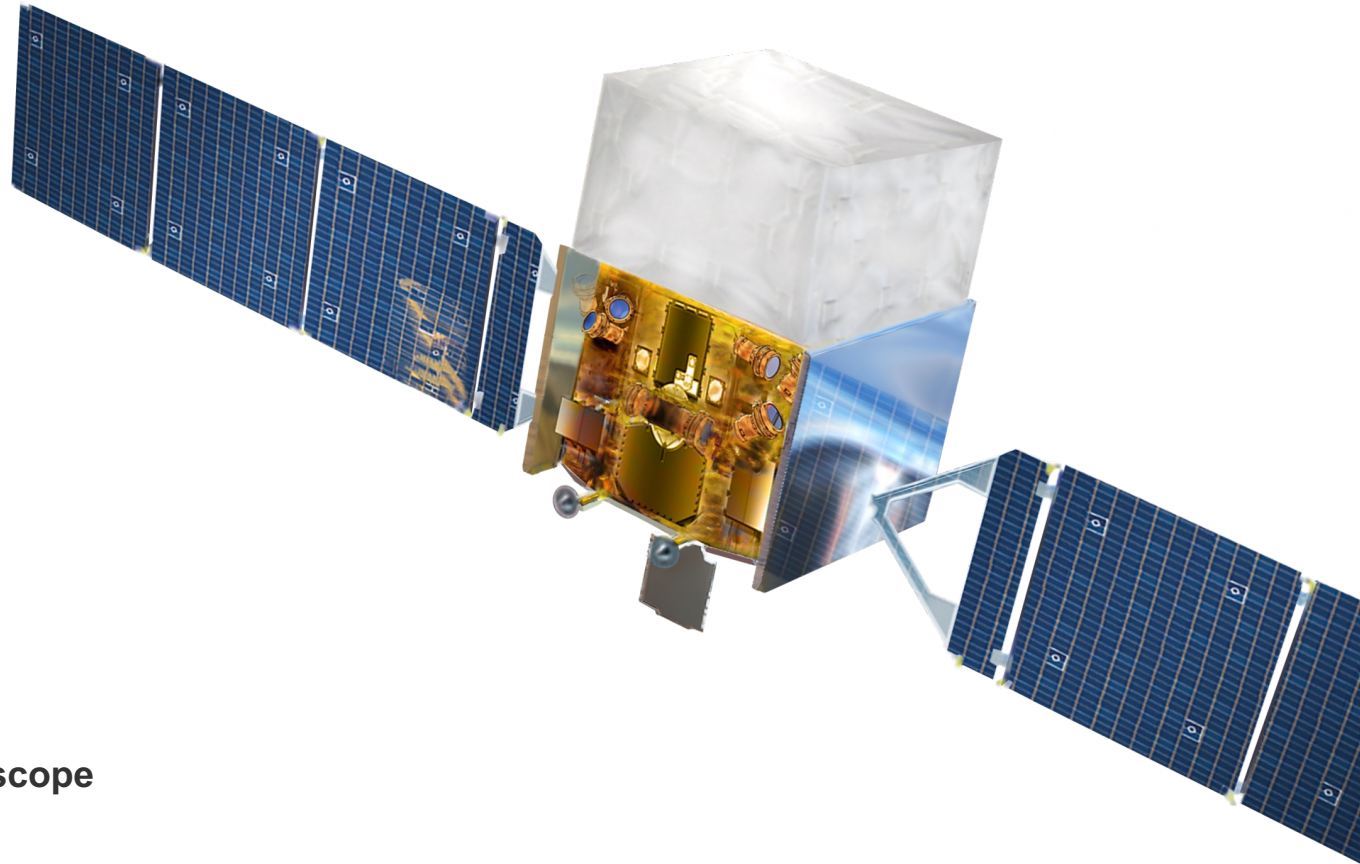




Universität Hamburg  
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## The Fermi Large Area Telescope

Henry Grell

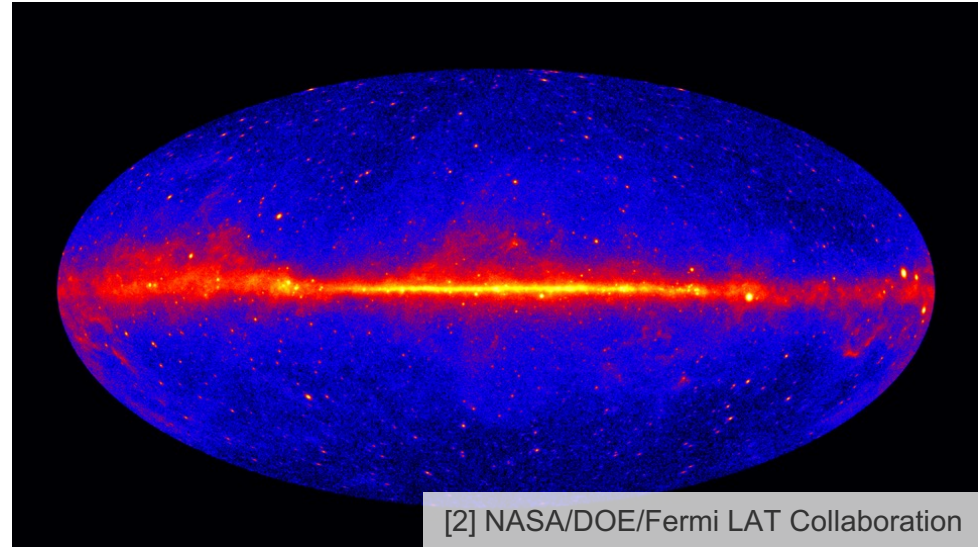
30.06.2026

# Structure

- Gamma-ray astronomy
- The Fermi Satellite
- The Large Area Telescope (LAT)
  - Tracking and Calorimeter Modules
  - Anticoincidence Detector and Data Acquisition
- Discoveries
  - Gamma-Ray Bursts
- Summary

# Gamma-ray astronomy

- $\gamma$ -rays allow viewing very high energy events
- Electrically neutral  $\rightarrow$  Origin is easy to trace
- Easier to detect than neutrinos and gravitational waves
- Goals of  $\gamma$ -ray astronomy:
  - Determine the origin of cosmic rays
  - Search for  $\gamma$ -rays from dark matter decay/annihilation
  - Research the structure/evolution of the universe



$\gamma$ -ray sky at over 1GeV, observed by Fermi

# Gamma-ray observation

- Space based instruments:
  - Direct  $\gamma$ -ray detection
  - Broad sky coverage and high angular resolution
  - Small detector size
  - Sensitive at lower energies
- Ground based observation:
  - Atmosphere blocks  $\gamma$ -rays → Indirect detection only (Cherenkov radiation)
  - Large detection/collection area
  - Atmospheric Cherenkov detection only works at night
  - Very high energy detection



[3] Robert Wagner

The MAGIC telescope. Focusing reference lasers are visible due to fog



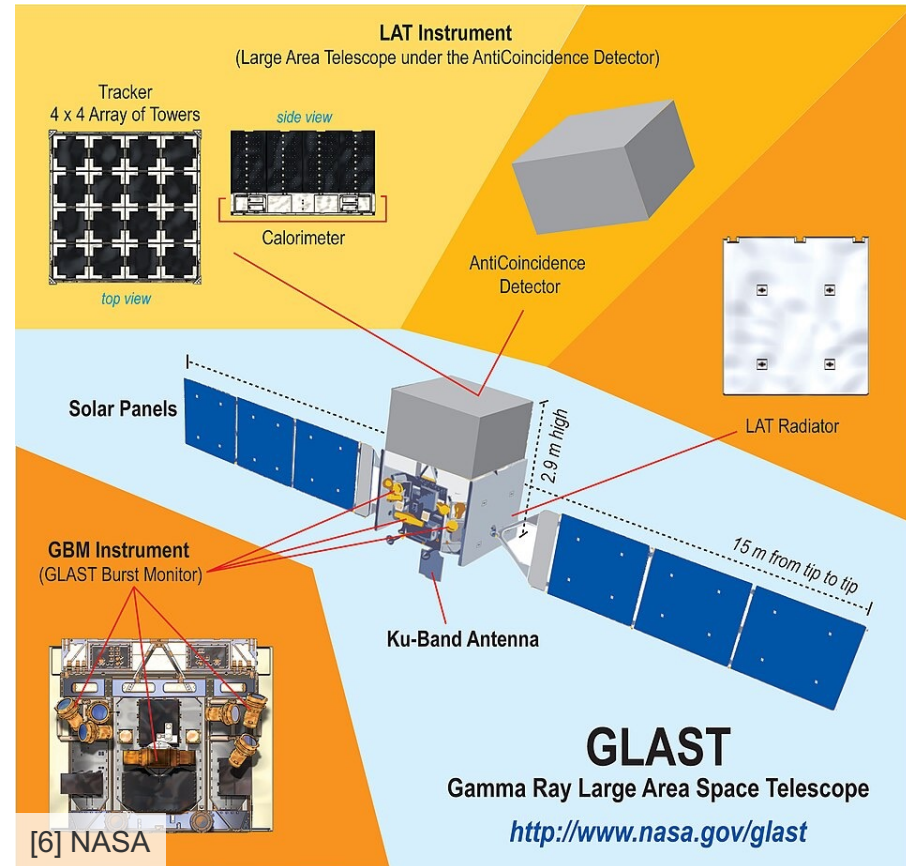
# The Fermi satellite

- Launched 11.06.2008 as Gamma-ray Large Area Space Telescope (GLAST)
- Renamed Fermi Gamma-ray Space Telescope 23.08.2008
- Mission goals:
  - Determine origin of cosmic rays
  - Image the  $\gamma$ -ray sky
  - Detect and research  $\gamma$ -ray bursts (GRBs)
  - Search for dark matter
- Orbits the Earth every 95 minutes, full sky sweep every 3 hours



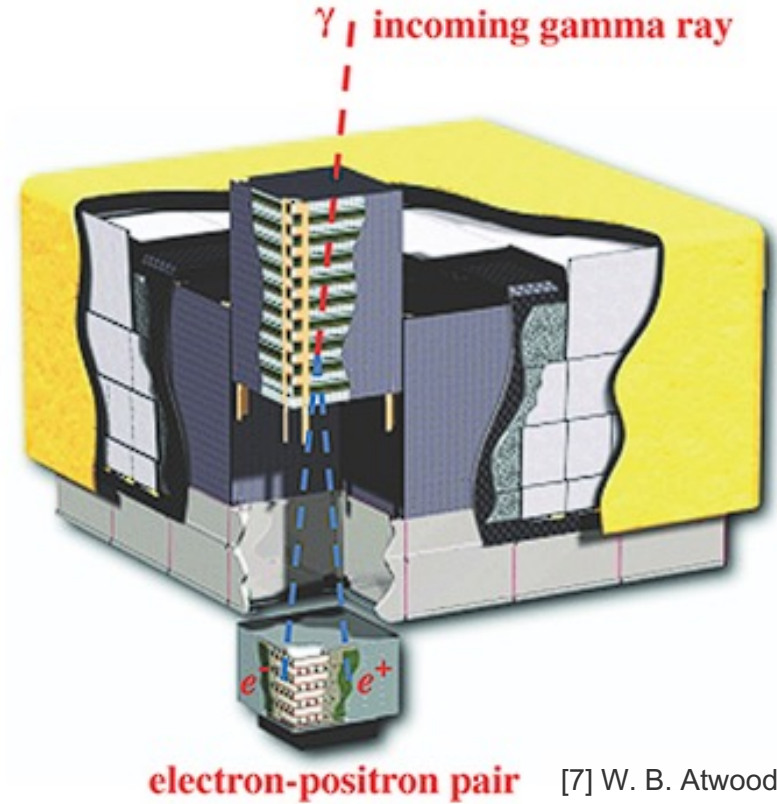
# Fermi: Onboard instruments

- Large Area Telescope (LAT):
  - Imaging  $\gamma$ -ray pair conversion telescope
  - Energy range: 20MeV – 300GeV
  - Field of view: 20% of the sky
  - Successor of the Energetic Gamma Ray Experiment Telescope (EGRET) in most aspects
- Gamma Burst Monitor (GBM):
  - Scintillation detector passively searching for GRBs
  - Energy range: 10keV – 30MeV
  - Can „see“ the entire unoccluded sky



# The Large Area Telescope

- $e^+e^-$ -pair conversion telescope  $\rightarrow$   $\gamma$ -ray creates electron-positron pair, which can be detected
- 4x4 „towers“ of tracker and calorimeter modules
- Anticoincidence detector (ACD) to filter charged cosmic rays
- FOV: 2.4sr ( $\sim$ 20% of the sky)
- Angular resolution:  $\sim$ 0.15° at  $>10\text{GeV}$
- Effective area:  $\sim 9500\text{cm}^2$
- Full sky sweep every 3 hours



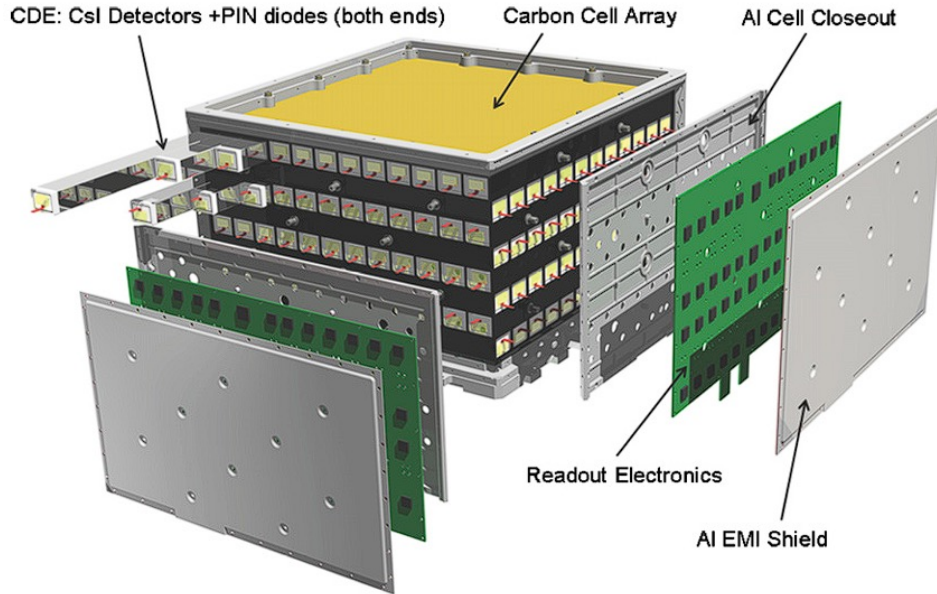
# LAT: Tracker Modules

- 18 stacked tracking planes per module
  - Tungsten foil (converter) and silicon strip detectors (SSDs)
  - „Front“ converters are thin for better angular resolution
  - „Back“ converters are 6x thicker for better conversion efficiency
- $\gamma$ -ray hits converter and creates  $e^+e^-$ -pair
  - SSDs detect  $e^+e^-$ -pair
  - Multiple planes allow tracing the trajectory
  - Converter directly above SSDs for best resolution
- Designed for low deadtime and redundancy
- Tracker provides trigger for LAT



# LAT: Calorimeter Modules

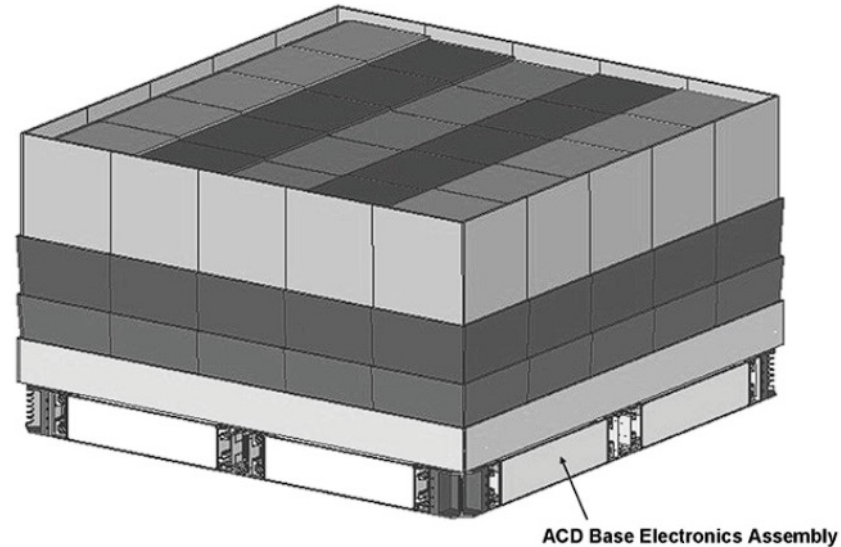
- 96 CsI(Tl) scintillators per module
  - Hodoscopic arrangement allows 3d tracking
- Calorimeter measures energy of particle shower
  - Profile allows for background discrimination
  - Position resolution scales with energy



[9] W. B. Atwood et al.

# LAT: Anticoincidence Detector

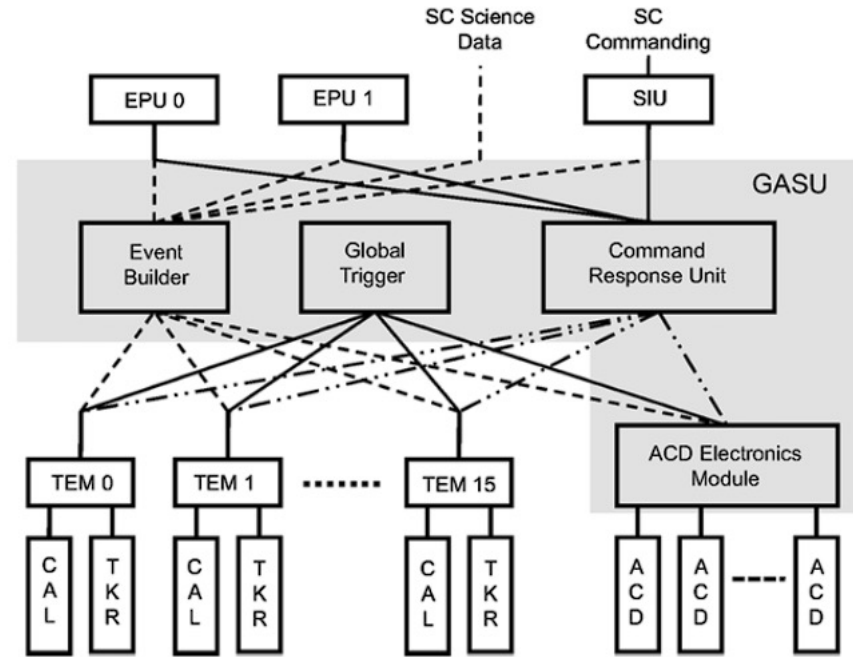
- Plastic scintillators surrounding the LAT assembly
- Detects charged cosmic rays to filter false signals
  - High detection efficiency
- Segmented to prevent false veto from backscatter effect
  - High energy photons from calorimeter may Compton-scatter in ACD
  - Sufficiently high energy deposition in calorimeter disables veto
  - Segmentation reduces area that can contribute
- ACD is encased by micrometeoroid shield
  - Maintains light-tight seal



[10] W. B. Atwood et al

# LAT: Data Acquisition System

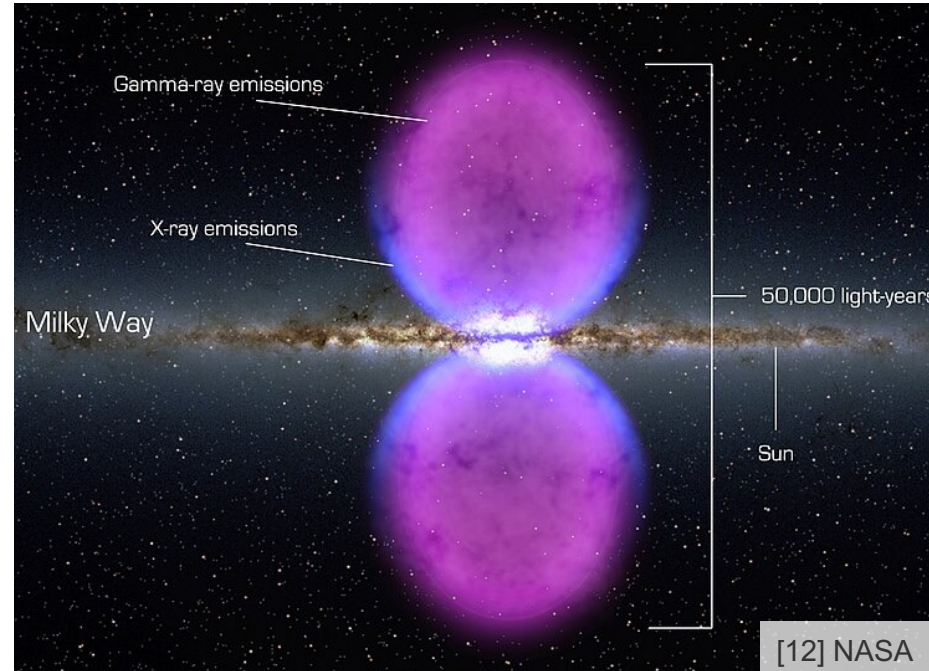
- Onboard signal processing
  - Filters out charged particle background
  - Can process 1000s of events per second
  - Low deadtime ( $\sim 26.5\mu\text{s}$ )
- Triggers are provided by tower modules:
  1. If 3 tracker planes trigger in a row
  2. If certain energy thresholds are exceeded
- ACD can veto trigger signals



[11] W. B. Atwood et al.

# Discoveries

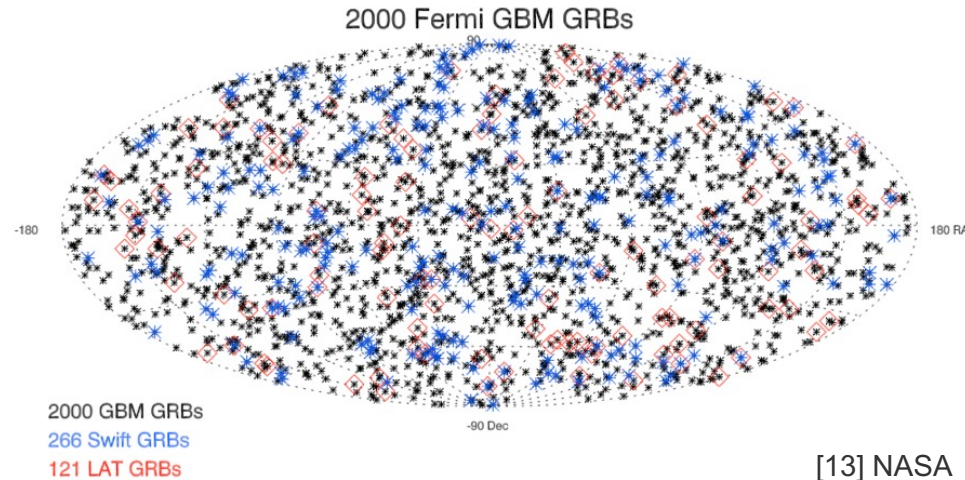
- Highest energy GRB to date (on 2 separate occasions)
  - ~32GeV photon in 2008
  - 94GeV photon in 2013
- High  $\gamma$ -emission from galactic center
- $\gamma$ -ray emitting bubbles expanding 25000 ly above and below galactic center (Fermi bubbles)
- Confirmation of particle acceleration in supernovas
- Background  $\gamma$ -ray sources
- And more...



Fermi Bubbles

# $\gamma$ -Ray Bursts

- Extremely bright and energetic events
- Duration from milliseconds to hours
- Supernovas and neutron star mergers are known sources
- No recorded intragalactic GRBs
- Can have x-ray and/or optical afterglow



# GRBs: Short and long bursts

## Short bursts (sGRBs):

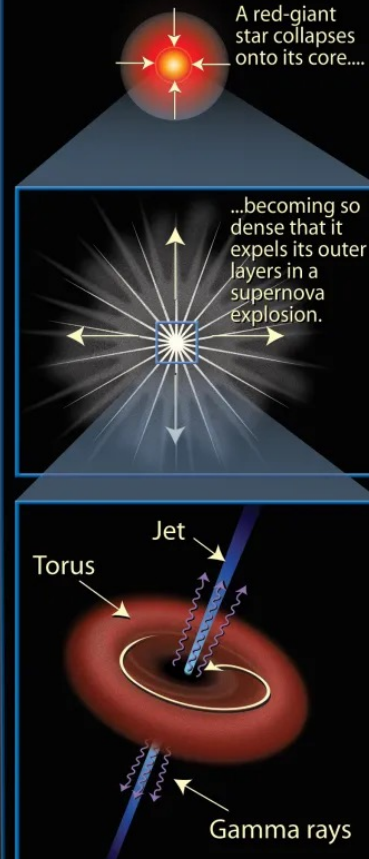
- ~30% of observed GRBs
- No link to massive stars
- Concurrent measurement of sGRB and gravitational wave confirmed neutron star merger as source

## Long Bursts:

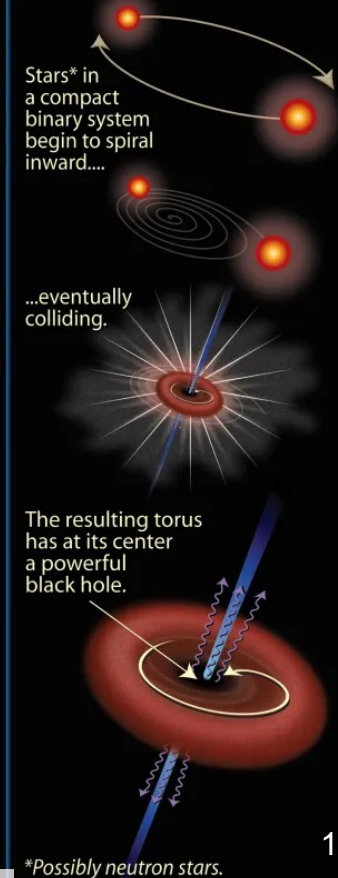
- Originate from galaxies with rapid star formation
- Caused by deaths of massive stars

## Gamma-Ray Bursts (GRBs): The Long and Short of It

### Long gamma-ray burst ( $>2$ seconds' duration)

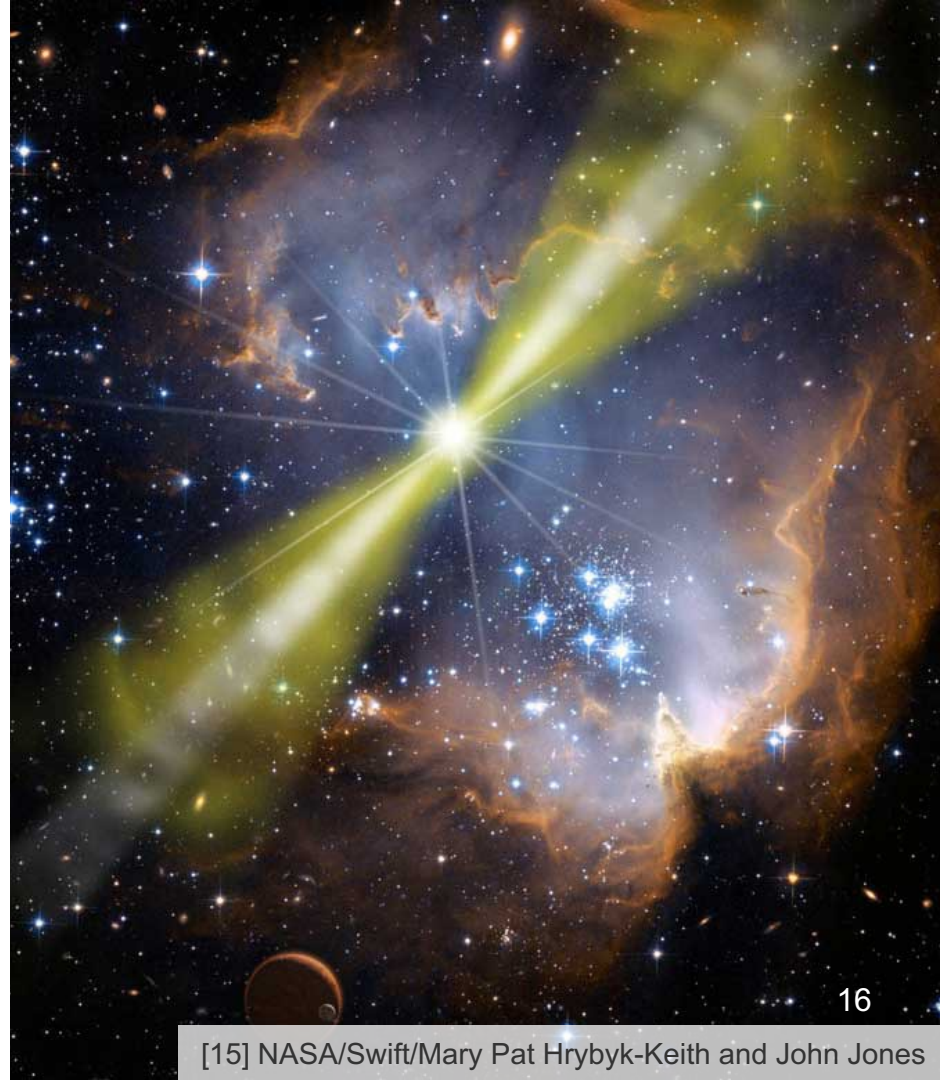


### Short gamma-ray burst ( $<2$ seconds' duration)



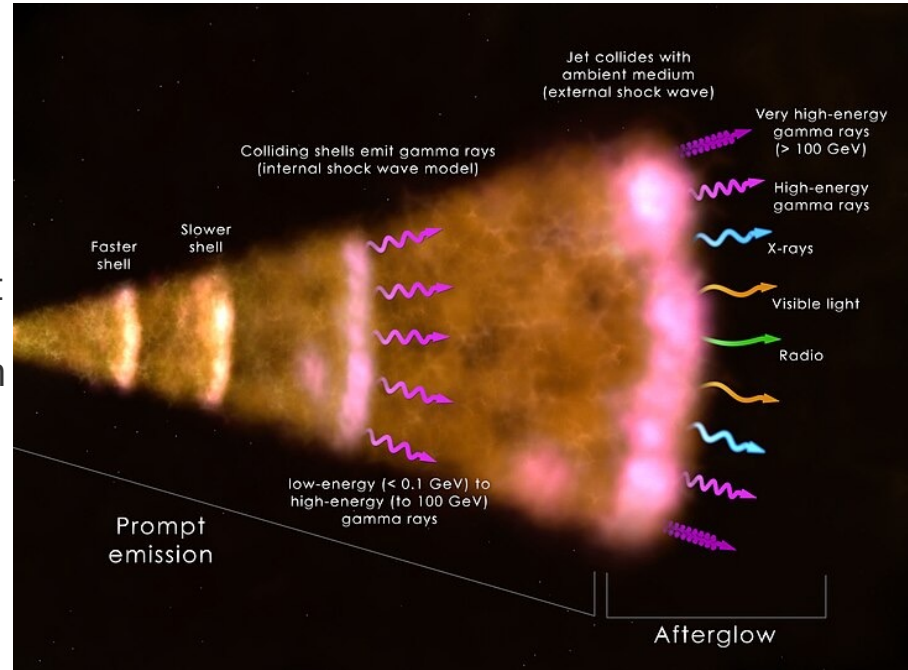
# GRBs: Energy

- Often accompanied by extremely bright optical emission
  - Highest energy events known in astrophysics
- Energy is highly focused into ultra-relativistic jets
  - Up to 99.9999% c, possibly even greater
- Total energy estimated  $\sim 3 \cdot 10^{44}$  J
  - Greater than ordinary supernovas ( $\sim 10^{44}$  J)



# GRBs: Emission

- Exact emission mechanism unknown
- Very high emission efficiency (~50%)
- Likely emitter is inverse Compton scattering from high energy particles accelerated by the source event
- Collision of shockwave “shells” likely drives emission
- Afterglow is emitted by relativistic shockwave and synchrotron radiation



[16] NASA/Goddard Space Flight Center/ICRAR

# Summary

- $\gamma$ -rays show us the highest energy processes in the universe
- Fermi LAT is a powerful space-based instrument to detect  $\gamma$ -rays
- Fermi has detected 1000s of  $\gamma$ -ray sources and collected valuable data
- Open questions remain:
  - Ongoing search for dark matter
  - How do supernovas, etc. accelerate particles so efficiently
  - How are relativistic jets produced/accelerated
  - Unidentified  $\gamma$ -ray sources
  - And more...

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# Image Sources

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