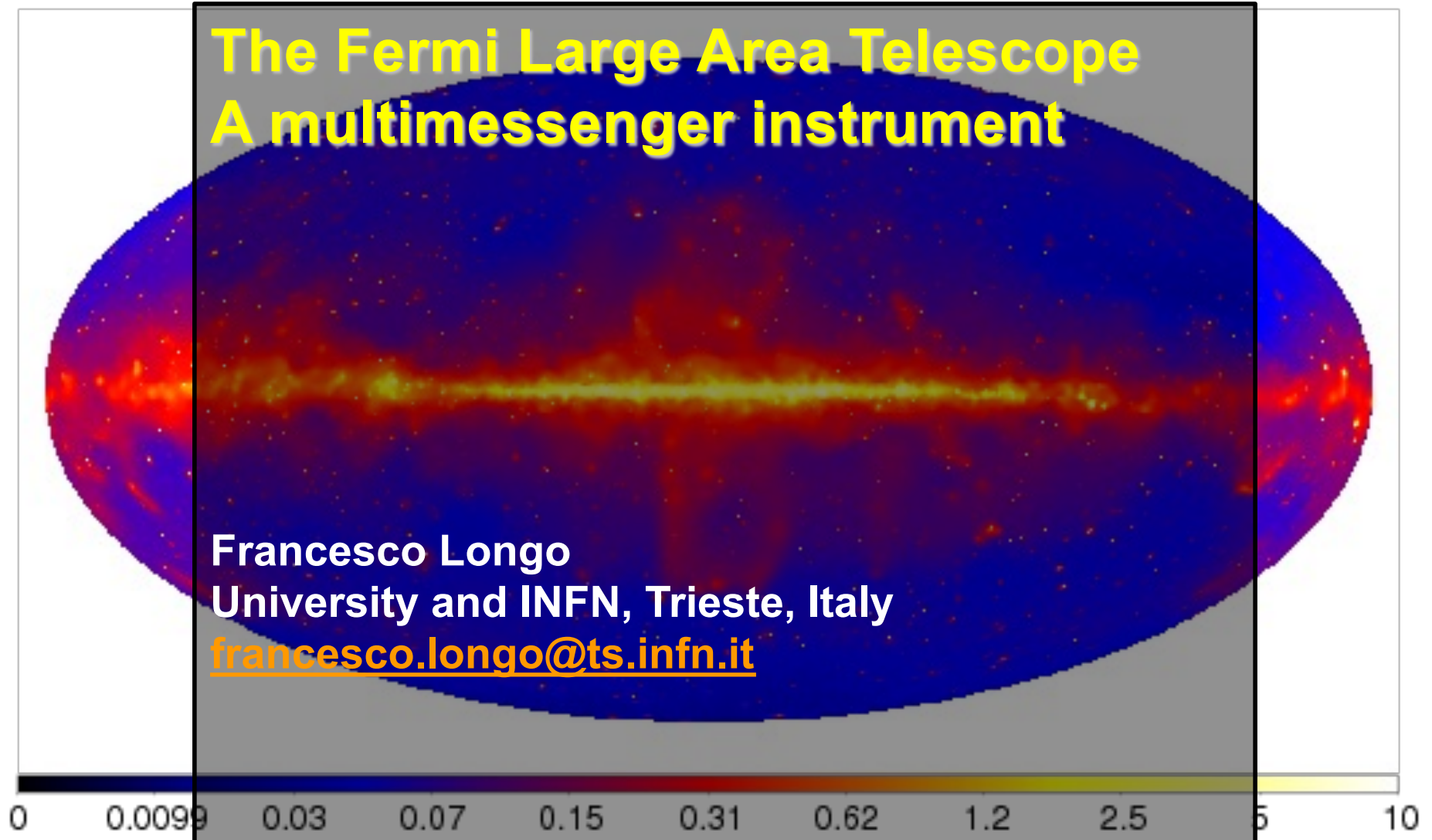
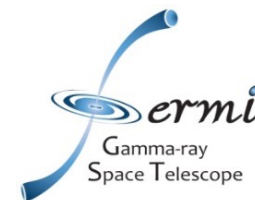


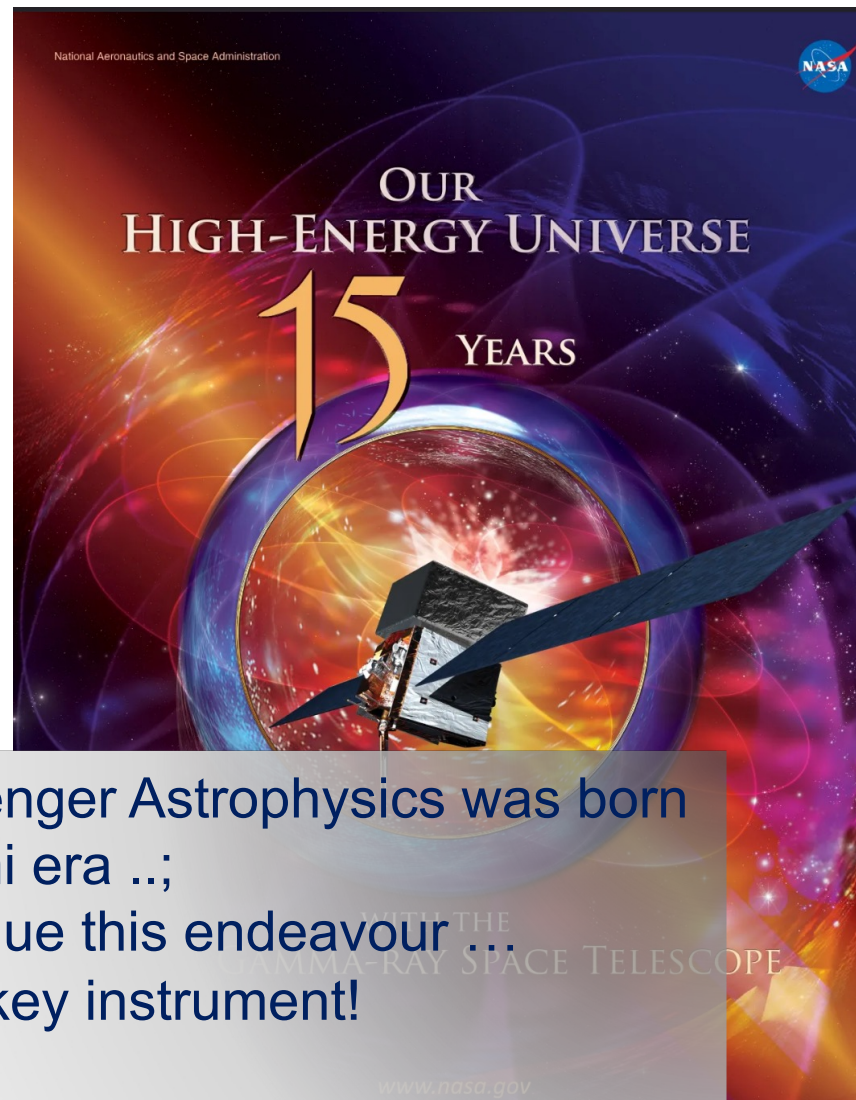
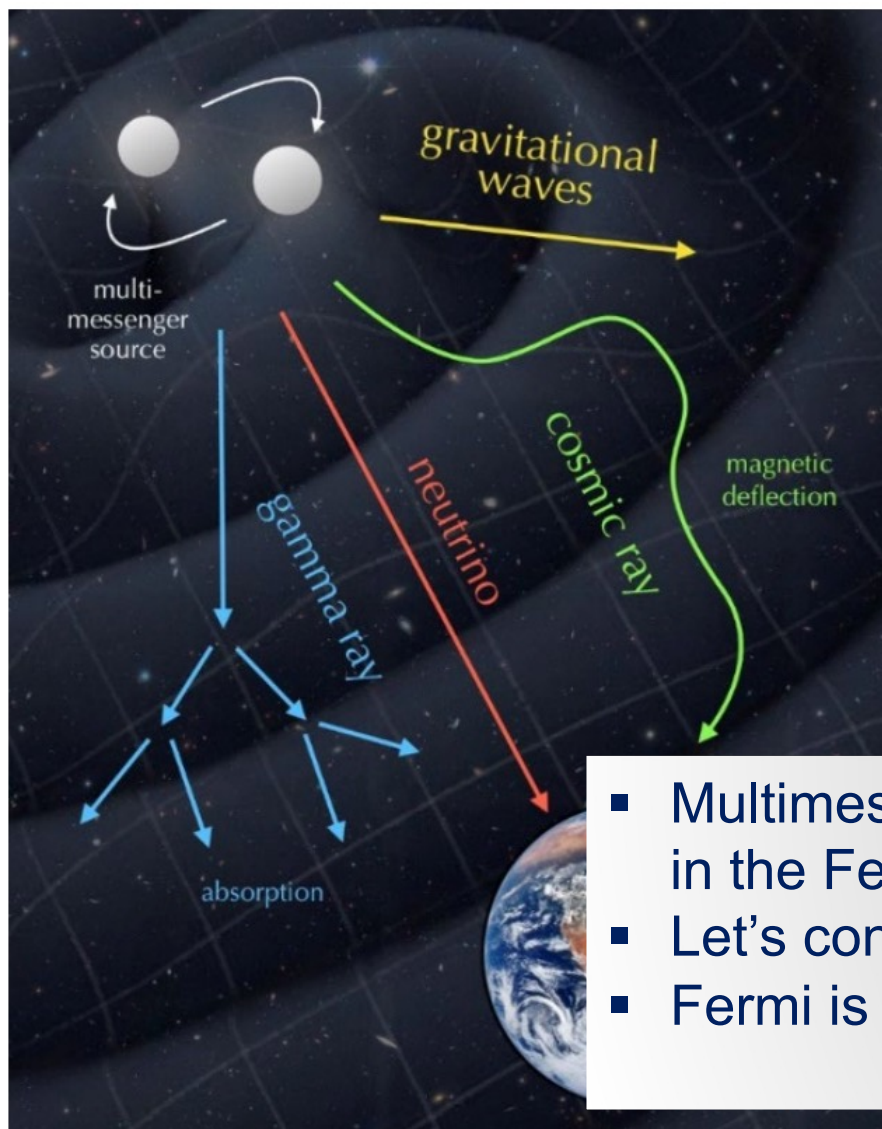
The Fermi Large Area Telescope A multimessenger instrument

Francesco Longo
University and INFN, Trieste, Italy
francesco.longo@ts.infn.it

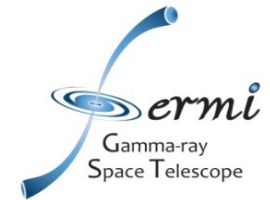




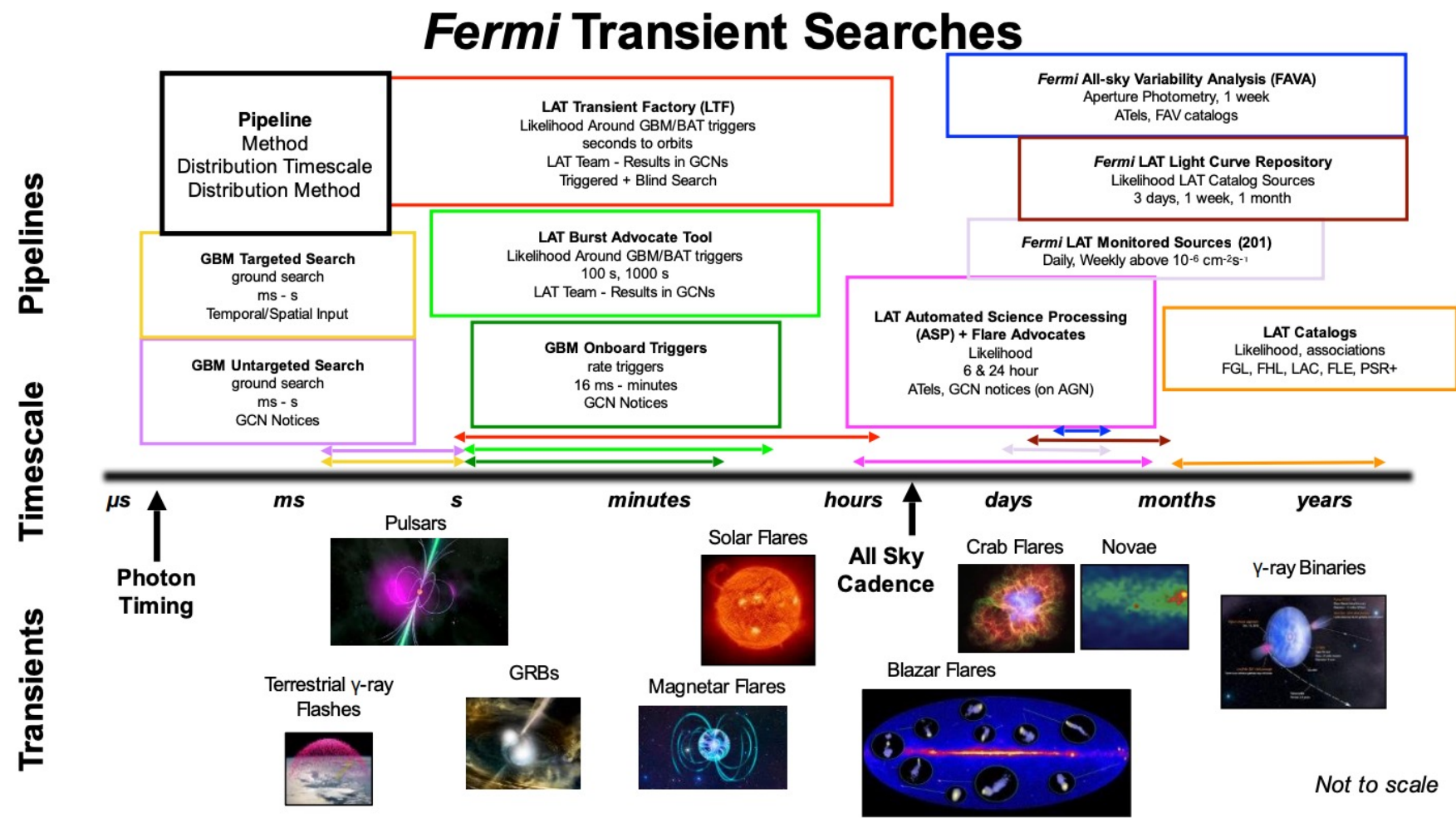
Take away message ...



- Multimessenger Astrophysics was born in the Fermi era ..;
- Let's continue this endeavour ...
- Fermi is a key instrument!



LAT as Transient Machine ...

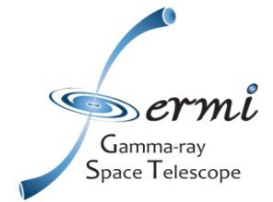




Outline

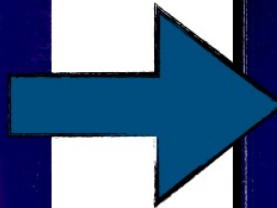
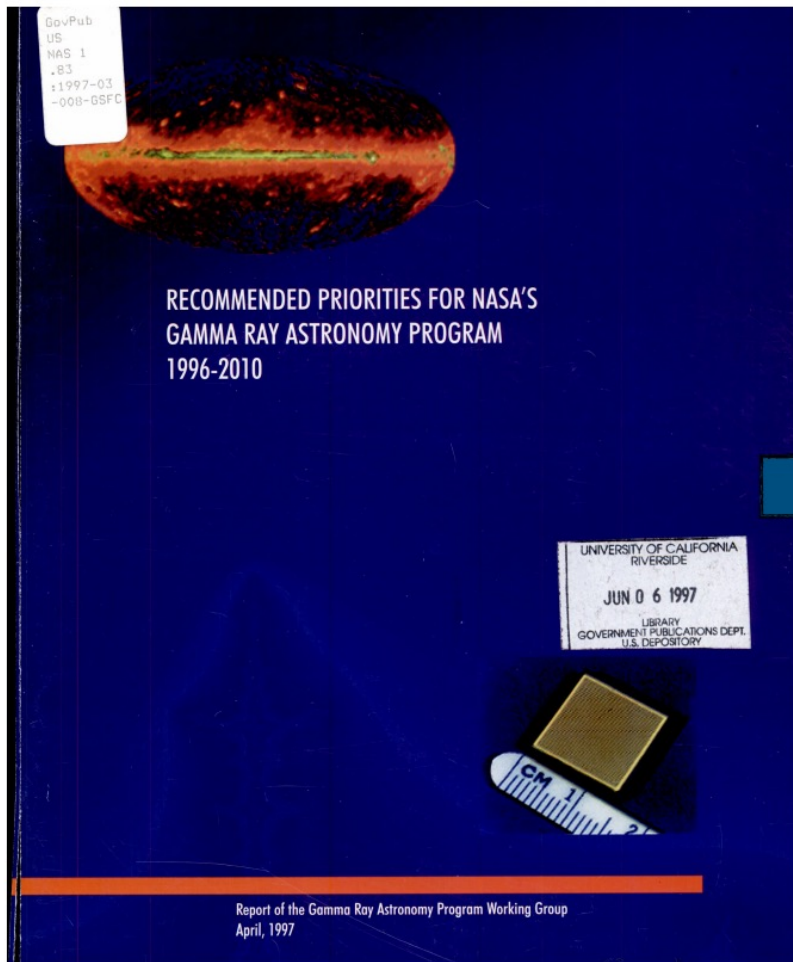
- **The Fermi/LAT telescope**
 - A brief history ...
 - Science main topics
- **A few key decisions**
 - Data processing
 - Data dissemination
- **Multimessenger results in Fermi**
 - GRB and GW
 - AGN and neutrinos
 - Solar Physics and CR
 - Diffuse emission and CR / neu
 - Dark Matter
 - LAT as CR instrument
- **Challenges and prospects for MMA with Fermi**

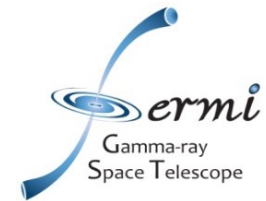




A brief of history ..

R.Caputo @ 2nd CTAO symposium





A brief of history ..

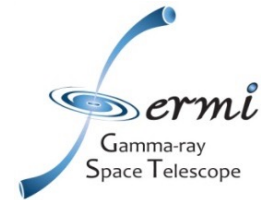
R.Caputo @ 2nd CTAO symposium

KEY QUESTIONS IN GAMMA-RAY ASTRONOMY FROM 1997

- What is the origin and nature of gamma-ray bursts?
- What are the physical conditions and processes near accreting black holes and neutron stars?
- How does matter behave in extreme conditions like those in neutron stars, supernova expulsions and active galactic nuclei?
- How do astrophysical accretion processes work and what are their instabilities, periodicities and modes?
- What is the nature of the jets emanating from galactic black holes and AGN and how are the particles accelerated?
- What is the origin of the diffuse gamma-ray background?
- What is the nature of the unidentified high energy gamma-ray sources?
- What are the sites of nucleosynthesis?
- How do supernovae work? What are the progenitors and explosion mechanisms? What has been the rate in the last several hundred years?
- What and where are the sites of cosmic ray acceleration?

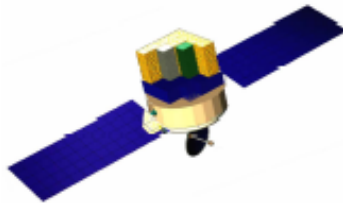
Why did they recommend these missions?

- They developed a series of **Key Science Questions** that pointed to the need for this diverse set of missions.
 - Lesson: Lead with the Science
 - Lesson: Don't shy away from the big problems
 - Lesson: Make strong/bold recommendations
- Many of these questions are still open but we have made significant progress.



Detector Project

N.Gehrels - SWG presentation ~ 2002



Sources Classes Predicted for GLAST

Source Class	Basis for Prediction
Active Galactic Nuclei (AGN)	EGRET quasars
Diffuse Cosmic Background	EGRET, Theory
Gamma Ray Bursts (GRBs)	EGRET, BATSE, Milagro
Molecular Clouds, Supernova Remnants Normal Galaxies	COS-B, EGRET, Theory
Galactic Neutrons Stars (NS) & Black Holes (BHs)	COS-B, EGRET
Unidentified Gamma-ray Sources	COS-B, EGRET
Dark Matter	Theory

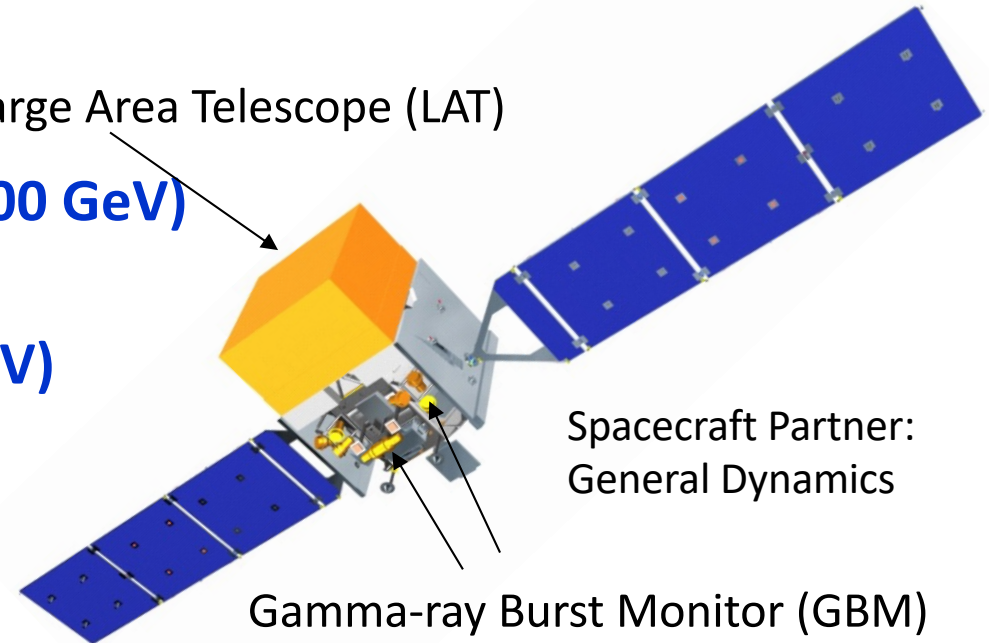


Key Features

- **Two instruments:**

- **LAT:**
 - high energy (20 MeV – >300 GeV)
- **GBM:**
 - low energy (8 keV – 40 MeV)

Large Area Telescope (LAT)



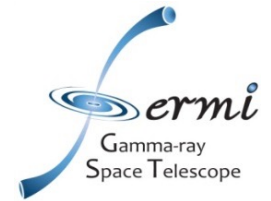
Spacecraft Partner:
General Dynamics

Gamma-ray Burst Monitor (GBM)

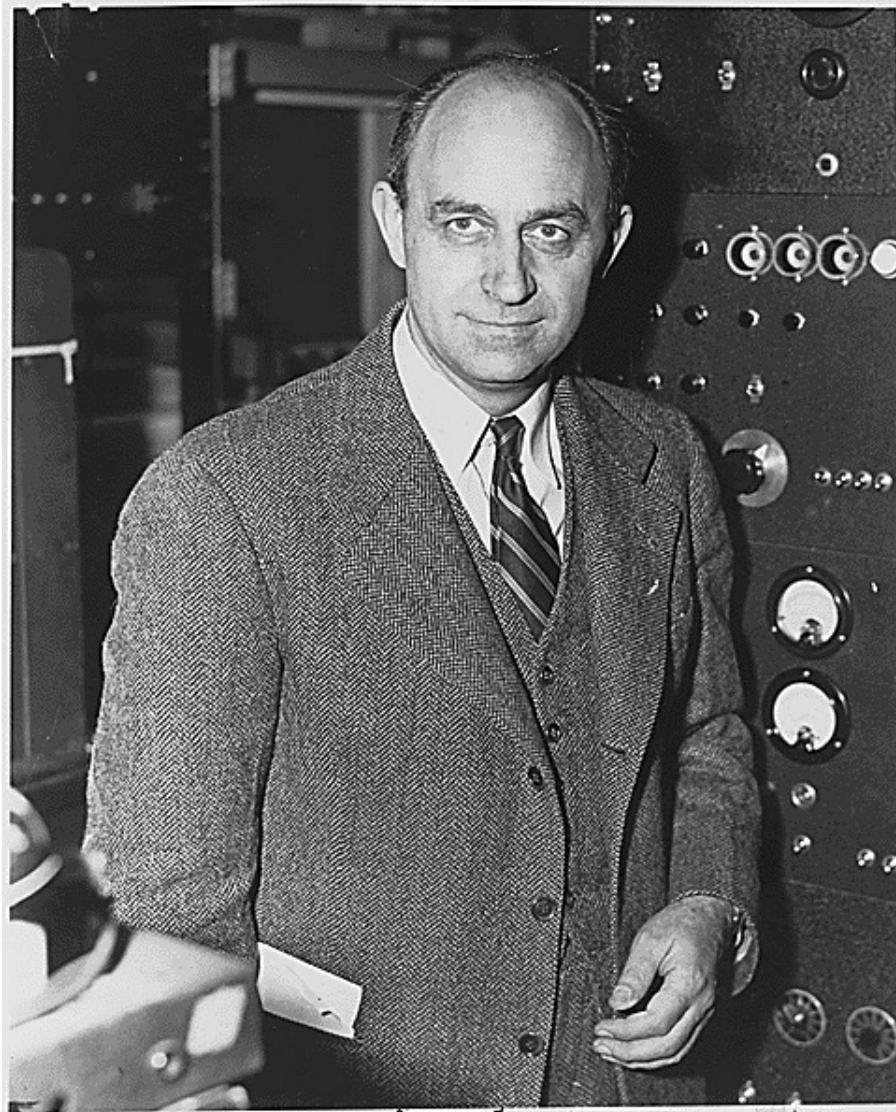
- **Huge field of view**

- **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 unoccluded sky at any time.**

- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV**
- **Large leap in all key capabilities. Great discovery potential.**



Fermi Gamma-ray Space Telescope

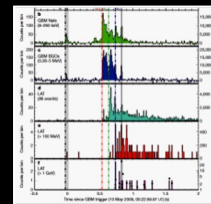
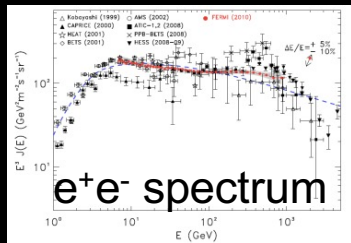


GLAST renamed *Fermi* by NASA on August 26, 2008

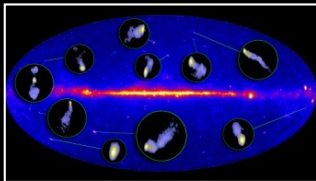
<http://fermi.gsfc.nasa.gov/>

“ Enrico Fermi (1901-1954) was an Italian physicist who immigrated to the United States. He was the first to suggest a viable mechanism for astrophysical particle acceleration. This work is the foundation for our understanding of many types of sources to be studied by NASA’s Fermi Gamma-ray Space Telescope, formerly known as GLAST. ”

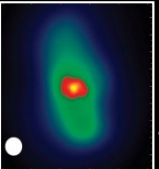
Fermi Reveals the High Energy Universe



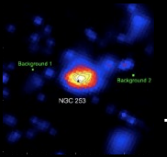
GRBs



Blazars

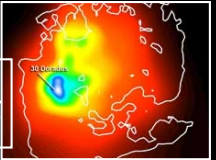


Radio Galaxies

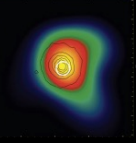


Starburst Galaxies

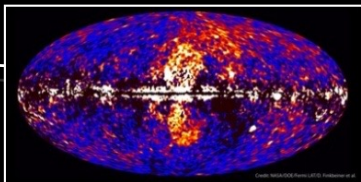
LMC SMC



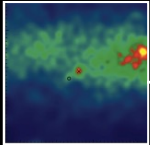
Globular Clusters



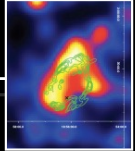
Fermi Bubbles



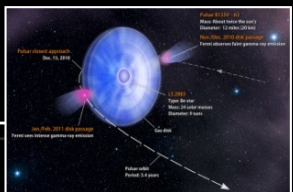
Novae



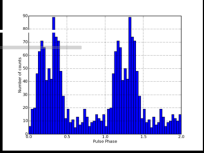
SNRs & PWN



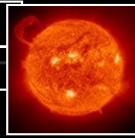
γ -ray Binaries



Pulsars: isolated binaries, & MSPs



Sun: flares & CR interactions



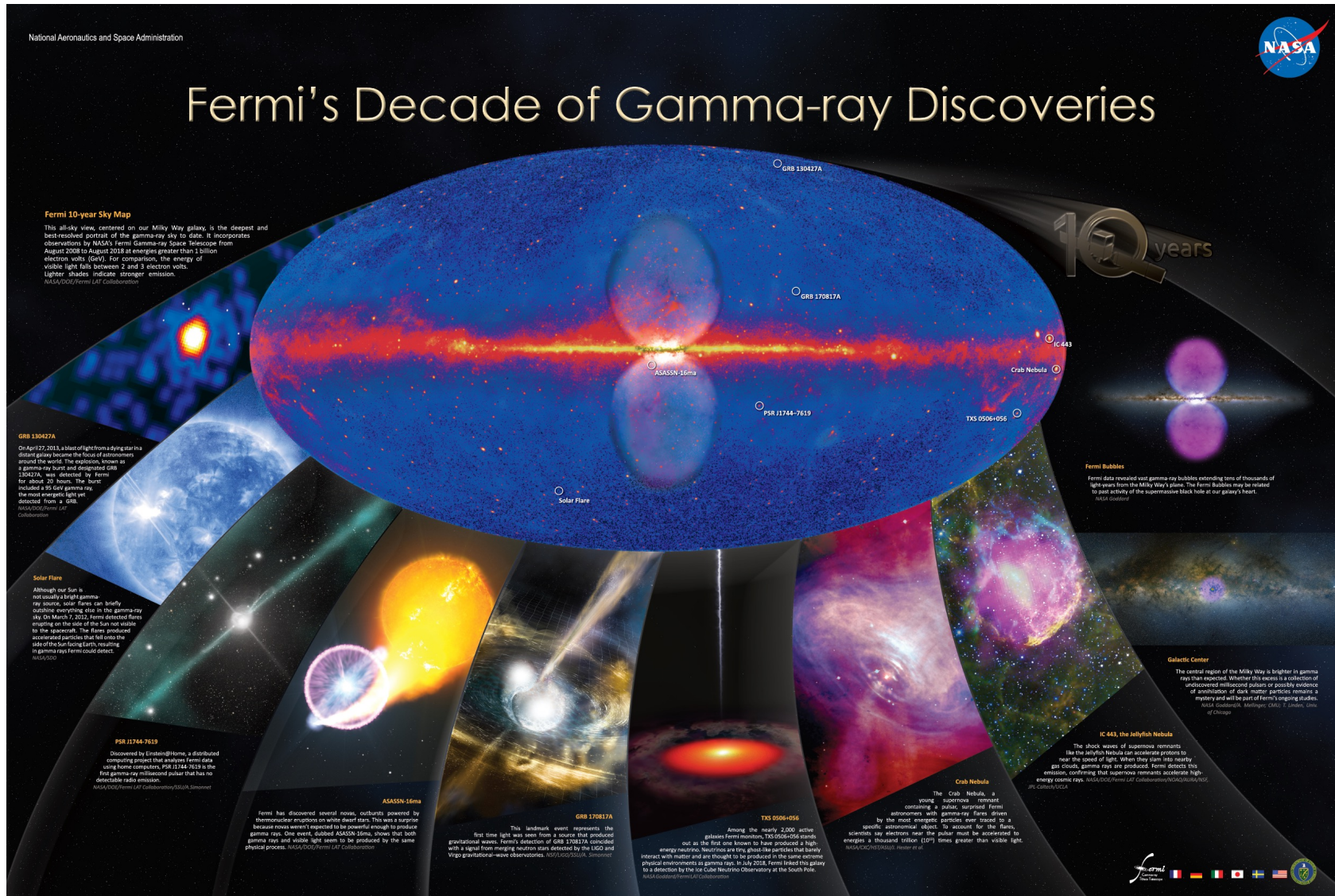
Local

Terrestrial γ -ray Flashes



Unidentified Sources

Scientific Highlights of the LAT



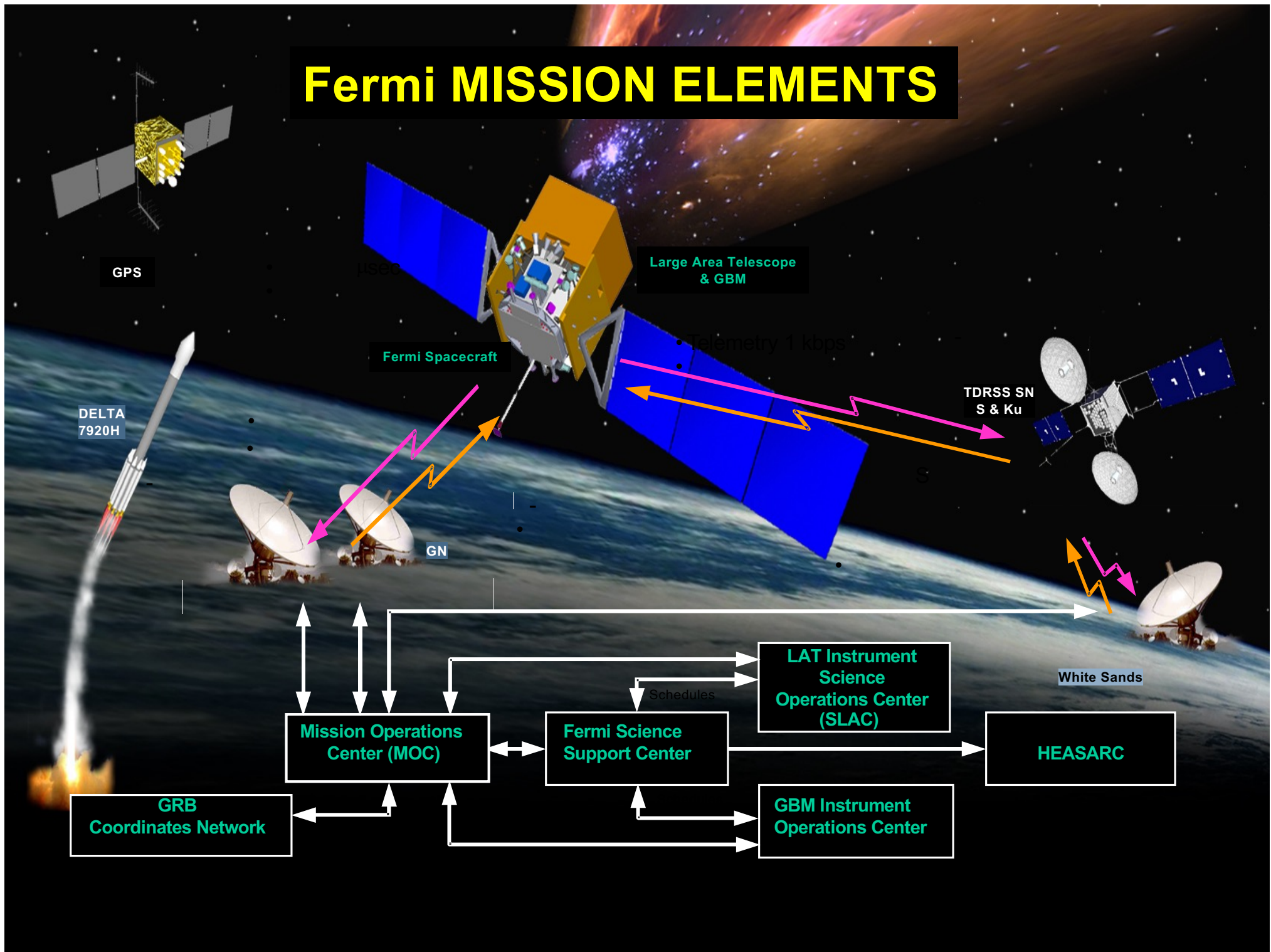


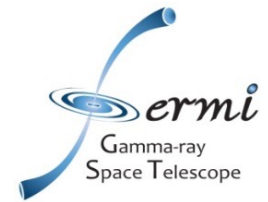
Outline

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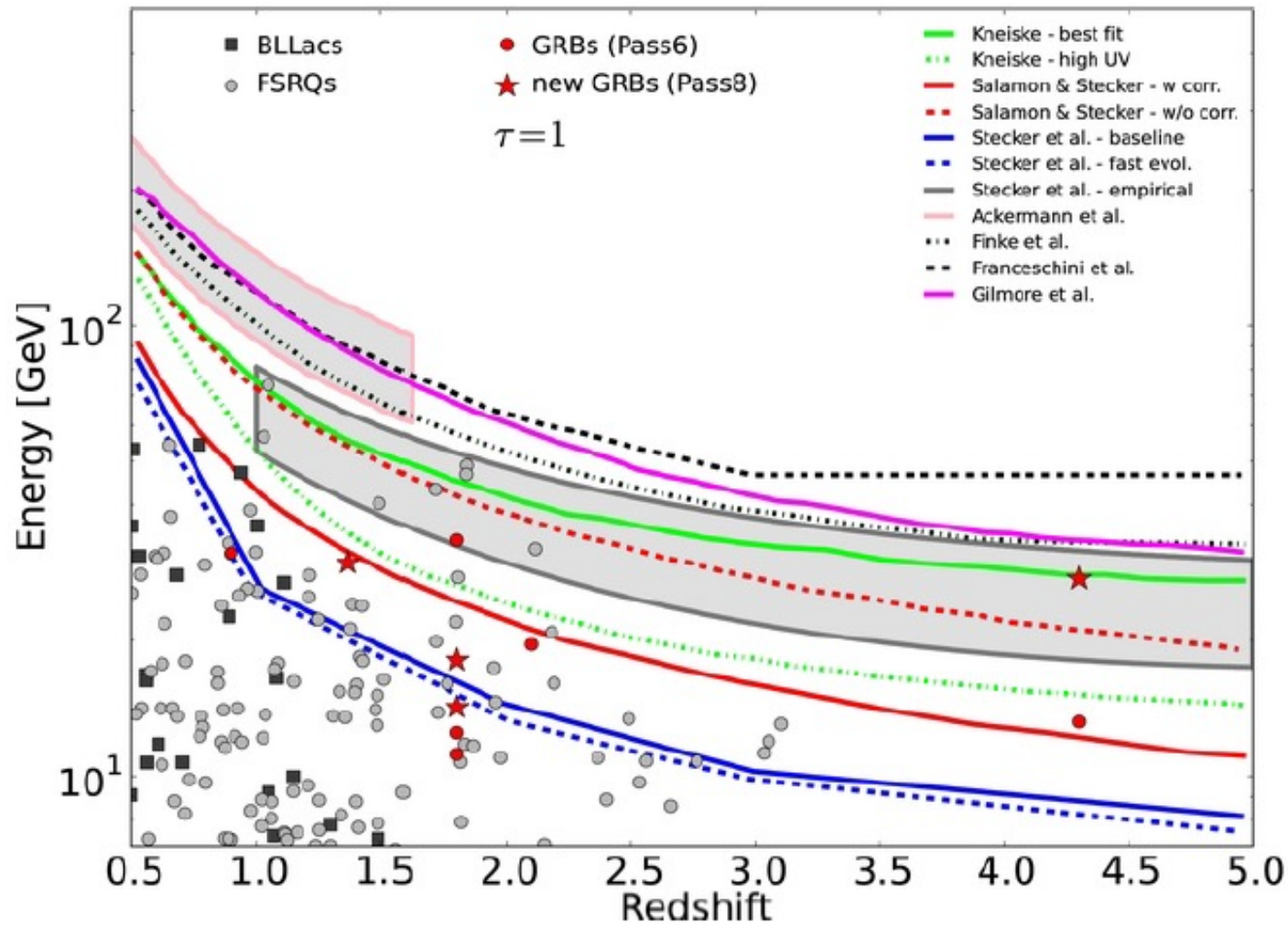


Fermi MISSION ELEMENTS





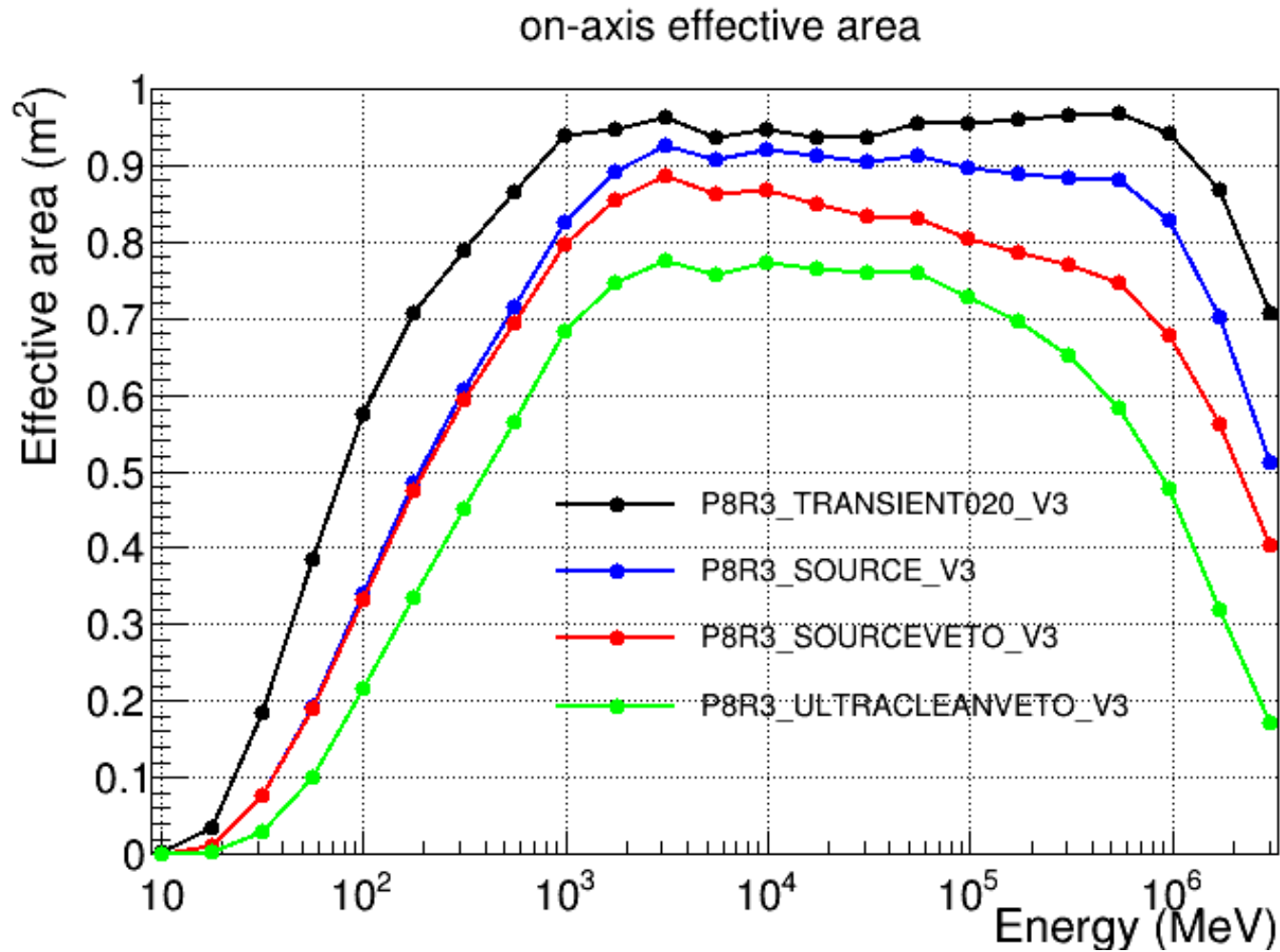
Data processing



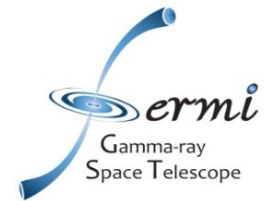
Atwood et al. 2013



Data Processing

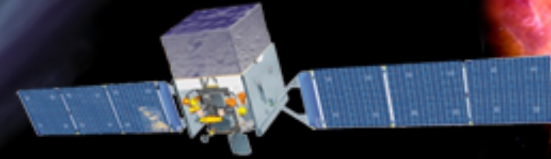


https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm



Data Dissemination

Fermi Gamma-ray Space Telescope



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▶ [Data Access](#)

- + [LAT Data](#)
- + [LAT Catalog](#)
- + [LAT Data Queries](#)
- + [LAT Query Results](#)
- + [LAT Weekly Files](#)
- + [GBM Data](#)

▶ [Data Analysis](#)

▶ [Caveats](#)

▶ [Newsletters](#)

▶ [FAQ](#)

Currently Available Data Products

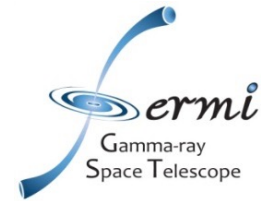
The Fermi data released to the scientific community is governed by the [data policy](#). The released instrument data for the GBM, along with LAT source lists, can be accessed through the [Browse interface specific to Fermi](#). LAT photon data can be accessed through the [LAT data server](#).

The FITS files can also be downloaded from the Fermi [FTP site](#). The file version number is the 'xx' in the characters before the extension in each filename; you should keep track of the version numbers of files you analyze since the instrument teams may update them.

Note that the LAT and GBM data are accompanied by [caveats](#) about their use.

- LAT Photon and Extended Data
 - [LAT Data Server](#) (updated with P8R3 data 26-Nov-2018)
 - [LAT Low-Energy \(LLE\) Data](#) (Browse table)
 - Products available on the [FTP Site](#) (current processing version of the data).
 - [Weekly Photon Files](#)
 - [Weekly Spacecraft Files](#)

<https://fermi.gsfc.nasa.gov/ssc/data/access/>



Data Dissemination

- **Data from Fermi**

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Gamma-ray Space Telescope

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- ▶ **Data Access**
 - + LAT Data
 - + LAT Catalog
 - + LAT Data Queries
 - + LAT Query Results
 - + LAT Weekly Files
 - + LAT Light Curve Repository
 - + GBM Data
- ▶ Data Analysis
- ▶ Caveats
- ▶ Newsletters
- ▶ FAQ

Currently Available Data Products

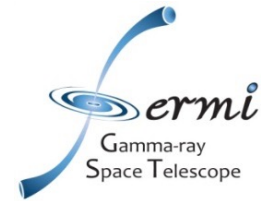
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 - [Weekly Spacecraft Files](#)
 - [Mission Long Spacecraft File](#)
 - [Weekly 1-second Spacecraft Files](#)
 - [Filtered Weekly Photon Files](#) with Diffuse Response Columns
 - Previous processing versions available on the FTP site
 - [Pass 8 \(P8R2\) Weekly Files](#)
 - [Pass 7 \(V6d\) Weekly Files](#)
 - [Pass 7 \(V6\) Weekly Files](#)
 - [Pass 6 \(V11\) Weekly Files](#)
 - [Pass 6 \(V3\) Weekly Files](#)
 - [SSDC data server](#) (external)

<https://fermi.gsfc.nasa.gov/ssc/data/access/>



Data Dissemination

- **The Fermi Catalogs**

- LAT catalogs and associated products (high-level products only)
 - LAT Source Catalog
 - LAT 14-year Source Catalog (4FGL-DR4)
 - LAT 12-year Source Catalog (4FGL-DR3)
 - LAT 10-year Source Catalog (4FGL-DR2)
 - LAT 8-year Source Catalog (4FGL)
 - Preliminary LAT 8-year Source List (FL8Y)
 - LAT 4-year Source Catalog (3FGL)
 - LAT 2-year Source Catalog (2FGL)
 - LAT 1-year Source Catalog (1FGL)
 - LAT 3-month Bright Source List (0FGL)
 - Light Curve Repository
 - Aperture Photometry Light Curves
 - Aperture Photometry Light Curves for LAT 10-year Catalog Sources (Updated Weekly)
 - Flaring Sources in the LAT 10-year Aperture Photometry Light Curves (Updated Weekly)
 - Aperture Photometry Light Curves for LAT 4-year Catalog Sources
 - Flaring Sources in the LAT 4-year Aperture Photometry Light Curves
 - Aperture Photometry Light Curves for the LAT 2-year Source Catalog
 - Flaring Sources in the LAT 2-year Aperture Photometry Lightcurves
 - LAT High Energy Source Catalog
 - LAT Third High Energy Source Catalog (3FHL)
 - LAT Second High-Energy Source Catalog (2FHL)
 - LAT First High-Energy Source Catalog (1FHL)
 - LAT Third Catalog of Gamma-ray Pulsars (3PC)
 - The First Fermi-LAT Solar Flare Catalog (FLSF)
 - Fourth LAT AGN Catalog (4LAC,4LAC-DR2,4LAC-DR3)
 - LAT Monitored Source List Light Curves
 - LAT GRB Catalog
 - Extended Sources in the Galactic Plane (FGES)
 - Fermi All-sky Variability Analysis Catalog (FAVA)
 - 1st Fermi-LAT SNR Catalog
 - LAT Second Catalog of Gamma-ray Pulsars (2PC)
 - Other useful LAT related products
 - 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

<https://fermi.gsfc.nasa.gov/ssc/data/access/>



Data Dissemination

- The Fermi Catalogs (4FGL – DR4)

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 - + LAT Light Curve Repository
 - + GBM Data
- ▶ Data Analysis
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LAT 14-year Source Catalog (4FGL-DR4)

The Large Area Telescope (LAT) on board NASA's *Fermi* Gamma-ray Space Telescope (launched June 11, 2008) surveys the entire sky each day. This web page presents an incremental version (4FGL-DR4, for Data Release 4) of the fourth full catalog of LAT sources, based on 14 years of survey data in the 50 MeV-1 TeV energy range. For a full explanation about the catalog and its construction see the [DR4 document](#). The DR4 data analysis is similar to 4FGL-DR3 (with a few differences explained in the text), so the reference is still the [DR3 paper](#). Please cite both documents when you use this data release.

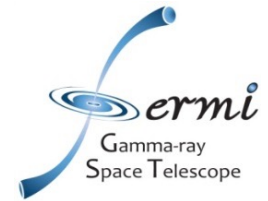
The source designation is the same as 4FGL, 4FGL JHHMM.m+DDMM(c,e,i,s) where the 4 refers to the fourth catalog (1FGL was released at 1 year, 2FGL at 2 years, and 3FGL at 4 years) and FGL represents Fermi Gamma-ray LAT. The "DataRelease" column set to either 1, 2, 3 or 4 tells when a source was introduced in the catalog. The optional "e", "i" and "s" designators are explained in the caveats below.

LAT Catalog Data Products

The LAT 14-year Source Catalog is currently available as a FITS file to be used for data analysis within the Fermitools. Supporting tools and documentation have been provided and are linked below.

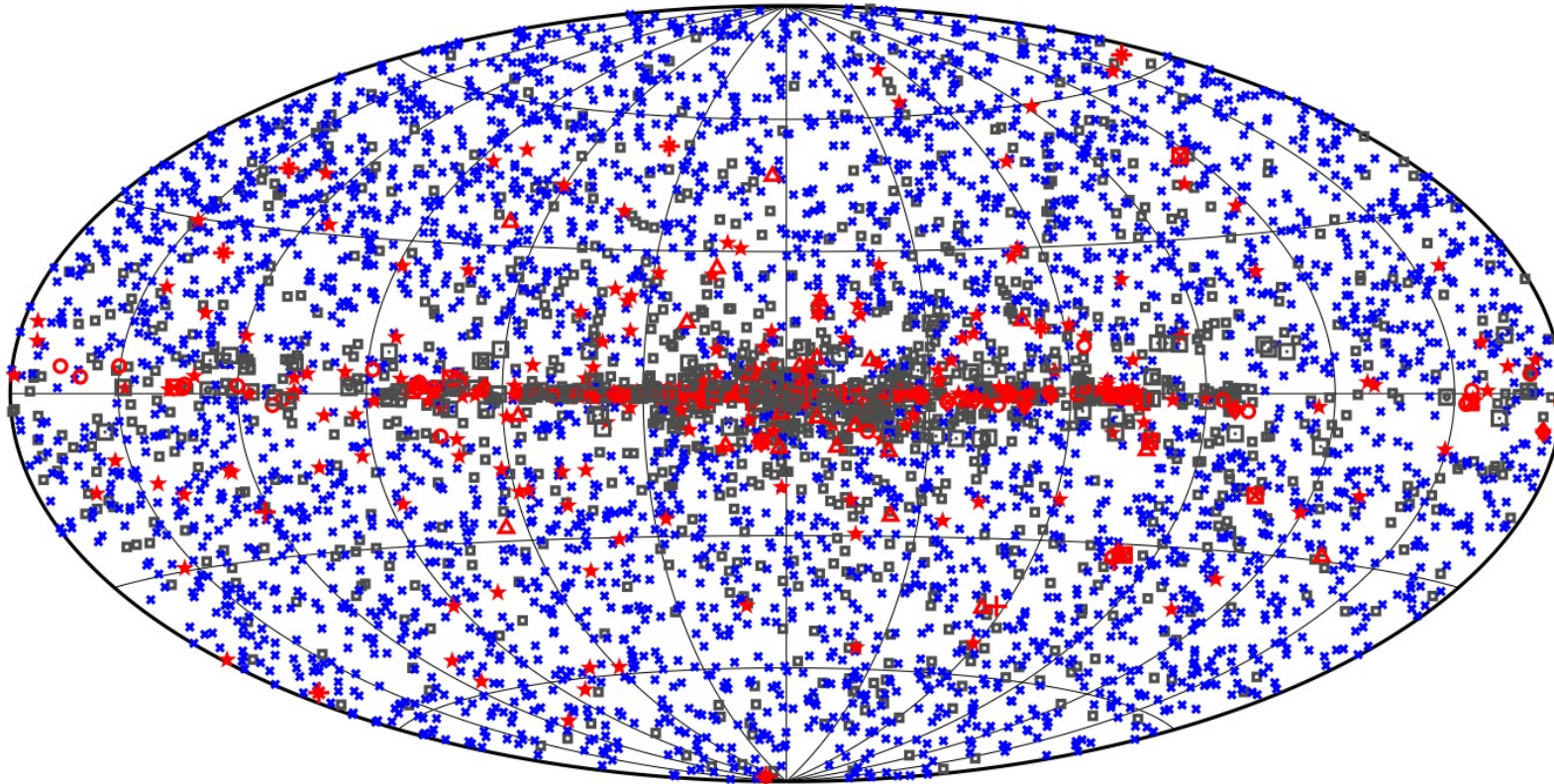
- [LAT 14-year Source Catalog](#) (4FGL-DR4 in FITS format)
- [LAT 14-year Source Catalog](#) (BROWSE table)
- [LAT 14-year Source Catalog](#) (XML format)
- [LAT 14-year Source Catalog Paper](#)
- [Map of the 14-year LAT Detection Threshold](#) (in FITS format)
- [Python script](#) (and [instructions](#)) to convert the 4FGL-DR4 source list into an XML file.

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/14yr_catalog/

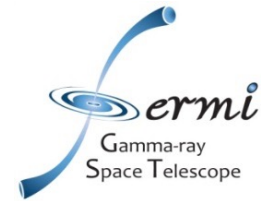


Data Dissemination

- The Fermi Catalogs



□ No association	▣ Possible association with SNR or PWN	✱ AGN
★ Pulsar	△ Globular cluster	✳ Starburst Galaxy
⊠ Binary	+ Galaxy	◇ PWN
★ Star-forming region	□ Unclassified source	● Nova
	○ SNR	



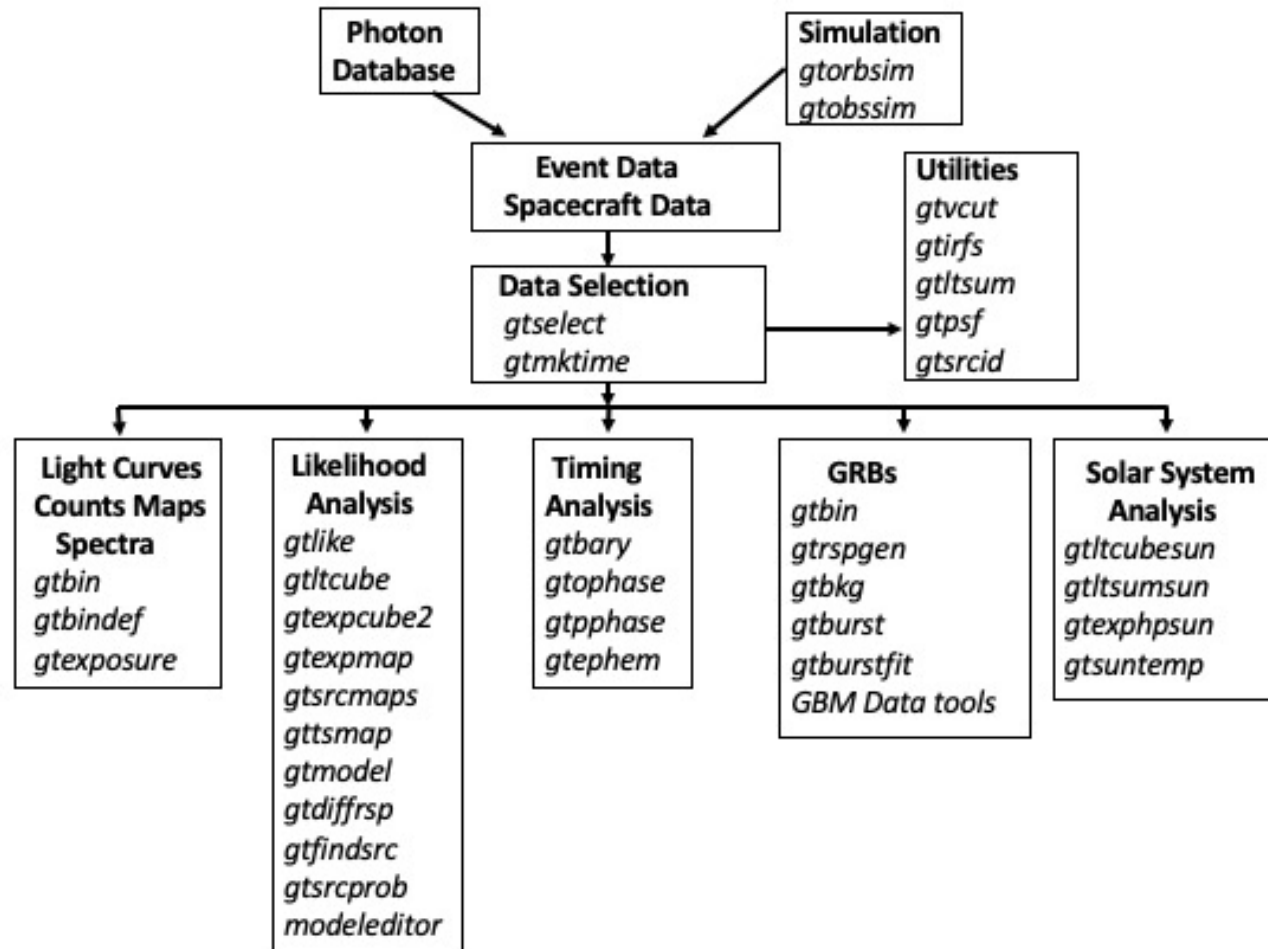
Data dissemination

The screenshot shows the NASA website for the Fermi Gamma-ray Space Telescope. At the top left is the NASA logo and the text "National Aeronautics and Space Administration Goddard Space Flight Center". To the right is a search bar with "Fermi" entered and a "GO" button. Below the search bar is the text "Fermi • FSSC • HEASARC Sciences and Exploration". The main header features the text "Fermi Gamma-ray Space Telescope" and an image of the satellite. A navigation menu includes "Home", "Support Center", "Observations", "Data" (highlighted), "Proposals", "Library", "HEASARC", and "Help". The "Data" section is expanded, showing a sidebar with links to "Data Policy", "Data Access", "Data Analysis" (with sub-links for System Overview, Software Download, Documentation, Cicerone, Analysis Threads, and User Contributions), "Caveats", "Newsletters", and "FAQ". The main content area is titled "Data Analysis" and contains the following text: "The Fermi mission provides a suite of tools called the [Fermitools](#) for the analysis of both LAT and GBM data. This suite was developed by the FSSC and the instrument teams. Originally called the ScienceTools, the suite was [renamed](#) when the software hosting and distribution were changed to use [Github](#) and [Conda](#). In addition, the GBM team has developed [specialized tools](#) for analyzing GBM data, and the FSSC maintains a library of [contributed software](#) developed by the Fermi user community, such as [Fermipy](#), that may be useful to your analysis." Below this is a paragraph: "You may want to look at this [overview](#) of how the Fermitools work and what they do. Then, you can:" followed by a bulleted list: "• [Download currently released Fermitools](#)", "• [Download currently released GBM software](#)", "• [Download user contributed software](#)". Another paragraph follows: "Once you have the software, you should go to the FSSC [documentation section](#). Besides the [overview](#), it provides a number of resources including:" followed by a bulleted list: "• A [getting started guide](#)", "• A [detailed description](#) of the analysis environment and its methodology", "• [Step-by-step guides](#) to various analyses". The final paragraph states: "You may also want to subscribe to the [fermi-soft mailing list](#) to keep up with new software releases and related notices."

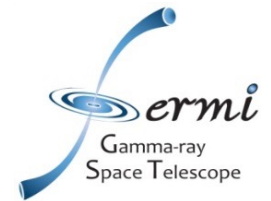
<https://fermi.gsfc.nasa.gov/ssc/data/analysis/>



Data dissemination



<https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/overview.html>



Data dissemination

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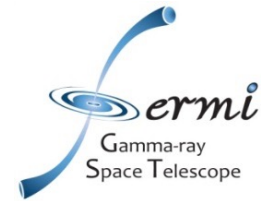
- ▶ Data Policy
- ▶ Data Access
- ▶ **Data Analysis**
 - + System Overview
 - + Software Download
 - + Documentation
 - + Cicerone
 - + Analysis Threads
 - + User Contributions
- ▶ Caveats
- ▶ Newsletters
- ▶ FAQ

User Contributions

The FSSC welcomes contributions to the Fermi Science Tools from the scientific community. If you have developed an extension to the science tools or any other tool useful for Fermi data analysis, please let us know and we will post it on this website. While the FSSC will work with the developer to resolve any issues with the software the contribution is provided "as is" and may not work after a software or data upgrade (e.g. to pass 8 data), updating the tool or script remains the responsibility of the developer. For the moment, please direct any communication to the [Help Desk](#).

Program	Purpose	Read Me	Last Update	Author
jrag-timing.py	The jrag timing script allows to do joint radio and gamma-ray pulsar timing using the PINT pulsar timing software.	README	September 20, 2024	L. Nieder
gtpsmap.py	The gtpsmap python script compares the data and model 3D maps of an ROI and quantifies the level of deviation by computing the PS map.	README	June 03, 2024	P. Bruel
LATSourceModel (replaces make4FGLxml.py)	Produce XML spatial-spectral models of gamma-ray sources within a specified region of the sky for analysis of Fermi LAT data (works with 4FGL-DR4).	Text	July 19, 2023	T. Johnson

<https://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>



Multiwavelength Opportunities

- **Fermi Timeline**

Fermi
Gamma-ray Space Telescope

Home Support Center **Observations** Data Proposals Library HEASARC Help

Observations

- ▶ [Observatory Status](#)
- ▶ [Observing Timeline](#)
 - + [Timeline Posting](#)
 - + [Target-of-Opportunity Status](#)
 - + [Predicted Pointing \(FT2\)](#)
- ▶ [Observation Types](#)
- ▶ [Multiwavelength Observations](#)
- ▶ [Targets-of-Opportunity](#)
- ▶ [Alternate Observing Strategies](#)

Observing Timeline

In this section you can determine where Fermi pointed in the past and is scheduled to point in the future. Also, you can learn the status of target-of-opportunity (TOO) observations that have been approved.

Timeline Utilities

The following are utilities that provide you with these capabilities:

- [Timeline posting](#) - through this webpage you can determine Fermi's pointing history in the past, and find future observing plans. The most accurate observing information available is used.
- [TOO status](#) - the status of accepted TOO requests is reported here. The utility presents all available information at the time of a query.
- [Time system conversions](#) - different utilities and tools use different time systems (e.g., Mission Elapsed Time, calendar date, modified Julian date). Note that Fermi and Swift use the same 'Mission Elapsed Time' conventions. This is a HEASARC tool.
- [Coordinate conversions](#) - this utility can convert between source names and coordinates for single sources and lists of sources. This is a HEASARC tool.

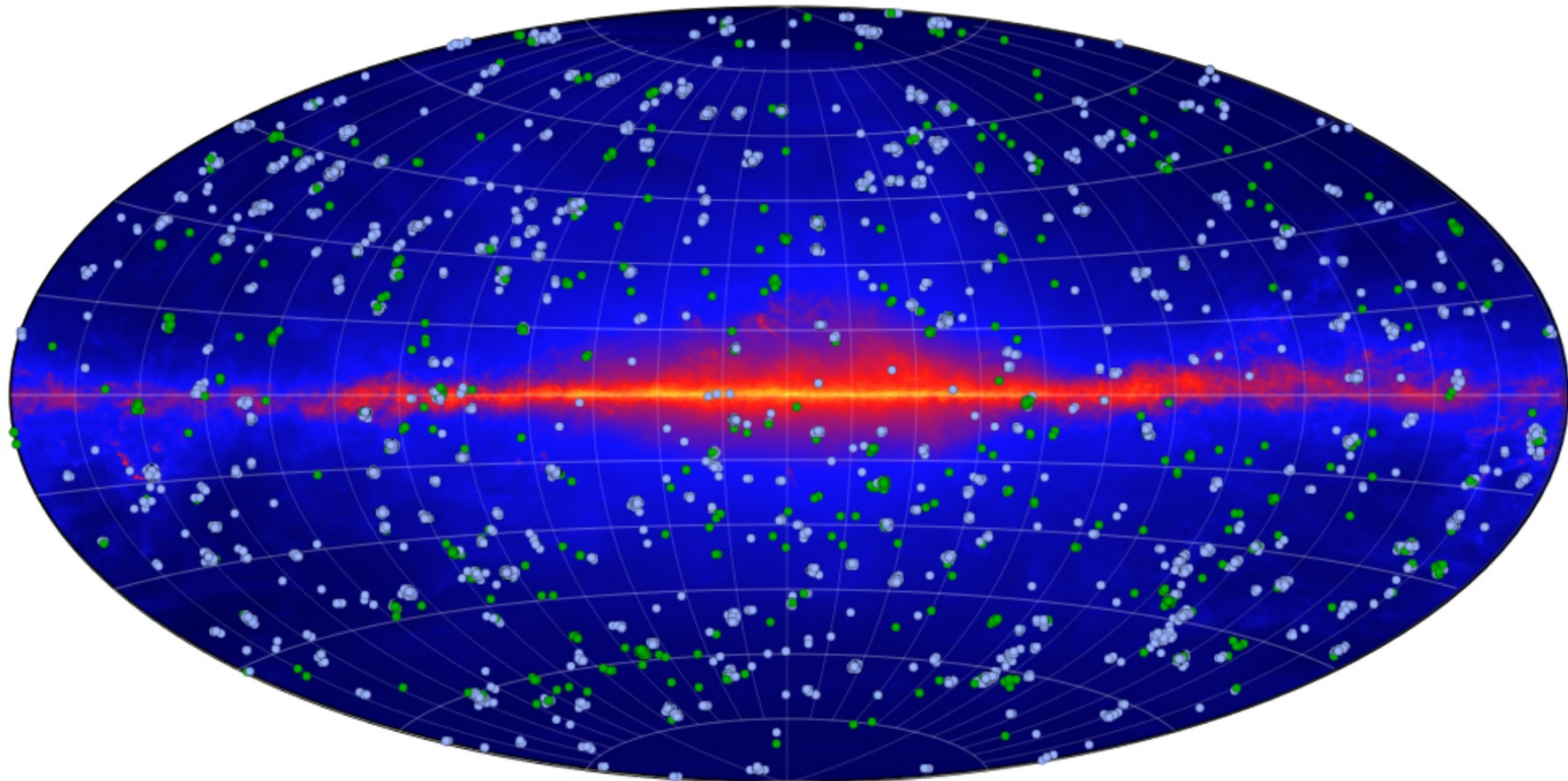
Overview of the Timeline Process

<https://fermi.gsfc.nasa.gov/ssc/observations/timeline/>

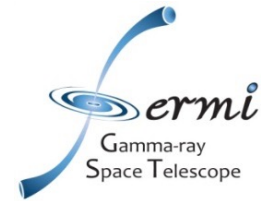


Data Dissemination

- FAVA tool (weekly runs)

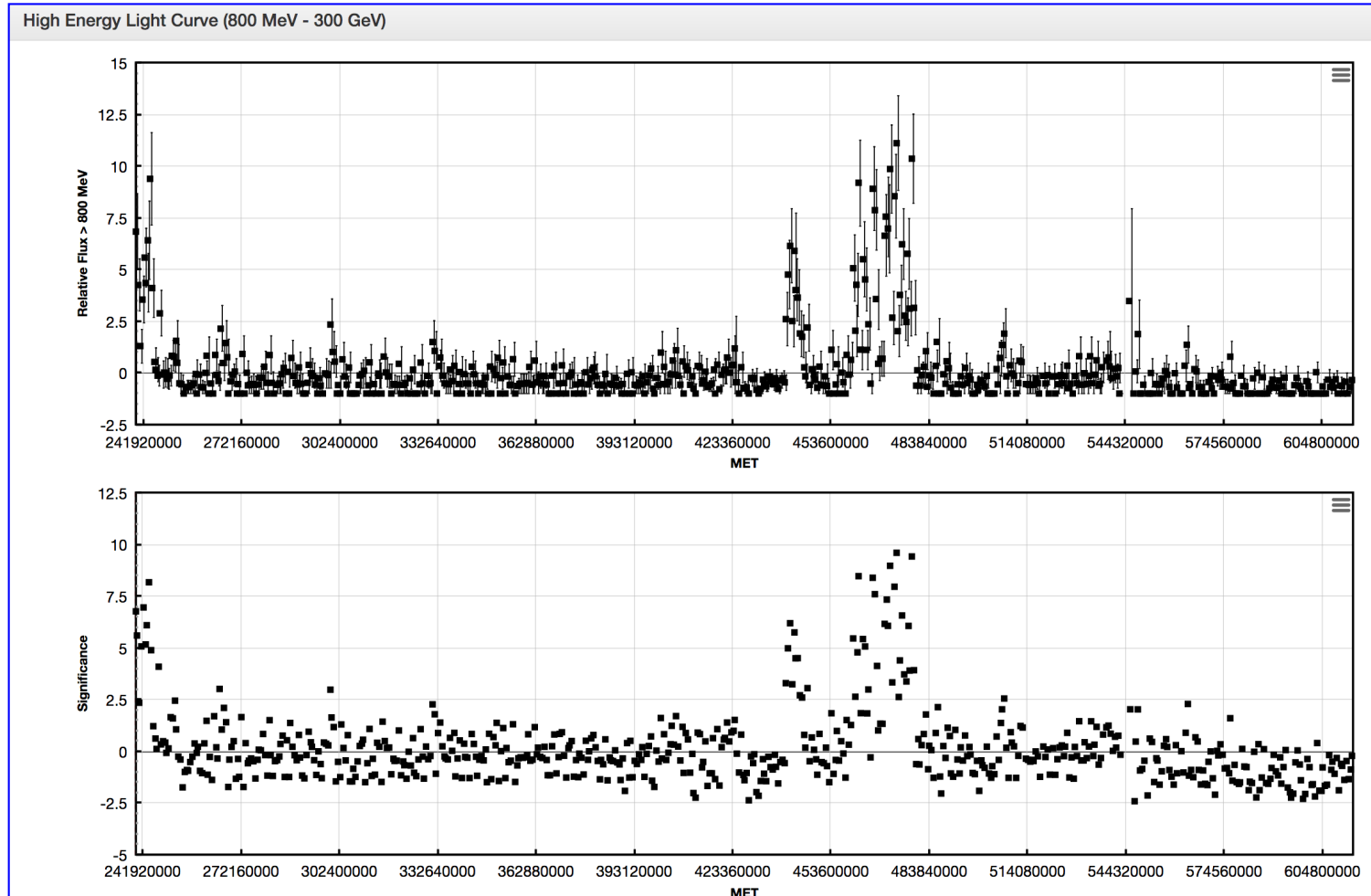


<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/>



Data Dissemination

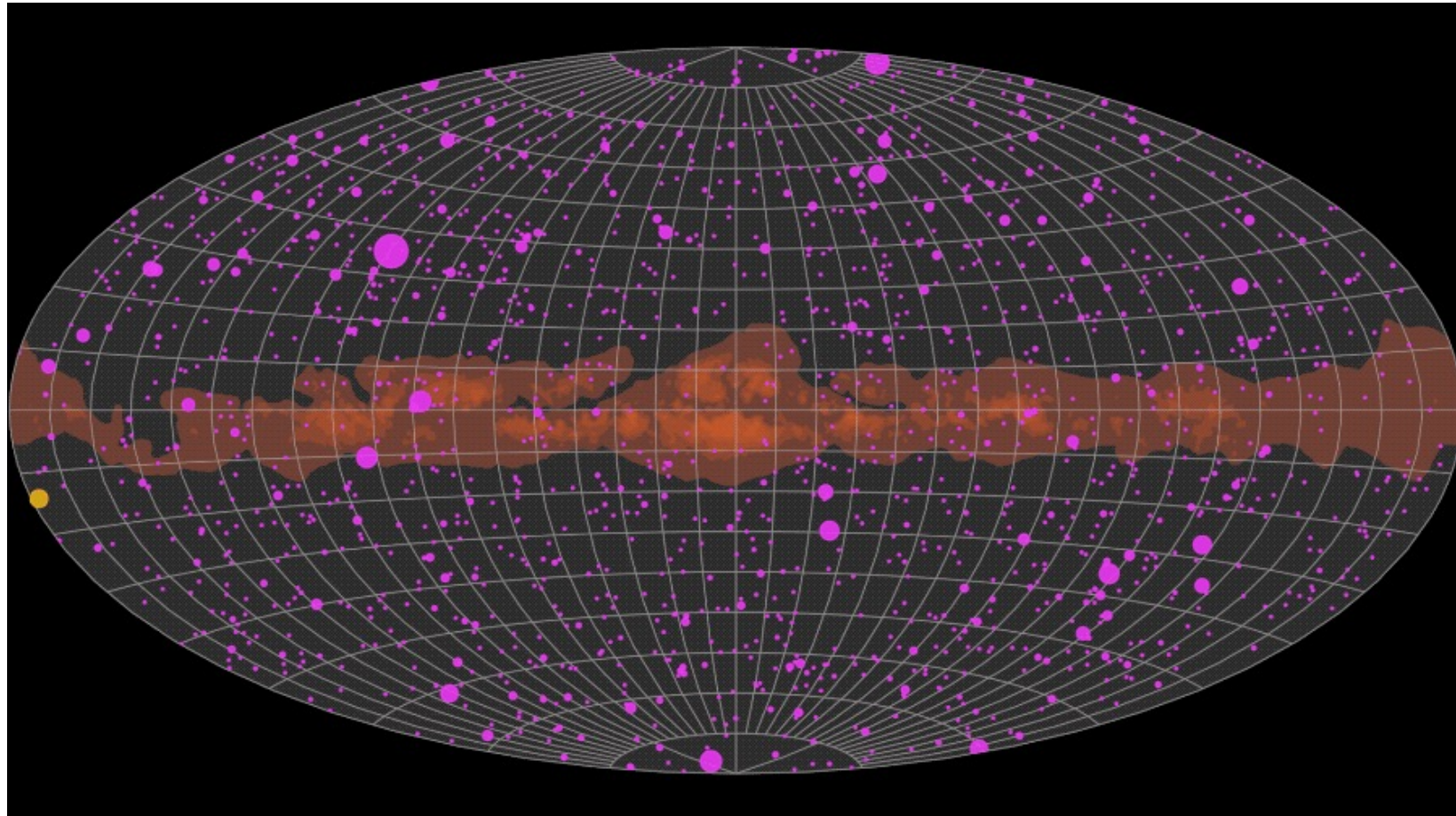
- FAVA tool



<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/>



Data Dissemination



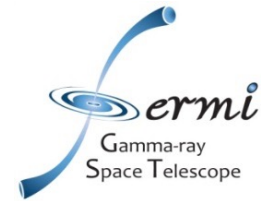
<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/about.html>



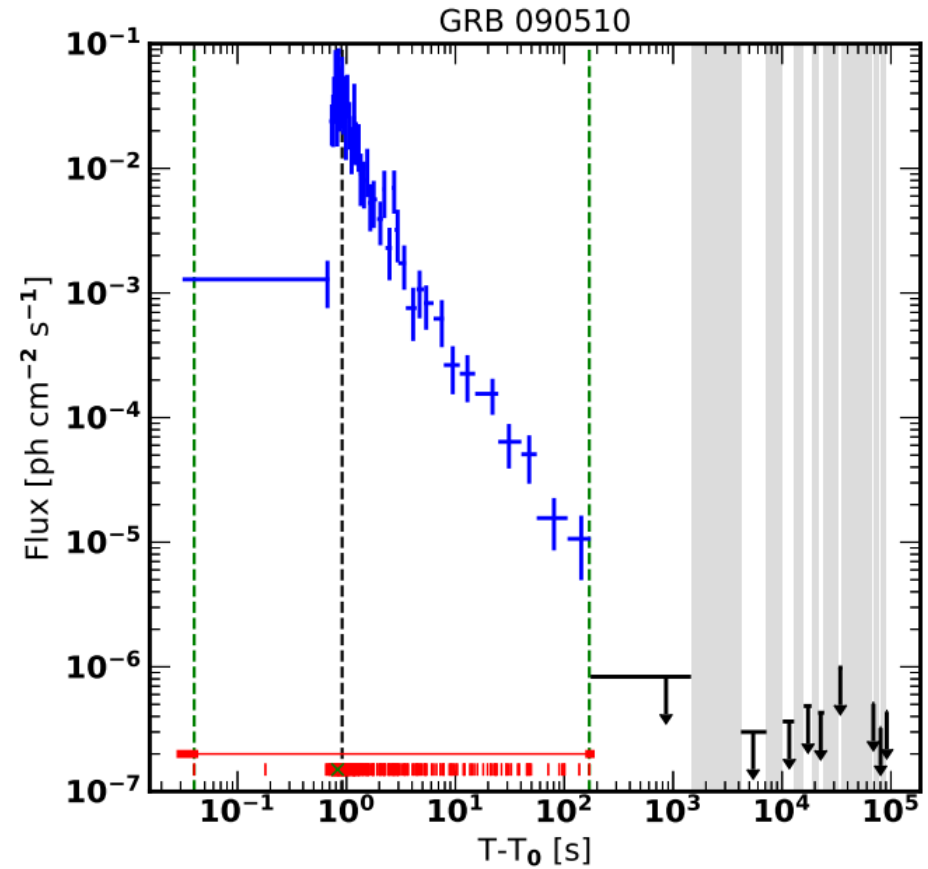
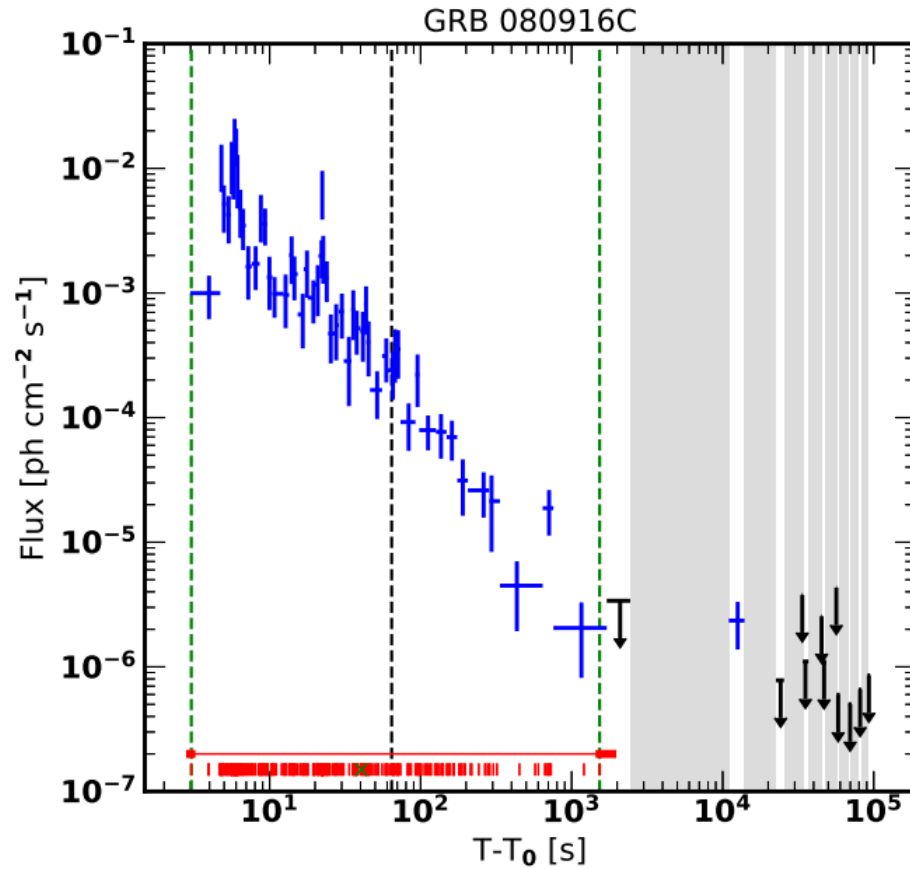
Outline

- **The Fermi/LAT telescope**
 - **A brief history ...**
 - **Science main topics**
- **A few key decisions**
 - **Data processing**
 - **Data dissemination**
- **Multimessenger prospects for Fermi**
 - **GRB and GW**
 - **AGN and neutrinos**
 - **Solar Physics and CR**
 - **Diffuse emission and CR / neu**
 - **Dark Matter**
 - **LAT as CR instrument**
- **Challenges and prospects for MMA with Fermi**





GRB and GW

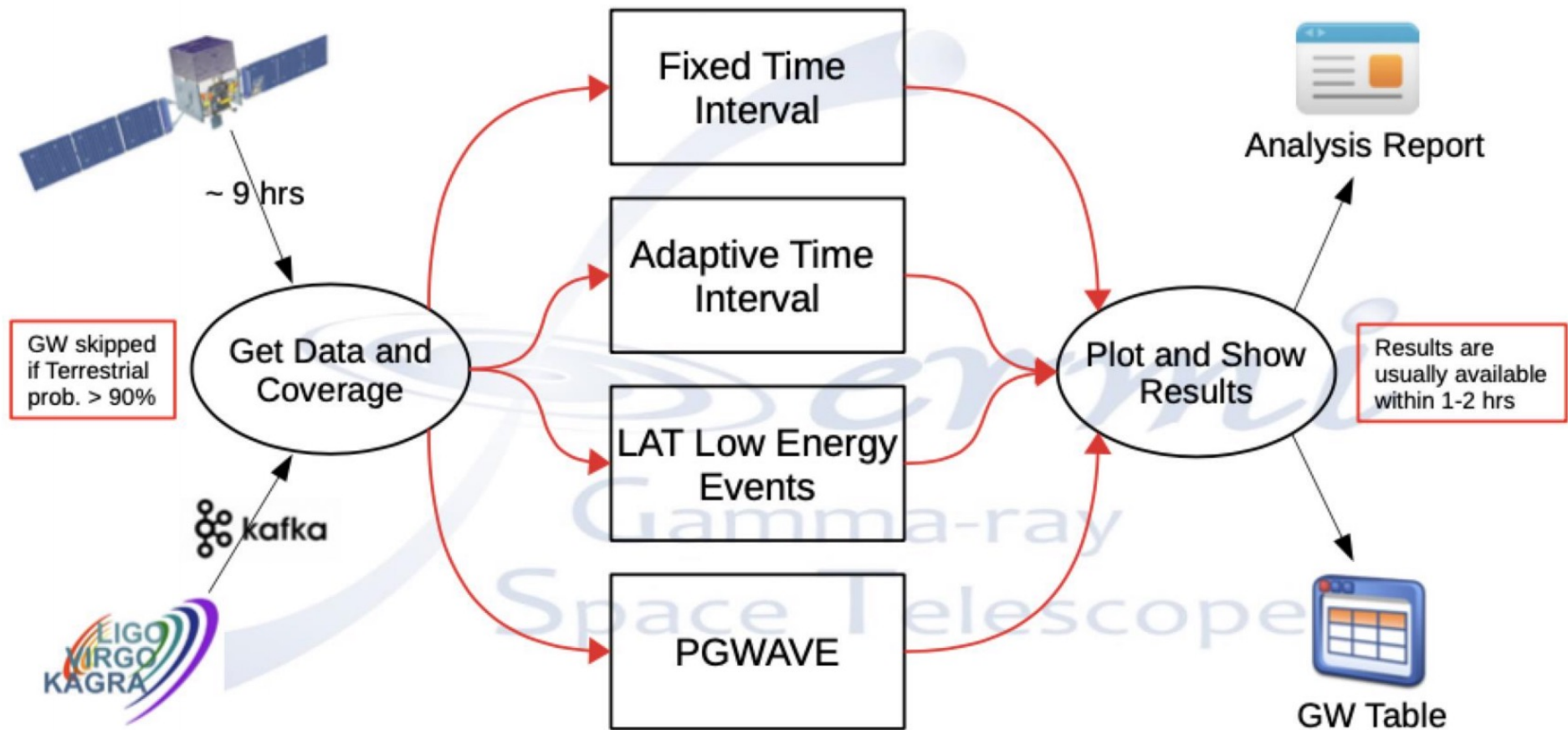


Ajello et al. 2019

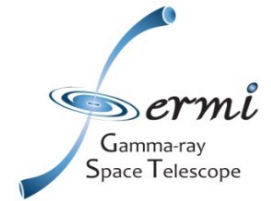


GRB and GW

LAT GW Follow-up Pipeline



N. Di Lalla et al.



GRB and GW

Fermi-LAT Gravitational Waves Table

This page displays the outcomes of the Fermi-LAT automatic follow-up analysis pipeline used to search for electromagnetic counterparts of gravitational waves (GW). For a detailed explanation of the analysis techniques, please refer to [2017ApJ...841L..16V](#). Furthermore, the Fermi-LAT Collaboration has published additional papers on GW events such as [GW150914](#), [LVT151012](#) and [GW151226](#), [GW170104](#), and [GW170817](#)

All analysis results presented here should be considered preliminary, unless otherwise stated. If you have any questions, please write to [Niccolò Di Lalla](#).

Click on the following buttons to access the table associated with the corresponding observing cycle:

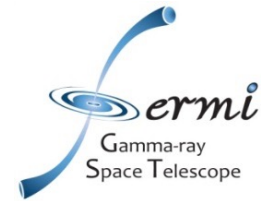
O3	O4
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Stop your mouse cursor over the table headings to view a short explanation of the columns in the table or check the legend [here](#).

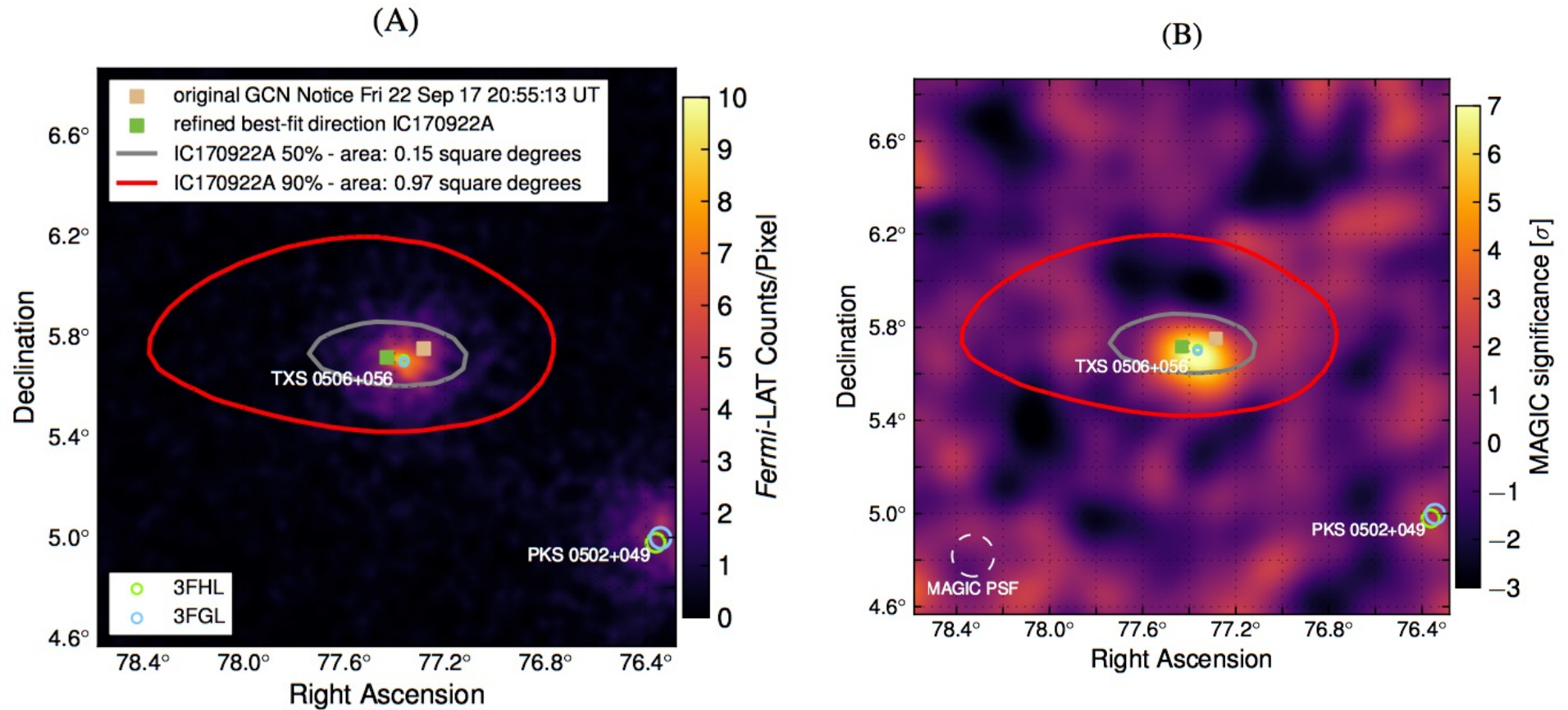
* Information taken from [GraceDB](#) (LIGO-Virgo-KAGRA Collaboration).

Trigger Name*	Date*	Time (UTC)*	GraceDB*	FAR (Hz)*	Highest Probability*	Has NS? (%)*	Has Remnant? (%)*	Has MassGap? (%)*	Inst. Coverage (%)	FTI TS max	ATI TS max	Flux UB (erg/cm2/s)	Analysis report
S240917cb	2024-09-17	13:02:37	Link	5.4e-08	BBH: 96.0%	0.0	0.0	5.9	SAA	23.5	24.4	6.8e-10	Link (v01)
S240916ar	2024-09-16	18:43:52	Link	1.7e-08	BBH: 98.7%	0.0	0.0	3.8	59.0	13.8	13.7	7.6e-10	Link (v01)
S240915bd	2024-09-15	10:51:51	Link	3.3e-14	BBH: 100.0%	0.0	0.0	10.1	3.0	24.0	25.0	8.4e-10	Link (v02)
S240915b	2024-09-15	00:13:57	Link	3.2e-10	BBH: 85.9%	0.0	0.0	1.5	SAA	4.1	4.2	3.5e-10	Link (v01)
S240910ci	2024-09-10	10:35:35	Link	3.2e-10	BBH: 69.1%	0.0	0.0	4.9	31.9	13.5	12.7	9.2e-10	Link (v02)
S240908dg	2024-09-08	12:51:34	Link	7.2e-08	BBH: 95.0%	0.0	0.0	0.0	0.0	11.4	11.5	7.1e-10	Link (v02)

<http://fermigrb.stanford.edu/GWTable/>



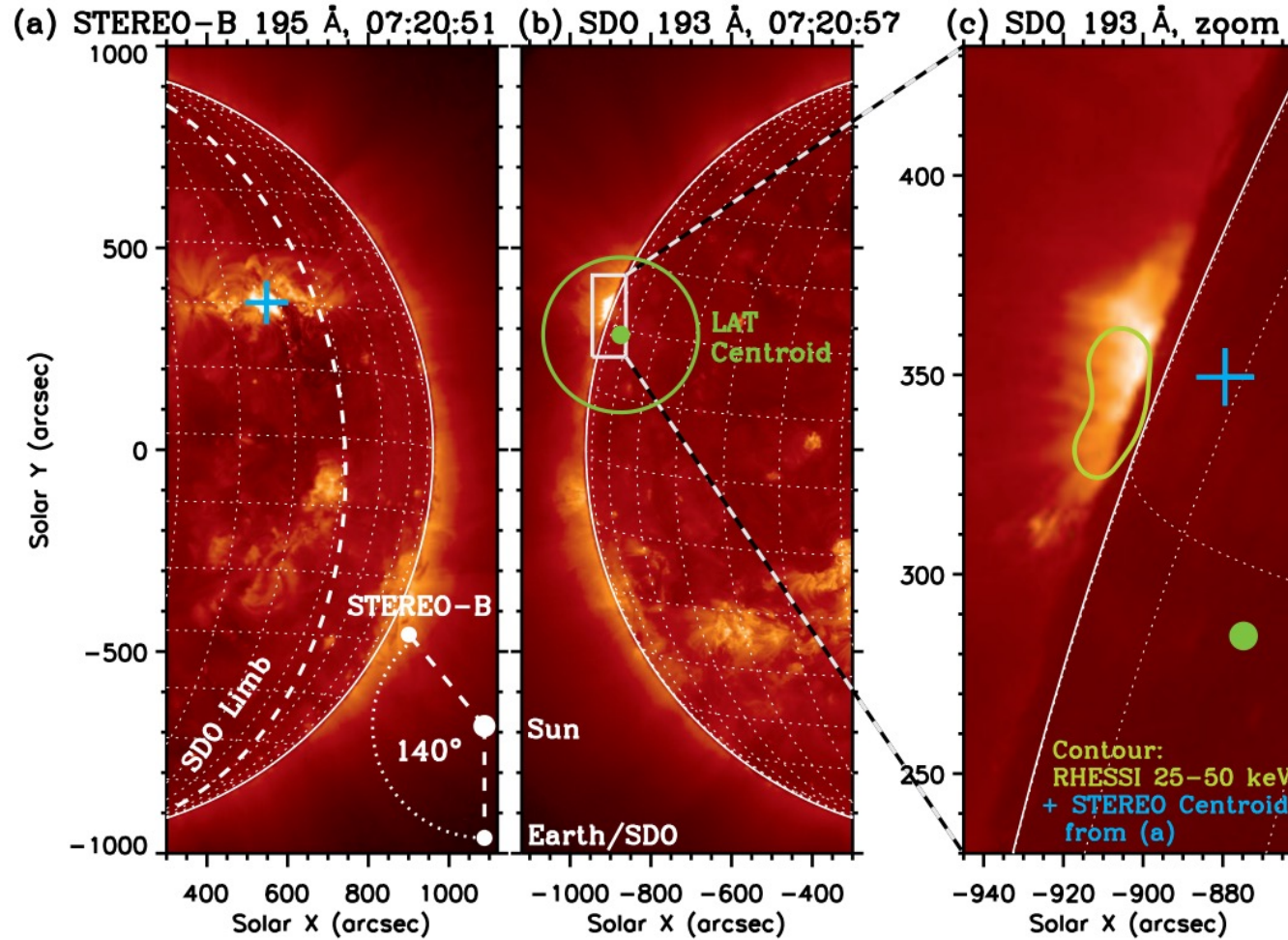
AGN and neutrinos



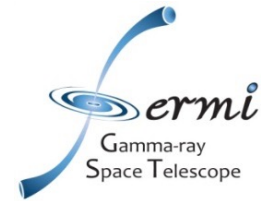
Icecube coll. et al. 2018



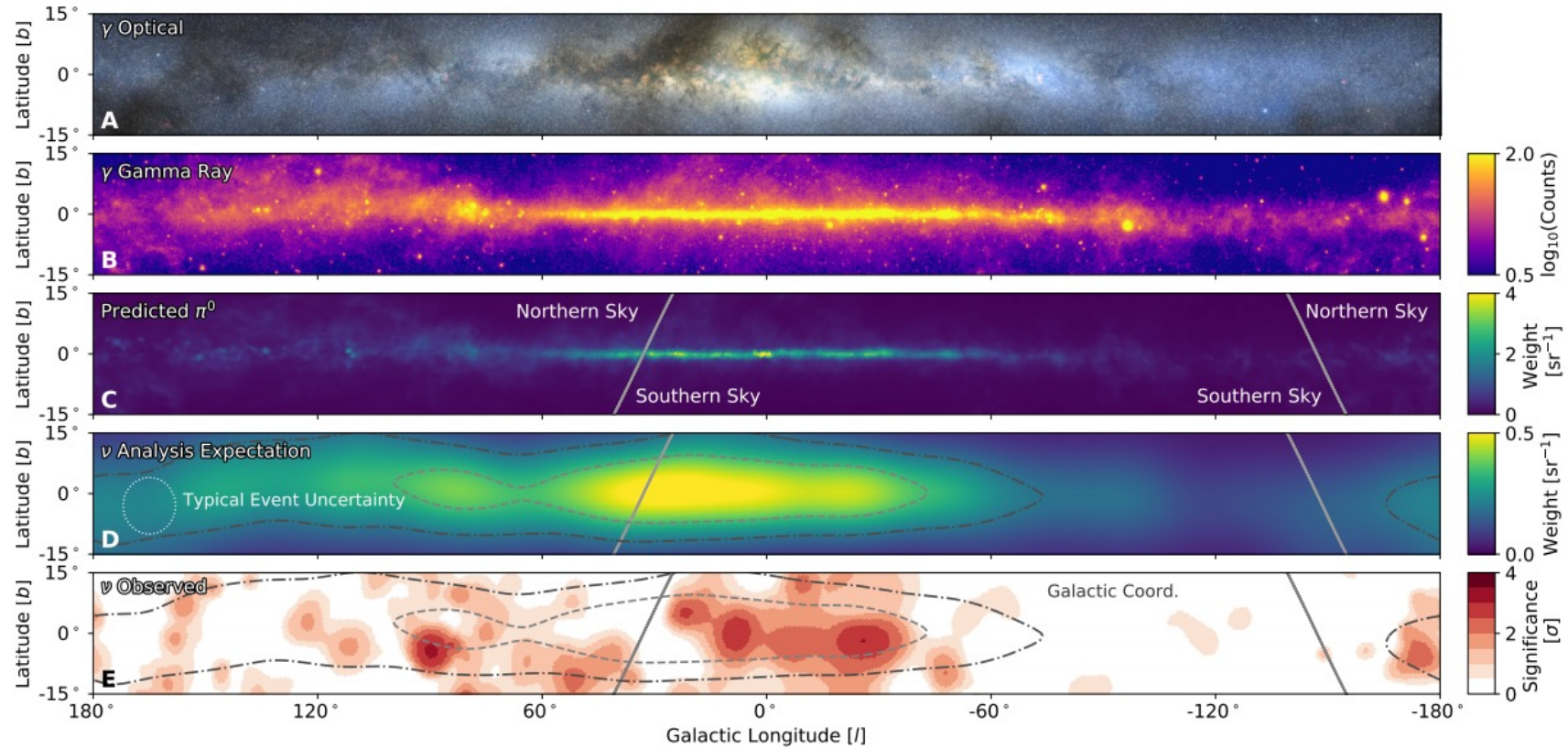
Solar physics and CRs



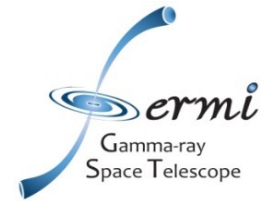
Ackermann, M. et al. 2017



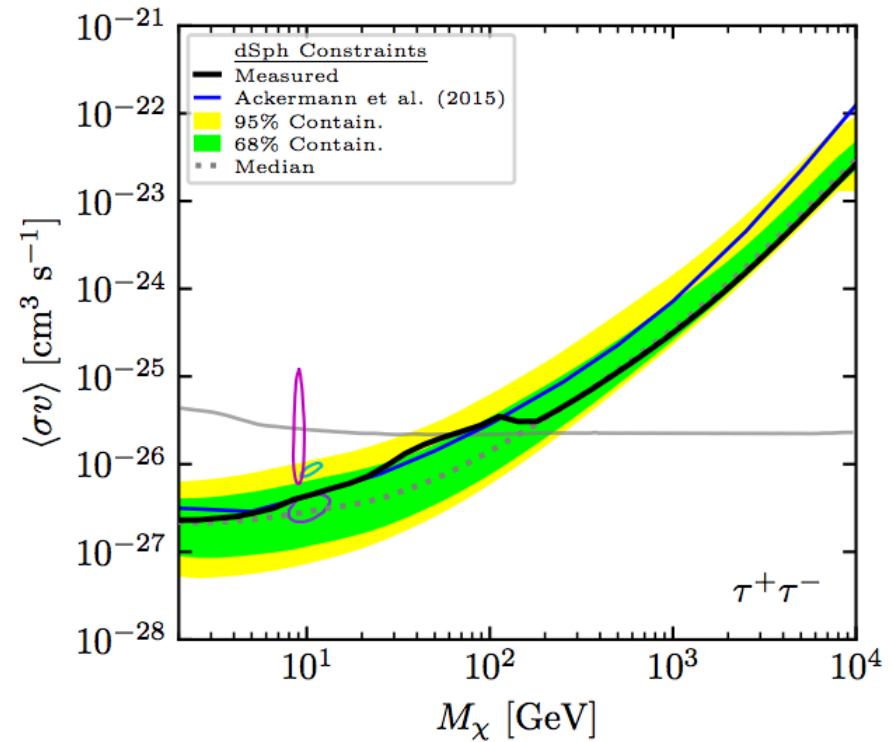
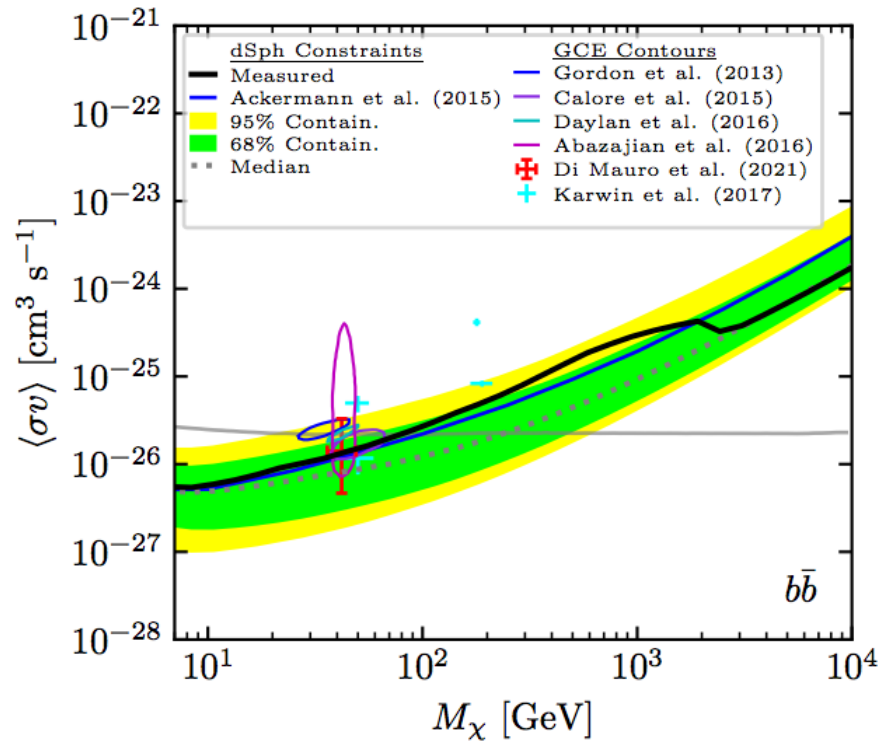
Diffuse emission and CR / nu



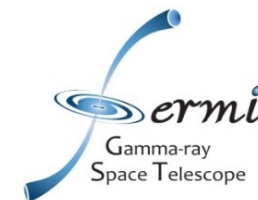
Abbasi et al 2024



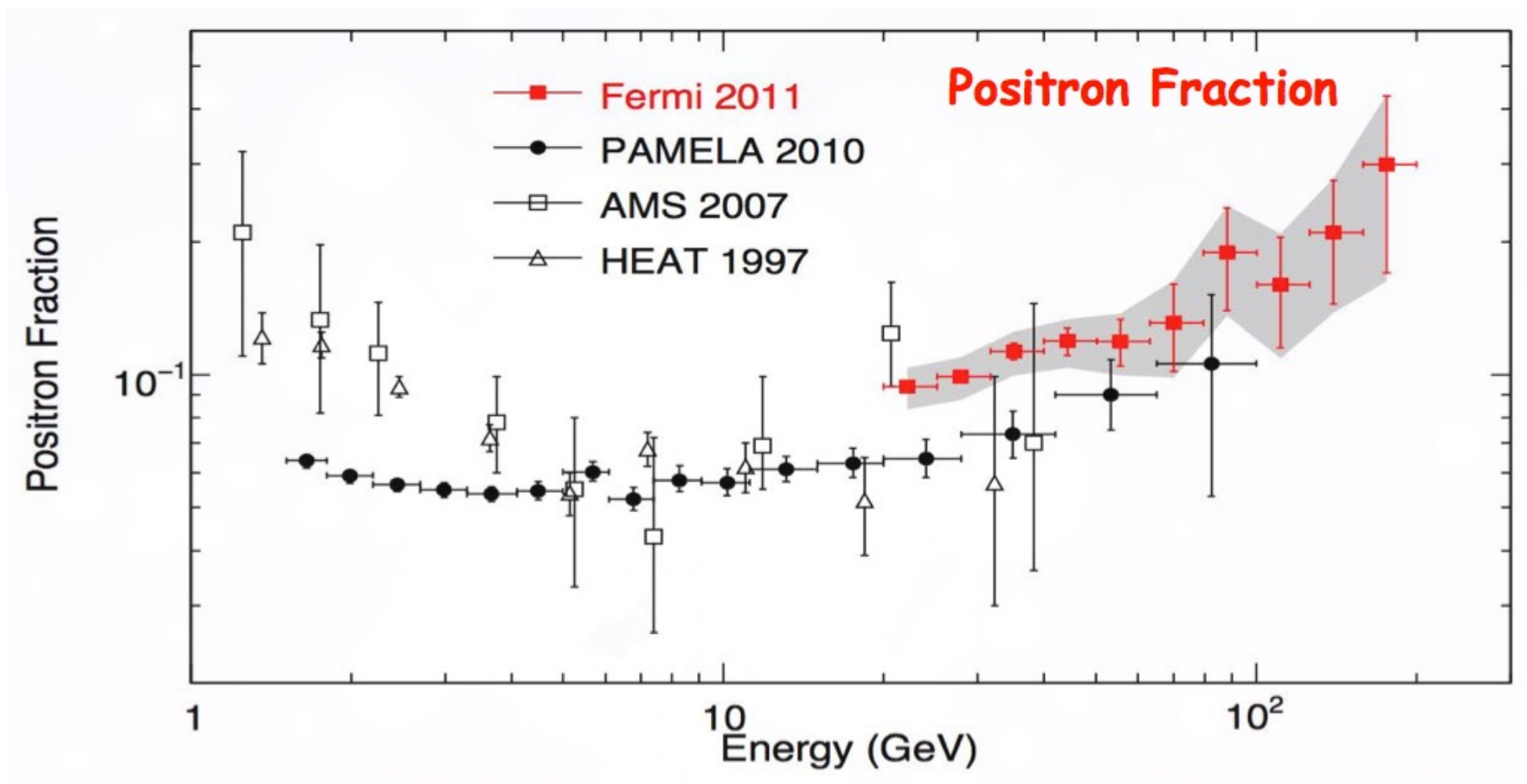
Dark Matter searches



Mc Daniel et al 2024



LAT as CR detector



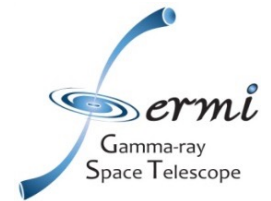
Ackermann et al 2012



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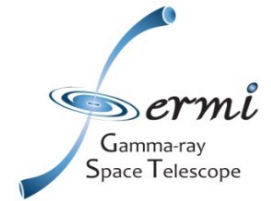




Challenges and Prospects...



Stratta et al 2018



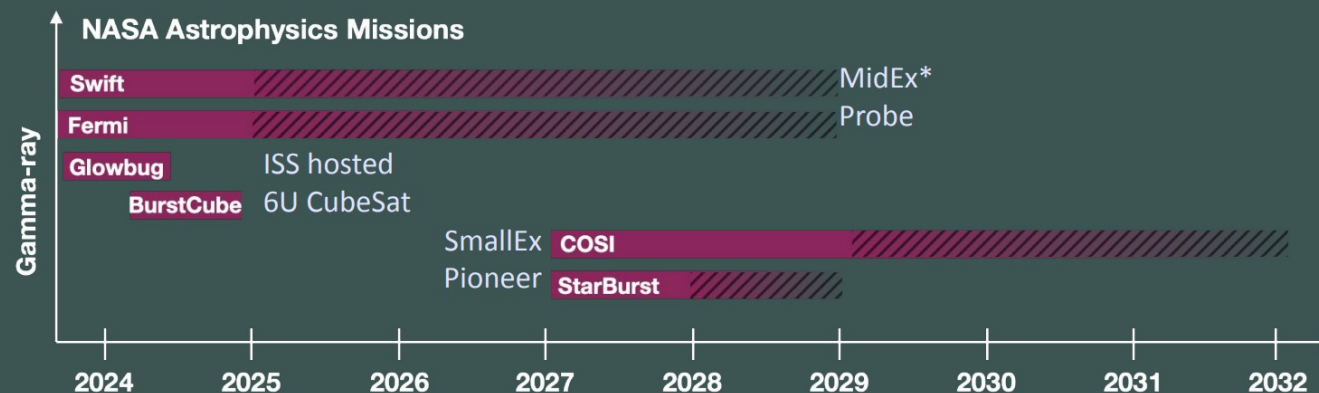
Challenges and Prospects...

Gamma-ray Astronomy



Revolutionizing Astrophysics through continuous observations

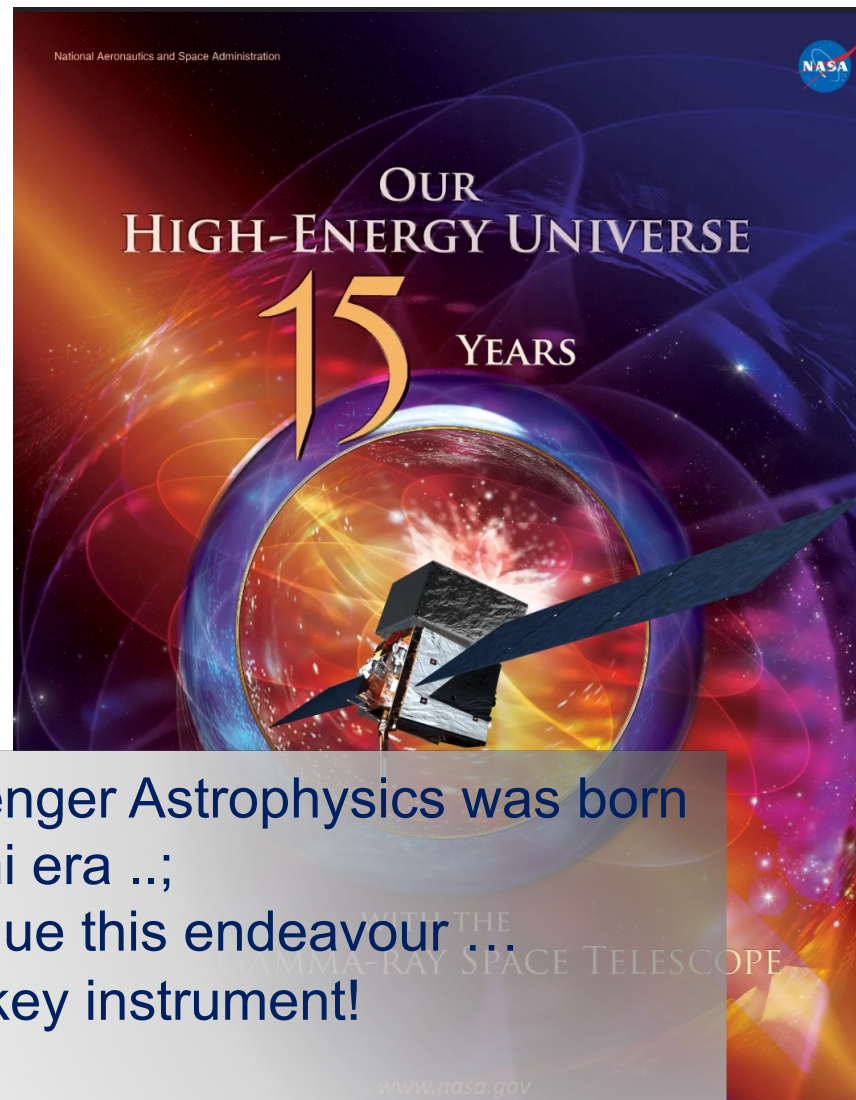
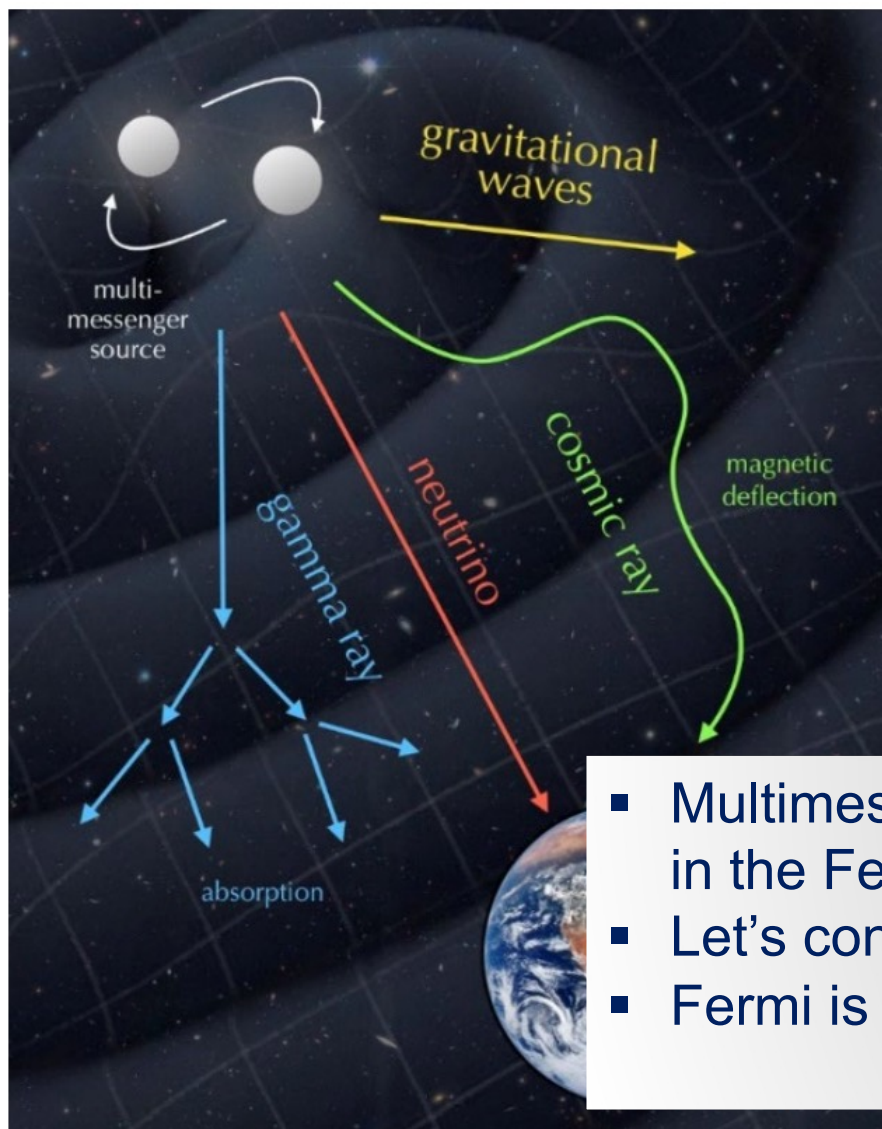
- Discoveries: new classes of transients and flares (GRBs, magnetars, novae, AGNs, multimessenger), large-scale/extended structures (Fermi Bubble), CR acceleration sites (SNR), particle interactions and accelerations (pulsars, jets etc.), constraints on DM.
- Issue: current major missions are all in their decade+ extended operational. Only smaller-scale missions have been funded.
- Action: Reassess current and future priorities for a gamma-ray vision towards 2040.



Hui - Fermi Symposium 2024



Take away message ...



- Multimessenger Astrophysics was born in the Fermi era ..;
- Let's continue this endeavour ...
- Fermi is a key instrument!