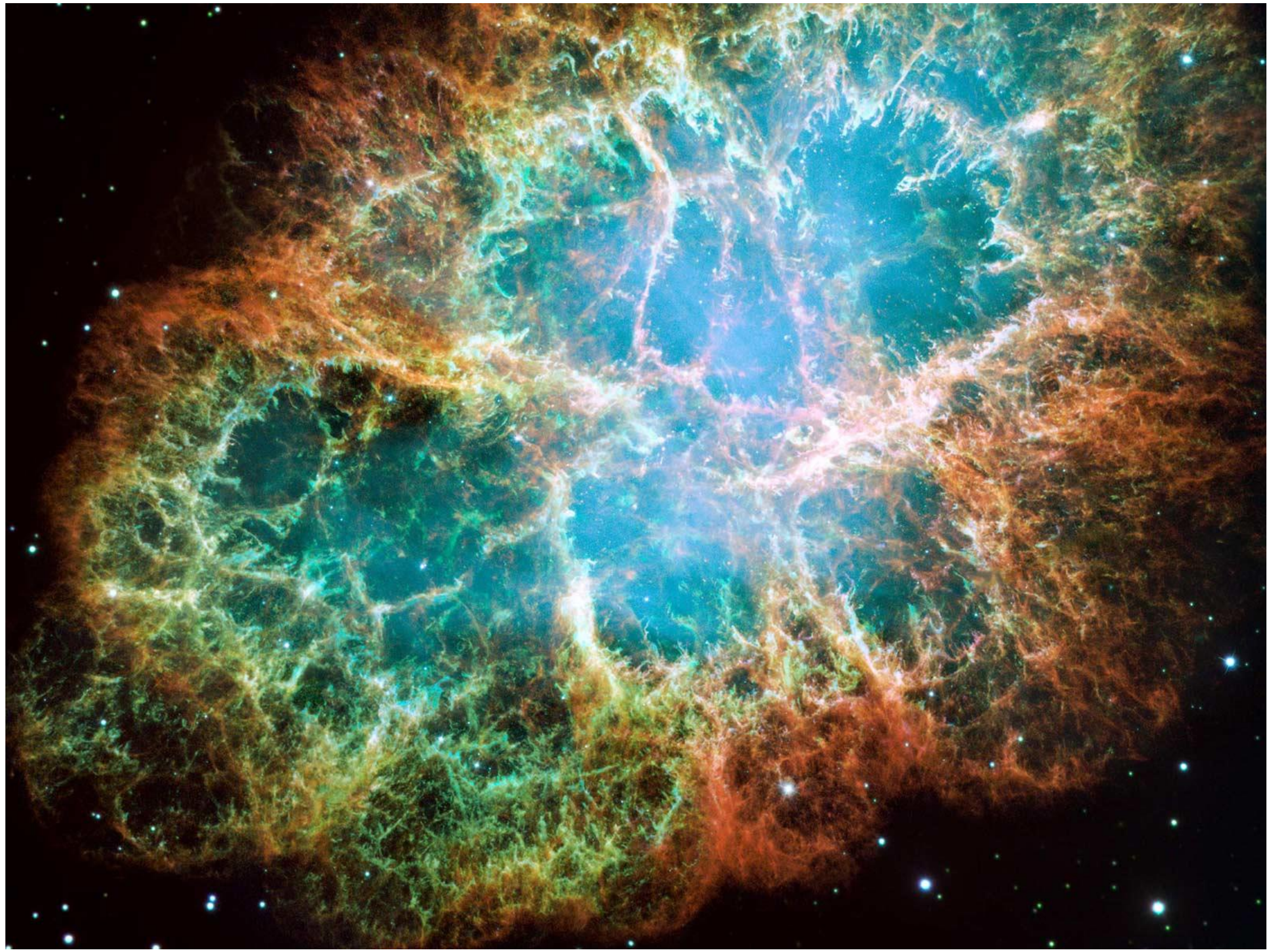
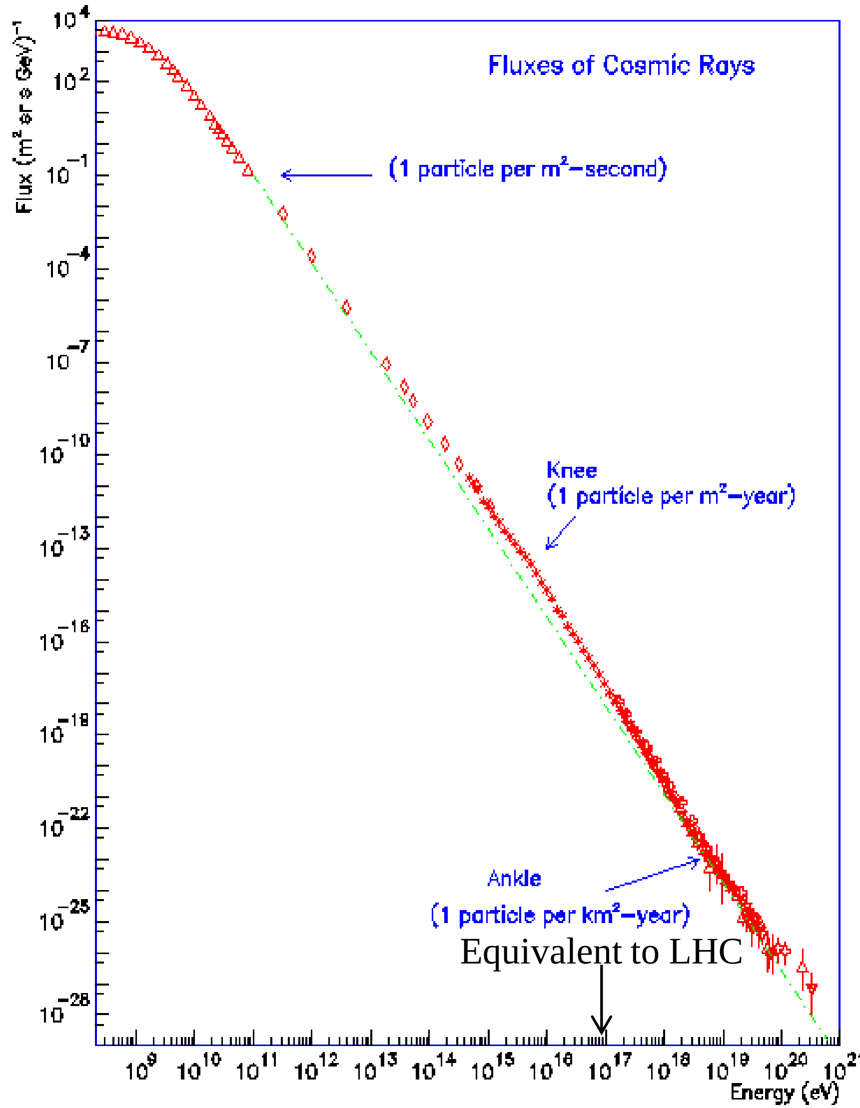
Cosmic Rays

- Introduction
- The Pierre Auger experiment
- Accelerating Cosmic Rays
- Cosmic Rays and high energy photons
- The Cherenkov Telescope Array
- Summary



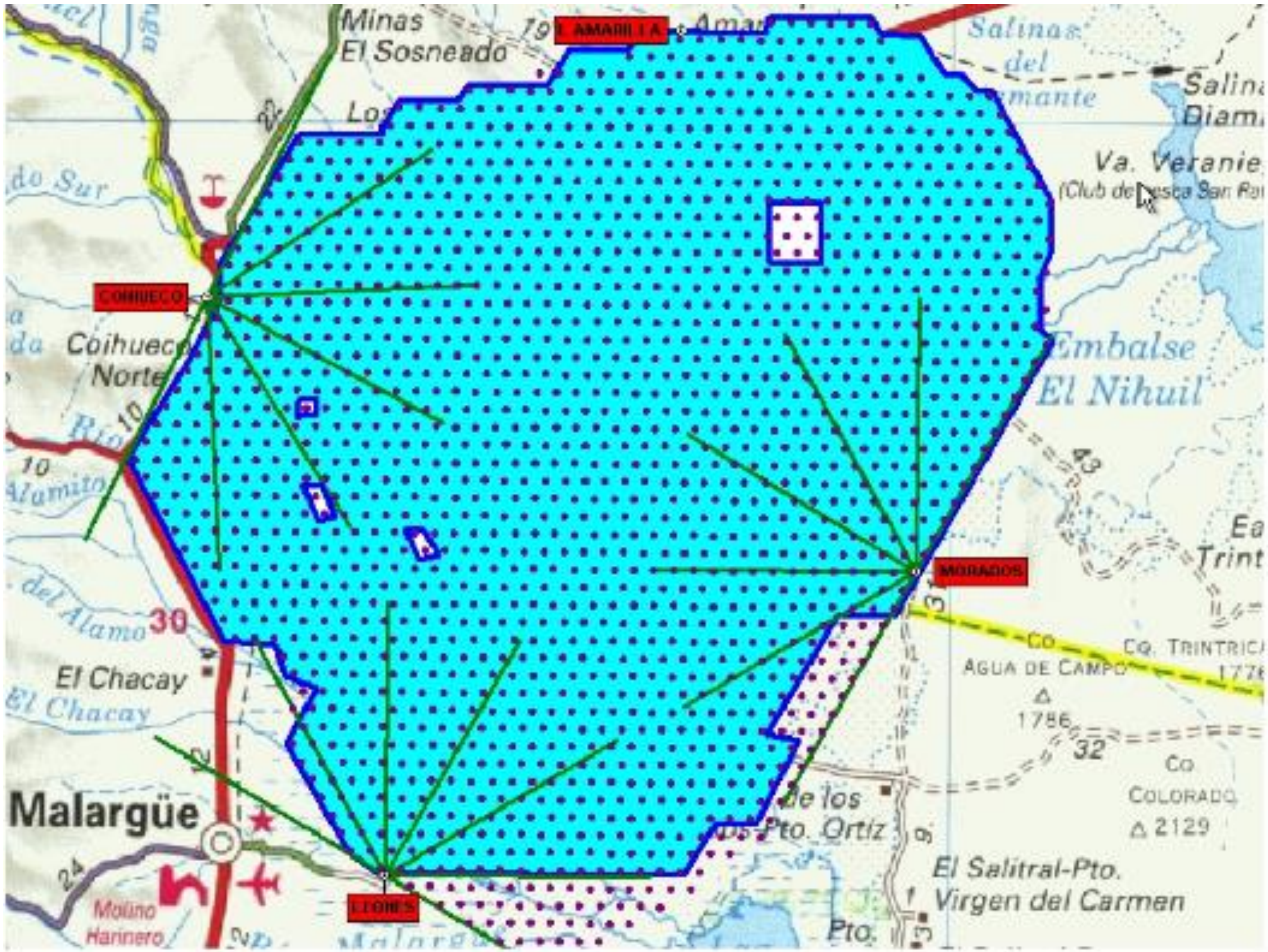
Introduction

- Cosmic Rays are high energy particles incident on the atmosphere from outer space.
- High energy means:
  - From about 10^9 eV = 1.6 10^{-10} J, the energy of a red blood cell moving at a few m/s…
  - …to about 3×10^{20} eV = 48 J, the energy carried by a tennis ball moving at 90 mph.
- How do we know about these particles?
- Where do they come from and how are they accelerated?
- What effects do they have?
- How can we learn more about them?



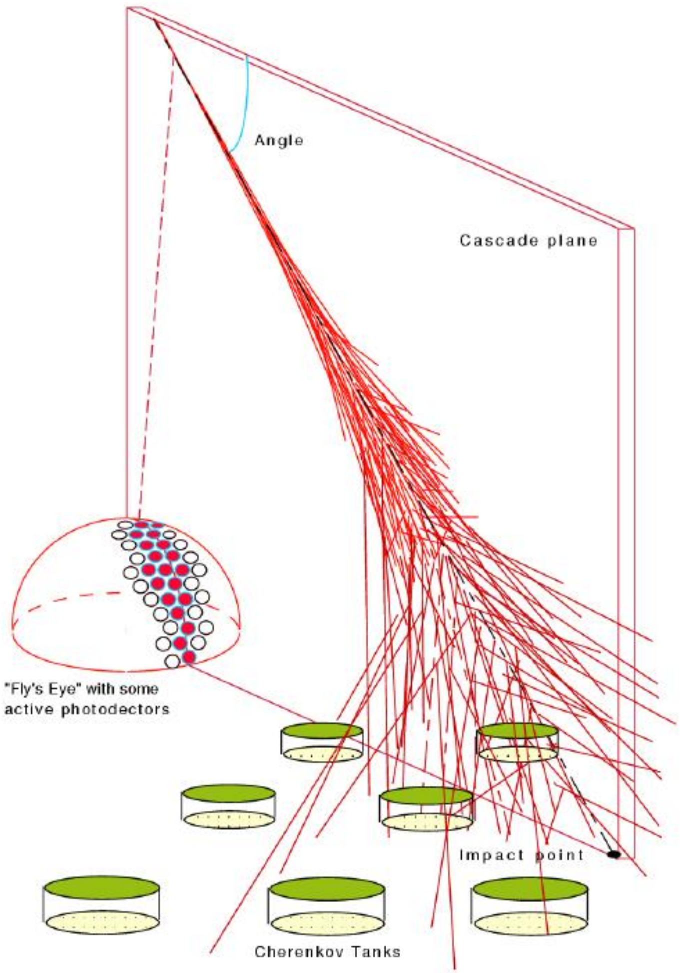
The Pierre Auger Observatory

- Located near Malargüe, Argentina.
- Proposed in 1992, completed in 2008.
- Area over 3000 km^2, about twice the area of Greater London.
- Consists of 1650 Surface Detectors and four Fluorescence Detectors.



The Pierre Auger Observatory

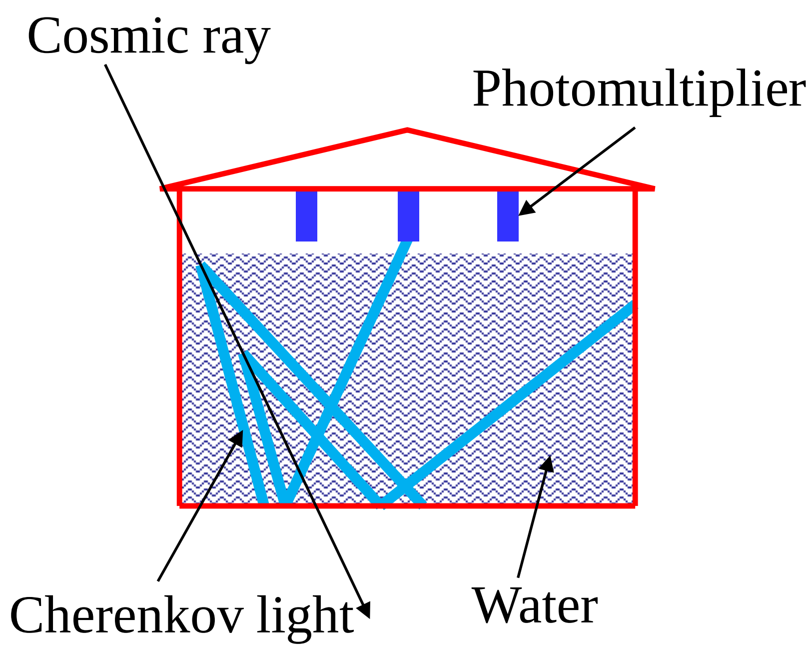
- In principle...



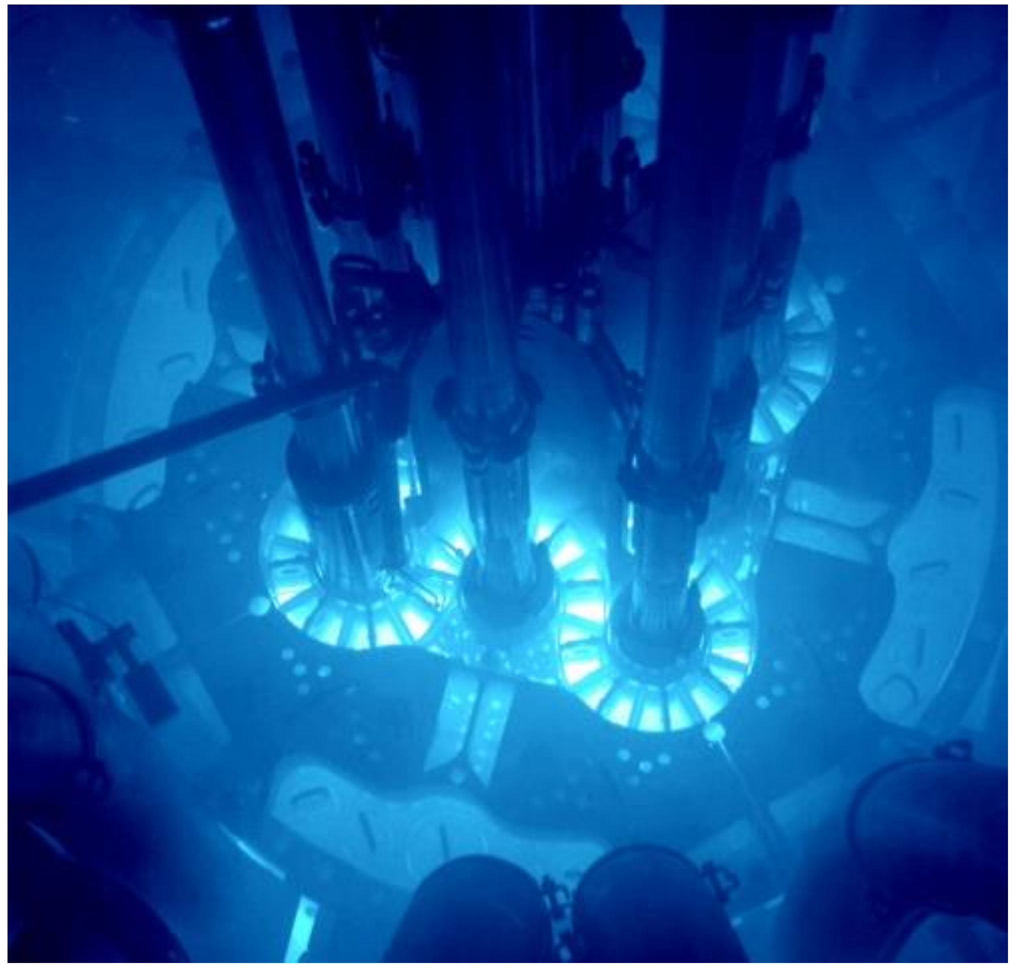
- ...and in practice

The Pierre Auger Observatory

- Surface detectors:

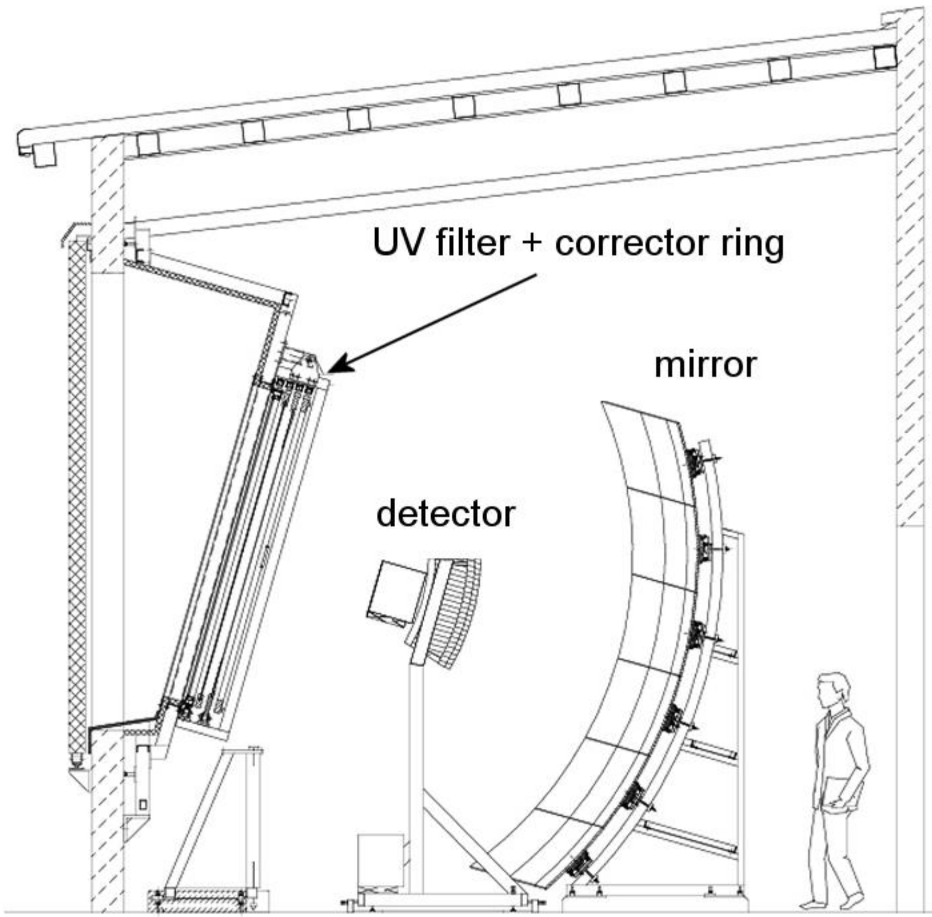


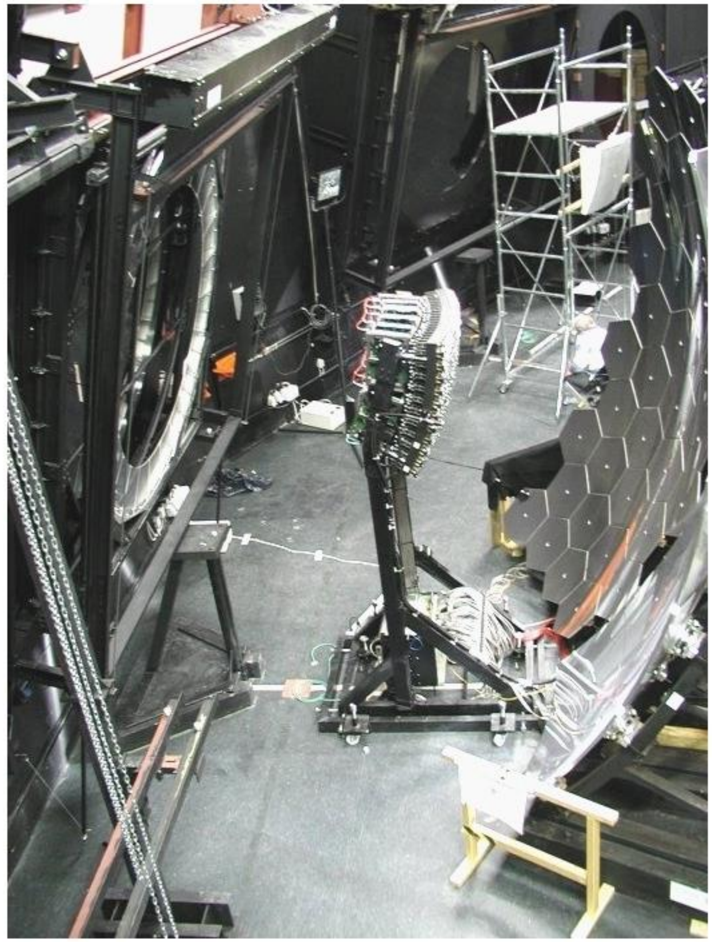
- Cherenkov light in a nuclear reactor:



The Pierre Auger Observatory

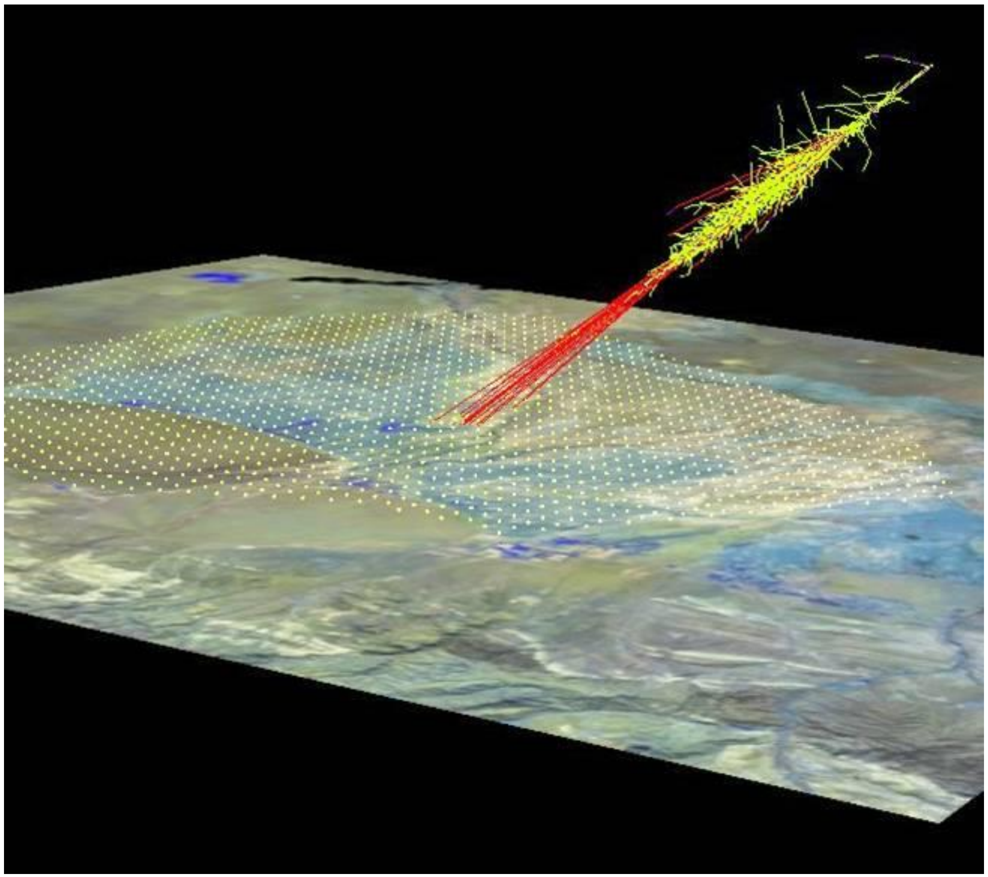
- Fluorescence detectors:



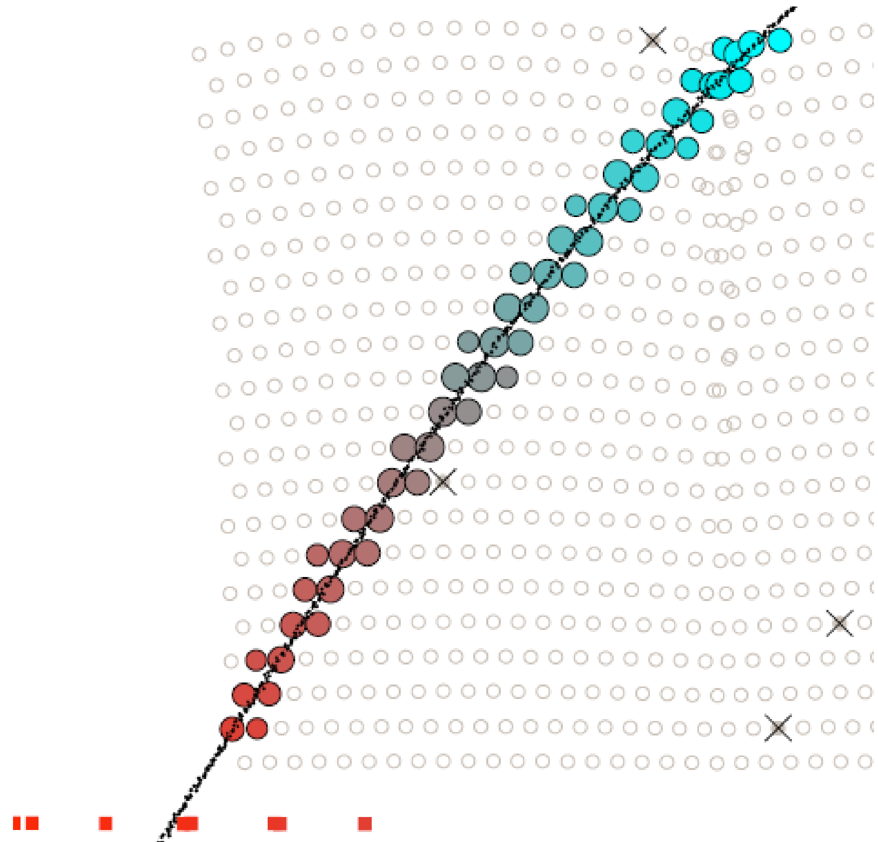


High energy event at Auger

- Computer simulation:

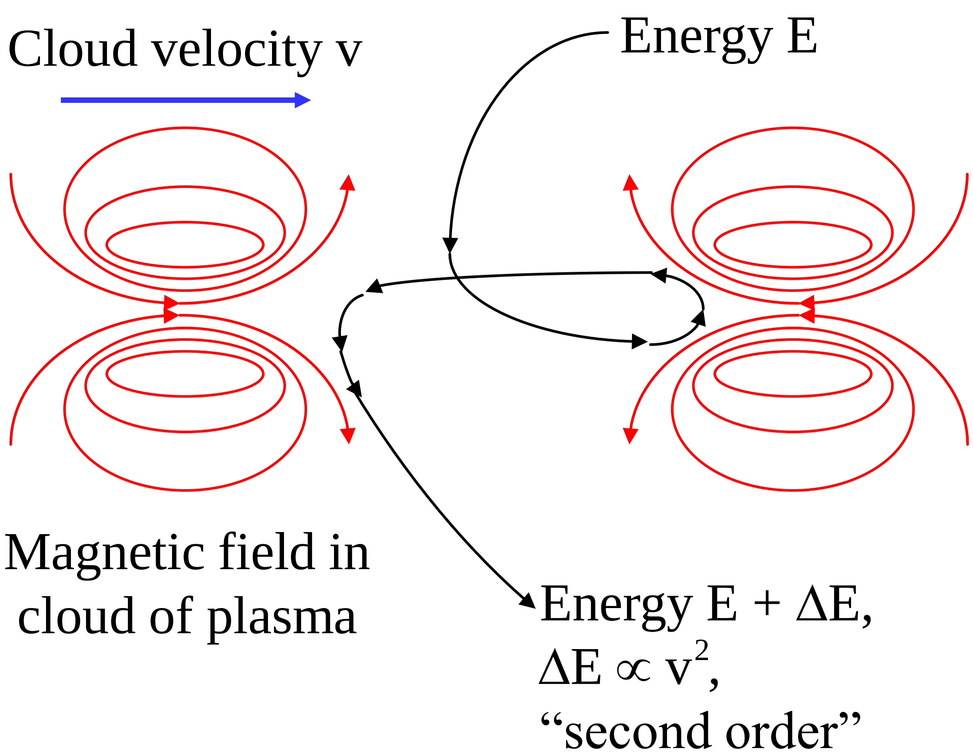


- Measurement:



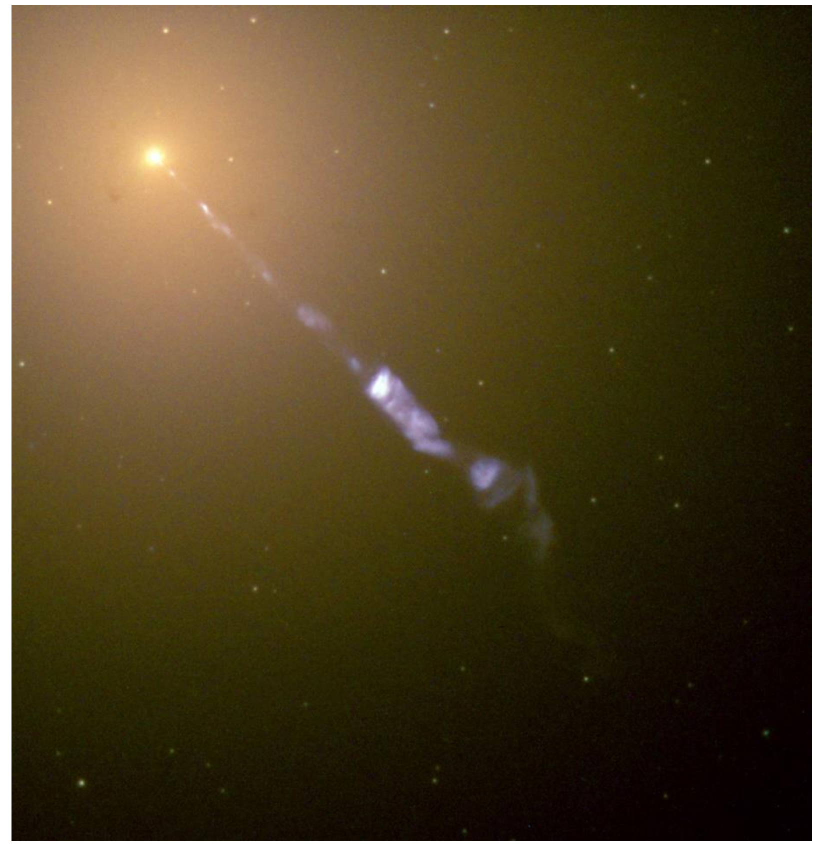
Acceleration of Cosmic Rays

- Fermi mechanism:



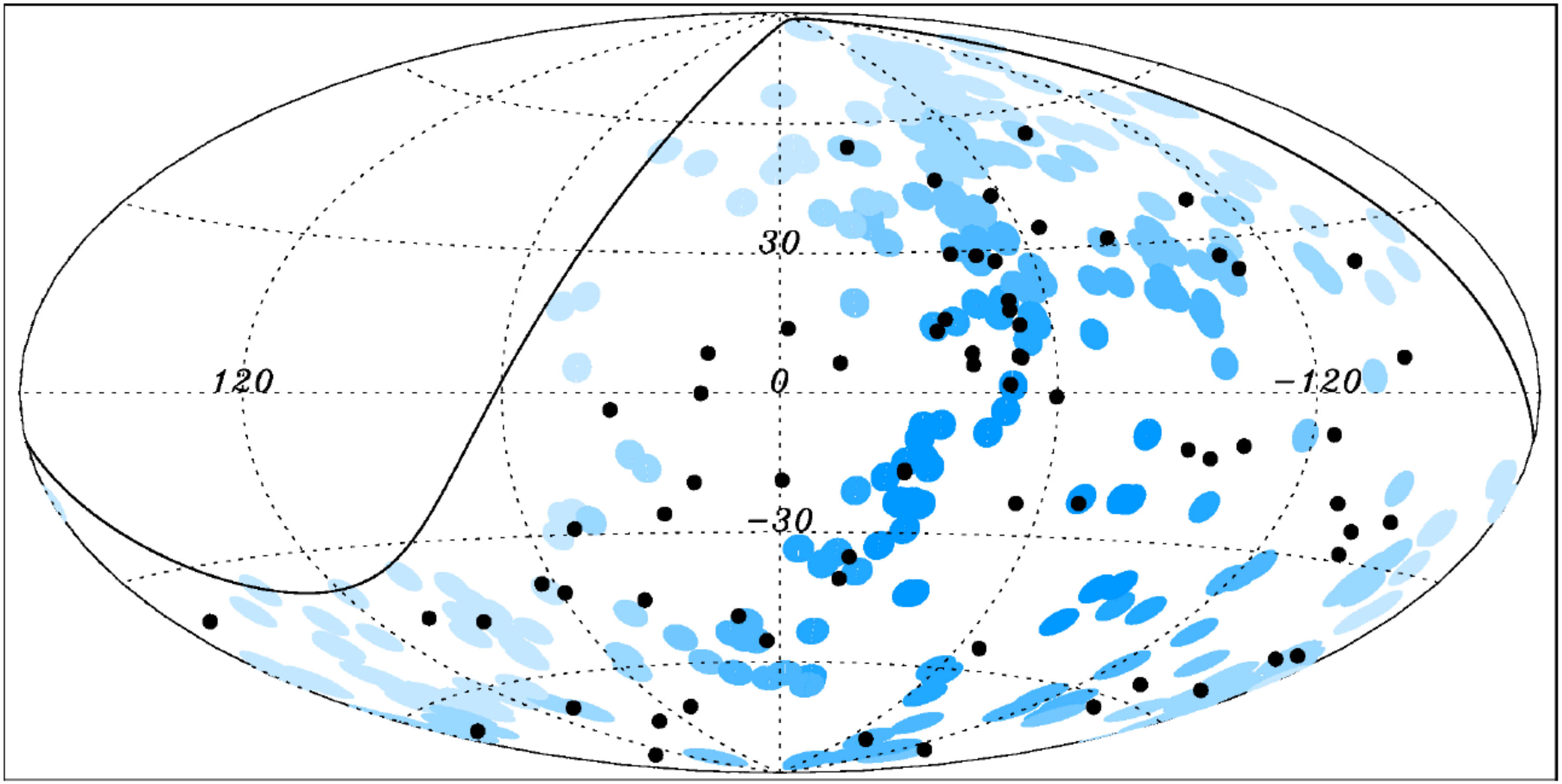
- These clouds are thought to occur around supernovae, or in jets from Active Galactic Nuclei.

- Jet visible in Hubble image of M87:



- Jet is 1500 pc (5000 LY) long!
- Seen because of synchrotron radiation.

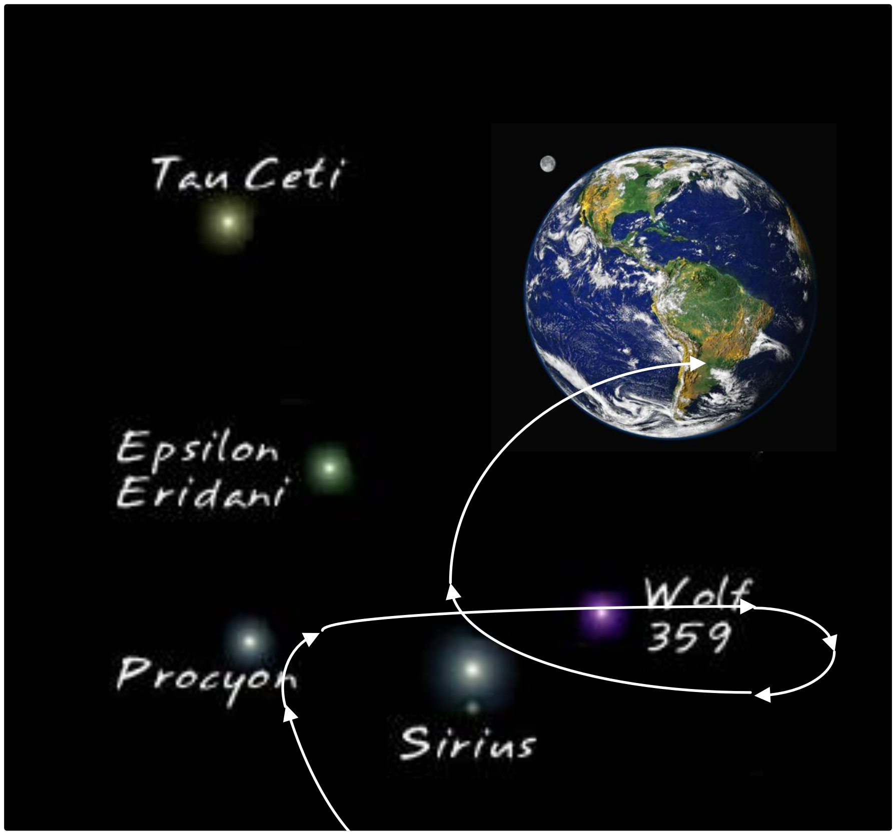
Origins of high energy Cosmic Rays



- Arrival directions of 69 CRs with E > 55 EeV (10^{18} eV) and position of AGNs within 75 Mpc (about 250 MLYs) of earth.

Origin of high energy Cosmic Rays

- Charged particle directions influenced by magnetic fields.

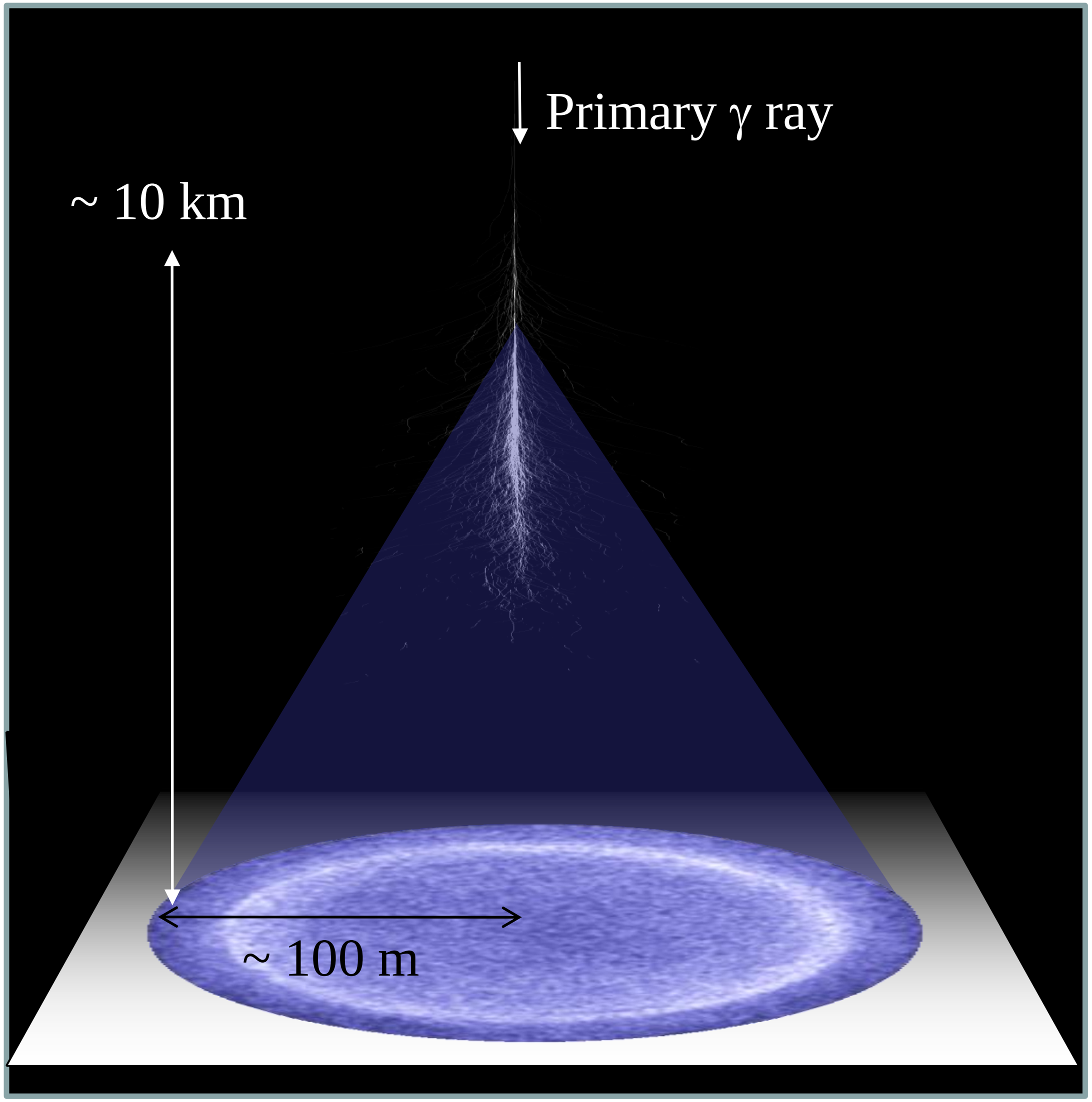


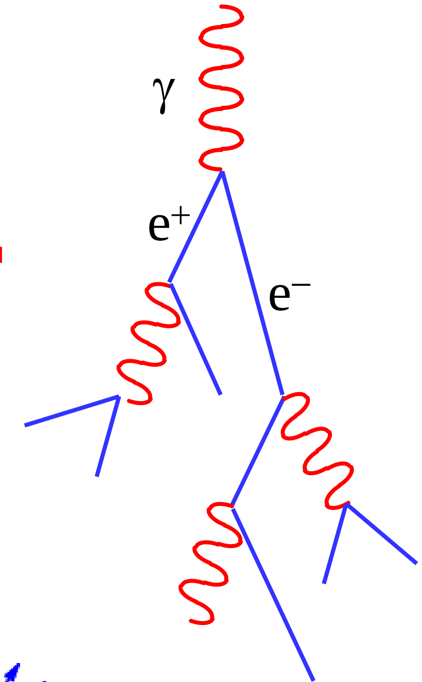
- Difficult to track Cosmic Rays back to their origins.
- Need particles that travel in straight lines through magnetic fields…photons.
- Fortunately, these are produced by Cosmic Rays!

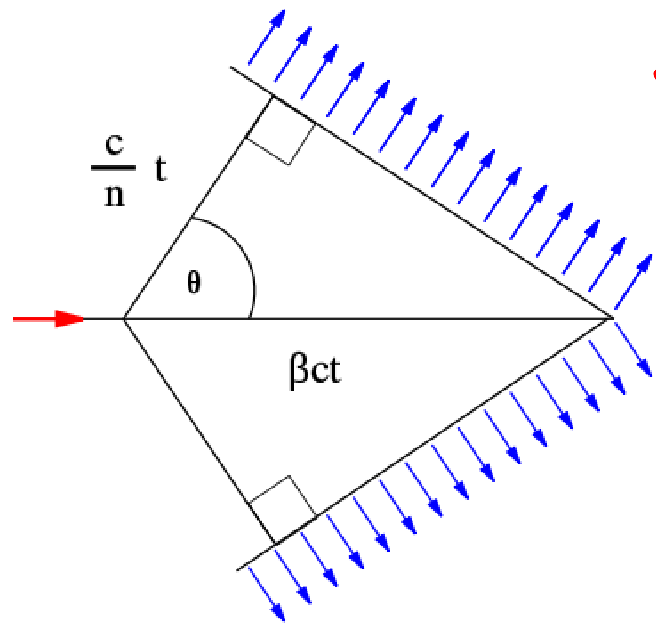
$$p + N \rightarrow \pi^0 + X, \quad \pi^0 \rightarrow \gamma\gamma$$

- Can we detect these very high energy photons?
- Can they show us where Cosmic Rays are being produced?

Detecting high energy γ rays

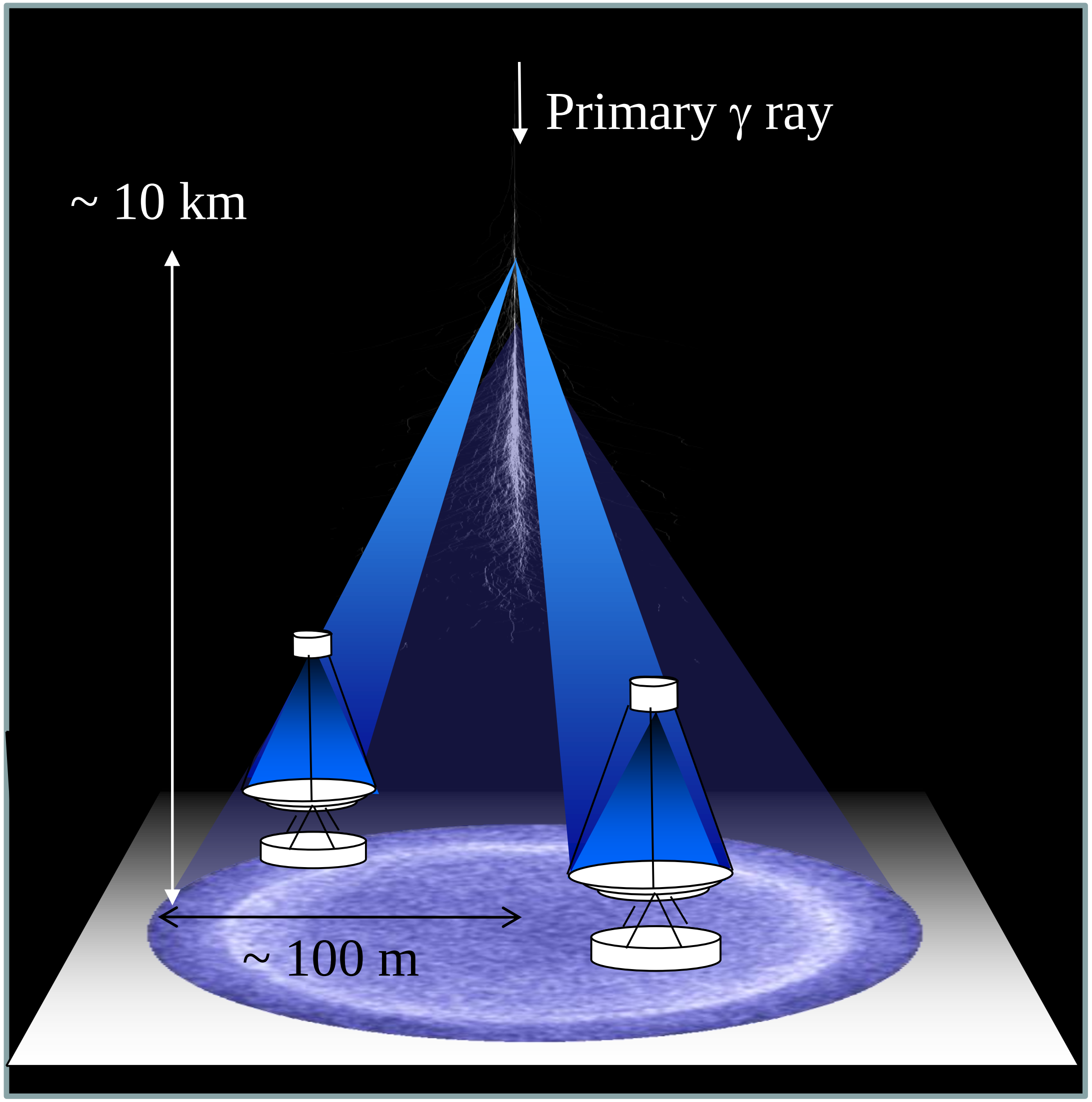




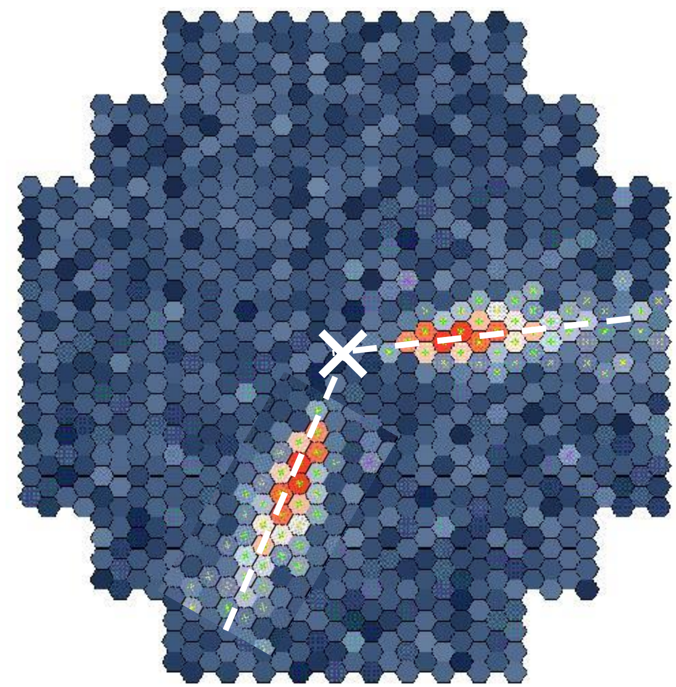


- cos θ = 1/n, so light cone angle about 1° in air.

Detecting high energy γ rays

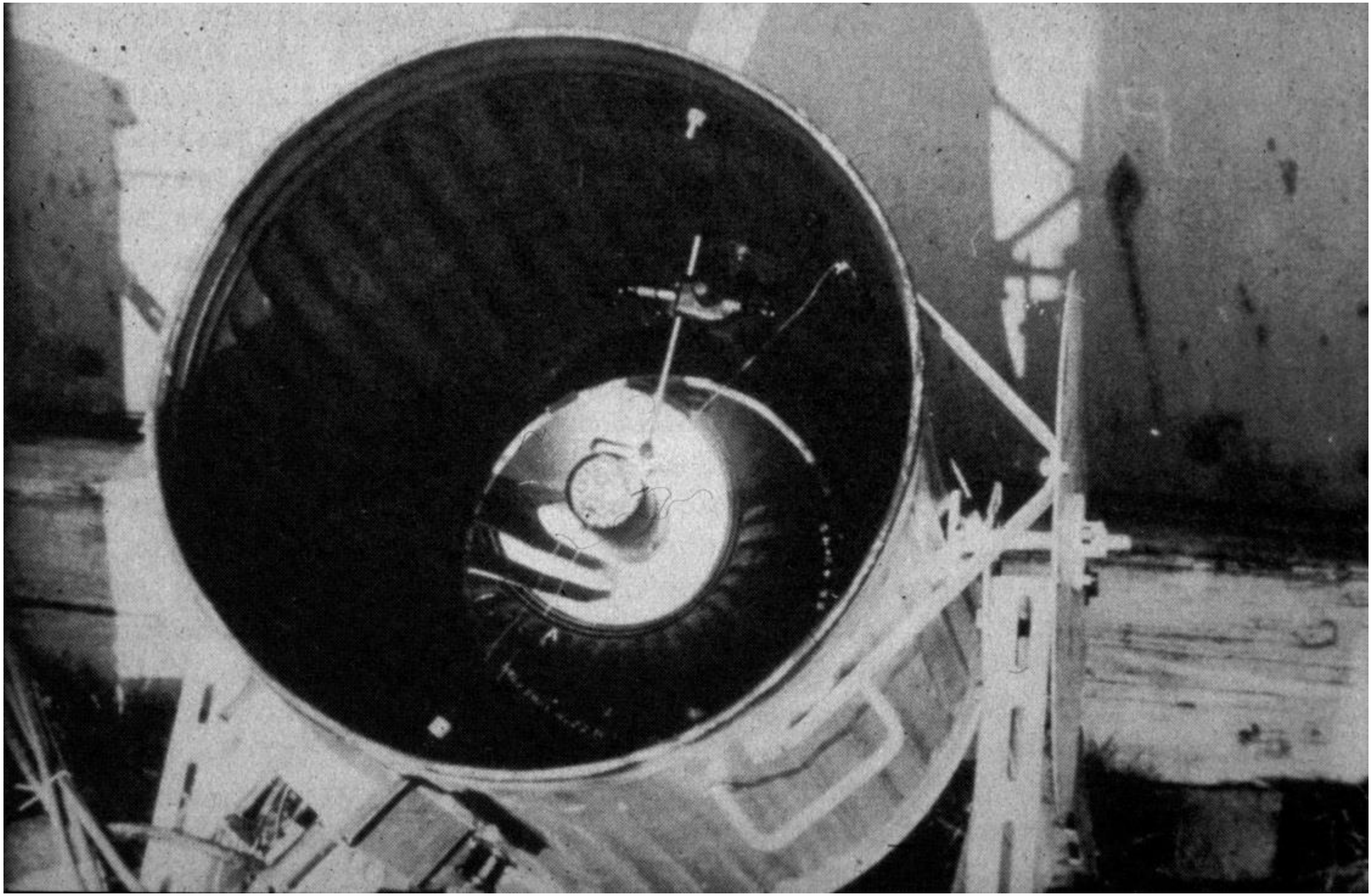


- Light flash lasts about 10 ns.
- Detect with "camera" made of photomultiplier tubes.
- Superimpose telescope images, find γ-ray source.



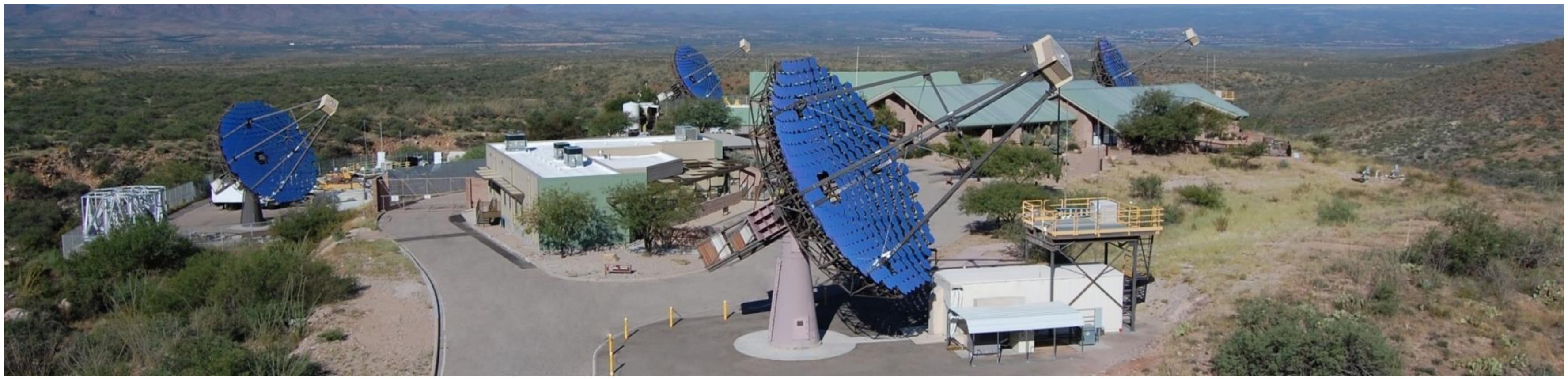
The first Atmospheric Cherenkov Telescope

- Galbraith and Jelley, Harwell, 1953.



Current IACT arrays

- VERITAS



- HESS

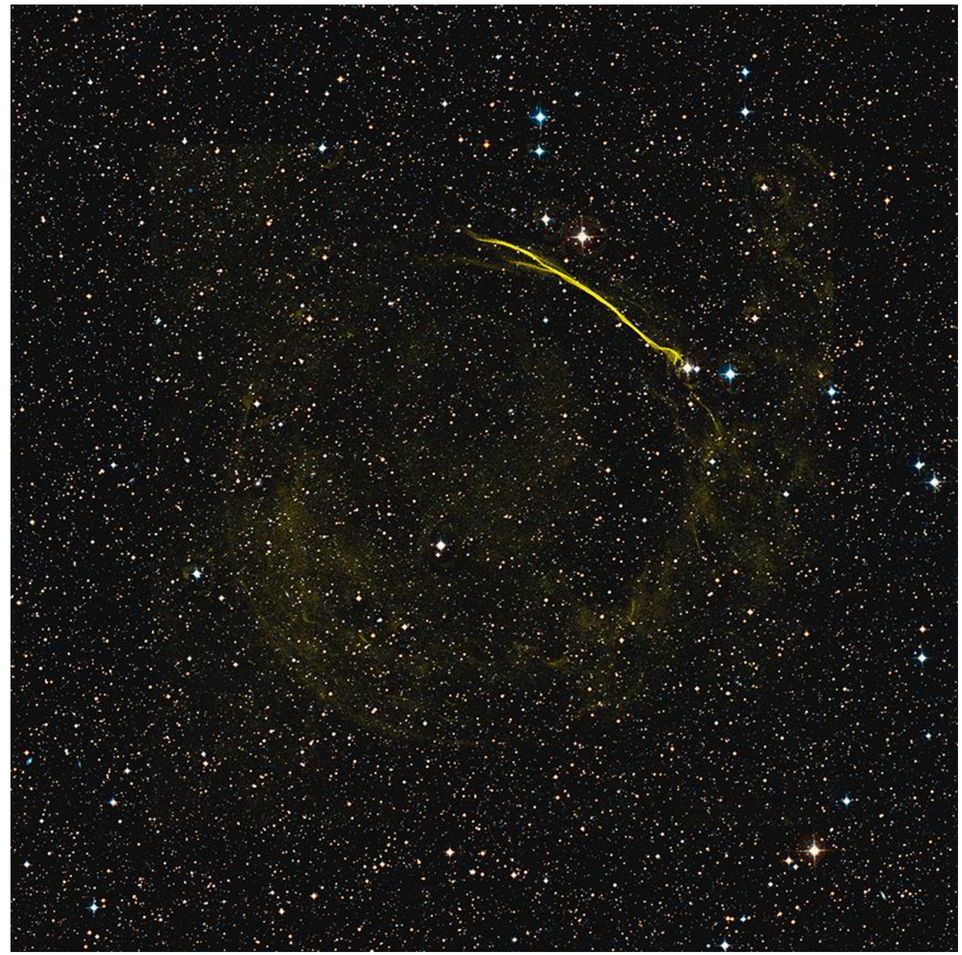
Current IACT arrays

- MAGIC

A source of gamma rays – Supernova 1006

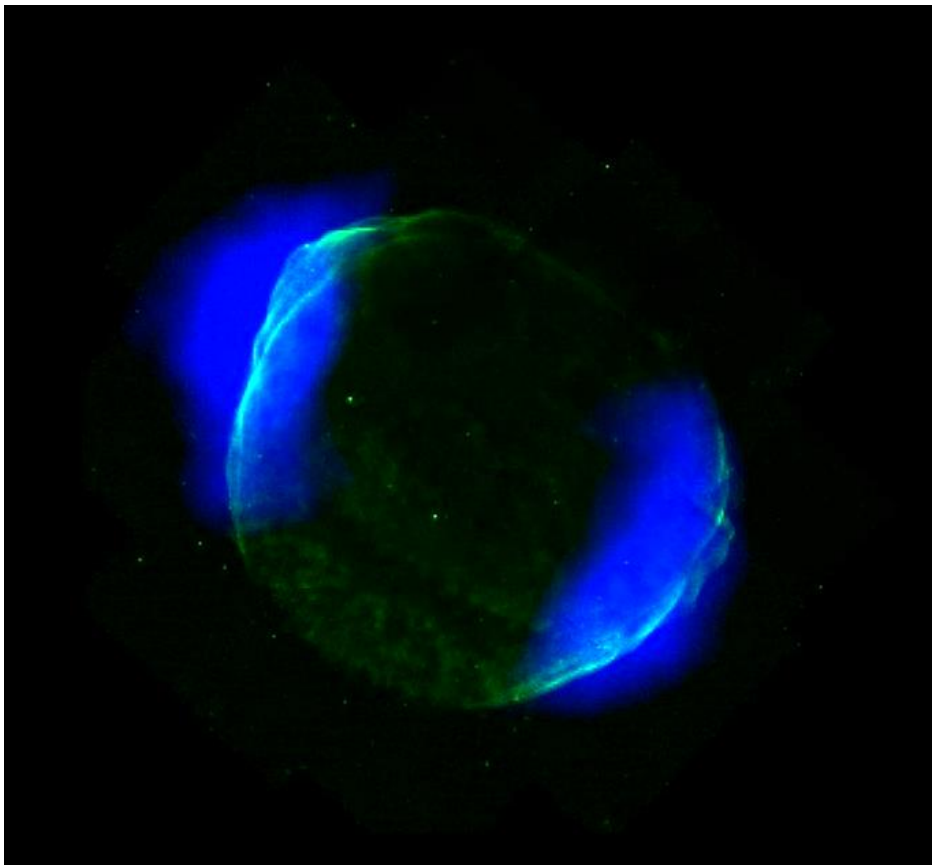
- Distance 6000 Ly.
- Diameter about 60 Ly.
- First seen 1009 years ago:

- Optical

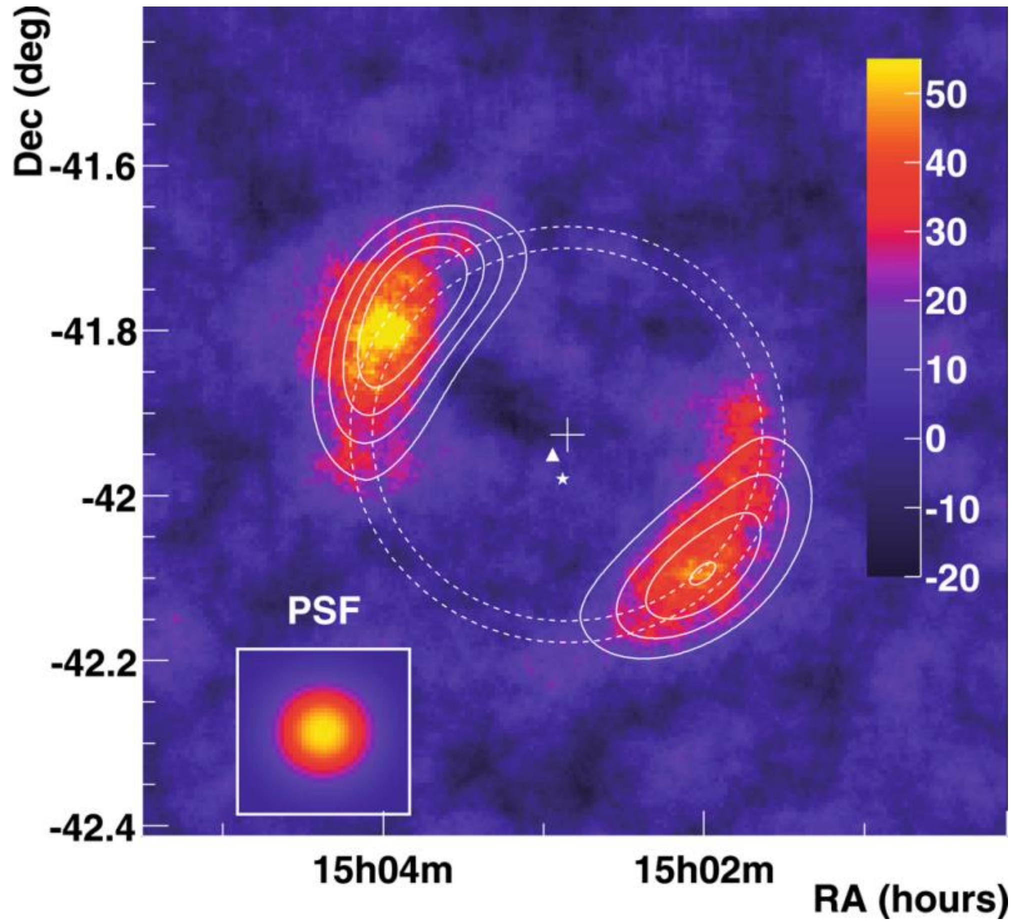


Supernova 1006

- Satellite X-ray (green) and "low energy" γ-ray images (blue):

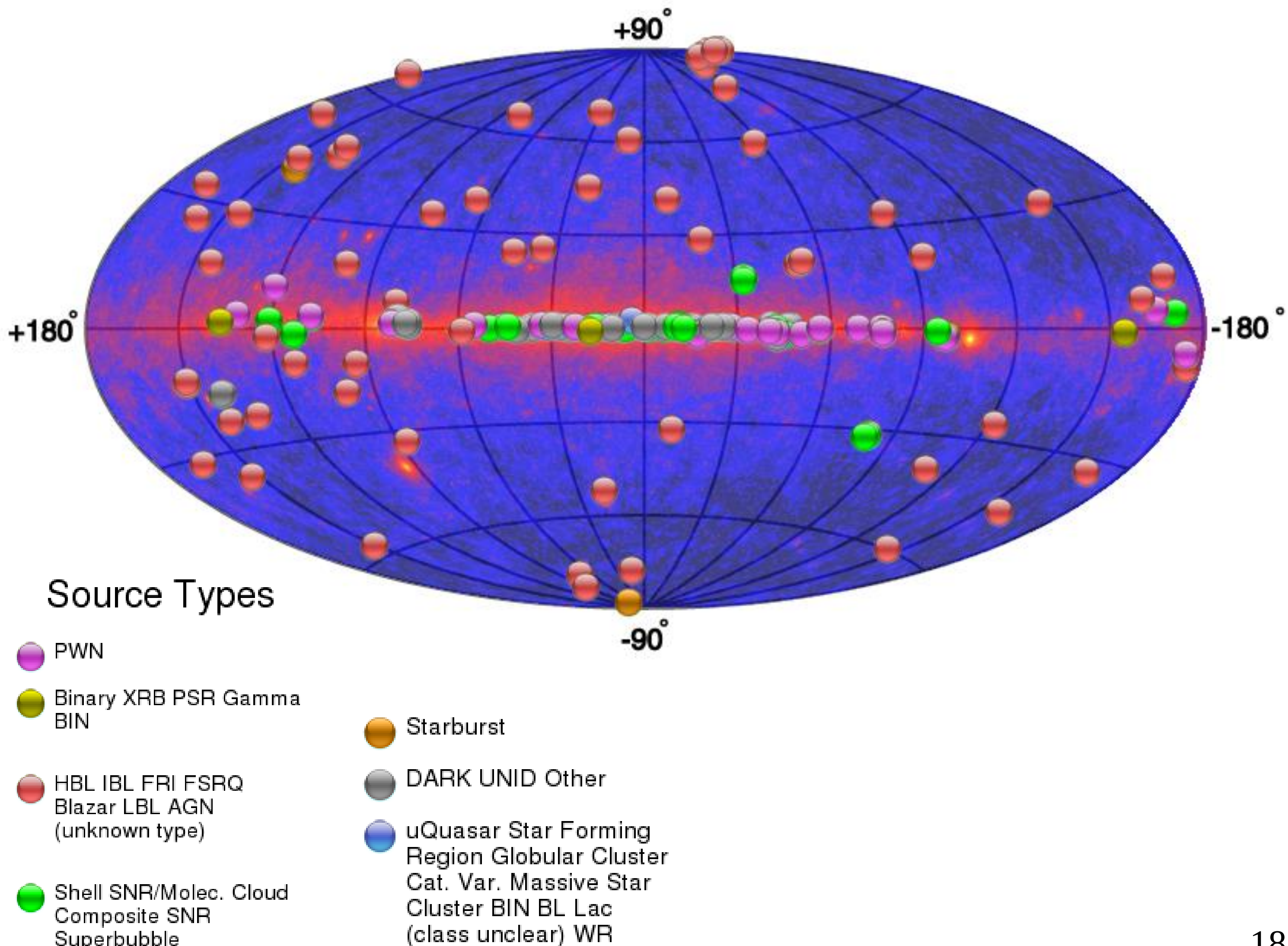


- HESS very high energy γ-ray image:



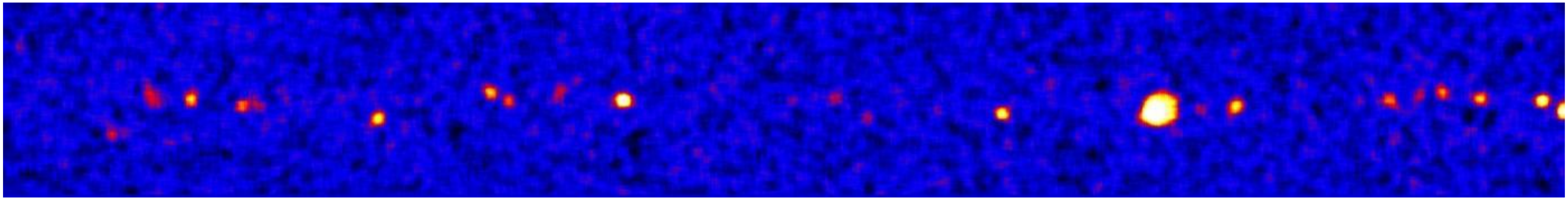
All known sources of very high energy gamma rays.

- 25th March 2015.
- 157 γ-ray sources.
  - ~ 100 galactic.
  - ~ 130 found with IACTs.
- Further progress requires:
  - Improved sensitivity.
  - Better energy and...
  - ...angular resolution.

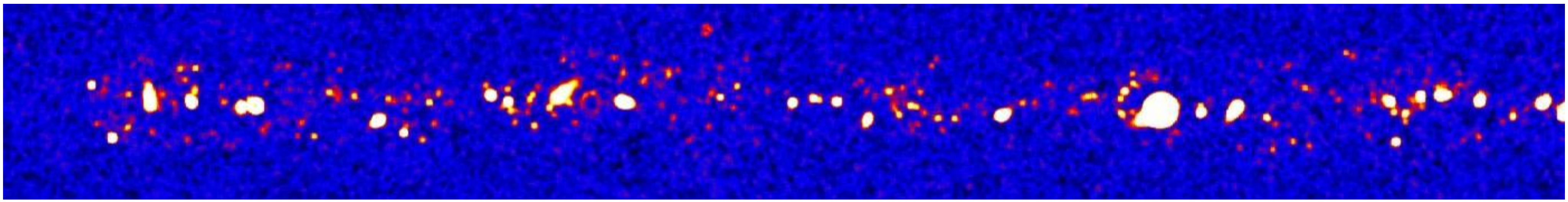


Performance goals for next-generation IACT

- Aim for factor of 10 improvement in sensitivity.
- Compare HESS ~ 500 hour image of galactic plane...



- ...with expectation with increased sensitivity, same exposure.



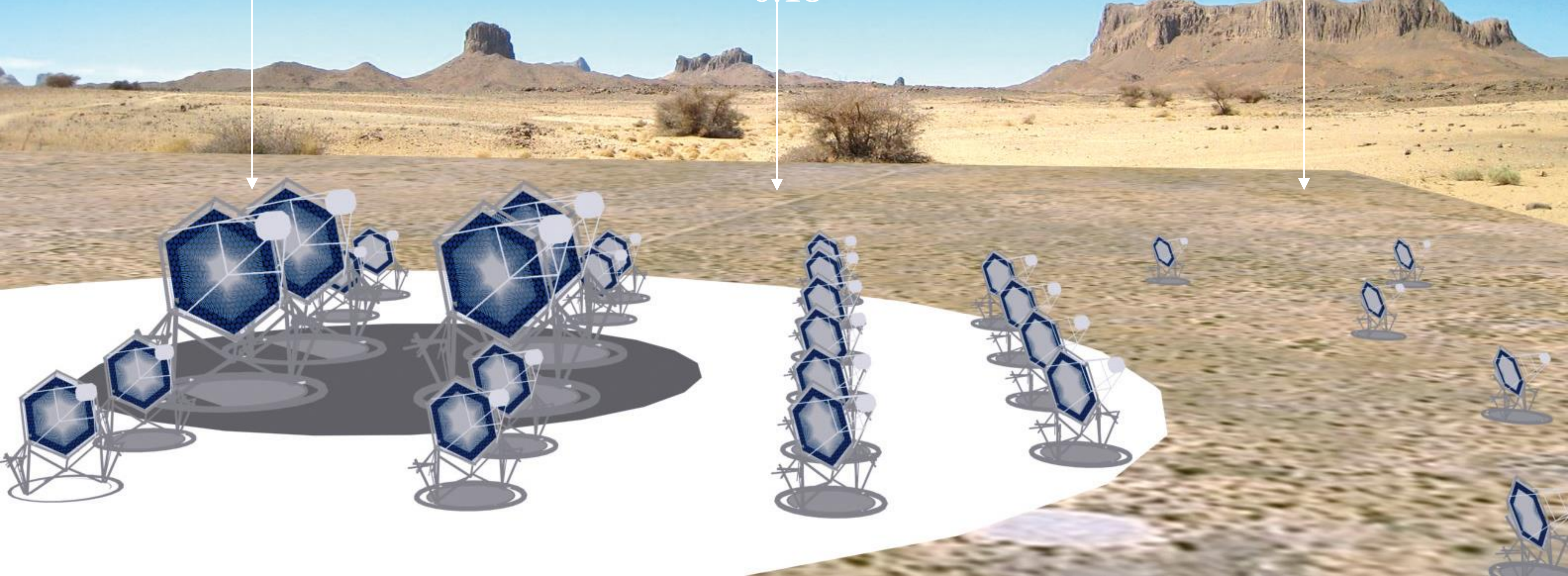
- Expect to observe around 1000 sources (galactic and extra-galactic).

The Cherenkov Telescope Array concept

Low energy
Four 23 m telescopes
4…5^{o} FoV
~2000 pixels
~ 0.1^{o}

Medium energy
About twenty-five 12 m telescopes
6…8^{o} FoV
~2000 pixels
~ 0.18^{o}

High energy
About seventy 4 m telescopes
8…10^{o} FoV
1000…2000 pixels
~ 0.17^{o}…0.23^{o}



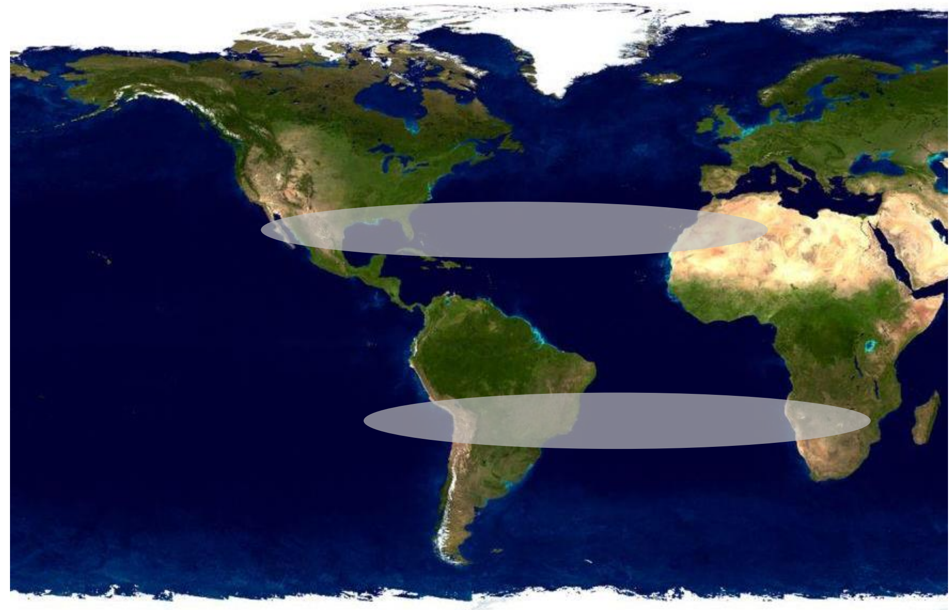
CTA performance goals

- Improve angular resolution by factor ~ 5.
- Substructure of SNR shock fronts can then be resolved:

Resolution 0.1°.

Resolution 0.02°.

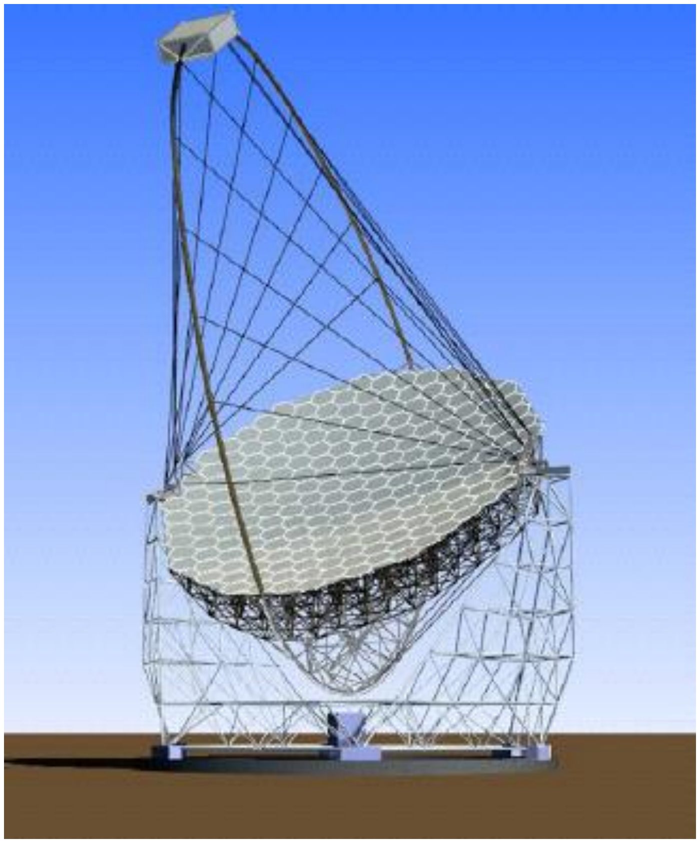
- Larger field of view (up to 10°).



- Southern array:
  - Galactic and extragalactic sources.
  - 20 GeV...100 TeV.
  - Angular resolution 0.02...0.2°.
- Northern array:
- Mainly extragalactic sources.
  - 20 GeV...1 TeV.

Large size telescope design

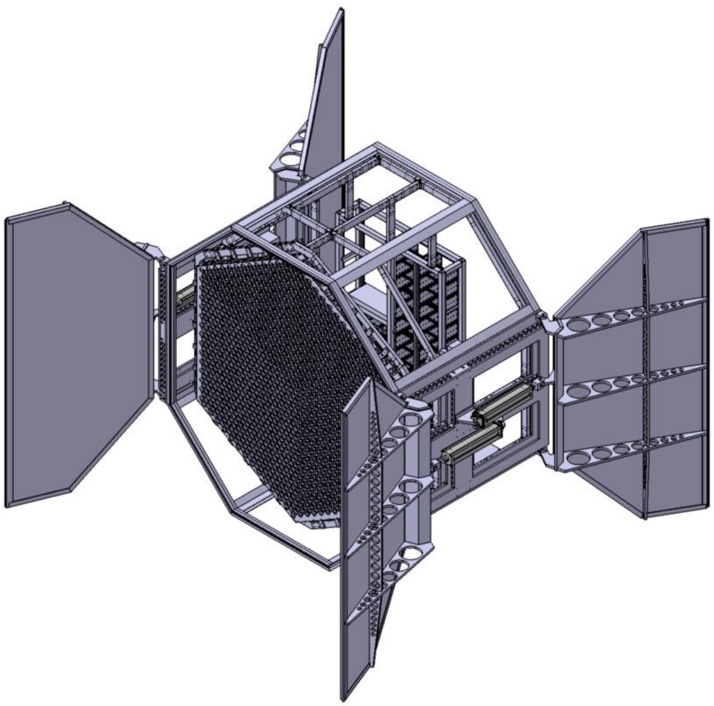
- Diameter 23 m, focal length 28 m.
- (Modified) Davies-Cotton optics.
- Support structure carbon fibre.

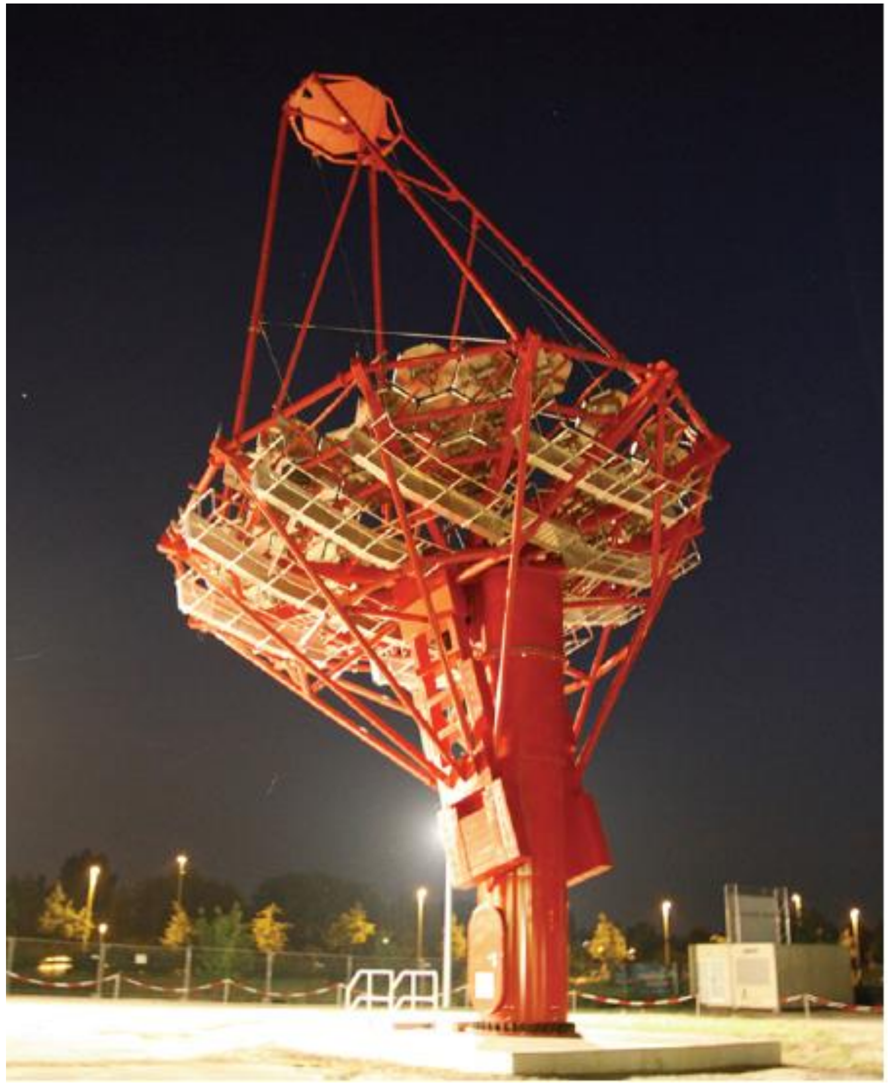


- Camera diameter ~ 2.2 m, mass ~ 2 t, uses conventional 1.5 inch (super-bialkali) photomultipliers.
- Similar to that for HESS II:

Medium size telescope

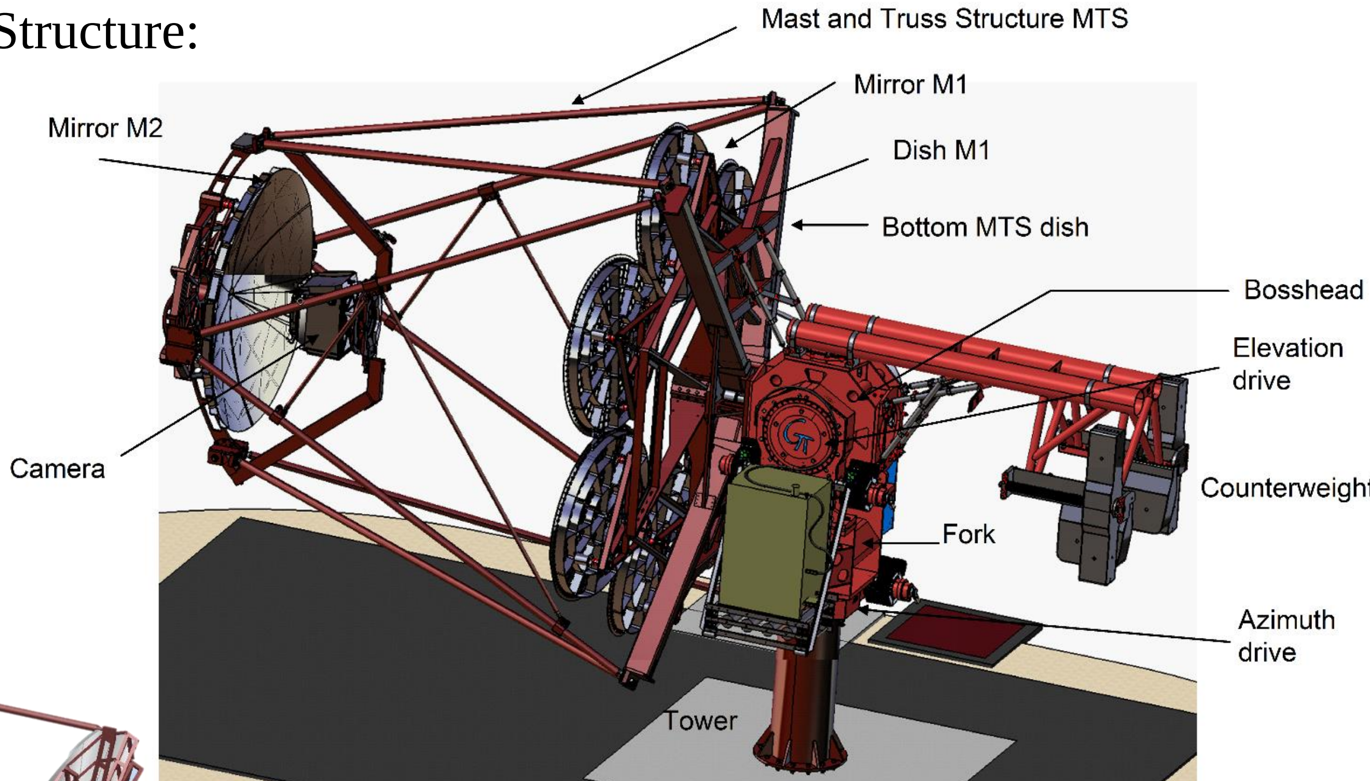
- Diameter 12 m, focal length 17 m.
- Davies-Cotton optics.
- Camera support and dish structure steel.
- Camera diameter ~ 2.2 m, mass ~ 2 t.

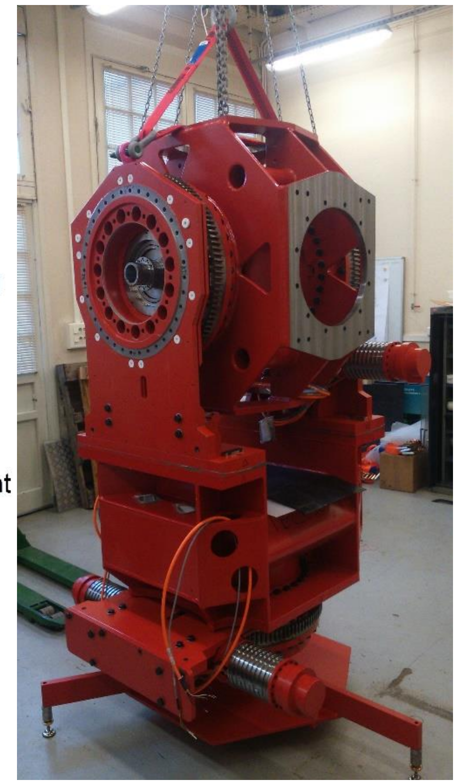


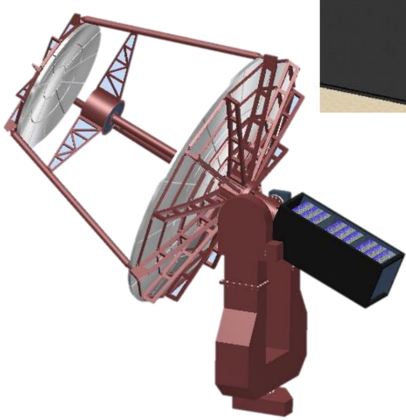


One SST design,
the Gamma-ray Cherenkov Telescope

- Structure:

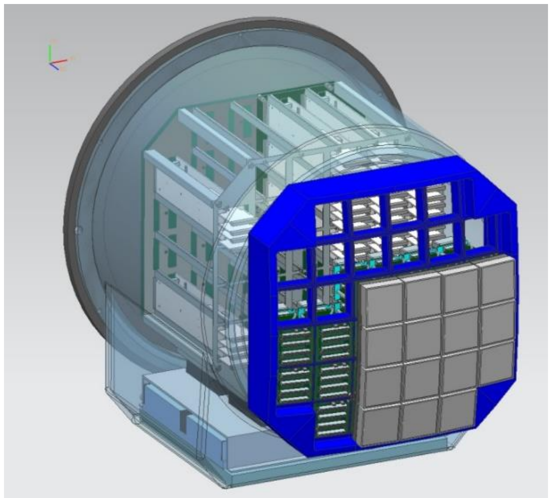


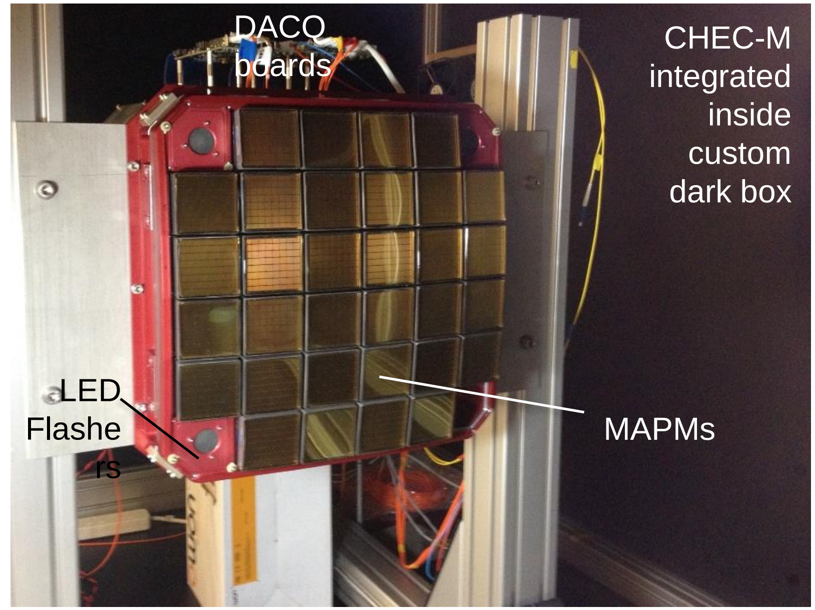


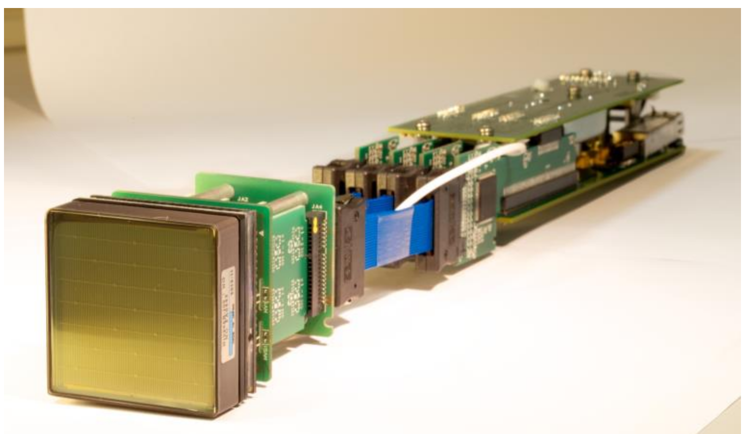


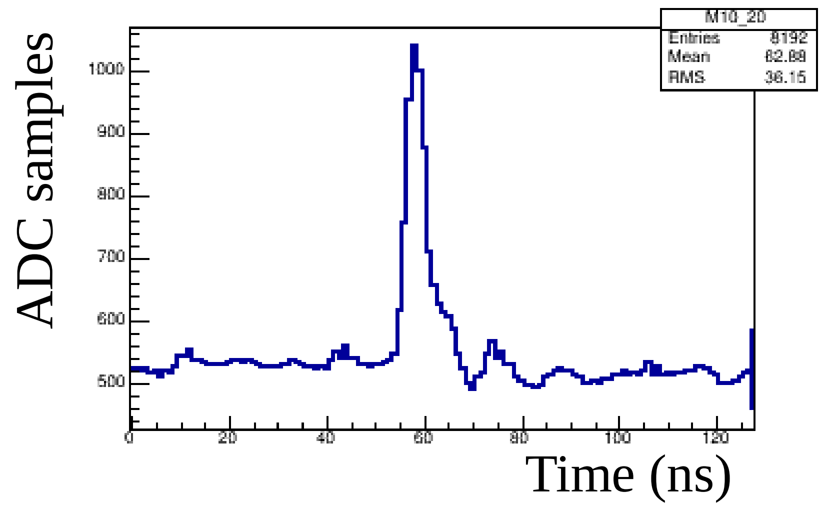
Compact High-Energy Camera

- In theory and practice…









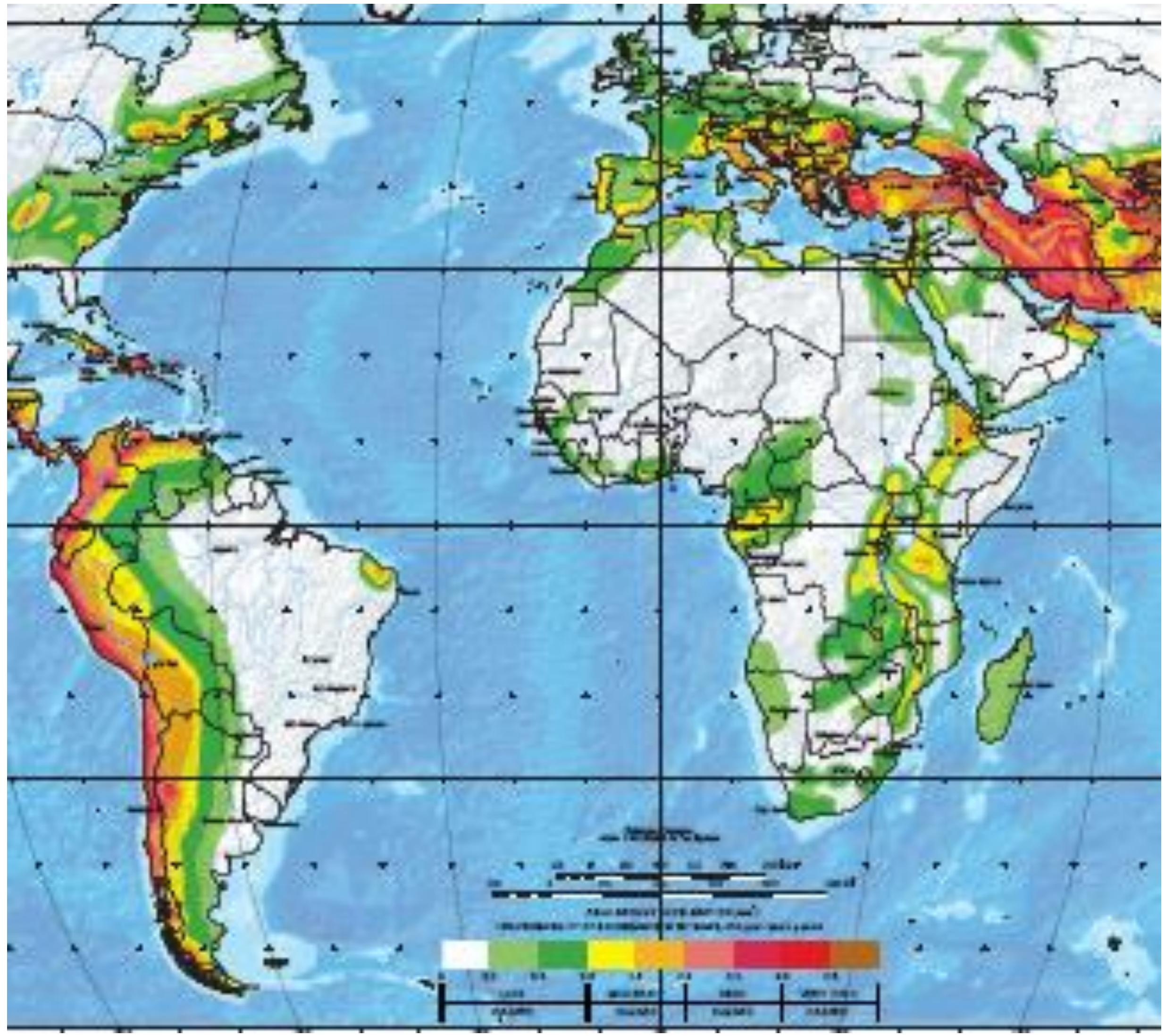
Prototypes and tests

- Camera will be tested on a prototype SST-GATE telescope in Paris in autumn 2015…

- …and on a second (ASTRI) SST prototype on Etna towards the end of 2015…

CTA site

- Sites under consideration in:
  - Namibia, Chile and Argentina.
  - Mexico, USA and Spain (La Palma).
- Considerations include:
  - Altitude.
  - Cloud cover.
  - Wind speed.
  - Dustiness.
  - Seismic loads...

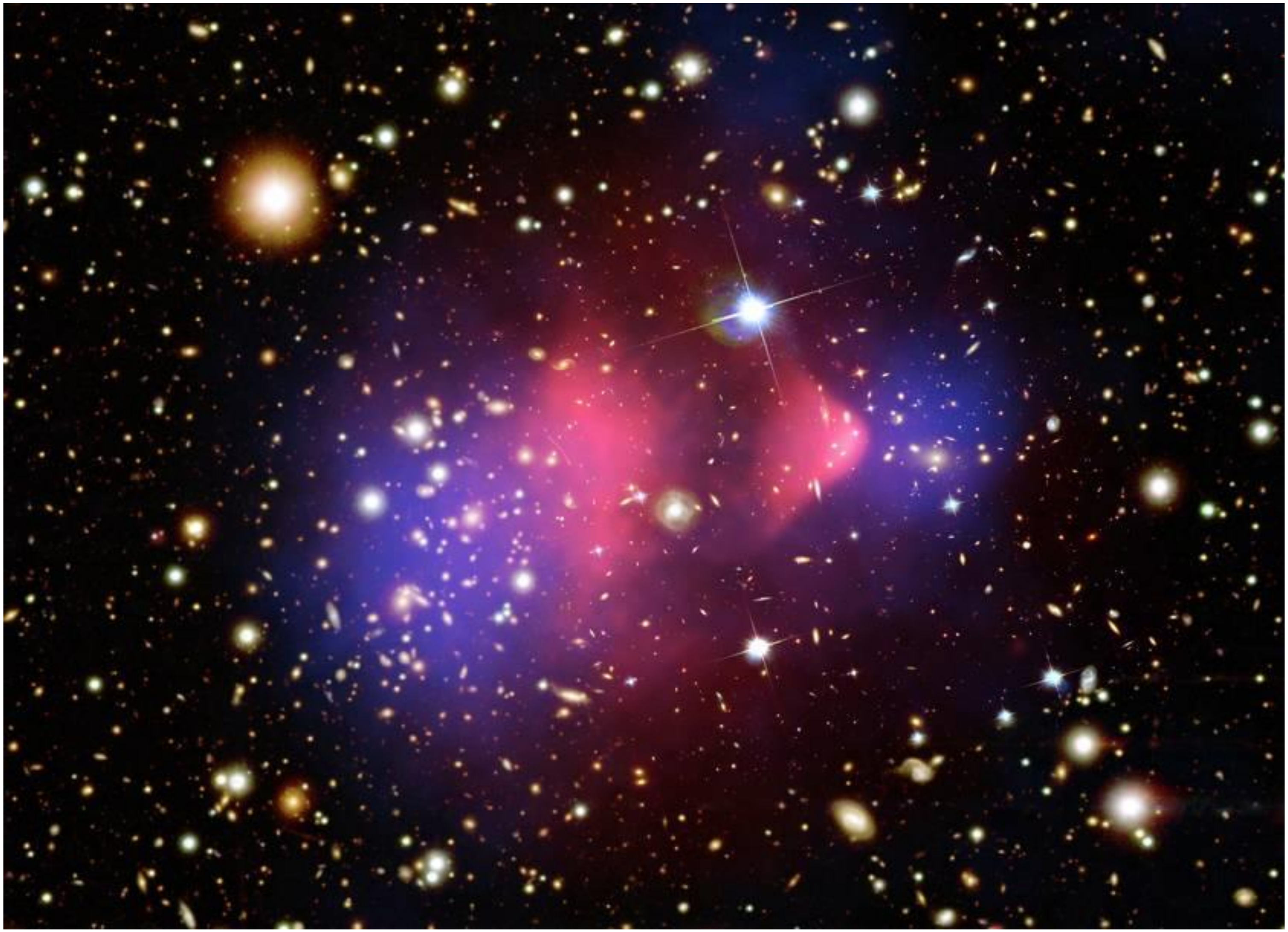


Namibia: advantages and disadvantages

ESO Paranal site in Chile

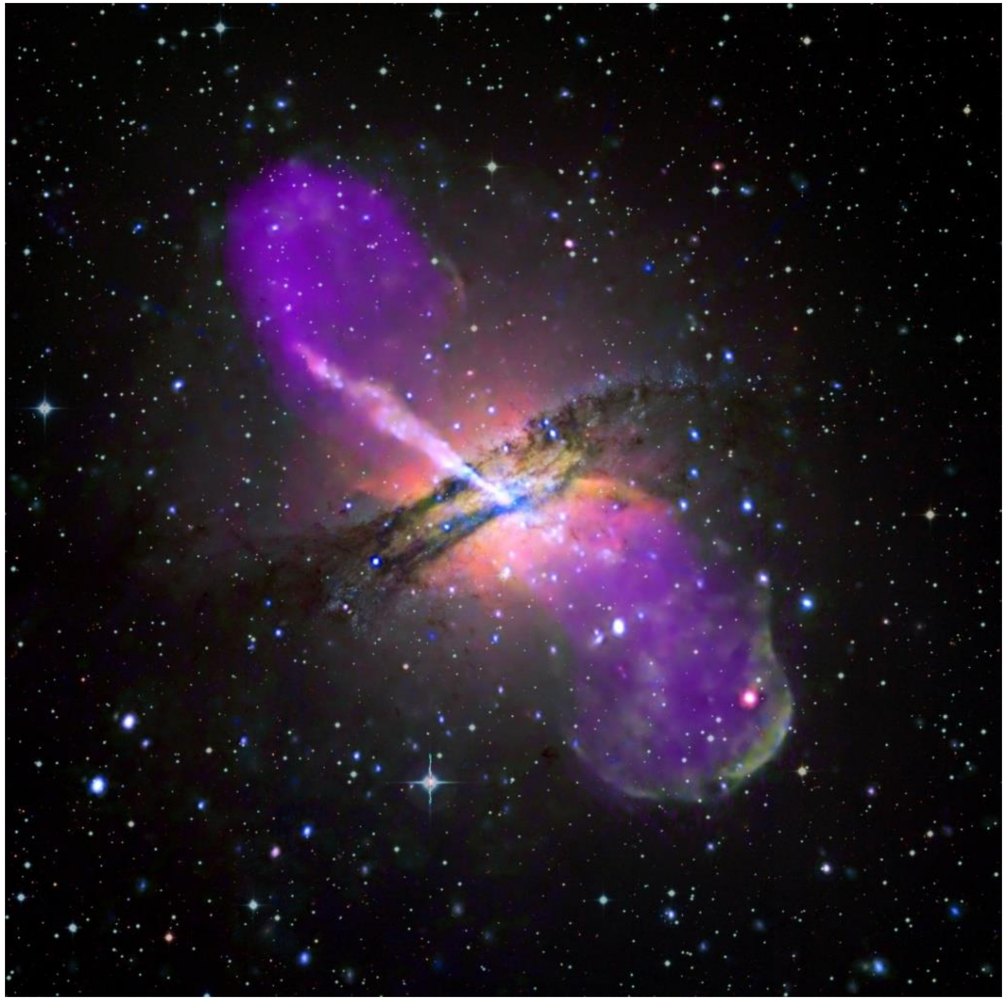
Detect Dark Matter?

- Dark Matter forms most of material of Universe, (“seen” e.g. in Bullet Cluster).
- Annihilation of Dark Matter particles could produce high energy photons that CTA could measure.



Summary

- Cosmic Rays continually bombard the atmosphere and some of them have astonishing energies.
- The best way of learning about how these particles are accelerated is to measure the photons they produce when they interact.
- Studying these photons with current and future instruments will help us to understand the most violent events occurring in the Universe...
- ...and also to learn more about fundamentally new physics, such as Dark Matter.



Centaurus A