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Reminiscences of cosmic ray research in Mexico

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Abstract

Cosmic ray research in Mexico dates from the early 1930s with the work of the pioneering physicist, Manuel Sandoval Vallarta and his students from Mexico. Several experiments of international significance were carried out during that period in Mexico: they dealt with the geomagnetic latitude effect, the north–south and west–east asymmetry of cosmic ray intensity, and the sign of the charge of cosmic rays. The international cosmic ray community has met twice in Mexico for the International Cosmic Ray Conferences (ICRC): the fourth was held in Guanajuato in 1955, and the 30th took place in Mérida, in 2007. In addition, an international meeting on the Pierre Auger Collaboration was held in Morelia in 1999, and the International Workshop on Observing UHE Cosmic Rays took place in Metepec in 2000. A wide range of research topics has been developed, from low-energy Solar Energetic Particles (SEP) to the UHE. Instrumentation has evolved since the early 1950s, from a Simpson type neutron monitor installed in Mexico City (2300 m asl) to a solar neutron telescope and an EAS Cherenkov array, (within the framework of the Auger International Collaboration), both at present operating on Mt. Sierra La Negra in the state of Puebla (4580 m asl). Research collaboration has been undertaken with many countries; in particular, the long-term collaboration with Russian scientists has been very fruitful.

Keywords: Cosmic rays; Early times; Present times; Mexican–Russian collaboration

1. Introduction

The first cosmic ray detector was the *electroscope*, by means of which scientists at the end of nineteenth century had noted that the gases in the atmosphere were being constantly ionized. It was learned that even when electroscopes were placed at a distance from laboratory radioactive sources, they still detected a slight ionization. By 1900 Thomas Rees Wilson and Hans Geitel had observed that even when electroscopes were totally isolated, they slowly discharged with time; radioactivity had recently been discovered, so this phenomenon was attributed solely to natural radioactive sources on earth. If that was true, the background signal should decrease far from the earth's surface. To test such a hypothesis, in 1912 the Austrian physicist Victor F. Hess carried out a series of experiments with electroscopes carried aloft in balloons to a height of 5300 m. Above 1500 m he observed an important increase of ionization that he attributed to an ionization source located in the upper layers of the atmosphere. For some time it was believed that such radiation was electromagnetic in nature generated in the Cosmos, hence the term cosmic *rays.* In the following years, Robert Andrews Millikan repeated the experiments, with the balloons ascending to a height of 15,000 m: they confirmed the existence of a very high penetrating radiation, with different penetration powers. For some years it was thought that such radiation of cosmic origin was composed of a mixture of gamma-rays of different energies, which were much higher than those discovered recently in earth-based experiments.

The hypothesis that cosmic radiation could be corpuscular in nature was disregarded in those days. Its possible association with beta-rays was highly improbable, since they have energy which is 100 times lower than that of gamma-rays. Up to 1927 this understanding of the photonic nature of cosmic rays was not seriously challenged.

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However, that year the Dutch physicist Jacob Clay measured a decrease of about 15% of the radiation at sea level, when moving from middle to equatorial latitudes. Since photons are not affected by magnetic fields, the hypothesis of corpuscular origin was broached again. In 1929, experiments performed in a vapor chamber by the Russian scientist D. Skobeltzyn led him to propose the argument that cosmic rays could be electrons expulsed from matter by gamma-rays. However, the same year experiments using Geiger-Müller counters carried out by Bothe and Kolhöerster refuted such a hypothesis, thus strengthening the concept of a charged-particle nature. Clay's preliminary results were exhaustively corroborated by a series of experiments carried out by Arthur H. Compton, who measured the geomagnetic effects brought about by changing latitude and longitude: he conducted his experiments from New Zealand, Hawaii, Peru, and Panama and went all the way up to Mexico. Using a theoretical point of view, Lemaitre (1931) gave greater support to the corpuscular hypothesis by seeing cosmic rays as byproduct particles of the primordial big-bang explosion.

2. The early Mexican contribution to cosmic ray research

Once the work of Compton and Clay had shown that cosmic rays were charged particles, the next enigma to be confronted concerned the nature of their charge, was it positive or negative? The answer to this question would have important implications for cosmological theories of the origin of the universe, such as the Big Bang theory recently proposed at that time by the Belgian abbot Lemaitre. In a series of papers Lemaitre and Vallarta (1933) (Fig. 1) and Vallarta (1933, 1935, 1937) explained the latitude and azimuth effects discovered by Clay and Compton: they showed that cosmic rays, since they are affected by the geomagnetic field, can only be charged particles, excluding the possibility that they were only gamma-rays, as had been suggested by Milikan and others. Based on the results of Fredrik Carl Störmer published on those days and on the Liouville's theorem, Lemaitre and Vallarta also determined the minimal threshold value of particle magnetic rigidity for particles to be able to penetrate up to a given geomagnetic latitude, namely the geomagnetic cutoffs, and also determined the allowed acceptance cones for the arrival of cosmic rays on earth.

Fig. 1. The abbot George Lemaitre and Prof. Manuel Sandoval Vallarta in 1938.

One of the most important predictions of Lemaitre and Vallarta calculations was the west–east asymmetry effect: it showed that the effect of the geomagnetic field was not only the selective access to different latitudes according to their magnetic rigidity (momentum per charge unit), but it deviated particles in different directions according to the sign of the charge. They predicted that positive-charged particles would deviate to the west and negative-charged ones, to the east. Prof. Vallarta convinced Prof. Compton to make new measurements in Mexico to test their predictions.

Compton sent his student, the American physicist Luis W. Alvarez (a future Nobel Prize Laureate) to conduct the experiments in the mountains around Mexico City and on the roof of the Genève Hotel, near the center of the city: in the latter location he put the counters in a bricklayer's wheelbarrow and measured the cosmic ray intensity by varying the orientation of the wheelbarrow. Through these experiments, Compton and Alvarez determined that there was an excess of about 10% in the intensity of deviations to the west, implying that cosmic radiation consisted principally of protons. This was a surprising result. Owing to the omnipresence of electrons in nature and the facility with which they could separate from atoms, it had been expected that they would be predominant in geomagnetic field-sensitive radiation. The north–south asymmetry discovered in 1934 by T.H. Johnson of the Bartol Research Foundation in experiments carried out in México with Vallarta (in the Copilco area and at the *Nevado de Toluca* volcano) as well as their studies on east–west, in Veracruz, San Rafael and México City, were also interpreted by Lemaitre et al. (1935).

Up to 1946 Professor Vallarta did not spend all of his time in Mexico. He was a full time professor at the Massachusetts Institute of Technology (MIT), and would return home during the holidays to teach at the Faculty of Sciences and the Institute of Physics of the *Universidad Nacional Autónoma de México* (UNAM). Beginning in the 1930s, during his frequent visits to Mexico, he began to form an incipient group of scientists interested in cosmic ray research: among the prominent physicists that he introduced to this field, one can mention Jaime.

Lifshitz, Nabor Carrillo, Alberto Barajas, Manuel L. Perrusquia, Juan de Oyarzabal, Hector Uribe, Fernando Alba Andrade, Alfredo Baños and Carlos Graef Fernández. The latter two went to the MIT to do their doctoral dissertations with him in 1934 and 1935, respectively: Carlos Graef Fernandez completed his Ph.D. dissertation, "Study of the Distribution of Periodic Orbits", at MIT in 1938; Alfredo Baños completed "On Asymptotic Orbits in the Theory of Primary Cosmic Radiation" in 1939 (Baños, 1939a,b). During the period from 1933 to 1939 Vallarta and his colleagues published a series of papers in *Nature*, *Physics Review, the Review of Modern Physics*

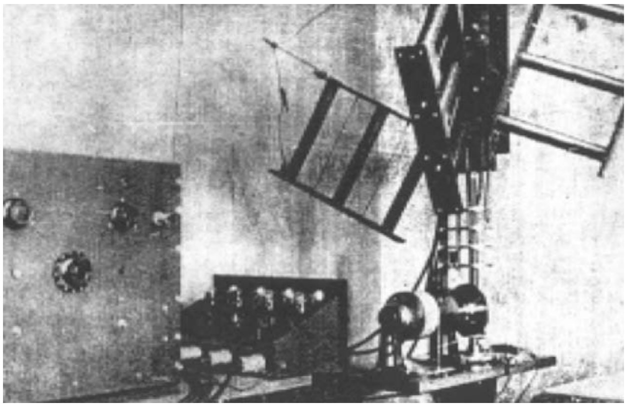


Fig. 2. The first Mexican cosmic ray detector placed on the roof of the Mining Palace in 1941.

and in other publications on the application of cosmic ray theory to the magnetic momentum of the sun and galactic rotation, to mention a few examples (Vallarta et al., 1939).

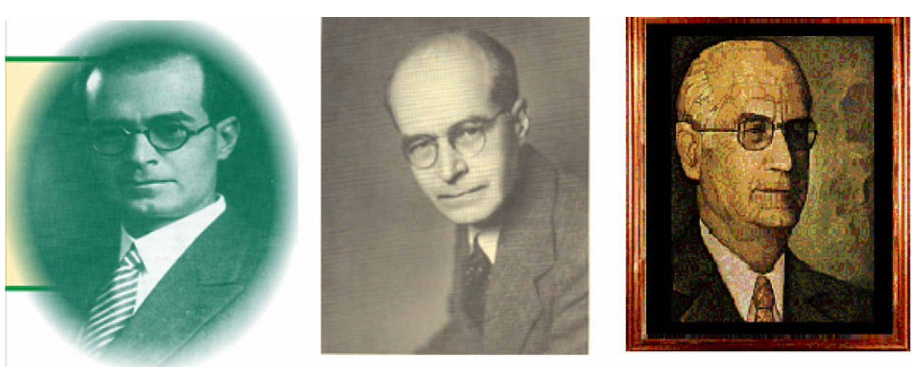
In 1940, under the guidance of Alfredo Baños, the young students Fernando Alba Andrade and Manuel I. Perrusquia constructed a rotating rail system of Geiger counters to measure cosmic ray intensity as a function of time at azimuth and zenith angles of 0, 20, 40 and 60 degrees, and mounted it on a meteorological station placed on the roof of the Palacio de Minería, an eighteenth-century building in the heart of downtown Mexico City, where the Faculty of Sciences of UNAM was located in those days (Fig. 2). The counters operated automatically, with photographic records of events being taken every 32 min. There were uninterrupted records spanning at least 100 days up to May, 1946. On the basis of the data obtained with this counter system, Alfredo Baños wrote the first research article on cosmic ray physics published in a Mexican professional journal (Baños, 1941). With the help of Hector Uribe, Jaime Lifshitz calculated the trajectories of cosmic rays within the geomagnetic field using very simple electric calculators (Lifshitz, 1942). Juan de Oyarzabal was in charge of the statistical analysis of data and, along with Vallarta and Manuel I. Perrusquia, published "*The determination of the sign of the energy spectrum of primary cosmic radiation*" (Vallarta et al, 1947).

On February 17, 1942, on the occasion of the inauguration of the Astronomical Observatory of Tonatzintla in the state of Puebla, the Inter-American Congress of Astrophysics was held, with the participation of scientists from Mexico, the United States, and Canada. One of the presentations was given by a group from the Institute of Physics of the UNAM. Graef, Lifshitz, Uribe, Martinez and Baños discussed the dynamics of the symmetric, periodic orbits of cosmic rays in the magnetic field of the Earth and the measurements of the azimuthal variation of cosmic ray intensity taken from different zenital angles. Unfortunately, the proceedings were never published, but a good narrative account of the event was given in *Sky and Telescope* under the title *Sojourn in Mexico* (Menzel and Donald, 1942).

In 1954, Prof. John Simpson of the University of Chicago regaled to UNAM a Neutron Monitor that was installed on the new campus of the UNAM. Principal research from 1954 to 1958 was focused on the albedo of cosmic rays, as exemplified in the invited talk that Professor Vallarta gave at the International Conference of Theoretical Physics held in Tokyo in 1954 (Vallarta, 1954).

In 1955, Prof Vallarta and his collaborators organized the 4th ICRC, which was held in the city of Guanajuato from September 5th to the 12th. For the first time in the history of these events, there were Soviet scientists in attendance. The conference was presided over by the Nobel Prize Laureate, Prof. P.M.S. Blackett, and around 90 papers were presented on that occasion.

At the beginning of the 1960s, the UNAM acquired a Carmichael Neutron Super Monitor equipped with six proportional counters. By 1958 the center for research on cosmic rays had already been moved to the Institute of Geophysics of the UNAM, where a new group was organized in 1962 by Ruth Gall, with the aim of developing a program devoted to space science. One of the main research topics cultivated in those years dealt with the motion and capture of charged particles in the so-called



(a) (b) (c)

Fig. 3. Three stages in Prof. Manuel Sandoval Vallarta's professional life (a) during his time at MIT (b) during the days of consolidation of research groups in Mexico. (c) during his days as consultant to the IAEA and the Instituto Nacional de Energía Nuclear of Mexico [Mexican National Institute of Nuclear Energy].

Van Allen rings. Under the guidance of Ruth Gall, important work was done, mainly related to magnetospheric models and trajectory computation, asymptotic directions, variational coefficients, Forbush decreases, and cutoff rigidities. The results of this research were published in conjunction with her students – A. Orozco, S. Bravo, J. Jimenez and L. Camacho; among the most significant of them are Gall et al. (1968, 1982).

Prof. Vallarta (Fig. 3) continued to publish in the field of cosmic rays up to 1962: some examples include "*Geomagnetic Coordinates and Cosmic Radiation*" (Vallarta et al., 1958) and "*Theory of the geomagnetic effects of cosmic radiation*" (Vallarta, 1961). He even explored the field of solar cosmic radiation in "*On the mechanism of sudden increase of cosmic radiation associated with solar flares*" (Forbush et al., 1949).

An amusing anecdote associated with the latitude effect can be found in George Gamow's book "Biography of Physics: After Compton and Vallarta had taken several measurements in different places in Mexico – Veracruz, Orizaba, Mexico City and the Nevado de Toluca volcano –, Compton wanted to find somewhere to work that was far enough away from cities to avoid interference and noise from electricity lines, traffic etc., but that also had electrical power, so he could use his instruments. The best place he found was a monastery located some distance from Mexico City, which had its own energy station and an abbot interested in science. Compton arrived at the nearest train station with 12 heavy boxes: two of them holding Kohlrausch electrometers and the rest containing lead bricks. He was immediately surrounded by a large group of boys that wanted to help him. He carried the boxes containing the electrometers, and the boys carried the heavier ones on their shoulders. In those days the Mexican Government and the Catholic Church did not enjoy good relations, so Catholic institutions were under permanent surveillance. Two soldiers on duty at the monastery opened the boxes with the electrometers inside and found "four black bombs", along with many boxes full of lead that could be used to make bullets. Compton was held for several hours at the police station, until someone from his embassy interceded. Ever since then, scientists have been seen as "dangerous people".

Exhaustive compilations of Prof. Vallarta's works can be found in Mondragón and Barnés 1978; Mendoza, 1995; Mondragón, 1999; del Rio Haza, 2007.

The distinction between the early and current periods of cosmic research in Mexico is based only on the fact that most of the previously mentioned people have already died.

3. The new era of *cosmicists in M*exico

At the beginning of the 1970s, Javier Otaola and Jorge Pérez-Peraza, who had finished their doctoral studies in

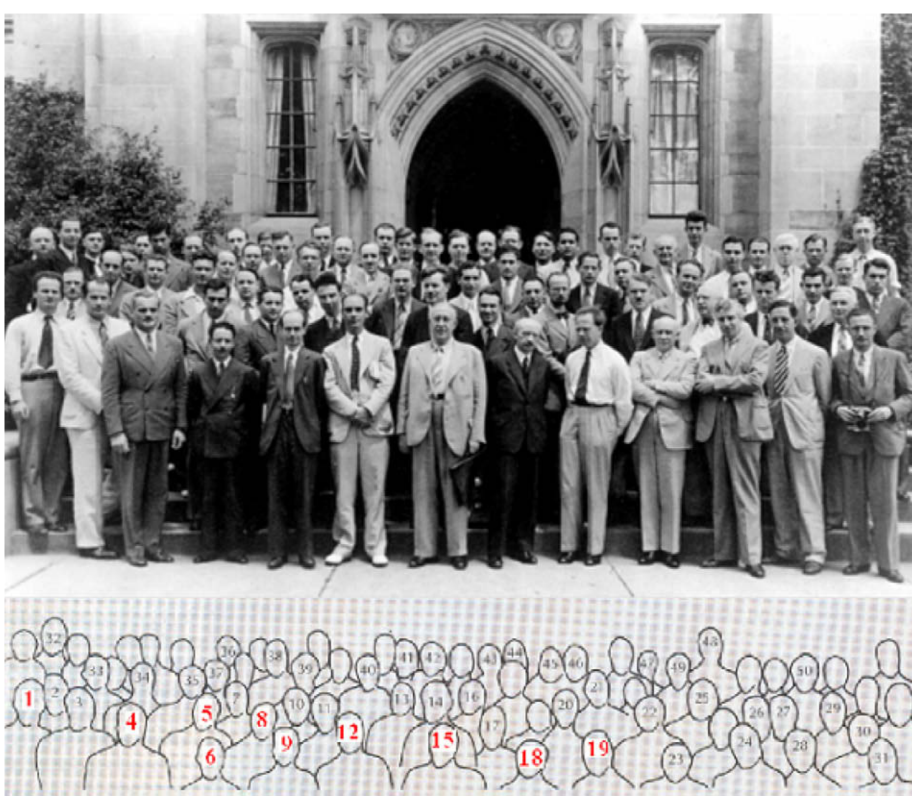


Fig. 4. Alfredo Baños and M.S. Vallarta (6 and 9) at the Cosmic Ray Symposium at the University of Chicago in 1939. Also in attendance were eight Nobel Prize Laureates: Hans Bethe (1), Arthur Holy Compton (4), Edward Teller (5), S. Goudsmit (8), Carl D. Andersen (12), Victor Hess (15), Wilhelm Bothe (18) and Werner Heisenberg (19).

Europe, returned to Mexico. They trained a new generation of young scientists who had also traveled abroad to work on their doctoral theses: José Valdés-Galicia, Julio Martinell-Benito, Blanca Mendoza and Miguel Gálvez-González, to name a few. Some of them returned to Mexico and, in turn, trained further generations of students during the 1980s. In those years, a new policy of the Mexican Council for Science and Technology granted scholarships for students who wanted to do their doctoral studies in Mexico: this group included Apolonio Gallegos-Cruz, Rogelio Caballero and Manuel Alvarez-Madrigal, among others. In addition to the traditional cosmic ray studies then cultivated in Mexico, the range of disciplines was then substantially enlarged to a wide range of Space Physics disciplines; it is to be mentioned the field of planetary magnetospheres under the guidance of Prof. Hector Pérez de Tejada, coronal holes and coronal mass ejections with Alejandro Lara and Xochitl Blanco, solar–terrestrial relationships and climate variability (Victor Velasco), and so on.

The main contributions to cosmic ray physics in this new era have been in the fields of modulation, galactic cosmic ray transport, SEP (e.g., Miroshnishenko and Perez-Peraza, 2008)), acceleration theory (e.g., Gallegos-Cruz and Pérez-Peraza 1995), azimuthal coronal transport (e.g., Pérez-Peraza, 1986), interplanetary cosmic ray propagation (e.g., Valdés-Galicia, 1992), relativistic solar proton events, energy spectrum, composition, charge spectrum, solar flare neutrons and UHE cosmic rays (Pérez-Peraza et al., 2005). Particular impetus has been given to the field of cosmic ray and SEP influence on terrestrial phenomena (e.g., Pérez-Peraza et al., 1997); Valdés-Galicia and Velasco, 2008).

With regards to the experimental end of the field, Javier Otaola and José Valdés took care of and modernized the neutron monitor station. In addition, solid state nuclear track detectors (SSNTD) were developed (Pérez-Peraza et al., 1991, 1992) by synthesizing and polymerizing the monomers of the full Allys-Bis carbonate family (CR-39 type): Mexican patents 162004 and 162100, in 1991. In collaboration with Japanese scientists, José Valdés and his students recently installed a solar neutron monitor on Mt. Sierra Negra, in the state of Puebla. Several Mexican Universities, with about 15 scientists and 20 students involved, are now participating in the International Pierre AUGER Program. Those participating include, Lukas

Fig. 5. Dublin 22nd ICRC, 1991: Silvia Bravo (1), Jorge Pérez-Peraza (2), José Valdés-Galicia (3).

Nelsen, José Valdés and Juan Carlos D'Olivo from the UNAM; Humberto Zalazar and Arturo Hernández from the BUAP (Benemérita Universidad Autónoma de Puebla), Arnulfo Zepeda from the Centro de Investigaciones Avanzadas (CINVESTAV) of the Instituto Politécnico Nacional and Luis Villaseñor from the UMSNH (Universidad Michoacana de San Nicolas de Hidalgo). An EAS Cherenkov array is also being constructed on the Sierra Negra Volcano, which, to a certain extent, can be seen as a continuation of the Milagro program.

Collaborative scientific arrangements have been established with many countries: the United States, Spain, France, Germany, Greece, England, Japan, Bulgaria, India, and Argentina, just to name a few. The longest term cooperation has been with Russia, resulting in the publication of more than fifty research articles since 1985. Among the Russian colleagues to be mentioned are Prof. Leonty I. Miroshnishenko, Prof. Lev Dorman, Dr. Igor Libin, Dr. Yuri Stenkin and others from the former IZMIRAN (now Pushkov Institute), along with Prof. Eduard Vashenyuk and his colleagues from the Polar Geophysical Institute (PGI) of Apatity, Murmansk.

In addition to the 4th ICRC already mentioned, three international workshops on UHE cosmic rays and the Auger collaboration were organized and held: in the city of Puebla in 1966, in the city of Morelia in 1999, and in Metepec in 2000 (Salazar et al. 2001). The 30th ICRC was held in Merida, Yucatan, organized by José Valdés and the local cosmic ray community and featuring more than 1000 contributions. One highlight was the participation of the Nobel Prize Laureate James W. Cronin.

4. Conclusions

Cosmic rays together with relativity were the two first branches of physics cultivated in Mexico at the beginning of the twentieth century. Cosmic ray research has taken on new vigor during the last few decades. A new enthusiastic generation is being trained. Mexican *cosmicists* have participated in almost all of the ICRC's and several European Cosmic Ray Symposiums (Figs. 4 and 5). There have been many achievements in cosmic ray research to celebrate in the last 70 years, along with very rewarding experiences to enjoy during the course of those years, including the welcoming to Mexico of colleagues from many parts of the world, one of the most exciting of all of them.

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