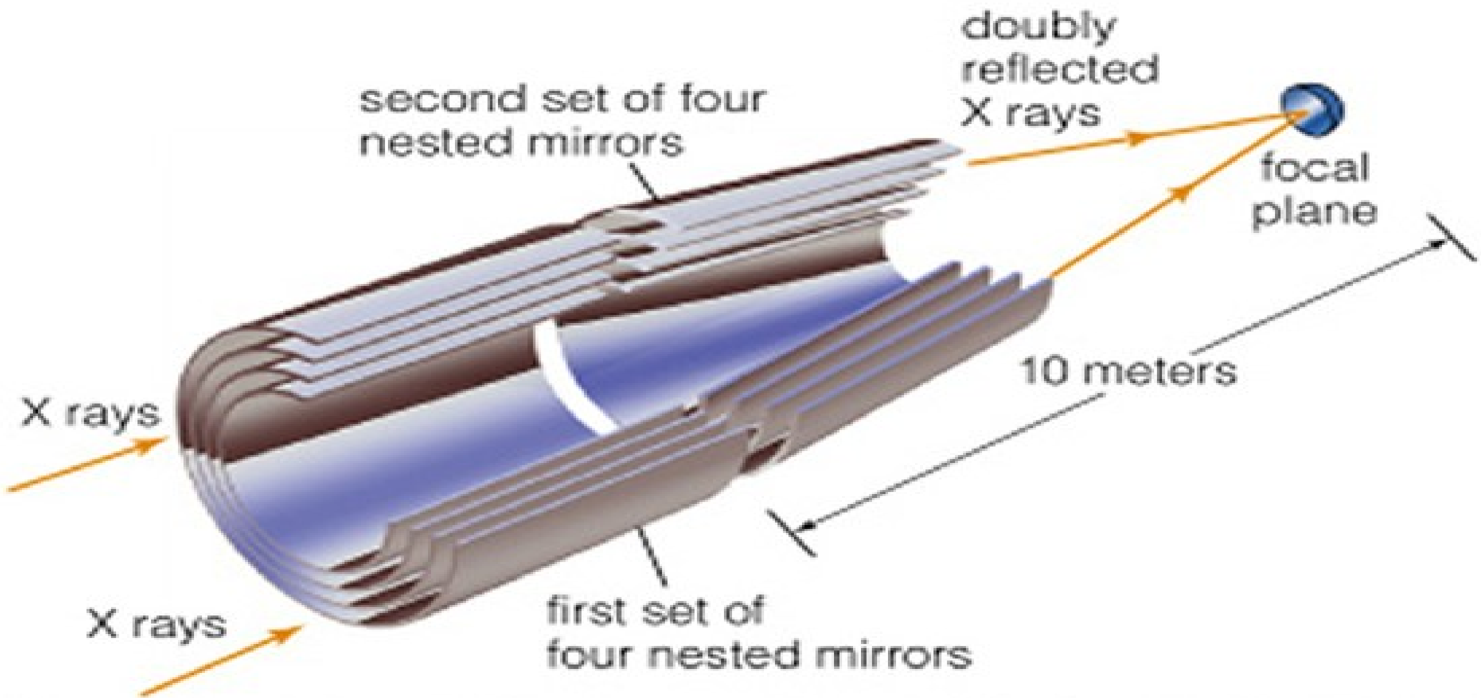
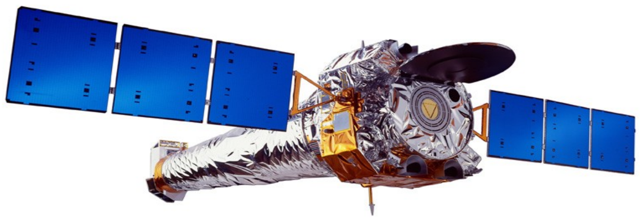
Gamma-rays telescopes

X-rays telescopes



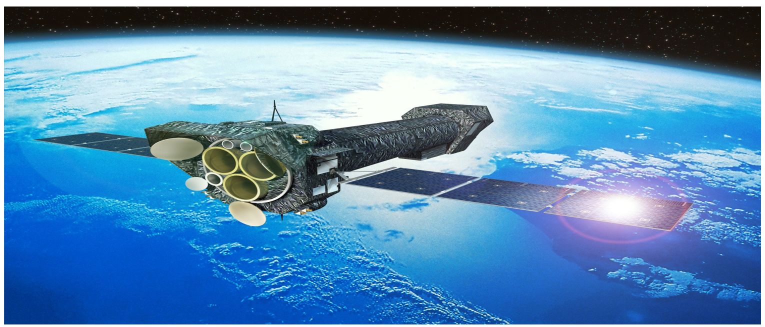
Mirror elements are 0.8 m long and from 0.6 m to 1.2 m in diameter.

X-rays telescopes in space



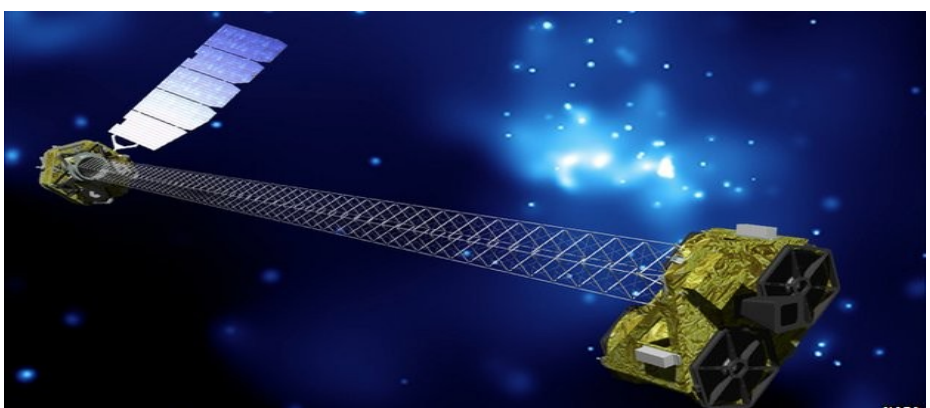
Chandra Xrays Observatory (NASA)
1999 -

Energy range : < 10 keV
Ang. Res : 0.5''



XMM-Newton Telescope (ESA)
2000 -

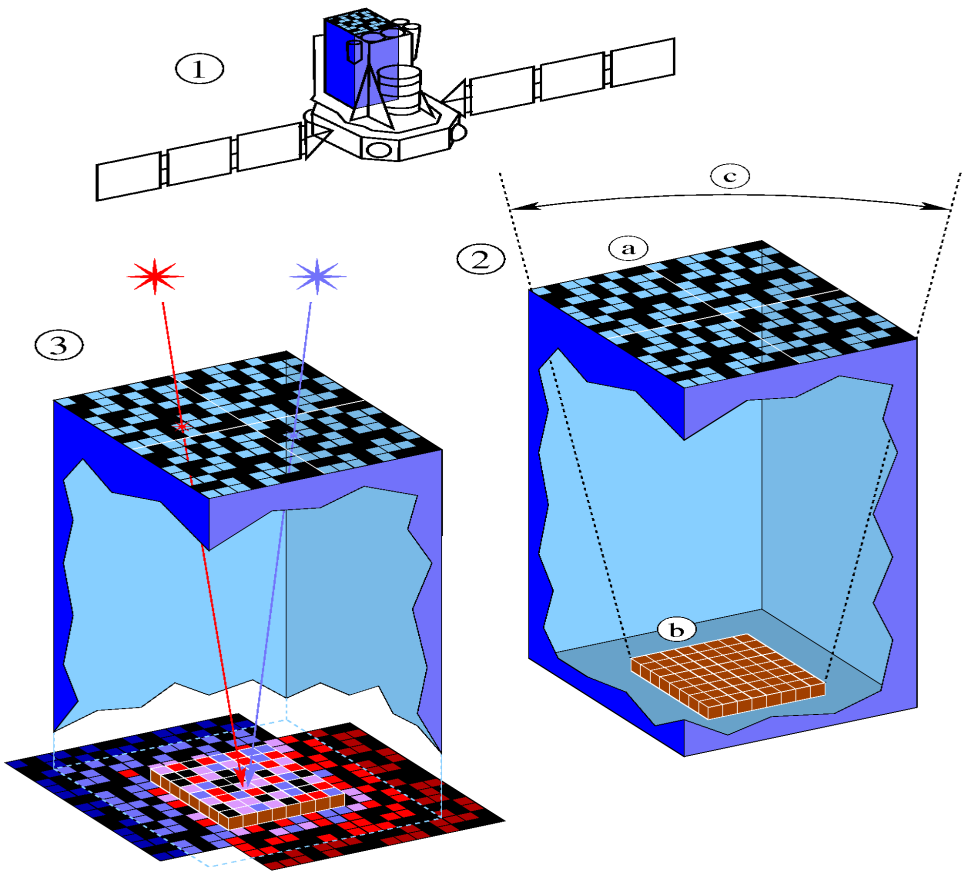
Energy range : < 15 keV
Ang. Res : 5'' – 10 ''



NuSTAR (NASA)
2014 -

Energy range : < 80 keV
Ang. Res : 10 ''

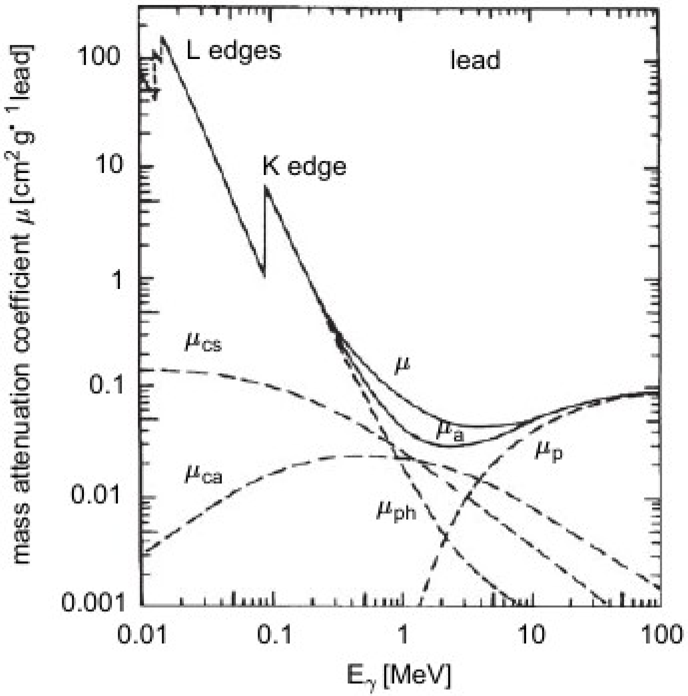
Coded Mask Telescopes

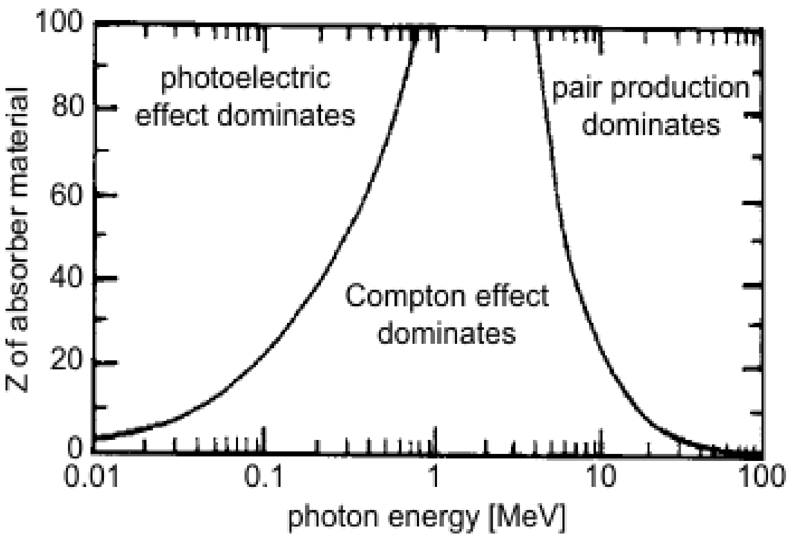


INTEGRAL/SPI (ESA)
2003 –

E range : 20 keV - 5 MeV
Ang. Res : 0.2 deg

Photons interaction with matter

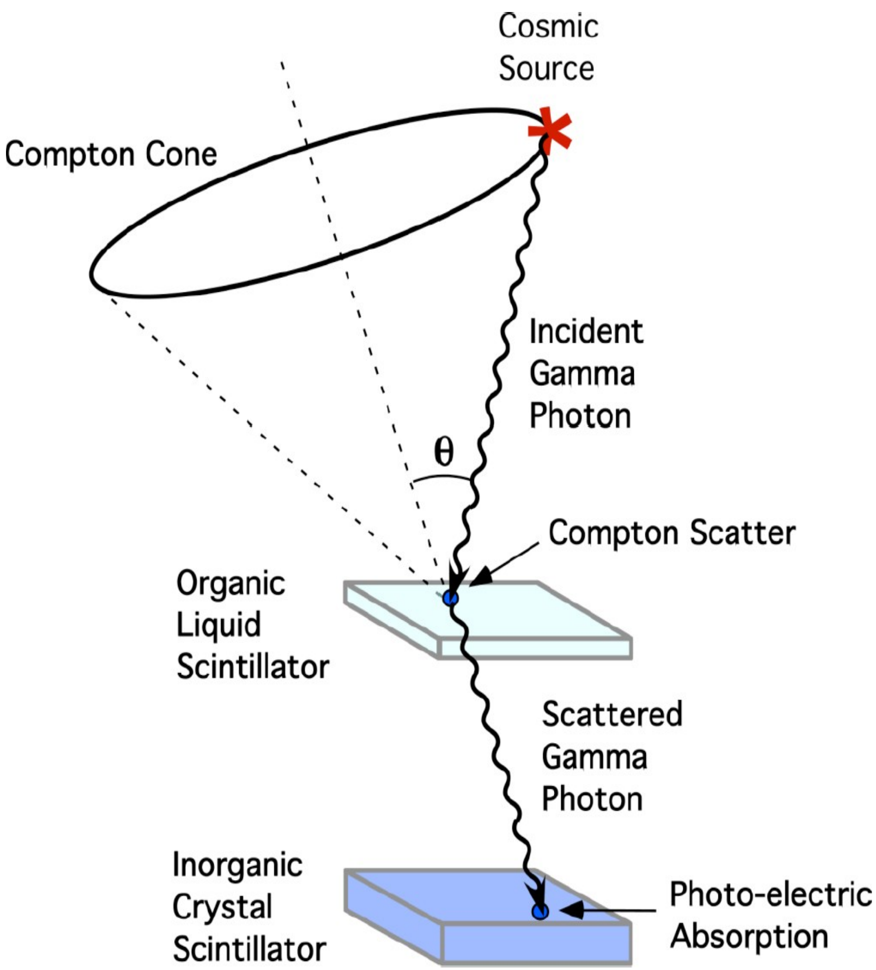


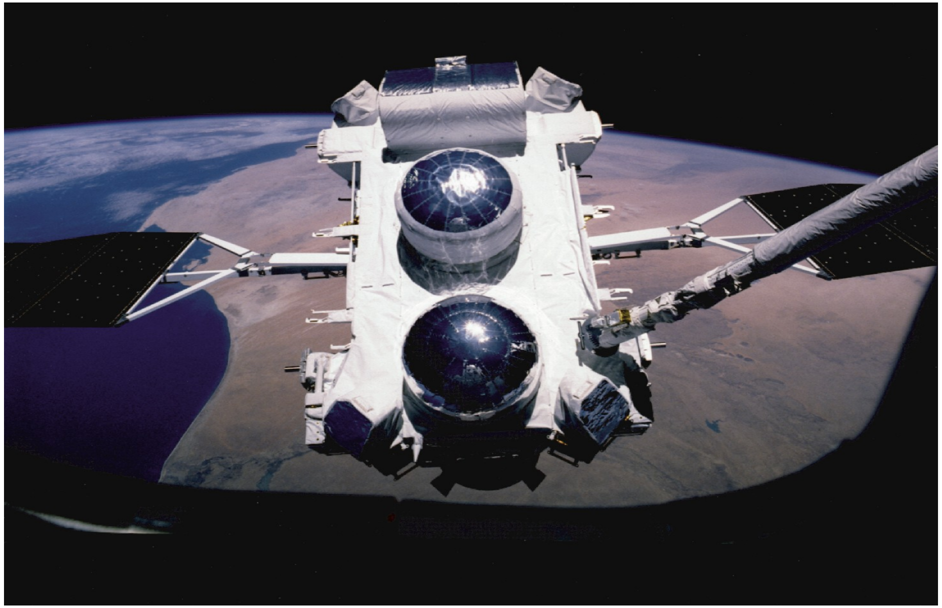


μph → photoelectric effect,
μcs → Compton scattering,
μca → Compton absorption
μp → pair production.
μa → total mass absorption coefficient (μa = μph + μp + μca)
μ → total mass attenuation coefficient (μ = μph + μp + μc where μc = μcs + μca).

(from Grupen, Particle Detectors)

Compton Telescopes

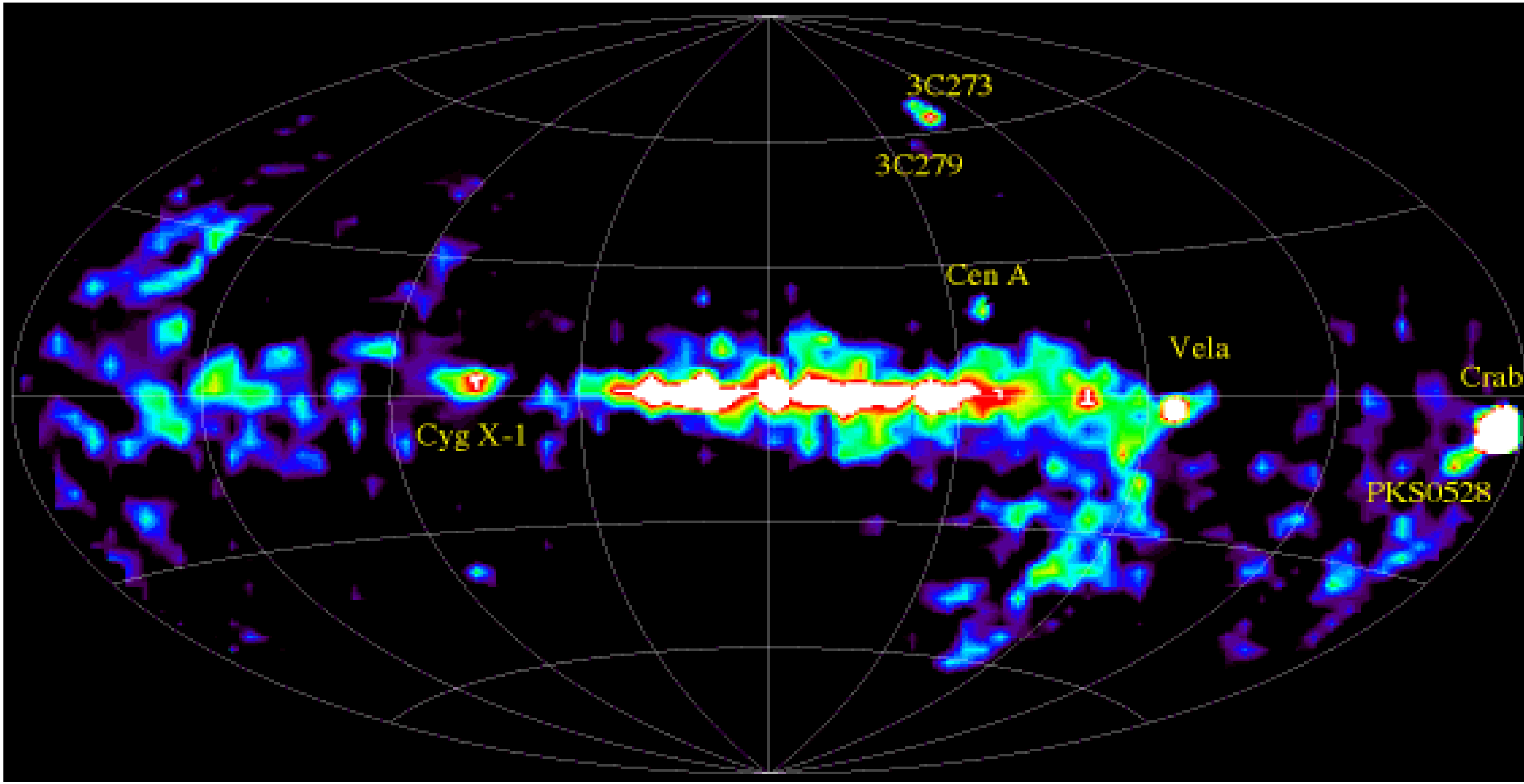




GCRO/COMPTEL (NASA)
1991 - 2000

En. range : 0.75 - 30 MeV
Ang. Res : few deg

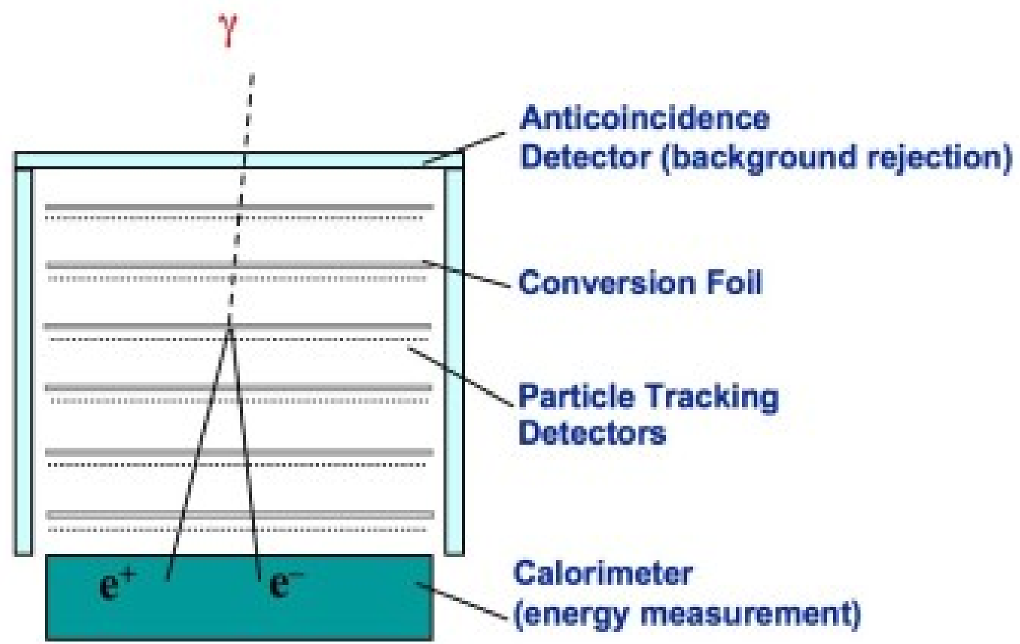
The MeV sky



Pair Production Telescopes

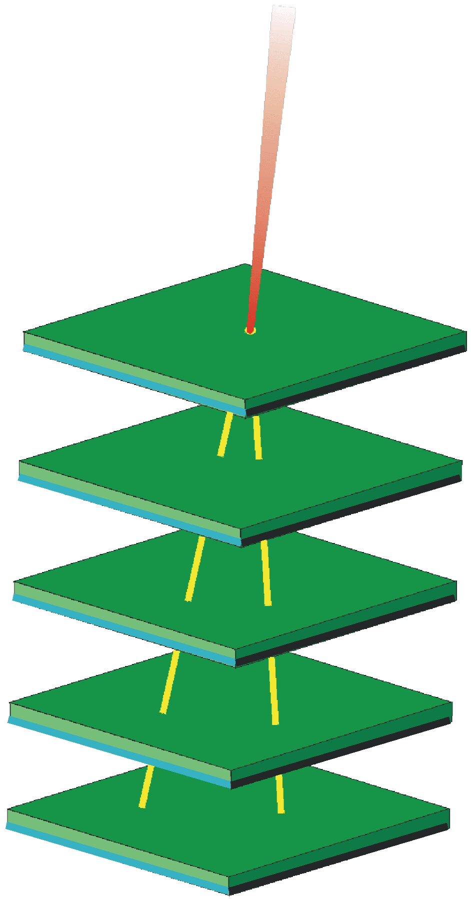
En. range : > 30 MeV

Ang. Res : few deg / E



Detection in pair production telescopes

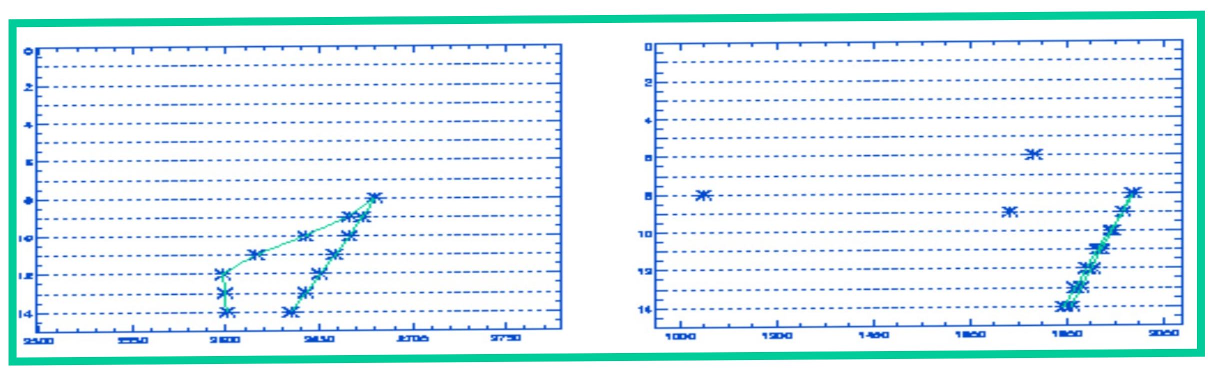
$\gamma \rightarrow e^+e^-$



the pair conserves p and E

but:

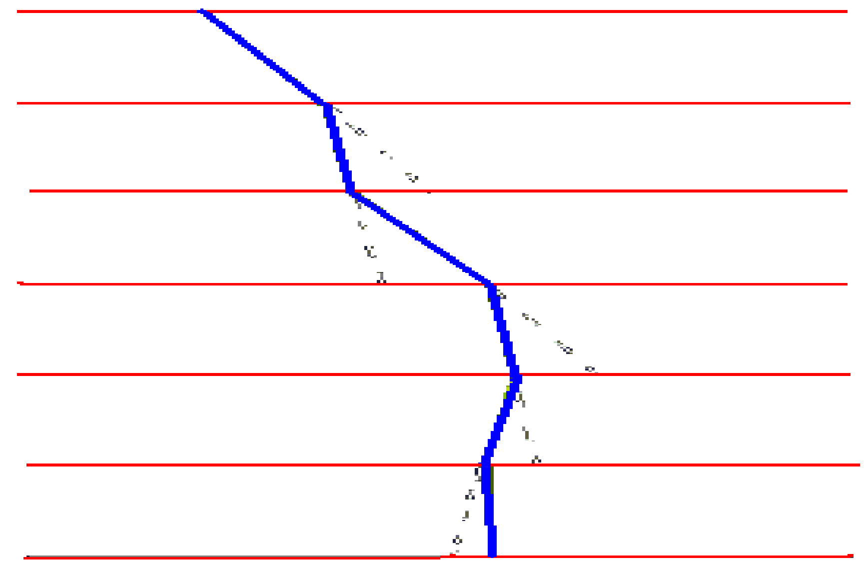
- **Only projection information**
- **Multiple Scattering**
- **Noise hits**

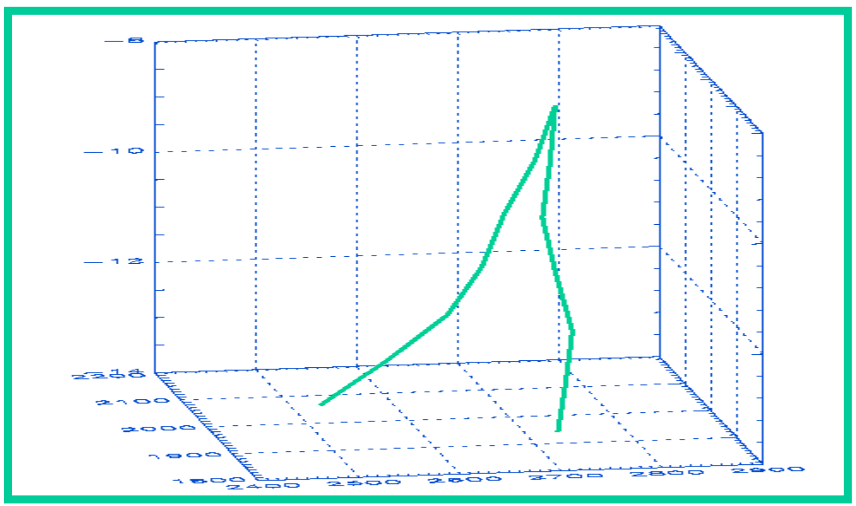


Multiple scattering

Moliere formula :

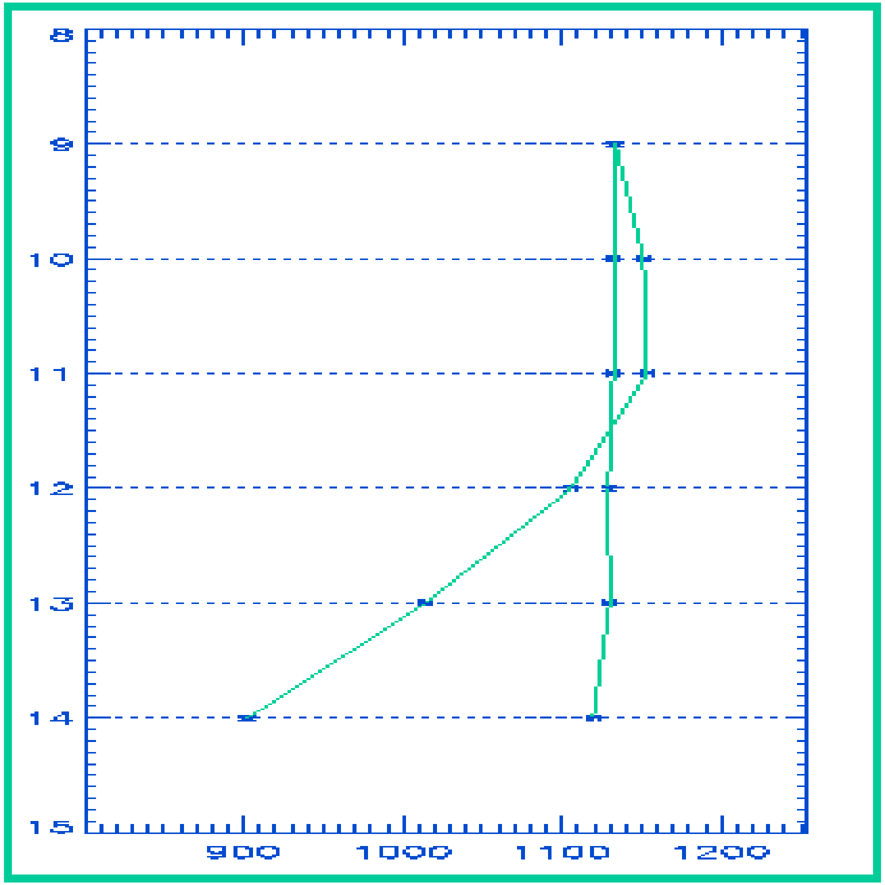
$$\theta_{rms} = \frac{13.6}{E_c[MeV]}\sqrt{\frac{z}{X_0}}\left(1+0.038\ln\frac{z}{X_0}\right)$$

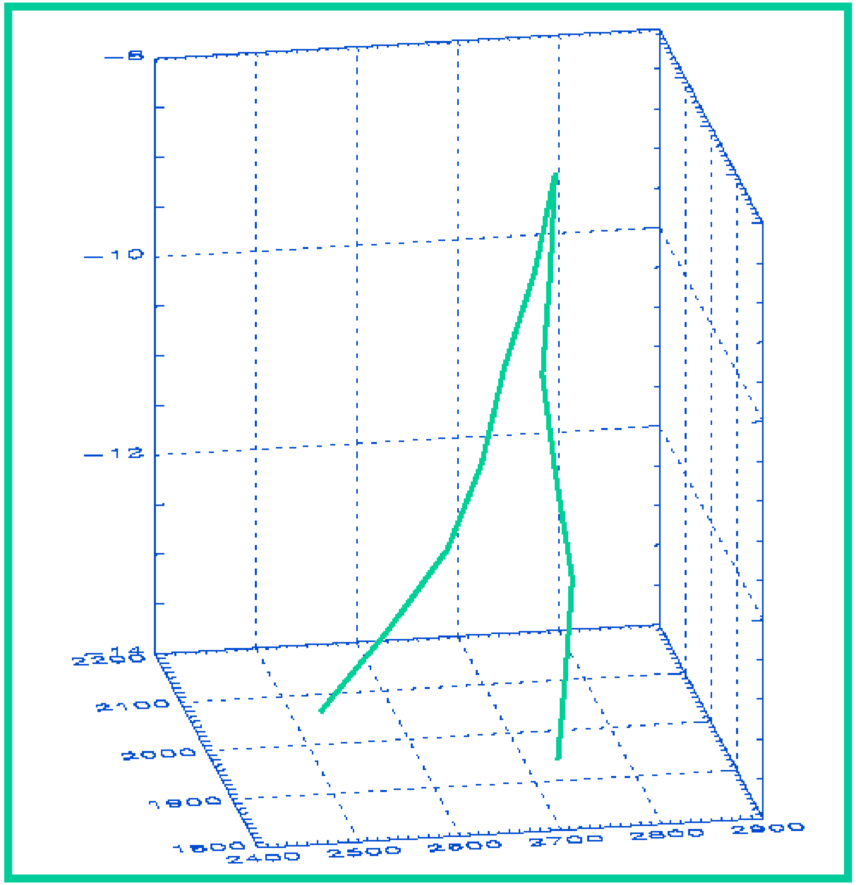




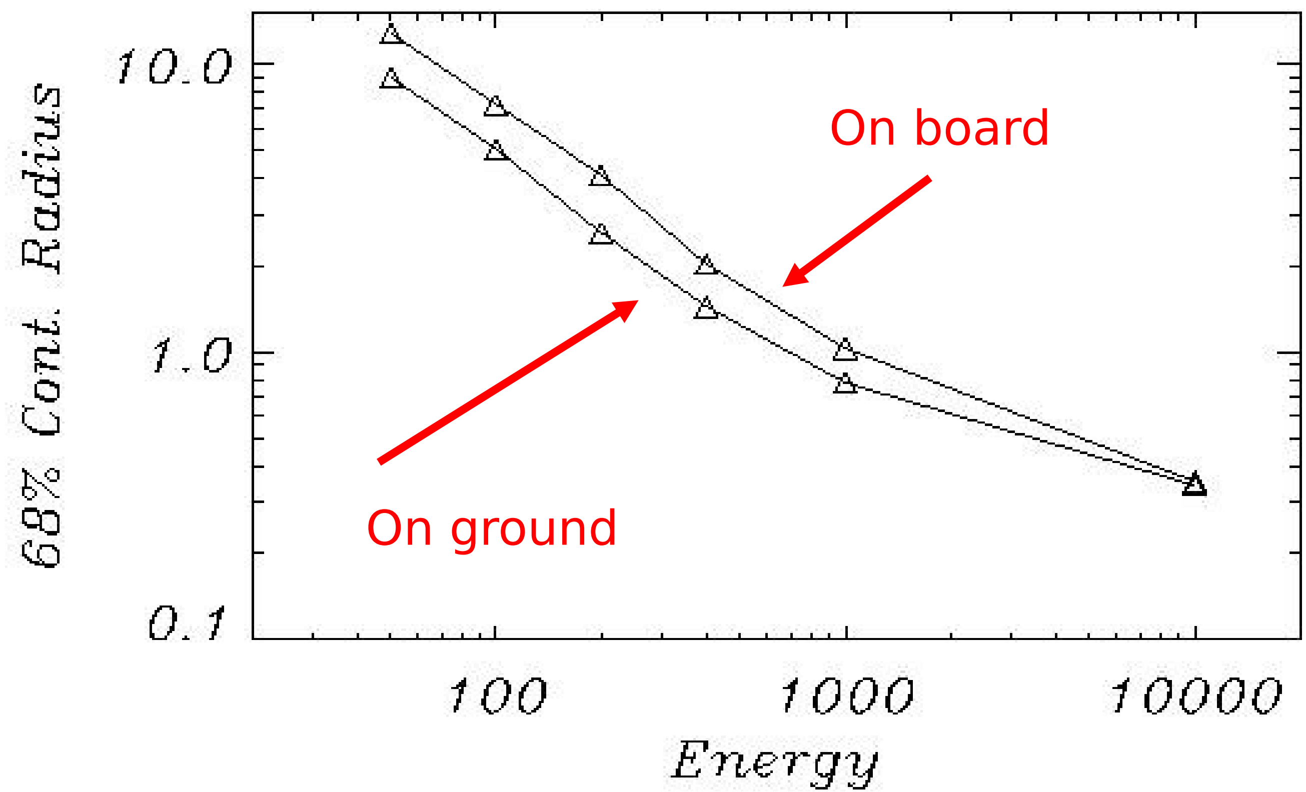
- *Measure of MS angles along the track and crossed thickness*
- *Three-dimensional track reconstruction*
- *Energy loss (bremsstrahlung and ionization)*

Track reconstruction – Kalman F.





Angular Resolution

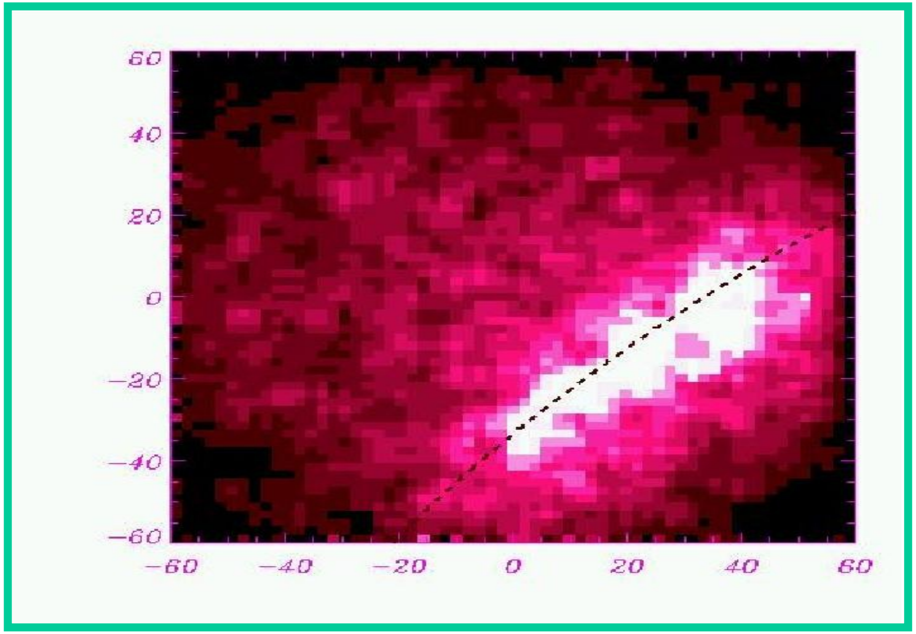


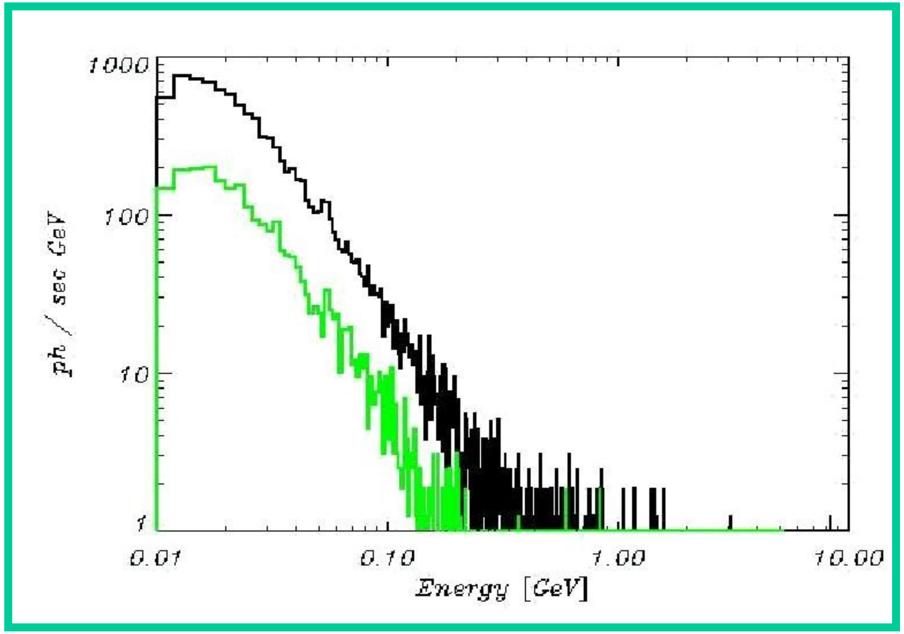
Albedo Photons Cut

The earth atmosphere is an intense source of gamma-ray photons

$$F = 5 \cdot 10^{-5} \left(\frac{E}{100\ MeV} \right)^{-2} \frac{ph}{cm^2\ s\ sr\ MeV}$$

Direction reconstruction allows to discriminate the events

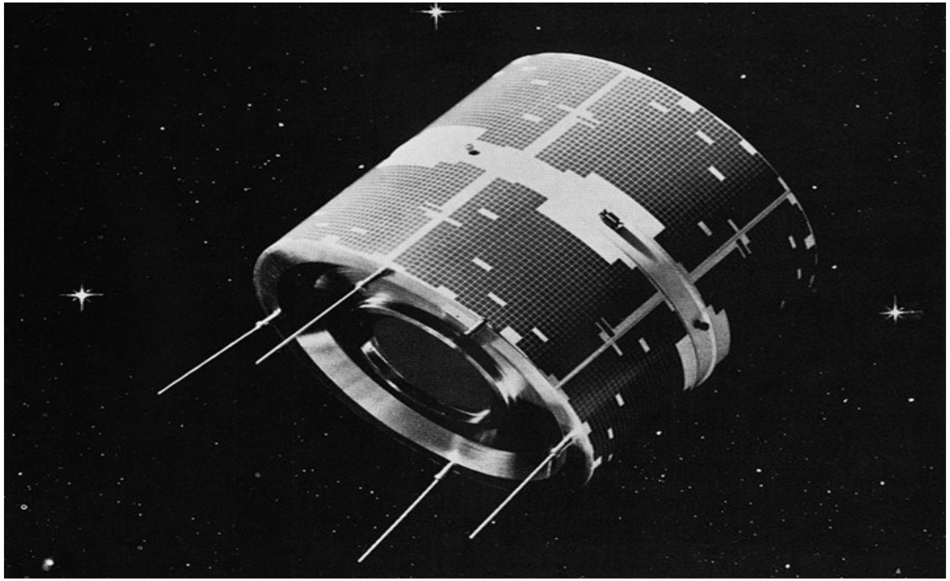




Pair Production Telescopes

SAS 2 (NASA)

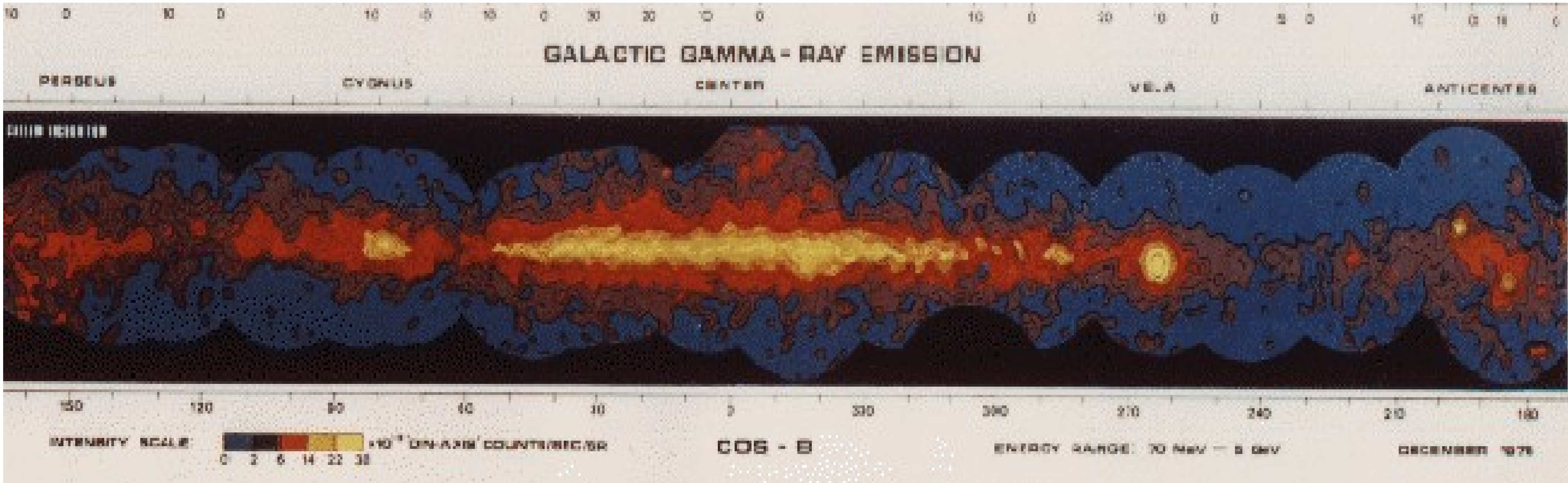
1973 - 1974



COS B (ESA)

1975 - 1982

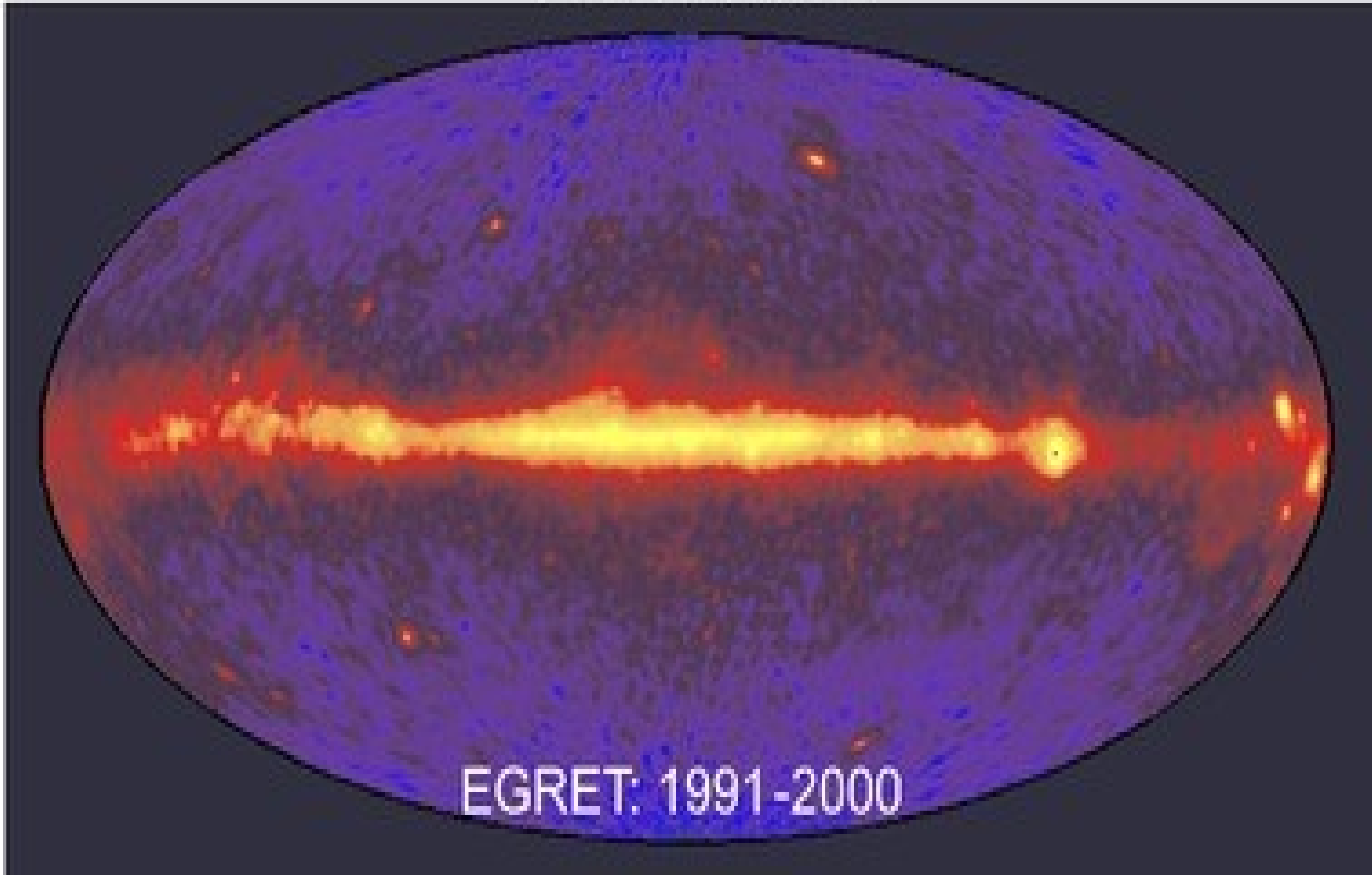
Pair Production Telescopes



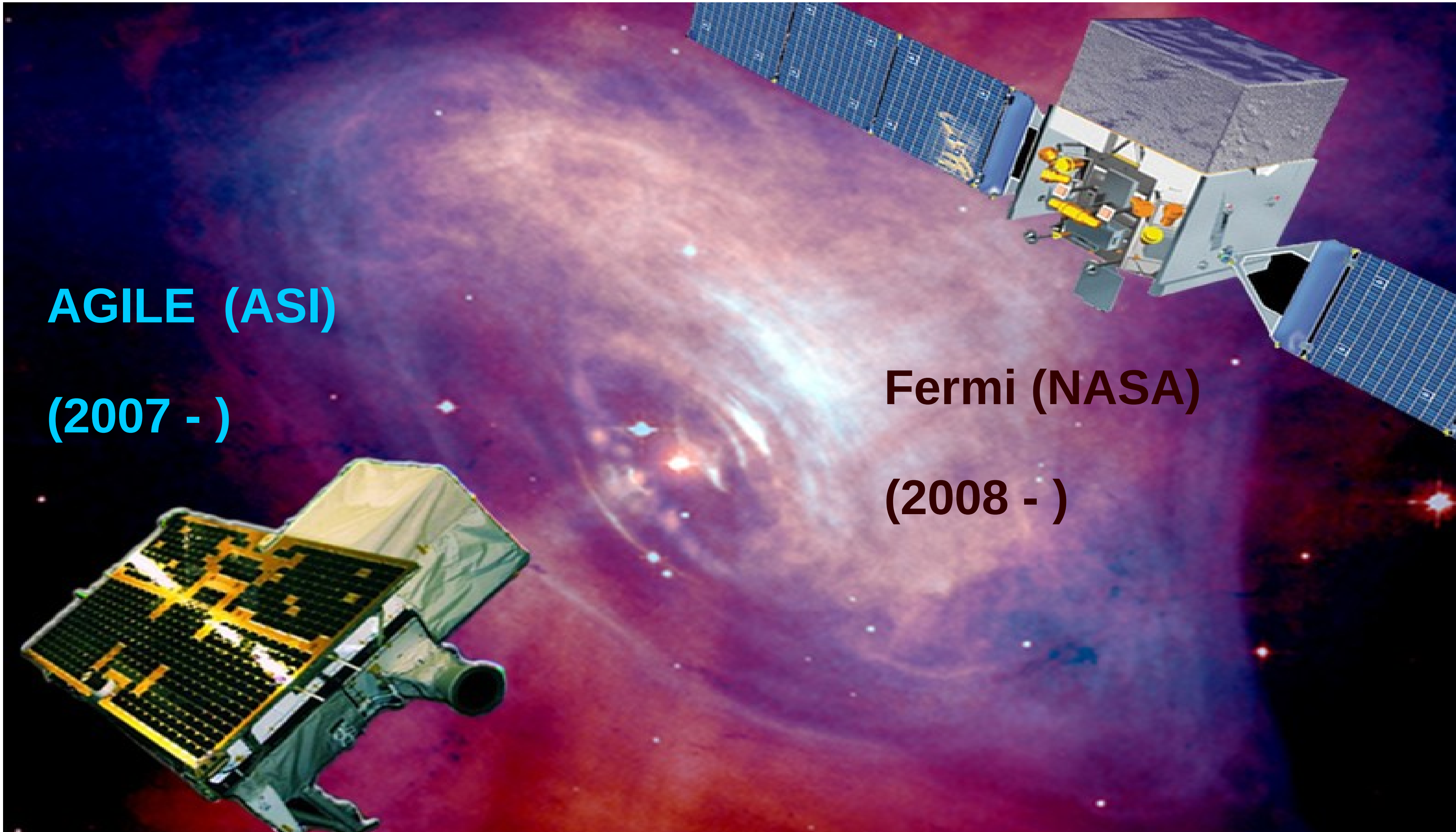
Pair Production Telescopes

GCRO/EGRET (NASA)

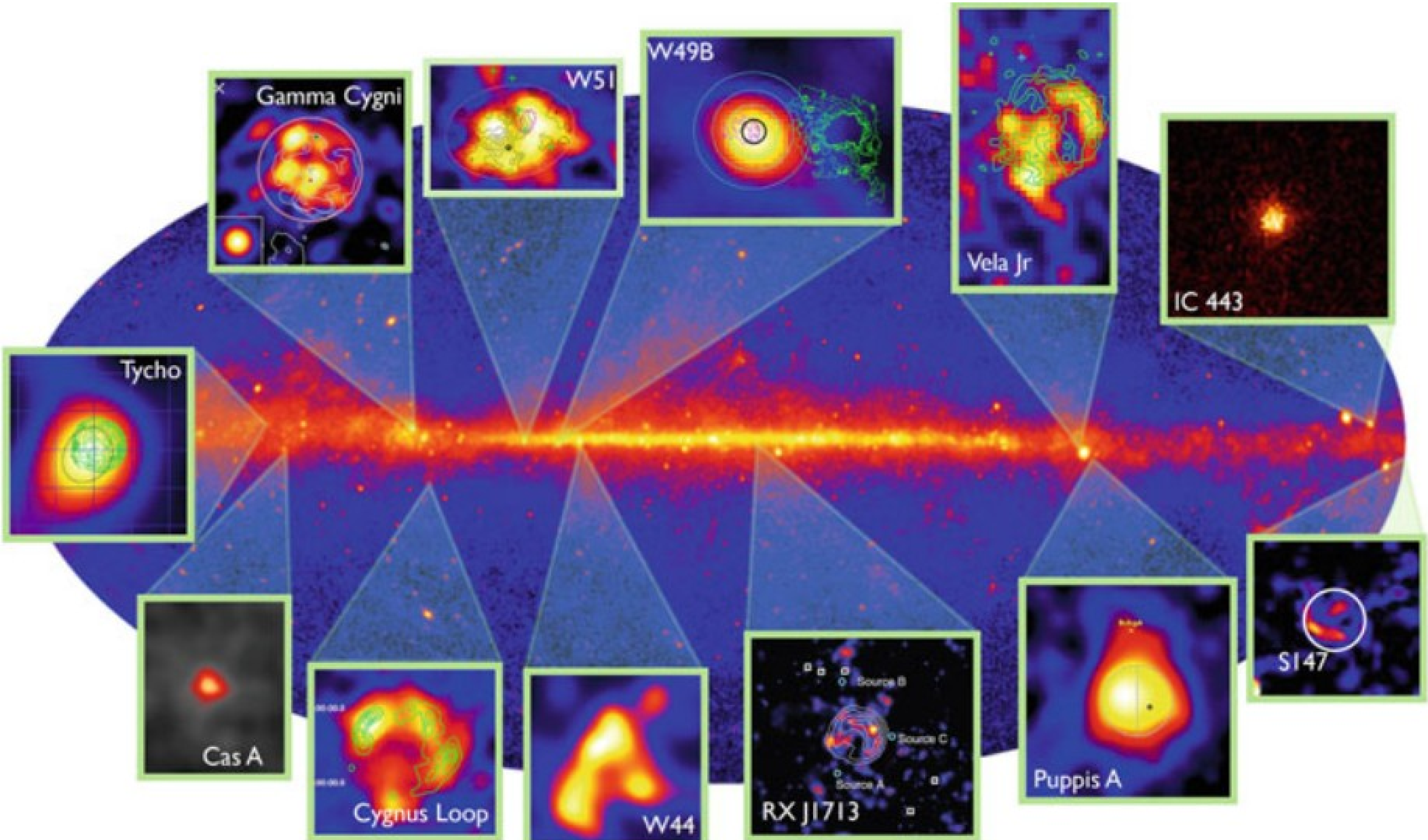
1991 - 2000


EGRET: 1991-2000

Pair Production Telescopes

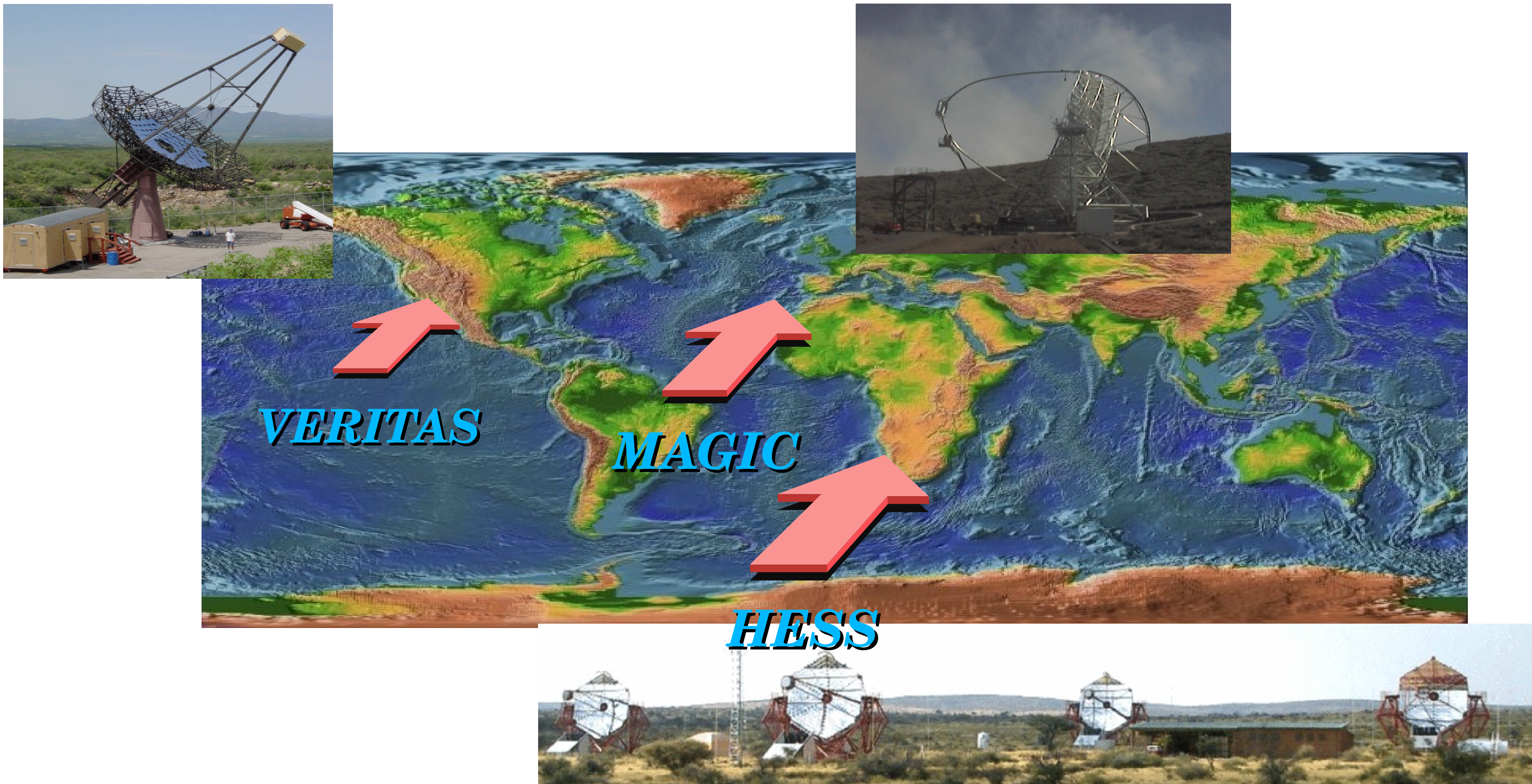


The GeV Sky



Gamma Cygni
W51
W49B
Vela Jr
IC 443
Tycho
Cas A
Cygnus Loop
W44
RX J1713
Source B
Source C
Source A
Puppis A
S147

Existing Cherenkov Telescopes



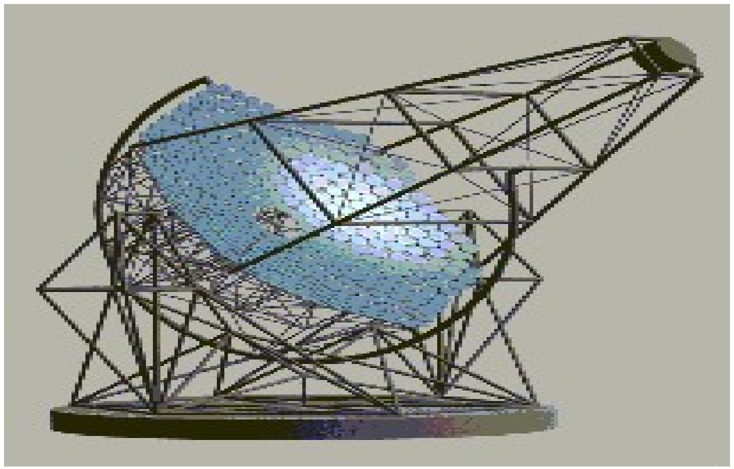
HESS telescope

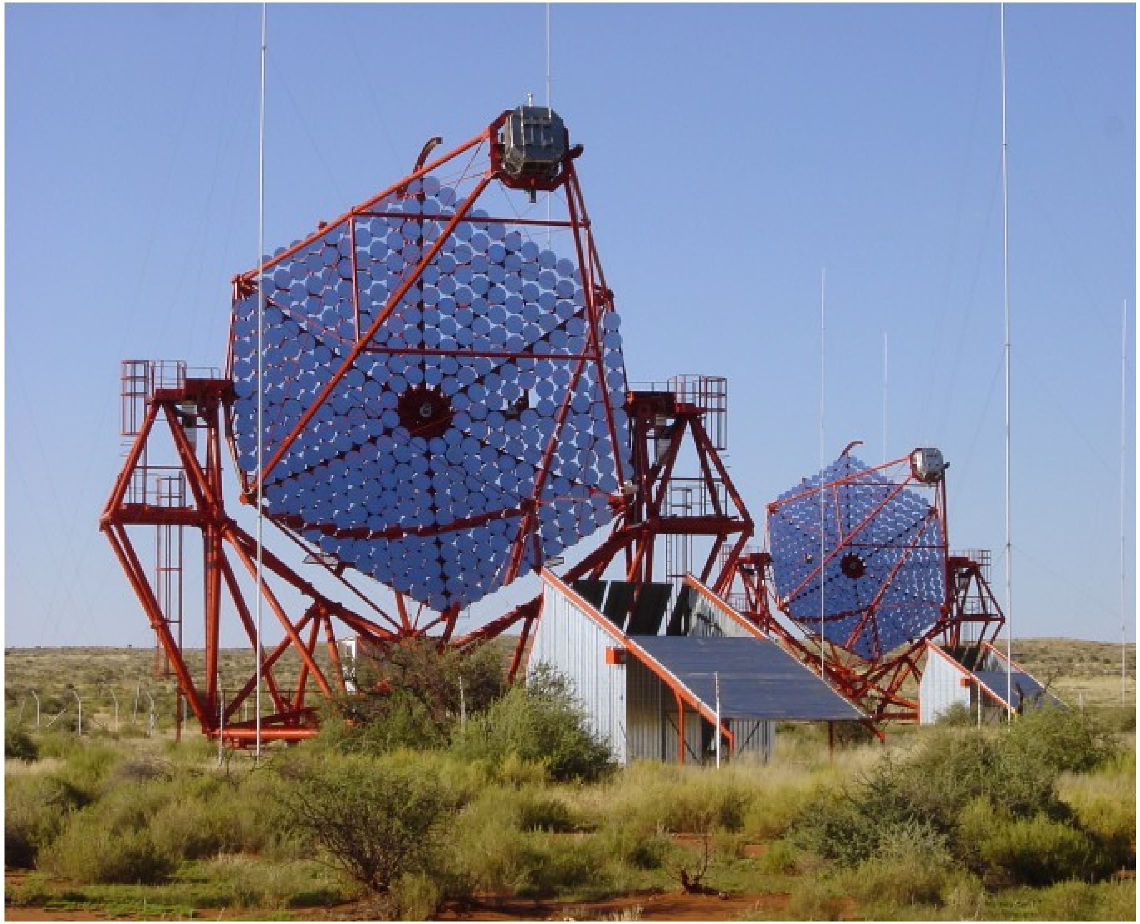
H.E.S.S consists currently of 4 telescopes arranged in a square with 120 m side length and provide multiple stereoscopic view of air showers.

Each telescope consists of a dish with an effective area of 107 m^2 and a camera.

The mirrors collect Cherenkov light from air showers and focus it onto the camera.

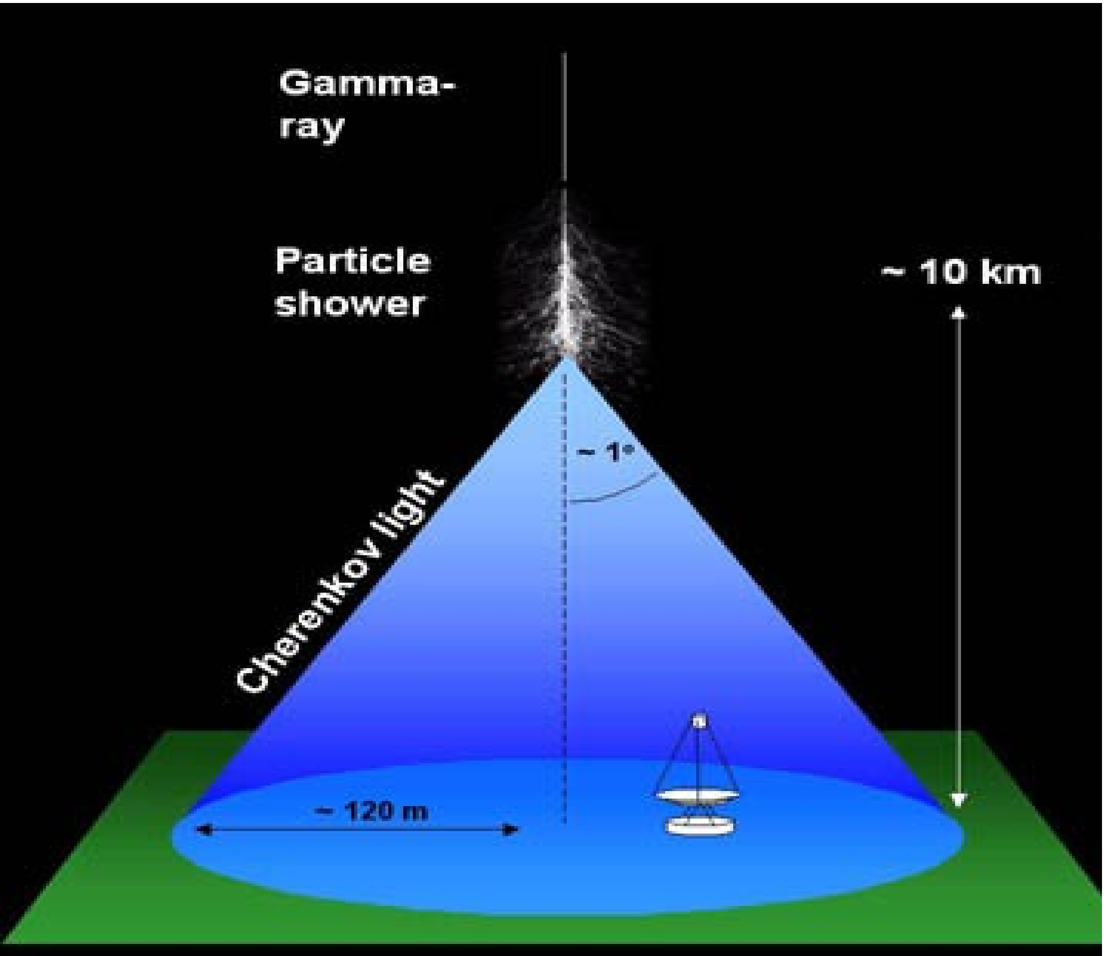
Maximum slewing speed: 100°/ min.

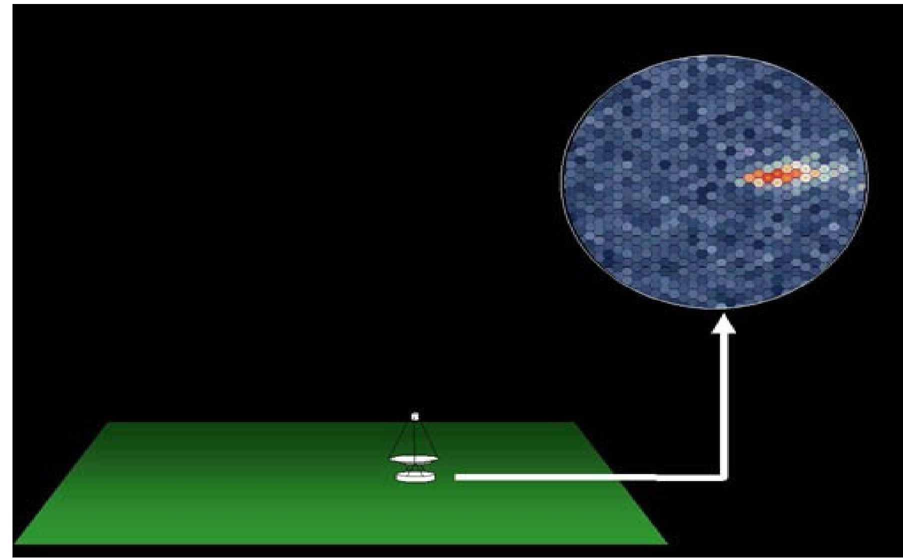




The Davies Cotton telescopes have a focal length of 15 m and a reflectivity of ~80 %.

Air showers with a single telescope

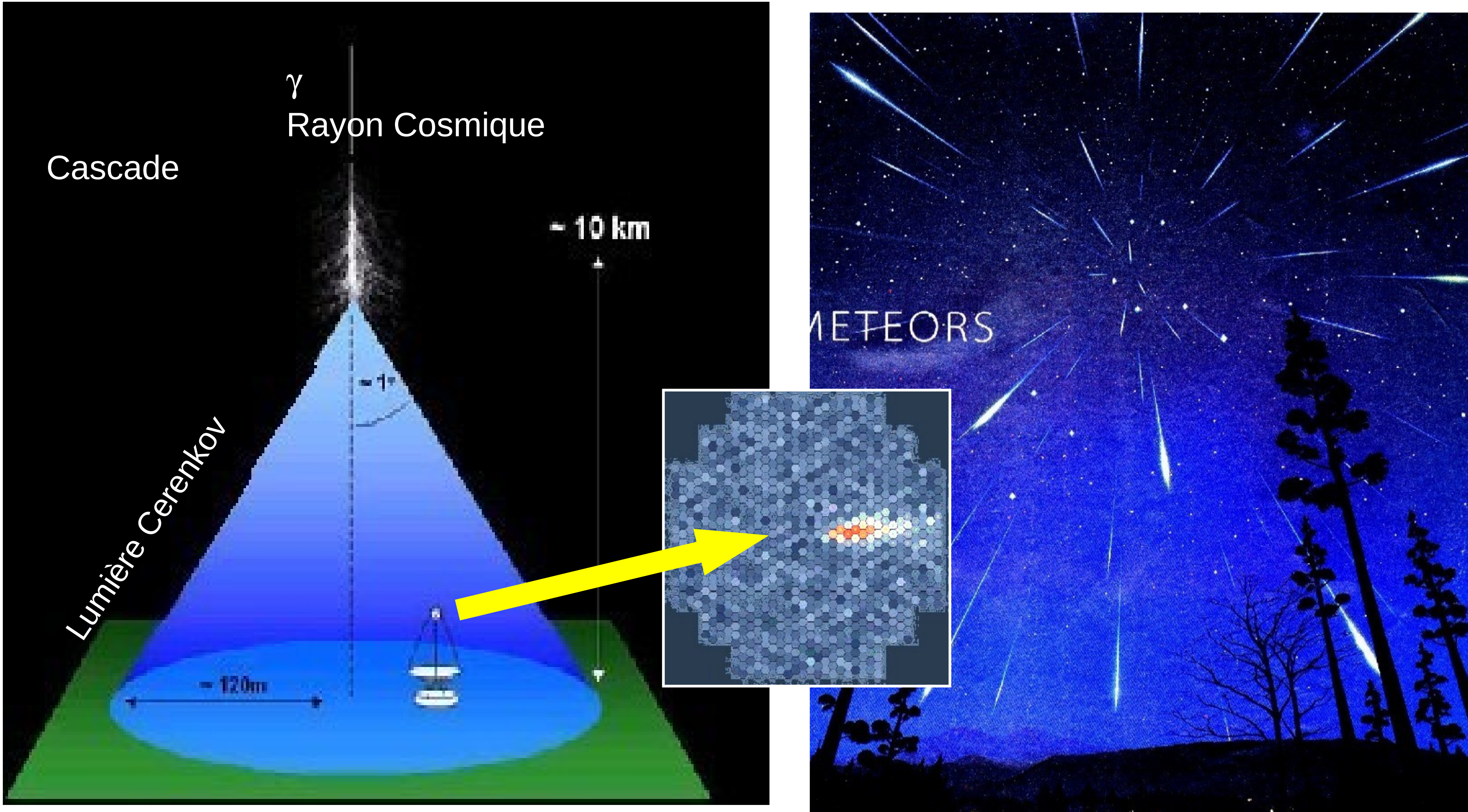




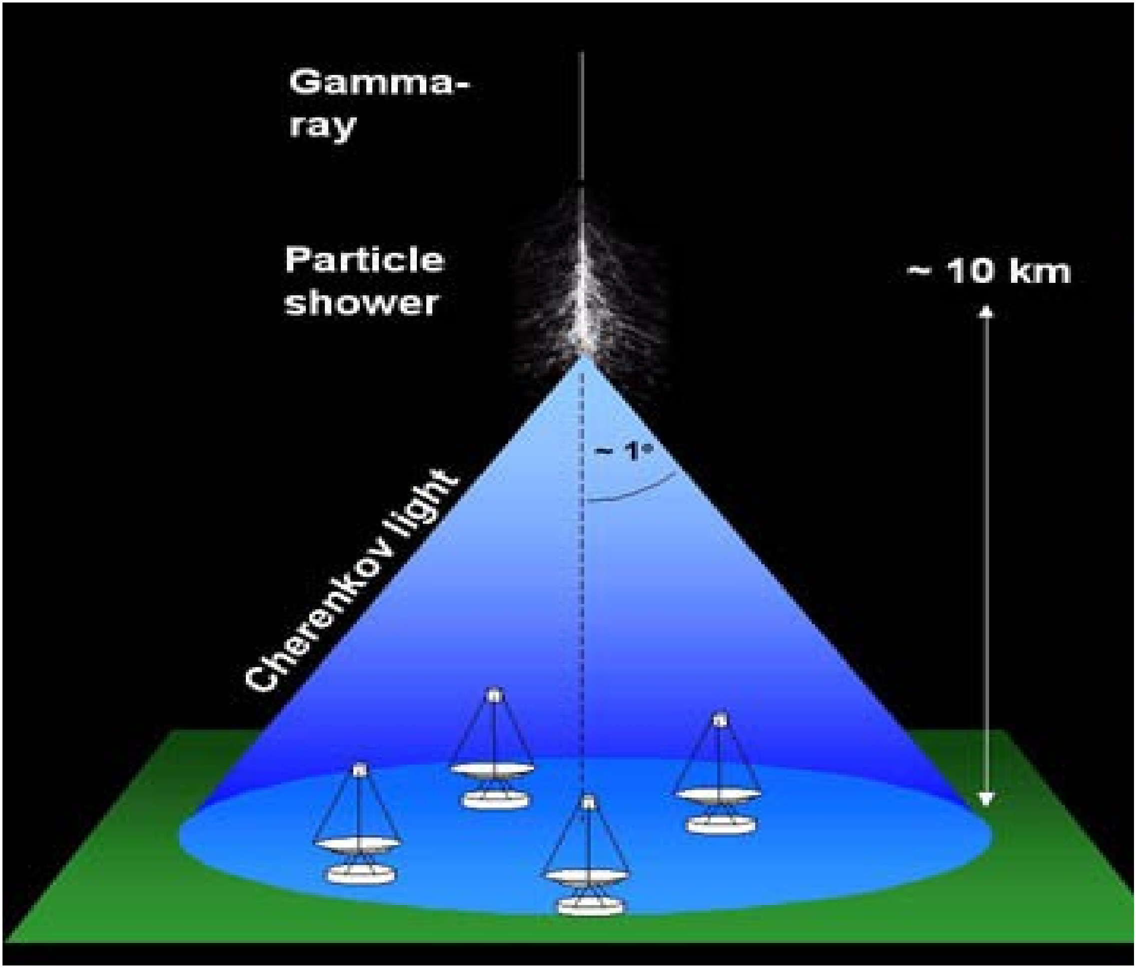
Air showers from gamma rays with E >100 GeV develop at a height of about 10 km. A pool of Cherenkov light from the shower with a radius of ~120 m reaches the ground.

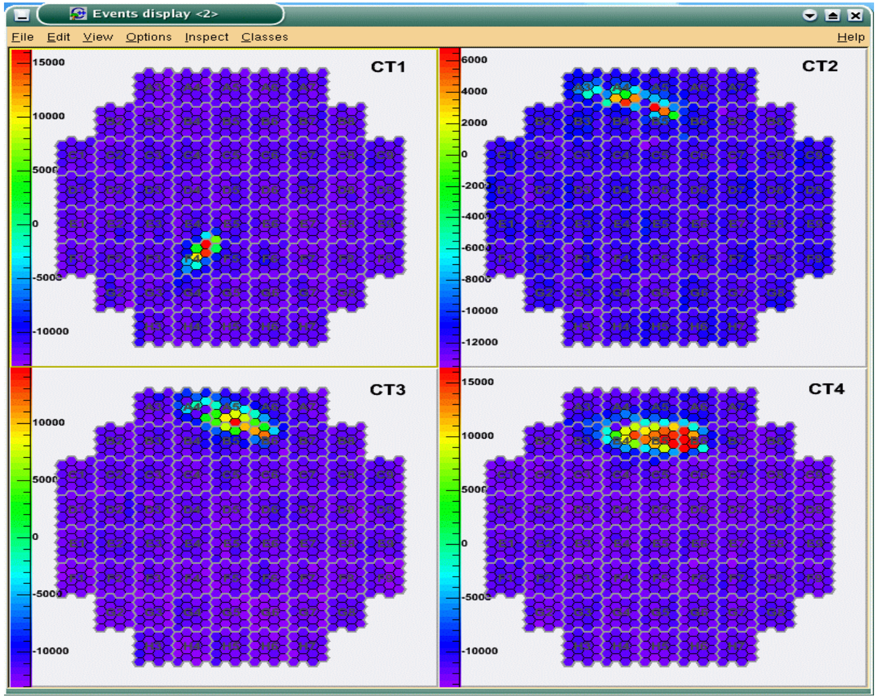
The image of the shower can be seen as a single track with the camera of one telescope.

Air showers with a single telescope



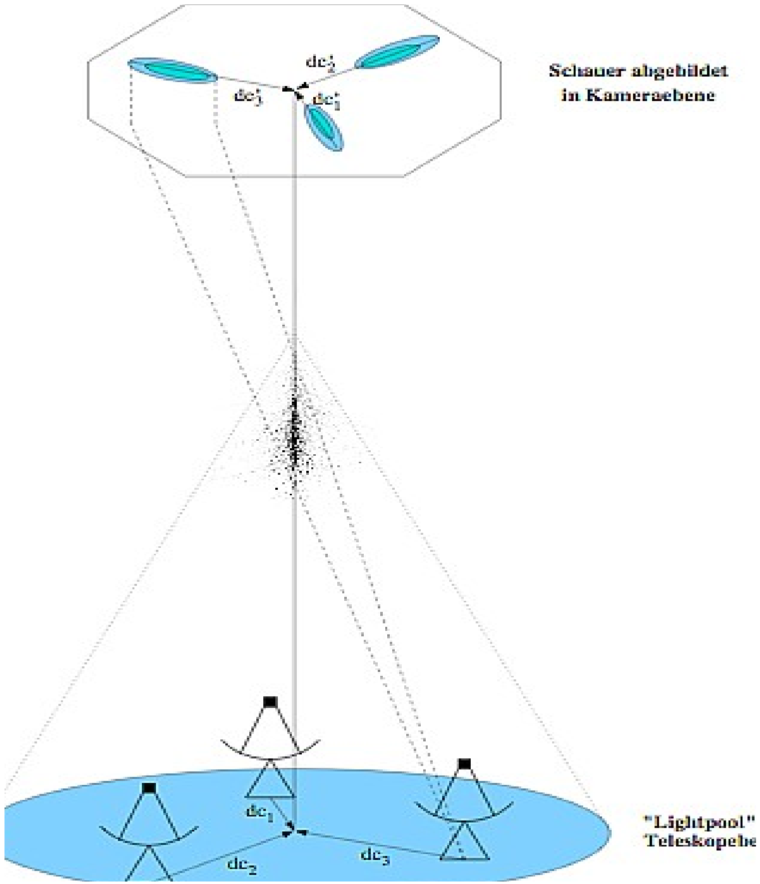
Stereoscopic Observation of an Air Shower





With several telescopes, a stereoscopic (or multiscopic) view of a single shower is possible. This allows to reconstruct the shower geometry and to reject background signals.

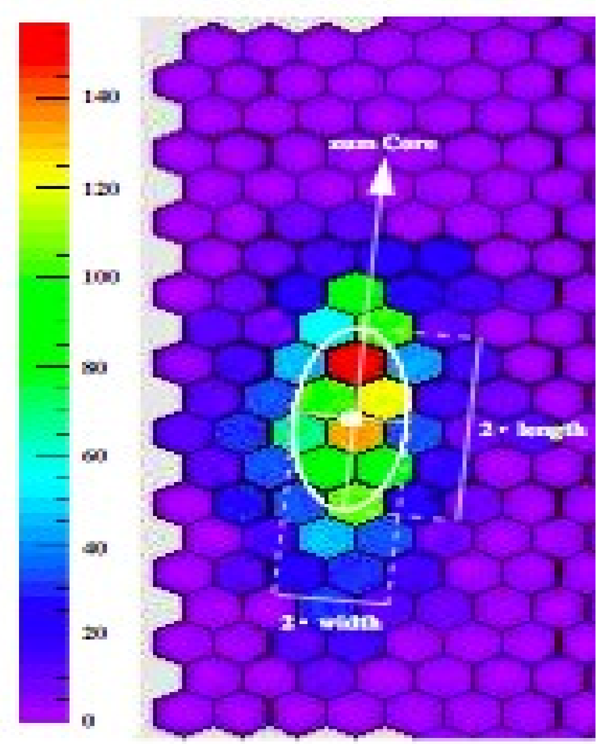
Air Shower Image Projection



(figures taken from the Ph.D. thesis by Oliver Bolz, Ludwigshafen 2004)

The image of the air shower that is projected onto the camera has the form of an ellipse.

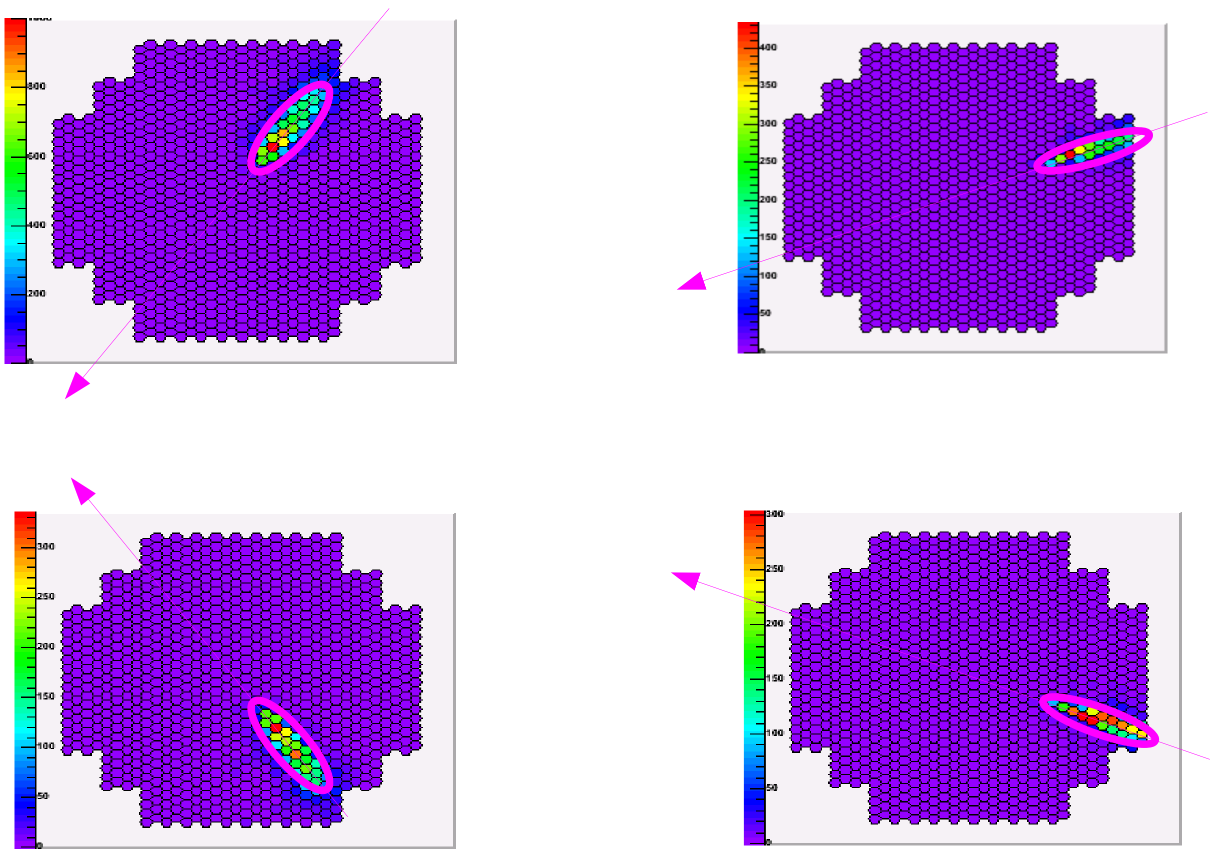
In the reconstruction of the air shower, one fits an elliptical form to the image to extract the "Hillas-parameters" that characterize the air shower. Two important parameters are the width and the length of the ellipse.



One also takes into account the distribution of intensities over the PMTs that are part of the image.

In the image shown here, the red pixel has the largest number of photoelectrons. It indicates the direction of the shower core.

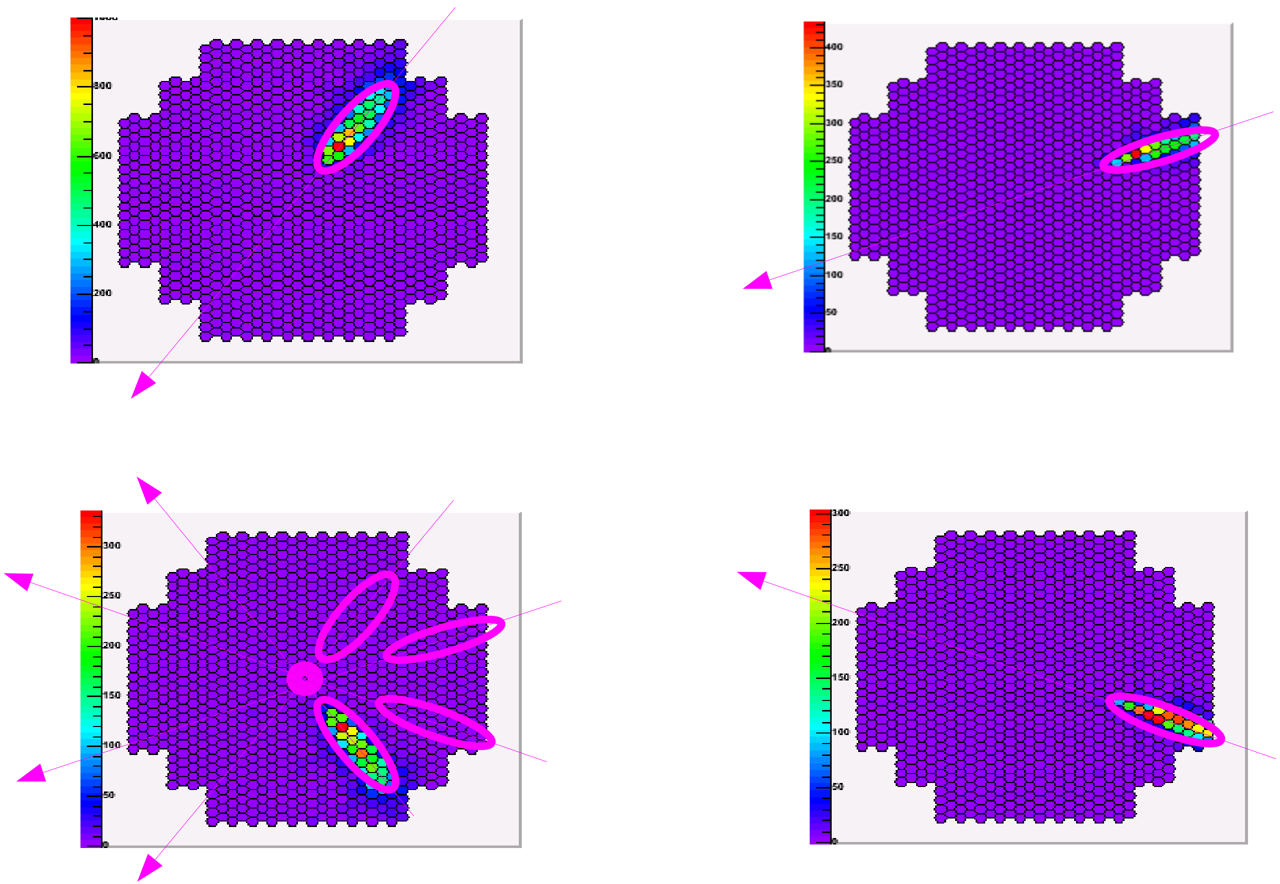
Reconstruction of the Direction of the Air Shower



The stereoscopic observation provides information on the direction of the air shower.

All telescopes point at the same direction in the sky, so we can superpose the images from the air shower seen in different cameras.

Reconstruction of the Direction of the Air Shower

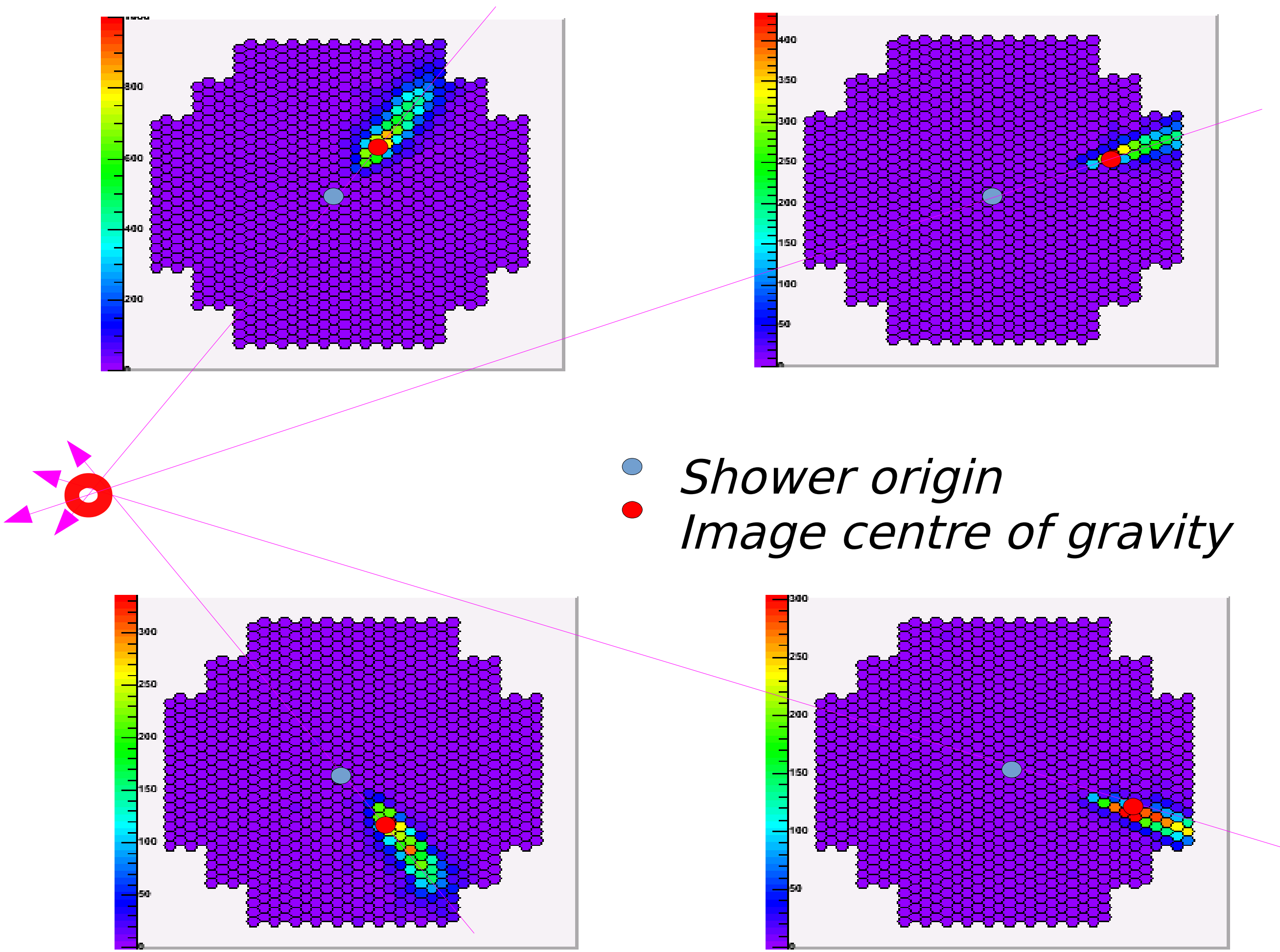


In this case, the air shower came directly from the direction the telescopes are pointing at.

If they are pointing at a known source, one would identify the shower with a photon from that source.

The angular resolution of H.E.S.S. is a few arc minutes.

Reconstruction of the Shower Impact Point



Geometrical determination of the shower impact point on the ground provides a better understanding of the shower geometry.

This is very useful for the energy reconstruction of the event.

Reconstruction of the Shower Energy

The energy of the primary particle, i.e. the γ-ray, is determined from the total recorded signal size, which can be converted into a flux of Cherenkov photons.

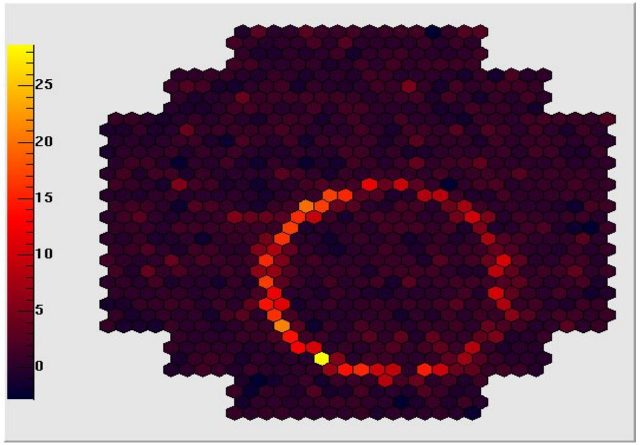
Once the geometry of the air shower – i.e. the inclination of the shower axis and the impact point – has been determined, one compares the recorded signal to lookup tables.

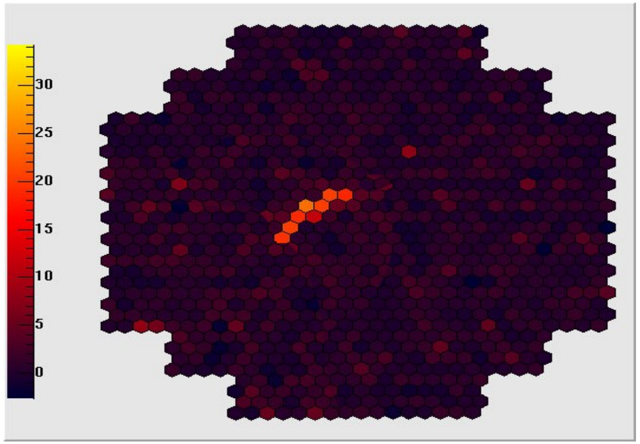
These lookup tables are generated with Monte Carlo simulations of γ-ray induced air showers at different energies and geometries. They contain lateral distributions of Cherenkov photon densities for each simulated shower.

A comparison of the recorded signal size and the simulated photon fluxes provides the energy of the observed shower.

The energy resolution of H.E.S.S. is on the order of 15 %.

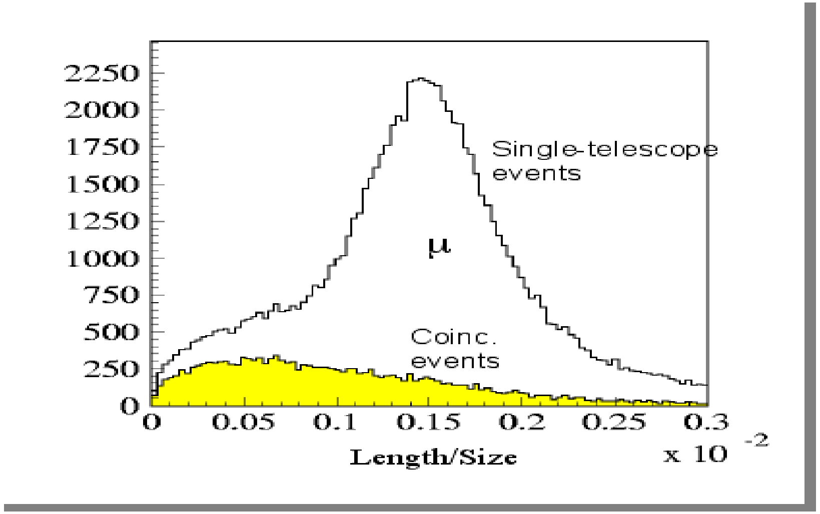
Background - Muons





Muons that hit the telescope leave a ring-shaped Cherenkov light signal and are easily identifiable. Muons that pass the telescope at some (not too large) distance can leave a signature that is not easy to distinguish from the image of an air shower. Due to the large muon flux in the atmosphere, this is a considerable source of background.

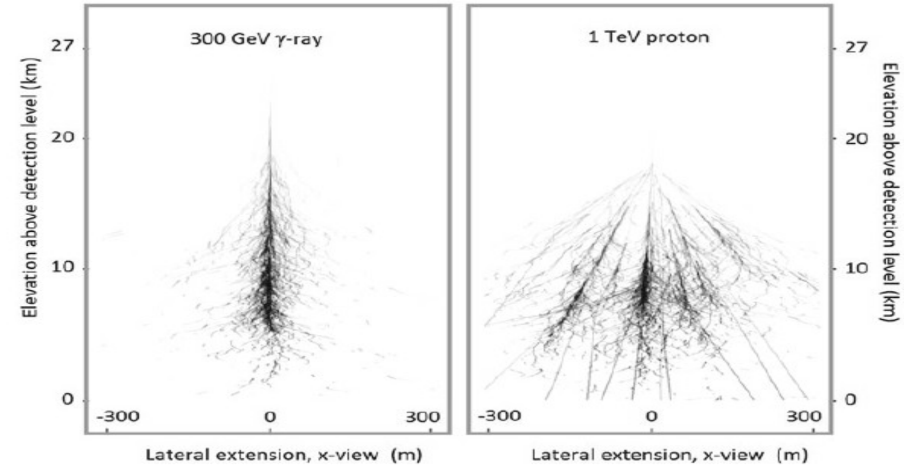
Muons can however be rejected by requiring at least two telescopes to be triggered simultaneously.



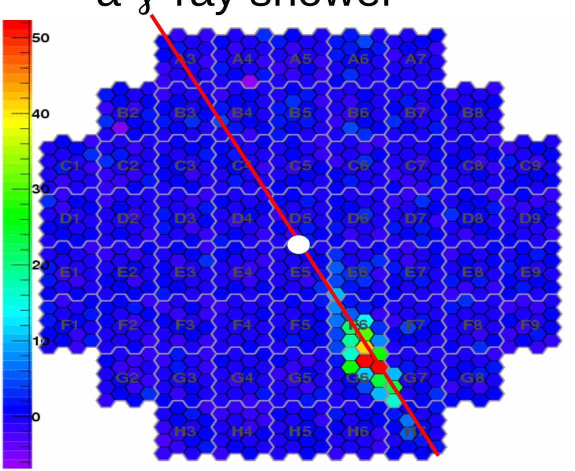
Background – Hadronic Showers

Hadronic showers do not leave a clear track. They look more like a "blob". When fitting an ellipse to the image, the width of the ellipse is usually larger than in the case of a γ-ray shower.

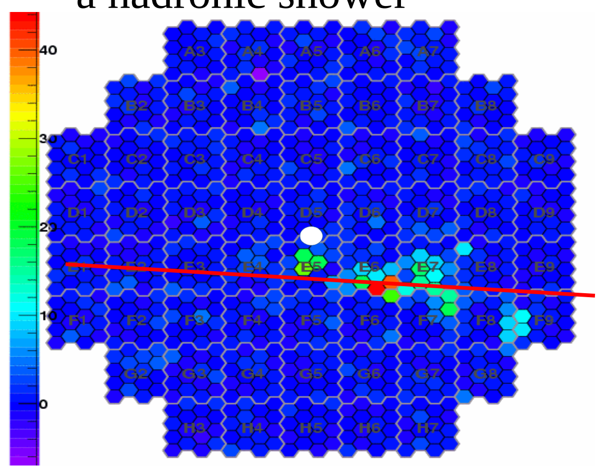
One rejects hadronic showers by applying a cut on the observed width.

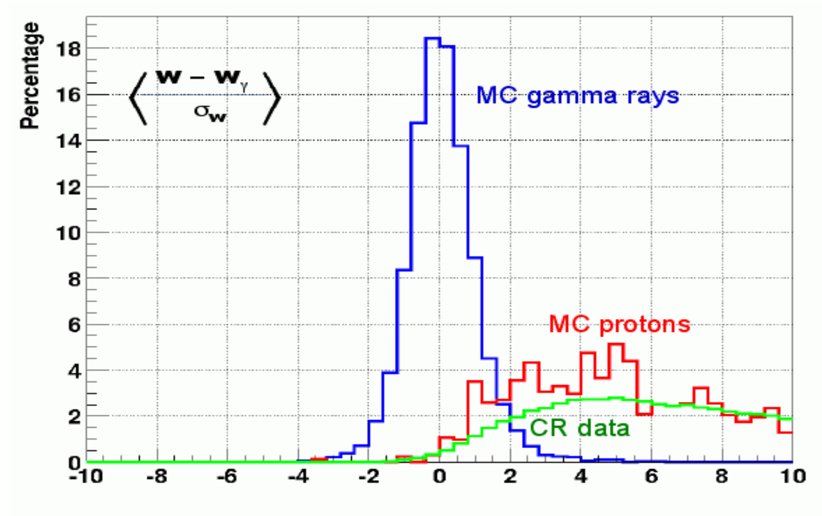


a γ-ray shower

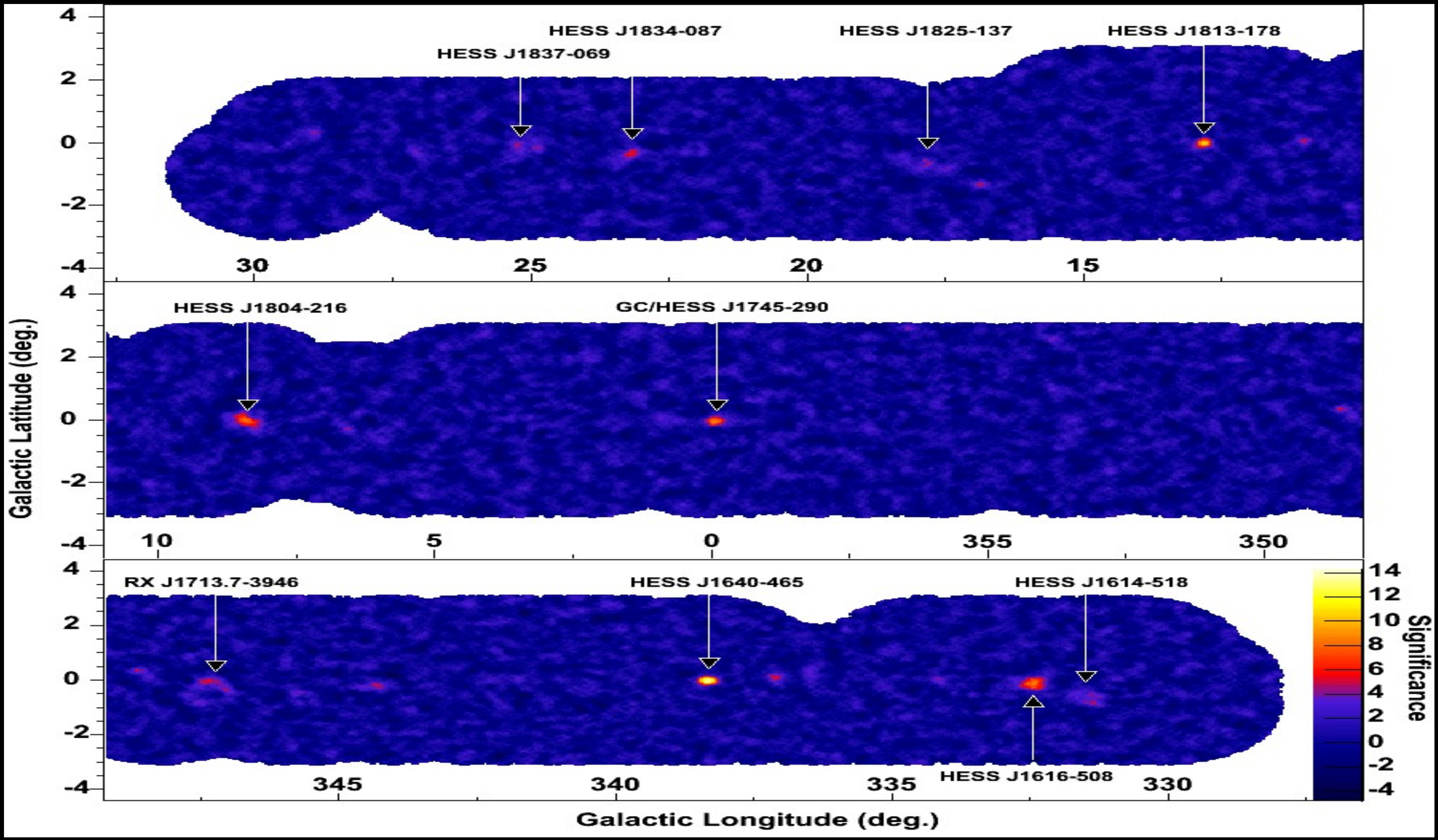


a hadronic shower





Galactic Plane Survey



All sky telescopes – Milagro

- located near Los Alamos, NM, USA; altitude 2650 m
- a pond of size 80m x 60m x 8 m filled with pure water
- 175 tanks in a larger array
- 2 layers of PMTs (723 in total) observe Cherenkov light from air shower particles
- upper layer: electrons, positrons
  lower layer: muons

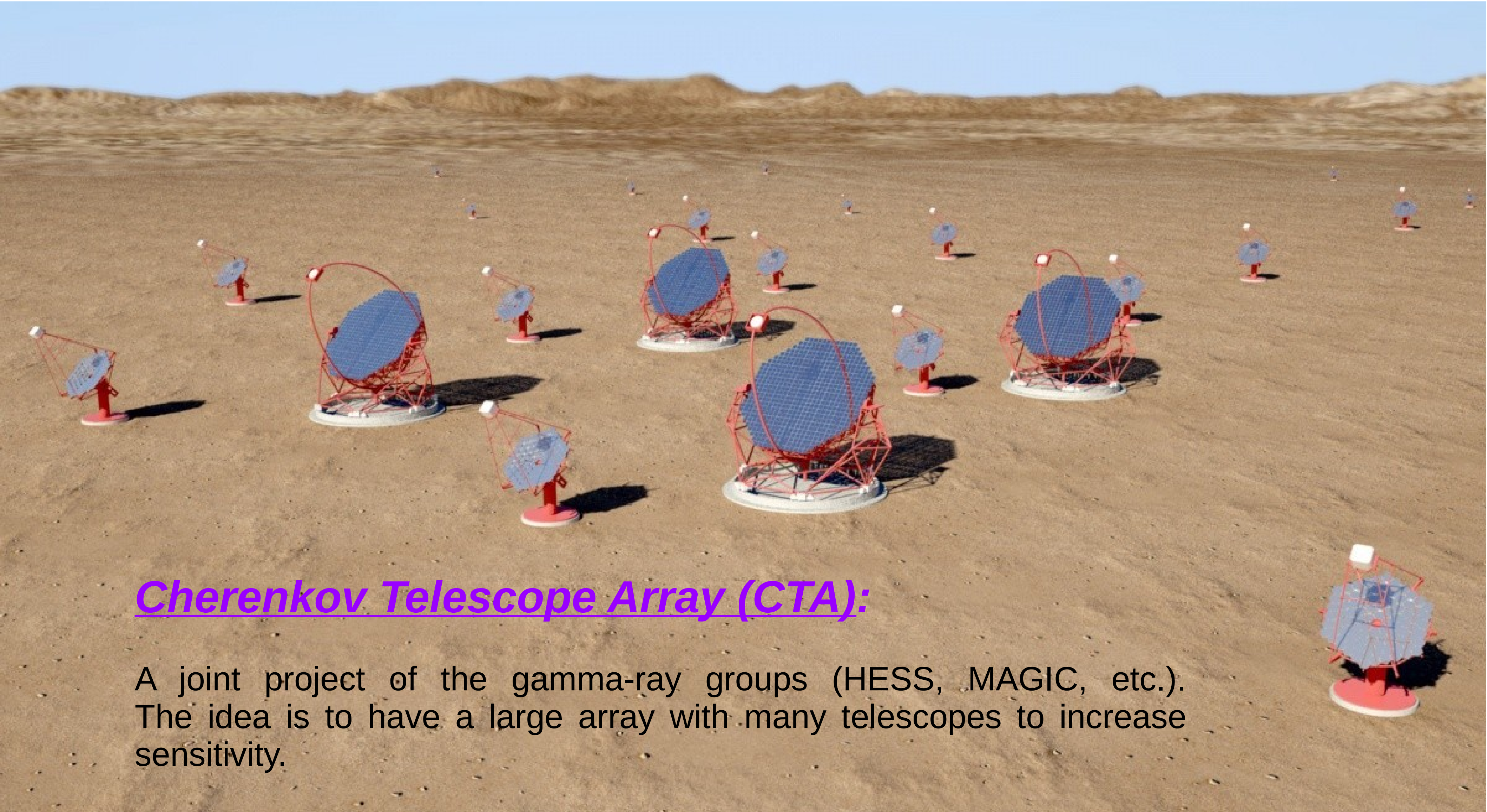
All sky telescopes: Milagro

100% duty cycle, very large field of view (~ 1 sr), good sensitivity at TeV energies
=> ideal for all (northern) sky survey of gamma-ray sources

Only 0.8 degree angular resolution, higher energy threshold than IACTs

=> complementary method to IACTs and satellites; similar method used by ARGO (Tibet)

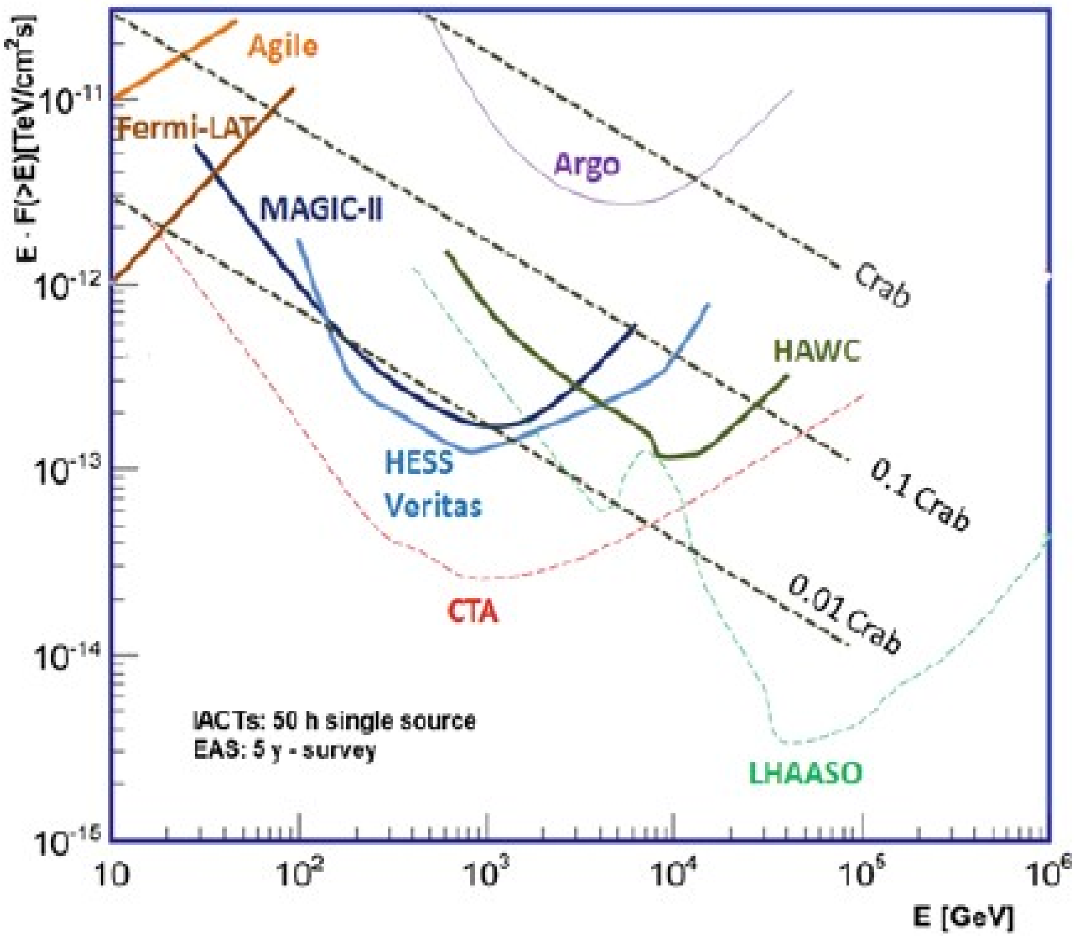
Future Projects



Cherenkov Telescope Array (CTA):

A joint project of the gamma-ray groups (HESS, MAGIC, etc.). The idea is to have a large array with many telescopes to increase sensitivity.

Future Projects



Cherenkov Telescope Array (CTA):

A joint project of the gamma-ray groups (HESS, MAGIC, etc.). The idea is to have a large array with many telescopes to increase sensitivity.

High Altitude Water Cherenkov array (HAWC):

next generation of the Milagro style detectors, larger effective area, higher altitude (lower E threshold)