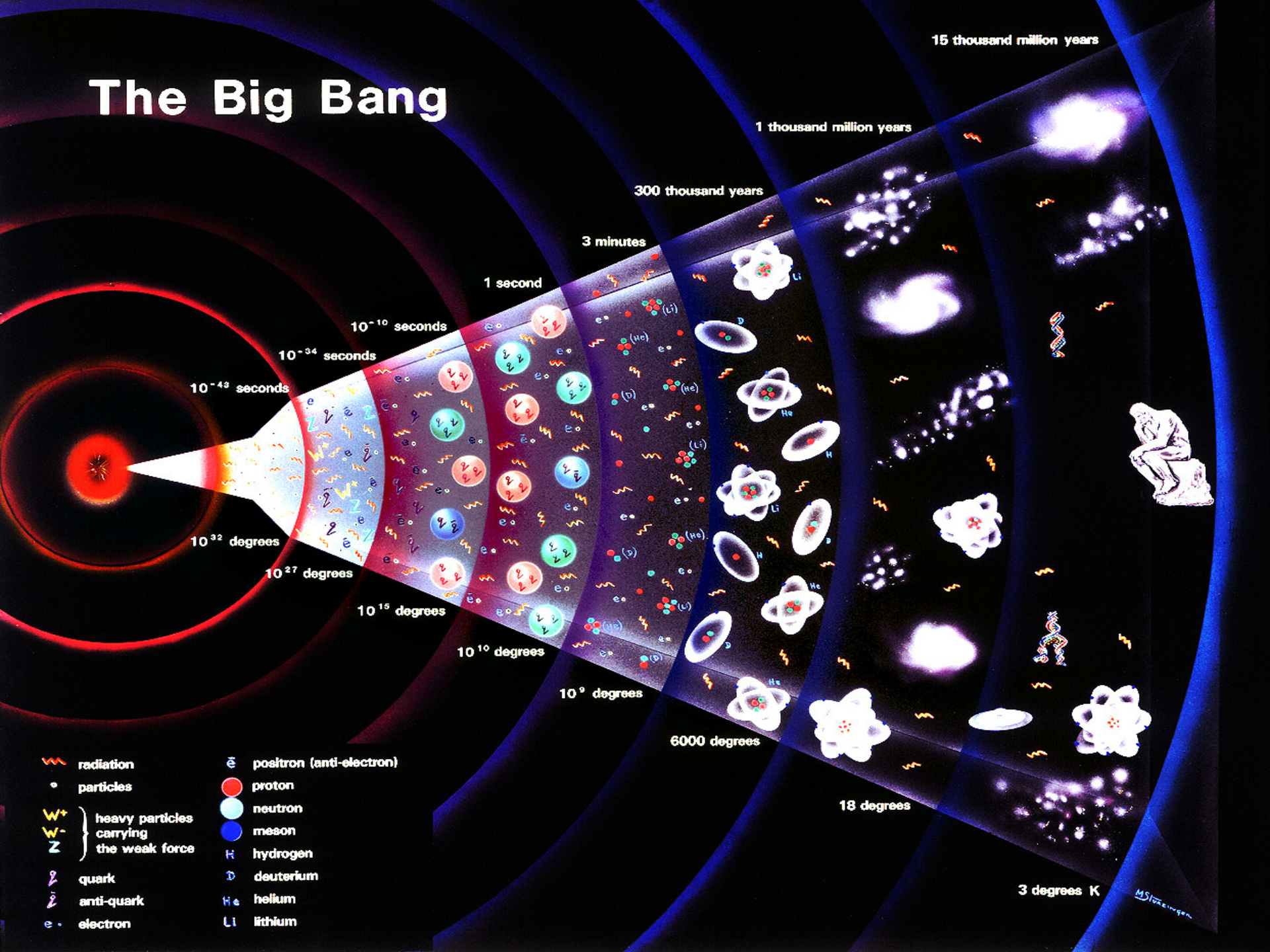


The Big Bang



15 thousand million years

1 thousand million years

300 thousand years

3 minutes

1 second

10^{-10} seconds

10^{-34} seconds

10^{-43} seconds

10^{32} degrees

10^{27} degrees

10^{15} degrees

10^{10} degrees

10^9 degrees

6000 degrees

18 degrees

3 degrees K

radiation

particles

heavy particles carrying the weak force

quark

anti-quark

electron

positron (anti-electron)

proton

neutron

meson

hydrogen

deuterium

helium

lithium

M. S. ...

Materie-Antimaterie Asymmetrie:

- Dirac: jedes Teilchen besitzt ein Anti-Teilchen
- Frühes Universum: thermische Produktion von Teilchen und Anti-Teilchen, e.g. : $\gamma + \gamma \leftrightarrow p + \bar{p}$
gesamt Baryonzahl $B=0$
- Wenn Teilchen und Anti-Teilchen identische Eigenschaften haben (Masse, Lebensdauer, Zerfallskanäle,)...
- ...dann sollte Universum auch noch heute zu gleichen Teilen aus Materie und Anti-Materie bestehen!!
- Beobachtung (kosmische Strahlung): $\frac{N_{\bar{B}}}{N_B} < 10^{-4}$

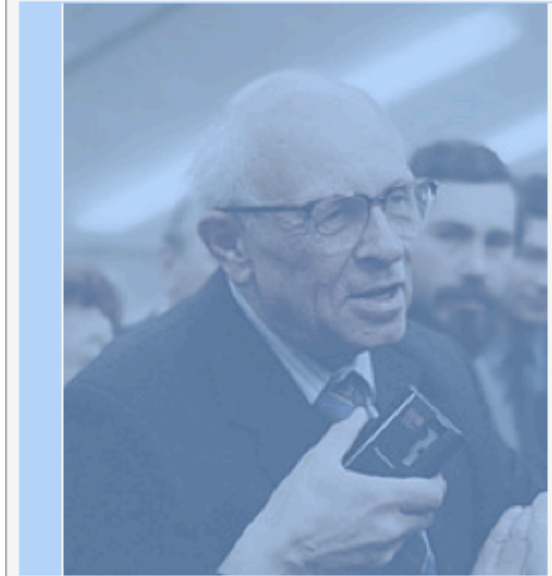
Sacharov Kriterien (1966)

Unter Annahme, dass anfänglich $B=0$ ist, kann sich Baryon-Asymmetrie entwickeln, falls

1. Baryonzahl verletzende WW
2. Nicht-Gleichgewichtssituation für Teilchen, die Baryonzahl verletzende Reaktionen durchlaufen (Zeit zwischen zwei Kollisionen $>$ Alter des Universums \Rightarrow Reduktion der Rate von Teilchen-Antiteilchen Annihilation)
3. CP und C Verletzung

State-of-the-Art:

1. bisher nicht beobachtet!
2. ok
3. Im Quark-Sektor beobachtet (CPV allerdings nicht gross genug); im Lepton-Sektor Experimente in Vorbereitung



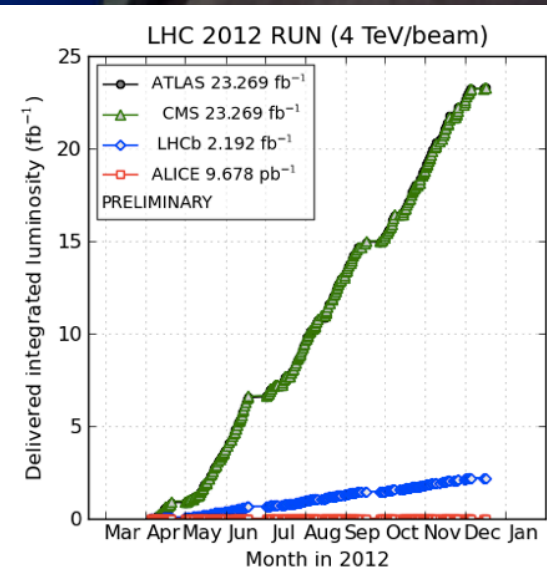
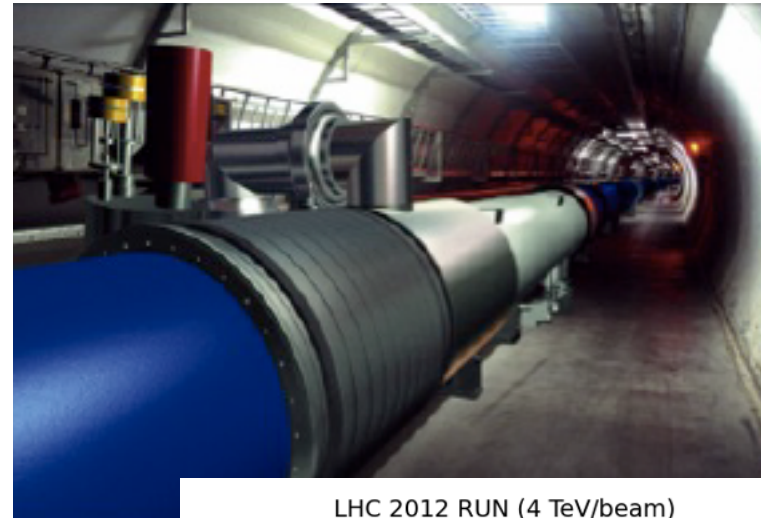
Andrei Sakharov

Born	May 21, 1921 Moscow, Russian SFSR
Died	December 14, 1989 (aged 68) Moscow, Union of Soviet Socialist Republics
Residence	Moscow, Soviet Russia
Citizenship	Soviet Union
Fields	Nuclear physics
Alma mater	Moscow State University FIAN
Known for	Third Idea Soviet nuclear program Dissidence Human rights activism
Notable awards	Hero of Socialist Labor (1953 1955 1962) Stalin Prize (1953) Lenin Prize (1956) Nobel Peace Prize (1975) Elliott Cresson Medal (1985)

... back to accelerators and cosmic rays

LHC: pp-Kollision mit 8 TeV

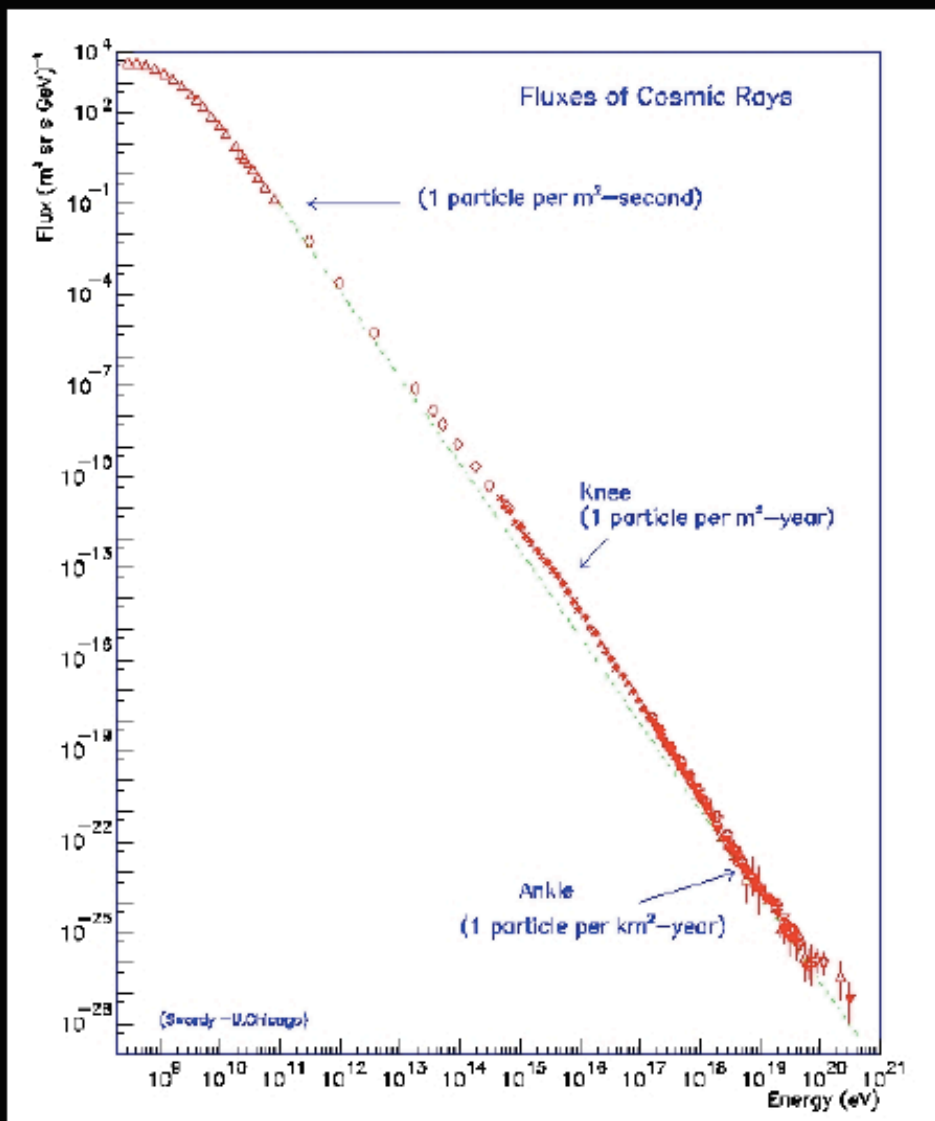
Schwerpunktenergie



WHAT DO WE KNOW ON COSMIC RAYS?

The energy spectrum

“Coming out of space and incident on the high atmosphere, there is a thin rain of charged particles known as the primary cosmic ray radiation” (Cecil Powell, Nobel Prize Lecture, 1950)



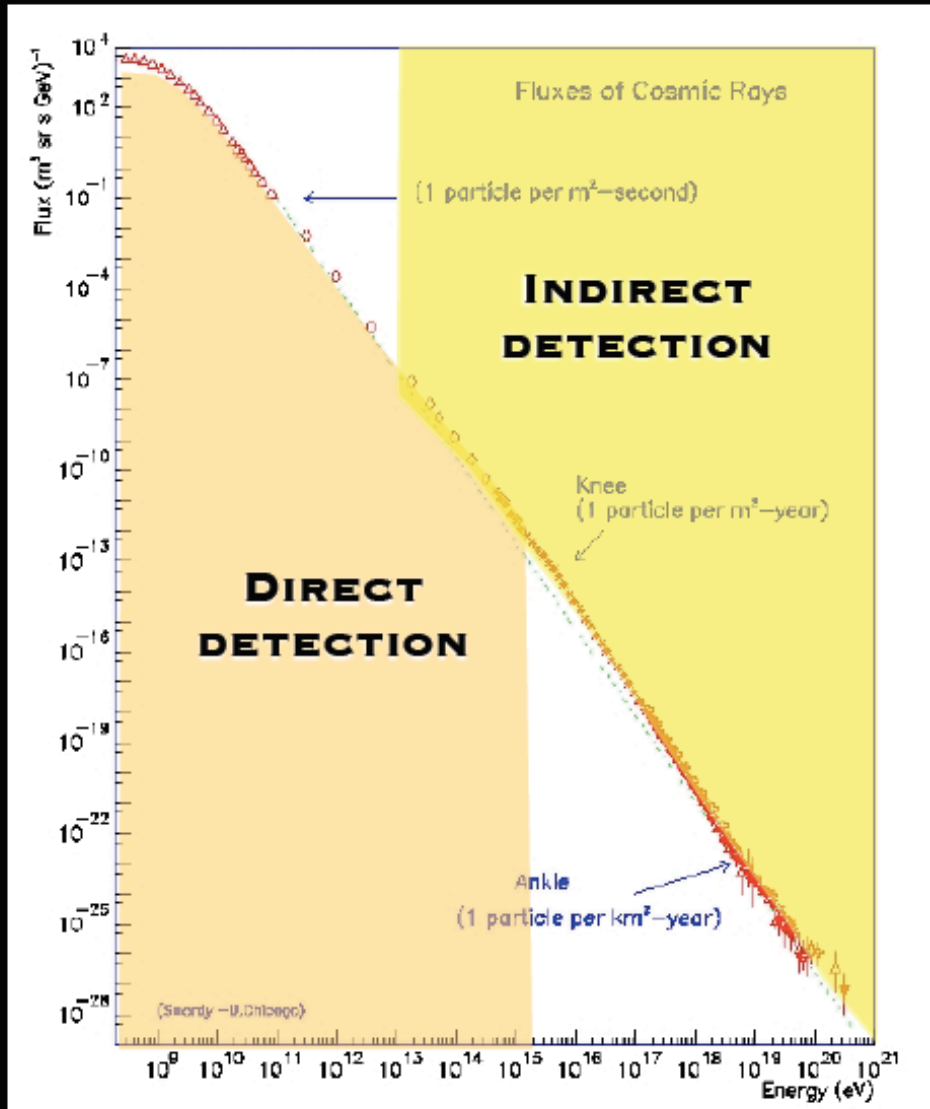
The most striking feature of the cosmic rays is the fact that they span a very wide range of energies.

The energy spectrum is of power-law form ($E^{-\gamma}$, $\gamma \approx 3$): it is extremely regular over ≈ 13 decades (spanning 32 decades in flux!)

WHAT DO WE KNOW ON COSMIC RAYS?

The flux (vs detection)

“Coming out of space and incident on the high atmosphere, there is a thin rain of charged particles known as the primary cosmic ray radiation” (Cecil Powell, Nobel Prize Lecture, 1950)



Low-energy CRs: rather high flux ($1/\text{m}^2 \text{ s}$) but absorbed in the upper atmosphere.

Direct detection (top of the atmosphere or in space)

Balloons
Rockets
Satellites

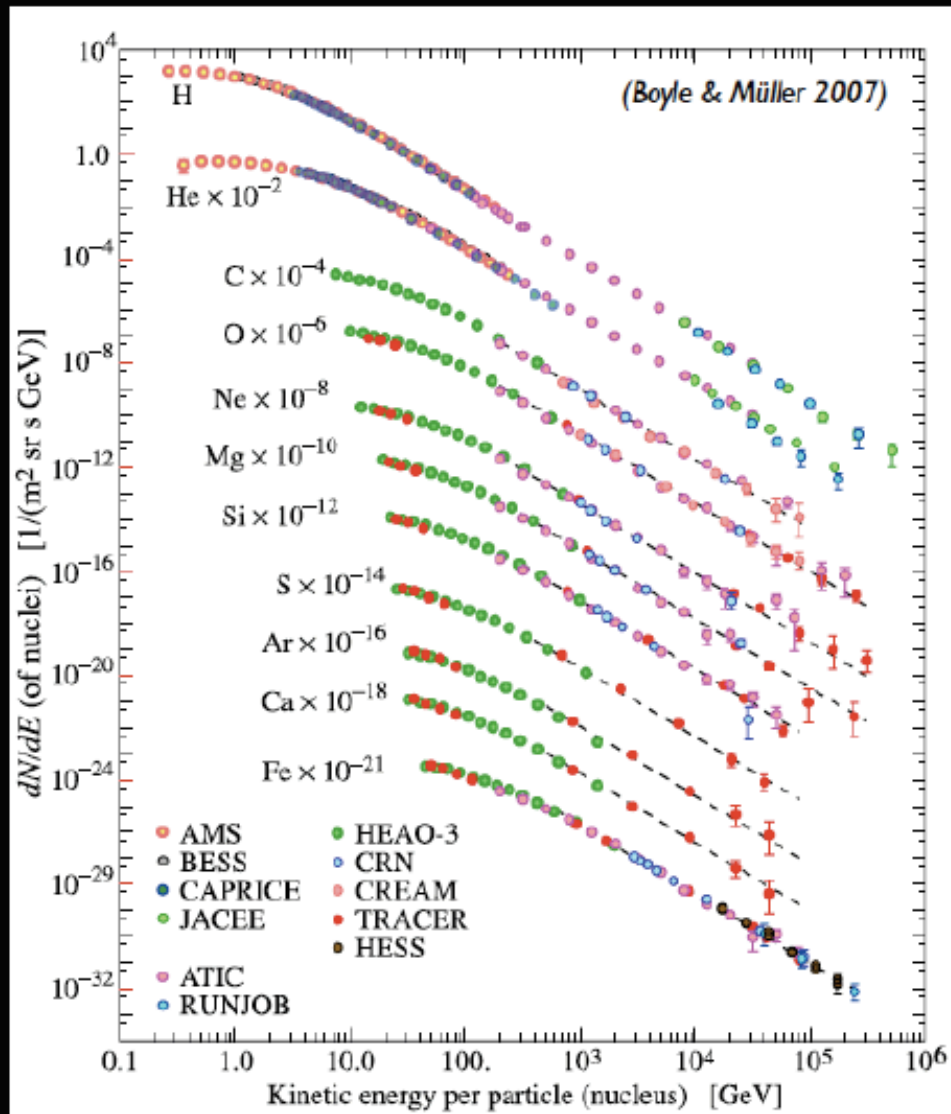
High energy cosmic rays: very rare ($1/\text{km}^2 \text{ y}$), but “penetrating” up to ground (atmospheric air-showers). Indirect detection: long-lived large arrays (ground level)

Large telescopes
Extensive Air showers arrays

WHAT DO WE KNOW ON COSMIC RAYS?

The spectrum and chemical composition at low energies

At energies up to $\approx 10^{14}$ eV, cosmic rays are directly measured, through detectors on balloons or satellites (see later ;-)



In the direct-measurement energy region, about 98% of the particles are protons and nuclei; $\approx 2\%$ are electrons. Of the protons and nuclei, $\approx 87\%$ are protons, $\approx 12\%$ are helium nuclei and the remaining $\approx 1\%$ heavier nuclei

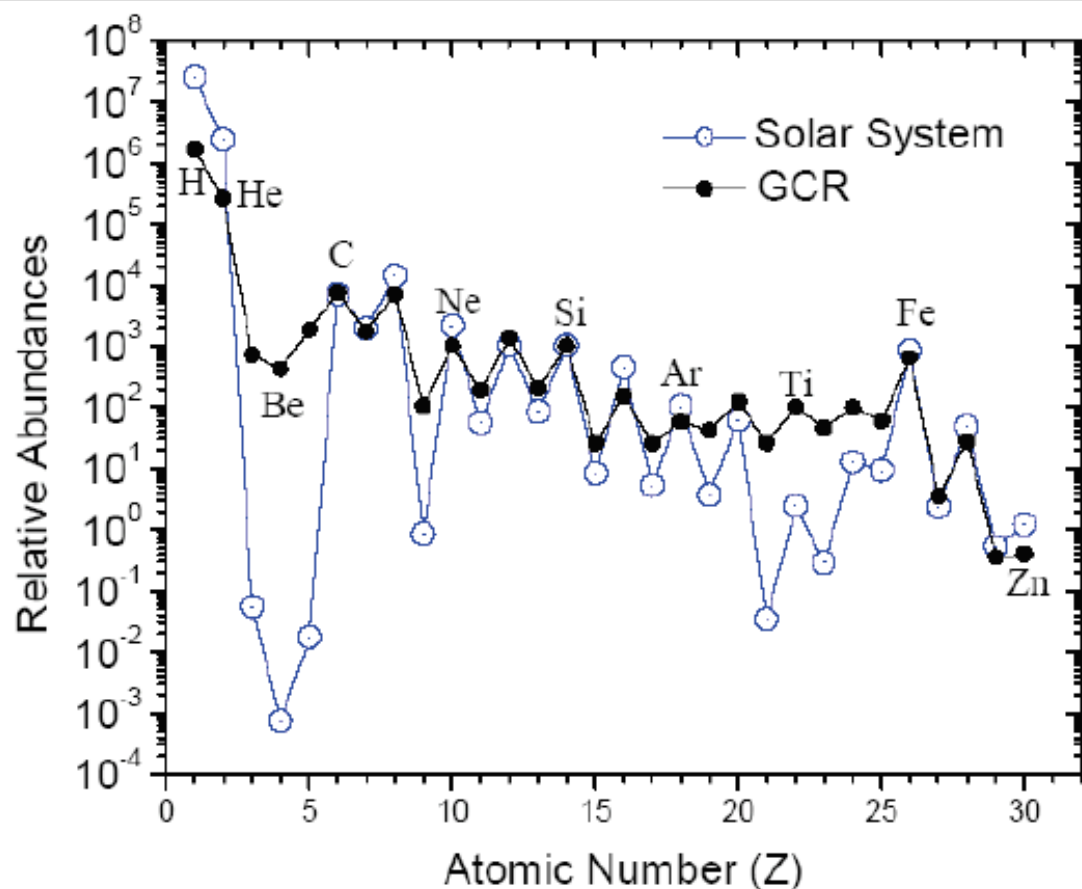
Power laws holds also for individual elements

Index almost identical for all of them. Slightly harder for heavier elements

WHAT DO WE KNOW ON COSMIC RAYS?

The spectrum and chemical composition at low energies

At energies up to $\approx 10^{14}$ eV, cosmic rays are directly measured, through detectors on balloons or satellites (see later ;-)



The distribution of elemental abundances in the CR is not so different from those of typical Solar System abundances.

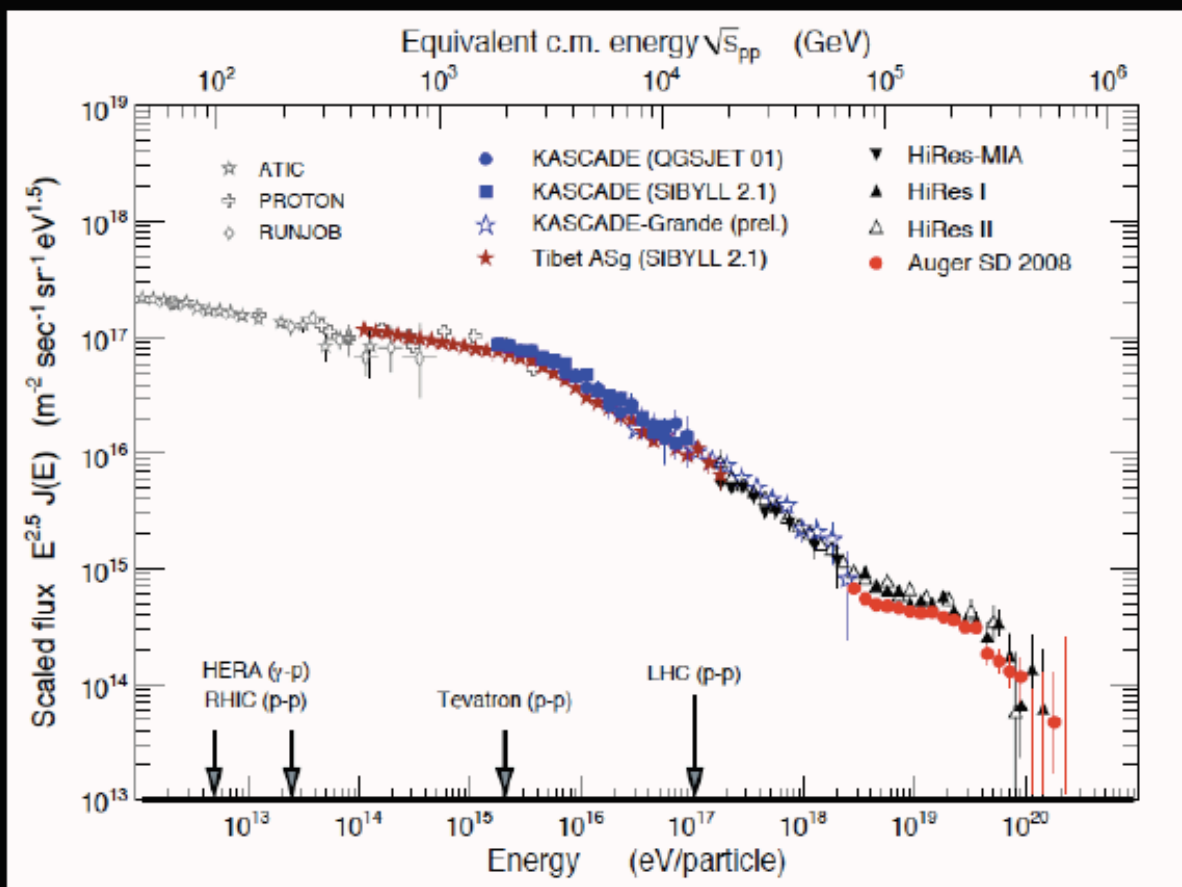
Light elements (Li, Be, B) in CRs are overabundant relative to Solar System ones. Excess also of elements with atomic number and mass just less than those of Fe (i.e., elements between Ca and Fe). This is due to CR propagation in the inter-stellar medium: spallation collisions.

ABUNDANCES OF ELEMENTS IN CR AT ≈ 1 GEV
COMPARED TO THOSE OF THE SOLAR SYSTEM

WHAT DO WE KNOW ON COSMIC RAYS?

The spectrum and chemical composition at high energies

At energies above $\approx 10^{14}$ eV, cosmic rays are indirectly measured, through detectors at ground level through extensive air showers (see on thursday ;-).



The CR spectrum shows three “irregularities”:

a “knee” at 5×10^{15} eV: due to the “bending” of lighter elements, it could be due to source (maximum energy) or propagation effects (escape from the Galaxy)

an “ankle” at 3×10^{18} eV: it could either mark the transition between a galactic and an extra-galactic CR origin, or be the signature of interactions of EG protons on background photons

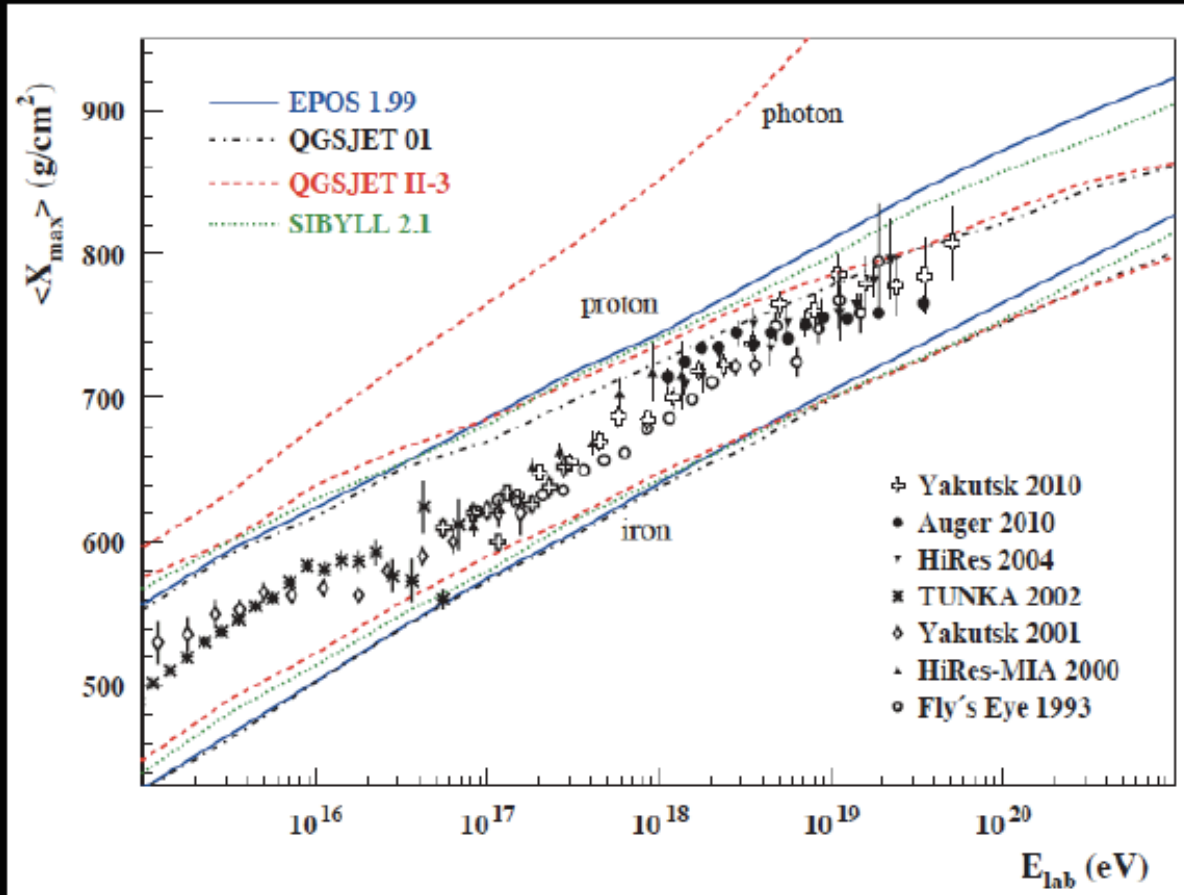
a “suppression” at 5×10^{19} eV: it could be due either to propagation (GZK effect) or source effects (maximum energy)

ALL-PARTICLE PRIMARY ENERGY SPECTRUM MEASURED BY DIFFERENT EAS ARRAYS. SPECTRUM SCALED BY $E^{2.5}$ TO BETTER EVIDENCE THE “IRREGULARITIES”

WHAT DO WE KNOW ON COSMIC RAYS?

The spectrum and chemical composition at high energies

At energies above $\approx 10^{14}$ eV, cosmic rays are indirectly measured, through detectors at ground level through extensive air showers (see later ;-). Single elements cannot be distinguished but only "inferred"



XMAX VS ENERGY, AS MEASURED BY DIFFERENT EAS ARRAYS.
EXPECTATIONS FOR SIMULATED EAS ARE ALSO SHOWN

The most common way of inferring the primary composition by indirect measurements is by the determination of the depth of shower maximum in atmosphere, X_{\max} (see on thursday ;-)

X_{\max} depends on primary mass. From comparisons with what expected from shower simulations, one can infer the trend of average mass vs energy

WHAT DO WE KNOW ON COSMIC RAYS?

Arrival directions (sources)

Although CR above 10^{12} eV are likely to preserve information about their arrival direction at the Solar System when they arrive at Earth, due to deflections in the galactic magnetic field, they do not preserve information about their original travel direction and hence, about their sources.

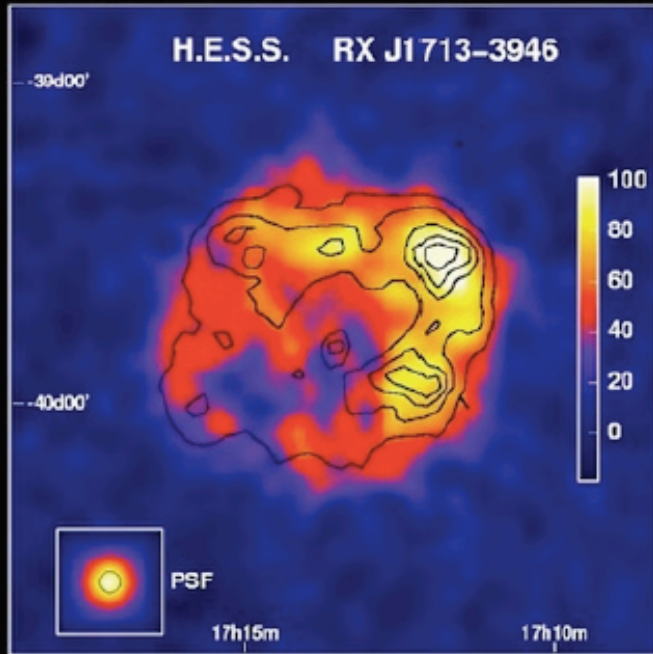
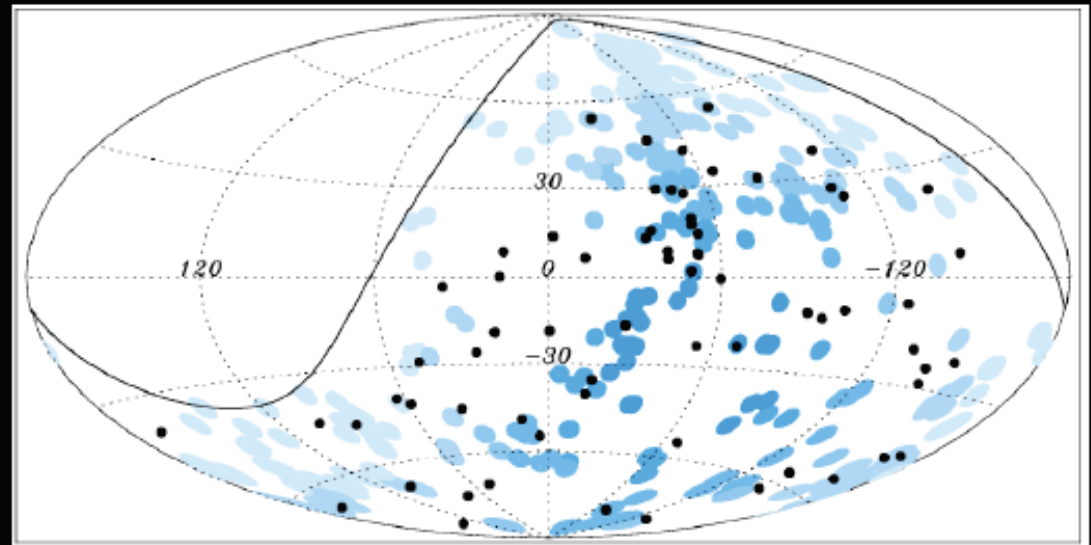


IMAGE OF A SNR IN GAMMA
(HESS EXPERIMENT)



DISTRIBUTION OF AUGER EVENTS (E>50
EEV) IN THE SKY VS AGNs POSITIONS

Supernovae are prime candidates for the acceleration of galactic cosmic rays. Only possible observation through neutral gammas, produced by CR interactions in the source. No smoking gun found yet.

At energies $> \approx 10^{19}$ eV, low-Z CR are slightly deflected by magnetic fields. In principle, charged-particle astronomy may be possible. Possible source candidates: AGNs, gamma-ray bursts, radio-galaxies...

HOW DO WE DETECT COSMIC RAYS?

Cosmic rays are particles

Cosmic ray detectors are particle detectors



AMS SCINTILLATORS
(TIME OF FLIGHT)



PAMELA CALORIMETER

Wide choice of detectors:

dE/dX

Secondary/cascades measurements

Magnetic deflections

Transition radiation

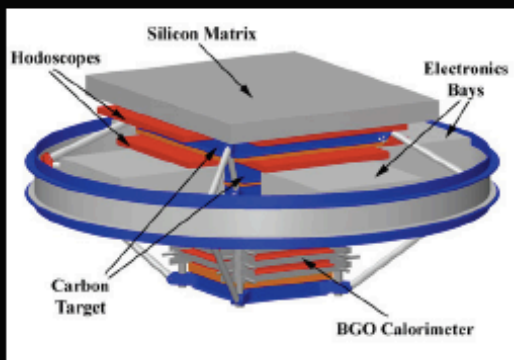
Cherenkov

Radio

HOW DO WE DETECT COSMIC RAYS?

Cosmic rays are particles

Cosmic ray detectors are particle detectors



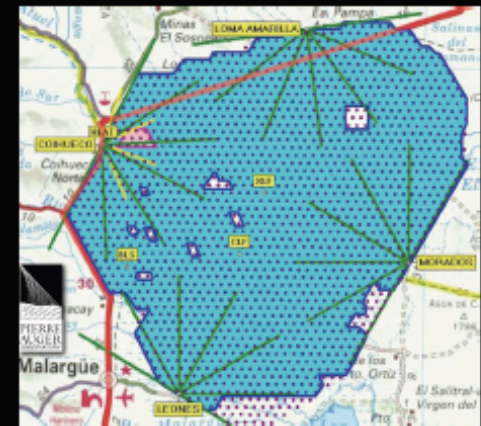
ATIC DETECTOR (60X60 CM)

Wide energy range: $10^6 - 10^{21}$ eV

Wide range of dimensions:

On balloon/space: O(m)

At ground: O(0.01-1000 km²)



AUGER DETECTOR (60X60 KM)

Wide choice of detectors:

dE/dX

Secondary/cascades measurements

Magnetic deflections

Transition radiation

Cherenkov

Radio

HOW DO WE DETECT COSMIC RAYS?

Detectors (vs observables)

Velocity:

Time-of flight

$$\tau \propto 1/\beta$$

Cherenkov angle

$$\cos \theta = 1/\beta n$$

Transition radiation

$$\gamma \geq 1000$$

γ, β

Energy loss:

Bethe-Bloch

$$\frac{dE}{dx} \propto \frac{z^2}{\beta^2} \ln(a\beta\gamma)$$

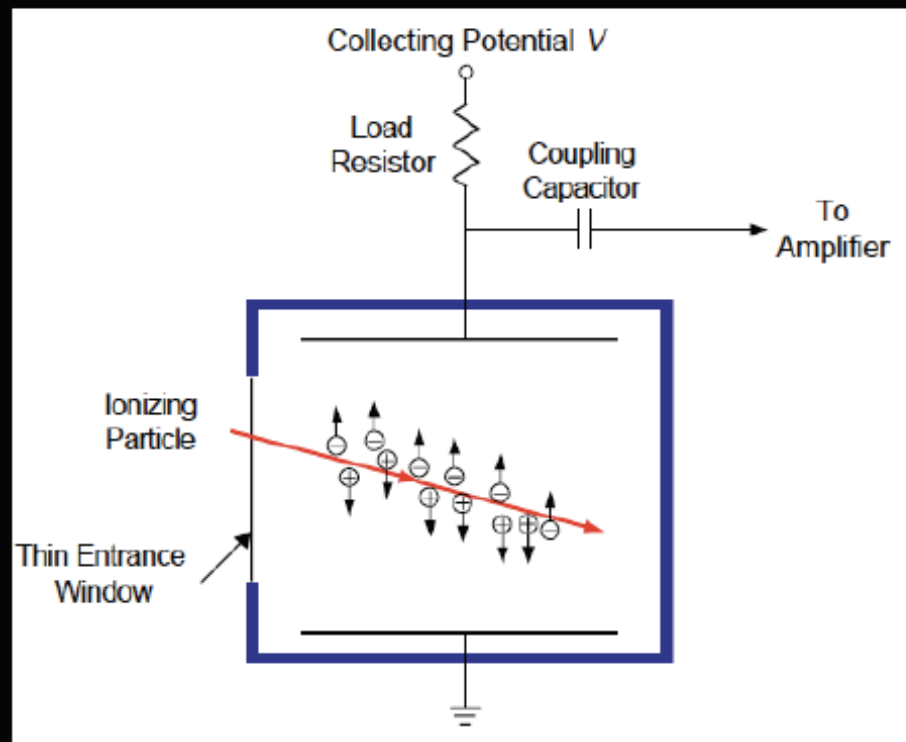
Total energy:

Calorimeter

$$E = \gamma m_0 c^2$$

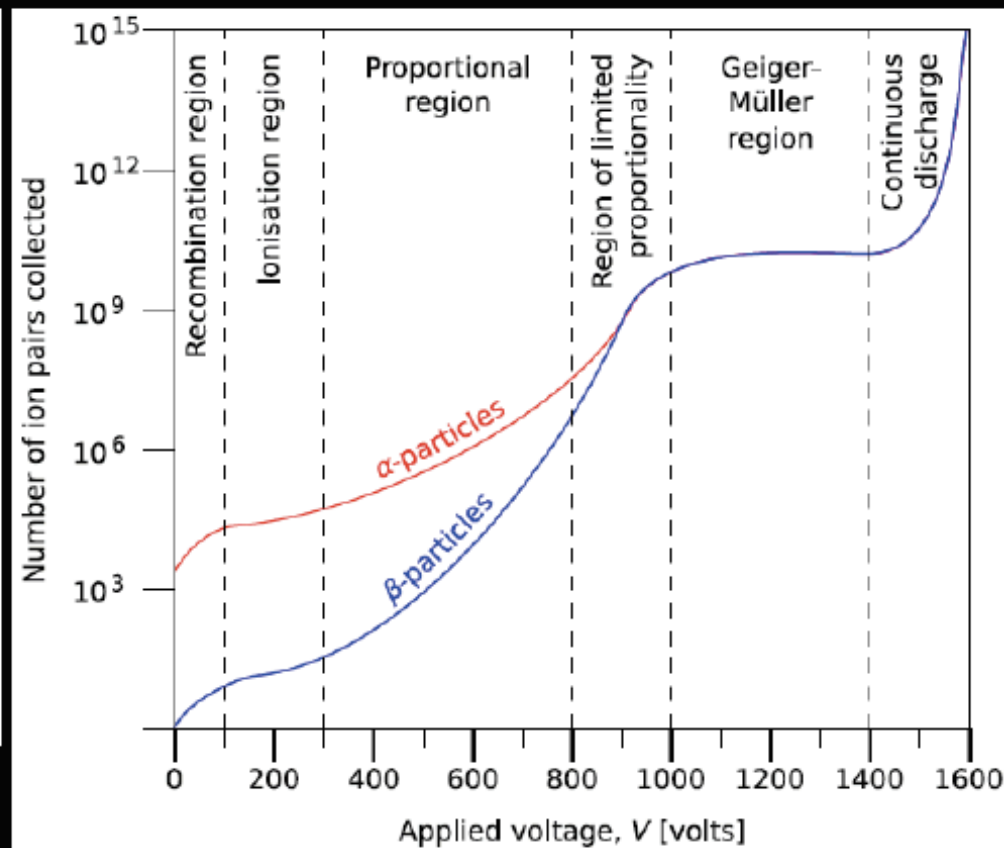
HOW DO WE DETECT COSMIC RAYS?

Ionization detectors



A particle passing through a gas-filled counter will ionize the gas along its path

The applied voltage V between the electrodes will sweep the positive and negative charges toward the respective electrodes causing a charge Q to appear on the capacitor.



The charge Q collected (amplitude of pulse) depends on voltage V .

Higher mass particles produce more initial ions pairs

HOW DO WE DETECT COSMIC RAYS?

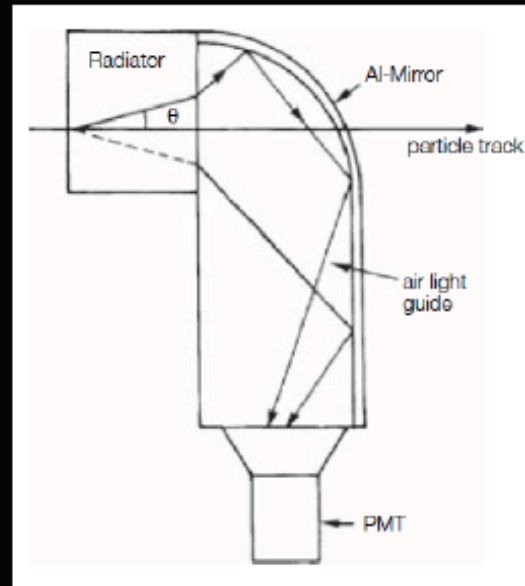
Cherenkov detectors

When a particle moves through a medium at a velocity greater than that of the light in that medium, Cherenkov radiation is emitted.

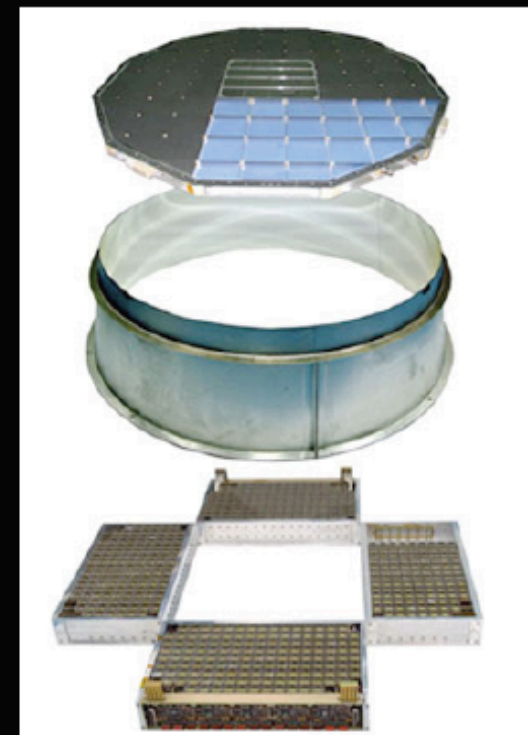
This phenomenon can be used to construct “threshold” detector, i.e., only if the velocity is large enough, it will emit radiation (and hence a signal)

The total emitted light is measured, this providing information on velocity of the particle

The light yield is very small. The light is focalized through mirrors towards PMTs used to produce a detectable signal



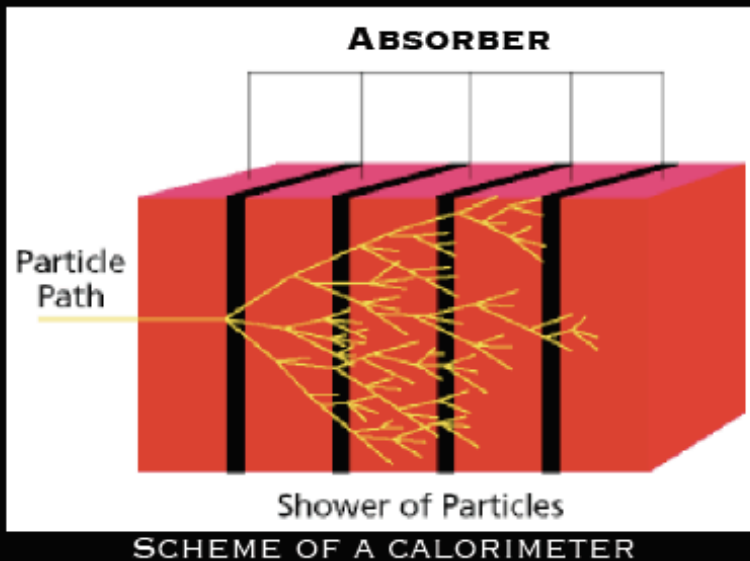
WORKING PRINCIPLE OF A
CHERENKOV DETECTOR



AMS CHERENKOV DETECTOR:
RADIATOR, MIRROR, PMTS

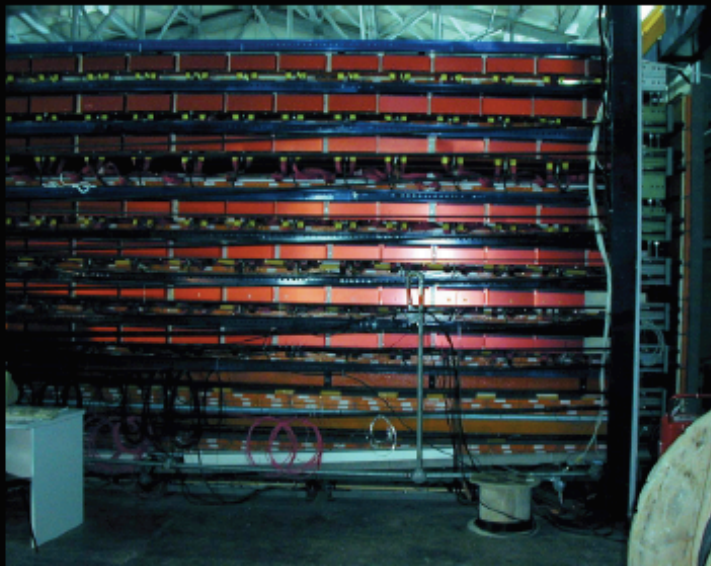
HOW DO WE DETECT COSMIC RAYS?

Calorimeter



A calorimeter measures the energy lost by a particle that goes through it. It is usually designed to entirely stop or 'absorb' most of the particles coming from a collision, forcing them to deposit all of their energy within the detector.

Calorimeters typically consist of layers of 'passive' or 'absorbing' high-density material (lead for instance) interleaved with layers of 'active' medium such as scintillator or gaseous detectors (sampling calorimeters)



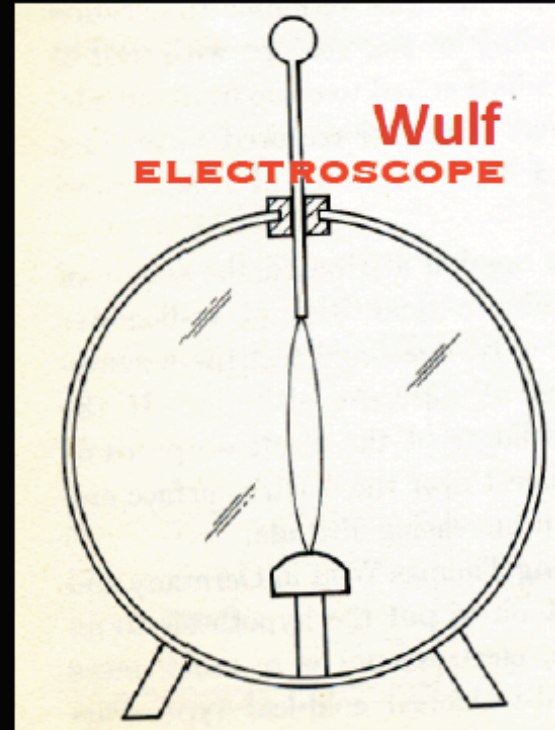
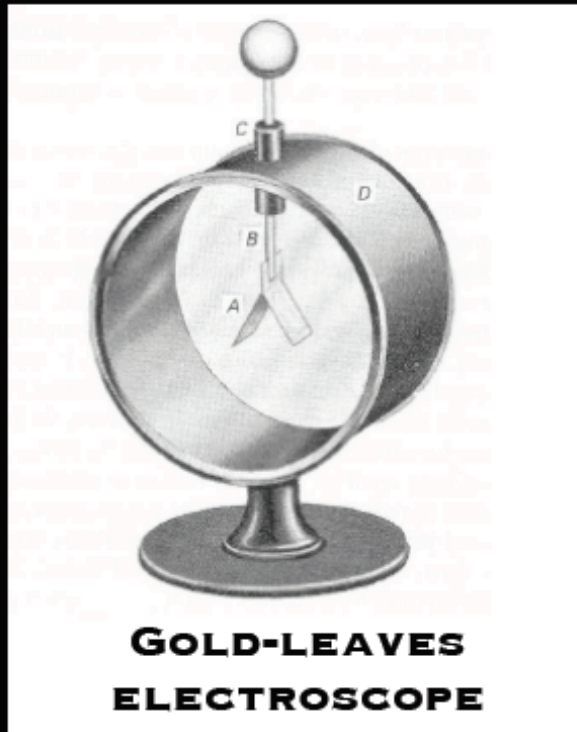
THE CALORIMETER OF THE EAS-TOP EXPERIMENT

Electromagnetic calorimeters measure the energy of light particles – electrons and photons – as they interact with the electrically charged particles inside matter. Hadronic calorimeters sample the energy of hadrons as they interact with atomic nuclei.

HOW DID DETECTION OF COSMIC RAYS START?

Electroscopes

First hints of the presence of cosmic rays came quite unexpectedly at the turn of 20th century, during the golden days of research into radioactivity. Radioactive elements ionize gases, enabling the gas to conduct electricity. Electroscopes were widely used to explore radioactive materials.



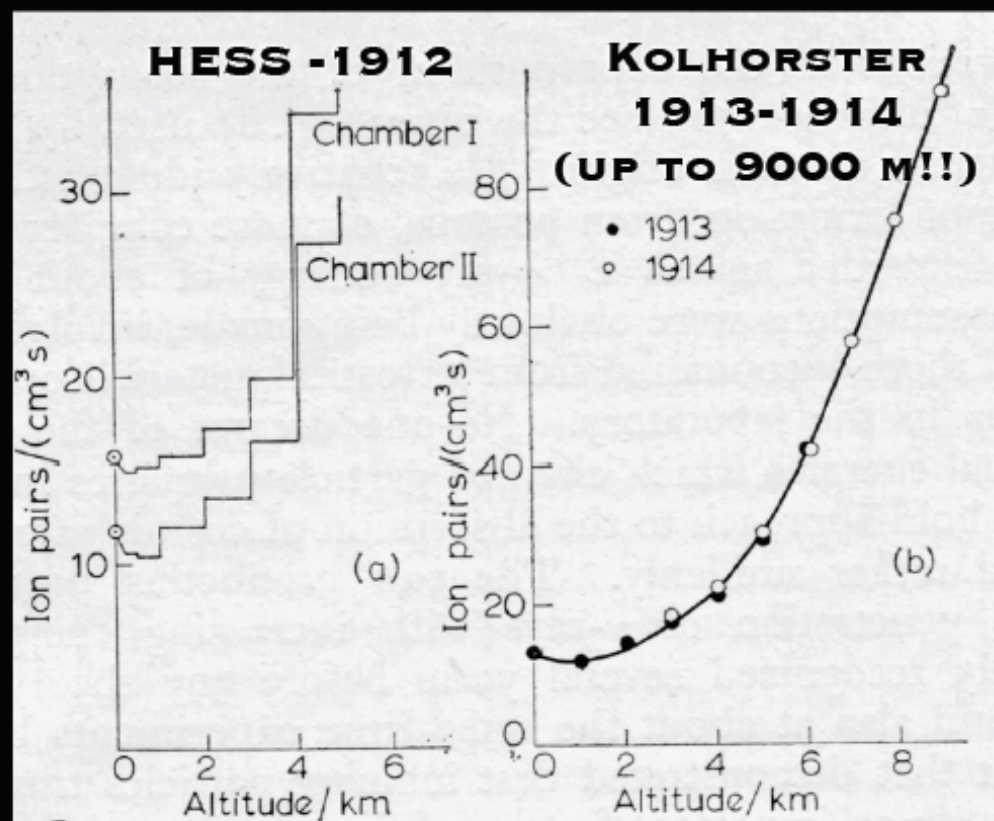
When an electroscope is given an electric charge, the leaves (or wires) repel each other and stand apart. Radiation can ionize the air in the electroscope and allow the charge to leak away: leaves or wires slowly come back together.

Puzzling inference: No matter how good the electroscopes, the electric charge continued to leak away even when there was no obvious nearby source of X-rays or radioactivity!

HOW DID DETECTION OF COSMIC RAYS START?

Electroscopes on balloons

To reduce possible effect of sources of radiation at ground, electroscopes were carried to the tops of tall buildings (Father Wulf, 1910, Eiffel Tower) or even to greater heights, using balloons (Victor Hess, 1912, Werner Kolhorster, 1913-1914)



Intensity of the ionizing radiation first decreased as the balloon went up and then was becoming more intense than at sea level. Experiments of great danger, great courage and great success

"The only possible way of interpret my findings was to conclude to the existence of a hitherto unknown and very penetrating radiation, coming from above and probably of extra-terrestrial origin" [V. Hess 1912]

Ballooning: let's come to even more recent times...

In the more recent generation of direct experiments, data is recorded electronically in-flight and transmitted to the ground. The design of the instrument usually includes a combination of charge detection and energy measurements, with detectors such as scintillator hodoscopes, Silicon detectors combined with a Calorimeter or a Transition Radiation Detector

ATIC BALLOON



CREAM BALLOON

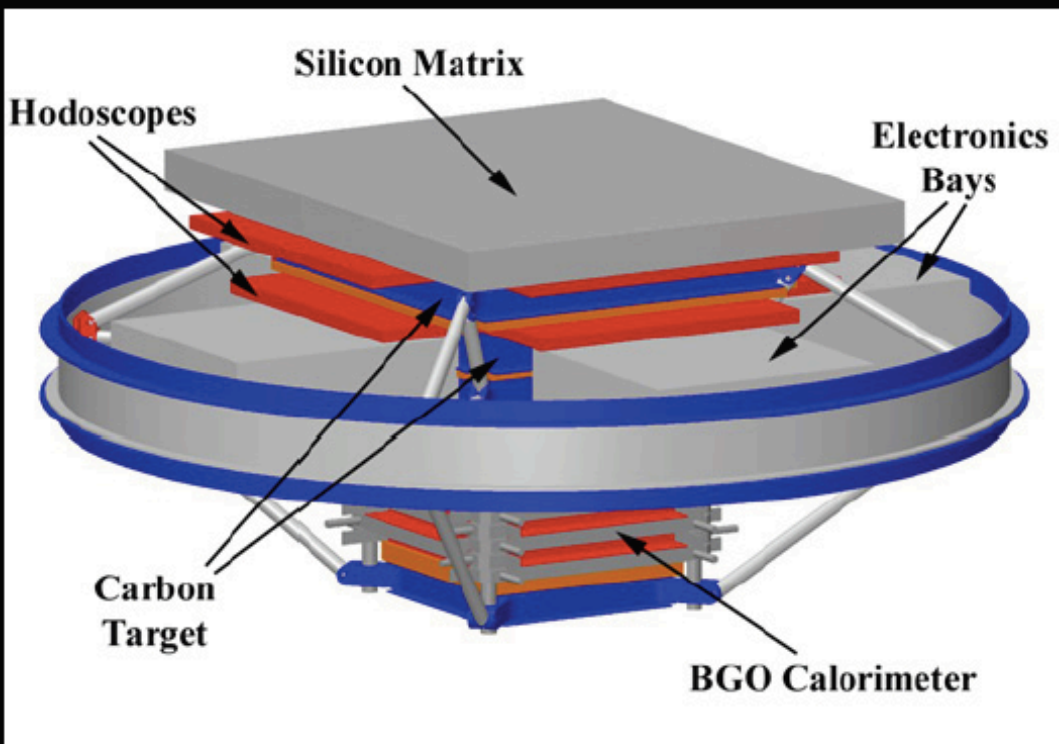


TRACER BALLOON



Ballooning: ATIC

The Advanced Thin Ionization Calorimeter (ATIC) is designed to measure the energy spectrum of individual cosmic ray elements in the energy range 50 GeV-100 TeV (flown in 2007-2008)



Charge measurement with silicon detectors

Target: hodoscopes (scintillators) and carbon. Charge and trajectory measurements

Energy measurement with ionization calorimeter. Layers of carbon and of Bismuth-Germanium-Oxide (BGO) scintillating crystals

TOTAL WEIGHT: 1500 KG

PRINCIPLES APPLICATION ON SATELLITES

ACE [Advanced Composition Explorer] Mission mainly for solar particles

AMS [Alpha Magnetic Spectrometer]. International Space Station

ASCA [Advanced Satellite for Cosmology and Astrophysics]

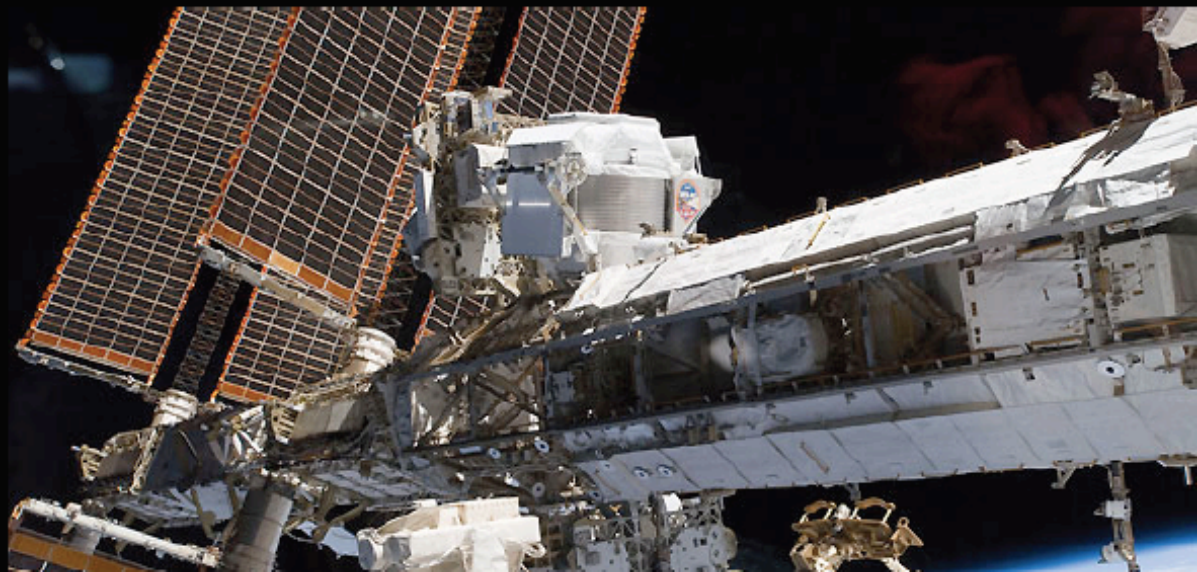
Fermi Gamma-ray Space Telescope, (also cosmic rays)

NINA [New Instrument for Nuclear Analysis], low energy cosmic rays.

PAMELA (magnet spectrometer).



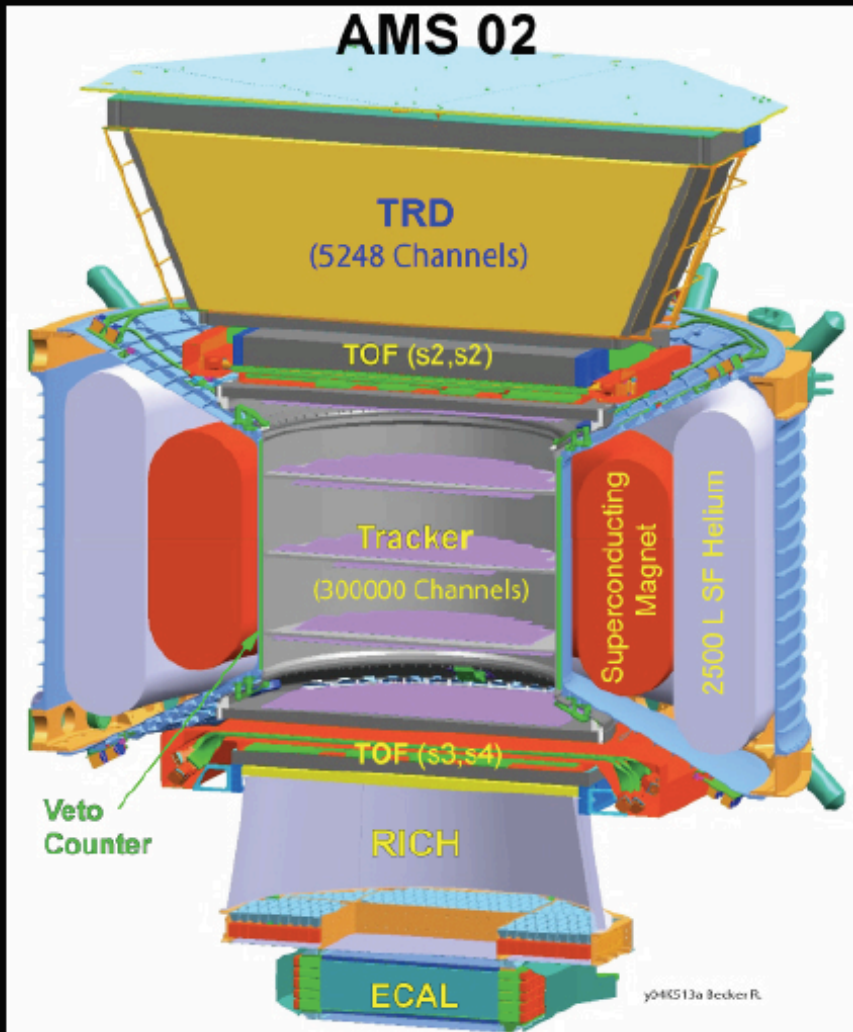
**PAMELA LAUNCH:
15 JUNE 2006**



**AMS ON THE ISS
LAUNCH: 19 MAY 2011**

Space: AMS

The Alpha Magnetic Spectrometer (AMS-02) is designed to operate as an external module on the International Space Station. It mainly aims to search for antimatter, but it will perform too precision measurements of cosmic rays composition and flux.



Velocity and charge measurement: Time of Flight (scintillators)

Lorentz factor measurement: Transition Radiation Detector (tube straws and plastic radiator)

Charge sign (and value) measurement: Spectrometer (Si tracking system and magnet)

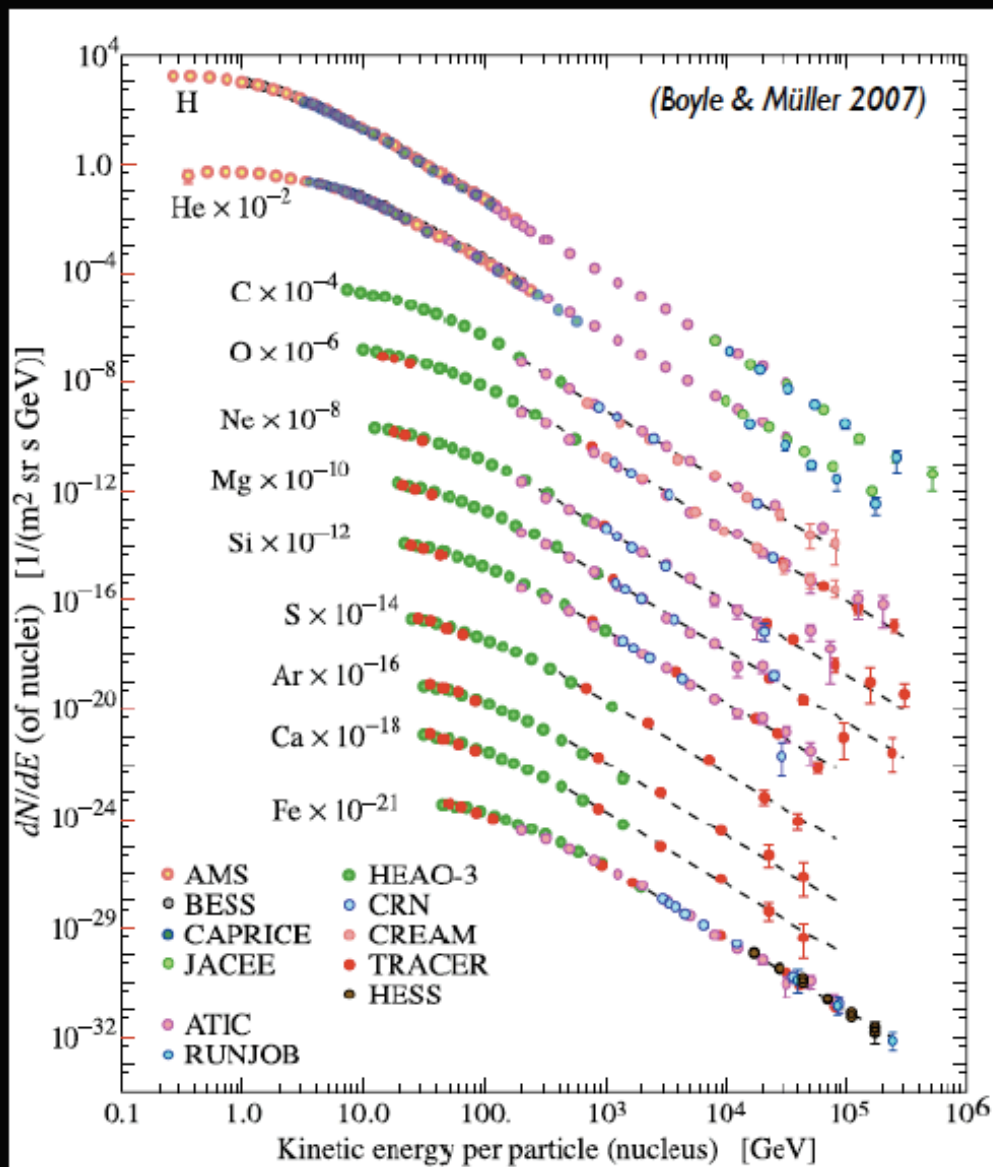
Velocity measurement: Ring Cherenkov detector (RICH)

Energy measurement: electromagnetic calorimeter . Scintillating fibers alternated to lead absorber

TOTAL WEIGHT: 8500 KG

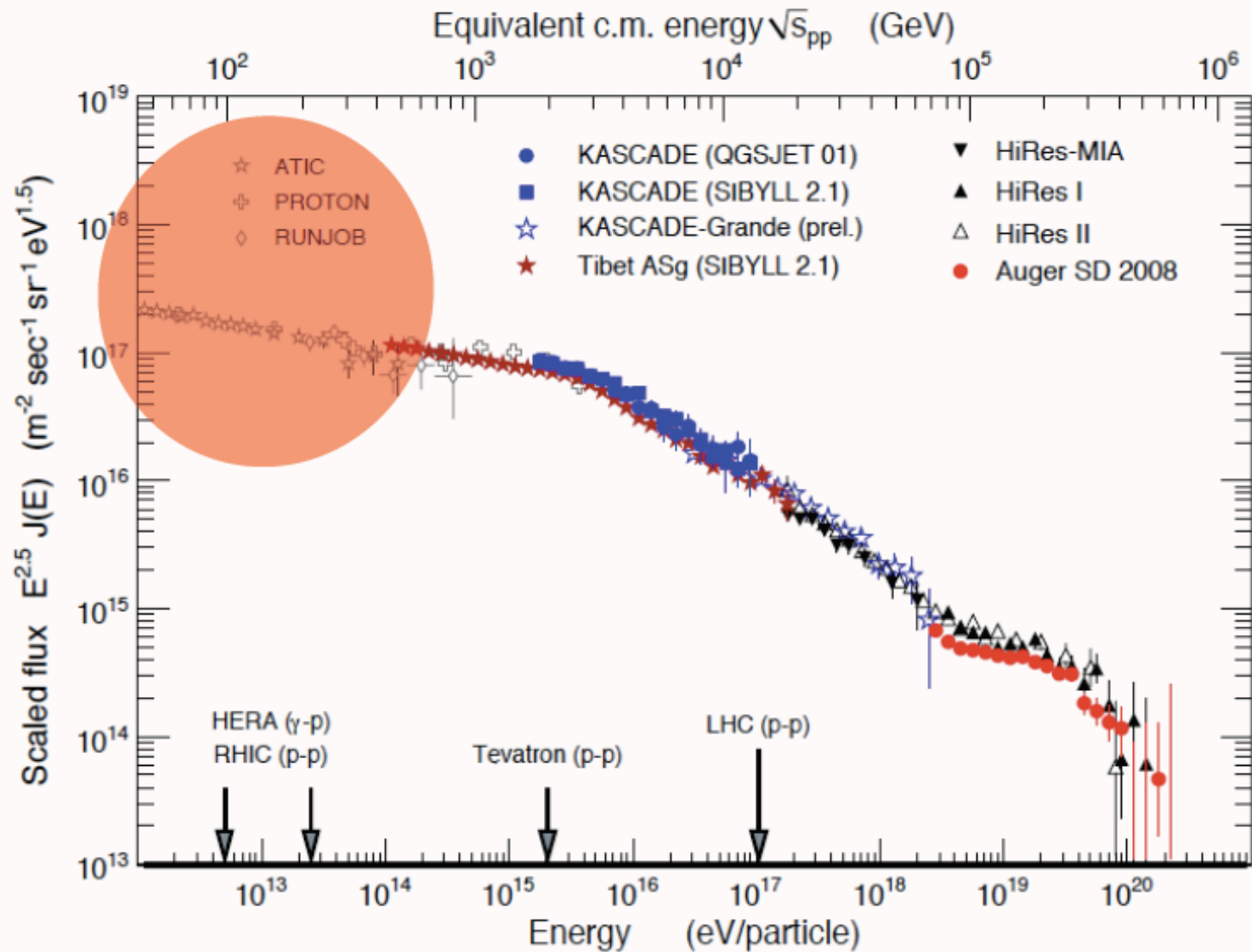
And to finish...

Grandeur of inferences: Fluxes of individual elements



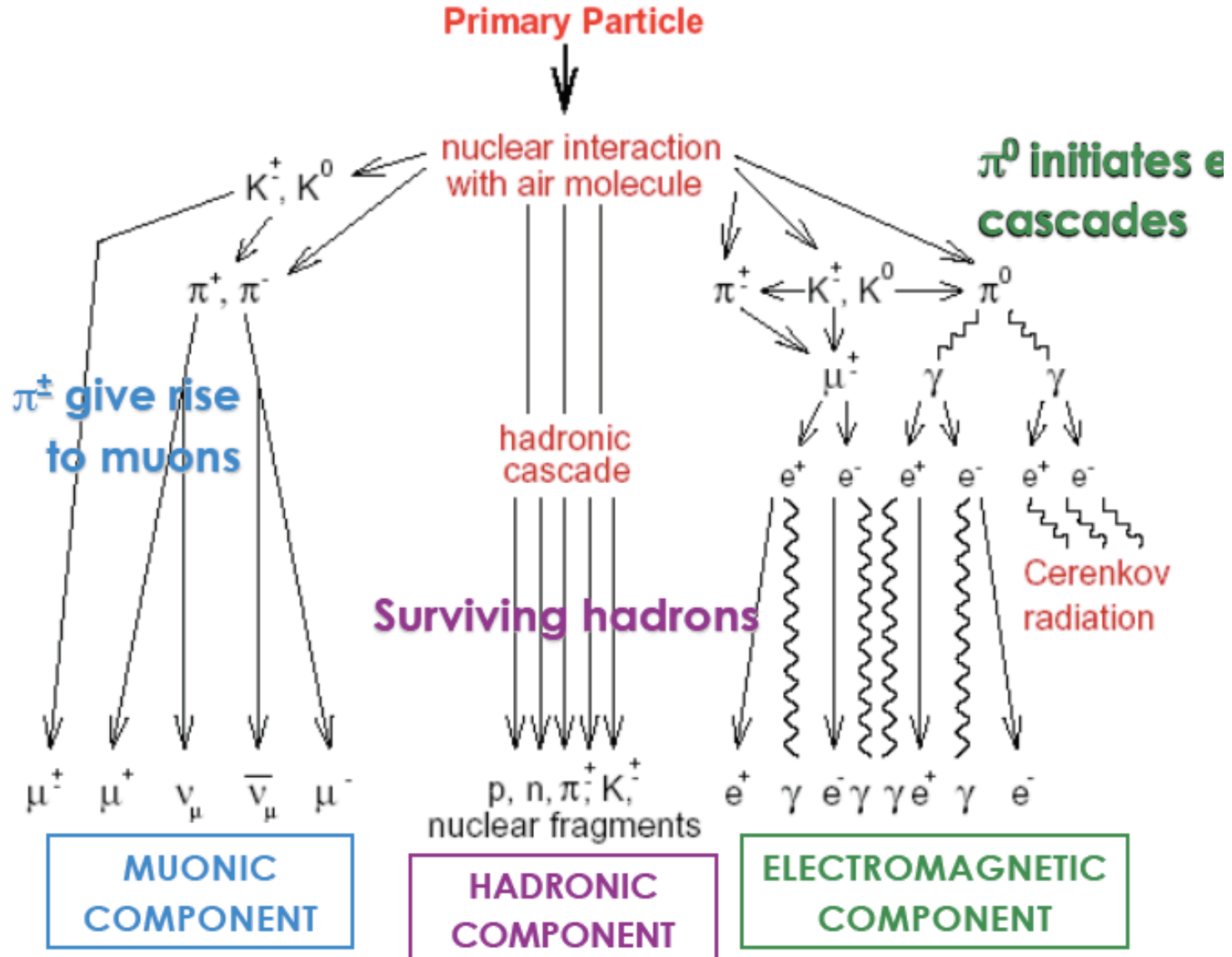
And to finish...

Grandeur of inferences: All-particle spectrum

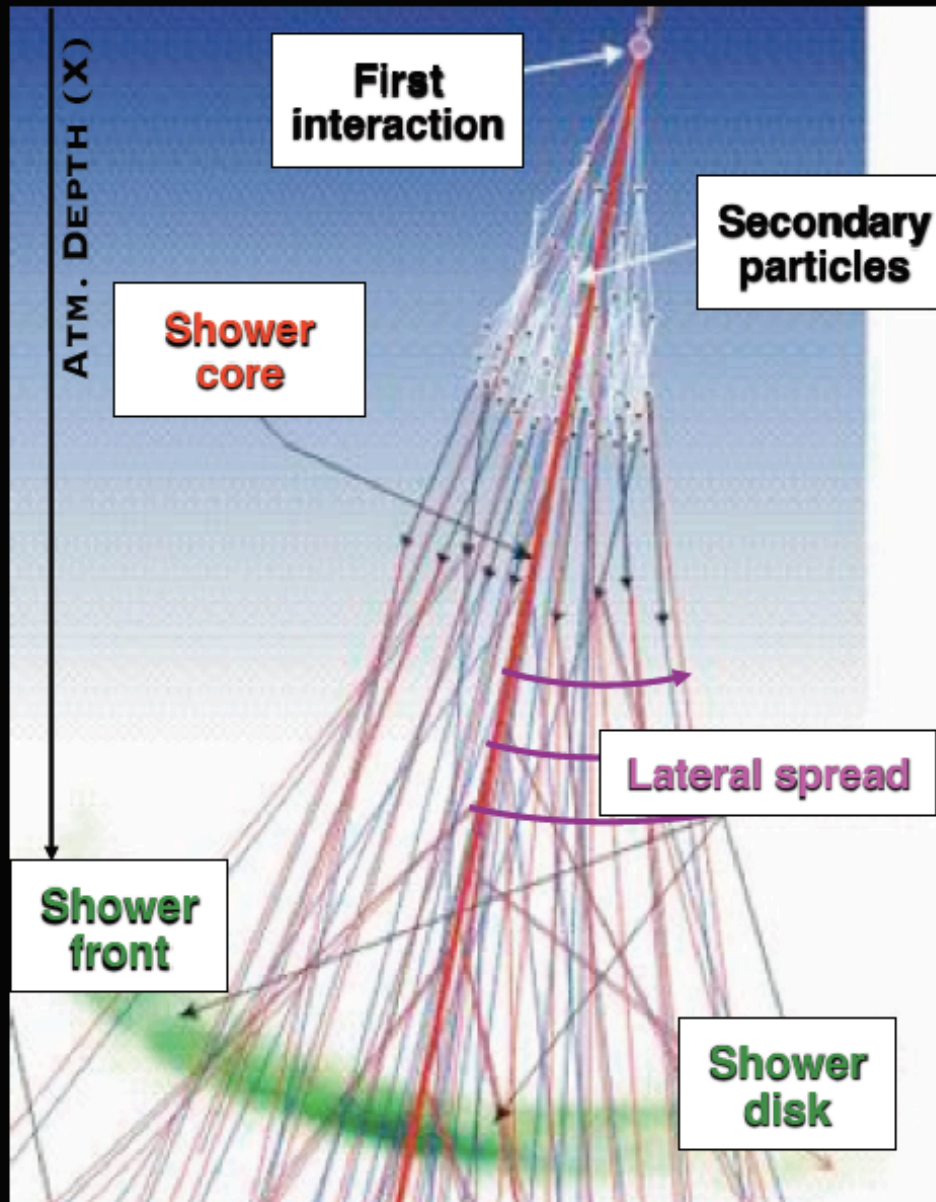


EXTENSIVE AIR SHOWERS

A high energy primary particle, upon entering the atmosphere, initiates a chain of nuclear interactions



EAS LATERAL DEVELOPMENT

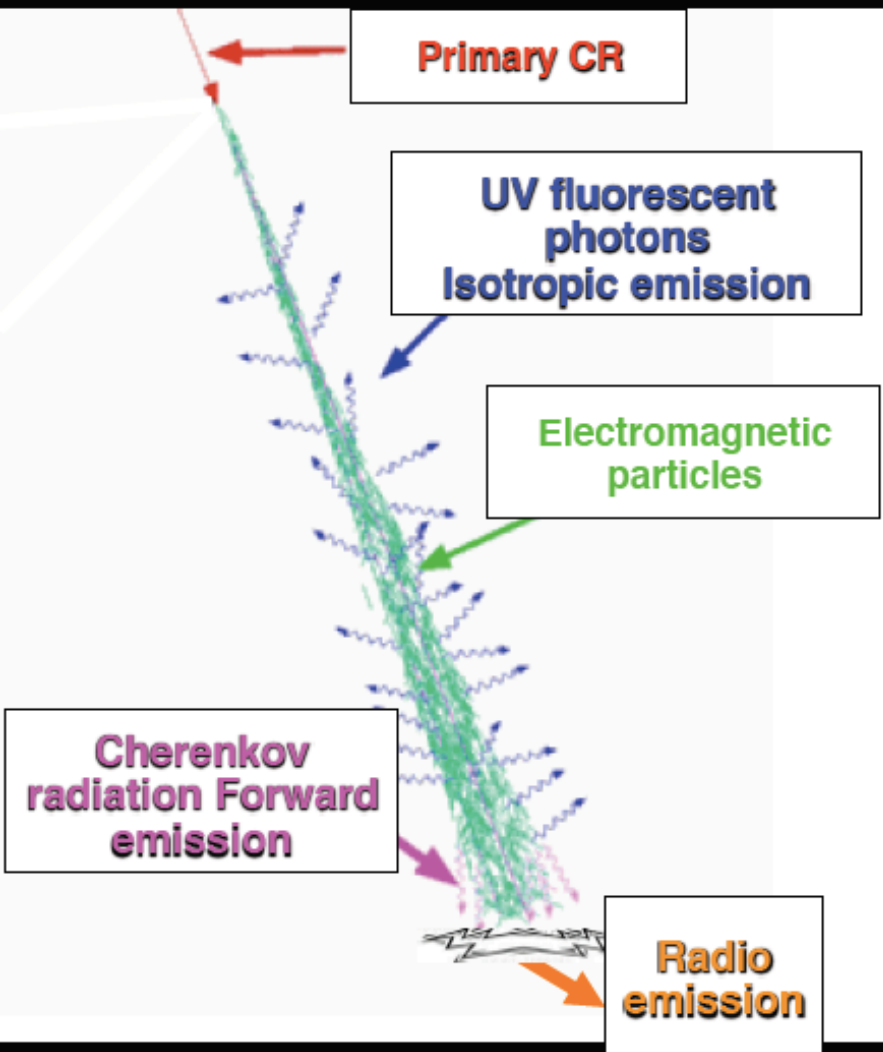


Secondary particles form a narrow “bundle”: **the shower core**

Initial transverse momentum and multiple scattering in atmosphere causes particles to **spread out laterally** from the core -> **lateral distribution**: particle density is greatest at the core and it decreases with increasing distance from it

Due to different path lengths and velocities across the atmosphere shower particles are distributed over a wide area in a **thin curved disk**

RADIATION FROM SHOWER DEVELOPMENT



Cherenkov radiation: Electrons and positrons in the shower travel faster than the speed of light in air and emit Cherenkov radiation, mostly in the forward direction

Fluorescence radiation: The passage of air shower e.m. particles in atmosphere results in the excitation of the gas molecules (mostly nitrogen). Some of this excitation energy is emitted in the form of isotropic visible and UV radiation.

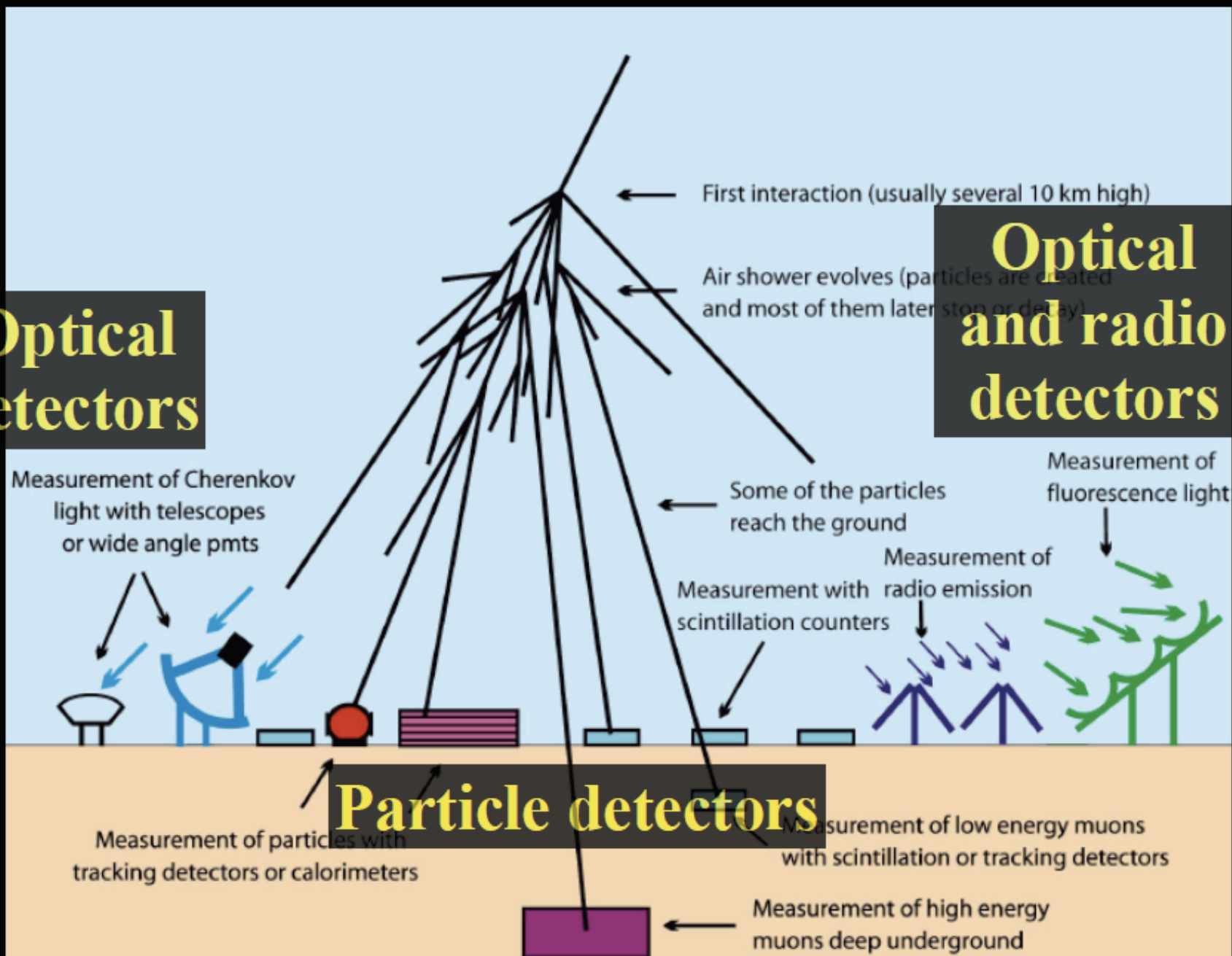
Radio emission: Air shower electrons and positrons are deflected in the Earth's magnetic field. Because of their relativistic velocities, they emit synchrotron radiation, beamed very sharply downwards, at radio frequencies below 100 MHz. Many sparkles together produce a bright radio flash

DIFFERENT DETECTORS FOR DIFFERENT EAS OBSERVABLES

Optical detectors

Optical and radio detectors

Particle detectors



Measurement of Cherenkov light with telescopes or wide angle pmts

First interaction (usually several 10 km high)

Air shower evolves (particles are created and most of them later stop or decay)

Some of the particles reach the ground

Measurement of fluorescence light

Measurement with radio emission

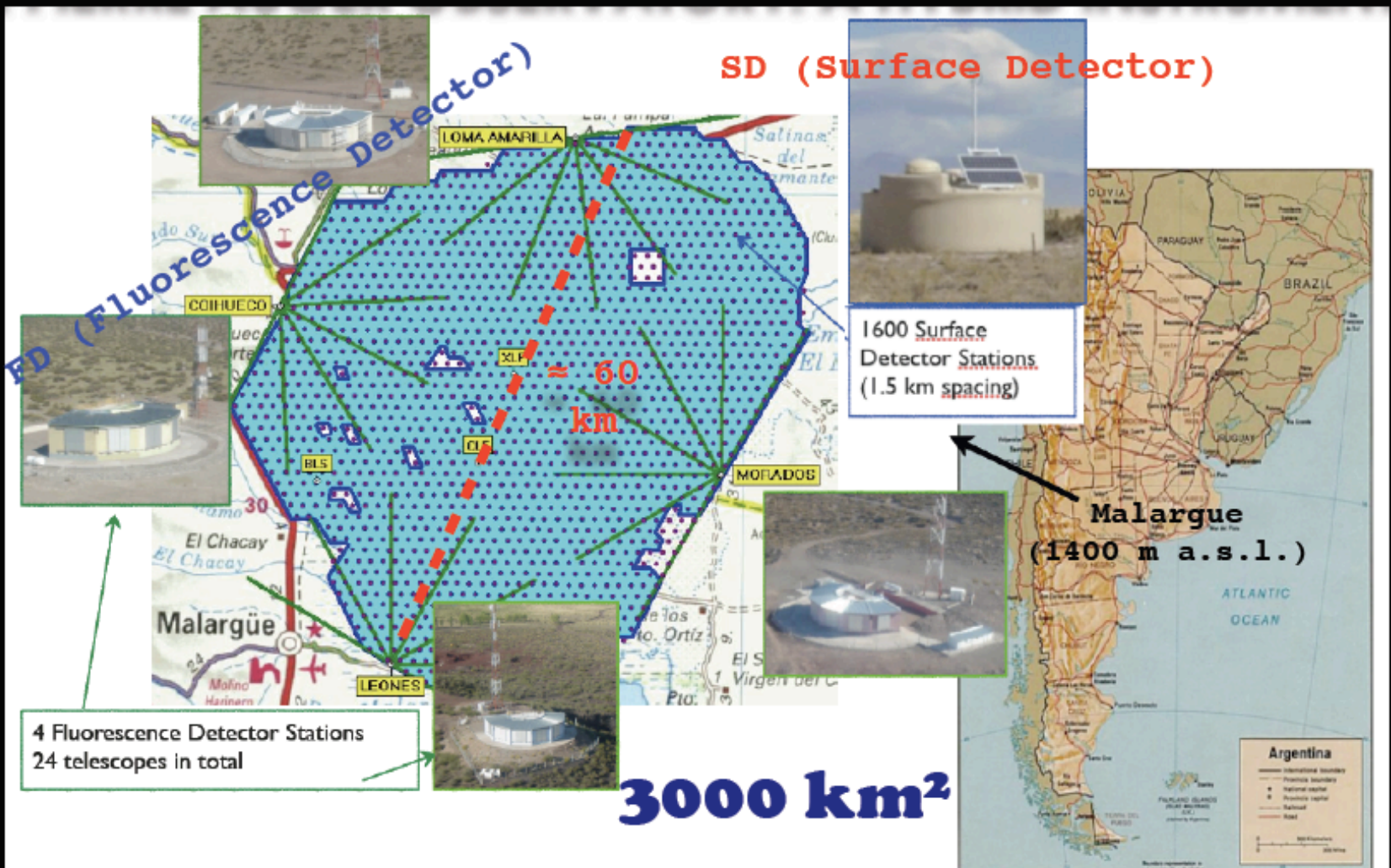
Measurement of

Measurement of particles with tracking detectors or calorimeters

Measurement of low energy muons with scintillation or tracking detectors

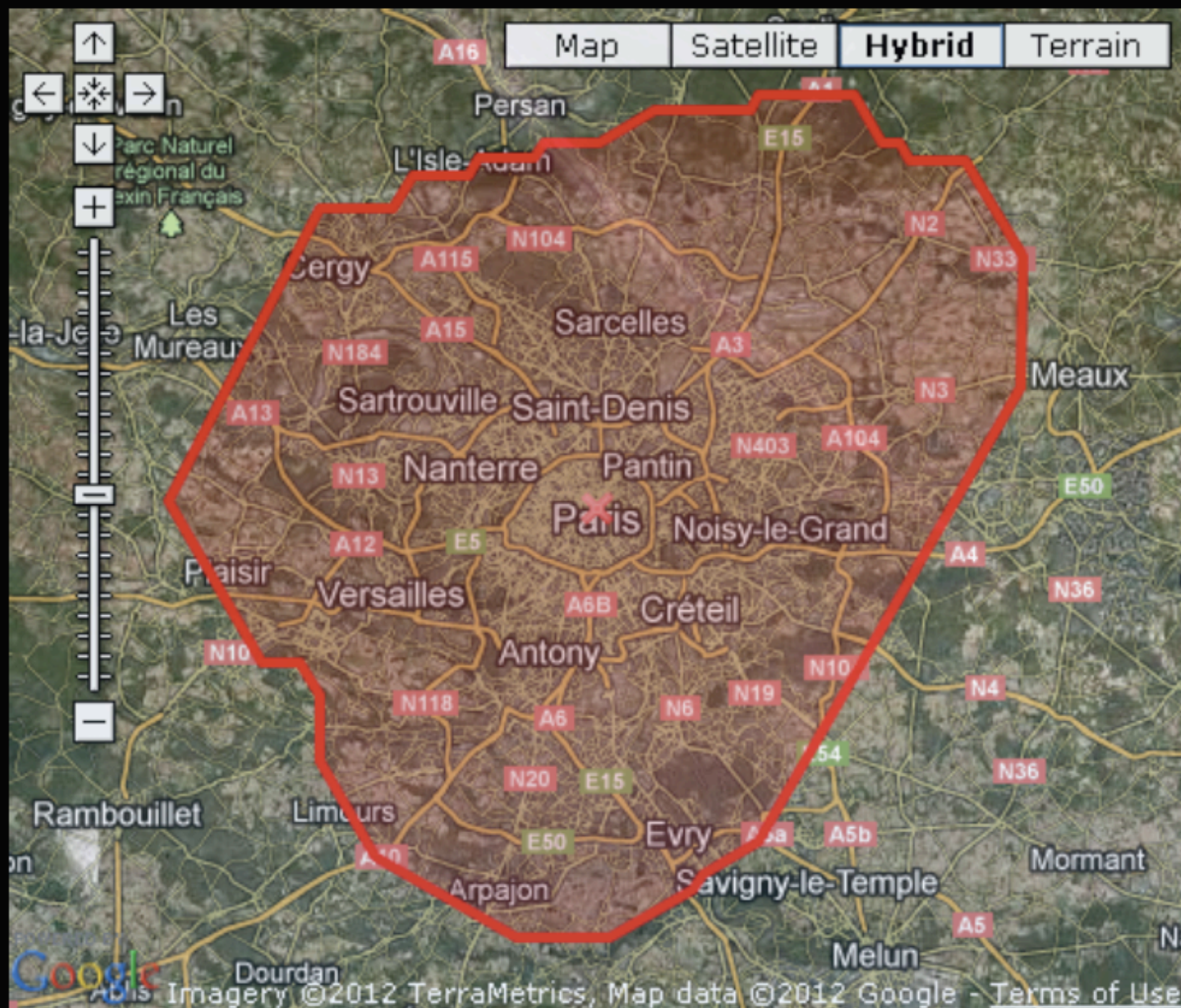
Measurement of high energy muons deep underground

THE PIERRE AUGER OBSERVATORY: A HYBRID INSTRUMENT



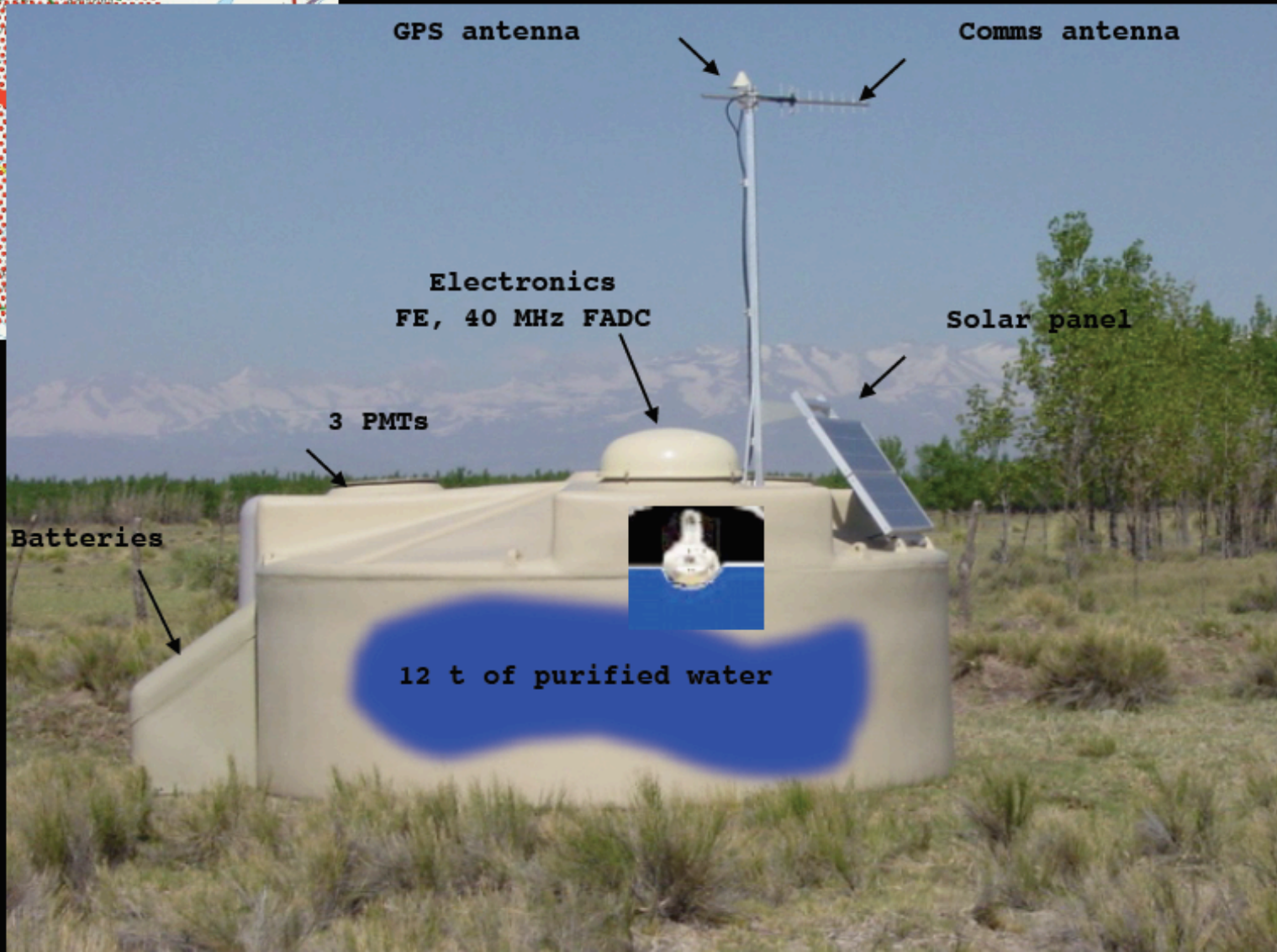
- “Hybrid” detector: 1600 water Cherenkov (SD) + 4x6 fluorescence detectors (FD)
- SD fully efficient above 3 EeV (100% d.c), FD&&SD above 1 EeV (but ≈ 13% d.c.)
- In operation from 2004 (completed in 2008)
- Full Auger: ≈ 1500 (100) (2) events/month above 3×10^{18} (10^{19}) (5×10^{19}) eV

THE SIZE OF THE PIERRE AUGER OBSERVATORY :-)



THE SURFACE DETECTOR ARRAY

Surface Detector (SD): 1600 water Cherenkov tanks, 100% duty cycle



GPS antenna

Comms antenna

Electronics
FE, 40 MHz FADC

Solar panel

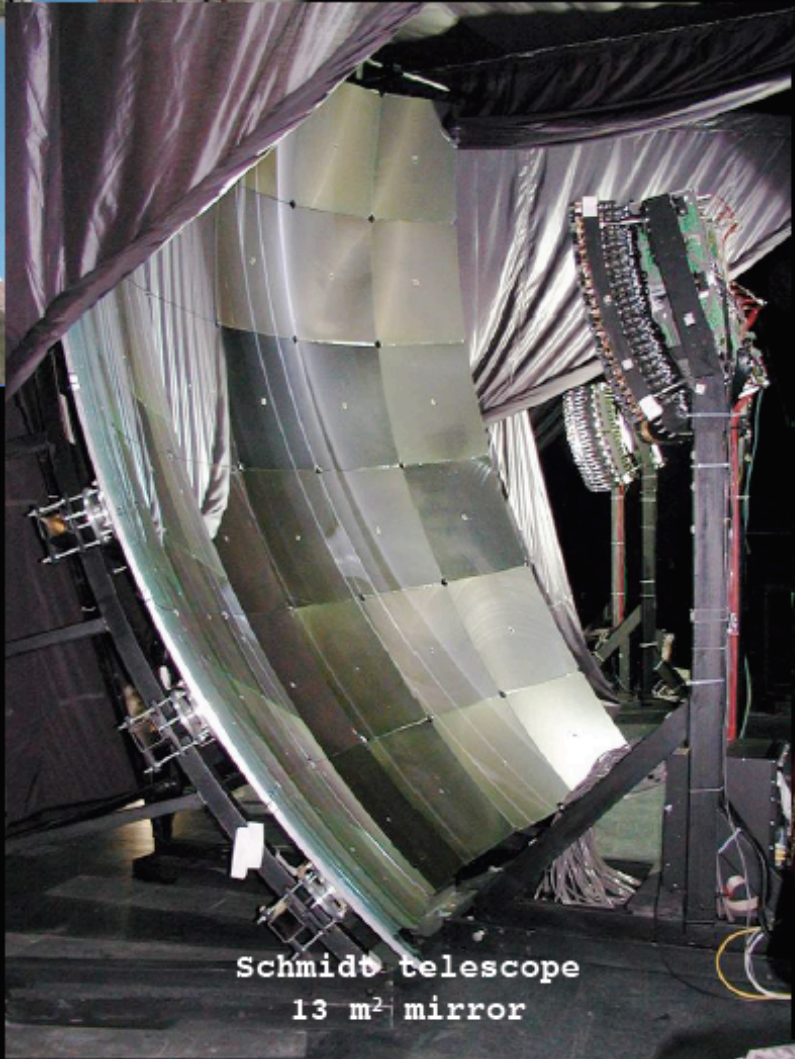
3 PMTs

Batteries

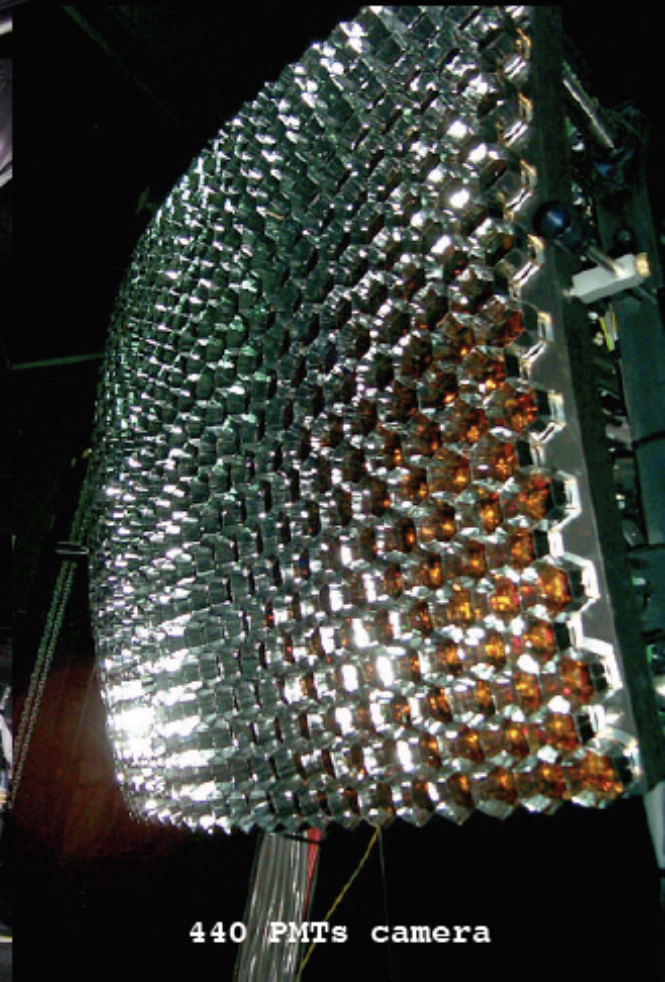
12 t of purified water

THE FLUORESCENCE DETECTOR

Fluorescence Detector (FD): 4 x 6 telescopes
10% duty cycle

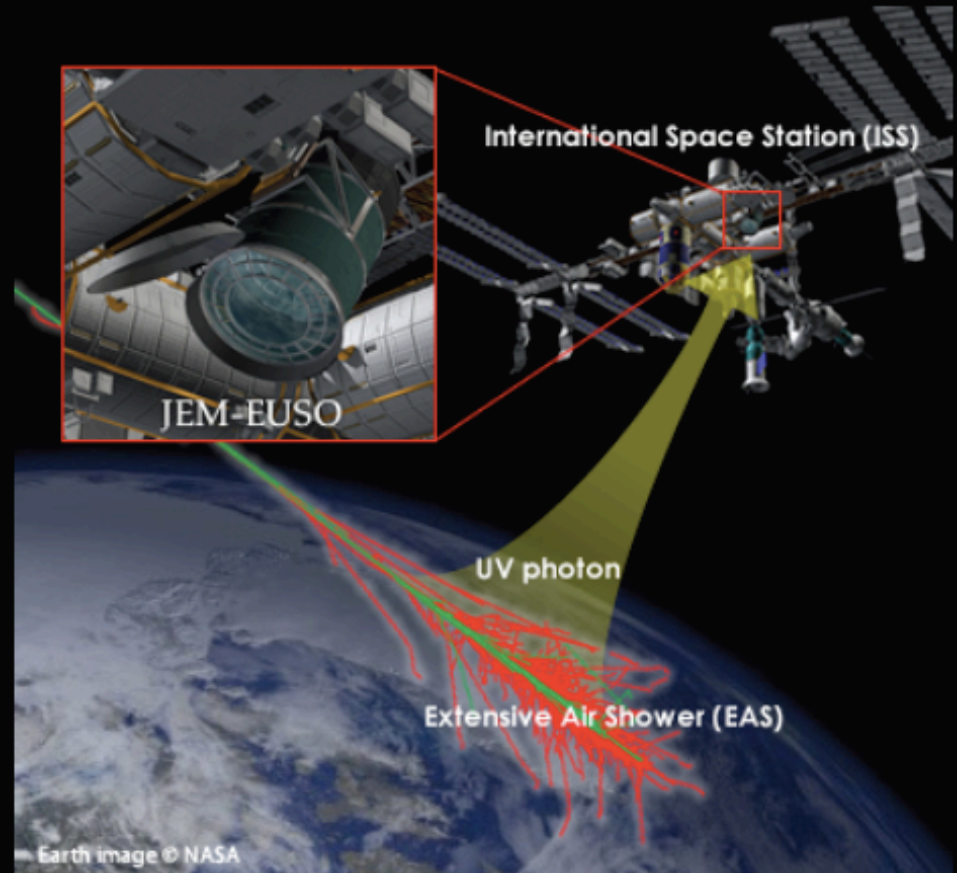
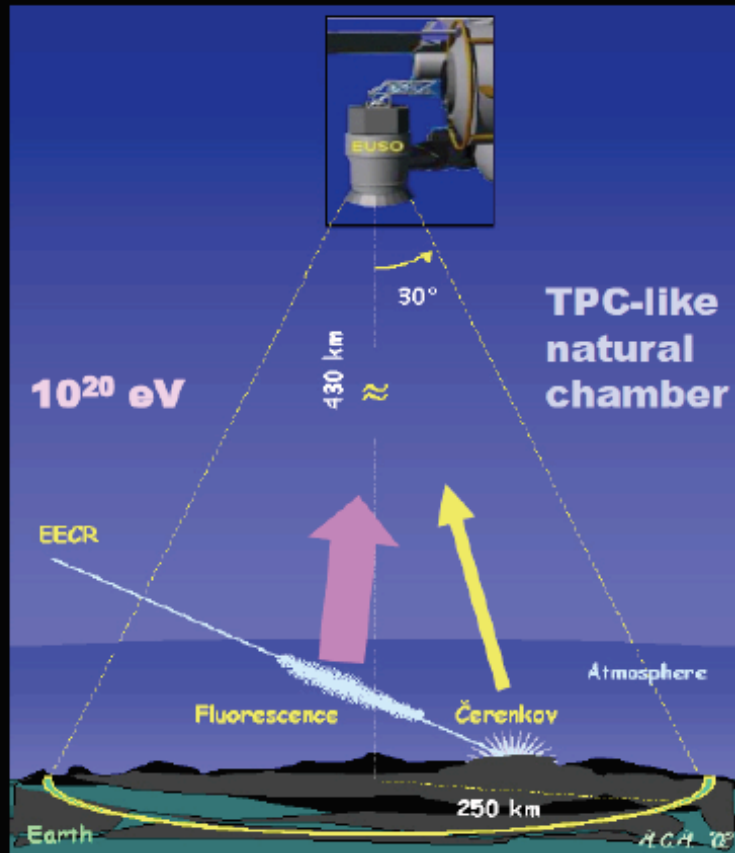


Schmidt telescope
13 m² mirror



440 PMTs camera

TO MEASURE COSMIC RAYS AT $> 10^{20}$: JEM-EUSO



In space: to be installed on ISS (altitude ≈ 400 km)

Fluorescence detector

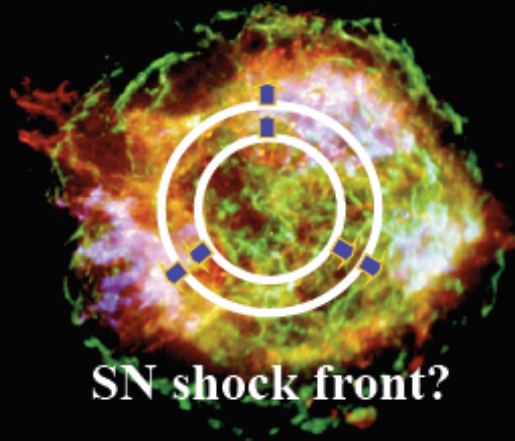
6000 PMTs for a 2.25 m focal surface

Fresnel lenses

Aperture: 10^5 - 10^6 km² sr; Energy range: $>10^{20}$ eV

BECAUSE WE WOULD LIKE TO IDENTIFY THEIR SOURCES...

GALACTIC CRS



SN shock front?

PRODUCTION

Fermi mechanism:
diffusive shock
acceleration.

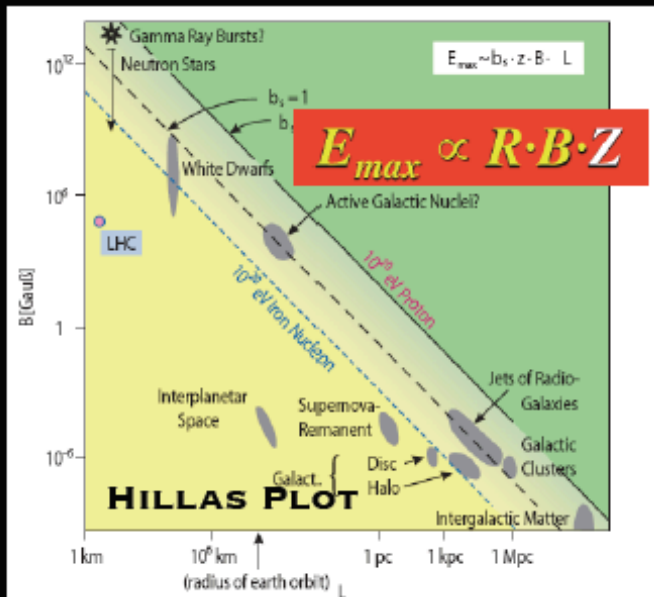
Natural power law.
Cutoff energy of different
elements $\approx Z$

Best candidates: SNR

PROPAGATION

Galactic CRS completely
diffused and isotropized
by GMF. CR-astronomy
not possible. γ -rays and
neutrinos smoking-gun

EXTRA--GALACTIC CRS

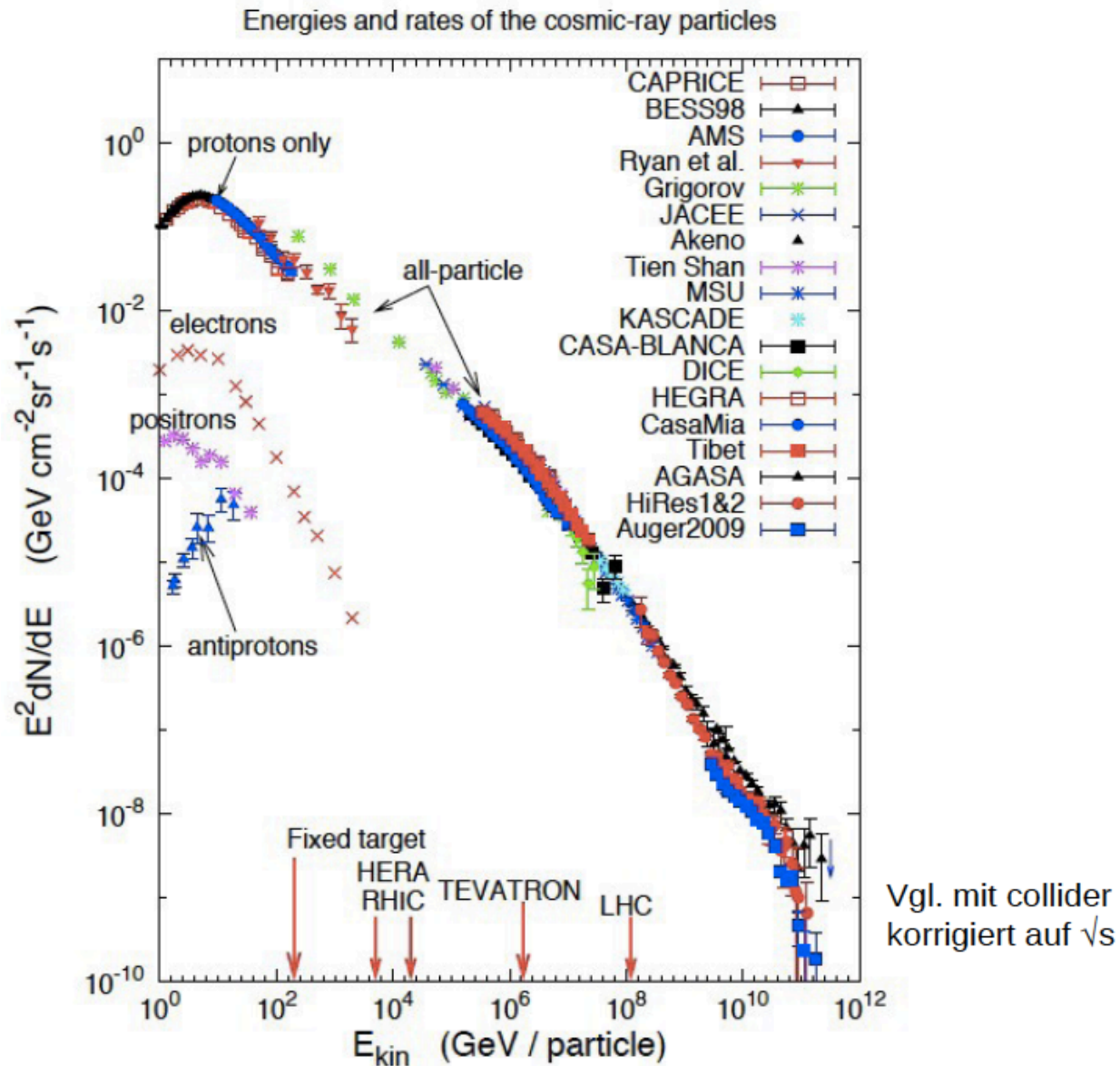


Source size & magnetic
field constraint to
accelerate CRS to the
highest energies: AGNs,
GRBs, Radiogalaxies lobes

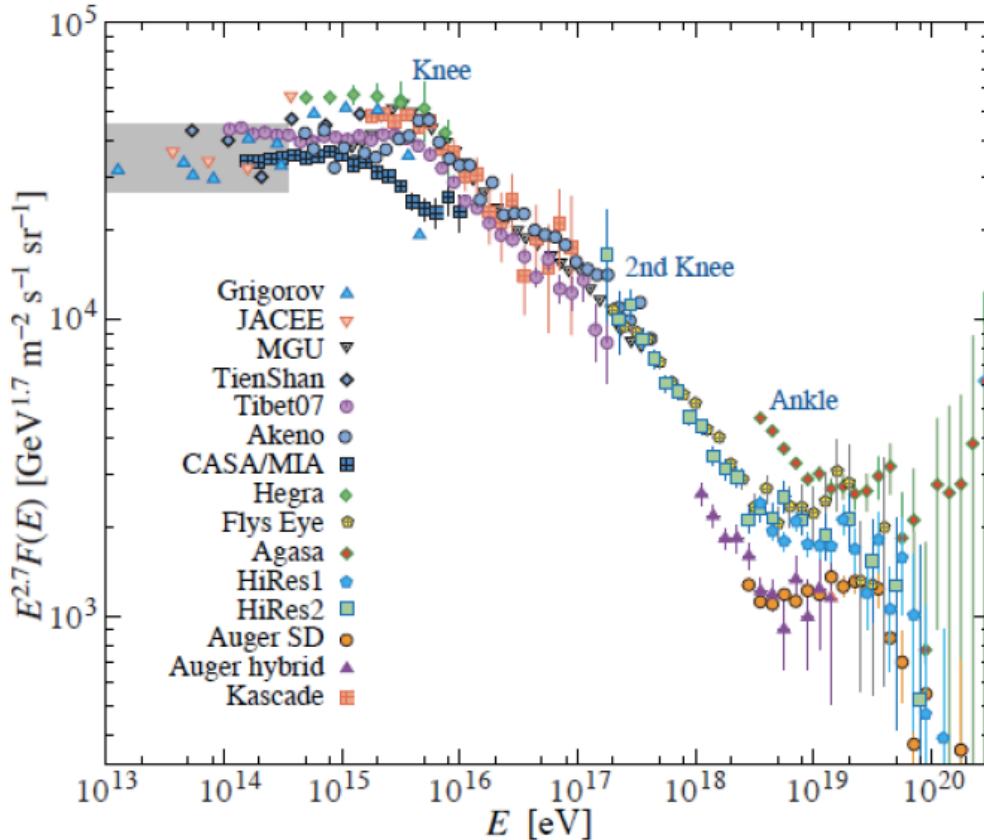
...

Highest energy (low-Z)
CRs marginally
deflected by GMF. CR-
astronomy possible

Spektrum der kosmischen Strahlung



How to accelerate particles to 10^{20} eV ?



10^{20} eV = 16 Joule!!

Compare:

Tennis ball with 100 km/h: 44 J

to reach 10^{20} eV

LHC magnetic field,

radius $\sim 10^7$ km (Sun - Mercury)

or 10 GT fields!

Figure 24.8: The all-particle spectrum from air shower measurements. The shaded area shows the range of the the direct cosmic ray spectrum measurements. See full-color version on color pages at end of book. T. Gaisser, T. Stanev in www.pdg.lbl.gov

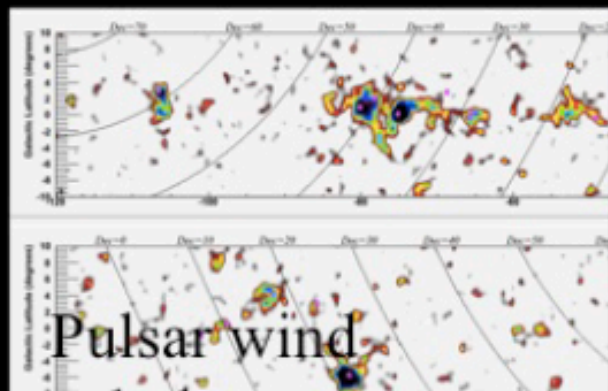
Astrophysical

High Energy Accelerators

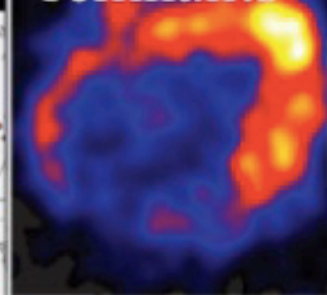
Extragalactic



Galactic



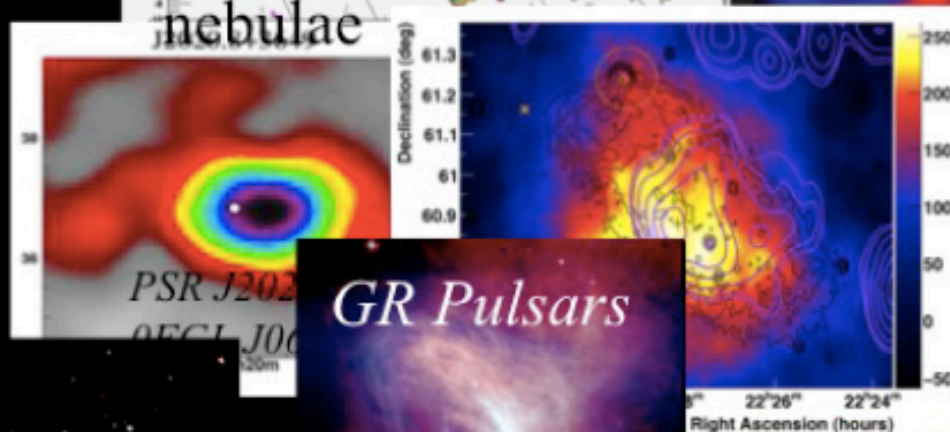
Supernova remnants



Blazars:

Jets

Starburst galaxies

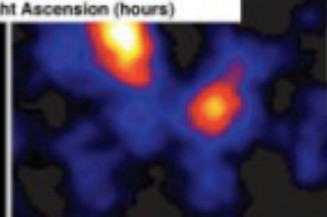
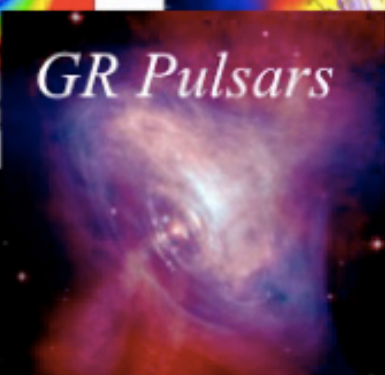


EBL in IR



Unidentified γ -ray sources

Stellar clusters



Plausible source of ultra-high cosmic rays (UHECRs)

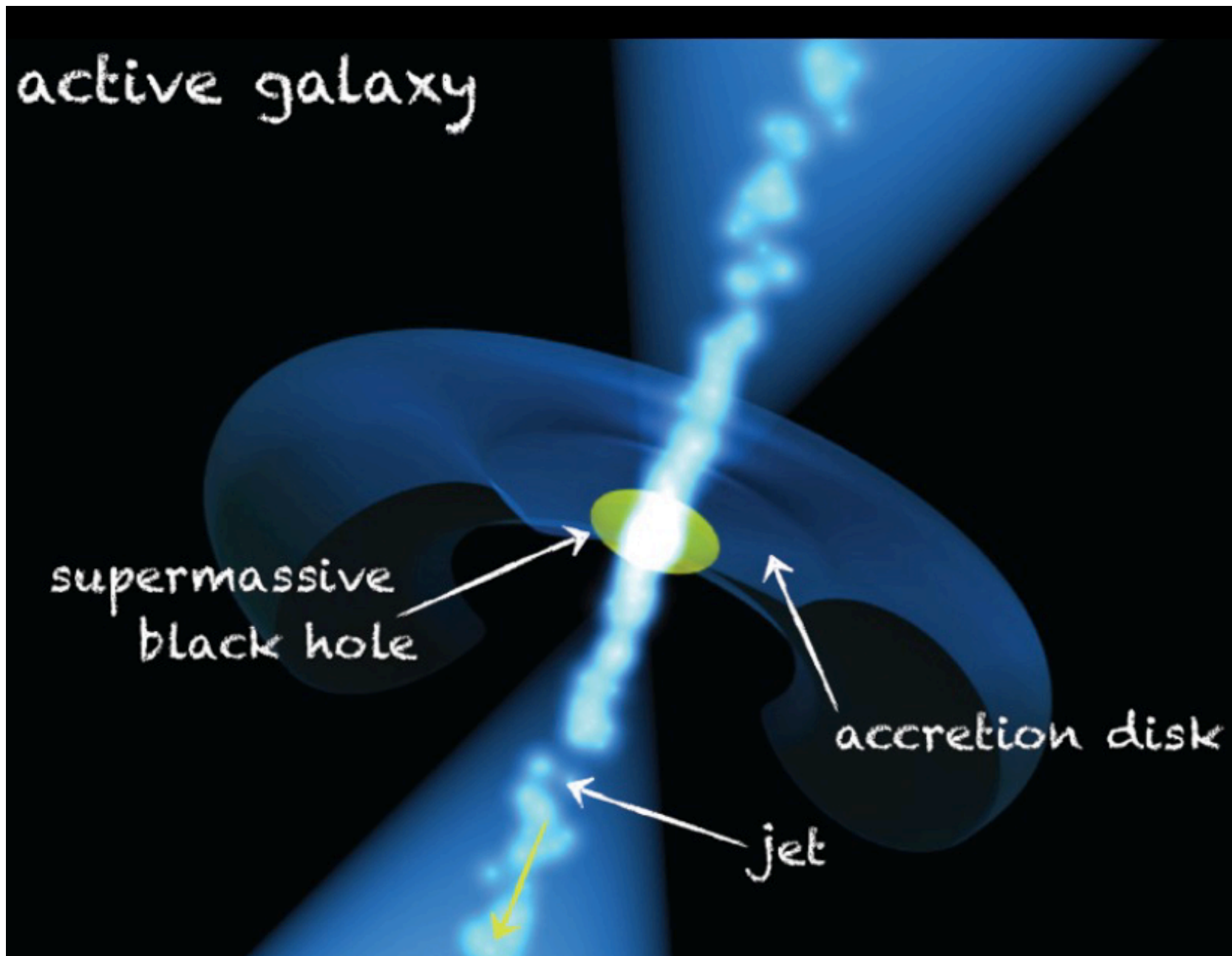
1. Extragalactic $E > 10^{18}$ eV (maybe even lower)
2. Transition from Galactic to Extragalactic is ill constrained.
3. UHE Spectral shape fit \rightarrow degeneracies.
4. Luminosity–number density relationship
5. E_{\max} hard to reach: GRBs, AGN, NSs, IGM shocks,?

active galaxy

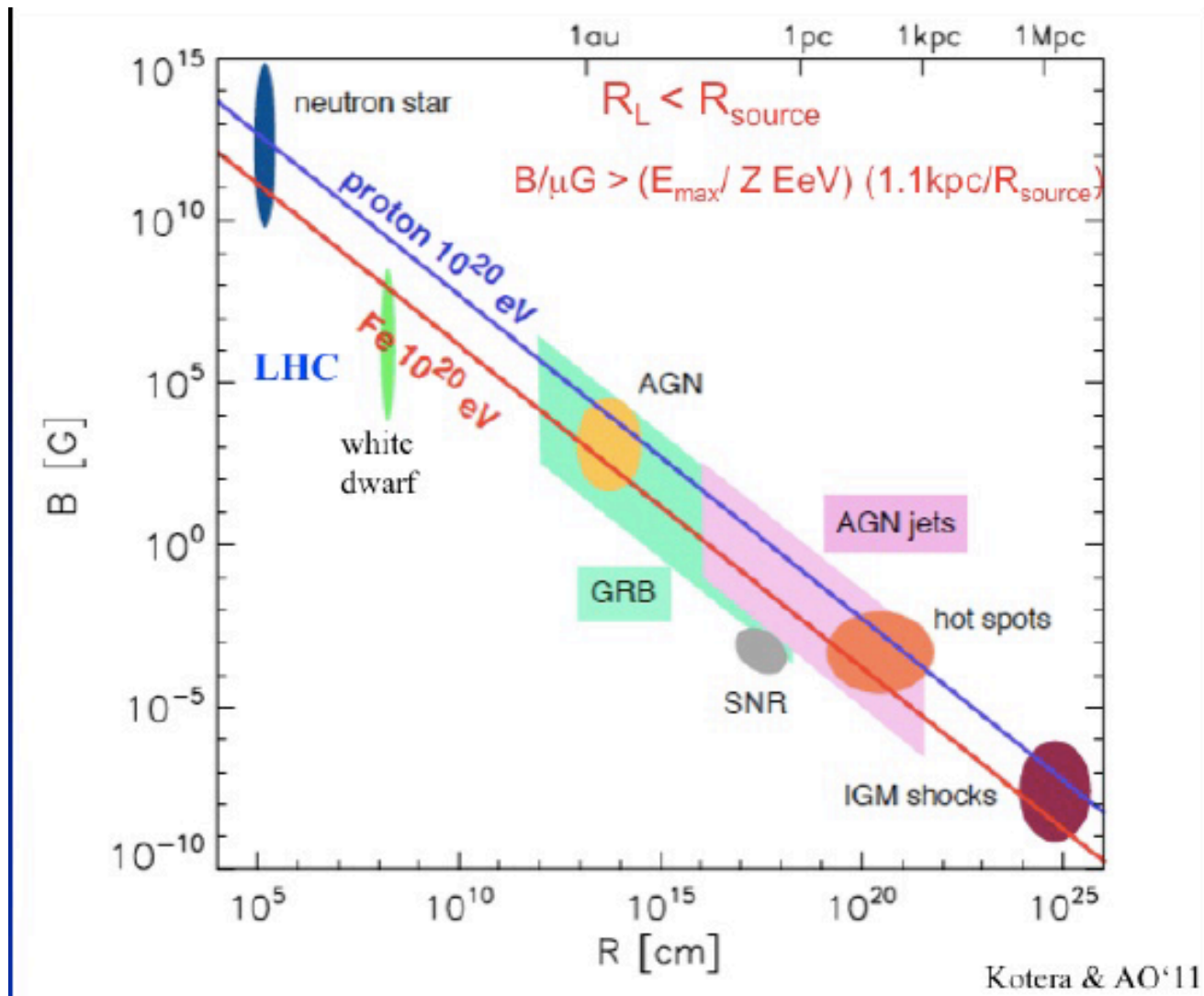
supermassive
black hole

accretion disk

jet



Hillas plot



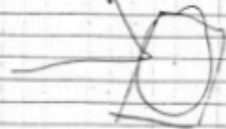
Dec 4 1948

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Theory of cosmic rays

a) Energy acquired in collisions against cosmic magnetic fields



Non relativistic case

$$Mv^2$$

(M = mass of particle v = velocity of moving field)

(Proof: head on collision gives energy gain

$$\begin{aligned} \frac{M}{2}(v+2V)^2 - \frac{Mv^2}{2} &= \frac{M}{2}(4vV + 4V^2) = \\ &= M(2vV + 2V^2) \quad \text{Prob} = \frac{v+V}{2v} \end{aligned}$$

Running after collision (prob = $\frac{v-V}{2v}$) gives energy gain $M(-2vV + 2V^2)$

Average gain order

$$Mv^2$$

Relativistic: order

$$\omega p^2$$

E. Fermi, 1946

Shock acceleration describes spectrum from galactic sources

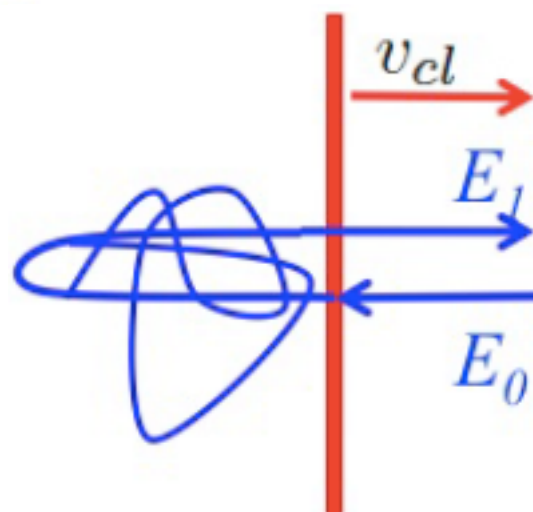
On the Origin of the Cosmic Radiation

ENRICO FERMI

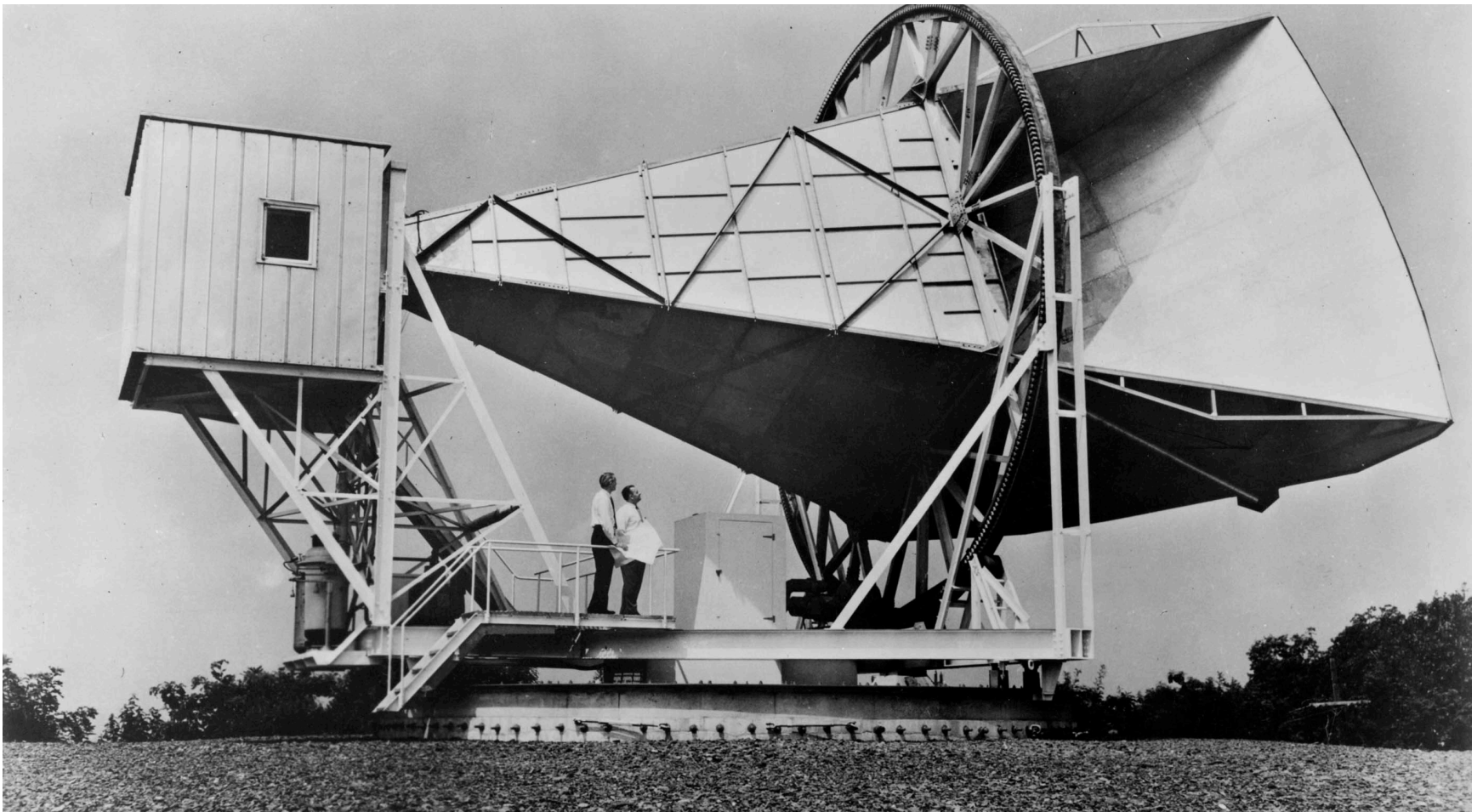
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received January 3, 1949)

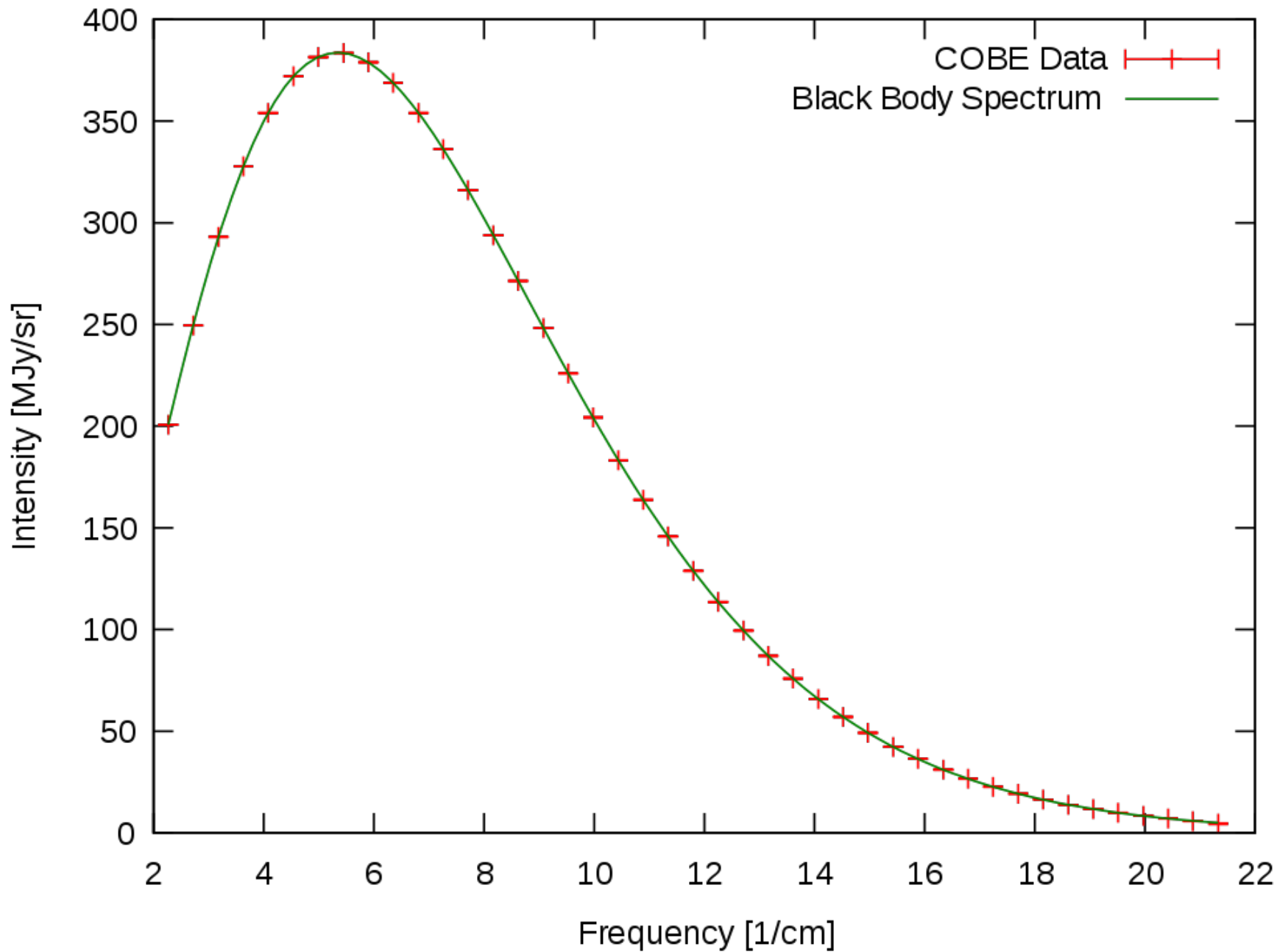
A theory of the origin of cosmic radiation is proposed according to which cosmic rays are originated and accelerated primarily in the interstellar space of the galaxy by collisions against moving magnetic fields. One of the features of the theory is that it yields naturally an inverse power law for the spectral distribution of the cosmic rays. The chief difficulty is that it fails to explain in a straightforward way the heavy nuclei observed in the primary radiation.



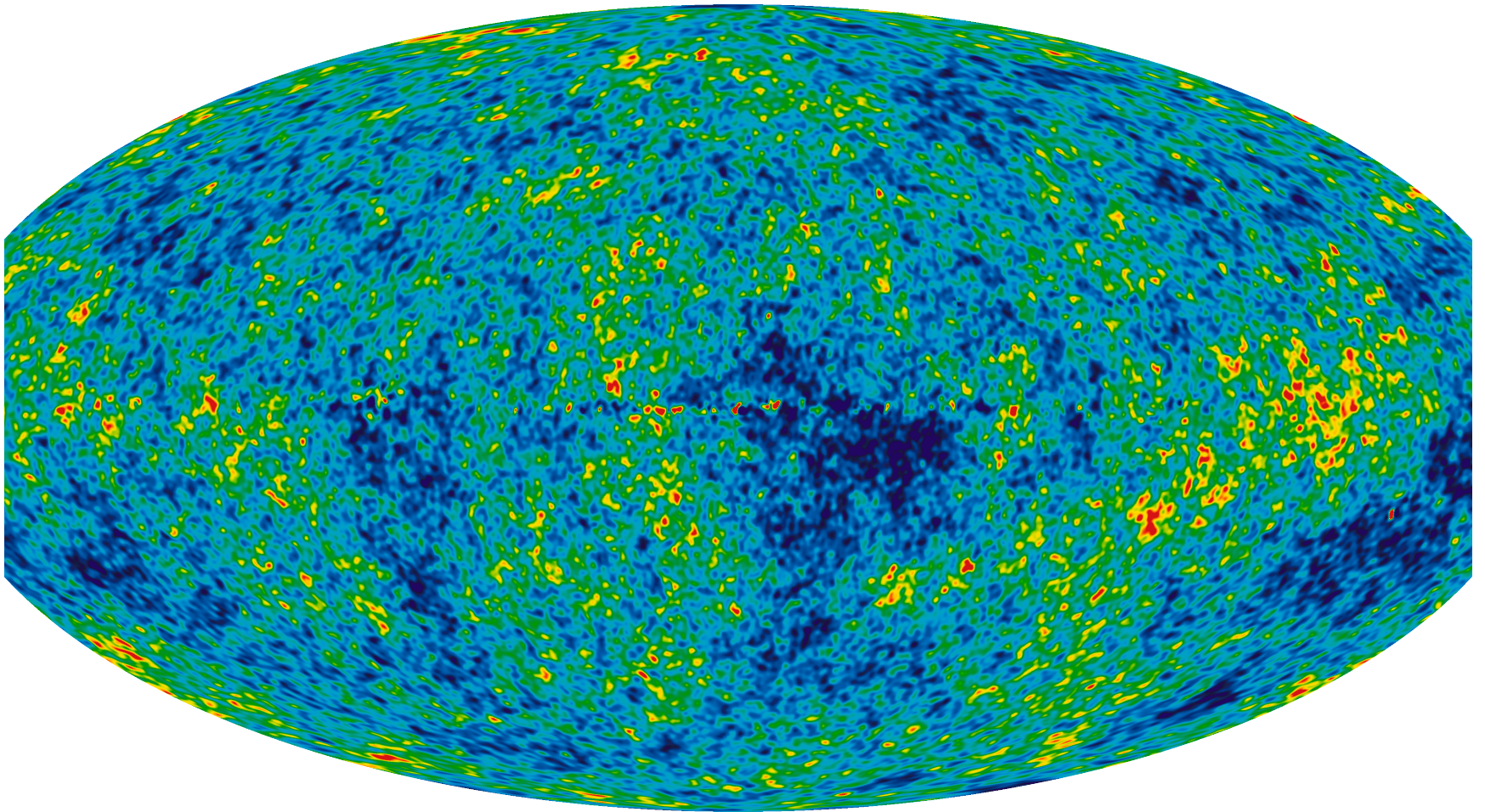
1965: Entdeckung der kosmischen Hintergrundstrahlung durch Penzias und Wilson



(CMB) Cosmic Microwave Background Spectrum from COBE



Today: Measurement of anisotropy of the CMB





Propagation of UHECRs

Greisen-Zatsepin-Kuzmin (GZK) pioneered the field in 1966

END TO THE COSMIC-RAY SPECTRUM?

Kenneth Greisen

Cornell University, Ithaca, New York

(Received 1 April 1966)

One cannot save the day for superhigh-energy cosmic rays by calling on heavy nuclei. The threshold for photodisintegration against photons of 7×10^{-4} eV is only 5×10^{18} eV/nucleon, and at 10^{19} eV/nucleon most of the photons can excite the giant dipole resonance, for which the cross section is on the order of 10^{-25} cm². At this energy the mean

protons & nuclei



G. T. Zatsepin and V. A. Kuz'min

P. N. Lebedev Physics Institute, USSR Academy of Sciences

Submitted 26 May 1966

ZhETF Pis'ma 4, No. 3, 114-117, 1 August 1966

Notice should be taken of the disintegration of α particles and other nuclei [6] as they pass through metagalactic space. This occurs at an α -particle energy somewhat lower than the proton energy at which the pion photoproduction process begins. The rather large cross section of this process should lead to total disappearance of the nuclei from the cosmic rays at energies above 10^{19} eV.

Zazepin & Kusminov (1966)

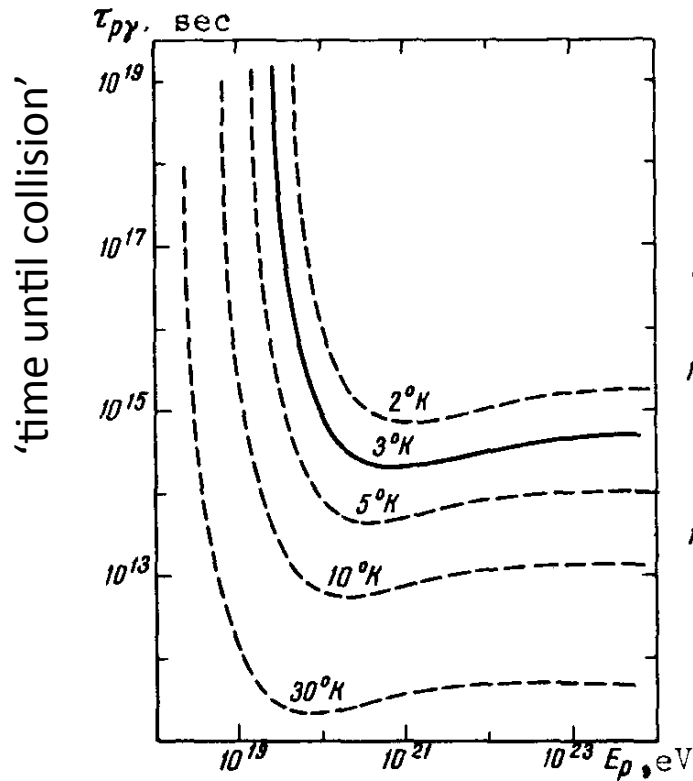


Fig. 1

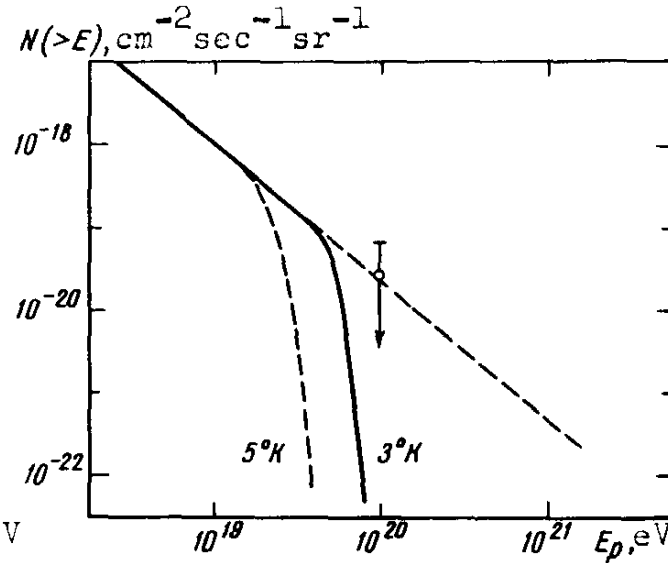
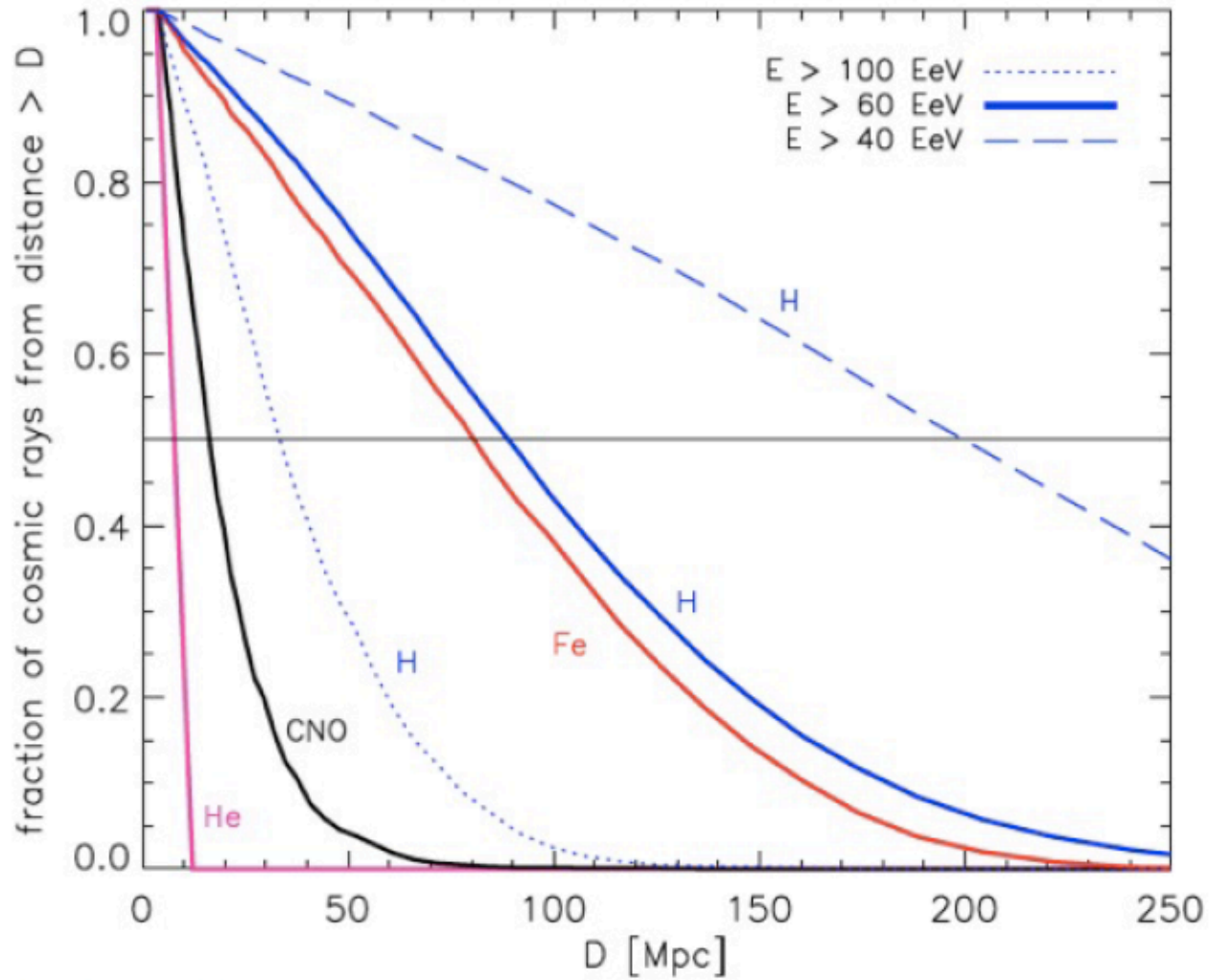
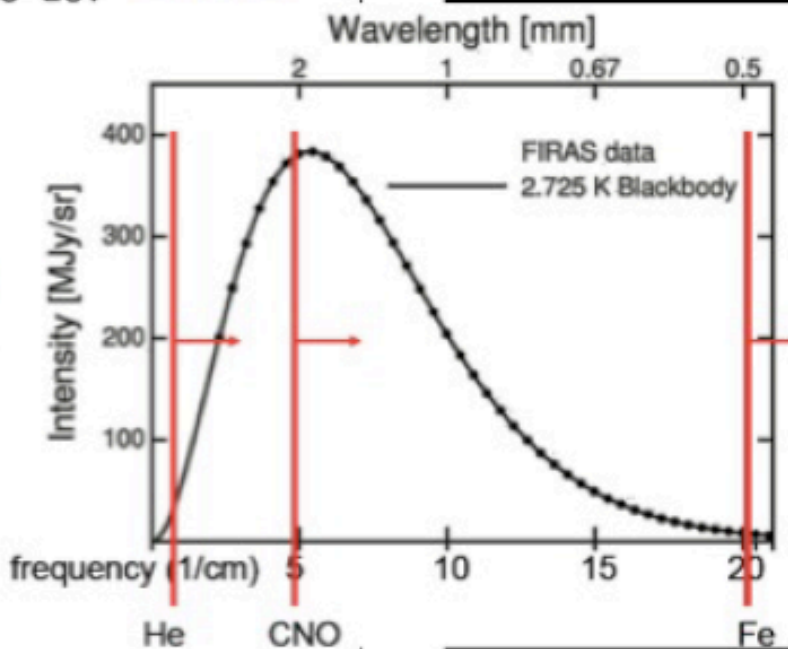
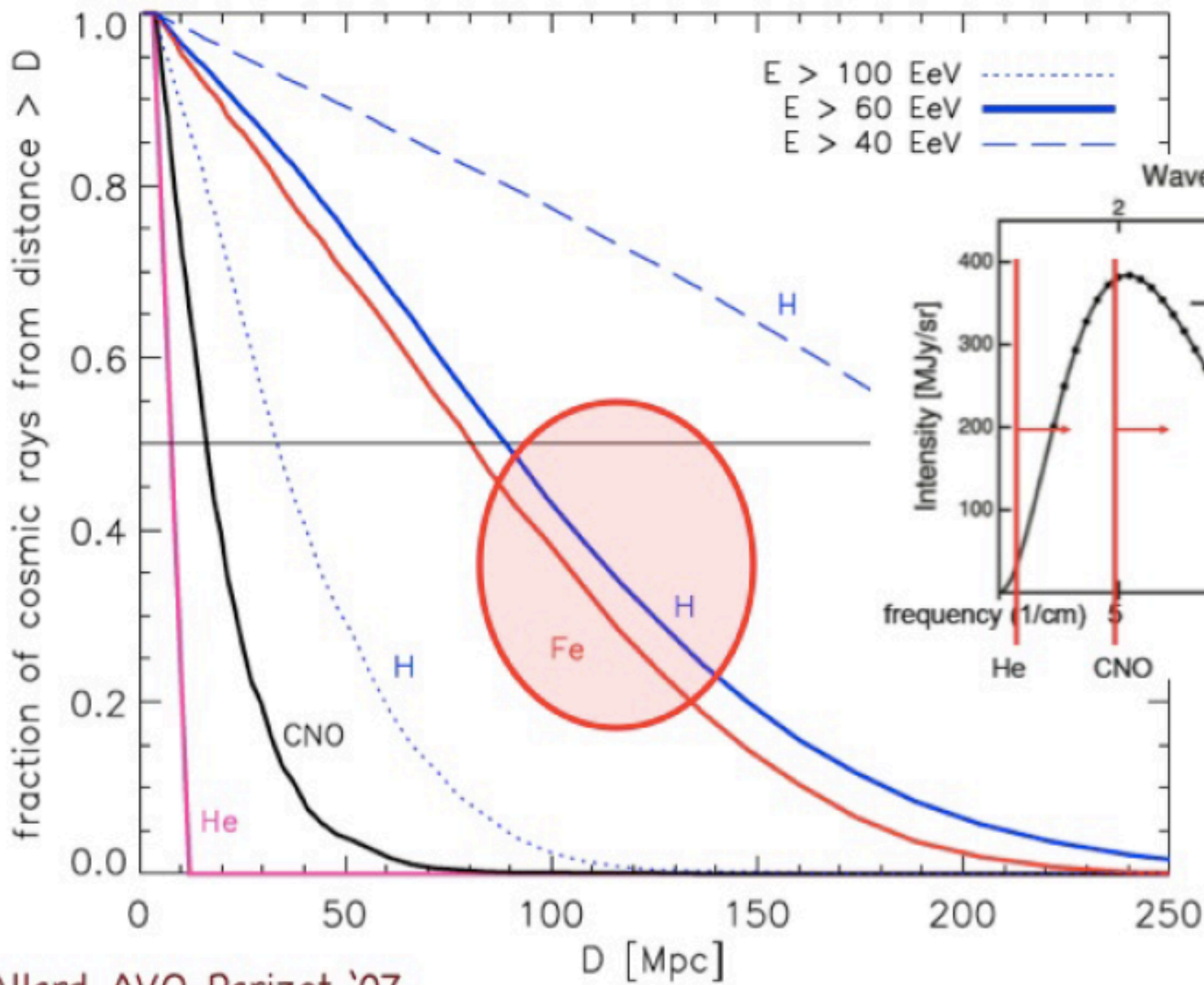


Fig. 2

The values of $\tau_{p\gamma}$ calculated by formula (1) for different proton energies are shown in Fig. 1 for several photon gas temperatures, $T = 2, 3, 5, 10,$ and 30 . We see that at proton energies $E_p \gtrsim 10^{20}$ eV, proton interactions with the photon gas become quite frequent, $\tau_{p\gamma} \approx 10^7$ years. This means that at the age $t \gtrsim 10^8$ of the cosmic rays with energies under consideration, their initial spectrum should be cut off in the high-energy region, even if the acceleration mechanism had been sufficiently effective in producing particles having these

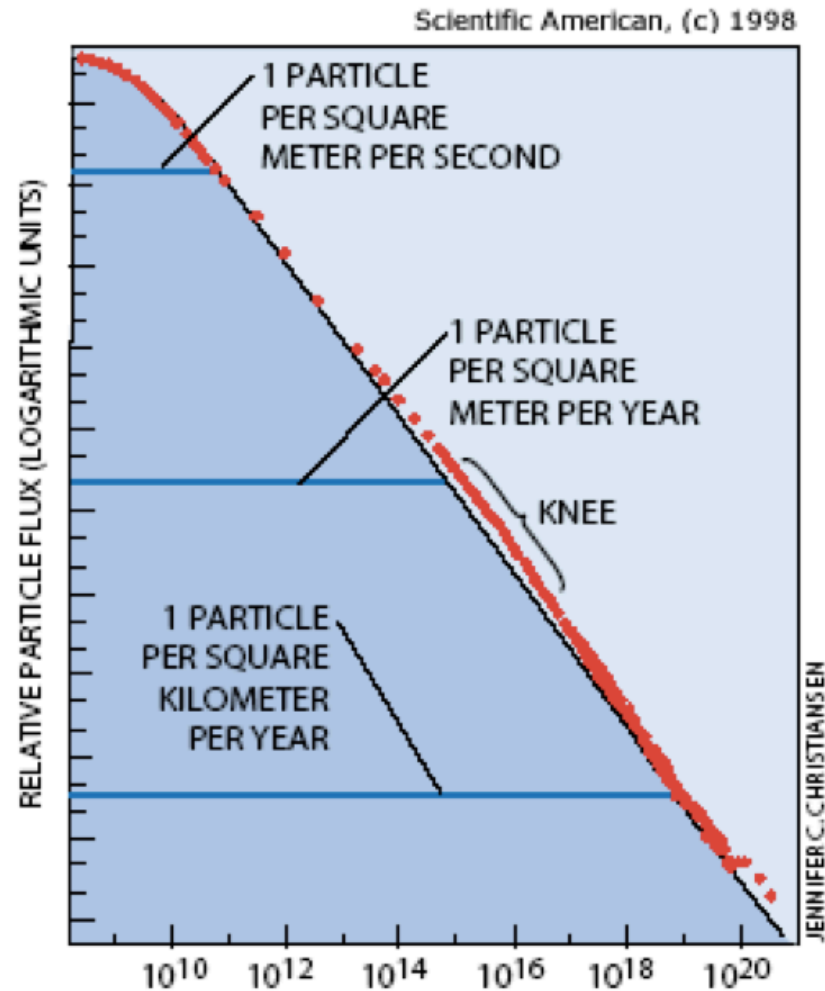
GZK Horizon



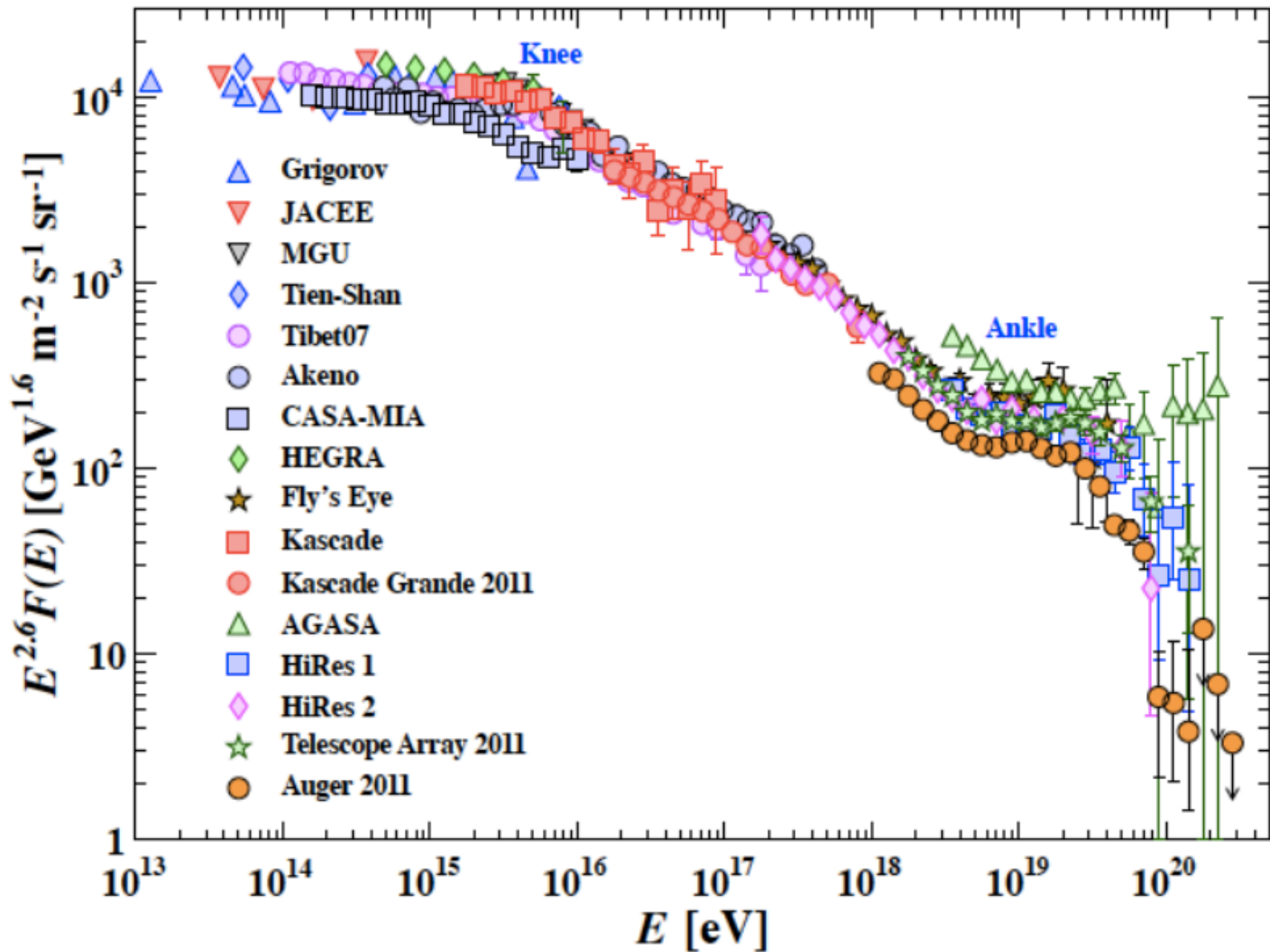


Allard, AVO, Parizot '07

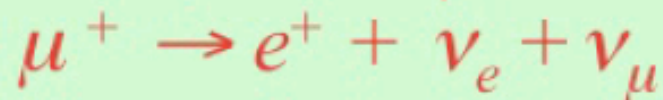
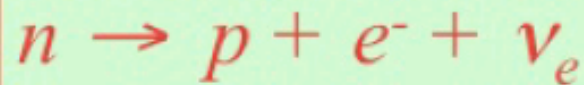
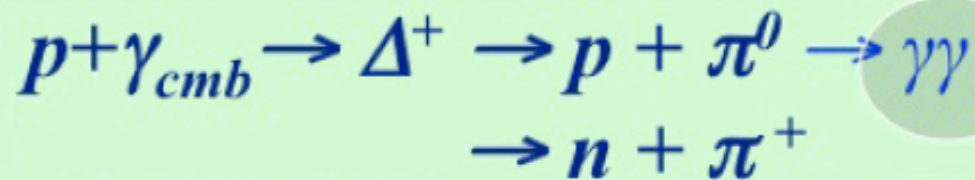
The cosmic ray spectrum



The all-particle energy spectrum of cosmic rays.

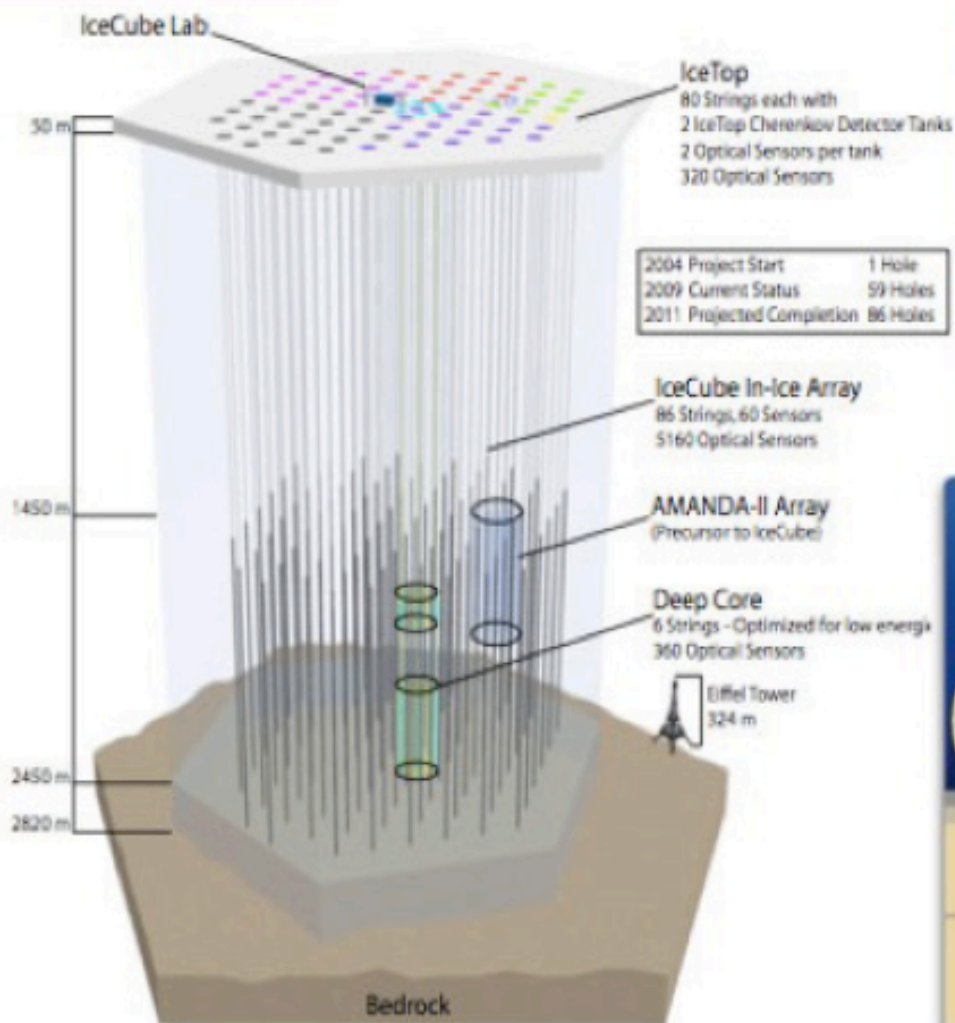


Cosmogenic (GZK) Neutrinos & Photons and UHECR composition



Highest Energy Neutrino Observatories

IceCube



ANITA

