Recent Results from the Fermi Gamma-ray Space Telescope

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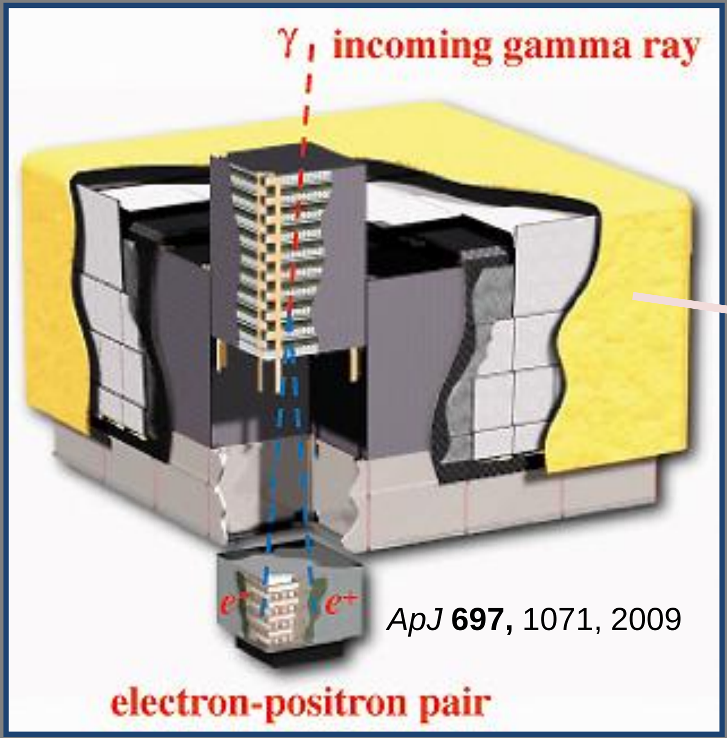
Fermi Observatory

D.o.E.



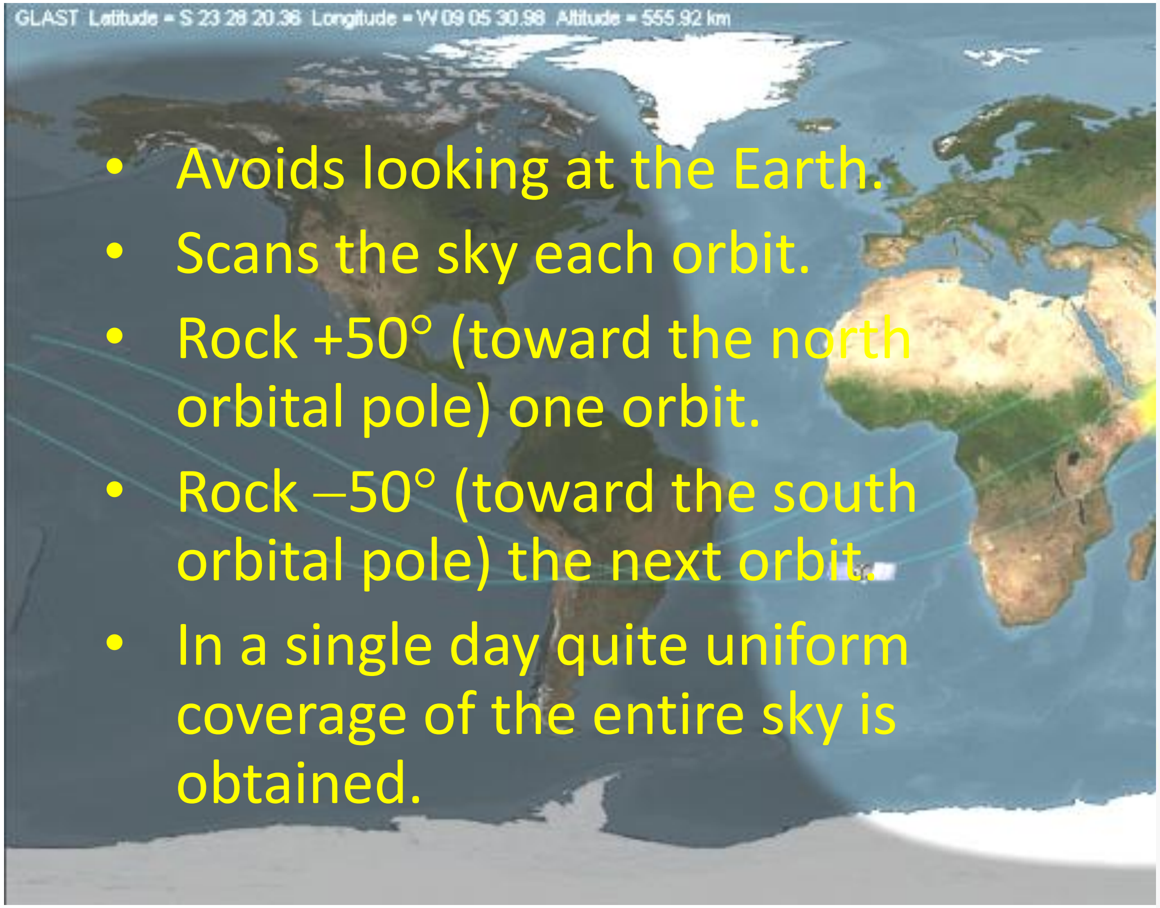
ApJ **697,** 1071, 2009

Large Area Telescope (LAT)

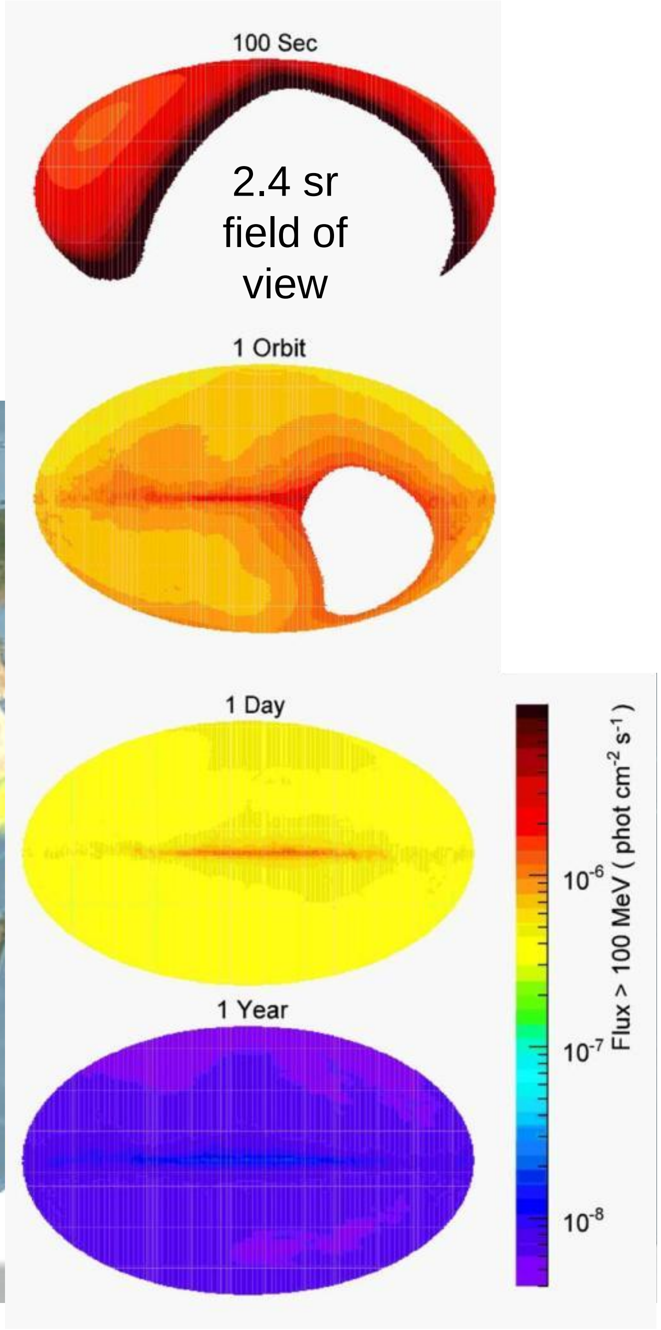
- 4×4 modular design
- Mass: 3 tons
- ~million amplifiers; 5 computers
- <650 Watts power!

All Sky Monitor

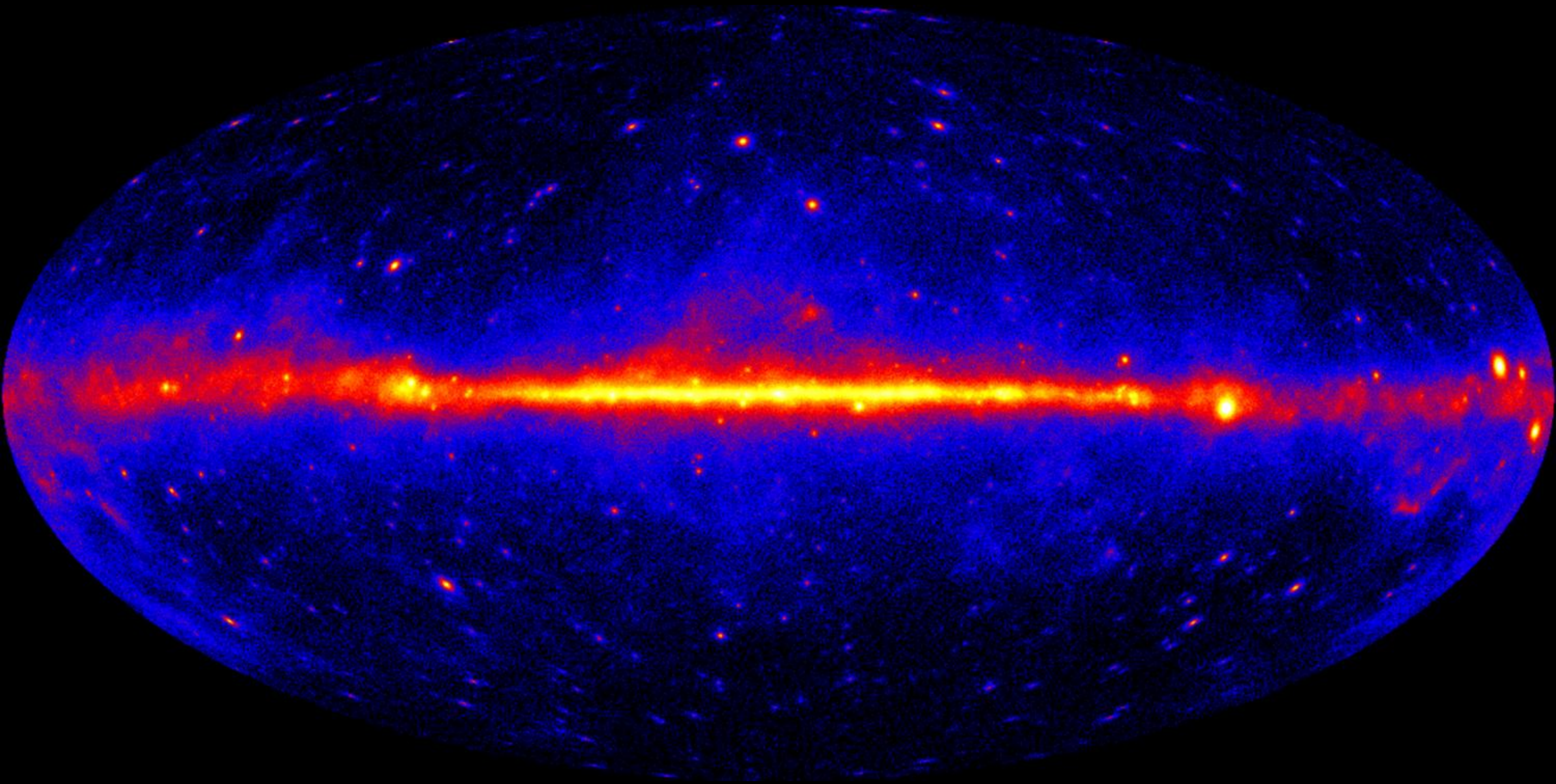
- **The normal operating mode of Fermi is more-or-less zenith pointed.**



- Avoids looking at the Earth.
- Scans the sky each orbit.
- Rock +50° (toward the north orbital pole) one orbit.
- Rock –50° (toward the south orbital pole) the next orbit.
- In a single day quite uniform coverage of the entire sky is obtained.

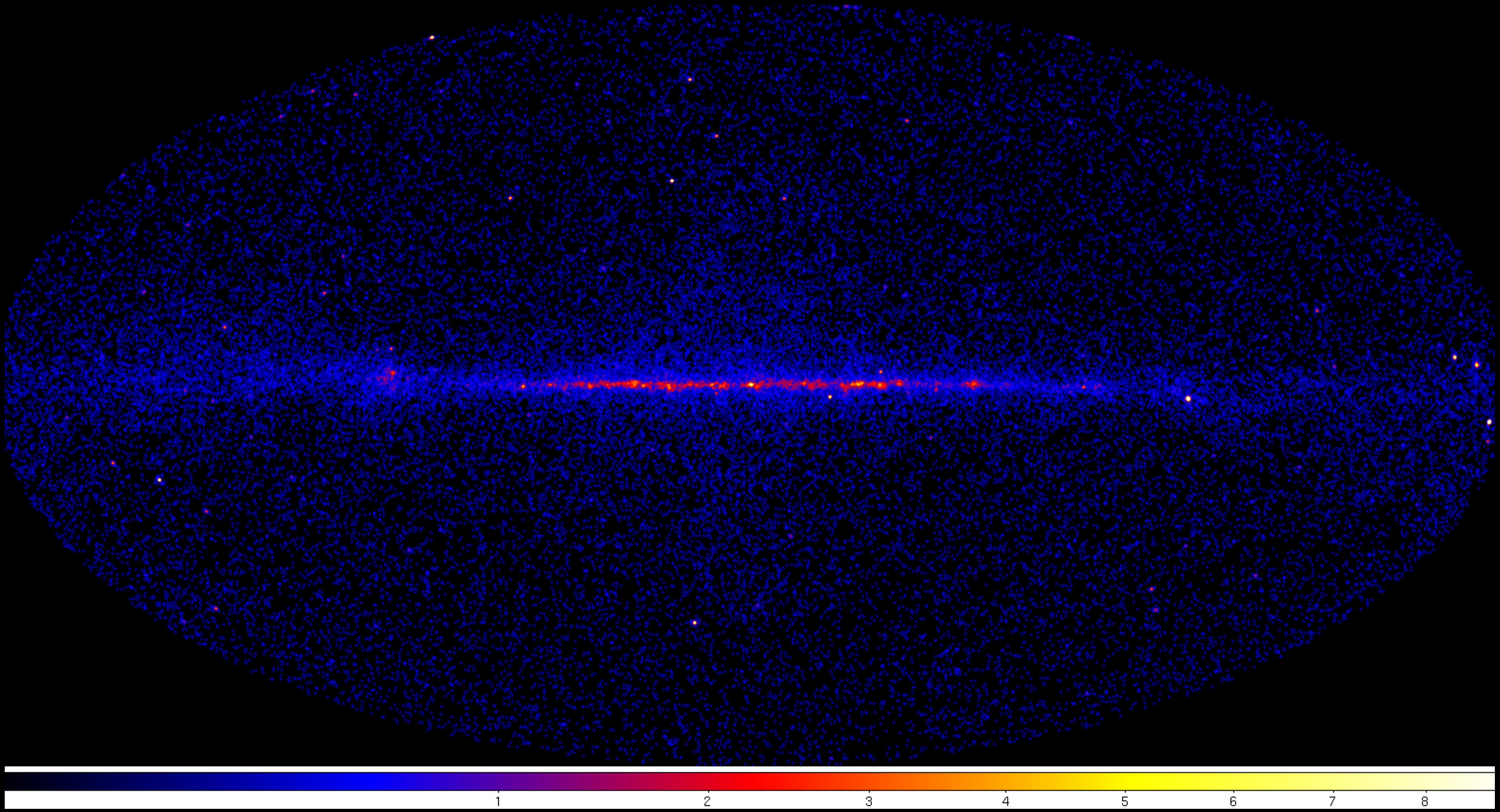


1-Year All-Sky Map, E>200 MeV



Rate map, exposure corrected, log scale.

1-Year All-Sky Map, E>10 GeV

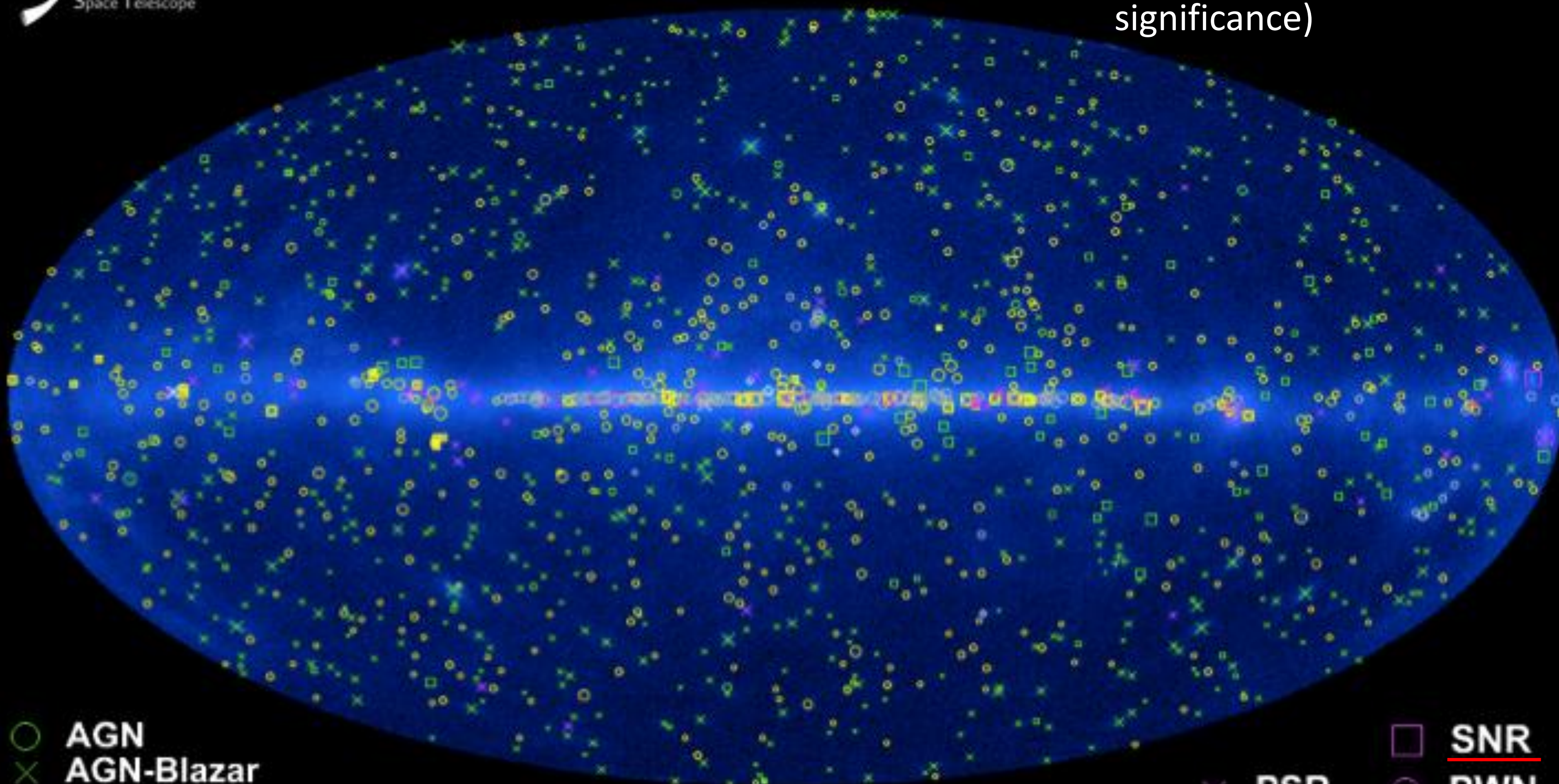


Counts map.

The Fermi LAT 1FGL Source Catalog

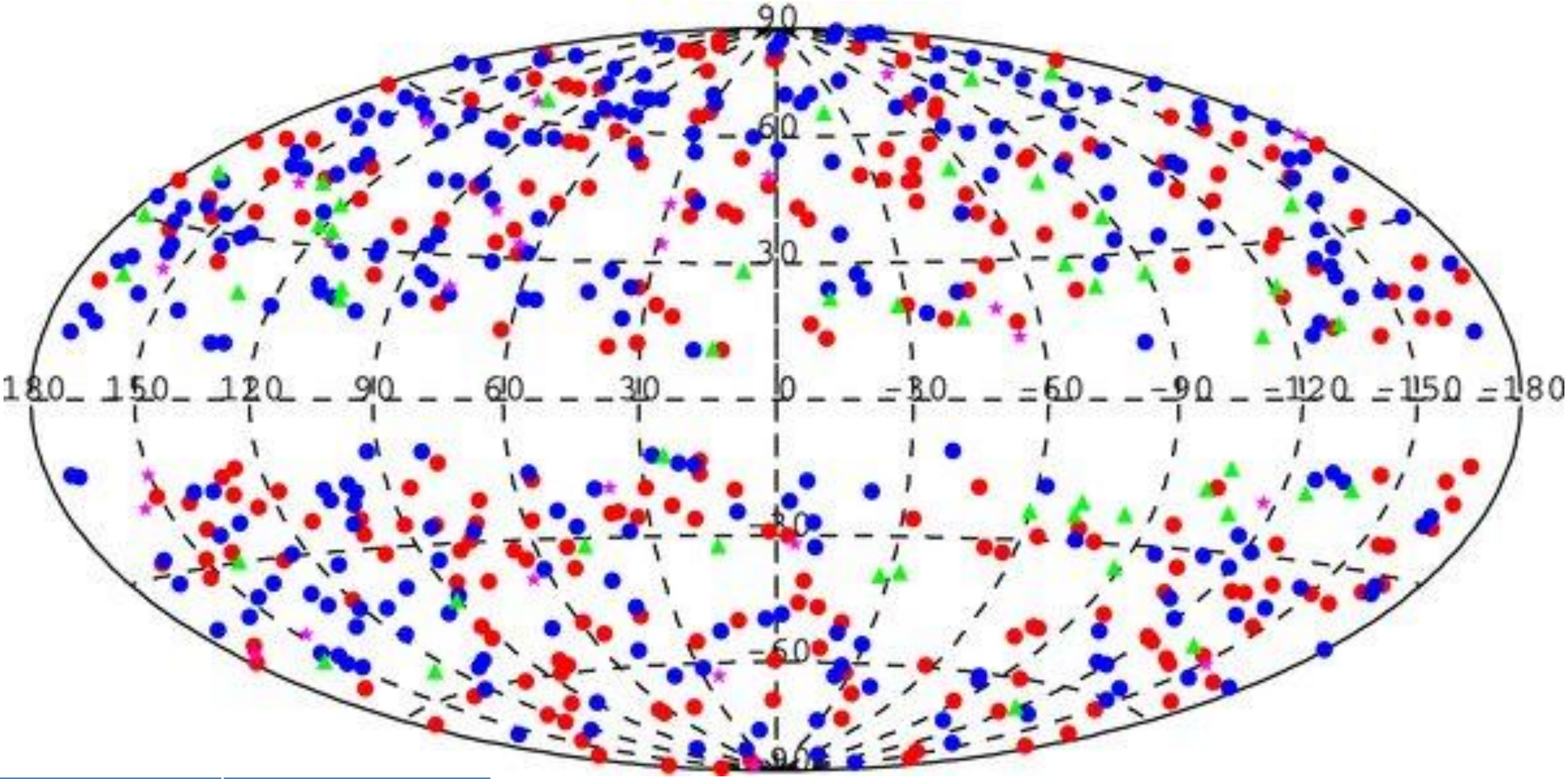
First 11 months of data

1451 Sources (>4σ significance)



New classes not associated (confidently) with γ-ray sources in 3[rd] EGRET catalog.

AGN Catalog

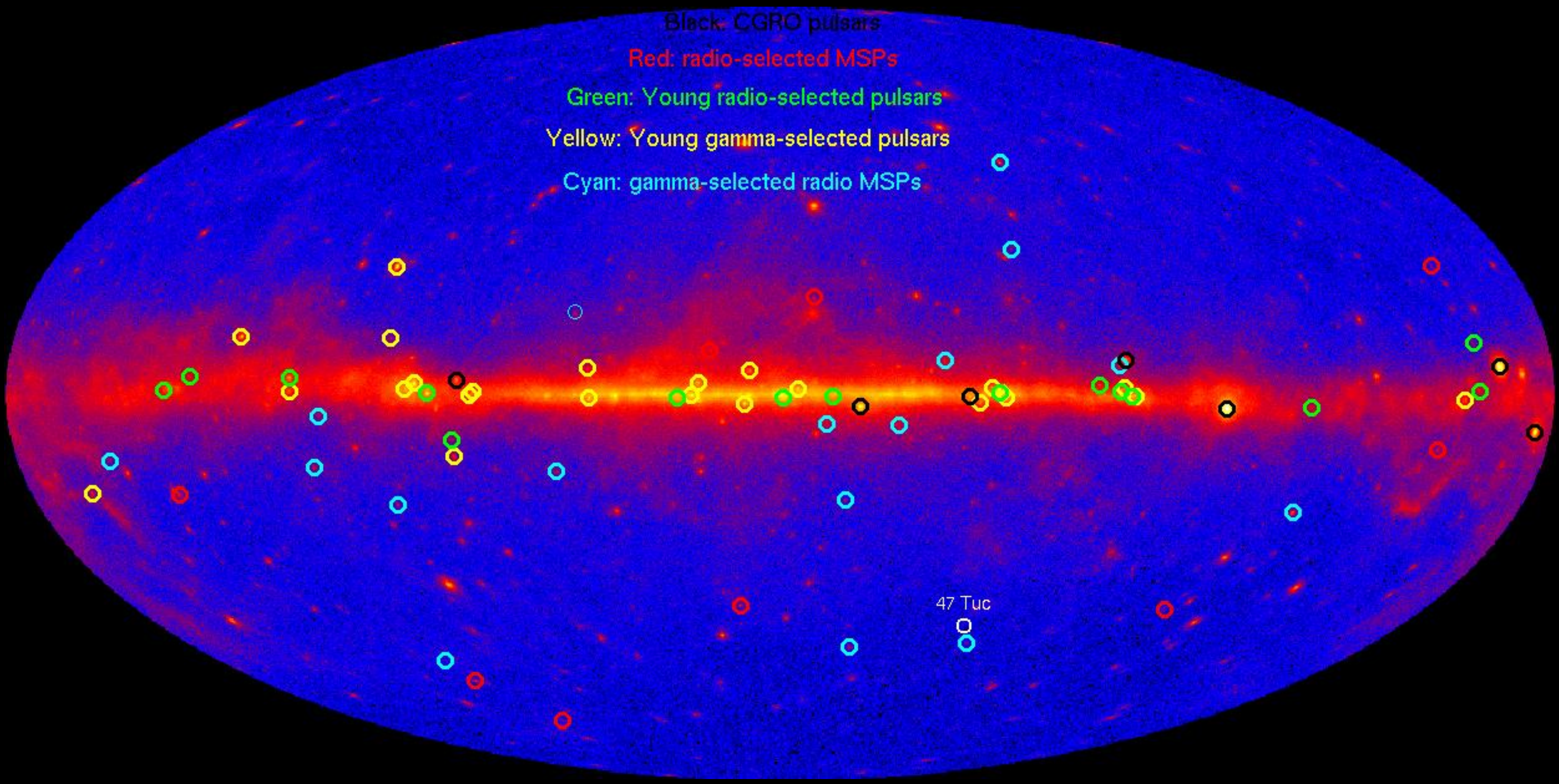


Type	Number
FSRQ	296
BL Lac	300
Other AGN	41
Undetermined	72

First 11 months of data.
709 sources identified as AGN.

ApJ **715**, 429, May 2010

Gamma-Ray Pulsars

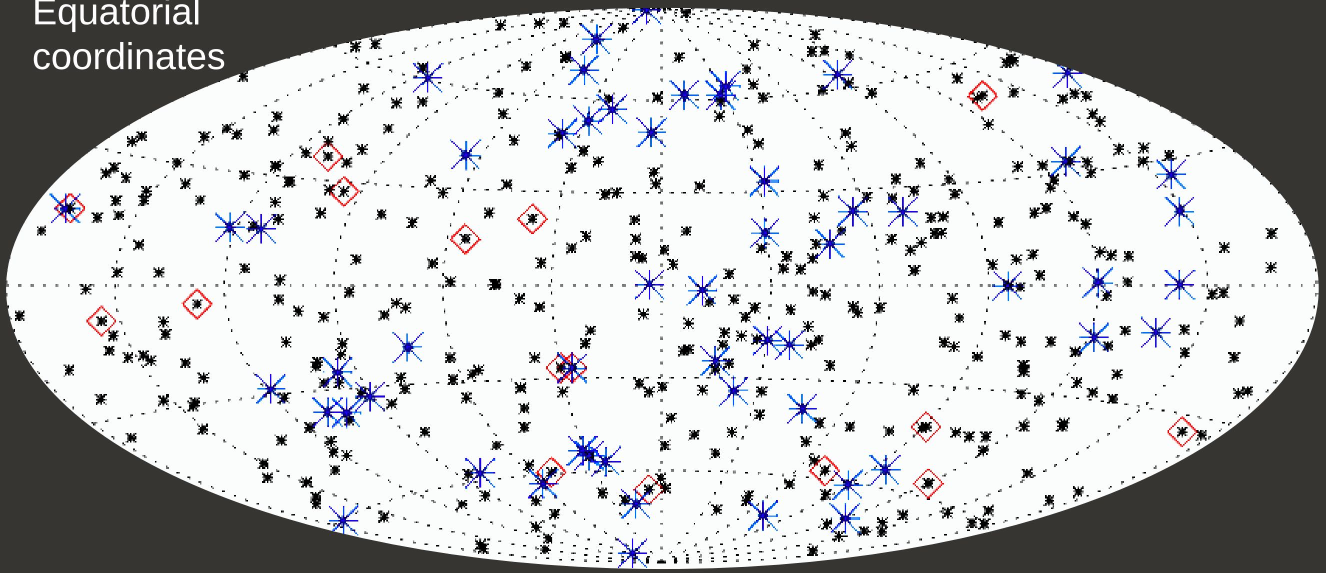


More than 56 gamma-ray pulsars in the first year
Plus gamma-selected MSPs

ApJS, 187, 460 (2010)
arXiv:1006.2134v1

Gamma-Ray Bursts (GRB)

Equatorial coordinates



As of April, 2010:
- 427 GBM GRB.
- 56 also observed by the Swift BAT.
- 16 LAT GRB (~½ of GBM bursts are in the LAT field of view).

First 12 LAT-detected bursts (high-energy photons):

GRB 080825C	
GRB 080916C	z = 4.35 +/-0.15 (GROND/photometric) 13 GeV photon!
GRB 081024B	short-duration burst
GRB 081215A	
GRB 090217	
GRB 090323	z = 3.6 (Gemini/spectroscopic)
GRB 090328	z = 0.736 (Gemini/spectroscopic)
GRB 090510	z = 0.903 (VLT/spectroscopic); short duration; 31 GeV photon!
GRB 090626	
GRB 090902B	z = 1.822 (Gemini/spectroscopic) 33 GeV photon!
GRB 090926A	z=2.1 (VLT/spectroscopic) 19.6 GeV photon!
GRB 091003	

Fermi
Gamma Ray
Space Telescope

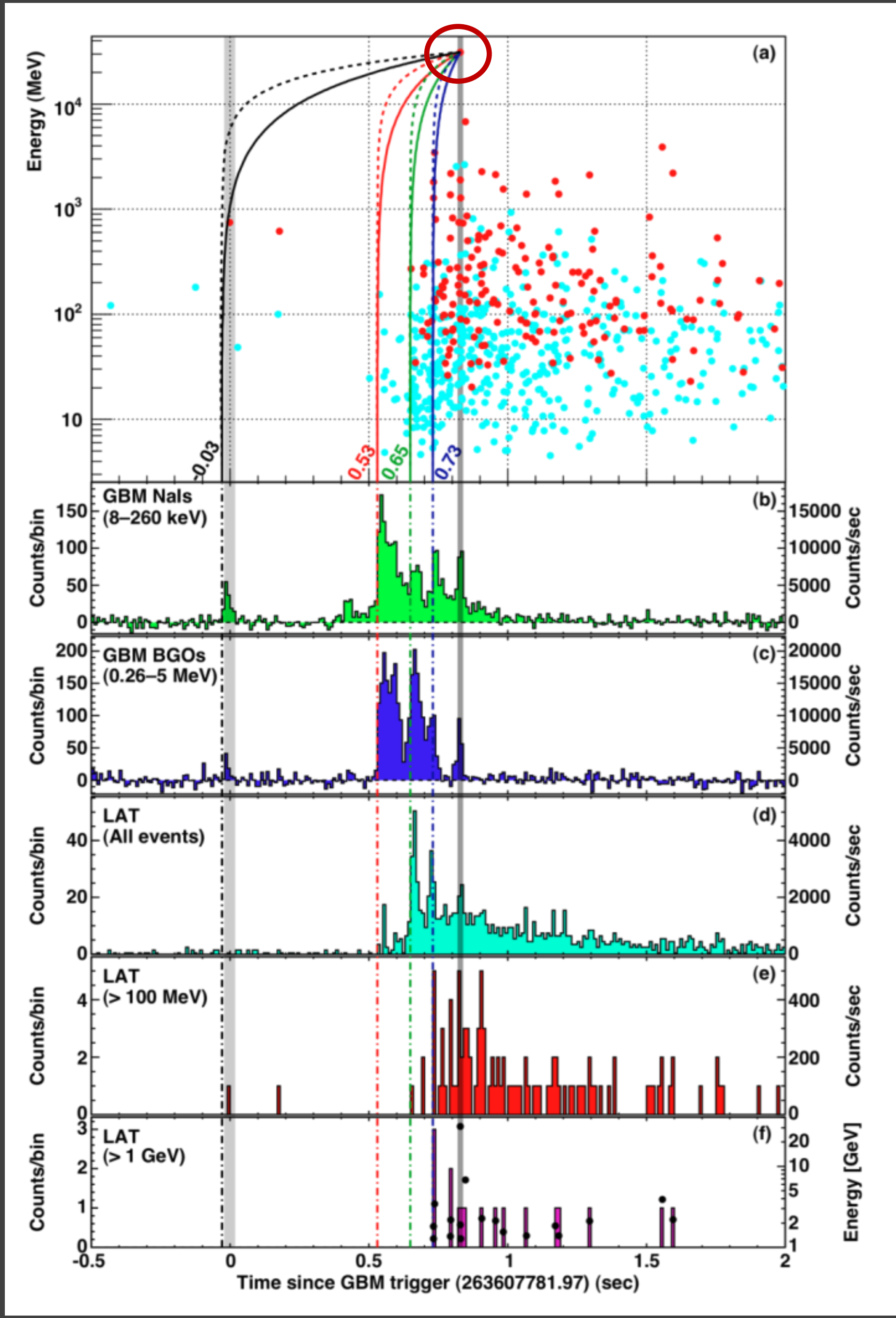
GRB 090510

Interesting constraint on Quantum Gravity ideas:

Some quantum gravity "theories" predict that high energy photons should travel slightly more slowly than low-energy photons.

In this GRB we see a 31 GeV photon less than 1 second after the first X-ray photons, after traveling >7 billion light years.

This requires the quantum-gravity mass scale to be at least ***1.2 times the Planck mass.***



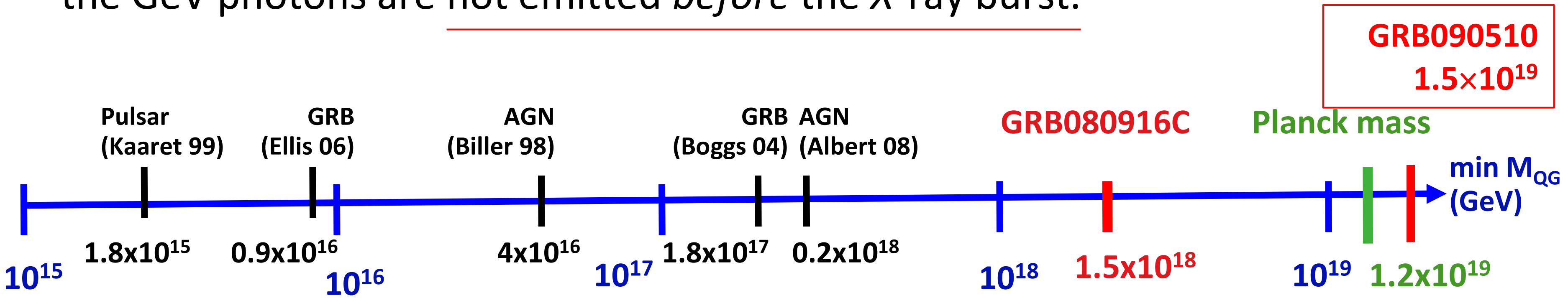
Nature **462**, pp 291, 331.

Limits on Lorentz Invariance Violation

- Assume dispersion: $v = \delta E/\delta P \sim c\,(1-(E/E_{QG})^n)$ with $n=1$
- Cosmological distance:

$$\Delta t = \frac{(1+n)}{2H_0}\frac{E_h^n - E_l^n}{(M_{\mathrm{QG},n}c^2)^n}\int_0^z \frac{(1+z')^n}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}\,dz'$$

- In GRB 080916C (z=4.2) the highest energy photon, 13.2 GeV, was detected 16.5 s after the GBM trigger.
- In GRB 090510 (z=0.90) the 31 GeV photon was detected only 0.83 s after the GBM trigger.
- The time delay due to quantum gravity cannot be more than this, assuming that the GeV photons are not emitted *before* the *X*-ray burst.



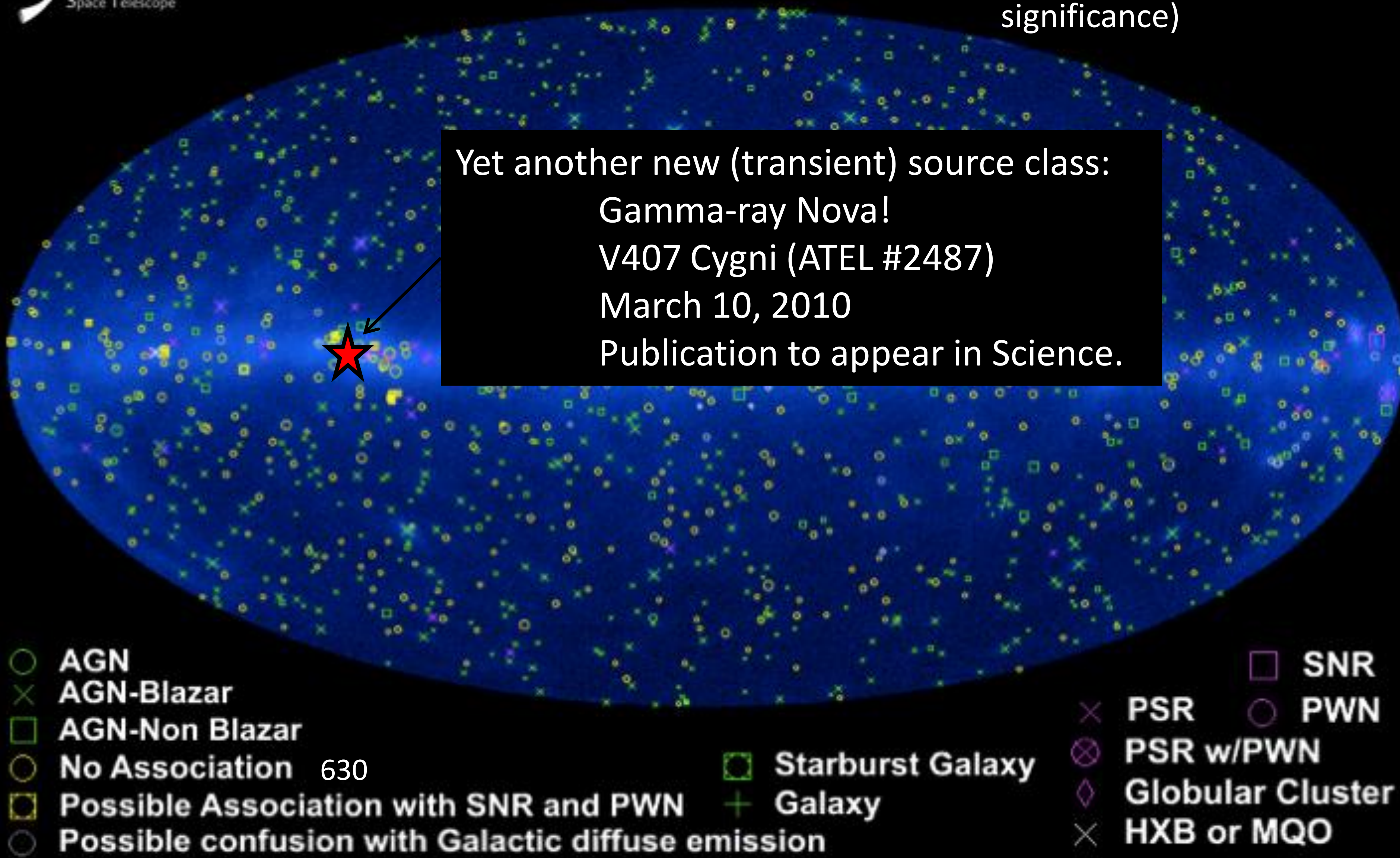
The Fermi LAT 1FGL Source Catalog

Fermi Gamma-ray Space Telescope

First 11 months of data

1451 Sources (>4σ significance)

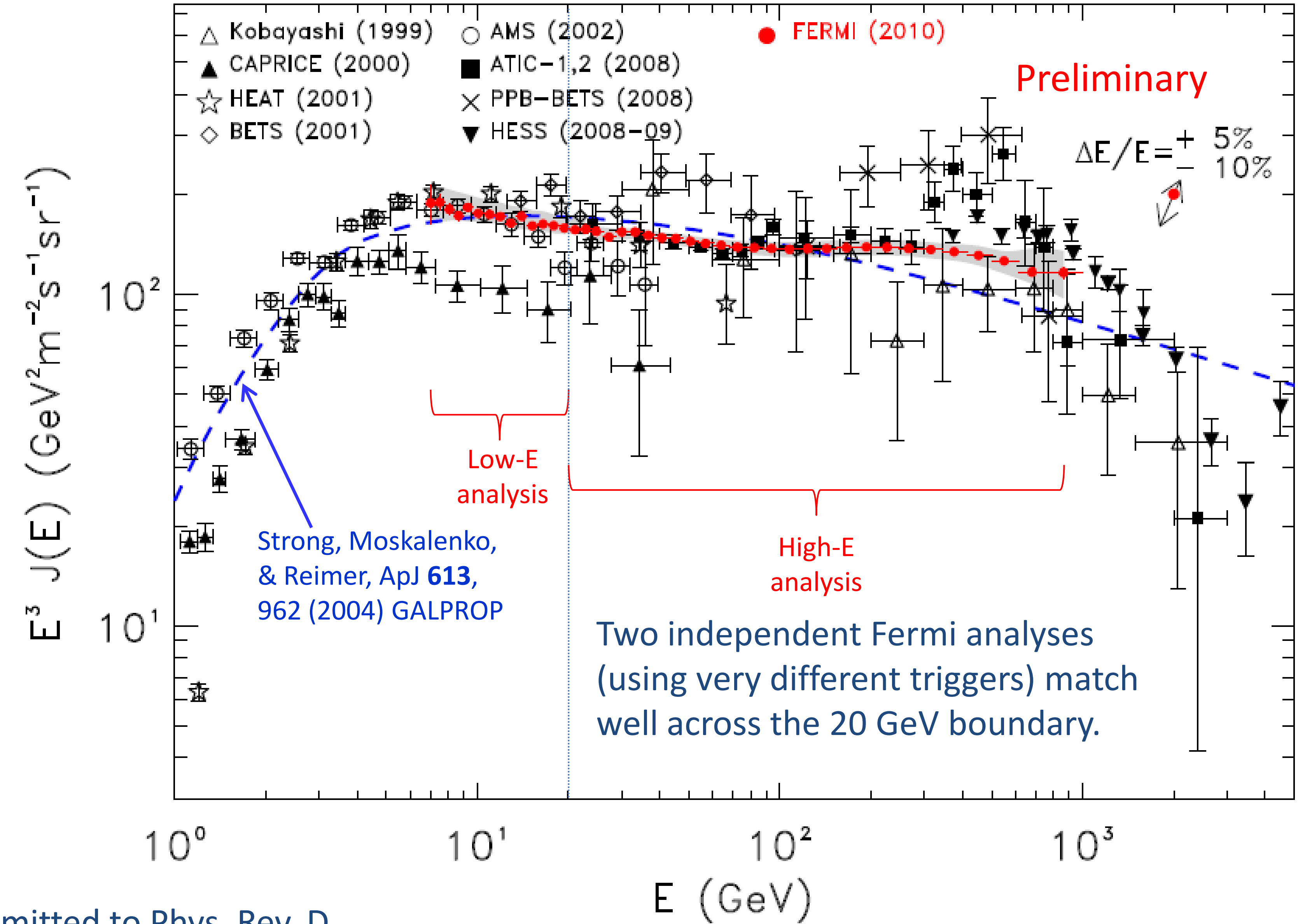
Yet another new (transient) source class:
Gamma-ray Nova!
V407 Cygni (ATEL #2487)
March 10, 2010
Publication to appear in Science.



arXiv:1002.2280

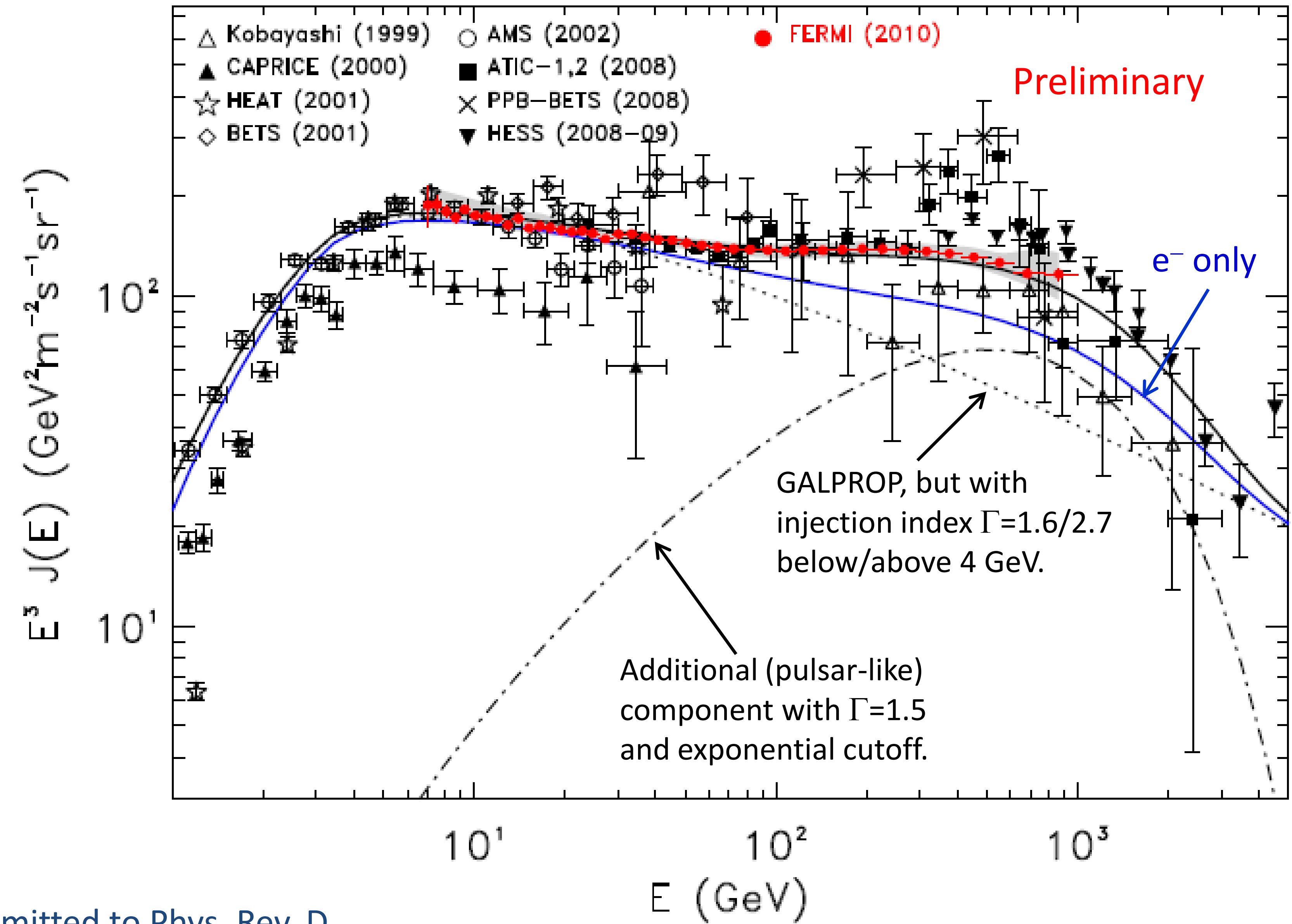
Credit: *Fermi* Large Area Telescope Collaboration

Cosmic-Ray Electrons (7 GeV to 1 TeV)



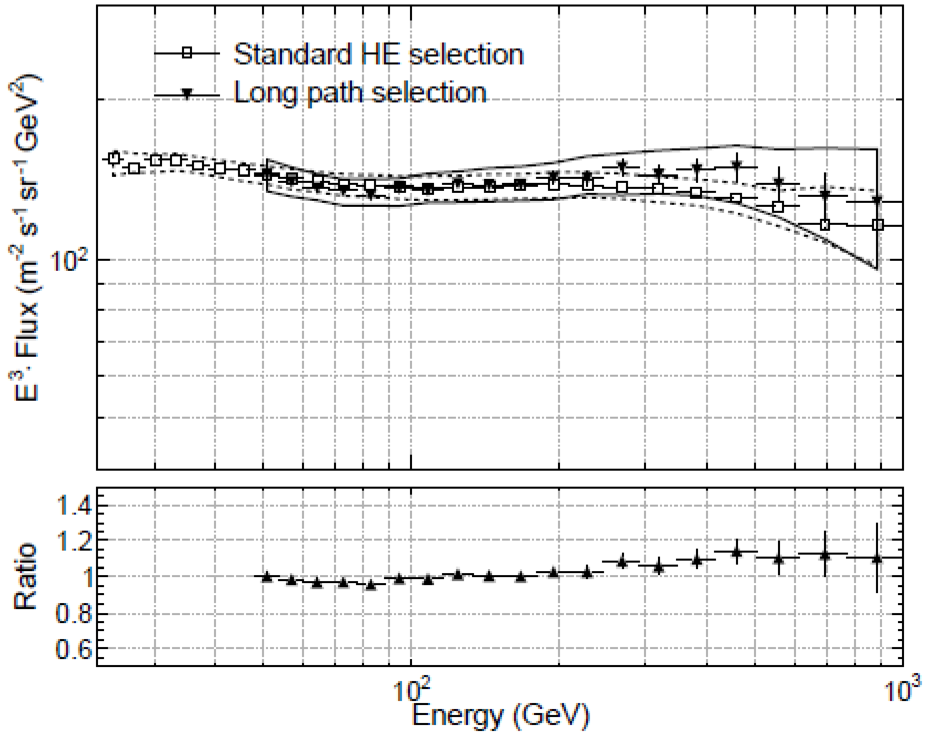
Submitted to Phys. Rev. D

Cosmic-Ray Electrons (7 GeV to 1 TeV)



Submitted to Phys. Rev. D

Cosmic-Ray Electrons



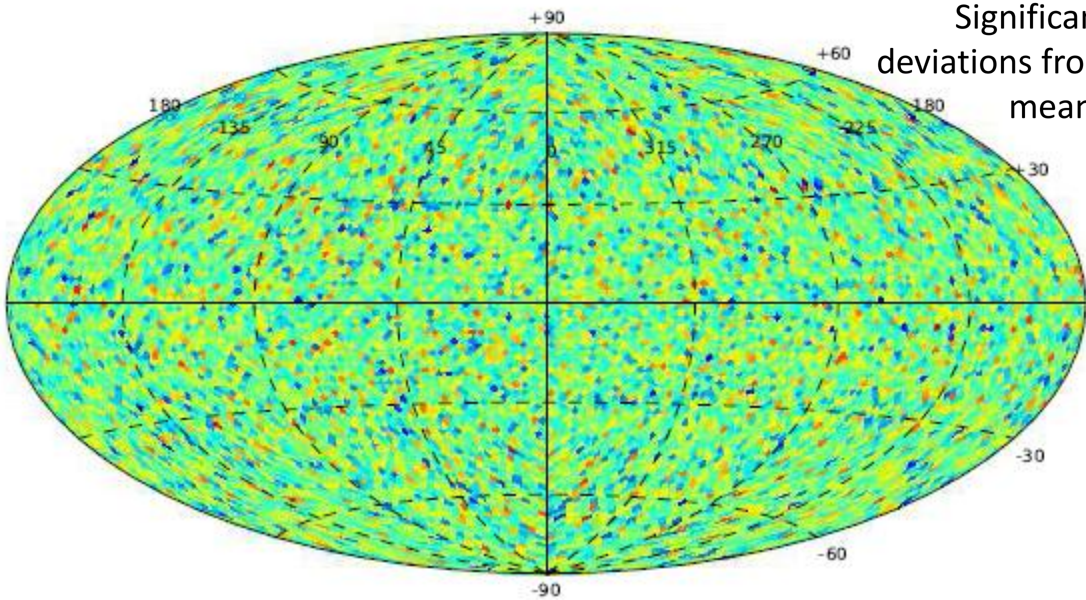
- To counter claims that our calorimeter is too thin at normal incidence to measure up to 1 TeV, we repeated the analysis using only electrons passing through at least 12 X_0 of material (average of 16 X_0).
- The results are consistent and still rule out any sharp peak around 800 GeV.

Submitted to Phys. Rev. D

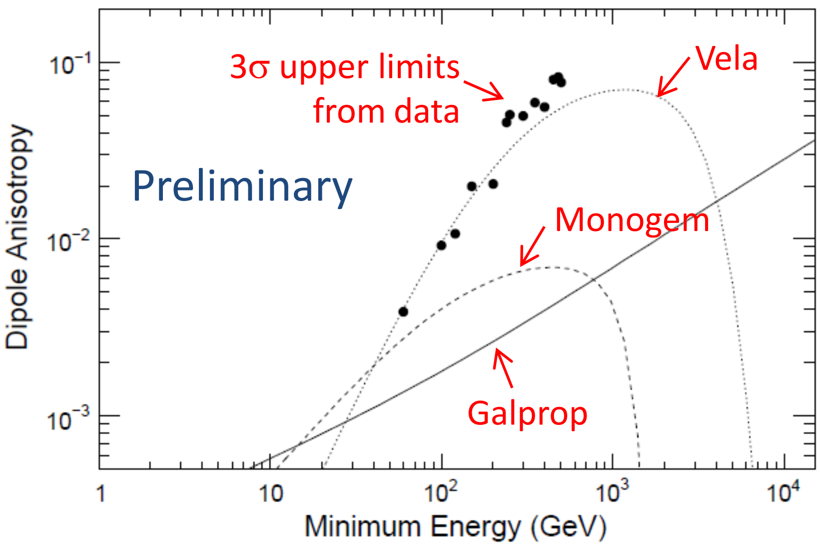
Cosmic-Ray Electron Anisotropy

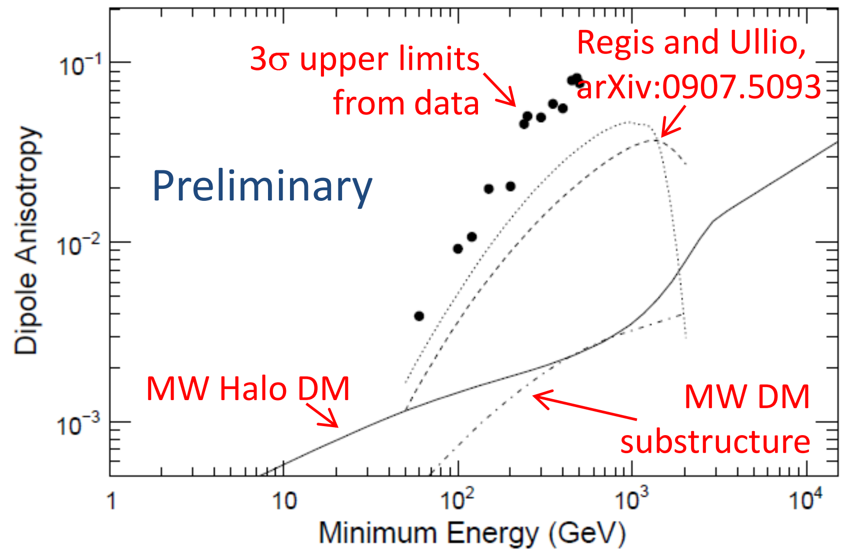
Submitted to Phys. Rev. D

- No significant anisotropy is observed in the CR electron flux.
- The results can rule out dominance of a very bright nearby source.

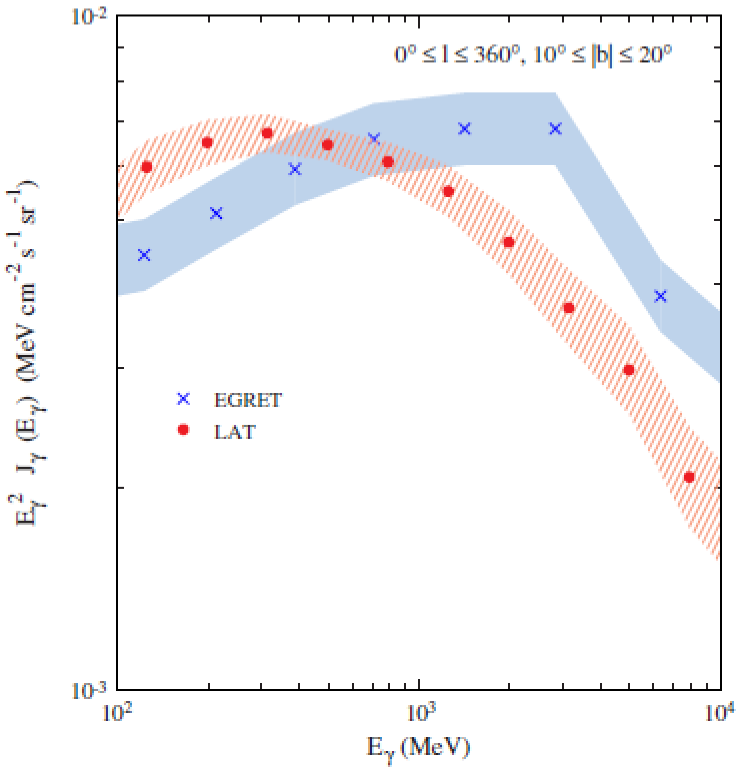


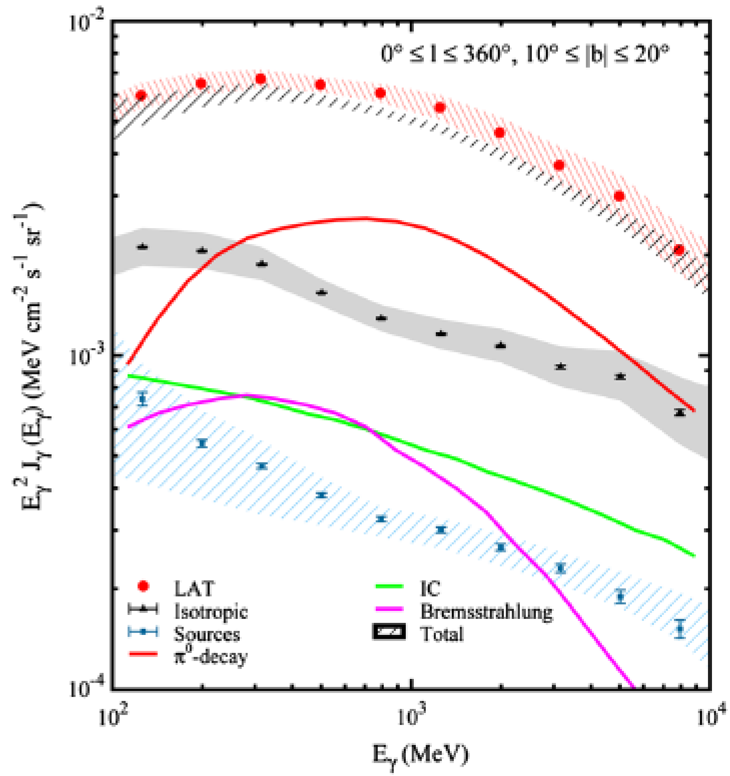
Significance of deviations from the mean rate.





Galactic Diffuse Emission

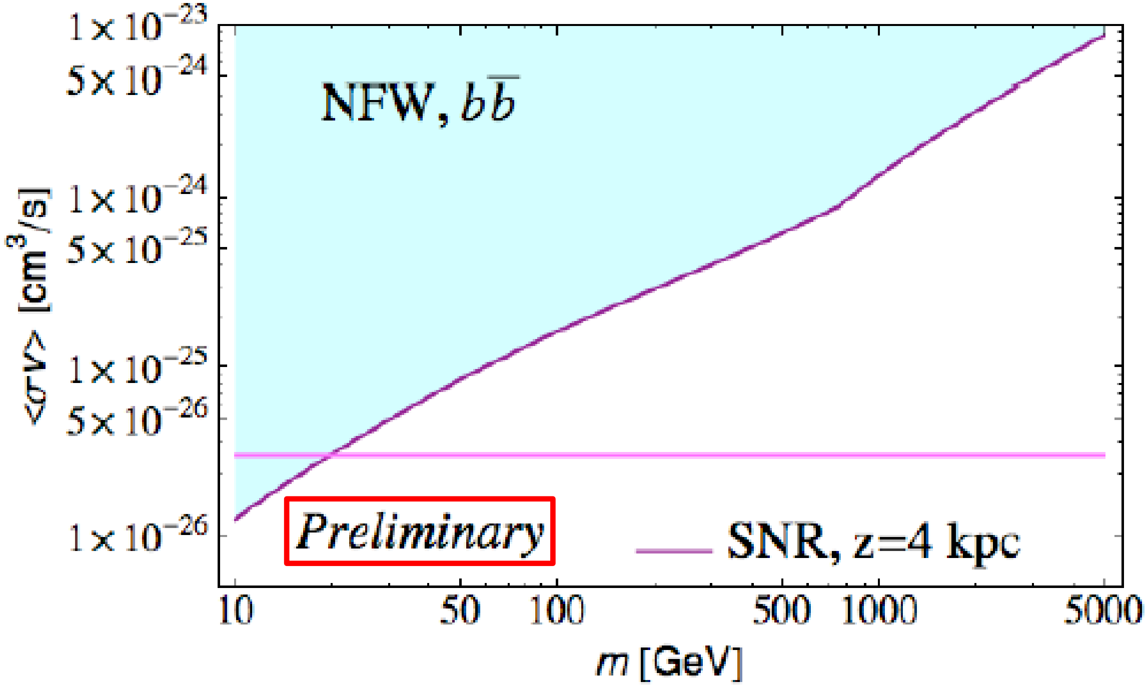




- The first Fermi-LAT publication on the galactic diffuse spectrum is in disagreement with the EGRET spectrum.
- In particular, there is no obvious “GeV excess” with respect to standard models of the diffuse production from cosmic rays.

PRL **103**, 251101 (Dec 2009)

Halo Dark Matter Limits (|b|>10°)

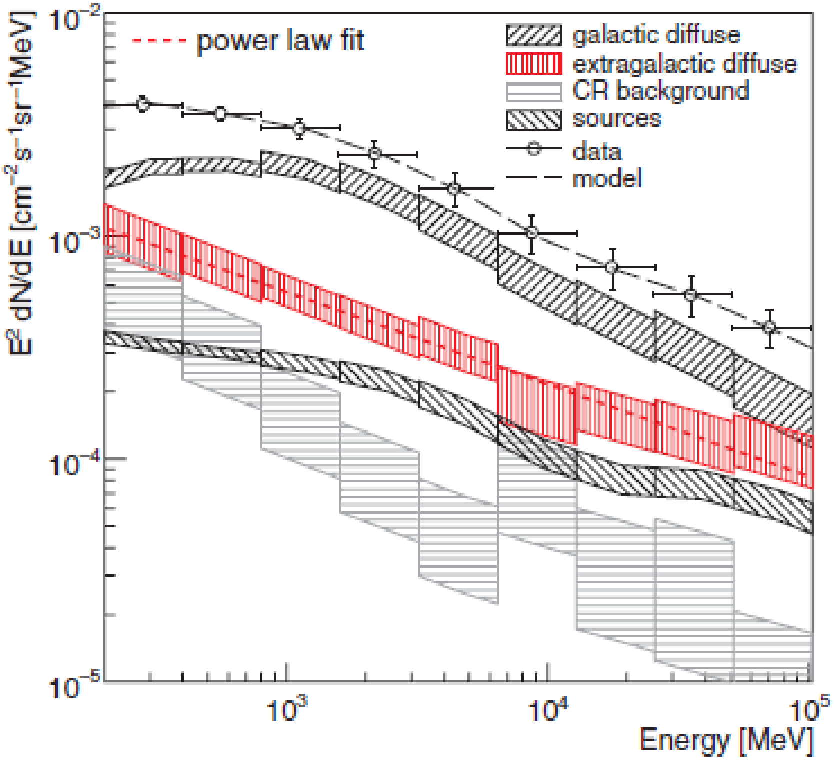


unpublished

The diffuse flux from the Galactic halo can be used to set limits on dark-matter annihilation.

- Relies on differences in the angular and spectral distributions of the diffuse production from cosmic rays versus dark matter.
- Still very preliminary. Investigations are still in progress of the dependence of the result on our astrophysical models of the Galaxy (e.g the CR source distribution, halo height, diffusion coef. etc.).

Isotropic (Extragalactic) Diffuse Emission



|b|>10°

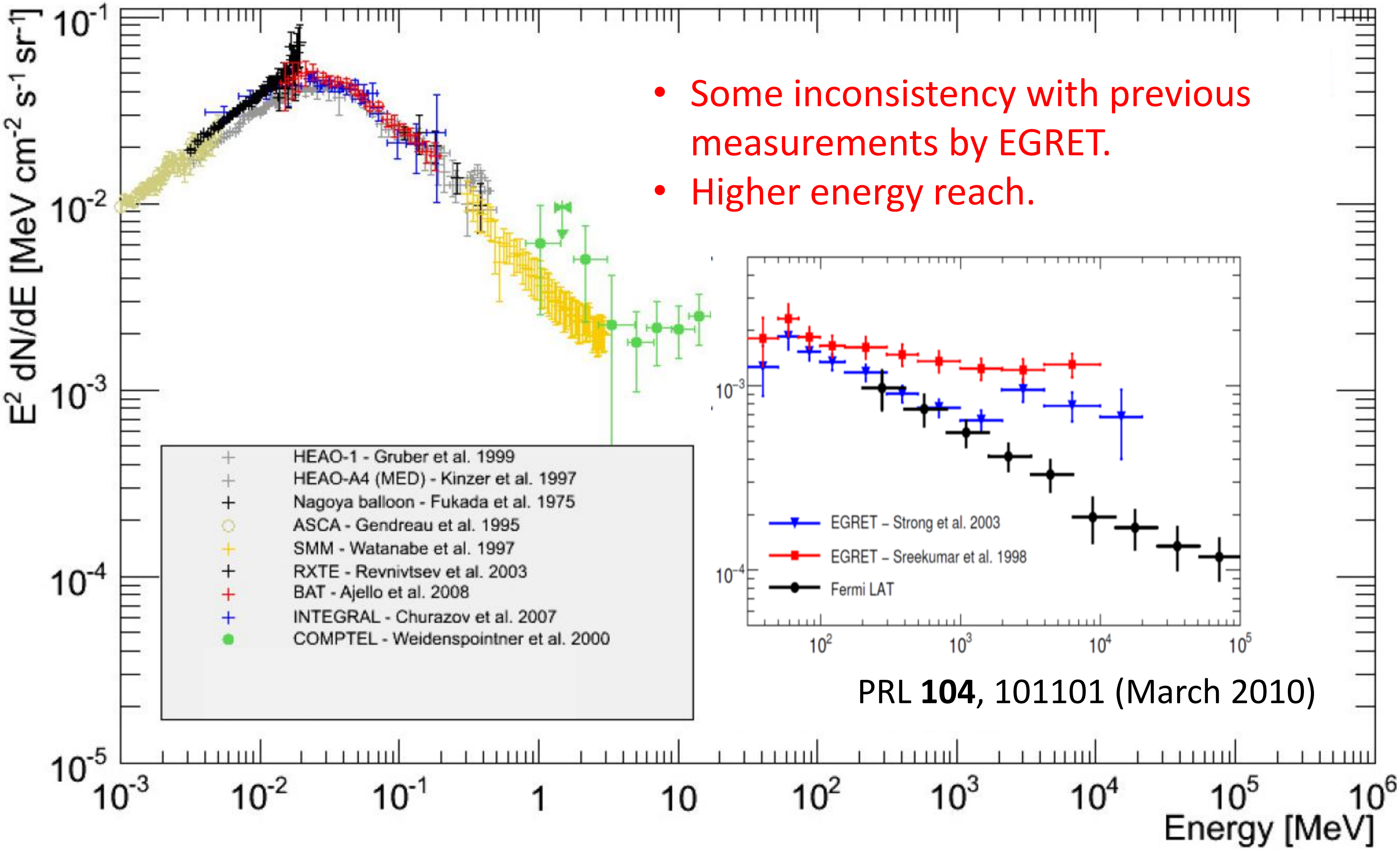
- Spectral Index γ=2.41 $\pm$ 0.05
- Intensity (E>100 MeV)= $(1.03 \pm 0.17)\times10^{-5}$ cm^{-2} s^{-1} sr^{-1}

PRL **104**, 101101 (March 2010)

A recently published analysis has extracted the isotropic flux of gamma rays (believed to be primarily extragalactic) by reducing and understanding the residual CR background.

- Based on Fermi measurements of the blazar luminosity function (arxiv:1003.0895), unresolved AGN can account for up to 30% of this diffuse.
- Star forming galaxies *may* be able to account for most of the rest (Fields et al., arxiv:1003.3647).

Isotropic SED from 1 keV to 100 GeV



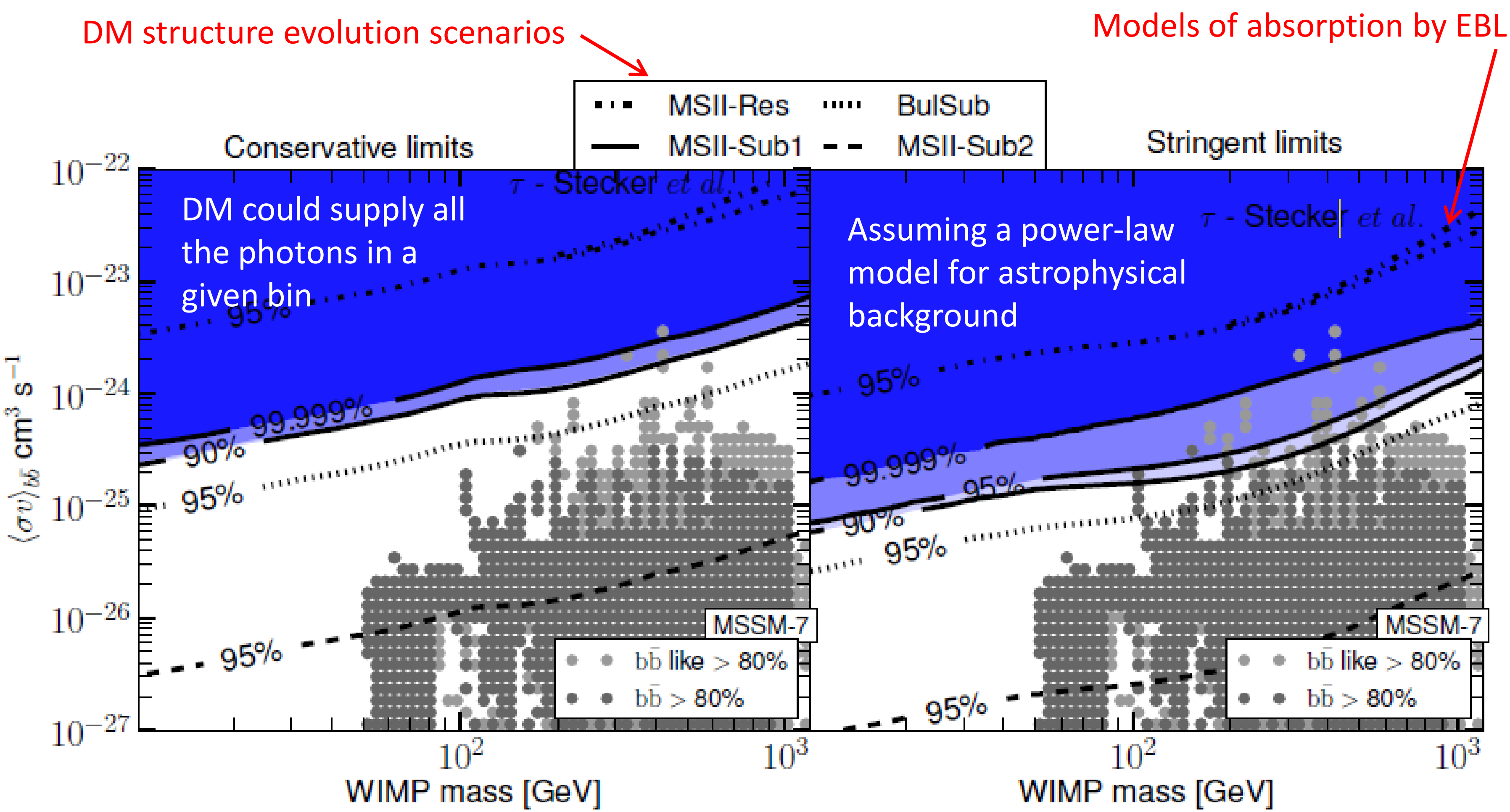
- Some inconsistency with previous measurements by EGRET.
- Higher energy reach.

PRL **104**, 101101 (March 2010)

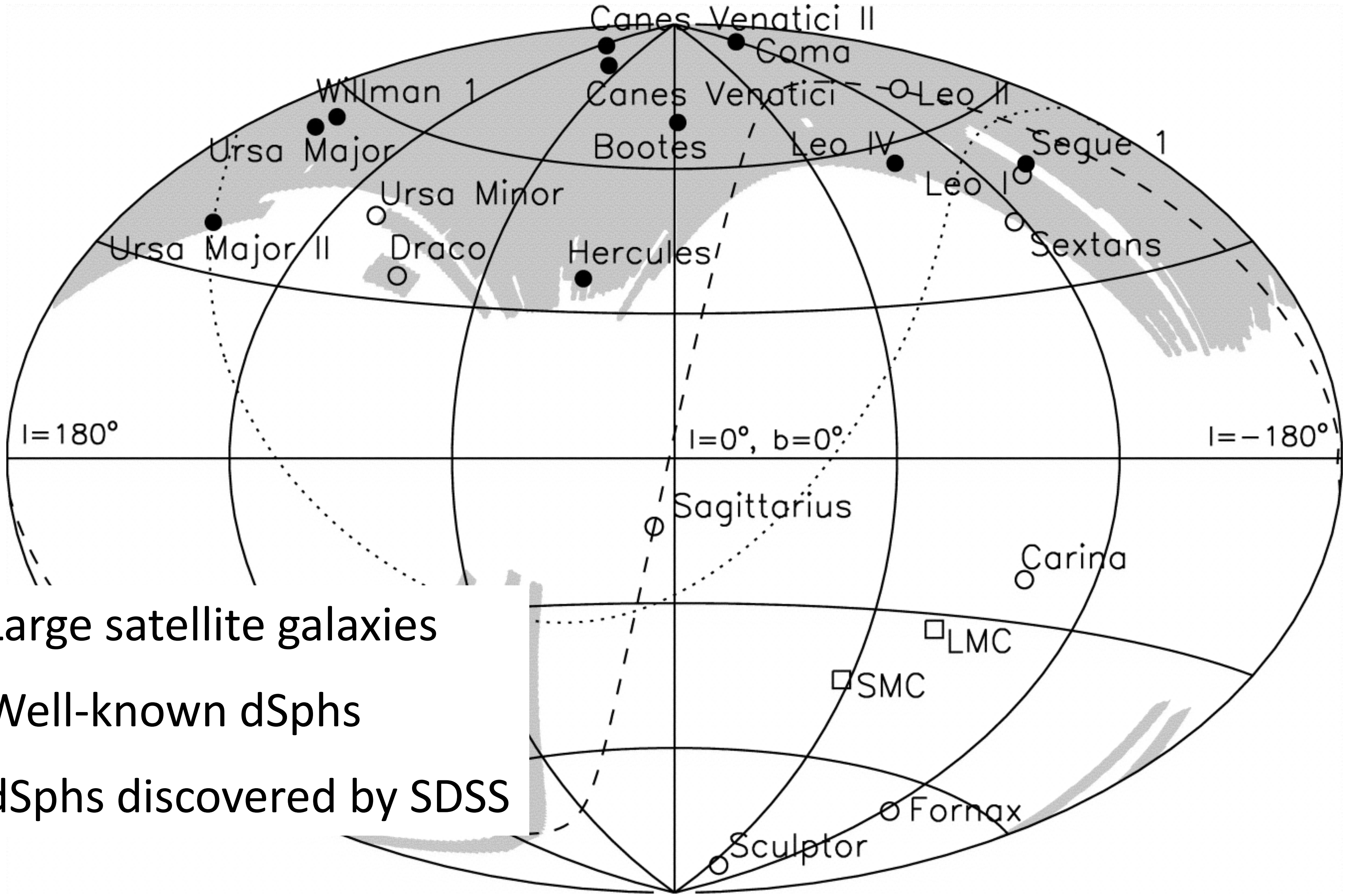
Cosmological Dark Matter

The isotropic extragalactic contribution have be interpreted in terms of limits on cosmological dark matter annihilation:

JCAP04 (2010) 014



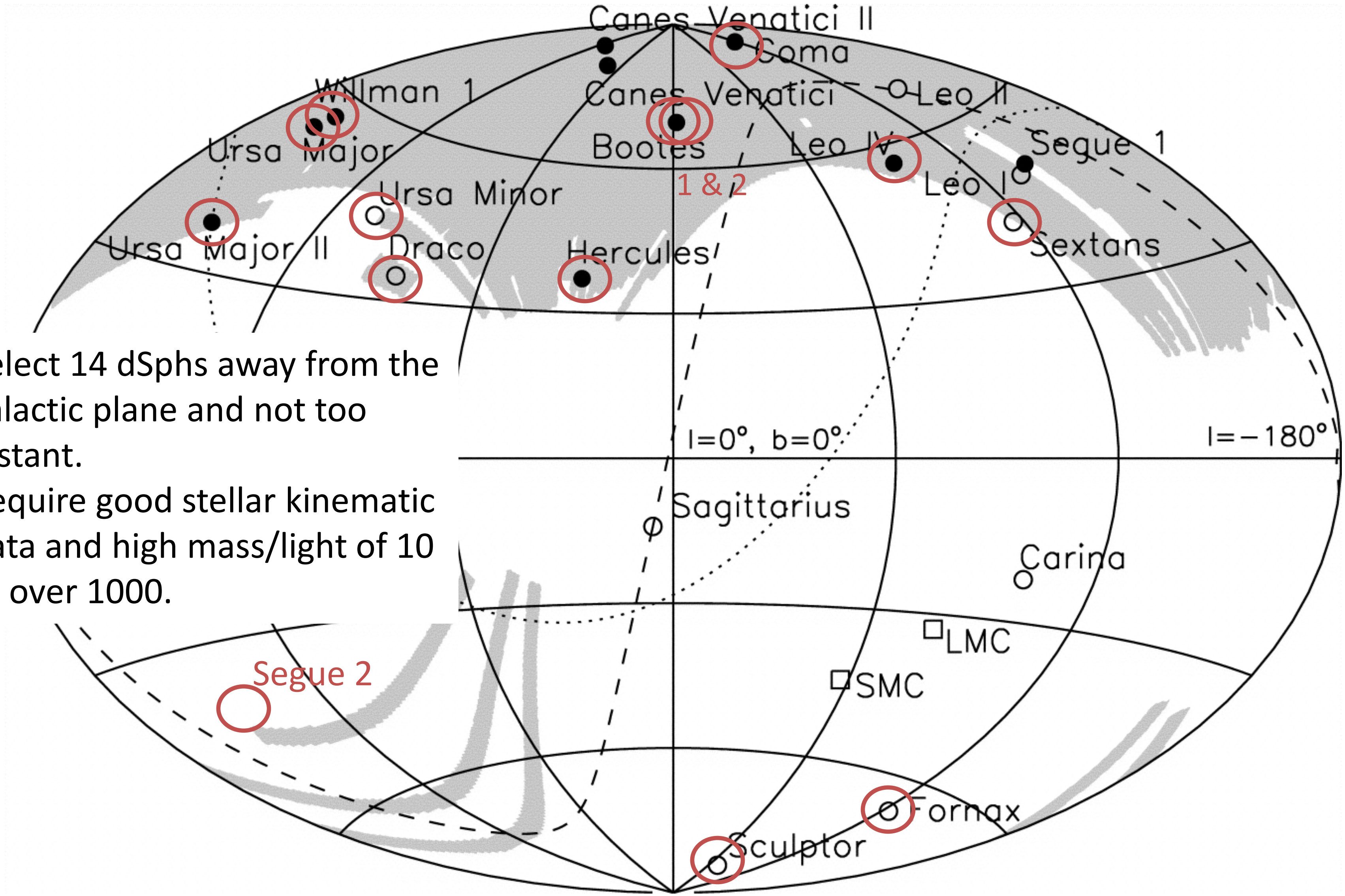
Dwarf Spheroidal Galaxies



- □ Large satellite galaxies
- ○ Well-known dSphs
- ● dSphs discovered by SDSS

Belokurov, V., et al. 2007, ApJ, 654, 897

Dwarf Spheroidal Galaxies, DM Search

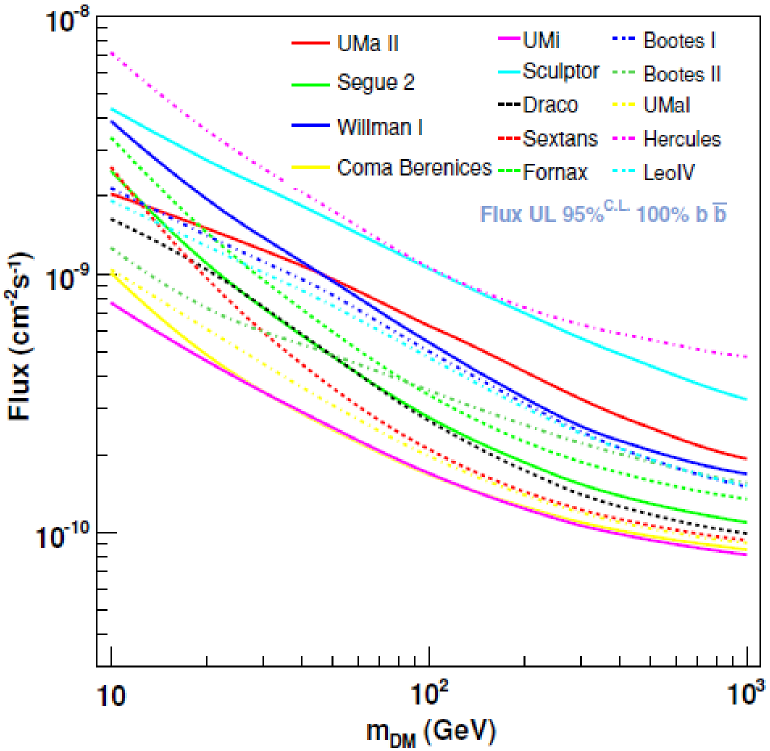


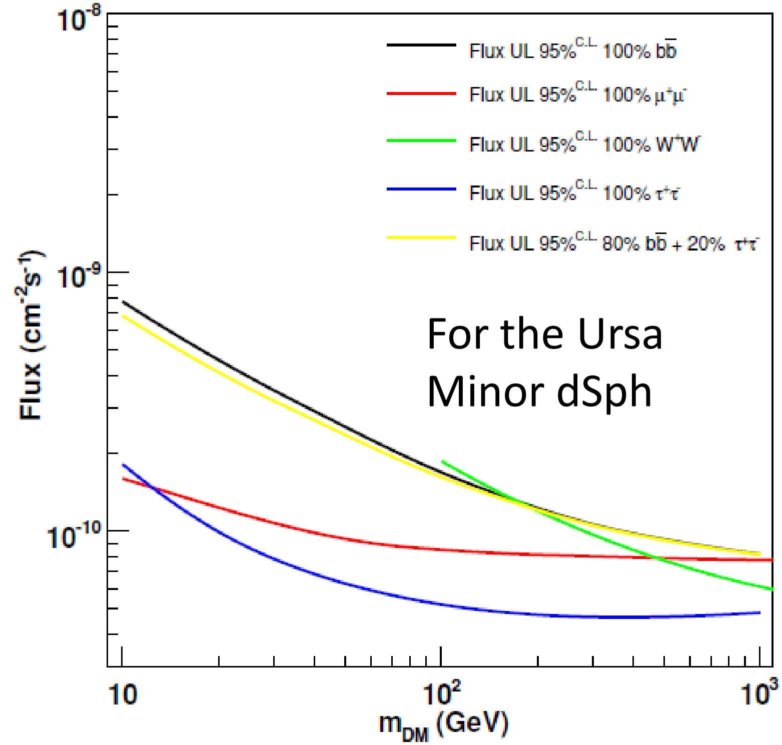
Select 14 dSphs away from the galactic plane and not too distant.
Require good stellar kinematic data and high mass/light of 10 to over 1000.

Belokurov, V., et al. 2007, ApJ, 654, 897

Dwarf Spheroidal Galaxies

- Flux limits for DM annihilation spectra
- The limit depends on the WIMP mass and the decay mode





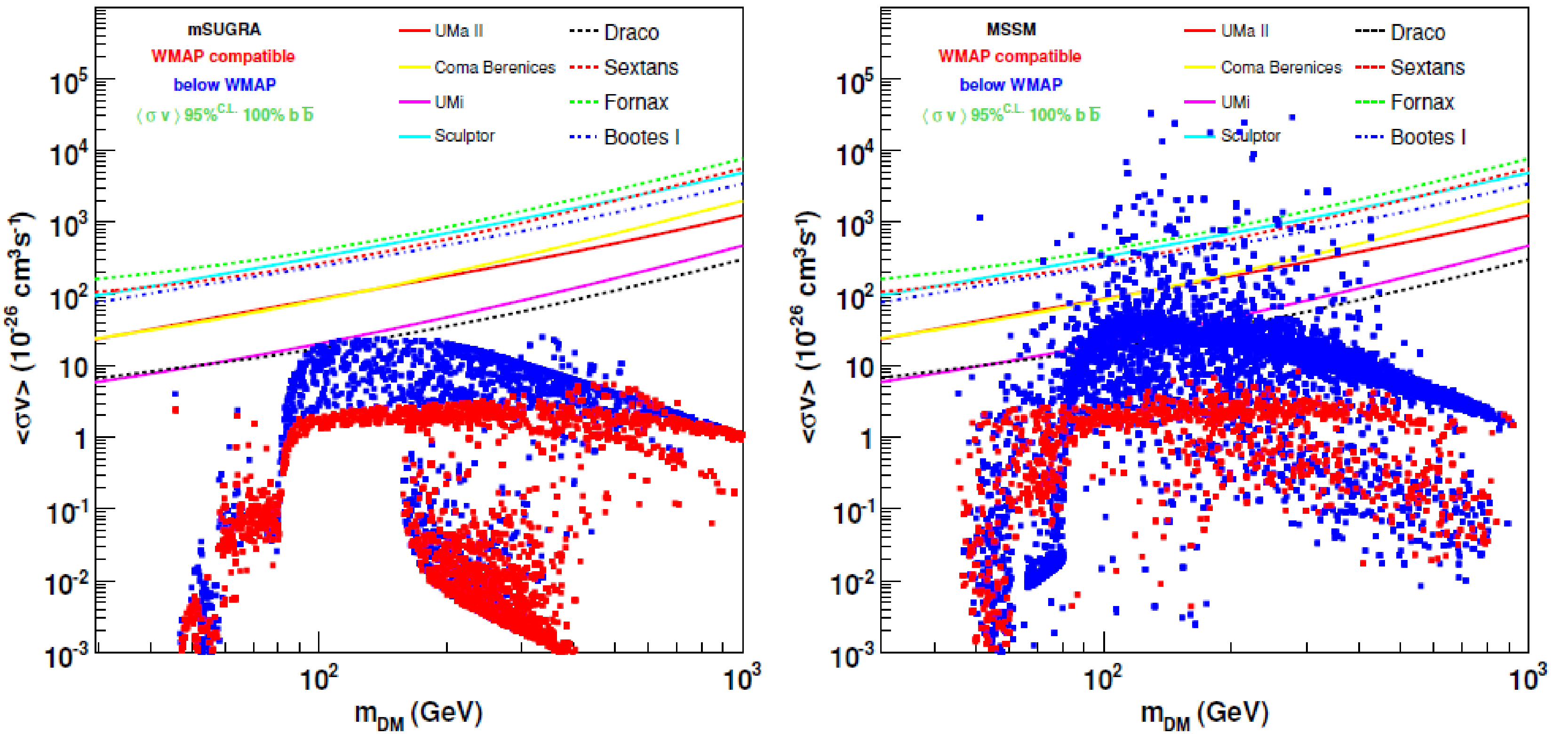
ApJ 712 (2010) 147.

Dwarf Spheroidal Galaxies

- Stellar data from Keck (Bullock, Kaplinghat, Martinez) were used to evaluate the DM content of each of 8 dwarfs, to translate the flux limits into annihilation cross section limits. *No substructure boost assumed.*
- Red points are models with a cosmological WIMP thermal relic density compatible with WMAP data.

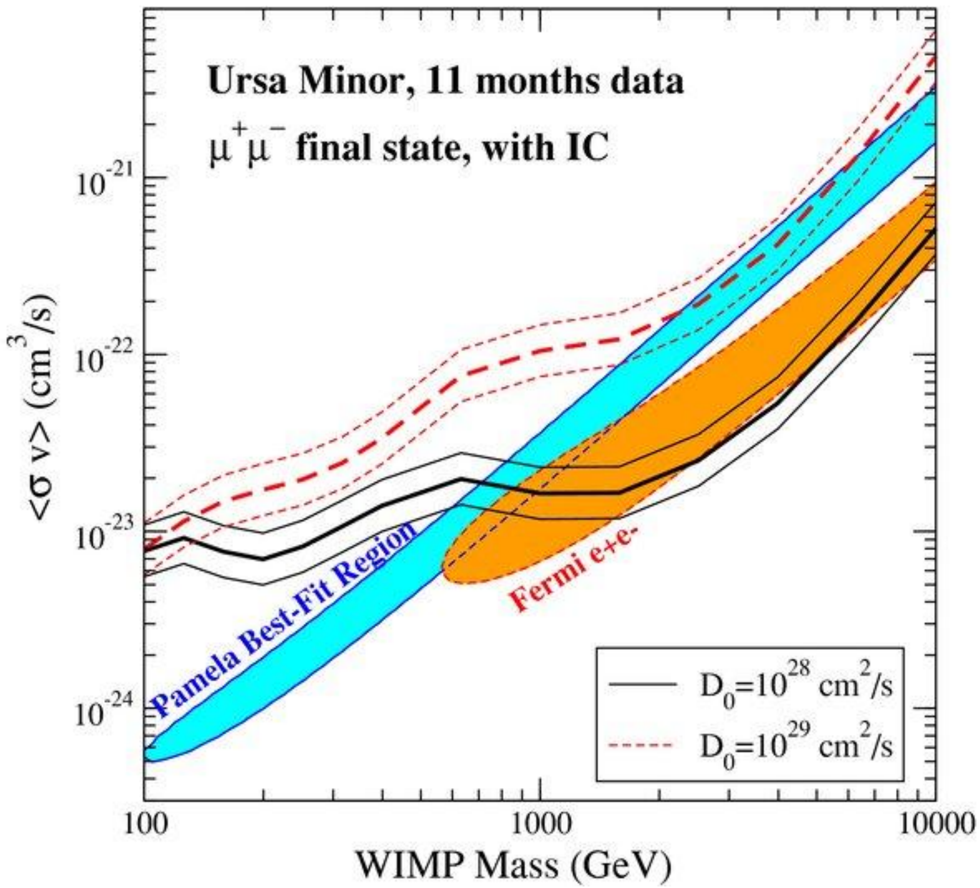
ApJ 712 (2010) 147.

- Work is in progress to combine all dwarfs into a single limit, giving about a 40% improvement over the best of these published results.



Dwarf Spheroidal Galaxies

Lepto-phylic models, such as those proposed to explain the Pamela positron excess *and* Fermi electron spectrum, are nearly ruled out by these (and other) FERMI dark-matter limits.



ApJ 712 (2010) 147.

Conclusions

- Fermi is now two years into its (at least) five year mission, with a large, high-quality all-sky data set of gamma rays and electrons.
  - *The photon data are available to the public* as well as to the LAT and GBM collaborations.
- The first catalog of nearly 1500 sources includes several new classes of gamma-ray sources.
  - Bonanza for particle astrophysics of high-energy sources and studies of cosmic particle acceleration.
- High quality, high statistics measurements of the galactic and extragalactic diffuse emission have also been made.
  - Crucial for studying cosmic ray acceleration and propagation.
- No evidence of dark-matter annihilation has been seen.
  - The limits are close to but do not yet cut very much into the most interesting theoretical parameter space.
  - But, there is still much work to do here with 5 to 10 times more data as well as analysis refinements and new search avenues.

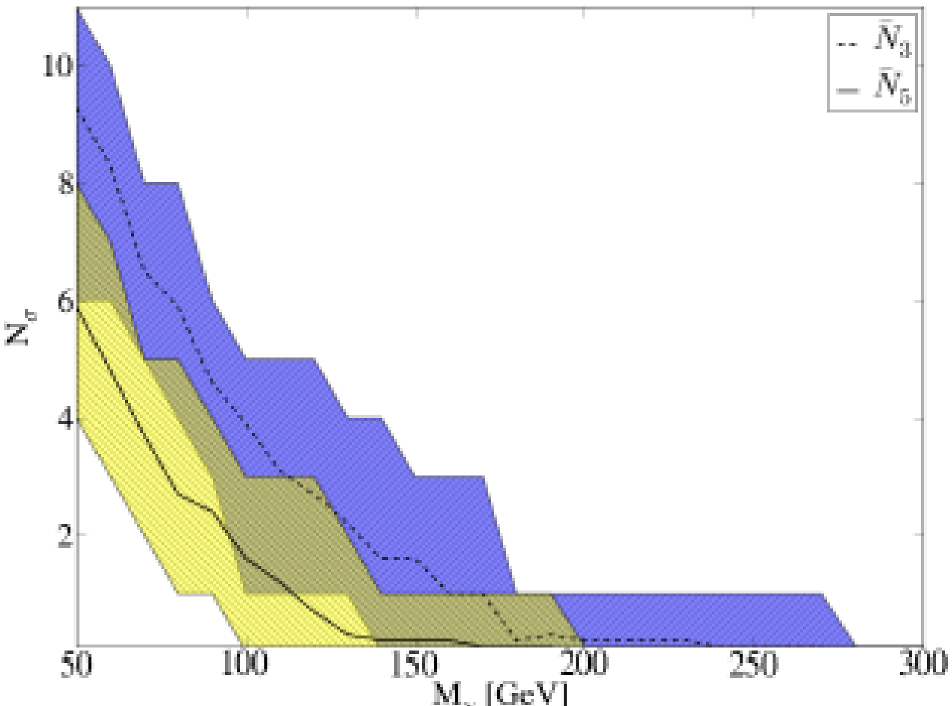
ADDITIONAL SLIDES

Dark Satellites

- Via Lactea-2 simulation of the DM galaxy (Nature **454**, 735)
  - Including a boost for unresolved substructure
  - Sample 10 viewing points 8 kpc from the Galactic center
- WIMP annihilation to b,b-bar using Dark-SUSY (JCAP 0407, 008)
  - Nominal expected cross section: $3{\times}10^{-26}$ cm^3/s
- MC simulation of the Fermi-LAT instrument response
- 10 year observation time

Number of DM halo objects visible at 3 std. dev. significance.

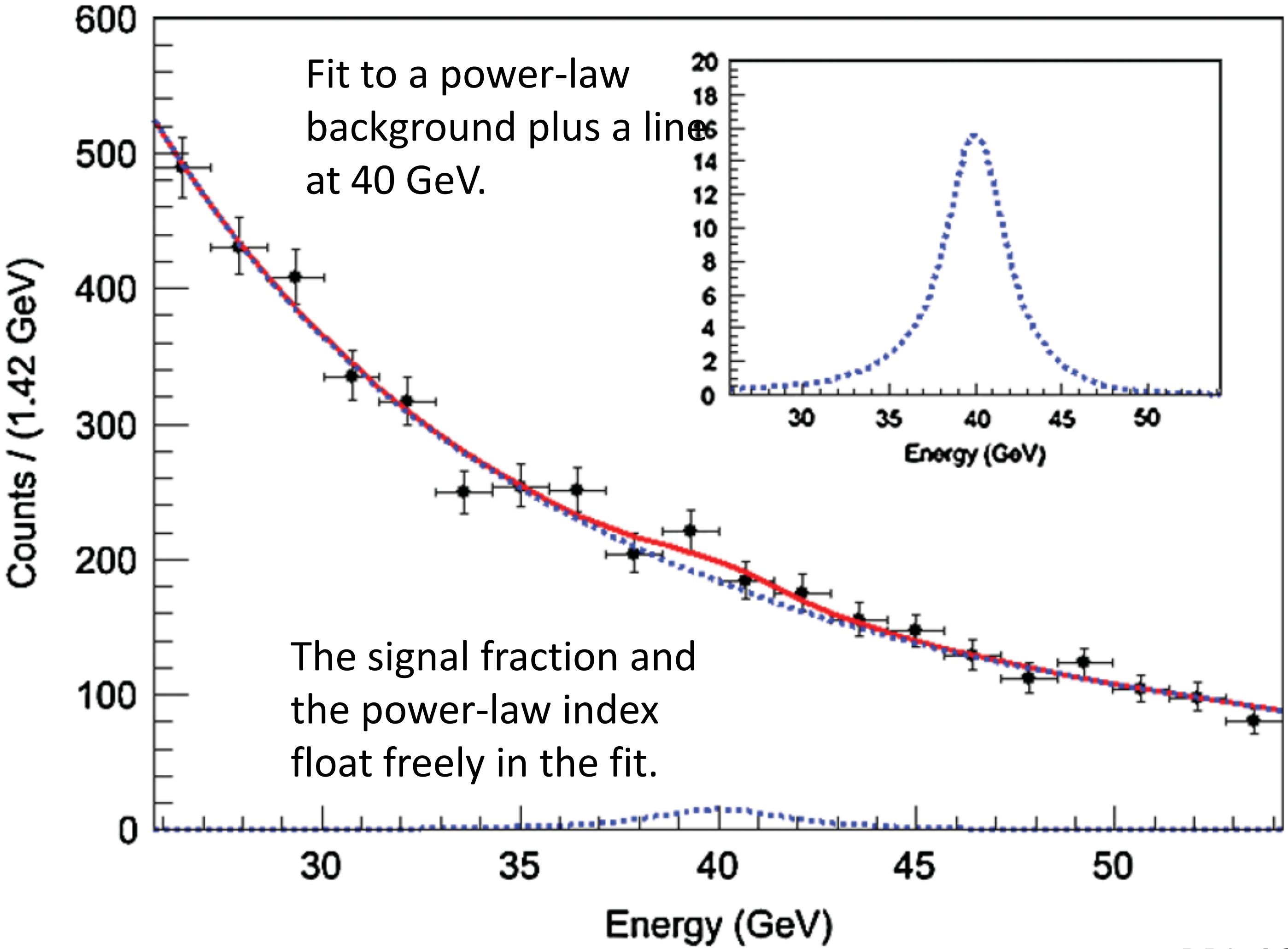
Number of DM halo objects visible at 5 std. dev. significance.



B. Anderson et al., arXiv:1006.1628v1.

Gamma-Ray Line Search

Example fit, at 40 GeV (the fit with the largest line "signal")



11 Months

Almost all sky:

Galactic plane removed, except for Galactic center.

Sources removed by 0.2° cut.

PRL **104**, 091302 (2010)

Gamma-Ray Line Search

Cross Section Upper Limits, for annihilation to $\gamma\gamma$