


Exploring the Extreme Universe

Fermi at Six Months


Elizabeth Hays
NASA/GSFC



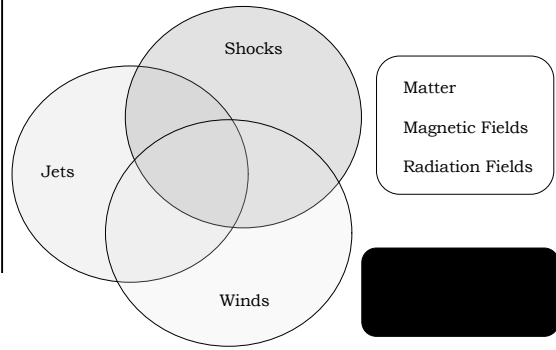
Overview

- + Astrophysics at a GeV
 - + Why we do it and some of the things we hope to find
- + The Fermi Gamma-Ray Space Telescope
 - + Working extremely well !
- + Science Highlights from the First Six Months
 - + 205 bright gamma-ray emitters
 - + The Solar System
 - + Our Galaxy
 - + Beyond our Galaxy

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Astroparticle Science at a GeV (in one slide!)



Matter
Magnetic Fields
Radiation Fields

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Some Big Questions

- + How and where does nature accelerate matter?
- + What is matter like throughout the Universe?
- + What characterizes our local environment?
- + What about the distant Universe?
- + How do Galaxies change over time?
- + Are there variations in the physics we know?

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The EGRET legacy

- + Catalog of ~270 MeV-GeV gamma-ray sources
 - + Blazars - bright, highly variable emission from the cores of galaxies
 - + Pulsars - bright pulses from rotating neutron stars
 - + Unidentifieds - many undetermined objects
- + The GeV excess - diffuse emission shows too many gamma rays at a GeV
- + GRBs - GeV emission detected from a few gamma-ray bursts, one burst over an hour after the trigger

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Fermi LAT Collaboration

- + France
 - + IN2P3, CEA/Saclay
- + Italy
 - + INFN, ASI, INAF
- + Japan
 - + Hiroshima University
 - + ISAS/JAXA
 - + RIKEN
 - + Tokyo Institute of Technology
- + Sweden
 - + Royal Institute of Technology (KTH)
 - + Stockholm University
- + United States
 - + Stanford University (SLAC and HEPL/Physics)
 - + University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
 - + Goddard Space Flight Center
 - + Naval Research Laboratory
 - + Sonoma State University
 - + Ohio State University
 - + University of Washington

Principal Investigator:
Peter Michelson (Stanford University)

construction managed by
Stanford Linear Accelerator Center
(SLAC), Stanford University

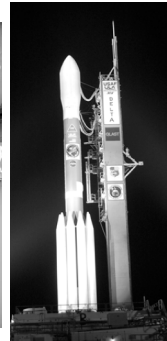
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Only a few short months ago...

GLAST with half of the fairing mounted, sitting on top of a Delta II Heavy rocket at launch complex 17-B in Cape Canaveral Air Force Base, FL
 June 2008



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Lift Off !

GLAST Mission Operation Control at GSFC

June 24, 2008 - Instrument Activation Day
The project and instrument teams made it look easy to turn on a million channels on a \$700 million mission in a single day.

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The satellite formerly known as GLAST

- + August 26, 2008
 - + First Light
 - + GLAST renamed in honor of Enrico Fermi
 - + The *Fermi* Gamma-ray Space Telescope
 - + Also fondly remembered as the day a few hundred web links broke...

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The Fermi Observatory

Large Area Telescope (LAT)

- + Large Field of View (>2.4 sr)
- + Views entire sky every 3 hrs (every 2 orbits)
- + Broad Energy Range (20 MeV - >300 GeV)

Gamma-ray Burst Monitor (GBM)

- + Views entire unocculted sky
- + NaI: 8 keV - 1 MeV
- + BGO: 150 keV - 30 MeV

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The Large Area Telescope

Anti-Coincidence Detector (ACD):

- + Segmented (89 tiles)
- + Self-veto @ high energy limited
- + Efficiency 0.9997 (overall)

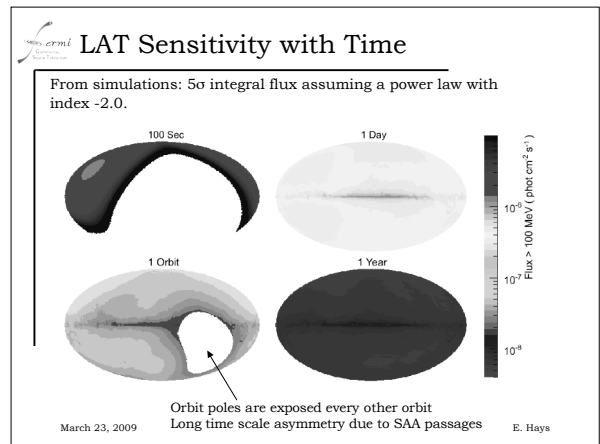
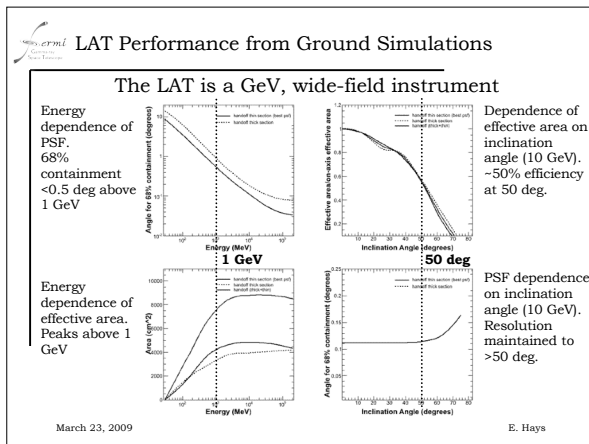
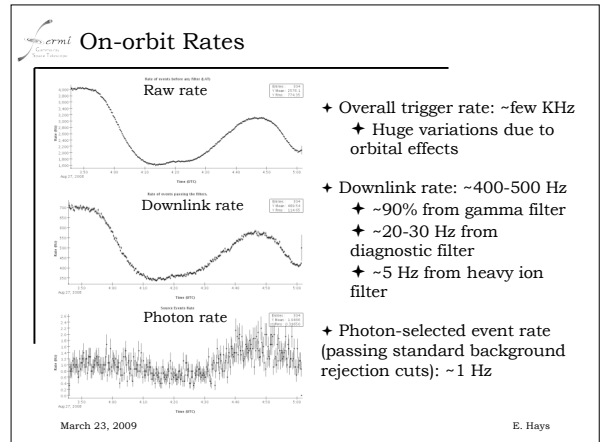
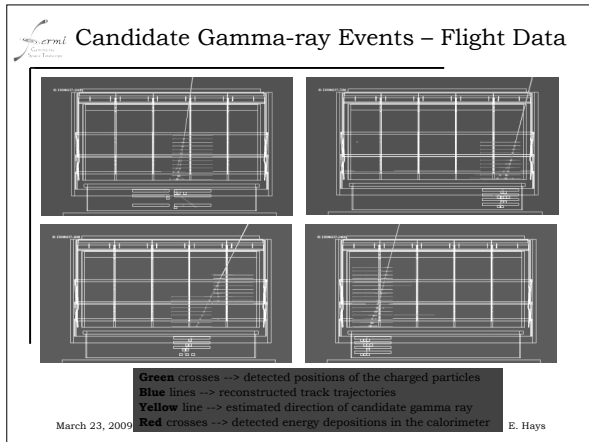
Tracker (TKR):

- + Tungsten foils convert
- + Silicon strip detectors (single sided, each layer rotated by 90 degrees)
- + ~80 m² of silicon (total)
- + ~10⁶ electronics channels
- + High precision tracking, low dead time

Calorimeter (CAL):

- + 1536 CsI crystals
- + 8.5 radiation lengths
- + Hodoscopic
- + Shower profile reconstruction (leakage correction)

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Overview

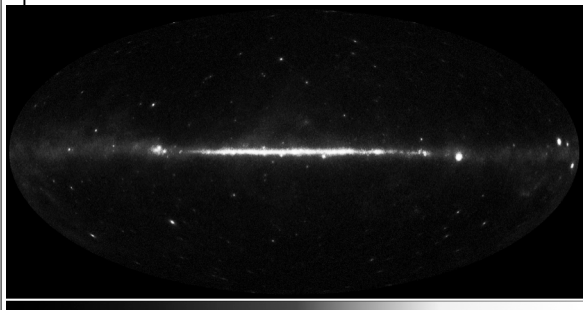
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The 3 Month Skymap



E>200 MeV (>400 MeV thick detector)

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Bright Source List

- + Basic Info
 - + <http://fermi.gsfc.nasa.gov/ssc>
 - + Released February 9
 - + Based on 3 months of data (Aug. - Oct.)
 - + 2.8 million events
 - + Detection significance, Location, Flux in two energy bands, Variability information
- + Important Caveats
 - + Incomplete (bright sources only)
 - + Not flux-selected (>10 σ)
 - + Not uniform (sensitivity varies over sky)
 - + Significance threshold favors
 - + Hard spectra
 - + High latitude (lower diffuse emission)

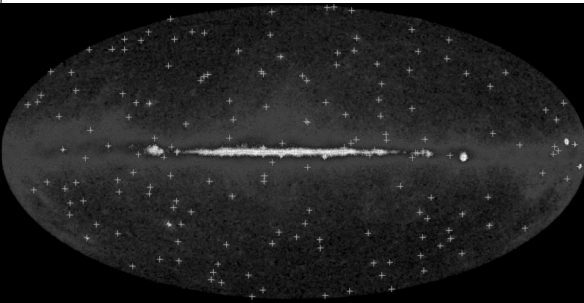


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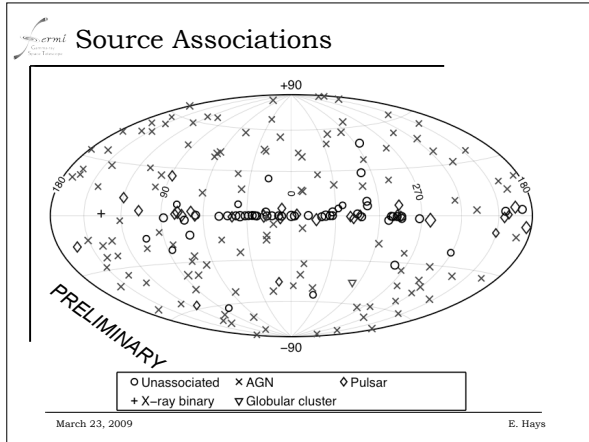
205 Preliminary LAT Bright Sources



>50% associated with blazars
 29 pulsars with gamma-ray pulsations
 Over 40 sources without clear associations

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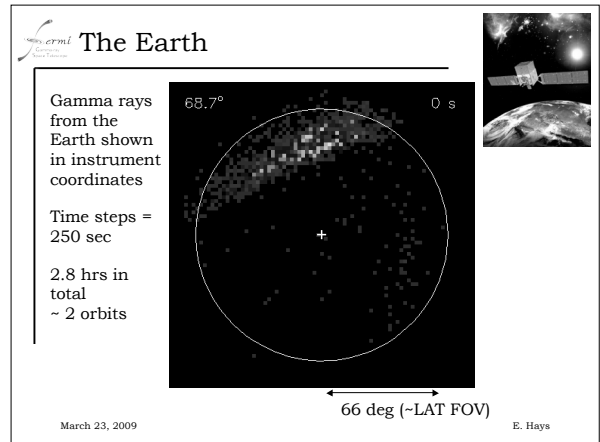


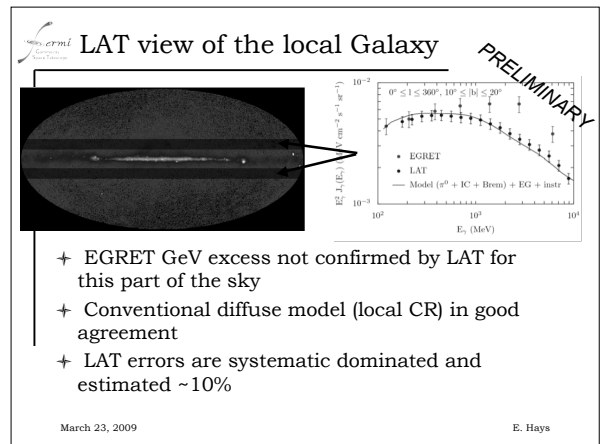
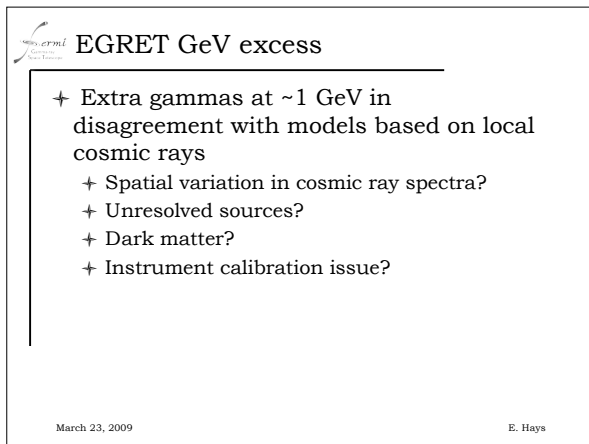
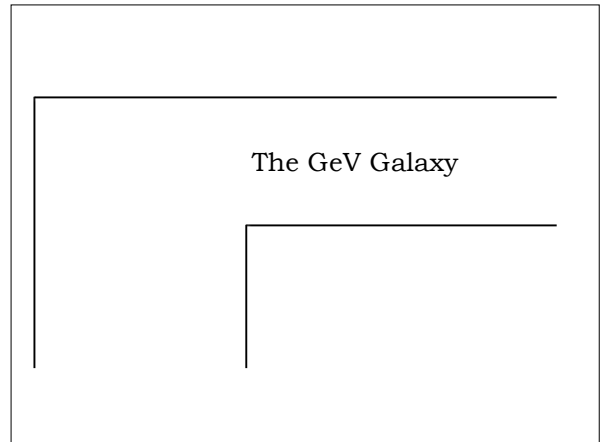
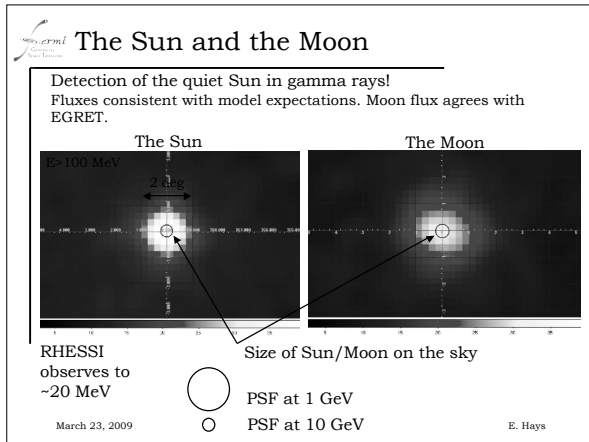
The GeV Solar System

Solar System Gamma Rays

- + Albedo gamma rays from cosmic rays impacting matter
 - + Earth
 - + Moon
 - + Sun
 - + Other planets, asteroids?
- + Inverse-Compton (e.g. Moskalenko Strong 2008)
 - + Scattering of solar photons by Galactic cosmic-ray electrons
- + Solar Flares (Solar Maximum in 2011)
 - + Electrons and Ions accelerated in solar magnetosphere
 - + Generates particle cascades

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Rotation Powered Pulsars

- Electrons (positrons) accelerated to relativistic speeds, emit synchrotron radiation
- Radio emission along magnetic axis
- > 1500 radio pulsars catalogued
- Rotational periods from msec to secs, increasing over time

Rotation Axis
Radio beam
20 km
Magnetic field lines

Neutron star ~ 1.4 x Mass Sun

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Gamma Ray Pulsars with CGRO

Radio
Optical
X-ray
Gamma Ray

CRAB PSR B1509-59 VELA PSR B1706-44 PSR B1951+32 GEMINGA PSR B1066-52

P = 33 mSEC P = 150 mSEC P = 89 mSEC P = 102 mSEC P = 38 mSEC P = 237 mSEC P = 197 mSEC

TIME IN FRACTIONS OF A PULSE PERIOD

D.J. Thompson (NASA / GSFC)

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EGRET Pulsars confirmed

Vela: P=89.3 ms
Geminga: P=237 ms
Crab: P=33 ms

100s γ 's per day
1 million over mission

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Bright Gamma-ray Pulsars

Gamma Only
MSP
Radio+Gamma

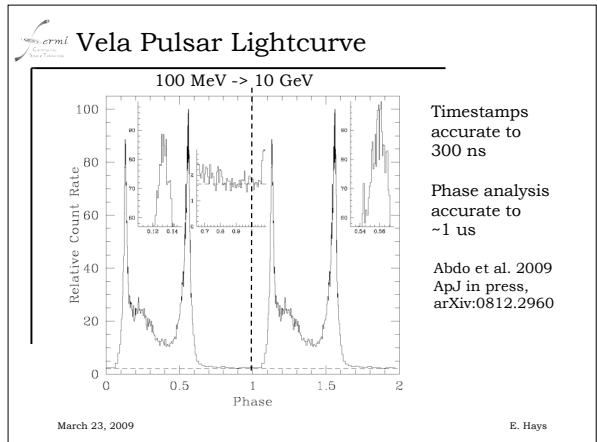
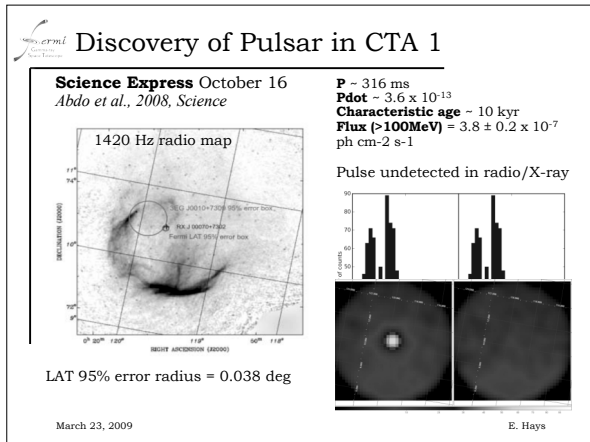
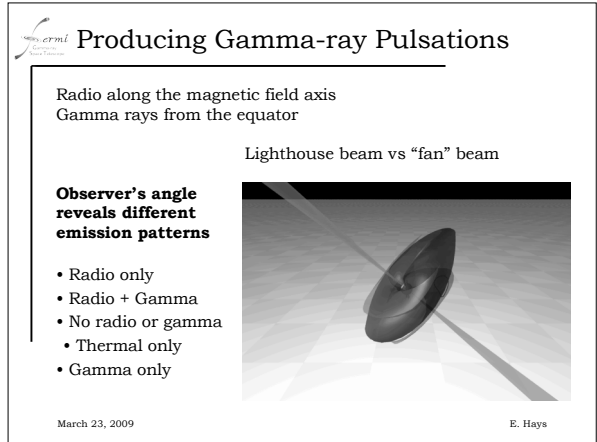
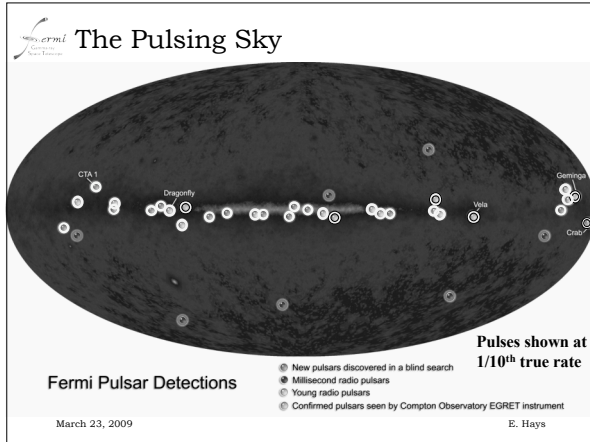
CTA 1
Dragonfly
Vela
Geminga
Crab

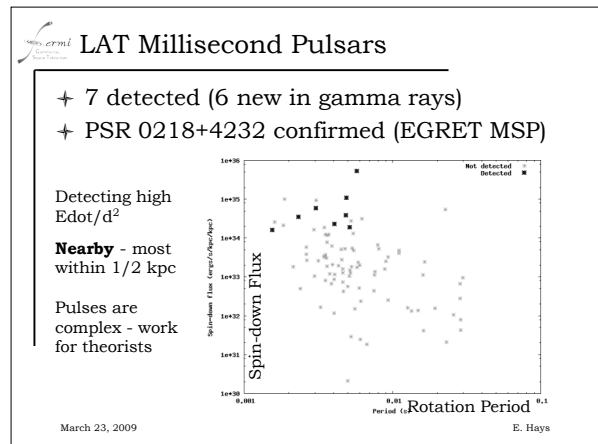
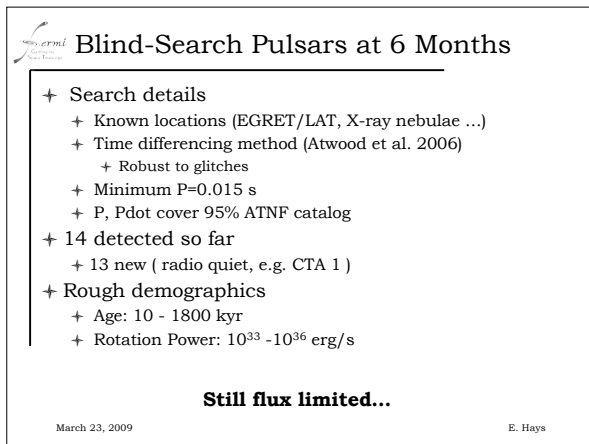
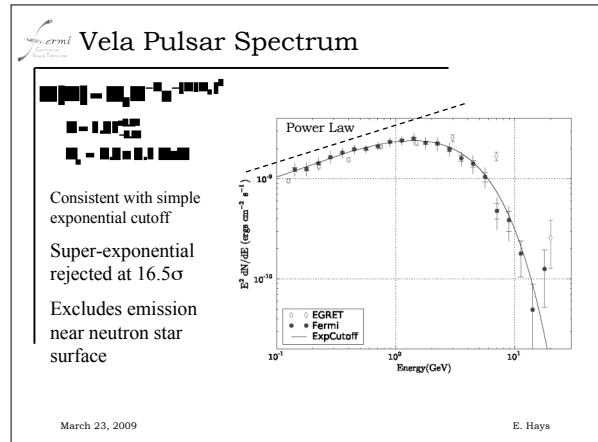
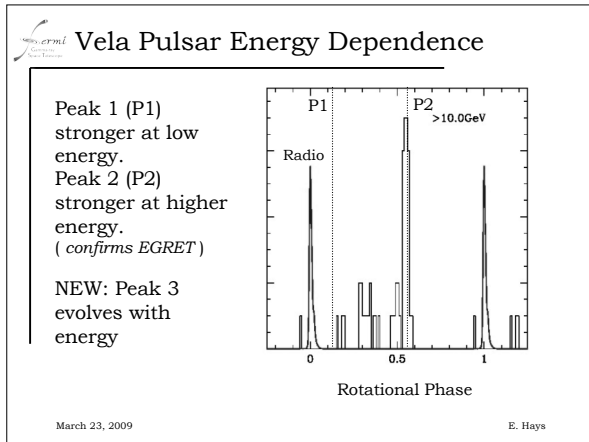
Fermi Pulsar Detections

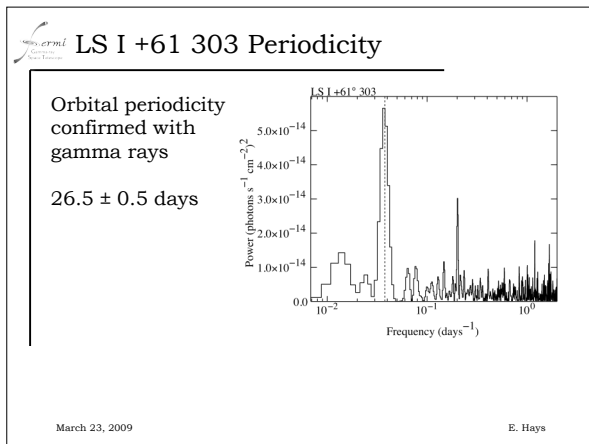
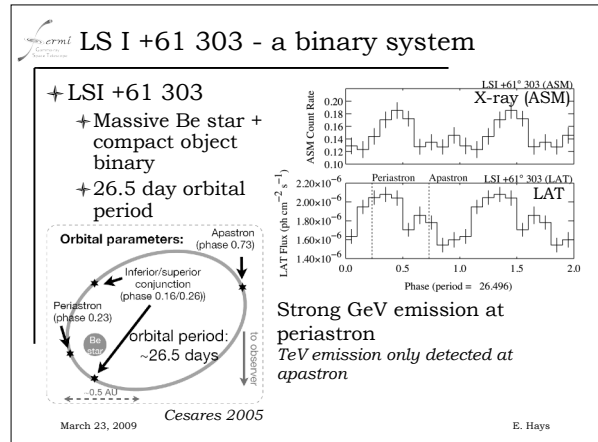
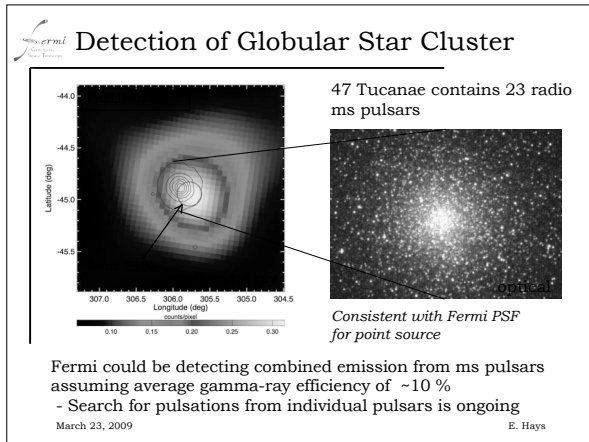
- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Confirmed pulsars seen by Compton Observatory EGRET instrument

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13
7
12
6

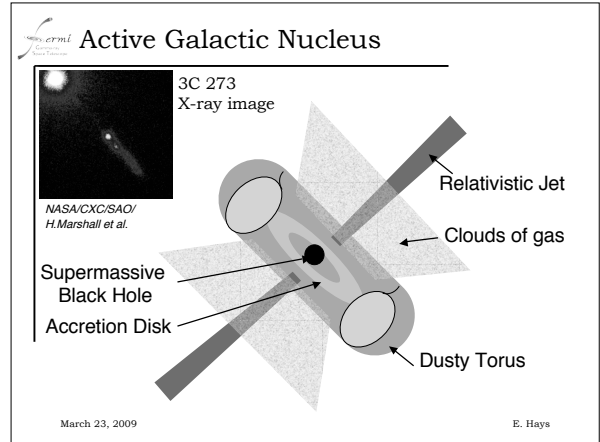






- A Multi-TeV to GeV Connection?**
- + Milagro Galactic Plane sources (Abdo et al. 2007)
 - + Median energy ~20 TeV
 - + 4 detections and 4 candidate sources in the Galactic Plane
 - + 6 coincide with EGRET sources (includes Crab nebula and Geminga pulsar)
 - + MGRO 1908+06, MGRO 2019+37*, MGRO 2031+41, and C4* overlap with new gamma-ray pulsars in the Bright Source List
 - + Pulsations tend to cut off at a few GeV
 - + Nebula emission formed by the pulsar particle outflow (PWN)?
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GeV emission from beyond our Galaxy



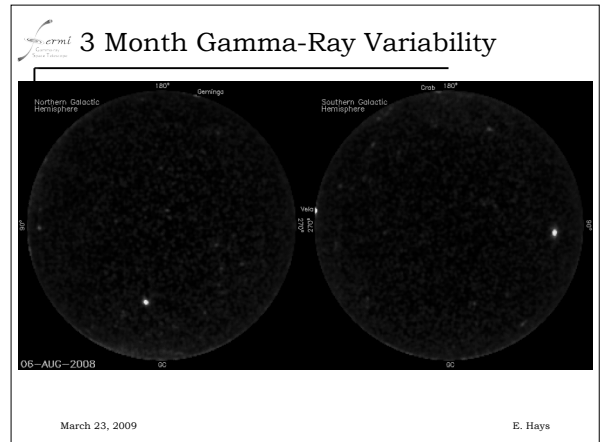
What's New?

- + 30% bright sources flagged as variable
 - + The gamma-ray sky is dynamic!
- + About 30% overlap with EGRET
 - + Expected due to weekly to yearly variability of AGN
- + Higher fraction of BL Lacs than EGRET
- + More distant AGN

Spectral index

Redshift

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Fermi Gamma-Ray Bursts

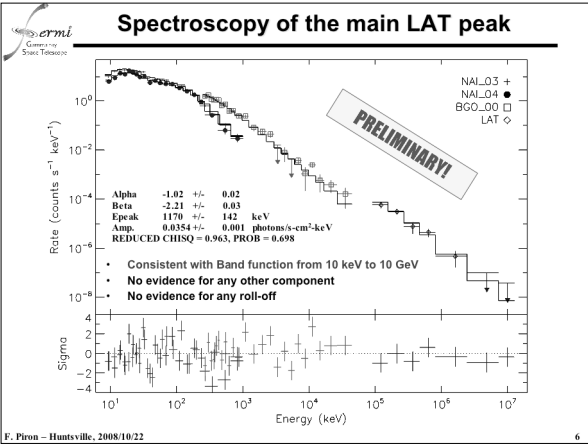
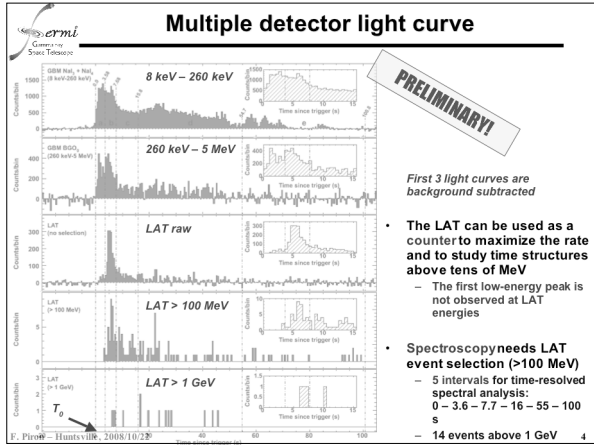
- + More than 115 GBM bursts since July
 - + More than expected - GBM trigger has improved time sensitivity
 - + 20 short GRBs
- + 4 bursts detected in LAT
 - + Roughly consistent with expectations
 - + GRB 080825C - the first one
 - + >10 events above 100 MeV
 - + GRB 080916C - the long one
 - + GRB 081024B - the short one
 - + detected >1 GeV photons
 - + GRB 081215A - the transverse one
 - + 86 deg from LAT on-axis - rate only, not imaged

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GRB 080916C - the long **bright one**

- + 2nd GRB detected by the LAT
 - + 1st since EGRET with imaged photons and energies > 1 GeV !
- + Brightest burst with a measured redshift
 - + GROND measurement of redshift $z = 4.24$
- + Prompt emission
 - + 1st GBM burst in fluence ($4.0 \cdot 10^{-5}$ erg/cm² in 50 - 300 keV) and in LAT FoV
 - + >140 LAT events for spectral analysis (>100 MeV)
 - + >3000 LAT events in first 100 seconds
 - + Time-resolved spectroscopy over **6 decades in energy** (10 keV to 10 GeV)
 - + High-energy emission peaks at later times
- + High-energy emission observed up to 23 min after the trigger time

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How Relativistic is the Jet?

- + High redshift and high fluence implies strongly collimated jet
- + No spectral cut off ($z=4.35$)
 - + Bulk Lorentz factor $\Gamma \geq 600$ for second peak in lightcurve (≥ 900 for later timeslice of lightcurve)
- + Also can set limit on Lorentz invariance violation
 - + Highest E photon $13.2 \text{ GeV} (1+z) = 70.6 \text{ GeV}$
 - + Arrived 16.7 sec after trigger
 - + $M_{\text{QG}} > 1.50e18 \text{ GeV}/c^2 \sim 0.1 M_{\text{Planck}}$

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Transients Unidentified and the Unexpected



Transients in the Galactic Plane

Fermi LAT Detection of Brightening of the Galactic Source 3EG J0903-3531

ATel #1771: E. Hays, C.C. Cheung (NASA/GSFC), L. Reyes (U. Chicago), on behalf of the Fermi LAT Large Area Telescope Collaboration
 on 8 Oct 2008; 21:37 UT
 Password Certification: Teddy Cheung (tcheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, Transients

The Large Area Telescope (LAT), one of two instruments on the Fermi Gamma-ray Space Telescope (formerly GLAST), launched June 11, 2008, has observed an increase in flux from a gamma-ray source in the Galactic Plane, as identified by the preliminary LAT position in Hays et al. (1999), ApJS, 123, 79, starting on 20081010.84513623 deg 2852--35.45 deg 0.08 deg (statistical). The systematic error of

Fermi LAT Detection of a New Gamma-ray Transient in the Galactic Plane: J0910-5041

ATel #1788: C.C. Cheung (NASA/GSFC), L. Reyes (U. Chicago), F. Longo (INFN Trieste), G. Ioffe (INAF/DA Triest) on behalf of the Fermi Large Area Telescope Collaboration
 on 17 Oct 2008; 20:00 UT
 Distributed as an Instant Email Notice (Transients)
 Password Certification: Teddy Cheung (tcheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, Transients
 Referred to by ATel # 1822, 1843

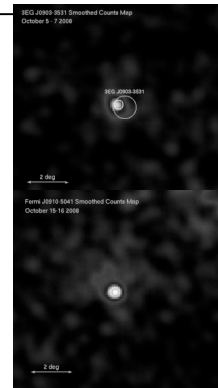
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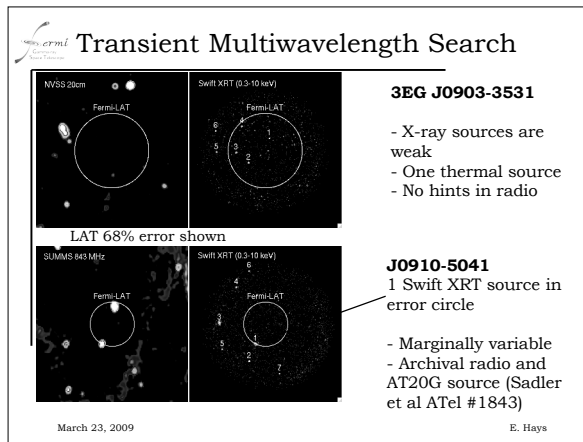
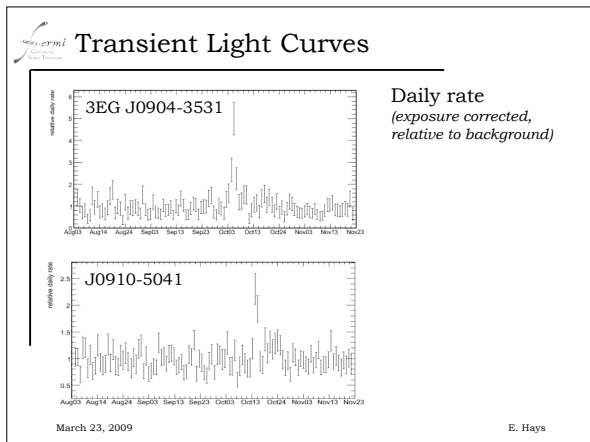


LAT Transients in the Galactic Plane

- + 2 ~day flares detected in the plane without obvious blazar counterpart
 - + ATel #1771
 - + Spatially coincident with 3EG J0903-3531
 - + Variable EGRET source appearing in several viewing periods
 - + 68% error radius 0.11 deg
 - + No firm identification
 - + ATel #1788
 - + New GeV source, Fermi J0910-5041
 - + 68% error radius 0.07 deg



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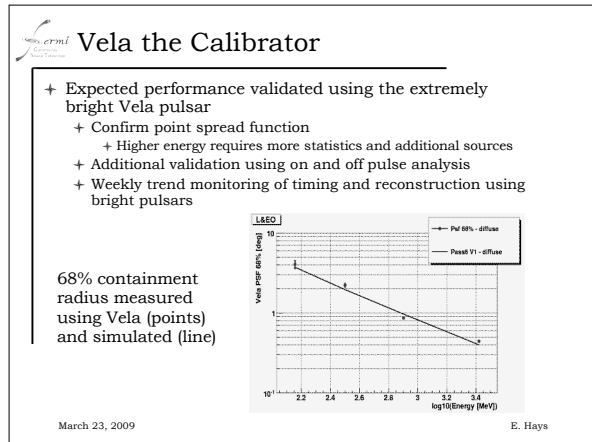
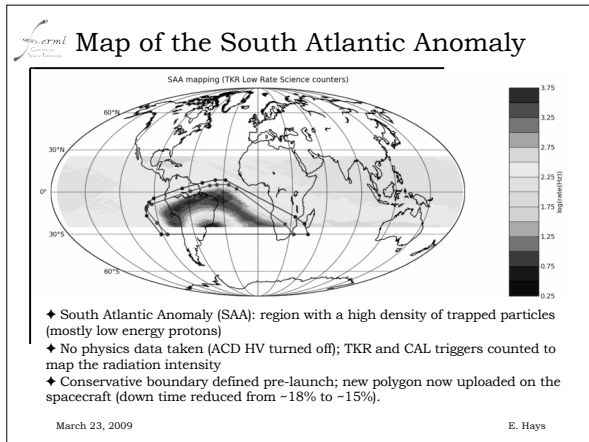
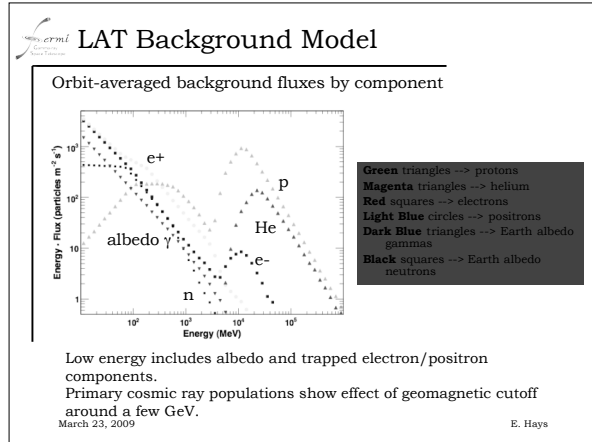
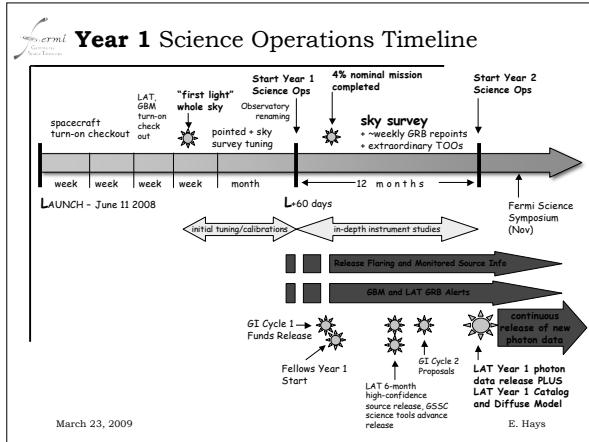


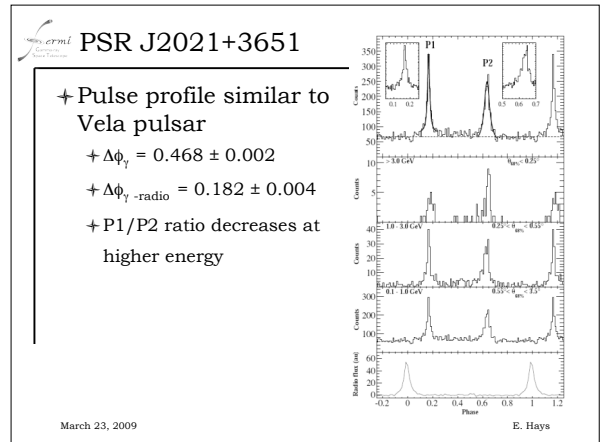
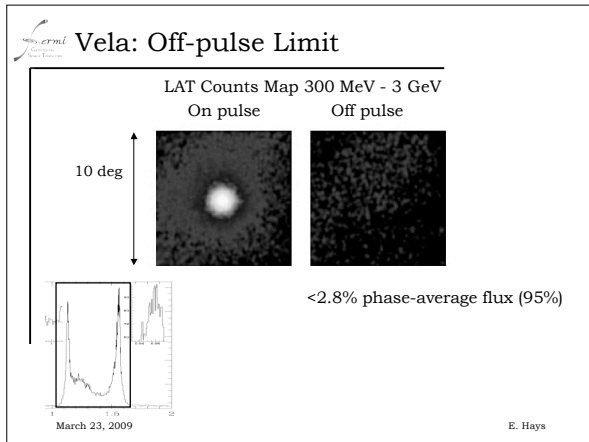
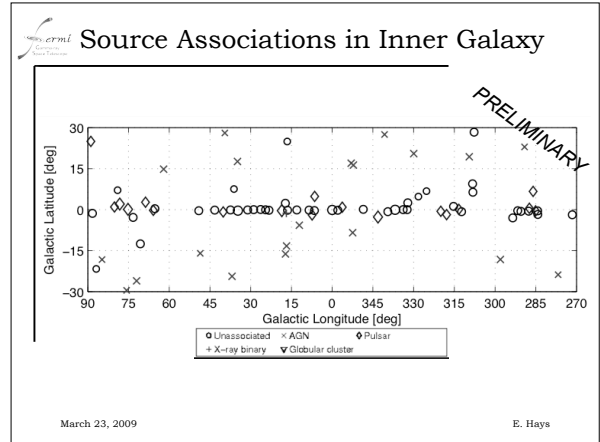
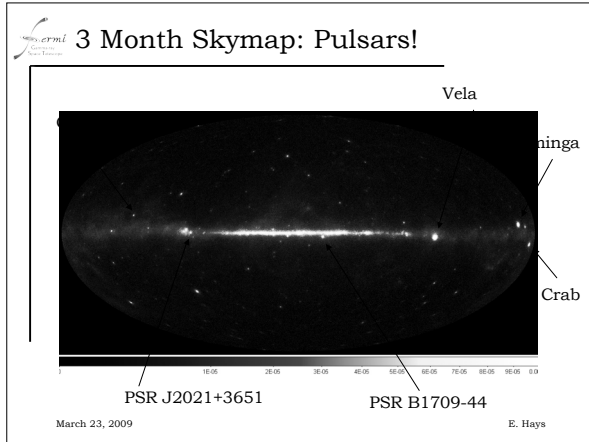
- ### Summary
- + The LAT is a powerful pulsar detector
 - + Already influencing pulsar models
 - + and a great flare monitor
 - + Ideal for multiwavelength campaigns (always on!)
 - + Excellent performance for GRBs bright at >100 MeV
 - + The Bright Source List is similar in size to entire EGRET catalog (at only 3 months)
 - + The Gamma-Ray sky is dynamic
 - + Lots more *Fermi* science to come!
- www.fermi.gsfc.nasa.gov
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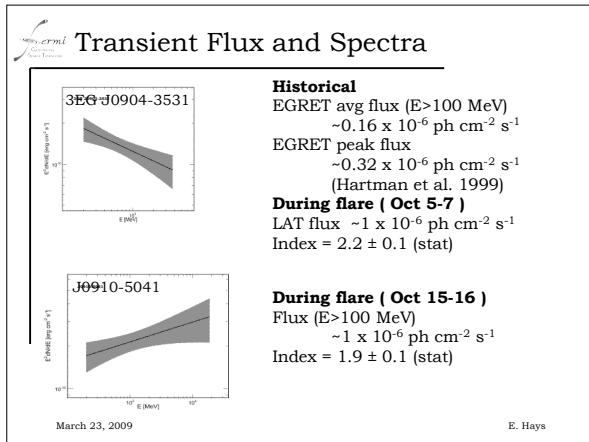
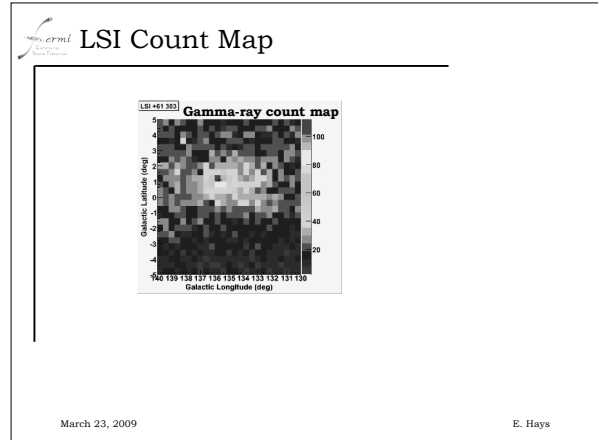
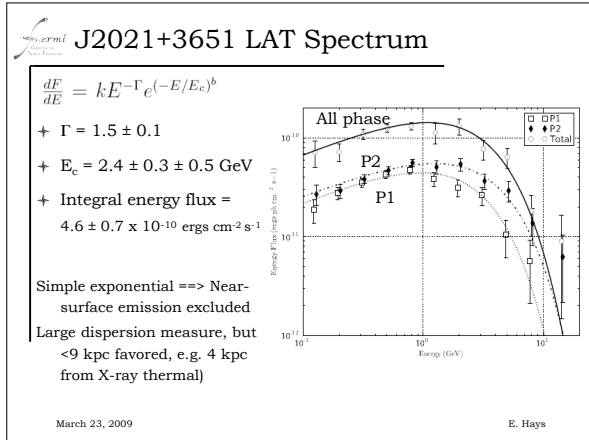
Back up slides...

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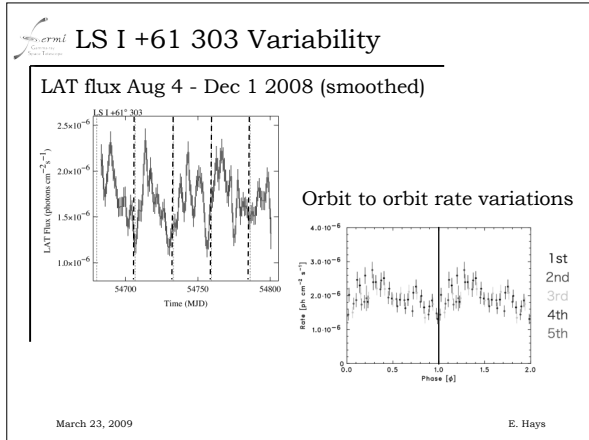
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- ### Galactic Transients
- + Monitored by the LAT team
 - + Weekly shifts covered by an AGN and galactic advocate
 - + Announced by ATels
 - + E-mail notice, request for observations
 - + 24 hr response time
 - + LAT contact person for updates and to coordinate multiwavelength follow-up
 - + Data release plan (1st year)
 - + $F(E > 100 \text{ MeV}) > 2 \times 10^{-6}$ $\text{ph cm}^{-2} \text{s}^{-1}$
 - + Daily flux in two energy bands
 - + Continues to flux $< 2 \times 10^{-7}$ $\text{ph cm}^{-2} \text{s}^{-1}$
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- TeV Added Value**
- + GeV + TeV detections
 - + Our pulsars are your PWNe?
 - + Identifying LAT sources in the Galactic plane
 - + TeV counterparts, localization, morphology
 - + TeV spectra - discerning components
 - + Gamma-ray Binaries
 - + Periodicity and variability
 - + Untangling progenitors and emission models
 - + TeV non-detections of LAT sources
 - + GeV populations with breaks/cutoffs?
 - + LAT non-detections of TeV sources?
 - + Does this become constraining at the 1 yr mark?
 - + Note this is a longer term item...
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- Summary**
- + Lots of exciting pulsar science
 - + Exquisite light curves and spectra of bright pulsars
 - + Gamma-ray only pulsars
 - + Millisecond pulsars
 - + Globular cluster
 - + Nebula observations possible in off-pulse
 - + Excellent and ongoing coverage of binary LS I +61 303 (5 orbits and counting)
 - + Searching for additional binaries
 - + Daily monitoring for transients in the Galactic plane
 - + Increasingly interesting with time...
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- Supernova Remnants?**
- + Too early to call...
 - + Yes, there are sources in the bright source list that are near supernova remnants
 - + But supernova remnants often coincide with pulsars
 - + Cannot claim associations for SNR this early
 - + At 1 year will have
 - + Improved instrument response
 - + Improved background models
 - + More statistics above 10 GeV
 - + Potential for studies of extended emission
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Limits on Lorentz Invariance

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