Latest results from indirect dark matter searches with the Fermi Large Area Telescope

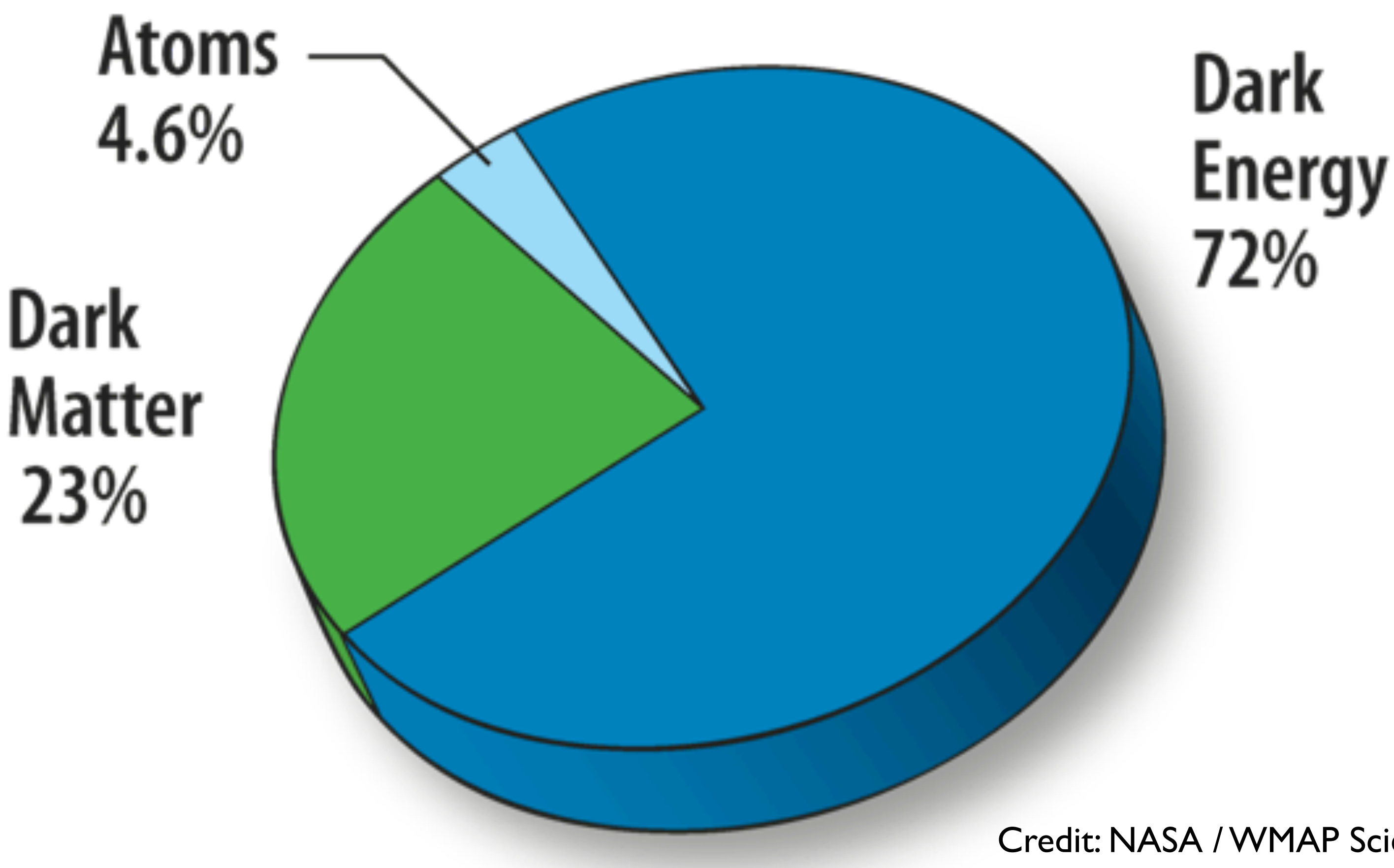
Jennifer Siegal-Gaskins
(Caltech)

on behalf of
the Fermi LAT Collaboration

The nature of dark matter

Observational evidence indicates:

- non-baryonic
- neutral
- virtually collisionless

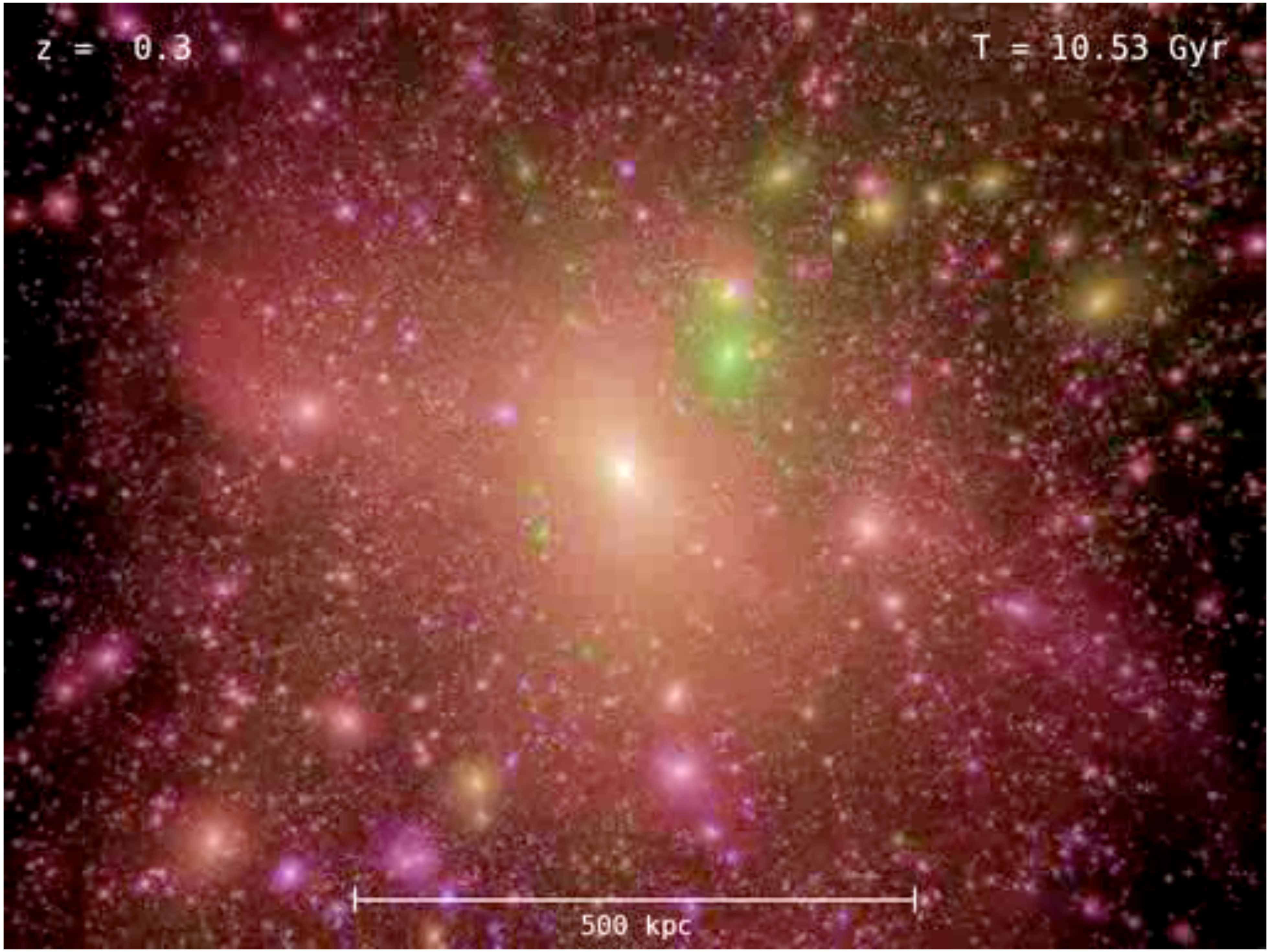


Credit: NASA / WMAP Science Team

Additional assumptions for this talk:

- dark matter is a weakly-interacting massive particle (WIMP)
- GeV - TeV mass scale
- can pair annihilate or decay to produce standard model particles
- accounts for the measured dark matter density

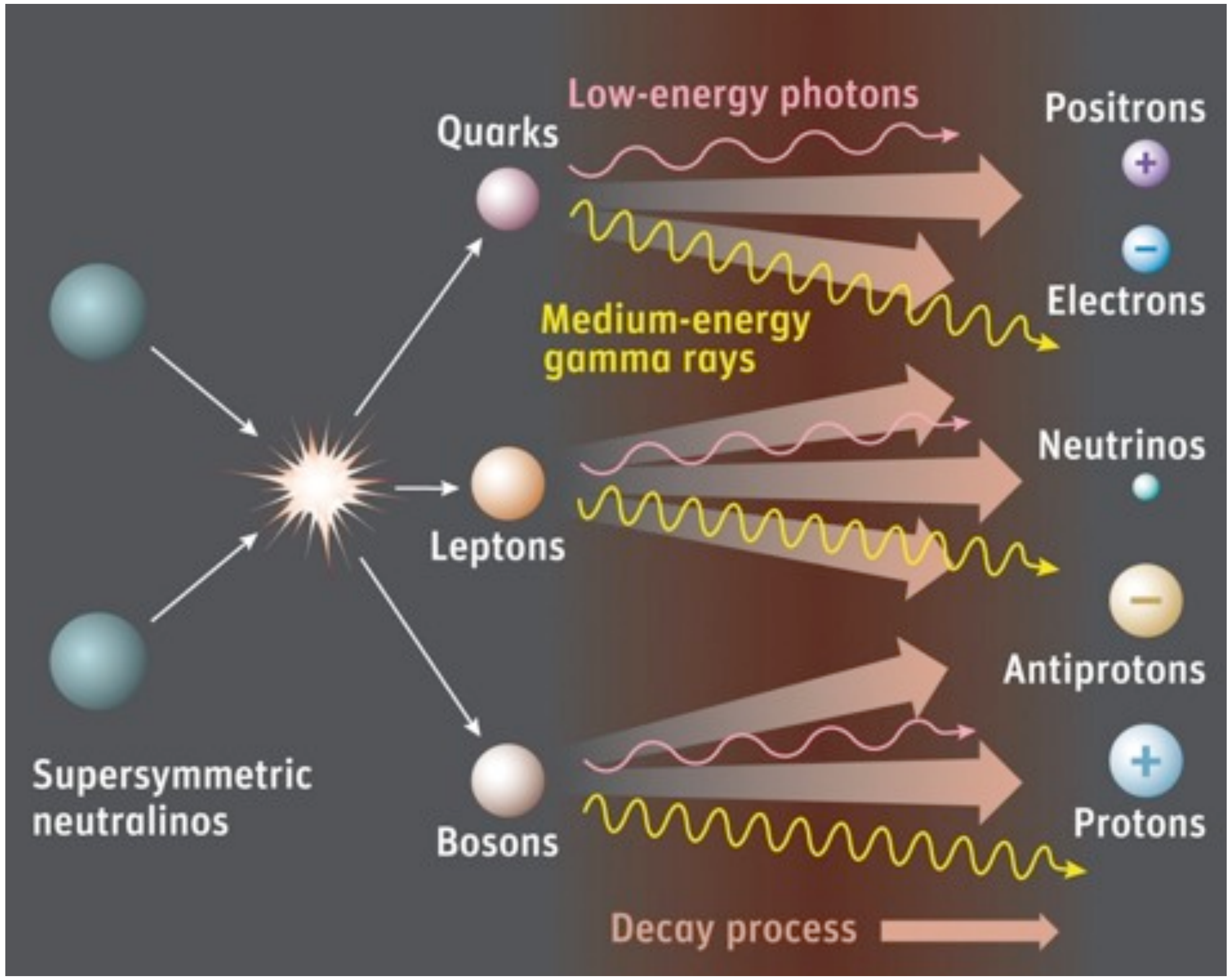
The dark matter spatial distribution



Credit: Springel et al. (Virgo Consortium)

Indirect dark matter signals

- annihilation or decay of dark matter can produce a variety of potentially detectable Standard Model particles
- spectrum of annihilation (or decay) products encodes info about intrinsic particle properties
- variation in the intensity of the signal along different lines of sight is determined exclusively by the distribution of dark matter



Credit: Sky & Telescope / Gregg Dinderman

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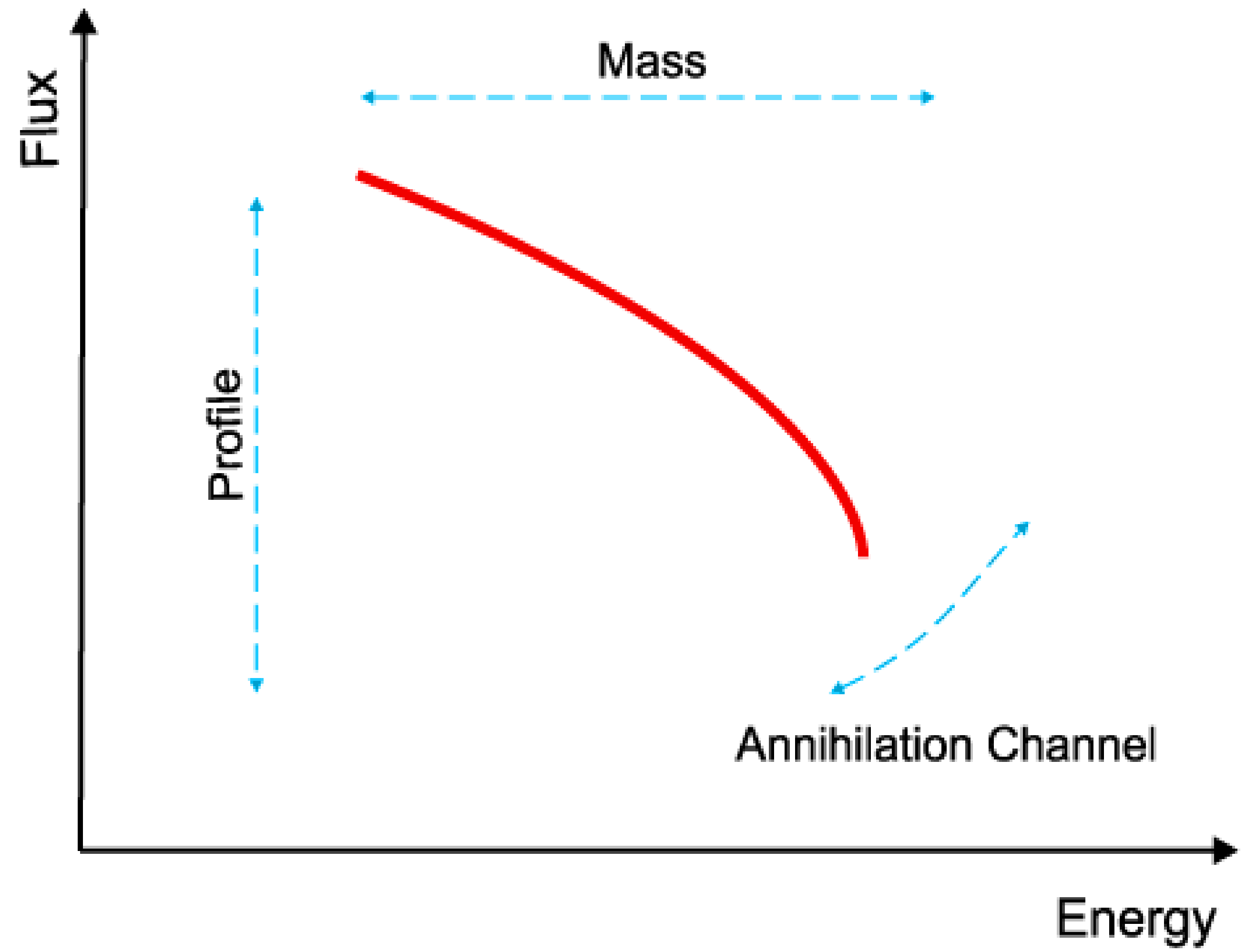

Bertone 2007

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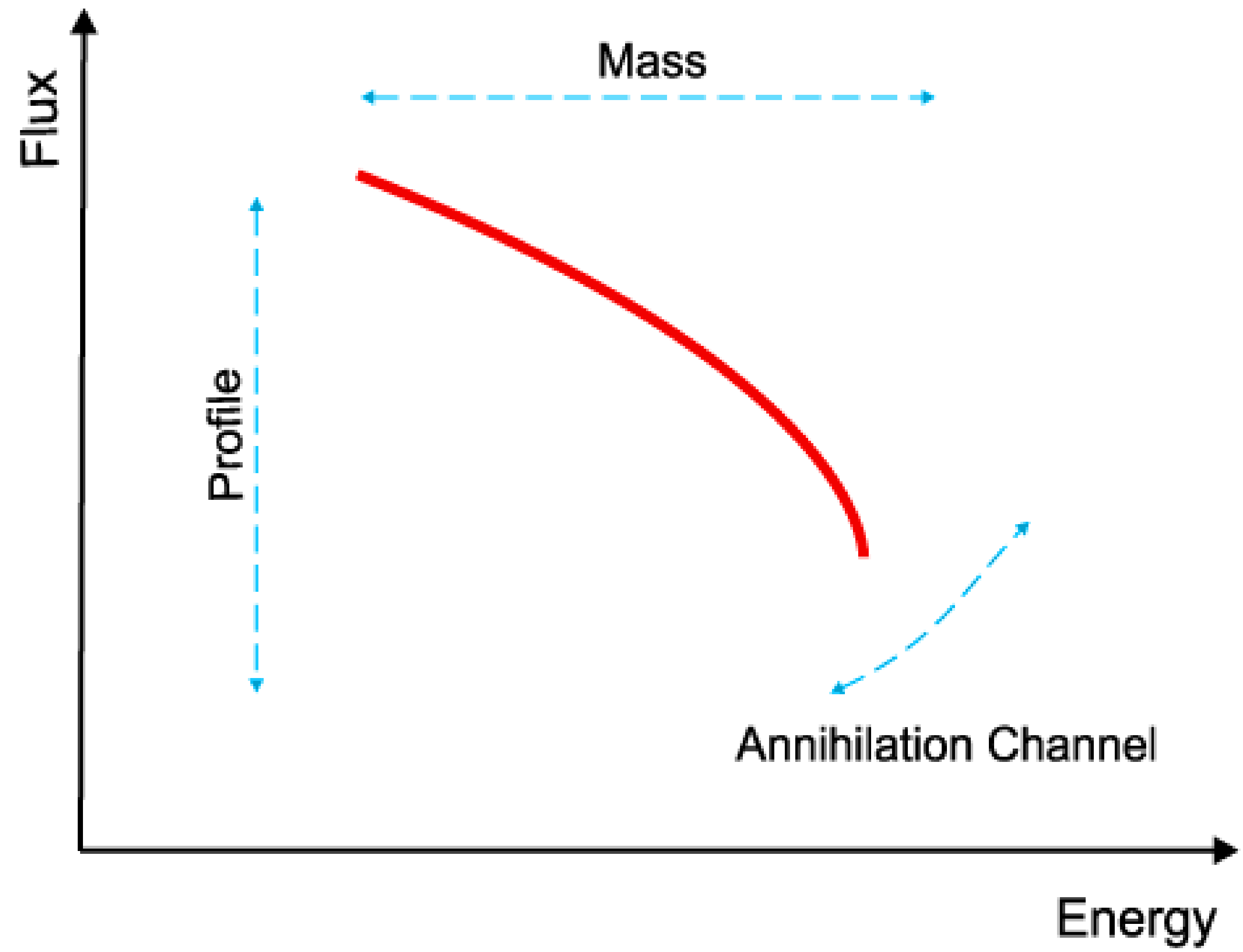

Bertone 2007

$$I(\psi) = \frac{K}{4\pi} \int_{los} \mathrm{d}s \; \rho^2(s,\psi) \qquad K = \frac{N_\gamma \langle \sigma v \rangle}{2 m_\chi^2}$$

(annihilation)

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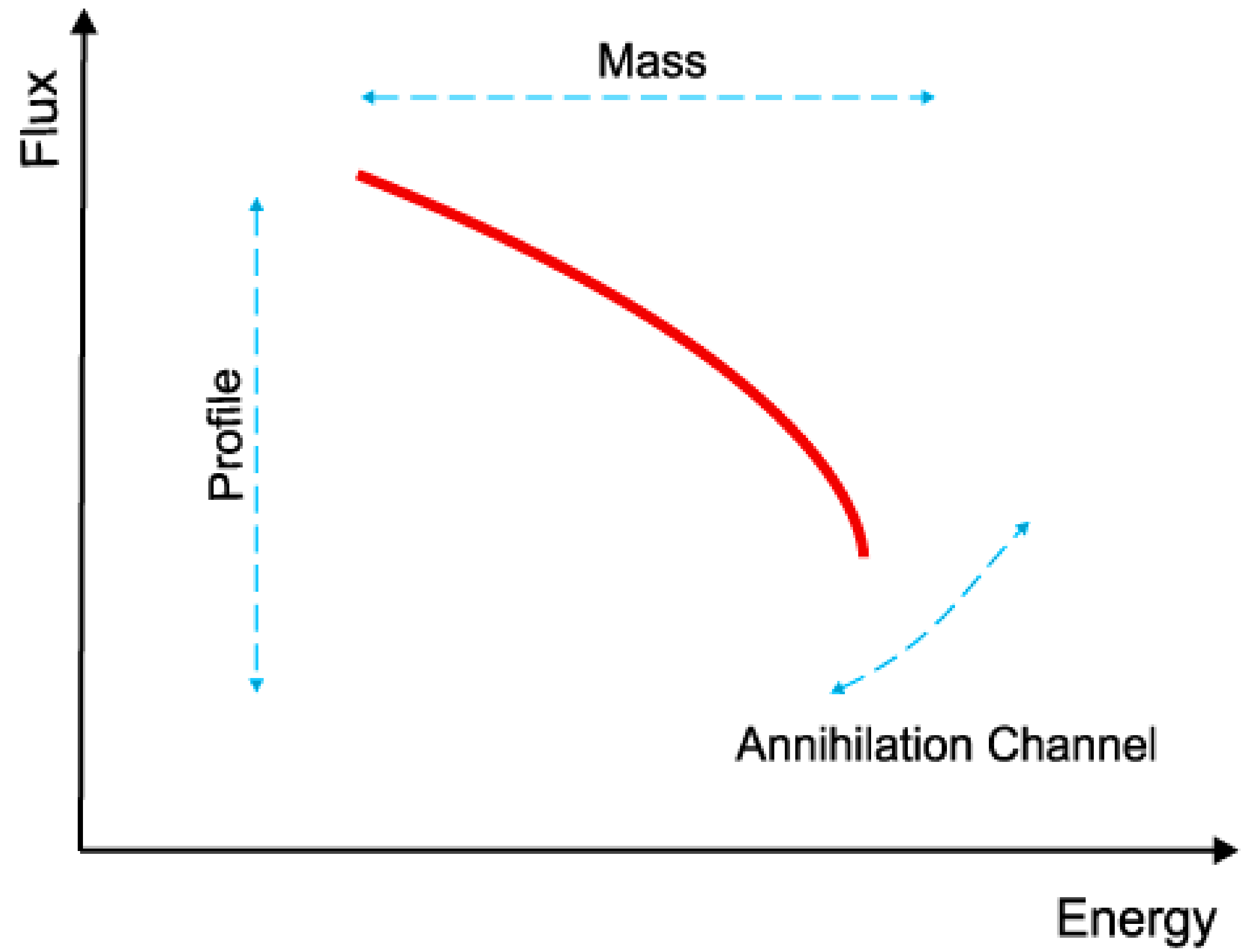

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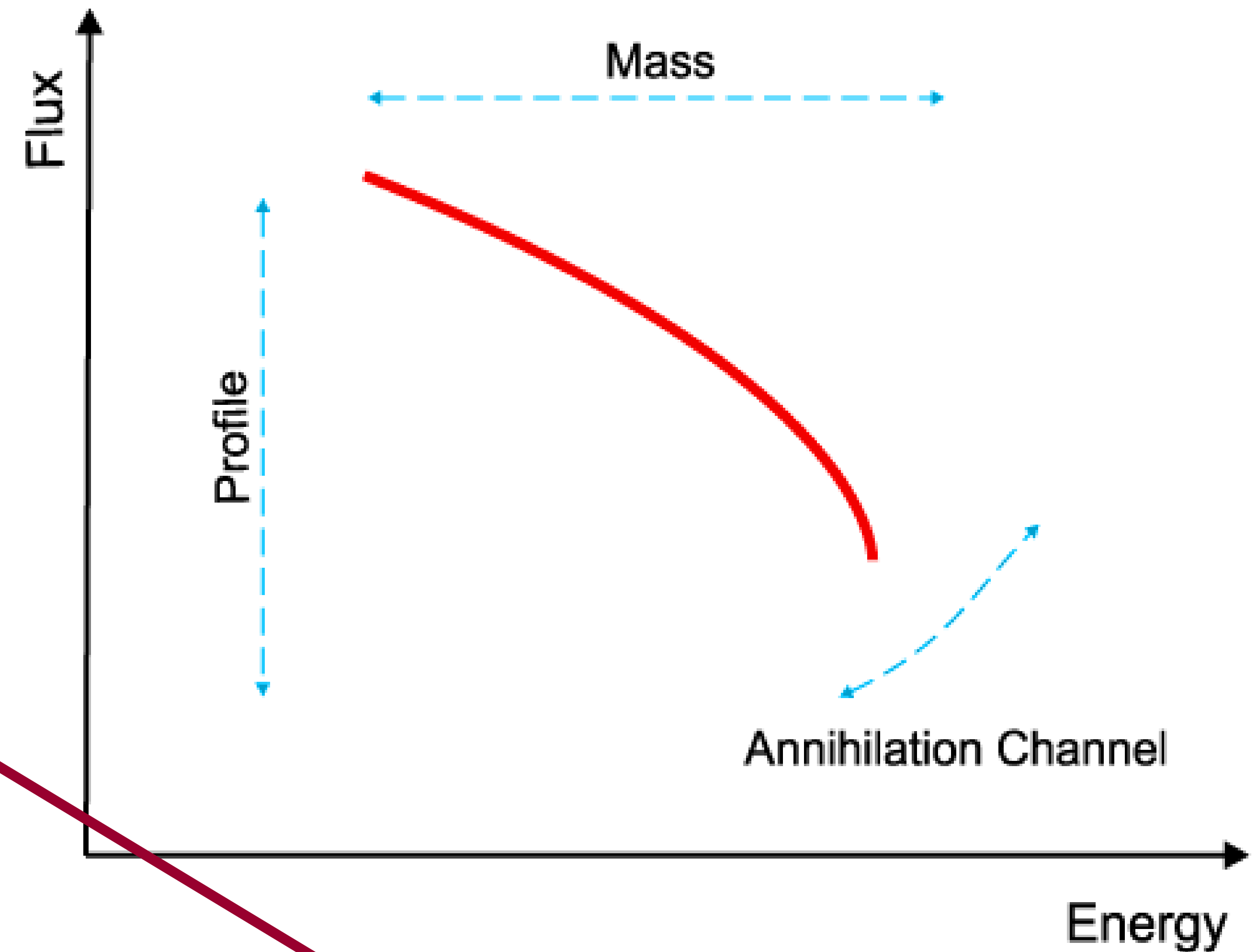

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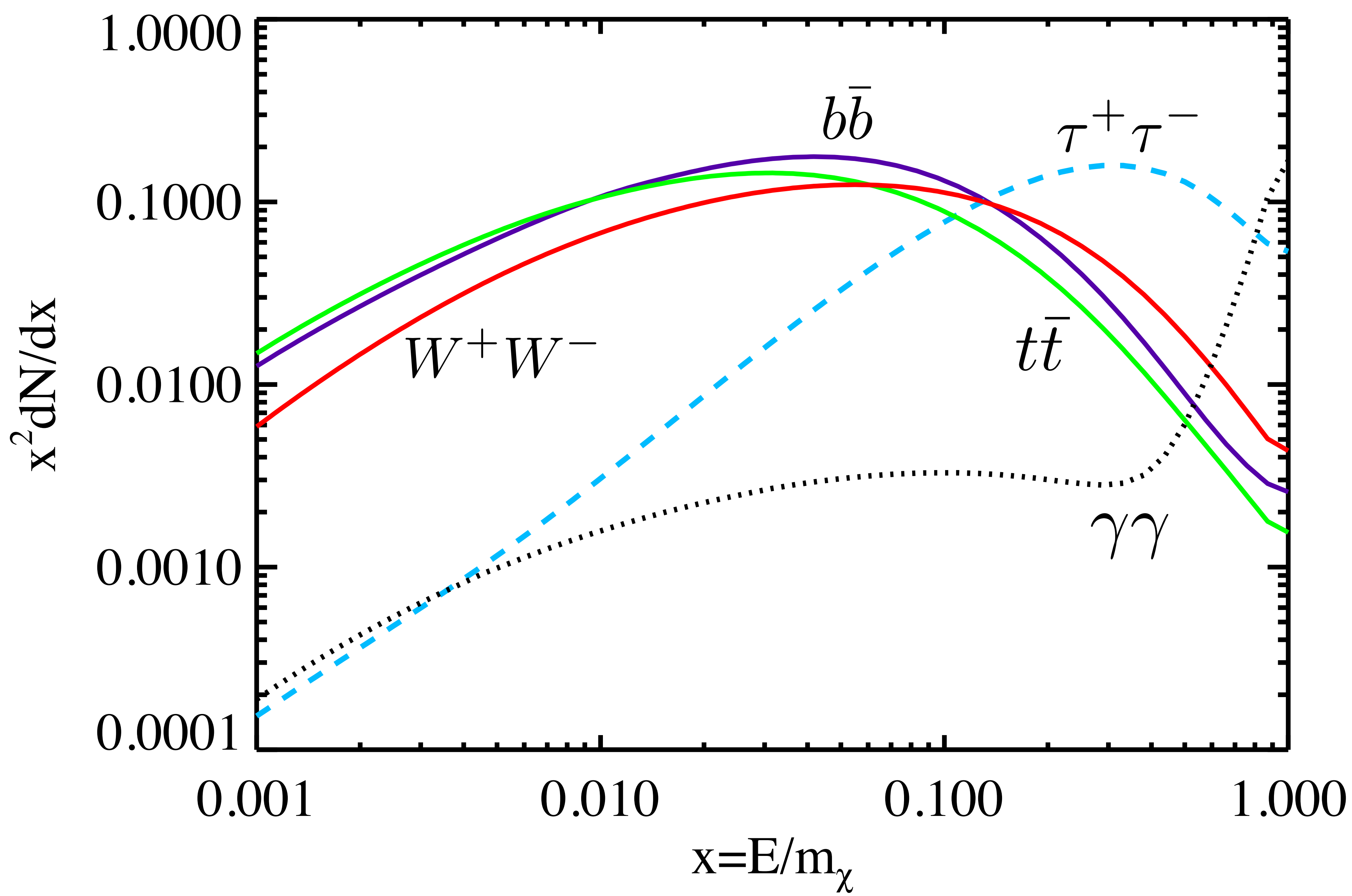
Dark matter photon spectra

- soft channels produce a continuum gamma-ray spectrum primarily from decay of neutral pions
- internal bremsstrahlung radiation from charged lepton final states (much harder)
- direct annihilation to photons, line emission (γγ, Zγ)



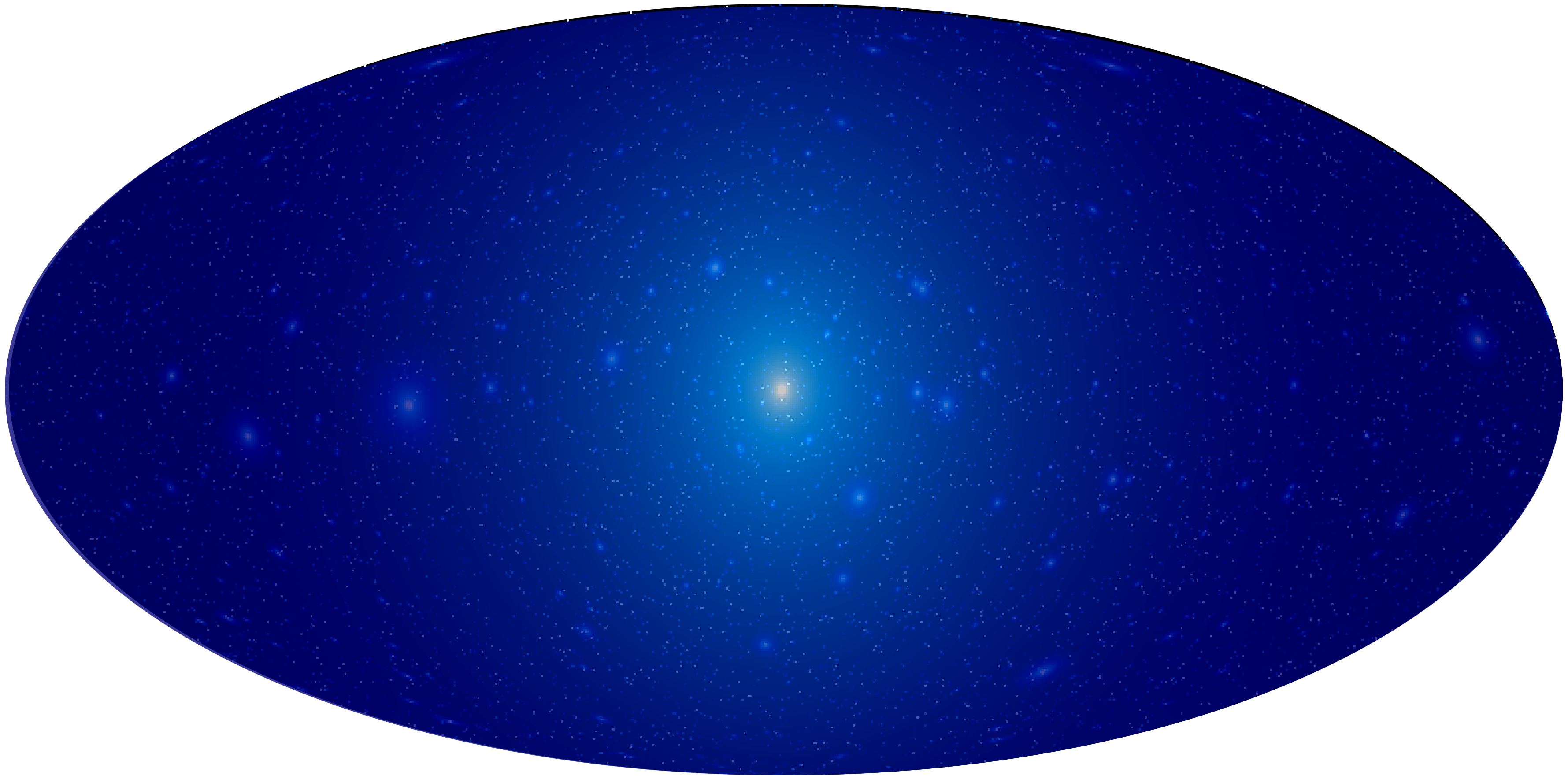
Spectra calculated with PPPC 4 DM ID [Cirelli et al. 2010]

The Fermi Large Area Telescope (LAT)

- pair-production detector: detects charged particles as well as gamma rays
- excellent charged particle event identification and background rejection
- 20 MeV to > 300 GeV
- angular resolution ~ 0.1 deg above 10 GeV
- uniform sky exposure of ~ 30 mins every 3 hrs

Credit: NASA/General Dynamics

Fermi LAT dark matter search targets



Gamma rays from dark matter annihilation

Image credit: JSG 2008

Fermi LAT dark matter search targets

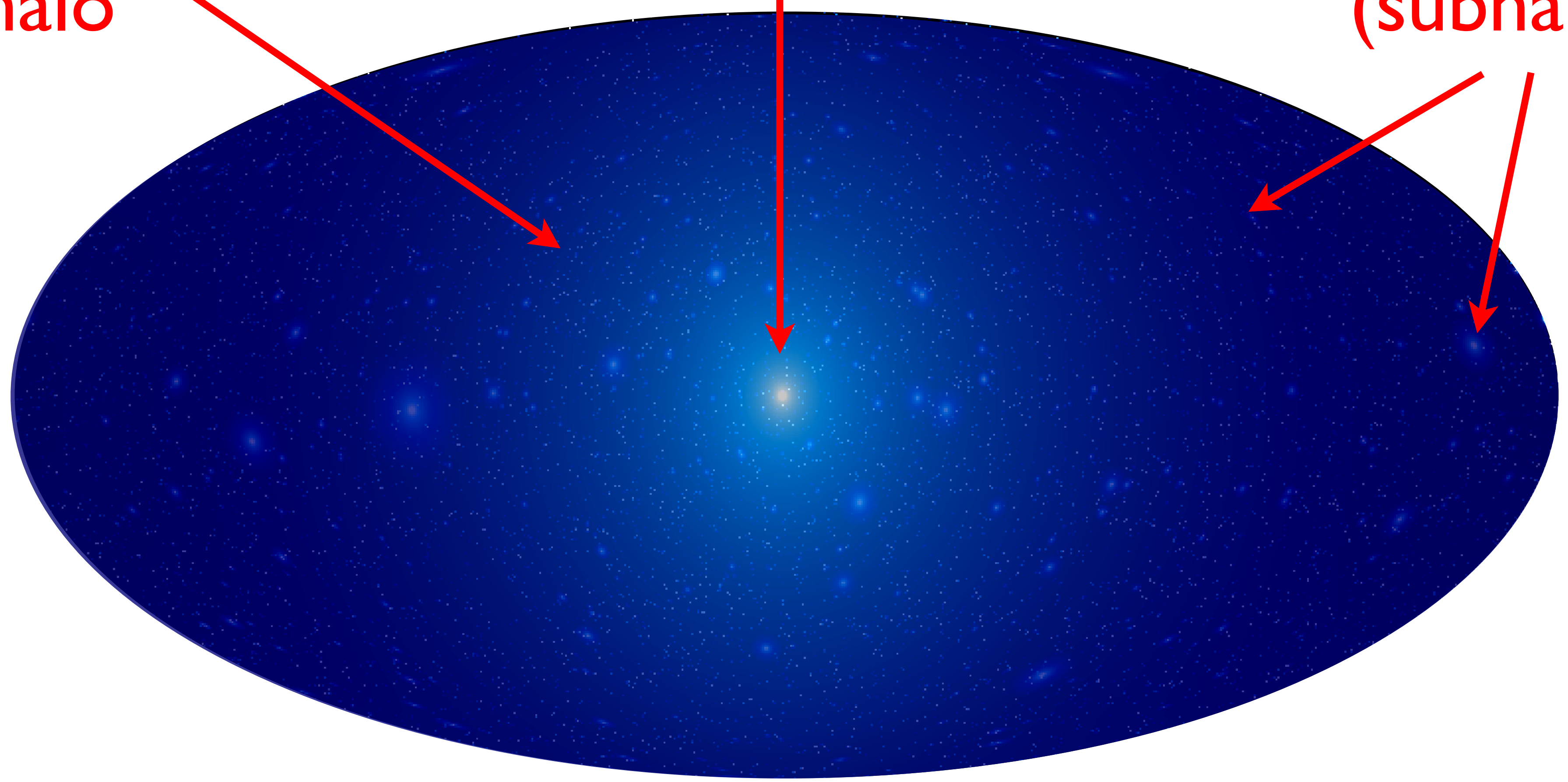
The inner galaxy

The Milky Way halo

Unassociated sources (subhalos?)

Galaxy clusters

Dwarf galaxies



The Sun

Spectral lines

Cosmic-ray electrons and positrons

Gamma rays from dark matter annihilation

Anisotropies

The isotropic gamma-ray background

Image credit: JSG 2008

The Fermi LAT gamma-ray sky

3-year all-sky map, E > 1 GeV

The inner galaxy

The Milky Way halo

Unassociated sources (subhalos?)

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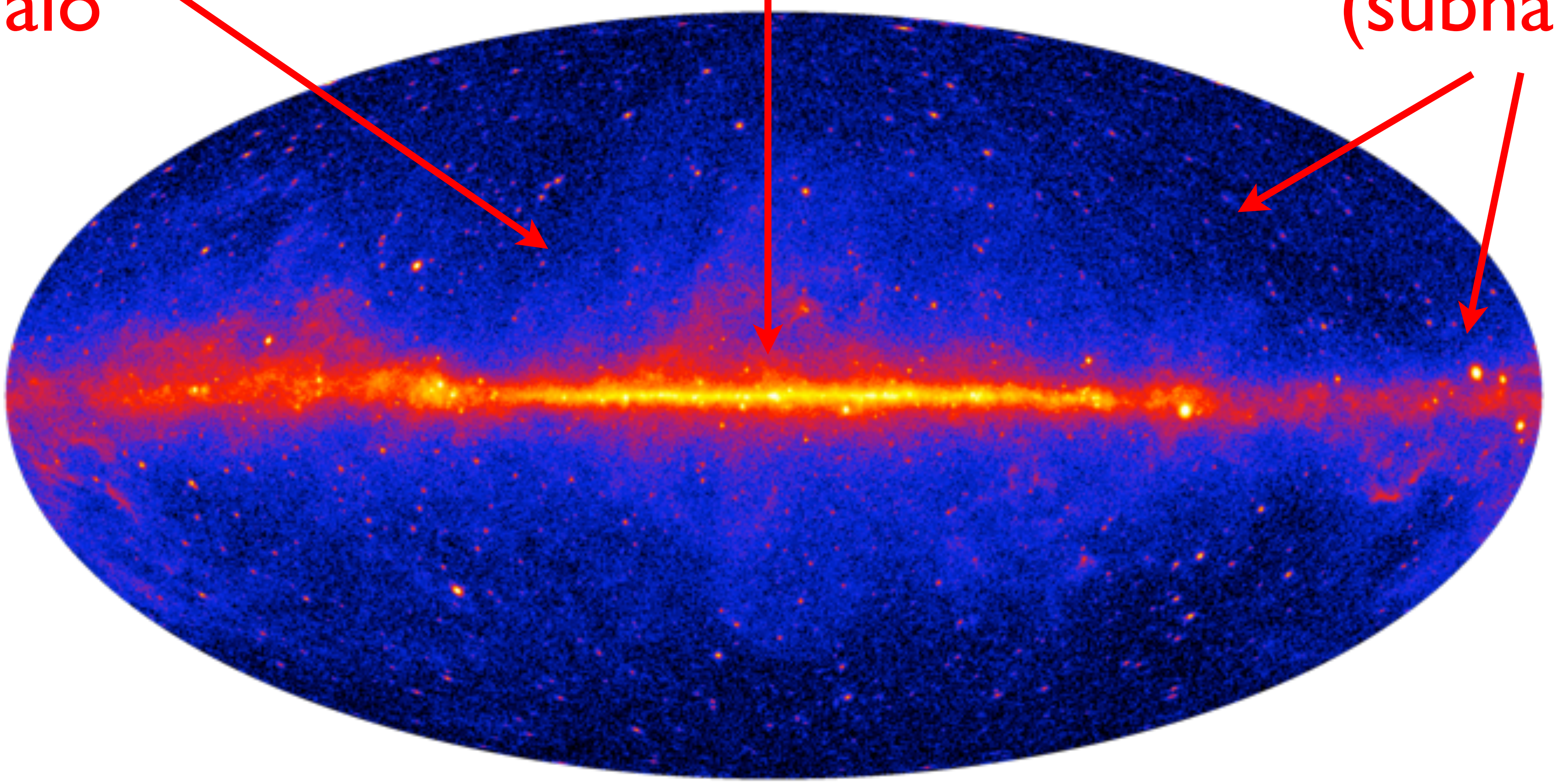
Dwarf galaxies



The Sun

Spectral lines

Cosmic-ray electrons and positrons

Image Credit: NASA/DOE/International LAT Team

Anisotropies

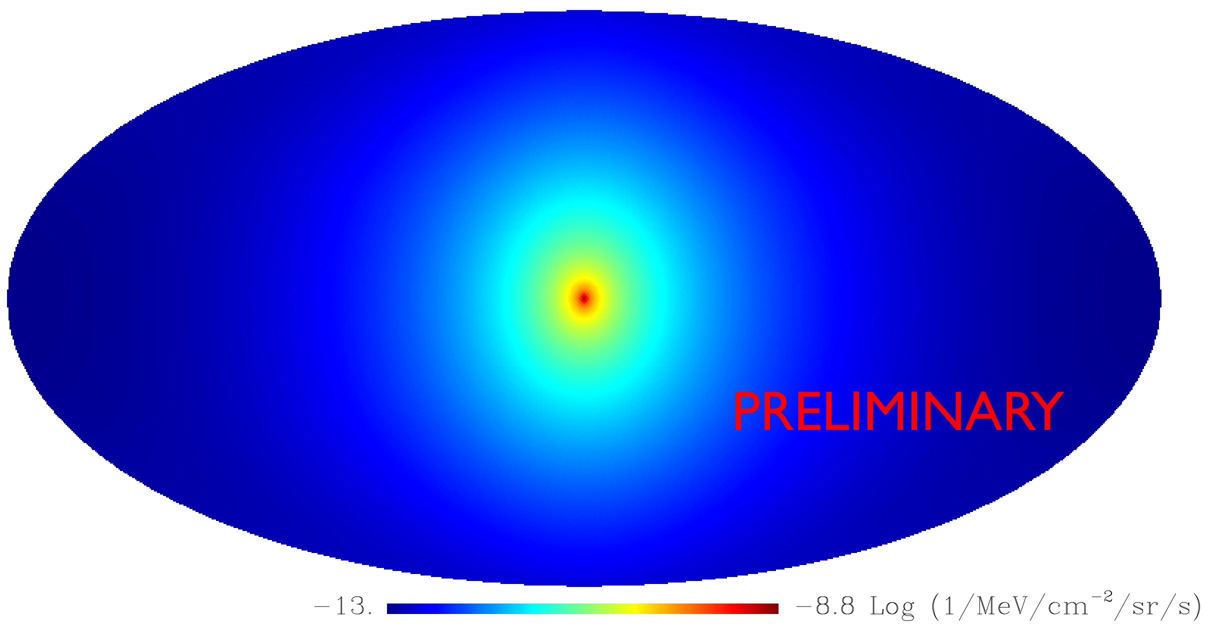
The isotropic gamma-ray background

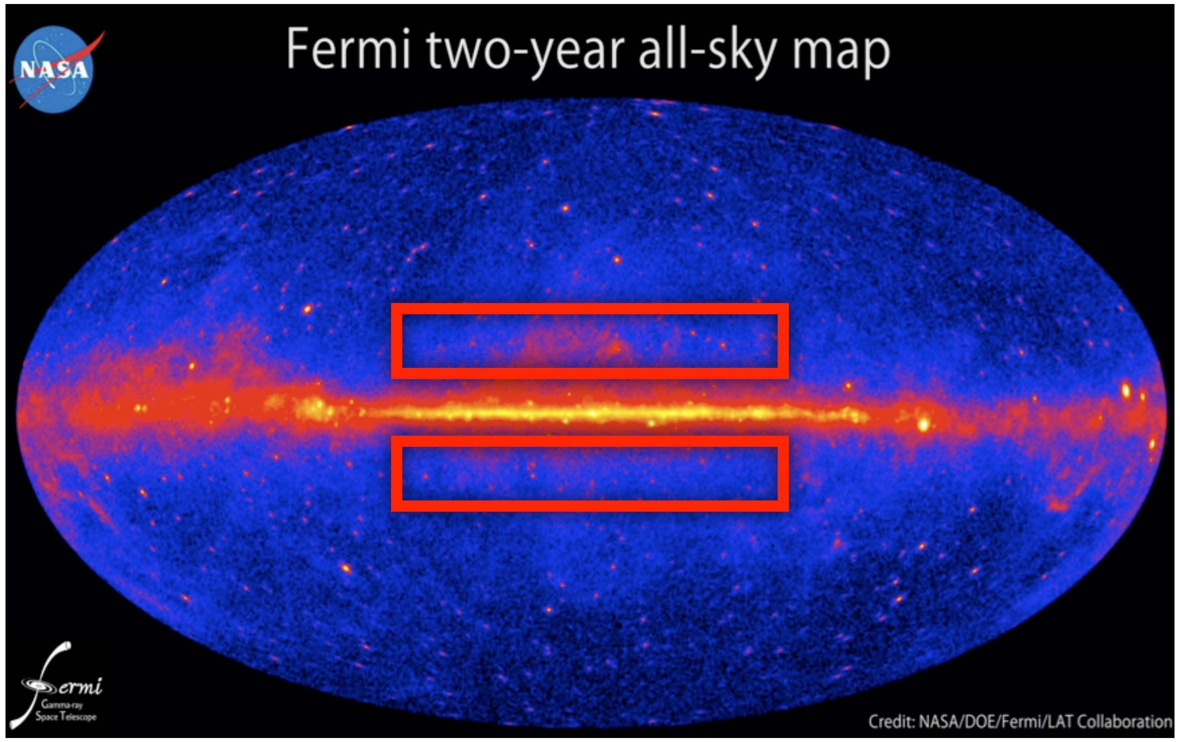
Image credit: JSG 2008

Constraints from the Milky Way halo

testing the LAT diffuse data for a contribution from a Milky Way DM annihilation/decay signal

DM annihilation signal





- data set: 24 months, p7 clean event selection (front+back) in the 1-100 GeV energy range
- ROI: 5° <|b|<15° and |l|<80°, chosen to:
  - minimize DM profile uncertainty (highest in the Galactic Center region)
  - limit astrophysical uncertainty by masking out the Galactic plane and cutting-out high-latitude emission from the Fermi lobes and Loop I

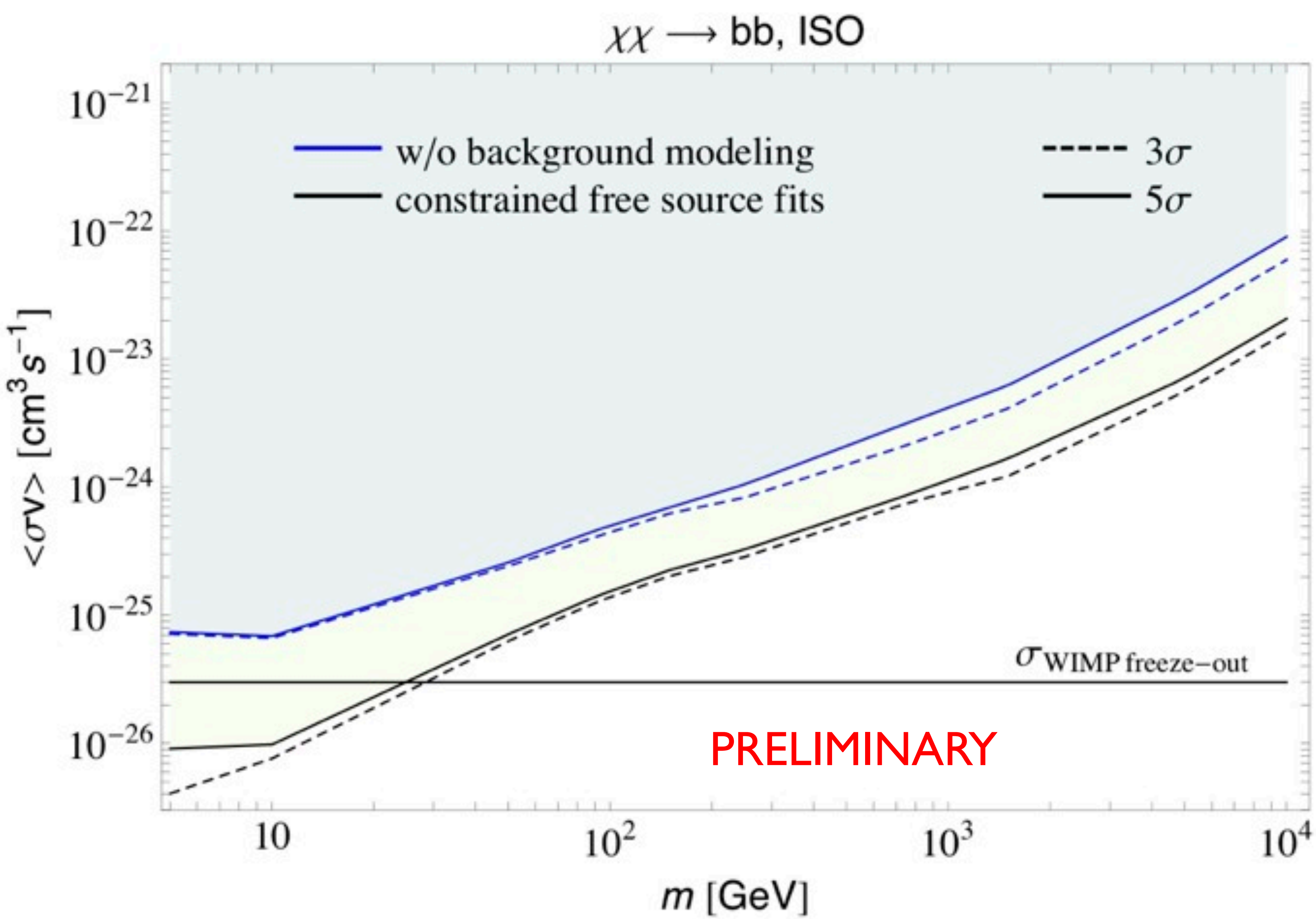
(see Gabrijela Zaharijas' talk this afternoon!)

see also: Malyshev, Bovy, & Cholis, PRD 84 (2011) 023013

Constraints from the halo: bb channel

- blue = “no-background limits”
- black = limits obtained by marginalization over the CR source distribution, diffusive halo height and electron injection index, gas to dust ratio, and in which CR sources are held to zero in the inner 3 kpc
- limits with NFW density profile (not shown) are only slightly stronger

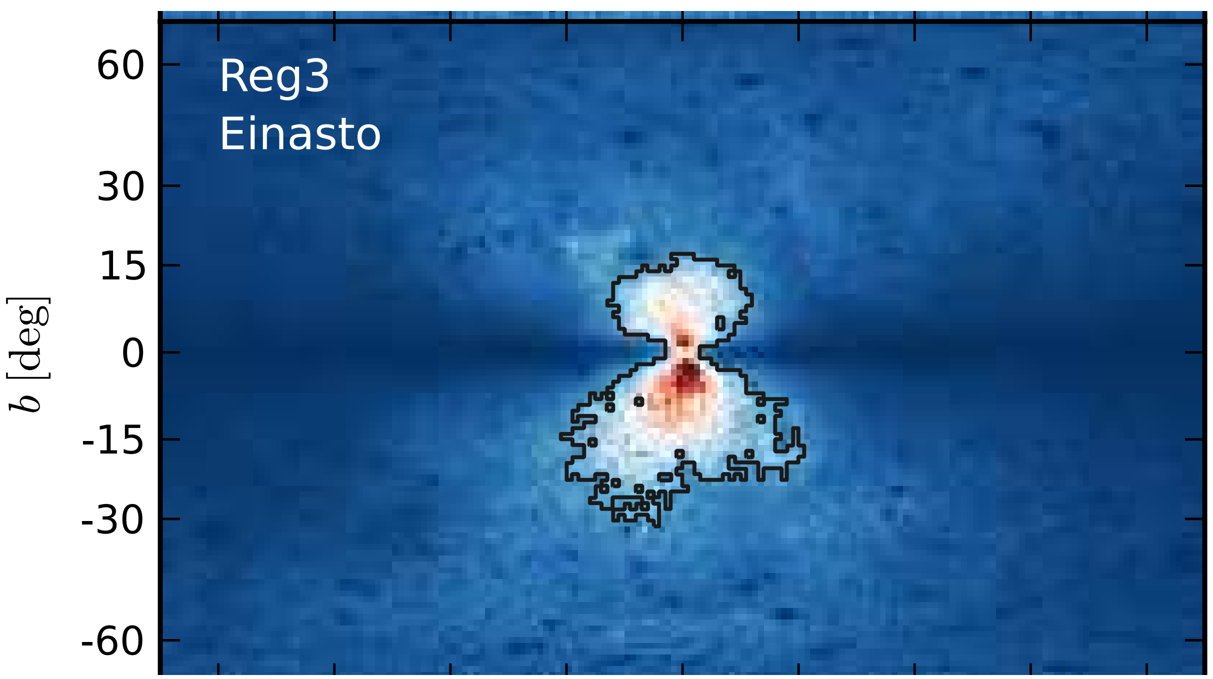
Annihilation



M. Ackermann et al. [Fermi LAT Collaboration], submitted

A 130 GeV line from dark matter?

One region-of-interest for Weniger's line search

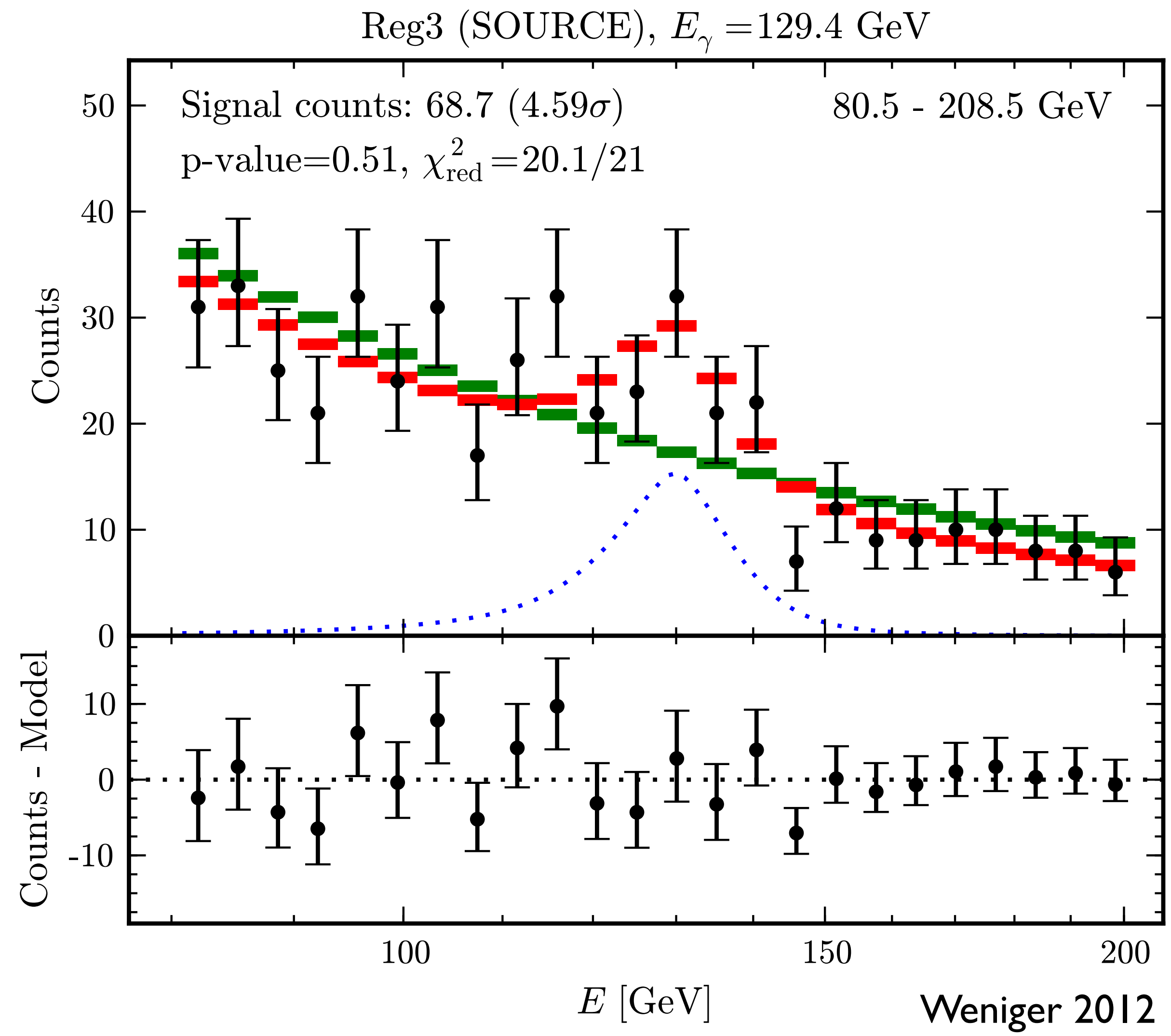


Weniger 2012

- Bringmann et al. find weak indication of a feature consistent with IB emission from DM annihilation
- Weniger claims a tentative gamma-ray line

(see also Christoph Weniger's talk this afternoon!)

Spectrum of ROI with power-law and power-law+line fits



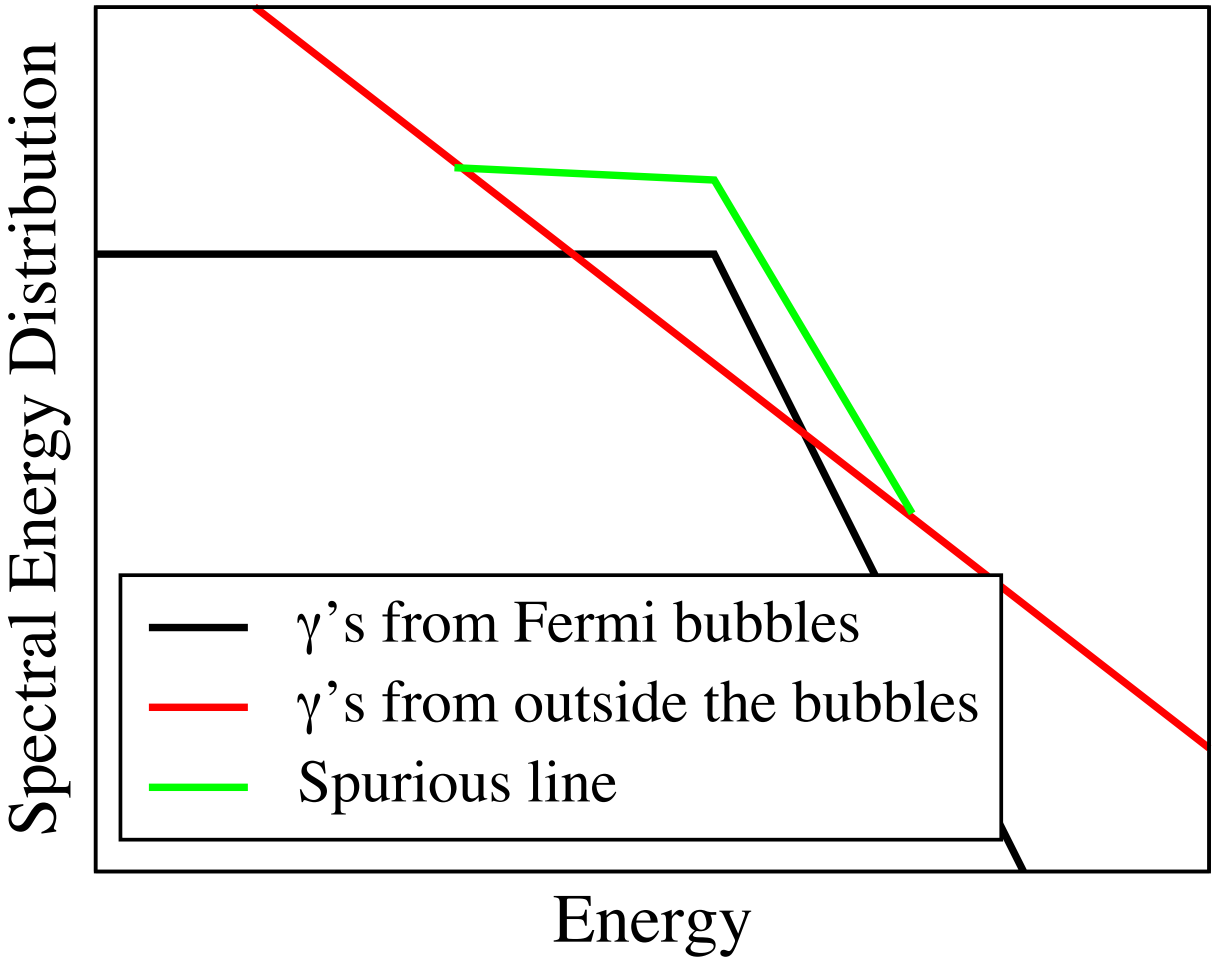
Weniger 2012

see also: Bringmann, Huang, Ibarra, Vogl, Weniger, arXiv:1203.1312; Weniger, arXiv:1204.2797; Tempel, Hektor, Raidal, arXiv:1205.1045; Boyarsky, Malyshev, Ruchayskiy, arXiv:1205.4700; Geringer-Sameth & Koushiappas, arXiv:1206.0796; Su & Finkbeiner, arXiv:1206.1616, Aharonian, Khangulyan, Malyshev, arXiv:1207.0458 ...

A 130 GeV line from dark matter?

- Many studies find similar line-like features
- Su & Finkbeiner 2012 localize the feature to a region offset from the GC
- Could a break in the spectrum of the Fermi bubbles be mistaken for a line? (Profumo & Linden 2012)
- Non-DM astrophysical sources of lines? (Aharonian et al 2012)
- Many unresolved questions remain: stay tuned!

Schematic demonstration of how a broken power law could lead to a spurious detection of a line

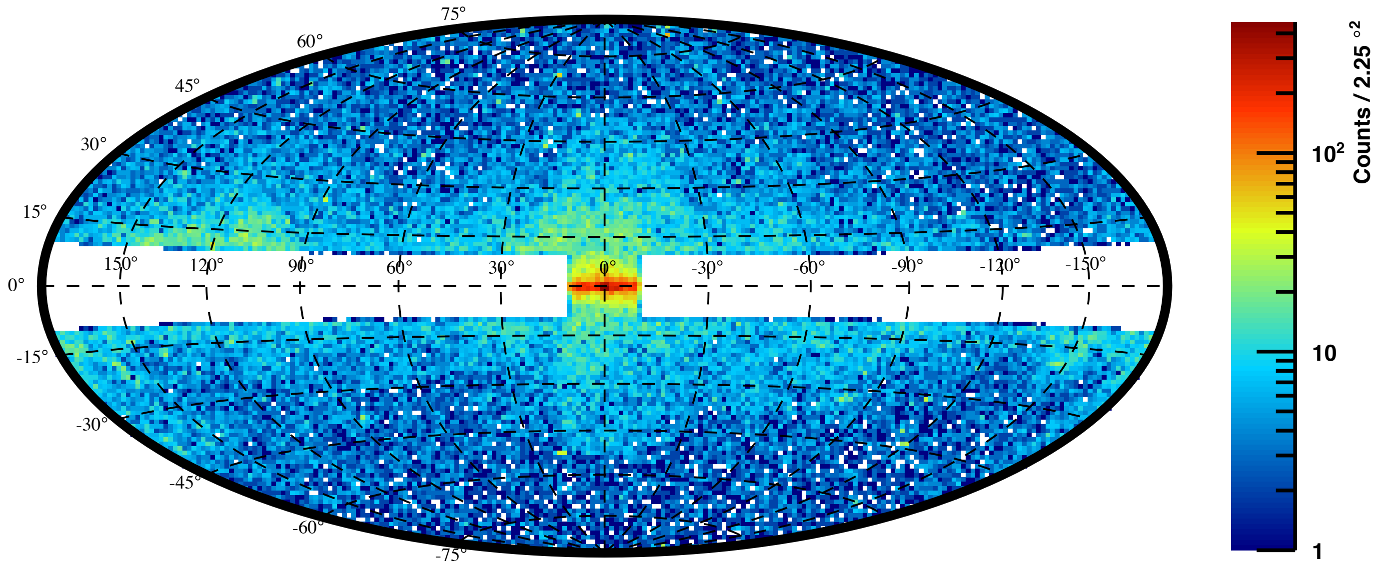


Profumo & Linden 2012

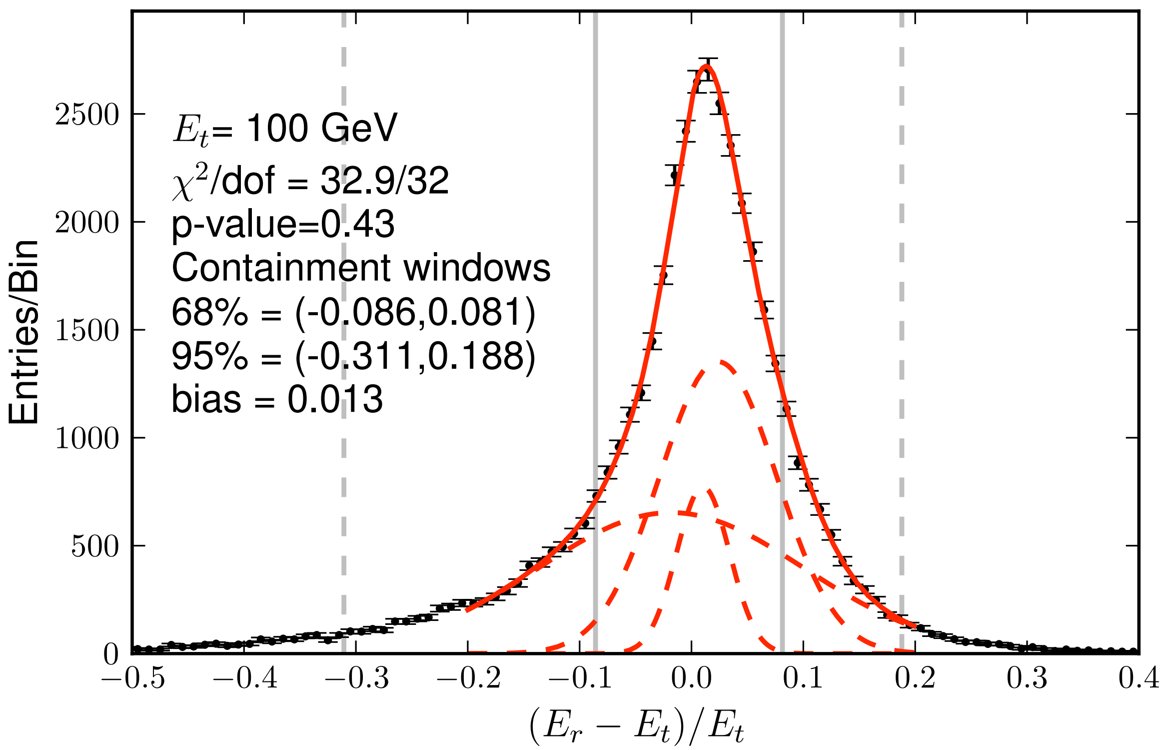
(see also Alex Geringer-Sameth's talk on Thursday!)

Search for spectral lines

Region-of-interest for line search



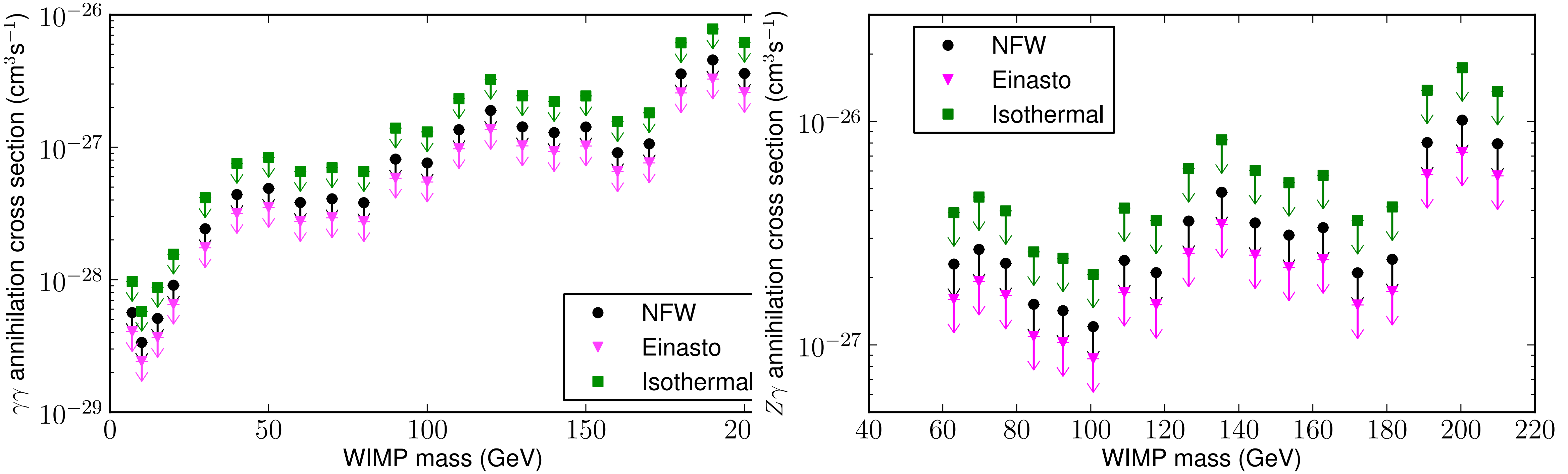
LAT energy response to 100 GeV line



- search for line emission from dark matter annihilation or decay ($\gamma\gamma$ and $Z\gamma$ channels)
- exclude Galactic plane and 1FGL sources
- assume power-law background (spectral index free to vary) in each energy window

Constraints from line search

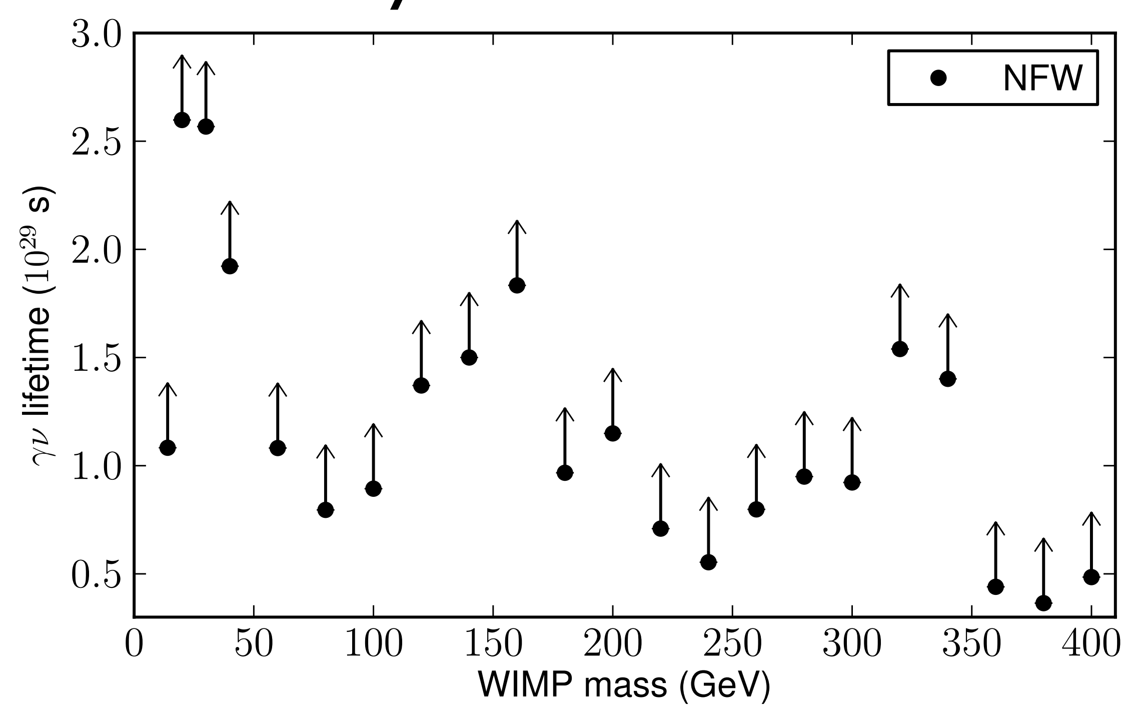
Annihilation cross-section constraints



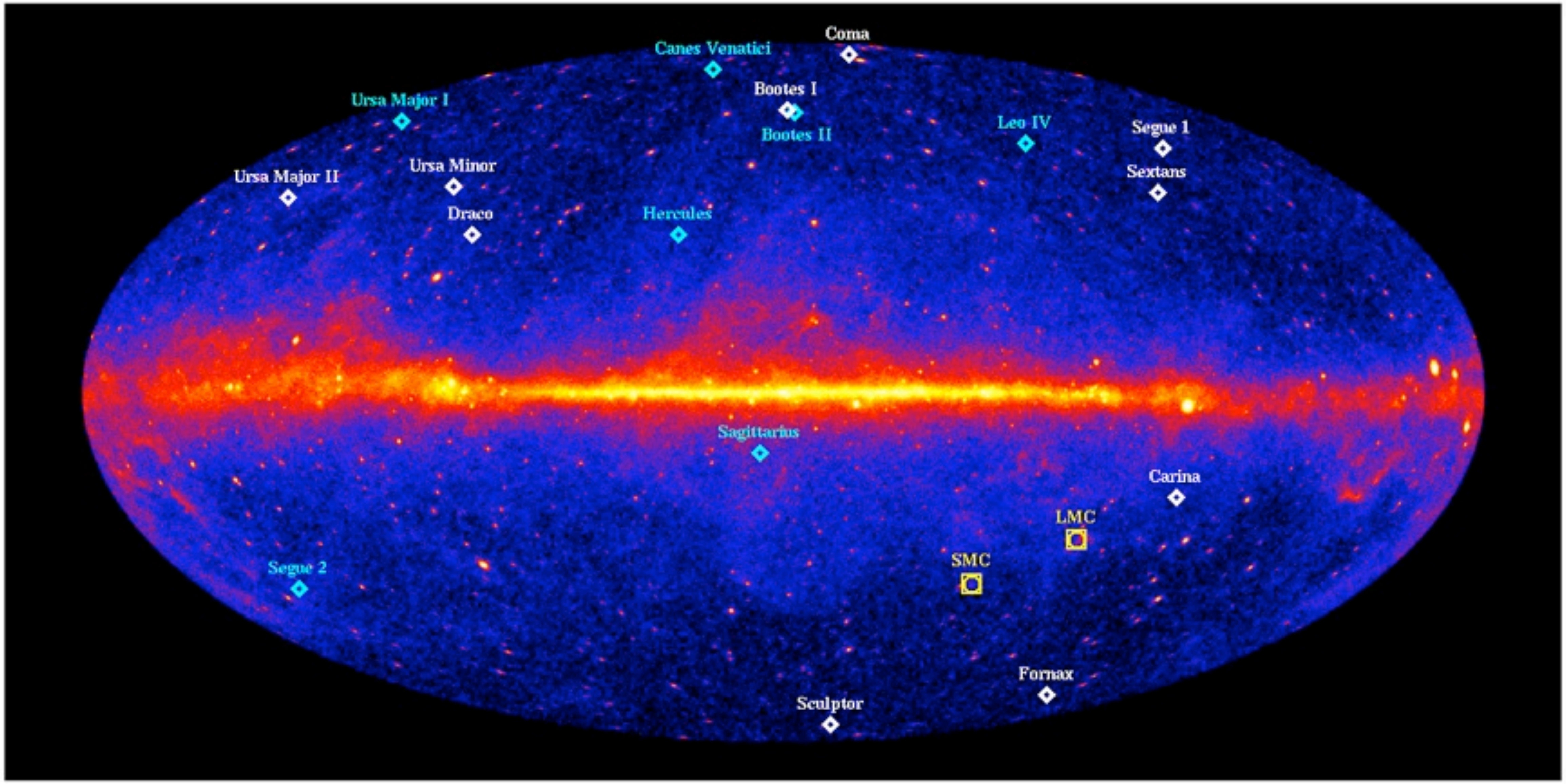
Ackermann et al. [Fermi LAT Collaboration], accepted to PRD

- non-detection places limits on annihilation cross section or decay lifetime to $\gamma\gamma$ and $Z\gamma$
- these limits not in strong tension with signal claims
- more data and analyses are needed!

Decay lifetime constraints



Search for gamma rays from dwarf galaxies



- there are roughly two dozen known dwarf spheroidal galaxies (dSphs) of the Milky Way
- some of the most dark-matter--dominated objects in the Universe
- no non-DM astrophysical gamma-ray production expected

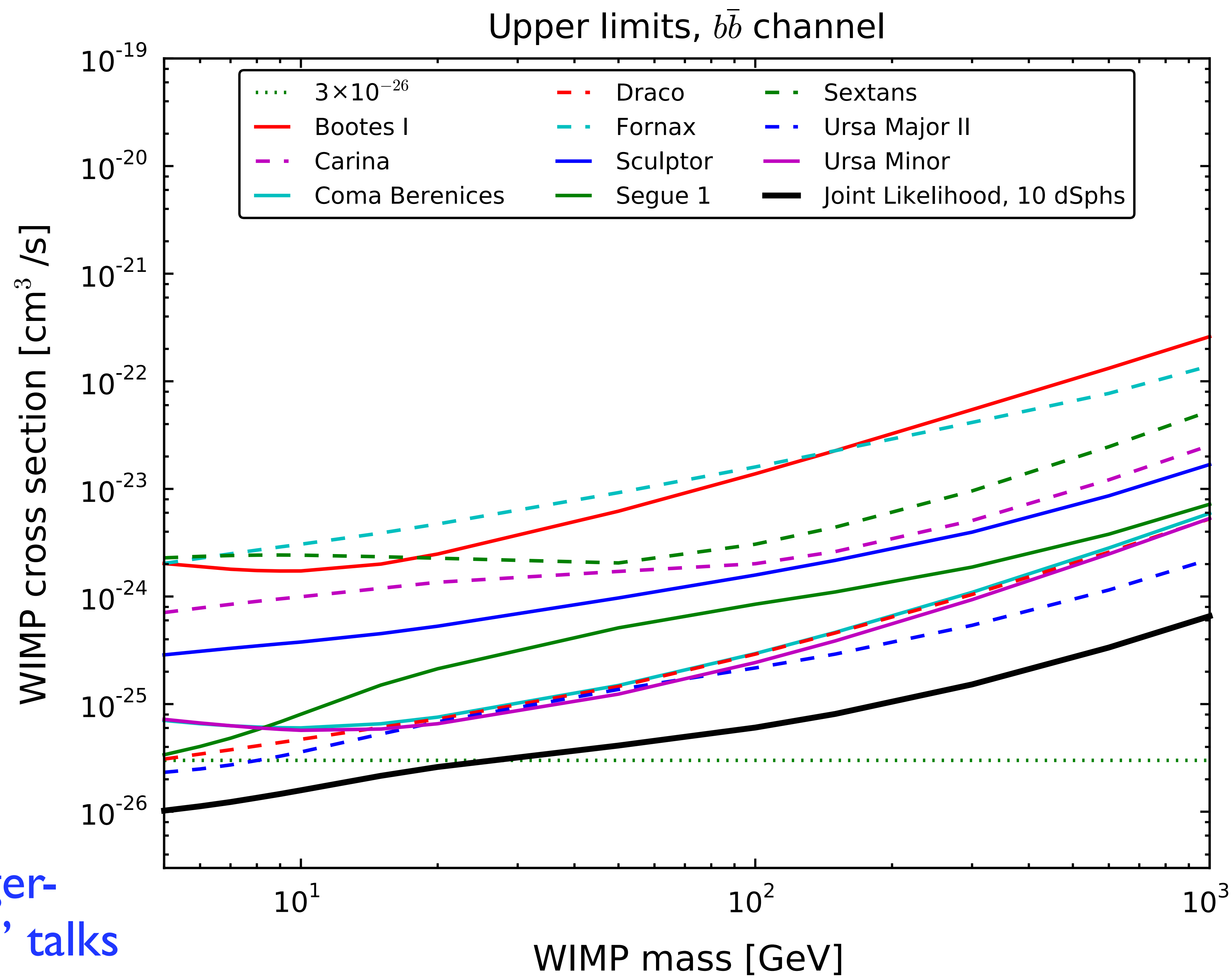
DM limits from combined analysis of dSphs

Joint likelihood analysis of Fermi LAT data:

- 10 dwarf galaxy targets
- 2 years data, energy range: 200 MeV - 100 GeV, P6_V3_diffuse
- 4 annihilation channels
- incorporates statistical uncertainties in the solid-angle-integrated "J-factor"

  (= "astrophysical factor" in the predicted signal, set by the dark matter distribution)

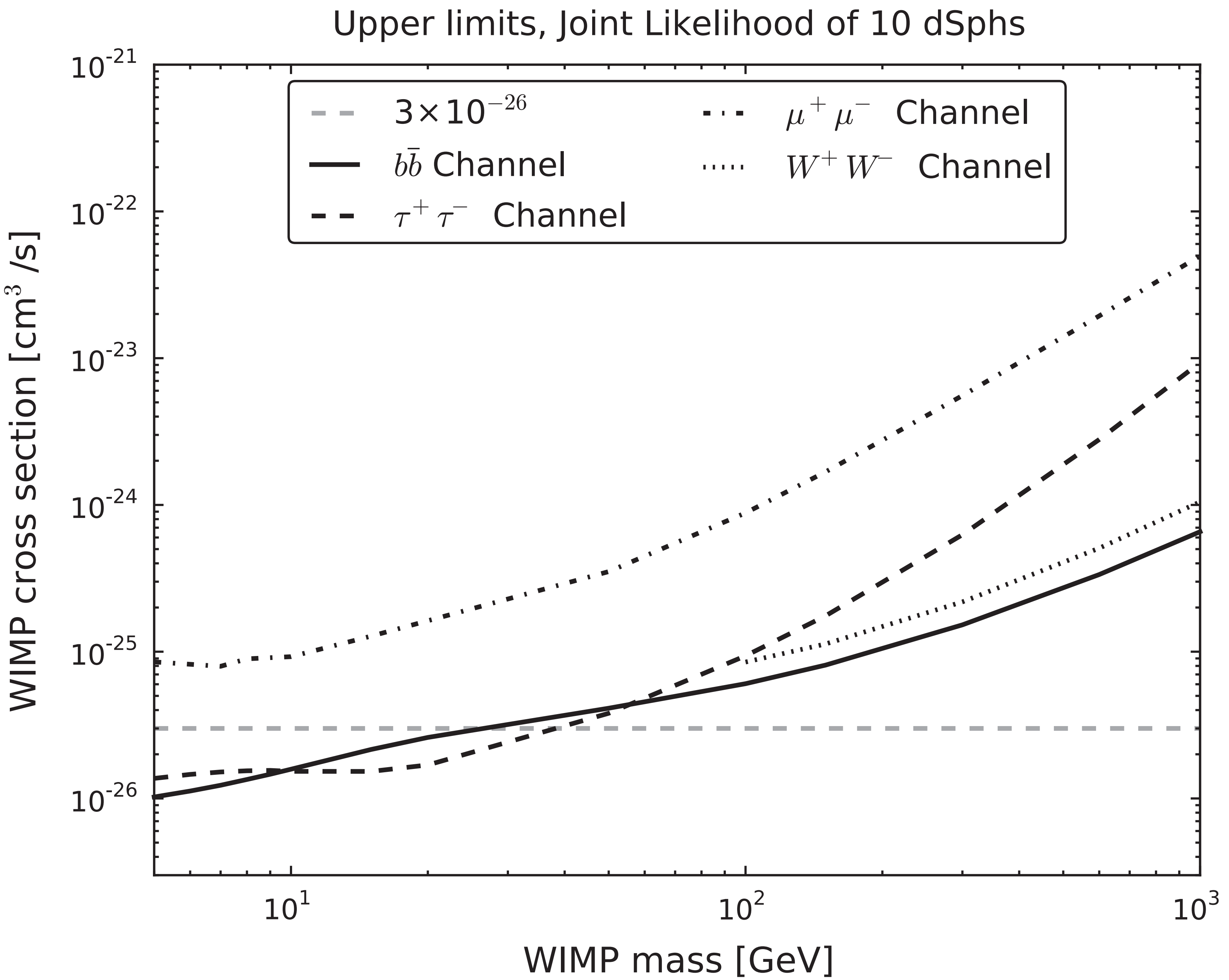
(see also Alex Geringer-Sameth's and Ilias Cholis' talks on Thursday!)



M. Ackermann et al. [Fermi LAT Collaboration], PRL 107, 241302 (2011)

see also: Geringer-Sameth & Koushiappas, PRL 107, 241303 (2011); Cholis & Salucci, arXiv:1203.2954

DM limits from combined analysis of dSphs



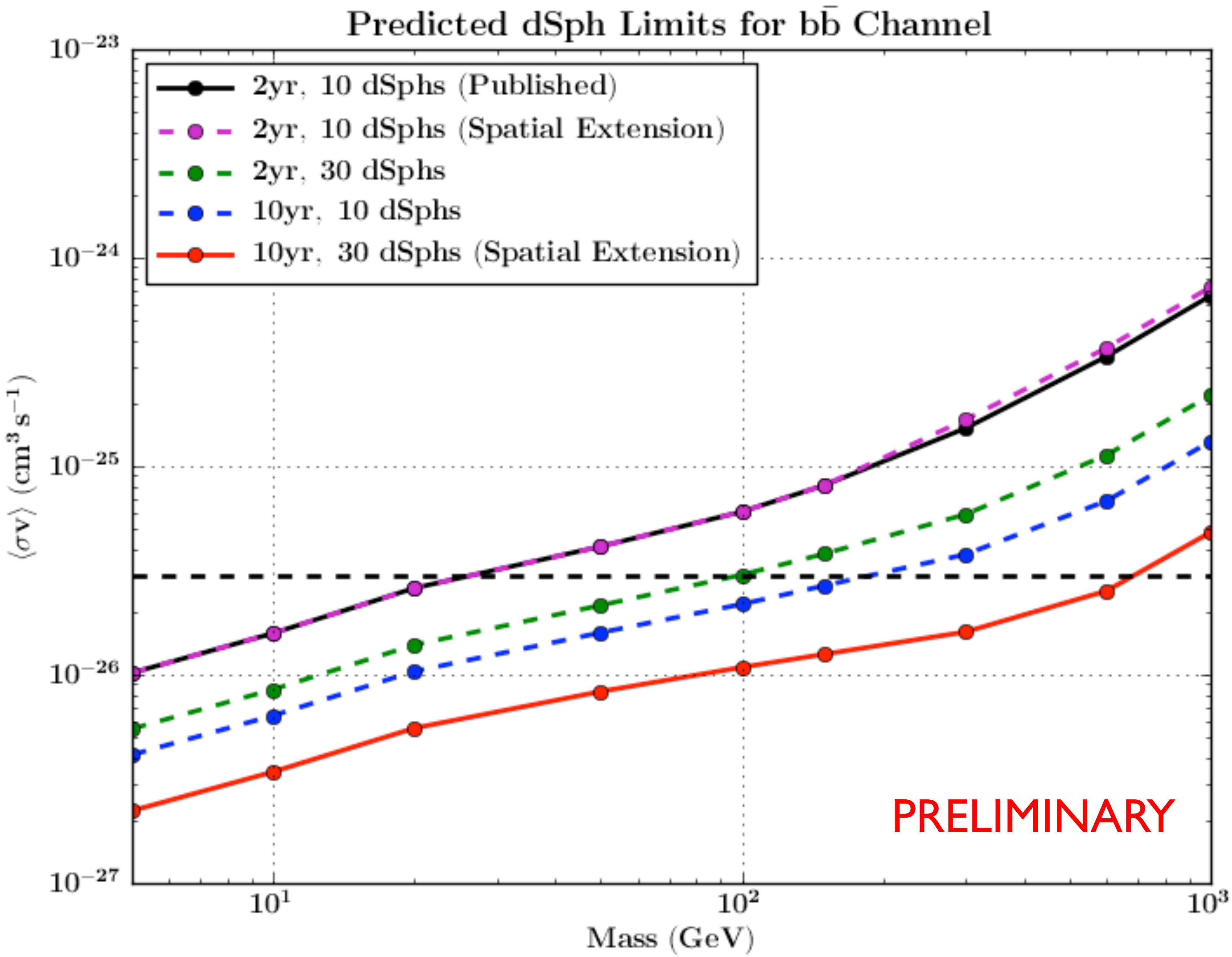
M. Ackermann et al. [Fermi LAT Collaboration], PRL 107, 241302 (2011)

results exclude the canonical WIMP thermal relic cross-section for annihilation to $b\bar{b}$ or $\tau^+\tau^-$ for masses below ~ 30 GeV

Future prospects for dwarf spheroidals

future DM limits from dSph projected to improve due to:

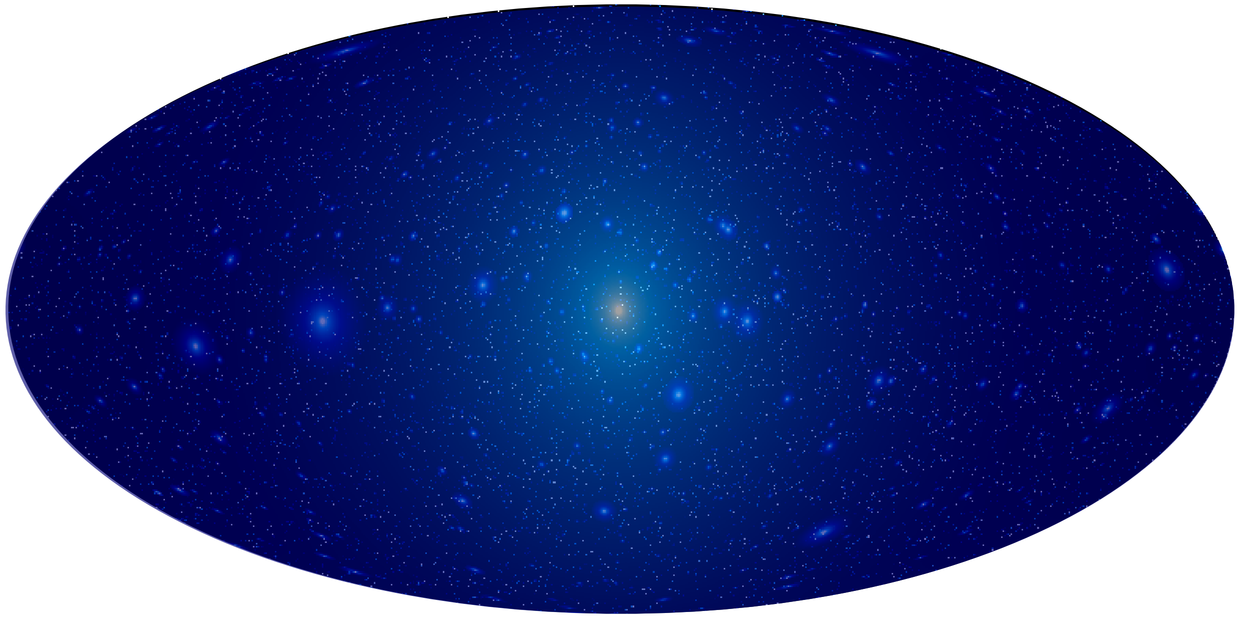
- increased observation time
- discovery of new dwarfs



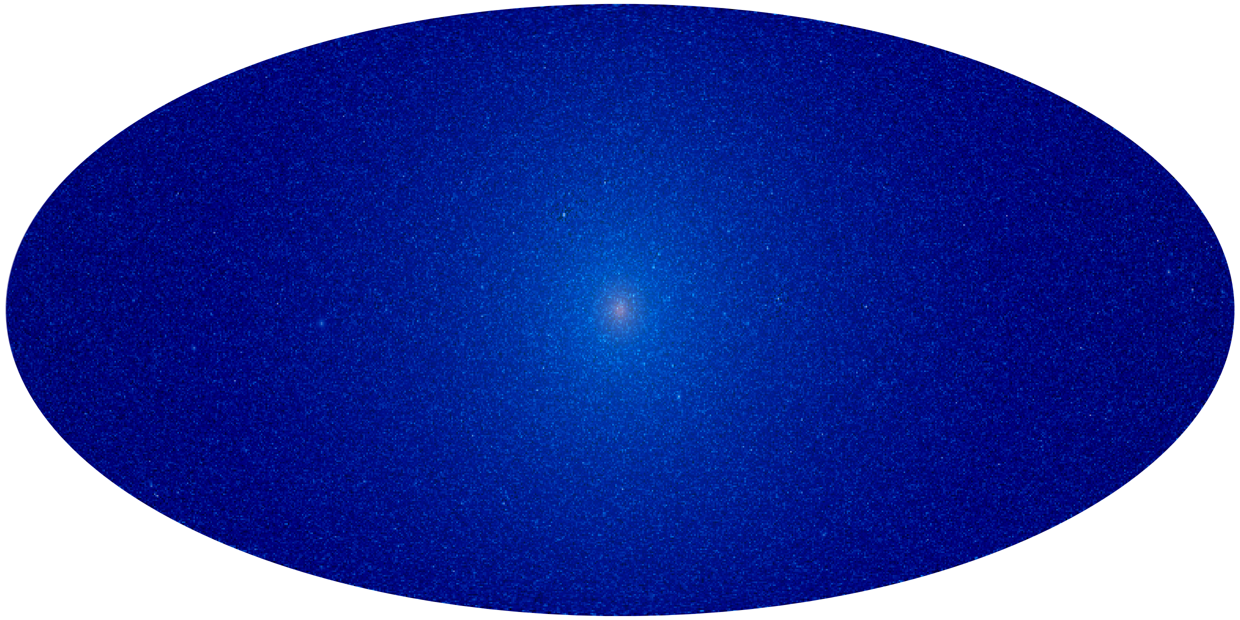
Gamma-ray anisotropies from dark matter

gamma rays from DM annihilation and decay in Galactic and extragalactic dark matter structures could imprint small angular scale fluctuations in the diffuse gamma-ray background

Gamma rays from Galactic DM



before accounting for instrument PSF



after convolving with 0.1° beam

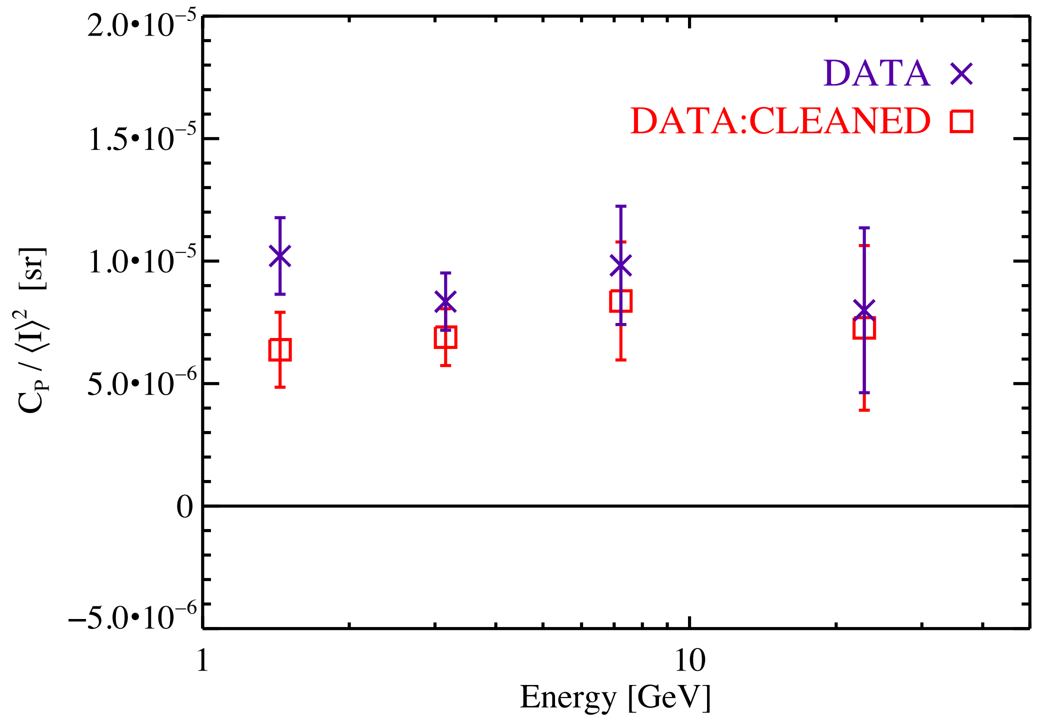
JSG, JCAP 10(2008)040

Anisotropy constraints on dark matter

- small angular scale IGRB anisotropy measured for the first time with the Fermi LAT
- angular power measurement constrains contribution of individual source classes, including DM, to the IGRB intensity

(see Alessandro Cuoco's and German Gomez-Vargas' talks on Friday!)

Fluctuation anisotropy energy spectrum



Ackermann et al. [Fermi LAT Collaboration] 2012
(to appear in PRD)

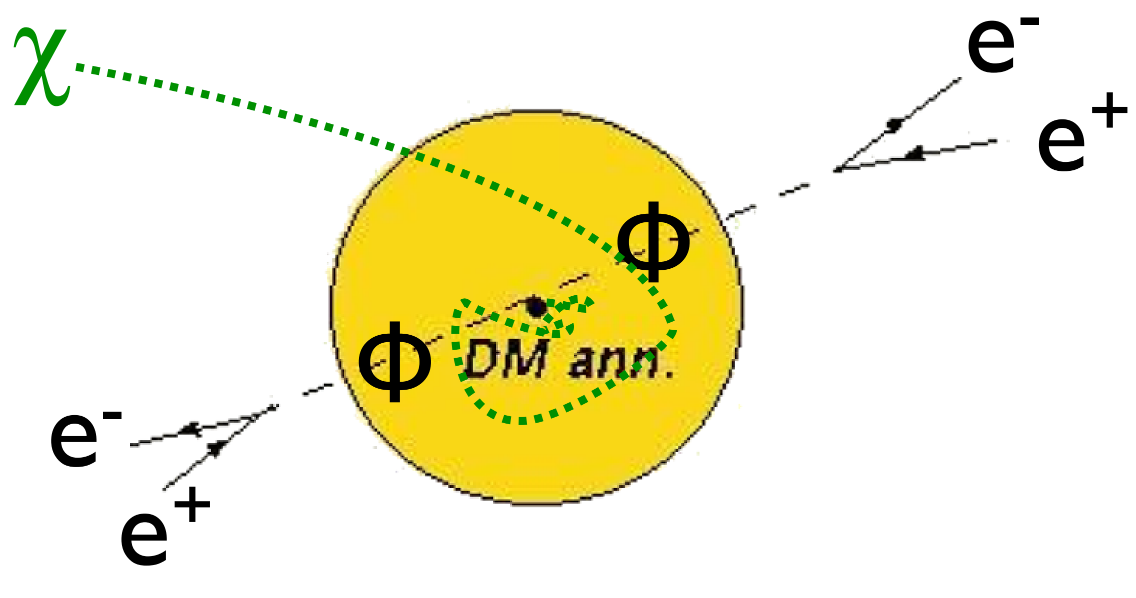
Constraints from best-fit constant fluctuation angular power (l ≳ 150) measured in the data and foreground-cleaned data

Source class	Predicted $C_{100}/\langle I\rangle^2$ [sr]	Maximum fraction of IGRB intensity DATA	DATA:CLEANED
Blazars	2×10^{-4}	21%	19%
Star-forming galaxies	2×10^{-7}	100%	100%
Extragalactic dark matter annihilation	1×10^{-5}	95%	83%
Galactic dark matter annihilation	5×10^{-5}	43%	37%
Millisecond pulsars	3×10^{-2}	1.7%	1.5%

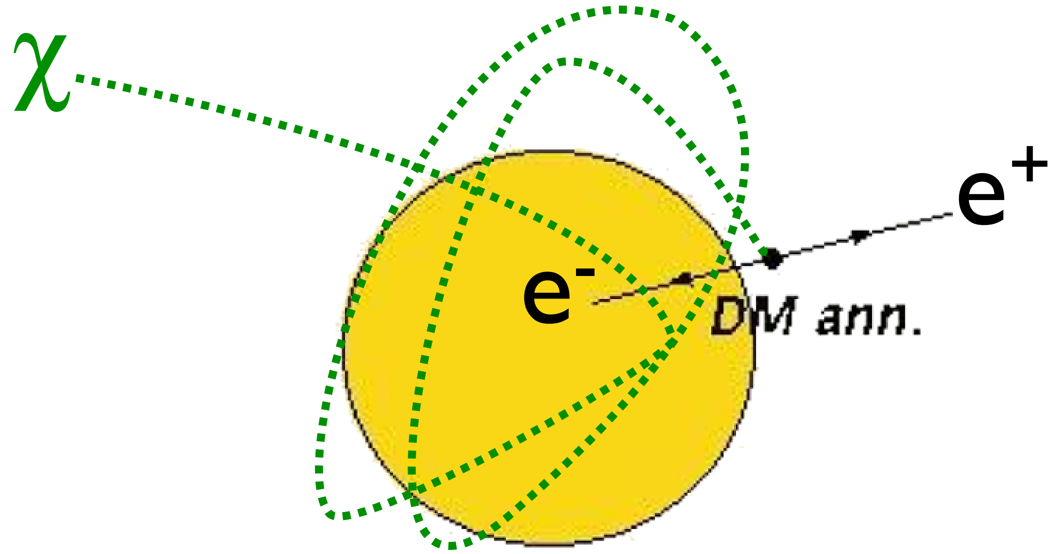
Solar CREs from DM annihilation

Schuster, Toro, Weiner, Yavin 2010 discuss 2 scenarios in which dark matter annihilation leads to cosmic-ray electron and positron (CRE) fluxes from the Sun:

- intermediate state scenario: Dark matter annihilates in the center of the Sun into an intermediate state Φ which then decays to CREs outside the surface of the Sun

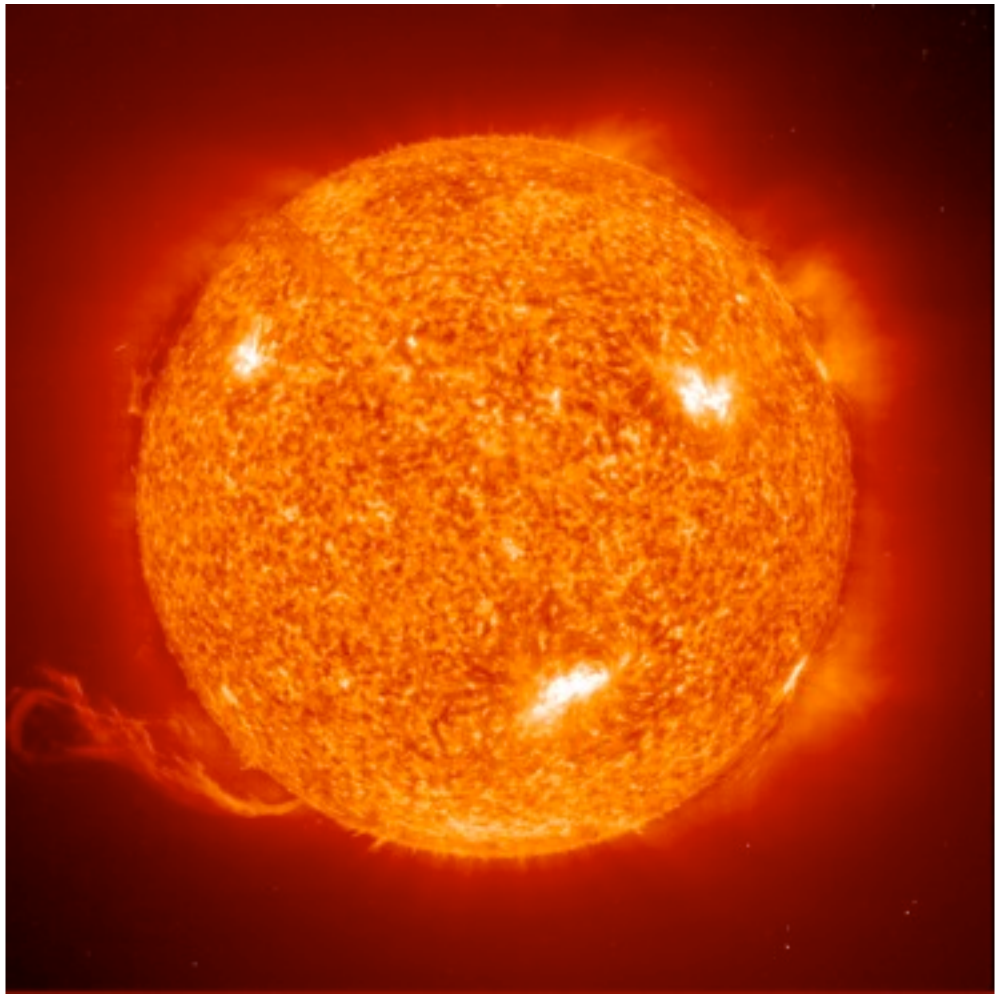


- iDM scenario: Inelastic dark matter (iDM) captured by the Sun remains on large orbits, then annihilates directly to CREs outside the surface of the Sun



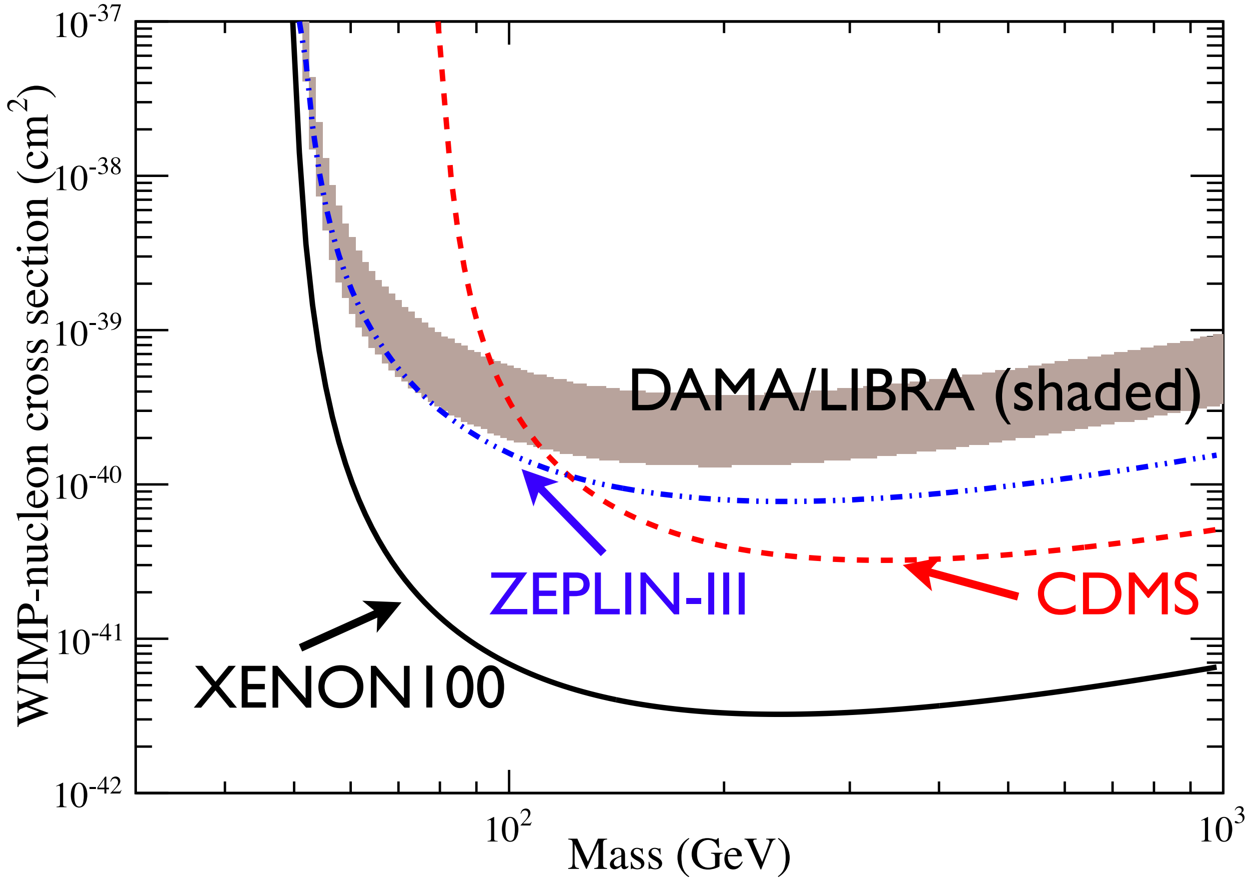
Fermi LAT search for CREs from the Sun

- ~10^6 CRE events (E > 60 GeV), from 1st year of operation
- analysis performed in ecliptic coordinates, in reference frame centered on the Sun
- search for a flux excess correlated with Sun's direction yielded no significant detection, flux upper limits placed



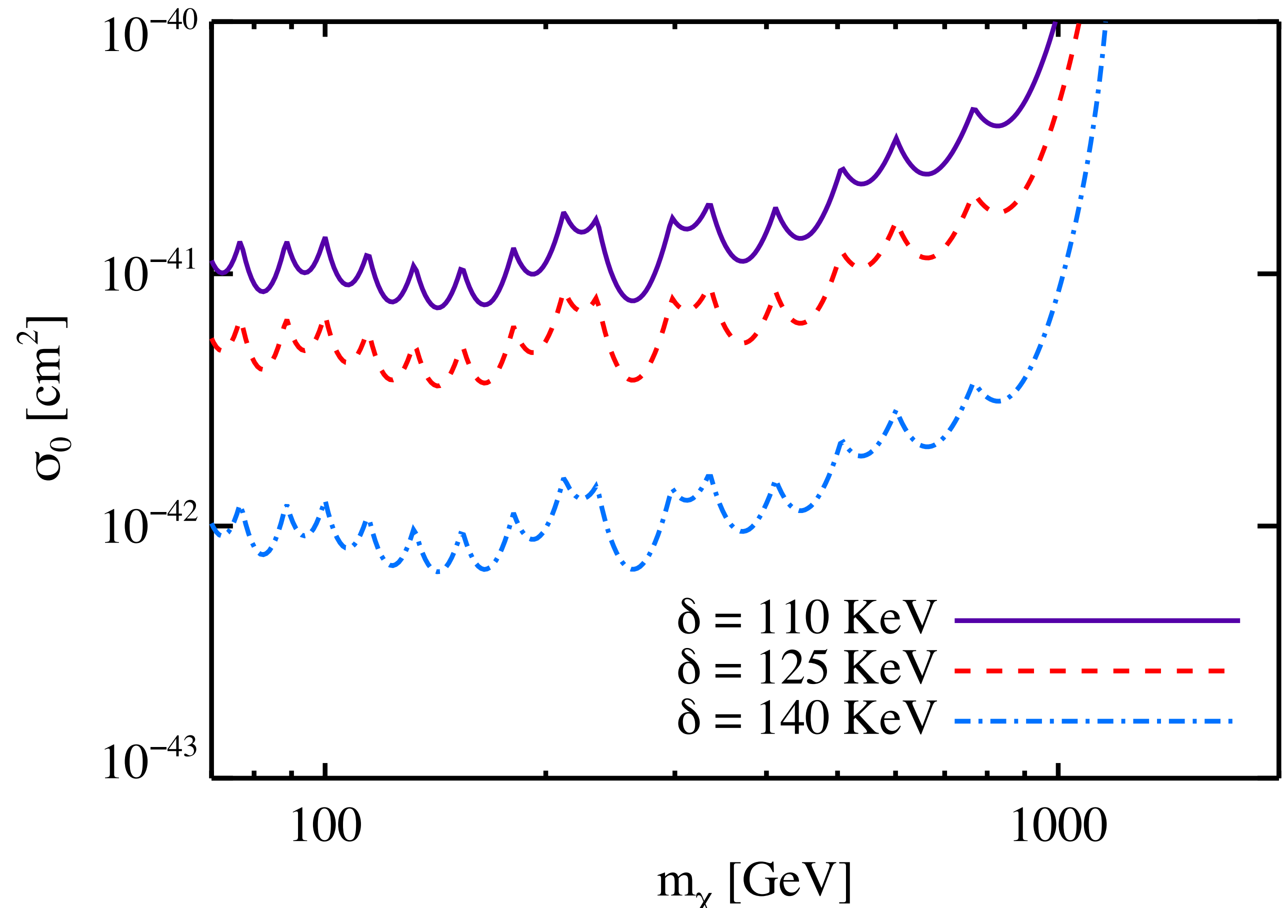
Complementarity with direct searches

Signal and exclusion regions for direct detection experiments at 90% CL (for δ = 120 keV)



Aprile et al. [XENON100 Collaboration] (2011)

Parameter space above curves excluded at 95% CL for CRE final state by Fermi LAT CRE analysis



Ajello et al. [Fermi LAT Collaboration] (2011)

Fermi solar CRE constraints are competitive with and complementary to direct detection results

- tests for a unique astrophysical signal arising from specific dark matter models
- different sources of uncertainties make solar CRE limits a valuable cross-check

Summary

- new constraints on dark matter models have been obtained from null searches for indirect dark matter signals in Fermi LAT data using a variety of targets
- searches for dark matter signatures in gamma rays from the Milky Way halo and dwarf galaxies exclude canonical thermal relic dark matter annihilation cross-sections for masses less than a few tens of GeV for some channels
- Fermi LAT CRE data provide a valuable probe of dark matter models; for some models LAT CRE analysis can provide complementary constraints to those from direct detection experiments
- current searches are already testing canonical WIMP dark matter models; there is great potential for discovery in future dark matter searches with the Fermi LAT!
- LAT data are public!!! Please (continue to) use them!!!