



Fermi Large Area Telescope highlights after 5 years of operations

L. Latronico

(luca.latronico@to.infn.it)

INFN-Torino

On behalf of the Fermi LAT Collaboration

RICAP, Roma – May 23 2013

The Fermi observatory



❑ Satellite gamma-ray telescope

- Large Area Telescope (LAT)
 - 20 MeV – > 300 GeV
- Gamma Burst Monitor (GBM)
 - 8 KeV – 40 MeV

❑ Key features

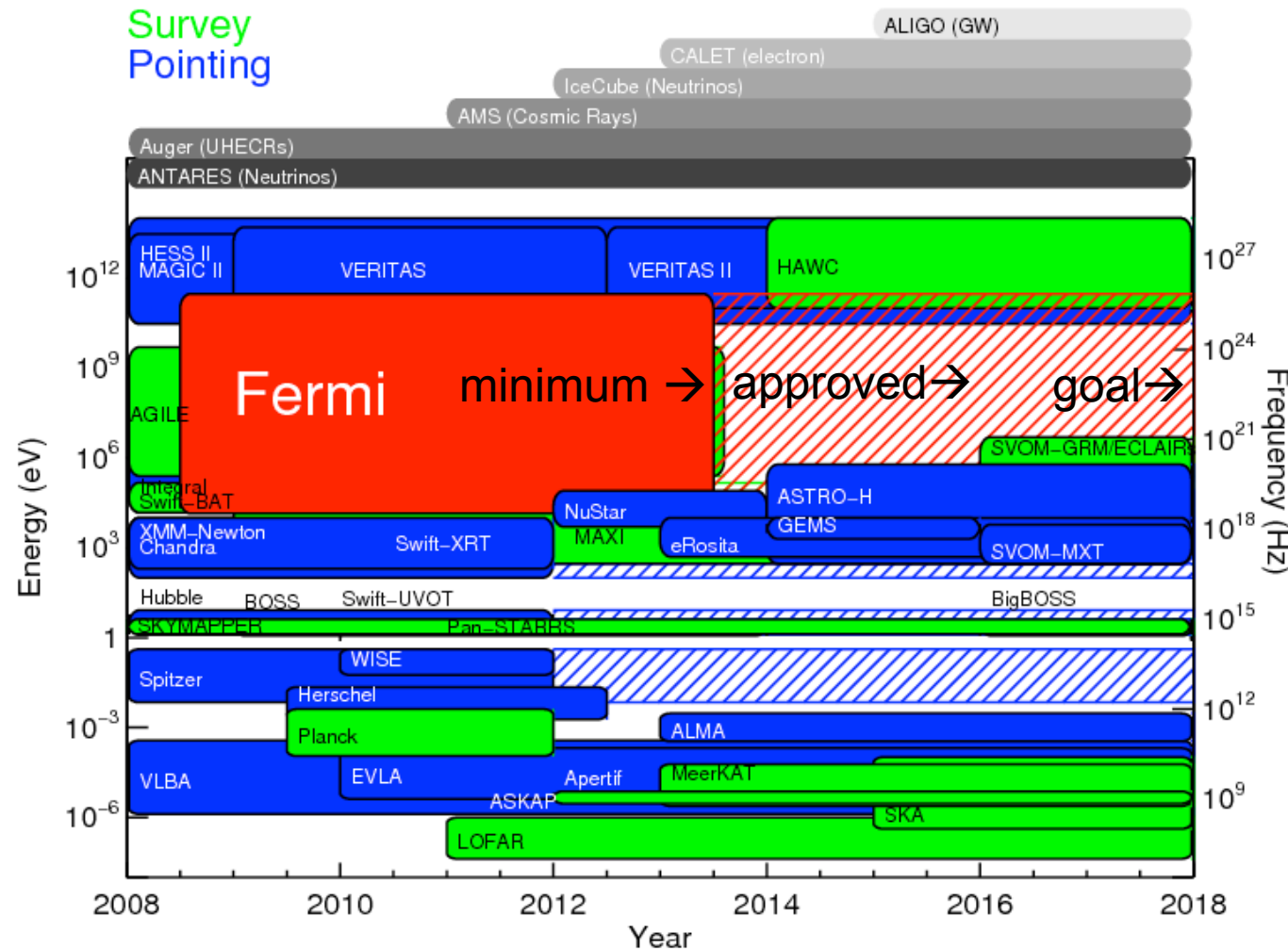
- Huge field of view (2.4sr)
 - 20% sky any instant
 - All sky for 30' every 3h
- Huge energy range
 - Including unexplored 10-100 GeV range



- ❑ Launch from Cape Canaveral, June 11, 2008
- ❑ Observing strategy
 - > 95% time in sky survey
 - ARR and ToO
- ❑ Excellent detector stability
 - > 262B triggers
 - > 50B events to ground
 - ~2000 transients
 - ~hours/year for calibrations

Fermi mission status

<http://science.nasa.gov/astrophysics/2012-senior-review/>



- ❑ NASA 2012 Senior Review recommended extended operations
- ❑ NASA HQ will extend the mission to at least 2016

Fermi as a public observatory

<http://fermi.gsfc.nasa.gov/ssc/>





National Aeronautics and Space Administration
Goddard Space Flight Center

Search:

FSSC • HEASARC • Sciences and Exploration

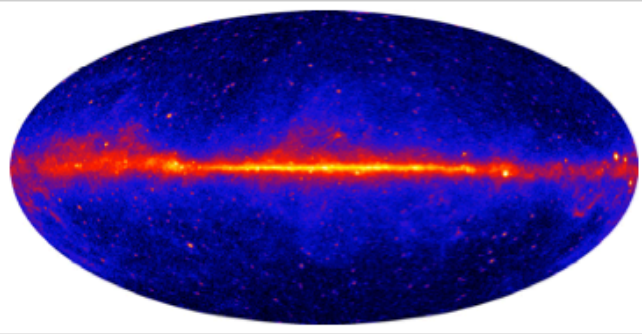
Fermi

Science Support Center

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The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This all-sky view from Fermi reveals bright emission in the plane of the Milky Way (center), bright pulsars and super-massive black holes.
Credit: NASA/DOE/International LAT Team

Latest News

» [Fermi Sky Blog](#)
» [Fermi Blog](#)

Jan 07, 2013

Galaxy's Gamma-Ray Flares Erupted Far From its Black Hole

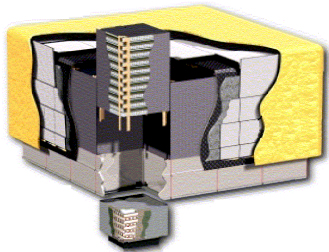
In 2011, a months-long blast of energy launched by an enormous black hole almost 11 billion years ago swept past Earth. Using a combination of data from NASA's Fermi Gamma-ray Space Telescope and the National Science Foundation's Very Long Baseline Array (VLBA), the world's largest radio telescope, astronomers have zeroed in on the source of this ancient outburst.
[+ Learn More](#)

Jan 2, 2013

- ❑ ~ 800M γ public since 8/2009 within ~hours from trigger
- ❑ Full Science Tools data analysis suite
- ❑ > 800 papers, > 10k citations collectively

Overview of the Large Area Telescope

Atwood, W. B. et al. 2009, ApJ, 697, 1071

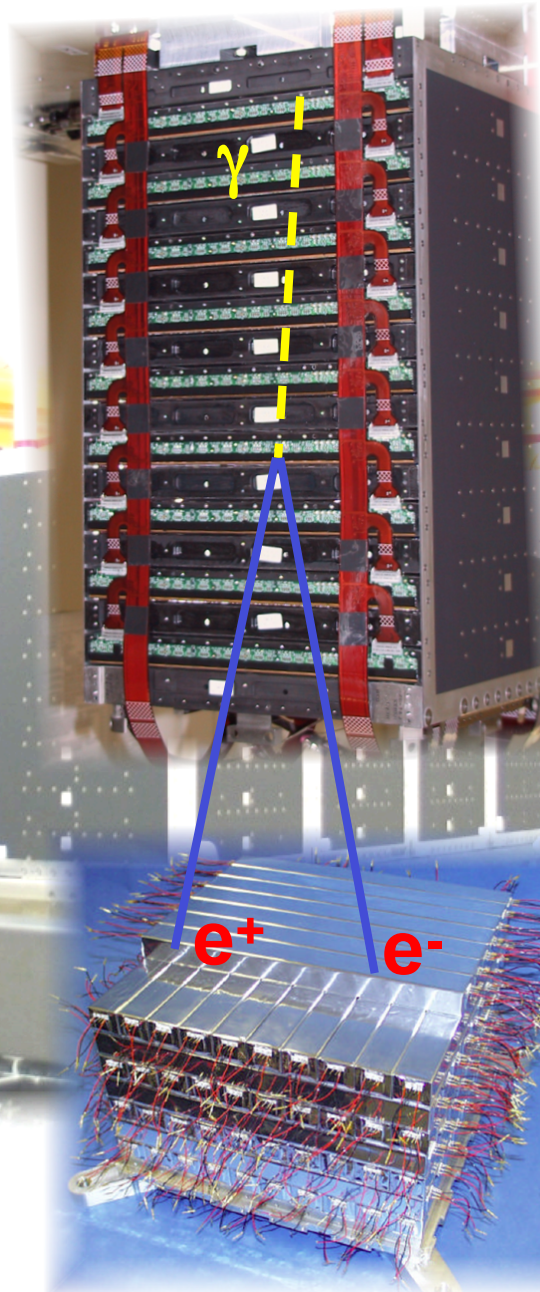


LAT:

- modular - 4x4 array
- 3ton – 650watts

Anti-Coincidence (ACD):

- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**



Tracker/Converter (TKR):

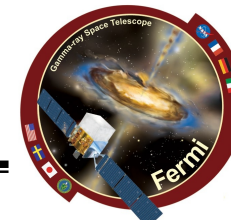
- Si-strip detectors
- ~80 m² of silicon (total)
- W conversion foils
- **1.5 X0 on-axis**
- 18XY planes
- ~10⁶ digital elx chans
- Highly granular
- High precision tracking
- Average plane PHA

Calorimeter (CAL):

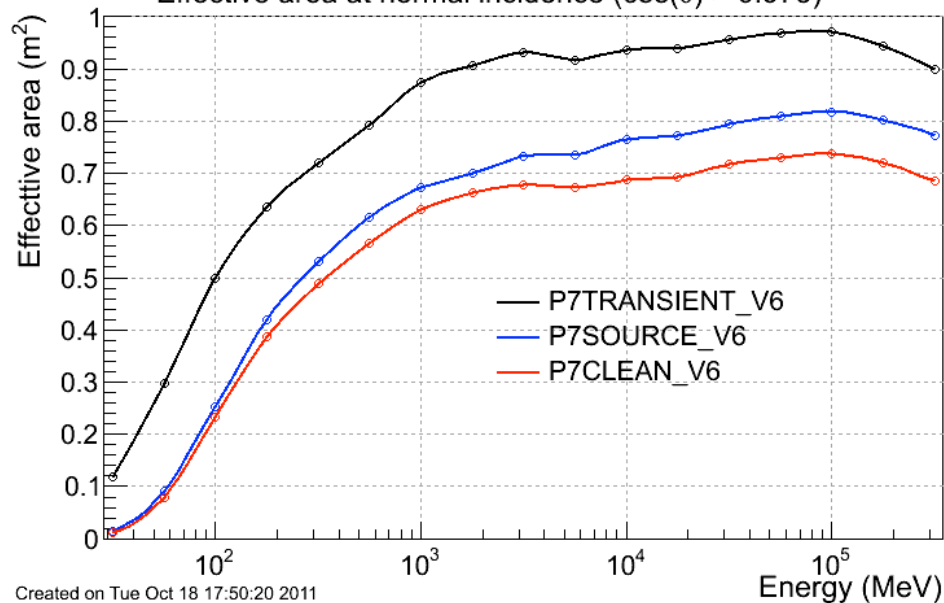
- 1536 CsI(Tl) crystals
- **8.6 X0 on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction
- EM vs HAD separation

LAT performance

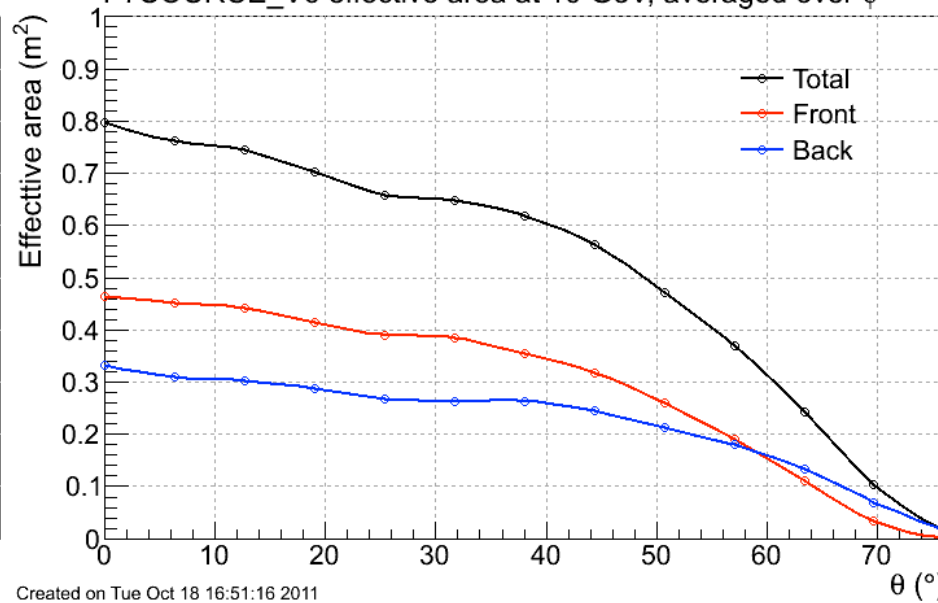
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm



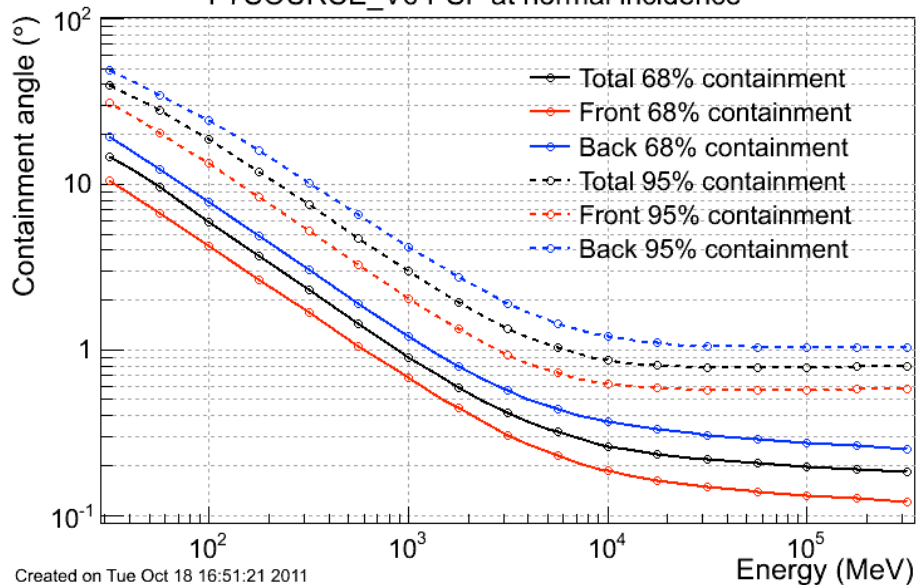
Effective area at normal incidence ($\cos(\theta) > 0.975$)



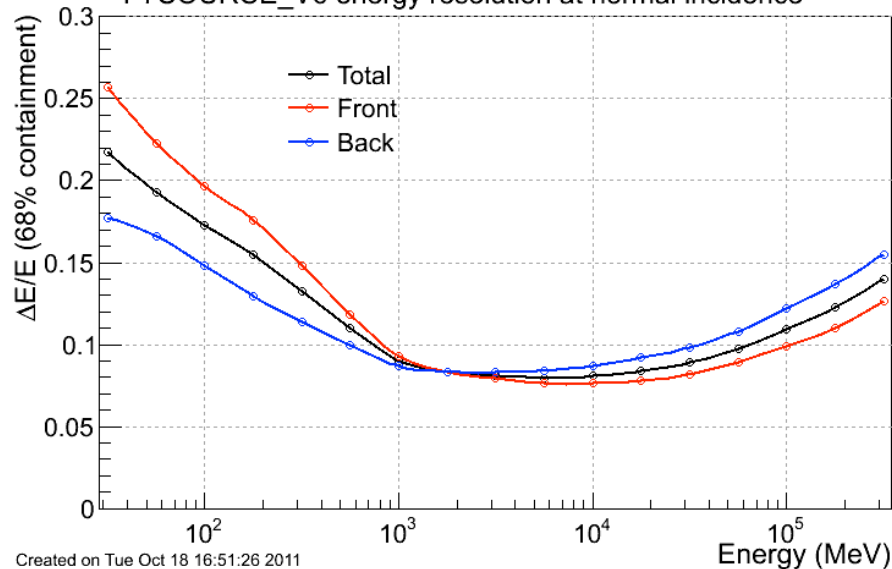
P7SOURCE_V6 effective area at 10 GeV, averaged over ϕ



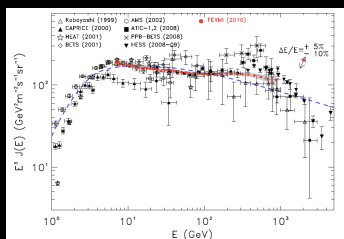
P7SOURCE_V6 PSF at normal incidence



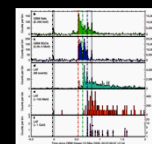
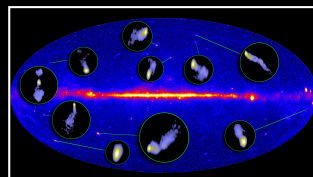
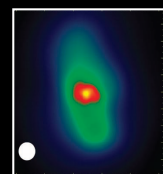
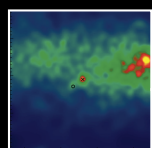
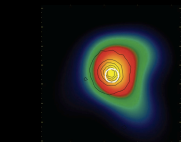
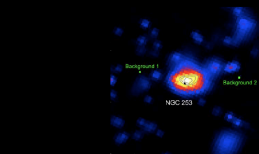
P7SOURCE_V6 energy resolution at normal incidence



Increasing Classes of Fermi-LAT Sources



e^+e^- spectrum



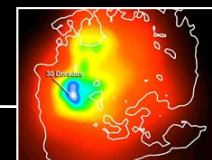
GRBs

Blazars (782)

Radio Galaxies (12)

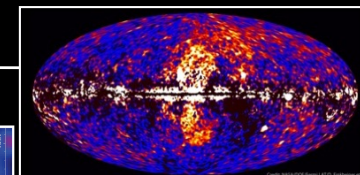
Starburst Galaxies (4)

LMC & SMC



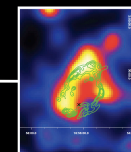
Globular Clusters (11)

Fermi Bubbles

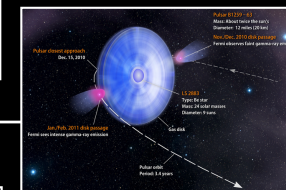


Nova (1)

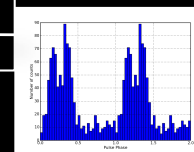
SNR & PWN (68)



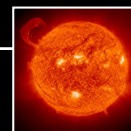
γ -ray binaries (6)



Pulsars: young & millisecond (MSP) (117+)



Sun: flares & CR interactions



Terrestrial Gamma-ray Flashes



Ackermann+ (LAT)
[arXiv:1108.1202]

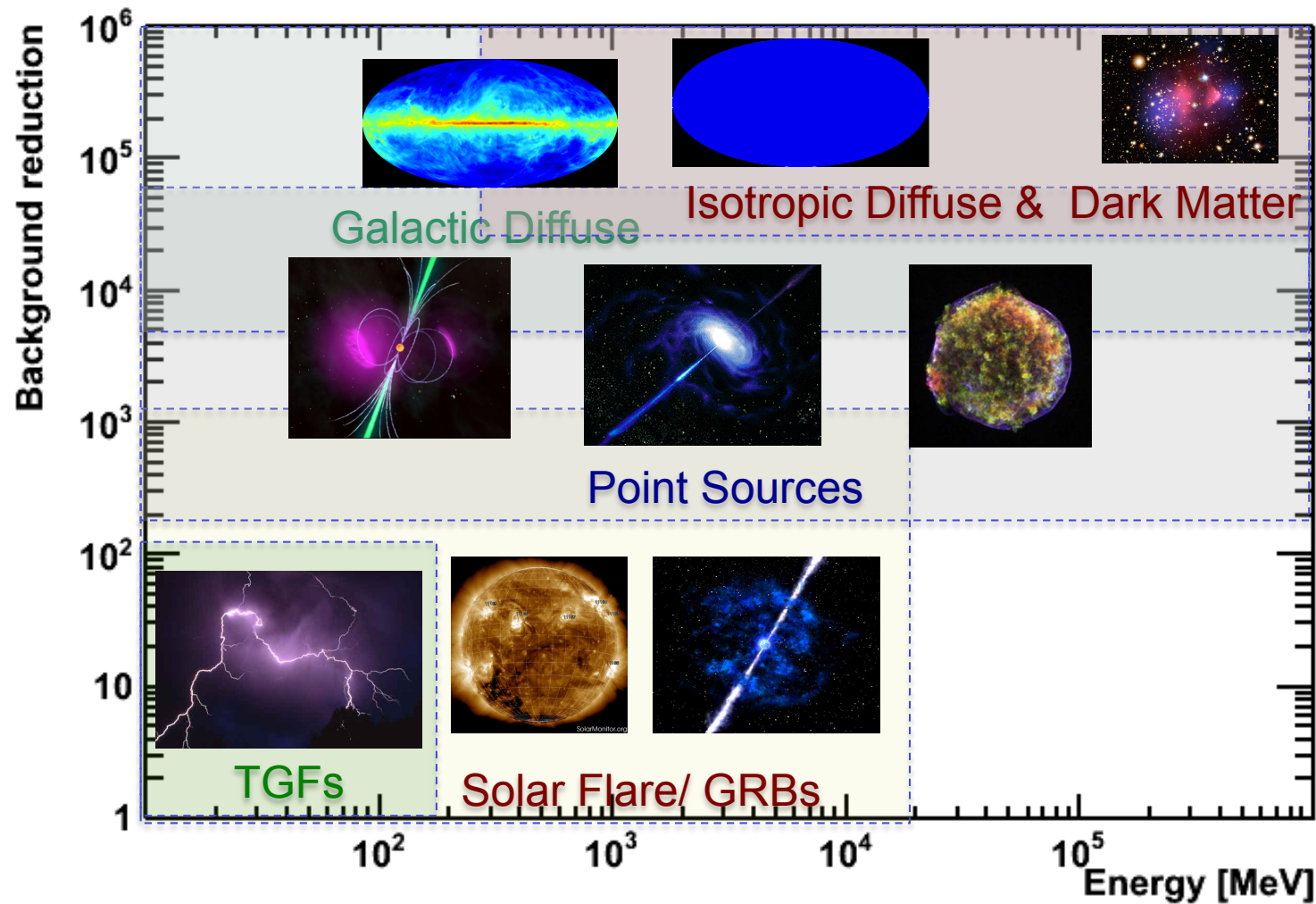
Unidentified Sources (~600)

Extragalactic

Galactic

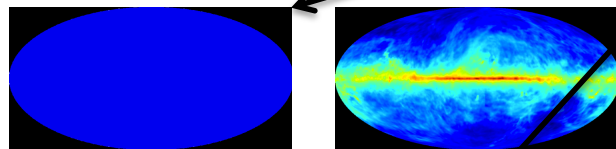
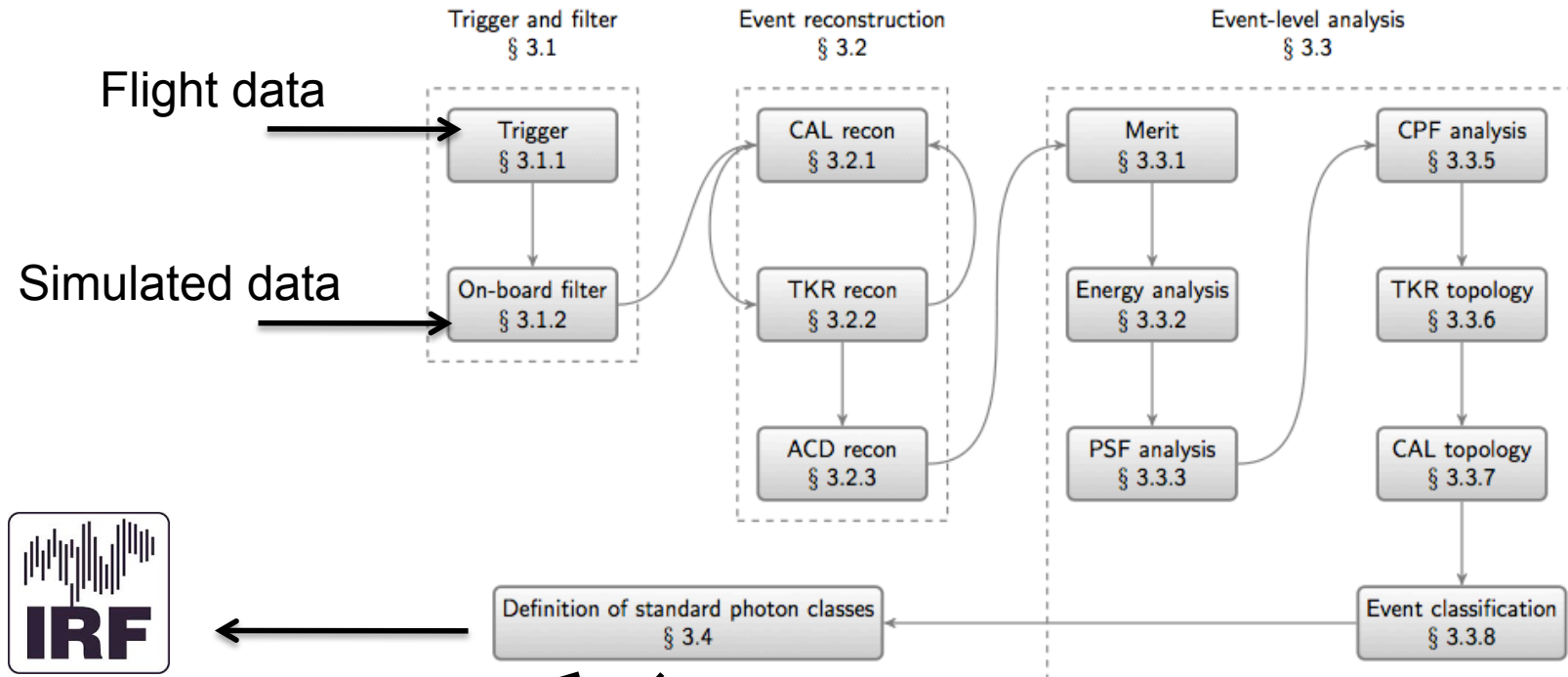
Local

Variety of analysis strategies and needs

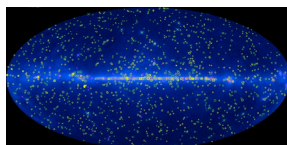


Analyses in time, energy, space domains

Fermi-LAT Analysis overview



Gamma-ray Sky templates



Source Catalogs



Science Tools



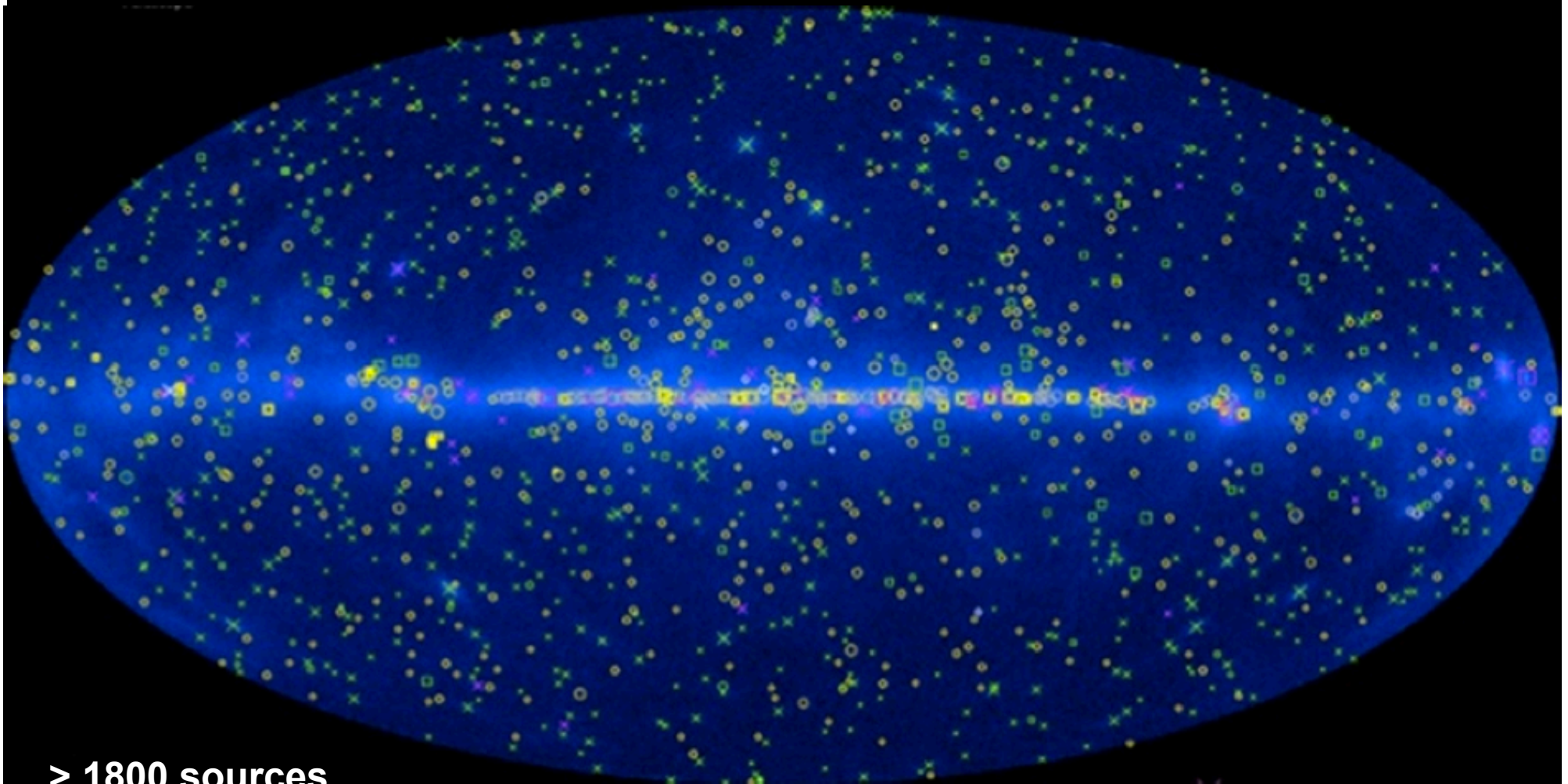
Papers



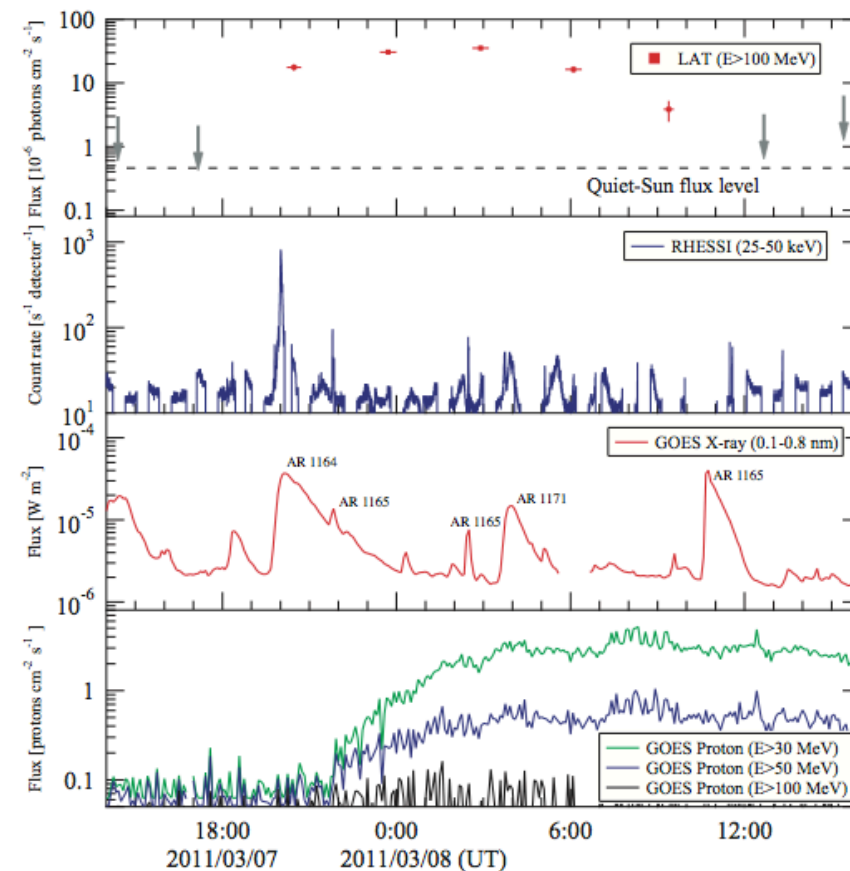
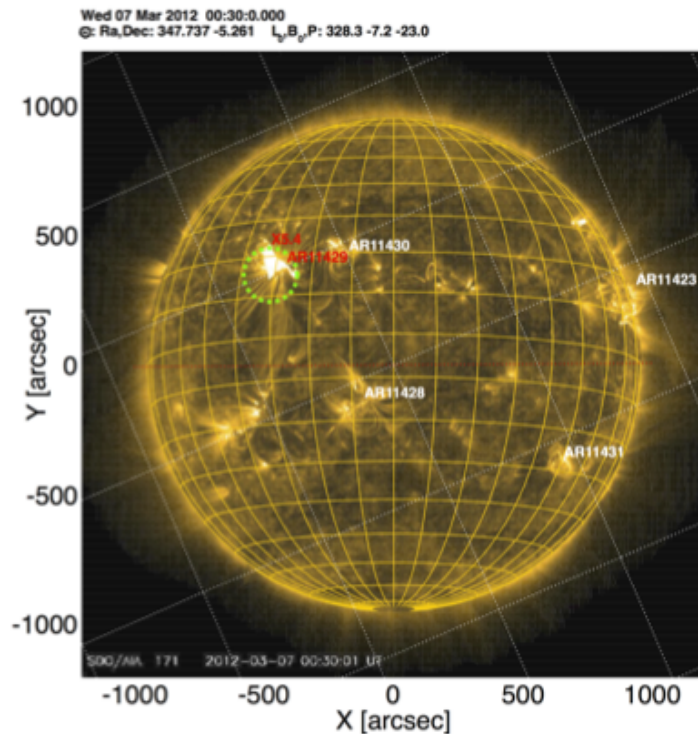
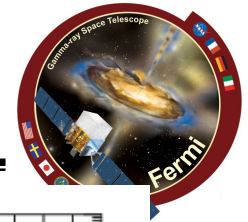
Public products

Fermi 2FGL catalog

Nolan et al.: 2012ApJS..199...31N



- > 1800 sources
- > 10 source classes
- known classes (AGN, Pulsars, PWN, SNR...)
- New emitters (Novae, ms PSR, starbursts,
- ~30% unidentified

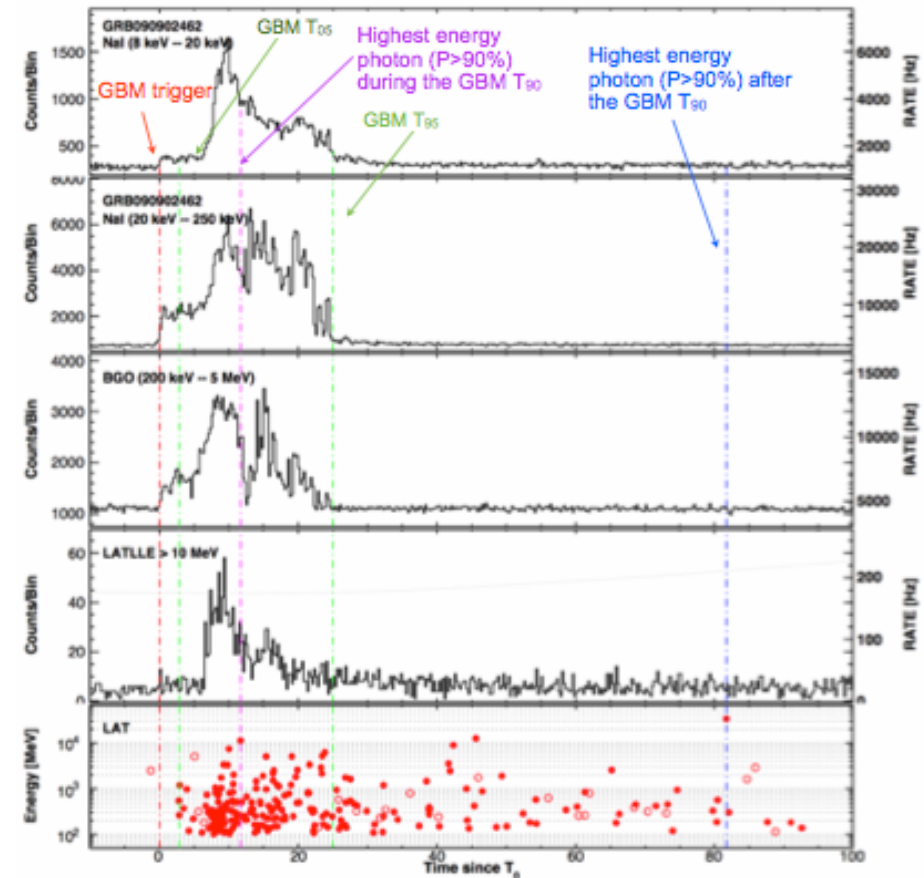


□ Full list of LAT solar flares

- 16 in total
- analysis of bright long flares
 - γ -rays localized on x-ray emission region for 1st time



- ❑ Individual bursts plus LAT GRB catalog
- ❑ Common properties in the sample
 - Delayed HE emission
 - Longer HE duration
 - Evidence for multi-component spectra
- ❑ Emission mechanism
 - And connection to Cosmic Rays
- ❑ Fundamental physics
 - Lorentz Invariance Violation
 - Limits on Extra Galactic Background Light from single high energy photons



Abdo, A. A. et al. 2009, Nature, 462, 331

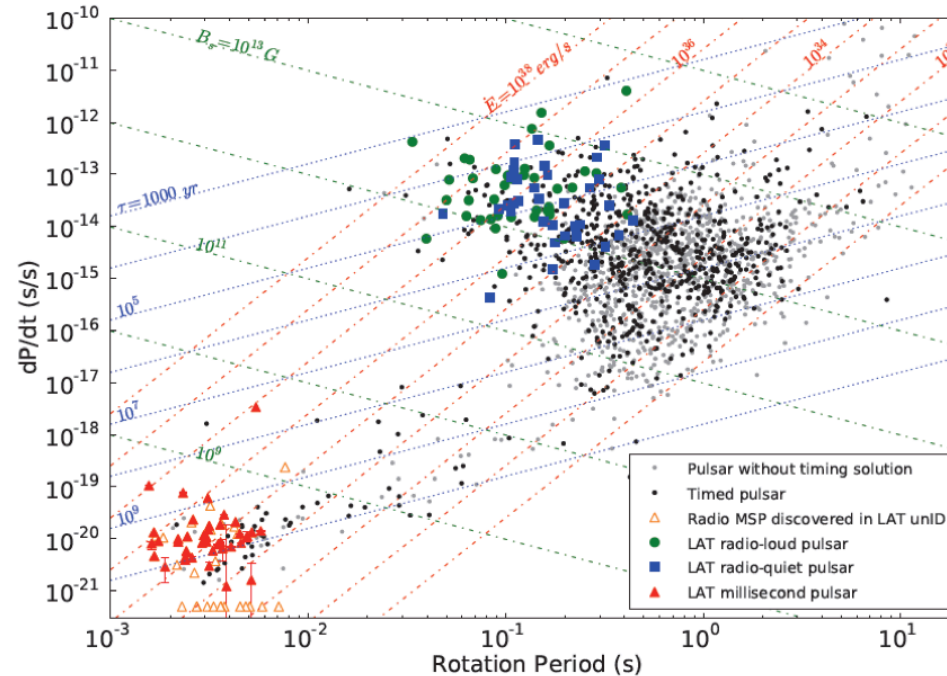
Abdo, A. A. et al. 2009, Science, 323, 1688

The First LAT GRB Catalog, arxiv 1303.2908,
Submitted to ApJS

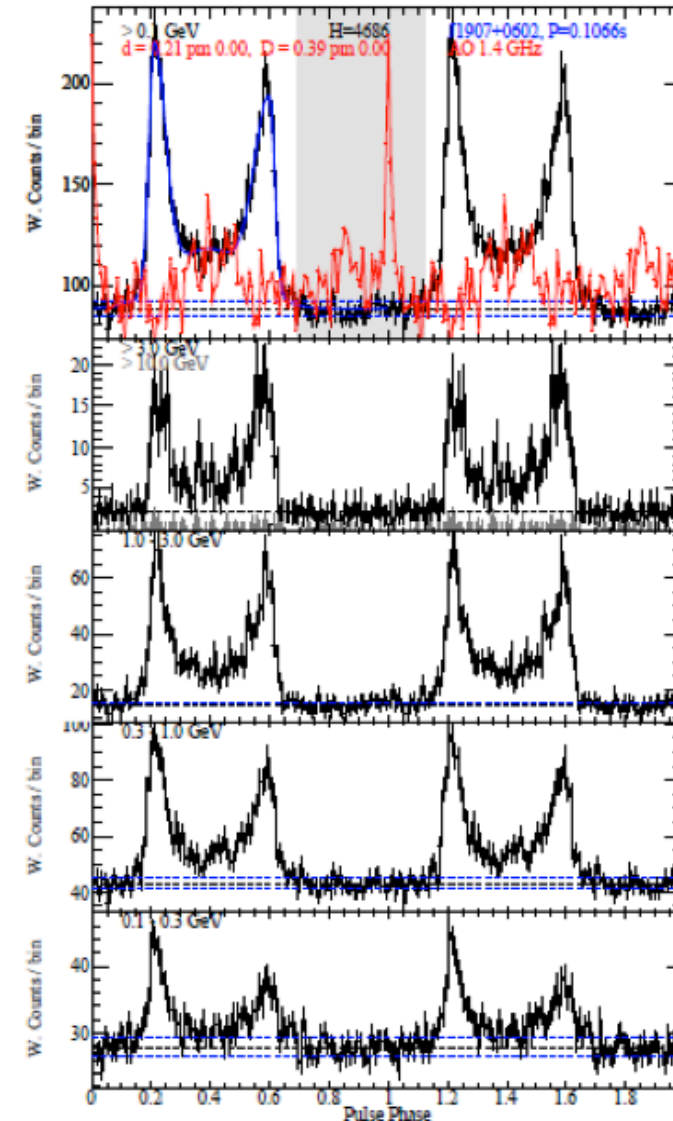
See talks by F. Longo, J. Bolmont¹³

The 2nd Fermi-LAT Catalog of γ -ray pulsars

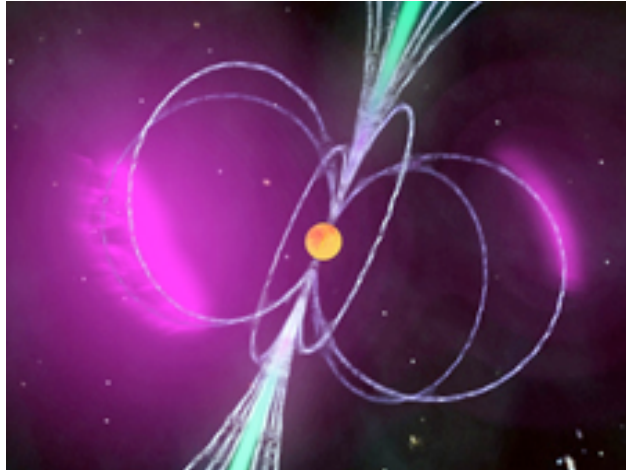
arxiv 1305.4385, submitted to ApJS



- ❑ 117 pulsars (and counting)
- ❑ Complementary searches
 - Blind searches, also on gravitational waves clusters
 - Constant synergy with radio (ephemeris, ms PSR in LAT UNIDs)

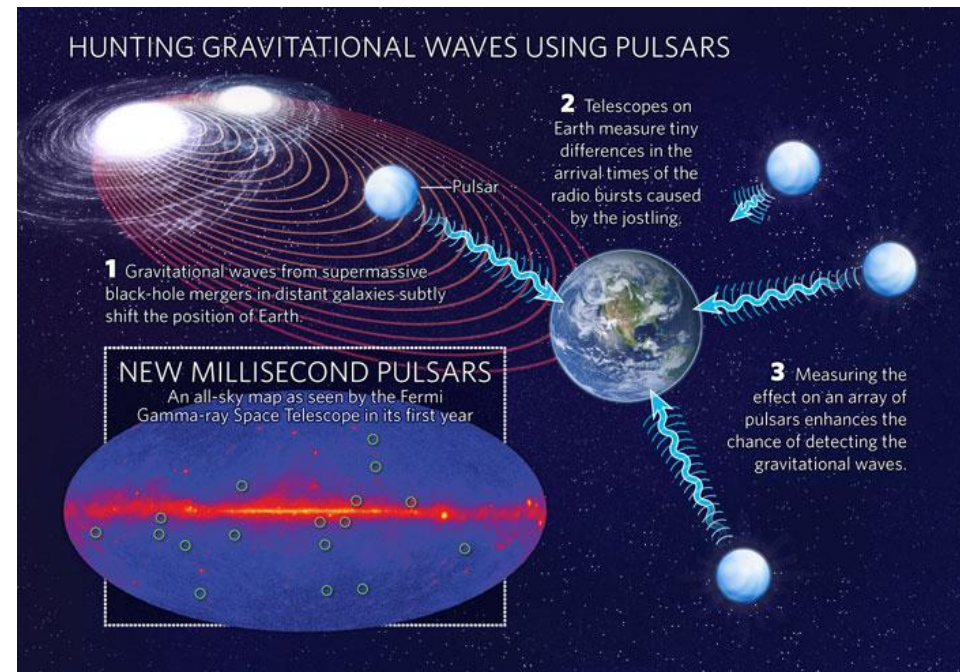


A new picture for pulsars

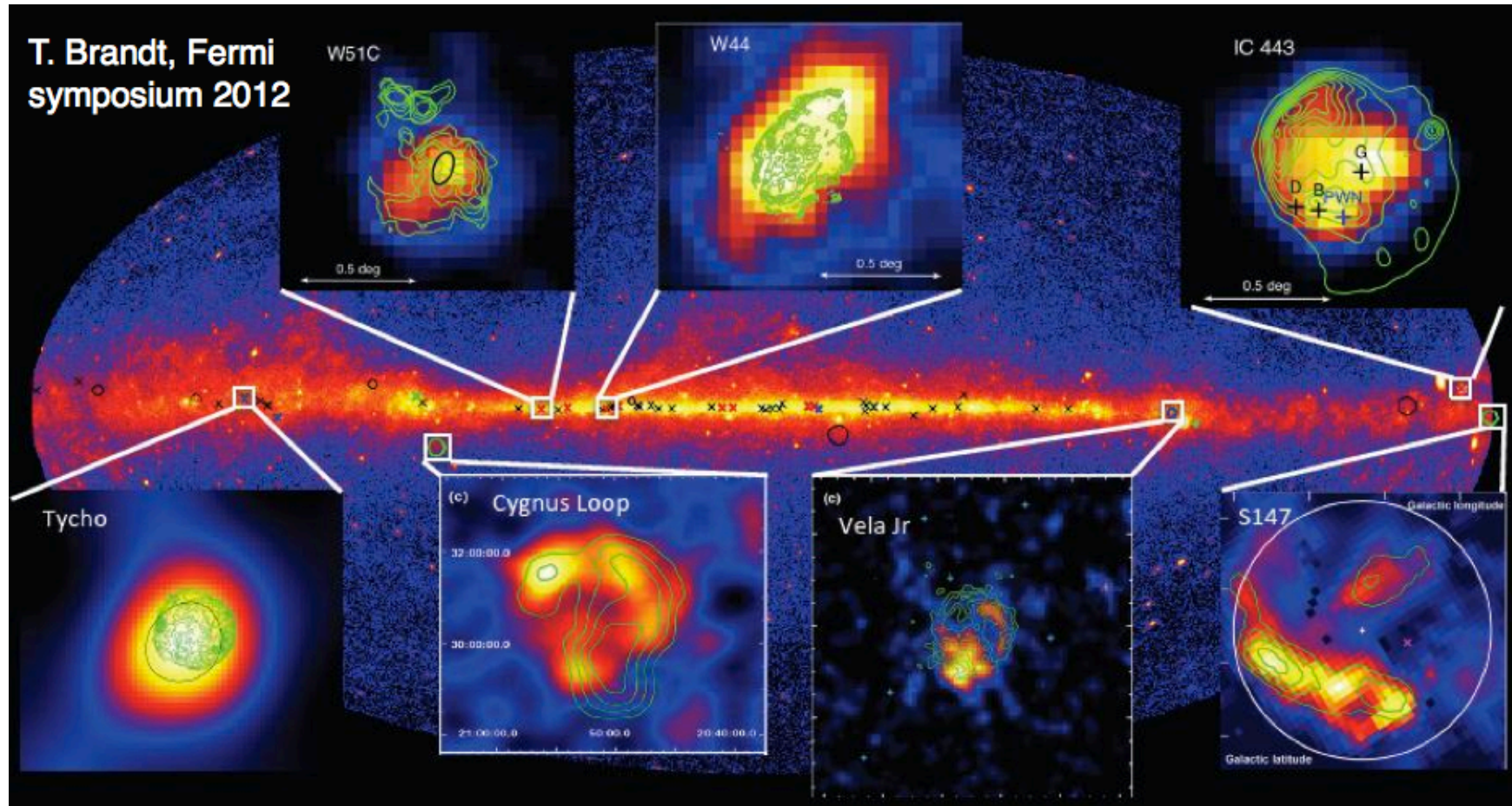


- ☐ Emission mechanism away from star
- ☐ Many γ -ray only PSR
- ☐ ms PSR in γ -ray
 - Pulsar timing array
- ☐ ms PSR in globular clusters

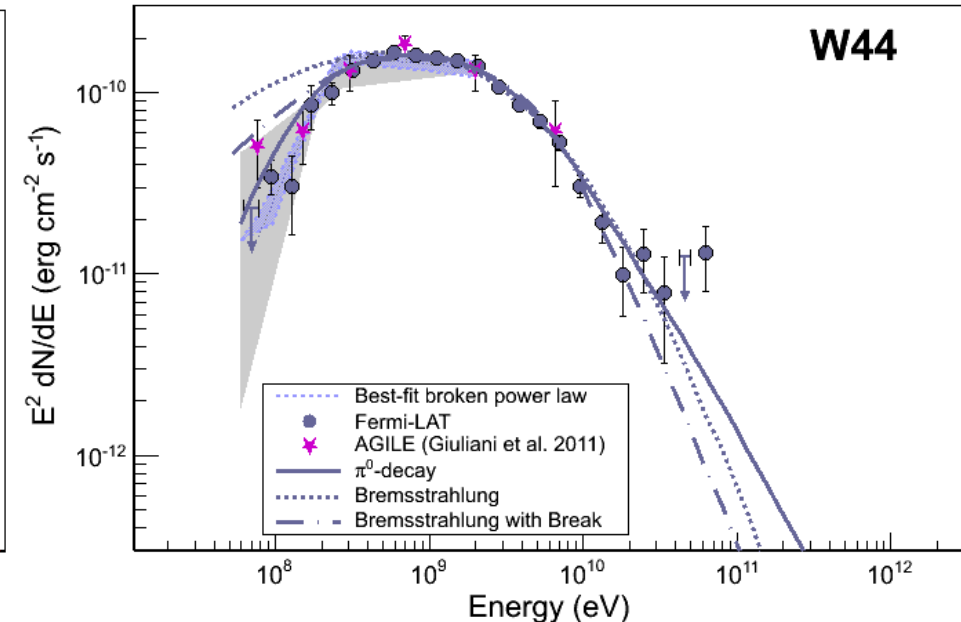
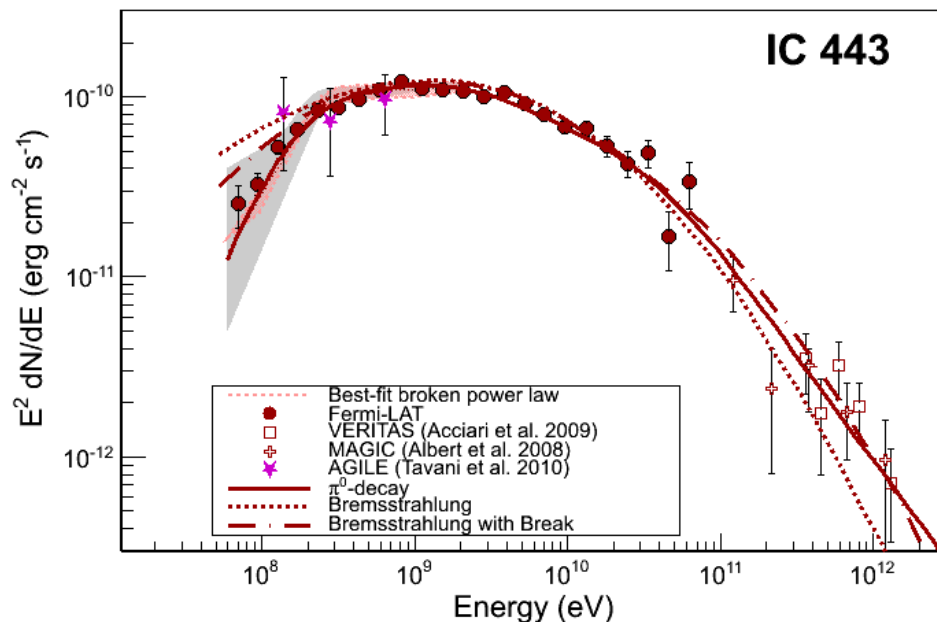
Pletsch, H. J. et al. 2012, ApJ, 744, 105
 Saz Parkinson, P. M. et al. 2010, ApJ, 725, 571
 Abdo, A. A. et al. 2010, ApJS, 187, 460
 Abdo, A. A. et al. 2009, Science, 325, 840
 Abdo, A. A. et al. 2009, Science, 325, 845
 Abdo, A. A. et al. 2009, Science, 325, 848
 Abdo, A. A. et al. 2008, Science, 322, 1218
 plus many other
 2013 AAS/HEAD Rossi Prize



SuperNova Remnants – towards a catalog



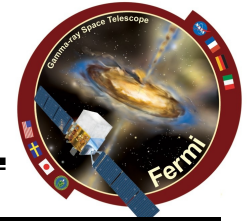
- ❑ 25 published SNRs + 30 candidates in 2FGL
- ❑ Requires combination of spatial and energy information
- ❑ Diffuse emission modeling is a key systematic uncertainty



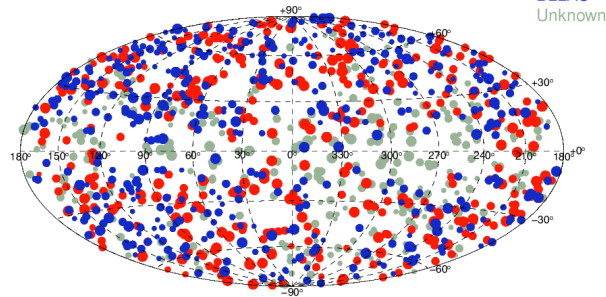
- ❑ Unambiguous and robust detection of pion decay bump in W44 and IC443 (thanks to increased low energy Pass7 acceptance)
- ❑ Proof that SNR accelerate protons

Detection of the pion-decay cutoff in Supernova remnants
2013, Science, 339, 807

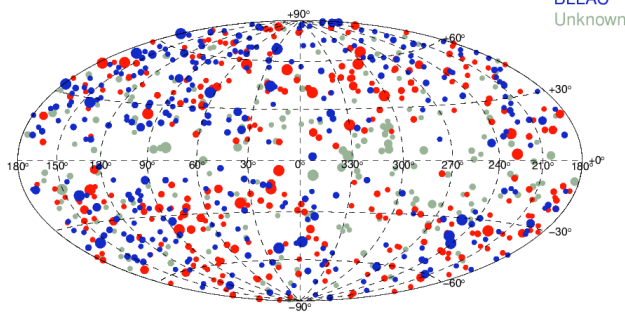
Active Galactic Nuclei



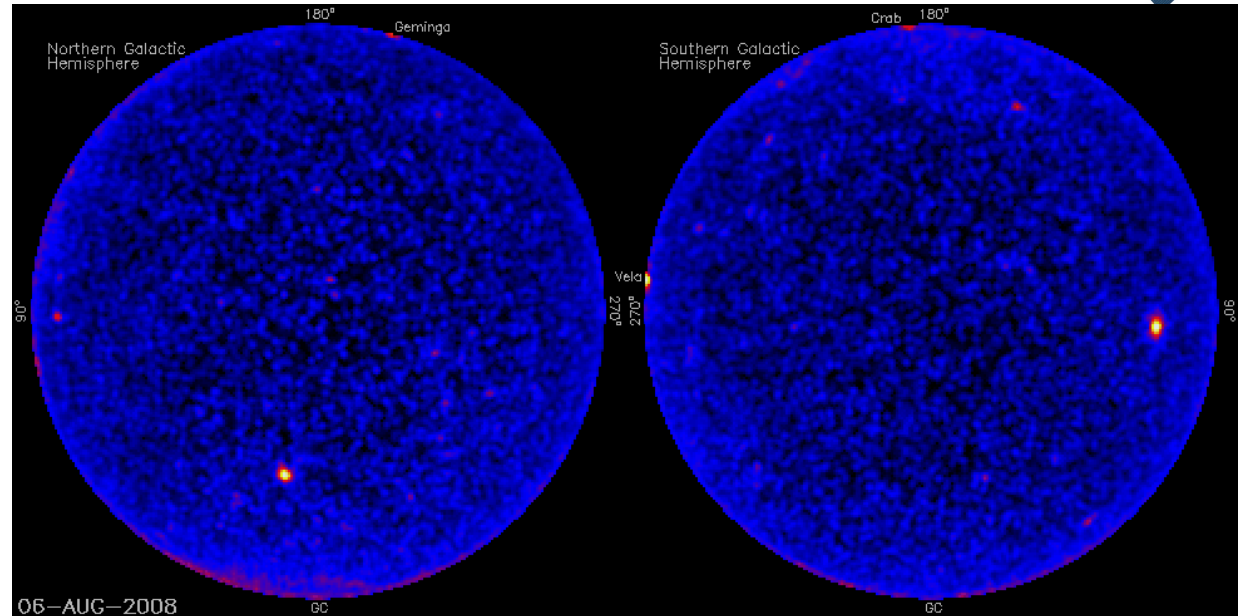
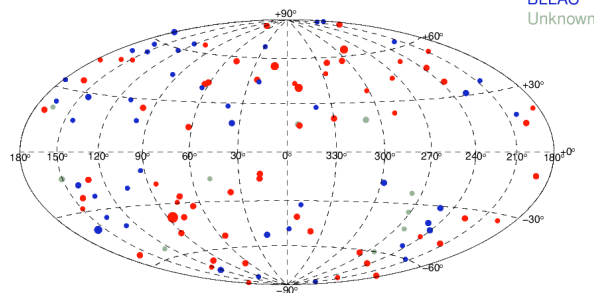
Second LAT Catalogue (2LAC)
TS>25, August 2008 – August 2010



First LAT AGN Catalogue (1LAC)
TS>25, August 2008 – July 2009



LAT Bright AGN Source List (LBAS)
TS>100, August 2008 – October 2008



- ❑ Most numerous Fermi sources (~60%)
- ❑ Highly variable
 - Require multi-wavelength campaigns for modeling
- ❑ Simple Self-Synchrotron Compton not adequate to explain variety of AGNs

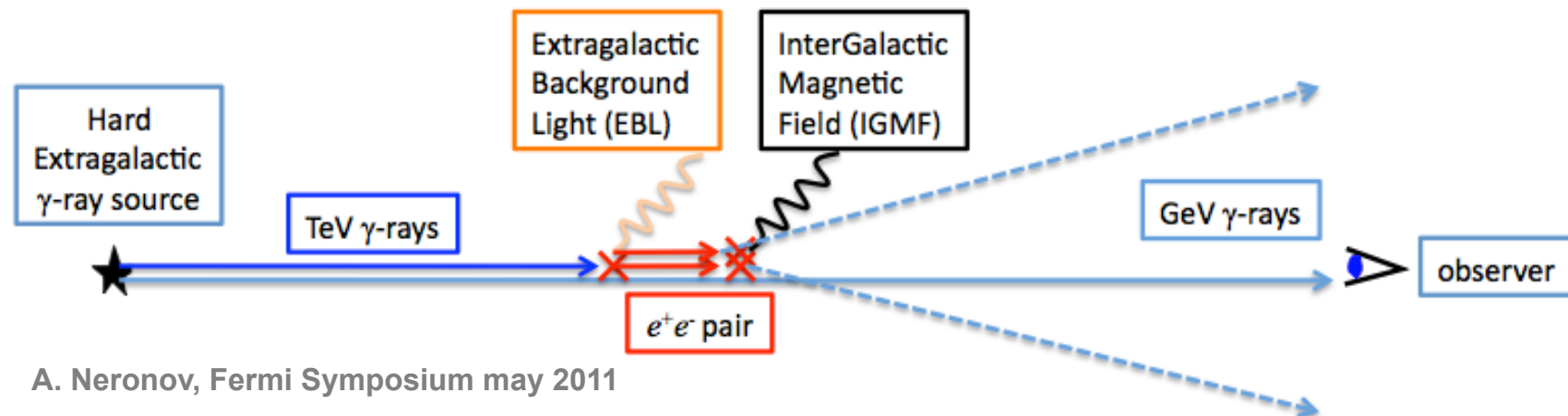
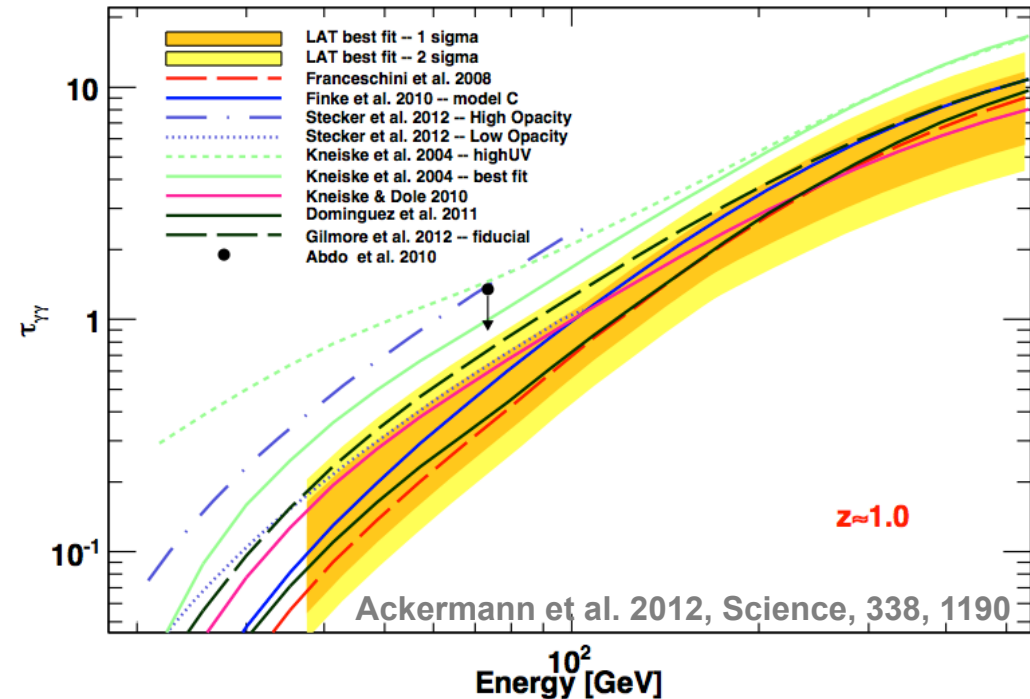
□ Opacity of the Universe

– **Constraining EBL models**

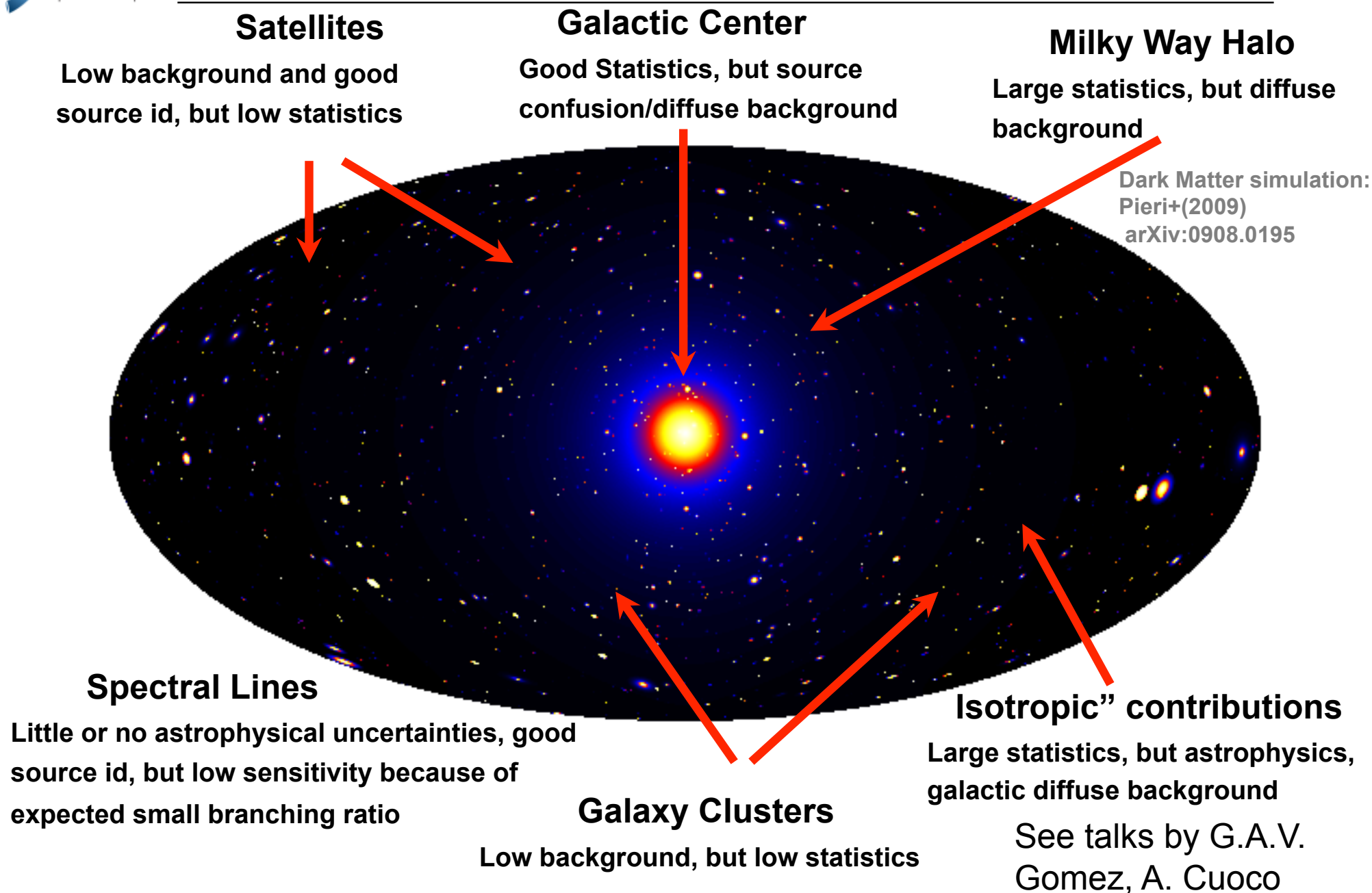
□ Axion searches

□ Pair halo and limits to inter-galactic magnetic fields

– **Currently lower bounds (no halo!) at $10^{-16} - 10^{-17}$ G**



Dark Matter Search Strategies



Search Strategies (against the g-ray Sky)

Satellites

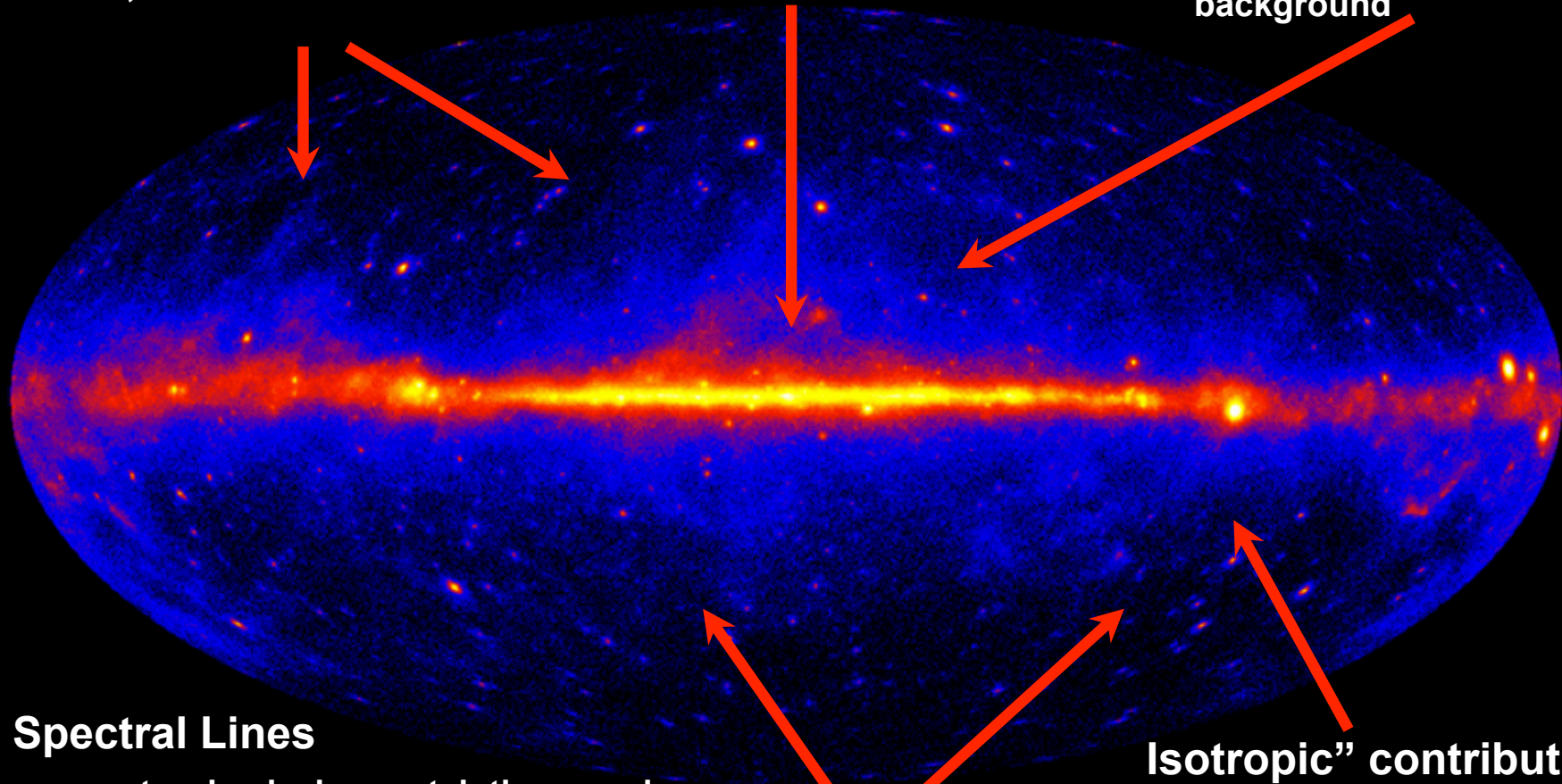
Low background and good source id, but low statistics

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

Galaxy Clusters

Low background, but low statistics

Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

3 Years Sky > 1 GeV

Limits on $\langle\sigma v\rangle$ at 10GeV (cm^3s^{-1})

Satellites

dSph $\sim 2 \times 10^{-26}$

UNID $\sim 2 \times 10^{-24}$

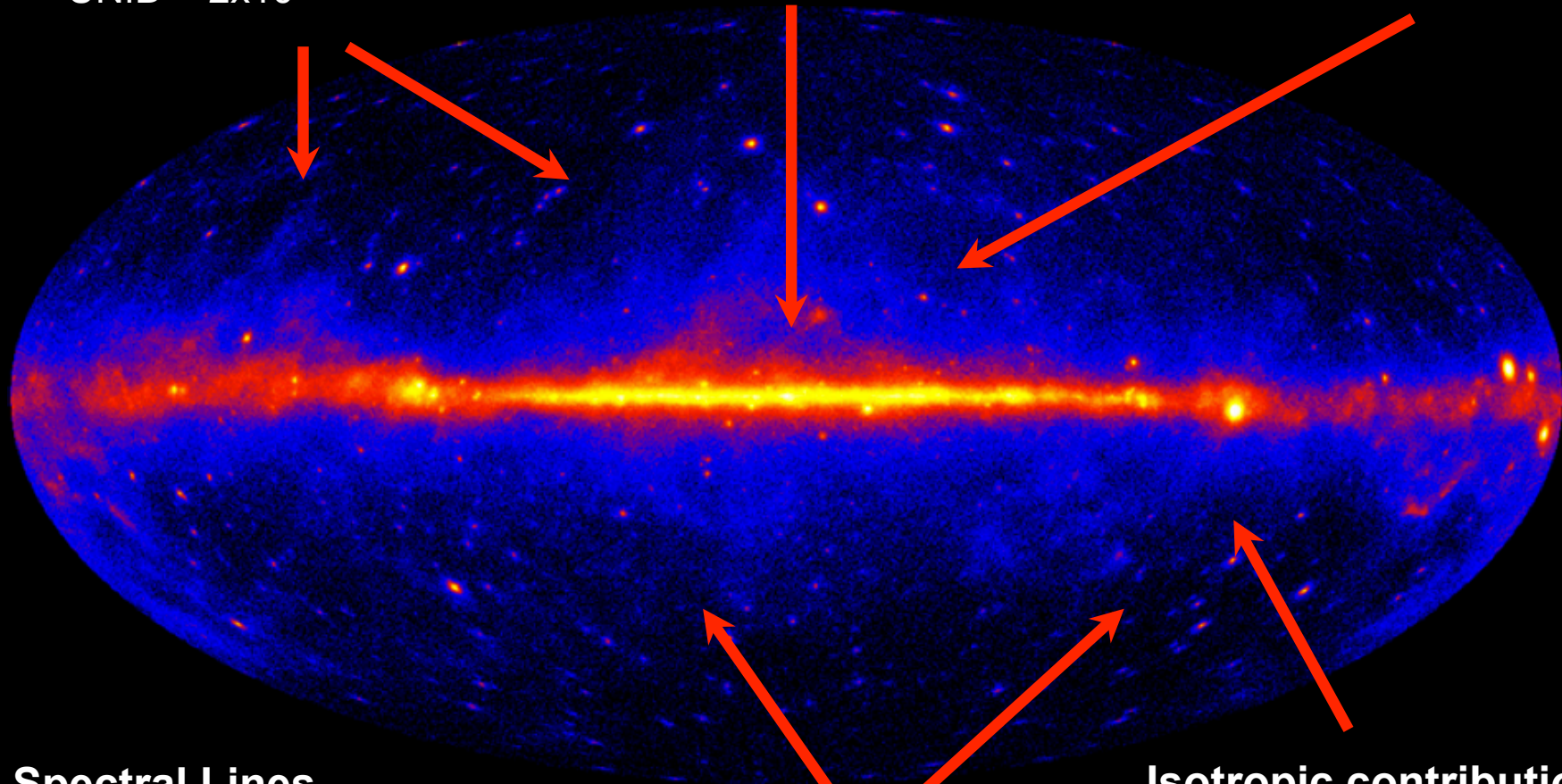
Galactic Center

Vary w/ model & method

Milky Way Halo

W/ bkg. model: 2×10^{-26}

No bkg. model: 2×10^{-25}



Spectral Lines

100 GeV $\sim 8 \times 10^{-27}$

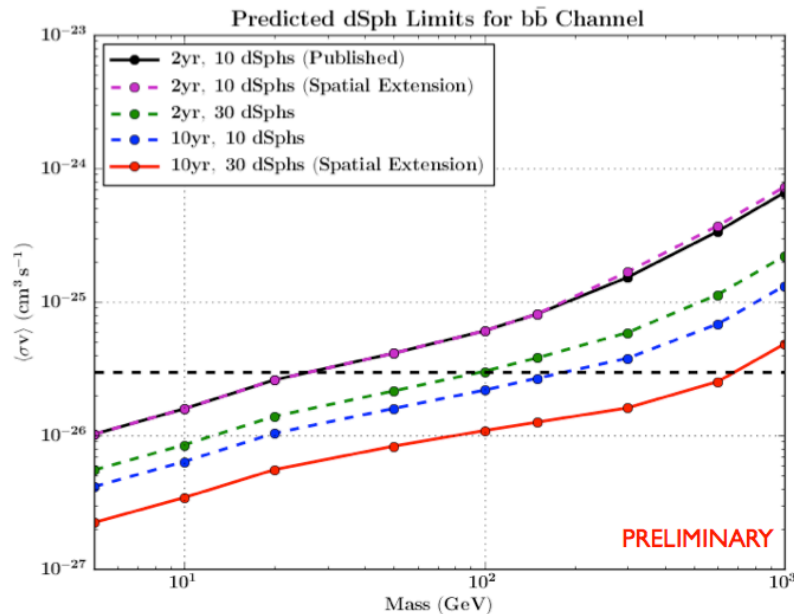
Galaxy Clusters

$\sim 5 \times 10^{-25}$

Isotropic contributions

Vary w/ model & method

No sign of Dark Matter yet



□ Search in dwarf spheroidals

- Free from astro background
- Current limit close to thermal relic $\sigma < \sim 30 \text{ GeV}$
- Prospects to constrain WIMP paradigm within next years

Ackermann, M. et al. 2011, Phys. Rev. Lett., 107, 241302

□ Line search

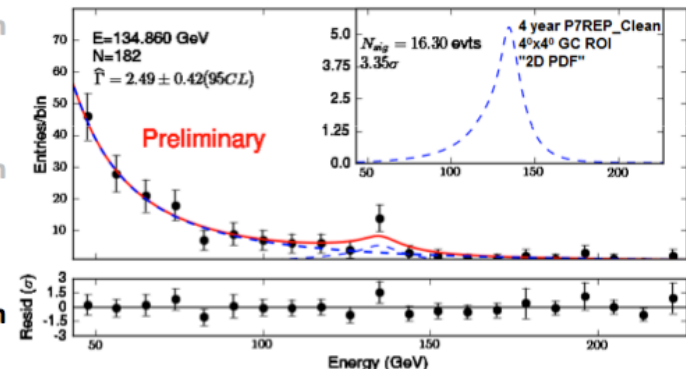
- No significant detection
- line-like feature in GC and control samples

A. Albert, Fermi Symposium 2012, in preparation

Ackermann, M. et al. 2012, Phys. Rev. D, 86, 022002

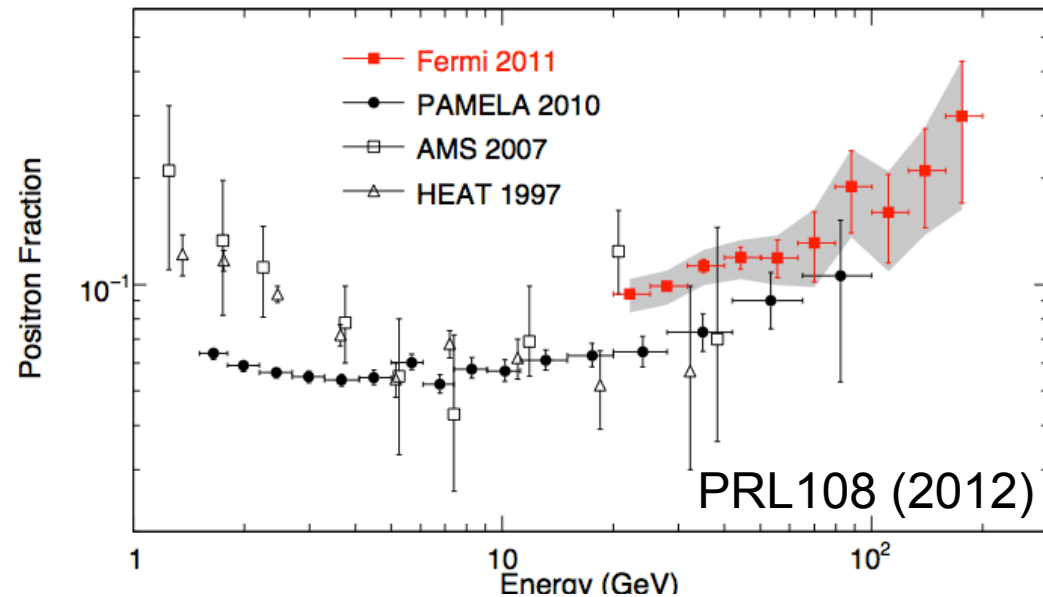
- Our blind search does not find globally significant feature near 135 GeV
 - Reprocessing shifts feature from 130 GeV to 135 GeV
 - Most significant fit was in R0, 2.23σ local ($<0.5\sigma$ global)
- Much interest after detection of line-like feature localized in the galactic center at 130 GeV
 - See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797

- 4.01σ (local) 1D fit at 130 GeV with 4 year unprocessed data
 - Look in $4^\circ \times 4^\circ$ 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 $4^\circ \times 4^\circ$ 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 $4^\circ \times 4^\circ$ GC ROI
 - Use 2D PDF



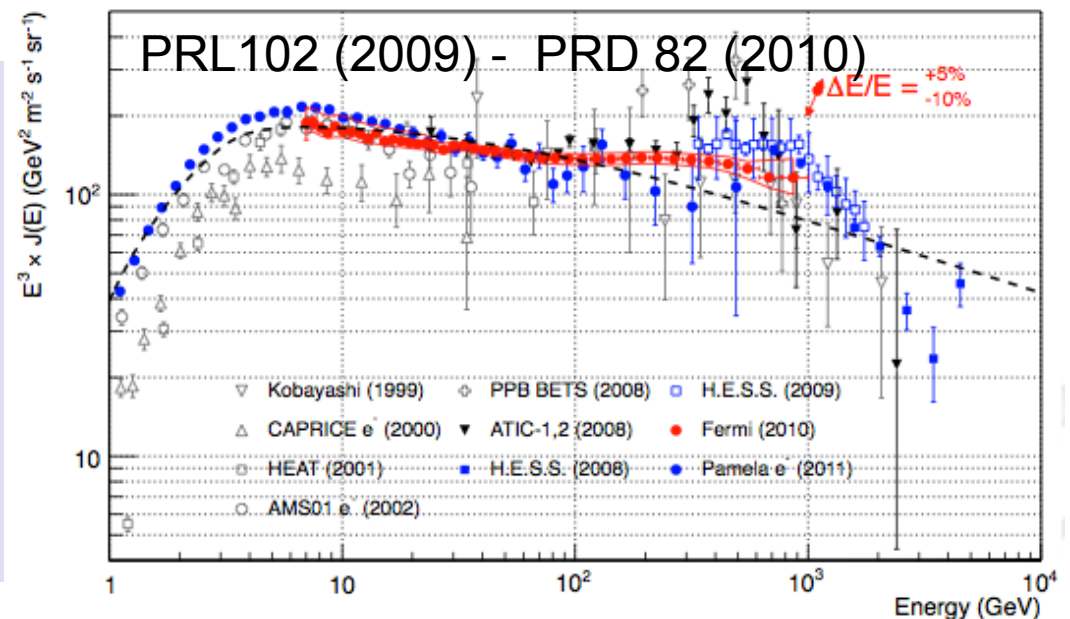
Note: Fit in $4^\circ \times 4^\circ$ GC ROI
Not one of our a priori ROIs

Cosmic Ray Highlights



Electrons in the LAT

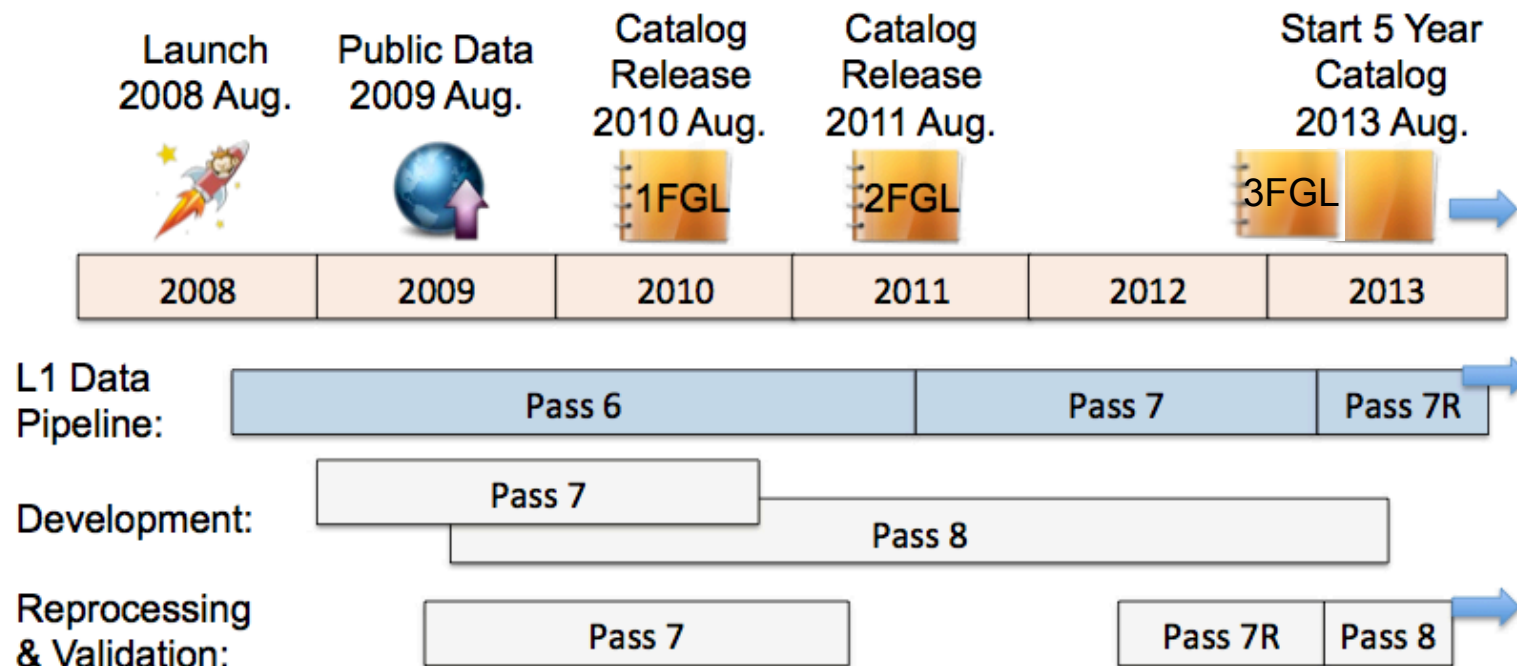
- ☐ On-board filter disengaged for > 20 GeV
- ☐ Standard γ reconstruction
- ☐ Optimized event selection (does require hit in ACD!)



Still improving the LAT Performance



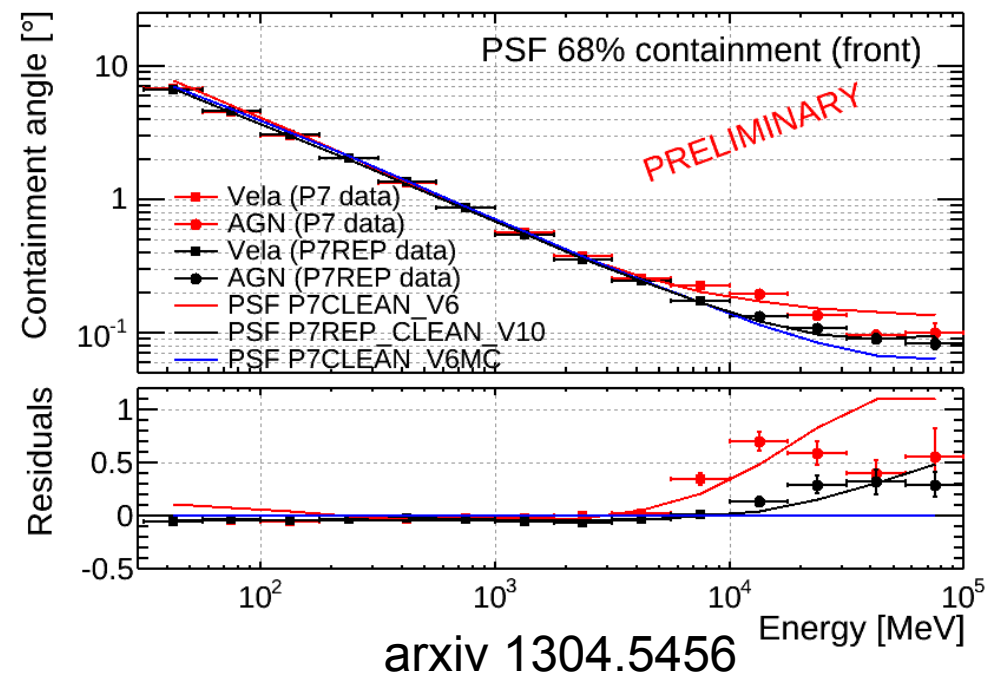
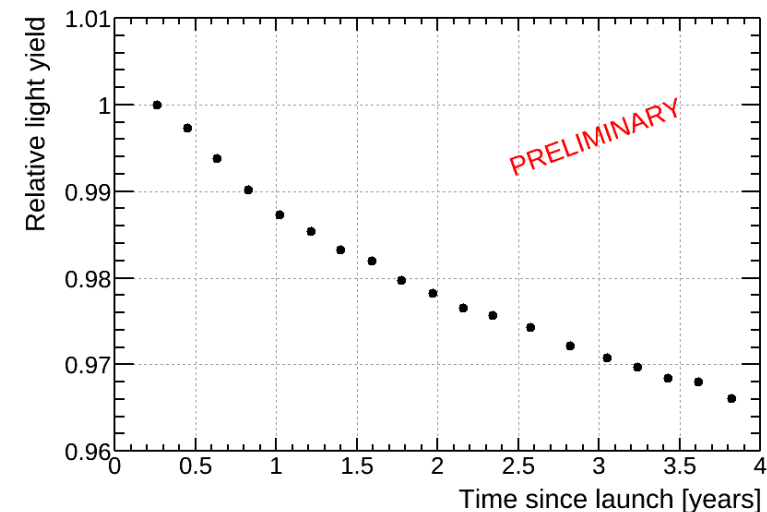
- ❑ Continuous effort to improve performance and release improved datasets
 - Pass6: pre-launch recon and event selection, optimized post-launch IRFs (to describe effect of ghosts)
 - Pass7: pre-launch recon, optimized post-launch event selection and associated IRFs
 - Pass8: post-launch recon, event selection and IRFs



P7 Reprocessed data and analysis elements



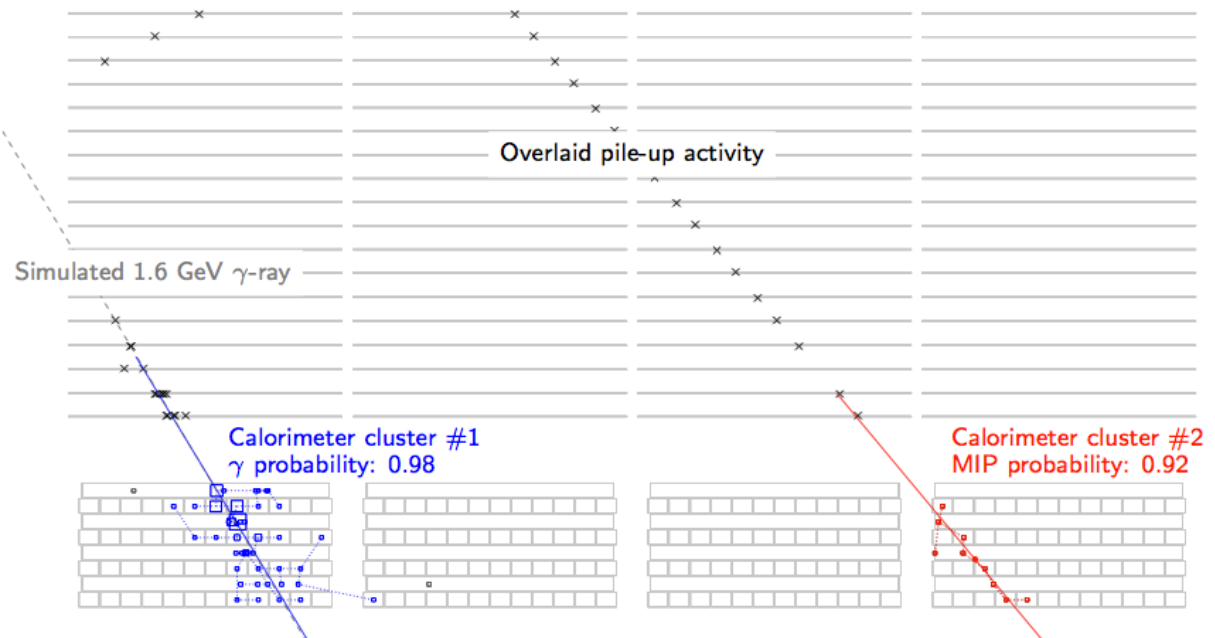
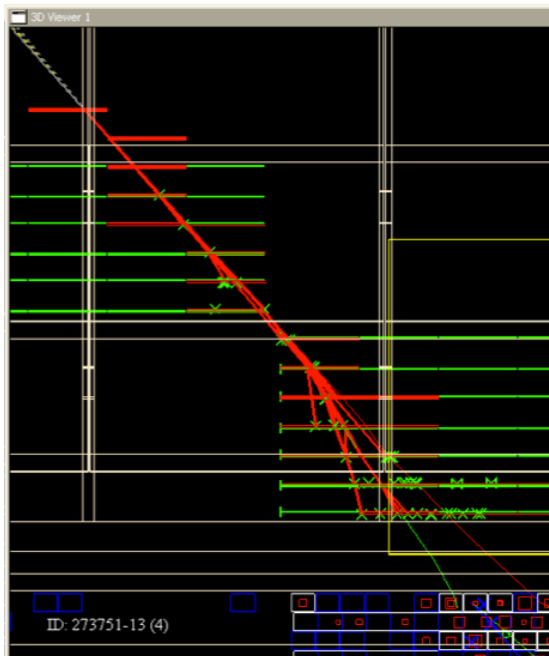
- ❑ Updated LAT calibrations
 - Correct for ~1%/year CAL light yield decrease (expected from irradiation)
 - CAL asymmetry
- ❑ Better IRFs
 - Better PSF
 - Flight PSF retains MC dependence on inclination angle
 - Better Aeff
 - Corrects for orbital effects and systematics
- ❑ Updated IEM
- ❑ 4 year source list
- ❑ Target release in July



Pass8 improvements



- ❑ Current Pass8 development has major advances in
 - CAL recon: multiple clusters + new full 3D shower profile recon to extend up to $\sim 3\text{TeV}$
 - TKR recon: improved pat-rec to reduce PSF tails
- ❑ Development heavily relies on LAT MC and data/MC agreement with flight datasets



Summary and look ahead



- ❑ The first 5 years of Fermi data provide are a rich, high quality public database for astrophysics and astro-particle physics
 - Building catalogs for known sources
 - Continuous discoveries of new emitters
 - Diffuse emission for Cosmic Ray physics and Dark Matter
- ❑ Extended operations begin June 2013
 - LAT operations extremely stable
 - New Pass8 gamma-ray analysis will enhance acceptance and resolution starting late 2013
 - Deeper view on published discoveries
 - Discovery potential for new physics
 - More opportunities for varied observation profiles
 - White papers under evaluation from the Mission
 - http://fermi.gsfc.nasa.gov/ssc/proposals/alt_obs/obs_modes.html

BACKUP





Summary of Fermi LAT science publications

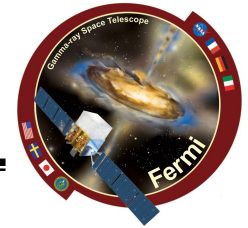
20 May 2013

Category I and II papers in refereed journals

Journal	Published	In press	Total
	0+1=1	-	1
Astronomical Journal	1+0=1	-	1
Astronomy and Astrophysics	6+16=22	-	22
Astroparticle Physics	2+3=5	-	5
Astrophysical Journal	72+39=111	0+1=1	112
Astrophysical Journal Letters	20+11=31	-	31
Astrophysical Journal Supplement	5+1=6	-	6
Journal of Cosmology and Astroparticle Physics	3+3=6	-	6
Monthly Notices of the RAS	0+16=16	-	16
Nature	2+1=3	-	3
Physical Review D	6+1=7	-	7
Physical Review Letters	6+0=6	-	6
Science	15+0=15	-	15
Total	138+92=230	0+1=1	231

2013 AAS/HEAD Rossi prize
2011 APS Panofsky Prize
2011 AAS/HEAD Rossi prize

plus > 290 rapid publications (ATels, GCN)



Missions

Missions Highlights

▼ Current Missions

Current Missions

Fermi Gamma-ray Space Telescope

Science

Launch

Multimedia

Spacecraft and Instruments

Team

News and Media

Past Missions

Future Missions

Launch Schedule

Mission Calendar

Resources



Fermi Science
Writers Guide

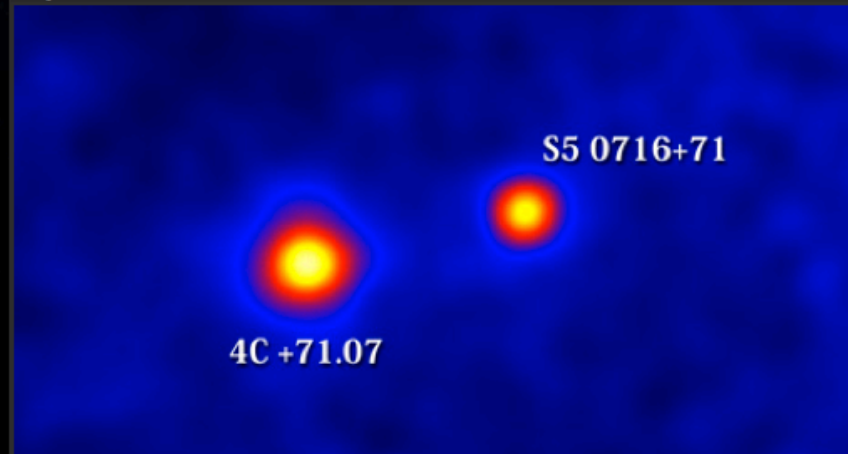


Fermi Education
and Outreach
Products

Fermi

Fermi Gamma-ray Space Telescope

Top Fermi Stories



Galaxy's Gamma-Ray Flares Erupted Far From its Black ...

Theorists expect gamma-ray outbursts occur only near a galaxy's central black hole. A few rare observations suggested otherwise.

[Read More](#)

01 02 II

[View Archives](#)

More Fermi Stories

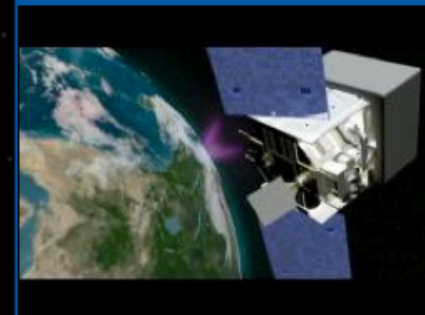


Fermi's Vision for Thunderstorm Gamma-Rays Improves

The Fermi space telescope is now 10 times better at catching brief outbursts of high-energy light produced above

Fermi Videos

Fermi's GBM Finds Radio Bursts from TGFs



[View This Video](#)

NASA's Fermi Explores the Early Universe

Fermi Detects Solar Flare's Gamma Rays

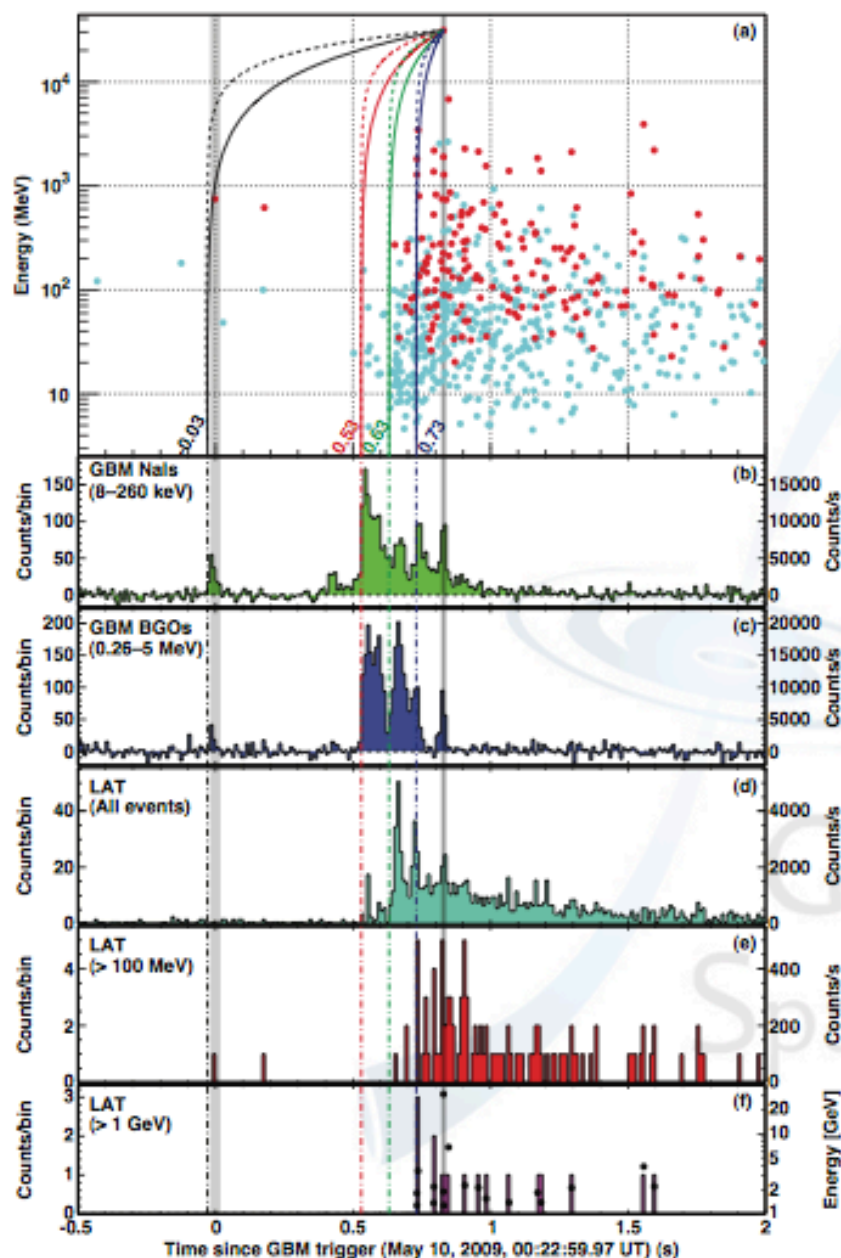
[More Videos](#)

Related Links

United States

[Fermi Mission Site](#)

GRBs AND LORENTZ INVARIANCE: GRB 090510



GRB 090510

- ▶ A 31 GeV photon detected 0.829 s after the GBM trigger ($z = 0.903 \pm 0.003$)
- ▶ We don't know when the photon has been emitted!
- ▶ Very reasonable assumption: the photon has not been emitted before the beginning of the burst. This translates into an upper limit on a possible (positive) time delay

$$\Delta t > 860 \text{ ms}$$

and a lower limit for the LIV (in a subluminal scenario) mass scale

$$M_{QG,1} > 1.19 M_p$$

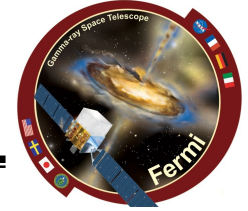
(the most stringent so far)

Abdo, A. A. et al. 2009, Nature, 462, 331

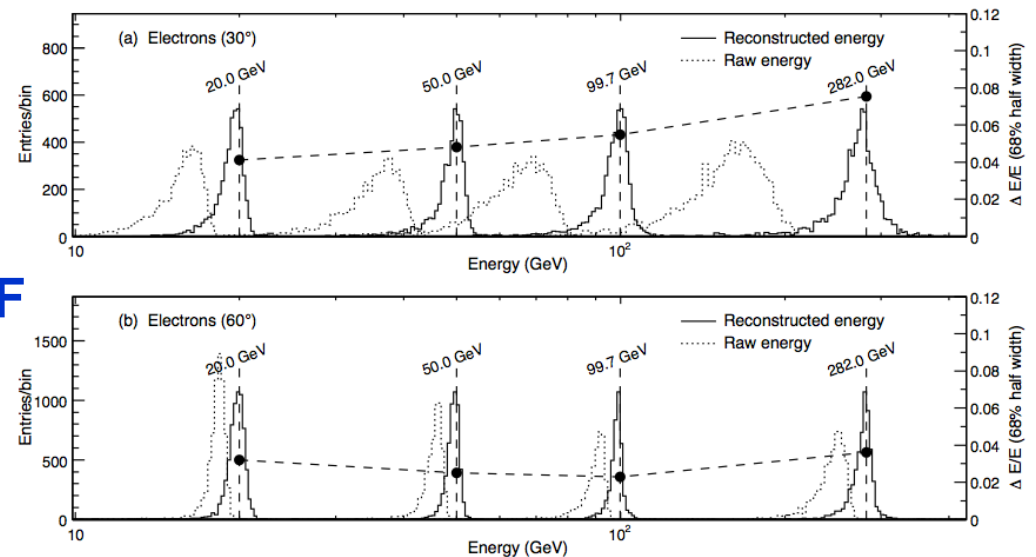
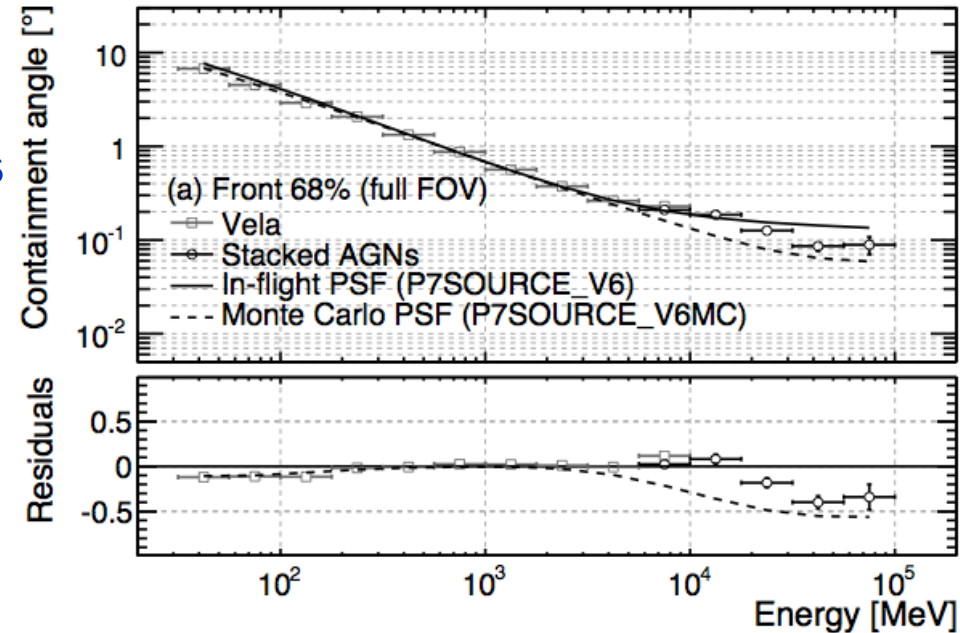
Abdo, A. A. et al. 2009, Science, 323, 1688

LAT Calibration and performance validation

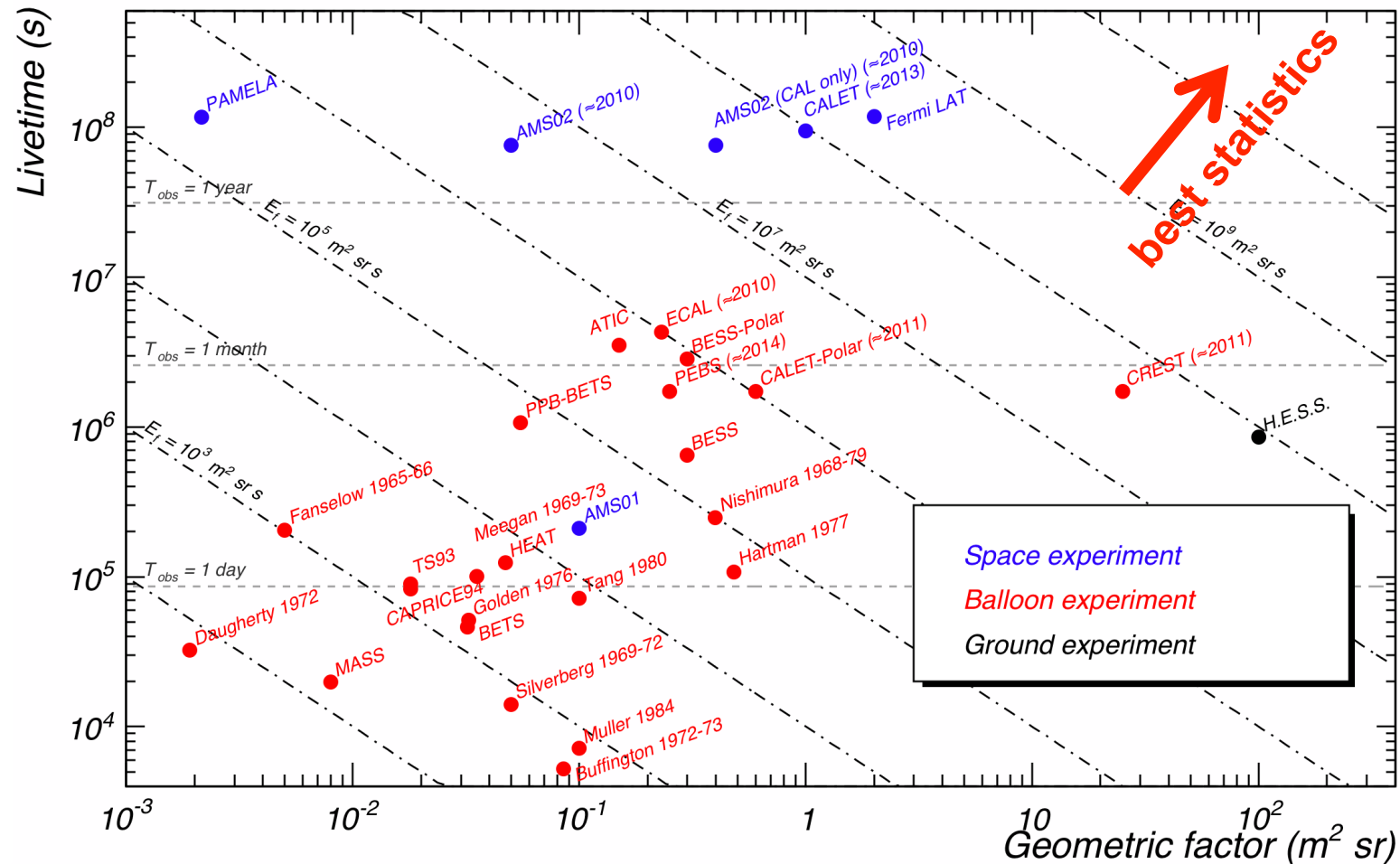
Ackermann et al. 2012, ApJS, 203, 4 and refs therein



- ❑ Monte-Carlo simulations
 - Over 50k active volumes
 - Geant4
- ❑ Flight data samples
 - Vela and bright pulsars
 - Earth Limb
 - Galactic ridge
 - Bright AGNs
- ❑ Beam Test
 - MC fidelity for basic detector quantities
 - Direct verification of PSF and energy resolution



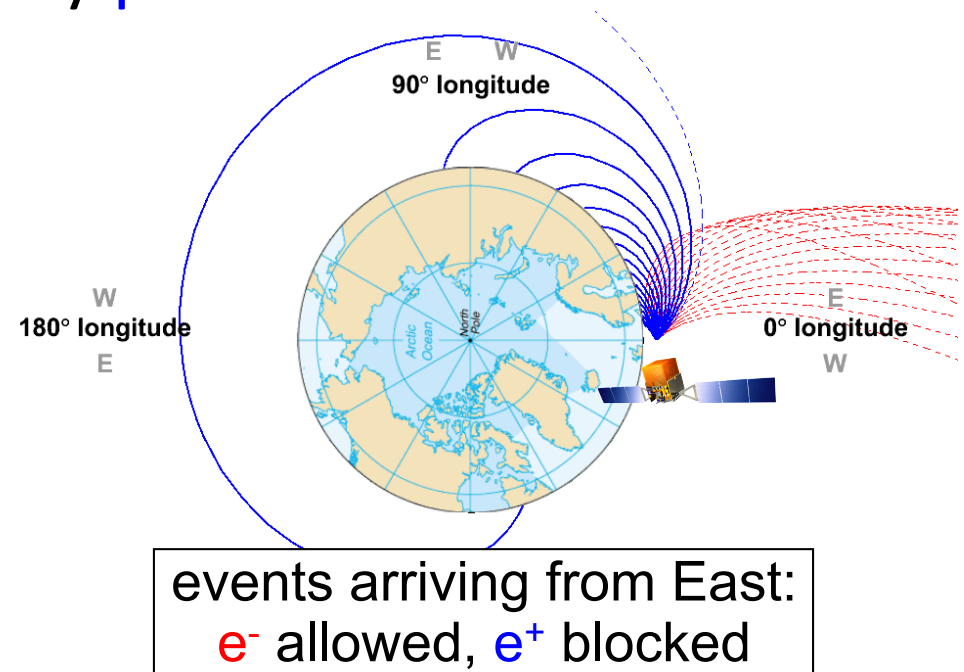
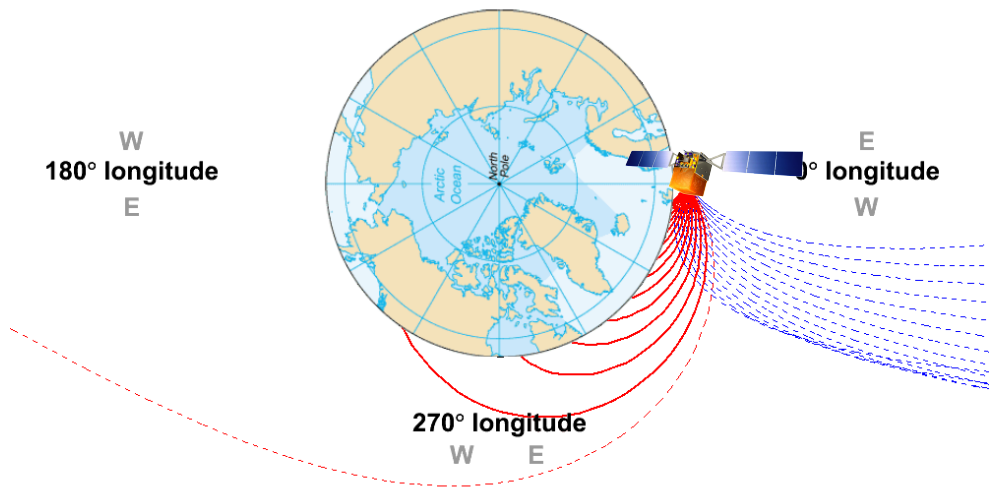
Fermi and the others



caveat1 – illustrative - 2x corrections possible
caveat2 – statistics is not enough

Geomagnetic field + Earth shadow = directions from which only **electrons** or only **positrons** are allowed

events arriving from West:
 e^+ allowed, **e^-** blocked

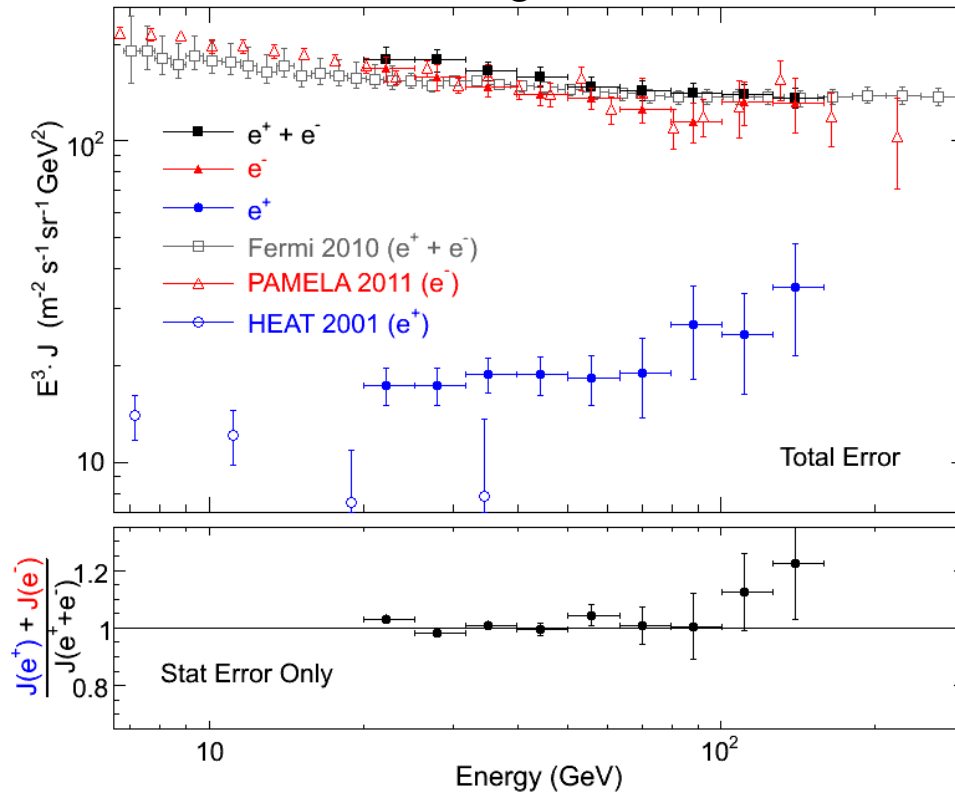


events arriving from East:
 e^- allowed, **e^+** blocked

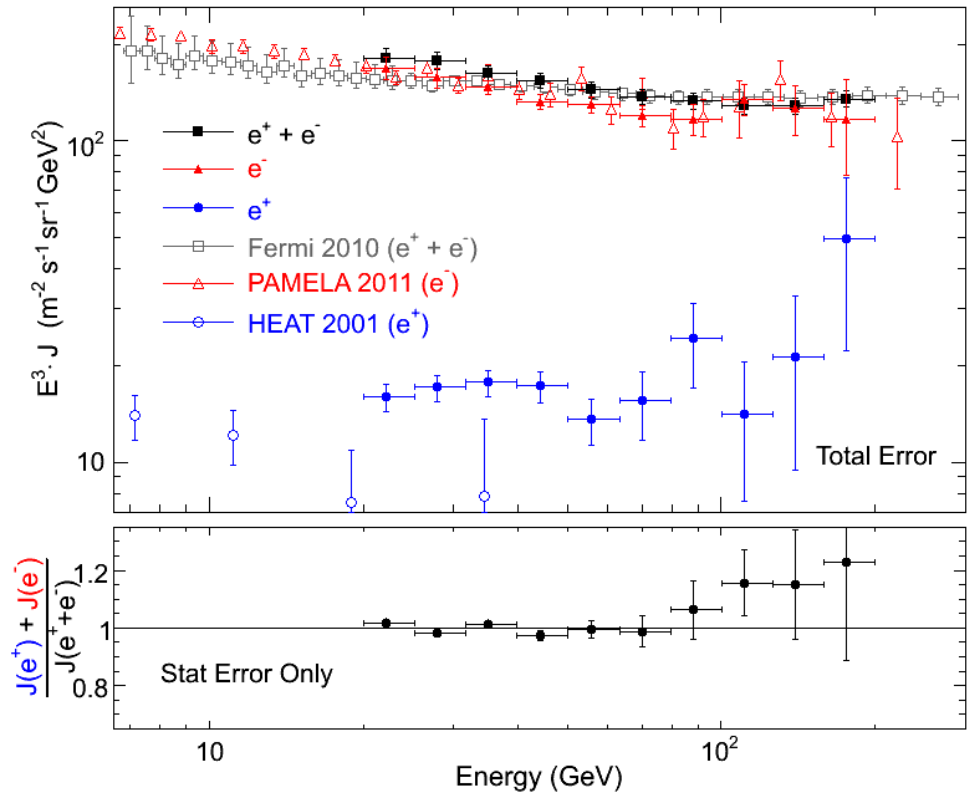
- For some directions, **e^-** or **e^+** forbidden
- Pure **e^+** region looking West and pure **e^-** region looking East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Don Smart and Peggy Shea (numerically traces trajectory in geomagnetic field)
- Using International Geomagnetic Reference Field for the 2010 epoch

Two background subtraction methods produce consistent results

Fit-based background subtraction



MC-based background subtraction



Three cross checks:

- Two background subtraction methods consistent
- Summed flux from e^- and e^+ regions matches flux from both-allowed region
- Flux from both-allowed region matches previously published e^+e^- total flux