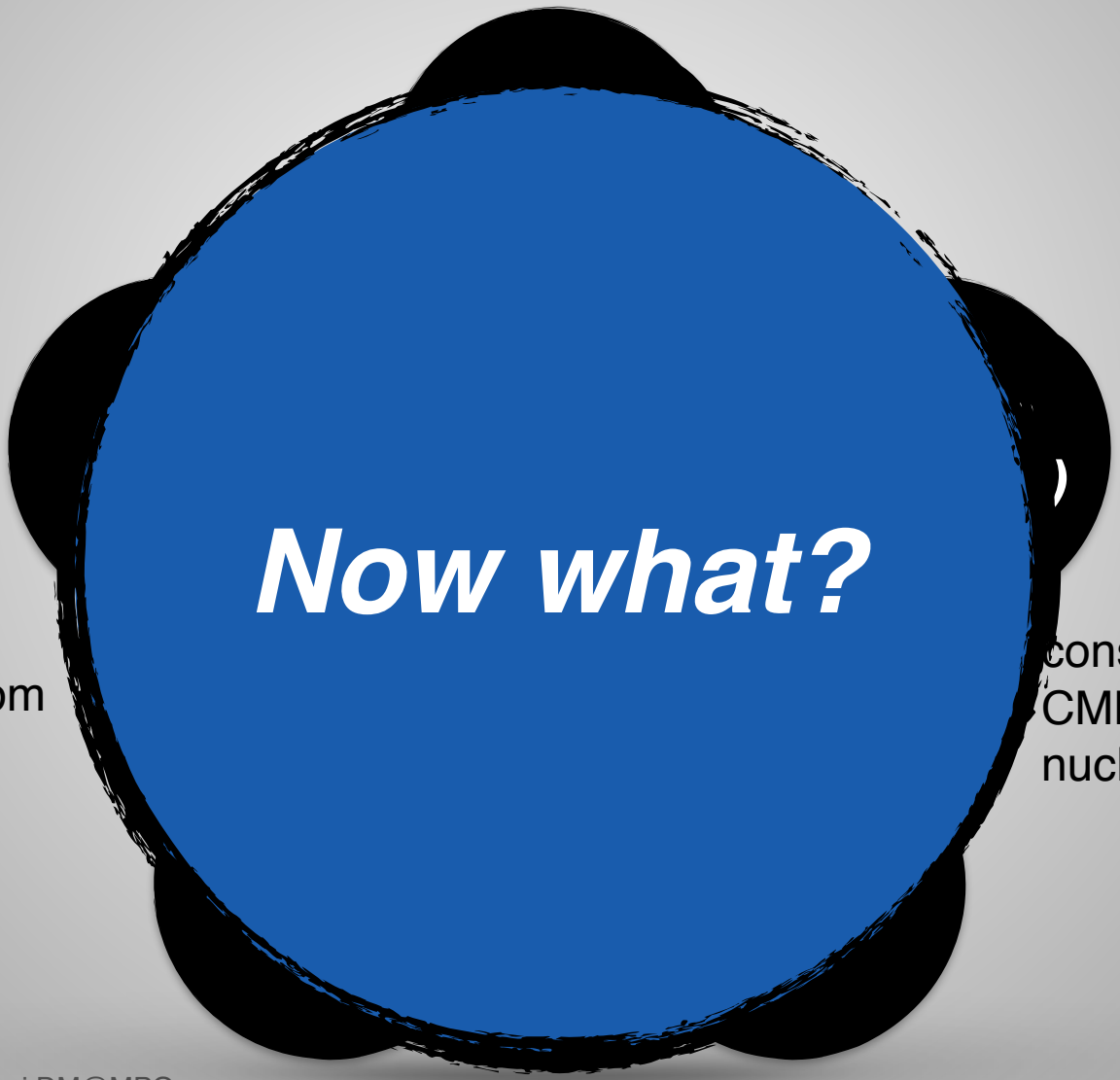
Dark Matter with the Fermi-LAT

R. Caputo
NASA/GSFC
On behalf of the Fermi-LAT Collaboration

Gravity Information and Fundamental Symmetries
MPQ, Garching
5 November 2019

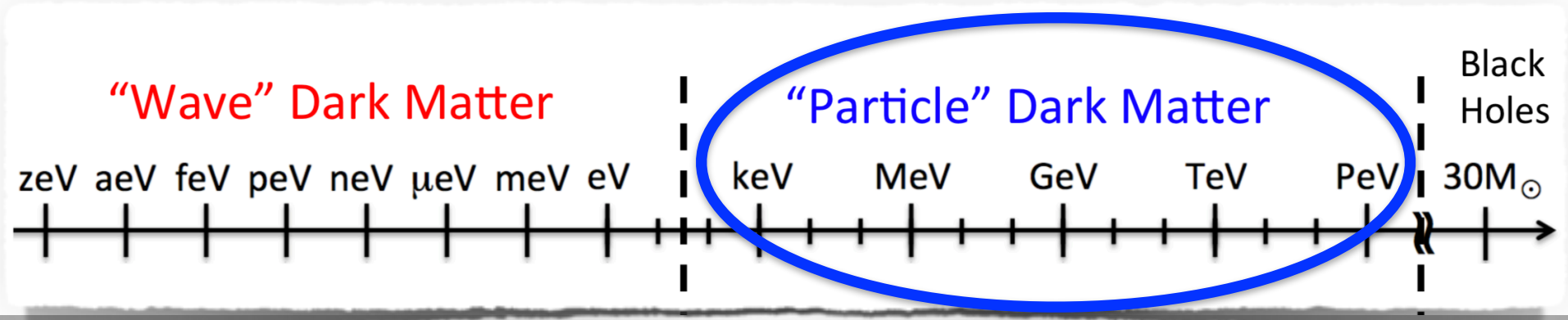
What do we know?



constraints from CMB, N-body simulations

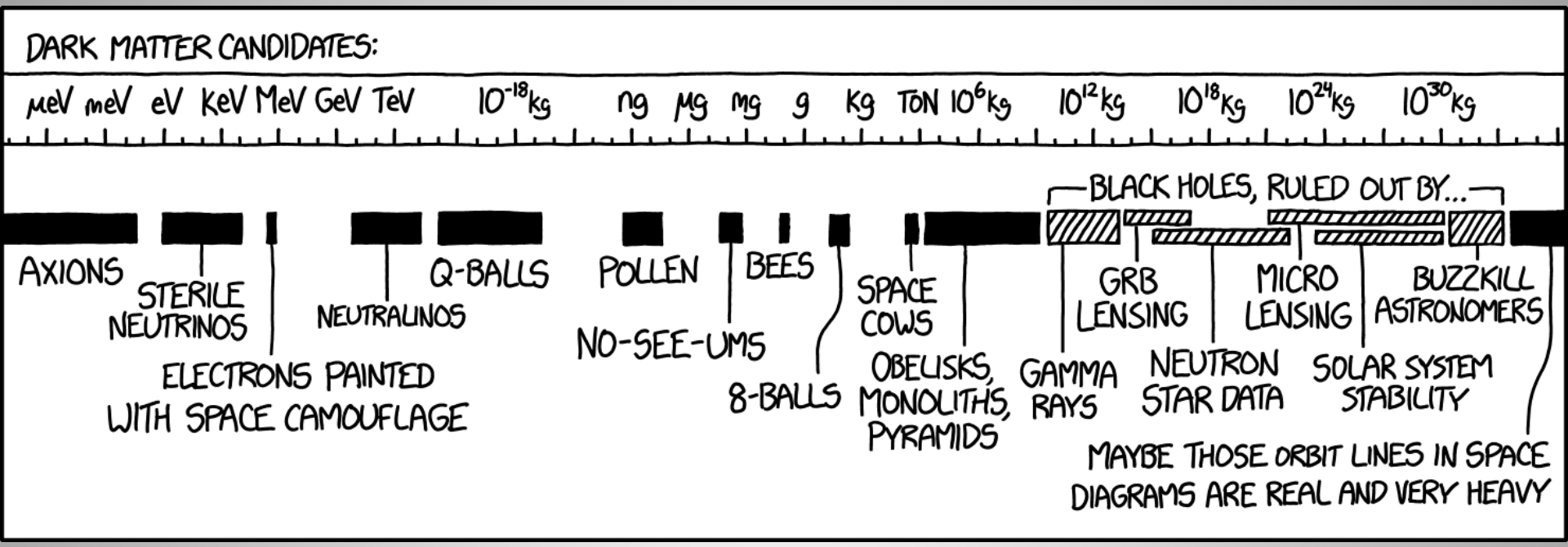
constraints from CMB, primordial nucleosynthesis

What do we know?



1. Does the candidate satisfy the previous requirements?
2. How do we look for the candidate?
3. How do we discover the candidate?

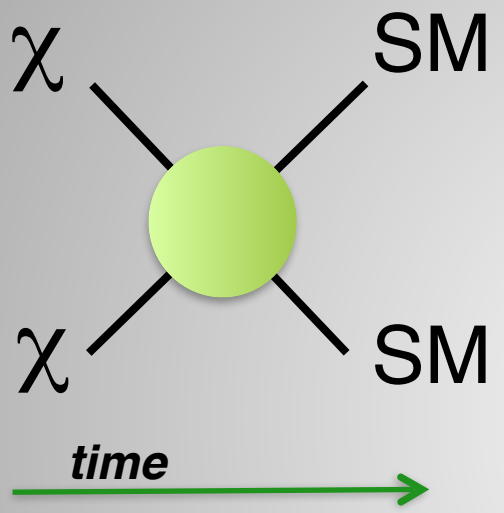
What do we know?



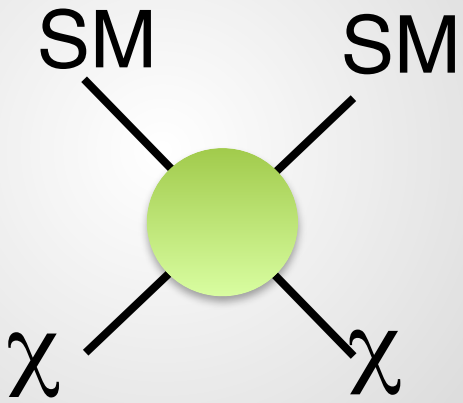
1. Does the candidate satisfy the previous requirements?
2. How do we look for the candidate?
3. How do we discover the candidate?

https://xkcd.com/2035/

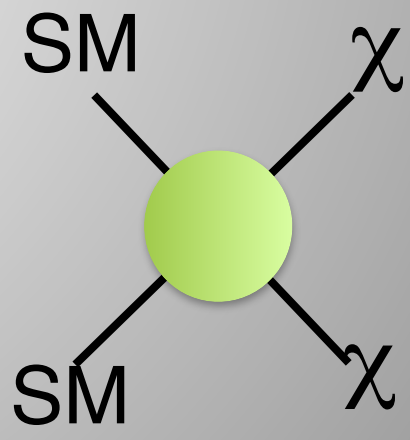
Detecting Particle Dark Matter



Indirect Detection



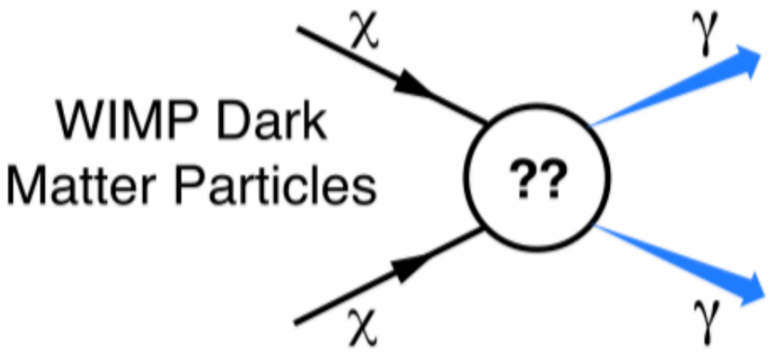
Direct Detection

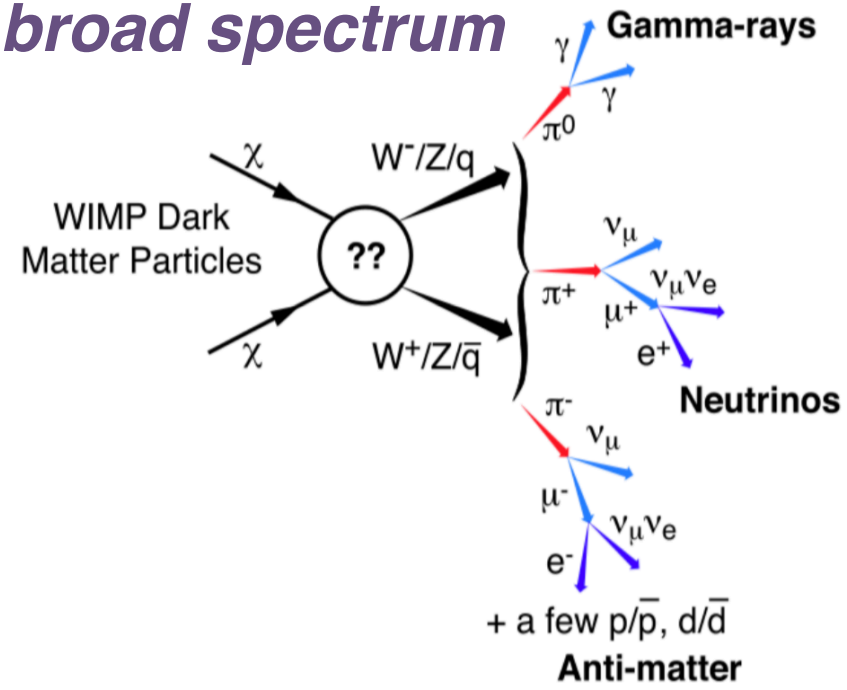


Collider

Searching for Dark Matter: γ-rays

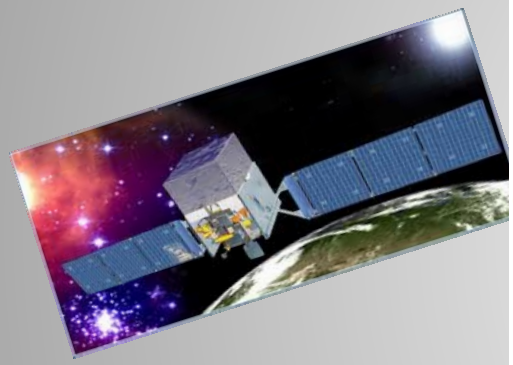
Spectral lines vs broad spectrum

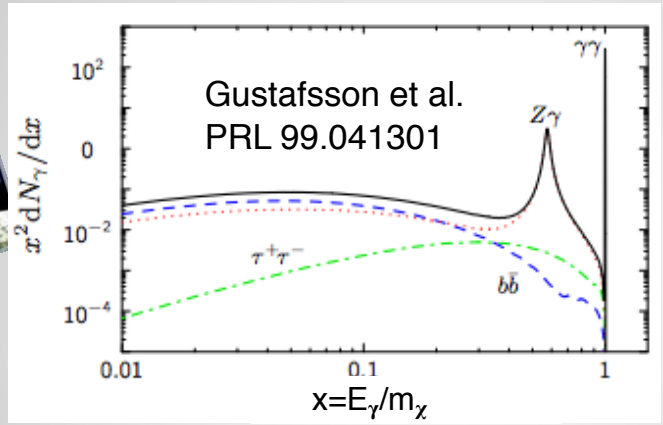


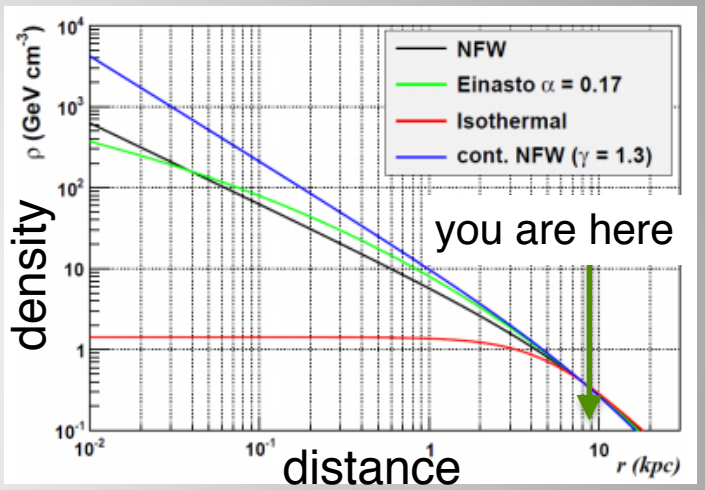


Searching for Dark Matter: γ-rays

Observed = Particle Properties x Astrophysics Properties







$$\Phi_\gamma(E,\psi) = \frac{1}{4\pi}\frac{\langle\sigma_\chi v\rangle}{2m_\chi^2} N_\gamma(E) \times J(\psi)$$

cross section

mass

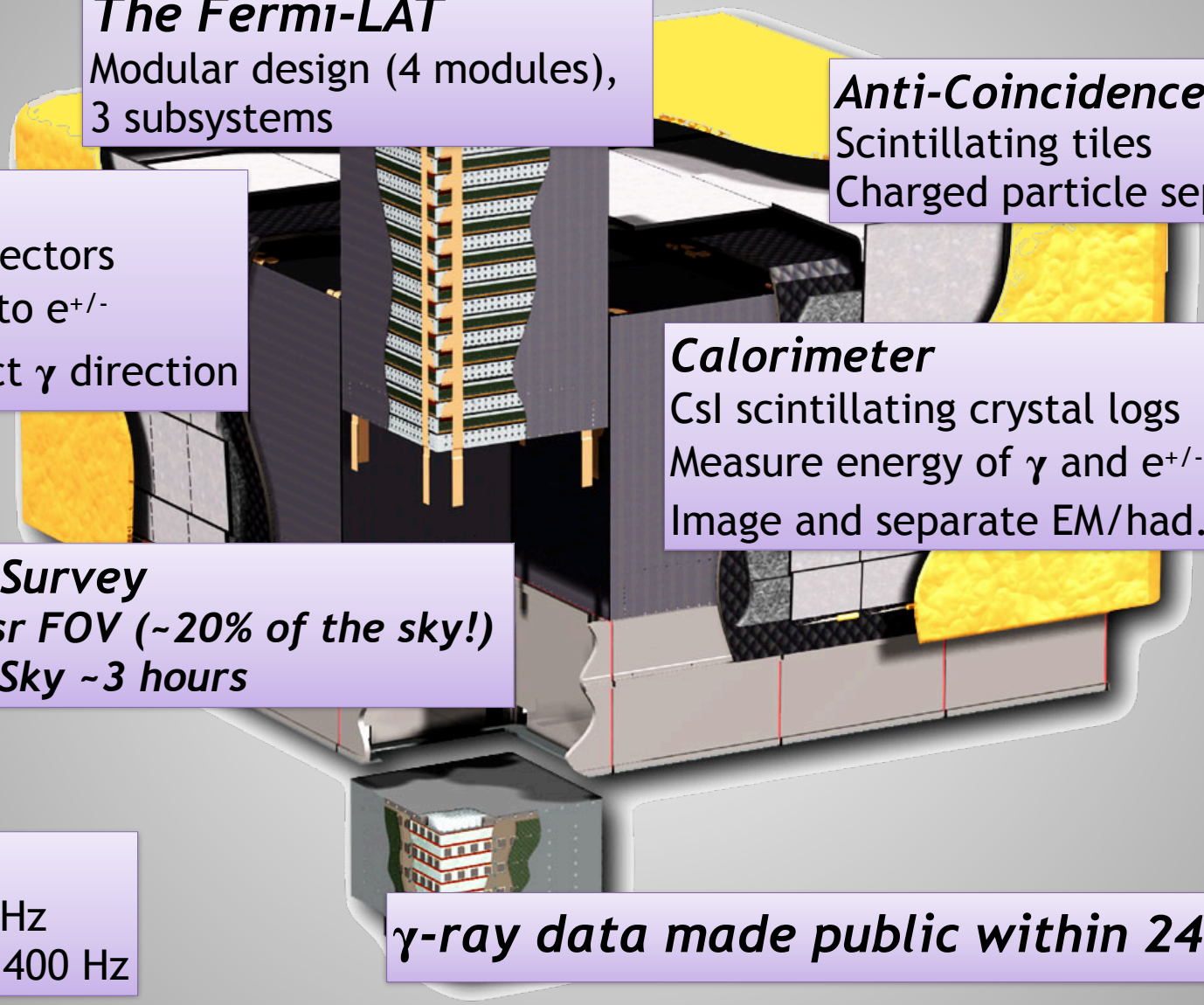
photons

J-Factor: ~ ∫ρ²

(solid angle, line of sight)

L. Bergstrom et al., ApJ. 9:137-162,1998

Fermi Large Area Telescope



The Fermi-LAT
Modular design (4 modules),
3 subsystems

Anti-Coincidence Detector
Scintillating tiles
Charged particle separation

Tracker
Silicon detectors
Convert γ to $e^{+/-}$
Reconstruct γ direction

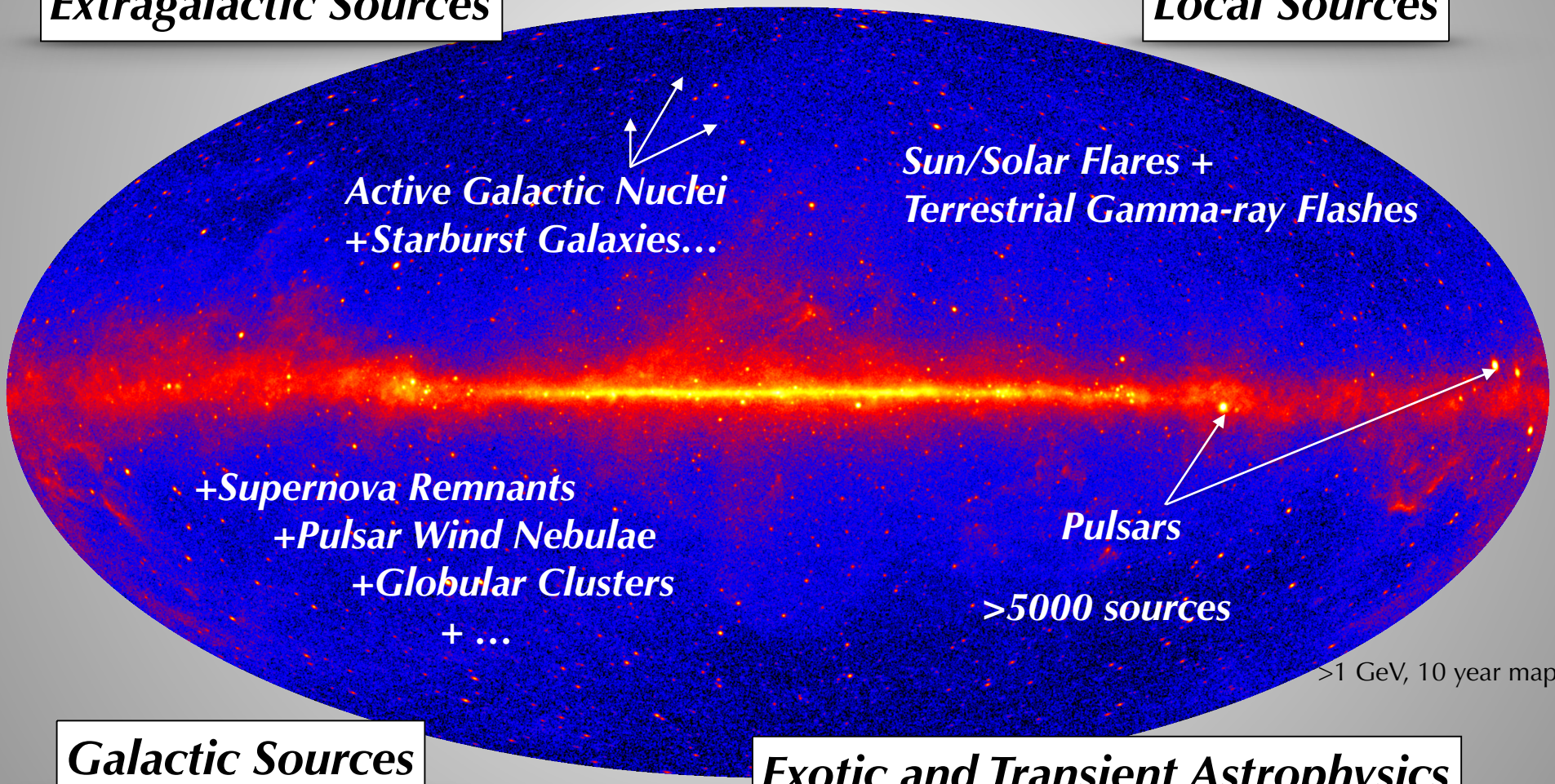
Calorimeter
CsI scintillating crystal logs
Measure energy of γ and $e^{+/-}$
Image and separate EM/had. showers

Sky Survey
2.5 sr FOV (~20% of the sky!)
Full Sky ~3 hours

Trigger
rate: ~10 kHz
read out: ~400 Hz

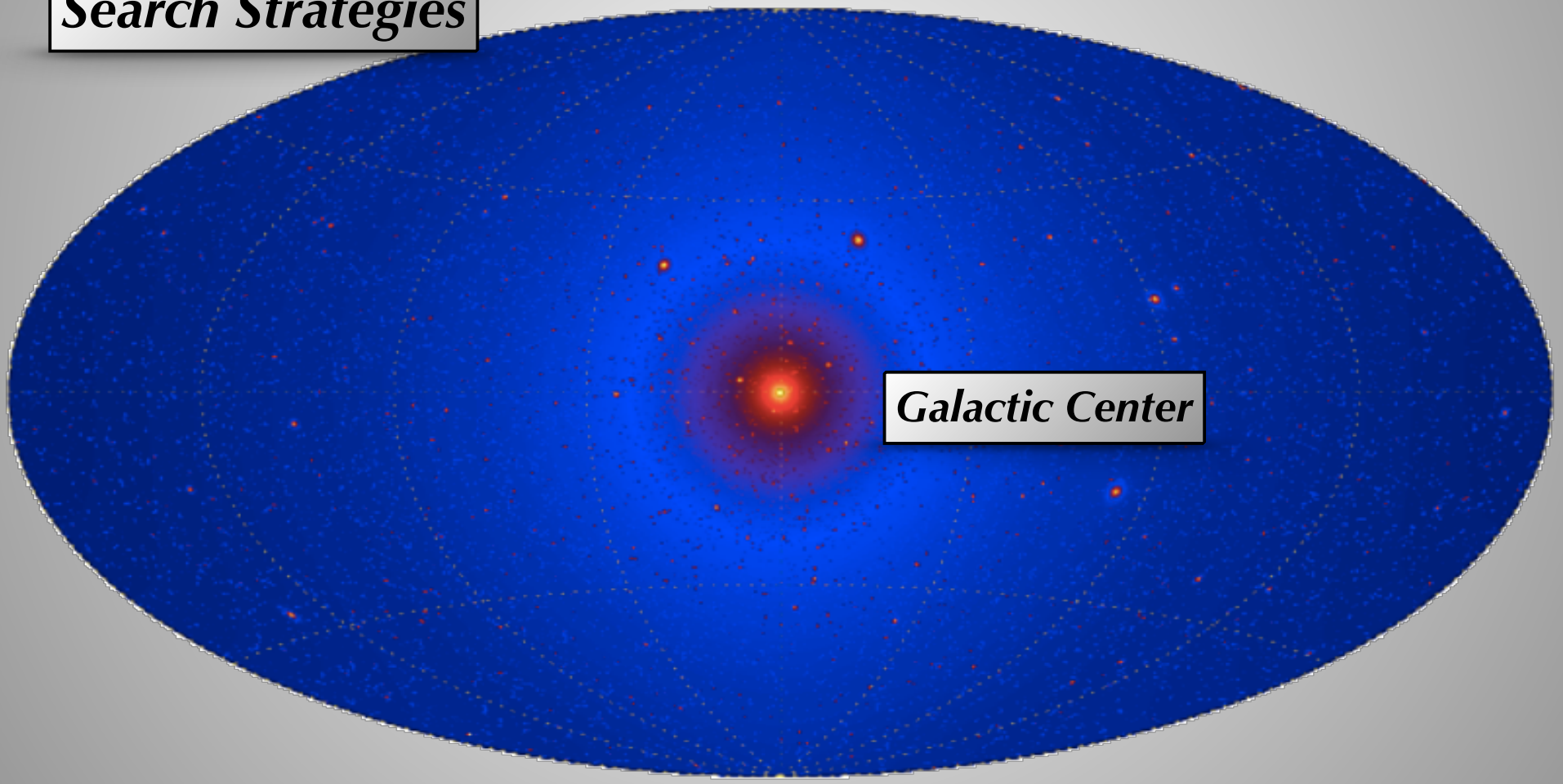
γ-ray data made public within 24 hours

Fermi-LAT γ-ray sky



Model of Dark Matter Distribution

Search Strategies



L. Pieri et al., PRD83:023518,2011

Galaxies shine in γ rays

Active Galactic Nucleus

accretion onto supermassive black hole

Population of particle accelerators

pulsars, supernova remnants, …

Interstellar Medium

cosmic rays interacting with gas and photons

Dark matter

particle annihilation/decay into gamma rays

Galaxies shine in γ rays

~~Active Galactic Nucleus~~

accretion onto supermassive black hole

Population of particle accelerators ✔

pulsars, supernova remnants, …

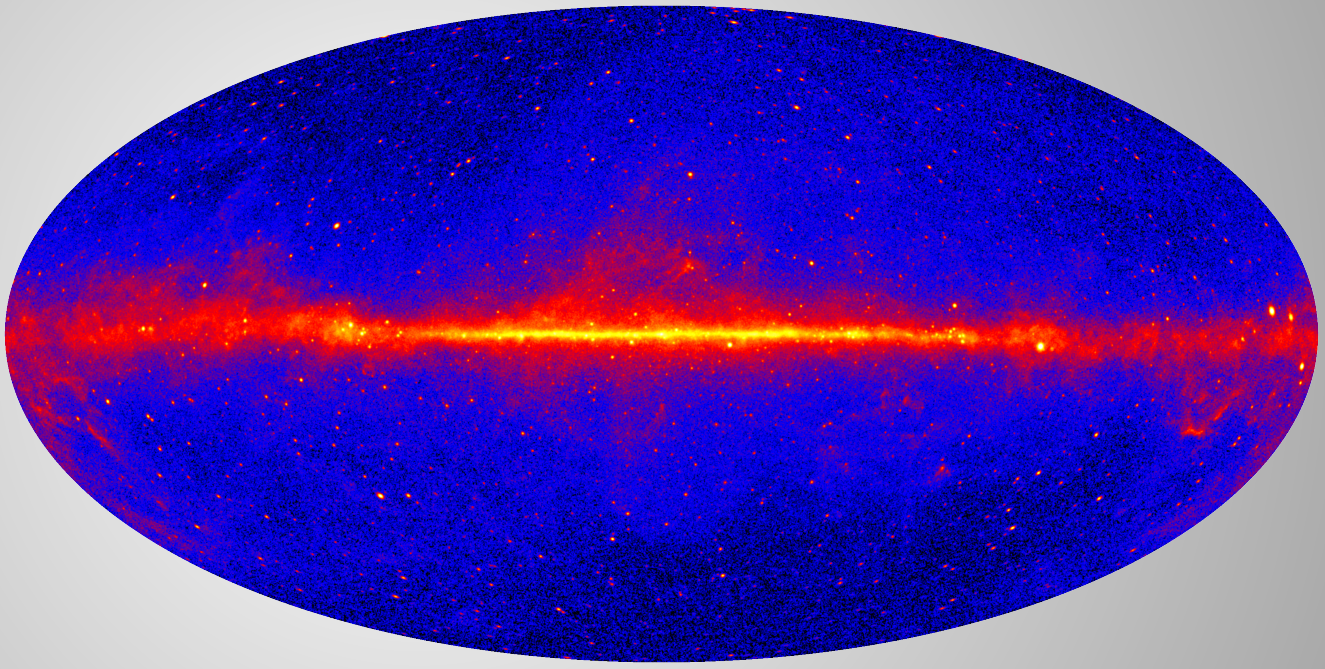
Interstellar Medium ✔

cosmic rays interacting with gas and photons

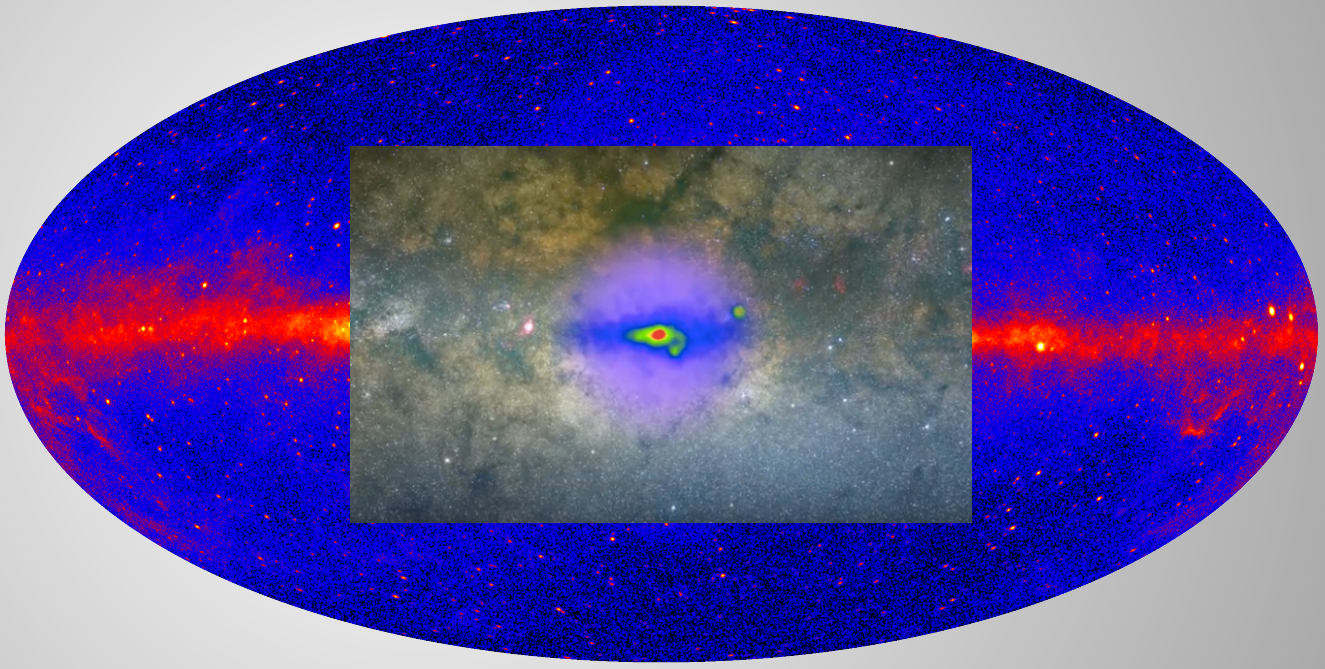
Dark matter ???

particle annihilation/decay into gamma rays

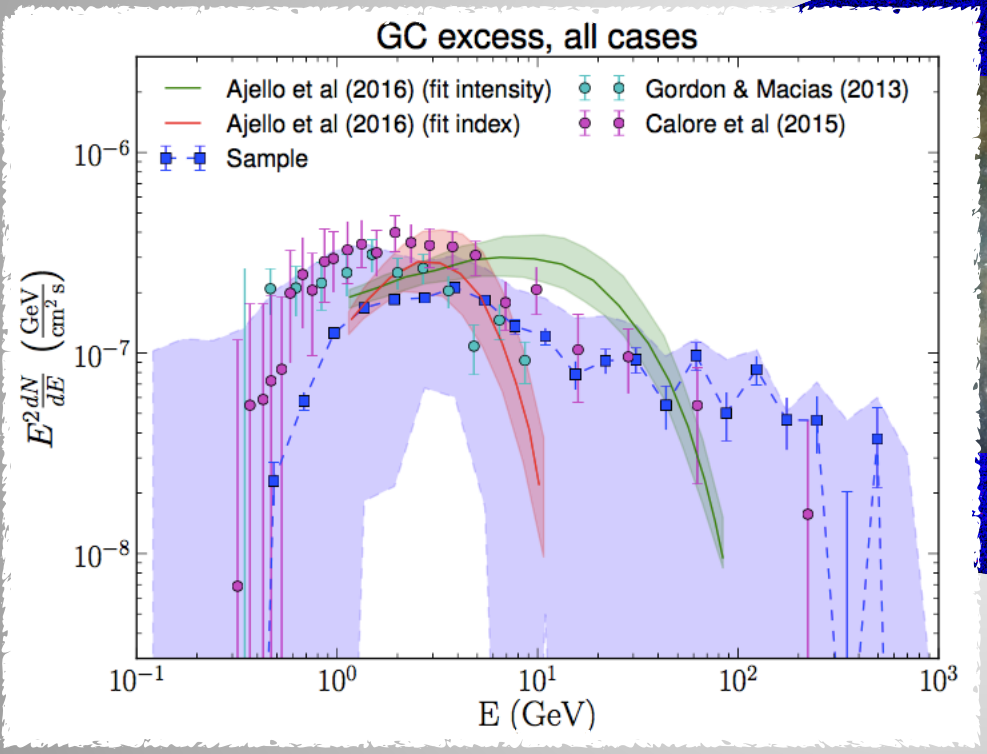
γ rays @ Galactic Center

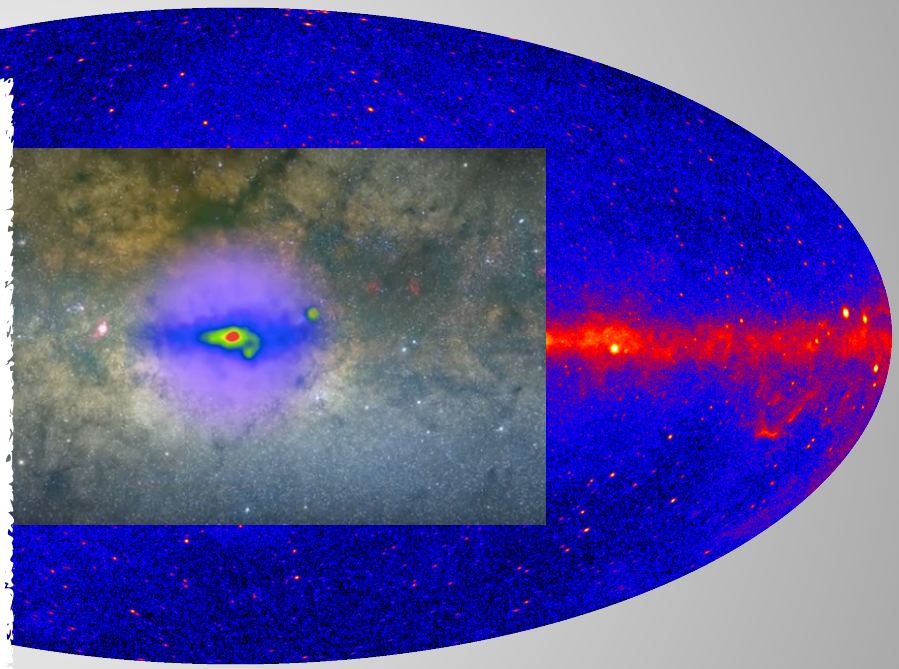


γ rays @ Galactic Center



γ rays @ Galactic Center



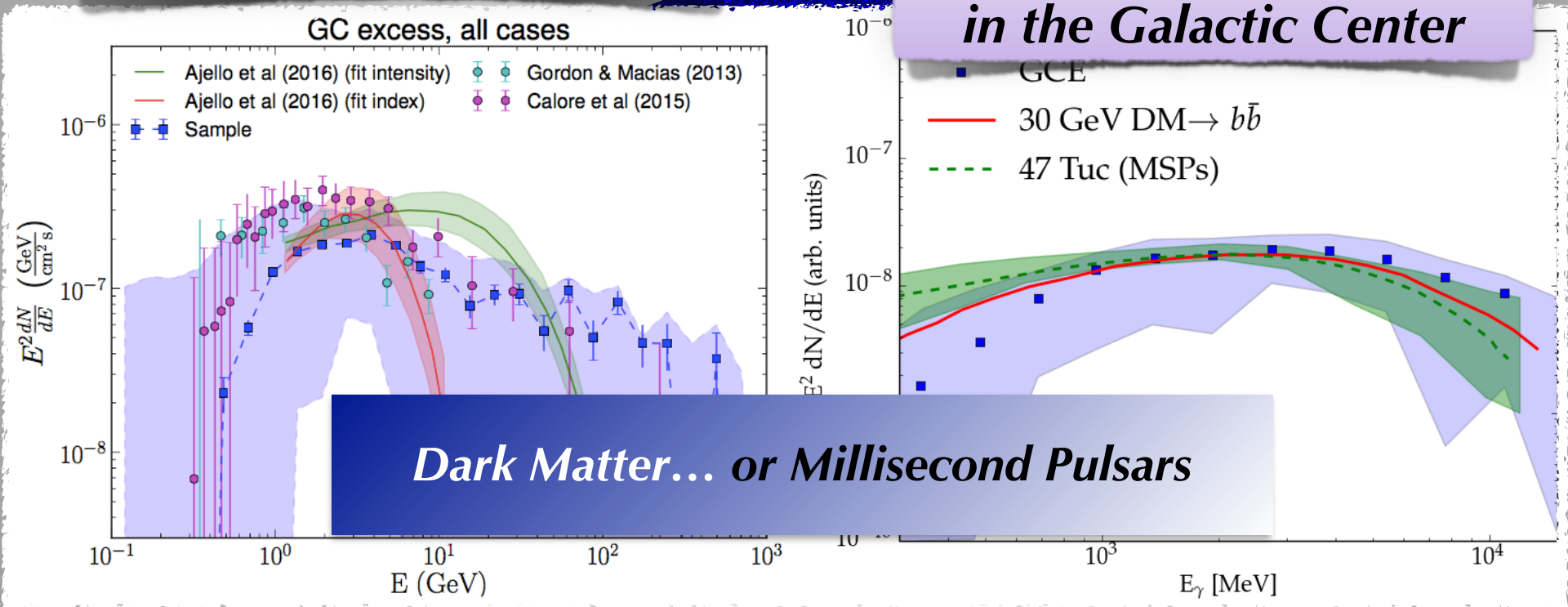


Ackermann et al., ApJ 2017

γ rays @ Galactic Center

Consistent with Thermal Relic cross sections

Current radio campaigns to identify pulsars in the Galactic Center

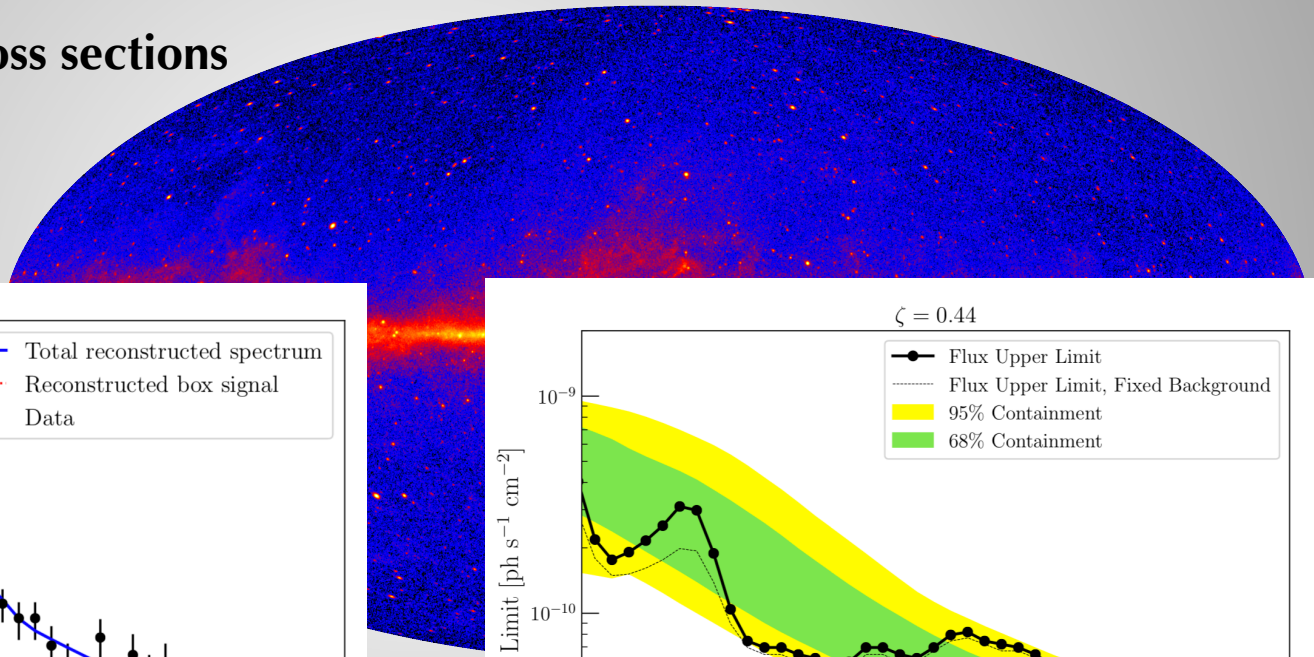


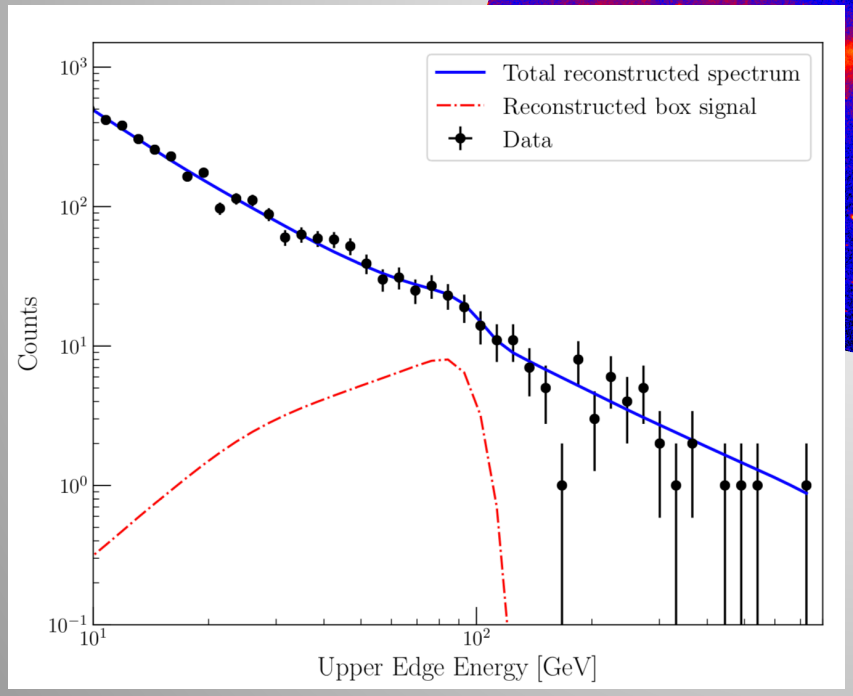
Dark Matter… or Millisecond Pulsars

Ackermann et al., ApJ 2017

γ rays @ Galactic Center

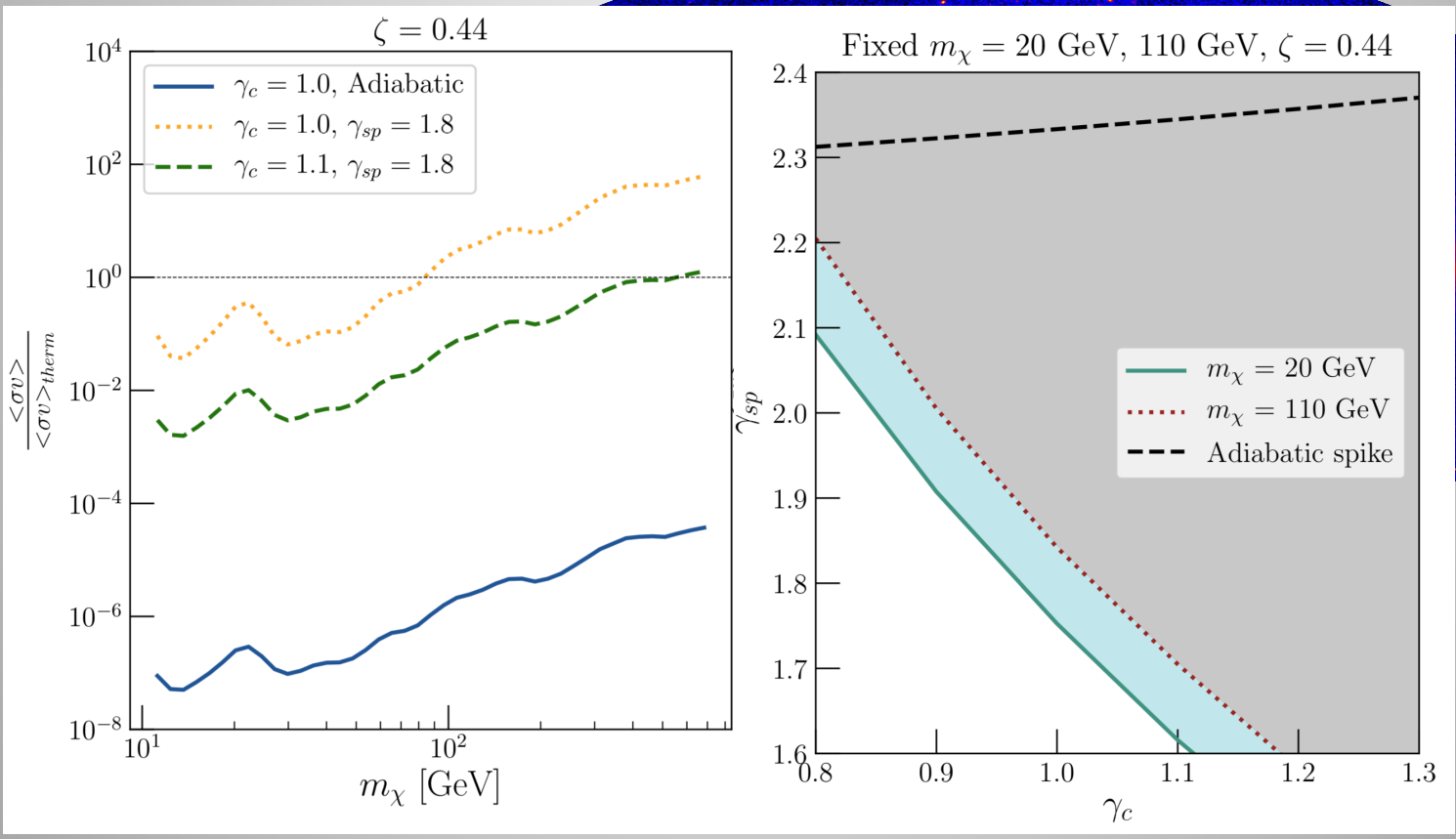
Velocity dependent cross sections
Mass splitting gives
"box" spectrum





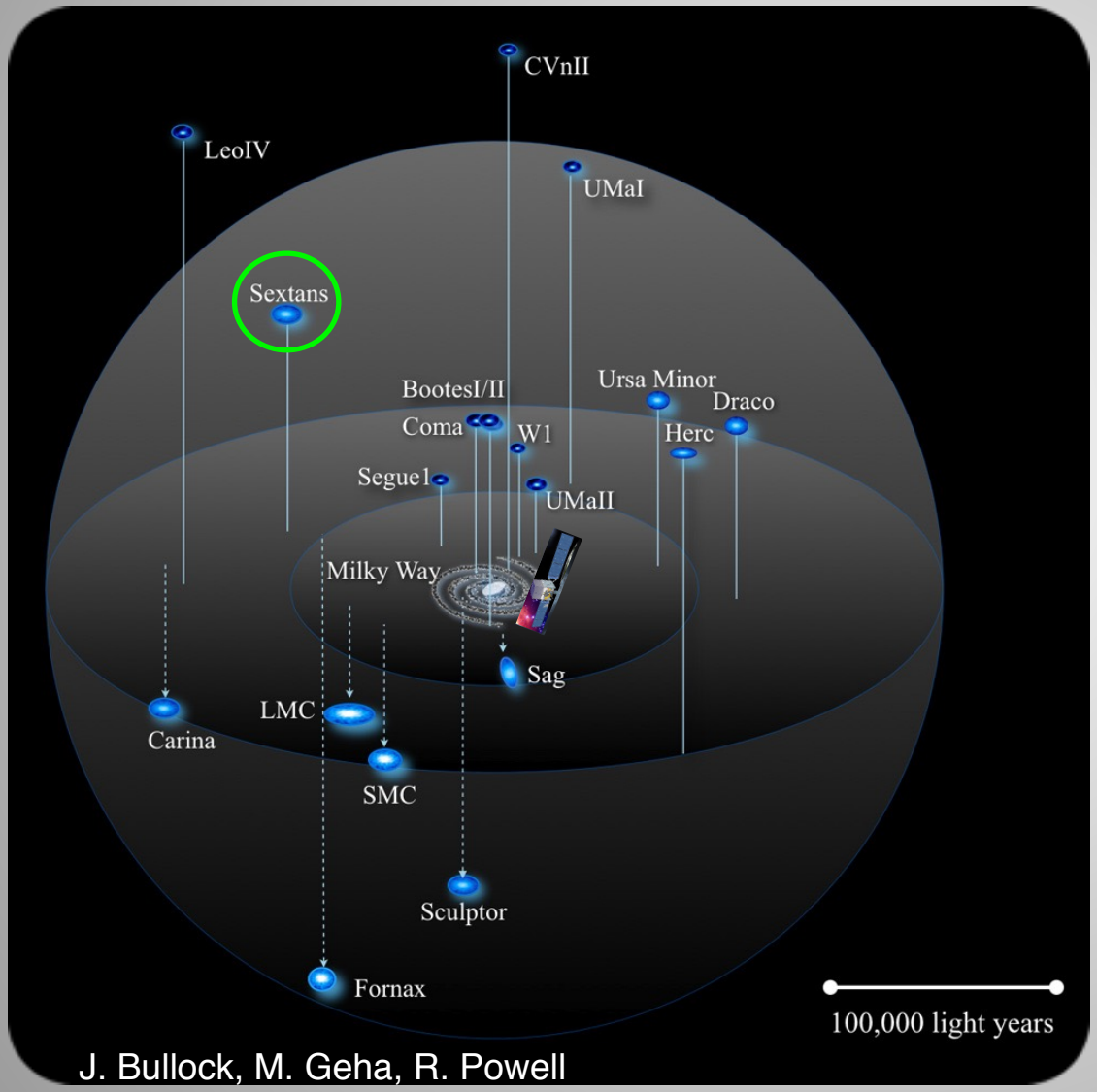
Johnson et al., PRD 2019

γ rays @ Galactic Center



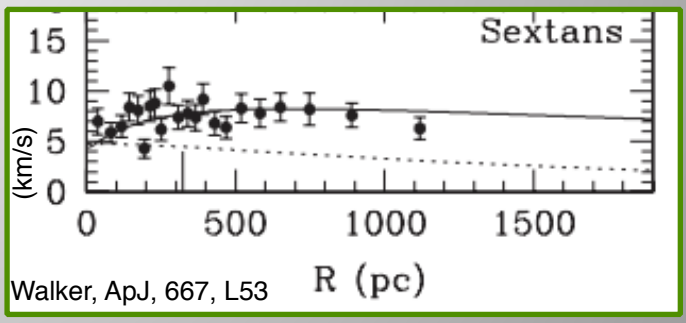
Johnson et al., PRD 2019

Dwarf Spheroidal Galaxies

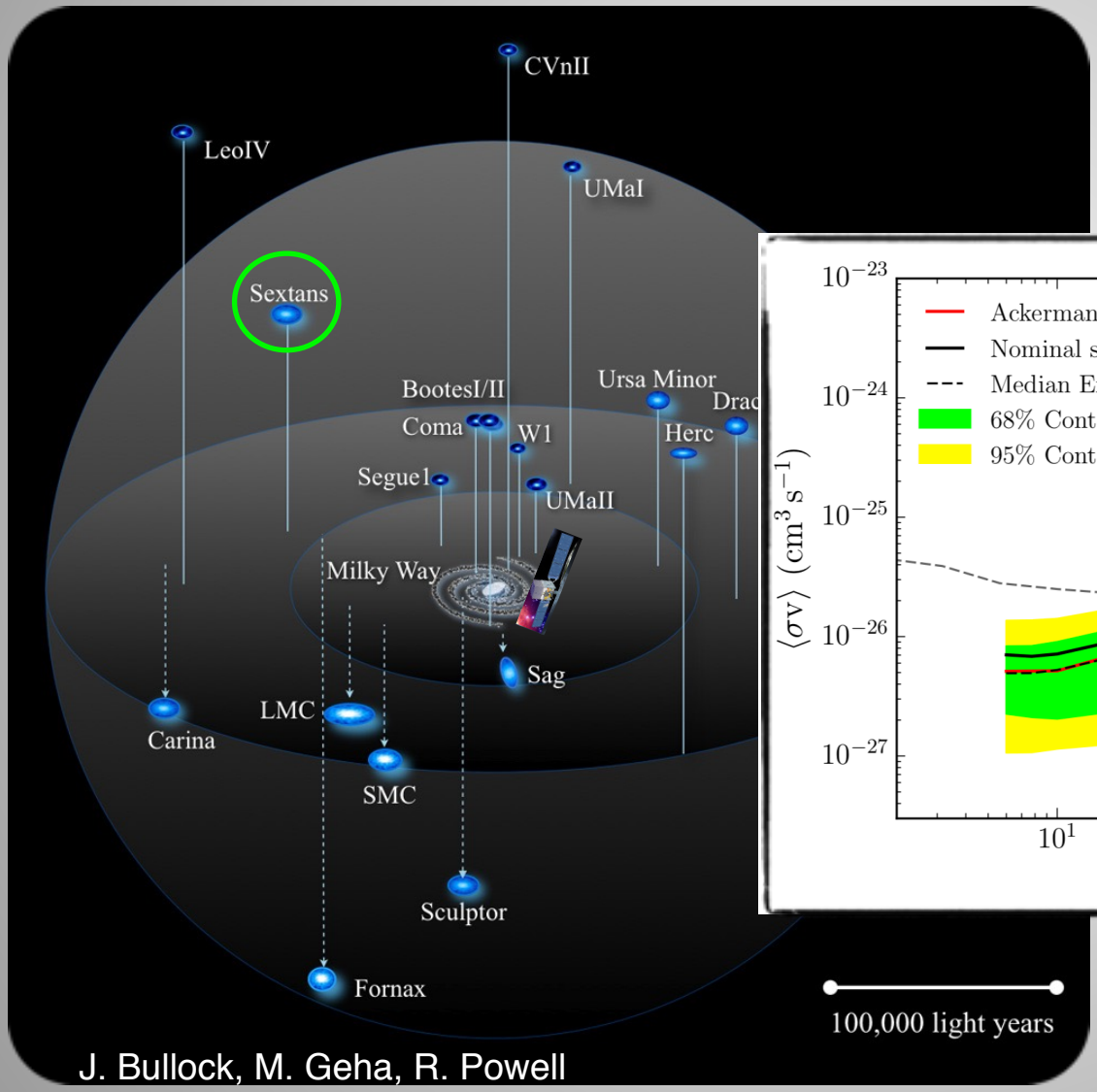


lower backgrounds but…
lower signal

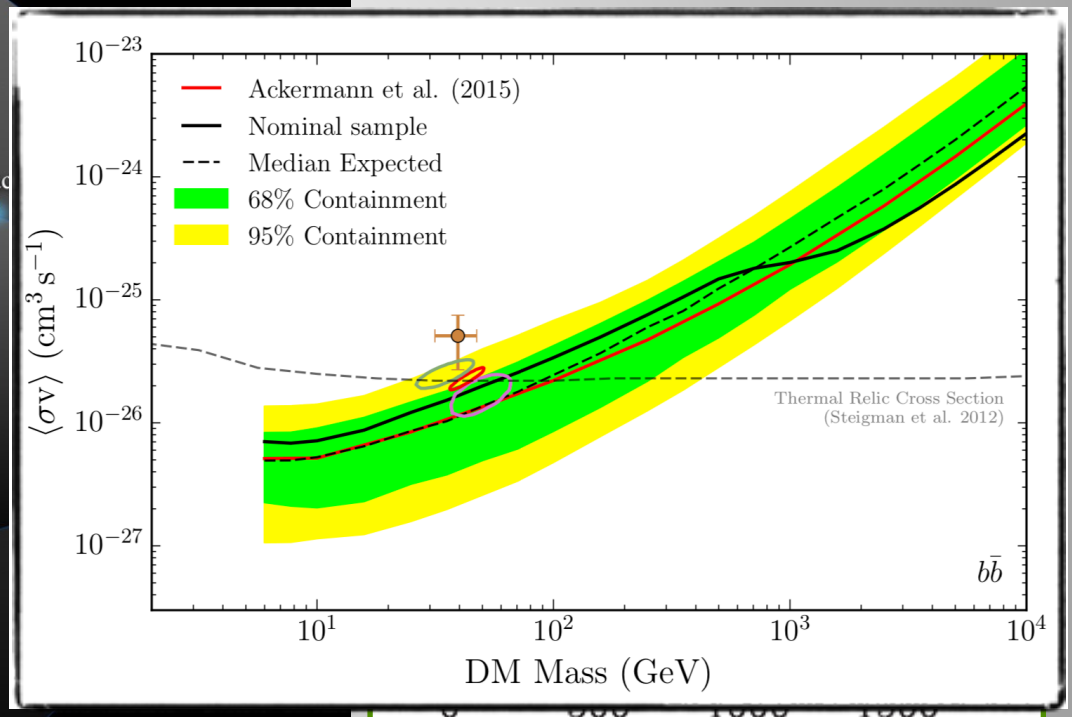
High Dark Matter to Baryonic Matter Ratio



Dwarf Spheroidal Galaxies



J. Bullock, M. Geha, R. Powell

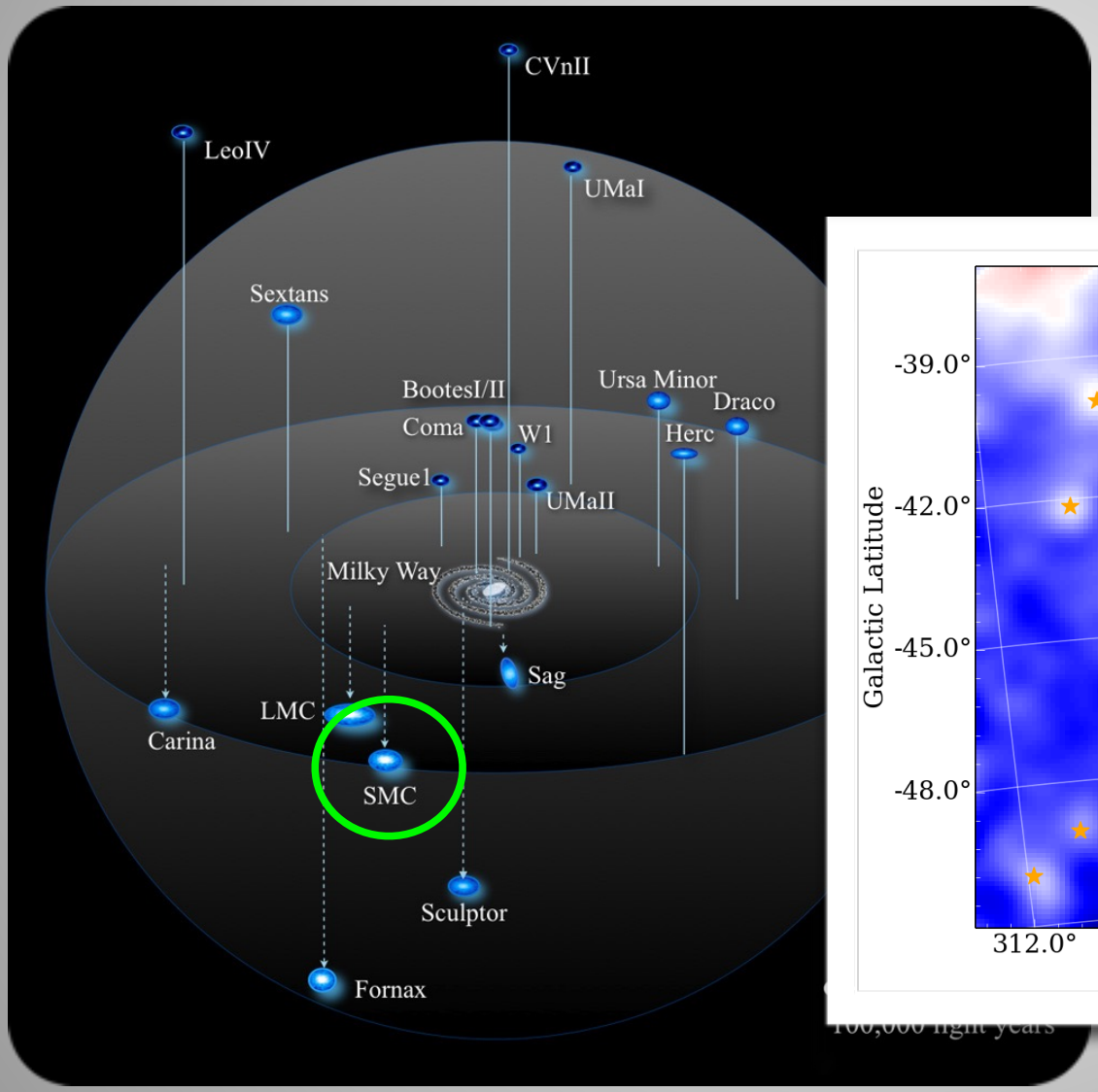


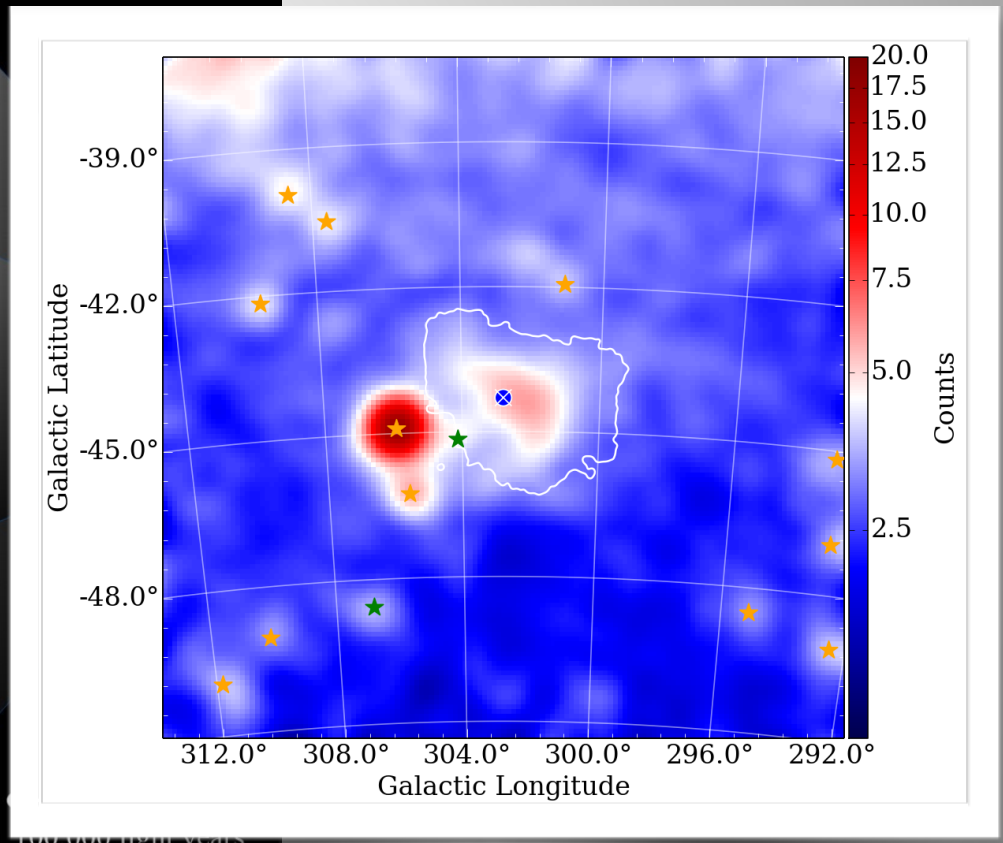
Walker, ApJ, 667, L53

R (pc)

A. Albert et al, ApJ 2017

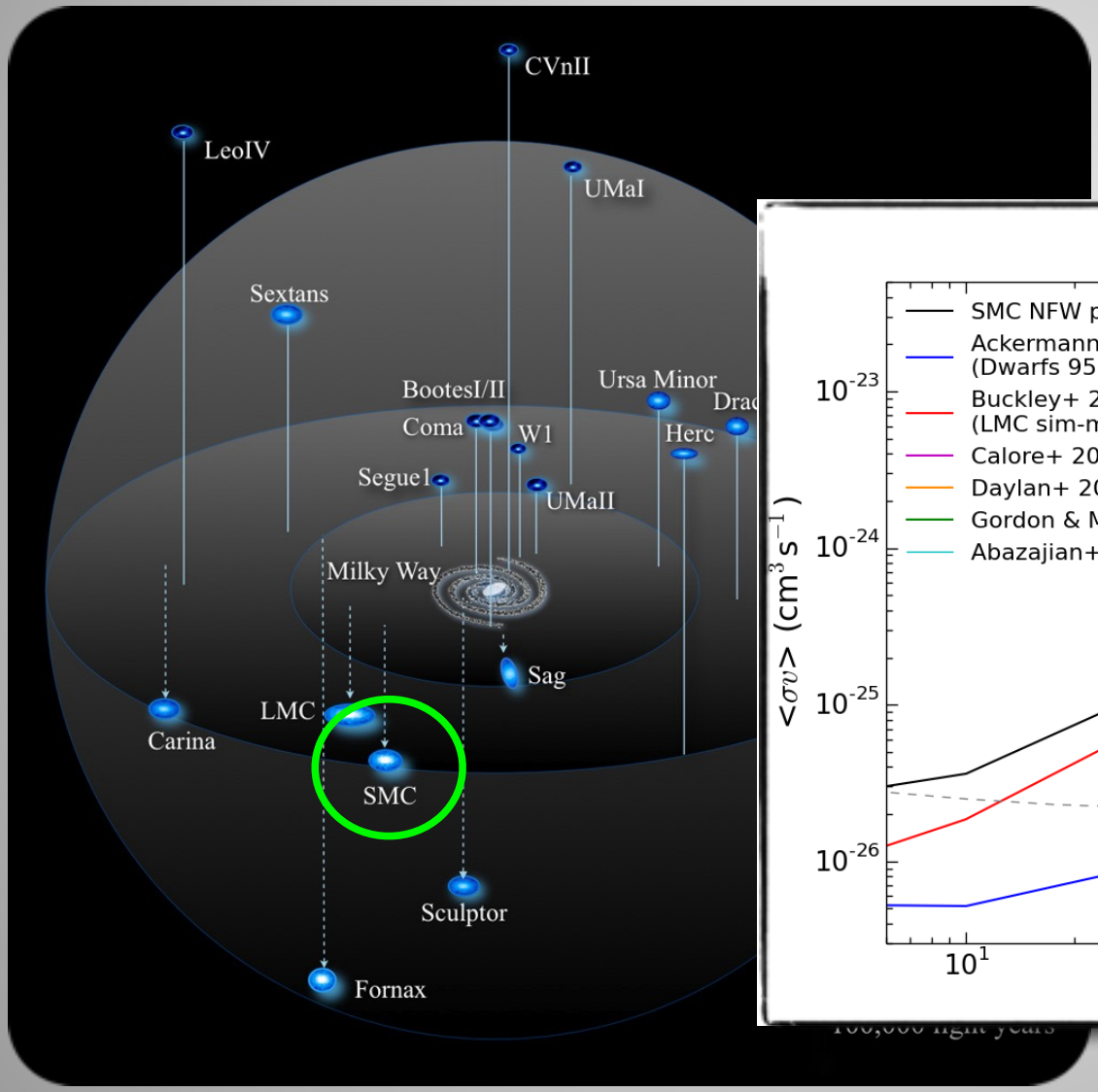
Star Forming Galaxies

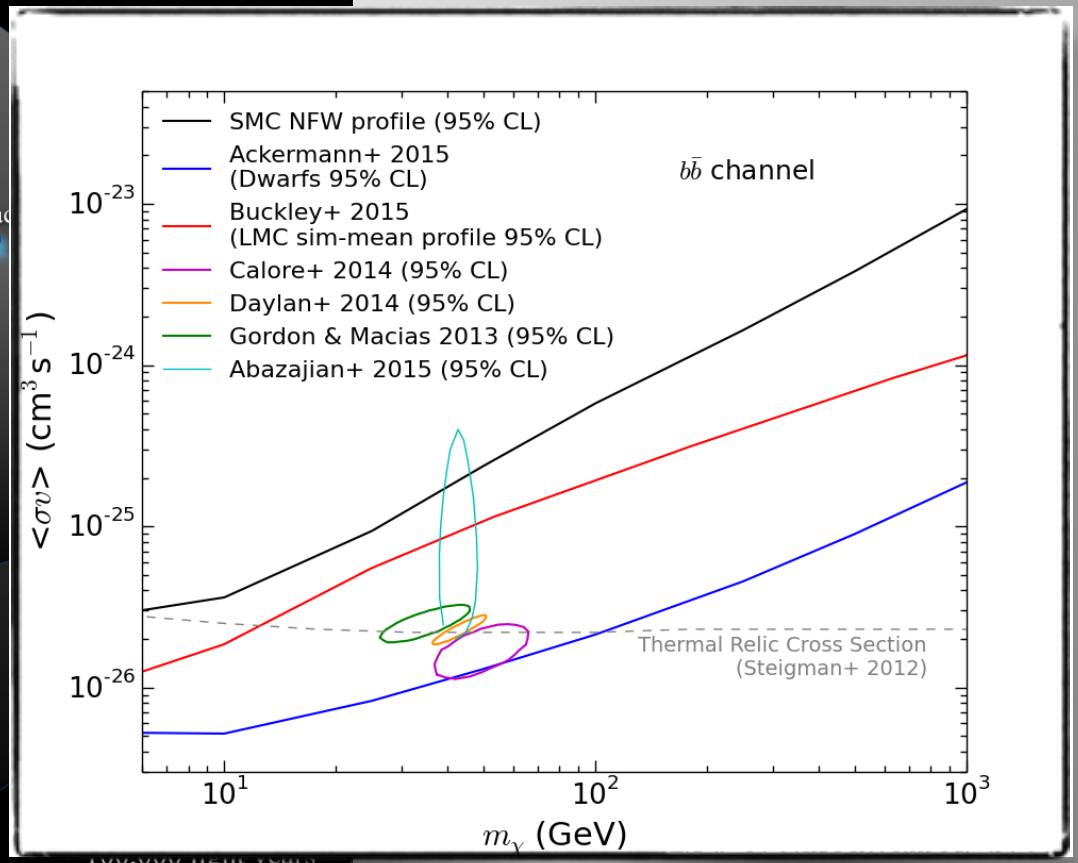




RC et al., PRD 2016

Star Forming Galaxies

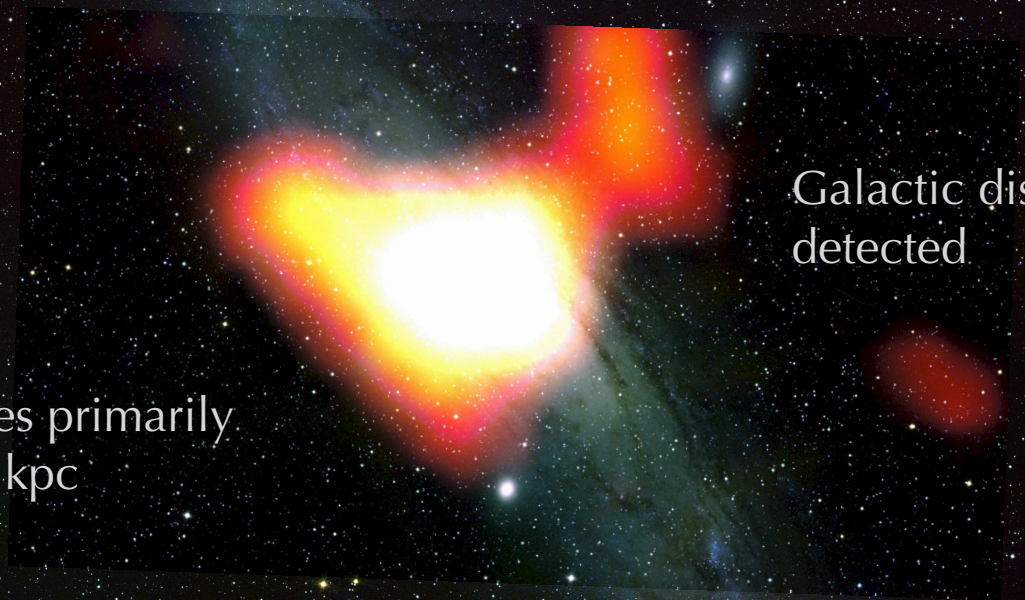




RC et al., PRD 2016

γ-ray emission in the Andromeda Galaxy

Another Milky Way-like excess??



Galactic disk not detected

Emission comes primarily from inner ~5 kpc

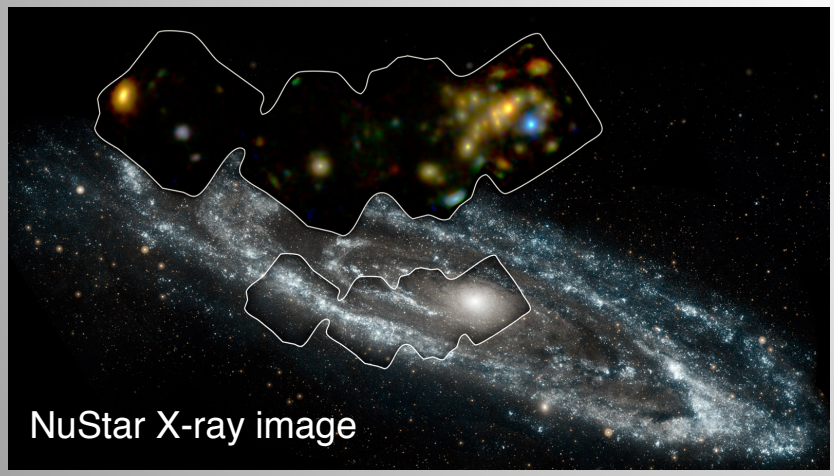
Not correlated with interstellar gas and star formation regions

Credit: NASA/GSFC

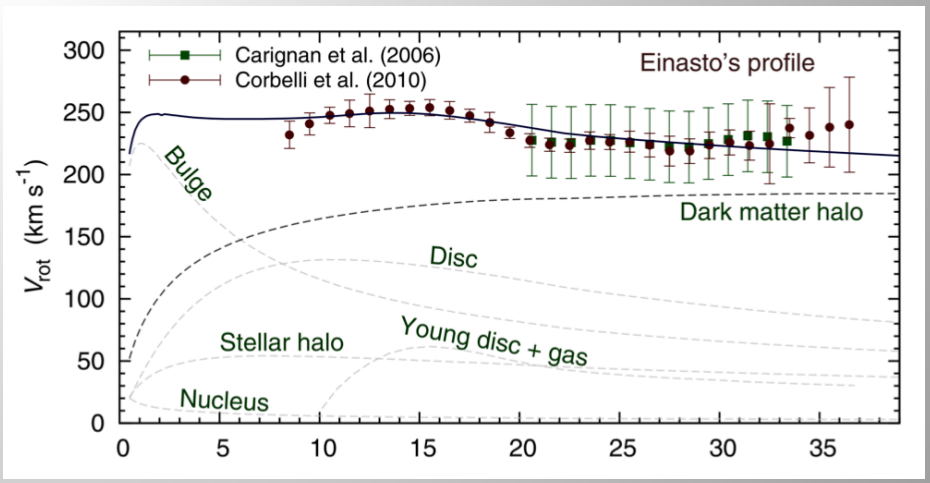
γ rays@M31: Interpretations

Old stellar populations: Low-mass X-ray binaries and MSPs… found in the inner regions of M31 *(reminiscent of the GCE)*

Consistent with DM from GCE?



https://www.jpl.nasa.gov/news/news.php?feature=4811

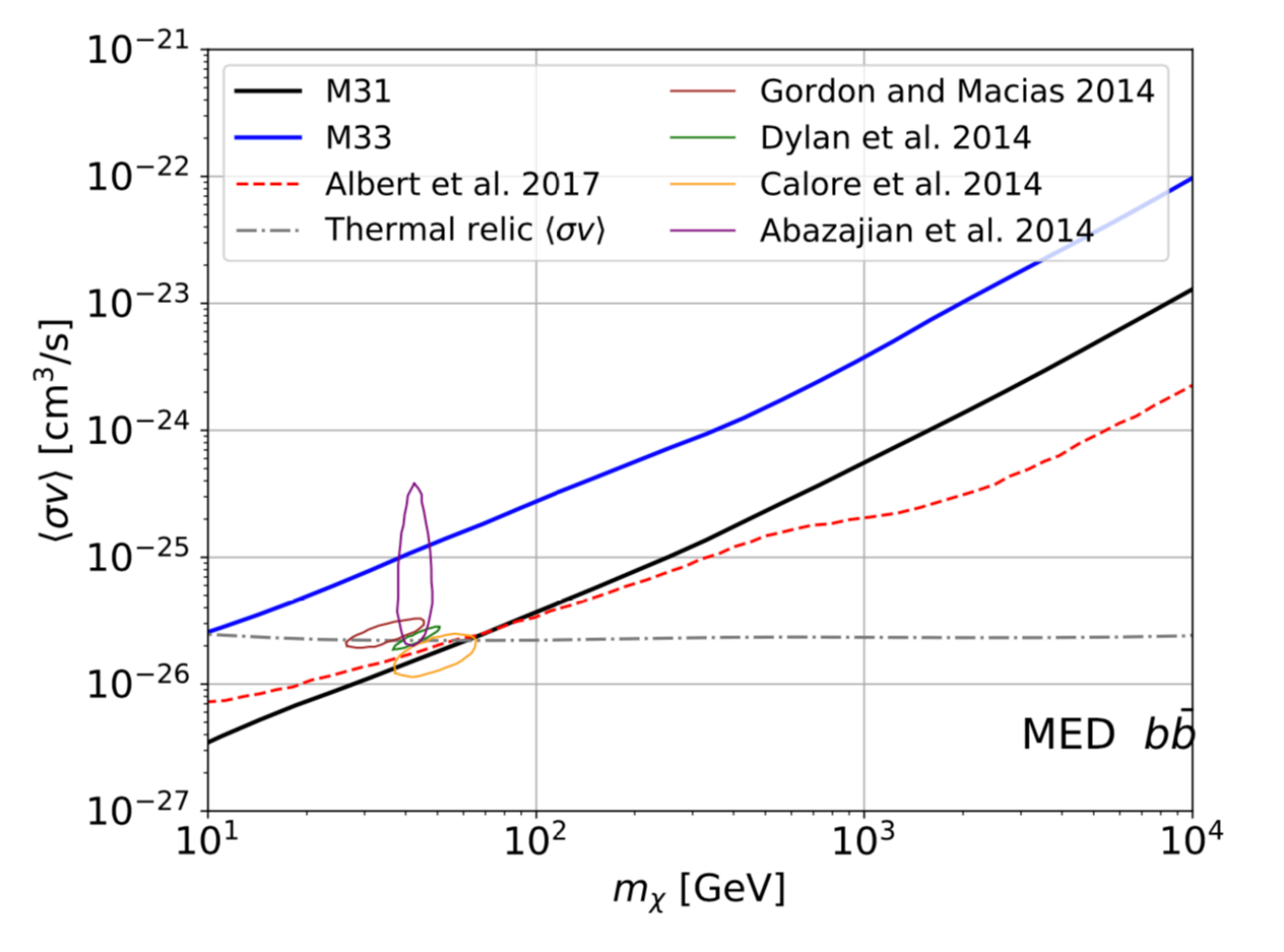


J-factors: Tamm et al. (2012)

Milky Way: 2×10^{22} GeV^2/cm^5

M31: 8×10^{18} GeV^2/cm^5

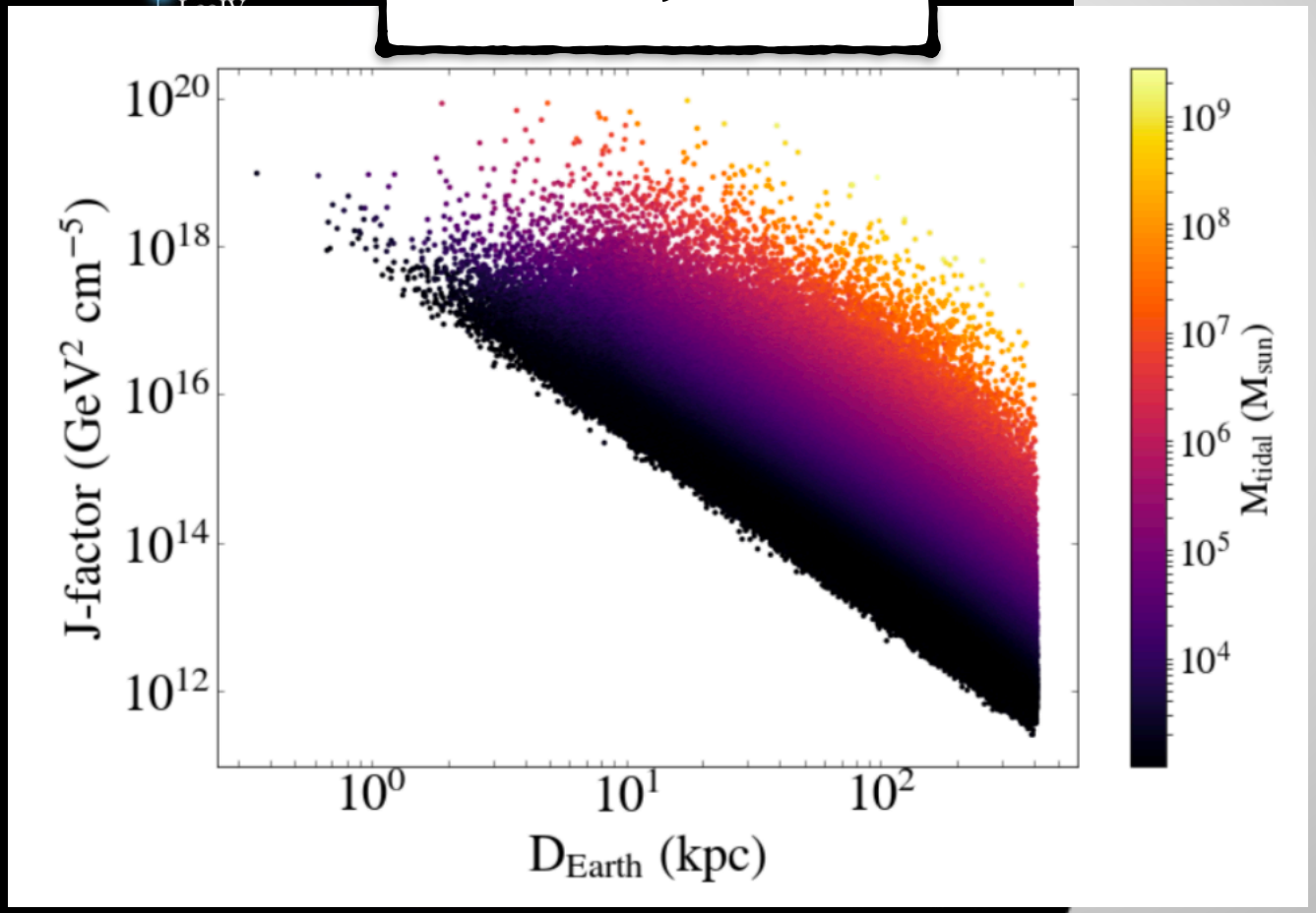
γ rays@M31: Dark Matter



M. Di Mauro et al., PRD 2019

Unidentified γ sources

Subhalo J-factors

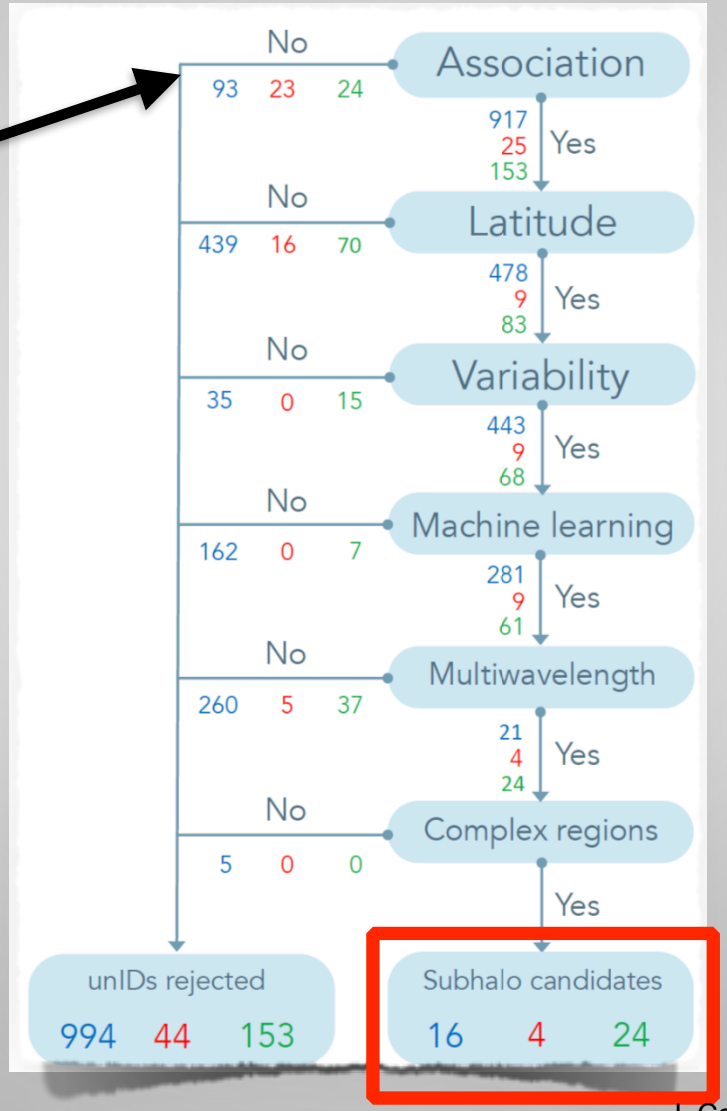


Could unidentified gamma-ray sources be evidence of dark matter annihilation in sub-halos?

J. Coronado-Blázquez *et al* JCAP07(2019)020

Unidentified γ sources

Fermi Catalog Sources (3FGL, 2FHL, 3FHL)



J. Coronado-Blázquez *et al* JCAP07(2019)020

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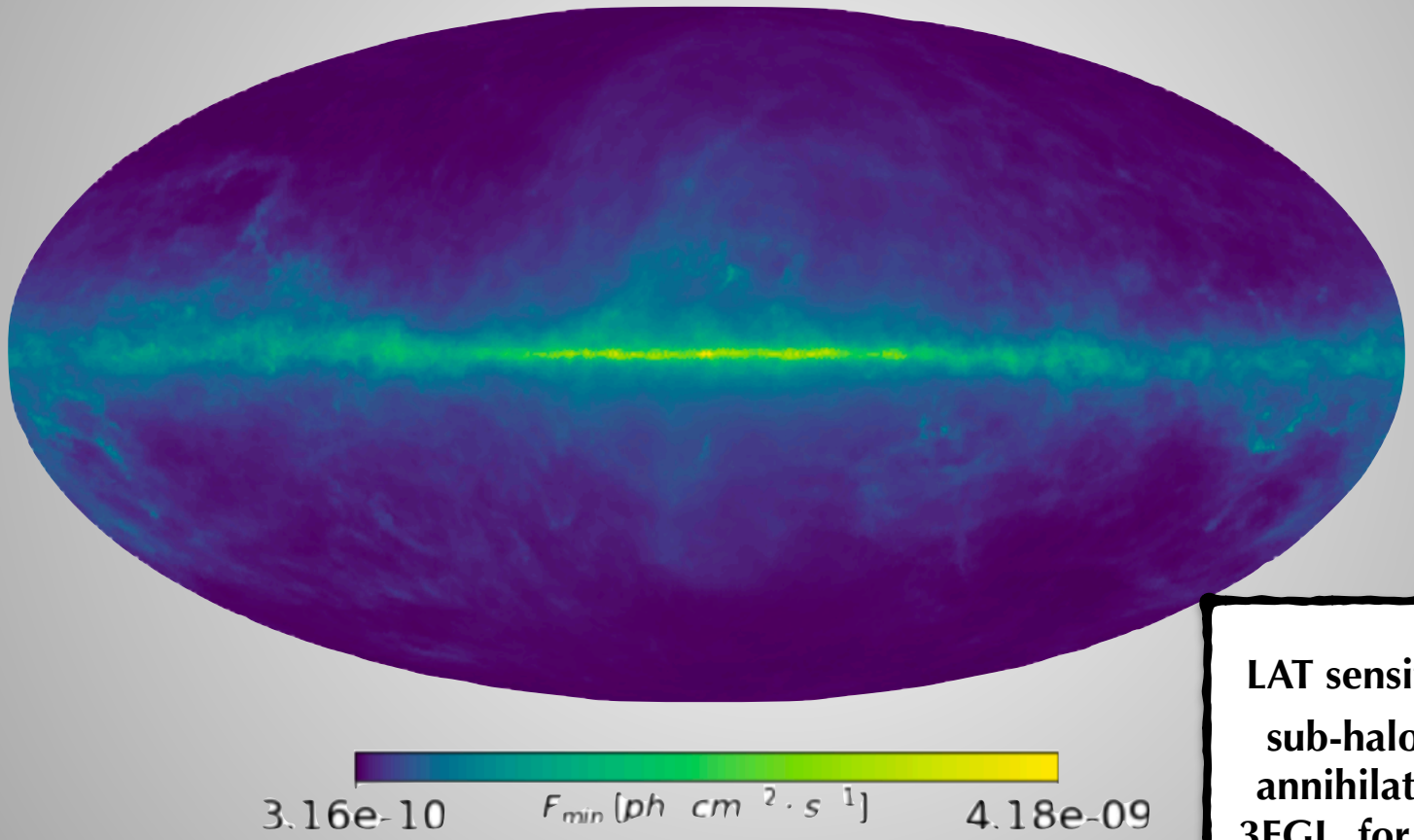
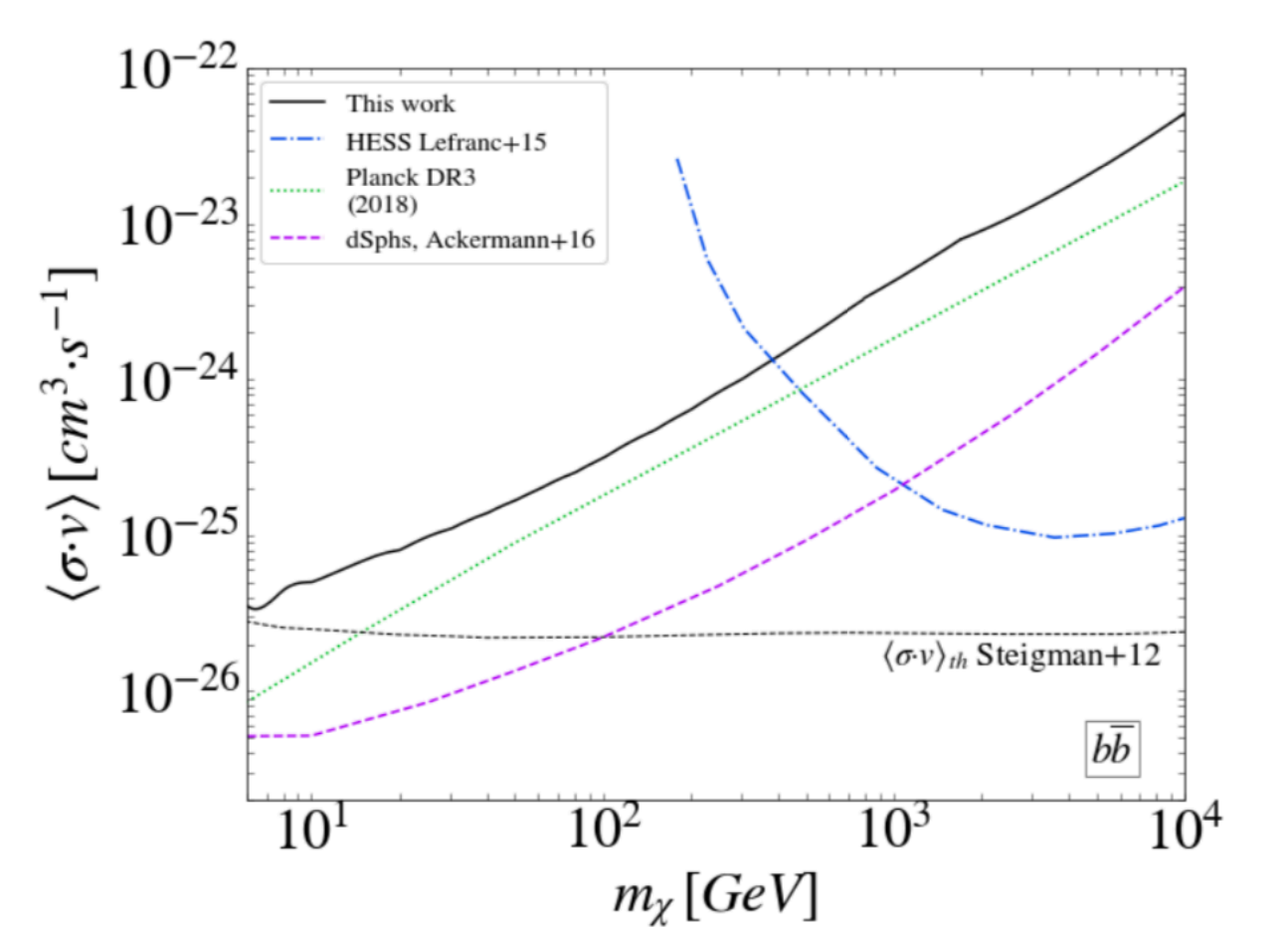


LAT sensitivity to DM sub-halos for $\tau^+\tau^-$ annihilation and the 3FGL, for DM Mass of 10 GeV

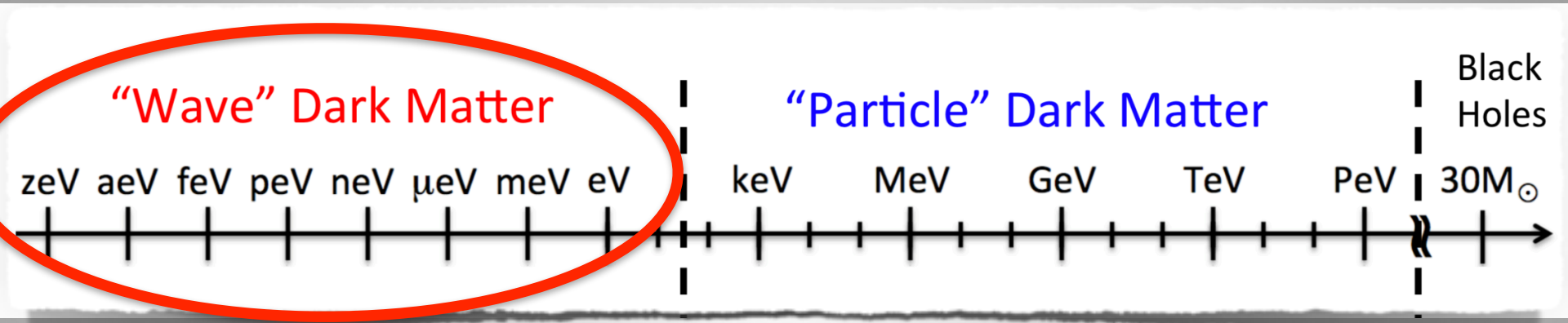
J. Coronado-Blázquez *et al* JCAP07(2019)020

Unidentified γ sources



J. Coronado-Blázquez *et al* JCAP07(2019)020

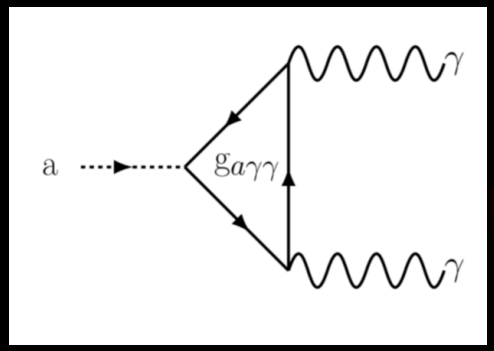
Beyond WIMP Dark Matter

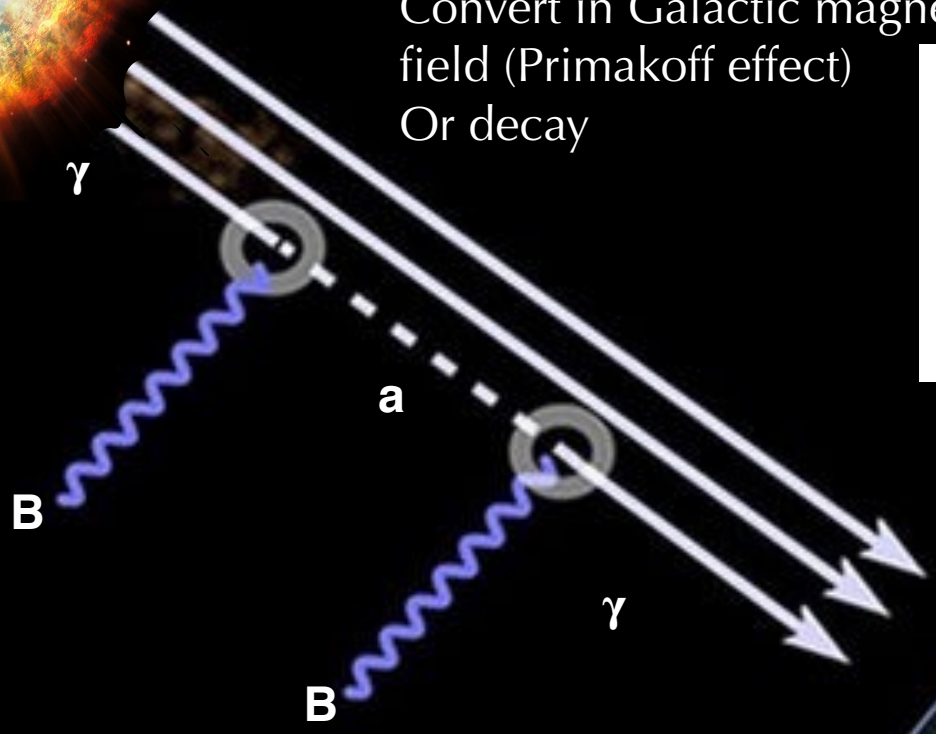


1. Does the candidate allow the present universe?
2. How do we look for the candidate?
3. How do we discover the candidate?

Axion-like Particles

Convert in Galactic magnetic field (Primakoff effect)
Or decay





[Peccei & Quinn 77; Wilczek 78; Weinberg 78; Preskill et al. 83; Abbott & Sikivie 83; Witten 84; e.g. Arvanitaki et al. 09; Cicoli et al. 12; Arias et al. 2012; Raffelt & Stodolsky 1988]

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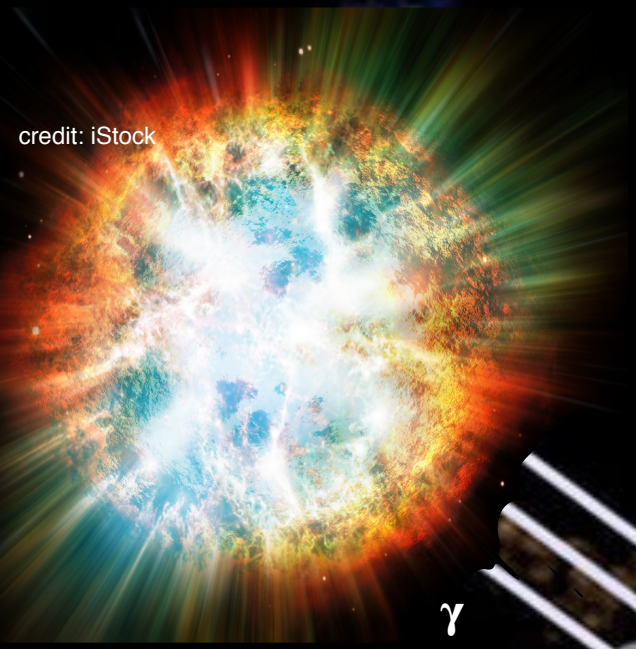

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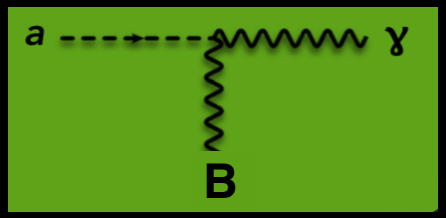

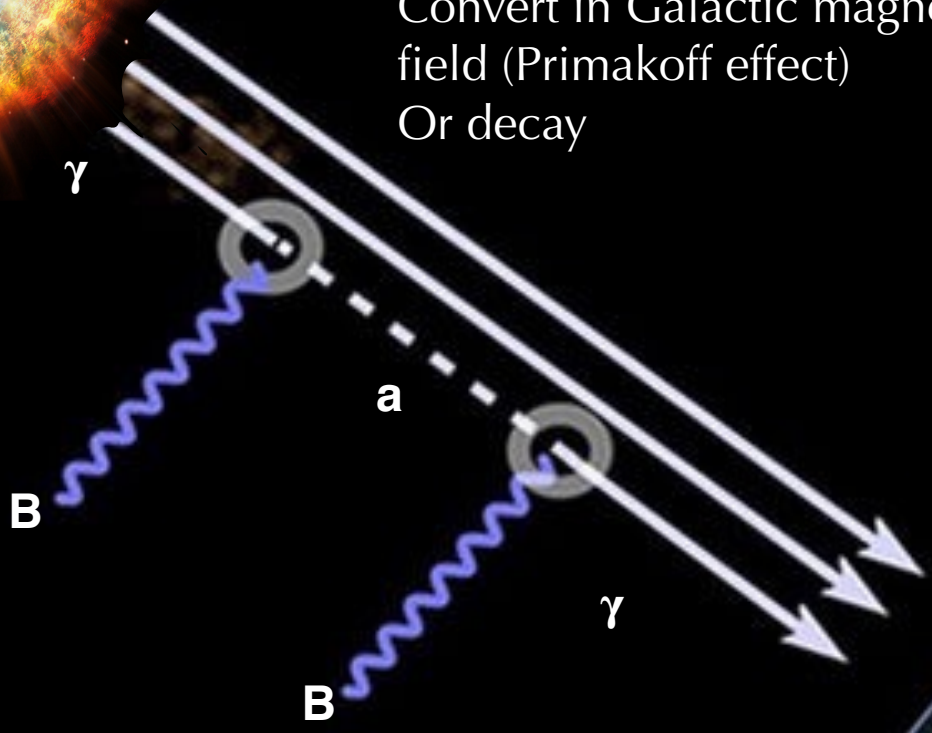

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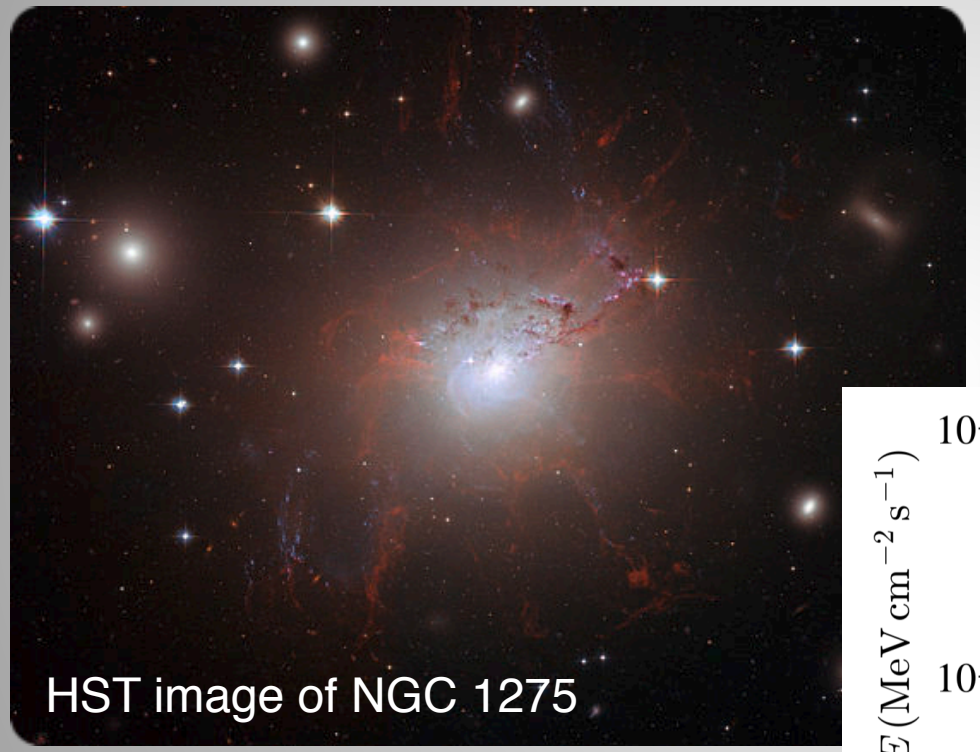
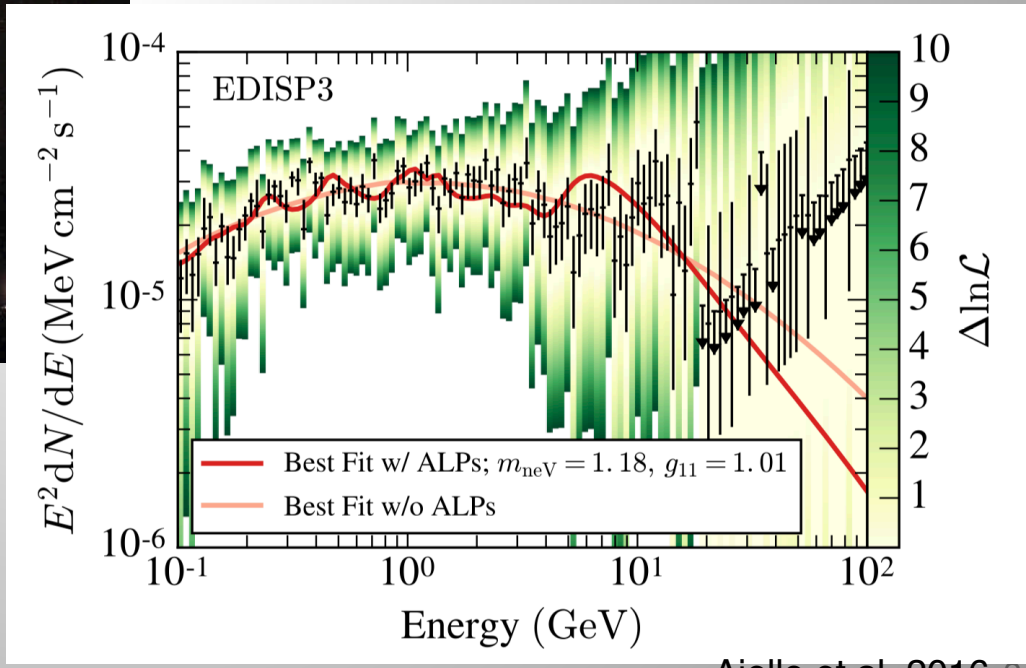
Axion Induced Spectral Modulations



- Central radio galaxy of Perseus cluster
- Bright ɣ-ray emitter
- Central B field of cluster: 25 μG

Taylor et al. 2006



Ajello et al. 2016

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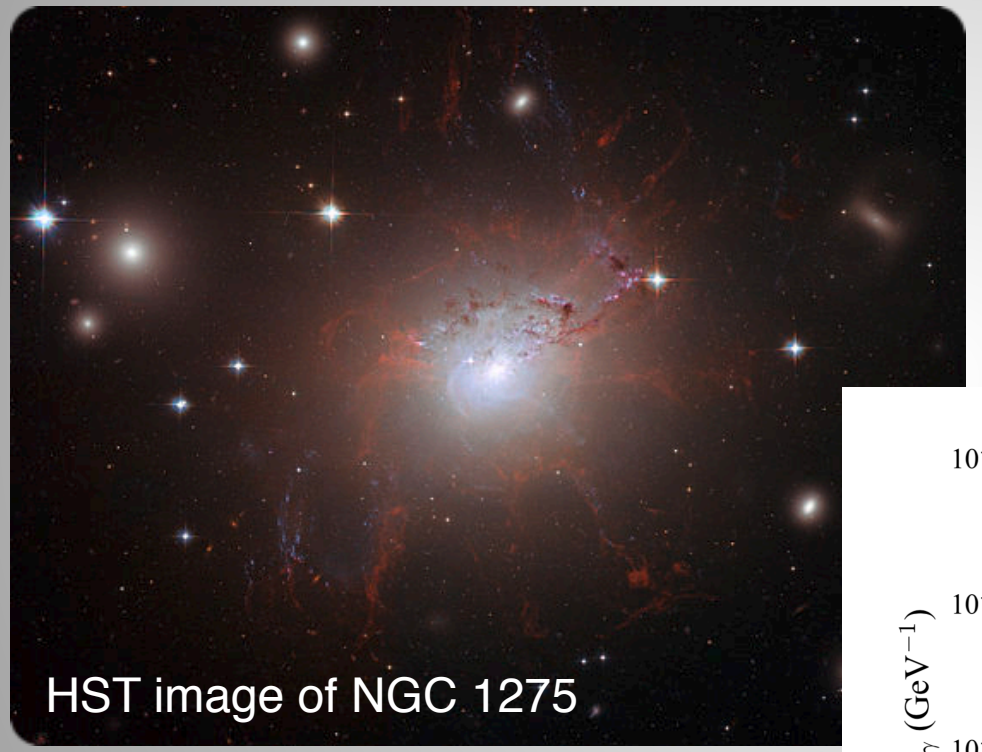

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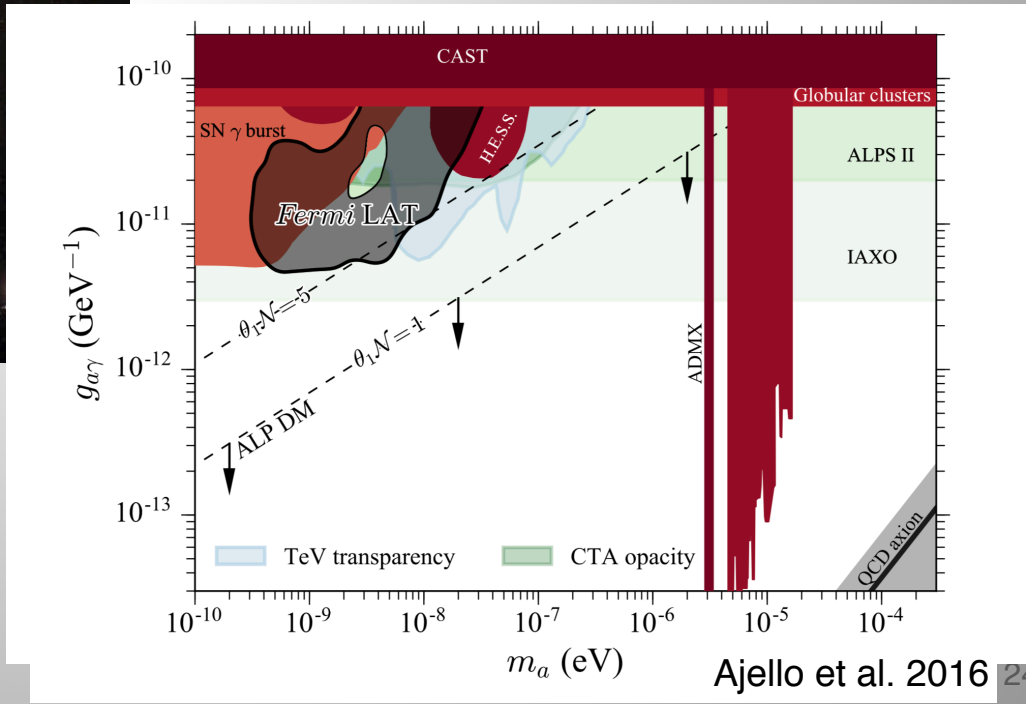
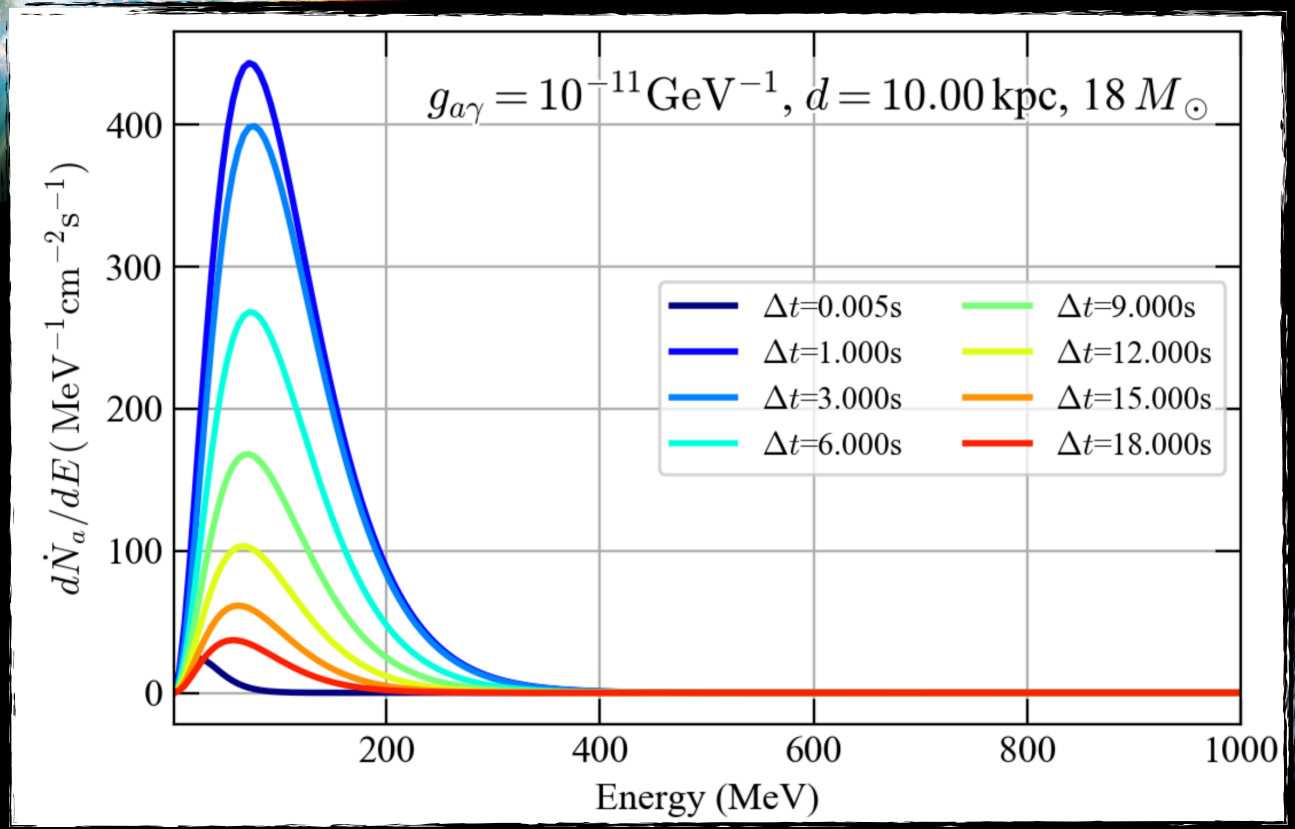


Ajello et al. 2016

Axions Produced in Core-Collapse Supernovae

credit: iStock



Produced ~10s with neutrinos

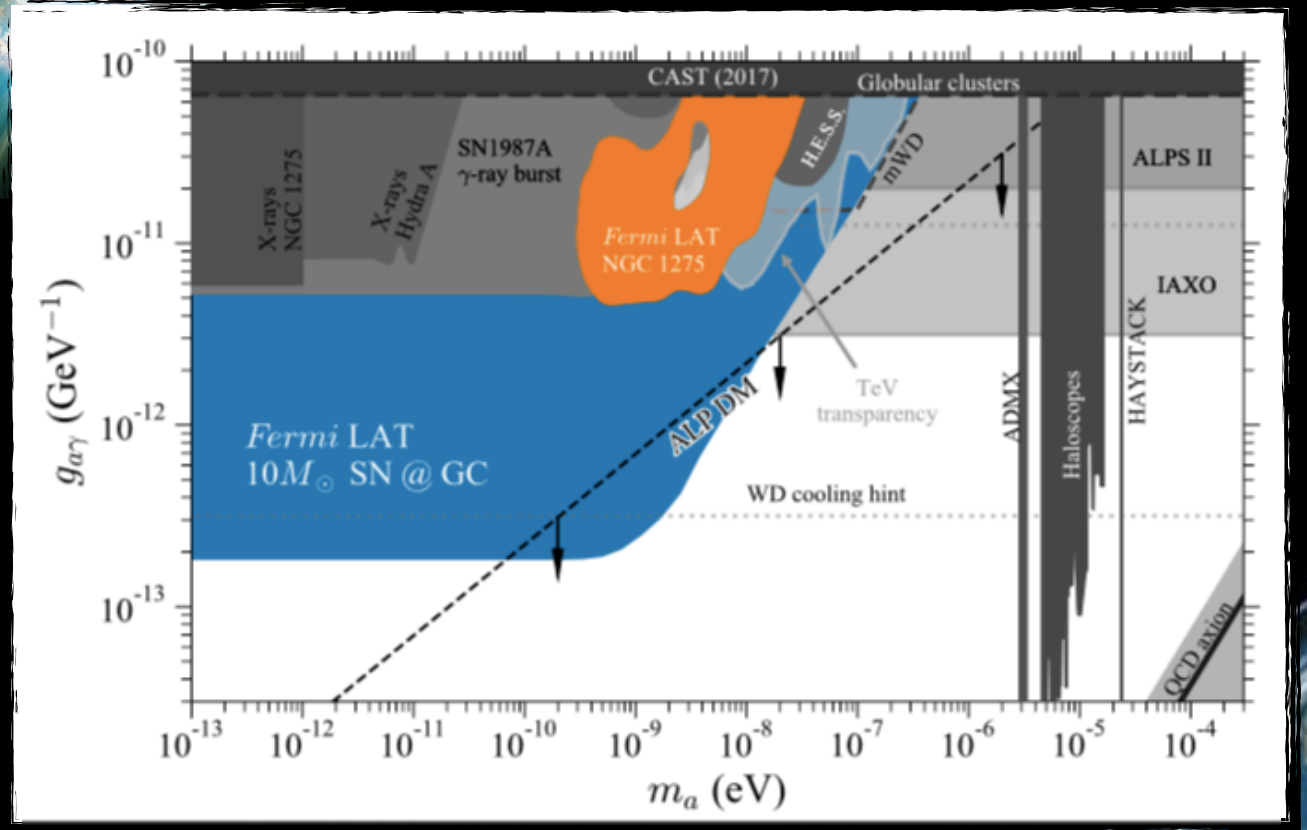
Peak ~60 MeV

Flux $\propto g_{a\gamma}{}^4$

Payez et al., 2015

credit: iStock

Axions Produced in Core-Collapse Supernovae



Produced ~10s with neutrinos

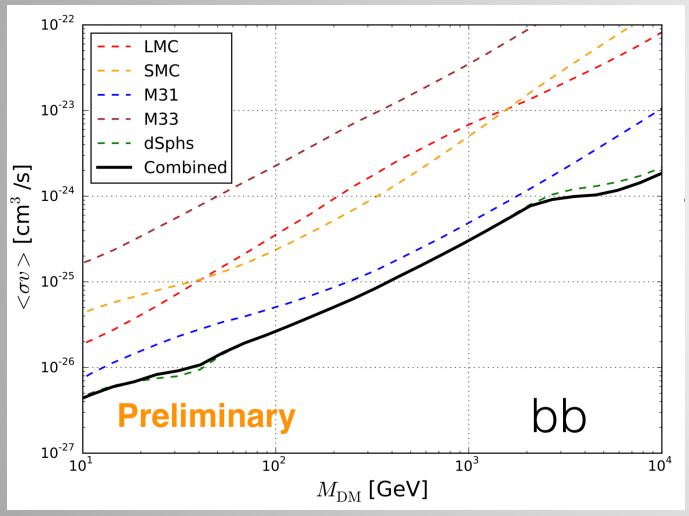
Peak ~60 MeV

Flux $\propto g_{a\gamma}{}^4$

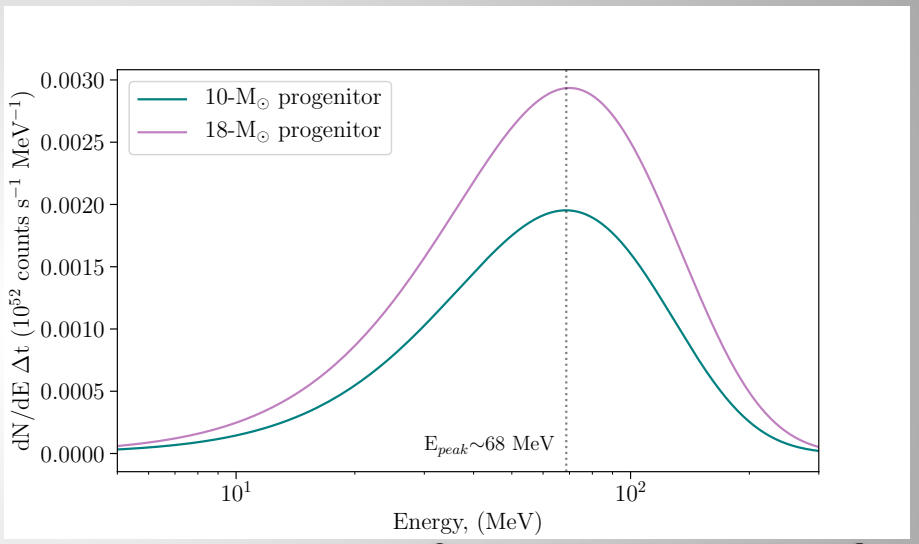
Meyer et al., 2017

Current/Future work

DM Catalog: uniform framework to test individual targets



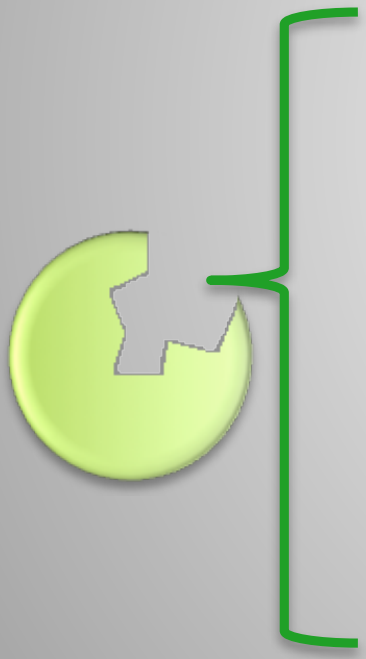
M. Di Mauro et al, Fermi Symposium 2018

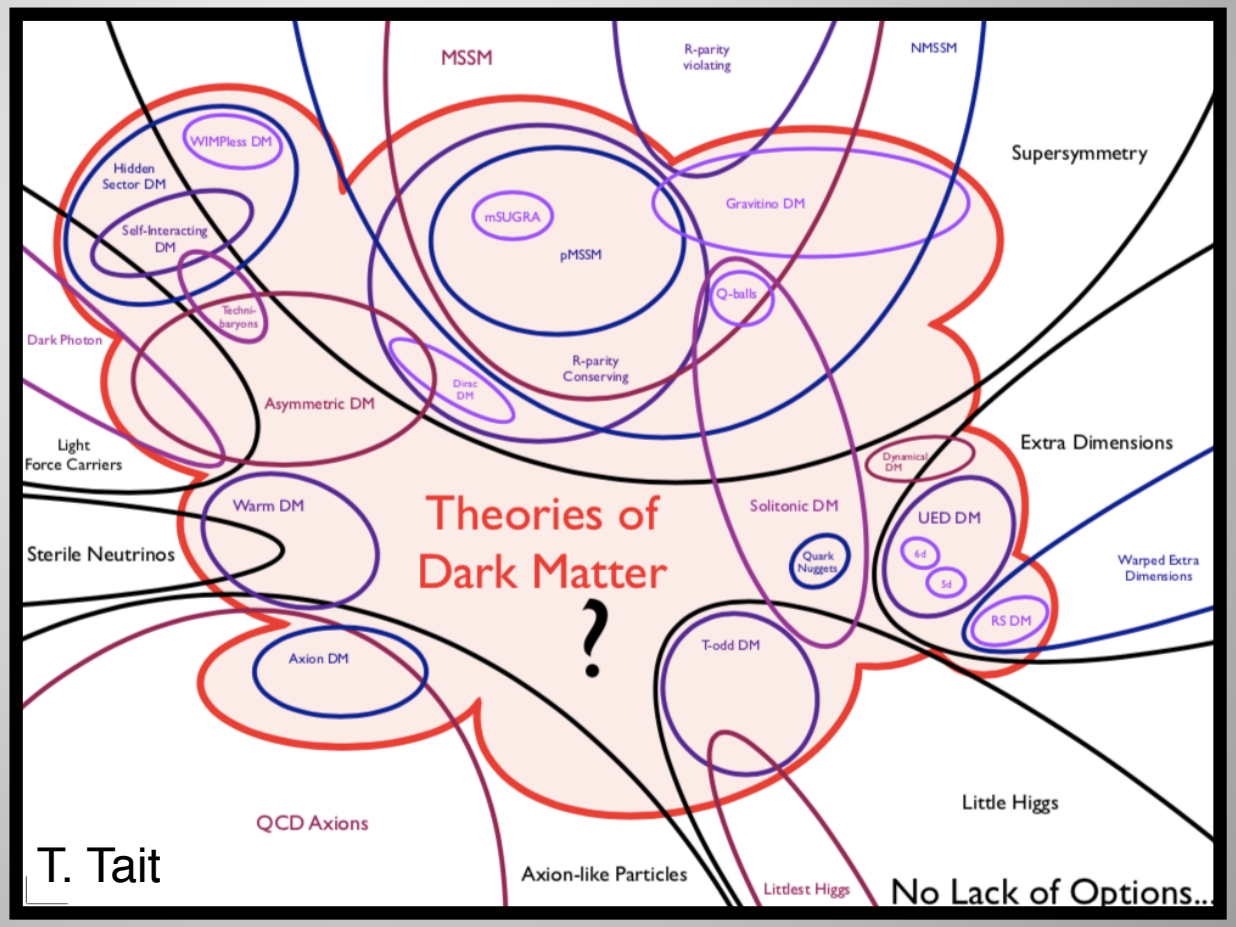


ALP searches in GRBs/AGN

Connecting the Pieces

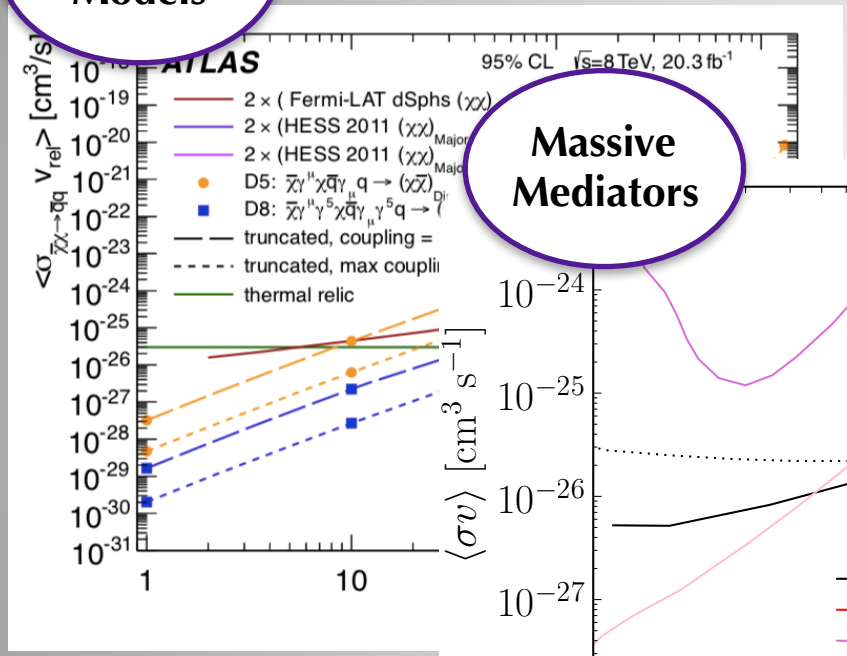
Need a theory to connect the measurements…





Combining the Theories

Simplified Models



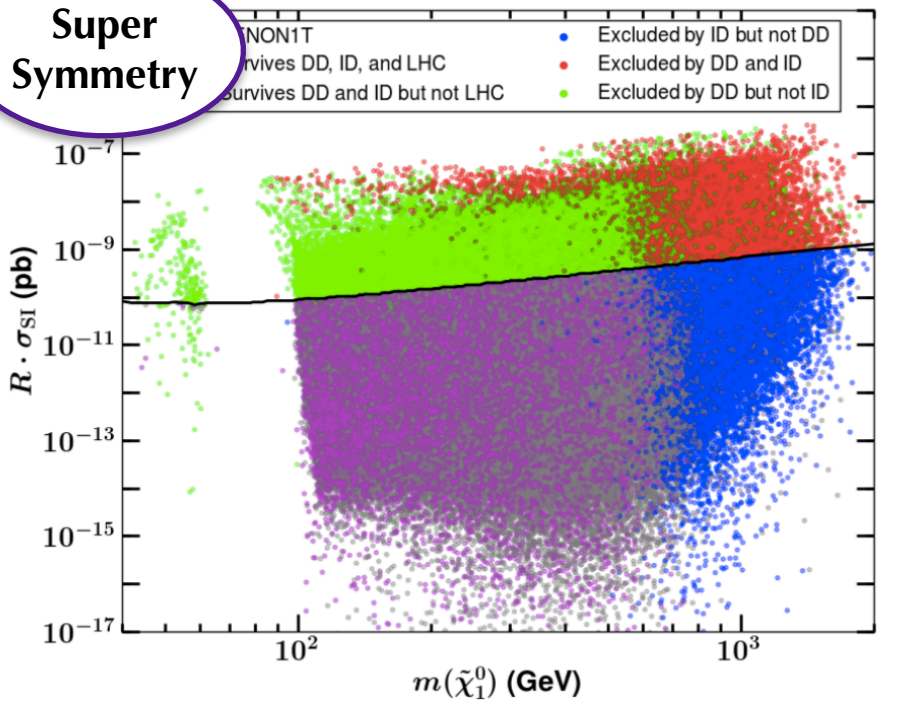
ATLAS arXiv:

Massive Mediators

Charles et al., arX

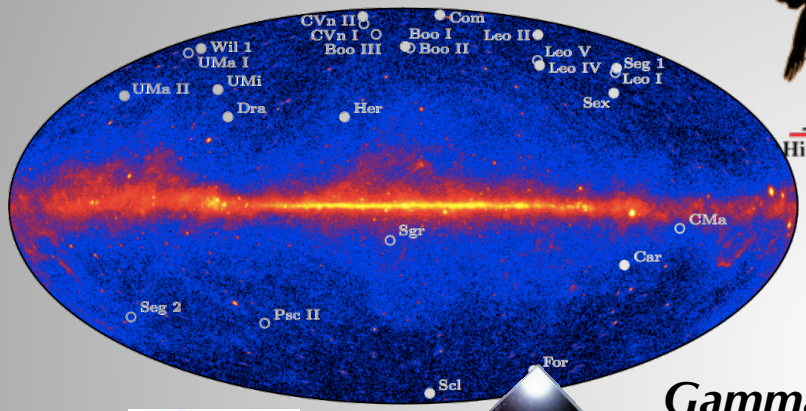
Data from Fermi-LAT is key to understanding dark matter models

Super Symmetry



Cahill-Rowley et al., arXiv:1305.6921

The Next Generation…



Gamma rays are a key player

Gamma-ray mission

New space-based gamma-ray missions are Essential and Urgent to understand anomalies in the current data and to complement upcoming facilities

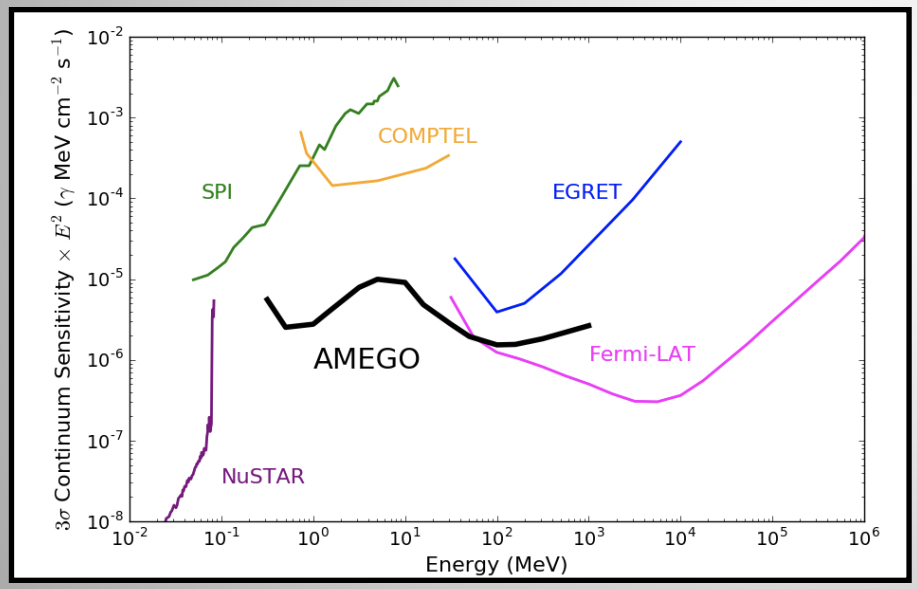
Fermi DES/IACTs/HAWC LSST CTA MeV Mission

Today 2020 2023 2020s

The Next Generation…

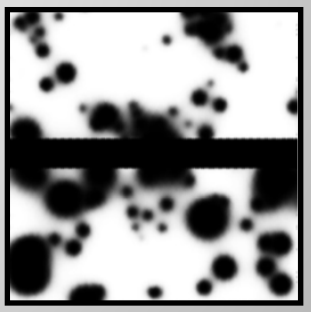
Gamma-ray mission concepts…

All-sky Medium Energy Gamma-ray Observatory: ***AMEGO, eAstrogam***



McEnery et al arXiv: 1907.07558

View of the Galactic Plane

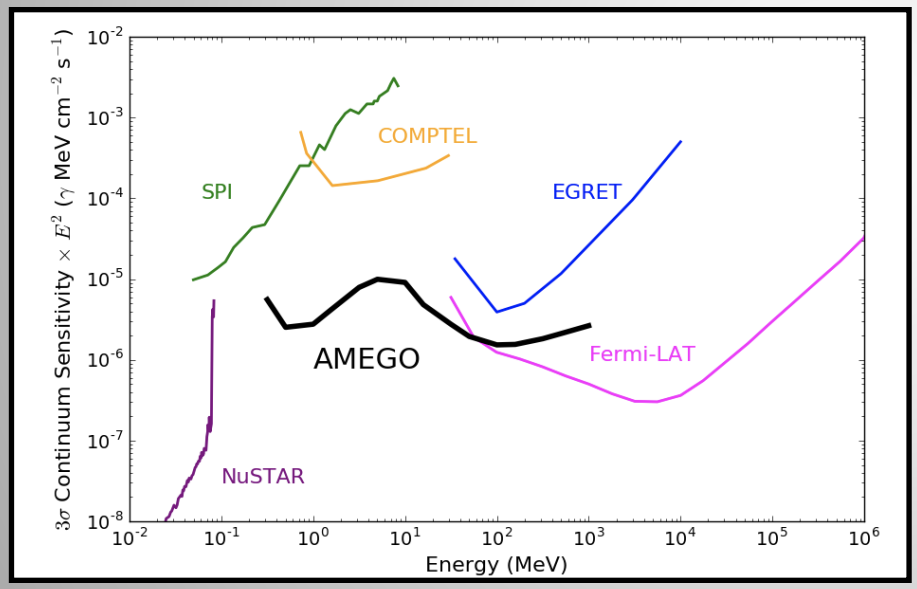


arXiv:1508.07349

The Next Generation…

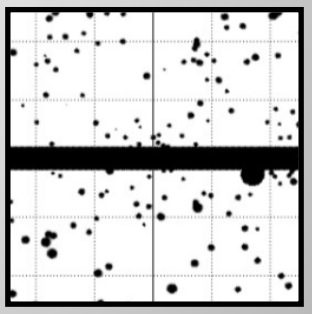
Gamma-ray mission concepts…

All-sky Medium Energy Gamma-ray Observatory: ***AMEGO, eAstrogam***



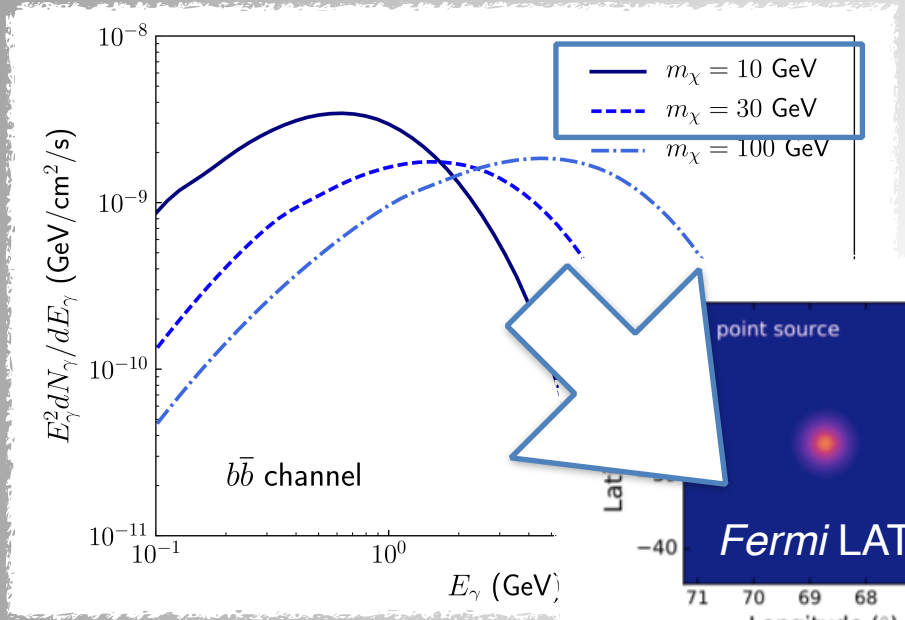
McEnery et al arXiv: 1907.07558

View of the Galactic Plane



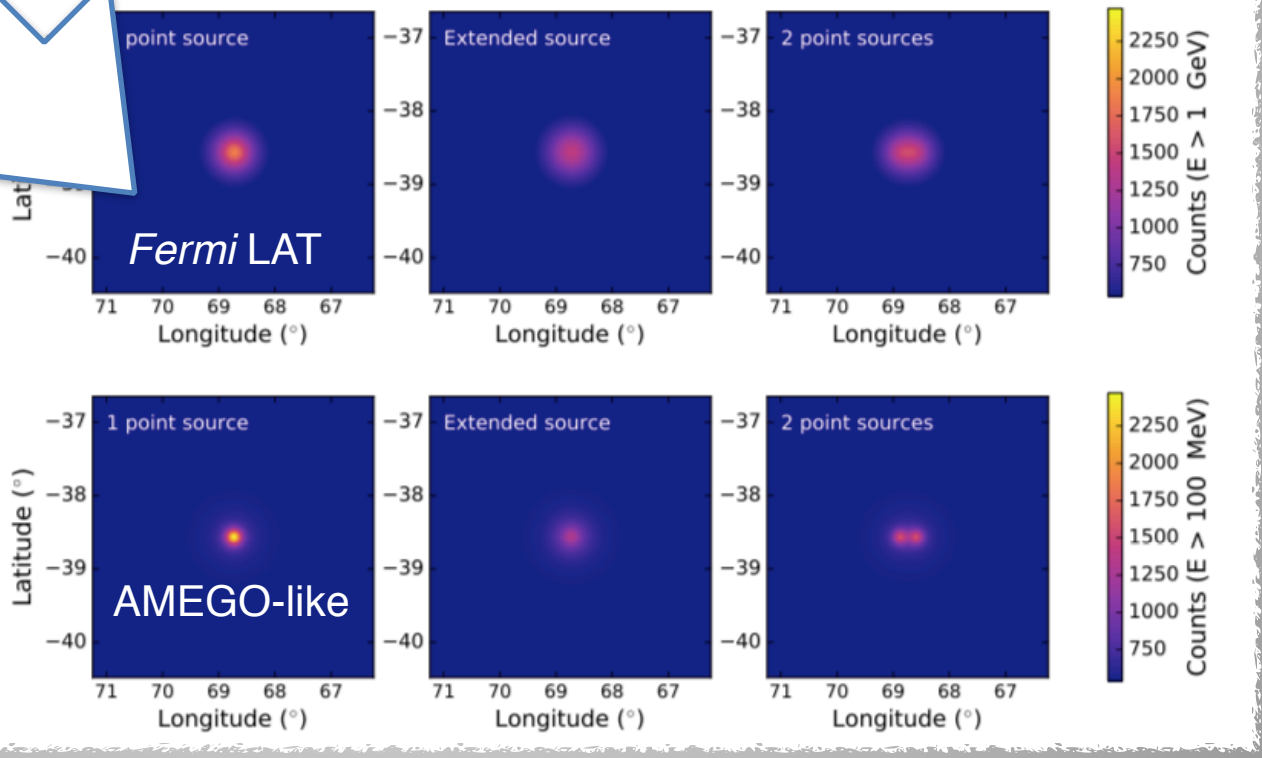
Next-Gen MeV
arXiv:1508.07349

Complementarity in the γ-ray Sky



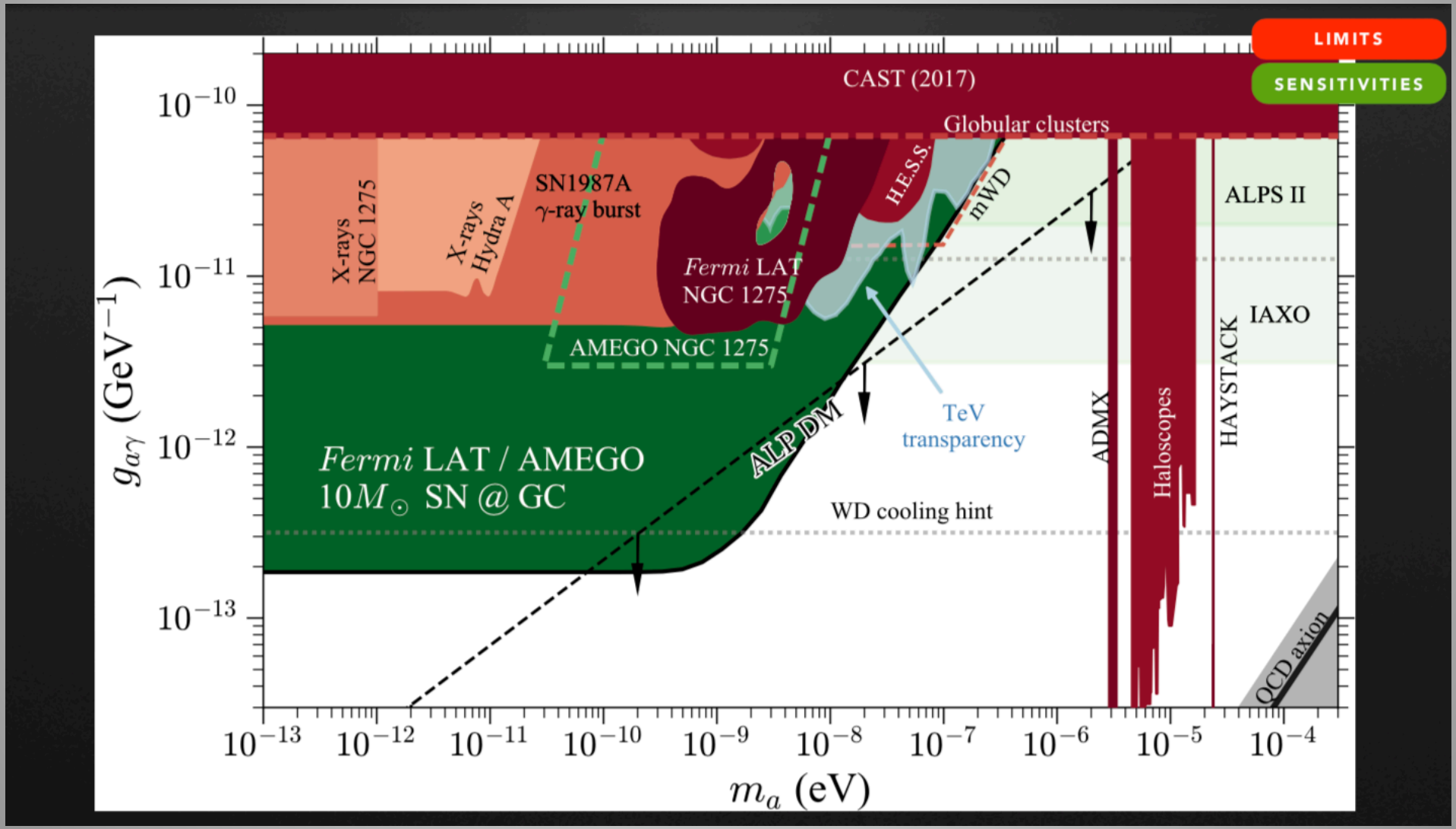
Relevant for extended sources and Galactic Center

Separated by 0.28°



Chou et al. arXiv: 1709.08562

Axion/ALP Dark Matter Sensitivities



Courtesy M. Meyer

Dark Matter and Fermi-LAT