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History of cosmic ray research in Finland

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Abstract

The history of cosmic ray research in Finland can be traced back to the end of 1950s, when first ground-based cosmic ray measurements started in Turku. The first cosmic ray station was founded in Oulu in 1964 performing measurements of cosmic rays by a muon telescope, which was later complemented by a neutron monitor. Since the 1990s, several research centers and universities, such as The Finnish Meteorological Institute, Helsinki University of Technology, University of Oulu, University of Turku and University of Helsinki have been involved in space science projects, such as SOHO, AMS, Cluster, Cassini, BepiColombo, etc. At the same time, ground-based cosmic ray measurements have reached a new level, including a fully automatic on-line database in Oulu and a new muon measuring underground site in Pyhäsalmi. Research groups in Helsinki, Oulu and Turku have also extensive experience in theoretical investigations of different aspects of cosmic ray physics. Cosmic ray research has a 50-year long history in Finland, covering a wide range from basic long-running ground-based observations to high-technology space-borne instrumentation and sophisticated theoretical studies. Several generations of researchers have been involved in the study ensuring transfer of experience and building the recognized Finnish research school of cosmic ray studies.

1. Introduction

Cosmic ray research in Finland has a history that can be traced back for 50 years. Ground-based cosmic ray measurements by a muon telescope started at the University of Turku in 1958 under the leadership of Professor Väinö Hovi (Hovi and Aurela, 1959, 1961). Later it was complemented with an experiment based on BF_3 counters to detect evaporation neutrons produced by secondary cosmic rays in lead layers (Aurela et al., 1968). In 1961, studies of cosmic rays and in general space physics research were declared as one of the new priority research areas at the Department of Physics of the University of Oulu, founded in 1958. The research, initiated by Pekka Tanskanen and supervised by Professor Pentti Tuomikoski, started by design and construction of a muon telescope for observations of cosmic ray muons. The construction of the telescope was completed in 1963, and soon thereafter it was complemented with a neutron monitor for measuring the nucleonic component of cosmic rays. Presently ground-based cosmic ray measurements continue at a modern level, including a fully automatic on-line database and a new underground muon shower array in a deep mine in Pyhäsalmi.

Since the 1990s, Finnish scientists have been involved in various space science projects, such as SOHO, AMS, Cluster, Cassini, Freija, and BepiColombo. The Finnish Meteorological Institute, Helsinki University of Technology, University of Oulu, University of Turku and University of Helsinki stay at the front end of technological space-borne studies.

Research groups in Helsinki, Oulu and Turku have also extensive experience in theoretical investigations of different aspects of cosmic rays, such as transport and modulation of

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galactic cosmic rays in the heliosphere, acceleration and propagation of solar energetic particles, and terrestrial effects caused by energetic cosmic rays.

In a wider perspective, the roots of Finnish cosmic ray research can be traced back even further, to the first International Polar Year of 1882–1883, when Prof. Selim Lemström from the University of Helsinki carried out significant research on aurora borealis and atmospheric electricity. Although his work was not directly related to cosmic rays (which were not known at that time), it did influence on the cosmic ray research (Punkkinen, 1989).

This paper is a brief account of cosmic ray research in Finland during the last 50 years.

2. Ground-based experiments

2.1. Neutron monitor

A neutron monitor (NM), based on BF_3-filled proportional counters, detects thermal neutrons produced in the instrument by the nucleonic cascade initiated by primary cosmic rays entering in the atmosphere. The concept and basic principles of this stable and reliable instrument were developed more than 50 years (Simpson, 1958). Full details of a NM construction can be found, e.g., in Niemi (1996). The world-wide NM network has been the main tool for studying cosmic ray variability on different time scales from minutes to decades since 1950s. In Finland, measurements with neutron monitors started in Turku (60.5°N 22.5°E, geomagnetic cutoff rigidity $P_c \approx 1.4$ GV) in the early 1960s. The purpose was to study the energy spectrum of evaporation neutrons produced by cosmic rays in lead (Aurela et al., 1968). Later, a special neutron monitor used for evaporation neutron multiplicity studies was designed and constructed (Valtonen et al., 1979). A permanent cosmic ray station, consisting of 9 NM64 proportional counters BP-28 was installed in Oulu (65.1°N 25.5°E, $P_c \approx 0.8$ GV) in April 1964 (Kananen et al., 1991). In 1973 the Oulu cosmic ray station was moved to the Linnanmaa campus area, where it is still situated and operated by the Sodankylä Geophysical Observatory (see http://cosmicrays.oulu.fi). The neutron monitor in Oulu is a part of the World Neutron Monitor Network and has provided unique data on cosmic ray intensities uninterruptedly for over 40 years. There are only a few stations in the world that can boast with such a long record of continuous measurements. Since 2008 the Oulu NM is an official member of a EU Project (NMDB: Neutron Monitor DataBase – see http://www.nmdb.eu) devoted to the construction of a modern database of ground-based cosmic ray observations and radiation hazards (Steigies, 2008).

2.2. Muon detectors

The first cosmic ray measuring instrument in Turku, a muon telescope consisting of Geiger counters, was used for studying the north–south asymmetry of cosmic ray muons (Hovi and Aurela, 1961). A large muon telescope, consisting of a number of plastic scintillators monitored by photomultipliers, was installed in Oulu in 1963 in Kotinkangas and moved to the Linnanmaa campus area in 1973. The telescope was collecting data until 1980s, when it was disassembled due to aging of scintillators and photomultipliers. From the dismantled parts of the telescope, a smaller multi-layer muon telescope MUG (Muon UnderGround) was built in 2000 and placed, under supervision of the Sodankylä Geophysical Observatory, underground in a copper–zinc mine in Pyhäsälmi in Central Finland (61.0°N 21.3°E, $P_c \approx 1$ GV). Presently, a large muon telescope (EMMA – Experiment with Multi-Muon Array) is under development by CUPP (Center for Underground Physics in Pyhäsalmi) as a part of a European Project, and is planned to be placed in the Pyhäsalmi mine in 2008.

2.3. Hadron spectrometer

Starting in 1980, a double-layer neutron monitor (Arvela et al., 1982) and a muon telescope consisting of large-area plastic and liquid scintillators as well as position sensitive streamer tubes were in operation in Turku. This set of detectors, operated together, was called a hadron spectrometer. It was able to distinguish between secondary cosmic ray neutrons and protons and measure their spectra in the energy range between 1 and 1000 GeV (Nieminen et al., 1982, 1985).

2.4. Extensive air-shower array

A small air-shower array was built around the hadron spectrometer in Turku in 1985 (Valtonen et al., 1985) and operated until 1994. The facility aimed to study multiple hadrons in extensive air showers produced by high-energy primary cosmic rays in the atmosphere. The array, consisting of 18 scintillation counters, was capable of measuring the size, core position, and angle of incidence of the showers.

All the ground-based equipment in Turku were disassembled in 1994 due to construction work of a new department building. At that time, the main emphasis of the research had shifted to solar physics and space-borne instrumentation. Major parts of the hadron spectrometer and the air-shower array electronics found re-use in the EMMA experiment in the Pyhäsalmi mine (Section 2.2).

3. Space-borne experiments

3.1. SOHO/ERNE

In the late 1980s, the main research interests in Turku moved to topics investigated with space-borne instruments. One of the most successful missions is SOHO (Solar and Heliospheric Observatory) launched in 1995 as a joint space program of ESA and NASA for studying the structure, chemical composition, and dynamics of the Sun, the solar atmosphere, and the solar wind. Onboard SOHO there is an energetic particle instrument ERNE (Energetic and Relativistic Nuclei and Electron experiment) designed, built, and operated by the University of Turku (Torsti et al., 1995). The main objectives of ERNE are to measure the composition and energy spectra of energetic particles from hydrogen to iron accelerated at the Sun and in the interplanetary space (Torsti et al., 1999, 2004; Lehtinen et al., 2008).

3.2. Alpha magnetic spectrometer (AMS)

AMS is a state-of-the-art cosmic ray detector that brings laboratory technology into space. A pilot version, AMS-01, flew for 10 days onboard the "Discovery" Space Shuttle mission STS-91 in June 1998 and provided unique high-resolution data on the cosmic ray composition and energy spectra, allowing for advanced knowledge of the galaxy and improved understanding of the origin of universe (e.g., Alcaraz et al., 1999, 2002). The main instrument, AMS-02, is planned to be installed onboard the International Space Station in 2010–2011, with participation of the University of Turku and the Helsinki University of Technology.

3.3. Solar intensity X-ray and particle spectrometer (SIXS)

The SIXS experiment on-board ESA/JAXA BepiColombo mission to Mercury, scheduled for launch in 2014, is a miniatyrized X-ray and particle spectrometer measuring the ionizing radiation hitting the surface of the planet Mercury. The instrument measures the spectrum of solar X-rays at 1–20 keV, and the spectra of energetic electrons (0.1–3 MeV) and protons (1–30 MeV). It will, therefore, produce valuable data on solar energetic particles and flares from the inner heliosphere. Together with other particle instruments on-board two spacecraft of the mission it will produce advanced knowledge of particle transport and acceleration at the Sun and in the innermost heliosphere.

Finnish groups have also participated in the other space missions, e.g., CASSINI, CLUSTER-II, VIKING, and FREIJA. However, they were not targeted on cosmic rays.

4. Theoretical work related to cosmic rays

Cosmic ray research in Finland also includes theoretical study and data analysis and interpretation. Cosmic ray measurements require correction methods. Such techniques were developed both in Turku and Oulu. These included studies of geometrical errors in directional intensities measured by counter telescopes, mathematical stabilization methods for unstable resolution corrections (Aurela and Torsti, 1967), atmospheric effect on ground-based flux of muons and neutrons (Tanskanen, 1968), scattering in cosmic ray muon spectrometers (Aurela and Torsti, 1968), a fast quadratic programming method for solving ill-conditioned systems of equations (Torsti and Aurela, 1972), and a special method to study solar neutrons by neutron monitors (Usoskin et al., 1997). For the interpretation of data obtained from the Turku hadron spectrometer, a comprehensive model of hadron cascades in the atmosphere and in the instrument was developed (Lumme et al., 1984).

A theory of cosmic ray transport in the heliosphere has been developed at the University of Oulu, including a full 2D stochastic simulation model (e.g., Alanko-Huotari et al., 2007). This model is devoted to studies of the solar modulation of galactic cosmic rays (Usoskin et al., 2005), including very long time scales (Solanki et al., 2004; Usoskin et al., 2003, 2007).

Cosmic ray induced effects in the atmosphere are also intensively studied. This includes influence of solar energetic particles on the atmospheric chemistry, e.g., the ozone layer, studied at the Finnish Meteorological Institute and Sodankylä Geophysical Observatory (e.g., Verronen et al., 2005). The effect of electric fields in the atmosphere has been studied in Turku (e.g., Aurela, 1989; Punkkinen, 1989). A full Monte-Carlo model of the atmospheric cascade initiated by energetic cosmic rays has been developed in Oulu with particular emphasis on cosmic ray induced ionization of the troposphere and production of cosmogenic isotopes (e.g., Usoskin and Kovaltsov, 2006).

State-of-the-art experiment-oriented modeling of solar energetic particle events, along with their acceleration and propagation in the interplanetary medium and magnetic fields, are successfully conducted at the Universities of Turku and Helsinki (e.g., Vainio et al., 2000; Kocharov and Torsti, 2003; Vainio and Laitinen, 2007; Sandroos and Vainio, 2007). The models are based on the Monte-Carlo simulation technique and can address practically all aspects of the solar energetic particle production and transport problem, including acceleration, propagation, charge states (e.g., Kocharov et al., 2003) and elemental abundances (Sandroos and Vainio, 2007) of solar energetic ions, as well as the low-frequency plasma turbulence generated by the accelerated particles in the corona and solar wind (Vainio and Laitinen, 2007). The results of such models are applied to space-borne observations of solar energetic particles.

5. Educational activity

Special educational programs in space research, including cosmic rays, heliosphere and magnetosphere, have been developed in Finland for physics students at graduate and postgraduate levels. For example, special courses on *Cosmic Rays* and *Heliosphere* are lectured at the University of Oulu, *Physics of the Sun and the solar system* and *Space research and space technology* at the University of Turku, *Energetic Particles and Shock Waves in Space Plasmas* at the University of Helsinki.

The cosmic ray research groups are actively involved in education and promotion of young researchers in the framework of the Finnish Graduate School in Astronomy and Space Physics. This guarantees a continuous inflow of young talented and well-educated researchers in the cosmic ray related research groups.

6. Summary of the present cosmic ray research in Finland

The present status of Finnish cosmic ray research can be briefly summarized as follows.

The University of Oulu, including Sodankylä Geophysical Observatory and Department of Physical Sciences is very active in both experimental (Ground-based neutron monitor since 1964; Muon telescope 1964–1980s and since 2000 an Underground Multi-muon telescope) and theoretical research (Heliospheric transport of galactic cosmic rays; solar energetic particles; atmospheric showers; terrestrial effect of cosmic rays).

The University of Turku is involved in state-of-the-art space-borne cosmic ray experiments (SOHO/ERNE and AMS) and in sophisticated theoretical research of solar energetic particle acceleration and transport processes.

The University of Helsinki, including the Department of Physics and the Observatory, is currently constructing the *Solar Intensity X-ray and particle Spectrometer* (SIXS) experiment on-board the BepiColombo mission to Mercury. In addition, the group at the Department of Physics conducts high-level theoretical research in the field of solar energetic particles, corona and heliospheric transients. The Department of Physics, together with the Helsinki Institute of Physics, also participates in the CLOUD project of CERN, investigating the connection between cloud formation and cosmic ray ionization, and performs measurements and modeling of atmospheric ions and aerosols, which are essential in trying to understand the cosmic ray – cloud connection.

The Finnish Meteorological Institute participates in the SIXS and the CLOUD projects as well. In addition, the institute performs studies of atmospheric chemistry induced by solar energetic particle events.

Helsinki University of Technology with its expertise in space technology, actively participates in the AMS space-borne cosmic ray experiment (see Section 3.2).

University of Jyväskylä participates in a high-energy cosmic experiment at CERN (ALICE/ACORDE).

Cosmic ray research has a 50-year long history in Finland, covering a wide range from basic long-running ground-based observations to high-technology space-borne instrumentation and sophisticated theoretical developments. Several generations of researchers have been involved in the study ensuring transfer of experience and building the recognized Finnish research school of cosmic ray studies.

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