Exploring the Extreme Universe with the Fermi Gamma-ray Space Telescope

Prof. Lynn Cominsky

Sonoma State University

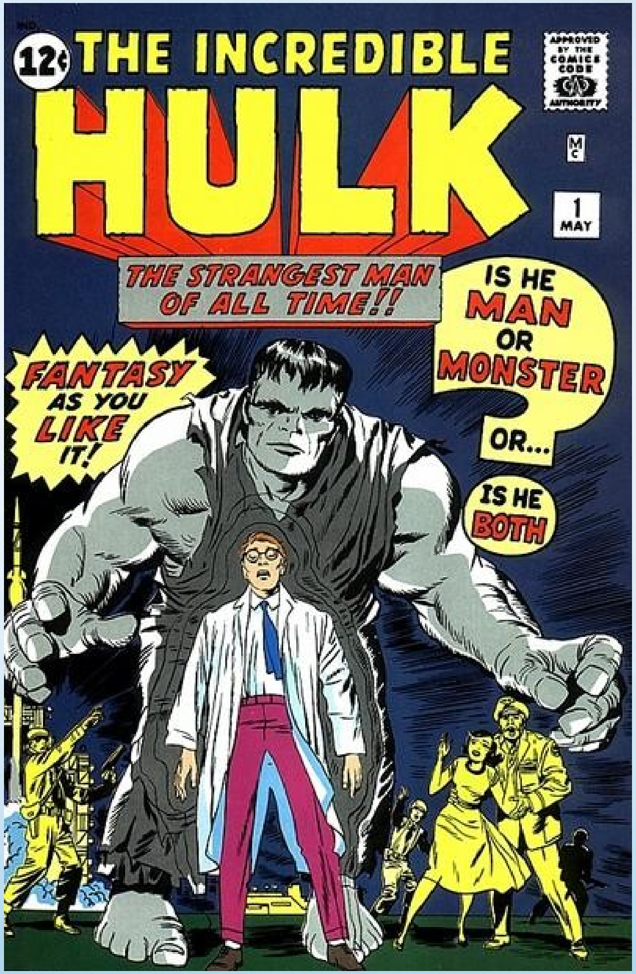
Director, Education and Public Outreach

What turned Bruce Banner into the Hulk?

Gamma rays!

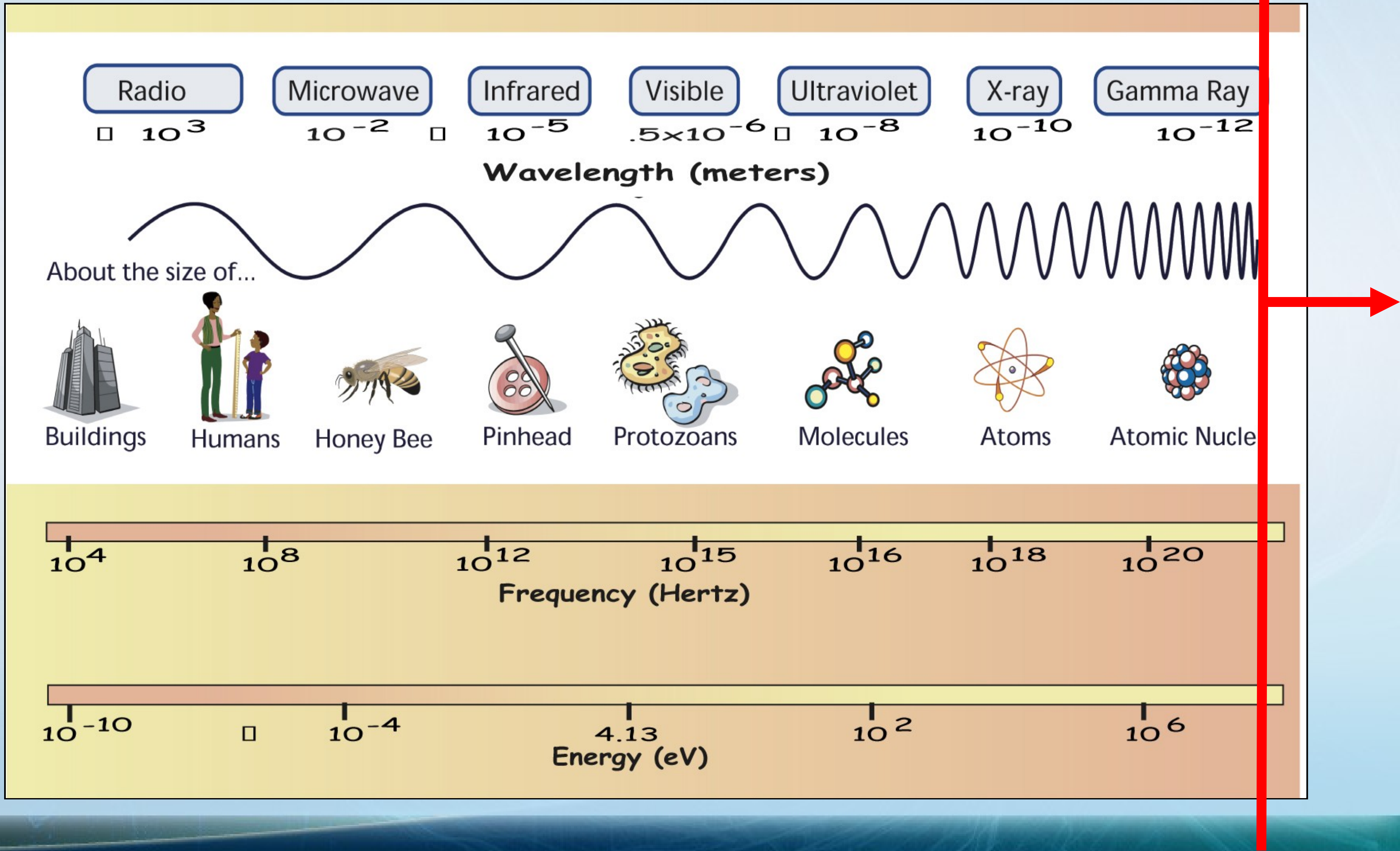
Why?

Because gamma rays are powerful!



How powerful?

100 MeV

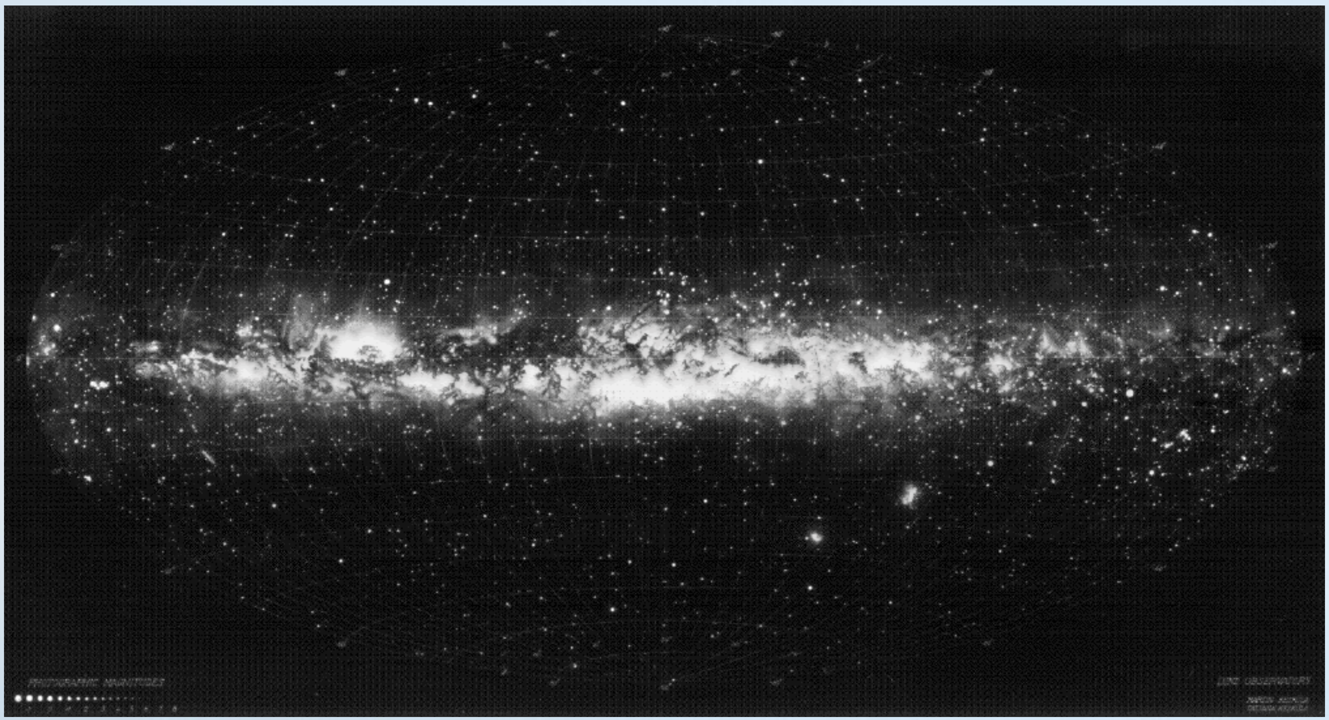


How to study gamma rays?

- Absorbed by the Earth’s atmosphere
- Use rockets, balloons or satellites
- Can’t image or focus gamma rays
- Special detectors: scintillating crystals, silicon-strips

Balloon experimen t

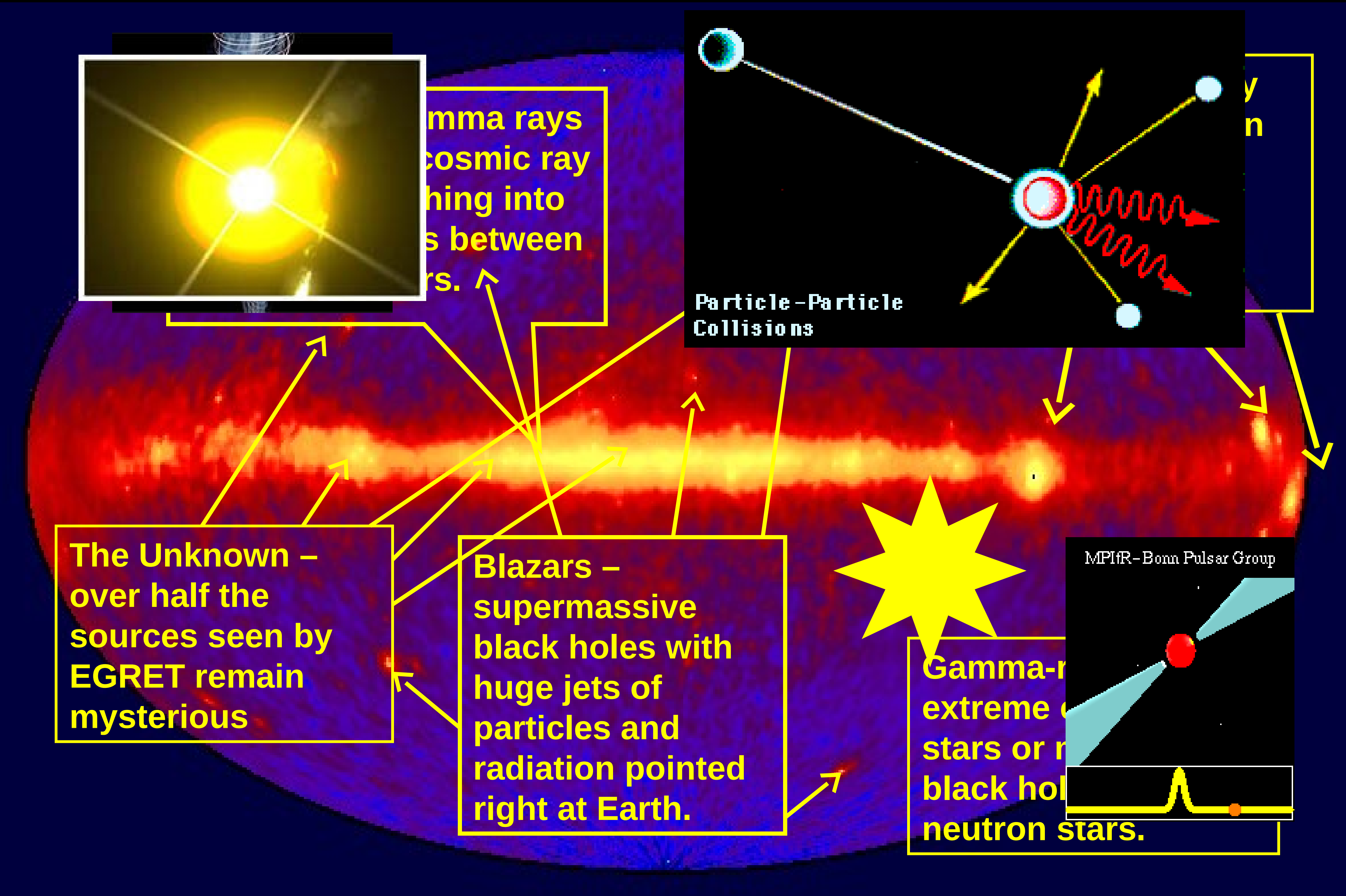
Why study the extreme Universe?



- Universe as seen by eye is peaceful


But what if you had gamma-ray vision?

The Gamma-ray Sky in False Color – from EGRET/Compton Gamma Ray Observatory



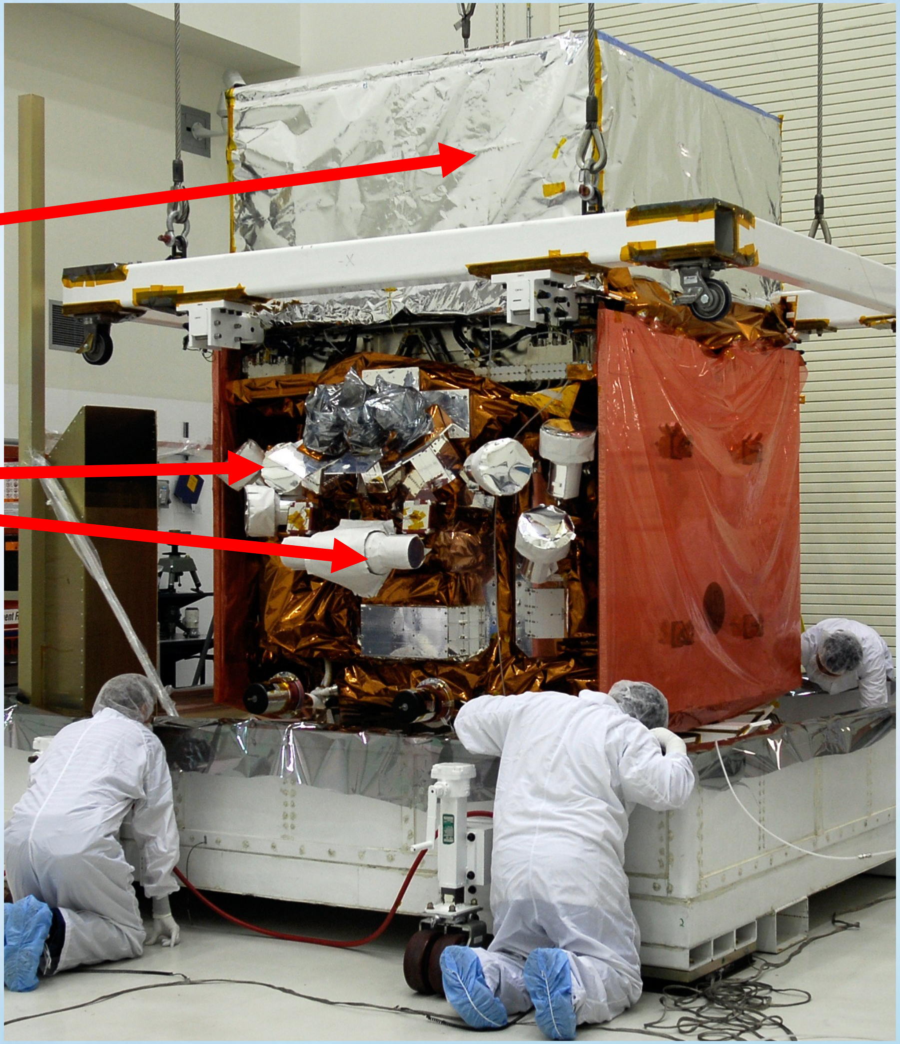
So we need a new mission…

- First space-based collaboration between astrophysics and particle physics communities
- International partners from France, Germany, Italy, Japan & Sweden
- Launched June 11, 2008
- Expected duration 5-10 years

Before launch

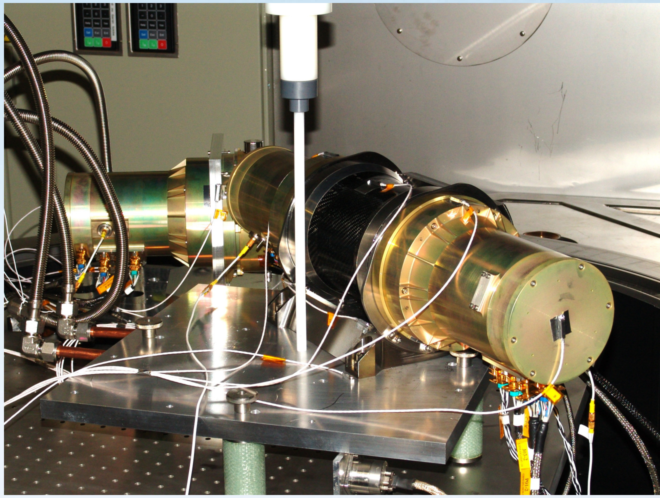
- Large Area Telescope

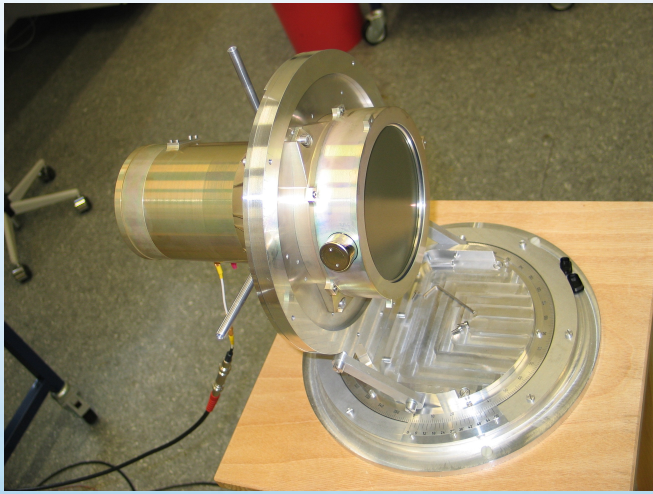
- Gamma-ray
  Burst Monitor



Gamma-ray Burst Monitor (GBM)

- PI Charles Meegan (NASA/MSFC)
- US-German secondary instrument
- 12 sodium iodide scintillators
  - 10 keV to 1 MeV
  - Burst triggers and locations
- 2 bismuth germanate detectors
  - 150 keV to 30 MeV
  - Overlap with LAT
- **http://gammaray.msfc.nasa.gov/gbm/**



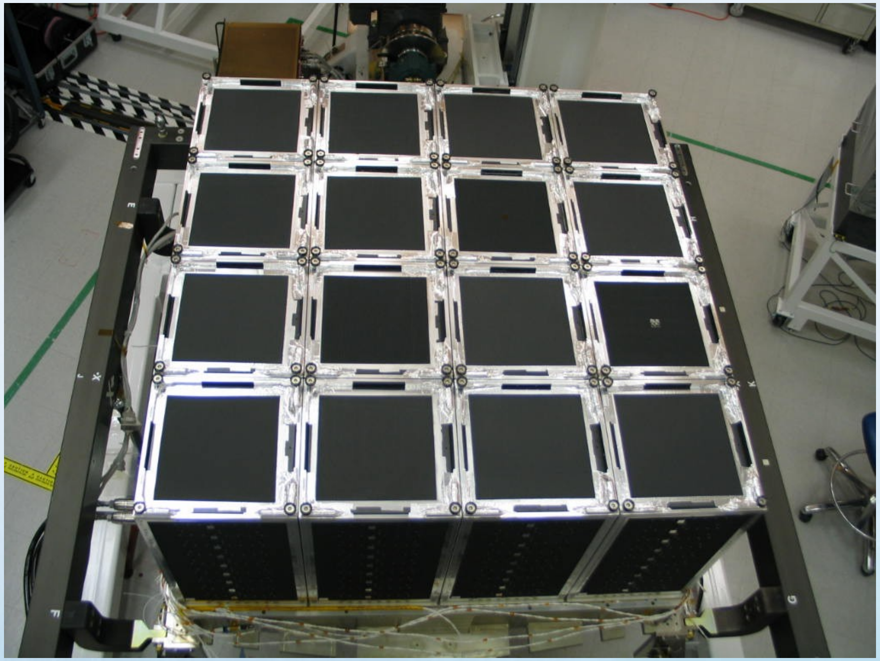


Large Area Telescope (LAT)

- PI Peter Michelson (Stanford)
- International Collaboration: USA NASA and DoE, France, Italy, Japan, Sweden

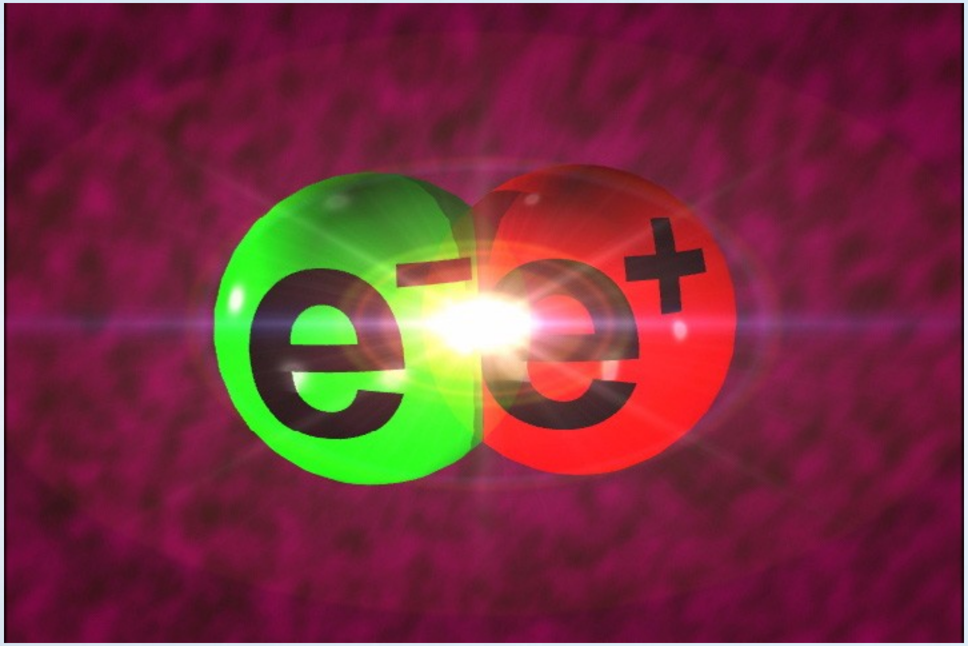
- LAT is a 4 x 4 array of towers

- Each tower is a pair conversion telescope with calorimeter



- http://glast.stanford.edu

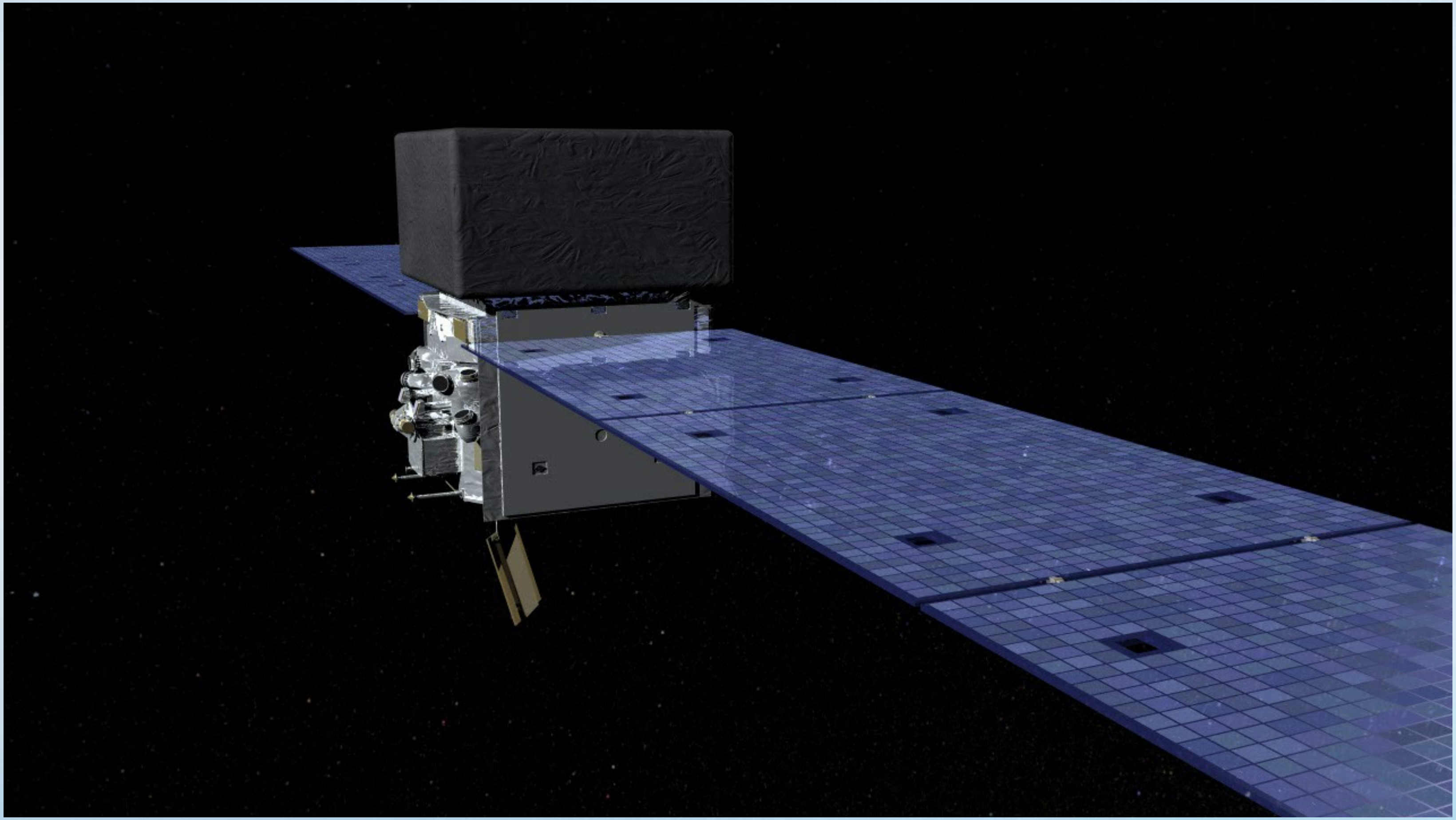
What is “pair-conversion”?



$E = mc^2$

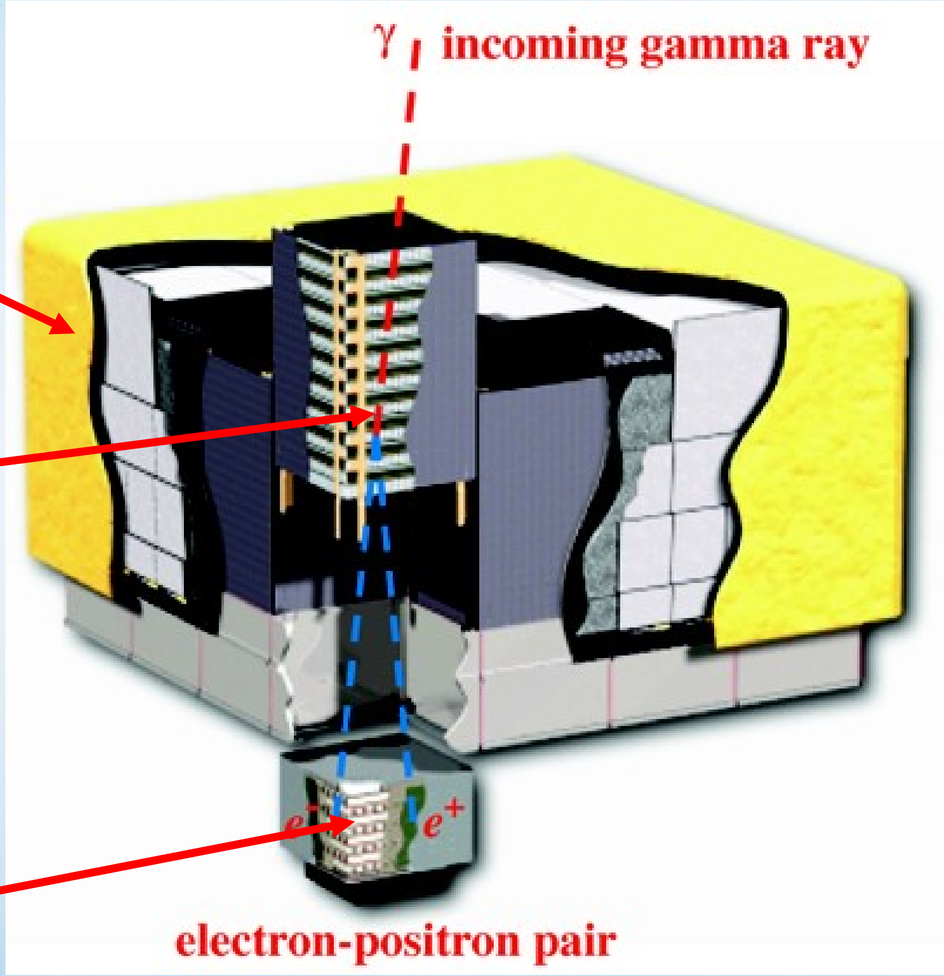
- Positrons are anti-electrons
- When they meet, they annihilate each other!

What is a Pair Conversion Telescope?



How does the LAT work?

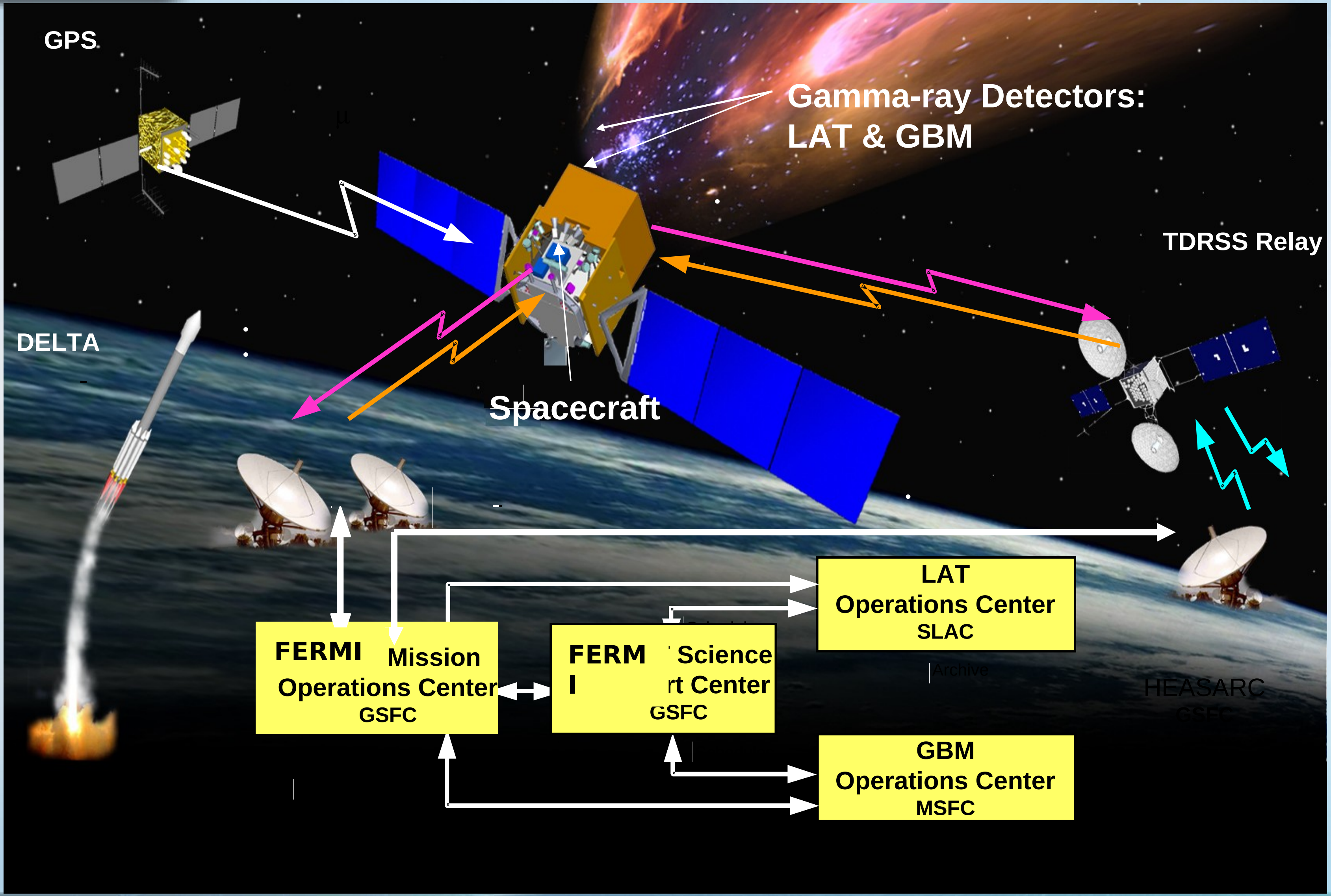
- Anticoincidence Detectors – screen out charged particles
- Tungsten converts gamma rays into e+ e- pairs
- Calorimeter measures total energy



Launched!

- June 11, 2008
- Delta II Heavy (9 solid rocket boosters)
- Mass is 4300 kg
- 555 km circular orbit
- 1500 W total power
- 40 Mb/sec downlink

Mission Data Relay

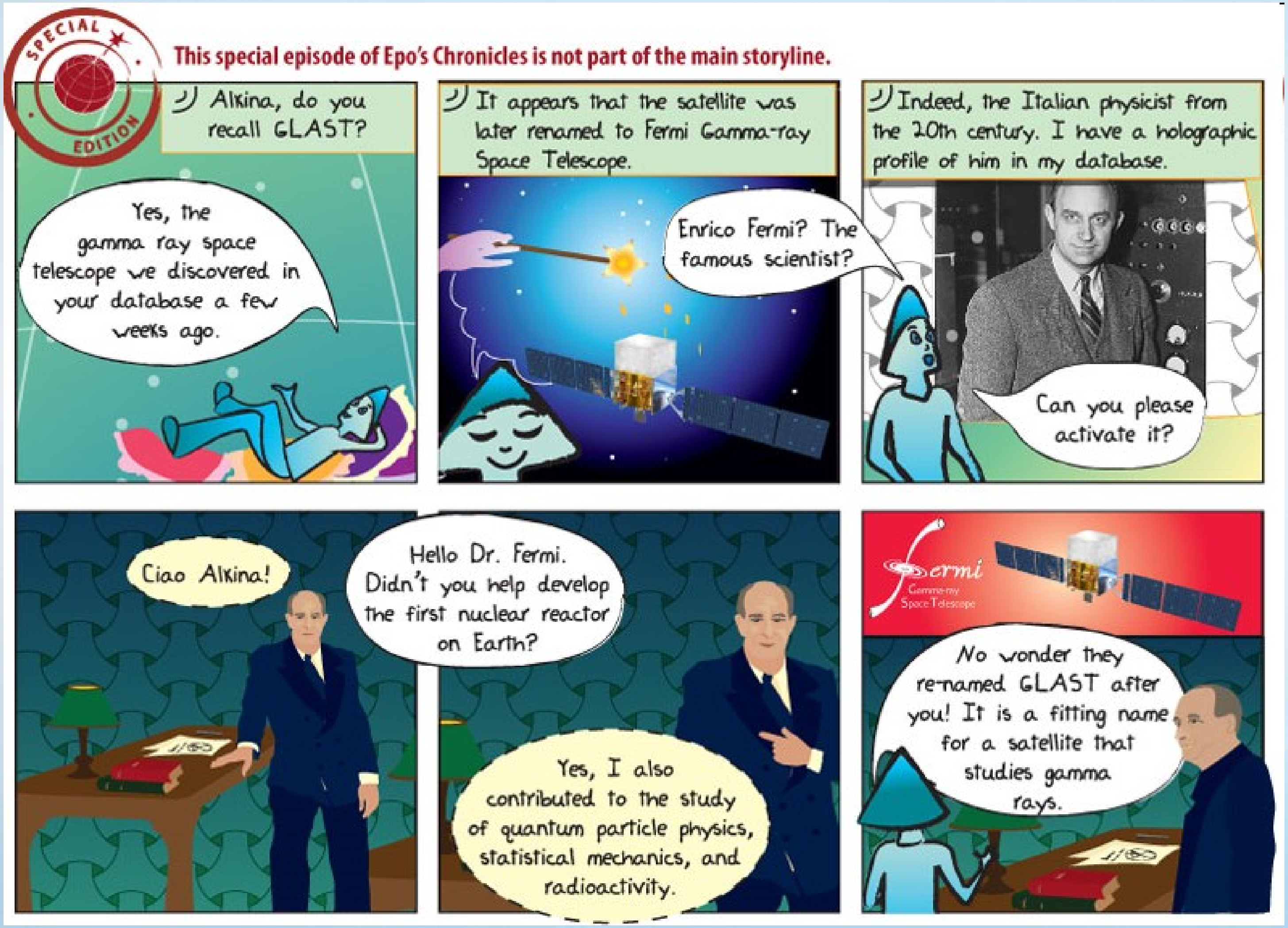


Renaming the satellite

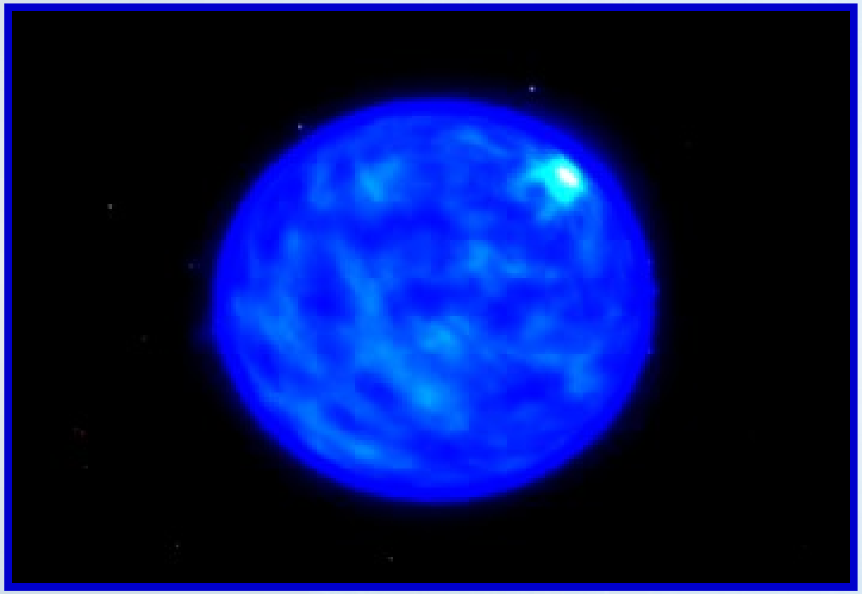
- We renamed the mission after Enrico Fermi, an Italian-American scientist on 8/26/08 when we announced our first results

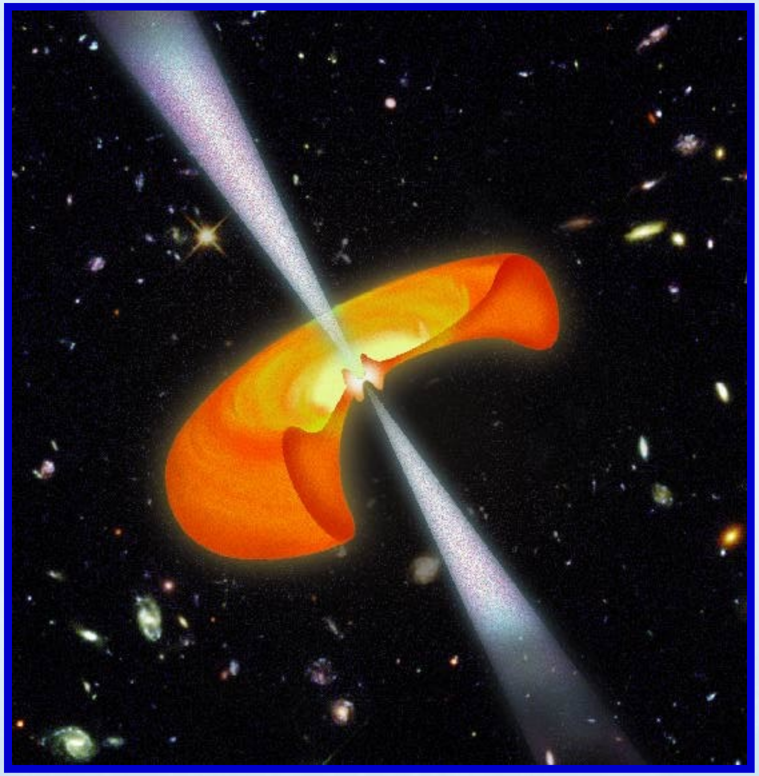
Enrico Fermi
1901-1954
Nobel in 1938

Special “Eposode” of Epo’s Chronicles



Gamma-ray Bursts from "Hypernovae"

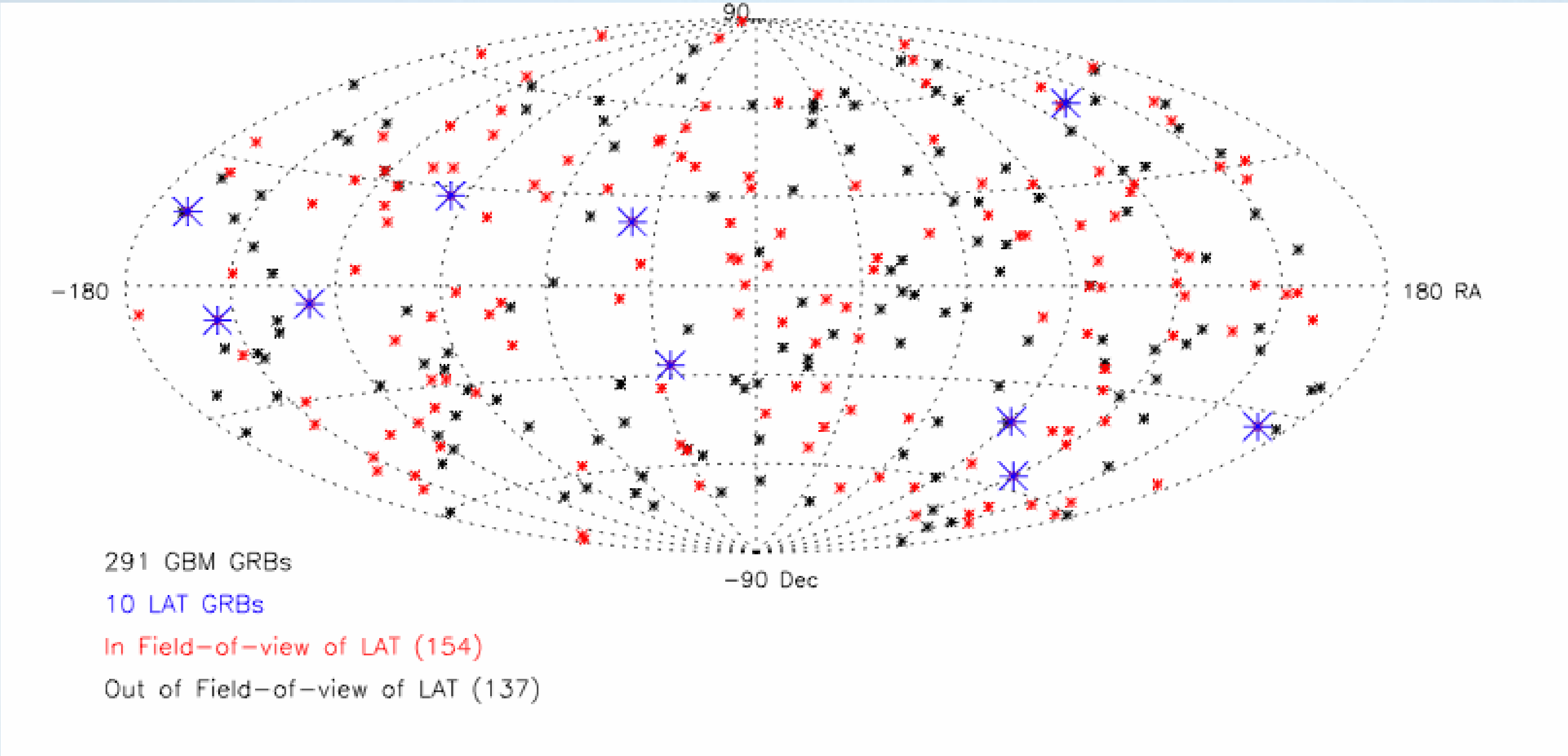




- A billion trillion times the power from the Sun

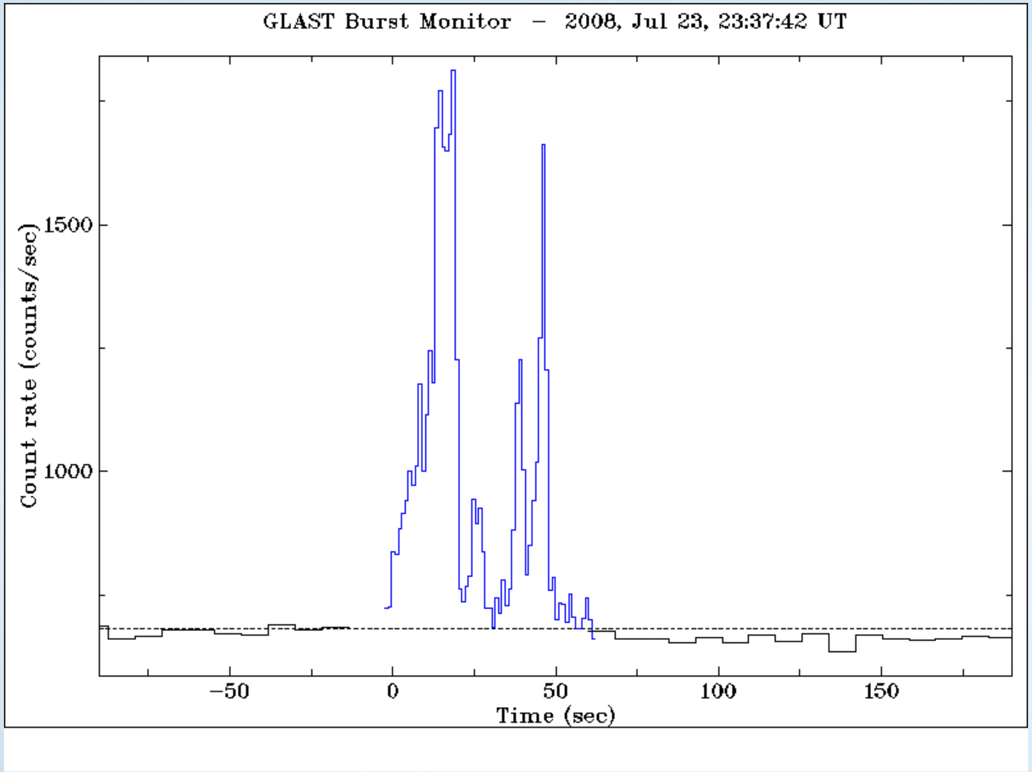
Fermi Bursts in first year

- As of 9/4/09



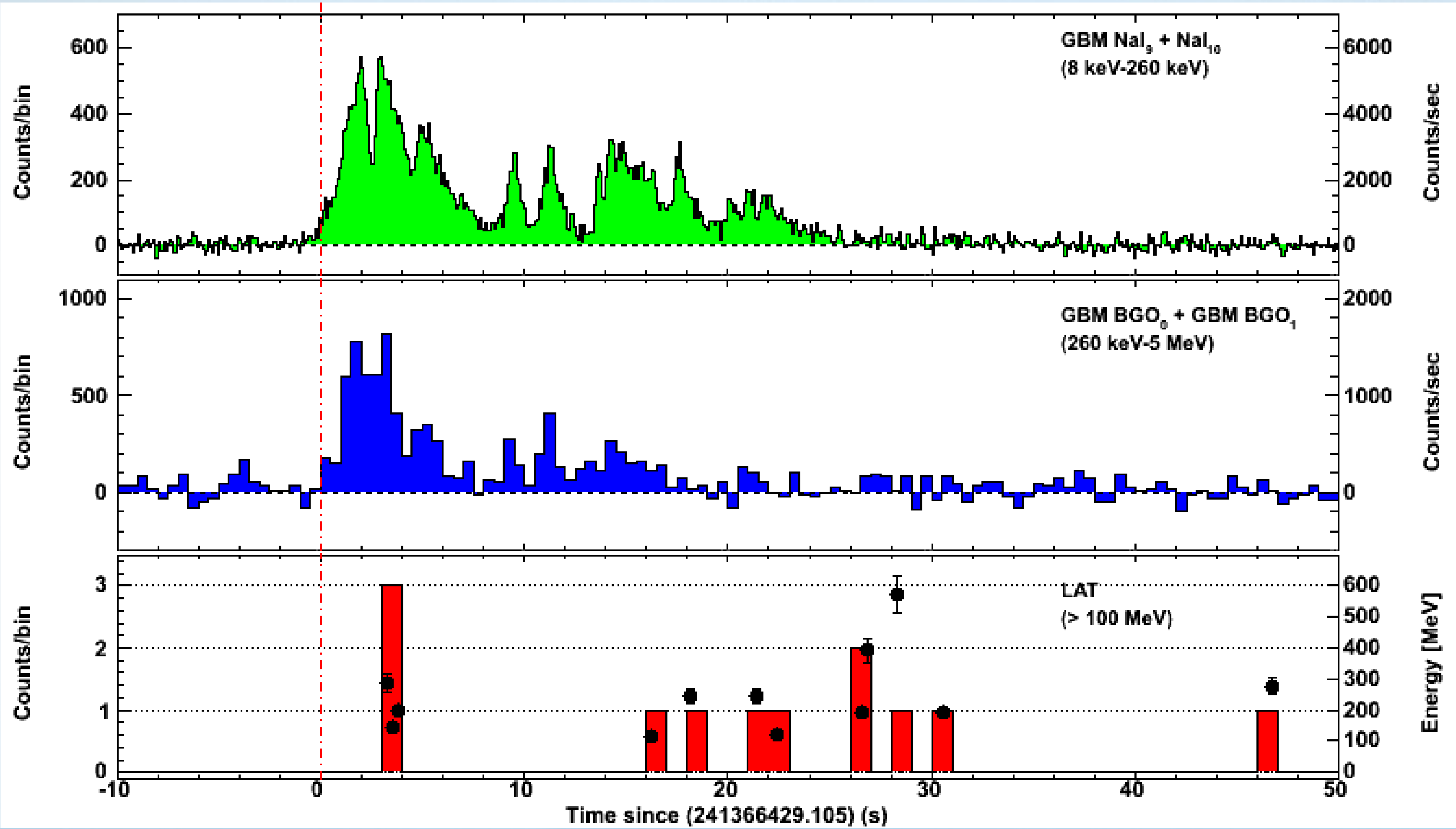
- About 4-5 bursts per week

Typical strong GRB seen by GBM



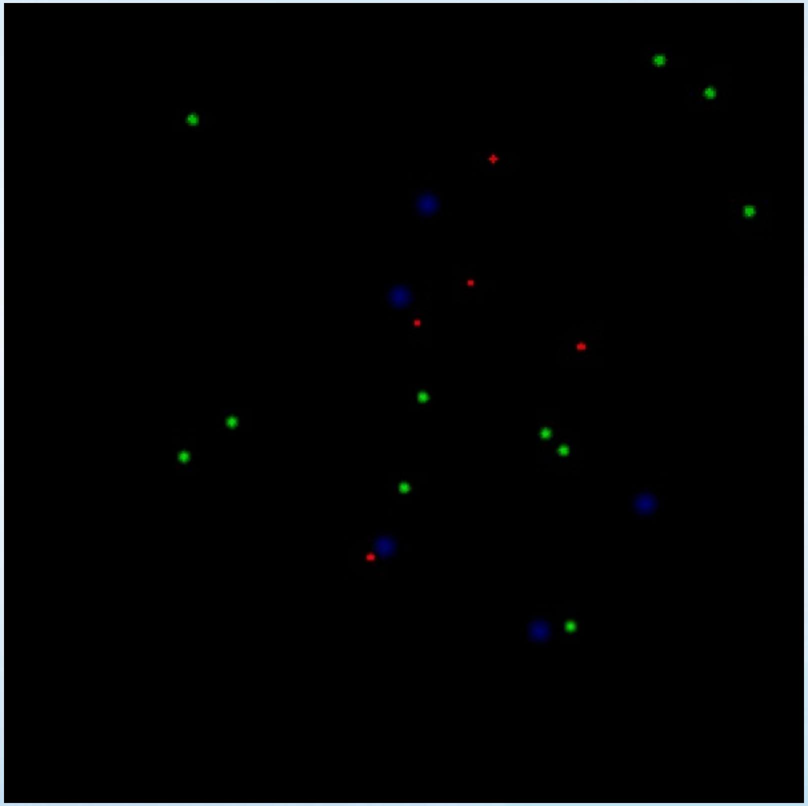
- 290+ GBM bursts seen to date
- 10 LAT-GBM bursts seen in first 10 months

GRB080825C: the 1st LAT GRB



GRB080916C: most extreme GRB yet

- Greatest total energy, the fastest motions and the highest-energy initial emissions ever seen
- Studying the high-energy gamma rays tells us that the charged particles which made those gamma rays were moving at 99.9999% of light speed
- Observing the GRB using visible light tells us that it happened12.2 billion years ago

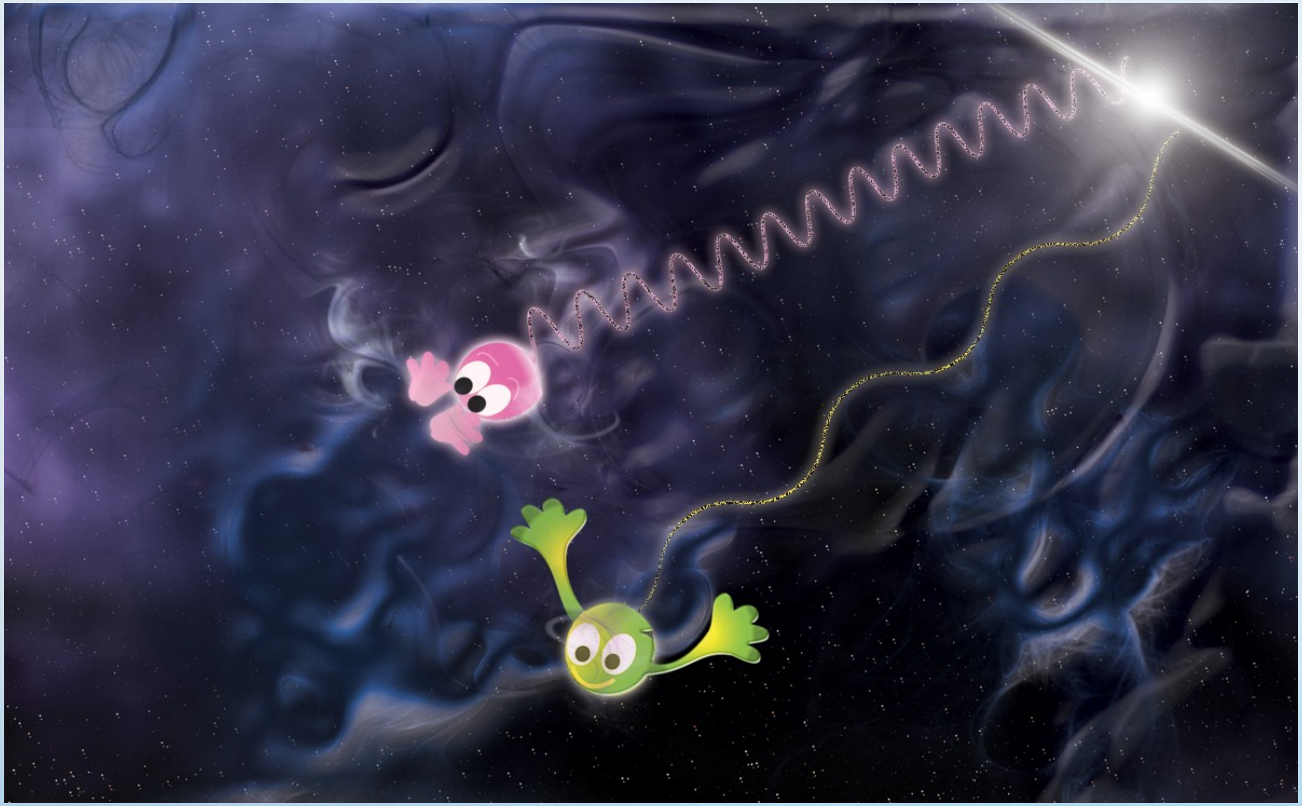


Using GRBs to test Special Relativity

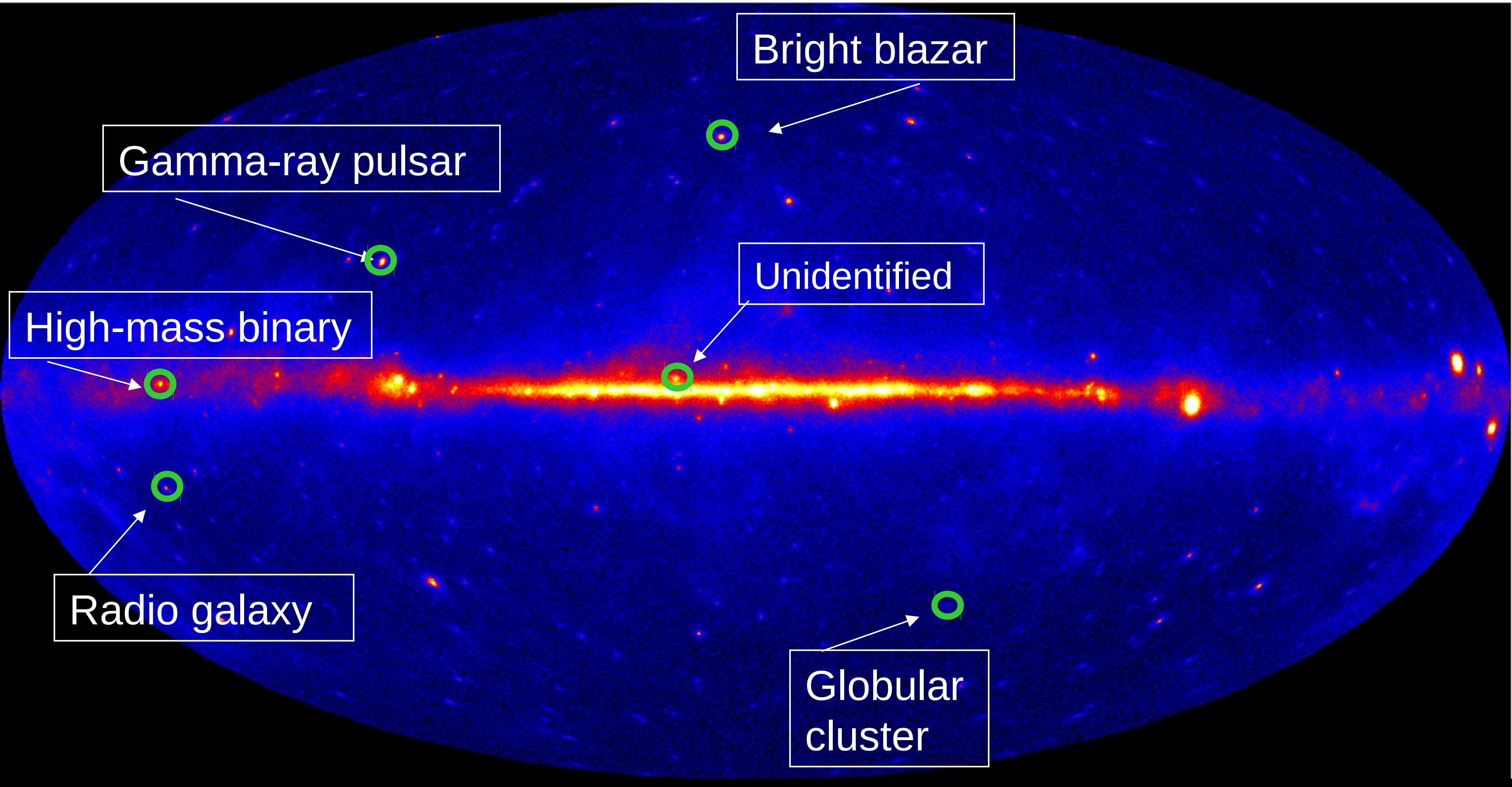
- Short GRBs can be used to test Einstein’s claim that light travels at a constant speed
- Some theories of quantum gravity predict that higher-energy photons will interact with the “quantum foam” of space-time and will travel slower than low-energy photons

Will quantum foam entangle photons?

- Fermi sees no evidence for this to date



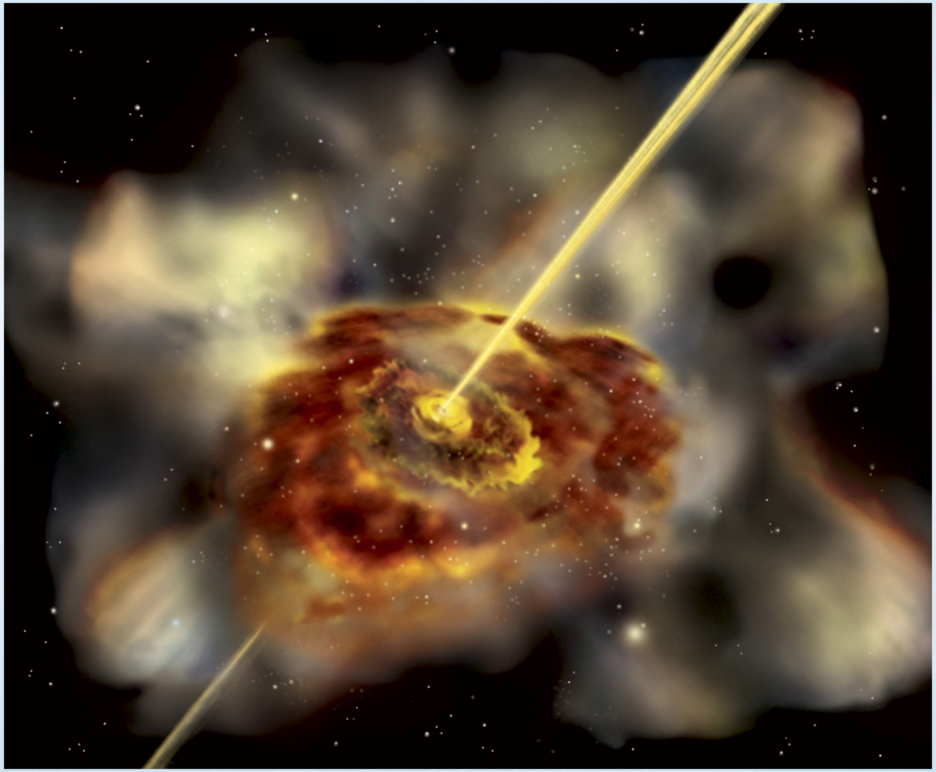
9 month skymap



Polar Views of the Fermi Sky

Gamma-ray Jets from Active Galaxies

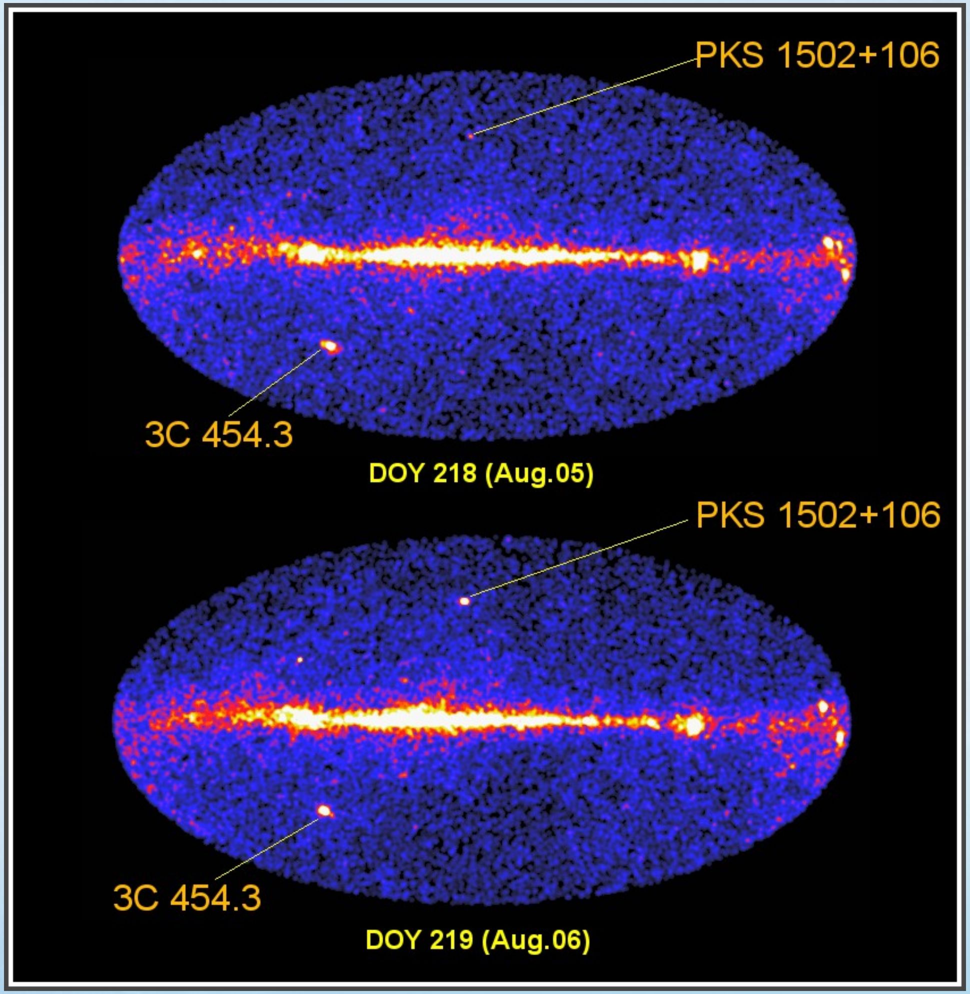
- Jets flare dramatically in gamma rays
- Galaxies that point their jets at us are called “blazars”
- How do the black holes send out jets?



Art by Aurore Simonnet

Monitoring Flares from “Blazars”

- Fermi scans the entire sky every 3 hours
- So blazar flares can be seen on relatively short time scales
- Coordinated campaigns with many ground-based telescopes are providing information about how the flares are occurring

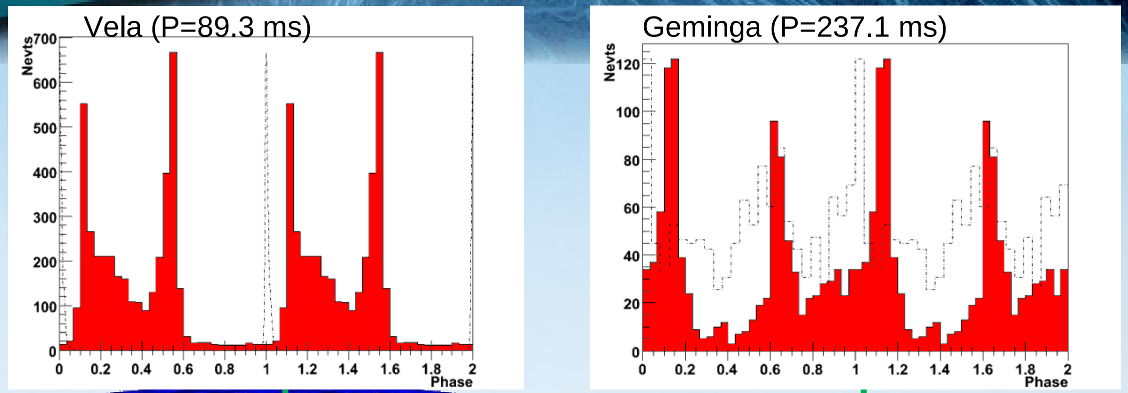


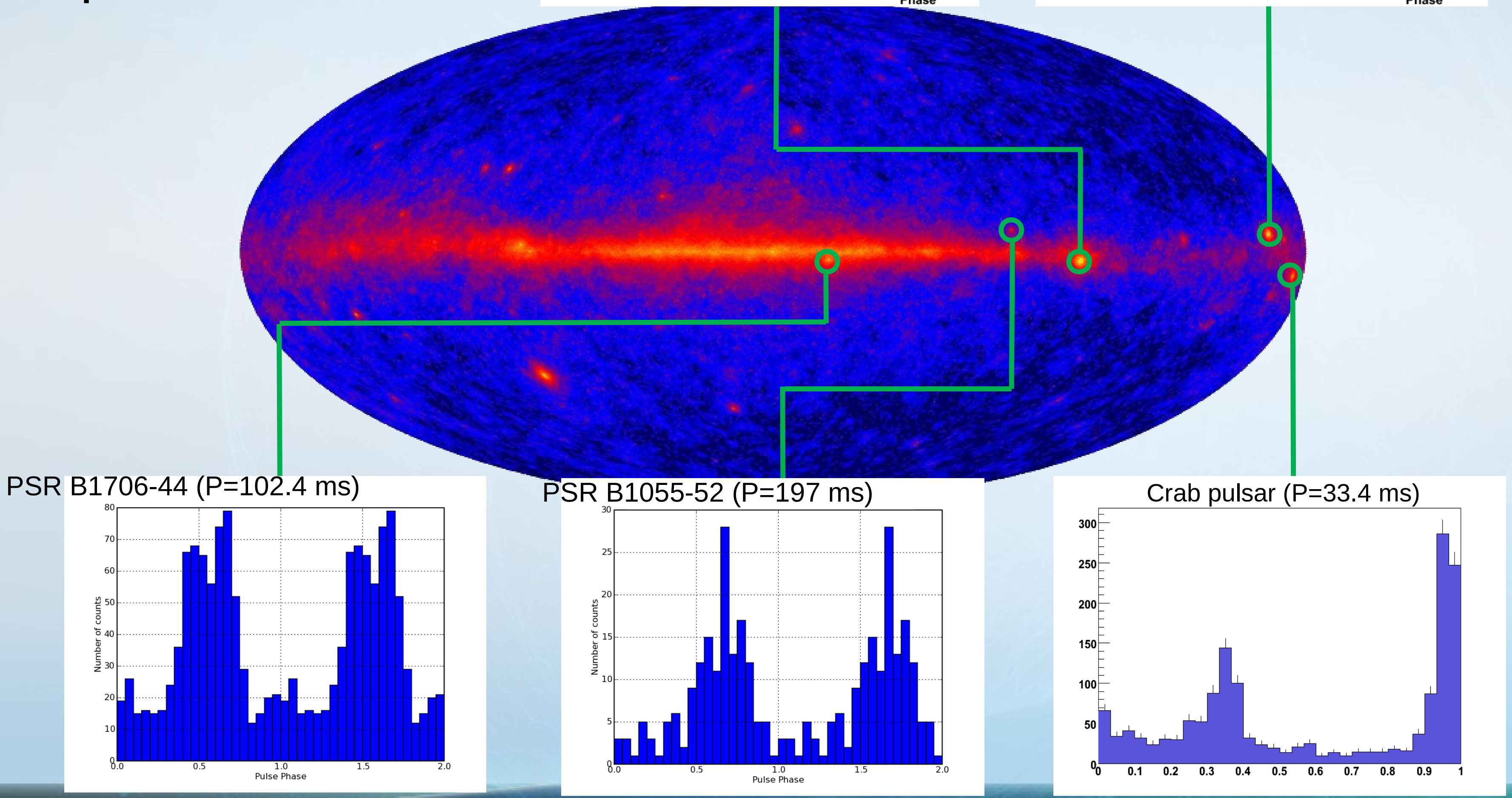
Global Telescope Network

- Students do ground-based visible-light observations using remote telescopes
- GRBs and flaring blazars
- Coordinated with Fermi and other satellite data
- http://gtn.sonoma.edu

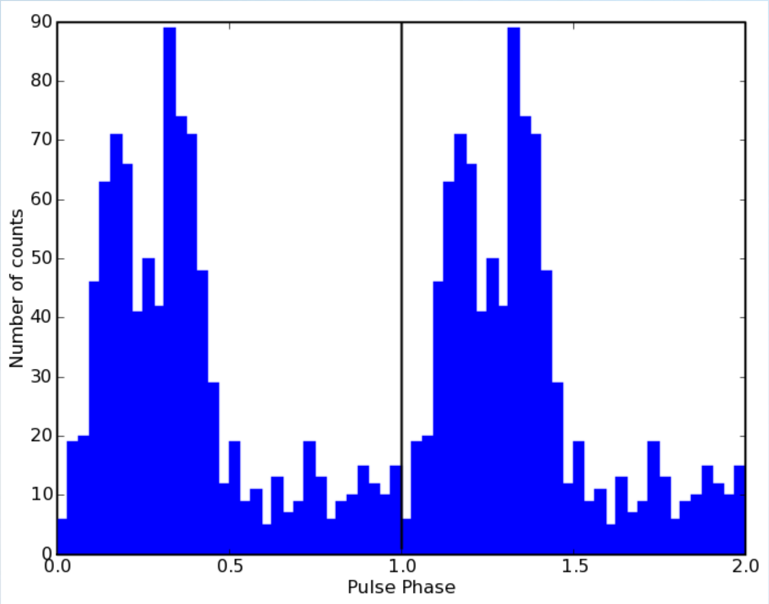
GORT at Pepperwood

Fermi sees the EGRET pulsars….

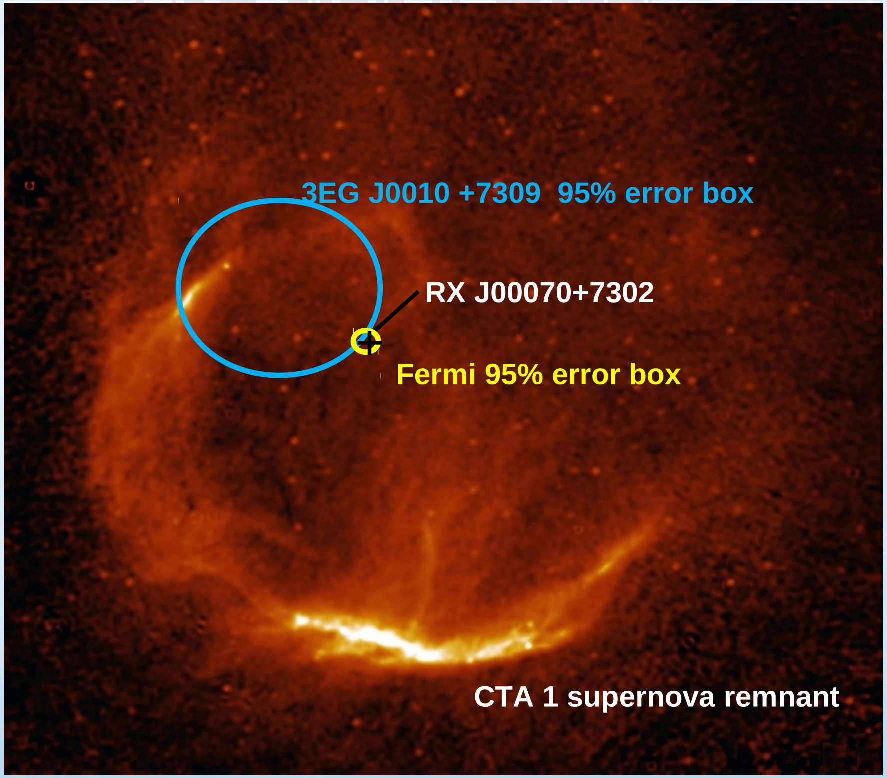




… discovers the 1st gamma-ray only pulsar in CTA1



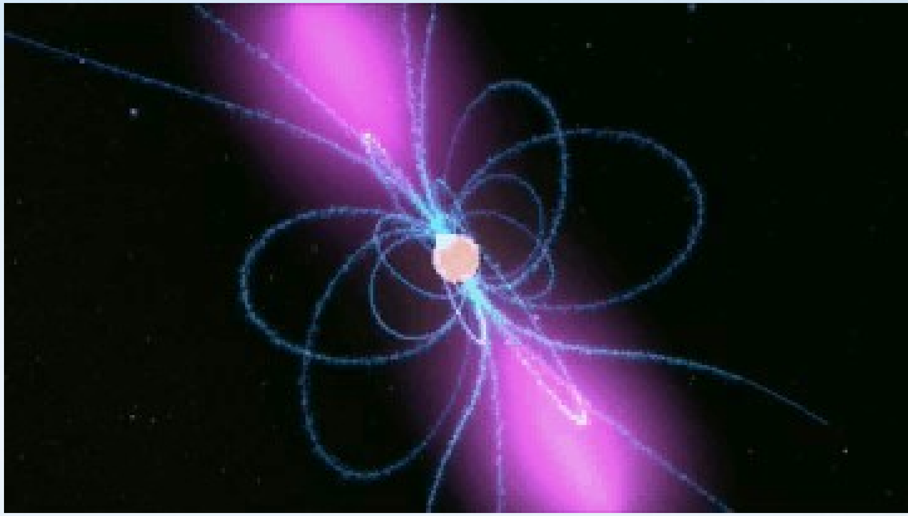
P = 315.86 ms
age ~1.4 x 10^4 yr



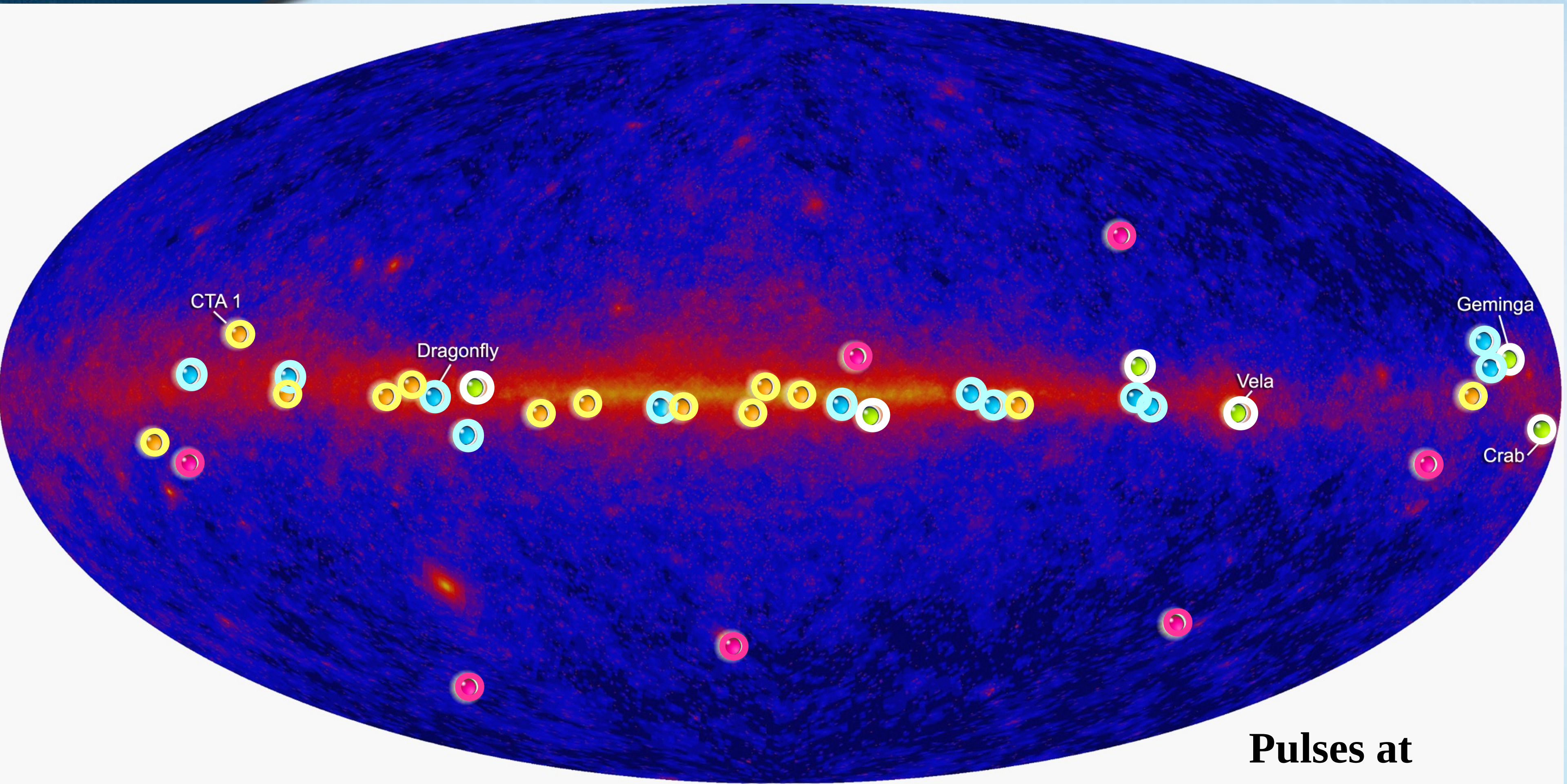
- Pulsar is not at center of SNR
- It's moving at 450 km/sec – kicked by the supernova explosion that created it

How do gamma ray pulsars work?

- Pulsars are not simply lighthouses anymore
- Radio beams are emitted from polar caps
- Gamma rays come from outer magnetosphere



The Pulsing Sky (Romani)



Pulses at 1/10th true rate

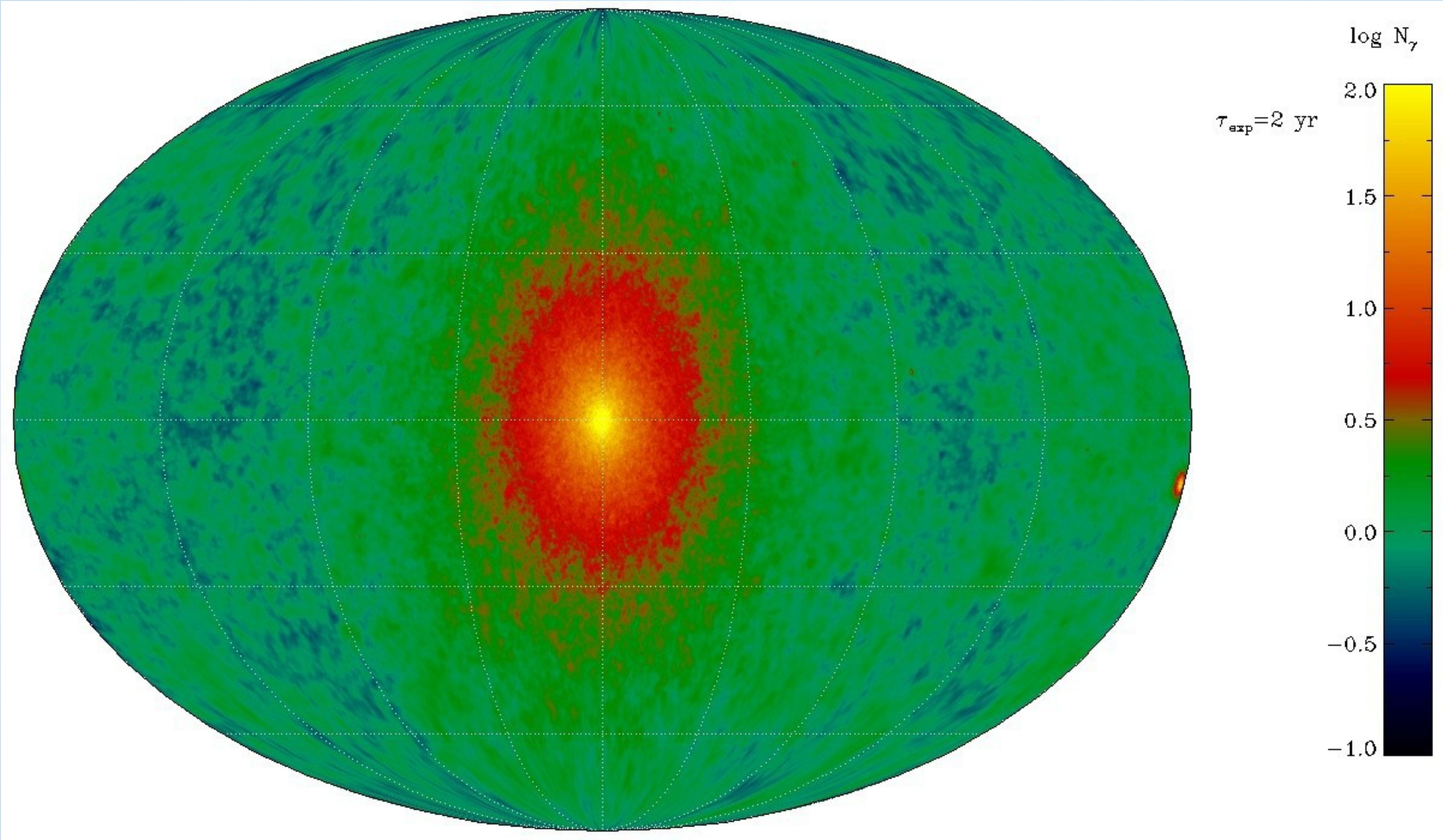
Fermi Pulsar Detections

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Confirmed pulsars seen by Compton Observatory EGRET instrument

Searching for dark matter

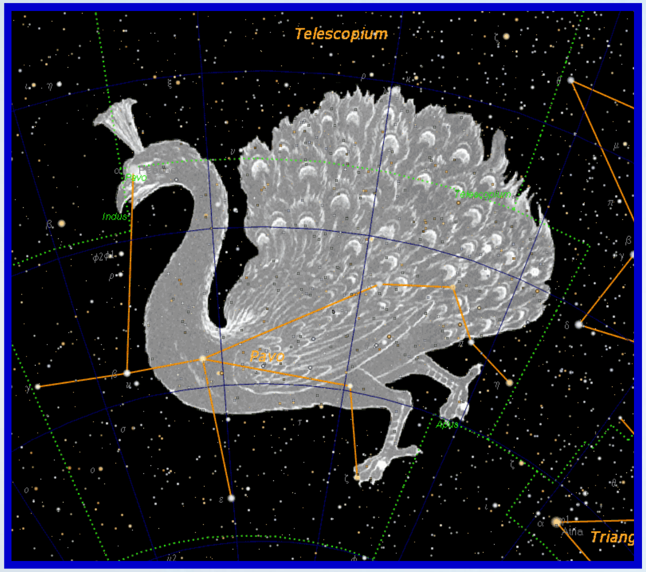
- Dark matter makes up 80% of the matter in the Universe
- The leading particle candidate for dark matter is theorized to self-annihilate, creating gamma-ray lines in the energy range 30 GeV - 10 TeV
- Fermi could see these lines up to 300 GeV (if they exist)
- More lines are expected near the center of our Galaxy

Dark Matter line detectability



2 years of simulated data – detectable galactic center halo from Kuhlen, Diamand and Madau 2007

Fly the Gamma-ray Skies



- Follow GRBs on the GRB Skymap site
- Join the Global Telescope Network

Conclusions

- Fermi has already gone far beyond the sensitivity of EGRET and is discovering new classes of high-energy gamma ray sources
- Fermi is opening wide a new window on the Universe – which may show us connections between the infinite and the infinitesimal
- Stay tuned – the best is yet to come!
- For more info: http://www.nasa.gov/fermi

For more information:

- http://fermi.sonoma.edu
- http://grb.sonoma.edu
- http://gtn.sonoma.edu
- http://eposchronicles.org

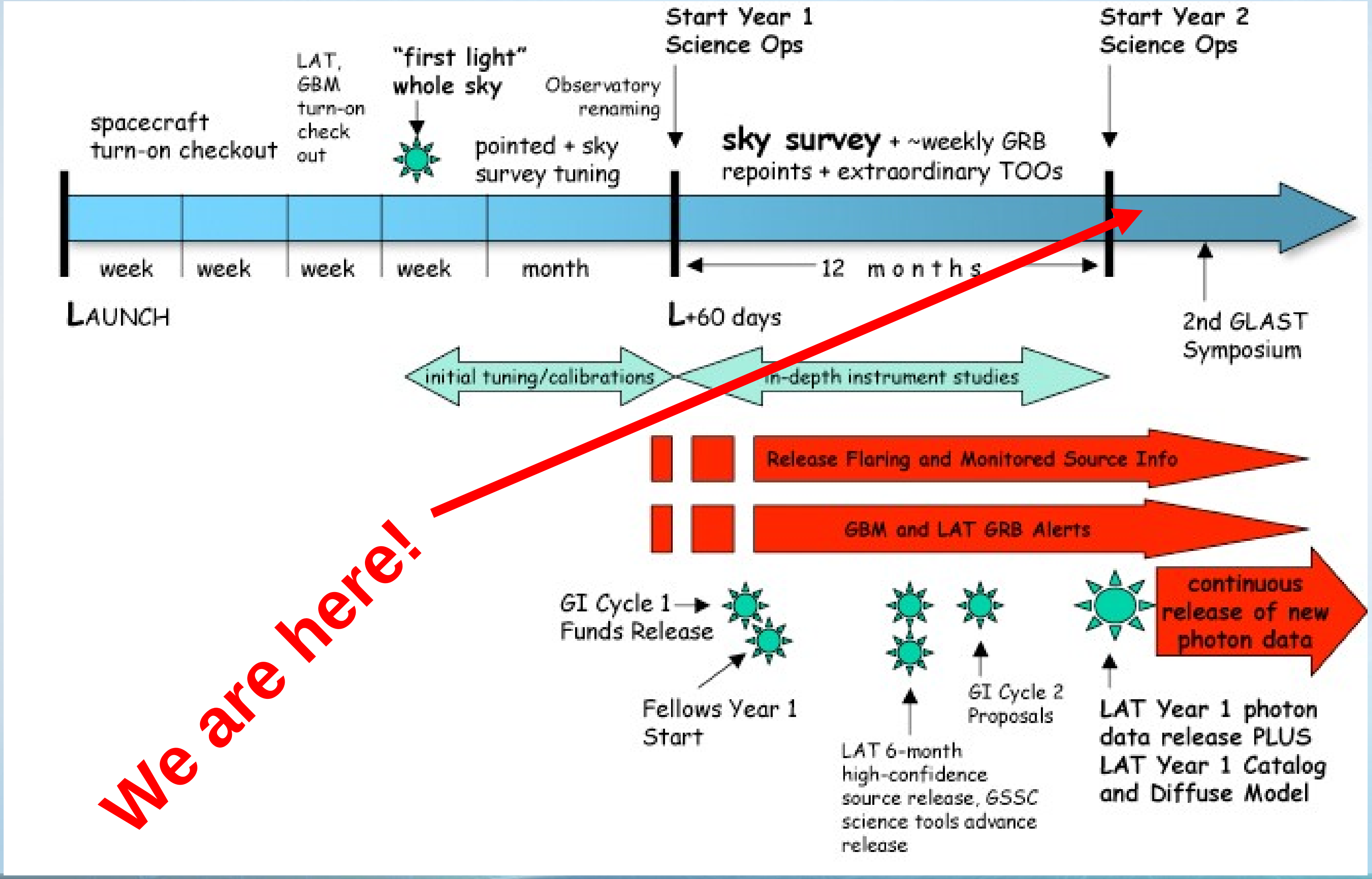
Also see my group's site:

http://epo.sonoma.edu

Photo Credit: Linnea Mullins

Backups Follow

Mission timeline



Unidentified Sources

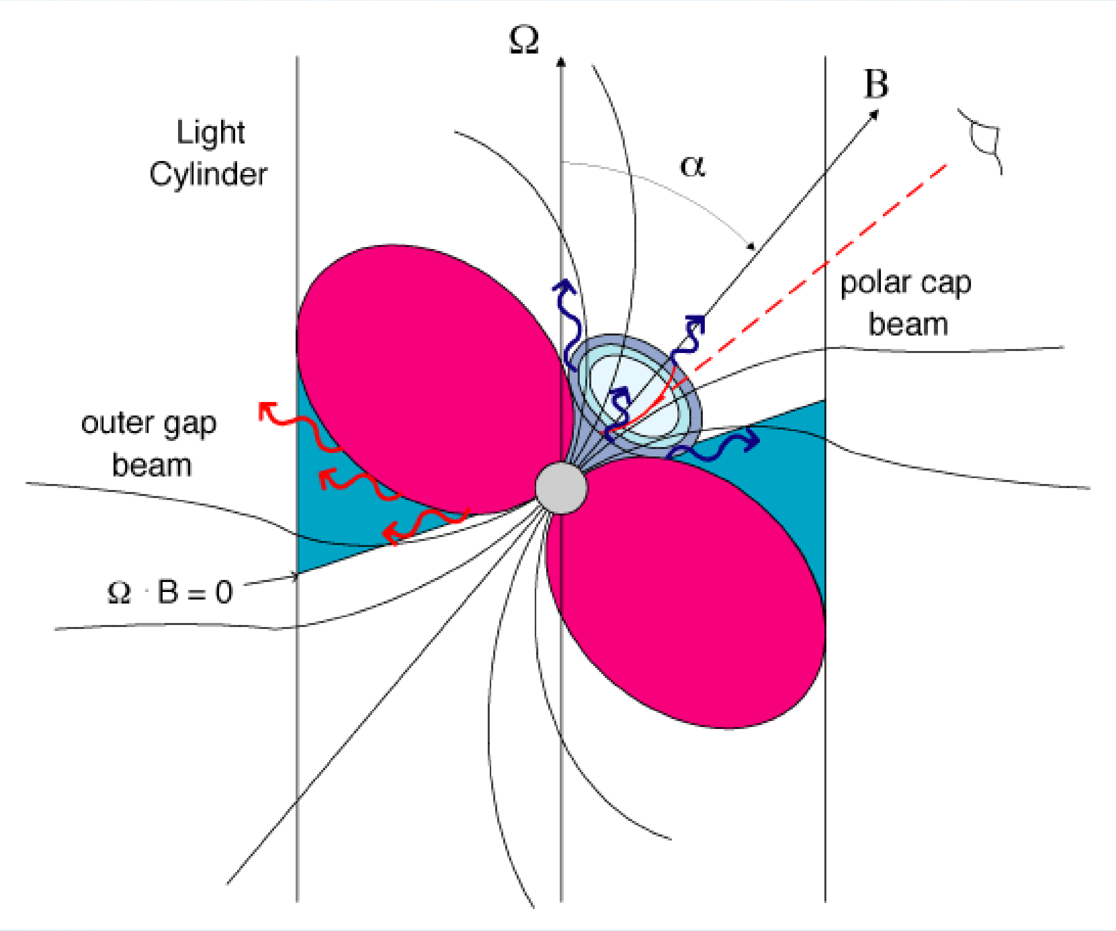
- 170 of the 270 sources in the 3rd EGRET catalog have no counterparts at longer wavelengths
- Variable sources appear at both low and high galactic latitudes
- High-latitude sources appear to be both extra-galactic and galactic
- Steady medium latitude sources may be associated with Gould's belt (star forming region)

Possible Unidentified Sources

- Radio-quiet pulsars: Geminga-like objects can be found with direct pulsation searches
- Previously unknown blazars: flaring objects will have good positions, helping IDs
- Binary systems: shocked winds between companions will show time variability
- Microquasars: time variability, X/γ correlation
- Clusters of galaxies: steady, high-latitude sources should show shock spectra

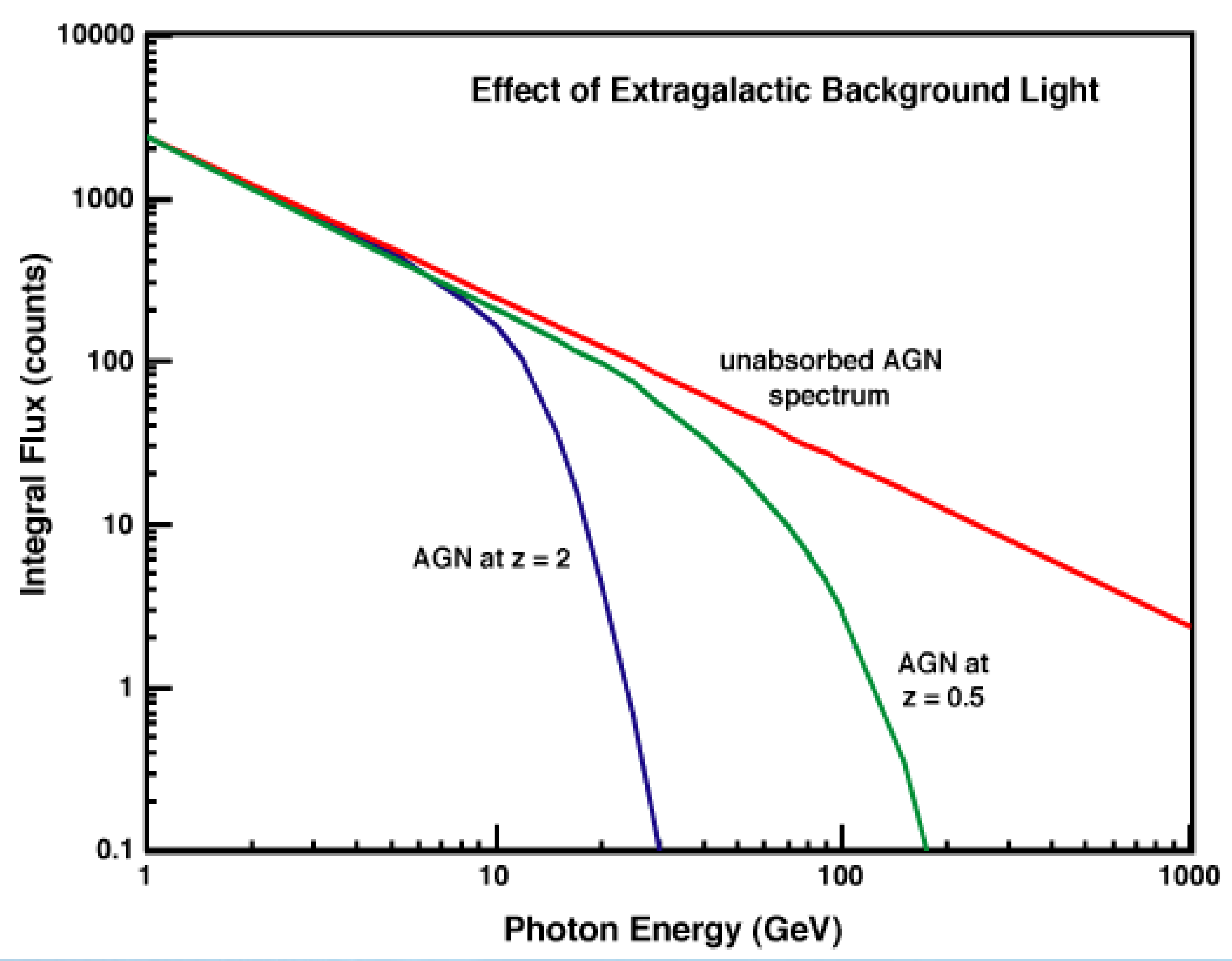
Outer gap vs. polar cap models

- Where are particles accelerated?
- How is particle beam energy converted into photons?
- What is shape of pulsar beam?
- How many pulsars are there? Birth rate?
- Where is most of the energy?

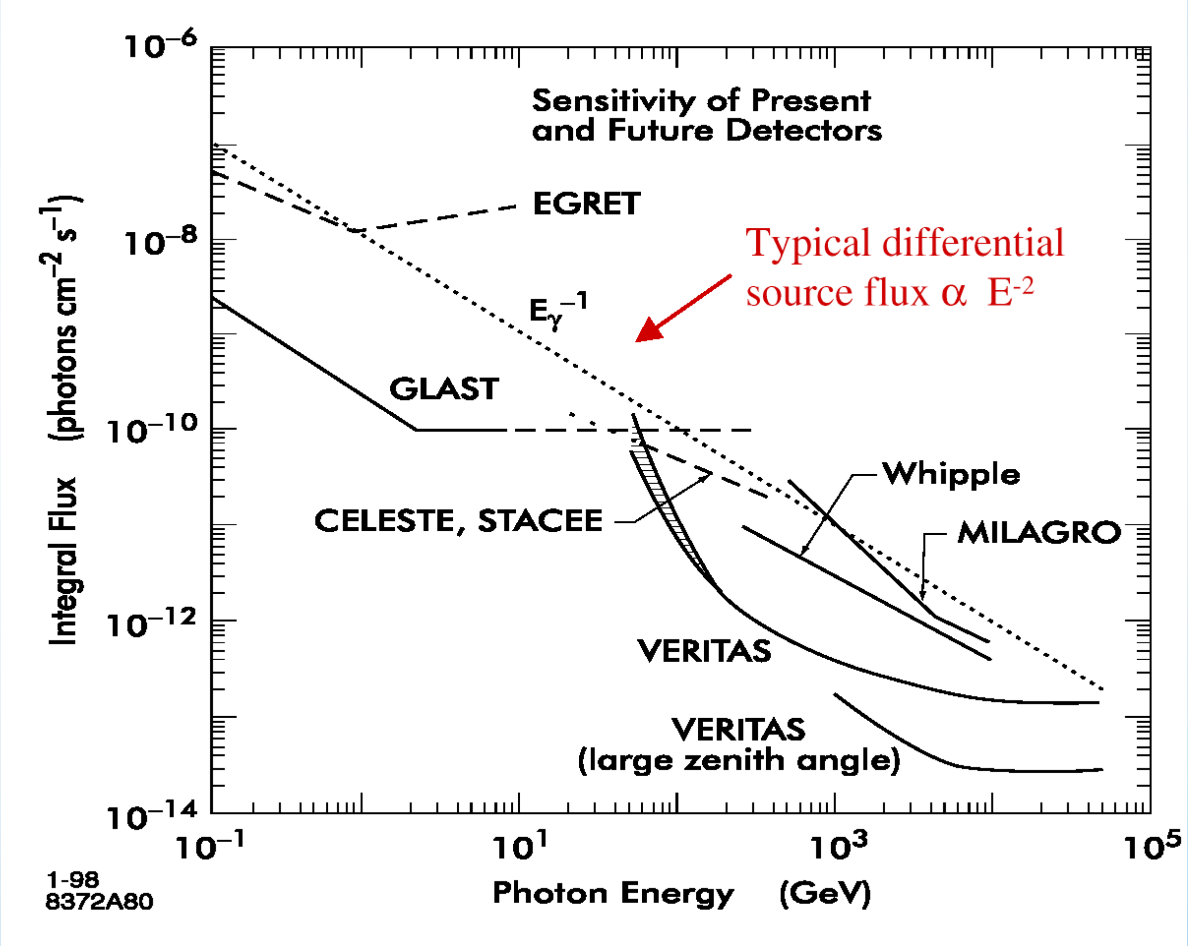


LAT studies EBL cutoff

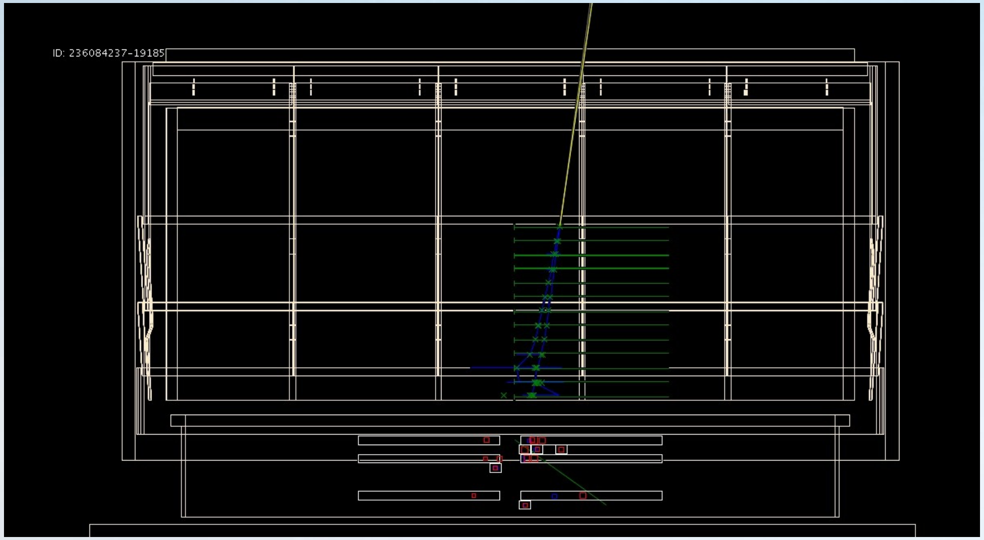
Probe history of star formation to z ~4 by determining spectral cutoff in AGN due to EBL

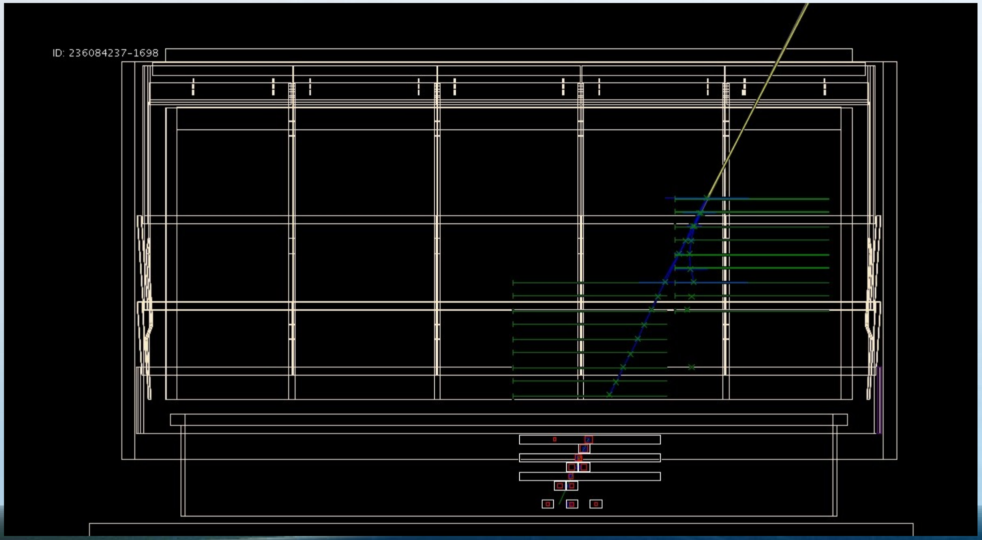


LAT vs. Ground-based HE Arrays



LAT Single GR Event Displays





- green = charged particles
- blue = reconstructed track
- yellow = gamma-ray estimated direction
- red = energy depositions in the calorimeter

Fermi
Gamma-ray
Space Telescope