Two centenaries: The discovery of cosmic rays and the birth of Lajos Jánossy

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Abstract. Centenaries provide useful perspectives for looking back upon long-past events and on their later consequences, and also on the activities of persons who made a lasting impact on some important field of research. Cosmic ray physics, as we now know it, had multiple roots. The most important puzzle that incited research in the early 20th century, however, was connected with the lack of understanding of the origin of an omnipresent extremely penetrating ionizing radiation. At least in hindsight, the balloon ascent of Victor Hess on the 7th August 1912 provided the first convincing evidence for the cosmic origin of that radiation, although Werner Kolhörster’s subsequent flights to even higher altitudes and with better instrumentation certainly provided important confirmation. General acceptance of the existence of that radiation came more than a decade later, and its basic properties were revealed only in the early 30’s. It was at about that time that a research student of Kolhörster, Lajos Jánossy, who happened to be born in the discovery year of 1912, started his research in cosmic ray physics. Later he did important research in London, Manchester and Dublin, and wrote one of the first comprehensive monographs on cosmic rays. After his return to Hungary in 1950, he played an important part in establishing cosmic ray research in a newly formed research institute in Budapest.

1. Introduction
The problem of the spontaneous discharge of electroscopes had been known since Coulomb, but it became acute only after the discovery of X-rays and radioactivity, and of their ionizing effects. It became soon obvious that the ionization caused by radioactivity provides a good explanation for the leakage of electric charge from unshielded electroscopes, but even a thick shielding that absorbs all radiation emitted by known radioactive substances cannot completely stop the discharge current. It was the consistent struggle by many scientists for understanding the causes of that discharge that led finally to the discovery of a penetrating component of radiation coming from high above (in German: Höhenstrahlung). That component finally became known as cosmic rays, and its properties and origin have been studied ever since.

It is now generally agreed that the most important step in the process of discovery can be attributed to the high-altitude (5300 m) balloon flight of Victor Hess on the 7th August 1912, when he proved that the intensity of the penetrating radiation increased with altitude above a height of about 2000 m. Victor Hess was an Austrian physicist, citizen of the Austro-Hungarian Monarchy that was soon to be swept away by the aftermath of the 1st World War. The reliability of the measurements of Hess was doubted by several experimenters, and confirmation was needed. A young German physicist, Werner Kolhörster rose to 9300 m in June 2014, confirming and substantially extending the results of Hess by
improved, more reliable instrumentation. According to some, the discovery of cosmic rays should be attributed jointly to Hess and Kolhörster, and not to Hess alone.

In what follows, a more detailed account will be given of the discovery process and of early investigations of cosmic rays. Use will be made of the personal reminiscences collected in the 1985 book "Early history of cosmic ray studies", Edited by Sekido and Elliot, and of some more recent information communicated during the centennial celebrations at the site of the landing of Hess at the Scharmützelsee in Germany. Then a tribute will be given to a Hungarian cosmic ray physicist, Lajos Jánossy, who was born in the year of the discovery flight of Victor Hess, and later made some lasting impact on cosmic ray physics in general, and on cosmic ray research in Hungary in particular.

2. Early investigations

Atmospheric electricity and its connections with the ionization of air were favoured fields of research at the end of the 19th and in the early years of the 20th century. Julius Elster and Hans Geitel in Wolfenbüttel, Germany, as well as C T R Wilson in Scotland were fascinated by atmospheric phenomena, and studied their possible connection with the ionizing effects of the recently discovered radioactivity. Simple open-air gold foil electroscopes were at first applied to measure ionization effects, but it was soon realized that precise measurements required closed vessels and sophisticated measuring equipment, and also the removal of dust and humidity. However, the ionization of air did not cease even when the ionization chambers were surrounded by thick walls. Elster and Geitel suspected some unknown process capable of ionizing air spontaneously, while Wilson proposed a possible extraterrestrial source of the penetrating ionizing radiation. In order to prove his point, Wilson placed his chamber underground in the Caledonian railway tunnel near Peebles, Scotland. He expected that the thick layer of rocks should surely provide sufficient shielding to absorb the external radiation. The ionizing effect, however, did not decrease, thus he was inclined to accept the spontaneous ionization proposal. Rutherford and Cook found in 1903 that a thick shielding did reduce the ionization rate to a certain extent, but further shielding had no effect. They assumed that an extremely penetrating external radiation was responsible.

In subsequent years it was realized that radioactive materials were present everywhere: in the ground, in air, and even in the material of ionization chambers. Apart from the instruments themselves, the major contributor appeared to be the ground, and its contribution varied with location. Ionization above water was less, while the contributions of radioactive substances in air (mostly radon) were usually also relatively small. Several researchers tried to separate the various causes of the ionization. Measurements over lakes and the sea were promising because of the lower radiation levels detected there. An Italian physicist, Domenico Pacini made measurements both above and below the surface of water, and concluded that at least some part of the radiation had to come from the air. Theodor Wulf, who invented a more sensitive and more robust portable electroscope that was then manufactured by the German instrument firm Günther and Tegetmeyer, measured the ionization rate for several days in 1910 at different levels of the Eiffel tower. There was some decrease, but much less than expected.

The Eiffel tower measurement was actually preceded by two balloon flights. One by Karl Bergwitz, a postdoctoral researcher in Braunschweig, who, as a boy, was taught in the secondary school by Elster and Geitel, and felt obliged to continue their pioneering work. The other by Albert Gockel from Fribourg, Switzerland, who had already extensively studied ionization at various locations and heights in the Swiss Alps, and was also a close collaborator of Theodor Wulf. Both used Wulf electrometers. Unfortunately some instrumental problems occurred at both flights, but they both found less decrease of the radiation with height than expected. Their results were however debated, and were considered less reliable than those of Wulf on the Eiffel tower.
3. Discovery and confirmation

Victor Hess prepared his series of balloon flights much more carefully. First he experimentally verified the absorption length of hard radium gamma rays, then made some low-level ascents both at day and night, and also at the time of a partial eclipse of the Sun. Thus he convinced himself that the Sun was not a dominant cause of the ionization. Earlier, he contacted the engineers of Günther and Tegetmeyer, and they jointly introduced some improvements to the Wulf instrument, making the walls thicker and the optical system more accurate. Hess was initially rather sceptic about an extraterrestrial origin of the ionizing radiation, and preferred the idea of either a radiation coming from the ground, or from radioactive substances of unknown origin in the atmosphere. After landing, he always checked his balloon for a possible radioactive contamination. His most important ascent to a height of 5300 m could be made only by using a hydrogen-filled balloon. The flight started near Aussig (now Ústi nad Labem) in Northern Czechia (then part of the Austro-Hungarian Monarchy), and ended at Pieskow at the Scharmützelsee, southeast of Berlin. A definite increase of the ionization was detected above about 2000 m. The day of that flight, the 7th August 1912, is now considered as the official date of the discovery of cosmic rays, although their existence was universally accepted only after many years of experimentation and debate.

An important confirmation of those results came from a young German researcher, Werner Kolhörster. He further improved the instrument, and rose even higher during his balloon ascents in 1913 and 1914. The highest altitude he reached was 9300 m, and at that level he measured a much higher ionization rate than Hess, while at low altitudes his results were consistent with those of Hess. Figure 1 shows the results of both Hess and Kolhörster. Note that the ionization rate $I$ (measured in ion pairs per second per cubic centimetre) at ground level is mainly due to the radioactivity of the ground and of the ionization chamber, and only about $I \approx 2$ ion pairs/(cm³/s) are produced by cosmic rays.

![Figure 1. Increase of the ionization rate in a closed vessel with increasing altitude.](image)

Although the above results appear now convincing enough, at that time there remained some doubt about their reliability. Then shortly the war broke out, and scientific debate in Europe came to a halt.
4. Developments after the 1st World War
Some American scientists were rather sceptical about the existence of the Höhenstrahlung or Ultra-Gammastrahlung, and also about the measurement techniques of Austrian and German researchers. CH Kunsman in 1920 for example refused to believe the high ionization rates measured at high altitudes, and attributed the high values to charge leakage of the Wulf electrometers at low temperatures. Robert Millikan was also interested in the subject, and decided to launch unmanned balloons to much higher altitudes. His conclusions also pointed toward much lower ionizations than measured by Hess and Kolhörster. As it became known later, his data were of rather poor quality. Further measurements were made by Otis on an air plane and by Millikan and Otis near the top of the mountain Pikes Peak, at 4300 m. Millikan concluded that an extraterrestrial radiation was unlikely. As Millikan received the Nobel price in 1923, his opinion had much weight. New measurements in two mountain lakes at different altitudes by Bowen and himself, however, convinced him in 1925 that a penetrating radiation of extraterrestrial origin did really exist, and he even gave a new name to it: cosmic rays. Popular press in America, however, preferred to write about Millikan rays.

While those developments occurred in the USA, research in Germany also started to recover. Kolhörster, who was working as a teacher after the war, was asked by Walther Nernst (Nobel laureate for Chemistry, 1921), to go to Switzerland for a few months and study the penetrating radiation at high altitude in the Alps. Nernst had a theory that the radiation may arrive from red giant stars in the Milky Way, and became interested in its directional distribution. Although the theory finally did not prove right, very useful absorption and directional measurements were made by Kolhörster and his Swiss colleagues during several such expeditions. In Germany the question of priority of the discovery of the high-altitude radiation of course resulted in bitter complaints against Millikan, but later the priority of the Europeans was acknowledged.

More importantly, new detection techniques became available for cosmic ray research in the second half of the 1920's: large Wilson chambers and Geiger-Müller tubes. The fortuitous discovery of cosmic ray tracks in a Wilson chamber by Dmitry Skobeltsyn had far-reaching consequences. Walter Bothe and Kolhörster constructed a shielded GM-tube arrangement with gold absorber between two tubes, and by a coincidence technique they were able to prove that cosmic rays at sea level were mostly particles, not gamma-rays. Bruno Rossi developed a more usable coincidence technique that helped Blackett and Occhialini to develop the coincidence-triggered Wilson chamber, and later to detect electron-positron pair creation, almost simultaneously with the discovery of the positron by David Anderson, who used a big Wilson chamber with strong magnetic field. Those measurements gave the first indications for the fundamental importance of cosmic rays for elementary particle physics.

At about the same time, the latitude distribution of cosmic ray intensities was investigated by a large international collaboration led by Arthur Compton, and it was proved that the primary cosmic rays were charged particles. The difference of the intensities arriving from East and West later showed that those particles were positively charged. The altitude dependence of the rate of ionization was also measured to much higher altitudes than earlier. In 1932 the automatic recording instruments aboard unmanned balloons of Erich Regener reached 26 kilometers. The new data fitted a smooth continuation of the data of Hess and Kolhörster, and also agreed well with new data of Millikan, who measured up to 8 km. Thus the long debate about the height-intensity curve ended in a sort of reconciliation. Hess, however, had some bitter memories of the controversy even after he received the Nobel price (shared with Carl Anderson) in 1936. Magdolna Forró, a Hungarian cosmic ray physicist and a good friend of Hess actually received a 16-page handwritten letter from him, complaining about Millikan’s unfair tactics.

The problems of the nature of the very penetrating particles and of the strange shape of the height-intensity curve were partially solved by the discovery of the muon in 1937 by Anderson and Neddermeyer. Another important development was the discovery of groups of particles arriving simultaneously, but separated by several meters or even by much larger distances. They were first
seen, but not studied in detail by Bruno Rossi. Later, the group of Auger in France and of Kolhörster in Germany almost simultaneously discovered the phenomenon of extensive air showers.

Figure 2 presents a "Hall of fame" of some of the most distinguished researchers who contributed to the development of the field of cosmic ray physics up to the end of the 1930's.

![Hall of Fame for early CR Research](image)

**Figure 2.** Some of the most important scientists of early cosmic ray research.

5. **Lajos Jánossy (1912-1978) in Potsdam and in Berlin Dahlem**

Lajos Jánossy was born in Budapest, and their family (with foster-father George Lukács, the well-known philosopher) moved to Vienna after the war, and then Jánossy was educated in Vienna and Berlin. Studying physics in the University of Berlin, he was impressed by the lectures of Erwin Schrödinger, and started his doctoral work with Werner Kolhörster in Potsdam.

Kolhörster was much interested in the directional distribution of cosmic rays, and he realized that coincidence techniques of GM tubes gave much better perspectives than his earlier methods of using absorption by ice in crevasses of alpine glaciers. At first Kolhörster mainly worked with Leo Tuwim, a Russian physicist who already had done some important cosmic ray research with Lev Myssowsky in Leningrad. Tuwim had a strong mathematical background, and developed in Potsdam a rather complicated method of determining the zenith angle distribution of cosmic rays from only a small number of coincidence measurements, using closely spaced GM tubes. Time windows for coincidences were then still quite wide, and accidental coincidences between pulses of far-spaced tubes too frequent for a good statistical accuracy. Tuwim’s method relied on some assumptions about angular distributions and on exponential absorption in the atmosphere, and required the solving of integral equations.

As Leo Tuwim died in a car accident in the South of France during the summer of 1933, the young Jánossy simplified and improved his methods, relying mainly on the geometrical properties of GM tubes. Kolhörster appreciated his work, and in 1934 already mentioned it as a "Jánossy theory". The
doctoral thesis of Jánossy was also based on the invariants he introduced for single-tube and coincidence counting. Figure 3 shows the far-spaced and closely-spaced (called G-arrangement by Tuwim) configurations of GM-tubes from a 1934 paper of Jánossy, co-authored by Kolhörster.

![Figure 3. Far-spaced and close-spaced Geiger-Müller tubes for measuring the directional distribution of cosmic rays at sea level. While far-spaced tubes were expected to give better directional accuracy, the low rates of genuine and higher rate of accidental coincidences made them less favourable.](image)

When the first cosmic ray research institute, under the direction of Kolhörster, was opened in Berlin Dahlem in 1935, Jánossy continued his work there. He compared methods of evaluation of cosmic ray absorption measurements made by directional and undirectional detectors, and in another paper discussed possible causes of directional asymmetries of cosmic ray directional distributions, including the effects of the terrestrial magnetic field. In a rather well-referenced paper he speculated about possible effects of the solar magnetic field on directional distributions of cosmic rays in the vicinity of Earth. Of course the solar wind and the Parker spiral field were unknown at the time, but his paper certainly proved thought-provoking.

6. Jánossy's activities in England and in Ireland

As the political situation deteriorated in Germany, Jánossy moved to England, and joined Patrick Blackett's cosmic ray team first in London, then in Manchester. Blackett's team was one of the best at the time, with strong leadership by Blackett, and with many first-class guests. Among the visitors of the Manchester team were, as mentioned by George Rochester, e.g. Auger, Bhabha, Carmichael, Cosyns, Occhialini, Heisenberg, Heitler, Rossi, Wataghin and Williams. Jánossy participated in several experiments, but his most important contributions were connected with penetrating showers containing both charged and neutral particles. In fact he is considered as one of the discoverers of those showers, important for understanding high-energy nuclear interactions.

First he worked mainly with Bernard Lovell, Bruno Rossi, Peter Ingleby (who was soon after the start of the war killed in a plane accident). During the war most members of the department were on war work, including Blackett, who was one of the top scientific advisers of the army, and had very little time for his department. Jánossy, as an alien, was left with a few others in Manchester to do teaching and take care of administration. He was, however, allowed also to do research, and was able to do very useful experimental work with George Rochester, with very little financial support, but a lot of inventiveness. They also had to do a lot of physical work in building sophisticated detector arrays with lots of GM tubes in coincidence and anticoincidence arrangements, containing of course a huge mass of shielding material as well. The equipment shown in figure 4 e.g. contained about 15 tons of lead bricks, and all of it had to be manually handled.
Figure 4. A sophisticated equipment of many GM tubes in coincidence and anticoincidence arrangement used for the study of penetrating showers by neutral particles. The weight of the lead bricks in the equipment amounted to about 15 tons.

Figure 5 shows the laboratory in Manchester, where most of the experimental work was done.

Figure 5. L. Jánossy, D Broadbent and G D Rochester in their Manchester laboratory in 1944.

The theoretical understanding of nuclear interactions was at a very primitive level at the time, as pions were discovered only later, in 1947. Jánossy had some contacts with Walter Heitler in Dublin, and they had discussions about the theoretical interpretation of some new experimental results of the Manchester group. The interpretation of several penetrating particles emerging from lead, seen by McCusker in Manchester in a cloud chamber, was one particular point for debate. Heitler’s theory
favoured the production in nucleon-nucleon collisions, while Jánossy favoured a production in a nuclear cascade inside a lead nucleus.

The Dublin Institute for Advanced Studies, directed by Erwin Schrödinger during the war, was also able to organize some symposia and summer schools during the war, as Ireland was, at least formally, a neutral state. Jánossy was invited to give lectures on cosmic rays in 1945, and at that time he was able to meet several distinguished scientists. Even Eamon de Valera, the political leader of Ireland and the founder of the Dublin Institute, participated in some discussions. Figure 6 shows Jánossy in the company of some of the most distinguished participants.

![Figure 6. Jánossy with Eamon de Valera and Dirac (left), and with Born and Schrödinger (right).](image)

Scientific contacts with the Dublin Institute, particularly with Walter Heitler, who later became director, continued, and finally Jánossy was invited to organize a new group of cosmic ray research as a senior professor of the Institute. Earlier there was a plan to invite Victor Hess as the head of a new School of the Institute for Advanced Studies, but negotiations with him ended before Jánossy was approached.

Although a senior professorship was more prestigious than his position in Manchester, Jánossy hesitated for some time. Research facilities were much better in Manchester, and he had also several friends there. He realized, however, that those returning from war work were advancing faster than he, who had worked particularly successfully on fundamental research throughout the war. In 1947 he was still participating in the work of the Manchester department to some extent, and actually he was (at least formally) the tutor of a particularly gifted BSc student, A W Wolfendale. He finally decided to leave, and to accept the offer of the Dublin Institute.

About his work in Manchester it is appropriate to refer to a remark by Carl Anderson in the "Early History of Cosmic Ray Studies", who was offered the use of a B-29 plane for cosmic ray research after the war. He did some experiments, but afterwards he was unsatisfied, and felt that he should have done better after a thorough discussion of possibilities. He wrote: "All the clues were present and published, one of the most important being the experiments by Lajos Jánossy in which he used counter arrays separated by various thickness of lead chosen to select nuclear collisions of high energy". And then: "We need only have added a small block of lead of about 20 cms thick, an additional counter, and required triple rather than double coincidences. This would have selected nuclear events, and undoubtedly would have given us hundreds of examples of the new unstable particles, heavy mesons and hyperons, subsequently discovered by George D Rochester and Clifford C Butler".

Good relations between Jánossy and Rochester survived also after Jánossy's return to Hungary in 1950, and the Department of Physics in Durham, led by Rochester, later by Wolfendale, had a fruitful collaboration with physicists from Hungary, including the present author. The following photos are
from 1973, the year of retirement of Rochester, when he took Jánossy and the present author to a car tour to show us his favourite county, Northumberland (figure 7).

Figure 7. G D Rochester (on the left in both photos) and L Jánossy in Northumberland (1973)

To start experimental work in Dublin was not easy, and there were also difficulties with the bureaucracy. Jánossy continued the evaluation of penetrating shower experiments made with D Broadbent in Manchester, started to write up his comprehensive monograph on cosmic rays, and did theoretical work, mainly with Walter Heitler, on both nuclear interactions and on the cascade theory of extensive air showers. He also continued the study of statistical methods applicable to the evaluation of measurements that later also resulted in a monograph. He enjoyed discussions with his earlier professor, Erwin Schrödinger, on quantum physics and on relativity, topics that later became his favourites.

7. Return to Budapest and cosmic ray research in the Central Research Institute for Physics
The mother and foster-father of Jánossy returned to Hungary from Moscow after the war, and the Hungarian government planned to establish a big new institute for physical research in Budapest. Scientists with international experience and fame were badly needed. As Jánossy apparently did not see much prospect in Dublin, he decided to return in 1950 and make use of the new opportunities. He soon became a member of the Academy and a university professor, and the head of the newly established cosmic ray department of the Central Research Institute for Physics of the Hungarian Academy of Sciences. He also became vice-director, then director of the Institute.

Although the experience of the staff of the department was initially quite limited, he used his vast experiences to train researchers and bring them up to international standards. Workshops were
established for the production of various mechanical and electronic equipment and GM-tubes, facilities were created for deep underground measurements, and members of the staff were given both instruction and appropriate tasks to learn the trade. Initially they reproduced measurements that have already been done by others under different conditions, then more ambitious projects leading to publishable results followed. The methods of Jánossy were described in more detail by Antal Somogyi in the Early History of Cosmic Ray Research. By 1969 cosmic ray research in Hungary was advanced enough to organize the 11th International Cosmic Ray Conference in Budapest, and later we also organized two of the European Cosmic Ray Symposia.

Jánossy himself later left the field of cosmic ray research, and followed his interests in quantum optics, relativity theory and the hydrodynamical model of wave mechanics. He had a long correspondence with Erwin Schrödinger concerning the last subject. He was very prolific in writing papers, both strictly scientific and popular, and his writings were collected in nine volumes. The title photo of his collected papers is reproduced below, together with the title pages of two of his monographs.

![Title page of collected papers and monographs](image)

**Figure 8.** Title pages of the collected papers and of two monographs of Lajos Jánossy

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