Physics 205

Opportunities with the
Fermi Gamma-ray Space Telescope

W.B. Atwood, R. Johnson, and S. Ritz
UCSC and SCIPP

See http://www-glast.stanford.edu/ and links therein

Physics 205

Opportunities with the
Large Synoptic Survey Telescope (LSST)

S. Ritz, C. Rockosi, R. Johnson
UCSC and SCIPP

See http://lsstcorp.org/

SCIPP

SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS

Intro and Overview

Much more at http://scipp.ucsc.edu/news.html

SCIPP Overview

- **UCSC Organized Research Unit**
  - **Includes faculty from Physics, Astronomy and Astrophysics, and SCIPP appointments.**
  - **14 post-docs and research physicists, 8 technical staff, 29 graduate students, >50 undergrads, plus visitors, administrative staff**
- **Primary focus is experimental and theoretical particle physics, including the development of technologies needed to advance that research.**
- **Also pursuing the application of those technologies to other scientific fields such as neurophysiology and biomedicine.**
- **A great strength is the close interplay between theory and experiment.**
- **Very strong support from the University.**
- **SCIPP is constantly evolving.**

Many Ongoing and New Activities

- **Active areas of research include**
  - Energy frontier (ATLAS at the LHC). Data analysis and upgrades.
  - Future collider detector development
  - Fermi Gamma-ray Space Telescope operation and data analysis; VERITAS and CTA; involvement also with HAWC; NuSTAR, ADELE, BARREL, RHESSI.
  - Dark Energy Survey (DES); Baryon Oscillation Spectroscopic Survey (BOSS); Large Synoptic Survey Telescope (LSST)
  - NeuroProject; Medical applications (pCT)
  - Heavy Photon Search (HPS)
  - Theoretical Astrophysics and Cosmology. Close connections to HIPACC and UCO.
  - Theoretical Particle Physics

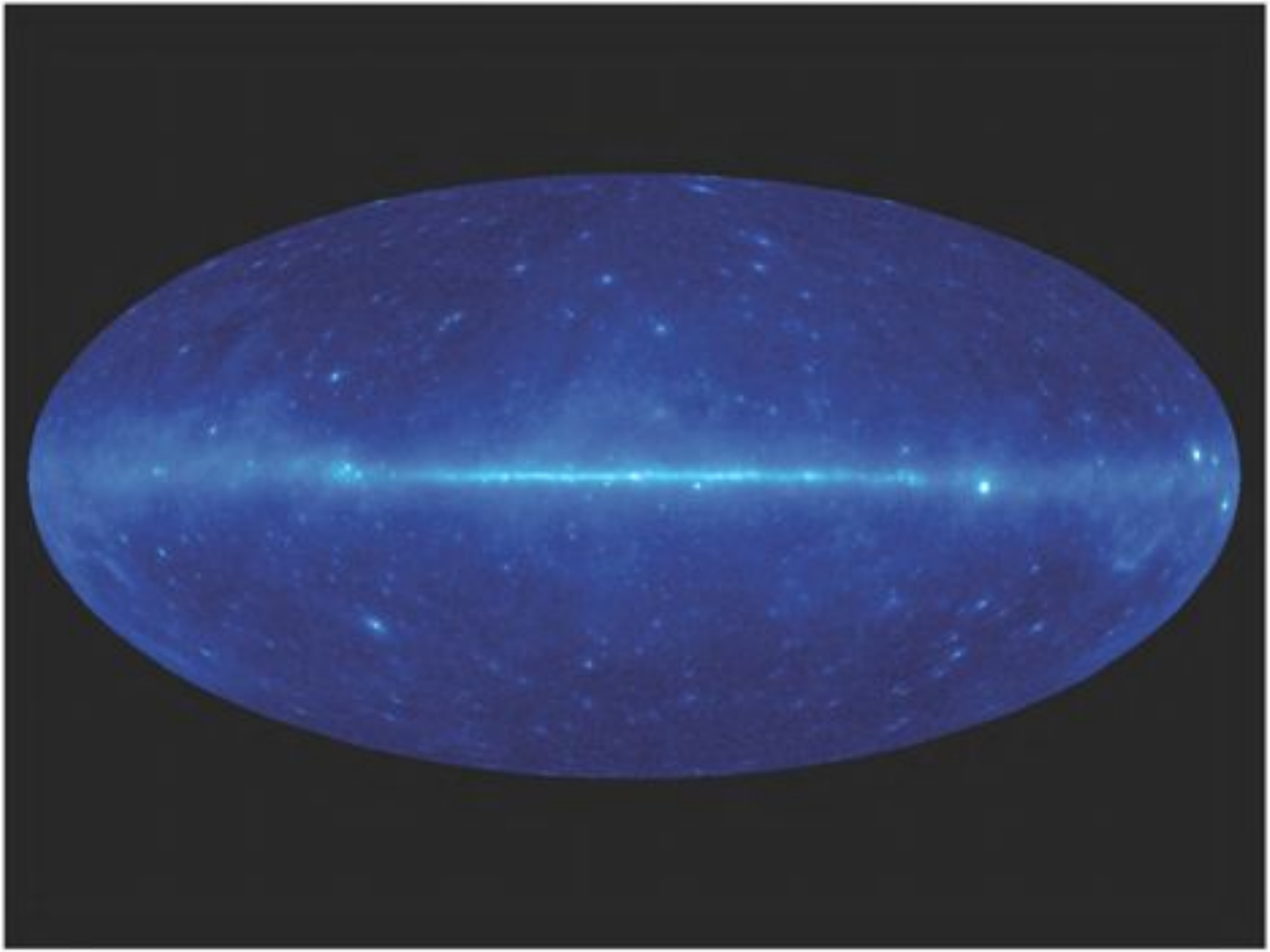
Recent Community Service (a lot!)

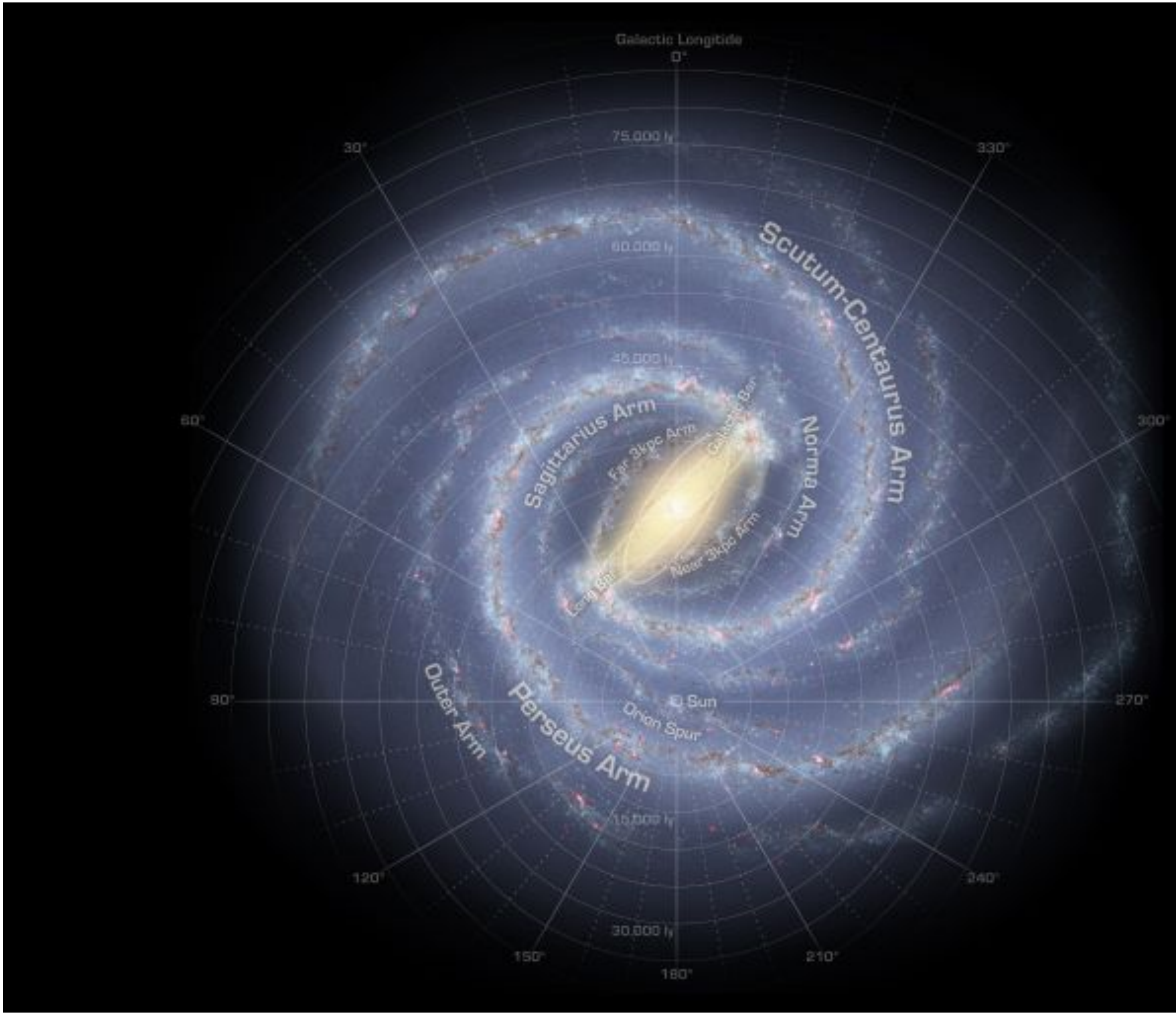
- Snowmass Leadership:
  - Cosmic Frontier (Ritz)
  - Dark Matter Indirect Detection (Profumo)
  - Theory (Dine)
  - Future Colliders (Battaglia)
  - Instrumentation (Seiden)
- Recent Reviews and Panels:
  - COV (Dine)
  - DOE Comparative Review University Program (Dine)
  - NSF PFC Review Panel (Profumo)
  - DOE Comparative Review of Labs (Ritz)
  - FNAL PAC (Ritz, chair)
  - LBNL Physics Division DOE Review (Ritz)
  - SLAC/SU KIPAC Visiting Committee (Ritz, chair)
  - P5 Chair (Ritz)
- DPF Officer (Haber)
- DPF MEETING @ UCSC (Seiden lead organizer)
- Outreach:
  - QuarkNet Center
    - High School Student Summer Program (Ritz)
    - Balloonfest (Schalk, Sadrozinski)
  - Public Talks:
    - "All you wanted to know about the Higgs but were afraid to ask" (Schumm)
    - Monterey Bay Physics Teachers' Alliance talk about Higgs and LHC (Nielsen)
    - Scotts Valley High School Keynote (Ritz)
    - FACULTY RESEARCH LECTURE 2014: Seiden and Haber, Higgs Discovery
  - "Particle Fever" Santa Cruz screening event 2014

Some History

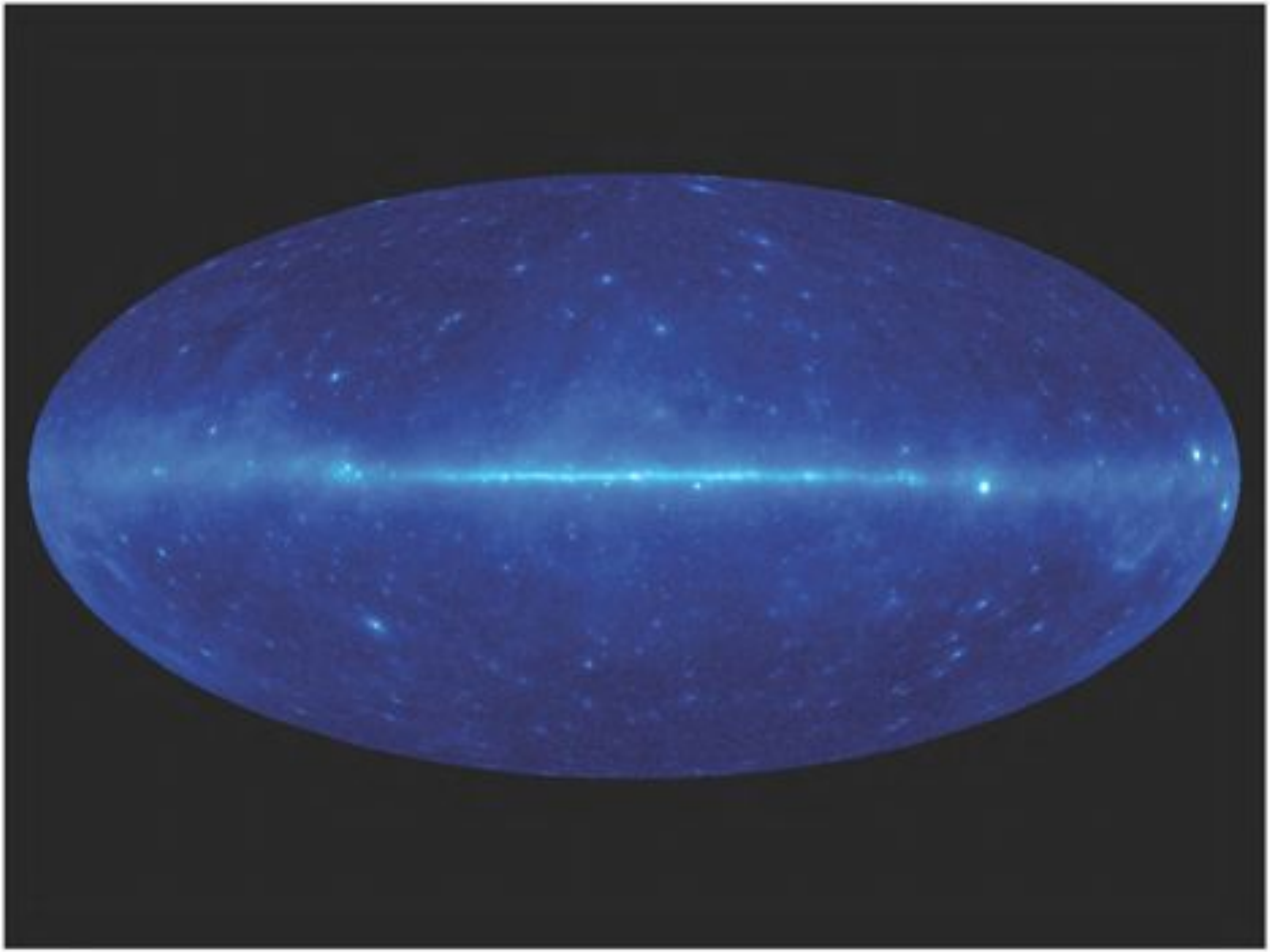
SCIPP personnel have been at the core of Fermi (originally called GLAST) since inception. Bill Atwood, together with Peter Michelson (Stanford), originated the mission in the early 1990s. Robert Johnson soon joined, and he became the leader of the LAT Tracker subsystem. Steve Ritz joined in 1996 and contributed to many aspects of the instrument, especially those crossing subsystem boundaries, and soon became the LAT Instrument Scientist and LAT Deputy PI, as well as the overall Mission Project Scientist.

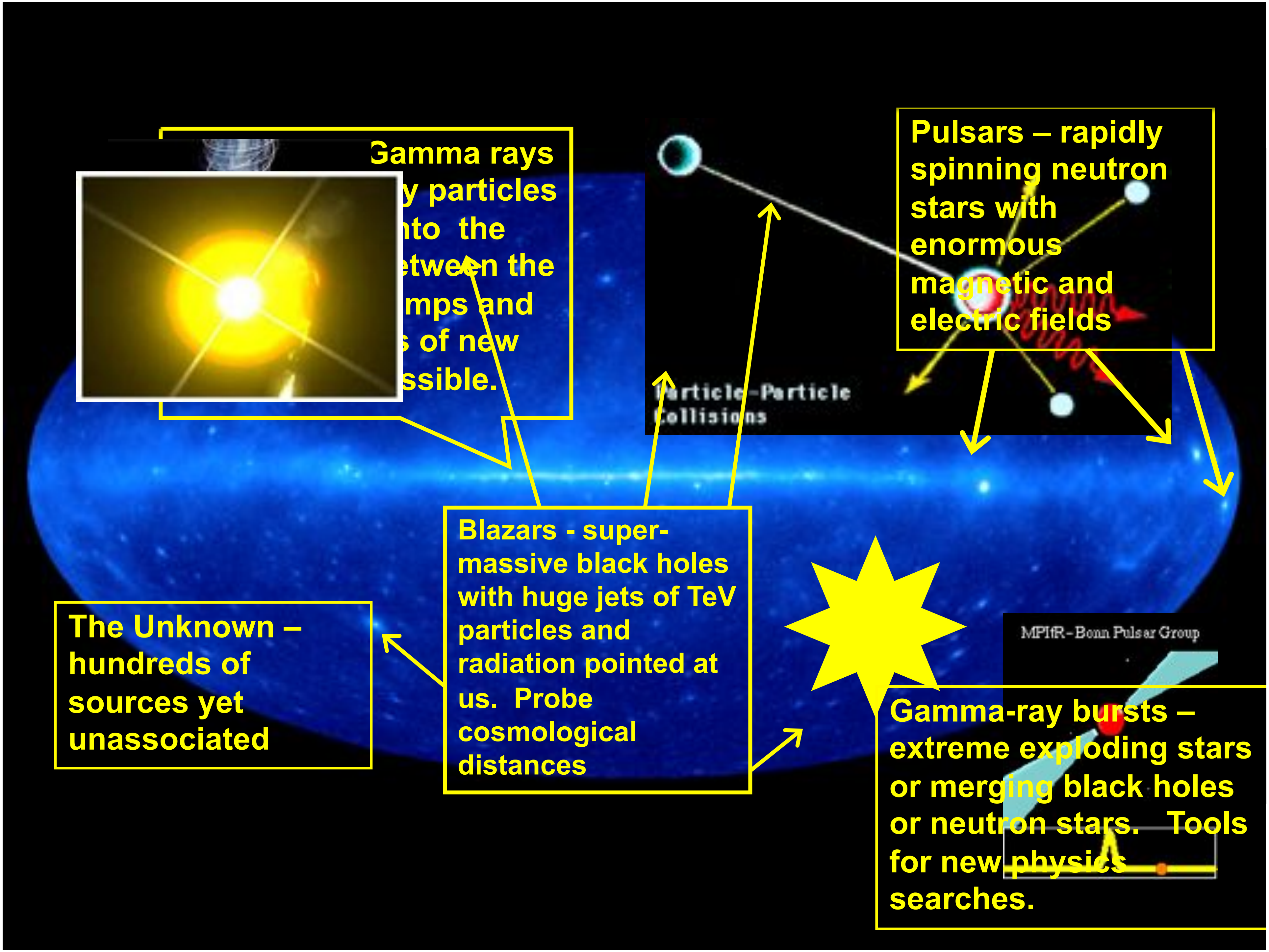
SCIPP members have been deeply involved in all aspects of the project, from detailed hardware design, construction, testing, and operation, through reconstruction software and physics analysis. The SCIPP group is a leading DOE-funded university group on Fermi.





Credit: R. Hurt




Gamma rays
y particles
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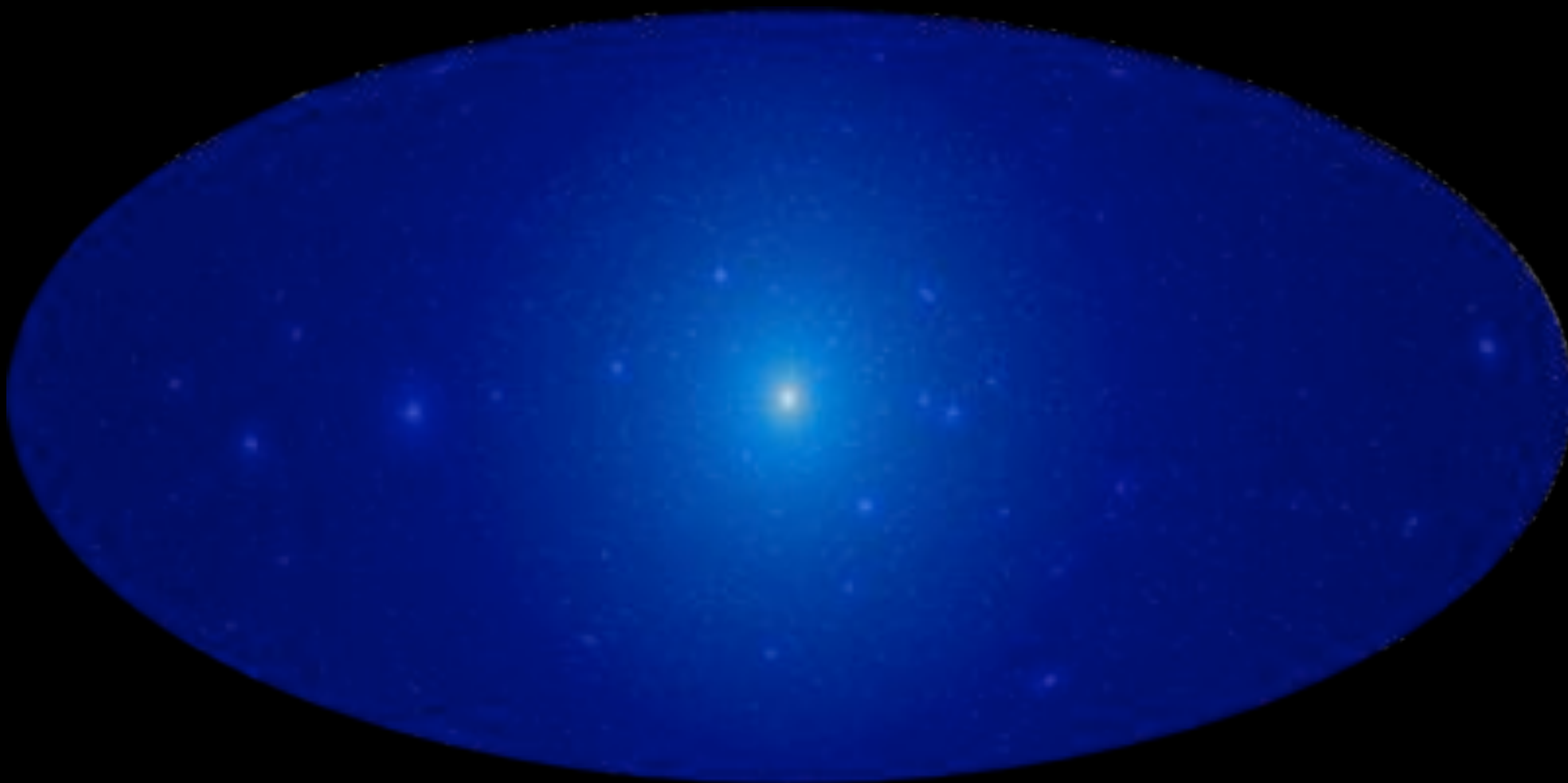
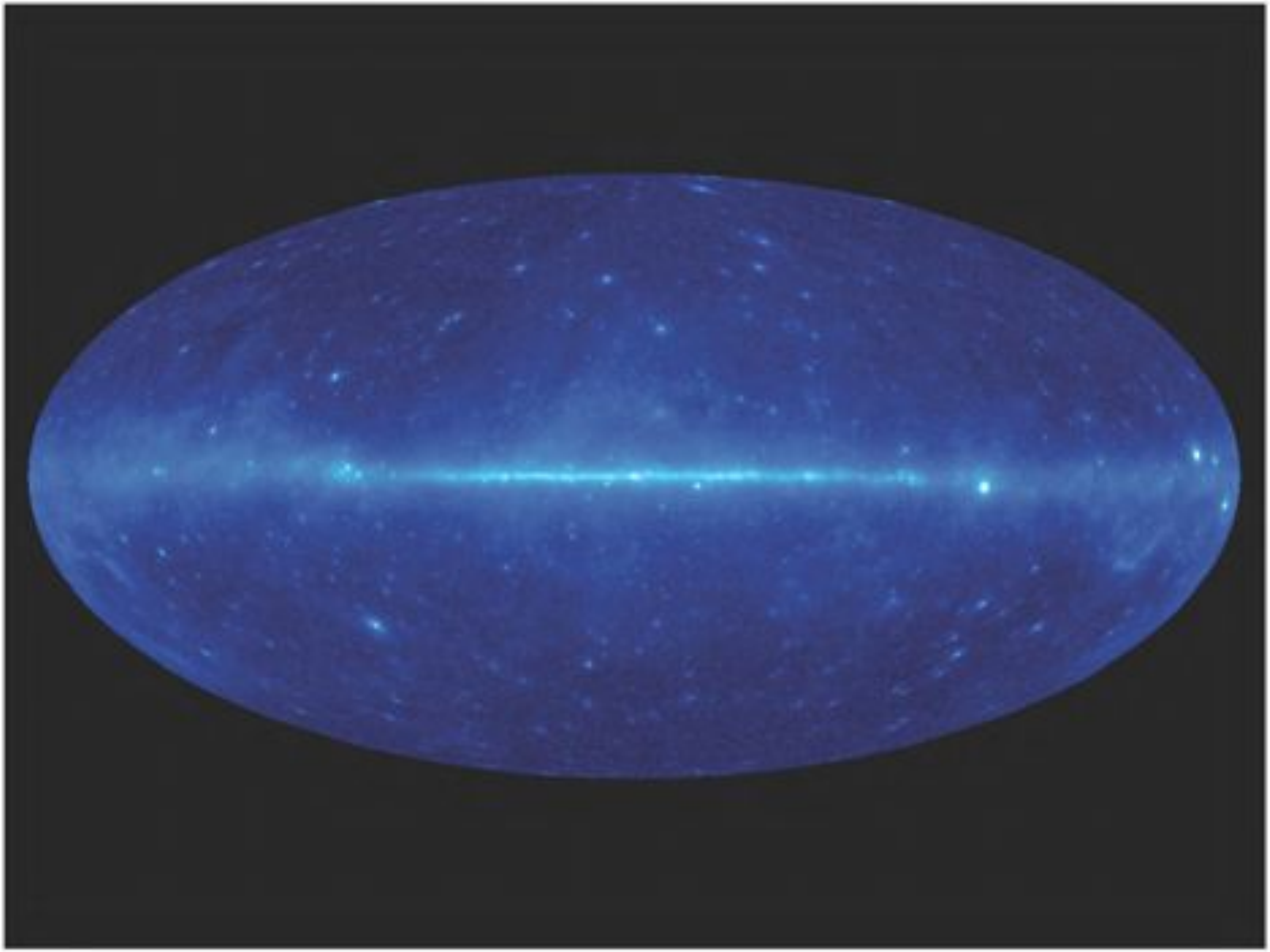
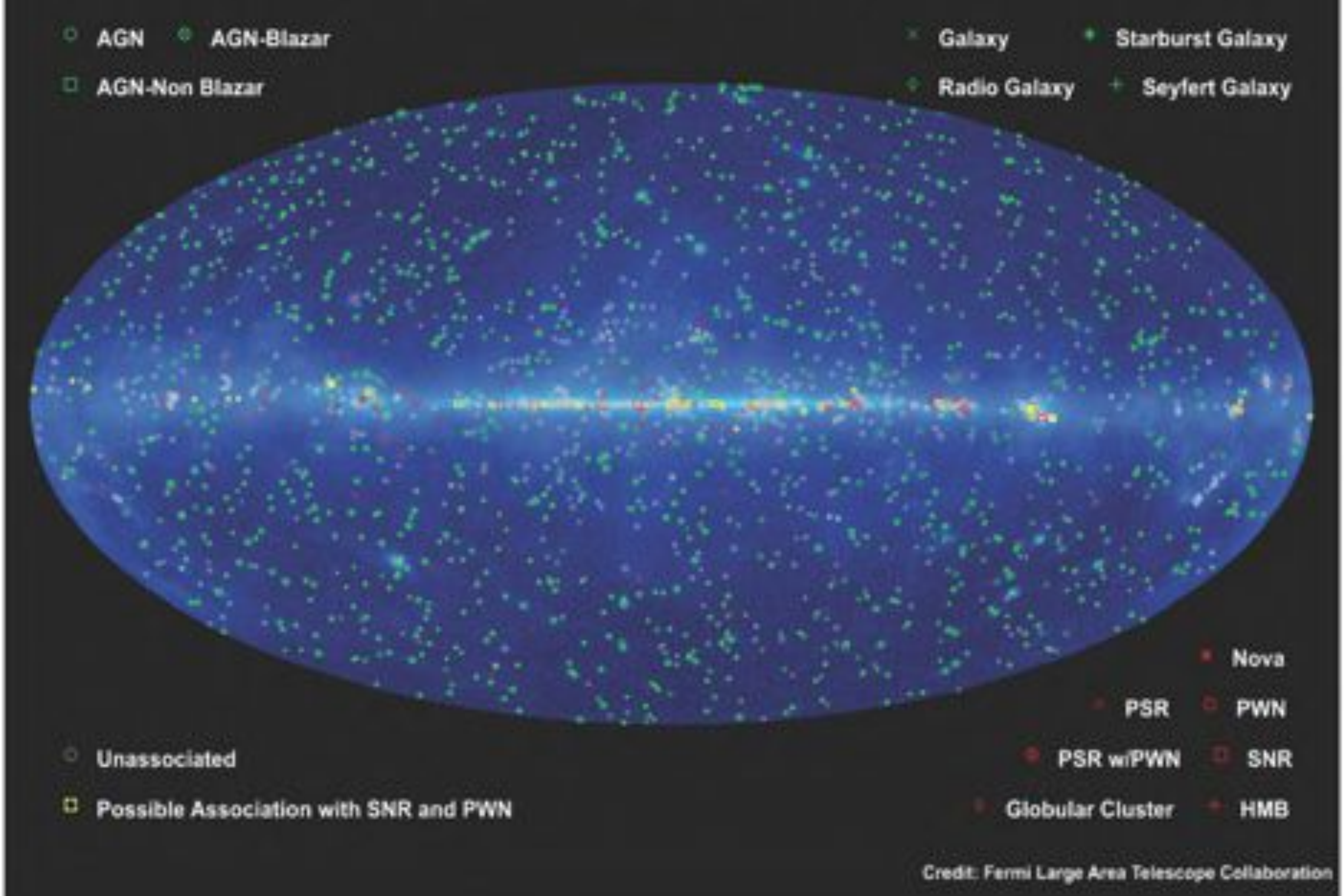
article-Particle
ollisions
Pulsars – rapidly spinning neutron stars with enormous magnetic and electric fields
Blazars - super-massive black holes with huge jets of TeV particles and radiation pointed at us. Probe cosmological distances
The Unknown – hundreds of sources yet unassociated
MPIfR-Bonn Pulsar Group
Gamma-ray bursts – extreme exploding stars or merging black holes or neutron stars. Tools for new physics searches.



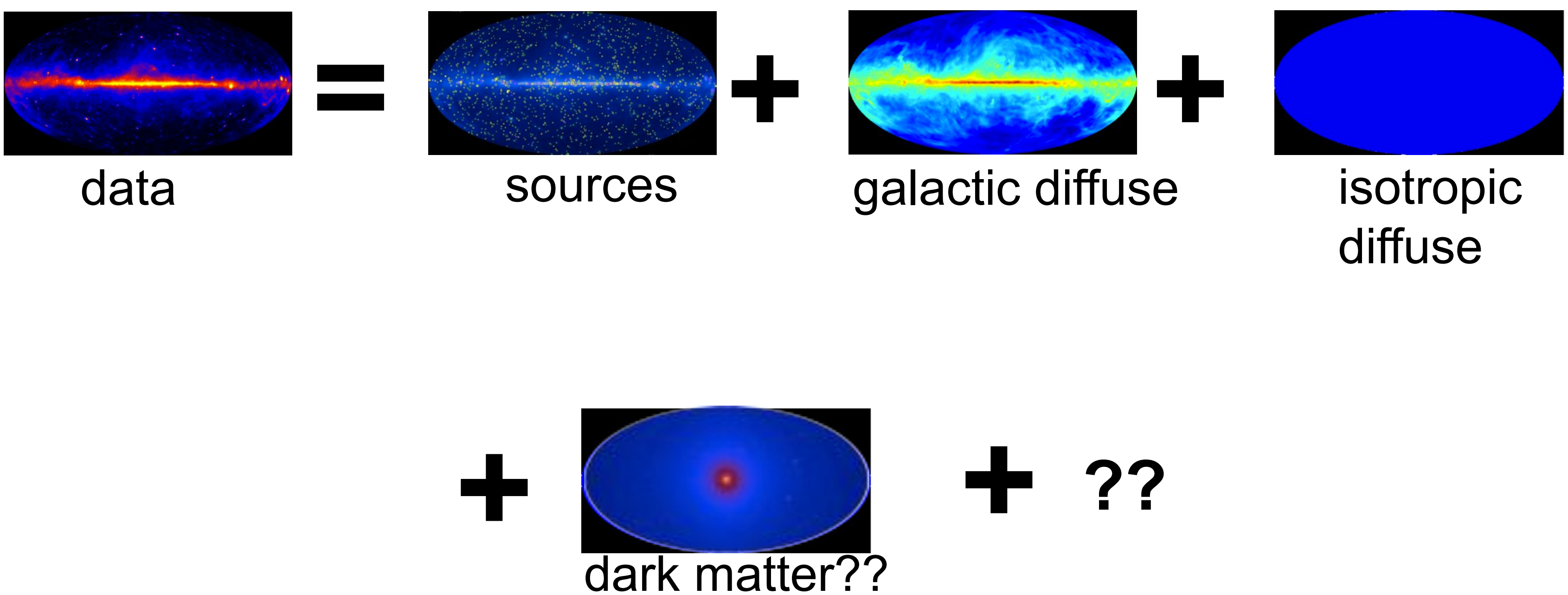
Gamma rays expected from Dark Matter Annihilation



Fermi Large Area Telescope 2FGL catalog



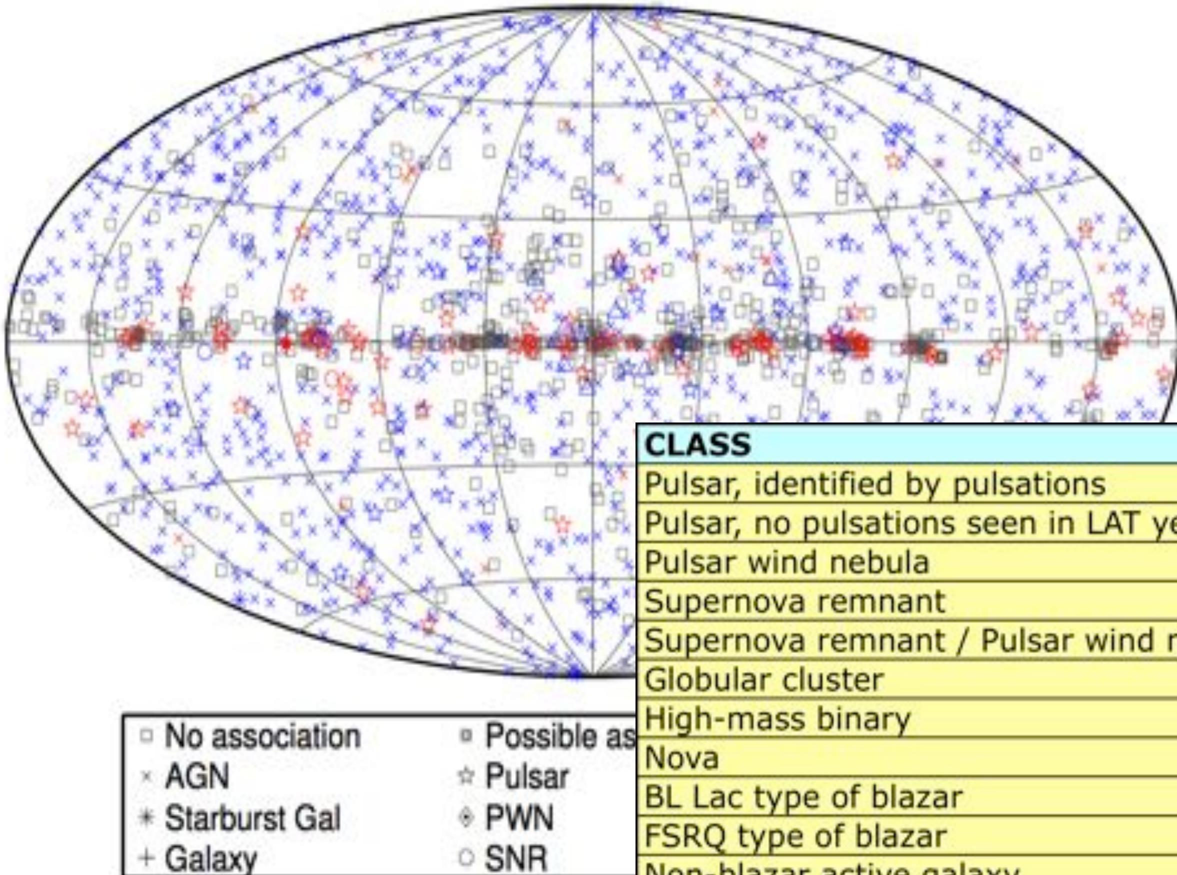
Understanding the Gamma-ray Sky



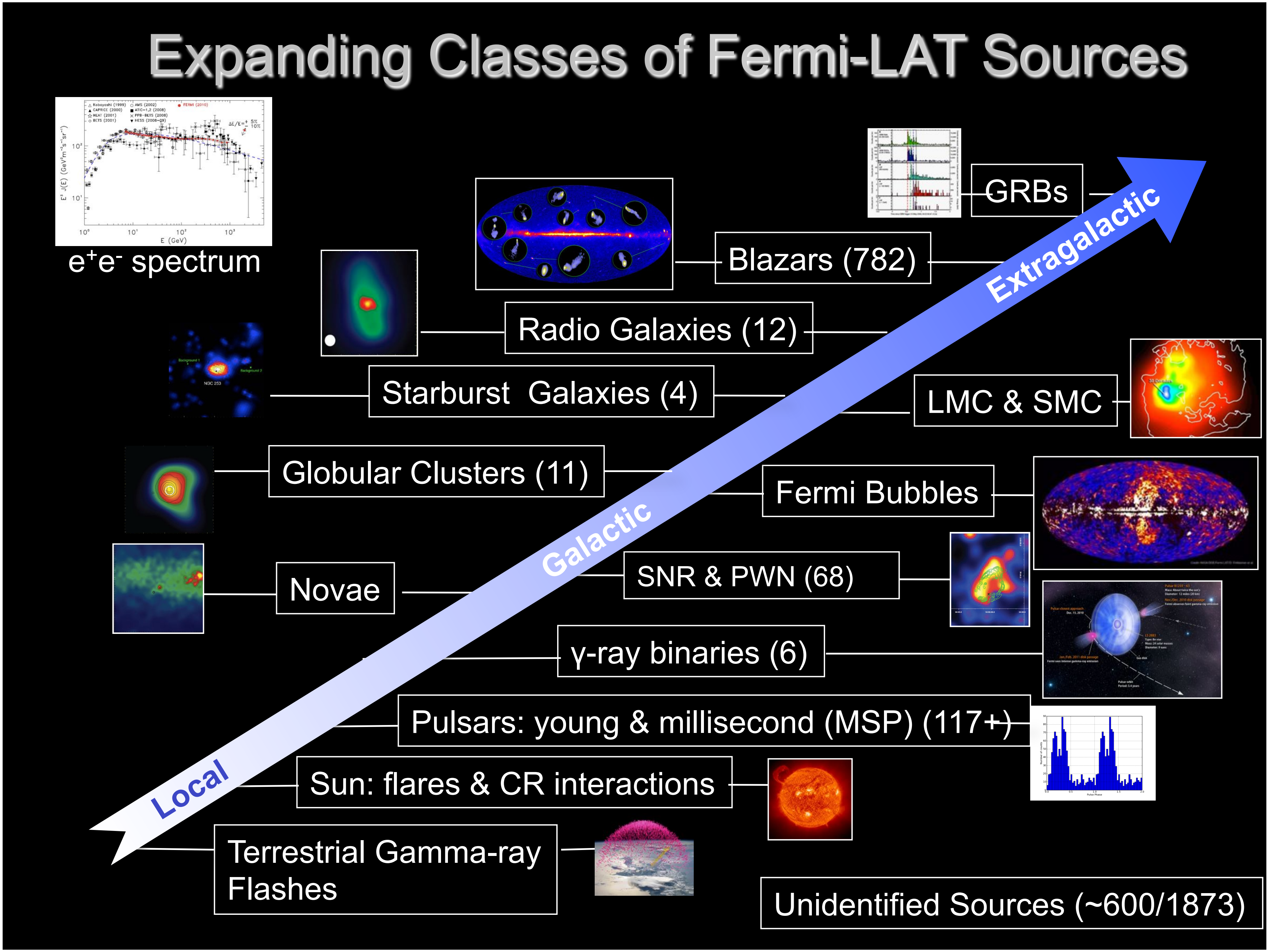
Bootstrapped, iterative process

2FGL Sources

Red symbols: Identified sources   Blue symbols: Associated sources

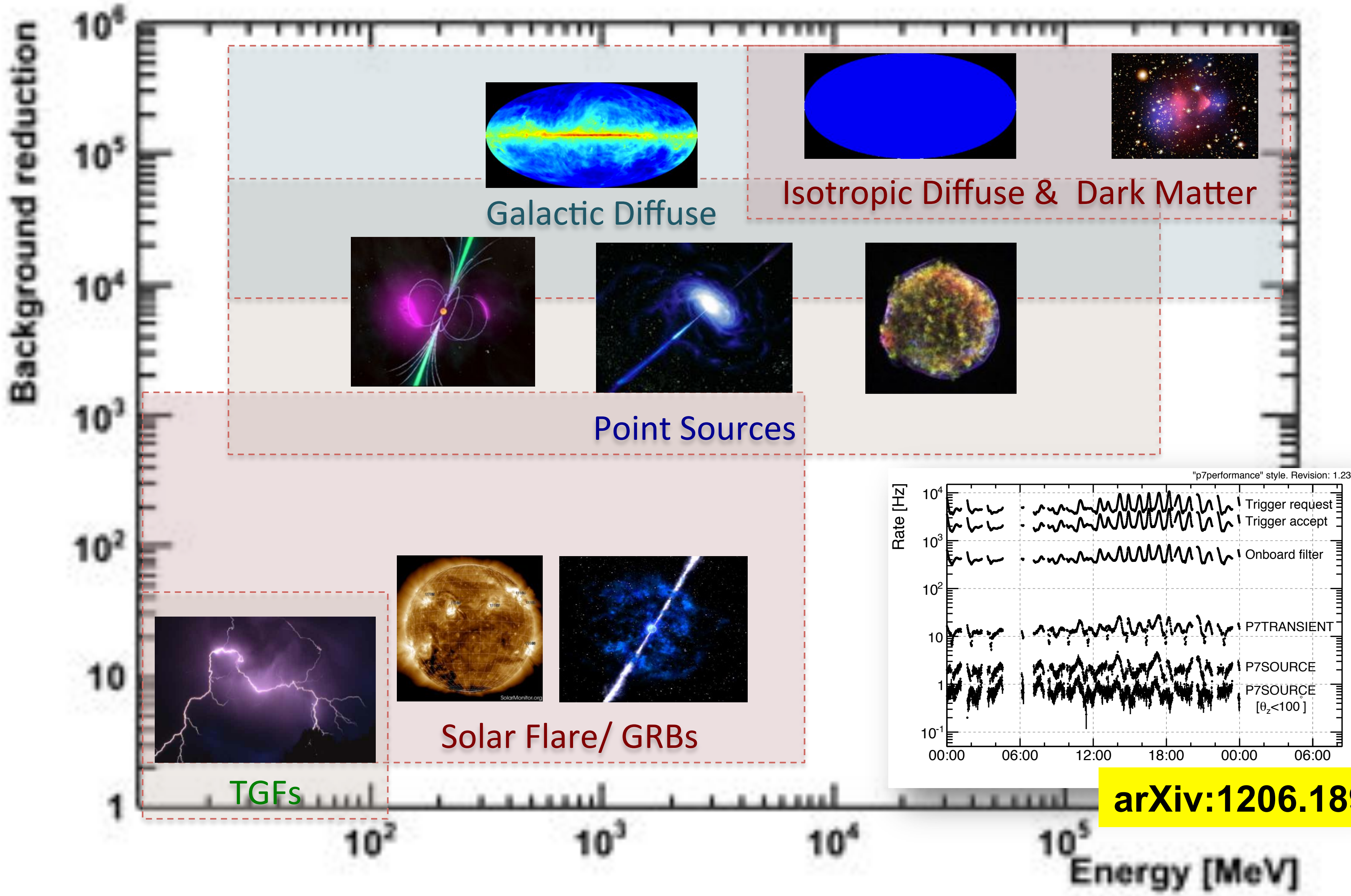


CLASS	Identified	Associated
Pulsar, identified by pulsations	83	-
Pulsar, no pulsations seen in LAT yet	-	25
Pulsar wind nebula	3	0
Supernova remnant	6	4
Supernova remnant / Pulsar wind nebula	-	58
Globular cluster	0	11
High-mass binary	4	0
Nova	1	0
BL Lac type of blazar	7	428
FSRQ type of blazar	17	353
Non-blazar active galaxy	1	10
Radio galaxy	2	10
Seyfert galaxy	1	5
Active galaxy of uncertain type	0	257
Normal galaxy (or part)	2	4
Starburst galaxy	0	4
Class uncertain	-	1
Unassociated	**-**	**576**
Total	**127**	**1746**



Expanding Classes of Fermi-LAT Sources
e+e- spectrum
GRBs
Blazars (782)
Radio Galaxies (12)
Starburst Galaxies (4)
LMC & SMC
Globular Clusters (11)
Fermi Bubbles
Novae
SNR & PWN (68)
γ-ray binaries (6)
Pulsars: young & millisecond (MSP) (117+)
Sun: flares & CR interactions
Terrestrial Gamma-ray Flashes
Unidentified Sources (~600/1873)
Extragalactic
Galactic
Local

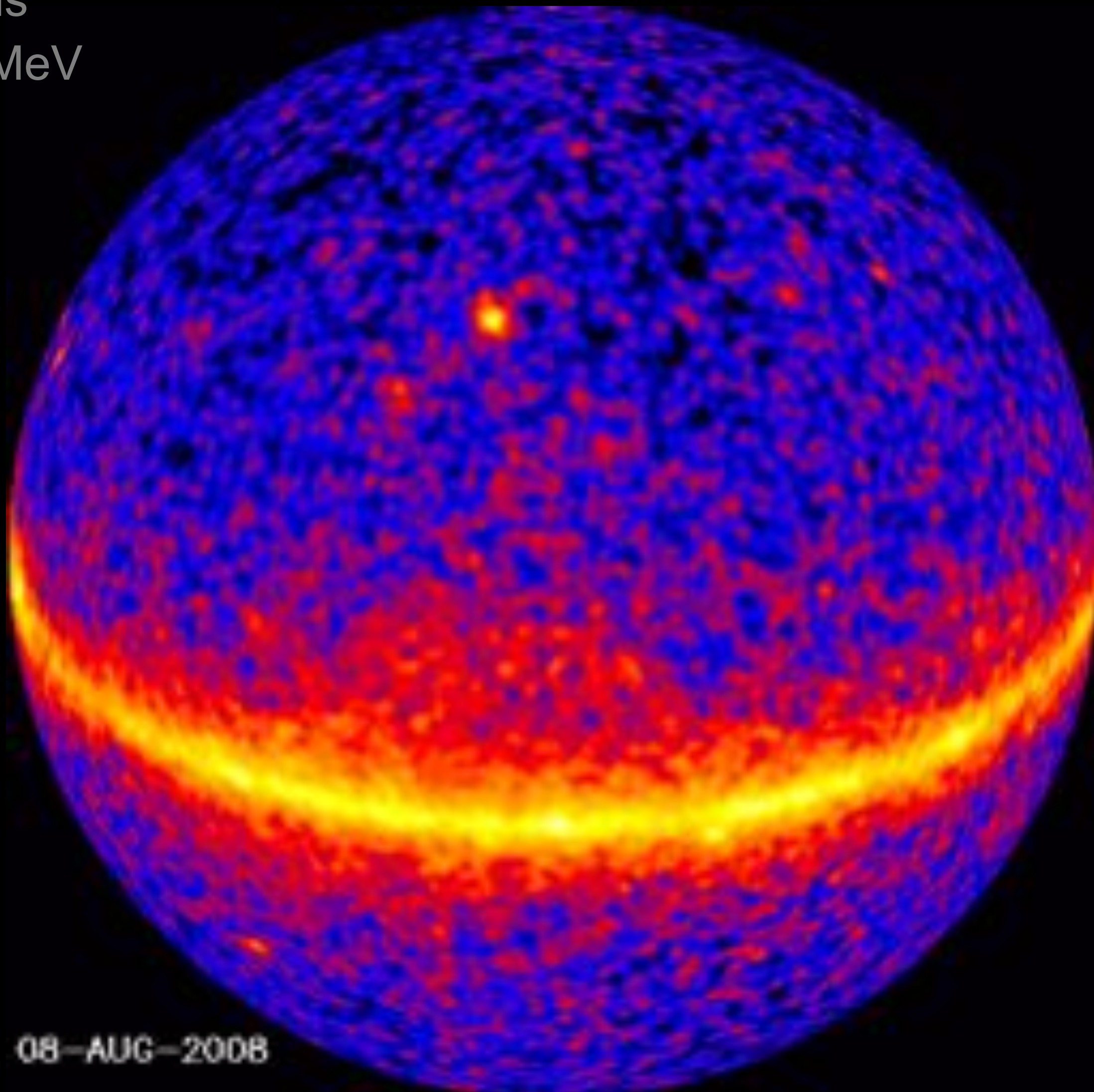
Huge Dynamic Ranges



arXiv:1206.1896

The Variable Gamma-ray Sky

36 months
E > 100 MeV

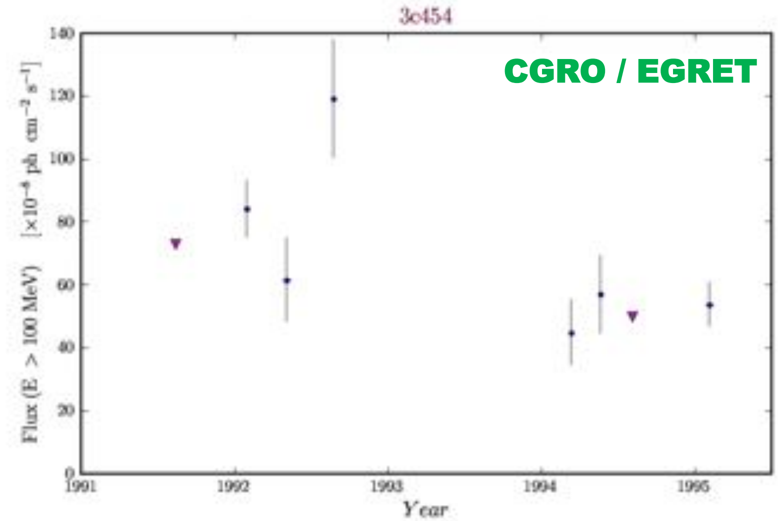


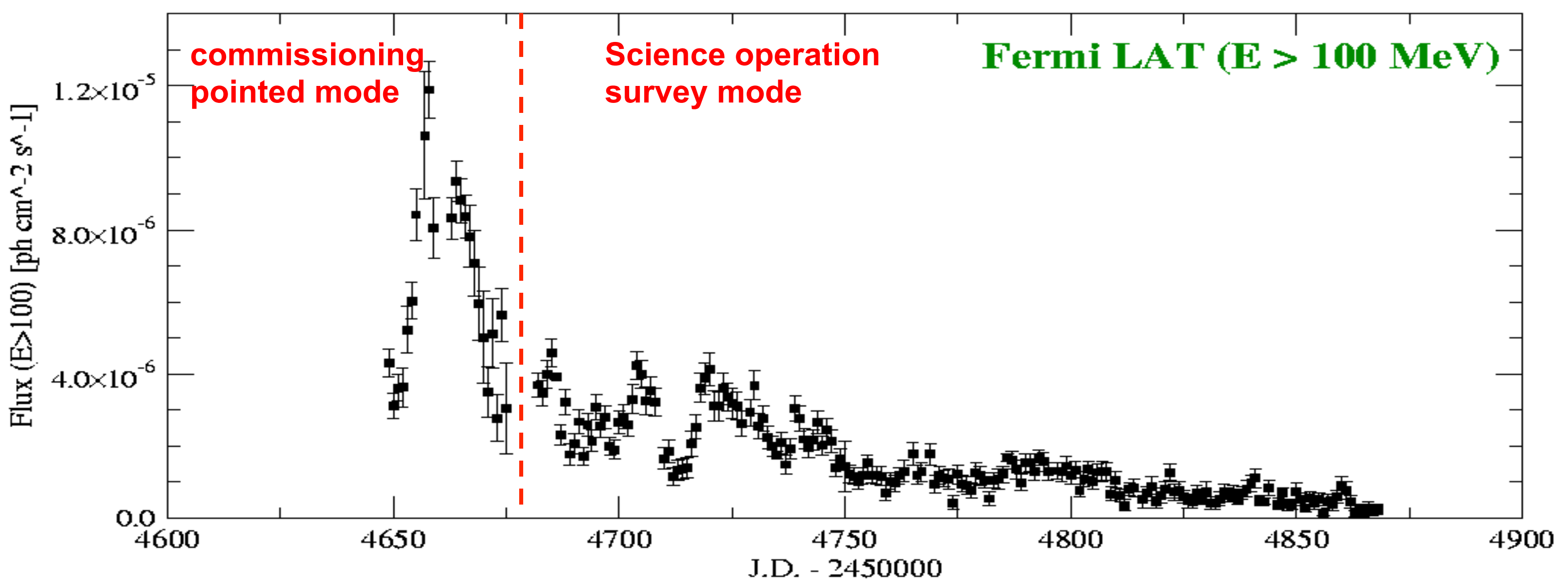
many transients in the γ-ray sky

with time, deeper exposure has revealed many new sources and new source classes

Example of all-sky payoff: 3C454.3

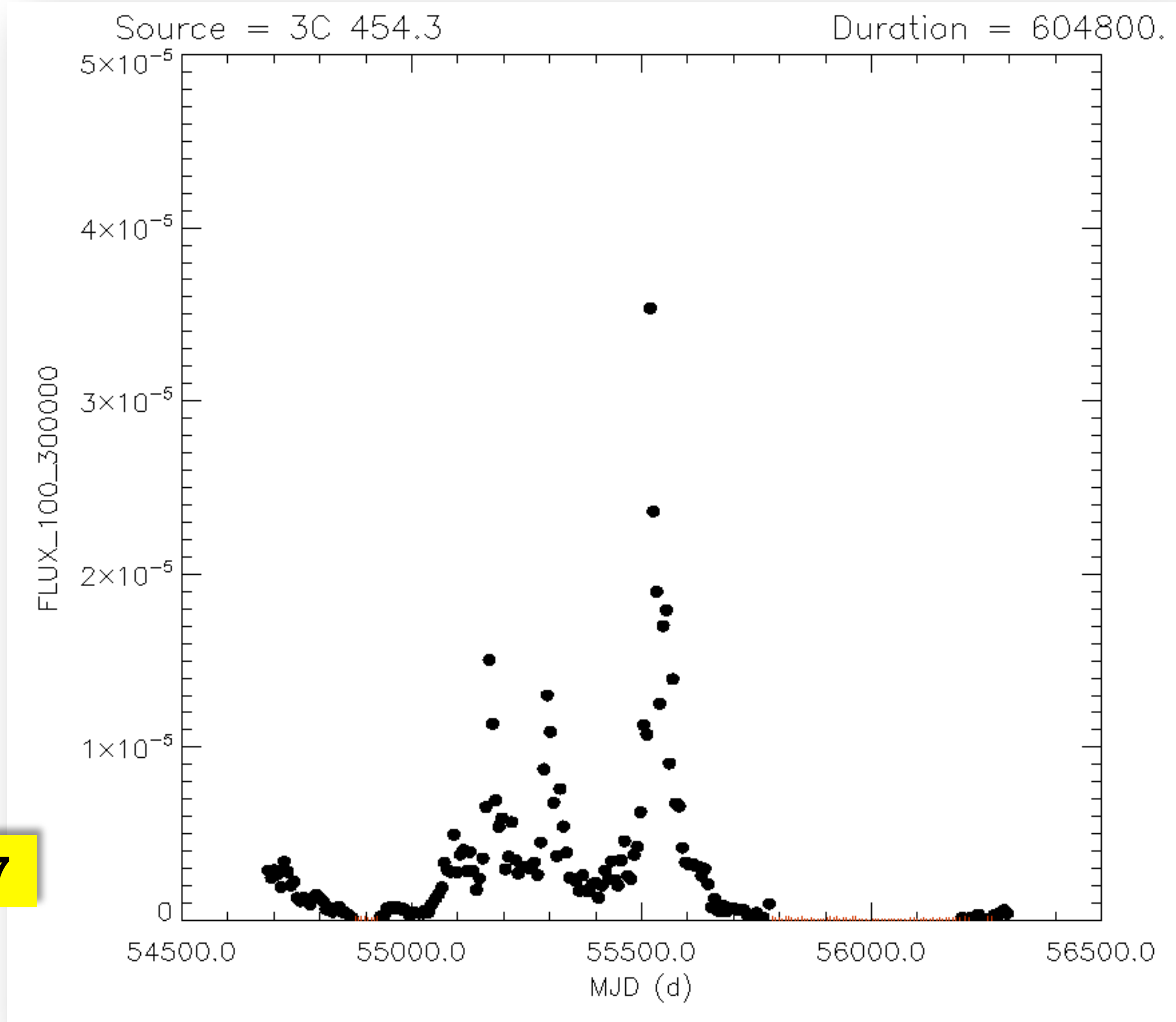
- Well-known radio source at z = 0.859; also detected by EGRET, AGILE





3C454.3

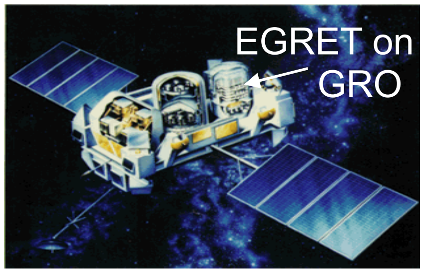
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

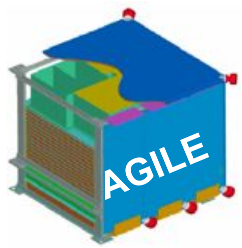


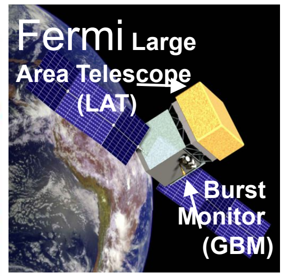
Also see **arXiv:1102.0277**

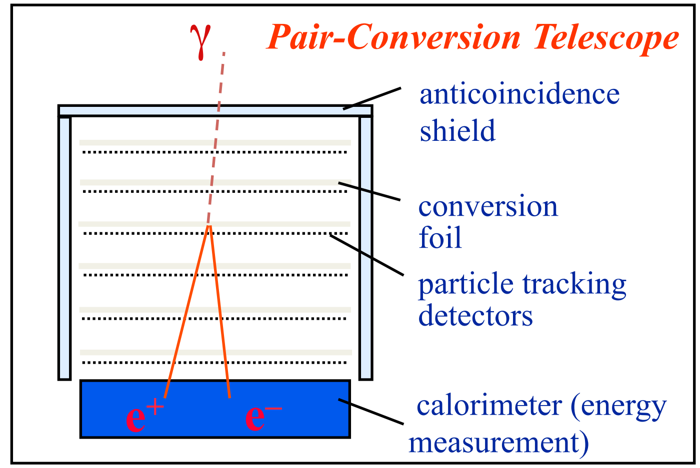
HE Gamma-ray Experiment Techniques

- Space-based:
  - use pair-conversion technique





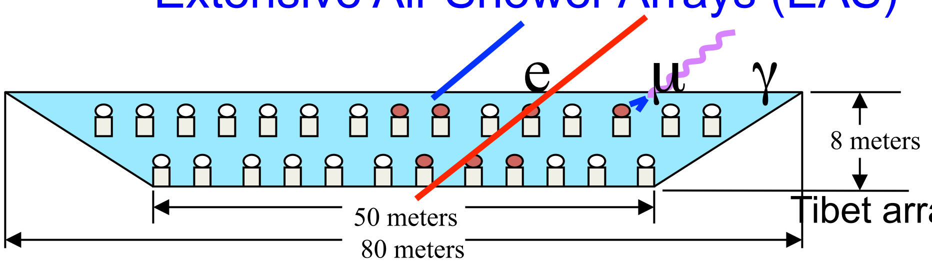




- Ground-Based:
  - Atmospheric Cerenkov Telescopes (ACTs)

image the Cerenkov nin from showers induced in the atmosphere. Examples: VERITAS, MAGIC, HESS; CTA.

  - Extensive Air Shower Arrays (EAS)

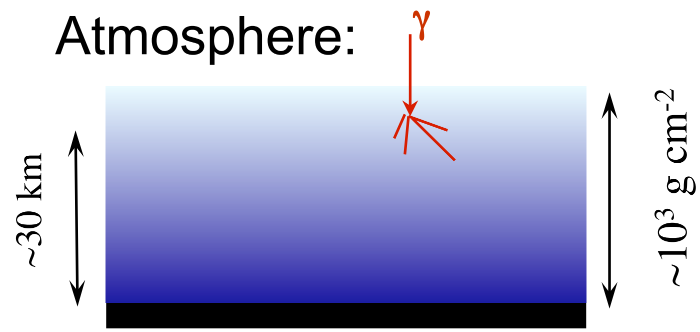


Tibet array

Directly detect particles from the showers induced in the atmosphere. Example: Milagro; HAWC,

Why Space?

Atmosphere:



To detect these gamma rays, must have an instrument above the atmosphere.

[Note, for very high-energy gamma rays, > ~100 GeV, information from showers penetrates to the ground.]

Photon interaction mechanisms:

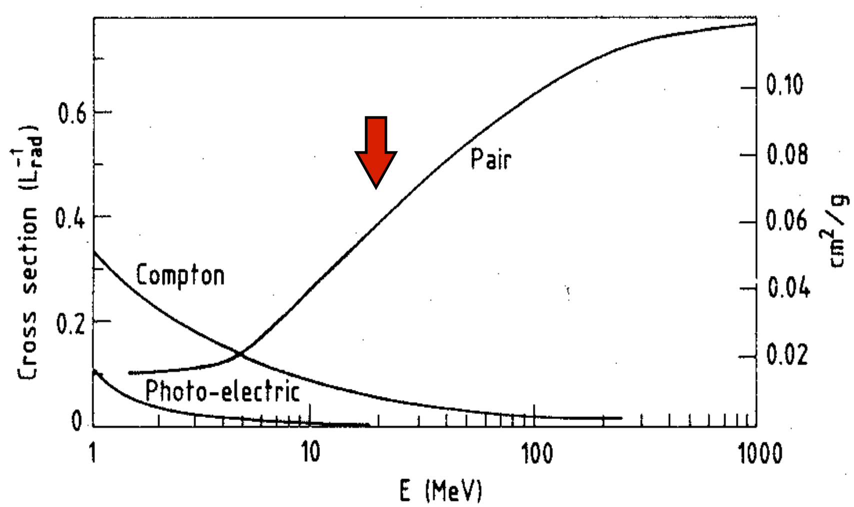
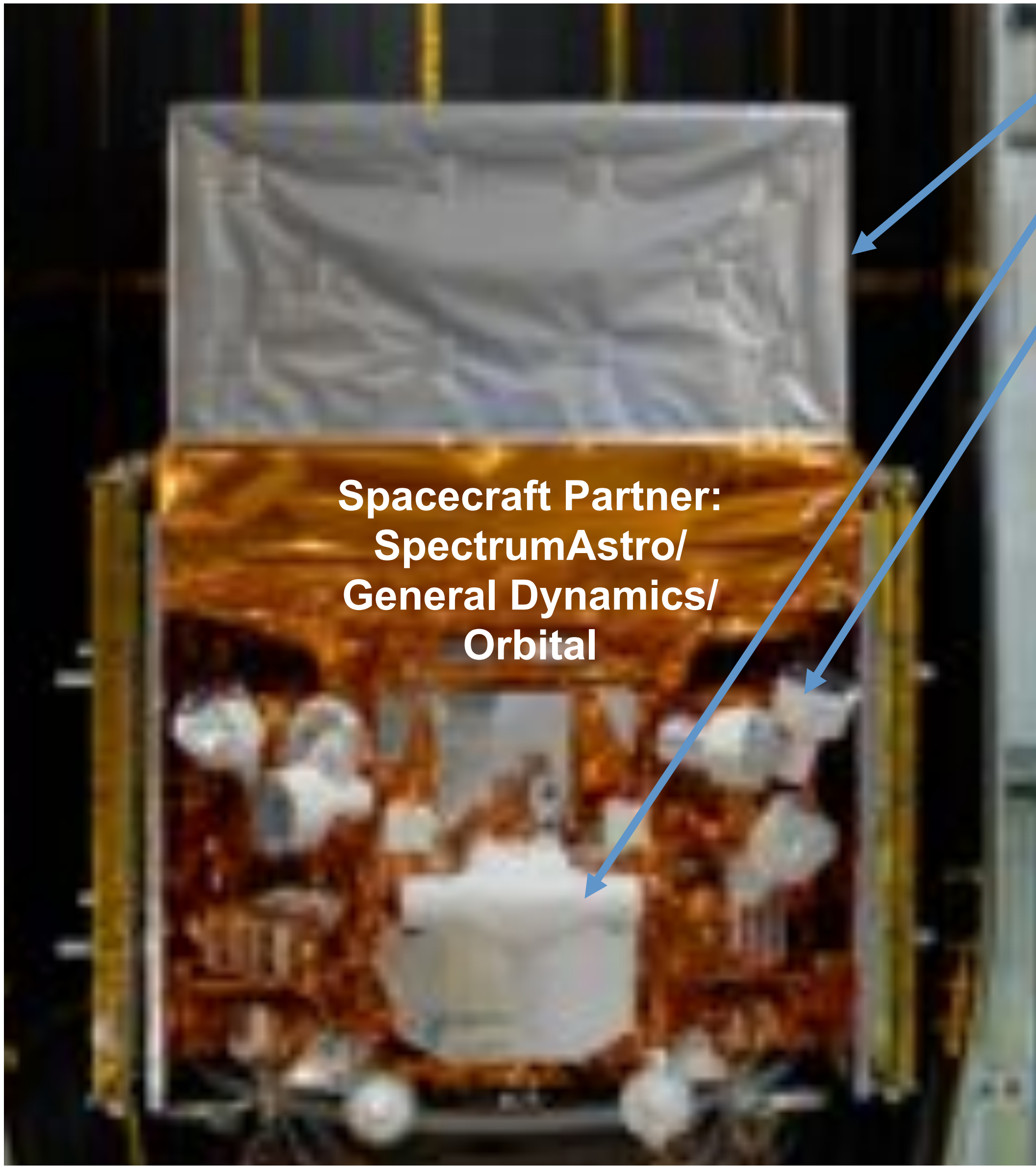


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

Fermi
Gamma-ray
Space Telescope

The Accelerator

The Observatory, Spring 2008



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

- **Huge field of view**
  - **–LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!**
- **Large leap in all key capabilities. Great discovery potential.**

Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

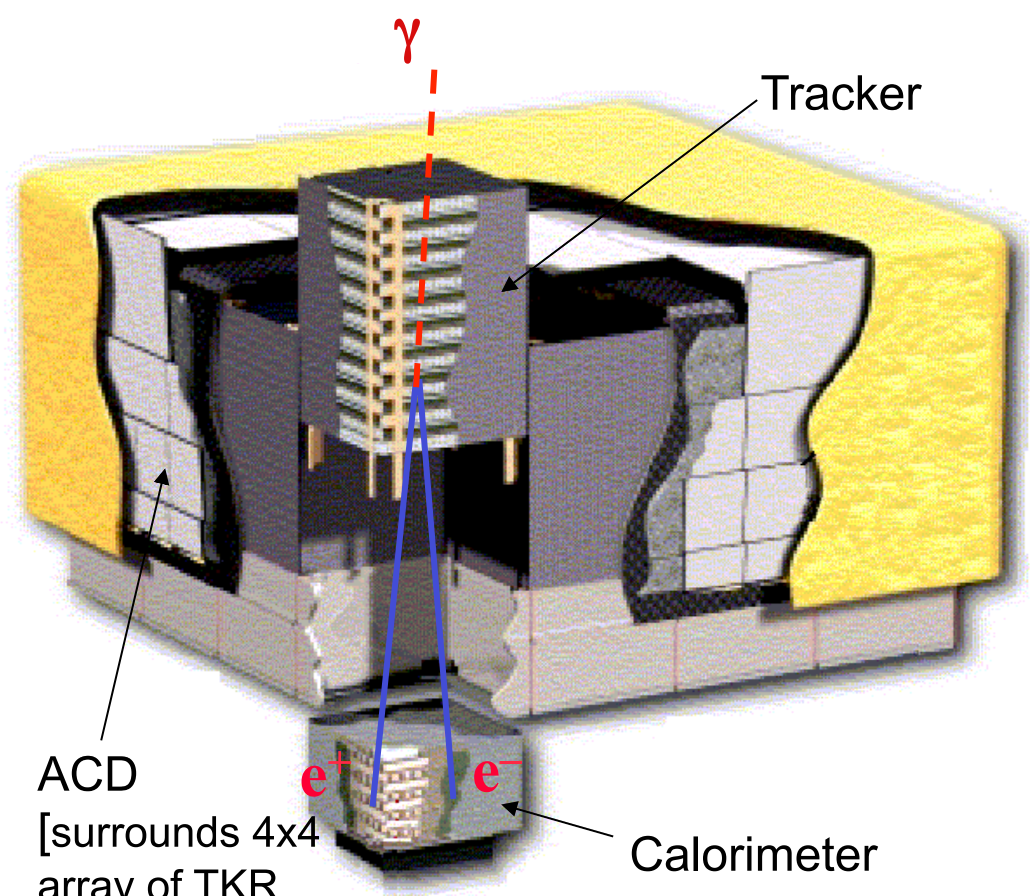
A moment later…

… and then …

… on its way!

LAT Overview

- Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.

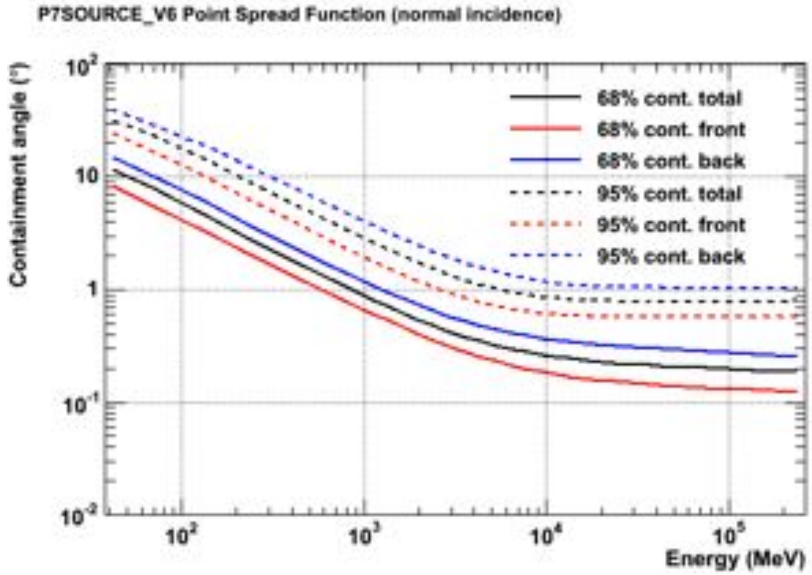


Atwood et al, ApJ

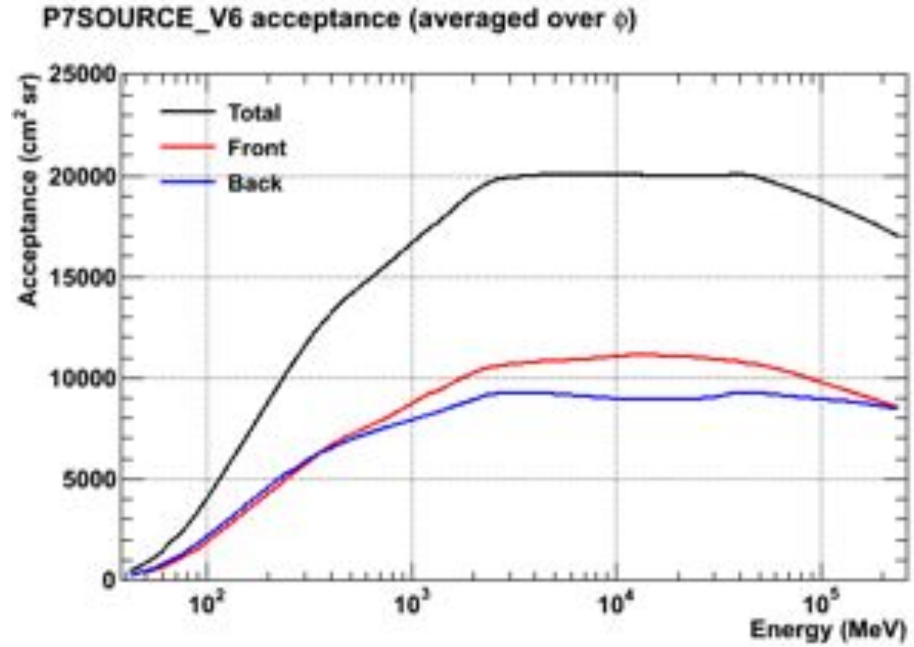
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Performance

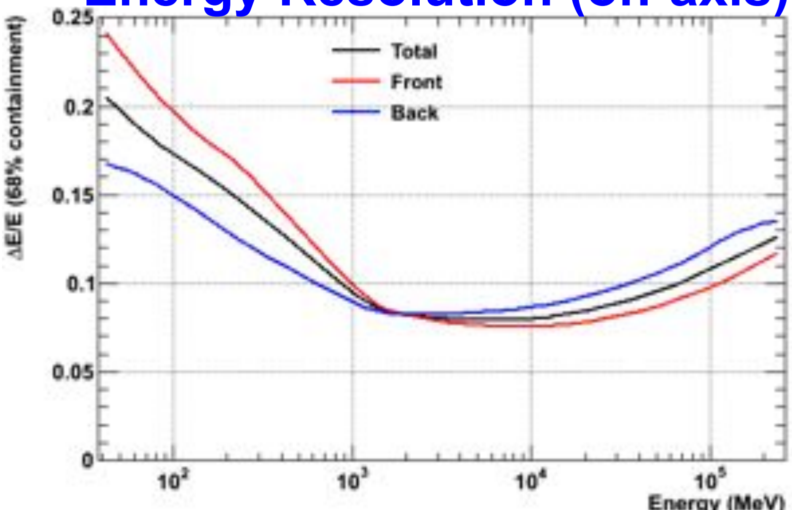
PSF

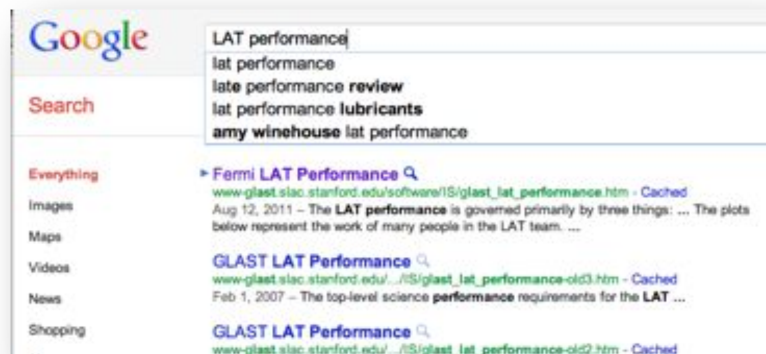


Acceptance



Energy Resolution (on-axis)





Different event classes trade background rejection and PSF against effective area

Data/MC Comparisons

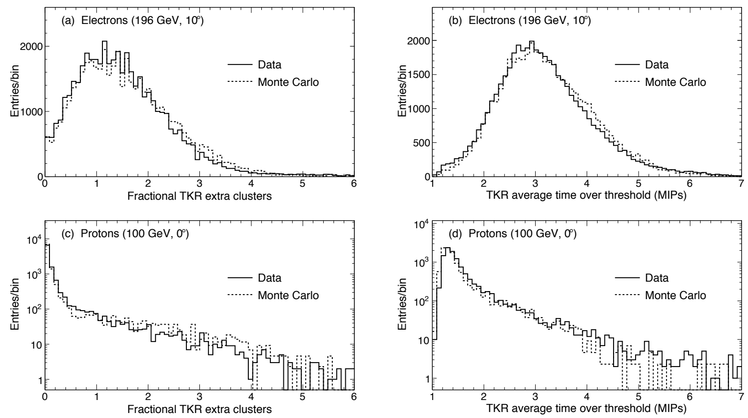


FIG. 1: Comparison of beam test data (solid line) and MC simulations (dashed line) for two fundamental tracker variables used in the electron selection: the number of clusters in a cone of 10 mm radius around the main track (left panels) and the average time over threshold (right panels). Both variables are shown for an electron and a proton beam.

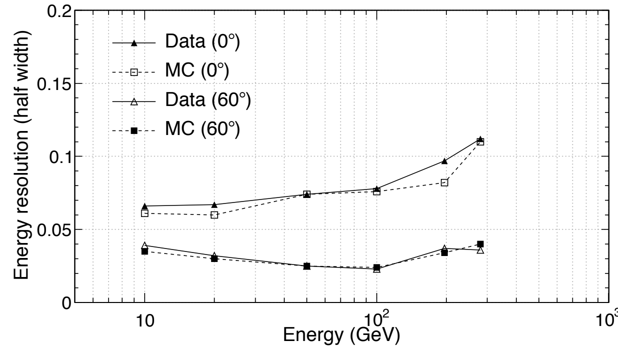


FIG. 3: Comparison of beam test data (triangles) and Monte Carlo simulations (squares) for the energy resolution for electron beams entering the CU at 0° and 60° and energies from 10 to 282 GeV. Lines are to guide an eye.

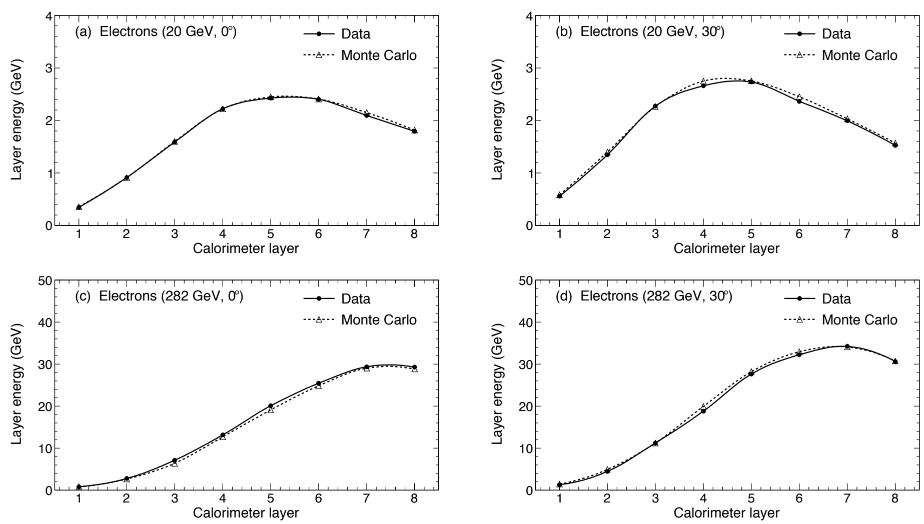


FIG. 4: Comparison of Beam test data and Monte Carlo simulations for the longitudinal shower profiles for electron beams entering the CU at 0° and 30° and energies of 20 and 282 GeV.

Many thanks to CERN, GSI, and SLAC!!

arXiv:1008.3999v1, PRD 82

LAT Collaboration

- France
  - CNRS/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, Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

PI: Peter Michelson
(Stanford)

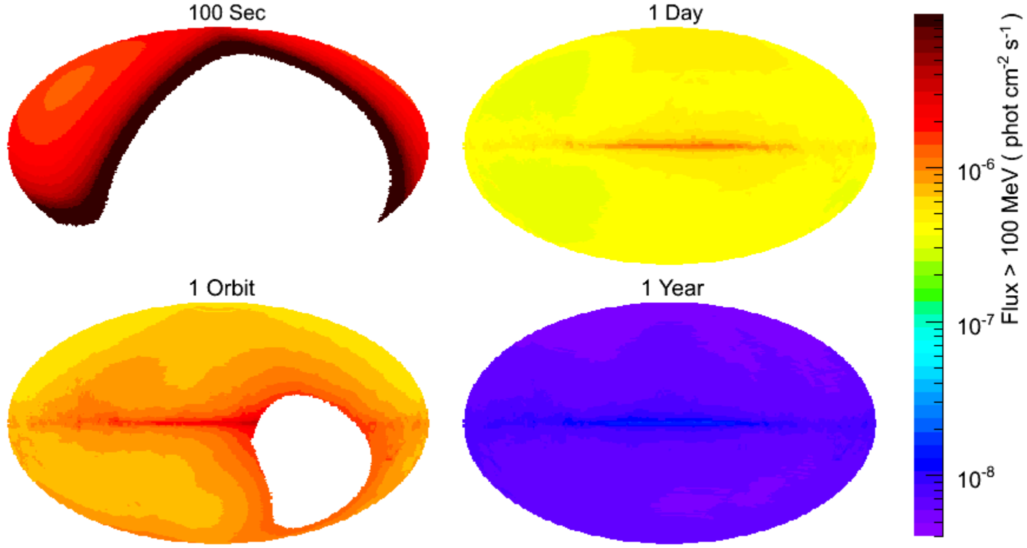
~400 Scientific Members (including 97 Affiliated Scientists, plus 71 Postdocs and 123 Students)

Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

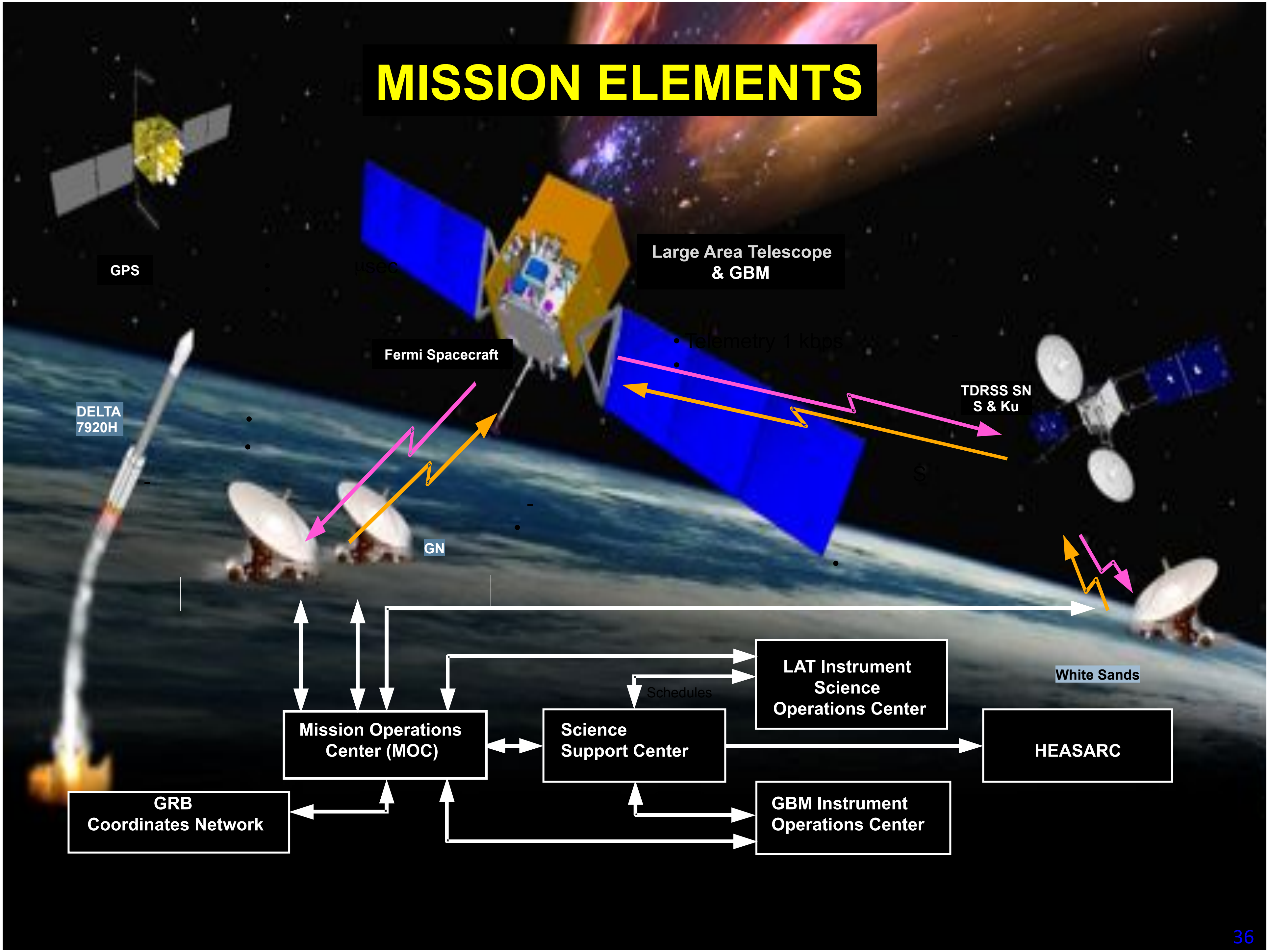
Project managed at SLAC.

Operating modes

- Primary observing mode is Sky Survey
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates multiwavelength observation planning
  - Exposure intervals commensurate with typical instrument integration times for sources
  - EGRET sensitivity reached in days



- **Pointed observations when appropriate (limited fraction, and selected by peer review) with automatic earth avoidance selectable. Target of Opportunity pointing.**
- **Autonomous repoints for onboard GRB detections in any mode.**


MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
Fermi Spacecraft
Telemetry 1 kbps
TDRSS SN
S & Ku
DELTA
7920H
GN
White Sands
LAT Instrument
Science
Operations Center
Schedules
Mission Operations
Center (MOC)
Science
Support Center
HEASARC
GRB
Coordinates Network
GBM Instrument
Operations Center

Overall Timeline

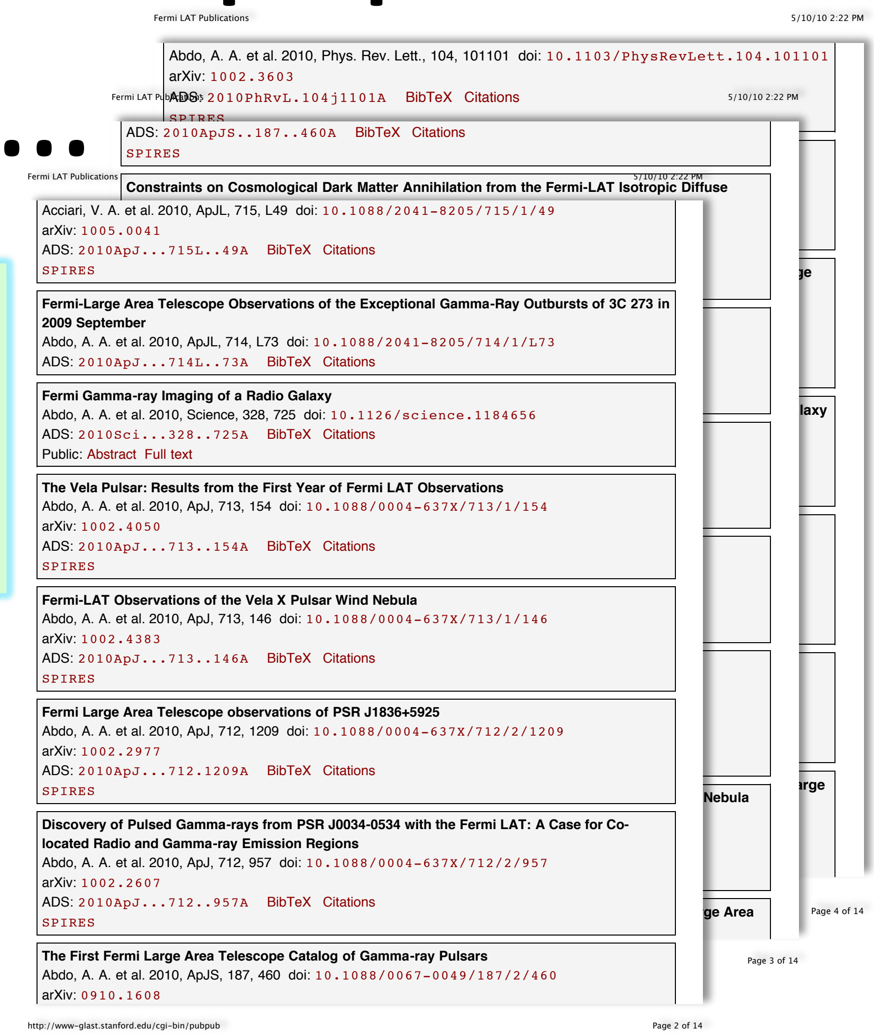
- Science operations start: 4 August 2008
- Plan: Five-year mission with a ten-year goal
  - with reviews to assess productivity in extended phase
- Mission extended by NASA to at least 2016, based on most recent Senior Review:
  - *"The first three years of Fermi have been very productive, and the committee believes we have yet to see the peak of Fermi's science output"*
  - The report 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.*"
- LAT international partners (agencies funding particle physics and astrophysics) are also planning continued support of the experiment.
- In the second Senior Review cycle right now.

Some LAT Highlights

- Discovery and study of >117 gamma-ray pulsars, 36 of which are seen to pulse only in gamma rays. 40 are ms pulsars.
  - 43 new ms radio pulsars discovered thanks to LAT data!
- Remarkable high-energy emission from gamma-ray bursts
  - Starting to see what was missing
  - w/GBM, provides interesting limits on photon velocity dispersion
- Very high statistics measurement of the cosmic e+e- flux to 1 TeV
- Nailing down the diffuse galactic GeV emission
- LAT determination of the isotropic diffuse flux
- Searches for Dark Matter signatures in different kinds of sources
- Many new results on supermassive black hole systems (AGN), including sources never seen in the GeV range
- More cosmic accelerators: Galactic X-ray binaries, supernova remnants, PWNe. Probing the cosmic-ray distributions in other galaxies; LMC and SMC.
- Extragalactic Background Light measurements
- New limits on large extra dimensions
- Crab short *flares*
- 2^{nd} catalog: 1873 sources

>270 LAT Team papers out…

ADS: LAT 2nd Catalog most highly cited paper of 2012 in Astronomy


Fermi LAT Publications 5/10/10 2:22 PM

Abdo, A. A. et al. 2010, Phys. Rev. Lett., 104, 101101 doi: 10.1103/PhysRevLett.104.101101
arXiv: 1002.3603
ADS: 2010PhRvL.104j1101A BibTeX Citations

ADS: 2010ApJS..187..460A BibTeX Citations
SPIRES

Constraints on Cosmological Dark Matter Annihilation from the Fermi-LAT Isotropic Diffuse

Acciari, V. A. et al. 2010, ApJL, 715, L49 doi: 10.1088/2041-8205/715/1/49
arXiv: 1005.0041
ADS: 2010ApJ...715L..49A BibTeX Citations
SPIRES

Fermi-Large Area Telescope Observations of the Exceptional Gamma-Ray Outbursts of 3C 273 in 2009 September
Abdo, A. A. et al. 2010, ApJL, 714, L73 doi: 10.1088/2041-8205/714/1/L73
ADS: 2010ApJ...714L..73A BibTeX Citations

Fermi Gamma-ray Imaging of a Radio Galaxy
Abdo, A. A. et al. 2010, Science, 328, 725 doi: 10.1126/science.1184656
ADS: 2010Sci...328..725A BibTeX Citations
Public: Abstract Full text

The Vela Pulsar: Results from the First Year of Fermi LAT Observations
Abdo, A. A. et al. 2010, ApJ, 713, 154 doi: 10.1088/0004-637X/713/1/154
arXiv: 1002.4050
ADS: 2010ApJ...713..154A BibTeX Citations
SPIRES

Fermi-LAT Observations of the Vela X Pulsar Wind Nebula
Abdo, A. A. et al. 2010, ApJ, 713, 146 doi: 10.1088/0004-637X/713/1/146
arXiv: 1002.4383
ADS: 2010ApJ...713..146A BibTeX Citations
SPIRES

Fermi Large Area Telescope observations of PSR J1836+5925
Abdo, A. A. et al. 2010, ApJ, 712, 1209 doi: 10.1088/0004-637X/712/2/1209
arXiv: 1002.2977
ADS: 2010ApJ...712.1209A BibTeX Citations
SPIRES

Discovery of Pulsed Gamma-rays from PSR J0034-0534 with the Fermi LAT: A Case for Co-located Radio and Gamma-ray Emission Regions
Abdo, A. A. et al. 2010, ApJ, 712, 957 doi: 10.1088/0004-637X/712/2/957
arXiv: 1002.2607
ADS: 2010ApJ...712..957A BibTeX Citations
SPIRES

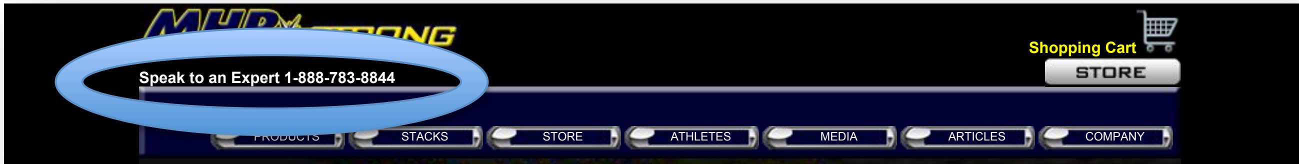
The First Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
Abdo, A. A. et al. 2010, ApJS, 187, 460 doi: 10.1088/0067-0049/187/2/460
arXiv: 0910.1608

http://www-glast.stanford.edu/cgi-bin/pubpub Page 2 of 14

…with many more in the pipeline…and many hundreds more using public LAT data.

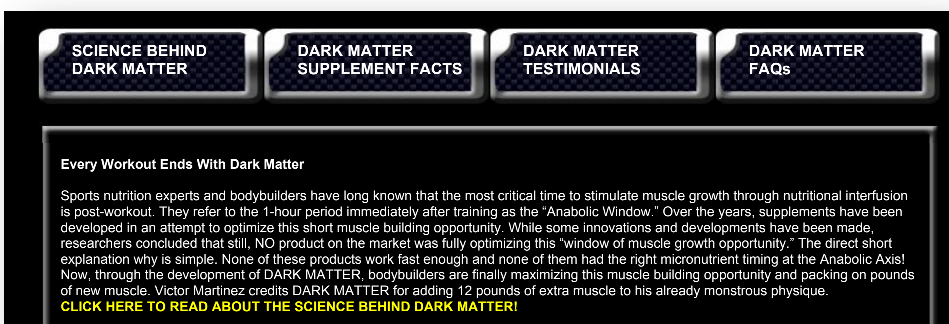
http://www-glast.stanford.edu/cgi-bin/pubpub

Fermi Gamma-ray Space Telescope



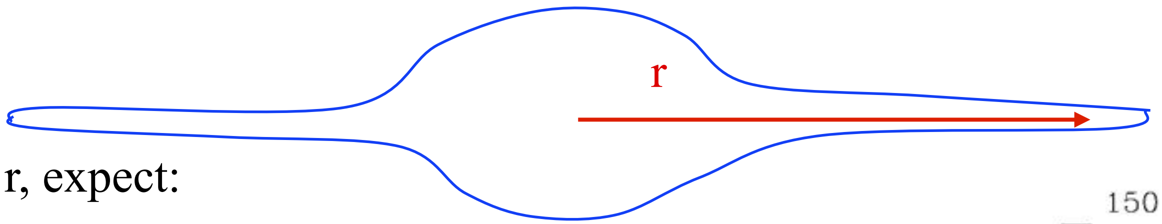
Dark Matter

A Quick Tour



The Dark Matter Problem

Observe rotation curves for galaxies:

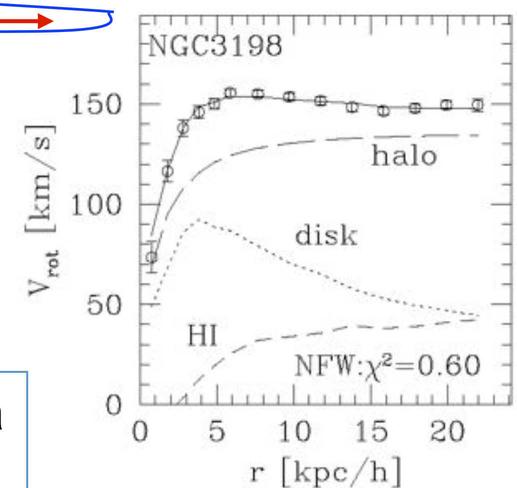


For large r, expect:

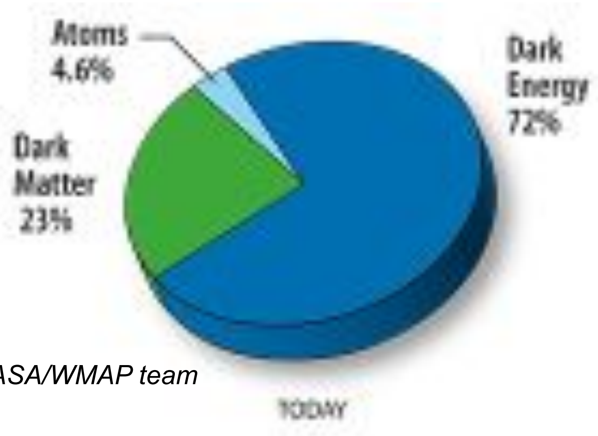
$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \qquad v(r) \sim \frac{1}{\sqrt{r}}$$

see: flat or rising rotation curves

Begeman/Navarro



Hypothesized Solution: the visible galaxy is embedded in a much larger halo of dark matter.

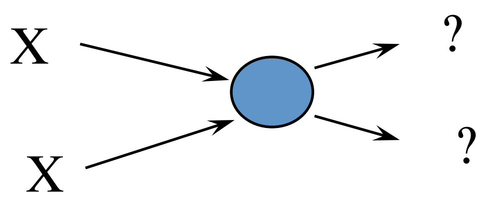


Credit: NASA/WMAP team

Bullet cluster

Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of cosmic particles ("indirect detection").



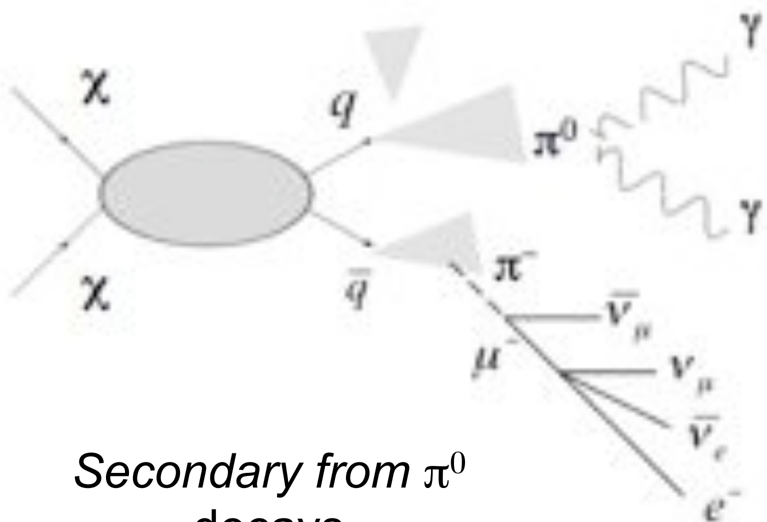
Anomalous gamma ray spectra and/or $\gamma\gamma$ or $Z\gamma$ "lines" and/or anomalous charged cosmic rays and/or neutrinos?

- If particles are stable: rate ~ $(\text{DM density})^2$
- If particles unstable: rate ~ (DM density)

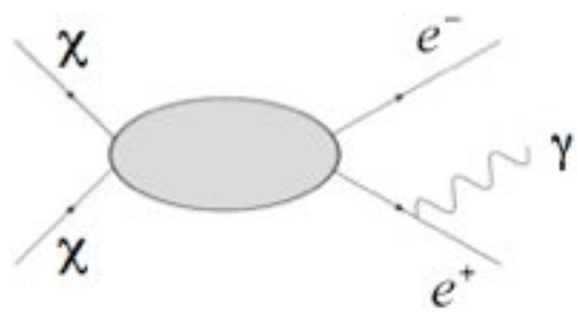
- Key interplay of techniques:
  - colliders (TeVatron, LHC)
  - direct detection experiments underground
  - indirect detection (most straightforward: gamma rays and neutrinos)
    - Full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - **Challenge is to separate signals from astrophysical backgrounds**

Just an example of what might be waiting for us to find!

Gamma rays from Dark Matter annihilation



Secondary from π^0 decays



Prompt lepton pair production

+ "lines" from 2-body final states

$$\Phi_{WIMP}(E,\Psi)=J(\Psi)\times\Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi)=\int_{l.o.s} dl(\Psi)\,\rho^2(l)$$

Particle physics factor

$$\Phi^{PP}(E)=\frac{1}{2}\frac{\langle\sigma v\rangle}{m^2_{WIMP}}\sum_f \frac{dN_f}{dE}B_f$$

Dark Matter: Many Places to Look!

Satellites

Low background and good source id, but low statistics, in some cases astrophysical background

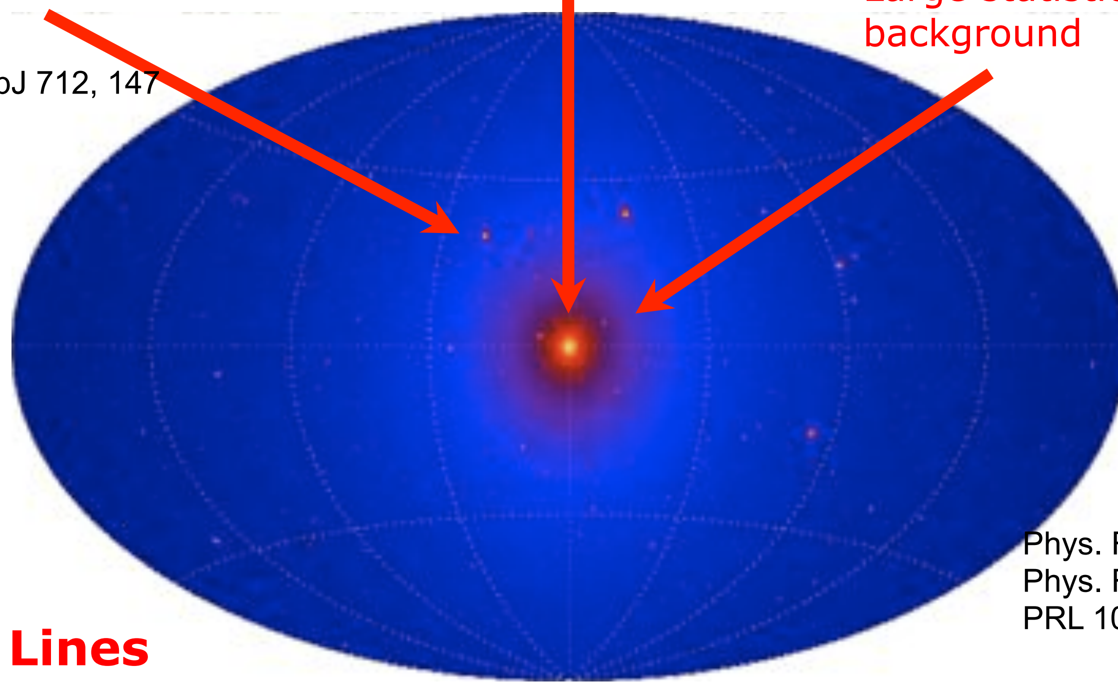
JCAP 1204 (2012) 016
ApJ 747, 121 (2012)
PRL 107, 241302 (2011) ApJ 712, 147 (2010)
JCAP 01 (2010) 031
ApJ 718, 899 (2010)

Galactic Center

Good Statistics but source confusion/diffuse background

Milky Way Halo

Large statistics but diffuse background arXiv:1205.6474



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

And anomalous charged cosmic rays (little/no directional information, trapping times, etc.)

Phys. Rev. D84, 032007 (2011)
Phys. Rev. D82, 092003 (2010)
PRL 108 (2012)

Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Phys. Rev. D, In press (2012)
Phys. Rev. Lett. 104, 091302 (2010)

Galaxy Clusters

Low background, but low statistics

JCAP 05 (2010) 025

Extragalactic

Large statistics, but astrophysics, galactic diffuse background JCAP 04 (2010) 014

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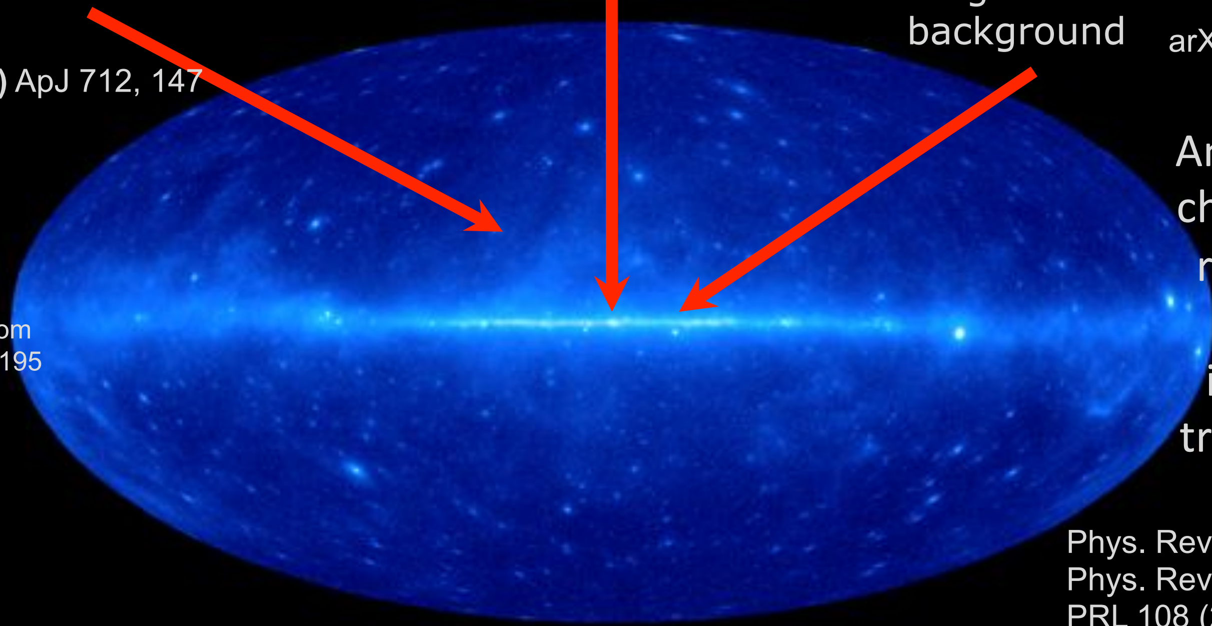

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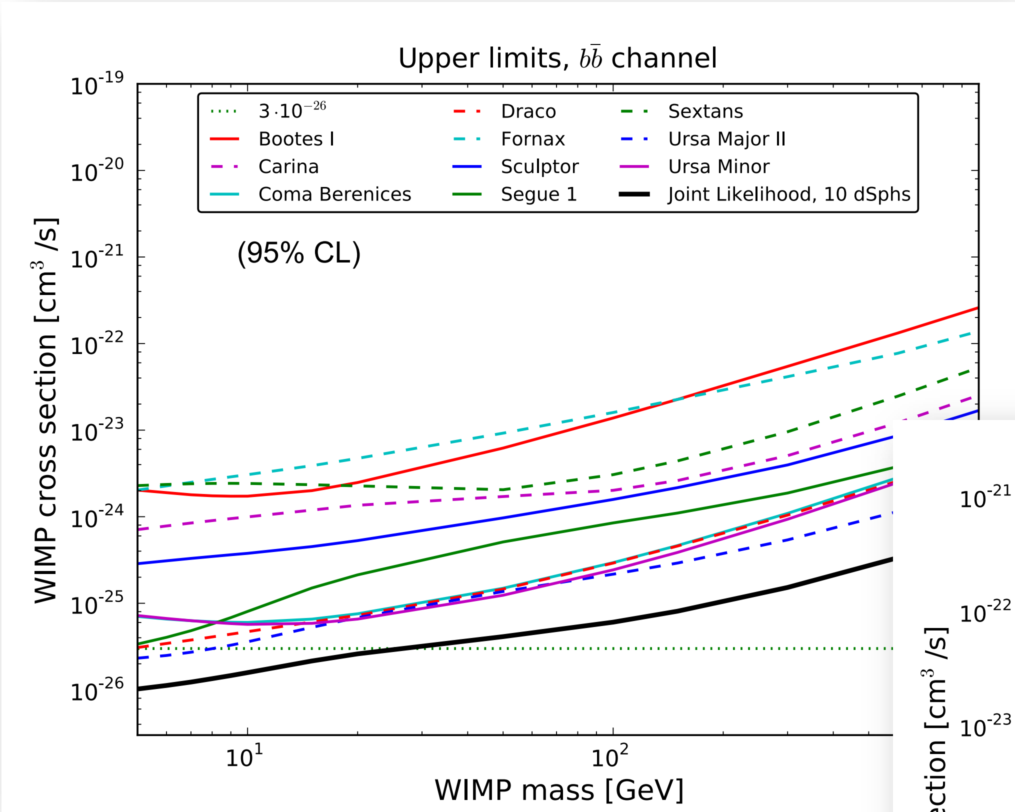
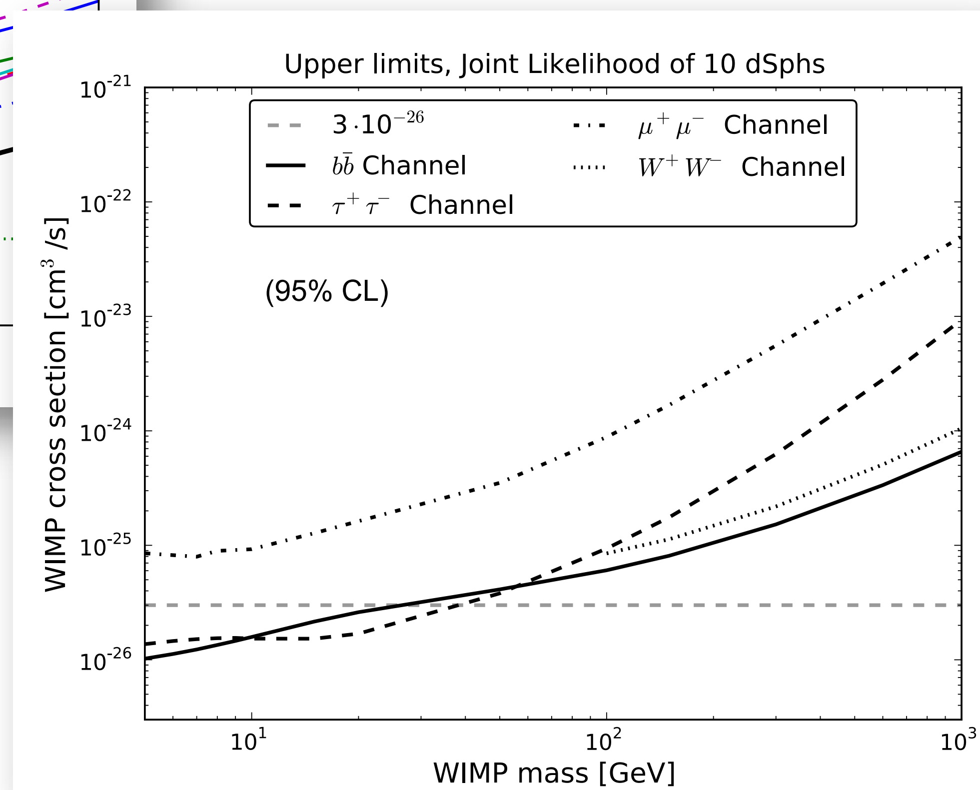
Combining dSph Limits

PRL **107**(2011)
arXiv:1108.3546v2

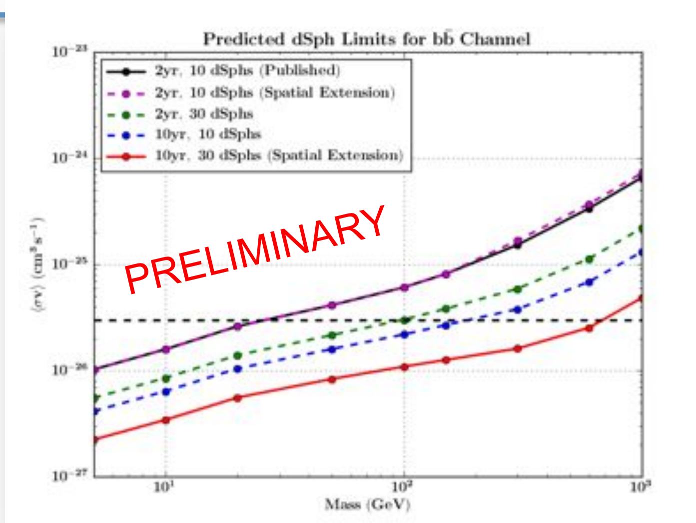




Now getting to very interesting sensitivity ranges!

DM: A Look Forward

- Much more to do in all areas:
  - future DM limits from dSph projected to improve due to increased observation time, discovery of new dwarfs
  - Lines: more data, improved analysis of high-energy events, optimization of regions, **checks!**
  - Halo: more detailed accounting of uncertainties in limits
  - Galactic Center
- Additional results:
  - Anisotropy analyses
  - Clusters
  - Satellites
  - …



More data needed!

- Altered observing strategy for increased exposure of the Galactic center
- Push WIMP sensitivity (see above) to O(100) GeV.

UCSC LAT Collaboration Members

- Full members
  - Atwood, Johnson, Ritz, Sadrozinski, Saz-Parkinson, Schalk
  - Wells, plus undergrads, plus new students…
- Affiliated members
  - Jeltema, Primack, Williams, Ramirez-Ruiz, Smith

- Graduate student Zalewski defended his thesis in 2013.

- A new post-doc, Regina Caputo, will join the group in May.

- The group is looking for 2 additional graduate students.

Current/Upcoming Projects

- Students are encouraged to define their own projects, but we also are happy to suggest directions of mutual interest.
- Some ongoing projects:
  - Several on dark matter, including combining information from various sources as we continue to collect more data
  - Final great leap in instrument performance: “Pass8”
  - Pair halos of distant objects, diagnostic of intergalactic magnetic fields and EBL
- Start ups (and restart ups) include:
  - Several studies related to dark matter
  - Better use of single-photon error information
  - The highest energy Fermi sky
  - Novel uses of AGN light curves
  - Intermediate timescale transients
  - Your idea here!

Discussion

- How the group functions
  - encourage students to work with people both at UCSC and within the international collaboration
- Path is largely up to the student
  - goal is for you to learn over time how to define your own research problems.
  - we suggest topics, but free to pursue others. we will help you stay on track.
  - we emphasize understanding of the instrument and the details of the data analysis. we will also try to create hardware opportunities
- Great return on hard work!

Tools for Your 205 Proposals

- All the LAT papers can be found here, sorted by topic: http://www-glast.stanford.edu/cgi-bin/pubpub
- The LAT gamma-ray data and a set of software tools are public.
  - See http://fermi.gsfc.nasa.gov/ssc/data/
- There is also public documentation and tutorials on how to do an analysis with the public data
  - See http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
- Come by to chat. Ask us questions!


Looking forward to
more great Fermi
results and Birthday
celebrations!

LSST Overview

Large Synoptic Survey Telescope

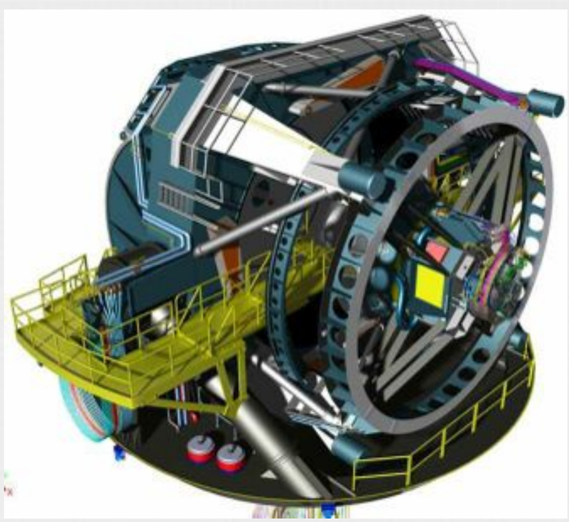
LSST in a Nutshell

- The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.

- Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time.

- The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.

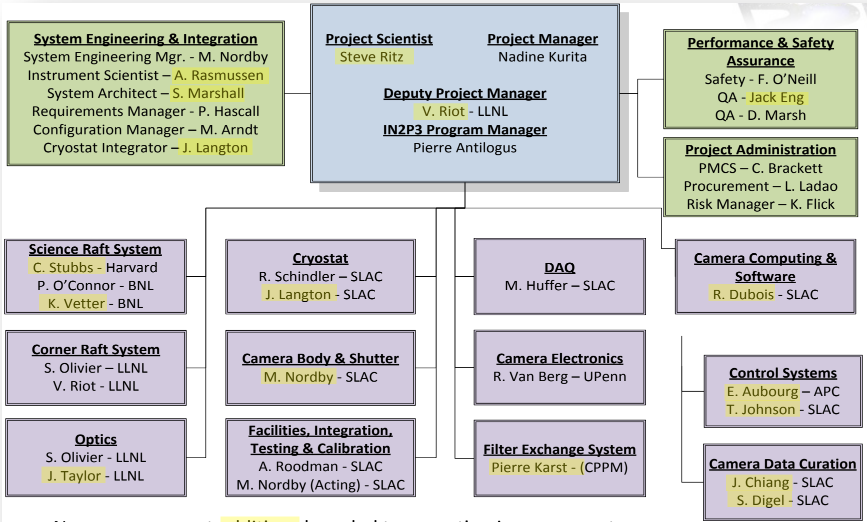
Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually



- **Points to new positions in the sky every 39 seconds**
- **Tracks during exposures and slews 3.5 to adjacent fields in ~ 4 seconds**

LSST Will be Sited in Central Chile

Large Synoptic Survey Telescope



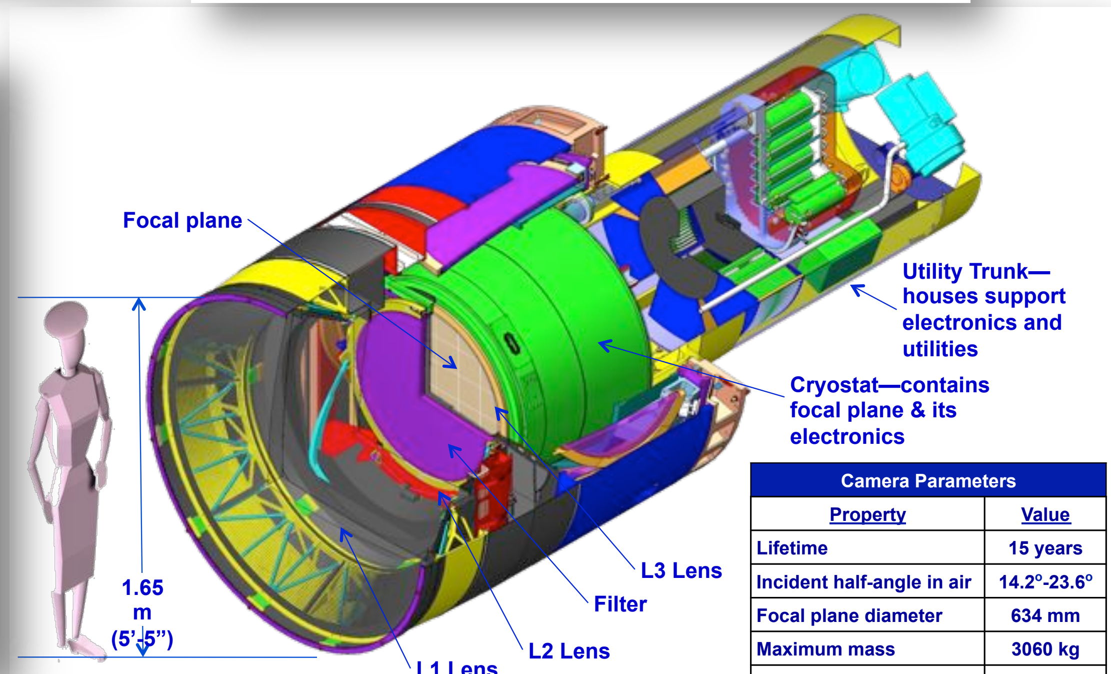
- New management additions have led to execution improvement.
- Key managers have been appointed .
- Large sub-systems are led by:
  - Sub-System Physicist.
  - Engineering Manager/Sub-system Architect.

The Large Synoptic Survey Telescope Wallet Card

- Three Mirror Anastigmat (TMA) optical design.
  - 8.4 meter primary, 6.5 meter effective aperture
  - 3.4 meter diameter secondary
  - 5 m tertiary is being fabricated in same substrate as primary mirror
  - three-element refractive corrector
  - f/1.2 beam delivered to camera
  - 9.6 square degree field (on science imaging pixels)
  - optics deliver < 0.2 arcsec FWHM spot diagram,
  - 6 filters: ugrizy: 320 nm to 1050 nm (UV atmospheric cutoff to Si bandgap)
- 3.0 Gpixel camera
  - 10 micron pixels, 0.2 arcsec/pixel
  - Deep depletion (100 μm), high-resistivity CCDs for NIR response
  - Dual 15 second exposures (to avoid trailing of solar system objects)
    - 2 second readout (trade between noise and imaging efficiency)
    - 550 kpix/sec through 16 amps/CCD x 189 CCDs = 3024 channels
    - 12 GBytes per image (as floating point numbers), 20 TBytes/night.
- Real-time frame subtraction for time domain alerts, ~850 visits for each patch of sky, allows co-adds to r ~ 27 (AB), over 18,000 square degrees.

Major recent/upcoming milestones

- ✓ Oct 2013 – Release sensor RFP package vendors
- ✓ Oct 2013 – CABAC1 Design Review
- ✓ Oct 2013 – Award AR broadband coat study
- ✓ Oct 2013 – Prototype ITL sensors delivered, partial for early testing
- ✓ Nov 2013 – Release L1-L2 RFP package to vendors
- ✓ Nov 2013 – Filter Exchange System Review
- ✓ Nov 2013 – Camera Optical Alignment Review
- Dec 2013 – NSF Final Design Review
- Jan 2014 – Award L1-L2 Design-Manufacture Contract
- Jan 2014 – DAQ & CCS Preliminary Design Review
- Jan 2014 – Wavefront Sensor Review
- Feb 2014 – Shutter & Camera Body Review
- Feb 2014 – SLAC Director's Review for CD-3a
- Mar 2014 – DOE CD-3a Review (start construction for long lead items)
- May 2014 – Award 1st Article Sensor Contract (waiting for funding)
- Apr 2014 – Cryostat Review
- Apr 2014 – Refrigeration Review
- Apr 2014 – L3 Optics Review

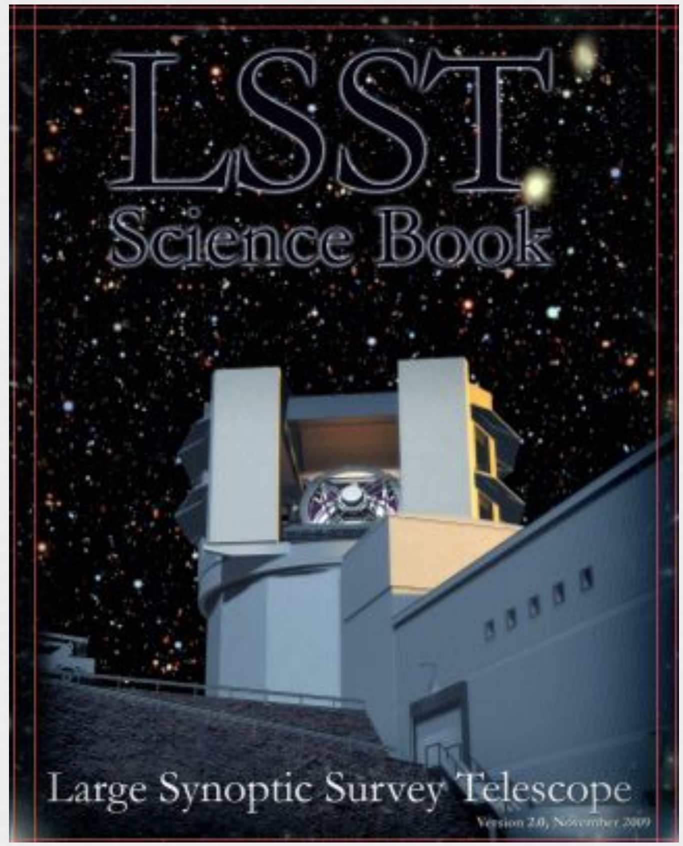


Camera Parameters	
Property	Value
Lifetime	15 years
Incident half-angle in air	14.2°-23.6°
Focal plane diameter	634 mm
Maximum mass	3060 kg
Maximum diameter	1650 mm
Total length	3732 mm

http://www.lsst.org/lsst/scibook

The LSST Science Book

- Contents:
  - Introduction
  - LSST System Design
  - System Performance
  - Education and Public Outreach
  - The Solar System
  - Stellar Populations
  - Milky Way and Local Volume Structure
  - The Transient and Variable Universe
  - Galaxies
  - Active Galactic Nuclei
  - Supernovae
  - Strong Lenses
  - Large-Scale Structure
  - Weak Lensing
  - Cosmological Physics



Main UCSC interests: testing ΛCDM

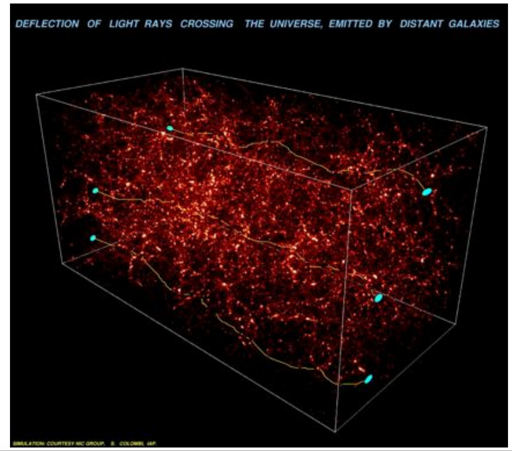
Plans for the coming year

- **Weak Lensing instrumental systematics:**
  - **push development of test objects for existing imager systems (with K. Gilmore at SLAC and T. Tyson UC Davis) using LSST CCDs to check systematic effects on shape measurements <u>using hundreds of exposures</u> – verify averaging down precision – and detailed comparisons with MC simulation. Ritz and Rockosi**
- **Continue consultations as needed on camera electronics system. Johnson**
- **Ramp up DESC work on Weak Lensing (Ritz), Clusters (Jeltema), and Dark Matter (Rockosi)**
- **Additional opportunities for science-prep studies, particularly connected with hardware development, likely.**

Weak Gravitational Lensing

Galaxy shapes appear **sheared** due to **all matter** along line-of-sight

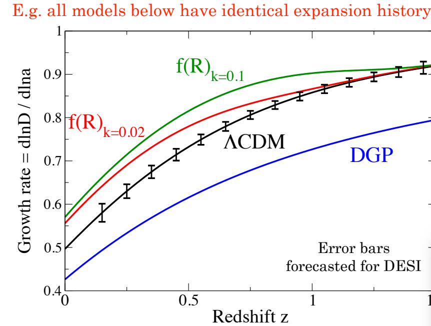
Measure **correlations** of those shears - not random



Two (of many) Examples

Growth distinguishes MG from "new-stuff" DE

E.g. all models below have identical expansion history H(z)

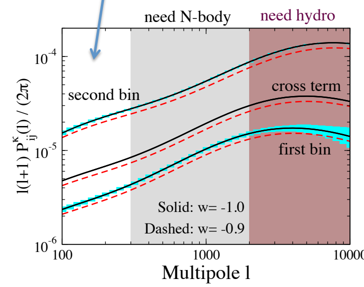


At large scales (>10 Mpc, *l<300*) and early times, predictions based on linear perturbations considered highly reliable (high-Q^2 analogy) at level of ~1%.

Smaller scales (<1 Mpc, *l >O(1000))* – also relevant to neutrino properties – more to do, but no show stoppers.

The same (DM) structures are probed in complementary ways.

Weak lensing shear correlation function



5 August 2013 Snowmas

Personnel Summary

- **Who:**
  - **Terry Schalk: early SCIPP efforts on Camera Controls System**
  - **Steve Ritz: transitioning earlier from Fermi toward LSST**
    - Camera Project Scientist (as of 5/2013)
    - Starting work on instrumental systematics affecting Weak Lensing
  - **Connie Rockosi**
    - LSST Board Member
    - Ramping up work over the next 6 months (instrumental systematics, commissioning camera)
  - **Robert Johnson**
    - Consultation on camera electronics system, will ramp up over the next few years
  - **Tesla Jeltema**
    - Dark Energy Science Collaboration (DESC) Cluster work (also working on DES)

Great opportunities for students to analyze Fermi LAT data while getting involved in LSST hardware development and science preparation.