The Circulation of Science and Technology

Proceedings of the 4th International Conference of the European Society for the History of Science

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Societat Catalana d'Història de la Ciència i de la Tècnica

European Society for the History of Sciences ESHS

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ROCA-ROSELL, A. (ed.).(2012) *The Circulation of Science and Technology: Proceedings of the 4th International Conference of the ESHS, Barcelona, 18-20 November 2010.* Barcelona: SCHCT-IEC, p. 799.

UNRAVELING THE NATURE OF COSMIC RAYS. BRUNO ROSSI AND THE SPREAD AND DEVELOPMENTS OF EXPERIMENTAL PRACTICES AND SCIENTIFIC COLLABORATIONS IN COSMIC-RAY PHYSICS BEFORE WORLD WAR II

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Abstract

During the late 1920s/beginning of the 1930s, particularly in connection with the birth of Enrico Fermi's and Bruno Rossi's research groups in Rome and Florence, strong relationships were established between Italy and other European countries such as Germany, Great Britain and France, as well as with some physicists of the US scientific community. Bruno Rossi, an outstanding scientist in the study of cosmic rays and the pioneer of this research field in Italy since the early 1930s, is a prominent example in this sense. His friendship with Fermi, Bothe, Blackett, Heisenberg, Bethe, was instrumental for the exchange of knowledge about experimental practices and for theoretical discussions. Rossi was also successful in attracting the interest of physicists such as Arthur H. Compton and Louis Leprince-Ringuet on the problem of cosmic rays. The ties established during the 1930s and the solidarity of many members of the international scientific community gave Rossi the courage to begin a new life in a new world when he was obliged to leave Italy after the enactment of fascist racist laws in 1938 and were instrumental for his later contribution to the rebirth and development of European physics after the war.

Cosmic-Ray research becomes a branch of physics

Between the end of the 1920s and the beginning of the 1930s, as Enrico Fermi (1901-1954) was building up a research group in Rome which was preparing to explore the nucleus, Bruno Rossi in Arcetri, near Florence, was eager to begin work on some experimental project addressing itself "to the fundamental problems of contemporary physics."[1] Then, in 1929, a paper by Walther Bothe and Werner Kolhörster on the nature of the extraterrestrial penetrating radiation appeared,[2] which was "like a flash of light revealing the existence of an unsuspected world, full of mysteries, which no one had yet begun to explore."[3]

At that time, the problem of the nature of cosmic rays did not actually attract general attention, probably because of the widespread belief that the astonishingly penetrating cosmic rays could not be anything else but gamma-rays of very high energy. Bothe and Kolhörster had used the brand new Geiger-Müller counter, which had an improved sensitivity and performance, if compared with other kind of counters and with ionization chambers. Their innovation was to place two Geiger-Müller counters one above the other, with a 4.1-centimeter layer of gold between them and then record the coincidences between the two counters. From this arrangement they argued that coincidences could be produced only by individual ionizing particles crossing both counters, which they thought to be high energy electrons.

Bothe and Kolhörster's experiment, in providing evidence of the enormous potential of the coincidence method, represented the very first attempt to determine the nature of cosmic rays, and contributed to focus the physicists' interest on the radiation found at the place where measurements were made. Both the novelty of the research topic and the low cost of the research tools were the key ingredients of Bruno Rossi's excitement. In just a few months he built his own Geiger-Müller counters, devised a new method for recording coincidences,[4] and began some experiments. The Geiger-Müller technique which Rossi introduced in Italian physics would play a crucial role in the well-known discoveries made by Enrico Fermi and his group in Rome in 1934.[5]

Internationalism and co-operation

In the meantime Rossi had written to Bothe, telling him that he would have liked to spend some months in his laboratory. Bothe's answer was a positive one, so Bruno Rossi left Arcetri in the late 1930 spring thanks to a grant of the Italian National Council of Research. At the time Germany was nearly a paradise for Italian physicists. Fermi himself had been in Göttingen and Leyden after getting his laurea in 1922. Berlin was then the heart of modern physics, and the 24-year-old Rossi had the occasion of meeting Albert Einstein, Max Planck, Otto Hahn, Lise Meitner, Max von Laue, Walther Nernst, Hans Geiger, and other prominent physicists of the time. In particular, he became acquainted with Werner Heisenberg, and with Patrick Blackett, the latter visiting from England; with both he established a friendly relationship. Blackett was a recognized expert on cloud chambers, so that Rossi asked him about the possibility of sending his collaborator Gilberto Bernardini to Cambridge in order to learn this important technique. Blackett's wife was Italian, one more reason to form close friendship with his Italian colleagues.

Rossi's experiments in Berlin provided a more direct and sharp proof of Bothe and Kolhörster's conclusion, but went further in finding the first hints of the phenomenon of a secondary radiation generated by cosmic rays in lead shields. It is to be remarked that Bothe must have been very confident in the young Italian physicist, so much as to reveal him his own secrets for preparing reliable Geiger-Müller counters.

When Rossi was in Berlin, Bothe and Kolhörster went for an expedition to the North Sea and the northern Atlantic Ocean to study the dependence of cosmic rays intensity on the geomagnetic latitude, even if with a negative result. The existence of this geomagnetic effect, connected with the charged nature of cosmic ray particles, had in fact not been definitely confirmed yet. Bothe made him aware of the extensive work that the Norwegian geophysicist Carl Störmer and his pupils had carried on for years on the very complicated mathematical problem of the motion of charged particles in the field of a magnetic dipole, a good approximation to the Earth's magnetic field. Störmer was interested in the trajectories of particles approaching the Earth in the direction of the Sun, but Rossi found out that the answer he was searching for was contained in a formula derived by Störmer. On July 3, during his stay in Berlin, Rossi sent a short note to the *Physical Review* where he arrived at the following conclusion: besides the already expected latitude effect, a second phenomenon

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[1] Rossi, *Moments in the Life of a Scientist* (Cambridge University Press, 1990) p. 6.

[2] W. Bothe and W. Kolhörster, "Die Natur der Höhenstrahlung," *Die Naturwissenschaften* 17 (1929), 271–273; idem, "Das Wesen der Höhenstrahlung", *Z. Phys*. 56 (1929) 751–777.

[3] Bruno Rossi, *Cosmic Rays* (McGraw–Hill, 1964) p. 43.

[4] Bruno Rossi, "Method of Registering Multiple Simultaneous Impulses of Several Geiger's Counters," *Nature* 125 (April 26, 1930) 636.

[5] Matteo Leone, Angelo Mastroianni, Nadia Robotti, "Bruno Rossi and the Introduction of the Geiger-Müller Counter in Italian Physics: 1929–1934," *Physis* 42 (2005) 453-480.

must exist, the East-West effect, which would be revealed by an asymmetry of the cosmic-ray intensity with respect to the plane of the geomagnetic meridian, with more particles coming from East or West, depending on whether the particle charge was negative or positive.[6]

Rossi must have discussed this topic with Werner Heisenberg, during one of the latter's frequent trips from Leipzig to Berlin, because, on August 19, 1930, Heisenberg wrote him a letter asking to summarize Rossi's calculations on the motion of a high-energy electron in the Earth's magnetic field. Rossi answered only on September 13, during the last days of his German sojourn. After a series of detailed passages, Rossi arrived to the same formula contained in his article on the *Physical Review*. A trace of the Rossi-Heisenberg dialogue on cosmic rays is contained in a series of letters now preserved in the Archives of Padua University (not accessible at the moment) which have been published in 1993.[7] As a theoretical physicists at the frontiers of quantum mechanics, and involved in the nascent quantum electrodynamics, Heisenberg had immediately become aware of the interesting new perspectives opened by the latest experiments on the nature of cosmic rays.

As soon as Rossi was back in Arcetri, he began to work searching the proof of the existence of the East-West effect, which could provide a completely different proof of the corpuscular nature of the cosmic radiation as well as an indication on the sign of the charge. However, within the errors, the experience gave a negative result. Being aware that the asymmetry would become pronounced only at low geomagnetic latitudes and at sufficiently high elevation to afford the observation of cosmic rays of comparatively small energy, Rossi planned an expedition to Asmara, the capital of the Italian colony in Eritrea, a town rising at an altitude of 2370 m, and at a geomagnetic latitude of 11° 30' N.

On November 19 Rossi wrote to Heisenberg in reply to the latter's letter of October 6. Rossi apologized for the great delay, and said that only in the previous days had he been able to look at Heisenberg's notes "on the nature of the Ultrastrahlung". He compared his results on the "forbidden regions" with Heisenberg's ones observing that their results were nearly coinciding, even if they had been obtained by different methods. Rossi announced, too, that he was going to publish a preliminary article on the work carried out in Germany.[8]

By the summer of 1931 Rossi had performed a series of experiments (deviation with an electromagnet and study of intensity of cosmic rays with a counter-telescope at different inclinations to the vertical line) aiming with different means at studying the nature and behavior of the cosmic rays.[9]

In the meantime, from May 20 to May 22, 1931, the first international −but European in character− conference on nuclear physics was held at the Eidgenössische Technische Hochschule in Zürich. Rossi had the occasion to meet Marie Curie, Frédéric Joliot, George Gamow (who delivered the opening lecture), Patrick Blackett, Lise Meitner, Bothe, Rudolf Peierls ,Wolfgang Pauli, Maurice De Broglie and Louis Leprince-Ringuet. At the time they were working in Paris on the artificial disintegration of elements, and like James Chadwick were performing their researches using the valve counter invented by Heinrich Greinacher, as a mean of detecting the passage of protons generated during the disintegration process. From the acquaintance with Leprince-Ringuet, and the interest in the new technique of the valve counter the idea of a visit to Paris aroused, which took place during the following year 1932, thanks to a Volta grant provided by the Accademia d'Italia. It was an important occasion for the exchange of knowledge about counters, and especially in arousing Leprince-Ringuet's interest in cosmic rays: "Le séjour de Rossi fut des plus fructueux: par un echange bien naturel, le laboratoire du duc de Broglie fut initié aux compteurs d'eléctrons et aux coïncidences qui permettent de reconnâıtre les rayons très pénétrants au milieu d'autres, plus mous, et definir leur direction. C'était la porte ouverte vers le monde merveilleux des rayons cosmiques [...]".[10] Rossi did not use the whole grant: he anticipated his return to Italy in order to participate to a competition for a chair of experimental physics. This proved a most lucky circumstance: when he was forced to emigrate in 1938, after the enactment of fascist laws against Italian jews, he requested to complete his stay abroad and was thus able to get some money and the visa on his passport in a short time. After the war, when Rossi was at the Massachusetts Institute of Technology, a tight collaboration was established with Leprince-Ringuet's group at the École Politechnique.

That same 1931, an international conference on nuclear physics was organized in Rome by Enrico Fermi with the support of Orso Mario Corbino. The meeting, to which prominent American physicists such as Robert Millikan and Arthur Compton participated, was held from October 11 to 17. The presence of the leading brains engaged at the frontiers of physics research in the field of nuclear physics and cosmic rays gave the event enormous importance, and put the seal on the new disciplinary identity, helping the young Italian physicists to familiarize with current problems. A well known

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[6] B. Rossi, "On the magnetic deflection of cosmic rays, " *Phys. Rev*. 36 (1930) 606.

[7] G. Gembillo, "Un carteggio inedito tra Werner Heisenberg e Bruno Rossi", *Scienza e Storia* 9 (1993)113-122.

[8] A more complete article summarizing his researches in Germany appeared at the beginning of 1931: B. Rossi, "Über den Ursprung der durchdringenden Korpuskularstrahlung der Atmosphäre," *Z. Phys*. 68 (1931) 64-84.

[9] B. Rossi, "Magnetic Experiments on the Cosmic Rays," *Nature* 128 (3225) (1931), 300-301; idem, "Measurements on the Absorption of the penetrating corpuscular Rays coming from inclined Directions," *Nature* 128 (3227) (1931) 408.

[10] L. Leprince-Ringuet, *Noces de diamant avec l'atome* (Flammarion, 1991), p. 300.

photograph taken during the Conference shows the group of physicists gathering on the stairs in front of the Physics Institute of Via Panisperna. Among the others Marie Curie, Louis Brillouin and Jean Perrin from France; Arnold Sommerfeld Paul Ehrenfest Werner Heisenberg, Walther Bothe, Hans Geiger, Otto Stern, Peter Debye from Germany and Holland; Francis W. Aston, Patrick Blackett, C. D. Ellis, R. H. Fowler and Nevill Mott from Great Britain; Niels Bohr from Copenhagen; Wolfgang Pauli from Zürich; Arthur Compton, Samuel Goudsmit and Robert Millikan from the US. Ernest Rutherford was the great absent, so that a telegram was sent by the group. The fourth day of the conference was dedicated to the problem of cosmic rays and Fermi invited Rossi to give an introductory speech. He made a detailed and cogent discussion, also explaining the reasons why he thought that Millikan's assumption, according to which cosmic rays were "ultra-gamma radiation" resulting from the synthesis of elements in the Universe, could not be correct. Millikan did not like Rossi's discourse; he considered him only an arrogant young man and for a number of years thereafter chose to ignore his work altogether.

On November 11, immediately after the conference, Heisenberg wrote again to Rossi: "I still remember the Roman days with joy, the congress was really one of the best and instructive I ever participated until now." Heisenberg, who had much reflected on these topics during the previous months and after the meeting, asked for Rossi's opinion: "I have lately made some calculations on cosmic radiation and I collected the formulas in a small manuscript. I would be very grateful if you could be so kind as to read it and write me how much its content is trivial, well known, and how much wrong, and then send it back. You probably will laugh at the theoretician's list of wishes [...]". On December 8 Heisenberg asked Rossi to send back his manuscript because he needed it for a discussion, and after 4 days he wrote again thanking him and mentioning something about the final draft of Rossi's article on the absorption experiment in 1 meter lead: "I am really burning with interest in the manuscript you announced."[11] A series of letters exchanged with Heisenberg between December 8, 1931, and March 21, 1932, are discussing Rossi's experiments on the absorption in 1 meter lead, and especially on the secondary radiation generated in the metal screens above the counters. According to what Rossi told later, a paper reporting on this effect was rejected by *Die Naturwissenschaft*, and was accepted by the *Physikalische Zeitschrift* only after Heisenberg had vouched for its credibility.[12] On February 10 Heisenberg thanked Rossi for his "new work" which he had "studied with great interest". Heisenberg also told how curious he was about the "angular distribution of secondary particles". That same spring Heisenberg published a long article discussing cosmic rays where Rossi's experiments were widely quoted.[13]

In the meantime Hans Bethe, who spent some time in Rome with a Rockefeller scholarship, wrote enthusiastically about Fermi to Arnold Sommerfeld. He was going to spend the rest of his Rockefeller fellowship in Cambridge, and was very sorry for having to leave Italy: "The stimulus I have here by Fermi, is larger by orders of magnitude [...] Dirac is well known for speaking only one word per light year, and the other people in Cambridge are far from having the general view of the quantum theory that Fermi has."[14] At that time Bethe had just published a landmark paper on the interaction of radiation with matter.[15] He disagreed with Millikan's views on cosmic rays, but at the same time he regarded Rossi's researches with great favor, and during his stay in Italy he visited Rossi in Florence. They were nearly the same age, and it was easy to establish a human relationship, which later proved crucial in Rossi's life. Actually, in being closely bound to the nascent quantum electrodynamics, the archetype of quantum field theories, Rossi's work was followed by theoreticians such as Heisenberg, Fermi, Bethe, Heitler and Bhabha. The latter, too, spent some time in Rome with Fermi during the 1930s, and well knew Rossi's work which widely quoted in his articles. Later, Bhabha and Heitler used Rossi's data to establish a satisfactory quantitative agreement with their theory of the electromagnetic cascade.

From co-operation to collaboration

Rossi's talk on cosmic rays during the Roman conference had stimulated Arthur Compton and provided the initial motivation for the latter's new research program in cosmic rays. Going back to the US Compton thoroughly studied Rossi's talk at the Rome Congress, as well as other recently published cosmic ray works, and decided to change his main research interest. He organized a worldwide cooperative project involving tens of physicists (with all investigators using identical large ionization chambers) eventually demonstrating that the intensity of cosmic rays is correlated to the magnetic rather than geographic latitude. This was one of the first examples involving so many physicists all over the world working at the same research project.

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[11] B. Rossi, "Absorptionsmessungen der durchdringenden Korpuskularstrahlung in einem Meter blei,'' *Die Naturwissenschaften* 20(4) (1932) 65.

[12] B. Rossi, "Nachweis einer Sekundärstrahlung der durchdringenden Korpuskularstrahlung," *Phys. Z.* 33 (1932) 304--305.

[13] W. Heisenberg, "Theoretische Überlegungen zur Höhenstrahlung," *Ann. Phys*. 405 (1932) 430-452. On his side, during this period Rossi thanked Heisenberg, Fermi and Bothe for discussions in his articles.

[14] H. Bethe to A. Sommerfeld, Rom, April 9, 1931 in M. Eckert and K. Märker (eds.) *Arnold Sommerfeld Wissenschaftlicher Briefwechsel*. Band 2: 1919-1951 (Deutsches Museum - GNT Verlag 2004), pp. 322-323.

[15] H. Bethe, "Zur Theorie des Durchgangs schneller Korpuskularstrahlen durch Materie," *Ann. Phys*. 5 (1930) 325-400.