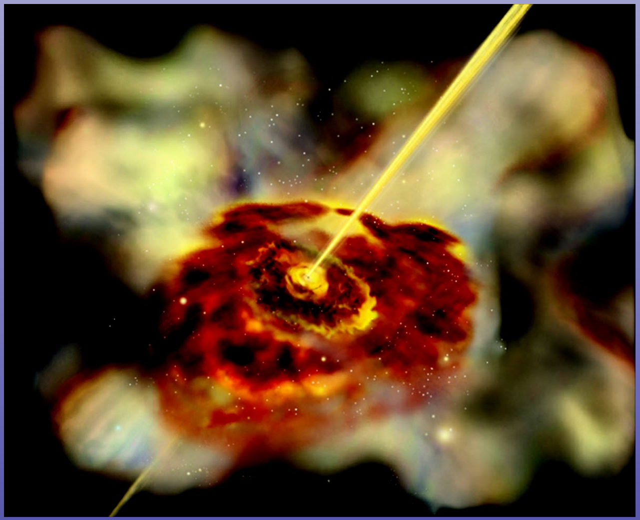
Blazing galaxies, exploding stars and monstrous black holes: High-energy visions of the Universe



Prof. Lynn Cominsky
NASA Education and Public Outreach
Sonoma State University

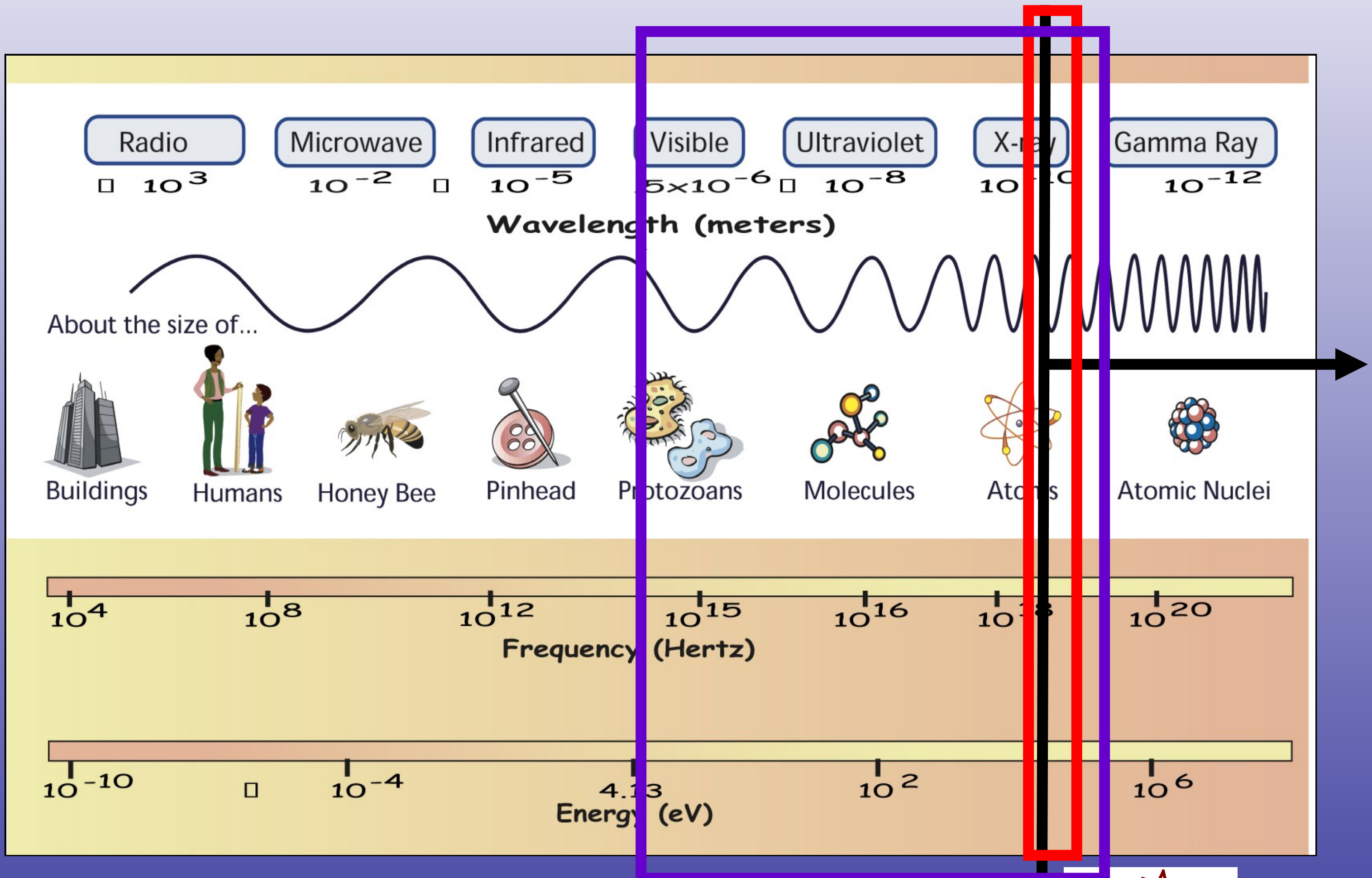
E/PO Group Satellite Missions

- *XMM-Newton* – launched 12/10/1999
  - – Focusing soft x-ray telescope
- *Swift* – launched 11/20/2004
  - – Gamma-ray burst explorer
- *Fermi* (aka *GLAST)* – launched 6/11/2008
  - – High energy gamma-ray sky survey +GRBs
- *NuSTAR* – launched 6/13/2012
  - – Focusing hard x-ray telescope

What we observe

NuSTAR 10-79 keV

Fermi 10 keV – 300 GeV



Swift – UVOT, XRT and BAT

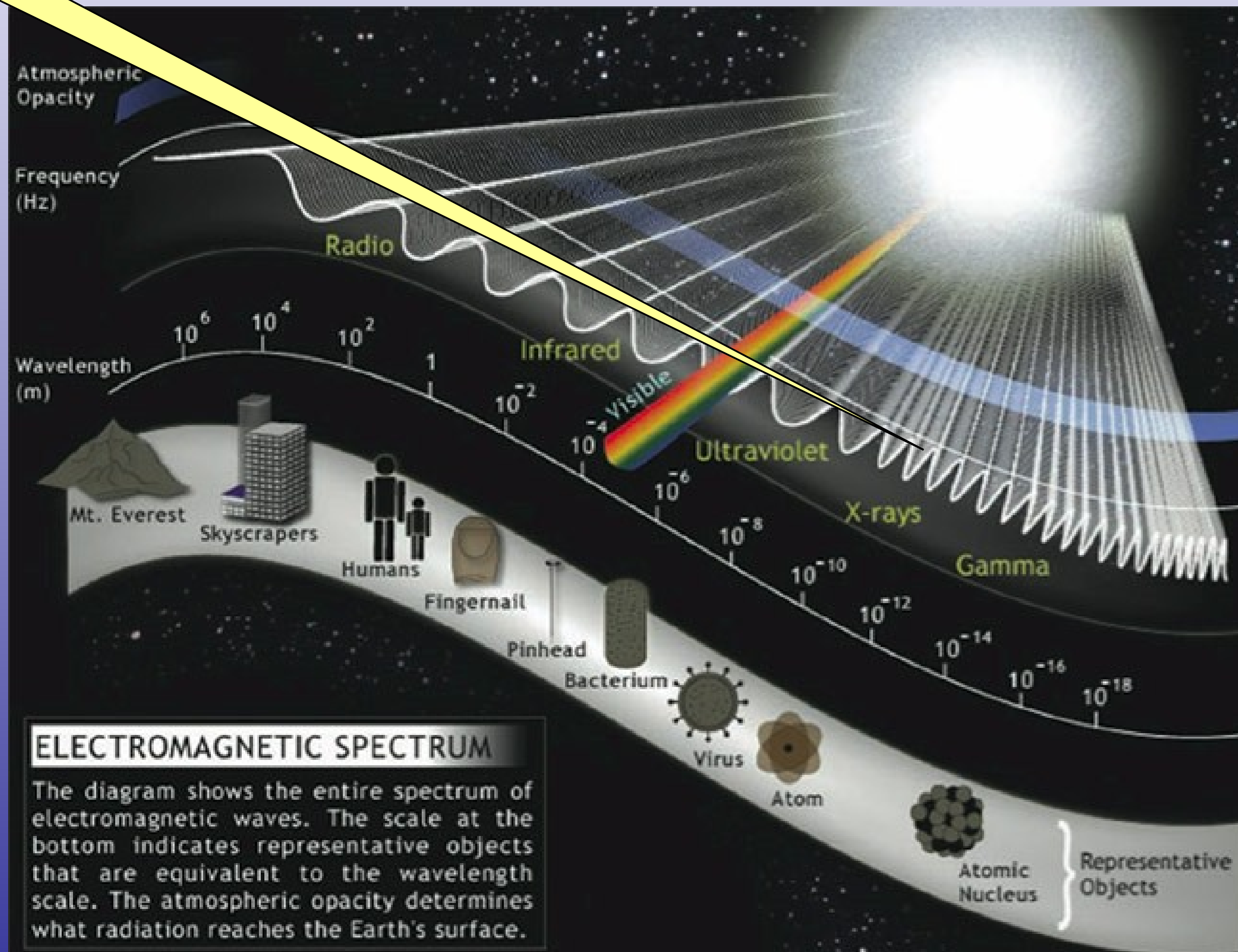
Exploring the Space Environment with X Rays

The second most energetic band of the EM spectrum

Wavelengths about the size of atoms

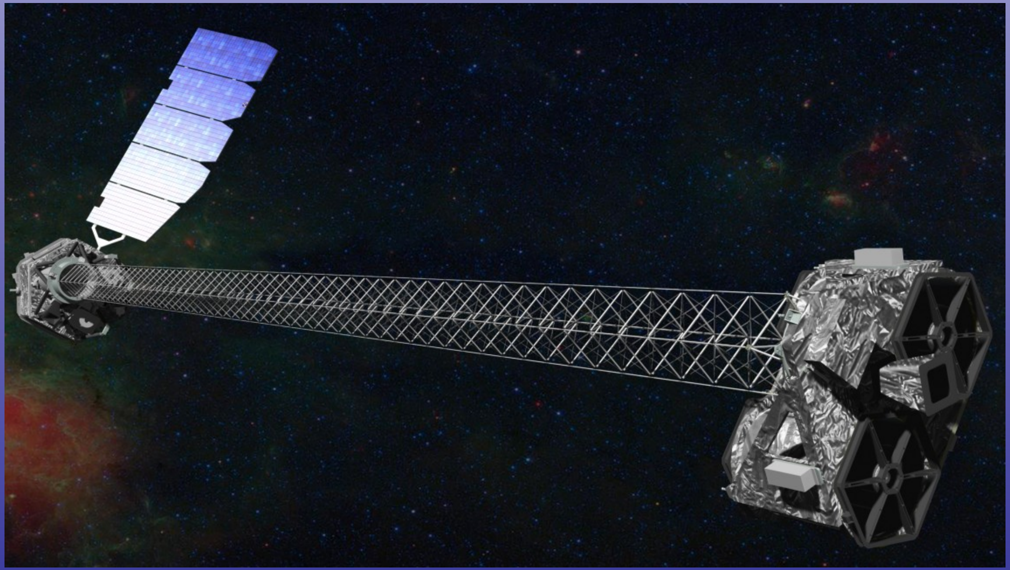
Photon Energies range from around 1000 to 100,000 times that of visible light

Emitted by objects at temperatures of millions of degrees. Including supernova remnants and disks of gas orbiting black holes



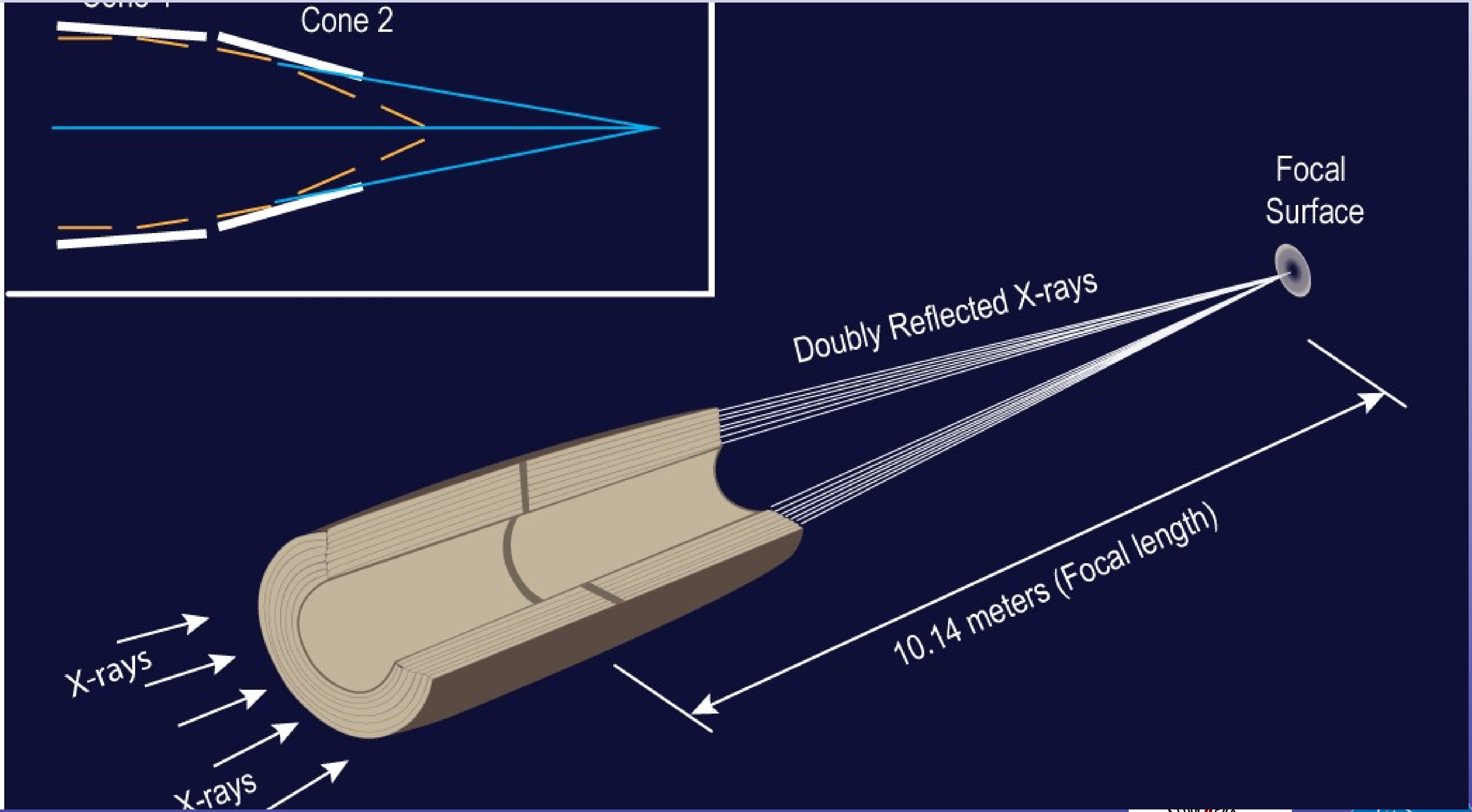
NuSTAR

- NASA's newest "Eyes on the Skies"
- Focuses X-rays creating images at higher energies than ever before



http://www.nustar.caltech.edu

How to focus X-rays



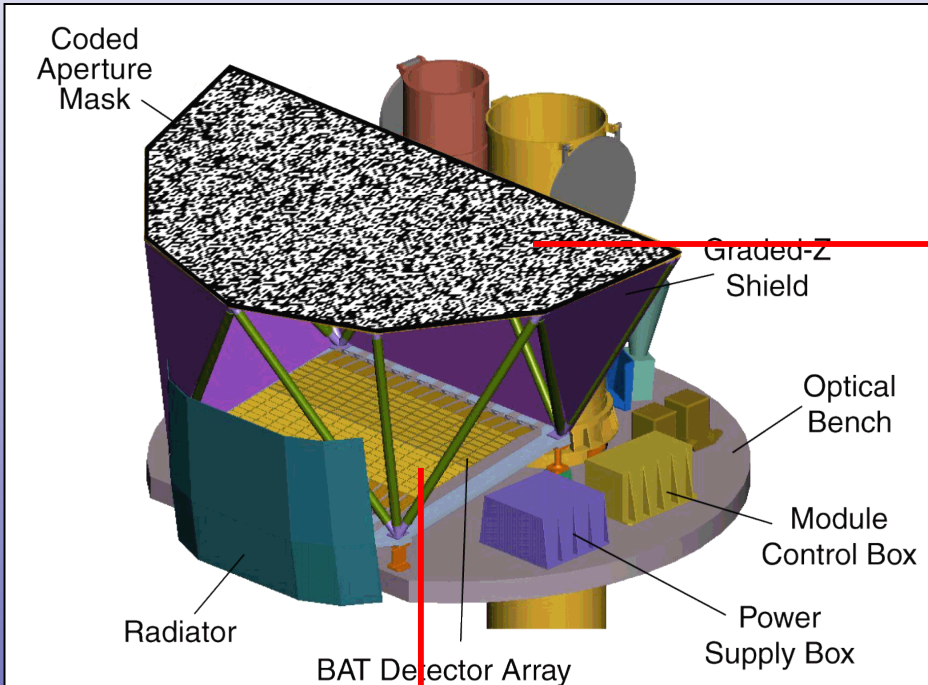
Swift GRB Mission

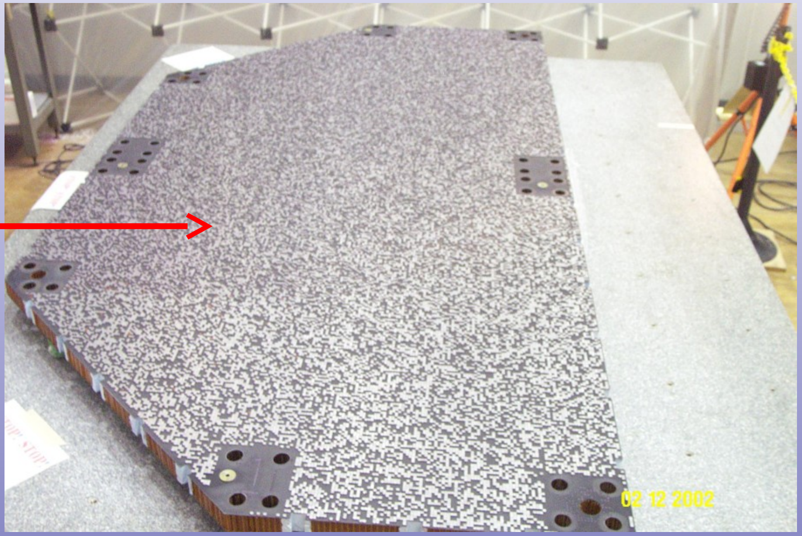
- Burst Alert Telescope (BAT)
- Ultraviolet/Optical Telescope (UVOT)
- X-ray Telescope (XRT)
- Studies Gamma-Ray Bursts with a *swift* response – usually within ~1 minute

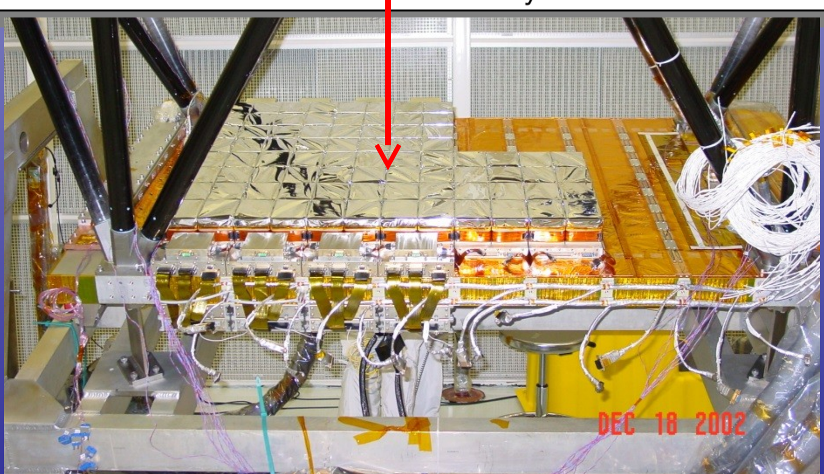
http://swift.sonoma.edu

Swift in GSFC clean room

Burst Alert Telescope







X-rays blocked by the lead tiles create a “shadow” on the detectors

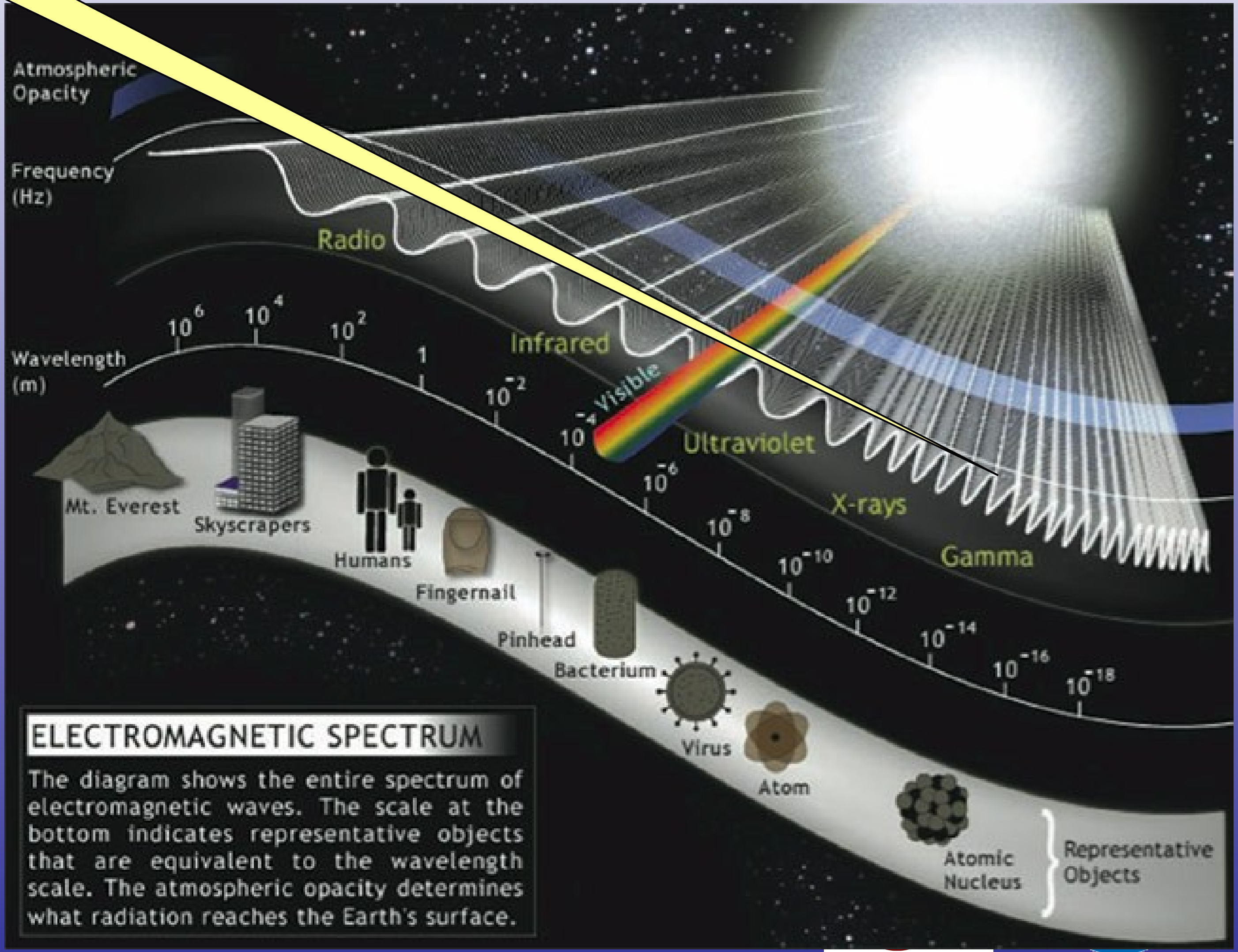
Exploring the Space Environment with Gamma Rays

The most energetic band of the EM spectrum

Wavelengths about the size of atomic nuclei

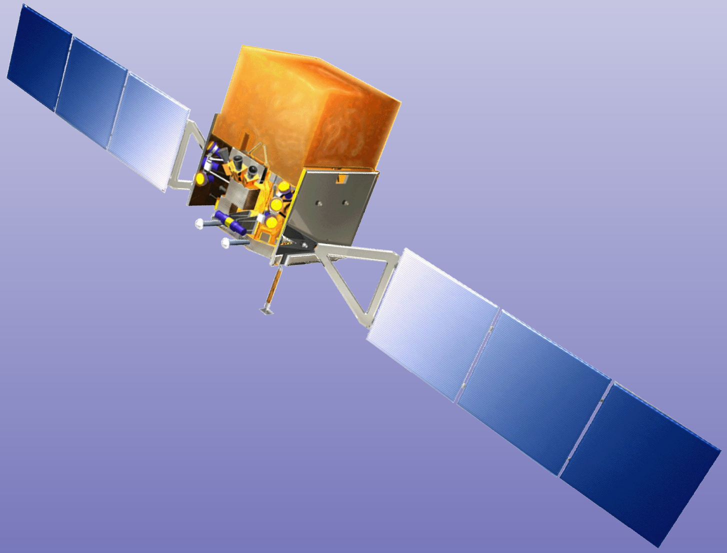
Energies more than a million times that of visible light

Only the most energetic events in the universe, like black holes and pulsars, can produce gamma rays by accelerating charges particles.



Fermi Gamma-ray Space Telescope

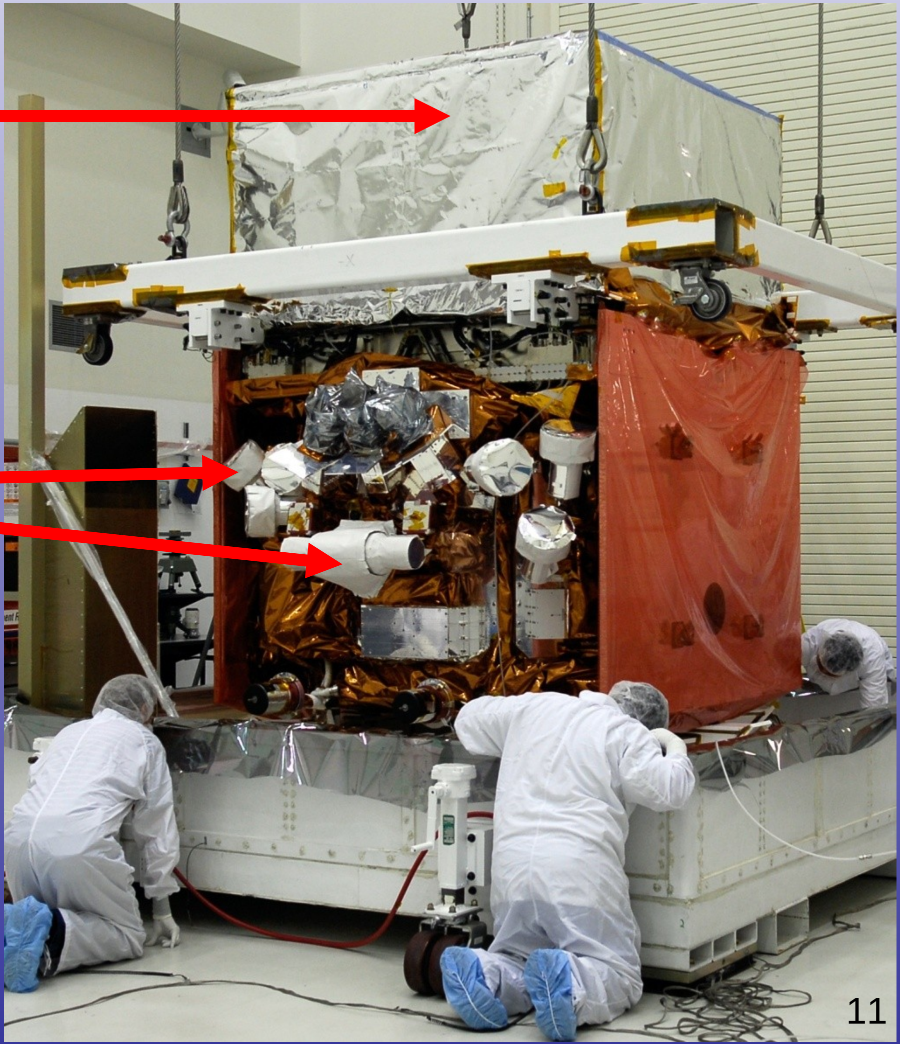
- Launched June 11, 2008
- Studies gamma rays over a very wide energy range
- http://fermi.sonoma.edu



Fermi before launch

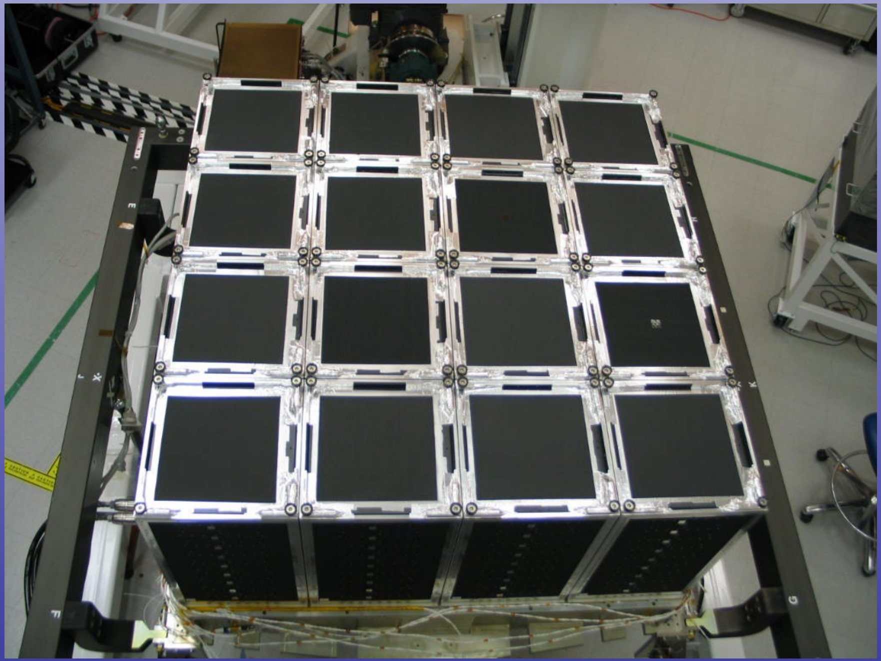
- Large Area Telescope

- Gamma-ray Burst Monitor



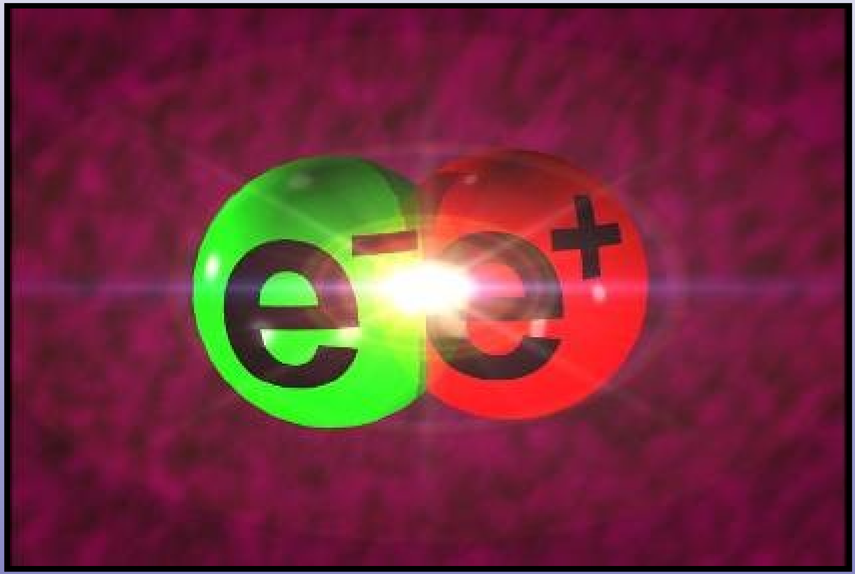
How to detect gamma rays?

- Can’t image or focus gamma rays
- Special detectors: scintillating crystals, silicon-strips



- This is Fermi’s Large Area Telescope
- It is a pair-conversion telescope with a calorimeter

Pair-annihilation



$E = mc^2$

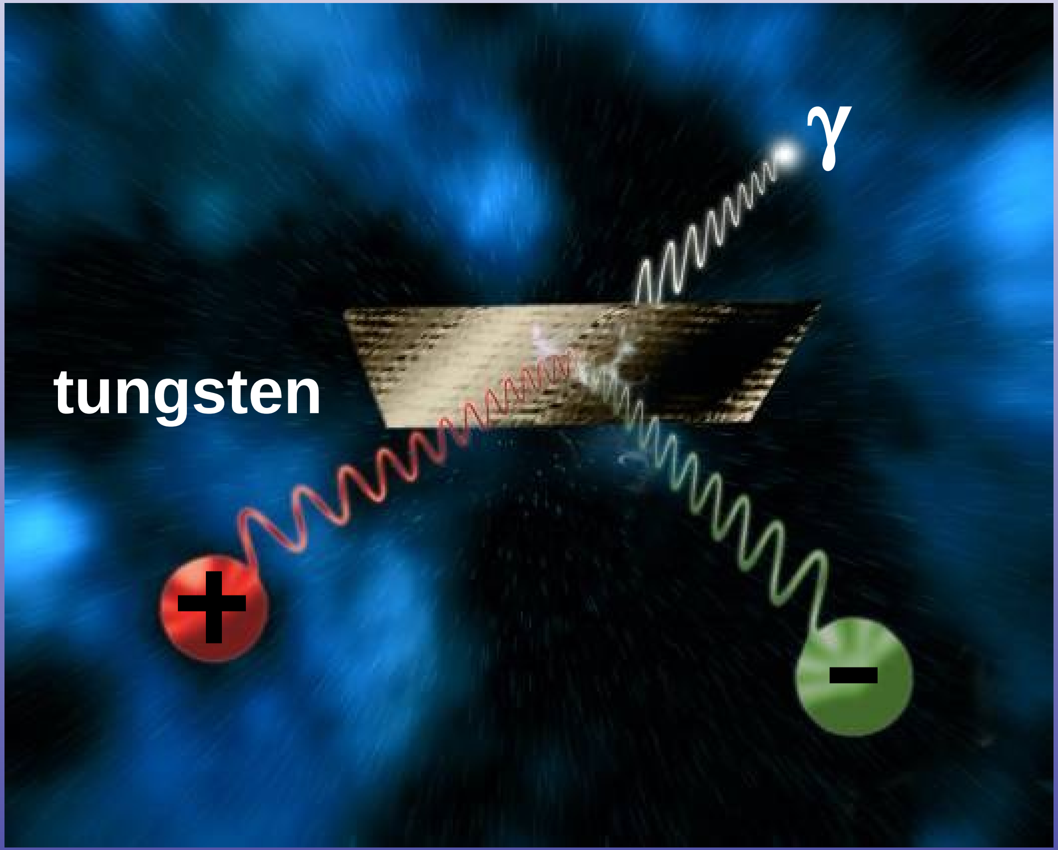
m = mass of the electron or positron

E = energy of gamma ray

- Anti-matter partners of e- are **positrons** (e+)
- When they meet, they annihilate each other!

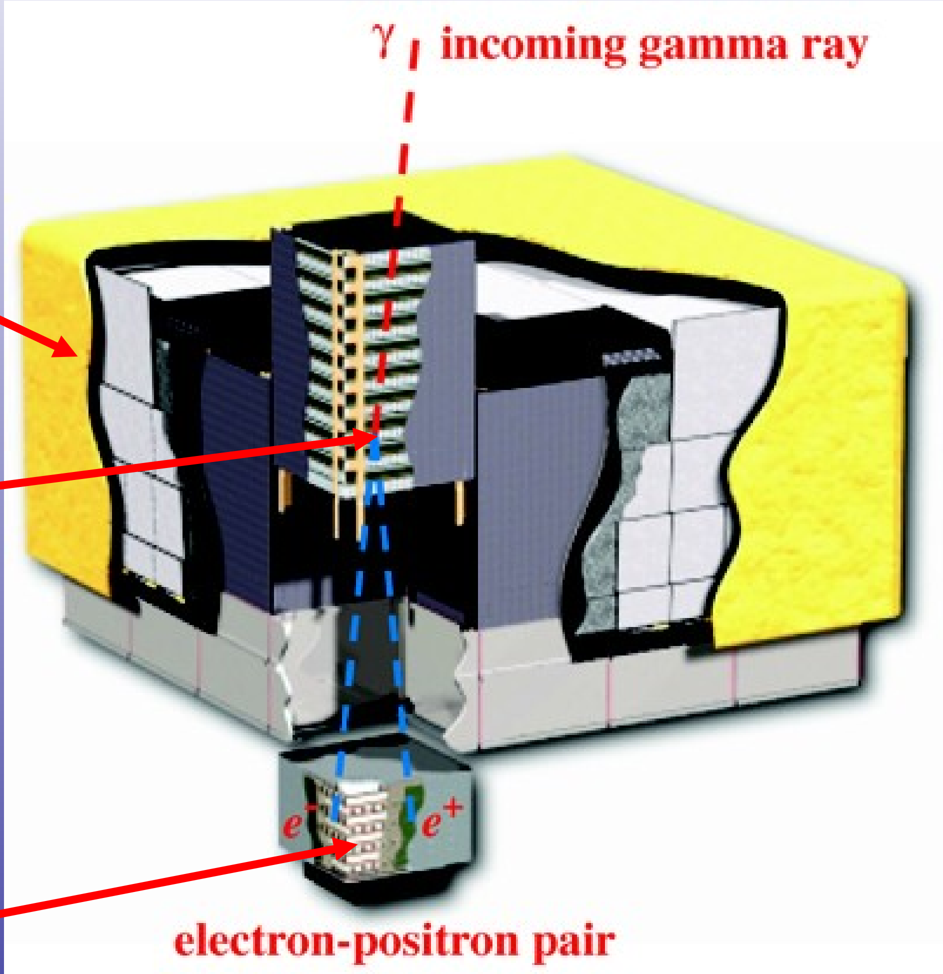
Now in reverse….

This process is called “pair conversion” as the incoming gamma-ray converts into an electron/positron pair



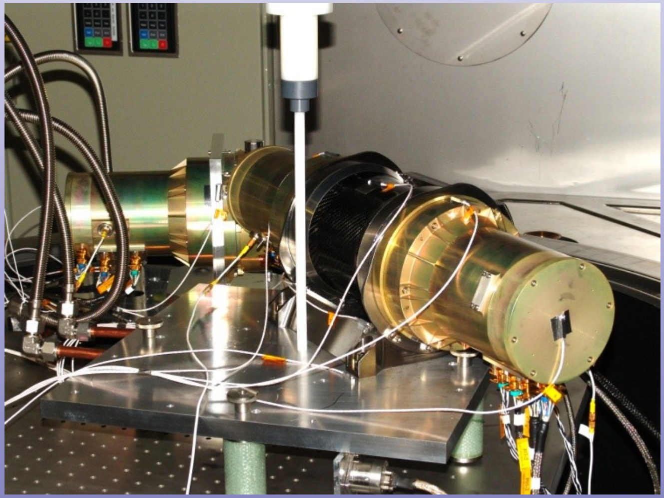
How the LAT works

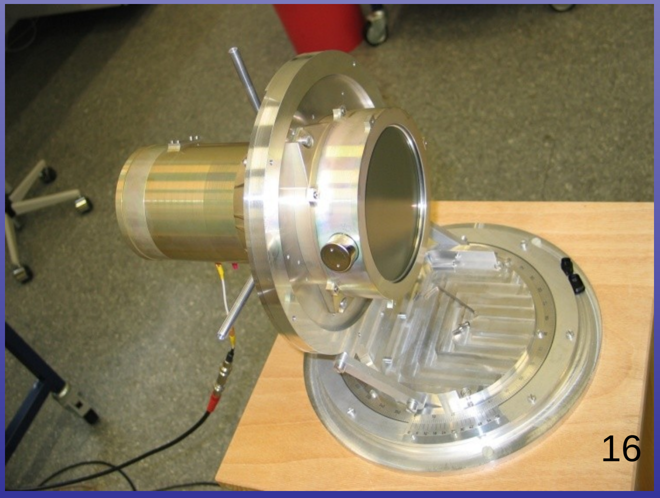
- Anticoincidence Detectors – screen out charged particles
- Tungsten converts gamma rays into e+ e- pairs
- Calorimeter measures total energy



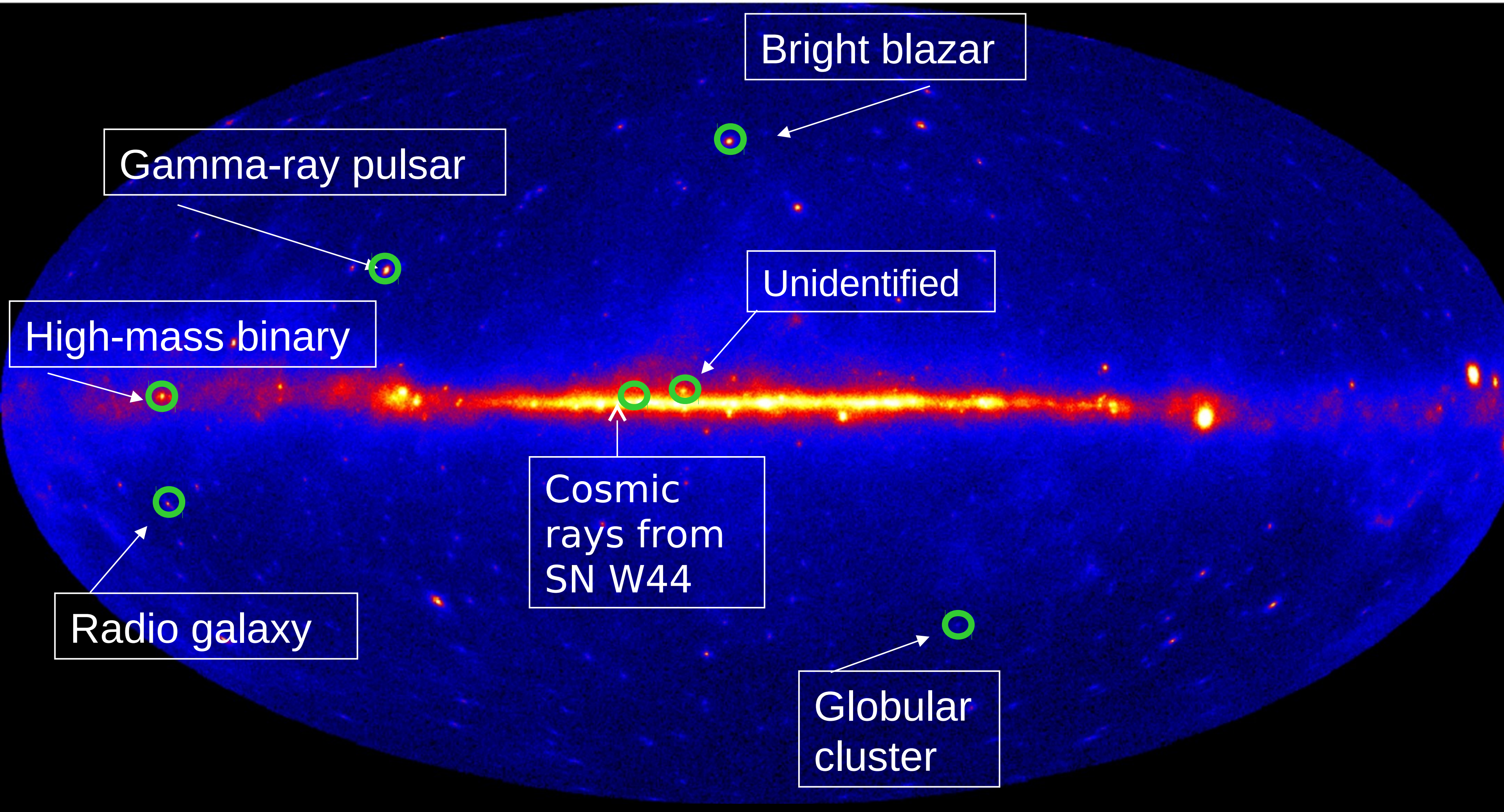
Gamma-ray Burst Monitor (GBM)

- All sky coverage
- 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/**



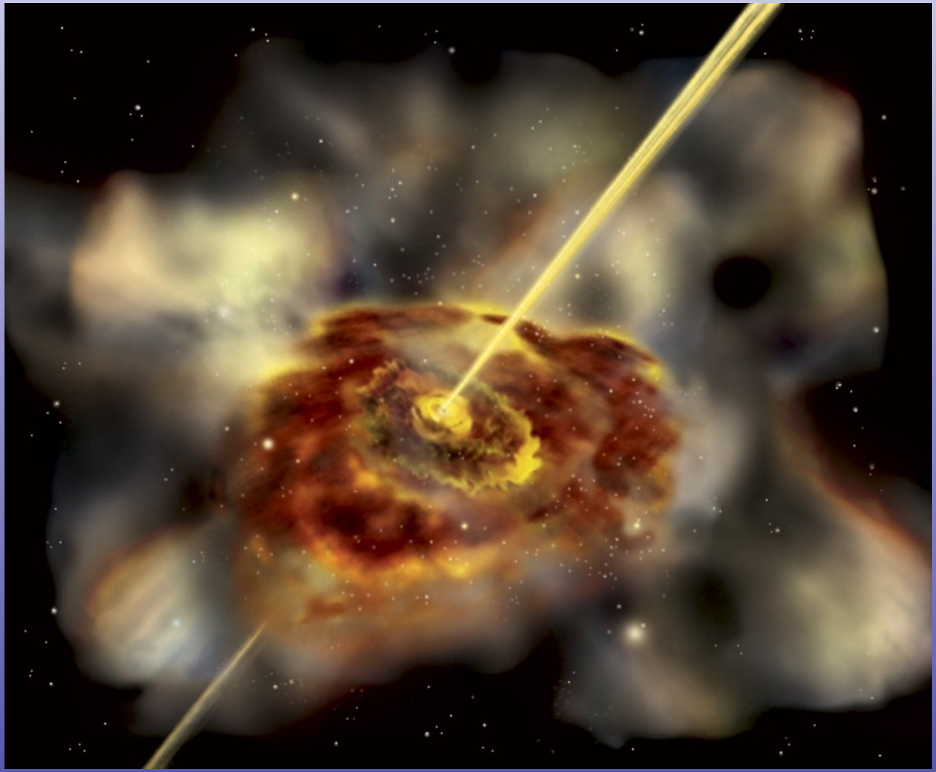


Fermi skymap – new discoveries



Studying Active Galaxies

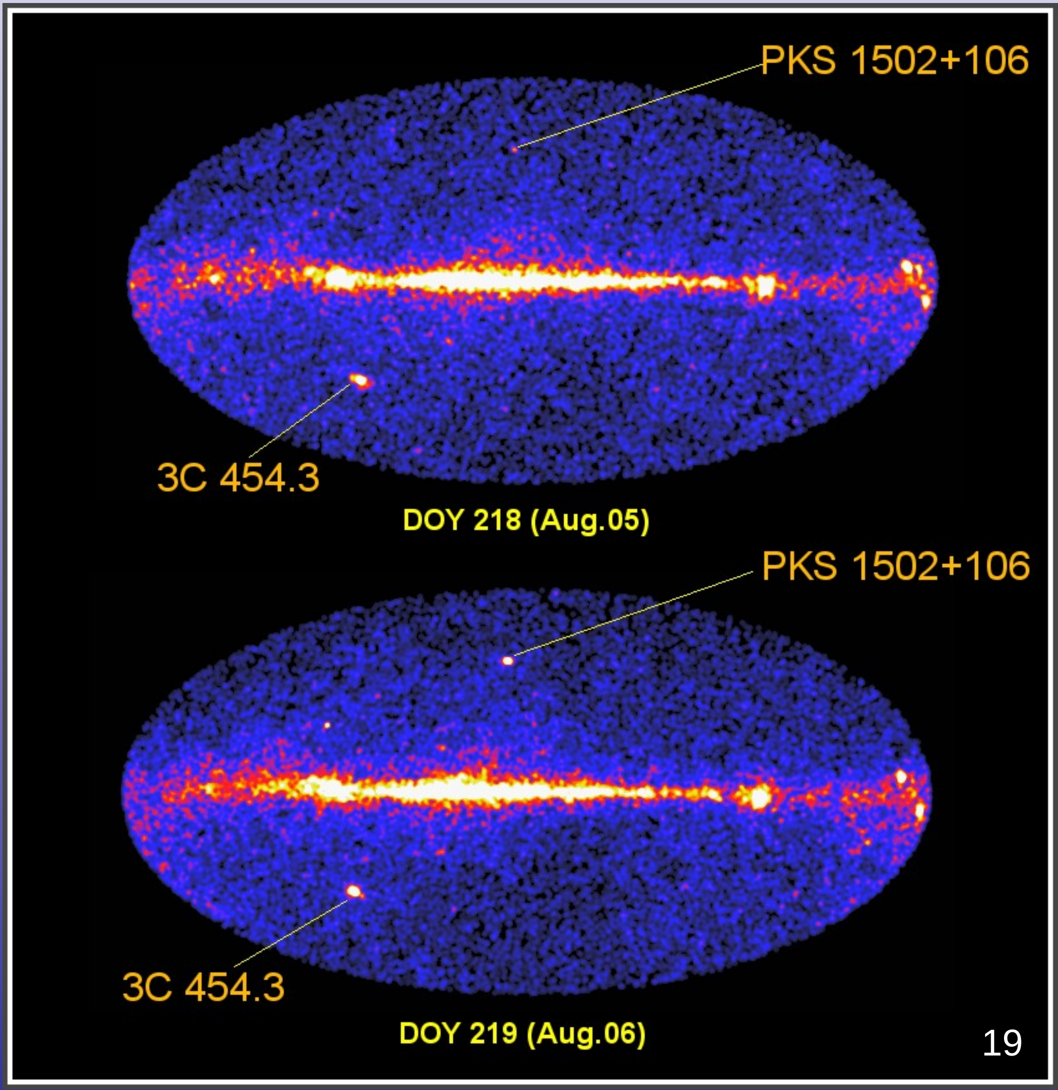
- Active Galaxies emits both X-rays and gamma rays
- Galaxies that point their jets at us are called “blazars”
- How do the black holes send out jets?



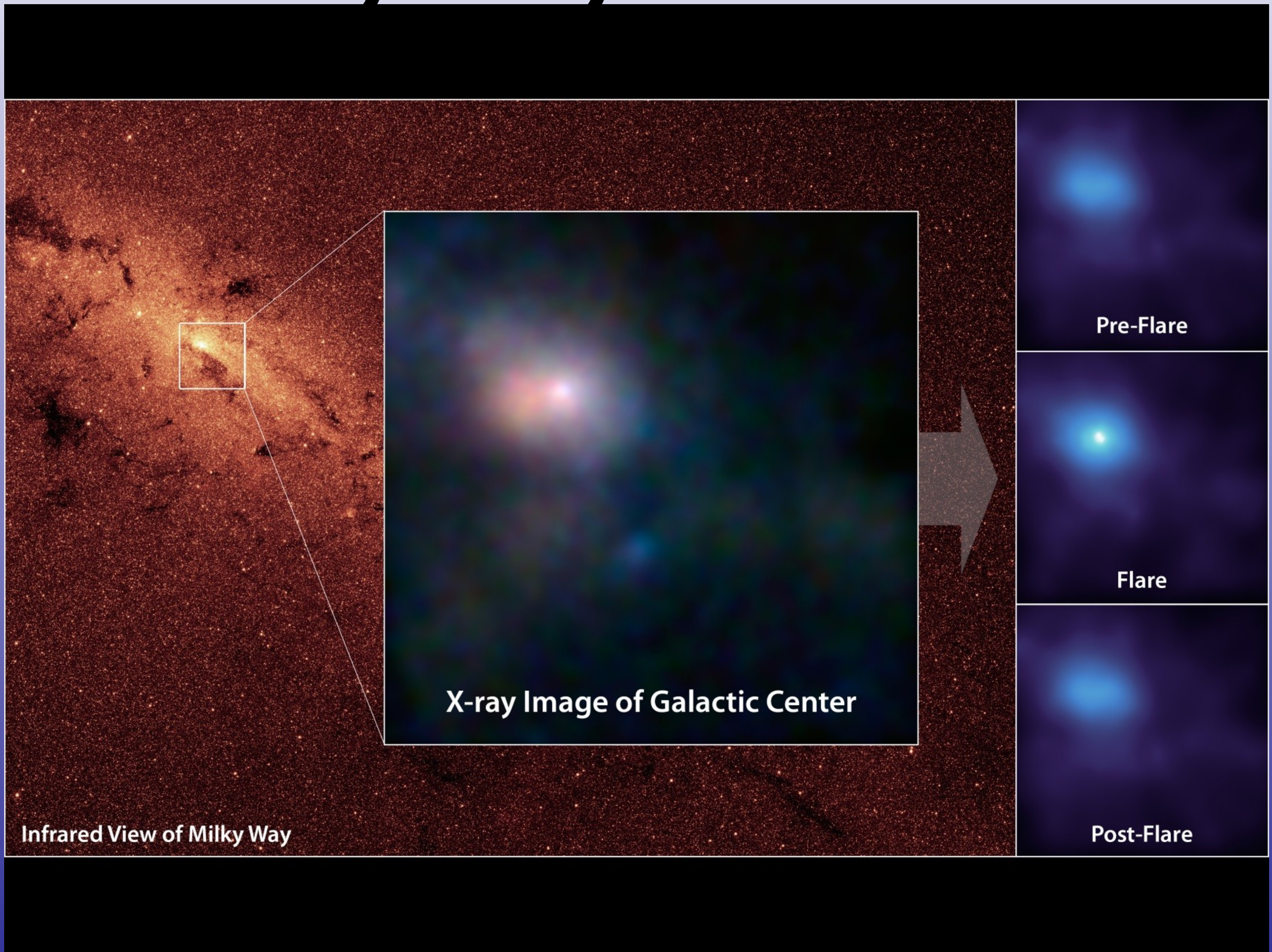
Art by Aurore Simonnet

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



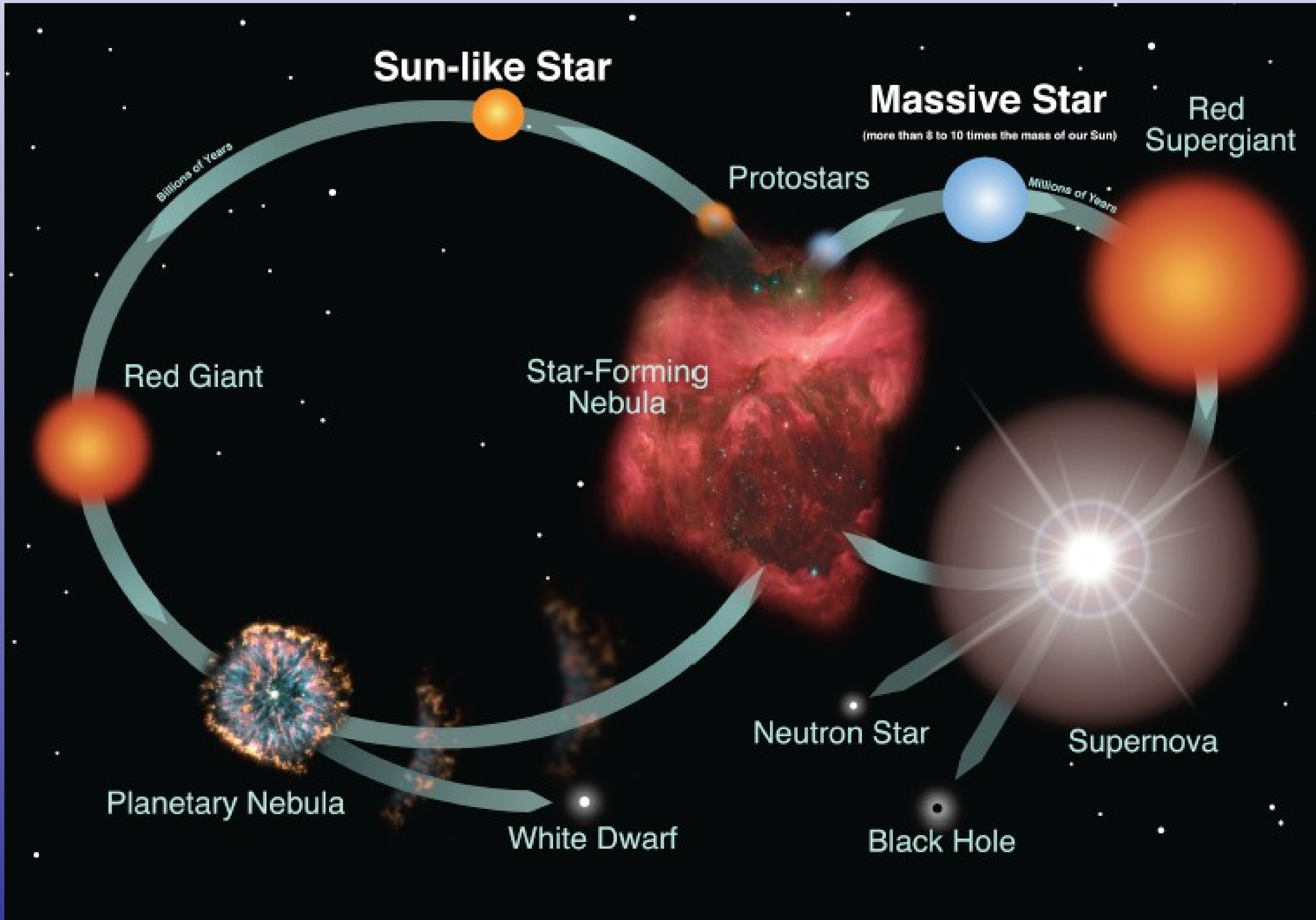
NuSTAR sees Flare from Milky Way's Black Hole



NuSTAR images two BHs in distant galaxy

Since BHs are not in center, they are probably “intermediate mass” BHs

Life Cycle of Stars



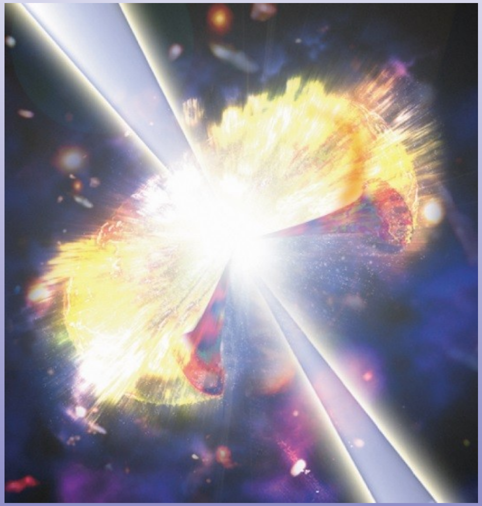
NuSTAR Cas A image

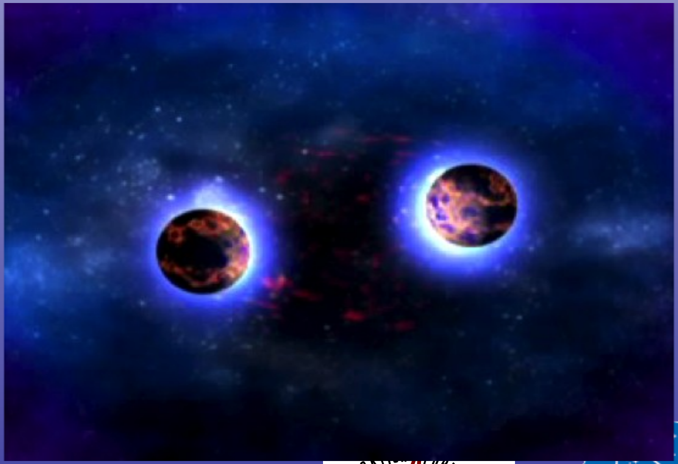
Blue shows the highest energy X-rays, not imaged before NuSTAR

Green and red show the lower energy X-rays, also seen with Chandra

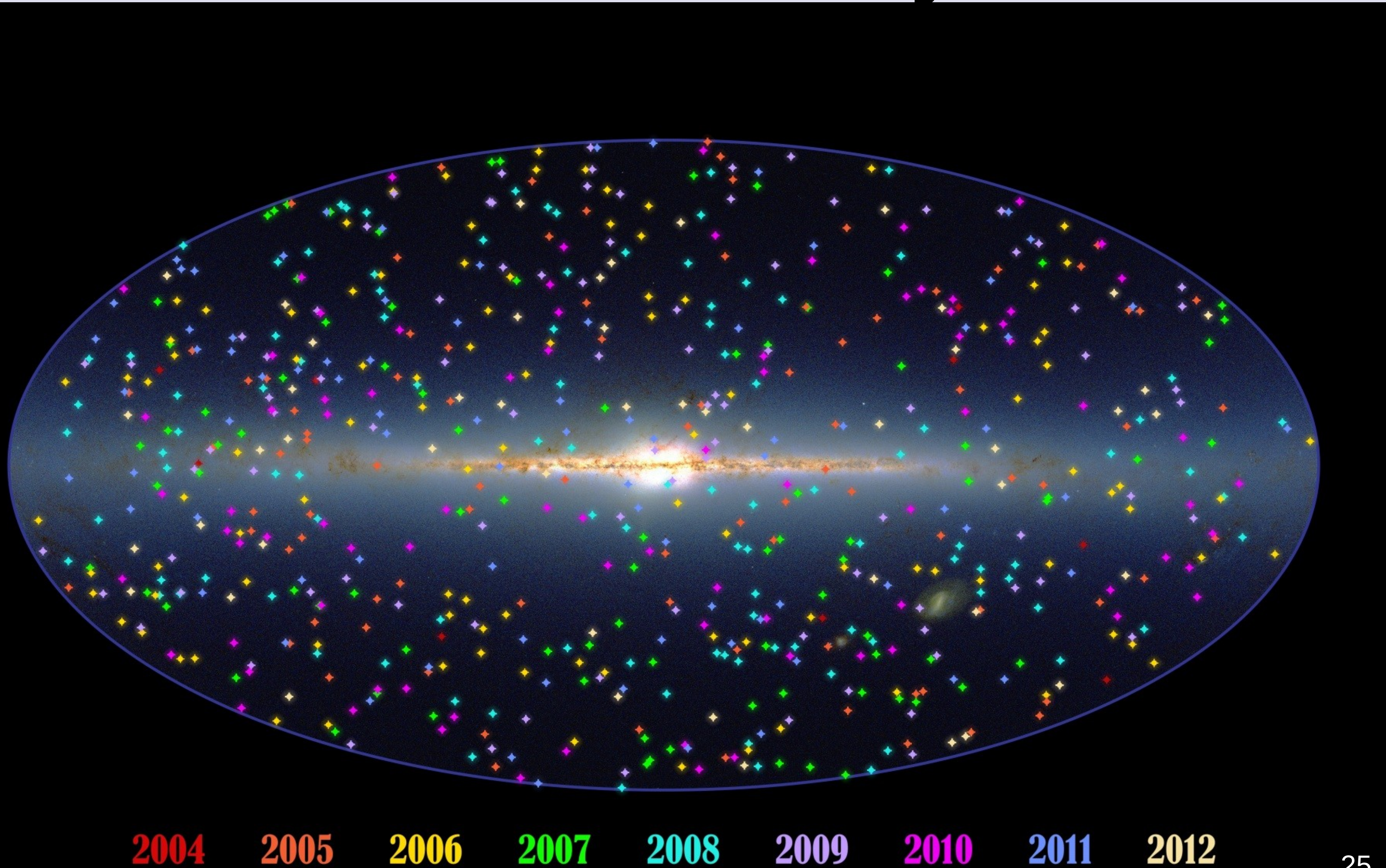
Gamma-ray Bursts

- Long bursts (>2 seconds) may be from a hypernova: a super-supernova
- Short bursts (<2 s) may be from merging neutron stars
- GRBs are birth cries of black holes
- Each GRB emits as much energy as our Sun in its entire lifetime!

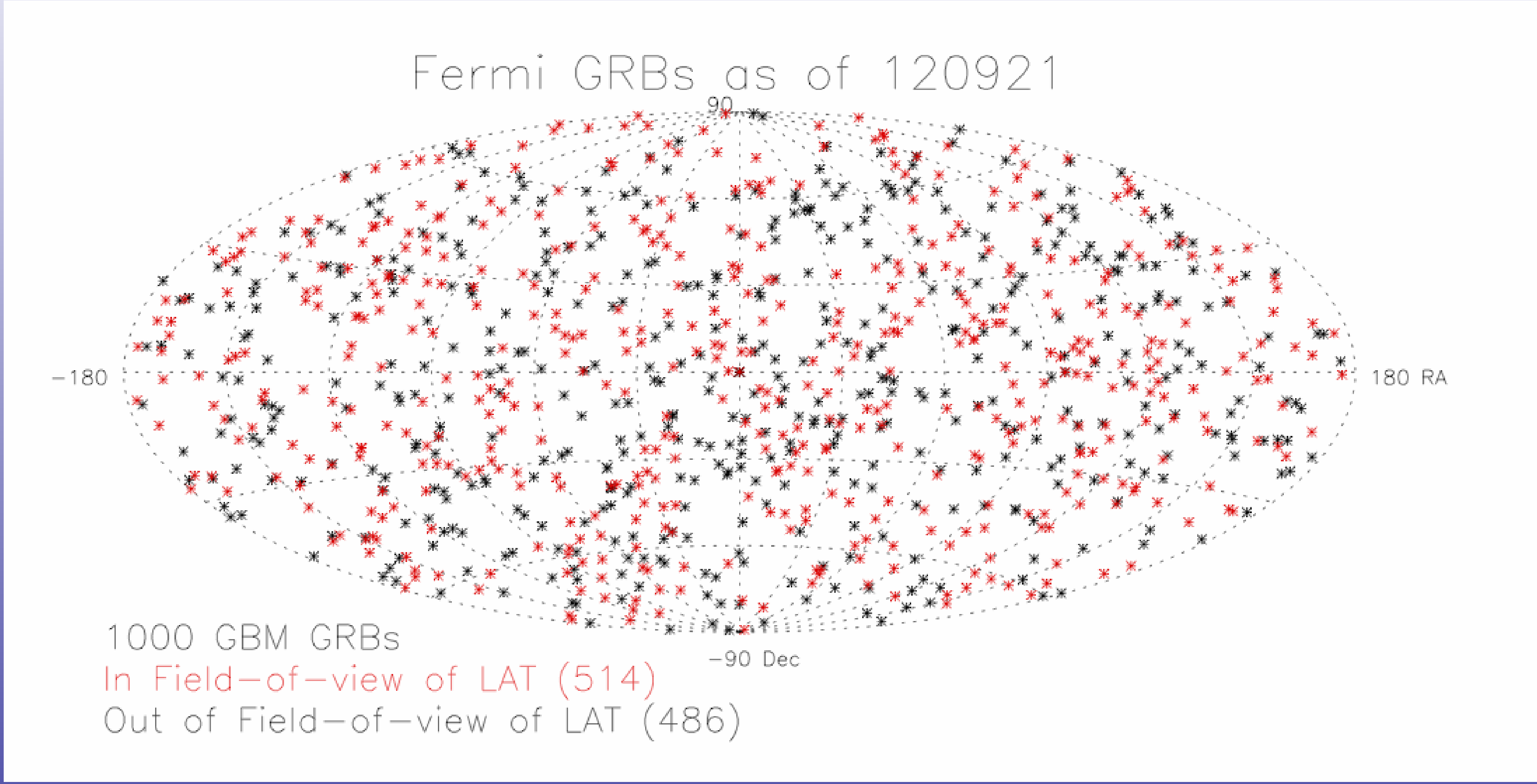




667 *Swift* Gamma-ray Bursts

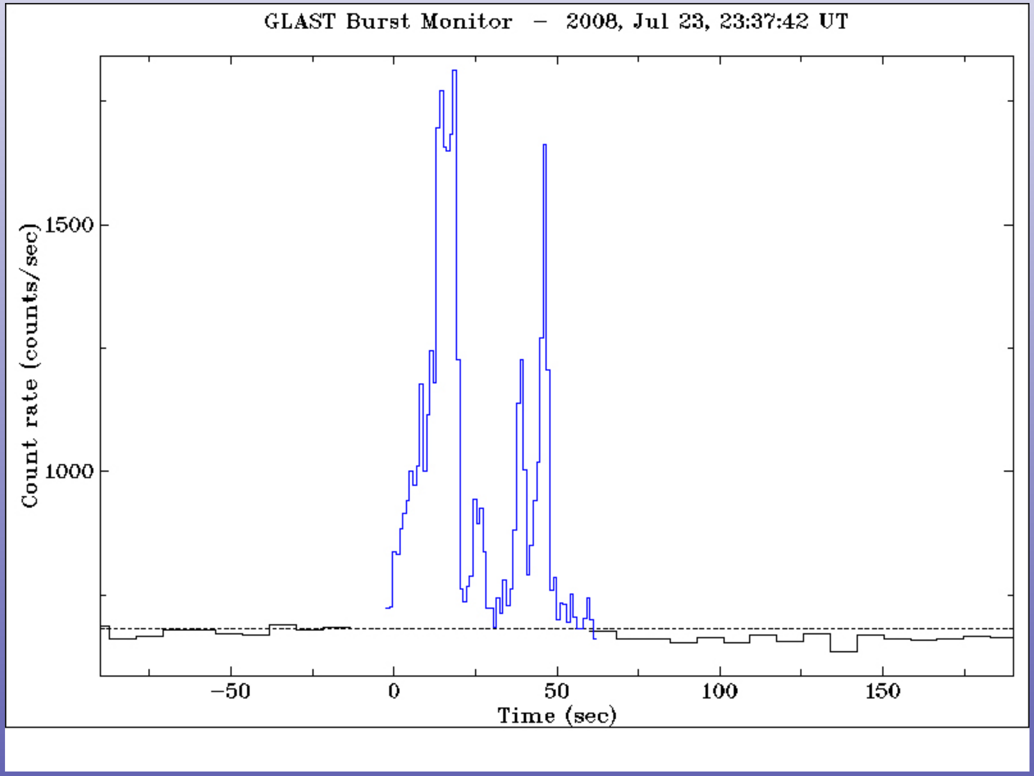


Fermi Gamma-ray Bursts



- About 4-5 bursts per week
- Follow bursts on http://grb.sonoma.edu

Typical strong GRB seen by GBM



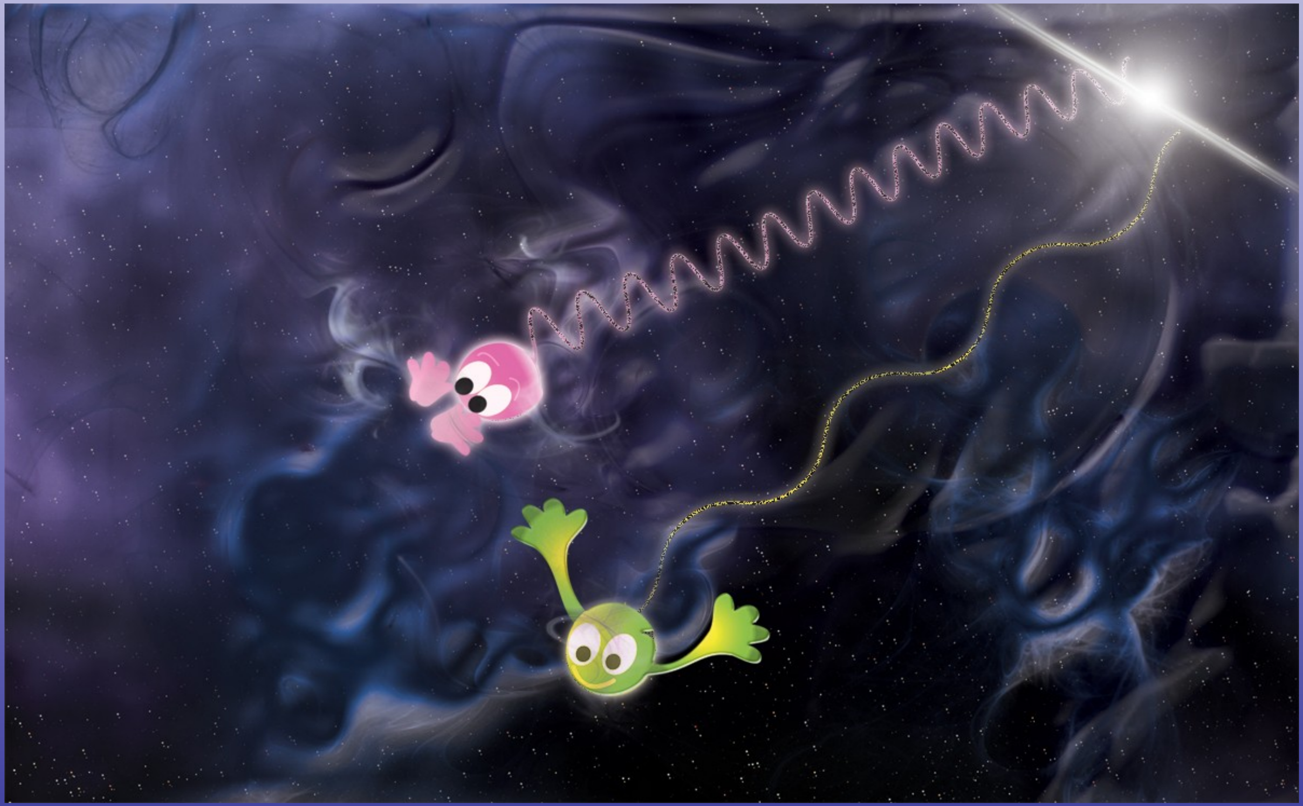
- 1000+ GBM bursts seen to date
- 40 LAT-GBM bursts seen in first 4 years

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

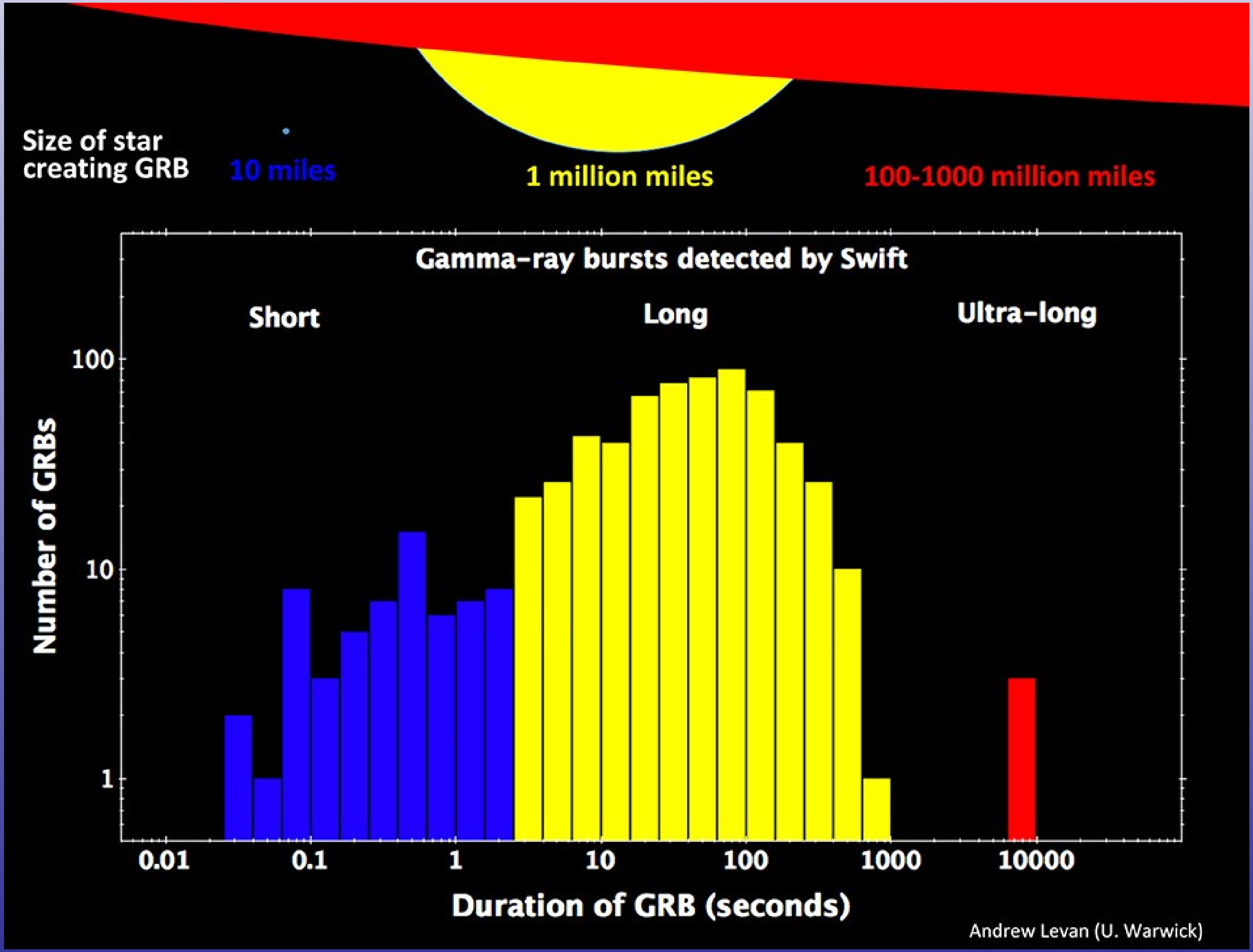
Will quantum foam entangle photons?

- Fermi sees no evidence for this to date

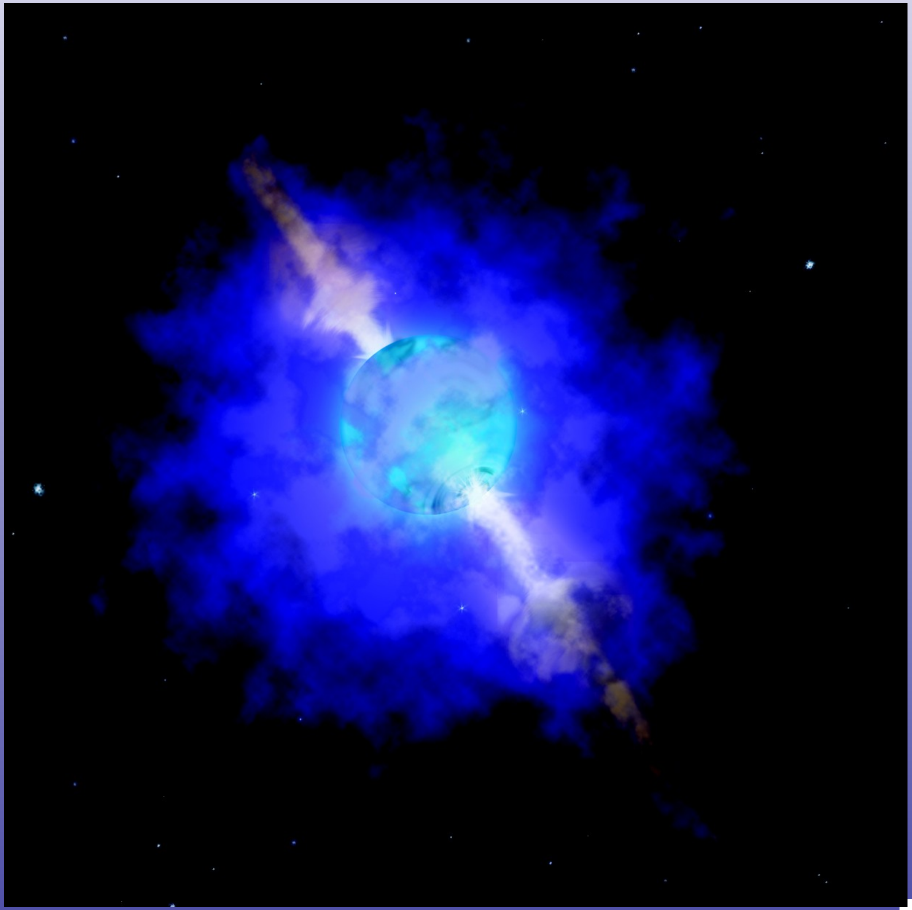


Two photons which differed in energy by 10^6 arrived at Earth within 1 second, after traveling for 12.2 billion years

Latest news – ultralong bursts



Blue supergiant system



Credit: CNRS/Céline Lavalade

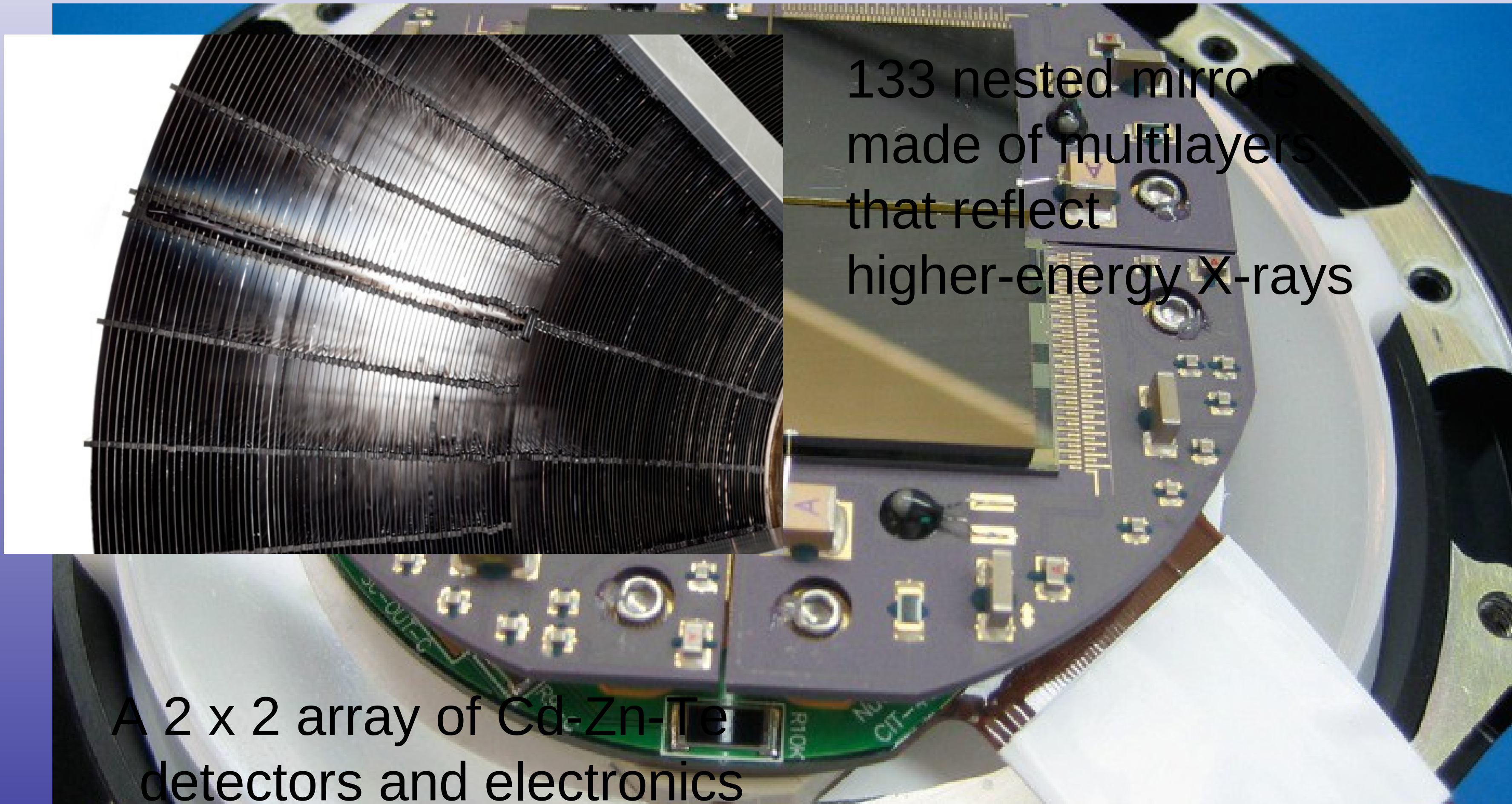
Resources

http://epo.sonoma.edu

- http://swift.sonoma.edu
- http://fermi.sonoma.edu
- http://grb.sonoma.edu
- http://gtn.sonoma.edu
- http://www.nustar.caltech.edu

Backups follow

NuSTAR's mirrors and detectors

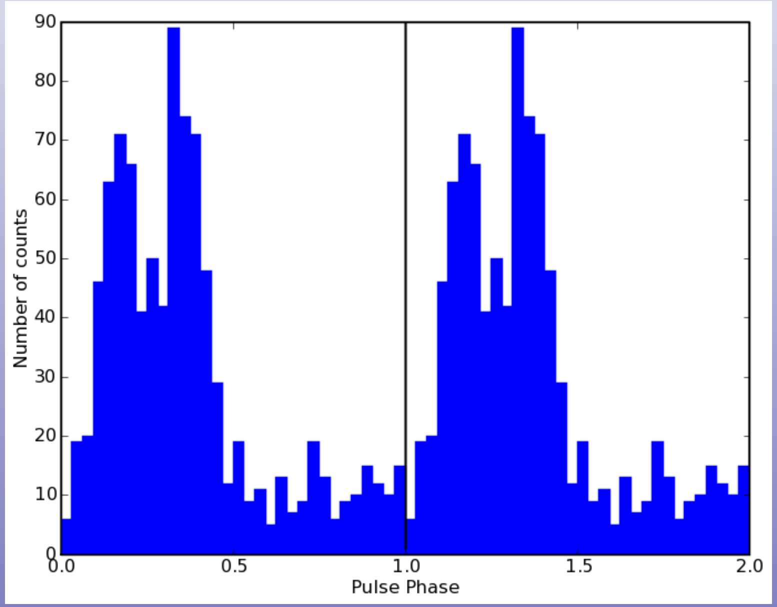


Global Telescope Network

- 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

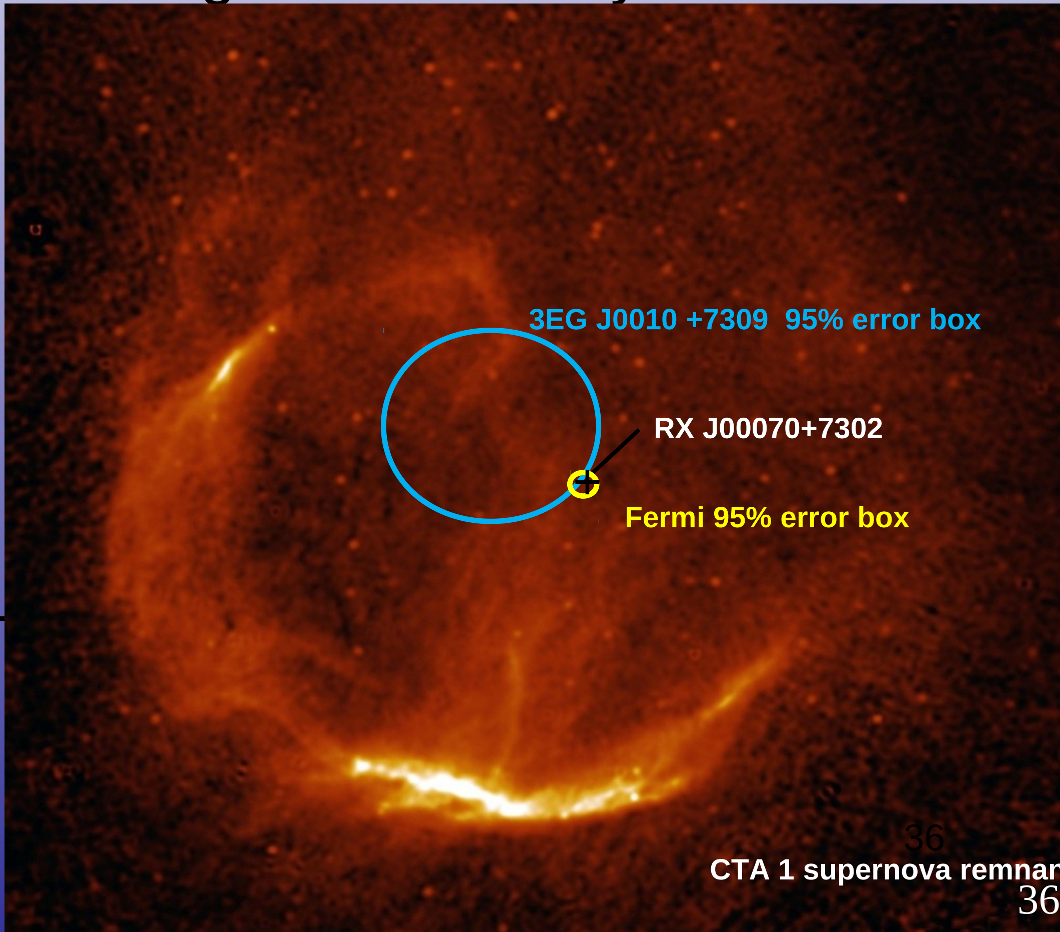
GORT at Pepperwood

Fermi finds 1st gamma-ray only pulsar in CTA1



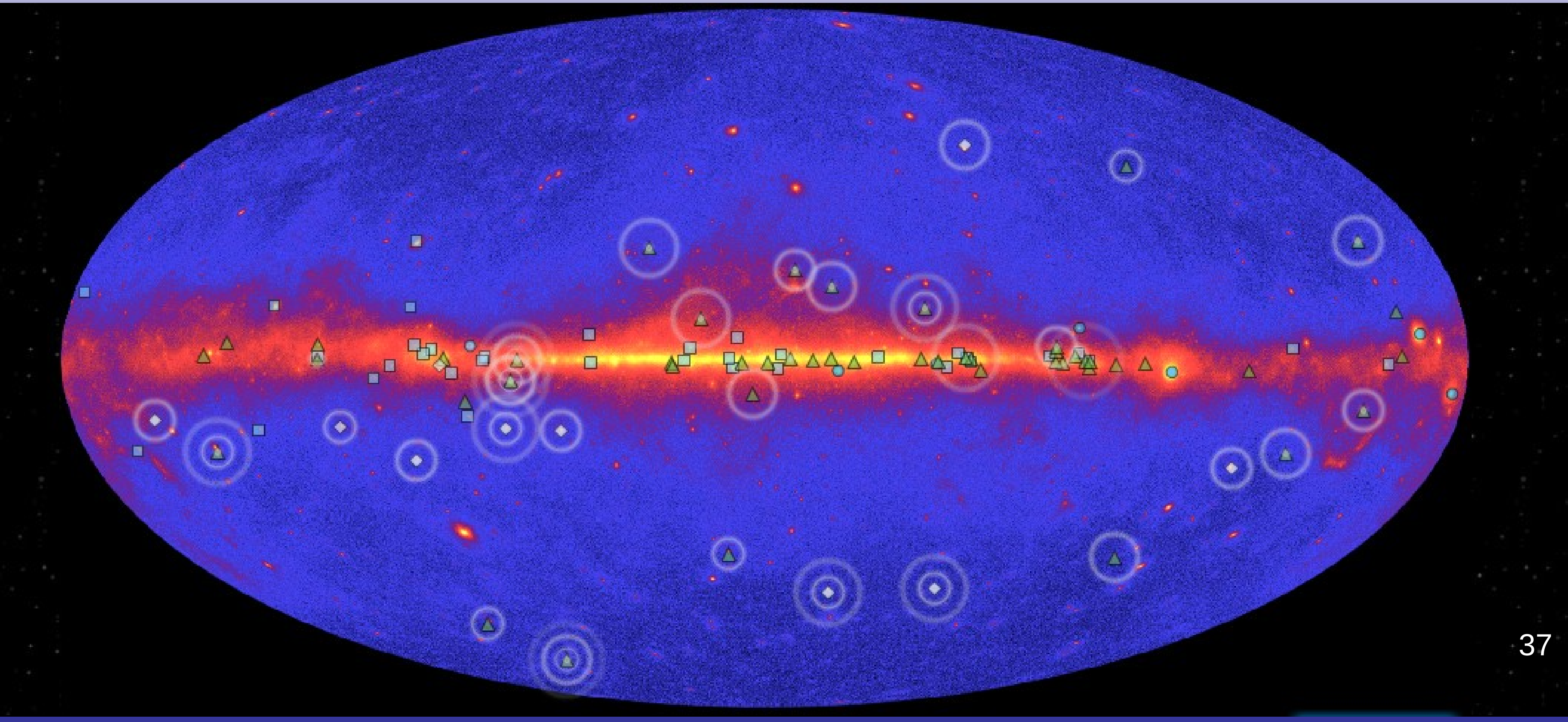
P = 315.86 ms
age ~1.4 x 10^4 yr

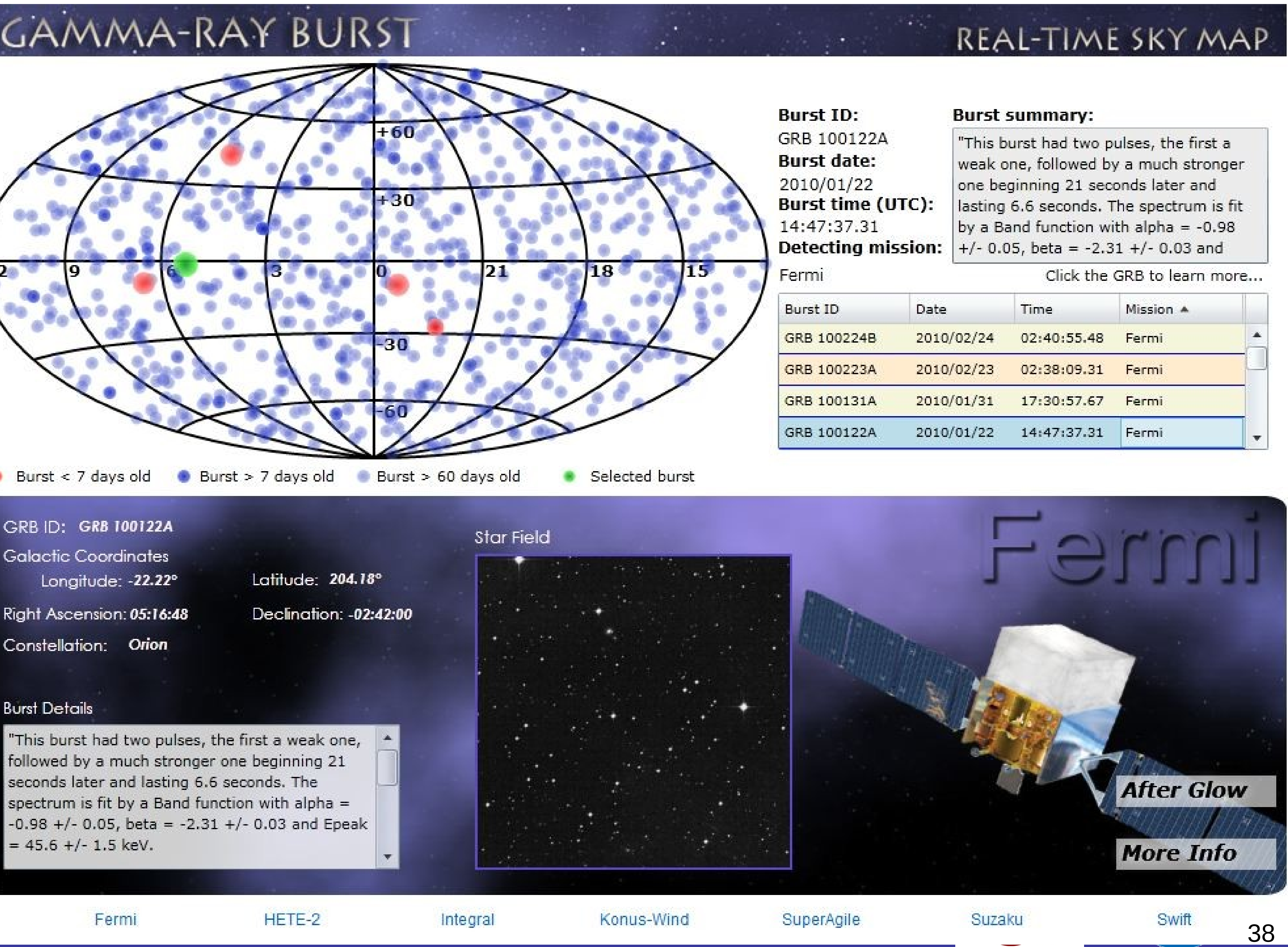
- Pulsar is not at center of SNR
- It's moving at 450 km/sec - kicked by the supernova explosion that created it



Pulsar Explorer interactive

- http://www.nasa.gov/externalflash/fermipulsar/




GAMMA-RAY BURST
REAL-TIME SKY MAP
+60
+30
0
-30
-60
9
6
3
0
21
18
15
Burst ID:
GRB 100122A
Burst date:
2010/01/22
Burst time (UTC):
14:47:37.31
Detecting mission:
Fermi
Burst summary:
"This burst had two pulses, the first a weak one, followed by a much stronger one beginning 21 seconds later and lasting 6.6 seconds. The spectrum is fit by a Band function with alpha = -0.98 +/- 0.05, beta = -2.31 +/- 0.03 and
Click the GRB to learn more...
Burst ID | Date | Time | Mission
GRB 100224B | 2010/02/24 | 02:40:55.48 | Fermi
GRB 100223A | 2010/02/23 | 02:38:09.31 | Fermi
GRB 100131A | 2010/01/31 | 17:30:57.67 | Fermi
GRB 100122A | 2010/01/22 | 14:47:37.31 | Fermi
Burst < 7 days old
Burst > 7 days old
Burst > 60 days old
Selected burst
GRB ID: GRB 100122A
Galactic Coordinates
Longitude: -22.22°
Latitude: 204.18°
Right Ascension: 05:16:48
Declination: -02:42:00
Constellation: Orion
Burst Details
"This burst had two pulses, the first a weak one, followed by a much stronger one beginning 21 seconds later and lasting 6.6 seconds. The spectrum is fit by a Band function with alpha = -0.98 +/- 0.05, beta = -2.31 +/- 0.03 and Epeak = 45.6 +/- 1.5 keV.
Star Field
Fermi
After Glow
More Info
Fermi
HETE-2
Integral
Konus-Wind
SuperAgile
Suzaku
Swift

Types of bursts