The Fermi Large Area Telescope at 4: the Surprising Gamma-Ray Sky

Eric Charles

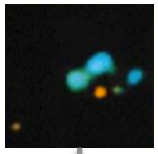
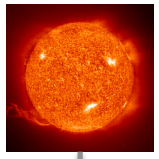
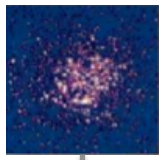
on Behalf of the Fermi-LAT Collaboration

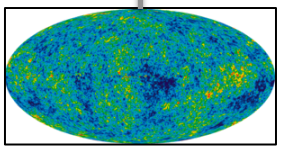
ICHEP 2012,

Melbourne, Australia

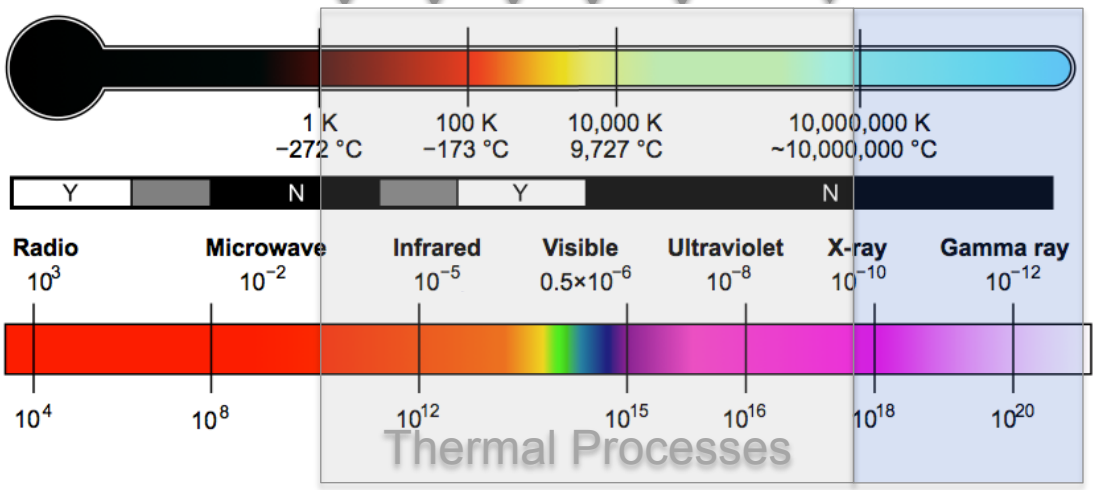
γ-rays Probe the Extreme, Non-Thermal, Universe

Dark Nebula | Dim, young star | Our Sun | Globular Cluster | Accretion Disk

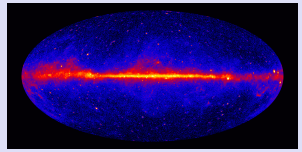



CMB



We are learning surprising things about all the aspects of γ-ray emission

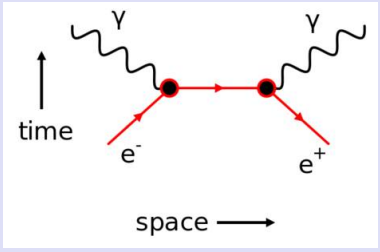
γ-ray sky



Energy & particle source

Acceleration mechanism

γ-ray production mechanism



Foreground Effects

The Fermi Large Area Telescope

Public Data Release:
All γ-ray data made public within 24 hours (usually less)

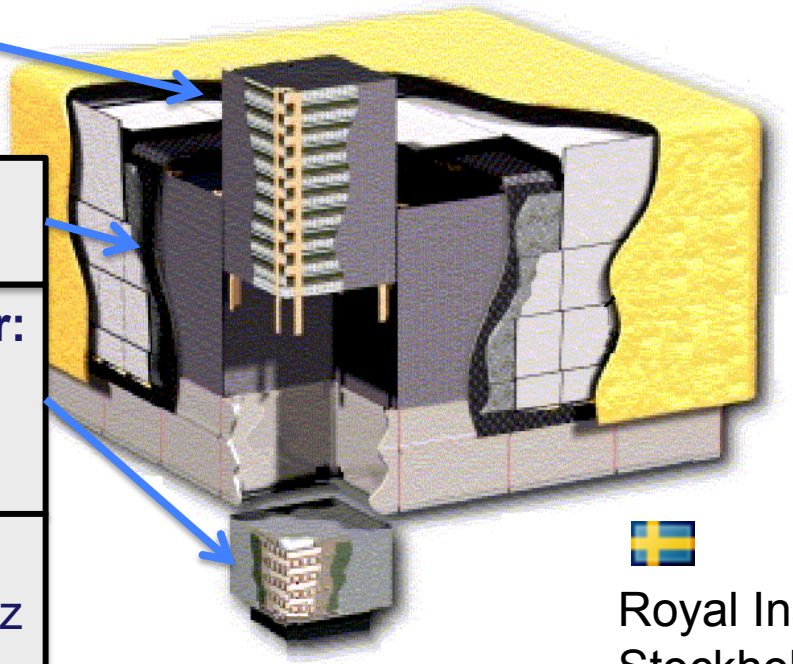
Si-Strip Tracker:
convert γ->e^+e^-
reconstruct γ direction
EM v. hadron separation

Anti-Coincidence Detector:
Charged particle separation

Hodoscopic CsI Calorimeter:
measure γ energy
image EM shower
EM v. hadron separation

Trigger and Filter:
Reduce data rate from ~10kHz to 300-500 HZ

Sky Survey:
With 2.5 sr Field-of-view LAT sees whole sky every 3 hours



Fermi LAT Collaboration:
~400 Scientific Members, NASA / DOE & International Contributions

CNRS/IN2P3
CEA/Saclay

INFN, ASI
INAF

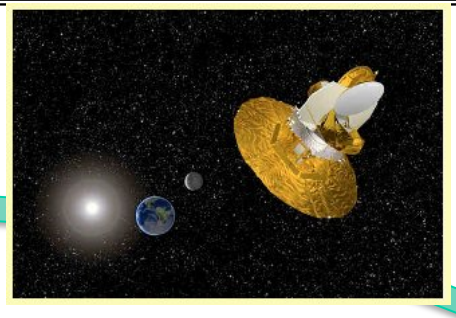
Hiroshima Univ.
ISAS/JAXA
RIKEN
Tokyo Inst. of Tech.

Royal Inst. of Tech. (KTH)
Stockholm Univ.

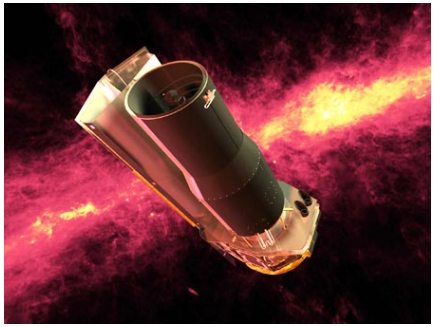
Stanford Univ./ SLAC, UC Santa Cruz/ SCIPP,
GSFC, NRL, Sonoma St. Univ.
Ohio St. Univ., Univ. of Washington

Synergy with Other Instruments

Radio: pulsations, synchrotron emission, ISM maps, high resolution imaging of jets AGN host galaxies…



Microwave: diffuse maps & morphology, Galaxy characteristics…

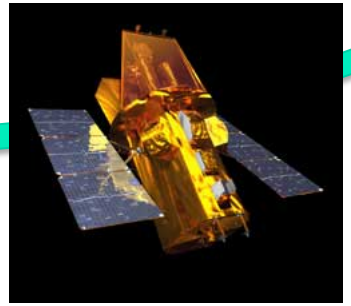


IR: ISM maps, AGN/GRB host galaxies…

LAT Source Localization ~0.1°--0.01° comparable to many field-of-views
LAT: 4+ decades energy band provides lever-arm for spectral fits

Energy

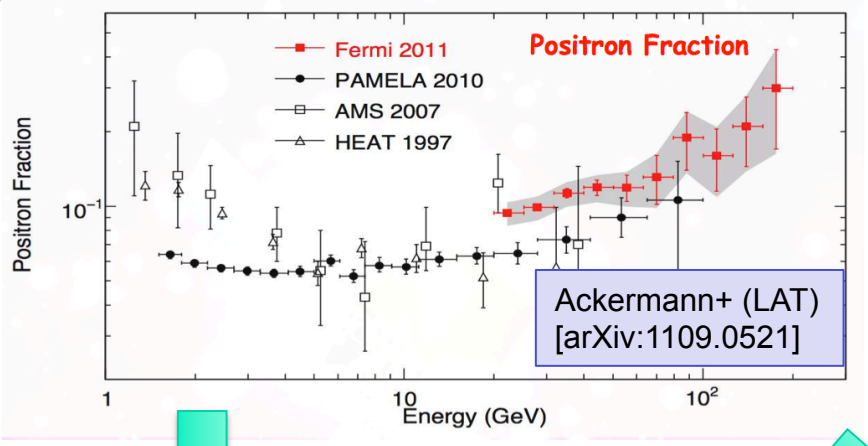
TeV: High-energy spectral breaks, SNR/ PWN morphology…



X-ray:
GRB & Flare afterglows, morphology & pulsar association…

Optical:
GRB afterglows, AGN/GRB redshits

New Fundamental Physics or New Astrophysics?

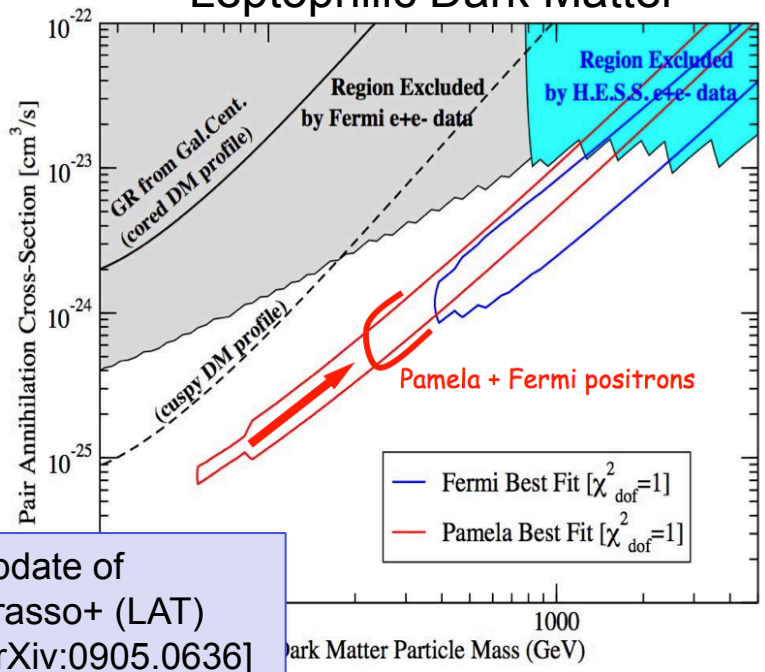


Ackermann+ (LAT) [arXiv:1109.0521]

Recall Aldo Morselli's talk: understanding γ-ray sources key to disentangling fundamental physics from astrophysics

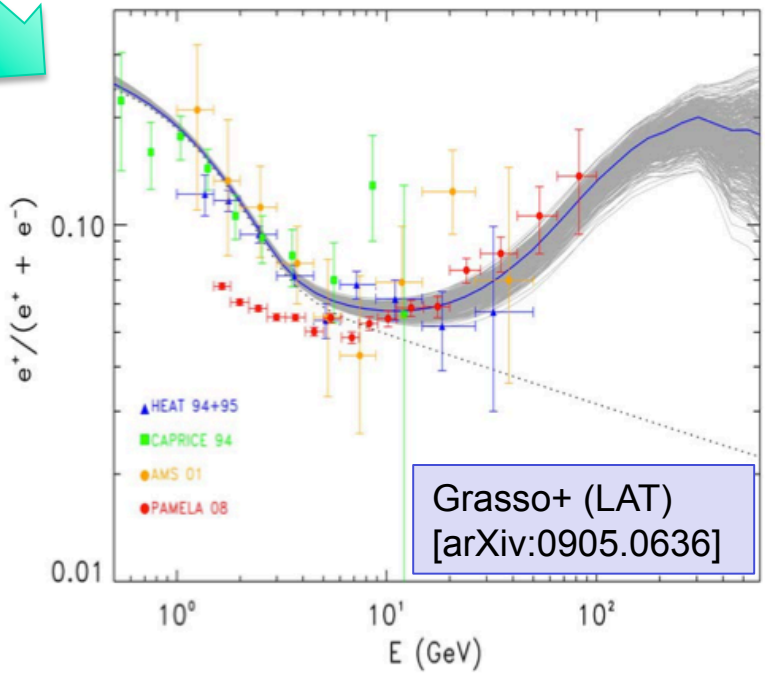
Increases discovery potential and allows more stringent constraints on DM

Leptophilic Dark Matter



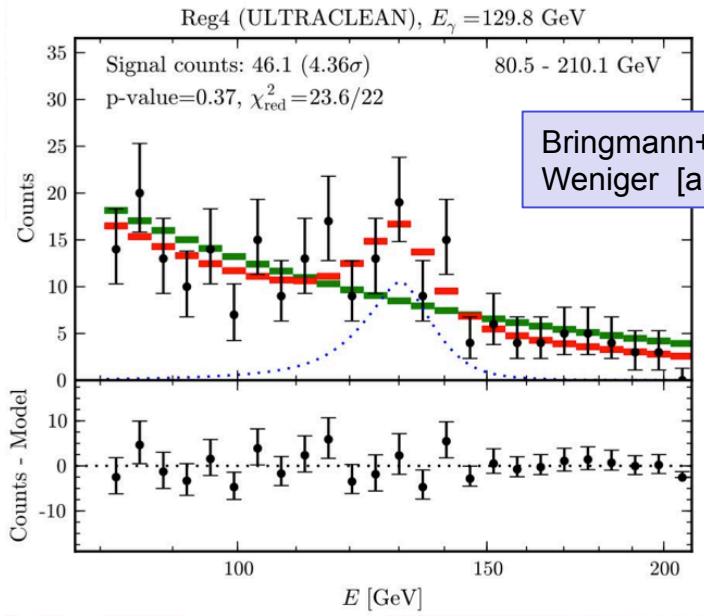
Update of Grasso+ (LAT) [arXiv:0905.0636]

Pulsars



Grasso+ (LAT) [arXiv:0905.0636]

New Fundamental Physics or New Astrophysics?



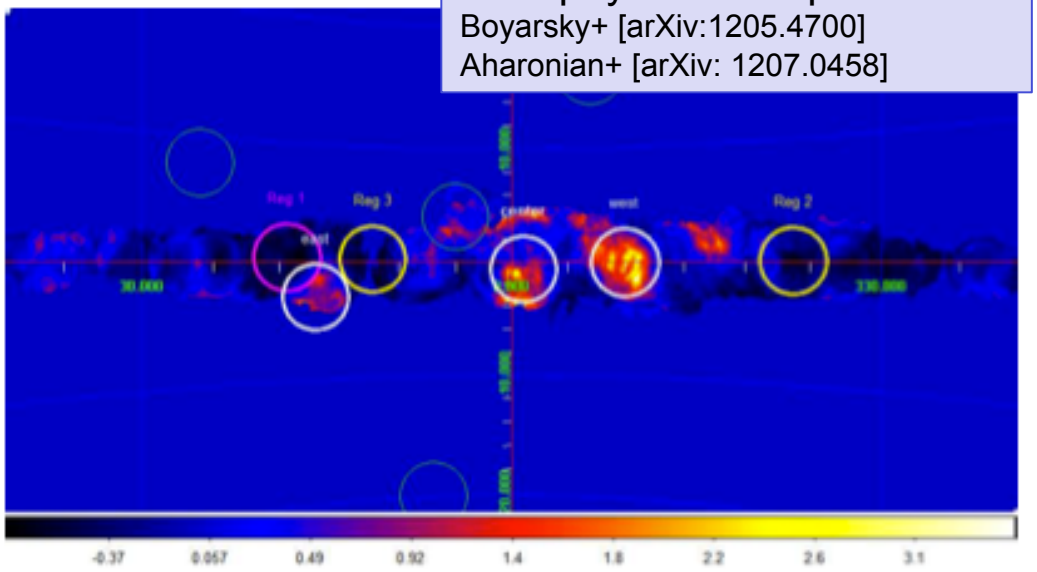
Bringmann+ [arXiv:1203.1312]
Weniger [arXiv:12.2797]

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

Recall Aldo Morselli's talk: narrow excess ~130GeV associated with Inner Galaxy

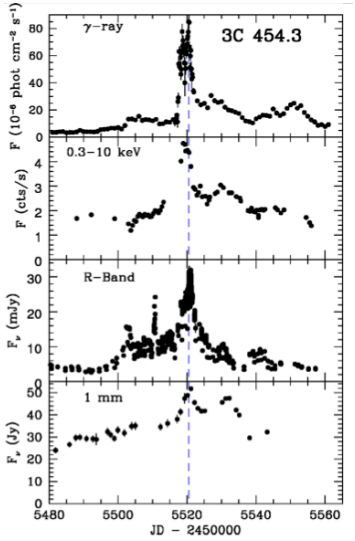
Many DM models, but also models of spectra features from astrophysics such as Pulsar Wind Nebulae (PWNe)

Need to extract more information from *morphology* and *MW observations*

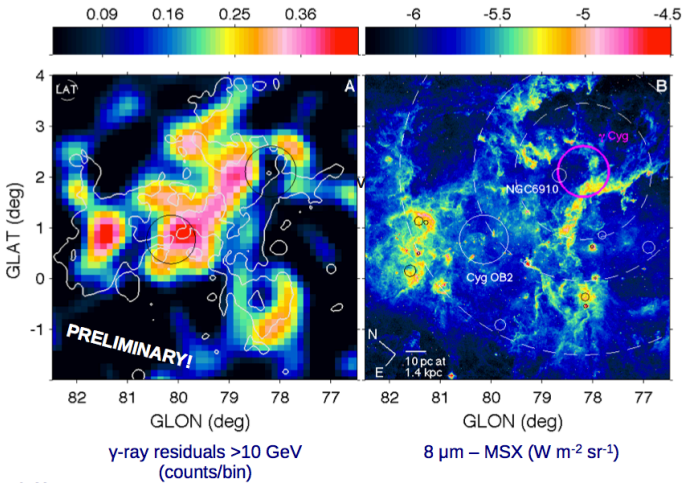


Astrophysical Interpretations:
Boyarsky+ [arXiv:1205.4700]
Aharonian+ [arXiv: 1207.0458]

Wide Variety of Analysis Techniques



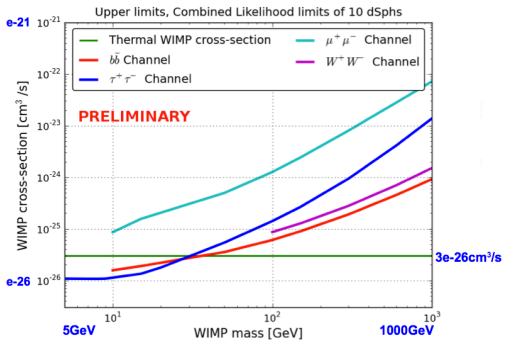
MW Variability & Pulsations



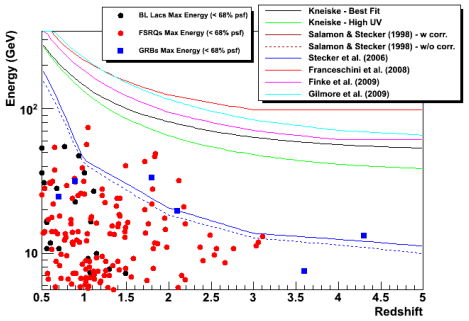
γ-ray residuals >10 GeV (counts/bin)

8 μm – MSX (W m^{-2} sr^{-1})

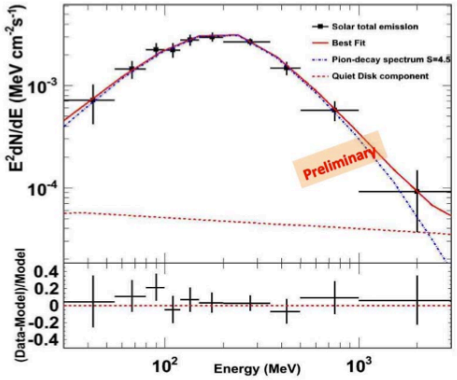
Morphology, Source Extension and Counterpart Identification



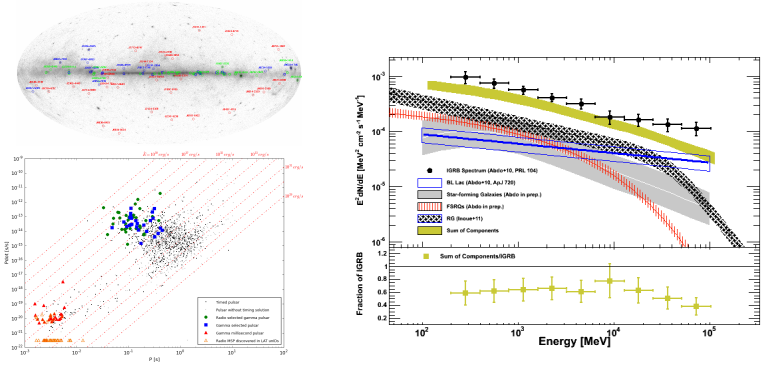
DM Searches



Single Photon Studies



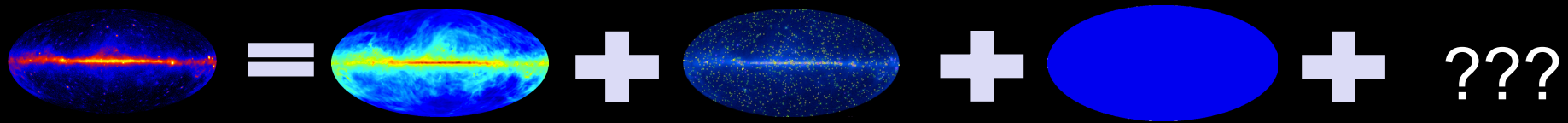
Spectra and Spectral Components



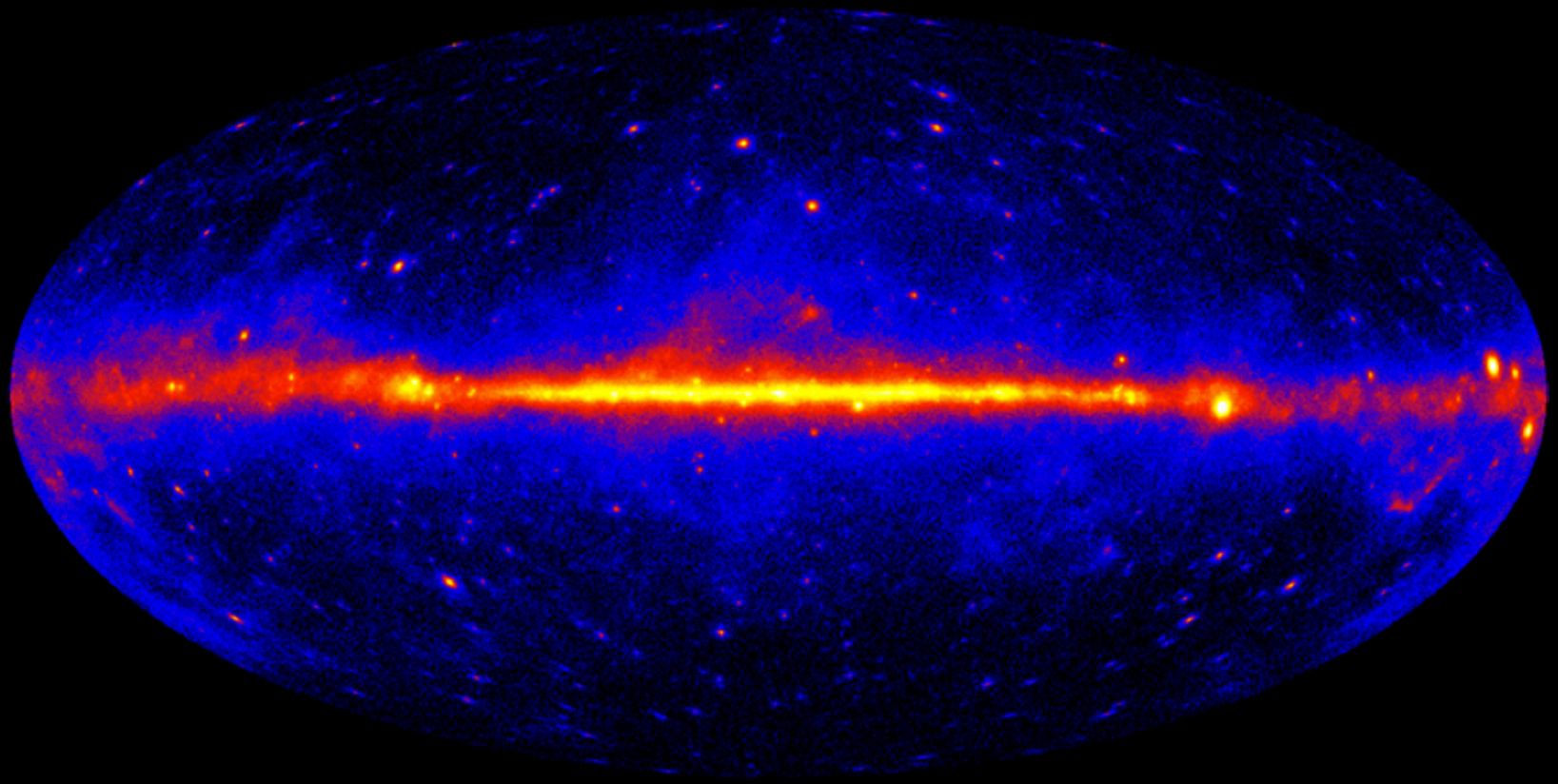
Catalogs, Population Studies and Luminosity Functions

No real "standard" analysis. Many complementary ways to extract information about the γ-ray sky.

Decomposing the Fermi-LAT Sky

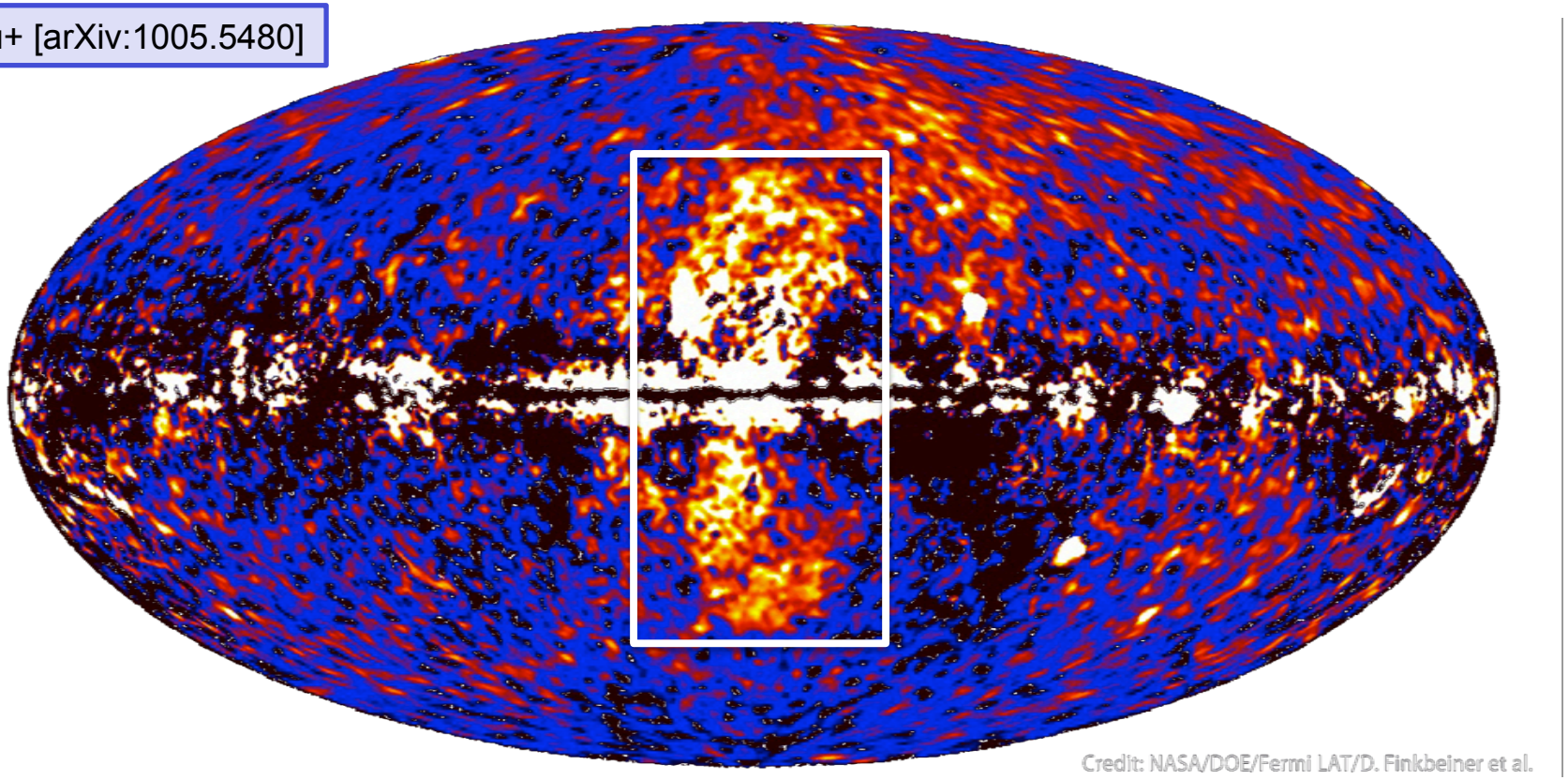


Galactic Point Sources Isotropic



Galactic Diffuse Emission

Su+ [arXiv:1005.5480]



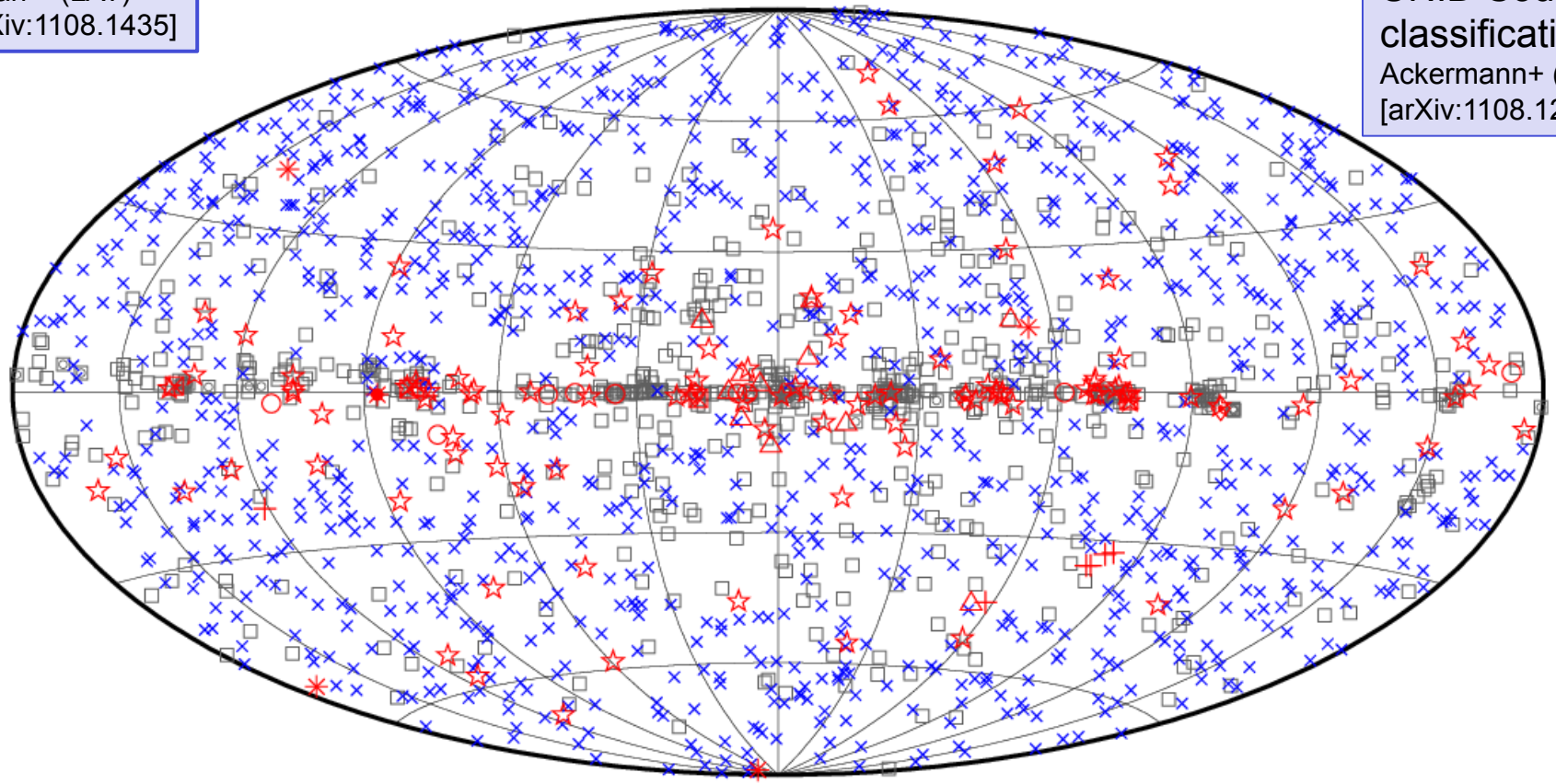
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

- **Large "bubbles" seen projecting from Galactic Center**
  - **Possible evidence of quasar-like or galactic-wind activity from the Galactic Center -> population of high-energy cosmic rays**

The Second Fermi-LAT Source Catalog

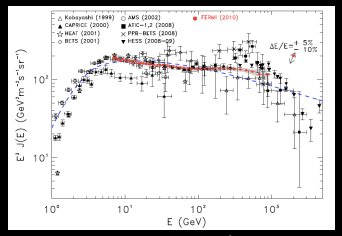
Nolan+ (LAT)
[arXiv:1108.1435]

UNID Source classification:
Ackermann+ (LAT)
[arXiv:1108.1202]

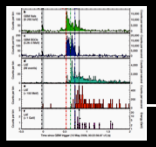


No association	Possible association with SNR or PWN	
AGN	Pulsar	Globular cluster
Starburst Gal	PWN	HMB
Galaxy	SNR	Nova

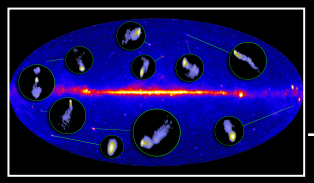
Increasing Classes of Fermi-LAT Sources



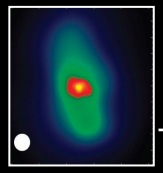
e^+e^- spectrum



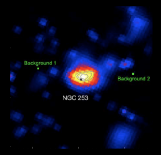
GRBs



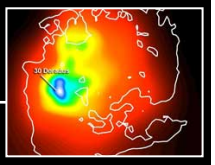
Blazars (782)



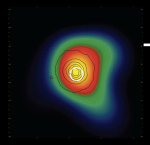
Radio Galaxies (12)



Starburst Galaxies (4)

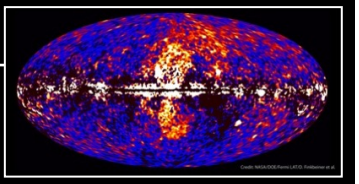


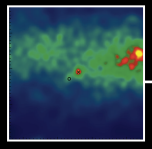
LMC & SMC



Globular Clusters (11)

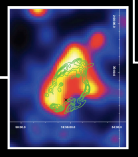
Fermi Bubbles

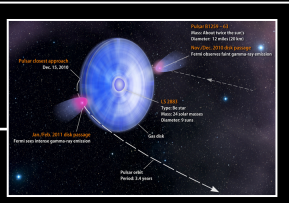




Nova (1)

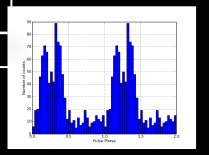
SNR & PWN (68)



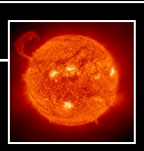


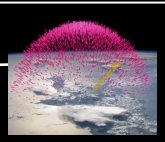
γ-ray binaries (6)

Pulsars: young & millisecond (MSP) (100+)



Sun: flares & CR interactions





Terrestrial Gamma-ray Flashes

Ackermann+ (LAT) [arXiv:1108.1202]

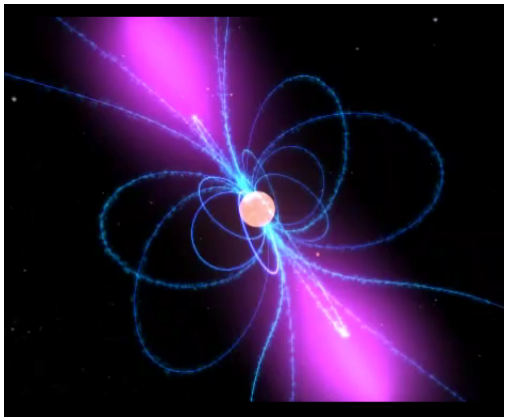
Unidentified Sources (~600)

Extragalactic

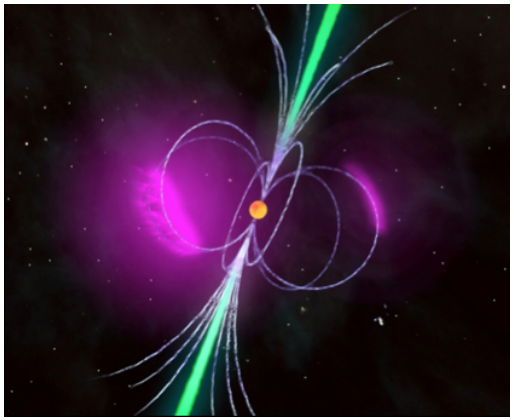
Galactic

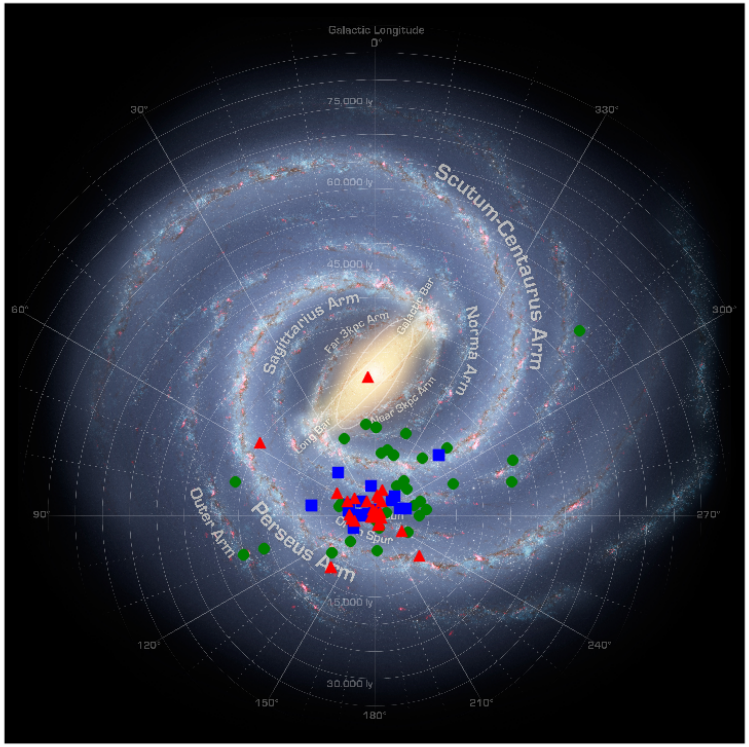
Local

Re-Writing the Book on Pulsars



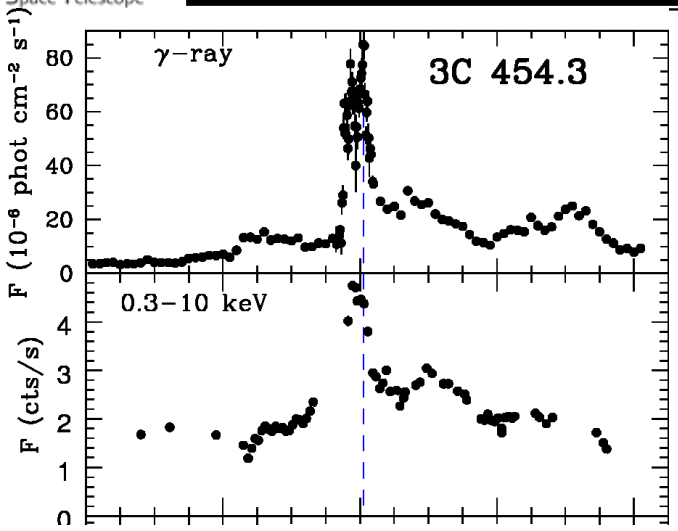
First Pulsar Catalog:
Abdo+ (LAT) [arXiv:0910.1608]



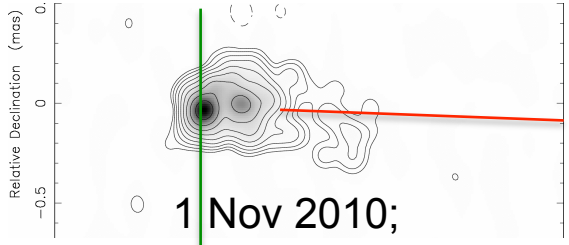


- Huge increase in number of known γ-ray pulsars
  - From ~6 pre-Fermi-LAT to over 117 now
- Large fraction (~1/2) of young γ-ray pulsars are radio-quiet
  - γ-ray beam is wider than radio beam
- Millisecond pulsars (MSPs) have similar γ-ray properties to young pulsars
- Radio searches on LAT sources discovered > 43 MSPs
  - Potential for nHz, kilo-parsec scale gravitational wave detection array, i.e., NANOGRAV

AGN Flares Correlated with Superluminal Knots



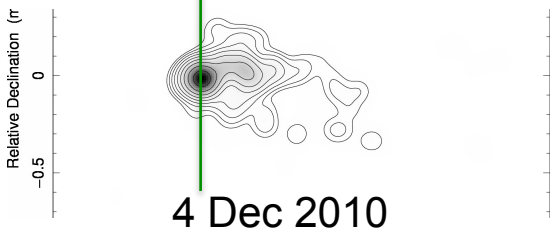
20 Nov. 2010



1 Nov 2010;

Knot ejected during γ-ray flare in late 2009,

v_{app} = 10c



4 Dec 2010

Fermi-LAT detects many AGN at z > 1.

As we improve our understanding we may use AGN as cosmological probes.

Abdo+ (LAT) [arXiv:1004.3828]
Marscher+ talk at Fermi Symp. 2011

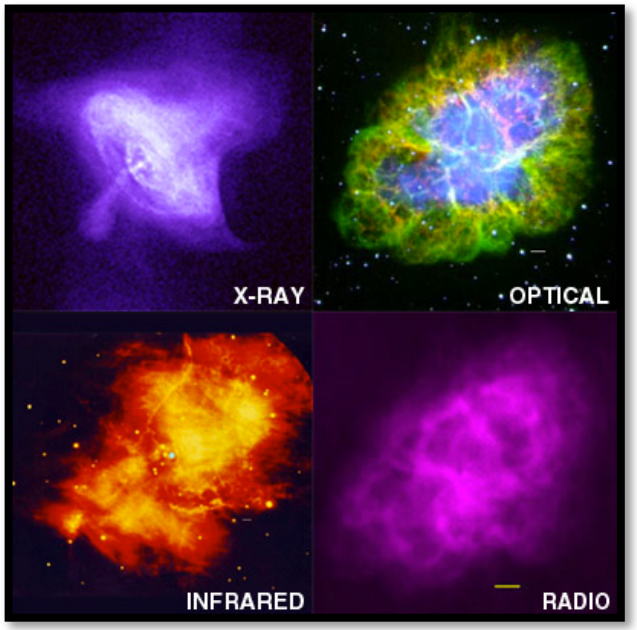
Multiwavelength observations of AGN show that γ-ray flares correlate with:
•resolved radio "knots" crossing the core of the AGN jet,
•very large changes in optical polarization.

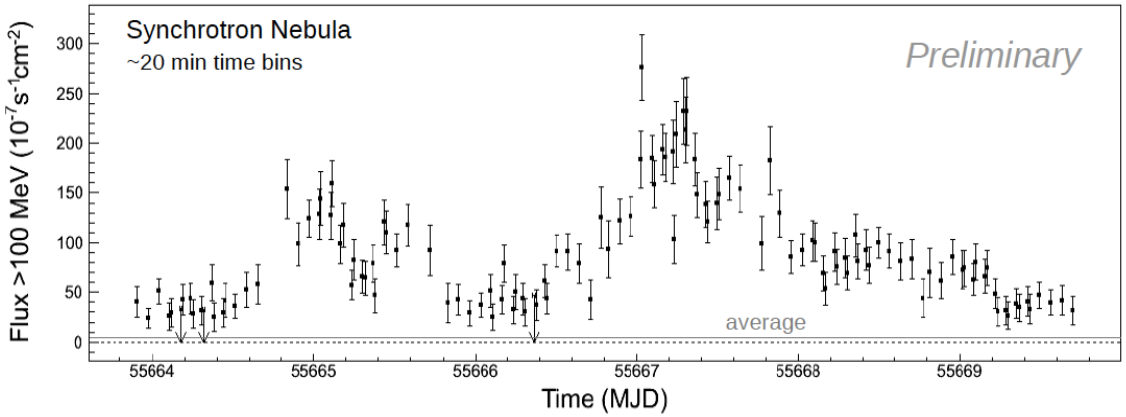
This suggests that the γ-ray emission region responsible for the flaring behavior is not the AGN engine, but a compact zone with turbulent fields away from the core.

Rapid variability, high energies and changing polarization suggest a population of pre-accelerated particles.

Crab Flares: Standard Candle No More

- The wind emanating from a rotating neutron star (Crab Nebula) produces strong γ-ray flux
- Those γ rays are produced by energetic (PeV) electrons (via synchrotron), but not clear how to accelerate them
- Rapid variability (~hours) constrains the size of electron acceleration region
  - shock acceleration in the "winds" probably not viable (gyroradius would be too large; cooling too efficient!)
  - currently studied process is magnetic reconnection (also under consideration for prompt Solar Flare emission)



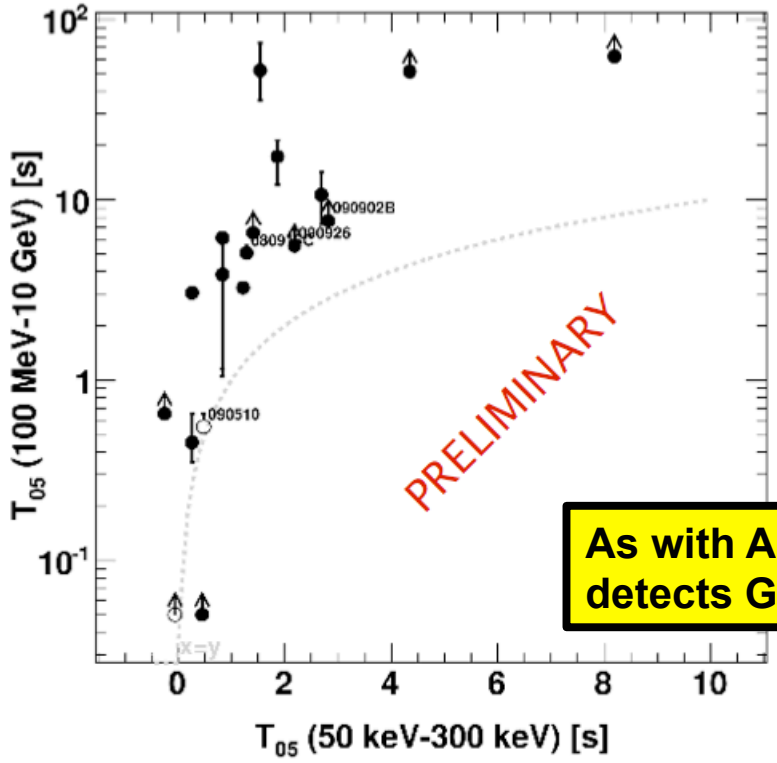


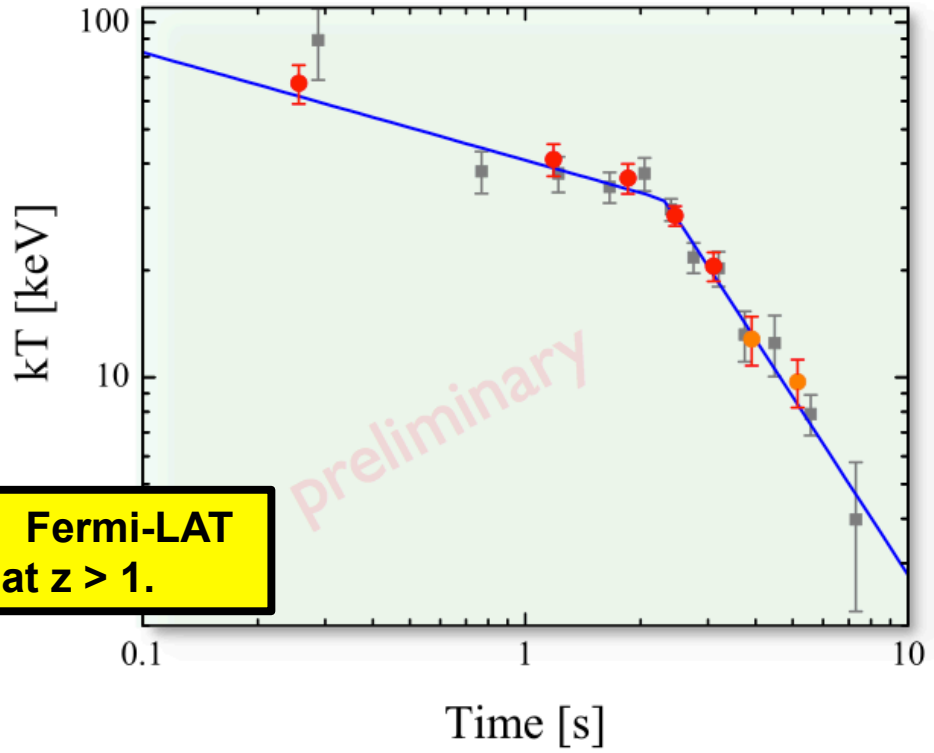
Fast variability (~1h)

Tavani+ (AGILE) [arXiv:1101.2311]
Abdo+ (LAT) [arXiv:1011.3855]
Buehler+ (LAT) [arXiv:1112.1979]

ATEL 4239 (LAT):
Crab Flare of 2012 July 4th
(the "Higgs discovery" flare)

GRBs: Photospheric Models of Emission

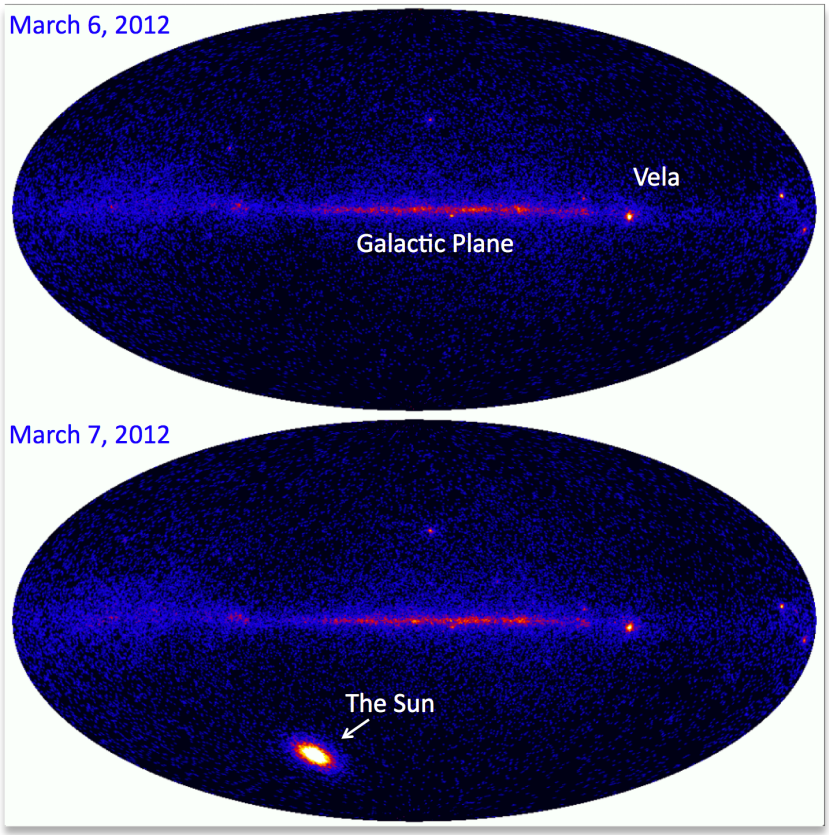


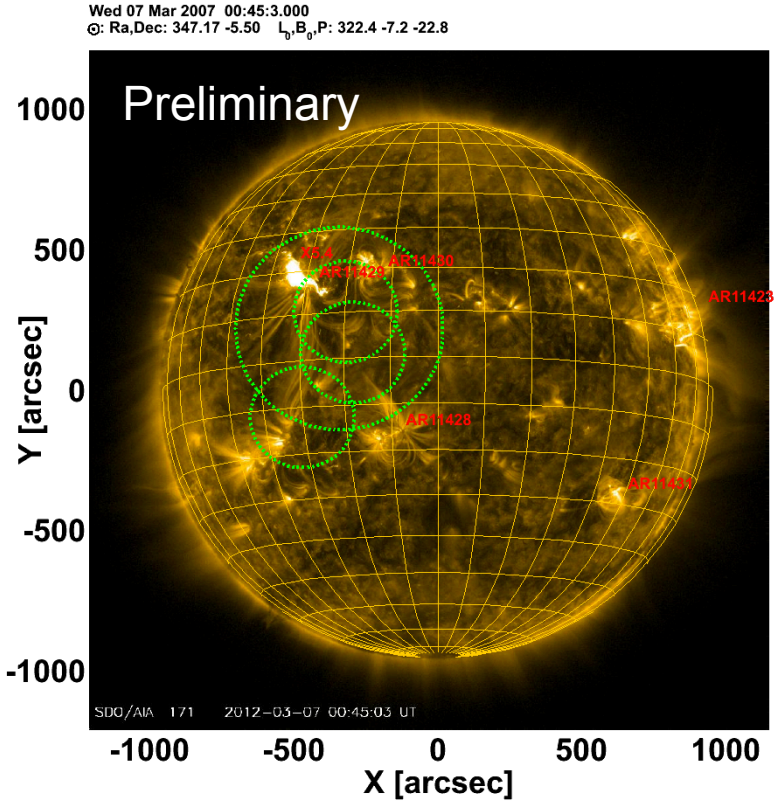


As with AGN, Fermi-LAT detects GRB at z > 1.

- LAT (> 100 MeV) GRBs among the brightest, most energetic GBM (8keV -30MeV) GRBs
- Evidence of a class of hyper-energetic GRBs (4 bursts)
- LAT emission has delayed onset and is temporally extended w.r.t. lower energies
- Spectral Cutoff just below LAT energy range (between 100keV and 100MeV)
- Photospheric emission/ (possible thermal components) observed cooling

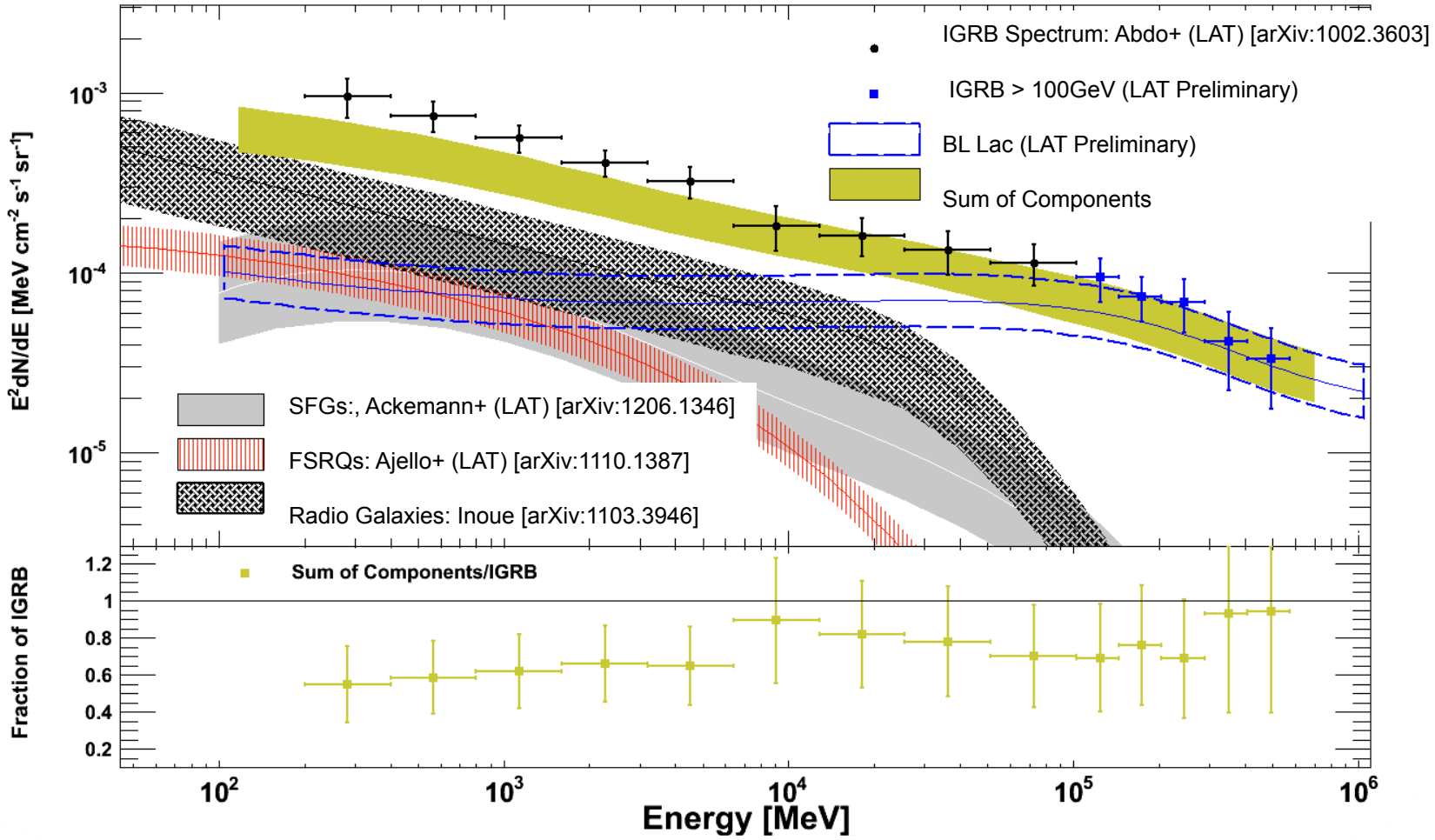
Long Duration γ-ray Emission from Solar Flares





- A very bright Solar Flare was detected on March 7, exceeding 1000 times the γ-ray flux of the steady Sun and 100 times the flux of Vela.
- Location of the γ-ray emission consistent with Active Region 11429
- High energy emission (>100 MeV, up to 4 GeV) lasted for ~20 hours
  - Continuous particle acceleration lasting almost 1 day challenges acceleration models

Unresolved Contributions to the γ-ray Sky



- **Fermi-LAT is measuring *isotropic* γ-ray spectrum to > 500 GeV**
- **Can compare measurements to expected *unresolved* contributions from sources**
- **Sub-degree scale (high-multipole) anisotropies sensitive to unresolved sources as well as DM sub-structures**

See other studies by: Stecker&Salomon+96, Pavlidou&Fields+02, Narumoto&Totani06,Dermer07, Bhattacharya+09, Inoue&Totani09, Fields+10, Makiya+10, Inoue+11,Abazajian+10, Ghirlanda+11,Stecker&Venters11,Malyshev&Hogg11

Summary

- The Fermi-LAT is opening a window on the sky from ~20 MeV to > 300 GeV
- We are making huge gains in understanding the non-thermal universe:
  - Several new γ-ray source classes
  - Profound changes in our understanding of previously know γ-ray sources
  - Understanding these sources is key uncovering or constraining fundamental physics with Fermi-LAT data

- Multiwavelength and theoretical studies are essential to make the best scientific use of the Fermi observations. The Guest Investigator program supports such work.
  - The Fermi Web site is http://www.nasa.gov/fermi
  - All the Fermi γ-ray data are public immediately

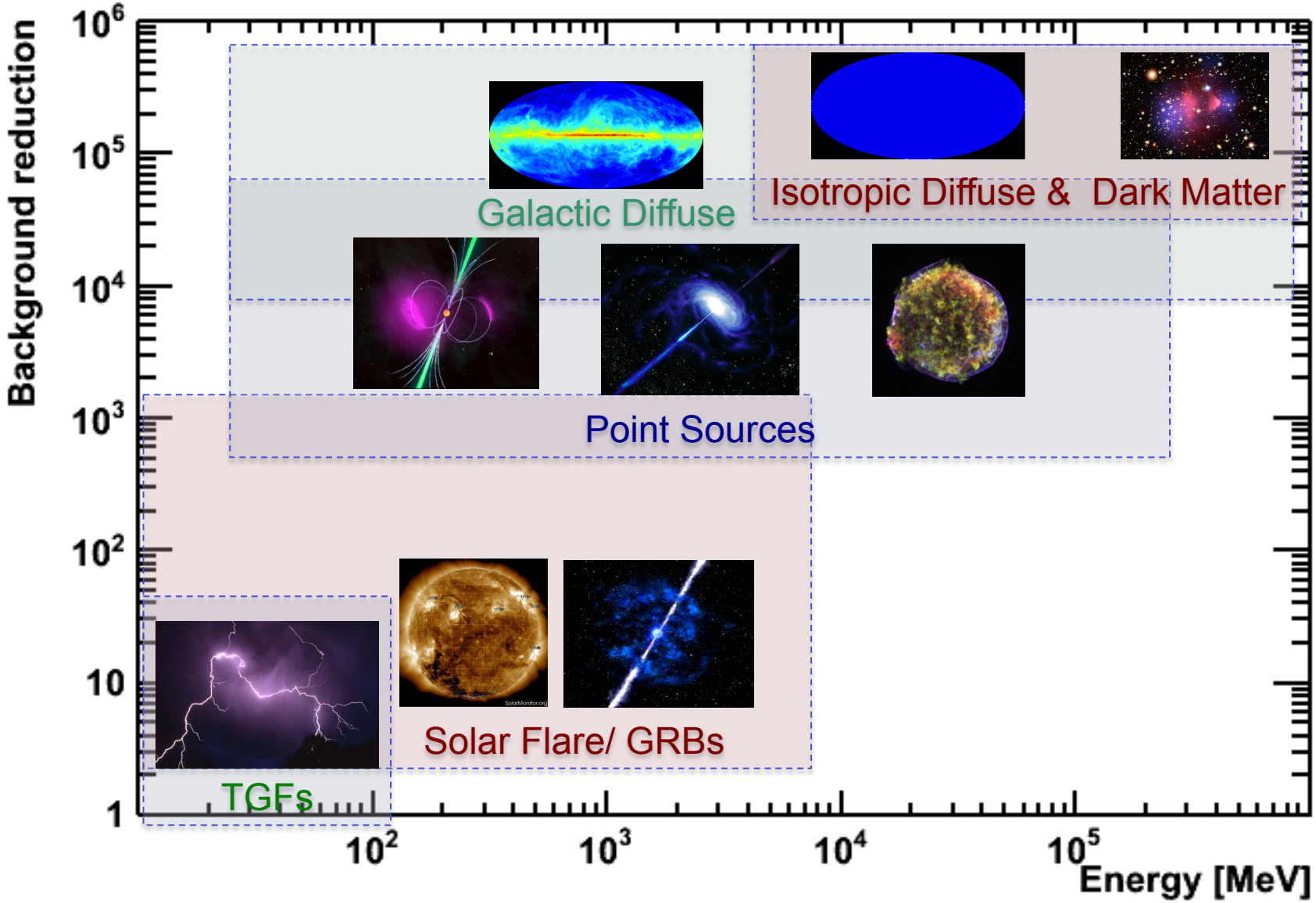
The 4th Fermi Symposium

The 4th Fermi Symposium:
Monterey, California
28 October 2012 - 2 November 2012

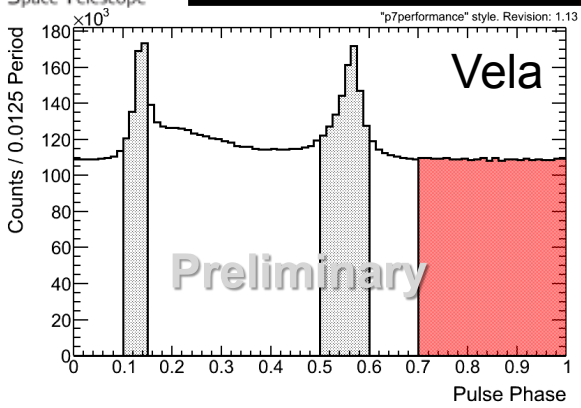
Abstract Submission Deadline:
21 August 2012

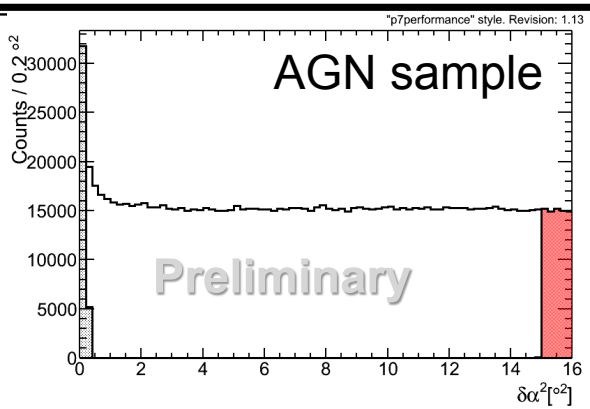
EXTRA SLIDES

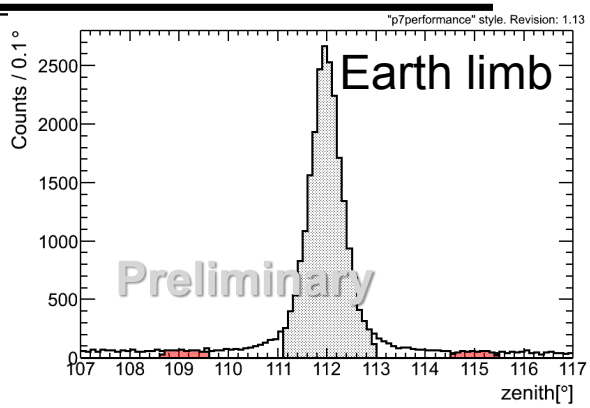
LAT Data is used for many types of analyses



Calibration and Validation Using Flight Data







Quantity	$A_{\rm eff}$	PSF	Energy	
			Dispersion	Scale
F_{25}	$\sim 8\%$ (§ 5.7)	$\sim 8\%$ (§ 6.5)	$\sim 3\%$ (§ 7.4)	$+13\% - 5\%$ (§ 7.4)
S_{25}	$\sim 10\%$ (§ 5.7)	$\sim 6\%$ (§ 6.5)	$\sim 2\%$ (§ 7.4)	$+4\% - 2\%$(§ 7.4)
Γ	~ 0.09 (§ 5.7)	~ 0.07 (§ 6.5)	~ 0.04 (§ 7.4)	-
Variability	$\sim 3\%$ (§ 5.6)	$\sim 3\%$ (§ 6.5)	-	-
Localization	-	$\sim 0.005°$ (§ 8.2)[a]	-	-

Ackermann+ (LAT) [arXiv:1206.1896]

LAT allows much higher precision measurement than previous missions.

LAT Collaboration has developed and is using controls samples of flight data to characterize instrumental uncertainties and study their effects on scientific measurements.

4 Years into the Fermi Era

- Over 1.37 billion Fermi LAT events in the public data set
- The LAT Collaboration has published 199 papers
  - Collectively these papers have been cited ~10,000 times
- Fermi satellite: the GBM has triggered on 1949 transients
  - at 939 GRBs are creeping ever closer to the 1000 mark
- The observatory has performed 77 autonomous repoints and the mission overall has produced over 800 refereed papers with new Fermi results or using/interpreting Fermi results and issued over 30 press/web releases