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The IGY and beyond: A brief history of ground-based cosmic-ray detectors

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Abstract

The state of art of ground-based cosmic-ray research from its discovery to present is reviewed. After discovery of cosmic rays by Hess in 1912, the nature of the primary and secondary radiation was established from recordings by a variety of instruments, sensitive to various components of cosmic rays and operated at different latitudes, longitudes and altitudes, including instruments carried by balloons. The IGY formalized international co-operation and coordinated study of cosmic rays, which is vital for meaningful interpretation of cosmic-ray data. Data collected at different geographic locations require an effective cutoff rigidity as a data ordering parameter. This parameter is obtained from tracing trajectories of primary cosmic rays in the Earth's magnetic field. After 50 years the world's neutron monitor network remains still the backbone for studying intensity variations of primary cosmic rays in the rigidity ranges between 1 and 15 GV, associated with transport and with transient events. Also the penetrating muon and neutrino components of secondary cosmic rays have a long history of recording and fundamental problem investigations. Valuable data about composition and spectrum of primary cosmic rays in ever increasing high-energy regions have been obtained during the years of investigations with various configurations and types of extensive air shower detectors. The culture of personal involvement of the physicist in carrying out experiments and data acquisition characterized the continued vitality of cosmic-ray investigations ranging from its atmospheric, geomagnetic and heliospheric transport through to its solar and astrophysical origins.

Keywords: Cutoff rigidity; Neutron monitor network; Penetrating muon component; Extensive air shower; Culture of personal involvement

1. Introduction

Originally the effects produced by cosmic rays in the atmosphere were attributed to very penetrating electromagnetic radiation entering from outer space (Neher, 1985). Clay and Berlage (1932) demonstrated that the intensity of cosmic rays at sea level decreased with decreasing geomagnetic latitude. They thereby proved that, since cosmic rays were affected by the Earth's magnetic field, the incoming primary radiation cannot be very energetic photons, but must consist of particles carrying an electric charge. Similarly, by comparing the data from different expeditions Compton (1933) concluded that a great part of primary cosmic rays consisted of charged particles.

Rossi (1930, 1931) showed that Störmer's (1930) theory of electron orbits in the magnetic field of the earth led to the prediction of an East–West asymmetry in the cosmic-ray intensity if the primary rays were predominantly of one sign of charge. Whereas the result of Rossi's (1931) experiment in Florence, Italy, was negative, Johnson and Street's (1933) similar experiment of higher precision on Mt. Washington confirmed that the primary radiation was largely positively charged (Johnson, 1933). Schein et al. (1941) concluded from their counter telescope experiment on board a balloon that the incoming cosmic radiation consists most probably of protons and that electrons in the atmosphere must be of secondary origin. Subsequently, recordings by detectors carried into the stratosphere by balloons proved that primary cosmic rays consisted of nuclei with a relative abundance closely related

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to the abundances of elements in the visible universe (Peters, 1952).

In the late 1930s and 1940s it became clear from diverse types of experiments that cosmic radiation, on entering the atmosphere, produces nuclear and electromagnetic interactions down to ground level (Puppi and Dallaporta, 1952). The discovery of mesons with short half-lives (of the order of nano- to microseconds) and fluxes of neutrons with ~15-min half-life in the atmosphere assured that these particles are products of atmospheric nuclear interactions. High energy mesons, generated in nucleon collisions, decay into the penetrating μ-meson (muon) component and into the soft electromagnetic component, which consists of electrons (positive and negative), neutrinos and gamma-rays. The penetrating component is detected also underground, down into the deepest mines (George, 1952).

2. Prologue to IGY

2.1. The Ionization chamber

Cosmic radiation was discovered by V.F. Hess on his historic balloon flight on August 8, 1912. He used an air-tight ionization chamber measuring the rate of discharge of electrified fiber in the chamber. In order to trace the nature of cosmic rays, several ship born expeditions were undertaken from Europe through the Suez channel to the Far East. The first was from 1927 to 1929 by Clay and Berlage (1932) with an ionization chamber on the "Potsdampfer (Steamship) Christian Huygens" from Amsterdam to "Batavia" (Indonesia). In order to correct for primary variations in cosmic rays, an ionization chamber was run simultaneously in Amsterdam (Fig. 1). The decreasing ionization towards the equator suggested screening by the Earth's magnetic field and proved that the incoming cosmic radiation must consist of particles carrying an electric charge.

Continuous recording of cosmic rays using ground-based detectors started in the 1920s with ionization chambers (Simpson, 1990). For studying the geographic dependence of cosmic-ray time variations in greater detail, a standardized ionization chamber was designed for world-wide distribution. This study was initiated in 1930 by A.H. Compton and R.D. Bennett of the University of Chicago, and J.C. Sterns of the University of Denver and resulted in the construction of a special precision ionization chamber (Compton et al., 1934). Seven of these chambers were installed as part of the first world-wide network of cosmic-ray stations. In 1949–1951 this network of ionization chambers was significantly extended by the former USSR (Dorman, 2004, p. 10) and was operated continuously for more than three solar cycles (Dorman, 2004, p. 203).

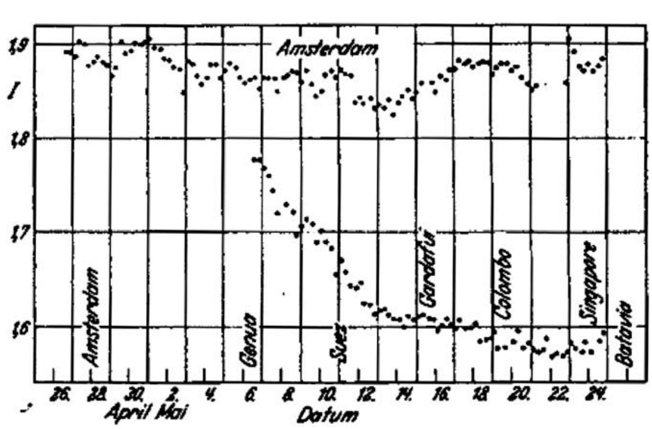

Fig. 1. Cosmic-ray intensity recorded from Amsterdam to Indonesia and simultaneously at Amsterdam (Clay and Berlage, 1932).

In these early measurements, pressure and temperature variations in the atmosphere hampered the recognition of variations in primary cosmic rays. Papers by Forbush (1938,1946) provided the first convincing evidence for intensity variations that were due to other effects than atmospheric (Simpson, 1990). Forbush (1938) observed world-wide decreases in cosmic-ray intensity (named Forbush decreases) during magnetic storms and ascribed these decreases to ring currents, or their equivalents, which account for the world-wide magnetic field changes. Later he (Forbush, 1946) reported on "The unusual cosmic-ray increases possibly due to charged particles from the Sun" on February 28, 1942, March 7, 1942 and July 25, 1946 (Fig. 2). These increases drew attention to the importance of high energy particles from solar eruptions. These observations demonstrated also the sequential connection between a solar flare intensity increase, followed a few days later by a Forbush-type of decrease. Ring currents are, therefore, not the primary reason for world-wide decreases in cosmic-ray intensity.

2.2. Geiger counter and meson telescope

The number of ions generated during an interval by charged particles in the gas of an ionization chamber, is closely related to the rate by which particles are recorded by a Geiger counter. The altitude and latitude effects of these two types of recordings will, therefore, correspond with each other.

A meson telescope consists usually of two or three layers of Geiger counters or plastic scintillators with coincidence recording. An absorber, usually lead, between the layers ensures the recording of the penetrating μ-meson component of secondary cosmic rays in a particular direction. Neher (1952) reported on the original investigations on the directional dependence of muons in the atmosphere in relation to the effect of the geomagnetic field on incoming primary cosmic rays.

The importance of asymptotic directions and cutoff rigidities for studying cosmic rays that have to transverse the geomagnetic field before they enter the atmosphere at a particular latitude and longitude, became apparent in the pioneering work of Störmer (1950). This knowledge is necessary for directional studies and for work using the geomagnetic field as a spectral analyzer. These studies have been refined since then by the computer trajectory-tracing