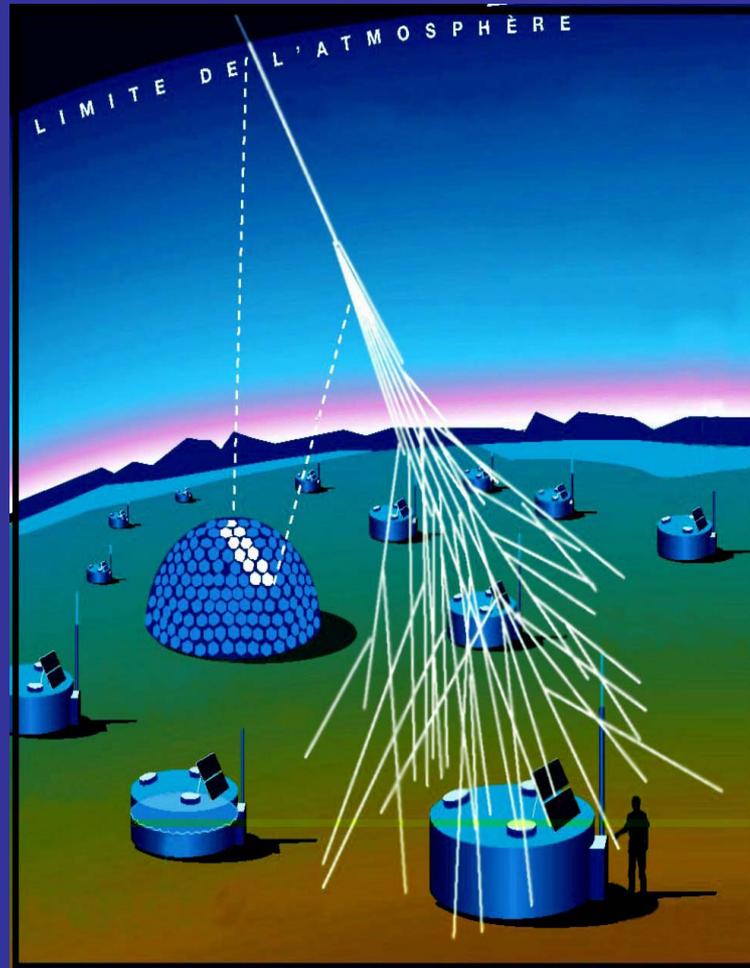


# COSMIC RAY FRONTIERS



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AAAS Annual Meeting  
16 Feb 2003, Denver CO

# Questions

- What are cosmic rays and how do we detect them?
- Why are they interesting?
- What are we doing to understand things better?

# What are Cosmic Rays?

According to Merriam-Webster:

Main entry: cosmic ray

Function: noun

Date: 1925

: a stream of atomic nuclei of extremely penetrating character that enters the earth's atmosphere from outer space at speeds approaching the speed of light.



**Cosmic rays = “energetic particles from outer space”**

# Energy Scales

1 electron-Volt (eV) =  $1.6 \times 10^{-19}$  Joules

1 eV  $\sim$  visible light

$10^3$  eV  $\sim$  X-ray

$>10^6$  eV  $\sim$   $\gamma$ -ray

$10^6 - 10^{21}$  eV  $\sim$  cosmic rays

**Enormous range!**

# Coming from outer space

**Discovery (1912):**

Victor Hess

Balloon flights in Bohemia

Apparatus:

simple electroscope

**Found radiation increased as he went higher up.**

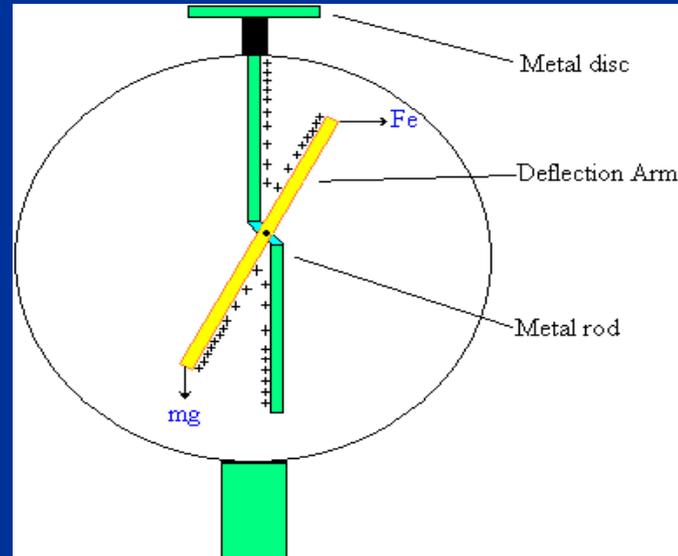


Figure 1: Electroscope

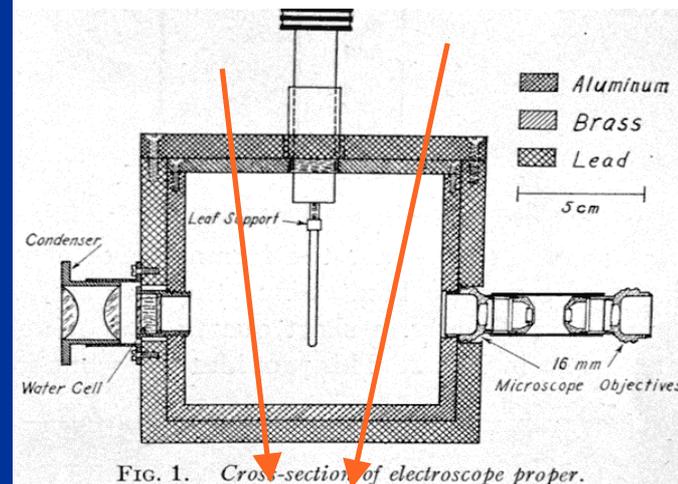


FIG. 1. Cross-section of electroscope proper.

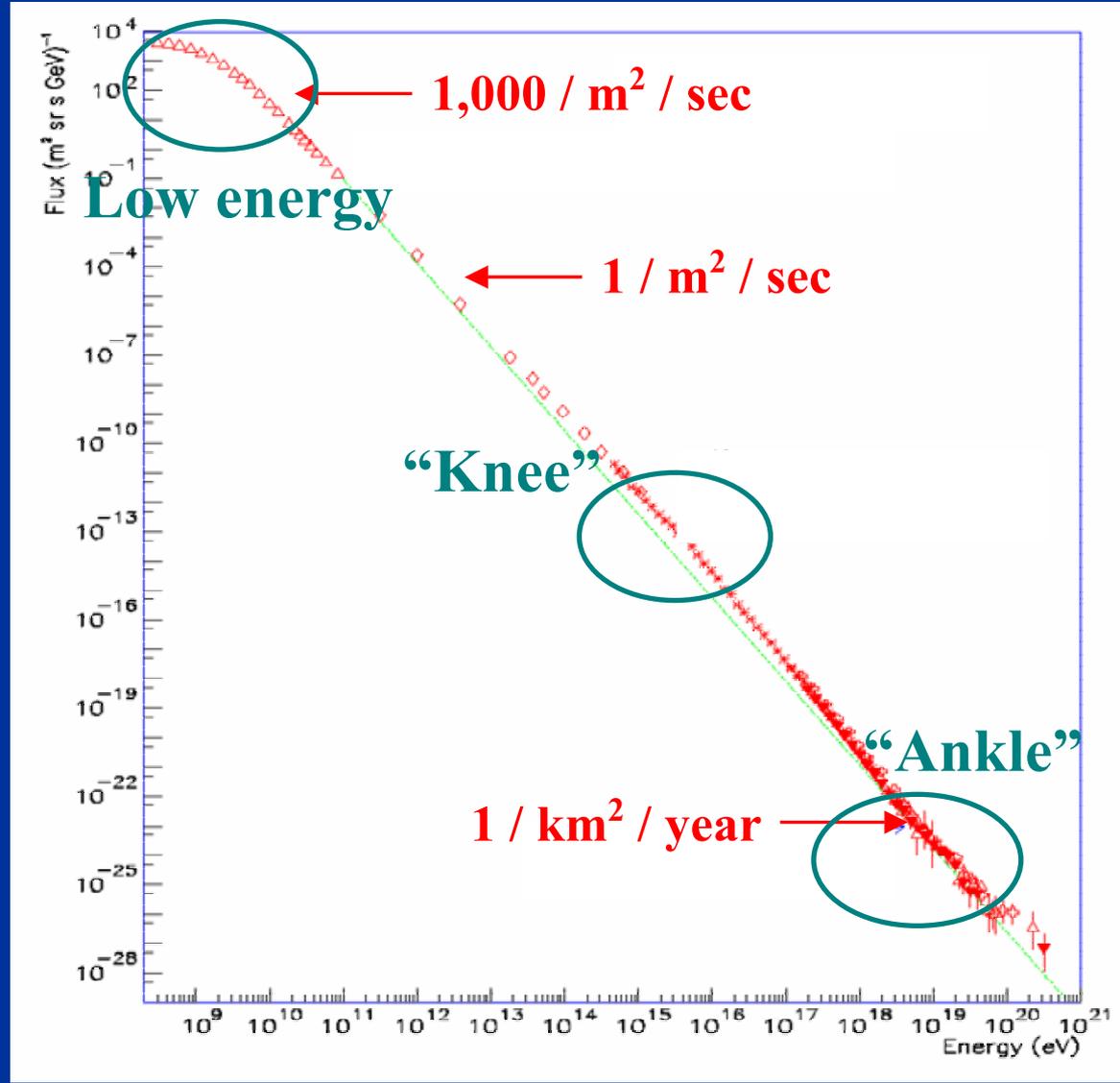
# Cosmic Ray Properties

- **Particles**      nuclei, p, e      → not “rays”
- **Charged**      nuclei usually stripped
- **Energetic**      produced in violent processes  
“non-thermal” or “acceleration”
- **Isotropic**      no preferred direction on sky  
(mostly)

# Energy Spectrum

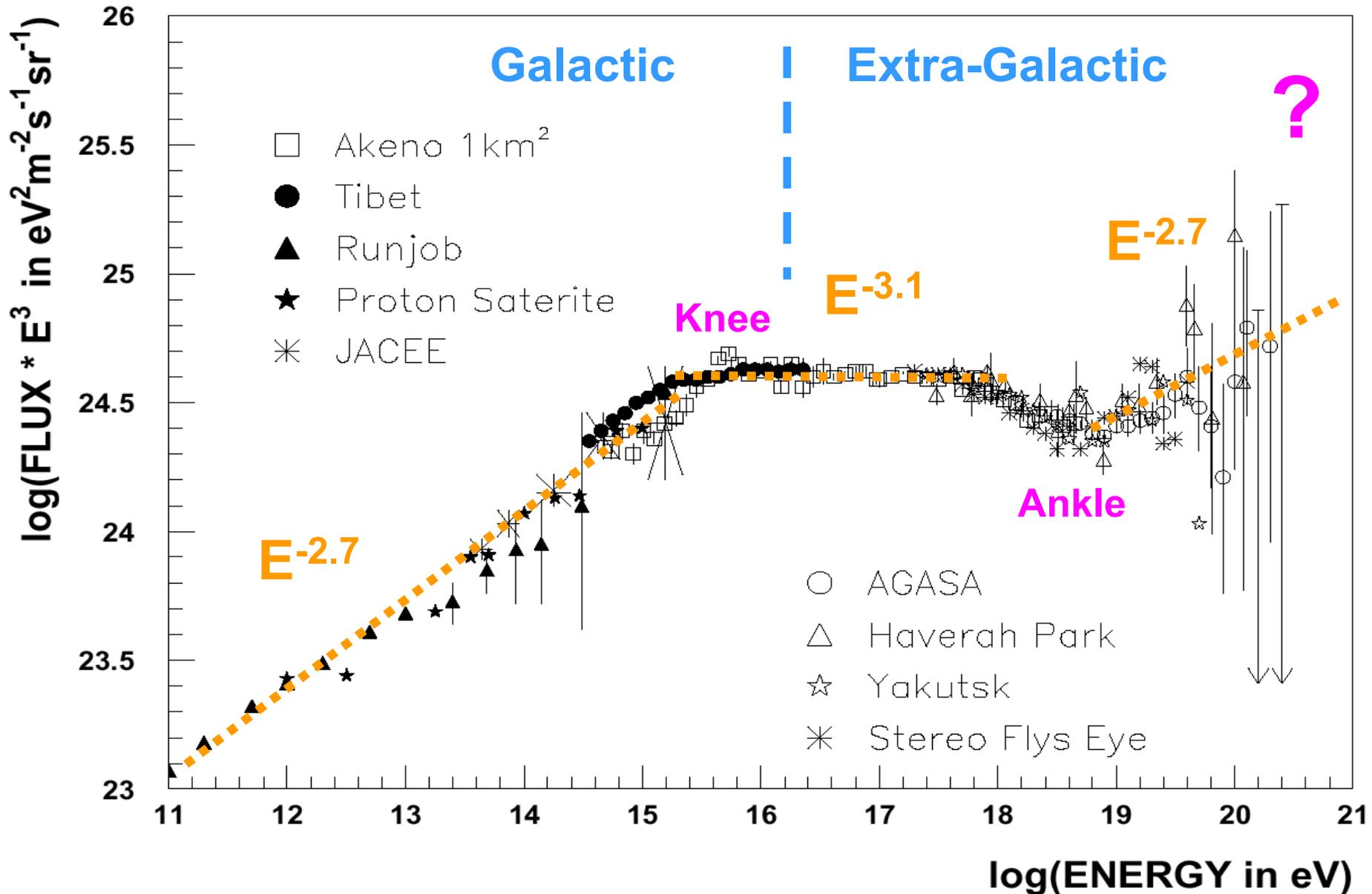
- Rapid decrease in flux with energy.
- Different regions, different sources?
- Composition info is important.

FLUX ↑

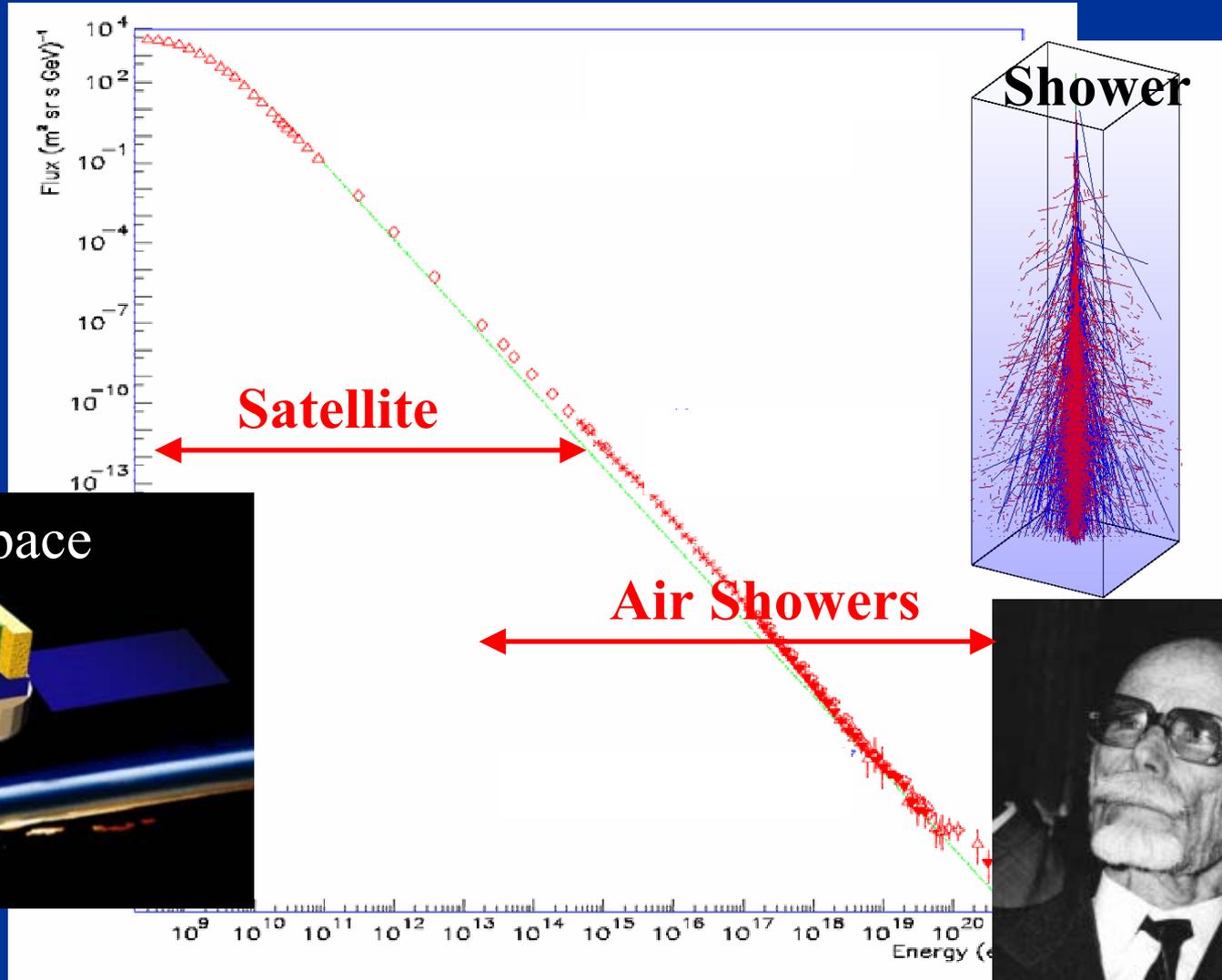


Energy →

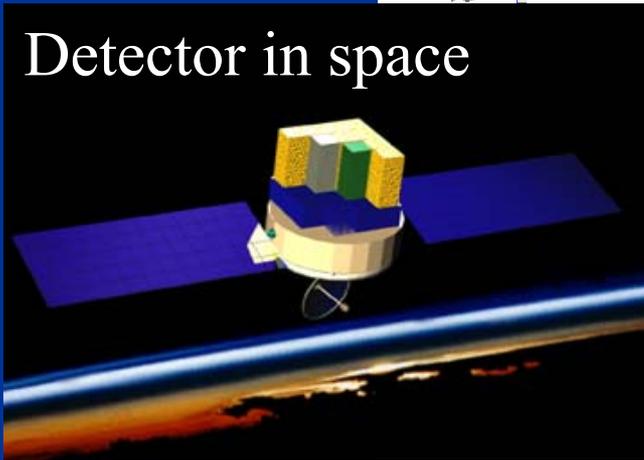
# Energy Spectrum - Flattened



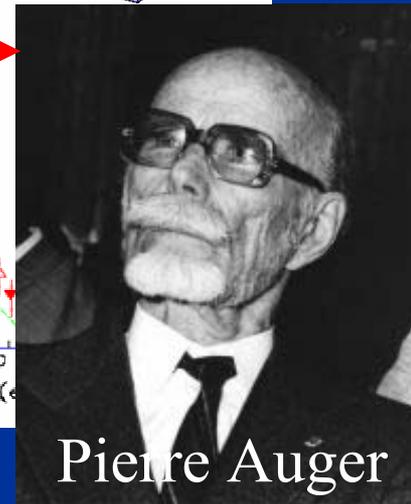
# So... How do we detect them?



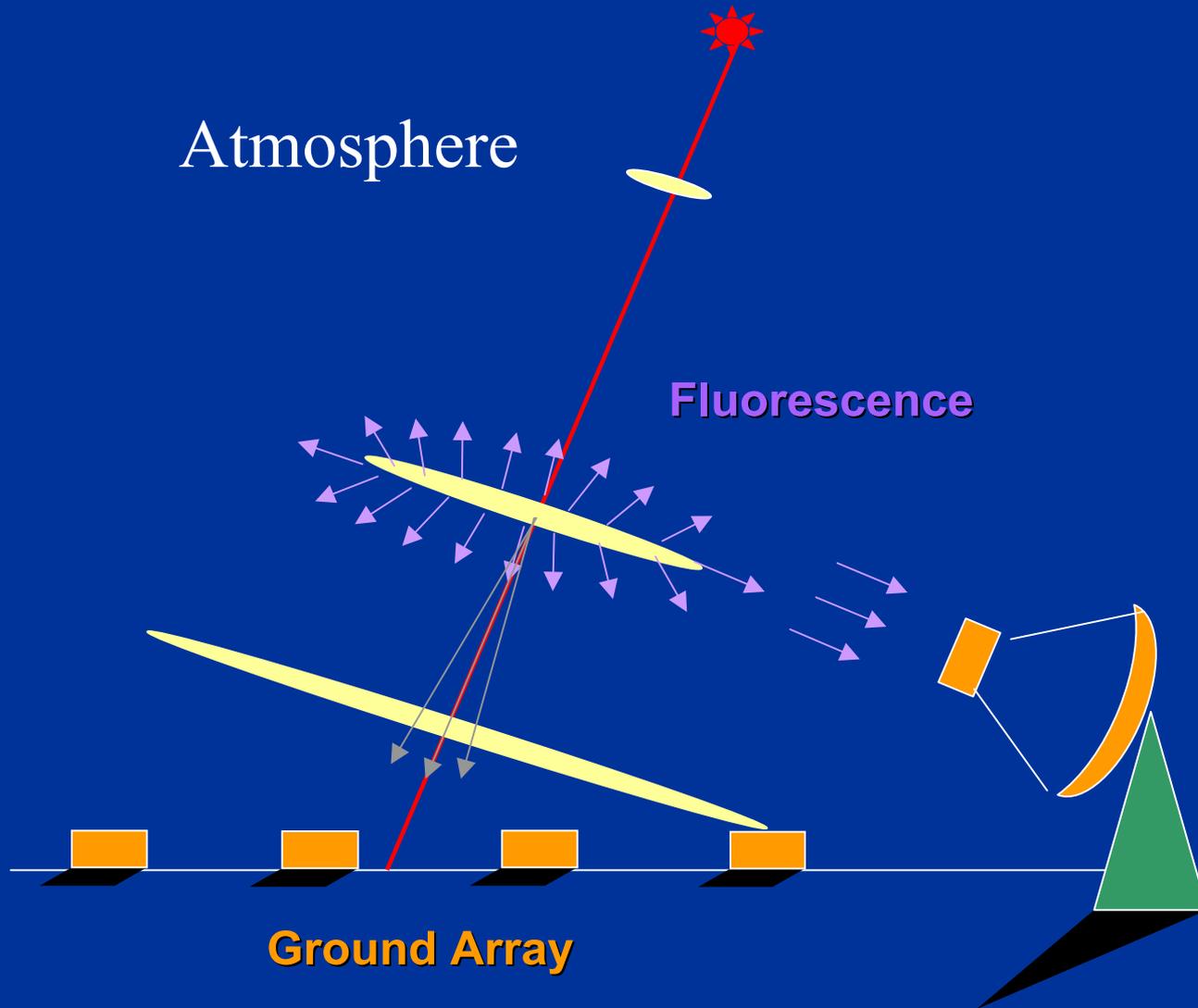
Detector in space



Pierre Auger



# Extensive Air Showers



# Giant Air Showers ( $> 10^{20}$ eV)

**Figure of Giant Showers hitting the Earth.  
(removed because of size).**

# Why are cosmic rays interesting ?

- Major source of extra-terrestrial material
- Important in dynamics of solar system
- Abundant – fill galaxy with energy
- Remarkable energies reached  $> 10^{21}$  eV

**There must be powerful and renewable sources,  
but ... we still do not know what they are!**

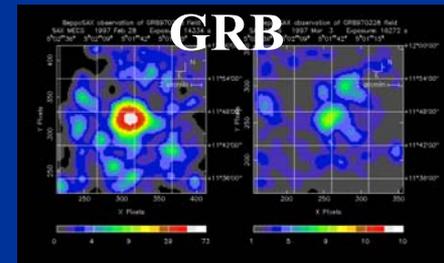
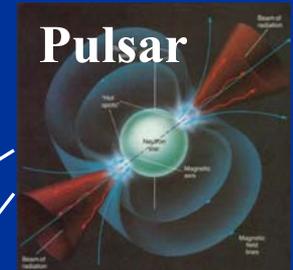
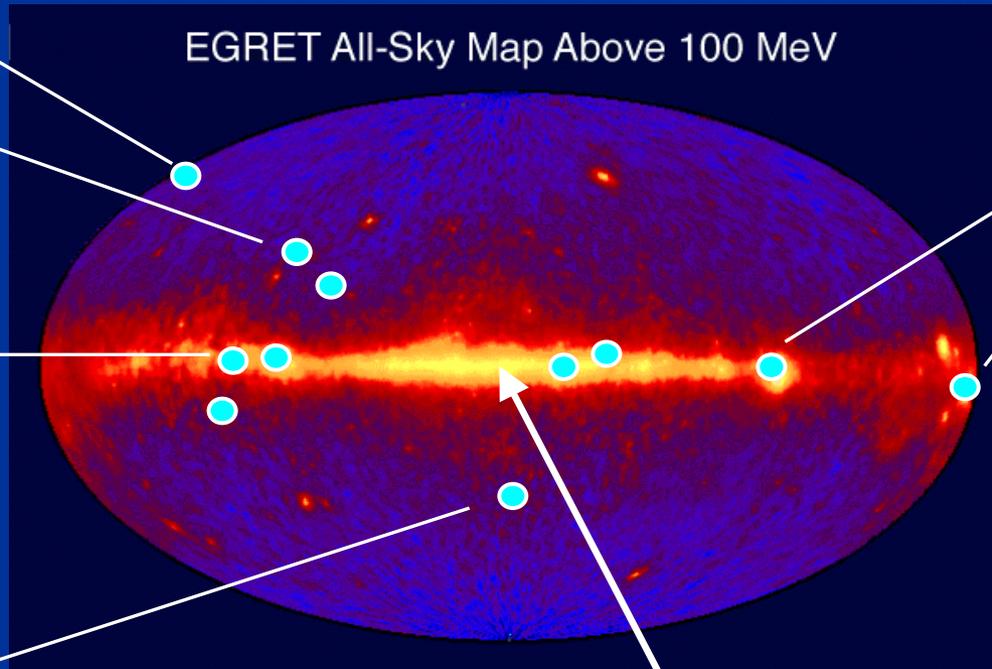
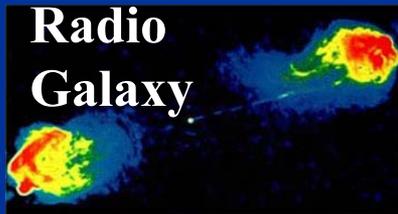
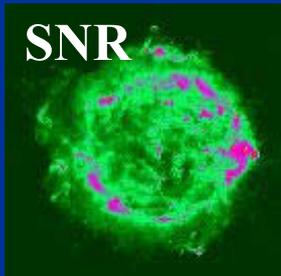
# General possibilities for origin

## Cosmic accelerators

- LE: Sun, interplanetary space
- HE: Supernova remnants
- EHE: Active galaxies – massive black hole systems.  
Gamma-ray bursts

# Cosmic Accelerators

Viewed in  $\gamma$ -rays

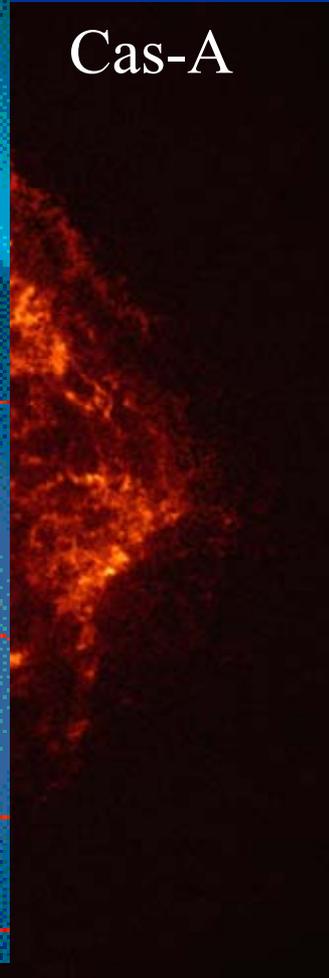
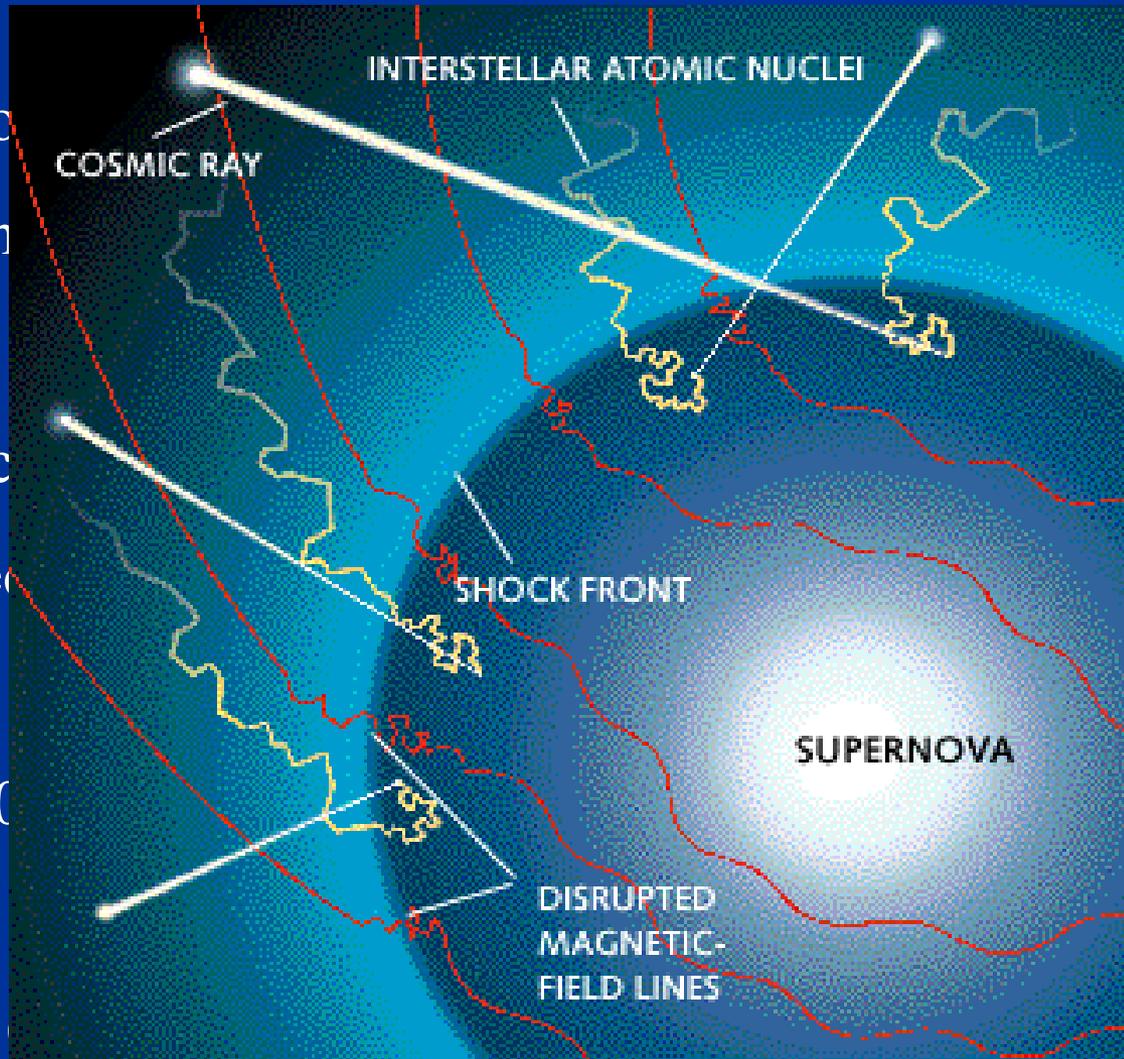


Cosmic Rays !

# Supernova Remnants

- Collapse of
- Expansion
- Particle acceleration

Energy  $\sim 10^{51}$  erg  
Rate  $\sim 1$  per century  
Luminosity  $L \sim 10^6 L_{\odot}$



# General possibilities for origin

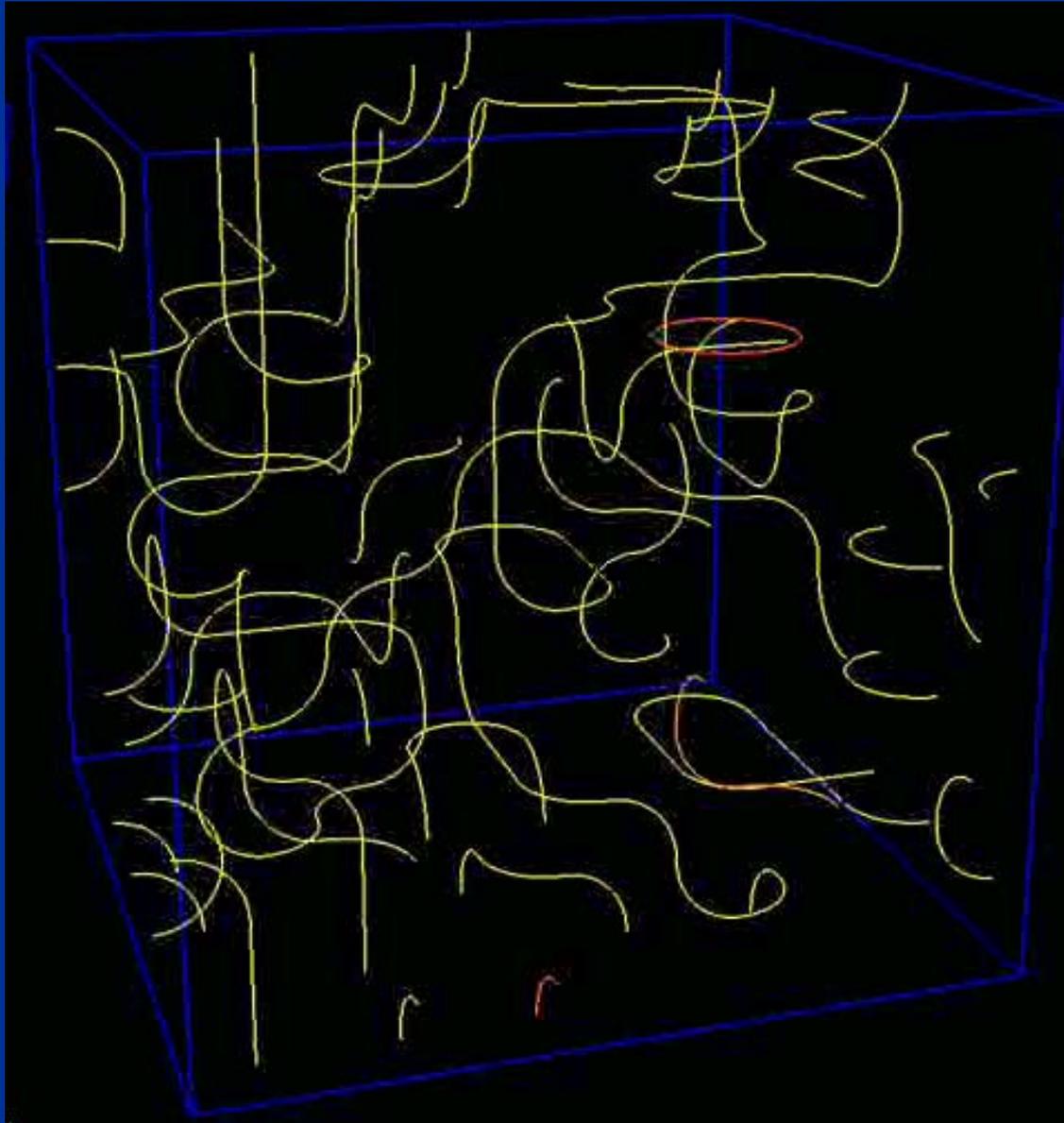
## Cosmic accelerators

- LE: Sun, interplanetary space
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Gamma-ray bursts

## New particle physics

- Defects in universe – e.g. cosmic strings.  
– not favored cosmologically
- Heavy relic particles
- Other ?

# Cosmic Strings



# Mysteries - Frontiers

## 1. Nature of low-energy component

- Solar modulation, anomalous CR - F. McDonald

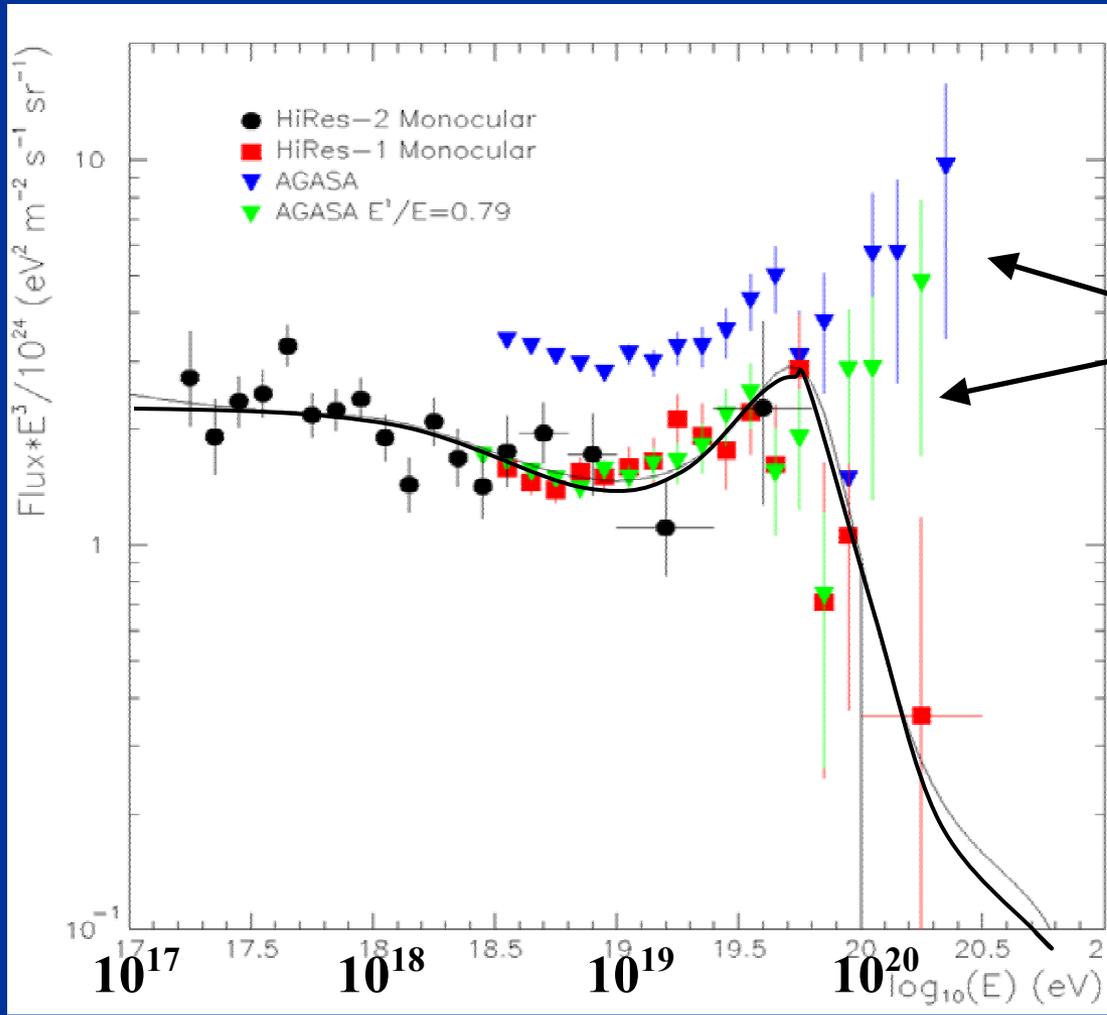
## 2. “Knee” – bend near $10^{15}$

- New composition ? - R. Engel, S. Swordy

## 3. Extremely energetic events $> 10^{20}$ eV

- Should these events even be there? - A. Olinto

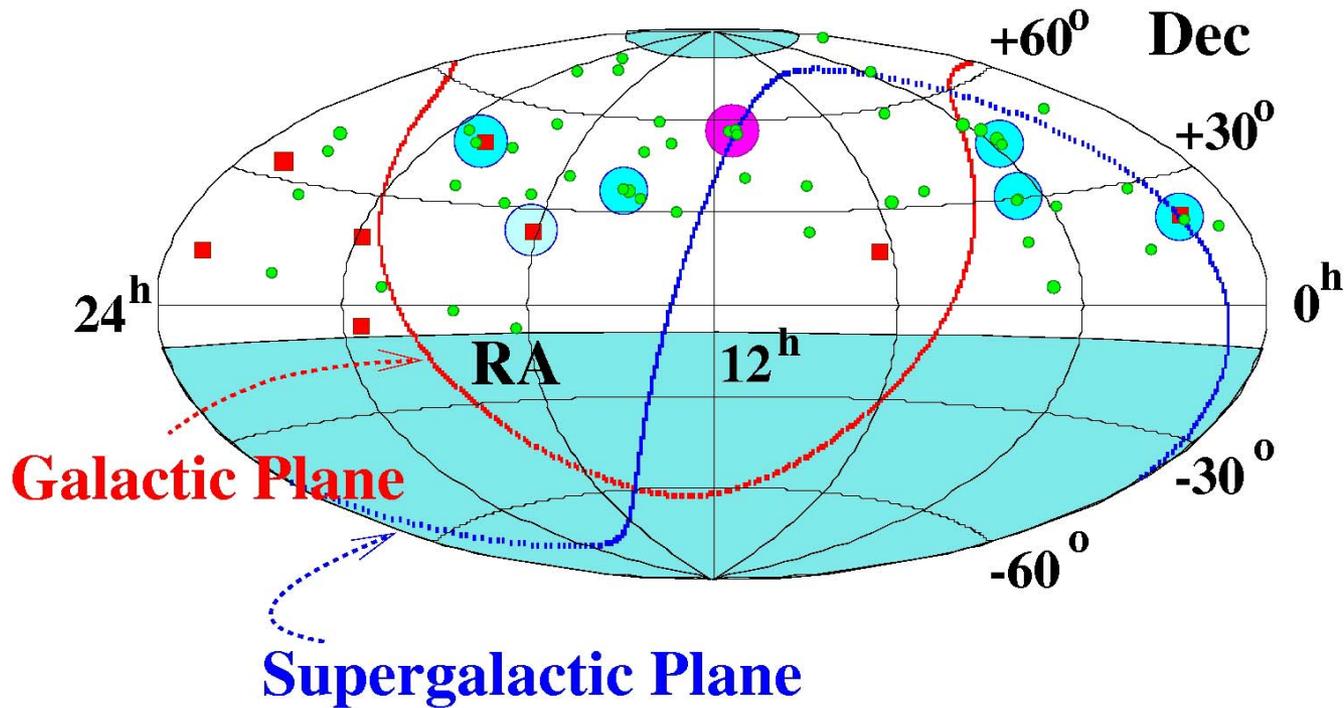
# Spectrum at Highest Energies



Should these  
be there?

# Sky Map at Highest Energies

## Equatorial Coordinates



Are there point sources ?

# What are we doing to understand things better?

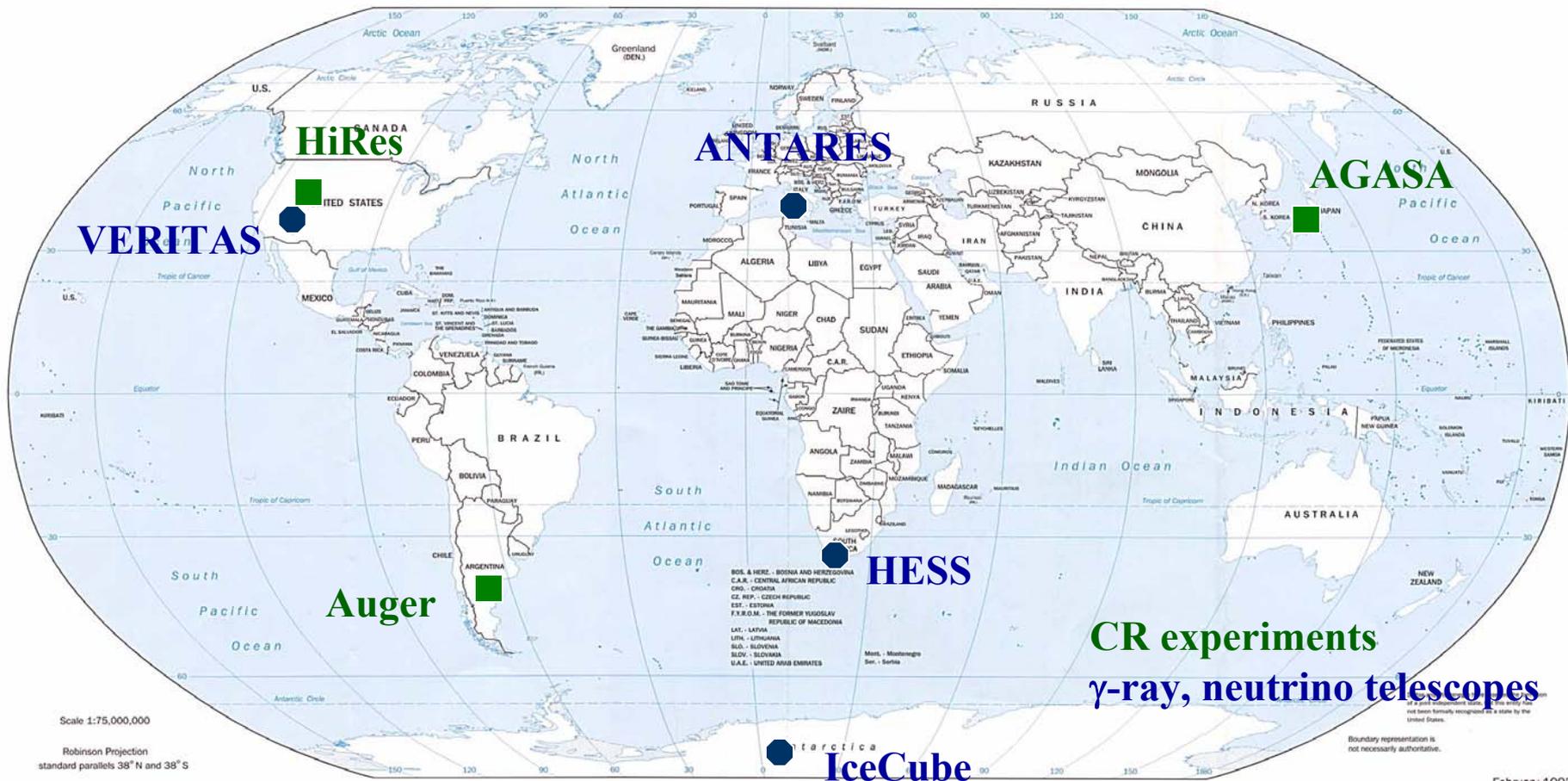
## **Experiments**

- Cosmic ray detectors – in space and on ground
- Gamma-ray and neutrino telescopes

## **Theory & Simulations**

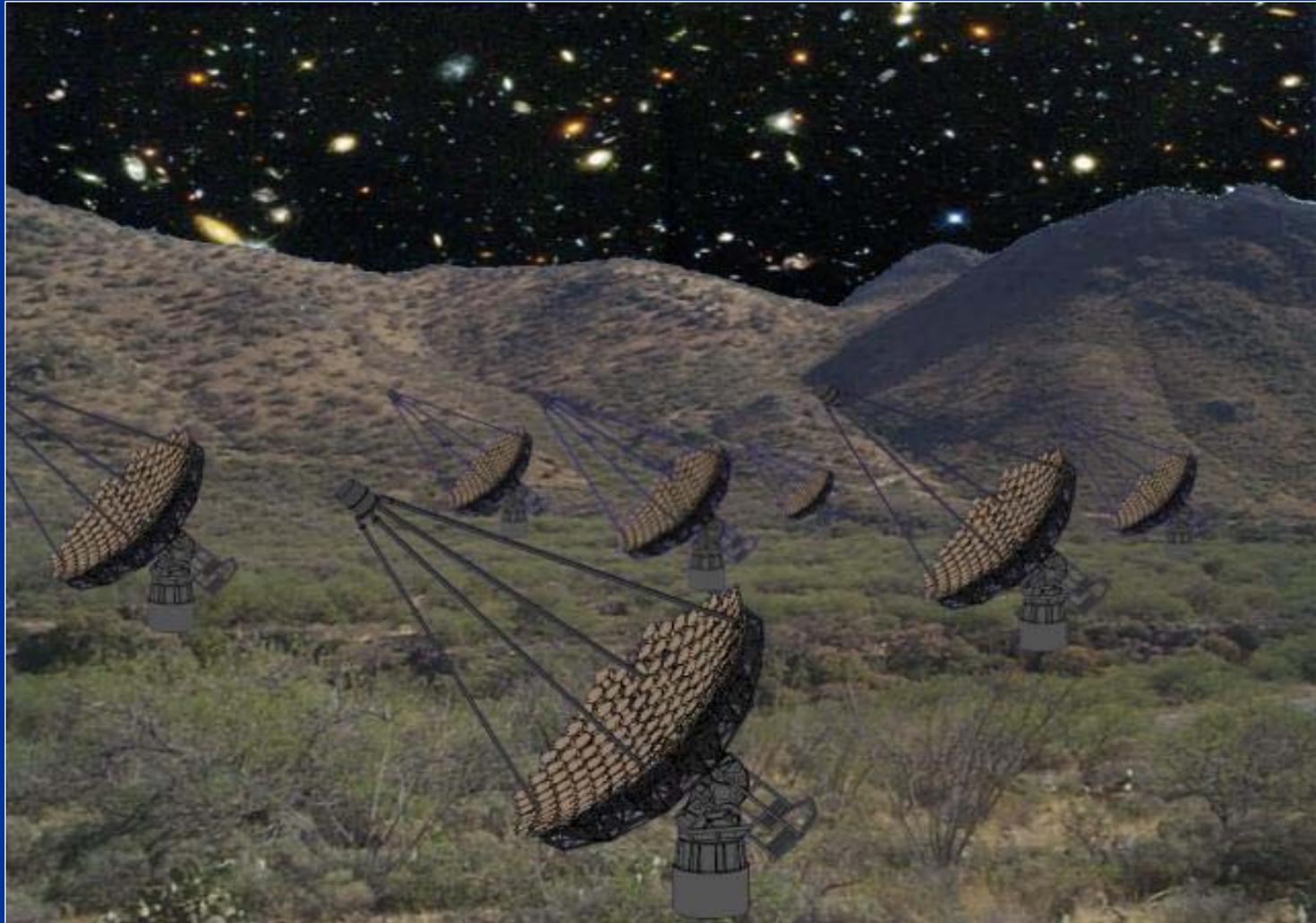
- Models of acceleration & propagation
- Simulations of air shower interactions
- Beyond standard particle physics & cosmology

# World-wide experiments, c2003



CR experiments  
γ-ray, neutrino telescopes

# VERITAS – $\gamma$ -ray Telescope

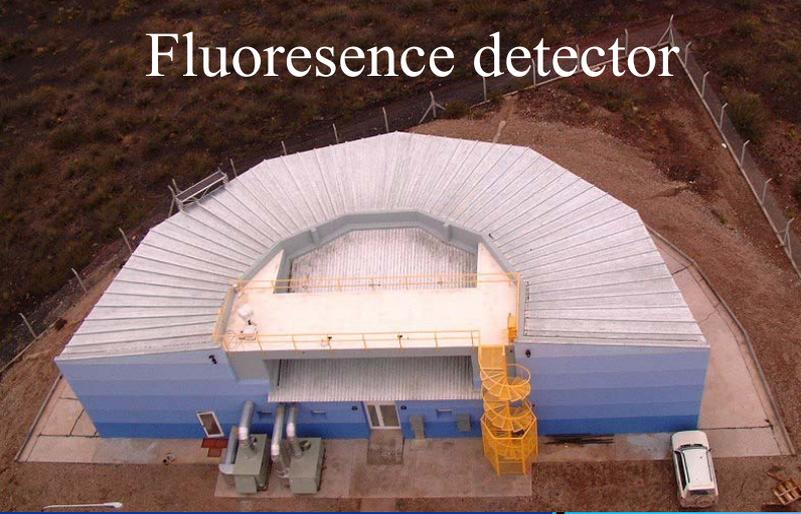


Arizona, USA

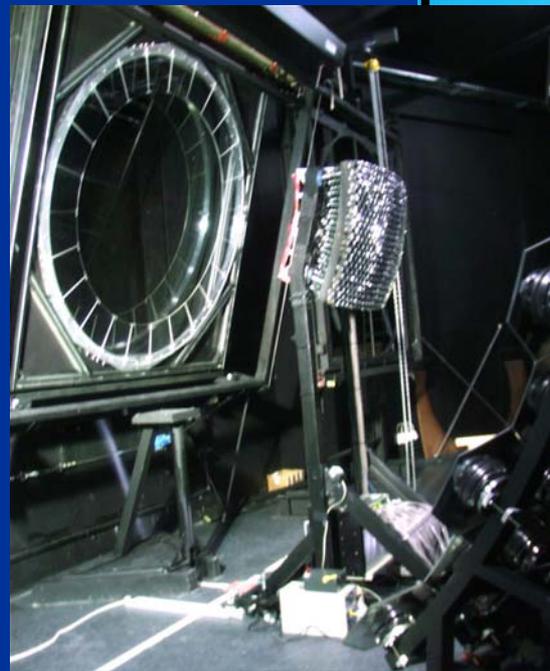


# Pierre Auger Project

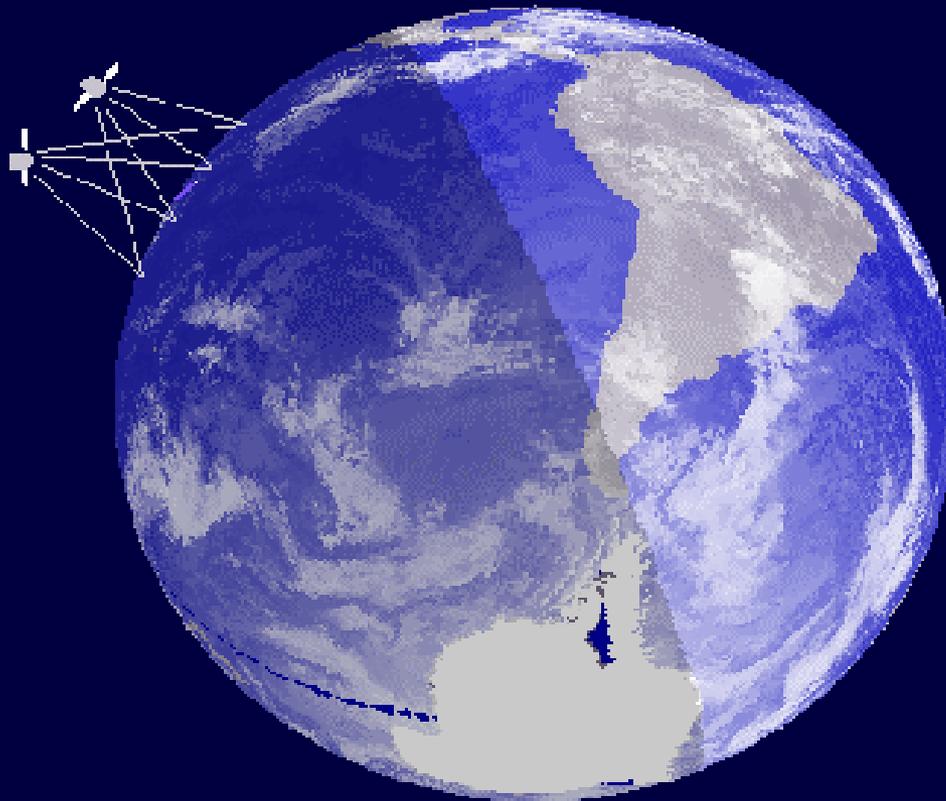
Fluorescence detector



Surface detector



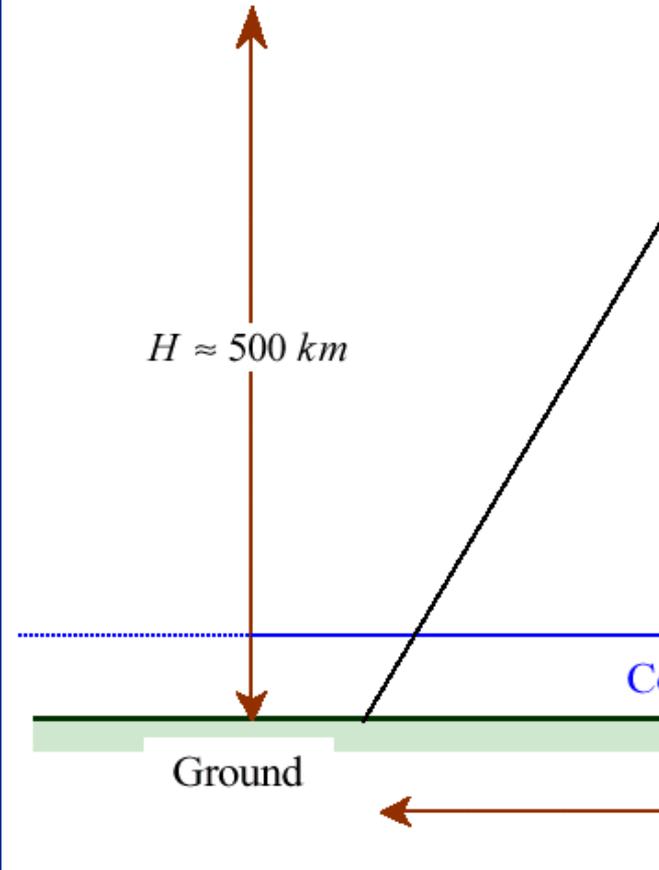
# Air Showers From Space



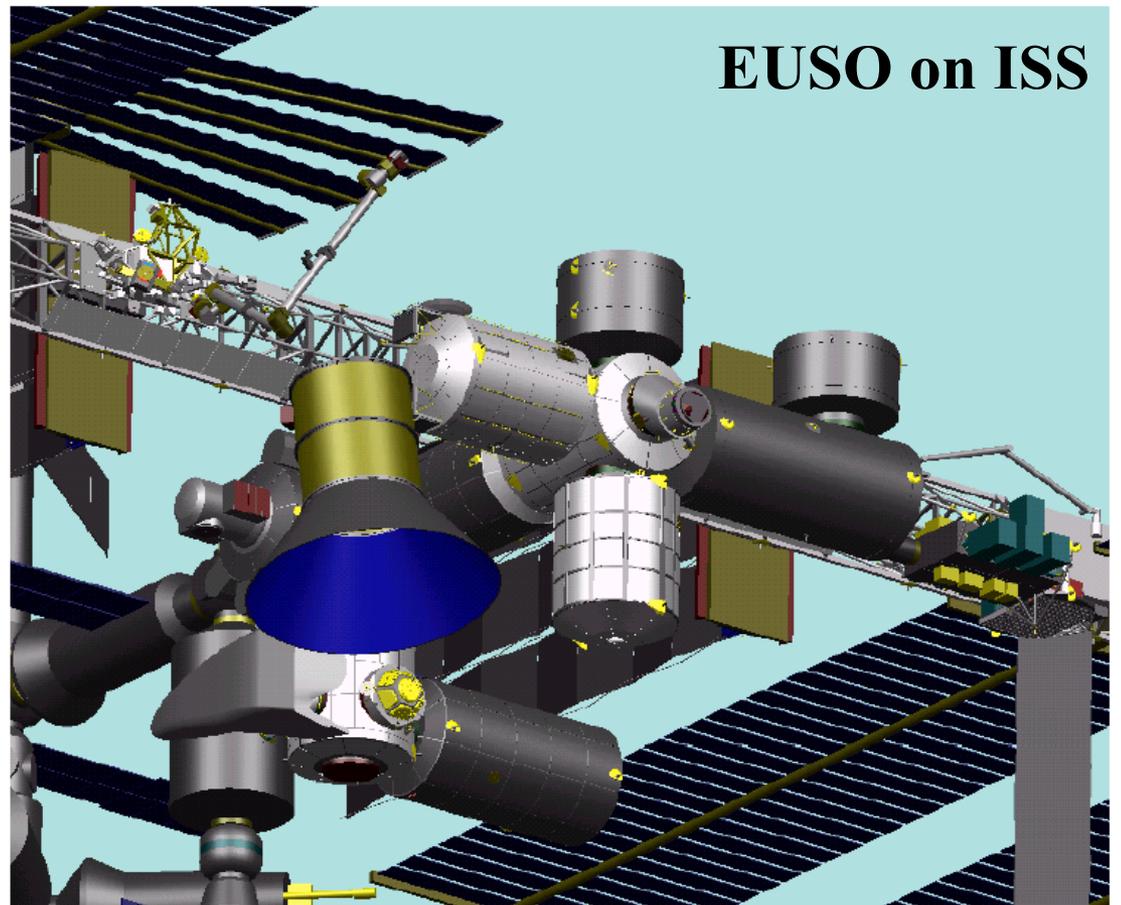
EUSO or OWL

# Air Showers From Space

Owl-AirWatch Detector



General concept



# Summary

- Cosmic Rays are remarkable objects.  
~ 90 years of forefront science.
- There are deep mysteries of origin  
– at least three!
- Probing the most energetic processes in the universe.
- World-wide network of instruments to tackle these mysteries – please stay tuned!

# Final Words

... At present, however, we do not know nearly enough about these rays to come to any decision as to their nature; it is evident, however, that they raise questions of the greatest interest and importance. It would be one of the romances of science if these obscure and prosaic minute leakages of electricity from well-insulated bodies should be the means by which the most fundamental problems in the evolution of the cosmos had to be investigated.

J.J. Thomson, 1928

“Conduction of Electricity Through Gases”