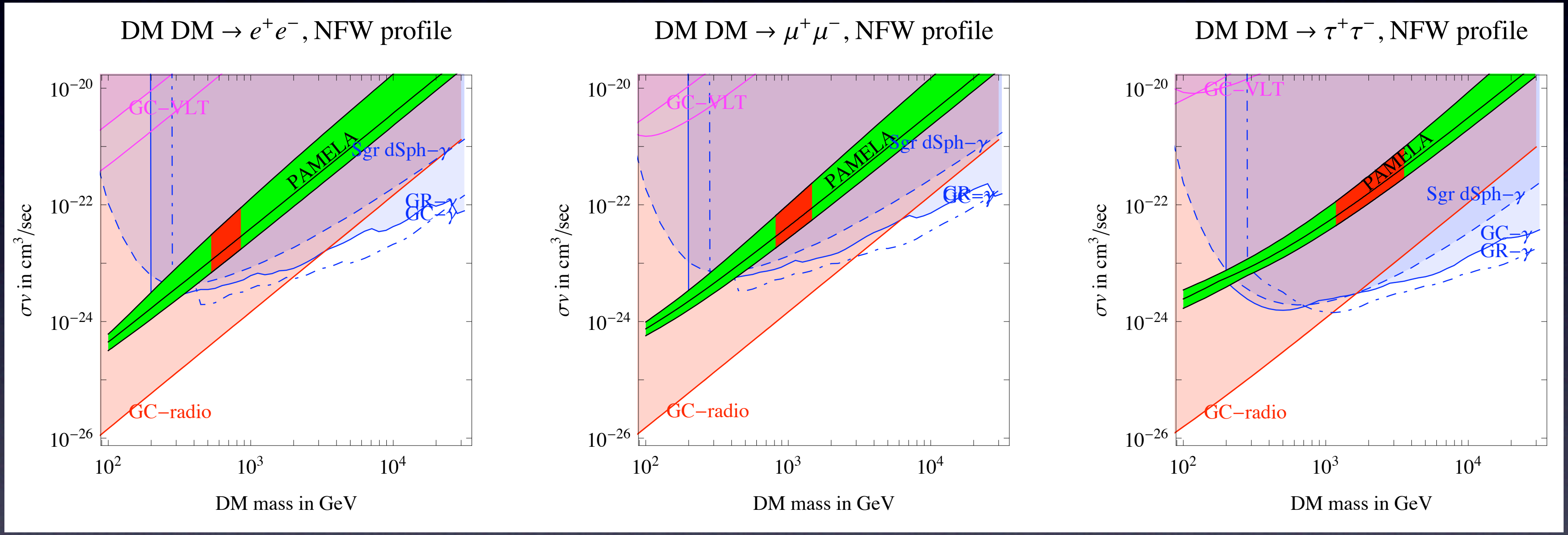
Fermi/PAMELA fits



Grasso et al. 2009

Constraints on a smooth halo explanation

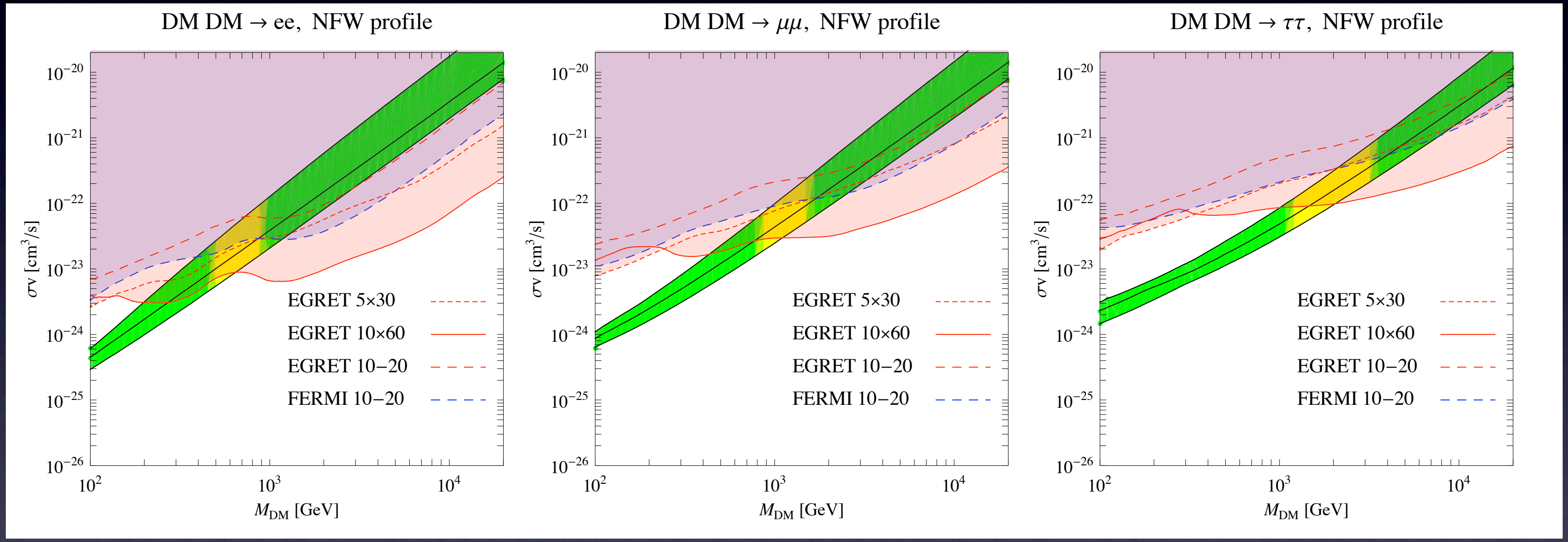
GC radio, GC & GR gamma-ray



Bertone, Cirelli, Strumia, Taoso 2009

Constraints on a smooth halo explanation

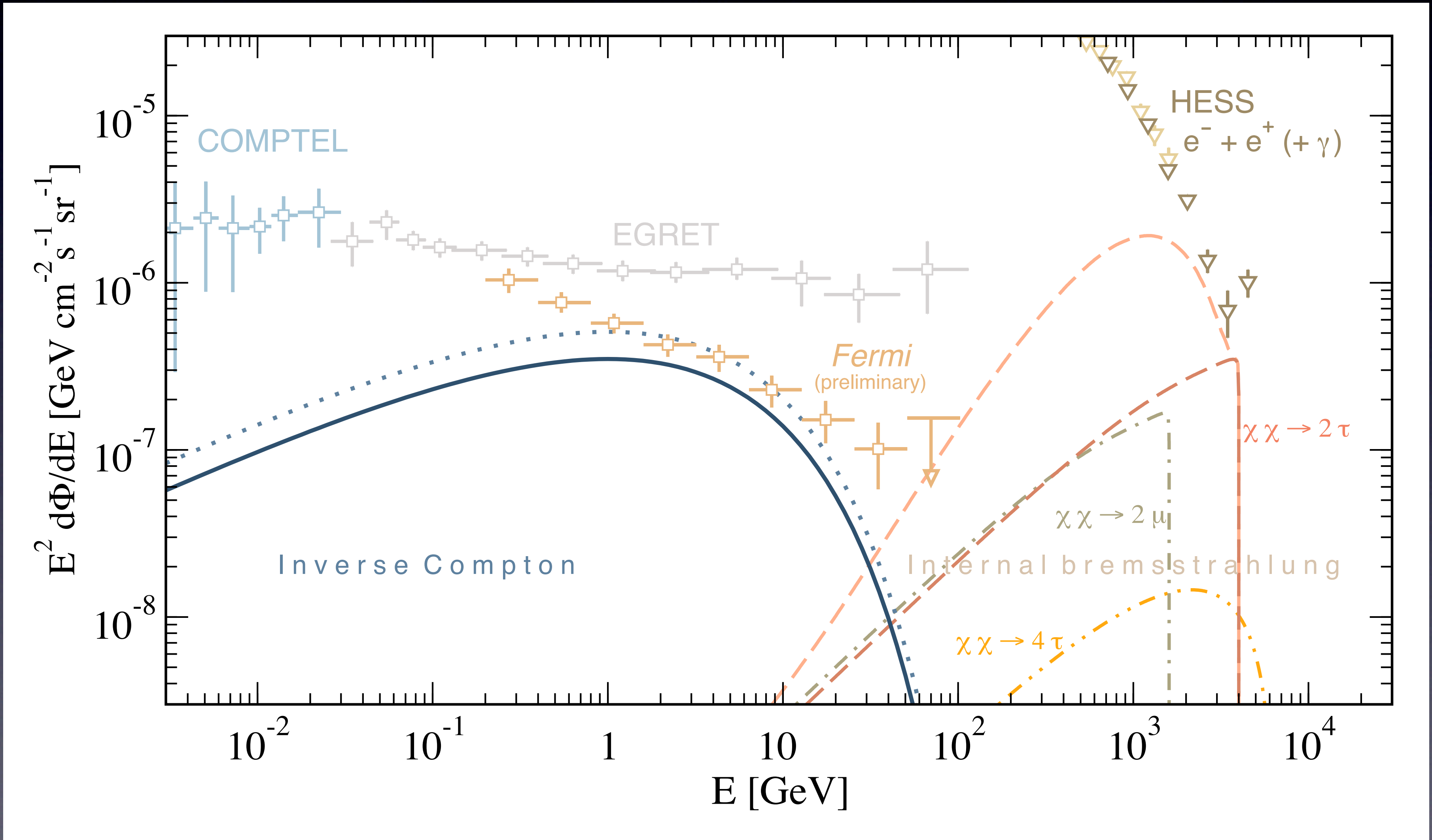
ICS in the inner Galaxy



Cirelli & Panci 2009

High-latitude gamma-rays from MW subhalos

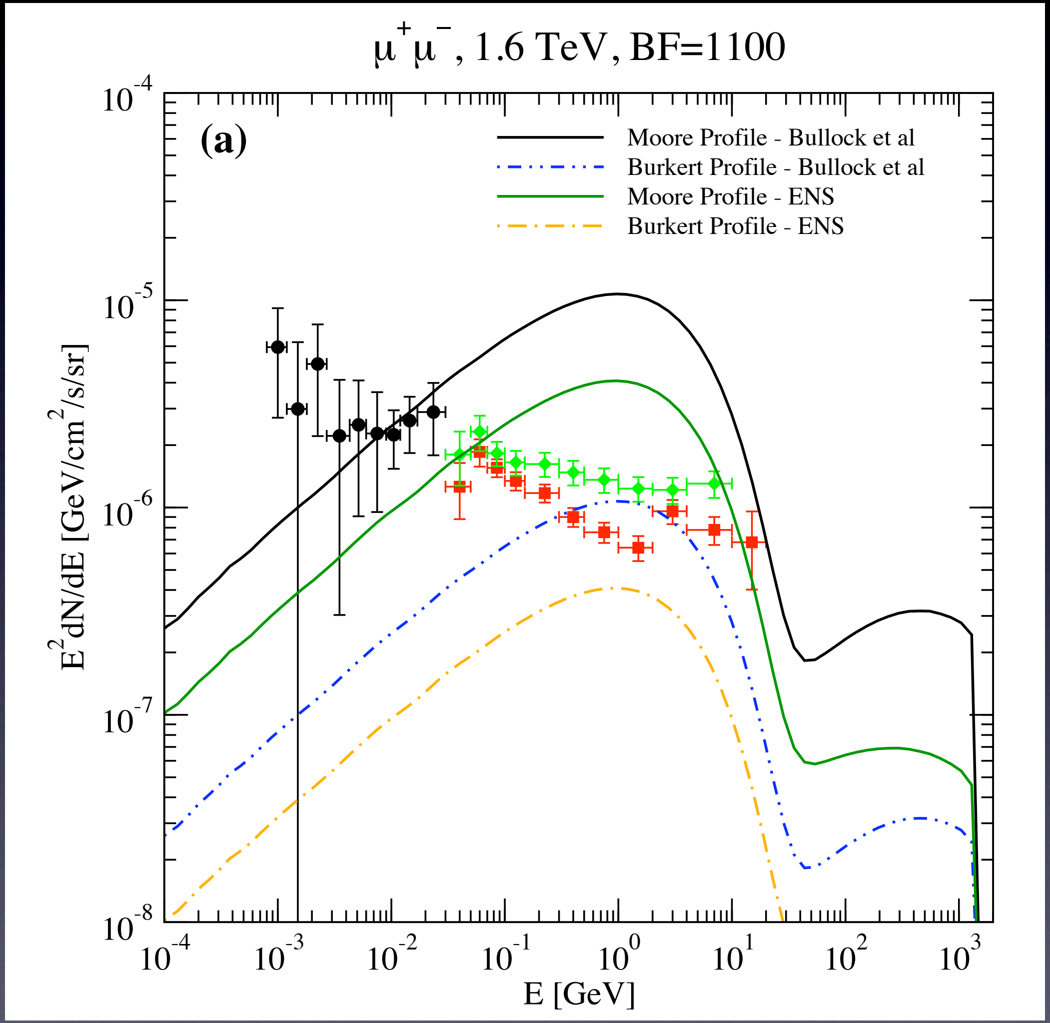
Gamma-rays from annihilation in MW substructure only, assuming substructure accounts for local cosmic ray fluxes



Kistler & JSG 2009

Other constraints

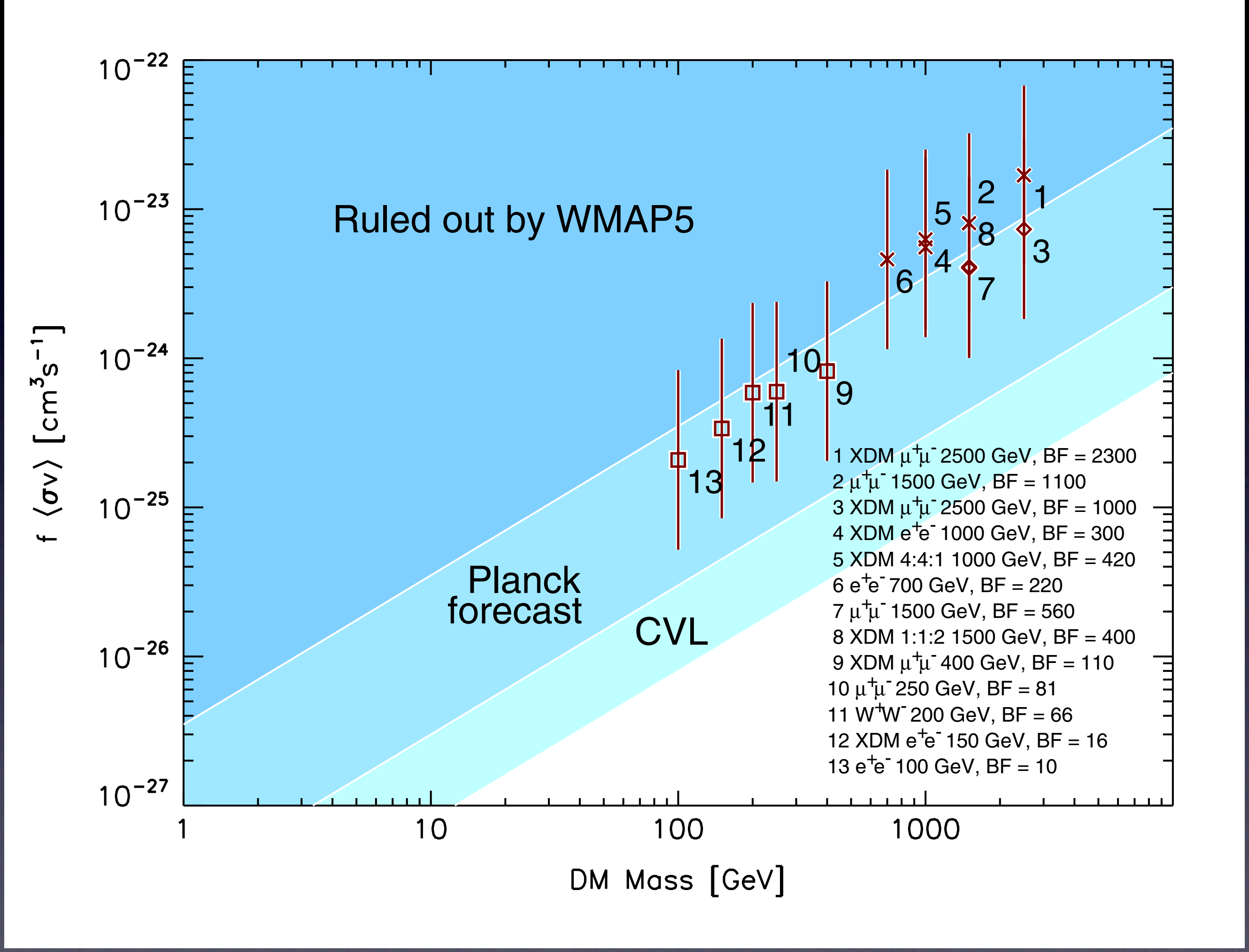
- extragalactic gamma-rays (e.g., Profumo & Jeltema 2009, Belikov & Hooper 2009)



Profumo & Jeltema 2009

Other constraints

- extragalactic gamma-rays (e.g., Profumo & Jeltema 2009, Belikov & Hooper 2009)
- CMB (e.g., Slatyer et al. 2009, Galli et al. 2009)



Slatyer et al. 2009

Maximizing the potential of Fermi data

- new approaches / analysis techniques?
- multi-wavelength, multi-messenger approaches to indirect detection?
- how to robustly detect DM in the presence of substantial and uncertain foregrounds? are there unique DM signatures?