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Domenico Pacini and the discovery of cosmic rays

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Abstract: The discovery of cosmic rays, a milestone in science, comprised scientists in Europe and in the New World and took place during a period characterised by nationalism and lack of communication. Many scientists that took part in this research a century ago were intrigued by the penetrating radiation and tried to understand the origin of it. Several important contributions to the discovery of the origin of cosmic rays have been forgotten and in particular that of Domenico Pacini, who in June 1911 demonstrated by studying the decrease of radioactivity with an electroscope immersed in water that cosmic rays could not come from the crust of the Earth. Several historical, political and personal facts might have contributed to the substantial disappearance of Pacini from the history of science.

Keywords:

1 Introduction

By 1785 Coulomb found [1] that electroscopes spontaneously discharge due to the action of the air and not because of defective insulation. Detailed studies by Faraday confirmed the effect. The explanation of this phenomenon came in the beginning of the 20th century and originated one of mankind's revolutionary scientific discoveries: cosmic rays.

Following the discovery of radioactivity around 1900, it became evident that spontaneous discharge discharge was (at least in part) due to ionising agents. The obvious questions concerned the nature of such radiation, and whether it was of terrestrial or extra-terrestrial origin. An experimental conclusion seemed hard to achieve.

Wilson [2] tentatively made the visionary suggestion that the origin of such ionisation could be an extremely penetrating extra-terrestrial radiation. However, his investigations in tunnels with solid rock overhead showed no reduction in ionisation.

In 1903 Rutherford & Cooke [3] and McLennan & Burton [4] showed that the ionisation was significantly reduced when the electroscope was surrounded by shields of metal kept free from radioactive impurity. Later investigations showed that the ionisation in a closed vessel was due to "penetrating radiation" partly from the walls of the vessel and partly from outside.

In a famous 1909 review by Kurz [5] three possible sources for the penetrating radiation are discussed: an extra-terrestrial radiation possibly from the Sun, radioactivity from the crust of the Earth, and radioactivity in the atmosphere. Kurz concludes from the ionisation measurements in the lower part of the atmosphere that an extra-terrestrial radiation was unlikely. It was generally assumed that large part of the radiation came from radioactive material in the crust. Calculations were made of how the radiation should decrease with height (see for example Eve [6]) and measurements were performed.

Theodor Wulf, a German scientist and a Jesuit priest serving in the Netherlands and in Rome, had the idea to check the variation of radioactivity with height to test its origin. In 1909 [7], using a transportable electroscope in which the two leaves had been replaced by two metalised silicon glass wires, with a tension spring made also by glass in between, he measured the rate of ionisation at the top of the Eiffel Tower in Paris (300 m above ground). Supporting the hypothesis of the terrestrial origin of most of the radiation, he expected to find at the top less ionisation than on the ground. The rate of ionisation showed, however, too small a decrease to confirm the hypothesis. Wulf concluded that the most likely explanation of his puzzling result was still emission from the soil.

In 1909 by balloon ascent Bergwitz found [8] that the ionisation at 1300 m altitude had decreased to about 24% of the value at ground, consistent with expectations if the radiation came from the Earth's surface. However, Bergwitz results were questioned because the electrometer was damaged during the flight (see, for example [9]). Other measurements with similar results were also made (McLennan and Macallum [10], Gockel [11]). The general inter-

Figure 1: Domenico Pacini [14].

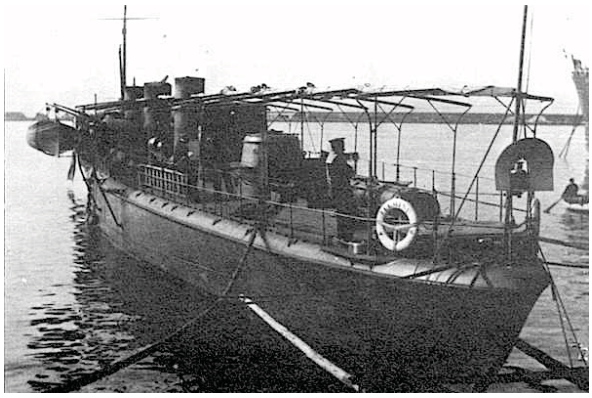

Figure 2: The cacciatorpediniere "Fulmine", used by Pacini for his measurements on the sea (courtesy of the Marina Militare Italiana).

pretation was that radioactivity was mostly coming from the Earth's surface [5], although the most precise measurements, those by Gockel who reached a height of 3000 m, where not completely consistent.

The conclusion that radioactivity was mostly coming from the Earth's crust was questioned by Domenico Pacini [12, 13, 14]. Pacini (figure 1) had graduated in Physics in 1902 in Rome, where, for the following three years, he studied electric conductivity in gaseous media. In 1906 Pacini was appointed assistant at Italy's Central Bureau of Meteorology and Geodynamics, heading the department that was in charge of studying thunderstorms and electric phenomena in the atmosphere. Pacini held the position until 1927, when he was promoted to Principal Geophysicist. Finally in 1928 he was appointed full professor of Experimental Physics at the University of Bari; he died of pneumonia in 1934 at the age of 56.

2 The experiments by Pacini

Pacini first compared the rate of ionisation on mountains, over a lake, and over the sea, to establish the level of the fluctuations and of the daily variations [15, 16].

Then he placed the electroscope on the ground and on the sea (in the Tyrrhenian, onboard the Navy ship "Fulmine" from the Accademia Navale di Livorno, figure 2) a few kilometres off the coast; the results and the fluctuations were comparable. A summary of these results indicate, according to Pacini's conclusions, that "in the hypothesis that the origin of penetrating radiations is in the soil, since one must admit that they are emitted at an almost constant rate (at least when the soil is not covered by remaining precipitations), it is not possible to explain the results obtained" [15].

Pacini continued the investigations of radiation and developed in 1911 an experimental technique for underwater measurements. He reported these measurements, the ensuing results, and their interpretation, in a note titled *La radiazione penetrante alla superficie ed in seno alle acque (Penetrating radiation at the surface of and in water)* [17]. He wrote: "Observations carried out on the sea during the year 1910 [16] 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. ... [To prove this conclusion] the apparatus ... was enclosed in a copper box so that it could immerse in depth. ... From June 24 to June 31 [sic!] [1911], observations were performed with the instrument at the surface, and with the instrument immersed in water, at a depth of 3 metres."

With the apparatus at the surface 300 m from land, Pacini measured seven times during three hours the discharge of the electroscope, obtaining a loss of 12.6 V/hour, corresponding to 11.0 ions per second (with a RMS of 0.5 V/hour); with the apparatus at a 3 m depth in the 7 m deep sea, he measured an average loss of 10.3 V per hour, corresponding to 8.9 ions per second (with a RMS of 0.2 V/h). Consistent results were obtained during measurements at the Lake of Bracciano a few months later.

The underwater measurement was 20% lower than at the surface, consistent with absorption by water of a radiation coming from outside. "With an absorption coefficient of 0.034 for water, it is easy to deduce from the known equation I/I_0 = exp(-d/λ), where d is the thickness of the matter crossed, that, in the conditions of my experiments, the activities of the sea-bed and of the surface were both negligible. The explanation appears to be that, due to the absorbing power of water and the minimum amount of radioactive substances in the sea, absorption of radiation coming from the outside happens indeed, when the apparatus is immersed." Pacini concluded [17]: "[It] appears from the results of the work described in this Note that a sizable cause of ionisation exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the soil."

As a curiosity, in 1910 Pacini looked for a possible increase in radioactivity during a passage of the Halley's comet (and he found no effect of the comet itself).

3 The measurement by Hess and the recognition of the discovery of cosmic rays

In spite of Pacini's conclusions, and of Wulf's and Gockel's puzzling results on the dependence of radioactivity on altitude, physicists were however reluctant to give up the hypothesis of a terrestrial origin. The situation was cleared up thanks to a long series of balloon flights by the Austrian physicist Victor Hess, who established the extra-terrestrial origin of at least part of the radiation causing the observed ionisation.

After graduating in Graz in 1906, Hess worked under professor Meyer at the Institute of Radium Research of the Viennese Academy of Sciences, where he performed most of his work on cosmic rays, and in 1919 he became professor of Experimental Physics at the Graz University. Hess was on leave of absence from 1921 to 1923 and worked in the United States. In 1923 he returned to Graz University and in 1931 he moved to Innsbruck. In 1936 he was awarded the Nobel Prize in physics for the discovery of cosmic rays. After moving to the USA in 1938 as professor at Fordham University, Hess lived in New York until his death in 1964.

Hess started his experiments by studying Wulf's results: he wrote that "a clarification can only be expected from further measurements of the penetrating radiation in balloon ascents" [18].

Hess continued his studies with balloon observations. The first ascension took place in August 1911. From April 1912 to August 1912 he had the opportunity to fly seven times; in the final flight, on August 7, 1912, he reached 5200 m. In this flight the measurements clearly showed that ionisation, after passing through a minimum, increased considerably with height. "(i) Immediately above ground the total radiation decreases a little. (ii) At altitudes of 1000 to 2000 m there occurs again a noticeable growth of penetrating radiation. (iii) The increase reaches, at altitudes of 3000 to 4000 m, already 50% of the total radiation observed on the ground. (iv) At 4000 to 5200 m the radiation is stronger [more than 100%] than on the ground" [19].

Hess concluded that the increase of the ionisation with height must be due to radiation coming from above (höhenstrahlung), and he thought that this radiation was of extra-terrestrial origin. He also excluded the Sun as the direct source of this hypothetical penetrating radiation due to there being no day-night variation. The results by Hess were later confirmed by Kolhörster [20] in a number of flights up to 9200 m.

During the war in 1914 - 1918 and the following years thereafter very few investigations of the penetrating radiation were performed. After the war, the focus of research moved to the US.

As a consequence of his first experiments on cosmic rays, Millikan believed that there was no extraterrestrial radiation (in 1925 he reported to the American Physical Society that "the whole of the penetrating radiation is of local origin"). In 1926, however, Millikan and Cameron [21] carried out absorption measurements of the radiation at various depths in lakes at high altitudes. Based upon the absorption coefficients and altitude dependence of the radiation, they concluded that the radiation was high energy gamma rays and that "these rays shoot through space equally in all directions"; they called them "cosmic rays".

Few years later, Clay [22], during two voyages between Java and Genova, found that ionisation increased with latitude, demonstrating that cosmic rays were mostly charged particles. In 1933, Alvarez & Compton [23], based on an experiment designed by Rossi [24], discovered that more cosmic rays were coming from West than from East close to the Equator: this is due to the interaction with the magnetic field of the Earth, and it demonstrated that cosmic rays are mostly positive. While watching the tracks of cosmic rays passing through his cloud chamber, Anderson in 1933 discovered antimatter in the form of the anti-electron, later called the positron [25].

Times were mature for the recognition of the discovery of extraterrestrial radiation: the 1936 Nobel Prize in Physics was assigned to Hess for the discovery of cosmic rays and Anderson for the discovery of the positron in cosmic rays.

The Committee of the Royal Academy of Sweden points out [13] that the discovery of cosmic rays has opened new areas of greatest significance to our understanding of the structure and origin of matter. It is clear, the Committee says, that Hess with his skillful experiments has proven the existence of an extraterrestrial penetrating radiation, a discovery more fundamental than that of the radiation's corpuscular nature and that of the latitude variation of its intensity. The final report quotes the fact that Gockel's balloon results, 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; it observes, however, that Hess' careful work includes an accurate measurement of the absorption of gamma rays, confirming the results of Eve, and several balloon ascents in 1911 and 1912, finally finding an increase by a factor of two in the ionisation at an altitude of 5200 m.

4 Discussion

Hess is today remembered as the discoverer of cosmic rays; his discovery was based on contributions of many other scientists. It seems to us that in particular the important contribution by Pacini has been forgotten. Pacini reached important conclusions on the origin of the "penetrating radiation" one year before Hess; the technique used by Pacini, however, could not fully disprove a possible atmospheric origin of the background radiation. Pacini's work is not often

cited in reviews of the history of cosmic rays. It was however cited in the report of the Nobel Committee in 1936.

Scientific research is today characterised by openness and rapid communication of results. This was not the case when cosmic rays were discovered. Communication was slow, there were language barriers combined with nationalism and there were important effects of World War I. Several other causes might have contributed to the lack of credit given in present days to Pacini's work, including the fact that he was not belonging to Academy.

The correspondence occurred between Hess in 1920 (see [14] for a more extended version) is illuminating.

On March 6, 1920, Pacini wrote to Hess: "...I had the opportunity to study some of your papers about electrical-atmospherical phenomena [...]. While I have to congratulate you for the clarity in which this important matter is explained, I have to remark, unfortunately, that the Italian measurements and observations, which take priority as far as the conclusions that you, Gockel and Kolhörster draw, are missing; and I am so sorry about this, because in my own publications I never forgot to mention and cite anyone". The answer by Hess, dated March 17, 1920, was: "My short paper [...] has no claim of completeness. Since it reported the first balloon measurements, I did not provide an in-depth explanation of your sea measurements, which are well known to me. Therefore please excuse me for my unkind omission, that was truly far from my aim.".

On April 12, 1920, Pacini in turn replied to Hess: "[Your article] lingers quite a bit on measurements of the attenuation of this radiation made before your balloon flights, and several authors are cited whereas I do not see any reference to my relevant measurements (on the same matter) performed underwater in the sea and in the Bracciano Lake, that led me to the same conclusions that the balloon flights have later confirmed."

Finally, on May 20, 1920, Hess replied to Pacini: "...Coming back to your publication in 'Nuovo Cimento', (6) 3 Vol. 93, February 1912, I am ready to acknowledge that certainly you had the priority in expressing the statement, that a non terrestrial radiation of 2 ions/cm^3 per second 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."

The Hess-Pacini correspondence, nine years after Pacini's work and eight years after Hess' 1912 balloon flight, shows how difficult communication was at the time. Also language difficulties may have contributed: Pacini publishing mostly in Italian and Hess in German.

The work behind the discovery of cosmic rays, a milestone in science, comprised scientists in Europe and the New World and took place during a period characterised by lack of communication and by nationalism caused primarily by the World War I. The many scientists that took part in this research starting a century ago, either alone or as a two-person group, were fascinated by the penetrating radiation and wanted to understand the origin and properties of it. It took from the turn of the century until 1926 before the extraterrestrial nature of the penetrating radiation was generally accepted.

In the work that culminated with high altitude balloon flights, many important contributions have been forgotten and in particular those of Pacini in 1909-1911. Several historical, political and personal facts might have contributed to the lack of references to the work of Pacini in the history of cosmic rays.

References

[1] C.A. de Coulomb: 1785, Troisième mémoire sur l'Electricité et le Magnétisme

[2] C.T.R. Wilson, Proc. Roy. Soc. of London, 1901, **68:** 151-161

[3] E. Rutherford, H.L. Cooke, Phys. Rev., 1903, **16:** 183

[4] J.C. McLennan, F. Burton, Phys. Rev., 1903, **16:** 184-192

[5] K. Kurz, Phys. Zeit., 1909, **10:** 834-845

[6] A.S. Eve, Phil. Mag., 1907, **13:** 248-258

[7] T. Wulf, Phys. Zeit., 1909, **1:** 152-157

[8] K. Bergwitz, Hab. Paper (Braunschweig 1910)

[9] A. Gockel, Measurement of penetrating radiation during balloon flights. Phys. Zeit., 1911, **12:** 595-597

[10] J.C. McLennan, E.N. Macallum, Phil. Mag., 1911, **VI/22:** 639-646

[11] A. Gockel, Phys. Zeit., 1909, **10:** 845-847

[12] G.B. Rizzo, Nuovo Cim., 1934, **11:** 509

[13] P. Carlson, A. De Angelis, Eur. Phys. J. H, 2010, **35:** 309-330

[14] A. De Angelis, Riv. Nuovo Cim., 2010, **33:** 713-756

[15] D. Pacini, Rend. Acc. Lincei, 1909, **18:** 123-129

[16] D. Pacini, Ann. Uff. Centr. Meteor., 1910, **XXXII, parte I:** 1; Le Radium, 1910, **VIII:** 307. Translated in English and commented by M. De Maria and A. De Angelis, *Penetrating radiation on the sea.* (arXiv:1101.3015 [physics.hist-ph])

[17] D. Pacini, Nuovo Cim., 1912, **VI/3:** 93 Translated and commented by A. De Angelis, *Penetrating radiation at the surface of and in water.* (arXiv:1002.1810 [physics.hist-ph])

[18] V.F. Hess, Phys. Zeit., 1911, **12:** 998-1001

[19] V.F. Hess, Phys. Zeit., 1912, **13:** 1084-1091

[20] W. Kolhörster, Phys. Zeit., 1913, **14:** 1153-1156

[21] R.A. Millikan, G.H. Cameron, Phys. Rev., 1926, **28:** 851-868

[22] J. Clay, Acad. Amsterdam Proc., 1927, **30:** 1115-1127; ibid., 1928, **31:** 1091-1097

[23] L.W. Alvarez, A.H. Compton, Phys. Rev., 1933, **43:** 835-836

[24] B. Rossi, Phys. Rev., 1930, **36:** 606

[25] C.D. Anderson, Phys. Rev., 1933, **43:** 491-494