Upper Limit of the Spectrum of Cosmic Rays

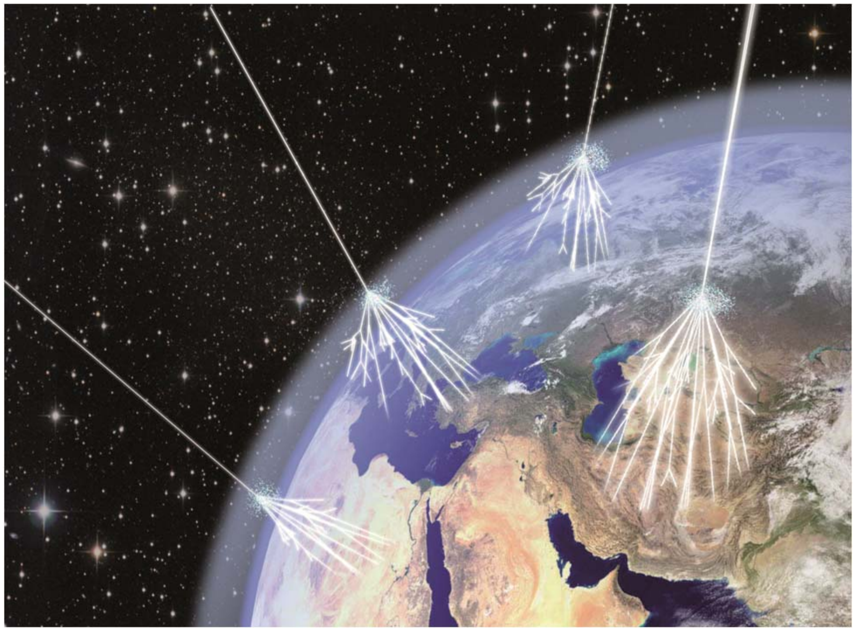
David Fraebel, Cristian Gaidau, Allycia Gariepy, Rita Garrido Menacho

Friday 22.11.2013

G.T. Zatsepin and V.A. Kuzmin 1966, *JETP Let.* 4, p.78

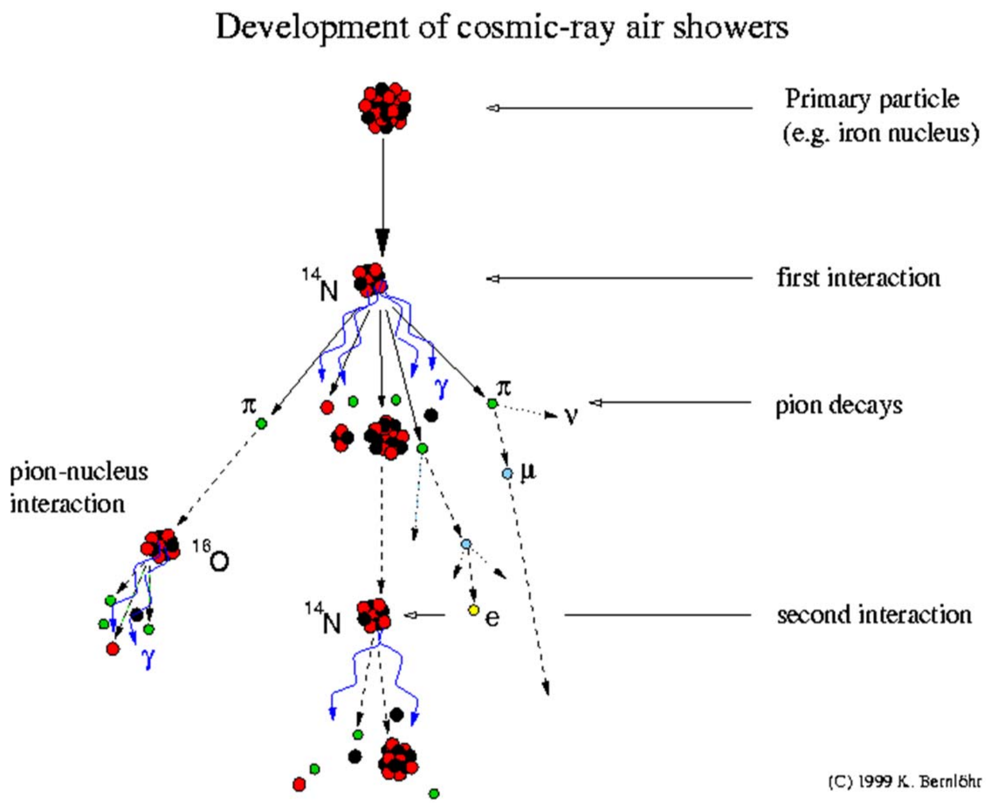
Outline

- Motivation
- Background
- Historical Prelude
- Methods and Results
- Critique and Citations
- Summary



Why should we care about cosmic rays?

- They have higher energy scales than in accelerators
- They can give a better understanding of background in HEP experiments
- They provide insight into cosmic/galactic structures



Cosmic Rays: History

- Pre-1920: Wulf (Eiffel Tower), Hess (balloon at 5.3km in eclipse) and Kolhorster (balloon at 9km) all find increasing ionizing radiation with increasing elevation
- 1921: Millikan is first to call them “cosmic rays”
- 1927: Clay determines primary cosmic rays must be charged particles (geomagnetic deflection) [1]
- 1929: Bothe and Kolhorster use coincidence detection, confirm they are charged particles [2]
- 1930-1945: Various experiments point to protons as cosmic rays

[1] J. Clay 1927, Acad. Amsterdam Proc. 30, p.633
[2] W. Bothe and W. Kolhorster 1929, Zeischrift fur Physik 56, p.751

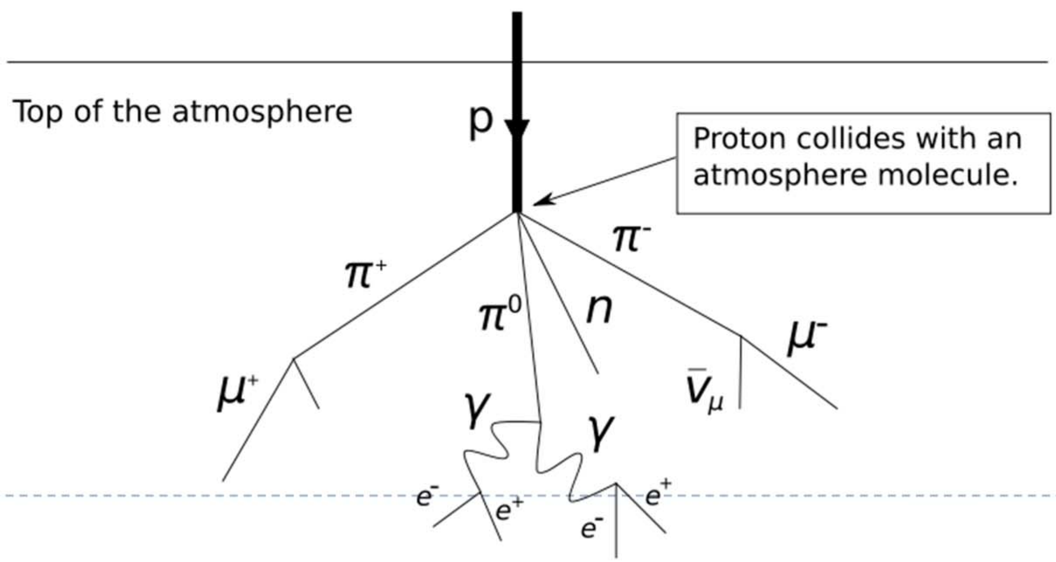
Historical Background (cont.)

- 1951: Zatsepin discovers that cosmic ray protons can interact with a photon gas [1]
- 1963: Hayakawa and Yamamoto calculate the proton's energy loss in such events [2]
- 1965: Dicke *et al.* predict the cosmic microwave background,[3] Penzias and Wilson serendipitously discover it [4]
- 1966: Zatsepin and Kuzmin propose upper energy limit [5], Greisen gets similar result independently [6]

[1] G.T. Zatsepin 1951, *DAN SSSR* 80, p.577
[2] S. Hayakawa and Y. Yamamoto 1963, *Progr. Theor. Phys.* 30, p.71
[3] R.H. Dicke et. al. 1965, *Astrophys J.*, 142, p.414
[4] A.A. Penzias and R.W. Wilson 1965, *Astrophys. J.* 142, p.419
[5] G.T. Zatsepin and V.A. Kuzmin 1966, *JETP Let.* 4, p.78
[6] K. Greisen 1966, *Phys. Rev. Let.* 16, p.748

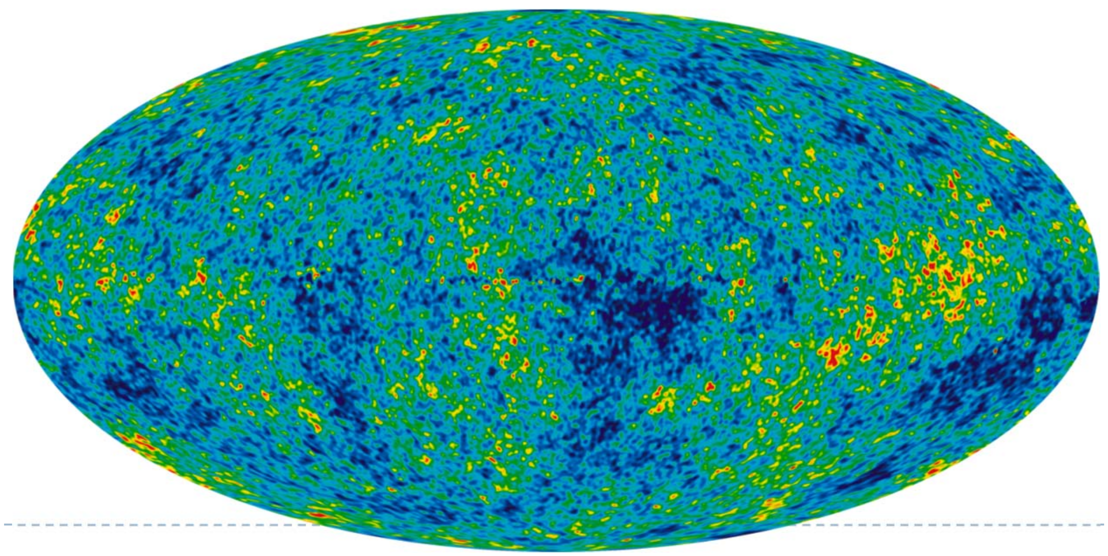
Cosmic Rays: What are they?

- Not actually radiation, but were named by Robert Millikan as such because he believed they were high-energy photons
- Primarily (~99%) hydrogen and helium nuclei (protons and alpha particles), with some (~1%) heavier elements such as lithium, beryllium and boron
- Primary cosmic rays decay into a shower of (secondary) daughter particles once they enter the atmosphere



Cosmic Microwave Background (CMB)

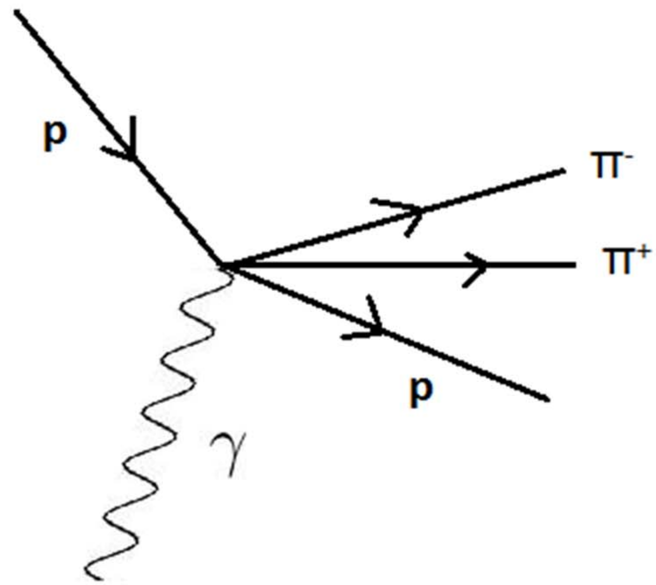
- In 1964, radio astronomers Penzias and Wilson kept detecting background noise in their instrument
- These and other measurements of the CMB have determined that it is isotropic and indicative of a blackbody spectrum at ~3 K, which is consistent with the predictions of Dicke *et al.* about the Big Bang



Secondary particles are produced in proton-photon collisions

If the incoming particle is sufficiently energetic, pions can be produced in such collisions. The threshold proton energy is given by:

$$E_p \sim \frac{M_p c^2 M_\pi c^2}{E_\gamma} \sim 10^{20} eV$$

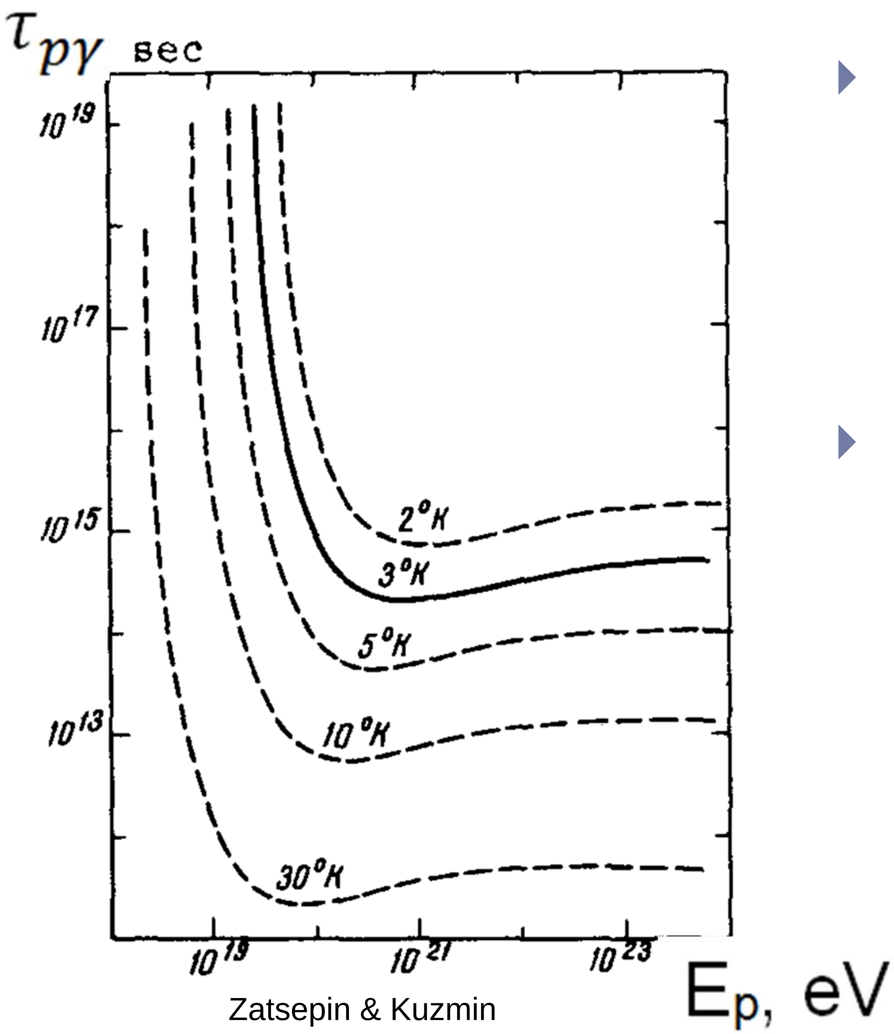


M_p, M_π – proton and pion mass

E_γ- photon energy

- The proton loses on average 20% of its initial energy.

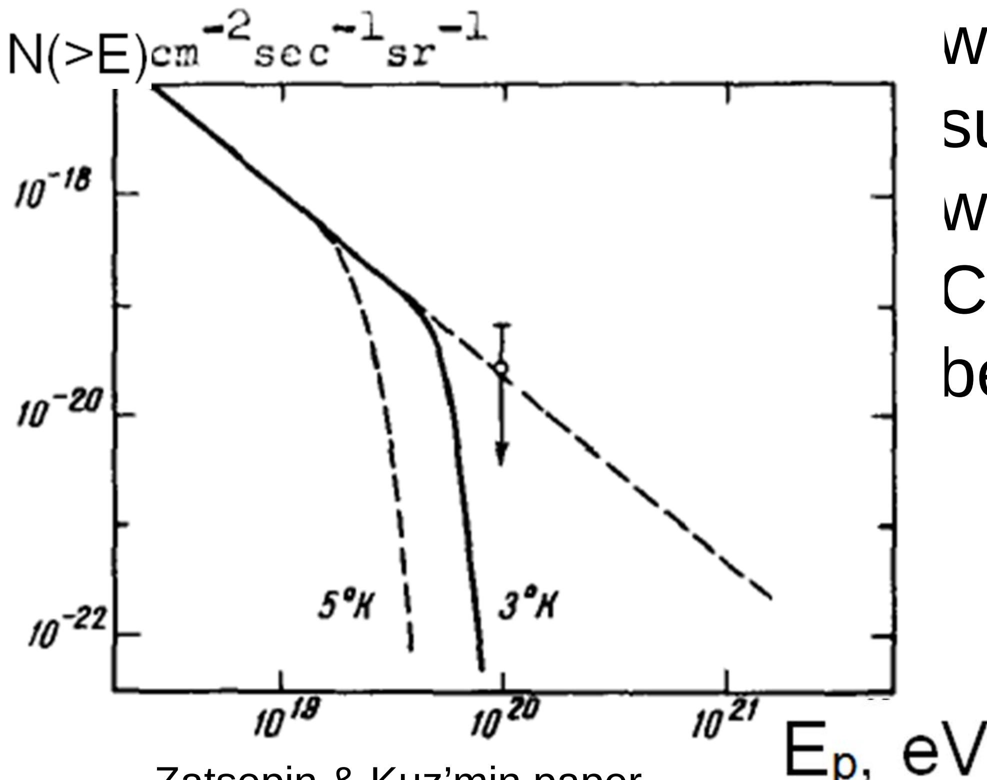
Proton-Photon Collision Time is a minimum for proton energies on the scale of 10^{20} eV



Zatsepin & Kuzmin paper

- Proton travelling through an isotropic photon sea (550 photons/cm^3 at T = 3 K, Planckian distribution).
- Can associate a mean free path, or characteristic time between collisions. For a 10^{20} eV proton this corresponds to 10^7 years.

Greisen-Zatsepin-Kuzmin predicts suppression of cosmic rays above 10^{20} eV



Zatsepin & Kuz'min paper

- If a cosmic ray is produced with energy above 10^{20} eV, sufficiently far way, then it will pair produce against the CMB, until its energy is below 10^{20} eV.

What has happened since?

- The paper has been cited 2833 times according to Google Scholar
- In 1966 the Greisen–Zatsepin-Kuzmin (GZK) limit for cosmic ray energies was proposed at 10^{20} eV
- In 1967 the Haverah Park cosmic ray detector in England began operation
- In 1991 the Fly's Eye cosmic ray research group in the US detected the highest energy cosmic ray event to date at 3×10^{20} eV
- In 1994 the Akeno Giant Air Shower Array (AGASA) in Japan detected a high energy cosmic ray at 2×10^{20} eV

Haverah Park Cherenkov detector

Fly's Eye detector

AGASA in Japan

What has happened since (cont.)

- In 1995 the Pierre Auger cosmic ray observatory project begins
- In 2007 the Pierre Auger project announced that active galactic nuclei are the possible origin of the highest energy cosmic rays
- In 2008 the southern site of the Pierre Auger observatory in Malargue, Argentina was inaugurated

Above: Pierre Auger observatory is a hybrid observatory using both fluorescence detectors and surface detectors.

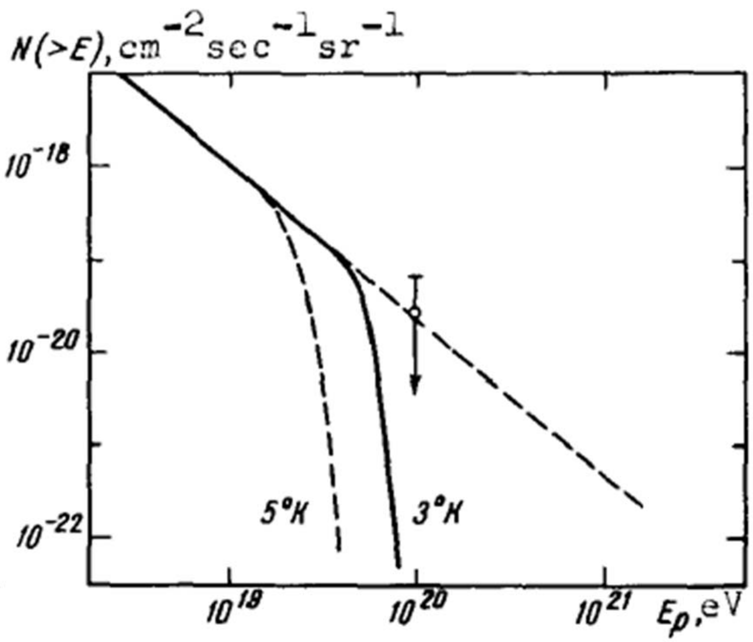
Right: Active galactic nuclei as the source for the highest energy cosmic rays

Critiques

- Simple idea with far reaching implications
- Compact, accessible (except for one equation)
- Honorable acknowledgement of Greisen's work
- No abstract
- No actual organization into sections

Summary

- Cosmic rays are high-energy protons
- They interact with the CMB and lose energy
- Kuz'min and Zatsepin predicted that the high energy tail of the cosmic ray spectrum should be suppressed



Questions?