

Exploring Nature's Accelerators with the Fermi Gamma-ray Space Telescope

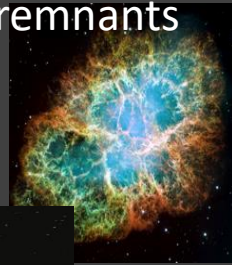


Julie McEnery
NASA/GSFC

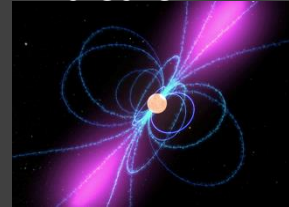


Active
Galactic
Nuclei

Supernova
remnants

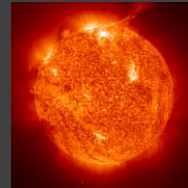


Pulsars



Gamma-ray
Bursts

Sun



Black
Hole
Binaries



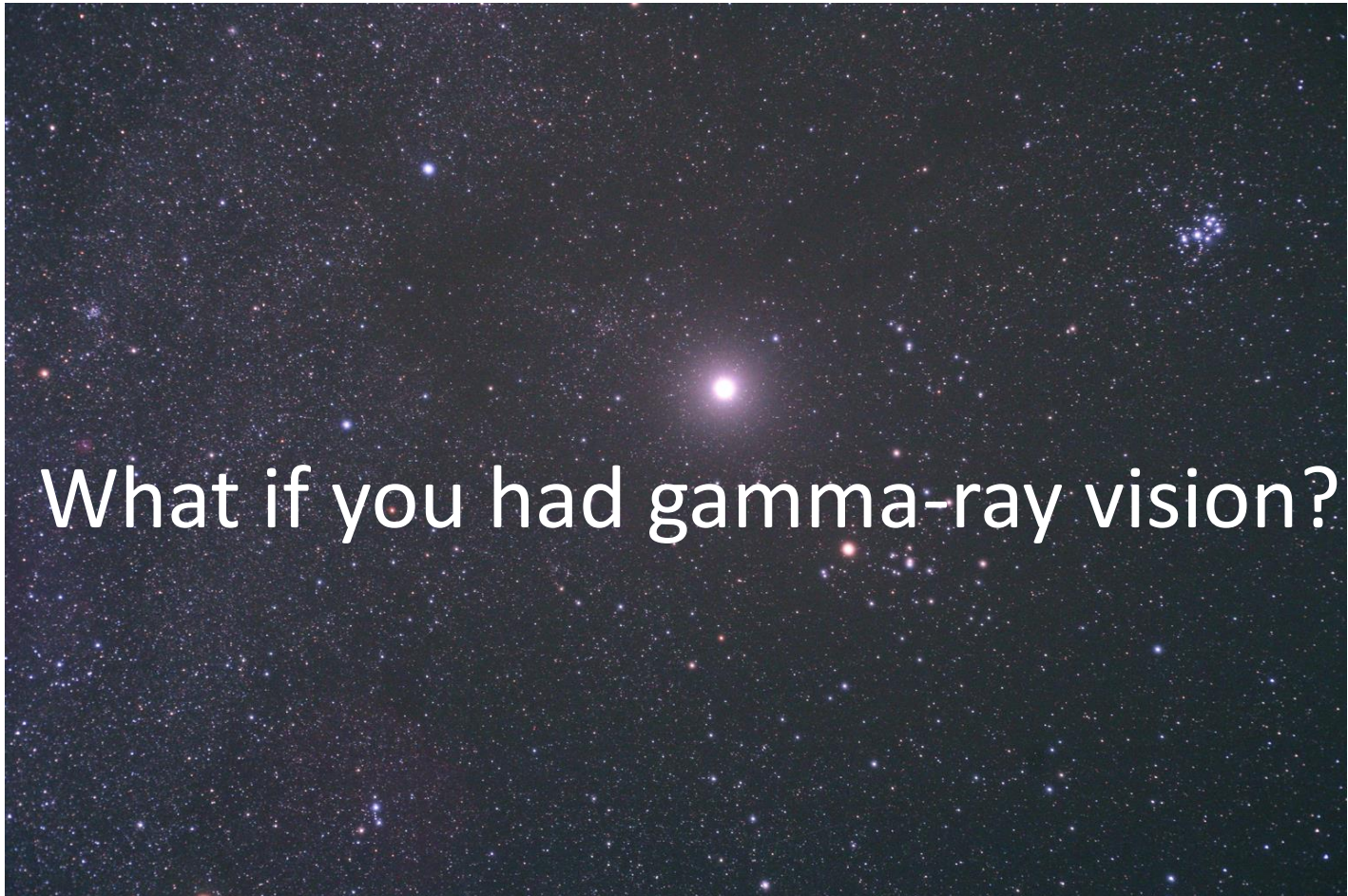
Novae



The Sky at Night

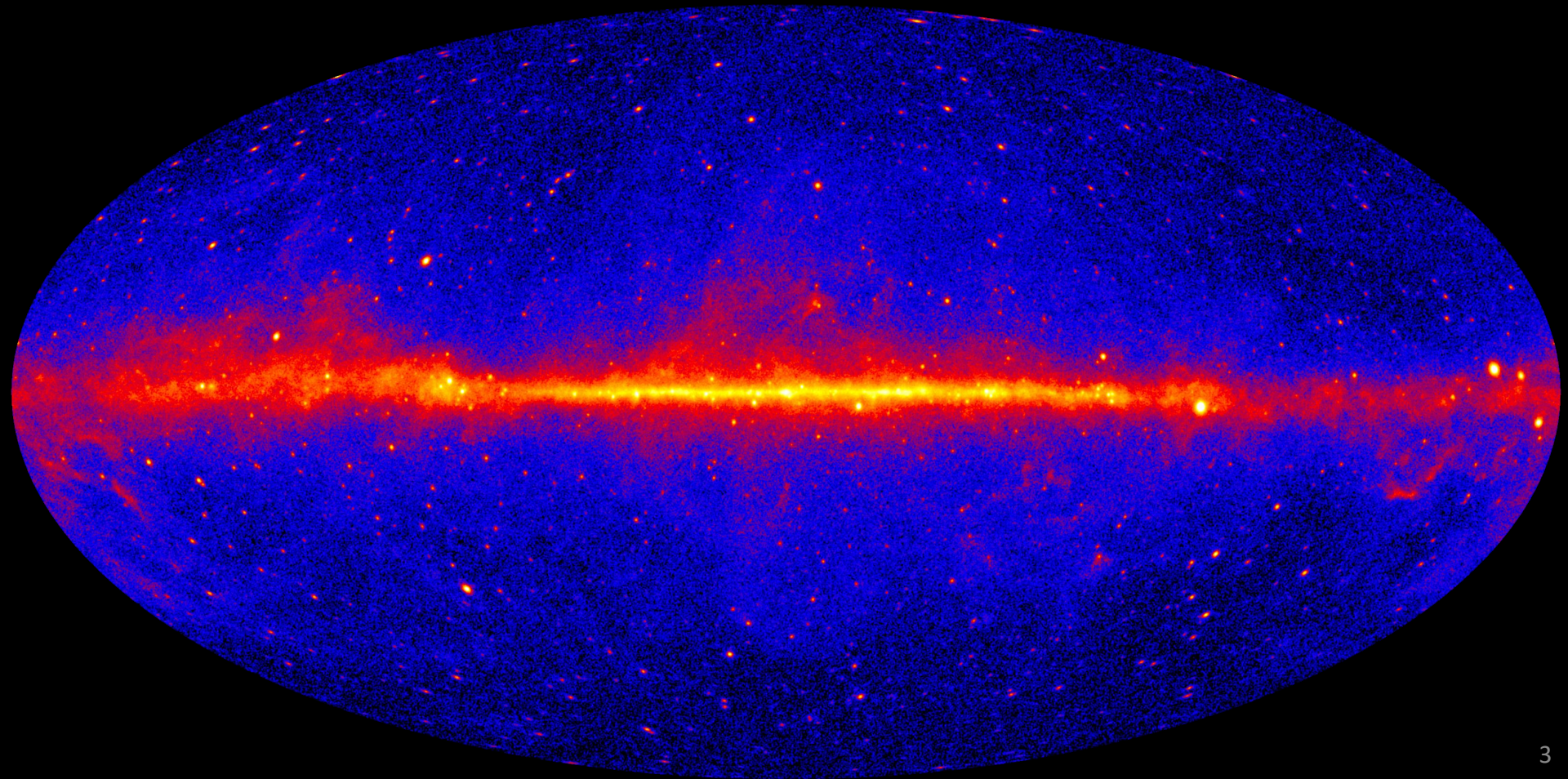


The Sky at Night



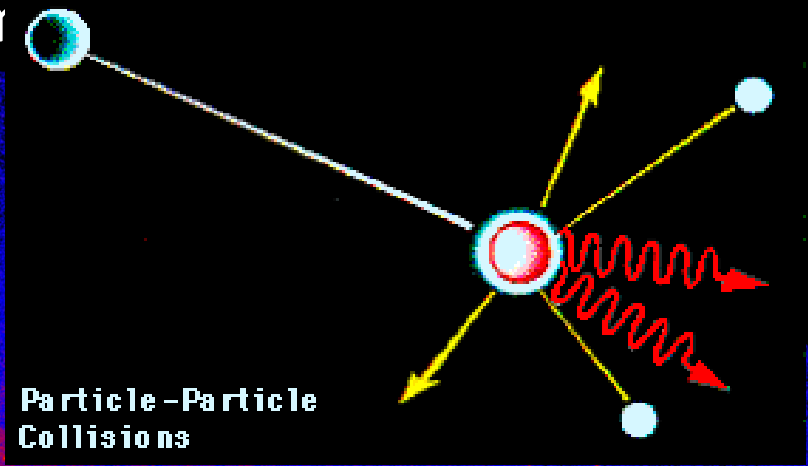
What if you had gamma-ray vision?

The Gamma-ray Sky



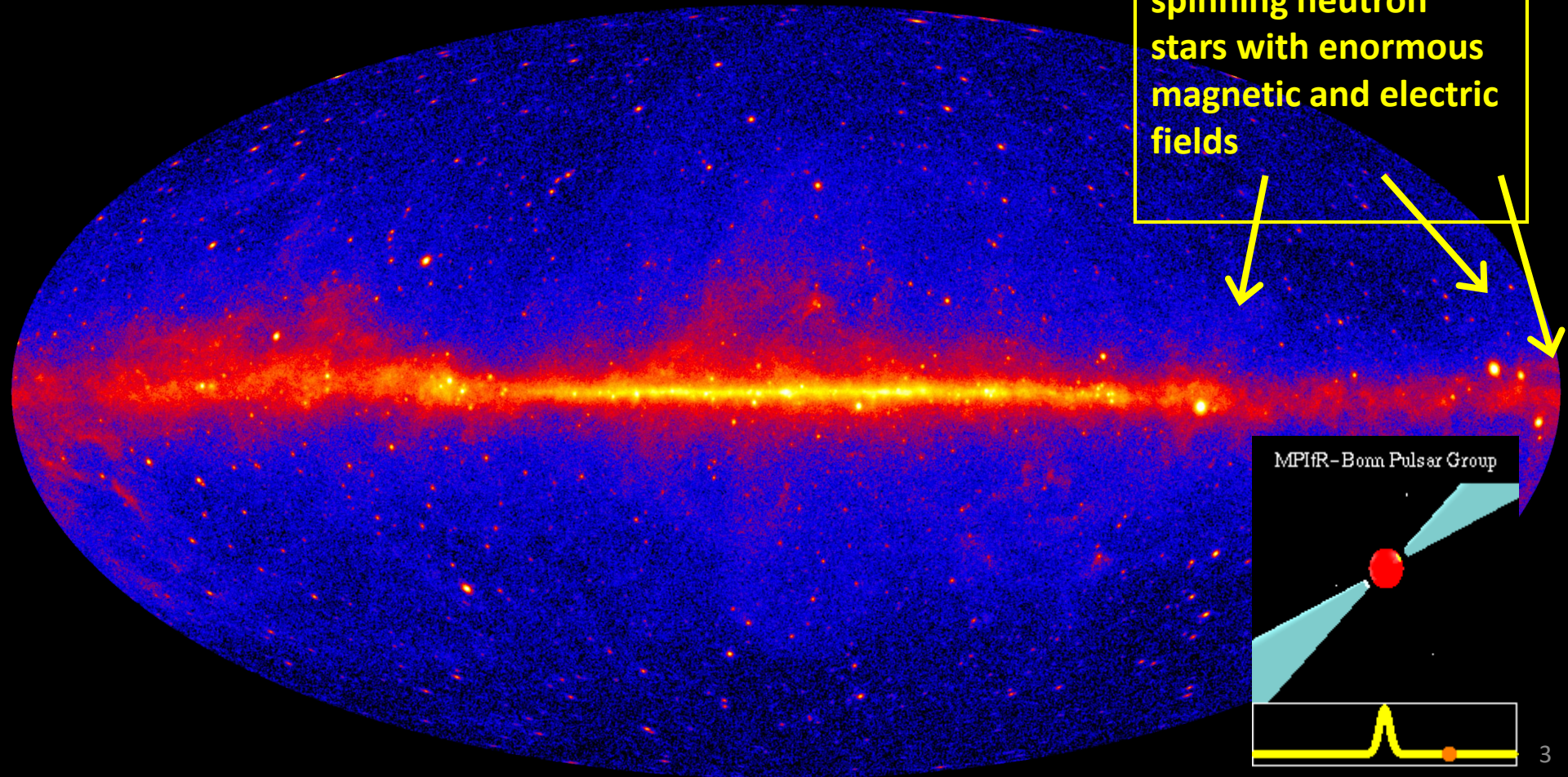
Milky Way – Gamma rays from powerful cosmic ray particles smashing into the tenuous gas between the stars.

The Gan

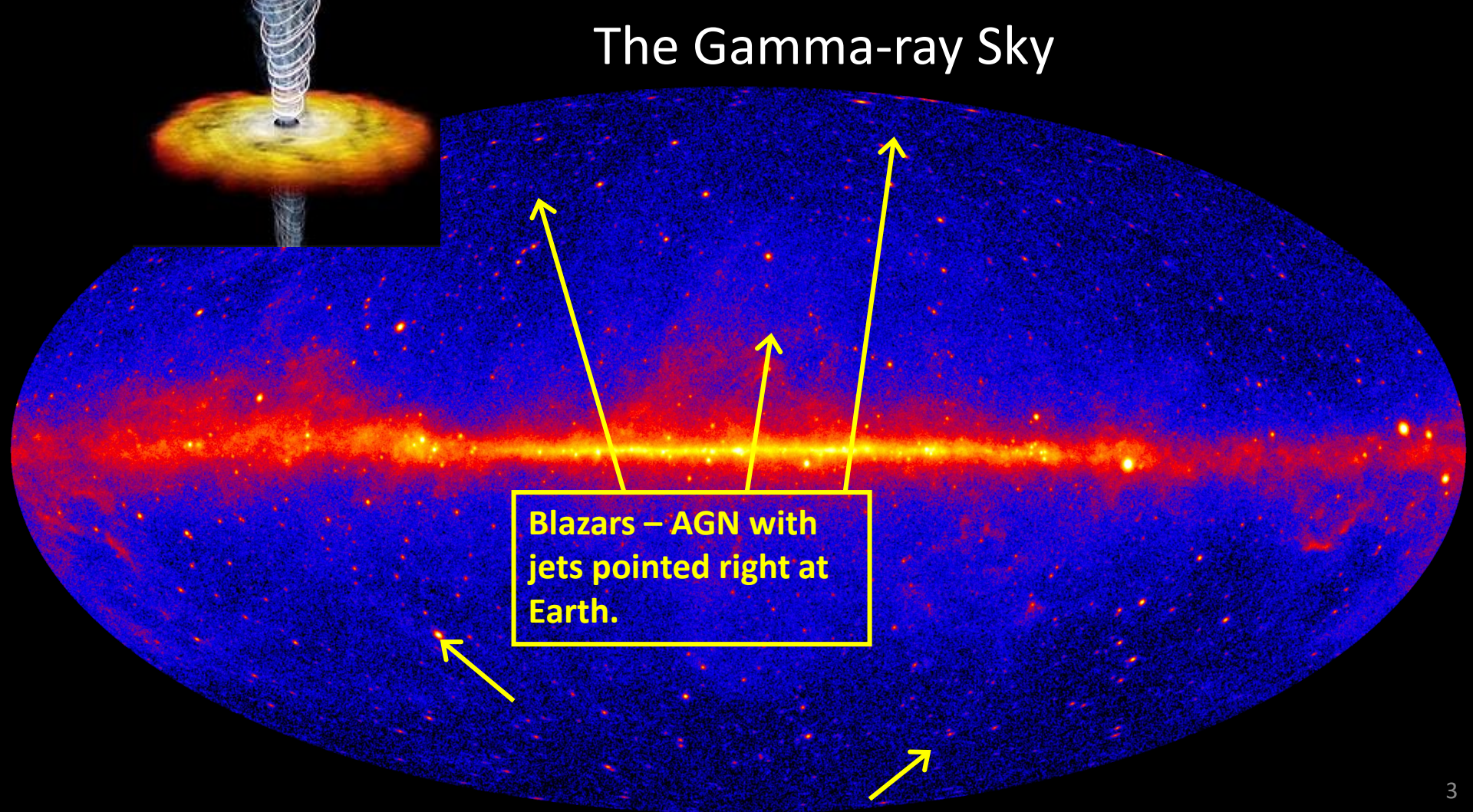


The Gamma-ray Sky

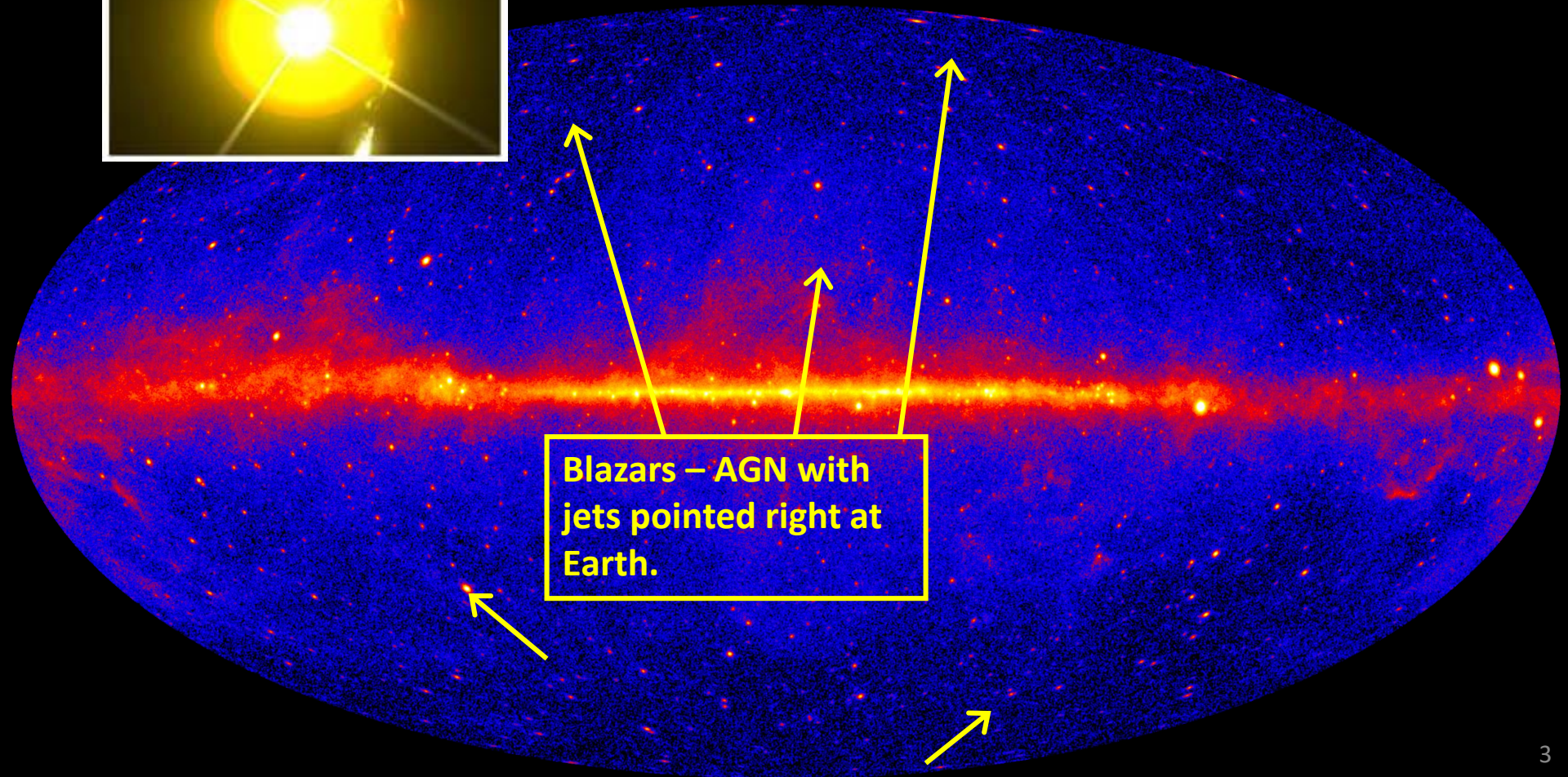
Pulsars – rapidly spinning neutron stars with enormous magnetic and electric fields



The Gamma-ray Sky

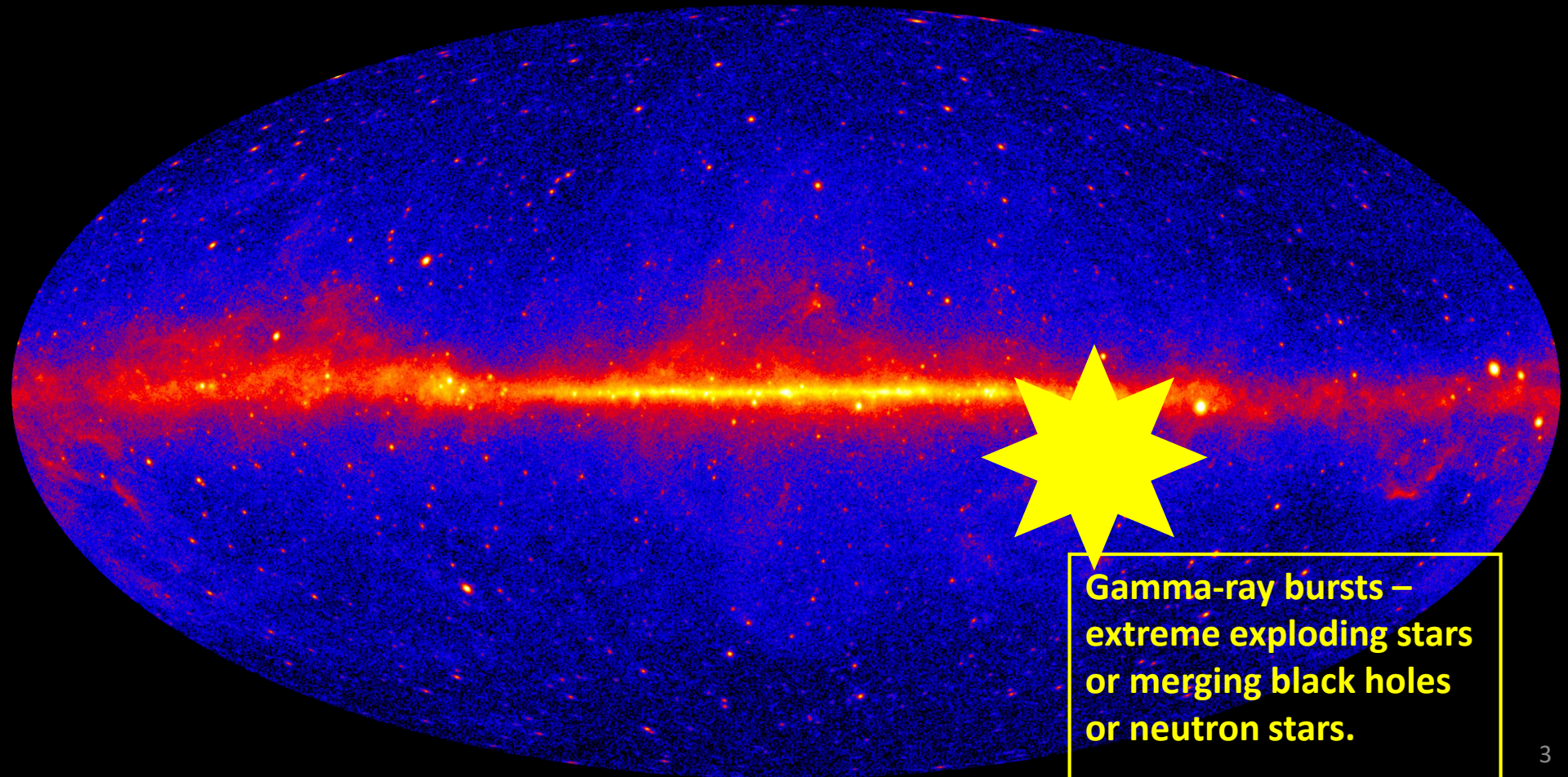


The Gamma-ray Sky



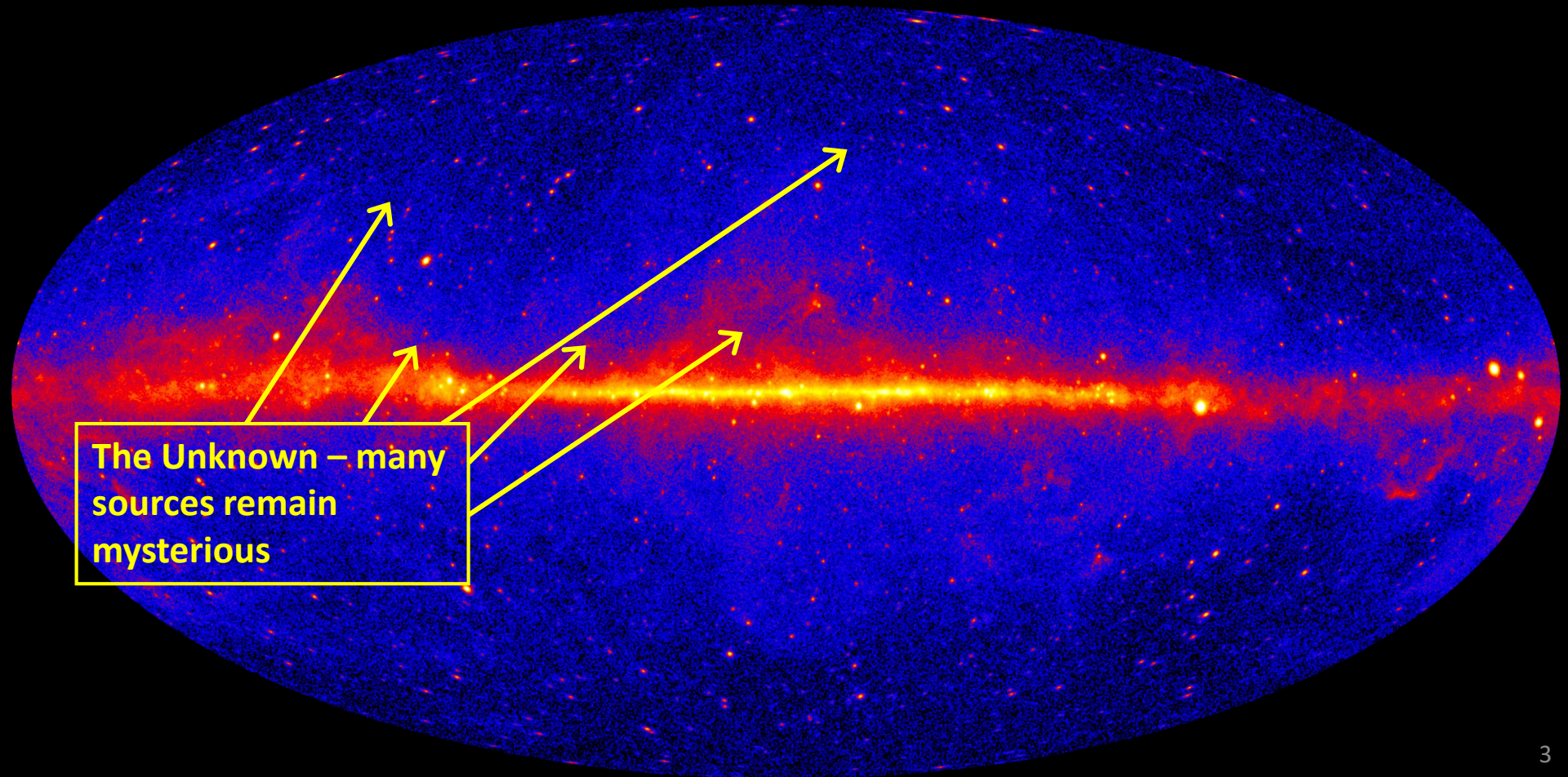
Blazars – AGN with jets pointed right at Earth.

The Gamma-ray Sky



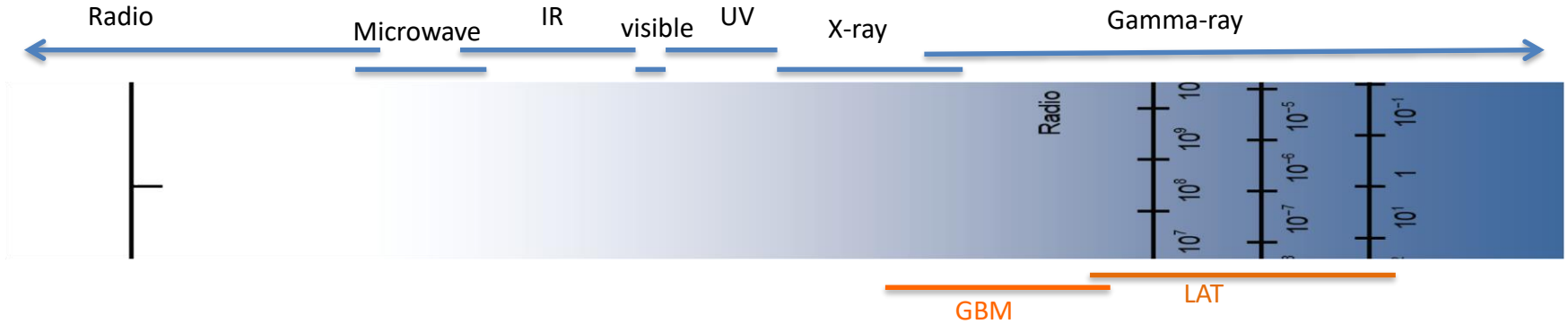
**Gamma-ray bursts –
extreme exploding stars
or merging black holes
or neutron stars.**

The Gamma-ray Sky



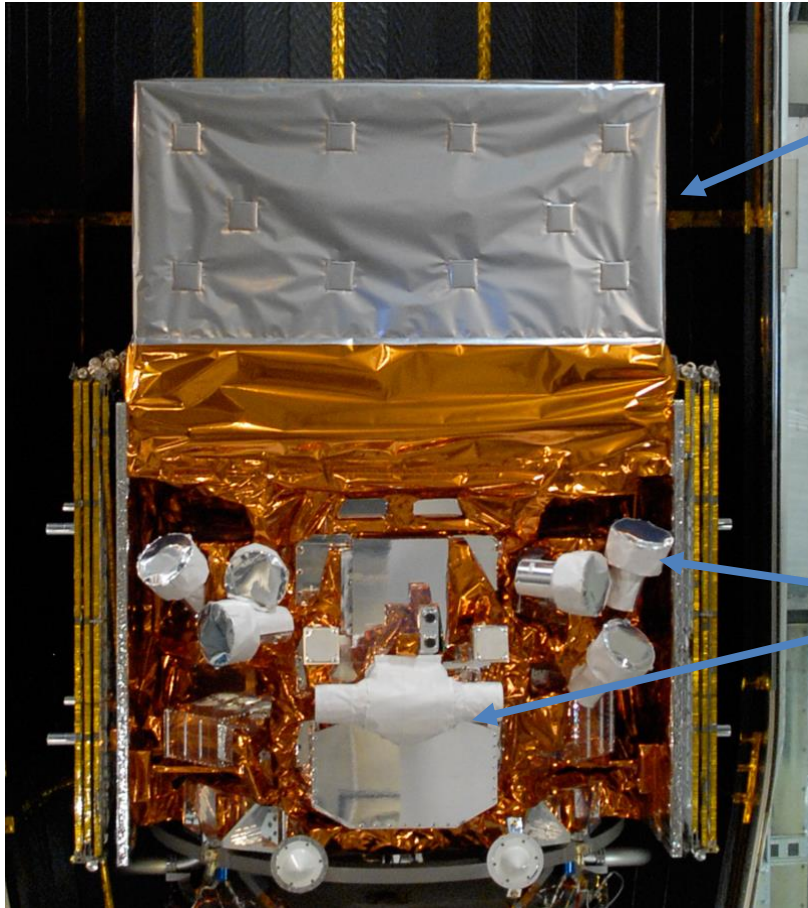
The Unknown – many sources remain mysterious

Gamma-ray Astrophysics



- Gamma-rays cover a huge swath of the electromagnetic spectrum
- High Energy gamma-rays produced in non-thermal processes -> i.e. by energetic charged particles
 - Explore extreme environments hosting powerful particle accelerators
 - Natural connections to neutrino and cosmic-ray astrophysics

Fermi Observatory



Large Area Telescope (LAT):

- 20 MeV - >300 GeV
- 2.4 sr FoV (scans entire sky every ~3hrs)

Gamma-ray Burst Monitor (GBM)

- 8 keV - 40 MeV
- views entire unocculted sky

Launched on June 11, 2008

Detecting Gamma-rays

$$E=mc^2 \text{ matters!}$$

E - Energy

m - mass

c - speed of light in a vacuum

Detecting Gamma-rays

$E=mc^2$ matters!

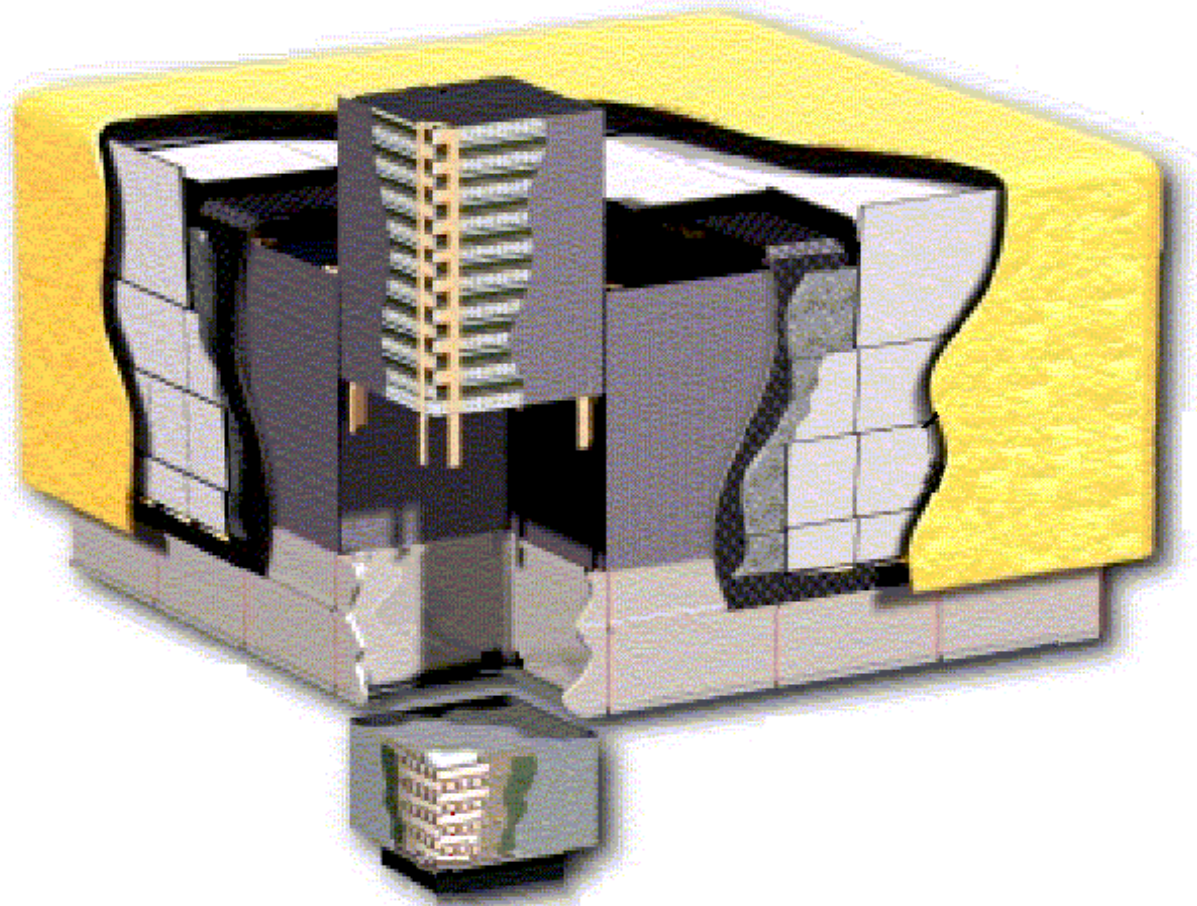
E - Energy

m - mass

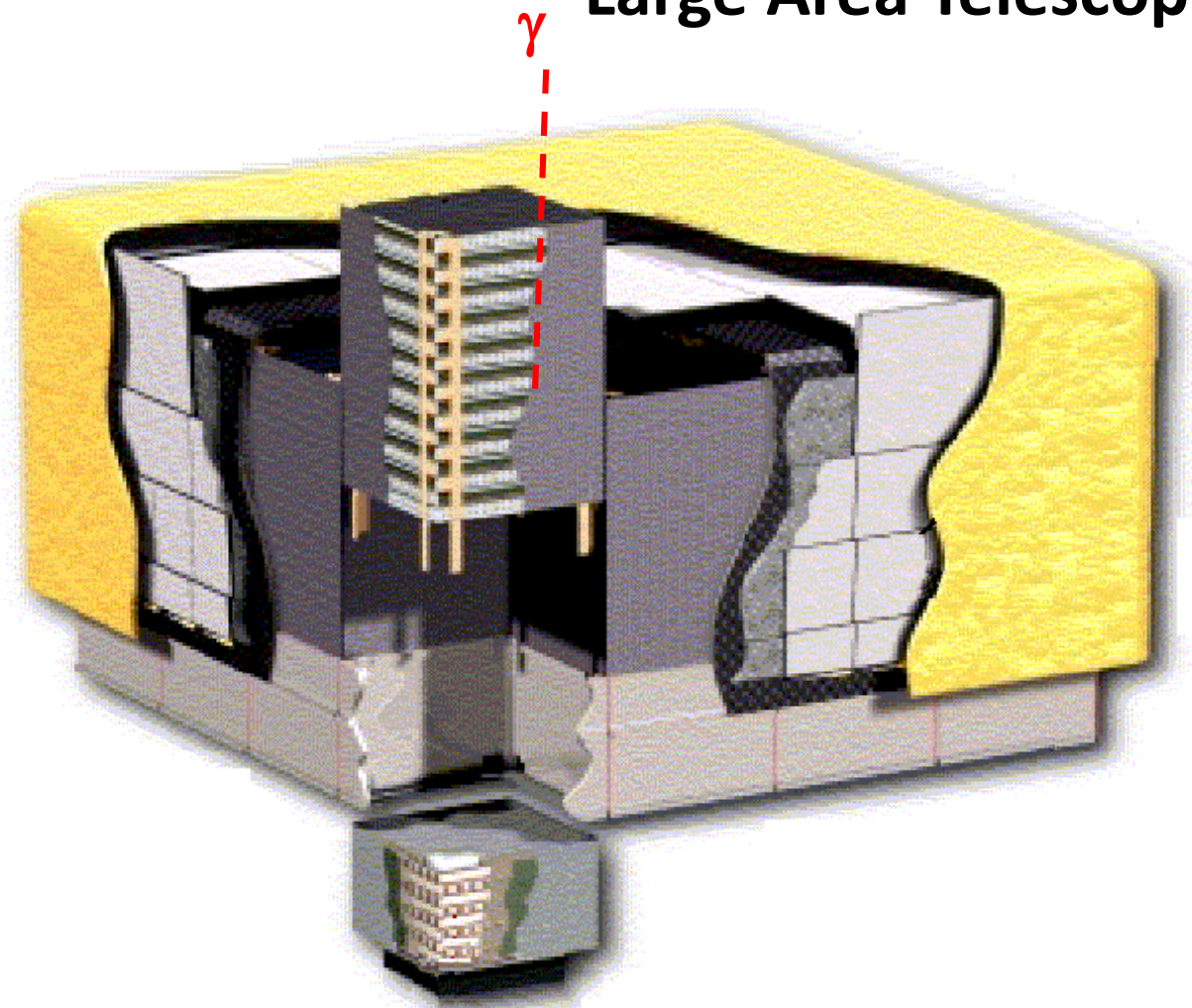
c - speed of light in a vacuum



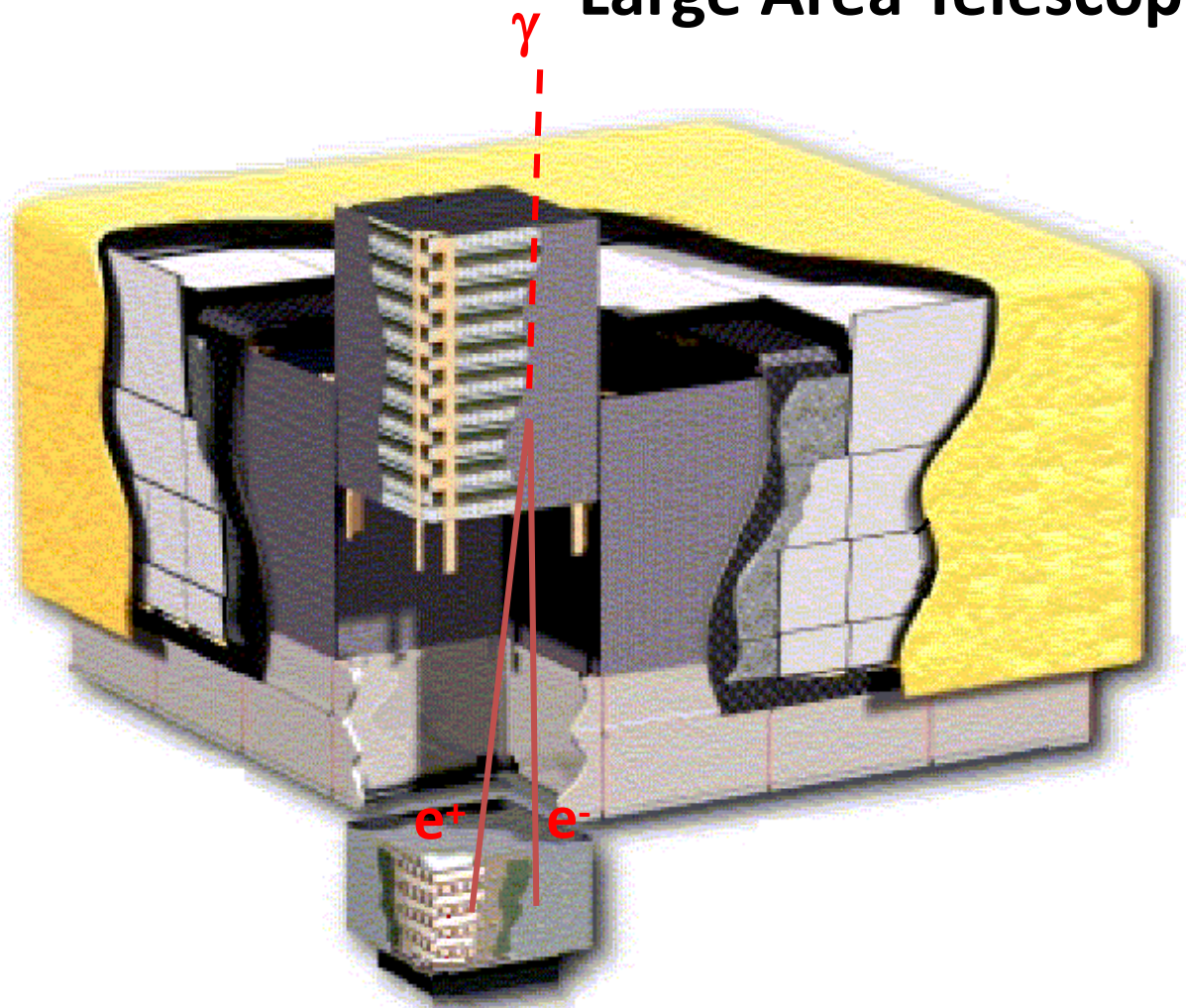
Large Area Telescope



Large Area Telescope



Large Area Telescope



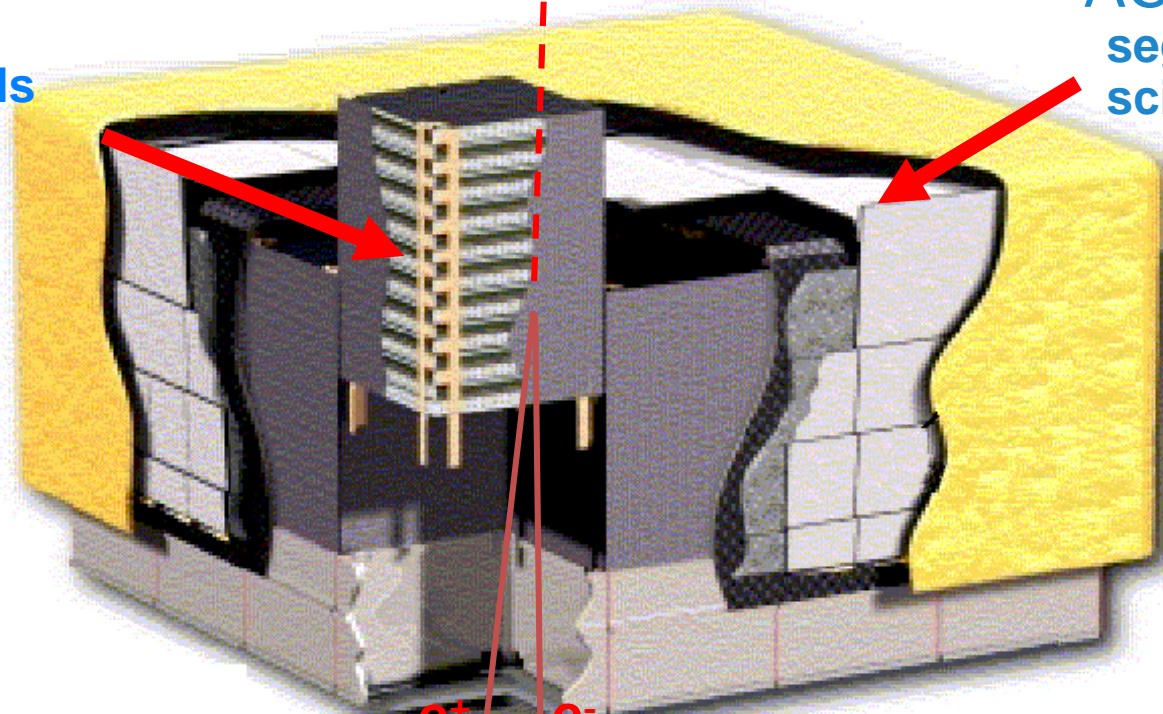
Large Area Telescope

Si Tracker

pitch = 228 μm
8.8 10^5 channels
18 planes

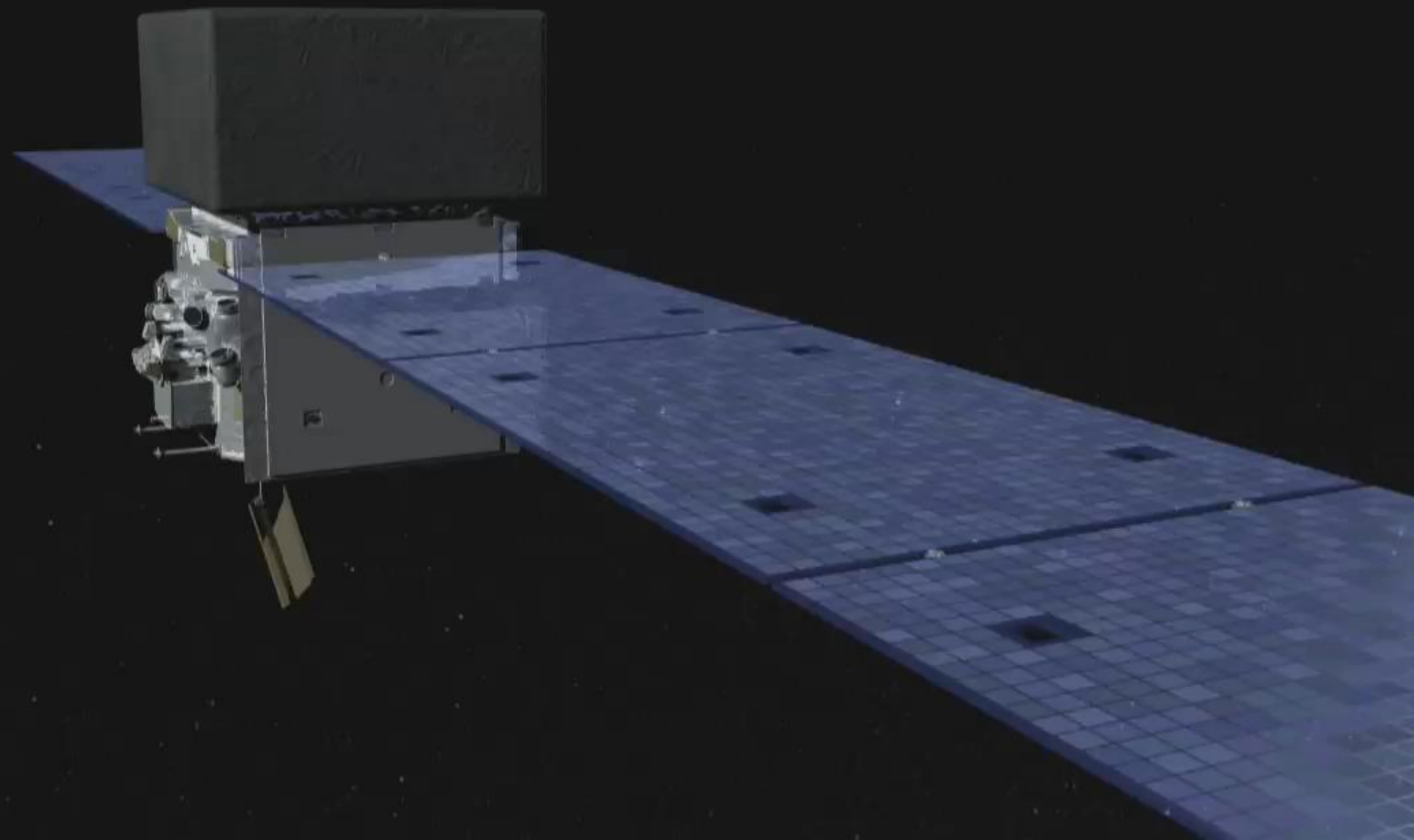
ACD

segmented
scintillator tiles

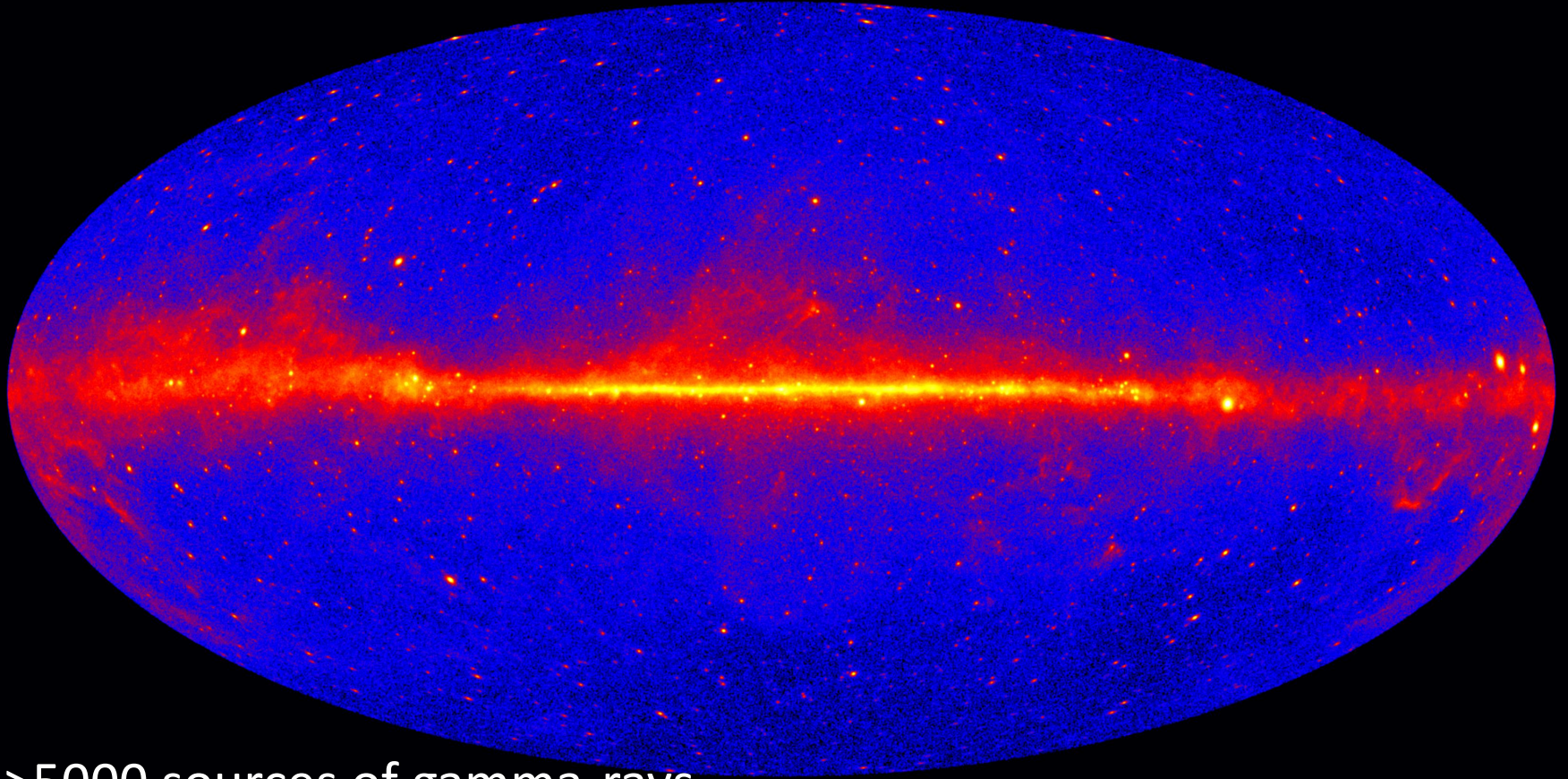


CsI Calorimeter
hodoscopic array (8 layers)
6.1 10^3 channels

LAT: 4 x 4 modular array
3000 kg, 650 W
20 MeV – 300 GeV



The Sky Above 1 GeV

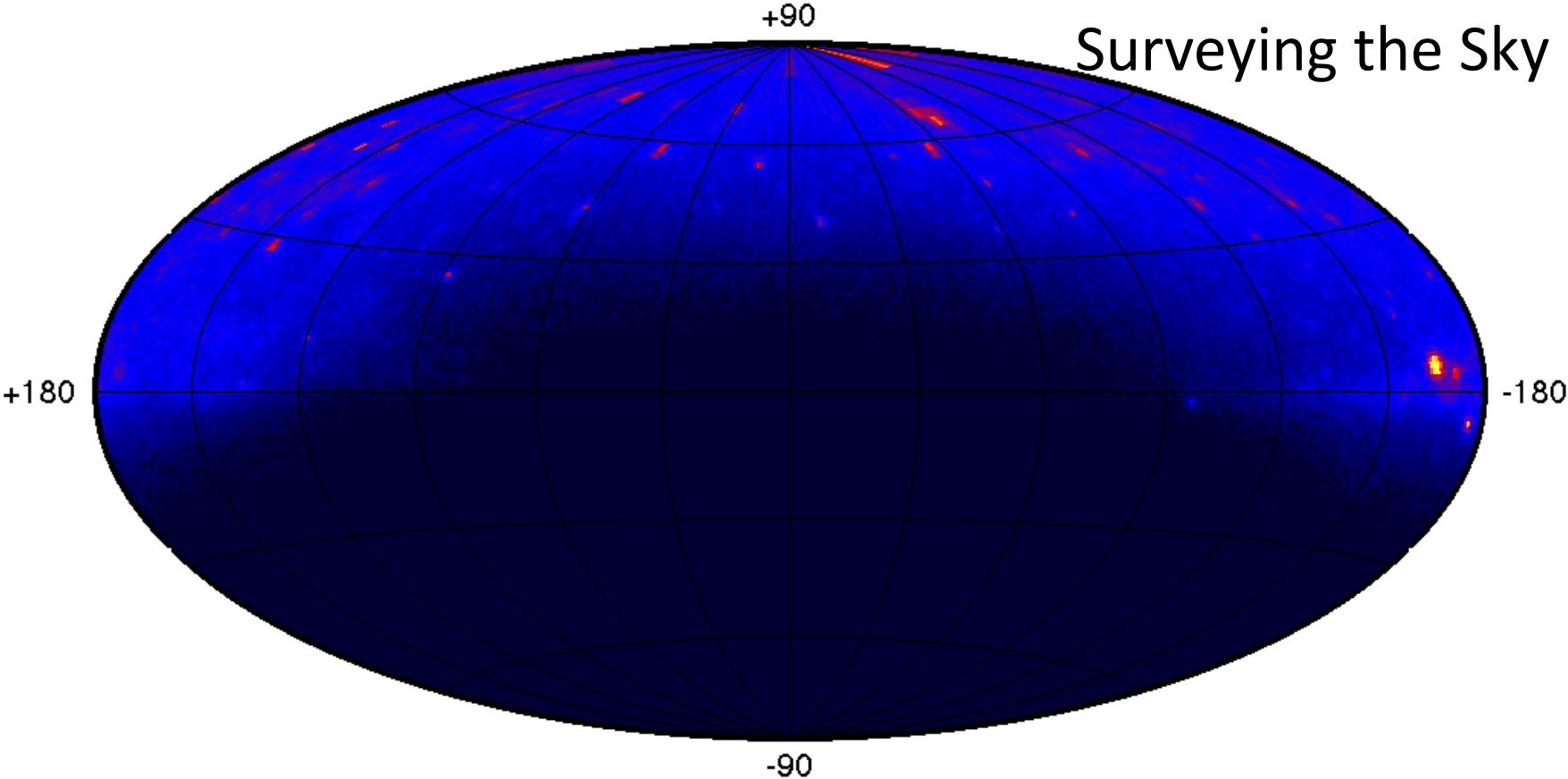


- >5000 sources of gamma-rays

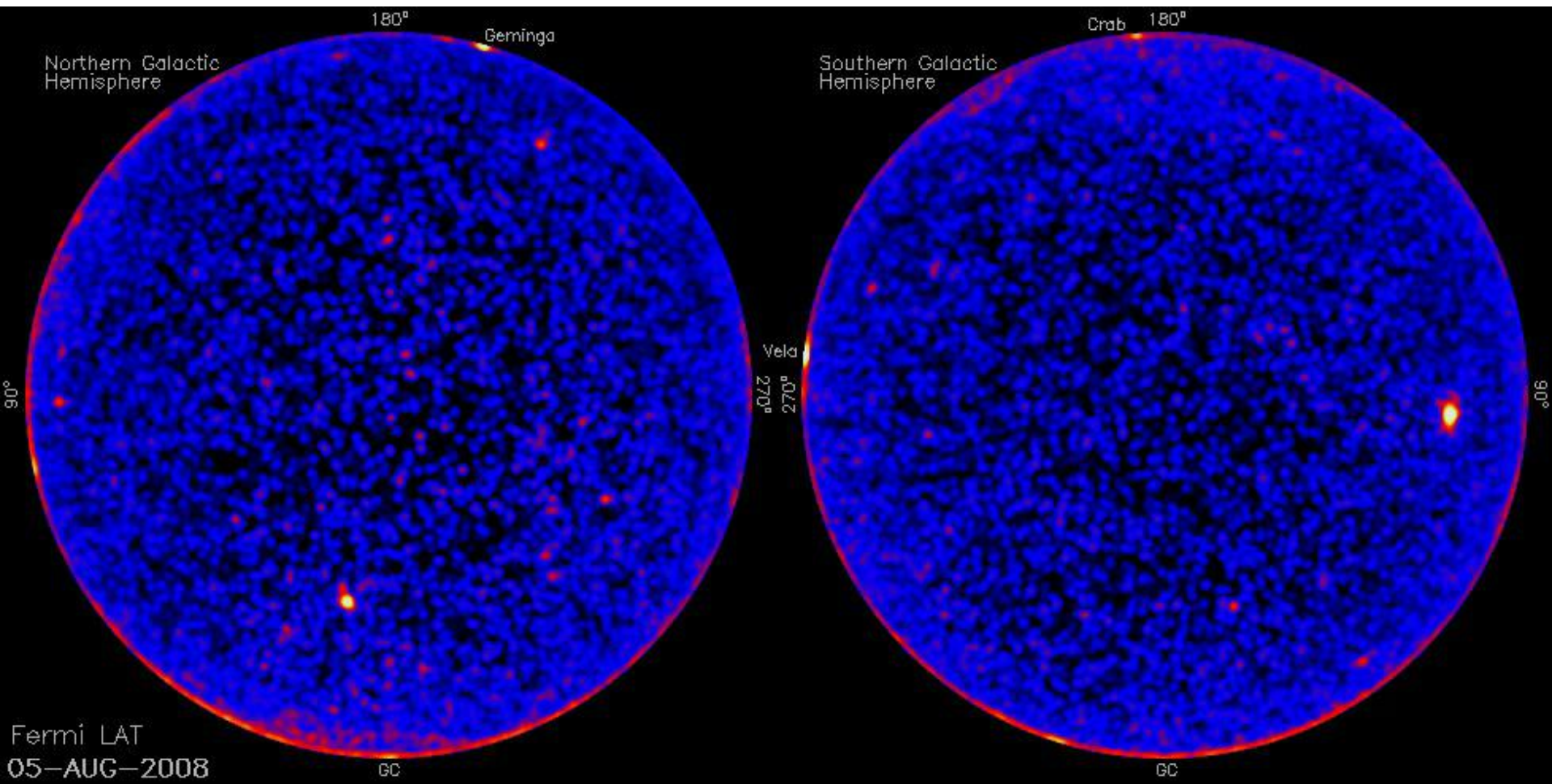
The Sky above 50 GeV

- 
- >250 sources
 - With more observations we continue to push the upper energy range of Fermi-LAT higher

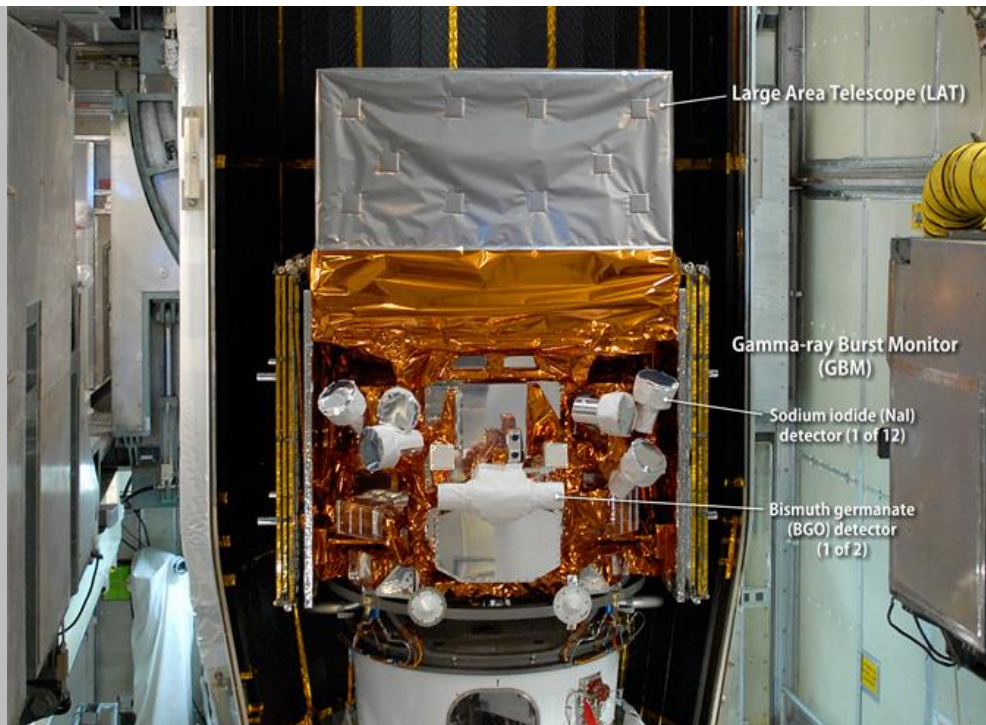
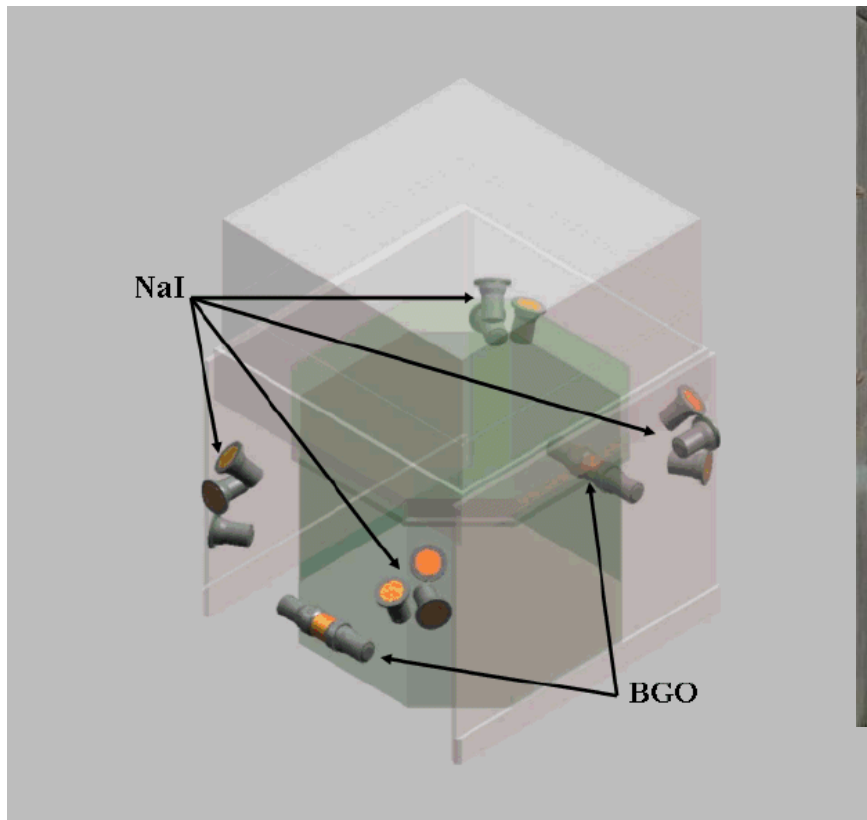
Surveying the Sky



The Variable Gamma-ray Sky



Gamma-ray Burst Monitor



Views entire sky!

Detects flashes of gamma-rays at lower energies than the LAT

Bursts of Gamma-rays from Near and Far

Gamma-ray Burst



rays from Near and Far

Gamma-ray Burst



Magnetar



Gamma-ray Burst



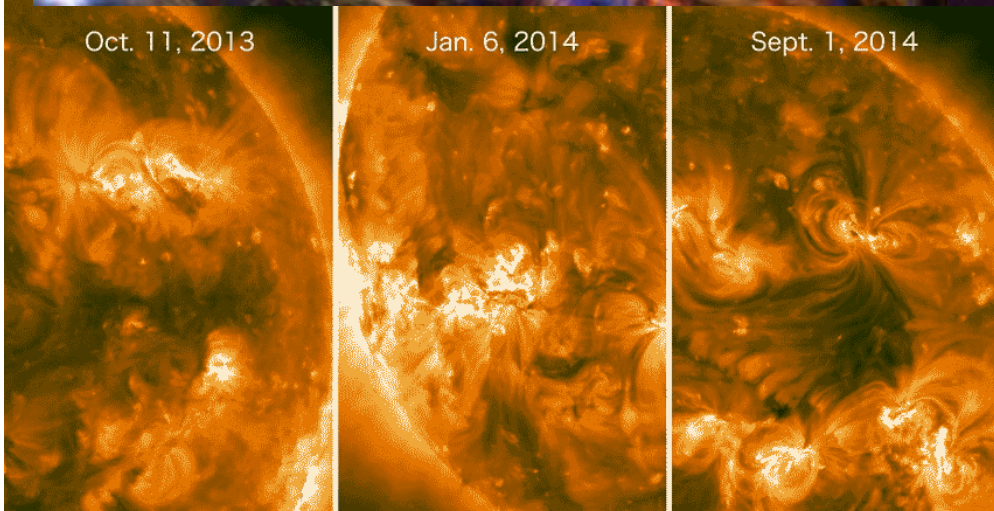
Magnetar



Oct. 11, 2013

Jan. 6, 2014

Sept. 1, 2014



Gamma-ray Burst



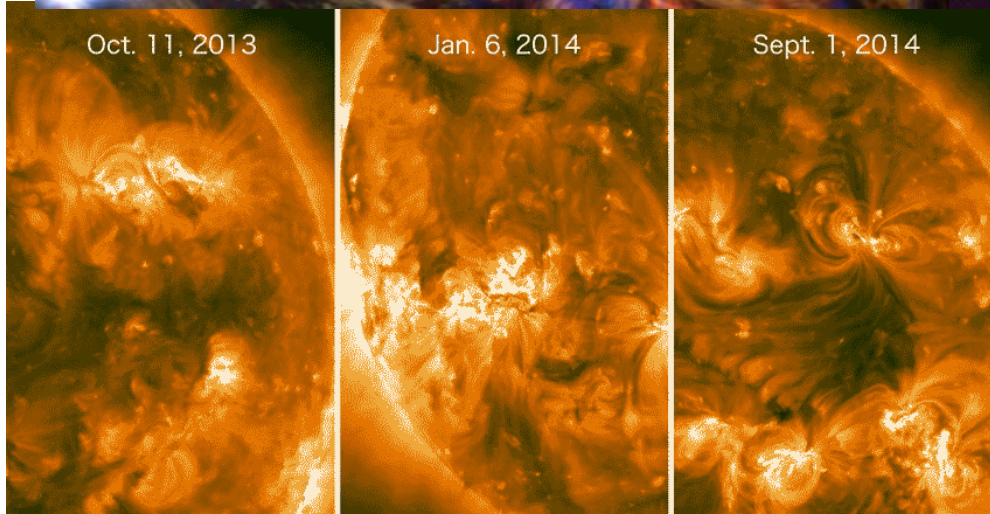
Magnetar



Oct. 11, 2013

Jan. 6, 2014

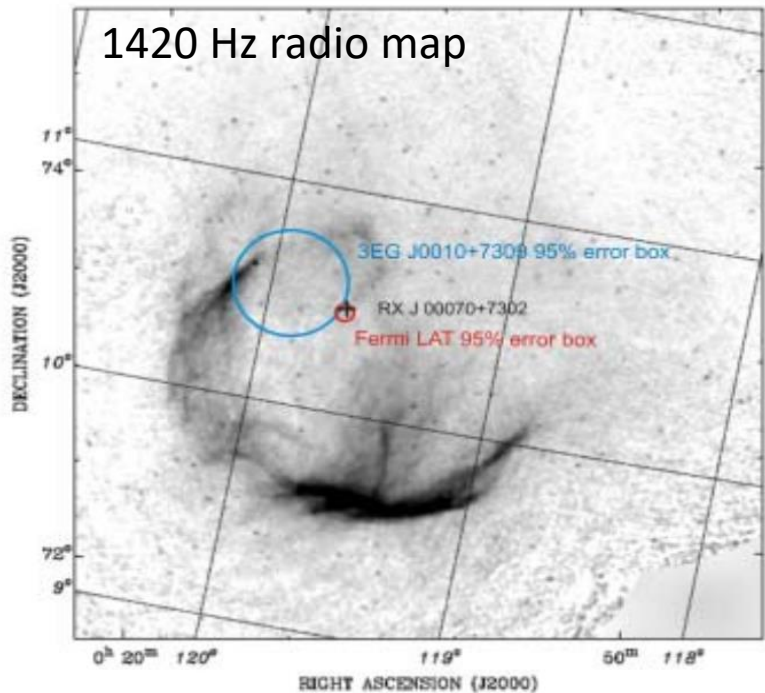
Sept. 1, 2014



Selected Results from the last 10 years

2008 – Solving a mystery and opening a new field

Abdo et al., 2008, Science



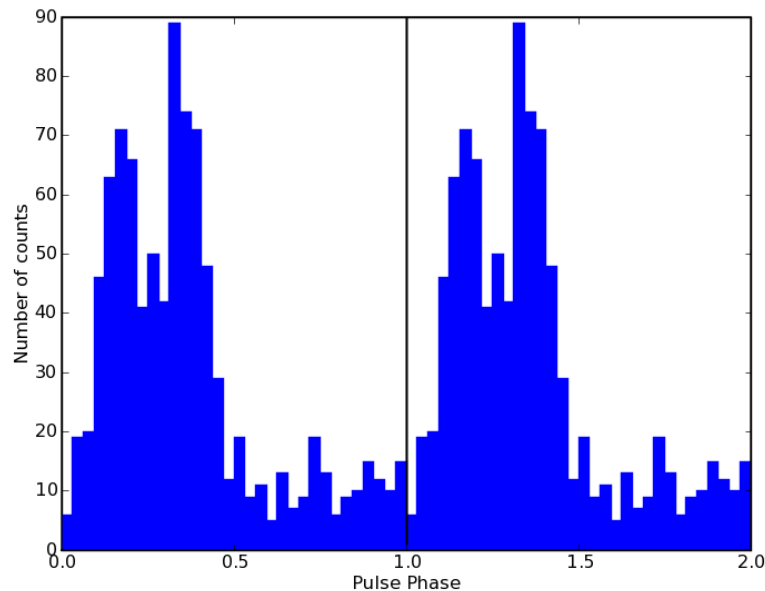
LAT 95% error radius = 0.038 deg
EGRET 95% error radius = 0.24 deg

$P \sim 316$ ms

$\text{Pdot} \sim 3.6 \times 10^{-13}$

Flux (>100 MeV) = $3.8 \pm 0.2 \times 10^{-7}$ ph $\text{cm}^{-2} \text{s}^{-1}$

Pulse undetected in radio



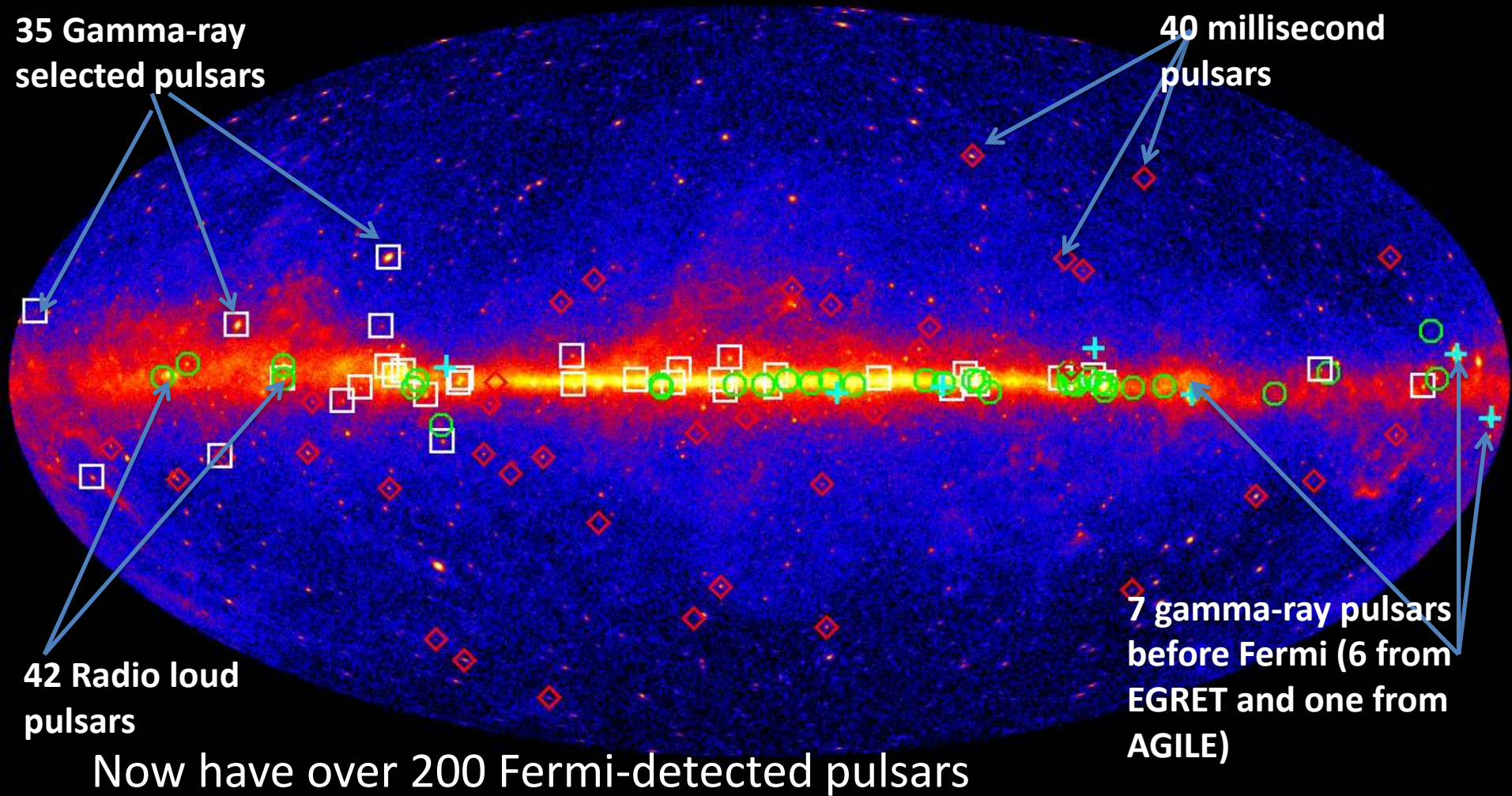
**35 Gamma-ray
selected pulsars**

**40 millisecond
pulsars**

**42 Radio loud
pulsars**

**7 gamma-ray pulsars
before Fermi (6 from
EGRET and one from
AGILE)**

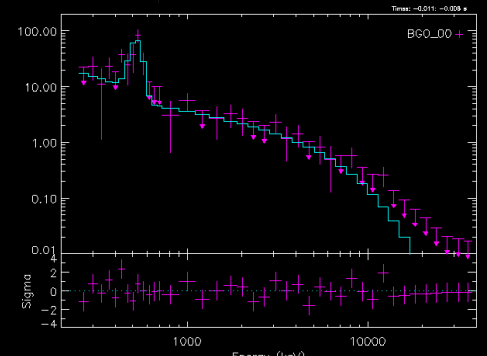
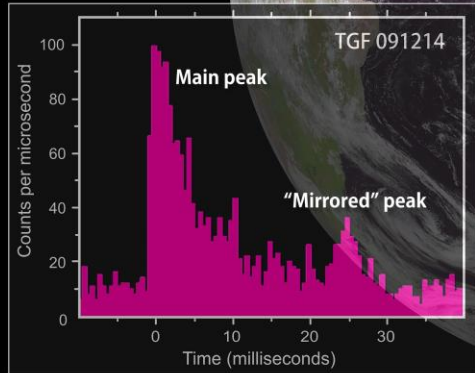
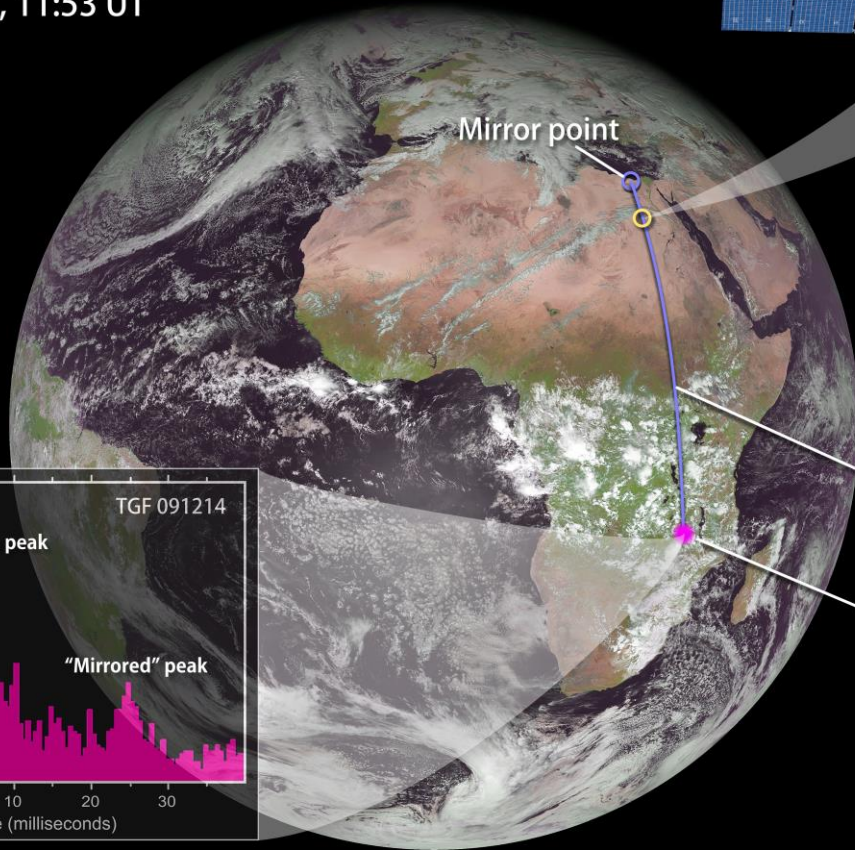
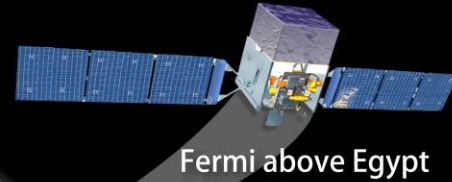
Now have over 200 Fermi-detected pulsars



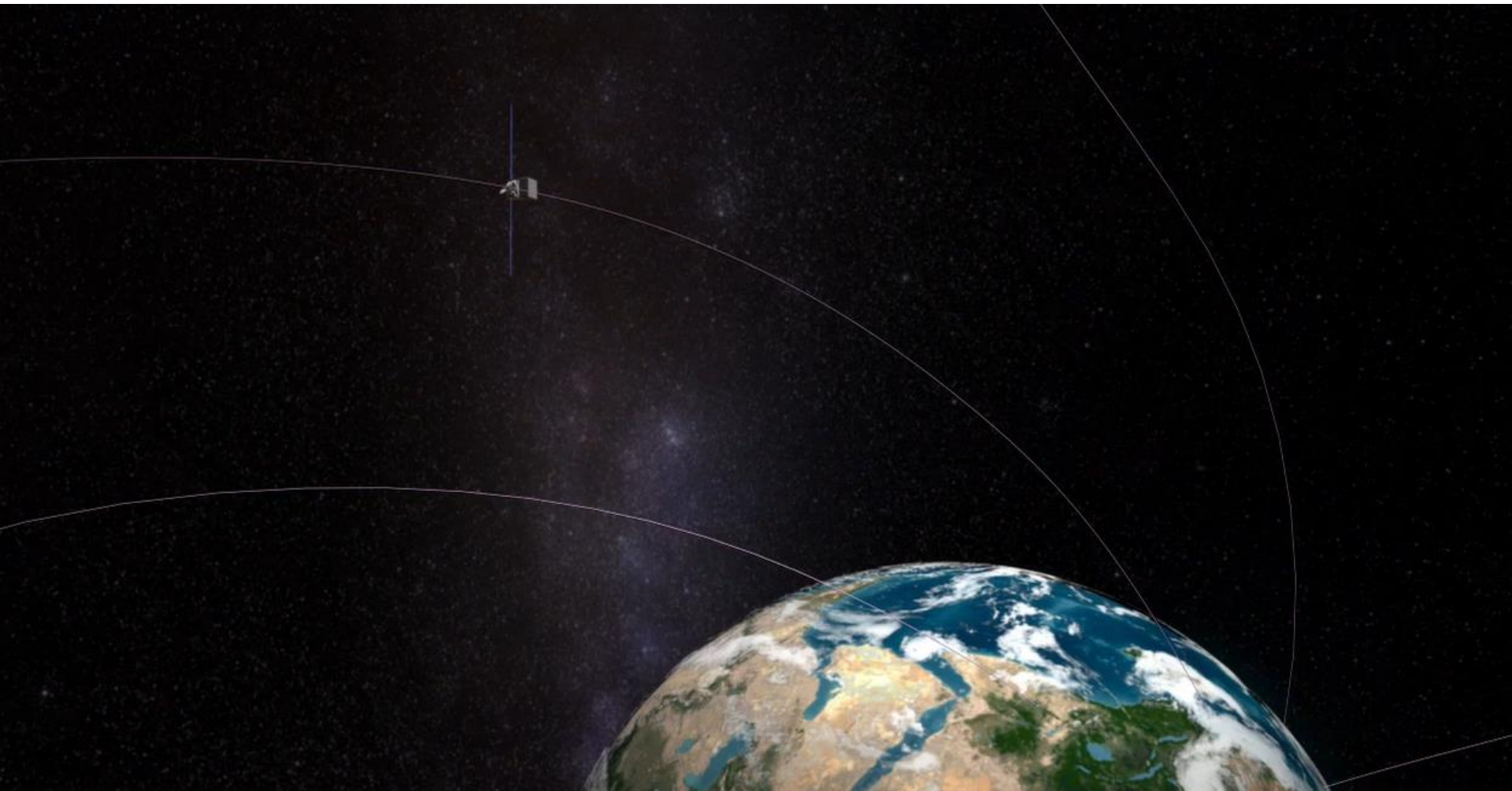
2009: Antimatter from Thunderstorms

Fermi GBM positron event

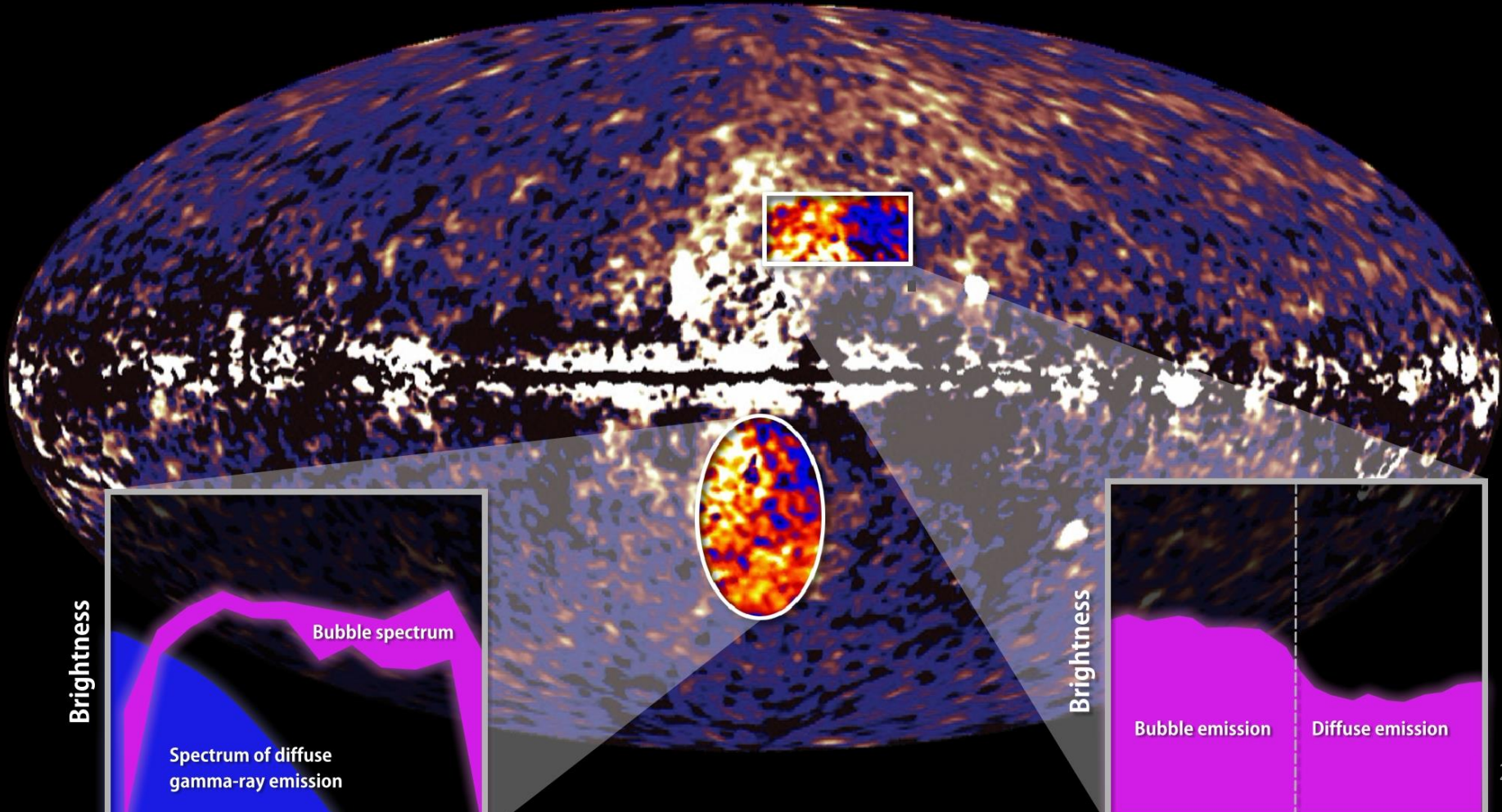
Dec. 14, 2009, 11:53 UT







2010: Fermi Bubbles



2010: Fermi Bubbles

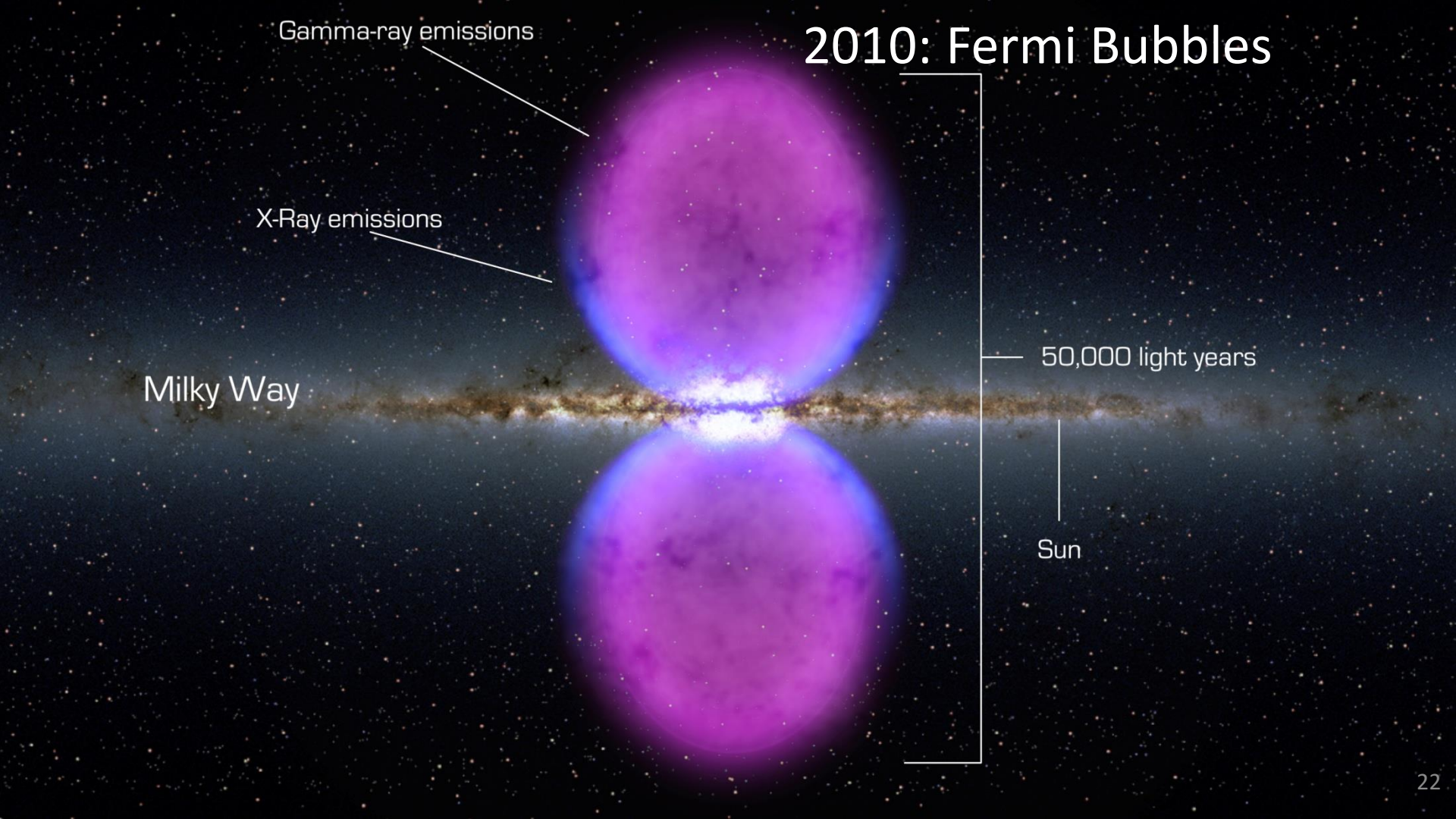
Gamma-ray emissions

X-Ray emissions

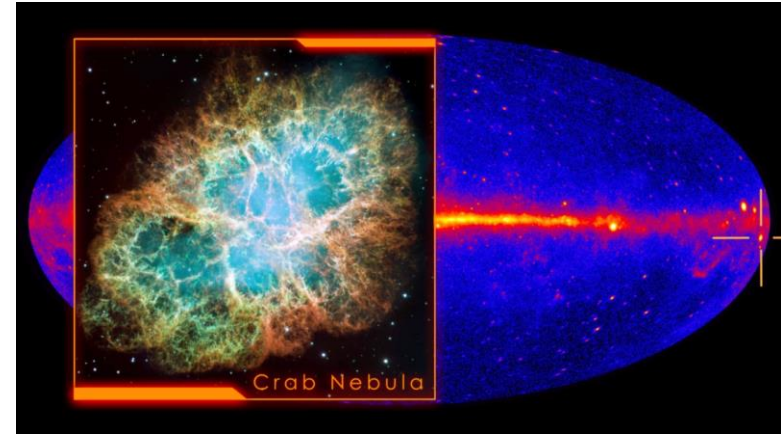
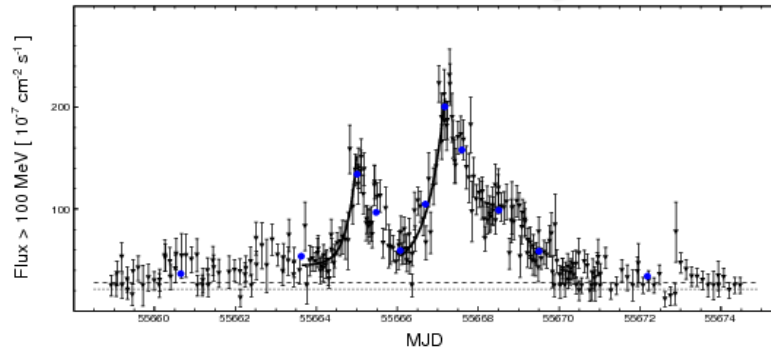
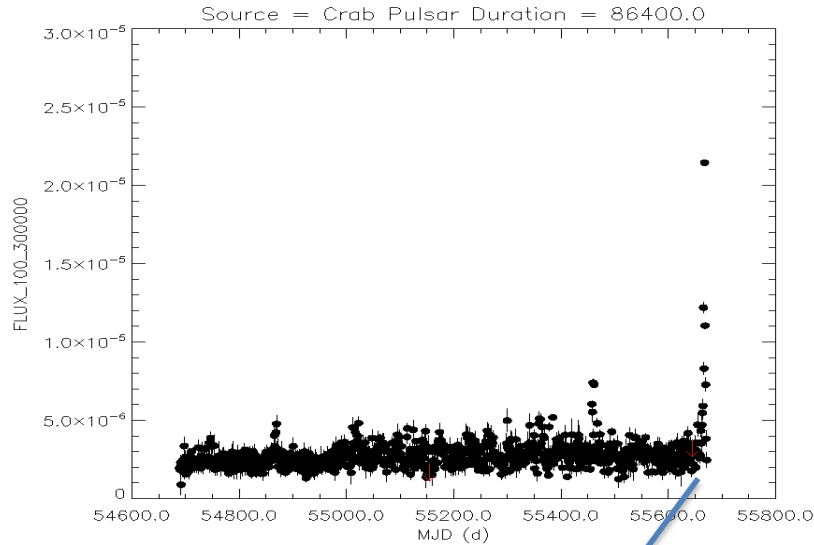
Milky Way

50,000 light years

Sun

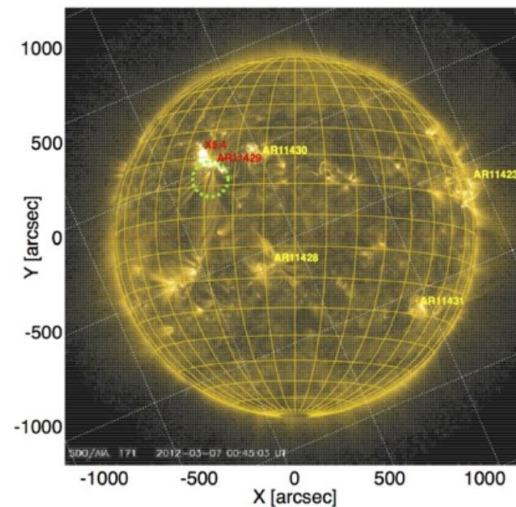
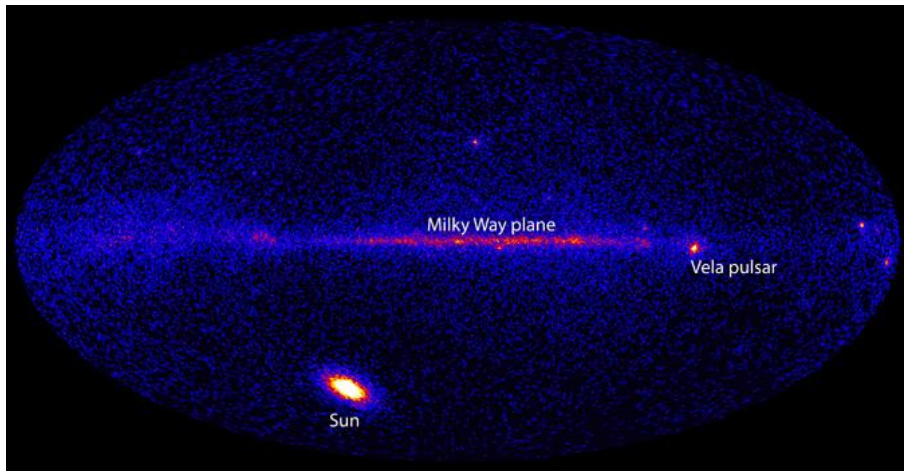


2011 – A not so standard candle



- Shockingly bright flares from the Crab Nebula in Sept 2010 and April 2011 observed by AGILE and Fermi-LAT
- Rapid (hourscale) variability of PeV electrons poses severe challenges for acceleration mechanisms

2012: A High Energy Solar Flare



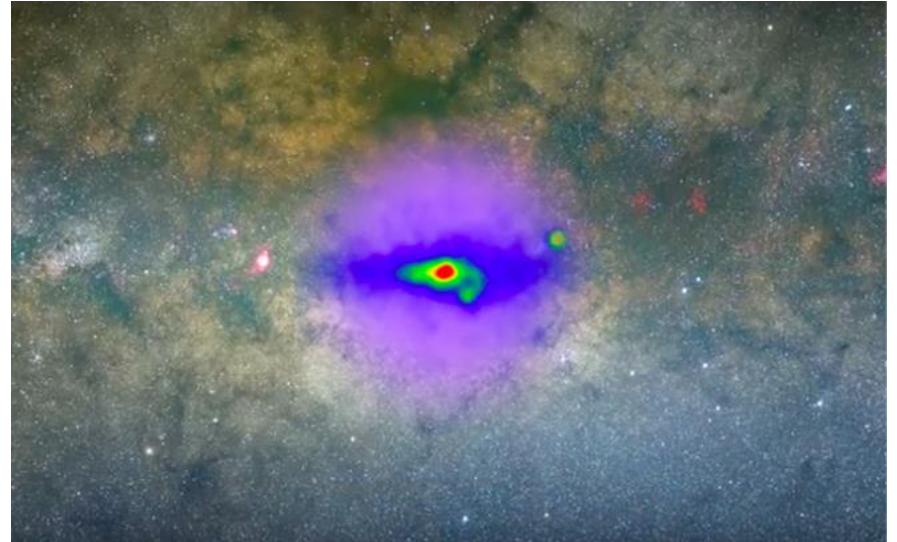
- March 7, 2012 Fermi-LAT detected an intense solar flare lasting 20 hours with emission up to energies of 4 GeV
 - Highest energy photons ever seen from the Sun
 - Longest duration gamma-ray flare
 - First time localizing high energy gamma-ray emission on the Sun's disk

2013: Dark Matter At the Galactic Center?

Fermi detected an unexpected source of gamma-rays from the center of our Galaxy

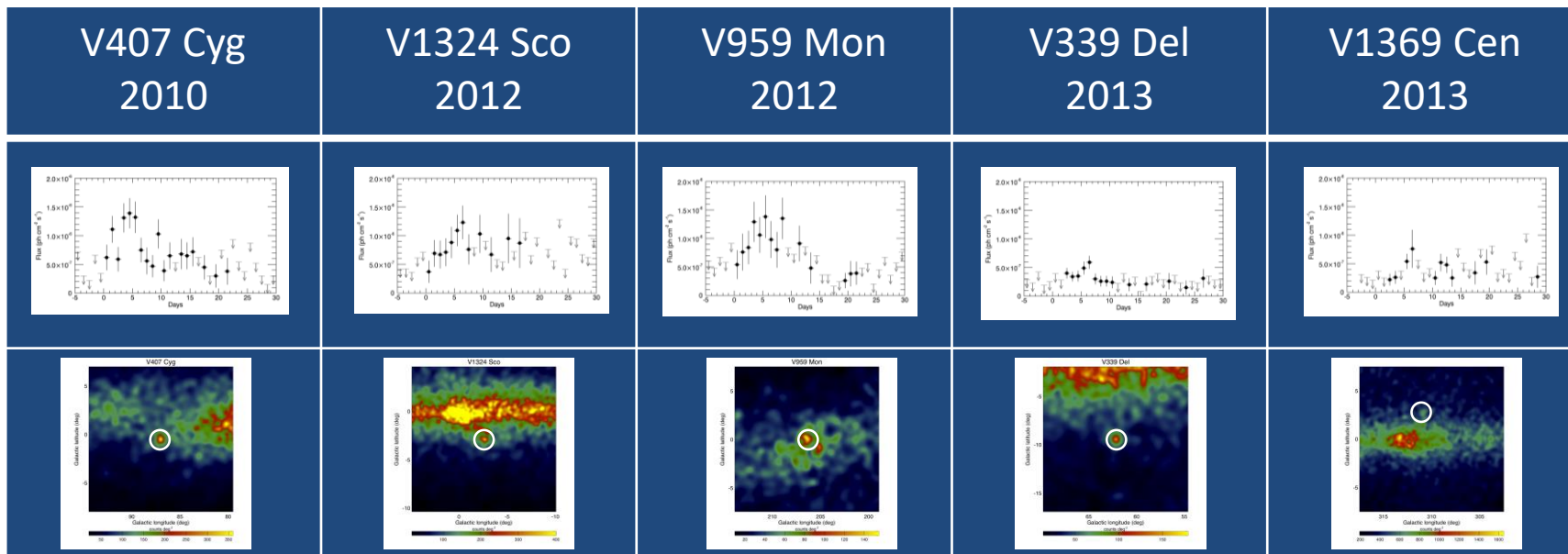
Likely the densest dark matter source in the Galaxy

- Fermi observations show that spectrum and spatial distribution consistent with
 - signal of dark matter,
 - a yet-to-be-identified population of dim gamma-ray emitting objects.



Starting in Dec 2013, we spent a year with observations focused on the Galactic Center

2014: Stellar Novae Produce High Energy Gamma-rays



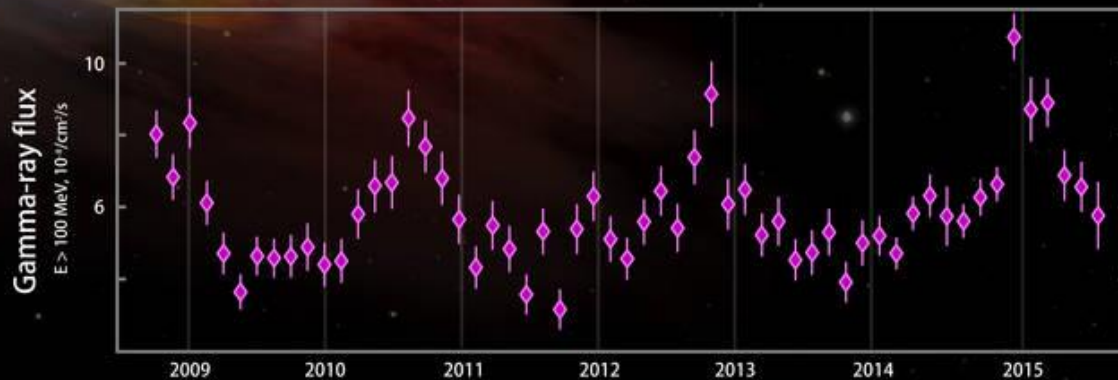
Fermi-LAT Collaboration, Science 2014

- Serendipitous discovery of gamma-ray transient at the time and location of V407 Cyg – found something that we were not looking for!
- Later found many more...

2015: Gamma-ray periodicity in an Active Galaxy

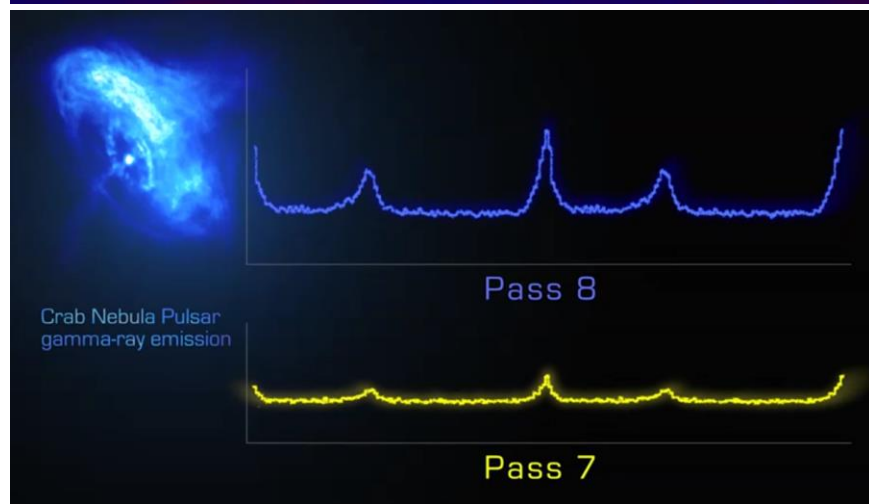
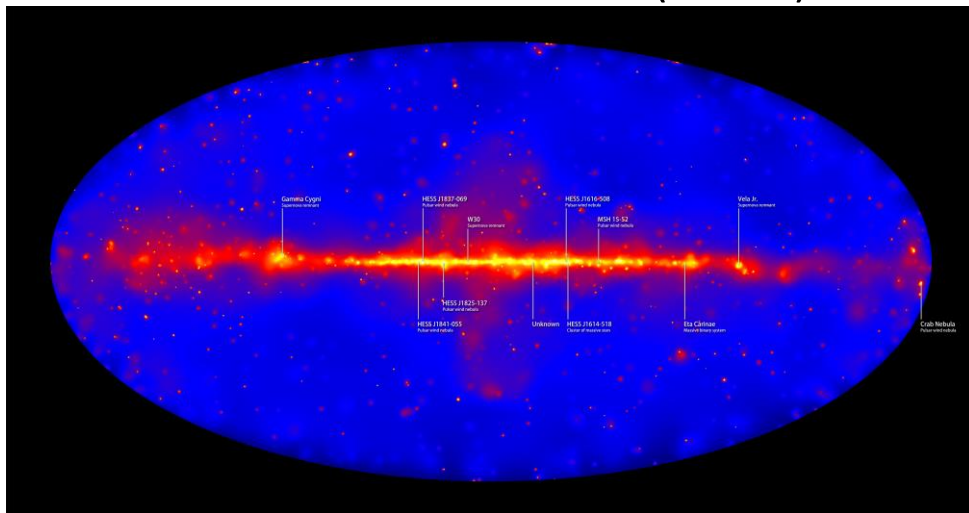
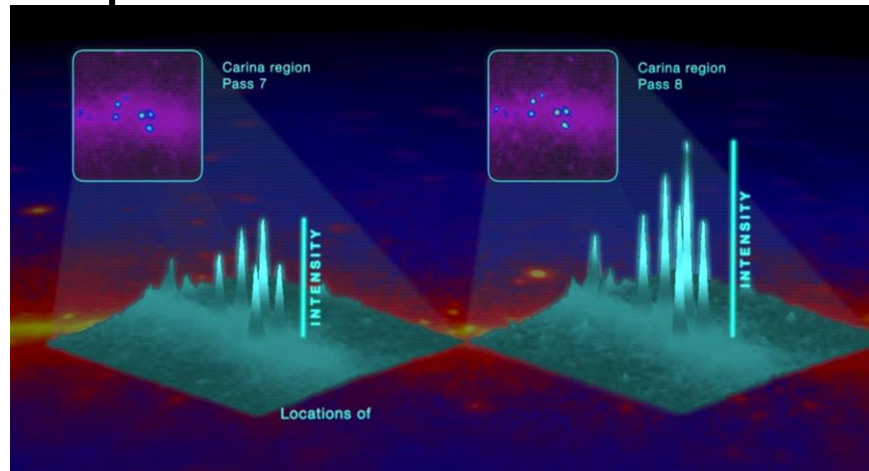
Binary black hole?

The gamma-ray cycle of PG 1553+113



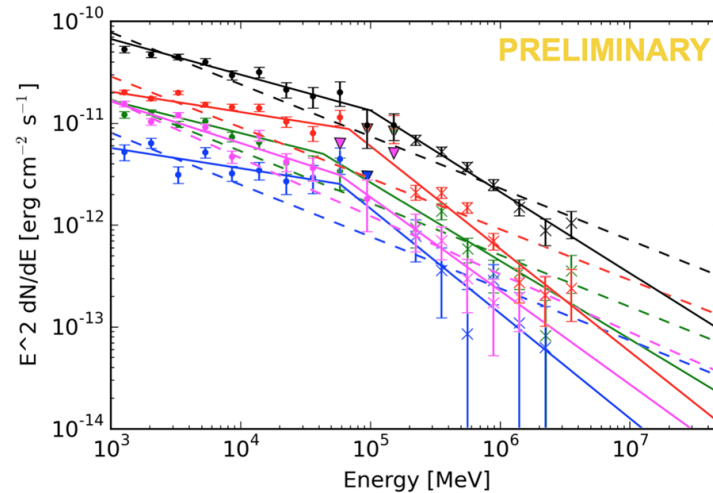
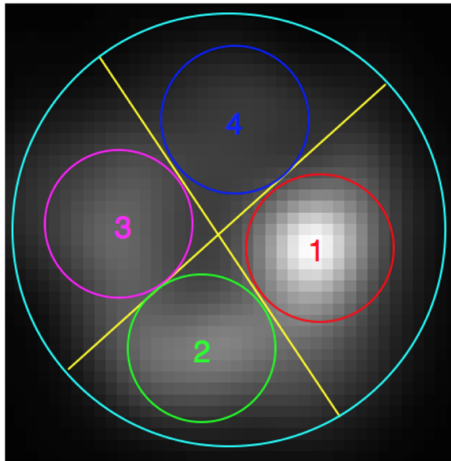
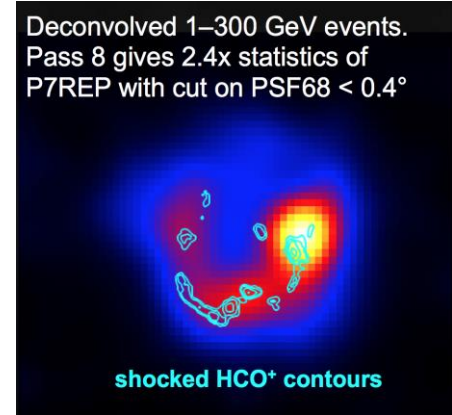
2016: A Sharper View

- A major revamp of the data processing pipeline produces sharper images (right) and more gamma-rays (lower right) **dramatically improving** Fermi Large Area Telescope performance.
- Expanded Fermi-LAT coverage to higher energies allows the **first census of the sky between 50 GeV and 2 TeV** (below).



2016: Resolving a Proton Accelerator

- Improved data resolve the shell of supernova remnant IC 443 at physical scales of ~ 5 pc
- Dense molecular and diffuse atomic (fast shock) regions differ in brightness by ~ 10 x, but spectra are surprisingly consistent



2017: Gamma-ray Burst and Gravitational Waves

Fermi



Gamma rays, 50 to 300 keV

GRB 170817A

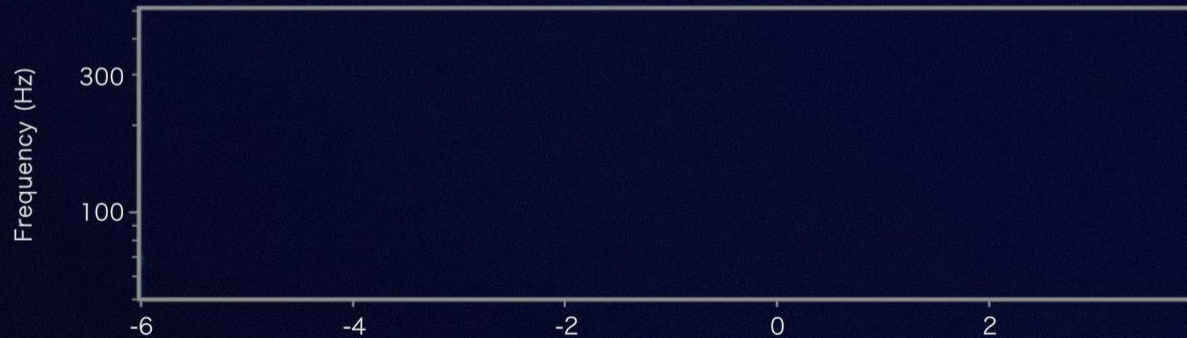


LIGO



Gravitational-wave strain

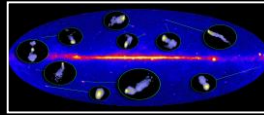
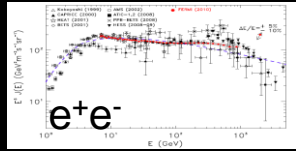
GW170817



Time from merger (seconds)

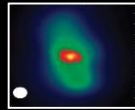
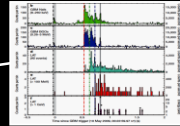


Fermi Highlights and Discoveries



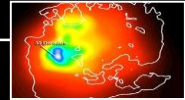
Blazars

GRBs

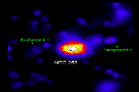


Radio Galaxies

LMC & SMC

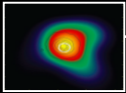


Starburst Galaxies

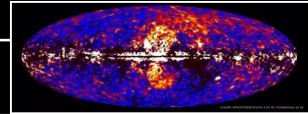


Extragalactic

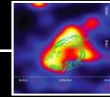
Globular Clusters



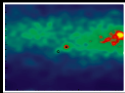
Fermi Bubbles



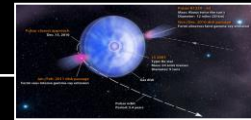
SNRs & PWN



Nova

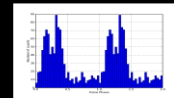


γ -ray Binaries



Galactic

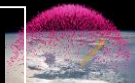
Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interactions



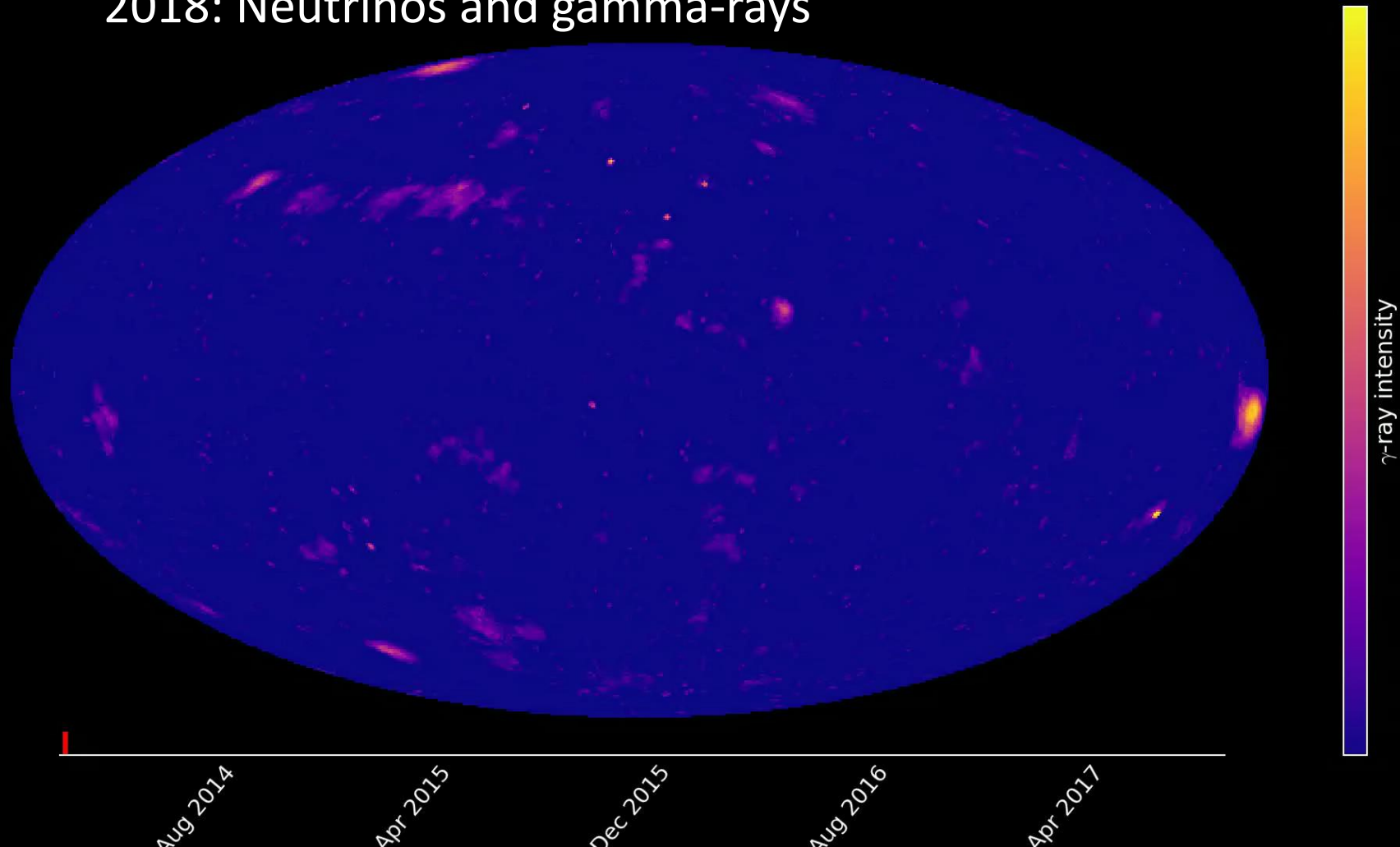
Terrestrial γ -ray Flashes

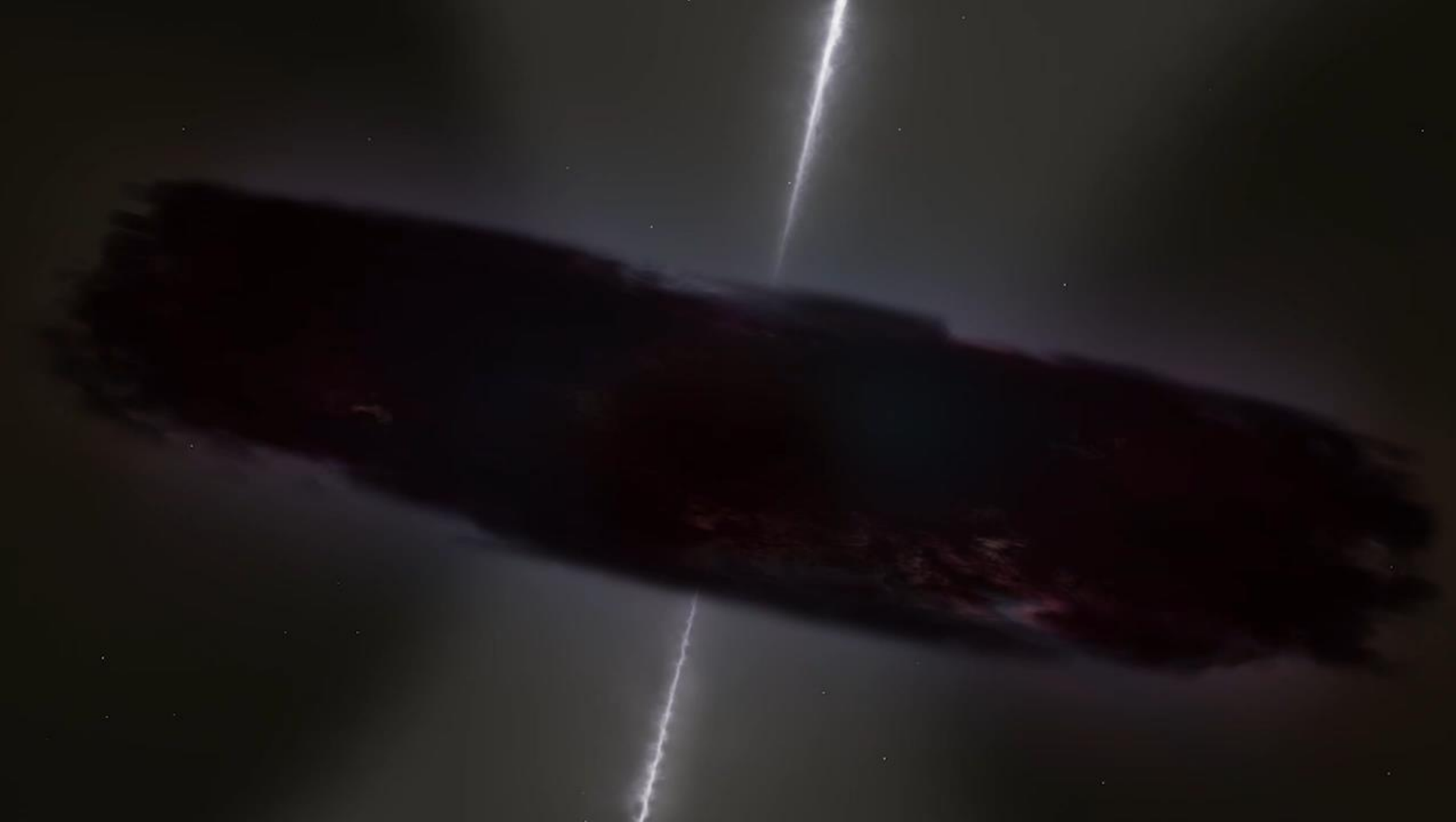


Dark Matter

The first 10 years of Fermi have been great – I'm looking forward to what is yet to come!

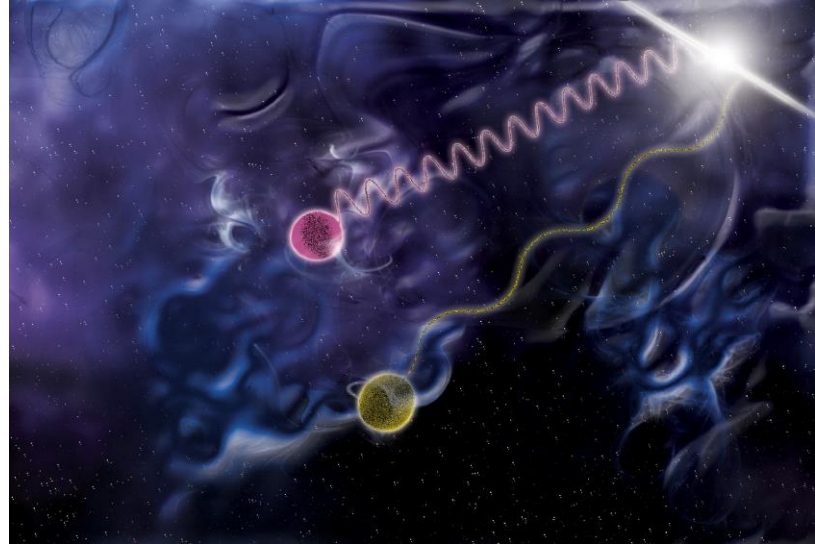
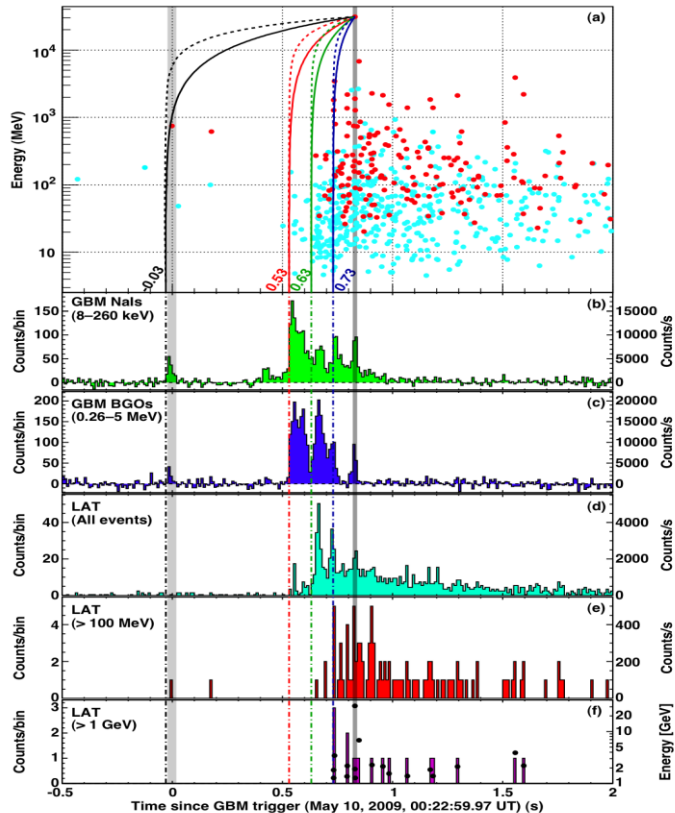
2018: Neutrinos and gamma-rays





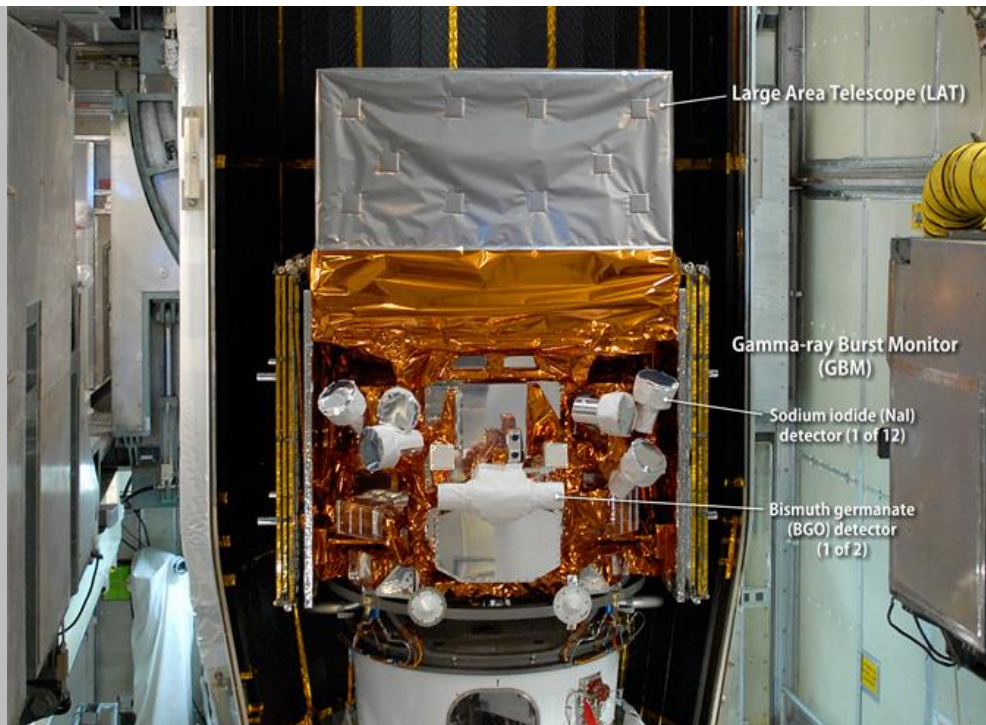
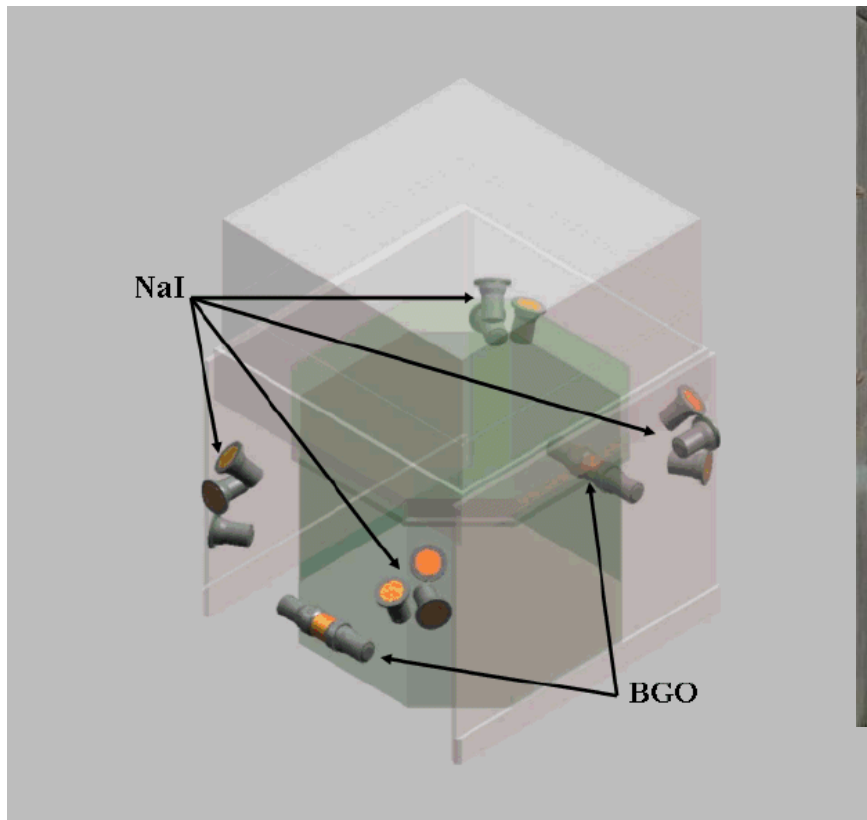


2009 – Testing Einstein’s Theory with a Gamma-ray Burst



- Highest energy gamma-ray arrives within 0.9s of the lower energy photons after traveling 7 billion years
- Eliminates theories of quantum gravity which predict that space-time is “foamy” enough to interfere strongly with light.

Gamma-ray Burst Monitor

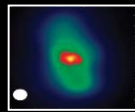
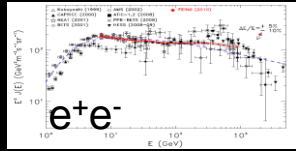


Views entire sky!

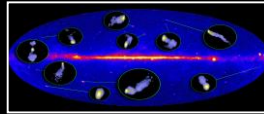
Detects flashes of gamma-rays at lower energies than the LAT

2011: Cosmic Fireworks!

Fermi Highlights and Discoveries

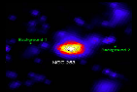
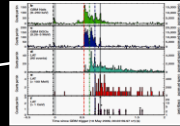


Radio Galaxies



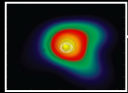
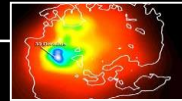
Blazars

GRBs



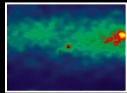
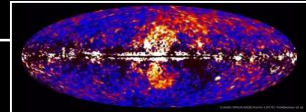
Starburst Galaxies

LMC & SMC



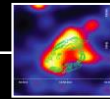
Globular Clusters

Fermi Bubbles

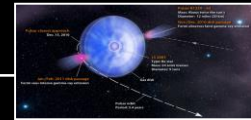


Nova

SNRs & PWN

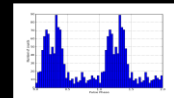


γ -ray Binaries



Galactic

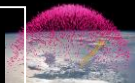
Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interactions

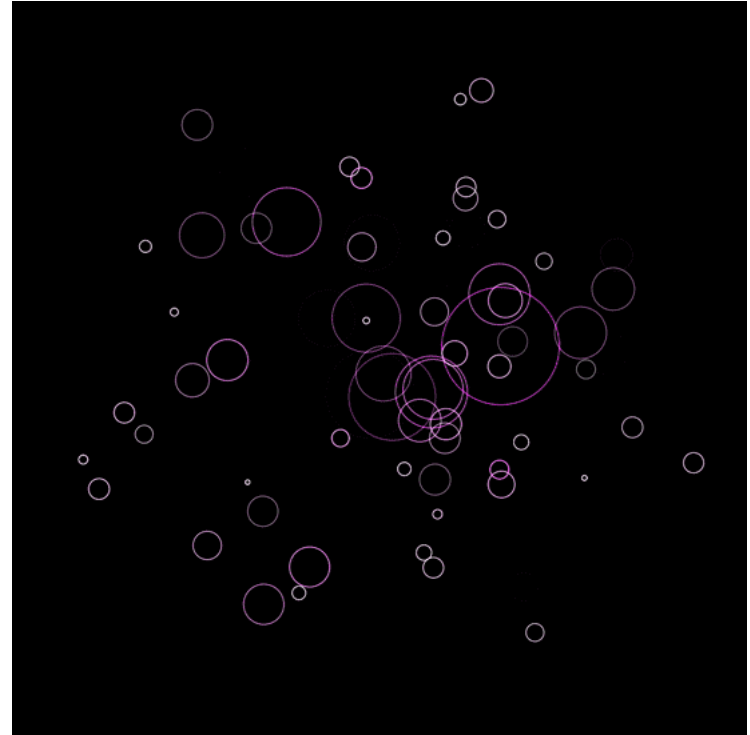
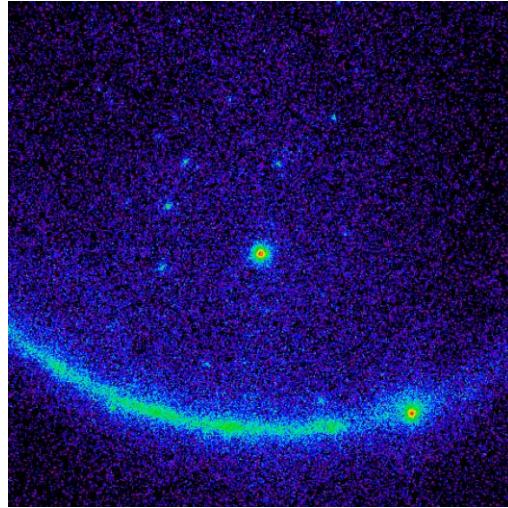
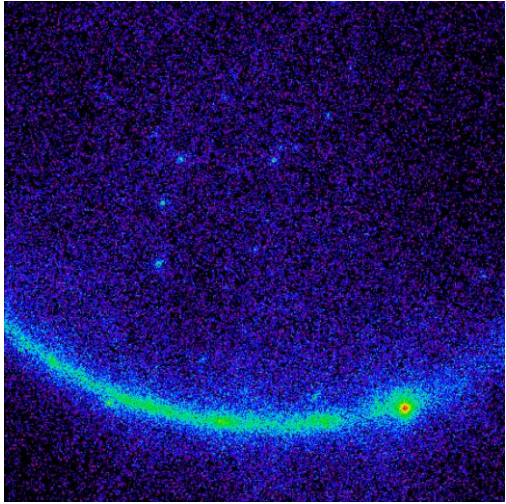


Terrestrial γ -ray Flashes



Dark Matter

2015: Record Flare from the Active Galaxy 3C279



- Huge rapid flare from 3C279 challenges standard ideas of particle acceleration in relativistic jets

2018: Stay Tuned for Another Fermi Multimessenger
Announcement on July 12!

