Fermi

Gamma-ray Space Telescope

Mission Update
June 27, 2023

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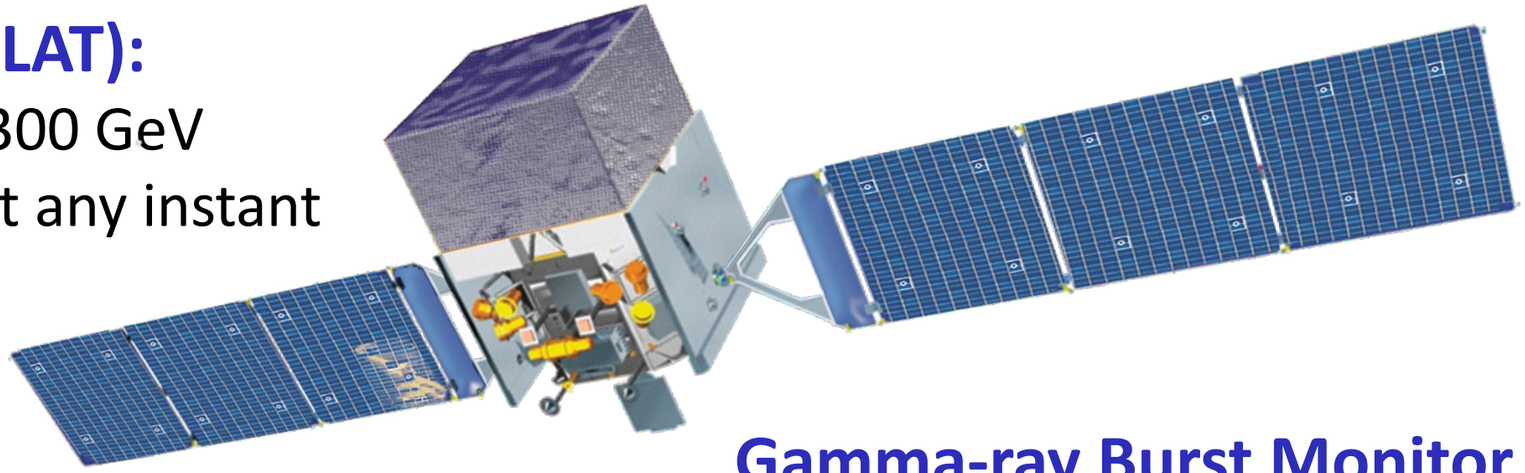
Fermi Mission Overview

Probe class mission to study the extreme high-energy Universe

Large Area Telescope (LAT):

20 MeV to more than 300 GeV
Views 20% of the sky at any instant
Entire sky in ~3 hrs



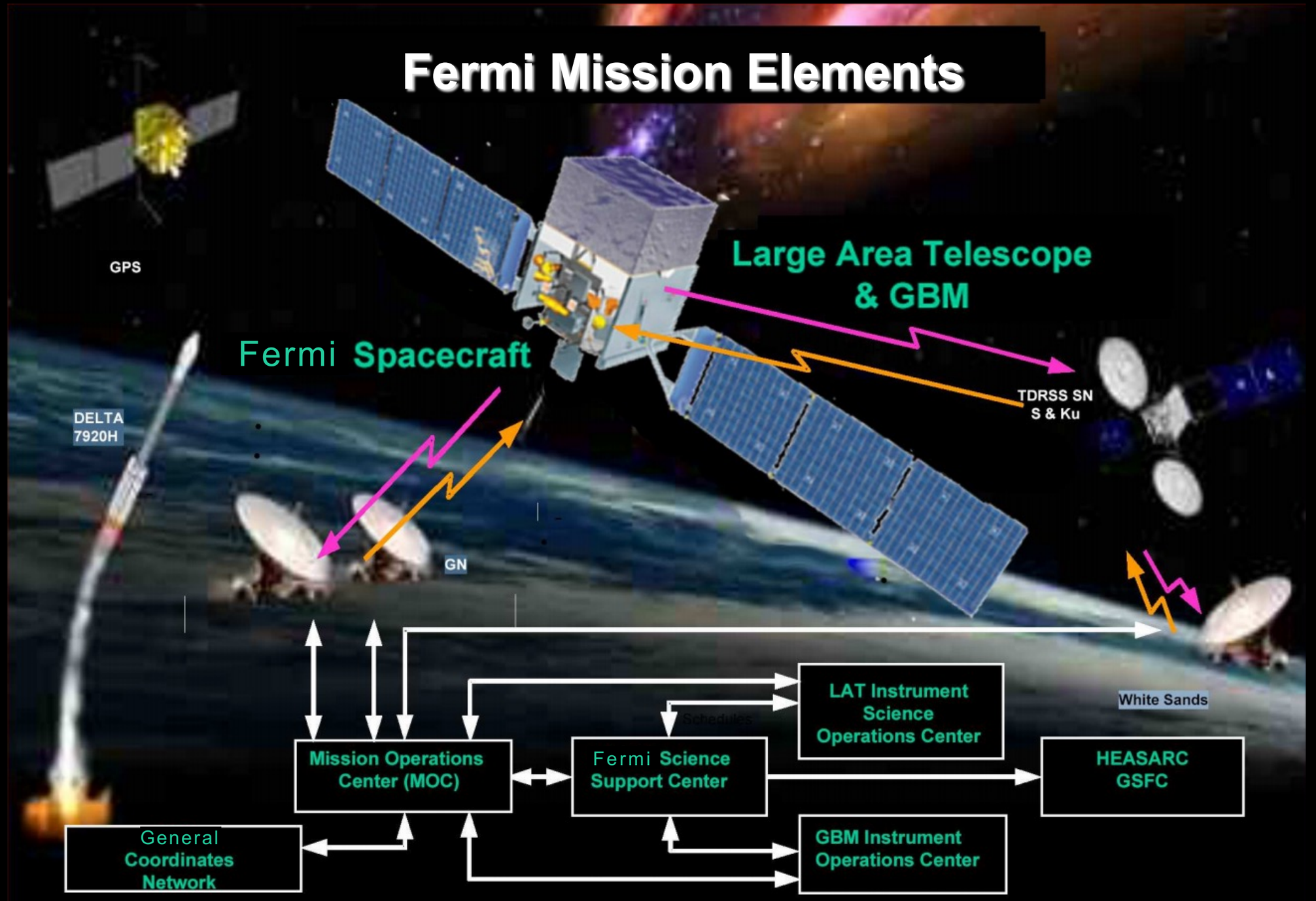
International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

Gamma-ray Burst Monitor (GBM):

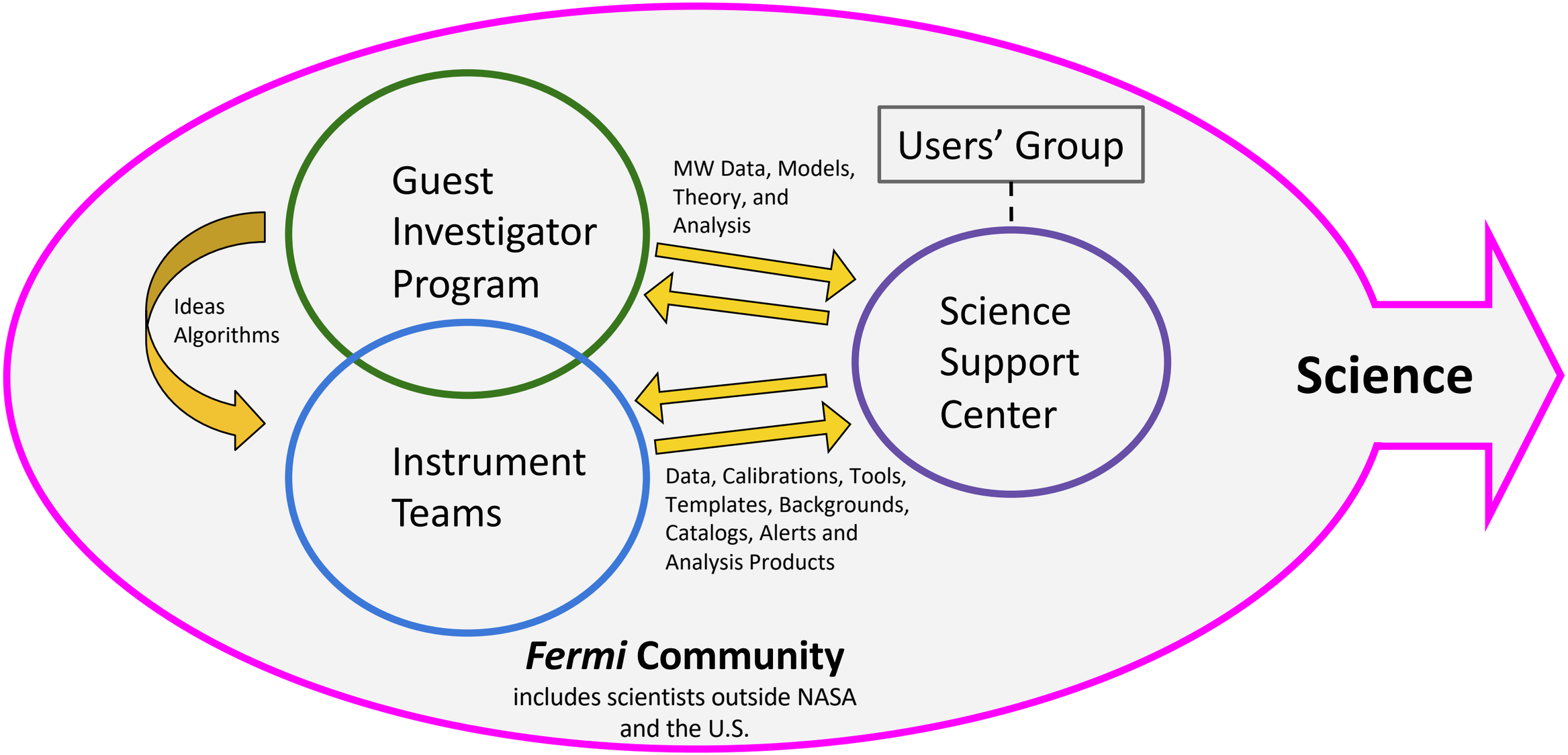
8 keV to 40 MeV
Views unocculted sky

- Community involvement is central to the mission
  - Guest Investigator program supports NASA-funded *Fermi* science
  - Data available publicly immediately after processing
- Science operations rely on integrated effort from instruments (LAT: SLAC/Stanford/NRL/ GSFC; GBM: MSFC/UAH), *Fermi* Science Support Center (FSSC; GSFC), and Flight Operations Team (FOT; GSFC)

Fermi Mission Elements



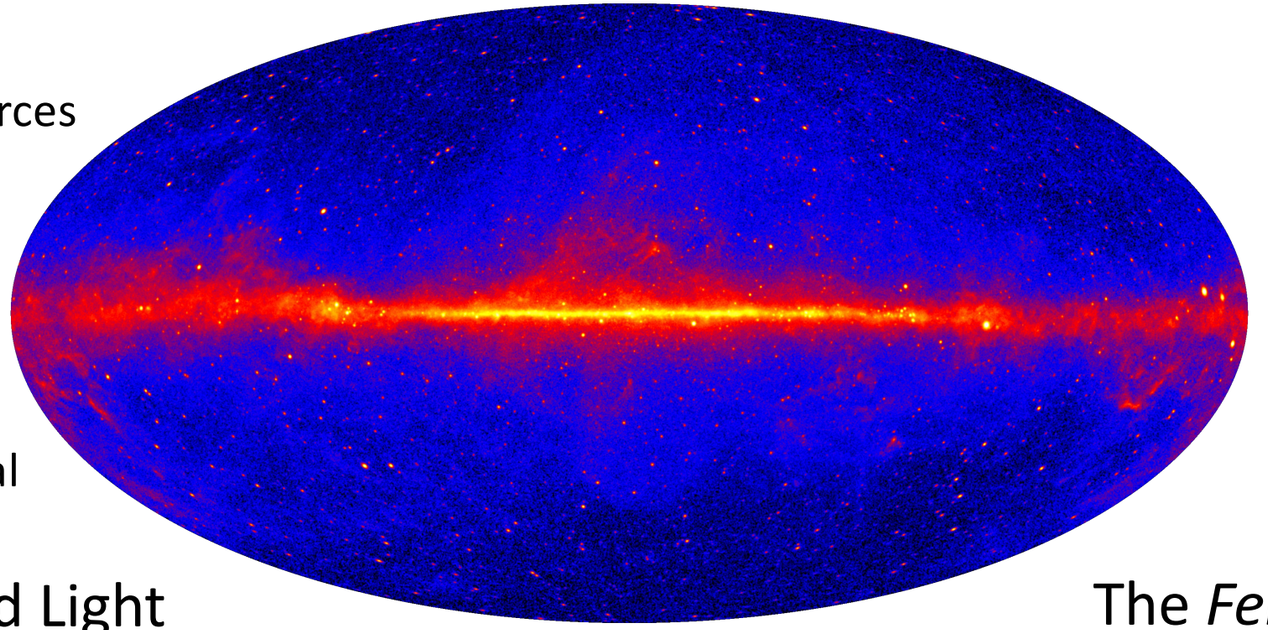
Fermi Community Organization



New Views of the Energetic Universe from 15 Years of *Fermi* Survey and Monitoring

Unveiling the sky

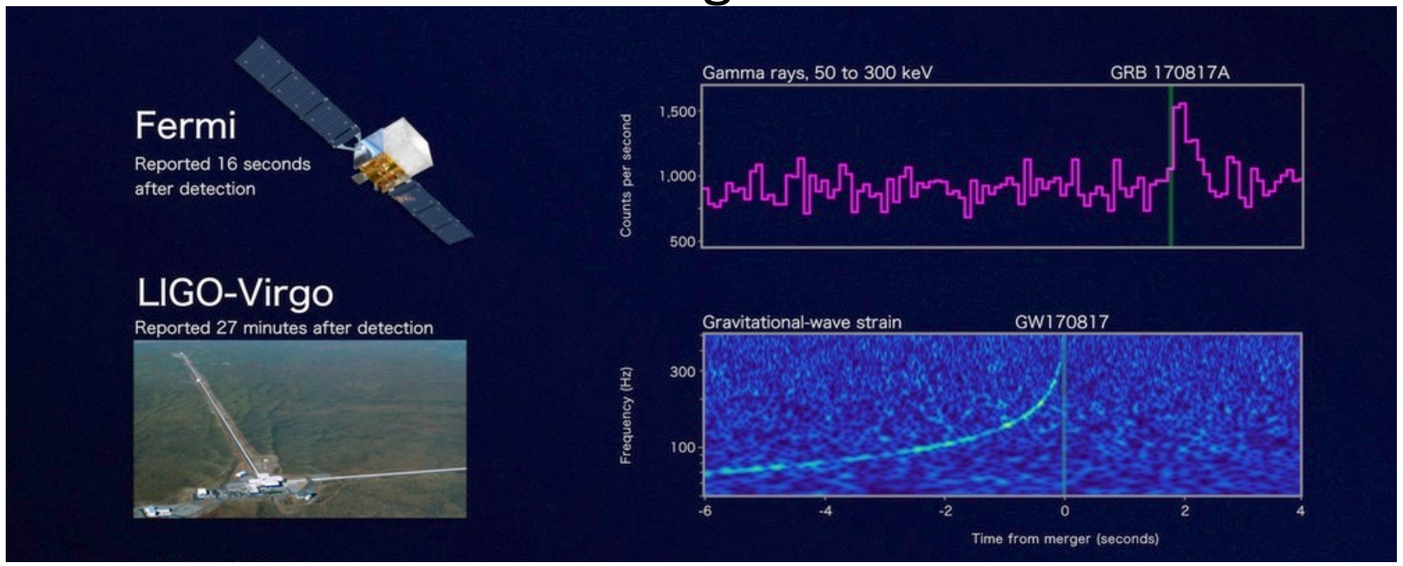
- >20x gamma-ray catalog sources
  - New source classes
  - New large-scale features
- >6000 transients
  - Gamma-ray bursts, magnetars, novae, solar flares and terrestrial gamma-ray flashes



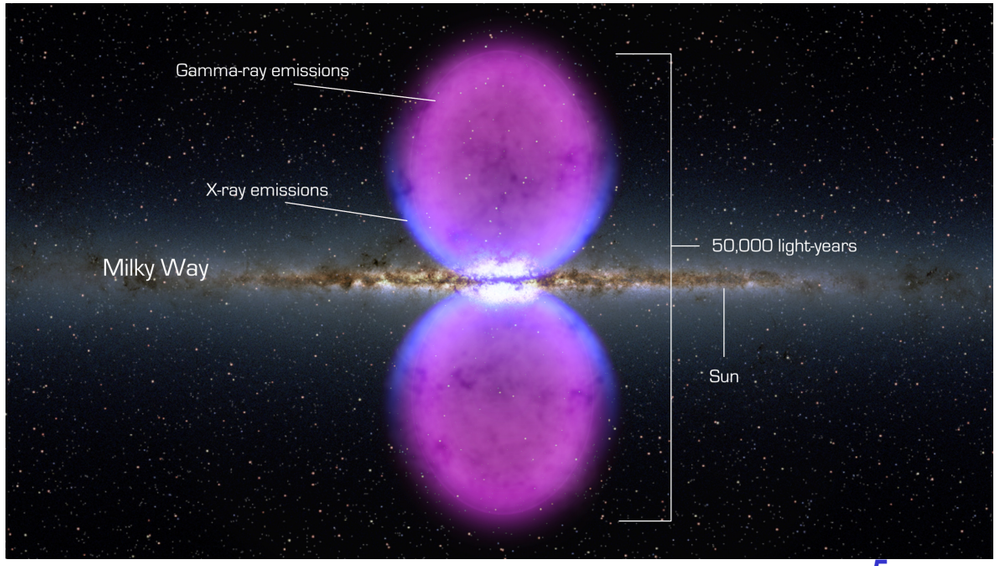
Enabling Discovery

- Immediate availability of photon data
- Automated public alerts
- Open access to analyzed source characteristics
- Continued development of public data products

Gravitational Waves and Light



The *Fermi* Bubbles

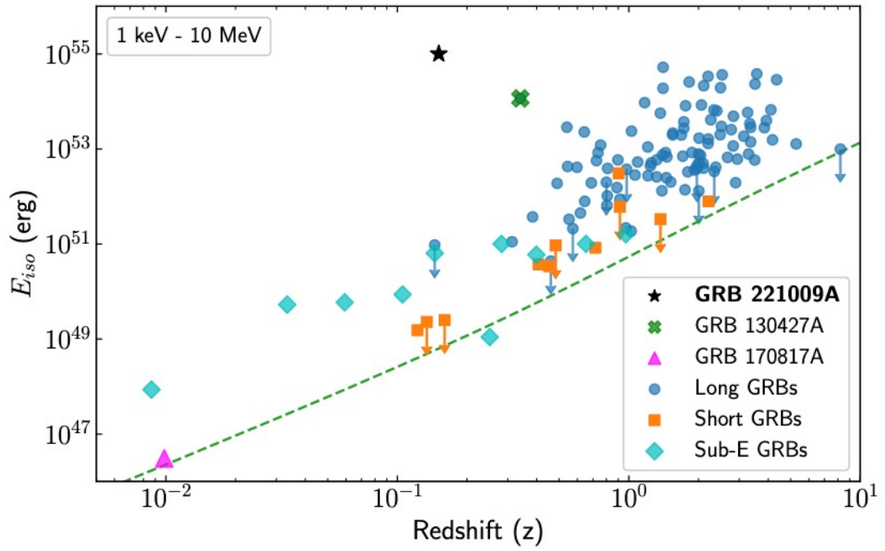


Game-changing Gamma-ray Burst Observations

First joint detection of a gamma-ray burst and a binary neutron star merger seen in gravitational waves – GRB 170817A

- Confirmed origin of (many) short-duration gamma-ray bursts
- Known mass of initial and final remnants from GW
- Speed of gravity consistent with speed of light
- Measured time lag for jet emergence following merger
- Characterized relativistic jet launched from a newly formed black hole

"Brightest of all time" burst - GRB 221009A

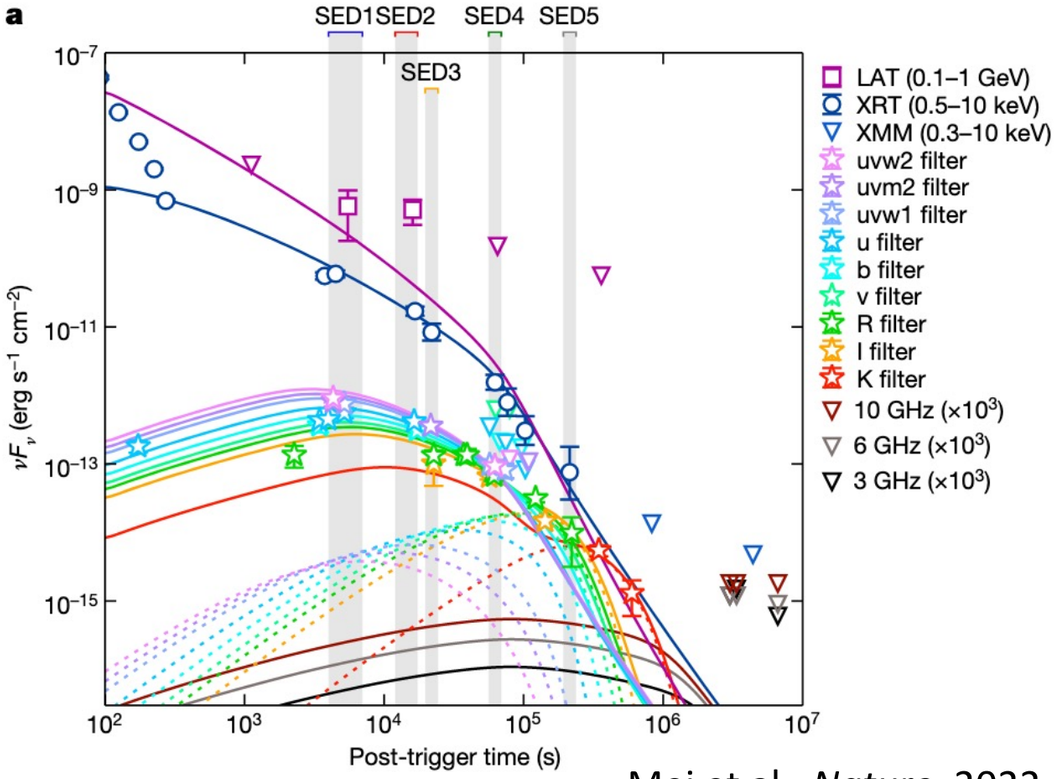


Highest isotropic equivalent energy, fluence and peak flux

Observed variability and evolution of a highly-collimated jet from a collapsar

Kilonova associated with a long-duration gamma-ray burst identified as a binary neutron star merger - GRB 211211A

- Gamma-ray afterglow detected by LAT several hours after the trigger suggests interaction of the jet with the kilonova

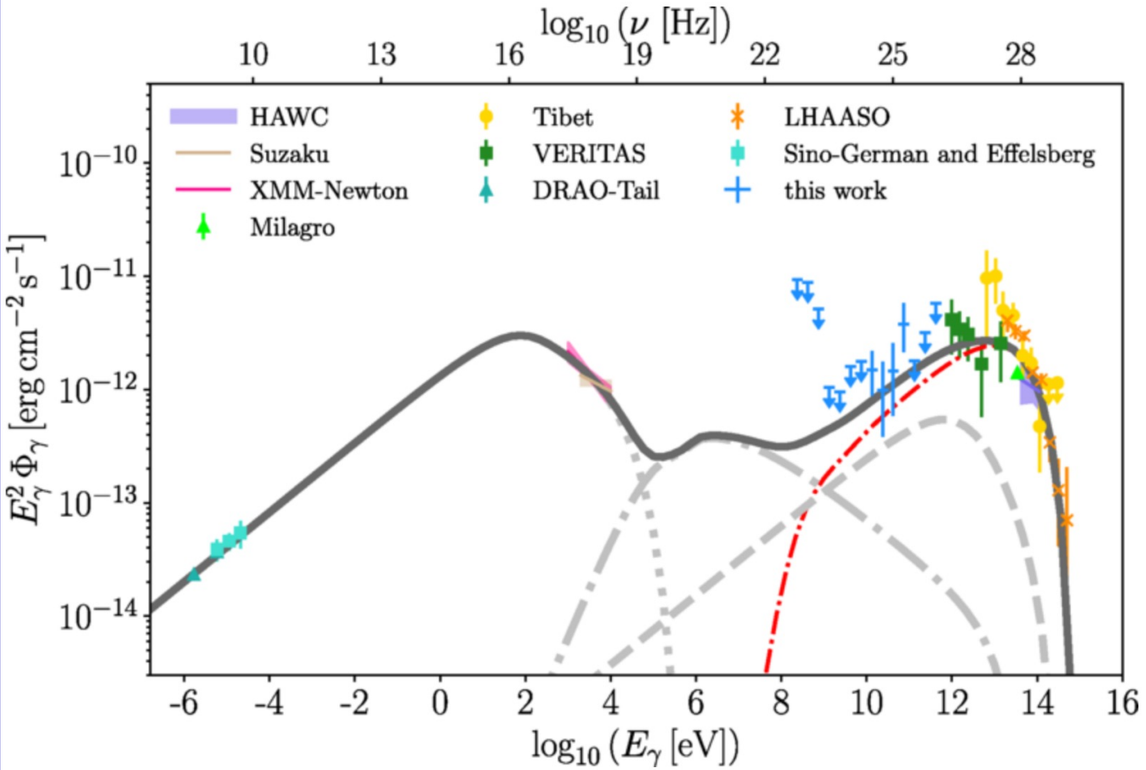


Mei et al., *Nature*, 2022

Cosmic-ray and Neutrino Origins

Fermi data reveal sources of proton acceleration in the Galaxy and candidate sources of extragalactic neutrinos.

Gamma-ray spectrum indicates PeV proton acceleration in SNR G106.3+2.7.

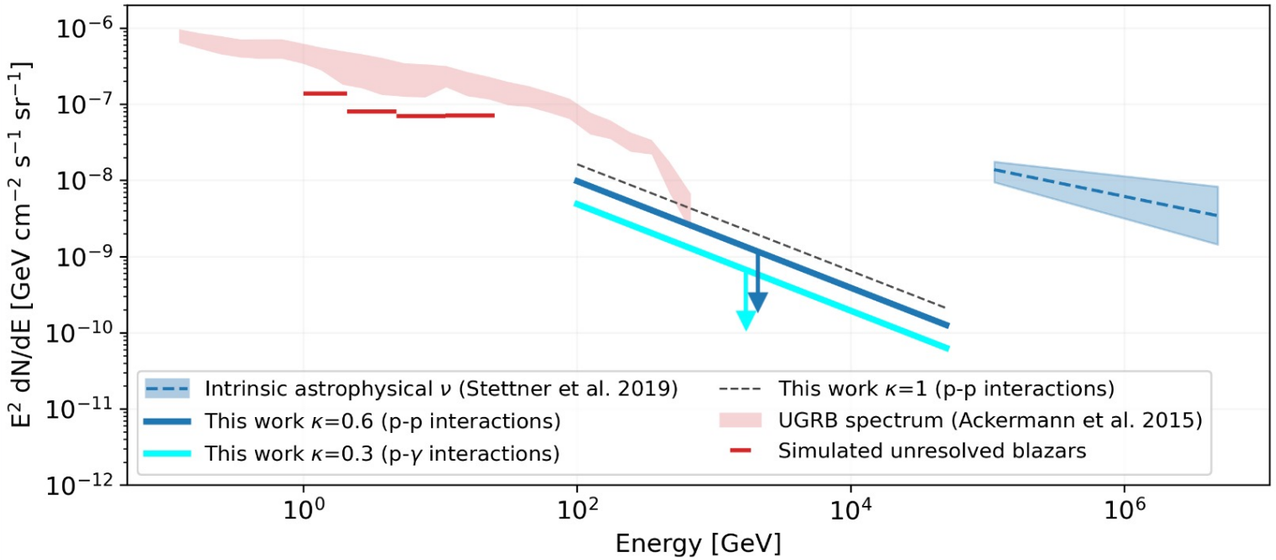


Fang et al., *Phys Rev Letters*, 2022

Neutrino counterpart candidates have been found through follow-up searches of events and catalog correlations, e.g.

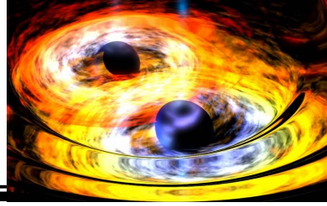
- TXS 0506+056, gamma-ray blazar
- NGC 1068, luminous Seyfert II galaxy detected by LAT

2D cross-correlation study of gamma-ray and neutrino data finds that unresolved blazars could contribute up to 1% of the astrophysical neutrino flux at 100 TeV.

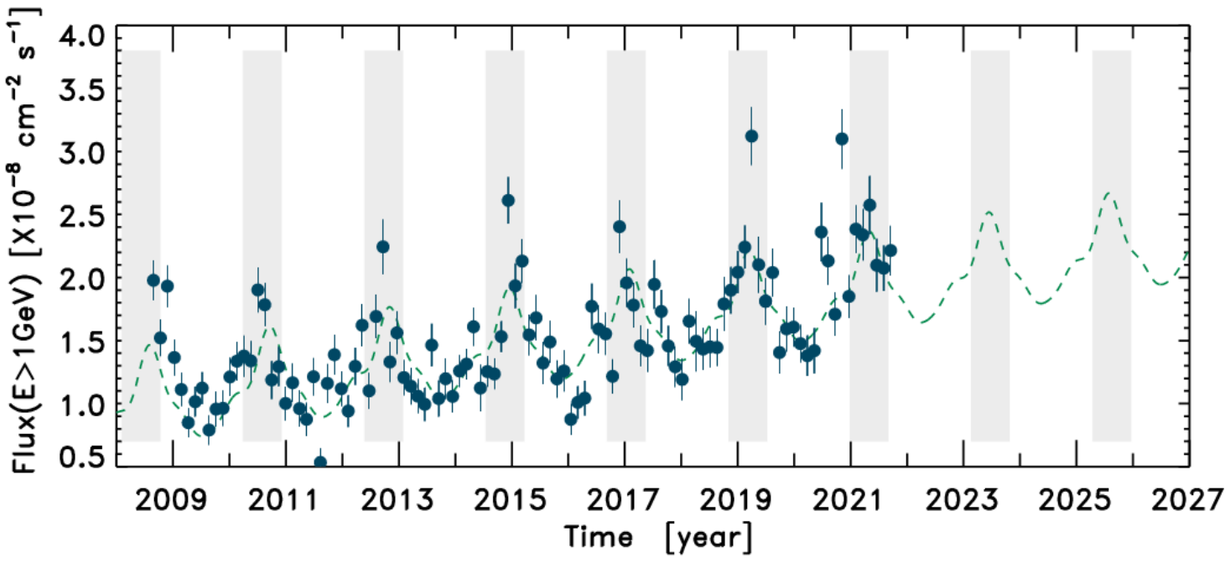


Negro et al., *ApJ*, 2023

Supermassive Black Hole Binaries

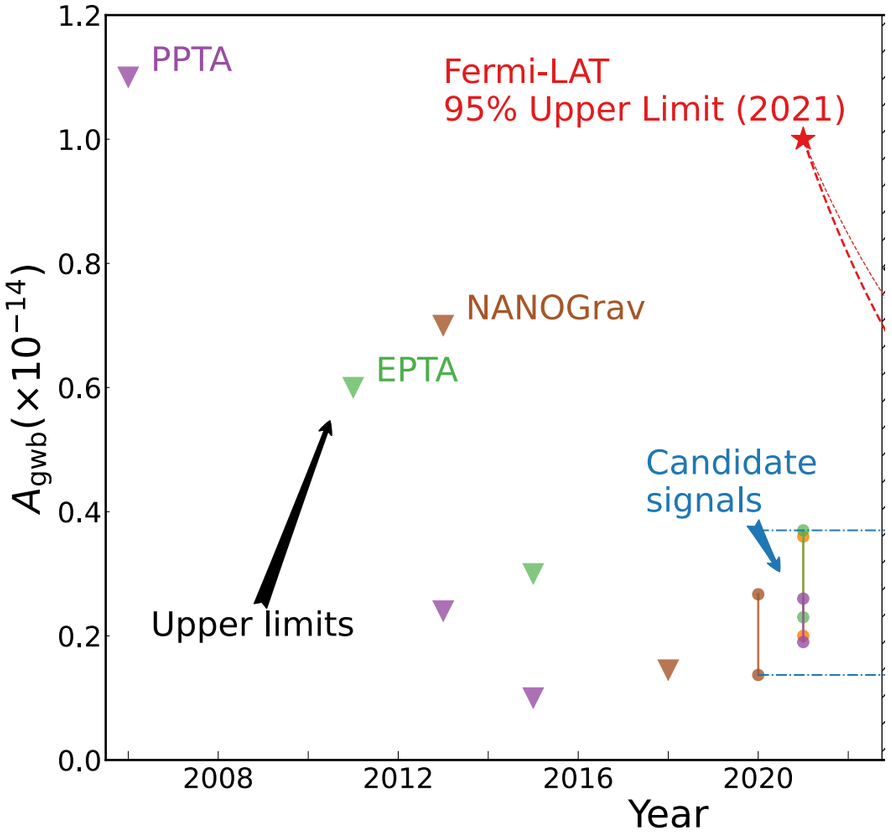


Mission-length observations of the entire sky provide highly unique data for time-domain and multimessenger studies.



SMBH binary candidate PG 1553+113 shows 2.2-year quasi-periodicity for >6 cycles. Data suggest emerging quasi-periodic signatures from additional candidates.

Otero-Santos et al., MNRAS, 2023; Peñil et al., ApJ, 2020



LAT millisecond pulsars create a gamma-ray pulsar timing array for independent measurement of the nHz gravitational wave background signal from SMBH binaries.

Ajello et al., Science, 2022

Fermi Science Support Center Highlights

- **GI Program Cycle 16 starts August 4. Award selections were announced May 2023.**
- **Data, software and catalog highlights**
  - **12-year catalog (4FGL-DR3) – January 2022**
    - **14-year catalog (4FGL-DR4) release planned later this year**
  - **Fermi GBM improved localizations for entire GRB catalog – July 2022**
  - **Caveats for GRB 221009A analysis – December 2022**
  - **LAT Light Curve Repository method publication – March 2023**
  - ***Fermi* GBM Data Tools code available on GitHub**
  - **Third Pulsar Catalog in review for release later this year**
- **Community highlights**
  - **10th *Fermi* Symposium – October 2022**
  - ***Fermi* Users' Group met December 14, 2022**
  - **Community workshop for fermipy developers held at SLAC in January 2023**
  - **GI proposers' workshop held online on January 24, 2023**
  - ***Fermi* Summer School – May 30 – June 9, 2023**

Subscribe to Fermi mailing lists for news and updates at https://fermi.gsfc.nasa.gov/ssc/library/newsletter/)

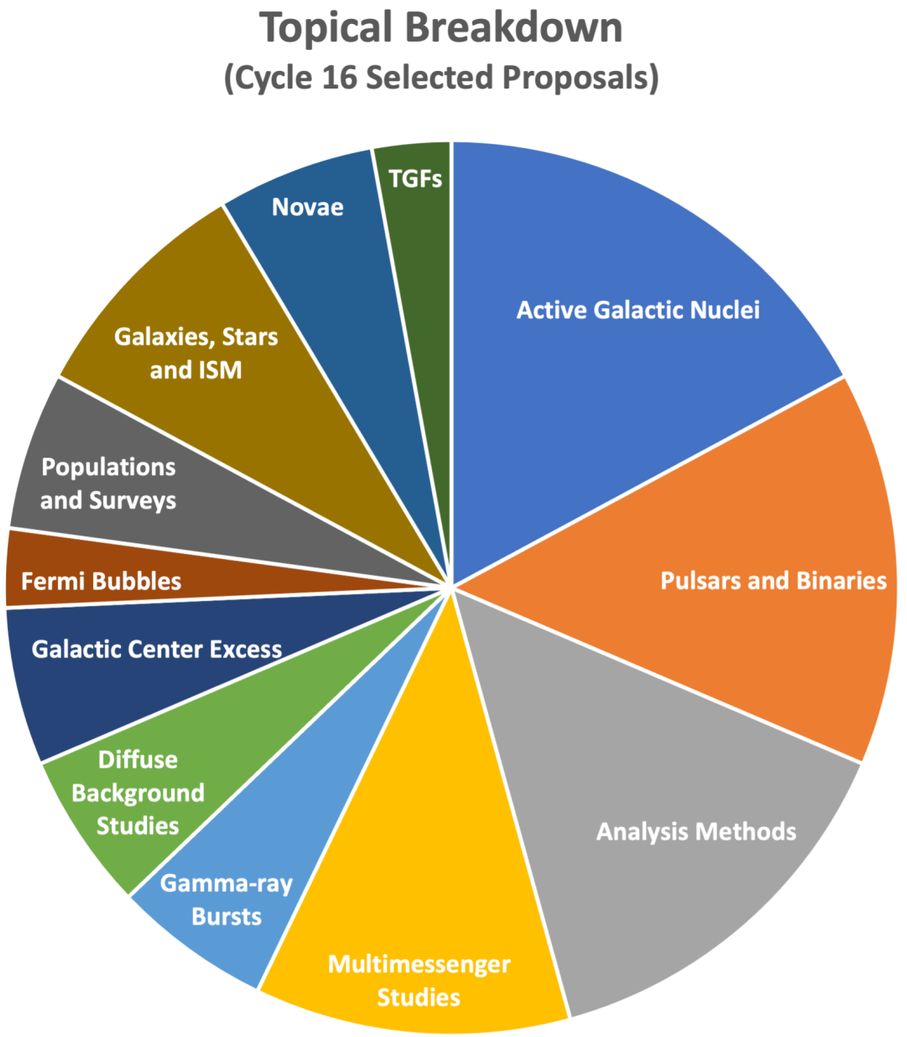
Topical Evolution of the Guest Investigator Program

The *Fermi* Guest Investigator Program provides funding for

- Analysis of LAT and GBM data
- Supporting observations in other wavebands
  - Joint programs include NRAO, NOIRLab, VERITAS, Integral, and TESS
- Complementary theoretical studies
- Analysis methods

Awarded topics have evolved throughout the mission with a growing emphasis on multimessenger studies and analysis methods.

New trend for Cycle 16: 11% of proposals incorporate machine learning



10th *Fermi* Symposium in Johannesburg, South Africa

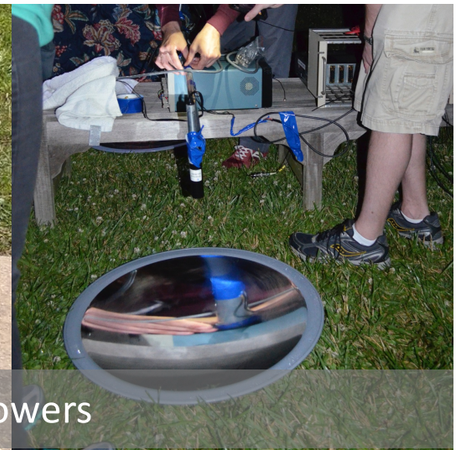
Fermi Gamma-ray Summer School

10-day workshop on gamma-ray science, analysis and instrumental techniques hosted at the University of Delaware.

Lectures and hands-on tutorials for graduate students and postdoctoral researchers.

Held annually since 2011 (1 yr canceled and 1 virtual for COVID-19.)

Lectures and tutorials on gamma-ray astrophysics



Muon and Cherenkov detectors reveal cosmic-ray showers

Fermi IDEA Highlights

- Challenges include serving international and widely distributed teams and community
- Inclusive practices to support training, development and collaborative science include
  - LAT and GBM mentoring program provides mentorship outside of science advising
    - Professional training provided at start and feedback gathered during and at completion of each 1-year cycle (previously 6 months)
    - Matching considers mentee preferences related to background, language, geographical locations+
    - 46 mentor/mentee pairs since Spring 2021
  - LAT Collaboration leadership model uses rotational coordinator roles for science analysis leads and science working groups to bring diverse perspectives to decisions and policies
    - Roles are frequently filled by early- to mid-career scientists
    - Enables feedback channels through regular coordinator, science group and collaboration meetings along with direct solicitations from leadership and PI on policy updates
    - Ombuds program provides additional path for dispute resolution external to leadership chain
  - *Fermi* Summer School introduces gamma-ray analysis to graduate students and postdocs from a variety of backgrounds
    - >250 students from ~20 countries (6 continents) in 11 years (+ ~60 participants in 2021 virtual workshop)
    - Imposter syndrome workshop included since 2022 with strong positive response from participants
    - Anonymous feedback collected annually by organizers

Observatory Highlights

- **Spacecraft and instrument performance is excellent at 15 years**
  - No consumables or rapid degradation of spacecraft or instrument components
  - One solar array drive no longer rotates; modified survey strategy maintains power margin while avoiding loss of observational efficiency
  - Gradual degradation in instrument components is compensated by calibration
- **Orbit outlook**
  - Lifetime of orbit extends into the mid-2030s
  - Studying orbit adjustment to lower planning frequency for collision avoidance maneuvers
    - Frequency of maneuver planning for collision avoidance has increased due to increasing number of objects for this orbit
    - Have not had to execute a maneuver since 2012, but planning impacts operations even when the maneuver is waived
    - Onboard activities will resume after completion of LIGO/Virgo/KAGRA O4 gravitational wave run
- **Communications outlook**
  - Near-term: outages of TDRS Demand Access Service cause a loss of real-time notices for GRBs and other transients. Ground-generated notices are not available for several hours.
    - Storm damage to Guam station caused total DAS outage for ~2 weeks; ongoing gaps in DAS coverage require continued manual scheduling until full service is restored
  - Long-term: *Fermi* uses TDRS for all commanding, data, and real-time alerts – phase out planned in 2030s

4th Gravitational Wave Observing Run (O4) Has Begun

- **LIGO/Virgo/KAGRA observations began in May 2023 and will continue for 18 months**
  - ***Fermi* observatory activities that disrupt observations are kept to a minimum**
  - **GBM**
    - **Normal GRB activities supplemented with follow-up of LVK public alerts**
    - **Coordinating with Swift and LVK on joint sub-threshold searches for binary neutron star mergers in O4 – these will be fully automated for distribution through GCN Kafka**
    - **Combined GBM targeted search and Swift-BAT 1-s rates search allows flux upper limits as a function of sky position**
    - **Joint efforts with Swift provide arcminute localizations for a subset of GBM bursts**
    - **Nearby, very massive binary black hole mergers interesting to constrain signals from a neutrino anti-neutrino wind scenario**
  - **LAT**
    - **Gravitational wave region search pipelines updated and operating**
    - **Searches of probable binary neutron star mergers and neutron star black hole binary mergers. Circulars will be issued for events of significant interest.**
    - **Summary tables of LAT observations to be released during O4**

Key *Fermi* Capabilities for TDAMM

- Unique and highly dynamic energy range
  - 8 keV - >300 GeV provides triggers and observations for a wide variety of energetic astrophysical events
- Sensitivity reaches beyond outliers in many transient and variable source classes
- All-sky survey provides both instantaneous access and history
  - Real-time or near real-time observation data of events anywhere in the sky
    - GBM within 1.5 hrs
    - LAT within ~ 3 hrs (typical time to cover 80% of GW event region 1000 sec)
  - Archival searches from ms to years available for 15 years and counting
- Real-time monitoring and automated communications
- Data available immediately after processing
  - Catalogs + public data products provide insight and context for multiwavelength and multimessenger studies
  - Team-operated science pipelines generate added alerts and information
- Partnerships among science support center, instrument teams, MW/MMA observational facilities and community enable innovations in analysis and tools

Fermi Transient Searches 2008-2009

Transients Timescale Pipelines

Pipeline
Method
Timescale
Distribution
Status

GBM Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices

LAT Automated Science Processing (ASP) + Flare Advocates
Likelihood
6 & 24 hour
ATels

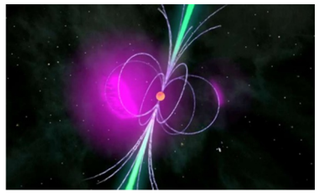
***Fermi* LAT Monitored Sources (21)**
Daily, Weekly above 10^{-6} cm^{-2}s^{-1}

LAT Catalogs
Likelihood, associations
FGL

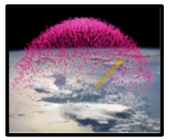
μs ***ms*** ***s*** ***minutes*** ***hours*** ***days*** ***months*** ***years***

Photon Timing

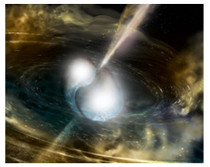
Pulsars



Terrestrial γ-ray Flashes



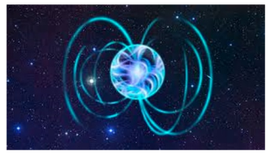
GRBs



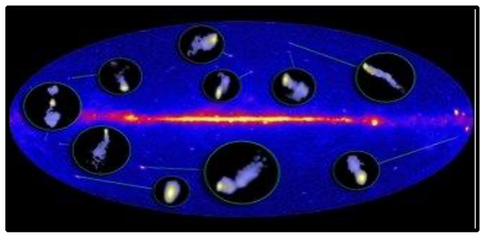
Solar Flares

All Sky Cadence

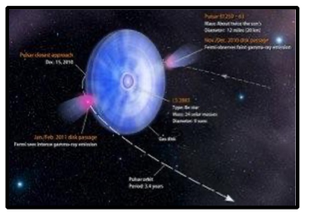
Magnetar Flares



Blazar Flares



γ-ray Binaries



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Fermi Transient Searches

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 + Blind Search

***Fermi* All-sky Variability Analysis (FAVA)**
Aperture Photometry, 1 week
ATels, FAV catalogs

***Fermi* LAT Light Curve Repository**
Likelihood LAT Catalog Sources
3 days, 1 week, 1 month

GBM Targeted Search
ground search
ms - s
Temporal/Spatial Input

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

***Fermi* LAT Monitored Sources (187)**
Daily, Weekly above 10^{-6} cm^{-2}s^{-1}

GBM Untargeted Search
ground search
ms - s
GCN Notices

GBM Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices

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

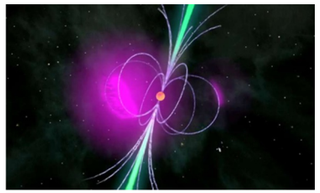
LAT Catalogs
Likelihood, associations
FGL, FHL, LAC, FLE, PSR+

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

Photon Timing

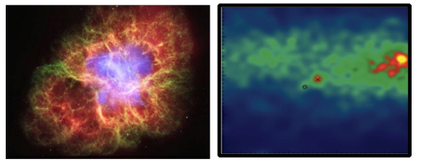
All Sky Cadence

Pulsars



Solar Flares

Crab Flares Novae



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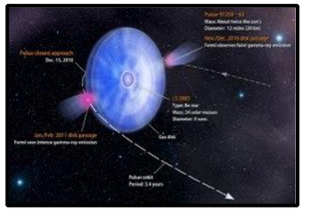

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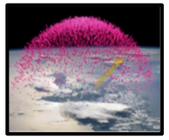

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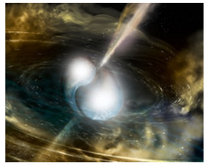

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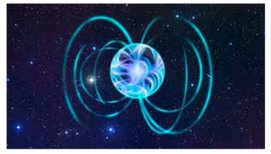

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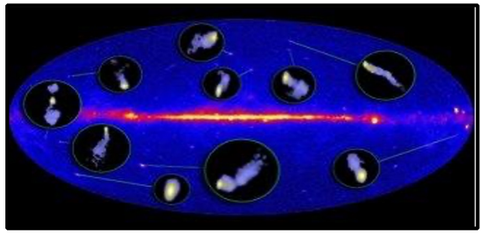

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Mission Responses to TDAMM Priorities

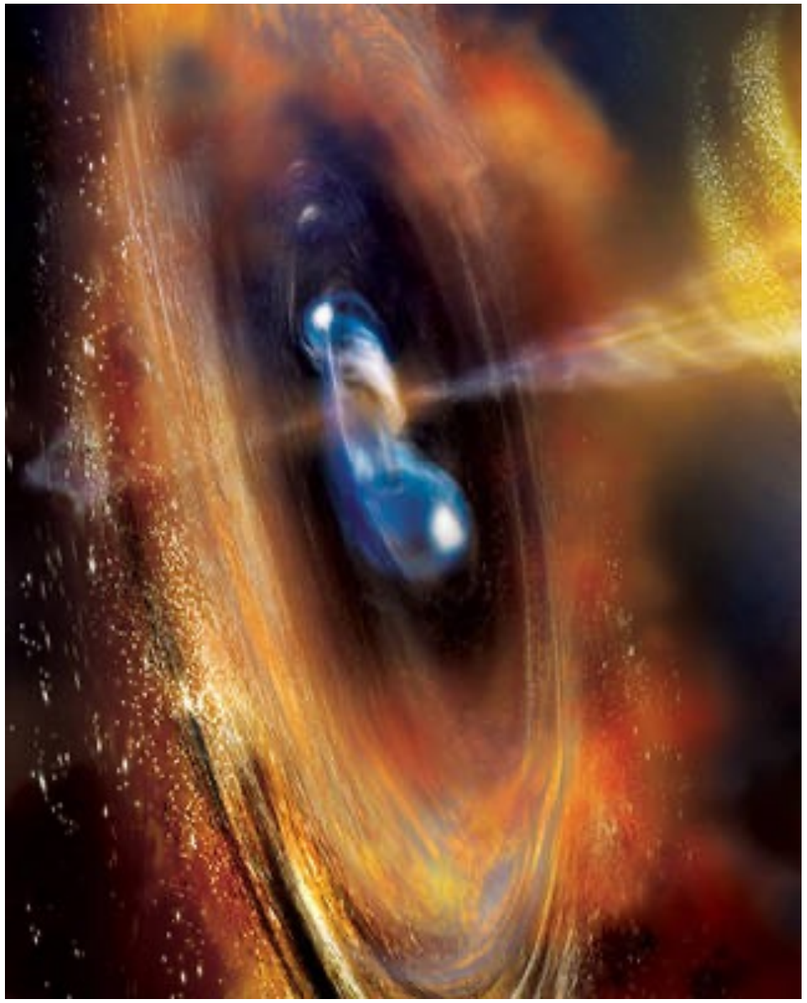
- **Observational responses**
  - Continue to provide high efficiency survey of the sky – maximize probability of coincident observations of neutrino and gravitational wave events
  - Minimize down time for instruments
    - Reduced region where LAT pauses data acquisition for the South Atlantic Anomaly
    - Limiting calibration and engineering activities during LIGO/Virgo/KAGRA O4 run
    - Adjusted collision avoidance maneuver process to avoid interruption of science data taking
  - Maintain high efficiency for receiving real-time alerts containing onboard GRB locations
  - Exploratory tests to lower onboard GBM trigger threshold in planning

Mission Responses to TDAMM Priorities

- **Added emphasis on enabling community multiwavelength and multimessenger activities**
  - **Dedicated analysis pipelines and public communications of results**
    - **Updates to use new GCN system for communicating transient events**
    - **Targeted search developed for gravitational wave counterpart searches is general and can be used for other astrophysical events**
    - **Enhancement of subthreshold searches of GBM data for external events**
      - **Additional automation streamlines search and notification process**
      - **Joint activities provide improved localization and enhance sensitivity of searches**
  - **New public data products support multimessenger and time-domain activities**
    - **LAT light curve repository provides updated, high-quality, mission-length light curves for ~1500 variable sources – expanding to include time series analysis**
    - **Third pulsar catalog will provide timing and spectral characterizations over 14 years for >280 pulsars**
    - **Summary tables of LAT observations of GW events to be released during O4**

Fermi Press Highlights

- NASA Looks Back at 50 Years of Gamma-ray Burst Science – June 2023
- NASA Missions Study What May Be a 1-In-10,000-Year Gamma-ray Burst – March 2023
- NASA's Fermi Captures Dynamic Gamma-Ray Sky in New Animation – March 2023
- NASA's Fermi detects first gamma-ray eclipses from 'spider' star systems – January 2023
- NASA Missions probe game-changing cosmic explosion – December 2022
- NASA's Swift, Fermi Missions detect exceptional cosmic blast – October 2022
- NASA's Fermi Confirms Star Wreck as Source of Extreme Cosmic Particles – August 2022



Credits: A. Simonnet (Sonoma State Univ.) and NASA's Goddard Space Flight Center