VI: Experimental results

All experiments measure (with different accuracy):

- The primary energy,
- its composition,
- its direction.

All these measurements are indirect due to the very low flux. The first results were made in 1962 (Volcano Ranch) and go on today (Hires, AGASA).

4 experiments lead the way:

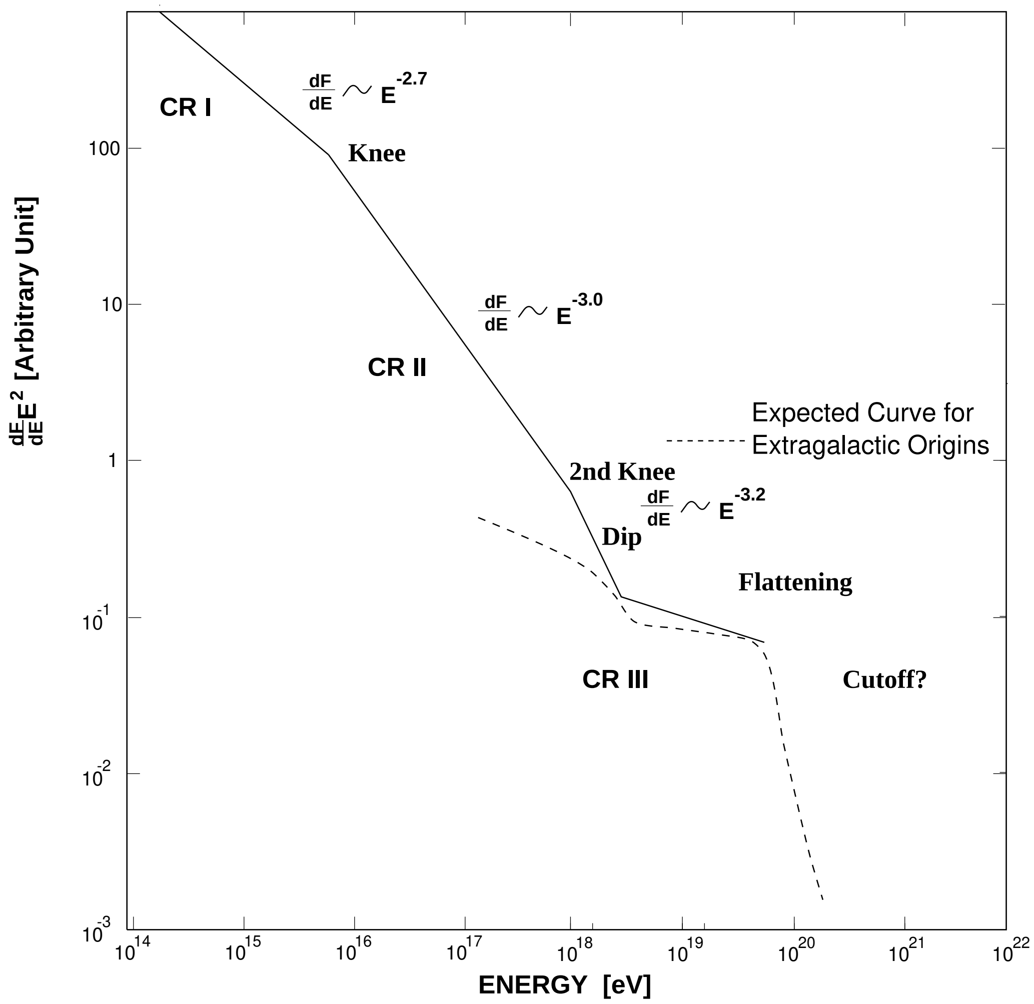
+ Havera Park (Scotland) (1968-1981). Water Čerenkov array of $12\ km^2$. Detector spacing $\sim 500m$. Developed the $\rho(600)$ technique.
+ Yakutz (Russia) (1973-1992-...). Array of 58 scintillators (4 and 2 m^2) covering $20\ km^2$. Detector spacing $\sim 500m$, 5 muon detectors of 20 m^2 and 1 of 192 m^2.
+ AGASA Akeno (Japan) (1991-...). Array of 111 scintillators covering $100\ km^2$. Detector spacing $\sim 1000m$, 27 muon detectors.
+ Fly's Eye (USA) (1981-1986-1995). Fluorescence detector, 880 PM for FE-I and 460 for FE-II. The stereo data gave redundancy and constrained shower development models.

A Fly's Eye detector

AKENO

Data

Energy spectrum structures:

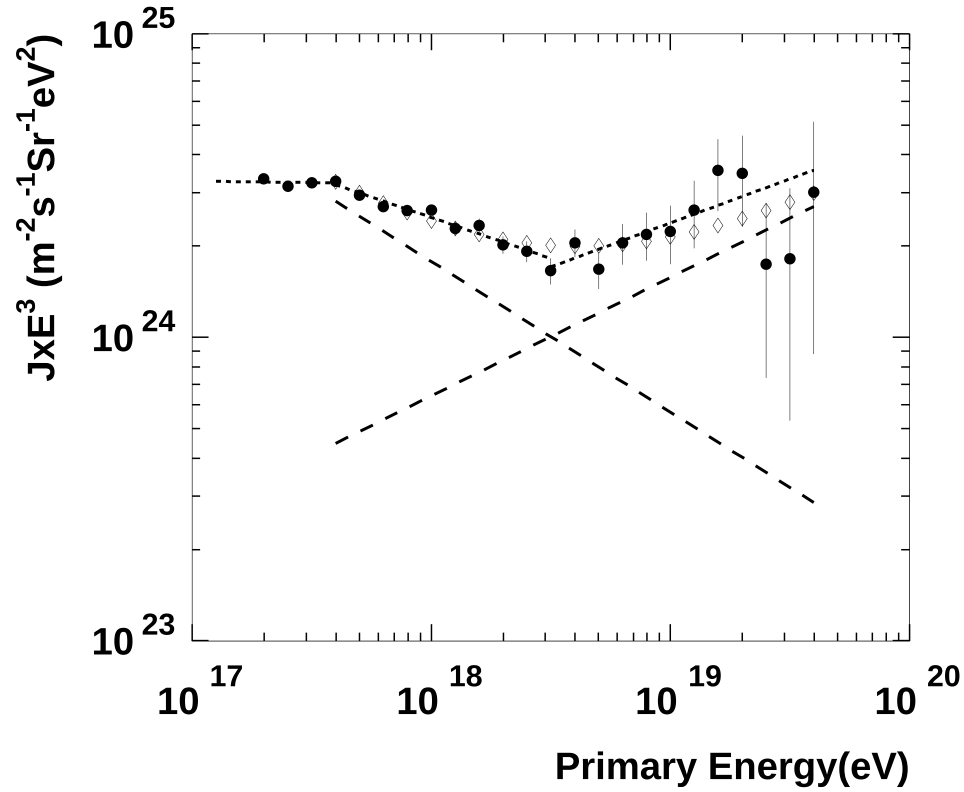


+ Knee at $3 \times 10^{15}\ eV$. Index : $E^{-2.7} \longrightarrow E^{-3.0}$
+ Knee at $\sim 10^{17}\ eV$. Index : $E^{-3.0} \longrightarrow E^{-3.2}$
+ Ankle at $\sim 10^{19}\ eV$. Index : $E^{-3.2} \longrightarrow E^{-2.7}$

The Ankle is the only point in the spectrum where the slope decreases.

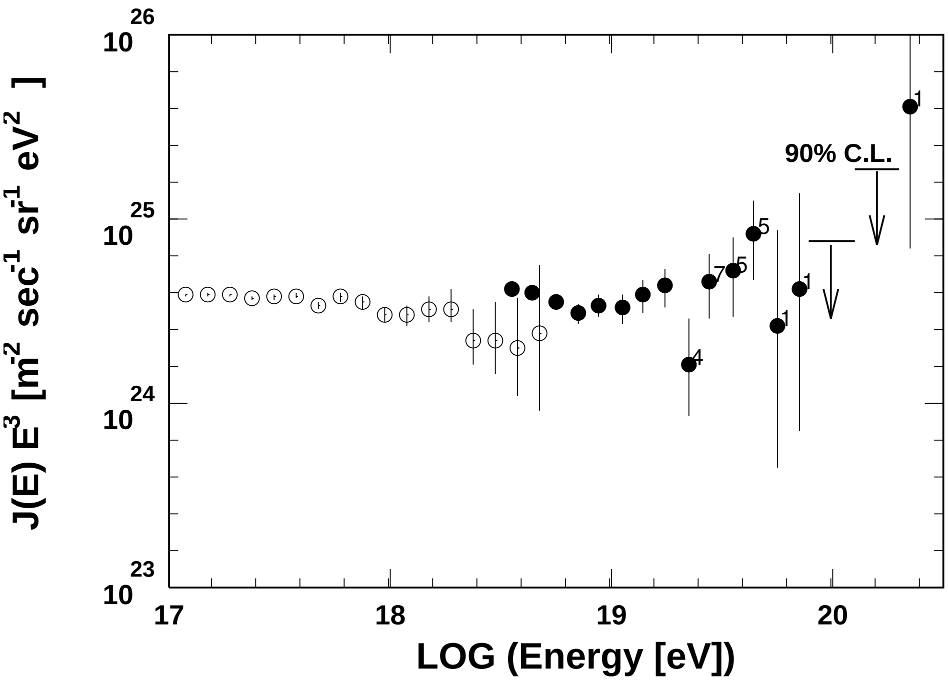
This index change creates a dip.

Fly's Eye data :



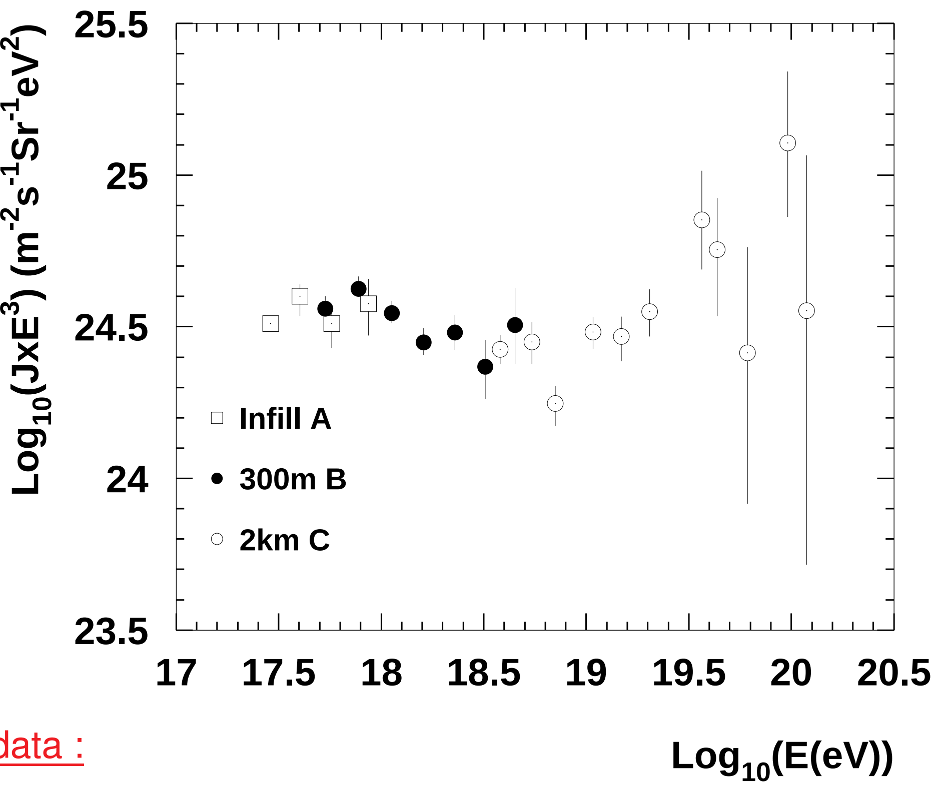
Dip at $10^{18.5}$eV, 6σ.

AGASA data:

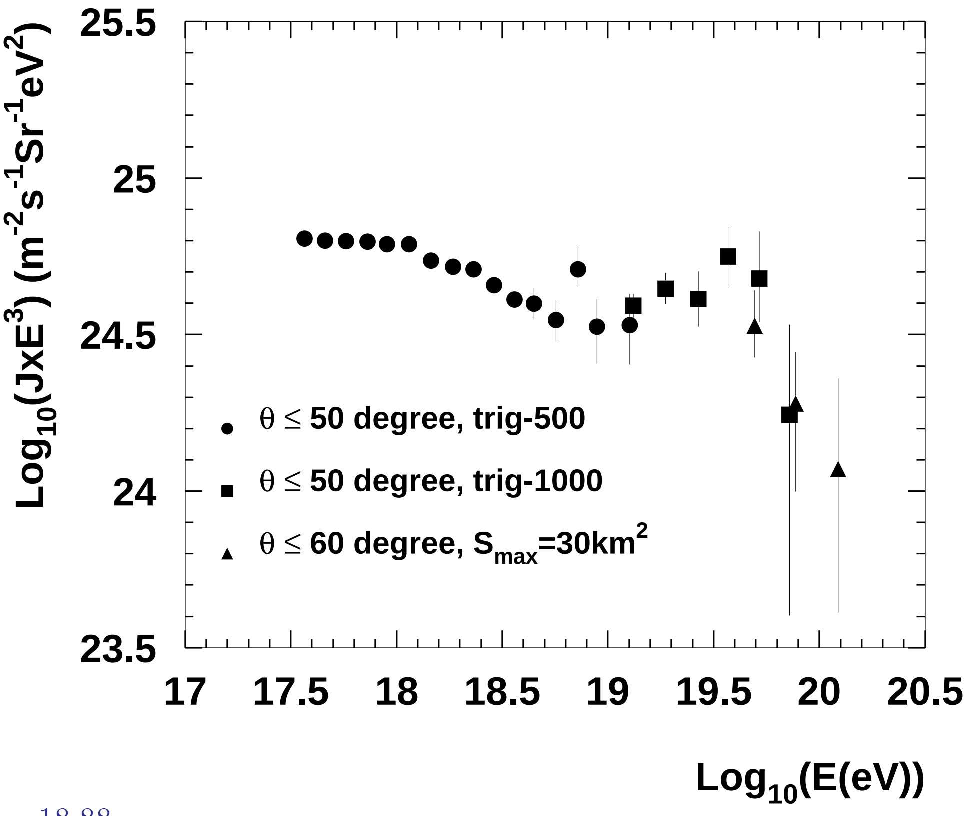


Dip at $10^{18.8}$eV, 3.2σ.

Havera Park data :



Yakutz data :



Dip at $10^{18.88}$eV, 8σ.

N.B. :normalization difference (ref FE) $\times 2.5$

Interpretation

The Fly's eye group proposed to describe the observation with a two component spectrum.

- Below 10^{19}eV a component with index -3.5 of galactic origin
- Above 10^{19}eV a component with index -2.6 of extra-galactic origin

Composition consequences :

At 10^{18}eV the Larmor radius of protons is $\sim 0.3\ kpc$, about the galactic disk thickness. $\Rightarrow$ the first component must be "heavy".

At 10^{20}eV nuclei photo-desintegrates $\Rightarrow$ the second component must be "light".

If nucleons are dominant in the second component one must observe the GZK cutoff (with eventually only gamma above 10^{20}eV).

Consequences on anisotropy :

Below 10^{18}eV not visible on heavy elements, but eventually visible between 10^{18}eV and 10^{19}eV.

Above 10^{19}eV anisotropy depends on the source distribution and on their nature (cf. section III).

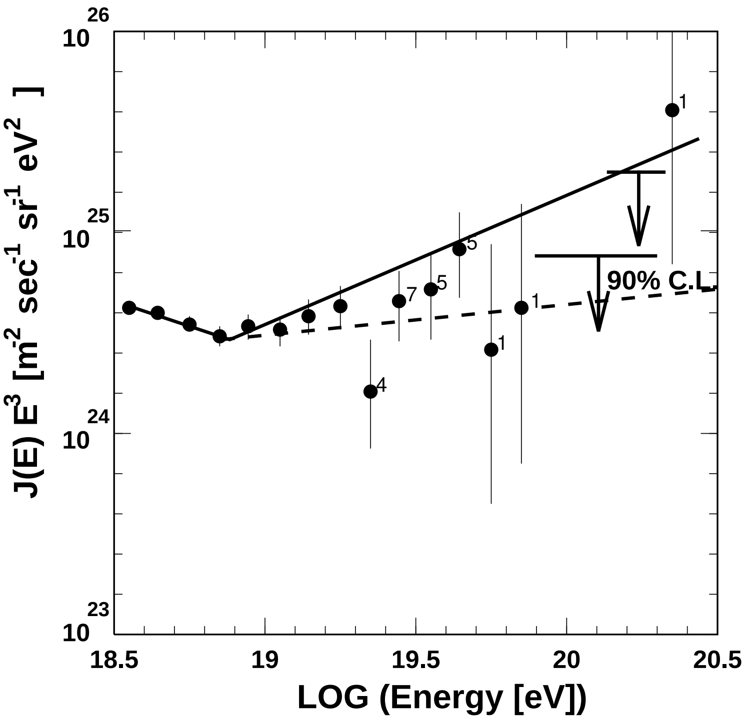
Searching for GZK

Difficult today due to the lack of statistics.

Strategy :

Predict the number of events above 10^{20}eV and compare to observations.

But predictions depend on observations below 10^{20}eV...

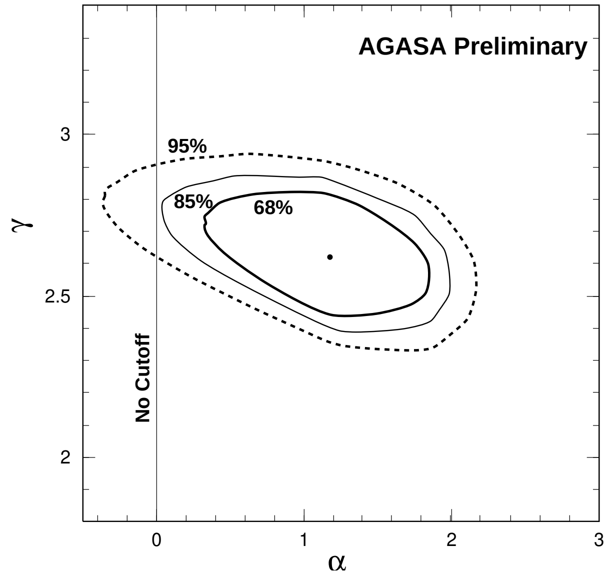


Which extrapolation to choose? Where to put the line between observation and prediction?

AGASA : likelihood analysis from :

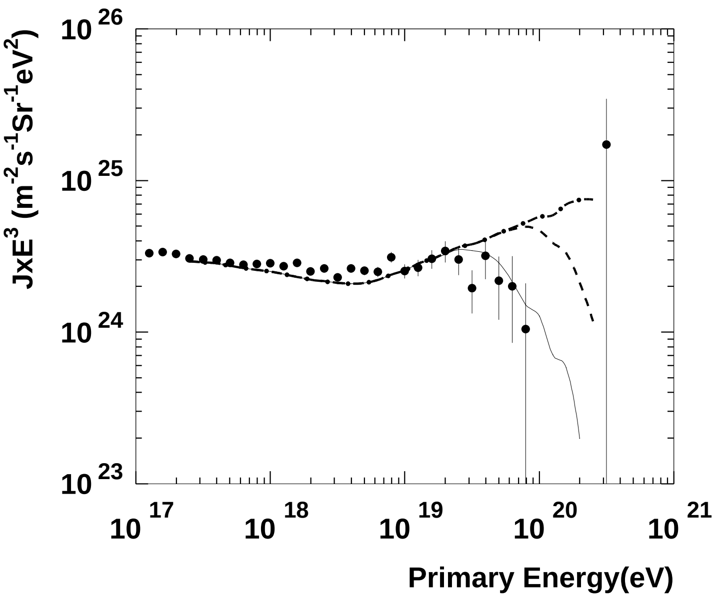
$$\frac{dN}{dE} = k \times E^{-\gamma}\left[1 + \alpha f_c(E)\right] \text{ où } f_c(E) = e^{-E_c/E}(E_c/E - 1)$$

f_c represents the cutoff effects and α represents its influence on the total spectrum.



$P(\alpha \leq 0) \simeq 15\%$ thus the cutoff likelihood is 85%.

Fly's Eye : stereo/mono analysis :



N.B. : 9 (+7 Hires) events above 10^{20}eV with 3 (+?) above 90% of confidence. New population?

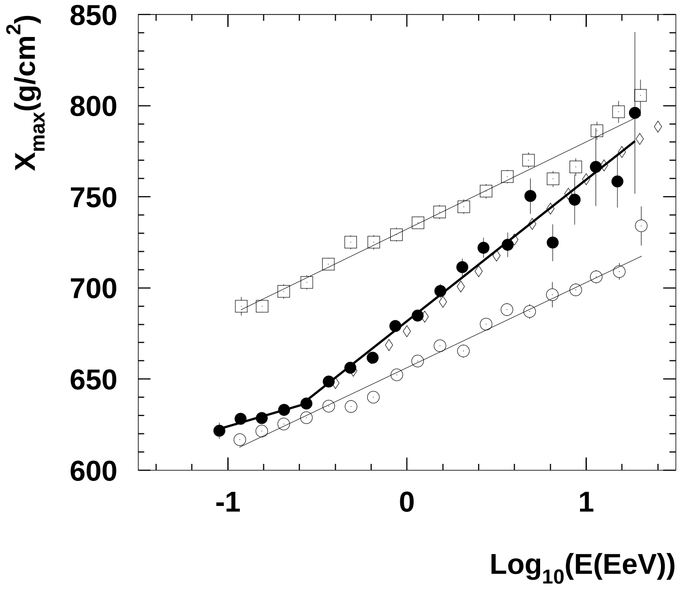
Composition

Fly's Eye : predict the evolution of X_{max} as a function of E and of the primary mass from a Monte Carlo. (QCD Pomeron Model, KNP).

Experimentally both $< X_{max}(E) >$ and the elongation rate ($\delta < X_{max}(E) > / \delta E$) are measured :

- at 3x10^{17}eV $< X_{max} >$ is small : 630 g
- the elongation is large : 80 g per decade of energy

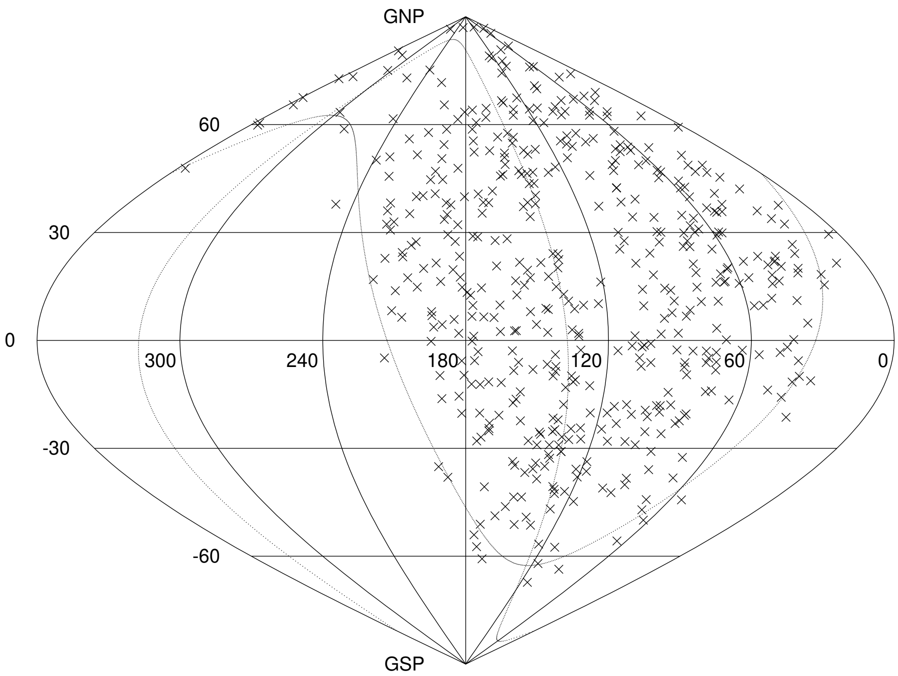
$\Longrightarrow$ composition goes from "heavy" to "light"



Those results were confirmed by the Yakutz data and more recently (after some interaction model studies) by AGASA.

Anisotropy

Again results on anisotropy are only partial due to lack of statistics. However, below 10^{19}eV, all observation are perfectly compatible with a uniform distribution.



Remark :

The statistical significance of the observed clusters above $10^{19.5}$eV depends on the angular distance below which events are considered as a pair. (2.9% for $\delta\theta \sim 2.5^o$)