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The cosmic radiation

INTRODUCTORY REMARKS

Cosmic ray research has developed as one of the most spectacular and vital contributors to science in the Twentieth Century. From a humble beginning early in this Century, the quest for an understanding of this radiation and the challenges confronting investigators led to the rise of new scientific disciplines, technologies and astrophysical concepts. Particle and high energy physics, radiocarbon dating and magnetic fields and plasmas of astrophysical origin are representative of the many research fields born from cosmic ray research. Examples of technological contributions include radiation instruments and balloon and space flight concepts required to reach the cosmic radiation beyond Earth's atmosphere.

From our concept of a quiet universe at the beginning of the century to the recognition of a violent universe today, the cosmic radiations have – and continue to be – a vital component for understanding these dynamical phenomena on all astrophysical scales. Indeed, cosmic ray particles have become, towards the end of this century, part of what is now called astroparticle physics.

At night, when we look at the Milky Way with naked eyes, we observe an overall glow like that shown in the lower panel in Figure 1. This is the visible light from the excitation of atoms by very low energy processes – i.e., tens of electron volts. On the other hand, recent observations by the EGRET instrument on the Compton Gamma Ray Observatory satellite have revealed a dramatically more energetic view of our galaxy. The light in the upper panel in Figure 1 is from gamma-rays of approximately one-hundred million electron volts.

Nuclear interactions arising from accelerated cosmic rays with atoms in the interstellar medium result in the creation of many fundamental particles, among them pions of zero electrical charge that promptly decay into the gamma rays observed in the upper panel of Figure 1. Thus, it is clear that the cosmic rays propagate throughout the galactic disc.

The early years of cosmic ray research were both exciting and romantic since the investigators worked alone or in small groups world-wide. In the 1930's K.K. Darrow, for many years the secretary of the American Physical Society captured the spirit of these early years by noting:

> [The study of cosmic rays] is unique in modern physics for the minuteness of the phenomena, the delicacy of the observations, the adventurous excursions of the observers, the subtlety of the analysis and the grandeur of the inferences. (Darrow 1932)

This culture of personal involvement of physicists in carrying out experiments and personally recording data on mountains, in aircraft or balloons continued into the 1950's. In return for the personal risks were the rewards of instant discovery.

With the opening of the so-called Space Age it became possible to study directly the acceleration mechanisms and the propagation of charged particles in interplanetary magnetic fields. It also became necessary to include engineers and other technologists to assist in the design, construction and testing of space flight instrumentation.

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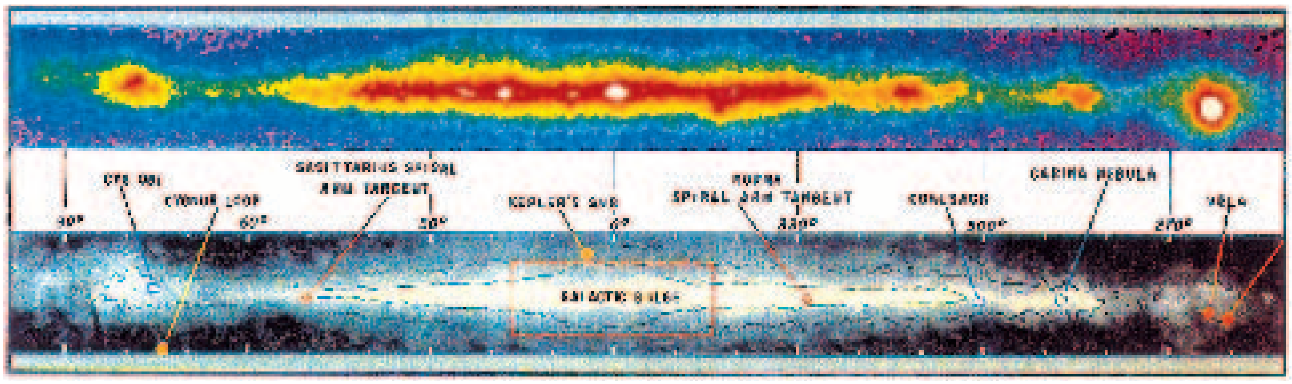

Figure 1 Lower: The galaxy in visible light. Upper: The ~100 MeV Galaxy (NASA).

This cultural change now largely pervades experimental cosmic ray physics. Experimental research in many areas is a big science effort with some young investigators having contact with experiments only by way of computer screens. For many theorists there also has been a cultural shift to massive computer code modeling.

The editors of this publication have requested this author's personal account of the history of cosmic ray research and of his early entry as a cosmic ray researcher into the space era, to be directed to a general scientific readership, and to be carried through to the 1970's or 1980's. Accordingly, this account is divided into two parts: the first part being mainly historical efforts to understand the radiation through the atmosphere; followed in the second part by both the international and the author's research in space beginning in 1958. A guide of references to our present knowledge of cosmic ray physics at the end of the 20th century is also included.

PART A: REACHING TOWARDS SPACE

1. THE DISCOVERY OF EXTRATERRESTRIAL RADIATION

The events leading to the discovery of the cosmic radiation were, in many respects, mysterious and misleading. By the late 1890's the basic instrument for measuring electric charge was the electroscope often used to demonstrate the presence of an electrostatic charge. Aside from leakage of stored charge from imperfect insulators, the electric charge imparted on the electroscope should hold this charge indefinitely. However, even the most highly developed electroscopes slowly lost their charge due to ionization in the atmosphere.

At that time the explanation for this leakage of electric charge appeared obvious – it must arise from radioactivity in the atmosphere ionizing the air around the electroscope.

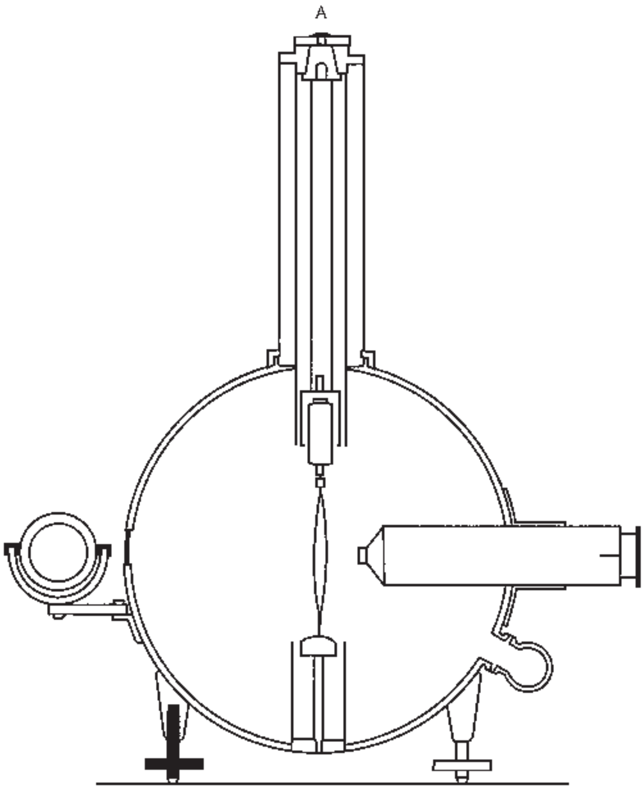

Figure 2 Electroscope and ionization chamber (Th. Wulf 1909).

This explanation had become popular as a result of the discovery of X-ray by Roentgen and discovery by H. Becquerel in 1896 of radioactivity in a compound of Uranium and with the realization that radioactive materials were to be found everywhere on Earth. Even with 5 cm of lead surrounding the electroscope the leakage of charge persisted.

The Dutch physicist, Th. Wulf (1909) had developed a highly stable electroscope and ionization chamber (Figure 2) that he used to test this hypothesis. He carried

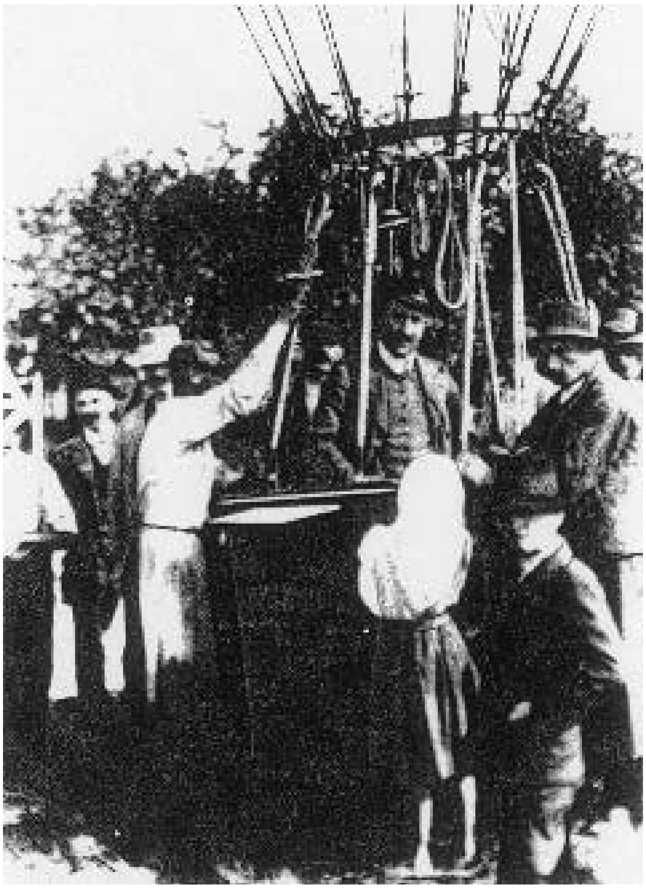

Figure 3 Viktor Hess after a balloon landing (1912).

his electroscope up the Eiffel Tower and found a radiation level of only 64% below the value on the Earth's surface for the leakage rate – much lower than he had calculated. He surmised, therefore, that there was either an additional source of radiation from the upper atmosphere, or that the absorption of gamma rays in air was much smaller than had been assumed. At about the same time Gockel (1911) in Switzerland carried a Wulf instrument in a balloon flight to 4500 m. He also questioned from his qualitative measurements whether there might exist a new radiation superposed on the radiation from Earth.

The 28 year old Victor Hess had been following these reports on the source of radiation producing the leakage charge in electroscopes. In a recounting of those years (Figure 3) he stated (Hess 1912, 1940):

> … At that time in the Spring of 1911, after reading an account of Father Wulf's Eiffel-Tower experiments, I was inclined to believe that a hitherto unknown source of ionization may have been in evidence in all these experiments; and I decided to attack the problem by direct experiments of my own.
>
> It seemed to me necessary to measure accurately the absorption of gamma rays from radium in air in order to find out how far above the ground gamma rays could act as an ionizing agency.
>
> The next step was the construction of an air-tight ionization apparatus which could be used during balloon flights and fitted with a sensitive electrometric system which was not influenced by the large fluctuations of temperature occurring in the flights. I used a modification of Th. Wulf's apparatus with walls of zinc, thick enough to withstand the excess pressure of one atmosphere and a temperature compensation for the fiber electrometer. Furthermore, I found it very important always to use two or three of the instruments simultaneously in order to avoid errors from instrumental defects. With such instruments, I made ten balloon ascents: two in 1911, seven in 1912 and one in 1913. Five of them were carried out at night, and some of them continued during the following morning. One flight was made during a solar eclipse, in April 1912.
>
> By taking successive readings of the ionization with two or three instruments at a time, much more reliable data were obtained. I found that at 500 meters above the ground the ionization was, on the average, about $2\mathbf{I}$ ($\mathbf{I}$ = ion pairs-cm^{-3} sec^{-1}) lower than on the ground and that, from about 1800 meters upwards, an increase of ionization is undoubtedly in evidence. At 1500 meters, the ionization increased to the same value as had been found on the ground. At 3500 meters, the increase amounted to no less than 4 I, at 5000 meters to 16 I above the ground value. No difference between day and night observations was noticed.
>
> An explanation of the increase of ionization with increasing altitude on account of the action of radioactive substances was impossible.…
>
> The only possible way to interpret my experimental findings was to conclude to the existence of a hitherto unknown and very penetrating radiation, coming mainly from above and being most probably of extra-terrestrial (cosmic) origin …

Within a year Kolhörster (1913) confirmed Hess's observations and conclusions. Nevertheless, many investigators disputed their measurements and conclusion with arguments concerning the stability of the electroscopes. It was not until after World War I that experiments were resumed. Millikan and Bowen (1923) developed a low mass (~190 g) electrometer and ion chamber for unmanned balloon flights using radiosonar technology developed during World War I. In balloon flights to 15,000 m in Texas they were surprised to find a radiation intensity not more than one-fourth the intensity reported by Hess and Kolhörster. They attributed this difference to a turnover in the intensity at higher altitude, being unaware that a geomagnetic latitude cutoff existed between the measurement in Europe and Texas. Thus, Millikan believed that there was no extraterrestrial radiation until he and Cameron (1926) carried out absorption measurements of the radiation at various depths in snow-fed 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" calling them "cosmic rays". They argued that the radiations are "… generated by nuclear changes having energy values not far from [those that they recorded] in nebulous matter in space."

Millikan than proclaimed that this cosmic radiation was the "birth cries of atoms" in our galaxy. His lectures drew considerable attention from, among others, Eddington and Jeans, who struggled unsuccessfully to describe processes that could account for Millikan's claim (cf. De Maria and Russo 1990).

2. COSMIC RAY CHARGED PARTICLES

A key experiment, which would decide whether the incoming radiation was electrically charged or uncharged, was the measurement of the dependence of cosmic ray intensity on geomagnetic latitude. If the radiation was electrically neutral, such as gamma rays, there would be no dependence on the strength of the magnetic field. On the other hand, if the cosmic rays were electrically charged particles – say electrons or protons – their deflection in the Earth's magnetic field would limit access at all but the highest latitudes. Thus the cosmic ray intensity would be less at the equator than at high latitudes.

In 1927, J. Clay (1928) from the Netherlands – by carrying ionization detectors on ships that traveled over a large latitude range – observed a geomagnetic latitude effect in cosmic ray intensity. If confirmed, the radiation must consist, at least in part, of charged particles interacting in the external geomagnetic field. Although Clay's work was disputed by Millikan, A.H. Compton (1933) carried out in 1932 a world-wide survey to settle the dispute. The Earth was divided into nine zones and teams, with all investigators using identical ion chambers. He then reported (1933) that there was a latitude effect, that cosmic rays were charged particles and that Millikan was wrong.

At about the same time, Millikan had sent Victor Neher (his junior colleague from the California Institute of Technology) on another latitude survey to South America. Unknown to the survey party, their electroscope had malfunctioned on the way down and they reported no latitude effect. This was triumphantly proclaimed by Millikan who attacked Compton in a debate at the Christmas meeting of the American Association for the Advancement of Science in 1932.

The electroscope did not fail on the Millikan party's return northward across the equator. This dispute ended in February 1933 when Millikan admitted that there was a latitude effect and that the cosmic rays must be charged particles.

Since Compton and Millikan were supported for their research by the Carnegie Corporation through its Department of Terrestrial Magnetism (DTM), the DTM was eager to settle the acrimonious debate by deciding which instrument was superior – that is, which instrument (Compton's or Millikan's) was the better one to use as a world standard.

In the early 1930's, Auguste and Jean Picard received much publicity for their manned balloon flights in the stratosphere that claimed to study the origin of cosmic rays. In 1933 the promoters of the Chicago "Century of Progress" World's Fair engaged them to make such a flight, with Compton agreeing to arrange all the scientific instrumentation to be carried in the manned gondola. Compton seized on this opportunity to seek a collaboration with Millikan. "It would seem too bad to let an expensive flight of this kind occur without making use of it for some high altitude measurements," he wrote (DeVorkin 1989). He invited Millikan to supply his automatic recording electroscope to be flown with the Chicago instruments in order to reconcile differences in their performance. Millikan, who had claimed his instrument was superior, agreed to meet Compton's challenge.

The Compton-Millikan venture appeared to have no impact on the advancement of cosmic ray physics. However, the development of the Compton-Bennett model-C ionization chamber (Figure 4) (Compton *et al*. 1934) became in the long run the standard adopted by the Carnegie Institution when a worldwide network of stations to search for cosmic ray variations with time was set up with the Chicago-built instruments at world-wide sites of the Institution's Department of Terrestrial Magnetism. The work of Scott E. Forbush, who was responsible for the stations, led to the proof that the observed intensity of cosmic rays within the atmosphere of Earth varied with time (Forbush 1938).

3. CHARGED PARTICLES, + OR −?

In the period 1928–1932 it was clear that cosmic rays included charged particles, but what was the sign of the electrical charge that they carried – plus or minus?

Until about 1930 the only property of cosmic rays that could be measured was their specific ionization (ions $cm^{-3} sec^{-1}$). Fortunately, Geiger and Müller (1928) had invented a cylindrical charged particle detector which made http://www.springer.com/978-0-7923-7196-0

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