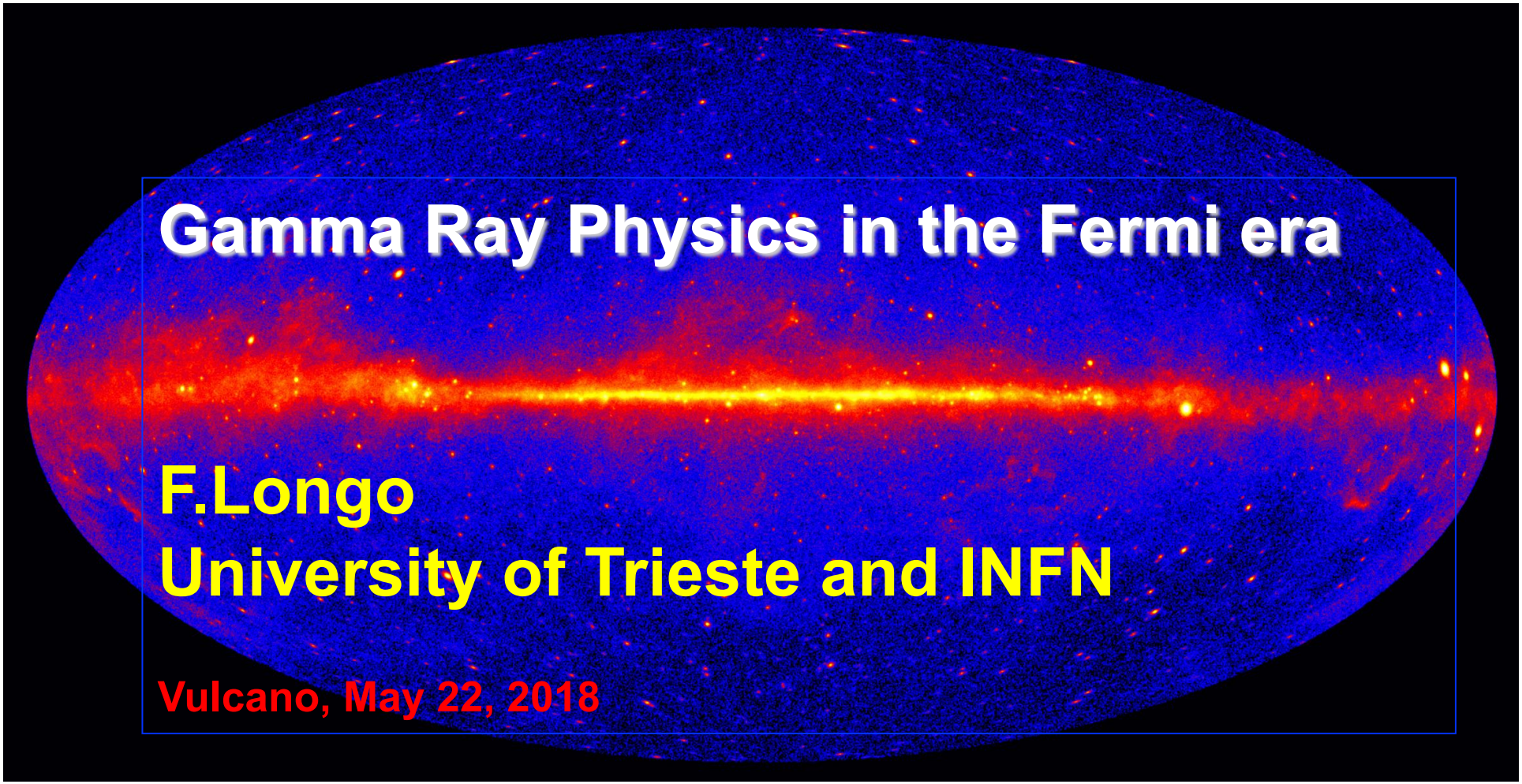
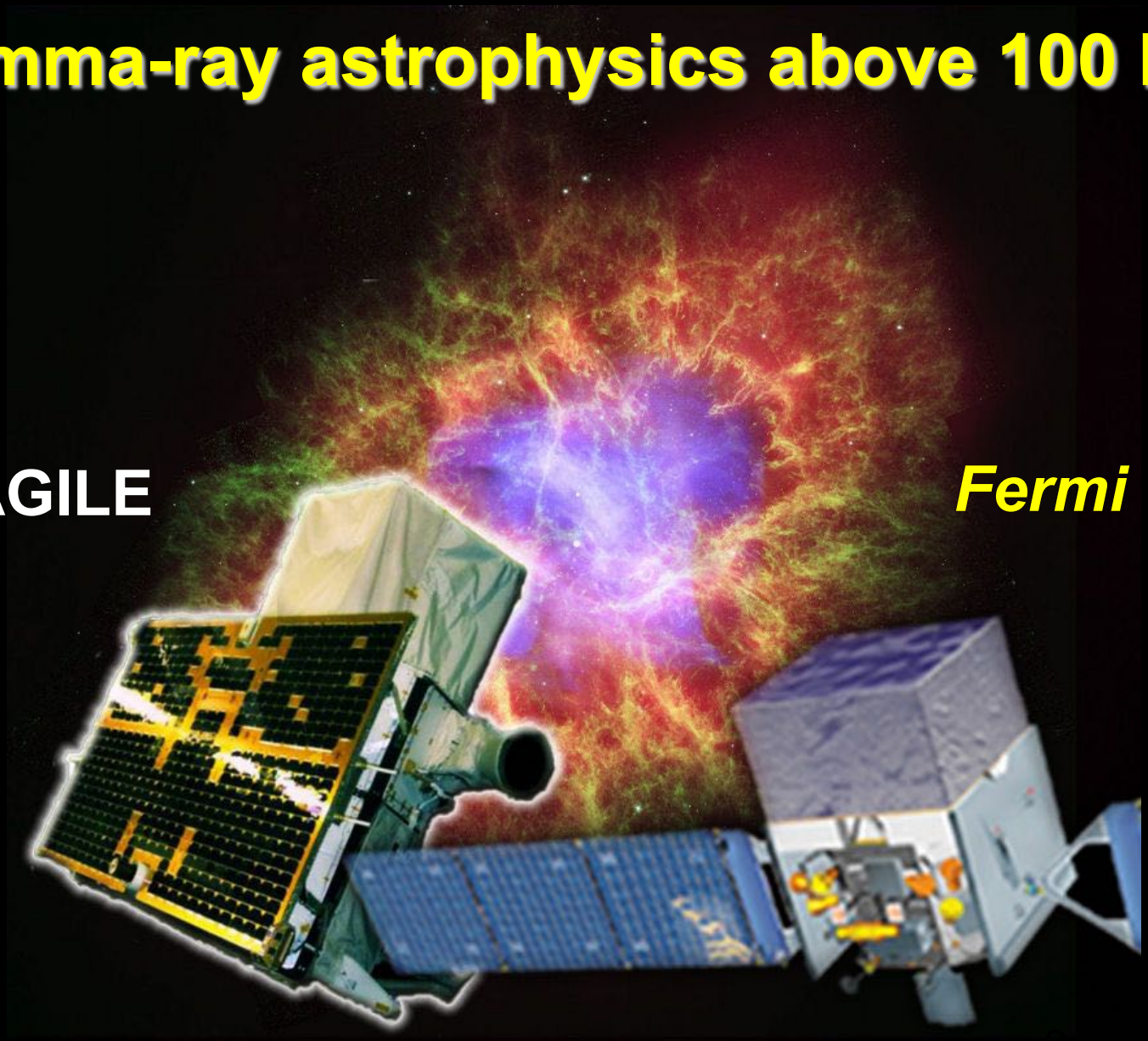


Gamma Ray Physics in the Fermi era

F.Longo
University of Trieste and INFN

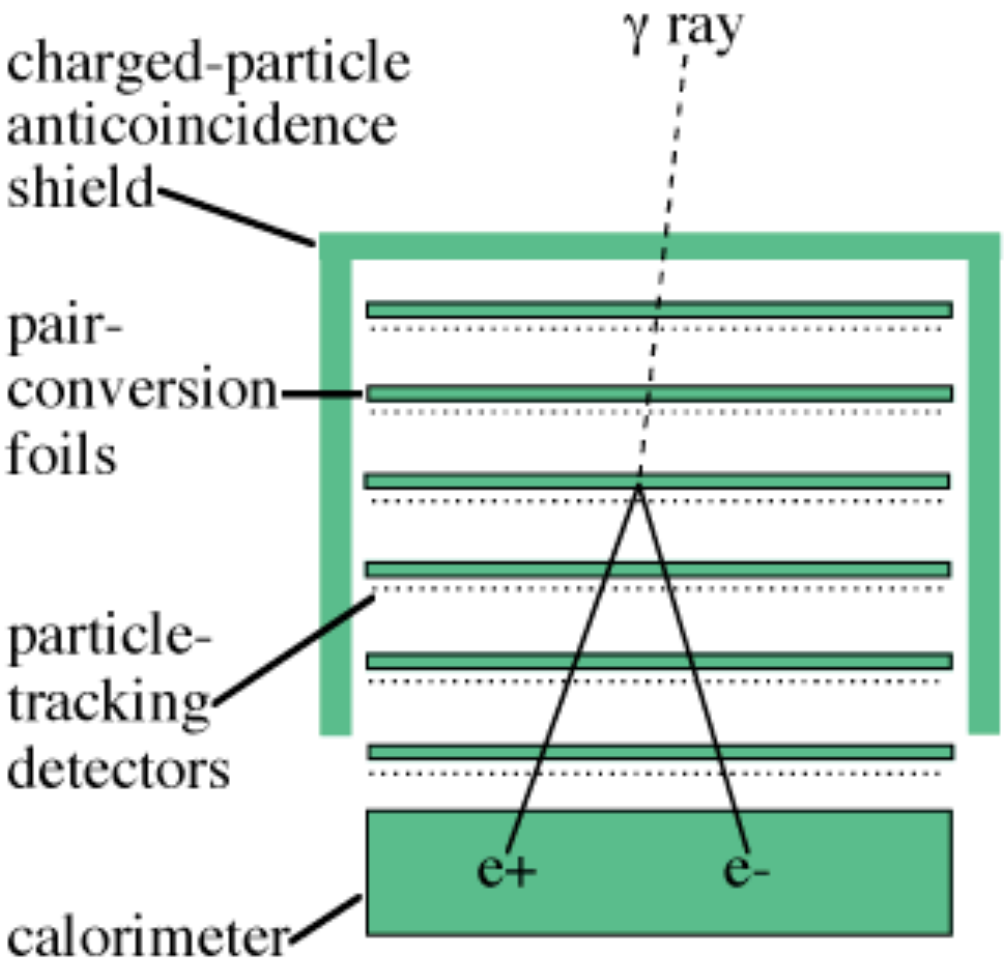
Vulcano, May 22, 2018

Gamma-ray astrophysics above 100 MeV



Picture of the day, Feb. 28, 2011, NASA-HEASARC

Gamma Ray detectors

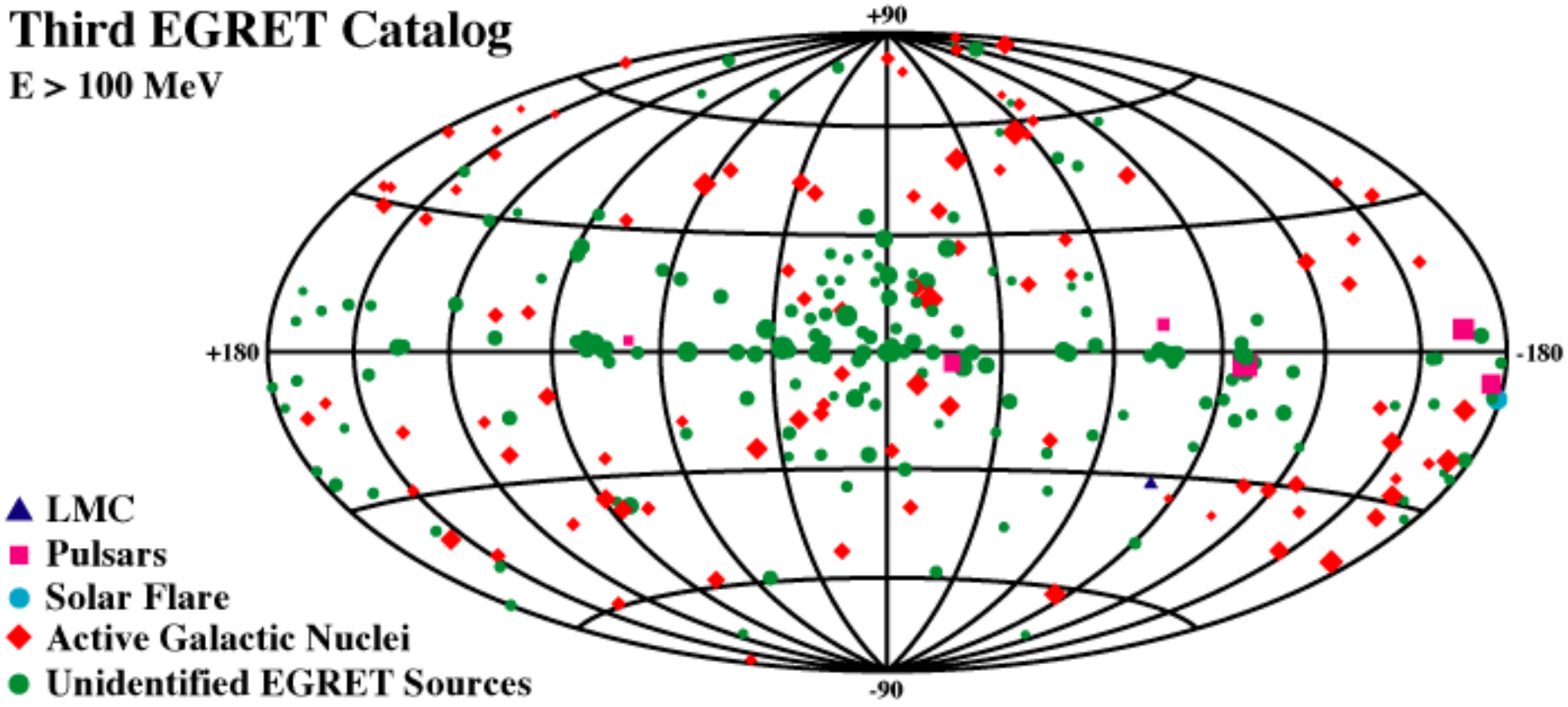


Science topics in HE γ-ray Astrophysics

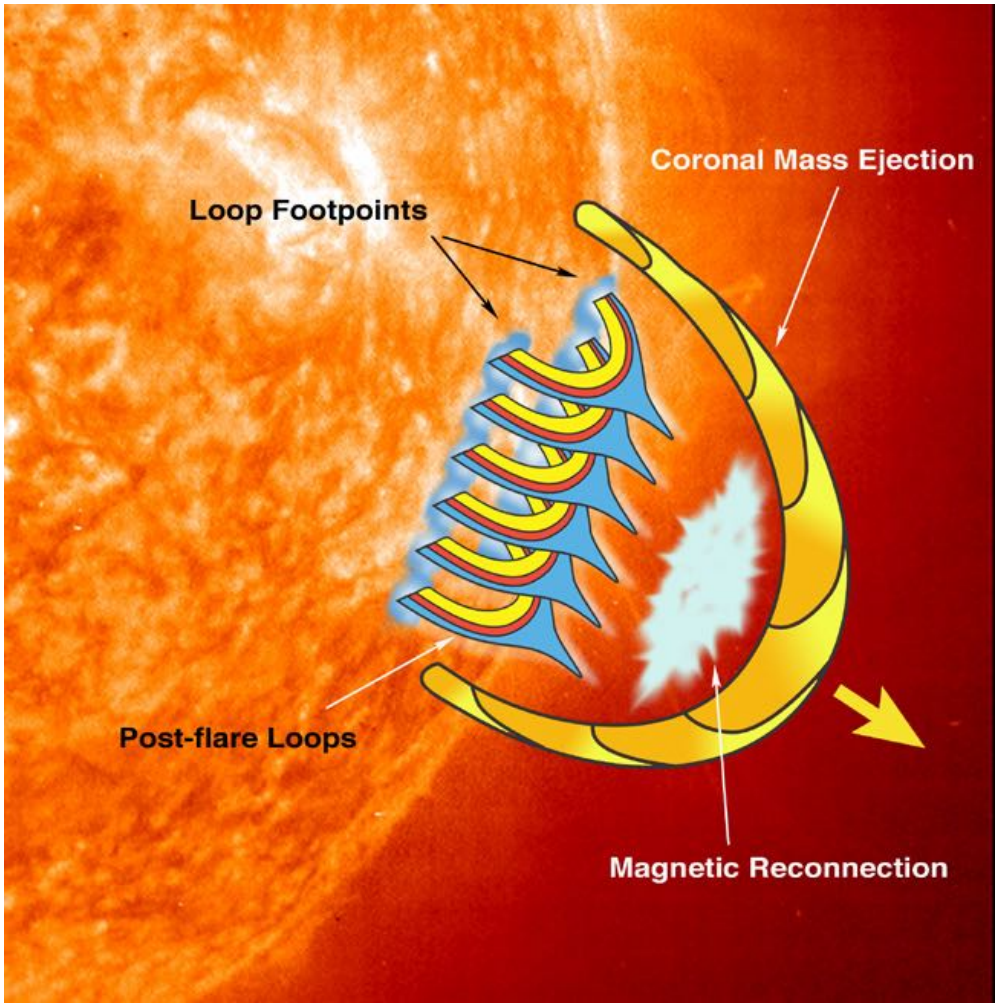
- **High Energy Cosmic Rays Sources**
  - **Particle Acceleration mechanisms**
  - **Highest power gamma-ray sources**
- **The propagation of Cosmic Rays**
  - **The diffuse emission**
- **The nature of Dark Matter**

- **Multimessenger connections**
- **The EM counterparts of GWs**

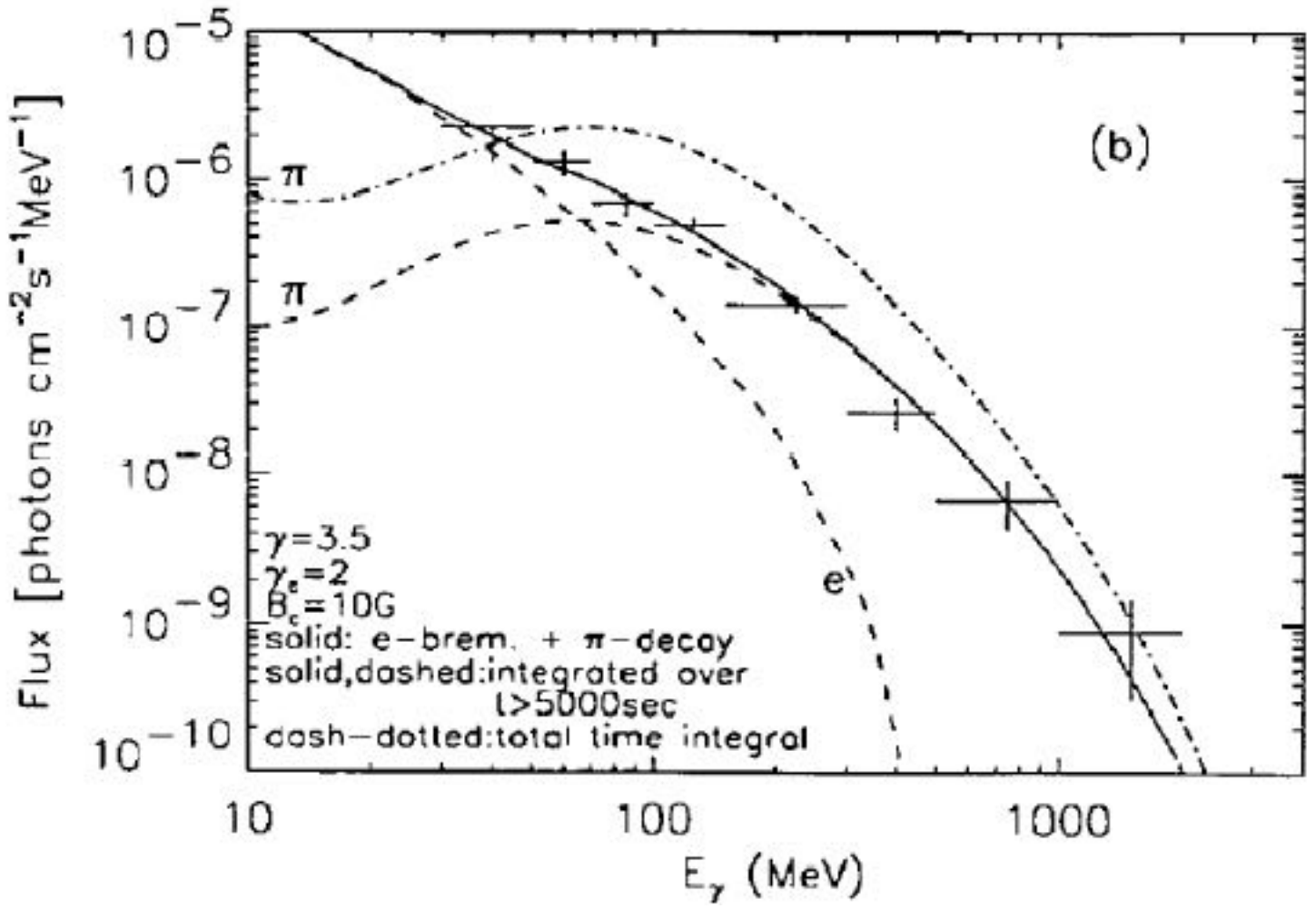
EGRET Gamma-ray Sources



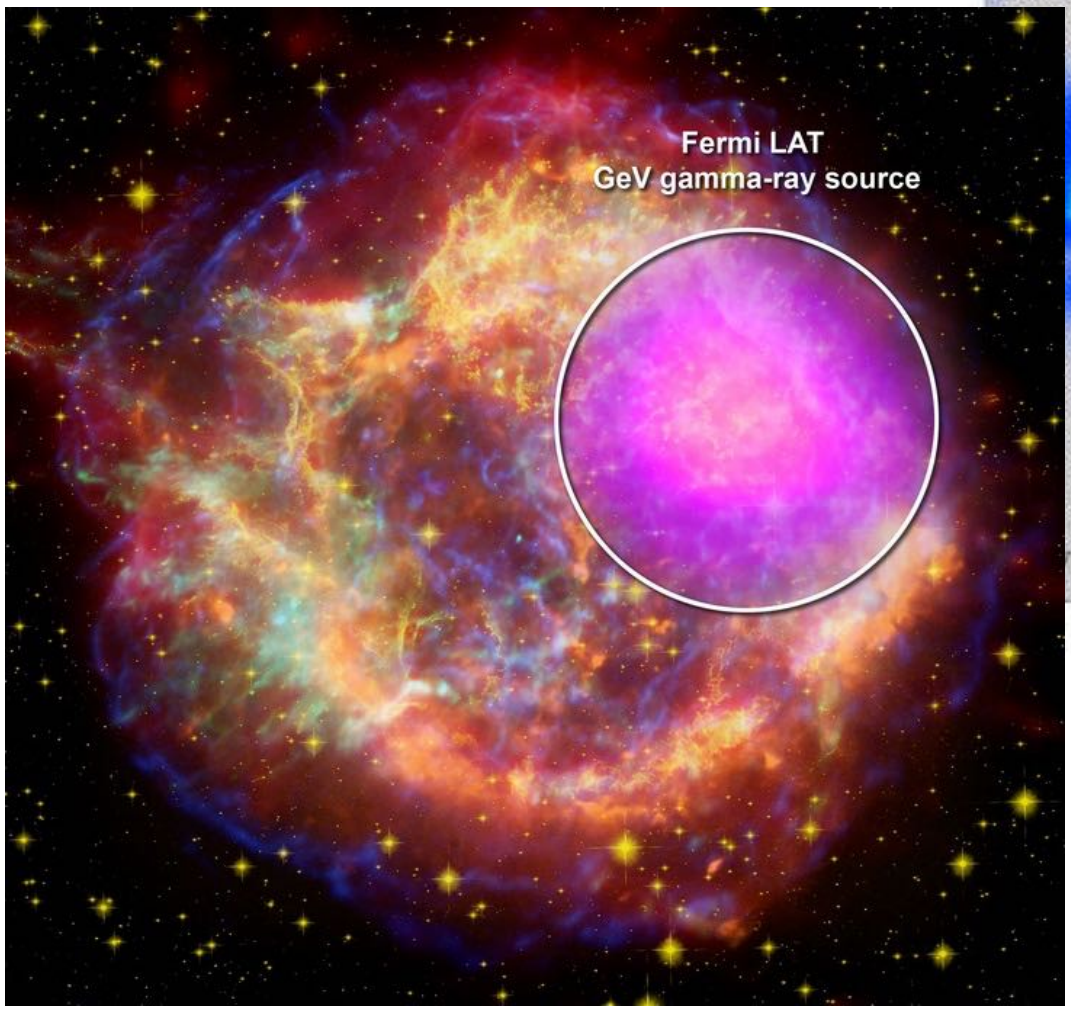
Solar Flares

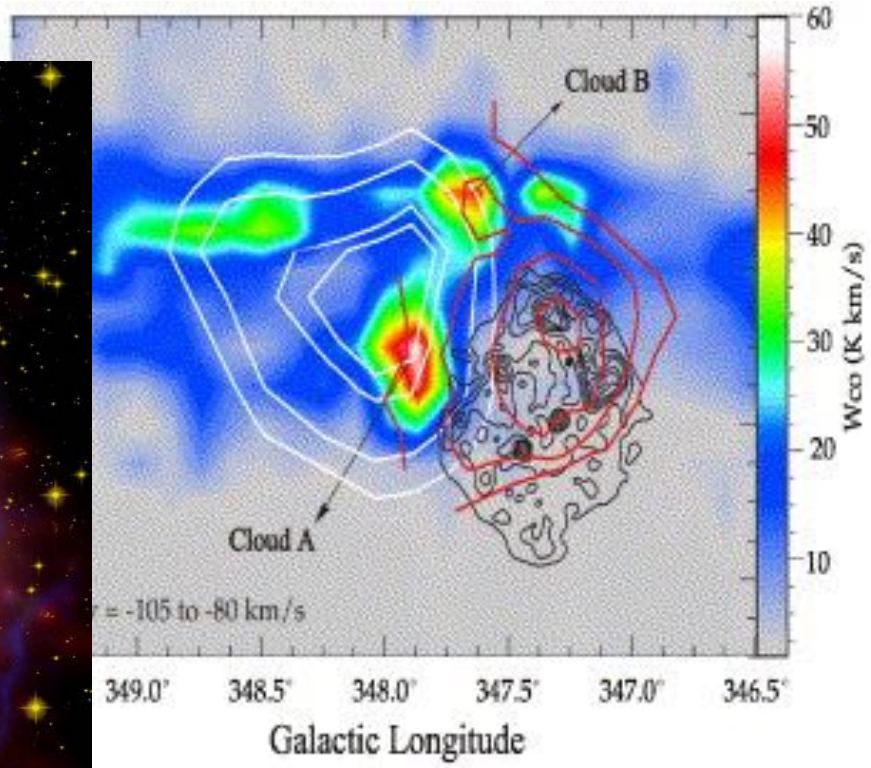


Solar Flares

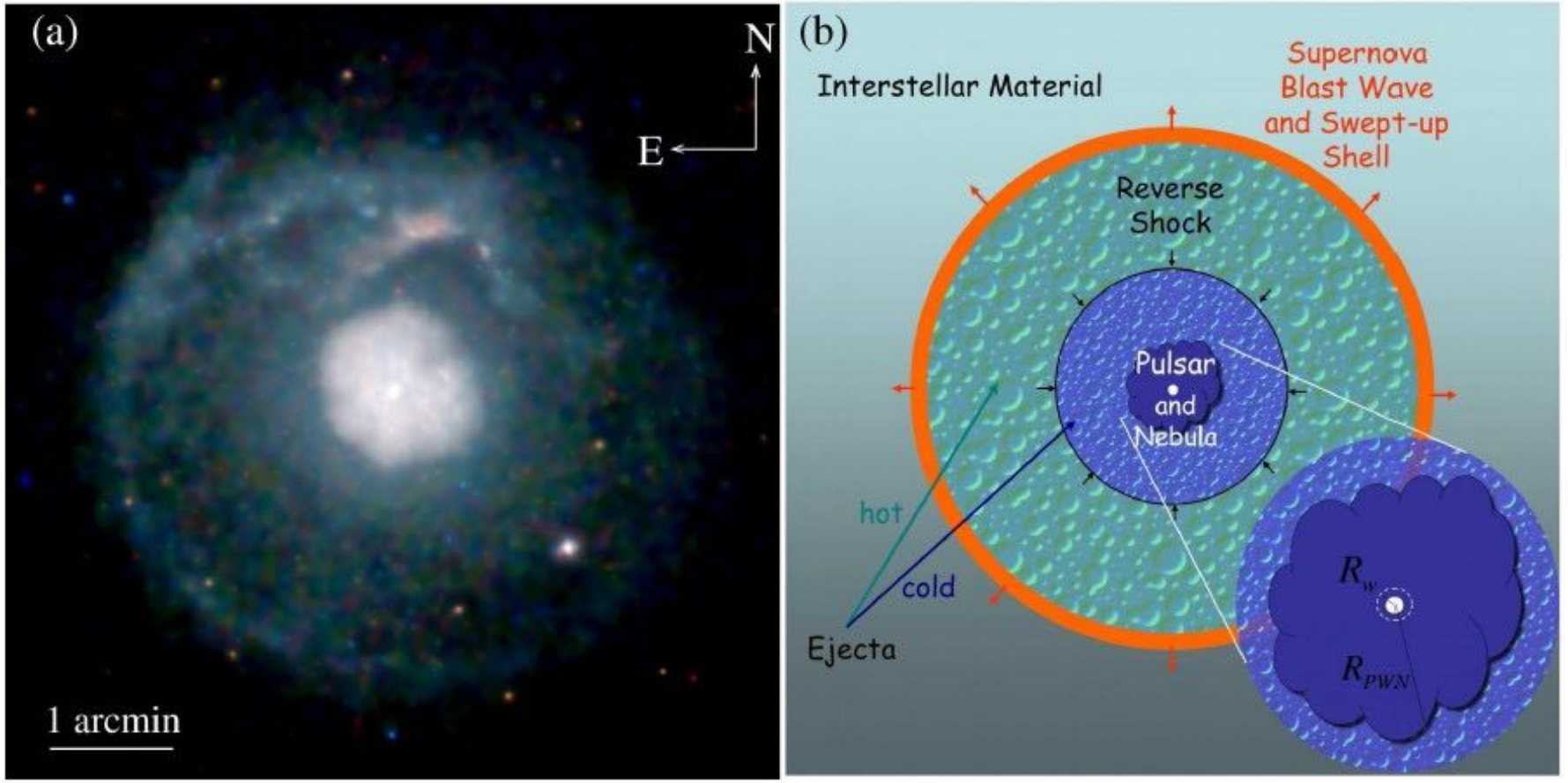


Supernova Remnants

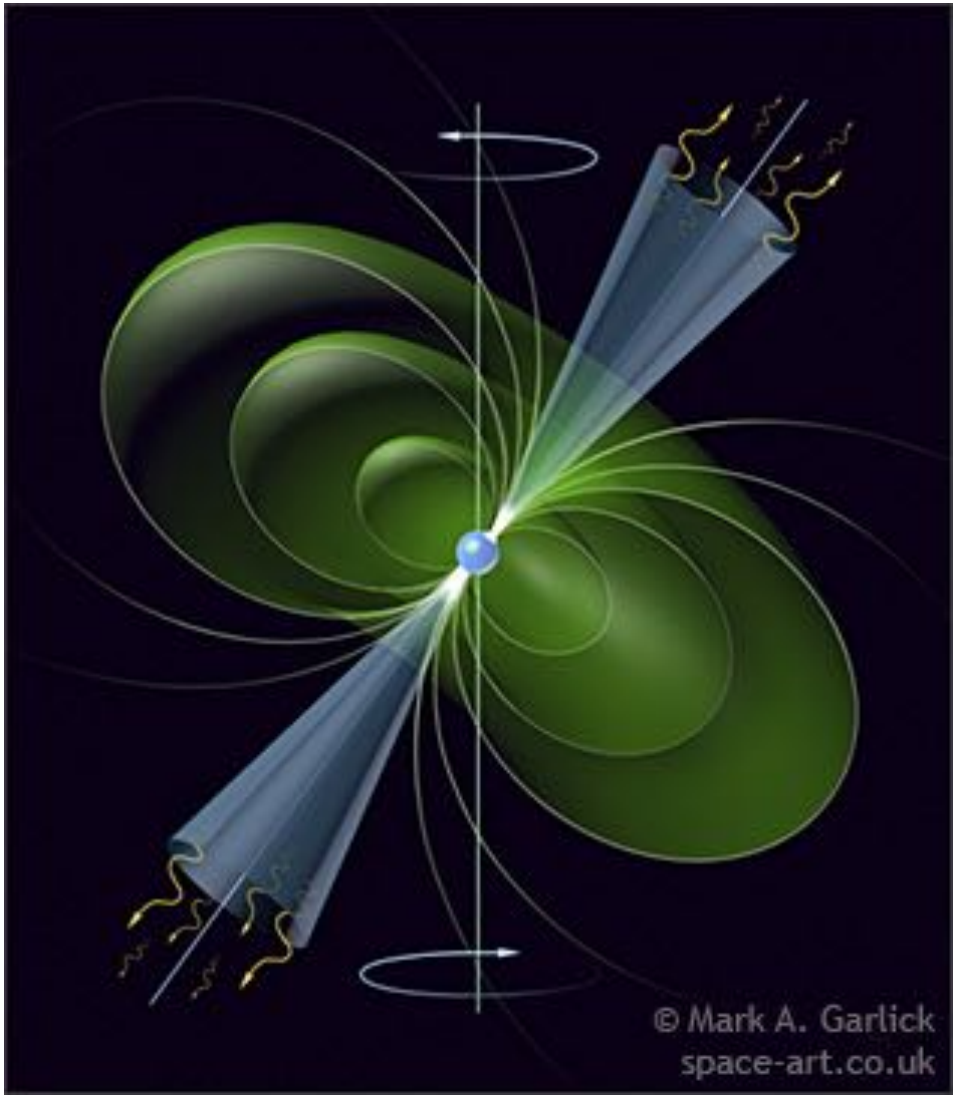




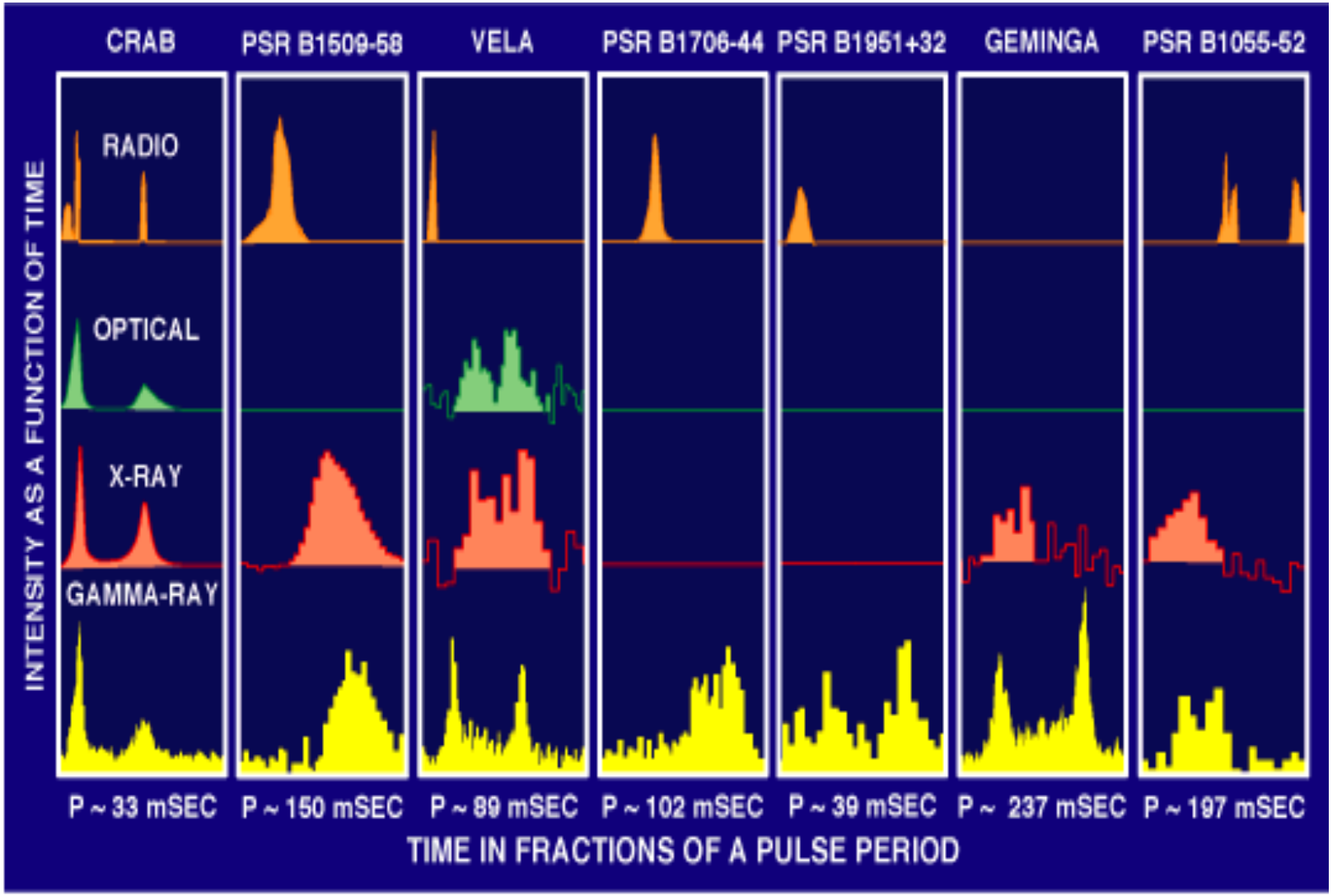
Pulsar Wind Nebulae



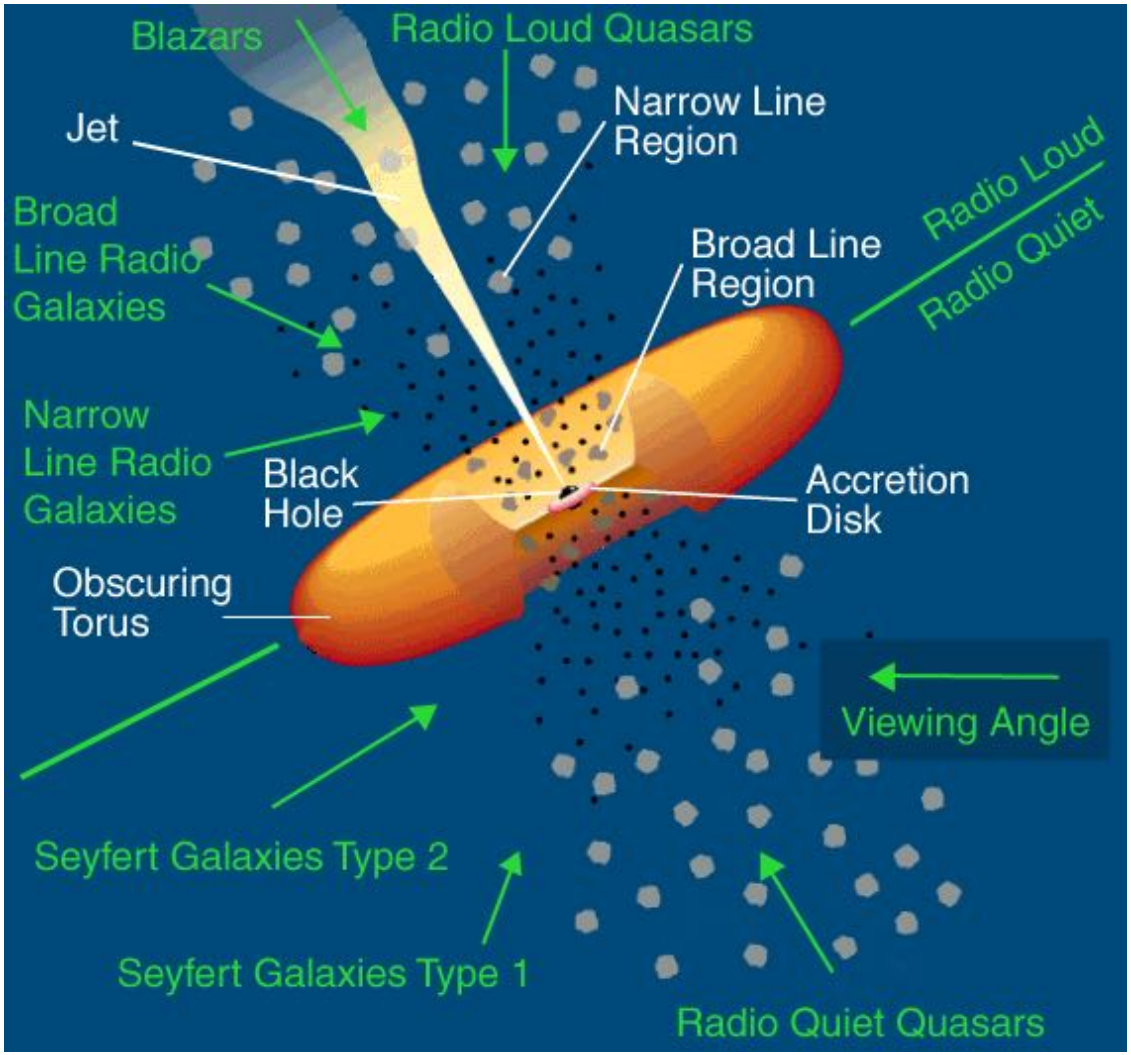
Pulsars



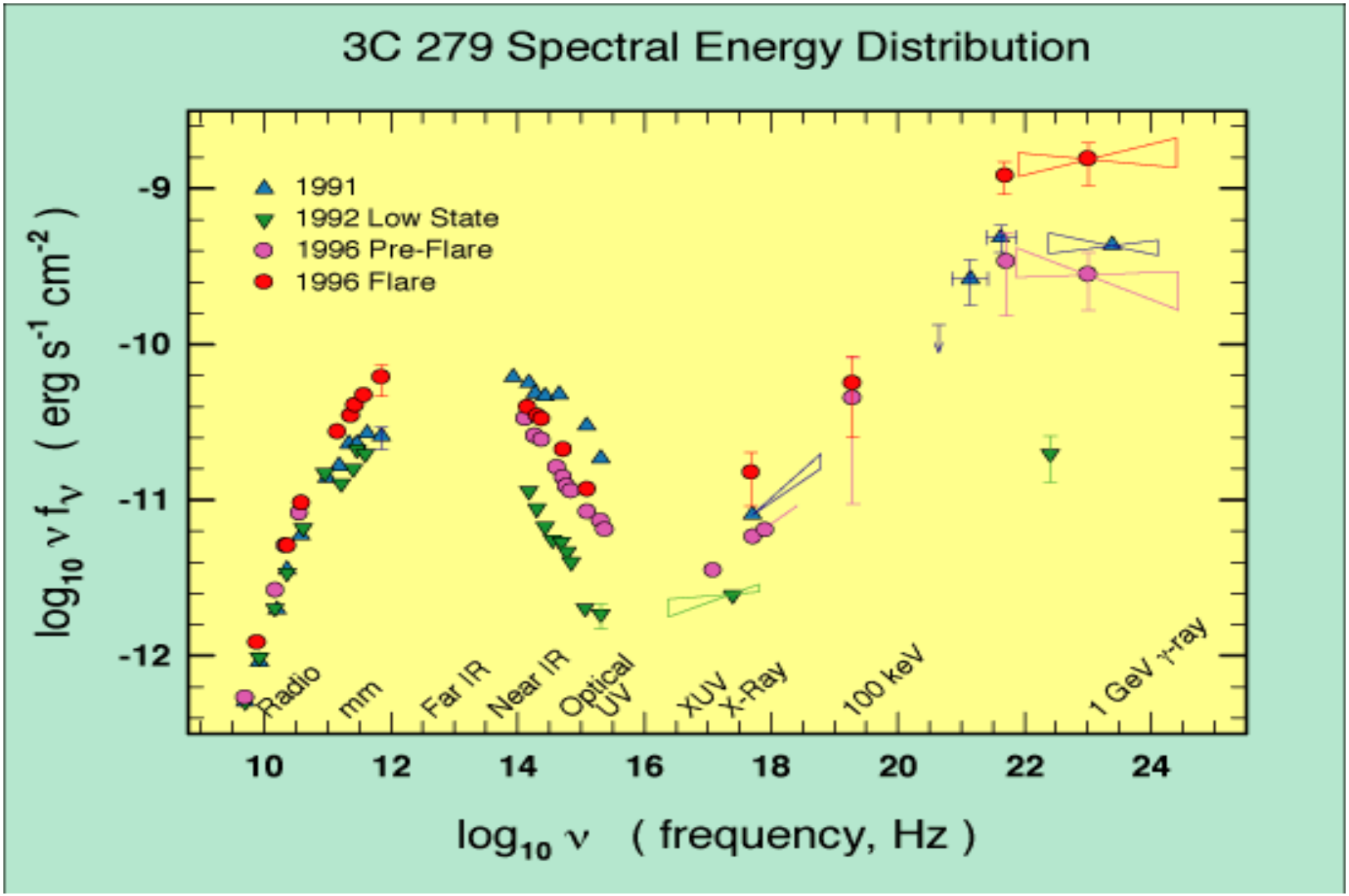
Pulsars


CRAB
PSR B1509-58
VELA
PSR B1706-44
PSR B1951+32
GEMINGA
PSR B1055-52
RADIO
OPTICAL
X-RAY
GAMMA-RAY
INTENSITY AS A FUNCTION OF TIME
P ~ 33 mSEC
P ~ 150 mSEC
P ~ 89 mSEC
P ~ 102 mSEC
P ~ 39 mSEC
P ~ 237 mSEC
P ~ 197 mSEC
TIME IN FRACTIONS OF A PULSE PERIOD

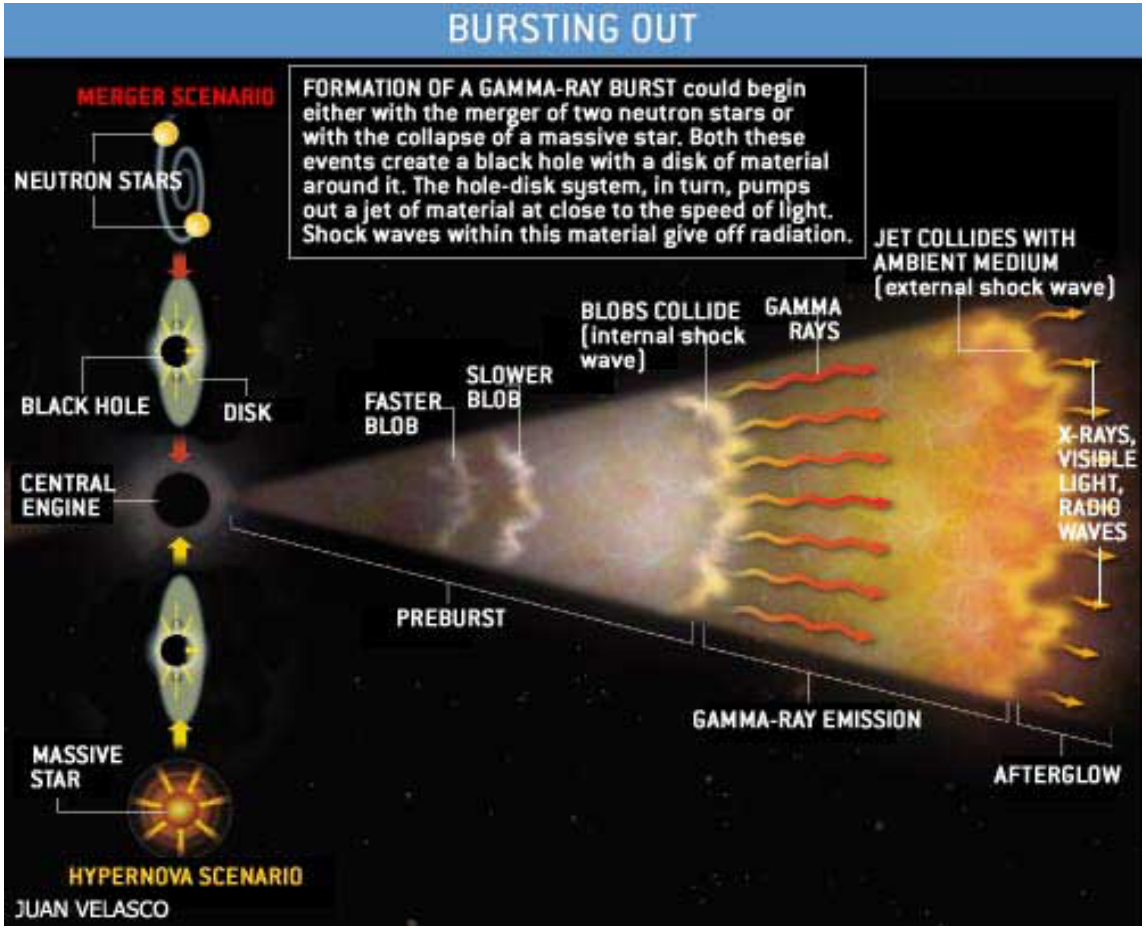
Active Galactic Nuclei

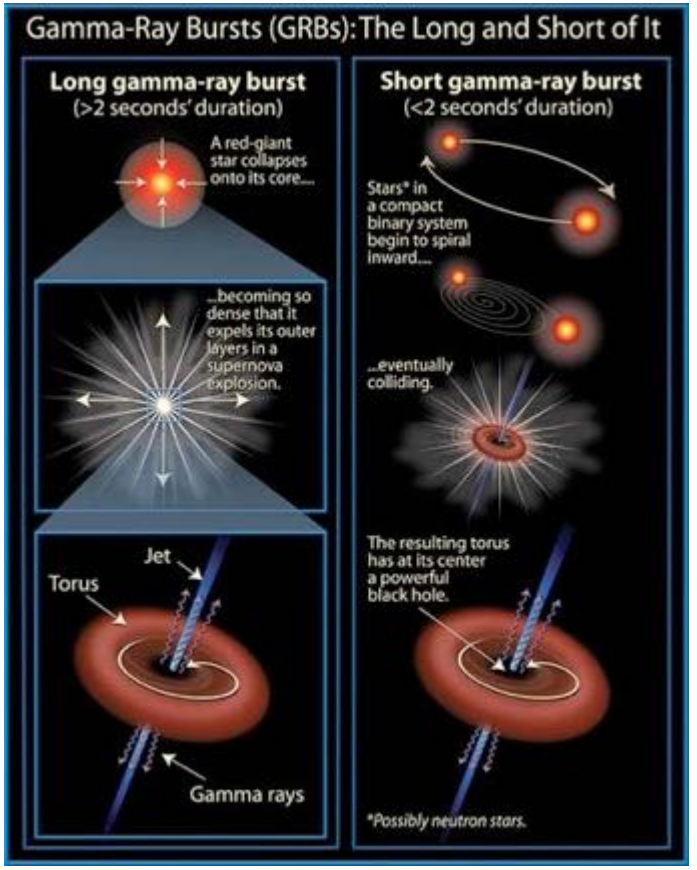


Active Galactic Nuclei



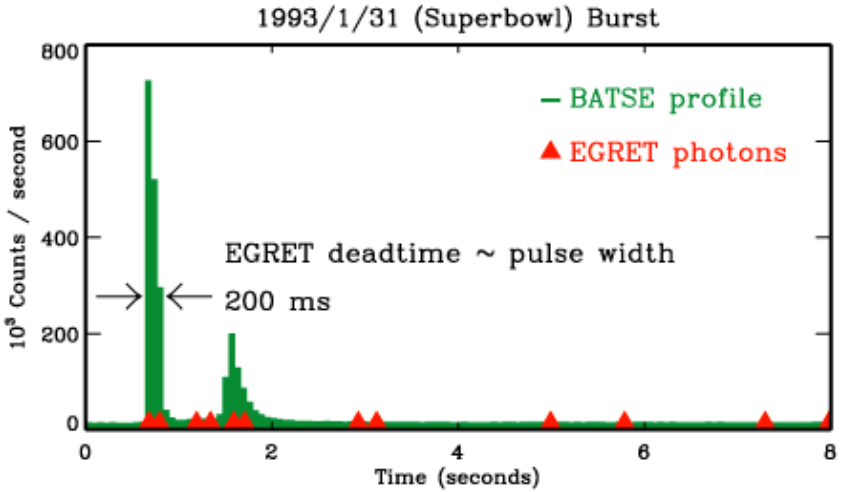
Gamma-ray Bursts



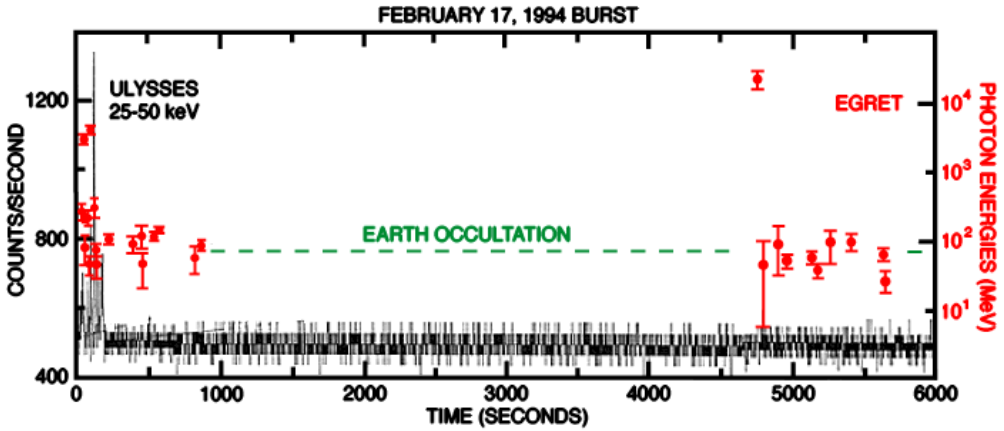


Gamma Ray Bursts

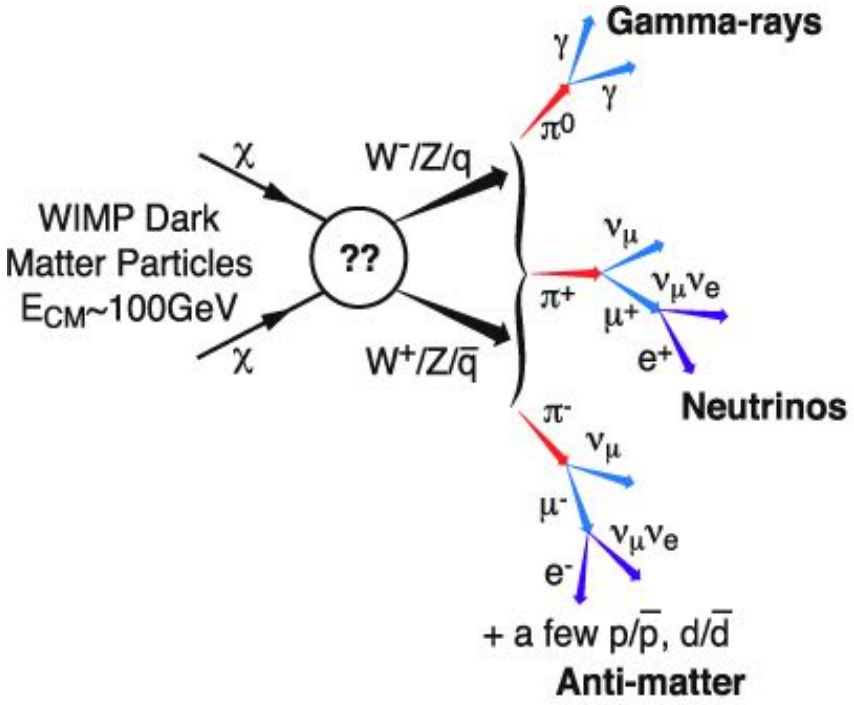
Prompt Emission (GRB 930131)

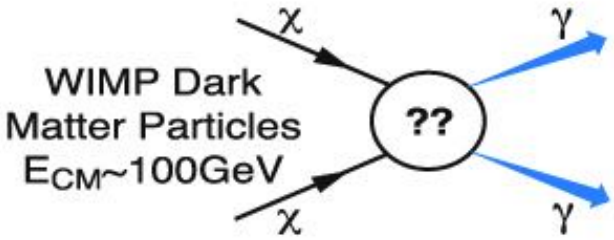


Delayed Emission (GRB 940217)

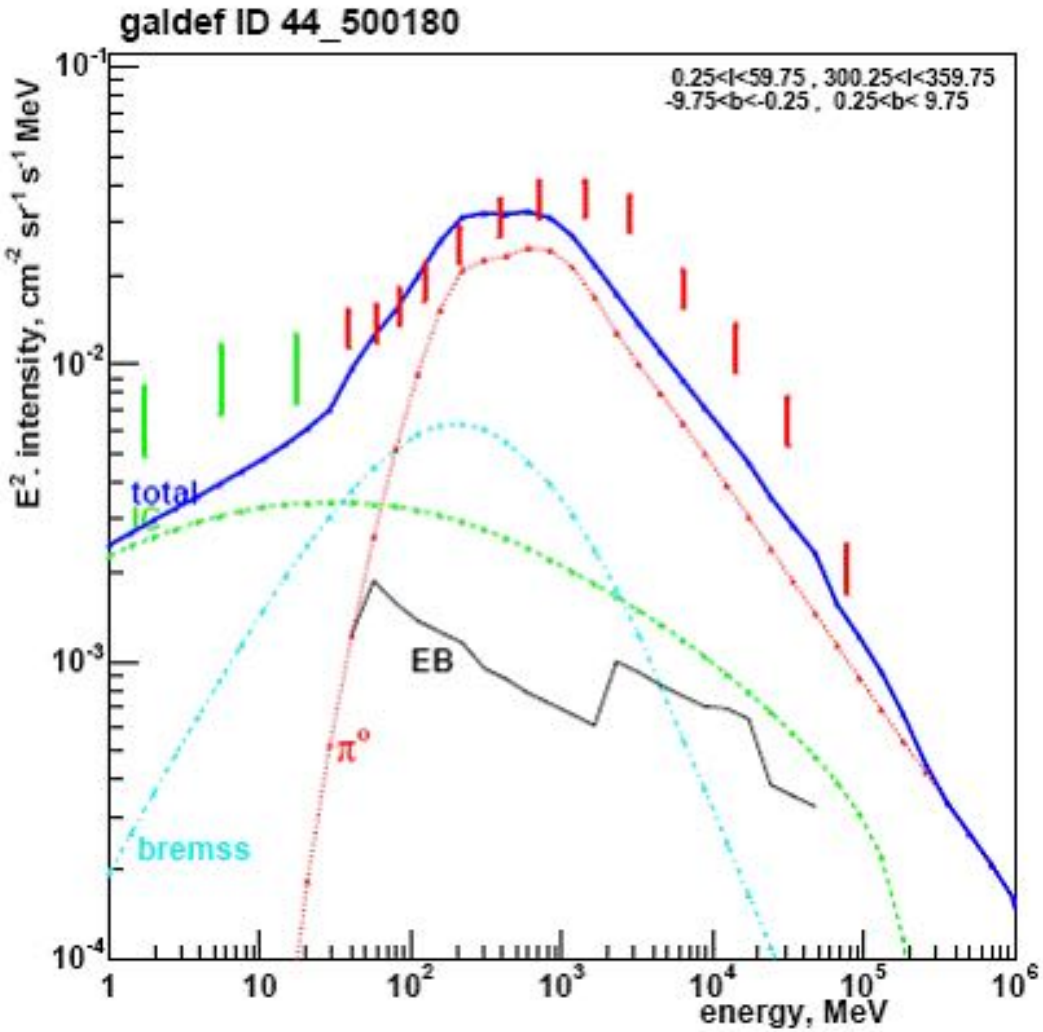


Dark Matter

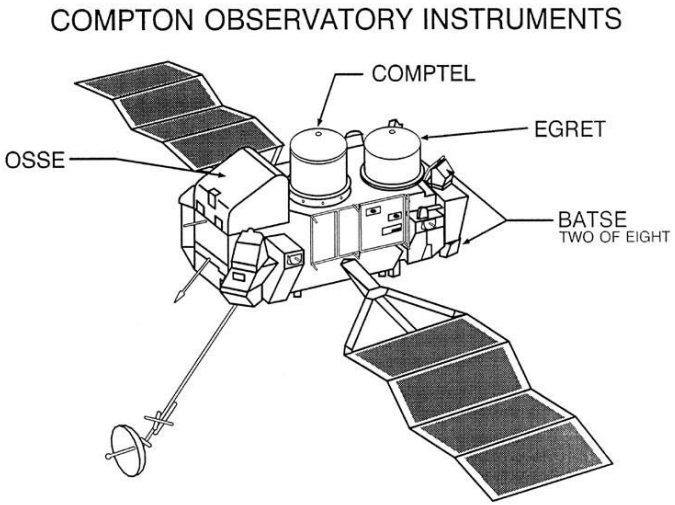

Gamma-rays
γ
γ
π0
χ
W-/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q̄
νμ
π+
νμνe
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter

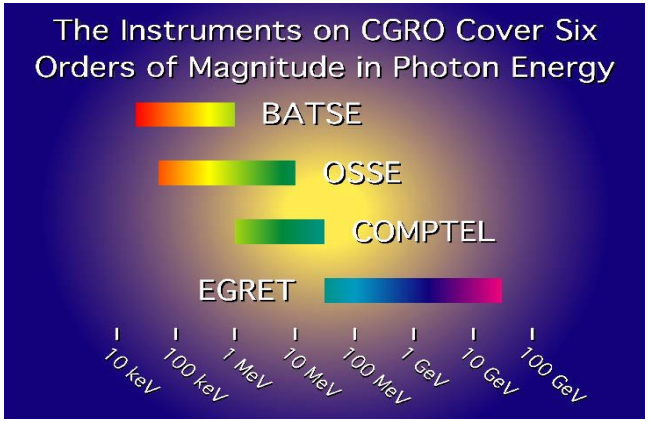

χ
γ
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
γ

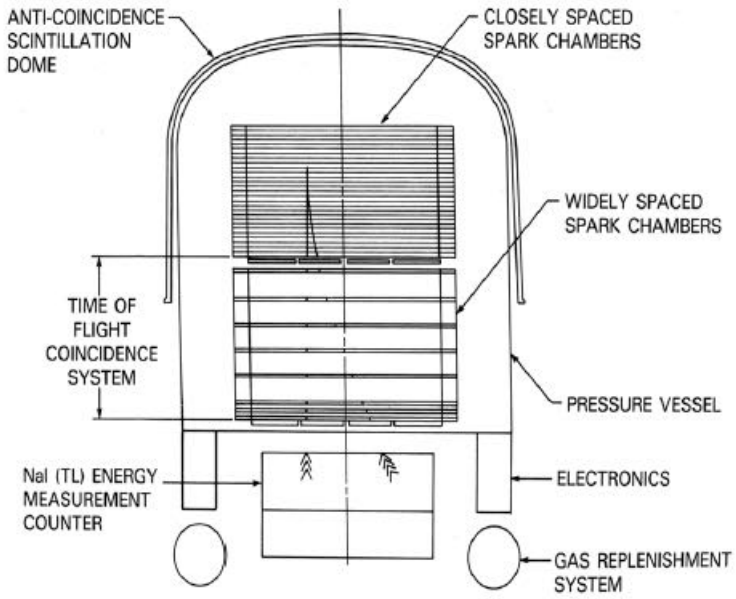
Dark Matter (?)


galdef ID 44_500180
0.25<l<59.75 , 300.25<l<359.75
-9.75<b<-0.25 , 0.25<b< 9.75
E². intensity, cm⁻² sr⁻¹ s⁻¹ MeV
energy, MeV
total
IC
EB
π°
bremss

EGRET





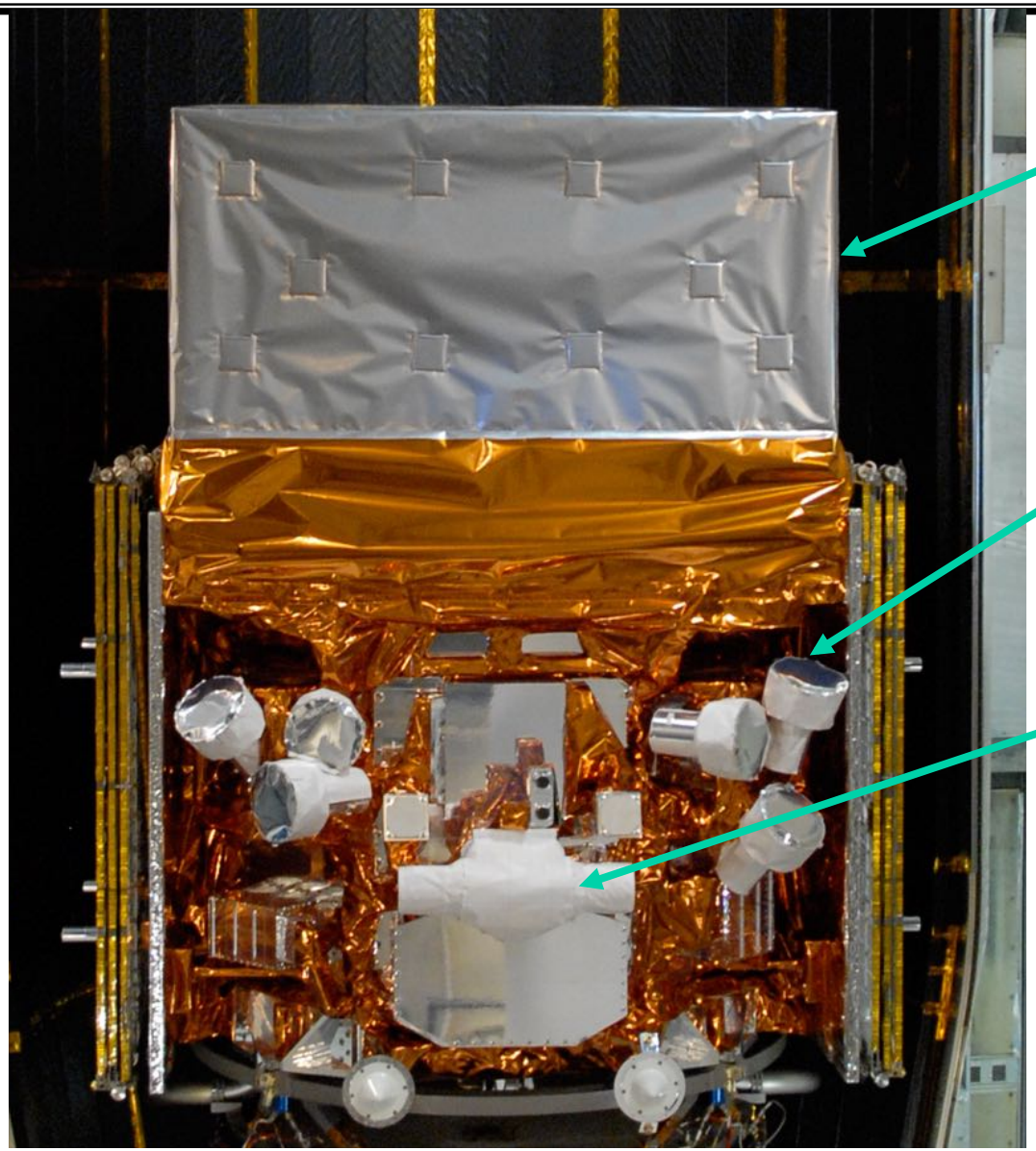


EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

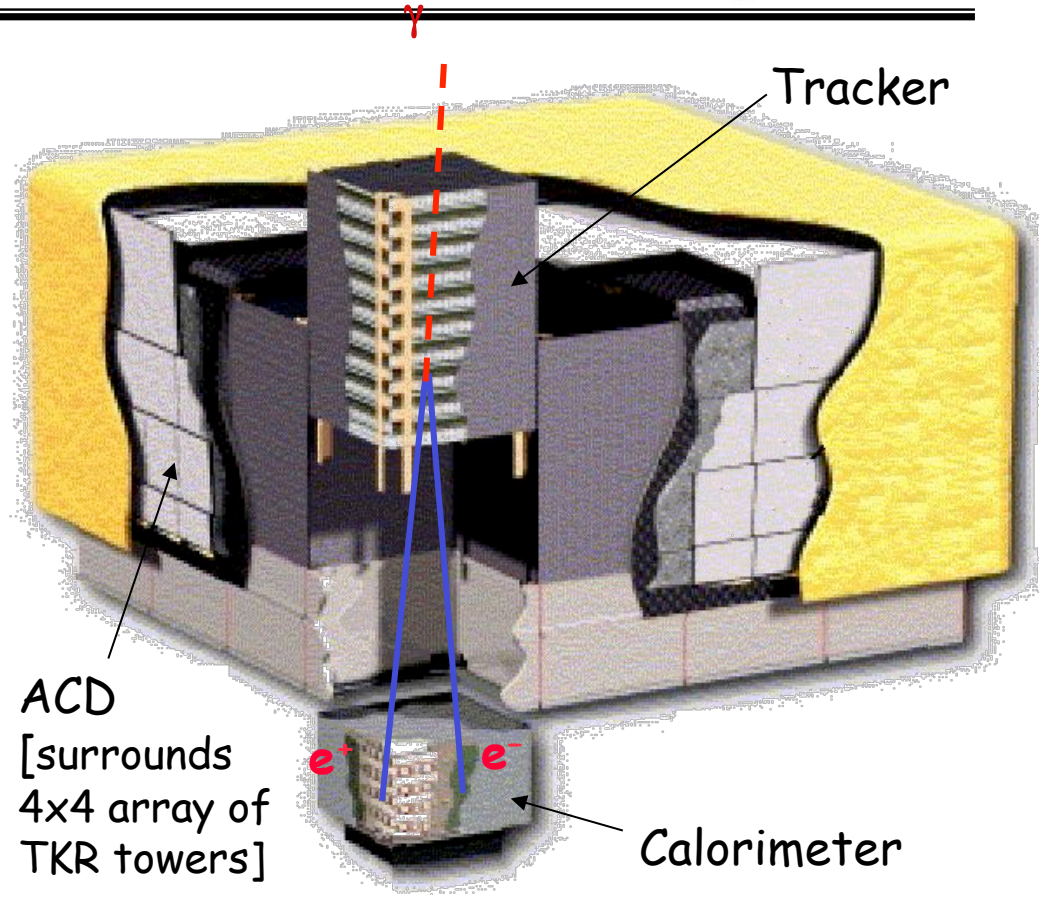
Fermi LAT

The Fermi Observatory



Overview of LAT

- **Precision Si-strip Tracker (TKR)** 18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter(CAL)** Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- **Segmented Anticoincidence Detector (ACD)** 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- **Electronics System** Includes flexible, robust hardware trigger and software filters.

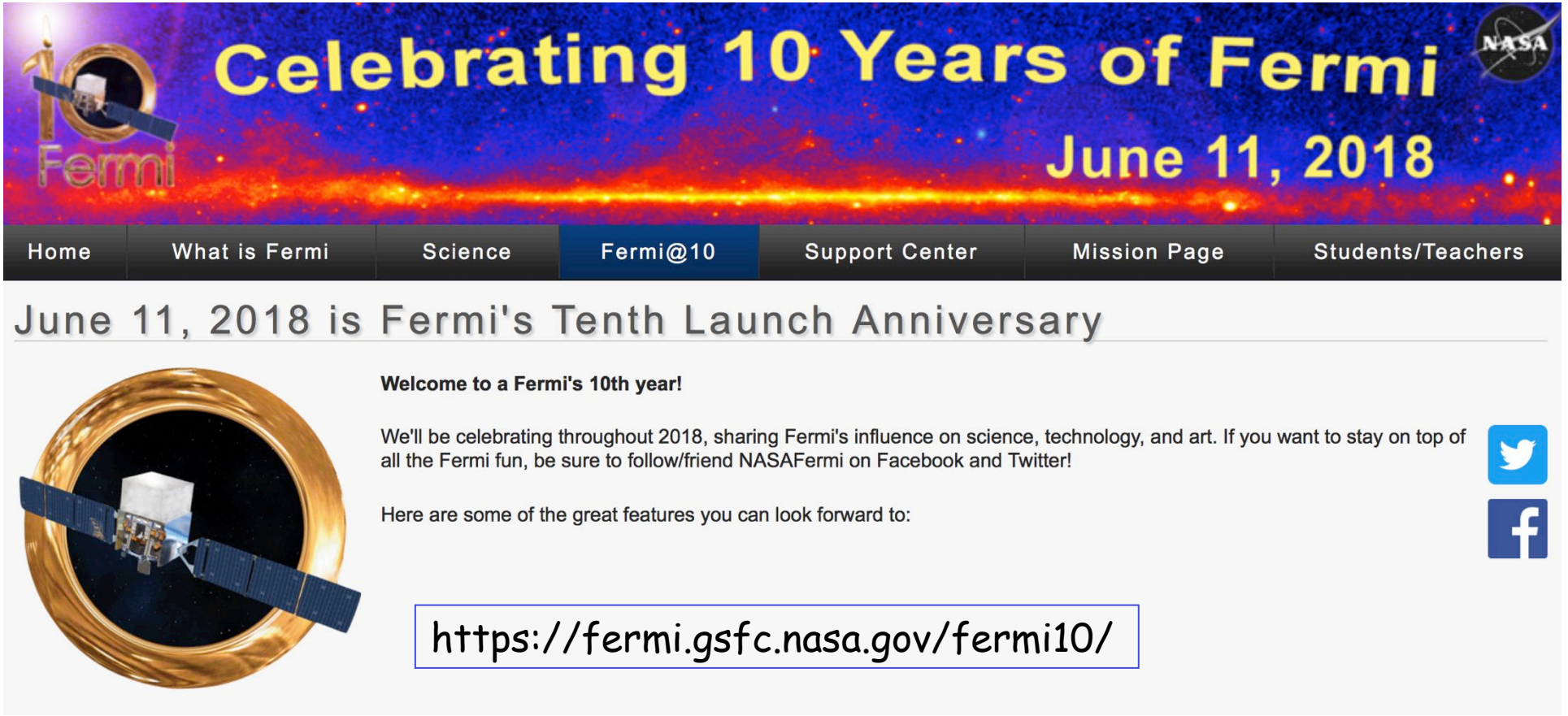


Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

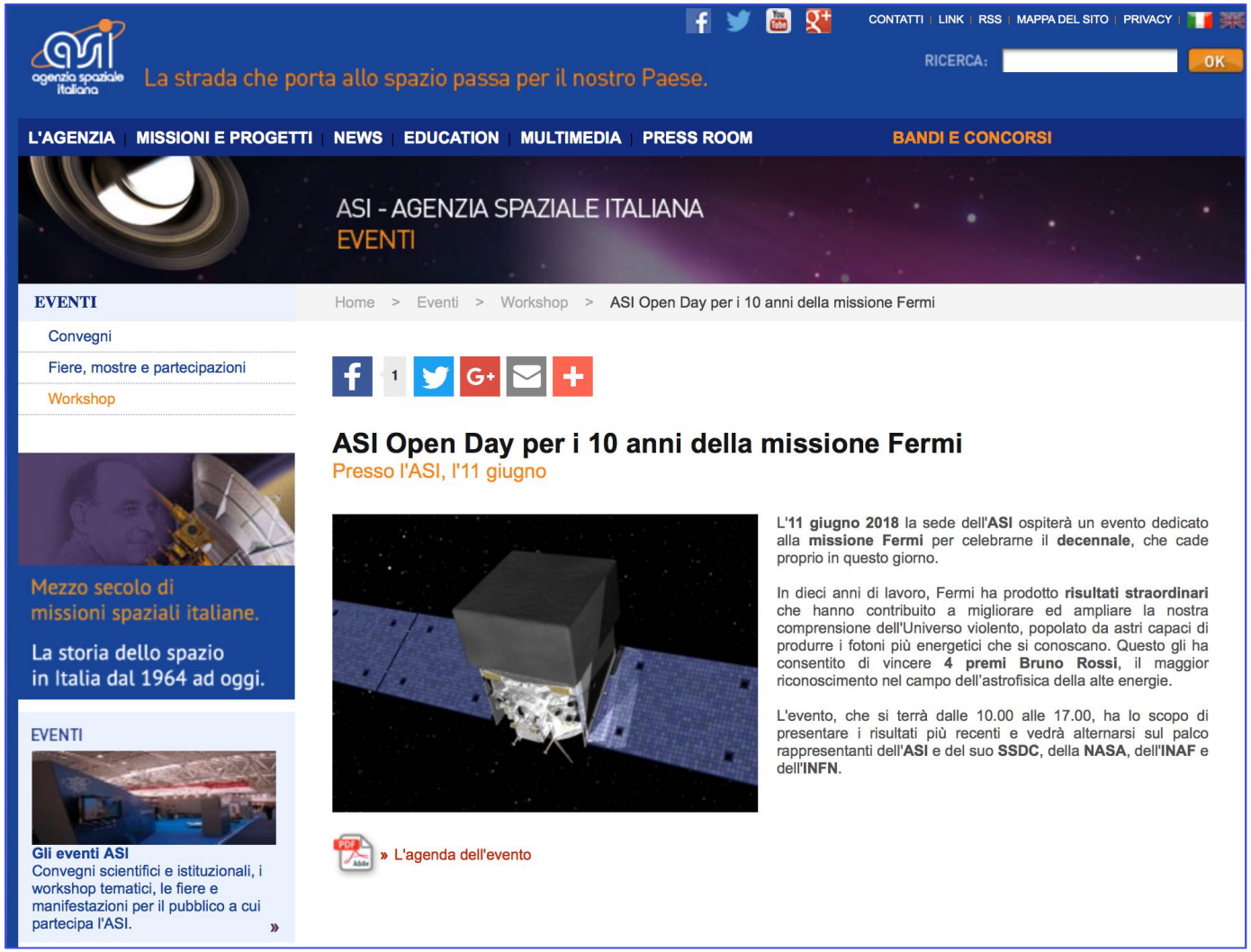
Fermi Launch

- 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.

10th Fermi Anniversary



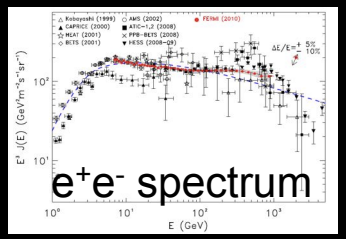
10th Fermi Anniversary

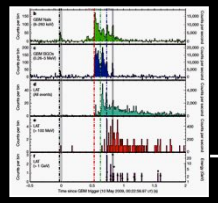


https://www.asi.it/it/eventi/workshop/decennale-missione-fermi

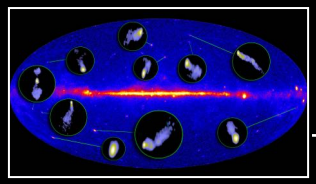
10th Fermi Anniversary

Fermi Highlights and Discoveries

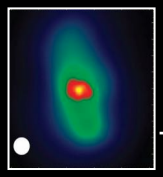




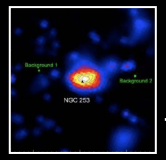
GRBs



Blazars

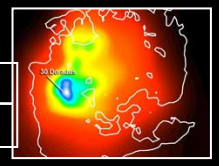


Radio Galaxies

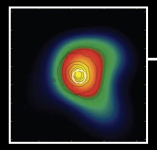


Starburst Galaxies

Extragalactic

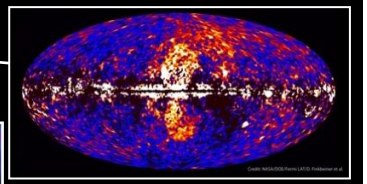


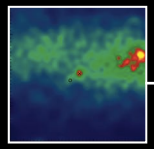
LMC & SMC



Globular Clusters

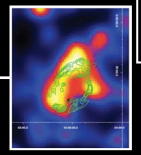
Fermi Bubbles

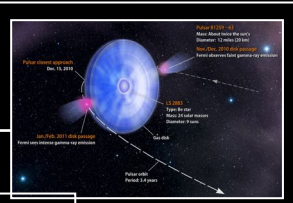




Novae

SNRs & PWN

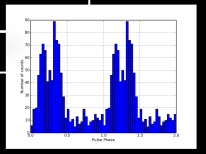




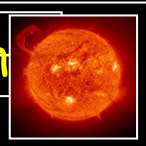
Galactic

γ-ray binaries

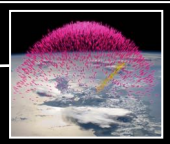
Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interaction

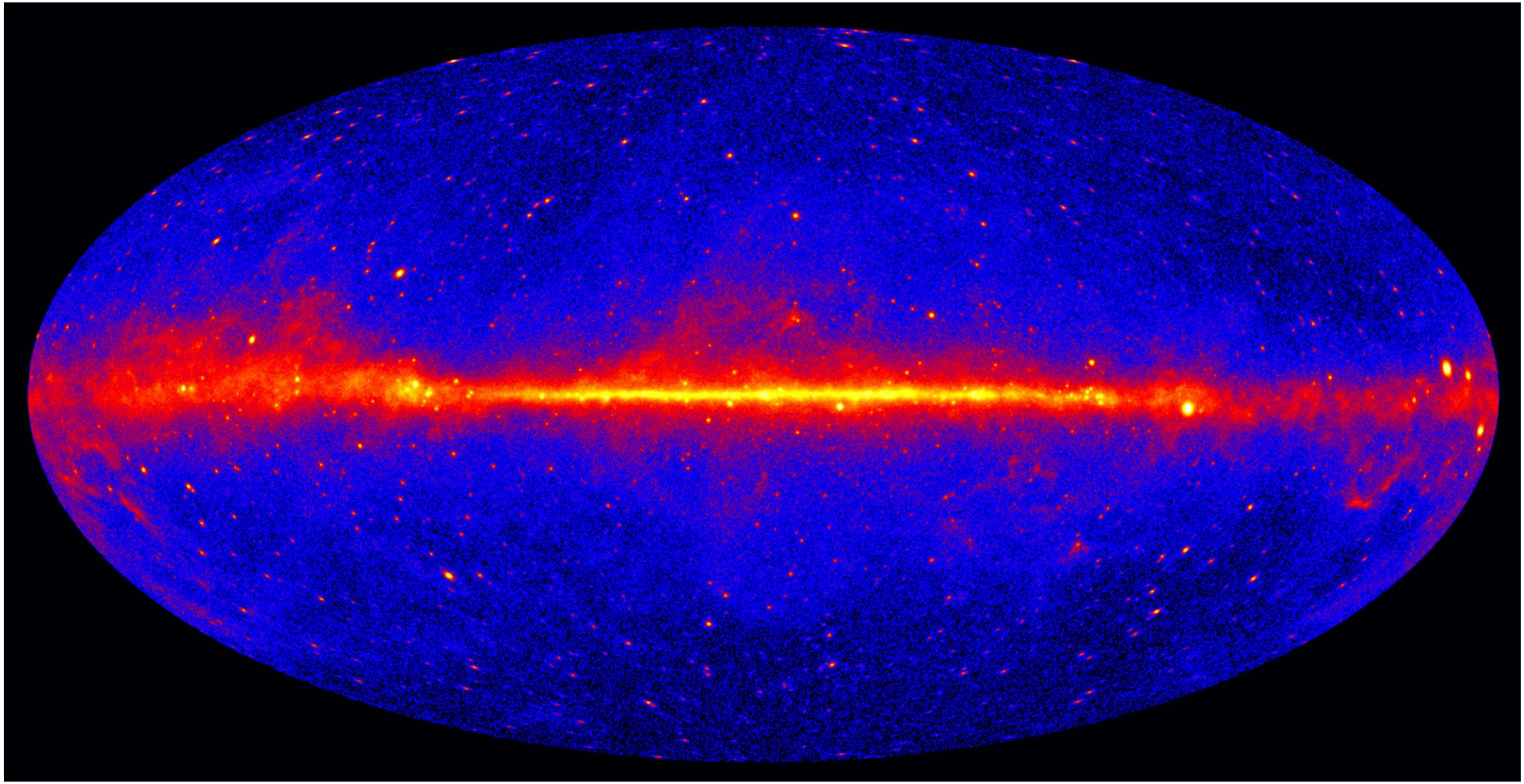


TGF

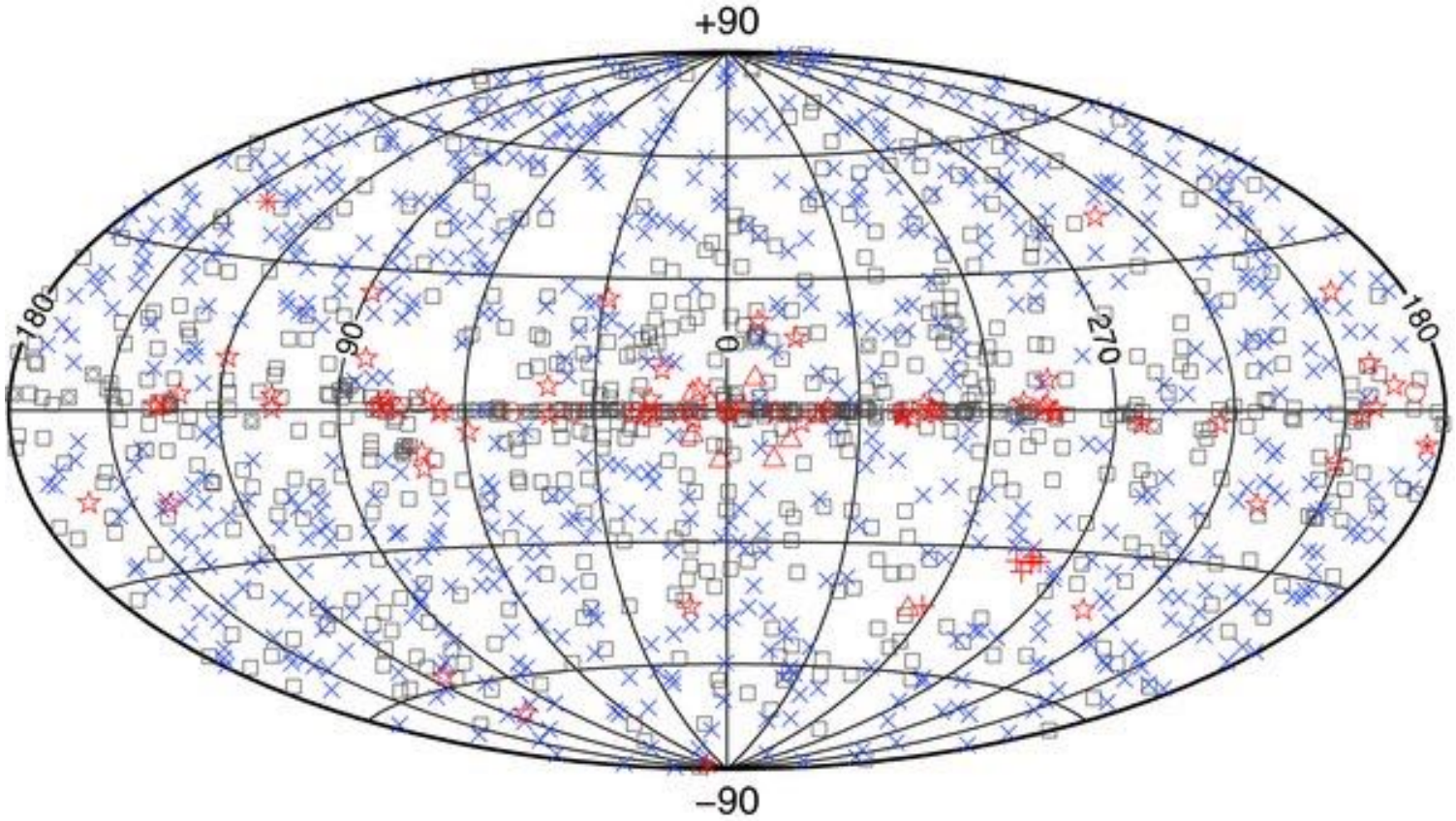


Unidentified Sources

The full sky map



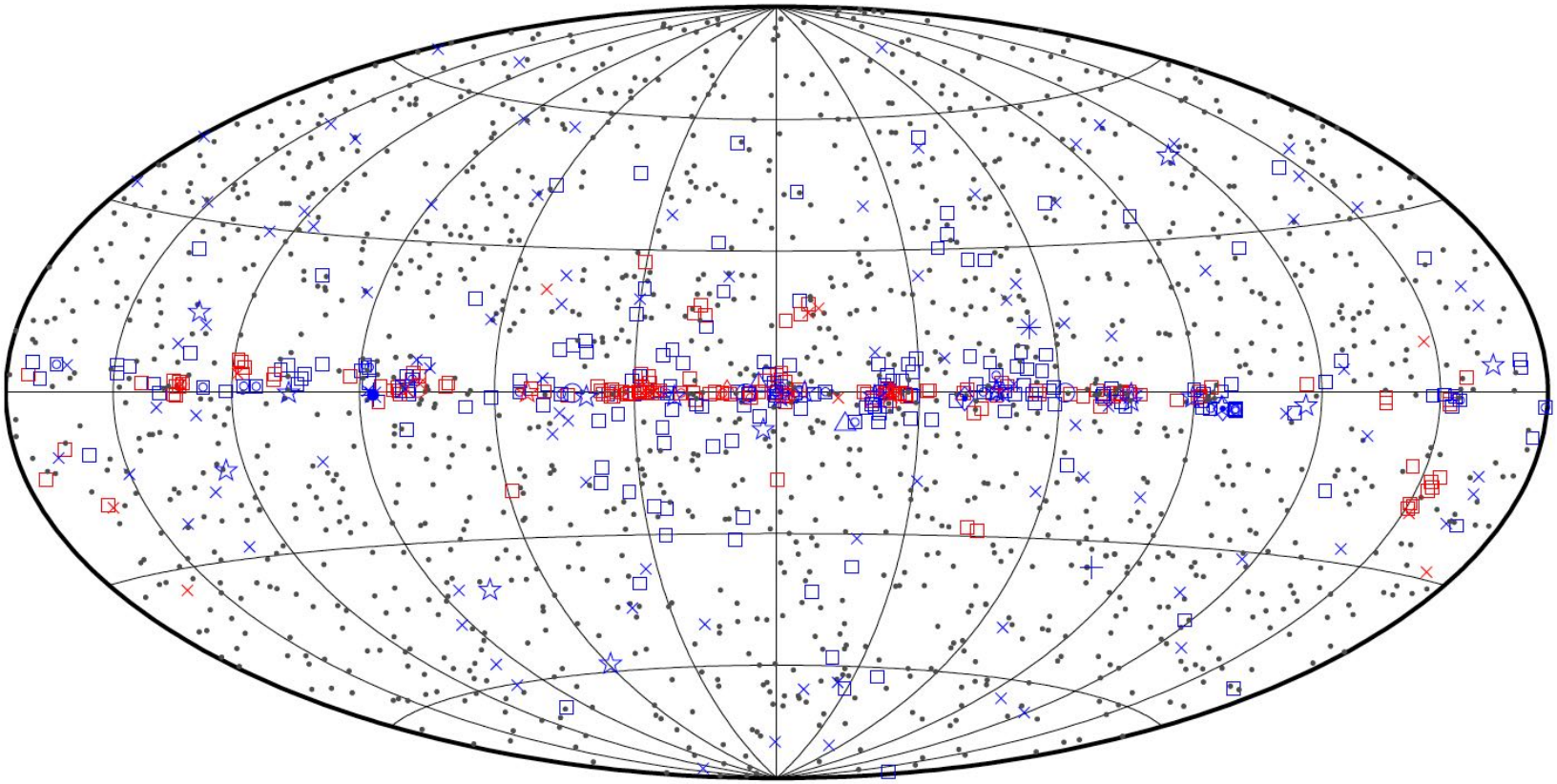
1 FGL catalog



No association	Possible association with SNR or PWN	
AGN	Pulsar	Pulsar w/PWN
Starburst Gal	PWN	Globular cluster
Galaxy	SNR	XRB or MQO

Abdo, A. A. et al. 2010

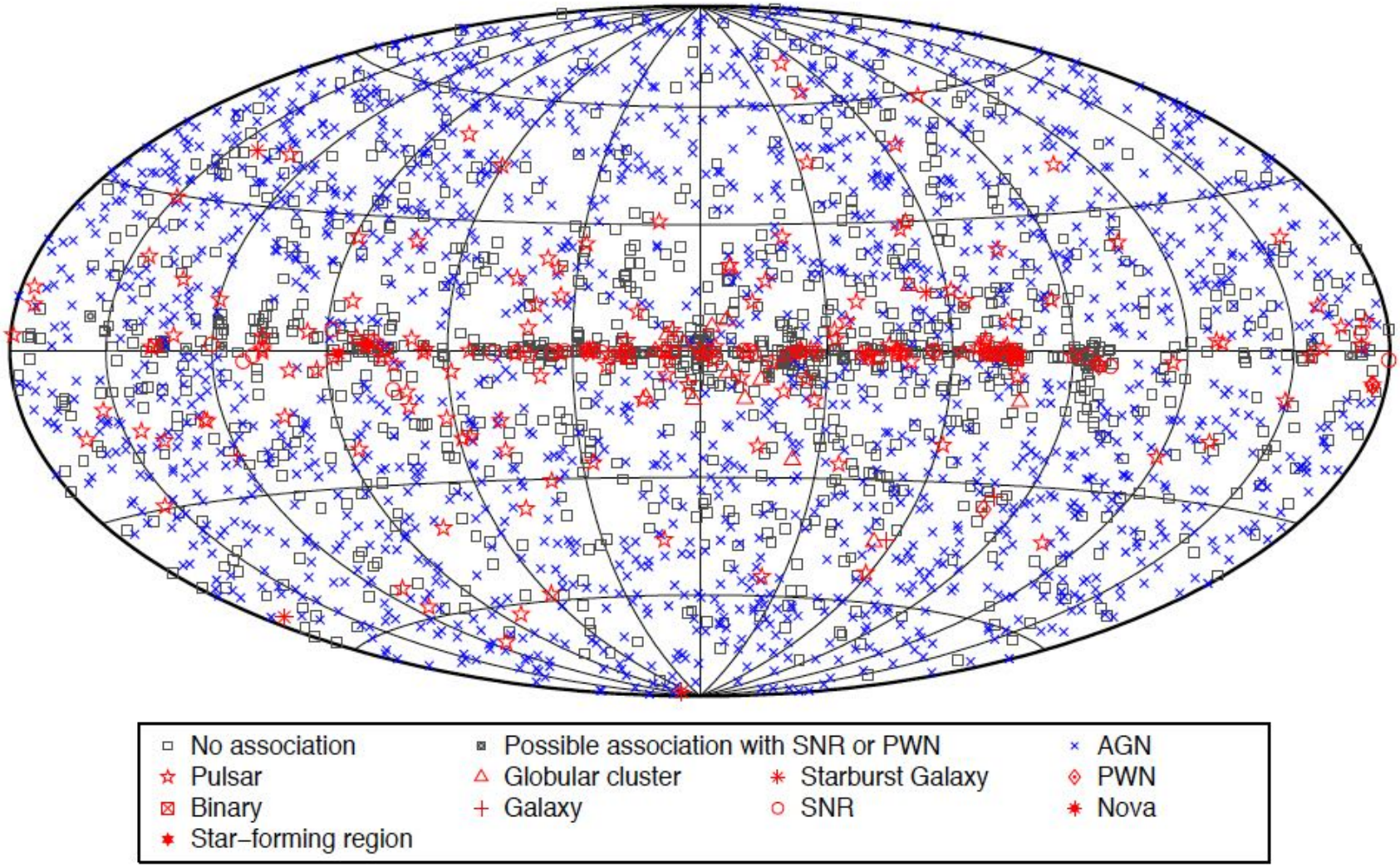
2 FGL catalog



□ No association	⊡ Possible association with SNR or PWN	
× AGN	☆ Pulsar	△ Globular cluster
✳ Starburst Gal	⋄ PWN	⊠ HMB
+ Galaxy	○ SNR	✷ Nova

Nolan, P. L. et al. 2012

3 FGL catalog

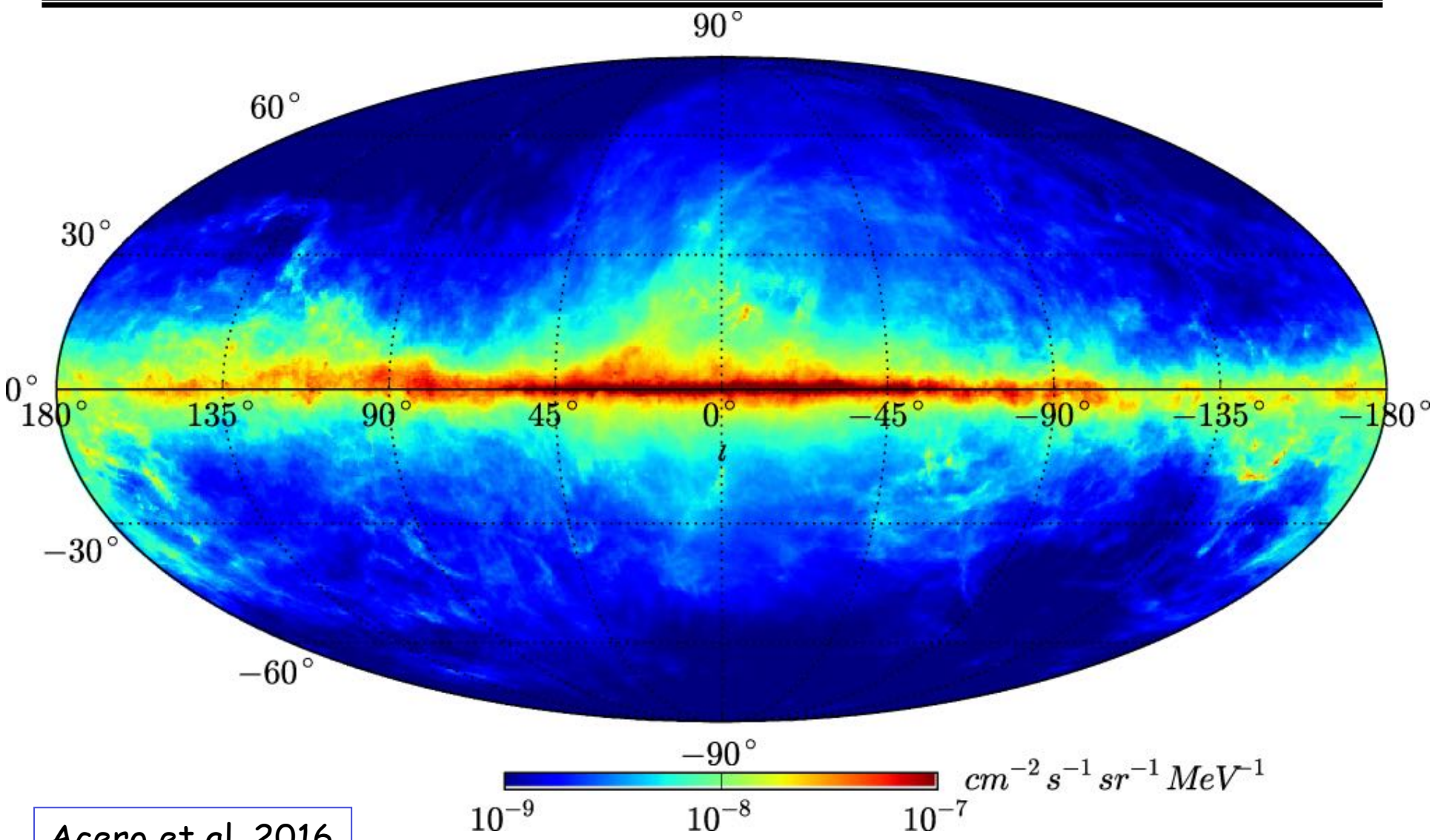


Acero, F. et al. 2015

Other catalogs

- LAT Data (high-level products only)
  - Catalogs and associated products
    - Preliminary LAT 8-year Source List (FL8Y)
    - LAT Third High Energy Source Catalog (3FHL)
    - Extended Sources in the Galactic Plane (FGES)
    - Second Fermi All-sky Variability Analysis Catalog (2FAV)
    - 1st Fermi-LAT SNR Catalog
    - LAT Burst Catalog
    - LAT 4-year Point Source Catalog (3FGL, Interactive Table)
    - Aperture Photometry Light Curves for LAT 4-year Catalog Sources (Updated Weekly)
    - Flaring Sources in the LAT 4-year Aperture Photometry Light Curves (Updated Weekly)
    - LAT Second High-Energy Source Catalog (2FHL)
    - LAT 2-year Point Source Catalog (2FGL)
    - Aperture Photometry Light Curves for the LAT 2-year Point Source Catalog
    - Flaring Sources in the LAT 2-year Aperture Photometry Lightcurves
    - LAT 3-year High-Energy Source Catalog (1FHL)
    - LAT 1-year Point Source Catalog (1FGL)
    - LAT 3-month Bright Source List (0FGL)
    - LAT 3-year Catalog of Gamma-ray Pulsars
  - Other useful data products
    - LAT Monitored Source List Light Curves
    - FAVA (Fermi All-sky Variability Analysis)
    - List of LAT GRBs announced via GCN notices (external)
    - List of LAT Sources announced via ATels
    - LAT List of Detected Gamma-Ray Pulsars (updated frequently)
    - LAT Pulsar Ephemerides from Publications
    - LAT Background Models

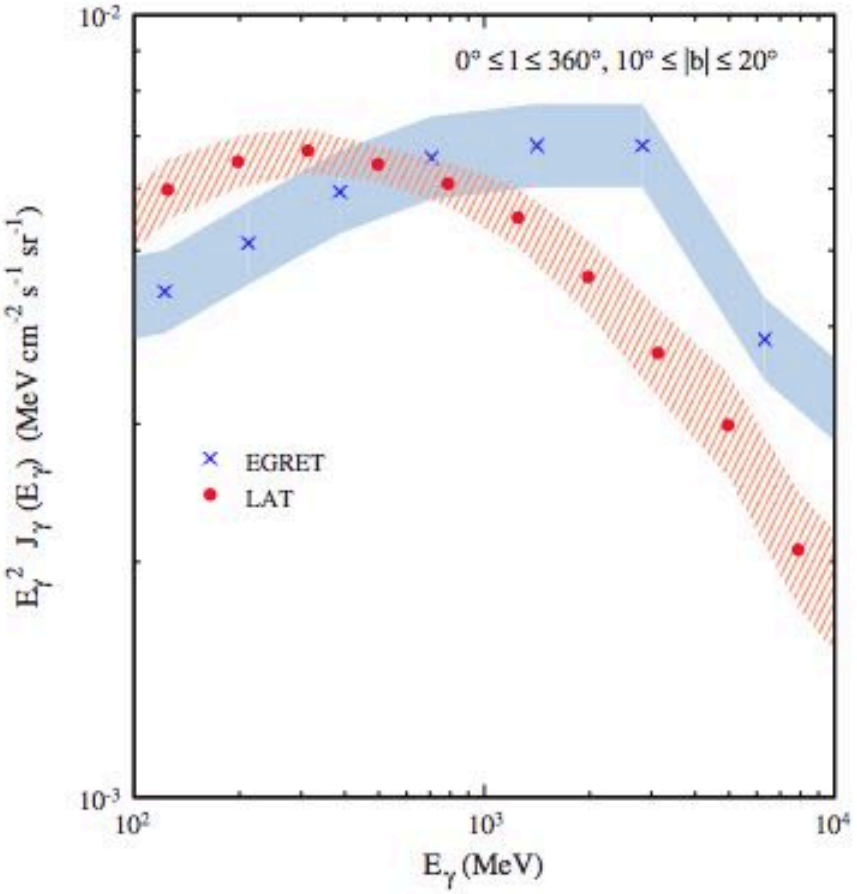
The Galactic Model

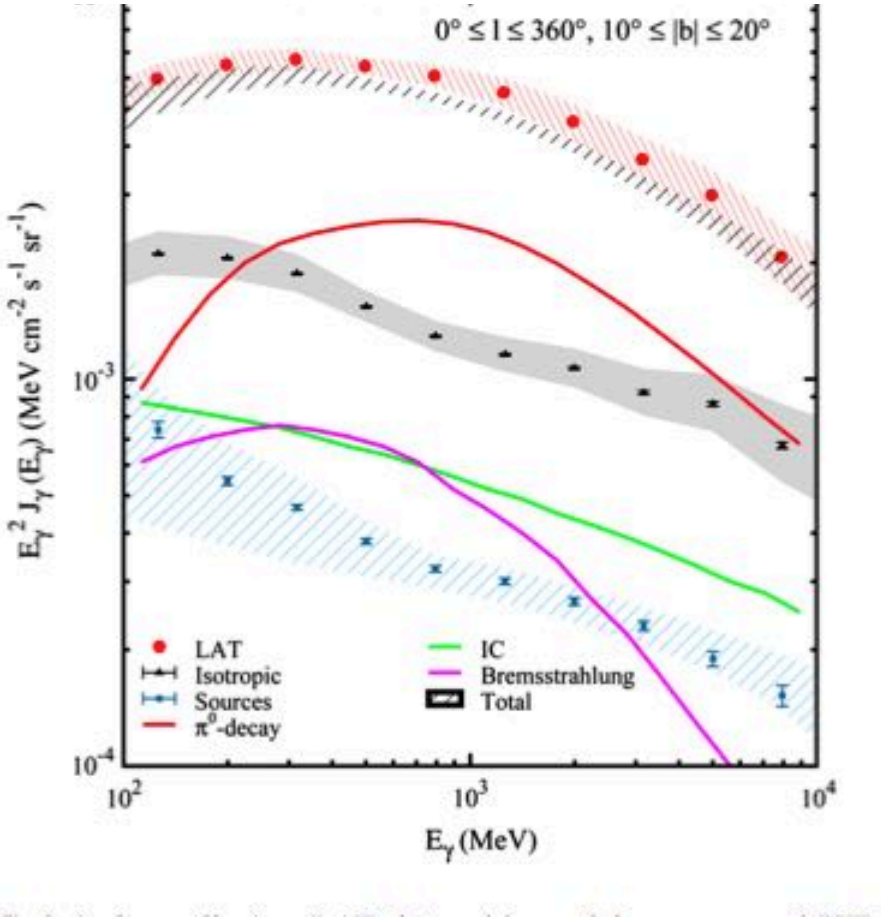


Acero et al. 2016

The Galactic Background

Fermi Large Area Telescope Measurements of the Diffuse Gamma-Ray Emission at Intermediate Galactic Latitudes





Abdo, A. A. et al. 2009

Publications

Fermi Gamma-ray Space Telescope

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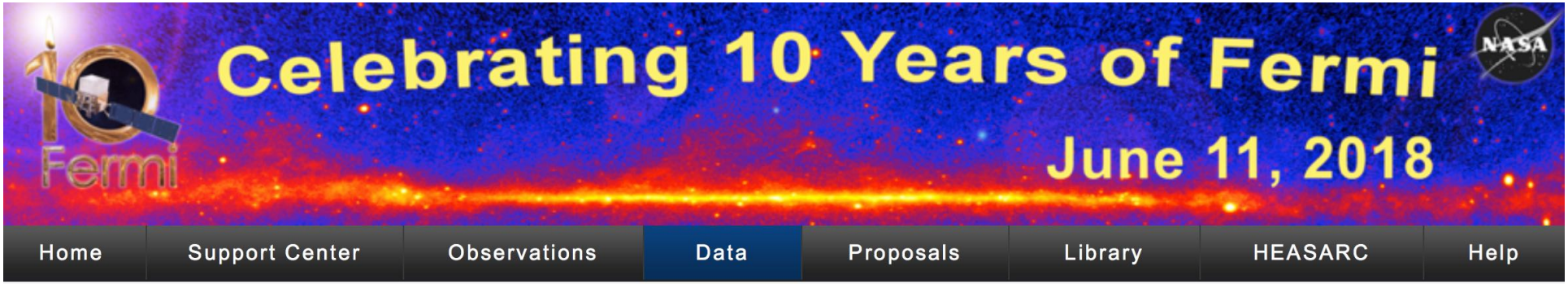
#	Bibcode Authors	Score Title	Date	List of Links Access Control Help
1	2018PDU....20...88B Bartels, Richard; Hooper, Dan; Linden, Tim; Mishra-Sharma, Siddharth; Rodd, Nicholas L.; Safdi, Benjamin R.; Slatyer, Tracy R.	1.000 Comment on "Characterizing the population of pulsars in the Galactic bulge with the Fermi large area telescope" [arXiv:1705.00009v1]	06/2018	A E X R C U
2	2018NatAs...2..387M Macias, Oscar; Gordon, Chris; Crocker, Roland M.; Coleman, Brendan; Paterson, Dylan; Horiuchi, Shunsaku; Pohl, Martin	1.000 Galactic bulge preferred over dark matter for the Galactic centre gamma-ray excess	05/2018	A E R
3	2018MNRAS.tmp.1174P Prokhorov, D. A.; Colafrancesco, S.	1.000 Testing spatial uniformity of the CR spectrum in the local ISM with γ-ray observations	05/2018	A E
4	2018arXiv180504588R Rani, B.; Jorstad, S. G.; Marscher, A. P.	1.000 High-resolution polarization imaging of the Fermi blazar 3C 279	05/2018	A X U
5	2018arXiv180503537J Johnson, T. J.; Wood, K. S.; Kerr, M.; Corbet, R. H. D.; Cheung, C. C.; Ray, P. S.; Omodei, N.	1.000 A Luminous and Highly-variable Gamma-ray Flare Following the 2017 Periastron of PSR B1259-63/LS 2883	05/2018	A X R U
6	2018arXiv180503406L Liu, Ruo-Yu; Yan, Huirong; Wang, Xiang-Yu; Shao, Shi; Li, Hui	1.000 Gamma-ray Production in the Extended Halo of the Galaxy and Possible Implications for the Origin of Galactic Cosmic Rays	05/2018	A X R U

http://adsabs.harvard.edu

Data Analysis Software



Data

- Data Policy
- Data Access
- **Data Analysis**
  - + System Overview
  - + Software Download
  - + Documentation
  - + Cicerone
  - + Analysis Threads
  - + User Contributions
- Caveats
- Newsletters
- FAQ

Data Analysis

The Fermi mission is providing a suite of tools called the Fermi Science Tools for the analysis of both LAT and GBM data. This suite was developed by the FSSC and the instrument teams, and was reviewed by the Fermi Users' Group.

The full suite of Fermi Science Tools, which have been public since February 2009, are listed here.

From this website the released Science Tools tools can be downloaded, and the documentation can be accessed. In addition, we will maintain a library of user-contributed software.

- List of tools in the Fermi Science Tools
- Download currently released Fermi Science Tools
- Download currently released GBM software
- Fermi Science Tools documentation
- User-contributed software

https://fermi.gsfc.nasa.gov/ssc/data/analysis/

Publications by the Fermi LAT collaboration

Select a topic: All

- Fermi LAT collaboration publication policy
- Independent publications by LAT collaboration members (Category III)
- Ph. D. dissertations
- Rapid publications: ATel, GCN, Monitor and Transient notices
- Public data files for Fermi LAT collaboration papers

- Review of the first-year results
- Technical description of the LAT instrument
- The 2009, 2011, 2012, 2014 2015 and 2017 Fermi Symposia
- Pre-launch publications and selected conference presentations
- Review of public talks

Jump to year: 2018 2017 2016 2015 2014 2013 2012 2011 2010 2009 2008 2007

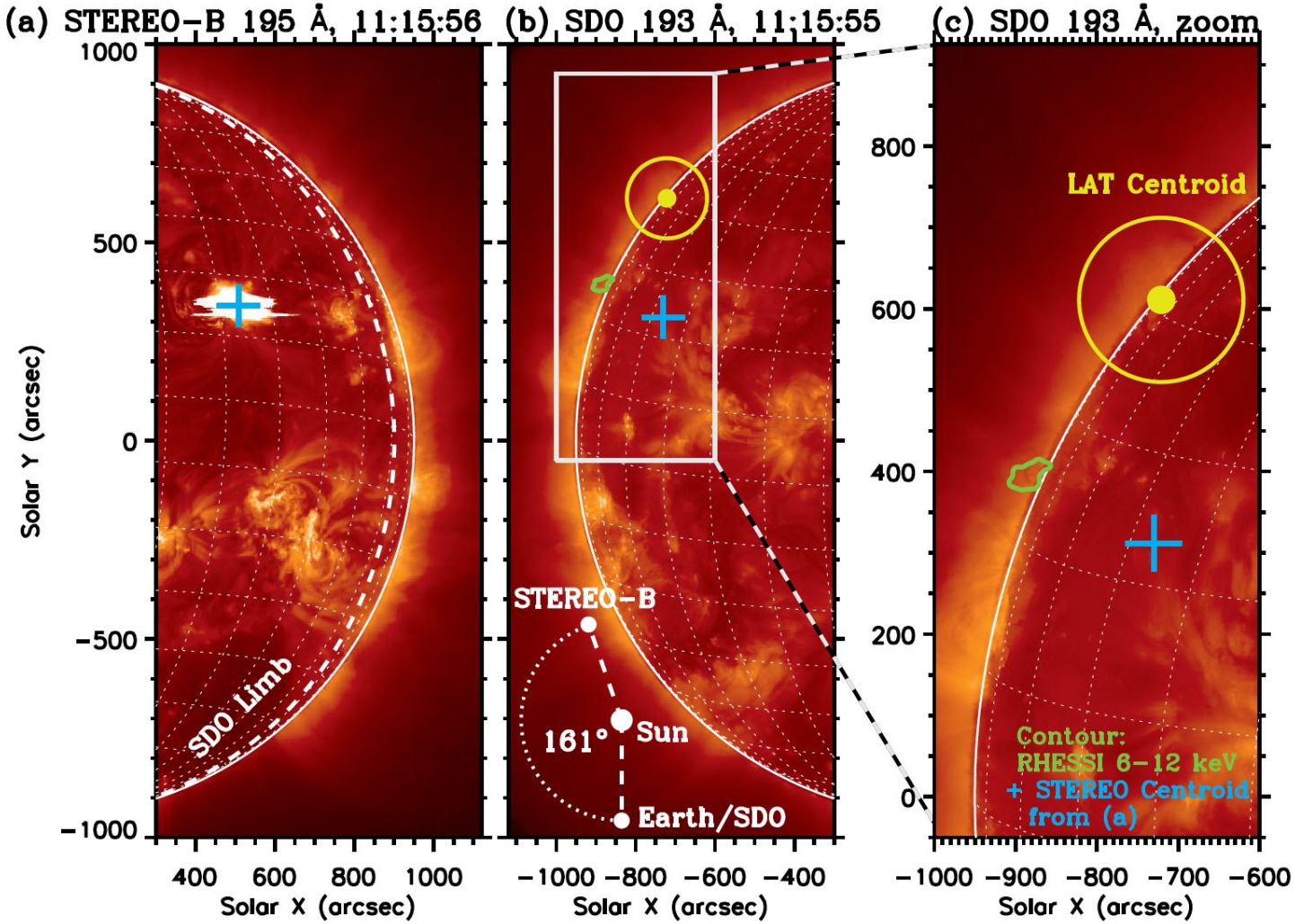
2018

A Luminous and Highly-variable Gamma-ray Flare Following the 2017 Periastron of PSR B1259-63/LS 2883 (Submitted for publication)
Johnson, T. J. et al. 2018, ApJ Show links

THE ORIGINS OF THE GAMMA-RAY FLUX VARIATIONS OF NGC1275 BASED ON 8-YEARS OF FERMI-LAT OBSERVATIONS (Accepted for publication)
Tanada, K. et al. 2018, ApJ Show links

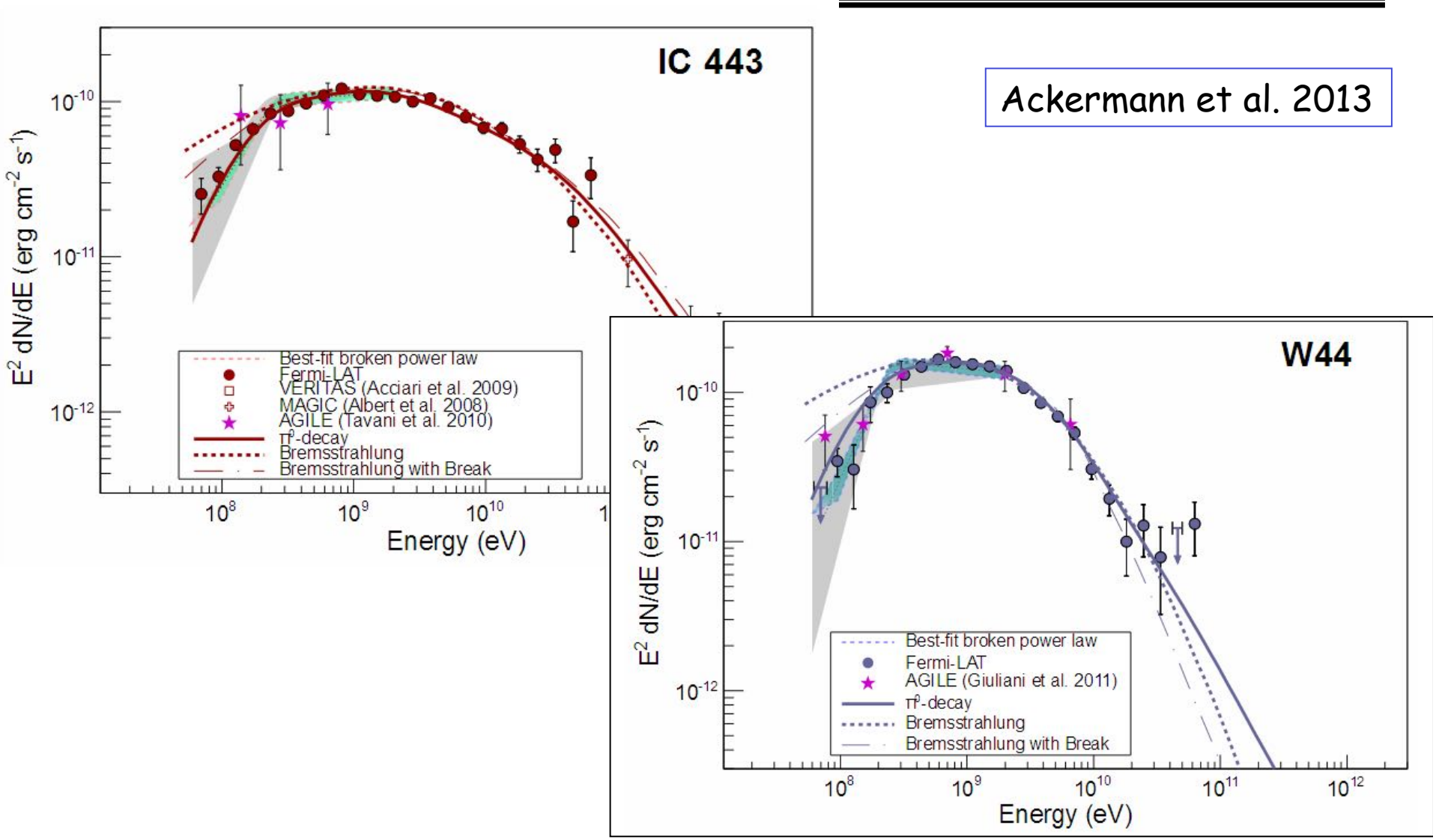
https://www-glast.stanford.edu

Solar Flares



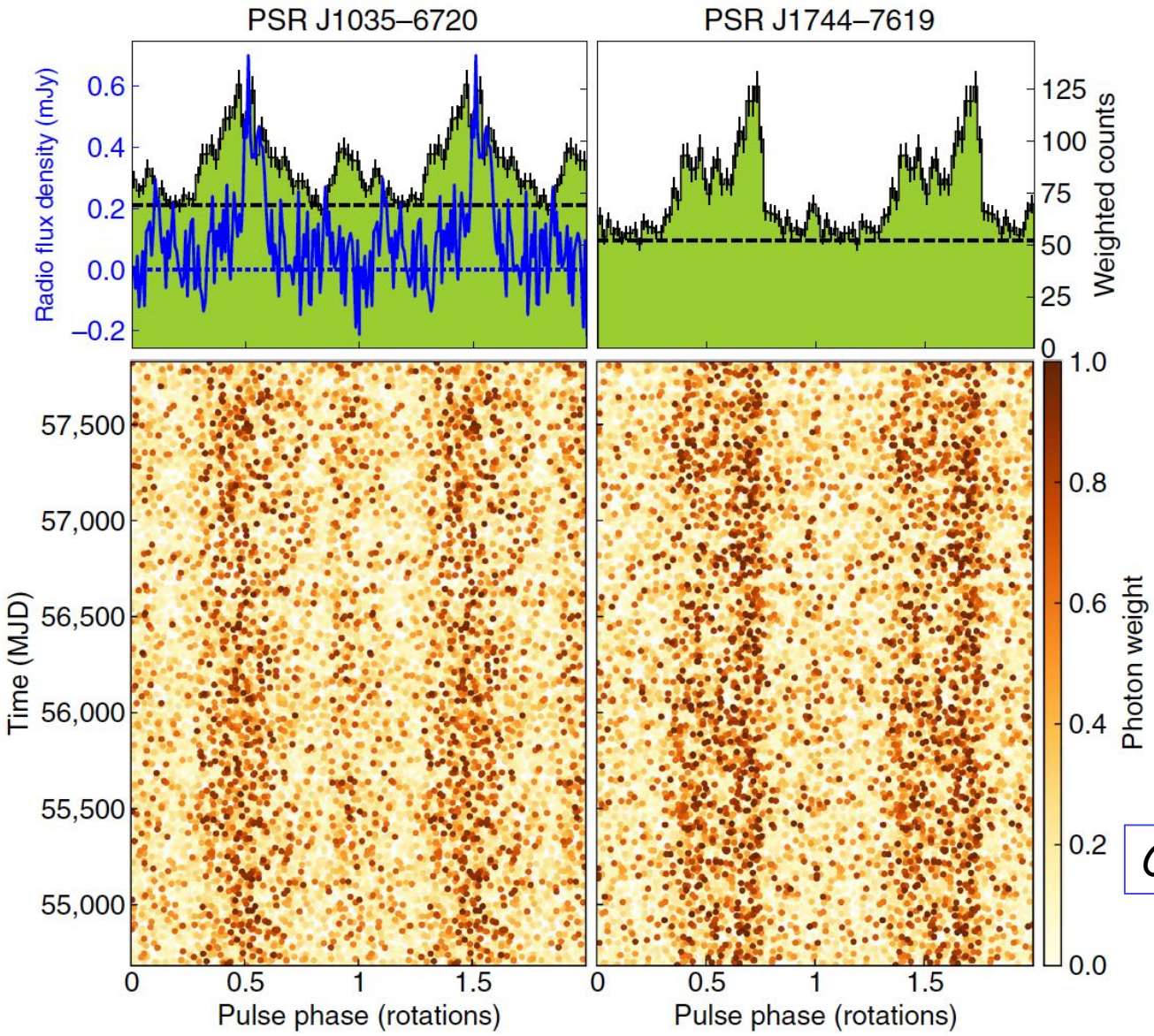
Ackermann, M. et al. 2017

Supernova Remnants



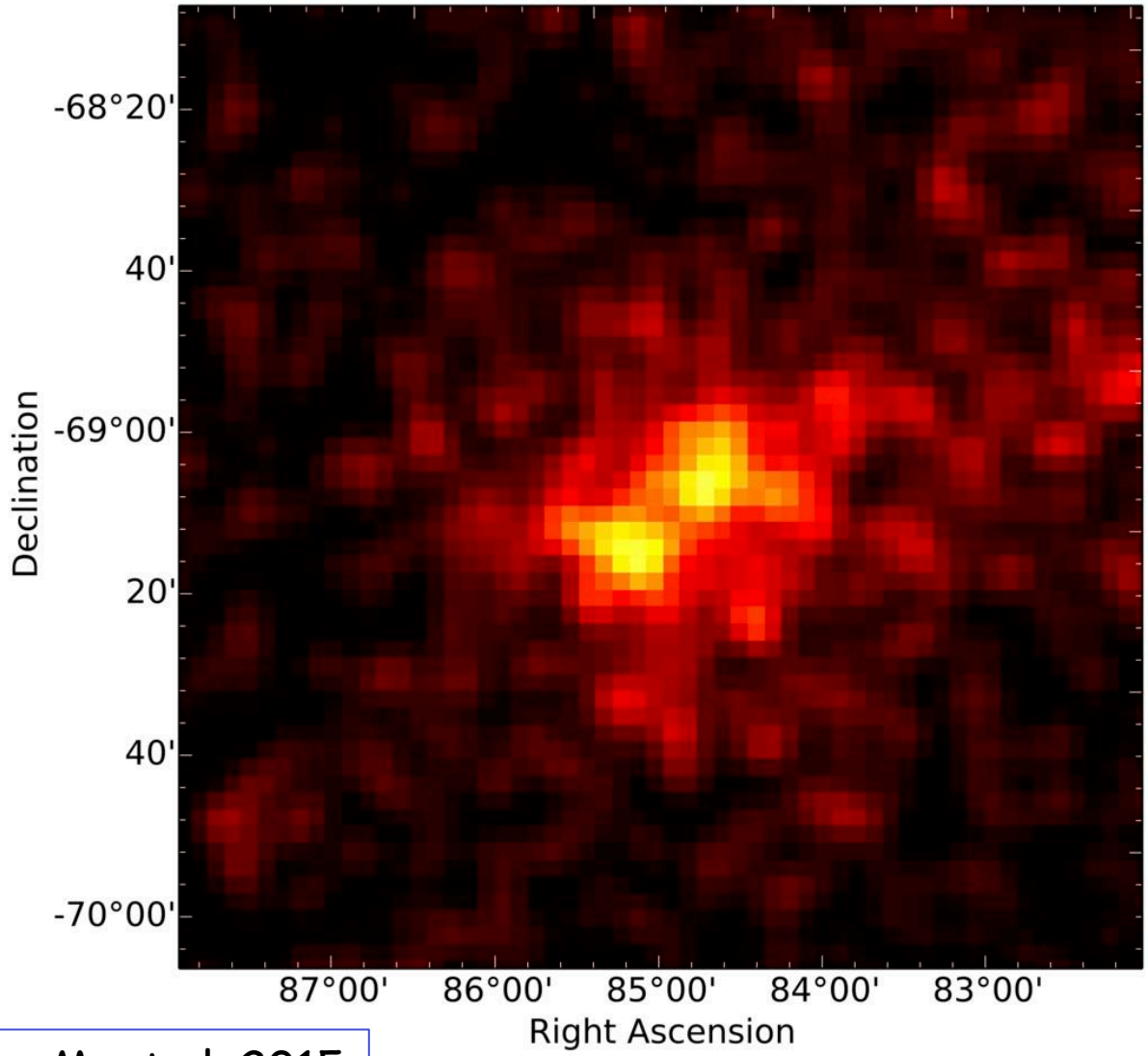
Ackermann et al. 2013

Pulsars



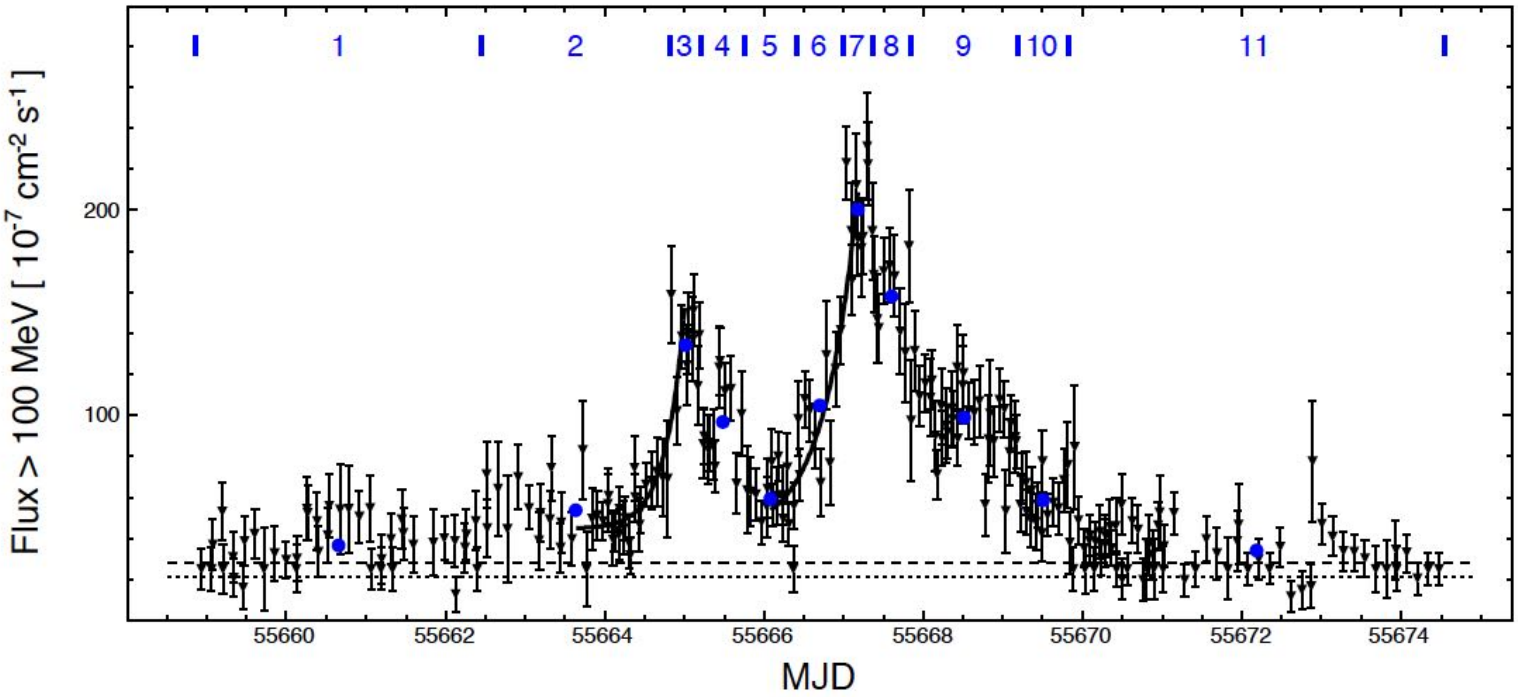
Clark, C. J. et al. 2018

Pulsars



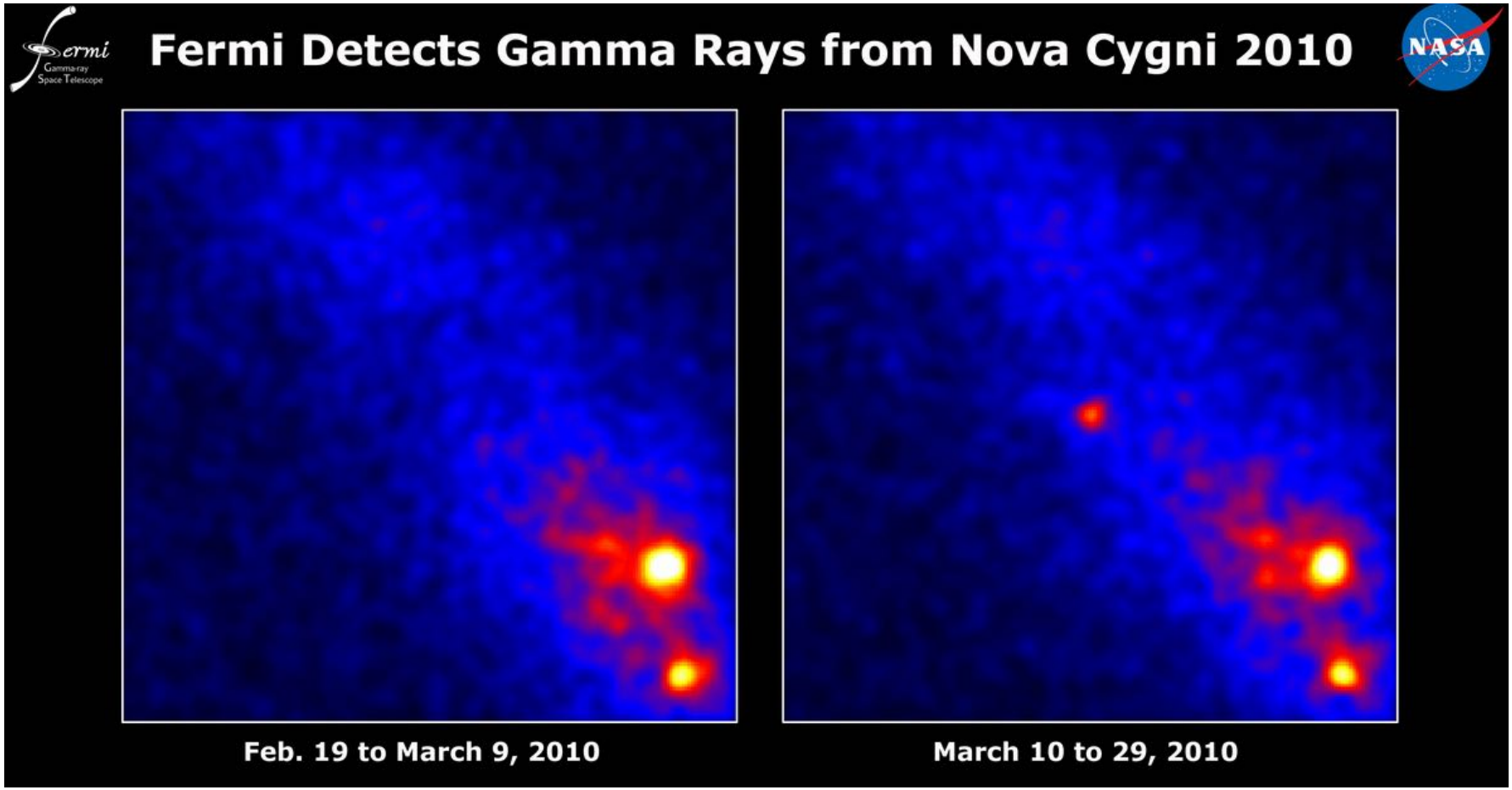
Ackermann, M. et al. 2015

Pulsar Wind Nebulae



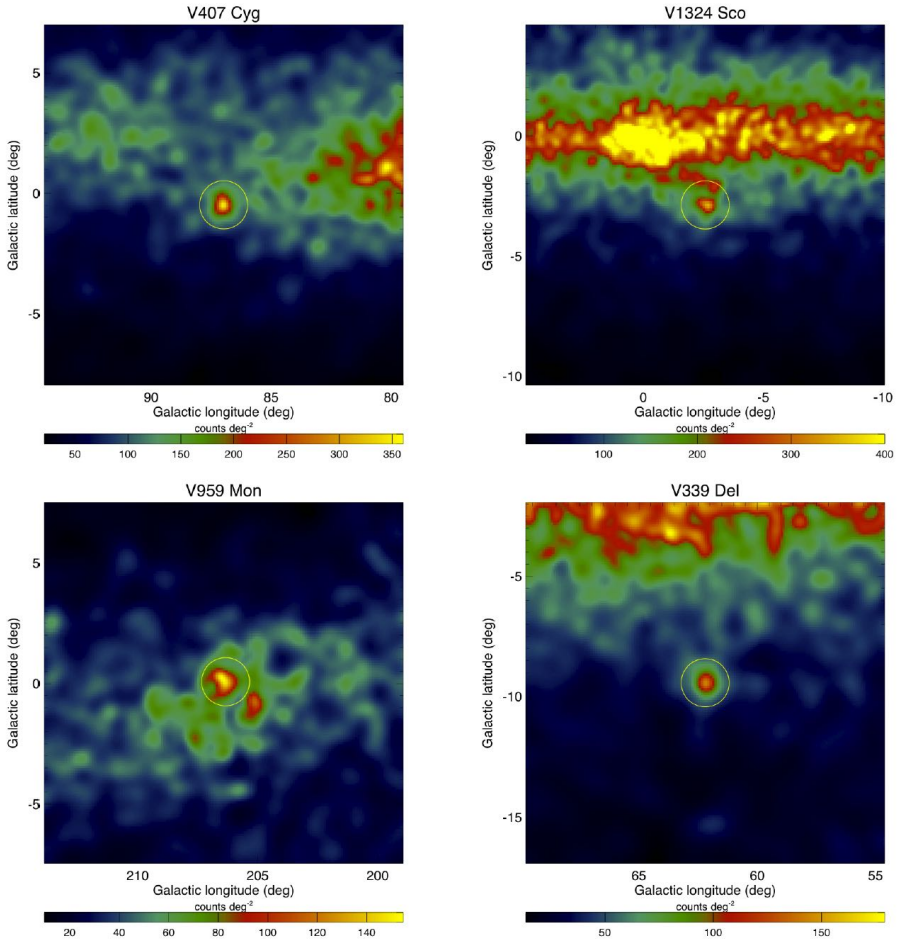
Buehler, R. et al. 2012

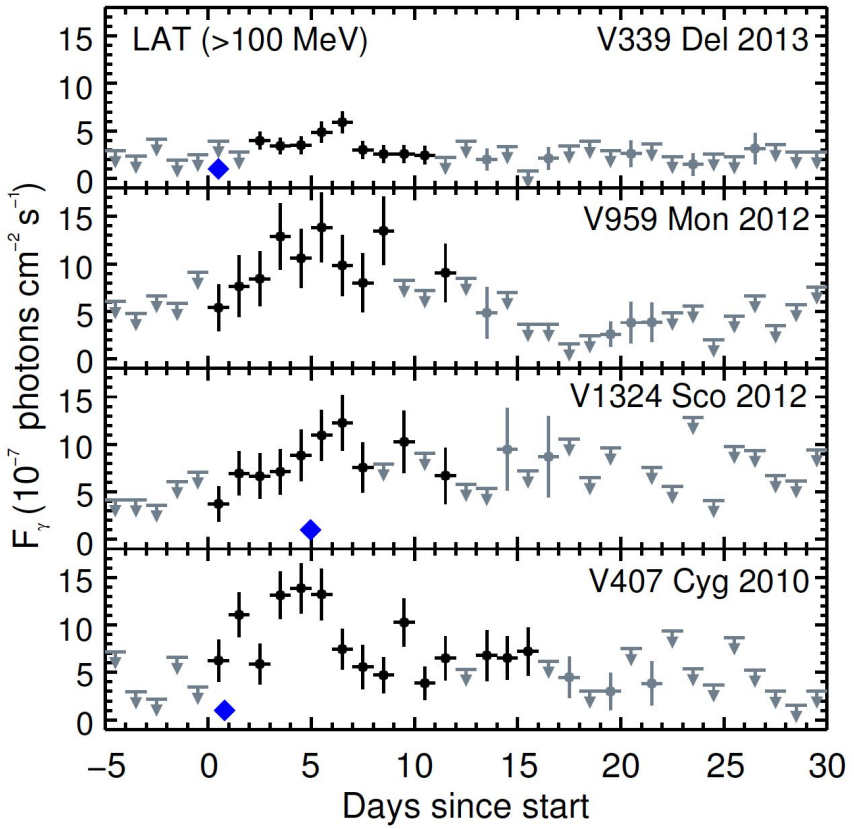
Gamma Ray Novae



Abdo, A. A. et al. 2010

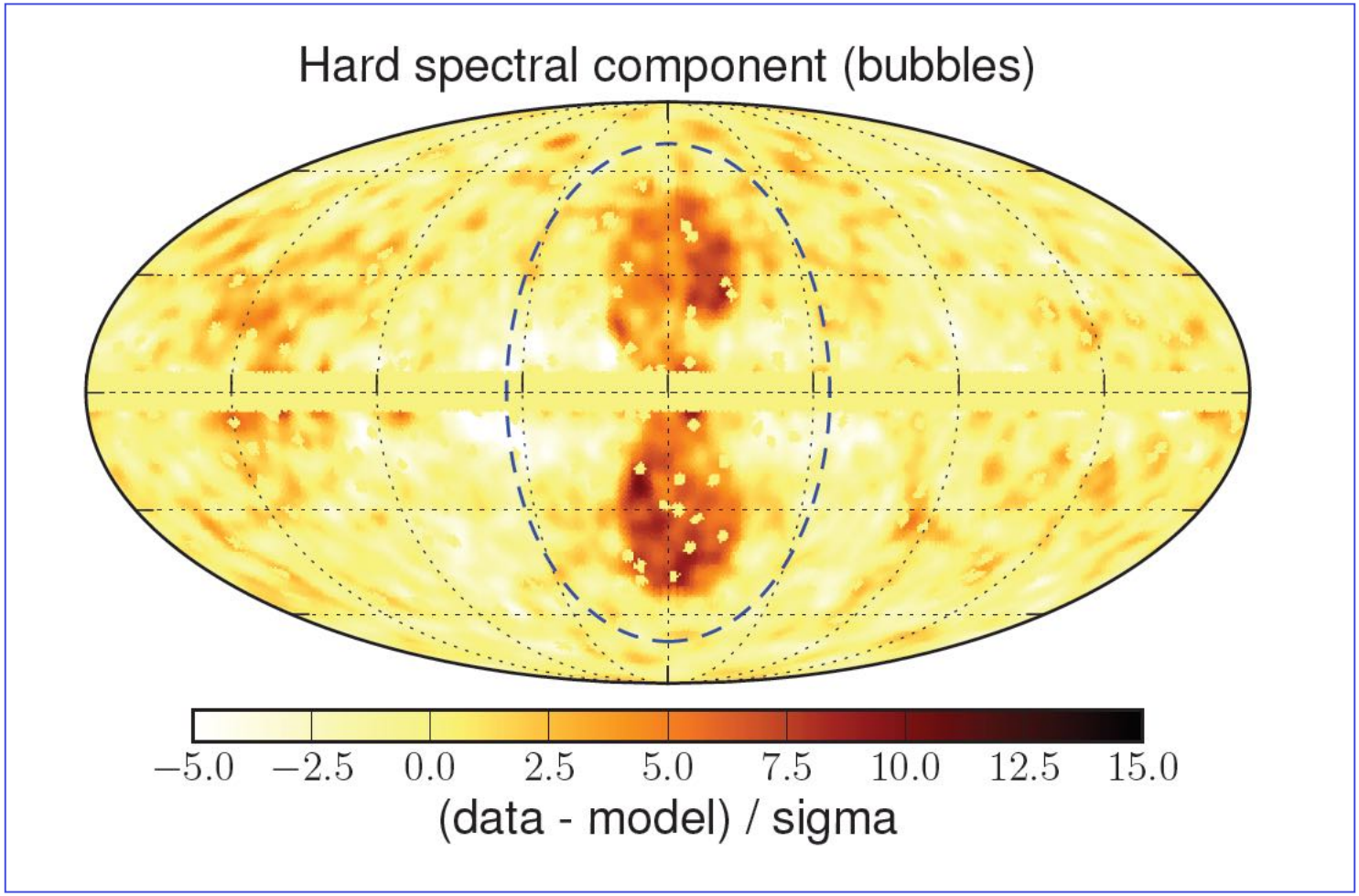
Gamma Ray Novae





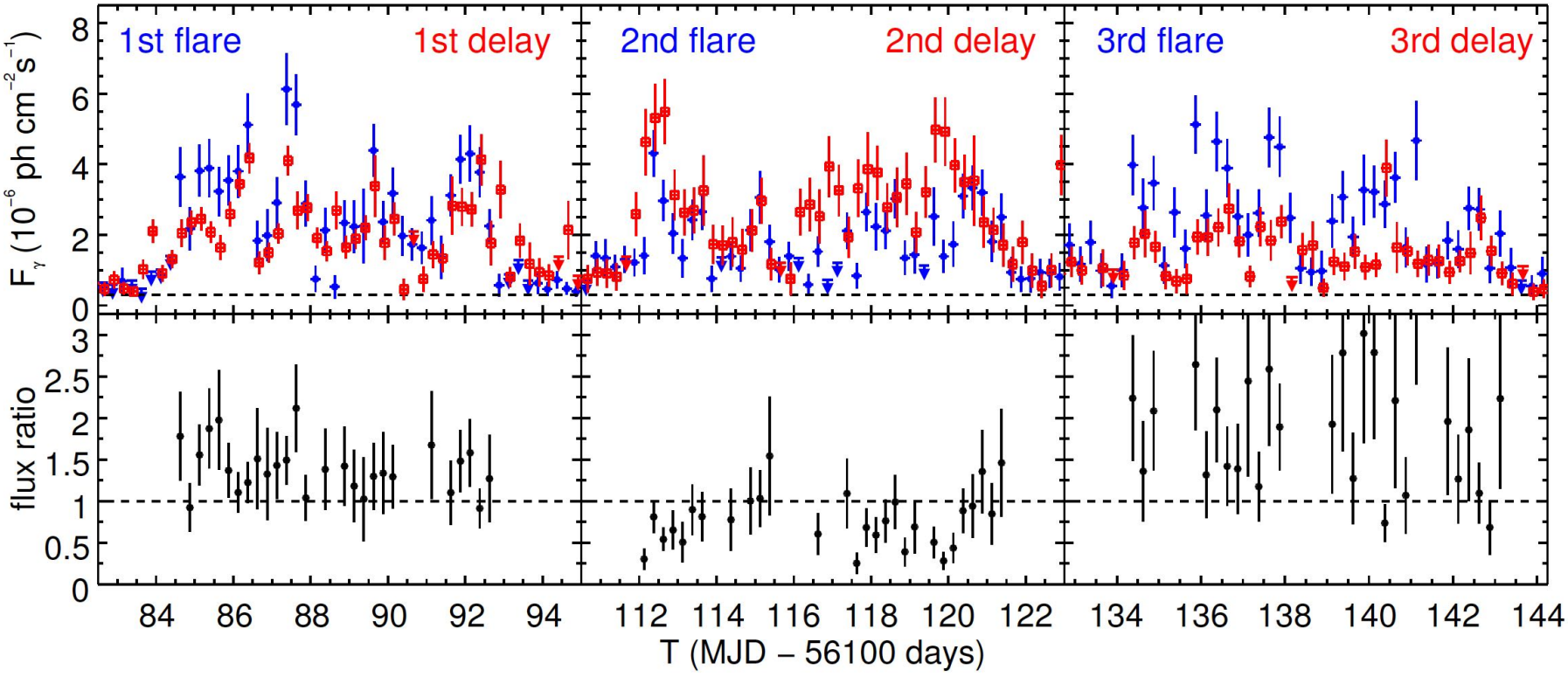
Ackermann, M. et al. 2014

The Fermi Bubbles



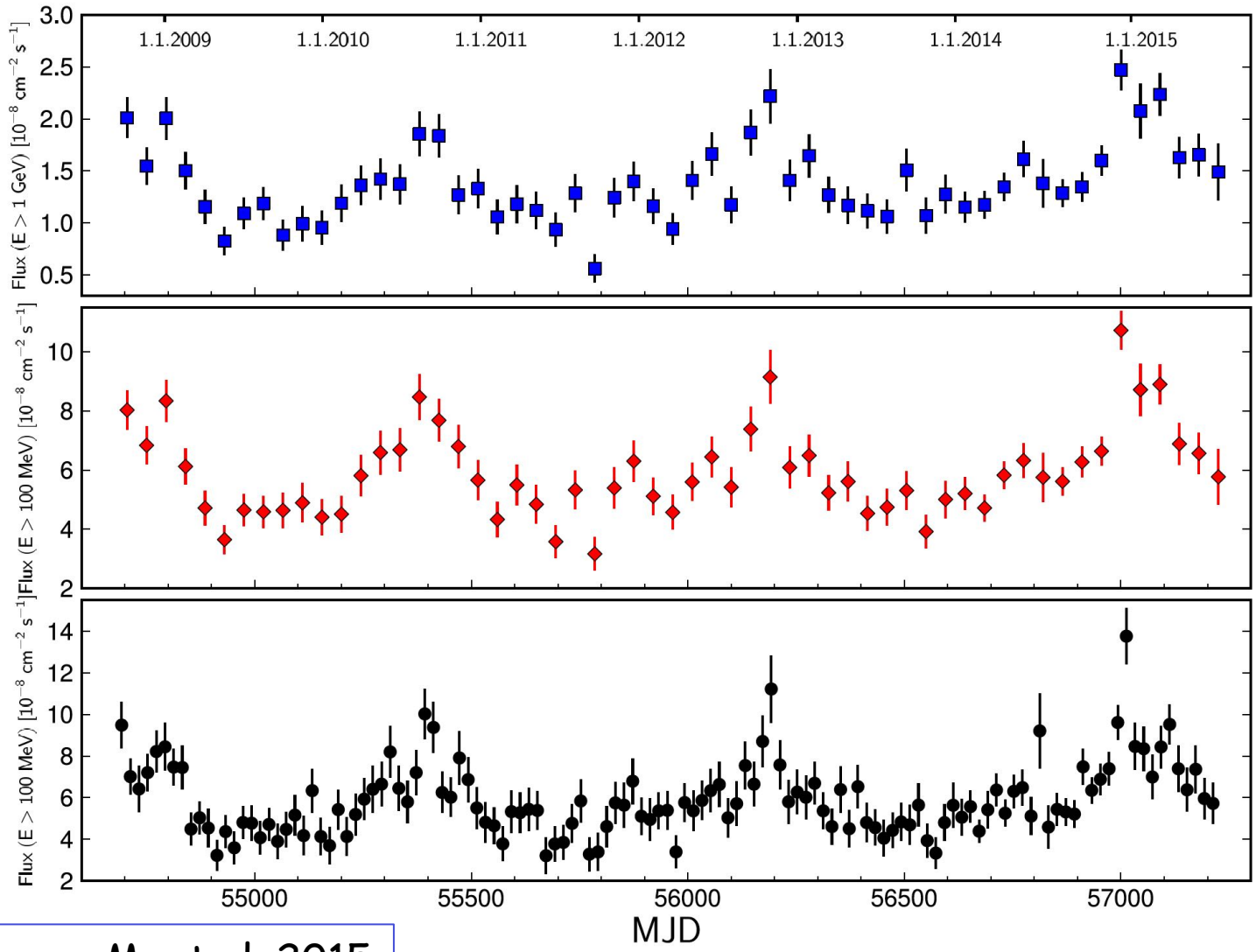
Ackermann, M. et al. 2014b

Active Galactic Nuclei



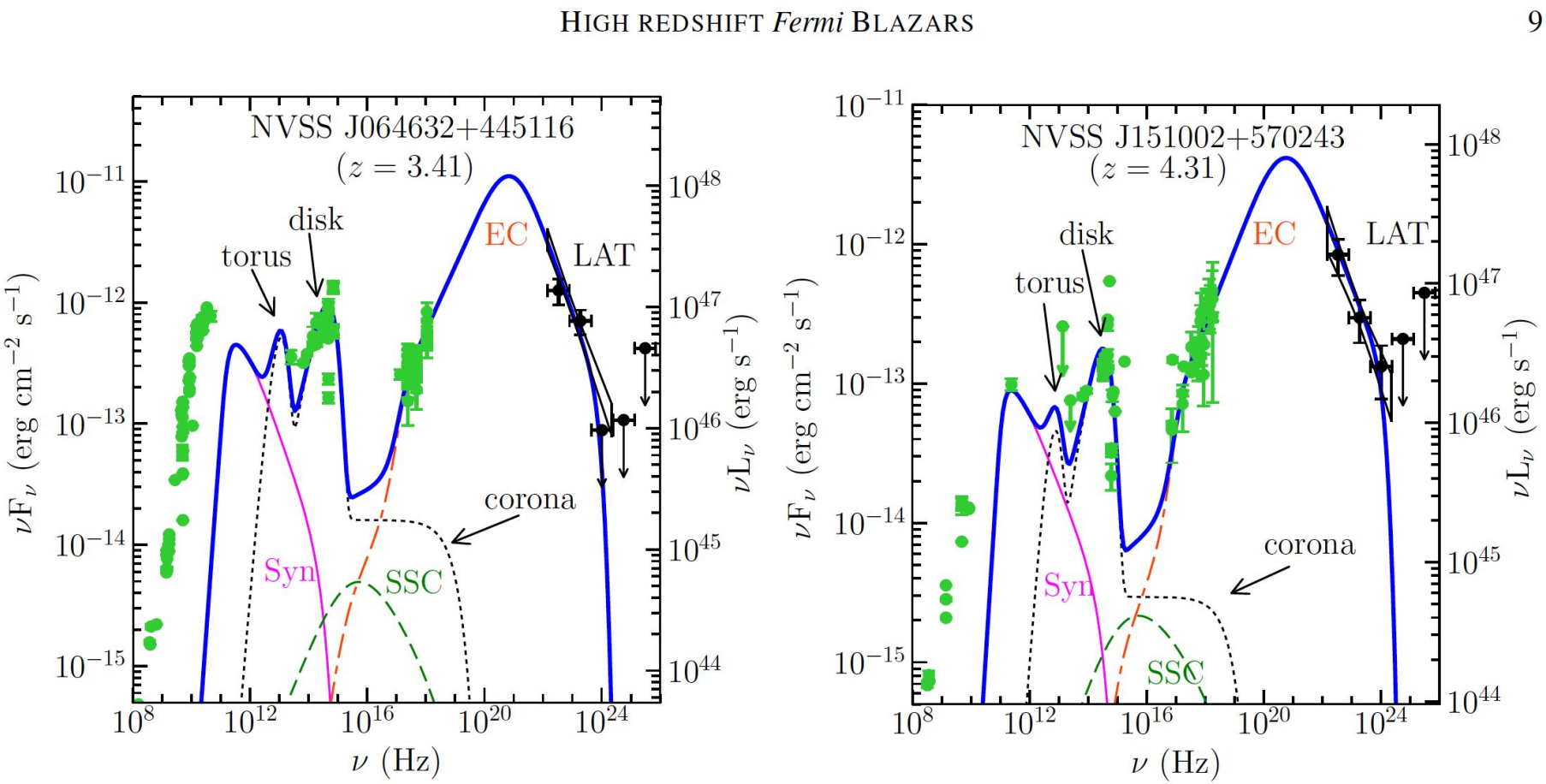
Cheung, C.C. et al. 2014

Active Galactic Nuclei



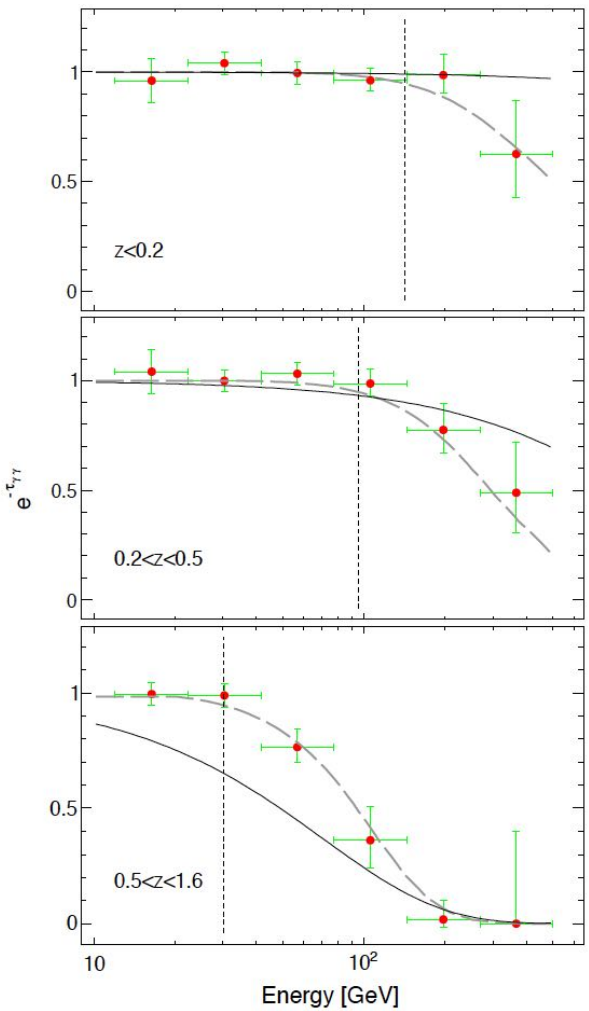
Ackermann, M. et al. 2015

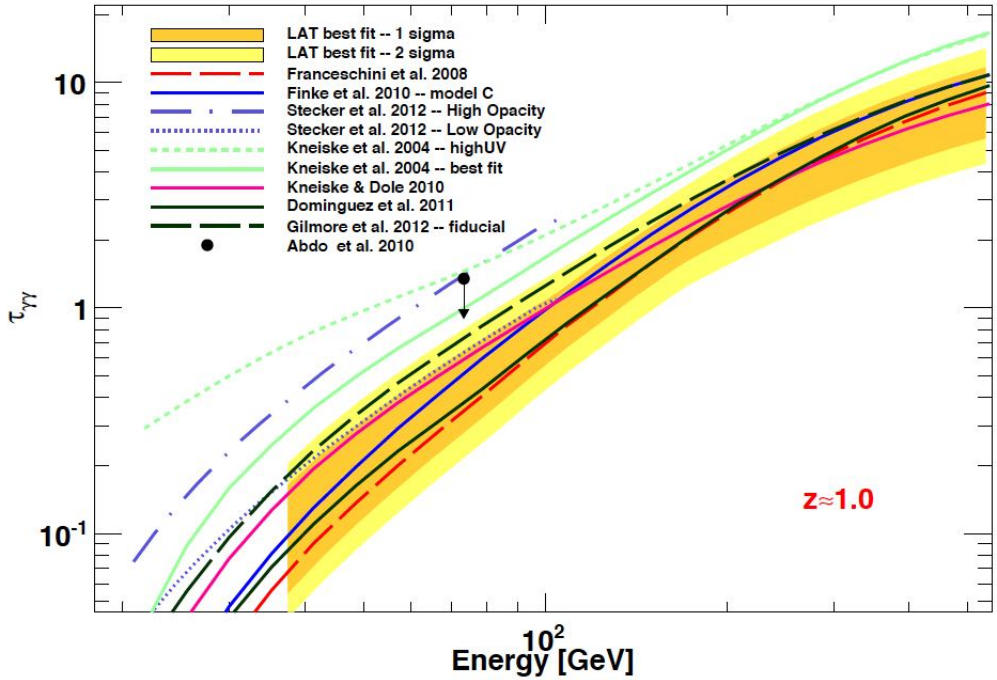
Active Galactic Nuclei



Ackermann, M. et al. 2017

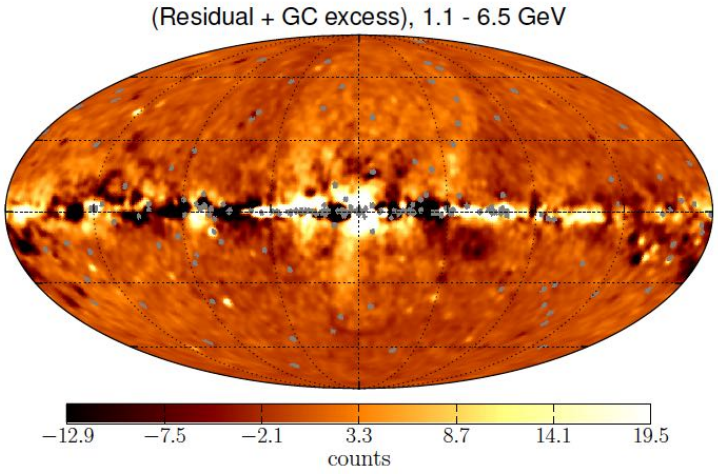
Extragalactic Background Light

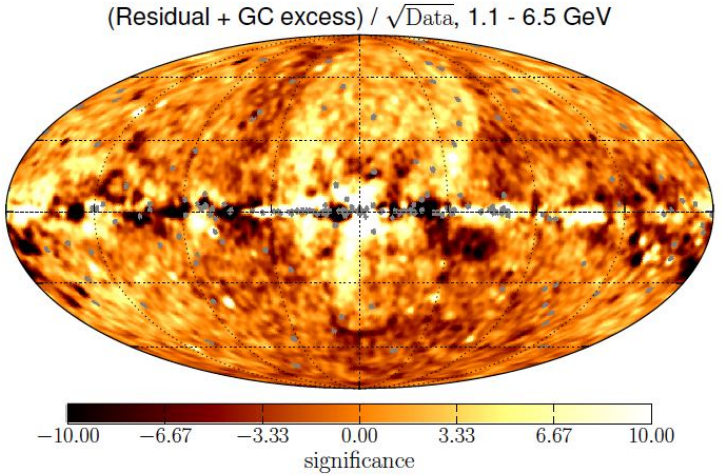


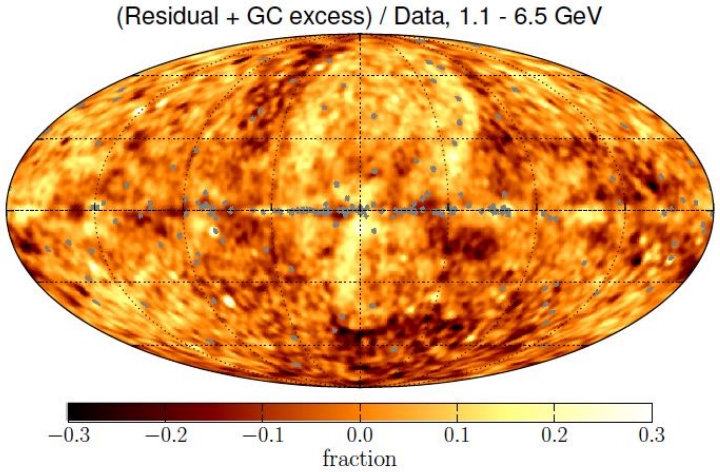


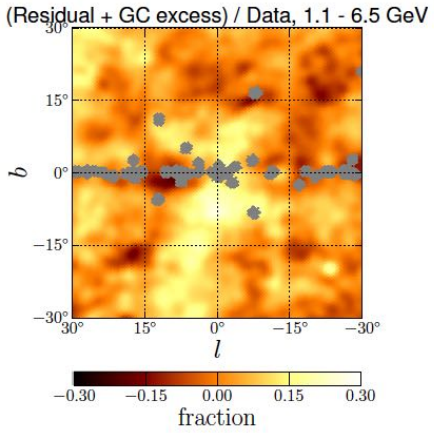
Ackermann, M. et al. 2012

Searches for Dark Matter



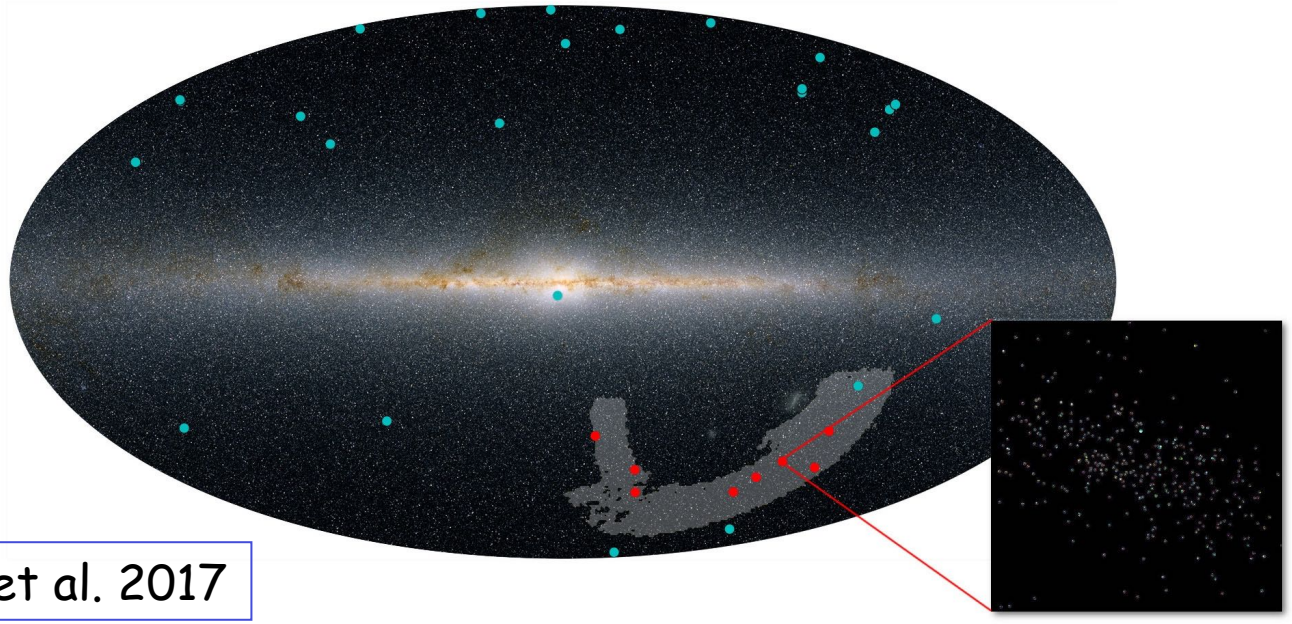




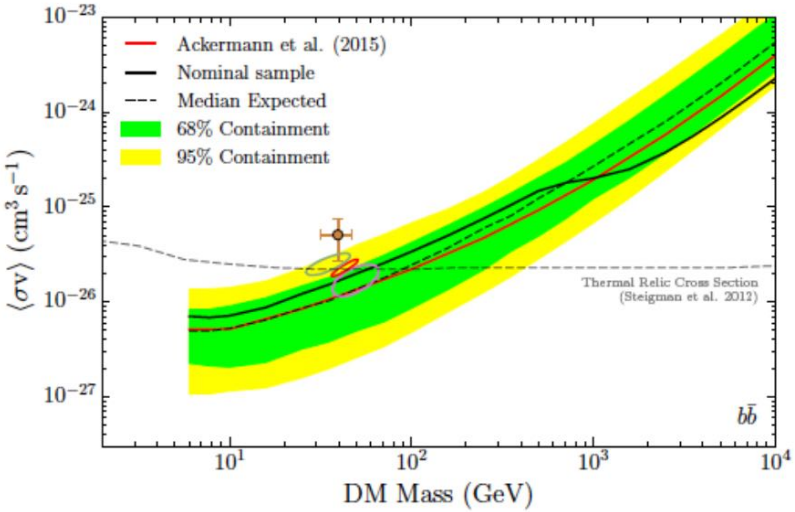


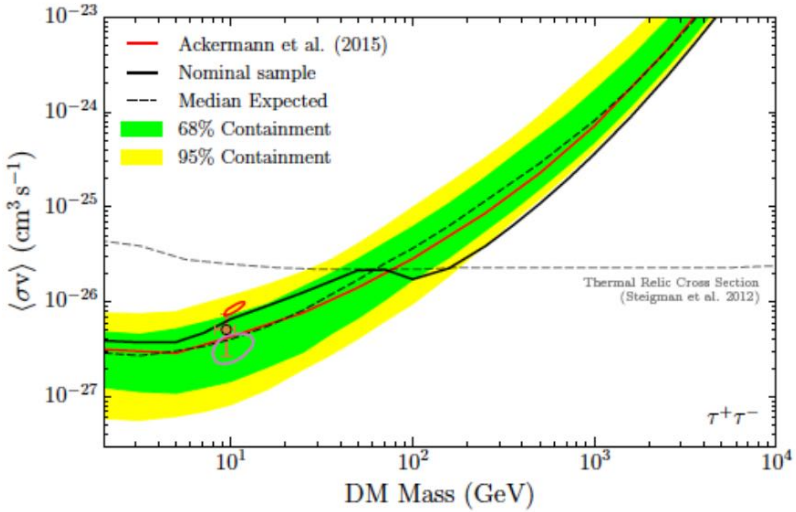
Ackermann, M. et al. 2017

Searches for Dark Matter

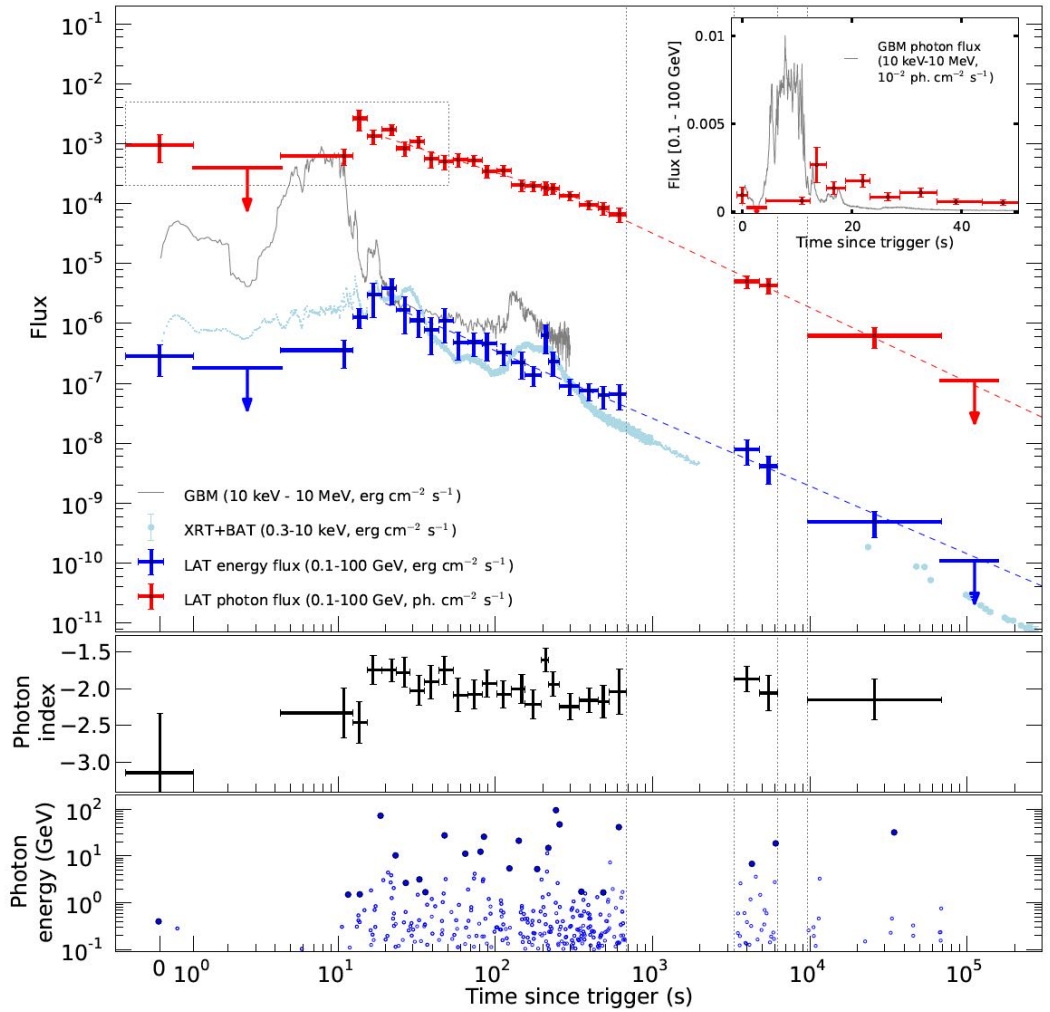


Albert, A. et al. 2017



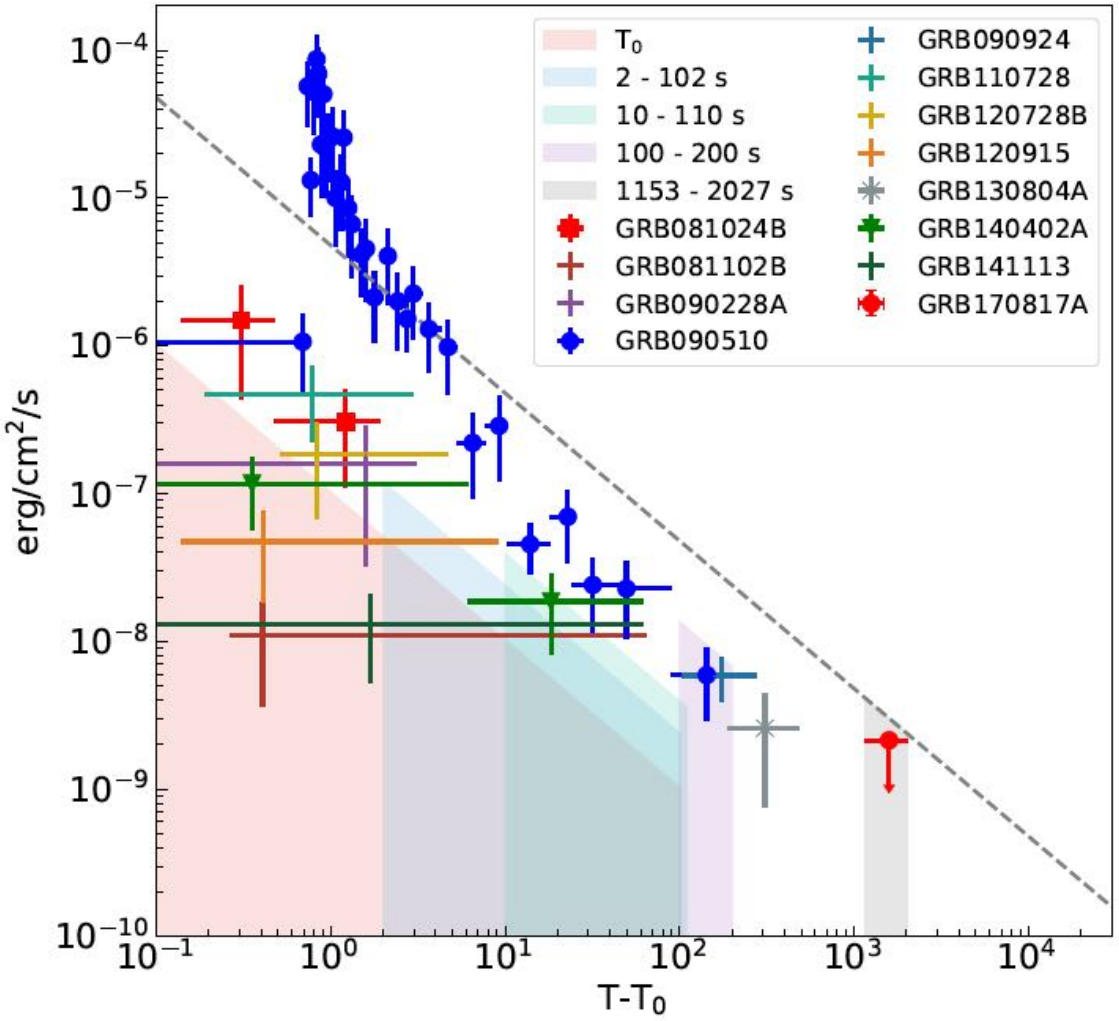


Gamma Ray Bursts



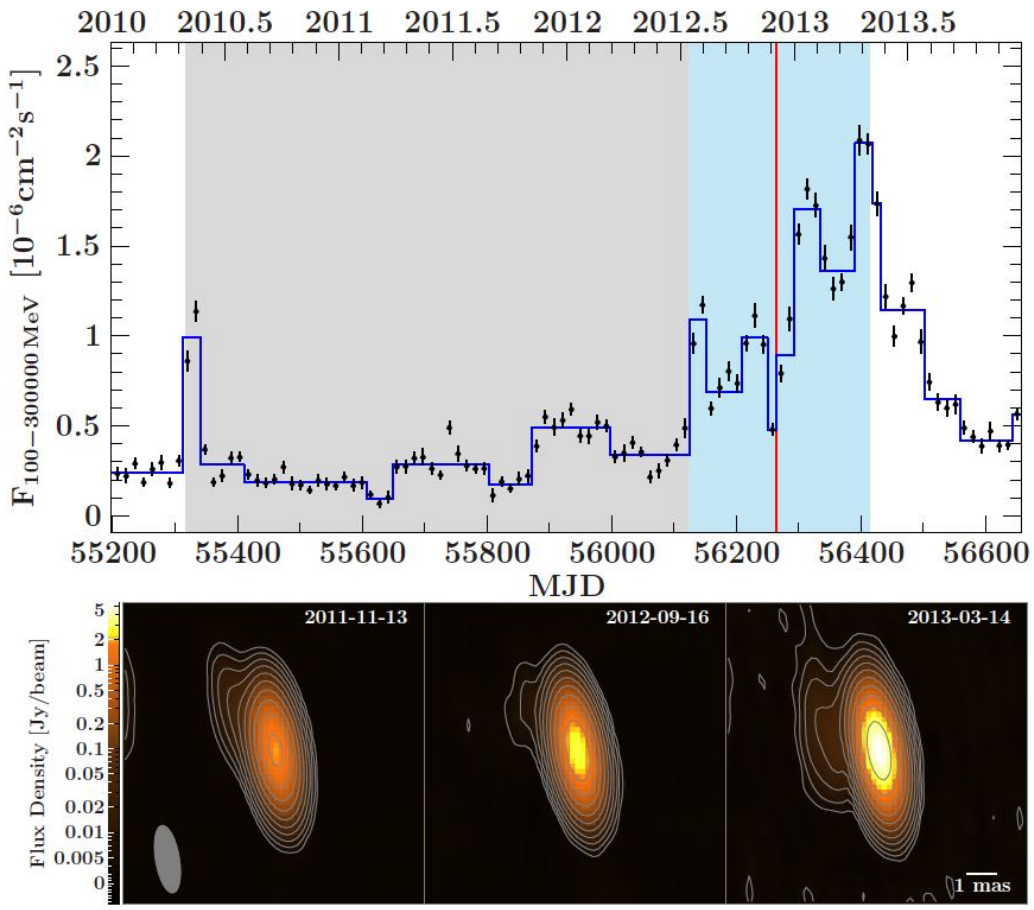
Ackermann, M. et al. 2014a

Search for EM counterparts of GW



Ajello, M. et al. 2017

Multimessenger Astrophysics



Kadler, M. et al. 2016

Multimessenger Astrophysics

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942, 11419, 11430, 11489

Tweet

We searched for Fermi-LAT sources inside the extremely high-energy (EHE) IceCube-170922A neutrino event error region (https://gcn.gsfc.nasa.gov/gcn3/21916.gcn3, see also ATels 10773, 10787) with all-sky survey data from the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope. We found that one Fermi-LAT source, TXS 0506+056 (3FGL J0509.4+0541 and also included in the 3FHL catalog, Ajello et al., arXiv:1702.00664, as 3FHL J0509.4+0542), is located inside the IceCube error region. The FAVA (Fermi All-sky Variability Analysis) light curve at energies above 800 MeV shows a flaring state recently (https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/SourceReport.php?week=477&flare=27). Indeed, the LAT 0.1--300 GeV flux during 2018 September 15 to 27 was (3.6+/-0.5)E-7 photons cm-2 s-1 (errors are statistical only), increased by a factor of ~6 compared to the 3FGL flux, with nearly the same power-law index of 2.0+/-0.1. We strongly encourage multiwavelength observations of this source. We also encourage optical spectroscopy for this source, because the redshift is still unknown. According to NED, the R-band magnitude is reported as 15.1 (Healey et al. 2008, ApJS 175, 97). Radio observations show that this blazar has had increasing flux during the past year: http://www.astro.caltech.edu/ovroblazars/data.php?page=data_query, http://www.physics.purdue.edu/astro/MOJAVE/sourcepages/0506+056.shtml.

Because Fermi operates in an all-sky scanning mode, regular gamma-ray monitoring of this source region will continue. For this source the Fermi-LAT contact person is Yasuyuki T. Tanaka (ytanaka@astro.hiroshima-u.ac.jp). The Fermi-LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

11489 Optical and near-infrared polarimetric observations of the IceCube-170922A counterpart candidate TXS 0506+056
11430 Optical polarimetry of TXS 0506+056 (possible counterpart of IceCube-170922A)
11419 Fermi-LAT detection of enhanced gamma-ray activity and hard spectrum of TXS 0506+056, located inside the IceCube-170922A error region
10942 IceCube-171106A: Swift observations
10890 Subaru/FOCAS Optical Spectroscopy for a possible IceCube-170922A counterpart TXS 0506+056
10861 VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event
10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)
10838 MAXI/GSC observations of IceCube-170922A and TXS 0506+056
10833 VERITAS follow-up observations of IceCube neutrino event 170922A
10831 Optical photometry of TX0506+056
10830 SALT-HRS observation of the blazar TXS 0506+056 associated with IceCube-170922A
10817 First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino

Fermi Transient Searches

Fermi Gamma-ray Space Telescope

Transients Timescale Pipelines

Pipeline
Method
Timescale
Distribution
Status

LAT Transient Factory (LTF)
Likelihood Around GBM/BAT triggers
seconds to orbits
LAT Team - Results in GCNs
Triggered Operating + *Blind Search Coming Soon*

***Fermi* All-sky Variability Analysis (FAVA)**
Counts Map Aperture Photometry
3 day (coming soon), 1 week
ATels
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/

LAT Burst Advocate Tool
Likelihood Around GBM/BAT triggers
100 s, 1000 s
LAT Team - Results in GCNs
Operating

LAT Catalogs
Likelihood, associations
3 month (0FGL), 1 year (1FGL), 2 years (2FGL), 4 years (3FGL)
http://fermi.gsfc.nasa.gov/ssc/data/access/
4FGL in progress

GBM Untriggered Search
ground search
ms - s
GCN Notices
http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

GBM/LAT Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices
Operating

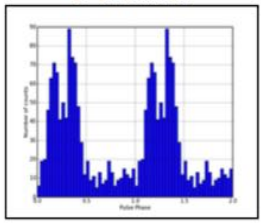
LAT Automated Science Processing (ASP) + Flare Advocates
Likelihood
6 & 24 hour
ATels, GCN notices (on AGN)
Operating

μs ***ms*** ***s*** ***minutes*** ***hours*** ***days*** ***months*** ***years***

Photon Timing

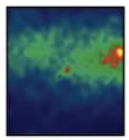
All Sky Cadence

Pulsars

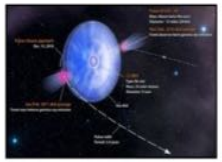


Solar Flares

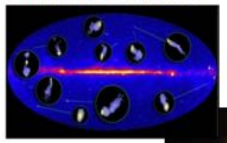
Novae



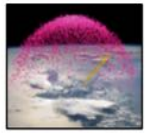
γ-ray Binaries



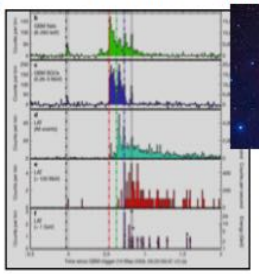
Blazar Flares



Terrestrial γ-ray Flashes



GRBs



Magnetar Flares

Crab Flares

Not to scale

Fast response

Rapid Publications from the Fermi LAT Collaboration:
LAT Astronomer's Telegrams, LAT GCN Circulars and LAT Monitor and Transient Notices

Add a new LAT-GCN or LAT-ATel

Visit the Astronomer's Telegram web site

https://www-glast.stanford.edu/cgi-bin/pub_rapid

List of the LAT Astronomer's Telegrams (ATels):

date	number	title
2018-May-15	11644	Fermi LAT detection of renewed and strong GeV gamma-ray flares from blazars PKS 0903-57 and PKS 0346-27
2018-Apr-18	11546	Fermi-LAT Bright Gamma-ray Detection of Nova ASASSN-18fv
2018-Apr-17	11542	Fermi LAT detection of renewed strong GeV activity from the FSRQ 3C 279
2018-Mar-14	11419	Fermi-LAT detection of enhanced gamma-ray activity and hard spectrum of TXS 0506+056, located inside the IceCube-170922A error region
2018-Mar-12	11412	Fermi-LAT detection of enhanced gamma-ray activity from the Crab nebula
2018-Mar-06	11378	Fermi-LAT detection of increased gamma-ray activity from the FSRQ PKS 1004-217
2018-Feb-10	11283	Fermi LAT detection of a GeV gamma-ray flare from the distant blazar PKS 0226-559
2018-Feb-03	11251	Fermi-LAT detection of strong gamma-ray activity from the FSRQ PKS 0346-27
2018-Feb-01	11249	Fermi-LAT detection of increased gamma-ray activity from the FSRQ OT 355 (B2 1732+38A)
2018-Jan-25	11227	Fermi-LAT detection of renewed gamma-ray activity from the FSRQ PKS 0336-01

Conclusions (I)

- **Fermi is an astroparticle mission exploring the high energy to very high energy gamma-ray sky.**
- **Results from its first 10 years of operations raised significant interest in a broad community of scientists that includes astrophysicists, particle physicists and quantum field theorists.**

Conclusions (II)