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The Pioneers of Cosmic Ray Research in India

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Abstract

Centenary symposium on Discovery of Cosmic Rays was organised in Denver, Colorado (USA) in June 2012. The proceedings of this conference published by American Institute of Physics (AIP) in 2013 are the most exhaustive survey of research carried out at global level. The glorious period of Cosmic Ray research began in India during 1940s simultaneously in JC Bose Institute, Calcutta under the supervision of DM Bose; Forman Christian College, Lahore under PS Gill, and Indian Institute of Science, Bangalore under HJ Bhabha. Experimental research in cosmic rays in India got a big boost with the establishment of the Tata Institute of Fundamental Research (TIFR) by Homi Bhabha in Bombay in 1945, the Physical Research Laboratory (PRL) by Vikram Sarabhai in Ahmedabad in 1947 and Cosmic Ray Laboratory by Piara Singh Gill at the Aligarh Muslim University (AMU) in Aligarh in 1949. TIFR has been the flagship for cosmic ray research in India. In recent years, TIFR has installed a sophisticated system of atmospheric cherenkov detectors at Hanle in the Ladakh region at an altitude of 4200 m, to continue studies on (very high energy) VHE sources of cosmic gamma rays. This paper presents an overview of cosmic ray research in India.

Keywords: *Cosmic rays, latitude effect, cosmic ray showers, JC Bose Institute, TIFR, AMU*

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INTRODUCTION

After the discovery of cosmic rays by Victor Hess and W. Kolhörster [1] during 1911–14, J.C. Clay (1927) in Holland demonstrated a remarkable variation of cosmic ray intensity with latitude, and the effect was pursued by A.H. Compton and his collaborators in world-wide survey. The first observation of cosmic rays in India was made by J.M. Benade of Forman Christian College, Lahore in 1932, who happened to be an associate of A.H. Compton, using a portable ionisation chamber. A.K. Das [2] working in Cambridge (1933) carried out cosmic ray intensity measurements during two sea voyages between India and Europe. This work was followed by Das and Salaruddin [3] during 1936–38 at Agra and at Kodaikanal at 7700 feet above sea level.

S.D. Chatterjee [4] of Kolkata made the first attempt in 1940 to measure the intensity of thermal neutrons at sea level and at 7000 feet in Darjeeling using boron-lined proportional counter and also BF_3-filled ionisation chamber. The experiment on the study of fast cosmic ray neutrons as a function of altitude and latitude was carried out by Gill and Curtis [5] simultaneously in India and USA. Experimental research in cosmic rays in India received a big push with the establishment of the Tata Institute of Fundamental Research by Homi Bhabha in Bombay in 1945, the Physical Research Laboratory by Vikram Sarabhai in Ahemedabad in 1947 and the setting up of a cosmic ray research group by Piara Singh Gill at the Aligarh Muslim University in Aligarh in 1949.

CONTRIBUTION OF P.S. GILL IN COSMIC RAY RESEARCH

The most significant contribution in the measurement of latitude effect was made by P.S. Gill [6, 7], who made 15 trips between Vancouver (Canada) and Sydney (Australia), from 40° N latitude to 38° S latitude, to extend the measurements of ‘Compton and Turner’. Gill found external temperature effect correction and established the "Latitude Knee" effect curve. During 1936–40, Gill worked at the University of Chicago for his Ph.D. under Nobel Laureate Arthur Compton. His thesis established the ‘latitude effect’ in cosmic ray intensity at sea level. In the course of this work, he travelled 15 times between Vancouver, Canada and Hobart, Tasmania during 1937–38 in a regular passenger steamship, the *S.S. Aurangi*, where he had installed an ionization chamber shielded by a 12cm thick lead enclosure. In June 1939, Gill attended the International Symposium on Cosmic Rays, presenting a paper on the 'Size-Frequency Distribution of Cosmic Ray Bursts', which described the first experiment to provide clues about meson spin [8].

On his graduation in 1940, Compton offered Gill a postdoctoral fellowship to continue his research at Chicago, but Gill was keen to carry out experiments on the azimuthal variation of cosmic ray intensity in India. So, the Chicago University awarded him a travelling research fellowship, and Gill sailed for India in April 1940, joining Forman Christian College, Lahore as a lecturer in physics, where he also set up a cosmic ray research laboratory. In the summer of 1945, he organized an expedition to the Himalayas to study the production of mesons by the non-ionizing component of cosmic rays, but the results showed no production of mesons. Later, these experiments [9] were repeated using RAF planes and meson production was detected at altitudes above 20,000 ft. Gill [10] made detailed study of the azimuthal effect of cosmic rays in India at Lahore (22° N latitude) using four triple coincidence telescopes mounted on a turn table. He deduced a power law energy spectrum for primary cosmic radiation. Using a similar arrangement, Gill and Vaze [11] measured E-W asymmetry at Bombay for the energy spectrum of primary radiation.

In 1946, Gill visited the USA and Europe, delivering invited lectures on cosmic ray experiments carried out in India. Upon returning, he became a Professor at the Tata Institute of Fundamental Research (TIFR), Bombay, where he initiated high altitude experiments with hydrogen balloons. Gill resigned from TIFR the next year (probably due to personality conflicts with its then Director, Homi Bhabha, himself an eminent cosmic ray physicist) and returned to the US to work at the Carnegie Institution of Washington, studying the relationship between solar flares and sudden increases in the intensity of cosmic rays, in collaboration with M. S. Vallarta and S. E. Forbush.

Piara Singh Gill joined Aligarh Muslim University (AMU) as Professor and Head of the Physics Department where he established well-equipped research laboratories (Figure 1). Under his leadership, AMU became a leading centre for cosmic ray research in India during the 1950s. The development of GM (Geiger-Müller) counters, neutron counters, nuclear emulsion techniques and sophisticated electronic circuitry for experiments was carried out at AMU under the direction of PS Gill. High altitude cosmic ray laboratory was set up at Gulmarg (Kashmir) under AMU. Gill [12] made detailed measurements of the absorption of cosmic rays in the lead at Gulmarg (8890 ft.) and Srinagar (5000 ft.). Nuclear emulsion plates were also exposed at Gulmarg to study meson production.

Fig. 1: *Piara Singh Gill (1911-2002).*

More than a dozen students got their Ph.Ds. working in the area of cosmic ray studies at AMU during 1949–63. S.P. Puri studied discharge-mechanism of GM counters, R.N. Mathur employed neutron counters to measure mean free path of cosmic ray neutrons in different absorbers, T.H. Naqvi and M.K. Khera studied composition and energy spectrum of primary cosmic rays as well as anomalies of absorption of cosmic rays in lead at Aligarh and Gulmarg. Yog Prakash, I.S. Mitra and A.P. Sharma used nuclear emulsions for investigation of high energy star production at mountain altitudes, east-west assymetry and charge distribution of relativistic particles. Along with experimental work, theoretical studies on cosmic rays were also encouraged in AMU. The 60th Birthday Volume presentation of Gill [13] has all the details of publications of AMU Cosmic Ray group.

CONTRIBUTION OF DM BOSE GROUP IN COSMIC RAY RESEARCH

D.M. Bose was a pioneer in cosmic ray research in India. D.M. Bose and Biva Chaudhuri were the first to identify meson tracks from the cosmic ray stars. Many believed that they missed the Nobel Prize for the discovery of mu-meson because of their lack of access to modern scientific tools and problems of interpretation of recorded data [14, 15]. A lesser known fact is that in the 1930s cosmic rays study was a part of the research programme at the J.C. Bose Institute, Calcutta. For instance, in 1934, R. Ghosh [16] measured the east-west asymmetry (the effect comes into play because the earth shadows certain trajectories of the cosmic rays, as a result of it the low energy cosmic rays from the East are suppressed compared to those from the West) in cosmic radiation at Darjeeling.

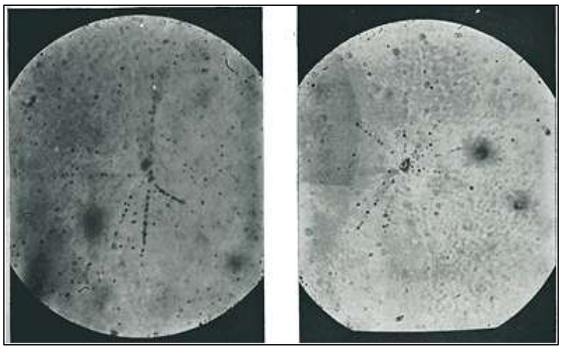

Fig. 2: *Ionization Tracks Recorded in Ilford Plates: Pair Track (left) and Star with 12 Multiple Tracks (right) [18].*

After D.M. Bose has taken the directorship of Bose Institute, under his guidance theoretical and experimental work on the nuclear model of Yukawa was started. Shortly after this, D.M. Bose and B. Chaudhuri with Blau-Wambacher's technique observed the "double tracks" and five and 12 prong multiple stars (Figure 2). For particular particles they found that the kinetic energy was 2 and 4 MeV, respectively. The effect was attributed to mesotrons. Their results were in agreement with W. Heisenberg's theory of scattering and collision processes between mesotrons and protons, and H. Meier-Leibnitz's formula for kinetic energy of slow mesotrons [17].

D.M. Bose (Figure 3) and Biva Chaudhuri [18–22] started using Ilford R2 and new halftone photographic plates for the study of cosmic rays at different altitudes (2130 m and 3660 m). They exposed photo-plates to cosmic rays for 5 months. After painstaking experiments for couple of years they observed "double tracks" using Blau-Wambacher technique, which had not been mentioned before. Later they observed five and 12 prong multiple stars. The next sets of observations were made for 202 days. This time the plates were kept under water, in air and in a lead box. The authors studied the mean grain spacing and curvature of tracks due to protons of known energy, and cosmic rays. From the comparison of the two they concluded that heavy ionisation tracks were mainly due to mesotrons. H.J. Bhabha and W. Heitler, and W Heisenberg had given different theories of multiple shower production by scattering due to cosmic particles. Bose and Chaudhuri were careful about giving their opinion on them.

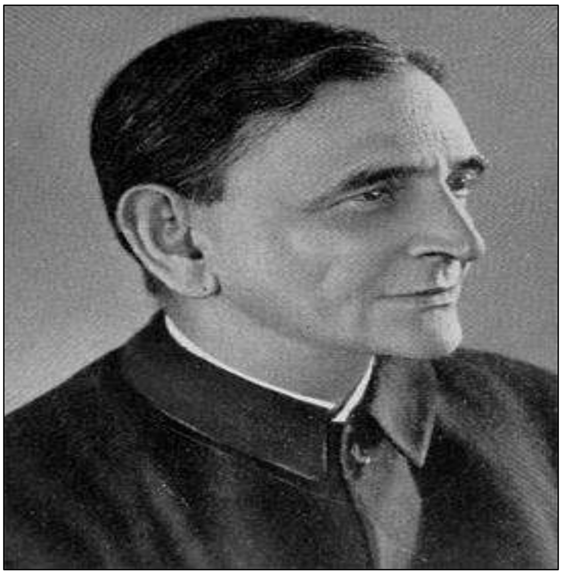

Fig. 3: *D.M. Bose (1885-1975) (Courtesy: University of Calcutta).*

Bose group's next publication deals with the estimation of the mass of the secondary particles with heavy ionisation tracks. The experiments were performed at high altitudes (12,000 and 14,500 ft). The plates were exposed under air and under 20 cm of water. The method was based upon the determination of the kinetic energies of these particles and of protons with the same initial velocities, which produce tracks with the same mean grain spacing in the emulsion. With E.J. William's method, they determined the energy of the particles from their mean scattering and also their velocities as function of the mean grain spacing along their tracks [23]. For calculating the kinetic energy of proton, they assumed that "in such emulsions particles of different masses, but with the same charge and the same initial velocity will have the same mean grain spacing along their tracks."

With Ra-Be source neutrons, they produced recoil protons in emulsion and prepared a calibration curve. They classified the results of measurements under: number of tracks for different mean graining space, total tracks in emulsion, total scattering in scattering cross-sections etc. and determined the mass of mesotrons. It varied between 149 and 265 m_e (m_e is the mass of electron). They indicated that the method is based on a number of assumptions and thus the numbers presented are indicative with certain statistical uncertainties. They concluded: "The results obtained are important in other respect; it has enabled us to verify our previous surmise that the star-like tracks found in our photographic plates are due to secondary mesotron showers produced chiefly by cosmic ray neutrons. This and the presence in such showers of three-, four- and five-star tracks in approximately equal numbers are results which do not appear to be capable of interpretation in terms of existing theories."

Sinha [24] reconfirmed the view of some scientists that the "Rossi curve for bursts is similar to that for small showers, the only difference being that the contribution from the hard component is comparatively large". In the same article, Sinha produced some photographs, which showed the burst-like phenomenon, with mesotron tracks which terminated inside the cloud chamber. He reported the presence of 12 mesotrons in a single shower, which was not observed so far.

This seemed to confirm Heisenberg's conception of multiple mesotron generation in a single act. From the above it is clear that D.M. Bose and B. Chaudhuri were indeed the first persons who observed the meson track in photographic plates. Not only that they have measured the mass of this cosmic particle for the first time long before Powell, and the measured mass (~200 m_e) is quite close to the accepted value (~216 m_e) as was measured by Powell using improved 'full tone' plates. So, there are enough reasons to feel that D.M. Bose and B. Chaudhuri missed the opportunity to get the Nobel Prize for this discovery.

BHABHA'S ROLE AND TIFR CONTRIBUTION IN COSMIC RAY RESEARCH

Homi Jehangir Bhabha, known as Father of Atomic Energy in India, was a highly accomplished scholar in Science, Technology and Culture, the like of which are born once in a century (Figure 4). Bhabha's first paper on: "Zur Absorption der Höhenstrahlung" (The absorption of high altitude rays) was based on the work done under the guidance of Wolfgang Pauli in Switzerland. In this article, he gave the explanation for electron shower production in cosmic rays [25]. In 1935, Bhabha wrote a paper [26], which was aimed to discuss the creation of electron pairs caused by the collision of the particles, which move at nearly the speed of light. He concluded that the effective cross-section for the pair creation by fast protons in the lead is more than a thousand times larger than the cross-section for pair creation by slow protons calculated by Heitler and Nordheim.

The qualitative explanation of cosmic ray showers as a cascade phenomenon was presented independently by H.J. Bhabha and W. Heitler [27] and by J.F. Carlson and J.R. Openheimer in 1937. Bhabha and W. Heitler gave a theory to explain the production of particles, which come into play due to the interaction of cosmic rays with the upper atmosphere of the earth. They found that under particular conditions the primary electron in the field of a nucleus has a large probability of emitting a hard light quantum which then creates a pair. The pair electrons emit light quanta again which create pairs and so on. The comparison with experiments shows that Rossi’s transition curve and Regener’s absorption curve in the atmosphere can be understood on this theory [27]. So far as the scientific publications and their standard are concerned, the most creative period of Bhabha’s life was in Europe. Between 1933 and 1938 he published 15 articles.

Fig. 4: *H.J. Bhabha (1909-1966).*

The most important publications were: “The passage of fast electrons and the theory of cosmic shower” [27]; “The scattering of positrons and electrons with exchange on Dirac's theory of the positrons” [28]; and “On the theory of heavy electrons and nuclear forces” [29]. In a short letter to “Nature” [30], he pointed out that the lifetimes of fast, unstable cosmic rays particles would be increased because of the time dilatation effect that follows as a consequence of Einstein’s special theory of relativity. The verification of this effect by means of cosmic rays experiments gave the most straightforward experimental evidence supporting special relativity [31].

At the Indian Institute of Sciences (IISc), Bangalore, Bhabha became the head of the cosmic rays unit. He proposed the establishment of an institution that would be devoted to advanced research and teaching in physics, particularly cosmic rays, nuclear physics and mathematics. The institute founded at the IISc, was later relocated in Bombay. Due to financial and technical reasons the purchase of a betatron was not possible, Bhabha concentrated his experimental efforts in the Institute upon the cosmic ray studies with balloons [32]. After 1950, most of his publications were in the form of popular lectures and science policies [33]. But Bhabha has left his imprint in the field of Cosmic Rays for naming ceremony of "meson" and "Bhabha Scattering".

Bhabha encouraged the formation of the three groups in TIFR to pursue these studies: direct observations on particle interactions using cloud chambers at mountain altitude (Ooty), observations on muons and their interactions deep underground at Kolar Gold Field (KGF) and direct observations on cosmic ray particles and their interactions with nuclear emulsion stacks flown to higher altitudes aboard balloon-borne platforms. Studies on muons and neutrinos were carried out at various depths in KGF mines. With the establishment of a laboratory at Ooty (2200 m) in the Nilgiri hills in southern India in 1954, TIFR started studies on interactions of cosmic ray particles using two multiplate cloud chambers, looking for production of new type of particles in the brass plates inside the chambers, such as the V-particles and particles stopping within the chambers.

The progress of research in cosmic rays in India over the last 100 years has been reviewed by Suresh C. Tonwar [34]. The contributions of Homi Bhabha have been summarized by B.V. Sreekantan, one of his brilliant students [35]. Studies on high energy interactions by B.V. Sreekantan and colleagues and on muons and neutrinos deep underground in KGF mines by M.G.K. Menon and coworkers were the highlights of the research work in India during 1950's and 60's. In 1970's and 80's, important advances were made in India in several areas, for example, search for proton decay in KGF mines by M.G.K. Menon et al, search for TeV cosmic gamma-ray sources at Ooty and Pachmari by

P.V. Ramanamurthy and colleagues, search for PeV cosmic gamma ray sources by S.C. Tonwar et al at Ooty and by M.V.S. Rao and coworkers at KGF. In 1990's, Sreekantan and Tonwar initiated the GRAPES-3 project at Ooty to determine the composition of cosmic ray flux around the 'knee' in the primary energy spectrum at PeV energies using a large muon detector and a compact air shower array. Another major effort to search for TeV gamma-ray sources was initiated by H. Razdan and C.L. Bhat of BARC Trombay, initially at Gulmarg in Kashmir in the 1980's, leading to successful observations with a stereoscopic imaging atmospheric Cherenkov telescope at Mount Abu in early 2000. In recent years, the Pachmari group of TIFR and the Mount Abu group of BARC have joined together to install a sophisticated system of atmospheric Cherenkov detectors at Hanle in the Ladakh region at an altitude of 4200 m to continue studies on VHE sources of cosmic gamma rays.

***Fig. 5:** Vikram Sarabhai (1919-1971).*

The quartet of pioneers in cosmic ray research in India is completed by Vikram Sarabhai (1919–1971) who completed his Ph.D. at Cambridge in 1947 with his thesis on “cosmic ray investigations in tropical latitudes” (Figure 5). He established the Physical Research Laboratory (PRL) at Ahmedabad in 1947 initiating experimental work on variations in cosmic ray intensity in relation to solar activities. Later on, Devendra Lal took over the reins of PRL, when Sarabhai shifted to Space Research, and started his research work on Lunar rocks and Meteorites, and dating the samples collected from river beds, Himalayan glaciers, ocean floor sediments and various rock formations using various nuclear isotopes formed by the incidence of cosmic ray flux.

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