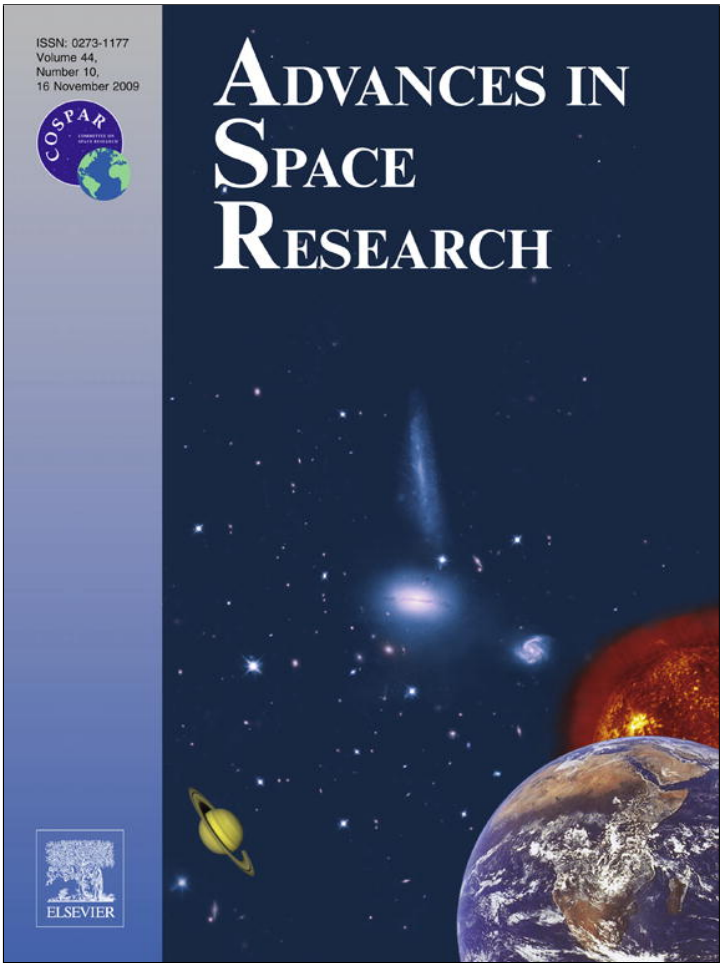
ISSN: 0273-1177
Volume 44,
Number 10,
16 November 2009
COSPAR
ADVANCES IN SPACE RESEARCH
ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 44 (2009) 1183–1193
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Cosmic Ray research in Armenia

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Received 4 March 2008; received in revised form 12 November 2008; accepted 14 November 2008

Dedicated to 100th anniversary of Artem Alikhanyan, born in 1908.

Abstract

Cosmic Ray research on Mt. Aragats began in 1934 with the measurements of East–West anisotropy by the group from Leningrad Physics-Technical Institute and Norair Kocharian from Yerevan State University. Stimulated by the results of their experiments in 1942 Artem and Abraham Alikhanyan brothers organized a scientific expedition to Aragats. Since that time physicists were studying Cosmic Ray fluxes on Mt. Aragats with various particle detectors: mass spectrometers, calorimeters, transition radiation detectors, and huge particle detector arrays detecting protons and nuclei accelerated in most violent explosions in Galaxy. Latest activities at Mt. Aragats include Space Weather research with networks of particle detectors located in Armenia and abroad, and detectors of Space Education center in Yerevan.

Keywords: Cosmic Rays; Particle detectors; Space weather; History of physics

1. Introduction

Particles of highest energies bombarding Earth's atmosphere provide vast information on the most violent processes in the Universe. One of the "main players" reflecting physical processes in stellar systems are particles and stripped nuclei arriving at Earth from interstellar space and from Sun. These are known under the name of Galactic and Solar Cosmic Rays (GCR and SCR). Cosmic Rays (CR) were discovered almost 100 years ago by the ionization effects of the secondary fluxes (particle showers), produced by the interactions of primary particles in the terrestrial atmosphere. Exploiting different physical processes of shower interactions with atmosphere (particle multiplication, fluorescence, Cherenkov light emission in atmosphere and in water, acoustic waves, and radio waves emissions) different experimental techniques were developed to detect cosmic rays above and on the Earth's surface, underground and underwater. Fifty years ago with the launch of the first satellite on 4 October 1957 experiments in space directly detected primary cosmic rays and confirmed that our nearest star, the Sun, is a particle accelerator.

Direct measurements of particle fluxes by facilities onboard satellites and balloons provide excellent charge and energy resolutions but, due to the severe limitation of payload and the progressively weaker flux of higher energy CR, can perform measurements mostly in KeV–GeV energy region. In TeV–PeV region only surface based techniques of detecting secondary particle showers can provide data on energy and types of primary particles, although with an uncertainty inherent to indirect methods, based on the extensive use of numerical models and simulation techniques.

One of the first permanent high-mountain research stations was established in Armenia 65 years ago. The *Aragats* and *Nor-Amberd* research stations of the Cosmic Ray Division (CRD) of the Yerevan Physics Institute (YerPhI) named after Alikhanyan are located on slopes of Aragats, the highest mountain of modern Armenia (see Figs. 1 and

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doi:10.1016/j.asr.2008.11.029

Fig. 1. Aragats research station (altitude 3200 m).

Fig. 2. Abraham Alikhanov (left) and Artem Alikhanyan.

4), at 3200 and 2000 m elevation, respectively. The scientific history of Cosmic Ray research at Aragats can be traced back to 1934 when a group from Leningrad Physics-Technical Institute and Norair Kocharian from Yerevan State University (YSU),[1] measured the East–West cosmic ray anisotropy (Kocharian, 1940). These measurements stimulated the interest of famous physicists, the brothers Artem and Abraham Alikhanyan (see Fig. 2), who organized a scientific expedition to Aragats in 1942. Since then, expeditions on Aragats continued uninterruptedly, in spite of the World War II, insufficient funding, and electricity and fuel shortages during the recent history of Armenia.

In the 40s and the 50's the cosmic rays were the main source of information about the properties of elementary particles. Later CR research has lead to new, modern branches of physics named "Astroparticle Physics", "High Energy Astrophysics" and "Space Weather". The most important dates and achievements of Cosmic Ray research at Aragats can be itemized as follows:

- 1942 – First expedition to Aragats;
- 1943 – Foundation of the Physical–Mathematical Institute of Yerevan State University; now Yerevan Physics Institute after Artem Alikhanyan;
- 1945–1955 – Foundation of Aragats high-mountain research station. Experiments at Aragats with mass spectrometer of Alikhanyan–Alikhanov: investigations of the composition of secondary CR (energies <100 GeV); exploration of the "third" component in CR; observation of particles with masses between μ-meson and proton;
- 1957 – Installation of the ionization calorimeter, detection of particles with energies up to 50 TeV;
- 1960 – Foundation of the Nor-Amberd high-mountain research station;
- 1970 – Modernization of the Wide-gap Spark Chambers;
- 1975 –Experiment MUON: measurements of the energy spectrum and charge ratio of the horizontal muon flux;
- 1975 – Installation of the Neutron supermonitors 18NM64 at Aragats and Nor-Amberd research stations;
- 1977 – Experiment PION: measuring pion and proton energy spectra and phenomenological parameters of CR hadron interactions;
- 1981–1989 – ANI Experiment: Commence of MAKET-ANI and GAMMA surface detector arrays for measuring cosmic ray spectra in the "knee" region (10^{14}–10^{16} eV);
- 1985–1992 – Design and tests of the system of atmospheric Cherenkov telescopes, introduction of multivariate methods for signal detection from γ-ray point sources;
- 1993–1996 – Development of new methodology of multivariate, correlation analysis of data from Extensive Air Shower detectors, event-by-event analysis of shower data from KASCADE experiment; classification of primary nucleus;
- 1996–1997 – Renewal of cosmic ray variation studies at Aragats: installation of the solar neutron telescope and resumption of Nor-Amberd neutron monitor;
- 2000 – Foundation of Aragats Space Environmental Center (ASEC) – for Solar Physics and Space Weather research; measurements of the various secondary fluxes of cosmic rays; inclusion of the large surface arrays in monitoring of the changing fluxes of secondary cosmic rays;
- 2003 – Detection of intensive solar modulation effects in September–November in the low energy charged particle, neutron and high energy muon fluxes;
- 2004 – Measurement of the spectra of heavy and light components of GCR, observation of very sharp "knee" in light nuclei spectra and absence of "knee" in heavy" nuclei spectra;
- 2005 – Measurements of highest energy protons in Solar Cosmic Rays (GLE 70 at 20 January; detection of Solar protons with $E > 20$ GeV);

[1] Later the first dean of the Physical Department of YSU.

- 2007 – Start of SEVAN (Space Environmental Viewing and Analysis Network) – a new type of world-wide network of particle detectors for monitoring of geophysical parameters.

2. The mass-spectrometric period of scientific research on Mt. Aragats

The history of scientific research on Mt. Aragats can be divided into several periods. The first – mass-spectrometric period – lasted about 15 years. Experiments with magnetic spectrometer designed by the Alikhanyan brothers lead to the discovery of protons in CR (Alikhanyan et al., 1945) and narrow air showers (Alikhanyan and Asatiani, 1945).[2] According to the viewpoint of that time, CRs were believed to have a pure electromagnetic origin (Anderson and Neddermeyer, 1937), therefore the presence of protons in CR strongly contradicted the established concepts. The origin of narrow showers could not be electromagnetic because of their great penetrability. Later narrow showers were thoroughly studied with the Aragats ionization calorimeter (Grigorov et al., 1958).

Using the Alikhanyan–Alikhanov magnetic spectrometer Kocharian obtained the energy spectra of muons and protons with energies up to several GeV (Kocharian et al., 1957). Till now this data remain one of the best measurements of the secondary cosmic ray fluxes at mountain altitudes.

The mass spectrometer method (see the picture of memorial magnet on Mt. Aragats in Fig. 3), performing the simultaneous measurement of the momentum and absorption length of charged particles, provided the effective particle mass analysis. This method presents the first evidence of the existence of particles with masses ranging from μ-meson to proton; however, only some of the many peaks in mass distributions measured at Aragats were later verified to be "real" particles and became known as π- and K-mesons. Other "particles" with masses heavier than μ-meson, including so called varitrons (Alikhanyan and Alikhanov, 1951), "discovered" using the Aragats mass spectrometer, turned to be artifacts due to fluctuations in the mass distributions. Nonetheless, the discussion on varitrons led to several 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. Also nowadays that are many groups using sophisticated mathematical methods cannot avoid mistakes and reported discoveries based on the fake peaks (see for example discussion about "discovery" of pentaquark in Seife, 2004).

Fig. 3. The memorial magnet of the Alikhanov–Alikhanyan spectrometer, erected on the entrance of the Aragats research station.

3. Calorimetric measurements on Mt. Aragats

The second phase of scientific research on Mt. Aragats, calorimetric measurements, covers the period from 1958 to 1970. The mass spectrometric method had reached its energy limit by that time. In 1958 a group of scientists from the Institute of Nuclear Physics of Moscow State University and Yerevan Physics Institute (team leader – Naum Grigorov) installed the first ionization calorimeter at Aragats station (Grigorov et al., 1958). Experiments with ionization calorimeter at Aragats proved the energy-dependence of the effective inelastic cross-section of the hadron interaction with nuclei. This fact was later confirmed by direct measurements on Proton satellites (Grigorov et al., 1970) and accelerator experiments. The ionization calorimeter also detected another interesting result concerning the peculiarities of multiparticle production of high energy pions (Babayan et al., 1965), which was later (1990) registered as a discovery in USSR: in some cases only few π^0-mesons, generated in the interaction with atmospheric nuclei, "takes away" almost the entire energy of the primary particle. The authors of this discovery were Babayan (deputy-director of YerPhI from 1956–1969), Naum Grigorov, Erik Mamijanyan (head of Cosmic Ray Division of YerPhI in 1969–1992) and Vladimir Shestoperov.

The Nor-Amberd station, which started operation in 1960 (see Fig. 4) at altitude 2000 m, considerably enlarged the possibilities for studying high energy cosmic ray hadrons and their interaction with different nuclei (head of laboratory in 1960–1986 – Gerasim Marikyan).

At that time physicists from various scientific institutions of the Soviet Union participated in the investigations on the Armenian mountains, also scientists from USA,

[2] Tina Asatiani, employee of YerPhI since 1943, is emeritus staff member of CRD.

Fig. 4. Nor-Amberd research station (altitude 2000 m).

France, Japan and Great Britain visited high altitude stations.

The method of wide-gap spark chambers was intensively investigated in YerPhI in late 50-s. The prestigious Lenin Prize was awarded to Artem Alikhanyan and Tina Asatiani (head of muon laboratory of YerPhI in 1960–1987) in collaboration with groups of Russian and Georgian physicists for developing the wide-gap spark chamber techniques.

In 1968–1969 a system of proportional counters was added to the Aragats ionization calorimeter. Using this facility, the neutron component of cosmic rays at mountain altitude was measured by E. Mamijanyan and his colleagues (Azaryan et al., 1977).

Babayan in early 70-s started his research of CR variations by installing neutron supermonitors of 18NM64 type at Aragats and Nor-Amberd research stations, which served as a basis for creating a unique center of cosmic ray monitoring in the "new history" of Aragats.

4. High Energy Astrophysics

During the next period (1970–1980) experiments PION (Avakian et al., 1978) and MUON (Asatiani et al., 1980) measured fluxes of 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 to 1993) and Tina Asatiani, respectively. PION was a unique facility (Alikhanyan et al., 1974), which included transition radiation detection system for particle identification, created by Albert Oganesian's group (head of laboratory from 1978 to 1996) and an ionization calorimeter for particle energy estimation.

The muon magnetic spectrometer for studying near-horizontal high energy muons was equipped with coordinate measuring systems based on the wire spark chambers and wide-gap spark chambers, thus increasing the range of reliable muon momentum measurement up to ~2.5 TeV/c. Both experiments used modern numerical algorithms and on-line computers for data analysis. One of the first soviet computers M220 was used to calculate horizontal muon energy spectrum. The PION experiment used the first Armenian minicomputer NAIRI-2 for data acquisition.

In 80s it became clear that larger detectors are necessary for the research of primary cosmic ray fluxes. The planned ANI experiment on Mt. Aragats (Danilova et al., 1982) met all these requirements. It was intended to register electrons and muons of Extensive Air Showers (EASs) by a system of surface scintillators; interactions of hadrons from EAS core with the world's largest calorimeter (surface area 1600 m^2); high energy muons by a huge underground muon detector and huge magnetic spectrometer (area 40 m^2). 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 leaders were 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 2 surface particle arrays MAKET-ANI (Fig. 5, experiment leader Gagik Hovsepyan, see details in Chilingarian et al., 2007) and GAMMA (Fig. 6, experiment leader Romen Martirosov, see details in Garyaka et al., 2002) made significant contribution to the "knee" region physics.

For selecting the proper model of the CR origin one has to measure the partial energy spectra of the different groups of primary nuclei, i.e. perform classification of the primary nuclei from largely smeared EAS information content. These very complicated tasks became feasible after the development of the nonparametric multivariate methodology of data analysis by Ashot Chilingarian in 1989.[3]

Event-by-event-analysis of EAS data, using Bayesian and Artificial Neural Network (ANN) information technologies (Chilingarian, 1989, 1994) helped to obtain the energy spectra of light and heavy primary nuclei from MAKET-ANI experiment and also three partial spectra, corresponding to light, intermediate and heavy nuclei groups from KASCADE experiment (Antoni et al., 2003, 2005). MAKET-ANI data (Chilingarian et al., 2004, 2007) demonstrates the existence of a sharp knee in the light component, and no evidence of knee in the heavy component up to $\sim 3 \times 10^{16}$ eV (see Fig. 7). The available data from other experiments confirm these results. In the KASCADE experiment, the position of the knee shifts towards higher energies with increasing mass number (Apel et al., 2006). In HEGRA experiment (Horns and Rohring, 2001) a steepening of the light mass group spectrum was detected. In EAS-TOP (Aglietta et al., 2004) the light nuclei

[3] Head of CRD since 1993.

Fig. 5. MAKET-ANI surface detector, Aragats research station.

Fig. 6. GAMMA surface array, Aragats research station.

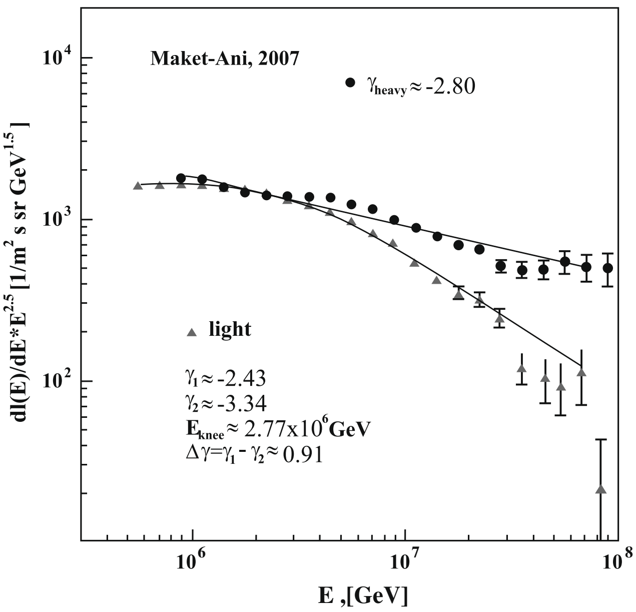

Fig. 7. Differential spectra of light and heavy nuclei groups of primary flux as measured by the MAKET-ANI surface array.

group also demonstrate sharp knee. Therefore, EAS evidence on the galactic CR origin consists in establishing charge proportional to acceleration of CR that is in general agreement with the model of shock acceleration in the blast waves of supernovae explosions. Further observations made by orbiting in space gamma-ray observatories and ground-based Atmospheric Cherenkov Telescopes (ACTs) also point on the Supernovae Remnants (SNR) as one of the major cosmic ray sources.

After publishing the final papers the MAKET-ANI detector ceased operation in 2007. The scintillators are used now for monitoring changing fluxes of low energy charged CRs. Arrangement was made also for making a test facility for the new precise timing system for a new large EAS array for measuring CRs far beyond the knee, now under consideration at CRD.

Direct evidence of shock acceleration in SNR shells can be deduced from joint detection of young SNRs in X and γ-rays. To prove that the young supernovae remnant RX J1713.7-3946 is a very efficient proton accelerator Uchiyama with colleagues (Uchiyama et al., 2007) include in the analysis information on broadband X-ray spectra (from 0.4 to 40 KeV) measured by the Suzaku satellite (Takahashi et al., 2008) and on high energy γ-ray spectra (extending over 10 TeV) measured by HESS Imagining Atmospheric Cherenkov Telescope (IACT) (Aharonyan et al., 2007). They exclude the inverse Compton origin of detected high energy γ-quanta, and taking into account the Tev–KeV correlations validate the hadronic model of detected γ-rays. Thus, the joint analysis of X-ray maps from Chandra and X-ray spectra from Suzaku satellites with high energy γ-ray spectra measured by HESS ACT provide very strong argument for the acceleration of protons and nuclei of 1 PeV and beyond in young SNR shells.

Armenian physicists have a significant impact in the development of the ACT technique. Pioneering system of IACTs "on the Canary island of La Palma" (HEGRA) followed by large IACTs HESS in Namibia and MAGIC on the Canary island of La Palma designed and operated by international collaborations with the participation of Armenian physicists.

In 1985 design and construction of the first system of five IACTs for the ANI experiment on the mountain Aragats started by YerPhI. The telescopes comprised tessellated reflectors of 3 m diameter and 37-pixel imaging cameras. The pixel construction was based on FEU-130 type Soviet PMTs of bialkali photocathode and GaP first dynode. High quality glass mirrors with quartz protection, equatorial mounts of the telescopes with drive electronics, the imaging cameras and the DAQ electronics also were produced by different workshops of YerPhI. The gamma ray group was lead by Felix Aharonyan and Razmik Mirzoyan. The group started measuring cosmic ray signals at Nor-Amberd research station and calibrating the telescope for the first measurements of the Crab Nebula when the collapse of the former Soviet Union stops experimental activities. Fortunately, the Armenian scientists togethers with German physicist Alkoffer have developed a program for installing the same system of ACTs on a newly created High Energy Gamma Ray Astronomy (HEGRA) cosmic ray detector on the Canary island of La Palma. Already prepared devices and materials for the construction of the five telescopes have been shifted from Armenia via Germany to La Palma and the construction started in 1991. In 1992 the first HEGRA telescope measured gamma rays from Crab Nebula (see Mirzoyan et al., 1994).

That was the first significant confirmation of the discovery of the 10 m diameter Whipple telescope in Arizona, USA. In 1993 second telescope was build and operated in stereo mode with the first one and later on four more telescopes were added to the system. The HEGRA telescopes were operated until 2002 and provided a rich harvest of gamma sources. The contribution of Armenian physicists in HEGRA was very significant because of their leading role both in the techniques of IACTs as well as their theoretical work on the very frontier of gamma astronomy.

After termination of HEGRA the astrophysicists from the collaboration continued to build new advanced instruments. Already in 1994 the 17 m diameter MAGIC telescope, intending to investigate gamma rays below 300 GeV down to energies of 30 GeV was proposed by Razmik Mirzoyan. An international collaboration was formed and in 1998 it became an official project in Max-Planck-Institute of Physics (MPI) in Munich. YerPhI and several institutions in Germany, Spain, Italy, Switzerland and Finland became member of the MAGIC collaboration. The first MAGIC telescope was built in La Palma in 2001–2003 and has been in operation since 2004. The second MAGIC telescope was built 85 m distance from the first one and since recently is operating together with the first one.

The other part of HEGRA collaboration continues its research with 10 m diameter class telescopes, with advanced optics and electronics. A new array, initiated in 1997 by Felix Aharonyan, under the name H.E.S.S., is comprised of four telescopes of 12 m diameter and was built by an international collaboration, mostly from Germany and France, in Namibia in 2001–2003. Scientists from YerPhI also became member in H.E.S.S. H.E.S.S. collaboration intends to complete their array with one 28 m diameter very large telescope in 2010.

The number of VHE gamma sources increased from $\sim$20 to more than 80 just in 3–4 years and very interesting publications, more than 100 by now, appeared in peer refereed journals, also in such famous ones as Science and Nature. It is expected that both instruments together with VERITAS from USA will increase the number of sources to $\sim$100 just in the next 2–3 years and finally long-standing questions of Cosmic Rays, Astrophysics, and Astroparticle physics can be understood and answered.

5. Solar Physics and Space Weather research

Cosmic Rays are accelerated not only in the depths of galaxies but also by our nearest star, the Sun. Strong solar flares sometimes accelerate particles in the Mev–GeV range to intensities more than the total galactic flux reaching terrestrial atmosphere. Solar particles interact with the magnetosphere, ionosphere and the atmosphere, thus influencing the near Earth environment and abruptly changing the "space weather", seriously impacting spaceborn and Earth-based technologies. Space Storms can harm astronauts in space and cause excessive radiation exposure for aircraft crew. 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 microscopic electronic devices create additional currents and change the state of the electronic circuits, 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 damage transformers at electric stations. Our civilization heavily depends on space-based technologies, including telecommunication, navigation, disaster warning, weather forecasting, military systems, etc. For this reason, Space Weather research attracts more and more scientists. At the end of last century USA, Canada, Europe and Japan adopted national programs to study space weather and to create reliable forewarning services. CRD physicists are contributed to this important endeavor.

Starting in 1996 we have been developing various detectors to measure fluxes of different components of secondary cosmic rays. In 1996 we restarted our first detector – the Nor-Amberd neutron monitor 18NM64. A similar detector started to take data at the Aragats research station in autumn 2000 (Tsuchiya et al., 2001). A Solar Neutron Telescope (SNT) has been in operation at the Aragats research station since 1997, as part of the world-wide network coordinated by the Solar-Terrestrial laboratory of Nagoya University (Chilingarian and Reymers, 2007). In addition to the primary goal of detecting the direct neutron flux from the Sun, the SNT also has the ability to detect charged fluxes (mostly muons and electrons) and roughly measure the direction of the incident muons. Another monitoring system is based on the scintillation detectors of the Extensive Air Shower (EAS) surface arrays, MAKET-ANI and GAMMA, located on Mt. Aragats. The charged component monitoring system at the Nor-Amberd research station started operation in 2002. Our Data Acquisition (DAQ) system was modernized in 2005. Modern electronics was designed to support the combined neutron-muon detector systems as well as measurement of the environmental parameters (temperature, pressure, humidity). Microcontroller-based DAQ systems and high precision time synchronization of the remote installations via Global Positioning System (GPS) receivers are crucial ingredients of the new facilities on Mt. Aragats. Information on changing secondary particle fluxes, measured by hundreds of detecting channels, is used for the enumerating solar modulation effects during large solar explosions.

The Aragats Space Environmental Center (ASEC, Chilingarian et al., 2003, 2005) operating since 2000, provided detailed coverage of the violent events of the 23rd solar activity ending in 2008. One of the most exciting results obtained recently at Mt. Aragats is the discovery of protons of highest energies (greater than 20 GeV) accelerated on the Sun during space-era largest Ground Level Enhancement (GLE) (Bostanjyan et al., 2007; Chilingarian and Reymers, 2007). On 20th of January 2005, during the recovery phase of the Forbush decrease a long lasting X-ray burst occurred near the west limb of the Sun (helio-coordinates: 14N, 67W). The start of the X7.1 solar flare was at 06:36 and maximum of the X-ray flux at 7:01. The fastest (relative to X-ray start time) GLE event of 23rd cycle was detected by space-born and surface particle detectors a few minutes after the flare onset. The start of GLE was placed at 6:48; the maximal amplitude of 5000% recorded by NM at the South Pole is the largest increase ever recorded by neutron monitors. ASEC monitors detected significant excess of count rates at 7:00–8:00 UT. From 7:02 to 7:04 UT, the Aragats Multichannel Muon Monitor (AMMM) detected a peak with a significance of $\sim 4\sigma$. It was the first time that we detected a significant enhancement of the >5 GeV muons coinciding with the GLE detected by the world-wide networks of neutron monitors. Detailed statistical analysis of the peak (Chilingarian, 2009) proves the non-random nature of the detected enhancement. This short enhancement (see Fig. 8) exactly coincides in time with peaks from Tibet neutron monitor (Miyasaka et al., 2005), Tibet solar neutron telescope (Zhu et al., 2005) and the Baksan scintillator surface array (Karpov et al., 2005), see Fig. 8. Another surface array (GRAND, located in Western hemisphere) demonstrated a very large peak ~10 min earlier (D'Andrea and Poirier, 2005).

The differential energy spectrum of the SCR protons at 7:02–7:04 UT measured by the space-born spectrometers and surface particle detectors covers more than 3 orders of magnitude from 10 MeV to 20 GeV and demonstrates very sharp "turn-over" at 700–800 MeV. The energy spectrum remains very hard up to ~800 MeV (with power index ~−1) and extended until tens of GeV with a power index between ~−5.

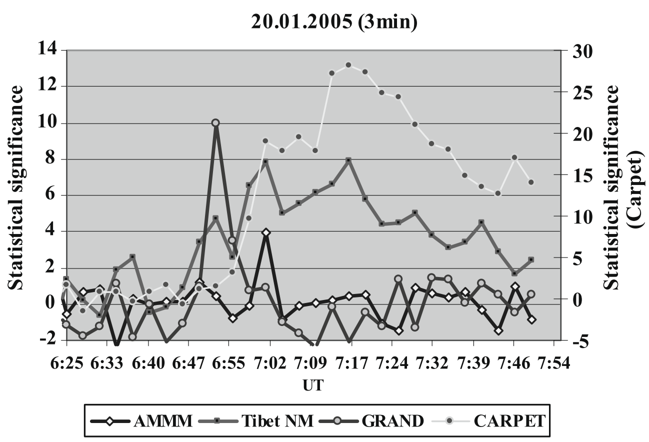

Fig. 8. Time series of muon detectors and neutron monitors detected GLE at 20 January, 2005. Note the peak at 7:02 detected by CARPET surface array, (most probable energy ~10 GeV), Tibet NM (most probable energy ~13 GeV) and AMMM (most probable energy >20 GeV).

6. CRD space education center

Artem Alikhanyan, whose 100th anniversary was celebrated on July 9, 2008 at Nor-Amberd station, was not only a brilliant scientist, but also an experienced educator. In early 60s when the international contacts were still suppressed by soviet authorities, he initiated the famous Nor-Amberd schools, where problems of High Energy and Elementary Particle Physics were discussed. Experienced, prominent and young scientists from many countries participated in the activities of these schools. This tradition has been preserved up to the present days. CRD organizes in its Yerevan headquarters the Space Educational Center, where lectures on High Energy Astrophysics, Cosmic Rays and Modeling of Physical processes are followed by experimental work in teaching laboratories, where students work with modern particle detectors and data acquisition electronics.

CRD developed an advanced Space Weather information product: Data Visualization Interactive Network (DVIN) for the Aragats Space Environmental Center. This 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 competition.

Students work with the DVIN package, revealing peaks in time series of Aragats monitors, enumerating the significance of the peaks and decide upon the physical nature of these abrupt enhancements of particle fluxes.

CRD is organising annual international symposia devoted to Solar Physics and Space Weather research. 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. The participants became acquainted with the ASEC monitors and capabilities of the Armenian physicists who created the Aragats Space Environmental Center. In September 28–October 3, 2008 an international symposium on *F*orecasting of the *R*adiation and *Ge*omagnetic *S*torms by networks of particle detectors (FORGES-2008) took place in Nor-Amberd (Chilingarian, 2008).

7. Future plans

Currently Aragats is a modern scientific center, equipped with key scientific equipment and necessary supporting infrastructure, which is constantly being updated. Information on changing fluxes of secondary cosmic rays is distributed world-wide to numerous CRD collaborators. 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, solar neutron telescopes and muon detectors.

Recently 12 countries of Europe decide to form joint data base for 1-min counts from neutron monitors (NMBD), supported by European FP7 programme. The joint project of muon detectors is currently implemented in collaboration with Germany, Switzerland and Israel. CRD initiated the development of a new world-wide particle detector network called "Space Environment Viewing and Analysis Network" (SEVAN) – (Chilingarian and Reymers, 2008; Chilingarian et al., 2009). The United Nations Office of Outer Space Affairs and the International Heliophysical Year (IHY) have launched a small instrument programme as one of United Nations Basic Space Science (UNBSS) activity. SEVAN Network aims to improve the fundamental research on particle acceleration in the vicinity of sun and in space environment conditions. The new type of particle detectors will simultaneously measure changing fluxes of most species of secondary cosmic rays, thus turning into a powerful integrated device for exploration of solar modulation effects. The first SEVAN modules are under test at the Aragats Space Environmental Center in Armenia, in Croatia and Bulgaria. The network will grow in 2009 with detectors deployed in Slovakia and India. Research groups from these countries participated in training on detector operation and data analysis during FORGES-2008 symposium.

The basic detecting unit of the SEVAN network (see Fig. 9) is assembled from standard slabs of $50 \times 50 \times 5\ cm^3$ plastic scintillators. Between two identical assemblies of $100 \times 100 \times 5\ cm^3$ scintillators (four standard slabs) are located two $100 \times 100 \times 5\ cm^3$ lead absorbers and thick $50 \times 50 \times 25\ cm^3$ scintillator assembly (five standard slabs). A scintillator light capture cone and Photo Multiplier Tube (PMT) are located on the top, bottom and in the intermediate layer of the detector. Incoming neutral particles undergo nuclear reactions in the thick 25 cm plastic scintillator and produce protons and other charged particles. In the upper 5 cm thick scintillator charged particles are detected very effectively; however for the nuclear interactions of neutral particles there is not enough substance. When a neutral particle traverses the top thin (5 cm) scintillator, usually no signal is produced. The absence of the signal in the upper scintillators, coinciding with the signal in the middle scintillator, points to neutral particle detection. The coincidence of signals from the top and bottom scintillators indicates the traversal of high energy muons. Lead absorbers microcontroller-based DAQ electronics

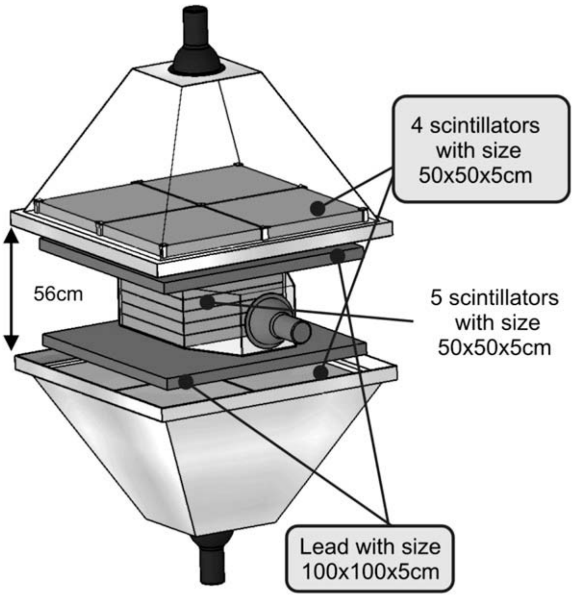

Fig. 9. Layout of basic model of SEVAN network.

and an Advanced Data Analysis System (ADAS) provide registration and storage of all logical combinations of the detector signals for further off-line analysis and for on-line alerts. The special ADAS sub-system allows the remote control of the PMT high voltage and of other important parameters of the DAQ electronics.

The network of hybrid particle detectors, measuring neutral and charged fluxes provide the following advantages over existing detector networks measuring single species of secondary cosmic rays:

- Enlarged statistical accuracy of measurements.
- Probe different populations of primary cosmic rays with rigidities from 7 GV up to 20 GV.
- Reconstruct SCR spectra and determine position of the spectral "knees".
- Classify GLEs in "neutron" or "proton" initiated events.
- Estimate and analyze correlation matrices among different fluxes.
- Significantly enlarge the reliability of Space Weather alerts due to detection of 3 particle fluxes instead of only one in existing neutron monitor and muon telescope world-wide networks.

A new trend in Astrophysics research is in the observation of celestial objects in several wavelengths simultaneously (e.g. in radio, optical, X-ray, and gamma rays). A variety of complementary measurements give sufficient information for building and testing models of the galaxy formation, of supernovae explosions, of accompanying gamma-ray bursts, of accretion disc interactions with super-dense objects, and finally of the evolution of the Universe itself. The additional information about the particles of highest energies arriving at the Solar system significantly enlarges the information on the most violent processes in the Universe.

Summarising the situation with investigation of the CR spectra in the energy interval lasting from 10^4 until 10^{20} eV we can say:

Lowest energies in keV – tens of TeV region are rather well measured by space-born/air-born spectrometers located at satellites, space stations and balloons.
The "knee" region spectra from 10^{14} to 10^{17} eV has been well explored during last 40 years by the surface arrays covering thousands of square meters.
The ultra-high energy region – above 10^{19} eV – after pioneering research of Haverah Park, Volcano-Ranch, Yakutsk, AGASA and HIGHRES detectors took a mature state with AUGER-South observatory started to present valuable data, to be confirmed in next decade by an expected large volume of data.

This picture contain two obvious gaps in satisfactory well established spectra: 10^{13}–10^{14} eV; and 10^{17}–10^{19} eV. If first gap can be filled with planned long-duration balloon flight and experiments on the Space Station, the second can be filled only by several square kilometre size particle arrays.

Recently CRD physicist started to prepare proposal of new large EAS surface array with the *main scientific goal of measuring partial energy spectra of the cosmic rays in the poorly explored energy region of* 10^{17}–10^{19} eV. The aim of the project is to build a large detector for investigation of the mentioned energy region, using already operating particle detectors on the slopes of Mt. Aragats and by installing new hybrid particle detectors measuring neutral and charged CR secondary fluxes. The main physical task *is* determination of the contribution of the extragalactic CR component to give a consistent description for the entire GCR spectrum after the "knee".

The energy region of 10^{17}–10^{19} eV is still poorly explored and the origin of the extragalactic cosmic rays is still mystery. To measure partial energy spectra (spectra of "light" and "heavy" nuclei groups) a very large area of EAS detection is required (at least several square kilometers). The optimal altitude (to measure maximal number of particles in EAS) is ~2000 m. above sea level. At these altitudes the EAS from primary proton with energy 10^{18} eV will produce 6×10^8 electrons. Therefore, also taking into account very severe climatic conditions at the altitude of 3200 m. at Aragats station, we propose to build the new large EAS detector in Nor-Amberd – Burakan region. We plan to use new type of hybrid particle detectors measuring electron, muon and neutron contents of EAS at 2 sites, separated by ~3.5 km, at Nor-Amberd research station and in the Antarut village (see Fig. 10).

Project objectives include:

- Development of a new-generation particle detector for measuring neutral and charged CR fluxes and their directions.

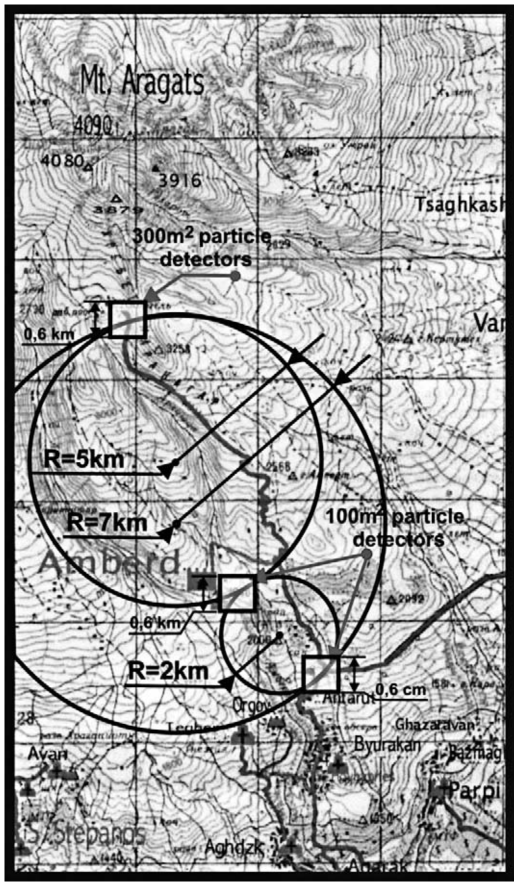

Fig. 10. NewANI EAS array planned at slopes of Aragats Mountain.

- Creation of a particle detector network for continuous detection of cosmic rays in the energy range 10^{17}–10^{19} eV.
- Determination of the characteristics of the "iron knee".
- Search for point sources of cosmic rays.
- Investigation of the "fine structure" of the partial energy spectra.

Two networks of particle detectors will be formed around the central part of ~ 20 m^2 hybrid particle detectors (see Fig. 8). Each array will be completed with detectors as soon as particle detectors are commissioned and assembled. The third site will be formed by the particle detectors of MAKET-ANI and GAMMA EAS arrays operating at Aragats research station of Alikhanyan Physics Institute. All three sites have total area ~0.35 km^2, and will detect primary particles with energies up to several units of 10^{17} eV (trigger conditions and corresponding EAS core collecting area will be obtained via Monte-Carlo simulations).

Huge events triggering 2 arrays out of 3 will indicate primary energies above 10^{19} eV. EAS core collection area will be ~15 and 75 km^2 correspondingly for 2 and 5 km radii circles.

Basic detectors tests and deployments started in 2008; with appropriate funding in 2011 new EAS detector will be equipped with enough modules for enlarging the investigated energy range up to 10^{18} eV.

Cosmic Ray research in the energy range of 10^{17}–10^{19} eV is a continuation of the MAKET-ANI and GAMMA arrays energy domain of 10^{14}–10^{17} eV, thus providing continuous partial energy spectra in the energy range covering 5 orders of magnitudes where almost all the significant features of energy spectra are taking place. No operating or planned surface array is intended to cover this very important and large energy domain: the KASCADE energy limit is $\sim 10^{18}$ eV, the energy range of HighRes and Auger is starting from 5×10^{18} eV. Therefore the proposed detector will provide unique information extending the already well investigated low energy domain with the enigmatic highest energy domain.

Among other projects started on Aragats we can mention planned correlated measurements of the disturbances of geomagnetic field and changes of secondary particle fluxes by starting precise measurements of the Earth's magnetic field and electric fields. First measurements are planned in fall of 2009.

The next project is connected with registrations of radio burst on the sun by a network of antennas. Outbursts of plasma and shocks on the sun accelerate electrons, which in turn produce the radio signal. The same strong shock must also accelerate atomic nuclei in the solar wind, which produce the radiation storm. Since the radio signal moves at the speed of light while the particles lag behind, we can radio signals from the sun to give warning that it is generating a radiation storm that will hit us soon. In collaboration with Hartmut Gemmeke from research center Karlsruhe, we started measurements of radio-noise at slopes of Aragts to select the best place to install a network of radio antennas for solar burst monitoring.

8. Conclusion

The CRD staff includes approximately 80 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. Many of the staff members are young graduate students or recent postgraduates. 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.

Acknowledgements

We thank the former and the present CRD employees for their dedicated work at Aragats as well as our collaborators and supporters all over the world.

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