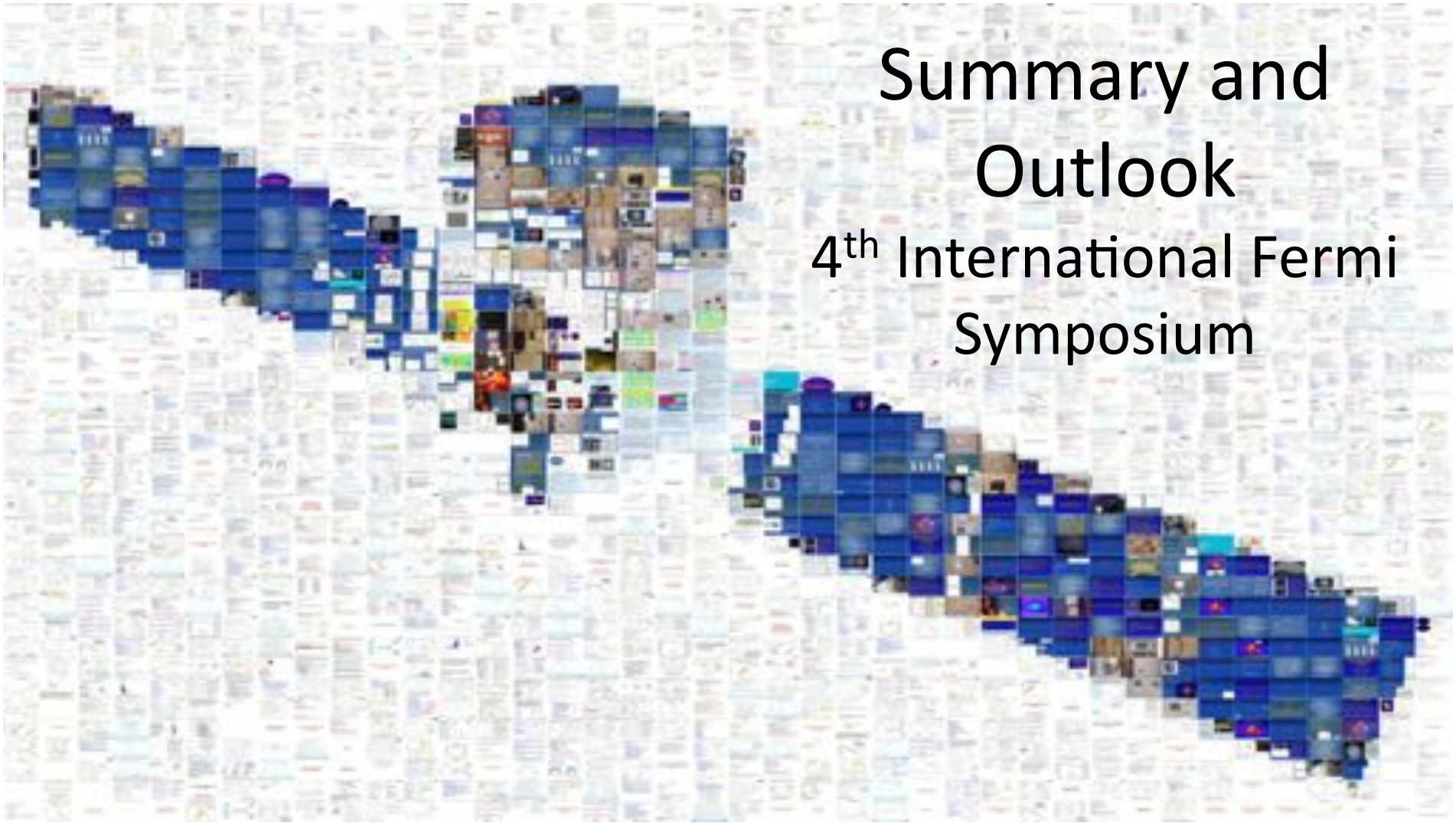

Summary and Outlook

4th 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 Senatore, Stanford University, USA

+ Bob Kahn
+ Dorrene Ross

International Science Organizing Committee (SOC)

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Ronaldo Bellazzini (INFN, Pisa)
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Isabelle Grenier (Laboratoire AIM, Saclay)
Elizabeth Hays (GSFC)
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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:	Atwood, W. B.; Bloom, E. D.; Godfrey, G. L.; Hertz, P. L.; Lin, Ying-Ch; Nolan, P. L.; Snyder, A. E.; Taylor, R. E.; Wood, K. S.; Michelson, P. F.
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

http://aas.org/baas/obits/obit?Full_Name=Patrick_L._Nolan&Date=2011-11-06

Outline

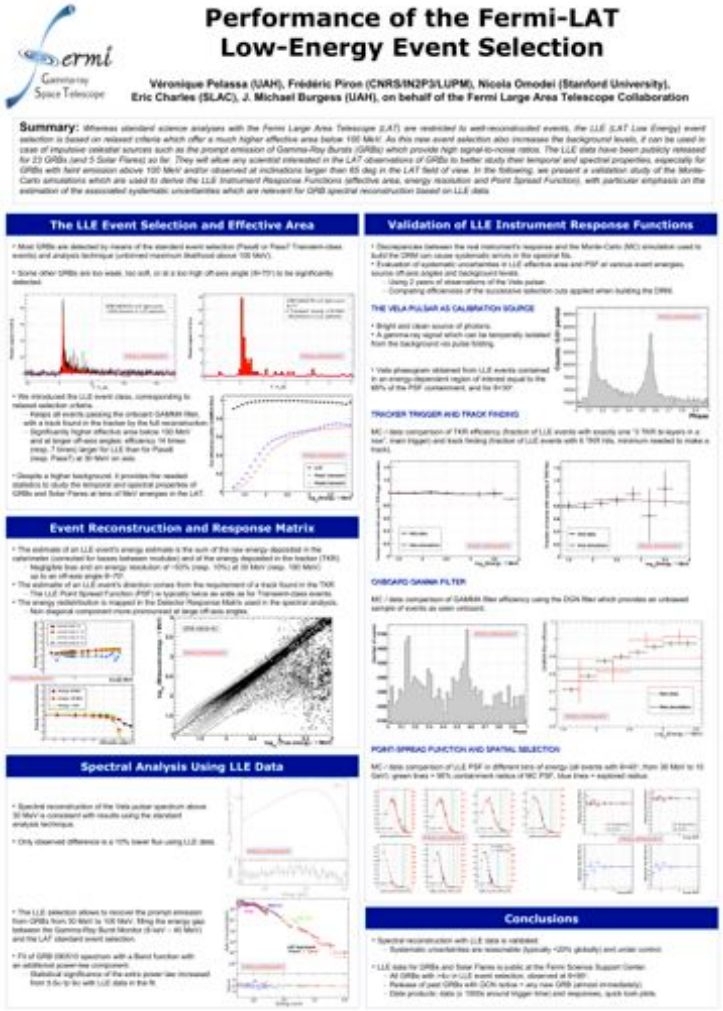
- State of *Fermi*
- State of *Fermi* Science
  - Subjective Symposium Summary
- Outlook

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



Performance of the Fermi-LAT Low-Energy Event Selection

Véronique Pelassa (UAH), Frédéric Piron (CNRS/IN2P3/LUPM), Nicola Omodei (Stanford University), Eric Charles (SLAC), J. Michael Burgess (UAH), on behalf of the Fermi Large Area Telescope Collaboration

Summary: Whereas standard science analyses with the Fermi Large Area Telescope (LAT) are restricted to well-reconstructed events, the LLE (LAT Low Energy) event selection is based on relaxed criteria which offer a much higher effective area below 100 MeV. As this new event selection also increases the background levels, it can be used in case of impulsive celestial sources such as the prompt emission of Gamma-Ray Bursts (GRBs) which provide high signal-to-noise ratios. The LLE data have been publicly released for 23 GRBs (and 5 Solar Flares) so far. They will allow any scientist interested in the LAT observations of GRBs to better study their temporal and spectral properties, especially for GRBs with faint emission above 100 MeV and/or observed at inclinations larger than 65 deg in the LAT field of view. In the following, we present a validation study of the Monte-Carlo simulations which are used to derive the LLE Instrument Response Functions (effective area, energy resolution and Point Spread Function), with particular emphasis on the estimation of the associated systematic uncertainties which are relevant for GRB spectral reconstruction based on LLE data.

The LLE Event Selection and Effective Area

Validation of LLE Instrument Response Functions

Event Reconstruction and Response Matrix

Spectral Analysis Using LLE Data

Conclusions

Pelassa*

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

State of *Fermi* – on the ground

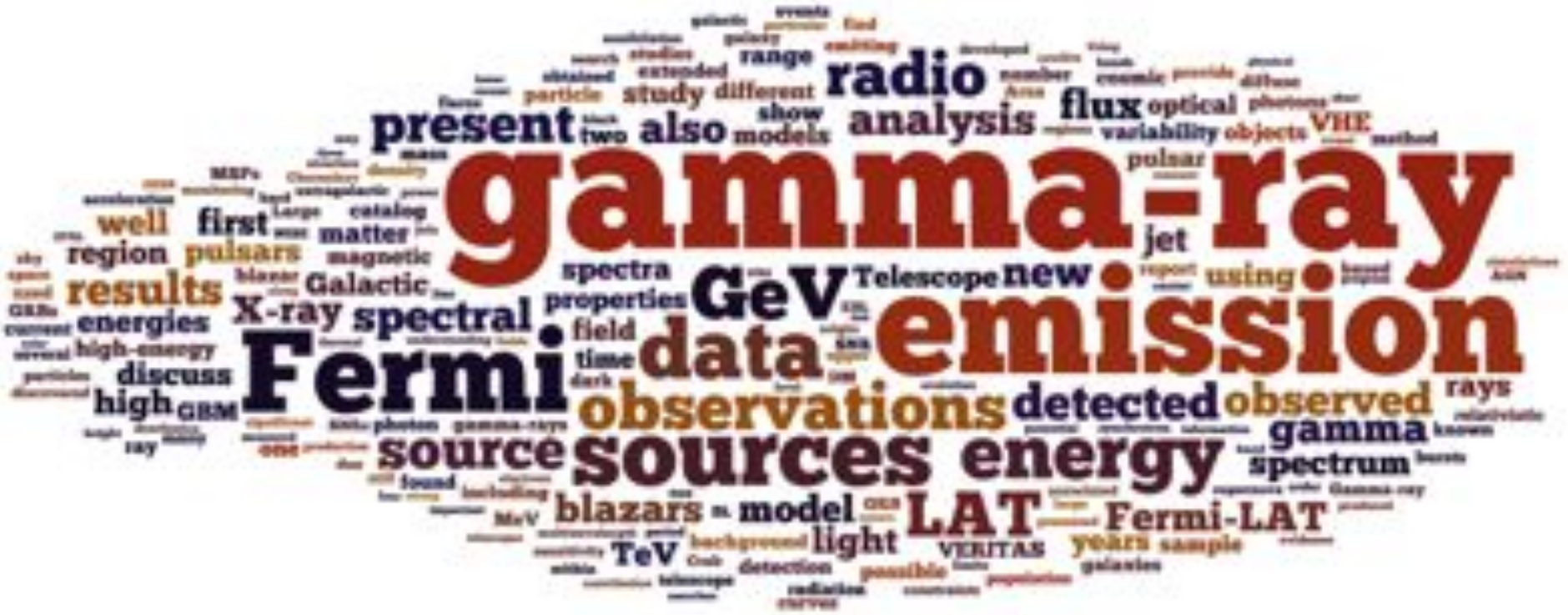
- 2012 NASA Senior Review

  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.

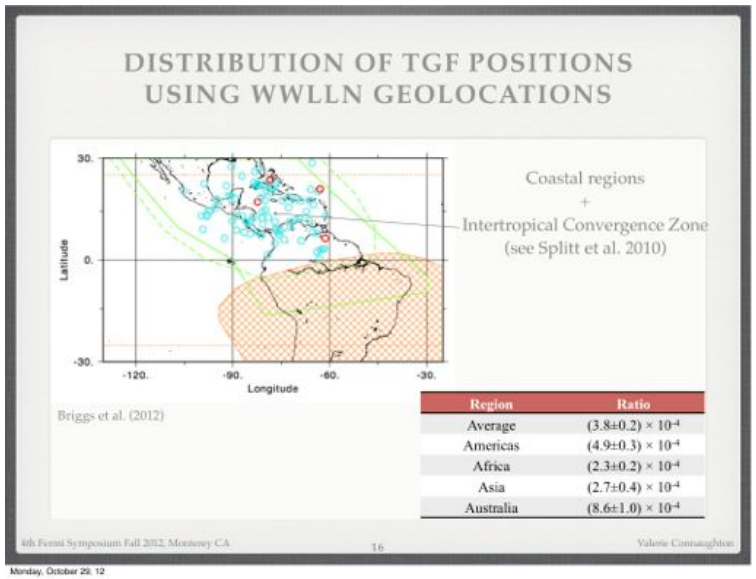
Symposium Summary



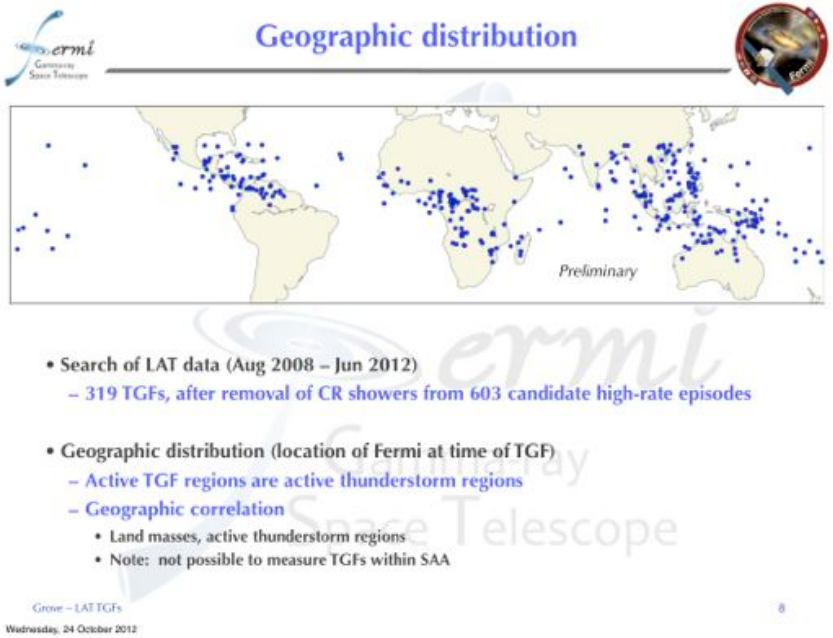
SOLAR SYSTEM

Terrestrial Gama-ray Flashes

- GBM observations and analysis with ground radio arrays



Connaughton

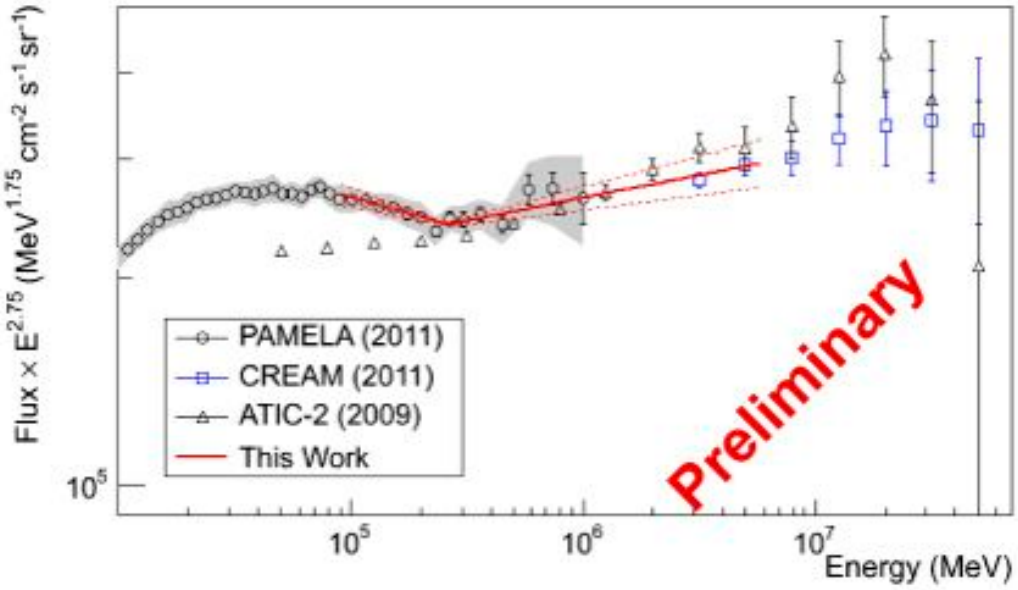


Grove

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

Cosmic-Ray Interactions in the Upper Atmosphere

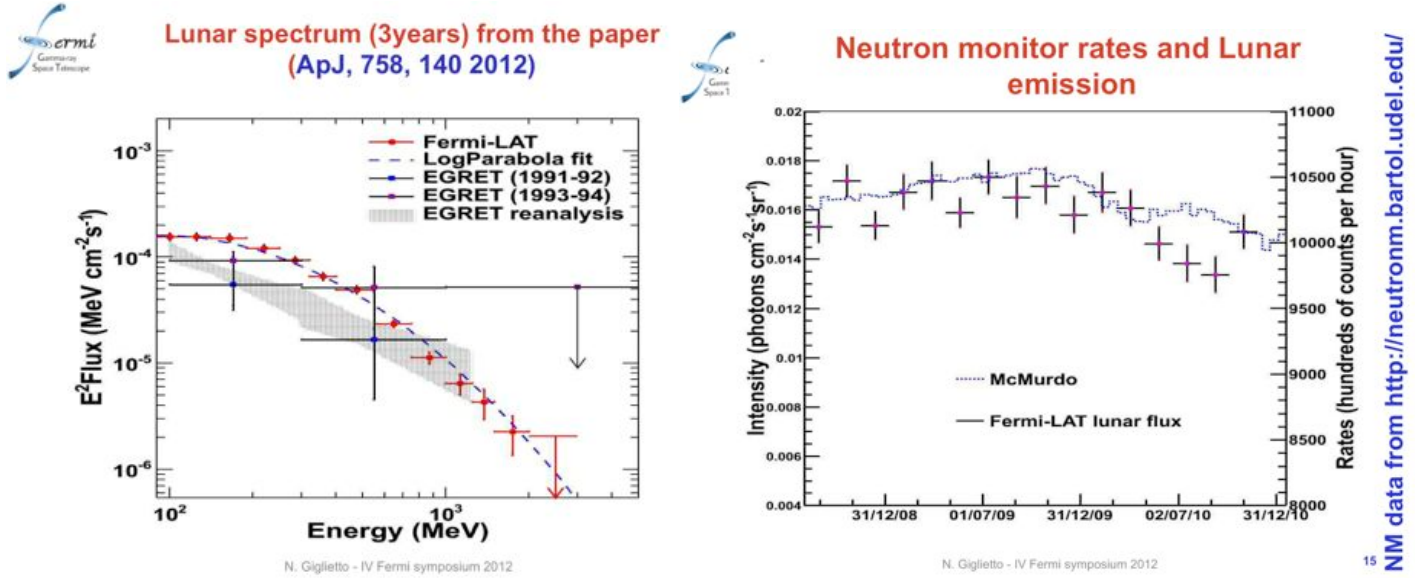
- Inferring the spectrum of CR protons
  - Indications are that it is consistent with the high-energy break reported by PAMELA



Mitthumisiri et al.

The Moon

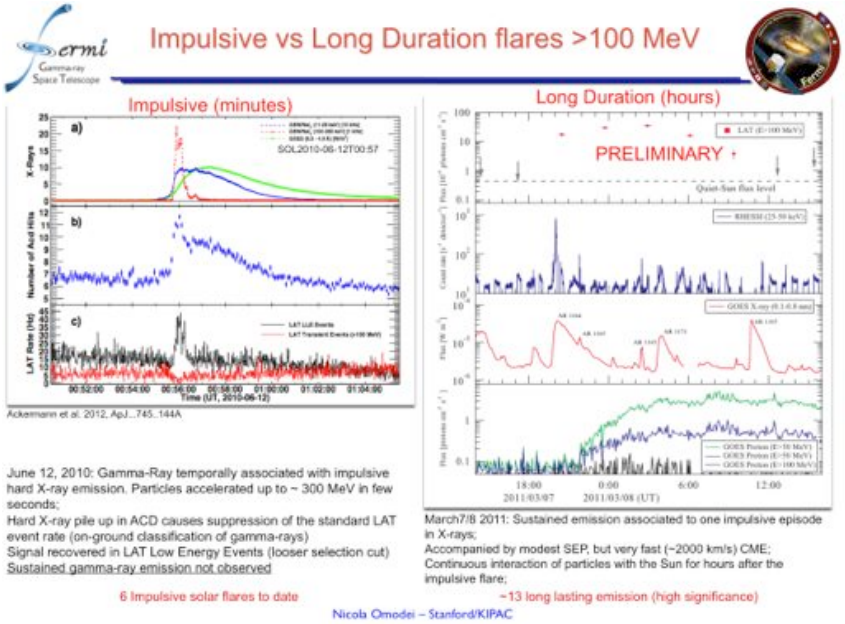
- A passive gamma-ray source – monitoring the CR flux outside the Earth's magnetosphere

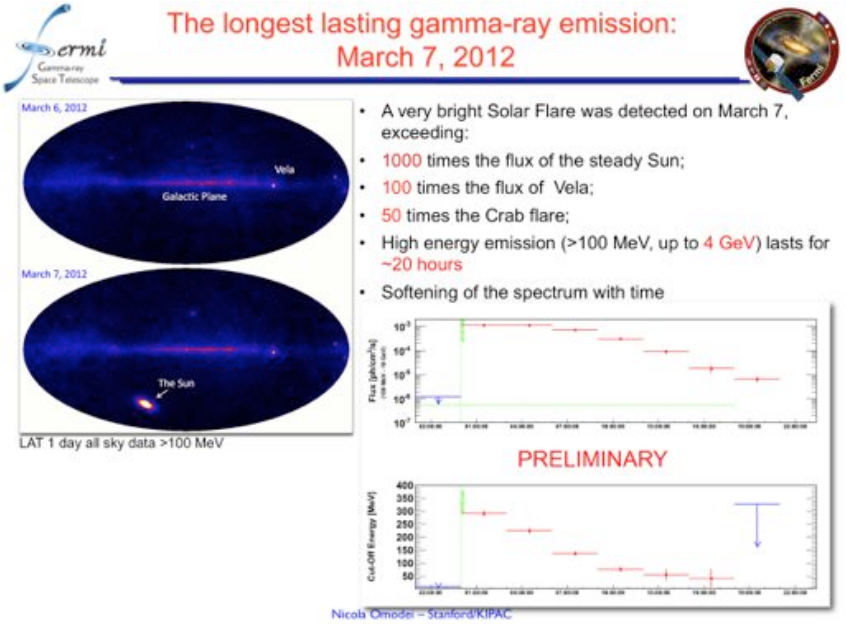


Giglietto

The Sun

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





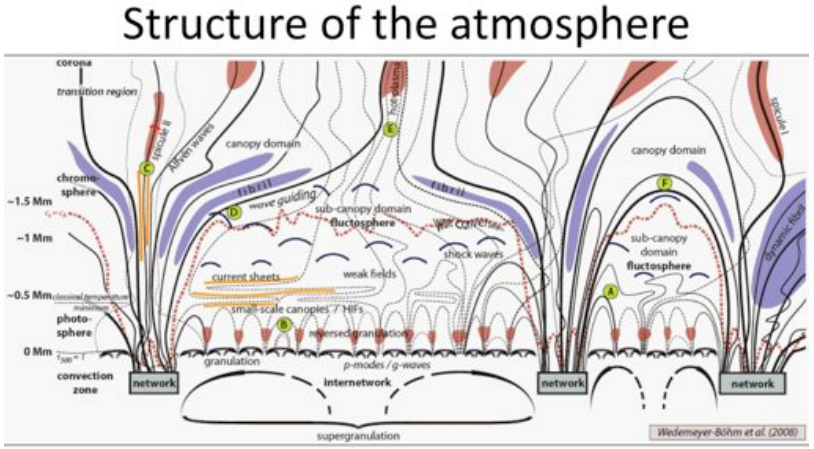
Omodei

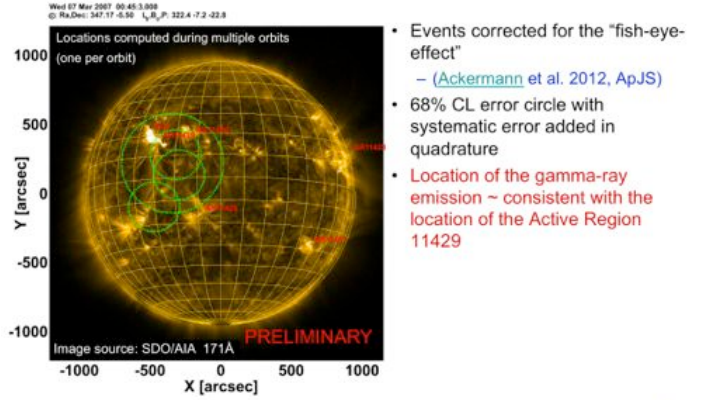
The Sun 2

- 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"

Hudson





Omodei

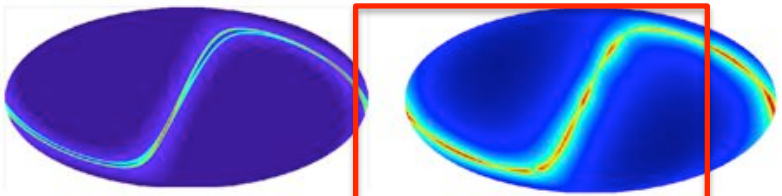
*Possibility of flare-induced shock acceleration depositing the high-energy particles in nearby large-scale static loops

Sun as a Background

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

Development for 5-year catalog

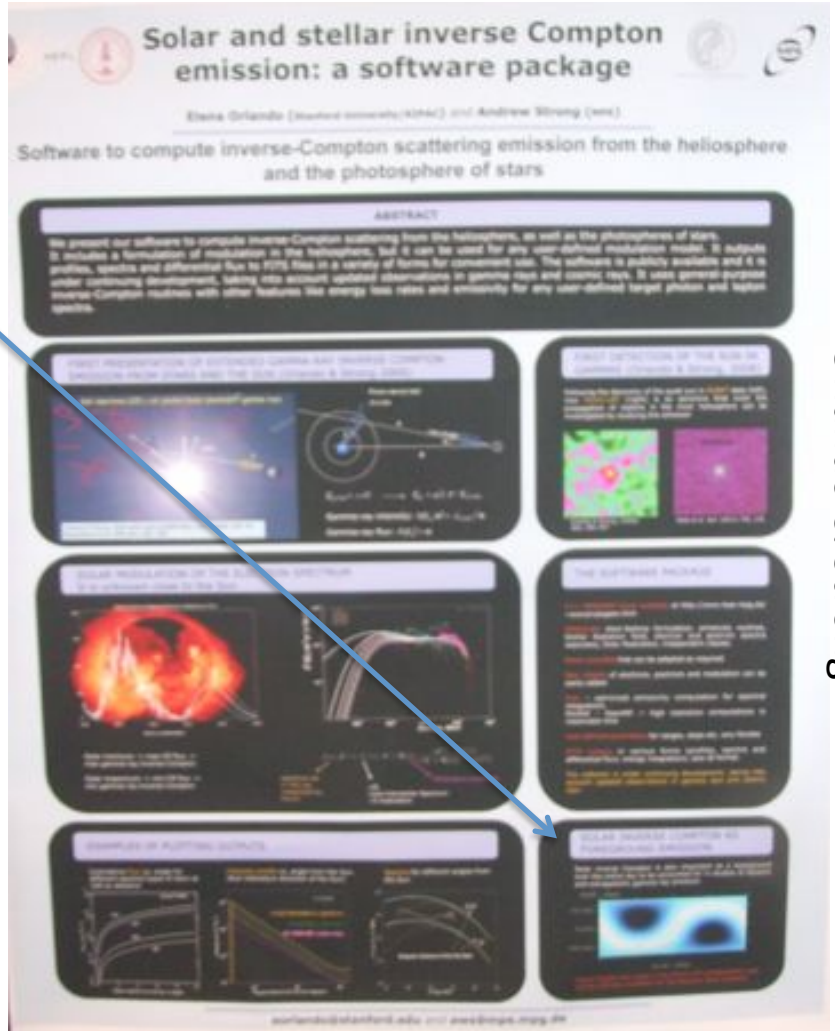
- **Both quiescent Sun and Moon can be seen in the 4-year integrated data set**
  - **Developing tools to calculate exposure-corrected templates using measured spectra**
  - **Sun and Moon templates will be included as an all-sky source in 5-year catalog analysis**



Example template with both sun and moon, using 1-year average exposure

Example template of sun using one year of actual exposure

22

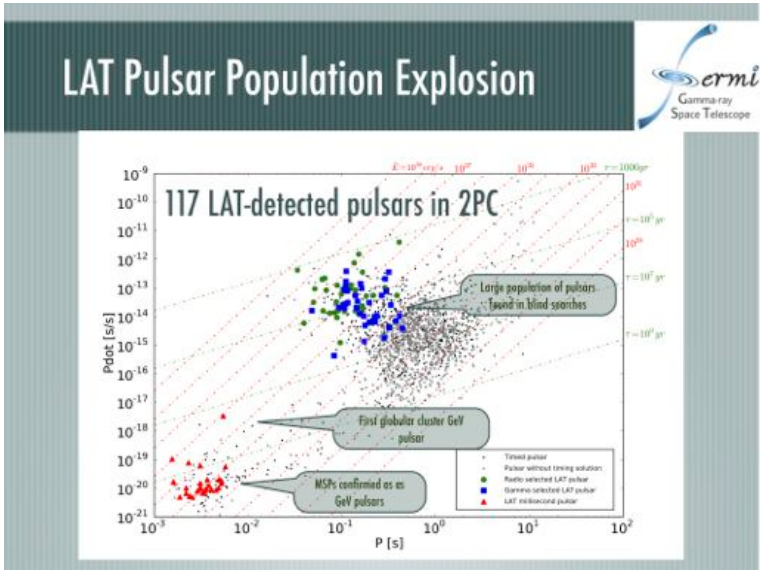


Orlando & Strong

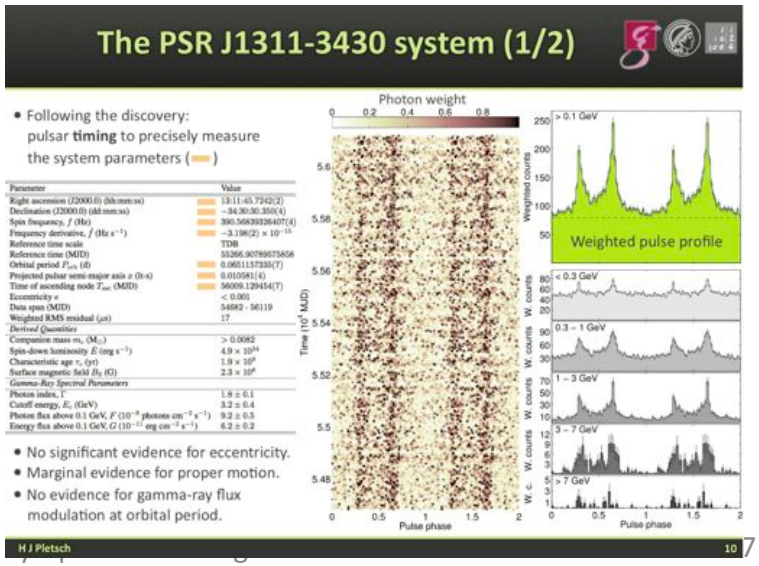
The Galaxy

Pulsars

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



Ray

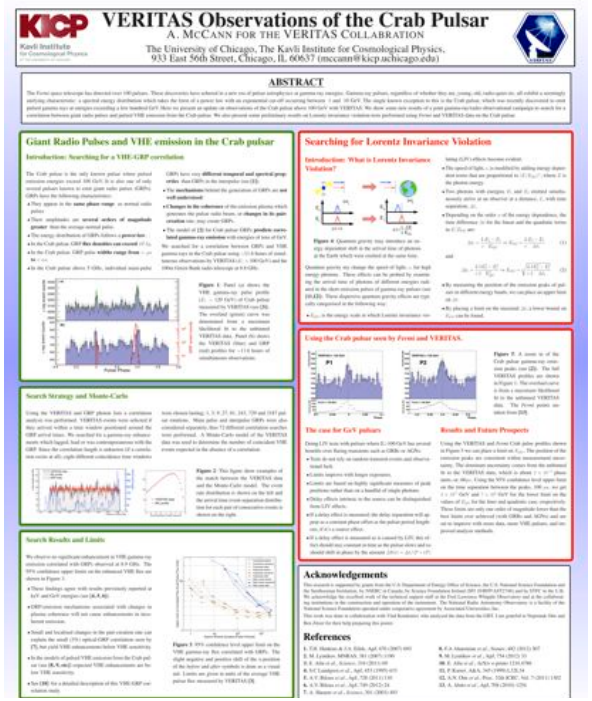


Pletsch

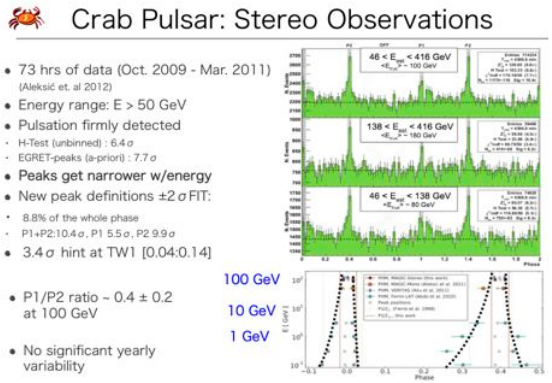
* Ongoing successful MW collaboration with Pulsar Timing and Pulsar Search Consortia

Pulsars at VHE

- Since the 3rd 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 ± 6 GeV and the nebula as steady > 300 GeV



McCann



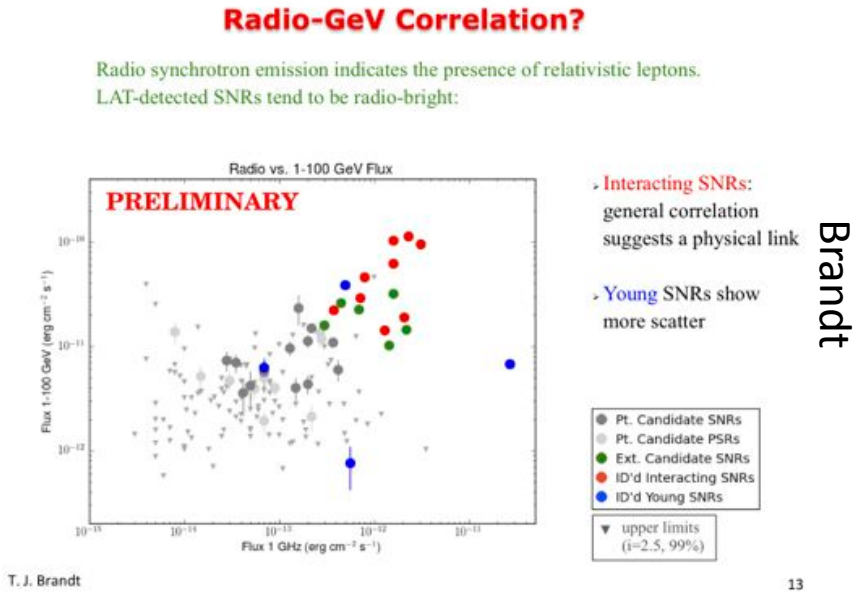
Saito/Paneque

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

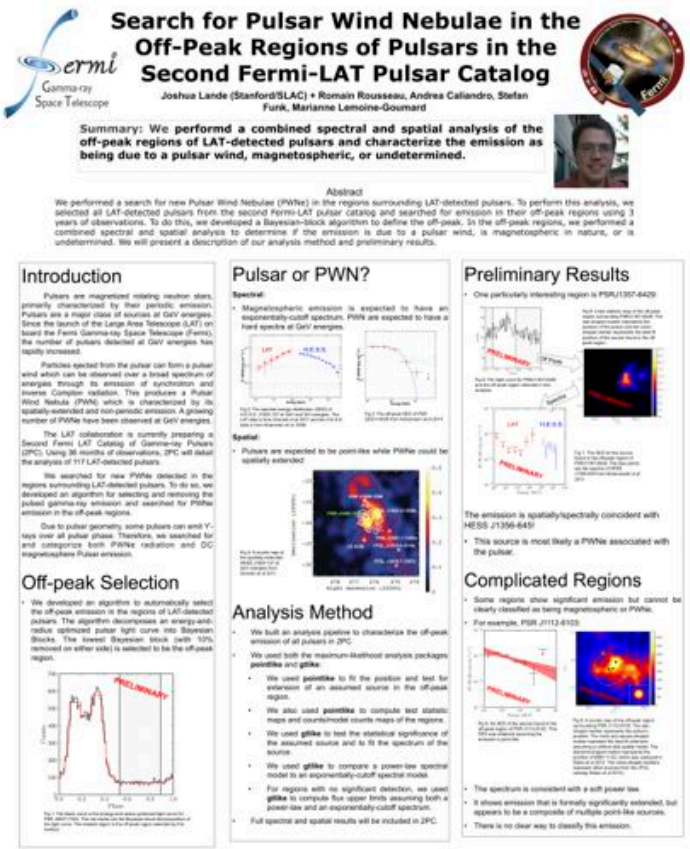


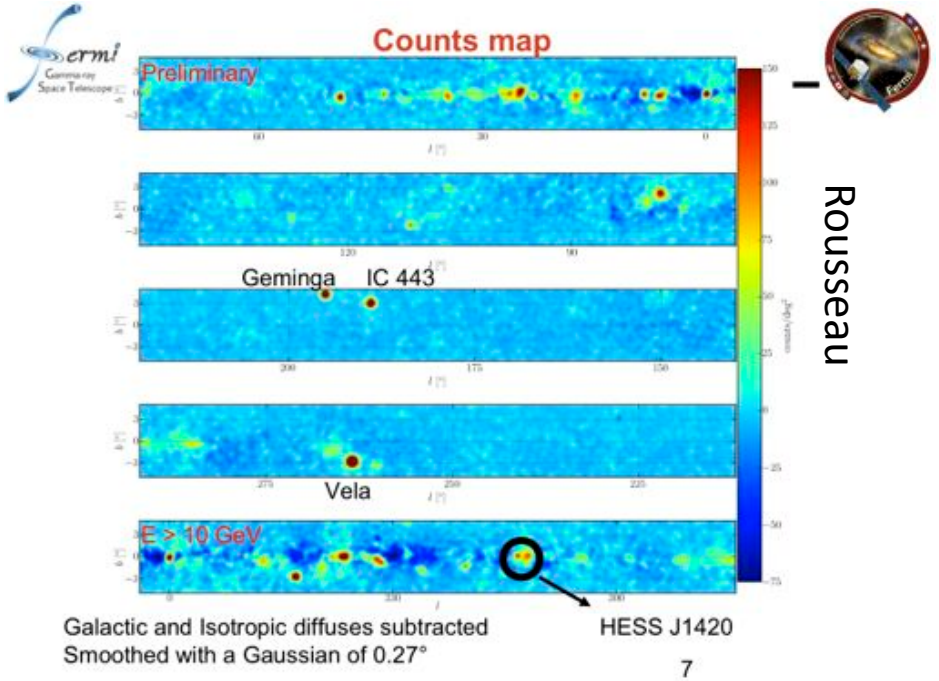
Brandt

Pulsar Wind Nebulas

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

Lande





Rousseau

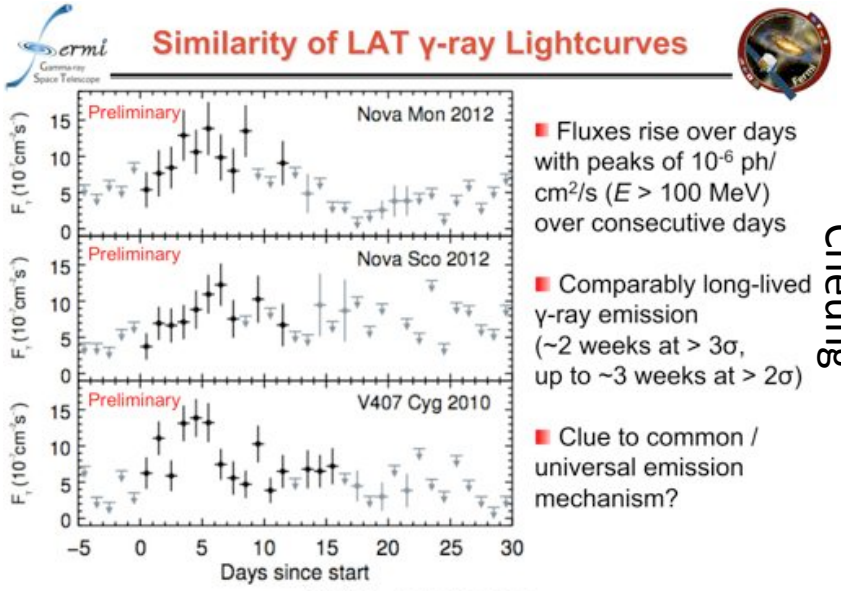
- Search for LAT sources in off-pulse regions of LAT pulsars
- Both involve spectral/spatial comparisons with HESS
- ~15 candidates found (large increment on known PWNs)

Other SNR/PWN studies

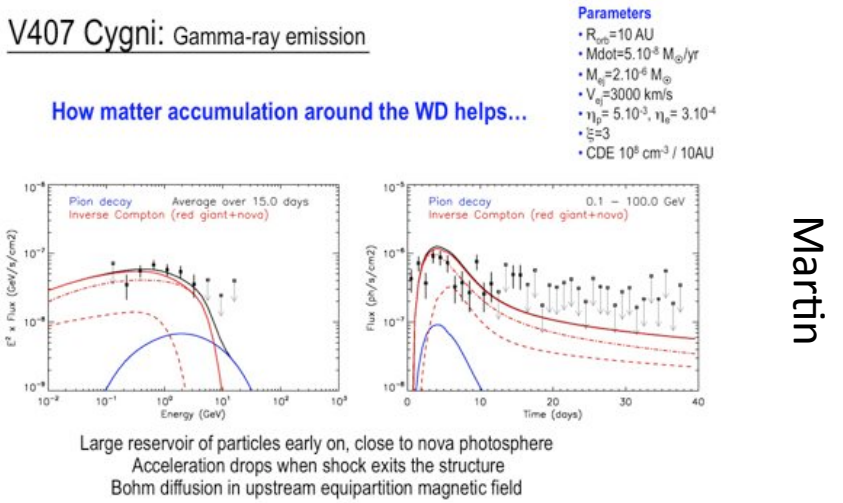
- Striani interpreted the LAT observations of the flaring Crab nebula in terms of flares and slower ‘waves’

New Novas

- Two found since the 3rd 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



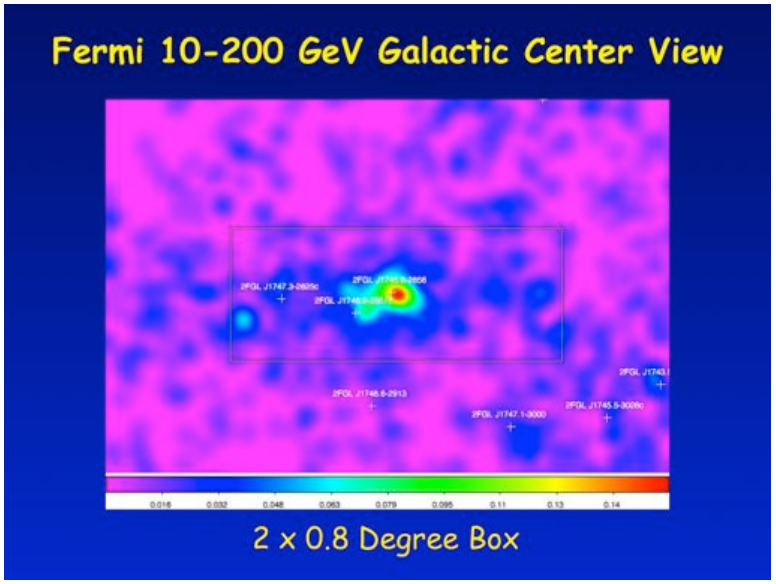
Cheung

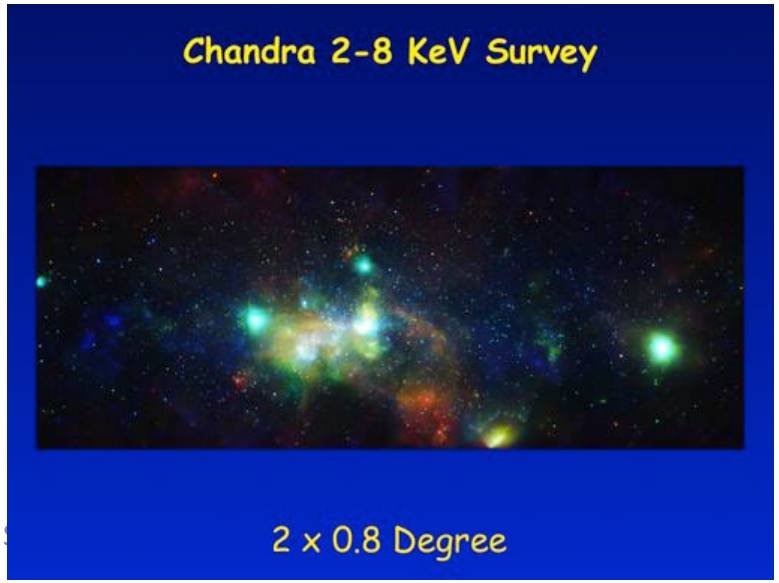


Martin

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_{Earth} cloud in Sept. 2013 [when you can use the word ‘peribothron’]





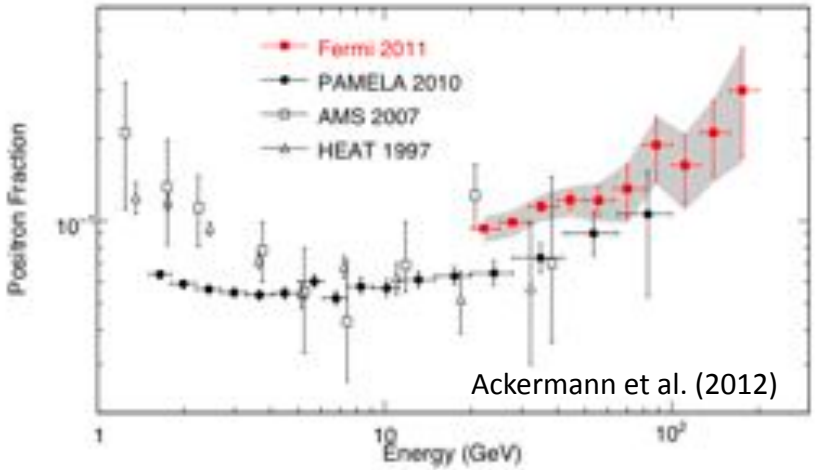
Baganoff

* More later

Cosmic Rays

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

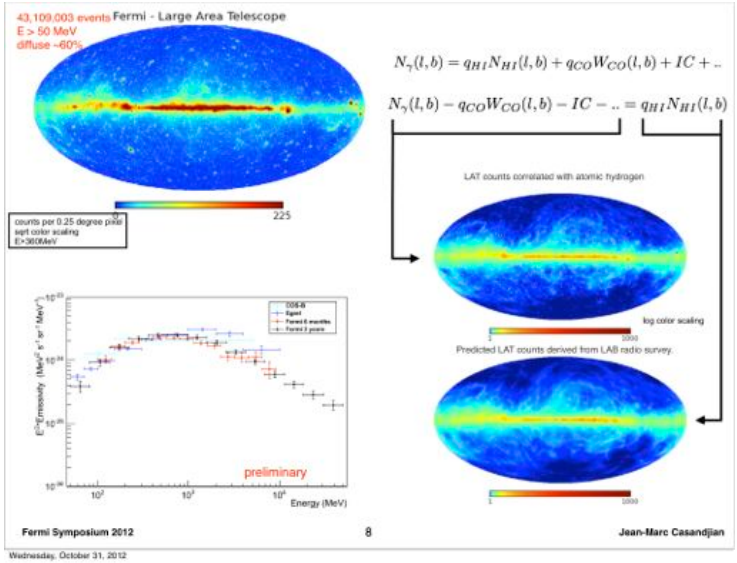
Positron Fraction



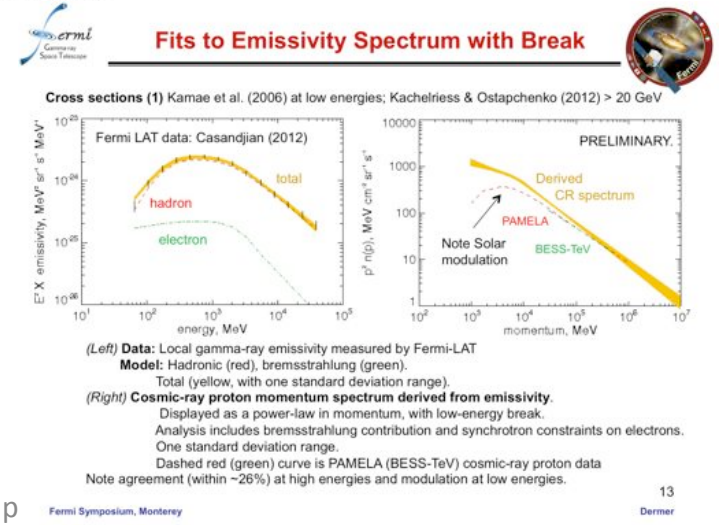
Kistler: CR $e^+ + e^-$ energy loss rate goes like E^2 (limits the number of sources that can contribute) & diffusion is along filaments (anisotropies do not necessarily point back to the sources)

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



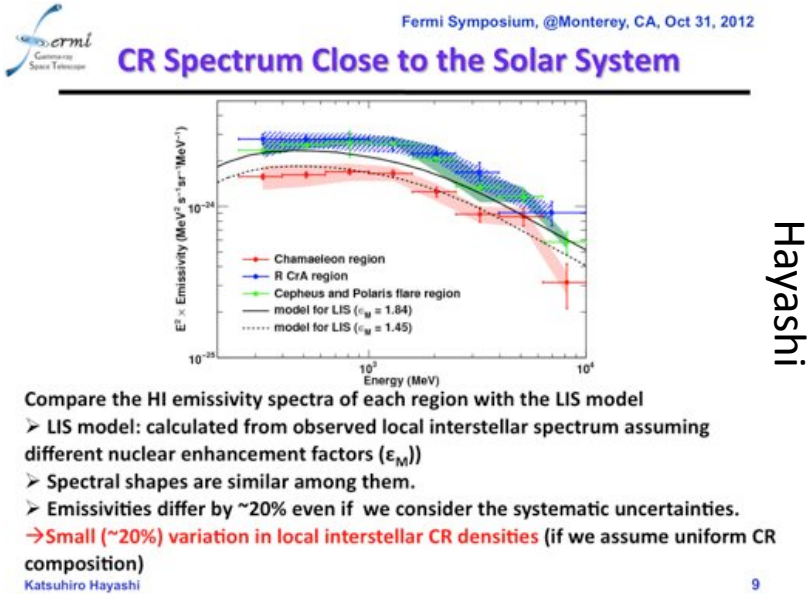
Casandjian



Dermer

Indirect detection of CRs 2

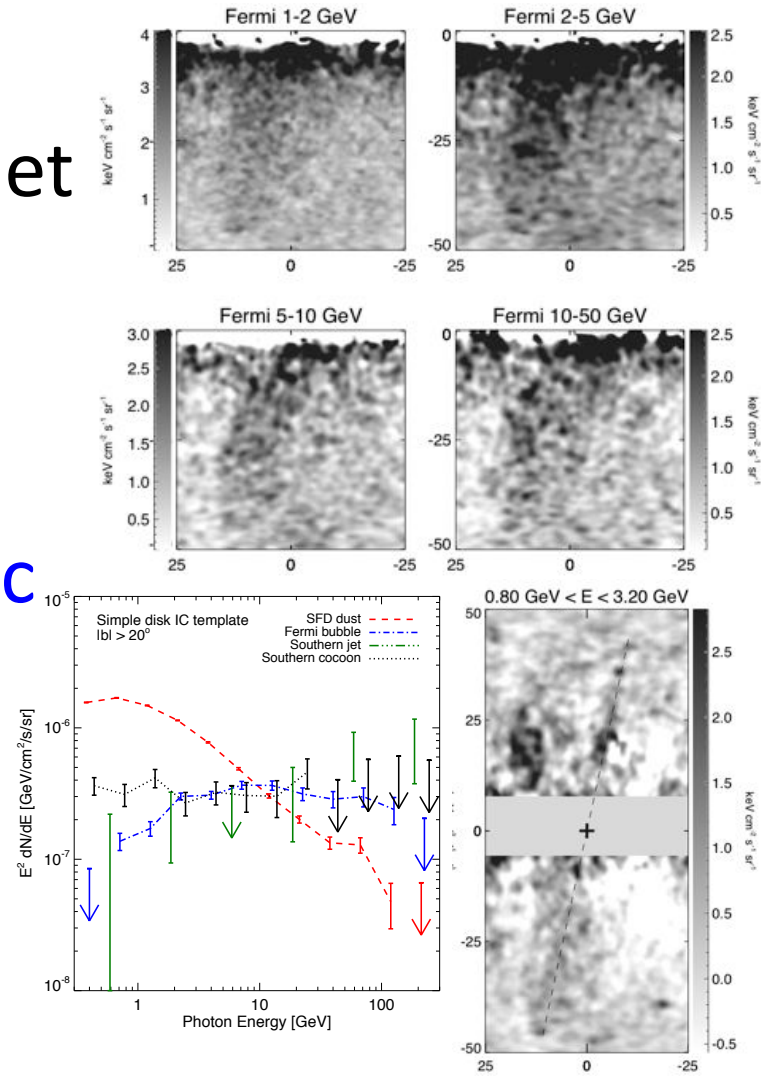
- On scales of individual local interstellar clouds LAT results indicate small but significant variations of CR density



Hayashi

Fermi Bubbles

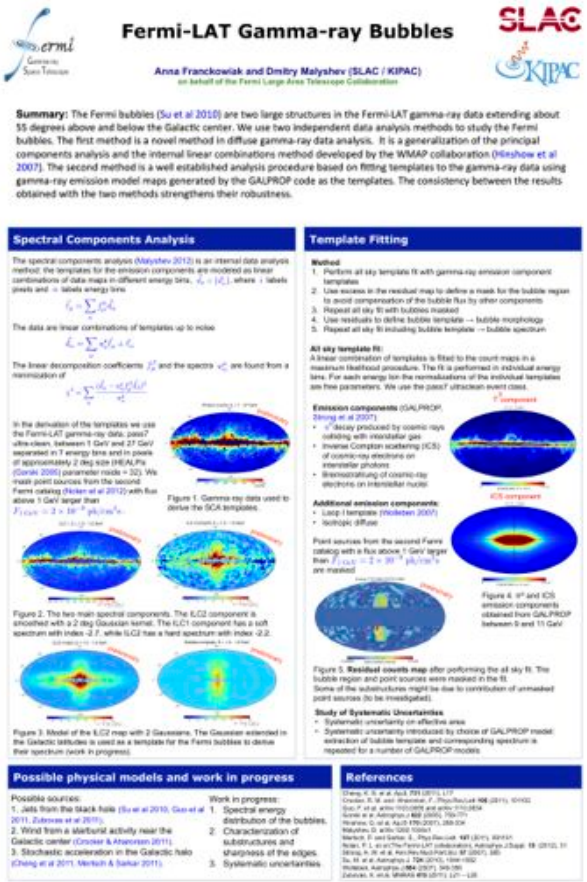
- Pushing ahead: Cocoon & jet interpretation - "The jet might be even more dangerous than claiming a 130 GeV line at the Galactic center" (Finkbeiner)



Su & Finkbeiner (2012)

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-LAT Gamma-ray Bubbles

Anna Franckowiak and Dmitry Malyshev (SLAC / KIPAC)
on behalf of the Fermi Large Area Telescope Collaboration

SLAC

KIPAC

Summary: The Fermi bubbles (Su et al 2010) are two large structures in the Fermi-LAT gamma-ray data extending about 55 degrees above and below the Galactic center. We use two independent data analysis methods to study the Fermi bubbles. The first method is a novel method in diffuse gamma-ray data analysis. It is a generalization of the principal components analysis and the internal linear combinations method developed by the WMAP collaboration (Hinshow et al 2007). The second method is a well established analysis procedure based on fitting templates to the gamma-ray data using gamma-ray emission model maps generated by the GALPROP code as the templates. The consistency between the results obtained with the two methods strengthens their robustness.

Spectral Components Analysis

Template Fitting

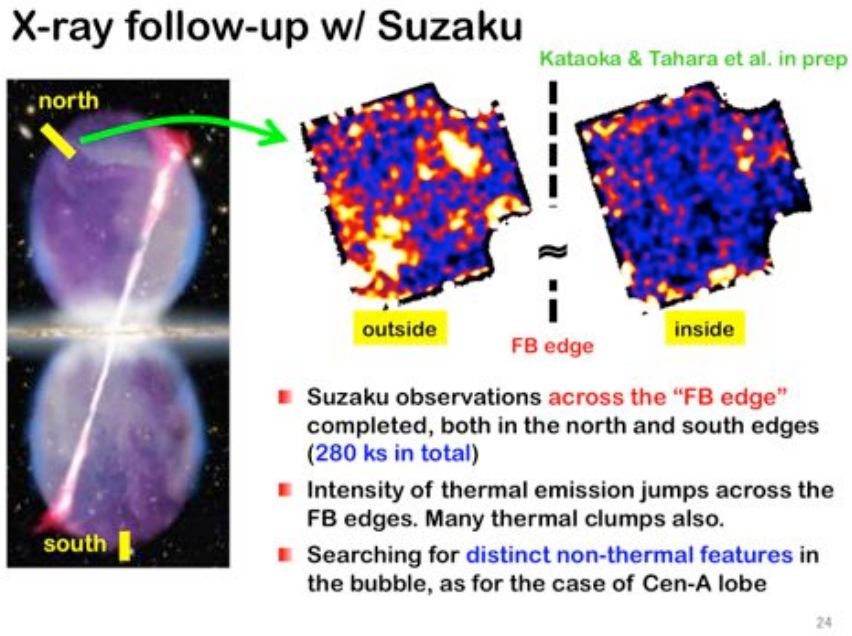
Possible physical models and work in progress

References

Franckowiak & Malyshev

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

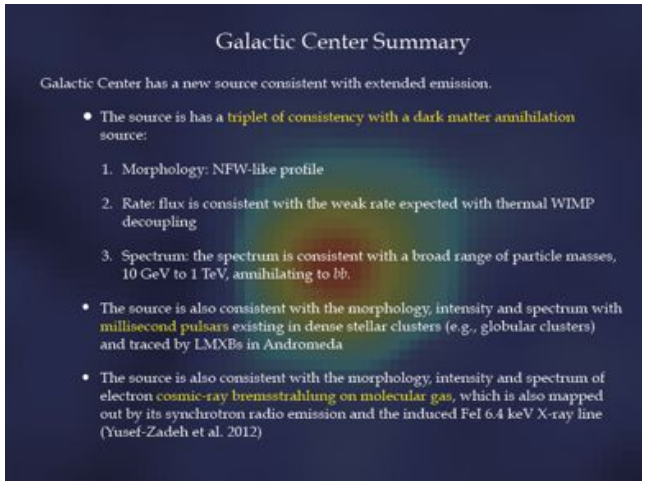


Indirect Searches for Dark Matter

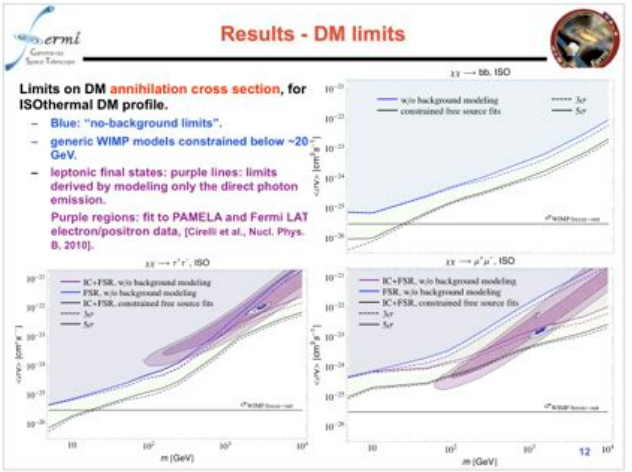
- More of a focus here than at 3rd Fermi Symposium
  - Dark Matter in the GC and Halo
  - Dark Matter in dSph galaxies
  - VERITAS Dark Matter Search
  - Dark Matter in Virgo?
  - 130-135 GeV Feature

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



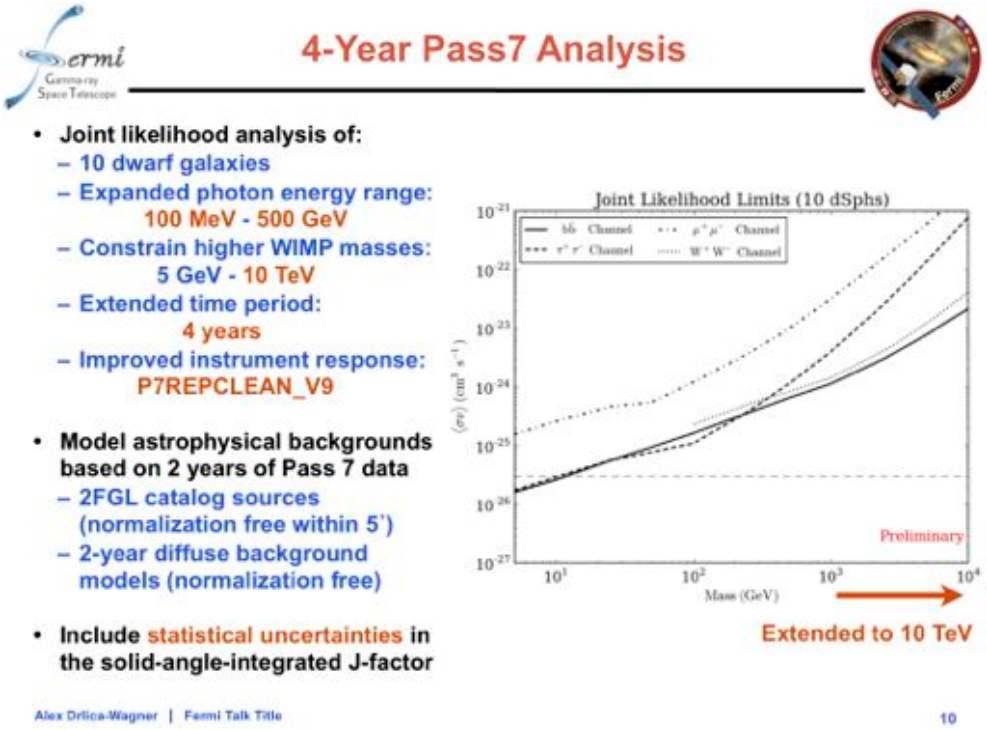
Abazajian



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



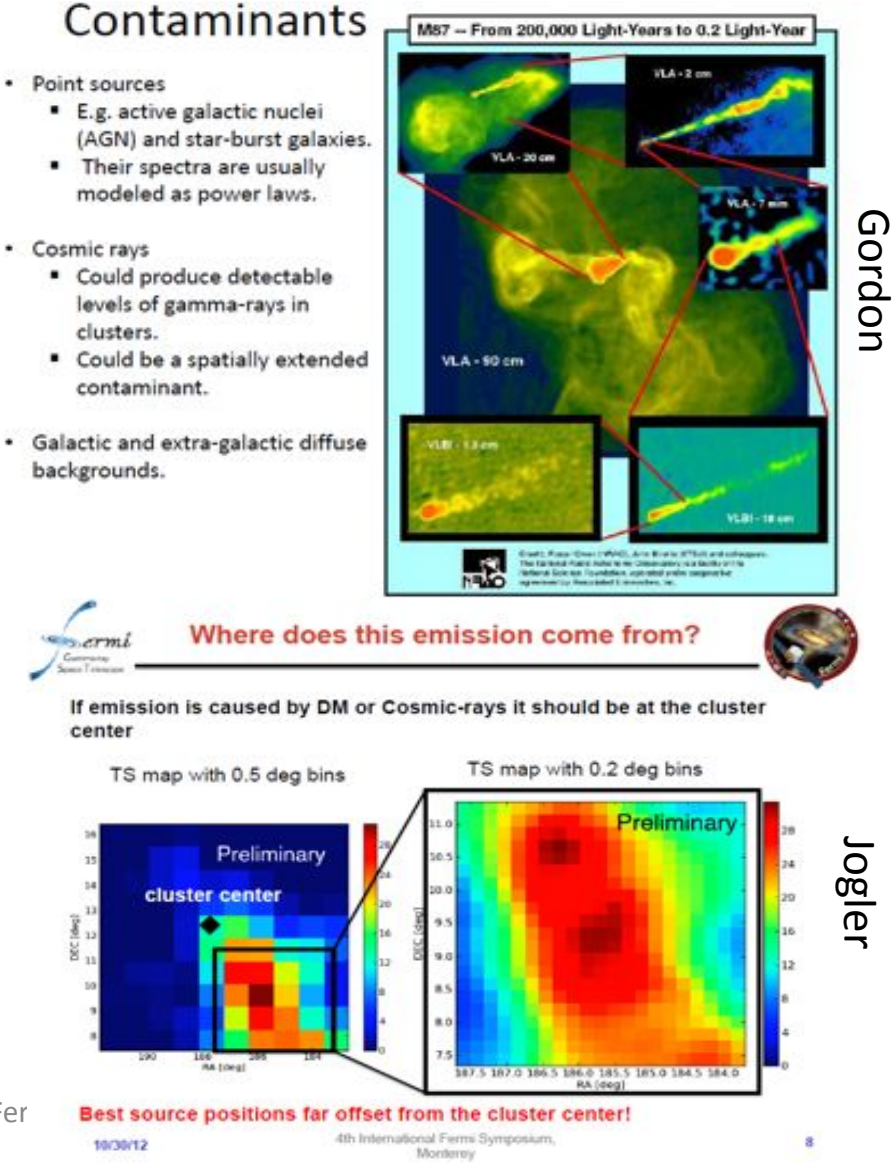
Drlica-Wagner

VERITAS Dark Matter Search

- VERITAS program was described by Geringer-Sameth – most sensitive in the ~>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 ~triple the observing time on 3 of them (total ~>200 hr) and make a stacked analysis
  - Strong detection of the GC (SgrA*); plan a close-by halo study

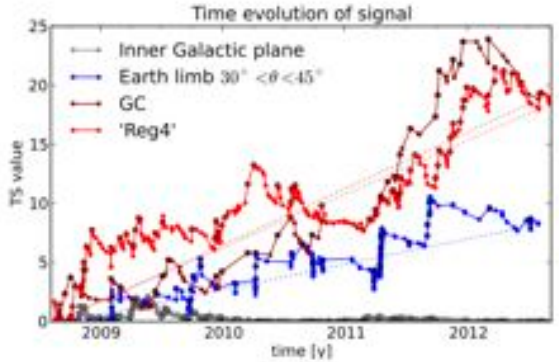
No Dark Matter Signal from Virgo

- New since 3rd 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



130-135 GeV Feature

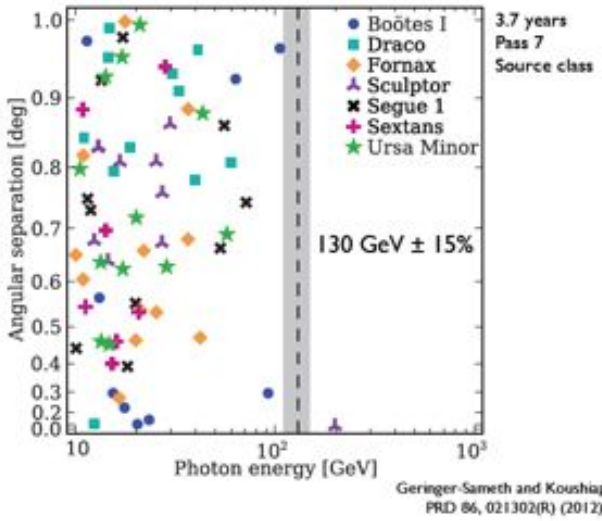
- New since the 3rd Fermi Symposium
- Presentations by Weniger (line search in the Galactic center), Albert (line search), Bloom (systematics from non-GC regions, Charles (potential instrumental effects in line searches), Koushiappas/Geringer-Sameth (line search in dSphs)



Finkbeiner, Su, & Weniger (arXiv:1209.4562)

Squeeze more information out of photons

e.g. line emission search from combined dwarfs

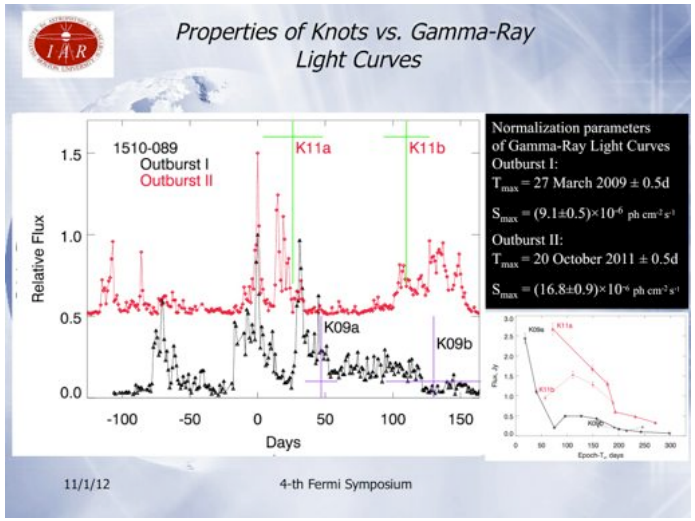


Koushiappas/Geringer-Sameth

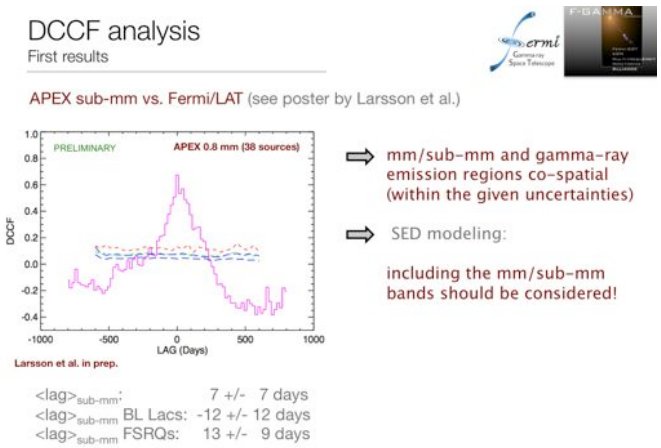
Extragalactic

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



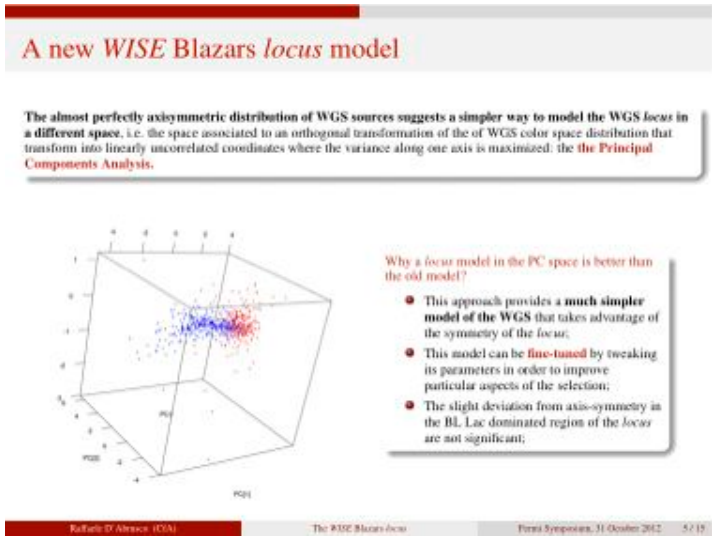
Jorstad



Fuhrmann

Active Galactic Nuclei 2

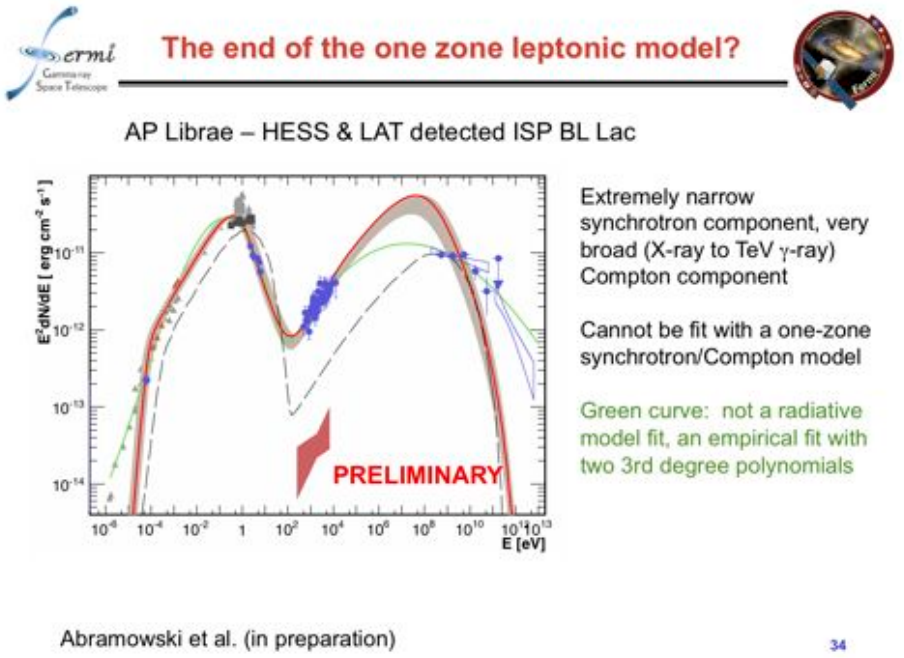
- The 500M+ source WISE infrared catalog has proven very powerful for finding blazars, which occupy a specific part of 3-color space
- In addition to a refinement of the implementation of the region, candidate associations for a number of 2FGL unassociated sources were presented (Massaro)



D'Abrusco

Active Galactic Nuclei 3

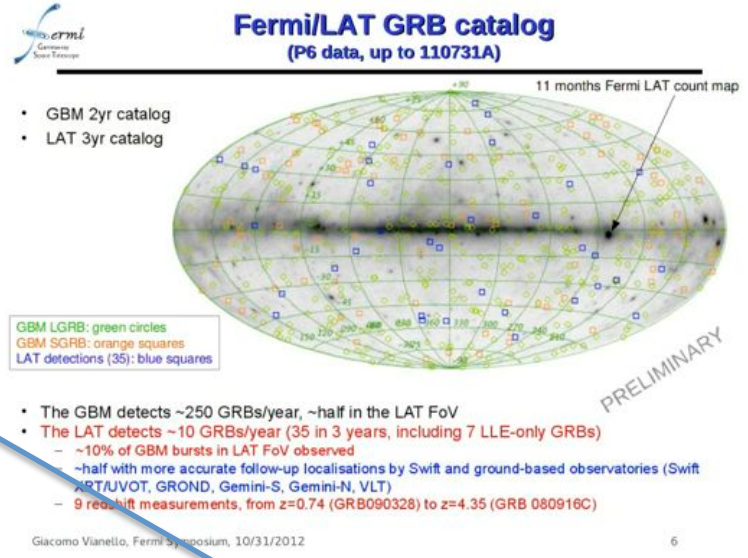
- The quality and quantity of LAT data are also spurring new directions in modeling



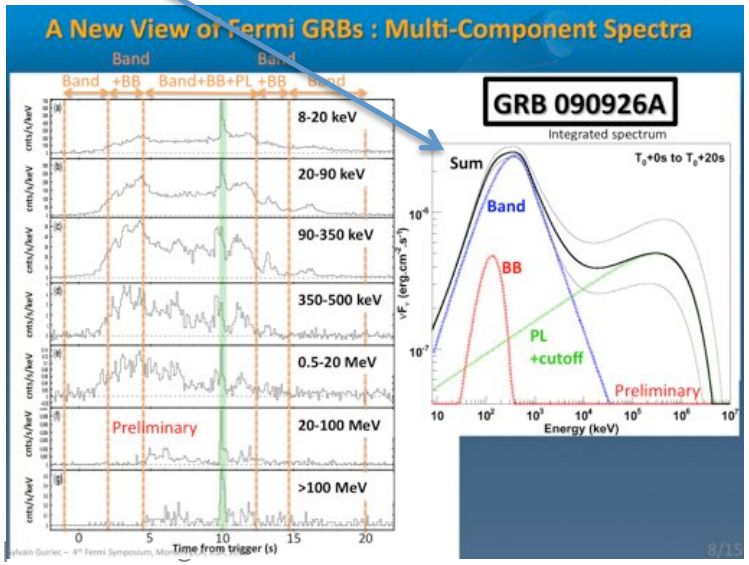
Finke

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



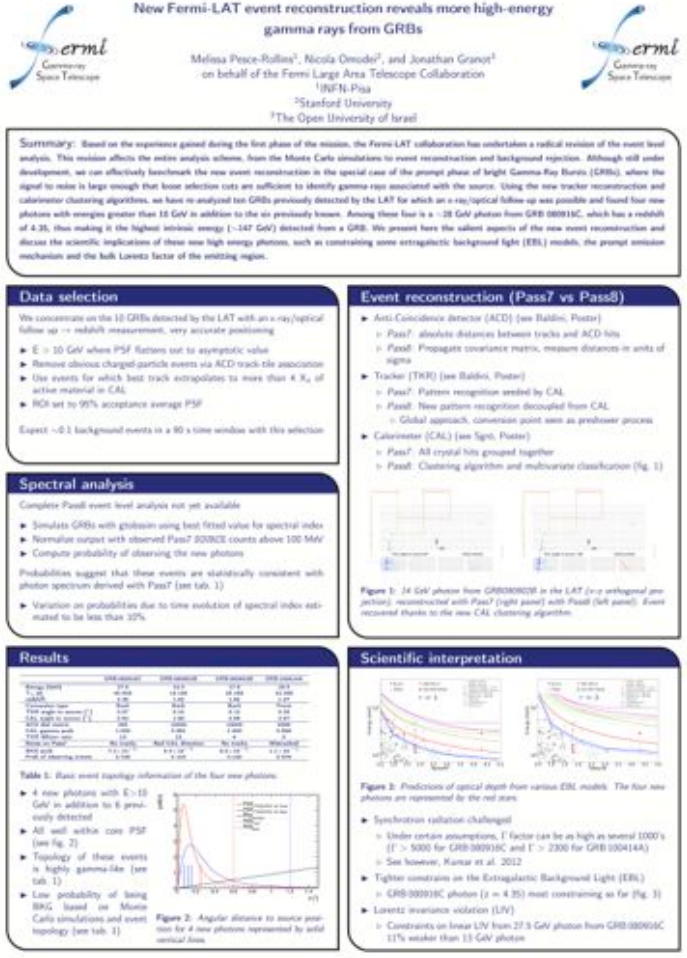
Vianello



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

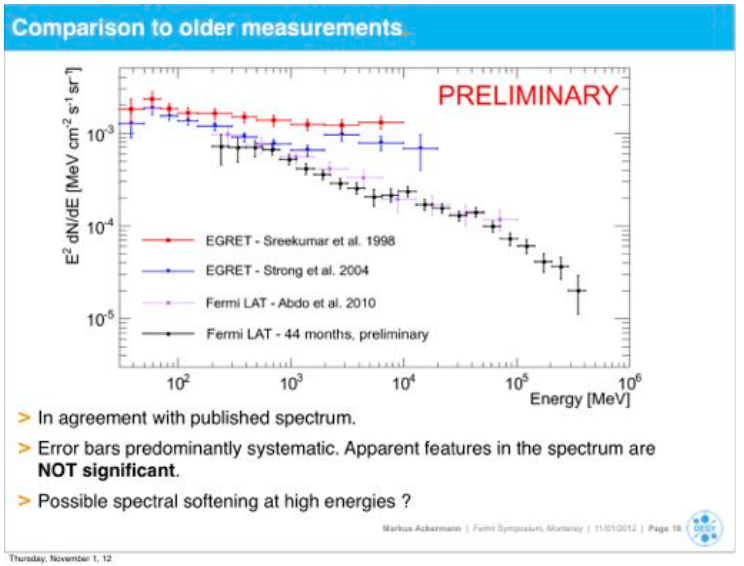


Pesce-Rollins

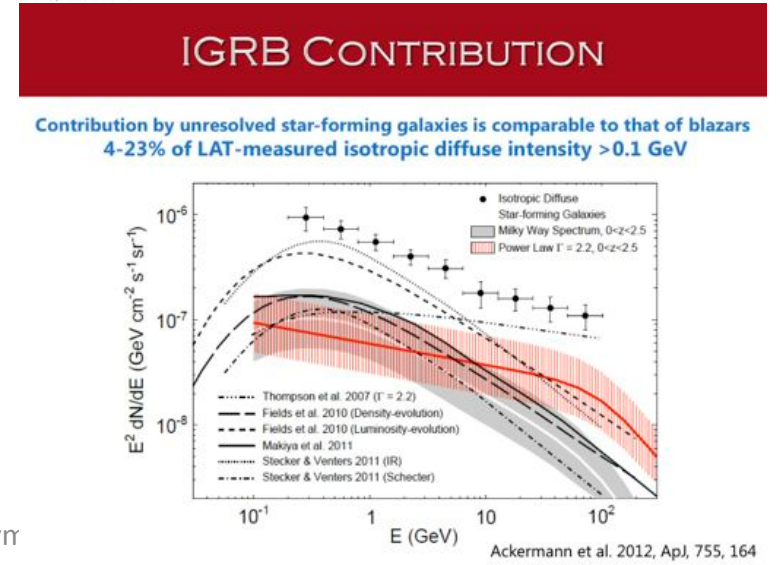
* More later

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



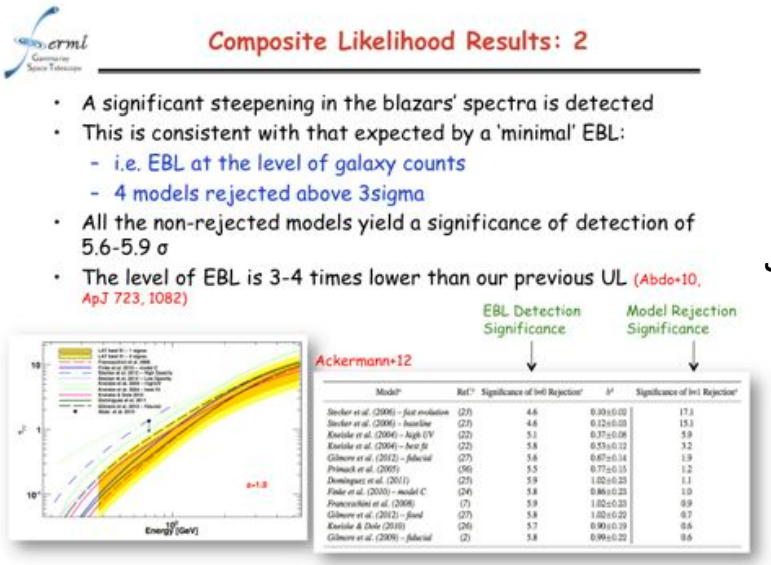
Ackermann



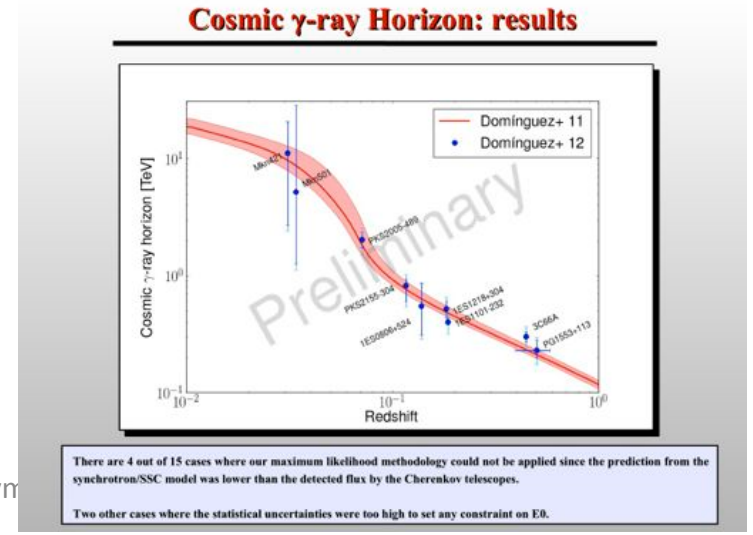
Bechtol

Extragalactic Background Light

- Much progress since 3rd 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



Ajello

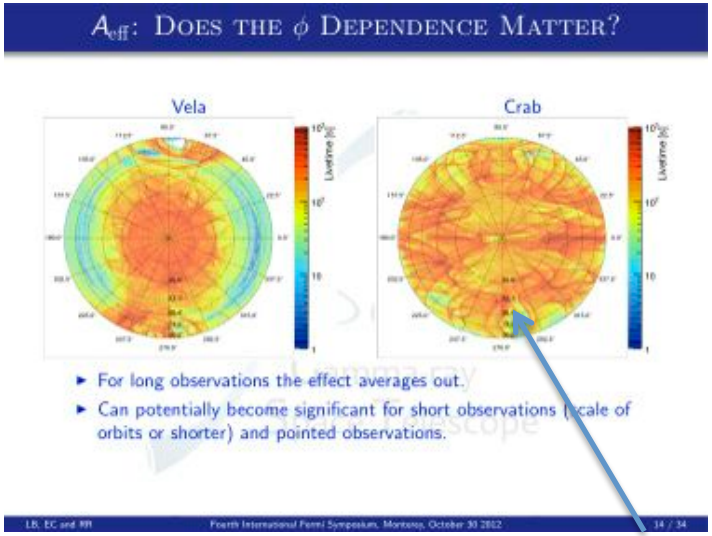


Dominguez

LAT Performance

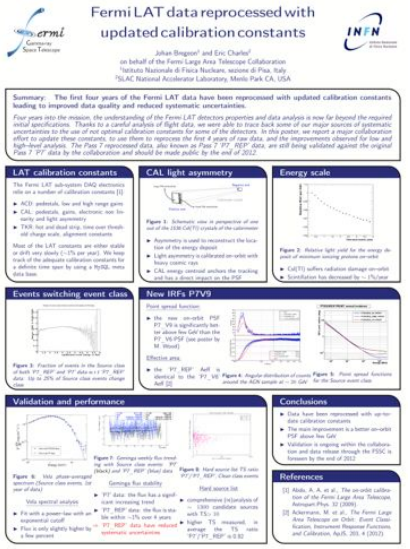
Pass 7 & Pass 7 Reprocessing

- Since the 3rd 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 Aeff 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



Baldini

(N.B. edge of FOV is at 3rd ring)

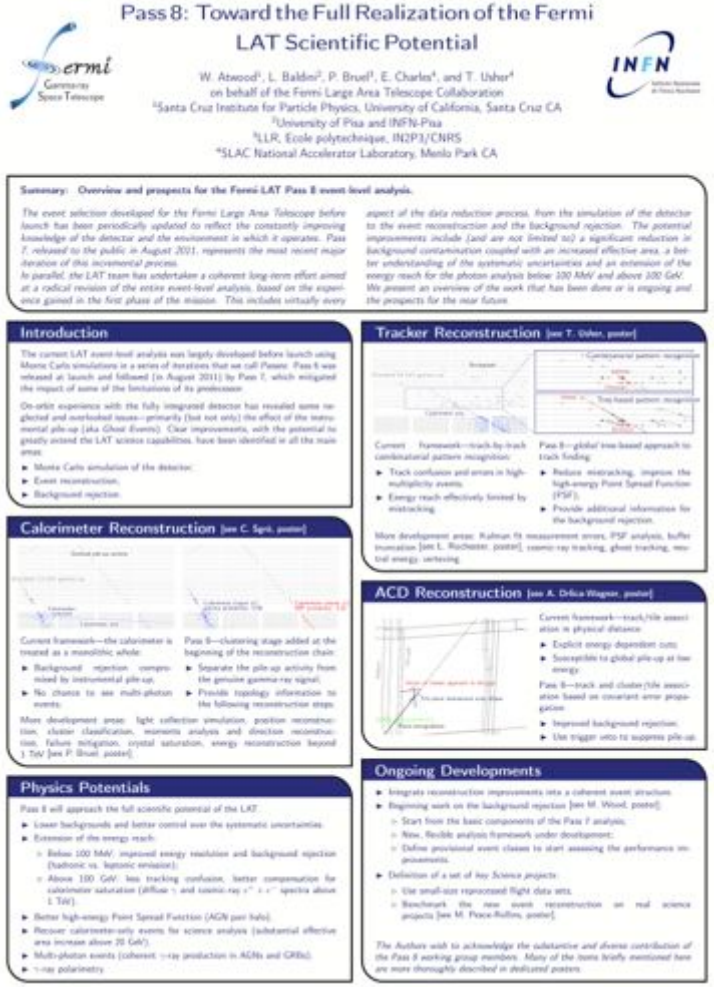


Bregeon

* arXiv:1206.1896

Pass 8

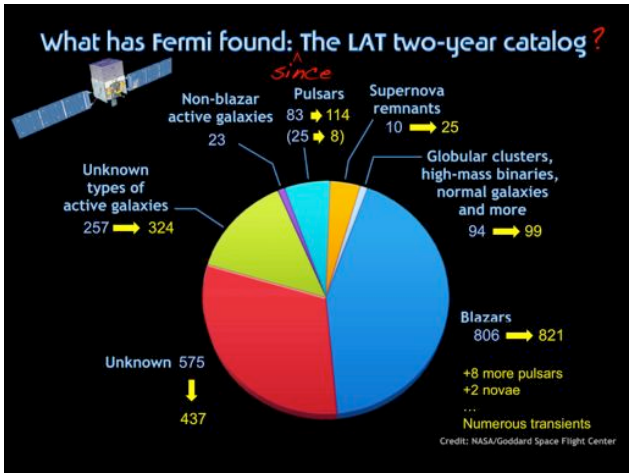
- Presented in detail in posters on **ACD pile-up correction, CAL reconstruction, track reconstruction, and event-level analysis, plus an overview**
- Pass 8 is built on a fundamental reimplementation of the reconstruction



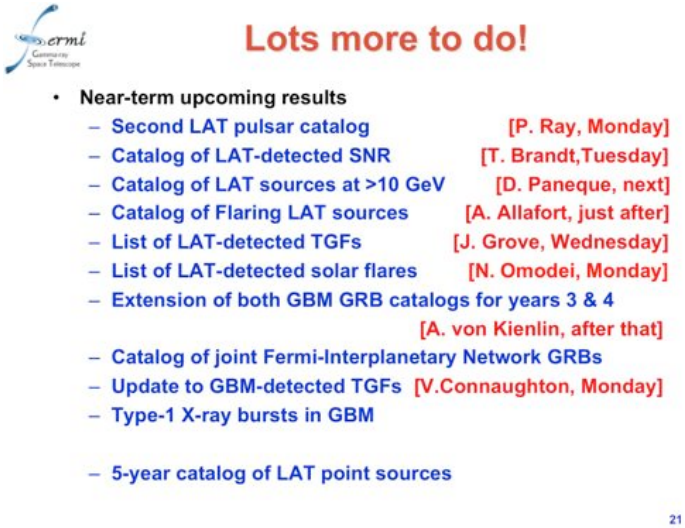
Atwood

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



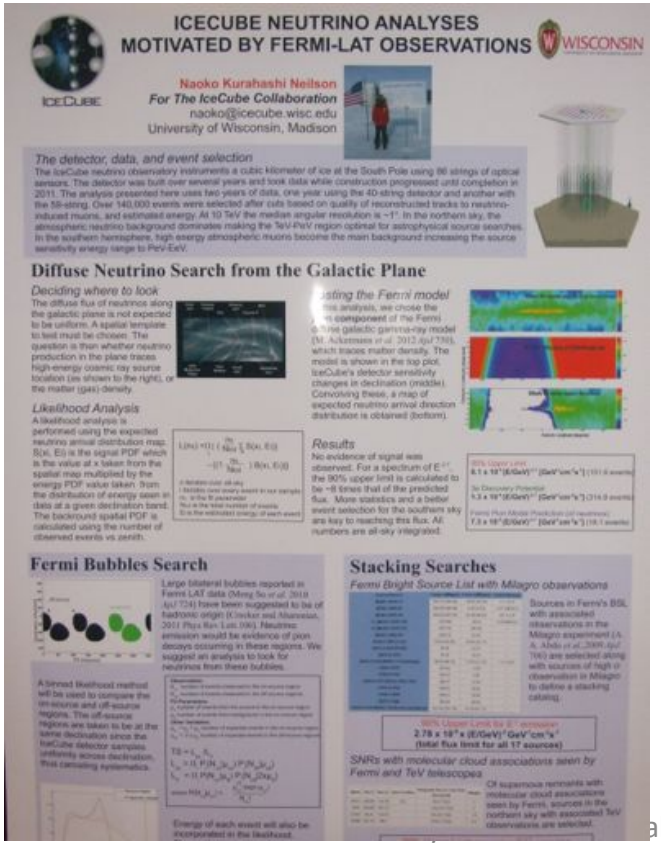
Multiwavelength Session

- 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"

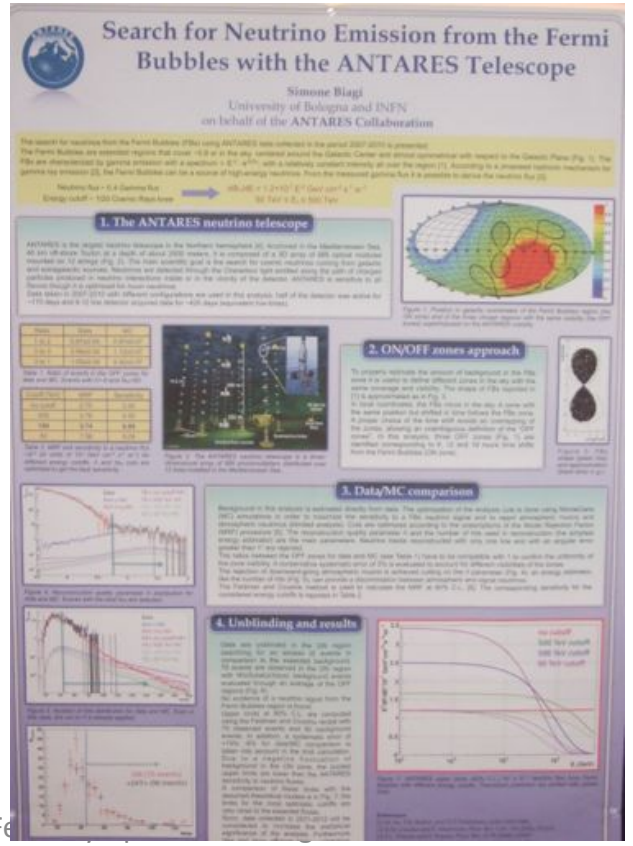
Multimessenger Too

- 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."

* see Nemmen contribution on "Unifying Black Hole Jets Across the Mass Scale"

Outlook: A Fermi Science Metric

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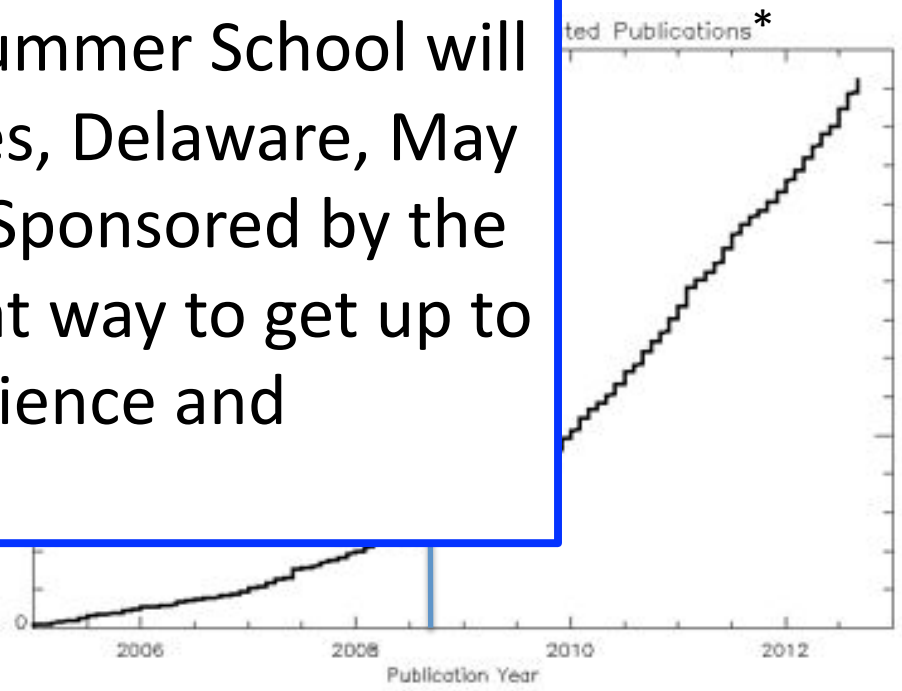
- Julie illustrated this with a chart of GI proposal submission counts

The 2013 Fermi Summer School will take place in Lewes, Delaware, May 27-June 5, 2013. Sponsored by the mission it is a great way to get up to speed on Fermi science and analysis.



* From 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

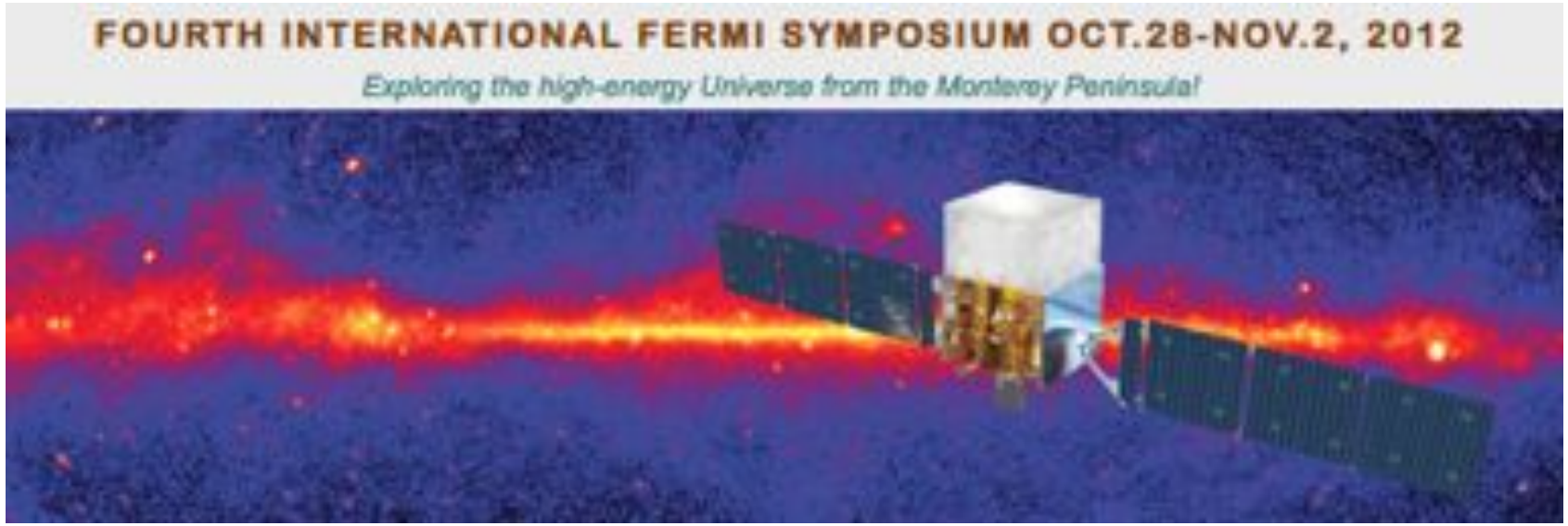
- Don Kniffen reminded us that the scientific drivers for the balloon and then satellite experiments in high-energy gamma-ray astronomy usually have **not** turned out to be the big discovery or selling point for the **next** experiment. Timeline:

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


FOURTH INTERNATIONAL FERMI SYMPOSIUM OCT.28-NOV.2, 2012
Exploring the high-energy Universe from the Monterey Peninsula!

Highlights from the 5th Fermi Symposium

- Pass 8 in wide use
- 3FGL