Monitoring of the Cosmic Rays Intensity at the Royal Meteorological Institute of Belgium

Danislav Sapundjiev, Stanimir Stankov, Jean-Claude Jodogne

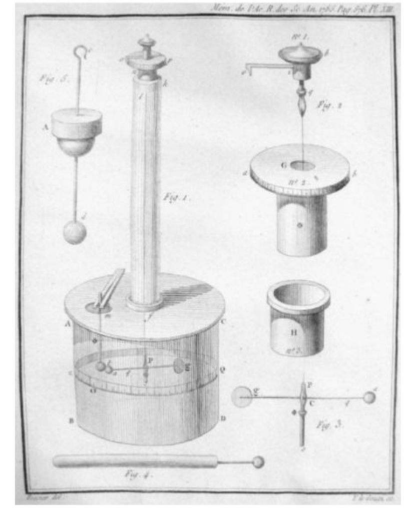
(KMI-IRM)

for the RMI conference on Ionosphere and Space Weather, 04 December 2013, RMI, Brussels

Coulomb's spontaneous self discharge:

1785 *Charles-Augustin de Coulomb* presents three reports on electricity and magnetism to the French Royal Academy of Sciences.

In the third of these reports he describes an experiment showing that **isolated charged bodies discharge spontaneously** without any technical reasons therefore.



Coulomb's torsion balance

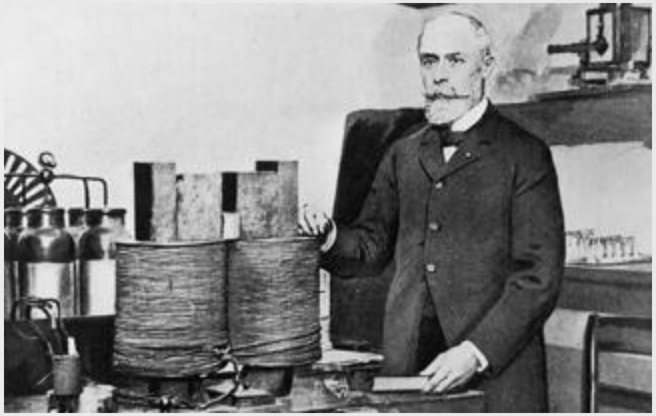
After dedicated studies by *Michael Faraday* around **1835**, *William Crookes* observed in 1879 that the speed of discharge decreased when the pressure was reduced: **the ionization of air was thus the direct cause**. But what was ionizing the air?

The attempts to answer this question paved the road to the discovery of the comic rays.

Discovery of Cosmic Rays

X-rays and Henry Becquerel

Several years later, in **1896,** *Antoine Henri Becquerel* was fascinated by two things: natural fluorescence and the new type of radiation called X-rays.



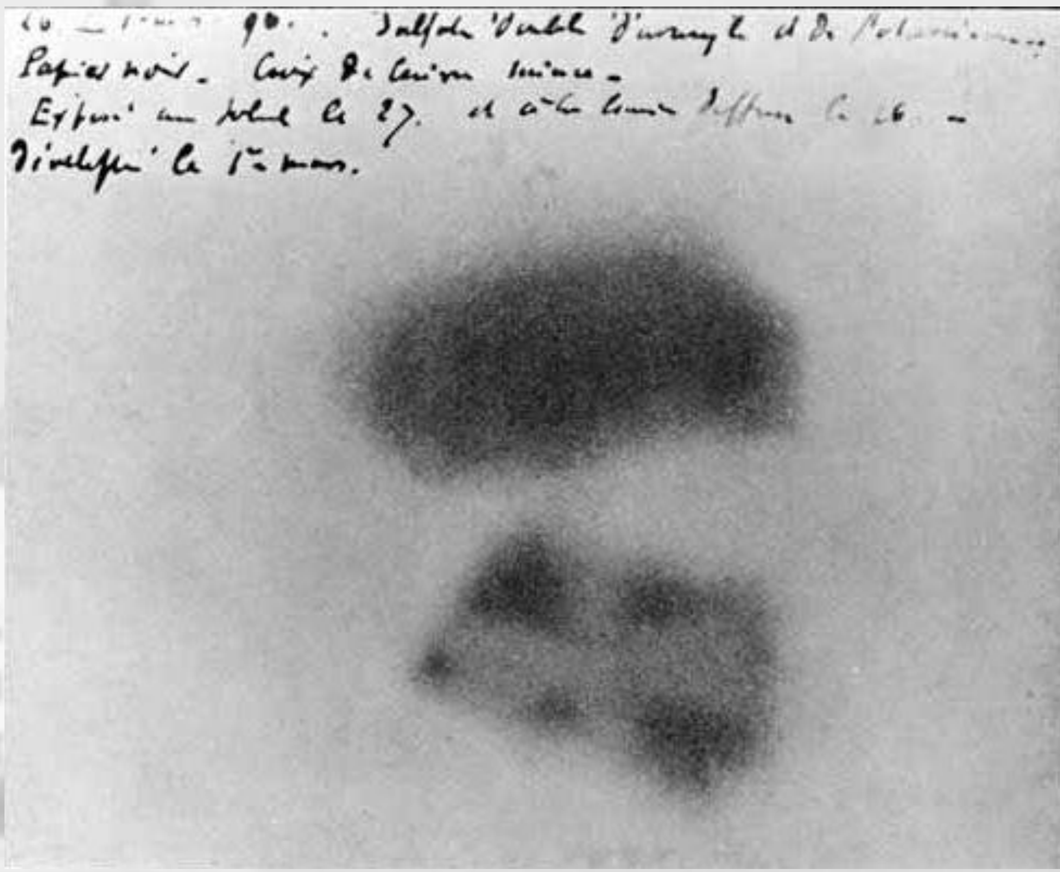
February 26, 1896, an overcast day in Paris — that posed a problem for the French physicist who was hoping **to demonstrate a link between minerals that glow when exposed to strong light and the X-rays**.

Discovery of Cosmic Rays

Radioactivity:

The bad weather spoiled this experiment — Becquerel realized that the uranium rock he had left in the drawer had imprinted itself on the photographic plate without exposure to sun light. There was something very special about that rock.

Working with Marie and Pierre Curie, he made an entirely new discovery: the natural **radioactivity**. His conclusion was that the crystals alone are emitting radiation!



Credit: Henri Becquerel

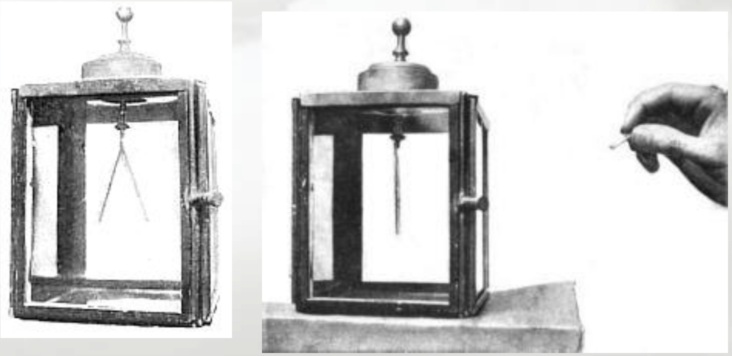
The photographic plate is developed by the radiation coming from the uranium salts; the metal Maltese cross between the ore and the plate was ``clearly photographed''.

Discovery of Cosmic Rays

Radioactivity measurements: The electroscope:

A charged electroscope promptly discharges at the presence of radioactive substances. **The discharge rate of an electroscope can be used to gauge the level of radioactivity**.

A new era of research into discharge physics opened up, this period being strongly influenced by the discoveries of the electron and the ions.



Discharge of an elctroscope in the presence of radioactive material (Duncan 1902)

Improvement of the electroscope (by Julius Elster and Hans Geitel) allowed more accurate measurements of the rate of spontaneous discharge.

They concluded that ionizing **agents were coming from outside the vessel** and that part of this radioactivity was **highly penetrating**: it could ionize the air in an electroscope shielded by metal walls a few centimetres thick

Discovery of Cosmic Rays

The obvious questions concerned the nature of such radiation and whether it was of terrestrial or extra-terrestrial origin.

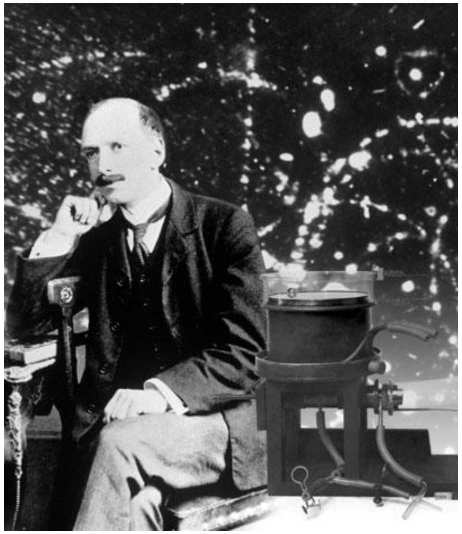
The simplest hypothesis was that its origin was related to radioactive materials in the Earth's crust (NORMs), which were known to exist following the studies by Marie and Pierre Curie on natural radioactivity: Uranium, Thorium, Potassium … Radium, Radon

A terrestrial origin was thus a commonplace assumption – an experimental proof, however, seemed difficult to achieve …

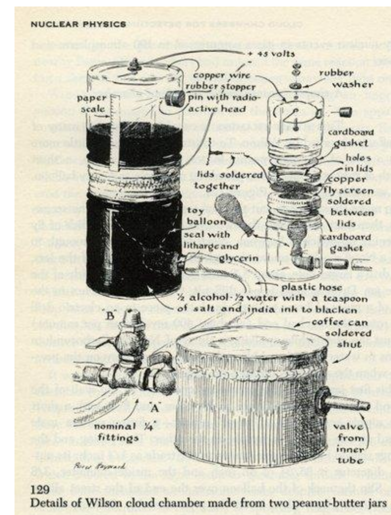
In September 1894, Charles Thomas Rees Wilson, was hiking to the summit of Ben Nevis, the highest mountain in Scotland. He was fascinated by the rainbow-like rings encircling the human shadows in the misty mountain air, called Brocken spectres. He returned to the Cavendish laboratory determined to recreate and study this phenomenon.

http://kerryclimbing.blogspot.be/2011/05/brocken-spectre.html

Wilson’s Cloud Chamber tests:



``Wilson designed a glass tank with a piston tightly inside. He misted the air in the tank with water until it was saturated, then rapidly pulled out the piston. This expanded and chilled the air, causing the water vapour to collect around dust particles and form a small cloud. **As long as the piston was pulled out far enough, clouds would form even if the air inside the chamber was thoroughly filtered. Wilson suspected, but couldn't prove, that the water droplets were forming around electrically charged ions”[*Nature*].**



Roger Hayward, http://scarc.library.oregonstate.edu/omeka/items/show/3226.

1901 Wilsons makes the suggestion that this radiation is an extremely-penetrating **extra-terrestrial radiation** – unfortunately tests in tunnels covered with a solid rock showed no reduction in ionization.

The hypothesis for extraterrestrial origin was left for many years …

credit: Nature

Discovery of Cosmic Rays

The situation in 1909:

The spontaneous discharge observed was explained by the existence of background radiation which is present even in ``isolated’’ environments.

3 possible sources were suggested:

- the Earth’s crust
- the Sun
- the atmosphere

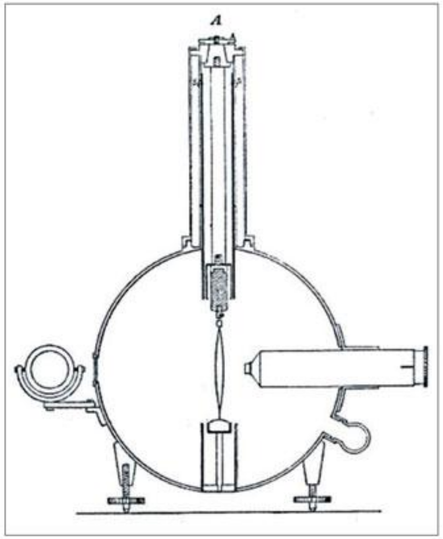
Early balloon experiments:
Ionisation measurements carried out by Karl Kurtz in the lower atmosphere lend the conclusion that radiation from an Extra-Terrestrial Origin(ETO) is not likely and all of the radiation comes from radioactive materials in the crust.

Air attenuation:
Calculations on how much the ground radiation would be **attenuated by height** were made but technological difficulties prevented accurate measurements to verify the calculations.

Discovery of Cosmic Rays

Despite efforts to build a transportable electroscope by the leading meteorological groups (at the time Vienna), the final construction of such instrument was made by Father Theodor Wulf.

In his electroscope the two metal leaves were replaced by two metalized silicon - glass wires. The separation due to charging could be very accurately measured by a microscope. The device was also adapted to measure discharge due to leaks.



(Image credit: left: Archiv der Norddeutschen Provinz SJ, Munich) right: Wulf's electroscope, from his own drawing. (Image credit: T Wulf 1909 *Phys. Zeit.* **1** 152. T. Wulf, "Über die in der Atmosphäre vorhandene Strahlung von hoher Durchdringungsfähigkeit," Phys. Zeit. 10 (1909), 152-157.

Wulf took his device and performed measurements of the inherent radioactivity at various locations: Zermatt, Switzerland (at the shadow of Matterhorn, in chalk mines near Valkenburg and in the caves of Han-sur-Lesse. **For the most part, the measurement showed that the radiation was coming from the ground…**

Discovery of Cosmic Rays

Some intriguing clues suggested otherwise:

- in one of the measurements Wulf placed the electroscope under a meter of water – this resulted in a slight decrease in the ionization loss which suggests that irradiation from above must contribute;
- Gockel and Bergwitz did independent measurements from balloons – the results were however ambiguous – one of them measured very small decrease, while the second large decrease – an ambiguity due to the uncertainty in the height and position of the balloons as well as variations as time of the day and weather …

stability in the measurement conditions was missing!

Fortunately Wulf lived at half a day travel from one of the tallest buildings at this time: the Eiffel Tower (*one of the reasons behind building the tower was possibility for meteorological observations and scientific research)*

Discovery of Cosmic Rays

Datum	Ort	Ionen ccm sec
28. März	Valkenburg	22,5
29. "	Paris, Boden	17,5
30. "	" Eiffelturm	16,2
31. "	" "	14,4
1. April	" "	15,0
2. "	" "	17,2
3. "	" Boden	18,3
4. "	Valkenburg	22,0

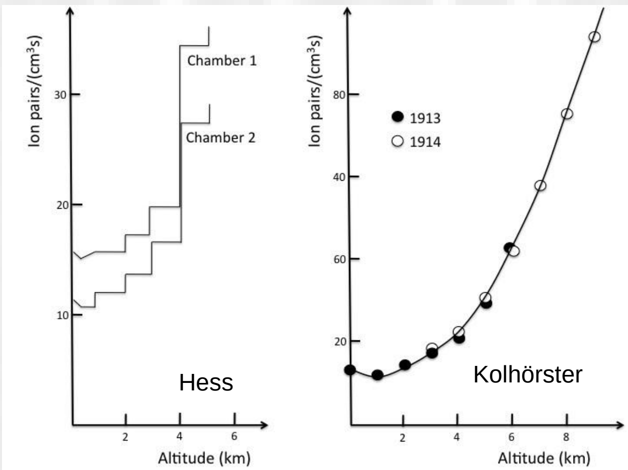
It can be seen that at the top of the tower the radiation rate is slightly lower: At that time, Wulf knew, the radiation from Radium required about 80 m of air to half the intensity ($e^{-h/\lambda}$) . Wulf concluded that **there must be another source of radiation** (gamma-rays?) higher in the atmosphere or a much weaker absorption in the air.

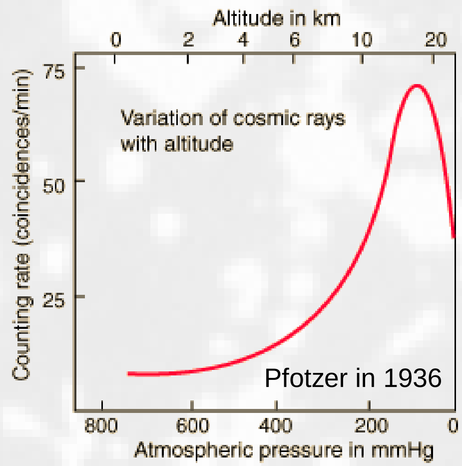
This is how Wulf provided the first evidence for the existence of the extraterrestrial radiation

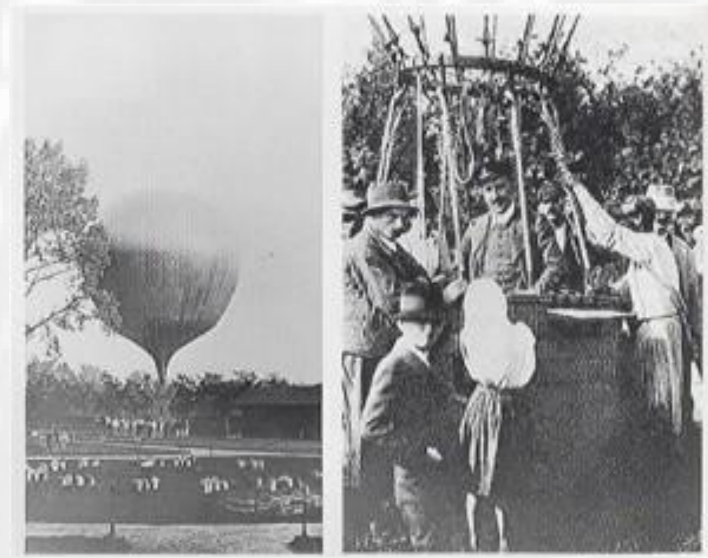
Domenico Pacini simultaneous ground level and marine measurements (under water, on sea surface) between 1906 – 1910 : He received correlated results that could not be explained by radiation originating from the ``soil'': `` a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the crust. '';

Discovery of Cosmic Rays

The situation was resolved in 1911 an 1912 after long series of balloon flights performed by *Victor Hess* during which he found that the radiation intensity increased from 1 kilometer upwards, and was several times the ground level intensity at 5 kilometers high. who confirmed the extra-terrestrial origin of at least part of the radiation causing the observed ionization.

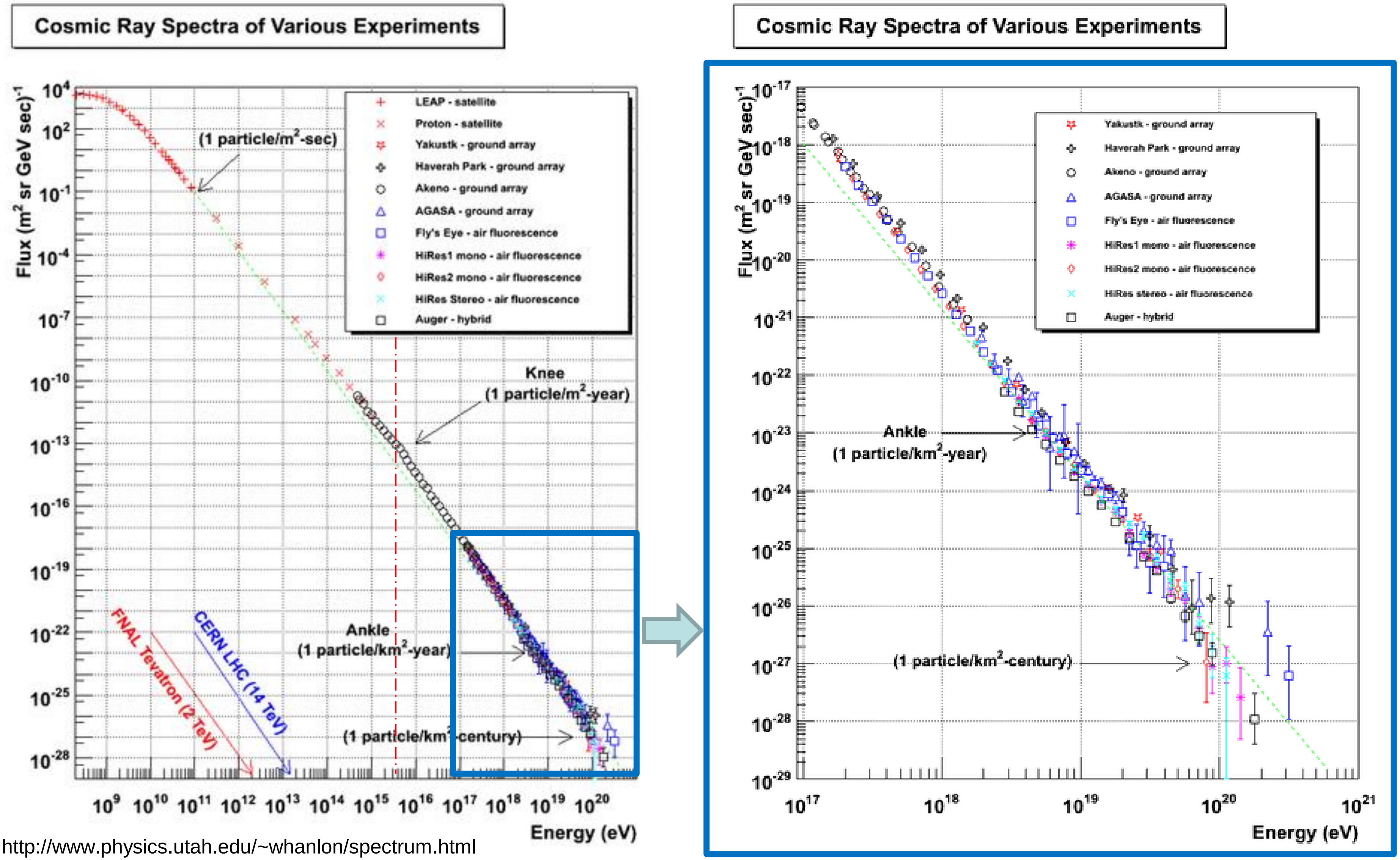






Also, he measured the radiation levels in a balloon during a solar eclipse and found that they did not appreciably decrease; this suggested that the cosmic rays were mostly coming from a source other than the sun.

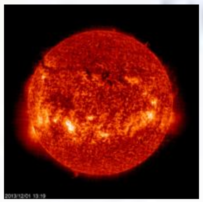
Energy spectrum



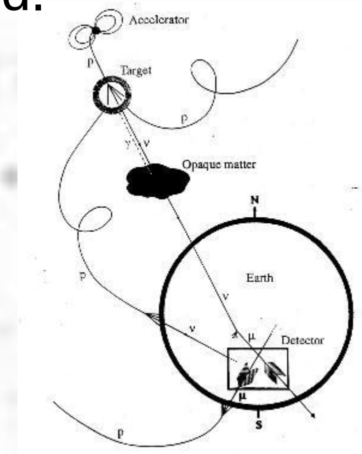
Source: http://www.physics.utah.edu/~whanlon/spectrum.html

Sources of Cosmic Rays:

The exact origins of cosmic rays is still a matter of debate, though the present hypothesis is that they are ejected from supernovas and propelled to high energies by the accompanying shockwave and magnetic field.



SOHO EIT 304



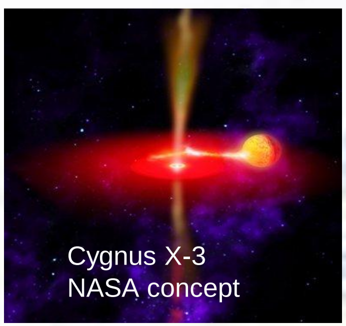
http://www.antarctic-adventures.de/muon1.html

Solar :

-*solar wind* - charged particles escaping from the surface of the sun: *p, e, α, ions (C, N, O, Ne, …) and Solar Proton Events – Solar Cosmic Rays (SCR)*

Galactic and Extra galactic:

Enrico Fermi in 1949 first proposed a way supernova remnants could accelerate protons. Now a widely accepted mechanism. On the other hand, sources like Black Holes, Neutron stars, Pulsars, Supernovae, Active Galactic Nuclei, Quasars, and the Big Bang itself are being considered Galactic Cosmic Rays (GCR)



Cygnus X-3
NASA concept

IC 443, NASA

Composition of the primary cosmic rays(PCR):

89 % are protons (hydrogen nuclei)
9 % alpha particles (ionised He nuclei)
1 % are electrons

0.25 % light nuclei: (Li, Be, B) produced by collisions between the PCR (protons) and carbon, oxygen in the interstellar space; the produced abundance could be resulting from passing of the PCRs through 4 cm of water.

medium elements C, N, O, and F which amounts for 10 times their abundance in the universe and heavier elements with abundance of about 100 times their normal abundance – this suggests that the part of the PCRs originate in regions greatly enriched in heavy elements.

The composition depends also on the energy - at higher energies the ratio is somehow different and the fraction of protons can be as low as 50 %.

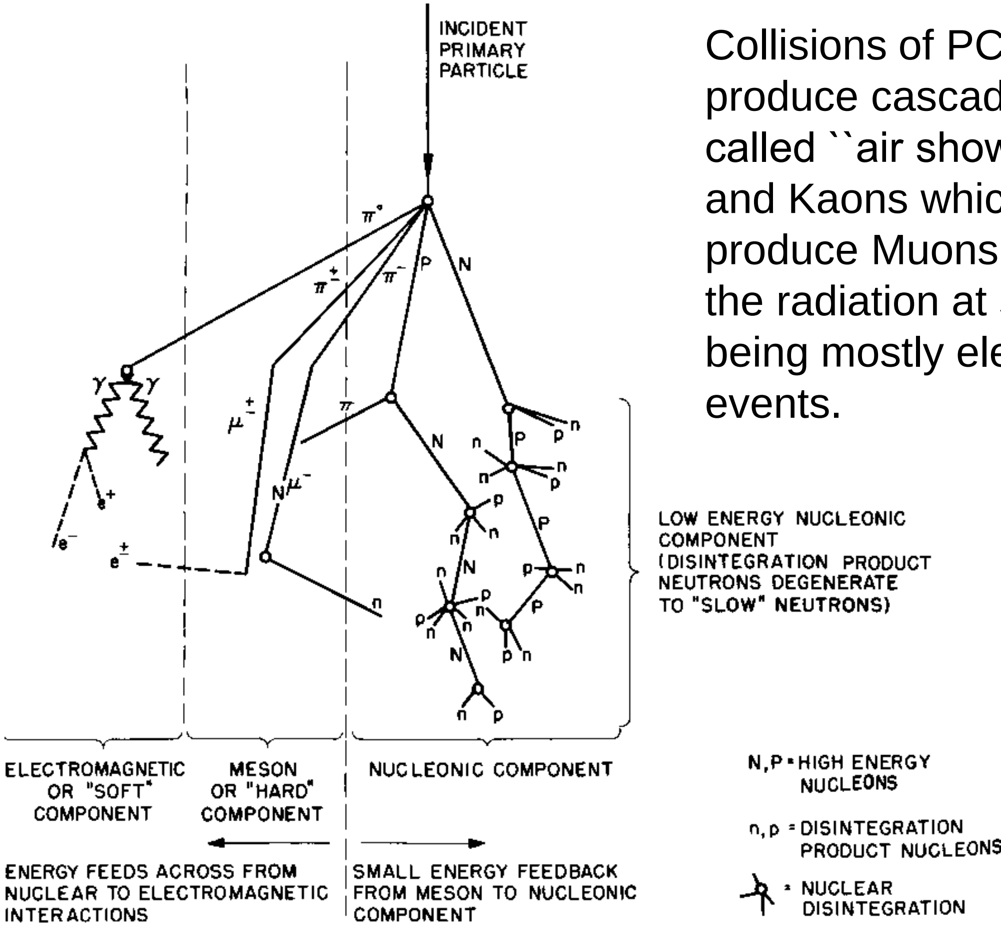
PCR are almost totally composed of matter - anti matter amounts for about 0.01 % in the PCR consistent with the matter-antimatter asymmetry.

picture: http://www.crystalinks.com/antimatter.html

Interaction with the atmosphere

The primary cosmic rays interacts with the atmosphere with the result the production of Great number of secondary particles – from 2 to several thousands of particles and more ...

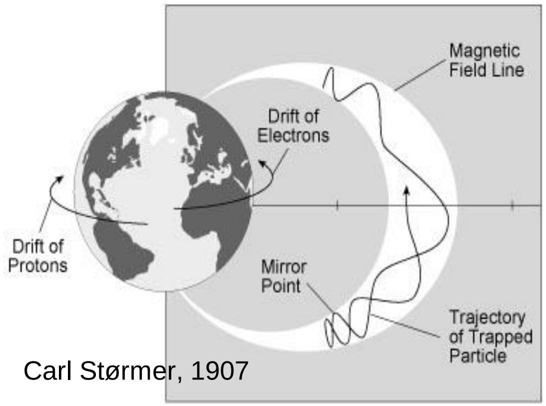
Collisions of PCR particles in the upper atmosphere produce cascades of lighter particles in what is called ``air showers''. The main products are Pions and Kaons which are short lived and decay to produce Muons – accounting for more than half of the radiation at sea level. The remaining particles being mostly electrons and photons from cascade events.



Schematic Diagram of Cosmic Ray Shower

air-showers discoverer - **Bruno Rossi** standing before the a large cloud chamber used by his Cosmic Ray Group at MIT, he is also the founder of the X-ray astronomy, 1954.(credit MIT museum)

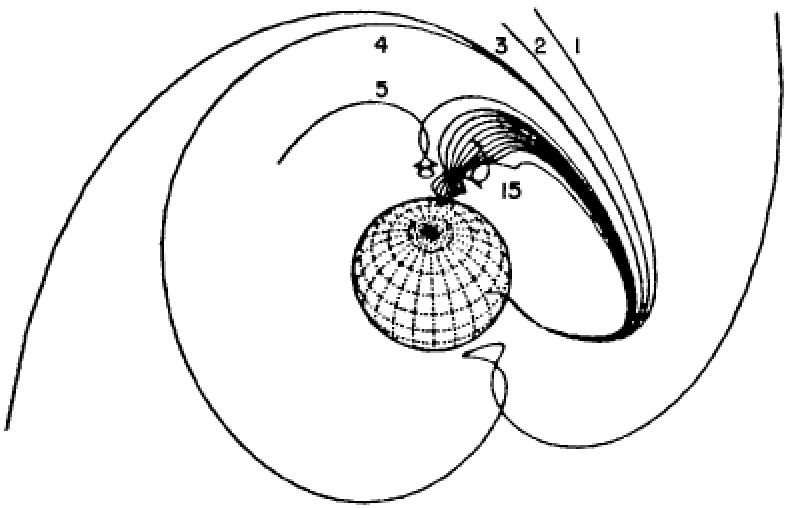
Low energy PCR and the Earth's magnetic field



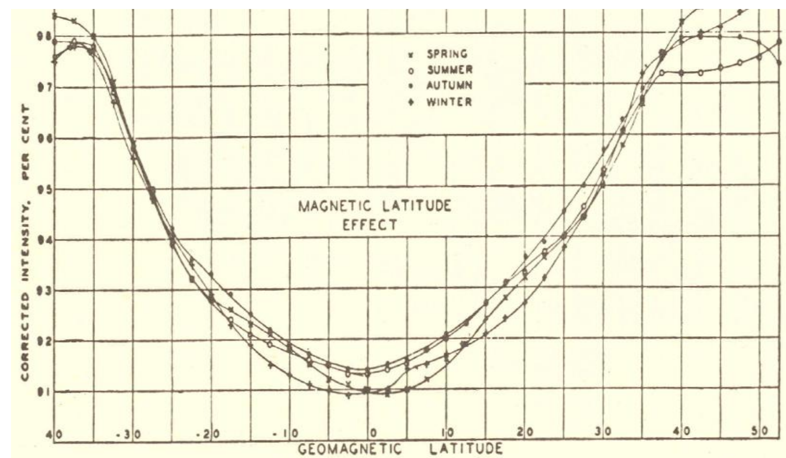
Carl Størmer, 1907

Effects of the geomagnetic field:

- rigidity cutoff (low energy cutoff) – particles with low energies are strongly influenced by the EMF
- low energy charged particles travel along complex trajectories and arrive to the ground often from different than the original direction



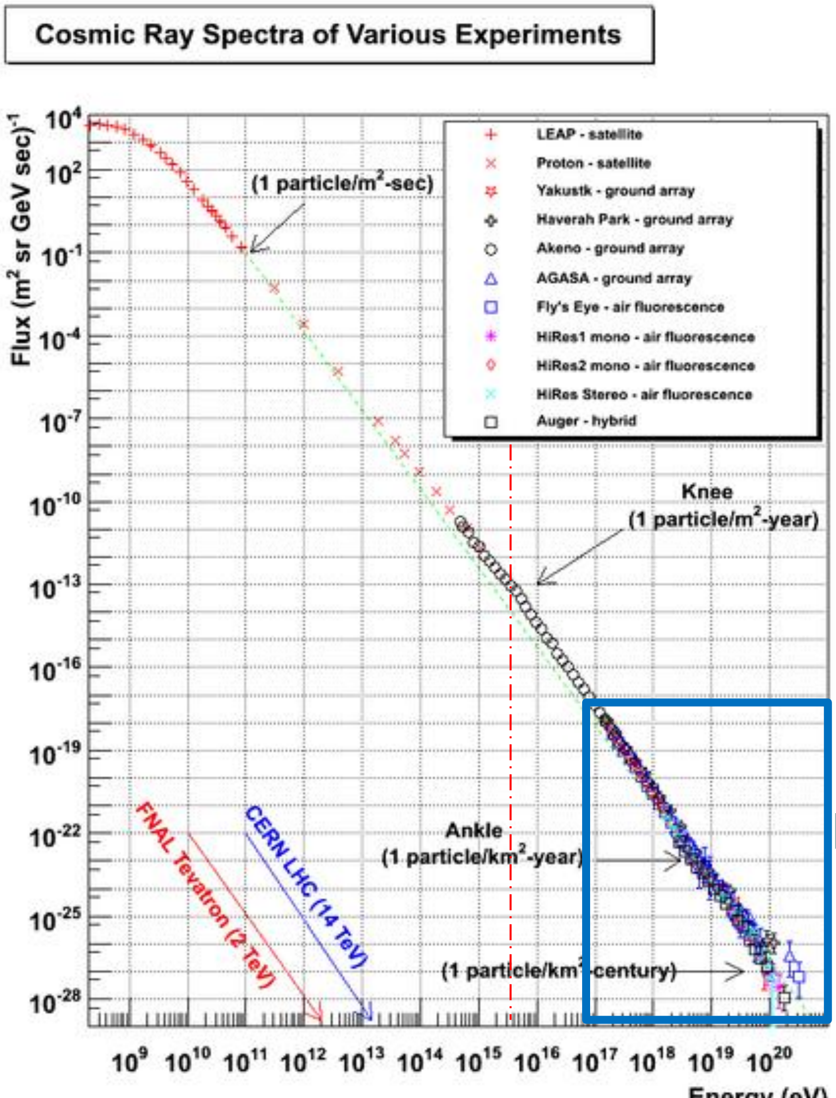
credit: D. F. Smart and M. A. Shea

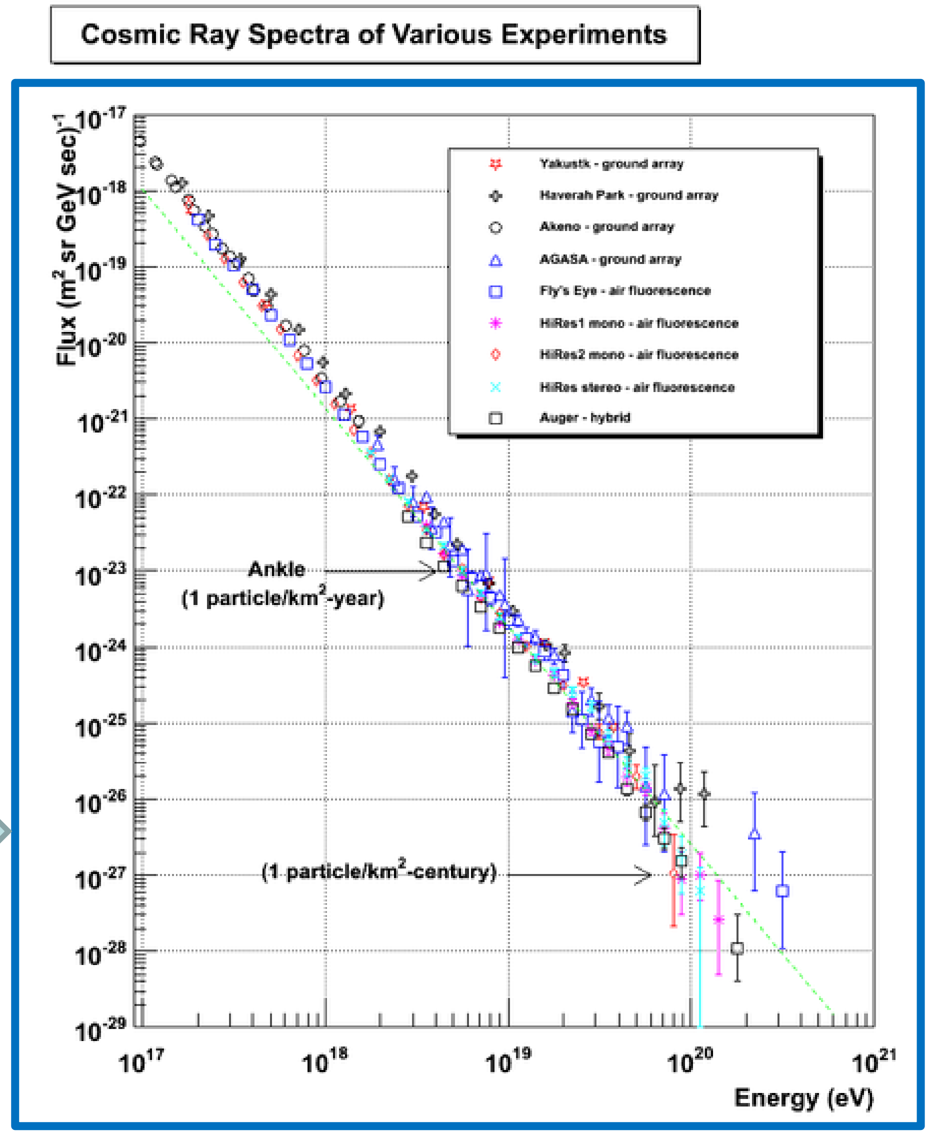


A. H. Compton and R. N. Turner, *Phys. Rev.* *52*, 799 (1937)

credit: http://cosray.unibe.ch/

Energy spectrum





Source: http://www.physics.utah.edu/~whanlon/spectrum.html

Cosmic rays detection:

High Energy and Ultra High Energy CR – based on shower detection using Cherenkov light , atmospheric fluorescence, muon and neutrino detection:

Super-Kamioka Neutrino Detection Experiment (Super-K)

High Resolution Fly's Eye

AMANDA and **IceCube** Observatories

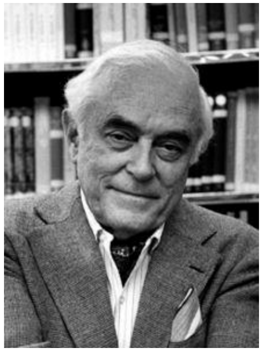
Akeno Giant Air Shower Array (AGASA) – surface detectors and muon detectors

Pierre Auger Observatory - hybrid observatory surface arrays and fluorescence telescopes

Fermi Gamma-ray Space Telescope - GLAST

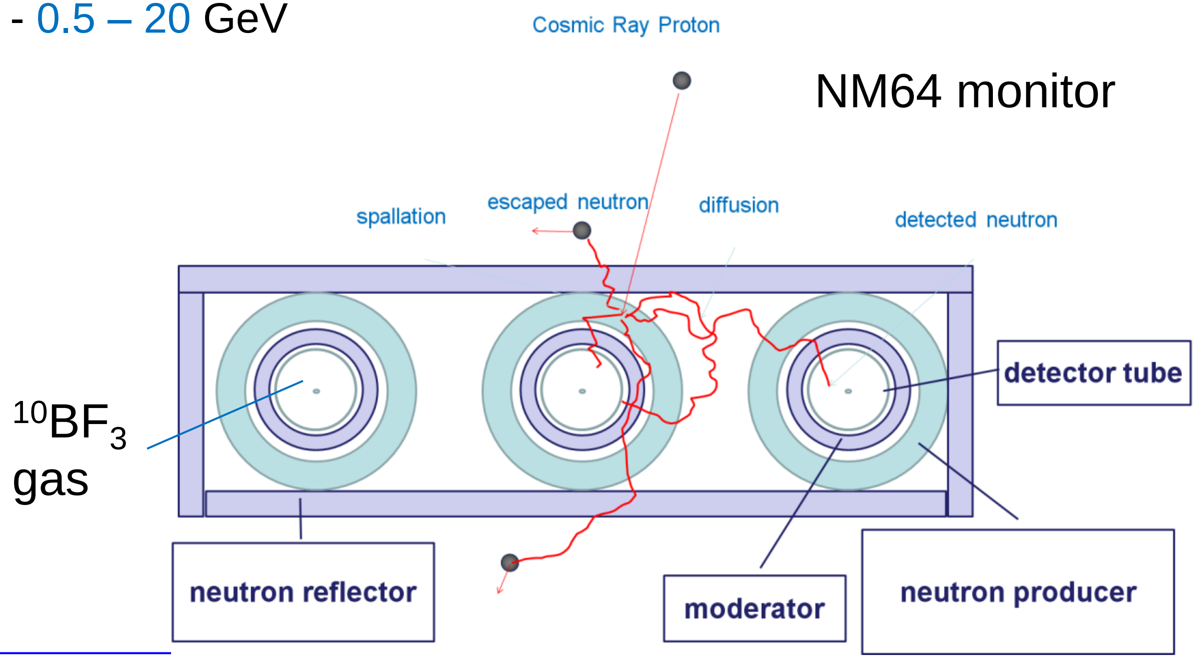
Alpha Magnetic Spectrometer

Nucleonic component: Neutron Monitors



Invented in 1948 by John A. Simpson it still remains the state of the art instrument for monitoring the GCRs.

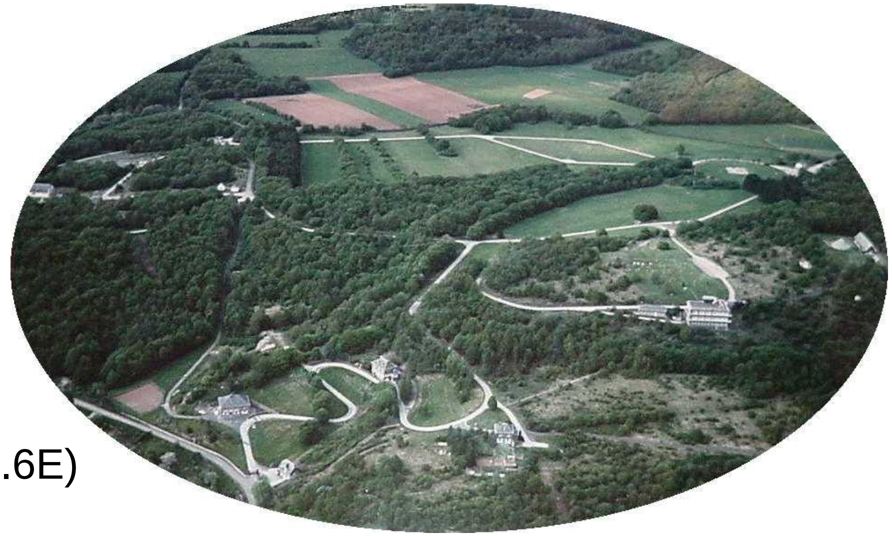
- very high counting rate in comparison with space (satellite) detectors: possible to observe small & short term changes (0.5 %)
- long-term reliability and automation
- no saturation by intense bursts of solar energetic particles – this makes them very useful for space weather applications
- narrow cone of viewing directions – the solid angle within which a NM sees the PCR piercing the magnetosphere
- 0.5 – 20 GeV



Dourbes Neutron Monitor(DBSNM)

Geofysisch Centrum van het KMI * Centre de Physique du Globe de l'IRM

Dourbes (50.1N, 4.6E)



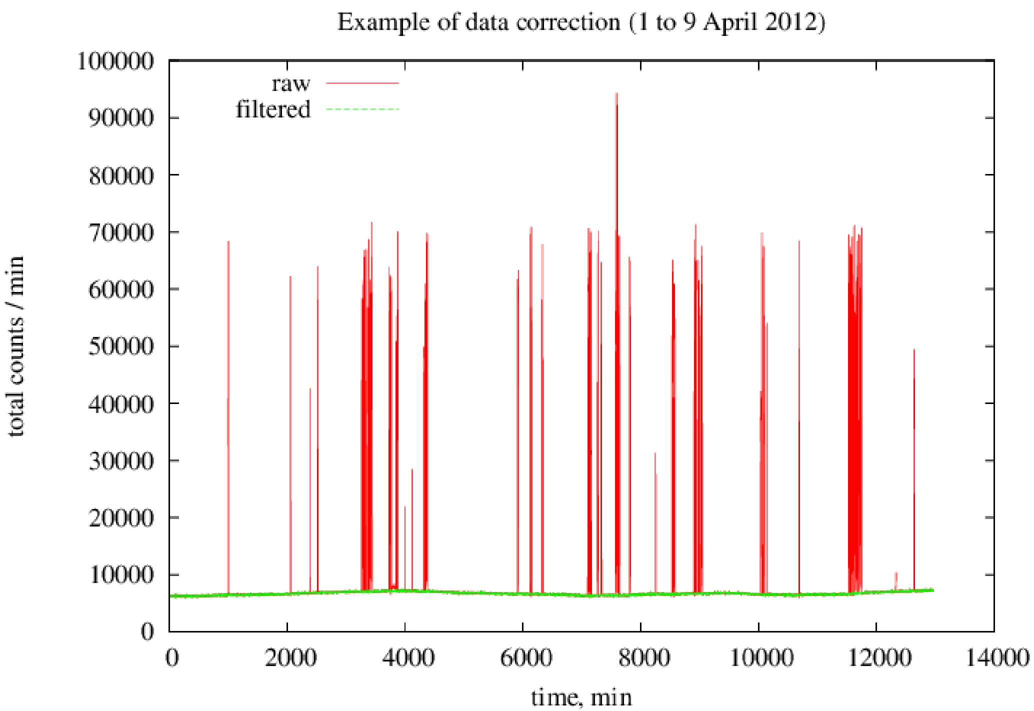
The Royal Meteorological Institute (RMI) Geophysics Centre at Dourbes (4.6°E, 50.1°N) is a complex observational site consisting of several observatories/stations – **atmospheric**, **ionospheric** sounding, **geomagnetic**, **GPS** and cosmic rays.

Dourbes Neutron Monitor(DBSNM)

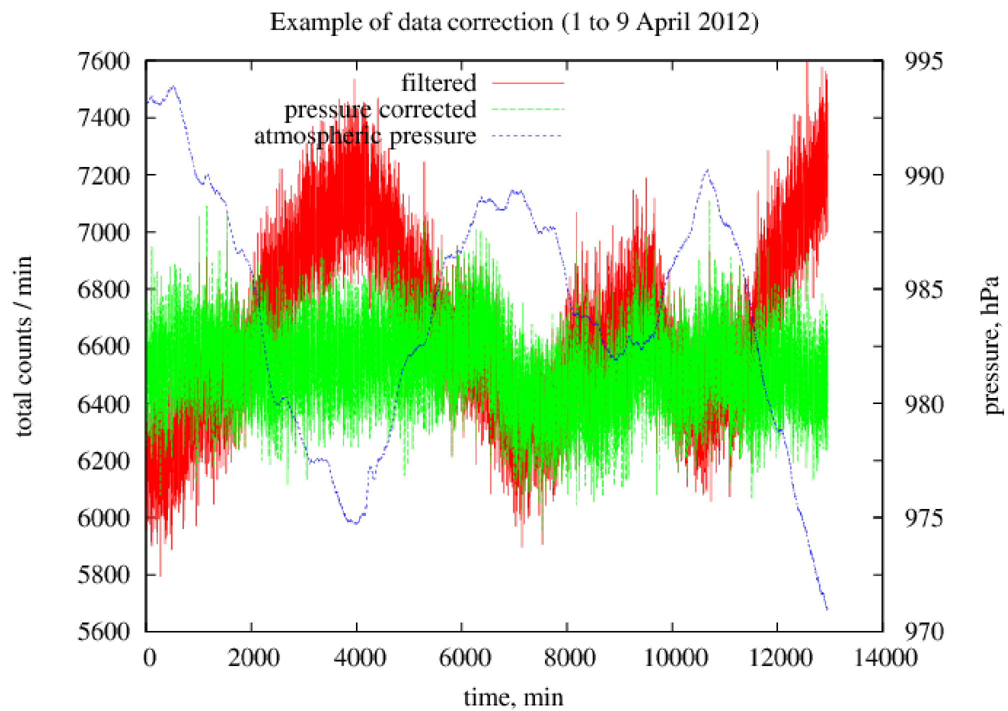
9-NM 64 $^{10}BF_3$ fluoride gas filled counter tubes and soon upgrading to 18

DBSNM output

raw

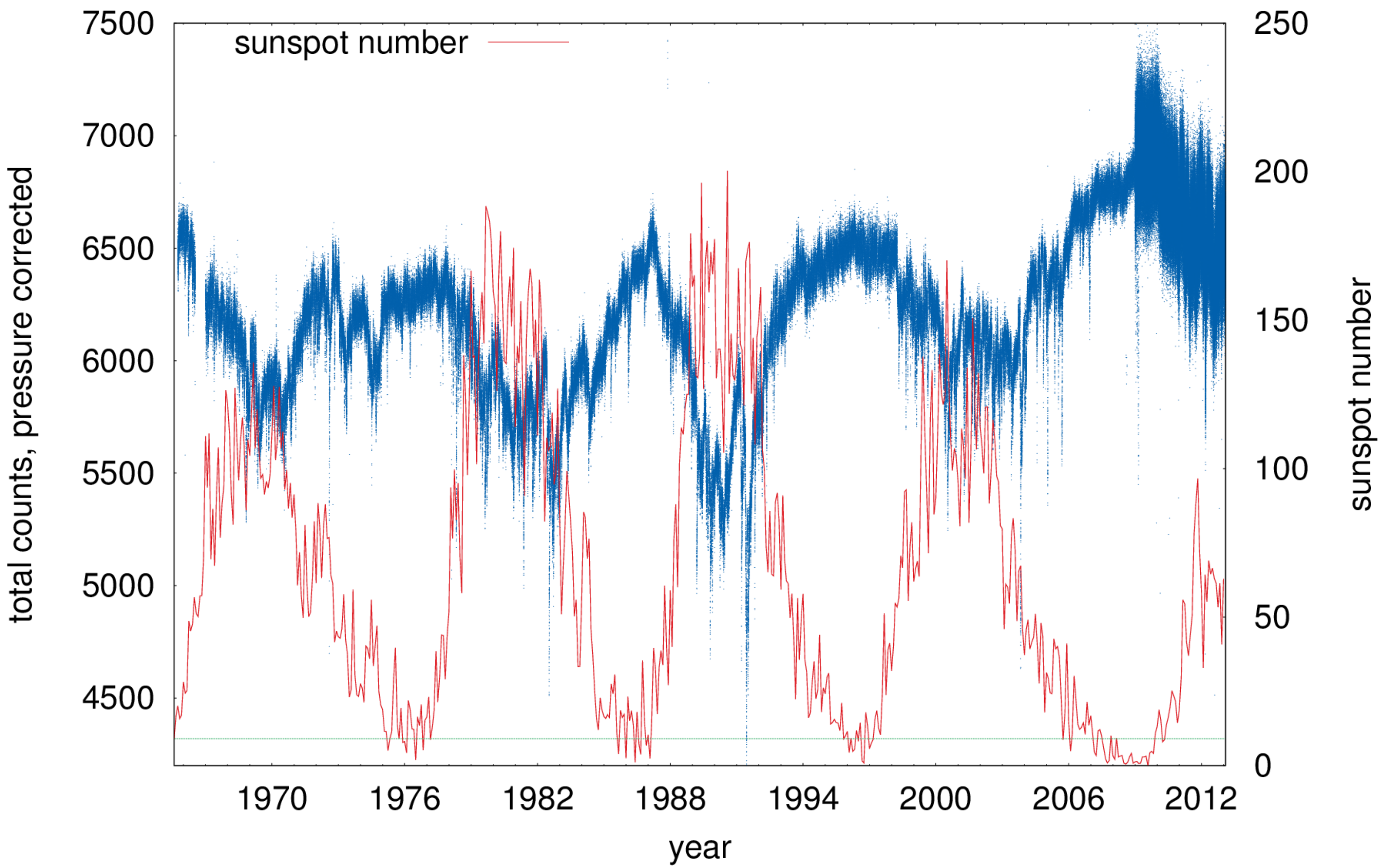


corrected



Comparison between raw and corrected data from the Dourbes Neutron Monitor

Neutron Monitor Intensity - Solar Modulation



Neutron Monitors are sensitive to the Solar Activity and therefore can be used for Space Weather application.

Neutron Monitor Intensity - Solar Modulation

Solar Wind – a current of charged particles escaping from the surface of the sun: *p, e, α, ions (C, N, O, Ne, …)*.
Heavy solar winds can lead to *interruptions in electricity network and communications - Bad Space Weather.*

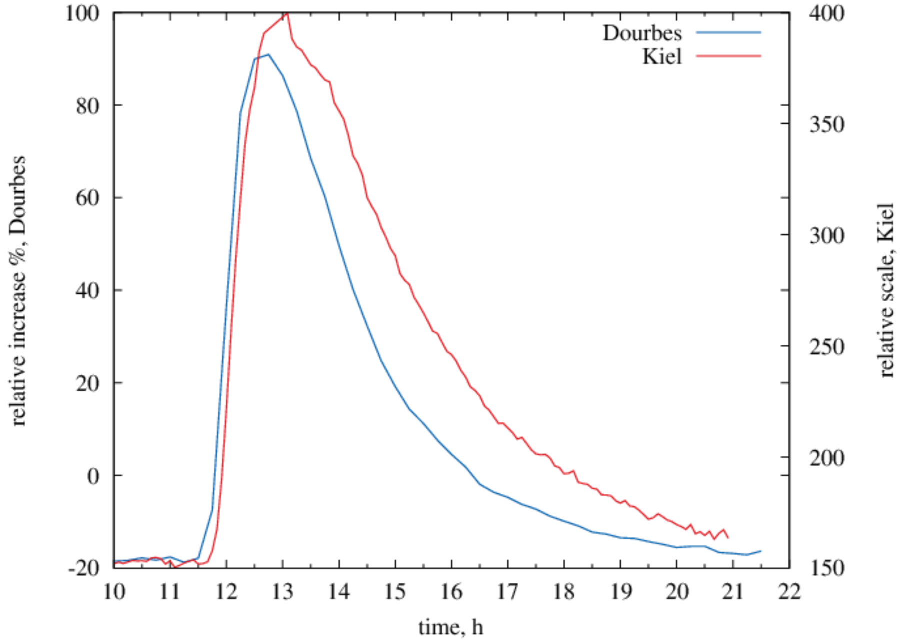
Strong Solar Wind may disturb the GMF – Geomagnetic Storms

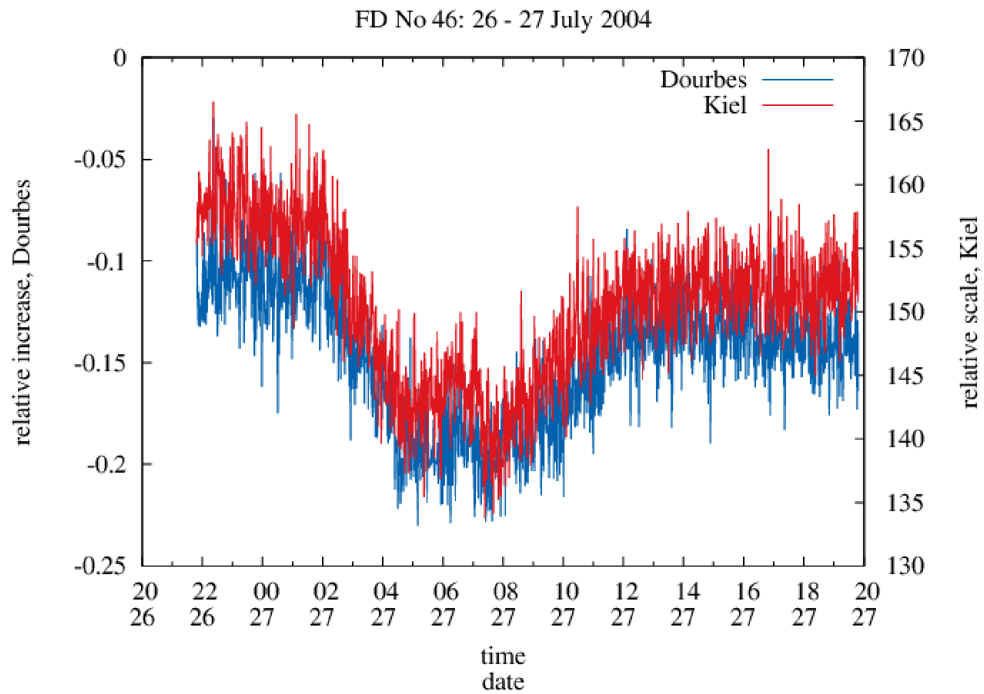
Space Weather originates from the Sun. The neutron monitors give a unique opportunity to monitor the solar activity.

Solar proton events:

- **Coronal Mass Ejection(CME)** explosion of solar wind material – travels to the Earth in about 3 to 4 days (extreme cases < 24 h)
- **Solar flare** – surface explosion of electro-magnetic energy held by the solar magnetic field

Solar events seen by a Neutron Monitor



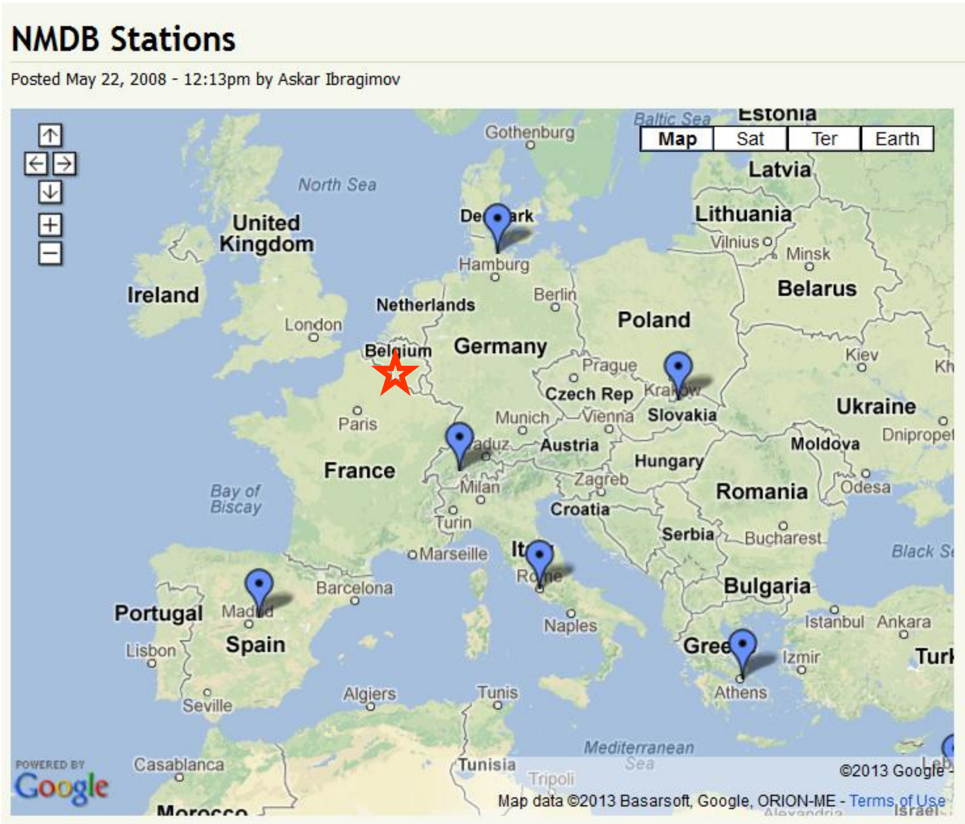


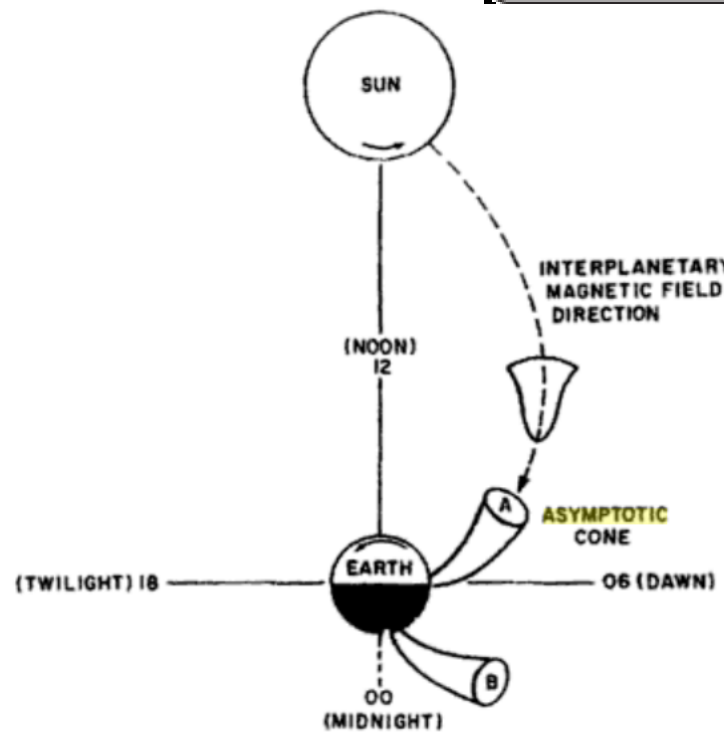
Ground Level Enhancement:
solar particles with sufficient energy to raise radiation levels at the surface

Forbush decrease:
result from magnetic fields following a CME suppressing the intensity of the GCR

Earth' magnetic field as a giant spectrometer – **Neutron Monitor Data Base**

neutron monitor database

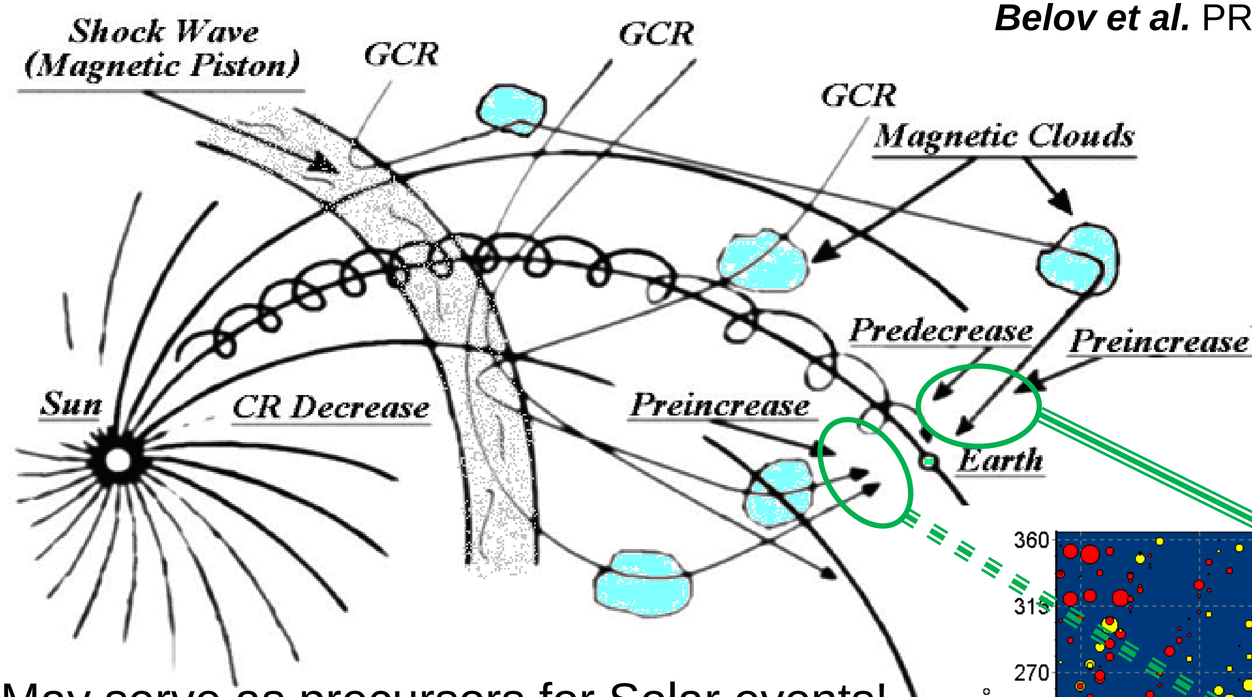


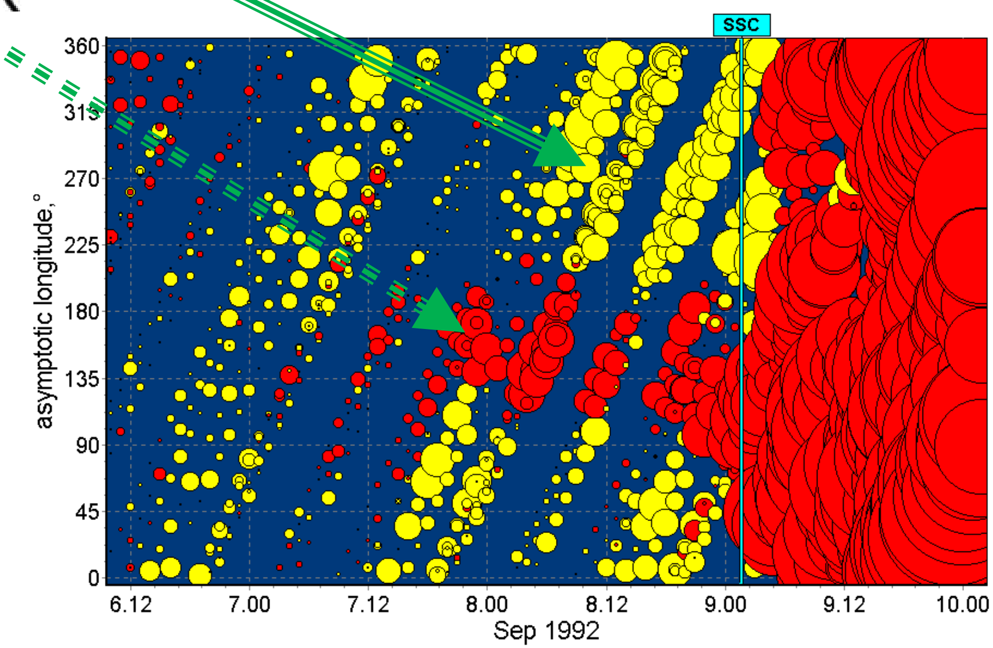


credit: Smart & Shea(1993)

CR’s Space Weather events forecasting

Belov et al. PROCEEDINGS OF THE 31 ICRC, 2009

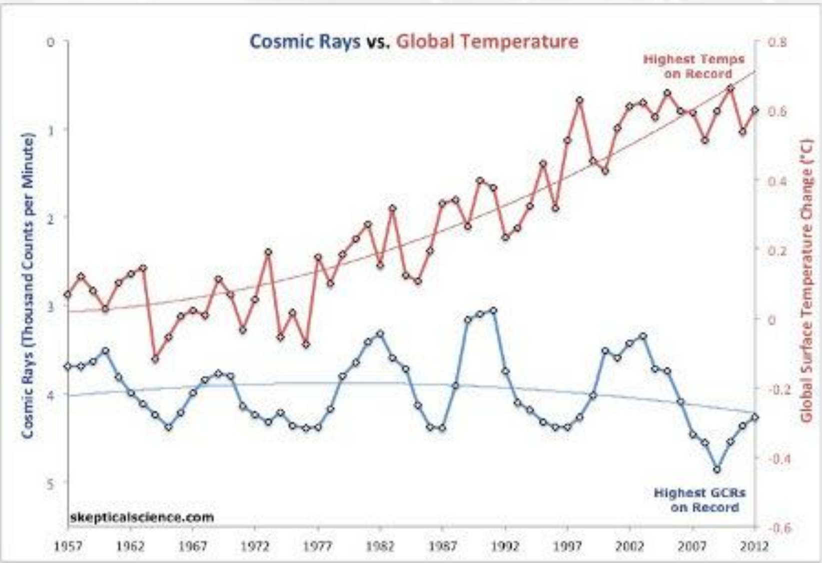




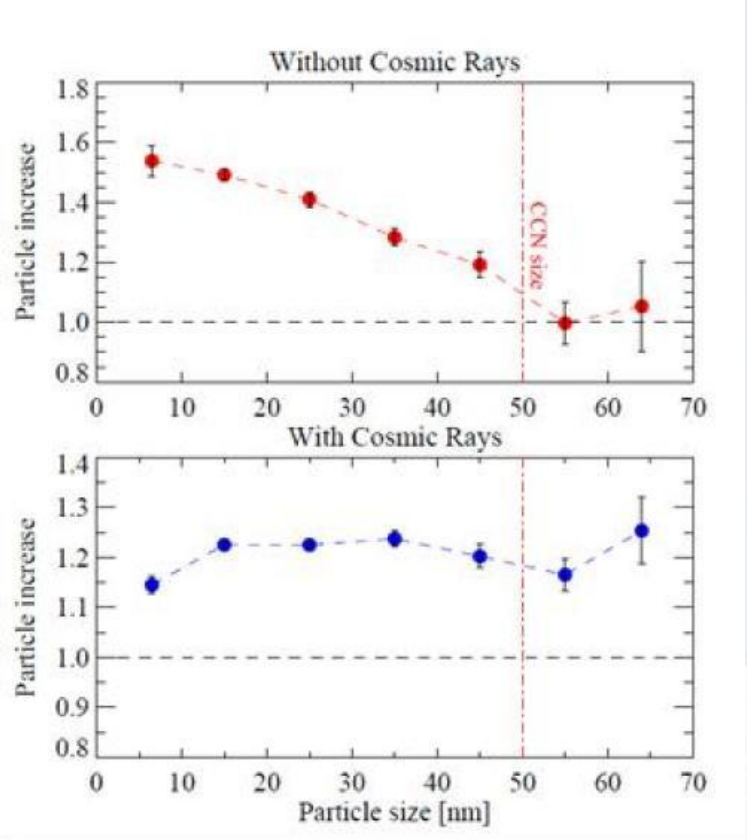
May serve as precursors for Solar events!
the complex interaction of the GCR with Solar Flare transients, magnetic clouds, IMF and GMF may lead to pre-increase or suppression;
can be measured: a worldwide net of Neutron Monitors
offers: long lead times – up to 4 h.

CR's and cloud formation hypothesis: ``cosmoclimatology''

1) Cosmic rays may be able to seed cloud formation.
2) Fewer cosmic rays reaching Earth means less cloud formation.
3) Fewer clouds reflecting sunlight means more solar radiation reaching the Earth's surface, and thus warming.



annual average CR vs. the annual average global surface temperature(NMDB & NOA) credit: the guardian



Credit: Danish National Space Institute

However the effect of CR's will cooling, not warming.

Svensmark et al. doi:10.1103/PhysRevLett.81.5027

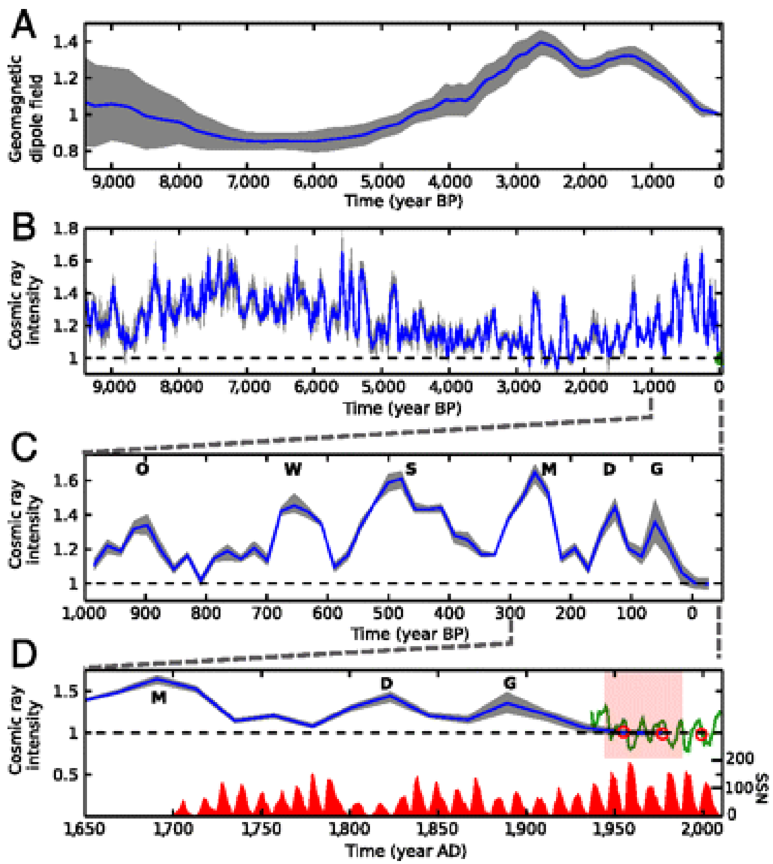
picture by falarae http://falarae.deviantart.com/

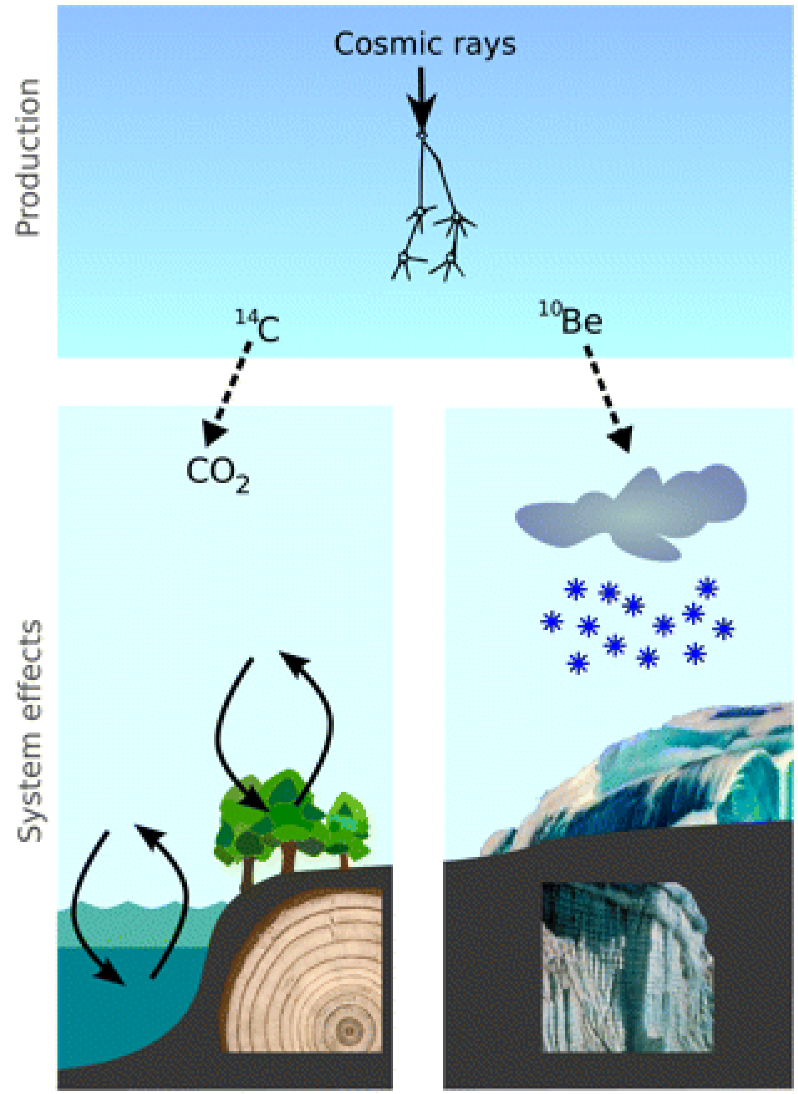
Cosmogenic radionuclide dating :

^{10}Be **spallation (N and O)** half life 1.39 x10^{16} y

^{14}C **^{14}N (n, p) ^{14}C** half life 5700 y

Paleocosmic measurements:





F. Steinhilber et al. doi: 10.1073/pnas.1118965109

CR contribution to the absorbed dose

GCR exposure doubles with every 2 km of altitude

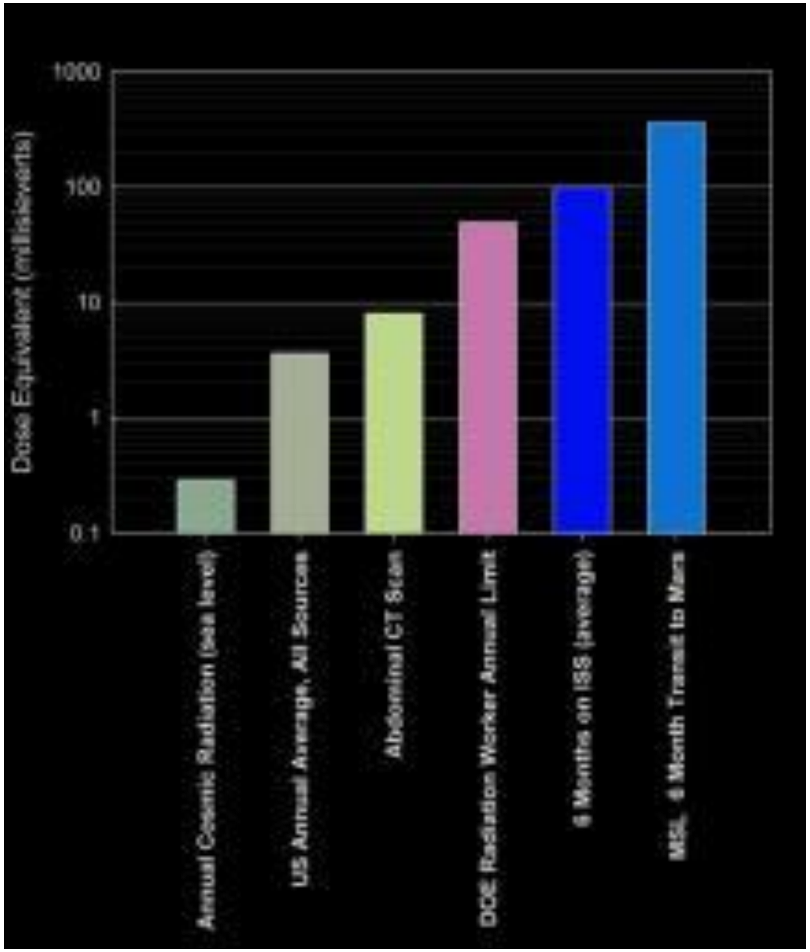


Image credit: NASA/JPL-Caltech/SwRI

On Earth, a 1-sievert (Sv) dose increases cancer risk by 5 %.
In space this might be different as little information is known about long term effect of PCR.

For those who fly frequently, such as aircrew and some business travelers, the annual exposure may be comparable with, or even exceed, that of radiation workers in ground-based industries.

How much contributes a GLE event to the absorbed dose?

- flight from Prague to New York during the GLE on 15 April 2001: 20 µSv (Spurny and Dachev (2001))
- GLE on 20 January 2005: 550 µSv for a flight from Buenos Aires to Auckland in a worst case scenario Bütikofer et al. (2009)

CRs and evolution

Are cosmic rays causing mutation and do they influence the evolution?

Facts: any ionising radiation that alters the DNA may either destroy it or result in rearrangement and subsequent changes in the offspring; this is not result of the evolutionary pressure but is considered as the random variation part of the evolution process;

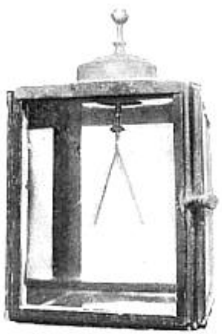
Cells however have an error correcting mechanisms (at least 7?) and single damage in the DNA is not sufficient to cause mutation. The ideas comes from the 1950s when it was observed that stressing organisms with ionising radiation both breaks the DNA and significant mutation rate (Gioacchino Failla). More detailed study have suggested that under increased radiation burden bodies will adapt by developing more correction mechanisms.

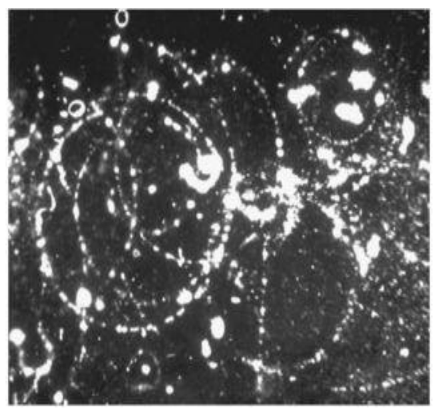
Final Notes:

Cosmic Rays monitoring offer the unique opportunity to forecast Space Weather events with significant lead times of up to 4 h.

There are studies that show possible strong relation between cosmic rays and cloud formation.

Primary and especially Ultra High Energy Cosmic Rays remain a subject theoretical and experimental research about the formation of the Universe.





(1927 by Dmitry Skobeltzyn)

AMS (credit NASA)