

# Cosmic Rays: Studies and measurements before 1912

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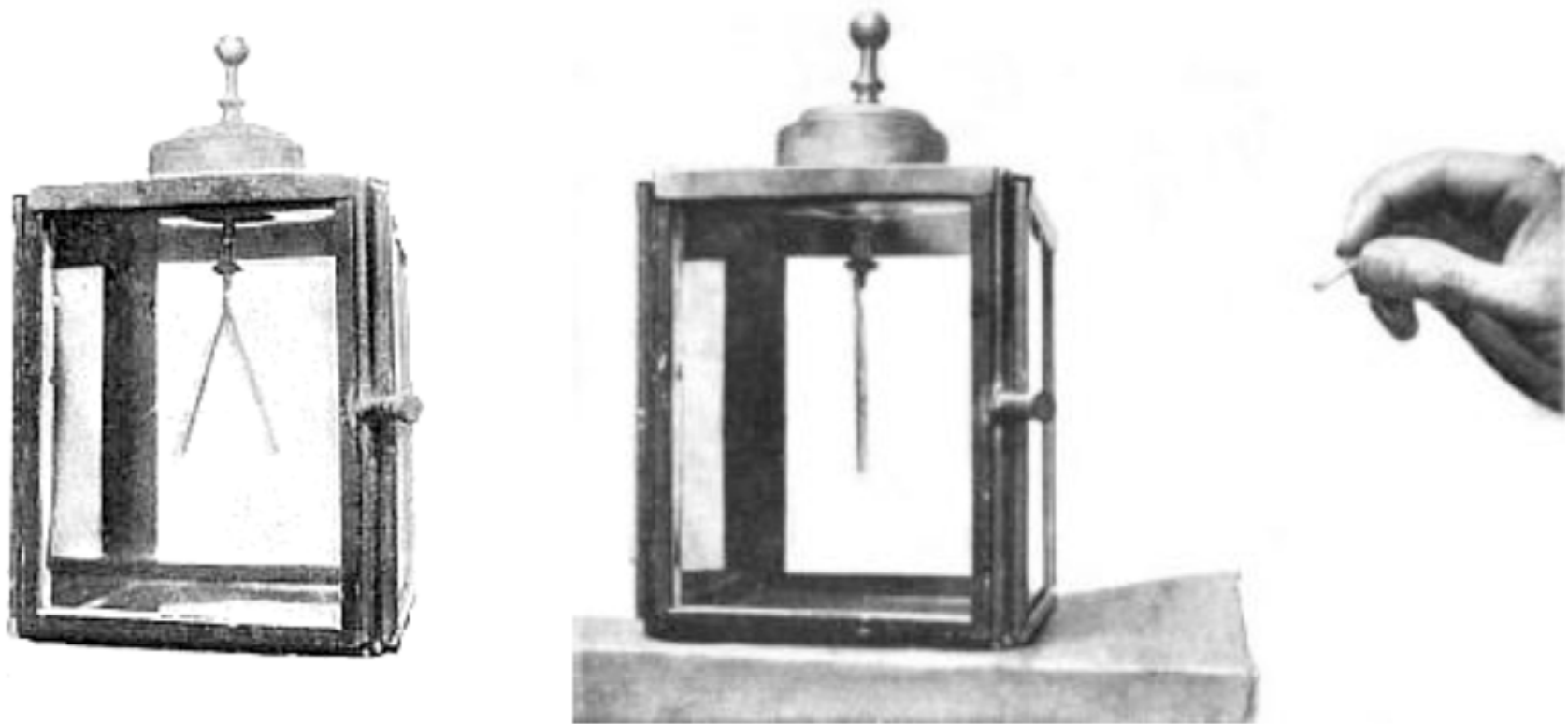
## Why does an electrostatic voltmeter spontaneously discharge?

- 1785: Coulomb found that electrostatic voltmeters 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 electrostatic voltmeter decreases when pressure is 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 2<sup>nd</sup> 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 in the beginning of the XX century

- 1900: CTR Wilson I Scotland and Elster & Geitel in Germany improve the technique for a careful insulation of electroscopes in a closed vessel, improving the sensitivity
- 1901: Wilson makes the visionary suggestion that the origin of such ionisation could be an extremely penetrating extra-terrestrial radiation.
  - Wilson's measurements in tunnels with solid rock overhead (to check if the radiation was coming from outside) show no reduction in ionization

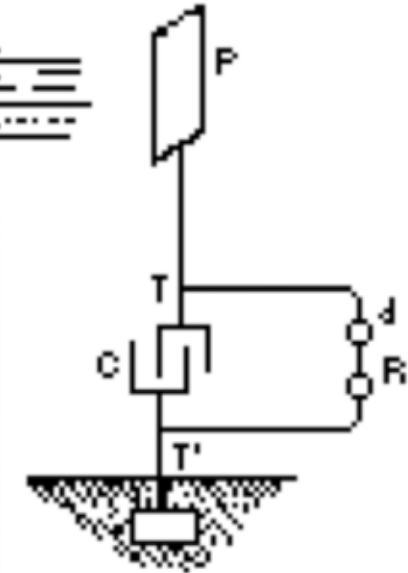
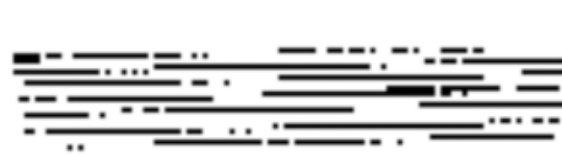


- In 1901 Nikola Tesla patented (US patent #685,957/8) an “Apparatus for the Utilization of Radiant Energy”

*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*

*It could use as energy sources “the Sun, as well as other sources of radiant energy, like cosmic rays” (added by Tesla in 1933)*

## Tesla



- Could it work?

Yes

- How much power can it generate

$$P < 3 \text{ GeV} \times 10000 \text{ CR/sm}^2$$

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

*(Solar energy:  $\sim 200 \text{ W/m}^2$ )*

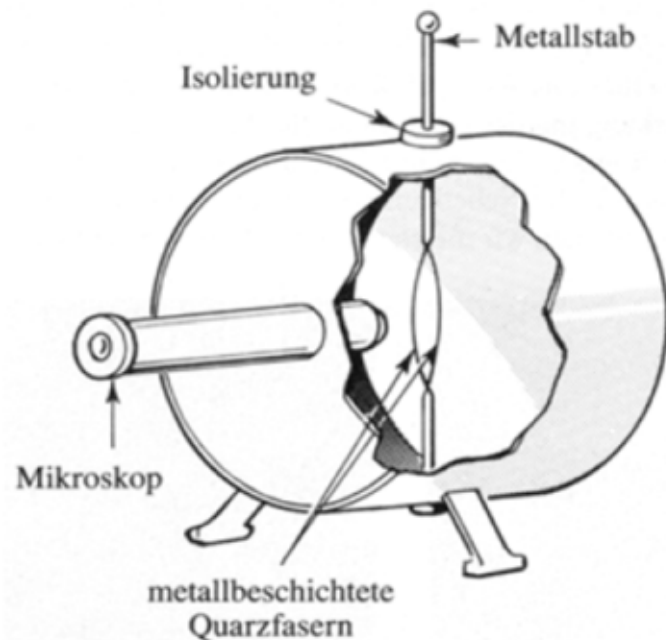
# The experiments in the beginning of the XX century

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



# Father Wulf: a true experimentalist

- Despite the fact that Wien leads this research, it is Theodor Wulf, German Jesuit and professor in Holland and in Rome, who improves the electroscope making it transportable
  - The leaves were replaced by metallized glass
- Improved accuracy to 1 volt



# Wulf's experiment at the Eiffel tower

- In 1909-10 Wulf had the idea of measuring ionization 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: reduction too small to be explained by radioactivity coming from Earth
  - Note: people were convinced that natural radioactivity was mostly due to gamma rays





The dominant opinion that radioactivity comes from the crust was not accepted by Domenico Pacini, since 1906 an assistant at the Institute of Meteorology in Roma

## Who was Domenico Pacini?

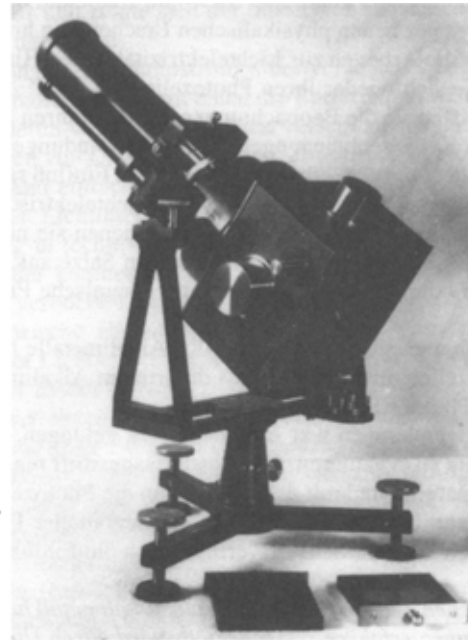
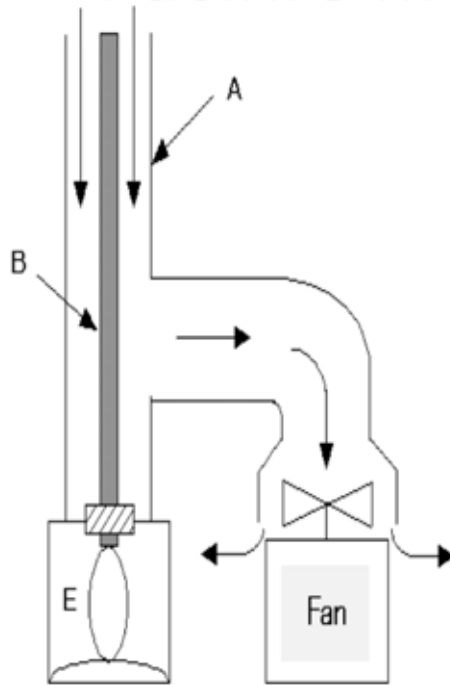
- 1878: Born in Marino, near Roma
- 1885: moves with his family in Forme, a small mountain village in the Apennines, central Italy
- 1892: high school (technical) in Roma
- 1902: graduation in Physics (supervised by Blaserna, who keeps him as assistant)
- 1902-1905: as an assistant, he specializes in the measures of ionization
- 1905: obtains a permanent position at the Central Bureau of Meteorology and Geodynamics
- 1913: obtains the “habilitation to teach”
- 1928: full professor in Experimental Physics in Bari, he moves there
- 1934: shortly after marrying, dies in Roma, as a consequence of pneumonia.

# Pacini's supervisor: Pietro Blaserna



- Aquileia 1836 - Roma 1918
  - Graduated in Wien in 1859
    - Supervised by Andreas von Ettingshausen
      - Electricity, magnetism, air ionization (Exner)
- Became Italian citizen in 1862
- Co-founder and President of the Italian Bureau of Meteorology and Geodynamics
- Worked on electromagnetic induction, and on properties of gases
  - Fields in which the Wien school was leading
- He was among the founders of the Italian Physical Society, its first president in 1897 (and of the Alpine Club!)
- Named senator, and since 1906 vice-president of the Senate

# Pacini's first researches on atmospheric ionization



- Improves the the electroscope for the measurement of ionization (reaches sensitivities 3x Wulf)
- In August 1907, tests his instrument by comparing measurements at different quotas ascending to Mount Velino (2400 m)
  - Fluctuations and daily variations
    - Work referred by M. Curie in her "Traité de Radioactivité"
  - Difference of ionization at different quotas? Below the level of the fluctuations
  - Difference of ionization according to the charge of the electroscope? Below the level of the fluctuations
- In 1907, he starts a collaboration with the Italian Navy, and makes measurements aboard boats





Pacini's instruments

# Researches in 1908-1910

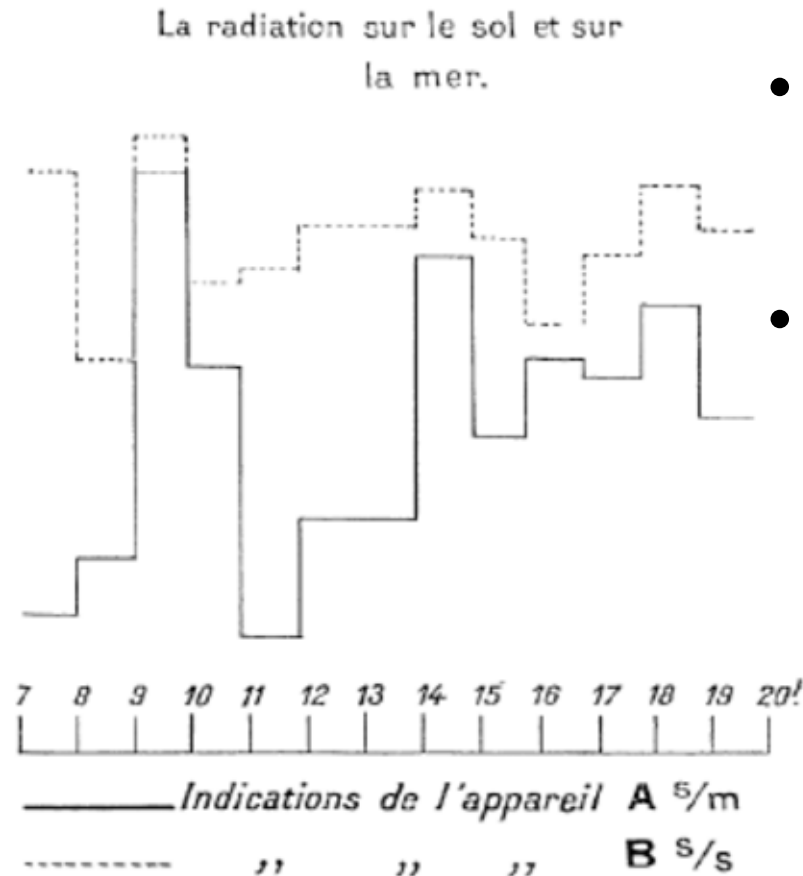
- Since end 1908, Pacini can use the destroyer “Fulmine” from the Navy
- 1908/1910: compares measurements on the shore with values on the sea, and with previous measurements on the mountains and in Forme
- Fluctuations appear similar, which raises in Pacini doubts about the Terrestrial origin



- In 1909 he presents his results to the “Accademia dei Lincei” (the national Academy of Sciences)
  - *“in the hypothesis that the origin of all penetrating radiations is in the soil [...] it seems not possible to explain the results obtained.”*

# The 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 [...]"

*"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."*



“Observations that were made on the sea during the year 1910 led me to conclude that a significant proportion of the pervasive radiation that is found in air had an origin that was independent of direct action of the active substances in the upper layers of the Earth's surface. The results indicated that a source of ionization existed on the sea surface, where possible effects from the soil are small, that had such an intensity that could not be explained on the basis of the known distribution of radioactive substances in water and in air.”

*In 1910 Pacini looked for a possible increase in radioactivity during a passage of the Halley's comet, and he found no evidence of a measurable effect from the comet itself*

## June-October 1911 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  $4.3\sigma$ ) 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  $\text{cm}^3$  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  $\text{cm}^3$  al 1".

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

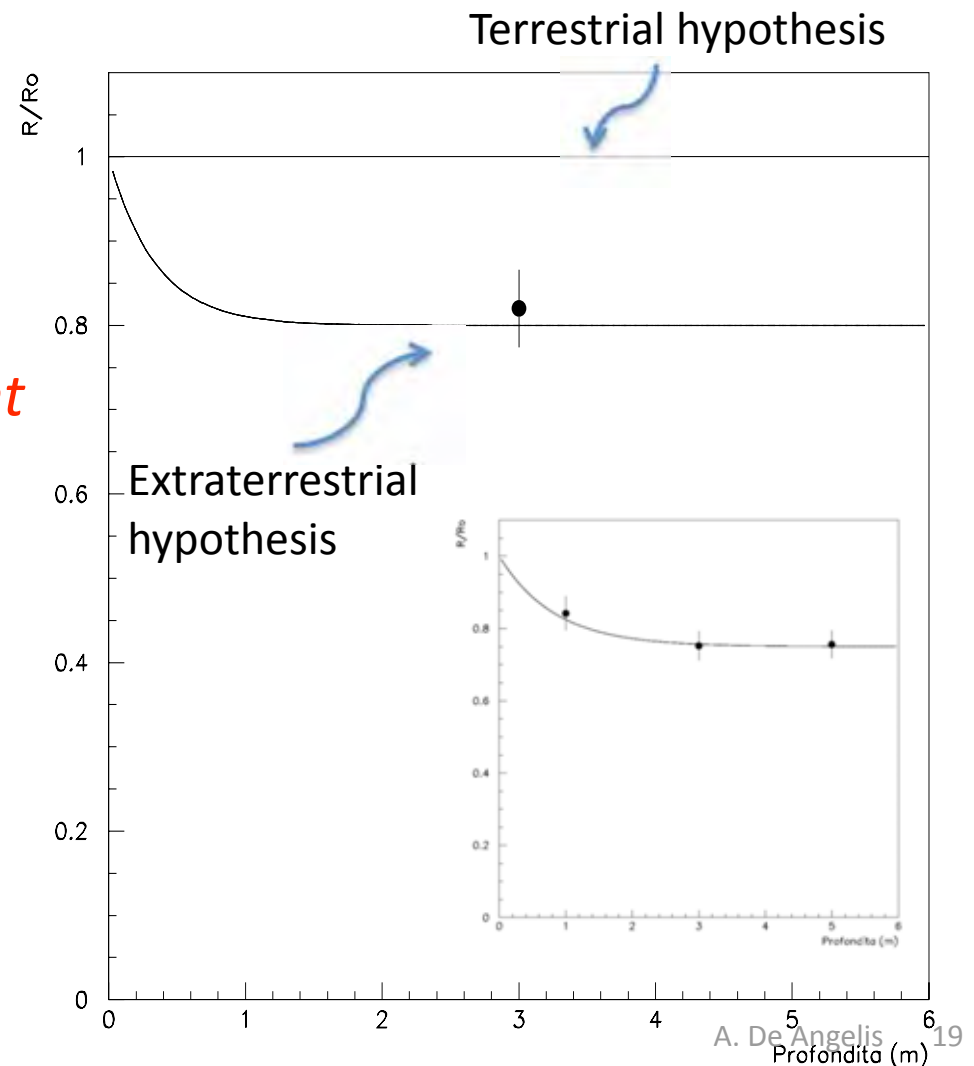
Il coefficiente d'assorbimento per l'acqua essendo 0,034 è facile dedurre dalla nota equazione  $\frac{I}{I_0} = e^{-\lambda d}$ , dove  $d$  è lo spessore di materia traversata, che nelle condizioni delle mie esperienze, l'azione del fondo e quella della superficie erano trascurabili.

“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)”

## Is this the discovery of Cosmic Rays?

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 soil.”*

Pacini’s experiment marked the beginning of the underwater technique for cosmic-ray studies



[...]

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.

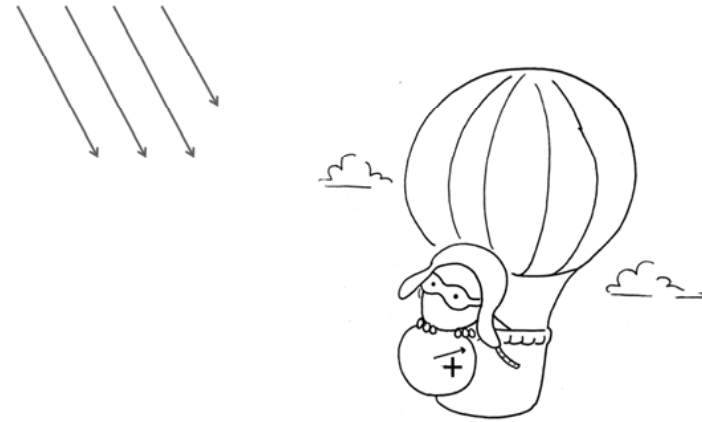
Two thousand feet from the top, they had to shoulder the boats, lumber to build rafts, and instruments their mules had carried.

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 (Zeit. Phys. 1928).

# Intermezzo: two notes

1. In 1910 Pacini looked for a possible increase in radioactivity during a passage of the Halley's comet, and he found no evidence of a measurable effect from the comet itself
2. Italy had already in the beginning of the century aerostatic balloons capable to fly up to 5000 m; although Pacini had published in 1909 an article on the perturbations produced by balloons on the Earth's electric field, he never organized a measurement of ionization on balloon



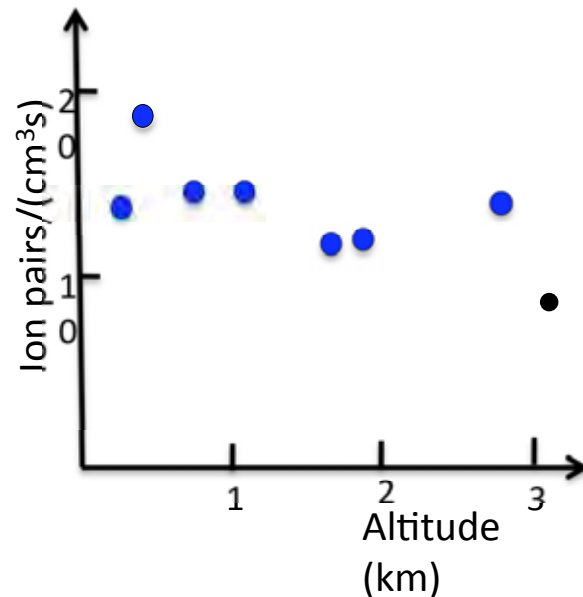
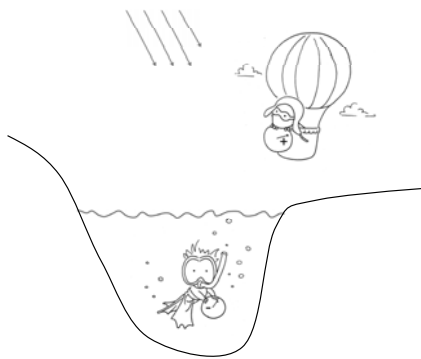


Note: Gay Lussac and Biot flew to 6400 m in 1804 to study properties of air at different p, T. Robertson and Lhoest had reached nearly 7000 m in a 5 h flight from Hamburg to Hannover in 1803, to measure B



## Balloon experiments: Bergwitz; Gockel

- How to increase the sensitivity of Wulf's measurements? Flying on balloons!
- Balloon flights with the purpose of studying the properties of penetrating radiation were arranged in 1909 in Germany by Bergwitz
  - Result: ionisation at 1300 m altitude had decreased to about 24% of the value at ground. However, Bergwitz's results were questioned because the electrometer was damaged during the flight. Later he investigated electrometers and reported no significant decrease
- In 1910 measuring up to 3000 m, A. Gockel, professor at Fribourg, found that the ionization did not decrease with height contrary to what expected if terrestrial origin



## The need for balloon flights at higher altitudes was then clear

- Need to explain the results by Wulf, Gockel, Pacini. This motivation will open the way to the masterpiece work by Hess in 1911-12
- However, it was not until 1936 that Hess was rewarded with the Nobel Prize for the discovery of cosmic radiation. By then the importance of CR was clear, as they had lead to the discovery of the positron by co-awarded Anderson
- Meanwhile, Pacini had died in 1934, his contributions mainly forgotten through a combination of historical and political circumstances.

# Why was Pacini's contribution overlooked?

- Nobel to Hess: a sufficient condition. When the Nobel for Cosmic Rays was assigned Pacini was dead
  - Pacini (who was shy and an ordinary guy) was ignored by the Italian community, and never nominated for the Nobel
  - Anyway he was referenced (on same footing as Wulf and Gockel) in the report by the committee charged by the Academy of Sweden to study the case
- The years after WWI were characterized by nationalism
- Charm of the flight?
- Pacini could not completely exclude the atmosphere as a cause of the radiation



# 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: ... *anyway several authors are cited but 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<sup>3</sup>/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. ...*

# Hess' book on cosmic radiation

- Hess published in 1940 the book *Weltraumstrahlung und ihre biologische Wirkung*, with Eugster. A translated/ updated edition (Cosmic radiation and its biological effects) was published by Fordham University Press in 1949
- Chapter 1 (written by Hess) was dedicated to the history of CR. Hess made the clear statement that Pacini was the first to oppose the idea that radioactivity on the soil is the only source of the radiation:
  - *“The first who expressed some doubts as to the correctness of this view was D. Pacini, who, in 1910, from measurements over sea and on shores at Livorno concluded that part of the observed ionization might be due to sources other than the known radioactive substances.”*

# E. 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, Kholerster 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 articoli 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.

(Eduardo Amaldi)

- E. Amaldi had no doubt that 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
- Letter motivated by an article 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 was the discoverer of the cosmic rays"**

# Conclusions

- The discovery of the origin of cosmic rays in the beginning of the XX century was the result of the effort of many scientists
- In the work that culminated with the high altitude balloon flights by Hess, several important contributions have been overlooked, in particular the work by Pacini (and by Wulf)
- 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 had a negative influence on the correct recognition of the scientific property of ideas
  - communication was difficult, also because people were publishing in different languages
- It is impressive to observe the evolution of an original, coherent and successful research line in the studies by Pacini between 1907 and 1911, based on the belief, expressed since the first works, that the direct action of active substances in the soil is not sufficient to explain the observed properties of penetrating radiation.

**After 1911, the need for balloon experiments at higher altitudes became evident to clarify the findings by Wulf, (Bergwitz), Gockel, Pacini**

