

## Cosmic Ray Research in Armenia

The Aragats research station of Cosmic Ray Division (CRD) of Alikhanyan Physics Institute is located on Mount Aragats (3200m above the sea level, N 40 25', E 44 15') on the shore of Lake Kari. The scientific history of the station can be traced back to 1934 when the colleagues of academician D. Skobeltsin, N. Dukelsky and T. Ivanova from Leningrad Physics-Technical Institute and N. Kocharian from Yerevan State University who later became the first dean of the Physics Department, measured the East-West cosmic ray anisotropy. These measurements stimulated the interest of famous physicists, Artem and Abraham Alikhanyan brothers, who organized a scientific expedition to Aragats in 1942. Since then, expeditions to Aragats have been regularly organized, in spite of World War II, insufficient finances, electricity and fuel shortages.

In 40s and 50s cosmic rays (CR) were the main source of information about the properties of elementary particles. Cosmic Ray investigations have led the way to new, modern branches of physics later termed "Physics and Astrophysics of High Energies". The history of scientific research on Mt Aragats can be divided into several periods. The first - mass-spectrometric - lasted for about 15 years. The magnetic spectrometer designed by Alikhanyan brothers allowed them to obtain such revolutionary results as the discovery of protons in CR and "exotic" narrow showers. According to the viewpoint of that time, CR were believed to have electromagnetic origin, therefore the presence of protons in CR strongly contradicted the established concepts. The nature of narrow showers differed from that of ordinary Extensive Air Showers (EAS). Their origin could not be electromagnetic because of their great penetrability. Later narrow showers were thoroughly studied with the Aragats Ionization Calorimeter.

Using the Alikhanyan-Alikhanov magnetic spectrometer N. Kocharian obtained the energy spectra of muons and protons up to several GeV; until now, this data has been one of the best measurements of secondary cosmic ray fluxes.

The mass spectrometer method, allowing the simultaneous measurement of the momentum and absorption length of charged particles, facilitates effective CR mass analysis. This method provided the first evidence of the existence of particles with masses ranging from  $\pi$ -meson to proton, however, only some of many mass distribution peaks turned out to be "real" particles by other experiments which later became known as  $\pi$ - and K-mezons. Other  $\pi$ -particles, with masses heavier than  $\pi$ -meson, including the so called varitrons,  $\pi$ -discovered, using the Aragats mass-spectrometer, were artifacts due to fluctuations in the uniform mass distribution. This work led to the discovery of the  $\pi$ -meson, for which Cecil Frank Powell received the Nobel prize. The discussion on varitrons in scientific literature led to a variety of excellent experimental and theoretical investigations and Alikhanyan brothers' idea about a variety of elementary particles became very popular among physicists all over the world, making the Aragats research station one of the most important centers of cosmic ray physics. It should be mentioned that defining the reliability of peaks in one- and two-dimensional distributions is still one of the most important and complicated problems in High Energy Physics and Astrophysics today. The second stage of scientific research on Mt Aragats, calorimetric measurements, covers the period from 1958 to 1970. In the 1950s scientists from Moscow State University proposed the calorimetric principle for the measurement of the energy of high energy particles. The mass spectrometric method had reached its energy limit by that time. In 1958 a group of scientists from the Scientific Research Center of Nuclear Physics of Moscow State University and Yerevan Physics Institute (team leader- Naum Grigorov) created the first ionization calorimeter in the world. It allowed direct experimental indication on the energy growth of the effective inelastic cross-section of the hadron interaction with lighter nuclei. This fact was later confirmed by direct measurements on Proton satellites and acceleration experiments in Serpukhov, Russia; Batavia USA; and Geneva Switzerland. The ionization calorimeter also detected another interesting result concerning the peculiarities of multiparticle production of high energy pions, which was later (1990) asserted as a discovery. The authors were Khachik Babayan (vice-director of Yerevan Physics Institute from 1956-1969), Naum Grigorov, Erik Mamijanyan (head of Cosmic Ray Division of Alikhanyan Physics Institute

in 1969-1992) and Vladimir Shestoperov. The experiment proved the existence of events where a small quantity of  $\pi$ -mesons, generated in the interaction with atmospheric nuclei, takes away almost the entire energy of the primary particle.

The Nor Amberd station, which started operation in 1960, considerably enlarged the experimental base for studying high energy cosmic ray hadrons and their interaction with different nuclei (head of laboratory Gerasim Marikyan in 1960 - 1986).

At that time not only physicists from various scientific centers of the Soviet Union and Eastern Europe participated in investigations at the Armenian high-altitude stations but also scientists from USA, France, Japan and Great Britain visited these stations and worked there. The method of wide-gap spark chambers of various configurations, economical and simple, was later used in different laboratories in the world. The coveted Lenin Prize was awarded to Artem Alikhanyan and Tina Asatiani (head of muon laboratory of Alikhanyan Physics Institute in 1960-1987) as well as a group of Russian and Georgian physicists for developing the wide-gap spark chambers.

In 1968-69 a system of proportional counters was added to the Aragats calorimeter. Using this facility, characteristics of the neutron component of cosmic rays at mountain altitude were measured by Erik Mamijanyan and his colleagues. Khacik Babayan contributed to the installation of new detectors - neutron supermonitors - at both stations, which served as a basis for creating a unique center of cosmic ray monitoring in the new history of Aragats.

During the next period (1970-1980) experiments PION and MUON aimed to measure fluxes of primary and secondary cosmic rays and some phenomenological characteristics of strong interactions. The team leaders of the experimental groups were Vahram Avakyan (head of Aragats station from 1963 - 1993) and Tina Asatiani, respectively. PION was a unique facility, which includes various particle detectors. The transition radiation detection system, created under the guidance of Albert Oganesian (head of laboratory from 1978 - 1996), allowed the separation of protons from  $\pi$ -mesons, the main components of the secondary charged particles.

The muon magnetic spectrometer for studying near-horizontal high energy muons was equipped with wire spark chambers and a wide-gap spark chamber increasing the range of reliable muon energy measurement to record values. Both experiments used the most modern computing methods and machines for data collection and processing available at the time. One of the first Soviet computers ZM-20 was used to calculate muon energy. The PION experiment used the first Armenian minicomputer NAIRI-2 for data collection.

From 1970 to 1980s it became clear that facilities occupying much greater areas and using as many different independent registration techniques as possible are necessary for the research of the fundamental problems of high energy astrophysics. The ANI experimental facility on Mt. Aragats met all these requirements. It allowed the scientists to thoroughly and accurately register nuclear-electron cascades initiated by particles of super-high energies in the Earth's atmosphere. The ANI experiment was designed in cooperation with the Lebedev Physics Institute of USSR Academy of Science under the guidance of USSR Ministry of Medium Machinery (presently, Federal Nuclear Energy Agency of the Russian Federation). The experiment was carried out under the guidance of Sergey Nikolsky (director of the Division of Nuclear Physics and Astrophysics of Lebedev Physics Institute) and Erik Mamijanyan. The ANI complex was not completed because of the collapse of the USSR, followed by the collapse of the Armenian economy, but two large area detectors - GAMMA (registers muon and electro-photon components of CR) and MAKET ANI (registers electro-photon component) are still functioning. They are basic facilities used for the study of galactic cosmic rays in the, so called, knee region. Energy spectra of primary particles measured with Aragats facilities helps to identify possible sources of cosmic rays. Multivariate data analysis methods developed at YerPhI under the guidance of Ashot Chilingarian (head of the Cosmic Ray Division since 1992) allowed us to obtain

energy spectra of heavy and light nuclei separately. The same method implemented for similar experimental data at the Forschungszentrum, Karlsruhe (Germany) led to similar results: radical changes of the light nuclei spectra (mainly, protons and helium nuclei) were discovered in the knee region, while heavy nuclei spectra do not undergo significant changes. Such changes in spectra indicate a definite acceleration mechanism, which can happen during the most energetic processes in the Universe namely, supernova eruptions. To identify the origin of cosmic rays the long-lasting experiments, using space-born particle detectors and registration of  $\gamma$ -quanta from supernova remnants, are needed. Four of the largest atmospheric Cherenkov telescopes (MAGIC, H.E.S.S., VERITAS and CANGAROO), located in three continents, scan the sky searching for  $\gamma$ -quanta sources. Armenian physicists currently participate in two of these four experiments - MAGIC and H.E.S.S.

Cosmic Rays are generated not only in the depths of the galaxy but also our nearest star, the Sun, accelerates protons and nuclei. The energies of the particles accelerated from the Sun are about one thousand times less than those accelerated in the universe, however sometimes, during strong solar flares; they are much more intense than the galactic cosmic rays. Knowing how the Sun works, it is possible to understand the structure of the Universe. The physical processes during solar eruptions are registered by numerous monitors, located in space stations and man made satellites, or integrated into particle detector networks on Earth. Electromagnetic fluxes, interacting with the magnetosphere, ionosphere and the atmosphere influence space weather, which has an impact on space-born and earth technologies. Space weather can also be dangerous for astronauts in space and cause excessive radiation load for airplane passengers. Space weather changes very fast, the intensity of X-ray radiation and particles of high energies can greatly increase in a few seconds. Protons and nuclei, which penetrate into microscopic electronic devices, create additional currents and change the state of the electronics, generating false commands and damaging on-board management systems. Electron fluxes, rushing through the atmosphere, create polar flares and induce currents in surface conductors, which cause pipeline corrosion and transformer burning at electric stations. Our civilization heavily depends on satellite technologies, including telecommunication, navigation, disaster warning, weather forecast, military application, etc. For this reason, space weather research attracts more and more scientists. USA, Europe and Japan implemented costly space weather research programs at the end of the century. Armenia is a key participant in these research activities. New facilities are constantly added to the existing installations on Mt. Aragats, resulting in a unique facility complex, which allows detection of various species of particles of different energies and arrival directions. The necessity to get such information and to study solar-terrestrial connections becomes greater with each passing year.

Space-born X-ray, infrared and optical telescopes investigate the farthest parts of the Universe and identify objects that are 12 billion light-years away from Earth, including such exotic objects as black holes, neutron stars and supernova remnants. New data processing technology on Mt. Aragats allows the amplification of the scale of ground-based telescopes. Combining different kinds of detectors, it is possible to get a comprehensive picture of the Universe, to identify its origin, and to predict ways of its development. Scientific research carried out on Mt. Aragats contributes to understanding of these fundamental problems.

Prof. Artem Alikhanyan initiated the famous Nor-Amberd schools, where current problems of High Energy and Elementary Particle Physics were discussed. Seasoned prominent and young new scientists participated in the activities of these schools. This tradition has been preserved up to the present day. During the week of September 26 -30 2005, 75 scientists and students from 11 countries attended the second conference on Solar Extreme Events (SEE-2005) in Nor-Amberd, Armenia. Conference reports included information on consequences of Solar Extreme Events and Super Storms, the most violent explosions in the Solar System. This information is necessary for testing of such universal processes as particle acceleration and transport as well as for early diagnostics of the expected technology impact of severe solar storms. The conference site was near the experimental facilities of the Aragats Space Environmental Center (ASEC). The participants became acquainted with the ASEC monitors and capabilities of the Armenian physicists who created the

Aragats Space Environmental Center.

Currently Aragats is a modern scientific center, equipped with key scientific installations and the necessary supporting infrastructure, which is constantly being updated. Recently a new power source system was installed at the Aragats research center and modern electronics for the particle detectors was developed. Modern computers send information about the coming solar storms to the computer center in Yerevan and from there to other scientists via world-wide scientific networks. Modern science is impossible without large-scale scientific cooperation. This cooperation is especially important for cosmic ray physics, which relies on data obtained with detectors located at different longitudes and latitudes all over the earth, to develop a model of the solar-terrestrial connections. Aragats and Nor-Amberd Neutron monitors are a part of the world-wide network of neutron monitors and solar neutron telescopes. The Nor-Amberd Multidirectional Muon Monitor is a part of the world-wide network of muon detectors developed for the early forecasting of geomagnetic storms. Other similar detectors, which are a part of the same network, are located in Japan, Australia, Brazil, Kuwait and Germany.

Armenia initiated the development of a new world-wide space weather forecasting network called Space Environment Viewing and Analysis Network (SEVAN). It is planned to locate new type of particle detectors, developed by the Cosmic Ray Division of Alikhanyan Physics Institute in 9 different countries at different longitudes at low latitudes. The UN commission on outer space recommended the implementation of this project within the framework of the International Heliophysical Year (IHY-07). It is planned to carry out coordinated measurements of all the aspects of solar activity using both the existing world-wide networks and the networks that are still being developed in 2007-2008. IHY activities emphasize the importance of educational aspects and the participation of developing countries in space research.

CRD developed an information product: Data Visualization Interactive Network (DVIN) for the Aragats Space Environmental Center (ASEC). The product aims at visualizing scientific information about radiation conditions on Earth caused by the strong radiation and geomagnetic storms from the sun. DVIN was officially announced as the world's best project in the e-science category at the World Summit on Information Society (WSIS) in Geneva in 2003. On June 10, 2005 DVIN was declared the winner of the Pan-Armenian e-content Mashtots 1600.

The CRD staff includes approximately 100 people, who work at the Aragats and Nor-Amberd high altitude stations and at the headquarters in Yerevan where most of the data analysis and computation takes place. The Lebedev Institute branch (heads of the branch were Evgeny Tukish 1985 . 1993, Vladimir Romakhin 1993 . 1995 , and Erik Mamijanyan since 1995 ), operates in Yerevan within the framework of the ANI Experiment.

Many of the staff members are young graduate students or recent postgraduates. CRD has created an educational center for students at the Yerevan headquarters. Lectures on astrophysics of high energy particles, simulation of physical processes, and applied electronics are given for students from the Physics Department of the Yerevan State University. The students have an opportunity to use DVIN, to study solar events as well as to get acquainted with particle detector systems in specially equipped classes. All this contributes to involving young people in scientific activities: annually about 10 courses and graduation thesis are written under the guidance of the CRD scientists. CRD also supports a secondary school in Antanut village, not far from the Nor-Amberd station. One of the particle detectors of SEVAN was installed in this school. The school also received several computers as a donation from CRD when they became free as the CRD upgraded its own fleet.

Scientific research on Mt Aragats is constantly searching for new methods and new frontiers as the Armenian physicists do their best in the quest of solving the mysteries of the Universe.