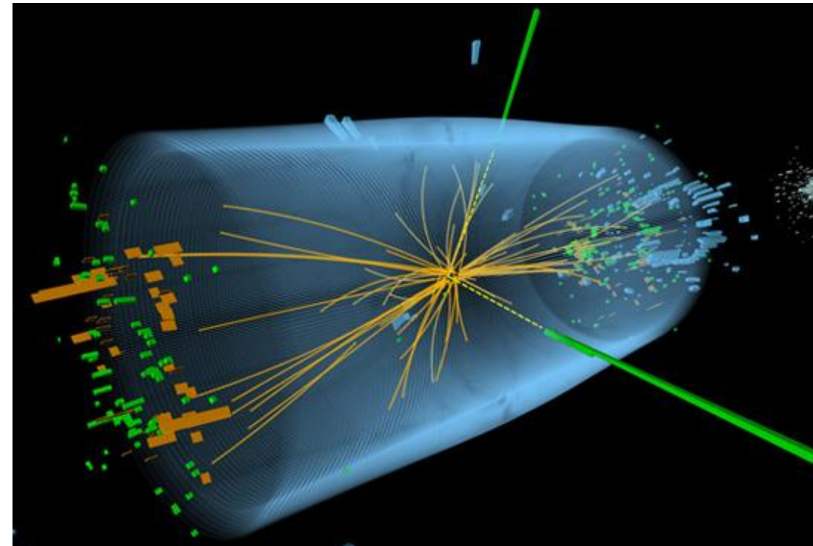
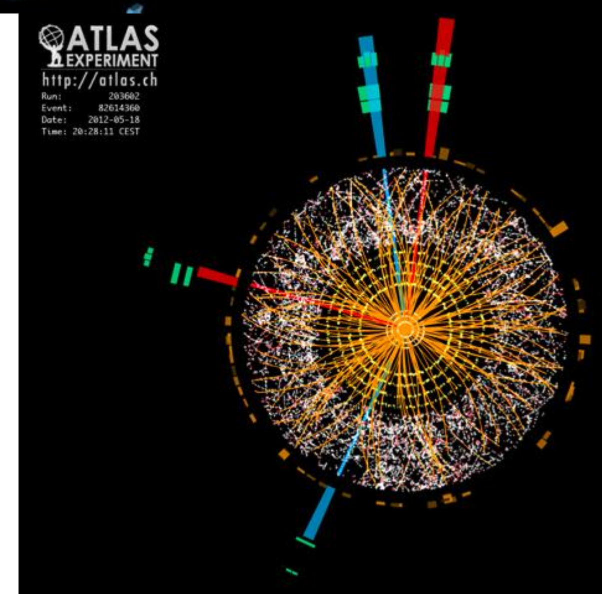
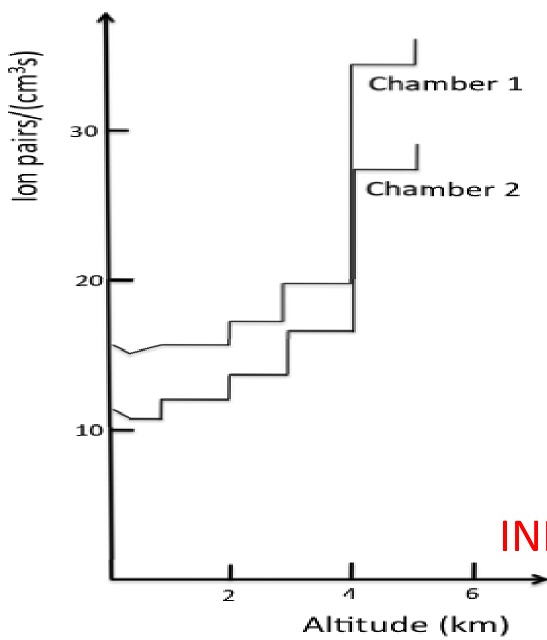
Spontaneous Ionization to Subatomic Physics: Victor Hess to Peter Higgs







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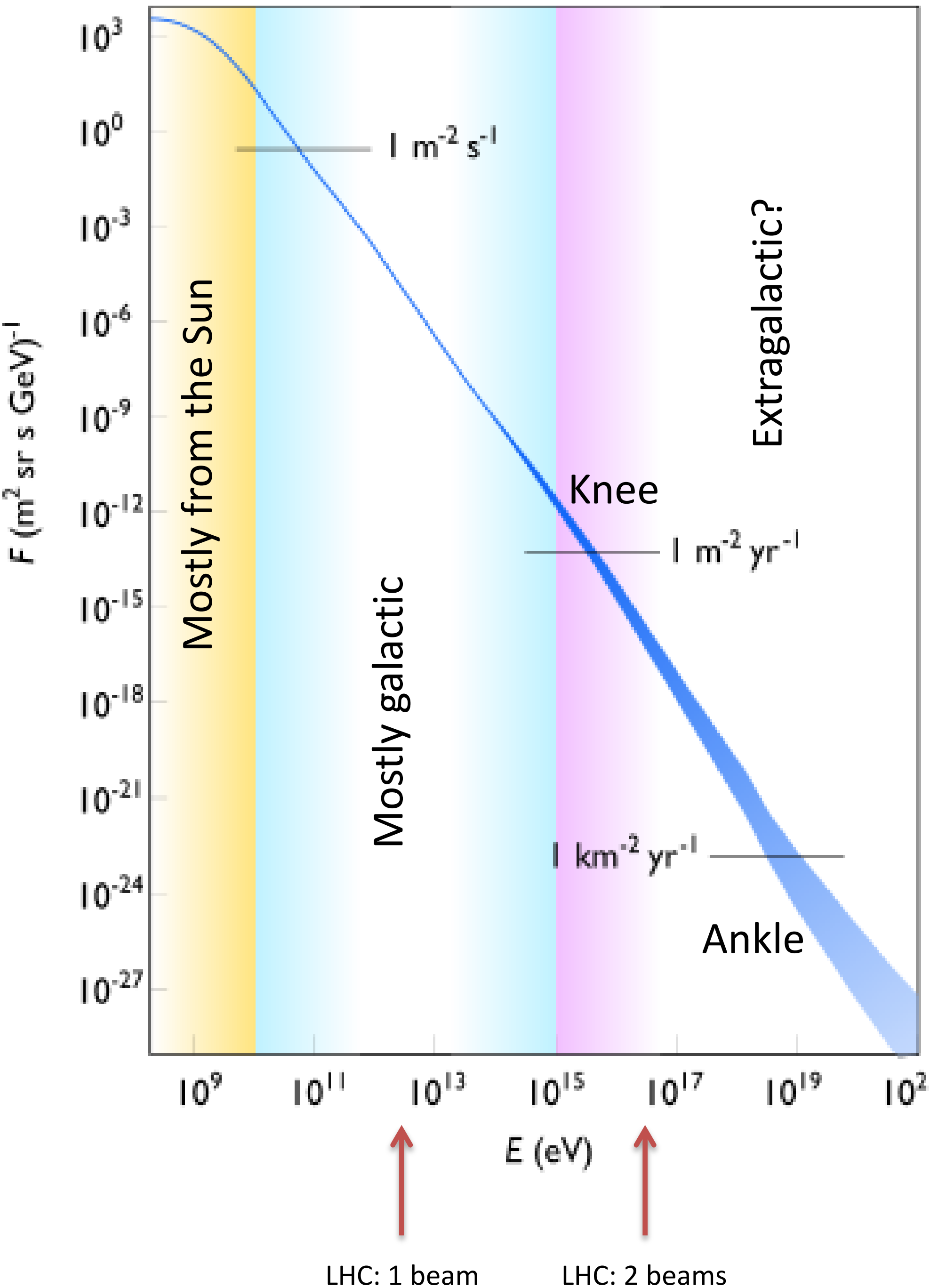
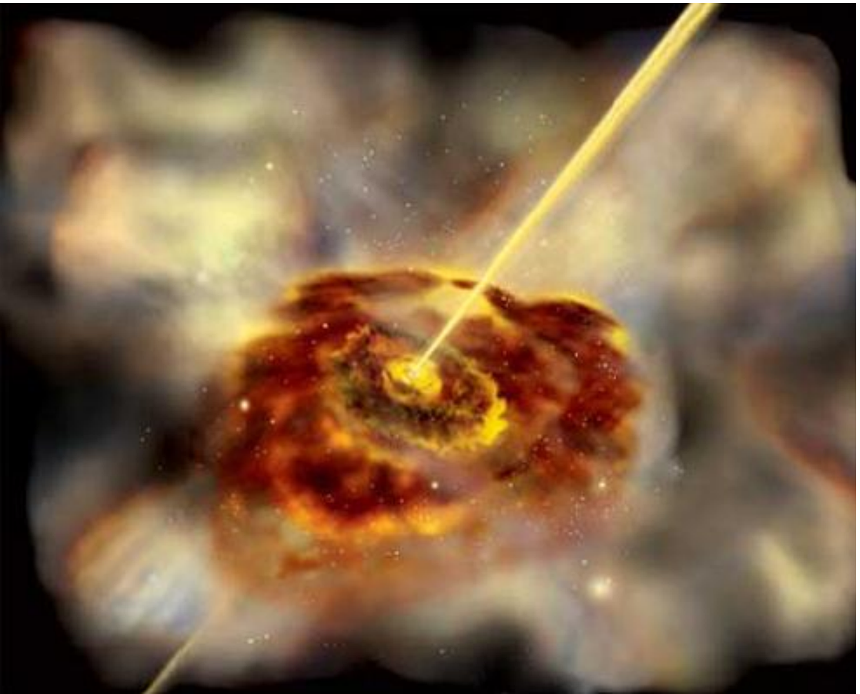
Spacepart CERN, November 2012

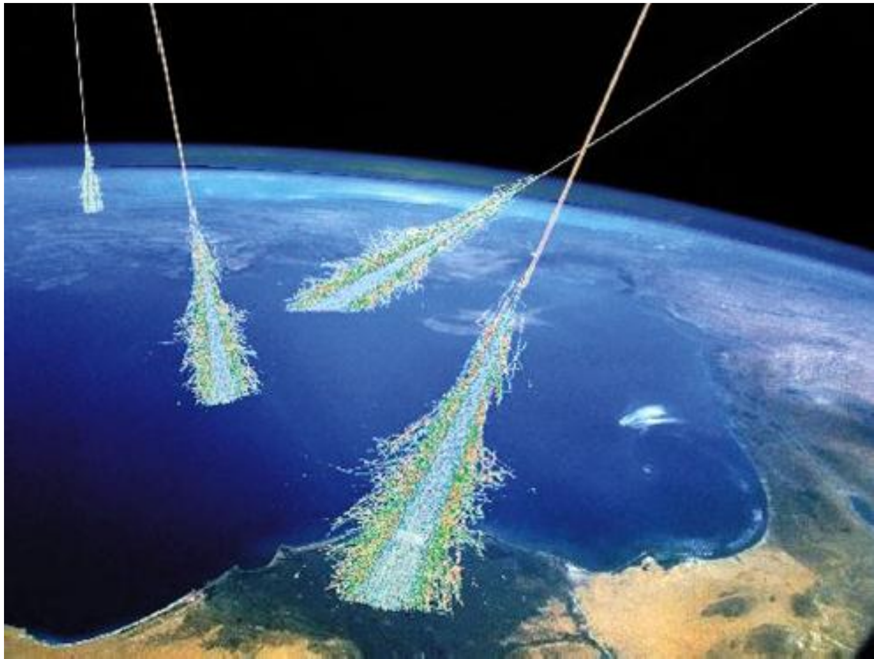
Short phenomenology of Cosmic Rays



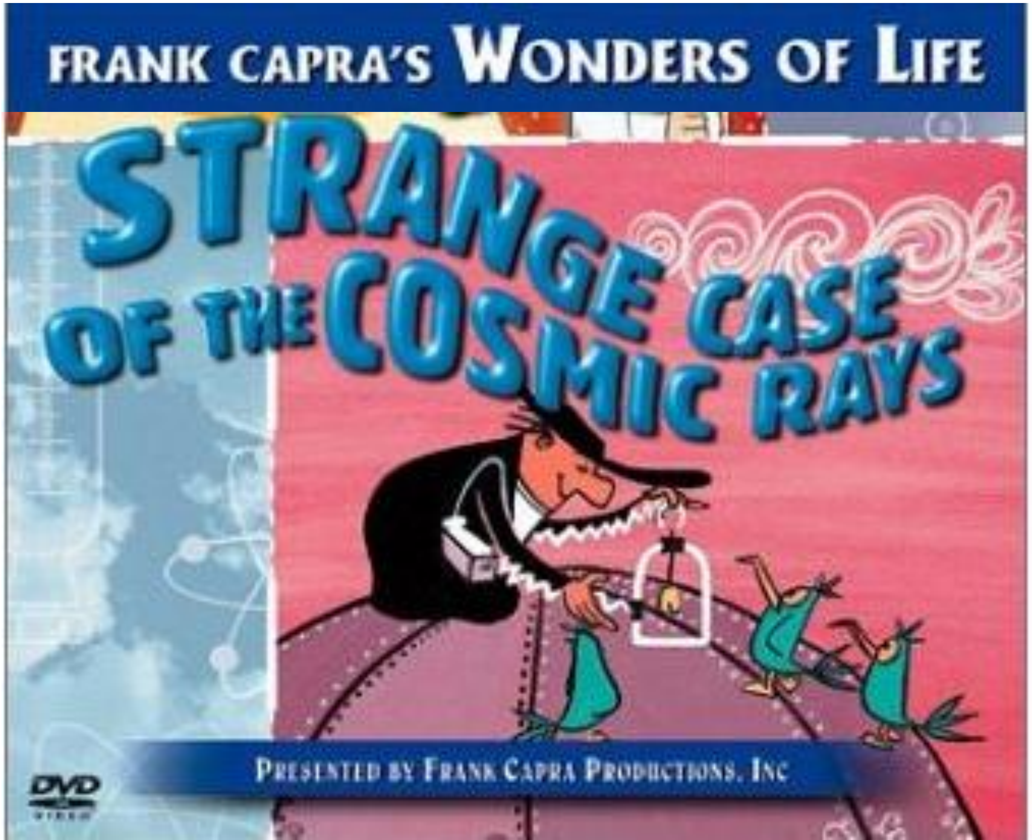
- Cosmic rays (CR) are subatomic particles reaching the Earth from outside
- They are mostly protons
  - But the minority (heavy nuclei, neutrinos, gammas, antimatter… is very important)
- The flux depends strongly on energy
  - They reach the highest energies, up to 10^{21} eV
  - Once per second, a single subatomic particle with the energy of a tennis ball hits the atmosphere

- Kinetic energy is likely to come from potential gravitational energy (collapses of astrophysical objects)
  - Below ~10^7 GeV: likely to be Galactic (supernova remnants)
  - Above: likely to be extragalactic (accreting supermassive black holes: Active Galactic Nuclei)
- Once CR hit the atmosphere, they are absorbed generating showers of particles





How did we learn all this?
(history of a 100-years investigation)



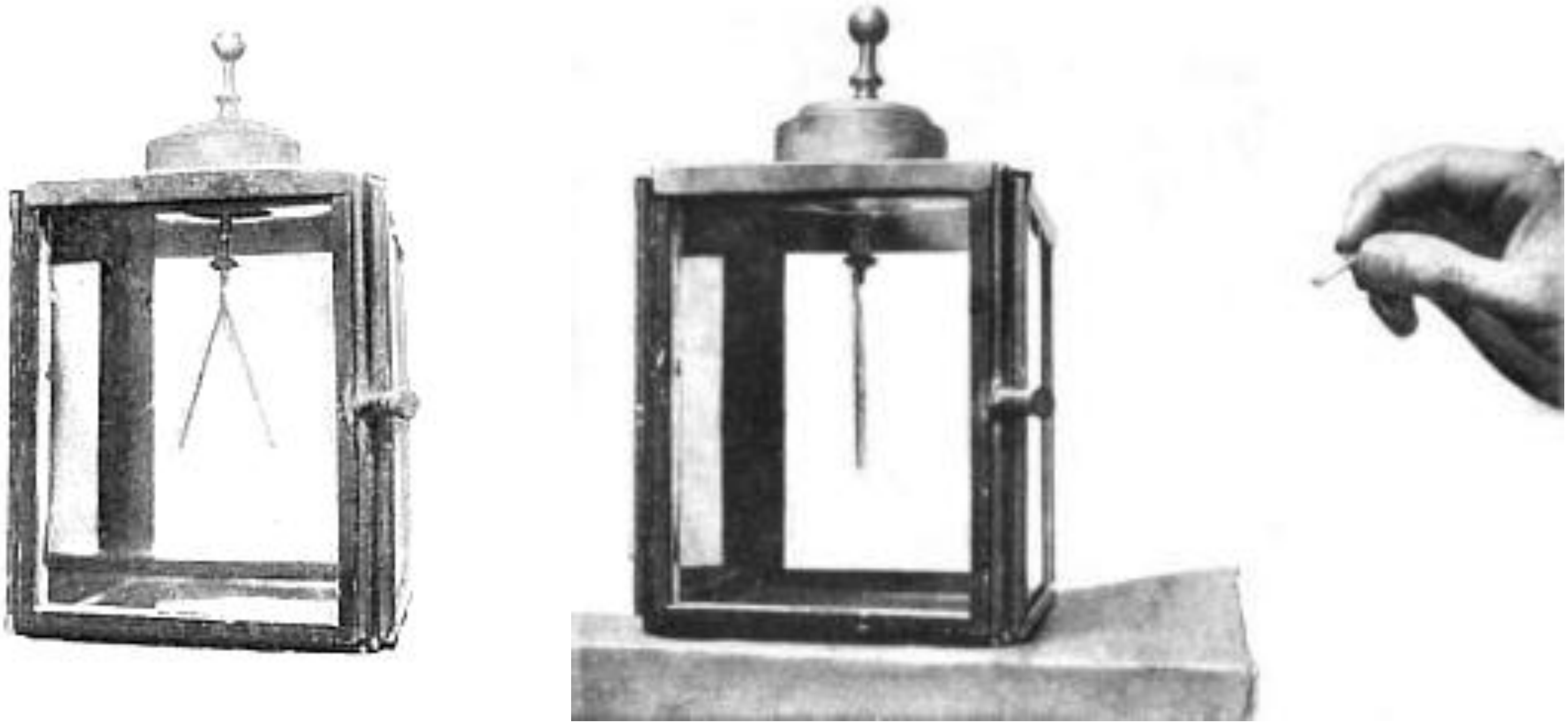
(F. Capra/W. Disney production, a 1957 movie written by Anderson & Rossi)

Electroscopes discharge spontaneously. Why?

- 1785: Coulomb found that electroscopes can spontaneously discharge by the action of the air and not by defective insulation
- 1835: Faraday confirms the observation by Coulomb, with better insulation technology
- 1879: Crookes measures that the speed of discharge of an electroscope decreased when pressure was reduced (conclusion: direct agent is the ionized air)

100 years later: cause might be radioactivity

- 1896: spontaneous radioactivity discovered by Becquerel
- 1898: Marie (31) & Pierre Curie discover that the Polonium and Radium undergo transmutations generating radioactivity (radioactive decays)
  - Nobel prize for the discovery of the radioactive elements Radium and Polonium: the 2nd Nobel prize to M. Curie, in 1911
  - In the presence of a radioactive material, a charged electroscope promptly discharges
  - Some elements are able to emit charged particles, that in turn can cause the discharge of the electroscopes.
  - The discharge rate of an electroscope was then used to gauge the level of radioactivity

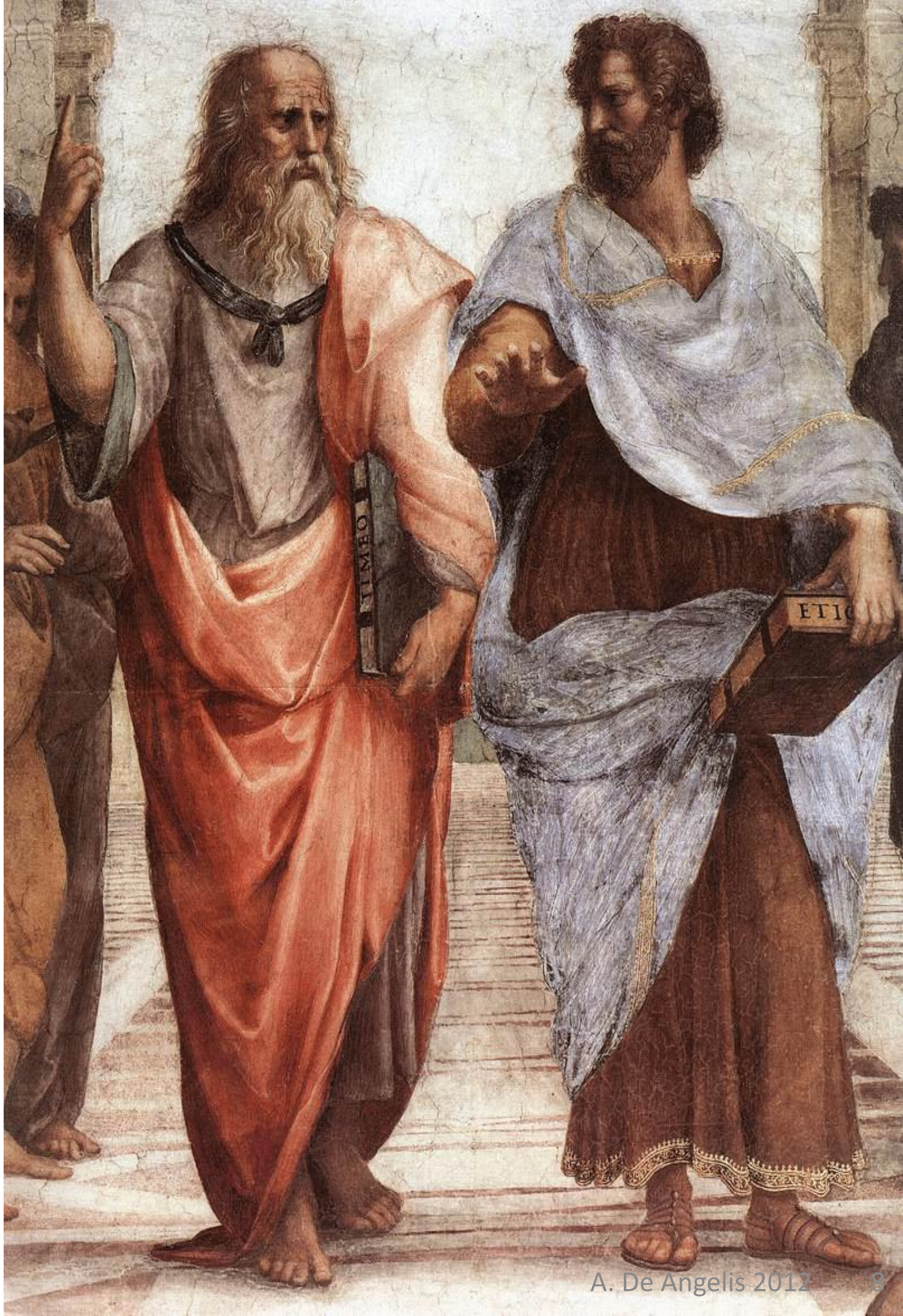


Discharge of an electroscope by a radioactive material (Duncan 1902)

Where does natural radioactivity come from?

- For sure in part from the soil
- For sure in part from the Sun
- From the atmosphere?
- Is this the full story?

- In the beginning, the dominant opinion was that (almost) all the high energy radiation was coming from the soil



The experiments at the beginning of the XX century

- 1900: Wilson and Elster & Geitel improve the technique for a careful insulation of electroscopes in a closed vessel, improving the sensitivity
- 1901: Wilson's measurements in tunnels with solid rock overhead (to check if the radiation was coming from outside) show no reduction in ionization

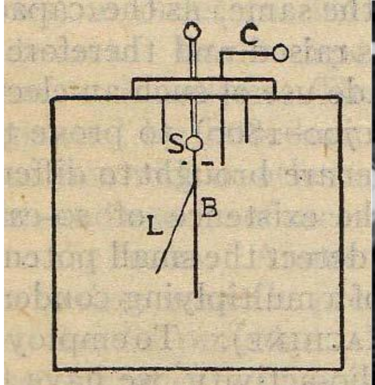
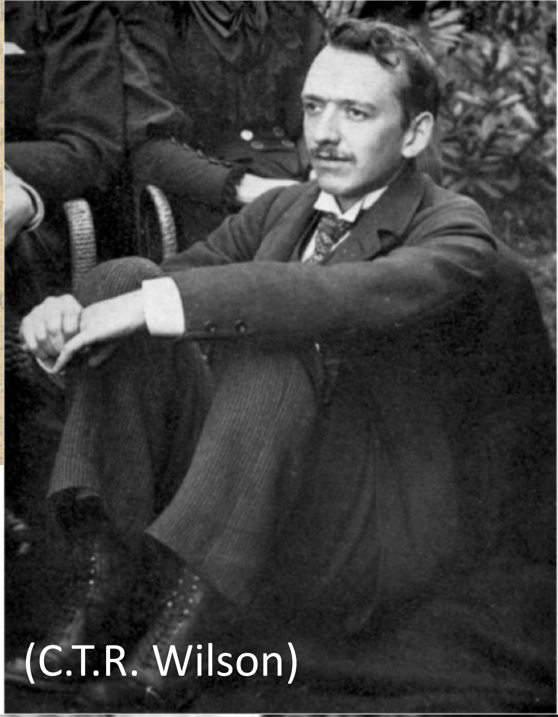


FIG. 6.—Elster and Geitel Electroscope.


(C.T.R. Wilson)

1903-06: Rutherford & Cooke and McLennan & Burton show that ionization is marginally reduced when an electroscope is surrounded by metal shields. McL&B put also the electroscope in a box, and they fill it with water. Mache compares the variations of the radioactivity when the electroscope is surrounded by shields of metal with the diurnal variations; no significant reduction


(Elster, Geitel)

Proc. Camb. Phil. Soc. 26 32 (1900)

On the leakage of Electricity through dust-free air. By C. T. R. WILSON, M.A., Sidney Sussex College.

[*Read* 26 November 1900.]

Elster and Geitel have shown than an electrified body gradually loses its charge when freely exposed in the open air or in a room. Their results are in agreement with previous experiments of Linss. They conclude from their experiments that free ions exist in the atmosphere. The experiments described in this paper prove that ionisation can be detected in a small closed vessel containing dust-free air not exposed to any known ionising agents. To

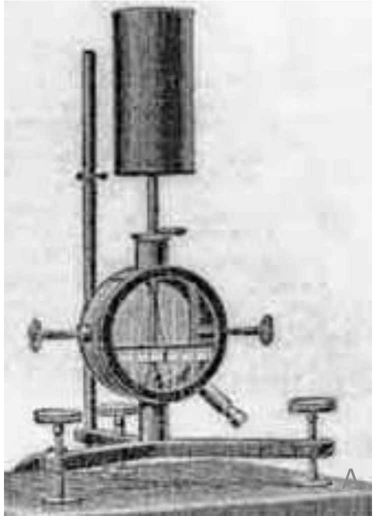
The rate of leak is to a first approximation proportional to the pressure; at a pressure of 43 millims. the leakage is about one-fourteenth of that at atmospheric pressure.

If we take the value found by Prof. J. J. Thomson for the charge carried by each ion, $6{\cdot}5 \times 10^{-10}$ E.U., we can take the experiments as indicating that 20 ions of either sign are produced per second in each c.c. of air at atmospheric pressure.

The experiments in the beginning of the XX century

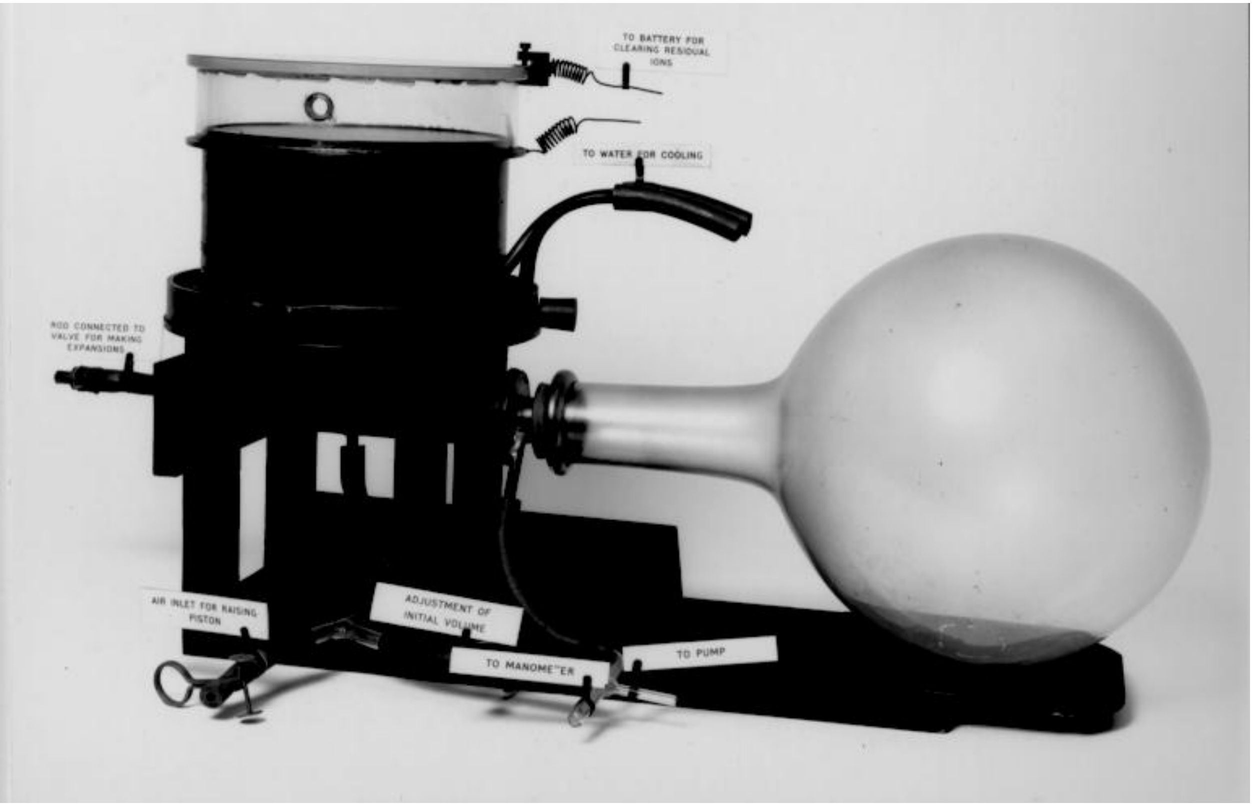
- 1907: Strong studies radioactivity in a variety of places including (1) his lab (2) the center of a cistern filled with rain water and (3) the open air; results dominated by statistical & systematic errors
- 1907-08: Eve makes measurements over the Atlantic Ocean, which indicate as much radioactivity over the centre of the ocean as he had observed in England and in Montreal. He makes also systematic measurements, later used by Wulf, Pacini, Hess
- 1908: Elster & Geitel observe a fall of 28% when the apparatus is taken from the surface down to the bottom of a salt mine. They conclude that, in agreement with the literature, the Earth is the source of the penetrating radiation and that certain waters, soils and salt deposits, are comparatively free from radioactive substances, and can therefore act as efficient screens

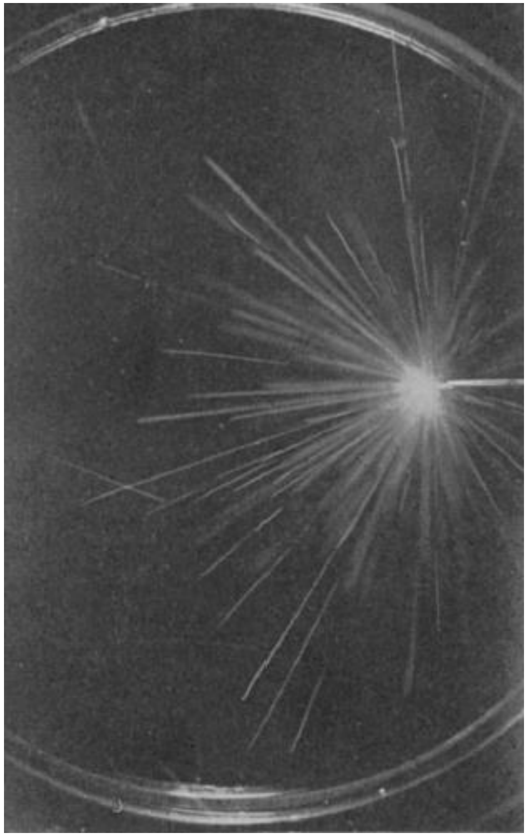
(Eve, Rutherford)



In parallel, the cloud chamber…

‘the most original and wonderful instrument in scientific history’ (Rutherford)

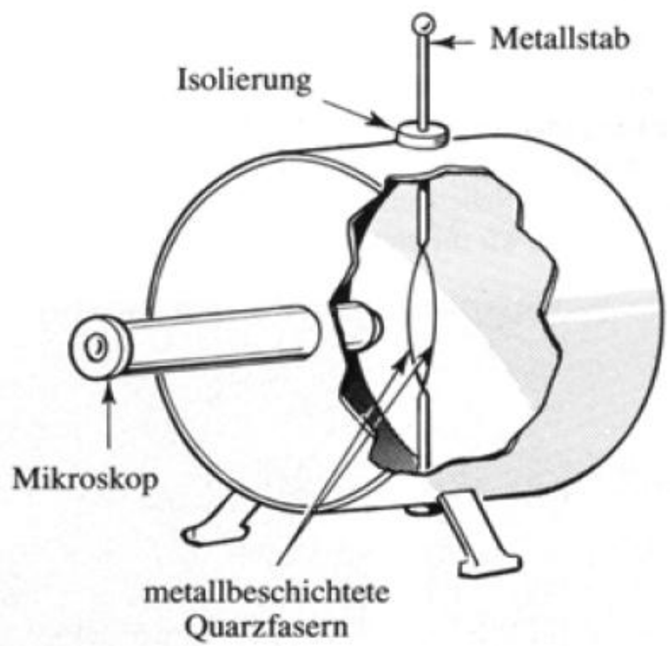




Wilson obtained the first images of the tracks of α and β particles. As Blackett remarked, ‘[The many exquisite photographs …] still remain among the technically best photographs ever made.’

Father Wulf: a true experimentalist

- Theodor Wulf, German Jesuit, professor in Holland and in Rome, perfected the electroscope in 1908-09, up to a sensitivity of 1 volt (and making it transportable)

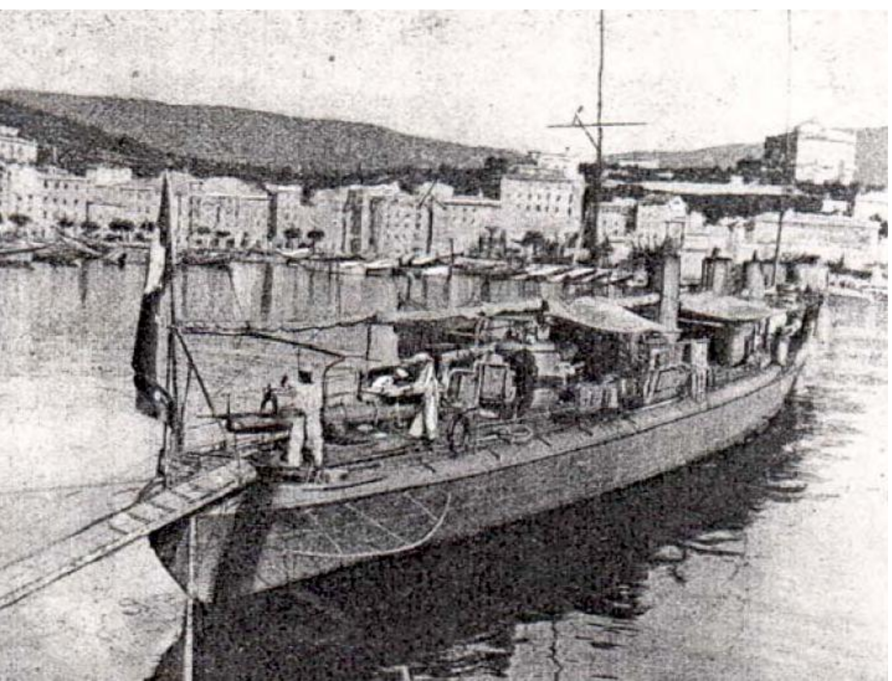


The Wulf experiments (1909-1910)

- Wulf had the idea if measuring radioactivity on top of the Eiffel tower (~300 m) and compare to ground, at day and night
  - The decisive measurement: Wulf was on a Easter holiday trip to Paris and brought a few electroscopes with him
- If most of the radioactivity was coming from the soil, an exponential decrease $e^{-h/\lambda}$ was expected
- Results were not conclusive
  - Note: at that time people were convinced that natural radioactivity was mostly due to gamma rays
- Taken as a confirmation of the dominant opinion: radioactivity came from the soil

Domenico Pacini's break-through

- Domenico Pacini (1878-1934), meteorologist in Roma and then professor in Bari, makes measurements in 1907-1911, first comparing the rate of ionization on mountains at different altitudes, over a lake, and over the sea
  - Comparing measurements on the ground and on a sea a few km off the coast in Livorno, a 30% reduction of radioactivity
  - A hint that the soil is not (the only) responsible of radiation: *in the hypothesis that the origin of penetrating radiations is only in the soil … it is not possible to explain the results obtained* (Pacini 1910; quoted by Hess)



- In June 1911, the winning idea: immersing an electroscope 3m deep in the sea (at Livorno and later in Bracciano) Pacini, 33-y-old, finds a significant (20% at 4.3σ) reduction of the radioactivity

Coll' apparecchio alla superficie del mare si ebbe una perdita oraria di Volta:

13,2 — 12,2 — 12,1 — 12,6 — 12,5 — 13,5 — 12,1 — 12,7

media 12,6 equivalente a ioni 11 per cm^3 al 1".

Coll' apparecchio immerso:

10,2 — 10,3 — 10,3 — 10,1 — 10,0 — 10,6 — 10,6.

media 10,3 equivalente a ioni 8,9 per cm^3 al 1".

La differenza fra questi due valori è di ioni 2,1.

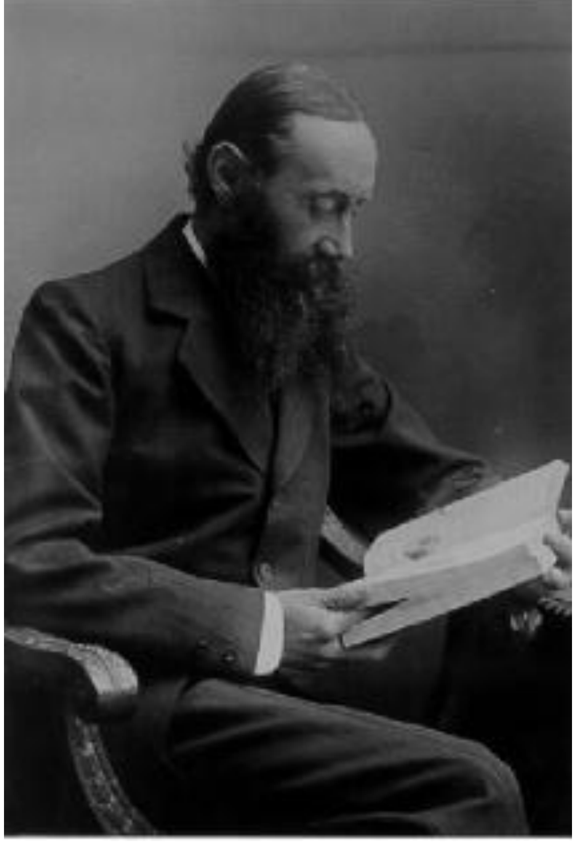
"The explanation appears to be, due to the absorbing power of water and the minimum amount of radioactive substances in the sea, that radiation coming from the outside is absorbed when the apparatus is immersed. (Nuovo Cim., February 1912)"

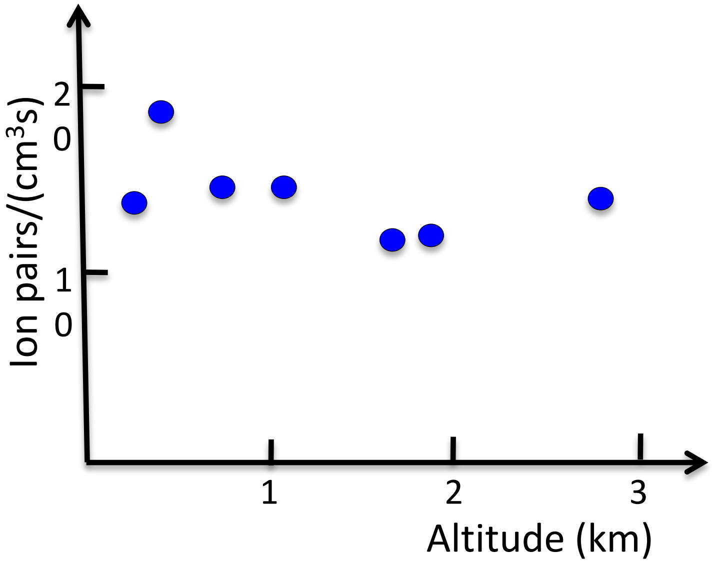
Pacini concludes that *"a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the ground."*

Pacini's experiment marked the beginning of the underwater technique for CR studies

Balloon experiments: Gockel

Note: Gay Lussac and Biot flew to 6400 m in 1804 to study properties of air at different p, T. Robertson and Lhoest had reached nearly 7000 m in a 5 h flight from Hamburg to Hannover in 1803, to measure B



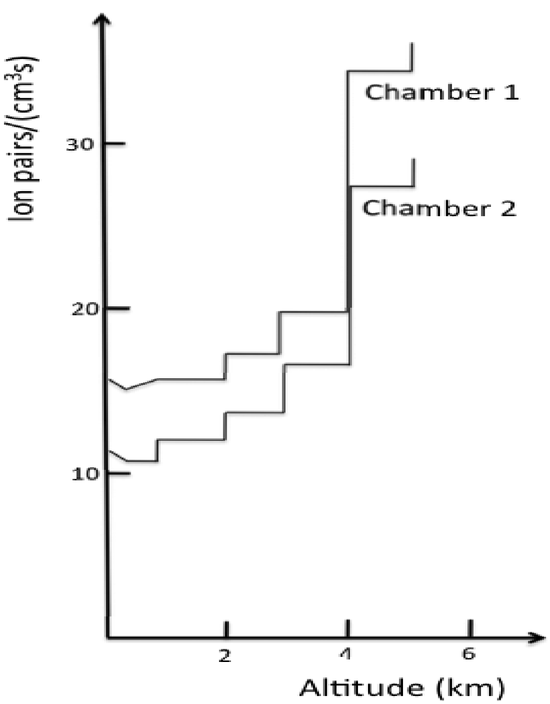


- How to increase the sensitivity of Wulf's measurements on the Eiffel tower? Flying on balloons!
- The first balloon flights with the purpose of studying the properties of penetrating radiation were arranged in 1909, in Germany by Bergwitz, and in Switzerland by A. Gockel, professor at the University of Fribourg
- Ascending up to 4000 m, Gockel found that the ionization did not decrease with height as expected on the hypothesis of a terrestrial origin
  - Copyright of the term "kosmische Strahlung"

A new boost: Hess

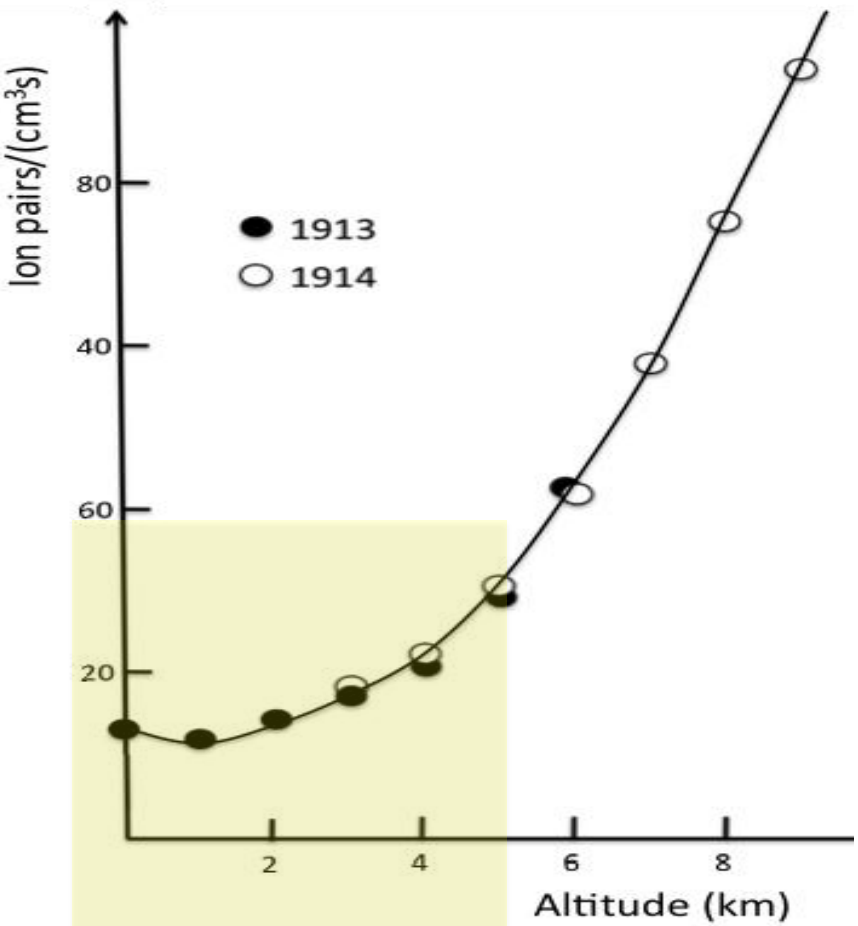
- The Austrian Victor Hess (1883-1964), at that time working in Wien and in Graz, started studying Wulf's electroscope, and measuring carefully the absorption coefficients of radioactivity in air
  - Thorough check & improvement of Eve's work; separation between alpha, beta, gamma
- In 1911, he continued his studies with balloon observations: he made 2 ascensions at ~1300 m, measuring possible variations of radioactivity, and found no effect. He had 3 Wulf electroscopes in Zn boxes of different thicknesses

Hess' final balloon flights



- From April 1912 to August 1912 Hess had the opportunity to fly 7 times. In the final flight, on August 7, Hess, 29-y-old, reached 5200 m
  - His results showed that the ionization, after passing a minimum, increased considerably with height
  - He concluded that the increase of the ionization with height is due to a radiation coming from above, and thought that this radiation had extra-terrestrial origin

Kolhörster and the final confirmation



The final flight by Kolhörster would be performed on 28 June 1914, the same day of the assassination of Archduke Franz Ferdinand of Austria on the roman bridge of Sarajevo: WWI starts

- The results by Hess were later confirmed by the 26-y-old Kolhörster in a number of flights up to 9200 m
  - An increase of the ionization up to 10x at sea level found
- The absorption coefficient of the radiation from top was also estimated, and turned out to be 8 times smaller than the absorption coefficient of air for gamma rays as known at the time
  - This result was neglected by the v s!

Word War I washes everything out… and science restarts in the new world

- During WWI and immediately after, few investigations were performed. Kolhörster improved his apparatus and made measurements in 1923 in agreement with earlier balloon flights

- There were, however, also negative attitudes against extraterrestrial radiation. Hoffmann (1924), and Behounek (1925), using newly developed electrometers, concluded that ionization was due to radioactive elements in the atmosphere

- After the war, the focus of the research moved to the US; Millikan & Bowen developed a low mass (200 g) electrometer and ion chamber for unmanned balloon flights using data transmission technology developed during the war

  – In flights up to 15000 m in Texas they found a radiation intensity ¼ the intensity reported by Hess and Kolhörster. They attributed this difference to a turnover in the intensity at higher altitude, being unaware that a (latitude) geomagnetic effect existed

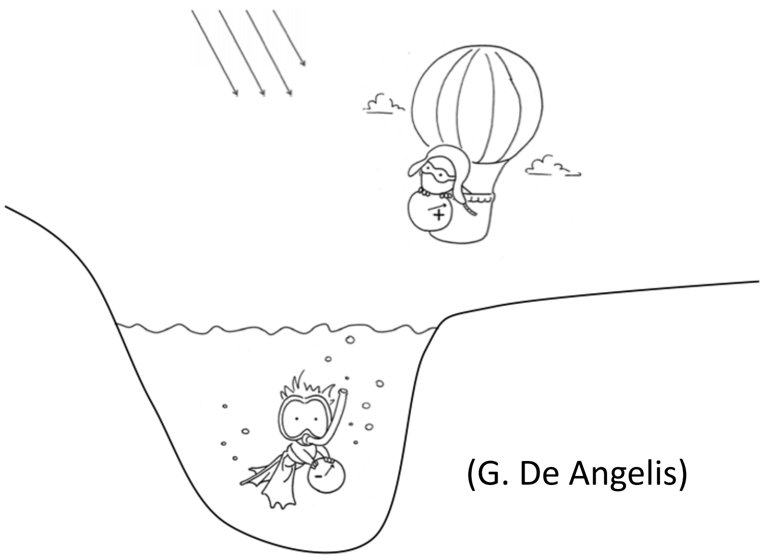
  – Millikan concluded that there was no extraterrestrial radiation: his statement at the American Physical Society in 1925 was “The whole of the penetrating radiation is of local origin". Millikan was strongly attacked, e.g., by Compton.

In the early 1920's the existence of hohenstrahlung was questioned.

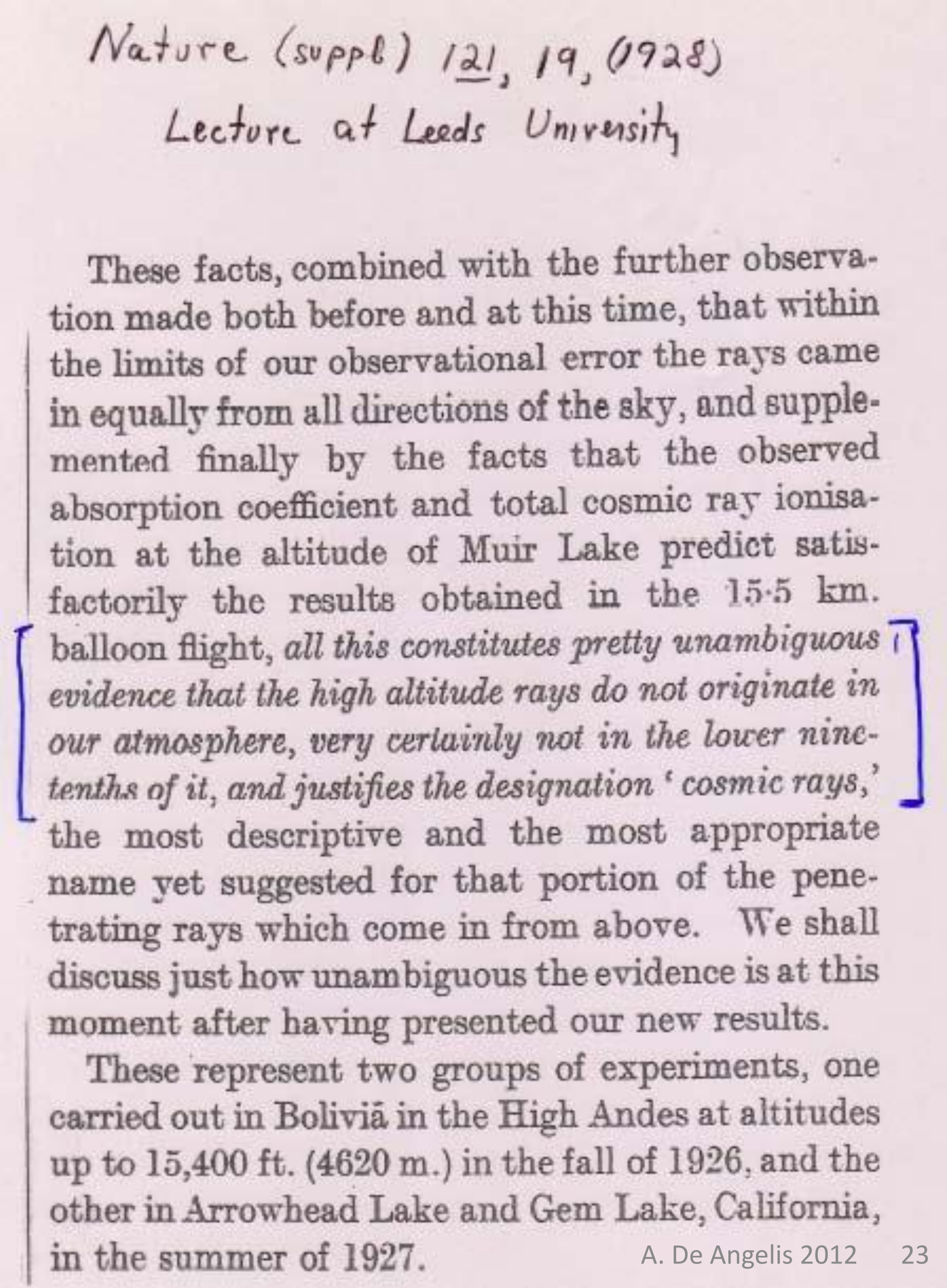
Otis and Millikan Phys Rev 23 778 (1924)

62. The source of the penetrating radiation found in the earth's atmosphere. Russell M. Otis and R. A. Millikan, California Institute of Technology.—Assuming, following Kolhorster's 1923 conclusions, a penetrating radiation of cosmic origin which produces 2 ions/cc/sec. at sea level and has an absorption coefficient per cm in water of 2.5×10^{-3}, we find that this radiation would produce 9 ions/cc/sec. on top of Pike's Peak (14100 ft). Inside our completely enclosing lead shield, 5 cm thick, it should produce 7.8 ions/cc/sec. The ionization in our apparatus contributed by the walls and the lead shield was found to be at least 7 ions/cc/sec., so that if there were no local radiation on Pike's Peak, the lowest obtainable value of the ionization in our shielded vessel should have been 14.8 ions/cc/sec. We observed as low as 11. We conclude, therefore, that there exists no such penetrating radiation as we have assumed. Second, we found as a result of a snow-storm on the mountain as large a percentage change (about 10 per cent) in the ionization inside our 5 cm lead shield as outside it. We interpret this result also as meaning that the whole of the penetrating radiation is of local origin. How such quantities of radioactive material get into the upper air is as yet unknown.

In 1926 upon further experimentation Millikan completely reverses his conclusions!



(G. De Angelis)



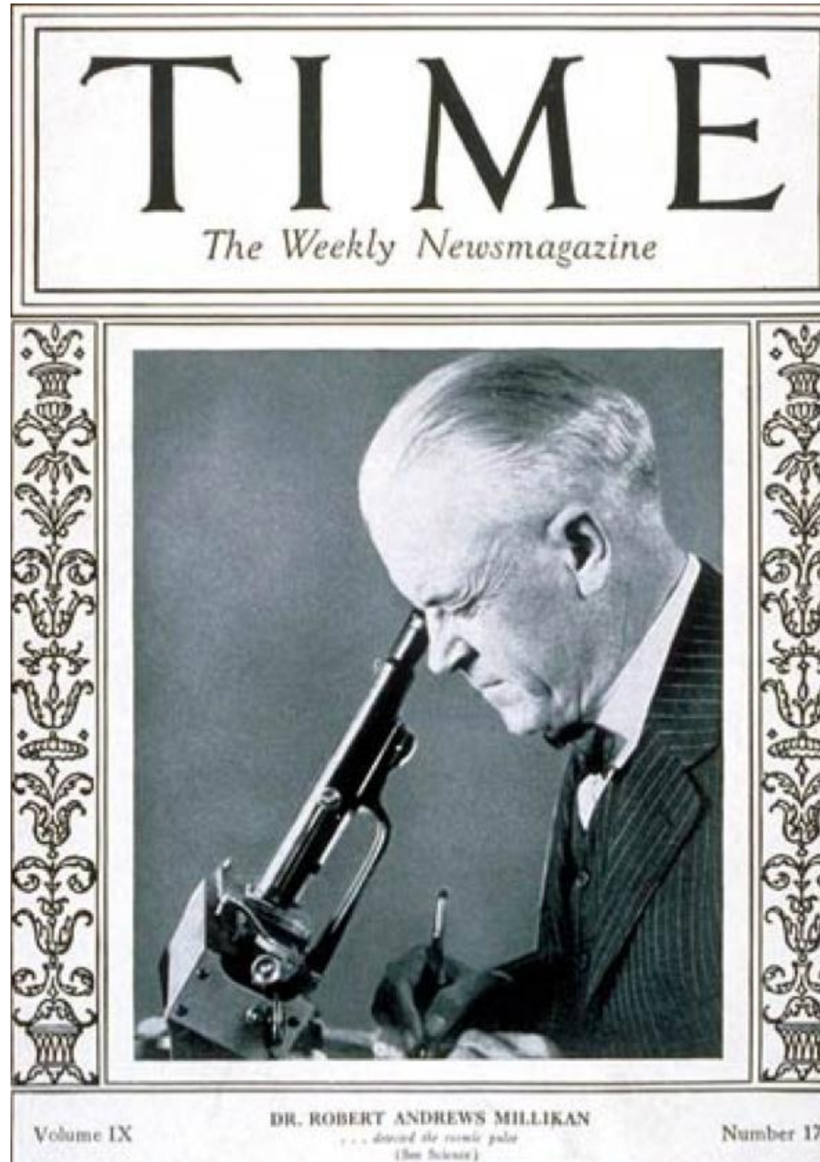
Nature (suppl) 121, 19, (1928)
Lecture at Leeds University

These facts, combined with the further observation made both before and at this time, that within the limits of our observational error the rays came in equally from all directions of the sky, and supplemented finally by the facts that the observed absorption coefficient and total cosmic ray ionisation at the altitude of Muir Lake predict satisfactorily the results obtained in the 15·5 km. balloon flight, *all this constitutes pretty unambiguous evidence that the high altitude rays do not originate in our atmosphere, very certainly not in the lower nine-tenths of it, and justifies the designation 'cosmic rays,'* the most descriptive and the most appropriate name yet suggested for that portion of the penetrating rays which come in from above. We shall discuss just how unambiguous the evidence is at this moment after having presented our new results.

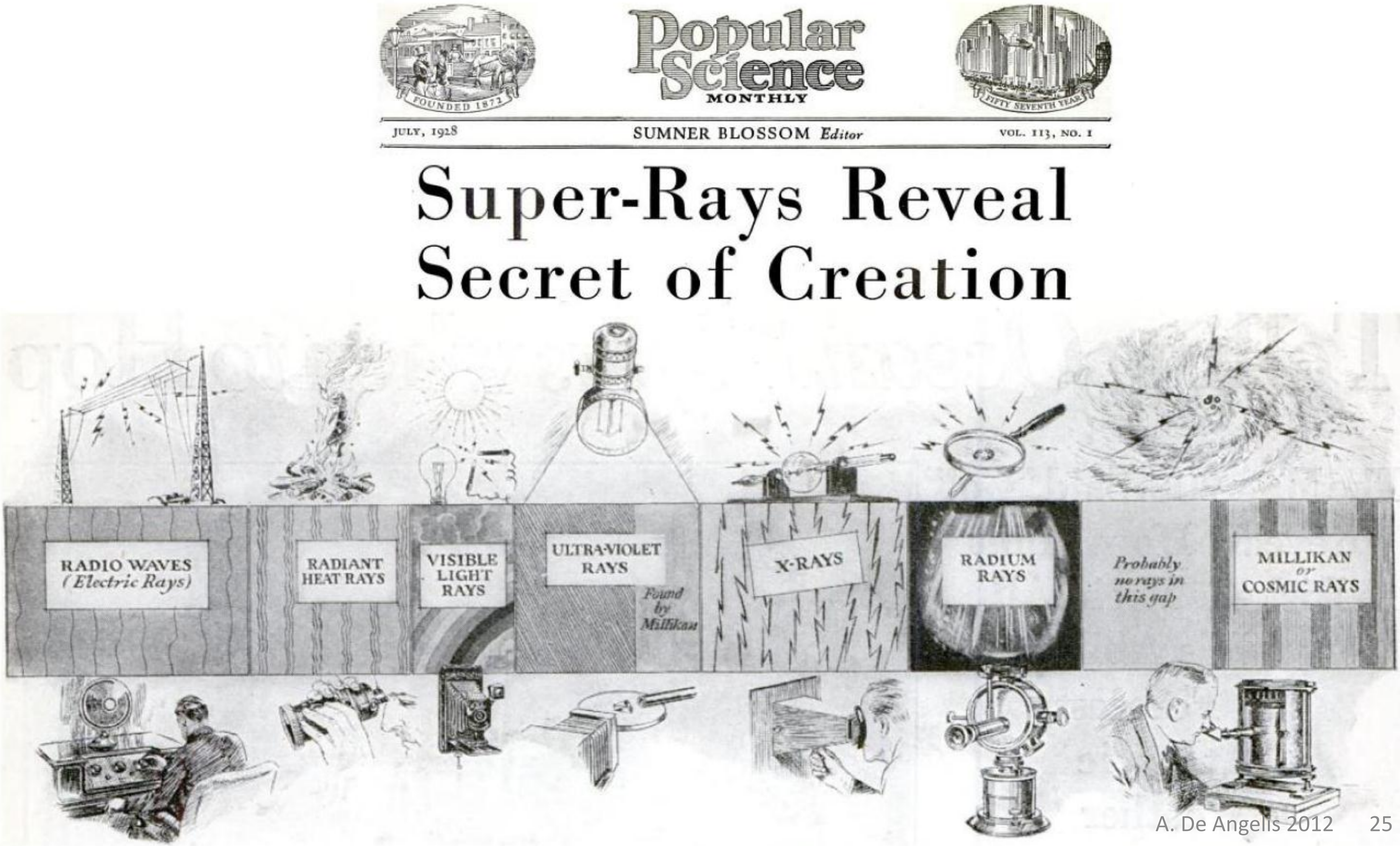
These represent two groups of experiments, one carried out in Boliviă in the High Andes at altitudes up to 15,400 ft. (4620 m.) in the fall of 1926, and the other in Arrowhead Lake and Gem Lake, California, in the summer of 1927.

Truth reestablished (but merit stolen)

- In 1926, however, Millikan and Cameron carried out absorption measurements of the radiation at various depths in lakes at high altitudes
  - They reproduced Pacini's depth effect, and they concluded that these particles shoot through space equally in all directions, calling them "cosmic rays"
  - In the conclusive Phys. Rev. article, they ignored Wulf, Gockel, Pacini, Hess
- Millikan was handling with energy and skill the communication with media, and in the US the discovery of cosmic rays became, according to the public opinion, a success of American science
  - Millikan argued that the cosmic rays were the "birth cries of atoms" in our galaxy



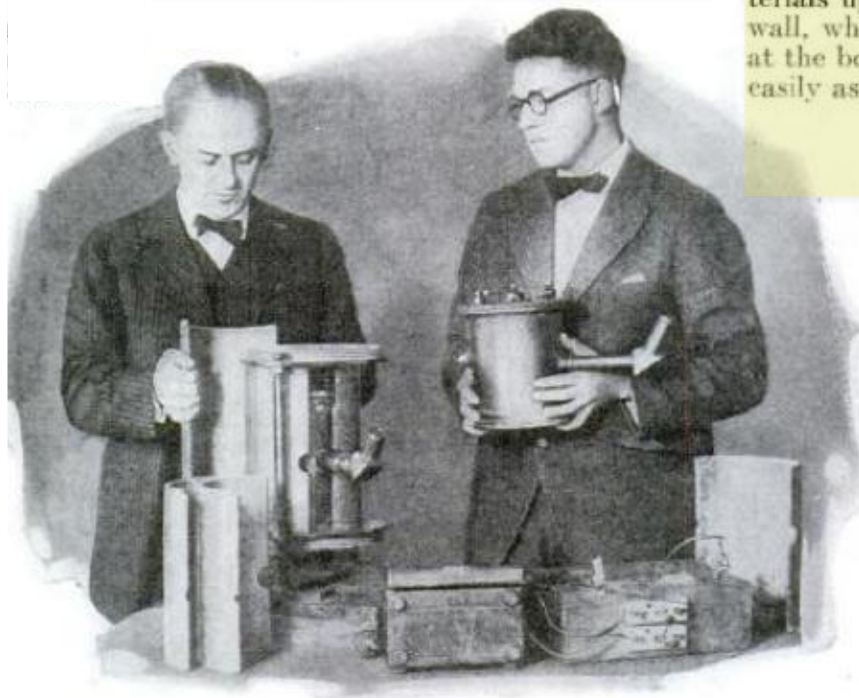
Marketing cosmic rays



[...]

From the lips of Dr. Millikan in Washington, I heard the thrilling story of his discovery. I found him a vital, dynamic man of sixty, whose handshake crushed my fingers and whose simple words carried the assurance of authority. That story was one of years of fruitless experiment, bitter disappointment, physical hardship, and final triumph. He told of struggles up rugged mountains on two continents to find and measure the elusive rays—then of a flash of inspiration only a few weeks ago that proved the rays the actual messengers of creation.

If the rays came from outside, Millikan reasoned, they should be hundreds of times stronger at the top of the earth's



Dr. Millikan (left) and Dr. G. Harvey Cameron with electroscopes they sank in California and Bolivia mountain lakes to detect cosmic rays. The instruments were raised and examined through the eyepiece

air than at the bottom. He resolved to send a sounding balloon with instruments to record them clear to the top of the atmosphere.

work apparently wasted.

"Then," said Millikan, "we saw what fools we had been to carry building materials up that mountain. Why build a wall, when you can bury an electroscope at the bottom of a mountain lake just as easily as you can hide it behind a lead screen, and the water of the lake will serve as the equivalent of many feet of lead. The next thing to do was to go at it sensibly. We would climb to the top of 15,000-foot Mount Whitney, in southern California—the highest mountain in the United States—and there, under its brow, would sink our electroscopes in the pure, snow-fed waters of Muir Lake."

With Dr. Cameron and a couple of students, Millikan toiled up Mount Whitney in August, 1925, and found the secret of the stars.

Two thousand feet from the top, they had to shoulder the boats, lumber to build rafts, and instruments their mules had carried.

Anxiously they sank their electroscopes. A cry of triumph echoed through the frosty air. There were cosmic rays—rays that pierced the water for fifty feet, downward, and then stopped!

- Anyway, also Hess and Kolhörster were not referenced (Gockel, whose measurement had not succeeded, was). Bergwitz, Hess and Kolhörster wrote an article emphasizing their priority on the balloon results (Phys. Zeit. 1926).

Hess Phys Zeit 27 159 (1926)

Not pleased with Millikan

Zu der eingangs zitierten Veröffentlichung von A. Millikan möchte ich vorerst bemerken, daß er die Geschichte der Entdeckung der Höhenstrahlung in einer Weise darstellt, die Mißverständnisse hervorrufen könnte[3]).

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1) Physik. Zeitschr. 13, 1084, 1912; Wien. Ber. IIa, 121, 2001, 1912.

2) Physik. Zeitschr. 14, 610, 1913; Wien. Ber. IIa, 132, 1053, 1913.

3) Die neuerliche Feststellung der Existenz und der hohen Durchdringungskraft der Höhenstrahlung durch Millikan und seine Mitarbeiter wurde von amerikanischen naturwissenschaftlichen Zeitschriften wie „Science", „Scientific Monthly" zum Anlaß genommen, um für die Höhenstrahlung die Bezeichnung „Millikan-Strahlen" vorzuschlagen. Da es sich hier nur um die Bestätigung und Erweiterung der Ergebnisse der von Gockel, von mir und von Kolhörster 1910 bis 1913 ausgeführten Strahlungsmessungen im Ballon handelt, ist diese Benennung als irreführend und unberechtigt abzulehnen.

Hess: Physik. Zeitschr. 27, 159, (1926)

As concerns the publication of Millikan, cited above, I would like to remark that he tells a story of the discovery of hohenstrahlung that could be easily misunderstood.

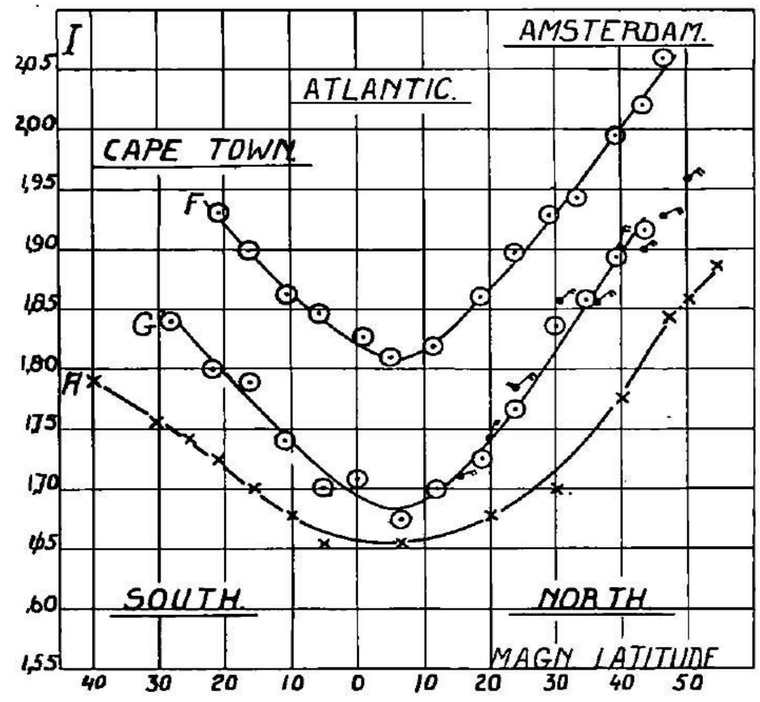
3) The recent determination by Millikan and his colleagues of the high penetrating power of hohenstrahlung has been an occasion for American scientific journals such as “Science” and “Scientific Monthly” to introduce the term “Millikan Rays”. Millikan’s work is only a confirmation and extension of the results obtained by Gockel, by myself , and by Kolhörster from 1910 to 1913 using balloon borne measurements of the rays. To refuse to acknowledge our work is an error and unjustified.

Exchange of letters between Pacini and Hess

- Pacini to Hess, March 1920: … *[in your] paper entitled `The problem of penetrating radiation of extraterrestrial origin' … the Italian measurements …, which take priority [for] the conclusions that you … draw, are missing; and I am so sorry about this, because in my own publications I never forgot to mention and cite anyone...*
- Hess to Pacini, March 1920: … *My short paper … is a report of a public conference, and therefore has no claim of completeness…*
- Pacini to Hess, April 1920: *[…but] several authors are cited whereas I do not see any reference to my relevant measurements … performed underwater in the sea and in the Bracciano Lake, that led me to the same conclusions that the balloon flights have later confirmed. …*
- Hess to Pacini, May 1920: *… I am ready to acknowledge that certainly you had the priority in expressing … in `Nuovo Cimento', February 1912, the statement that a non terrestrial radiation of 2 ions/cm^3/s at sea level is present. However, the demonstration of the existence of a new source of penetrating radiation from above came from my balloon ascent to a height of 5000 meters on August 7 1912, in which I have discovered a huge increase in radiation above 3000 meters. …*

Charged or neutral?

- It was generally believed that the cosmic radiation was gamma because of its penetrating power (the penetrating power of relativistic charged particles was not known)
  - Millikan had put forward the hypothesis that the gamma rays were produced when protons and electrons form He nuclei in interstellar space
- The geomagnetic effect in CR (the CR flux depends on latitude) was discovered accidentally in 1927 by the Dutch researcher J. Clay
  - Clay was measuring radiation in Java; in 1927 he carried his detector in a trip from Java to Genova
- Confirmed by Clay himself in 1928 (Java to Amsterdam), by Kolhörster, by Rossi, by Compton+



In the meantime (late '20s), Geiger counters enter the game

(Hans Geiger in 1928)

- Easier measurement
- Fast response (possibility of building coincidences)

Giuseppe Occhialini: "the Geiger-Muller counter was like the Colt in the Far West: a cheap instrument usable by everyone on one's way through a hard frontier."

Arthur Compton organized a world wide survey of the dependence of cosmic intensity on geomagnetic latitude.

Fig. 6. Compton with the special ionization chamber which he designed and used for his world-wide cosmic-ray survey during 1931–33, which proved that cosmic rays are charged particles.

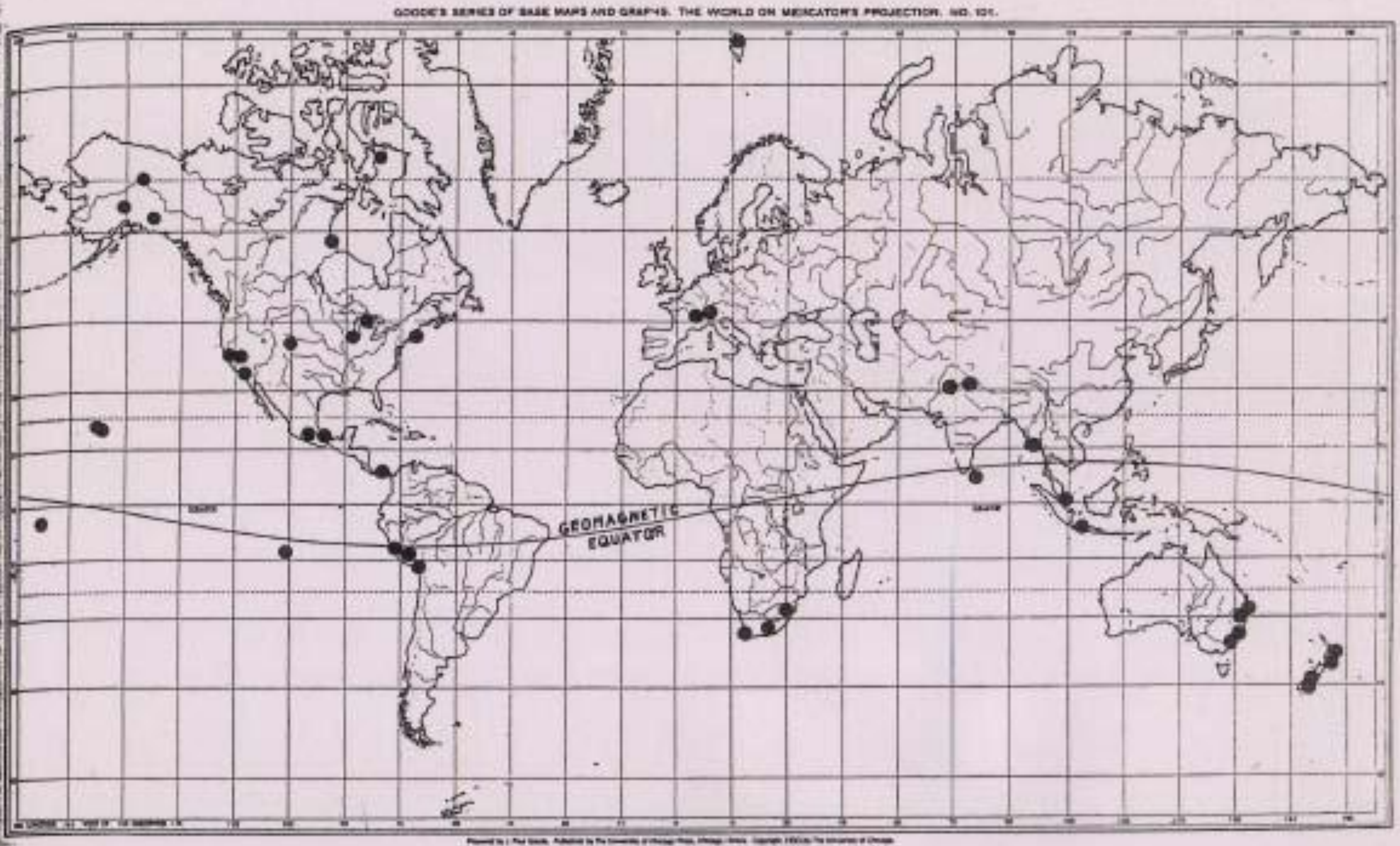


FIG. 1. Map showing location of our major stations for observing cosmic rays.

Bruno Rossi memoir 1984

For me, the turning point in the search came in the fall of 1929, with the appearance, in Zeitschrift für Physik, of the historical paper "Das Wesen der Höhenstrahlung" by W. Bothe and W. Kolhörster (Bothe and Kolhörster, 1929)

Until then, I had not been particularly interested in the phenomenon of the "Höhenstrahlung" or "cosmic radiation," using the suggestive expression introduced by Robert Millikan. I had not thought that it would offer, to me at least, a profitable field of research.

I had not been seduced by Millikan's well publicized theory, maintaining that cosmic rays were the "birth cry of atoms" in cosmic space, being born, in the form of γ-rays, when hydrogen atoms "fused" to form the heavier elements. To my skeptical mind, this was a romantic idea, lacking sound experimental support.

On the other hand, I had accepted, uncritically, the prevailing view that primary cosmic rays were high-energy γ-rays. Therefore I read with particularly keen interest the paper by Bothe and Kolhörster relating the first attempt to submit this assumption to a direct test.

Y. Sekido and H. Elliot (eds.), Early History of Cosmic Ray Studies, 53–73.

A dramatic result
by Bruno Rossi

B. Rossi
Zeit. f Physik 82 151 (1933)

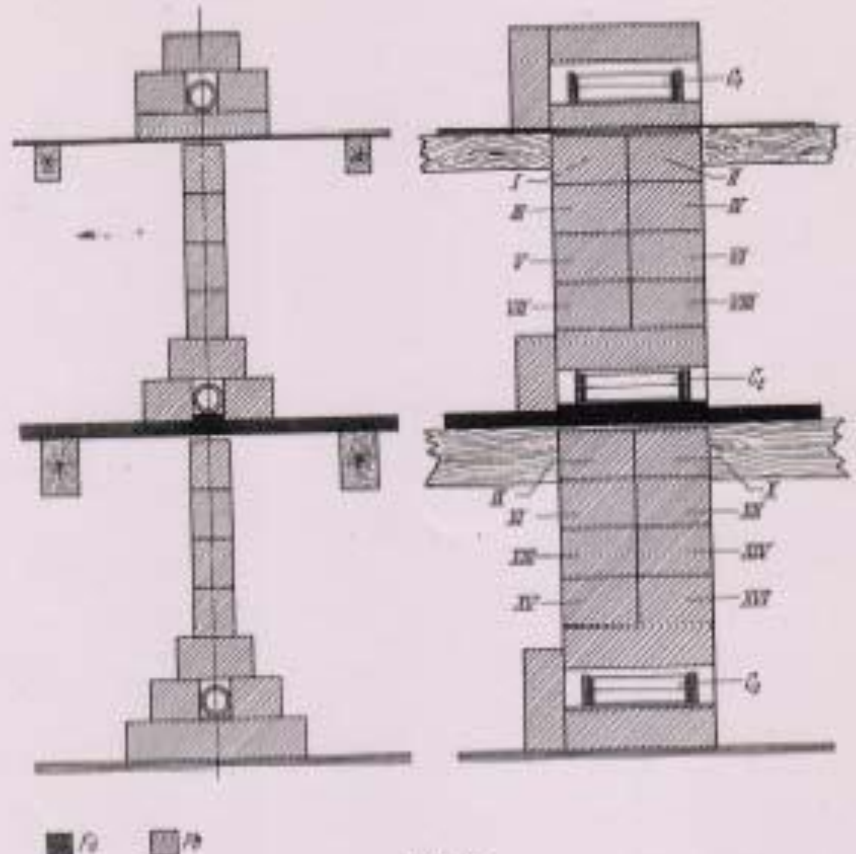


Fig. 2.

~ 50% of radiation at sea level
can penetrate 1 meter of lead.

Positive or negative?
The East-West effect

- 1933-34: three independent experiments (Alvarez & Compton, Johnson, Rossi) find that the intensity of CR is greater from the West than from the East => most primary cosmic rays are positively charged particles
  - In the course of his East-West experiment, Rossi (28 yr old) in Eritrea discovers cosmic-ray air showers, but does not study them in detail
    - Publication in Italian, again…
    - Auger will re-discover and study in larger detail in 1936

Rossi, La Ric. Sc. Suppl. 1 (1934) 579

Osservazione

La frequenza delle coincidenze registrate con i contatori lontani l'uno dall'altro e indicata nelle tabelle sotto il nome di « coincidenze casuali », appare più elevata di quella che sarebbe stata prevedibile in base al potere risolutivo delle registrazioni, misurato a Padova prima della partenza ($2 \cdot 10^{-4}$ sec. per la registr. II). Ciò fece nascere il dubbio che tali coincidenze non fossero, in realtà, tutte casuali. Questa ipotesi sembra essere avvalorata dalle due seguenti osservazioni:

1º) In 21 ore e 37 minuti vennero registrate fra tre contatori allontanati e disposti in modo che uno stesso corpuscolo non potesse attraversarli, 14 coincidenze. Se queste fossero da considerarsi come casuali, alla registrazione dovrebbe venir attribuito un potere risolutivo di circa 0,02 sec.; ma in questo caso fra due contatori scoperti dovrebbero prodursi circa 200 coincidenze casuali all'ora, mentre in realtà se ne osservano solamente 6.

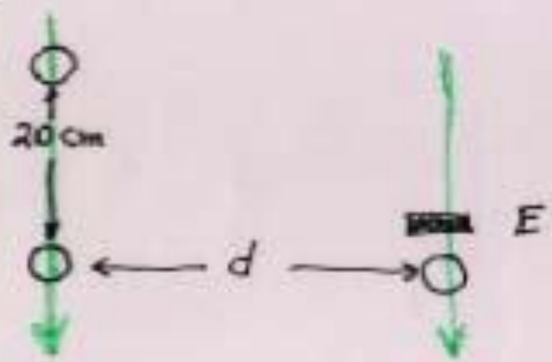
2º) Quando in una delle due registrazioni adoperate i contatori erano disposti in modo da registrare le coincidenze doppie « casuali », le rare coincidenze segnate da questa registrazione erano spesso accompagnate da una coincidenza simultanea della seconda registrazione.

Parrebbe dunque (poichè il dubbio di possibili disturbi venne escluso con opportune esperienze di controllo), che di tanto in tanto giungessero sugli apparecchi degli sciami molto estesi di corpuscoli, i quali determinassero coincidenze fra contatori anche piuttosto lontani l'uno dall'altro.

Mi è mancato purtroppo il tempo di studiare più da vicino questo fenomeno per stabilire con sicurezza l'esistenza dei supposti sciami di corpuscoli ed investigarne l'origine.

PHYSIQUE NUCLÉAIRE. — *Les grandes gerbes cosmiques de l'atmosphère.* Note (¹) de MM. **Pierre Auger** et **Roland Maze**, présentée par M. Jean Perrin.

1. Nous avons montré (²) l'existence de gerbes de rayons cosmiques produites dans l'atmosphère et dont les branches peuvent être distantes de plusieurs mètres. Nous avons pu étendre cette étude jusqu'à des distances de plusieurs dizaines de mètres et mettre ainsi en évidence les effets de corpuscules de très haute énergie dans leur traversée de l'atmosphère.



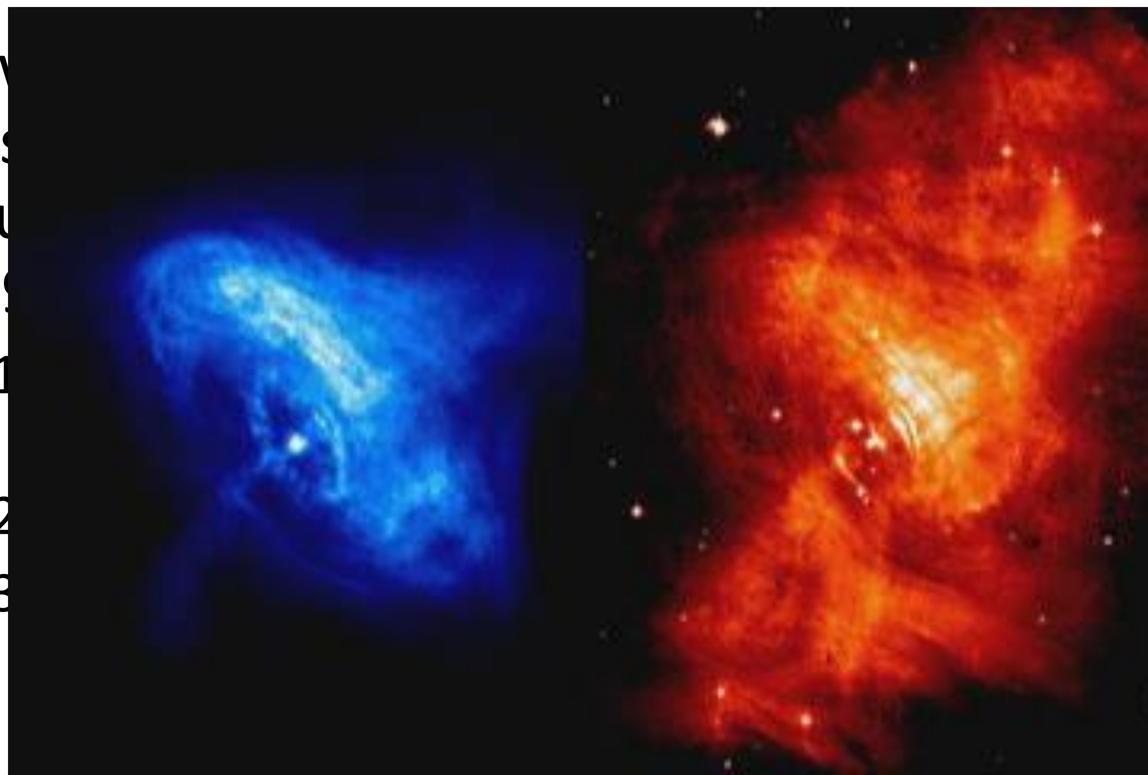
Discovery of extensive air showers.

	3 compteurs.					
d.	E = 0,2.	5.	10.	15.	4 compteurs.	Δ.
2^m	1,7	0,86	0,2	< 0,1	0,8	40
5^m	1,4	0,7	–	–	–	–
20^m	0,9	0,4	0,1	< 0,1	0,45	30

A hypothesis on the origin of CR

(Zwicky in 1930)

- In a 1931 lecture course at Caltech, Zwicky introduced the term "super-nova" to distinguish the explosion of an entire star from the less powerful nova, which involved violent and repeated outbursts on the surface of an unstable star
- Zv can as su n 19 :
  1 ich
  2
  3

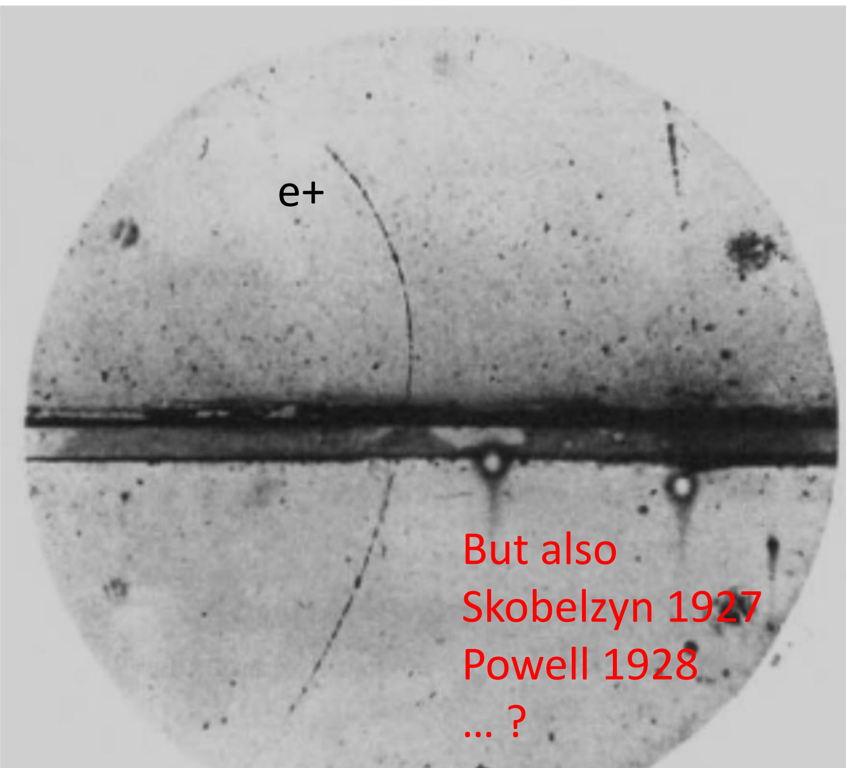


Most discoveries in elementary particle physics in the early years due to cosmic rays

- Thanks to the development of cosmic ray physics, scientists knew then that astrophysical sources were providing very-high energy bullets entering the atmosphere
- It was then obvious to investigate the nature of such bullets, and to use them as probes to investigate matter in detail, along the lines of the experiment made by Rutherford in 1900
  - Important contributions by W. Heisenberg in this phase
- Particle physics, the science of the fundamental constituents of matter, started with cosmic rays. Many fundamental discoveries were made…

Antimatter (the antielectron, or positron: Anderson 1933)

- *Consistent with Weil's interpretation of Dirac's equation (1927-28) …*



But also
Skobelzyn 1927
Powell 1928
… ?

- Picture taken by Anderson in 1932 of a cloud chamber (Nobel to Wilson in 1927) in the presence of a magnetic field
- The band across the middle is a Pb plate, which slows down the particles. The momentum of the track after crossing the plate is smaller than before
- From the direction in which the path curves one can deduce that the particle is positively charged
- Mass can be deduced from the long range of the track - a proton would have come to rest in a shorter distance

=> It is a positive electron!

At the same time, gamma -> e+e- (Occhialini & Blackett)

A note: Dirac's equation announced in '28 in Cambridge; at the same conference Skobelzyn spoke about some unexplainable "wrong charge" events.

1936: The Nobel prize to Hess (& Anderson)

Hess was awarded the 1936 Nobel Prize in physics, shared with Anderson. Hess was nominated by Clay, Compton:

- *The time has now arrived, it seems to me, when we can say that the so-called cosmic rays have their origin at remote distances from the Earth […] and that the use of the rays has by now led to results of such importance that they may be considered a discovery of the first magnitude. [...] It is, I believe, correct to say that Hess was the first to establish the increase of the ionization observed in electroscopes with increasing altitude; and he was certainly the first to ascribe with confidence this increased ionization to radiation coming from outside the Earth*

Nominations for Nobel Prize 1936

Hess

Prof Clay (Netherlands)
Prof Compton (Chicago) with Anderson

Anderson

Prof Millikan (Pasadena)
Prof Nagoya (Tokyo)
Prof Dressmann (Berlin)
Prof von Laue (Berlin)
Prof Planck (Berlin)
Prof Perrin (Paris) with Blackett
Prof M. de Broglie (Paris) with Blackett
Prof L. de Broglie (Paris) with Blackett and Occhialini

Later, many new discoveries in fundamental physics from cosmic rays

- 1937: The muon, or mu lepton, discovered by Neddermeyer+(mistaken for the pion until 1947: Conversi, Pancini, Piccioni)
- 1947: Pion (or π meson), the first meson, discovered by Lattes, Occhialini & Powell (predicted by Yukawa in 1935)
- 1947: Kaon (or K meson), the first strange particle, discovered by Rochester & Butler
- 1951: Λ, the first strange baryon, discovered by Armenteros+
- 1951-54: Parity violation (G-stack, the first European collaboration – mother of the modern HEP collaborations)

- CR physics is relatively cheap, which is important in the post-war conditions of European science (mountain-top labs, balloons…)

Particles found in cosmic rays

- Positron
- Muons
- Charged Pions
- K mesons
- Lambda
- Sigma
- Xi

3rd Rochester Conference 1952 December

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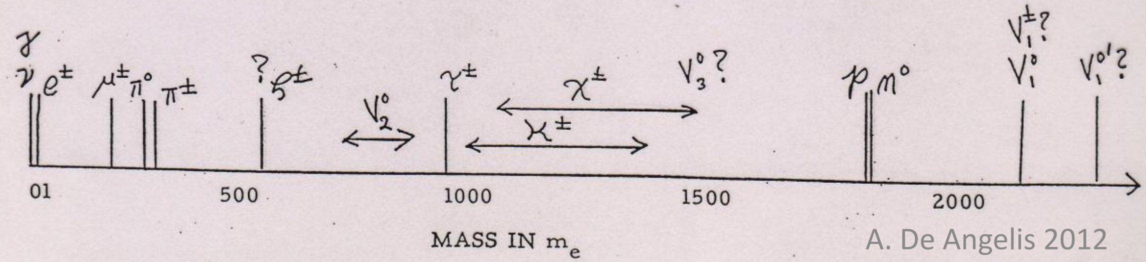
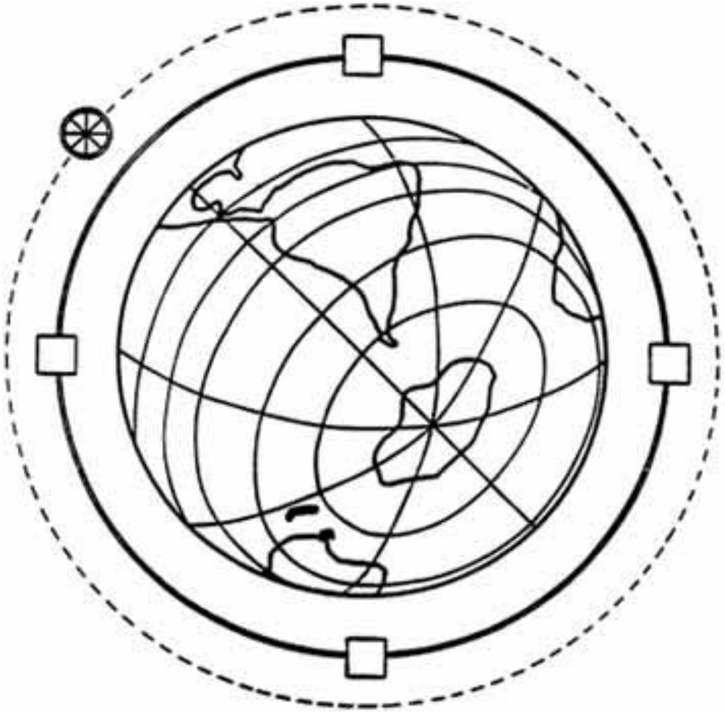
Appendix VI: THE UNSTABLE "ELEMENTARY" PARTICLES OR MEGALOMORPHS

Particle Products	Observed by	Lifetime (sec.)	Q	Mass	Statistics	Spin	Parity
? $V_1^{0\prime} \to p + \pi^-$	c. c.	$> V_1^0$	~75 Mev	$2270 m_e$?	F. D.	n/2?	-
$V_1^0 \to p + \pi^-$	c. c.	3.5×10^{-10}	37 Mev	$2190 m_e$	F. D.	n/2?	-
? $V_1^\pm \to p + (?)^0$	c. c.	?	?	?	?	?	?
$n^0 \to p + e^- + \nu$	Spectrograph & counters	740	783 Kev	$1837 m_e$	F. D.	1/2	-
$V_3^0 \to \Xi^- + \pi^+$	c. c.	?	?	$M_p > m_{V_3^0} > m_n$	?	?	?
K $\left\{ \begin{matrix} S^\pm \\ \chi^\pm \\ V^\pm \end{matrix} \right\} \to \pi^\pm + (?)^0$, $m_0 \sim 800 m_e$	c. c. c. c. & emul.	2×10^{-8} $- 2 \times 10^{-9}$	115 Mev	$1400 m_e$	B. E.	0?	S?
K $\left\{ \begin{matrix} \kappa^\pm \\ V^\pm \end{matrix} \right\} \to \mu^\pm + ?2\nu$	emul. c. c.	?	?	$1100 m_e$	F. D.?	1/2?	-
$\tau^\pm \to \pi^\pm + \pi^+ + \pi^-$	emul. & c. c.	10^{-8} $- 10^{-9}$	75 Mev	$975 m_e$	B. E.	0?	PS?
$V_2^0 \to \pi^+ + \pi^-$	c. c.	$\sim 10^{-10}$	210 Mev	$850 m_e$	B. E.	0?	S?
? $\zeta^\pm \to \pi^\pm + (?\pi^0)$	emul.	$?10^{-11}$	40 Kev $< Q <$ 6 Mev	$552 m_e$	B. E.	0?	S?
$\pi^\pm \to \mu^\pm + \nu$	counters	2.3×10^{-8}	5.9 Mev	$276 m_e$	B. E.	0	PS
$\pi^0 \to 2\gamma$ $\to e^+ + e^- + \gamma$	counters emul. & counters	$\lesssim 5 \times 10^{-15}$	135 Mev	$266 m_e$	B. E.	0	PS
$\mu^\pm \to e^\pm + 2\nu$	counters	2.15×10^{-6}	105 Mev	$212 m_e$	F. D.	1/2	-



…and new hints for understanding (Fermi 1949)

- Proposal of diffusive acceleration (Fermi, PR, 1949)



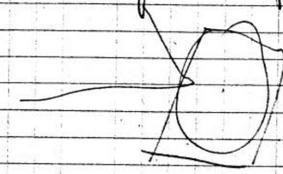
And also: the maximum possible energy for a terrestrial accelerator is ~ 5000 TeV (1954)

Fermi's 2nd order theory for acceleration of cosmic rays

Dec 4 1948

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

$$\frac{M}{2}(v+2V)^2 - \frac{Mv^2}{2} = \frac{M}{2}(4vV+4V^2) =$$

$$= M(2vV+2V^2) \qquad \text{Prob} = \frac{v+V}{2v}$$

Running after collision ($\text{prob} = \frac{v-V}{2v}$) gives energy gain

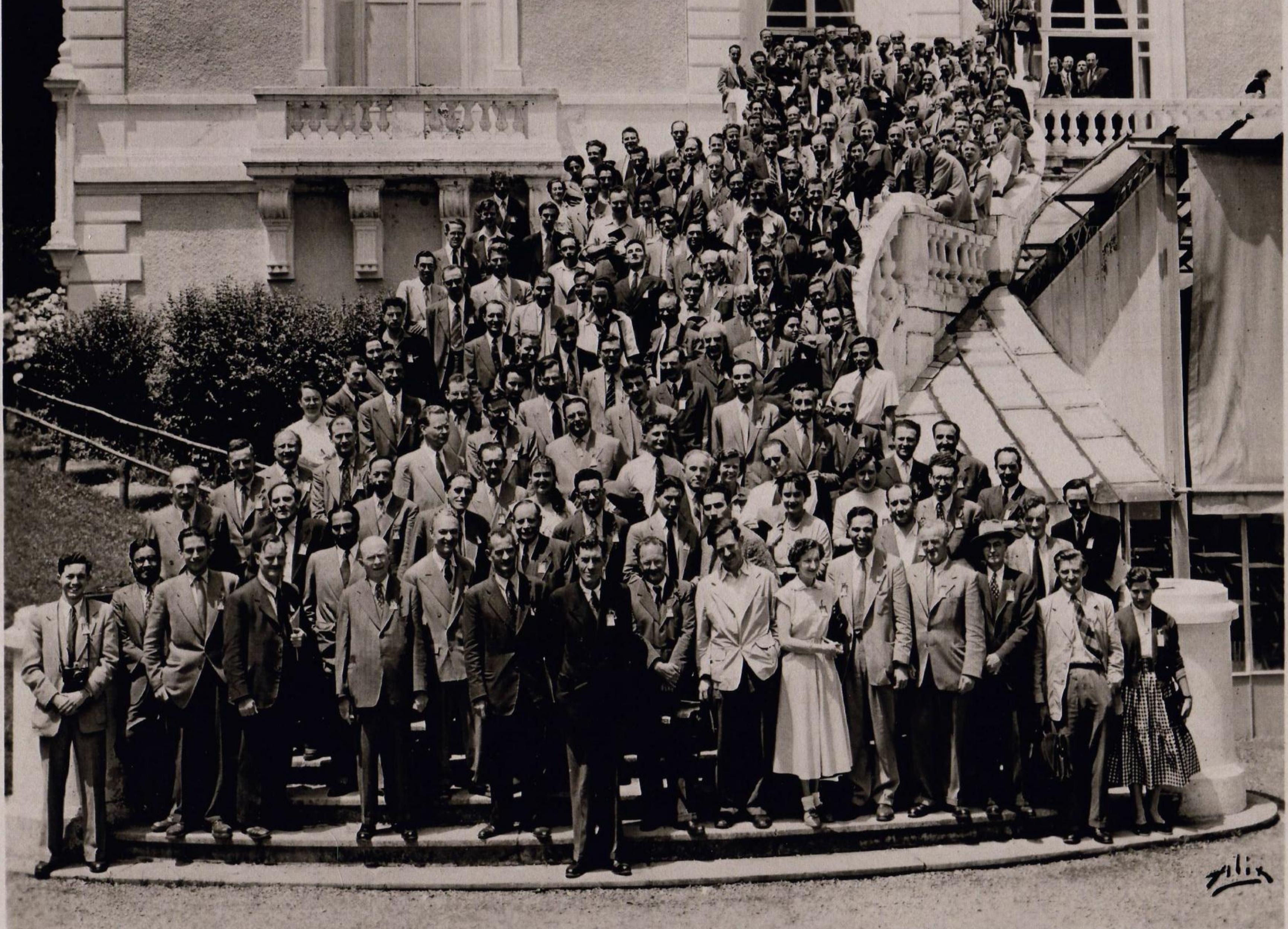
$$M(-2vV+2V^2)$$

Average gain order

$$MV^2$$

Relativistic: order

$$w\beta^2$$



CONGRÈS INTERNATIONAL SUR LE RAYONNEMENT COSMIQUE
BAGNÈRES-DE-BIGORRE, 6-12 Juillet 1953 Photo ALIX

Organized by Louis Leprince-Ringuet and Patrick Blackett

L. Leprince-Ringuet

J. de Physique (Colloque #8) V 43 (1982)

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Au Pic du Midi c'était Ch. Peyrou, B. Grégory, A. Lagarrigue, R. Armenteros, F. Müller puis A. Astier. Ont participé non seulement les français mais aussi des étrangers comme Ronald Rao de Princeotn, Tinlot de Rochester, Destaebler de Mit et aussi B. Le Fretter, en partie. Vous savez ce qui a été étudié au Pic. Le congrès de Bagnères de Bigorre en 1953, je dirais, a sonné le glas des rayons cosmiques et c'est Powell lui-même qui, dans son discours de clôture a dit : "Messieurs, maintenant nous sommes envahis, nous sommes sumbergés, ce sont les accélérateurs". Effectivement, la plupart des laboratoires de rayons cosmiques dont le nôtre, ici à l'Ecole Polytechnique, puis au Collège de France, se sont orientés vers les grands accélérateurs de particules et je voudrais vous dire aussi que le mot hypéron a été annoncé pour la première fois au congrès de Bagnères. Il y avait B. Rossi, E. Amaldi, C. Powell. Et on s'est demandé comment appeler ces nouvelles particules qui s'arrêtaient, qui étaient lourdes et qui donnaient un méson. Alors on a proposé divers noms. [Et je dois dire que c'est ma principale contribution à la physique, j'ai prononcé le mot hypéron] : le mot hypéron n'a pas été bien accueilli par Rossi. Rossi a dit "oh, hypéron, piperone, ça va pas". Et au contraire Powell était là et a dit "oh hypéron (prononcer haiperon) mervelous". Et on a dopté le mot hypéron. Et il a à Bagnères de Bigorre l'avenue de l'hypéron: c'est peut être le seul endroit au monde où une particule fondamentale a donné un nom à une avenue.

The 1953 CRC at Bagneres de Bigorre (Cronin 2011, arXiv:111.5338)

- From the concluding remarks by Leprince-Ringuet:

  "If we want to draw certain lessons from this congress let's point out first that in the future we must use the particle accelerators. Let's point out for example the possibility that they will permit the measurement of certain fundamental curves (scattering, ionization, range) which will permit us to dierentiate effects such as the existence of pi mesons among the secondaries of K mesons.

  I would like to finish with some words on a subject that is dear to my heart and is equally so to all the "cosmicians", in particular the "old timers". [...] We have to face the grave question: what is the future of cosmic rays? Should we continue to struggle for a few new results or would it be better to turn to the machines?

  One can no doubt say that that the future of cosmic radiation in the domain of nuclear physics depends on the machines [...]. But probably this point of view should be tempered by the fact that we have the uniqueness of some phenomena, quite rare it is true, for which the energies are much larger [...]"

- Then the accelerator era starts… And a particle zoo…

1953: research on cosmic rays is in CERN's constitution

CERN/GEN/8

CONSEIL EUROPEEN POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN COUNCIL FOR NUCLEAR RESEARCH

Organisme intergouvernemental créé par l'Accord de Genève du 15 Février 1952

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PARIS, 1ST JULY, 1953

CONVENTION

POUR L'ETABLISSEMENT D'UNE ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

PARIS, LE 1ER JUILLET 1953

3. The basic programme of the Organization shall comprise:

(...)

(c) The organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratory. This co-operation may include in particular:

(i) work in the field of theoretical nuclear physics;

(ii) the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;

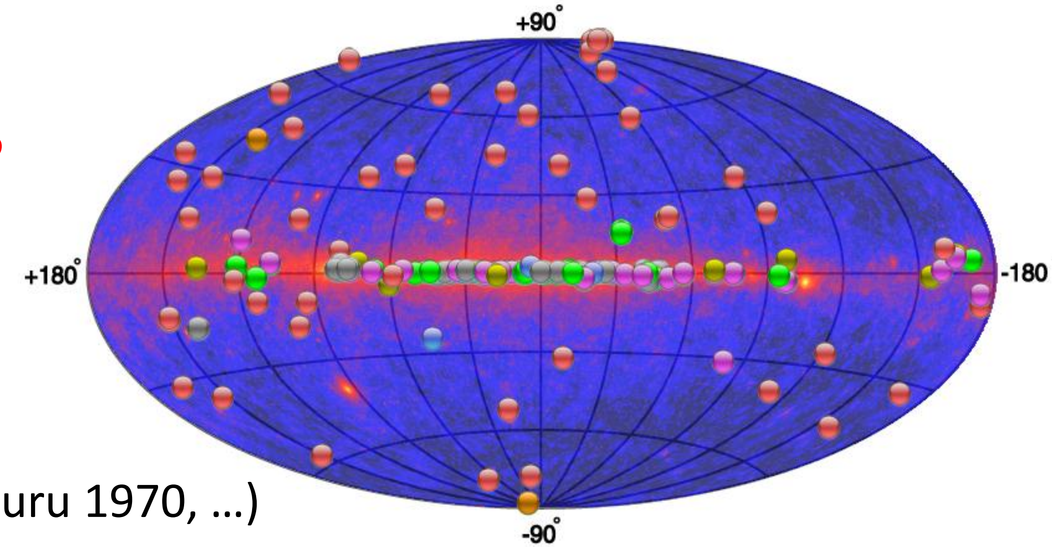
(iii) collaboration with and advising of national research institutions;

(iv) work in the field of cosmic rays.

Legacy from G-stack

The Organization shall (...) confine its activities to (...) the construction and operation of one or more international laboratories for research on high-energy particles, including work in the field of cosmic rays

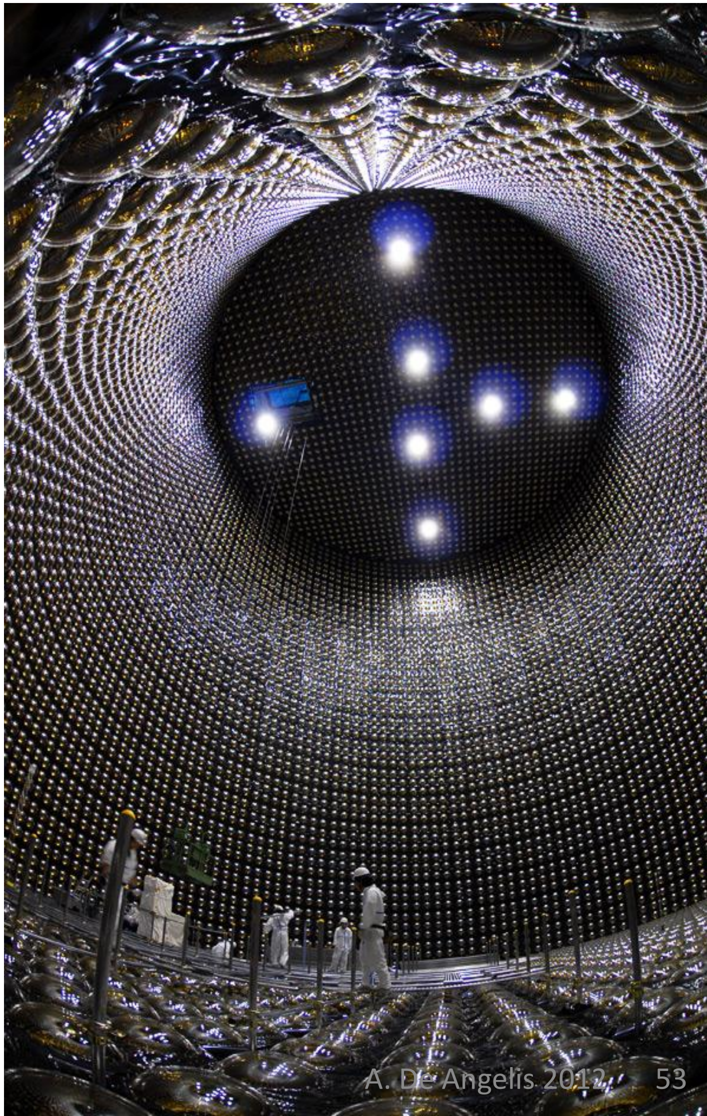
The flame still burns in the following years



- CMB (1964)
- X-ray astrophysics
  - Rockets (1962) and satellites (Uhuru 1970, …)
- VHE gamma-ray astrophysics
  - Many attempts in '60-'70; observation of Crab above 100 GeV, Weekes et al. 1989
  - Present large-scale IACTs HESS, MAGIC, VERITAS → CTA; Agile, Fermi satellites
- EHE cosmic detectors
  - Observation of a particle ~ 10^{20} eV in 1962 at Volcano Ranch (Linsley, Scarsi et al. 1962)
  - 1966: the GZK limit
  - …
  - Present large-scale detectors: the Pierre Auger laboratory
- Neutrino detectors
- …

and CR continue to contribute to fundamental physics

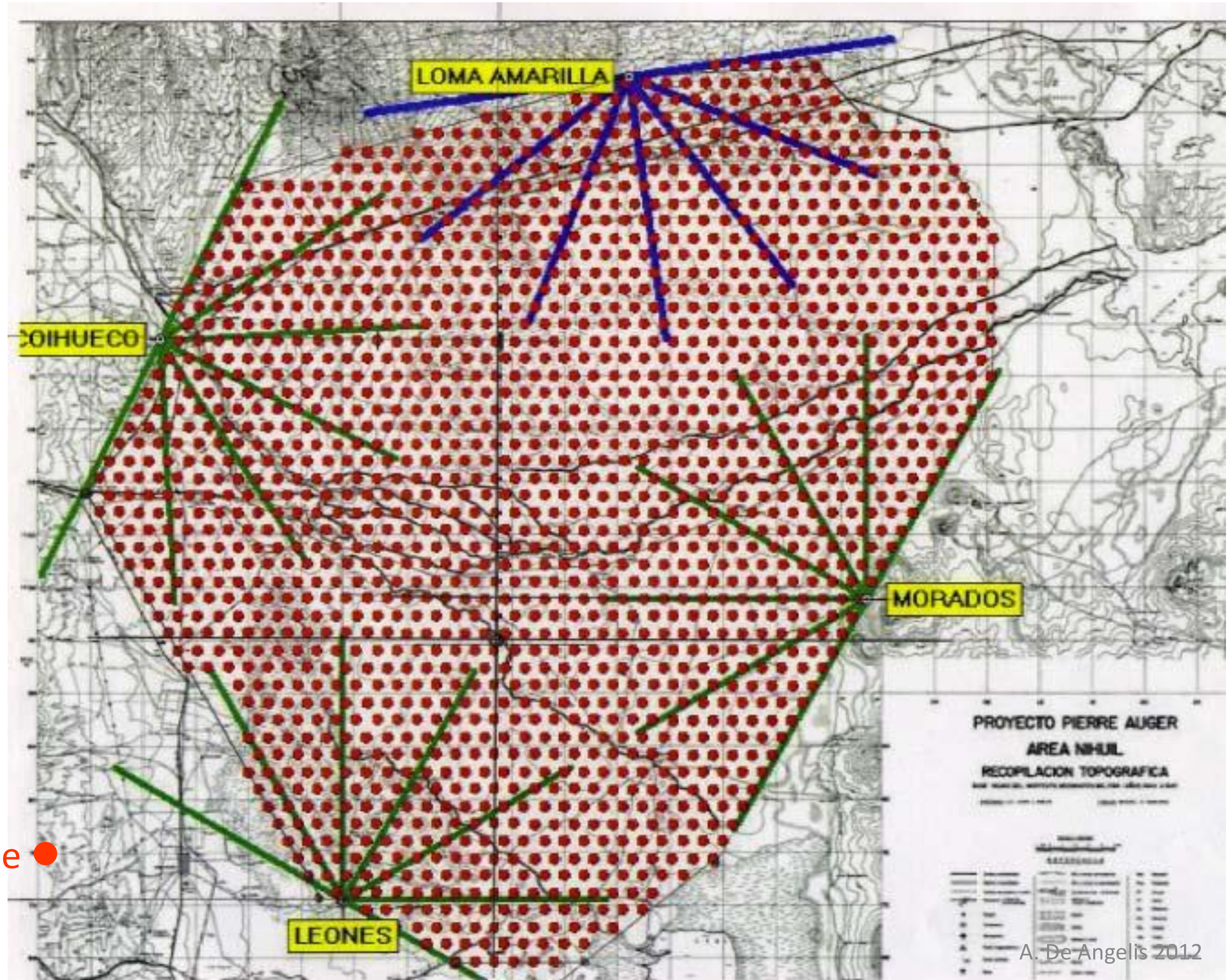
- Cosmic rays and cosmological sources again move into the focus of VHE particle and gravitational physics
- One of the most important recent result on elementary particle physics came from cosmic rays: neutrino has a nonzero mass
  - Interplay between CR and accelerator physics, again
  - Solar neutrinos; KamLAND 2002 (reactor), Gran Sasso 2010 (accelerator), T2K 2011



And vice versa: the progress of particle physics has allowed the project and construction of experiments otherwise unthinkable

The highest energy cosmic rays

3000 km^2



Malargue

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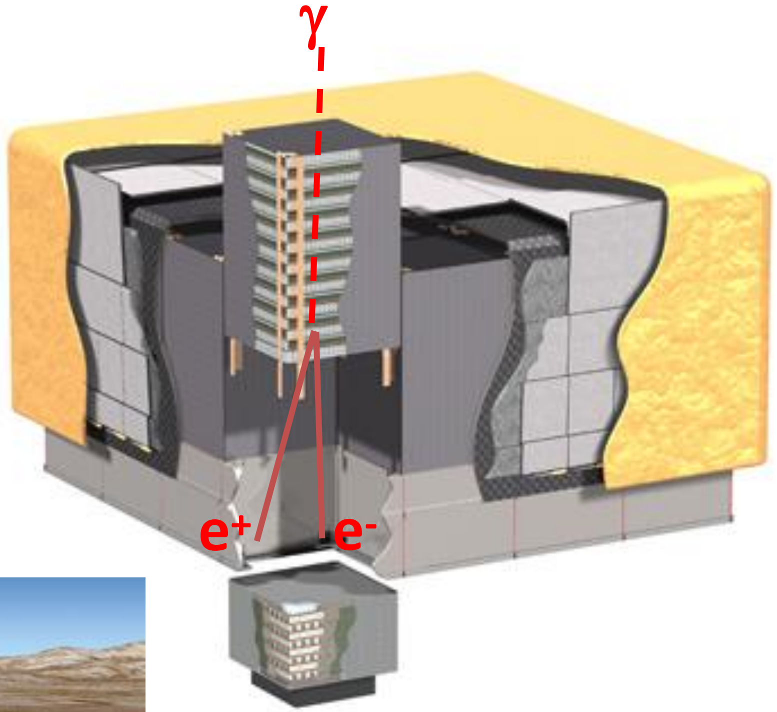
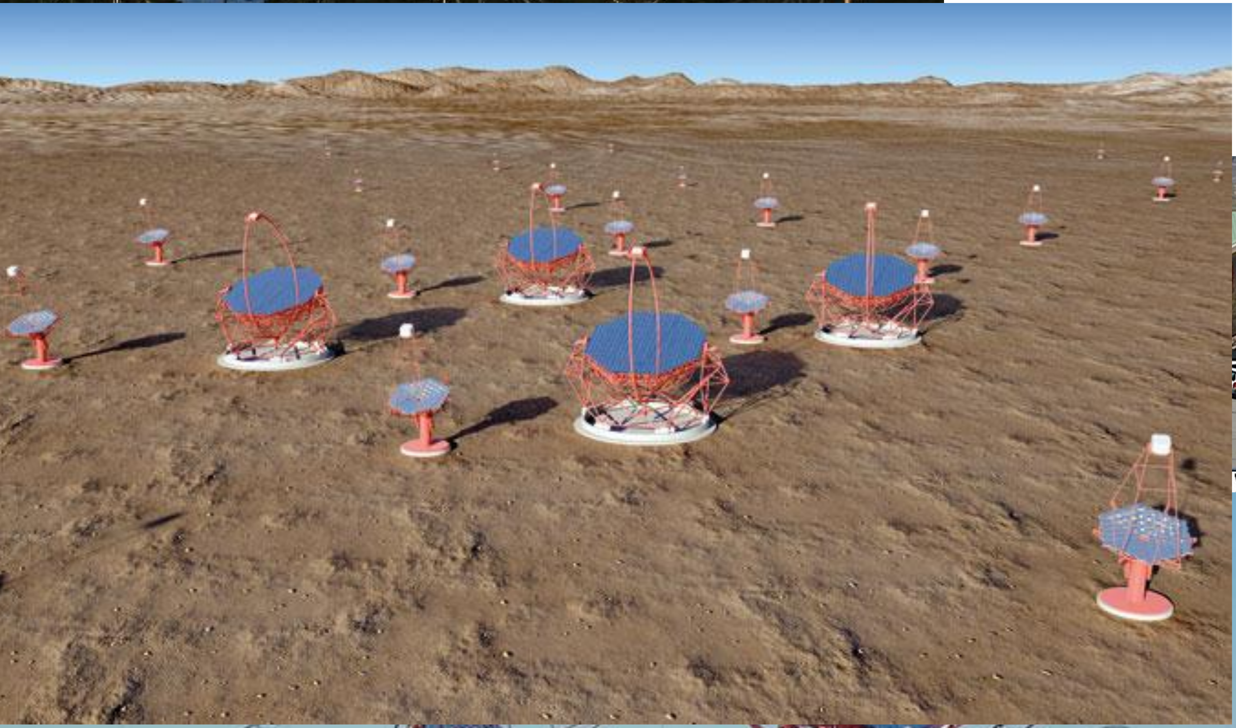
Alpha Magnetic Spectrometer

Measures in fine detail cosmic rays $< \text{some } 10^{11}$ eV : dark matter, antimatter, exotic particles

Launched May 16, 2011

The direct probes of cosmic particle accelerators





Conclusion

- Cosmic Ray physics and particle physics at laboratories/accelerators are a successful example of an interplay between disciplines; after 100 years this cooperation is still at the cutting edge
  - A century of great discoveries, and more to come
- The work behind the discovery of CR involved scientists all around the world. It is a successful example of international cooperation, with some clouds
- The story is fascinating, and many contributions are being rediscovered now
  - Several historical, political and personal facts might have contributed to unfair recognition of early works in the history of CR. In particular, rivalries between Europe and the US, and within Europe, had a negative influence on the correct recognition of the scientific property of ideas

Fortunately these problems appear to be far away from us


EUROPA-CEPT 1983
VIKTOR FRANZ HESS 1883-1964
NOBELPREIS FÜR PHYSIK 1936
6 S
REPUBLIK ÖSTERREICH
350 FCFA 2009
Prêmio Nobel da Física
Antoine Henri Becquerel (1852-1908)
Deteriorização Radioactiva
GUINÉ-BISSAU
REPUBLIQUE FRANÇAISE
0,60
POSTES
1867 MARIE CURIE 1934
ENRICO FERMI
1901-1954
800 ITALIA € 0,41
I.P.Z.S. - ROMA - 2001
C. BRUSCAGLIA
GUYANA $35.00
Arthur H. Compton (U.S.A.)
Physics, 1927
100th Anniversary of the Nobel Prizes
„ВЕНЕРА-13" ★ „ВЕНЕРА-14"
ПОЧТАМ
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ПОЧТА СССР 1982
120
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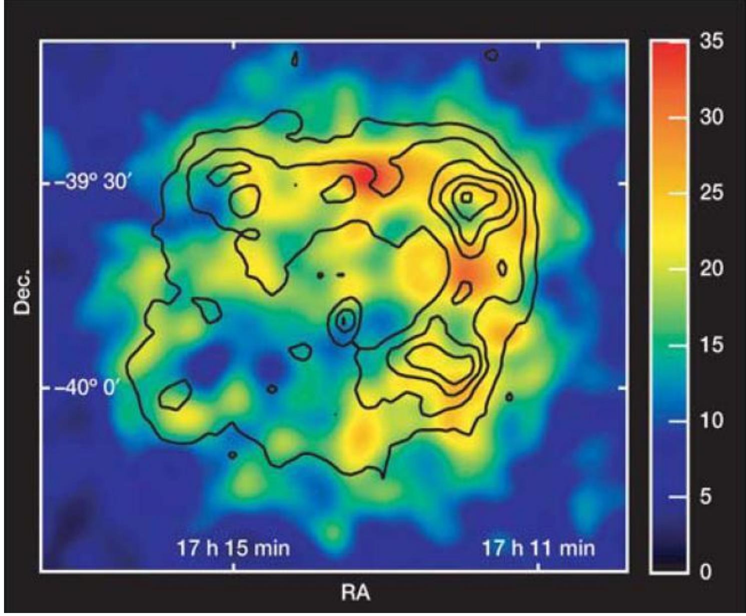
10^{20} ev
OBSERVATORIO PIERRE AUGER MALARGÜE MENDOZA ARGENTINA
REPÚBLICA ARGENTINA
CORREO OFICIAL
2007
The Royal Society 350 Years
Atomic Structure Rutherford
1ST
Robert Millikan
37c USA
80
NIPPON

BACKUP

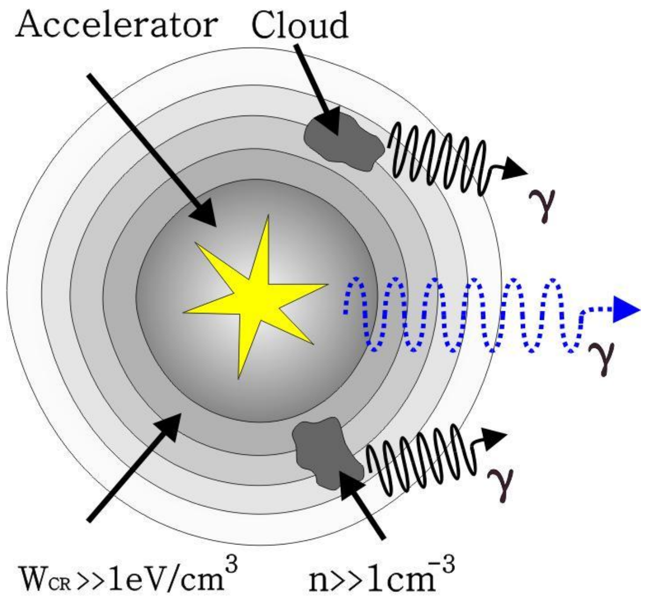

iblu
Alessandro De Angelis
L'enigma dei raggi cosmici
Le più grandi energie dell'universo
Springer

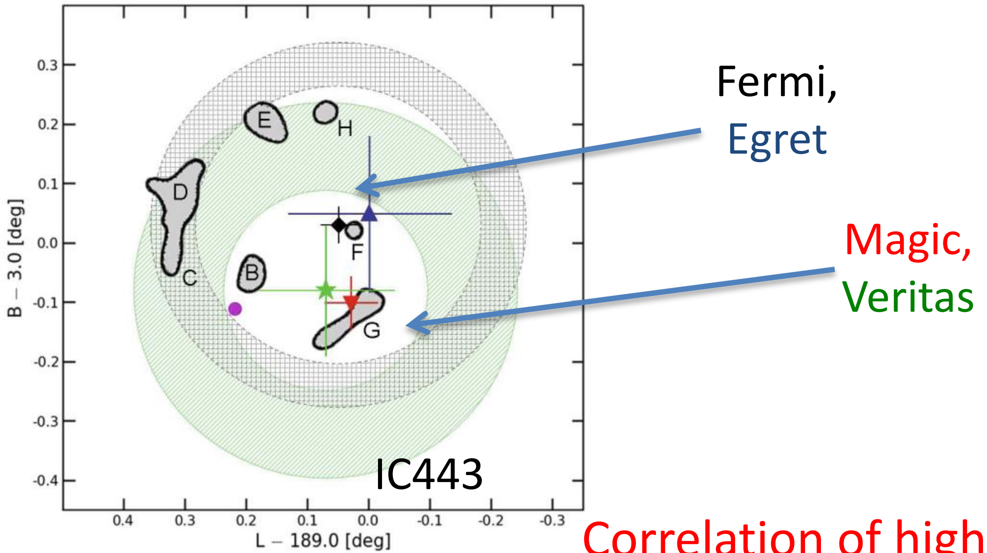
Sources of CR up to the knee

Cherenkov telescopes & X/gamma satellites



- Evidence that SNR are sources of CR up to ~1000 TeV came from morphology studies of RX J1713-3946 (H.E.S.S. 2004)
- Striking evidence from the morphology of IC443 (MAGIC + Fermi/Agile 2010)





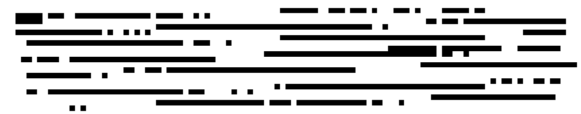
Correlation of higher energies with AGN (?)

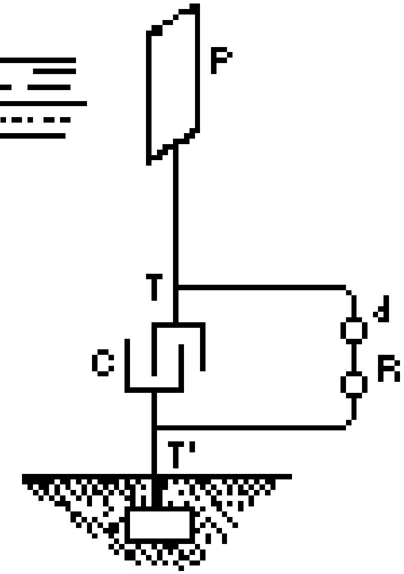
The flux of CR

- In 1901 Nikola Tesla patented (US patent #685,957/8) an “Apparatus for the Utilization of Radiant Energy”

These radiations are generally considered to be ether vibrations of extremely small wave lengths [...]

This phenomenon, I believe, is best explained as follows: the sun as well as other sources of radiant energy throw off minute particles of matter positively electrified, which [...] communicate an electrical charge





1 particle/cm²/s

<E> ~ 3 GeV

- Could it work?

  Yes

- How much power can it generate

  $P < 3$ GeV x 10000 CR/sm²

  $\Rightarrow P < 5\ \mu W/m^2$

  (Solar energy: ~ 200 W/m²)

Ahead of time

- Franz Linke, meteorologist; PhD: "Messungen elektrischer Potentialdifferenzen vermittels Kollektoren im Ballon und auf der Erde"
- 12 balloon flights: Sept. 1900 – Aug. 1903, with an Elster-Geitel 2-leaf electrometer
- Summary of his thesis: "Luftelektrische Messungen bei 12 Ballonflügen", Berlin 1904
- "Would one compare the presented values with those on ground, at 1000 m altitude where the measurements in general began the leakage [ionisation] is smaller than on ground, between 1 and 3 km of the same amount, and above larger than on Earth, with values increasing up to a factor of 4 at 5500 m altitude[…]. The uncertainties of the observations […] only allow the conclusion that the reason of the ionisation has to be found first in the Earth"

→ no reference in later papers, not known why

(Thanks to M. Walter)

Back to the early years: why so little to Pacini?

- Nobel: a sufficient condition. When the Nobel for Cosmic Rays was assigned Pacini was dead (in any case, the Nobel Committee referenced his contribution)
  - *(Hulthen:) Based on experiments by Eve, Pacini, Mache and others it became clear that [a] fraction of the […] ionisation could be attributed to radioactive substances. […E]stimates were made on the ionisation at different altitudes. However, early balloon based measurements by Bergwitz and Gockel did not show a significant decrease of the ionisation. Gockel's measurements, in agreement with measurements of Pacini, show that a not insignificant part of the radiation is independent of direct action of substances in the crust of the Earth.*

    (Pleijel:) The mystery of the origin of this radiation remained [however] unsolved until Hess made it his problem. ... With superb experimental skill Hess perfected the instrumental equipment used and eliminated its sources of error. With these preparations completed, Hess made a number of balloon ascents […] From these investigations Hess drew the conclusion that there exists an extremely penetrating radiation coming from space which enters the Earth's atmosphere.
- The years after WWI were characterized by nationalism
  - German scientists were initially boycotted by non-Germans. The International Research Council in 1919 officialized an exclusionary policy wrt Central Power: German scholars could not attend international meetings or participate in international scientific activities
    - Answer to the "Manifesto of the 93 German intellectuals" (1914)
  - Fixed in '26, with normalization of international relations; possible compensation mechanisms
- Pacini (who was an ordinary guy) was ignored by the Italian community, and never nominated for the Nobel
- Charm of the flight?

Edoardo Amaldi's opinion

Roma 14 luglio 1941 XIX

All'Eccellenza A. Lo Surdo
Direttore dell'Istituto Fisico della R. università
Roma

Sul Tevere del 2 luglio 1941 XIX è apparso un articolo a firma Giuseppe Pensabene, in cui si afferma che la Fisica nucleare ed i raggi cosmici sono scienze giudaiche.

Chiunque legga tale articolo si rende assai facilmente conto che chi scrive non conosce neppure lontanamente questi importanti campi di ricerca della fisica moderna.

La suddetta affermazione appare ancor più strana a chiunque sappia, come Voi sapete meglio di ogni altro, che il primo scopritore dei raggi cosmici fu l'italiano Pacini a cui seguirono i tedeschi Hess, Kholoerster eccetera.

Il largo pubblico ignora probabilmente un altro fatto e precisamente il notevolissimo sviluppo che hanno subito questi studi in Germania proprio negli ultimi anni. A testimonianza di questa mia affermazione Vi posso dire che sfogliando le Naturwissenschaften, oserei dire la più importante ed ufficiale rivista tedesca, ho trovato complessivamente nelle annate 1939-40 ben 65 articoli e lettere riguardanti i raggi cosmici e la fisica nucleare, su 188 aricoli e lettere riguardanti tutti i campi della fisica pura ed applicata. Da questo si vede che circa un terzo della produzione tedesca si svolge proprio in questo modernissimo campo di ricerca. Unisco alla mia lettera l'elenco nominativo delle 65 pubblicazioni in questione.

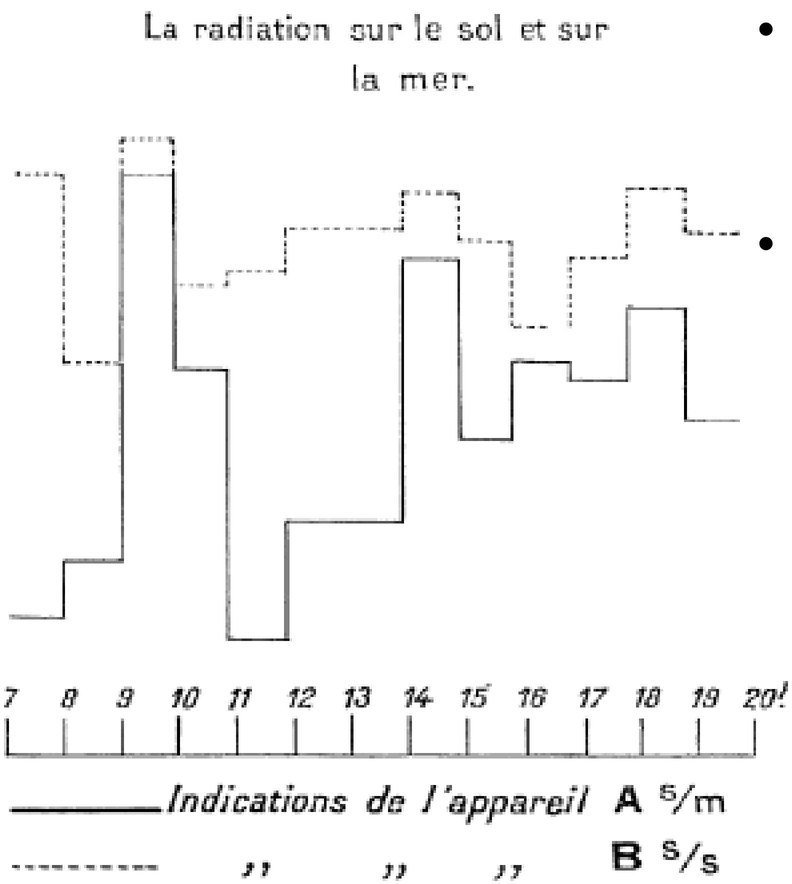
Questi fatti e moltissimi altri che potrei ancora citare mostrano in modo evidente la infondatezza delle affermazioni apparse sul Tevere e l'incompetenza di chi le ha scritte.

(Edoardo Amaldi)

- E. Amaldi had no doubt that Domenico Pacini was the discoverer of cosmic rays, as stated in a letter that he wrote on July 14, 1941 to the director of the Physics Institute of Roma, Antonino Lo Surdo
- The letter was motivated by an article that had appeared in the newspaper "Il Tevere", stating that nuclear physics and cosmic ray physics were Judaic sciences
  - Although "Il Tevere" was not the official journal of the Fascist Party, it had anyway a large political influence, as it was known that its content was dictated by Benito Mussolini
- E. Amaldi writes that *such a statement appears strange to anyone who knows … that the Italian Domenico Pacini, [a non Jew,] was the discoverer of the cosmic rays*

Pacini’s measurement in 1910

(quoted by Hess)



- First, two electroscopes (A and B) with walls of different thickness are cross-calibrated
- Simultaneous measurements are performed at ground and on the sea’s surface, and then the instruments are exchanged
- “The number of ions due to penetrating radiation on the sea is estimated to be 2/3 of that on the ground”
- ``the evolution of the phenomenon on the sea surface and on the land reveals for both the same trend of the penetrating radiation during the ten days of observation [...] But it is clear that in order to show the existence of a possible correlation [...] a period of time longer than that I dedicated to the experiment would be needed.’’

“such results seem to indicate that *a substantial part of the penetrating radiation in the air [...] has an origin independent of the direct action of active substances in the [...] Earth’s crust.”*

June-October 1911
(100 years ago)
the key experiment

- In June 1911, the winning idea: immersing an electroscope 3m deep in the sea at Livorno (and later in Bracciano's lake) Pacini finds a significant (20% at 4.3σ) reduction of the ionization

L'apparecchio fu disposto a bordo della medesima lancia che fu ancorata a oltre 300 metri dalla costa, sopra 8 m. di fondo e dal 24 al 31 giugno si fecero delle osservazioni coll'apparecchio alla superficie, e coll'apparecchio immerso nelle acque, a 3 m. di profondità.

Ecco i risultati di queste osservazioni, ciascuna delle quali ha all'incirca la durata di 3 ore:

Coll'apparecchio alla superficie del mare si ebbe una perdita oraria di Volta:

13,2 — 12,2 — 12,1 — 12,6 — 12,5 — 13,5 — 12,1 — 12,7

media 12,6 equivalente a ioni 11 per cm^3 al 1″.

Coll'apparecchio immerso:

10,2 — 10,3 — 10,3 — 10,1 — 10,0 — 10,6 — 10,6.

media 10,3 equivalente a ioni 8,9 per cm^3 al 1″.

La differenza fra questi due valori è di ioni 2,1.

Il coefficiente d'assorbimento per l'acqua essendo 0,034 è facile dedurre dalla nota equazione $\frac{I}{I_0} = e^{-\lambda d}$, dove d è lo spessore di materia traversata, che nelle condizioni delle mie esperienze, l'azione del fondo e quella della superficie erano trascurabili.

Remake of the Pacini experiment in 2011

(G. Batignani et al., Giornale di Fisica, September 2011)