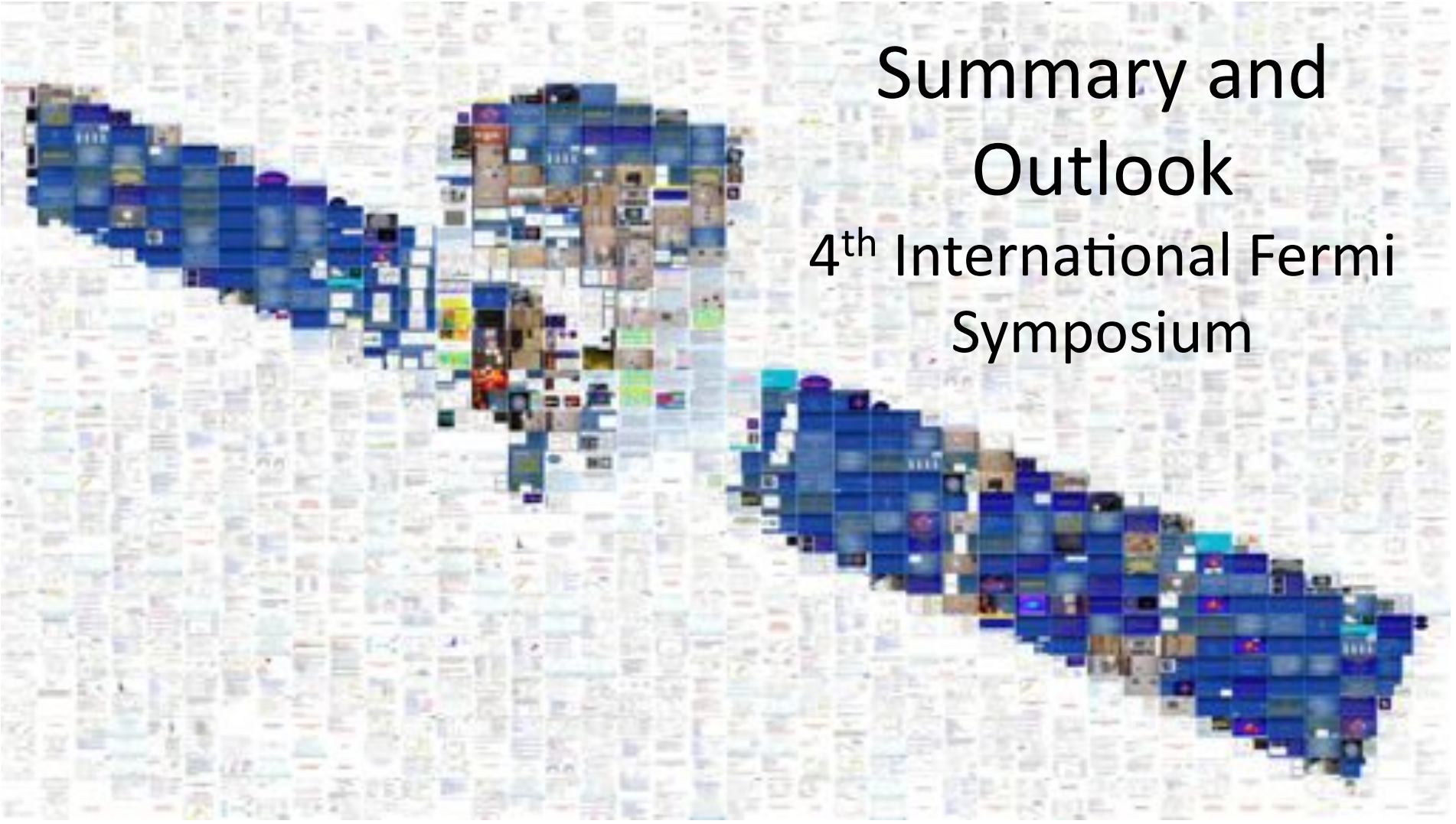




# Summary and Outlook

## 4<sup>th</sup> International Fermi Symposium

Seth Digel, KIPAC/SLAC, 2 November 2012

# Thanks

## Local Organizing Committee

Tom Langenstein - chair, Stanford University, USA  
Nancy Christiansen, Stanford University, USA  
Lynn Cominsky, Sonoma State University, USA  
Jan Goebel, Stanford University, USA  
WenLi Heffner (a.k.a. Lucy Zhou), Stanford University, USA  
Peter Michelson, Stanford University, USA  
Nicola Omodei, Stanford University, USA  
Steve Ritz, University of California Santa Cruz, USA  
Giovanna Benatone, Stanford University, USA

+ Bob Kahn  
+ Dorrene Ross



## International Science Organizing Committee (SOC)

William Atwood (UCSC)  
Ronaldo Bellazzini (INFN, Pisa)  
Roger Blandford (Stanford/KIPAC)  
Elliott Bloom (SLAC/KIPAC)  
James Buckley (WashU)  
Fernando Camilo (Columbia U and Arecibo)  
Patrizia Caraveo (INAF-IASF, Milano)  
Eric Charles (SLAC)  
Charles Dermer (NRL)  
Seth Digel (SLAC/KIPAC)  
Dale Frait (NRAO)  
Bryan Gaensler (U Sydney)  
Neil Gehrels (GSFC)  
Jochen Greiner (MPE)  
Isabelle Grenier (Laboratoire AIM, Saclay)  
Elizabeth Hays (GSFC)  
Dairine Horan (LLR)  
Buell Jannuzzi (U of Arizona)  
Victoria Kaspi (McGill U)  
Nobuyuki Kawai (Tokyo)  
Luca Latronico (INFN Torino)  
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Jonathan Ormes (Denver)  
William Paciesas (UA Huntsville)  
Anthony Readhead (Caltech)  
Steven Ritz (UCSC)  
Andrew Strong (MPE Garching)  
Gino Tosti (INFN and University Perugia)  
Stefan Wagner (Heidelberg)  
Colleen Wilson-Hodge (MSFC)

- To NASA, DOE, & international agencies for supporting the mission
- To all conference contributors (& session chairs!)

**Julie McEnery & Terri Brandt**

# Patrick Lee Nolan (1952-2011)



**Title:** Gamma large area silicon telescope: Applying SI strip detector technology to the detection of gamma rays in space

**Authors:** [Arwood, W. B.](#); [Bloom, E. D.](#); [Godfrey, G. L.](#); [Hertz, P. L.](#); [Lin, Ying-Chi](#); [Nolan, P. L.](#); [Snyder, A. E.](#); [Taylor, R. E.](#); [Wood, K. S.](#); [Michelson, P. E.](#)

**Affiliation:** AA(Naval Research Lab., Washington, DC.), AB(Naval Research Lab., Washington, DC.), AC(Naval Research Lab., Washington, DC.), AD(Naval Research Lab., Washington, DC.), AE(Stanford Univ., CA.), AF(Stanford Univ., CA.), AG(Stanford Univ., CA.), AH(Naval Research Lab., Washington, DC.), AI(Naval Research Lab., Washington, DC.), AJ(Stanford Univ., CA.)

**Publication:** In ESA, Proceedings of an ESA Symposium on Photon Detectors for Space Instrumentation p 227-232 (SEE N94-15025 03-19)

**Publication Date:** 12/1992

# Outline

- State of *Fermi*
- State of *Fermi* Science
  - Subjective Symposium Summary
- Outlook

# State of *Fermi* – in space

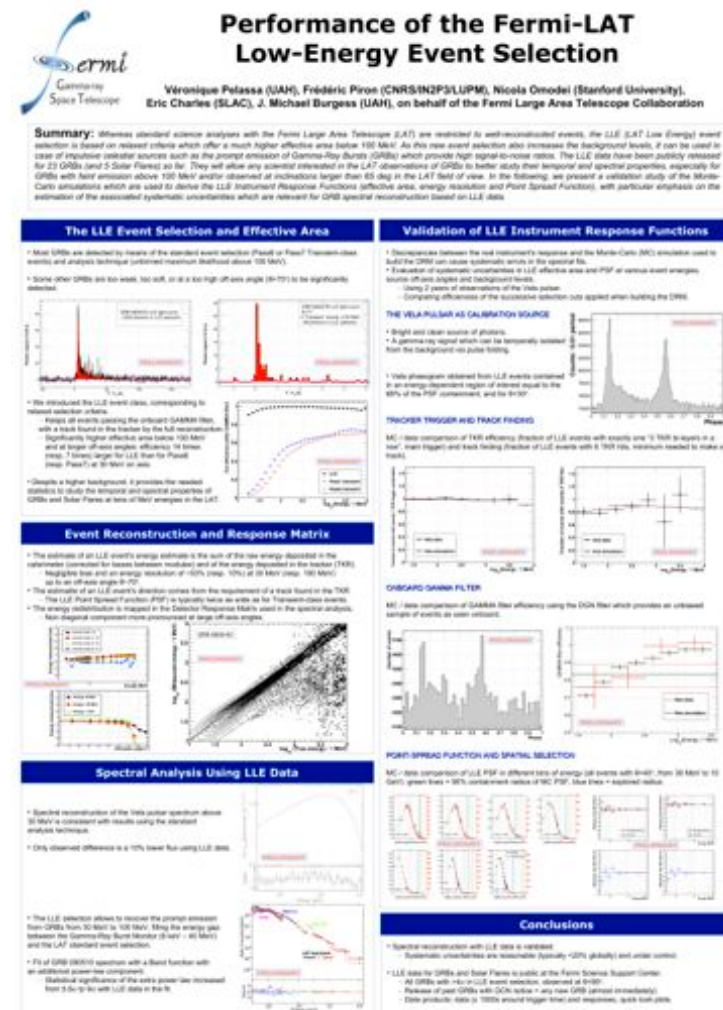
- Julie McEnery: “instruments and spacecraft operate as designed, no degradation in science performance since launch”
- LAT: ~275B triggers, 225M Source class events
- GBM: >1000 GRBs



# State of *Fermi* – on the ground

- Analysis and operations updates
  - LAT: LAT Low Energy selection, Pass 7 reprocessing, Pass 8 details (later)
  - GBM: Continuous Time Tagged Event data will be taken starting in November

\* N.B. Throughout I have listed only the first named author



Pelassa \*

# State of *Fermi* – on the ground

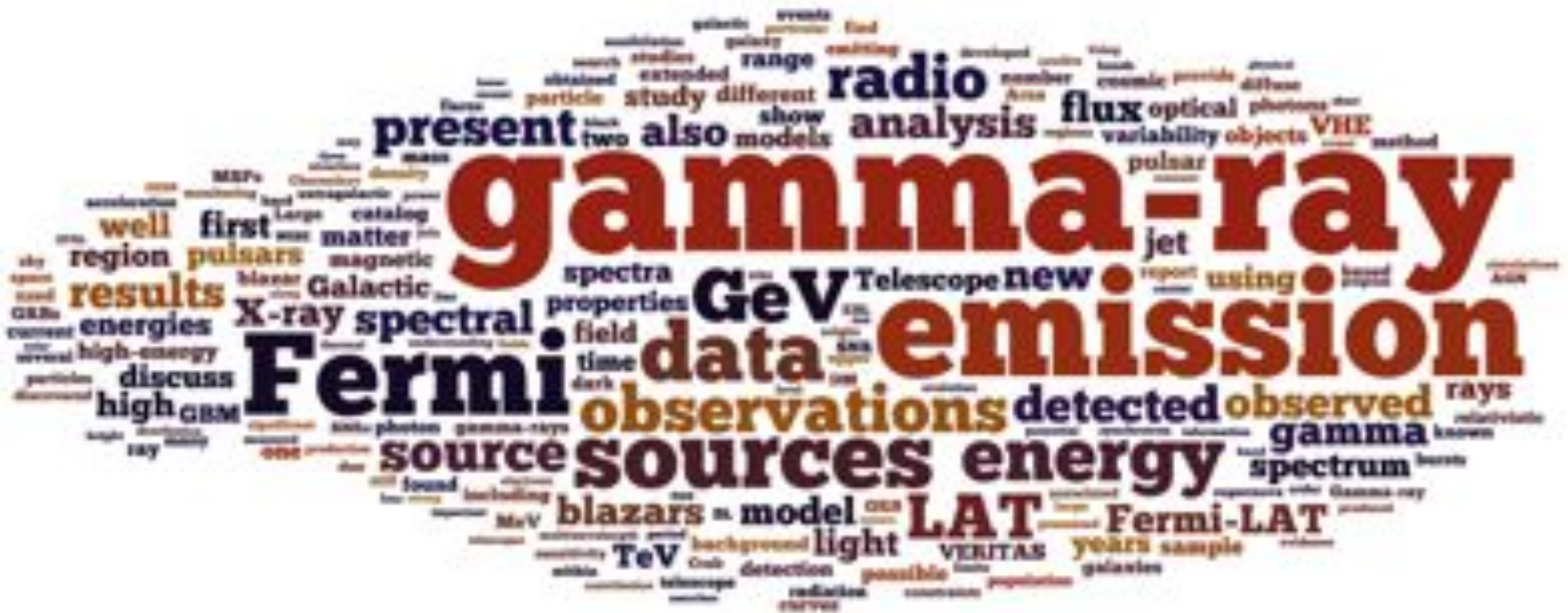
- 2012 NASA Senior Review

Panel recommended “funding at the desired level of augmentation to provide for full operations through FY14. We recommend an extension through 2016 with a review in 2014.”

- DOE HEP Cosmic Frontier Review (LAT operations)

“The Fermi team acquitted itself well.” – Roger B.

# Symposium Summary

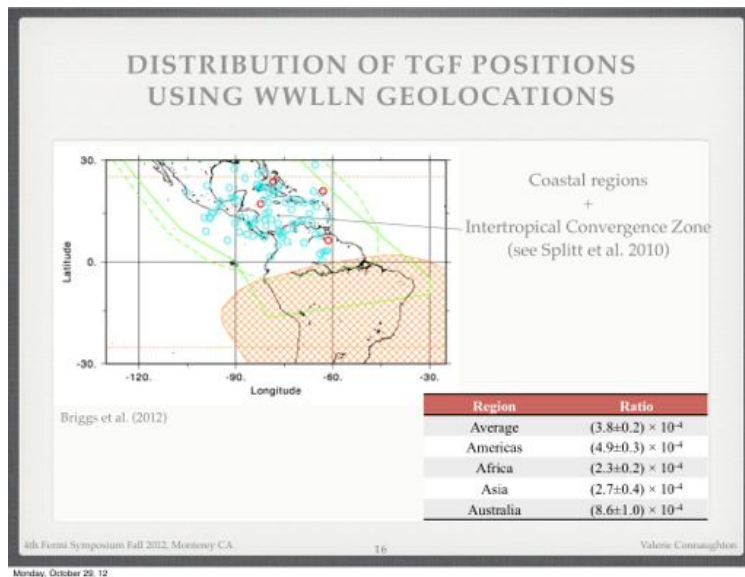




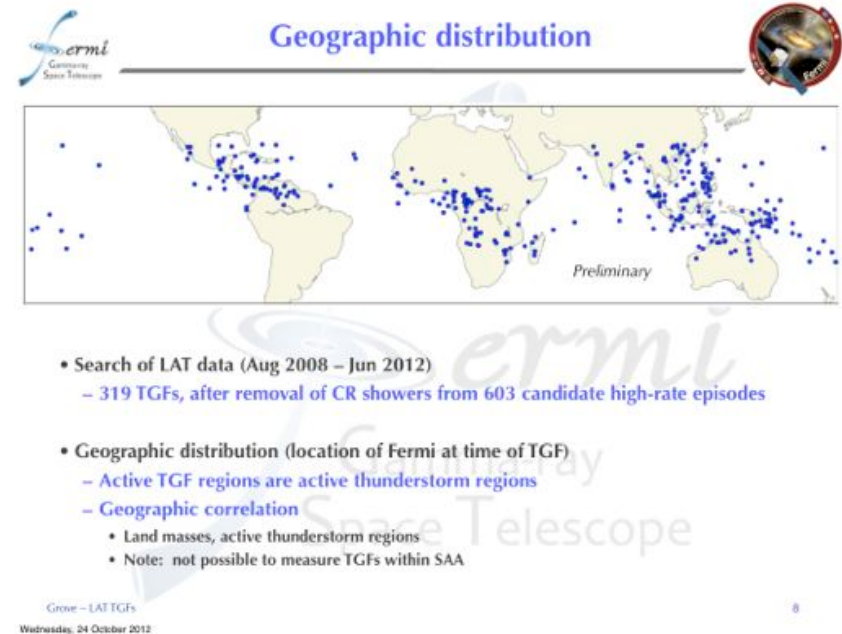
# **SOLAR SYSTEM**

# Terrestrial Gama-ray Flashes

- GBM observations and analysis with ground radio arrays



Connaughton

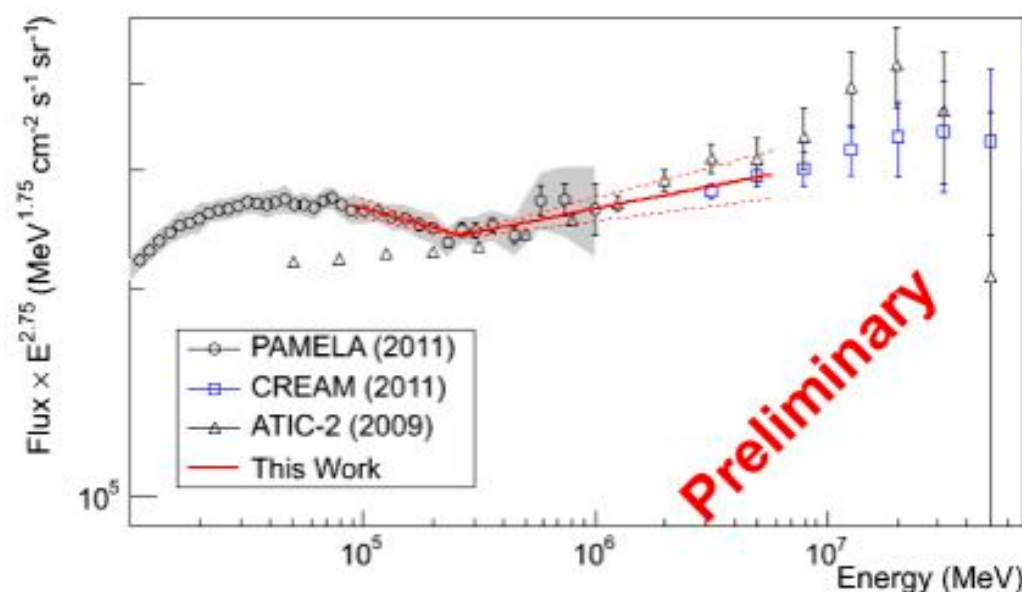


Grove

- LAT detections now also accumulating from carefully timed nadir observations
- Multiwavelength & rich science has continued to develop since 3<sup>rd</sup> Fermi Symposium

# Cosmic-Ray Interactions in the Upper Atmosphere

- Inferring the spectrum of CR protons
  - Indications are that it is consistent with the high-energy break reported by PAMELA



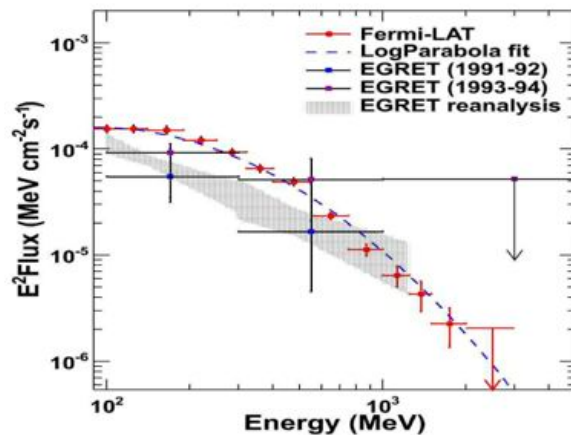
Mithumisiri et al.

# The Moon

- A passive gamma-ray source – monitoring the CR flux outside the Earth's magnetosphere



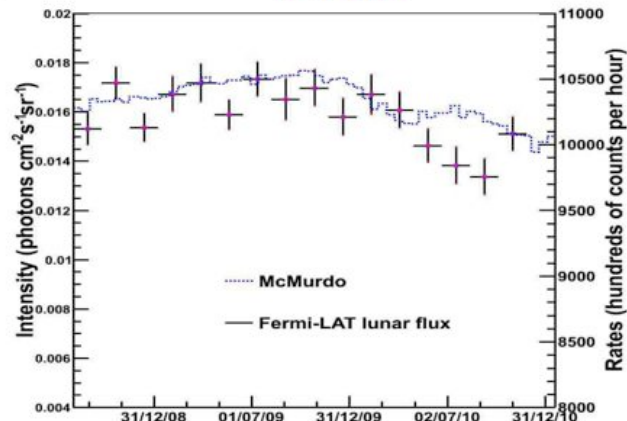
Lunar spectrum (3years) from the paper  
(ApJ, 758, 140 2012)



N. Giglietto - IV Fermi symposium 2012



Neutron monitor rates and Lunar emission



N. Giglietto - IV Fermi symposium 2012

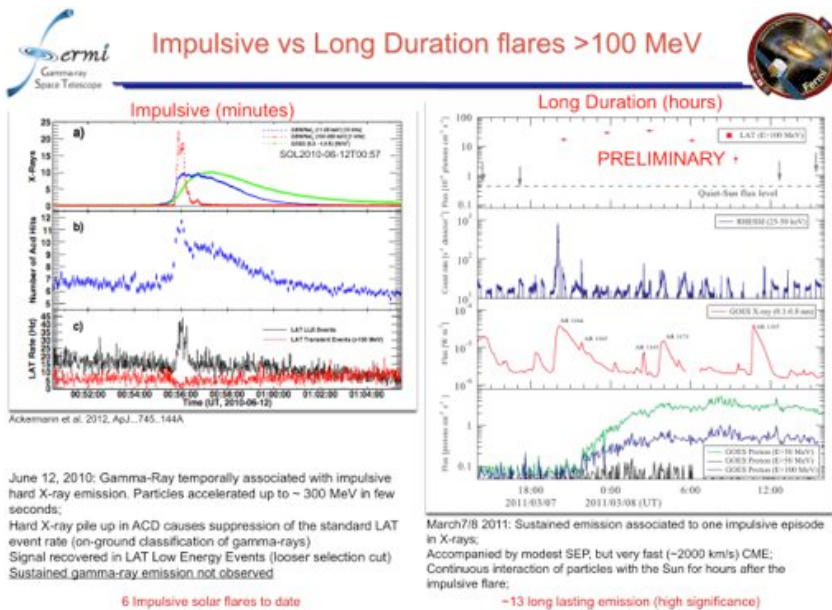
15

NM data from <http://neutronm.bartol.udel.edu/>

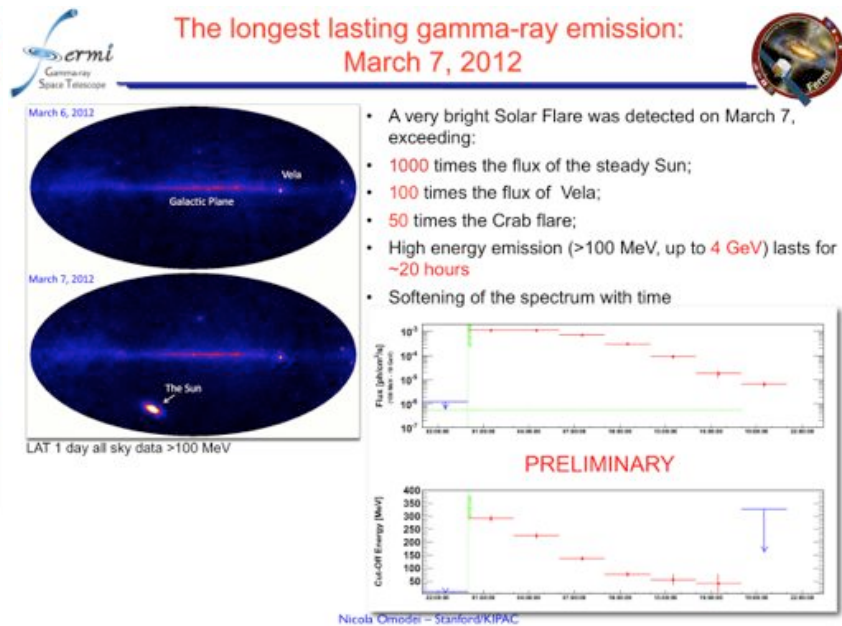
Giglietto

# The Sun

- Focus was the transient Sun – the Sun has helped a lot since the 3<sup>rd</sup> Fermi Symposium



Nicola Omodei – Stanford/KIPAC



Omodei

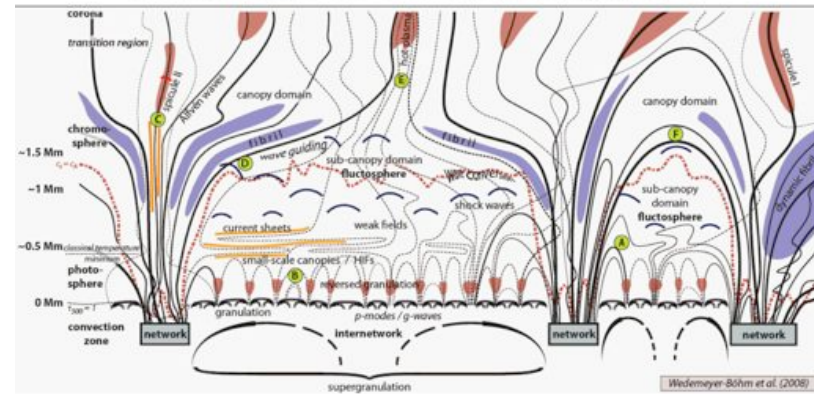


# The Sun 2

- Hugh Hudson made sure that we know what we are getting into
- With *Fermi* the heliospheric magnetic field can be studied in new ways
- Interesting speculation\* on the interpretation of the flare localization vs. time for the March 7, 2012 flare

**Last words: “Publish faster”**

## Structure of the atmosphere



Hudson

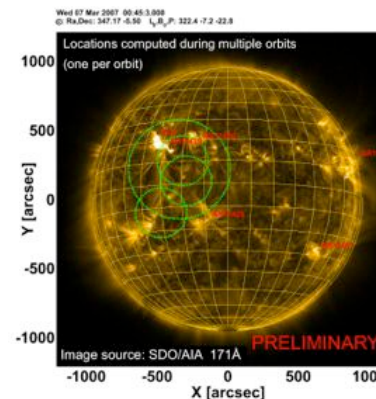
Corona  
Transition region  
Chromosphere  
Photosphere

Wedemeyer-Bohm 2004

Modeled in 1D “semi-empirical” style



Localization



- Events corrected for the “fish-eye-effect”  
– (Ackermann et al. 2012, ApJS)
- 68% CL error circle with systematic error added in quadrature
- Location of the gamma-ray emission ~ consistent with the location of the Active Region 11429

Omodei

Summary 4th International Fermi Sym

Nicola Omodei – Stanford/KIPAC

8

\*Possibility of flare-induced shock acceleration depositing the high-energy particles in nearby large-scale static loops

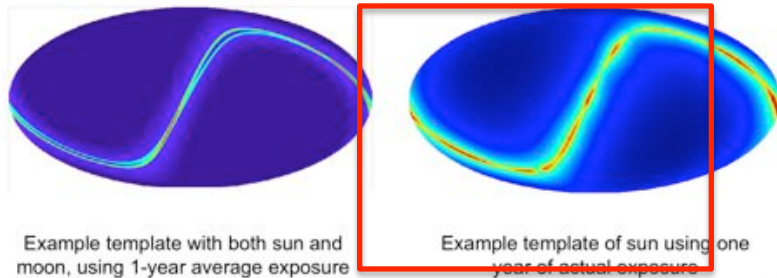
# Sun as a Background

- Inverse Compton scattering on the solar radiation field
- Ferrara:

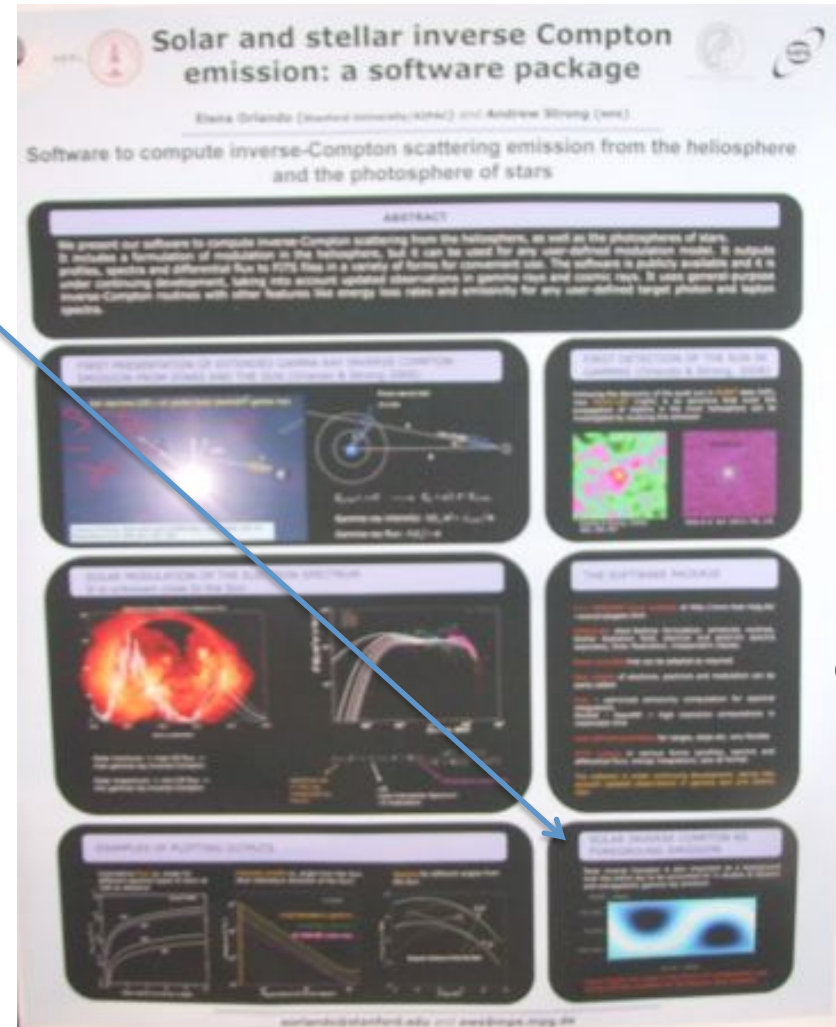


## Development for 5-year catalog

- Both quiescent Sun and Moon can be seen in the 4-year integrated data set
  - Developing tools to calculate exposure-corrected templates using measured spectra
  - Sun and Moon templates will be included as an all-sky source in 5-year catalog analysis



22

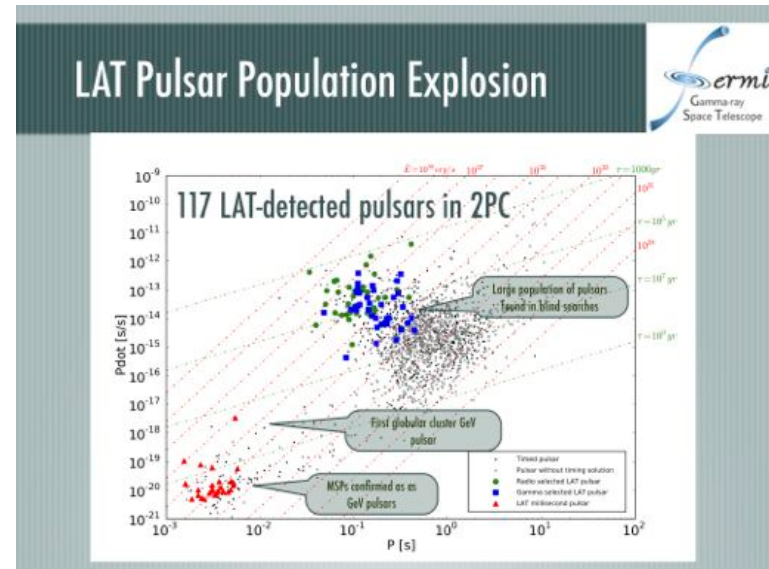


Orlando & Strong

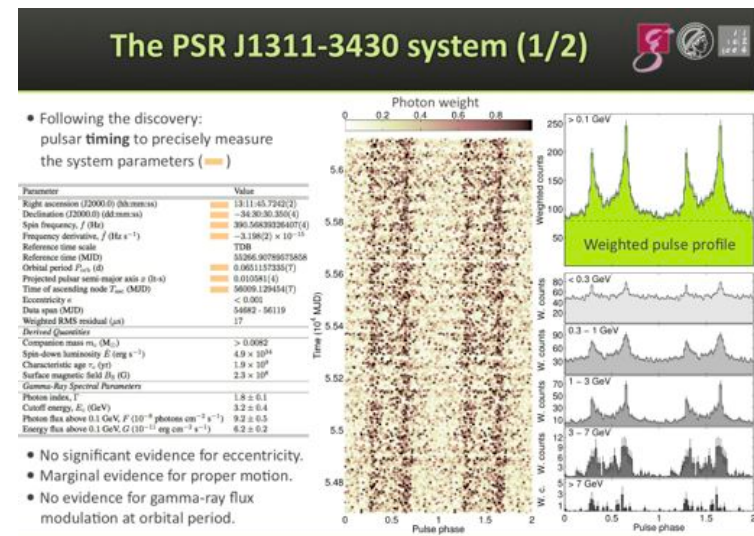
# The Galaxy

# Pulsars

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



Ray



Pletsch

Summary 4th International Fermi

H J Pletsch

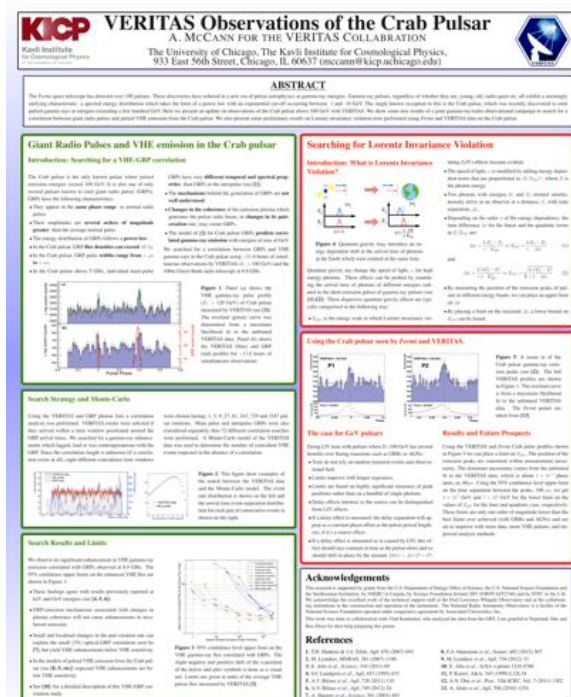
\* Ongoing successful MW collaboration with Pulsar Timing and Pulsar Search Consortia



# Pulsars at VHE

- Since the 3<sup>rd</sup> Fermi Symposium, **VERITAS** studies of the Crab pulsar at >120 GeV have advanced from discovery: Search for correlation with radio giant pulses, limits (with LAT) on Lorentz Invariance Violation
- MAGIC** reported a stereo measurement of the light curve down to ~50 GeV (and reported the nebula IC peak as  $59 \pm 6$  GeV and the nebula as steady > 300 GeV

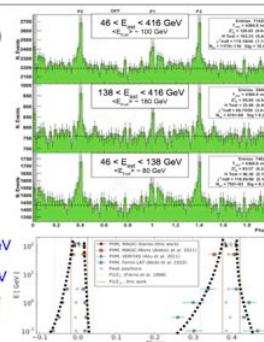
Summary 4th International Fermi Symposium



McCann

## Crab Pulsar: Stereo Observations

- 73 hrs of data (Oct. 2009 - Mar. 2011) (Aleksić et al 2012)
- Energy range:  $E > 50$  GeV
- Pulsation firmly detected
  - H-Test (unbinned) :  $6.4\sigma$
  - EGRET-peaks (a-priori) :  $7.7\sigma$
- Peaks get narrower w/energy
- New peak definitions  $\pm 2\sigma$  FIT:
  - 8.8% of the whole phase
  - P1+P2: 10.4°, P1 5.5°, P2 9.9°
- 3.4 $\sigma$  hint at TW1 [0.04:0.14]



- P1/P2 ratio  $\sim 0.4 \pm 0.2$  at 100 GeV

- No significant yearly variability

Saito/Paneque

# Pulsars

- Kerr on radio polarization measurements, Timokhin on theory of particle acceleration and gamma-ray production in pulsars

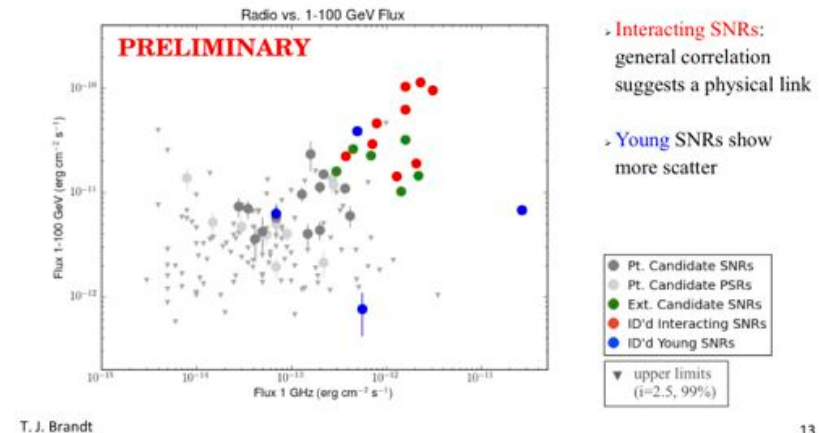


# Supernova Remnants

- First Fermi LAT Catalog of SNRs – a sign that SNRs are a useful LAT population
  - Uniform analysis, including for systematic uncertainties related to the Galactic diffuse emission model (de Palma et al.)
  - Catalog will include analysis of LAT data with multiwavelength data from radio to TeV

## Radio-GeV Correlation?

Radio synchrotron emission indicates the presence of relativistic leptons.  
LAT-detected SNRs tend to be radio-bright:

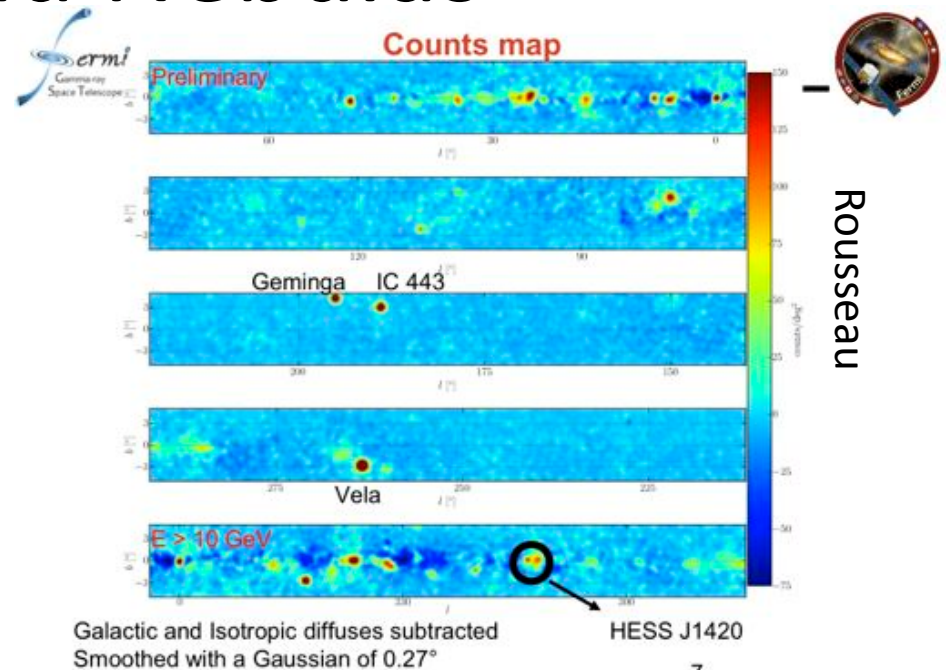
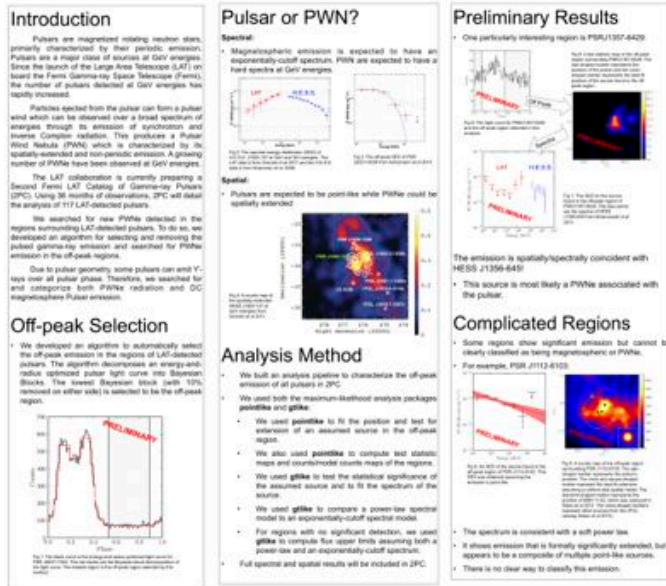
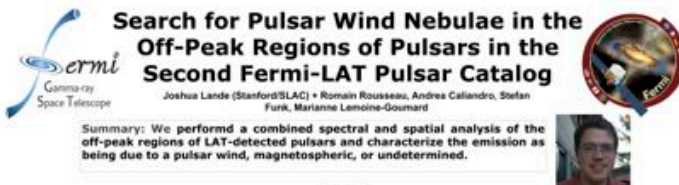


Brandt

13

# Pulsar Wind Nebulas

- Search for low-latitude  $>10$  GeV LAT sources near HESS TeV sources



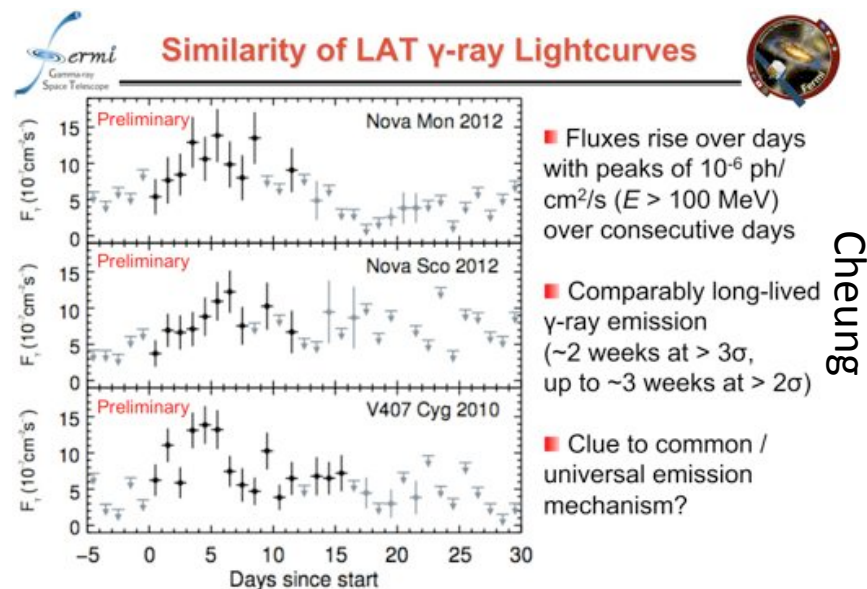
- Search for LAT sources in off-pulse regions of LAT pulsars
- Both involve spectral/spatial comparisons with HESS
- $\sim 15$  candidates found (large increment on known PWNe)

# Other SNR/PWN studies

- Striani interpreted the LAT observations of the flaring Crab nebula in terms of flares and slower 'waves'

# New Novas

- Two found since the 3<sup>rd</sup> FS
  - Unlike V407 Cyg (2010) they are of the much more common (but not recurrent) Classical Nova type
- In one case LAT detection preceded optical discovery (Cheung: LAT as a nova finder for  $d < 4-6$  kpc)
- Martin & Dubus have been grappling with understanding the light curve and X-ray-to-gamma-ray spectrum of V407 Cyg



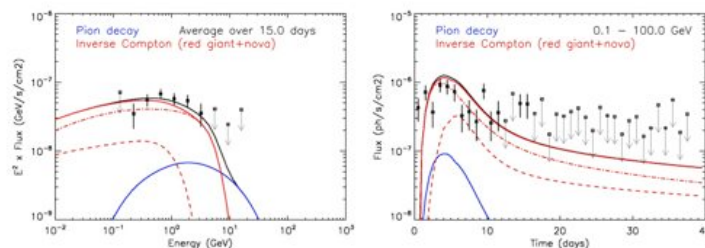
Cheung

V407 Cygni: Gamma-ray emission

How matter accumulation around the WD helps...

**Parameters**

- $R_{\text{WD}} = 10$  AU
- $\dot{M}_{\text{dot}} = 5 \cdot 10^{-8} M_{\odot}/\text{yr}$
- $M_{\text{ej}} = 2 \cdot 10^{-4} M_{\odot}$
- $V_{\text{ej}} = 3000$  km/s
- $\eta_p = 5 \cdot 10^{-3}$ ,  $\eta_e = 3 \cdot 10^{-4}$
- $\xi = 3$
- CDE  $10^8$  cm<sup>3</sup> / 10AU



Large reservoir of particles early on, close to nova photosphere  
Acceleration drops when shock exits the structure  
Bohm diffusion in upstream equipartition magnetic field

Martin

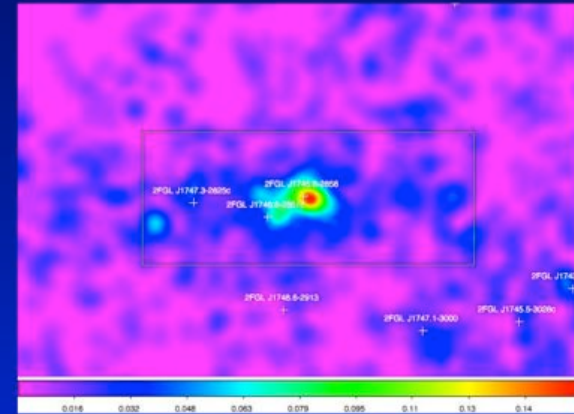
# Galactic Center\*

- Fred Baganoff gave beautiful talk on “the Fermi Galactic Zone of Avoidance”
  - Variety of X-ray evidence for potential gamma-ray sources – nonthermal filaments/shocks, PWNs, star-forming regions
- Looking forward to activity from the close approach of a  $3 M_{\text{Earth}}$  cloud in Sept. 2013 [when you can use the word ‘peribothron’]

\* More later

Summary 4th International Fermi

Fermi 10-200 GeV Galactic Center View



2 x 0.8 Degree Box

Chandra 2-8 KeV Survey



2 x 0.8 Degree

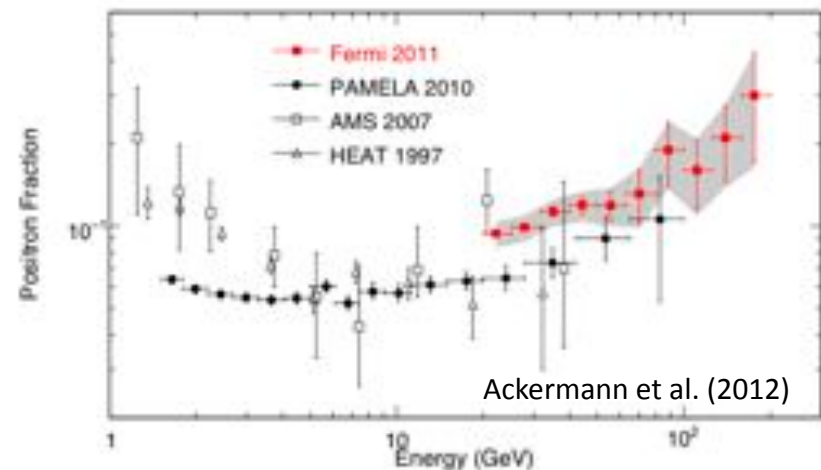
Baganoff



# Cosmic Rays

- Stefano Profumo discussed interpretations of the rising positron fraction with energy (PAMELA result confirmed by LAT, preliminary results presented at 3<sup>rd</sup> FS)
  - Briefly: If it is dark matter it needs to be heavier than 200 GeV and have  $100\text{-}1000 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$  annihilation rates
- “Any competent theoretician can fit any given theory to any given set of facts” (attrib. Redman)

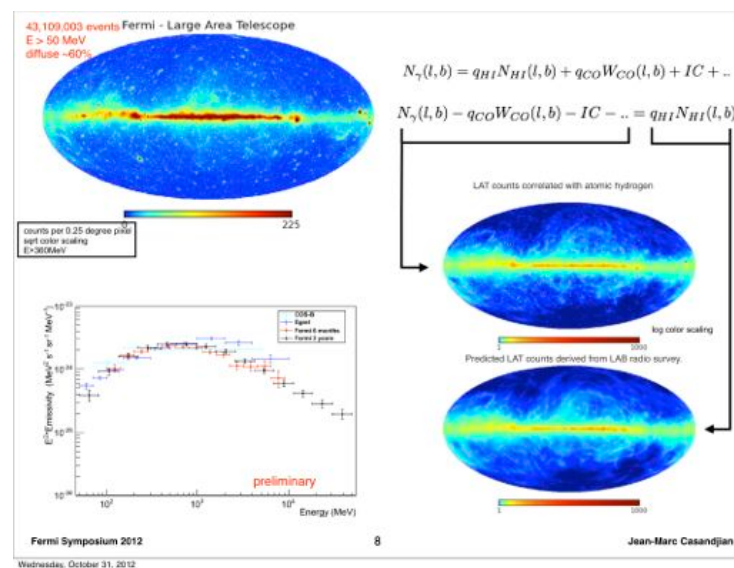
## Positron Fraction



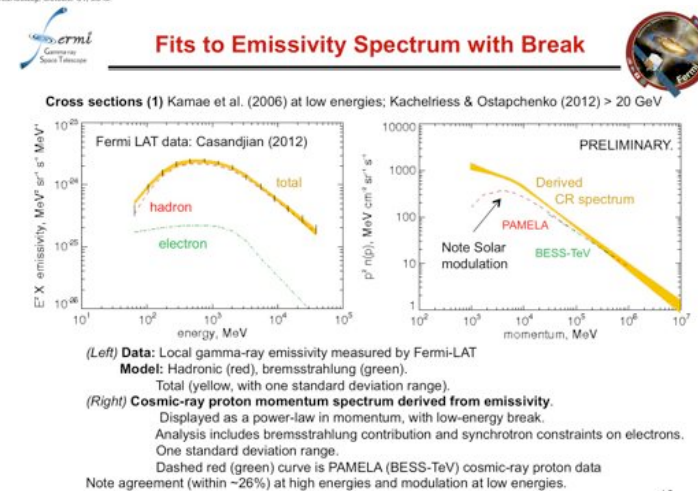
Kistler: CR  $e^+ + e^-$  energy loss rate goes like  $E^2$  (limits the number of sources that can contribute) & diffusion is along filaments (anisotropies do not necessarily point back to the sources)

# Indirect Detection of Cosmic Rays

- Jean-Marc Casandjian presented a decomposition of the LAT gamma-ray observations into the component correlated with H I:
  - “Fermi-LAT is a beautiful instrument and perfect for what we want to measure”
  - Demonstrates that the force field approximation works well, and that the LAT provides enough statistical precision that you need to worry about, e.g., He and the accuracy of the gamma-ray production functions, in addition to electrons
- Chuck Dermer described issues, approaches, and preliminary results for the proton spectrum, including a break in the low-energy demodulated spectrum



Casandjian



Dermer

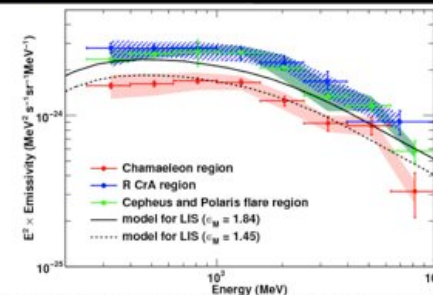
# Indirect detection of CRs 2

- On scales of individual local interstellar clouds  
LAT results indicate small but significant variations of CR density



Fermi Symposium, @Monterey, CA, Oct 31, 2012

## CR Spectrum Close to the Solar System



Compare the HI emissivity spectra of each region with the LIS model

➤ LIS model: calculated from observed local interstellar spectrum assuming different nuclear enhancement factors ( $\epsilon_M$ )

➤ Spectral shapes are similar among them.

➤ Emissivities differ by ~20% even if we consider the systematic uncertainties.

→ Small (~20%) variation in local interstellar CR densities (if we assume uniform CR composition)

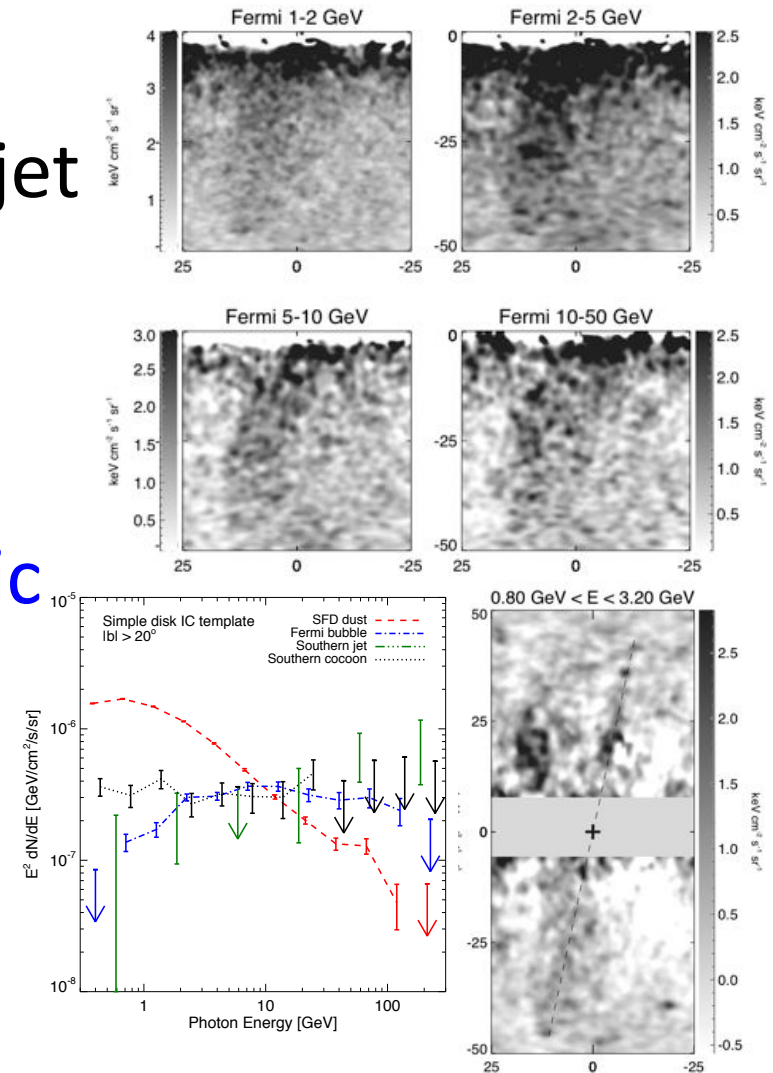
Katsuhiko Hayashi

Hayashi

9

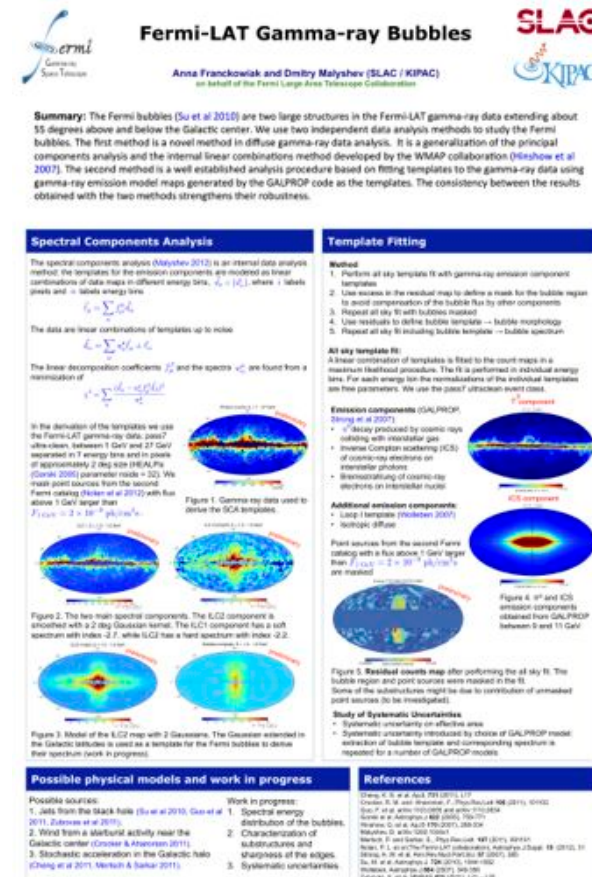
# Fermi Bubbles

- Pushing ahead: Cocoon & jet interpretation - “The jet might be even more dangerous than claiming a 130 GeV line at the Galactic center” (Finkbeiner)



# Fermi Bubbles 2

- A LAT team analysis using template and Internal Linear Combination (template-free) approaches was also presented
- Analyses related to the Fermi Bubbles were also presented by Su and by Dobler

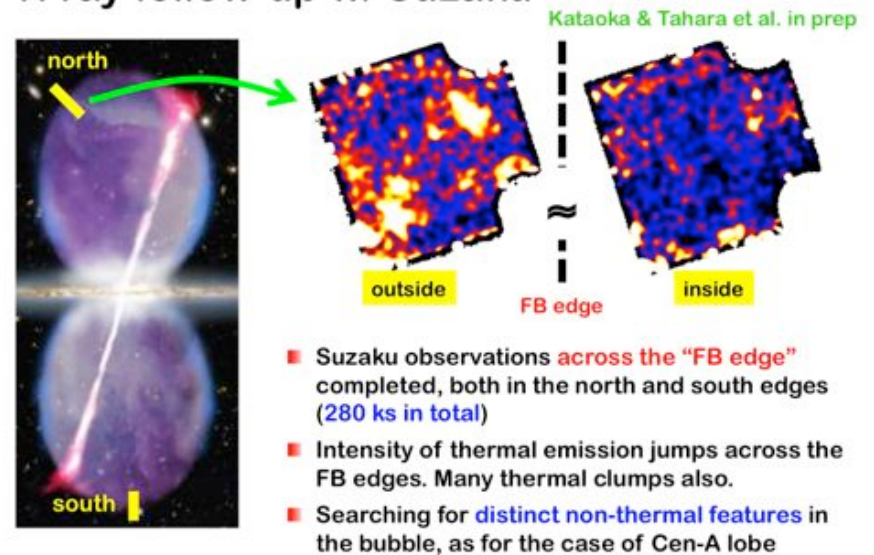




# Fermi Bubbles 3

- Jun Kataoka showed Suzaku observations of the interior and exterior of the northern lobe and indicated that the MAXI  $>2$  keV sky map is also being analyzed
- “There’s nothing like multiwavelength”  
Finkbeiner

## X-ray follow-up w/ Suzaku



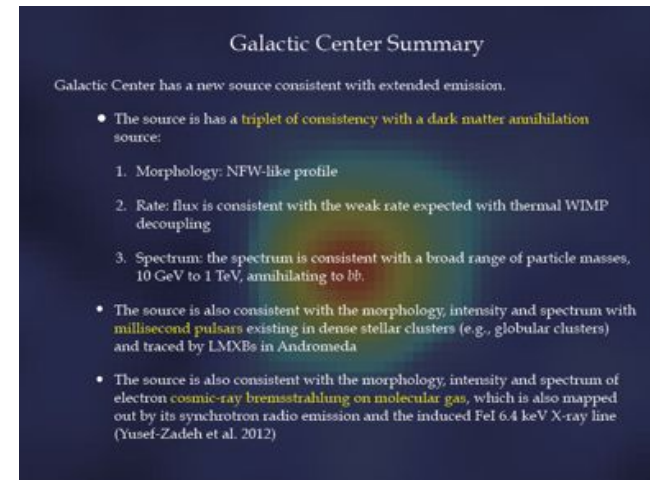
24

# Indirect Searches for Dark Matter

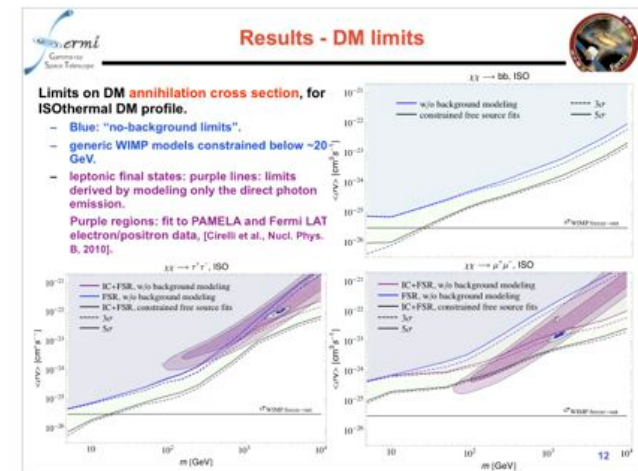
- More of a focus here than at 3<sup>rd</sup> Fermi Symposium
  - Dark Matter in the GC and Halo
  - Dark Matter in dSph galaxies
  - VERITAS Dark Matter Search
  - Dark Matter in Virgo?
  - 130-135 GeV Feature

# Dark Matter in the GC and Halo

- Kevork Abazajian presented results consistent with a Dark Matter signal from the Galactic center region, and also consistent with plausible astrophysical sources
- Zaharijas reported limits from the inner Galaxy (excluding low latitudes) based on modeling and removing the Galactic diffuse foreground, marginalizing over some GALPROP parameters that are otherwise poorly constrained



Abazajian



Zaharijas

# Dark Matter in dSphs

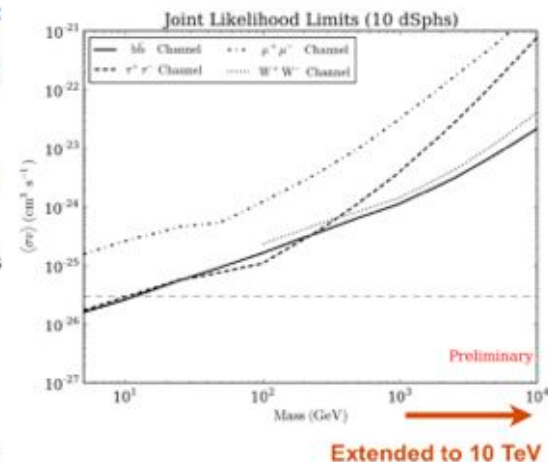
- Stacking analysis of dSph galaxies updated for 4 years and Pass 7, and careful explanation of the comparison with Pass 6 and expected statistical fluctuations
- See also contribution by Loparco on a model independent method for joint analysis



## 4-Year Pass7 Analysis



- Joint likelihood analysis of:
  - 10 dwarf galaxies
  - Expanded photon energy range: 100 MeV - 500 GeV
  - Constrain higher WIMP masses: 5 GeV - 10 TeV
  - Extended time period: 4 years
  - Improved instrument response: P7REPCLEAN\_V9
- Model astrophysical backgrounds based on 2 years of Pass 7 data
  - 2FGL catalog sources (normalization free within 5')
  - 2-year diffuse background models (normalization free)
- Include statistical uncertainties in the solid-angle-integrated J-factor



Drlica-Wagner

Alex Drlica-Wagner | Fermi Talk Title

10

# VERITAS Dark Matter Search

- VERITAS program was described by Geringer-Sameth – most sensitive in the  $\sim > 200$  GeV WIMP mass range
  - 1 Galaxy cluster (Coma, 19 hr)
  - 2 Unassociated 2FGL sources (20 hr total), with 2 more planned for observation
  - 5 dSphs observed and plan to  $\sim$ triple the observing time on 3 of them (total  $\sim > 200$  hr) and make a stacked analysis
  - Strong detection of the GC (SgrA\*); plan a close-by halo study

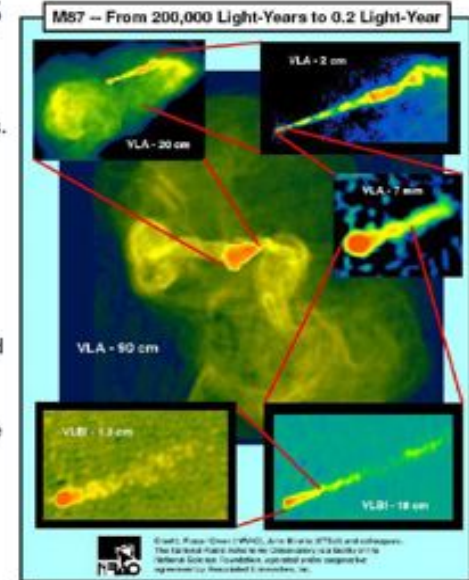


# No Dark Matter Signal from Virgo

- New since 3<sup>rd</sup> Fermi Symposium – a report by Han et al. (arXiv:1201.1003) of a detection of a broad emission region in Virgo consistent with a Dark Matter profile; superseded by Han et al. (arXiv:1207.6749) no longer claiming this
- Gordon & Jogler presented independent LAT analyses of this region, reaching the same conclusions

## Contaminants

- Point sources
  - E.g. active galactic nuclei (AGN) and star-burst galaxies.
  - Their spectra are usually modeled as power laws.
- Cosmic rays
  - Could produce detectable levels of gamma-rays in clusters.
  - Could be a spatially extended contaminant.
- Galactic and extra-galactic diffuse backgrounds.



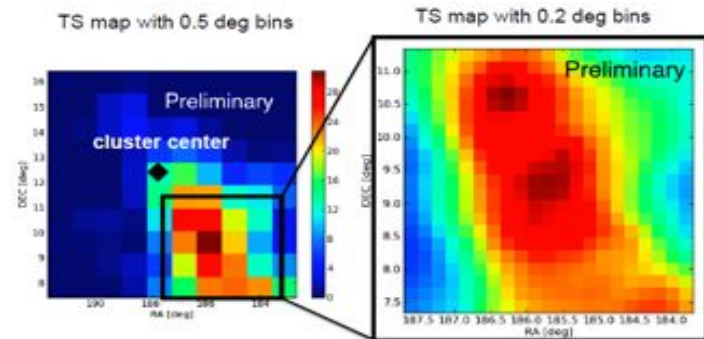
Gordon



Where does this emission come from?



If emission is caused by DM or Cosmic-rays it should be at the cluster center



Jogler

Best source positions far offset from the cluster center!

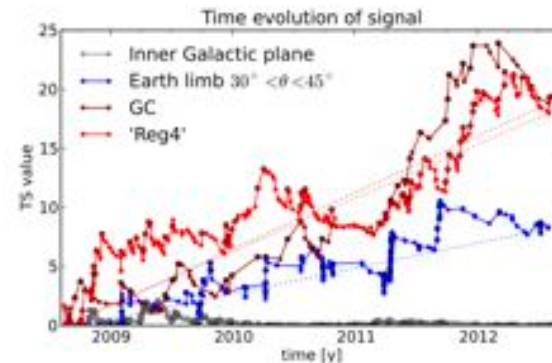
10/30/12

4th International Fermi Symposium, Monterey

8

# 130-135 GeV Feature

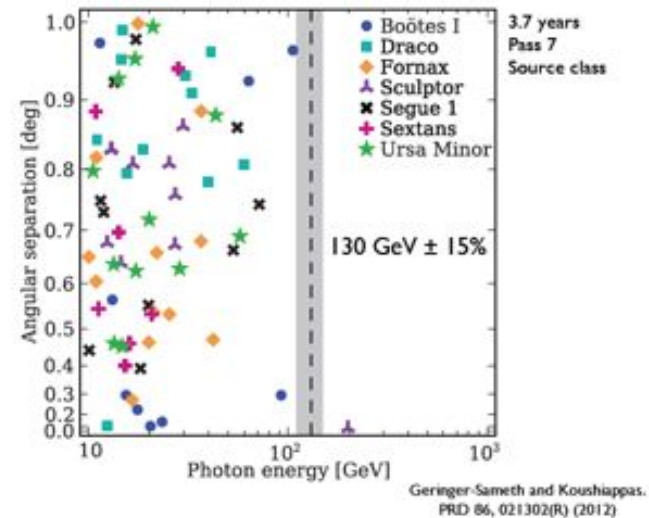
- New since the 3<sup>rd</sup> Fermi Symposium
- Presentations by Weniger (line search in the Galactic center), Albert (line search), Bloom (systematics from non-GC regions, Charles (potential instrumental effects in line searches), Koushiappas/Geringer-Sameth (line search in dSphs)



Finkbeiner, Su, & Weniger (arXiv:1209.4562)

Squeeze more information out of photons

e.g. line emission search from combined dwarfs

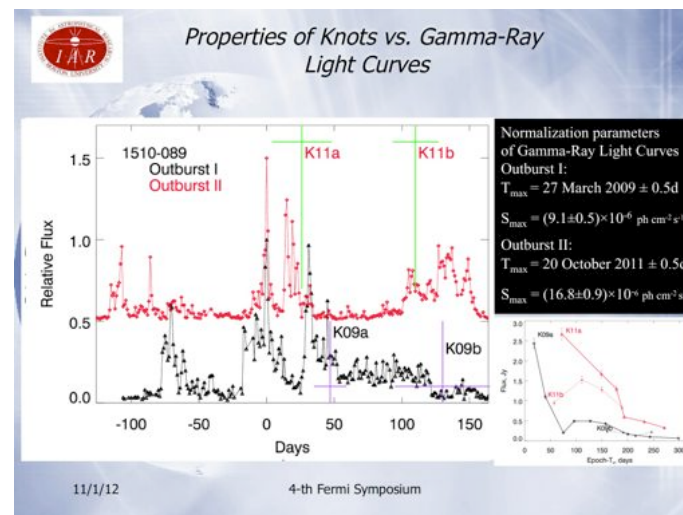


Koushiappas/Geringer-Sameth

# Extragalactic

# Active Galactic Nuclei

- Finke: “It seems that Fermi is a blazar machine”
- Gamma-ray flares appear to be correlated with the 43 GHz VLBI flux of the core
- F-GAMMA study of gamma-ray and cm-mm radio light curves finds strong correlations and results consistent with co-spatial emission regions on pc scales

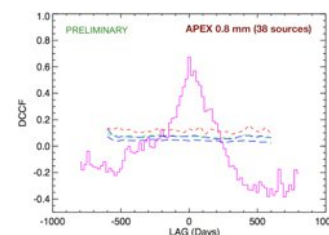


Jorstad

DCCF analysis  
First results



APEX sub-mm vs. Fermi/LAT (see poster by Larsson et al.)



⇒ mm/sub-mm and gamma-ray emission regions co-spatial (within the given uncertainties)

⇒ SED modeling:  
including the mm/sub-mm bands should be considered!

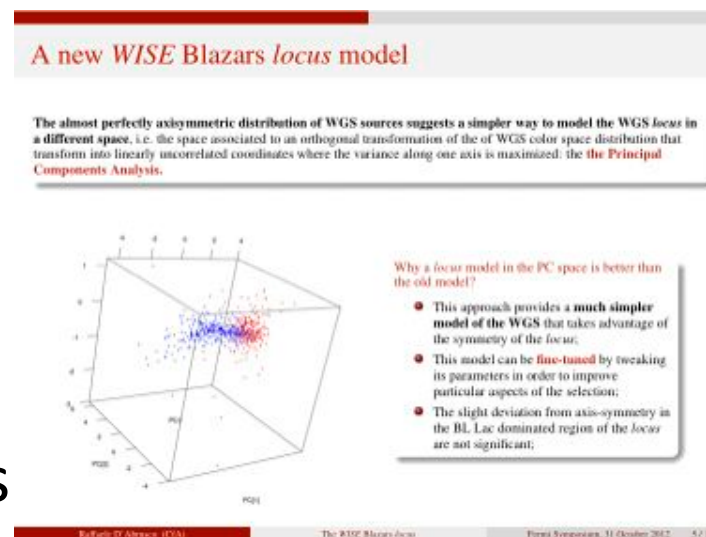
Larsson et al. in prep.

$\langle \text{lag} \rangle_{\text{sub-mm}} = 7 \pm 7 \text{ days}$   
 $\langle \text{lag} \rangle_{\text{sub-mm}} \text{ BL Lacs} = -12 \pm 12 \text{ days}$   
 $\langle \text{lag} \rangle_{\text{sub-mm}} \text{ FSRQs} = 13 \pm 9 \text{ days}$

Fuhrmann

# Active Galactic Nuclei 2

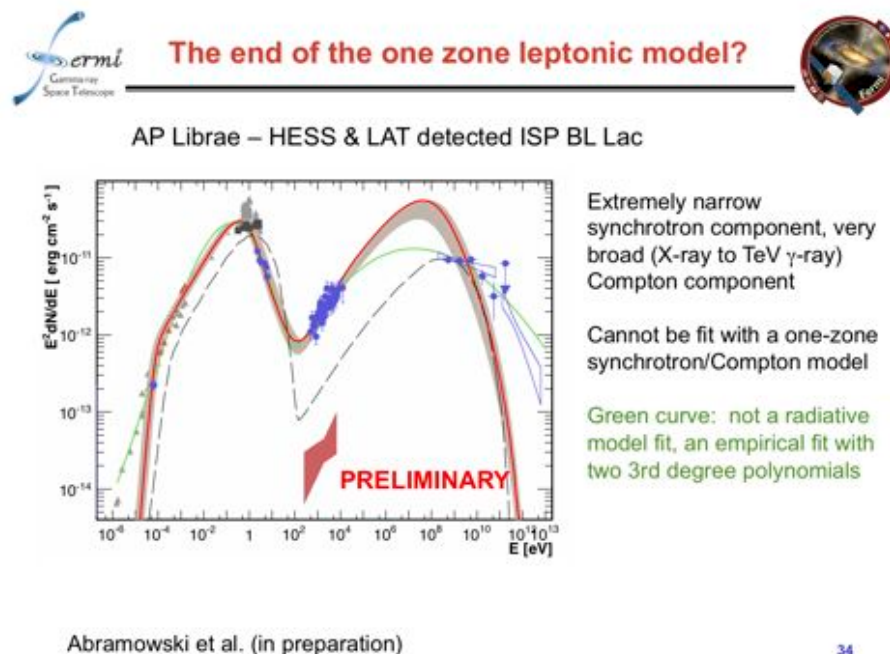
- The 500M+ source WISE infrared catalog has proven very powerful for finding blazars, which occupy a specific part of 3-color space
- In addition to a refinement of the implementation of the region, candidate associations for a number of 2FGL unassociated sources were presented (Massaro)



D'Abrusco

# Active Galactic Nuclei 3

- The quality and quantity of LAT data are also spurring new directions in modeling

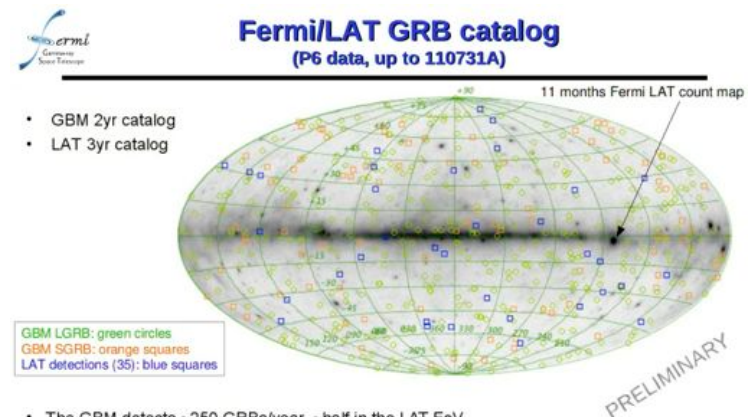


Finke



# Gamma-Ray Bursts

- LAT has about 35 GRBs (vs. 1000+ for GBM)
- Band model** crisis: GBM + LAT spectra often require additional PL, cutoff PL, or thermal components to be well modeled
- The interpretations are not clear and would like to fit more physically motivated models (Vianello)
- The delays of the long-lasting LAT high-energy afterglows are difficult to explain
  - But these GRBs are useful for investigating Lorentz Invariance Violation from evaluating the time rate of change of the spectral index for GRBs over a range of redshifts (Guetta)
  - See also contribution by Vasileiou

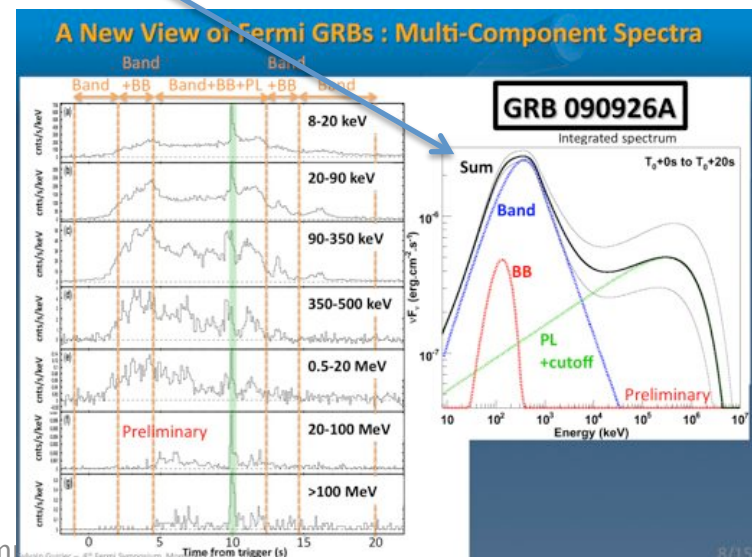


Vianello

- The GBM detects ~250 GRBs/year, ~half in the LAT FoV
- The LAT detects ~10 GRBs/year (35 in 3 years, including 7 LLE-only GRBs)
  - ~10% of GBM bursts in LAT FoV observed
  - ~half with more accurate follow-up localisations by Swift and ground-based observatories (Swift, ART/JVOT, GROND, Gemini-S, Gemini-N, VLT)
  - 9 redshift measurements, from  $z=0.74$  (GRB090328) to  $z=4.35$  (GRB 080916C)

Giacomo Vianello, Fermi Symposium, 10/31/2012

6

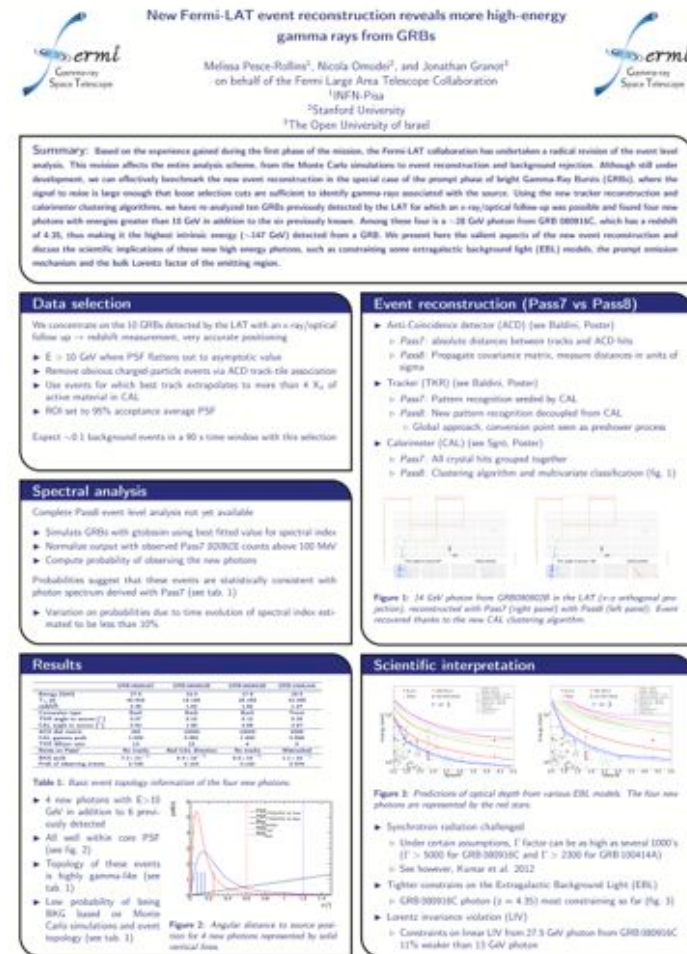


Guiriec

# Gamma-Ray Bursts 2

- Preliminary Pass 8\* analyses of LAT GRBs have recovered some additional (and in some cases more constraining) high-energy GRBs (**one with 28 GeV from GRB 080916C**)
- Simulations are now showing in detail how energy can be extracted from a spinning black hole with a thick accretion disk
  - All it takes is a **magnetic field and \$100** (Tchekhovskoy)
  - These studies indicate short-timescale QPO behavior near the end of the prompt phase – not clear yet whether this is detectable

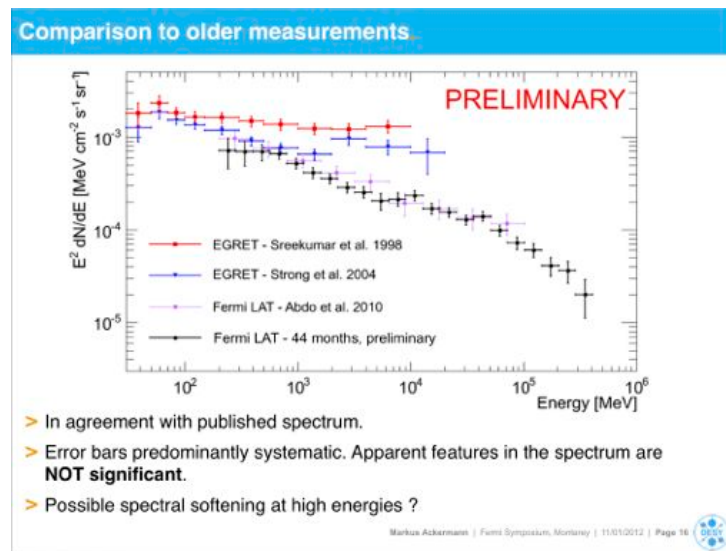
\* More later



Pesce-Rollins

# Extragalactic Diffuse Background

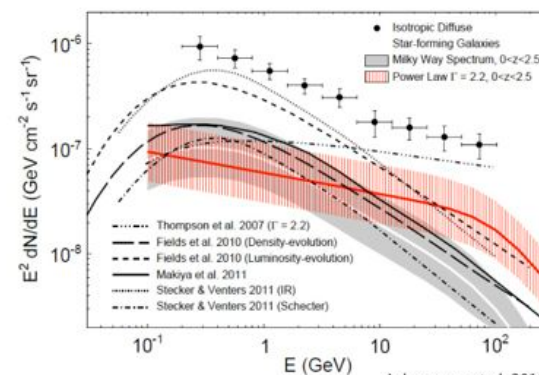
- Markus Ackermann presented an updated LAT analysis (44 months, 200 MeV to 410 GeV)
- Decomposition into contributions from various source classes remains a hot and important topic
  - See contributions by Chakraborty, Donato, Inoue, & Storm on star-forming galaxies, MAGN, and galaxy clusters
- Also thank Michael Shaw for his blazar redshift survey



Ackermann

## IGRB CONTRIBUTION

Contribution by unresolved star-forming galaxies is comparable to that of blazars  
4-23% of LAT-measured isotropic diffuse intensity >0.1 GeV



Bechtol

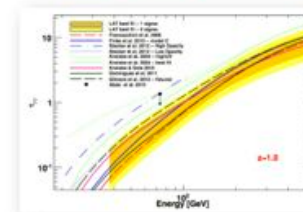
# Extragalactic Background Light

- Much progress since 3<sup>rd</sup> Fermi Symposium, in terms of analysis approaches and data
- LAT composite analysis of 150 gamma-ray bright BL Lacs, fitting scale factors for various published EBL models
- HESS measurements of EBL density (IR) at low redshift has better sensitivity than the LAT (contrib. by Giebels)
- Related contributions on the IGMF by Arlen, Venters, & Vovk



## Composite Likelihood Results: 2

- A significant steepening in the blazars' spectra is detected
- This is consistent with that expected by a 'minimal' EBL:
  - i.e. EBL at the level of galaxy counts
  - 4 models rejected above 3sigma
- All the non-rejected models yield a significance of detection of 5.6-5.9  $\sigma$
- The level of EBL is 3-4 times lower than our previous UL (Abdo+10, ApJ 723, 1082)

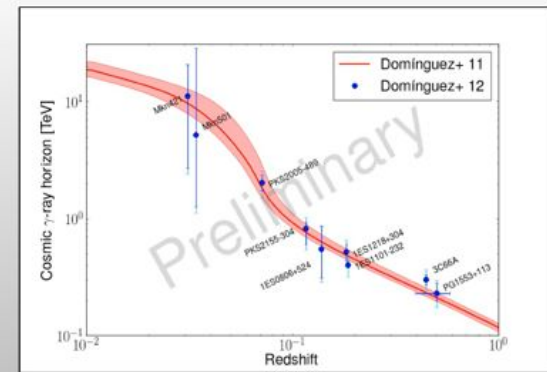


Ackermann+12

| Model <sup>a</sup>                     | Ref <sup>b</sup> | Significance of best Rejection <sup>c</sup> | $\chi^2$        | Significance of best Rejection <sup>c</sup> |
|----------------------------------------|------------------|---------------------------------------------|-----------------|---------------------------------------------|
| Stecher et al. (2006) - fast evolution | (27)             | 4.6                                         | 0.93 $\pm$ 0.02 | 17.3                                        |
| Stecher et al. (2006) - baseline       | (27)             | 4.6                                         | 0.12 $\pm$ 0.03 | 15.3                                        |
| Krawinkel et al. (2004) - high UV      | (22)             | 5.1                                         | 0.37 $\pm$ 0.08 | 5.9                                         |
| Krawinkel et al. (2004) - best fit     | (22)             | 5.8                                         | 0.53 $\pm$ 0.12 | 3.2                                         |
| Gleuermann et al. (2012) - fiducial    | (27)             | 5.8                                         | 0.67 $\pm$ 0.14 | 1.9                                         |
| Primack et al. (2005)                  | (56)             | 5.5                                         | 0.77 $\pm$ 0.15 | 1.2                                         |
| Dominguez et al. (2011)                | (27)             | 5.9                                         | 1.02 $\pm$ 0.23 | 1.1                                         |
| Finke et al. (2010) - model C          | (24)             | 5.8                                         | 0.86 $\pm$ 0.25 | 1.9                                         |
| Franceschini et al. (2008)             | (7)              | 5.9                                         | 1.02 $\pm$ 0.33 | 0.9                                         |
| Gleuermann et al. (2012) - fixed       | (27)             | 5.8                                         | 1.02 $\pm$ 0.22 | 0.7                                         |
| Krawinkel & Odeh (2010)                | (26)             | 5.7                                         | 0.90 $\pm$ 0.19 | 0.6                                         |
| Gleuermann et al. (2009) - fiducial    | (2)              | 5.8                                         | 0.99 $\pm$ 0.22 | 0.6                                         |

Ajello

## Cosmic $\gamma$ -ray Horizon: results



There are 4 out of 15 cases where our maximum likelihood methodology could not be applied since the prediction from the synchrotron/SSC model was lower than the detected flux by the Cherenkov telescopes.

Two other cases where the statistical uncertainties were too high to set any constraint on EBL.

Dominguez

# LAT Performance

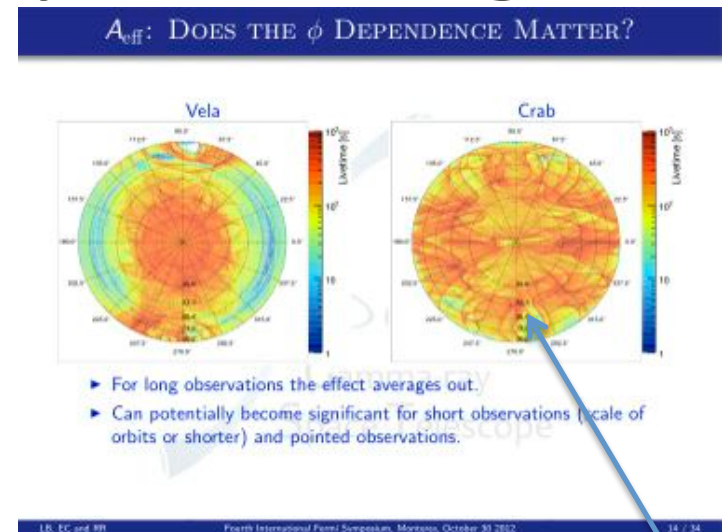


# Pass 7 & Pass 7 Reprocessing

- Since the 3<sup>rd</sup> Fermi Symposium the LAT Collaboration has moved to Pass 7 event selections
  - Not a new reconstruction but important improvements in classification (e.g., for increased  $A_{\text{eff}}$  at low energies)
- Luca Baldini summarized the recent LAT publication on the Pass 7 performance for high-level analysis. A Great Read\*
- Now a Pass 7 reprocessing has been undertaken to update calibration constants, affecting energy scale and PSF (for the better)
  - First results presented this week
  - See also Wood & Roth poster on the inflight PSF fitting
  - Release by the end of the year

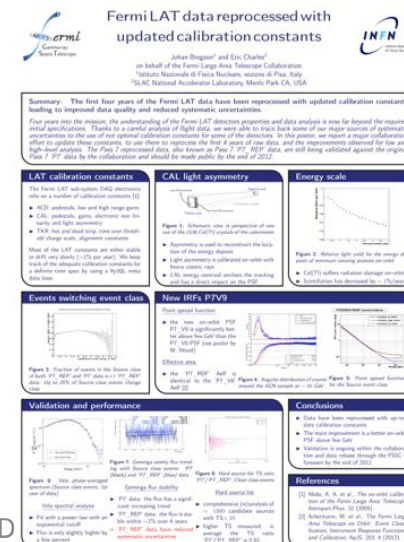
\* arXiv:[1206.1896](https://arxiv.org/abs/1206.1896)

Summary 4th International Fermi Symposium - S. D



Baldini

(N.B. edge of FOV is at 3<sup>rd</sup> ring)





# Pass 8

- Presented in detail in posters on **ACD pile-up correction, CAL reconstruction, track reconstruction, and event-level analysis, plus an overview**
- Pass 8 is built on a fundamental reimplementation of the reconstruction

**Pass 8: Toward the Full Realization of the Fermi LAT Scientific Potential**

W. Atwood<sup>1</sup>, L. Baldi<sup>2</sup>, P. Bruel<sup>3</sup>, E. Charles<sup>4</sup>, and T. Usher<sup>1</sup>  
 on behalf of the Fermi Large Area Telescope Collaboration  
<sup>1</sup>Santa Cruz Institute for Particle Physics, University of California, Santa Cruz CA  
<sup>2</sup>University of Pisa and INFN Pisa  
<sup>3</sup>ILLR, Ecole polytechnique, IN2P3/CNRS  
<sup>4</sup>SLAC National Accelerator Laboratory, Menlo Park CA

**Summary:** Overview and prospects for the Fermi LAT Pass 8 event-level analysis.

The event selection developed for the Fermi Large Area Telescope before launch has been periodically updated to reflect the constantly improving knowledge of the detector and the environment in which it operates. Pass 7, released to the public in August 2011, represents the most recent major iteration of this incremental process. In parallel, the LAT team has undertaken a coherent long-term effort aimed at a radical revision of the entire event-level analysis, based on the experience gained in the first phase of the mission. This includes virtually every aspect of the data reduction process, from the simulation of the detector to the event reconstruction and the background rejection. The potential improvements include (and are not limited to): a significant reduction in background contamination coupled with an increased effective area, a better understanding of the systematic uncertainties and an extension of the energy reach for the photon analysis below 100 MeV and above 100 GeV. We present an overview of the work that has been done or is ongoing and the prospects for the near future.

**Introduction**

The current LAT event-level analysis was largely developed before launch using Monte Carlo simulations in a series of iterations that we call Passes. Pass 6 was released at launch and followed (in August 2011) by Pass 7, which mitigated the impact of some of the limitations of its predecessor. On-orbit experience with the fully integrated detector has revealed some neglected and overlooked issues—primarily (but not only) the effect of the instrumental pile-up (aka Chatter Events). Clear improvements, with the potential to greatly extend the LAT science capabilities, have been identified in all the main areas:

- Monte Carlo simulation of the detector;
- Event reconstruction;
- Background rejection.

**Tracker Reconstruction** [see T. Usher, poster]

Current framework—track-by-track combinatorial pattern recognition.

- Track confusion and errors in high-multiplicity events;
- Energy reach effectively limited by mistacking;
- Provide additional information for the background rejection.

Pass 8—global tree-based approach to track finding.

- Reduce mistacking, improve the high-energy Point Spread Function (PSF);
- Provide additional information for the background rejection.

More development areas: Refine fit measurement errors, PSF analysis, buffer truncation [see L. Baldi, poster], cosmic-ray tracking, ghost tracking, neutral energy, vetting.

**Calorimeter Reconstruction** [see C. Sgró, poster]

Current framework—the calorimeter is treated as a monolithic whole.

- Background rejection, compromised by instrumental pile-up;
- No chance to see multi-photon events;
- Pass 8—clustering stage added at the beginning of the reconstruction chain:
- Separate the pile-up activity from the genuine gamma-ray signal;
- Provide topology information to the following reconstruction steps.

More development areas: light collection simulation, position reconstruction, cluster classification, moments analysis and direction reconstruction, false acquisition, crystal saturation, energy reconstruction beyond 1 TeV [see P. Bruel, poster].

**ACD Reconstruction** [see A. DeLuca-Wagner, poster]

Current framework—track/line association in physical distance.

- Explicit energy-dependent cuts;
- Susceptible to global pile-up at low energy;
- Pass 8—track and cluster/line association based on invariant error propagation;
- Improved background rejection;
- Use trigger veto to suppress pile-up.

**Physics Potentials**

Pass 8 will approach the full scientific potential of the LAT.

- Lower backgrounds and better control over the systematic uncertainties;
- Extension of the energy reach:
  - Below 100 MeV: improved energy resolution and background rejection (hadronic vs. leptonic emission);
  - Above 100 GeV: less tracking confusion, better compensation for calorimeter saturation (below  $\gamma$  and cosmic-ray  $\gamma$   $\rightarrow \pi^+ \pi^-$  spectra above 1 TeV);
- Better high-energy Point Spread Function (AGN pair halo);
- Recover calorimeter-only events for science analysis (substantial effective area increase above 20 GeV);
- Multi-photon events (coherent  $\gamma$ -ray production in AGNs and GRBs);
- $\gamma$ -ray polarimetry.

**Ongoing Developments**

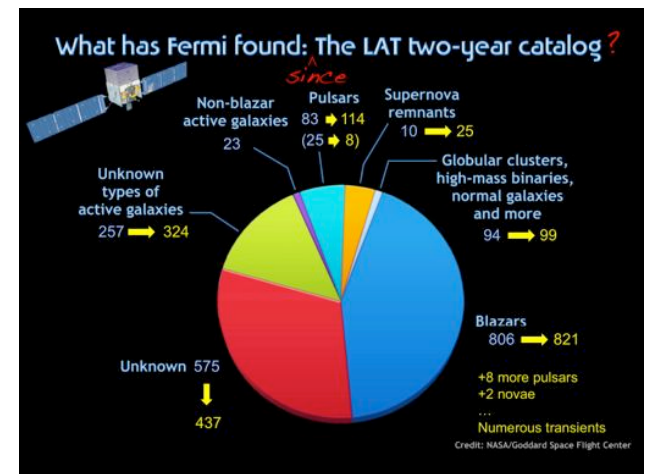
- Integrate reconstruction improvements into a coherent event structure;
- Beginning work on the background rejection [see M. Wood, poster];
  - Start from the basic components of the Pass 7 analysis;
  - Now, flexible analysis framework under development;
  - Define provisional event classes to start assessing the performance improvements.
- Definition of a set of key science projects:
  - Use small-size reprocessed flight data sets;
  - Benchmark the new event reconstruction on real science projects [see M. Pavesi-Rollin, poster].

The Authors wish to acknowledge the substantive and diverse contribution of the Pass 8 working group members. Many of the items briefly mentioned here are more thoroughly described in dedicated posters.

Atwood

# News on New Catalogs

- Ferrara overview of follow-up work on classifying, associating, and identifying 2FGL sources and plans for a 5-year LAT catalog
- 1FHL: >10 GeV LAT sources (3 years, 514 sources, 63 are not 2FGL and many of interest to IACTs) (Paneque)
- FAVA: Systematic search for variability on weekly timescales, sensitive and diffuse emission model-free – apparently a Nova detector (Allafort)
- LAT GRBs: 35 GRBs (7 LLE-only) (Vianello)
- GBM catalogs: Time-resolved Spectral (bright burst) catalog was also mentioned by von Kienlin/Greiner



Ferrara



## Lots more to do!

- Near-term upcoming results
  - Second LAT pulsar catalog [P. Ray, Monday]
  - Catalog of LAT-detected SNR [T. Brandt, Tuesday]
  - Catalog of LAT sources at >10 GeV [D. Paneque, next]
  - Catalog of Flaring LAT sources [A. Allafort, just after]
  - List of LAT-detected TGFs [J. Grove, Wednesday]
  - List of LAT-detected solar flares [N. Omodei, Monday]
  - Extension of both GBM GRB catalogs for years 3 & 4 [A. von Kienlin, after that]
  - Catalog of joint Fermi-Interplanetary Network GRBs
  - Update to GBM-detected TGFs [V. Connaughton, Monday]
  - Type-1 X-ray bursts in GBM
  - 5-year catalog of LAT point sources

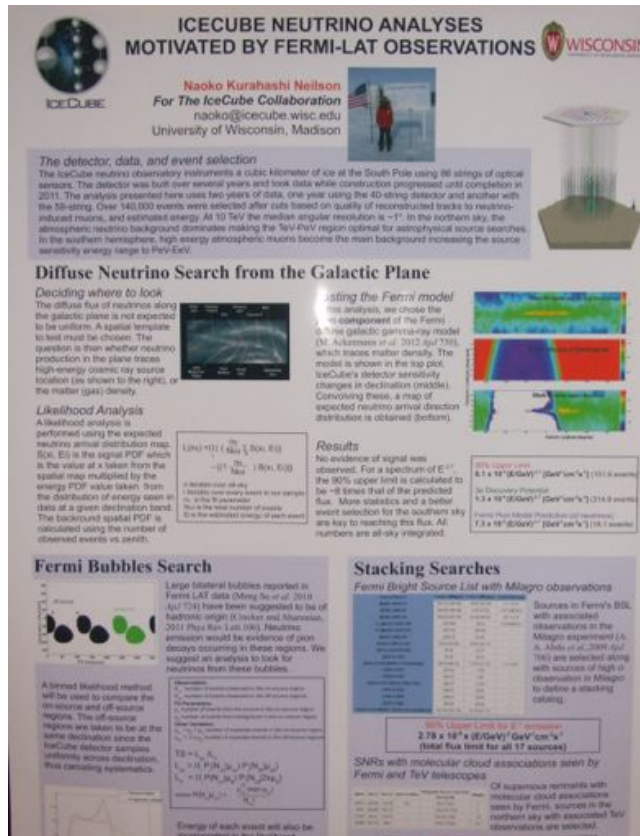
# Multiwavelength Session

- Organized by Chuck Dermer & Liz Hays: Radio through TeV in wavelength order + GW
- Dave Thompson opened by urging coordinated MW campaigns
- **Radio telescope arrays** (Alexander van der Horst)
  - With an emphasis on LOFAR and correlative studies with GBM
- **Planck & WMAP** (Isabelle Grenier) microwave
  - Impact on diffuse emission studies, SNRs, AGNs
- **NuSTAR** (Greg Madejski) hard X-ray imaging
  - Joint monitoring campaigns with *Fermi* are being planned
- **aLIGO** (Lindy Blackburn for Cole Miller) gravitational wave
  - Sensitivity will soon reach the level at which NS-NS mergers (face on) should be detected at a few per year rate
  - Contemporaneous operation with GBM is important
- **HAWC** (Brenda Dingus) sky monitoring in the >1 TeV range
  - 30 tanks now, 100 next year, on the way to 300 “HAWC will observe Galactic GeV sources with the same significance as *Fermi*”
- **CTA** (David Williams) will begin construction in “~2015”
  - Will “build on the *Fermi* legacy”

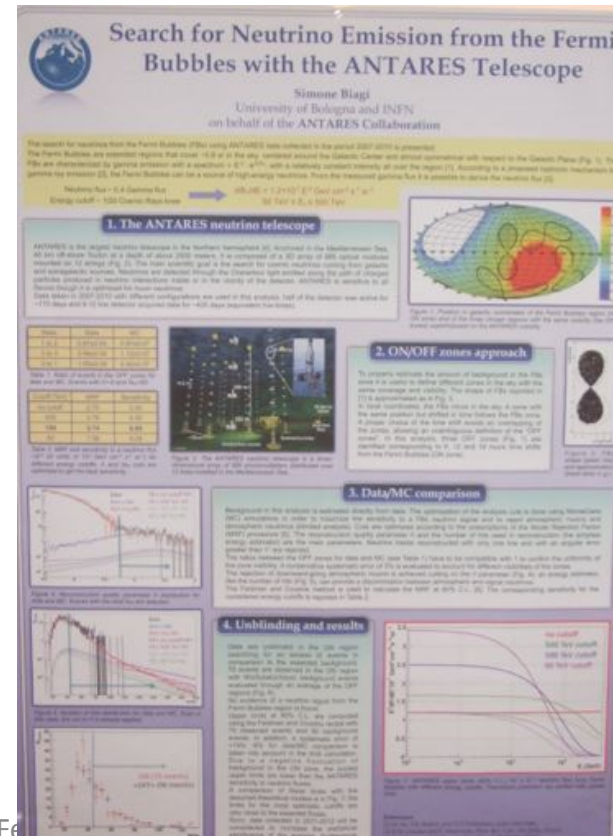
# Multimessenger Too

- Neutrino astronomy is being applied to follow up *Fermi* results

Neilson



Biagi



# Outlook

# A Broader Perspective

- Roger Blandford on “what will you have done for us lately?” described Fermi science in context of 5 broader topics in astrophysics, pointing out that discovery and understanding are more fun than upper limits
- **Dark matter** – 23% of contemporary universe
  - 30 direct detection experiments and they need to get bigger
  - Indirect detection (gamma rays, positrons) has astrophysical uncertainties
- **Black holes** from GRB scale (formation) to AGNs\*
- **Detection of gravitational radiation** – Fermi can help it become astronomy
- **Extreme electrodynamics** – EA currents and PV voltages
- “I believe that the best is yet to come from Fermi and that is not belittling the considerable accomplishments that have come before.”



# Outlook: A Fermi Science Metric

- As an O *The 2013 Fermi Summer School will*  
*Fermi* h take place in Lewes, Delaware, May  
the exp 27-June 5, 2013. Sponsored by the  
field and mission it is a great way to get up to  
of the s speed on Fermi science and  
from ga analysis.  
astrono  
*Compton Gamma Ray*  
Observatory fostered
- Julie illustrated this  
with a chart of GI  
proposal submission  
counts



\* From  
[http://fermi.gsfc.nasa.gov/cgi-bin/bibliography\\_fermi](http://fermi.gsfc.nasa.gov/cgi-bin/bibliography_fermi)  
selecting all publications that present analysis of Fermi  
data and/or refer to published Fermi results and/or  
predict Fermi results

# Outlook: Looking Back

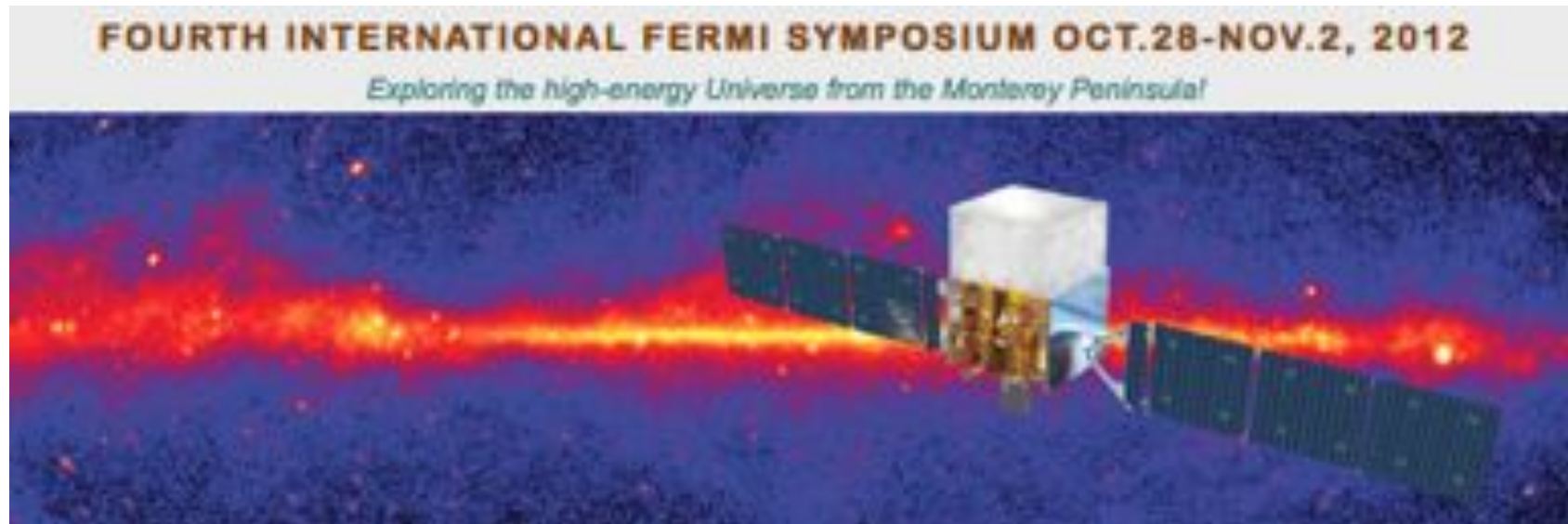
- Don Kniffen reminded us that the scientific drivers for the balloon and then satellite experiments in high-energy gamma-ray astronomy usually have **not** turned out to be the big discovery or selling point for the **next** experiment. Timeline:

Optimistic predictions -> Balloon experiments -> Better balloon experiments -> [Evidence for diffuse flux] -> SAS-2/COS-B -> [Diffuse flux and pulsars] -> EGRET -> [Blazars] -> AGILE, Fermi ->

# Current Outlook

- For **Fermi**: good if you keep making discoveries, writing papers, and finding the ‘science drivers’
- For high-energy gamma-ray astronomy more broadly: also good
  - Ground-based: **H.E.S.S. (I.I.)**, **MAGIC**, and **VERITAS** have all recently completed upgrades and big advances are coming from **HAWC** and **CTA**
  - **AGILE** is still flying and **Gamma-400** has promise as the next space mission in the GeV range

# Thank You



# Highlights from the 5<sup>th</sup> Fermi Symposium

- Pass 8 in wide use
- 3FGL