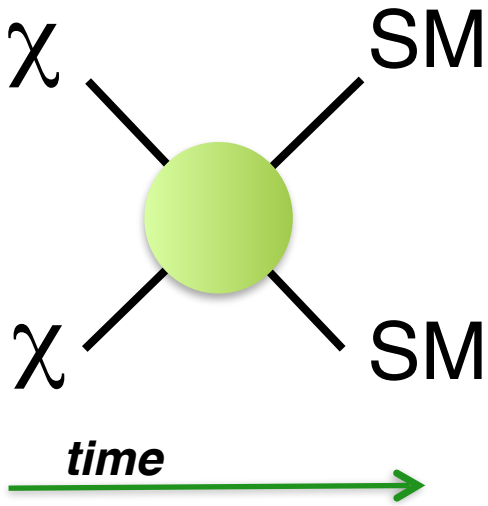
Dark Matter Searches with Fermi-LAT

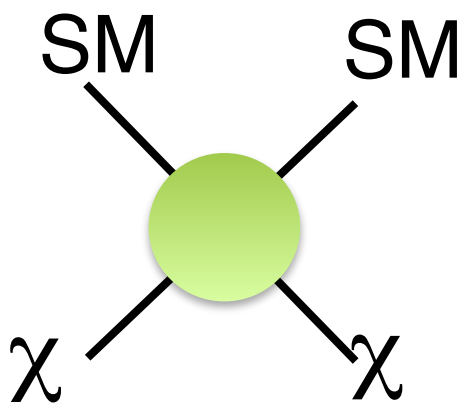
R. Caputo
UMD/NASA/GSFC

WIN2017, Irvine, CA
21 June 2017

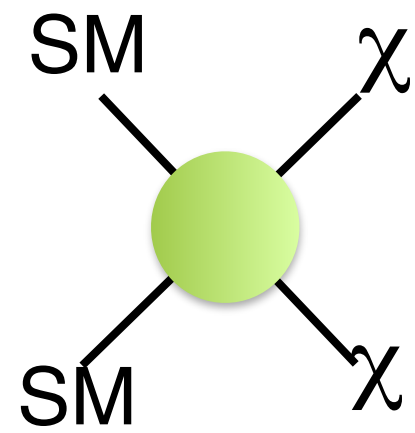
Detecting Particle Dark Matter



Indirect Detection

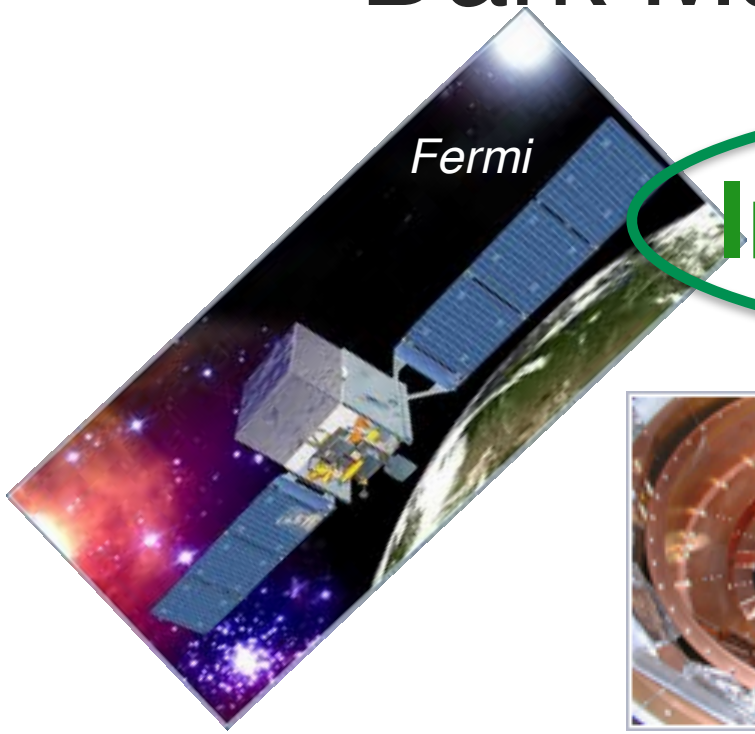


Direct Detection

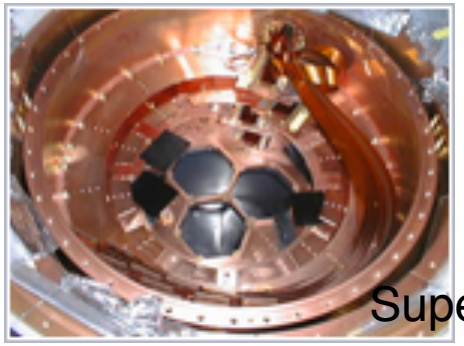


Collider

Dark Matter Searches



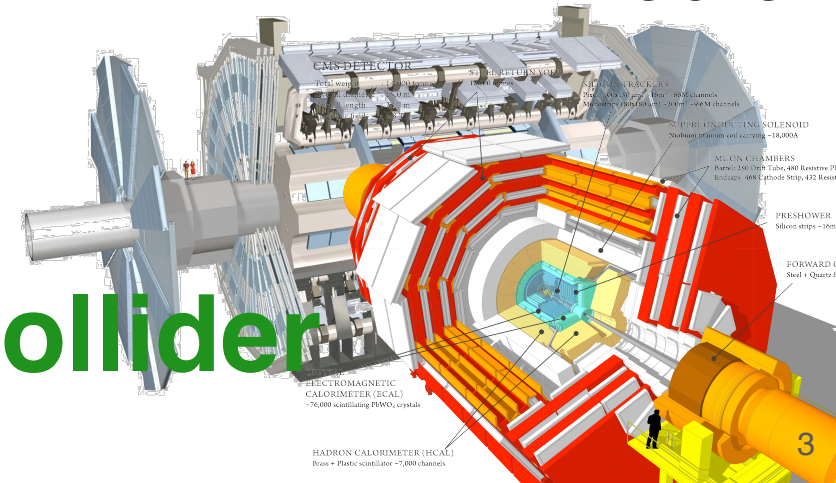
Indirect Detection



SuperCDMS

ATLAS/CMS

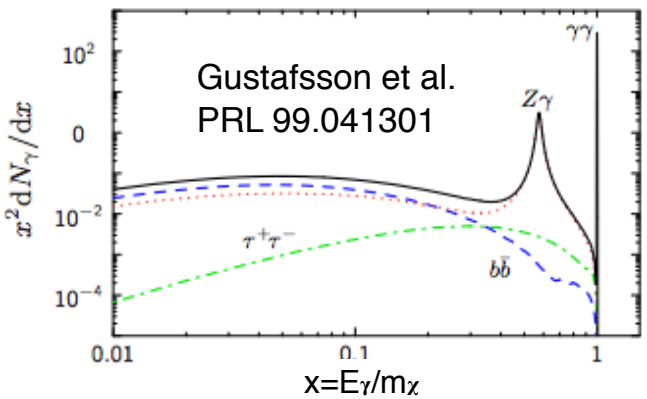
Direct Detection

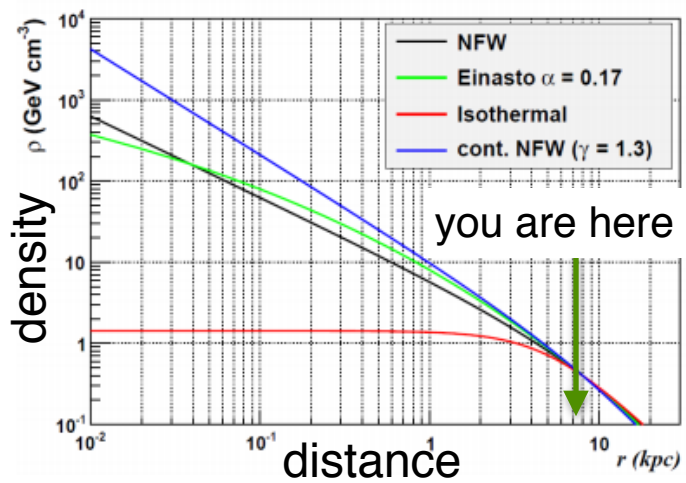


Collider

Indirect Searches: 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

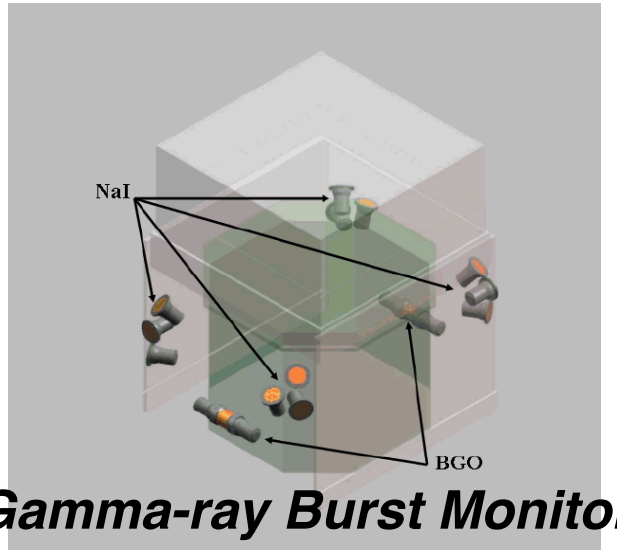
(solid angle, line of sight)

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

Fermi Gamma-Ray Space Telescope

Large Area Telescope

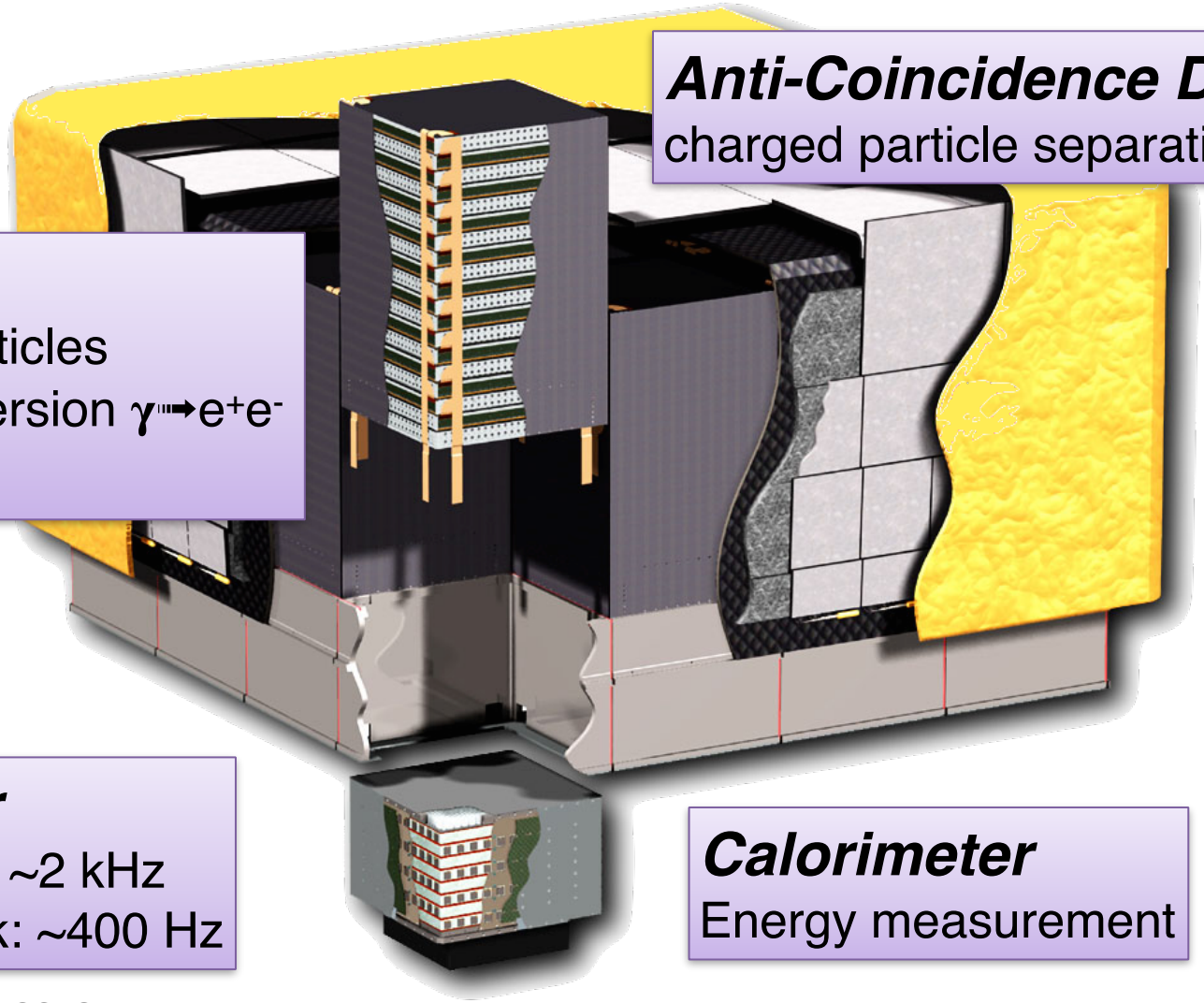
20% sky at once
full sky 3 hours
20 MeV- >300 GeV



Gamma-ray Burst Monitor

full unocculted sky continuous
8 keV - 40 MeV

Fermi Gamma-Ray Space Telescope



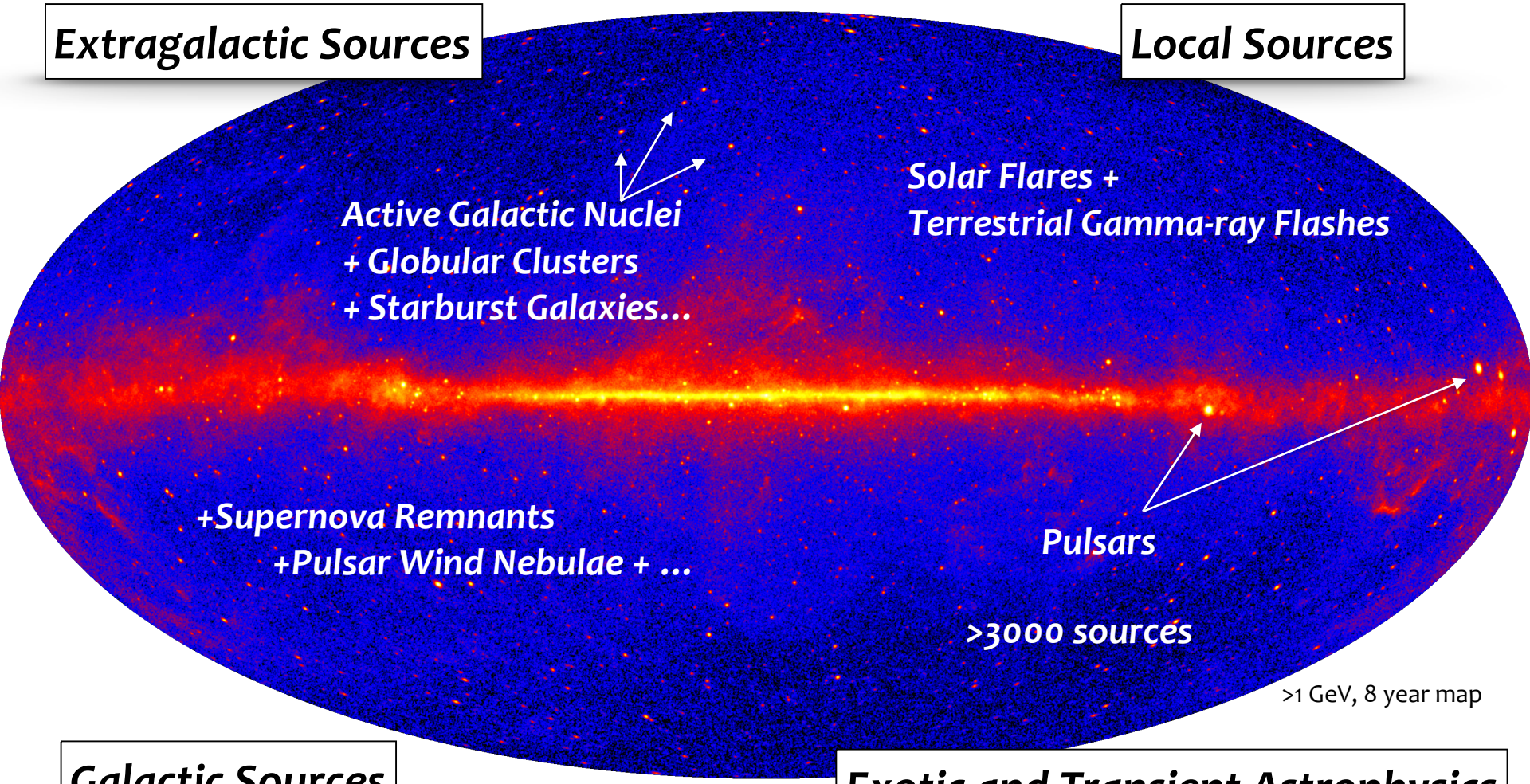
Anti-Coincidence Detector
charged particle separation

Tracker
charged particles
cause conversion $\gamma \rightarrow e^+e^-$
direction

Trigger
read out: ~2 kHz
down-link: ~400 Hz

Calorimeter
Energy measurement

Fermi-LAT γ-ray sky



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, …

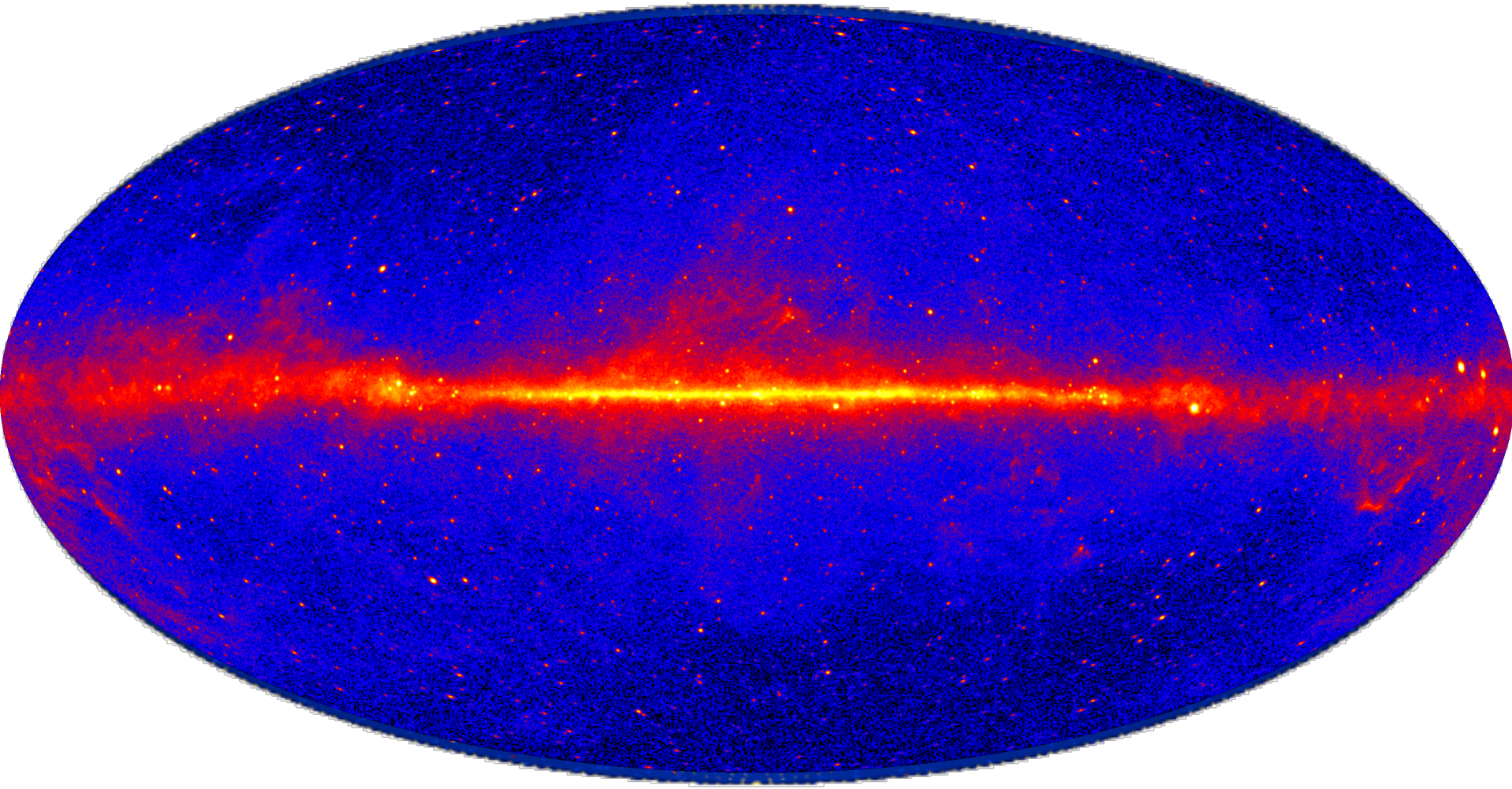
Interstellar Medium ✔

cosmic rays interacting with gas and photons

Dark matter ???

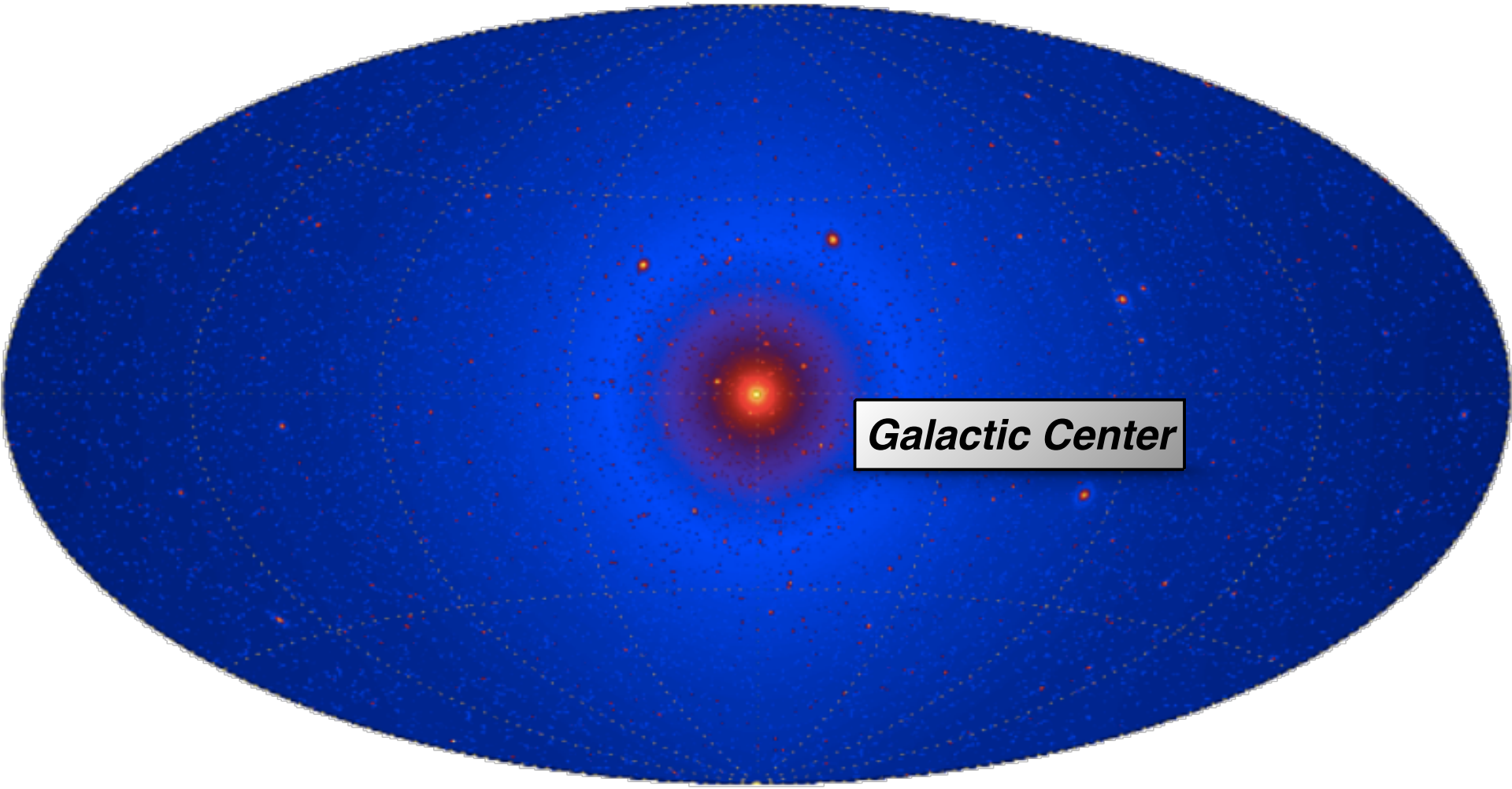
particle annihilation/decay into gamma-rays

Dark Matter Distribution



L. Pieri et al., Phys.Rev.D83:023518,2011

Dark Matter Distribution

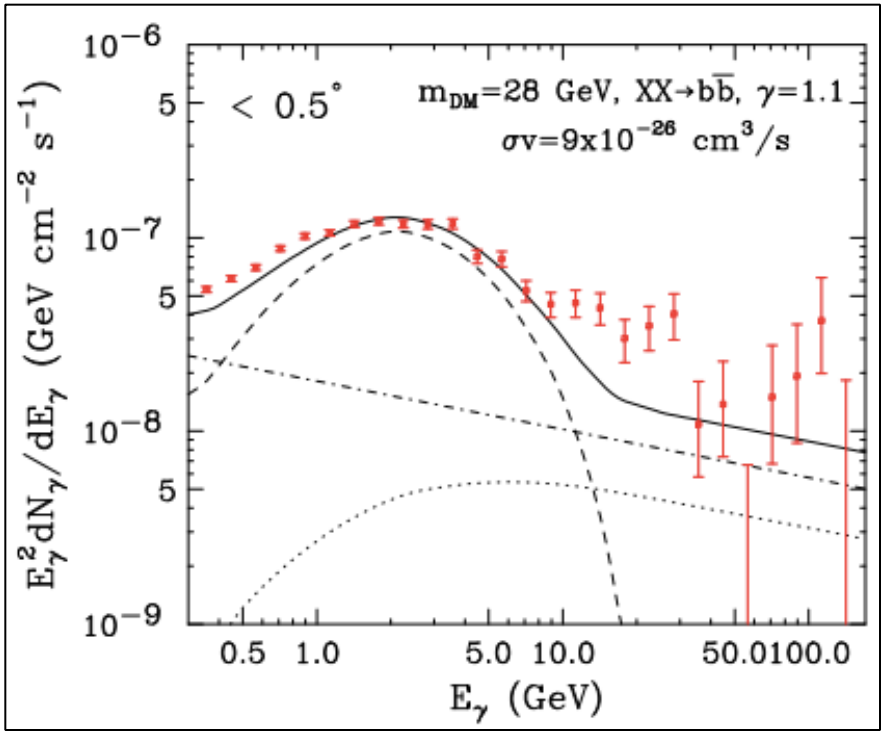


L. Pieri et al., Phys.Rev.D83:023518,2011

What's Going On in the Galactic Center?

2009

Excess in gamma-ray flux from GC



L. Goodenough, arXiv:0910.2998

What's Going On in the Galactic Center?

2009
Excess in gamma-ray flux from GC

2009 — now
Many papers confirming the excess
Speculation as to its origin

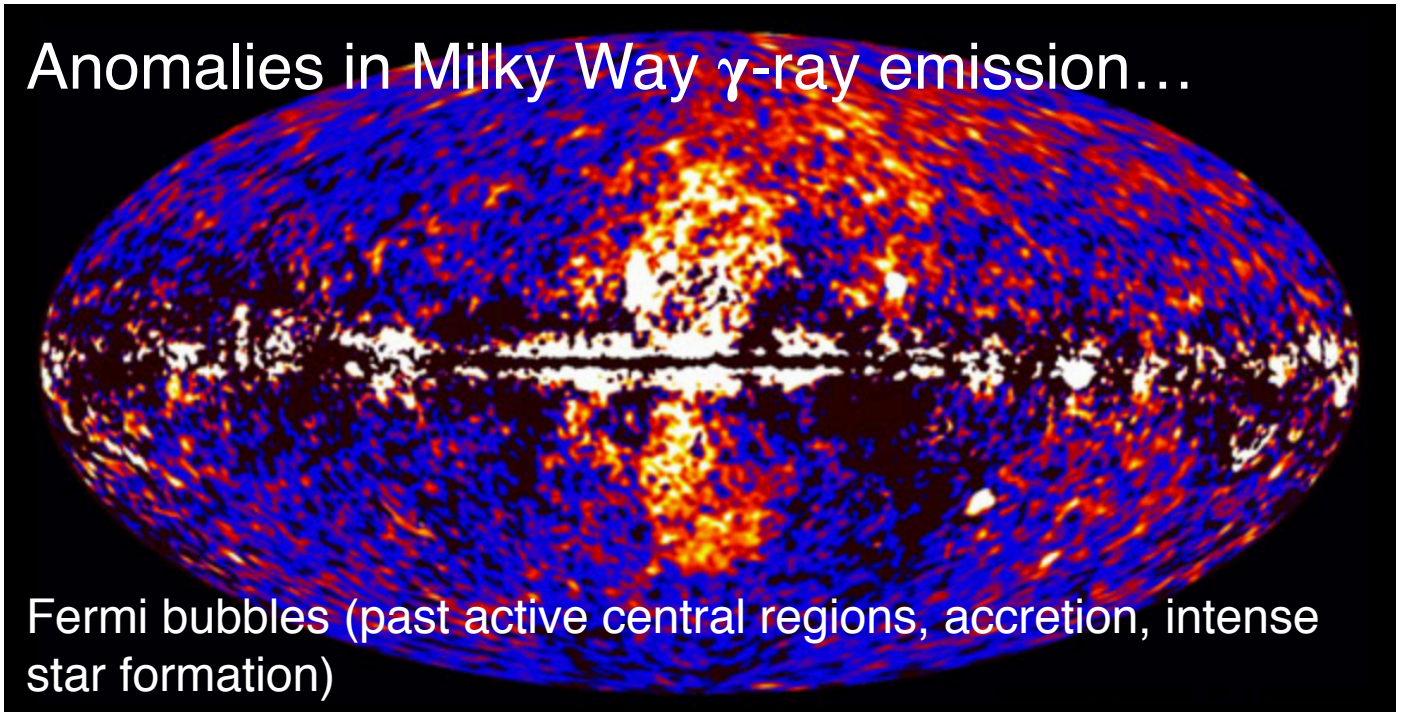
Not exhaustive:
L. Goodenough, D. Hooper, arXiv:0910.2998
V.Vitale and A.Morsell, 2009 Fermi Symposium, arXiv: 0912.3828
D. Hooper, L. Goodenough, PLB, arXiv:1010.2752
D. Hooper, T. Linden, PRD, arXiv:1110.0006
K. Abazajian, M. Kaplinghat, PRD, arXiv:1207.6047
D. Hooper, T. Slatyer, PDU, arXiv:1302.6589
C. Gordon, O. Macias, PRD, arXiv:1306.5725
W. Huang, A. Urbano, W. Xue, arXiv:1307.6862
K. Abazajian, N. Canac, S.Horiuchi, M. Kaplinghat, arXiv:1402.4090
T. Daylan, et al., PDU 12 1 (2016), arXiv: 1402.6703

Unresolved populations*

Dark Matter

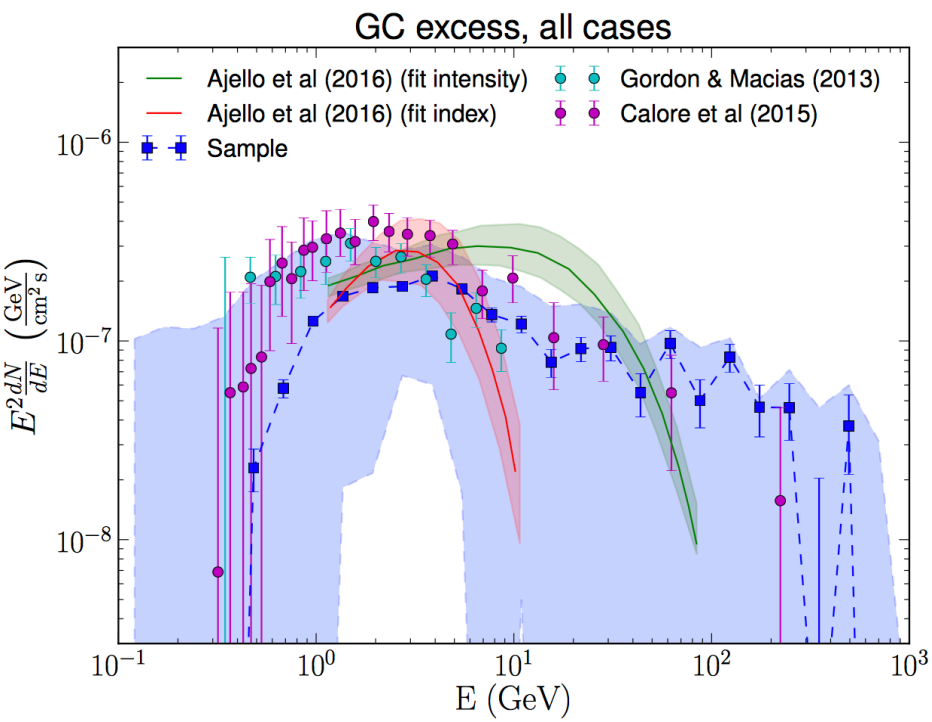
****Massive star formation (OB type stars)***
Unresolved point sources
Pulsars…

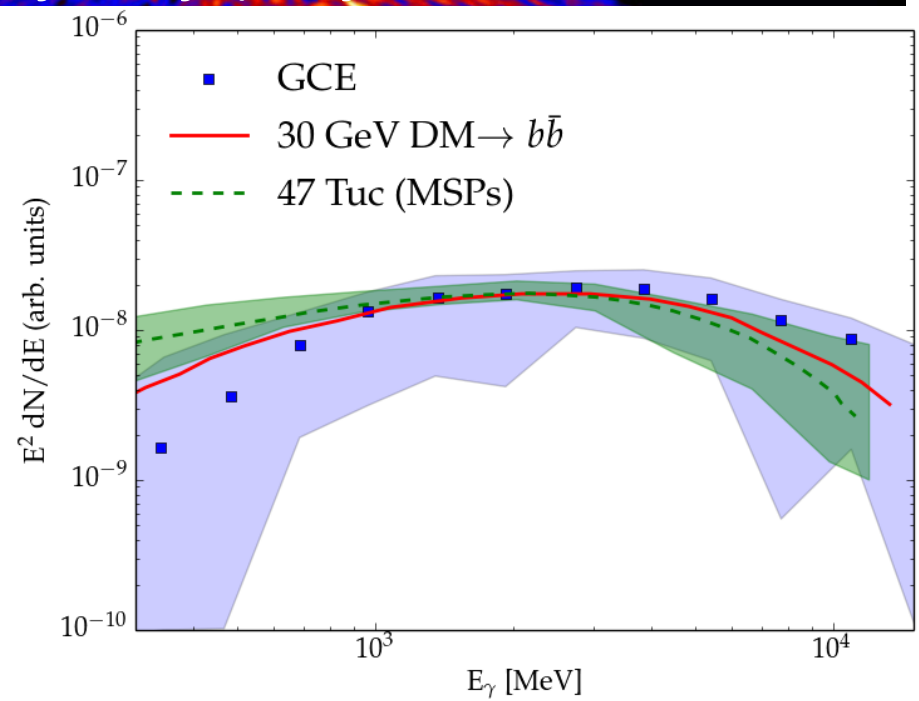
γ-rays @ Galactic Center



γ-rays @ Galactic Center

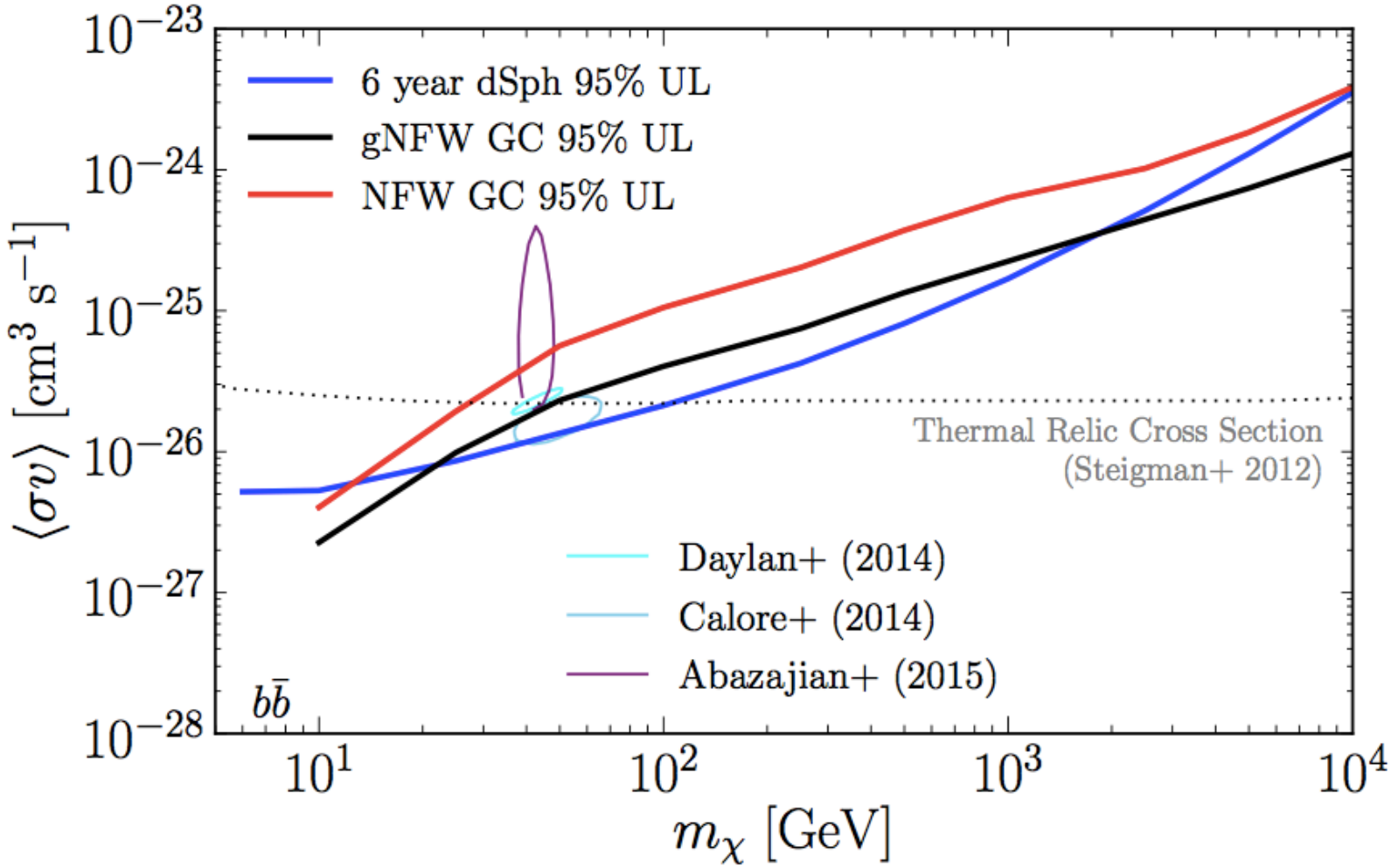
Anomalies in Milky Way γ-ray emission…



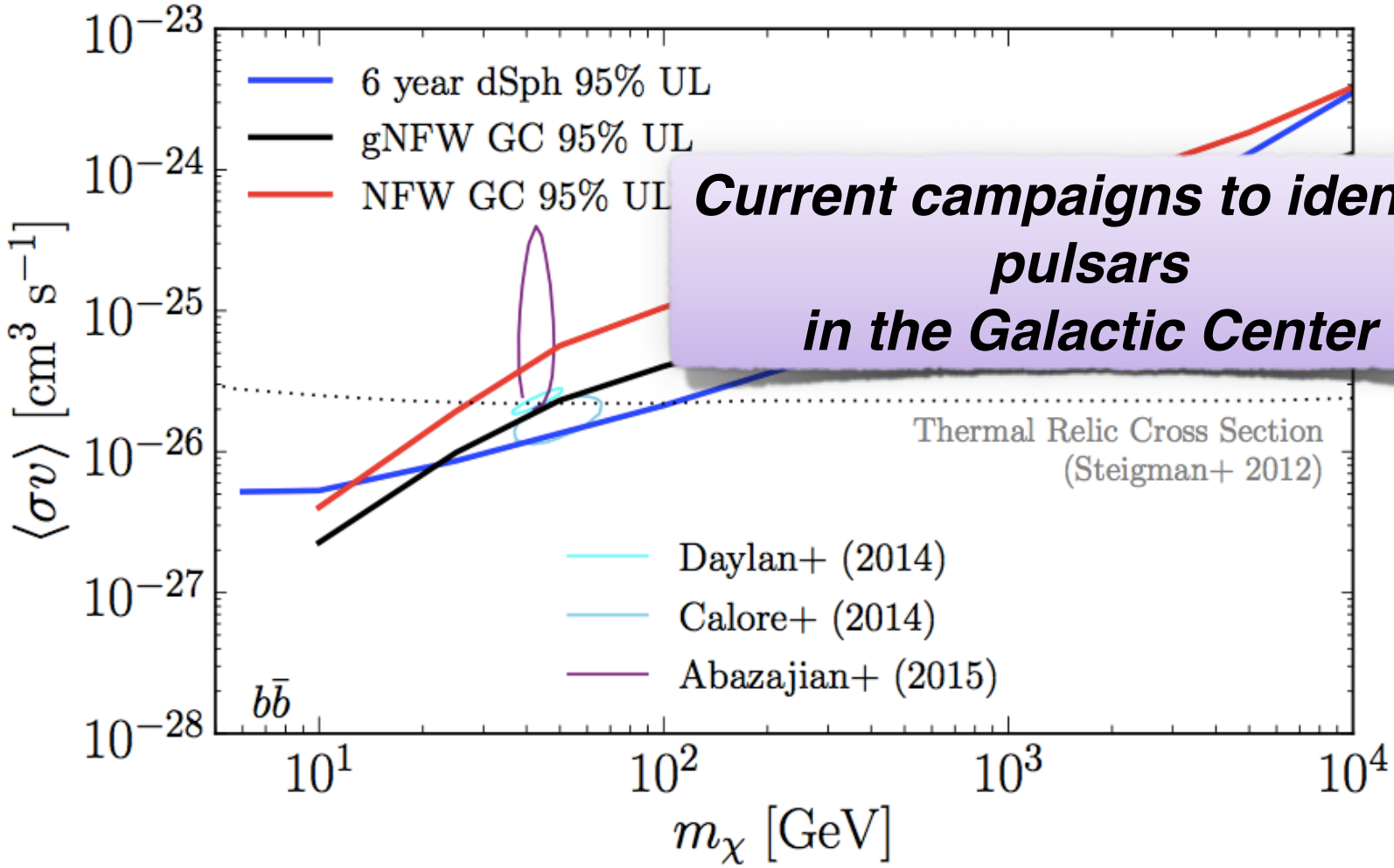


Ackerman et al., Astrophys. J. 840, 43 (2017)

γ-rays @ Galactic Center

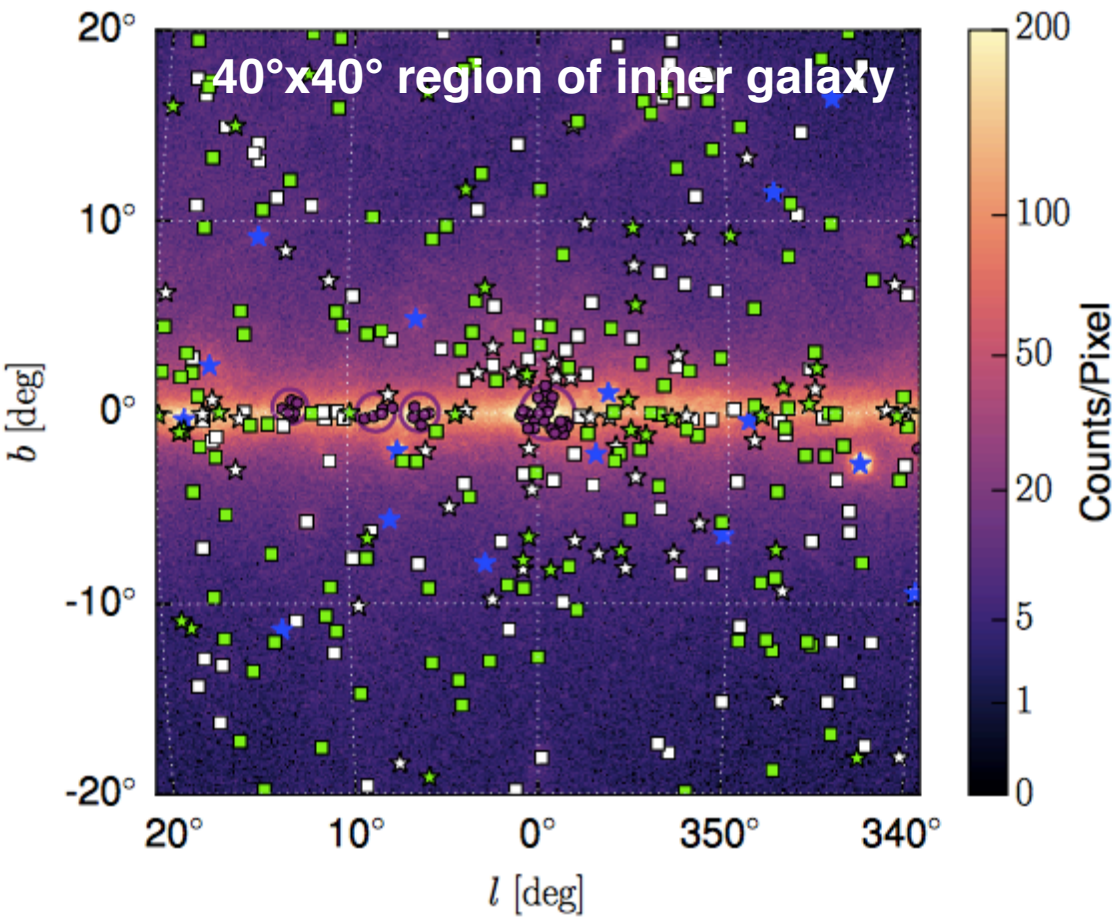


γ-rays @ Galactic Center



Current campaigns to identify pulsars in the Galactic Center

γ-rays @ Galactic Center



469 unique sources
(290 both IEM models) ⇨
select pulsar candidates

Recover >90% 3FGL sources (green)
PSRs identified in 3FGL (blue)

Recover >80% 1FIG sources

Ajello et al., Submitted ApJ, arXiv: 1705.00009

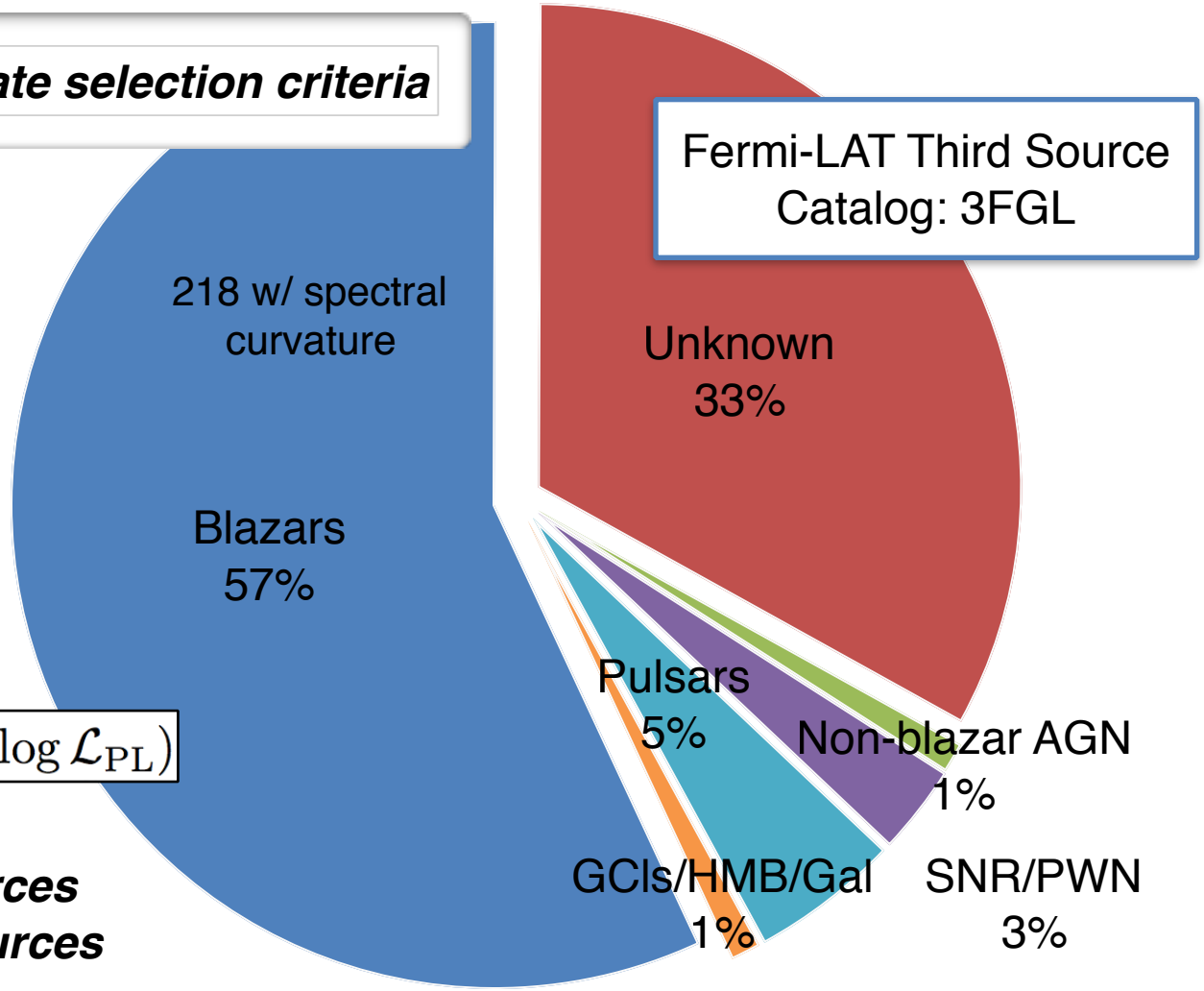
γ-rays @ Galactic Center

Cataloged PSRs to create selection criteria

Spectral curvature is a powerful tool to distinguish pulsars/blazars

$$TS^{\mathrm{PLE}}_{\mathrm{curv}} = 2 \cdot (\log \mathcal{L}_{\mathrm{PLE}} - \log \mathcal{L}_{\mathrm{PL}})$$

TS^{PLE} blazers ~153 sources
TS^{PLE} PSR ~172/169 sources



γ-rays @ Galactic Center

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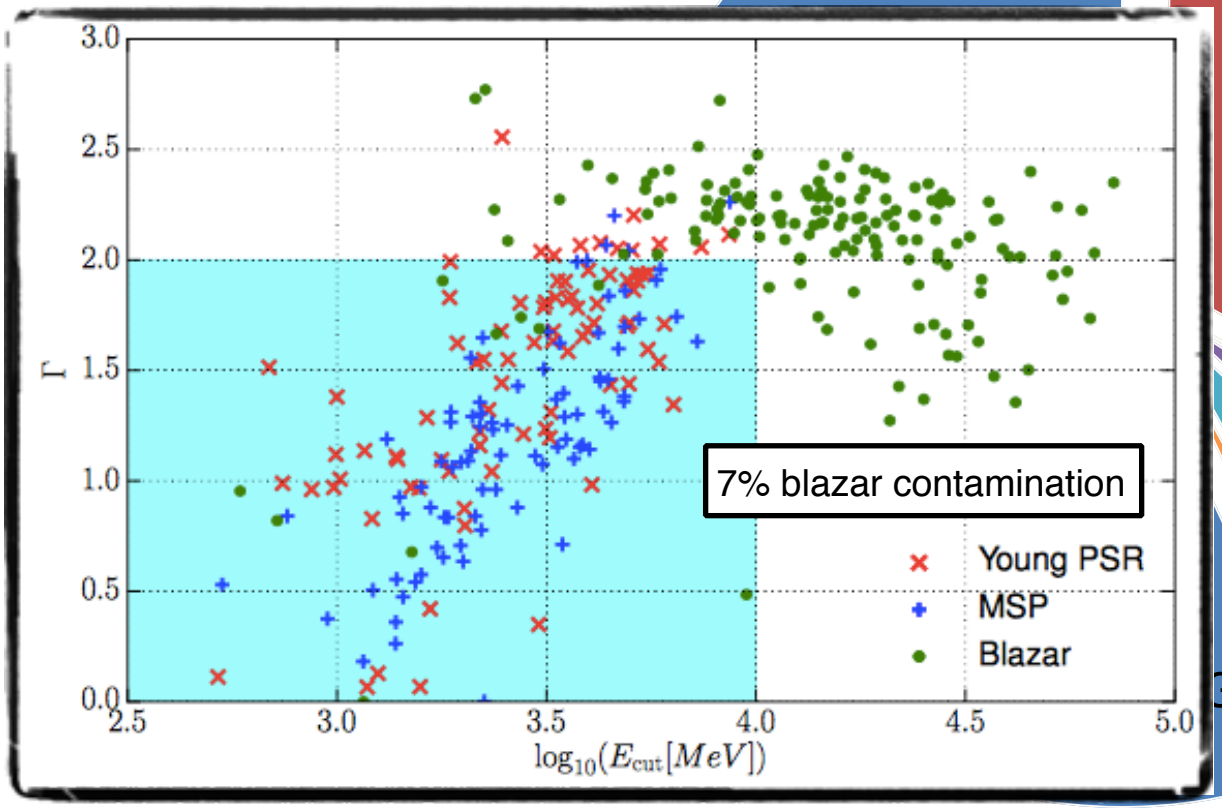

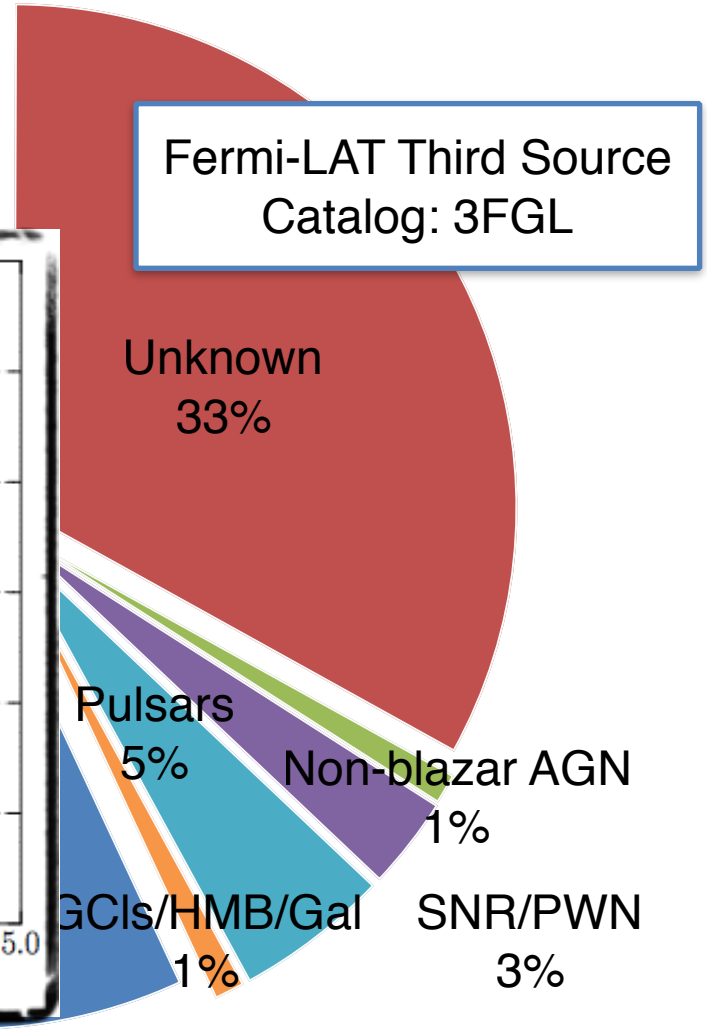

γ-rays @ Galactic Center

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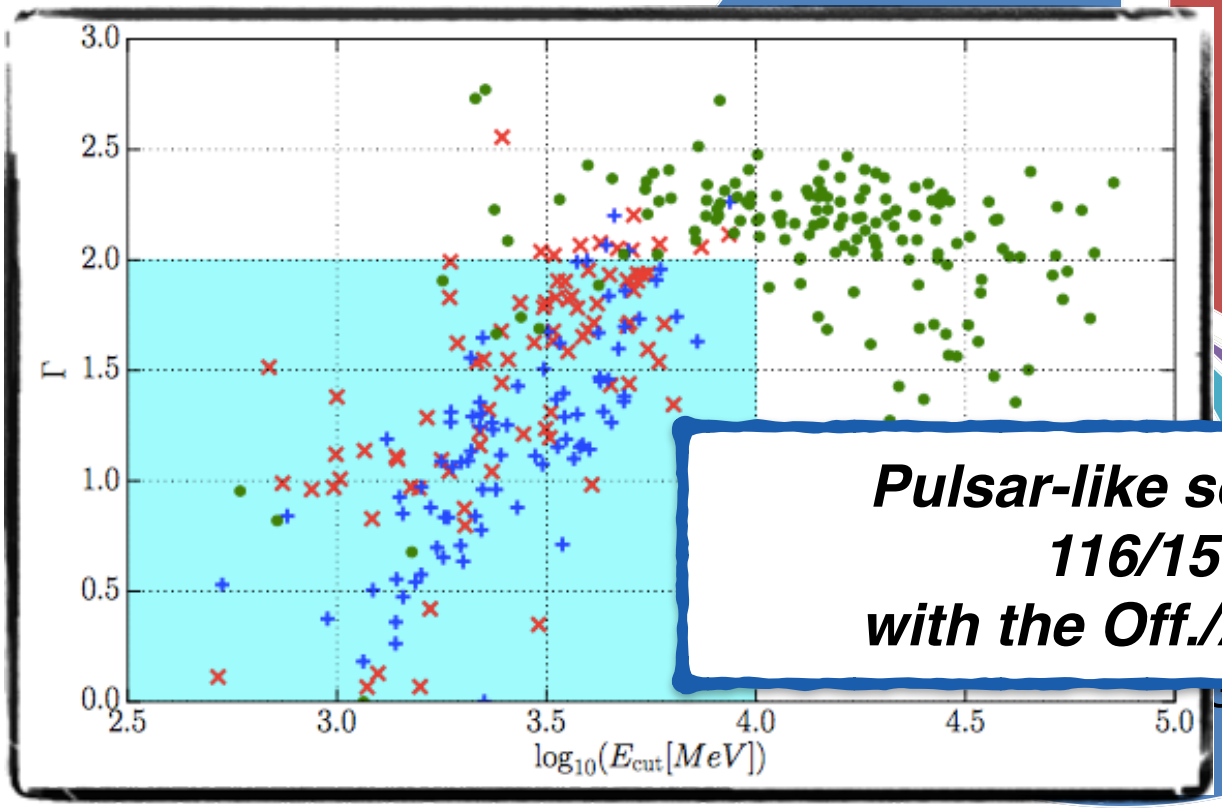

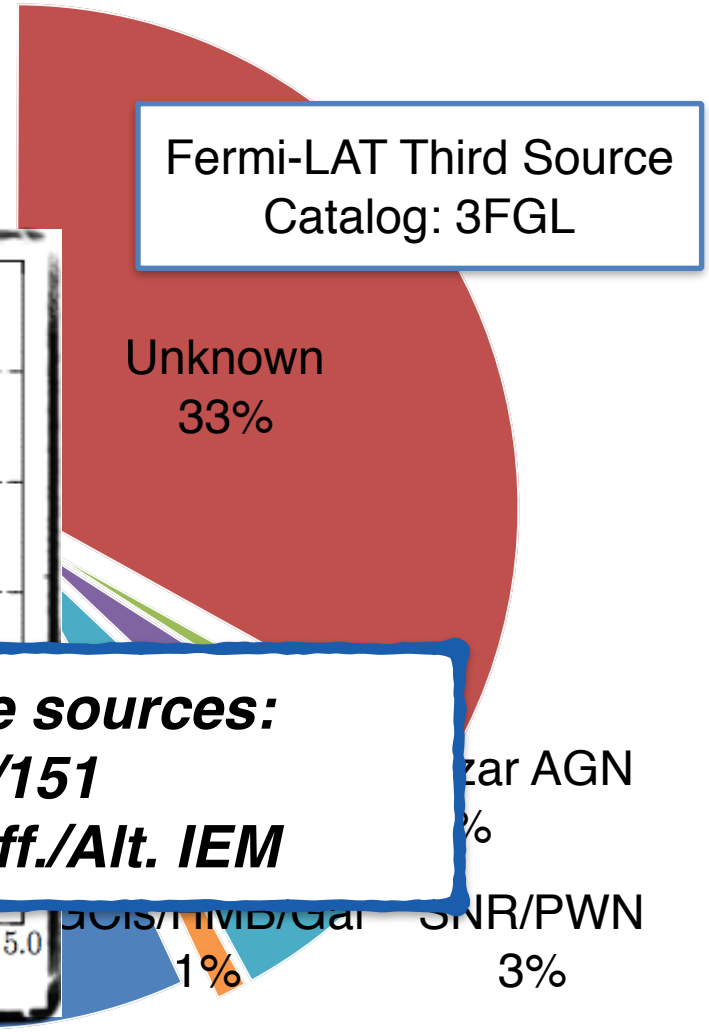

Pulsar-like sources:
116/151
with the Off./Alt. IEM

γ-rays @ Galactic Center

Simulate (bulge/disk) Pulsars, Blazars and DM

- Luminosity functions and representative distances
- Input best fit: N_{bulge}=1300, N_{disk}=2800, $N_{blazars}$=900
- Detect: N_{bulge}=77, N_{disk}=128, $N_{blazars}$=92
- Selection: N_{bulge}=56, N_{disk}=82, $N_{blazars}$=1

138 pulsars

Consistent with number found in data

Ajello et al., Submitted ApJ, arXiv: 1705.00009

γ-rays @ Galactic Center

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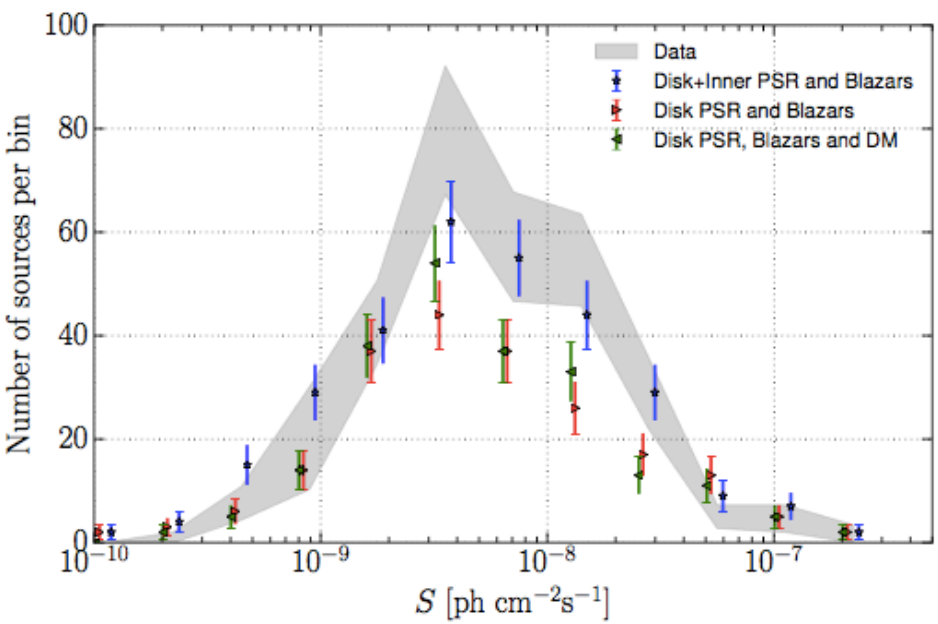
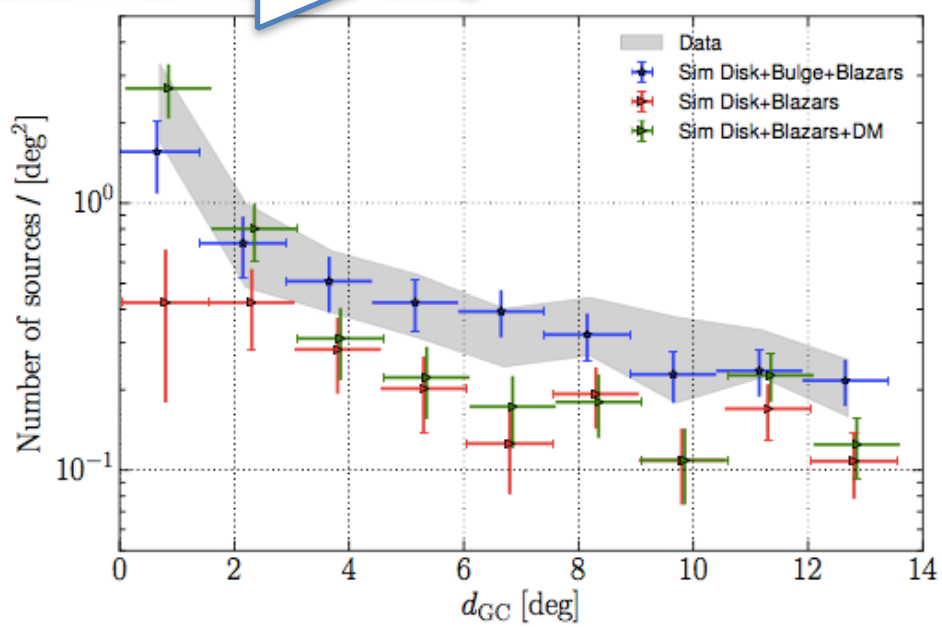
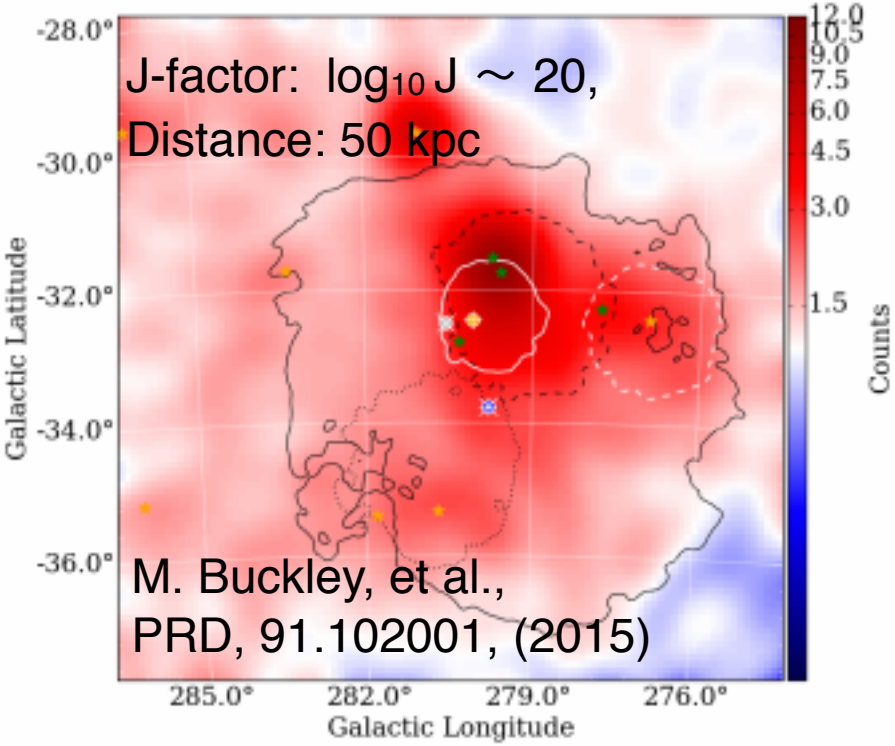




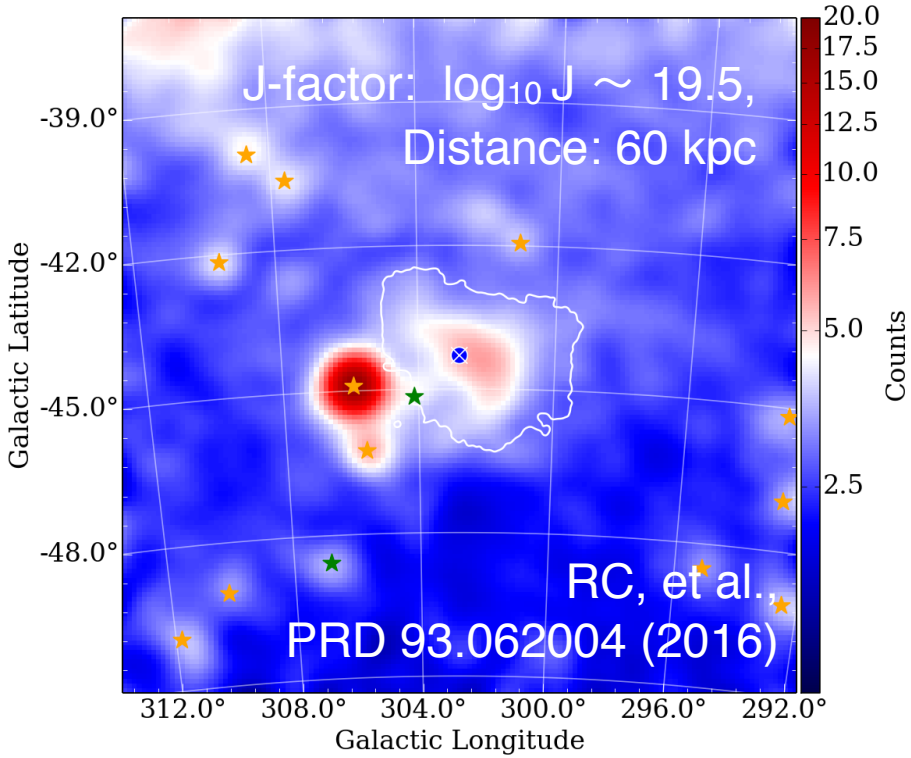
Ajello et al., Submitted ApJ, arXiv: 1705.00009

Magellanic Clouds

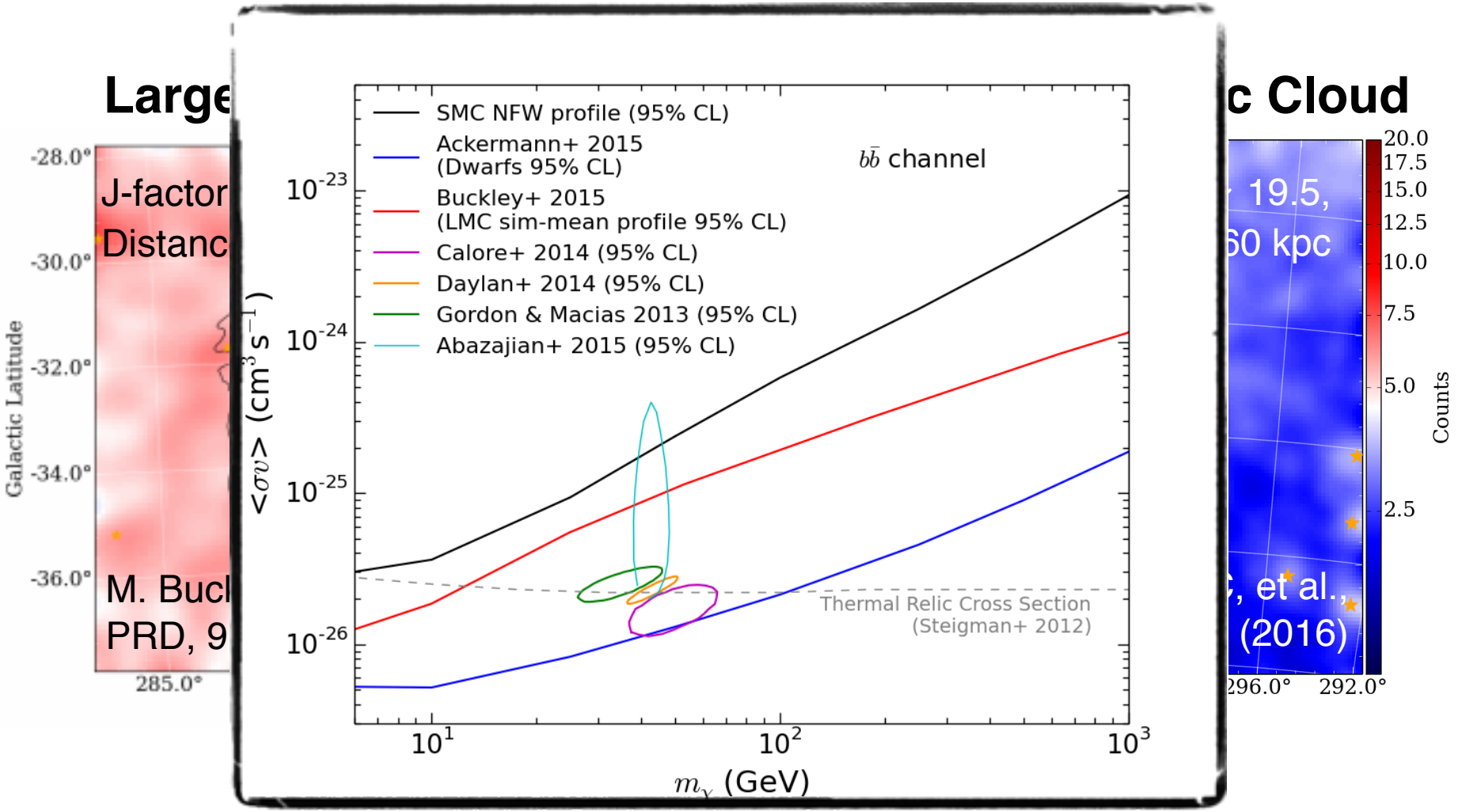
Large Magellanic Cloud



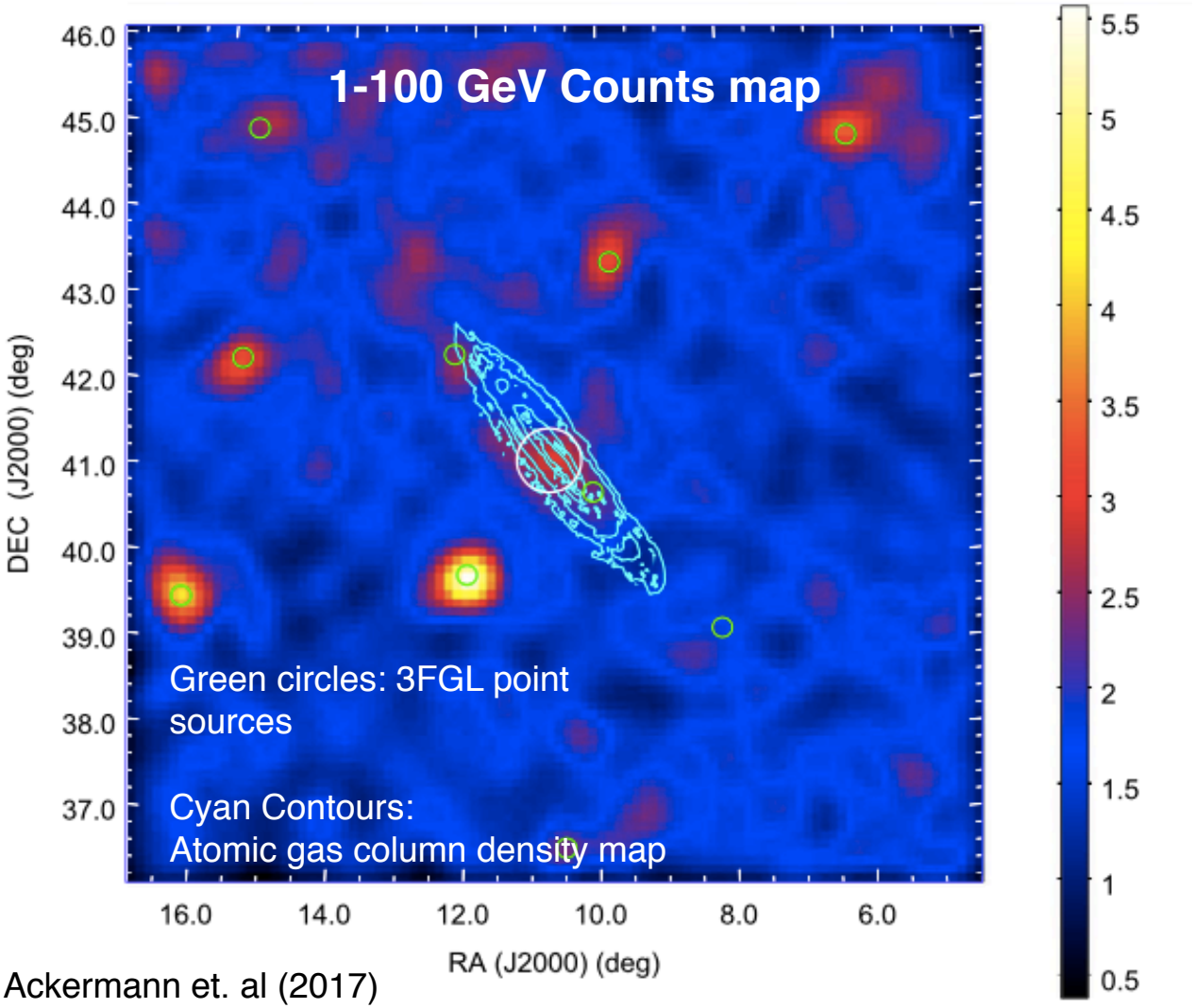
Small Magellanic Cloud



Magellanic Clouds



γ-ray emission in the Andromeda Galaxy

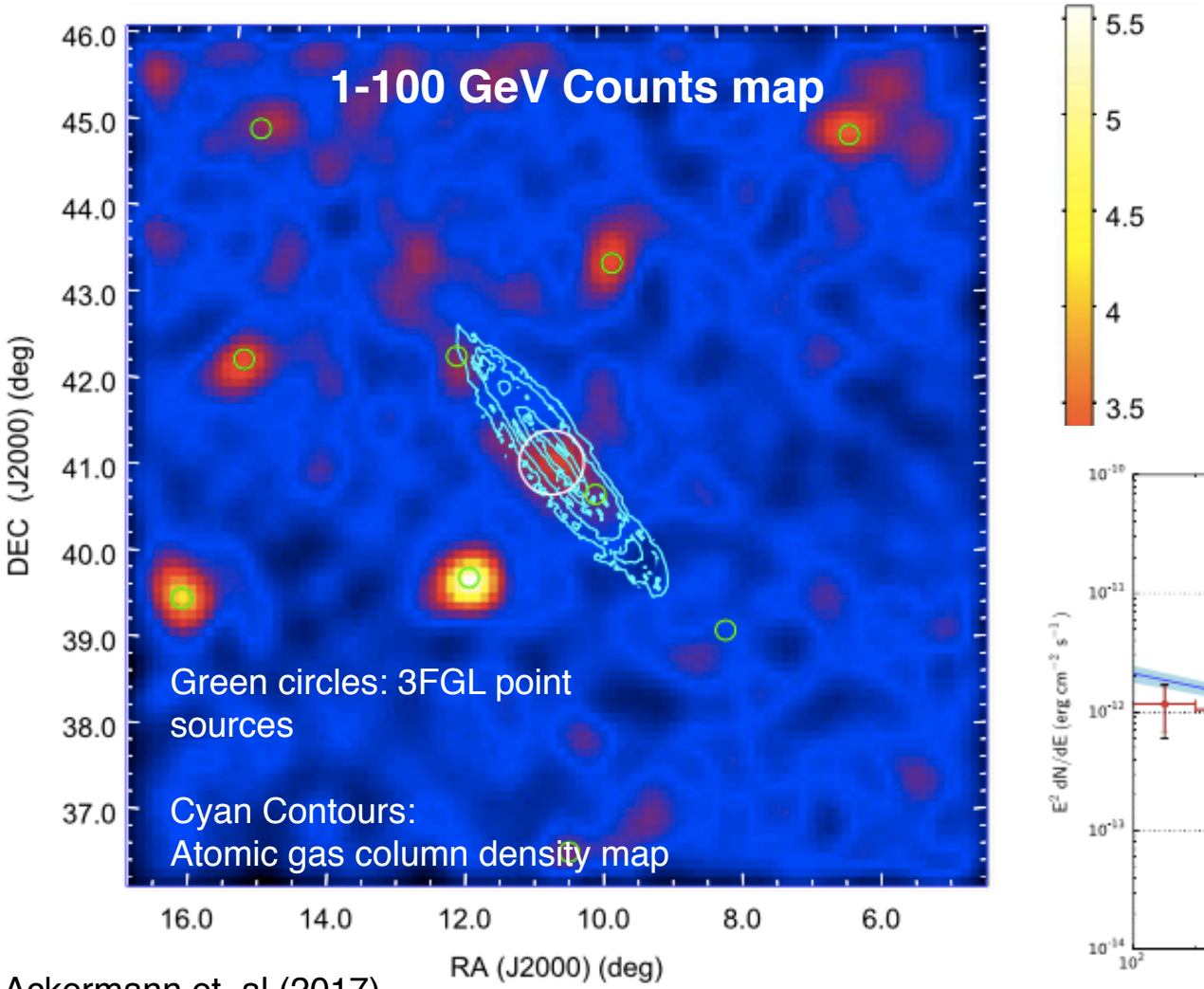


Ackermann et. al (2017)

What did we find…

- Emission comes primarily from inner 5kpc
- Not correlated with interstellar gas and star formation regions
- Galactic disk not detected

γ-ray emission in the Andromeda Galaxy



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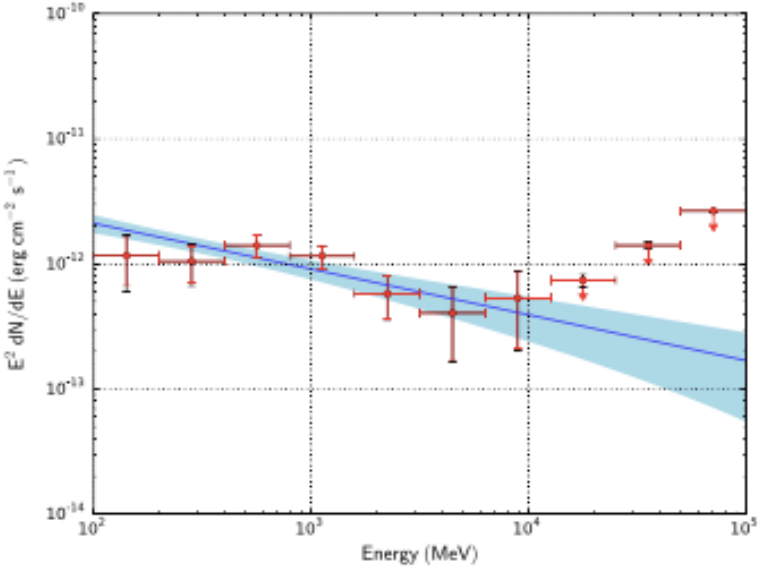
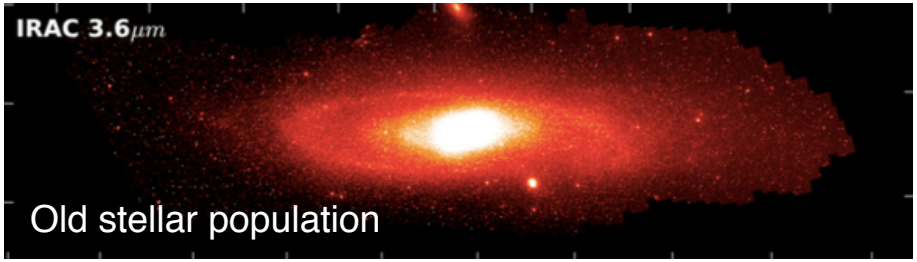
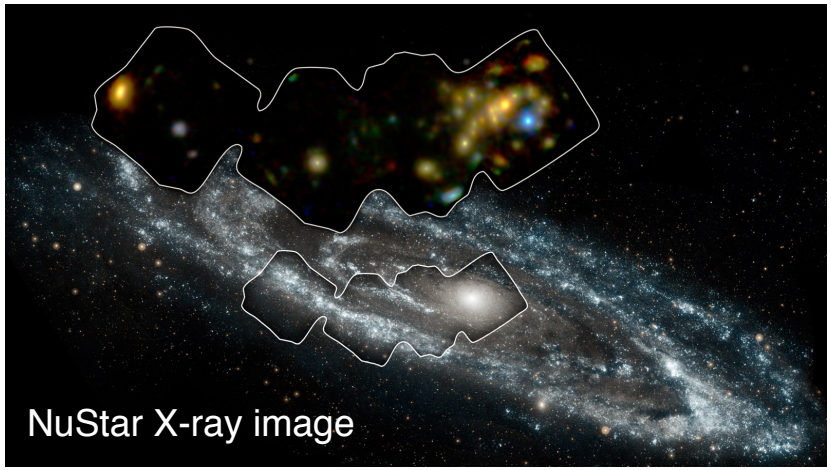


Interpretation: Unresolved Source Pop.

Short-lived massive stars: supernova remnants or normal pulsars…correlated with star formation but γ-rays are *not*

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





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

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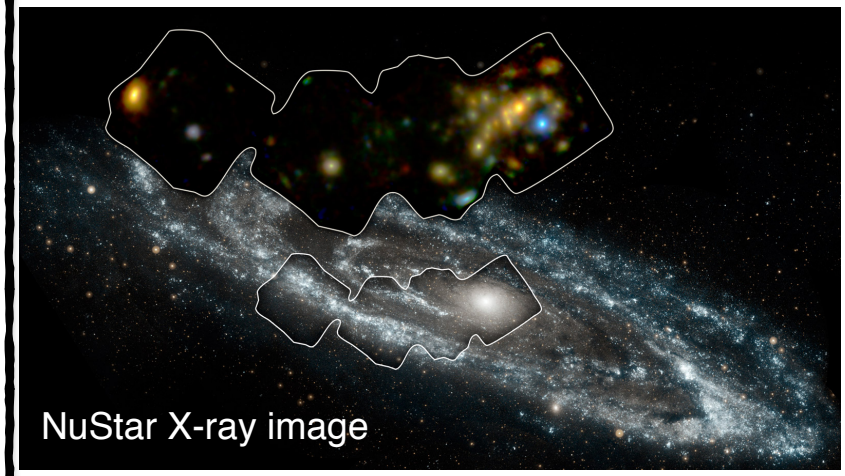
The details:
Gamma-ray signal 4-5x more luminous than GCE
10x lower star formation rate and 5-6x more massive bulge than MW
(follow up in progress…)
Best Astrophysical Interpretation



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

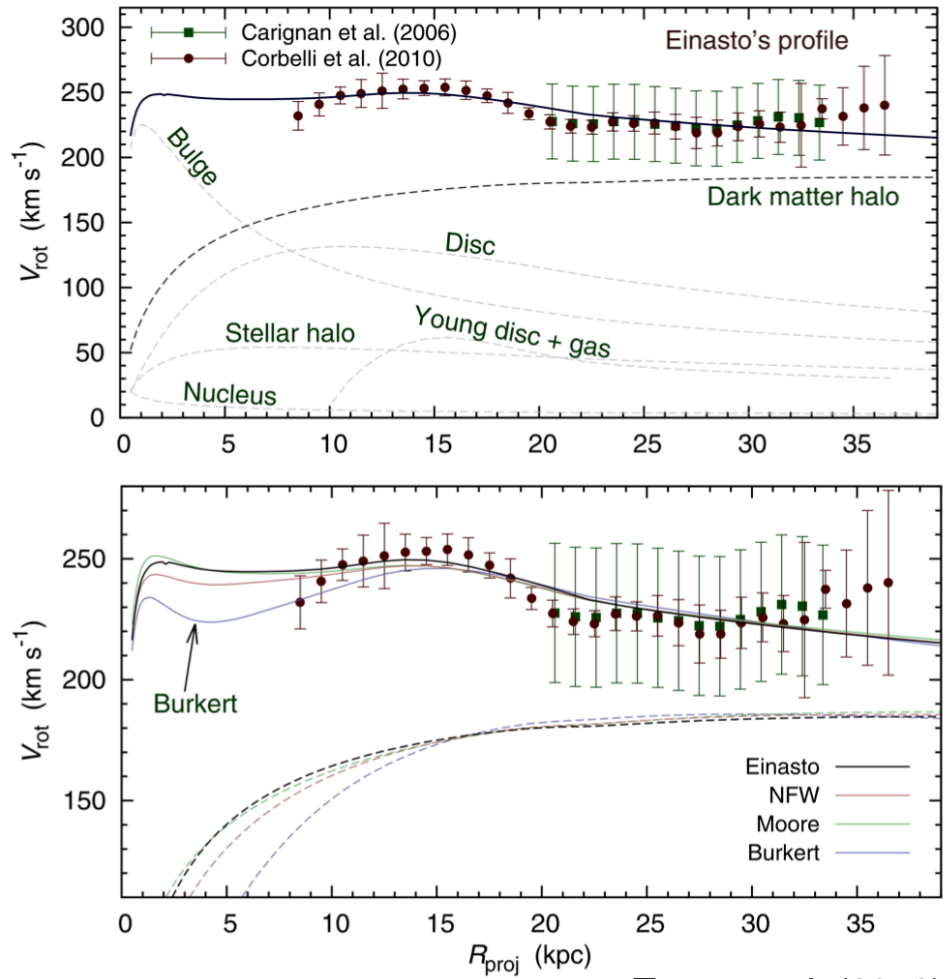
Interpretation: Dark Matter

Consistent with DM from GCE?

J-factors:
Milky Way: 2×10^{22} GeV^2/cm^5
M31: 8×10^{18} GeV^2/cm^5 (±20%)

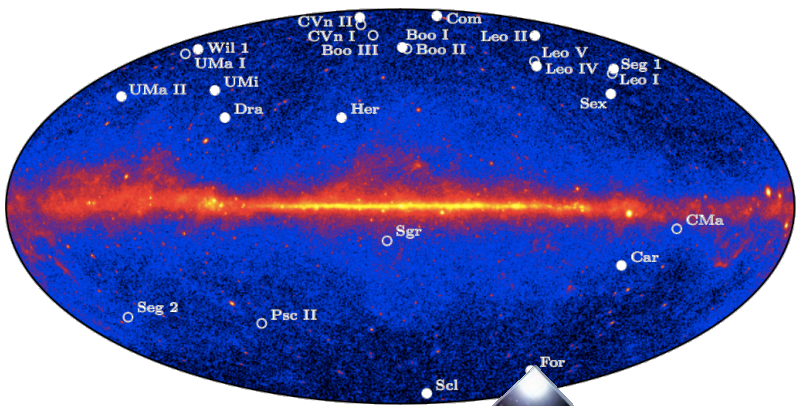
- Observed flux from M31 5x higher than expected value

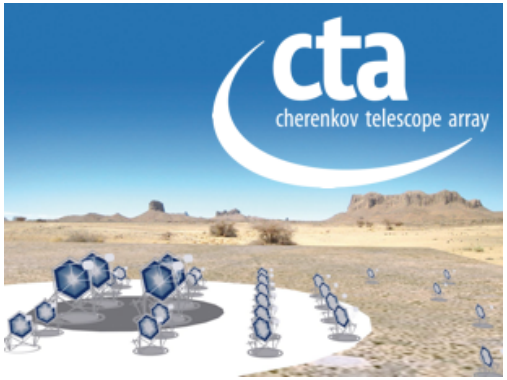
- However, uncertainties on J-factor of M31 and on GCE flux (follow-up in progress…)



Tamm et al. (2012)

The Next Generation…



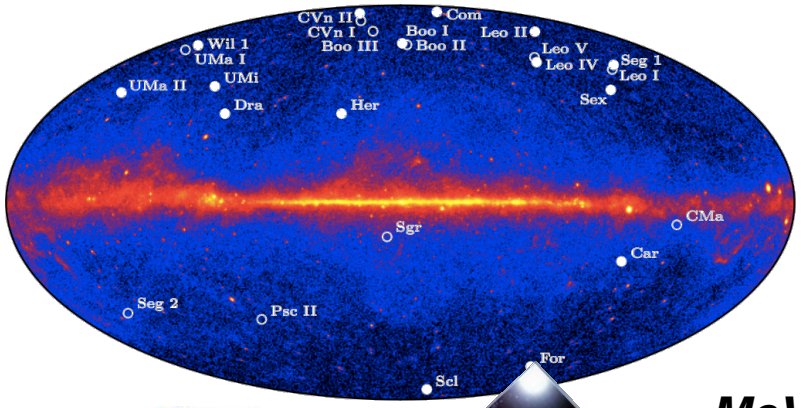


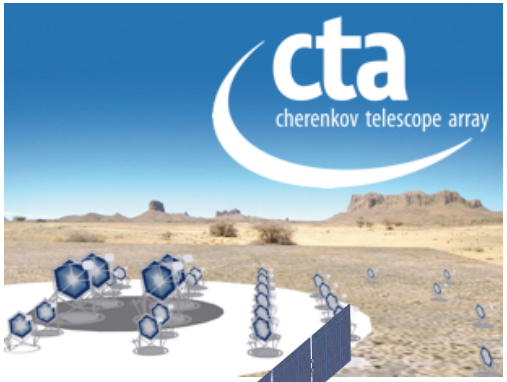
DARK ENERGY SURVEY

LSST

Fermi Today | DES 2018 | LSST 2020 | CTA 2023 | 2025

The Next Generation…





MeV mission

33% of Fermi Sources are unassociated

New MeV Missions are Essential and Urgent

Fermi	DES		LSST	CTA	MeV Mission
Today		2018	2020	2023	2025

The Next Generation…

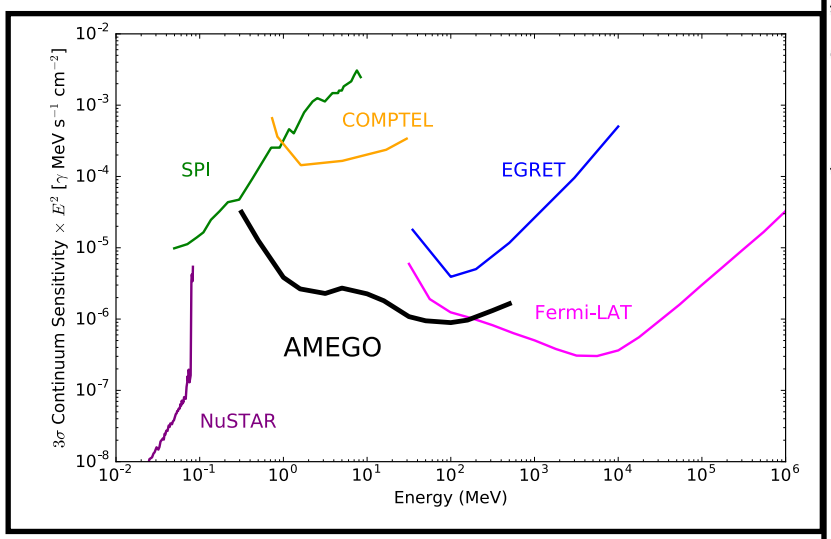
Proposed new gamma-ray missions…

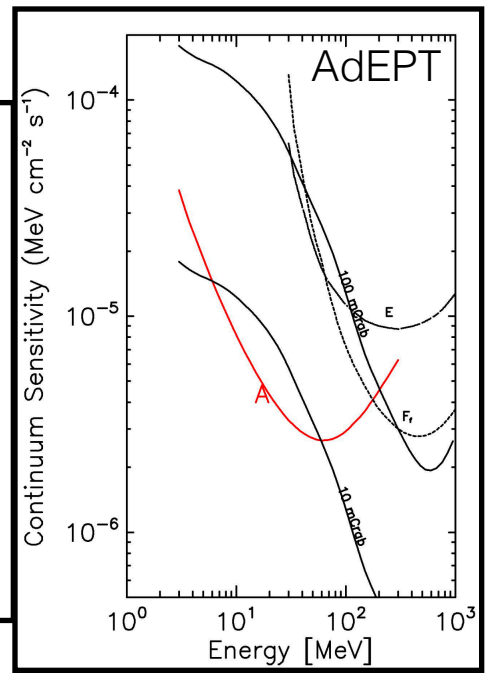
All-sky Medium Energy Gamma-ray Observatory: ***AMEGO***

enhanced ASTROGAM: ***eASTROGAM***

Advanced Energetic Pair Telescope: ***AdEPT***

- incomplete list -





Intense Star formation at GC necessitates understanding of the MeV rage

arXiv:1206.0772

Astropart.Phys. 59 (2014) 18-28

The Next Generation…

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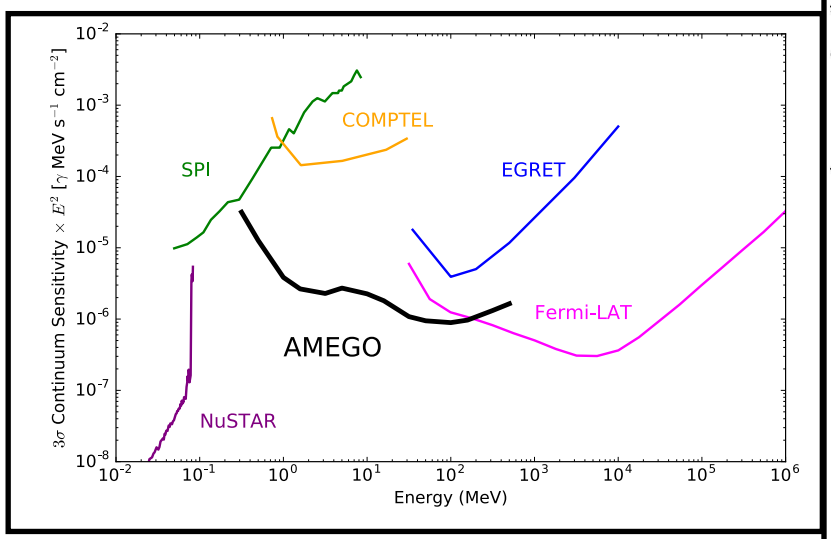
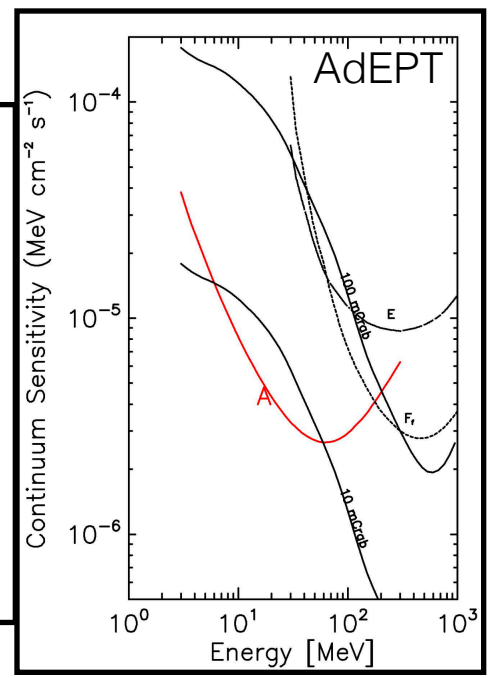




View of the Galactic Plane

ComPair arXiv:1508.07349

Astropart.Phys. 59 (2014) 18-28

The Next Generation…

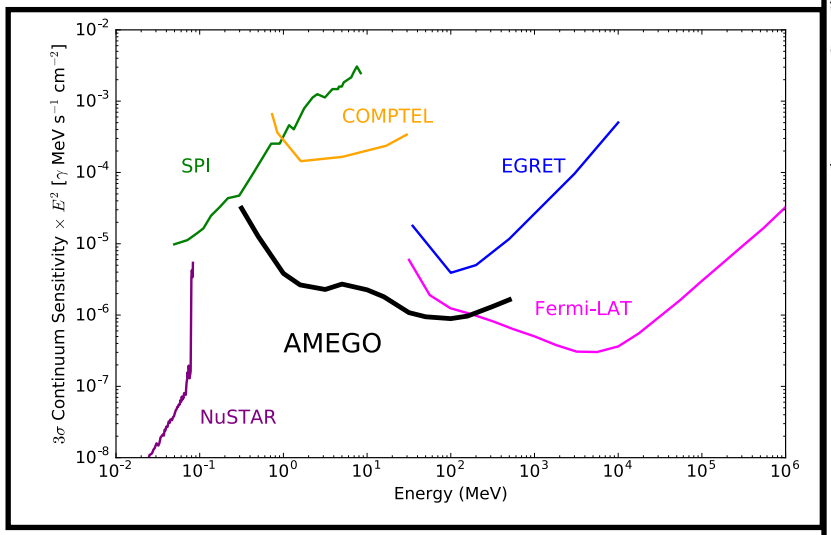
Proposed new gamma-ray missions…

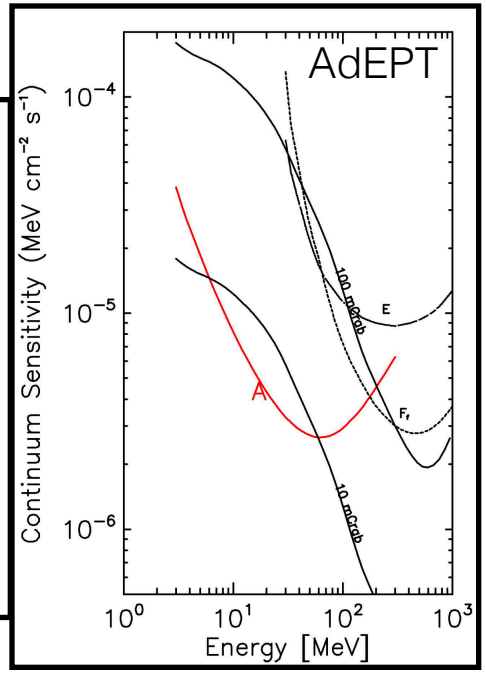
All-sky Medium Energy Gamma-ray Observatory: ***AMEGO***

enhanced ASTROGAM: ***eASTROGAM***

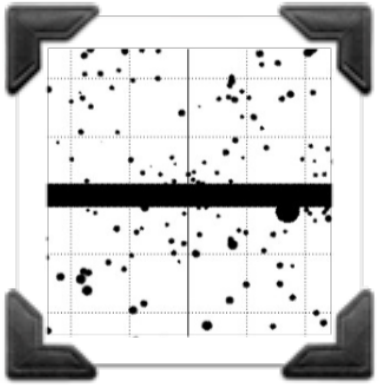
Advanced Energetic Pair Telescope: ***AdEPT***

- incomplete list -





View of the Galactic Plane

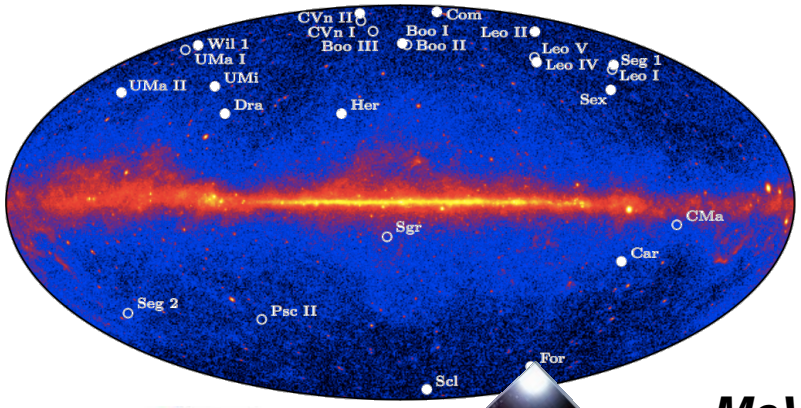


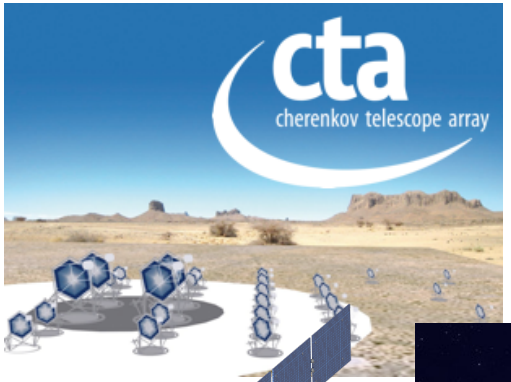
eAstrogam

ComPair arXiv:1508.07349

Astropart.Phys. 59 (2014) 18-28

The Next Generation…





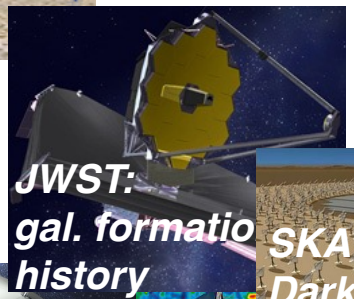
Astrophysics of Dark Matter (Special Dark)

Not to mention…

MeV mission

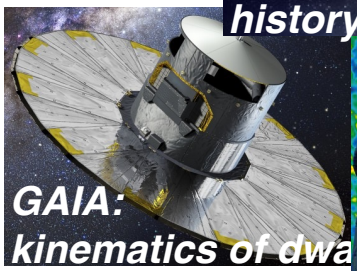
DARK ENERGY SURVEY

33% of Fermi Sources are unassociated



JWST: gal. formatio history

SKA: Dark sub-halos and HI



GAIA: kinematics of dwa

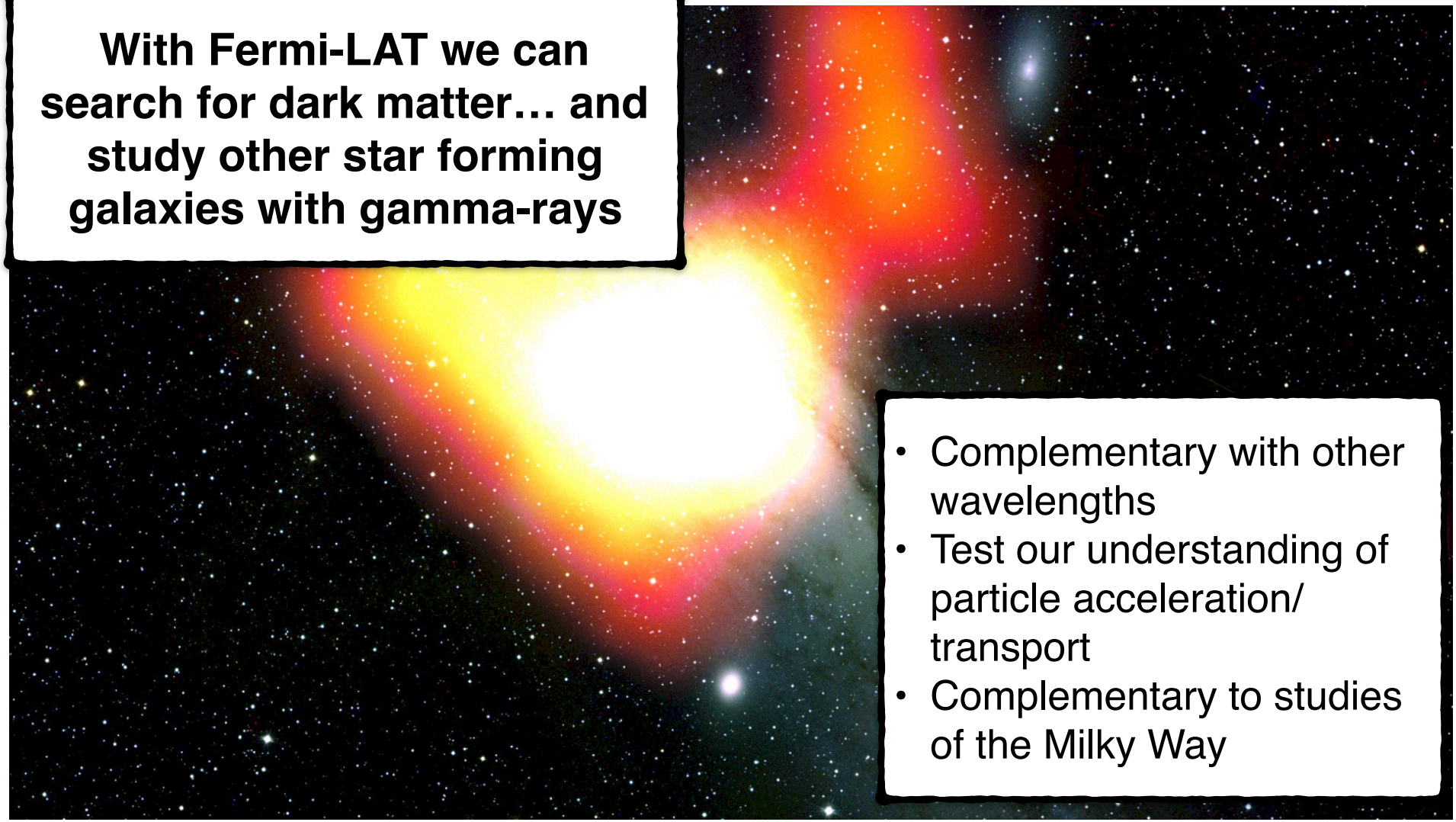
DESI: more dwarfs

Fermi DES LSST CTA AMEGO

Today 2018 2020 2023 2025

Summary

With Fermi-LAT we can search for dark matter… and study other star forming galaxies with gamma-rays



- Complementary with other wavelengths
- Test our understanding of particle acceleration/ transport
- Complementary to studies of the Milky Way