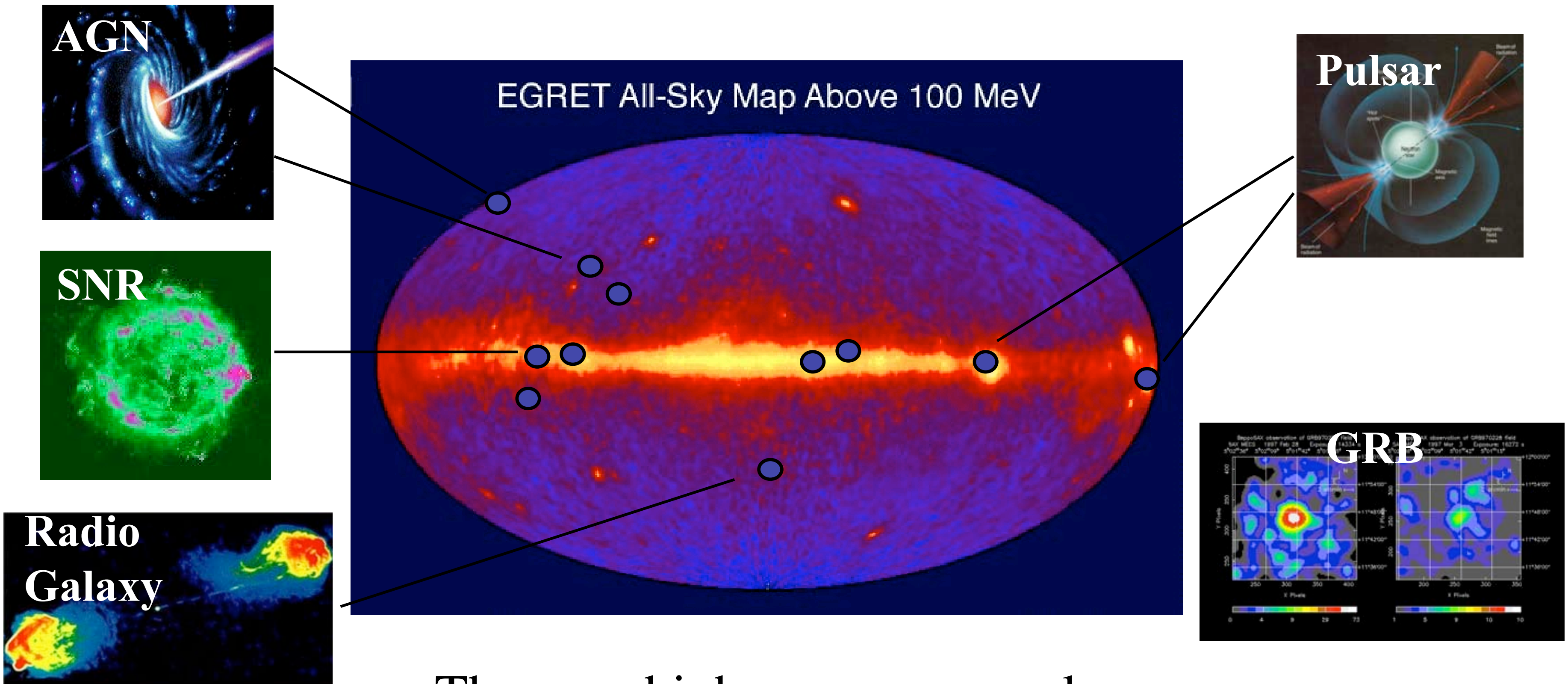
Gamma-ray Astrophysics

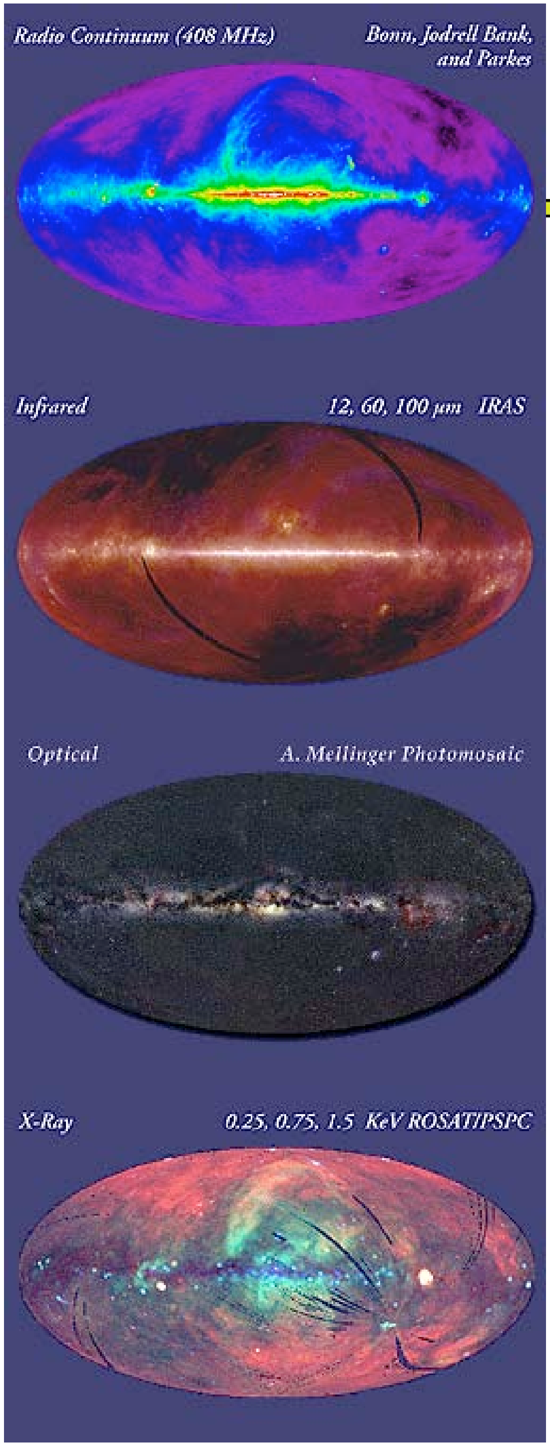


The very high energy γ-ray sky

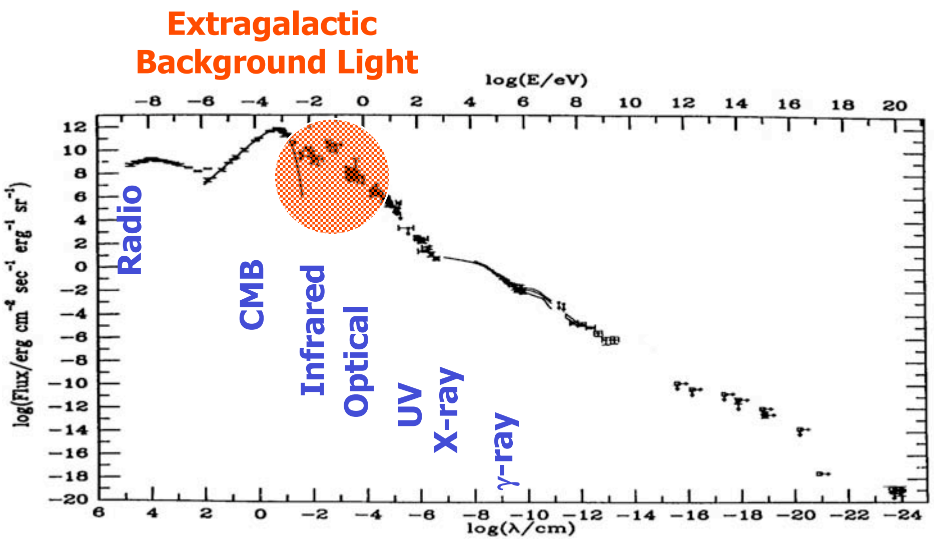
NEPPSR
25 Aug. 2004

Many thanks to
Rene Ong at UCLA

Guy Blaylock
U. of Massachusetts



Why gamma rays?



- provide insight into the most energetic and violent sources
- penetrate dust to see to the core of the galaxy

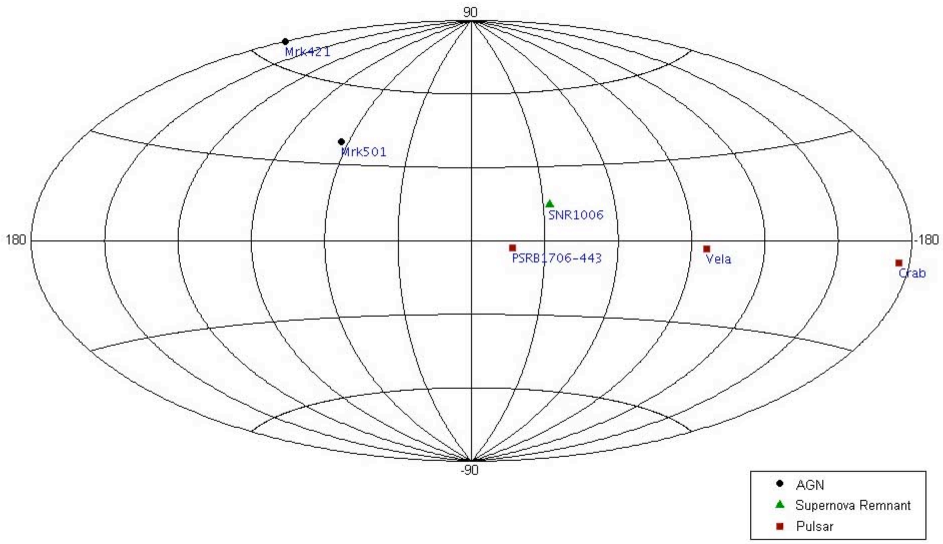
The Science of γ-rays

KNOWN (sort of)

AGN	HE γ from inverse Compton or proton cascade in jets?
γ ray pulsars	Six γ sources from EGRET. Want to see pulsed VHE γ signal.
pulsar nebulae	e.g. Crab nebula powered by central pulsar determine mechanism and nebular magnetic field
SN remnants	γ from Compton in shock wave, maybe also π^0 decay?
γ ray bursts	bursts of gamma rays lasting 10 msec to 1000 sec, some of which are associated with SN explosions

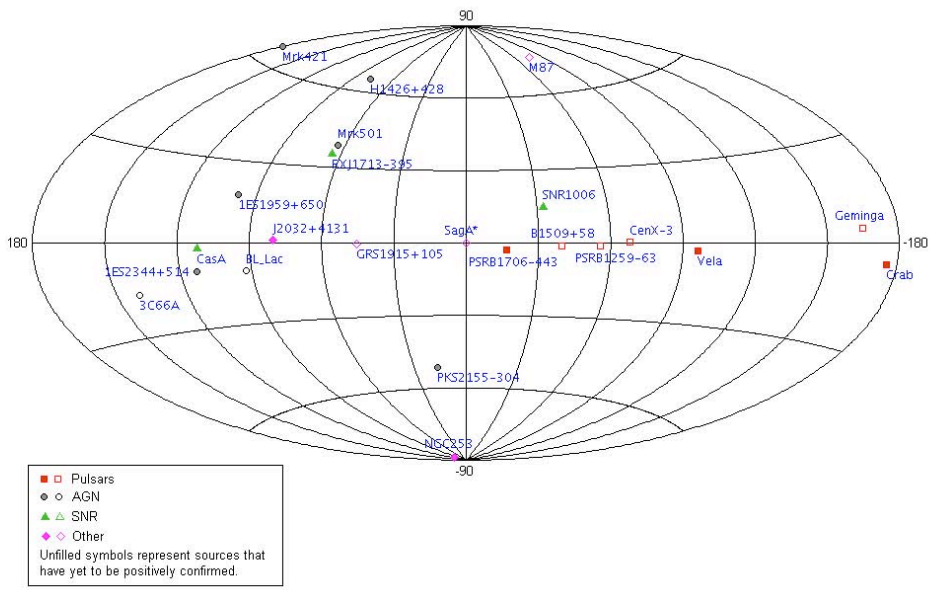
UNKNOWN

Unidentified	The majority of EGRET's ~600 sources are unidentified. New type of source still to be recognized?
New Physics	dark matter annihilation, quantum gravity, primordial black holes



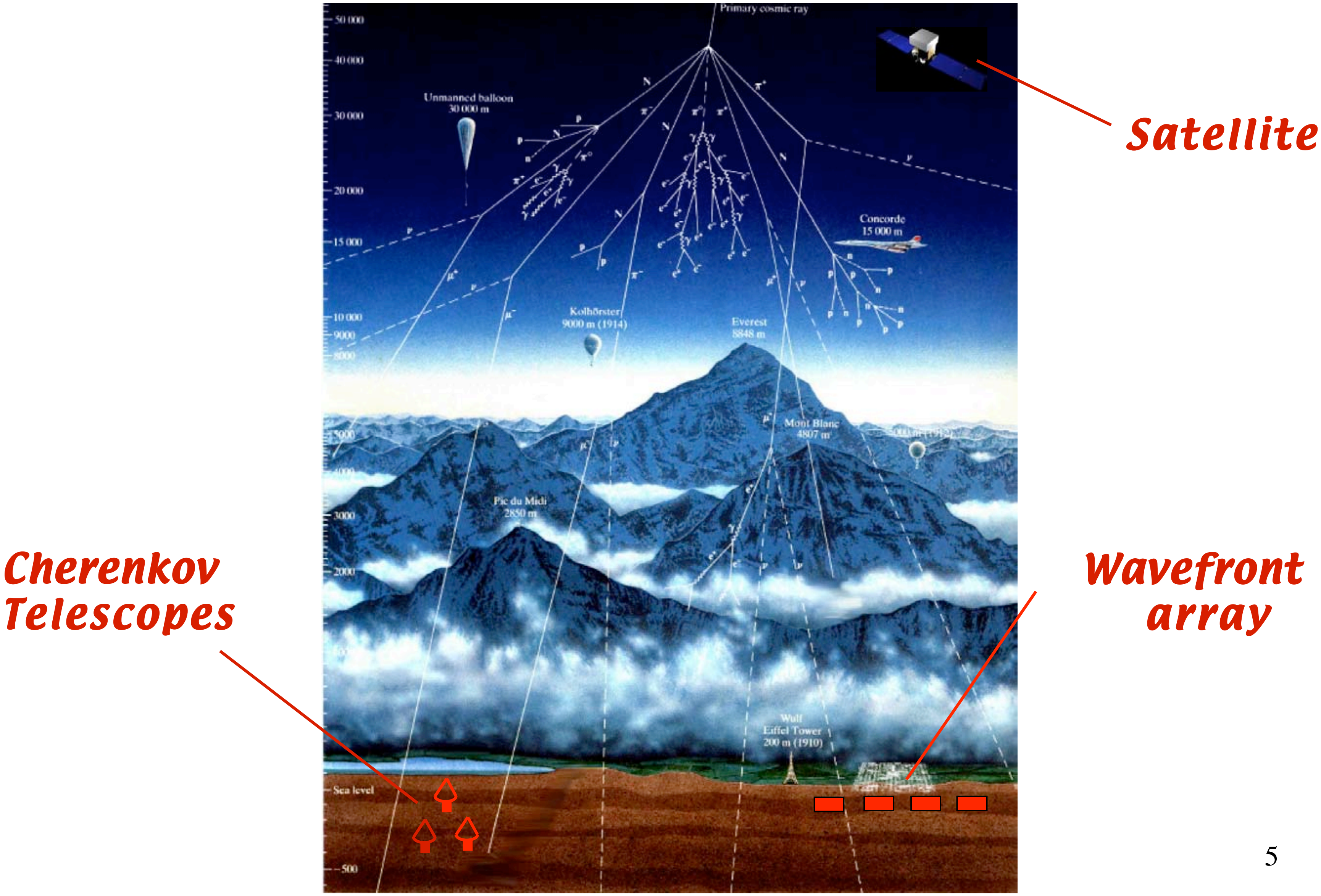
The VHE γ ray sky (2000)

Gamma ray physics is a young and rapidly growing field!



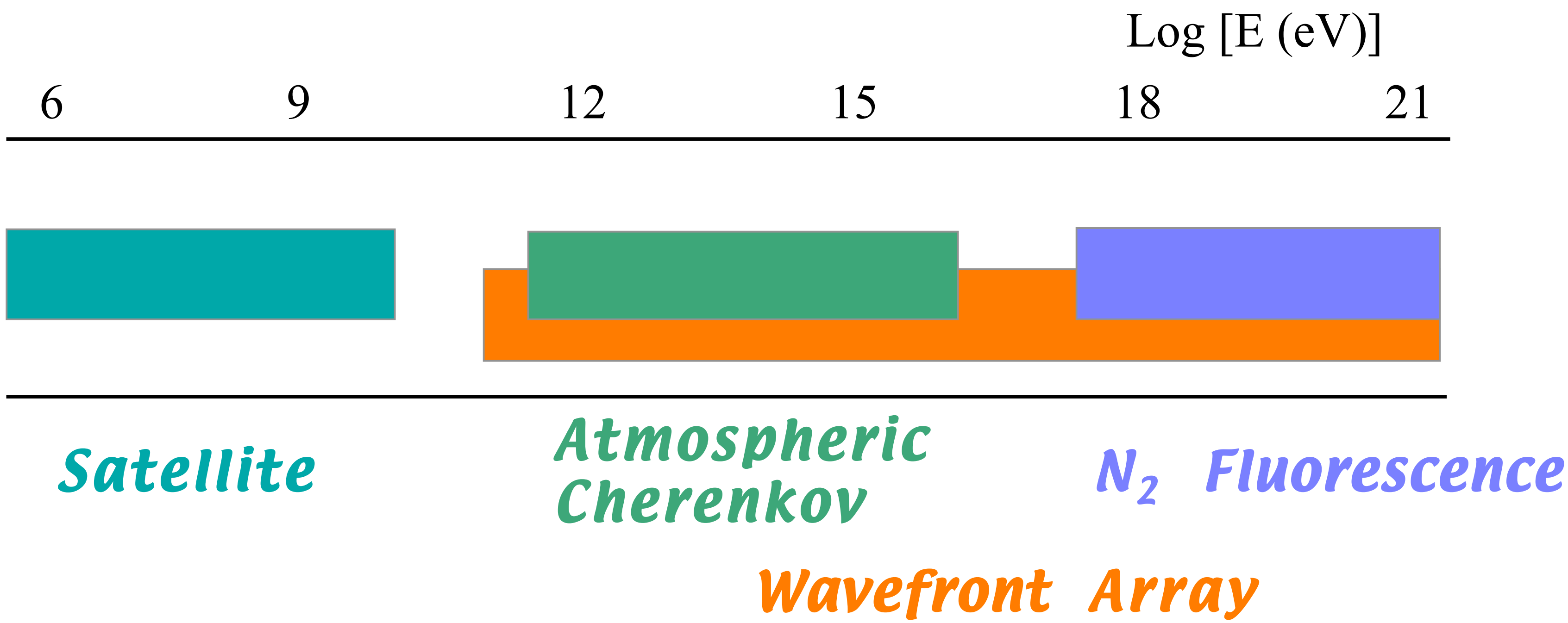
The VHE γ ray sky (2004)

Experimental Techniques



Detector Energy Ranges

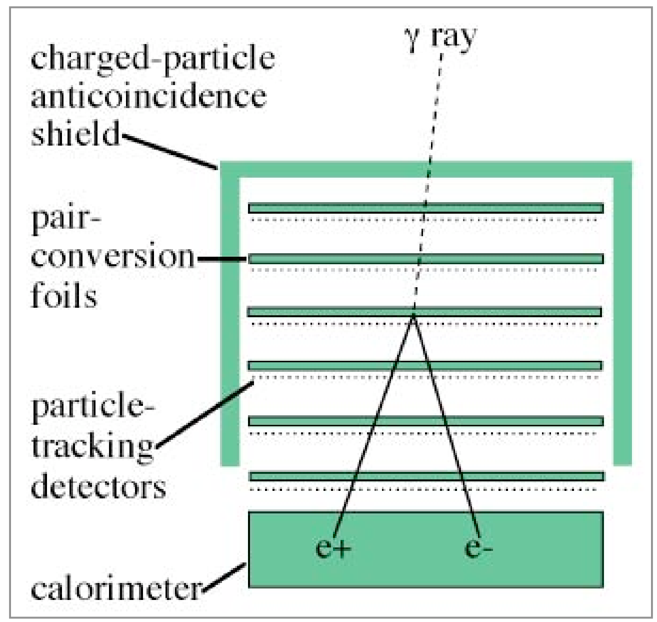
Broad energy coverage requires multiple techniques.



Satellite experiments

A γ-ray entering the detector produces an $e^+ e^-$ pair, whose direction and energy are measured.

EGRET

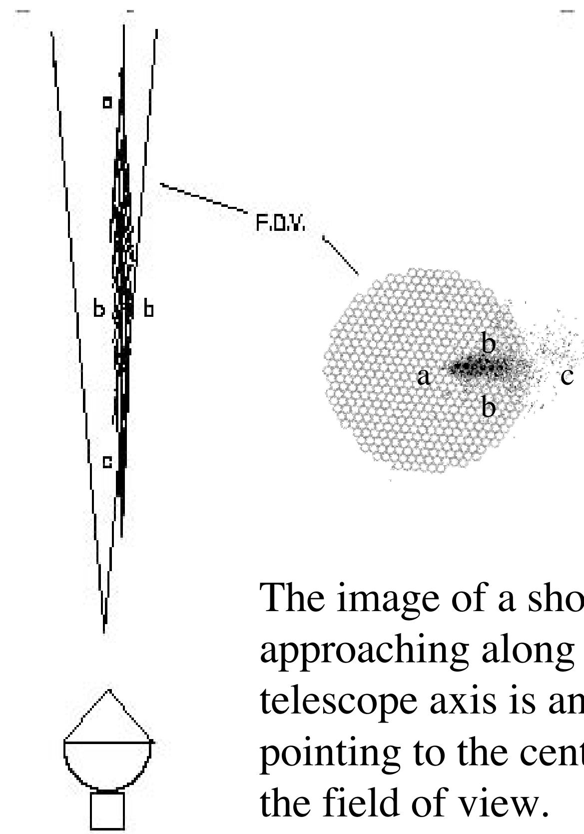


- *Flew 1991-2000.*
- *Very successful mission.*
- *Energy range 30 MeV - 20 GeV.*
- *Detected ~ 600 sources..*

Cherenkov Imaging Telescopes

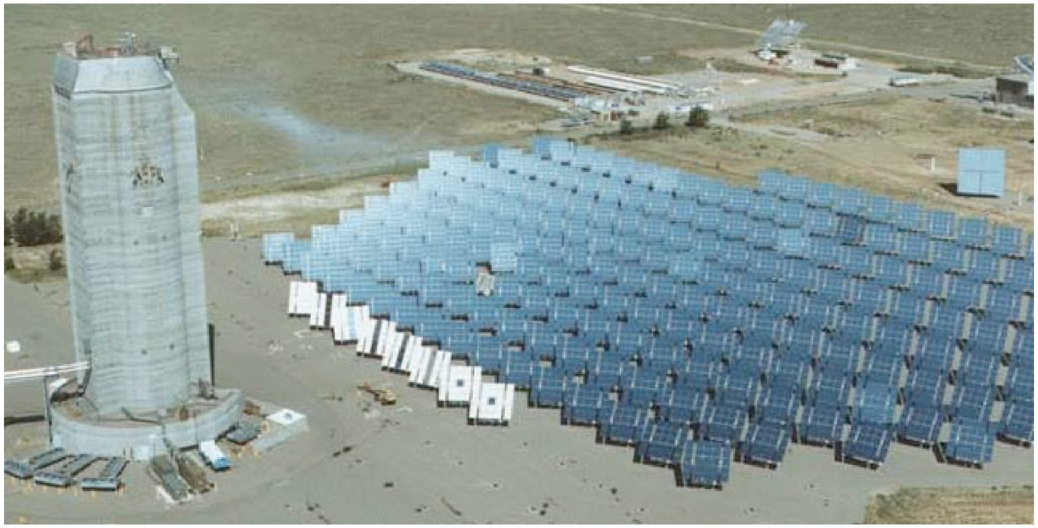
A γ ray interacts in the upper atmosphere and produces an EM shower. Particles in the shower produce Cherenkov radiation that is detected by the telescope.

Whipple 10m (Arizona)



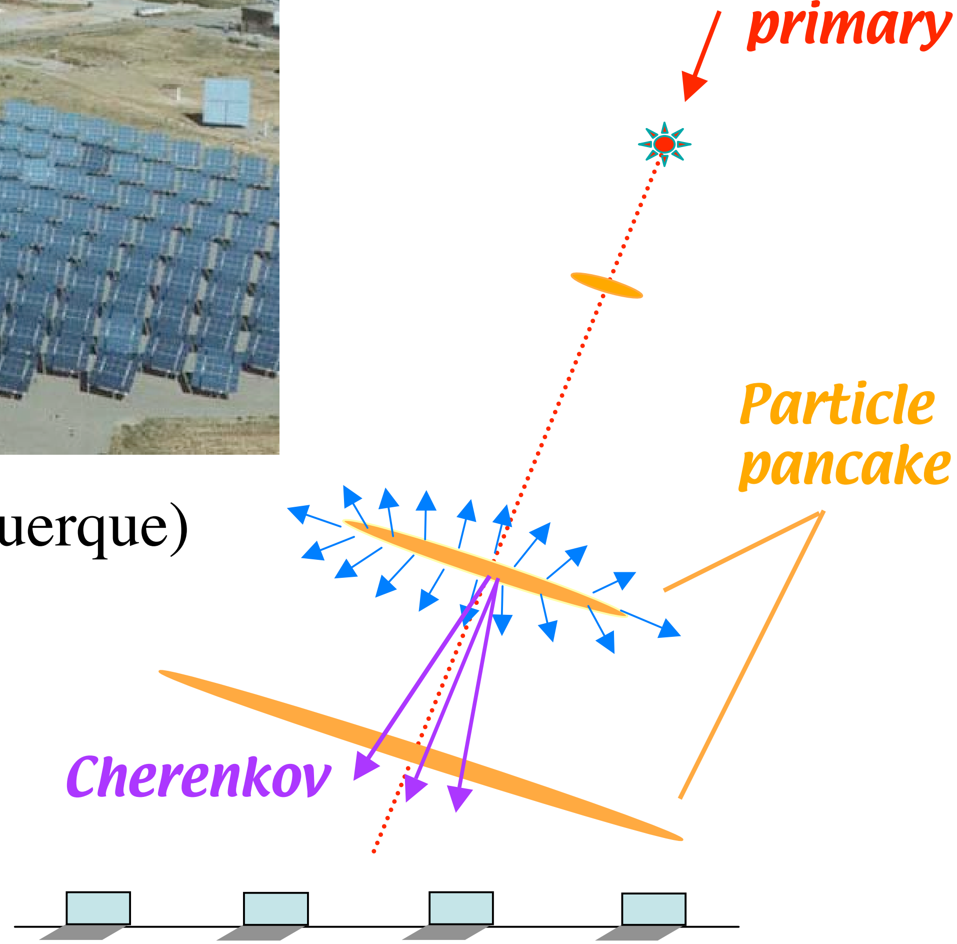
The image of a shower approaching along the telescope axis is an ellipse pointing to the center of the field of view.

Cherenkov Wavefront Detectors

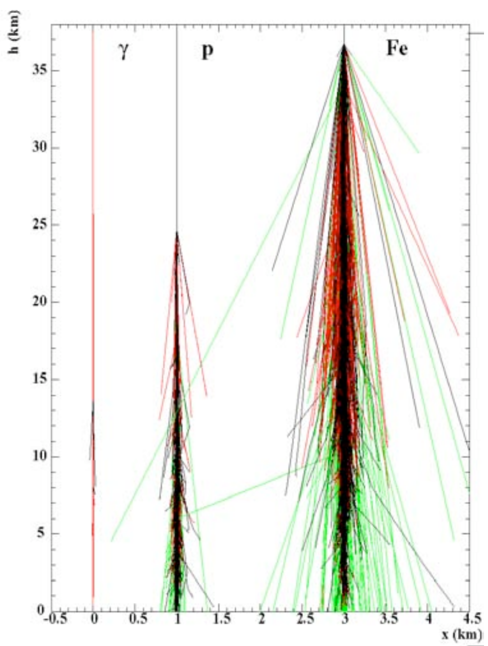


STACEE solar array (Albuquerque)

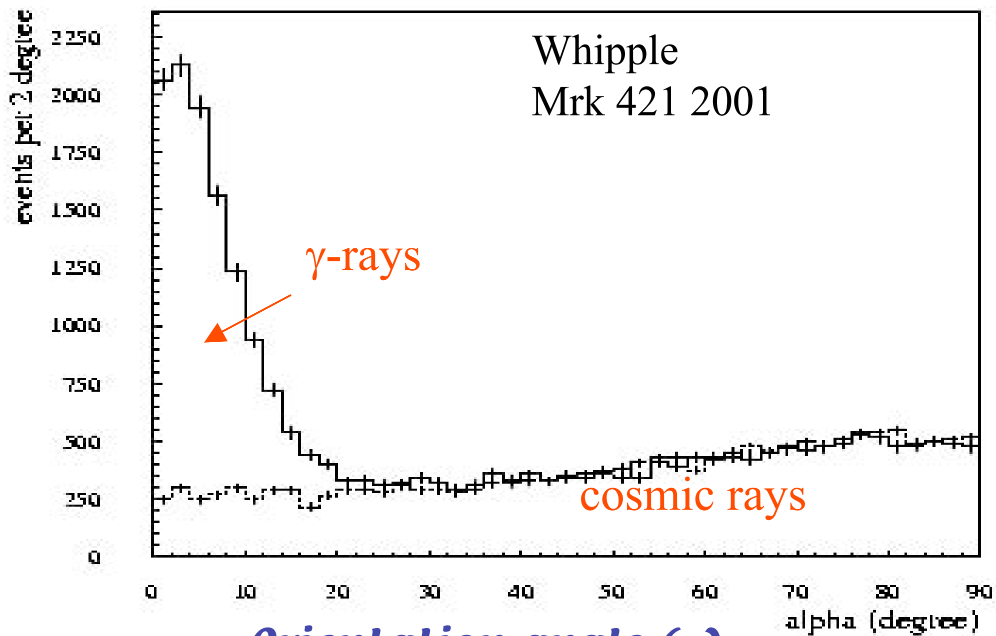
A flat Cherenkov wavefront only a few nanoseconds thick is measured by an array of detectors. Careful timing determines the direction of the wavefront.



Identifying γ-rays

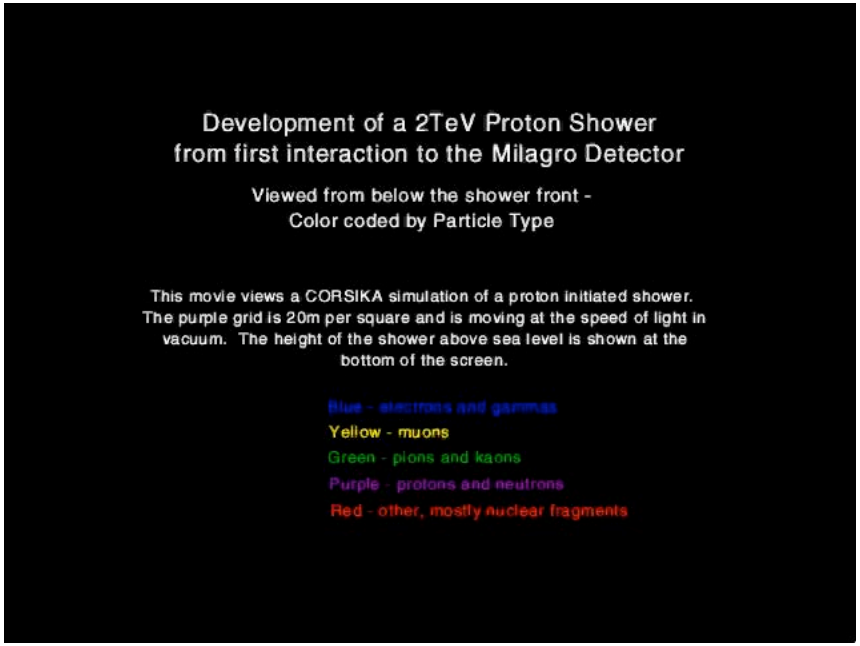


Shower profile in atmosphere



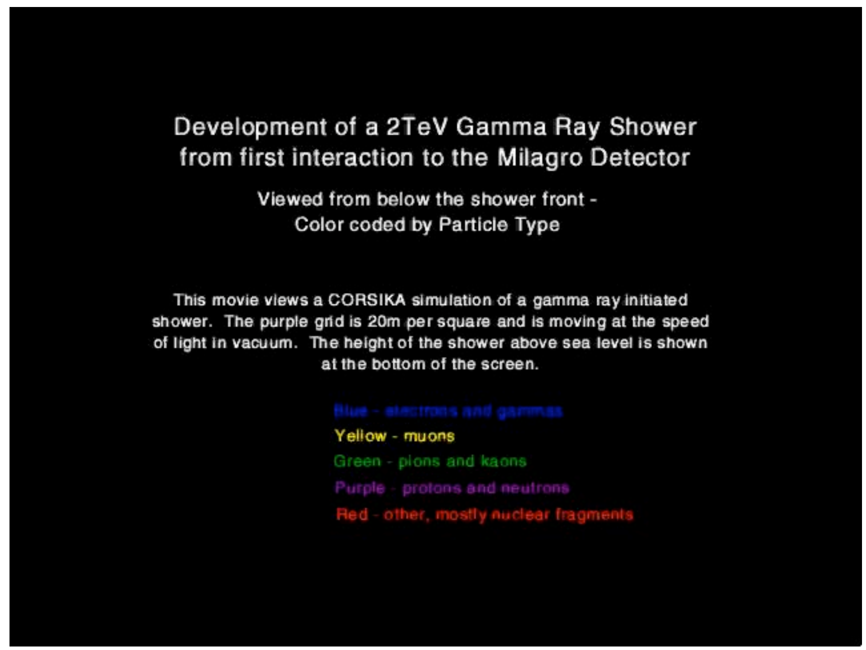
Orientation angle (α)

- ***Use shower shape and orientation to discriminate between gammas and hadrons***
- ***Rejection factor ~300 for a single telescope***



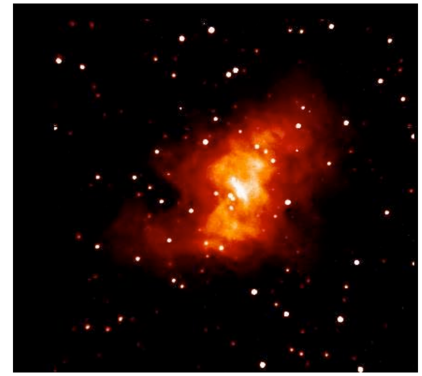
2 TeV proton shower

2 TeV gamma shower



VHE γ-ray Sources

Broadly speaking, there are two types of sources:



Crab nebula

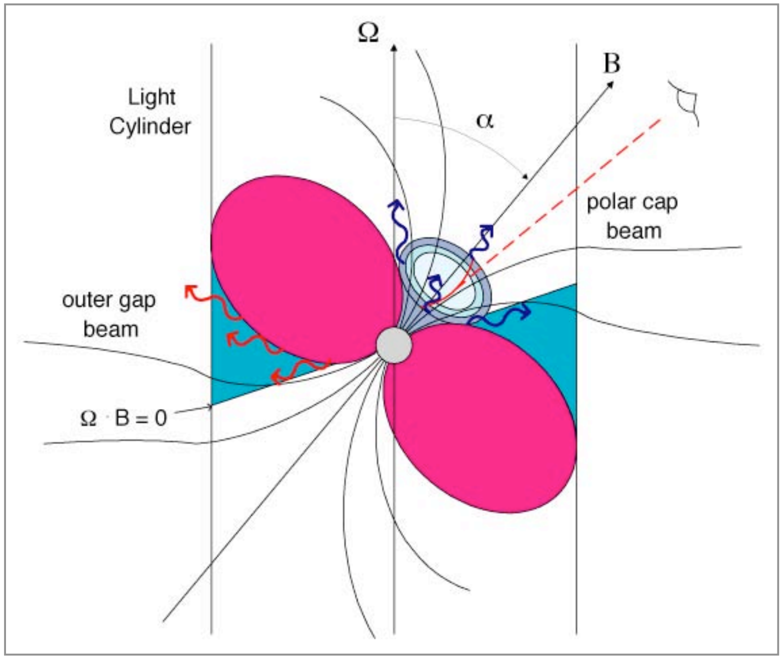
1. ***Electromagnetic***
   - ***Rotating magnetized object (Pulsar)***
2. ***Gravitational***
   - ***Core collapse of a massive star (SN and its remnant)***
   - ***Accretion onto a compact object (Black hole and other)***

BH model

These are somewhat intertwined - eventually acceleration is done electromagnetically, and often both are involved.

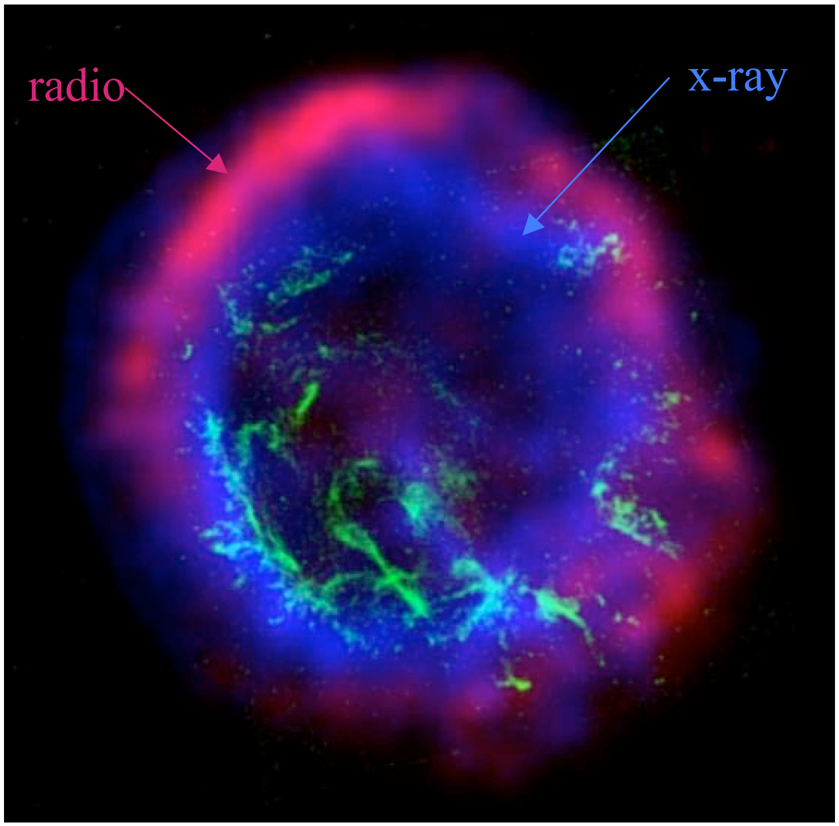
Pulsars

Crab Pulsar



- *Highly magnetized rotating neutron star accelerates charged particles.*
- *These charges escape along open magnetic field lines in jets.*
- *In the process, they radiate and scatter photons to high energies.*
- *Details depend on specific models.*

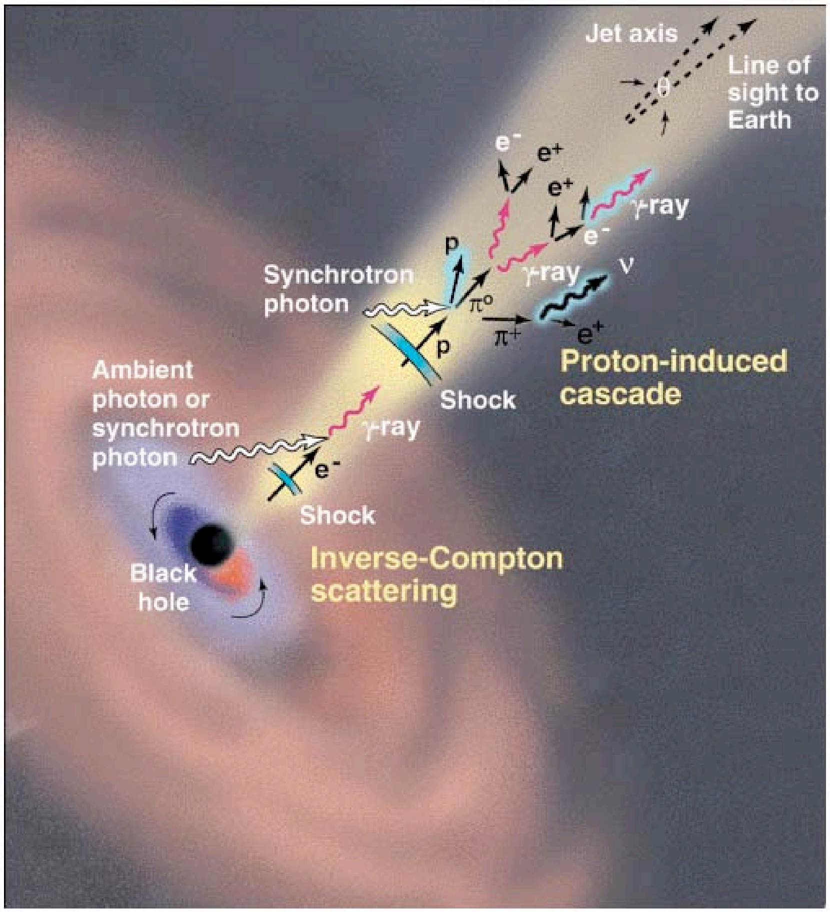
Supernova Remnants



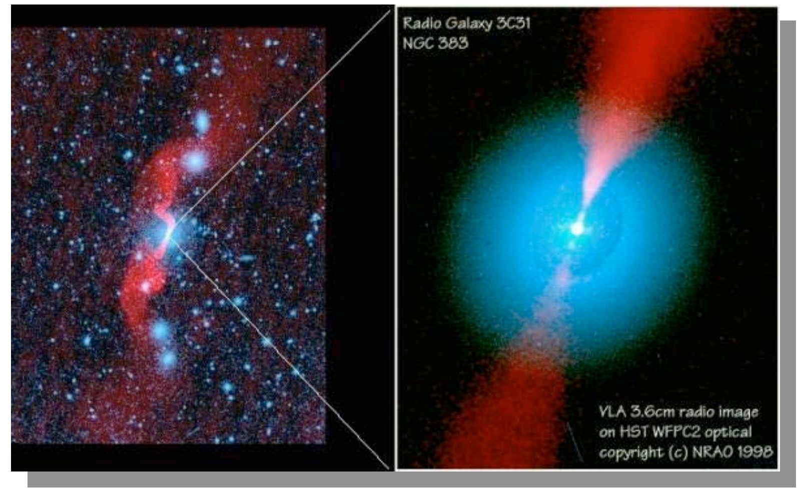
SNR E102

- *Collapse of massive star.*
- *Outer layers ejected with $v \sim 1\text{-}2 \times 10^7$ m/s.*
- *Shell expands and shock front forms as it sweeps up material from ISM.*
- *In ~ 10^4 yrs, the blast wave slows and dissipates.*
- *The particle acceleration mechanism is under study.*

Active Galactic Nuclei



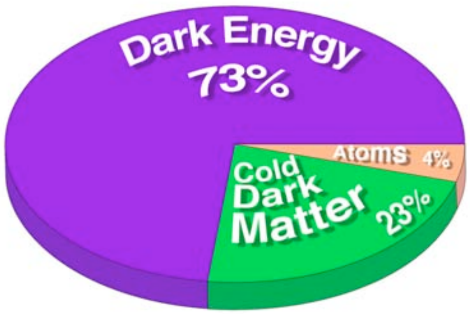
AGN model

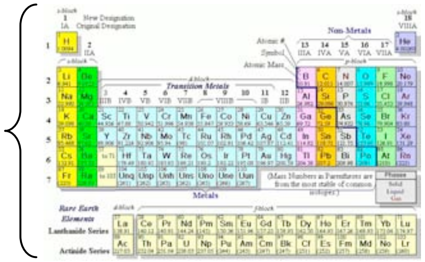


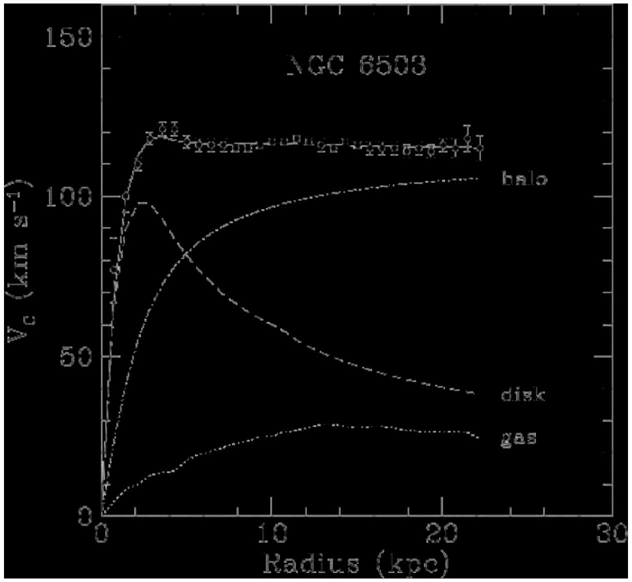
- *AGN are likely powered by accretion onto BH's of 10^6 - 10^9 solar masses.*
- *Matter falling in from rotating accretion disk powers relativistic jets.*
- *Time variations indicate gamma rays probe to within 10 Schwarzschild radii of the BH !*
- *Leading candidate for UHE cosmic rays.*

Dark Matter

- *The matter in galaxies can be determined from rotation curves.*
- *Galaxies are bound by mass far bigger, and distributed more diffusely, than baryonic mass.*



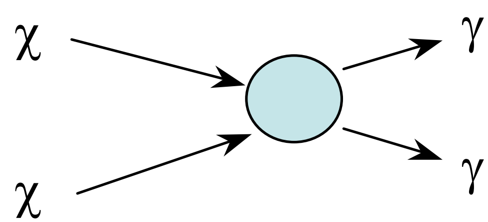




- *Known baryonic matter accounts for 4% of the universe.*
- *About 23% of the universe appears to be made of weakly interacting (non-clumping) heavy non-relativistic stuff not comprised of known particles.*
- *i.e. WIMP's*

Neutralino Annihilation

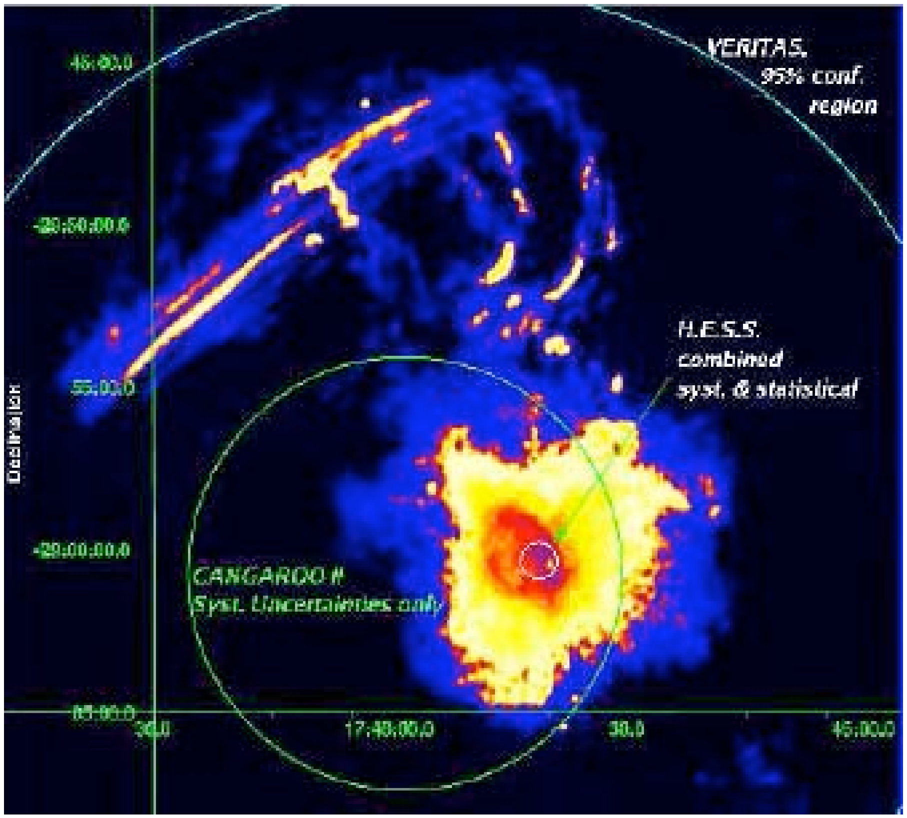
Galactic Center



$$Flux \sim (\rho / M_\chi)^2 \sigma$$

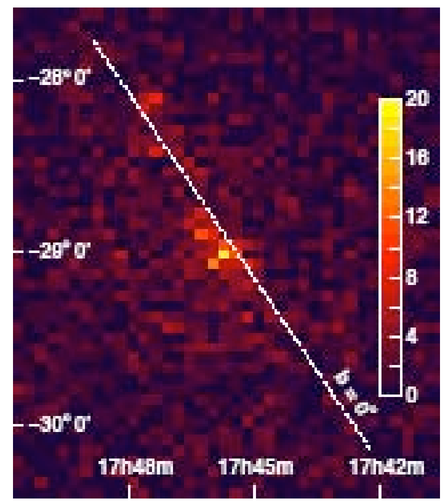
- The lightest SUSY particle (neutralino?) is a leading candidate for the WIMP.
- Density should be biggest in centers of galaxies
- Annihilation to γ-rays might be detectable.

The Galactic Center



VHE γ contours overlayed on radio (21cm) map.
Bright spot in the center is Sag A*.

Three experiments have seen VHE γ rays from the GC this year!



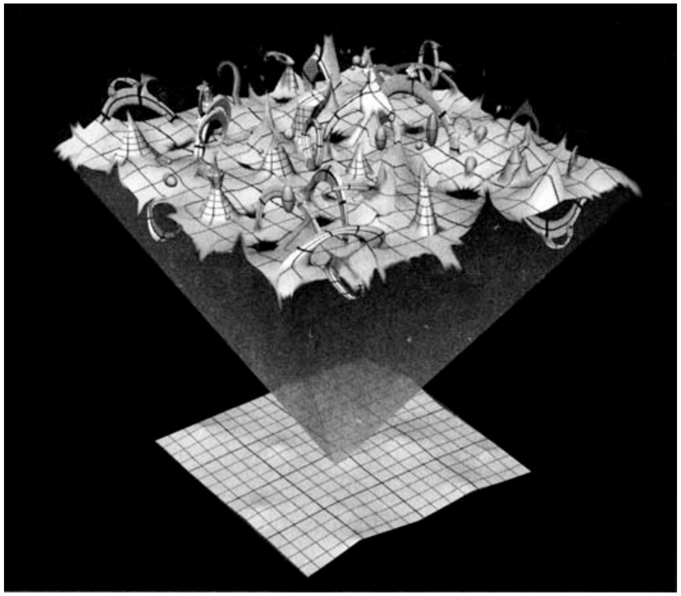
HESS 9 Aug 2004

Probably too bright for neutralinos…

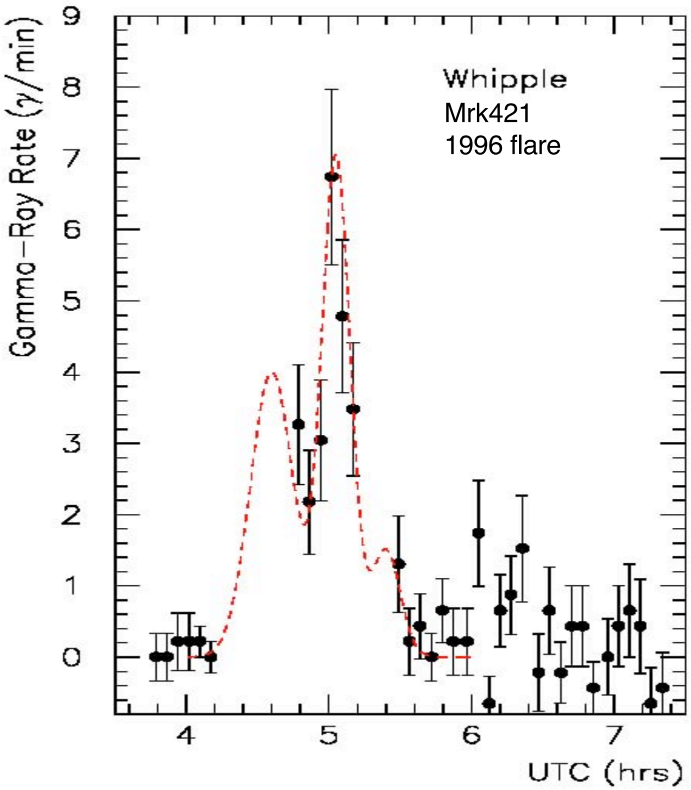
The Structure of Spacetime

Quantum gravity:

- ***Discrete space-time "foam" affects the propagation of short wavelength light***
- ***Results in dispersion (even in vacuum)***

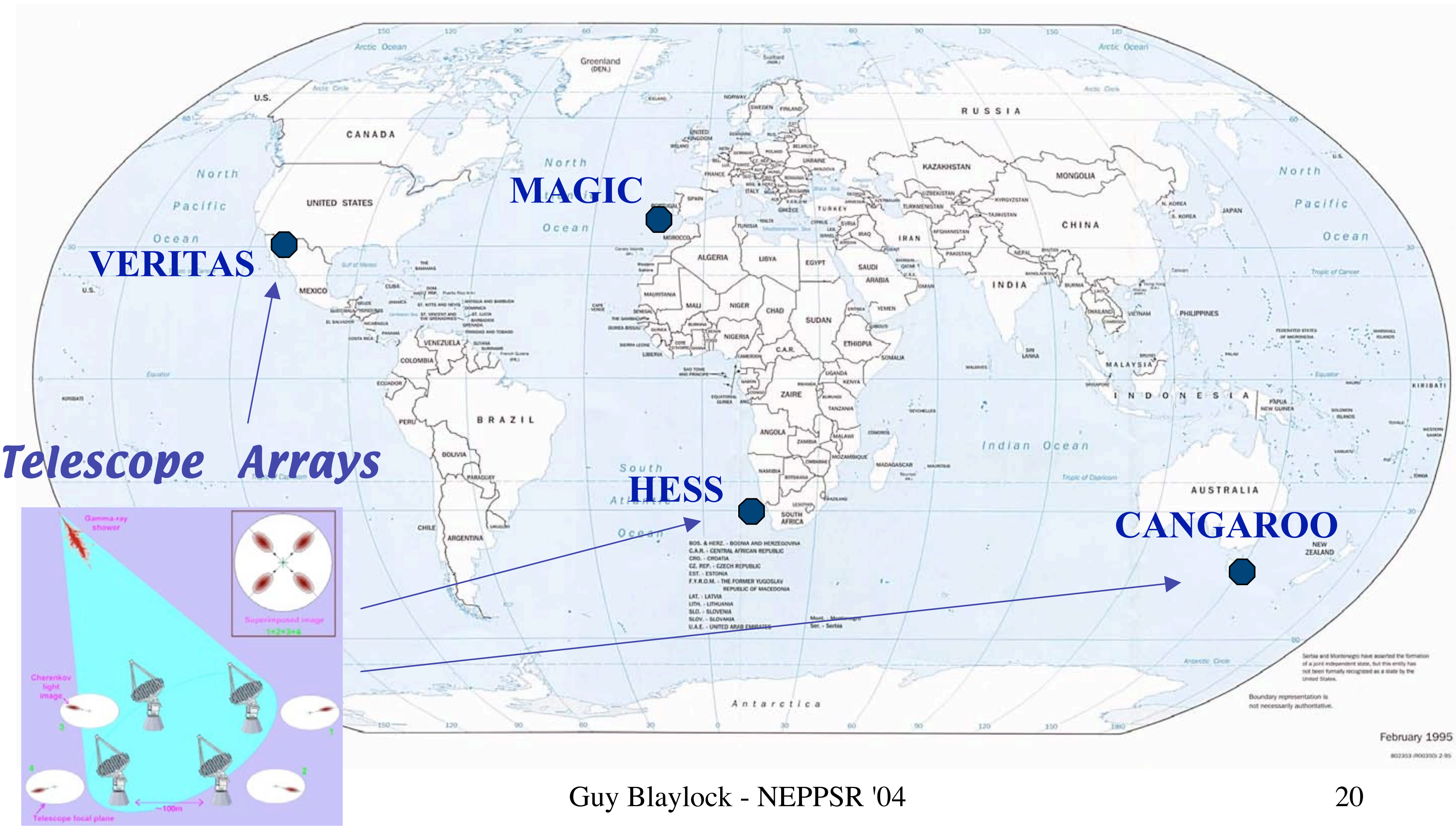


- ***Look for energy dependent arrival time difference in rapidly varying signal***

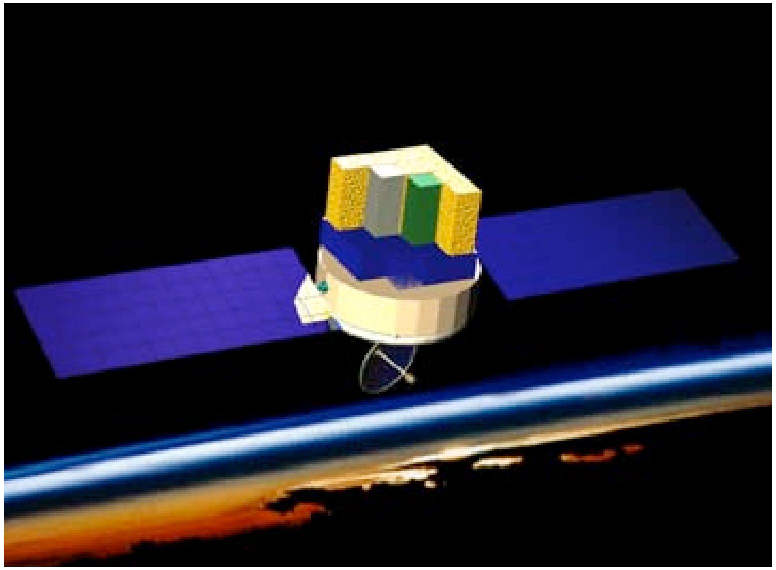


Future γ-ray Telescopes

In space **GLAST**

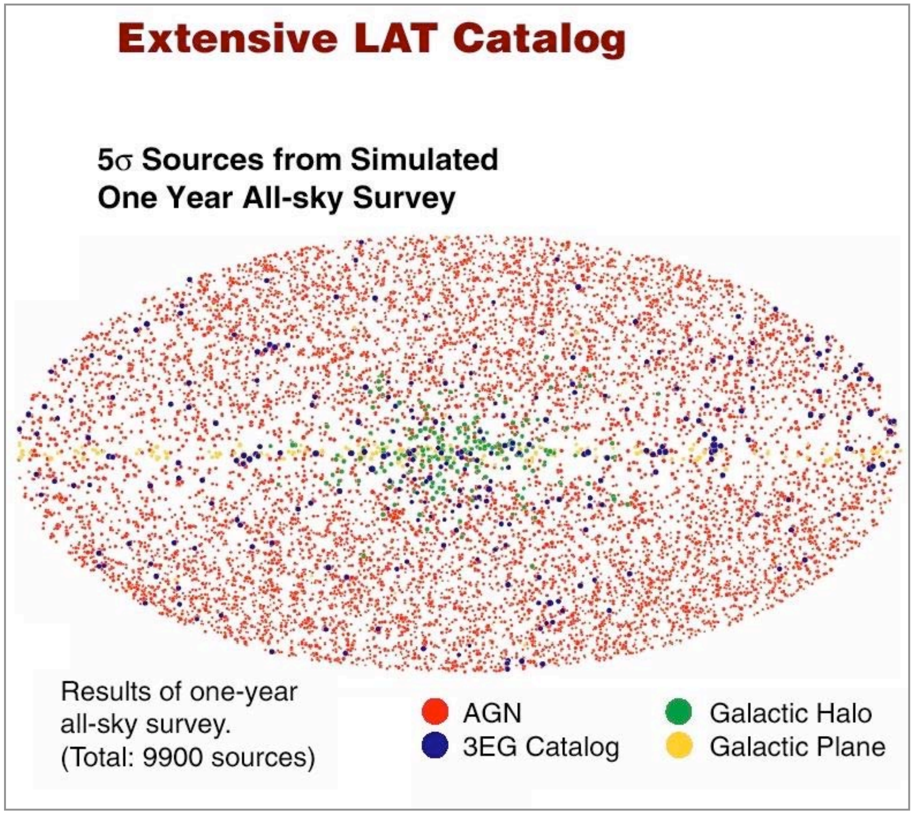


GLAST – Satellite Telescope



GLAST LAT Instrument:

- Si tracker
- CsI calorimeter
- Anti-coincidence veto
- Launch in 2007



HESS

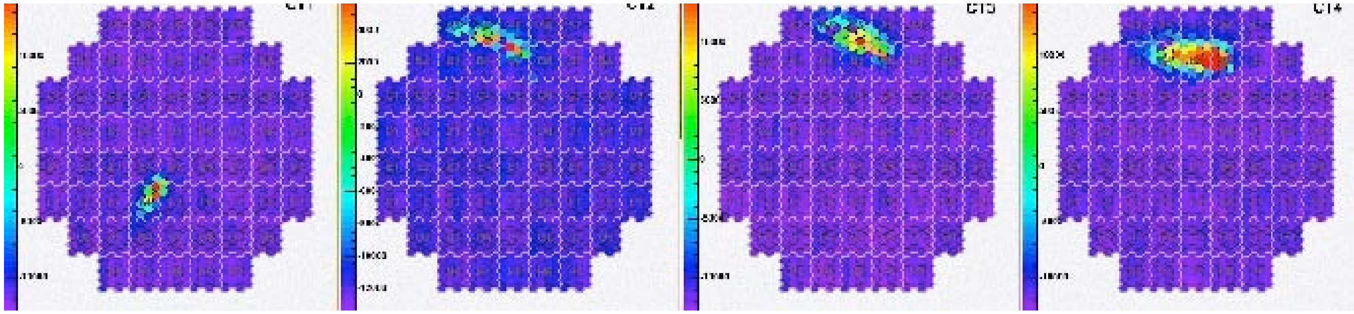
- **Jan 2004**

H.E.S.S.

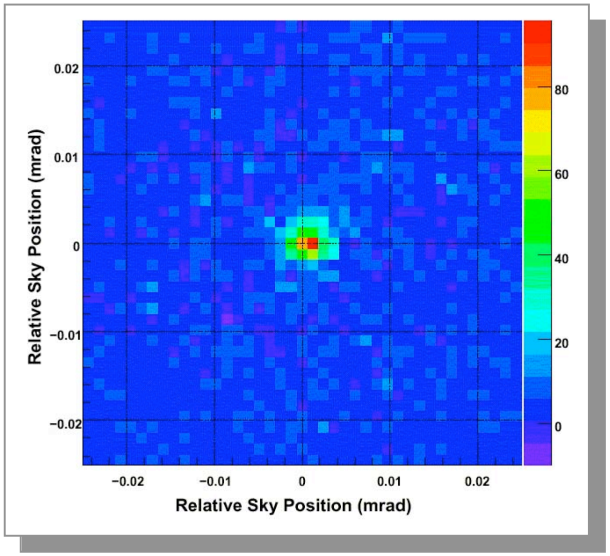
An array of four 12m telescopes in Namibia

HESS Operations

4 Telescope Event



- *4 photoelectron threshold*
- *2/4 telescope trigger*
- *Rate ~ 250 Hz.*



Detected Sources:

Crab Nebula
PKS 2155-304
Galactic Center

VERITAS

first of four telescopes

Very
Energetic
Radiation
Imaging
Telescope
Array
System

- *All major systems tested.*
- *Telescope 1 operational in fall 2004.*

CANGAROO

Four 10m telescopes in Woomera, Australia

Data taking started in March 2004

Collaboration of

Australia and

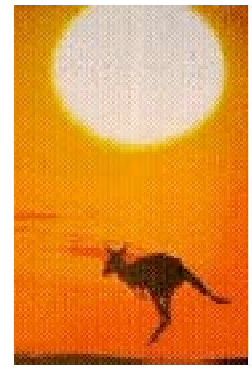
Nippon for a

Gamma

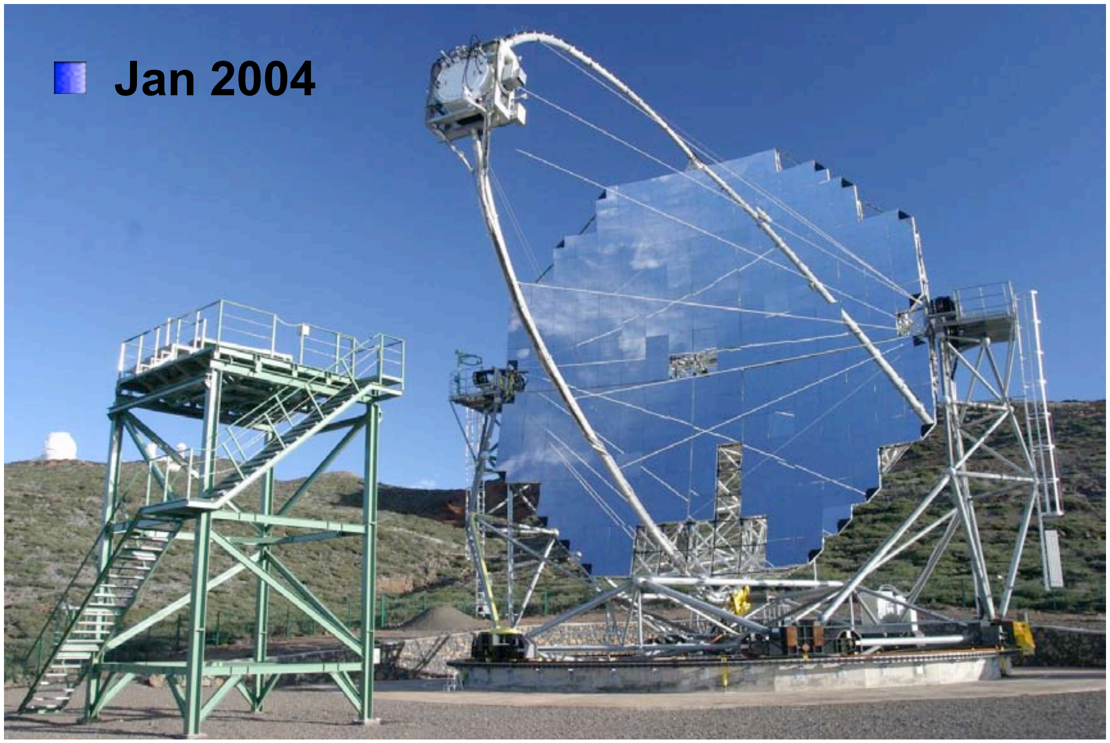
Ray

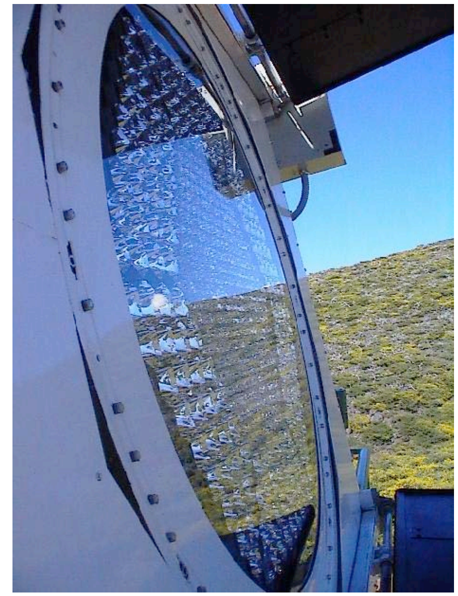
Observatory in the

Outback



MAGIC



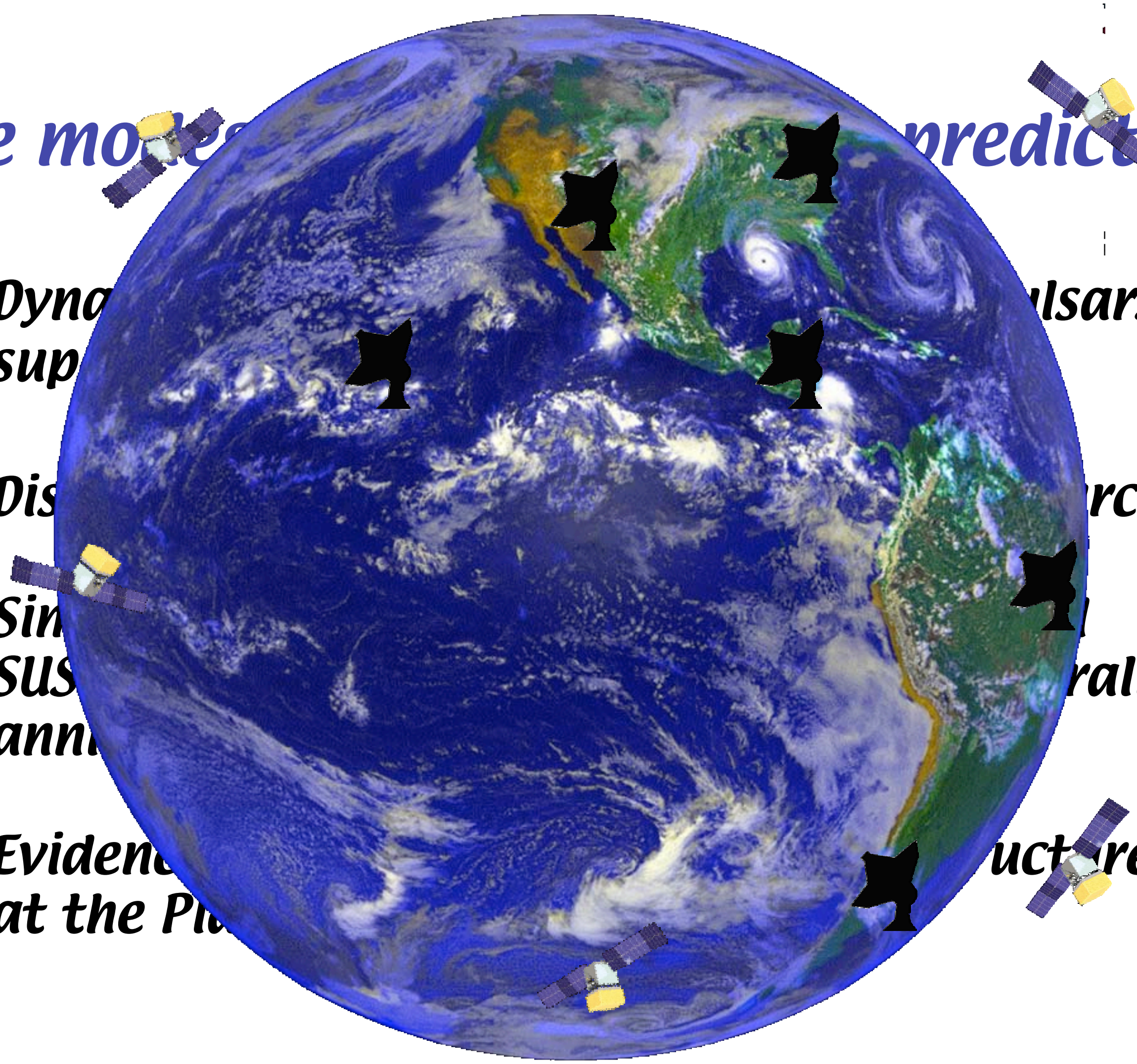


Camera

Single 17m reflector.
Started operation in 2004.

La Palma, Canary Islands

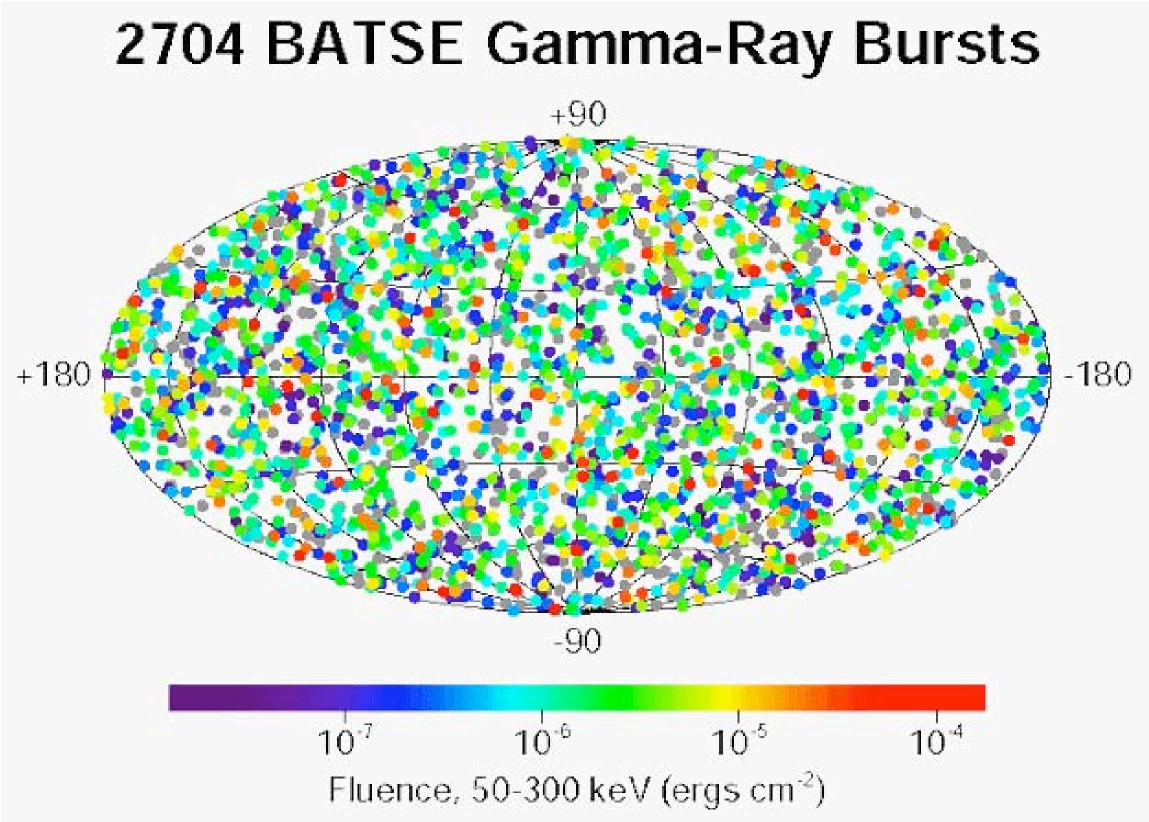
Predictions for 2020



Some mo… predictions:

- ***Dyna… ulsars, sup…***
- ***Dis… rces***
- ***Sin… SUS… ralino ann…***
- ***Eviden… ucture at the Pl…***

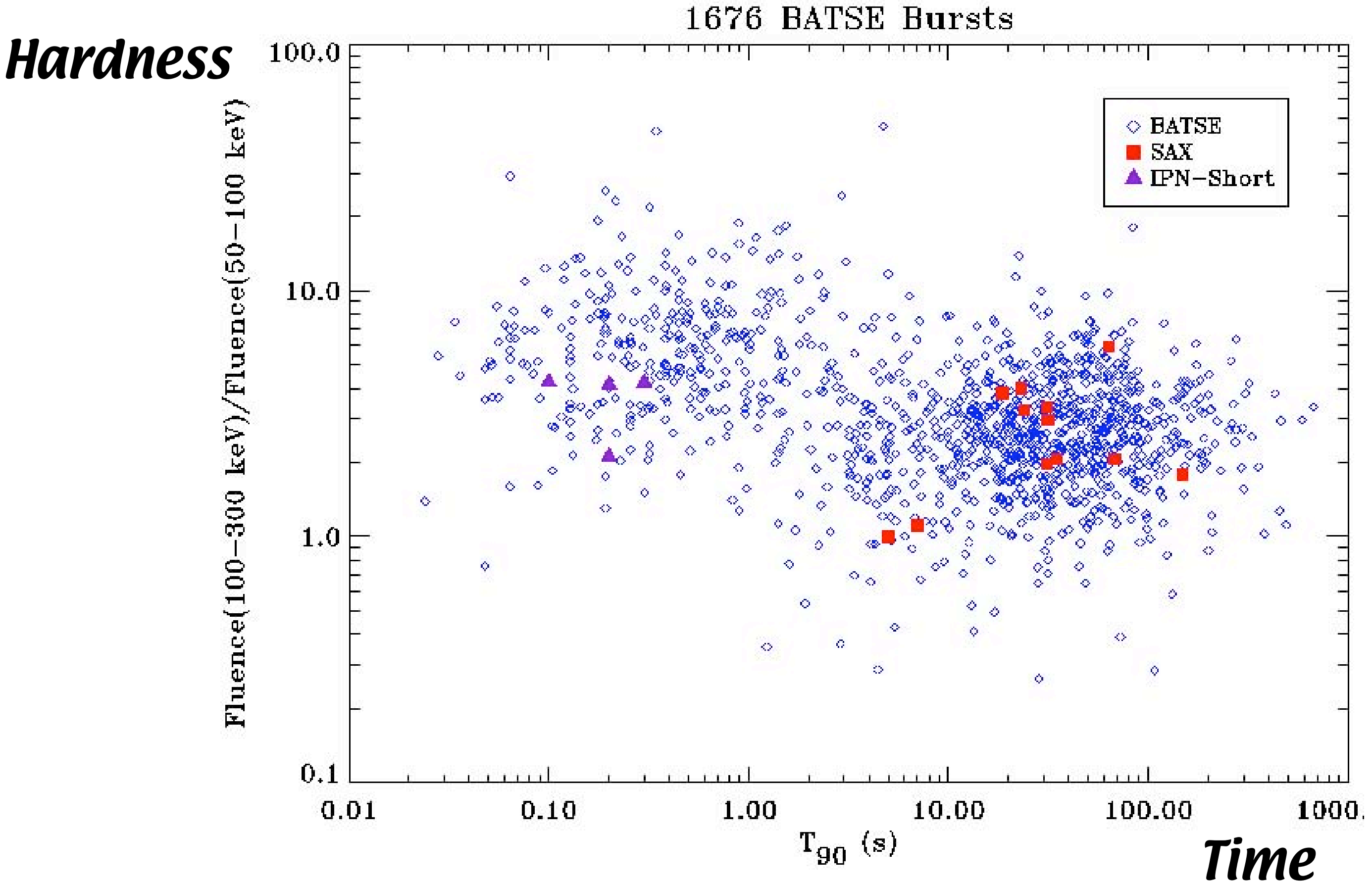
Gamma-Ray Bursts



- ***Isotropic distribution.***
- ***~ 1 burst /day.***
- ***0.01 s → hrs.***
- ***Several seen to GeV.***

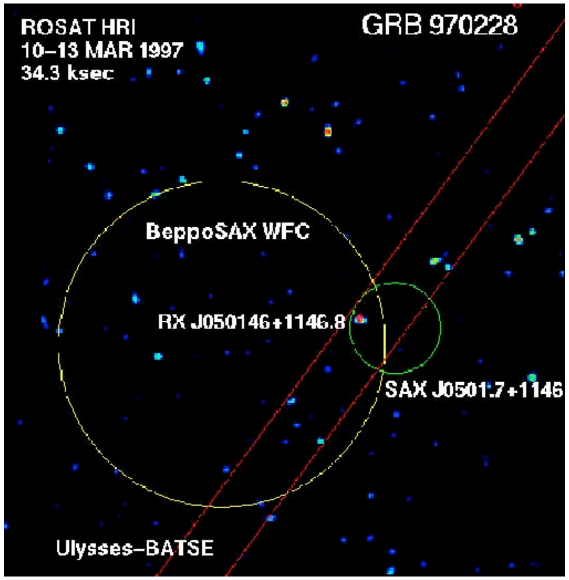
- ***Complicated & unpredictable profiles.***

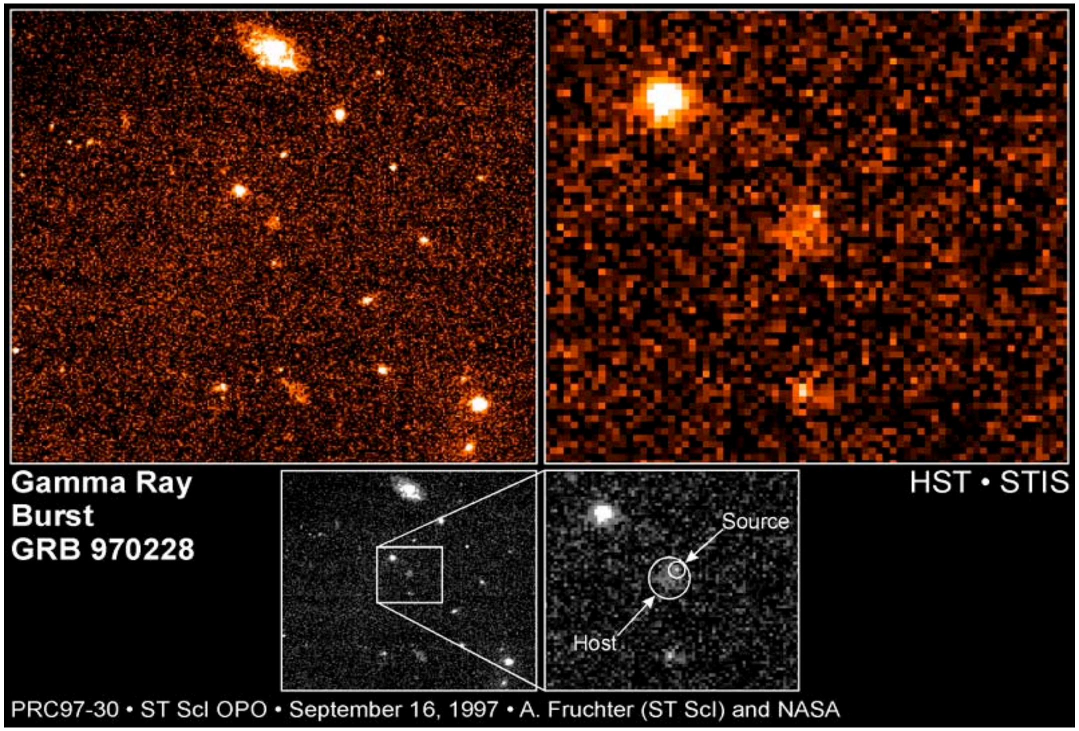
GRB Populations



- *Two populations - different origins?*

Afterglows Detected

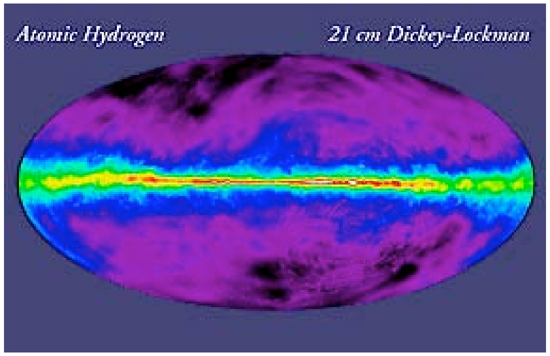


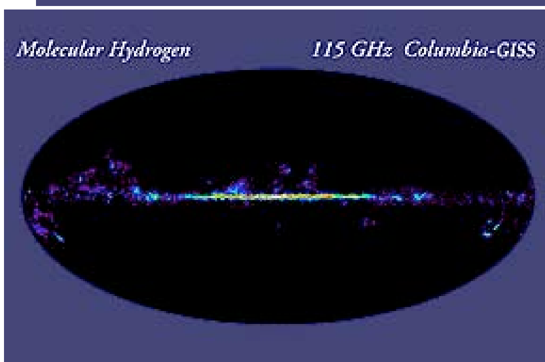


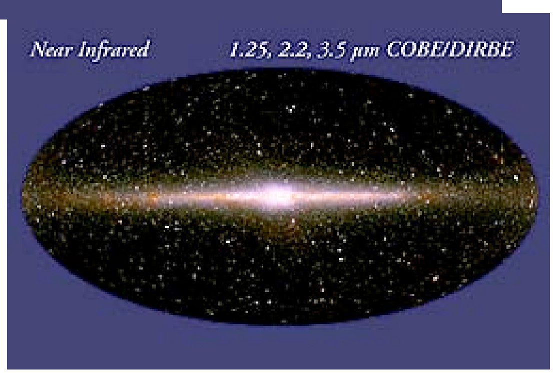
- ***1997: Detection of X-ray afterglow → optical counterparts.***

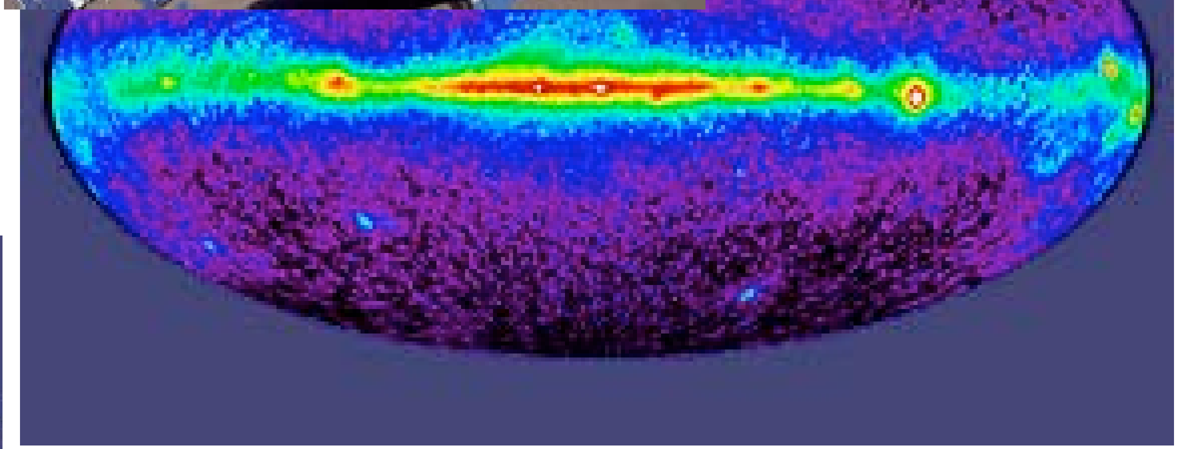
  → redshifts.

Extra figures









Extra Figures II