Announcements

Proposal Deadlines:

May 23 - draft of introduction due (1 week from today)

May 30 - full proposal due (2 weeks from today)

June 6 - proposal review (3 weeks) **attendance important

Before the review you will need to read your classmates proposals and prepare comments on the proposal for which you are the primary reviewer

Some example proposals are available on the class website. These may help you when thinking about proposal format and content.

High-Energy Astronomy

Some info in:

"Measuring the Universe" - G. Reike

"Observational Astrophysics" - Lena, Lebrun, Mignard

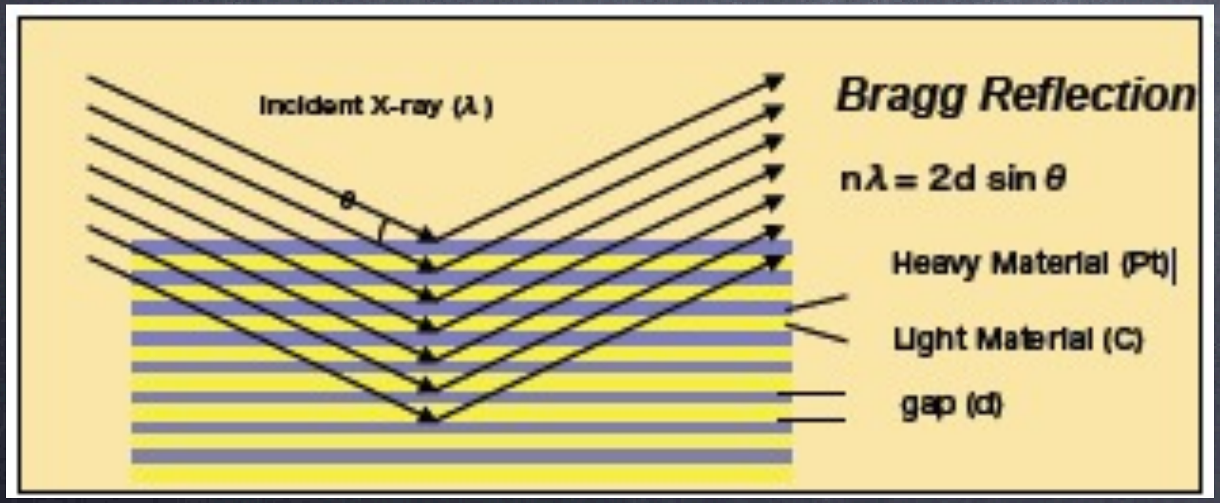
Focusing Hard X-rays/Soft Gamma-rays

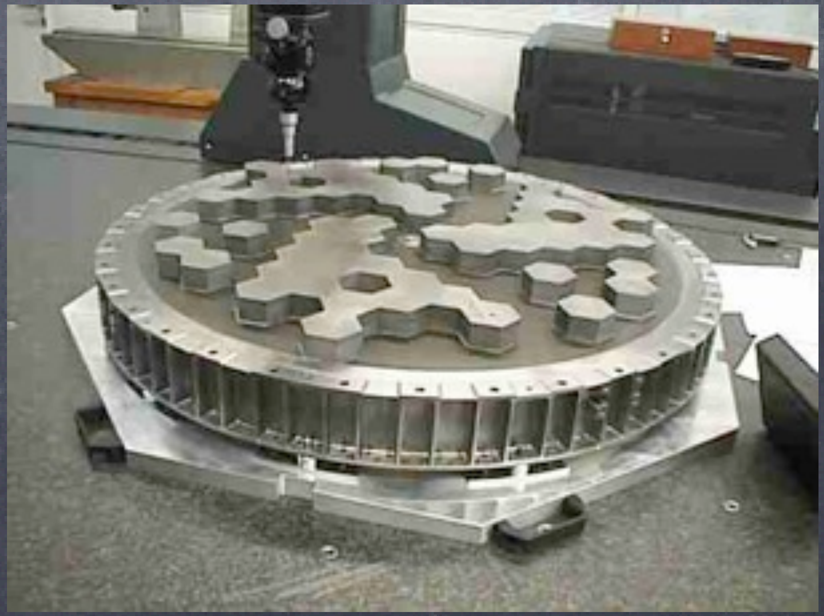
< 100 keV: grazing incidence optics with special multilayer coatings (NuSTAR)

The layers are depth graded with varying periodic length to broaden the energy response. Coatings include materials like tungsten and platinum.

> 100 keV: coded-mask technique (Integral, Swift)

The projection of the mask on the detector depends on the source direction. A computer algorithm is used to "decode" the image. (more complicated version of the pinhole camera.)





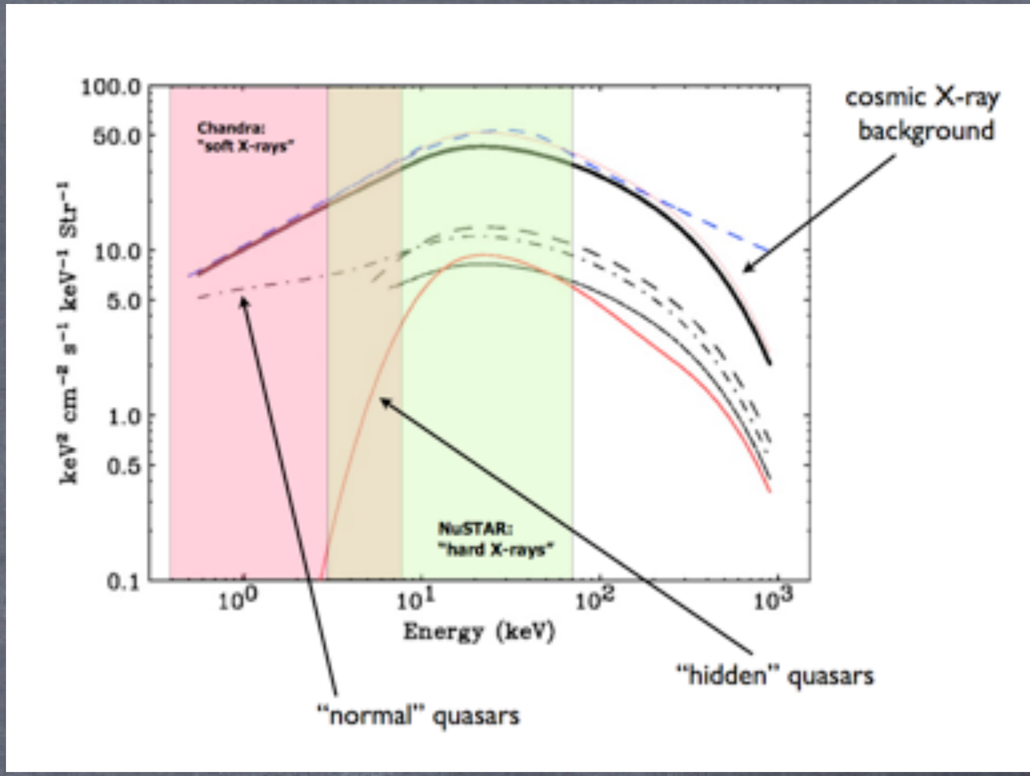
Hard X-ray Detectors

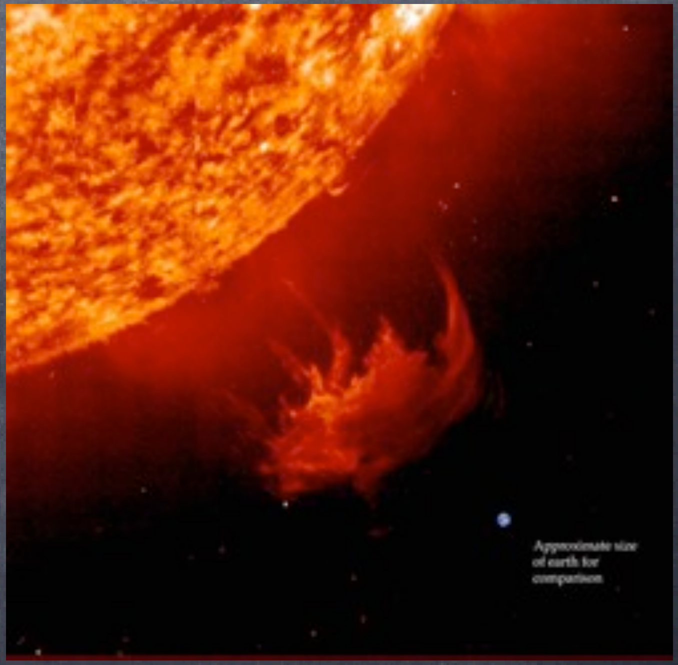
Cadmium zinc telluride detectors (CdZnTe or CZT): used above 10 keV, semiconductor with better sensitivity to high-energy photons than Si. Each pixel is readout independently like IR arrays.

Scintillators: crystals of varying composition (like NaI or CsI) which emit optical light when struck by X-rays. Good for higher energy X-rays and soft gamma-rays. The optical light is then detected with photomultipliers.

Hard X-ray Science

- AGN, particularly obscured AGN - what makes up the cosmic X-ray background?
- Shocks, non-thermal emission in supernovae and clusters of galaxies - trace sites of particle acceleration
- High energy emitters in the Galaxy (less extinction by dust) - the Galactic center, PWN, magnetars
- The Sun - solar flares and coronal mass ejections, how is the Solar corona heated?

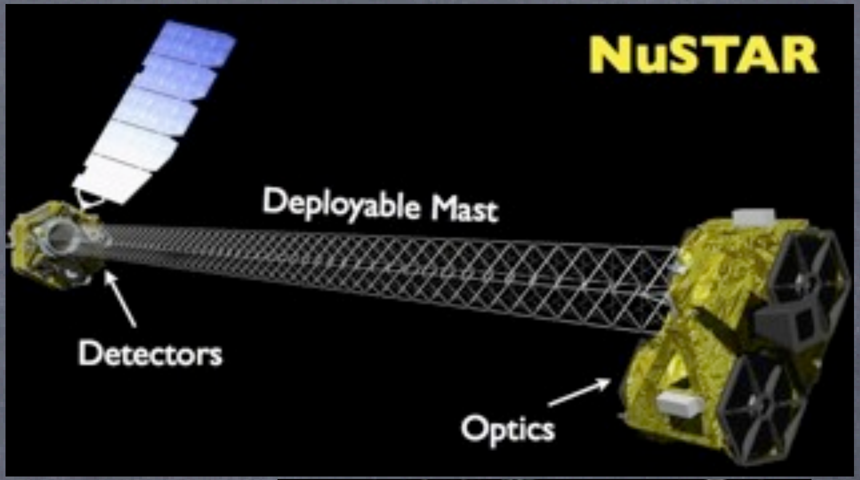




Hard X-ray Telescopes

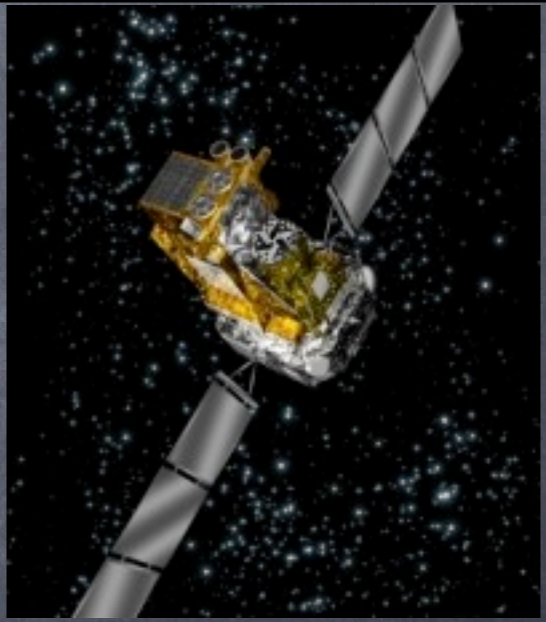
NuSTAR:

- launched in June 2012
- 5-80 keV, 10″ resolution, 13′ FOV



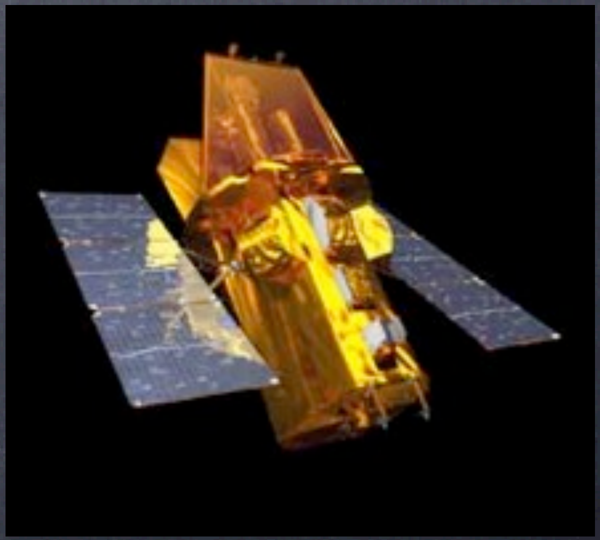
Integral:

- launched in 2002
- Instruments ranging from 3 keV to 10 MeV
- IBIS (soft-gamma) has 8 deg FOV with 12′ resolution

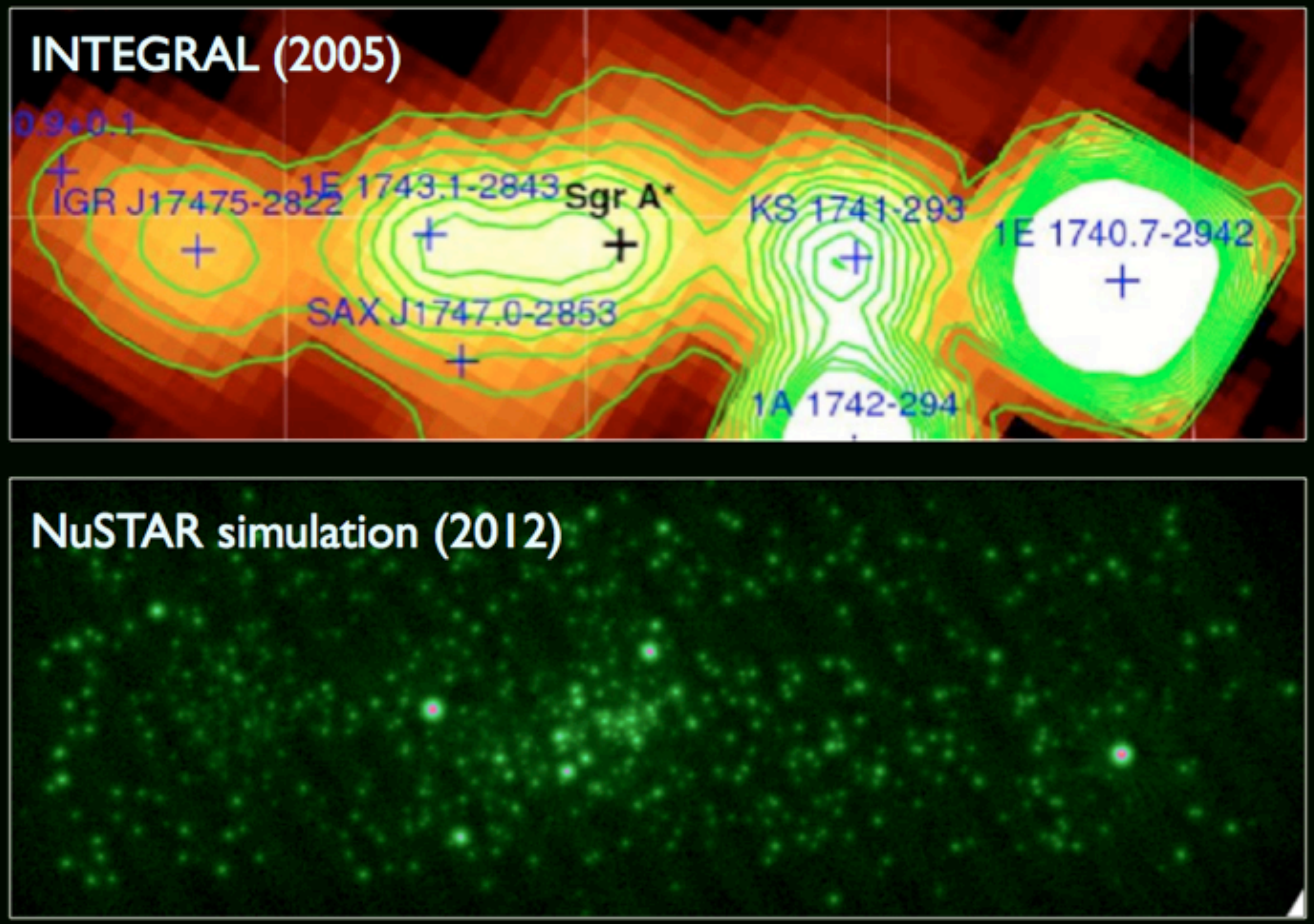


Swift:

- gamma-ray burst monitor also carrying X-ray and optical telescopes, launched in 2004
- Instruments:
  - BAT: 15-150 keV, coded mask, 1.4 steradian FOV, 17′ PSF
  - XRT: 0.2-10 keV, Wolter 1, 18″ PSF HPD

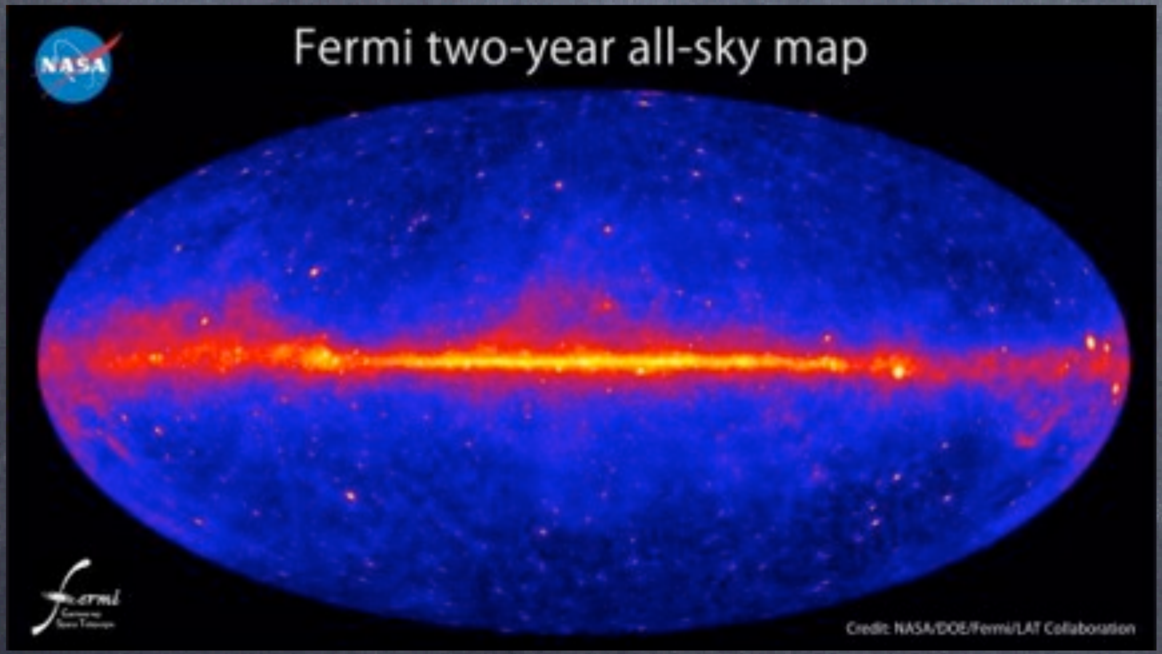


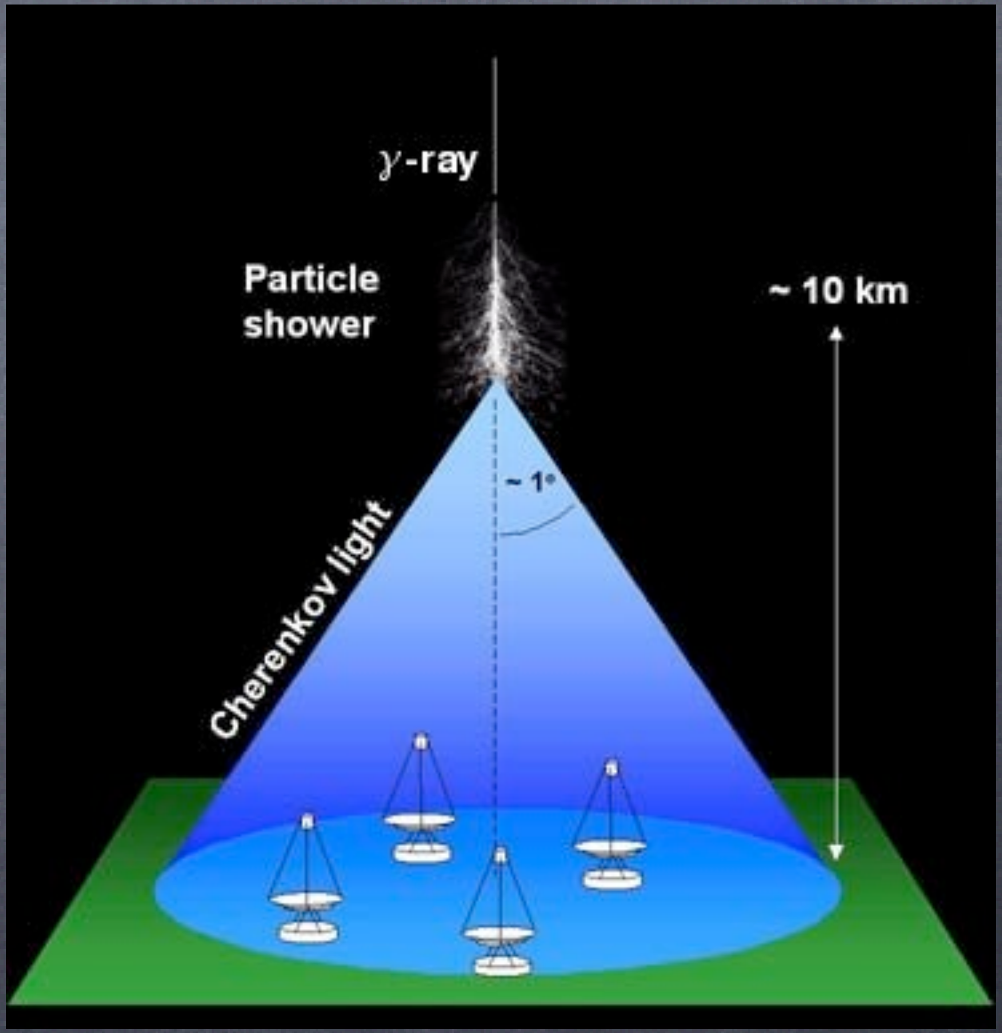
The Galactic Center



Dan Stern, AAS, Jan 2012

Gamma-Ray Astronomy



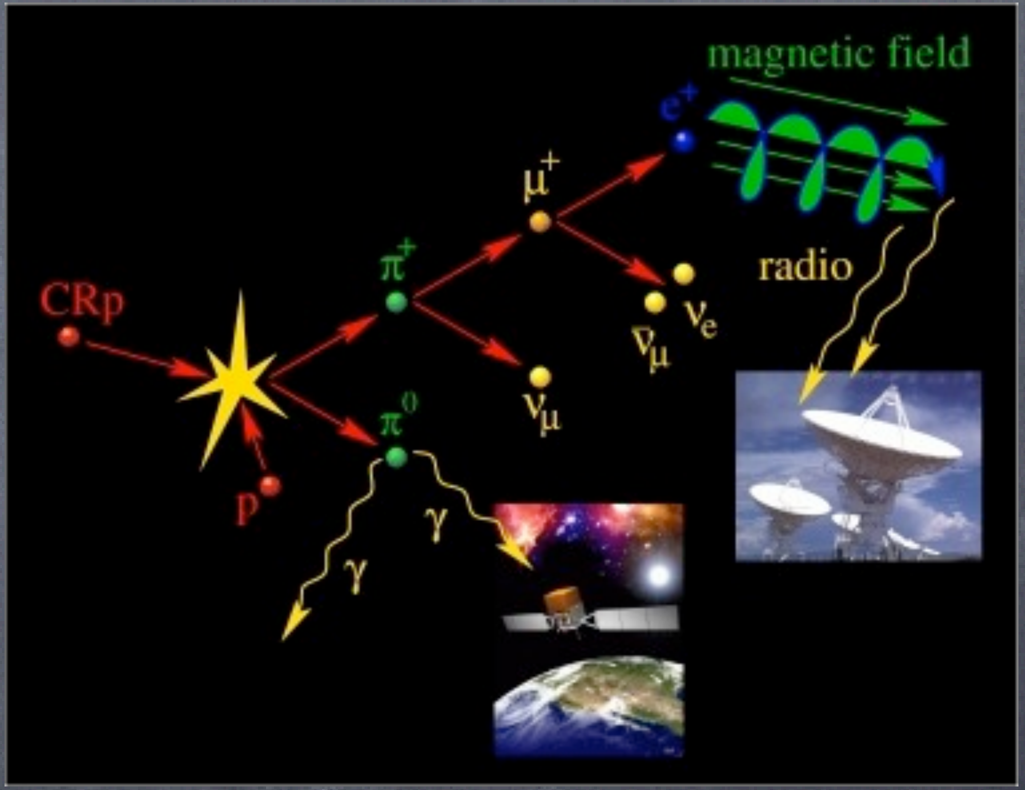


Gamma-Ray Sources

Processes leading to gamma-ray emission include proton-proton collisions, IC scattering, and bremsstrahlung.

Sources include:

- AGN/blazars
- pulsars, pulsar wind nebula
- supernova remnants
- gamma-ray bursts
- galaxies (star formation)
- globular clusters
- binaries
- thunderstorms!!

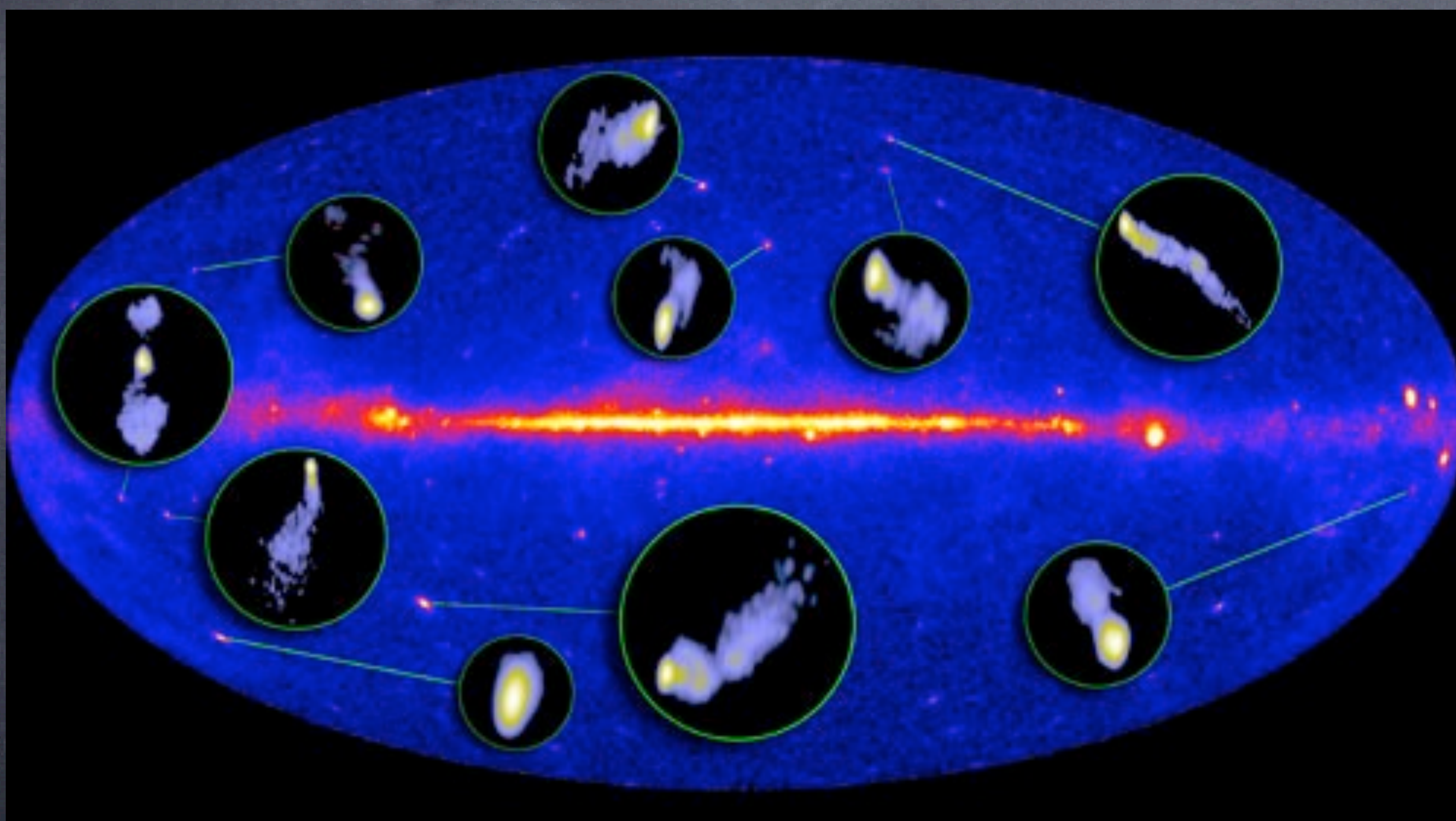


Potential sources not yet detected:

- clusters of galaxies
- dark matter annihilation or decay

Blazars/AGN

Something like 60% of the sources that Fermi detects



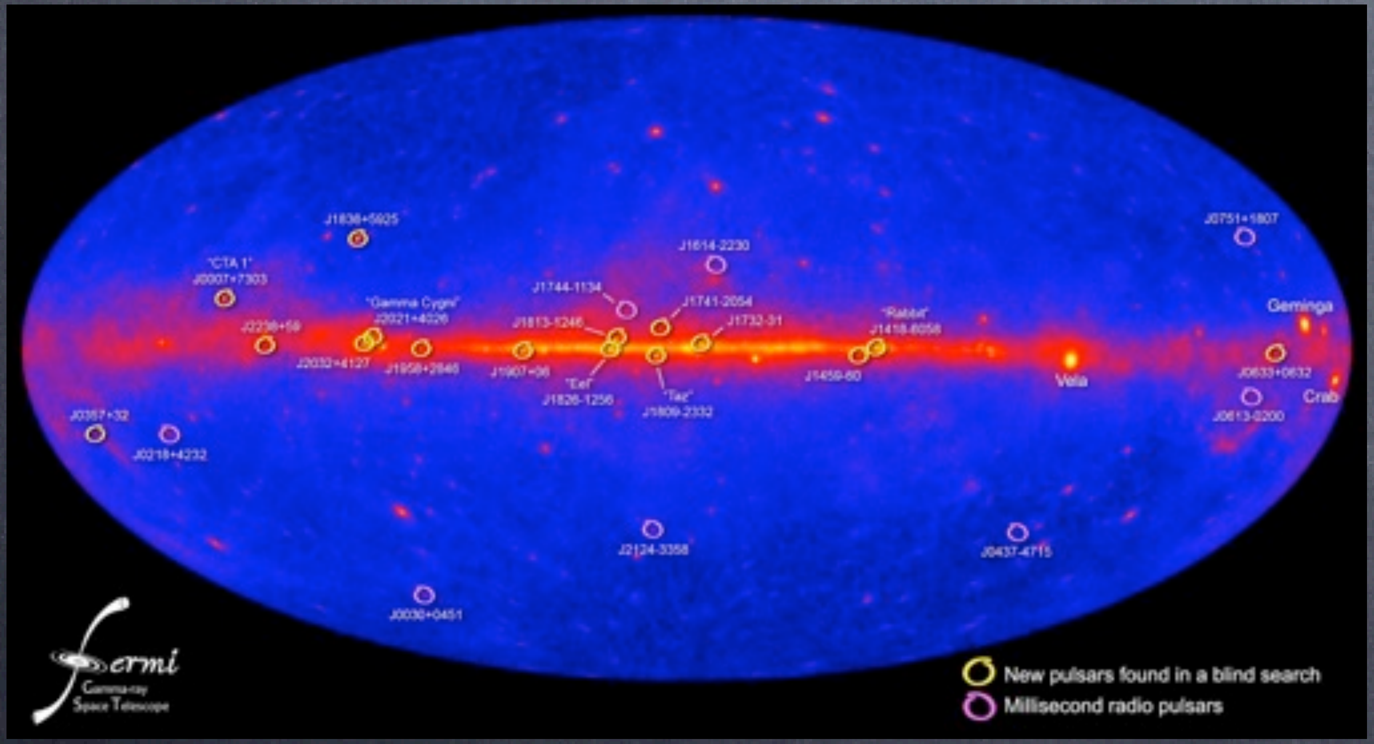
Cen A radio galaxy

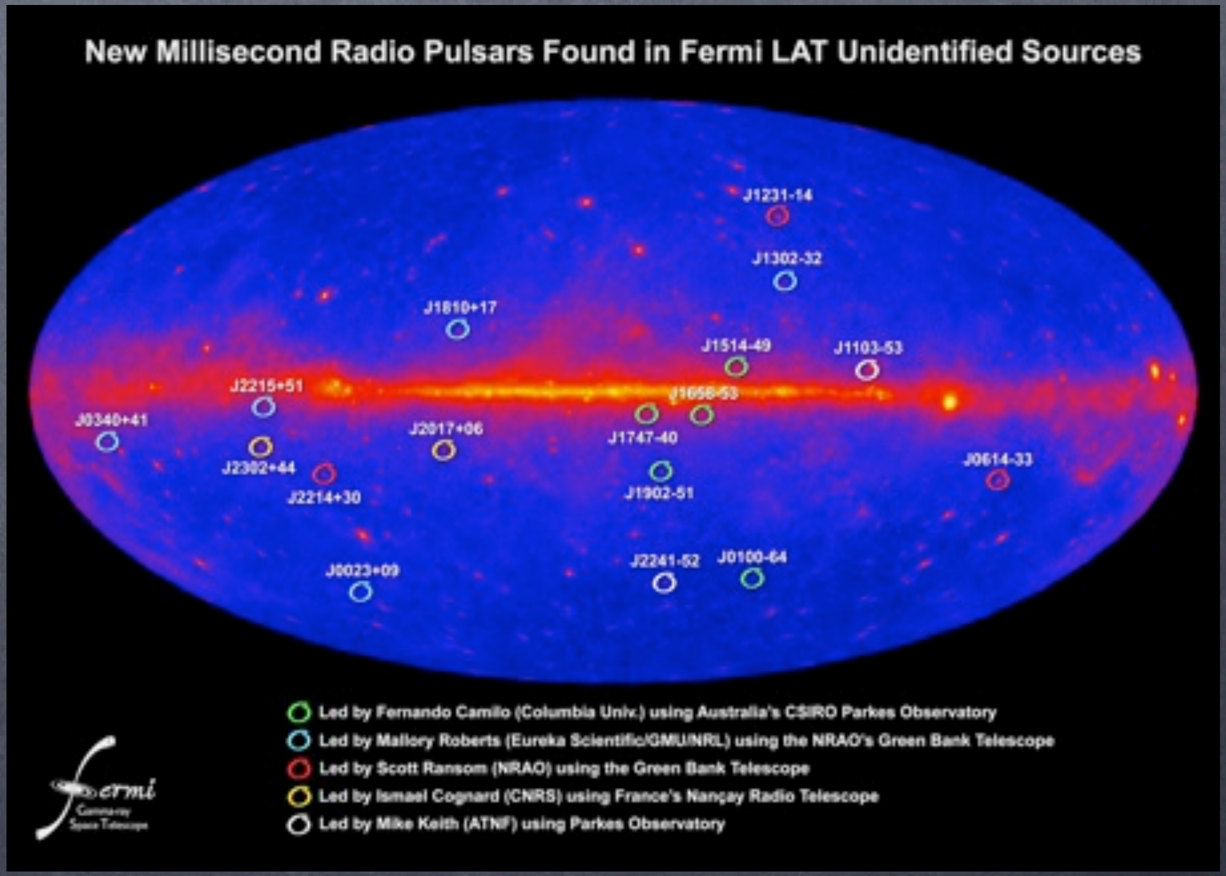
Credit: NASA/DOE/Fermi LAT Collaboration, Capella Observatory, and Ilana Feain, Tim Cornwell, and Ron Ekers (CSIRO/ATNF), R. Morganti (ASTRON), and N. Junkes (MPIfR)

Pulsars

There are over 100 known gamma-ray bright pulsars, some previously detected in radio, some detected solely in gamma-ray, and some millisecond pulsars detected by radio follow-up of unidentified gamma-ray sources.

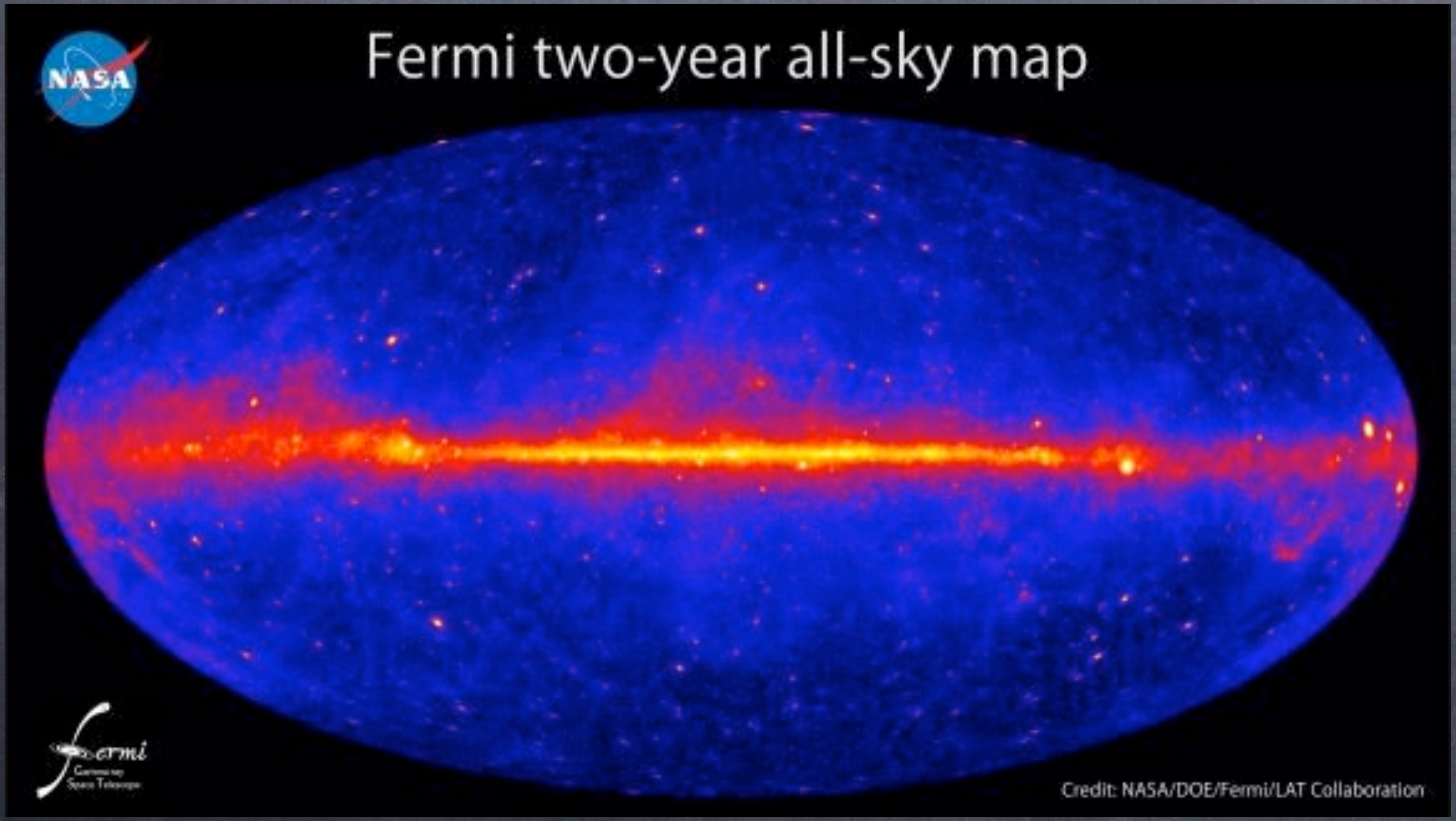
Fermi “blind search” pulsars

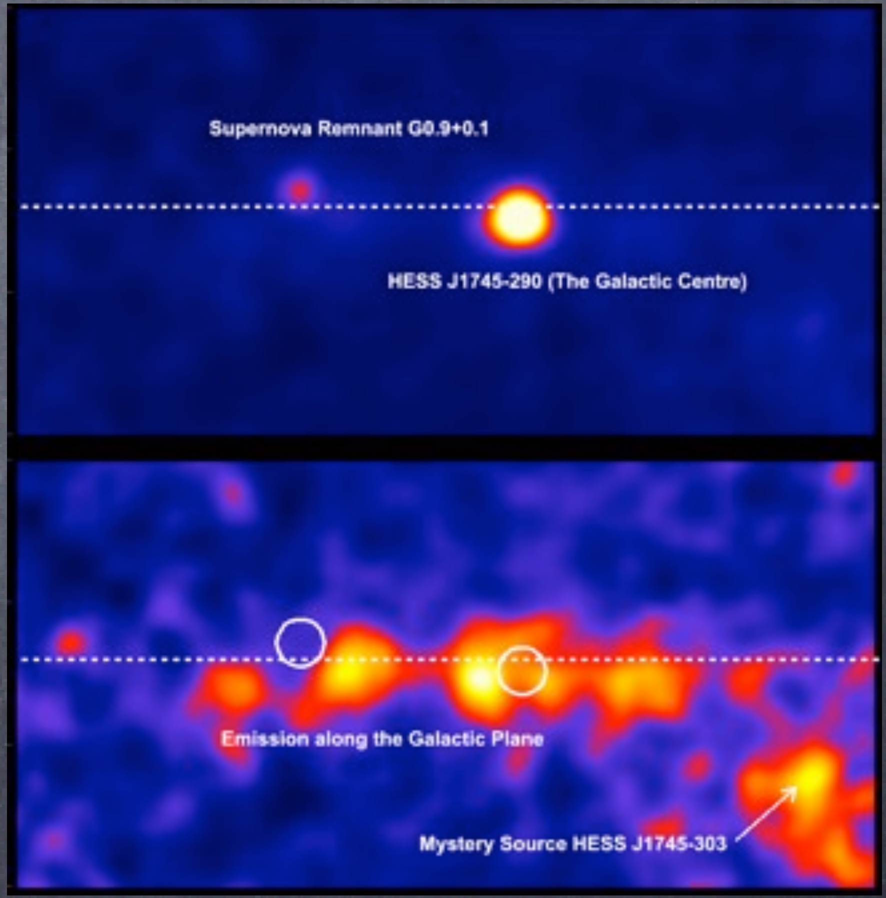




Galaxies

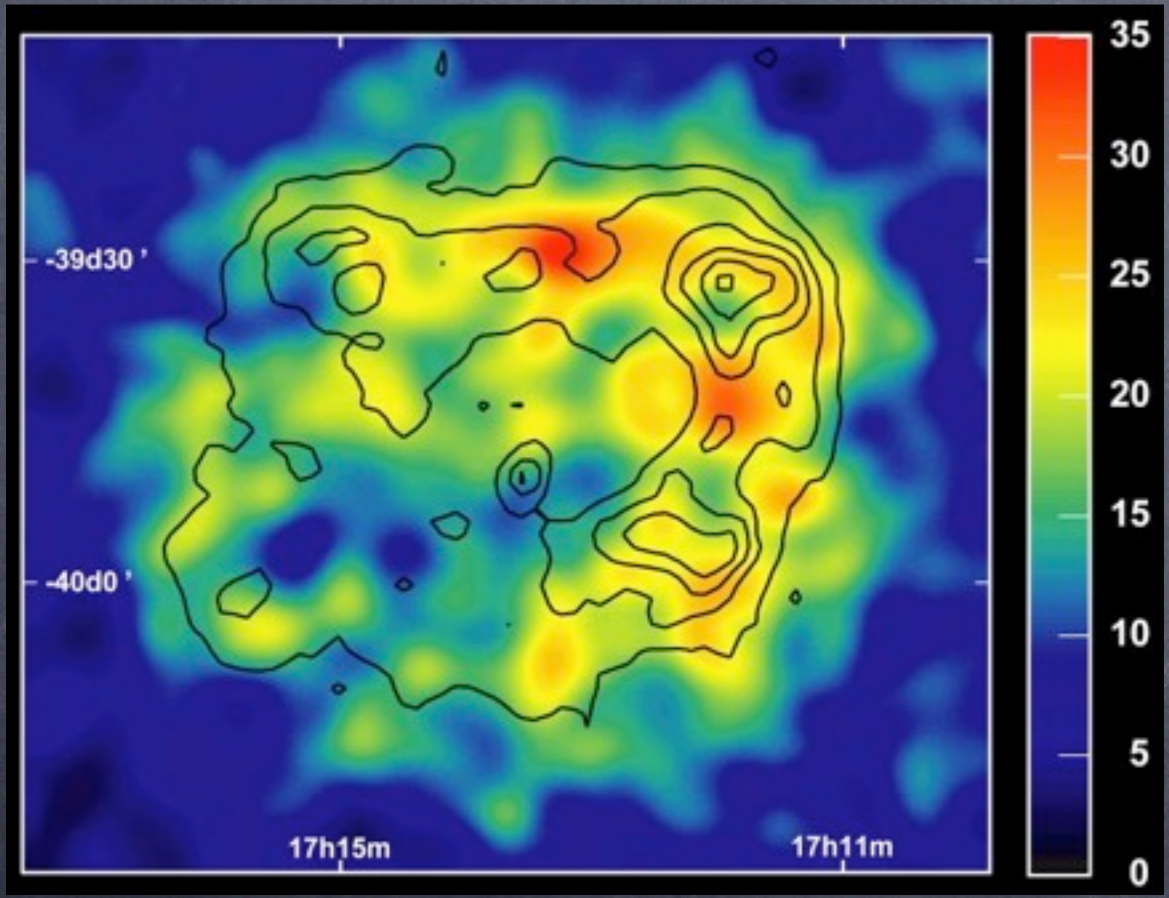
The Milky Way, LMC, SMC, Andromeda, and four starburst galaxies have been detected in gamma-rays. The emission from the Galaxy is dominated by pion decay (from p-p collisions) with contributions from IC and bremsstrahlung.





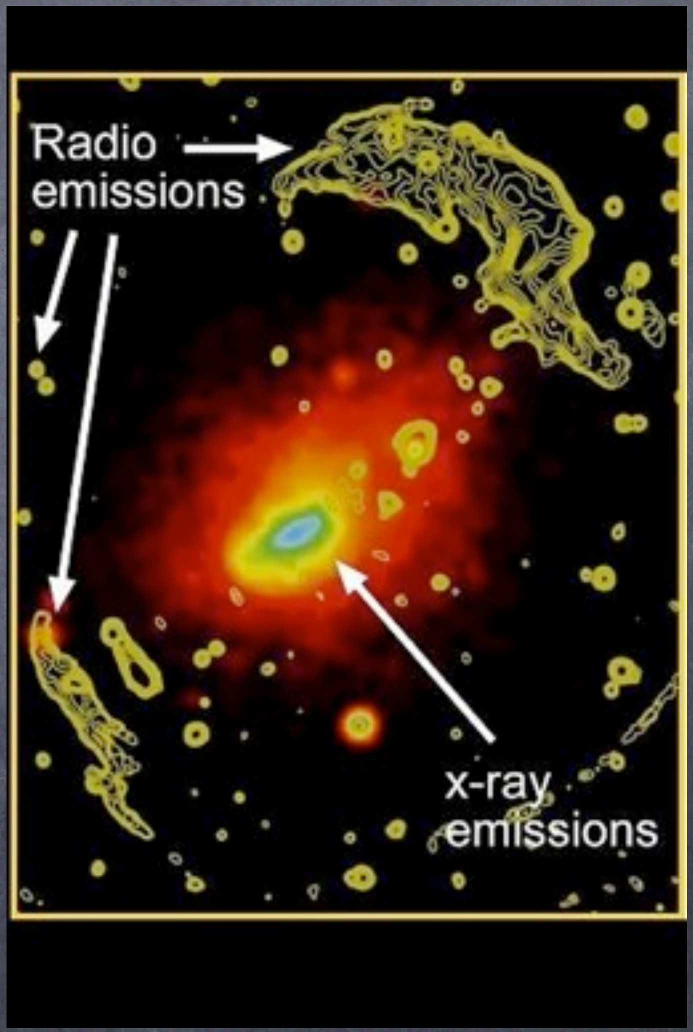
Sites of Particle Acceleration

Supernova Remnants



Credit: HESS Collaboration - image courtesy Werner Hofmann (MPI)

Clusters of Galaxies ??



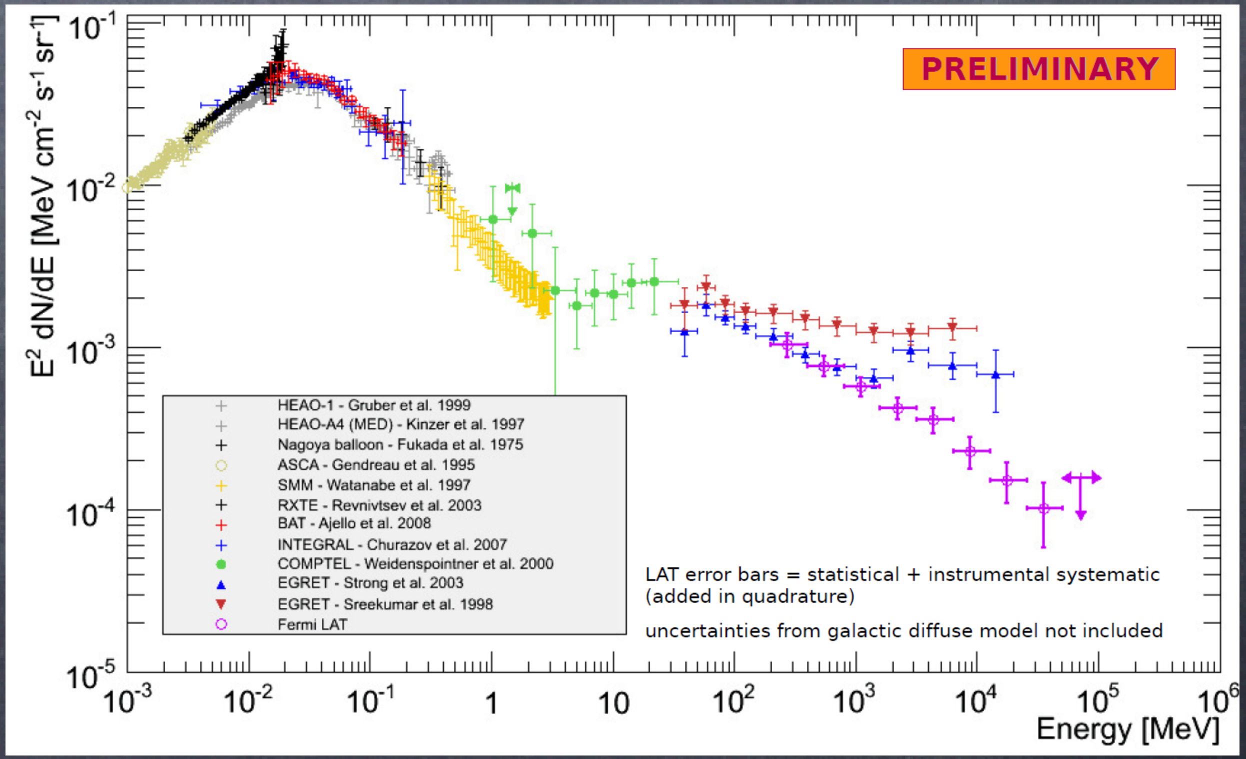
Abell 3667, X-ray and radio

Gamma-Ray Backgrounds

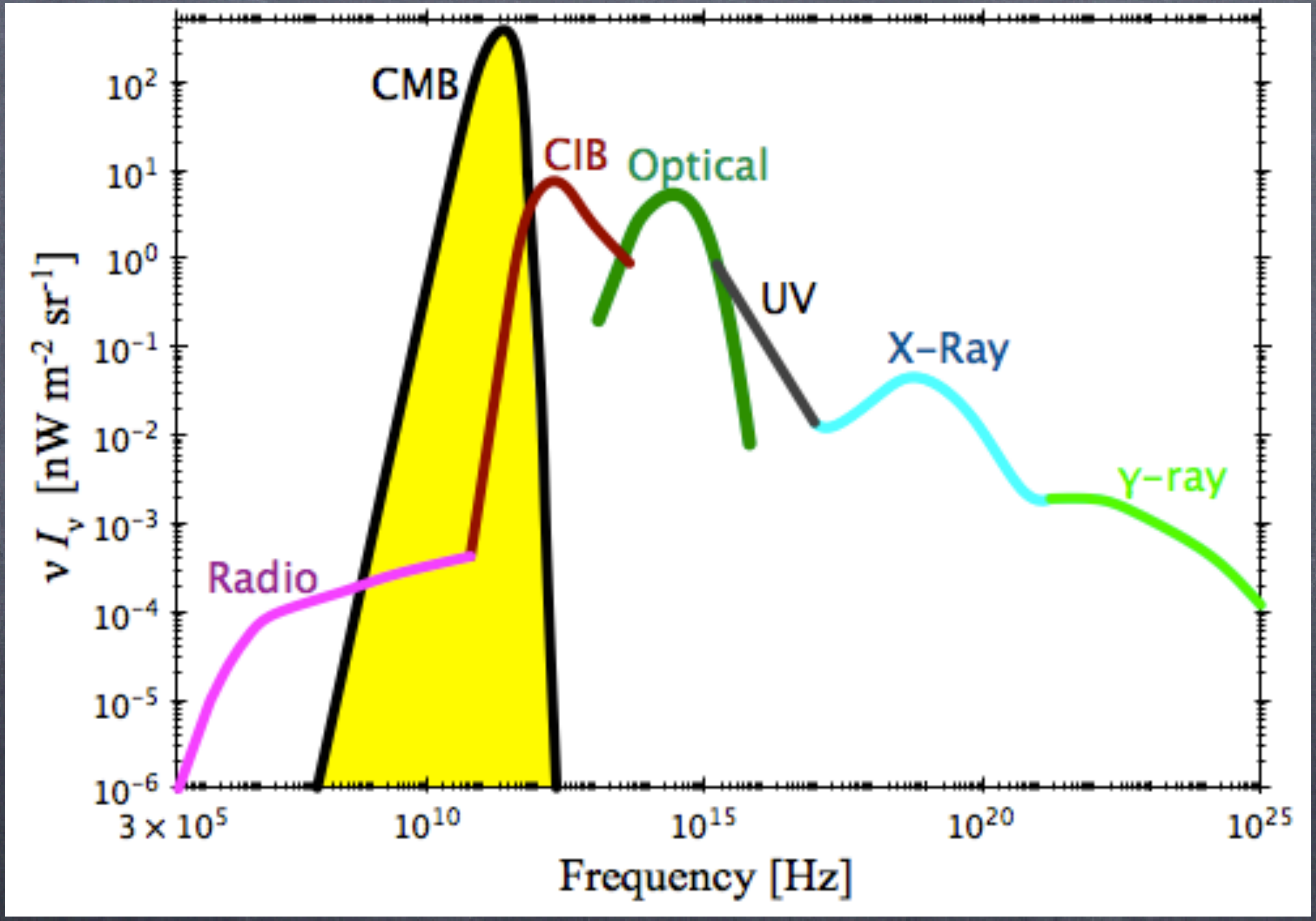
Galactic diffuse: The Galaxy is very bright in gamma-rays with correlation to sites of particle acceleration, gas density, etc.

Extragalactic diffuse: there is also a cosmic gamma-ray background from unresolved sources. This background is for the most part unresolved. AGN certainly contribute, star forming galaxies may also contribute. Other sources like dark matter have been theorized.

Gamma-ray Attenuation: the optical and IR extragalactic backgrounds lead to the attenuation of high energy gamma rays (~ TeV). Gamma-rays and background photons interact to produce $e^+ e^-$ pairs.



Multiwavelength Cosmic Background



Gamma-Ray Detectors - Space

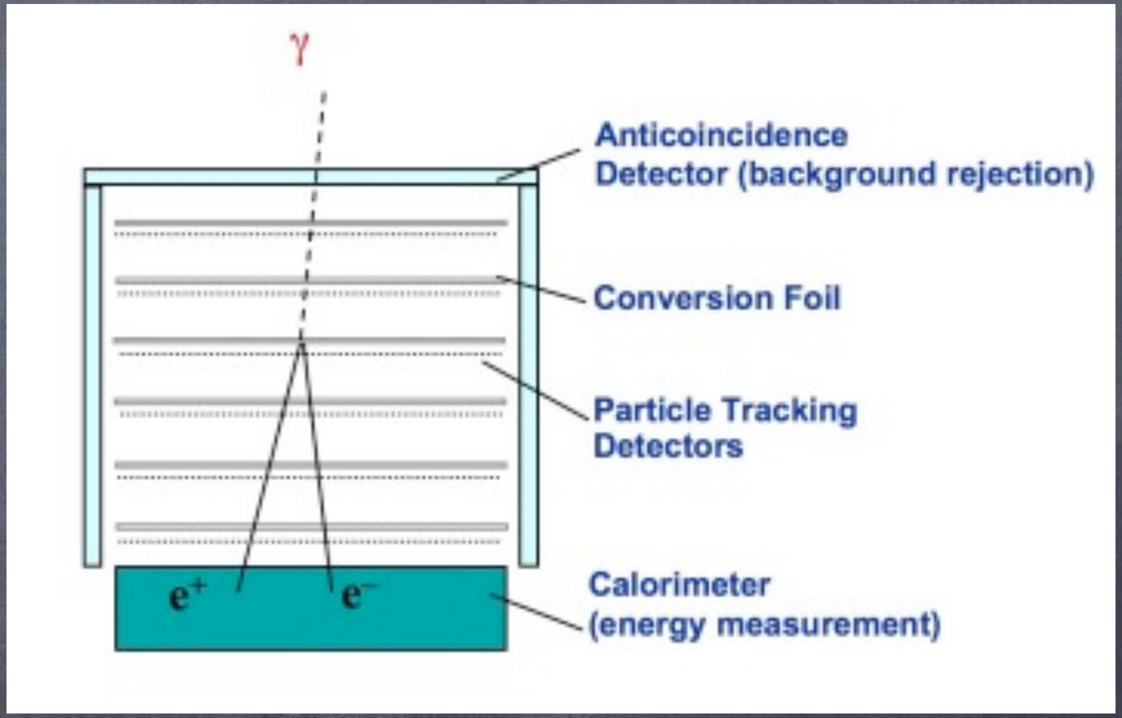
Low energy gamma ray detectors use scintillators similar to those used for hard X-rays.

The Large Area Telescope on Fermi is a pair conversion instrument.

- Gamma rays interact in one of a series of thin metal sheets (tungsten for Fermi) to produce an $e^+ e^-$ pair.

- The path of the $e^+ e^-$ pair is tracked using Si strips allowing reconstruction of the direction.

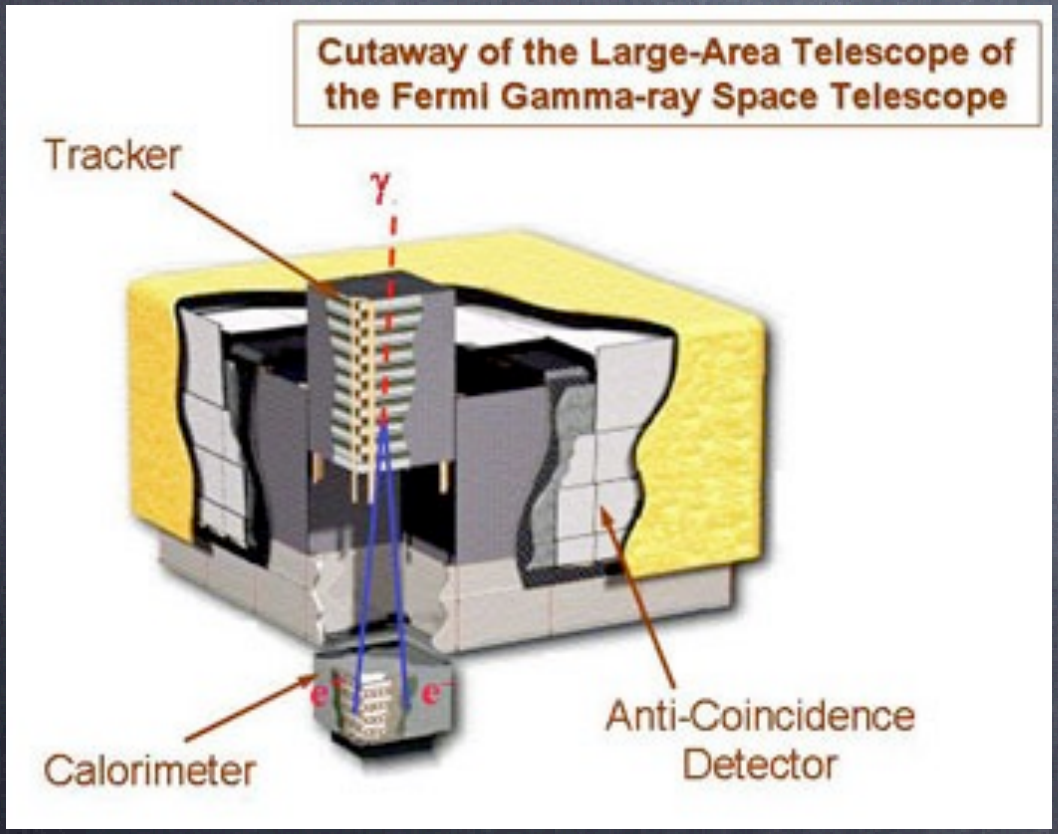
- A calorimeter (a stack of CsI scintillator crystals) measures the total energy.



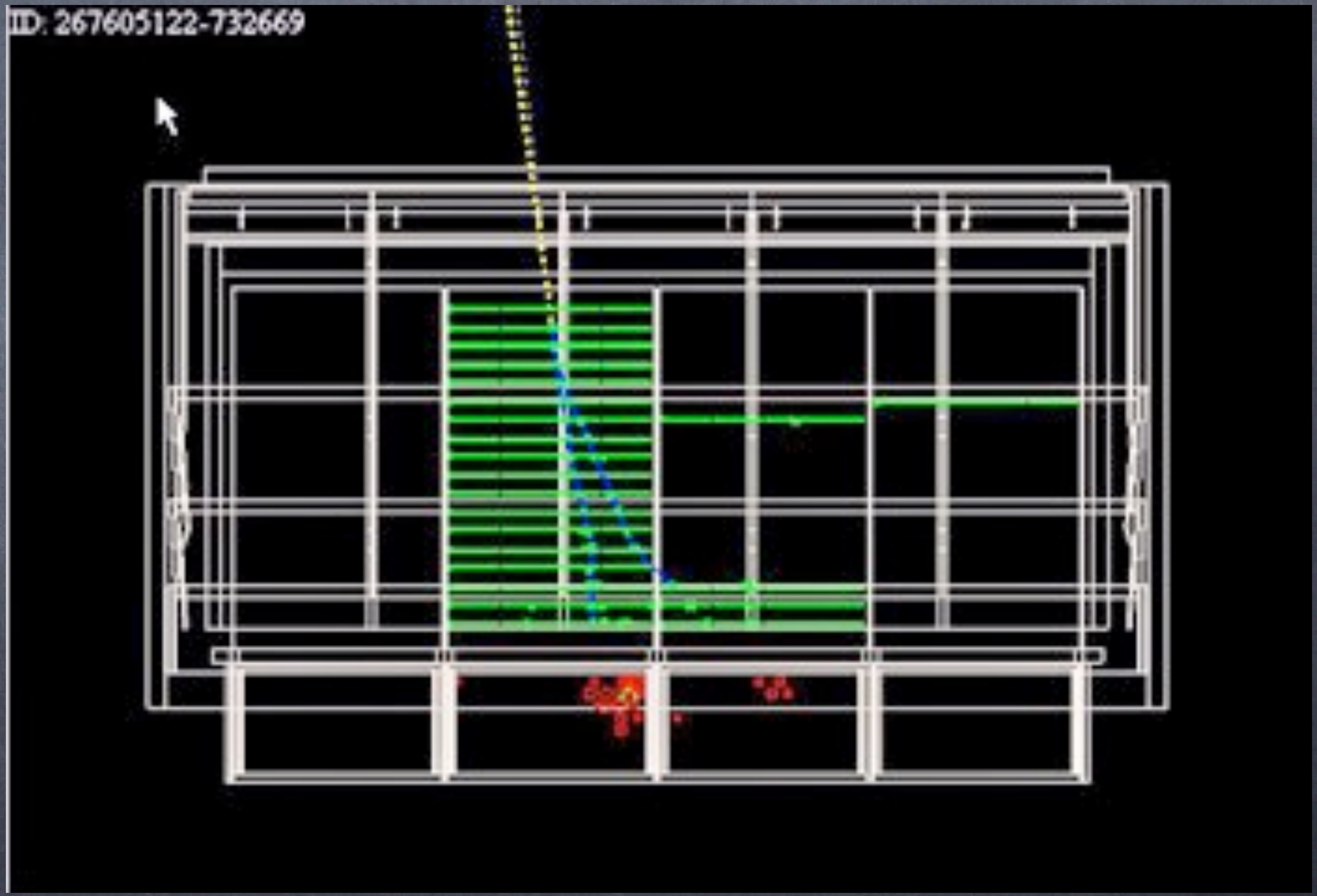
- Cosmic rays interact in the plastic anticoincidence detectors and can be rejected based on this signal.

Gamma-Ray Detectors - Space

The Fermi-LAT consists of 16 towers (4x4 array) with stacked converter and Si tracker layers and a calorimeter module.



Example gamma-ray event



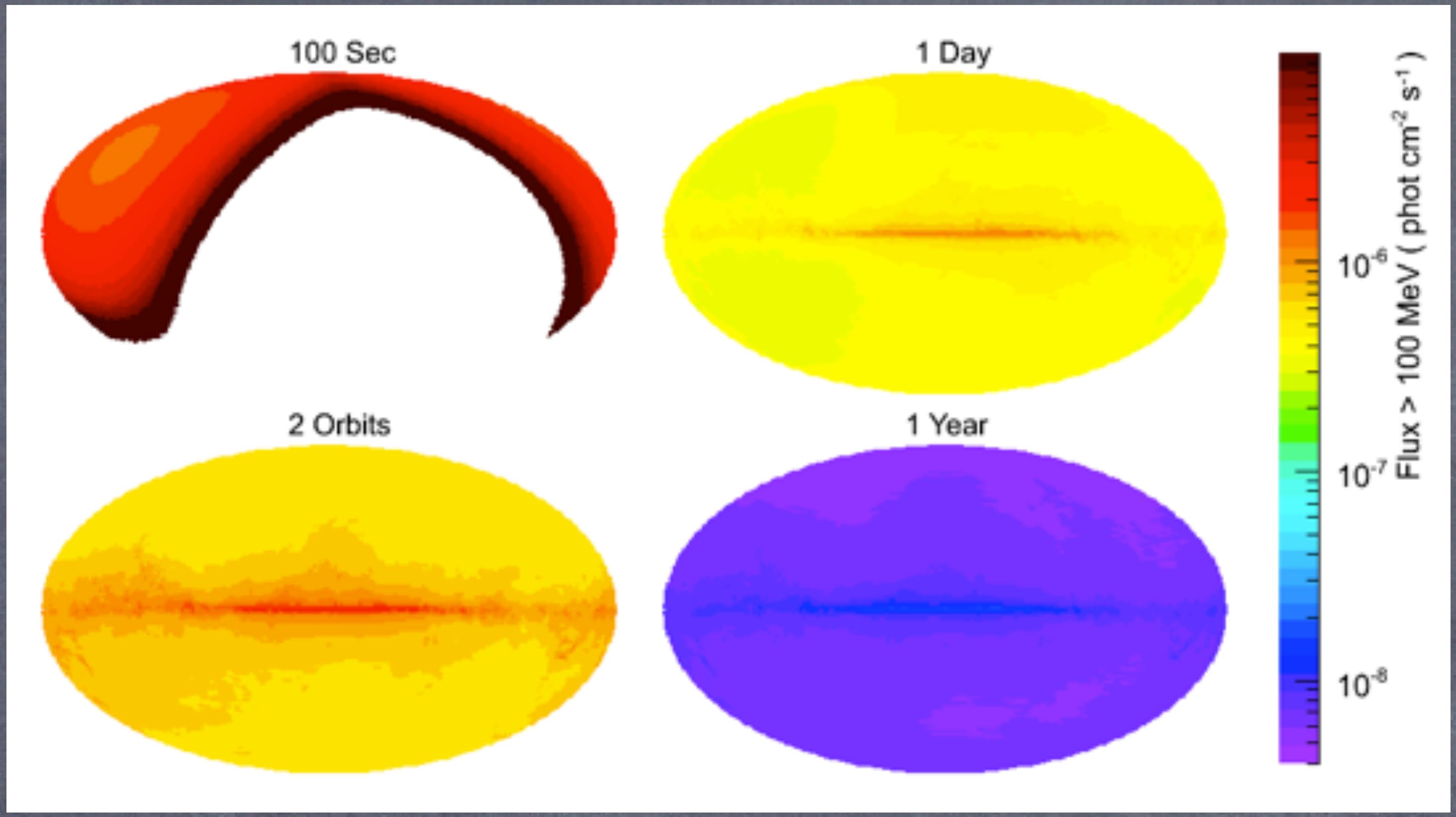
Fermi

- Launched in June 2008
- All-sky gamma-ray survey
- PSF ~4 deg @100 MeV, ~0.7 deg @1 GeV, ~0.2 deg @10 GeV
- Two instruments:

  Large Area Telescope (LAT):
  pair-conversion telescope
  30 MeV-300 GeV, 10x sensitivity of EGRET
  FOV covering 20% of the sky

  Gamma-Ray Burst Monitor (GBM):
  2 types of scintillators
  8 keV - 30 MeV
  covers full sky not blocked by the Earth

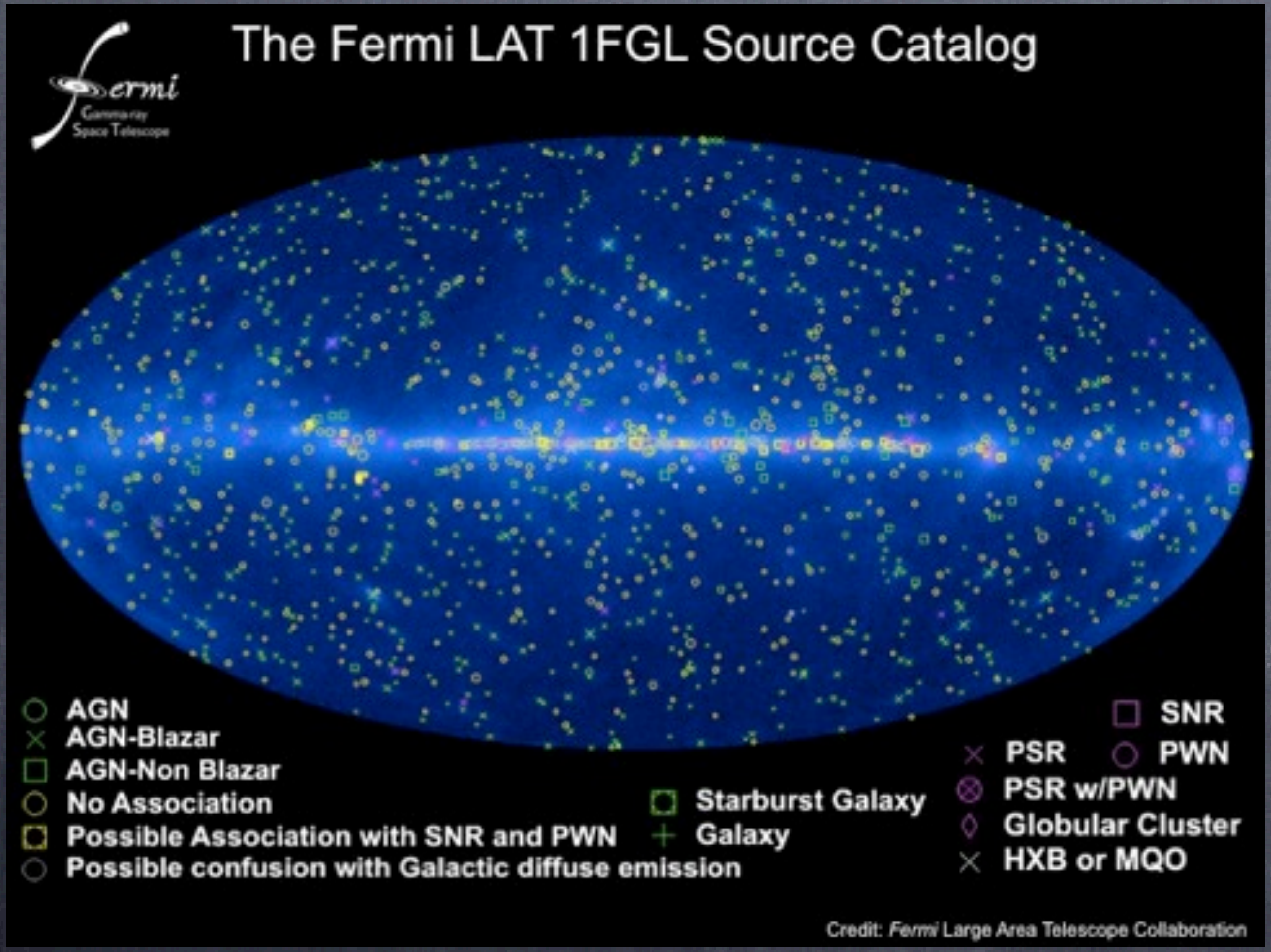
Fermi-LAT Survey Mode



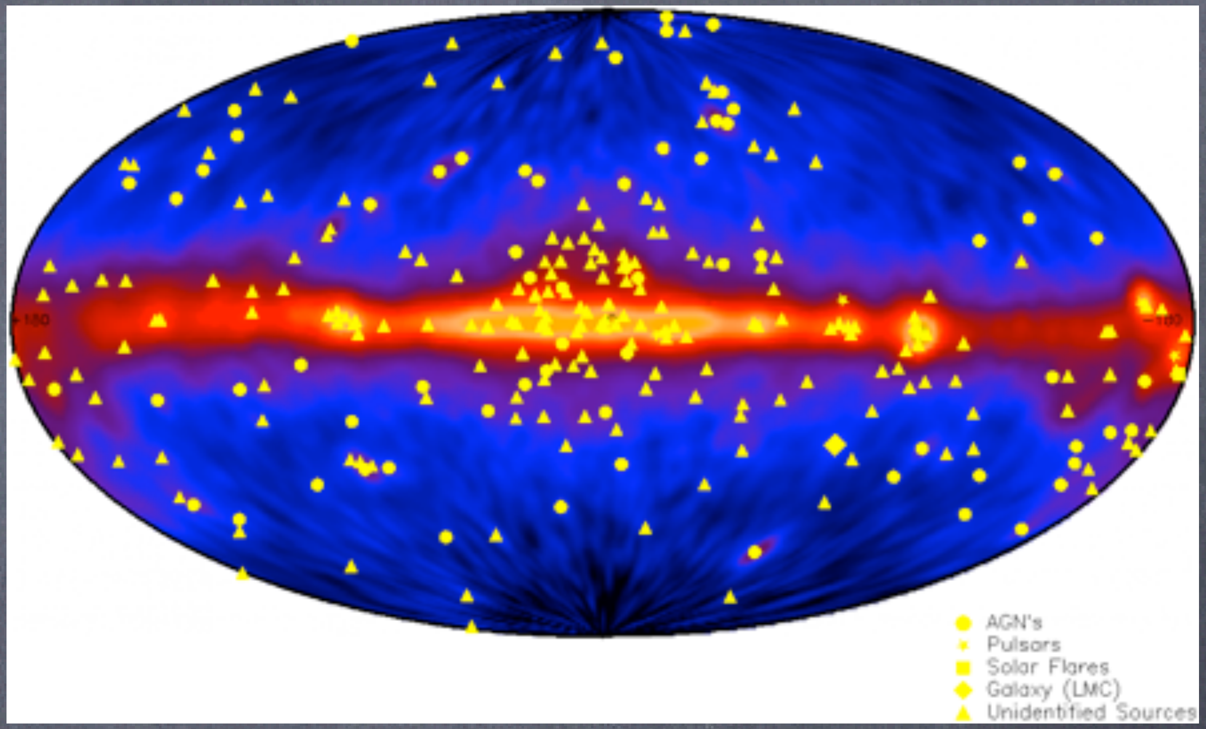
In survey mode Fermi-LAT scans the full sky every three hours with very uniform exposure. With its large FOV, Fermi is primarily a survey instrument. Pointed observations are possible, but not very efficient except for high time resolution studies.

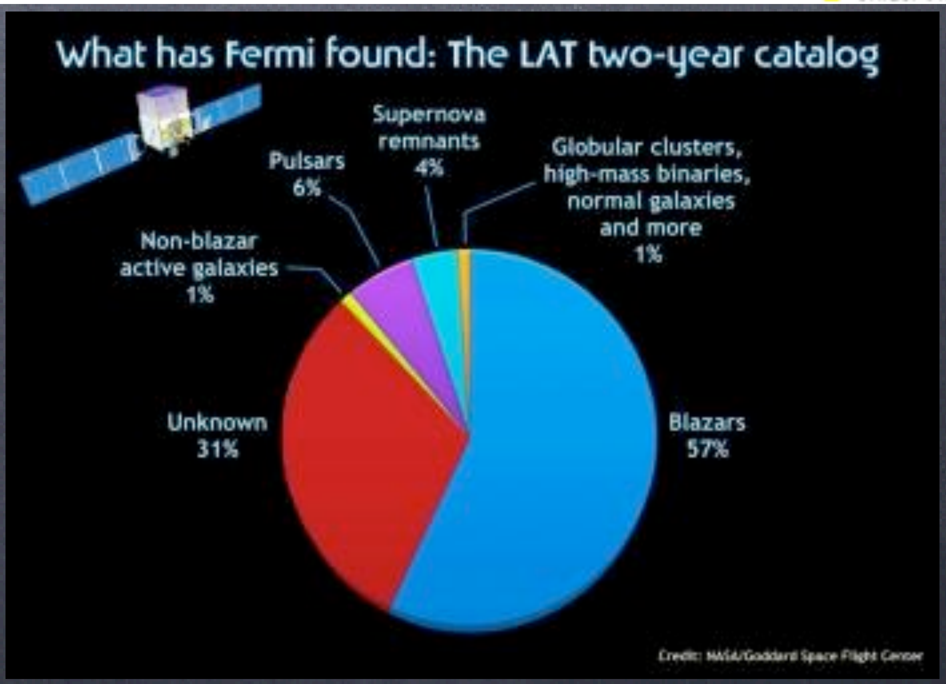
The Gamma-Ray Sky

Fermi-LAT: 1451 sources, year 1
1873 sources, year 2



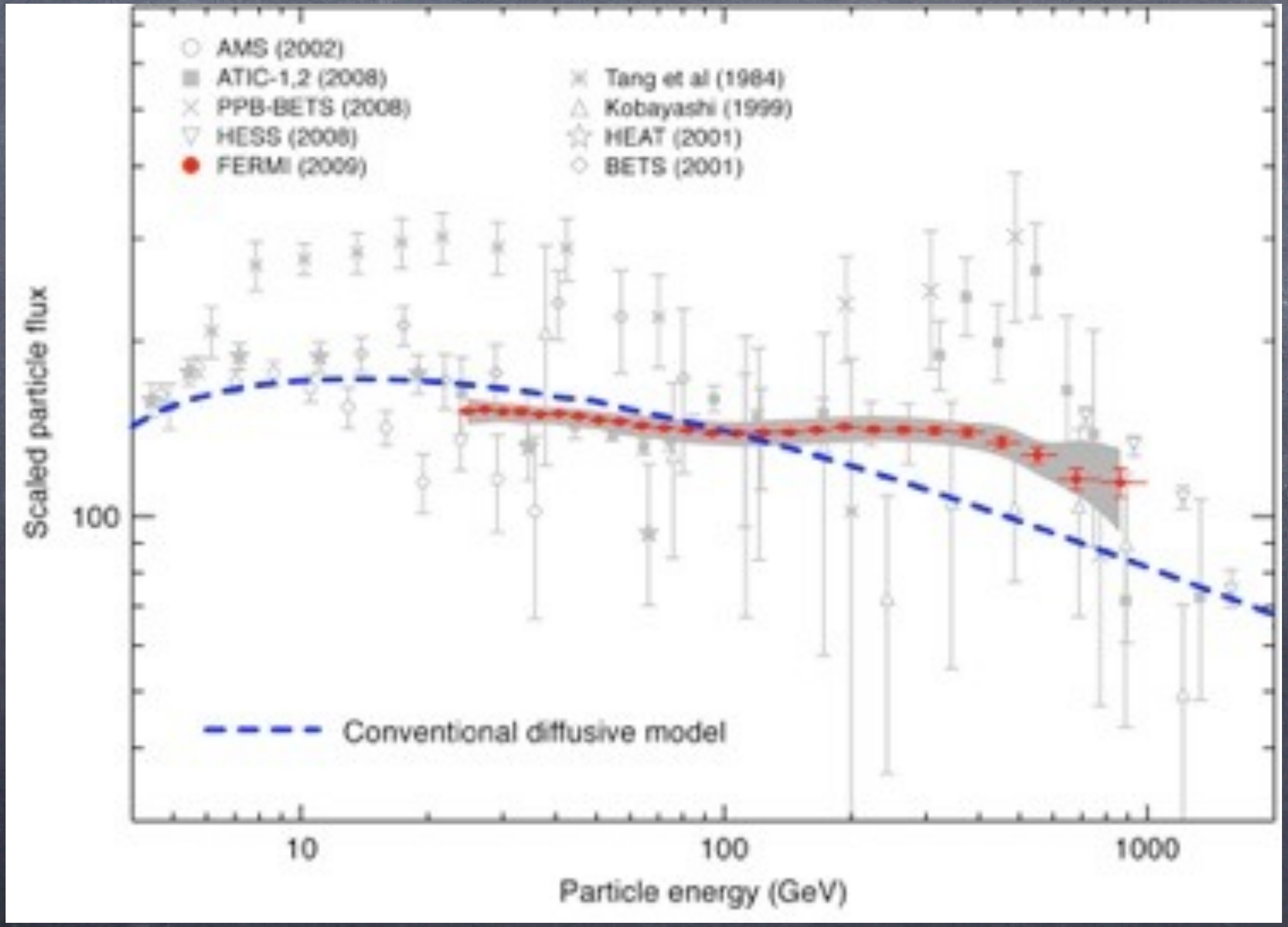
EGRET - 271 sources, full mission





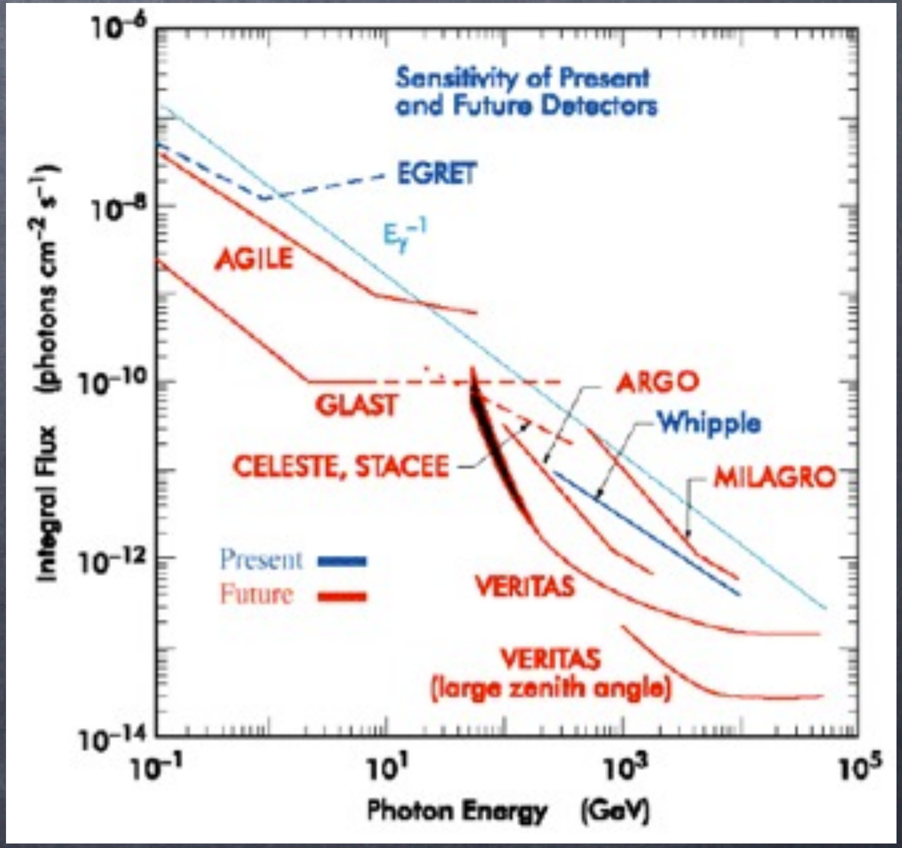
Also a Particle Detector

The Fermi-LAT is also an effective particle detector. All events with at least 20 GeV energy are sent to the ground. Particle events give a signal from the anti-coincidence detectors, the profile of the shower in the trackers can be used to separate out electron and proton events.



AGILE

- Italian Space Agency mission
- Launched in April 2007, launch was originally planned for 2005 for a pre-Fermi
- Not as sensitive as Fermi, but has been used effectively for transient/timing work using pointed observations including the detection of gamma-ray flares from the Crab nebula.
- Instruments: gamma-ray imager (30 MeV-50 GeV), hard X-ray imager (18-60 keV), and a calorimeter (350 keV-100MeV)

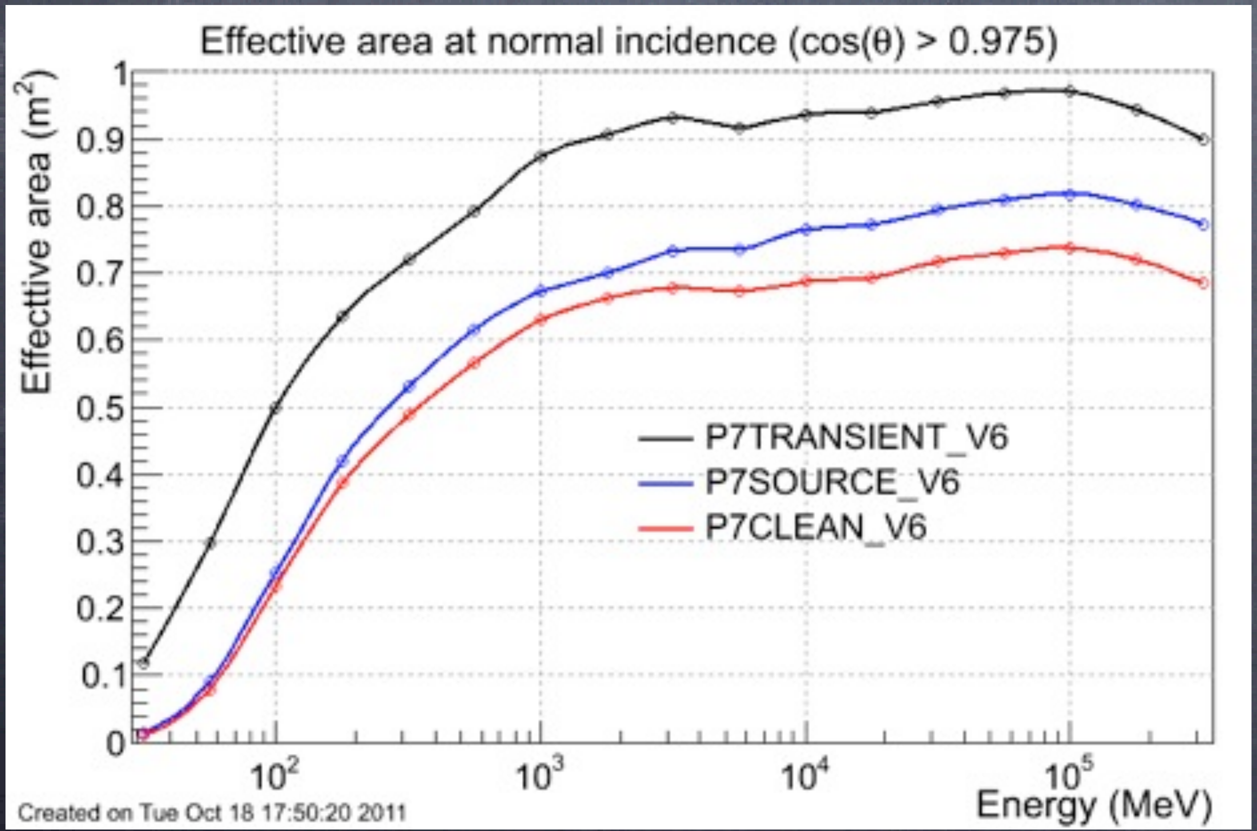


Major Science Results

- Discovery of dozens of gamma-ray only pulsars and dozens of millisecond pulsars
- Measurement of the electron and positron spectrum
- Discovery of gamma-ray emission from starburst and normal galaxies, correlation of gamma-ray emission with star formation
- Discovery of gamma-ray bubbles from the Galactic center (also potential gamma-ray line emission from the GC)
- Constraints on neutralino (and other) dark matter models
- Blazar population and contribution to the gamma-ray background
- Measurement of > GeV emission from gamma-ray bursts

Fermi Data

- Fermi data (in some form) has been made public since year 1.
- Only the "photon data" is released, which means that it has been pre-filtered to reduce the particle background. Depending on science aim, different filtering can be applied which is more or less conservative on background rejection.
- The released data is in FITS table format, similar to X-ray data.



Event classes include:

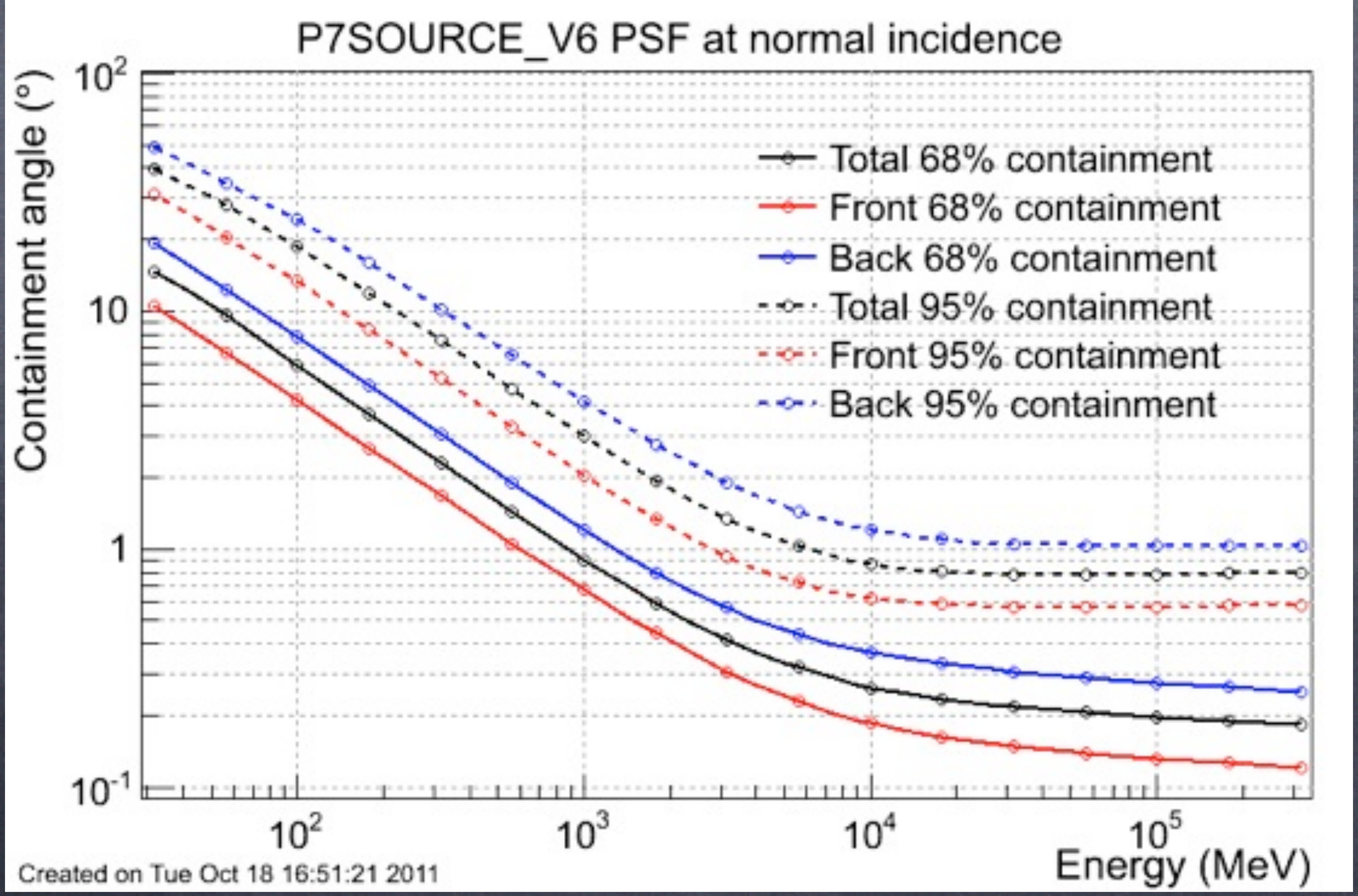
- transient
- source
- clean

with increasingly strict cuts for background events at the expense of losing some source photons.

Fermi PSF

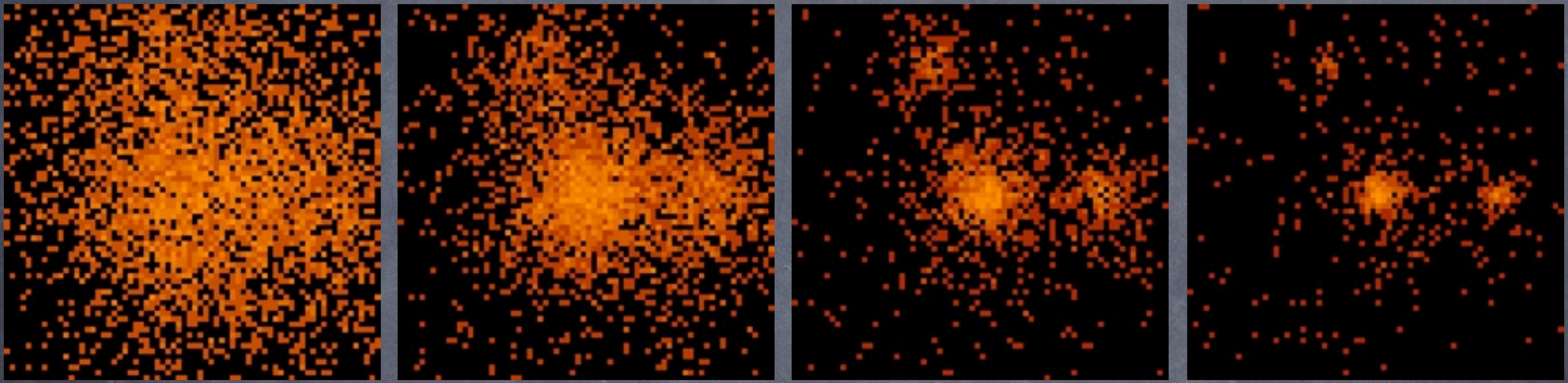
The Fermi-LAT PSF is highly energy dependent and also depends on where in the tracker events are converted (Front: 12 thinner layers of W, Back: 4 thicker W layers).

At high energies the PSF is good, but sources are typically faint.



Fermi PSF

increasing energy →



It is typically not possible to model one source independently or to use aperture photometry. Despite the relatively low density of gamma-ray sources, the large PSF means that sources far away can contribute background and this background depends on source spectrum.

➡ Jointly fit source, backgrounds, and surrounding sources

Basic Data Analysis

Fermi has its own set of software called the Fermi Science Tools. You can find more information on the NASA Fermi pages: http://fermi.gsfc.nasa.gov/ssc/

1. Filter data: filter on event class, energy range, and make a zenith angle cut to remove time periods when the Earth's limb would provide high background (cosmic rays interact in the atmosphere).

2. Extract data files: Lightcurves, images, and spectra can be extracted. Typically one jointly fits the spatial and spectral distribution. A mapcube consisting of an array of images in different energy bins is created and then fit.

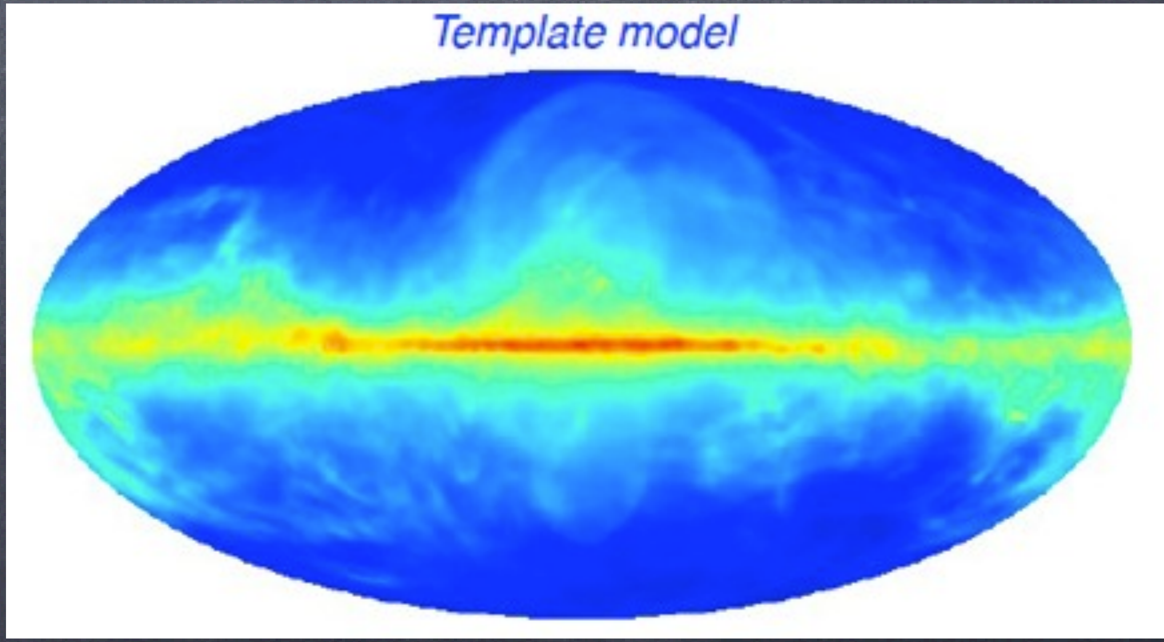
Basic Data Analysis

3. Lightcube: A spacecraft data file records where Fermi was pointing when and is used to reconstruct the exposure for a given patch of sky over the survey.

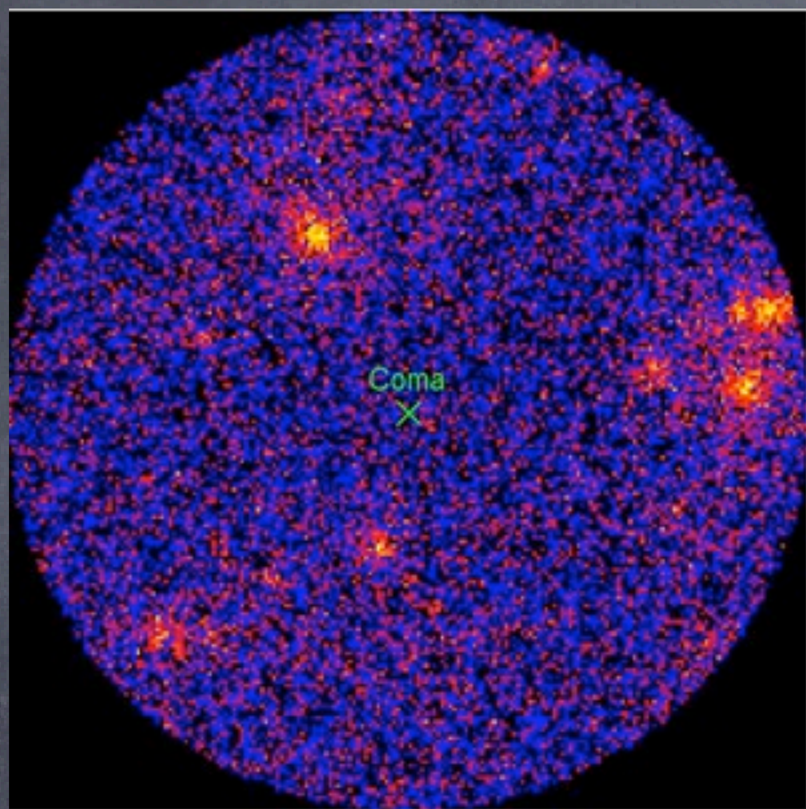
4. Exposure map: Response files specific to the event class selection are convolved with the livetime to compute exposure cubes (array of exposure maps for a set of energy bins).

5. Background maps: The Fermi collaboration provides models for the Galactic diffuse (mapcube) and an extragalactic diffuse spectrum for modeling the backgrounds.

Depend on event class selection



Example Fit

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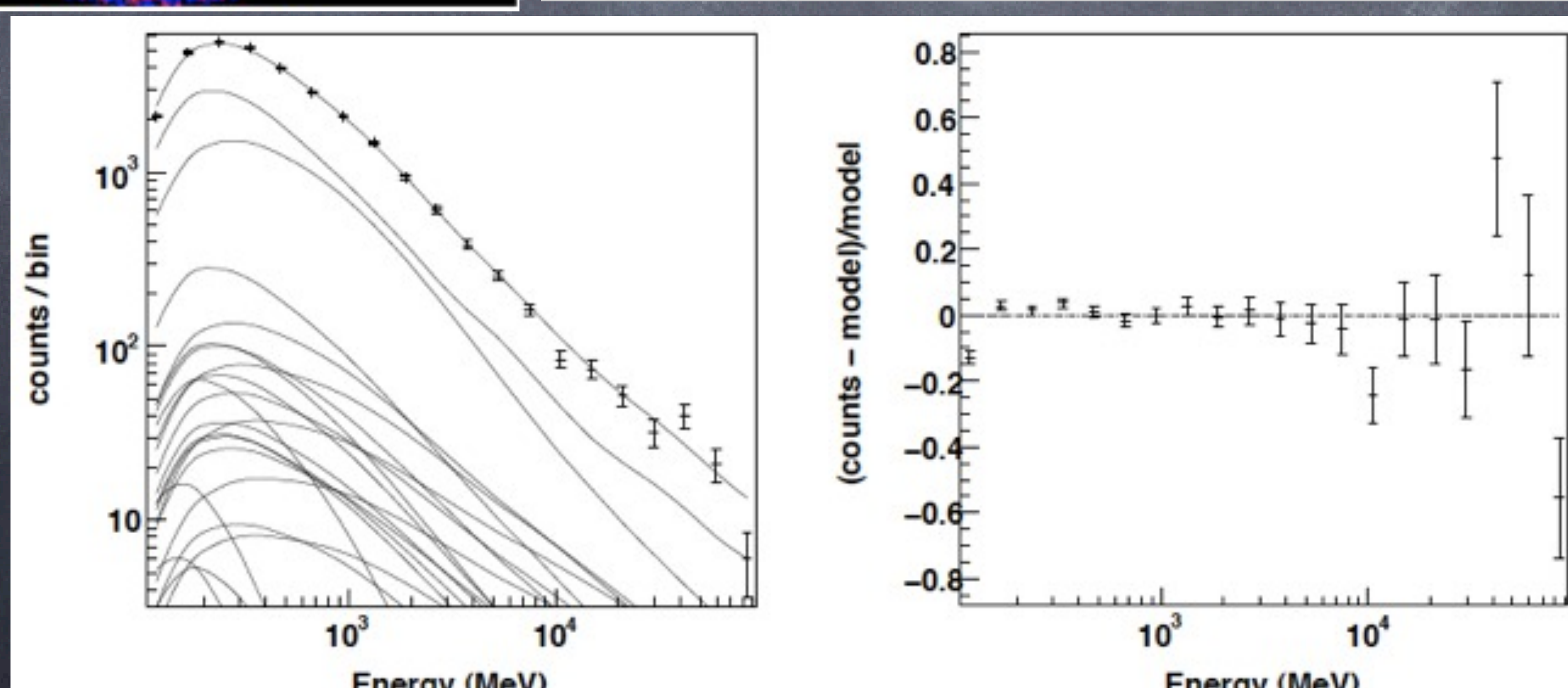
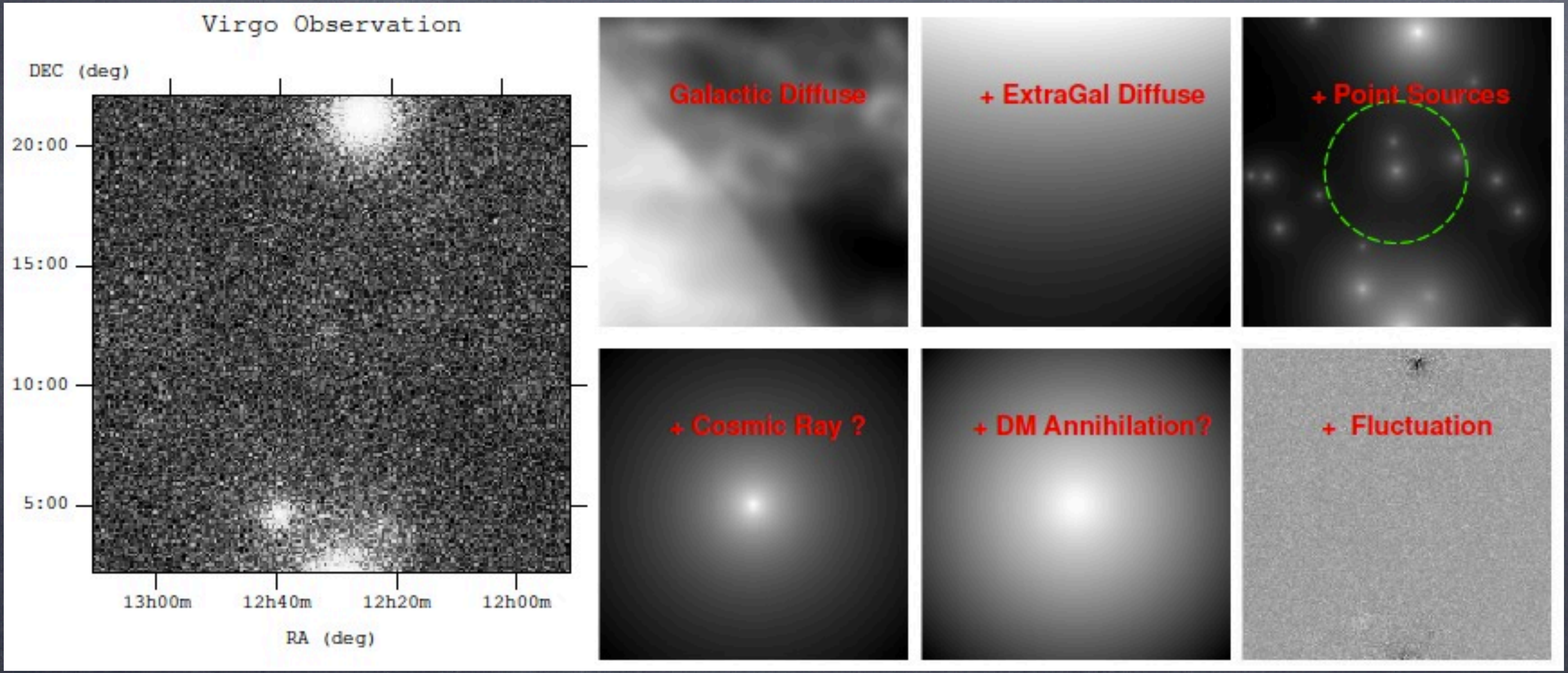
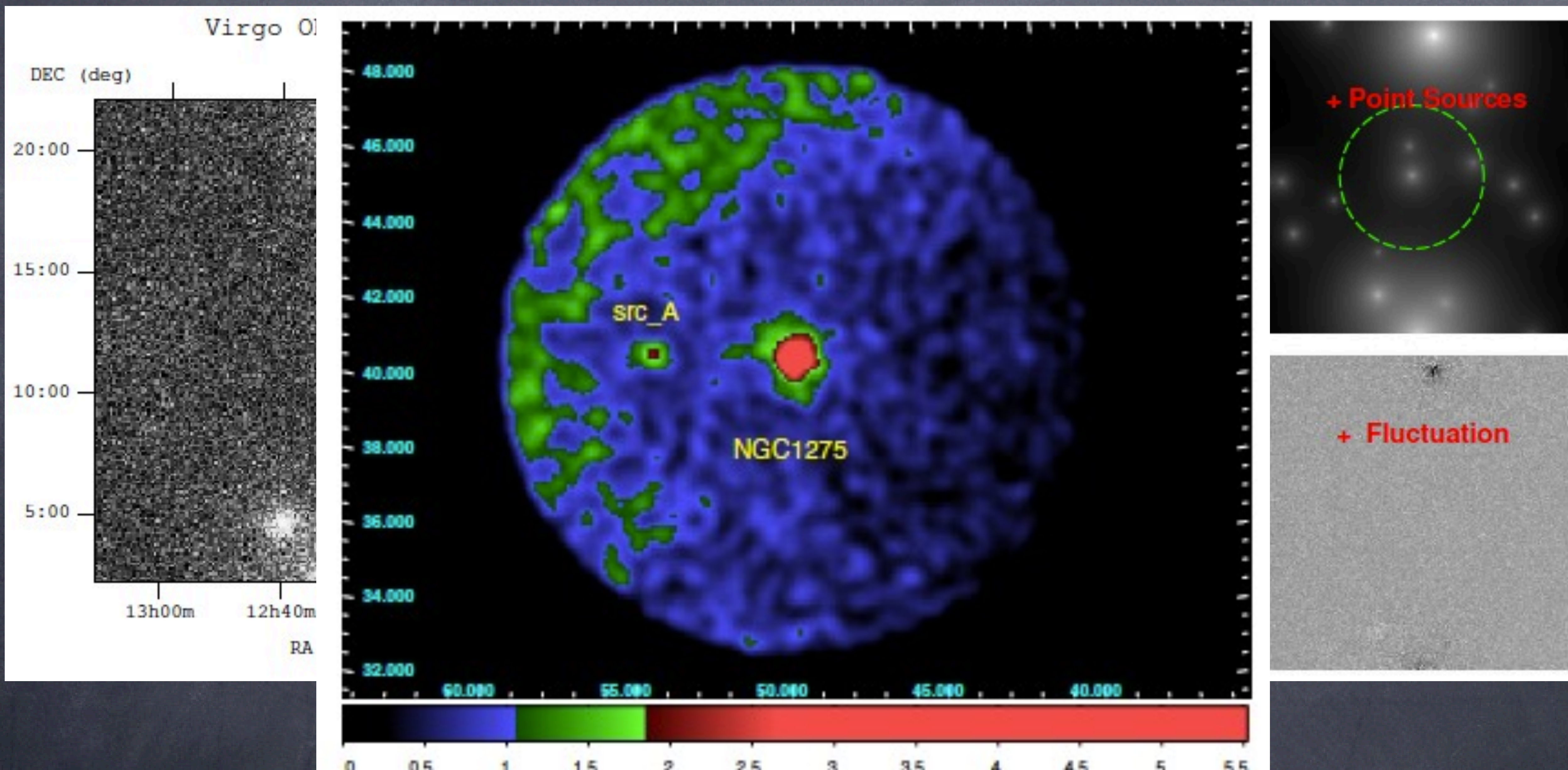


M87 with Fermi



Han et al. 2011

M87 with Fermi



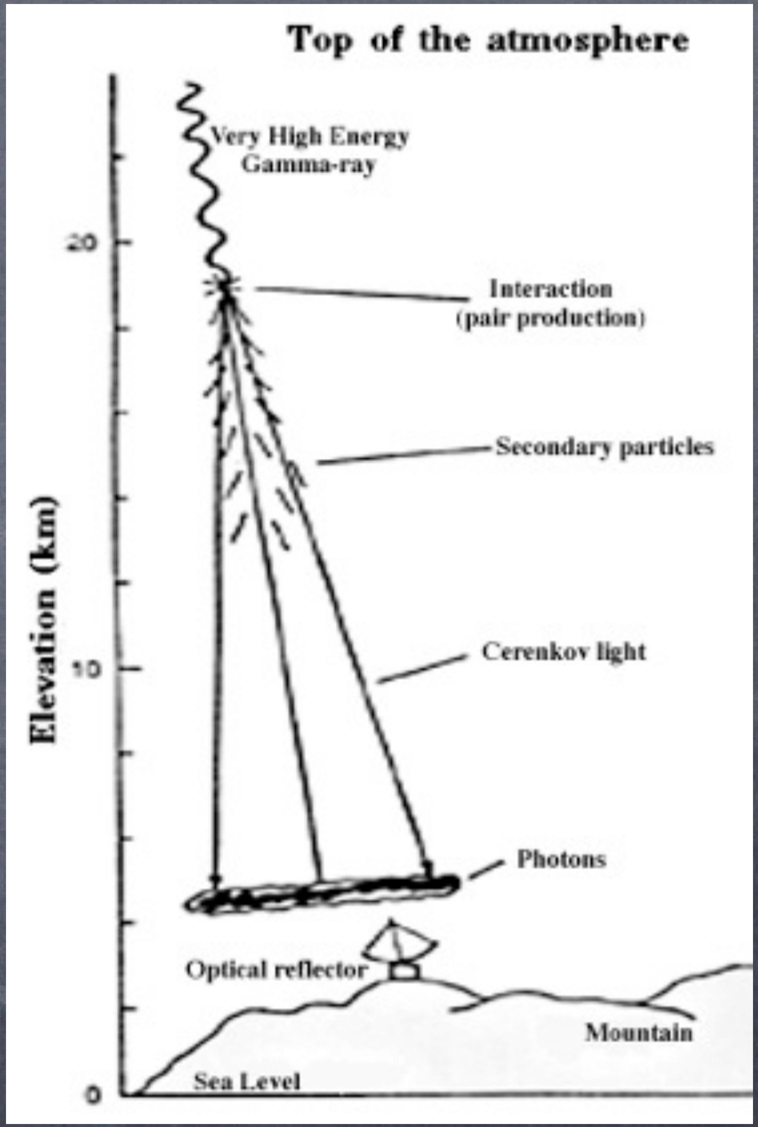
Abdo et al 2009

Gamma-Ray Telescopes - Ground

Very high energy gamma-rays can be detected from the ground.

The original gamma-ray photon undergoes pair production in the upper atmosphere to produce an energetic $e^{-}e^{+}$ pair which then interacts with the atmosphere leading to a cascade of energetic secondary particles.

These very fast moving charged particles temporarily polarize atoms in the atmosphere leading to Cherenkov radiation, faint bluish light.



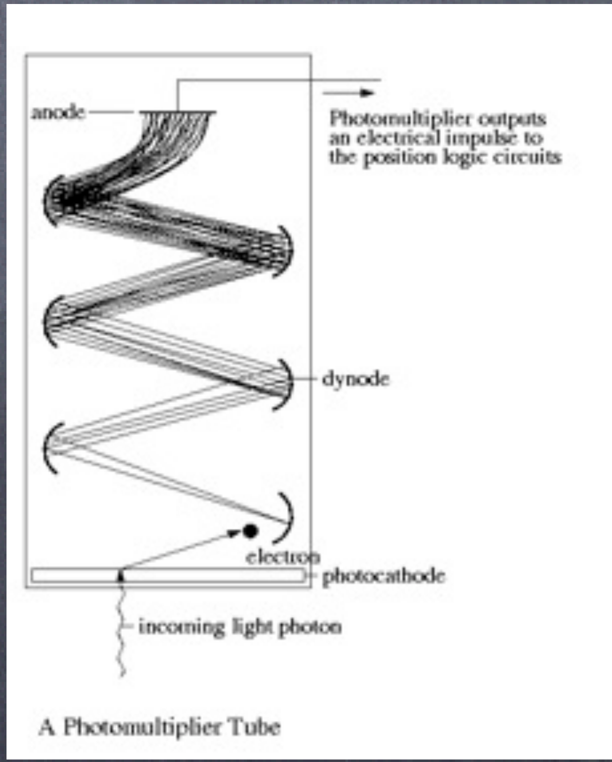
NASA Imagine the Universe: http://imagine.gsfc.nasa.gov/docs/science/how_l2/cerenkov.html

Detectors - IACTs

Atmospheric (or air) Cherenkov Telescopes detect the pool of Cherenkov radiation created.

The telescopes themselves are large optical reflectors at high, dry sites. The mirrors can be lower quality than optical telescopes, but need to be big.

The detectors are composed of an array of photomultiplier tubes (vacuum tube with a series of electrodes) coupled to fast electronics, which amplify and readout the signal and provide some imaging of the Cherenkov light pool.



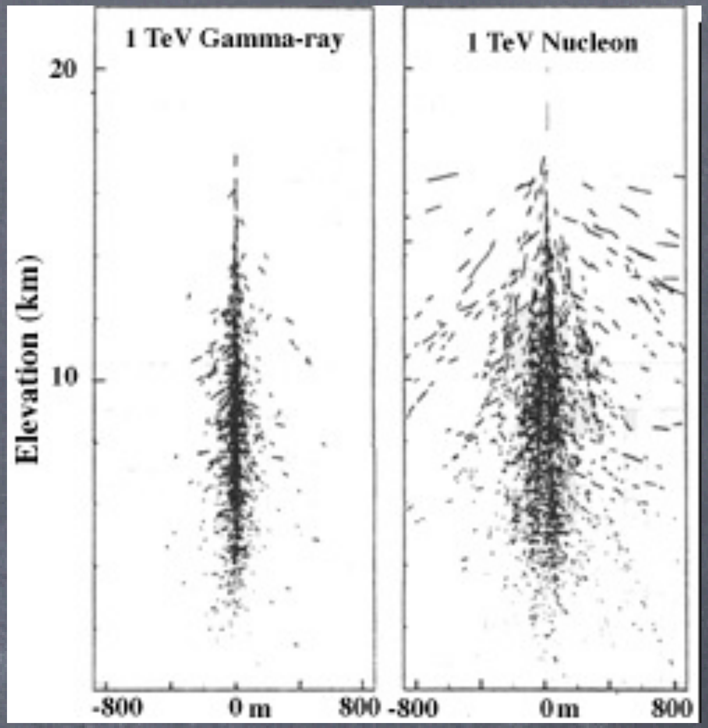
IACTs

The Cherenkov light is faint and spread over a large area, so low sky background is important (no moon). However, the signal is short lived (nanoseconds) aiding separation from the background.

Cosmic rays hitting the atmosphere create similar showers and Cherenkov light and these events are much more numerous. The shape of the signal is used to reduce this background.

Typically, arrays of telescopes are used to increase the sensitivity and aid in cosmic ray background rejection.

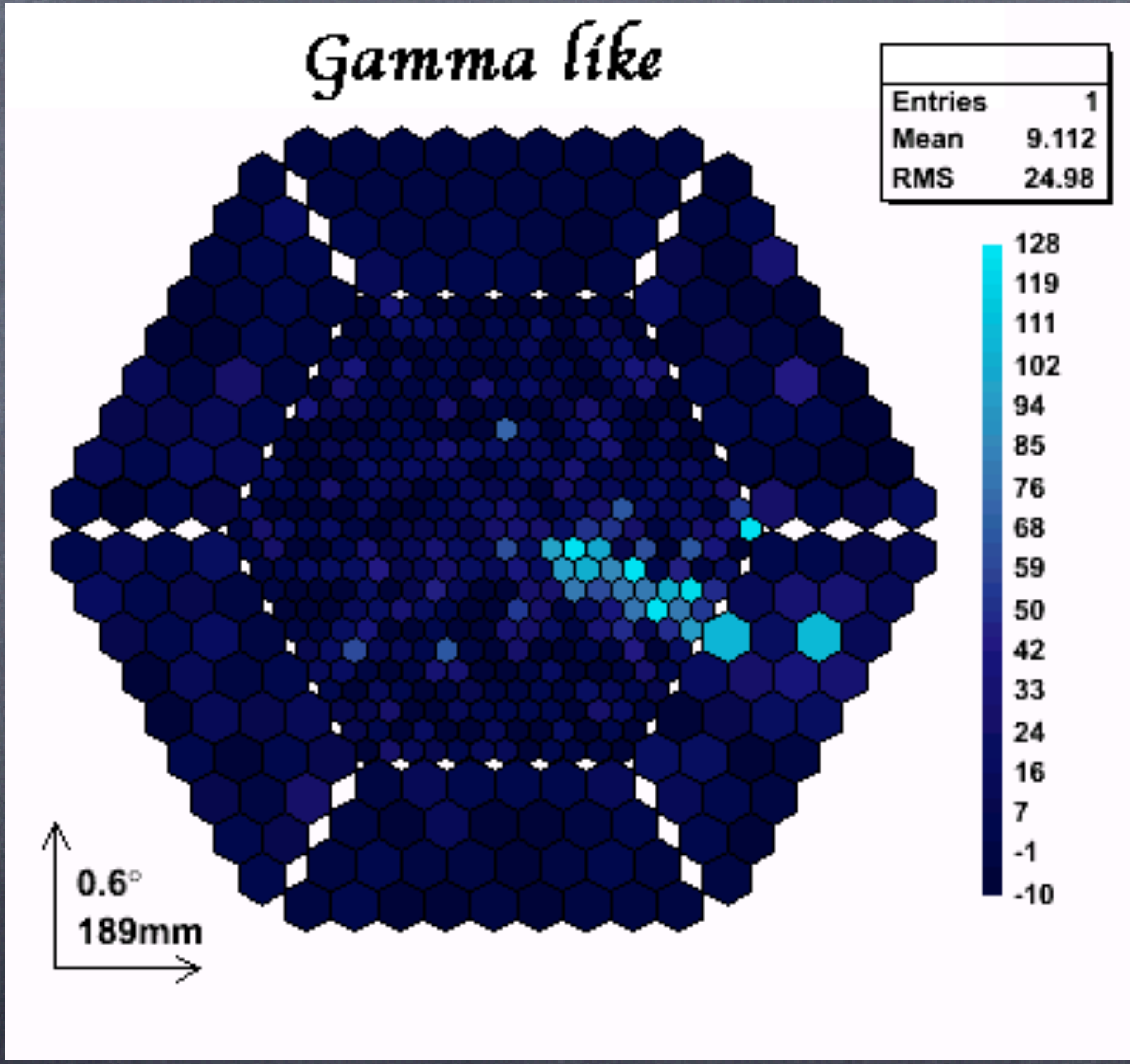
Angular resolution ~2′-4′



NASA "Imagine the Universe"

IACTs

Example events: MAGIC telescope

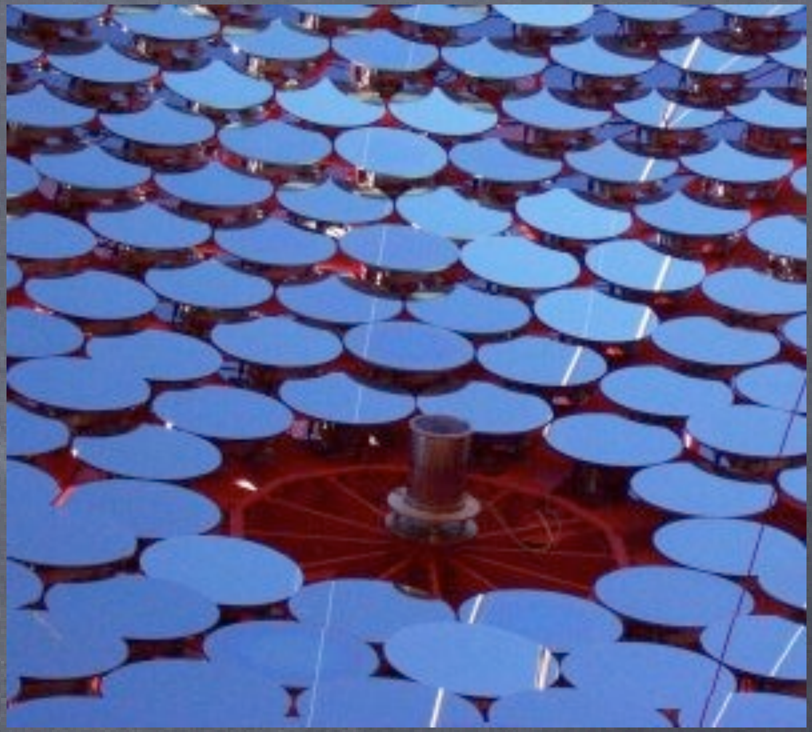


http://magic.mppmu.mpg.de/magic/iact.html

Current Telescopes

Atmospheric Cherenkov Telescopes (50 GeV-100 TeV):

- HESS (2002-, Namibia)
  4, 108 m^2 telescopes
  Phase 2 has add one 600 m^2 mirror
- MAGIC (2004-, Canary Islands)
  2, 17-m telescopes
- VERITAS (2007-, Arizona)
  4, 12-m telescopes
- CANGAROO III (2004, Australia)
  4, 10-m telescopes


one of the HESS telescopes

Extensive Air Shower Array (> few TeV):

- Milagro (1998-2008, near Los Alamos)
  4800 m^2 of water

Extensive Air Shower Arrays

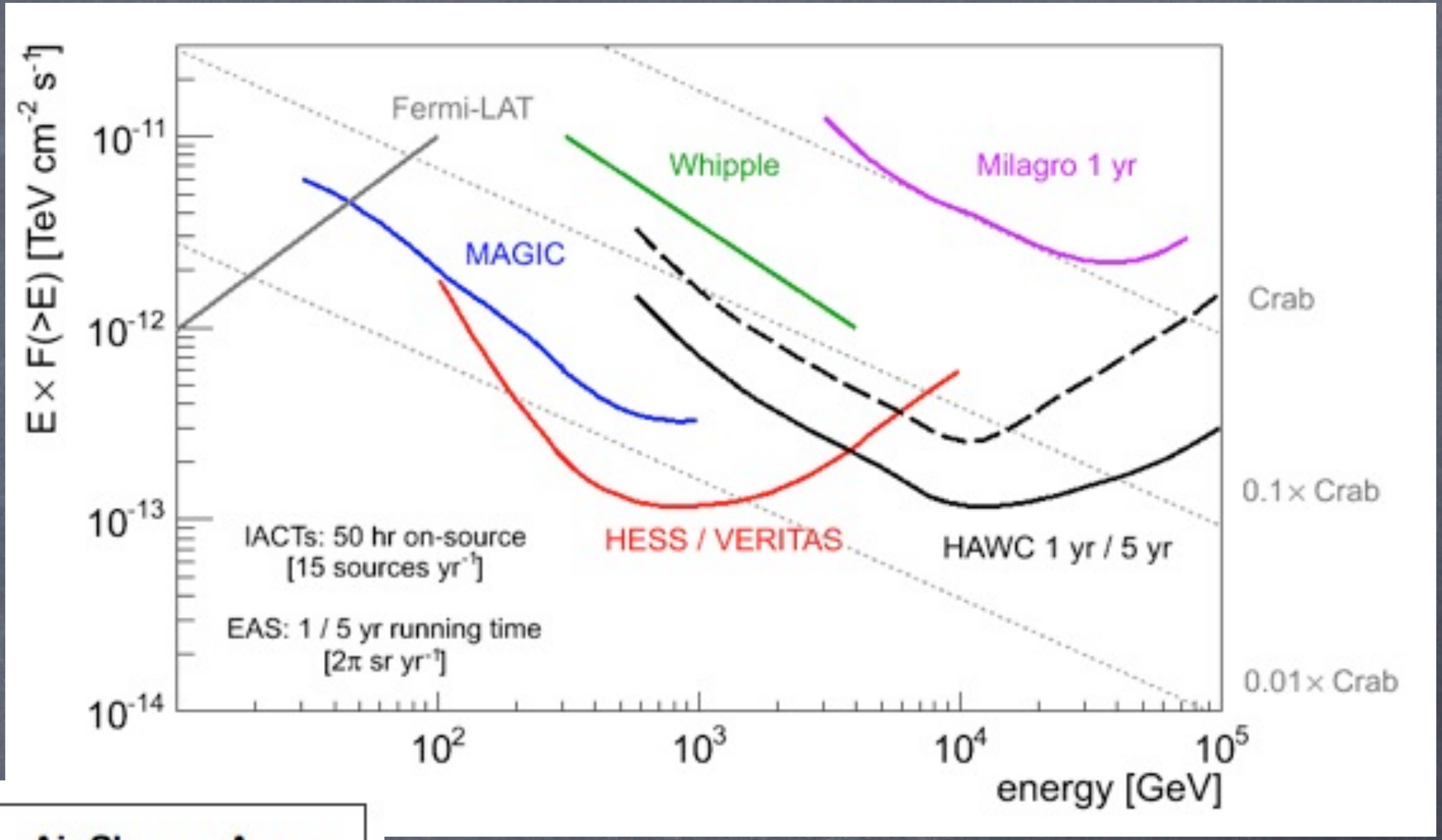
Secondary particles in the air shower produced when very high energy gamma-rays (> TeV) hit the atmosphere can survive to reach the ground.

Water Cherenkov detectors detect the Cherenkov light produced in water from these air showers.

Milagro (1998-2008) used a football sized pool of water filled with 723 photomultiplier tubes.

Milagro Gamma-Ray Observatory

Instrument Comparisons

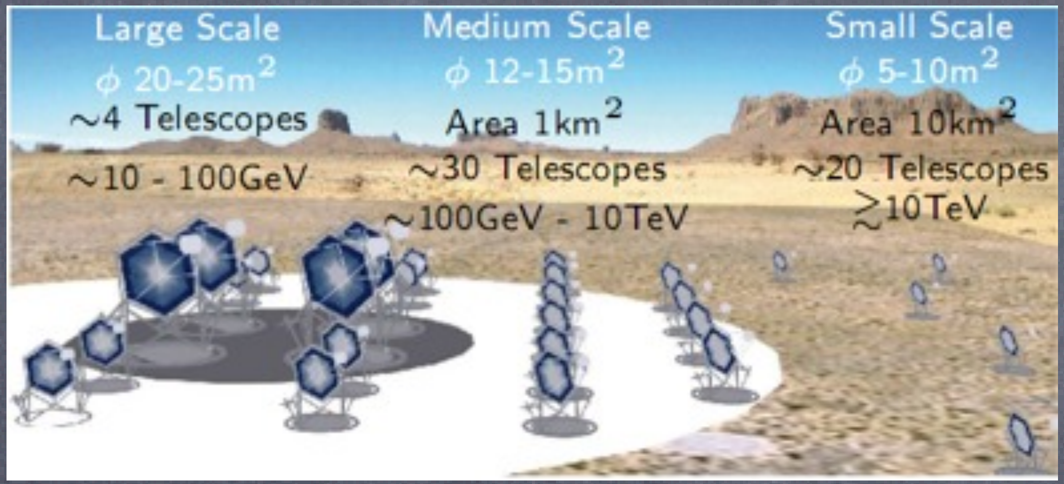


	Cherenkov Telescope	Air Shower Array
Energy Threshold	Low (<200 GeV)	High (>10 TeV)
Background Rejection	Excellent (>99.7%)	Moderate (>50%)
Field of View	Small (<2°)	Large (>45°)
Duty Cycle (uptime)	Low (5%-10%)	High (>90%)

Complementary detection characteristics of imaging air Cherenkov telescopes (IACTs) and extensive air shower arrays.

Future Telescopes

The Cherenkov Telescope Array (CTA): design is still under consideration. Both a northern and southern array are planned. Will consist of tens of telescopes of varying size (24m, 10-12m, 4-6m) to get sensitivity to both low and high energy gamma-rays.



sensitivity from tens of GeV to > 10 TeV

HAWC: will be a water Cherenkov detector composed of 300 closely packed steel water tanks each with 4 photomultipliers. Located at 4100m in Mexico.