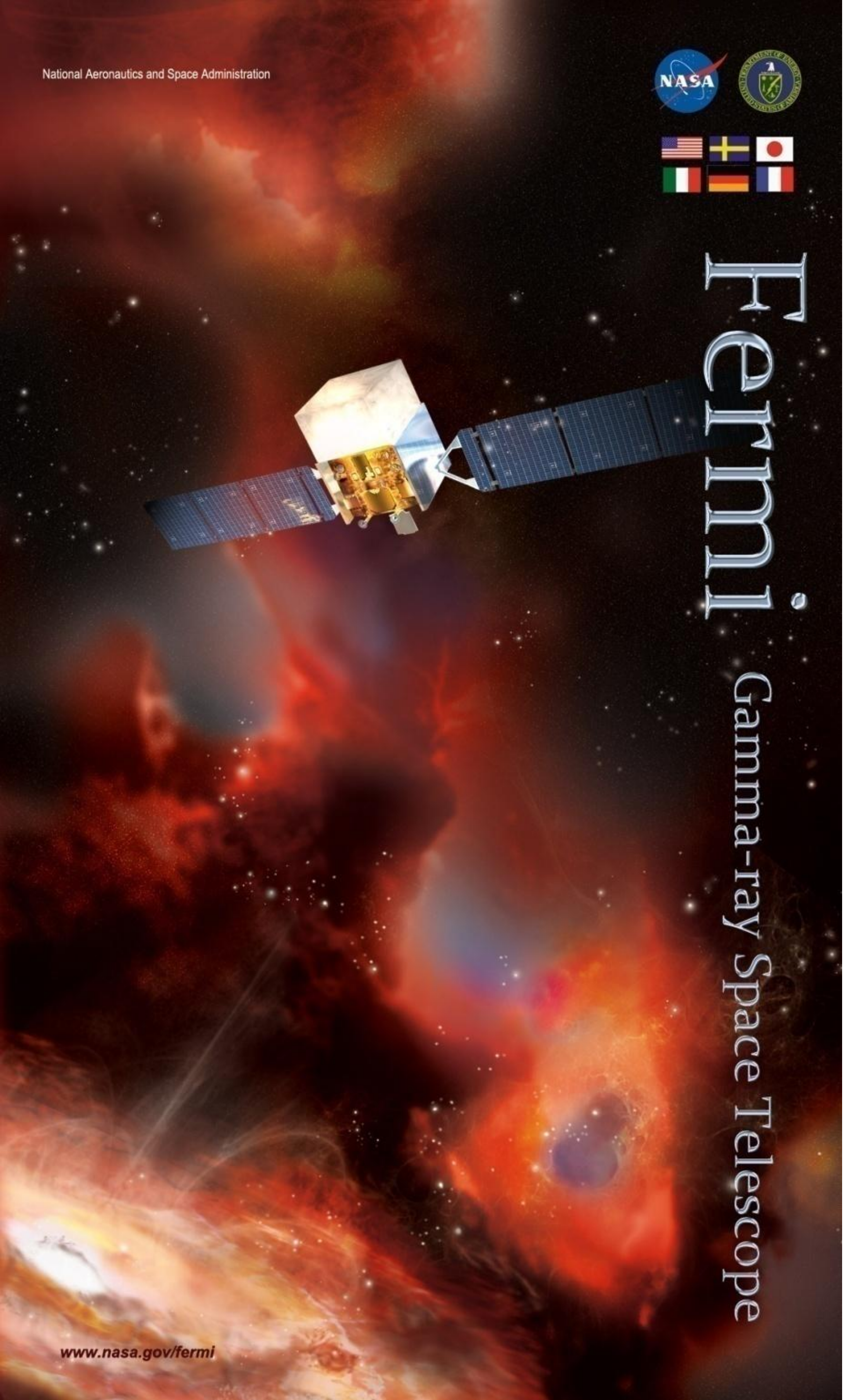


4+ Years Out and Just Getting Started!

W.B. Atwood
(SCIPP/UCSC)

on Behalf of the Fermi-LAT Collaboration

CERN Colloquium
Nov. 29, 2012

It all started in May, 1992

Nuclear Instruments and Methods in Physics Research A 342 (1994) 302–307
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Gamma Large Area Silicon Telescope (GLAST) Applying silicon strip detector technology to the detection of gamma rays in space *

W.B. Atwood

GLAST Collaboration ⁺

Stanford Linear Accelerator Center, Stanford, CA 94309, USA

The recent discoveries and excitement generated by space satilite experiment EGRET (presently operating on the Compton Gamma Ray Observatory (CGRO)) have prompted an investigation into modern detector technologies for the next generation of space based gamma ray telescopes. The GLAST proposal is based on silicon strip detectors as the "technology of choice" for space application: no consumables, no gas volume, robust (versus fragile), long lived, and self-triggerable. The GLAST detector basically has two components: a tracking module preceding a calorimeter. The tracking module has planes of crossed strip (x, y) 300 μm pitch silicon detectors coupled to a thin radiator to measure the coordinates of converted electron–positron pairs. The gap between the layers (~ 5 cm) provides a lever arm for track fitting resulting in an angular resolution of $< 0.1°$ at high energy. The status of this R & D effort is discussed including details on triggering the instrument, the organization of the detector electronics and readout, and work on computer simulations to model this instrument.

1. Introduction

Extra-terrestrial gamma rays were first directly observed in 1962 with the launch of EXP X1 [1]. Only 31 events were detected, but sufficient to provide direct evidence that indeed high energy photons were present in the emissions from distant objects. The next data arrived in 1968 when OSO-3 was put into orbit. The data yield increased by an order of magnitude and established that most of the γs were coming from the plane of our galaxy. SAS-2 was launched in 1972 and was the first to employ a triggered pair conversion telescope. It detected about 8000 γs over its 7 month lifetime and established that some of these high energy photons were coming from discreet sources. The COS-B experiment, launched three years later, employed similar technology adding a calorimeter capable of resolving energies up to ~ 3 GeV. This experiment accumulated events over the next 7 years, increasing by over an order of magnitude the data previously available.

Late in the 1960s Hofstadler and colleagues conceived a much larger gamma ray telescope [2]. The new instrument, named Egret, was initially scheduled to fly as part of HEO I, but its weight caused it to be reassigned to a spacecraft dedicated to observing X-rays and high energy γs. The spacecraft, the Compton Gamma Ray Observatory (CGRO), was to be part of an early NASA Space Shuttle mission, but with delays and then the tragic Challenger launch in 1986, CGRO did not get off the ground until 1991. Since then data has been successfully accumulated by all four experiments on board.

Egret has had a very successful initial data gathering period. Everything from unexpected solar flare phenomena, to hither to undiscovered pulsars, to new extra galactic high energy γ sources have been discovered. It is beyond the scope of this presentation to do more then just scratch the surface of these new observations. These early Egret results are the motivation for continuing this progression of astrophysics experiments.

Fig. 1 shows a schematic drawing of the Egret. It is obvious that the technologies employed were old even at the time of the initial proposal. Egret is comprised of three basic building blocks: 1) a pair conversion telescope made from triggered spark chambers interspersed with thin radiators; 2) a NaI calorimeter about 7.8 radiation lengths in depth; and 3) a triggering system consisting of an anti-coincident scintillator dome

* Work supported by Department of Energy contract DE-AC03-76SF00515.

⁺ The GLAST Collaboration: Ying-Chi Lin, P.E Michelson, P.L. Nolan (Physics Dept., Stanford University); W.B. Atwood, E.D. Bloom, G.L. Godfrey, A.E. Snyder, R.E. Taylor (Stanford Linear Accelerator Center, Stanford University); and P.L. Hertz, K.S. Wood (Naval Research Laboratory).

0168-9002/94/$07.00
SSDI 0168-9002(93)E1124-G

At this point there were just 10 collaborators!

* The GLAST Collaboration: Ying-Chi Lin, P.E Michelson, P.L. Nolan (Physics Dept., Stanford University); W.B. Atwood, E.D. Bloom, G.L. Godfrey, A.E. Snyder, R.E. Taylor (Stanford Linear Accelerator Center, Stanford University); and P.L. Hertz, K.S. Wood (Naval Research Laboratory).

And Now

Fermi LAT Collaboration

France
- 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, KIPAC, and HEPL/Physics)
- University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
- Goddard Space Flight Center
- Naval Research Laboratory
- Sonoma State University
- Ohio State University
- University of Washington

also members from Australia, Germany, Great Britain, Spain

Sponsoring Agencies

Department of Energy
National Aeronautics and Space Administration

CEA/Saclay ASI
IN2P3/CNRS INFN

MEXT
KEK
JAXA

K. A. Wallenberg Foundation
Swedish Research Council
Swedish National Space Board

LAT construction/operation managed by SLAC National Accelerator Laboratory, Stanford University

Fermi mission managed by NASA – Goddard Space Flight Center

High-Energy Gamma Rays
The Non-Thermal Universe

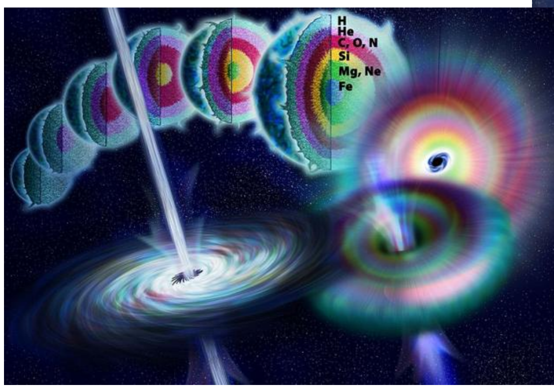
- Extreme environments accelerate particles
  - Neutron Stars
  - Black Holes (AGNs, etc.)
  - Black Hole Birth Annoucements: Gamma Ray Bursts (GRBs)
  - Supernova Remnants – and – more…
- Particles propagate and Interact
  - Interstellar Gas and Dust
  - Radiation fields – Radio, IR, Optical, …
  - Intergalactic Magnetic Fields, …
- Produced gamma rays travel to us!

Plus: New Physics (eg. Dark Matter)

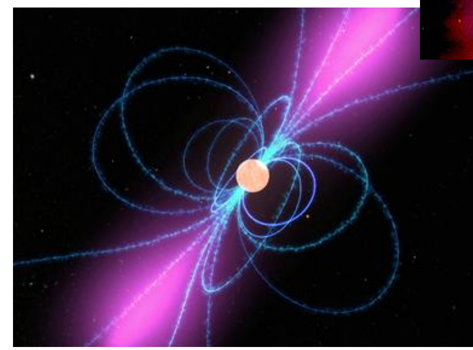
Studying Gamma Rays allows us to see these aspects of the Universe

Examples of Extreme Environments in Pictures

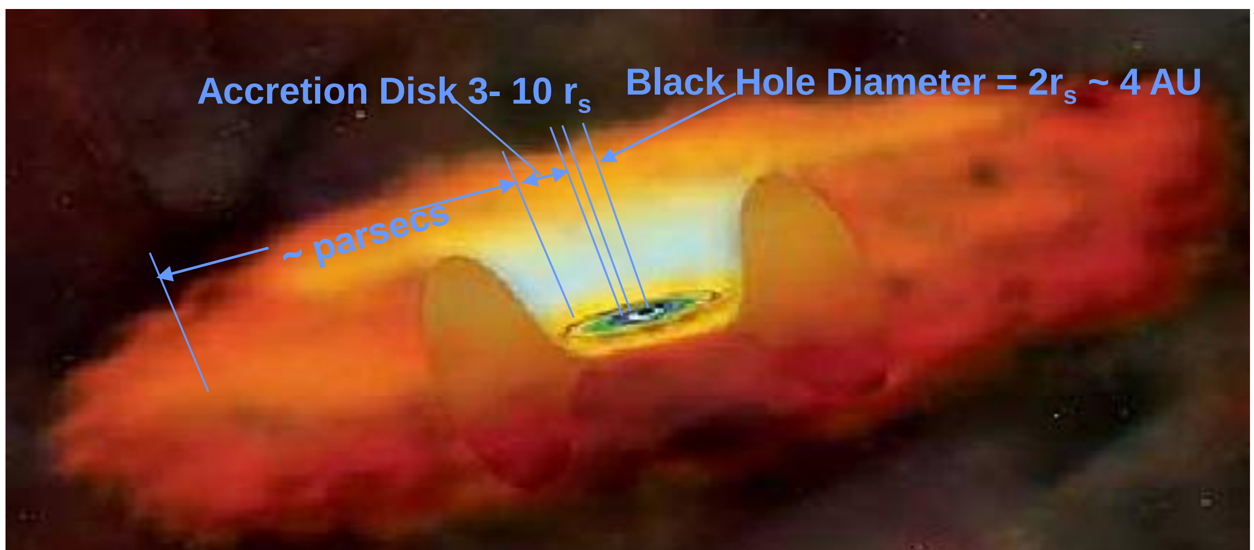
Gamma Ray Bursts



Pulsars



Active Galactic Nuclei



Detecting Gamma-rays: Pair Conversion

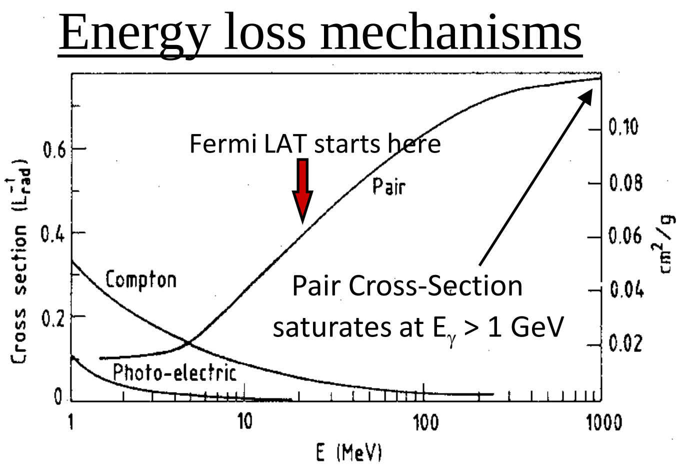
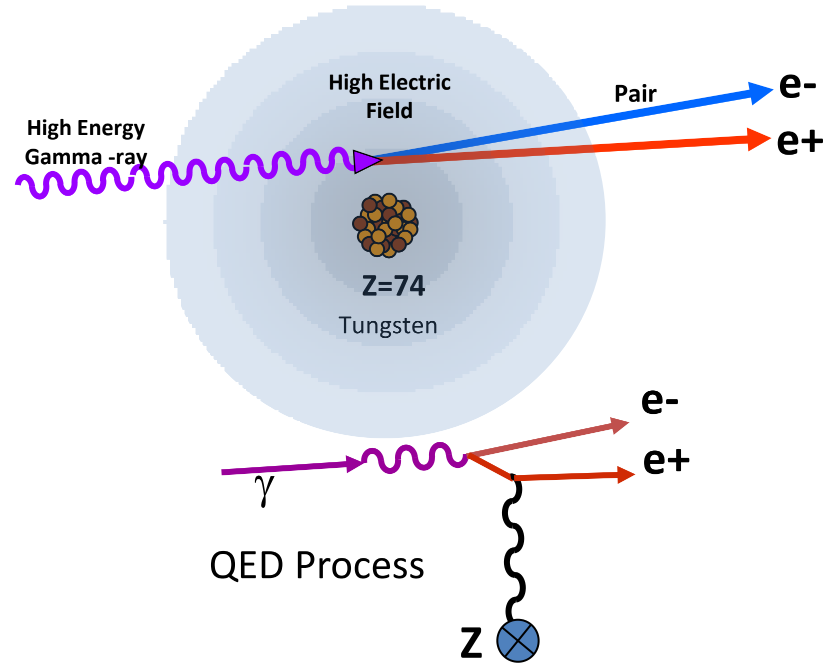
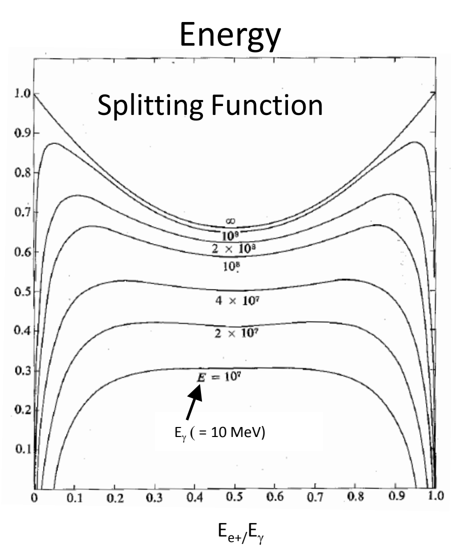


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).



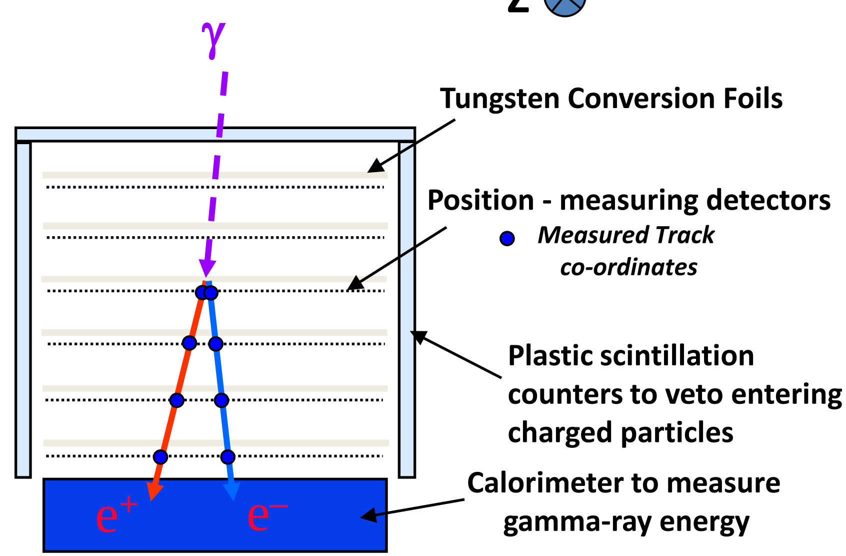


Opening Angle

$$\theta_{Open} \approx \frac{4m_e}{E_\gamma}$$

At 100 MeV

$\theta_{Open} \sim 1°$



Previous Satellite Detectors

- **1967-1968**, OSO-3 Detected Milky Way as an extended γ-ray source

  621 γ-rays
- **1972-1973**, SAS-2,

  ~8,000 γ-rays
- **1975-1982**, COS-B

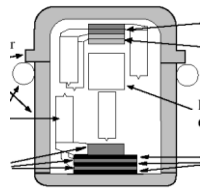
  orbit resulted in a large and variable background of charged particles

  ~200,000 γ-rays
- **1991-2000**, EGRET

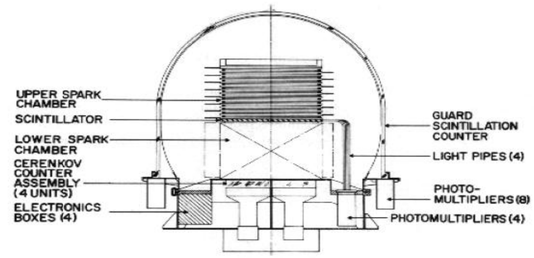
  Large effective area, good PSF, long mission life, excellent background rejection

  >1.4 × 10^6 γ-rays

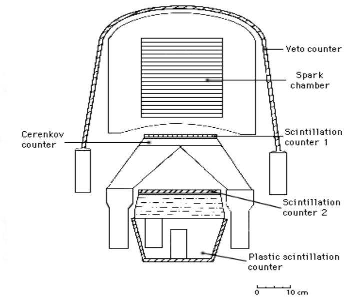
OSO-3



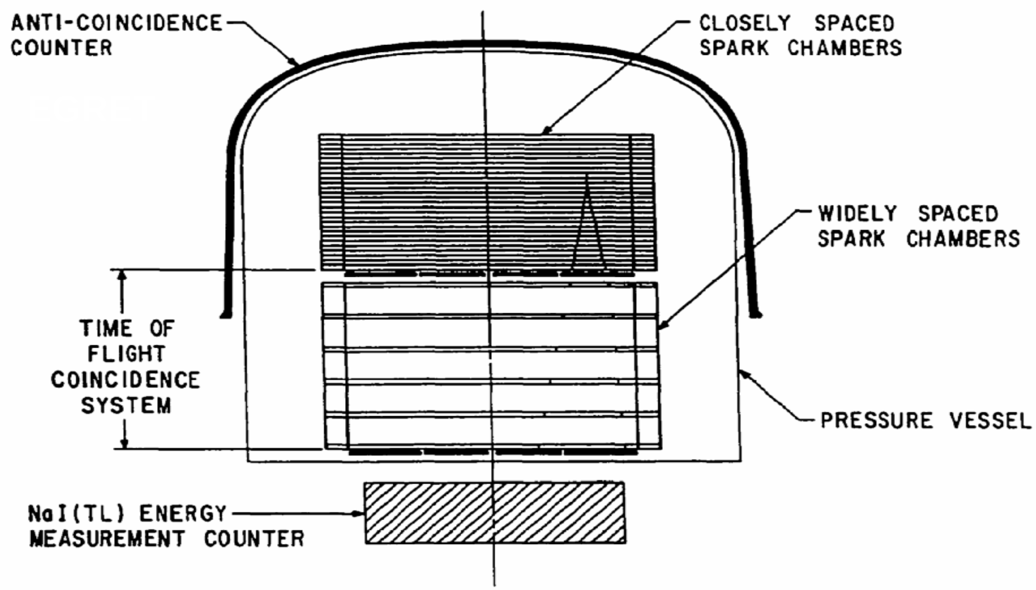
SAS-2



COS-B



EGRET



The Design Challenges

- **Signal–to-Noise**
  - Gamma Rays constitute a tiny fraction of the CR flux:

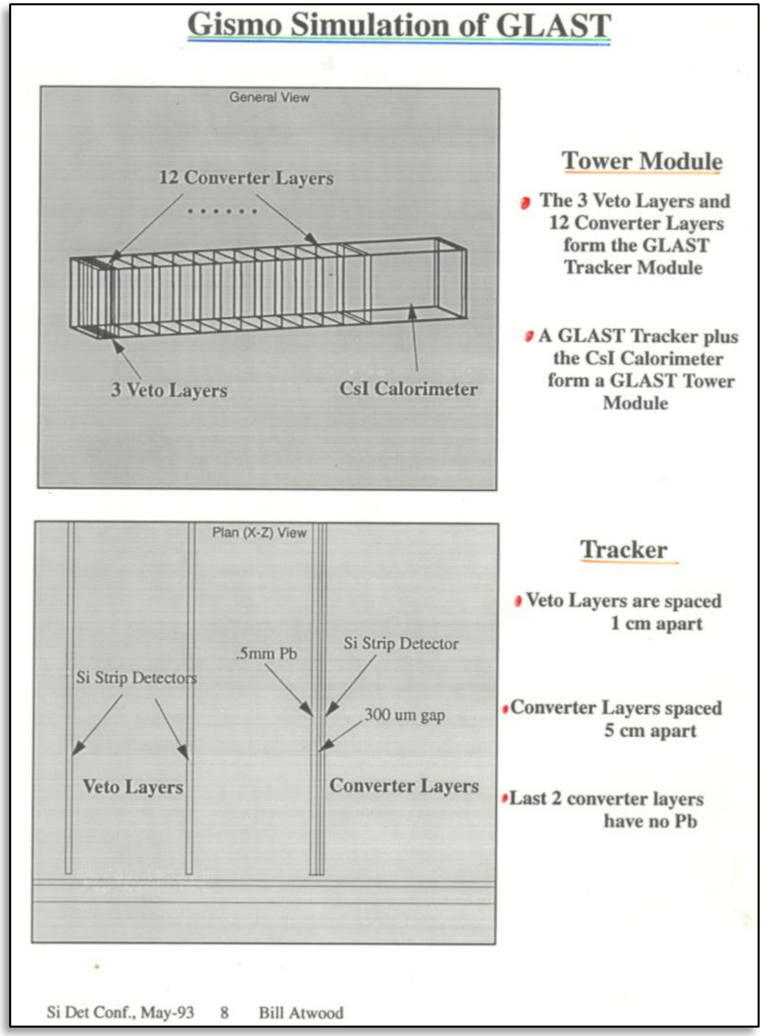
    1:1000 to 1:10000 depending on orbit
  - Uncertainties in the background fluxes in the 1990's large enough to affect design choices
- **Power**
  - In space, power is at a premium
  - Even with ample power, shedding waste heat is difficult
- **Detector must survive Rocket Launch & Space Environment**
  - Shake & Bake testing
- **Bandwidth**
  - Getting data to the ground is expensive and bandwidth limited
  - Computing in space is rudimentary
- **Image Resolution:** the Point-Spread Function (PSF)

Where to start? Monte Carlos!

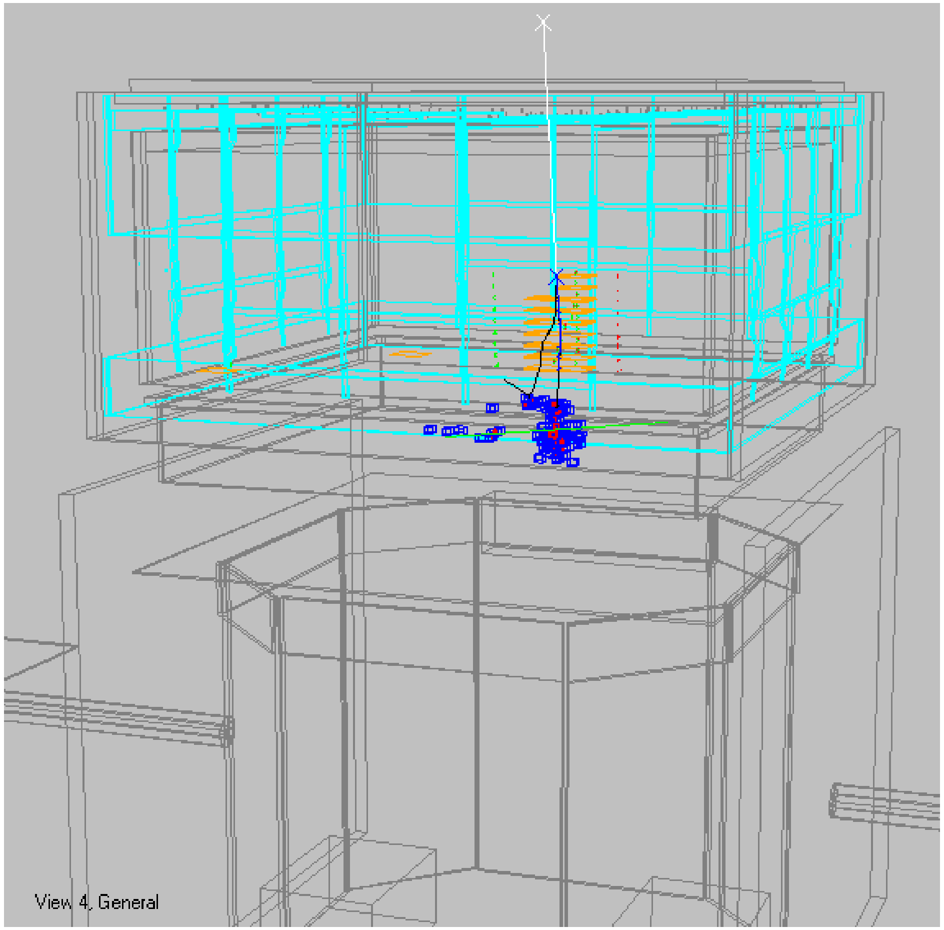
- The inside-out problem: Learning to invert our source models
- Getting particle interactions in the proposed structure: *simple*
- Providing a simulated readout: ***time consuming…***
- Creating the Reconstruction and Background Rejection: ***HARD***

Guiding principle: make the instrument as general as possible.
Resist limiting the science potential .

First Monte Carlo of GLAST 1993



Current GEANT4 Fermi-LAT MC



Level of detail greatly increased

- Over 50,000 volumes
- Spacecraft Mass Model
- Detector parametric readouts

The Observatory, Spring 2008

Large Area Telescope (LAT)
20 MeV - >300 GeV

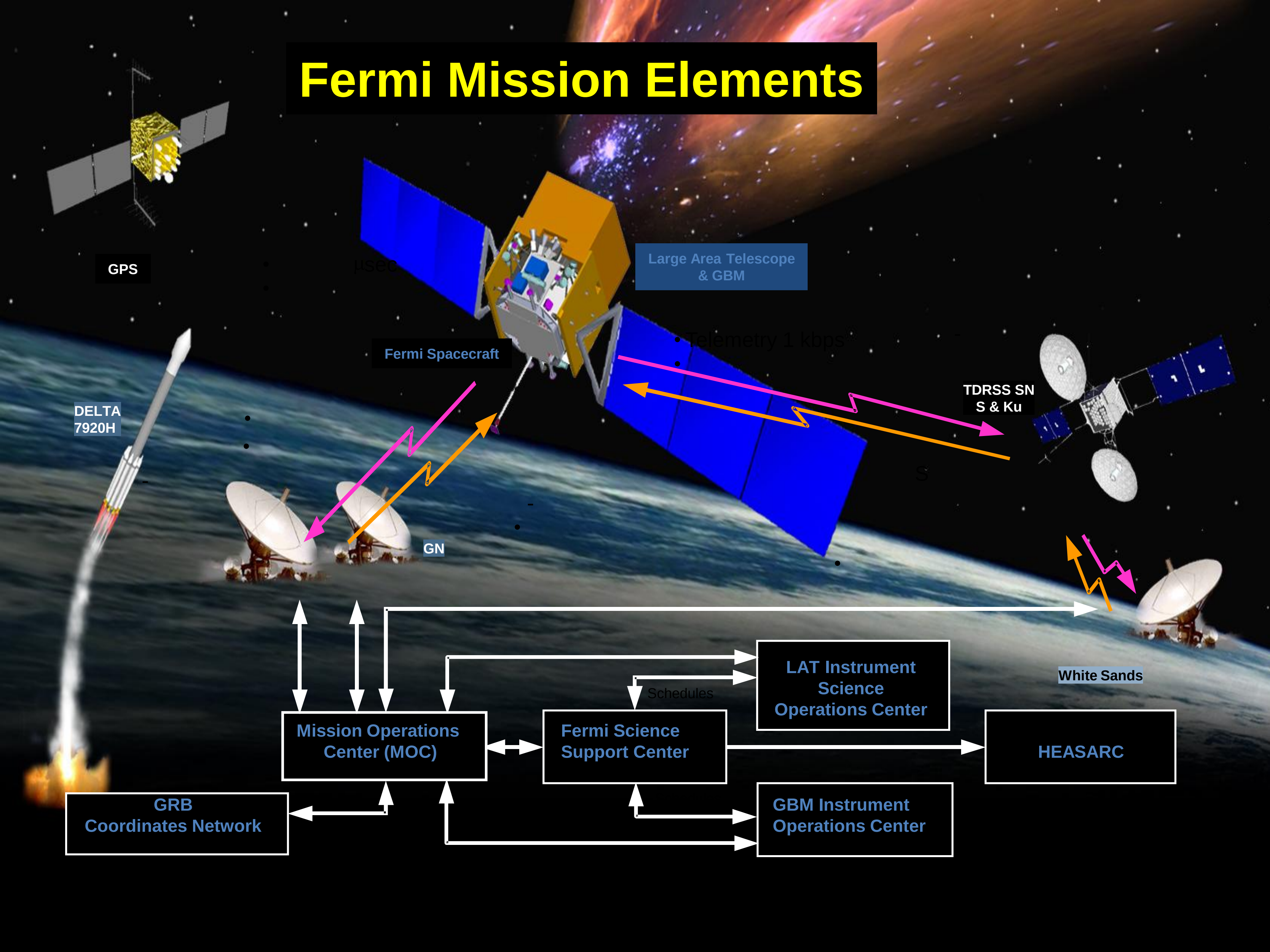
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

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.

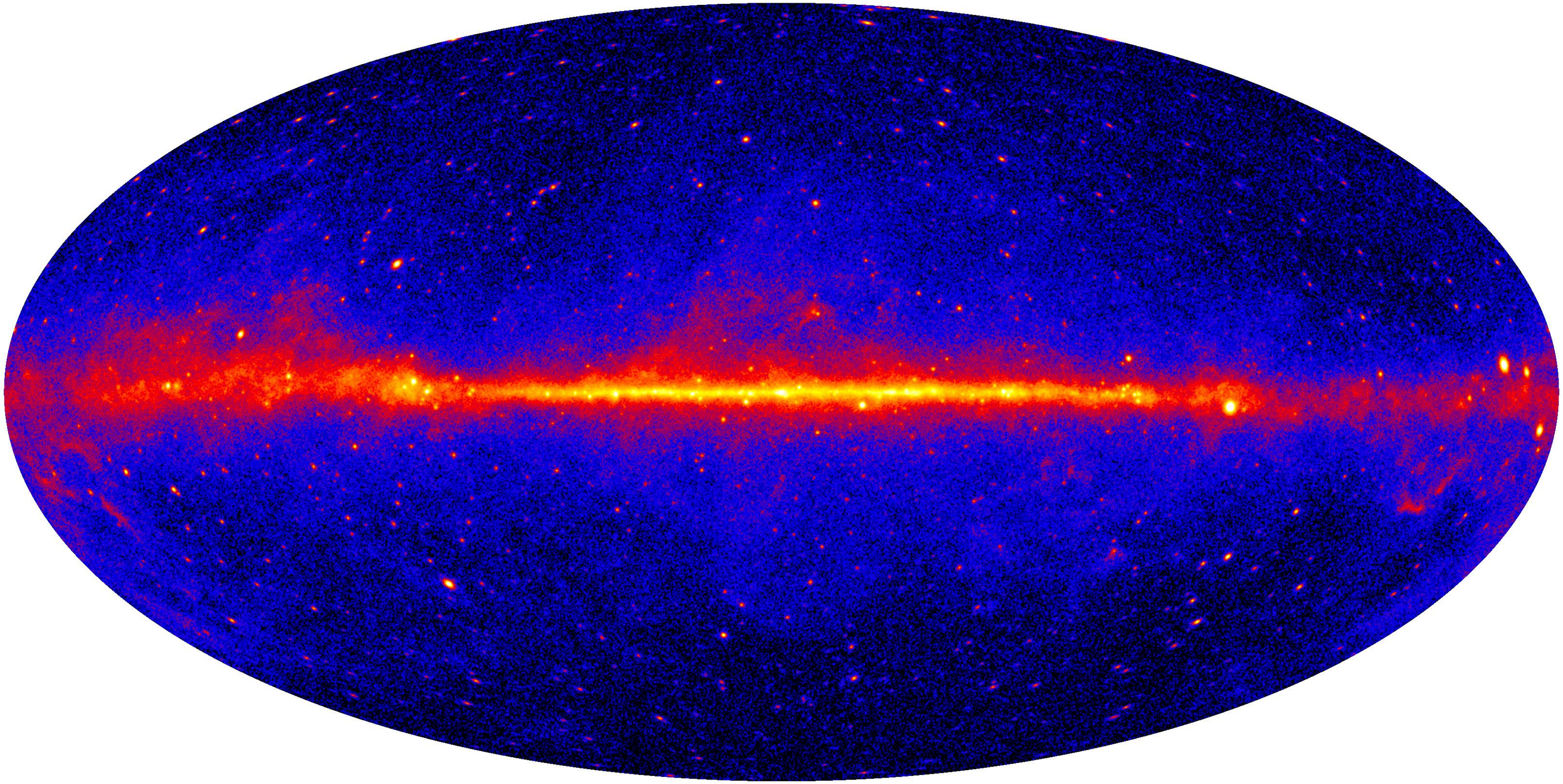
The Launch

Meanwhile, the Project Scientist Steve Ritz and the real flight operations crew were hard at work.


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

The Gamma ray Universe as seen by Fermi-LAT

(E > 1 GeV, 4 Years)



Aitoff projection of the Sky in Galactic Coordinates

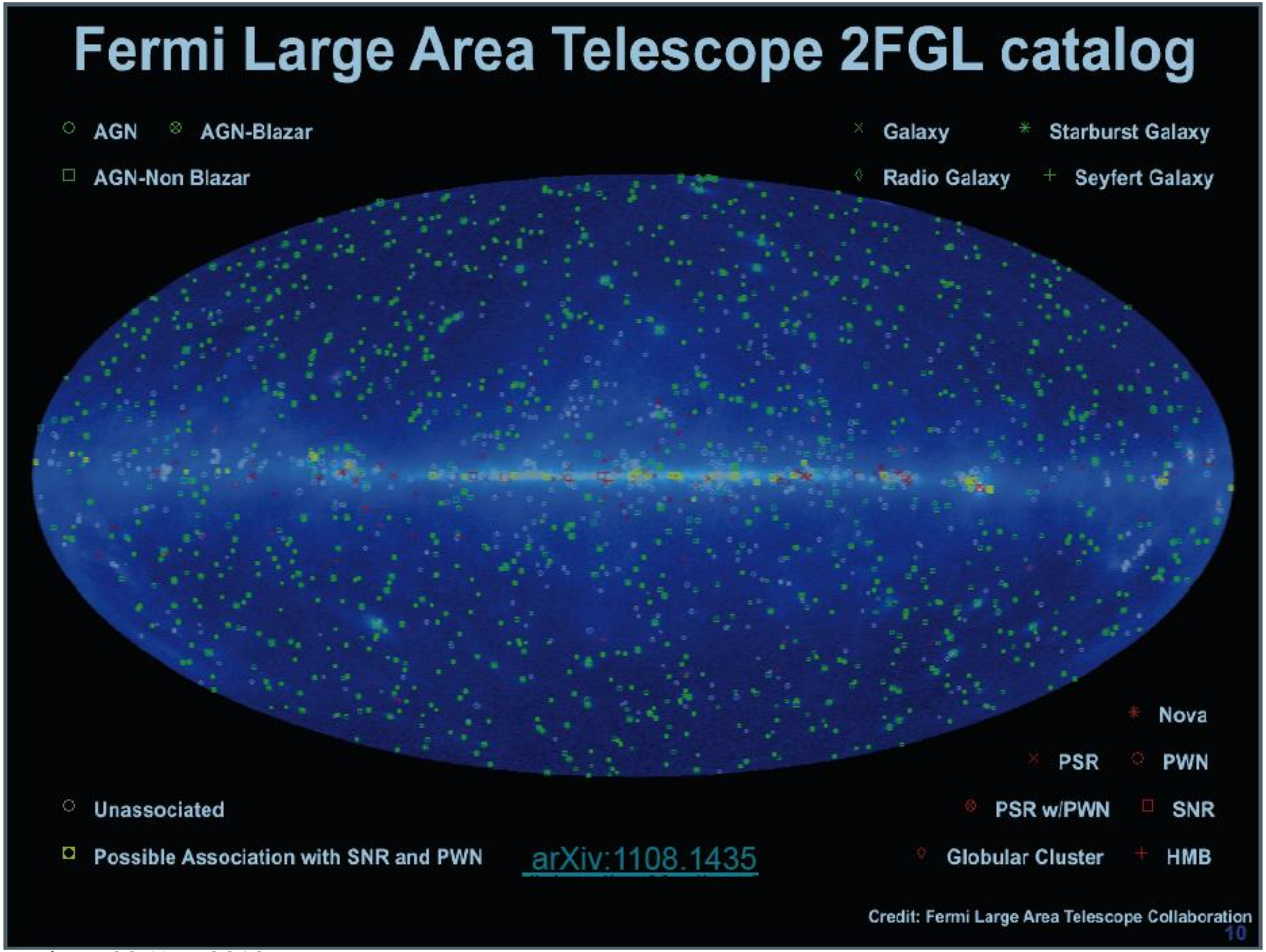
Doing Science in a *New Lab*

- First: How did it all work?
- Astrophysics presents opportunities at random (rather than scheduled by the PAC…)
- The parameter space of the Astro-Lab is quite different
  - Distances – not km but kpc –Mpc – Gpc *(parsec(pc): 3.26 light-years)*
  - Medium – interstellar/intergalactic medium NOT EMPTY!
  - Multiple things happening at the same time
  - Little control over "signal-on"/"signal-off"
- Few Calibration sources
  - Pulsars: on peak / off peak
  - Earth's Limb: brightest feature in the Sky
  - Galactic Ridge: on plane – low background / off plane – large background

"Chance favors the prepared mind" - *Louis Pasteur, 1854*

Original: "Dans les champs de l'observation le hasard ne favorise que les esprits prépares"

After 2 Years ~ 2000 Sources!

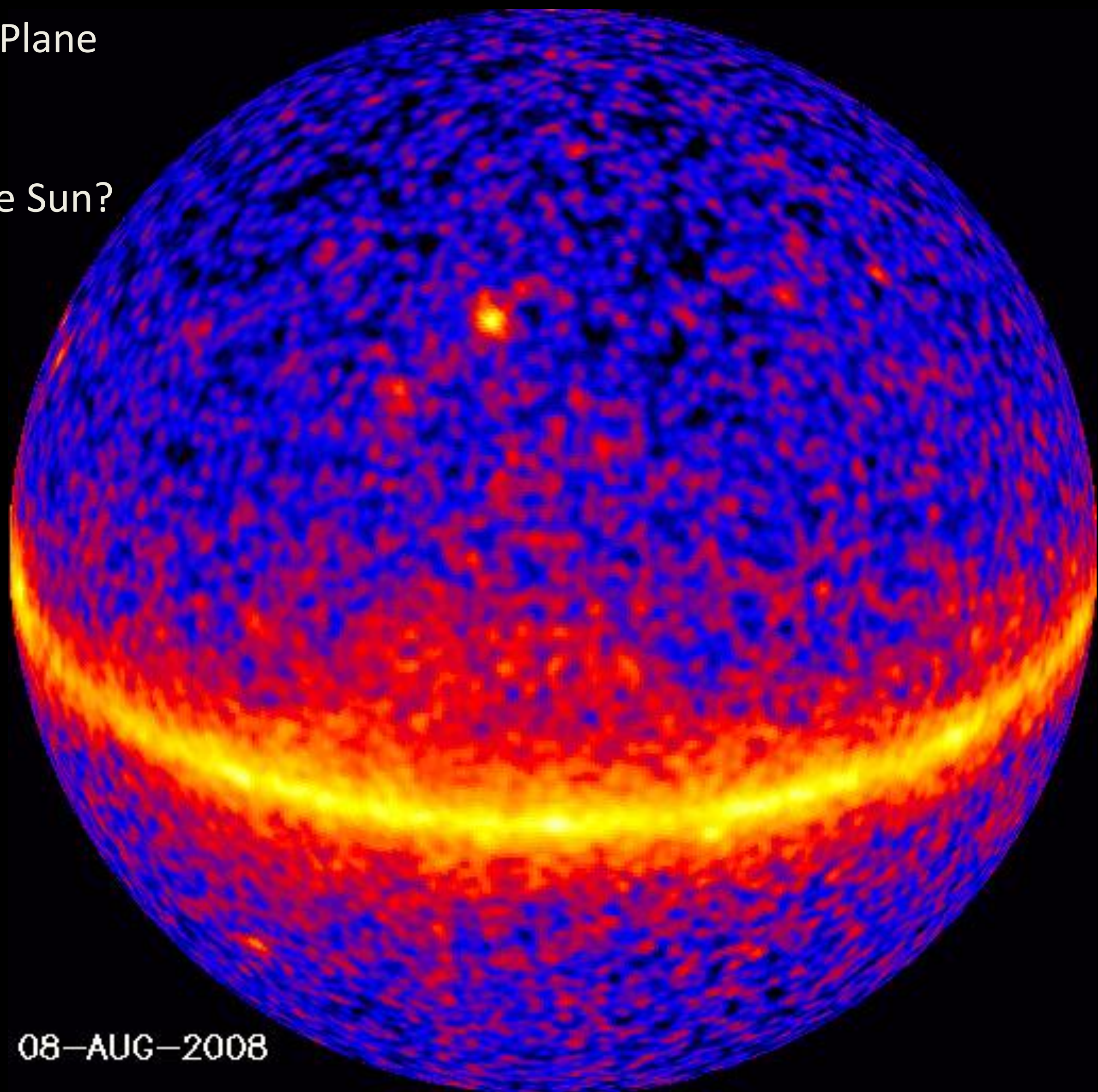


ApJ. Supp. Vol. 199, Issue 2, 2012

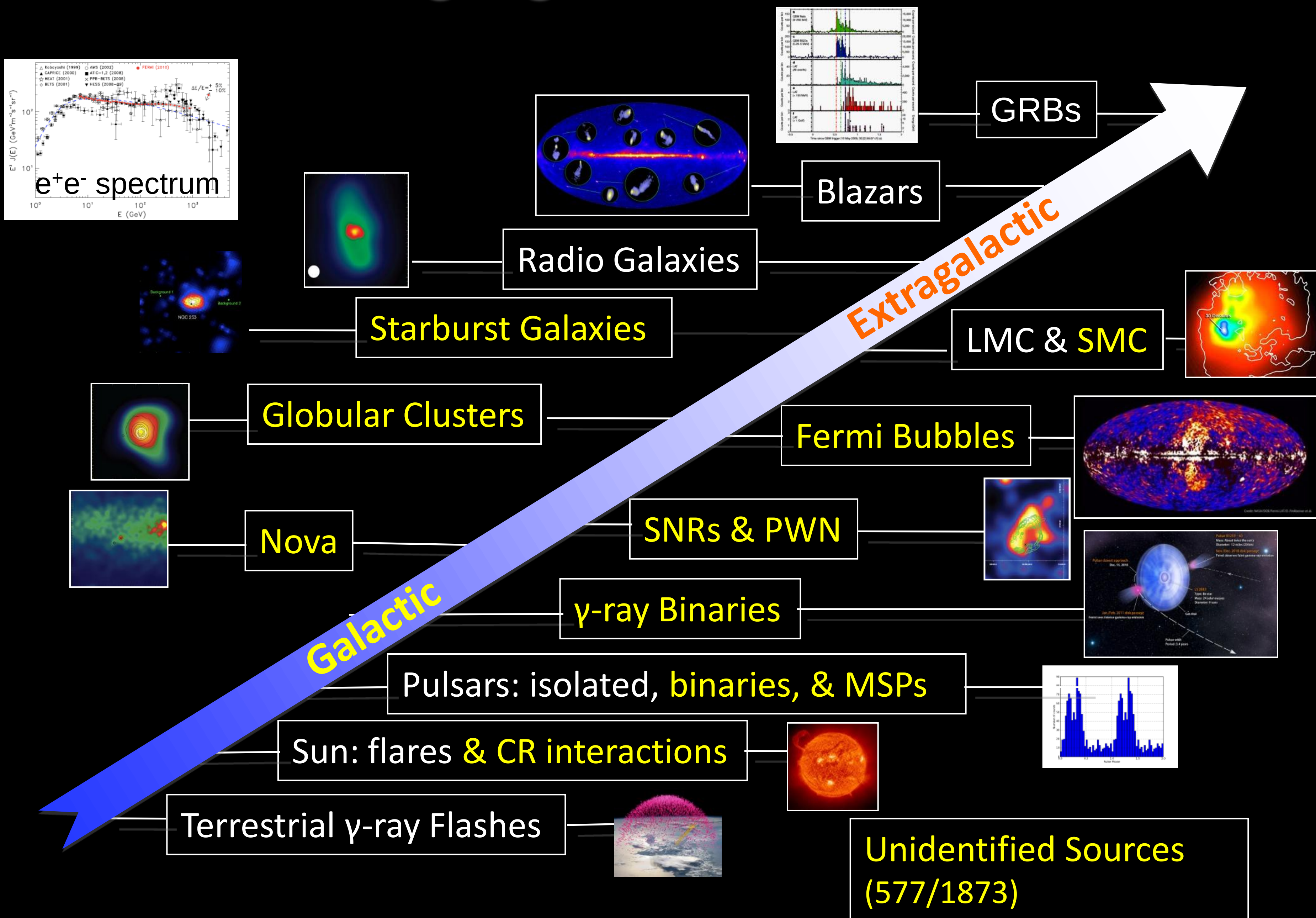
Variability of the High Energy Universe

Watch Off the Plane
AGNs Flare

Did you see the Sun?

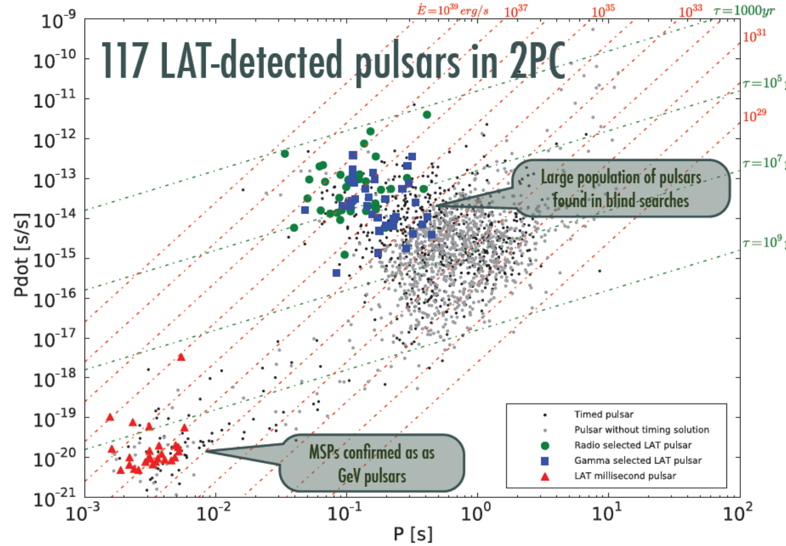


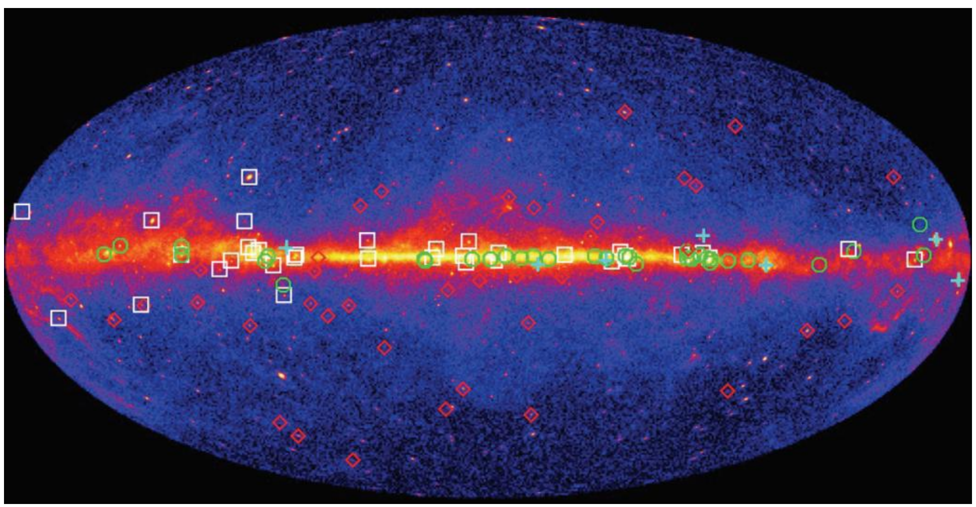
Fermi Highlights and Discoveries



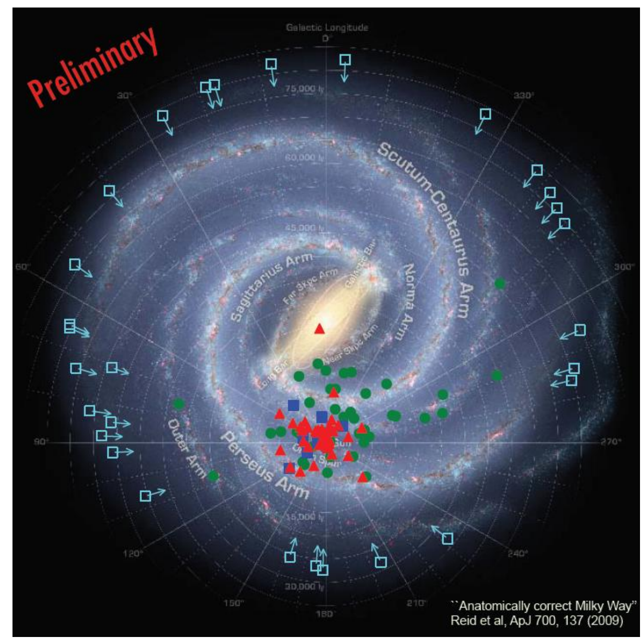
Pulsar Science

- EGRET found 6 gamma-ray Pulsars
- Radio Loud Pulsars: Consortium of Radio Telescopes provide timing solutions
- Gamma-Ray Only Pulsars: sparse data inspired new search Algs.
- Pulsars found 1st in gamma-rays – are then searched for radio pulsation
- Yield has been tremendous – estimate over 200 gamma ray pulsars within a year.



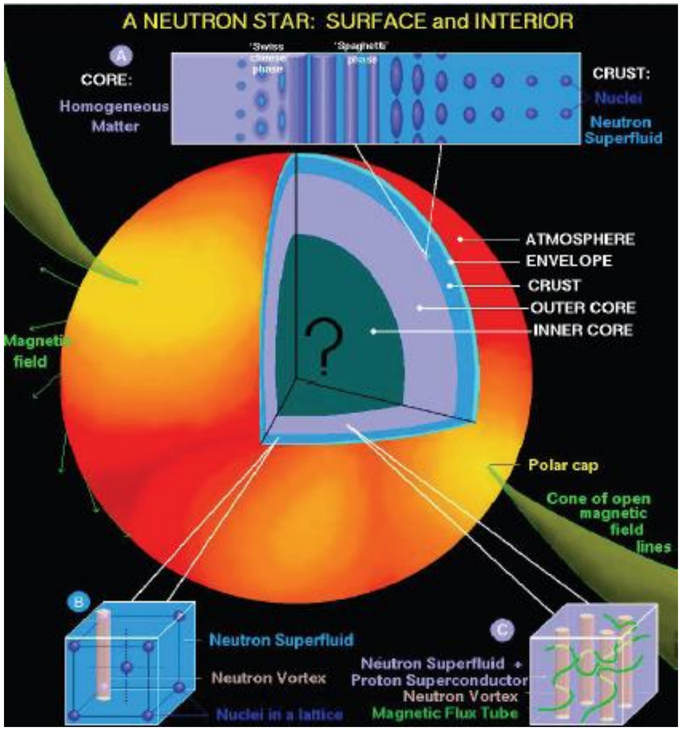


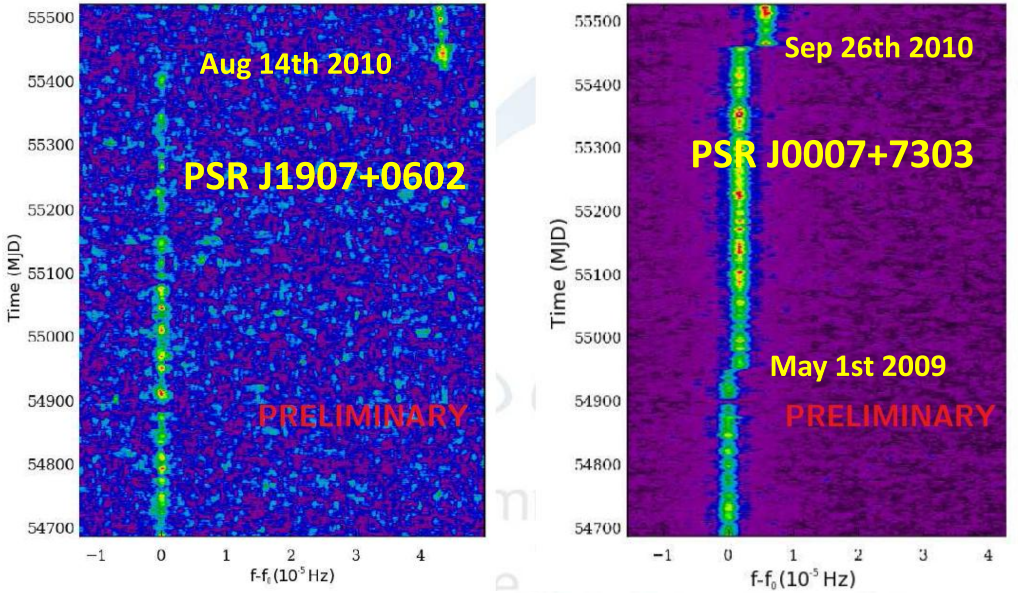
Most pulsars found near Galactic Plane

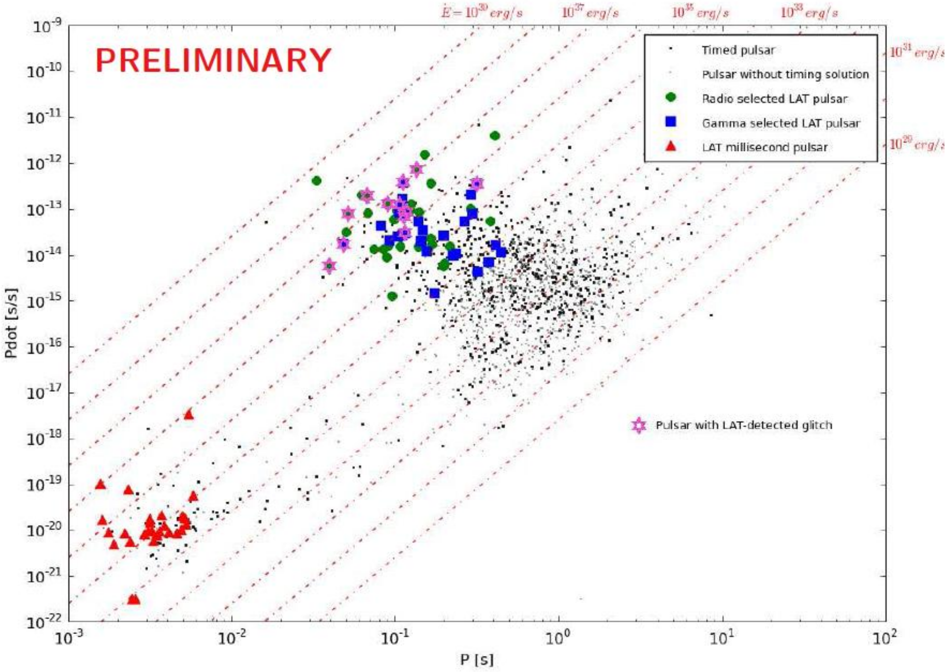


Found Pulsars near us!

Probing Neutron Star Structure







"Glitches" in Spin-Down might reveal aspects of internal structure

Near-continuous monitoring by LAT ideal for detecting Glitches

Using MSPs to Detect Gravity Waves

Unintended Consequences

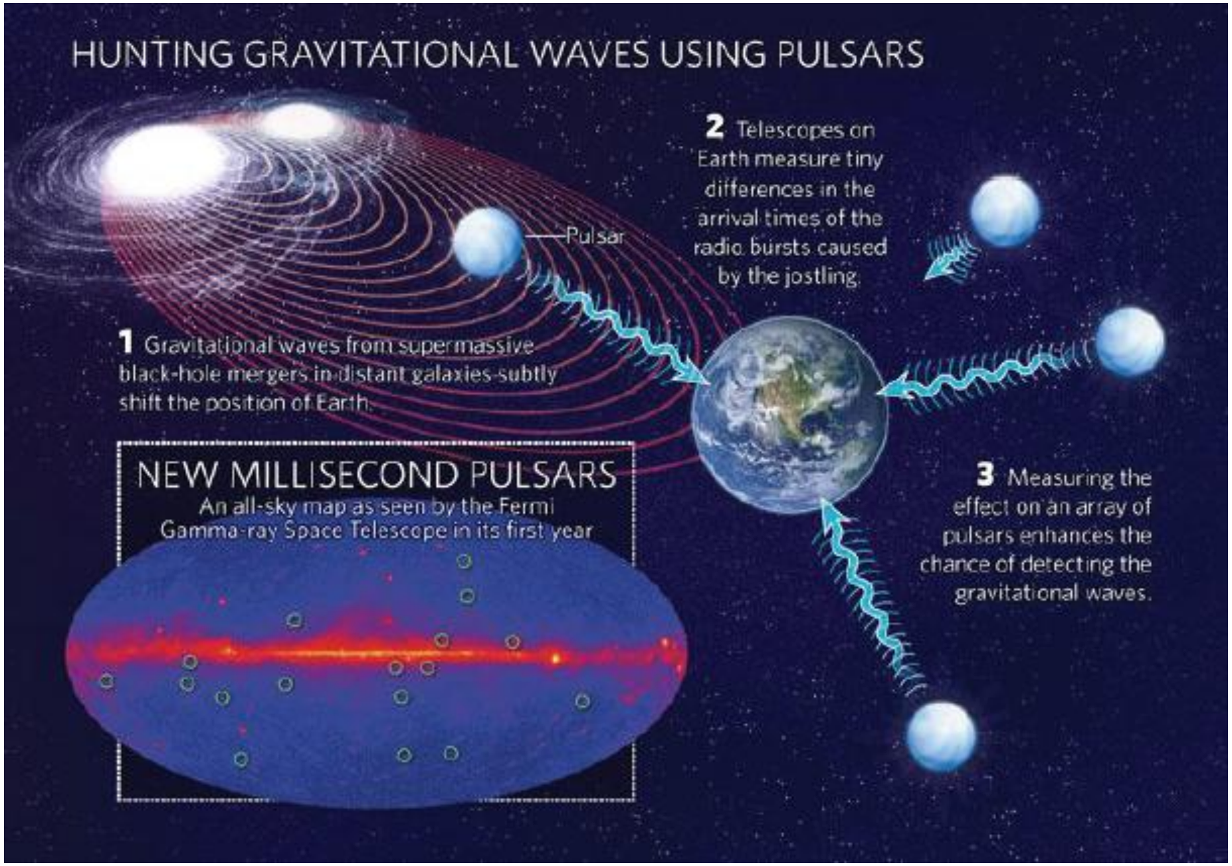
LAT Data provides a map for finding new MSPs

Just announced and published: 1st gamma-ray MSP found in blind search of LAT Data:

PSR J1311-3430

(Pletsch et al., 4th Fermi Symp)

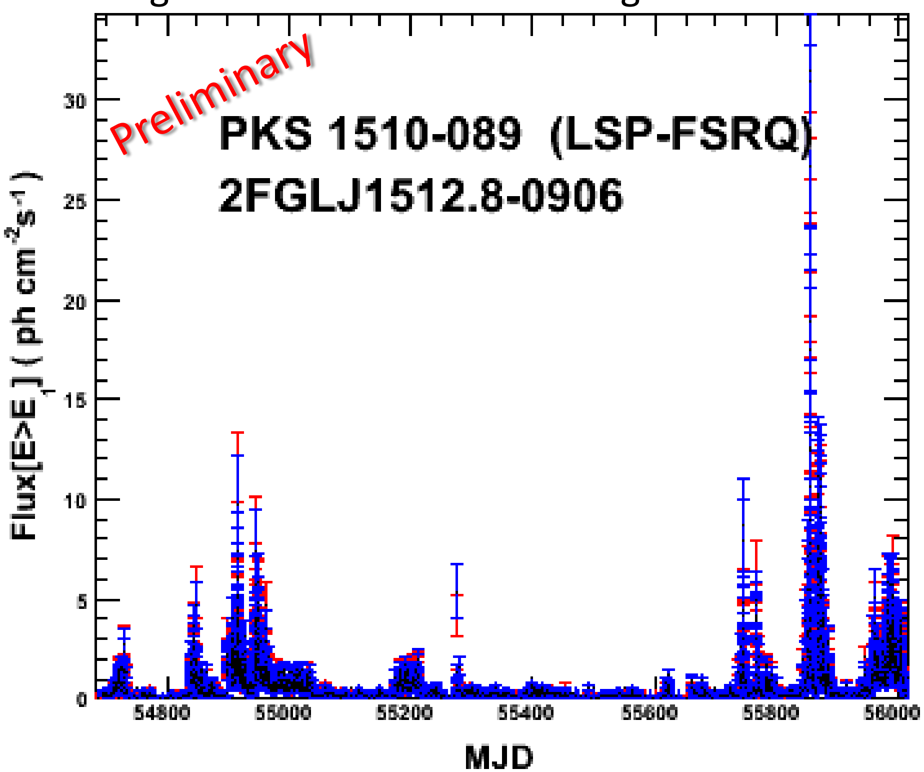
The sensitivity of detecting gravity waves using MSP timing increases with the number of MSPs being monitored

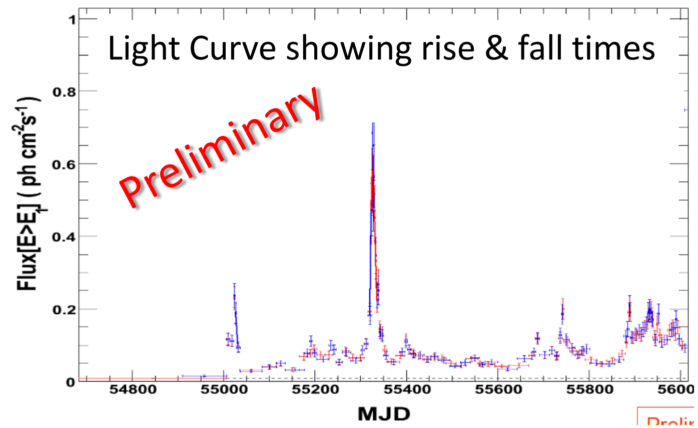


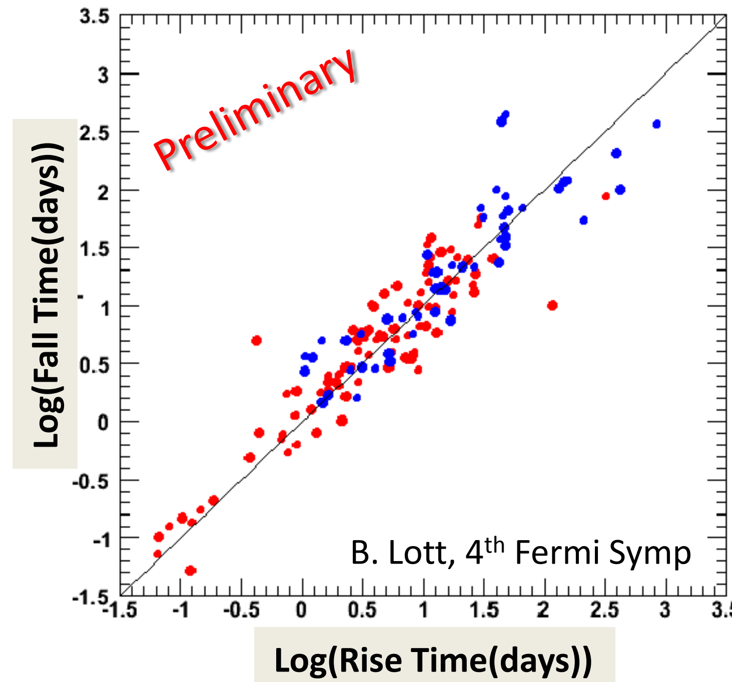
AGN Science

- Blazar: AGN with jet pointed at us
- Large variability
- Thought to be initiated by sporadic accretion events
- Clues as to how AGN engine works?

Light Curve for one of the brightest Blazars

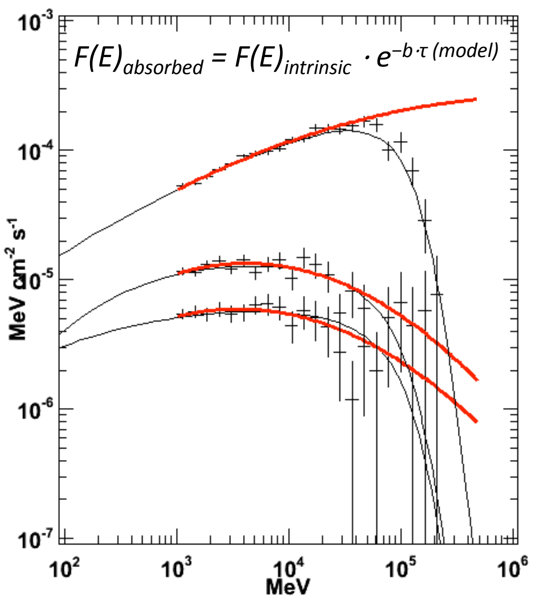




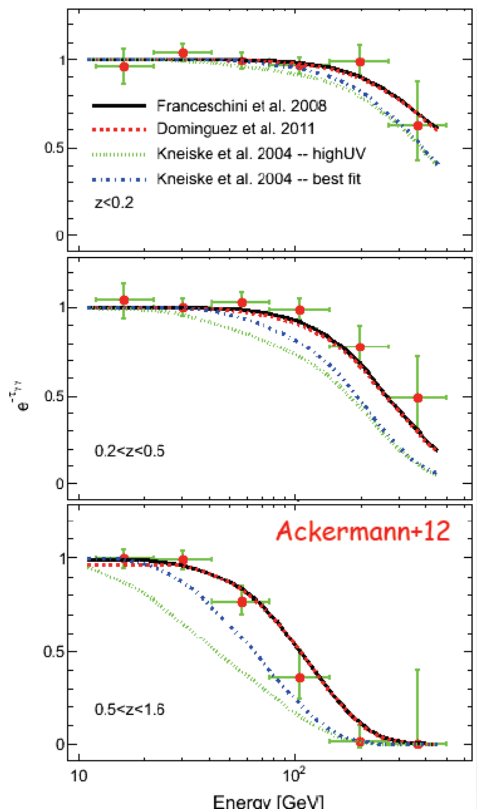


Using AGNs to Probe other Science

- AGN produce VERY high energy γ's
- γ's at high energy and large red-shift DON'T survive trip to Earth
- Pair Cascades off Extra-Galactic Background Light (EBL)
- History of Galaxy Formation determines EBL



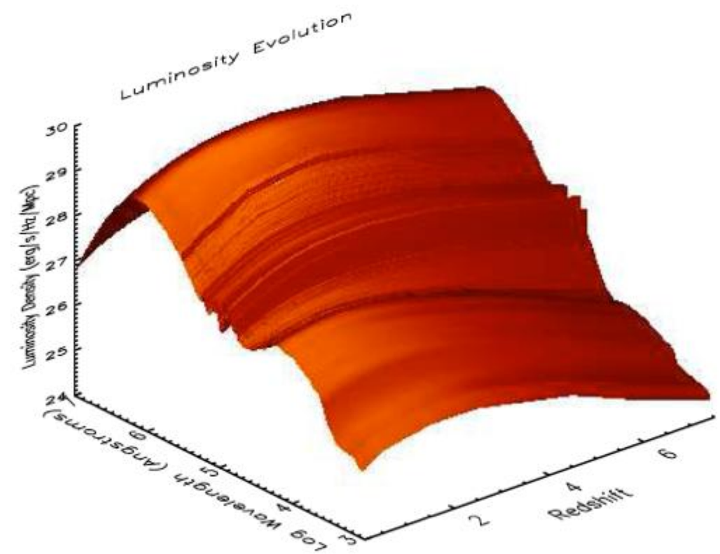
Ajello et al., 4th Fermi Symp.



Analysis

- 3 Bins in red-shift:
  0-0.2, .2 - .5, .5-1.6
- 50 Sources each bin
- Fit each to Intrinsic Spectra * Common Absorption

History of Galaxy Formation



Gilmore, Somerville, Primack and Dominguez (2012)

AGNs Up-Close: A Remote Possibility

(WBA, 2007 Les Houches Lecture)

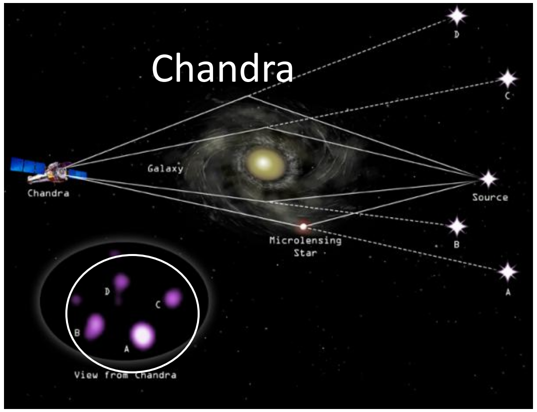
GLAST will see several thousand AGN
~1-in-1000 will be Gravitationally Lensed

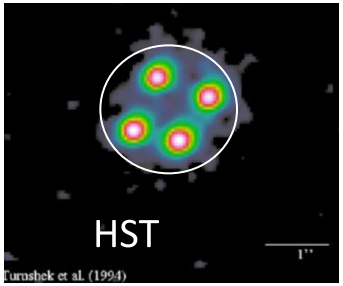
GLAST will not resolve the Individual images as does CHANDRA or OPTICAL Teles.

However each image will have a different light path.

When an AGN Flares -
GLAST will see the images in succession according to their Time delays. AGN ECHOES!

Clover Leaf Quasar





Notice the different relative intensities of the images!

Time delay for echo can be estimated by: $\mathbf{\Delta t \approx (1 - \cos(\theta)) \cdot Distance \approx \frac{\theta^2}{2} \cdot D \approx 9Days}$

where θ = 1 arcsec & D = 10^9 years (~300 Mpc)

Question: Will the ECHOES have the same temporal / spectral composition?
If not two possibilities:

1)(Likely) Correlating x-ray and optical images of lensed AGN is believed to reveal a magnified view into the AGN

2)(Unlikely) Reveal gravitationally lenses not to be achromatic - a violation of Lorentz invariance

Realistically the chance of GLAST having a bright enough flare in a BLAZAR which is gravitational lensed is quite small

AGN Lensing: A First Attempt

Astronomy & Astrophysics manuscript no. printer˙aa˙GL2010 © ESO 2(
November 22, 2010

First evidence for a gravitational lensing-induced echo in gamma rays with Fermi LAT

A. Barnacka[2,1], J-F.Glicenstein[1], and Y. Moudden[1]

[1] DSM/IRFU, CEA/Saclay, F-91191 Gif-sur-Yvette, France
[2] Nicolaus Copernicus Astronomical Center, Warszawa, Poland

Preprint online version: November 22, 2010

ABSTRACT

Aims. This article shows the first evidence for gravitational lensing phenomena in high energy gamma-rays. This evidence comes from the observation of a gravitational lens induced echo in the light curve of the distant blazar PKS 1830-211.
Methods. Traditional methods for the estimation of time delays in gravitational lensing systems rely on the cross-correlation of the light curves of the individual images. In this paper, we use 300 MeV-30 GeV photons detected by the Fermi-LAT instrument. The Fermi-LAT instrument cannot separate the images of known lenses. The observed light curve is thus the superposition of individual image light curves. The Fermi-LAT instrument has the advantage of providing long, evenly spaced, time series. In addition, the photon noise level is very low. This allows to use directly Fourier transform methods.
Results. A time delay between the two compact images of PKS 1830-211 has been searched for both by the autocorrelation method and the "double power spectrum" method. The double power spectrum shows a 3 σ evidence for a time delay of 27.5 ± 1.3 days, consistent with the result from Lovell et al. (1998). The relative uncertainty on the time delay estimation is reduced from 20% to 5%.

Key words. Gravitational lensing: strong – [Galaxies] quasars: individual: PKS 1830-211 – Methods: data analysis

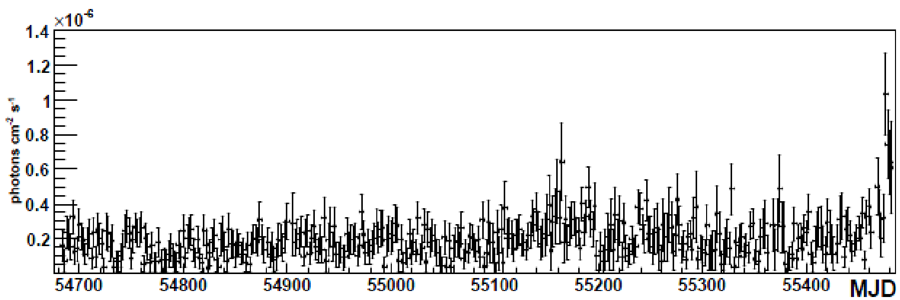


Fig. 1. Fermi LAT light curve of PKS 1830-211, with a 2 days binning. The energy range is 300 MeV to 300 GeV.

Barnacka et al showed we shouldn't have to wait for a giant flare
Use ongoing AGN noise
Autocorrelation & Double Power Technique

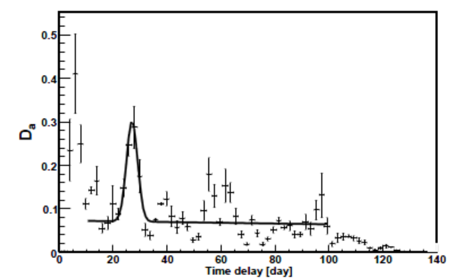


Fig. 6. Double power spectrum of PKS 1830-211 plotted in arbitrary units. The solid line is a fit to a linear plus Gaussian profile.

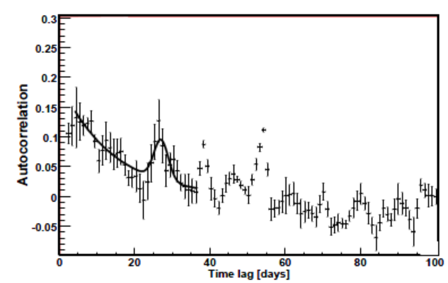


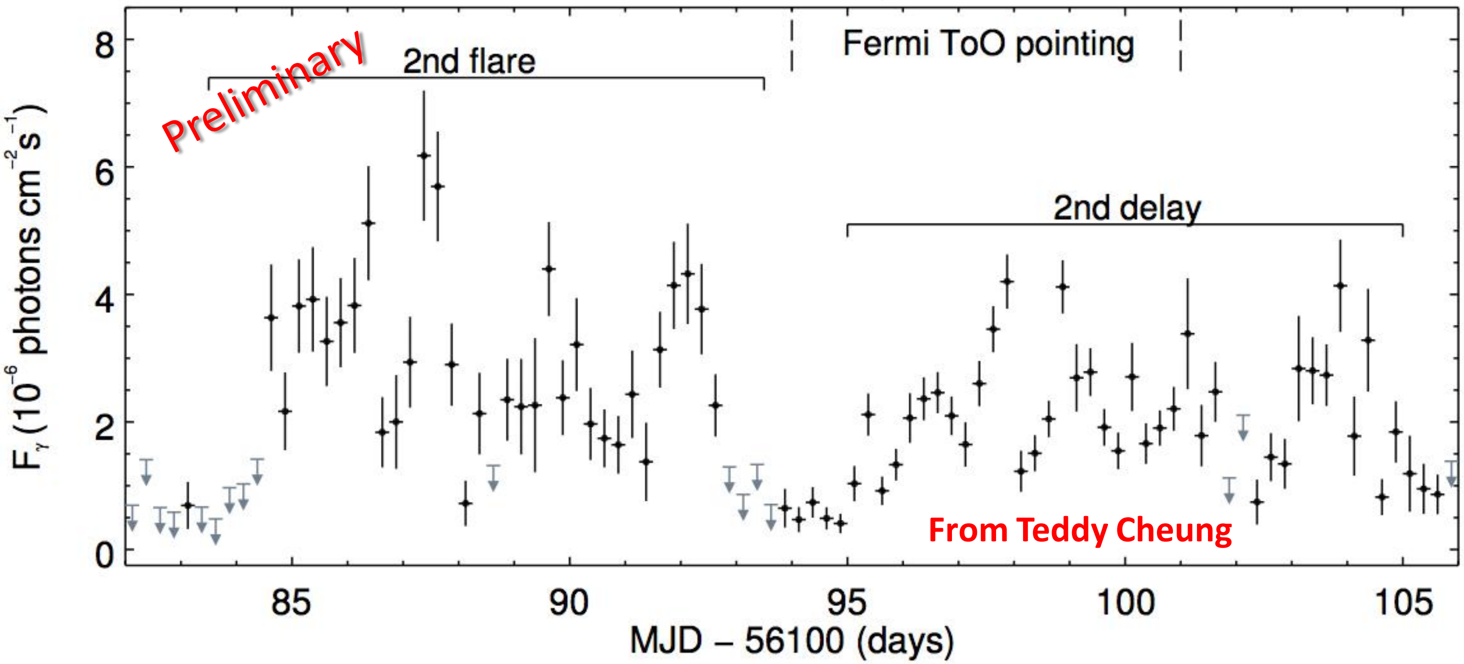
Fig. 7. Measured autocorrelation function of PKS 1830-211. The

False Alarm! Detected 27 day delay is a harmonic of *orbital precession period* (τ_{prec} ~ 53+ days). Orbital precession affects the viewing profile and hence the exposure.

PAYDIRT!

- Large flare in S3 0218+35 last summer
- Cheung et al. anticipated lensing event – requested a Target-of-Opportunity Observation
- Observed two lensed flaring events
- Delay consistent with that observed in the *optical band.*

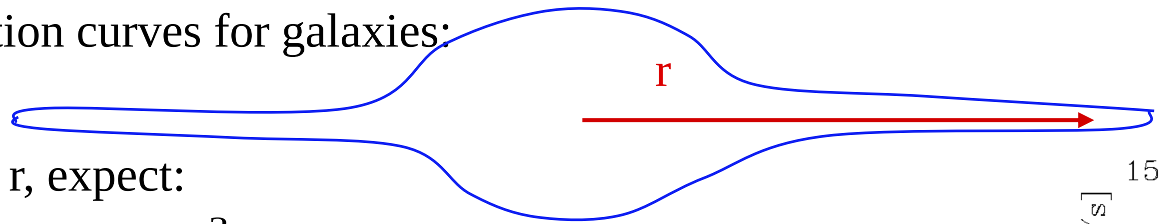
ToO on S3 0218+35 Sept 2012



Publication in preparation

The Dark Matter Problem

Observe rotation curves for galaxies:

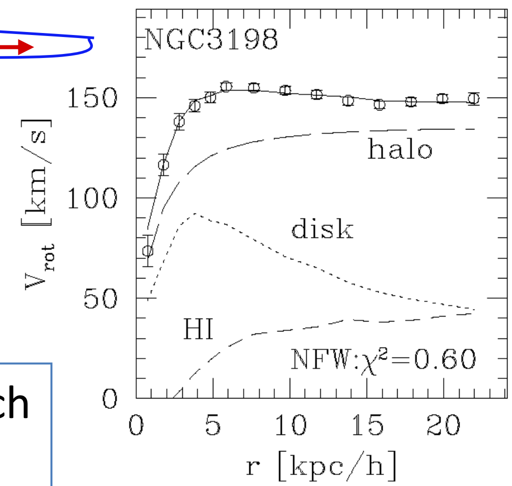


For large r, expect:

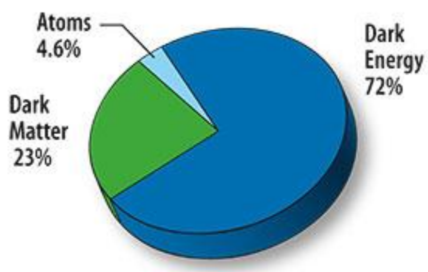
$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \qquad v(r) \sim \frac{1}{\sqrt{r}}$$

Observe: flat or rising rotation curves

Begelman/Navarro



Hypothesized Solution: the visible galaxy is embedded in a much larger halo of Dark Matter.



Credit: NASA/WMAP team

Famous Bullet Cluster

Showing separation of DM and Baryonic Matter

They seek it here, they seek it there
Those Physicists seek it everywhere
Is it in heaven or is it in hell?
That damned elusive Dark Matter Pimpernel!

Paraphrased from the ***Scarlet Pimpernel*** by Baroness Emma Magdolna Rozália Mária Jozefa Borbála "Emmuska" Orczy de Orczi

Gamma Ray Flux from WIMPS

The flux of gamma rays from WIMP annihilation has many terms:

$$\phi_\chi(E,\psi) = \frac{\langle \sigma v \rangle}{4\pi} \sum_f \frac{dN_f}{dE} B_f \int_{l.o.s.} dl(\psi) \frac{1}{2} \left(\frac{\rho(l)^2}{M_\chi^2} \right)$$

Annihilation Cross Section & Thermal Velocity

Branching Fraction & Photon Spectrum

WIMP Number Density Squared

ψ : Angle away from DM Clump

l.o.s : Line-of-Sight in direction

Recasting & Scaling in terms of nominal values

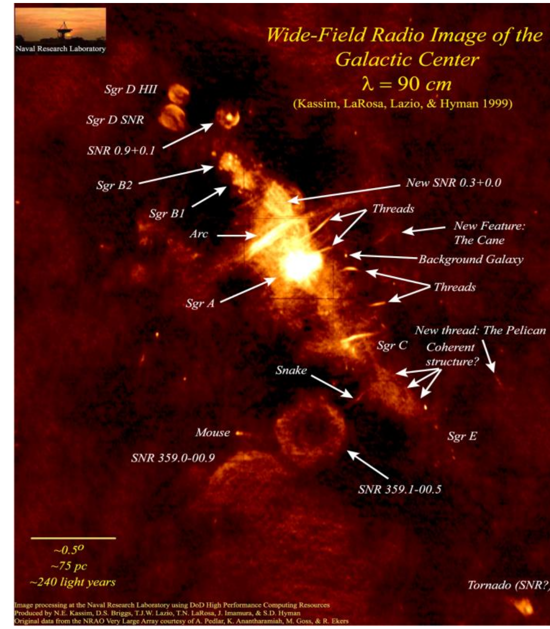
$$\phi_\chi(E,\psi) = 3.74 \cdot 10^{-10} \left(\frac{\sigma v}{10^{-26} cm^3 s^{-1}}\right)\left(\frac{50GeV}{M_\chi}\right)^2 \sum_f \frac{dN_f}{dE} B_f \cdot J(\psi)$$

Units: $cm^{-2}s^{-1}GeV^{-1}sr^{-1}$

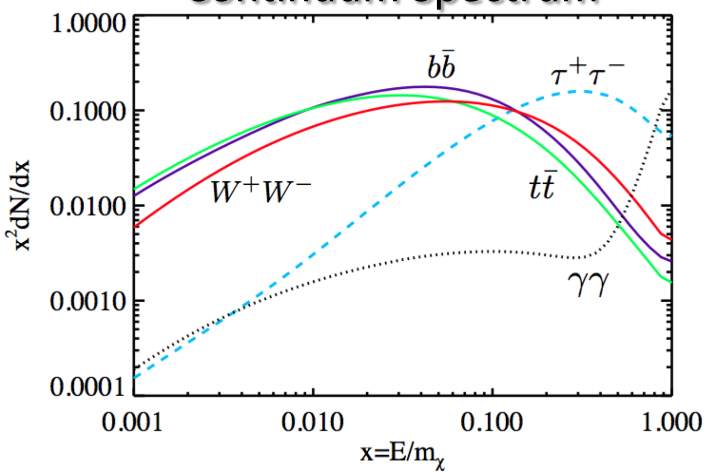
with: $$J(\psi) = \frac{1}{8.5kpc} \int_{l.o.s} \left(\frac{\rho(l)}{.3GeVcm^{-3}}\right)^2 dl(\psi)$$

Continuum or Lines

- Generic annihilation channels hard to distinguish from Astrophysical processes & sources
- *Smoking Gun:* 2-Photon -*or*- Photon-Z^0 gives sharp spectral feature
- Line-like rate estimated to be many orders of magnitude smaller than continuum emission from more complicated channels
- Many searches for "standard" channels such as $b\bar{b}$, $\tau^+\tau^-$, etc. - only upper limits set
- Line searches underway – possible signal(s) seen(!)
- Largest J-factor (by far) at the Galactic Center but it's a real mess!

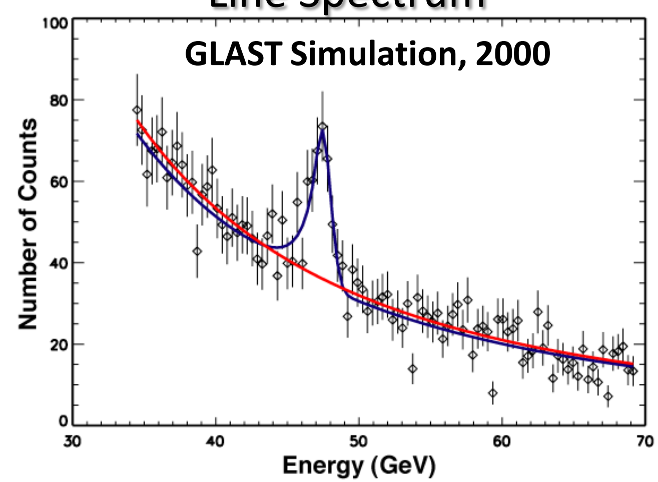


Continuum Spectrum



Spectra calculated with PPPC 4 DM ID [Cirelli et al. 2010]

Line Spectrum

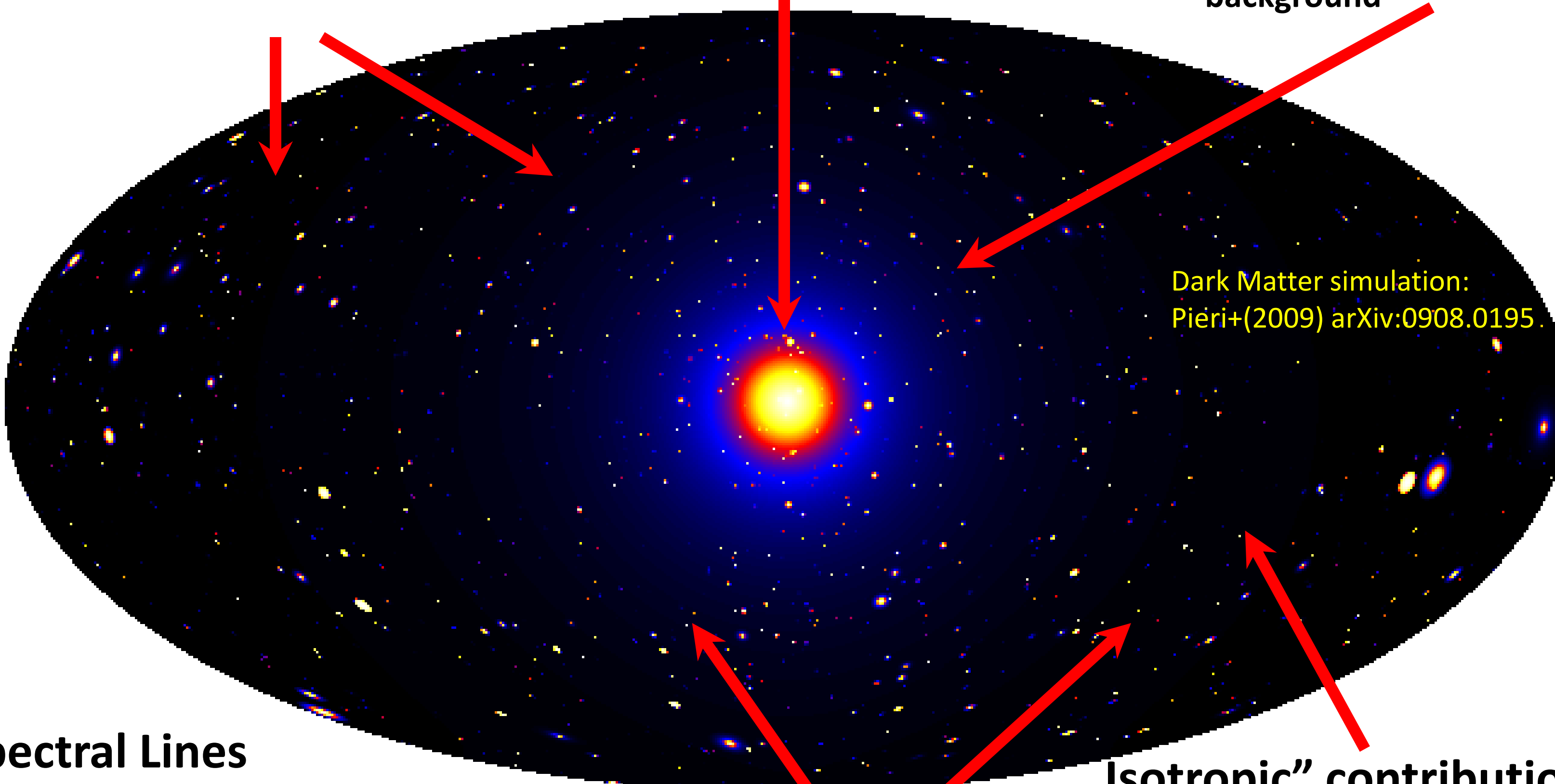


Many Places to Seek DM!

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

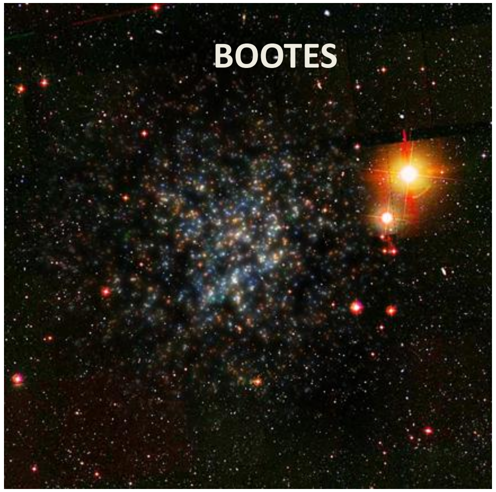
Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

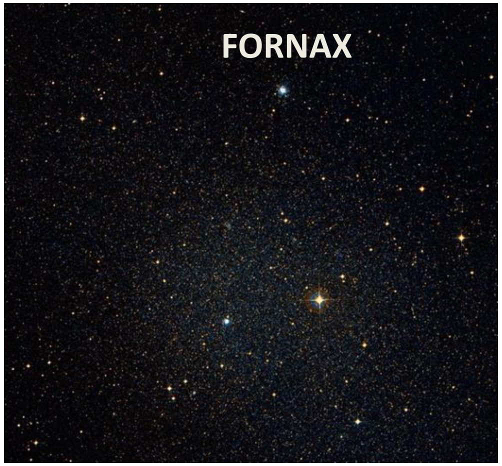
Galaxy Clusters
Low background, but low statistics

31

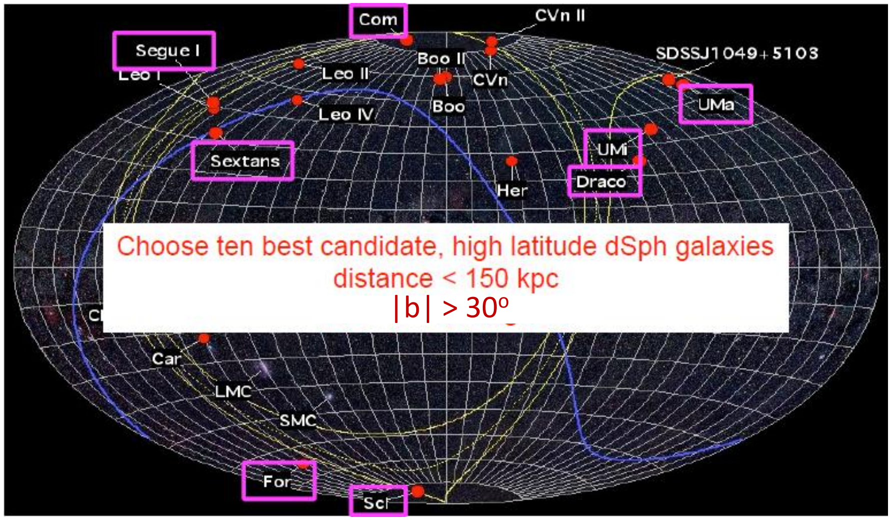
DM Search Focus: Dwarf Spheriodal Galaxies

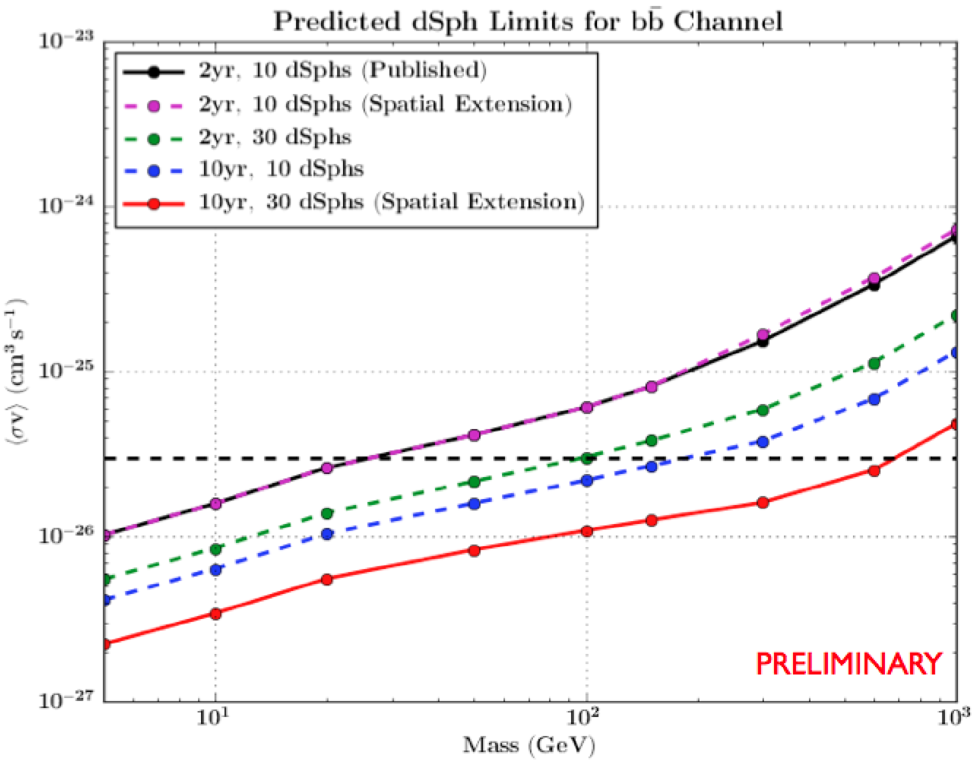
- Dwarf Spheriodal Galaxies (dSphs) are approx. “spherical” collections of stars orbiting the Milky Way, held together by DM
- Large Optical Surveys (*eg.* SSDS, HST,…) has enabled astronomers to identify 20 or more such objects.
- Mass–to-Light ratio (indicative of DM content) often > 100 and some > 1000!
- Ideal locations to search for gamma ray signals from Annihilation or Decay of DM





DM in dSph: Current & Future





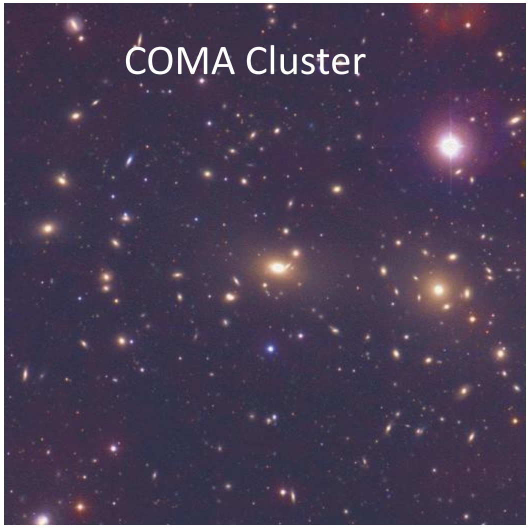
No gamma rays seen in dSphs

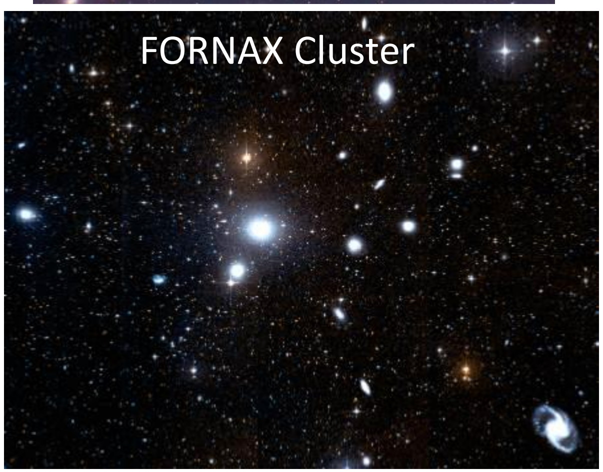
Published limits: arXiv: 1108:3546

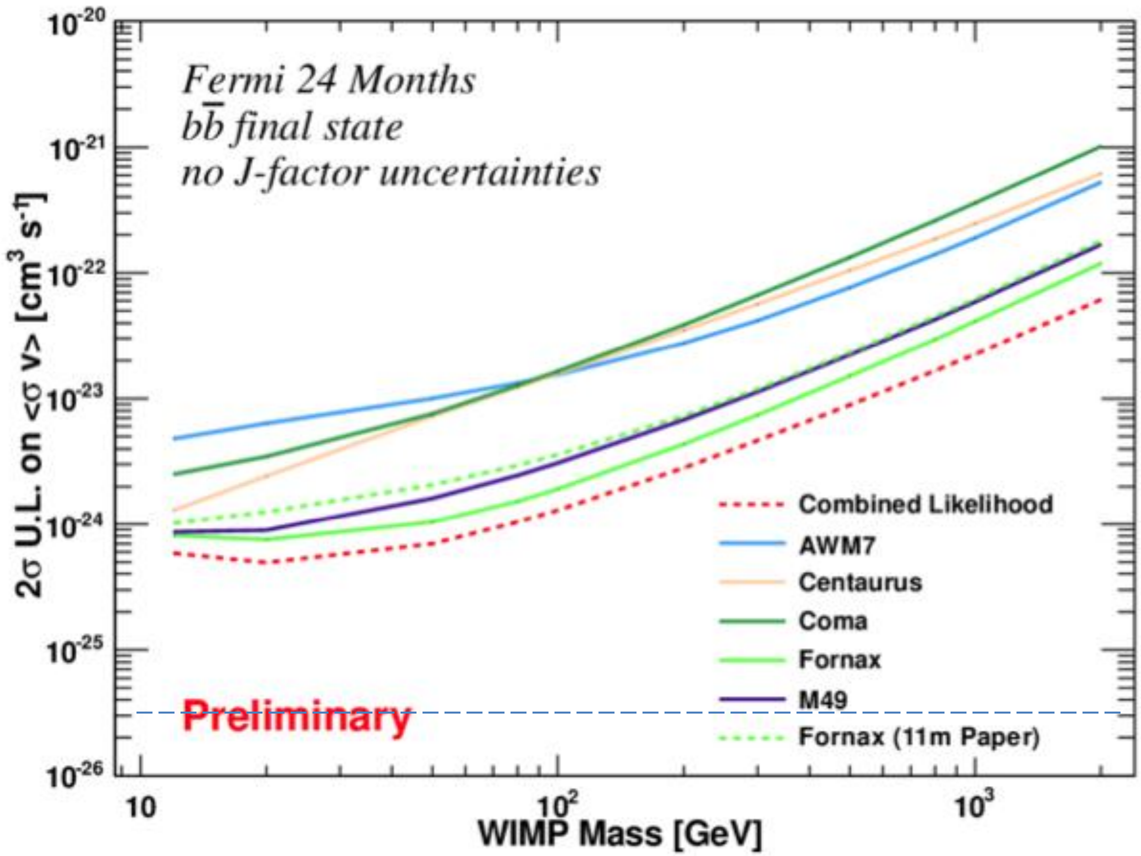
Discovery of new dSphs and increased observing time should allow us to explore the thermal relic cross section up to almost 1TeV by the end of the mission

Search for DM in Galaxy Clusters

Promising targets: large DM Content and low, but challenging backgrounds





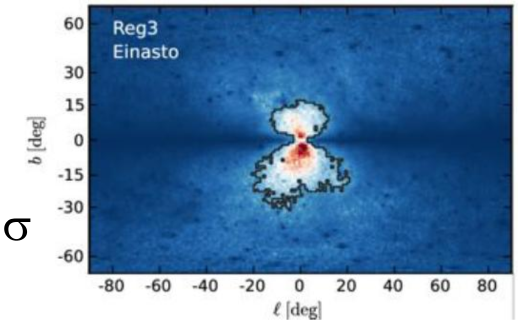


Note: Galaxy Clusters are competitive with dSphs *only* if there are large **Boost Factors**

The Evolving Story of DM Lines

Weniger et al remind us to
- Look in the Galactic Center
- Look for Line(s)
- Claims global significance 3.2σ

ROI selection

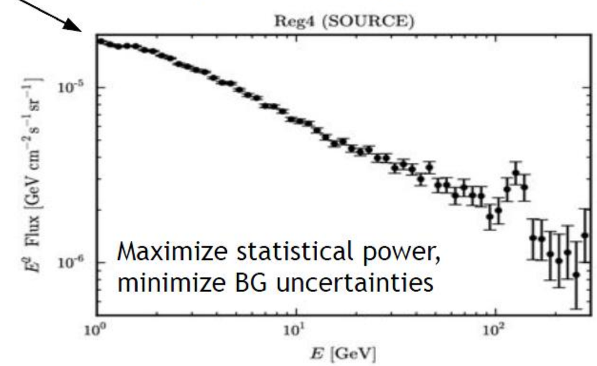


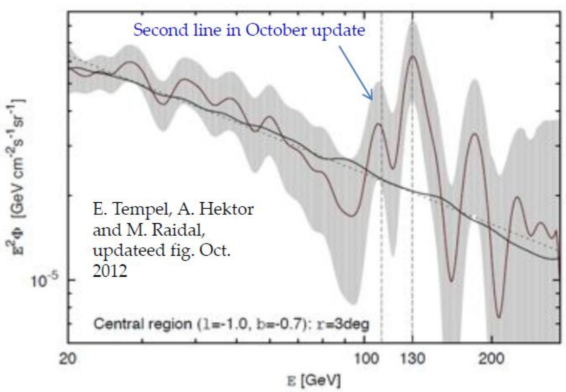
Maximize S/N

Optimize ROI using “low energy data” for Background and various DM Profiles

$$\int_{\Delta\Omega} d\Omega$$

Spectral analysis

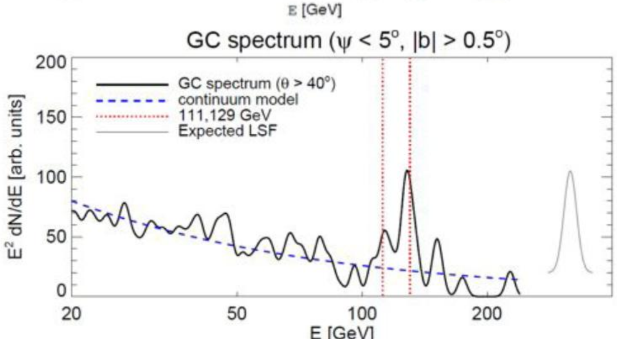




E. Tempel, A. Hektor and M. Raidal, May 2012: Independent confirmation of the existence of the excess, and that it is not correlated with Fermi bubbles.

Best fit: γγ line, mass m_χ = 130 GeV

Another independent verification, M. Su and D. Finkbeiner, June 2012 (template fitting). They note: maybe a second line; flux maximum is offset by 1.5 deg from g.c.



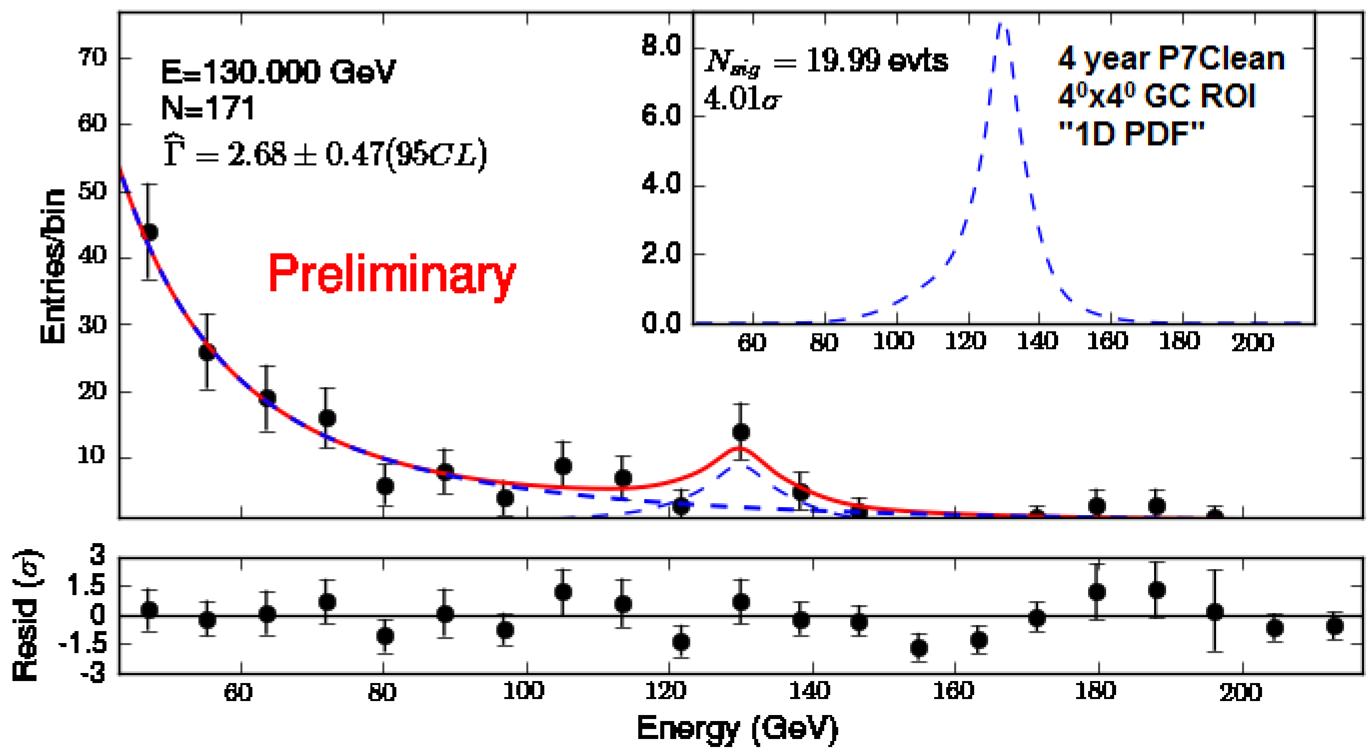
Tempel et al find a similar signature from stacked Galaxy Clusters.

Su & Finkbeiner find hints of 2 line structure at GC

Evidence for 2 Lines is ***VERY MARGINAL***

First LAT Line search without optimize ROIs only set limits

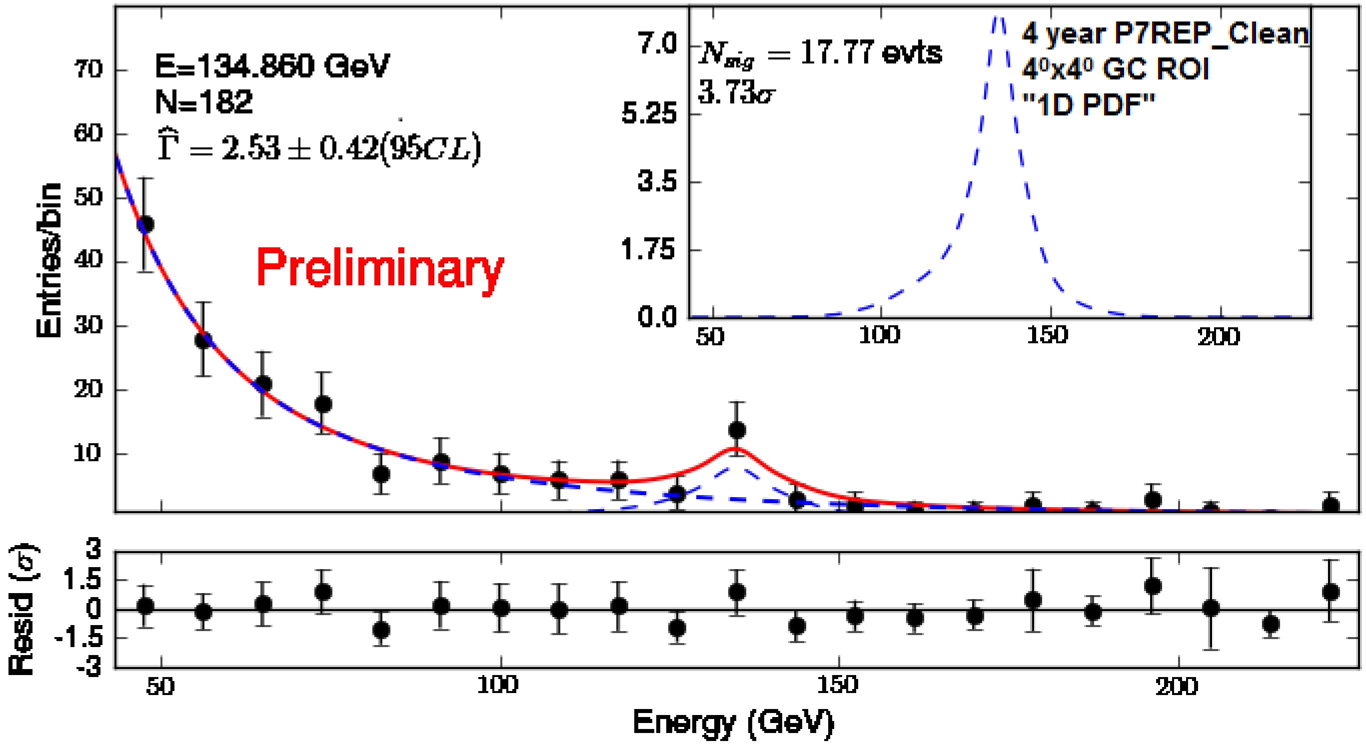
Fermi-LAT Team Line Search at 135 GeV



•4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data

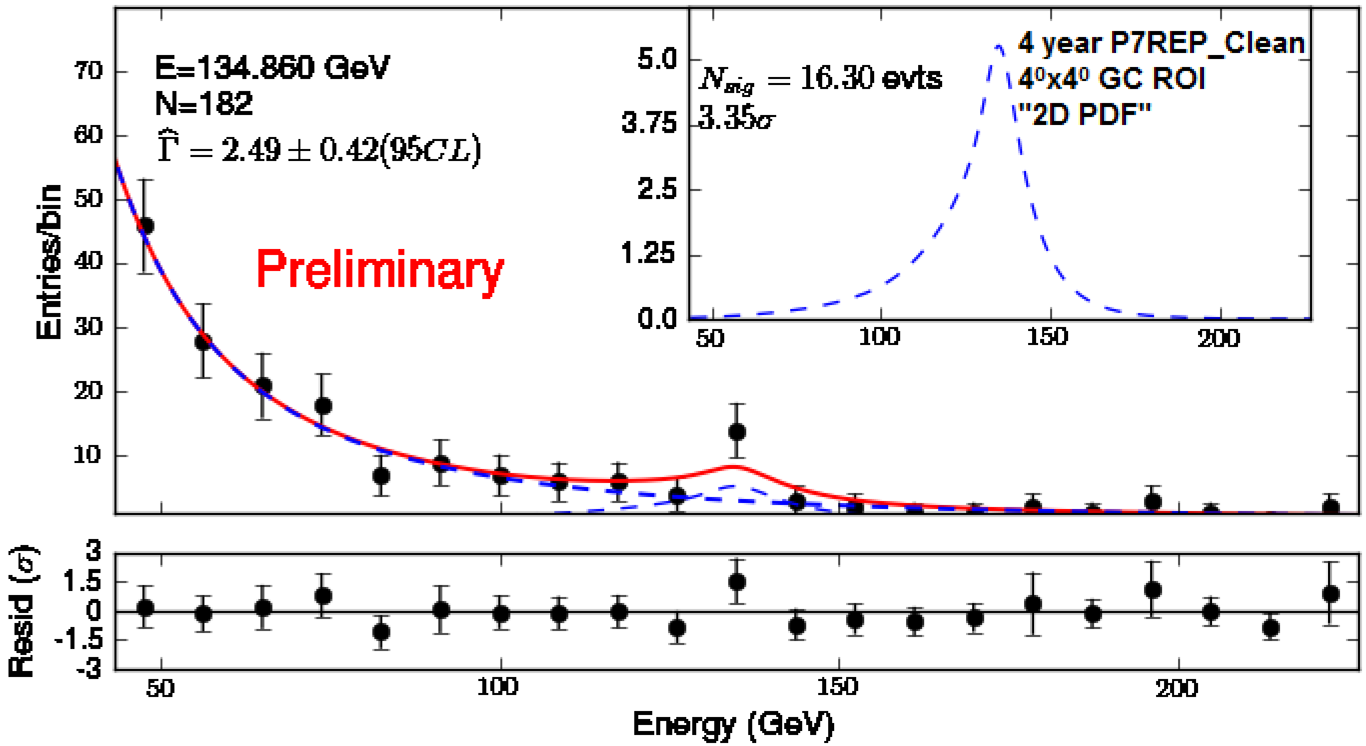
•Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)

Fermi-LAT Team Line Search at 135 GeV



- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- **3.73σ (local) 1D fit at 135 GeV with 4 year reprocessed data**
  - **Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)**

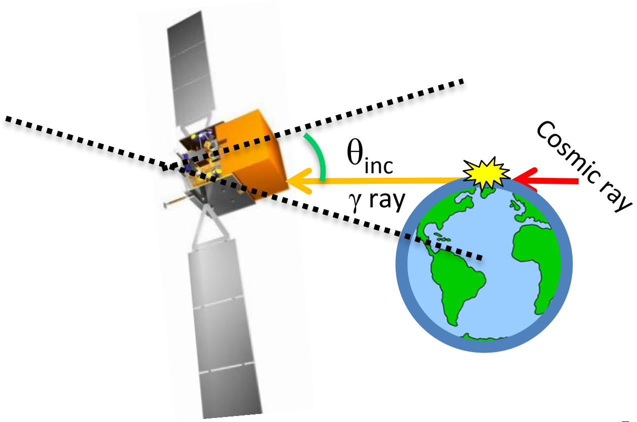
Fermi-LAT Team Line Search at 135 GeV



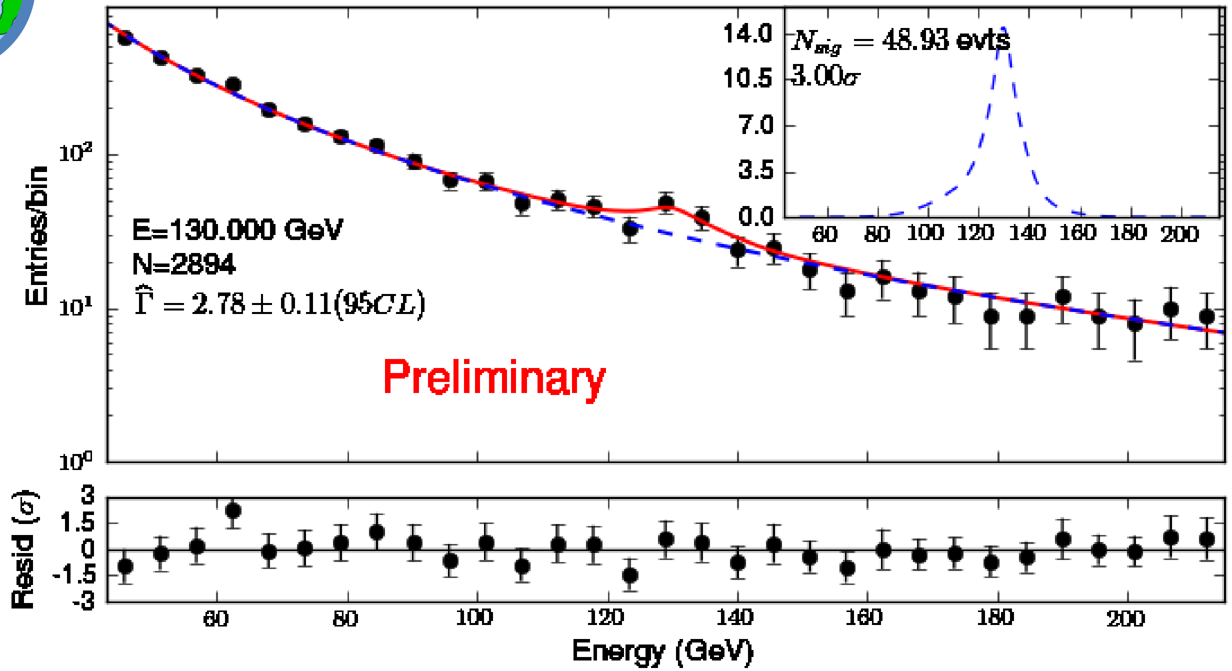
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- 3.73σ (local) 1D fit at 135 GeV with 4 year reprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- **3.35σ (local) 2D fit at 135 GeV with 4 year reprocessed data**
  - **Look in 4°x4°GC ROI, Use 2D PDF (P_E in data)**
  - **<2σ global significance after trials factor**

But… there's always a *but*…

- Signal tuning clouds the issue of "look elsewhere effect"
- All signals seem to be at the ~ 3σ level
- LAT Team – sees similar "signals" - *but* we call them *features*



And we see something in our Limb Data



Pros & Cons for DM Line

PROS

- Tantalizing signal from GC
- Similar signal seen in Gal. Clusters
- Possible γZ^0 Line present
- Signal consistent with DM Profiles

CONS

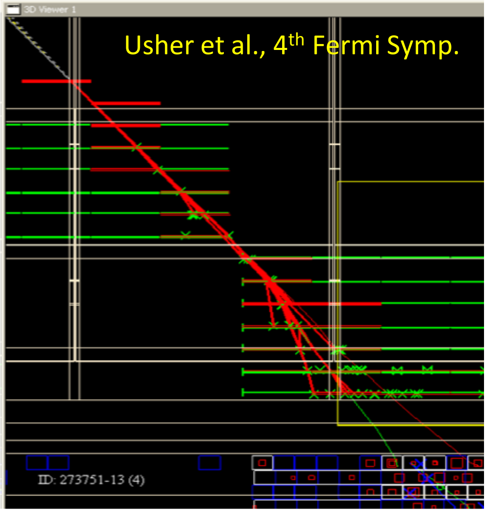
- GC Signal requires LARGE $\gamma\gamma$ BR
- GC Signal displaced from GC
- GC Signal *decrease* in significance with reprocessed data
- Similar Signal seen in Limb Data
- Gal. Cluster signal requires LARGE ROI's

Bottom Line: More data needed to clarify these results

- HESS II
- Fermi-LAT Pass 8
- Fermi-LAT Pointed Observation

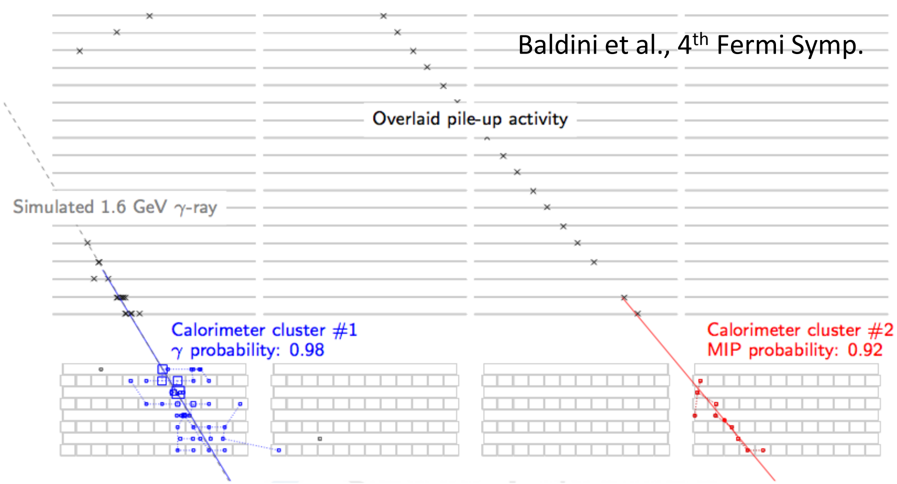
Pass 8

- Fermi-LAT results to date use pre-launch MC based Reconstruction and Event Level Analysis
- Several items to improve on
  - Better Tracker Pattern Recognition
  - Calorimeter Pattern Recognition
  - Calorimeter Energy Recon
  - Usage of Tracking Errors in linking Subsystems



Tree-based Tracking

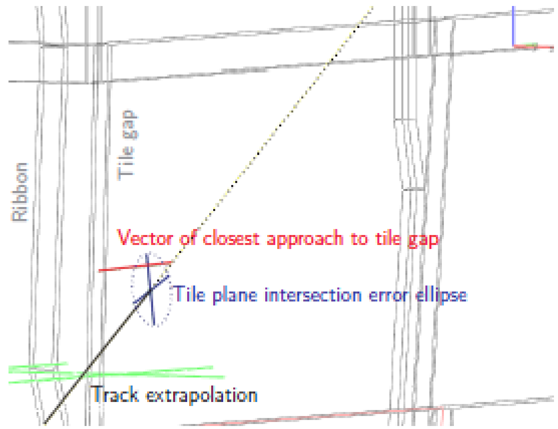
(better model for EM shower)



Calorimeter Cluster & Cluster Classification

More Pass 8 Improvements

Linking Tracks to ACD



Current framework—track/tile association in physical distance:

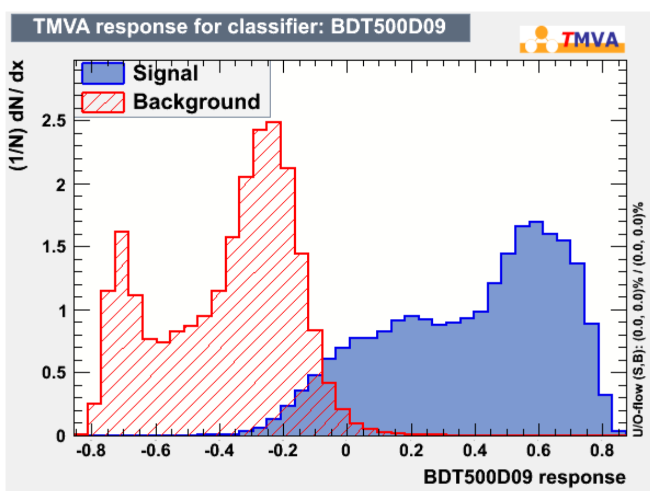
- Explicit energy dependent cuts;
- Susceptible to global pile-up at low energy.

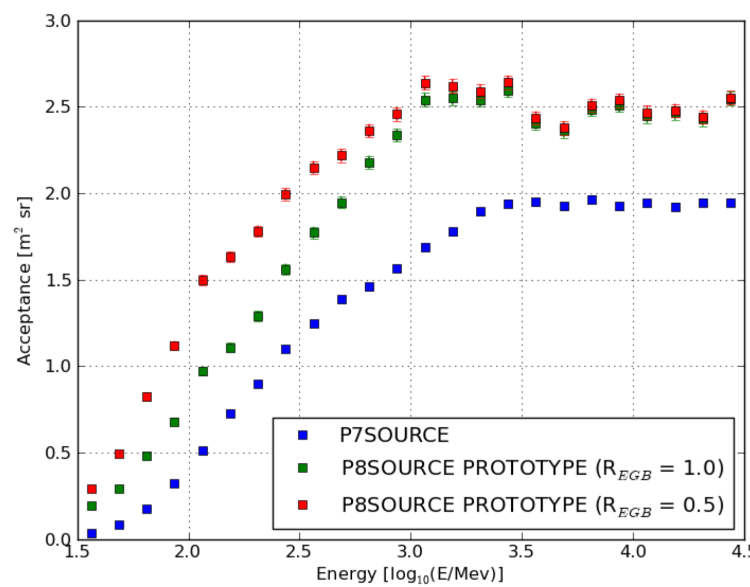
Pass 8—track and cluster/tile association based on covariant error propagation:

- Improved background rejection;
- Use trigger veto to suppress pile-up.

A. Drlica-Wagner et al, 4th Fermi Symp.

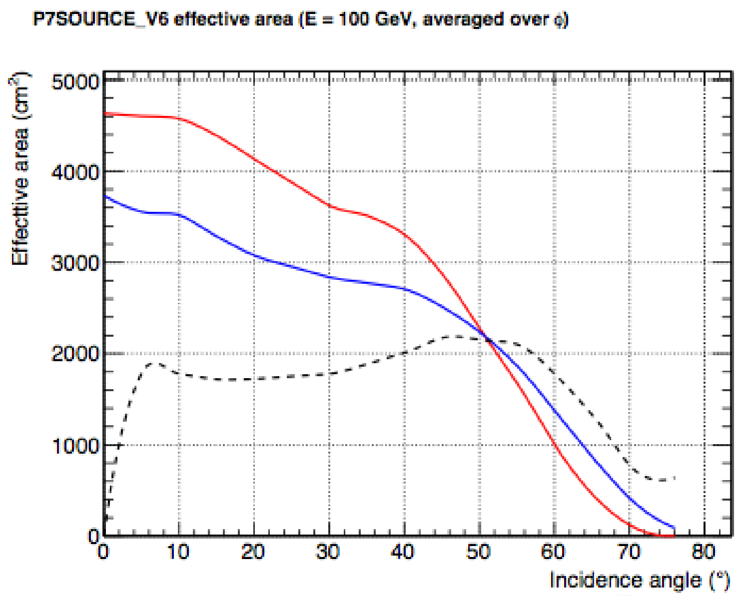
New-Event Level Analysis using TMVA

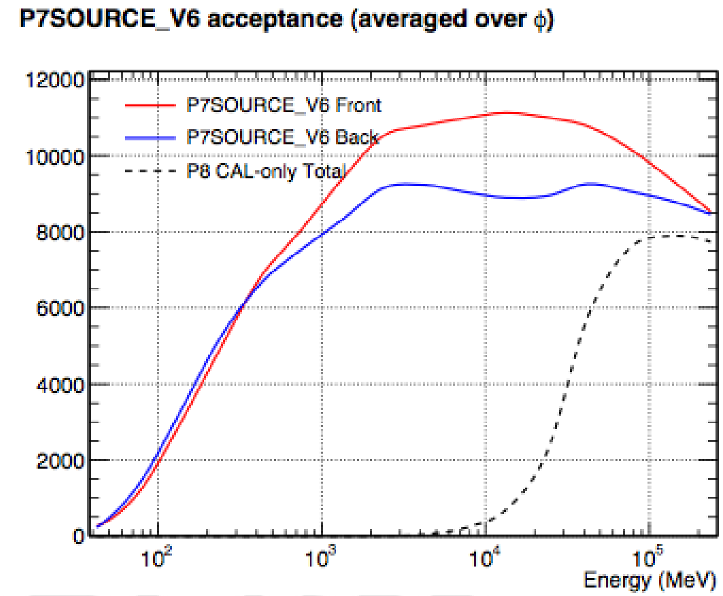


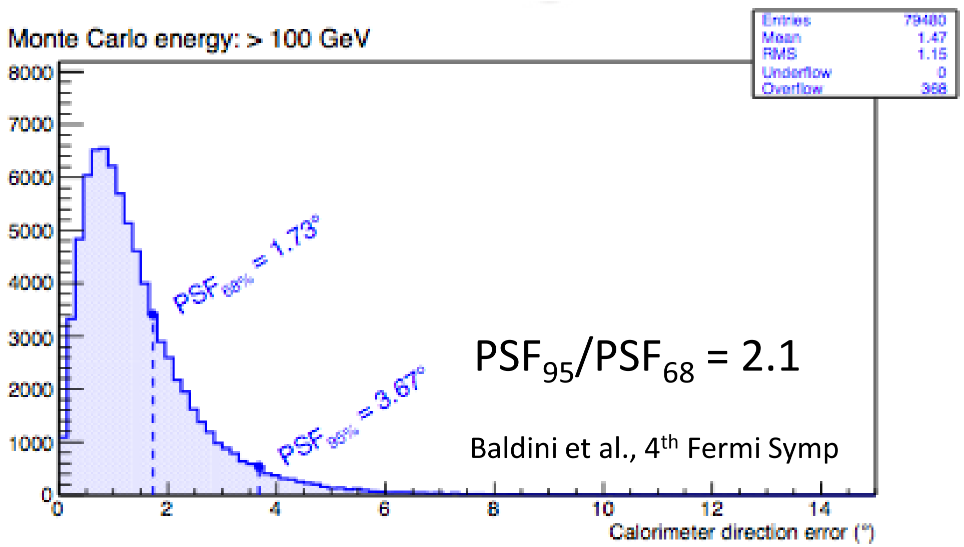


M. Wood et al, 4th Fermi Symp.

Example of "new" event class: CAL-Only







CAL-only: >40% more acceptance at 100 GeV.

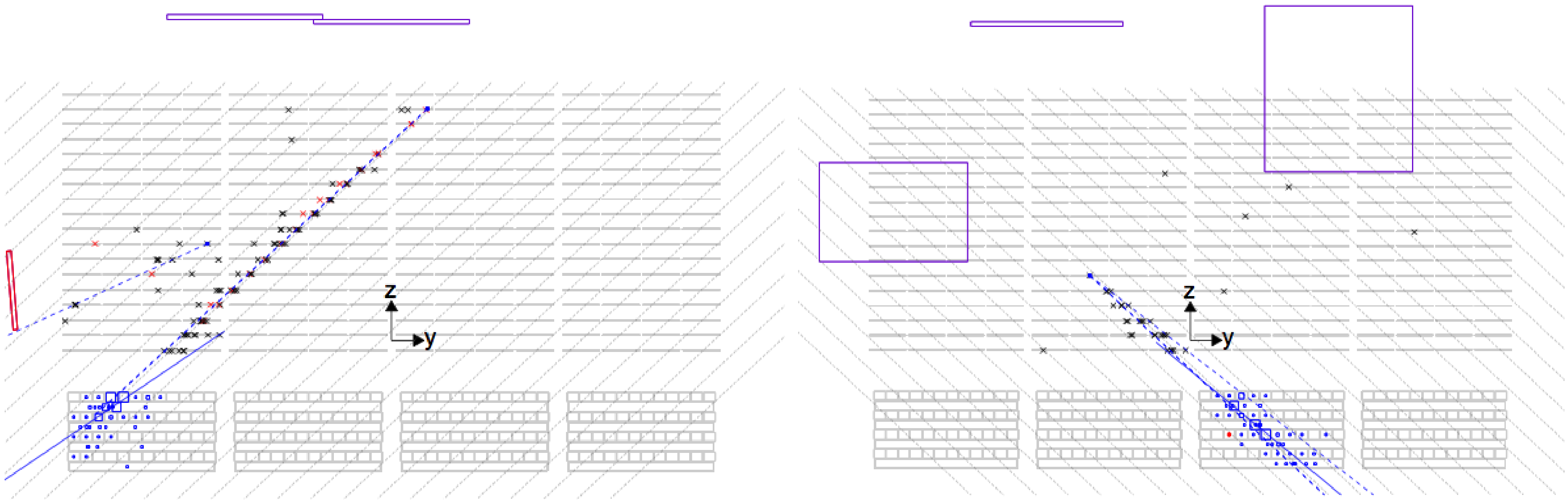
More coverage off axis.

$PSF_{68\%}$ ~ 1.7° (> 10X Tracker PSF at high energy)

Excellent for bright high energy transients

Other specialized Event Class: LAT Low Energy (LLE), Tracker-Only, etc.

GRBs using the New Pattern Recognition

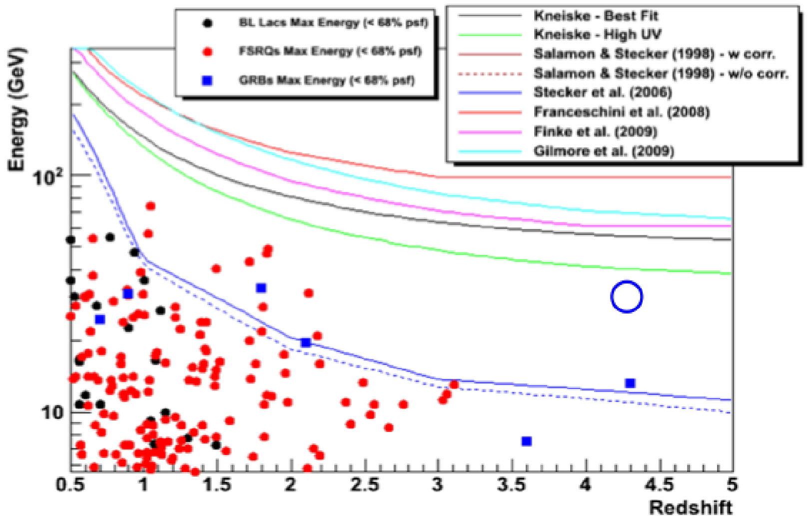


Two events from a skimmed of data from time intervals around bright GRB.
Grid of grey lines point towards GRB.

The event on the left was rejected from P6_V3_DIFFUSE as charged particle. Pass-6 code found 10 tracks, and some pointed close to ACD hit tiles.

The event on the right was rejected from P6_V3_DIFFUSE because the TKR direction didn't agree with the CAL information. This also might be b/c we found so many tracks in Pass 6.

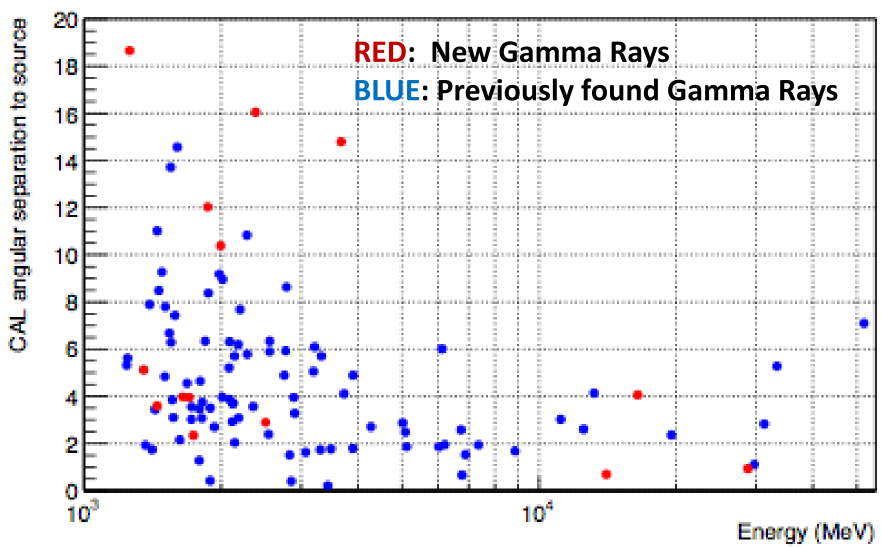
First Taste of Pass 8 Science Impact



3 more photons > 5 GeV from GRB with measured redshifts (18 photons originally) including a 29-GeV photon from a z=4.35 GRB

14 more photons > 1 GeV

CAL-Only directions for those photons are shown below versus energy



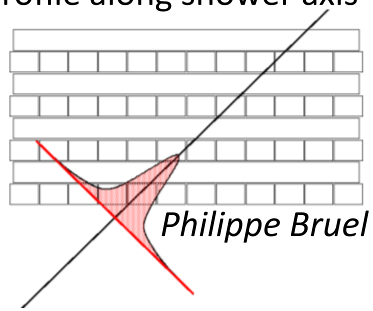
The 29-GeV Photon from GRB080916C is the highest energy photon seen in any GRB so far. In the source frame it is ~ 155 GeV.

It does not provide a more stringent limit of Lorentz Violation.

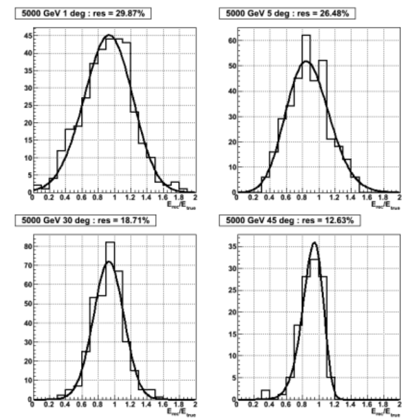
It does provide the most strick limit on the EBL however!

Extension to the TeV Band with an 8.6 Rad. Len. CAL!

Illustration of Shower Profile along shower axis

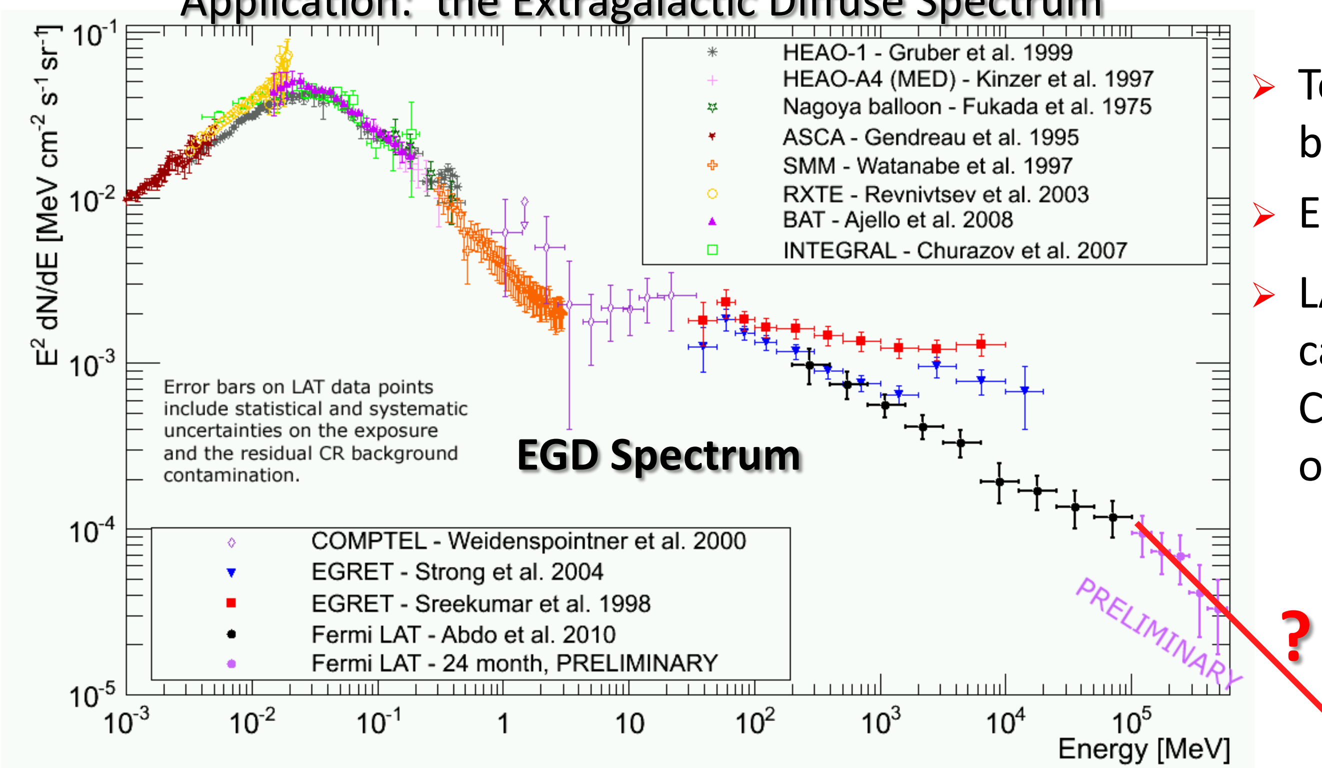


- 3D Shower Imaging allows for a detailed fit to the shower shape.
- Fit allows compensation for leakage and for saturated crystals
- Good energy resolution is achieved even at > 50% leakage



5 TeV Event Simulations at various incident angles

Application: the Extragalactic Diffuse Spectrum



- Too few photons in TeV band for most sources
- EGB is a major exception
- LAT is the only instrument capable of measuring EGB. Current LAT EGB meas. out to ~ 500 GeV

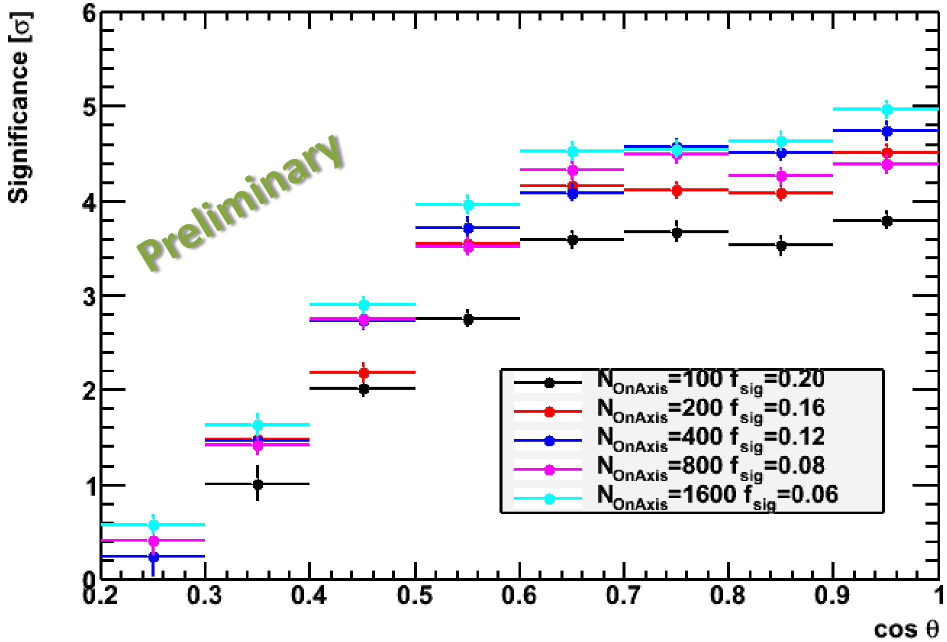
? What happens here?

Dedicated Galactic-Center Observation

(For Line Searches)

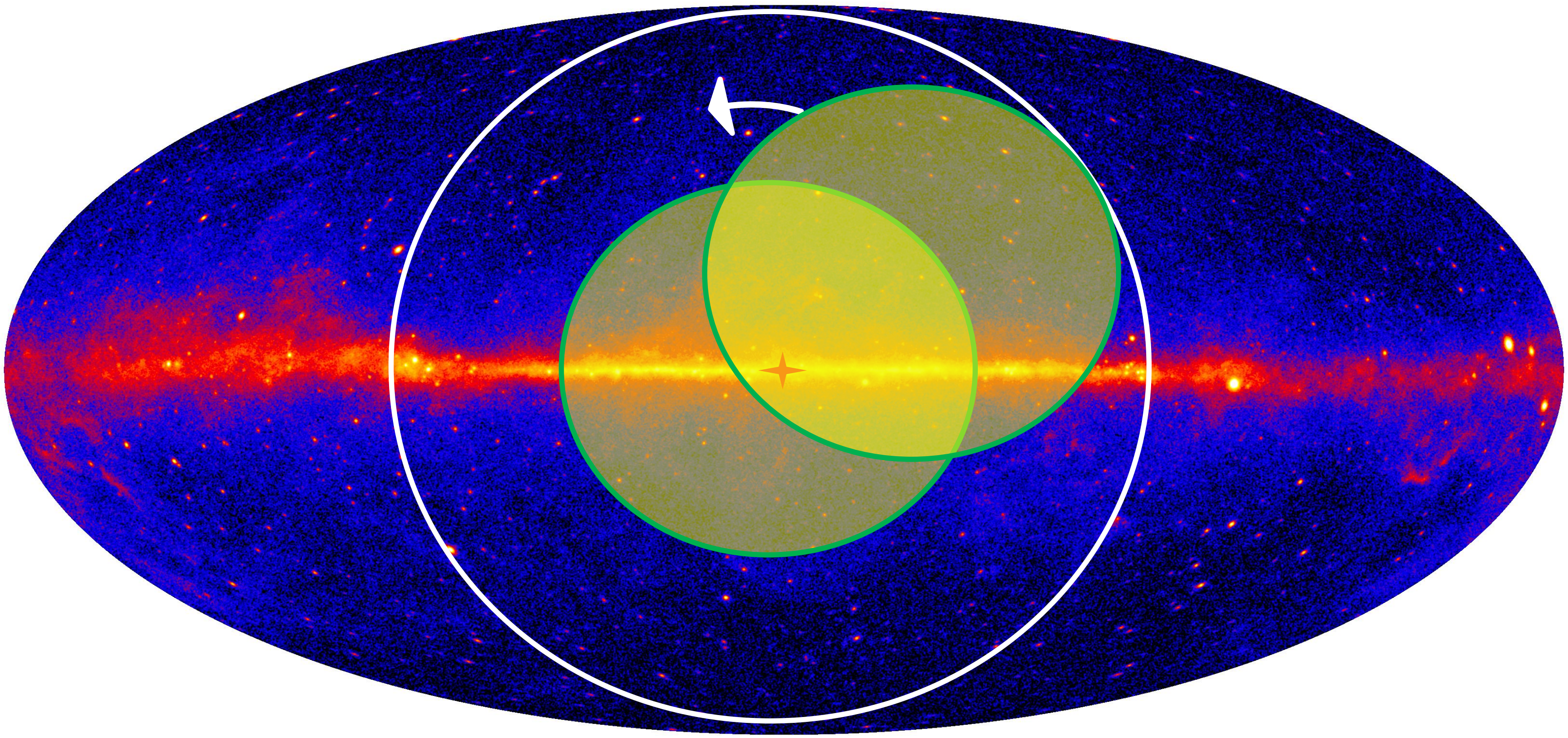
- Galactic-Center data so far has come from Survey Mode Observations
- Pointing directly at or close to GC increases rate by up to ~ 3X
- Energy resolution on-axis at 130 GeV ~ < 10%
- Energy resolution 45° off axis ~ 5%
- Lots of other science from GC region!
- How to optimize GC Pointed Mode with other science under study.

Toy MC simulations for a range of signal-to-noise ratios favor energy resolution over A_{eff} slightly less than naïve scaling predictions.



Out to about θ=50°, the improving energy resolution balances out the decreasing A_{eff}. Less sensitivity past θ=60°.

Examples of GC Pointed Mode



All Sky image showing approx. LAT Field-of-View.   LAT FoV covers ~ 20% of the Sky.
FoV offset from GC and rotated about it shown by white circle.

Note: This is an Aitoff projection of the sky and circular FoVs are not circles away from the origin…
When GC is occulted by the Earth, resume All Sky Survey Mode

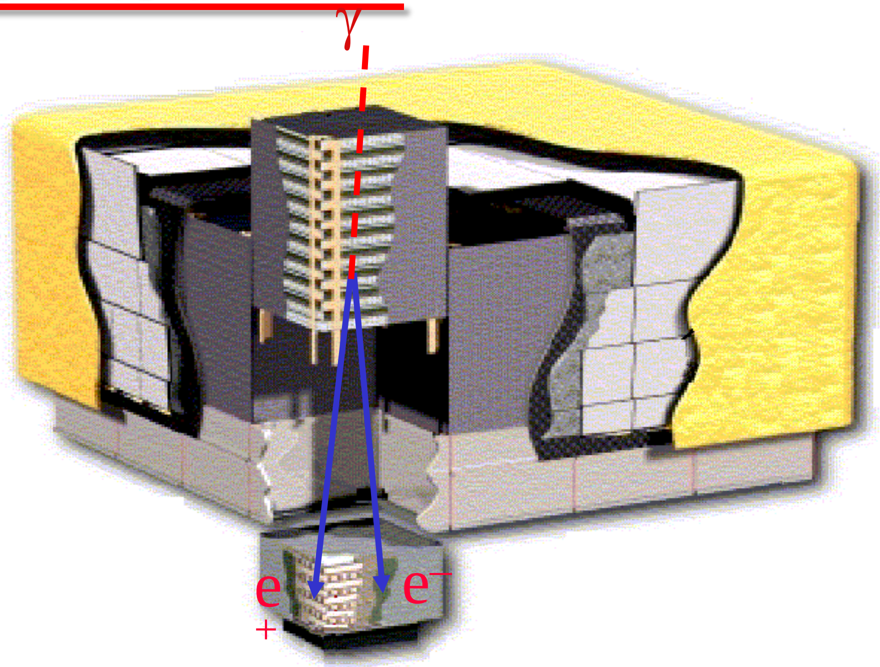
Changing from Survey Mode to a Pointed Mode is a Mission Level Decision

The Best is Still to Come…

- The full re-write of Reconstruction Software accounting for real Flight Data experience: Pass 8
- Adjustments to DAQ to better capture event data
- Full utilization of event-by-event information: covariant errors to sharpen images
- Extended Light Curves on Gamma Ray Sources
  - AGN Echos (from lensing)
  - Long AGN Light Curves – Long time scales for studying flaring
  - Pulsar Glitches – Neutron Star Equation of State
- Higher Statistics (not yet limited by systematic errors)
  - Improve Limits on DM or maybe find something!
  - Find Pair Halos – measure Intergalactic Magnetic Fields

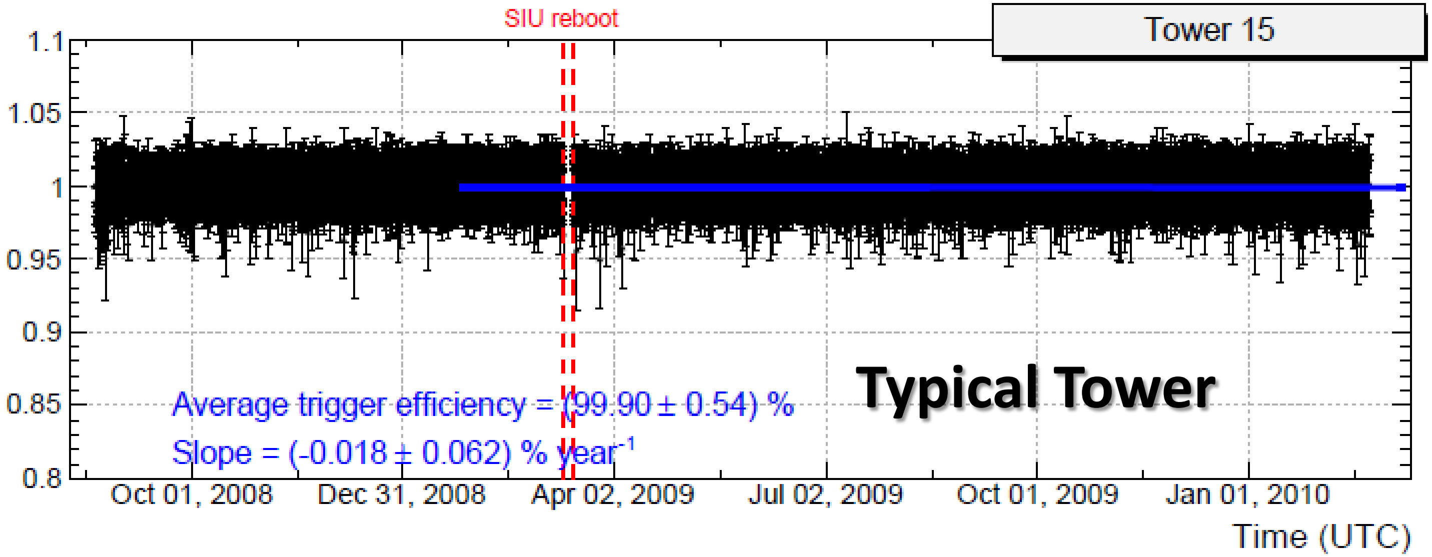
Backup

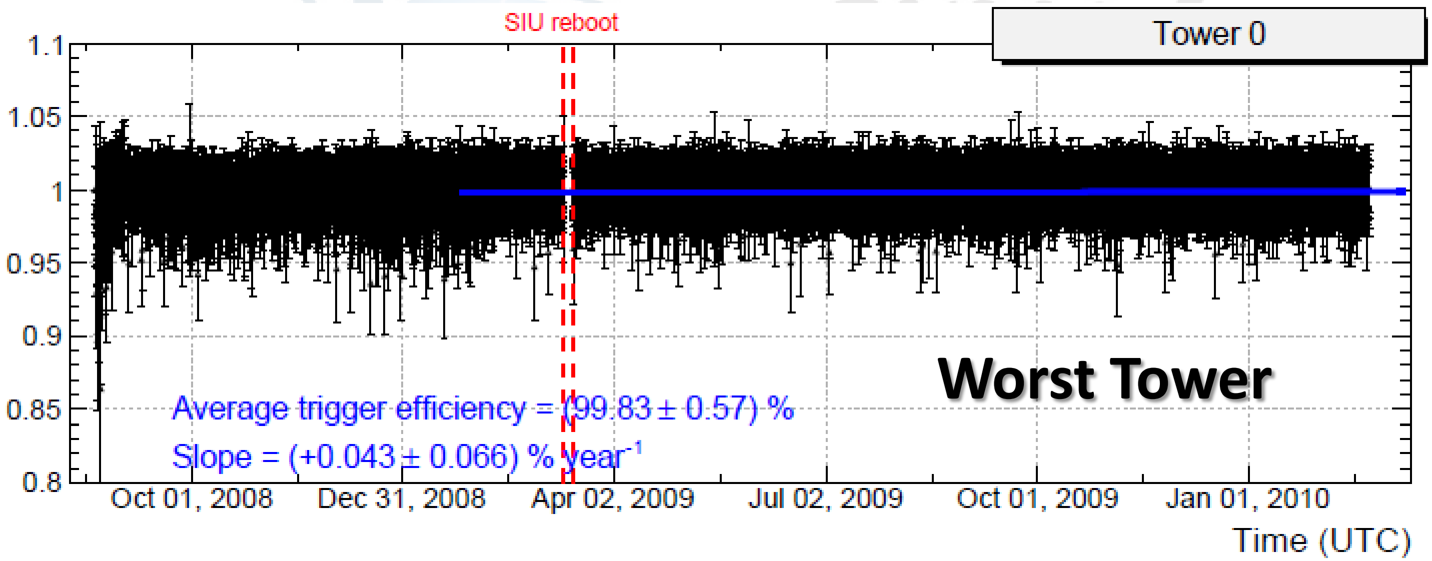
Overview of GLAST- LAT



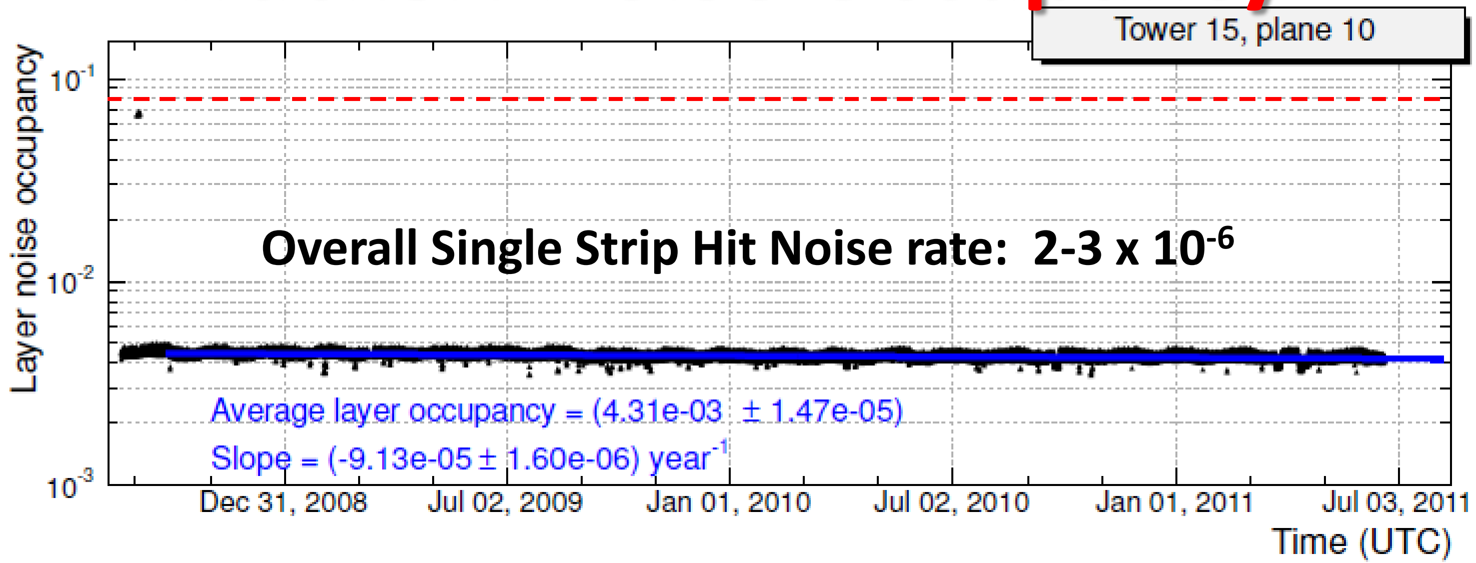
- Tracker: 18 X-Y tracking planes with interleaved W conversion foils.
  - 1.5 X_0 on-axis
  - 9,216 sensors
  - 73 m^2 of silicon active area 884,736 readout channels
  - High-precision tracking, short instrumental dead time
- Calorimeter: 1536 CsI(Tl) crystals in 8 layers
  - 8.6 X_0 on-axis
  - PIN photodiode readouts
  - Hodoscopic crystal arrangement: 3D Shower Imaging
- Anticoincidence Detector (ACD): 89 plastic scintillator tiles
  - Segmentation to reduce "self-veto"
  - Waveshifting Fiber readout to PMTs
- Electronics System Includes flexible, robust hardware trigger and software filters.

Tracker: Single-hit Efficiency ~ 100%





Tracker: Noise Occupancy



Calorimeter & ACD