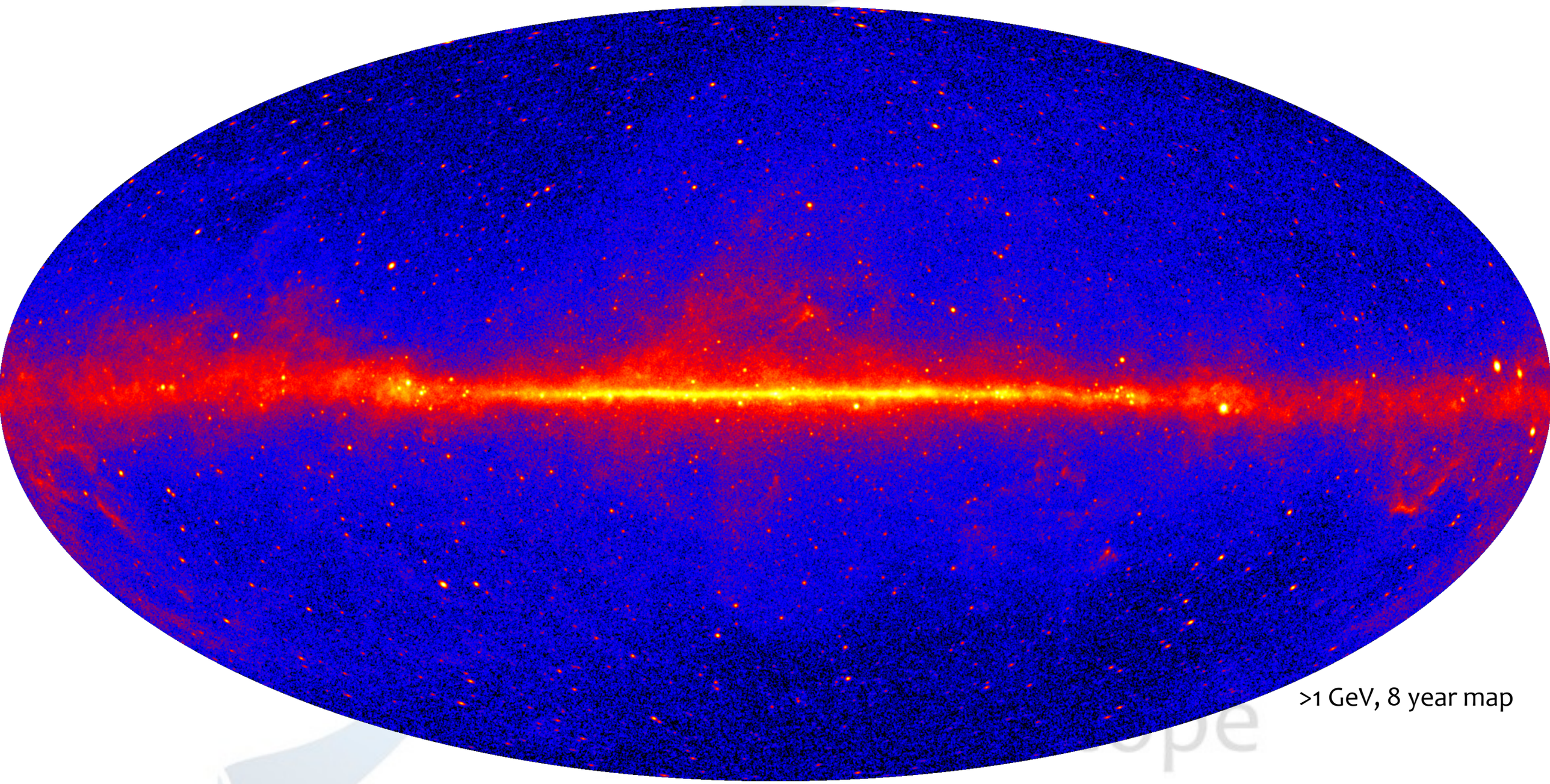
Fermi
Gamma-ray
Space Telescope

Latest Dark Matter Results with the *Fermi*-LAT

R. Caputo, UMD/GSFC
on behalf of the
Fermi-LAT Collaboration

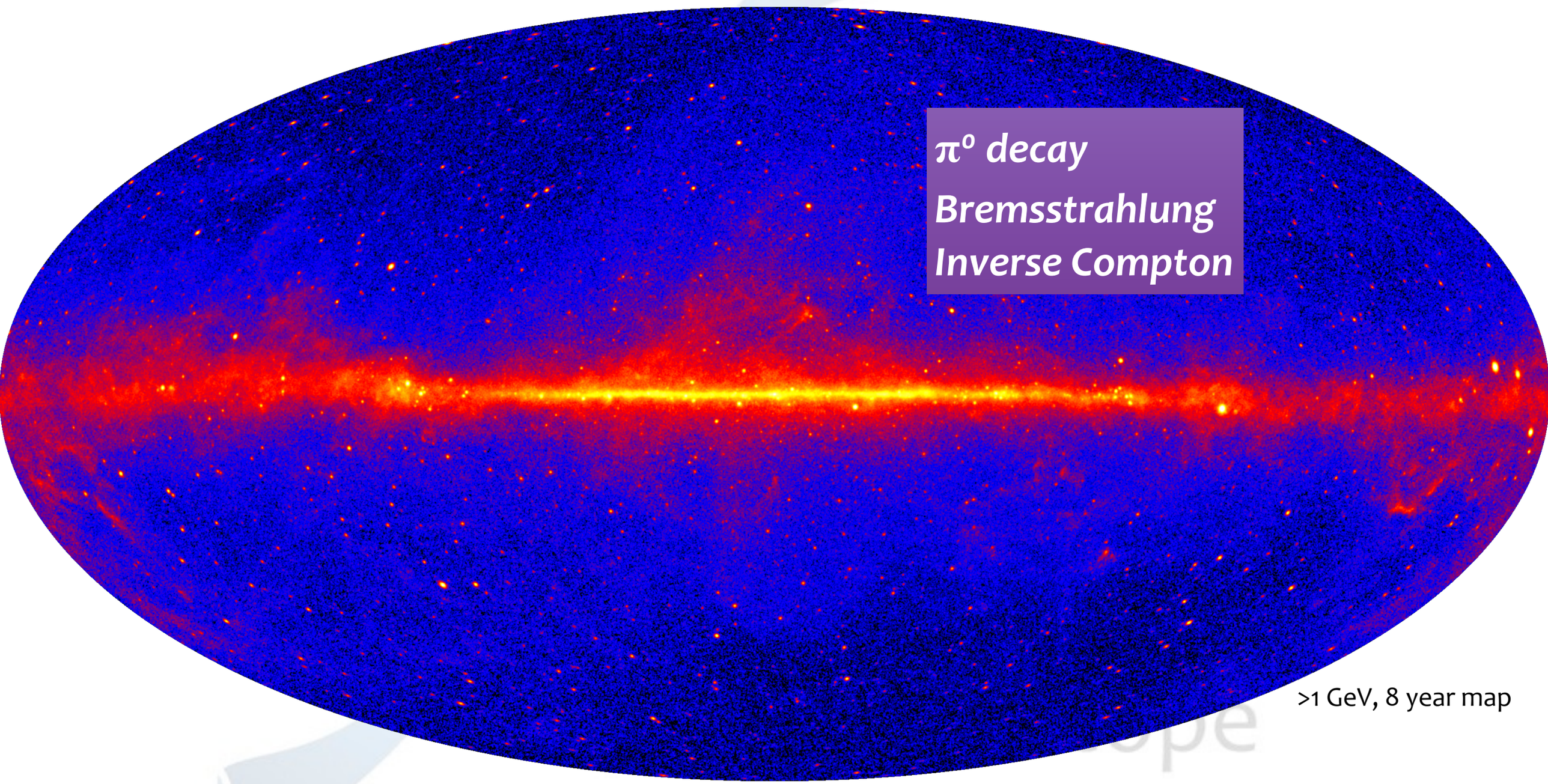
IPA 2017
Madison, WI

Fermi-LAT γ-ray sky



>1 GeV, 8 year map

Fermi-LAT γ-ray sky



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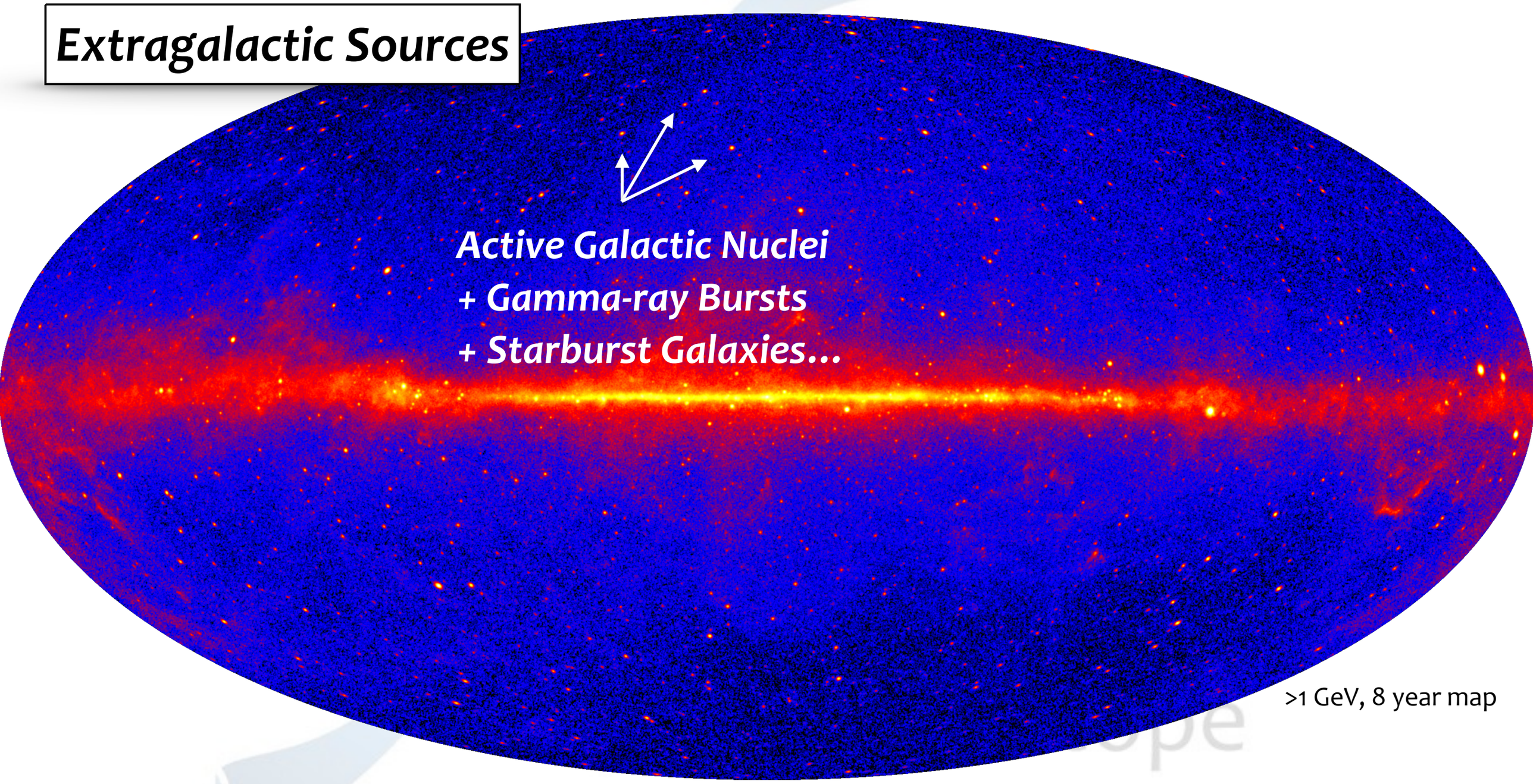
Fermi-LAT γ-ray sky

Extragalactic Sources



>1 GeV, 8 year map

Fermi-LAT γ-ray sky

Extragalactic Sources

Active Galactic Nuclei
+ Gamma-ray Bursts
+ Starburst Galaxies…

+Supernova Remnants
+ Globular Clusters
+ Pulsar Wind Nebulae + …

Pulsars

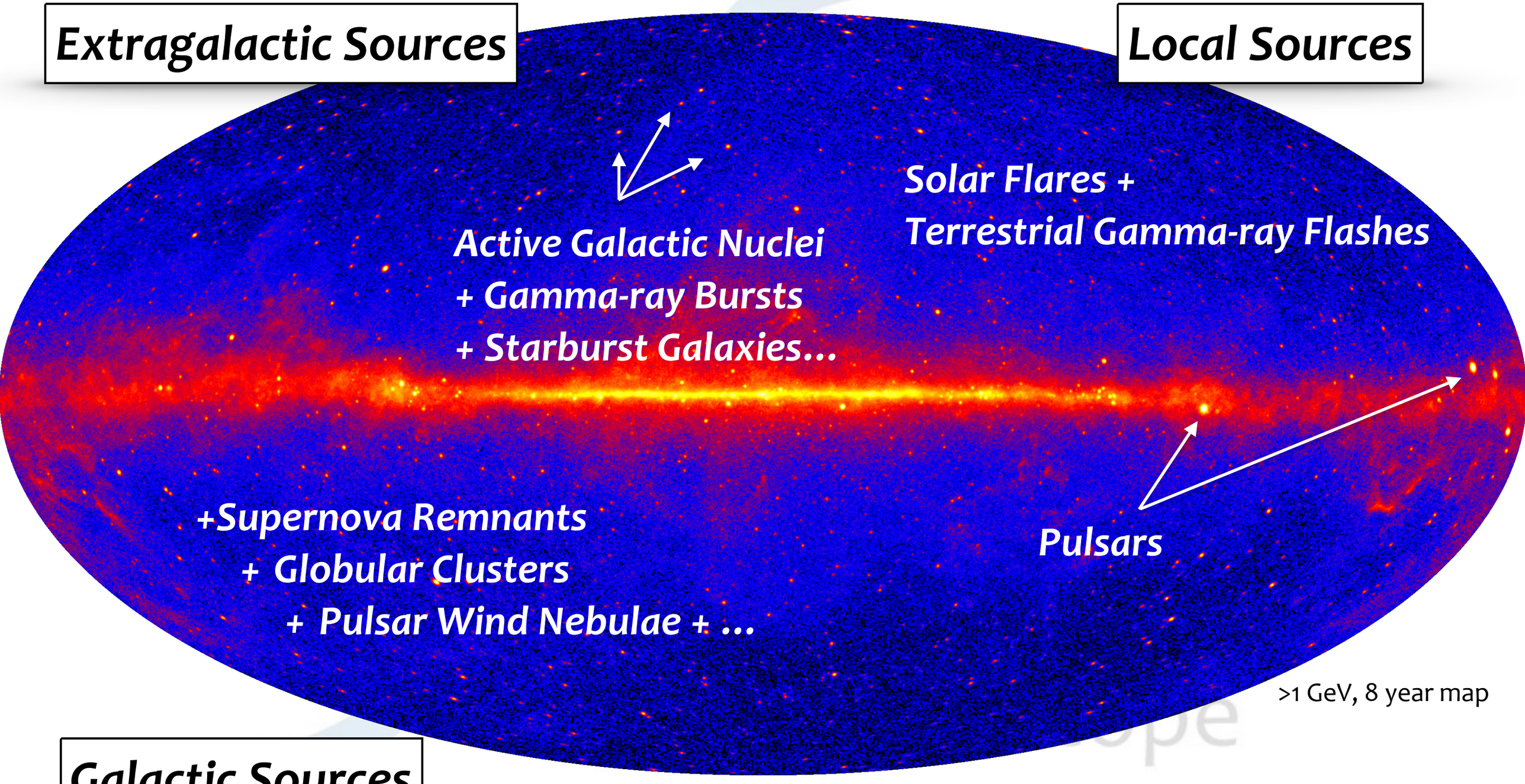
>1 GeV, 8 year map

Galactic Sources

Fermi-LAT γ-ray sky

Extragalactic Sources

Local Sources



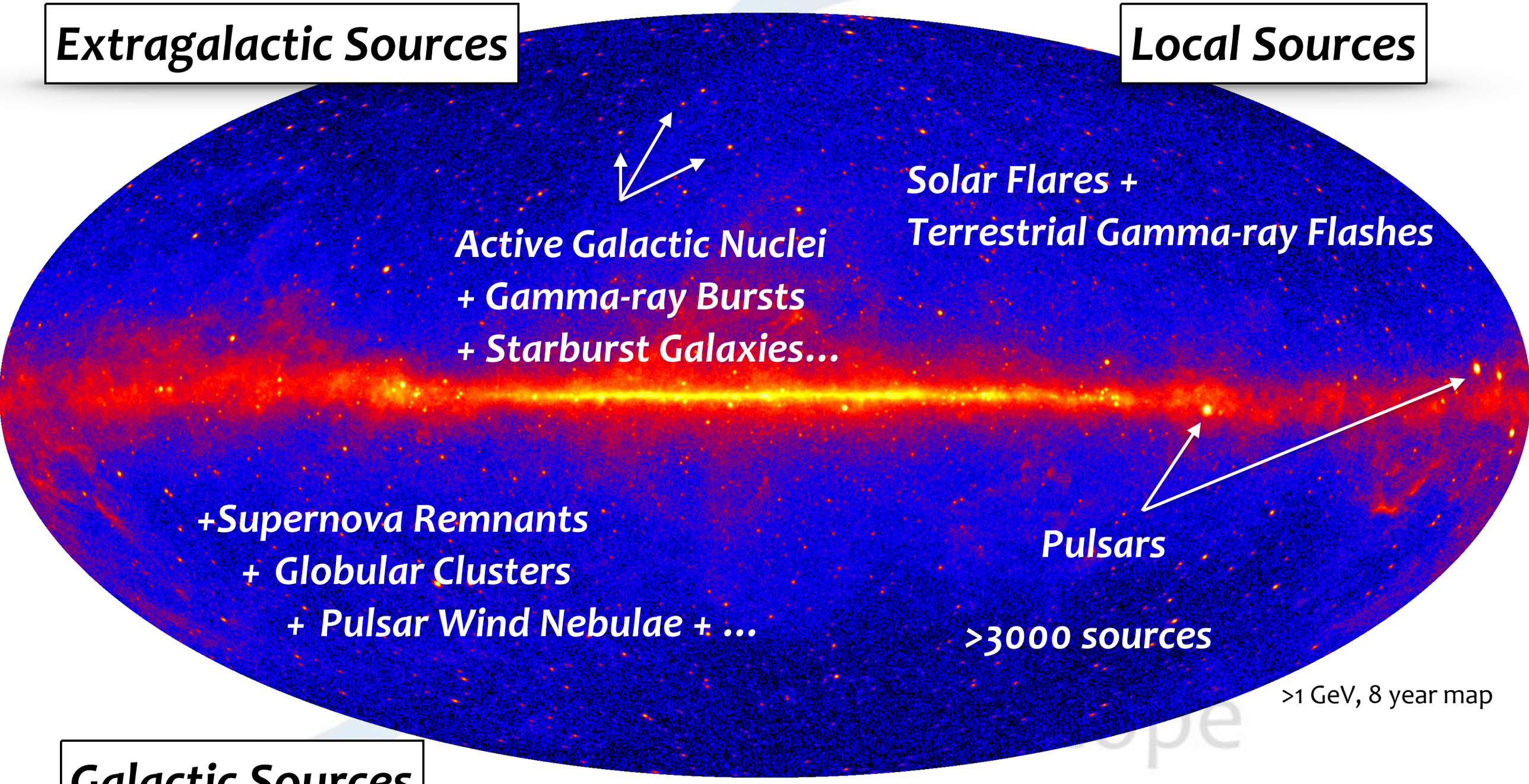
>1 GeV, 8 year map

Galactic Sources

Fermi-LAT γ-ray sky

Extragalactic Sources

Local Sources



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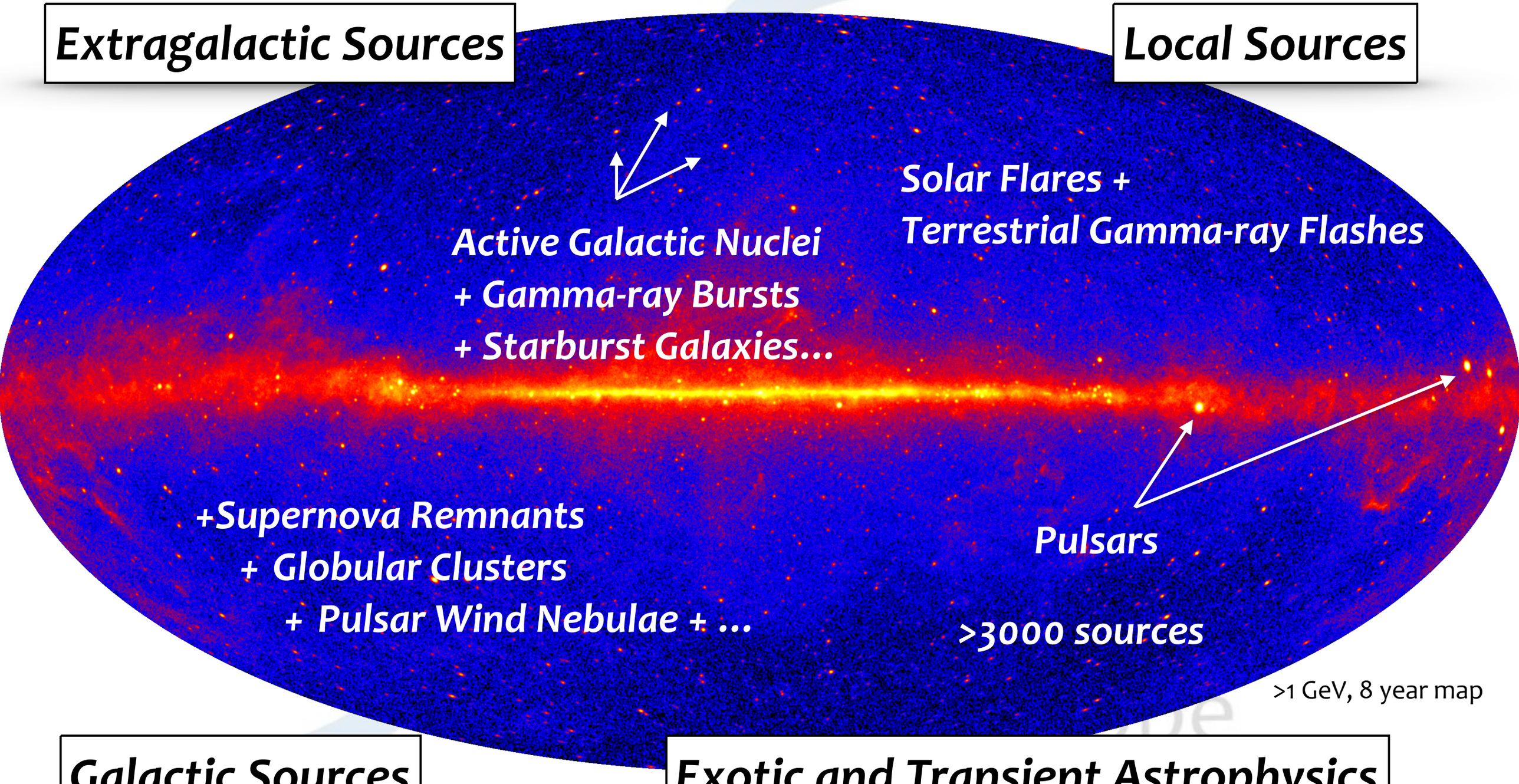
Galactic Sources

Fermi-LAT γ-ray sky

Extragalactic Sources

Local Sources



>1 GeV, 8 year map

Galactic Sources

Exotic and Transient Astrophysics

Dark Matter

Indirect detection of Dark Matter

Gamma-ray signatures of Dark Matter

Recent Fermi-LAT Searches for Dark Matter WIMPs and Axions

Dark Matter

Indirect detection of Dark Matter

Gamma-ray signatures of Dark Matter

http://www.symmetrymagazine.org/article/what-could-dark-matter-be

Indirect Searches: WIMPs and gamma rays

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

Indirect Searches: WIMPs and gamma rays

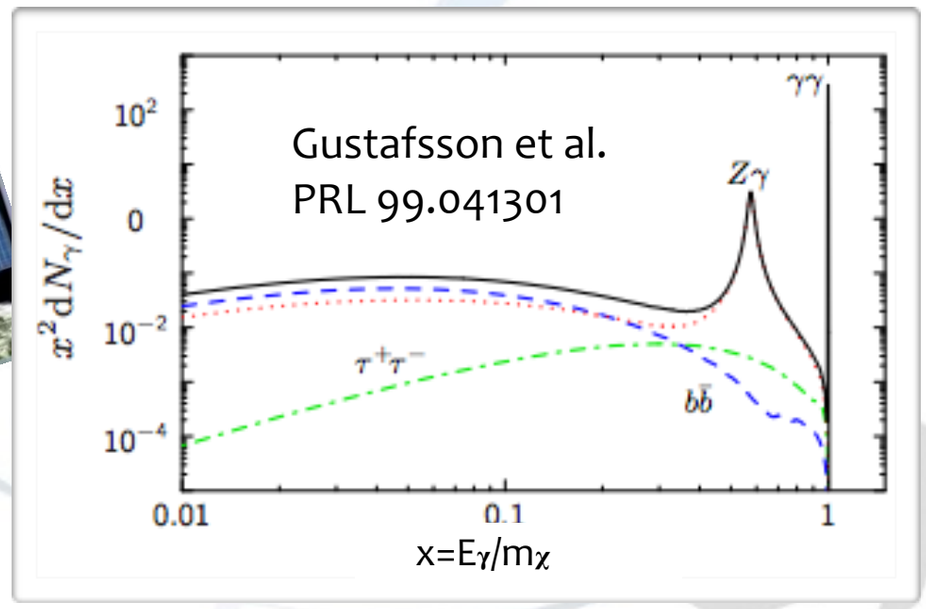
Observed =

$$\Phi_\gamma(E,\psi) =$$

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

Indirect Searches: WIMPs and gamma rays

Observed **=** ***Particle Properties*** **x**



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

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

Indirect Searches: WIMPs and gamma rays

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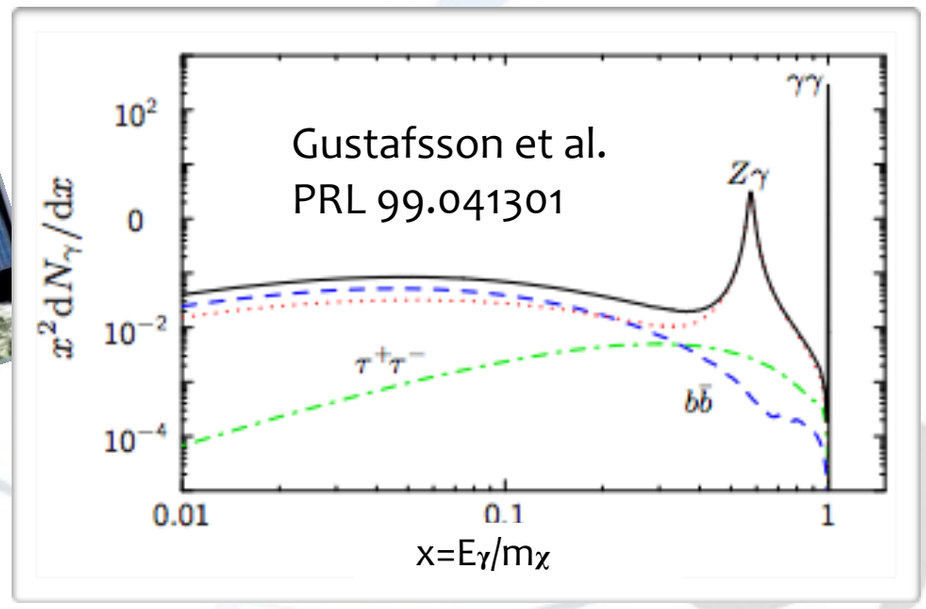

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cross section

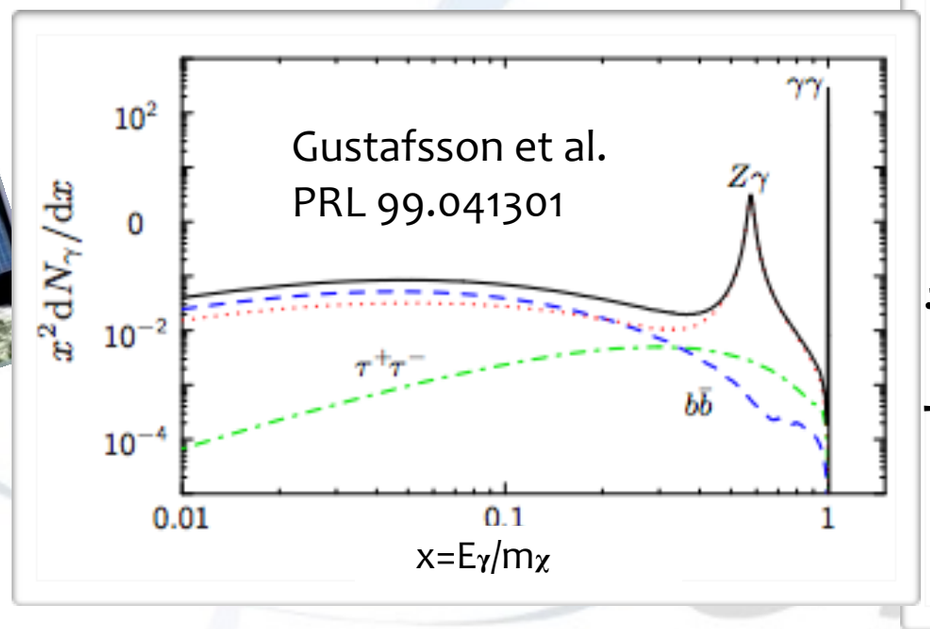
mass

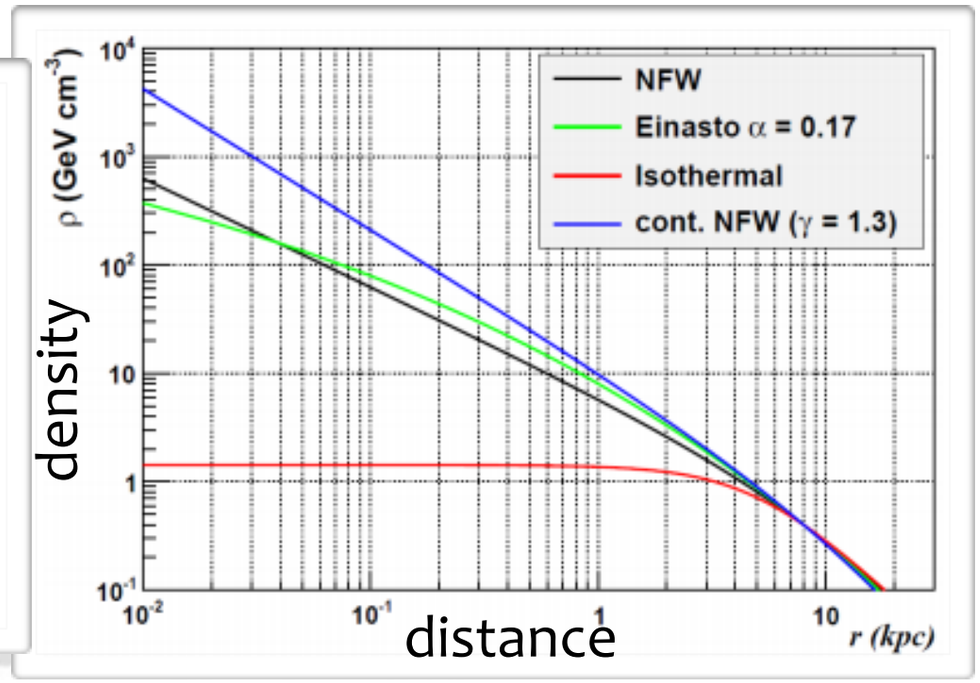
photons

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

Indirect Searches: WIMPs and gamma 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: ~ $\int\rho^2$

(solid angle, line of sight)

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

Indirect Searches: WIMPs and gamma rays

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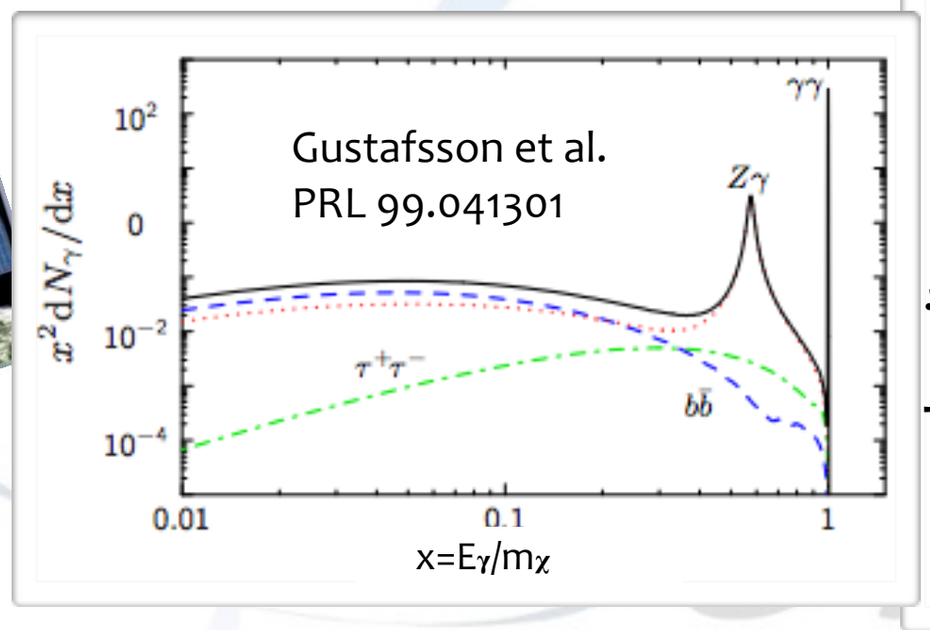

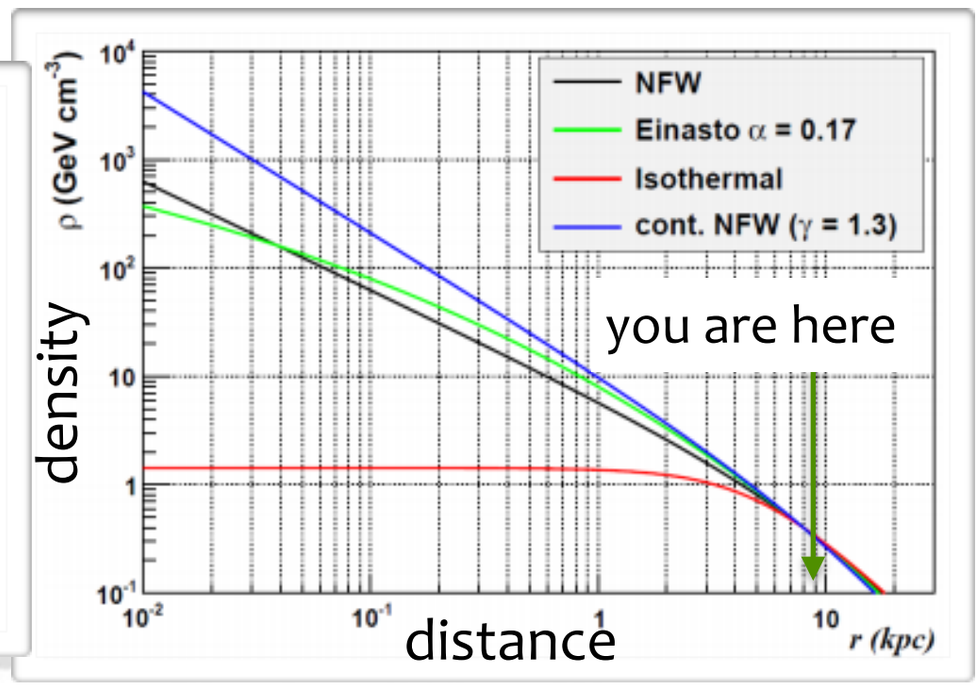

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cross section

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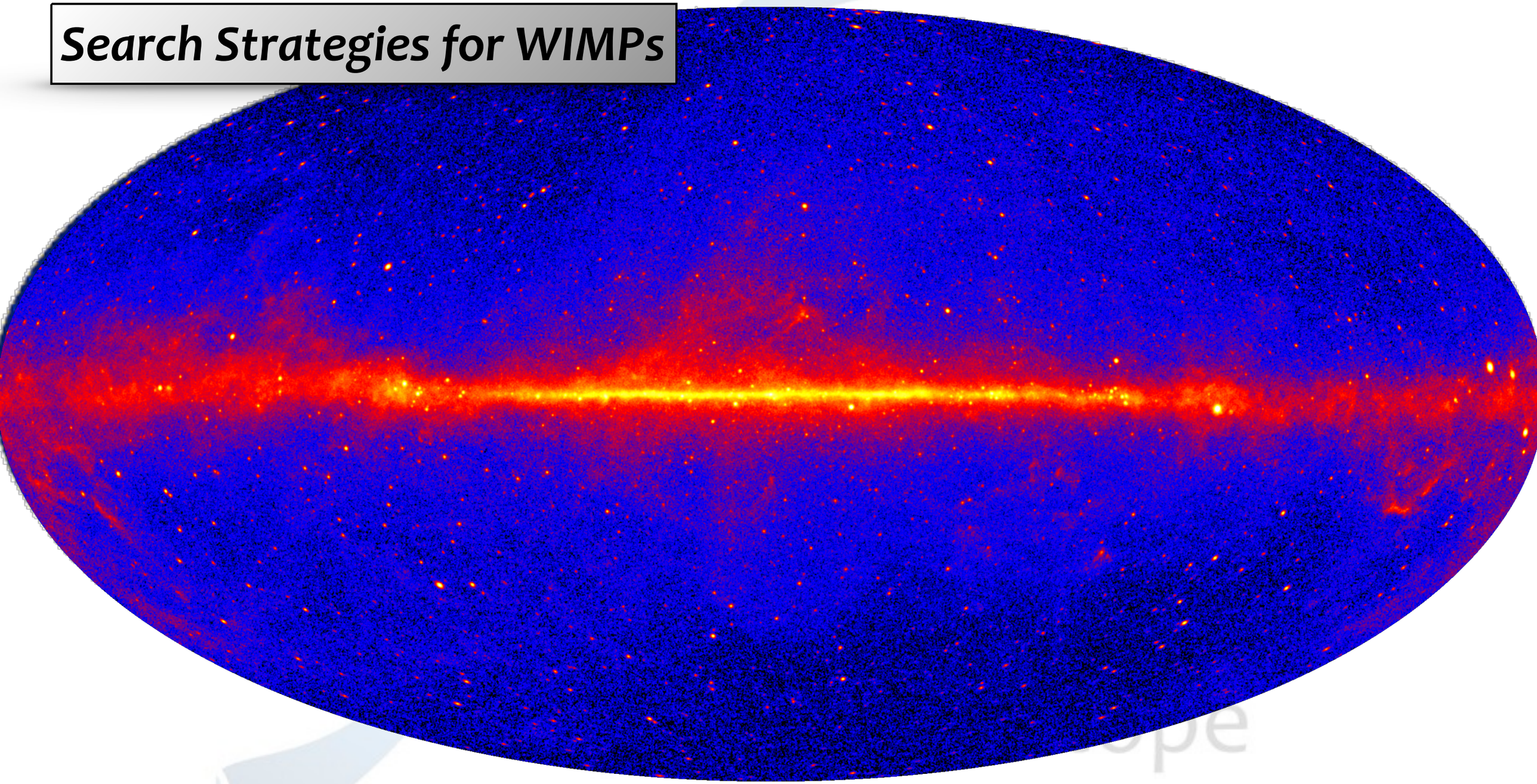
L. Bergstrom et al., Astropart.Phys.9:137-162,1998

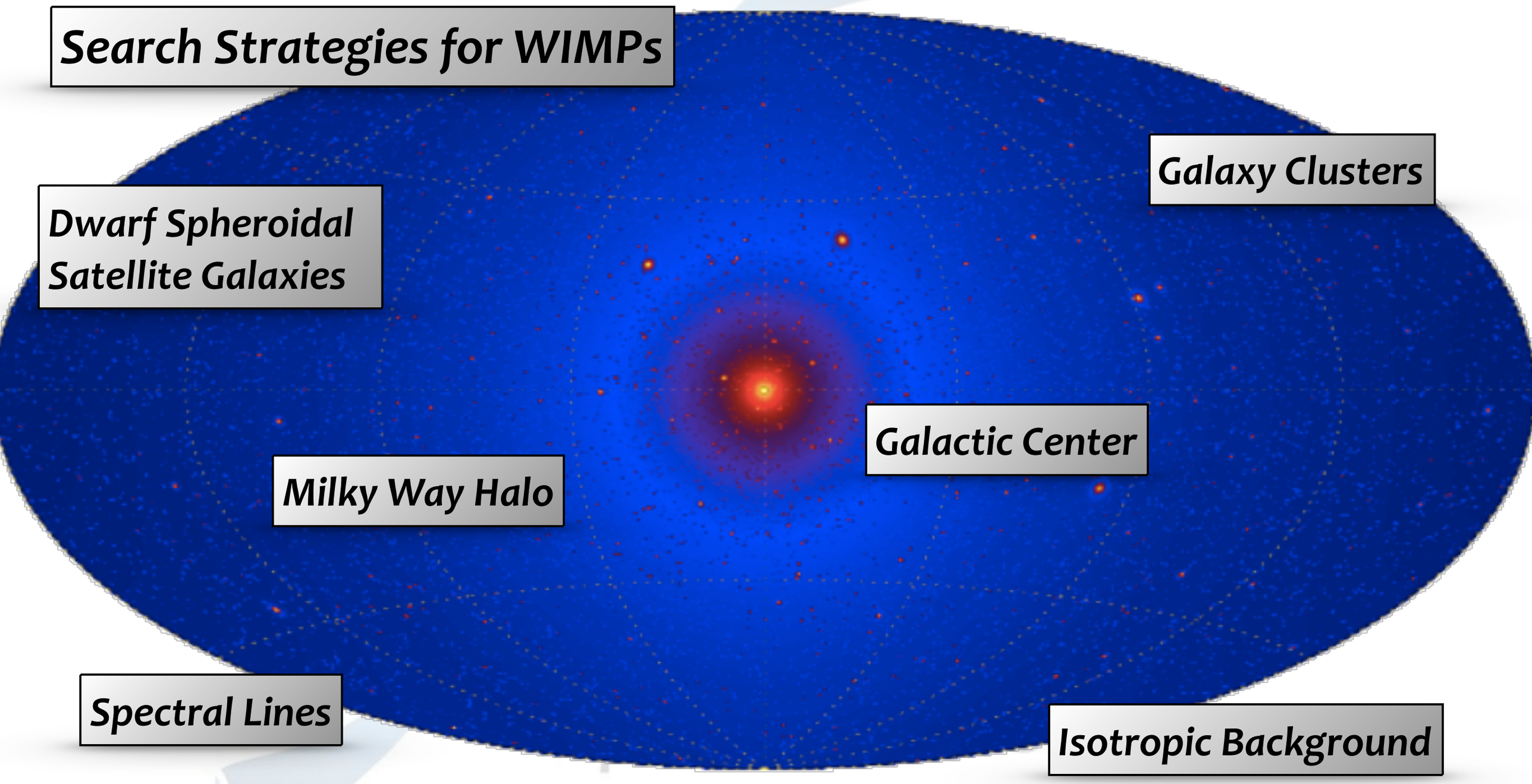
Dark Matter Distribution

Search Strategies for WIMPs



L. Pieri et al., PRD 83 023518 (2011)

Dark Matter Distribution



L. Pieri et al., PRD 83 023518 (2011)

Galaxies shine in γ-rays

Active Galactic Nucleus

accretion onto supermassive black hole

Galaxies shine in γ-rays

Active Galactic Nucleus

accretion onto supermassive black hole

Population of particle accelerators

pulsars, supernova remnants, …

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

Galaxies shine in γ-rays

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particle annihilation/decay into gamma-rays

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Population of particle accelerators ✔

pulsars, supernova remnants, …

Interstellar Medium ✔

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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

Galactic γ-ray sources

Pulsars (PSRs and MSPs)

- PSRs: young 10^3-10^6 yr, created in massive stellar collapse
  - Found in regions of star formation
- MSPs: old 10^8-10^9 yr, spun up by accretion of companion
  - Associated with old stellar populations
- Particle acceleration: rotating magnetosphere
- Curvature radiation and inverse-Compton emission, synchrotron radiation

>200 known

Supernova remnants (SNRs)

- 10^3-10^6 yr, resulting from death of a star (not only massive)
  - Found in regions of star formation
- Particle acc: repeated scattering across strong shocks
- Radiation from hadronic interactions and inverse-Compton, synchrotron radiation

~30 known

Courtesy: P. Martin

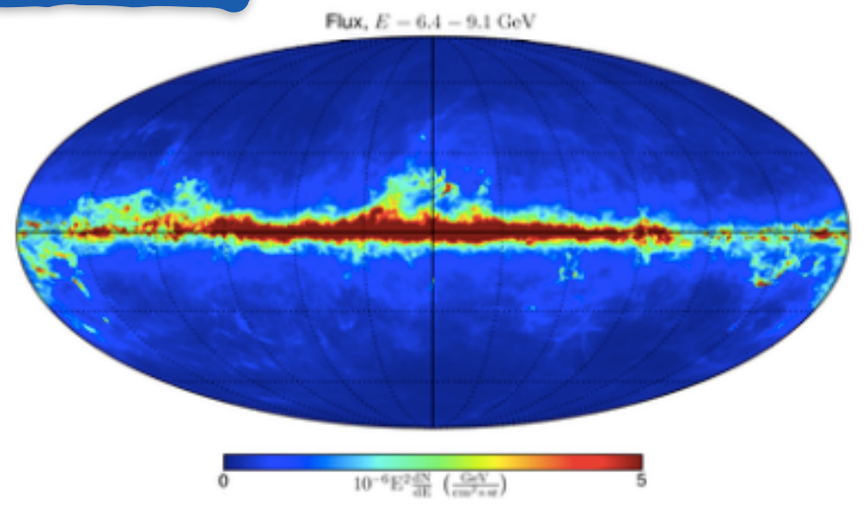
Interstellar γ-ray Emission

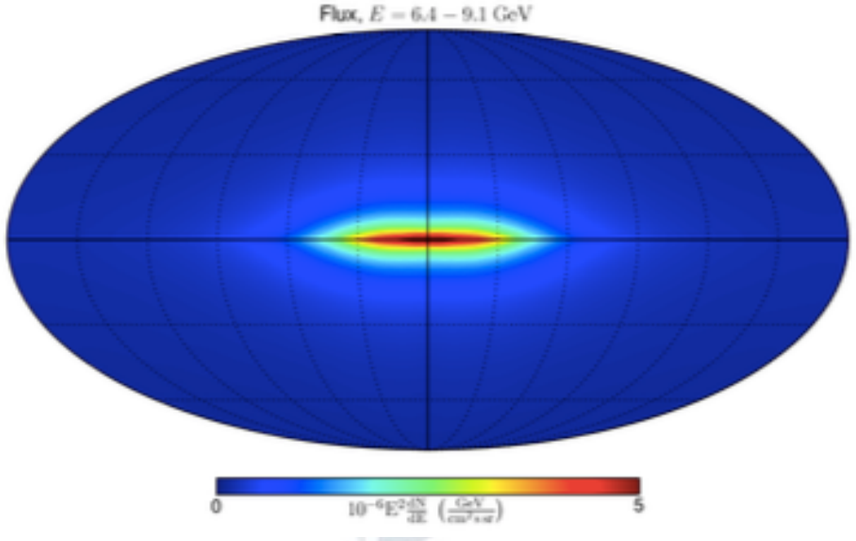
Galactic Cosmic Rays

- 90% protons, 9% Alphas, 1% electrons
- Energies up to ~10^{15} eV
- Confined to galactic volume >Myr by magnetic turbulence
- Dominant source thought to be SNRs

Pion Decay

- CR interaction with interstellar Gas
- 60-70% contribution in 0.1-100 GeV band
- Correlates with gas spatial distribution





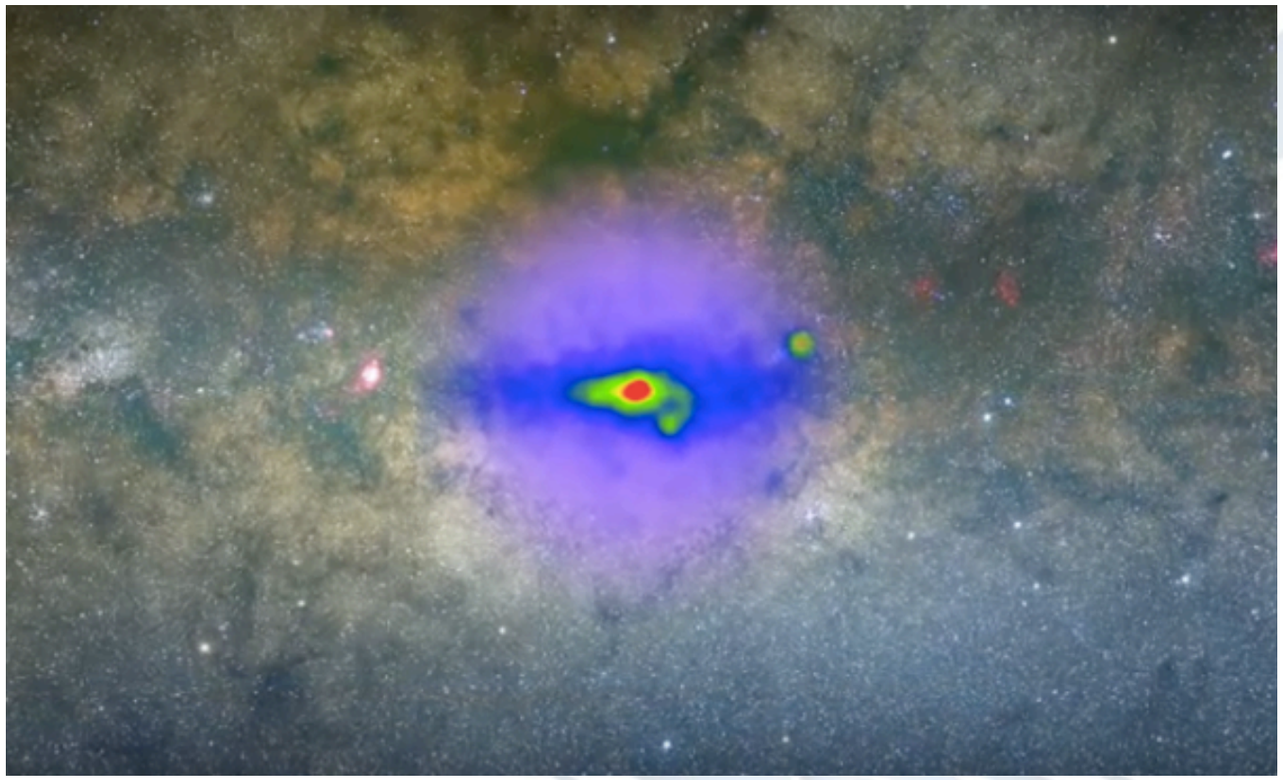
Inverse Compton Emission

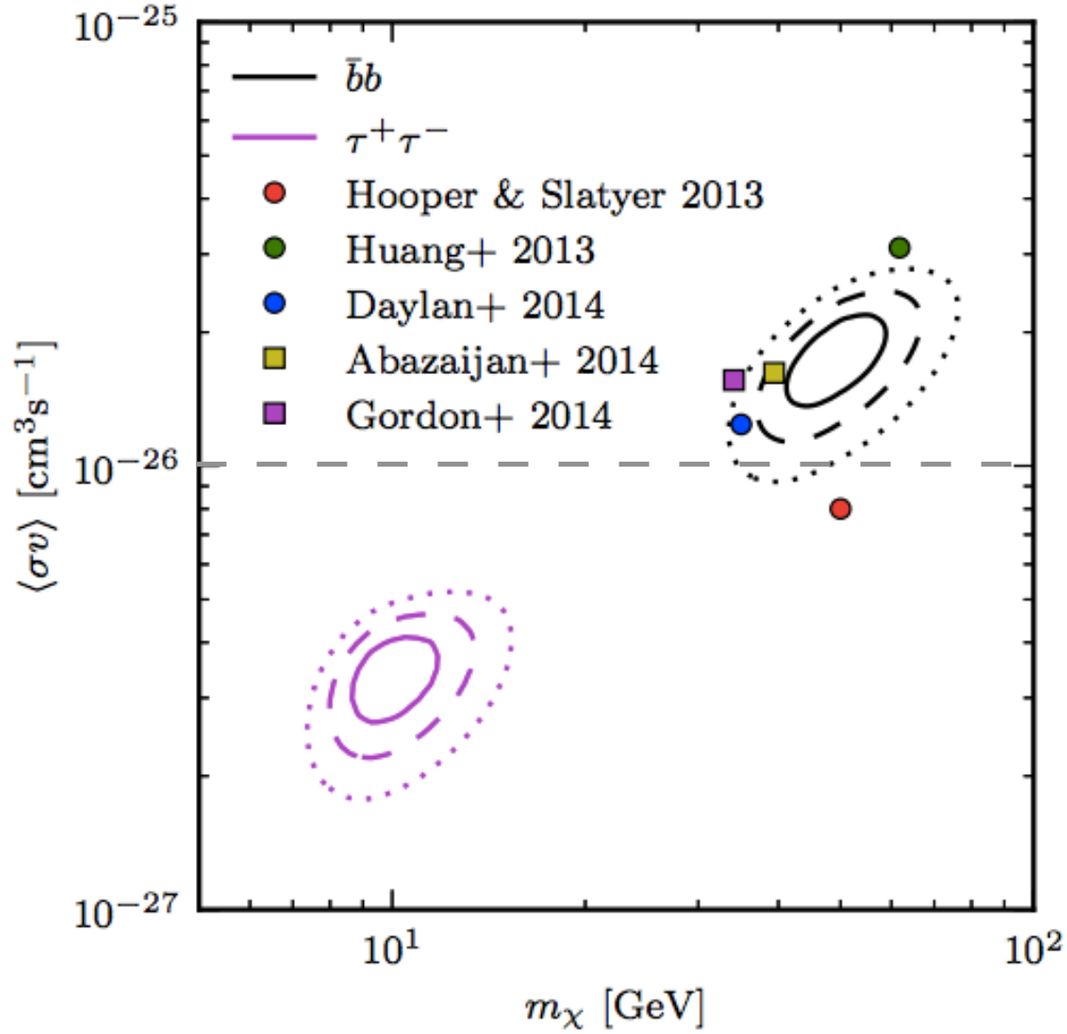
- CR interaction with UV/optical/IR/CMB photons
- 20-30% contribution in 0.1-100 GeV band
- Confined to inner regions

Strong et al. 2010

Courtesy: P. Martin

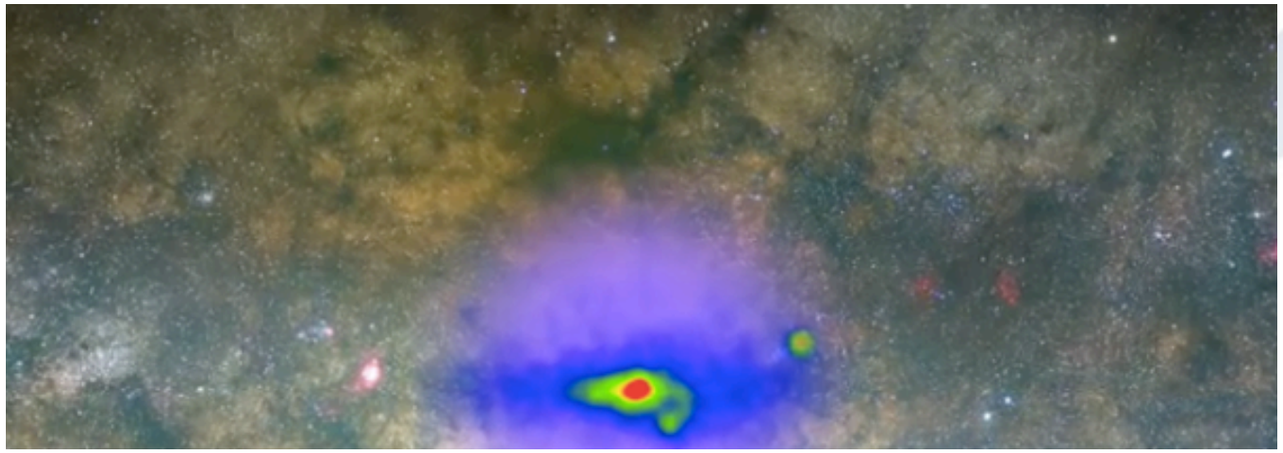
The Galactic Center



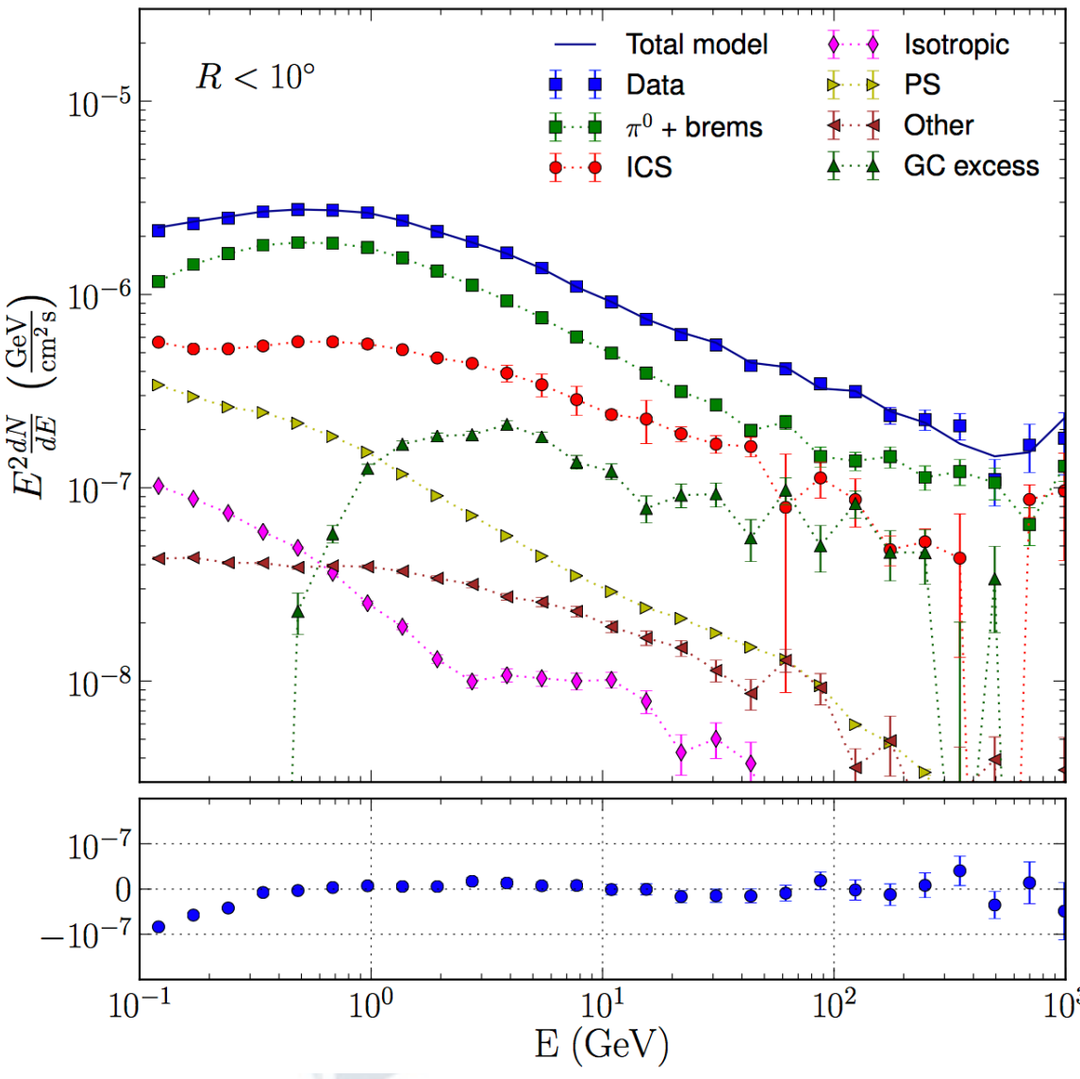


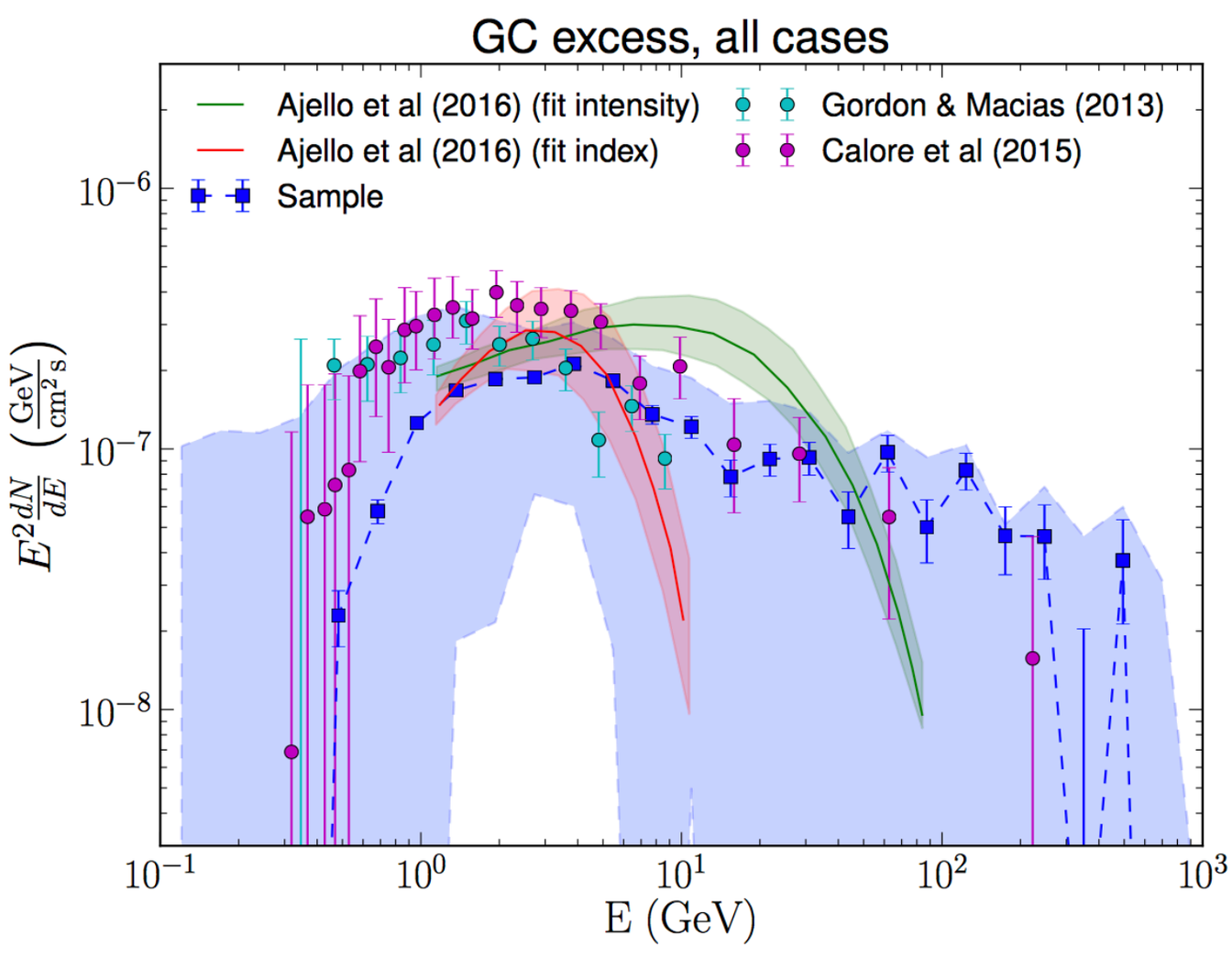
Calore et al. JCAP 1503 (2015)

The Galactic Center



Variation of excess within modeling uncertainties studied using Pass 8 data

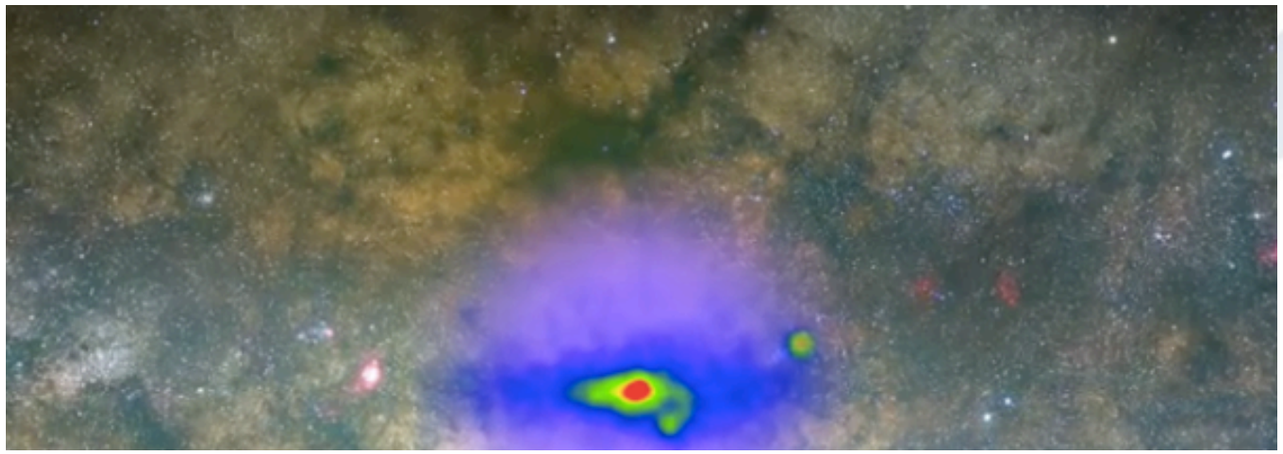




Ackermann et al. ApJ 840 1 (2017)

Calore et al. JCAP 1503 (2015)

The Galactic Center



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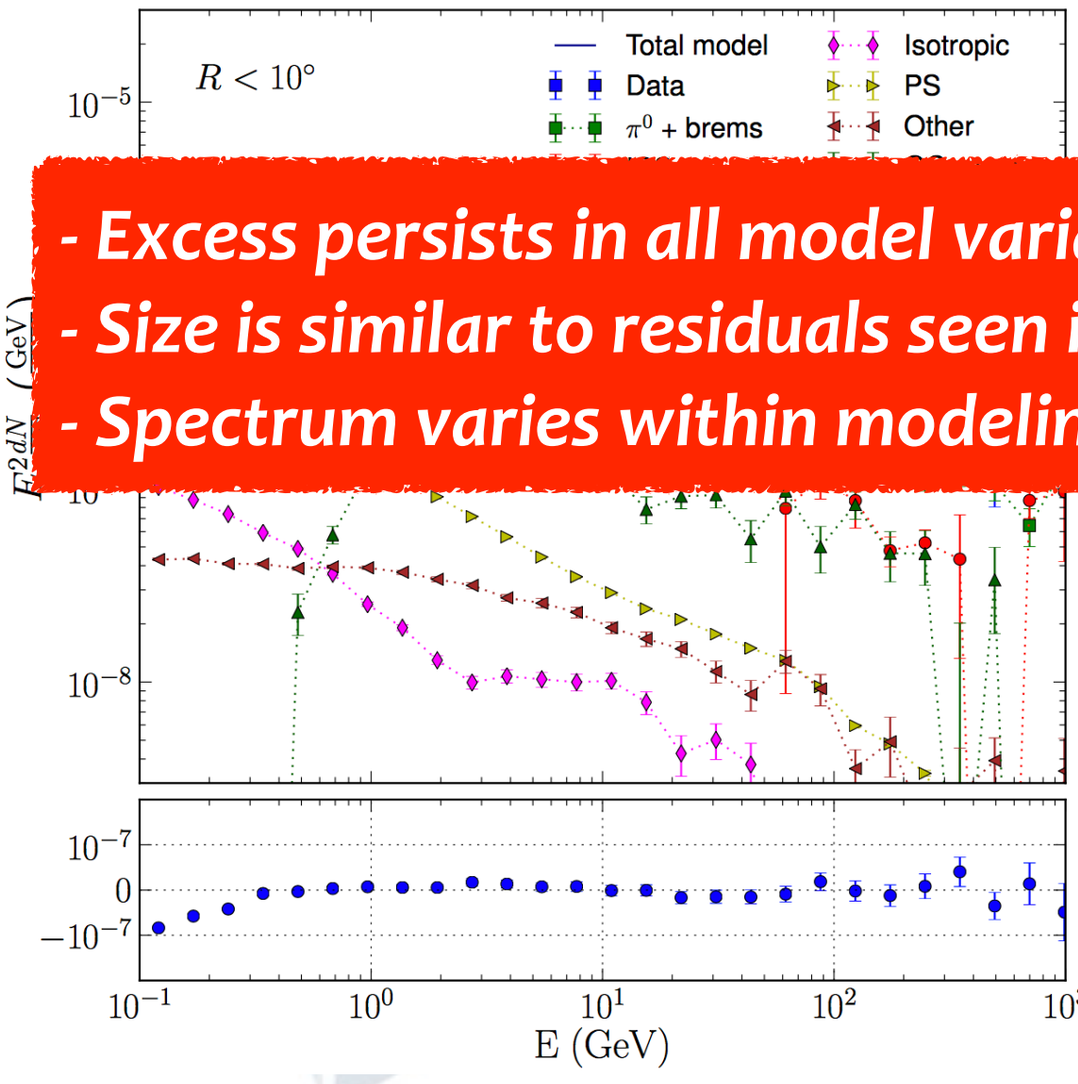
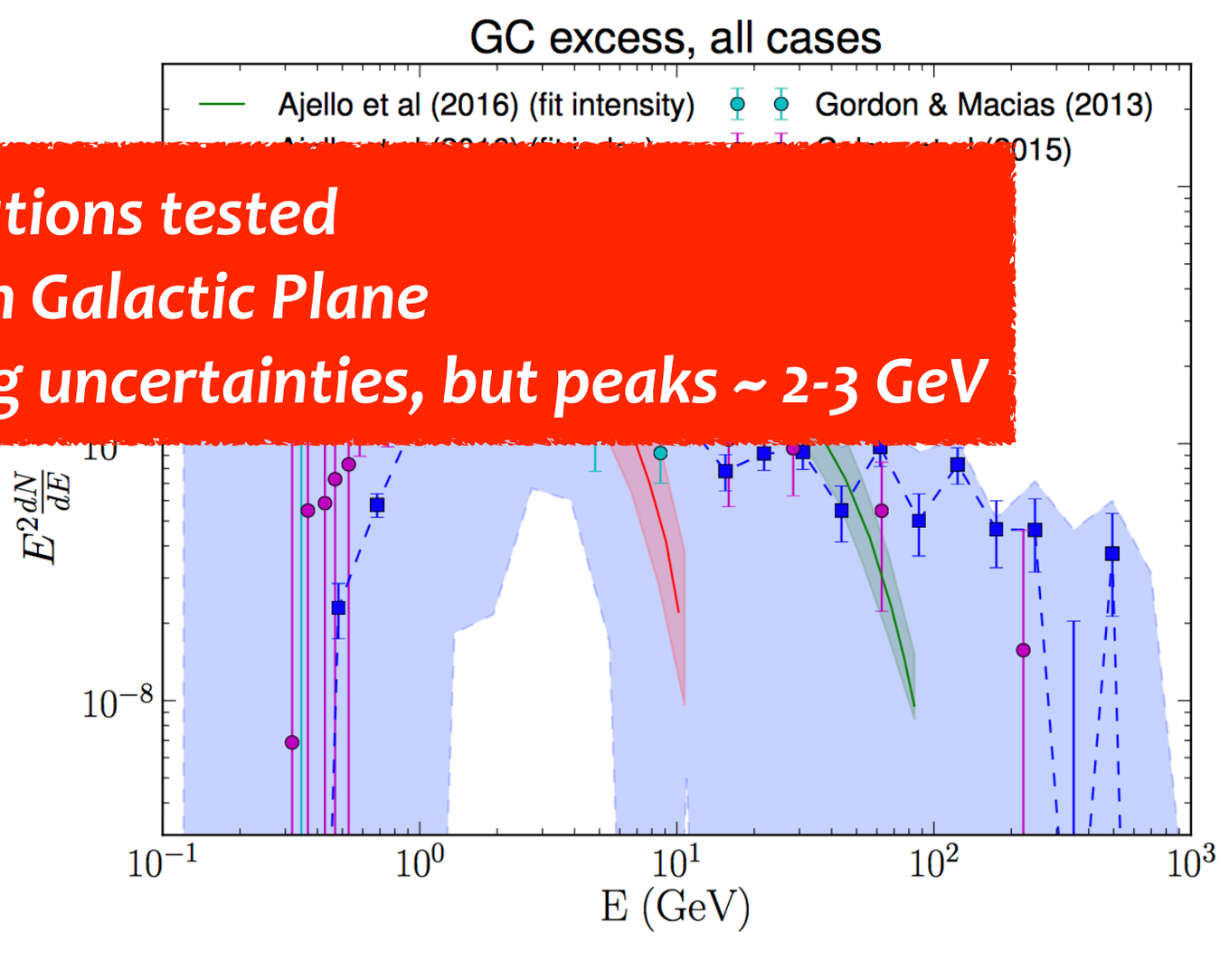




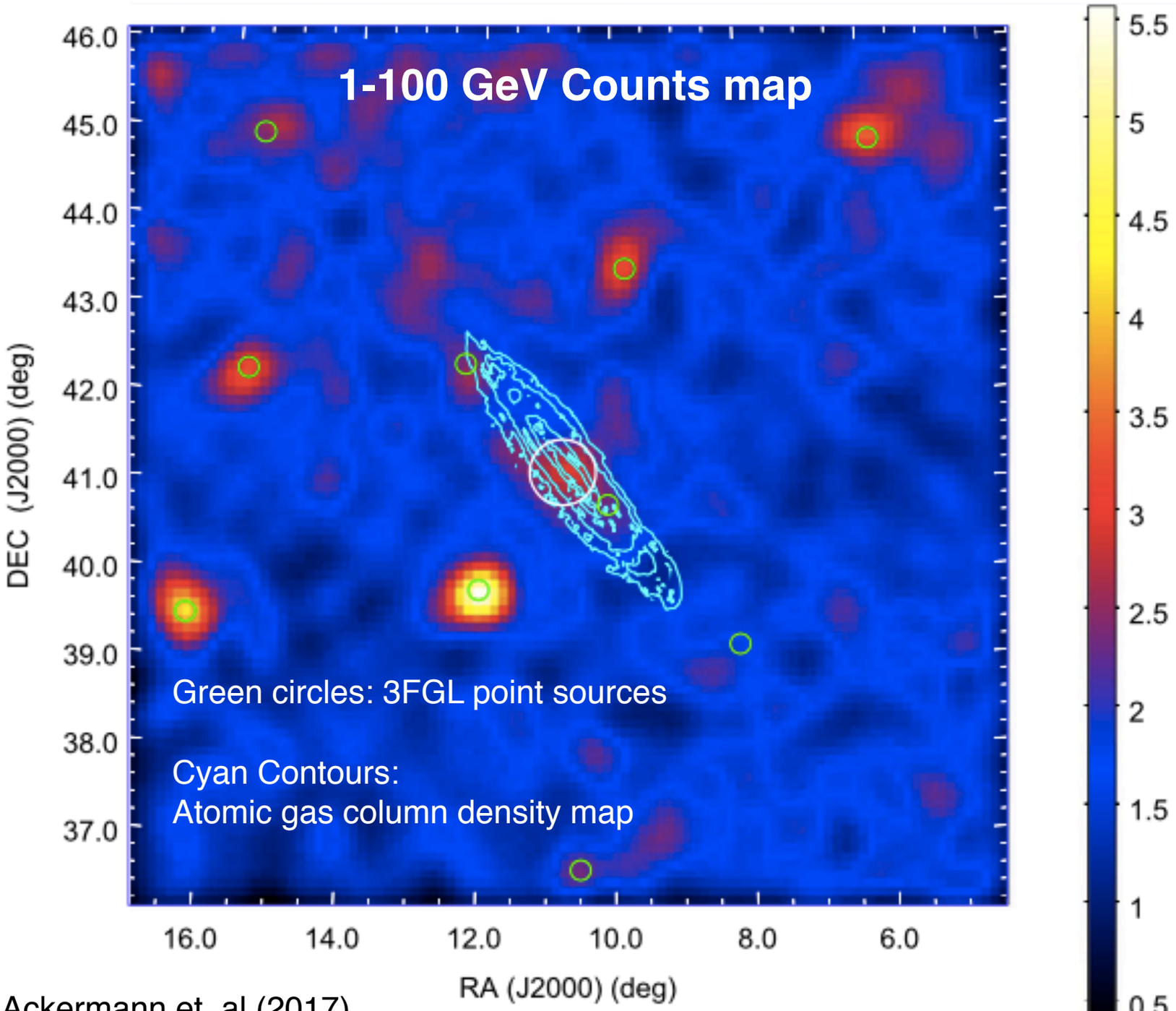
- *Excess persists in all model variations tested*
- *Size is similar to residuals seen in Galactic Plane*
- *Spectrum varies within modeling uncertainties, but peaks ~ 2-3 GeV*

Ackermann et al. ApJ 840 1 (2017)

Calore et al. JCAP 1503 (2015)

Nearest Spiral Galaxy

γ-ray emission in the Andromeda Galaxy



Ackermann et. al (2017)

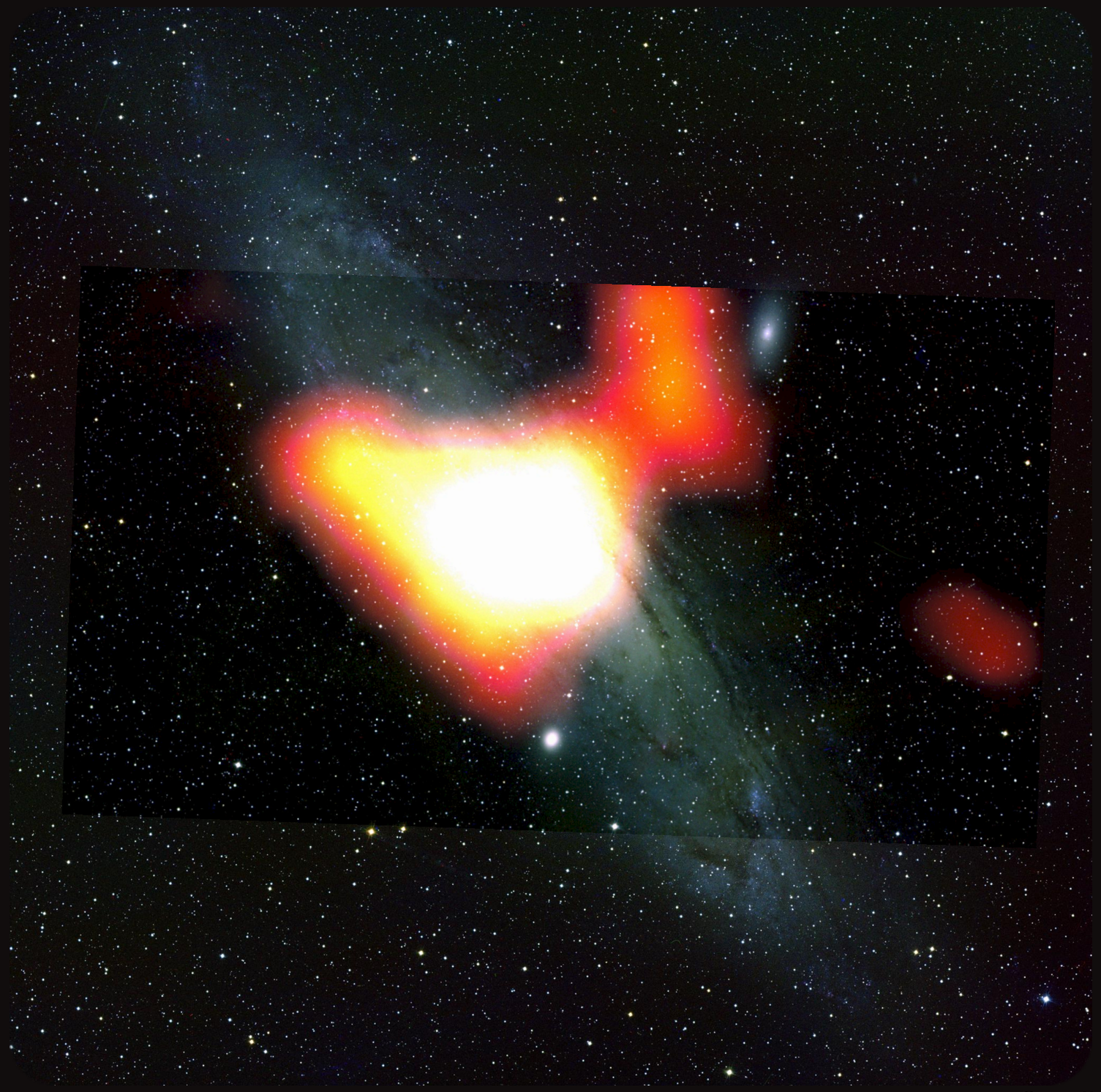
What did we find…

- 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

Credit: NASA/GSFC

γ-ray emission in the Andromeda Galaxy

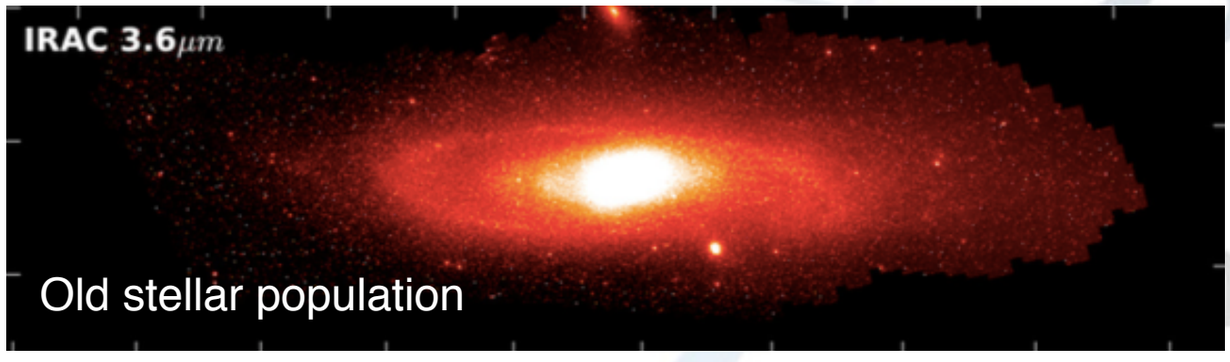


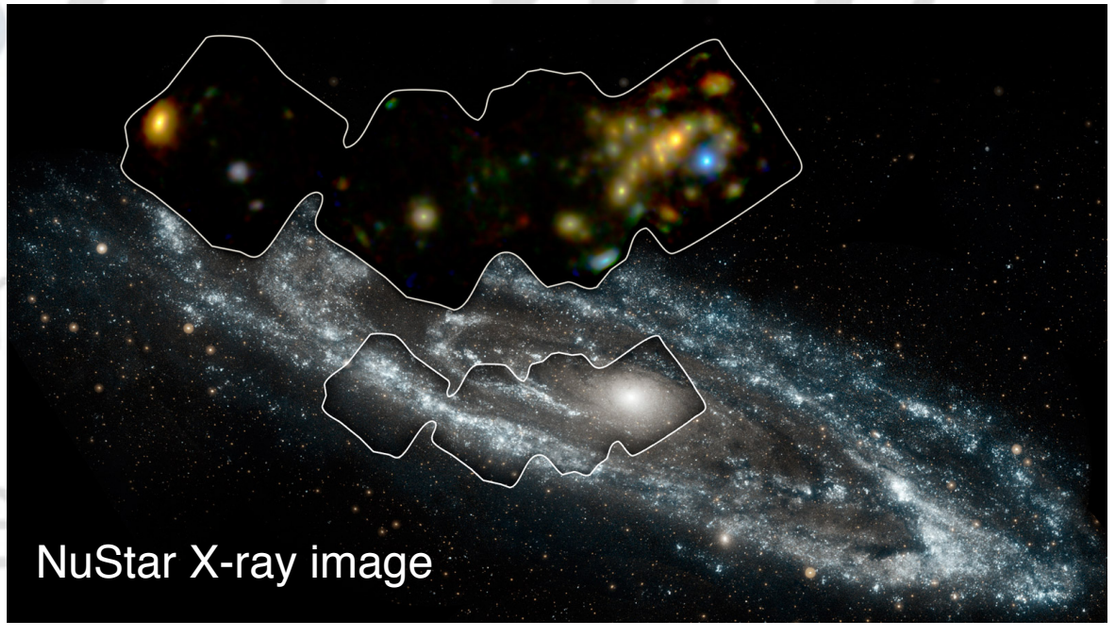
Credit: NASA/GSFC

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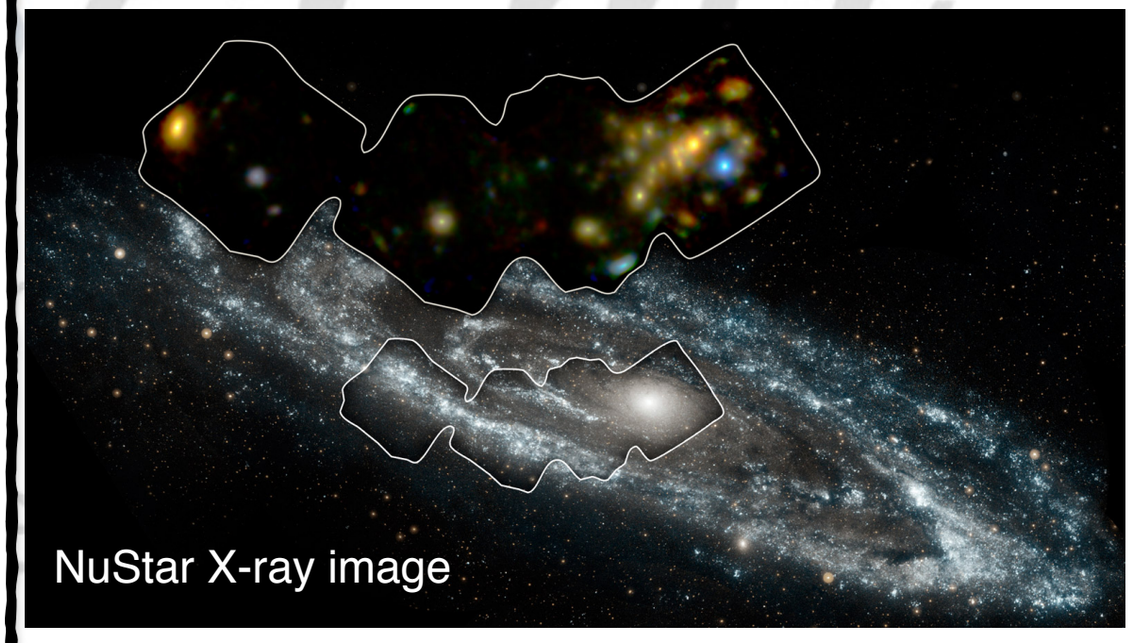
The details:
Gamma-ray signal 4-5x more luminous than GCE
10x lower star formation rate and 5-6x more massive bulge than MW
(follow up in progress…)
Best Astrophysical Interpretation



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

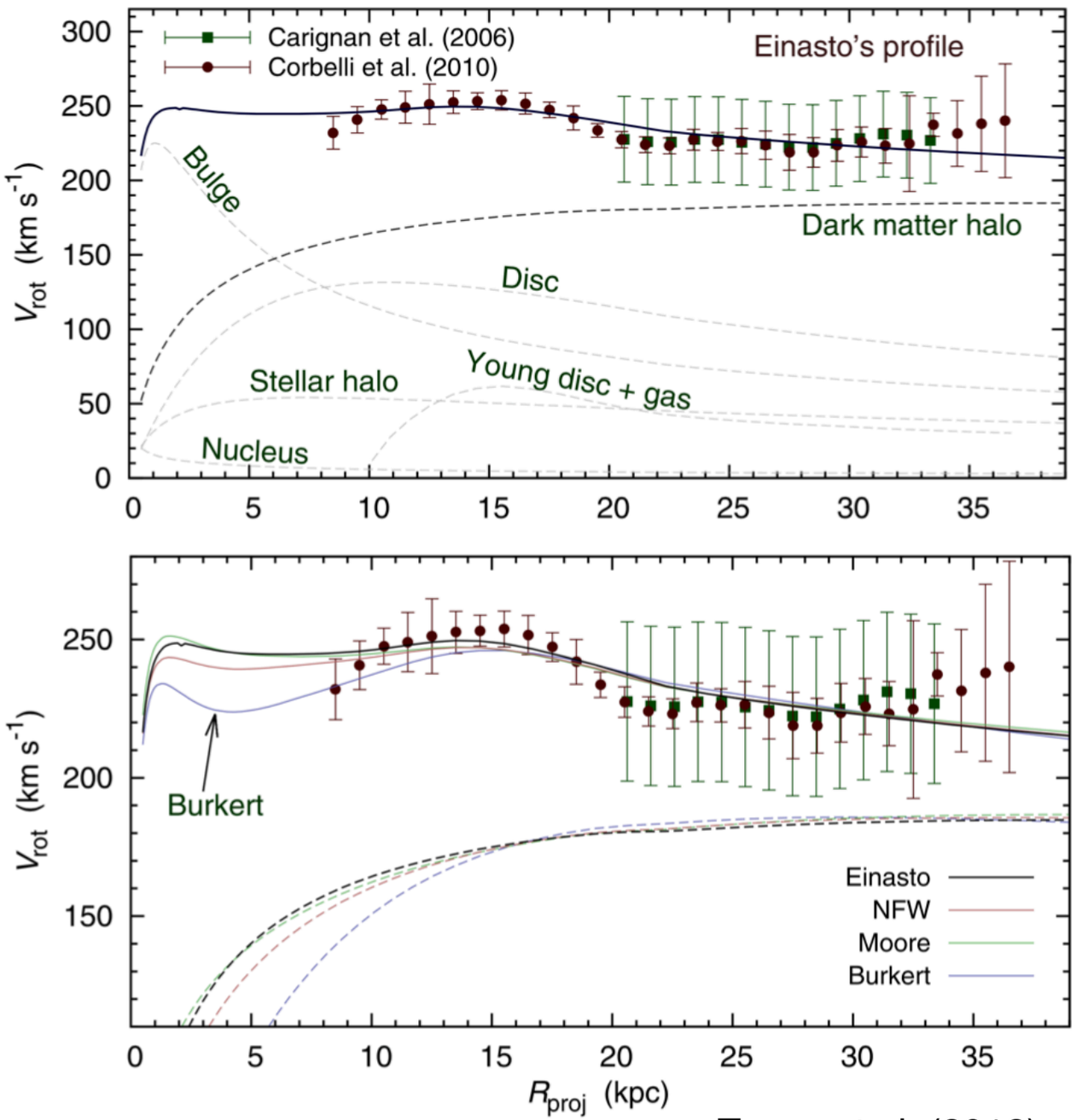
Interpretation II: Dark Matter

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%)

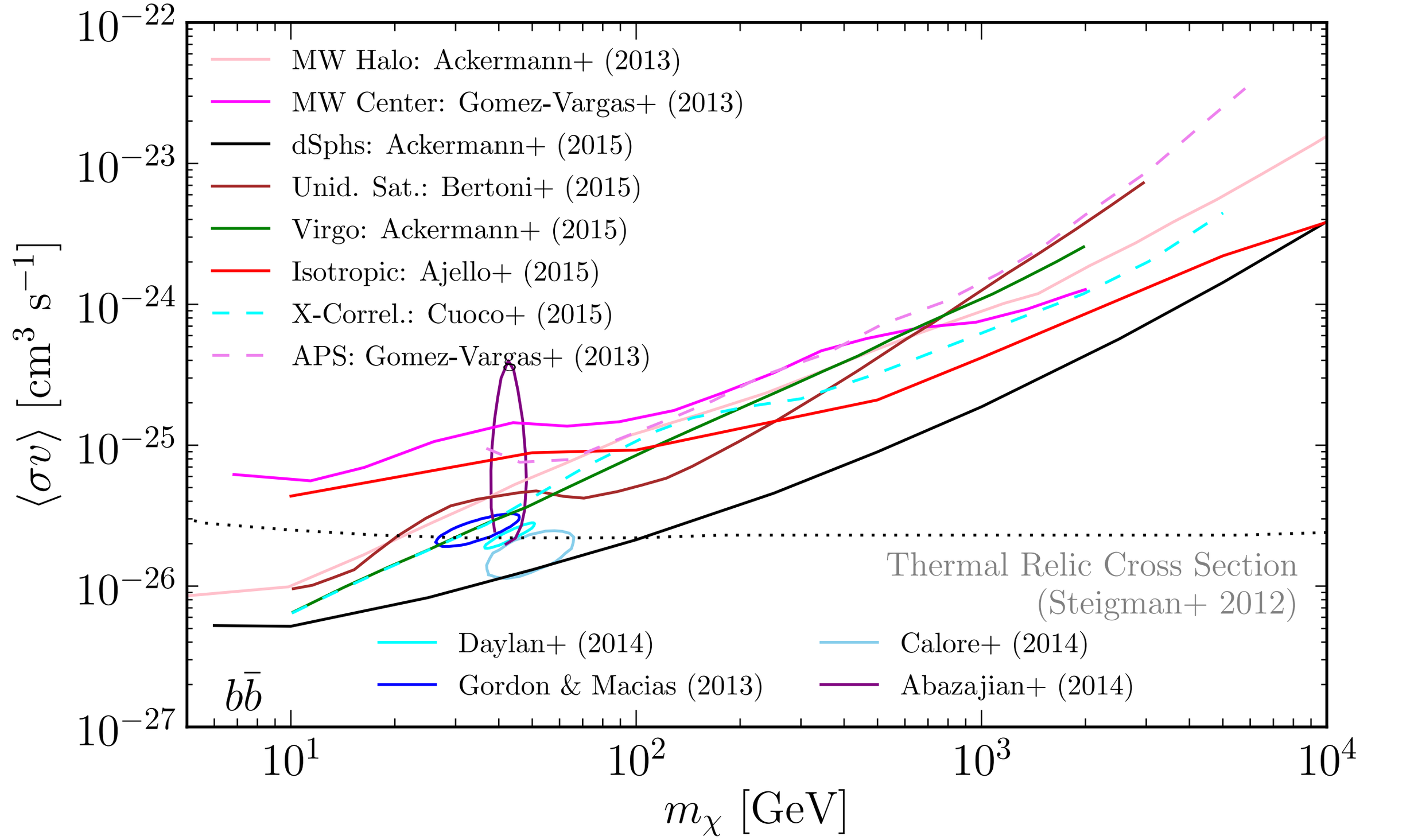
- Observed flux from M31 5x higher than expected value

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



Tamm et al. (2012)

Summary of WIMP Dark Matter Searches



E. Charles et al, Phys. Rep 636 (2016)

Results from *Fermi*-LAT

Gravitational Wave Astrophysics

Detection of Gravitational Waves

Electromagnetic counterparts to GWs

Recent followup observations of LIGO GW events

Transient Analyses with *Fermi*-LAT

Fermi Gamma-ray Space Telescope

Pipeline
Method
Timescale
Distribution
Status

LAT Transient Factor (LTF)
Likelihood Around GBM/BAT triggers
seconds to orbits
LAT Team - Results in GCNs
Triggered Operating + *Blind Search Coming Soon*

***Fermi* All-sky Variability Analysis (FAVA)**
Counts Map Aperture Photometry
3 day (coming soon), 1 week
ATels
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/

LAT Burst Advocate Tool
Likelihood Around GBM/BAT triggers
100 s, 1000 s
LAT Team - Results in GCNs
Operating

GBM Untriggered Search
ground search
ms - s
GCN Notices
http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

GBM Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices
Operating

LAT Automated Science Processing (ASP) + Flare Advocates
Likelihood
6 & 24 hour
ATels, GCN notices (on AGN)
Operating

LAT Catalogs
Likelihood, associations
3 month (0FGL), 1 year (1FGL), 2 years (2FGL), 4 years (3FGL)
http://fermi.gsfc.nasa.gov/ssc/data/access/
4FGL in progress

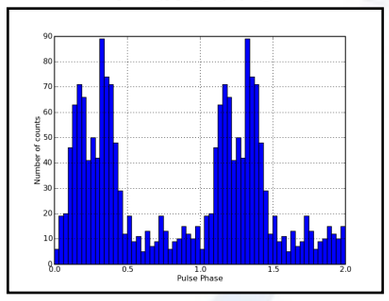
Transients Timescale Pipelines

μs ***ms*** ***s*** ***minutes*** ***hours*** ***days*** ***months*** ***years***

Photon Timing

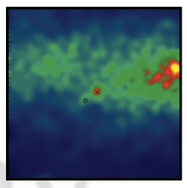
All Sky Cadence

Pulsars

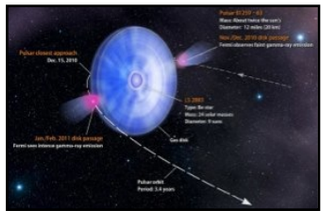


Solar Flares

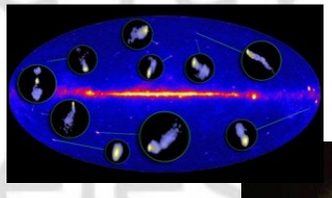
Novae



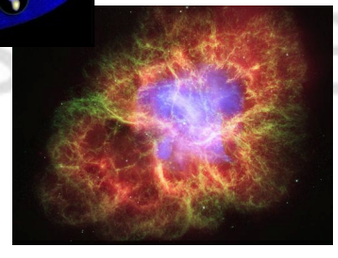
γ-ray Binaries



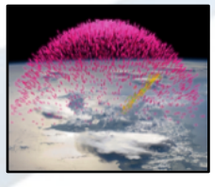
Blazar Flares



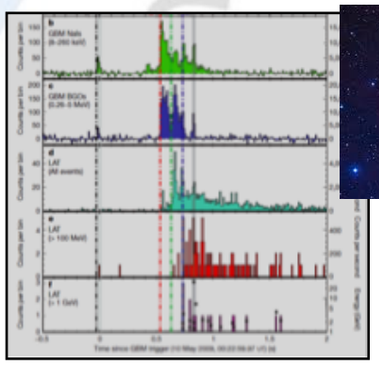
Crab Flares



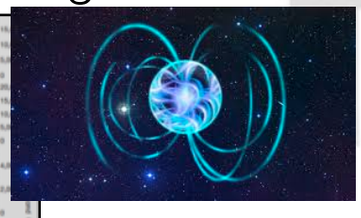
Terrestrial γ-ray Flashes



GRBs



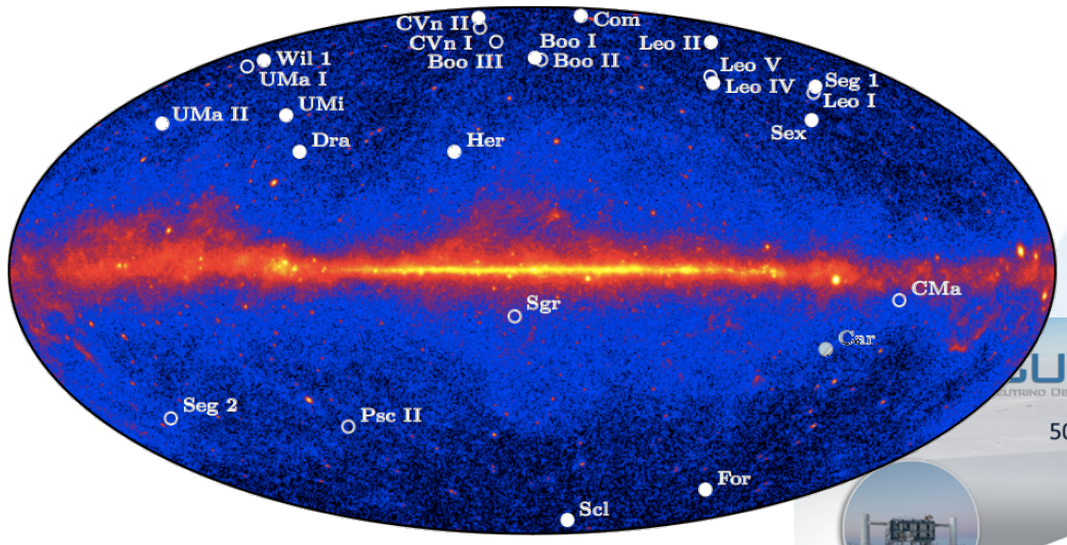
Magnetar Flares

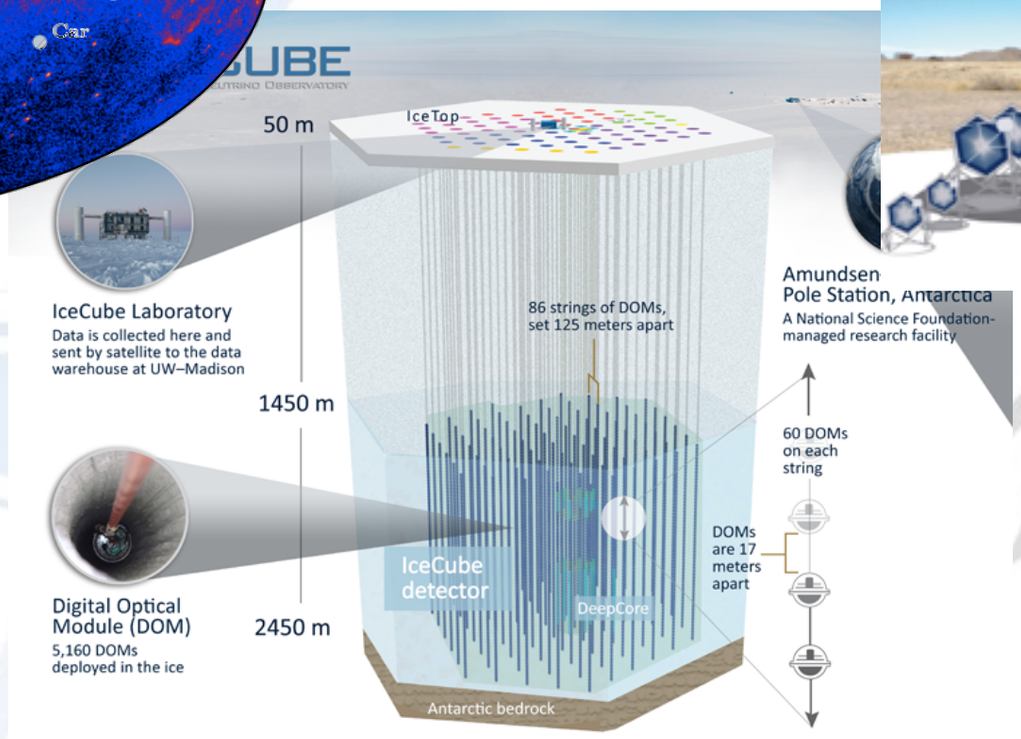


Credit: J. Racusin

Not to scale

The Future…



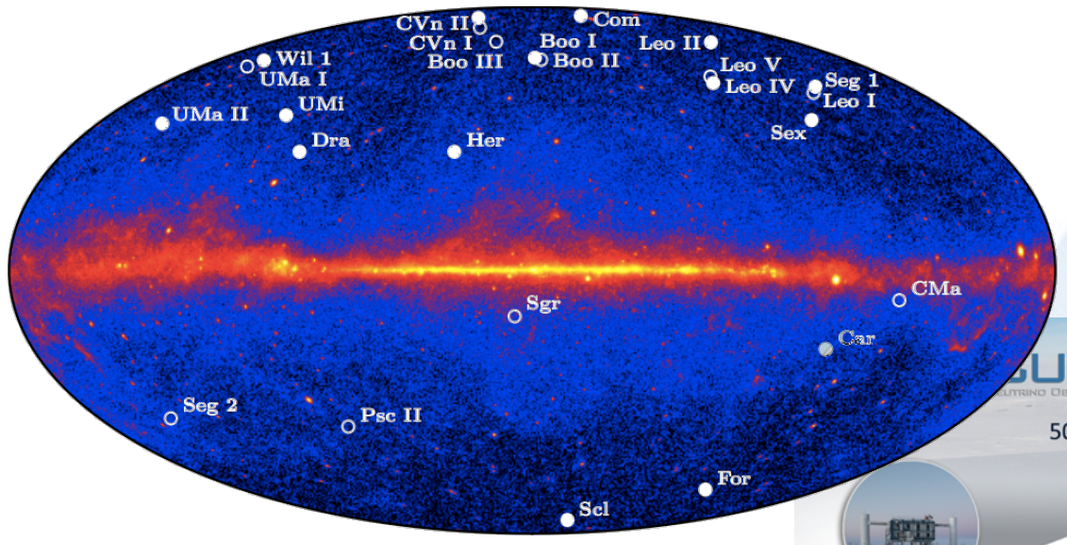


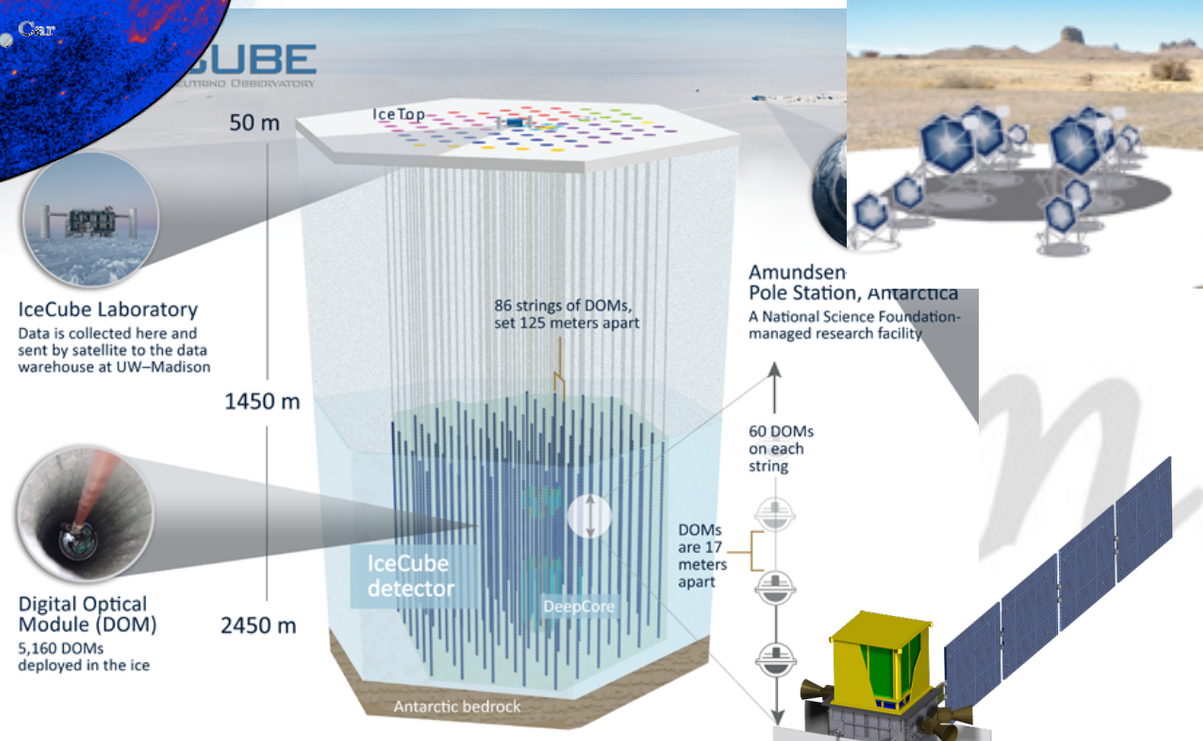
Amundsen Pole Station, Antarctica
A National Science Foundation-managed research facility

33% of Fermi Sources are unassociated

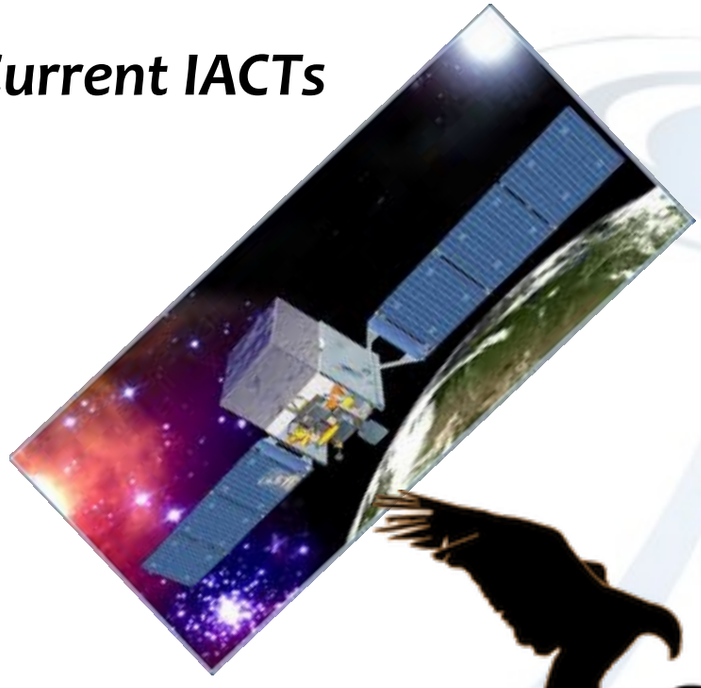
HAWC
High Altitude Water Cherenkov Gamma-Ray Observatory

The Future…





Current IACTs



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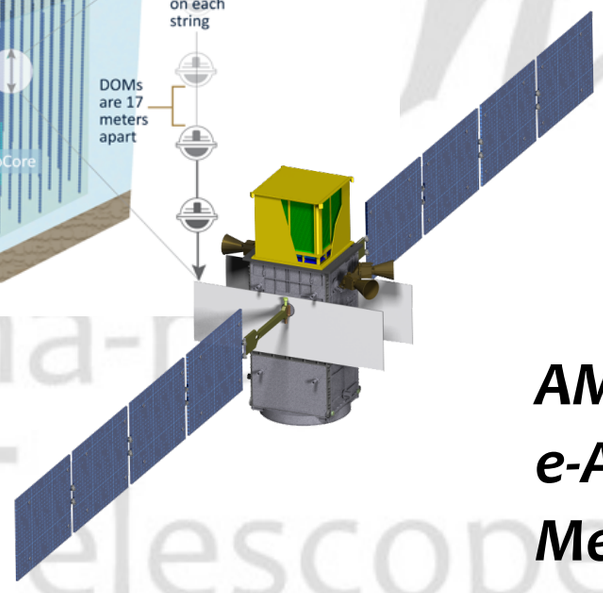


AMEGO/ e-ASTROGAM/ MeV mission

The Next Generation…

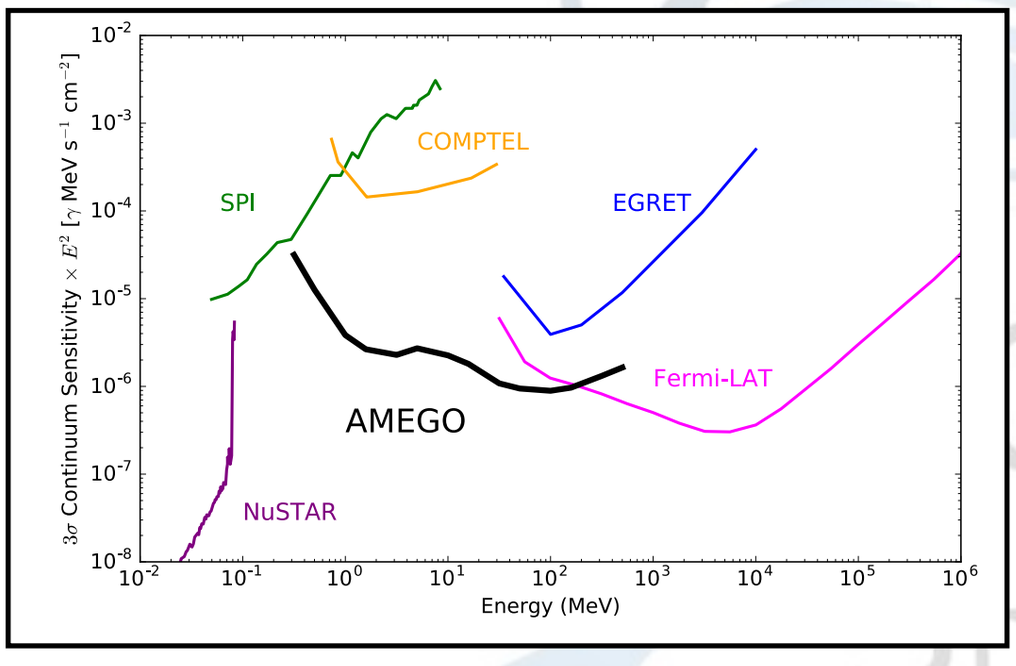
Proposed new gamma-ray missions…

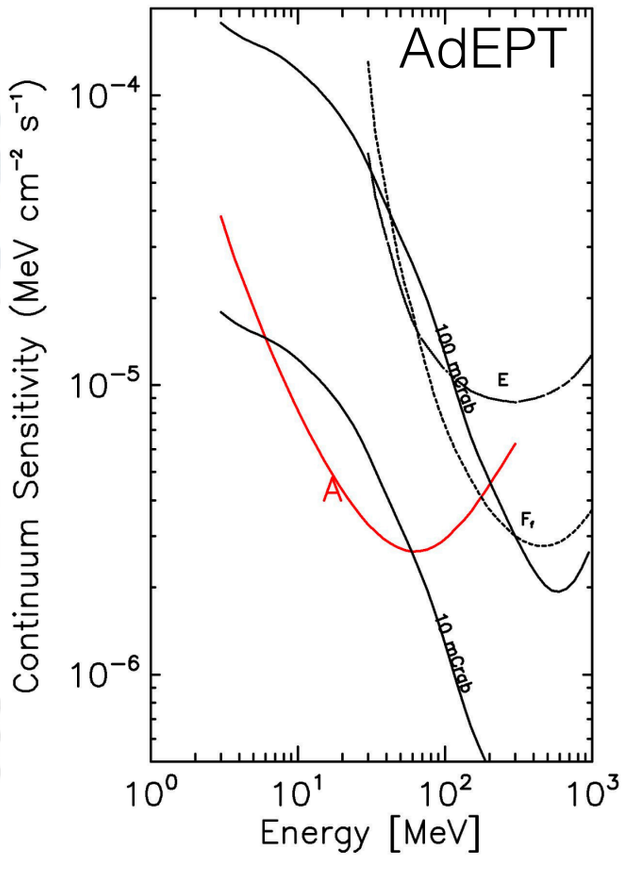
All-sky Medium Energy Gamma-ray Observatory: AMEGO

enhanced ASTROGAM: eASTROGAM

Advanced Energetic Pair Telescope: AdEPT

- incomplete list -





Intense Star formation at GC necessitates understanding of the MeV rage

arXiv:1206.0772

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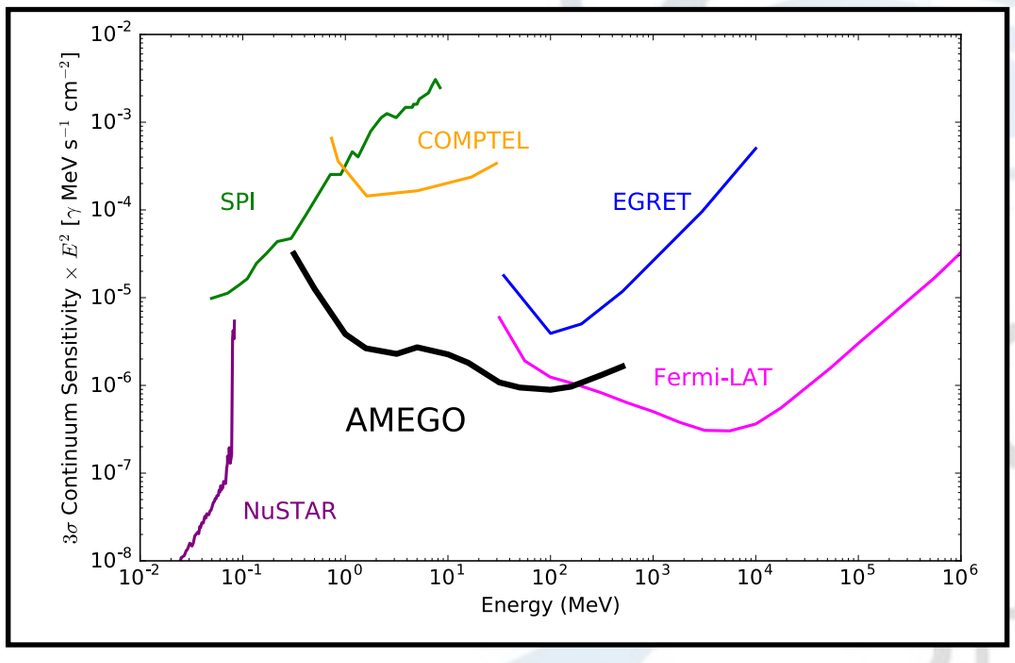

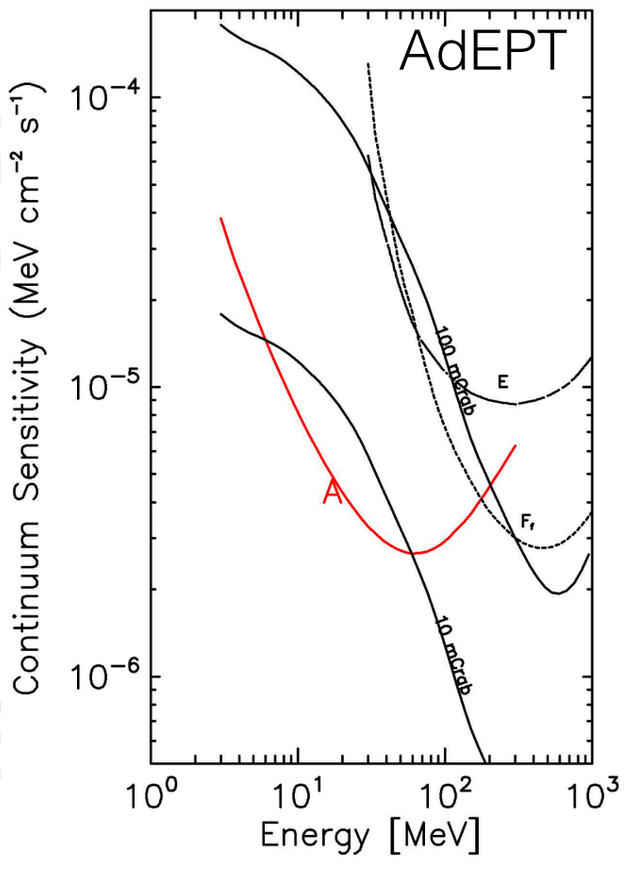

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View of the Galactic Plane

ComPair arXiv:1508.07349

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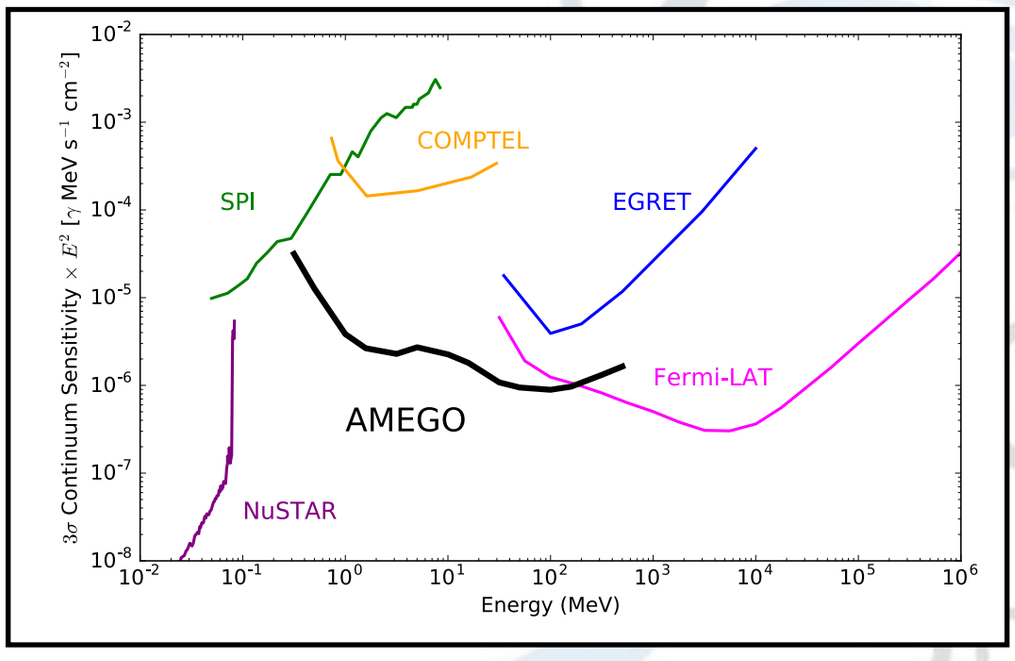

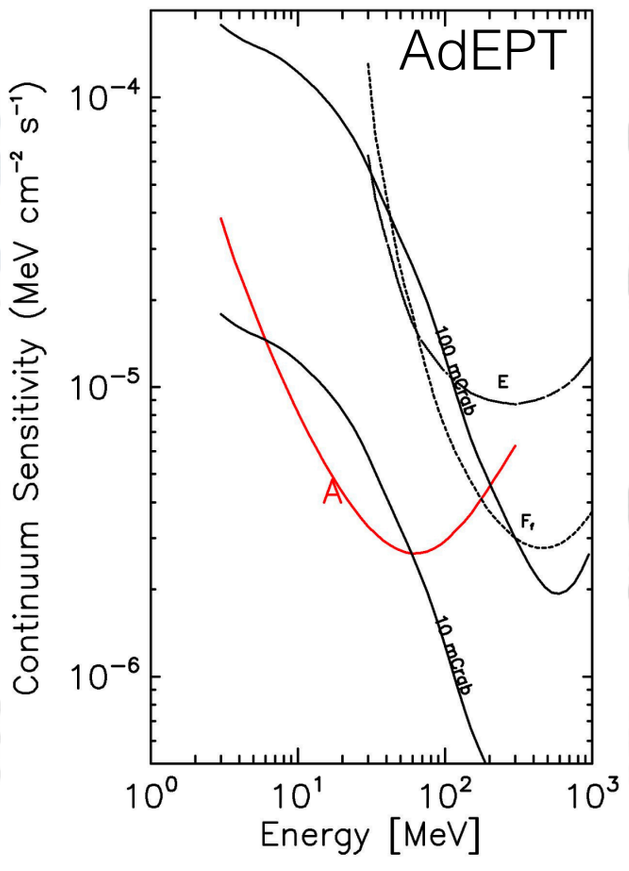

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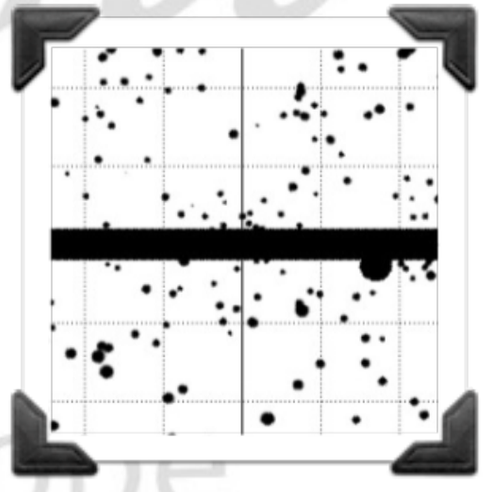

eAstrogam

ComPair arXiv:1508.07349

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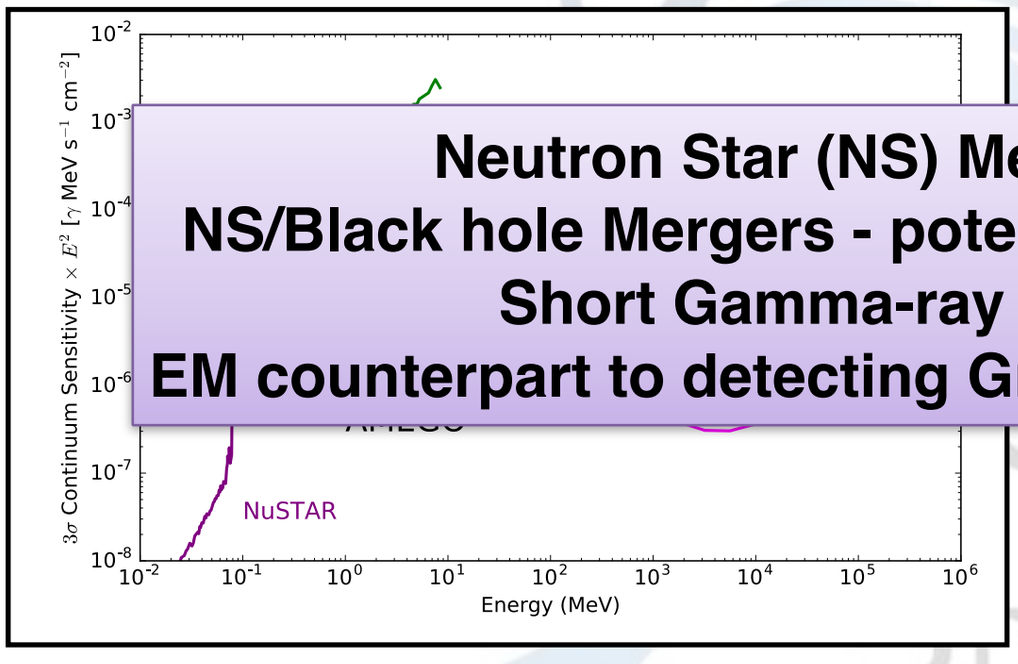
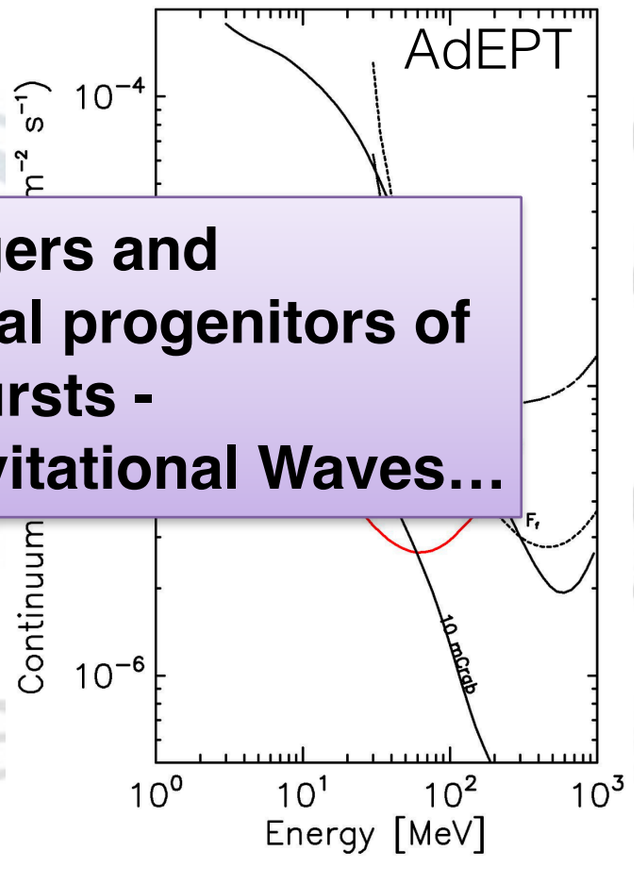


Neutron Star (NS) Mergers and NS/Black hole Mergers - potential progenitors of Short Gamma-ray Bursts - EM counterpart to detecting Gravitational Waves…



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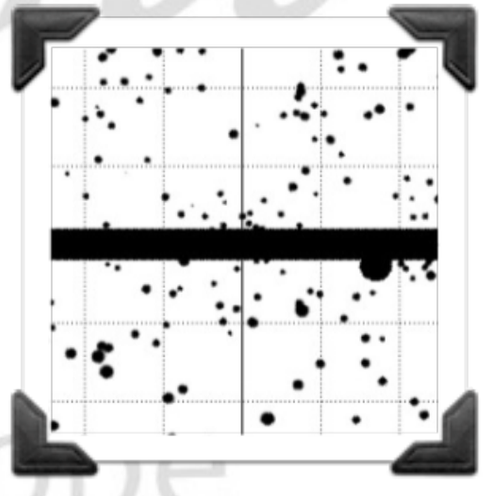

eAstrogam

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In Summary

- ***Fermi*-LAT is an excellent probe of particle Dark Matter**
  - **Indirect detection is the only detection technique that searches for DM in astrophysical targets**

- ***Fermi*-LAT is an essential part of multi-messenger studies**
  - **Astrophysical high energy neutrinos and cosmic rays**
  - **Catalogs provide a basis for connections**

- **Gravitational Wave counterparts**
  - **GBM the most prolific detector of sGRBs (~40 triggered per year, and 40-80 more in un-triggered ground sub-threshold searches)**
  - **LAT is the only instrument capable of detecting GRB afterglows over the entire sky during normal survey operations**

Thank you!