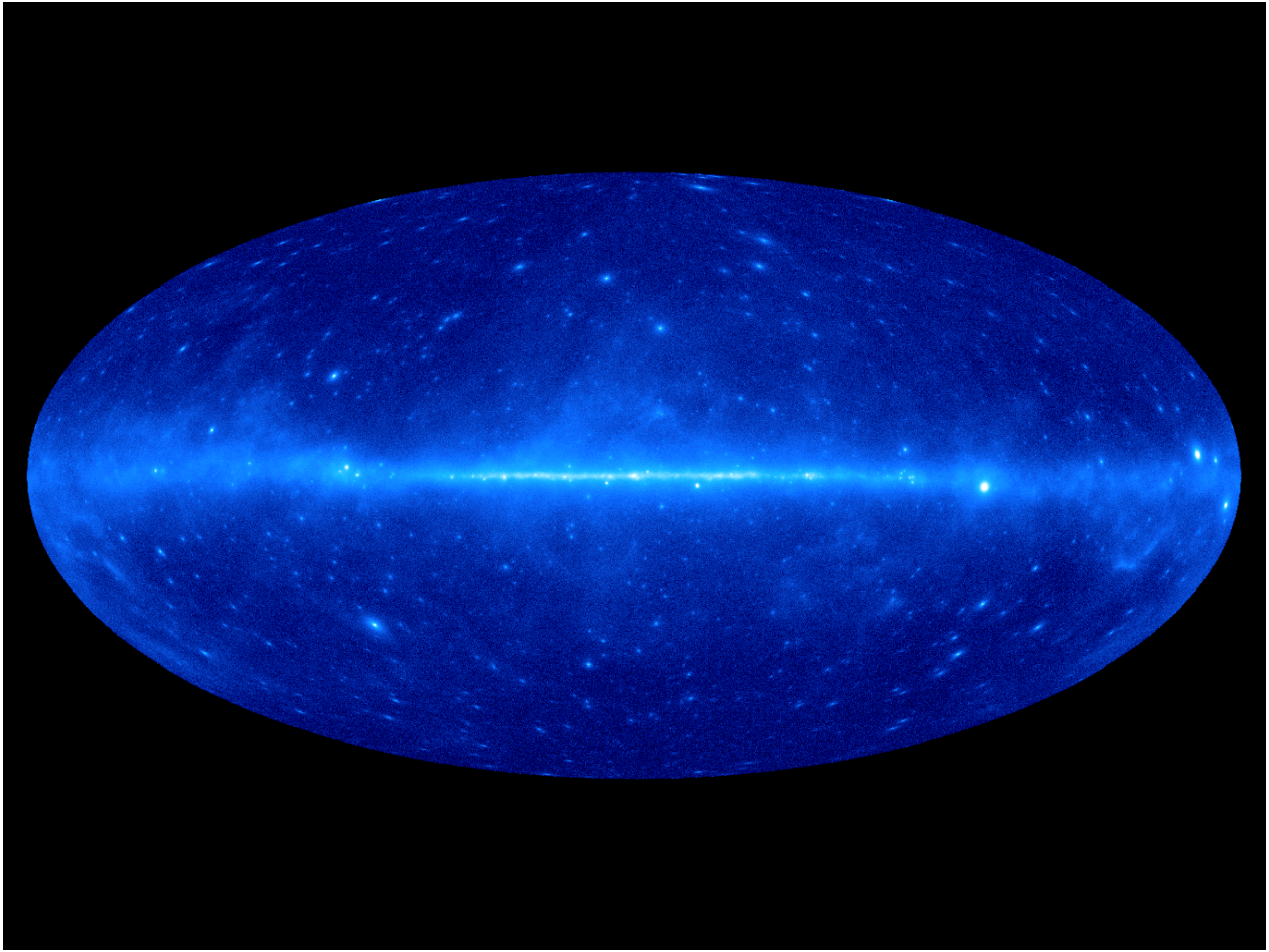
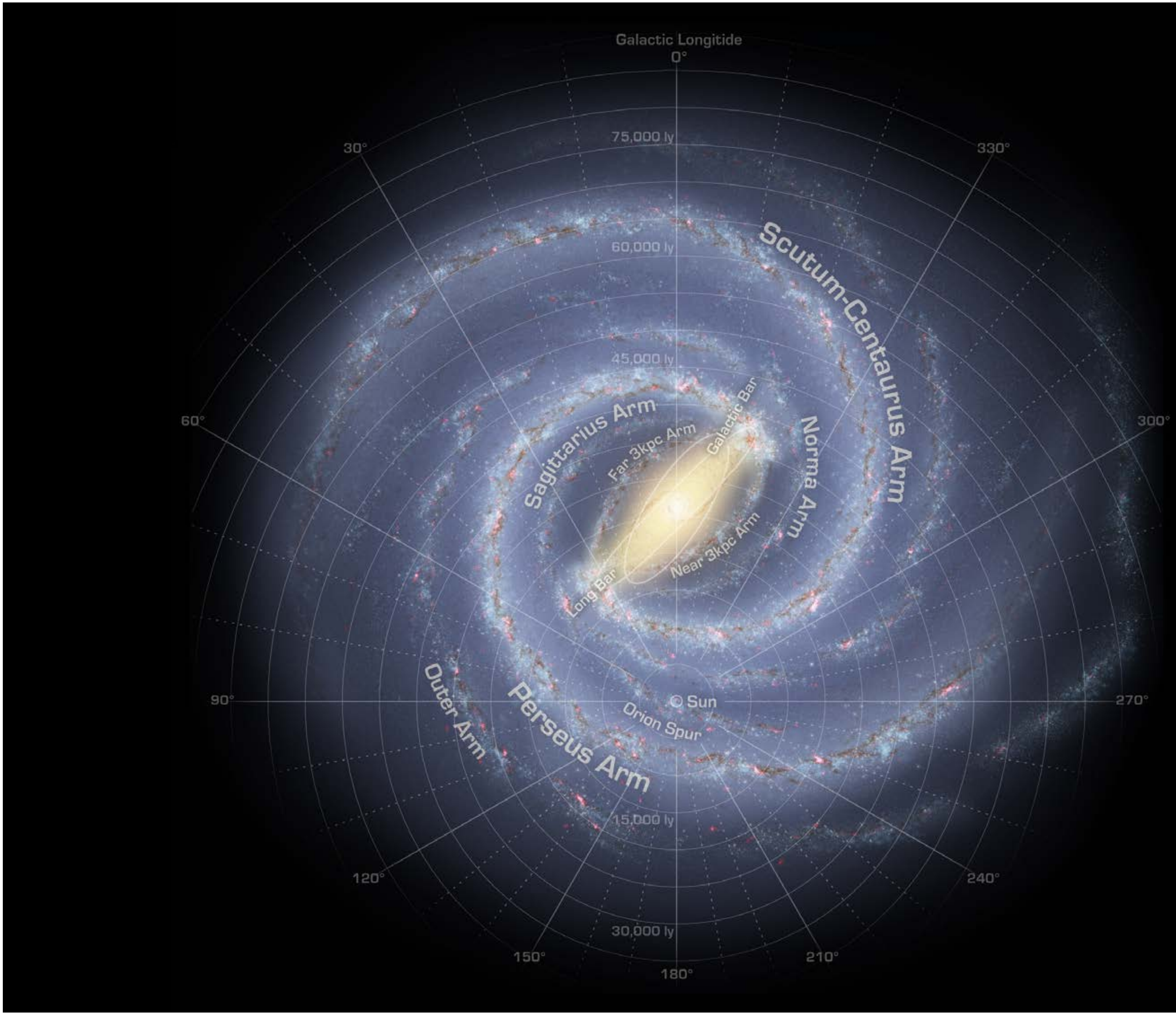
Physics 205

Opportunities with the Fermi Gamma-ray Space Telescope

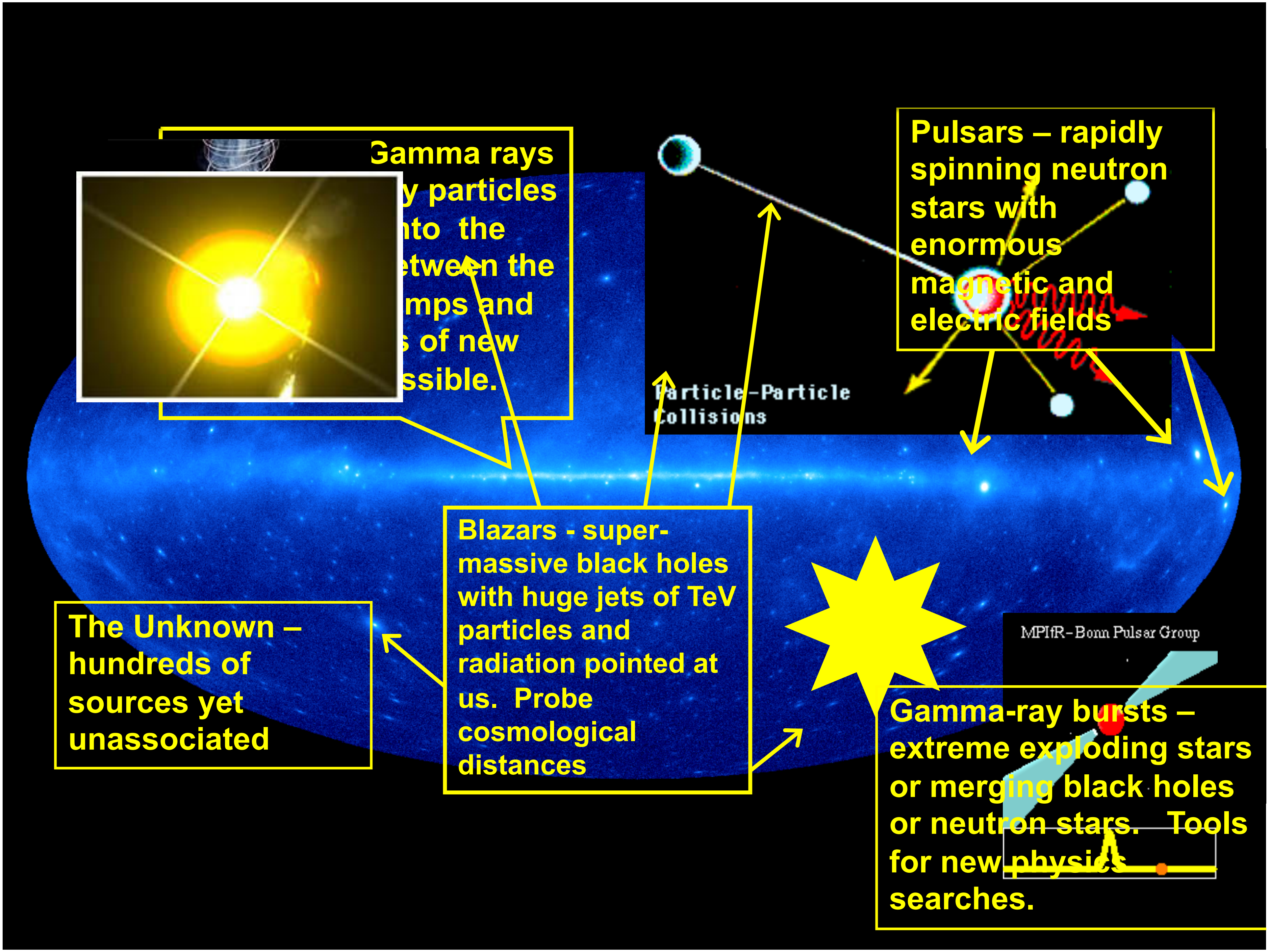
W.B. Atwood, R. Johnson, and S. Ritz
UCSC and SCIPP

See http://www-glast.stanford.edu/ and links therein





Credit: R. Hurt


Gamma rays
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mps and
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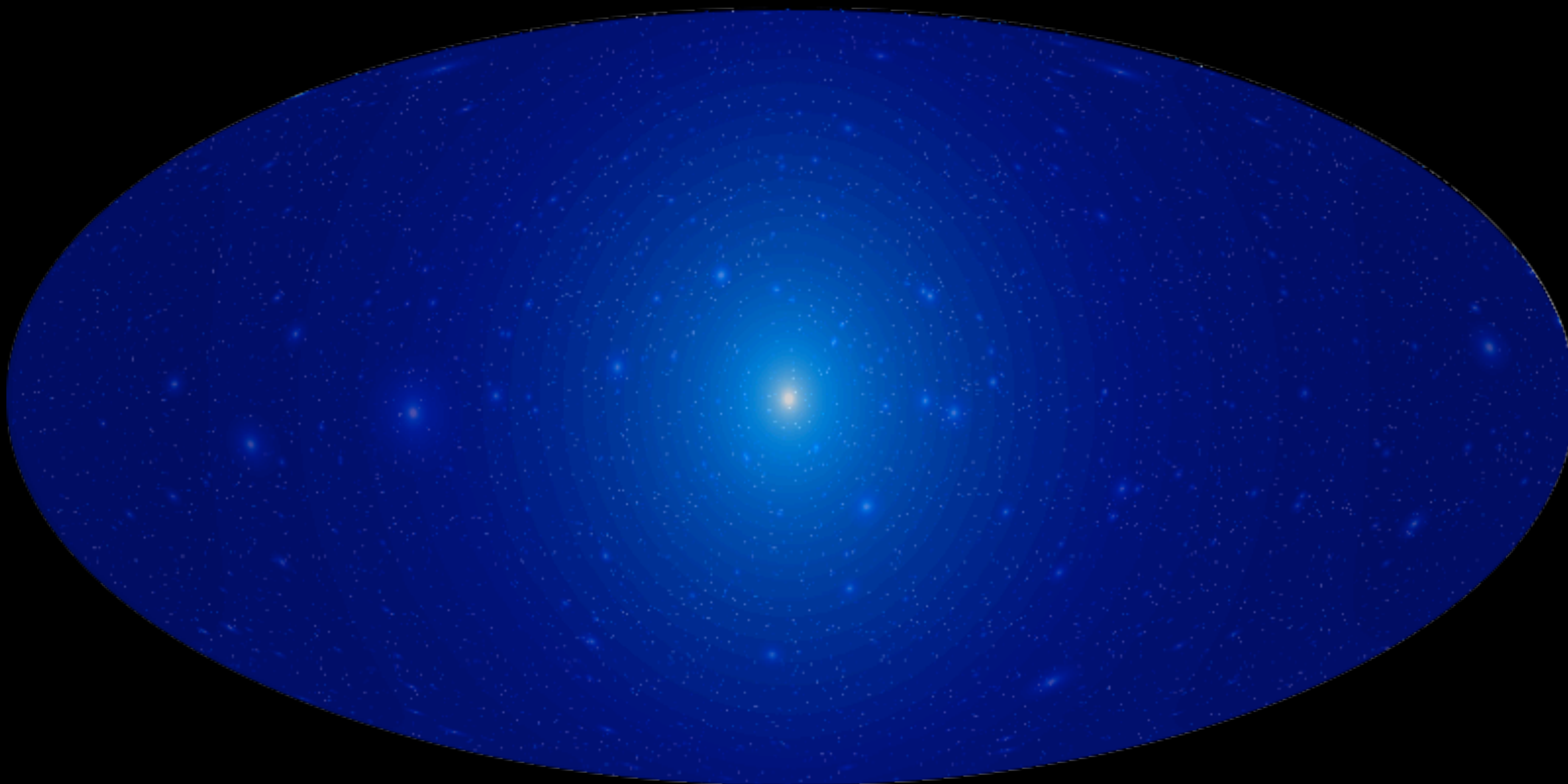
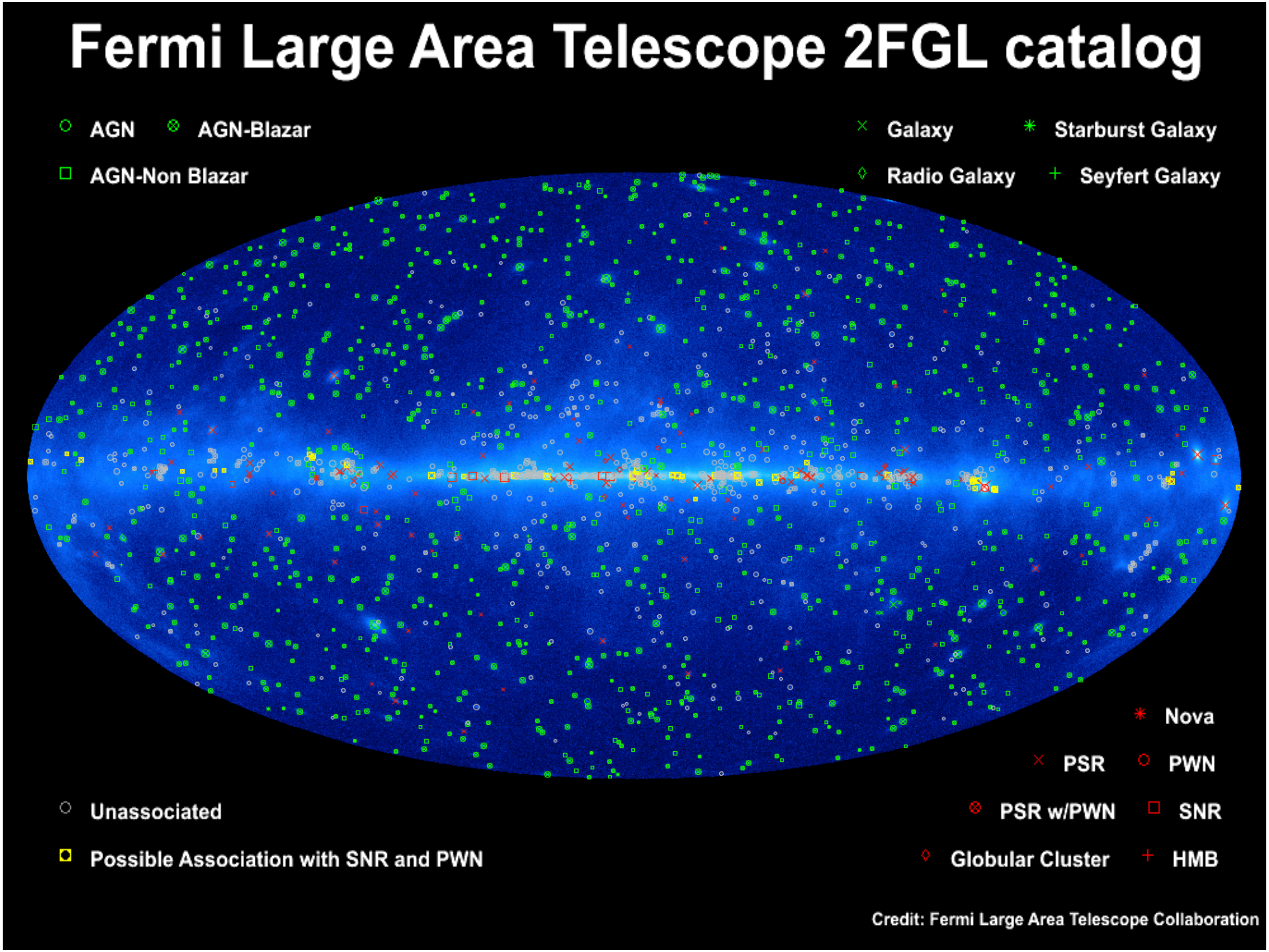
Particle-Particle
Collisions
Pulsars – rapidly spinning neutron stars with enormous magnetic and electric fields
Blazars - super-massive black holes with huge jets of TeV particles and radiation pointed at us. Probe cosmological distances
The Unknown – hundreds of sources yet unassociated
MPIfR-Bonn Pulsar Group
Gamma-ray bursts – extreme exploding stars or merging black holes or neutron stars. Tools for new physics searches.

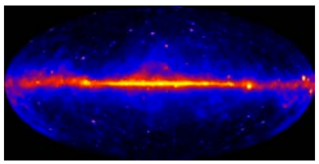


Gamma rays expected from Dark Matter Annihilation

Gamma rays from dark matter annihilation


Fermi Large Area Telescope 2FGL catalog
AGN
AGN-Blazar
AGN-Non Blazar
Galaxy
Starburst Galaxy
Radio Galaxy
Seyfert Galaxy
Nova
PSR
PWN
PSR w/PWN
SNR
Globular Cluster
HMB
Unassociated
Possible Association with SNR and PWN
Credit: Fermi Large Area Telescope Collaboration

Understanding the Gamma-ray Sky


data

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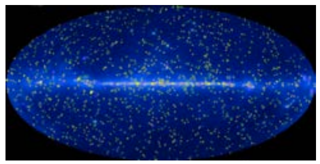
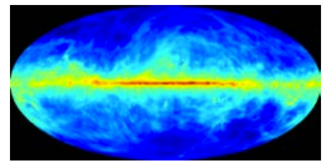
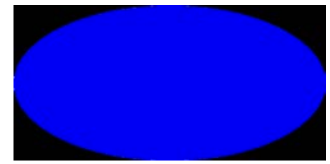

sources

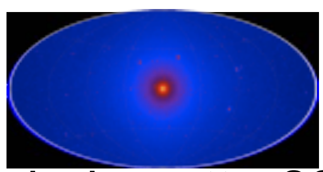
+


galactic diffuse

+


isotropic diffuse

+

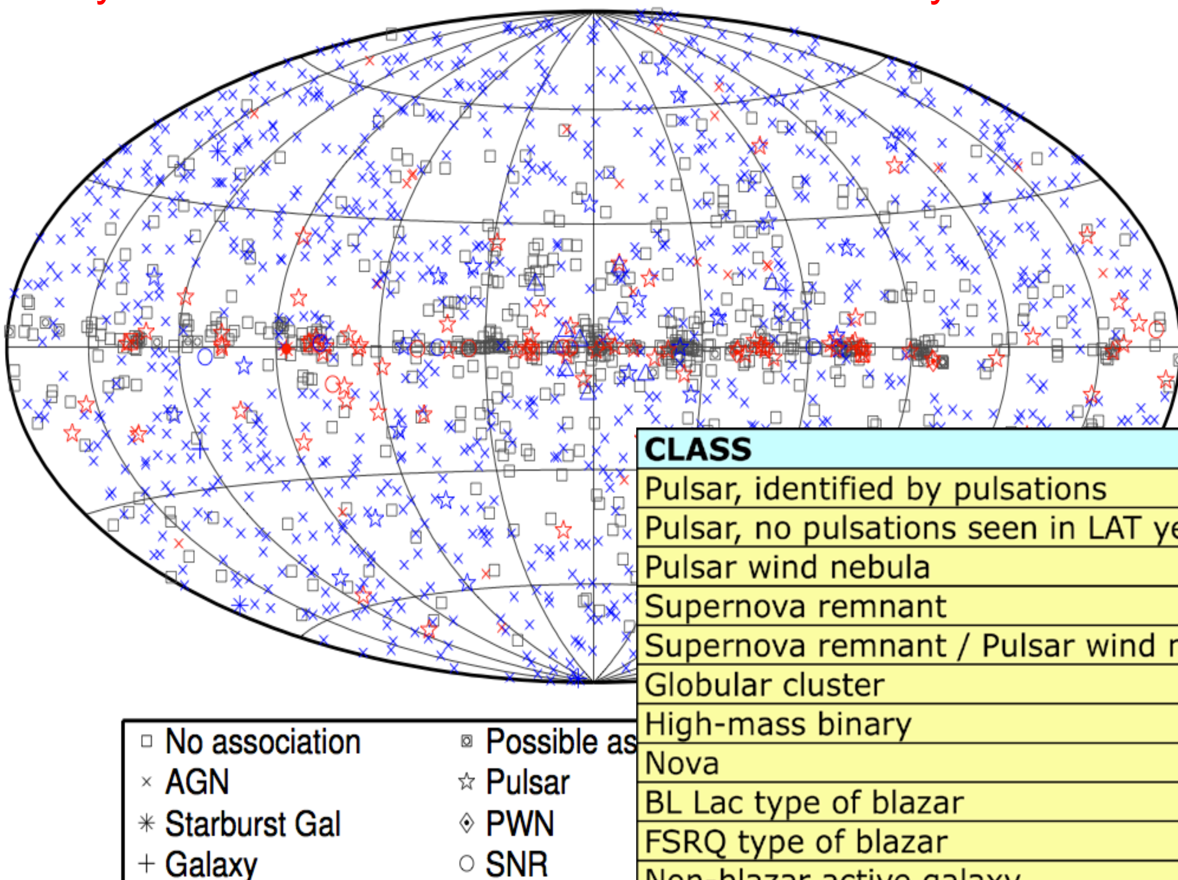

dark matter??

+ ??

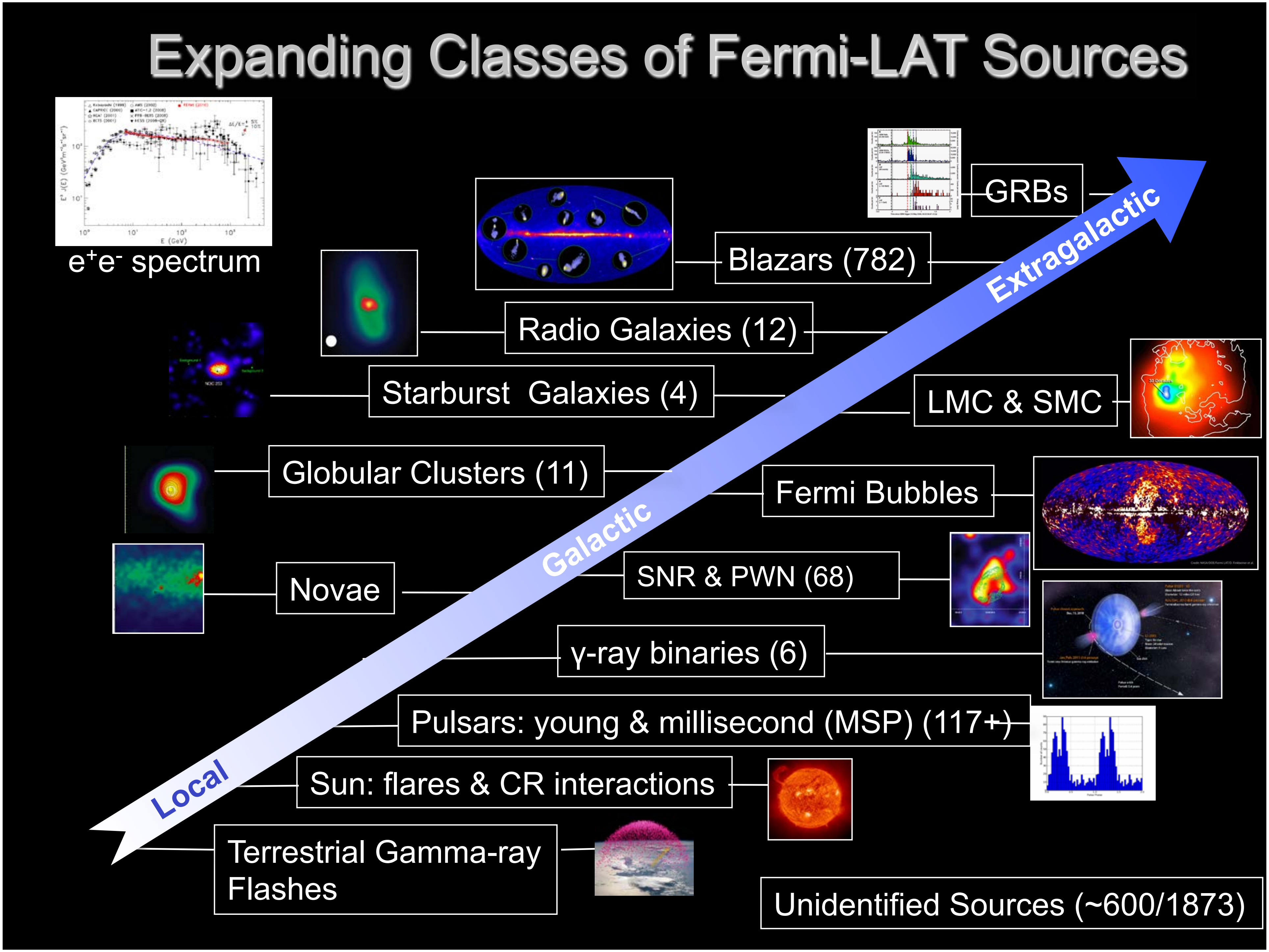
Bootstrapped, iterative process

2FGL Sources

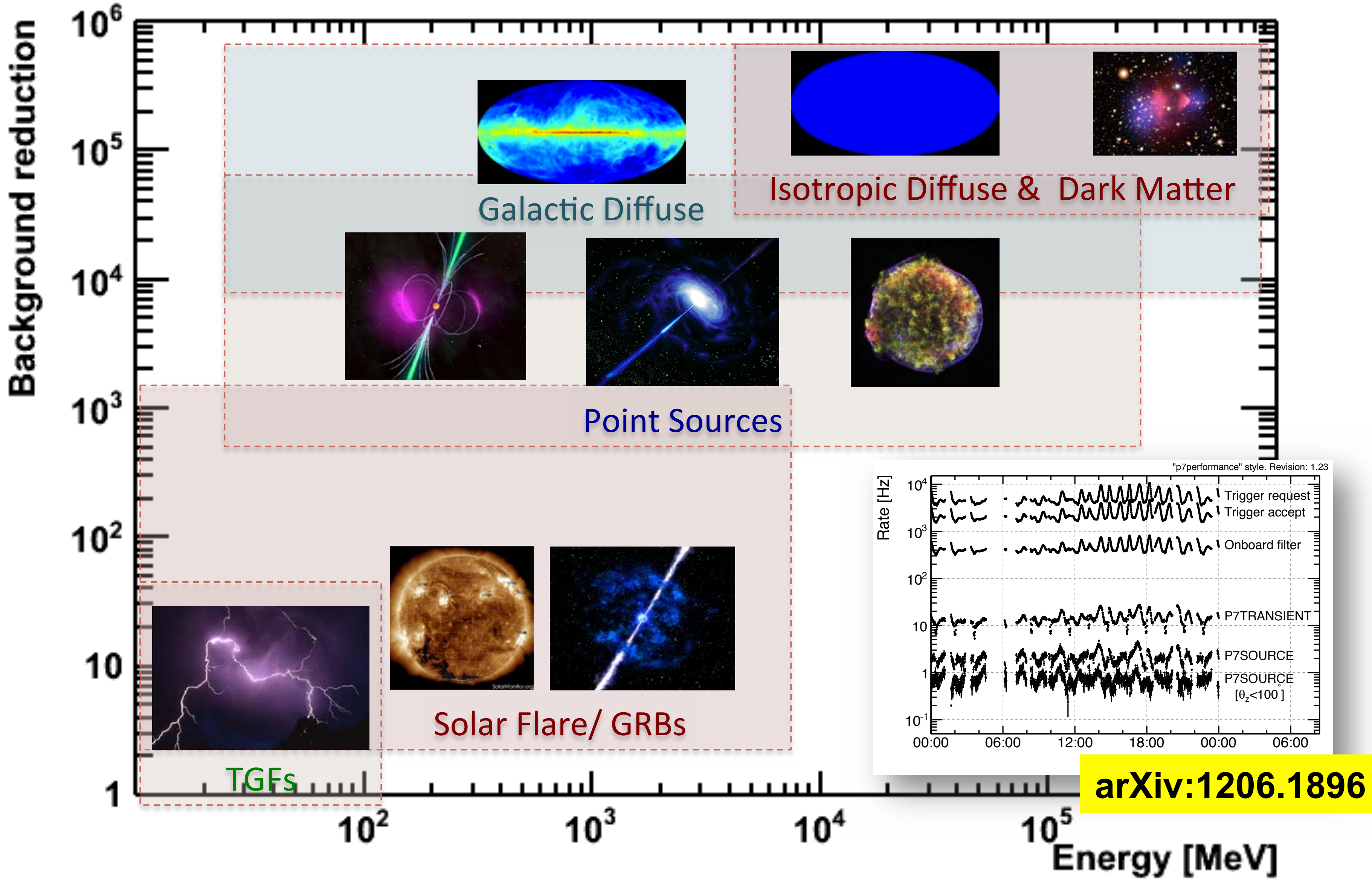
Red symbols: Identified sources   Blue symbols: Associated sources



CLASS	Identified	Associated
Pulsar, identified by pulsations	83	-
Pulsar, no pulsations seen in LAT yet	-	25
Pulsar wind nebula	3	0
Supernova remnant	6	4
Supernova remnant / Pulsar wind nebula	-	58
Globular cluster	0	11
High-mass binary	4	0
Nova	1	0
BL Lac type of blazar	7	428
FSRQ type of blazar	17	353
Non-blazar active galaxy	1	10
Radio galaxy	2	10
Seyfert galaxy	1	5
Active galaxy of uncertain type	0	257
Normal galaxy (or part)	2	4
Starburst galaxy	0	4
Class uncertain	-	1
Unassociated	**-**	**576**
Total	**127**	**1746**

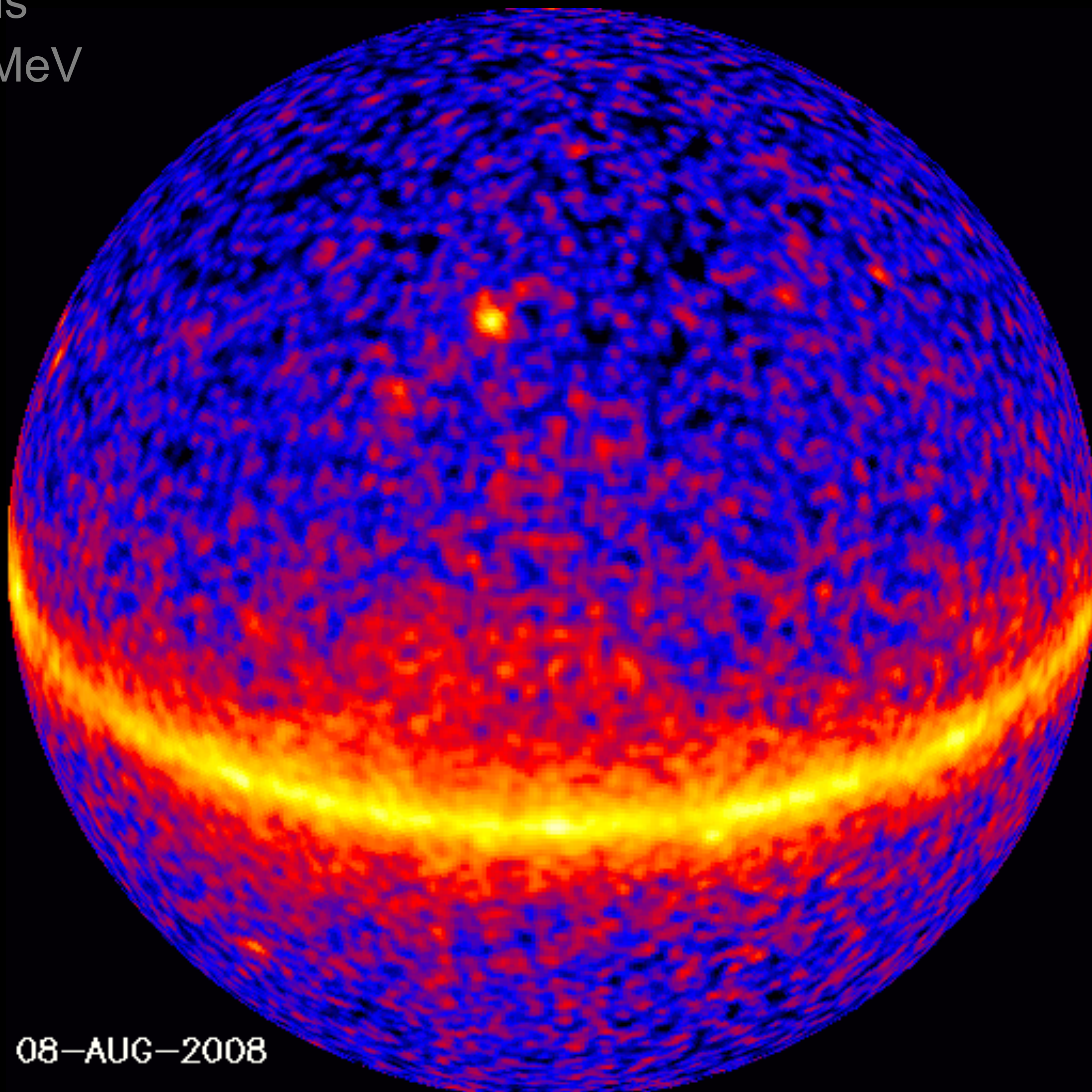

Expanding Classes of Fermi-LAT Sources
e+e- spectrum
GRBs
Blazars (782)
Radio Galaxies (12)
Starburst Galaxies (4)
LMC & SMC
Globular Clusters (11)
Fermi Bubbles
Novae
SNR & PWN (68)
γ-ray binaries (6)
Pulsars: young & millisecond (MSP) (117+)
Sun: flares & CR interactions
Terrestrial Gamma-ray Flashes
Unidentified Sources (~600/1873)
Extragalactic
Galactic
Local

Huge Dynamic Ranges



The Variable Gamma-ray Sky

36 months
E > 100 MeV

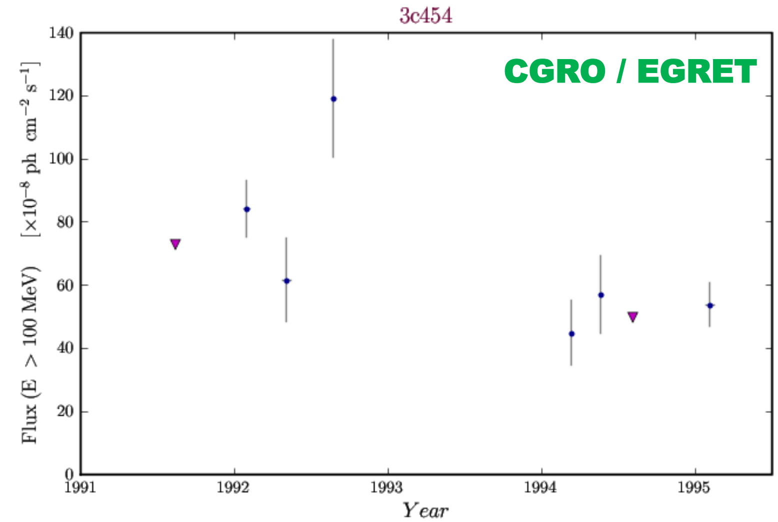


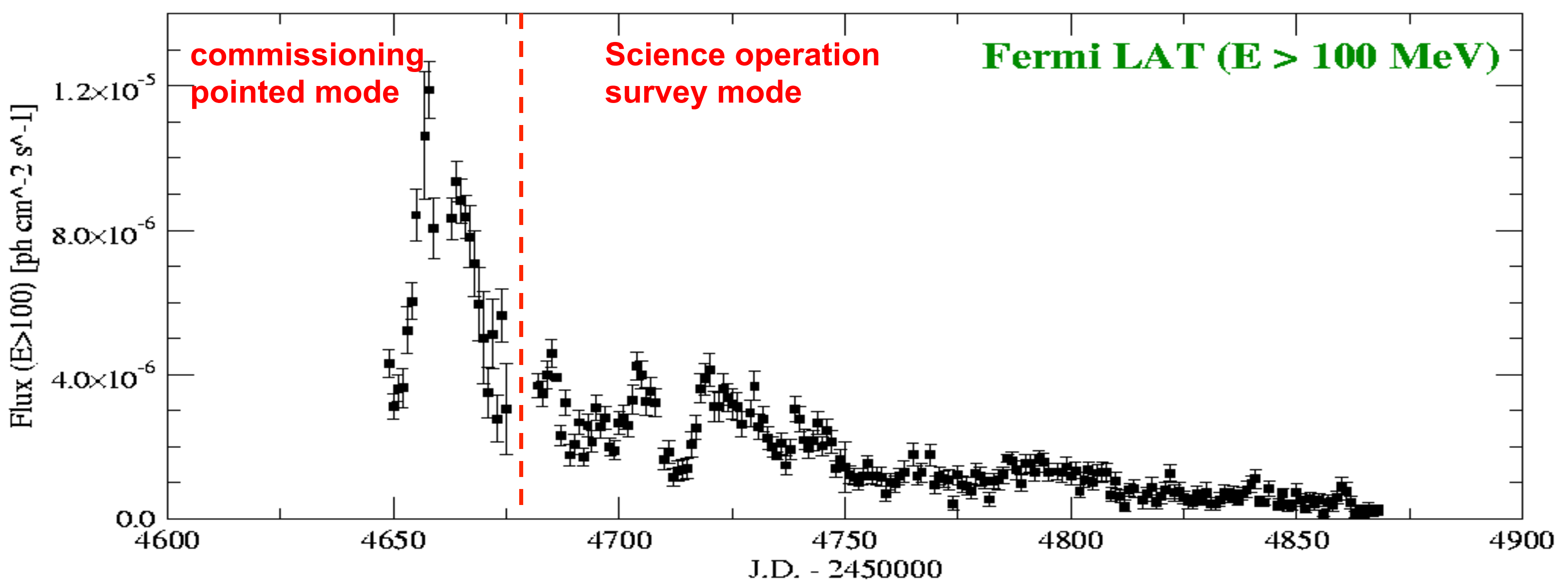
many transients in the γ-ray sky

with time, deeper exposure has revealed many new sources and new source classes

Example of all-sky payoff: 3C454.3

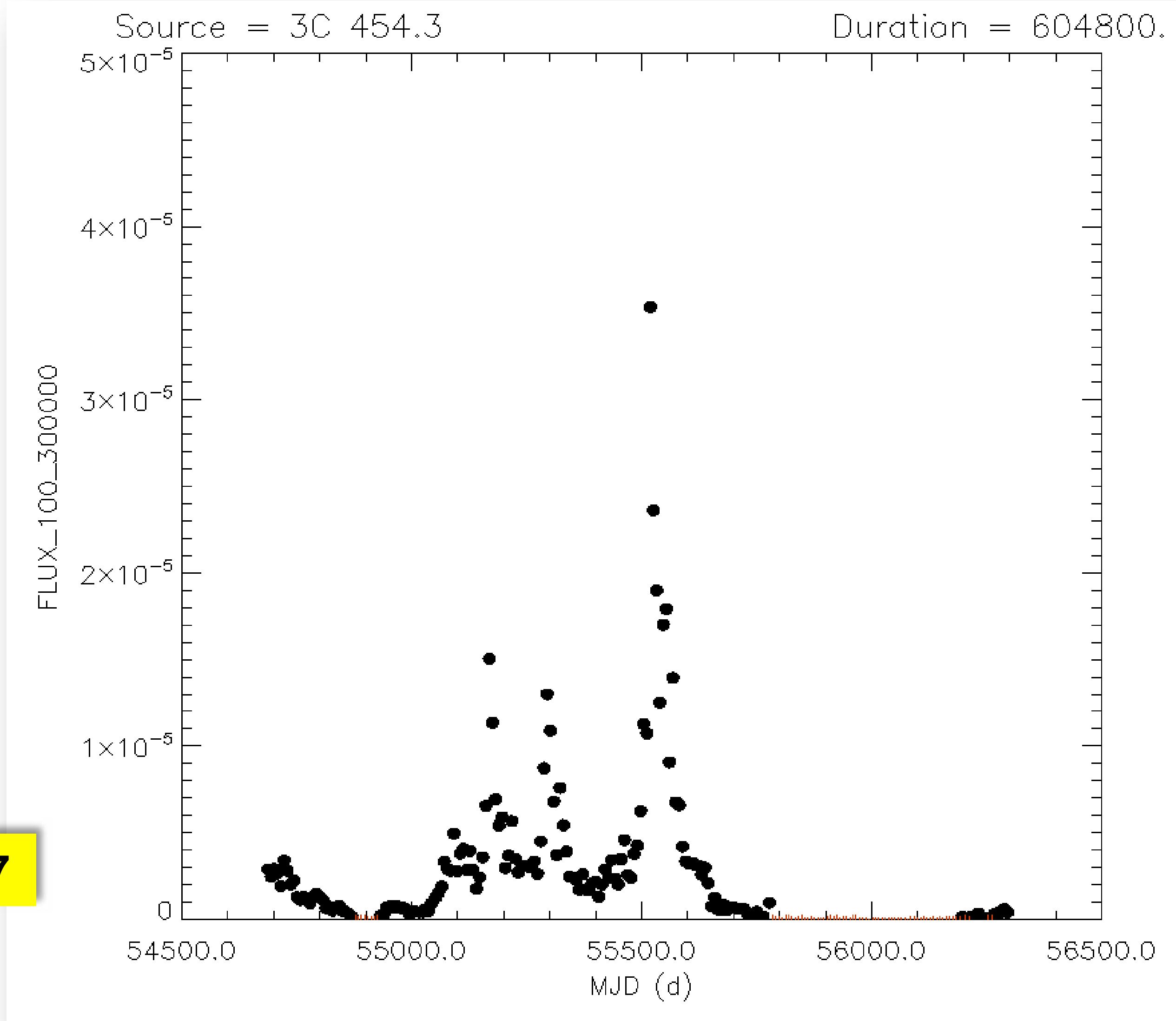
- Well-known radio source at z = 0.859; also detected by EGRET, AGILE





3C454.3

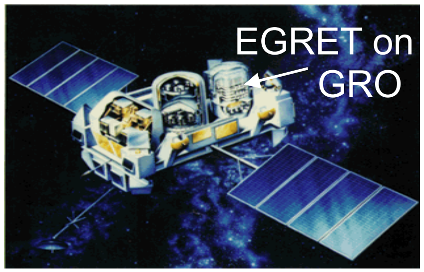
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

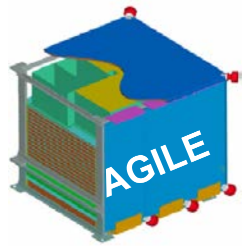


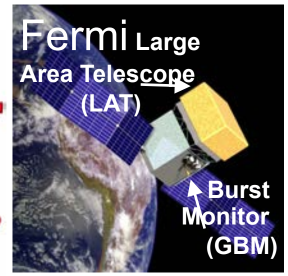
Also see **arXiv:1102.0277**

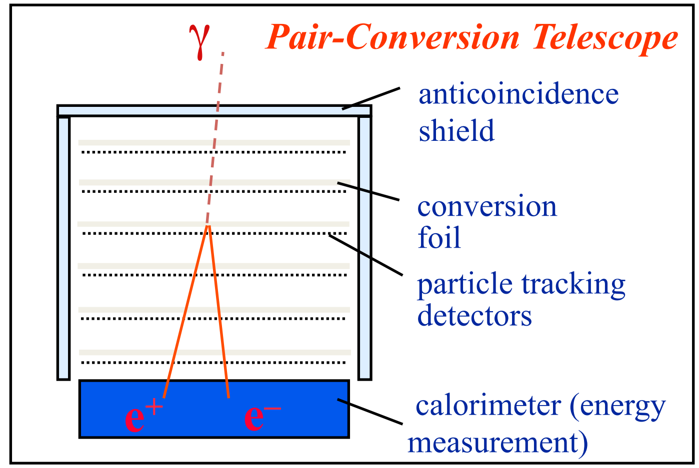
HE Gamma-ray Experiment Techniques

- Space-based:
  - use pair-conversion technique





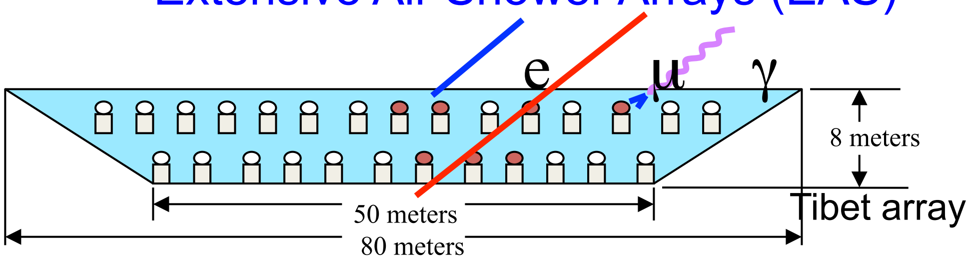




- Ground-Based:
  - Atmospheric Cerenkov Telescopes (ACTs)

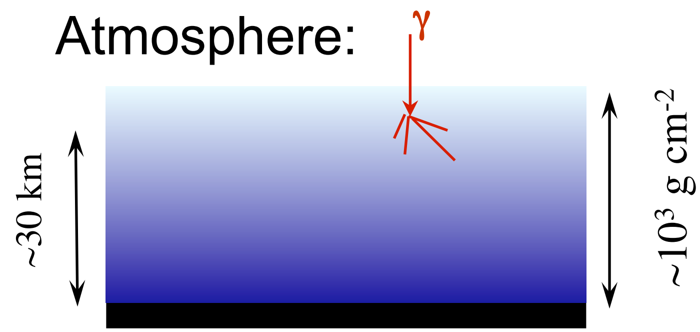
image the Cerenkov nin from showers induced in the atmosphere. Examples: VERITAS, MAGIC, HESS; CTA.

  - Extensive Air Shower Arrays (EAS)



Directly detect particles from the showers induced in the atmosphere. Example: Milagro; HAWC,

Why Space?



To detect these gamma rays, must have an instrument above the atmosphere.

[Note, for very high-energy gamma rays, > ~100 GeV, information from showers penetrates to the ground.]

Photon interaction mechanisms:

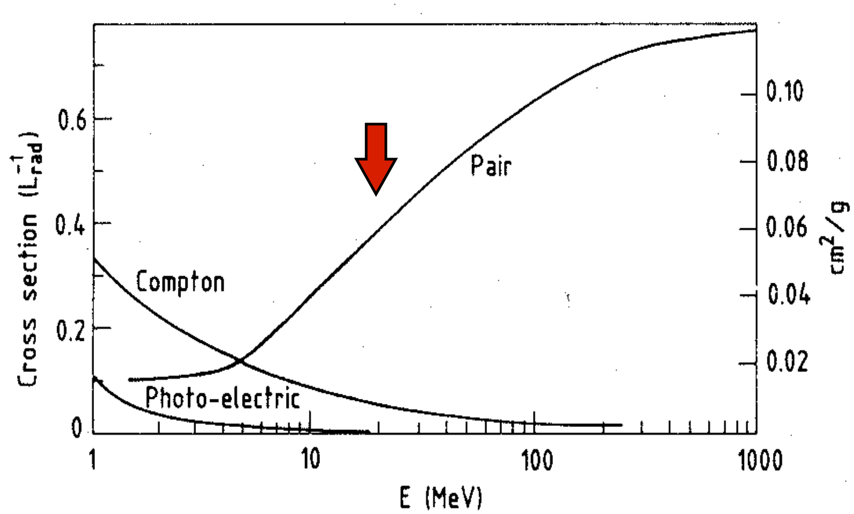
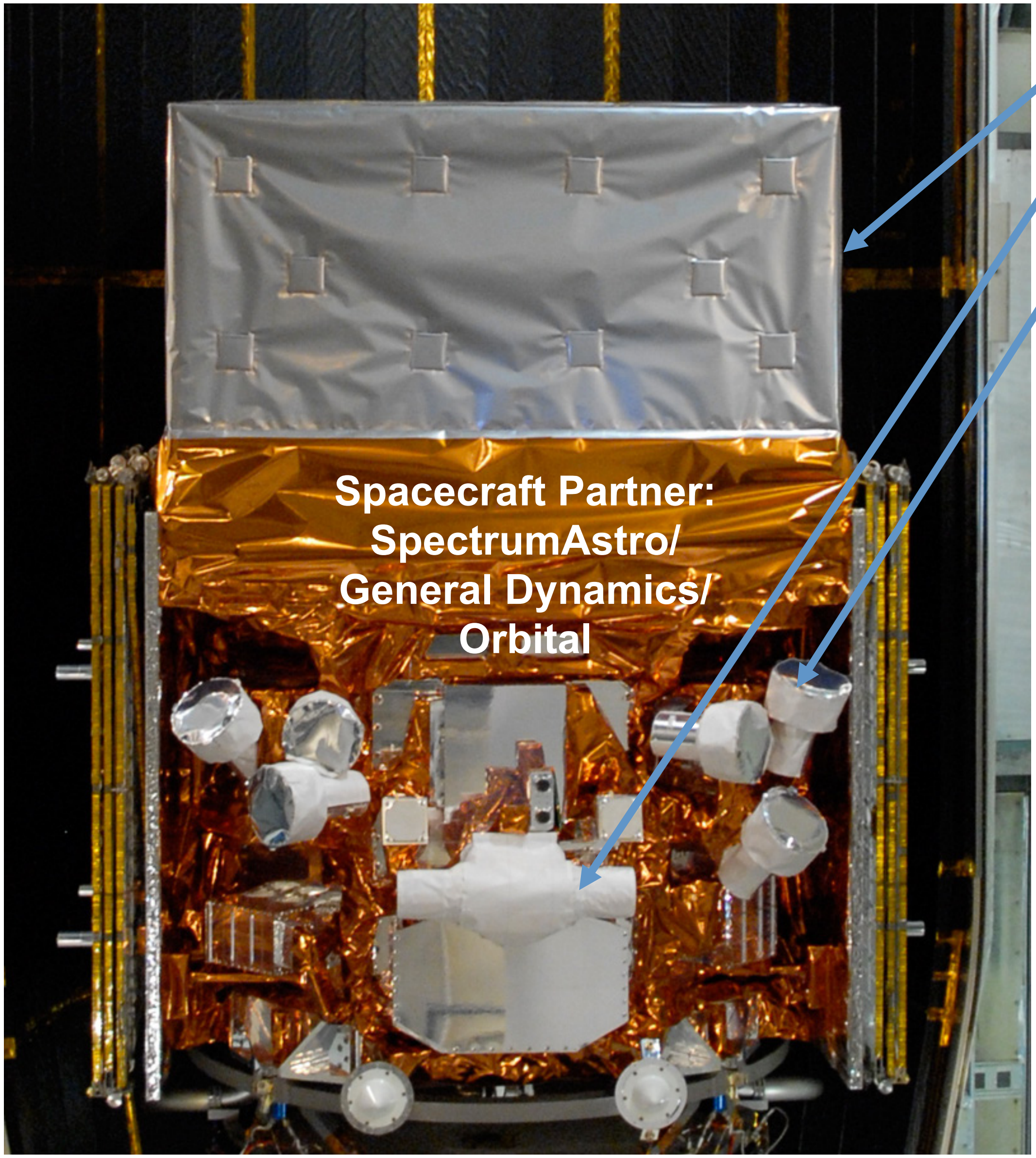


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

The Accelerator

The Observatory, Spring 2008



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

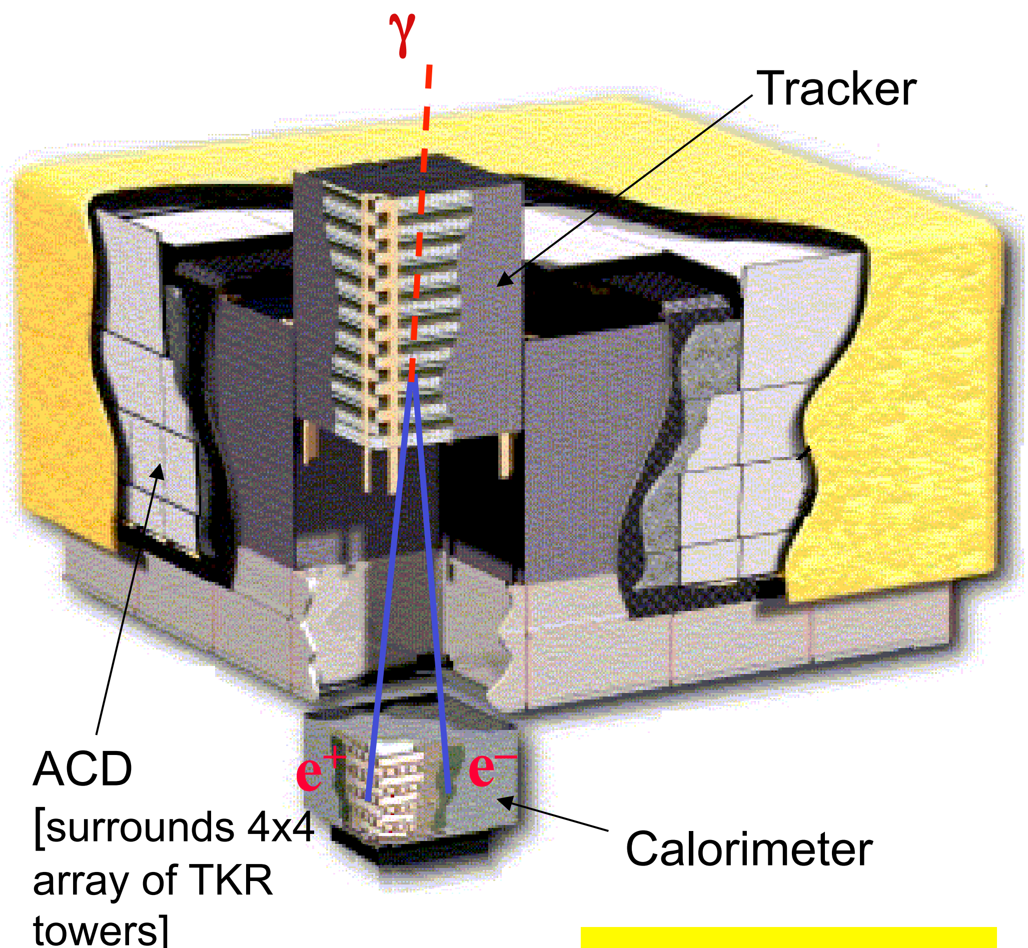
- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!**
- **Large leap in all key capabilities. Great discovery potential.**

Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

LAT Overview

- Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.

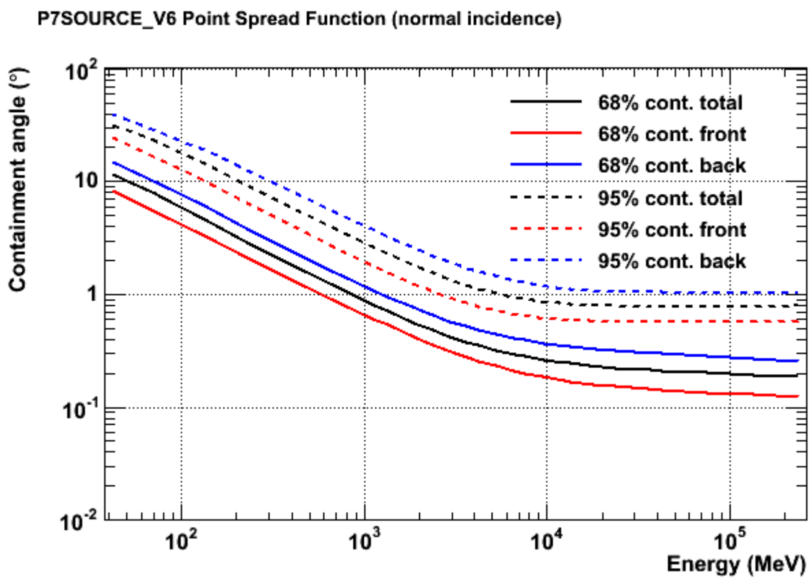


Atwood et al, ApJ

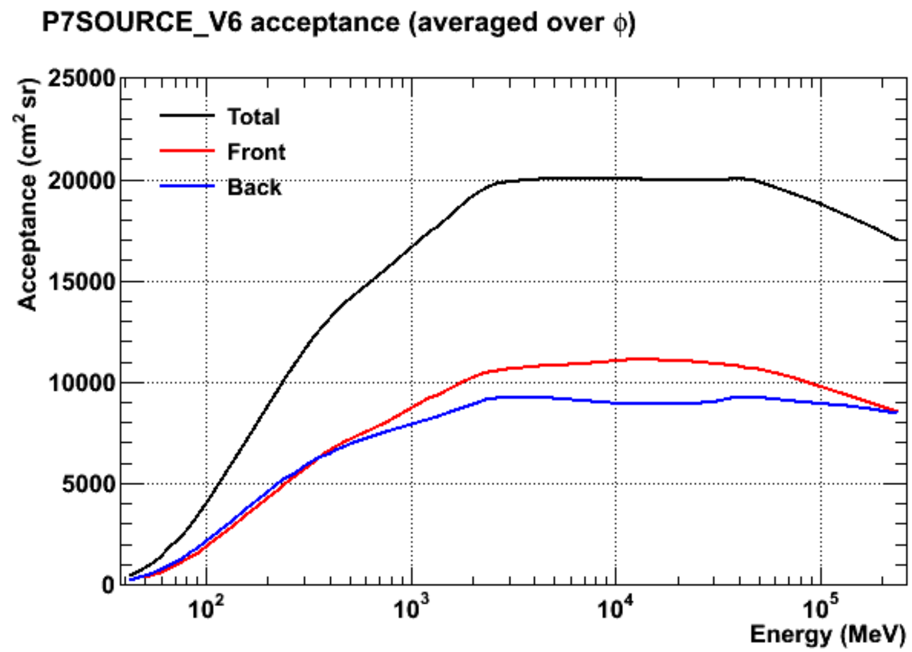
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Performance

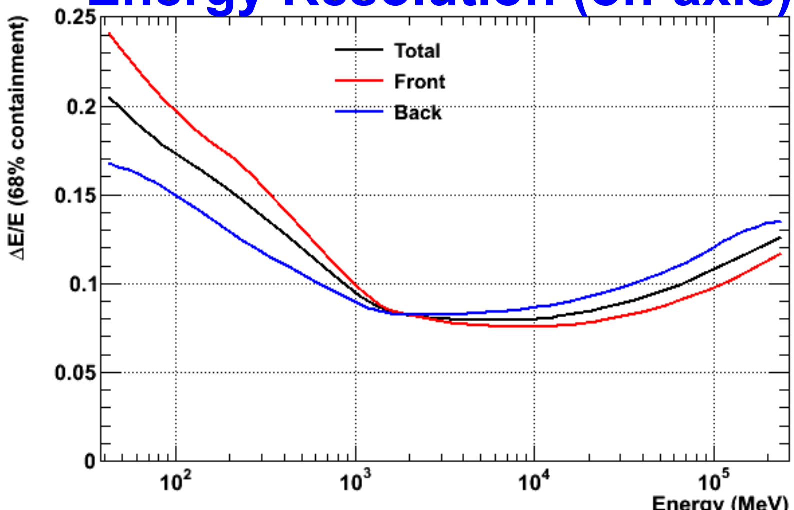
PSF

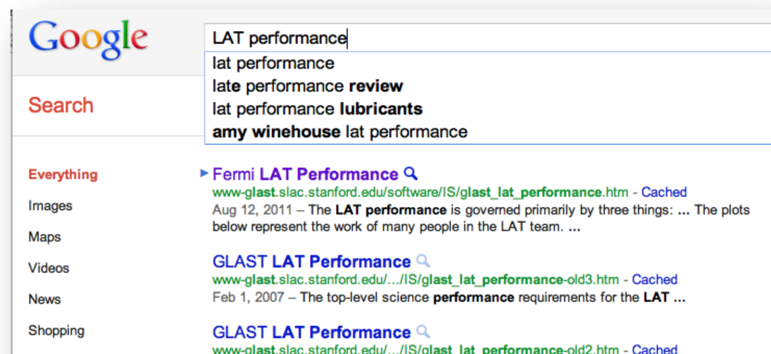


Acceptance



Energy Resolution (on-axis)





Different event classes trade background rejection and PSF against effective area

Data/MC Comparisons

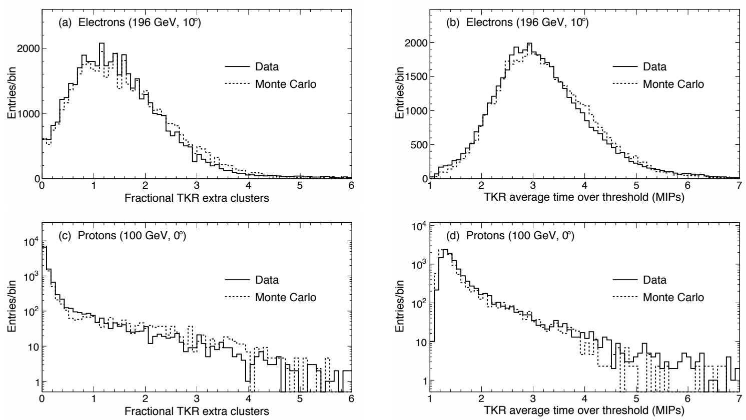


FIG. 1: Comparison of beam test data (solid line) and MC simulations (dashed line) for two fundamental tracker variables used in the electron selection: the number of clusters in a cone of 10 mm radius around the main track (left panels) and the average time over threshold (right panels). Both variables are shown for an electron and a proton beam.

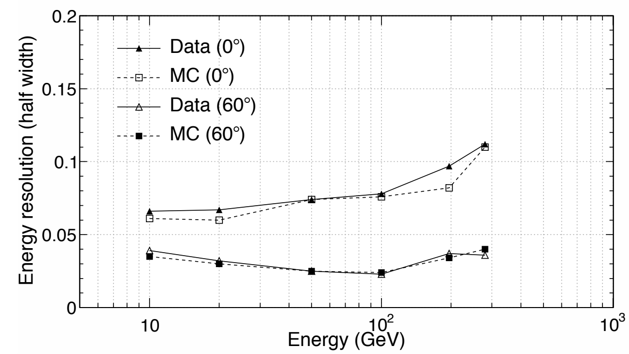


FIG. 3: Comparison of beam test data (triangles) and Monte Carlo simulations (squares) for the energy resolution for electron beams entering the CU at 0° and 60° and energies from 10 to 282 GeV. Lines are to guide an eye.

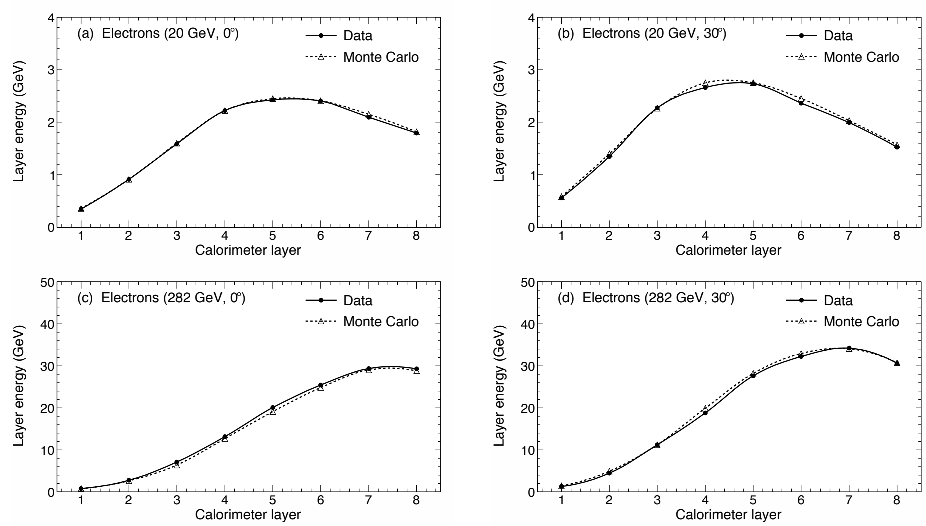


FIG. 4: Comparison of Beam test data and Monte Carlo simulations for the longitudinal shower profiles for electron beams entering the CU at 0° and 30° and energies of 20 and 282 GeV.

Many thanks to CERN, GSI, and SLAC!!

arXiv:1008.3999v1, PRD 82

LAT Collaboration

- France
  - CNRS/IN2P3, CEA/Saclay
- Italy
  - INFN, ASI, INAF
- Japan
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- Sweden
  - Royal Institute of Technology (KTH)
  - Stockholm University
- United States
  - Stanford University (SLAC and HEPL/Physics)
  - University of California, Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

PI: Peter Michelson
(Stanford)

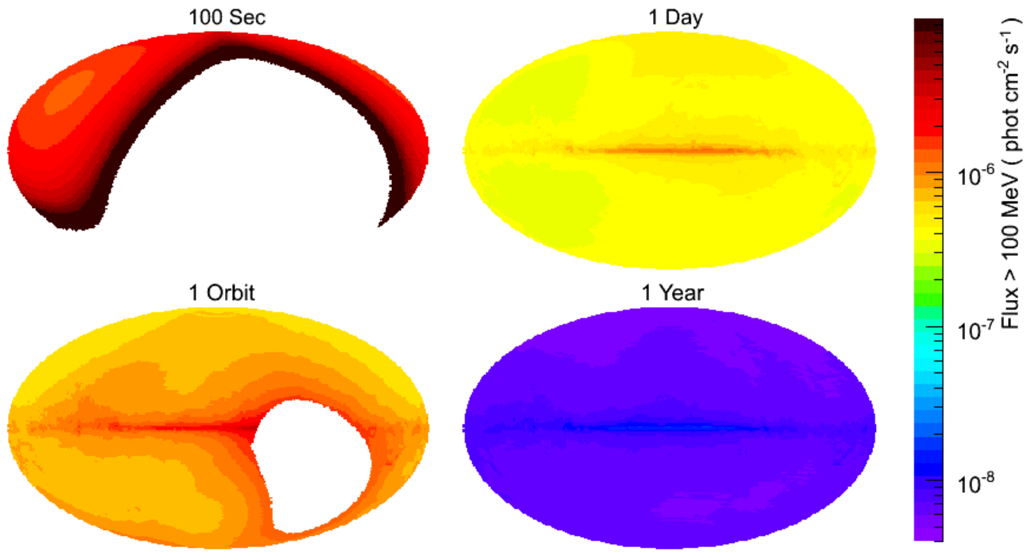
~400 Scientific Members (including 97 Affiliated Scientists, plus 71 Postdocs and 123 Students)

Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

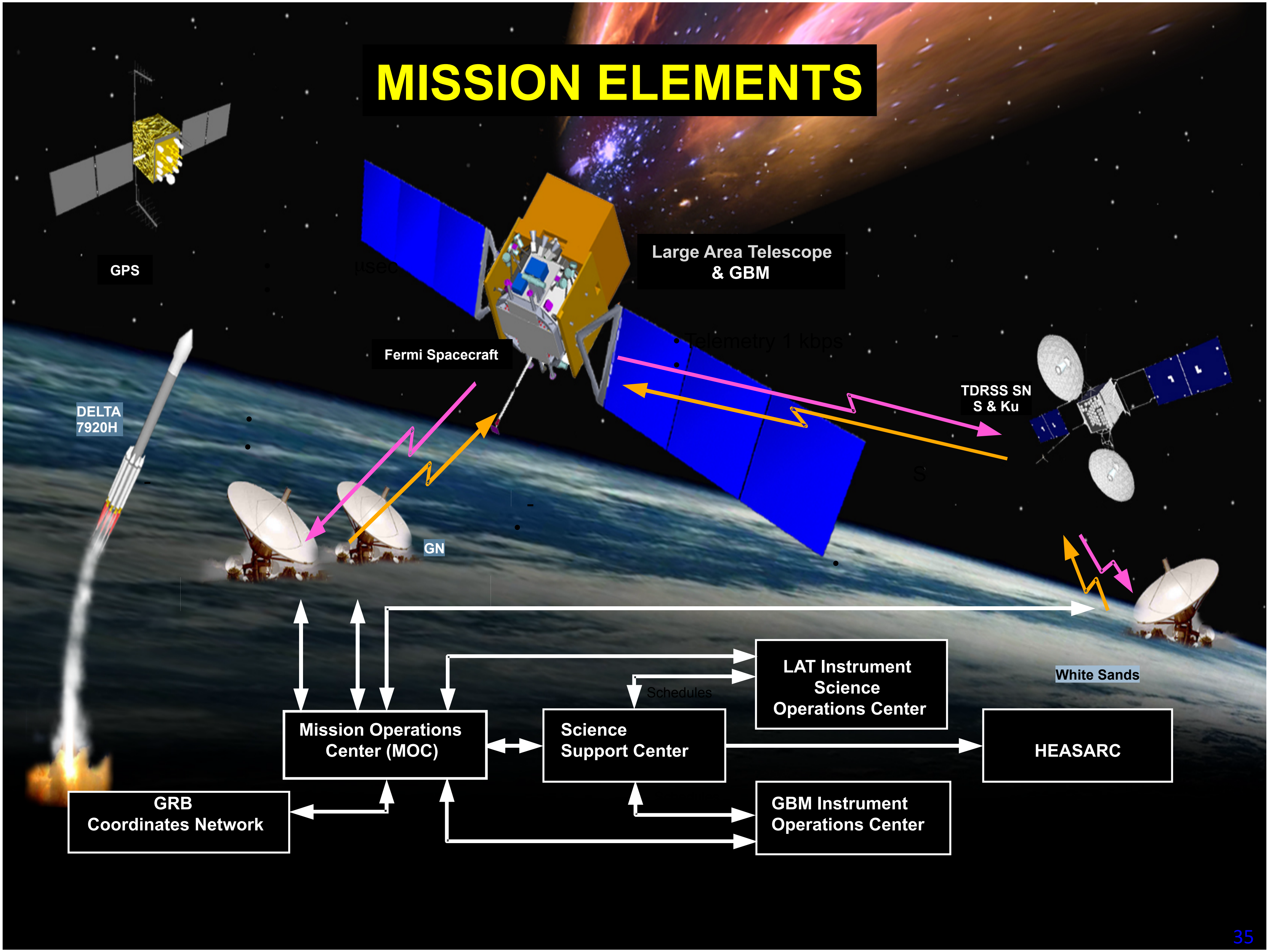
Project managed at SLAC.

Operating modes

- Primary observing mode is Sky Survey
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates multiwavelength observation planning
  - Exposure intervals commensurate with typical instrument integration times for sources
  - EGRET sensitivity reached in days



- **Pointed observations when appropriate (limited fraction, and selected by peer review) with automatic earth avoidance selectable. Target of Opportunity pointing.**
- **Autonomous repoints for onboard GRB detections in any mode.**


MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
Fermi Spacecraft
Telemetry 1 kbps
TDRSS SN
S & Ku
DELTA
7920H
GN
White Sands
LAT Instrument
Science
Operations Center
Schedules
Mission Operations
Center (MOC)
Science
Support Center
HEASARC
GRB
Coordinates Network
GBM Instrument
Operations Center

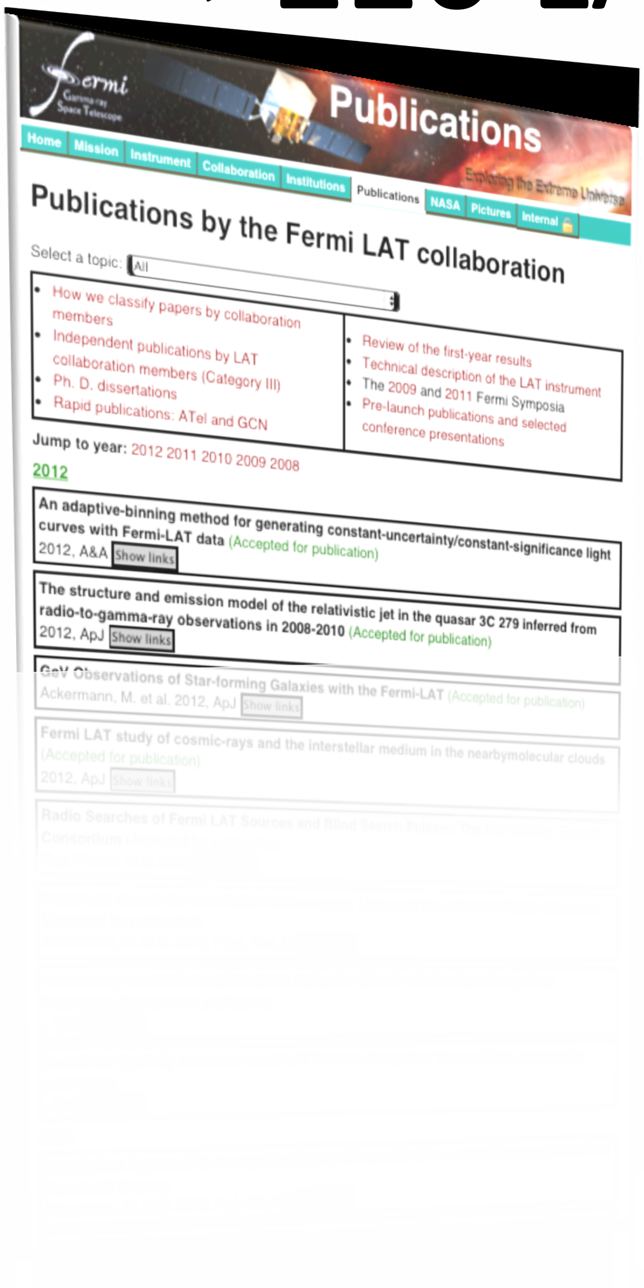
Overall Timeline

- Science operations start: 4 August 2008
- Plan: Five-year mission with a ten-year goal
  - with reviews to assess productivity in extended phase
- Mission extended by NASA to at least 2016, based on most recent Senior Review:
  - *"The first three years of Fermi have been very productive, and the committee believes we have yet to see the peak of Fermi's science output"*
  - The report recommended "*... funding at the desired level of augmentation to provide for full operations through FY14. We recommend an extension through 2016 with a review in 2014.*"
- LAT international partners (agencies funding particle physics and astrophysics) are also planning continued support of the experiment.

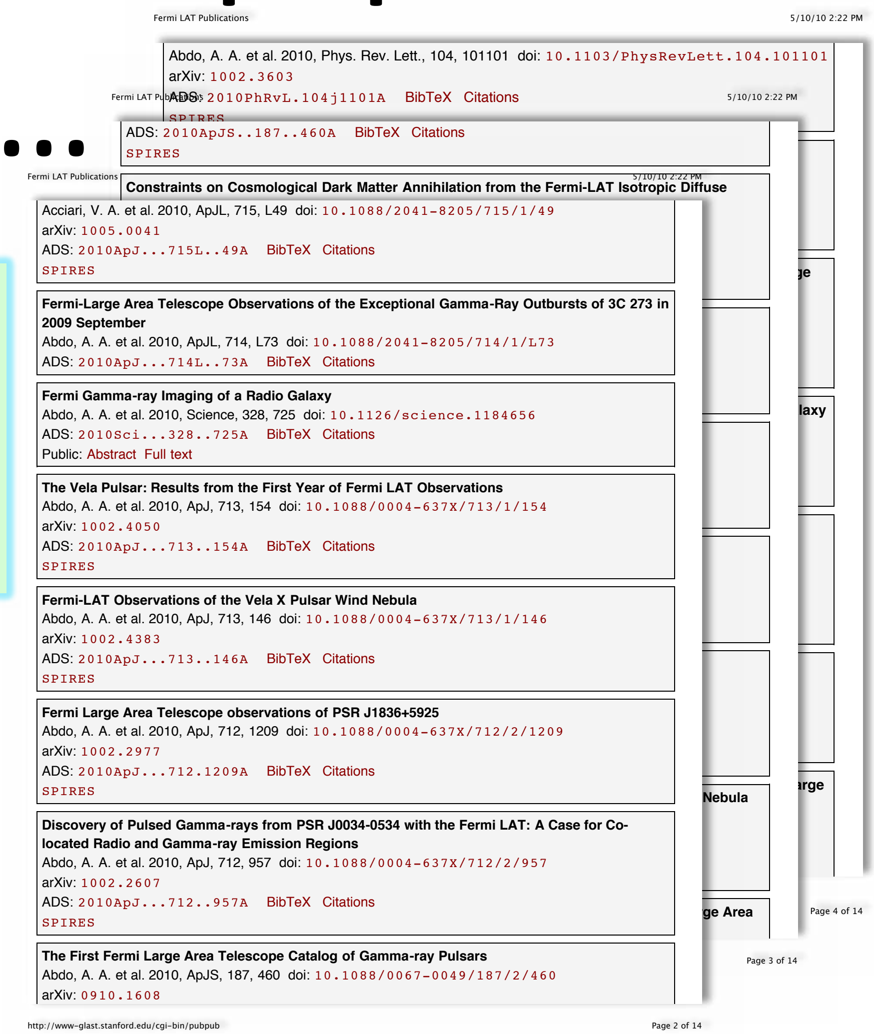
Some LAT Highlights

- Discovery and study of 117 gamma-ray pulsars, 36 of which are seen to pulse only in gamma rays. 40 are ms pulsars.
  - 43 new ms radio pulsars discovered thanks to LAT data!
- Remarkable high-energy emission from gamma-ray bursts
  - Starting to see what was missing
  - w/GBM, provides interesting limits on photon velocity dispersion
- Very high statistics measurement of the cosmic e+e- flux to 1 TeV
- Nailing down the diffuse galactic GeV emission
- LAT determination of the isotropic diffuse flux
- Searches for Dark Matter signatures in different kinds of sources
- Many new results on supermassive black hole systems (AGN), including sources never seen in the GeV range
- More cosmic accelerators: Galactic X-ray binaries, supernova remnants, PWNe. Probing the cosmic-ray distributions in other galaxies; LMC and SMC.
- Extragalactic Background Light measurements
- New limits on large extra dimensions
- Crab short *flares*
- 2^{nd} catalog: 1873 sources

>220 LAT Team papers out…



ADS: LAT 2nd Catalog most highly cited paper of 2012 in Astronomy



Fermi LAT Publications 5/10/10 2:22 PM

Acciari, V. A. et al. 2010, ApJL, 715, L49 doi: 10.1088/2041-8205/715/1/49
arXiv: 1005.0041
ADS: 2010ApJ...715L..49A BibTeX Citations
SPIRES

Fermi-Large Area Telescope Observations of the Exceptional Gamma-Ray Outbursts of 3C 273 in 2009 September
Abdo, A. A. et al. 2010, ApJL, 714, L73 doi: 10.1088/2041-8205/714/1/L73
ADS: 2010ApJ...714L..73A BibTeX Citations

Fermi Gamma-ray Imaging of a Radio Galaxy
Abdo, A. A. et al. 2010, Science, 328, 725 doi: 10.1126/science.1184656
ADS: 2010Sci...328..725A BibTeX Citations
Public: Abstract Full text

The Vela Pulsar: Results from the First Year of Fermi LAT Observations
Abdo, A. A. et al. 2010, ApJ, 713, 154 doi: 10.1088/0004-637X/713/1/154
arXiv: 1002.4050
ADS: 2010ApJ...713..154A BibTeX Citations
SPIRES

Fermi-LAT Observations of the Vela X Pulsar Wind Nebula
Abdo, A. A. et al. 2010, ApJ, 713, 146 doi: 10.1088/0004-637X/713/1/146
arXiv: 1002.4383
ADS: 2010ApJ...713..146A BibTeX Citations
SPIRES

Fermi Large Area Telescope observations of PSR J1836+5925
Abdo, A. A. et al. 2010, ApJ, 712, 1209 doi: 10.1088/0004-637X/712/2/1209
arXiv: 1002.2977
ADS: 2010ApJ...712.1209A BibTeX Citations
SPIRES

Discovery of Pulsed Gamma-rays from PSR J0034-0534 with the Fermi LAT: A Case for Co-located Radio and Gamma-ray Emission Regions
Abdo, A. A. et al. 2010, ApJ, 712, 957 doi: 10.1088/0004-637X/712/2/957
arXiv: 1002.2607
ADS: 2010ApJ...712..957A BibTeX Citations
SPIRES

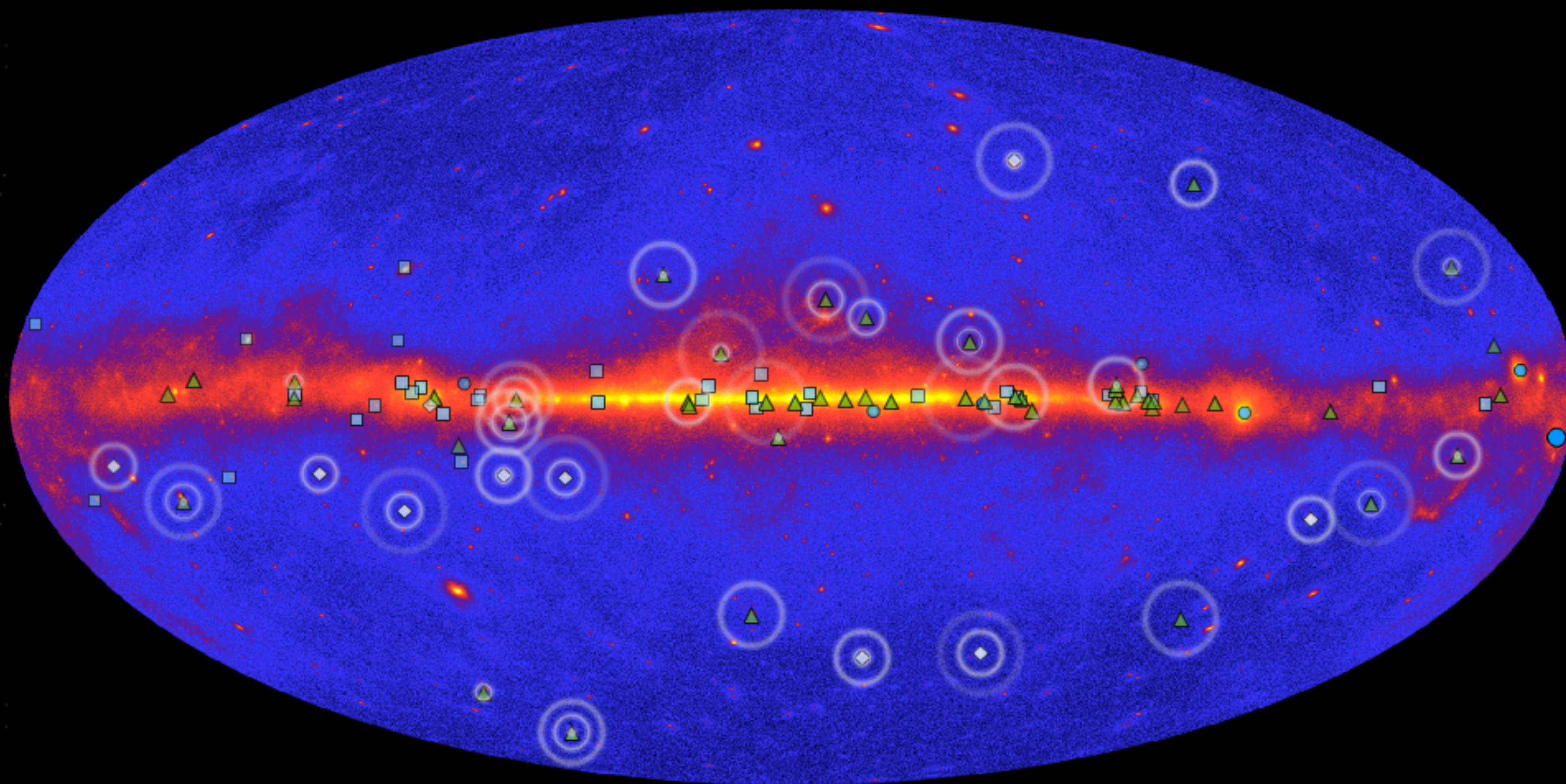
The First Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
Abdo, A. A. et al. 2010, ApJS, 187, 460 doi: 10.1088/0067-0049/187/2/460
arXiv: 0910.1608

http://www-glast.stanford.edu/cgi-bin/pubpub Page 2 of 14

…with many more in the pipeline…and many hundreds more using public LAT data.

http://www-glast.stanford.edu/cgi-bin/pubpub

The sky is full of pulsars!

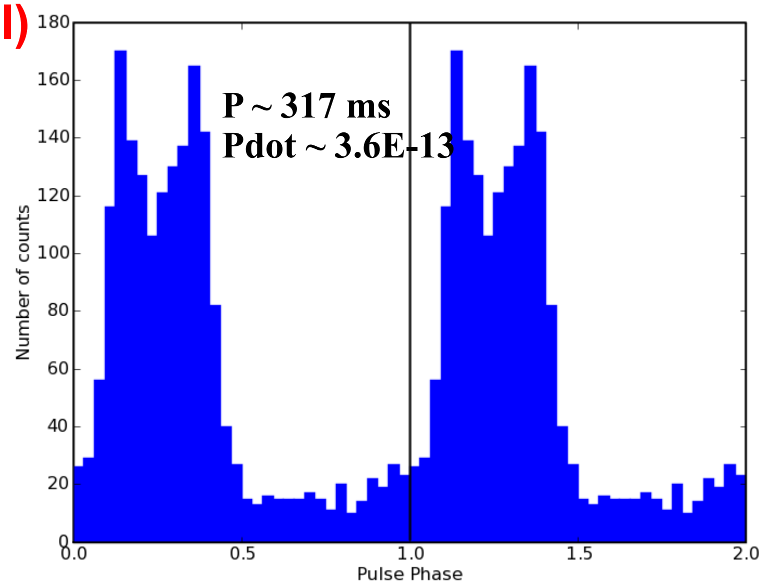


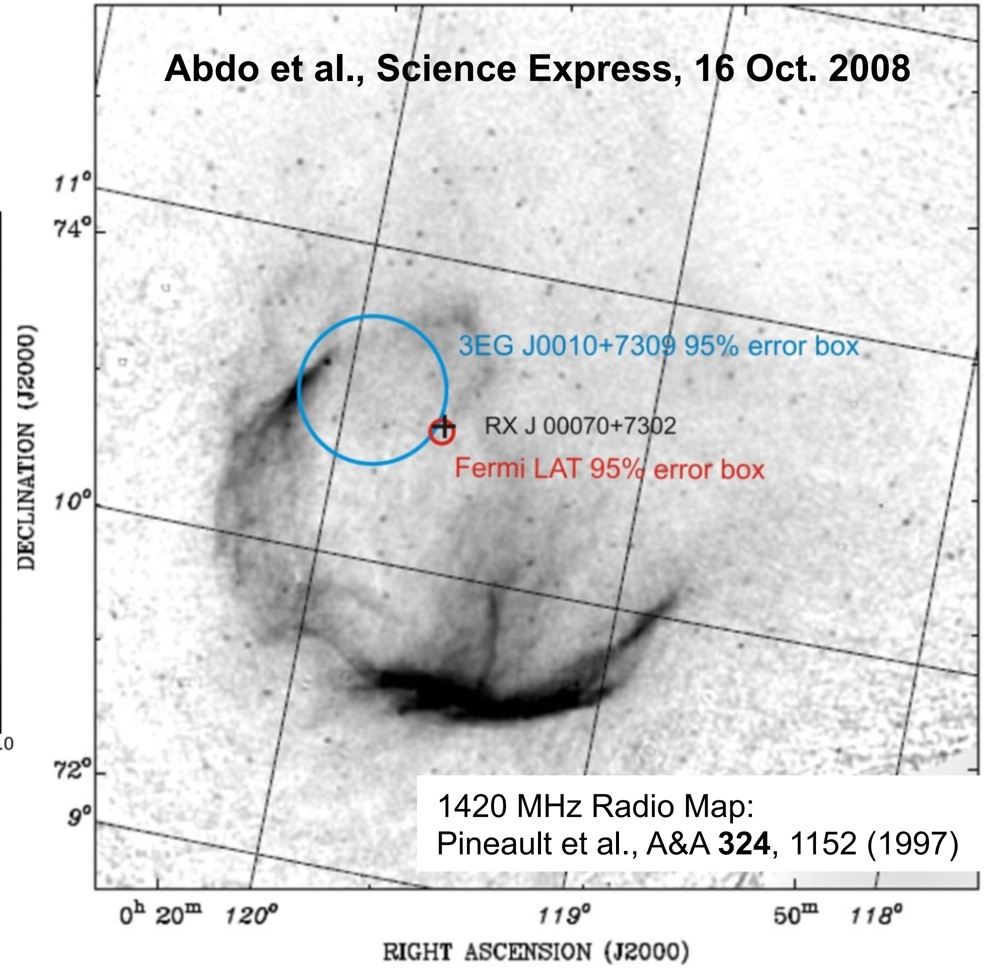
Now >100 detected
see http://www.nasa.gov/externalflash/fermipulsar/

Discovery of First Gamma-ray only Pulsar

A radio-quiet, gamma-ray only pulsar, in Supernova Remnant CTA1

Quick discovery enabled by
- **large leap in key capabilities**
- **new analysis technique (Atwood et al)**



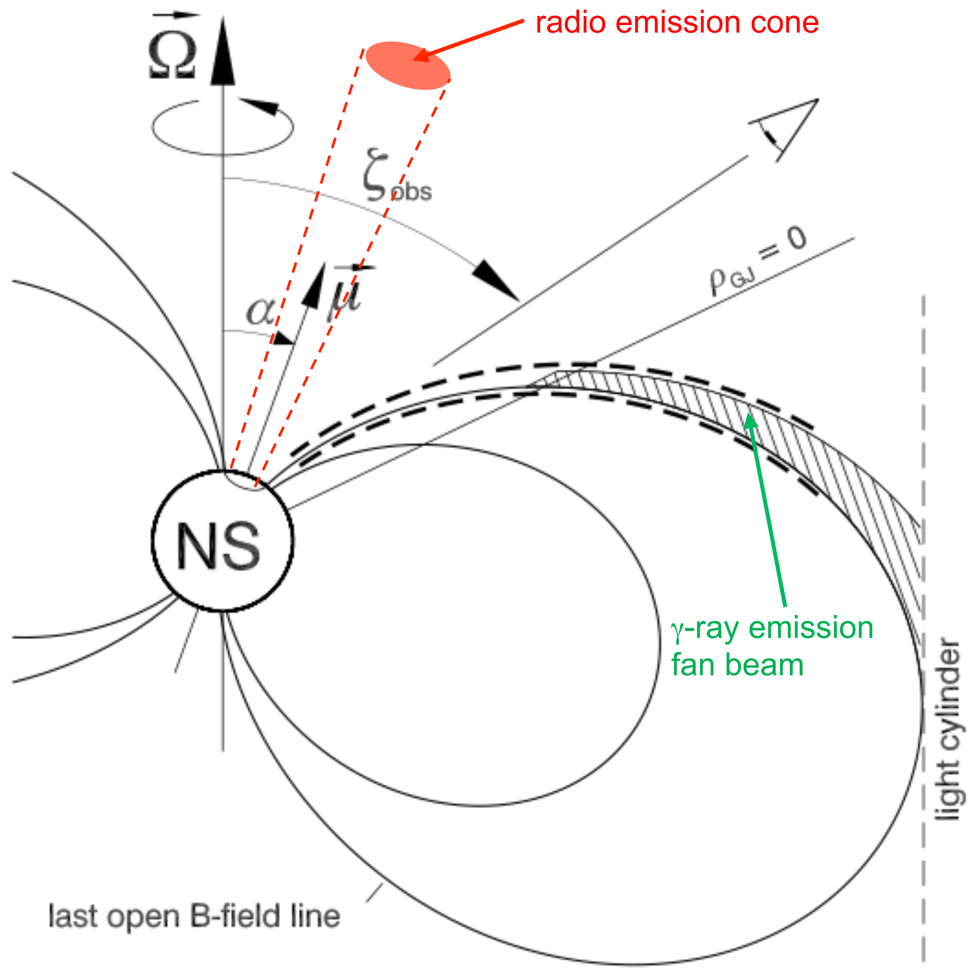


- Spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.

- The γ-ray flux from the CTA 1 pulsar corresponds to about 1-10% of E_{rot} (depending on beam geometry)

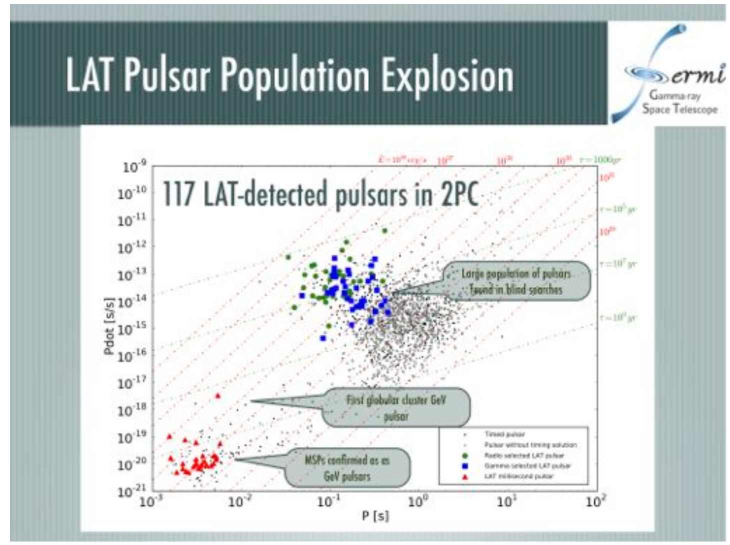
Age ~(0.5 – 1)x10^4 years
Distance ~ 1.4 kpc
Diameter ~ 1.5°

Pulsar Field Geometry Simplified

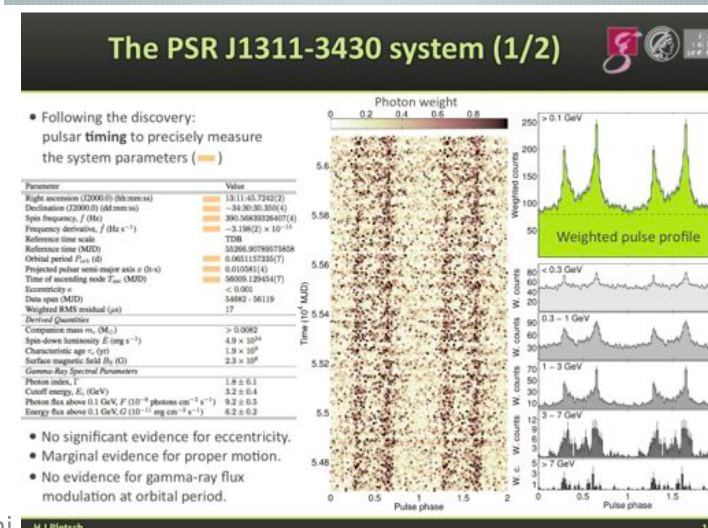


Pulsars

- Number is still increasing rapidly – projecting >200 soon
  - Increase since 3rd FS has been on all fronts: radio monitoring & follow-up* and blind searches, with spectacular MSP increase
- **First blind search MSP** announced this week: Pletsch et al. found PSR J1311-3430
  - Optical observations (Romani 2012) constrained the search *somewhat*
  - Most compact MSP known & $M_{pulsar} > 2.1\ M_{sun}$ (Romani et al.)



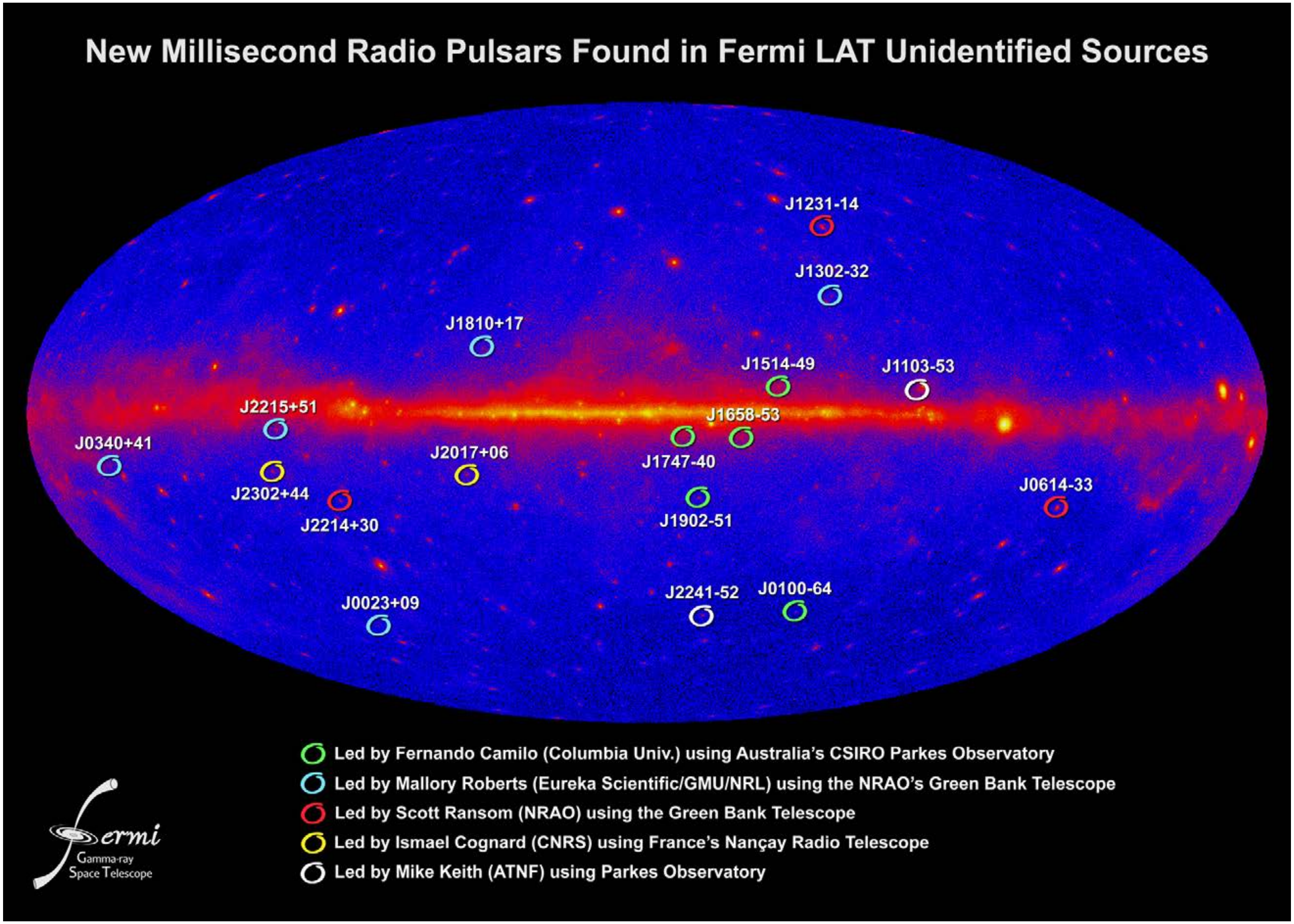
Ray

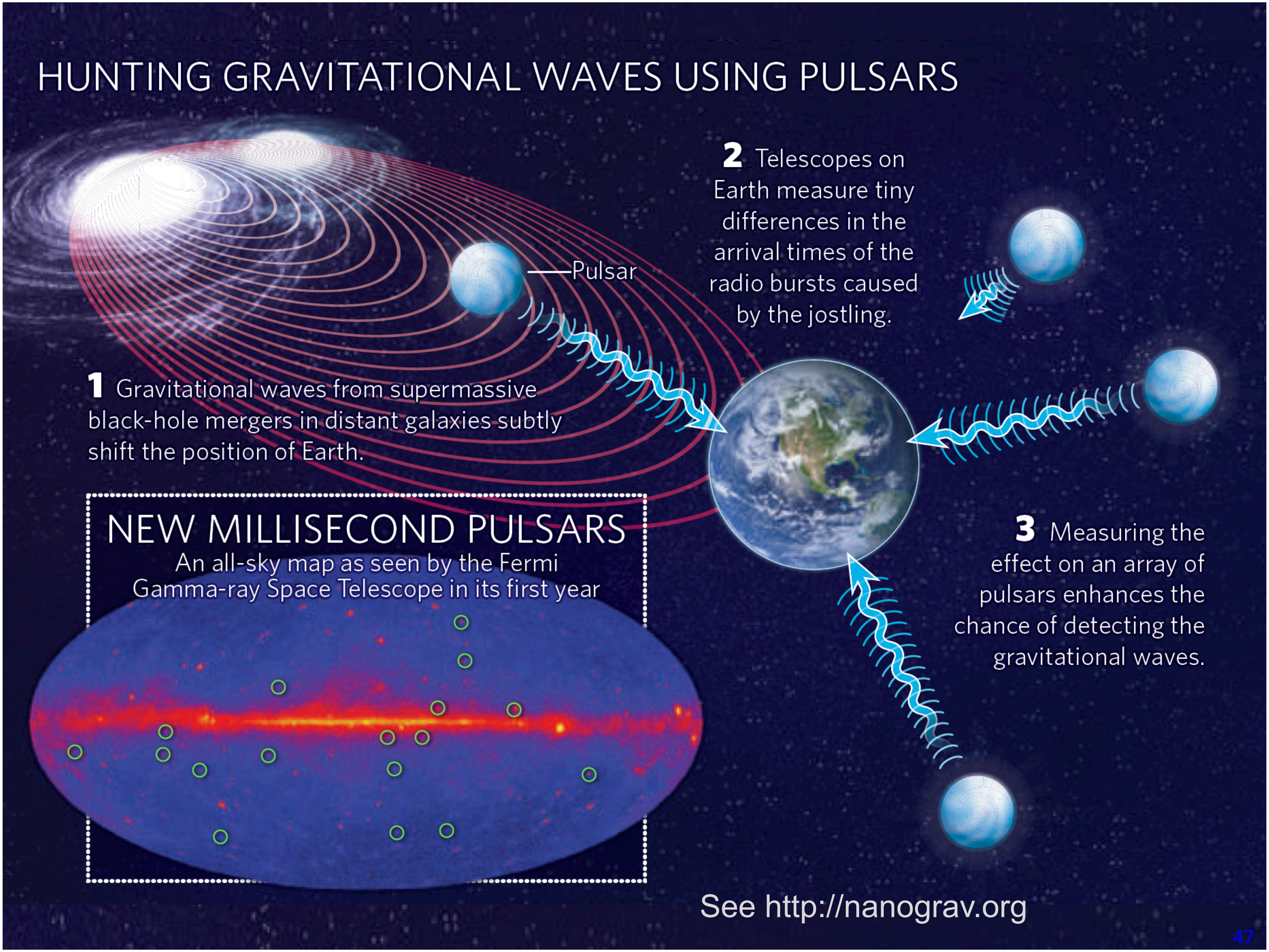


Pletsch

Ongoing successful MW collaboration with Pulsar Timing and Pulsar Search Consortia

Millisecond pulsars and Fermi




HUNTING GRAVITATIONAL WAVES USING PULSARS
Pulsar
1 Gravitational waves from supermassive black-hole mergers in distant galaxies subtly shift the position of Earth.
2 Telescopes on Earth measure tiny differences in the arrival times of the radio bursts caused by the jostling.
3 Measuring the effect on an array of pulsars enhances the chance of detecting the gravitational waves.
NEW MILLISECOND PULSARS
An all-sky map as seen by the Fermi Gamma-ray Space Telescope in its first year
See http://nanograv.org

A Variable Standard

A Variable Standard

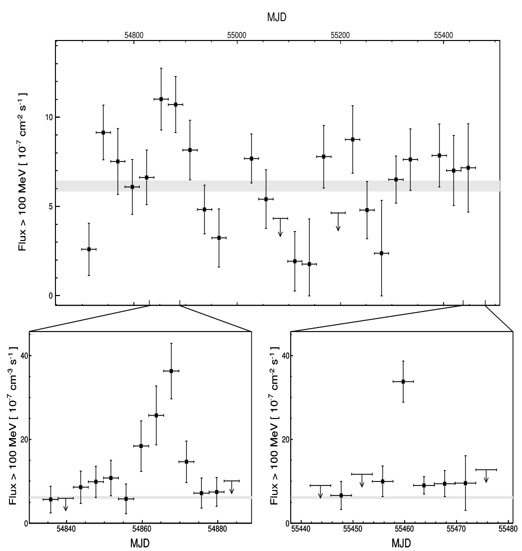
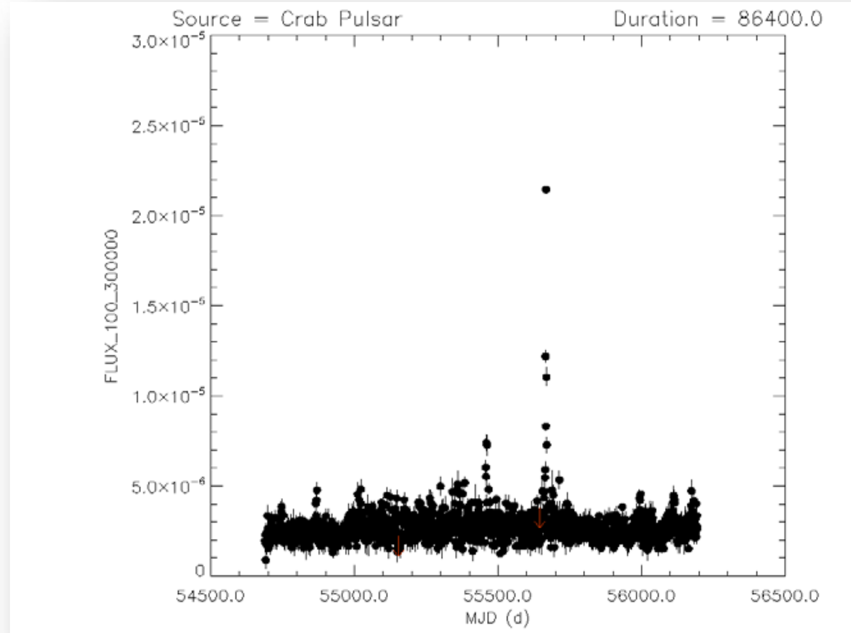


Figure 2: Gamma-ray flux above 100 MeV as a function of time of the synchrotron component of the Crab Nebula. The upper panel shows the flux in four-week intervals for the first 25 month of observations. Data for times when the sun was within 15° of the Crab Nebula have been omitted. The gray band indicates the average flux measured over the entire period. The lower panel shows the flux as a function of time in four-day time bins during the flaring periods in February 2009 and September 2010. Arrows indicate 95% confidence flux limits.



http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

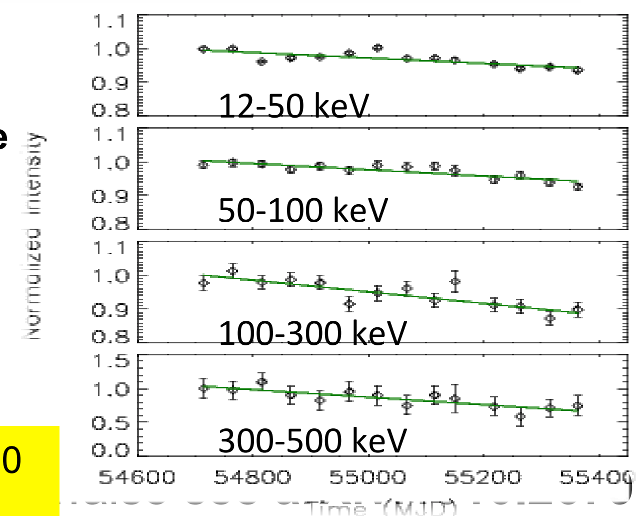
arXiv:1011.3855v1

Science, 331, 739

Now added to monitored source list

GBM:

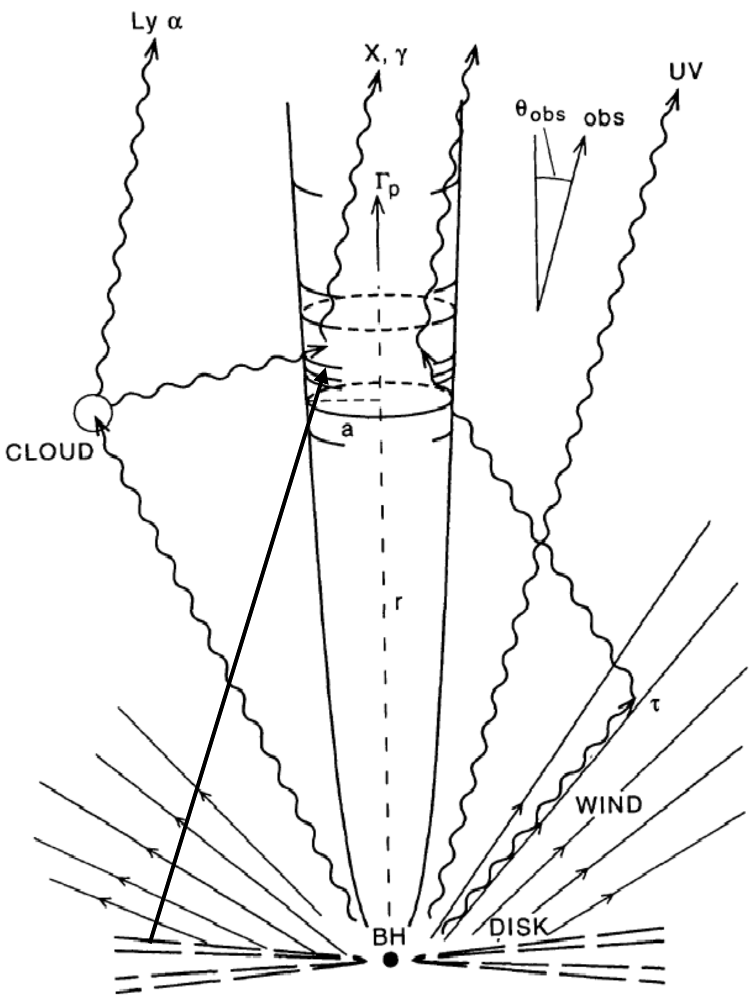
- **Normalized to long-term average in each band**
- **Decline in Crab flux (MJD 54690-55390)**
- **No changes in GBM response or calibration**



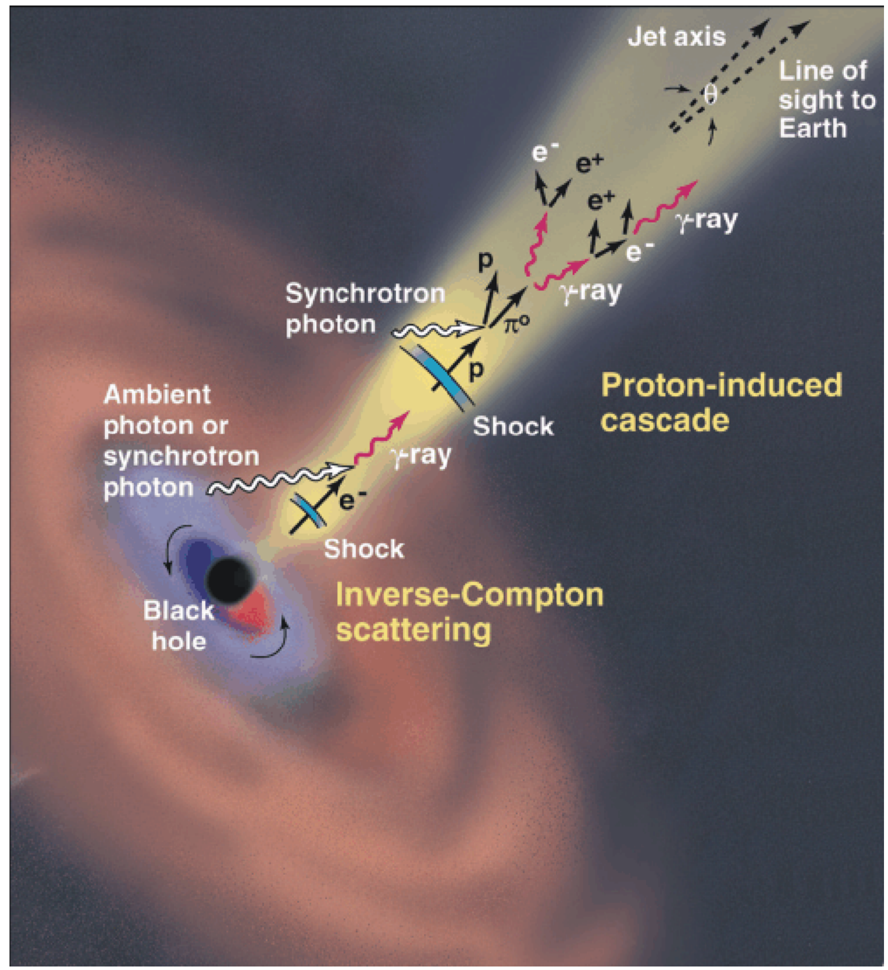
Wilson-Hodge et al 2010

arXiv:1010.2679

Models of Blazar Gamma-ray Production



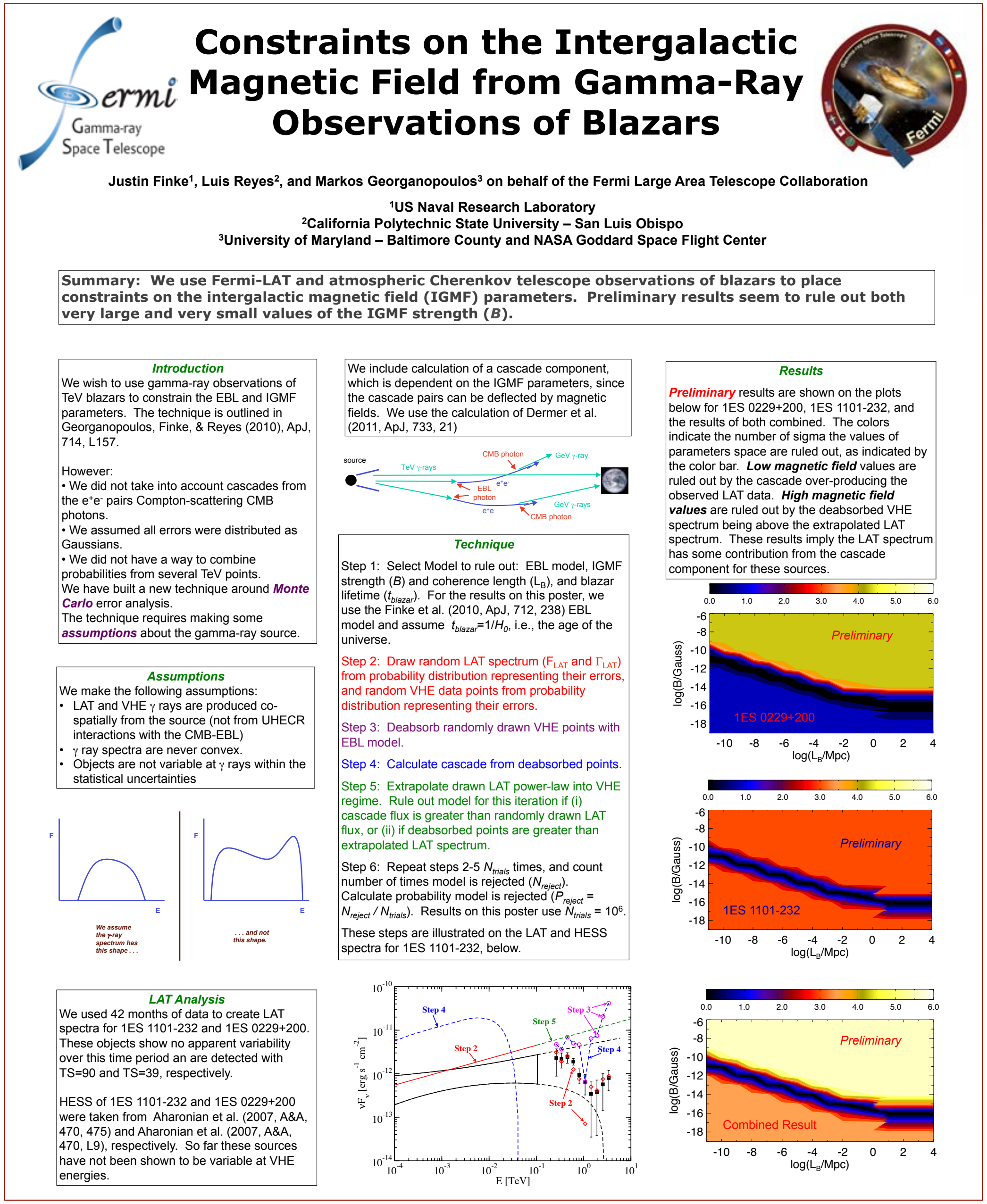
(from Sikora, Begelman, and Rees (1994))



(credit:J. Buckley)

Variability and MW keys

Probing the Intergalactic B Field



Constraints on the Intergalactic Magnetic Field from Gamma-Ray Observations of Blazars

Justin Finke[1], Luis Reyes[2], and Markos Georganopoulos[3] on behalf of the Fermi Large Area Telescope Collaboration

[1]US Naval Research Laboratory
[2]California Polytechnic State University – San Luis Obispo
[3]University of Maryland – Baltimore County and NASA Goddard Space Flight Center

Summary: We use Fermi-LAT and atmospheric Cherenkov telescope observations of blazars to place constraints on the intergalactic magnetic field (IGMF) parameters. Preliminary results seem to rule out both very large and very small values of the IGMF strength (*B*).

Introduction

We wish to use gamma-ray observations of TeV blazars to constrain the EBL and IGMF parameters. The technique is outlined in Georganopoulos, Finke, & Reyes (2010), ApJ, 714, L157.

However:
- We did not take into account cascades from the e^+e^- pairs Compton-scattering CMB photons.
- We assumed all errors were distributed as Gaussians.
- We did not have a way to combine probabilities from several TeV points.

We have built a new technique around ***Monte Carlo*** error analysis.
The technique requires making some ***assumptions*** about the gamma-ray source.

Assumptions

We make the following assumptions:
- LAT and VHE γ rays are produced co-spatially from the source (not from UHECR interactions with the CMB-EBL)
- γ ray spectra are never convex.
- Objects are not variable at γ rays within the statistical uncertainties

We assume the γ-ray spectrum has this shape . . . *. . . and not this shape.*

LAT Analysis

We used 42 months of data to create LAT spectra for 1ES 1101-232 and 1ES 0229+200. These objects show no apparent variability over this time period an are detected with TS=90 and TS=39, respectively.

HESS of 1ES 1101-232 and 1ES 0229+200 were taken from Aharonian et al. (2007, A&A, 470, 475) and Aharonian et al. (2007, A&A, 470, L9), respectively. So far these sources have not been shown to be variable at VHE energies.

We include calculation of a cascade component, which is dependent on the IGMF parameters, since the cascade pairs can be deflected by magnetic fields. We use the calculation of Dermer et al. (2011, ApJ, 733, 21)

Technique

Step 1: Select Model to rule out: EBL model, IGMF strength (*B*) and coherence length (L_B), and blazar lifetime (t_{blazar}). For the results on this poster, we use the Finke et al. (2010, ApJ, 712, 238) EBL model and assume $t_{blazar}=1/H_0$, i.e., the age of the universe.

Step 2: Draw random LAT spectrum (F_{LAT} and Γ_{LAT}) from probability distribution representing their errors, and random VHE data points from probability distribution representing their errors.

Step 3: Deabsorb randomly drawn VHE points with EBL model.

Step 4: Calculate cascade from deabsorbed points.

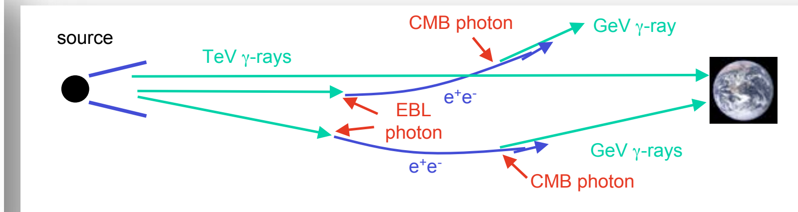
Step 5: Extrapolate drawn LAT power-law into VHE regime. Rule out model for this iteration if (i) cascade flux is greater than randomly drawn LAT flux, or (ii) if deabsorbed points are greater than extrapolated LAT spectrum.

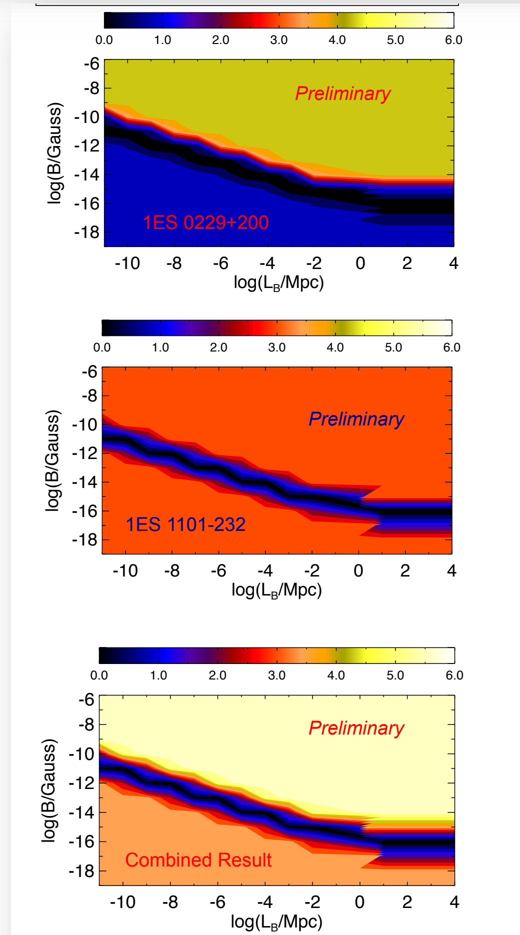
Step 6: Repeat steps 2-5 N_{trials} times, and count number of times model is rejected (N_{reject}). Calculate probability model is rejected ($P_{reject} = N_{reject} / N_{trials}$). Results on this poster use $N_{trials} = 10^6$.

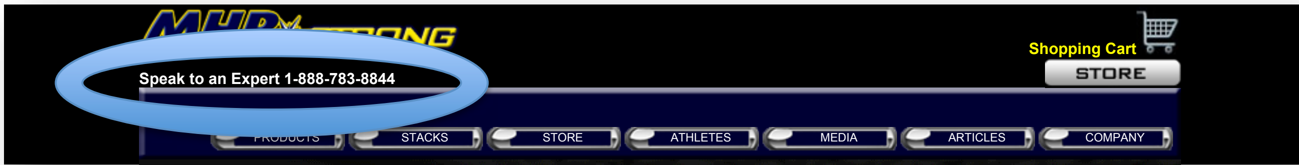
These steps are illustrated on the LAT and HESS spectra for 1ES 1101-232, below.

Results

Preliminary results are shown on the plots below for 1ES 0229+200, 1ES 1101-232, and the results of both combined. The colors indicate the number of sigma the values of parameters space are ruled out, as indicated by the color bar. ***Low magnetic field*** values are ruled out by the cascade over-producing the observed LAT data. ***High magnetic field values*** are ruled out by the deabsorbed VHE spectrum being above the extrapolated LAT spectrum. These results imply the LAT spectrum has some contribution from the cascade component for these sources.

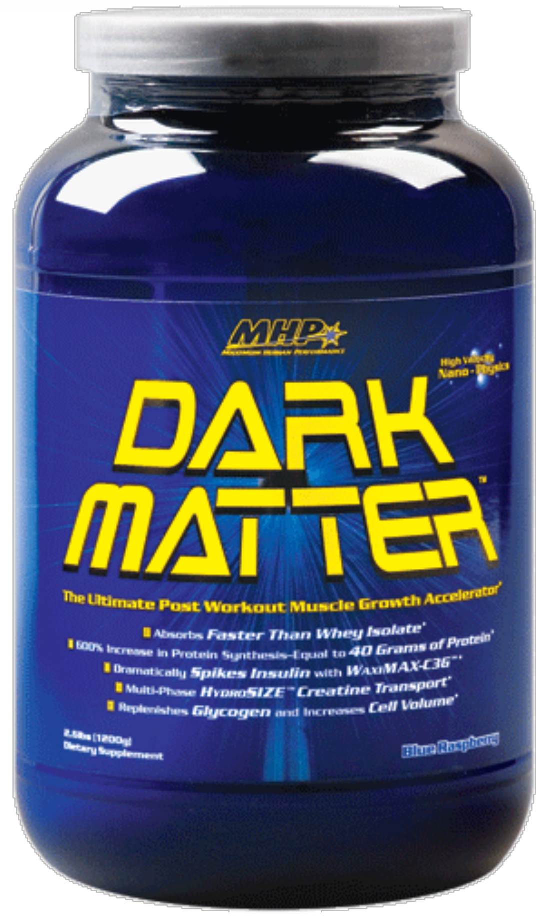


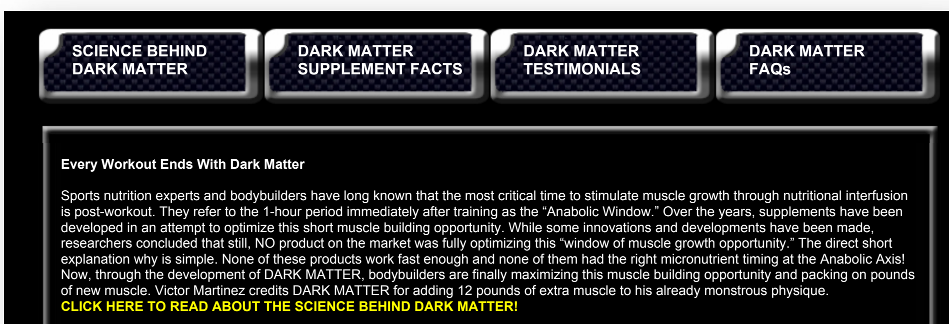




Dark Matter

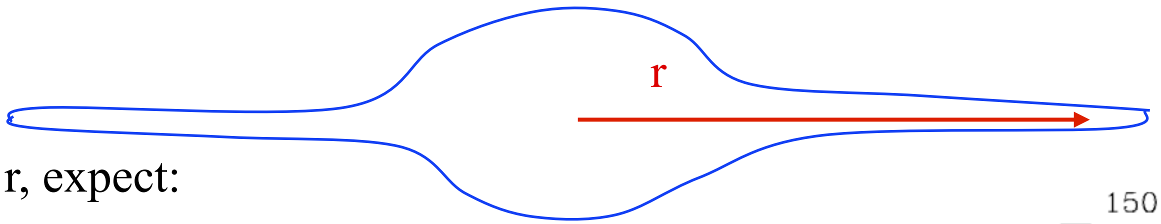
A Quick Tour





The Dark Matter Problem

Observe rotation curves for galaxies:

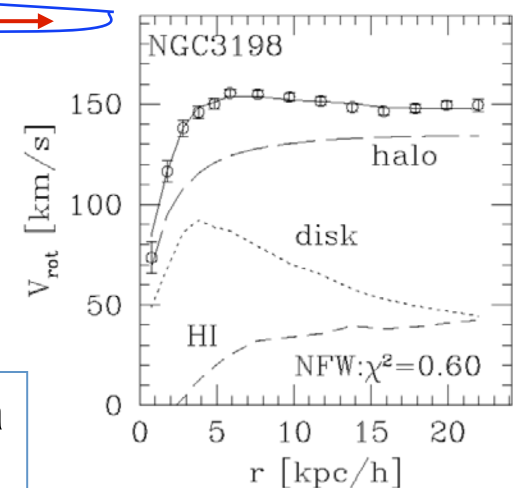


For large r, expect:

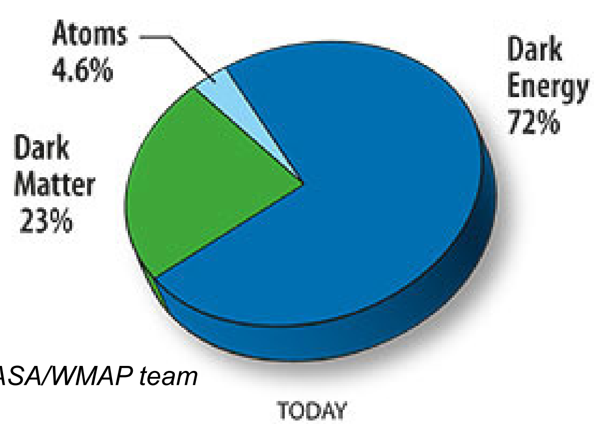
$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \qquad v(r) \sim \frac{1}{\sqrt{r}}$$

see: flat or rising rotation curves

Begeman/Navarro



Hypothesized Solution: the visible galaxy is embedded in a much larger halo of dark matter.

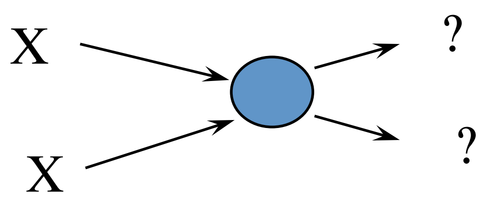


Credit: NASA/WMAP team

Bullet cluster

Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of cosmic particles ("indirect detection").



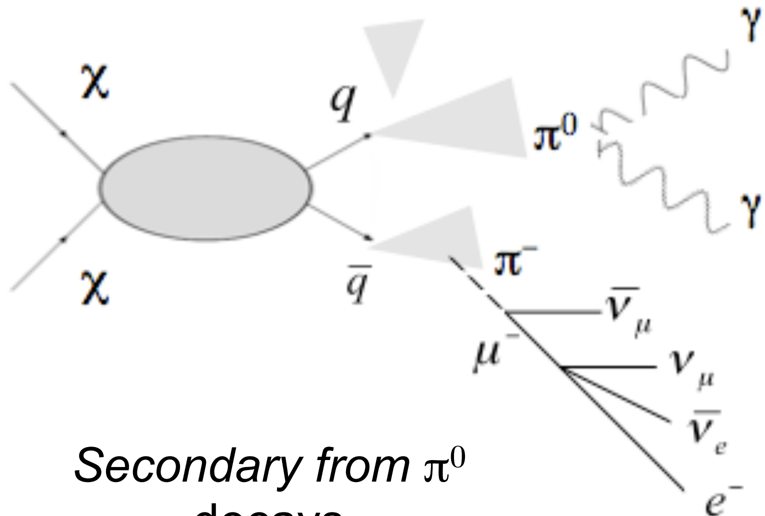
Anomalous gamma ray spectra and/or $\gamma\gamma$ or $Z\gamma$ "lines" and/or anomalous charged cosmic rays and/or neutrinos?

- If particles are stable: rate ~ (DM density)^2
- If particles unstable: rate ~ (DM density)

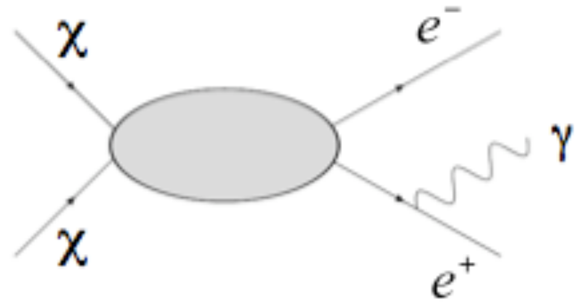
- Key interplay of techniques:
  - colliders (TeVatron, LHC)
  - direct detection experiments underground
  - indirect detection (most straightforward: gamma rays and neutrinos)
    - Full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - **Challenge is to separate signals from astrophysical backgrounds**

Just an example of what might be waiting for us to find!

Gamma rays from Dark Matter annihilation



Secondary from π^0 decays



Prompt lepton pair production

+ "lines" from 2-body final states

$$\Phi_{WIMP}(E,\Psi) = J(\Psi) \times \Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi) = \int_{l.o.s} dl(\Psi)\,\rho^2(l)$$

Particle physics factor

$$\Phi^{PP}(E) = \frac{1}{2}\frac{\langle\sigma v\rangle}{m^2_{WIMP}} \sum_f \frac{dN_f}{dE} B_f$$

Dark Matter: Many Places to Look!

Galactic Center

Good Statistics but source confusion/diffuse background

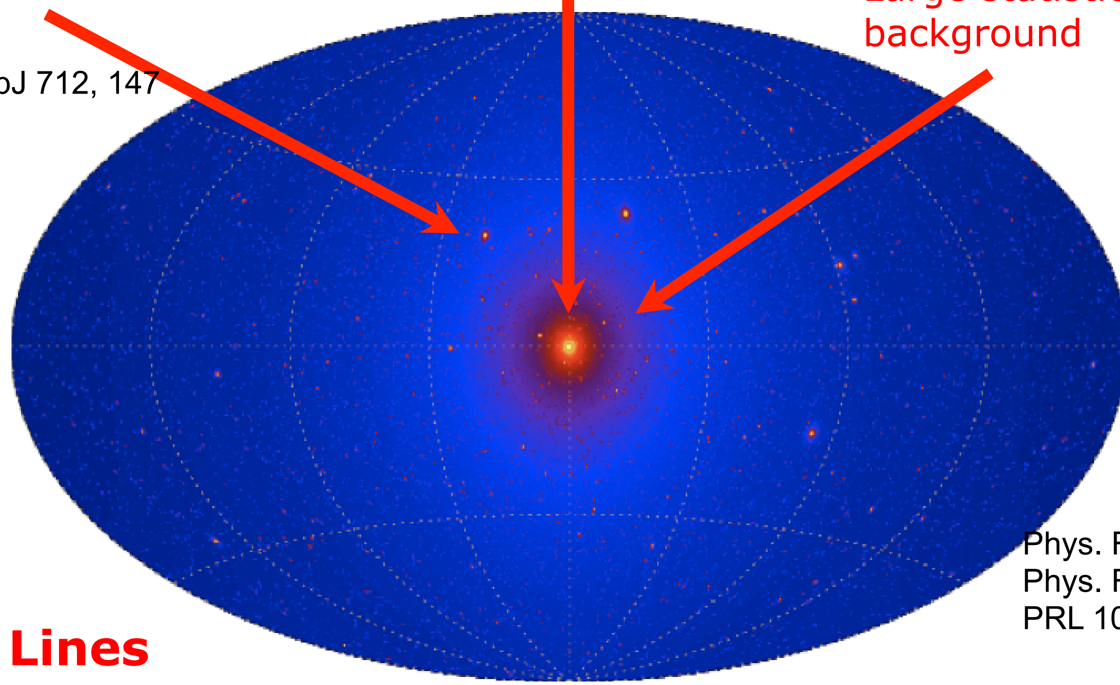
Satellites

Low background and good source id, but low statistics, in some cases astrophysical background

JCAP 1204 (2012) 016
ApJ 747, 121 (2012)
PRL 107, 241302 (2011) ApJ 712, 147 (2010)
JCAP 01 (2010) 031
ApJ 718, 899 (2010)

Milky Way Halo

Large statistics but diffuse background arXiv:1205.6474



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

And anomalous charged cosmic rays (little/no directional information, trapping times, etc.)

Phys. Rev. D84, 032007 (2011)
Phys. Rev. D82, 092003 (2010)
PRL 108 (2012)

Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Phys. Rev. D, In press (2012)
Phys. Rev. Lett. 104, 091302 (2010)

Galaxy Clusters

Low background, but low statistics

JCAP 05 (2010) 025

Extragalactic

Large statistics, but astrophysics, galactic diffuse background JCAP 04 (2010) 014

Dark Matter: Many Places to Look!

Galactic Center

Good Statistics but source confusion/diffuse background

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Low background and good source id, but low statistics, in some cases astrophysical background

JCAP 1204 (2012) 016
ApJ 747, 121 (2012)
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Phys. Rev. D84, 032007 (2011)
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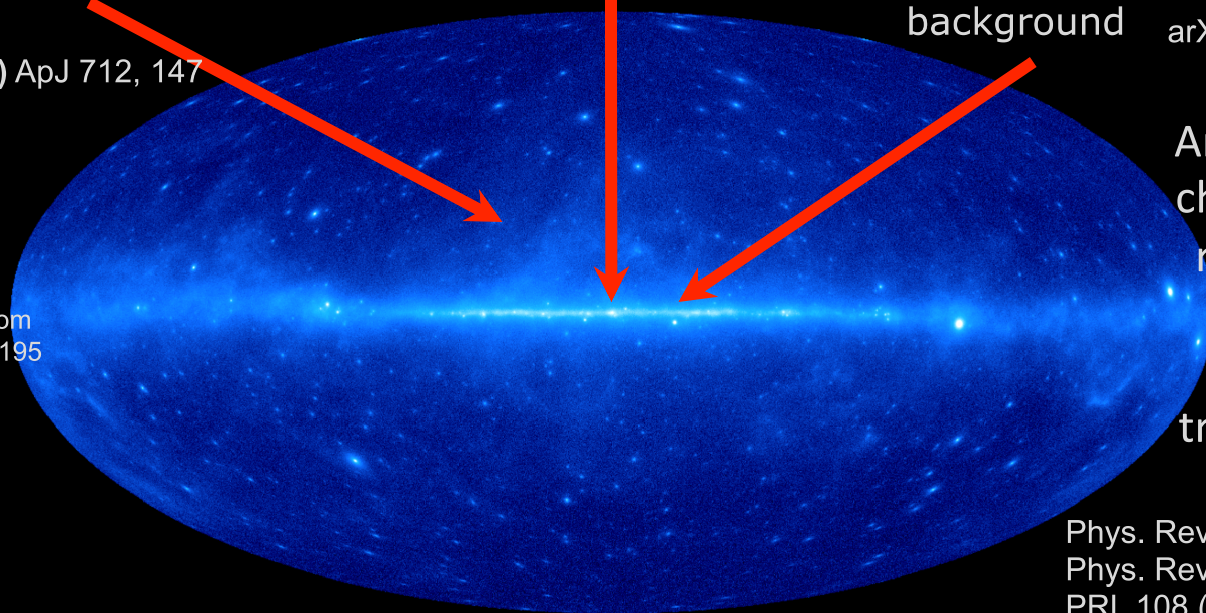
PRL 108 (2012)



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Phys. Rev. D, In press (2012)
Phys. Rev. Lett. 104, 091302 (2010)

Galaxy Clusters

Low background, but low statistics

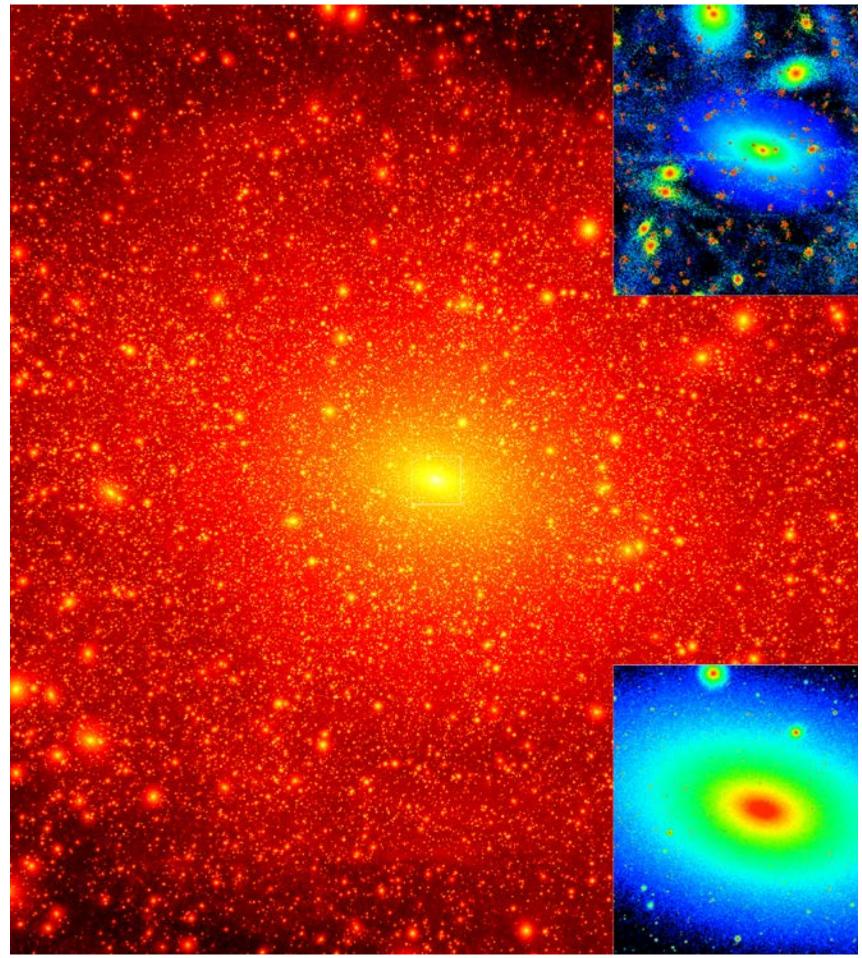
JCAP 05 (2010) 025

Extragalactic

Large statistics, but astrophysics, galactic diffuse background JCAP 04 (2010) 014

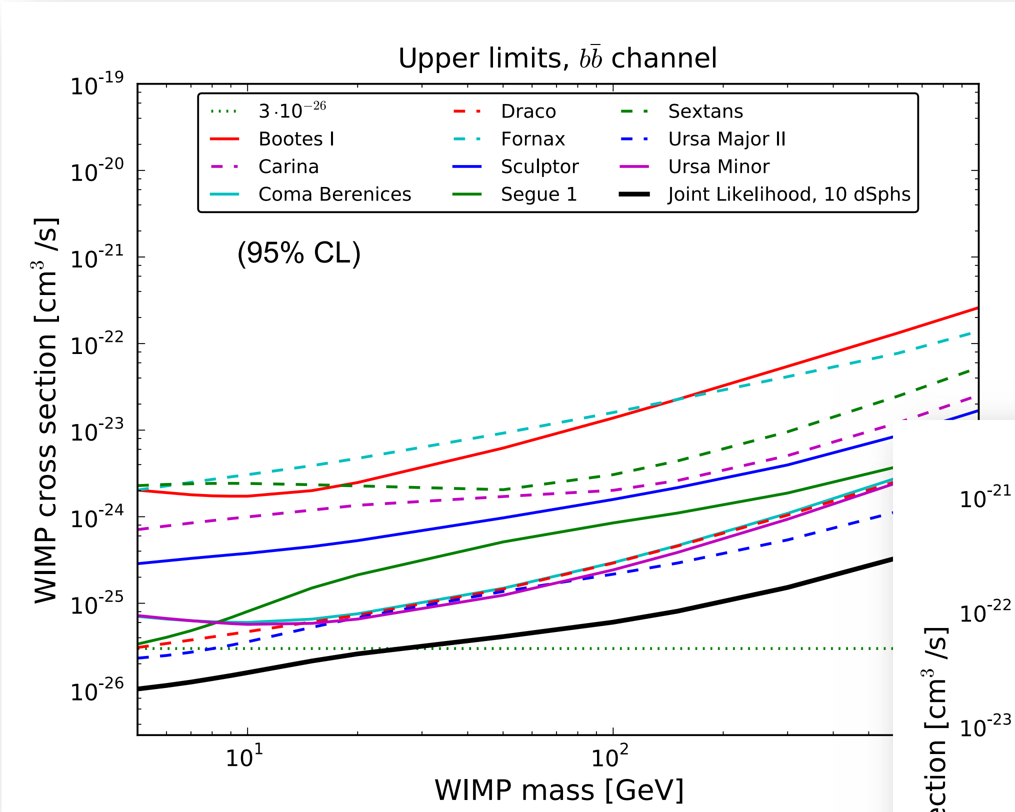
Dwarf Spheriodal (dSph) Galaxies

- Largest galactic substructures predicted (in ΛCDM)
- DM-dominated: mass-to-light ratios O(100-1000)
- Very low astrophysical backgrounds
  - no detected gas, low recent star formation activity
- SDSS discovery of many more ultrafaint Milkyway satellites
  - more are welcome!
- Great opportunity for indirect DM signal searches!

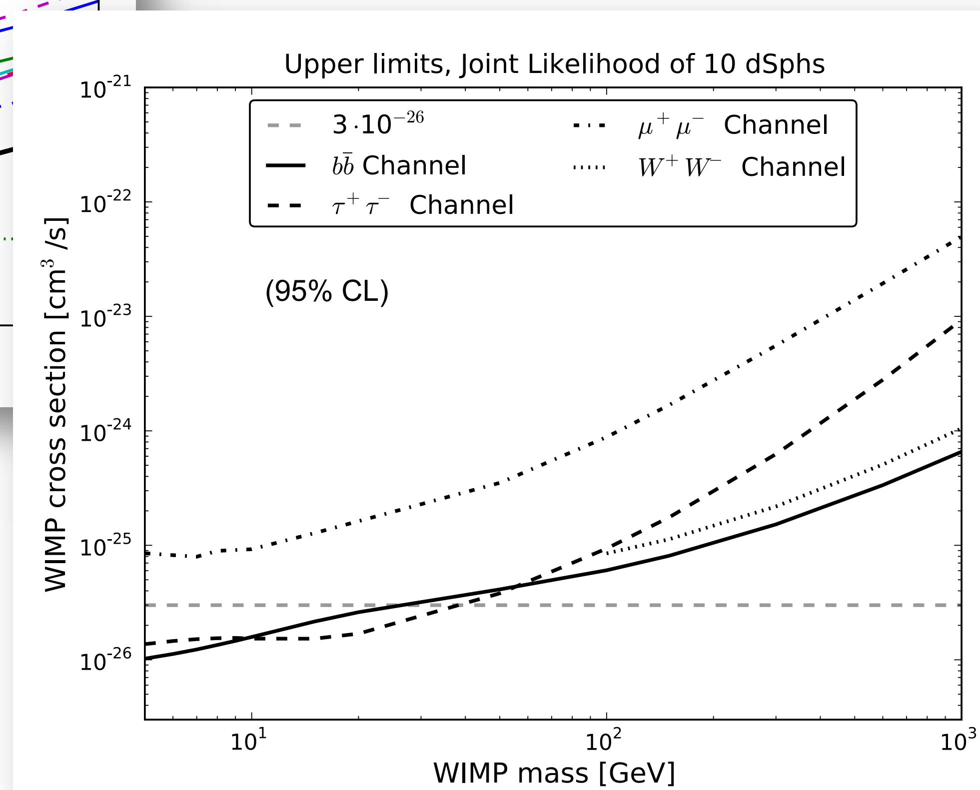


Via Lactea II simulation

Combining dSph Limits



PRL 107(2011)
arXiv:1108.3546v2

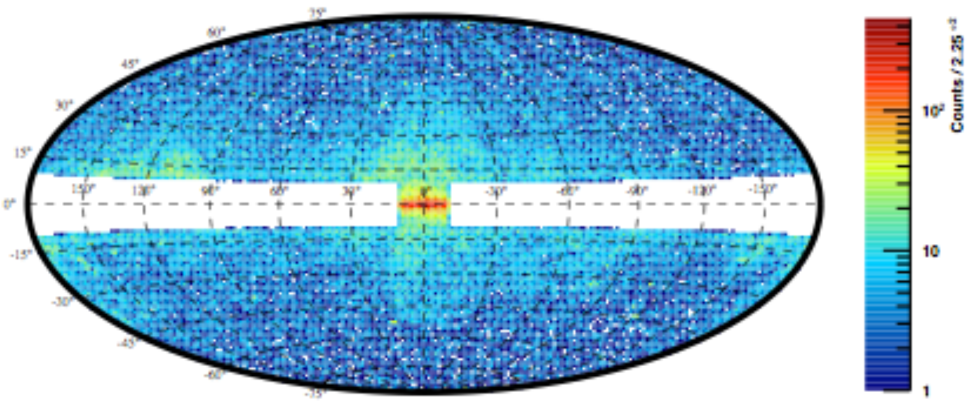


Now getting to very interesting sensitivity ranges!

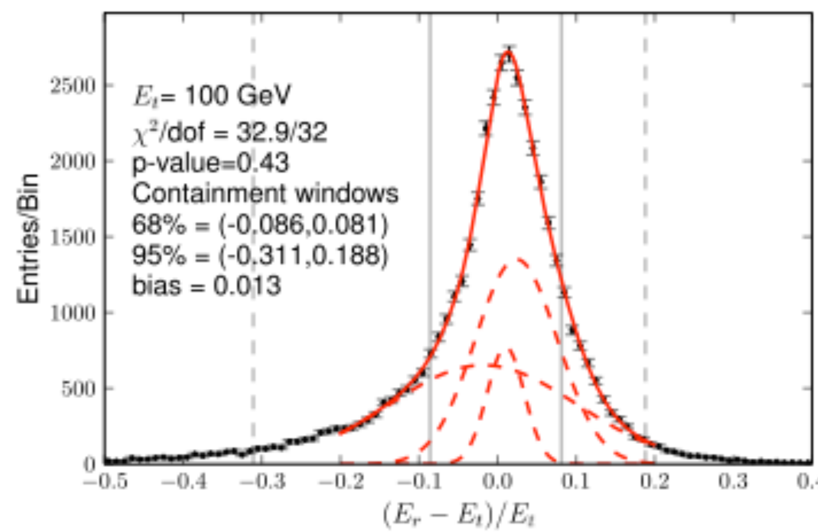
Search for spectral lines

arXiv:1205.2739

Region-of-interest for line search



LAT energy response to 100 GeV line

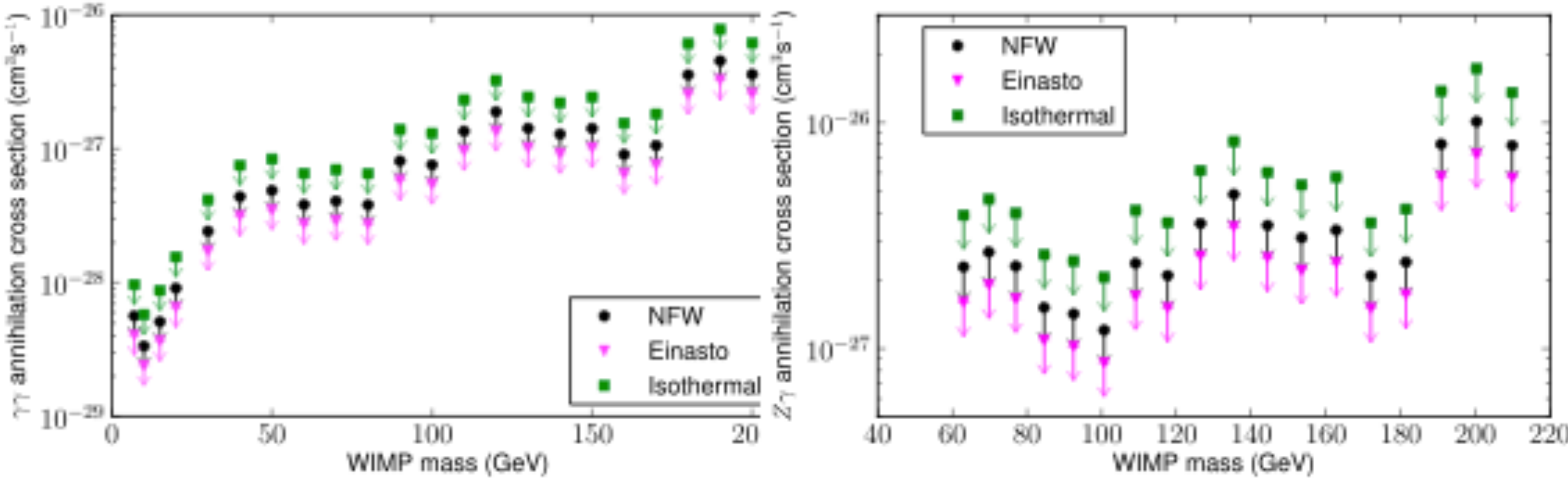


- search for line emission from dark matter annihilation or decay ($\gamma\gamma$ and $Z\gamma$ channels)
- exclude Galactic plane and 1FGL sources
- assume power-law background (spectral index free to vary) in each energy window

Constraints from line search

arXiv:1205.2739

Annihilation cross-section constraints

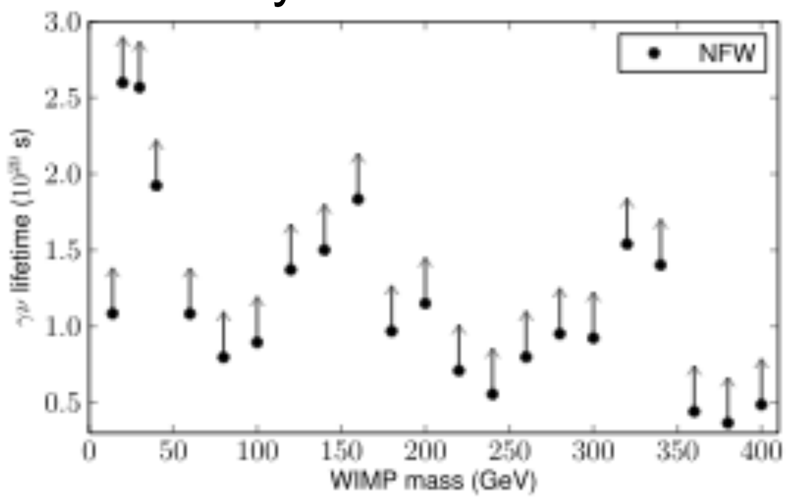


Ackermann et al. [Fermi LAT Collaboration], submitted to PRD

- non-detection places limits on annihilation cross section or decay lifetime to $\gamma\gamma$ and $Z\gamma$

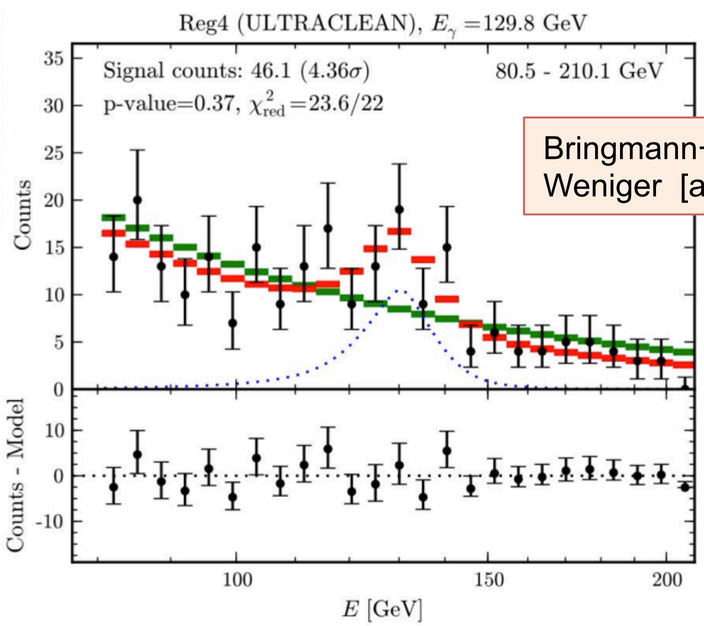
- **recent papers in the arXiv suggest lines or hard spectral features consistent with DM predictions – <u>much more to do!</u>**

Decay lifetime constraints



Fermi Gamma-ray Space Telescope

Things Going Bump



Bringmann+ [arXiv:1203.1312]
Weniger [arXiv:12.2797]

Interpretations and follow up analyses:

Tempel+ [arXiv:1205.1045]
Kyae & Park [arXiv:1205.4151]
Dudas+ [arXiv:1205.1520]
Lee+ [arXiv:1205.4700]
Acharya+ [arXiv:1205.5789]
Buckley & Hooper [arXiv:1205.6811]
Su & Finkbeiner [arXiv:1206.1616]
Chu,Hambye + [arXiv:1206.2279]
& many others

Astrophysical Interpretations:

Boyarsky+ [arXiv:1205.4700]
Aharonian+ [arXiv: 1207.0458]

Associated with Inner Galaxy and also possibly the Earth limb.

Much work going on! Next LAT team update at Fermi Symposium in November.

Also discussing how best to improve statistics.

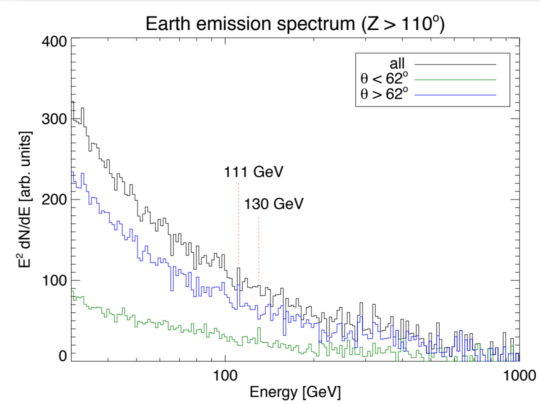
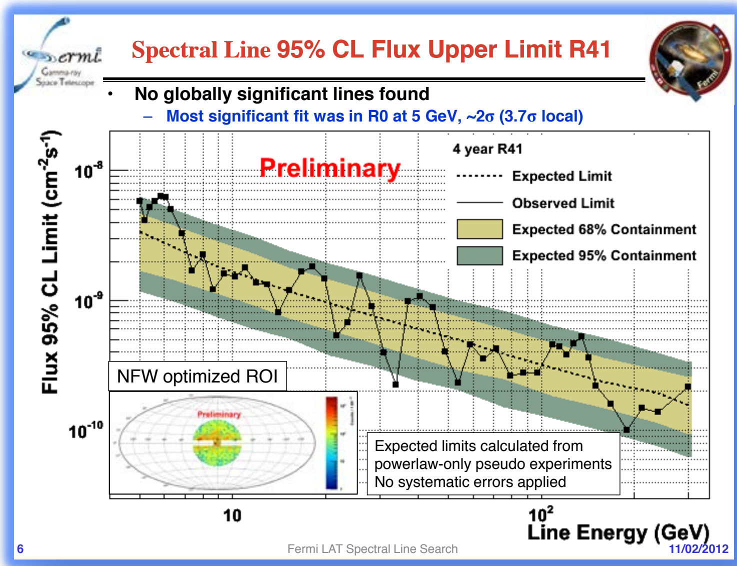


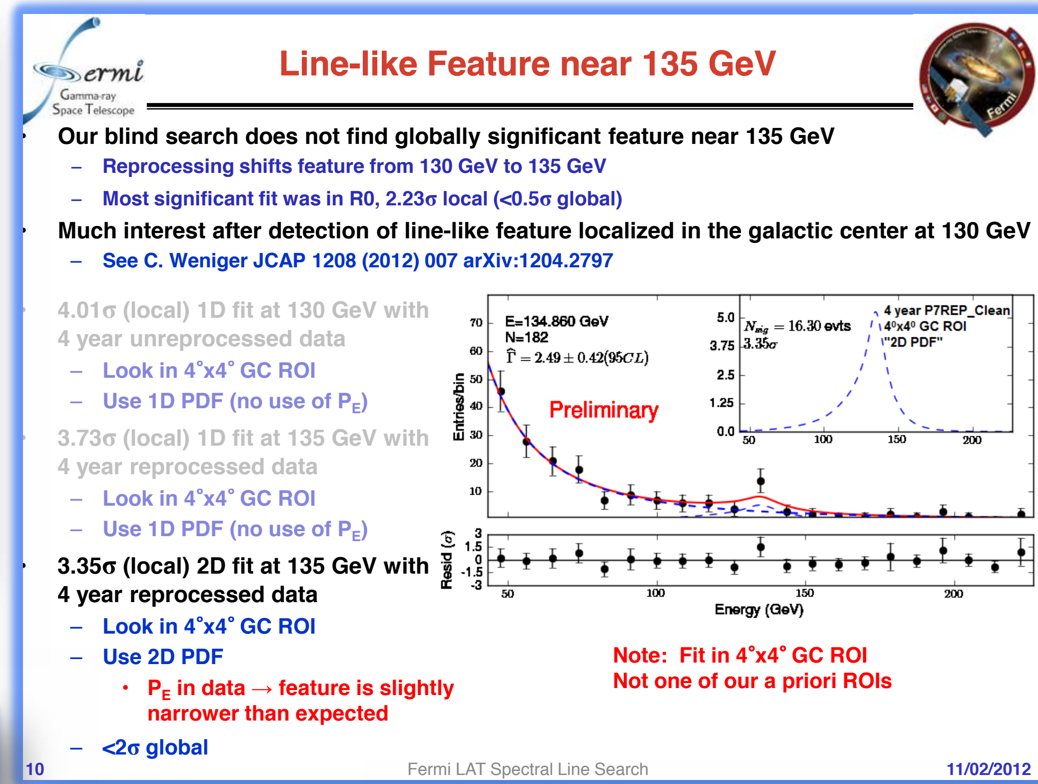
FIG. 21.— Photons from cascades in the Earth's atmosphere (sometimes incorrectly called "albedo" photons), and with 10° of the GC, show a slight excess at 111 and 130 GeV also. Because these photons arrive at high zenith angle ($Z > 110°$), they tend to have a high incidence angle (median $\theta = 63.2°$). The low-θ photons show a small bump at 130 GeV, and the high-θ photons show a small bump at 111 GeV. The cuts were chosen to maximize these features, so interpretation of this plot requires a modest trials factor.

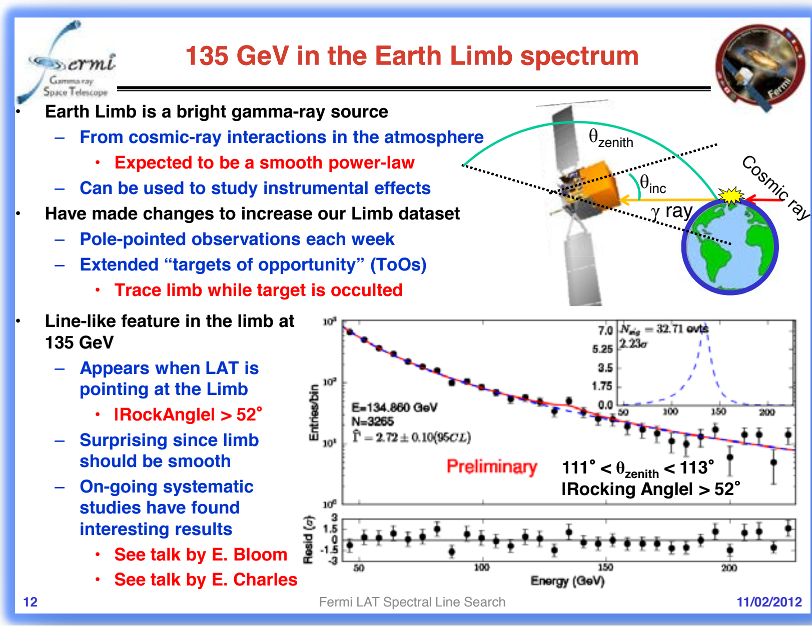
Su & Finkbeiner

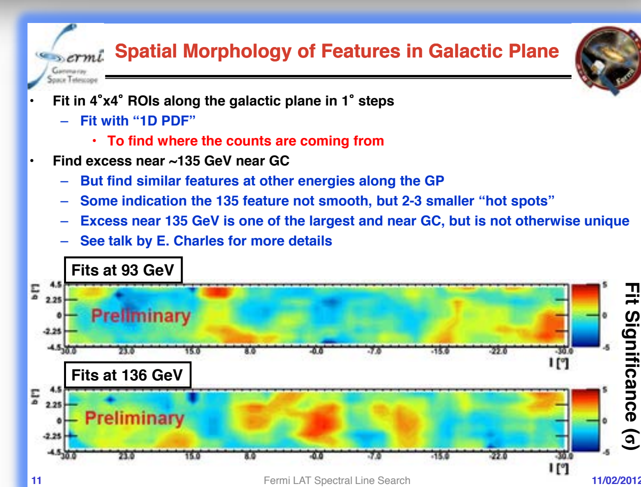
arxiv 1206.1616v2

Recent update at Fermi Symposium

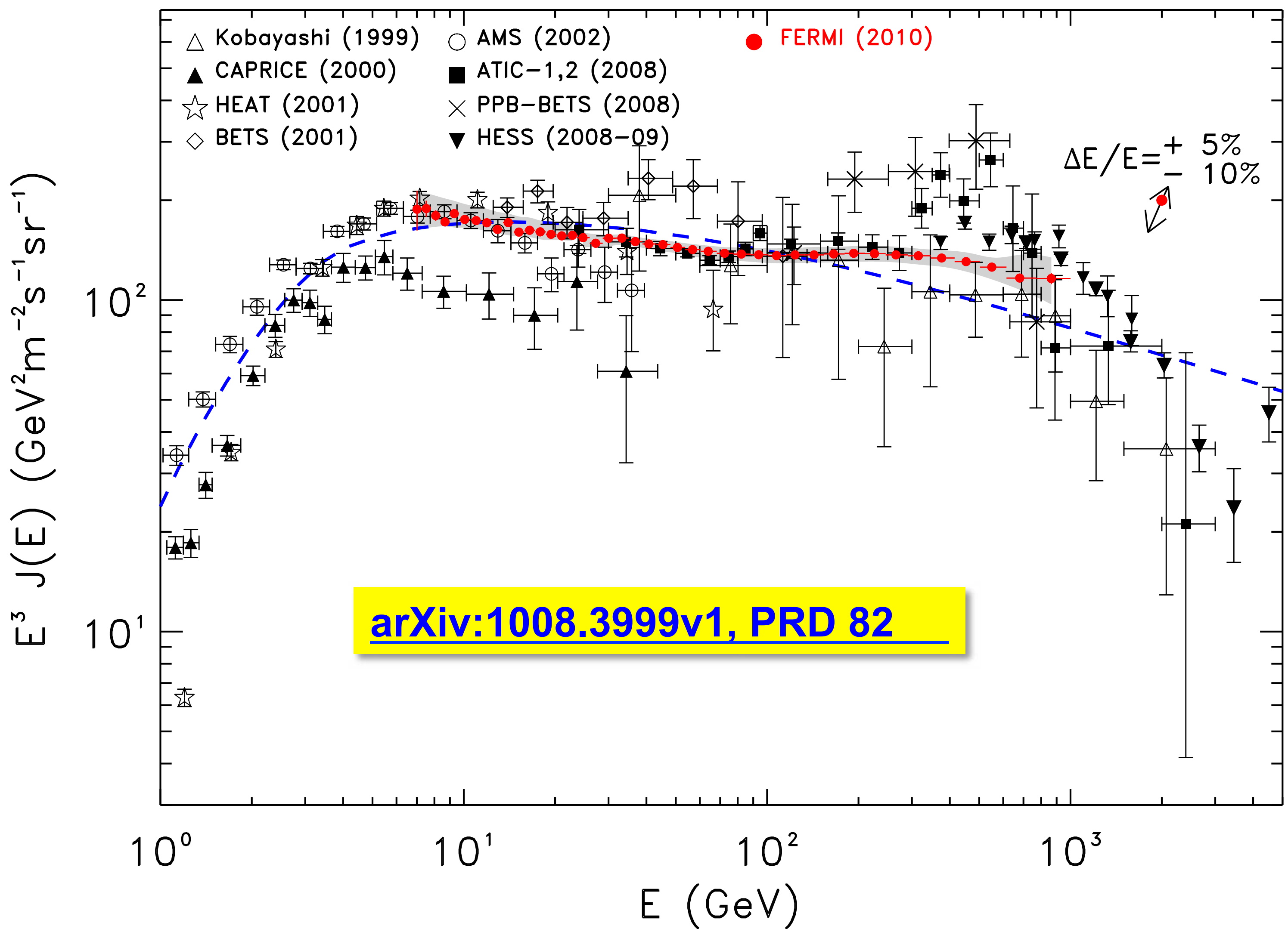






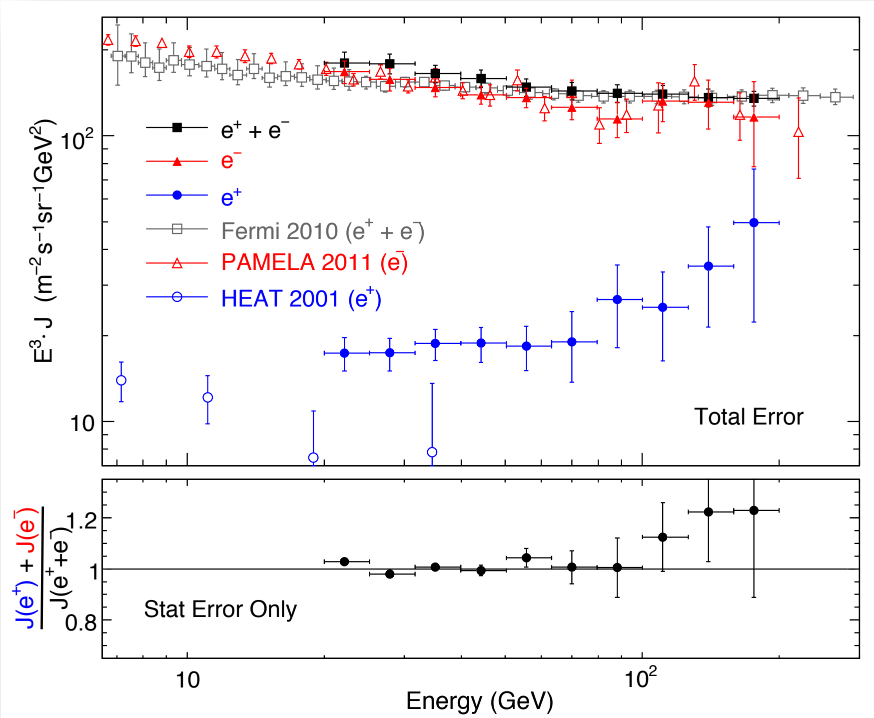


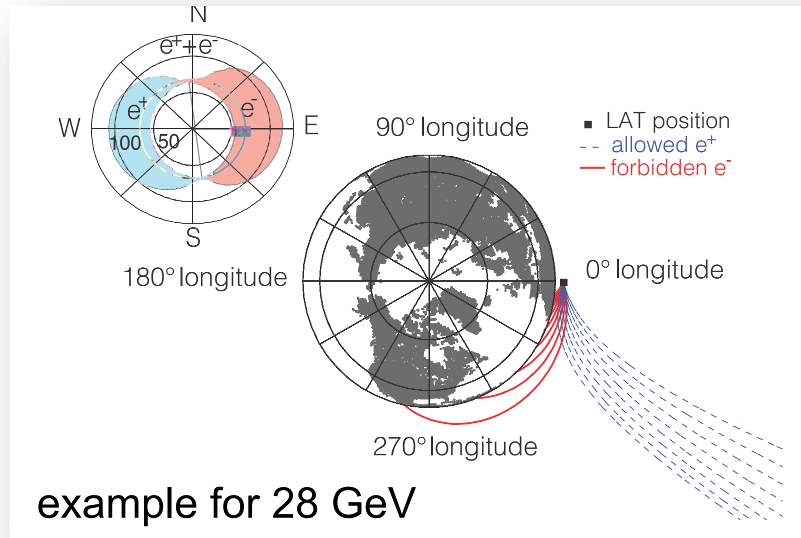
LAT e+e- Spectrum

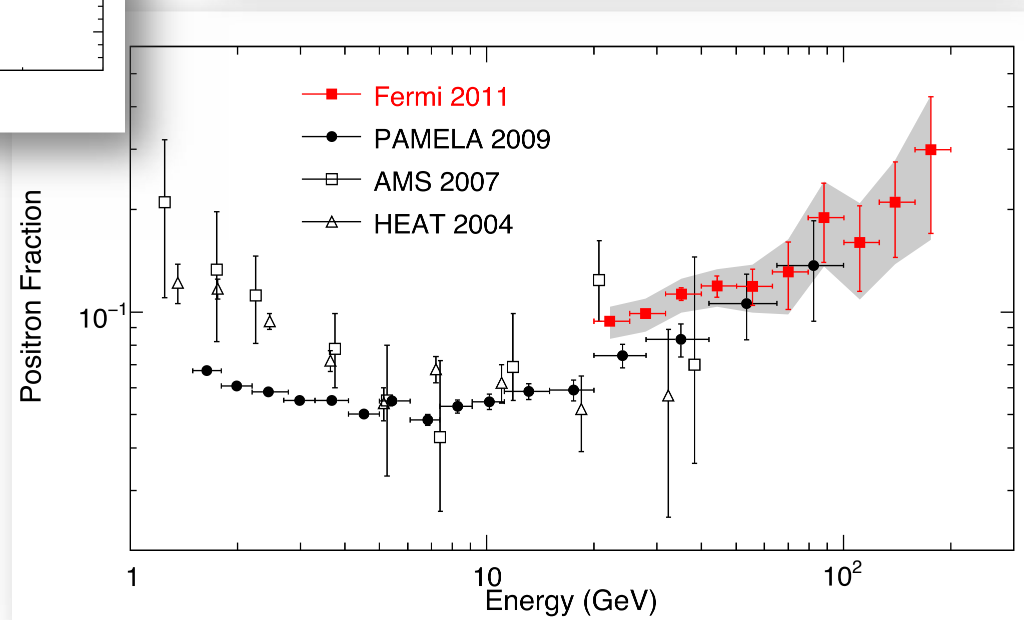


7 GeV – 1 TeV, double statistics (8M events)

LAT e+ and e- Measurement







arXiv:1109.0521

…and AMS-02 is flying!

No Significant e+e- Excess or Deficit from the Sun

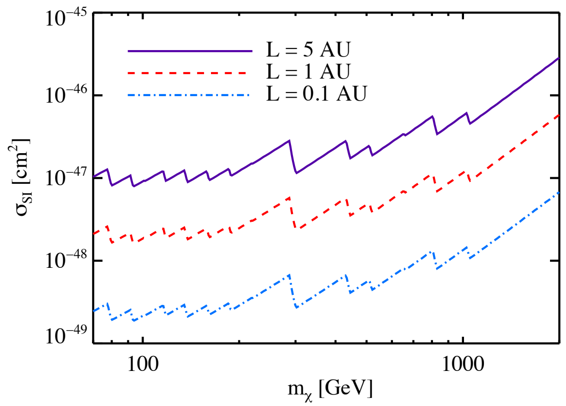


FIG. 6: Constraints on DM annihilation to e^+e^- via an intermediate state, from solar CRE flux upper limits. Solar capture of DM is assumed to take place via spin-independent scattering. The constraints obtained for three values of the decay length L of the intermediate state are shown. Models above the curves exceed the solar CRE flux upper limit at 95% CL for a 30° ROI centered on the Sun.

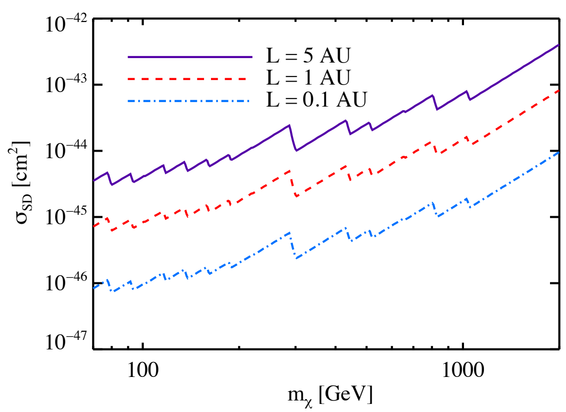
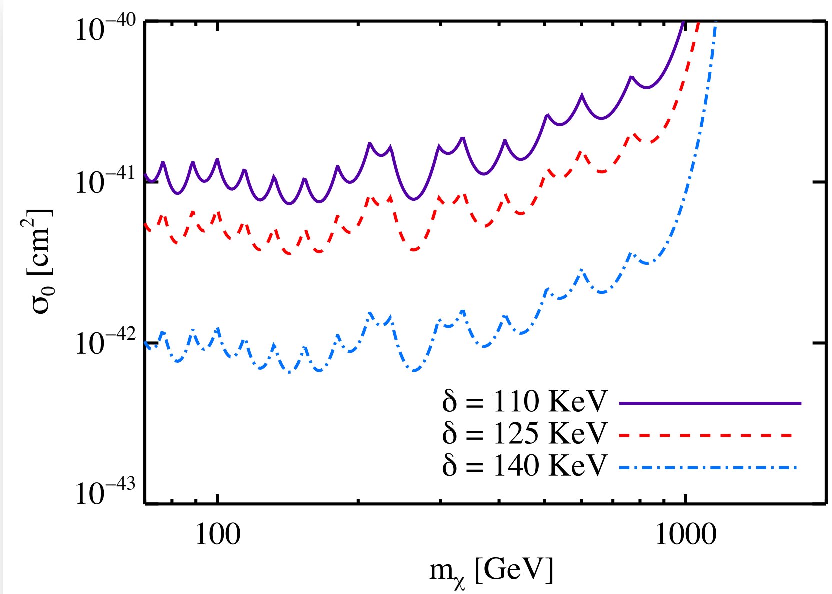


FIG. 7: Constraints on DM parameters for annihilation to e^+e^- via an intermediate state as in Fig. 6, except assuming solar capture by spin-dependent scattering.

arXiv:1107.4272

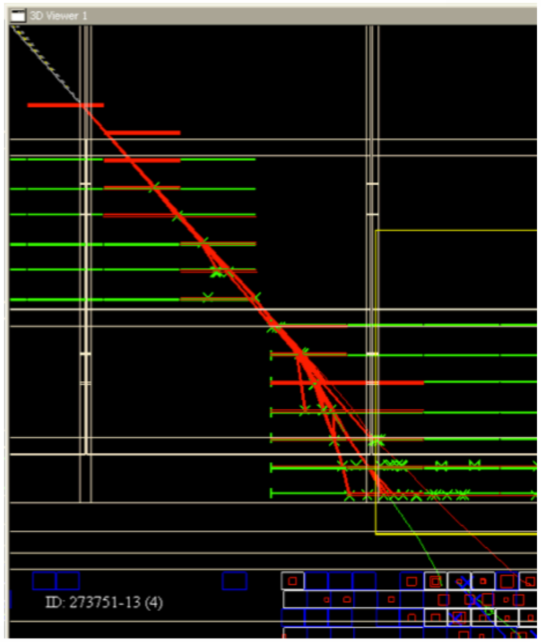


strongly excludes iDM explanation for DAMA/LIBRA – CDMS inconsistency for m>70 GeV and annihilation to e+e-

Intermediate state ➔ e+e- constraints

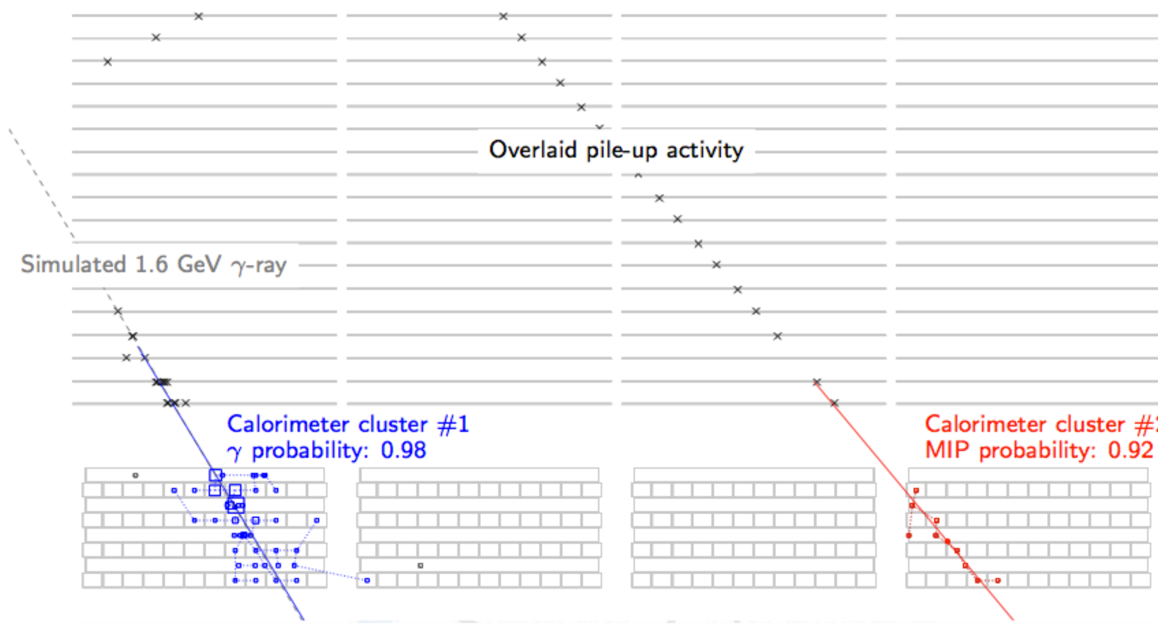
Pass 8 Synopsis

The two really MAJOR changes



Tree-based Tracking

(better model for EM shower)



Calorimeter Cluster & Cluster Classification

Also: cosmic ray track finder, handling of buffer overflows, improved cluster errors, removing ghost hits, improved track-fitting, vertex energy weighting, TKR-CAL matching, CAL-only events, improved GEANT modeling, updated simulation of CAL light yield, development of validation samples,…

Science analyses developed *along with* Pass8 => there may be some interim results. Main goal: release Pass8 data with 5-year catalog (w/updated diffuse model) based on Pass8.

Pass8 event reanalysis

- first comprehensive (and most significant) event level reanalysis since launch. Development underway for past 3 years; will be implemented in 2013.

- involves all area of event analysis
  - Event reconstruction;
  - Overall event structure;
  - Energy analysis;
  - PSF analysis;
  - Background rejection

- will be implemented for the LAT 5-year catalog analysis and readied for release at time of 5-year catalog release (i.e. ~ end of 2014)

Final Thoughts

- *Fermi* would not have been possible without great international and multicultural cooperation!
- Cultural differences among communities are not necessarily impediments, but rather reinforcing capabilities enabling important new opportunities. We're lucky to have each other!
- Great leaps in capabilities have broad impacts, *e.g.*,
  - Sloan Dwarf Spheroidal galaxies discoveries opening new opportunities for DM signal searches.
  - Fermi all-sky sensitivity => millisecond pulsars for use by Nanograv for gravitational wave searches
  - …
- Great leaps in measurement capabilities demand new analysis approaches *and* new theory.
- What a wonderful time – so much great data and new results!

Overview

SCIPP personnel have been at the core of Fermi (originally called GLAST) since inception. Bill Atwood, together with Peter Michelson (Stanford), originated the mission in the early 1990s. Robert Johnson soon joined, and he became the leader of the LAT Tracker subsystem. Steve Ritz joined in 1996 and contributed to many aspects of the instrument, especially those crossing subsystem boundaries, and soon became the LAT Instrument Scientist and LAT Deputy PI, as well as the overall Mission Project Scientist.

SCIPP members have been deeply involved in all aspects of the project, from detailed hardware design, construction, testing, and operation, through reconstruction software and physics analysis. The SCIPP group is a leading DOE-funded university group on Fermi.

UCSC LAT Collaboration Members

- Full members
  - Atwood, Johnson, Ritz, Sadrozinski, Saz-Parkinson, Schalk
  - Wells, Belfiore, Zalewski, plus new students…
- Affiliated members
  - Jeltema, Primack, Profumo, Williams, Ramirez-Ruiz, Smith
  - Bouvier, Furniss, Linden, Storm

Post-docs and Graduate Students

- Saz Parkinson (researcher): recently co-leader of Galactic Sources science group; leading several innovative searches for gamma-ray pulsars
- Anderson (student): recently completed thesis on halo dark matter searches
- Zalewski (student): completing thesis on searches for dark matter satellites
- Wells (student): instrument performance and application of covariant error information in analyses, including pair haloes to probe intergalactic B fields and possibly more incisive DM searches; LAT Operations data quality monitoring.
- 4 undergads, working on signals in AGN light curves and new DM topics
- More soon!

Current/Upcoming Projects

- Students are encouraged to define their own projects, but we also are happy to suggest directions of mutual interest.
- Some ongoing projects:
  - Several on dark matter, including halo, dwarf spheroidals, line searches, …
  - Final great leap in instrument performance: "Pass8"
  - Pulsars
- Start ups (and restart ups) include:
  - Several studies related to dark matter
  - Pair halos of distant objects, diagnostic of intergalactic magnetic fields and EBL
  - Better use of single-photon error information
  - The highest energy Fermi sky
  - Novel uses of AGN light curves
  - Intermediate timescale transients
  - Your idea here!

Discussion

- How the group functions
  - encourage students to work with people both at UCSC and within the international collaboration
- Path is largely up to the student
  - goal is for you to learn over time how to define your own research problems.
  - we suggest topics, but free to pursue others. we will help you stay on track.
  - we emphasize understanding of the instrument and the details of the data analysis. we will also try to create hardware opportunities
- Great return on hard work!

Tools for Your 205 Proposals

- All the LAT papers can be found here, sorted by topic: http://www-glast.stanford.edu/cgi-bin/pubpub
- The LAT gamma-ray data and a set of software tools are public.
  - See http://fermi.gsfc.nasa.gov/ssc/data/
- There is also public documentation and tutorials on how to do an analysis with the public data
  - See http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
- Come by to chat. Ask us questions!


Looking forward to the
5th Birthday this year!