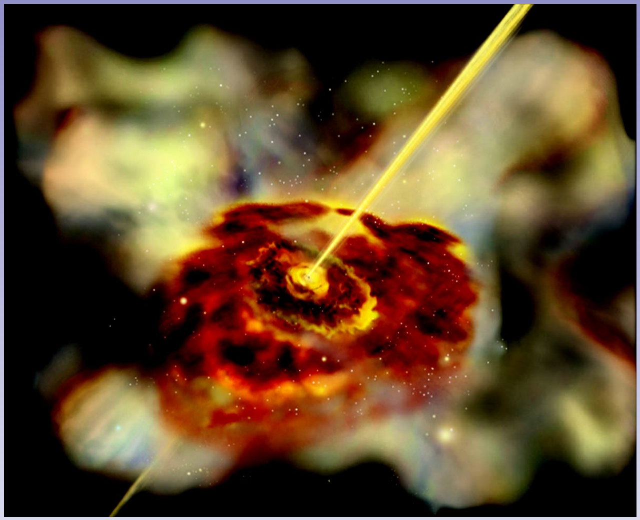
Blazing galaxies, exploding stars and monstrous black holes: High-energy visions of the Universe



Prof. Lynn Cominsky
Education and Public Outreach
Sonoma State University

E/PO Group Satellite Missions

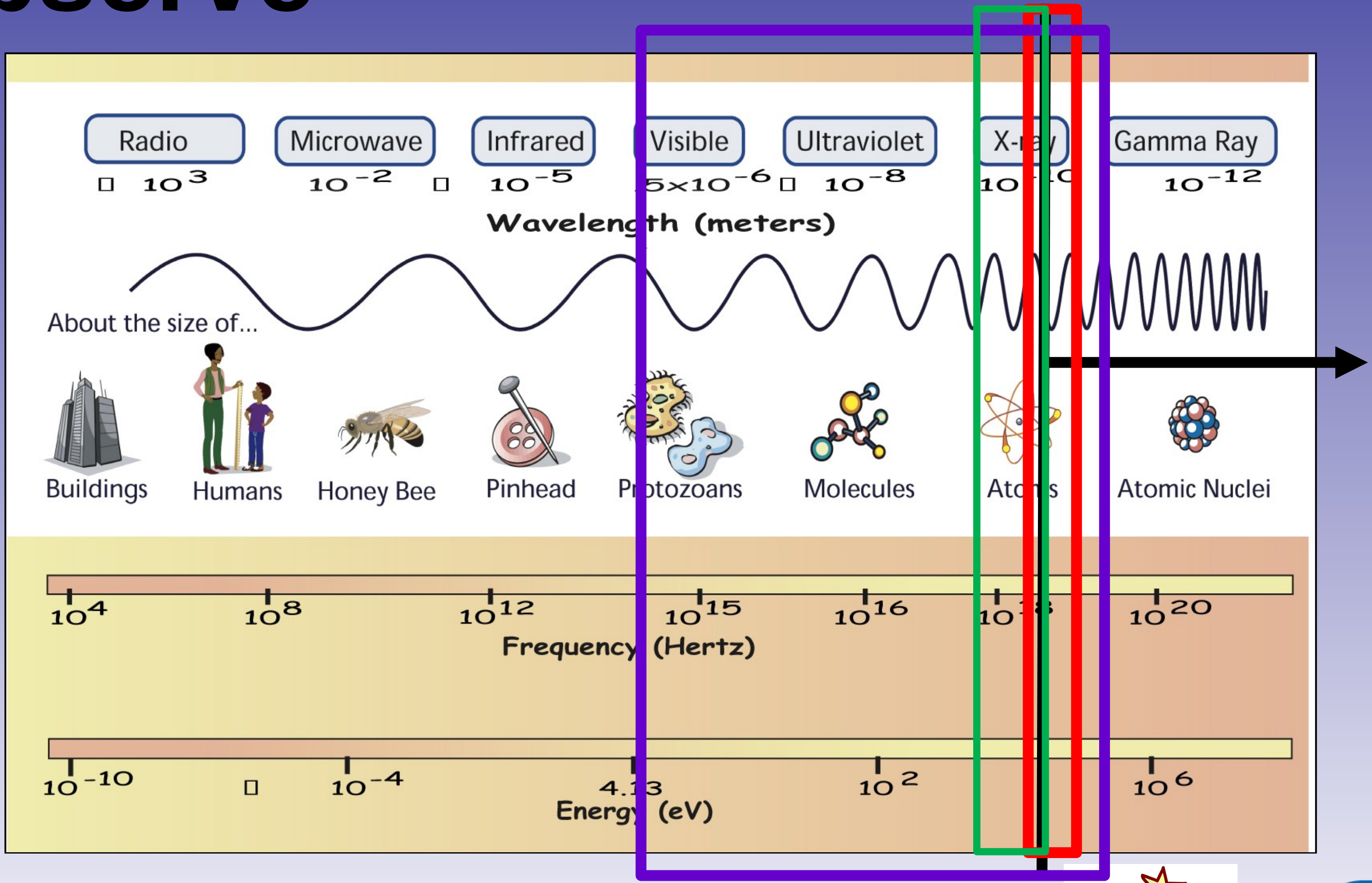
- *XMM-Newton* – launched 12/10/1999
  - Focusing soft x-ray telescope
- *Swift* – launched 11/20/2004
  - Gamma-ray burst explorer
- *Fermi* (aka *GLAST)* – launched 6/11/2008
  - High energy gamma-ray sky survey +GRBs
- *NuSTAR* – launched 6/13/2012
  - Focusing hard x-ray telescope

What we observe

XMM
1-10 keV

NuSTAR
10-79 keV

Fermi
10 keV – 300 GeV



Swift – UVOT, XRT and BAT

Exploring the Space Environment with

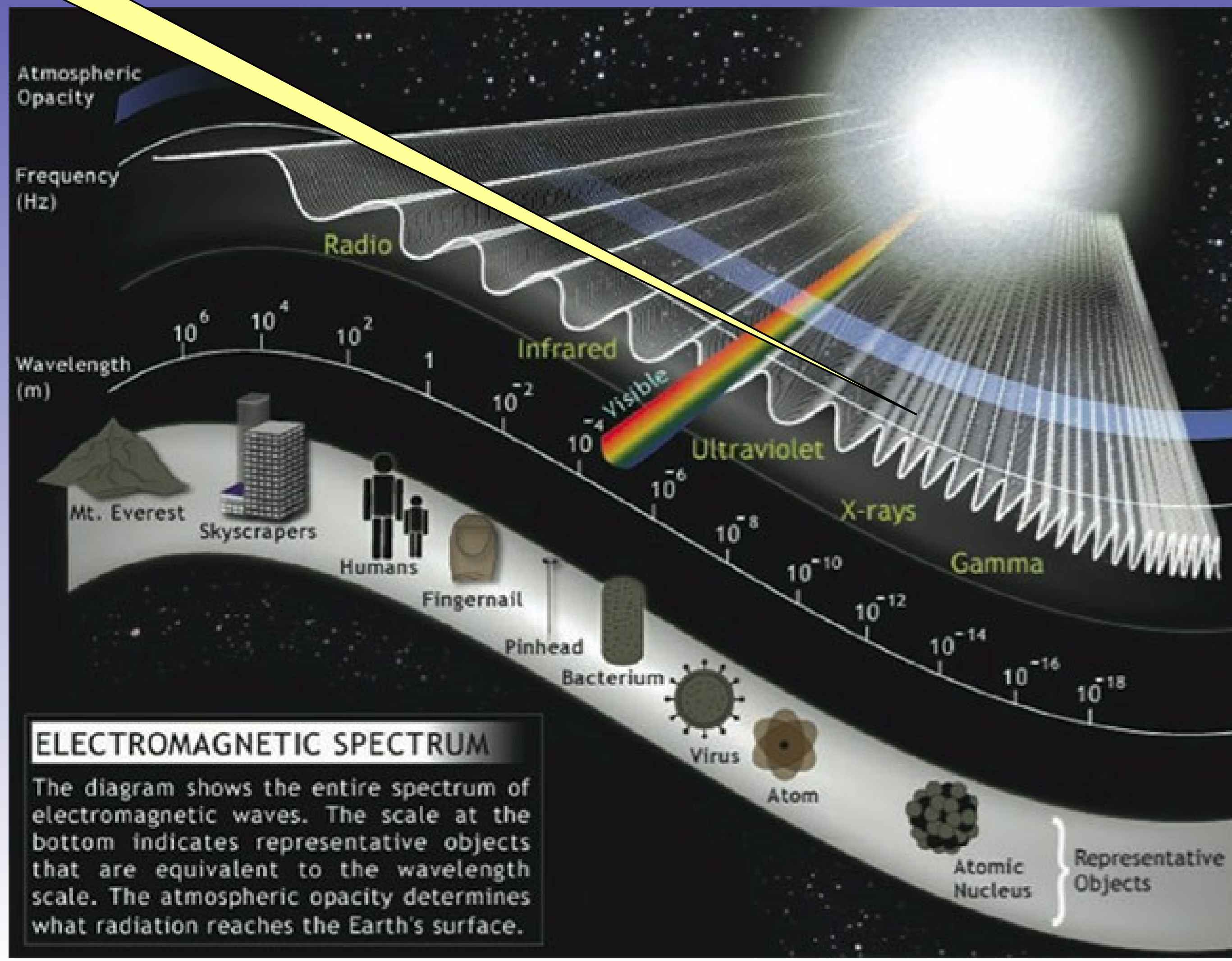
X Rays

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



EDUCATION PUBLIC OUTREACH SSU

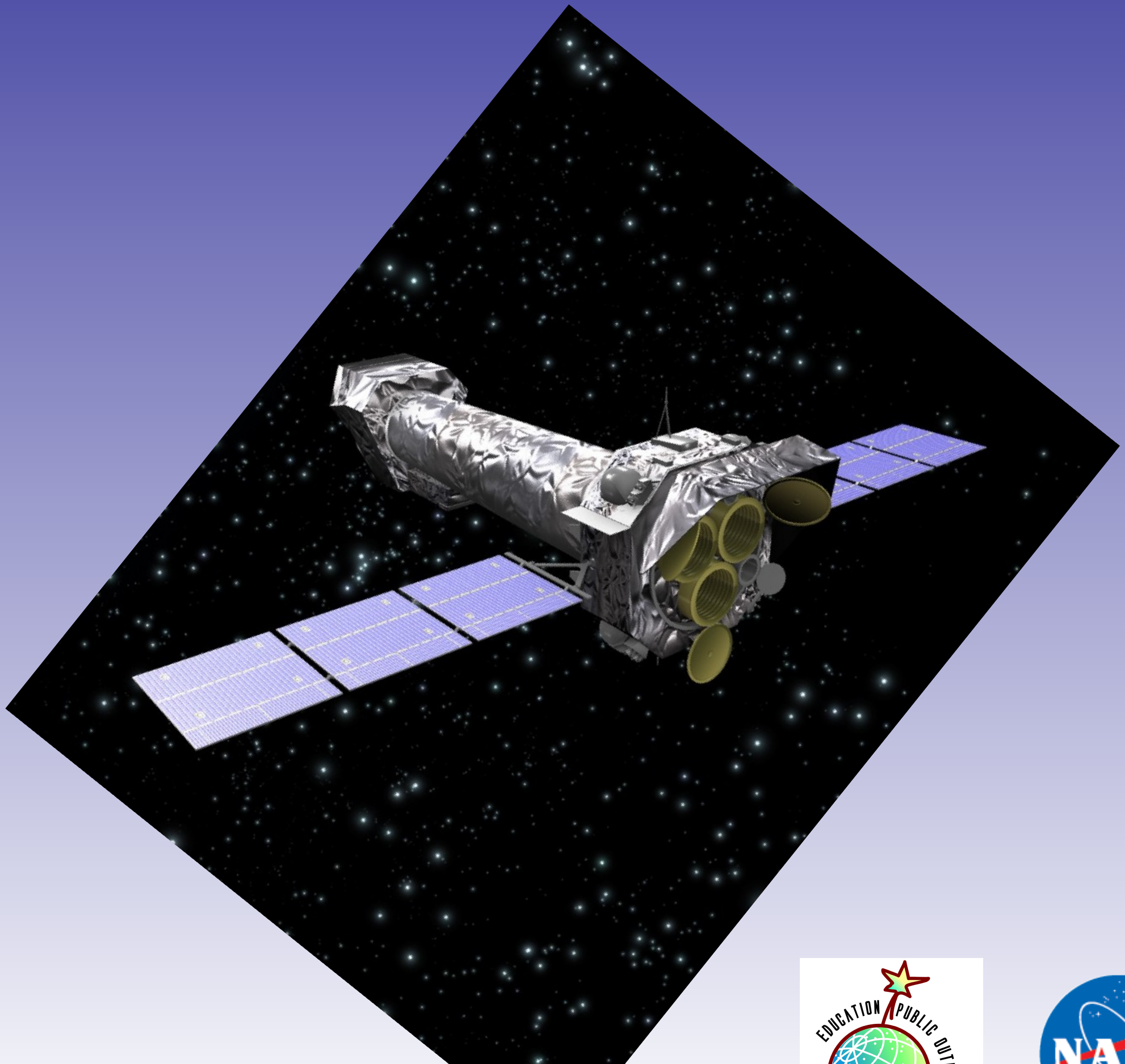
NuSTAR:

NASA's newest "Eyes on the Skies"

[redacted]

XMM-Newton

- Focuses lower energy X-rays
- Similar energy range to Chandra



Exploring the Space Environment with

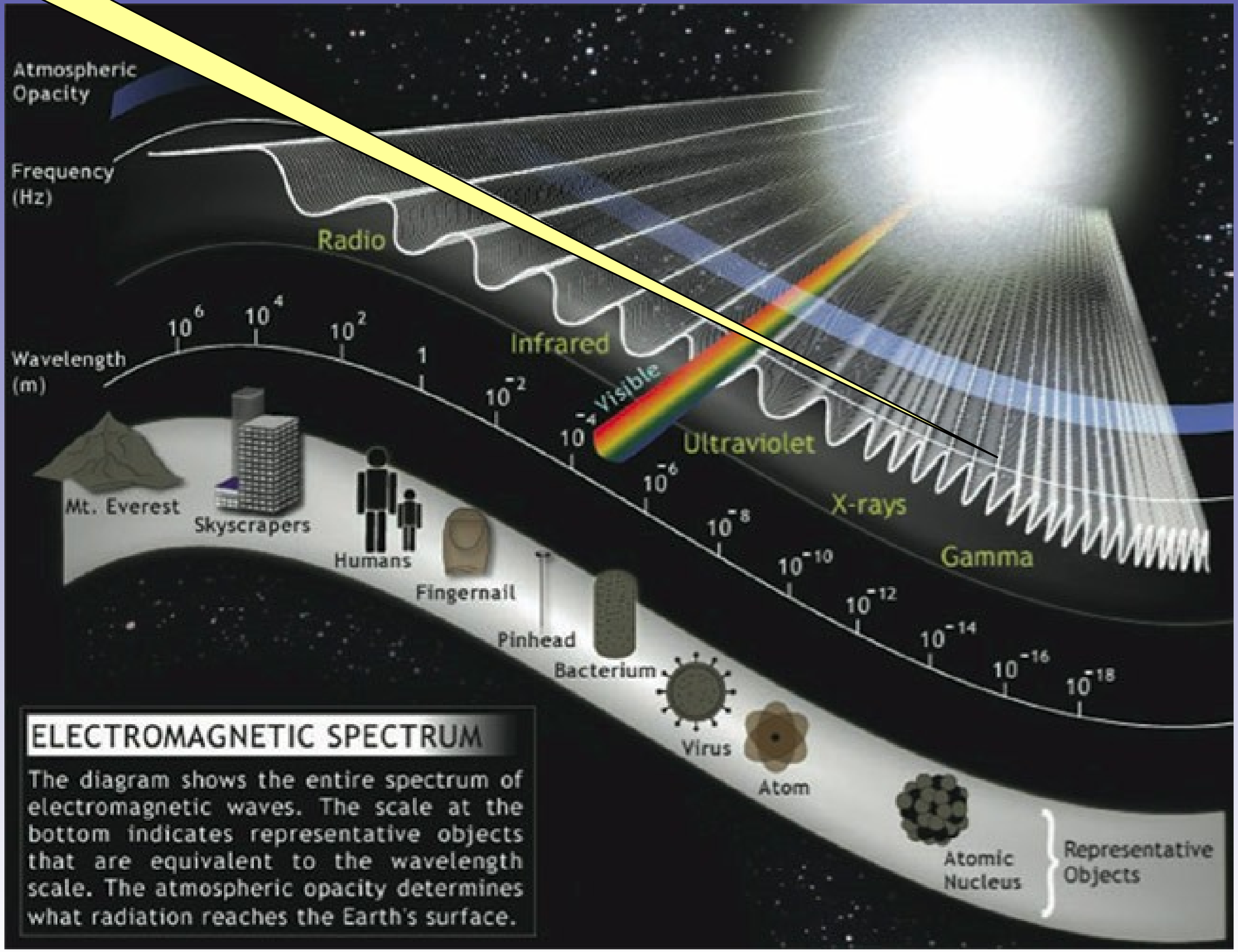
Gamma Rays

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.



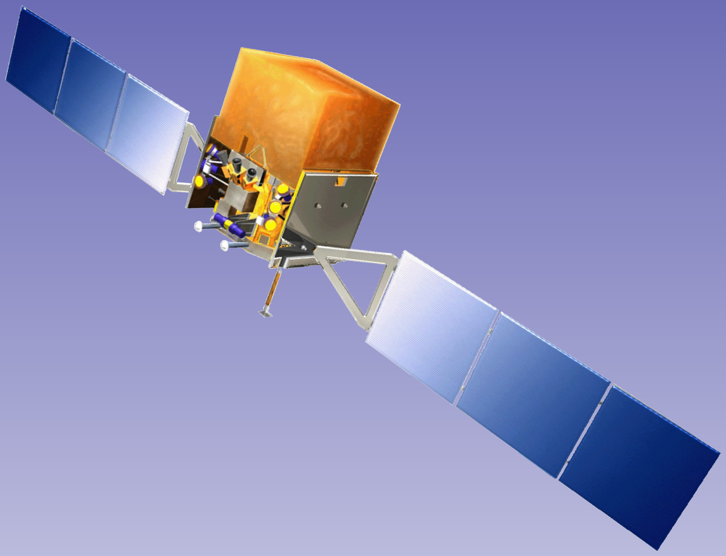
Swift GRB Mission

- 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

Fermi Gamma-ray Space Telescope

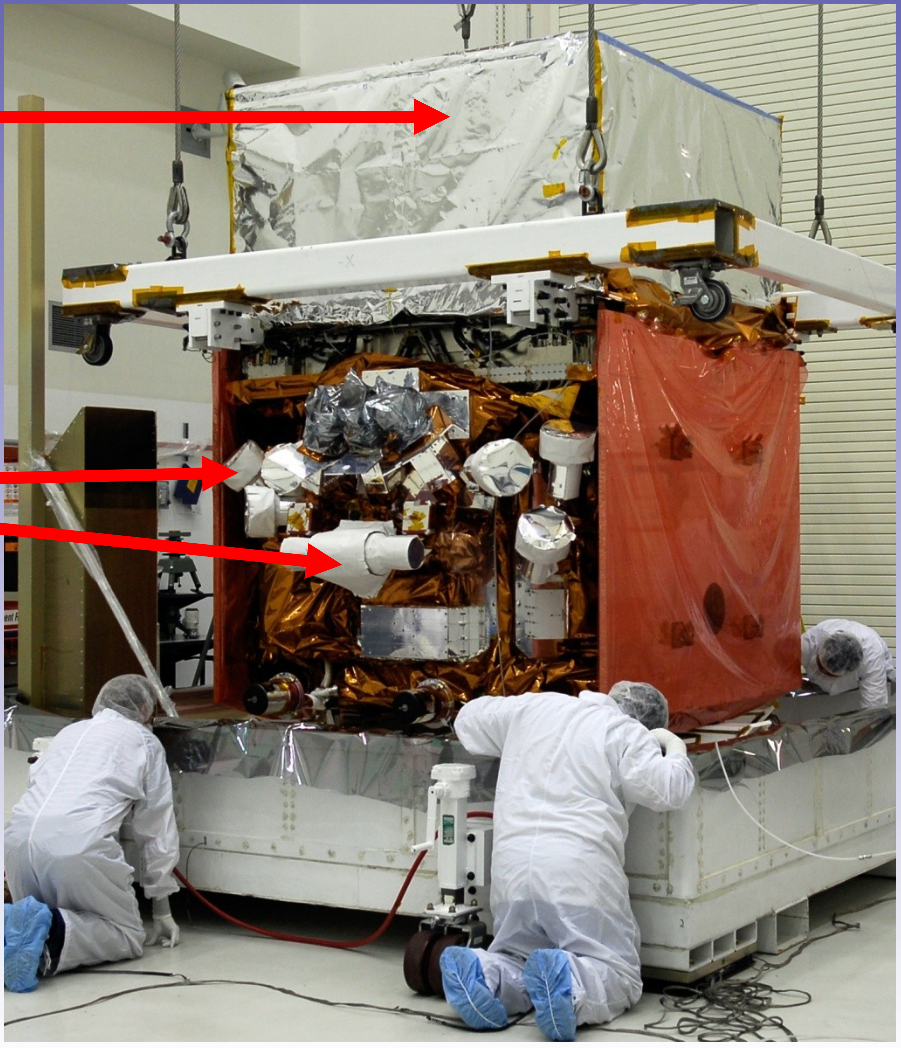
- Launched June 11, 2008
- Studies gamma rays over a very wide energy range
- http://fermi.sonoma.edu



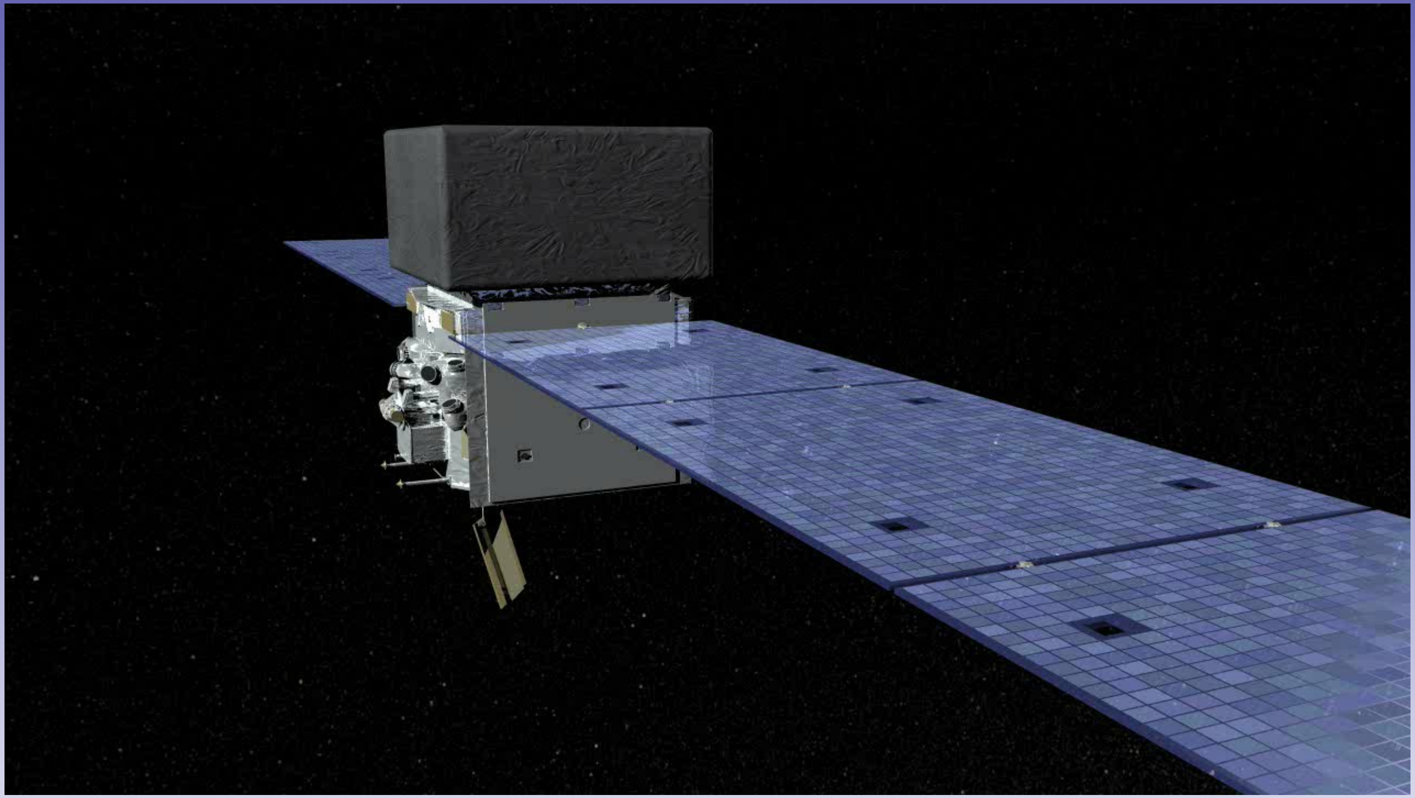
Fermi before launch

- Large Area Telescope

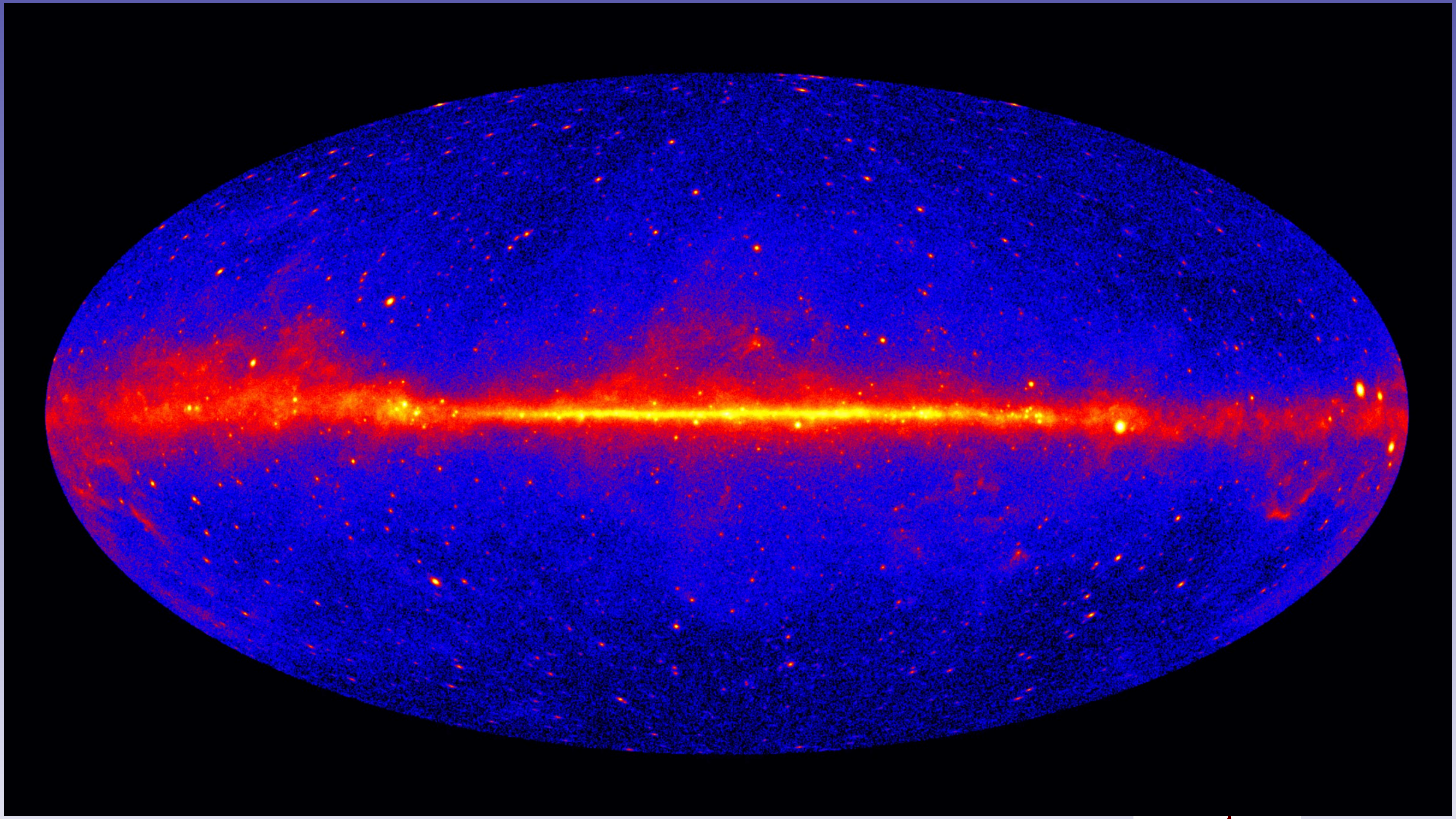
- Gamma-ray Burst Monitor



How Fermi images gamma rays

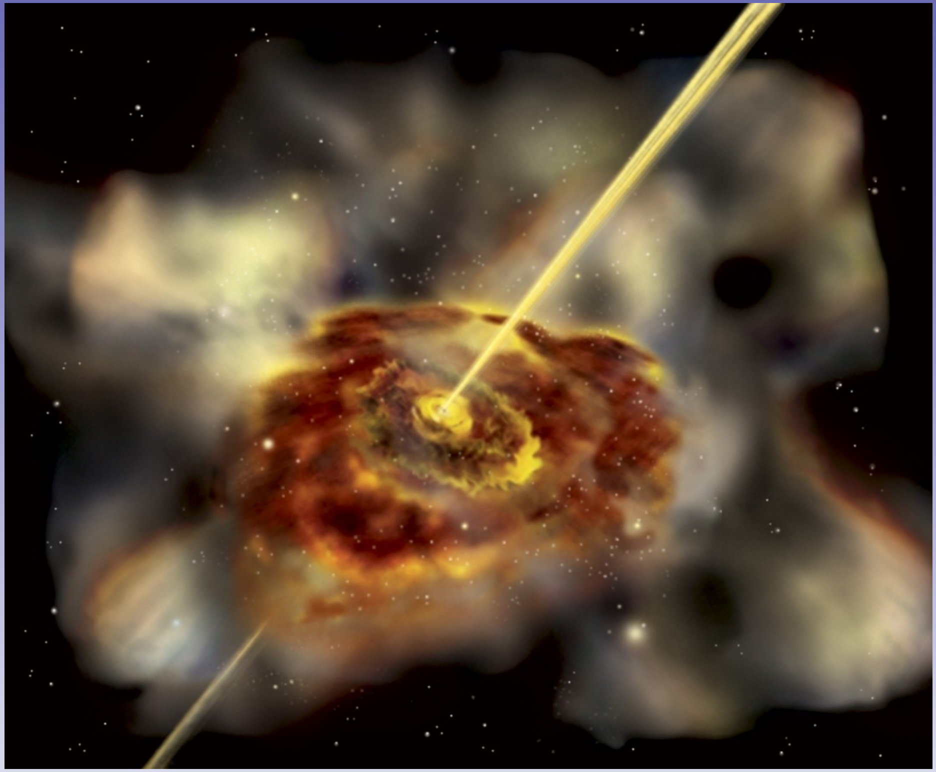


The gamma-ray sky



Studying Active Galaxies

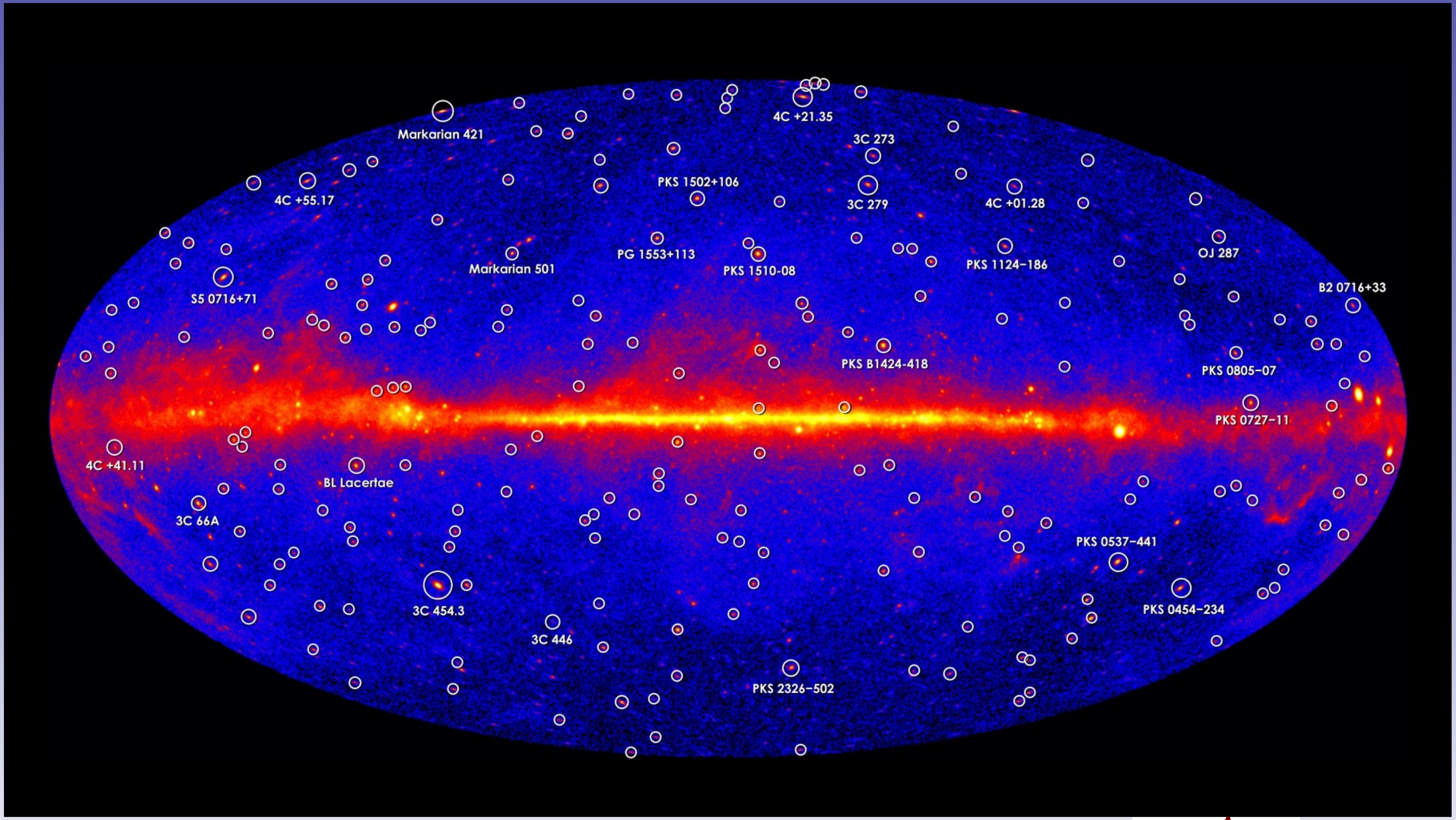
- Active Galaxies emit both X-rays and gamma rays
- Galaxies that point their jets at us are called “blazars”
- How do the black holes send out jets?



Art by Aurore Simonnet

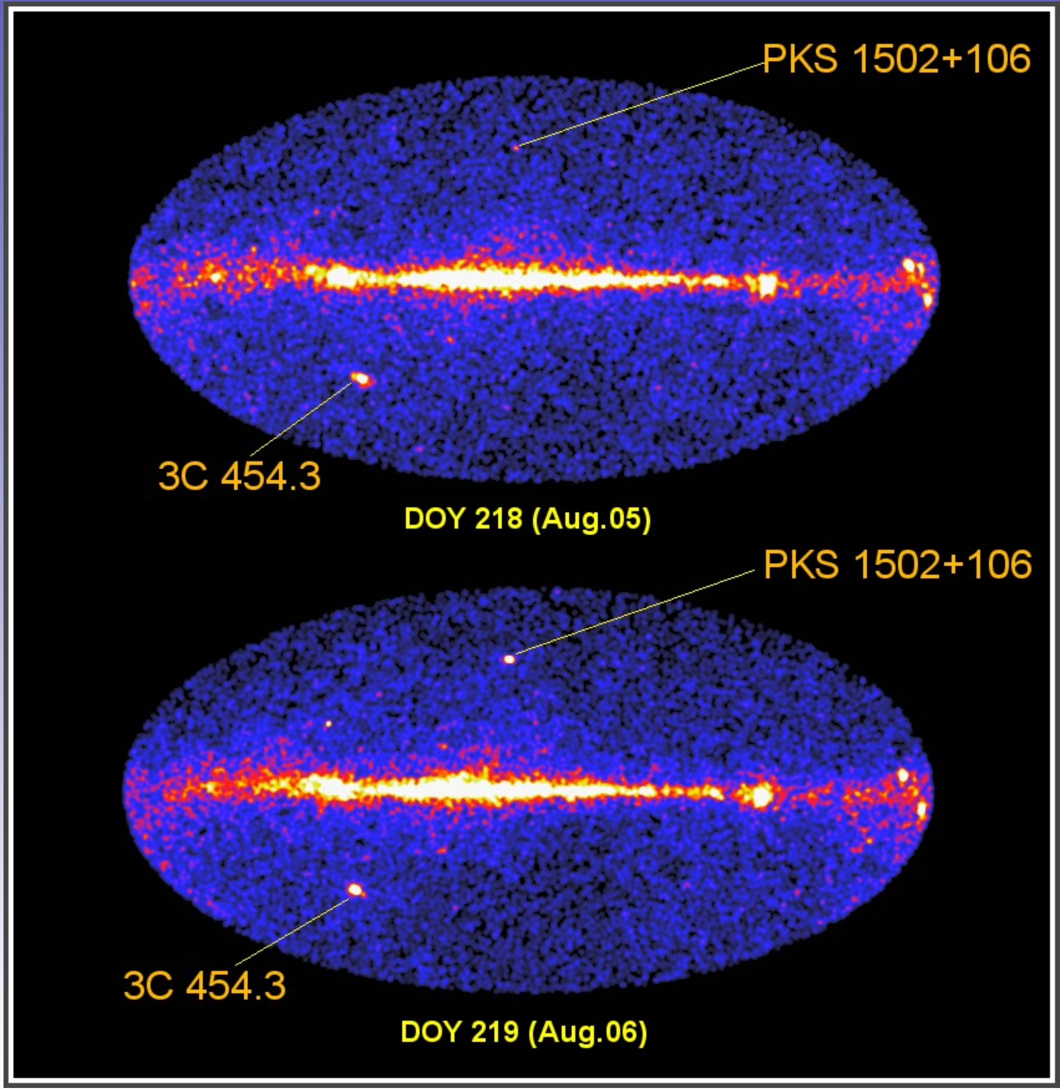
Blazing galaxies with monstrous black holes

Blazars in the gamma-ray sky

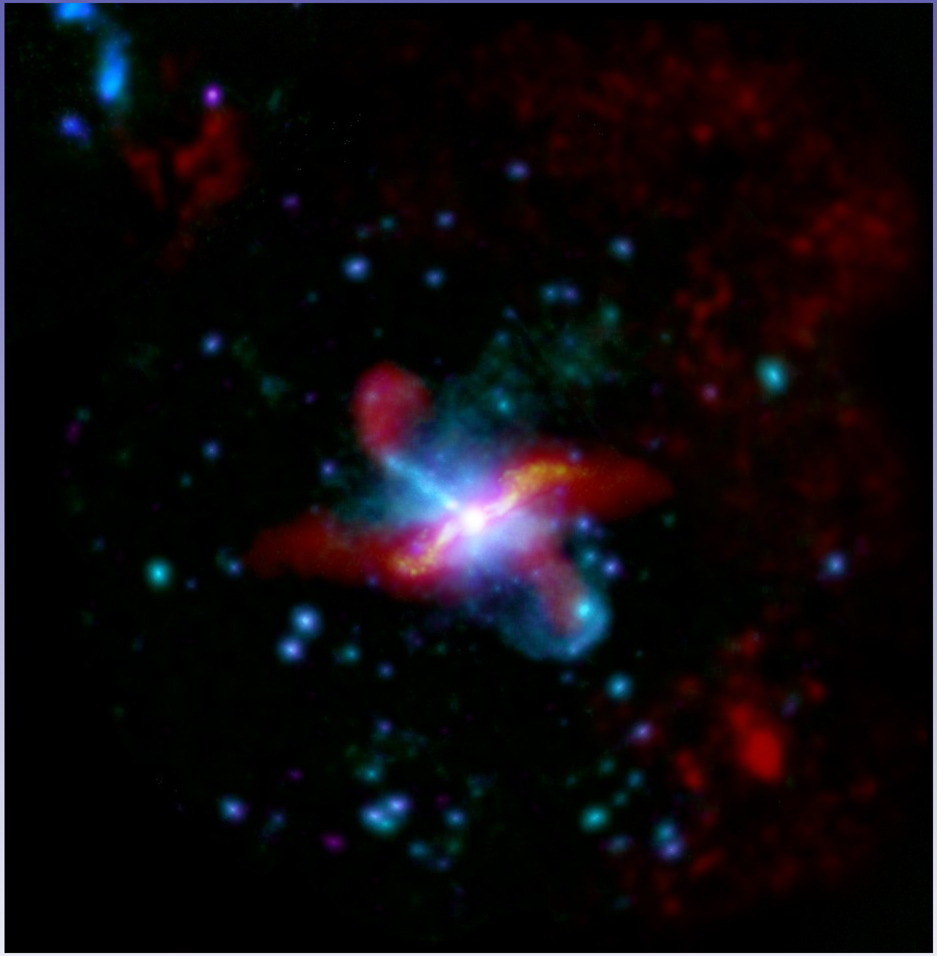


Monitoring Flares from “Blazars”

- 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



Multi-wavelength Active Galaxy



- Centaurus A
- Purple, blue and cyan are different X-ray bands from XMM-Newton
- Yellow is infrared and radio in red from Herschel Space Observatory

NuSTAR images two BHs in distant galaxy

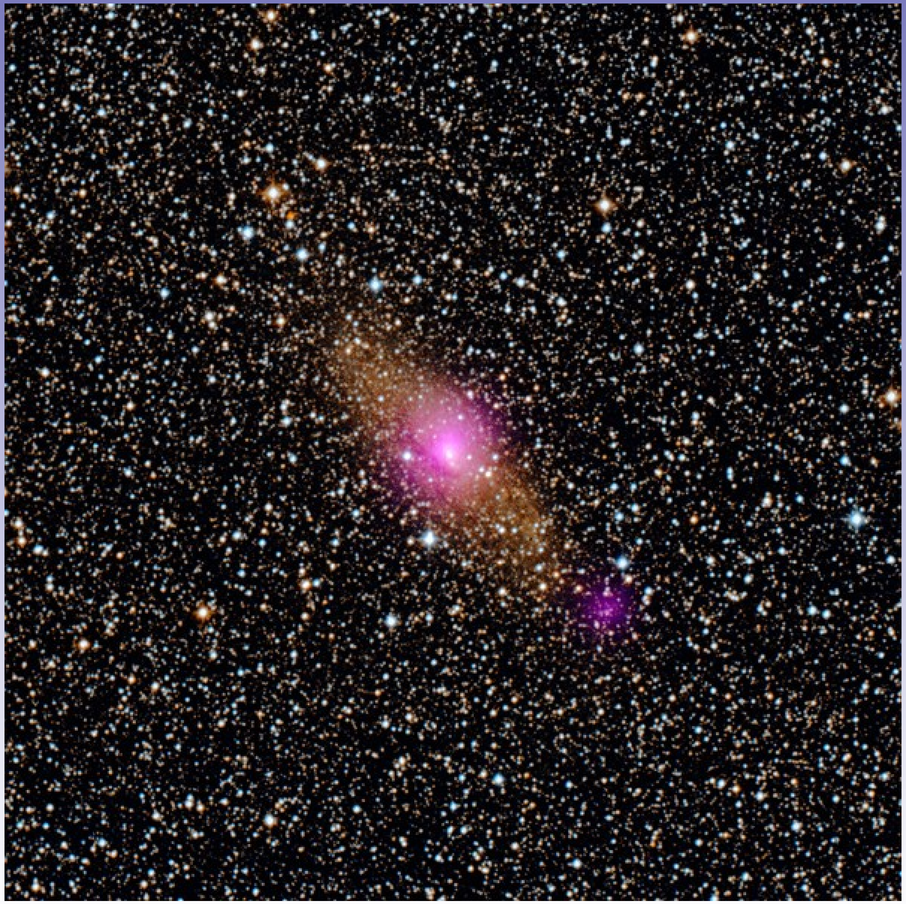
Since BHs are not in center, they are probably “intermediate mass” BHs

IC 342/Caldwell 5

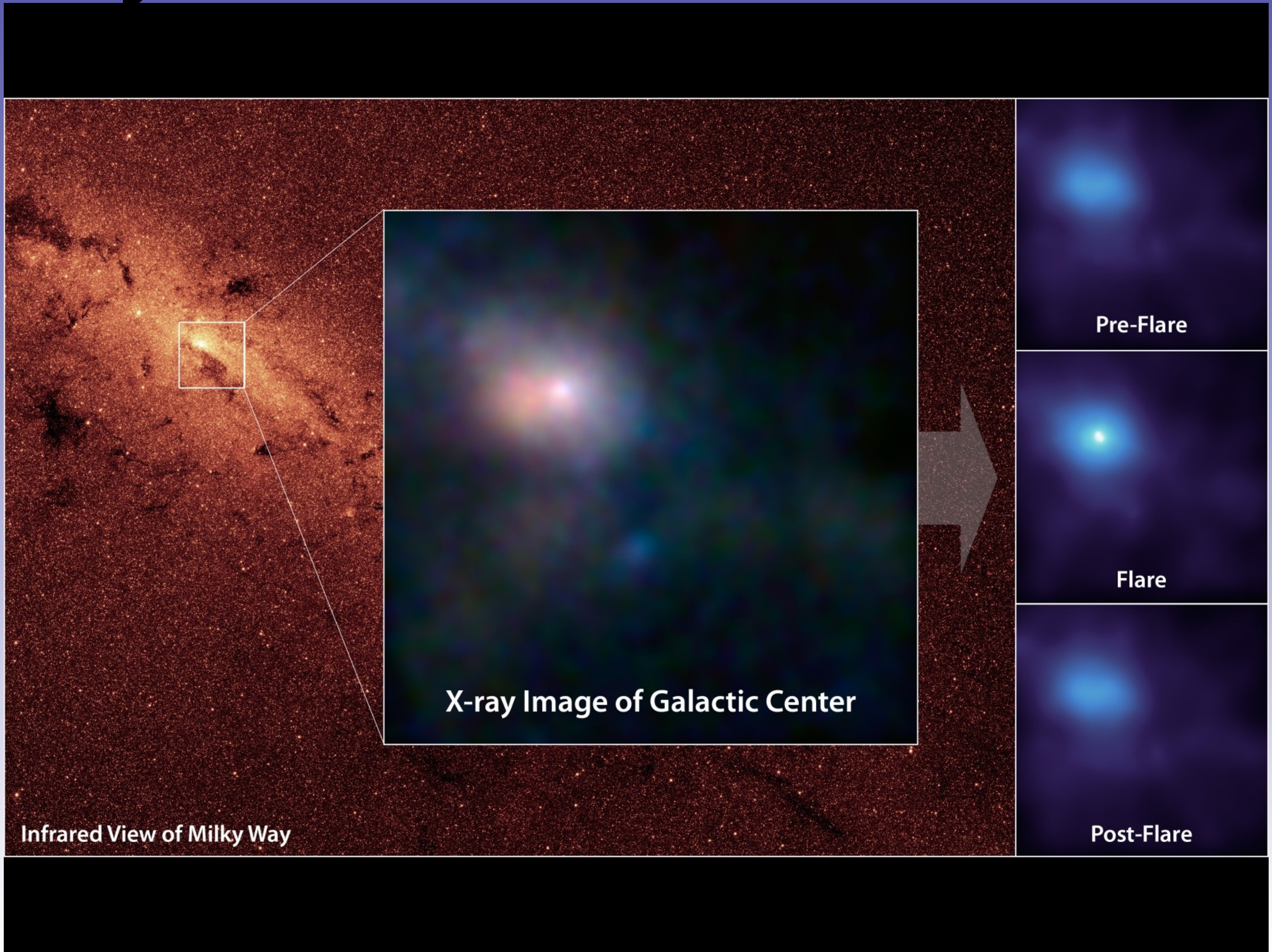
More Medium-sized BH

NGC 1313 (70 and 30 solar)

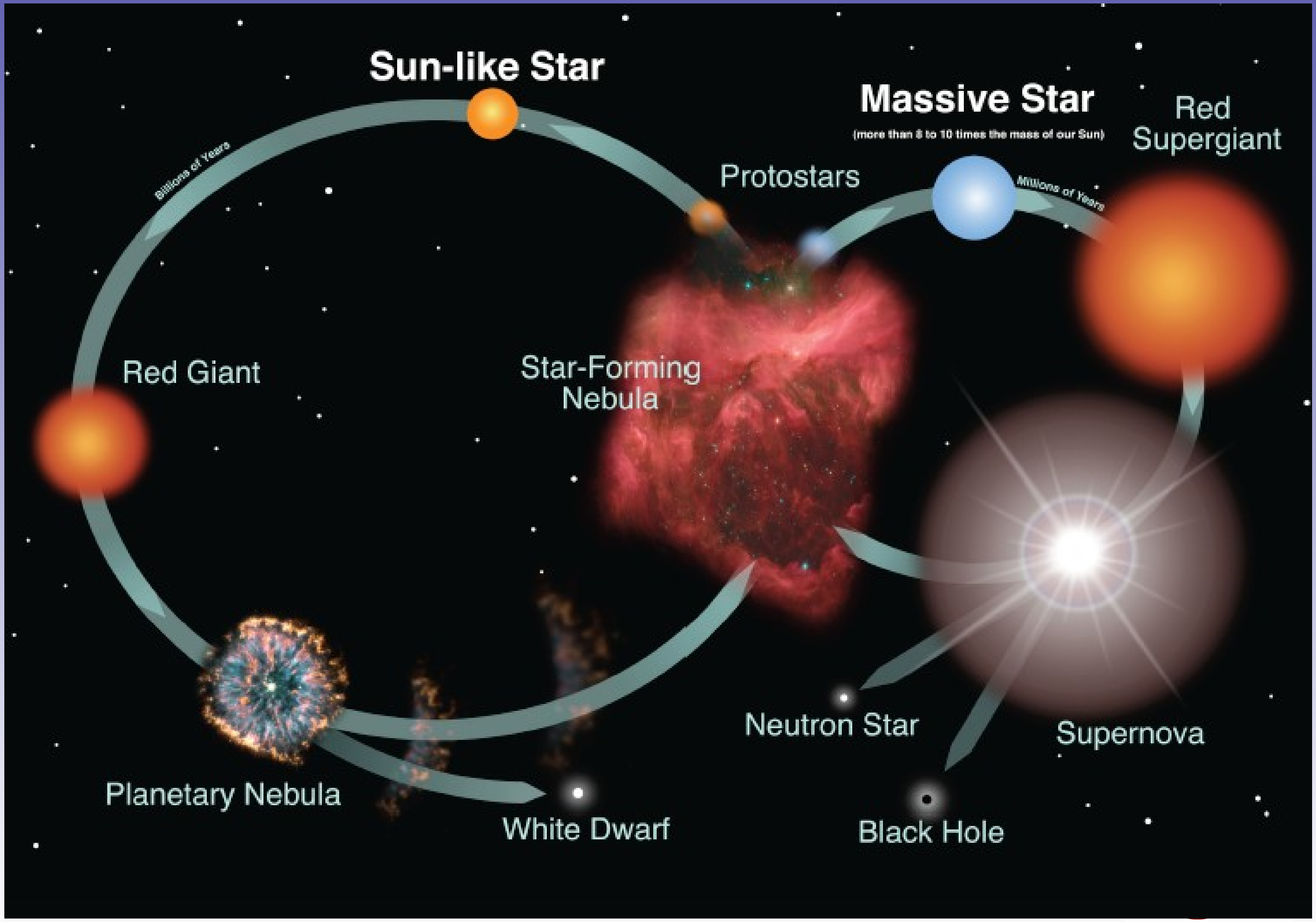
Circinus galaxy – SMBH + IMBH



NuSTAR sees Flare from Milky Way's Black Hole



Life Cycle of Stars



Find the Supernova

Credit: R. Jay GeBany

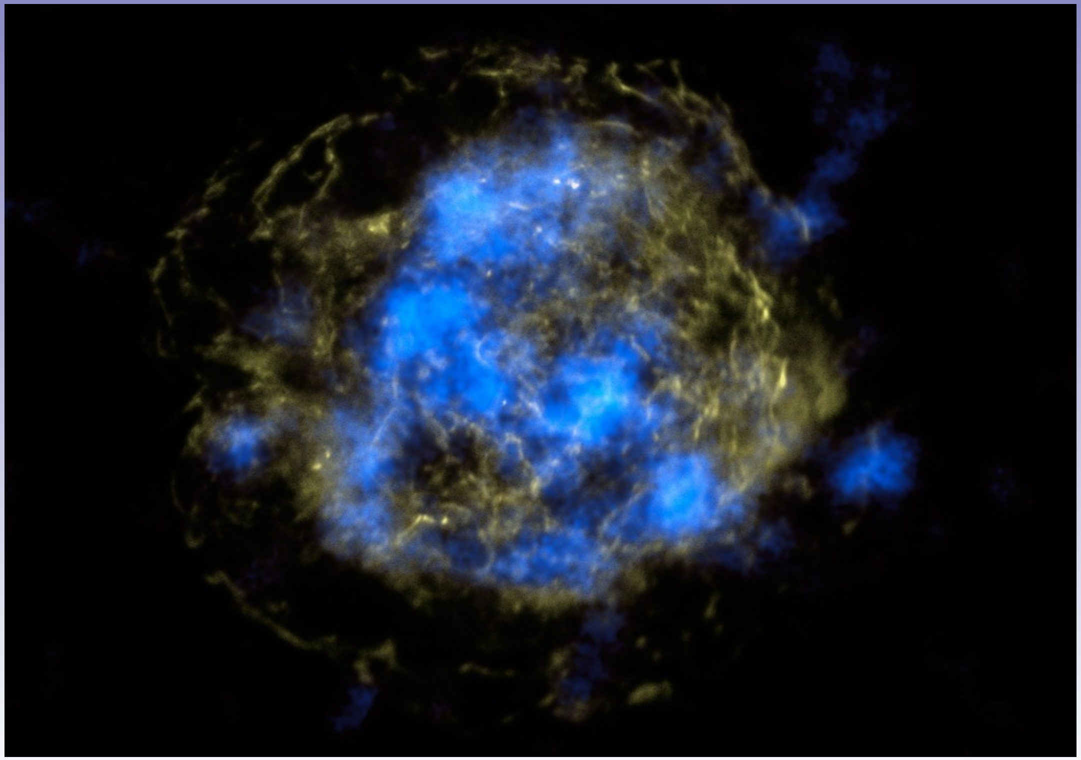
NuSTAR Cas A image

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

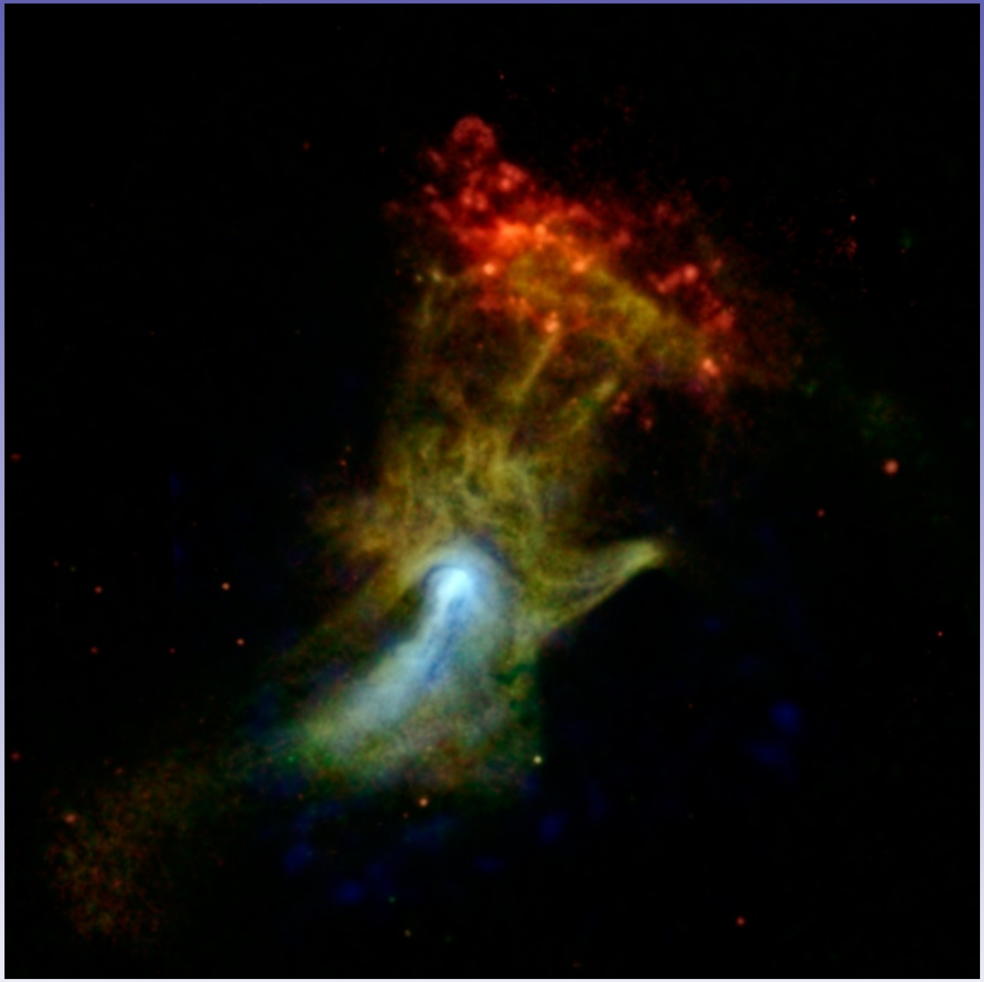
Green and red show the lower energy X-rays, also seen with Chandra

Radioactive “guts” in Cas A

- NuSTAR data are blue, and show high-energy X-rays from radioactive Titanium. Yellow is non-radioactive material emitting low-energy X-rays (from Chandra).



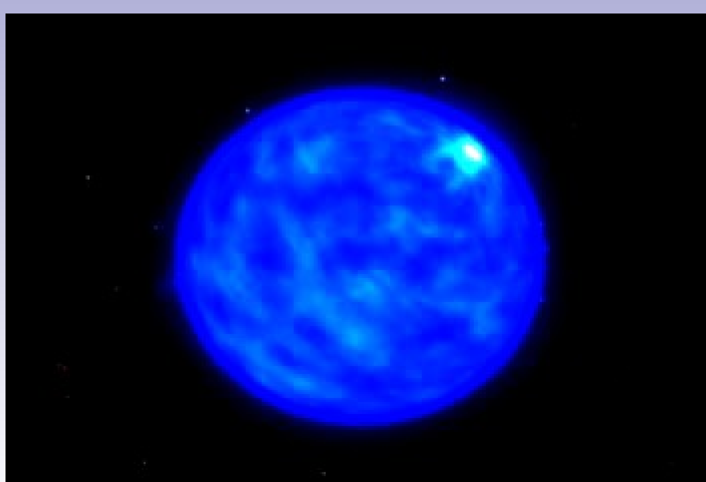
The "Hand of God"



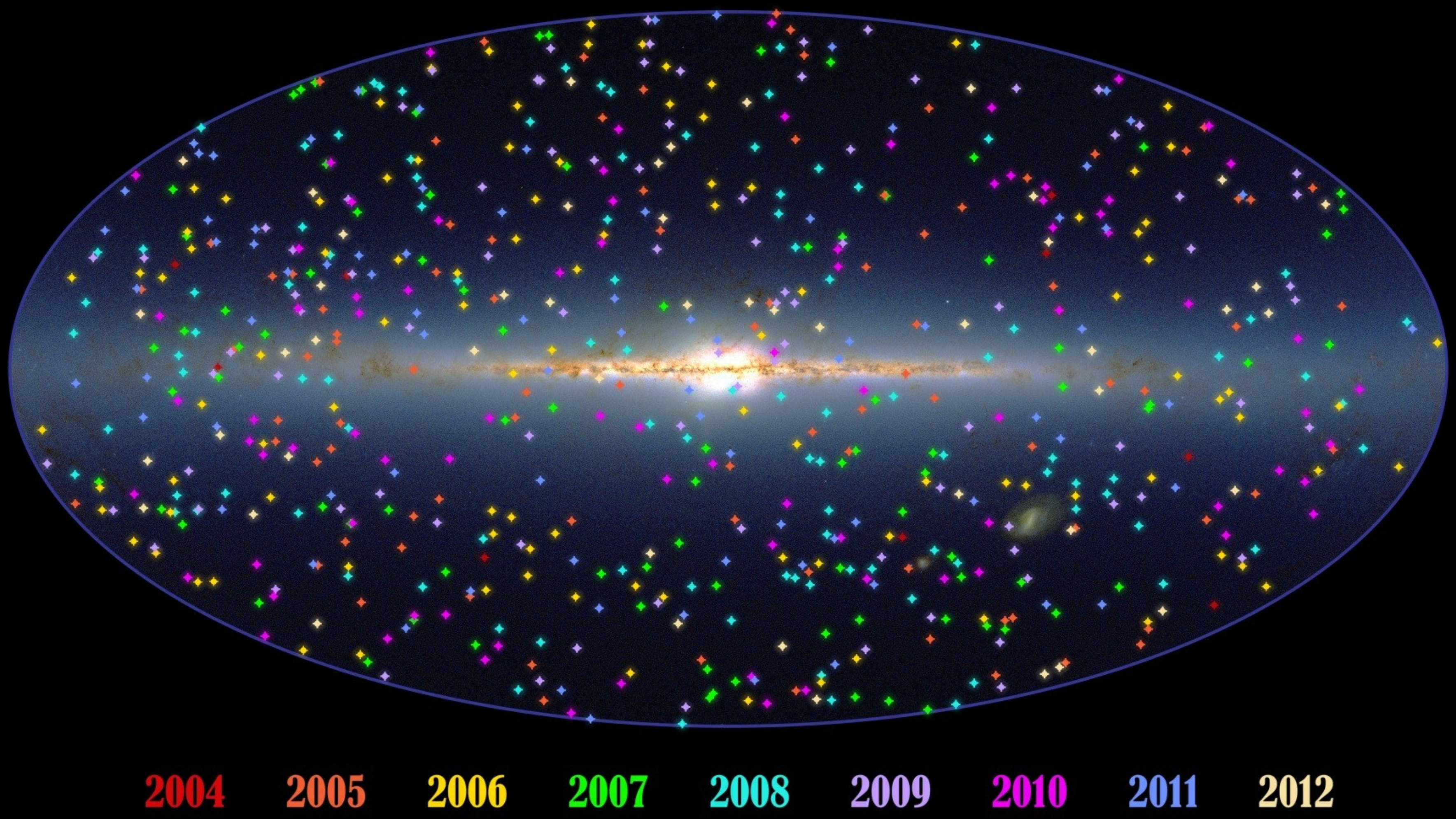
- Glowing gas blown out from a pulsar formed in a supernova explosion
- High-energy X-rays seen by NuSTAR are in blue (lower-energy in green and red from Chandra)

More super than a supernova?

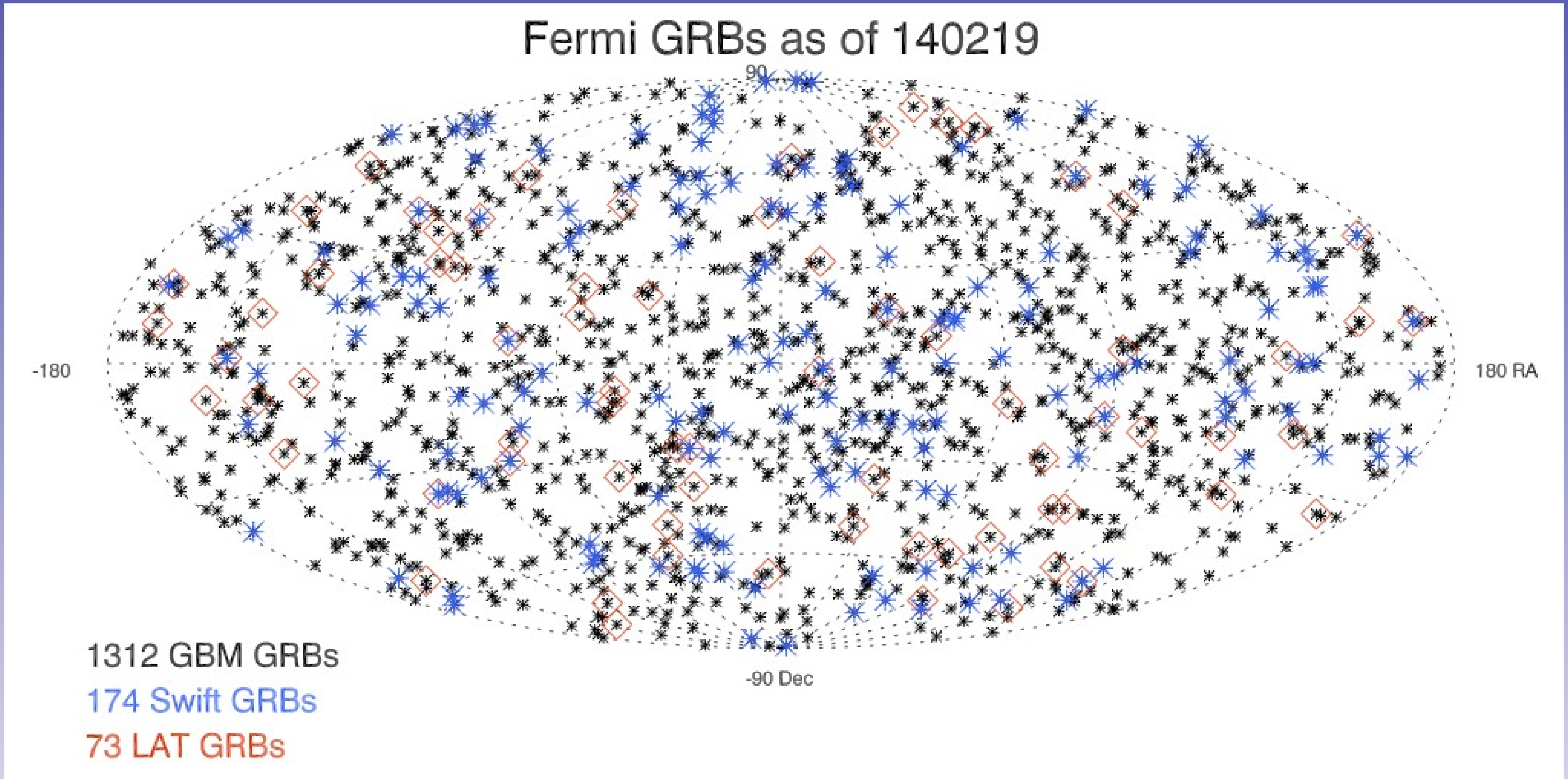
- A gamma-ray burst!
- Long bursts (>2 seconds) may be from a hypernova: a super-supernova
- Short bursts (<2 s) may be from merging neutron stars
- GRBs are birth cries of black holes
- Each GRB emits as much energy as our Sun in its entire lifetime!



667 *Swift* Gamma-ray Bursts

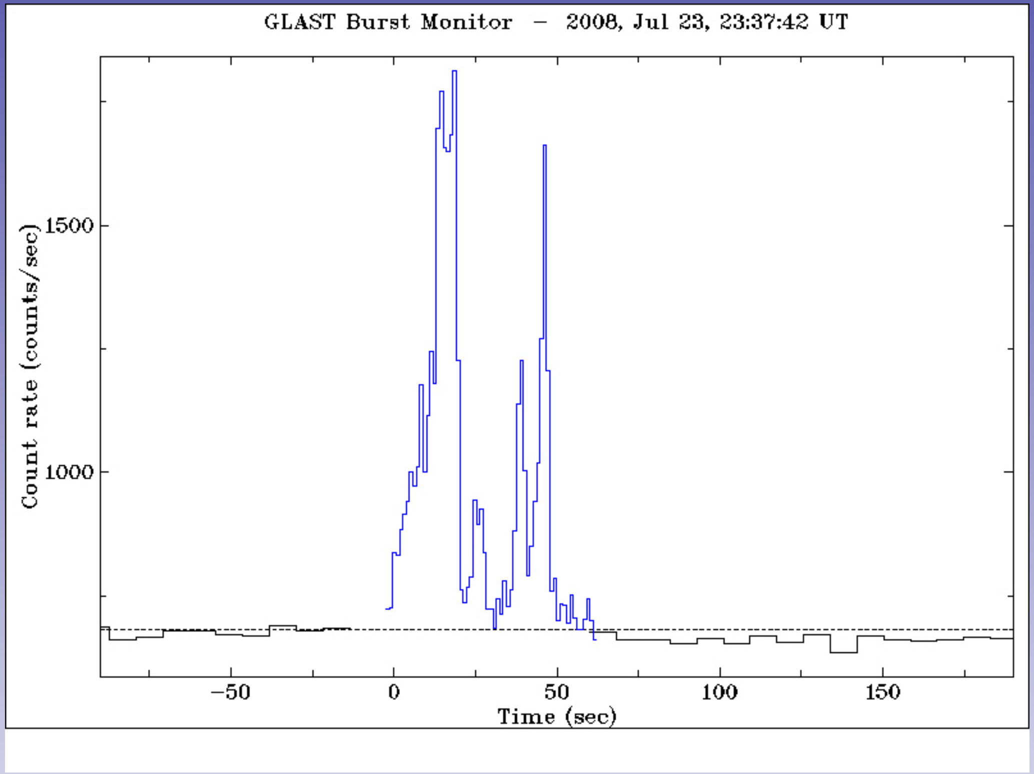


Fermi Gamma-ray Bursts



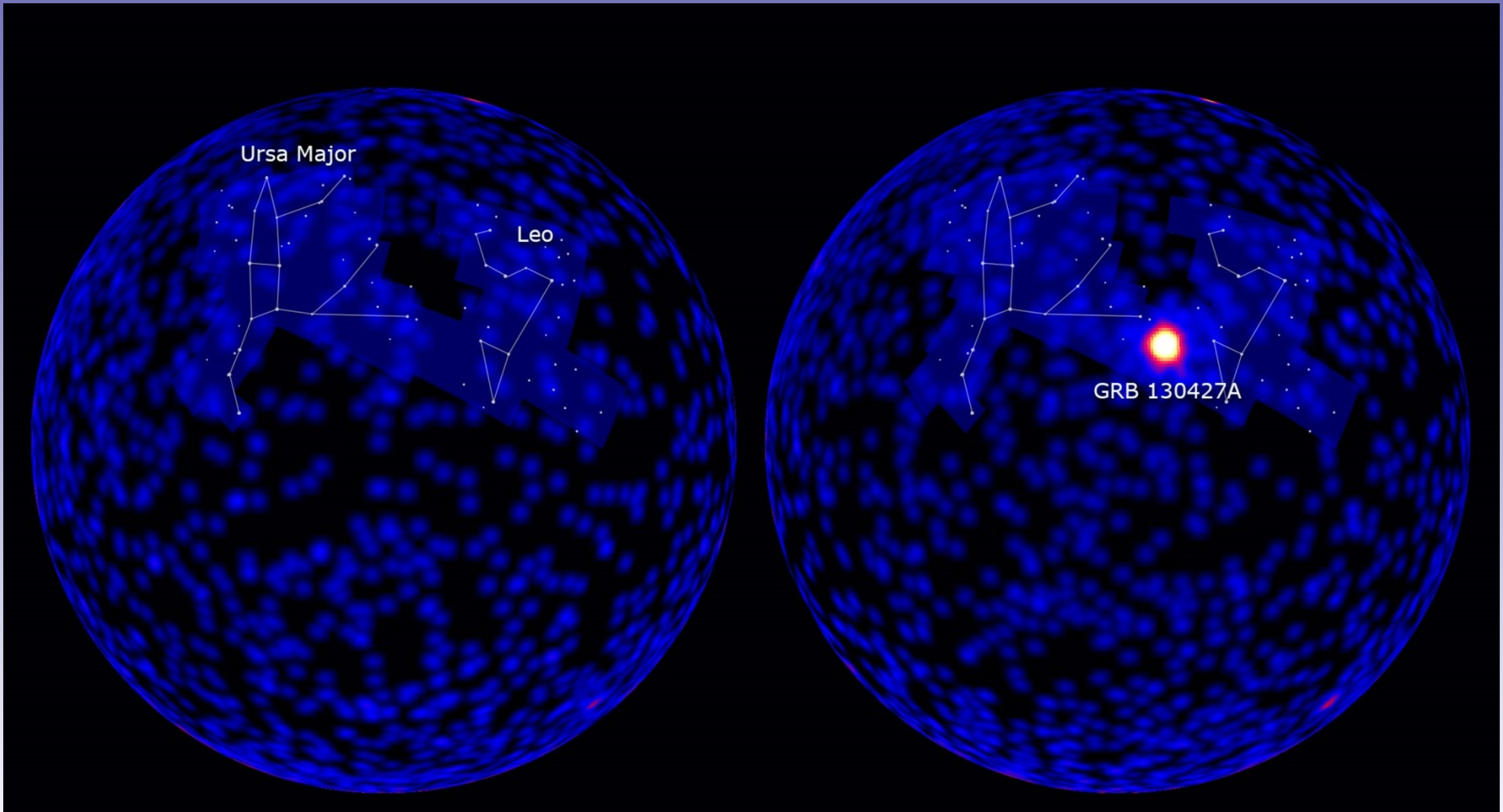
- About 4-5 bursts per week
- Follow bursts on http://grb.sonoma.edu

Typical strong GRB seen by GBM



- 1300+ GBM bursts seen to date
- 70+ LAT-GBM bursts seen in first 5 years

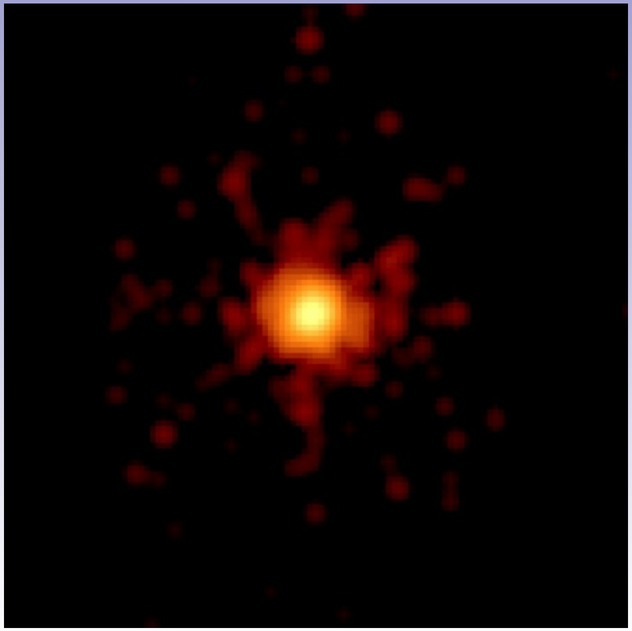
GRB130427A – a "shockingly bright" GRB



Before and after Fermi LAT views of GRB 130427A, centered on the north galactic pole

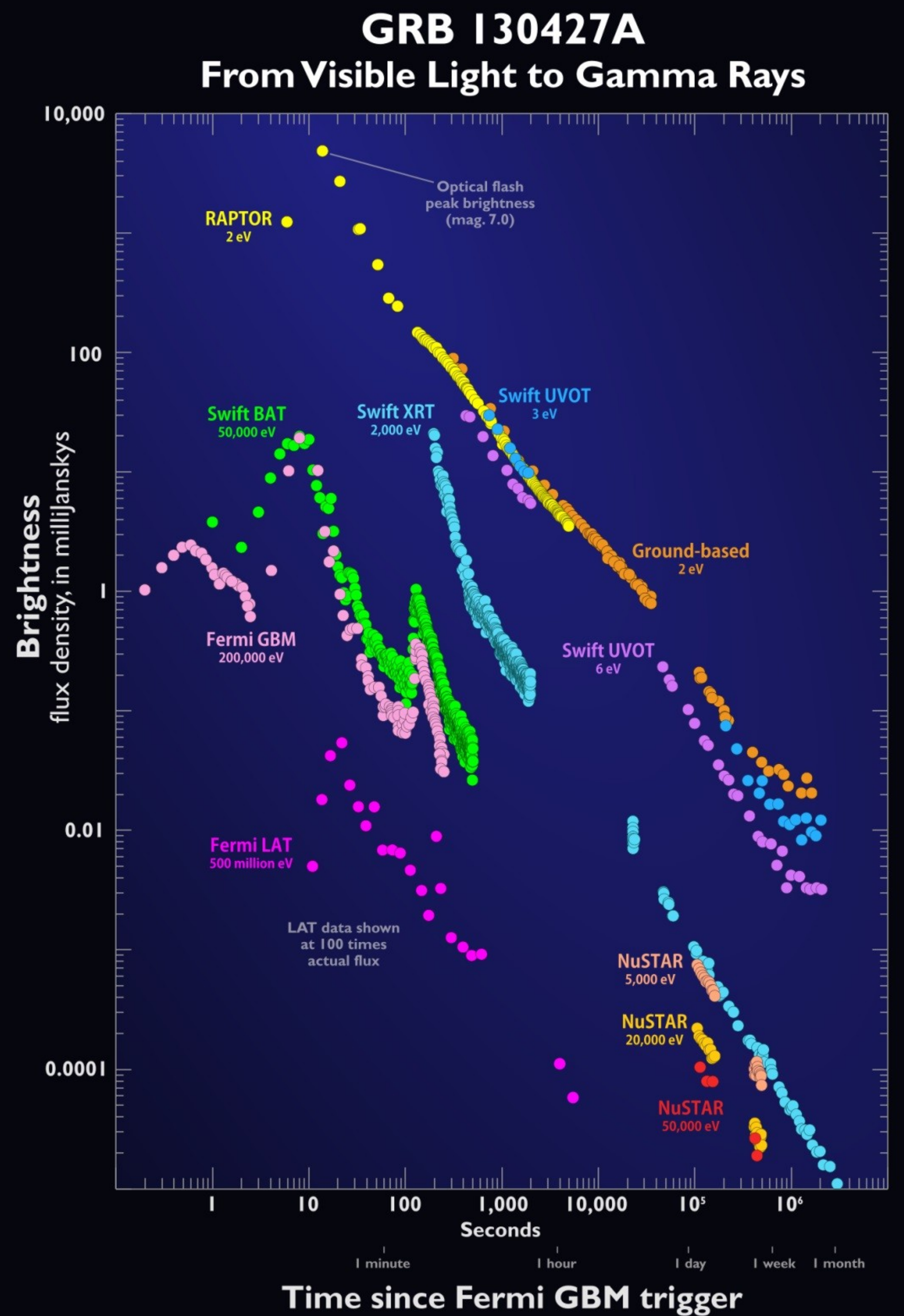
GRB 130427A

- Record photon energy – 94 GeV!
- Burst emission persisted for ~day
- Seen by many satellites, ground-based telescopes
- 3.6 billion light-years away



Swift X-ray image of
0.1 seconds of data

Observing from space and ground



Why the GRB was so bright

Conclusions

- The Universe as seen in X- and gamma rays shows us a different view of many extreme and exotic events
- It is only by putting together observations at many different energies that we can get a complete picture of our Universe

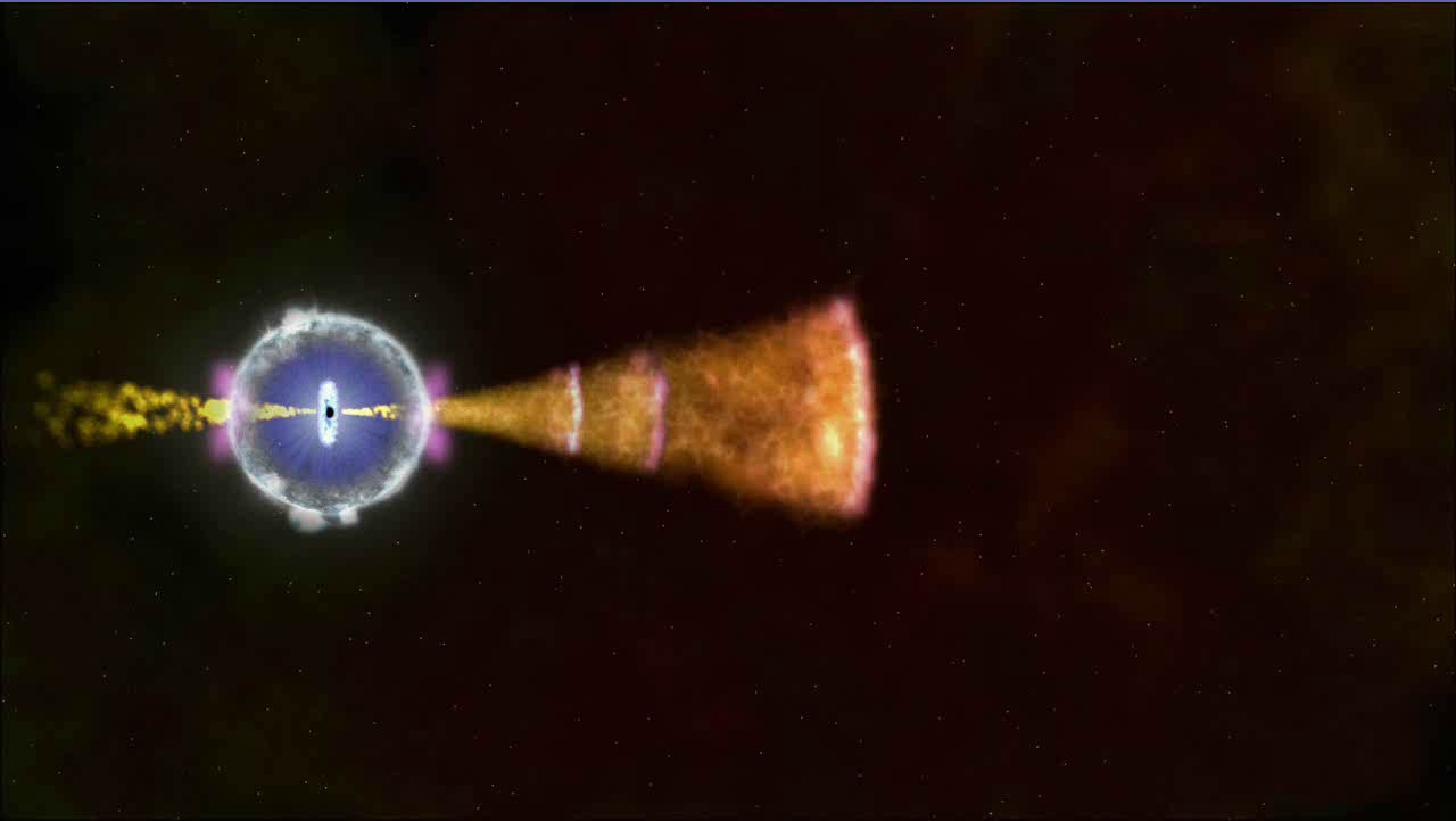
Resources

http://epo.sonoma.edu

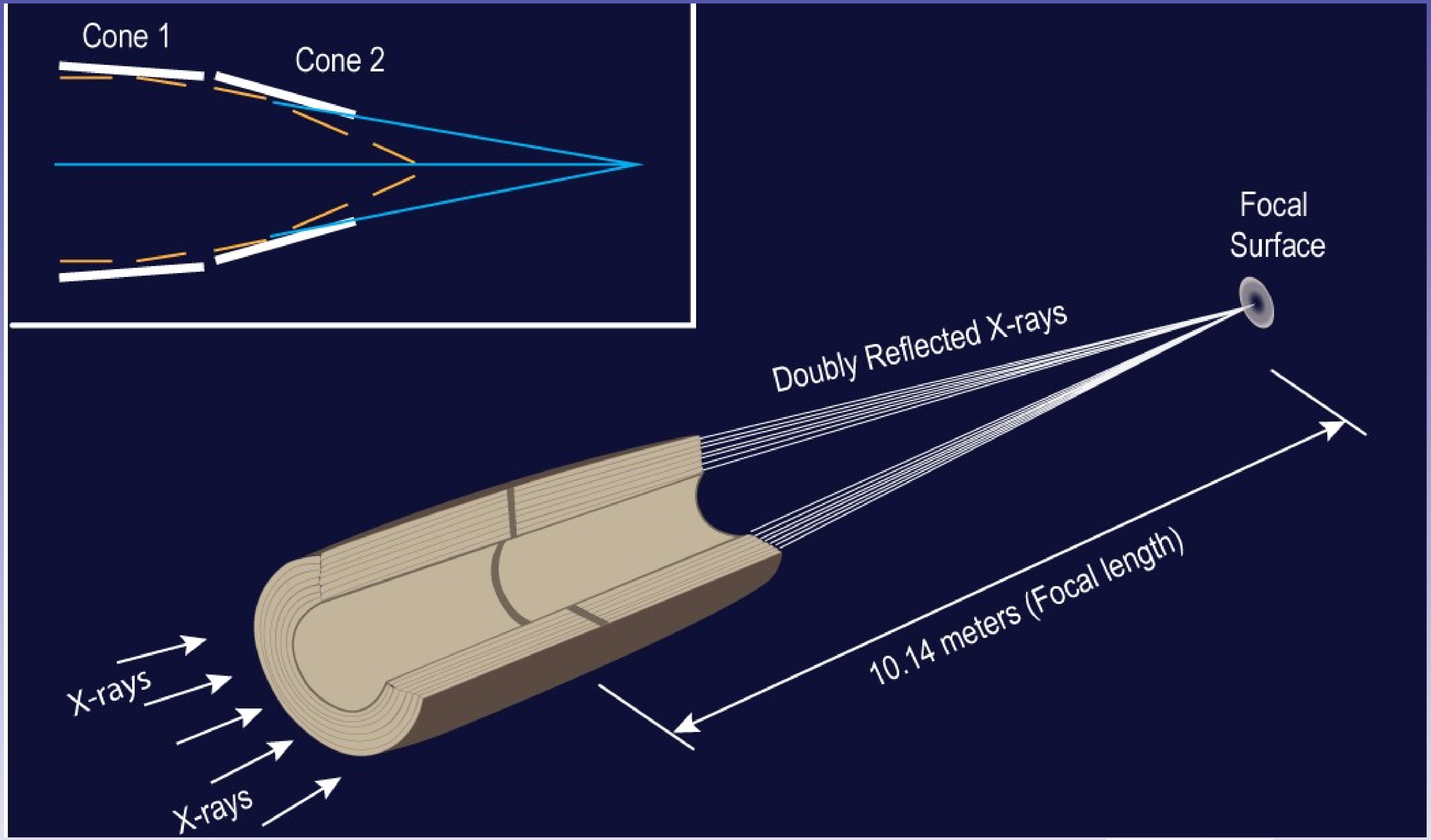
- http://swift.sonoma.edu
- http://fermi.sonoma.edu
- http://xmm.sonoma.edu
- http://grb.sonoma.edu
- http://www.nustar.caltech.edu

Backups follow

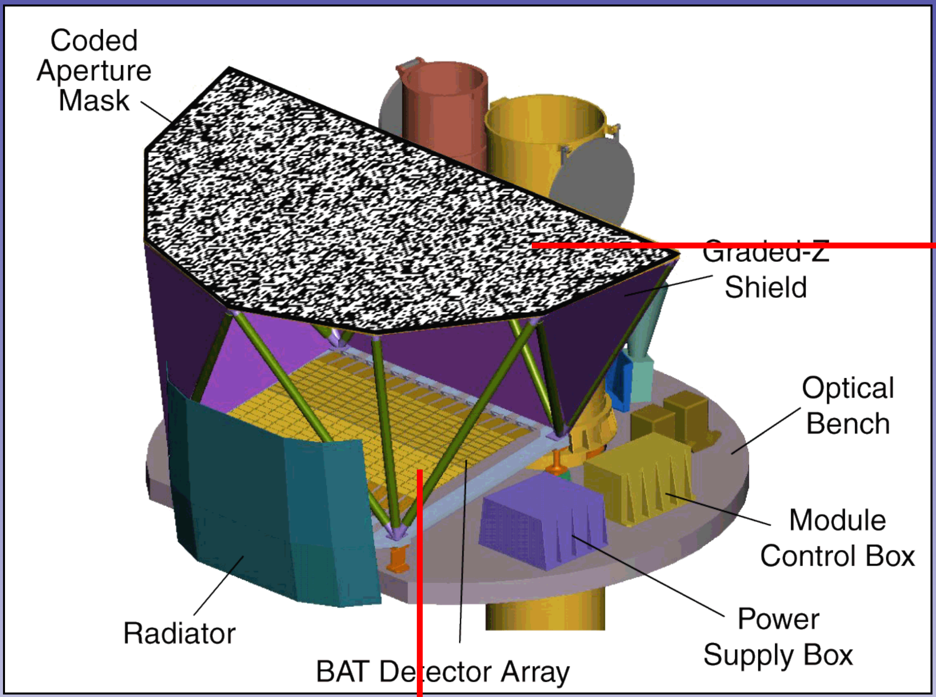
How the jets emit X and γ-rays

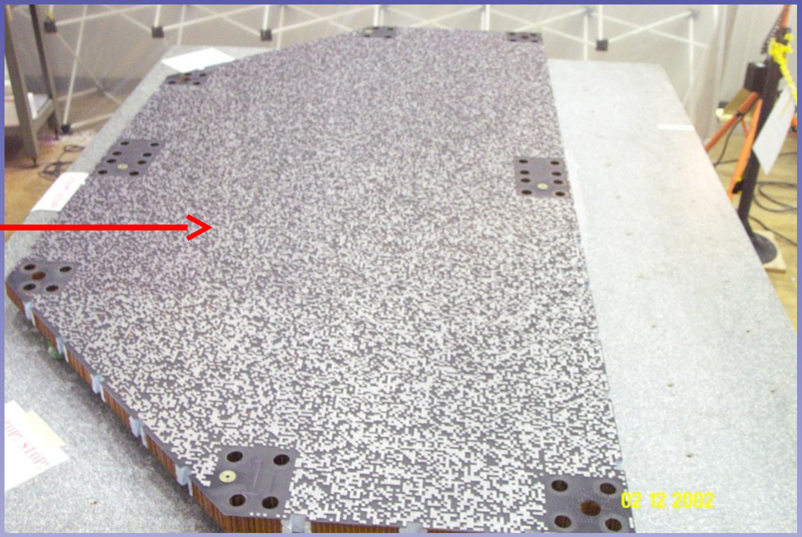


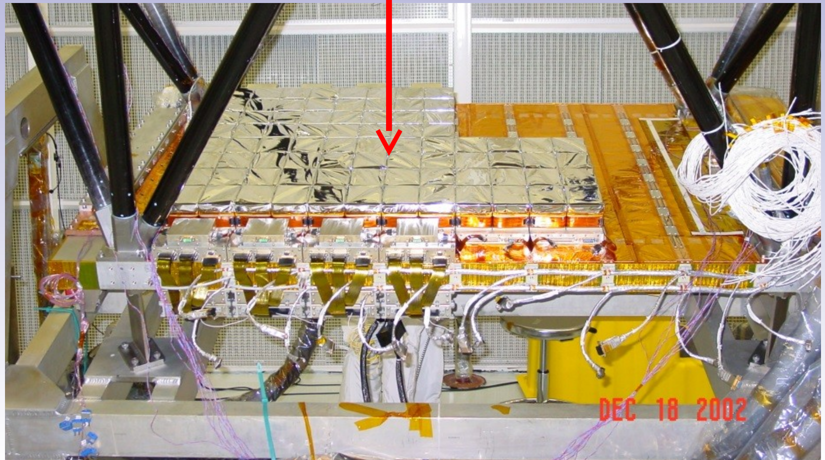
How to focus X-rays



Burst Alert Telescope



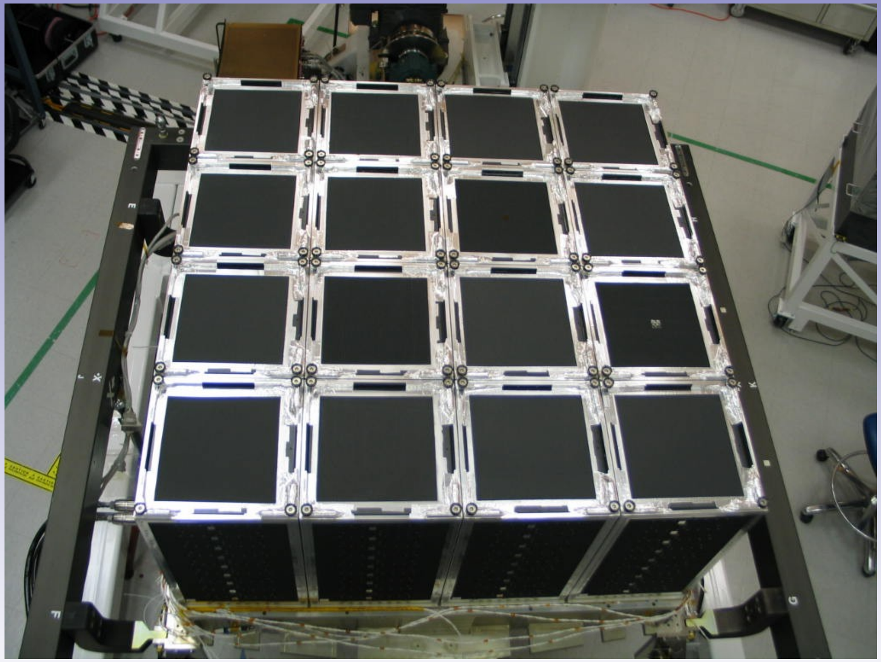




X-rays blocked by the lead tiles create a “shadow” on the detectors

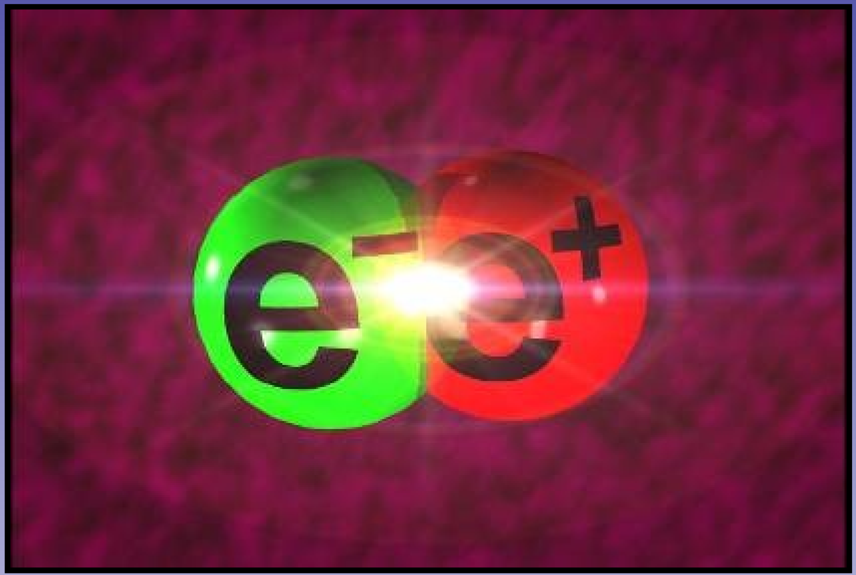
How to detect gamma rays?

- 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 = mc2

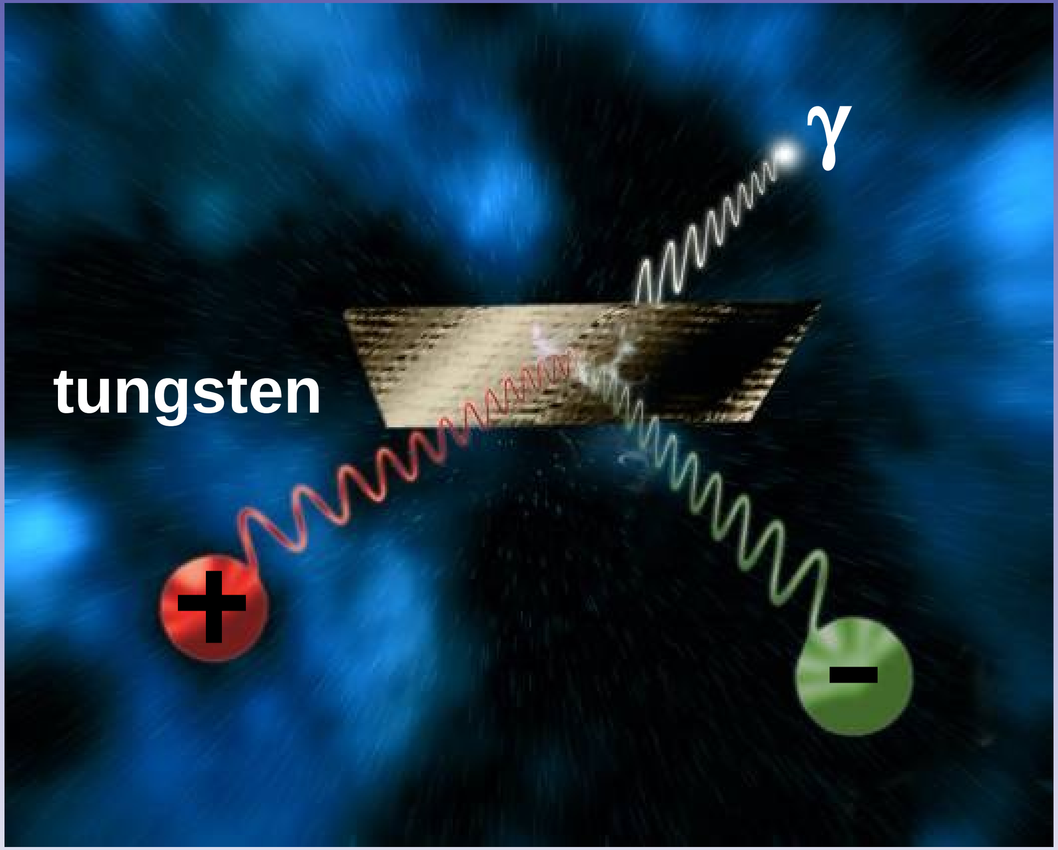
m = mass of the electron or positron

E = energy of gamma ray

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

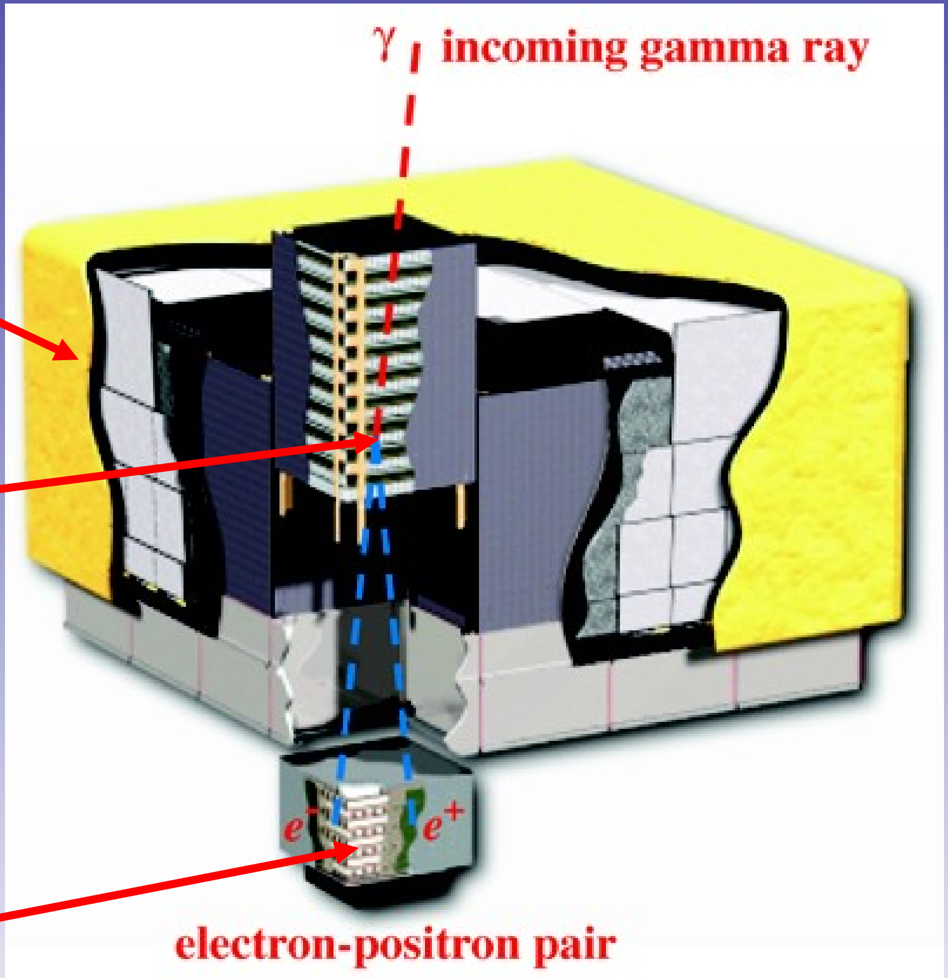
Now in reverse….

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

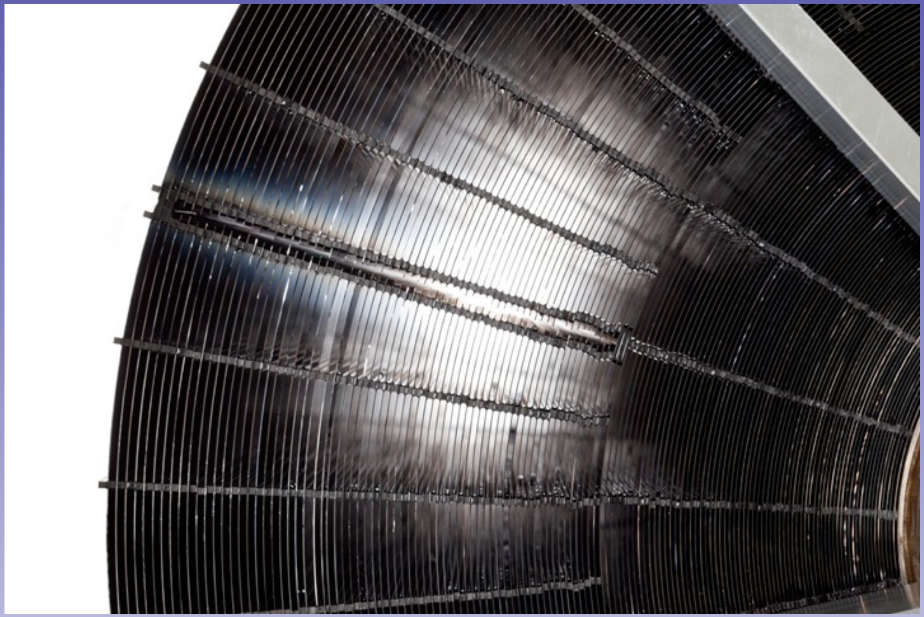


How the LAT works

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

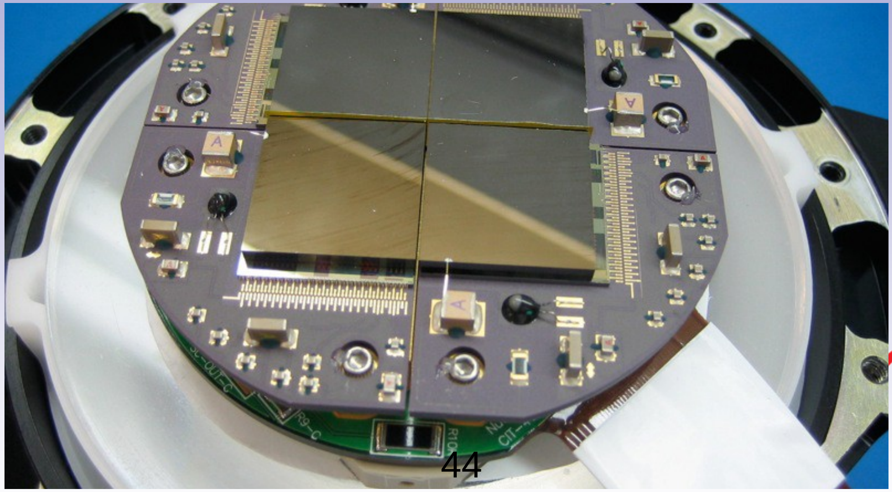


NuSTAR's mirrors and detectors



133 nested mirrors made of multilayers that reflect higher-energy X-rays

A 2 x 2 array of Cd-Zn-Te detectors and electronics

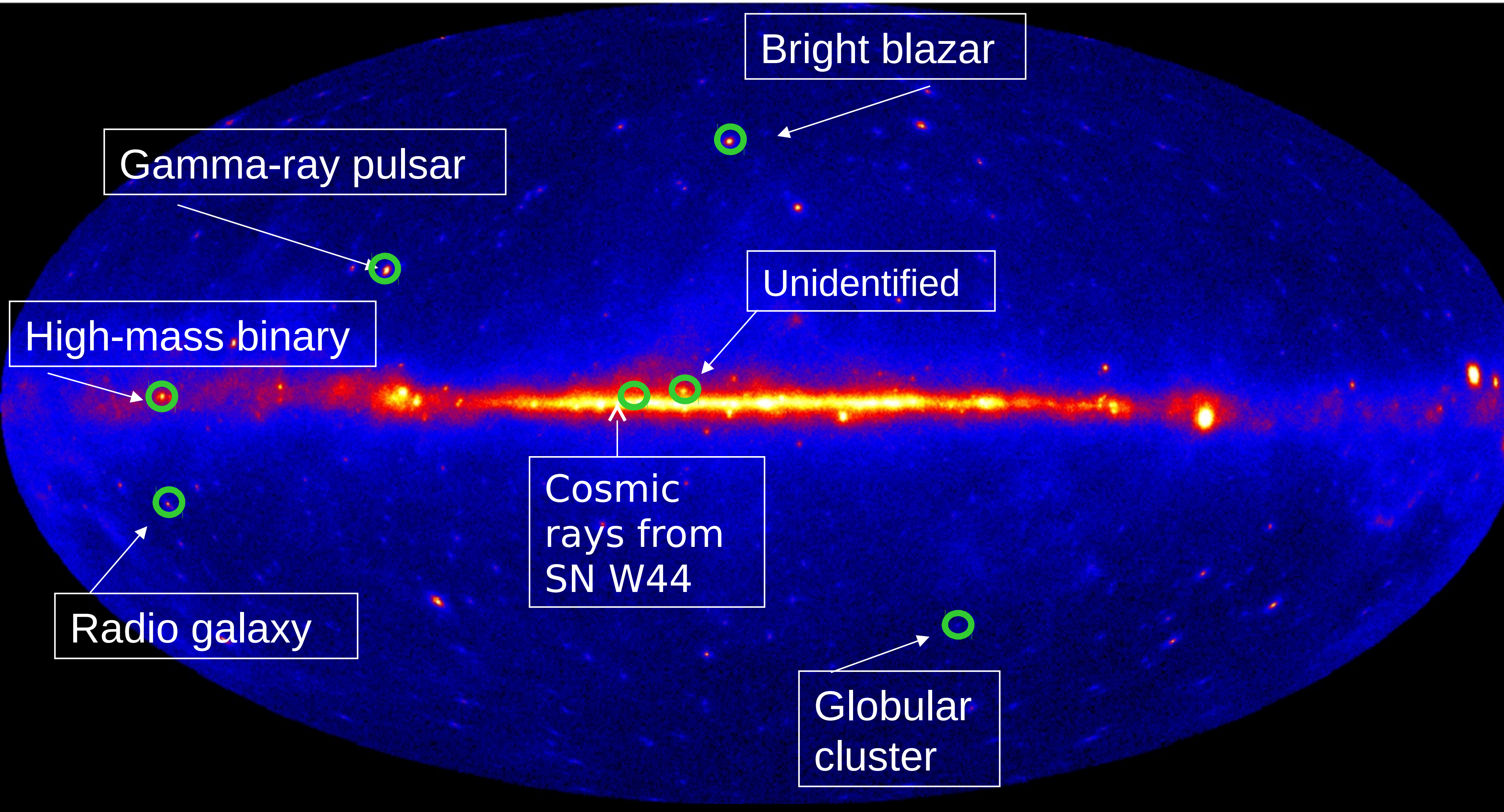


Global Telescope Network

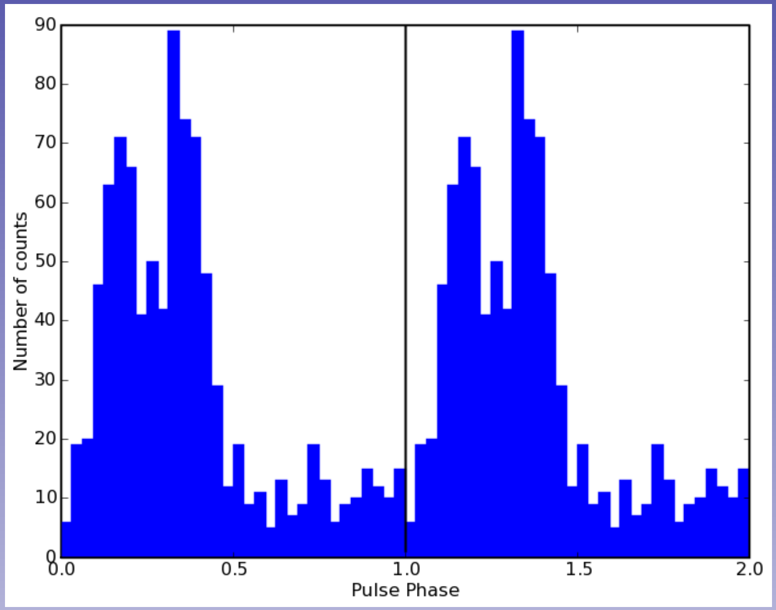
- Students do ground-based visible-light observations using remote telescopes
- GRBs and flaring blazars
- Coordinated with Fermi and other satellite data
- http://gtn.sonoma.edu

GORT at Pepperwood

Fermi skymap – new discoveries

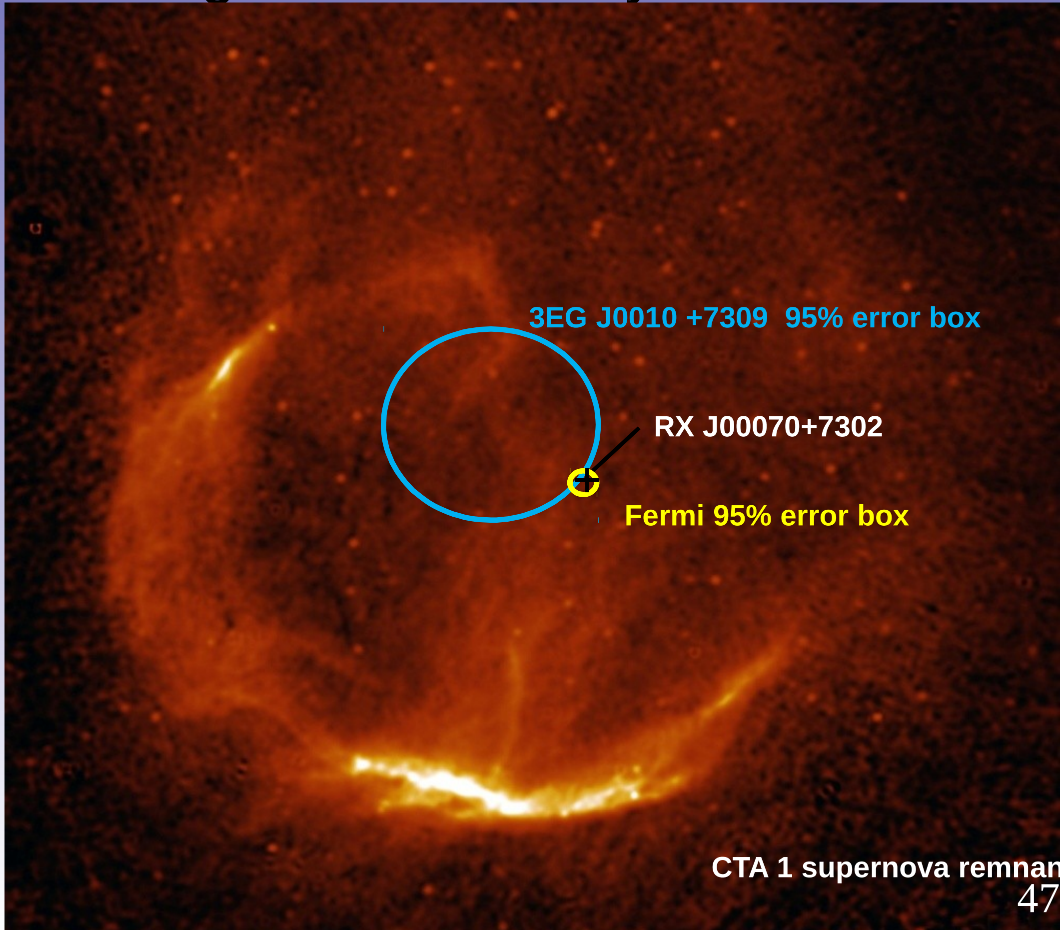


Fermi finds 1st gamma-ray only pulsar in CTA1



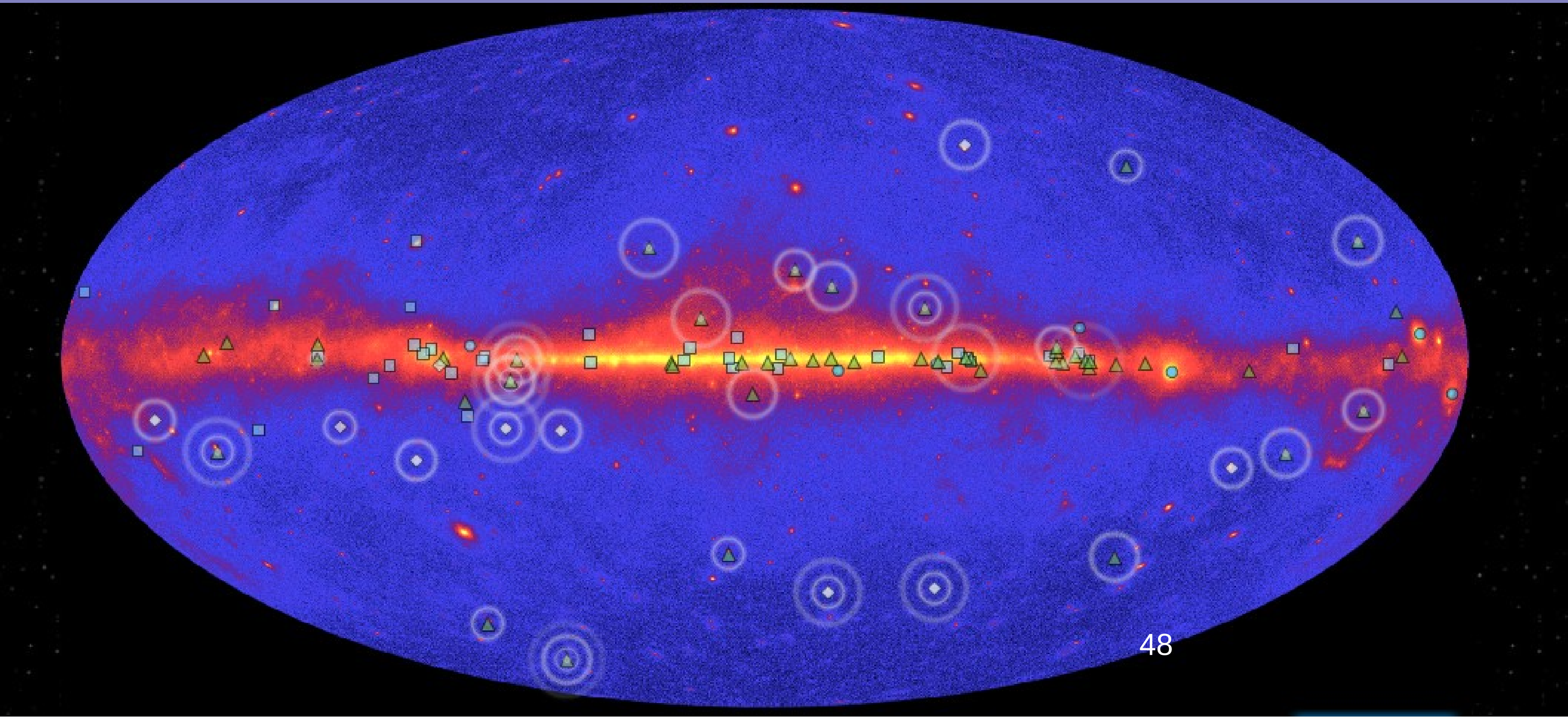
P = 315.86 ms
age ~1.4 x 104 yr

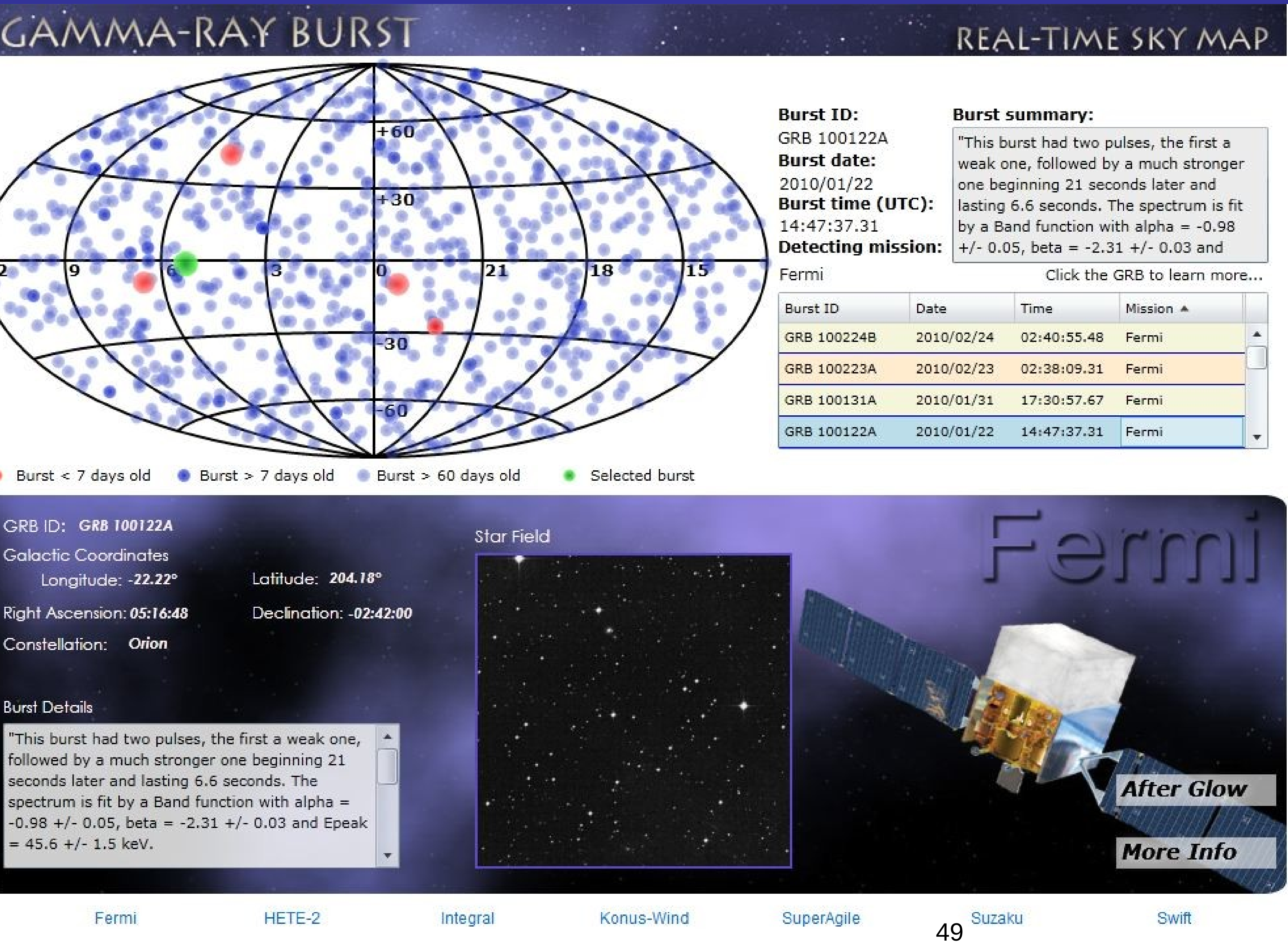
- Pulsar is not at center of SNR
- It's moving at 450 km/sec kicked by the supernova explosion that created it



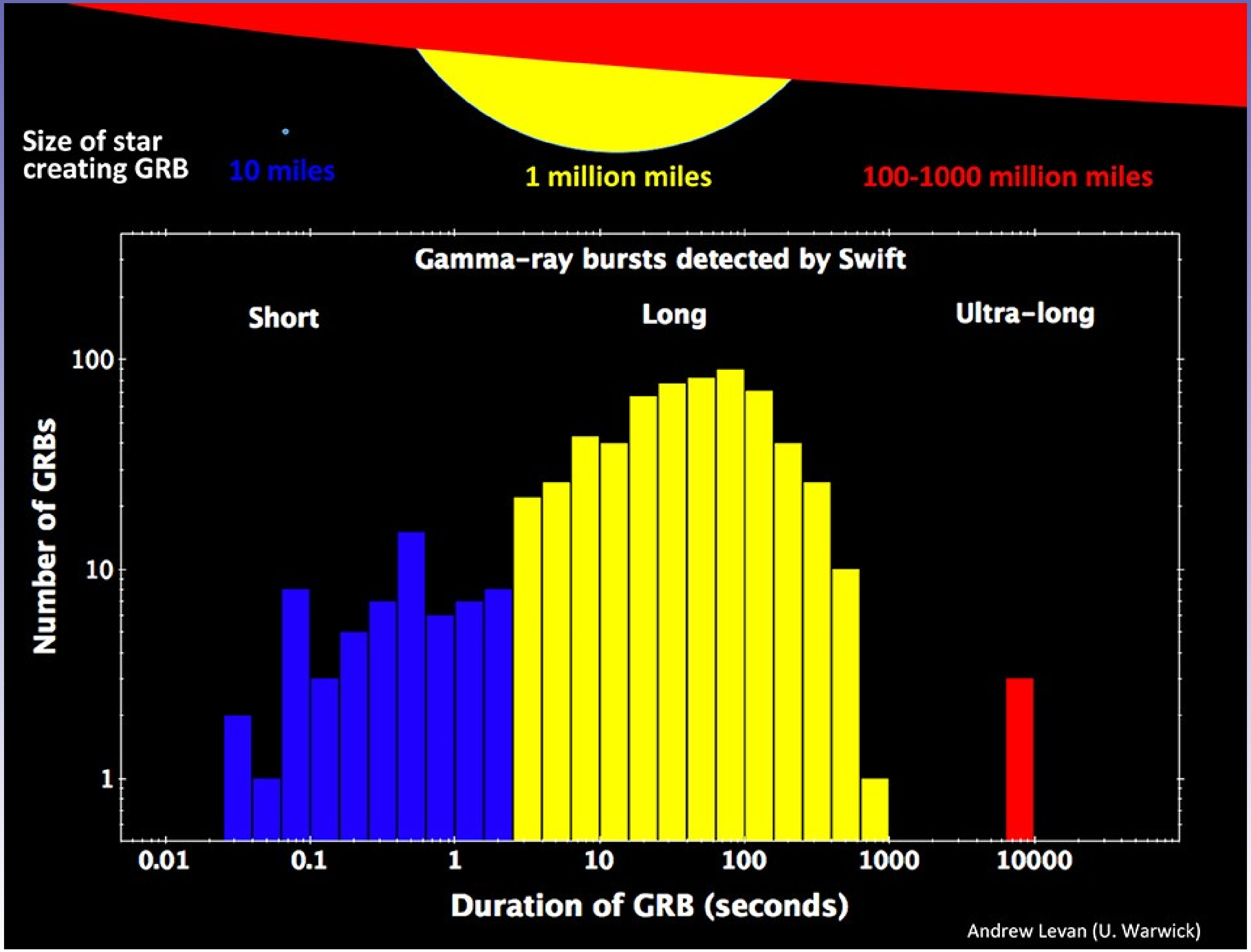
Pulsar Explorer interactive

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

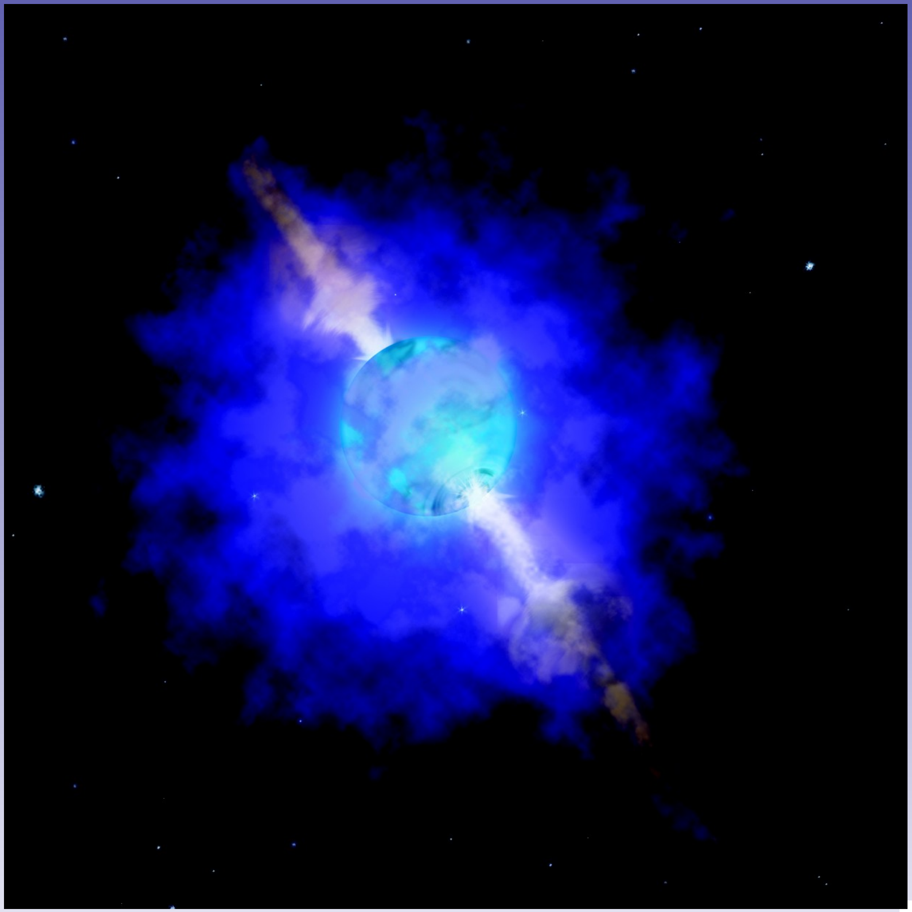



GAMMA-RAY BURST
REAL-TIME SKY MAP
+60
+30
0
-30
-60
9
6
3
0
21
18
15
Burst ID:
GRB 100122A
Burst date:
2010/01/22
Burst time (UTC):
14:47:37.31
Detecting mission:
Fermi
Burst summary:
"This burst had two pulses, the first a weak one, followed by a much stronger one beginning 21 seconds later and lasting 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

April news – ultralong bursts

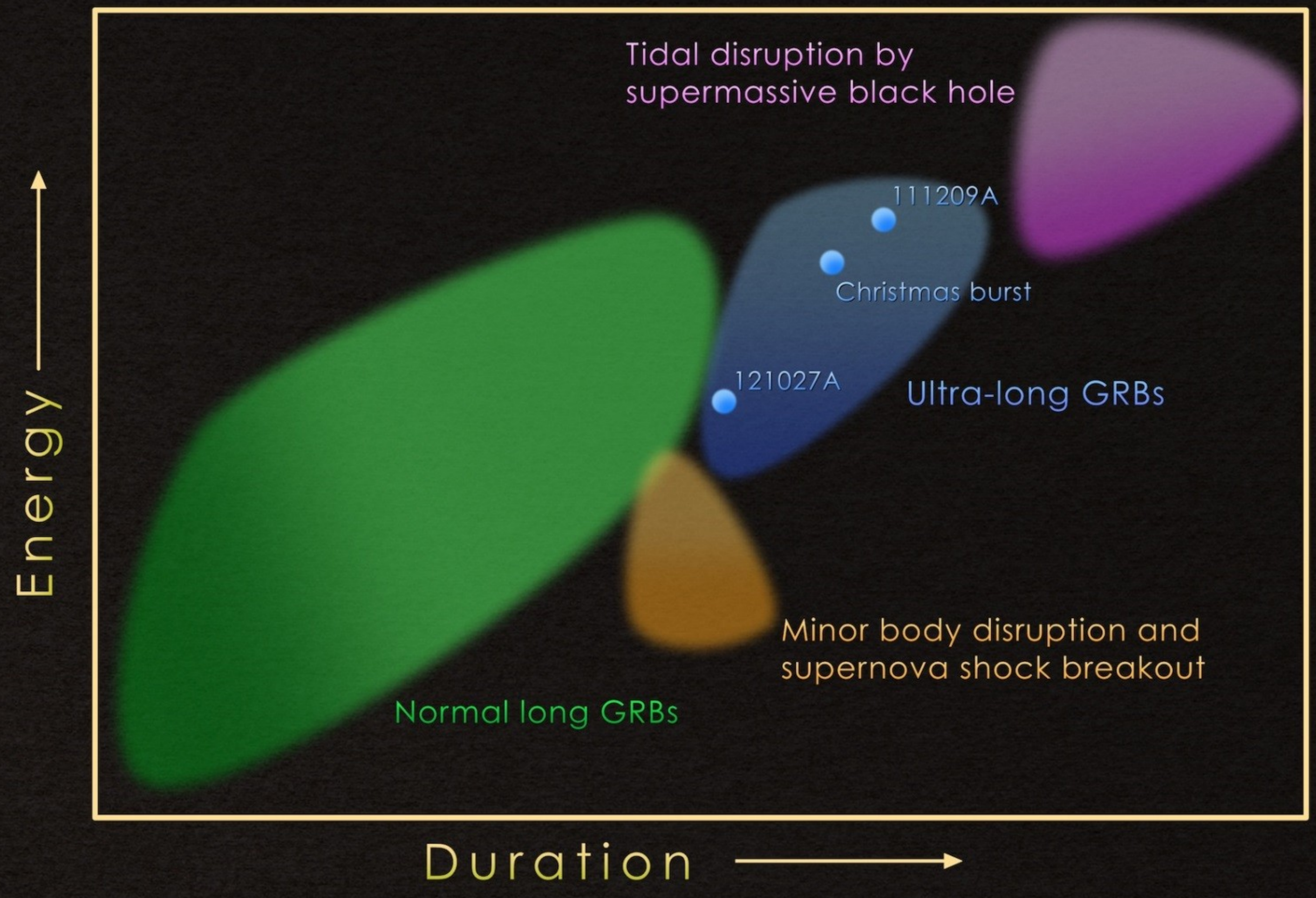


Blue supergiant system



Credit: CNRS/Céline Lavalade

Types of bursts

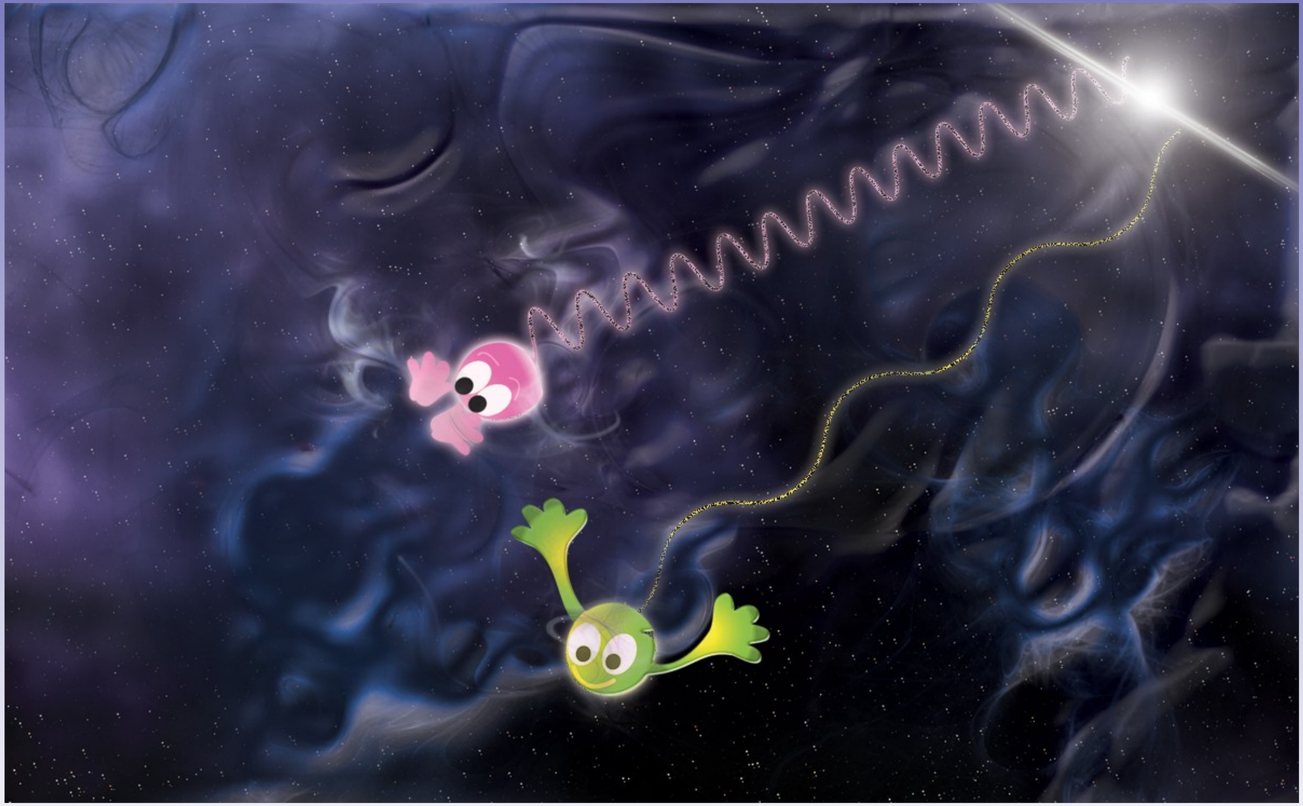


Using GRBs to test Special Relativity

- 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

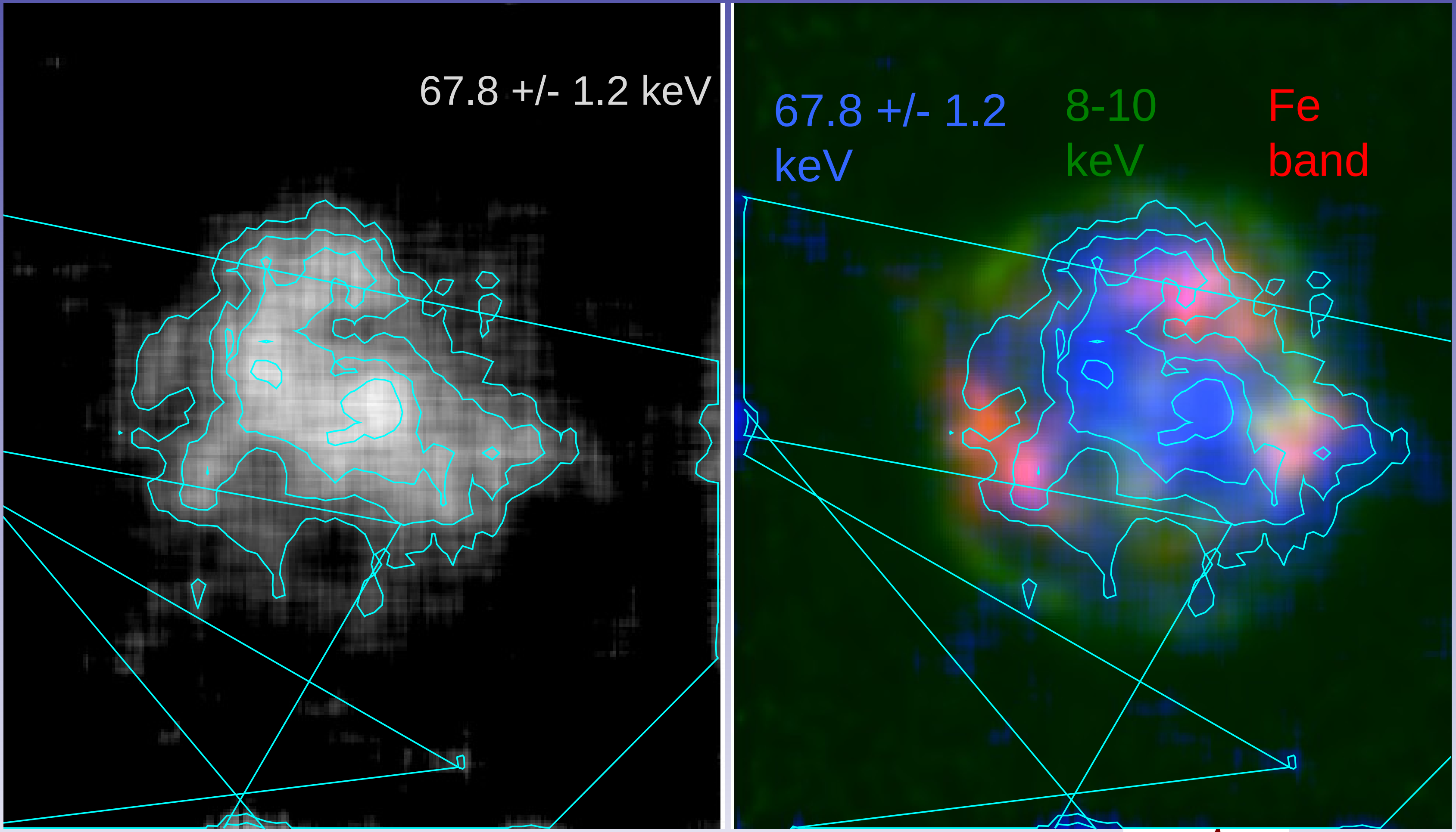
Will quantum foam entangle photons?

- Fermi sees no evidence for this to date

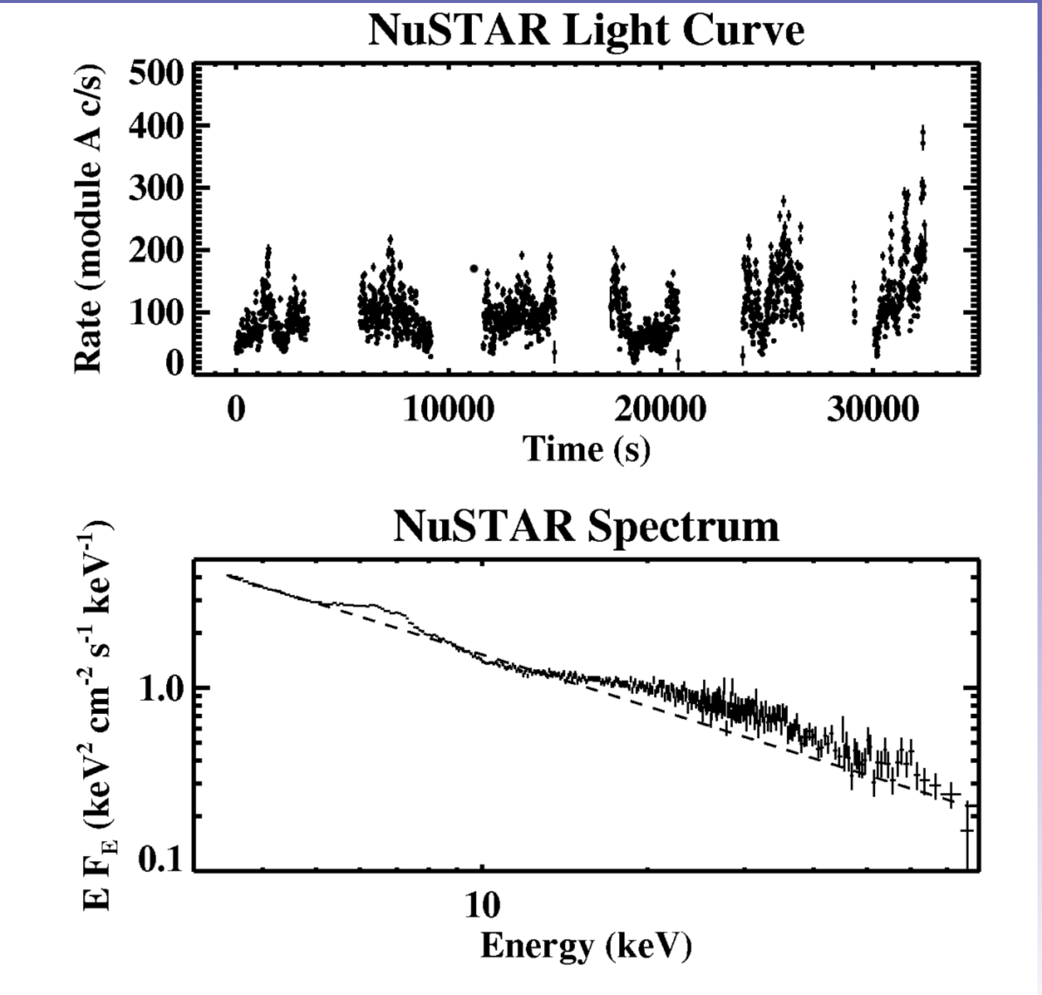


Two photons which differed in energy by 106 arrived at Earth within 1 second, after traveling for 12.2 billion years

44Ti Imaging Cas A

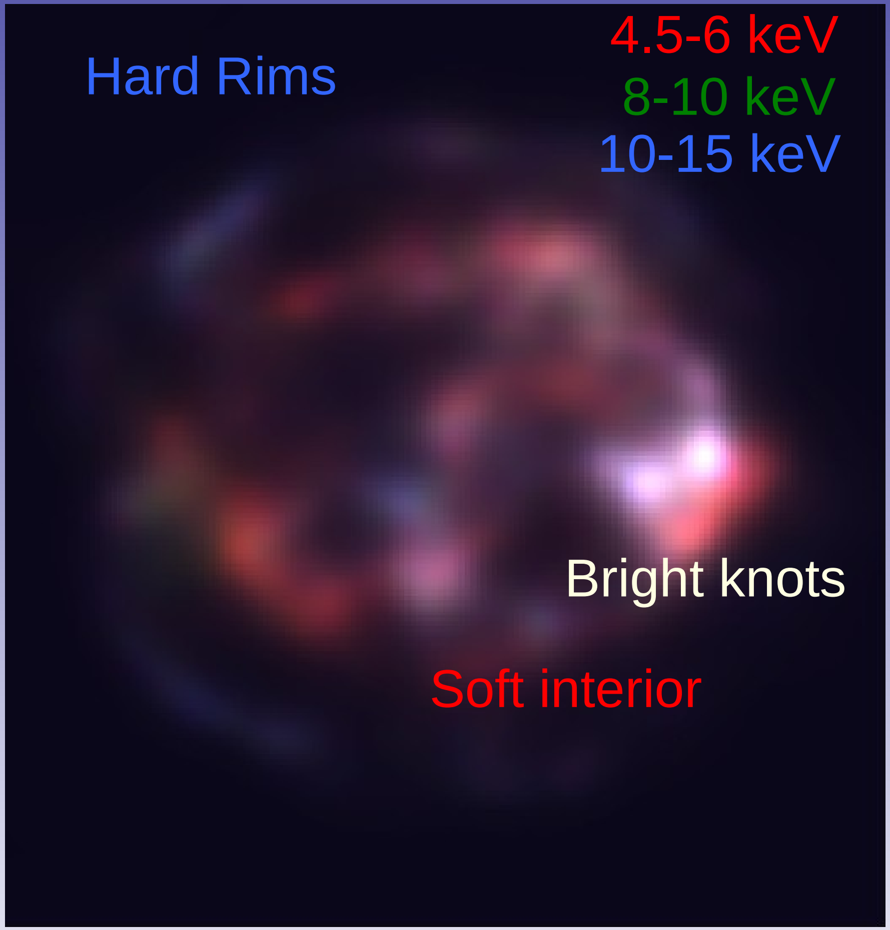


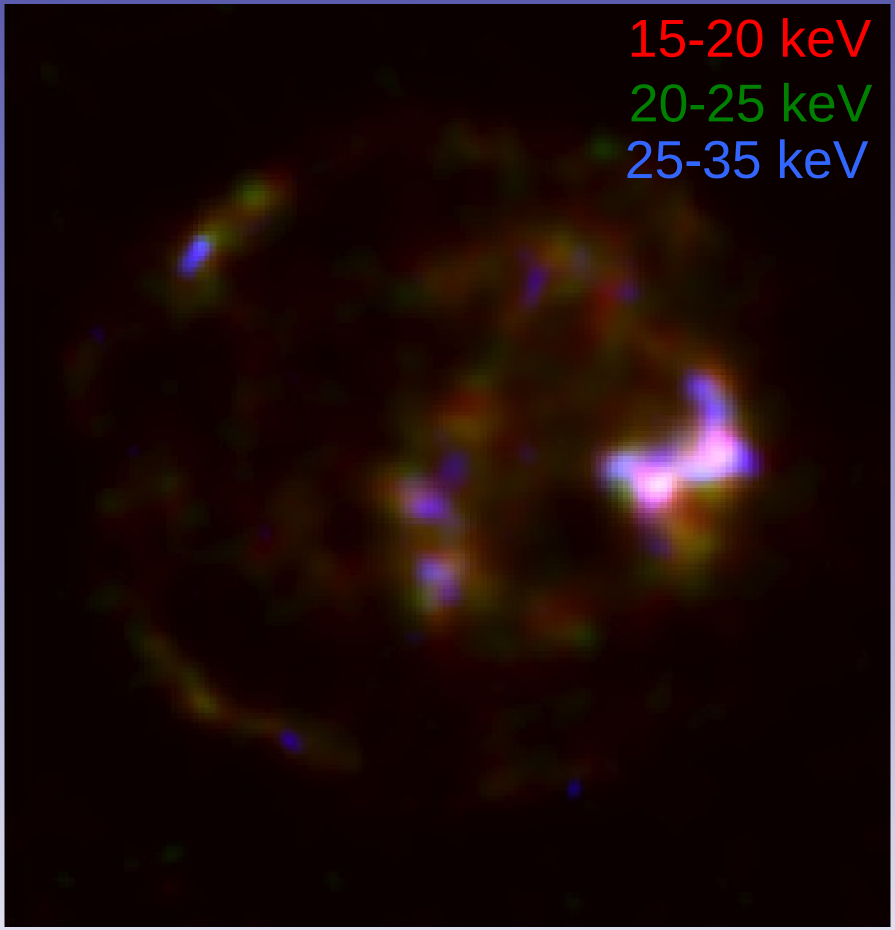
NuSTAR timing of Cyg X-1



- Cyg X-1 is a stellar mass black hole in a binary system that is accreting matter from a supergiant companion star
- *NuSTAR* saw it in the soft state

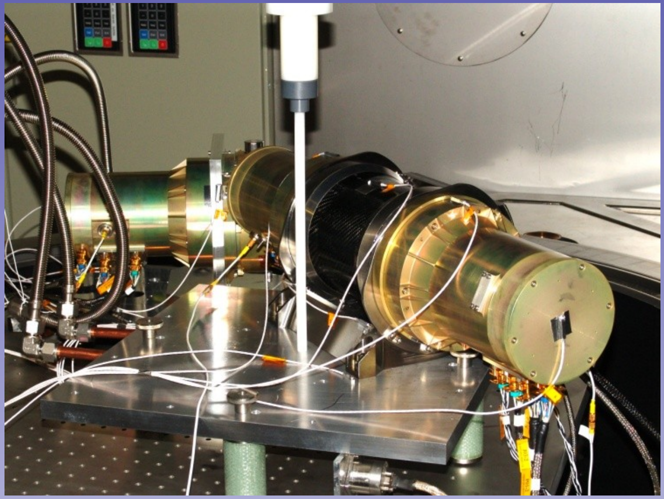
Detailed look at Cas A Continuum

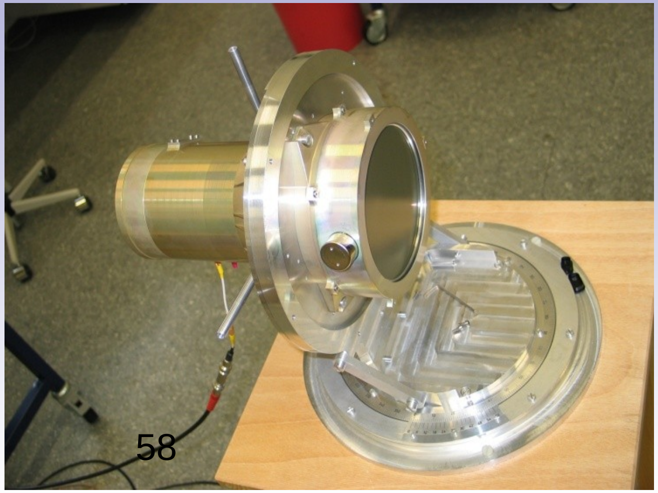




Gamma-ray Burst Monitor (GBM)

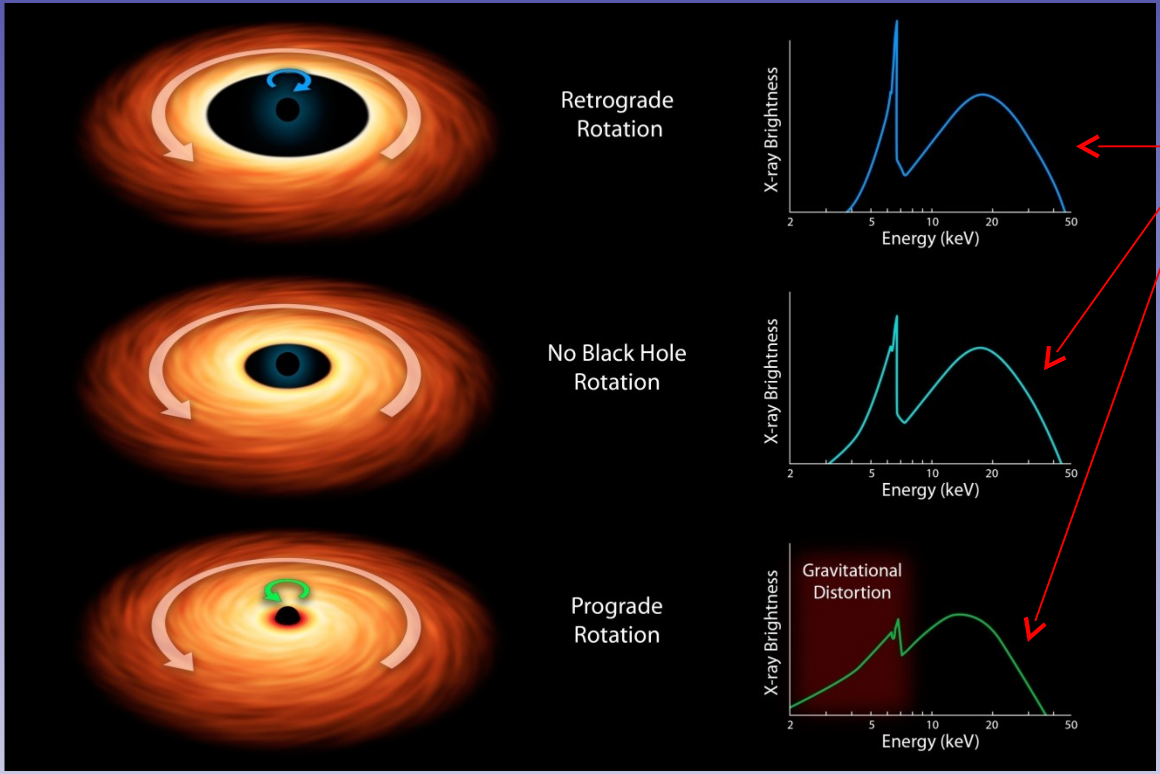
- All sky coverage
- 12 sodium iodide scintillators
  - 10 keV to 1 MeV
  - Burst triggers and locations
- 2 bismuth germanate detectors
  - 150 keV to 30 MeV
  - Overlap with LAT
- **http://gammaray.msfc.nasa.gov/gbm/**





NuSTAR and Black Hole Spin

Measuring black hole spin



NuSTAR measures the high energy X-rays which help to differentiate these models

- General Relativity predicts line shapes for spinning black holes
- Different spin directions produce different shapes

NuSTAR measures NGC 1365

- *NuSTAR*'s measurements revealed the BH spin rate is >84% of maximum