Yerevan Physics Institute
Cosmic Ray Division
History, status and development 2009-2014

1. Introduction

Information on the particles of highest energies bombarding the Earth's atmosphere provides 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 reaching the Earth from interstellar space and from Sun, the so called Galactic and Solar Cosmic Rays (GCR and SCR). These "primary" Cosmic Rays (CR) were discovered almost 100 years ago by the ionization effects of the secondary fluxes (particle showers), produced in their interactions with the terrestrial atmosphere. Exploiting different physical processes of shower interaction 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 first satellite on October 4, 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 resolution but, due to severe limitation of payload and the weak flux of high energy, CR perform measurements in KeV to GeV energy region. In hundreds of TeV - PeV region now and in the nearest future only surface based techniques of secondary particle showers detection 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 A.Alikhanyan are located on the slopes of Mount Aragats, the highest peak of Armenia (see Figure 1 and 4), at 3200 meter and 2000 m elevations 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

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[1] later the first dean of the Physical Department of YSU

(see Figure 2), who organized a scientific expedition to Aragats in 1942. Since then, expeditions on Aragats have continued uninterruptedly, despite the World War II, insufficient funding, electricity and fuel shortages during the recent history of Armenia.
In the 40's and 50's cosmic rays were the main source for 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 – Establishment of the Physical-mathematical Institute of Yerevan State University; now Yerevan Physics Institute after Artem Alikanyan;
- 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: measuring 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);
- 1989-1992 – 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 the 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 on January 20; detection of Solar protons with E>20GeV);
- 2007 - Launch of SEVAN (Space Environmental Viewing and Analysis Network) - a new type of world-wide network of particle detectors for monitoring of geophysical parameters
- 2008 - Multivariate analysis and classification of the solar transient events (Ground level enhancements, Geomagnetic effects, Forbush decreases) detected by ASEC monitors during 23rd solar activity cycle.

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 (Alikhanian et al., 1945) and narrow air showers (Alikhanian, Asatiani, 1945).[2] According to the viewpoint of the time, CRs were believed to have a pure electromagnetic origin (Anderson, 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 N. Kocharian obtained the energy spectra of muons and protons with energies up to several GeV (Kocharian et al, 1952). Till now this data remain one of the best measurements of the secondary cosmic ray fluxes at mountain altitudes. Figure 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.

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

Figure 1 Aragats research station (altitude 3200 m)

The mass spectrometer method (see the picture of memorial magnet on Mt. Aragats) in other "particles" with masses heavier than μ-meson, including so called varitrons (Alikhanian & 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. Nowadays there are also many groups using sophisticated mathematical methods that cannot avoid mistakes and who reported discoveries based on the fake peaks (see for example discussion about "discovery" of pentaquark in Seife, 2004).

Figure 2 Abraham Alikhanov (left) and Artem Alikhanyan

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, 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 Kh. 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 its operation in 1960 (see Figure 4) at the 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).

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

At that time physicists from various scientific institutions of the Soviet Union participated in the investigations on the Armenian mountains, scientists from the USA, France, Japan and Great Britain also 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 1968-69 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).
K. 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) the experiments PION (Avakyan 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 **V**ahram Avakyan (head of Aragats station from 1963 till 1993) and Tina Asatiani, respectively. PION was a unique facility (Alikhanian et al., 1975),

Figure 4 Nor Amberd research station (altitude 2000 m)

which includes transition radiation detection system for particle identification, created by Albert Oganesian's group (head of laboratory from 1978 – till 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 (EAS) 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

Figure 5 MAKET-ANI surface detector, Aragats research station

(Figure 5, experiment leader Gagik Hovsepyan, see details in Avakyan et al., 1986) and GAMMA (Figure 6, experiment leader Romen Martirosov, see details in Garyaka et.al., 2002) made significant contribution to the “knee” region physics.

To select 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 the classification of the primary nuclei by highly smeared EAS information content. These very complicated tasks became feasible after developing 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 3 partial spectra, corresponding to light, intermediate and heavy nuclei groups from KASCADE experiment (Antoni et al., 2003). MAKET-ANI data (Chilingarian, Hovsepyan 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 $\sim 3 \bullet 10^{16}$eV (see Figure 7). Analysis of the GAMMA detector data (Garyaka, 2002), located nearby MAKET-ANI and in addition measuring muon content of EAS also demonstrates sharp knee in proton flux (Garyaka et al., 2007). The available world data confirm these results. In the KASCADE experiment, the position of the knee shifts towards higher energies with increasing mass number (Apel et al., 2005). In HEGRA experiment (Horns et al., 2001) a steepening of the light mass group spectrum was detected. In EAS-TOP (Aglietta et al., 2004) the light nuclei group also demonstrate sharp knee.

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[3] head of CRD since 1993

Figure 6 GAMMA surface array, 40mx40m hadron calorimeter in the center; Aragats research station

Therefore, EAS evidence on the galactic CR origin consists in establishing charge dependent acceleration of CR in general agreement with 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 Remnant (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., 2007) and on high energy γ-ray spectra (extending over 10 TeV) measured by HESS Atmospheric Cherenkov Telescope (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 ACTs on Canarias (HEGRA) followed by large ACTs HESS in

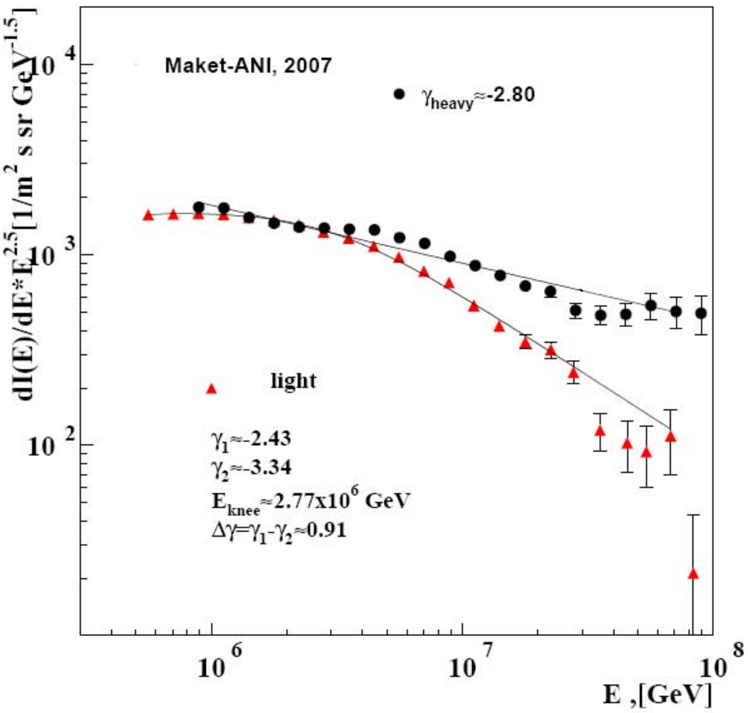

Figure 7 Differential Spectra of Light and Heavy nuclei groups of primary flux as measured by the MAKET ANI surface array

Namibia and MAGIC at Canarias designed and operated by international collaborations with the participation of Armenian physicists.

In 1985 design and construction of the first system of ACTs for the ANI experiment at Aragats started at YerPhI. The telescopes comprised tessellated reflectors of 3m diameter and an imaging camera in the focal plane of 37 pixels based on FEU-130 type Soviet PMTs of bialkali type. High quality glass mirrors with quartz protection, equatorial mounts of the telescopes, the imaging cameras and DAQ electronics also were prepared at YerPhI workshops. The gamma ray group was lead by Felix Aharonian; with leading role of Razmik Mirzoyan and Ruben Kankanian. 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 stopped the experimental activities. Fortunately, the Armenian scientists with German physicist O. Alkoffer prepared a proposal to install the same system of ACTs on a newly created HEGRA (High Energy Gamma Ray Astronomy) cosmic ray detector on the Canary island of La Palma. The prepared devices and materials for the construction of the 5 telescopes were 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 10m diameter Whipple telescope in Arizona, the USA. In 1993 the second telescope was build and operated in stereo mode with the first one and later on 4 more telescopes were added to the system. The HEGRA telescopes 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 17m diameter MAGIC telescope, intending to investigate gamma rays below 300 GeV down to energies of 30 GeV was proposed by Razmick Mirzoyan. An international collaboration was formed and in 1998 it became an official project in Max-Planck-Institute Physics (MPI) in Munich. YerPhI and several institutions in Germany, Spain, Italy, Switzerland and Finland became members of the MAGIC collaboration. The first MAGIC telescope was built in La Palma in 2001-2003 and has operated since 2004. The second MAGIC telescope was built on a 85m distance from the first one and will operate together with the first one in fall, 2008.

The other part of HEGRA collaboration continues its research with 10m diameter class telescopes, with advanced optics and electronics. A new array, one of initiators of which was Felix Aharonian, under the name H.E.S.S., is comprised of 4 telescopes of 12m diameter and was built by an international collaboration, mostly from Germany and France, in Namibia in 2001-2003. Scientists from YerPhI also became members in HESS. HESS collaboration intends to complete their array with one 28m diameter very large telescope in 2009.

The number of sources increased from ~20 to more than 80 just in 3-4 years and very interesting publications, more than 70 by now, appeared in peer refereed journals, also in such famous ones as Science and Nature. It is expected that both telescopes together will increase the number of sources to ~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. Felix Aharonian, Ashot Akhperjanyan and Vardan Sahakian , got the prize of the President of the Republic of Armenia in 2006 , and the YerPhI group got the Descartes' prize as a part for the HESS collaboration in 2007.

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 space-born 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 in electric stations. Our civilization strongly 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 the USA, Canada, Europe and Japan adopted national programs to study space weather and to create reliable forewarning services. CRD physicists have contributed to this important endeavor.

Since 1996 we have developed 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 recieve data at the Aragats research station in autumn 2000. A Solar Neutron Telescope (SNT) has operated at the Aragats research station since 1997, as a part of the worldwide network coordinated by the Solar-Terrestrial laboratory of Nagoya University (A. Chilingarian, A. Reymers et al, 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.

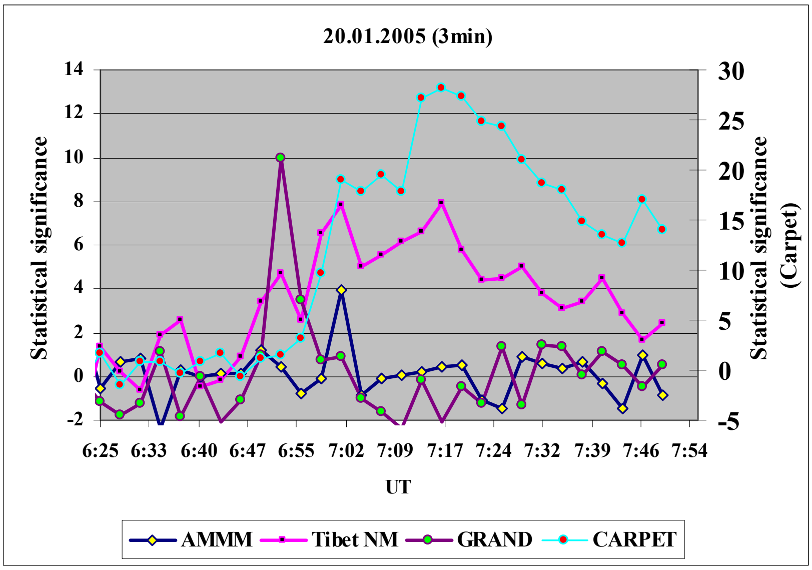

Figure 8 Time series of 3minute count rates of secondary muons and neutrons detected at 20 January, 2005. Note second peak at 7:02 detected by CARPET, (most probable energy of primary protons ~10 GeV), Tibet NM (most probable energy of primary protons ~ 13 GeV) and AMMM (most probable energy > 20GeV).

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, Reymers, 2007). On 20th 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, 67 W). 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 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 *~4σ*. 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, 2008) proves the non-random nature of the detected enhancement. This short enhancement (see Figure 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 Figure 8. Another surface array (GRAND, located in Western hemisphere) demonstrated a very large peak ~10 minutes earlier (D'Andrea and J. Poirier, 2005).

The differential energy spectra 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 and -6.

After detailed analysis of the GLE on January 20, 2005, we reanalyze the previous GLE occurred on October 28, 2003. We detected 3.3σ peak in 3 minute time series of the AMMM just after the maximum of the X-ray flare. However, the peaks of ~3.3 can occur several times a day by occasion without any noteworthy solar event. Therefore, we have to relate detected a peak with its possible trigger; i.e. a 4B/X17.2 solar flare located at S16 E08 that started ~ 11:01 with maximum at 11:10 UT. The earliest arriving particles were detected at Tsumeb, Namibia and Hermnus, South Africa (11:06 UT, Moraal et al, 2005); Cape Schmidt (11:14 UT) and Norilsk (11:14 UT, Miroshnichenko et al., 2005). The surplus of AMMM count rates can be related to primary protons with energy greater than 20 GeV. The fluxes of such great energies are very weak (and very short, we cannot expect duration greater than 3 minutes) and only relative large area of detector allows detecting weak signal. Calculated chance probability (see the techniques in Chilingarian, 2009) is equal to ~0.03; i.e. only once in 33 cases we can expect such an enhancement.

The 2003 October 28 event was one of the biggest solar flares of the 23rd cycle (X17.2 according to the NOAA scale, X-ray flux maximum at 11:10). The radiation storm (S4, according to the NOAA scale) was the fourth largest in history since NOAA began keeping records in 1976. Due to this storm many satellites experience extensive surface charging, problems with orientation, uplink/downlink and tracking. Instruments on SOHO space station were shut down for safety reasons. Astronauts at Space station hide themselves in Russian module Zvezda, having best shielding against space radiation. Seven over-polar flights were rescheduled. Therefore, it is of special interest to compare the forecasts issued by Space Environment Center in Boulder, Colorado with possible alerts from the ASEC particle detectors. Of course, ASEC provides only post-event analysis, because in 2003 there was not operational Space Weather service.

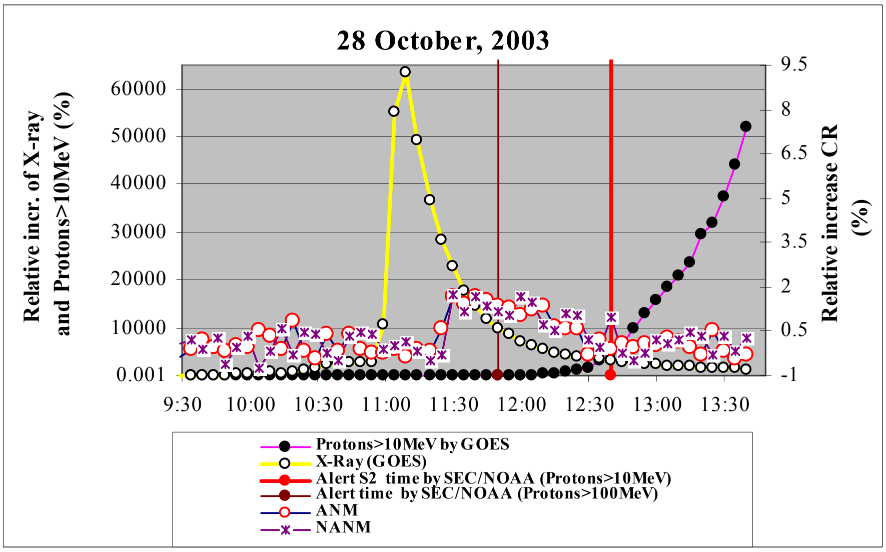

Figure 8 Radiation from 28 October 2003 X14.4 flare. X-ray count rate has multiplied by 2 (flux maximum at 11:10). SEC/NOAA alerts enhancement of 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.7% and reaches maximum at ~11:30.

In Figure 8 we can see that abrupt enhancement of the ASEC monitors count rates started at least 20 minutes earlier than 100 MeV protons alert and more than 1 hour earlier than S2 alert, both issued by SEC. In Figure 9 we can see that at 11:20 correlations between particle fluxes on 2 research stations of ASEC as well as "delayed" correlations of both fluxes with X-ray flux are reaching peak at 0.7-0.8.

Correlation information along with information on the GLE makes the false alarm probability extremely small. Only GLE information isn't enough due to not very big enhancement at middle-low latitudes (usually 1.5-2%) and rather large fluctuations of count rates. The relative accuracy of neutron monitor 5-minute count rate is at ASEC 0.3-0.4%, therefore, significance of 1.5-2% enhancement corresponds to 3.5 - 5σ, and related false alarm probability to 10^{-4} – 10^{-5}, i.e. occurs randomly several times in year by chance. The "delayed" correlations are calculated by the "memorization" of the X-ray flux enhancement (available on-line from SEC) and continuous (moving) calculations of the correlations with surface particle detector data.

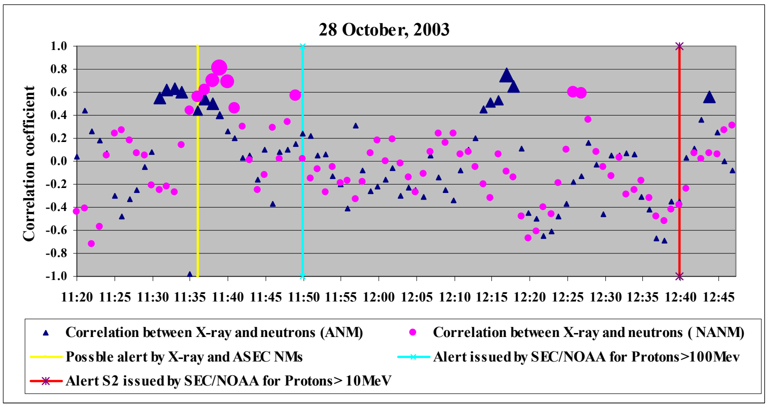

Figure 9 Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates. The triangles, circles and diamonds denote the correlation coefficient between changing fluxes of particle detectors and X-rays.

In Figures 8 and 9 we can see that X-ray flare maximum was at 11:10 and the dangerous flux of abundant 10-MeV protons reach the Earth more than1 hour later. 100 MeV protons alert was issued by SEC/NOAA 40 minutes after the flare and surface monitors at ASEC can alert on GLE 20 minutes earlier and 1 hour in advance of SEC S2 alert. The correlation analysis of multiple ASEC monitors make ASEC alert reliable and confident. Correlation of X-ray peak and Neutron monitors peaks reach values 0.6-0.8 at 10:35, 25 minutes after X-ray maximum. Correlations between X-ray radiation and particle fluxes unambiguously prove genetic relation between flare and surface particles and can be used for construction of an alert on most violent radiation storms. Continuous monitoring of the abrupt enhancement of monitors count rate and "moving" correlations calculation after severe solar flare will surely point on upcoming severe radiation storm. False alarm probability of such alerts will be negligible, efficiency for most violent storm – high. Detected radiation from 28 October 2003 flare demonstrates the power of combining information from space born spectrometers and surface particle detectors for constructing reliable and timely Space Weather forecasting services.

5. Solar-terrestrial connections and solar transient events

5.1 Interplanetary Coronal Mass Ejection

Huge magnetized plasma clouds and shocks initiated by Coronal Mass Ejections (CME) emitted by Sun travel in the interplanetary space with mean velocities up to 2500 km/sec (the so called Interplanetary Coronal Mass Ejection (ICME)), and are known as major drivers of severe geomagnetic storms when arriving at the Earth. On their way to the Earth ICMEs also "modulate" the flux of Galactic Cosmic Rays (GCRs) introducing anisotropy and changing energy (rigidity) spectra of the previously isotropic population of protons and stripped nuclei accelerated in the numerous galactic sources. Changes in

the rather stable flux of GCR are detected by space-born spectrometers (rigidities up to ~1GV) and by world-wide networks of particle detectors (rigidities up to ~100GV) located at different latitudes, longitudes and altitudes. Therefore, measurements of secondary fluxes can be used for ICMEs “probing”, providing highly cost-effective information on the key characteristics of these interplanetary disturbances. The size and magnetic field strength of ICMEs are correlated with the ICME modulation effects on the energy spectra and direction of GCRs. At the same time the presence of strong and long-duration southward magnetic field (-Bz) in ICMEs is the primary requirement for their geoeffectiveness (Valtonen, 2007 and references therein). Thus, strong magnet field “frozen” in ICMEs is both modulation agent of GCR and driver of GMS.
Although there is no one-to-one dependence between the variations of the GCR and the strength of GMS (see Kudela & Brenkus, 2004) and there exist other drivers of storms and modulation agents of GCRs, the large B_z value associated with approaching ICMEs is a best known diagnostics of GMS strength. Appropriate observations of the variations of the primary and secondary cosmic rays can be a proxy of B_z value available long before IMCEs reach the L1 libration point where B_z is measured directly (see e.g., Kudela and Storini, 2006).

5.2 Forbush decrease

The attenuation of the Galactic Cosmic Ray (GCR) flux due to passing Interplanetary ICME (Forbush decrease - FD) is dependent on the speed and size of the ICME, the magnetic field strength and orientation of the ICME and pre-shock conditions of Interplanetary Magnetic Field (IMF). All these parameters are rather difficult to measure; therefore, the explanation of the FD mechanisms still lacks many details. To improve the physical understanding of the FD and to explore the Space Weather drivers, we need to measure as many geospace parameters as possible, including the changing fluxes of secondary cosmic rays. At ASEC we measure neutral and charged fluxes coming from different directions by particle detectors located at 3 different altitudes. Each species have different most probable energy of primary “parent” proton/nuclei. New particle detectors now starting to operate at ASEC will extend this energy range from 7 to 200 GeV. Therefore, from ASEC monitor data we can estimate the GCR energy range affected by ICME and reconstruct actual spectra of the galactic cosmic rays incident terrestrial atmosphere. The FD magnitude measured at ASEC during the 23rd solar activity cycle ranges from about 1.5% to 20% in the secondary neutron flux, 1-15% in the charged low-energy particle flux and 0.6-6% in the >5 GeV muon flux. The modulation strength of the ICMEs is highly correlated with the speed and size of ICMEs, but not with its density.

Muon rate variations during some of the FDs of the 23rd solar cycle were registered by muon detectors DECOR, TEMP and URAGAN operating in the experimental complex NEVOD (MEPhI, Moscow, Barbashina et al., 2006). MEPhI data can path the gap between low energy charged particles and more than high energy muons (> 5 GeV) measured by ASEC. In Figure 10 we present the data on a FD, which occurred on May 15, 2005. Because MEFI group publish data corresponding to median energies of primary flux, we present ASEC data accordingly. In Figure 6 we see good agreement for data obtained by detectors located at different latitudes and altitudes. It is evidence that FD magnitude in the high energy muon flux measured on the Earth's surface is a global characteristic, approximately the same for different detector locations.

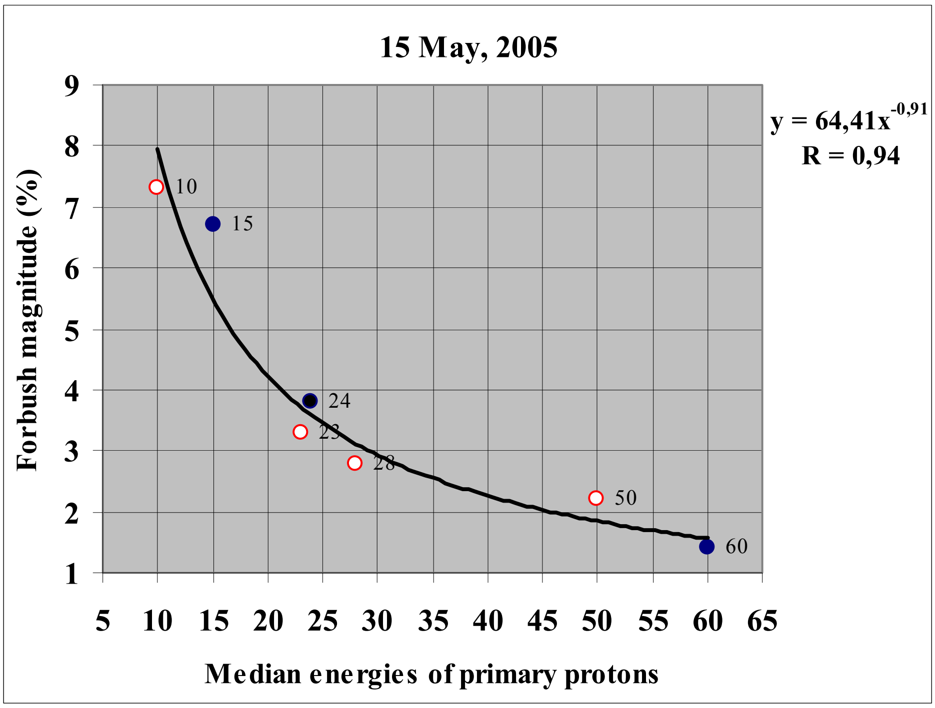

Figure 10 Observation of the FD on May 15, 2005 by MEPhI (for ASEC monitors we use medians of primary proton energy distributions). Open symbols – MEPHi data, close symbols – ASEC data.

5.3 Geomagnetic Effects

Our observations of another class of the Solar transient events, the Geomagnetic Effects (GME) demonstrates that the particle detector count rate increase occurs coherently (or up to one hour in advance) with the development of the Geomagnetic Storm (GMS).

We demonstrate that the ratio between the increases of neutron and charged fluxes is approximately constant in a large diapason of GMS severity. The neutron flux always undergoes larger changes comparing with the charged component. The difference in peak amplitude can be explained by the lower energy of the primary particles initiated neutrons comparing with primaries generated electrons and muons reaching the Earth's surface. Also we demonstrate that the main driver of GMS is a southward component of magnetic field of ICME (B_z).Thus, the information on the flux changes for different secondary particles help to "test" the Interplanetary Magnetic Field (IMF) and the magnetosphere for understanding of the level of disturbance and the specific mechanisms leading to cutoff rigidity reduction. Severe geomagnetic storms are known to be triggered by prolonged periods of negative Bz (when the later reconnects with the terrestrial magnetic field), thus the Dst index can be predicted from the solar wind and interplanetary magnetic field conditions. Cosmic Ray flux also change due to approaching ICMEs. Therefore, the changing fluxes of secondary cosmic rays measured at the Earth's surface can be used as proxies of ICME parameters when measurements at L1 Lagrange point are not feasible due to severe radiation storms.

Information on the simultaneous detection of GMS in neutral and charged fluxes gives clues on the disturbance of the IMF and the magnetosphere. The ratio between increases of neutral and charged fluxes is approximately constant in a large diapason of GMS severity and neutral flux always undergoes larger changes compared to the charged component. The maximal enhancement of the neutron flux during the GMS (the GME) was ~7.5% and the low energy charged particles ~3% during the 23rd solar cycle.

5.4 Colliding ICMEs

The most severe GMS of the 23rd cycle occurred on November 20, 2003 is well investigated and published in several papers (see for instance N. Gopalswamy et al., 2005 and V. Yurchyshyn et al., 2005). In both papers it is assumed that the immediate cause of ICME is the CME launched on November 18 at 08:50 UT. After abrupt jump of solar wind at B 7:28 on November 20, 2 hours the ACE spacecraft facilities detected fast changes of temperature, density and velocity of solar wind (transition of the ICME sheath). The time span from 10:00 until 24:00 characterized by the temperature decrease is treated as magnetic cloud passage (see Figure 1 in Gopalswamy et al., 2006).

Our approach to this event consists in assumption of 2 colliding ICMEs.

Table 1 Parameters of the fast CMEs unleashed on November 18, 2003 from ASR 501

Date	Time UT	Heliocoordinates	Angular depth (^{0})	CME velocity km/sec
18-11-2003	8:06	N01E19	>104	1223
18-11-2003	8:50	N02E18	360	1660
18-11-2003	9:50	S13E89	>197	1824

In Table 1 we can see that the first CME started at 8:06 with the initial speed of 1223 km/sec; the second CME launched after 44 minutes with an initial speed of 1660 km/sec. Both CMEs have approximately the same heliocoordinates, therefore the 08:50 CME is likely to collide with the 08:06 CME because both are from the same active region AR 501. The faster CME overtakes the first one after at a distance of ~ 17 R_{sun}. Third CME at 9:50 were from the eastern limb and could not interact with the central CMEs. If both ICME's are not mixed up and move together as a composite ICME with different magnetic structures at arrival to ACE spacecraft we expect to detect severe disturbance of IMF strength. Indeed, in Figure 11 we can see that B_z in the region (-49 - +36);in the same time B_y component of IMF abruptly decreases. We simultaneously detect pronounced (although not very large) jumps of solar wind velocity, density and temperature, see Figure 4). All these features indicate the complicated structure of arrived ICME.

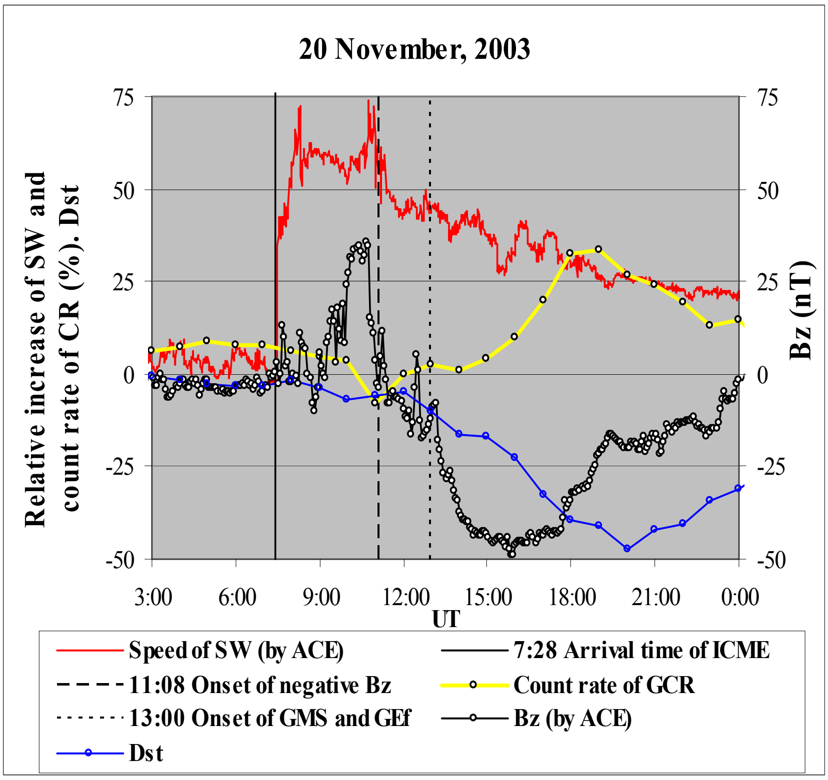

Figure 11. The time history of the disturbances of the major geomagnetic and Solar Wind parameters at arrival of the ICME to 1 AU on November 20, 2003. The CR count rate enhancement is multiplied by 5 to be noticeable relative SW speed changes. Dst values are divided by 10.

The collision of two ICMEs is rather complicated phenomena, depending on the polarity and orientation of the magnetic field of colliding ICMEs. We still lack observational information (unfortunately STEREO was launched too late) to form realistic models of ICME interactions. We have information only on the time history of the solar wind passage of L1 libration point where ACE and SOHO space stations are located. The existence of two ICMEs confirm the particle data: start of the Fd associated with the first ICME arrival (B_z oriented anti-southward) and after 6 hours arrives another ICME with B_z oriented southward triggers GME.

5.5 Classification of the Solar Transient events

Our studies of the particle time series variations during the 23rd solar activity cycle with particle detectors of the ASEC, confirm that the major modulation agent influences both particle fluxes and geomagnetic parameter is the Interplanetary Coronal Mass Ejection. Particle flux variations due to ICME arrival at 1 AU can be broadly distributed into 3 main categories:

1. Sudden, lasting few hours abrupt decrease of the particle detector count rate (Classical Forbush decrease, Fd);
2. Count rate increase (so called Geomagnetic Effect, GME), followed by decrease;
3. Count rate decrease analogical to described in point 1; followed by abrupt count rate increase (GME); producing a peak up to 5-6% (on middle latitudes) lasting 2-10 hours.

Detection of the parameters of Solar Wind at ACE and SOHO space stations allows connecting particle flux variations with ICME parameters. As a main trigger of magnetospheric disturbances is the southward component of the Interplanetary Magnetic Field (IMF), the causes of the mentioned three categories are as follows:

a. The magnetic field of ICME is randomly oriented at arrival to 1 AU (B_z is fast changing with mean value near zero);
b. B_z component of magnetic field of the ICME is oriented southward at arrival to 1 AU
c. Magnetic field of ICME has composite structure or rotates.

Count rate increases, mentioned in the points 2 and 3 strongly anti-correlate with DST index changes, i.e. with Geomagnetic Storm (GMS) severity.

26 transient solar events of 23rd solar activity cycle, i.e. abrupt changes of the particle detector count rates, allow the classification according to ICME characteristics:

- 16 ICMEs has southward orientation of the “frozen” magnetic field and arrival to 1 AU and simultaneously unleash GMS and increase of CR count rate due to decrease of the geomagnetic cutoff rigidity;

- 5 events, demonstrating increase of CR count rate after Forbush decrease were triggered by 2 consecutive ICMEs reaching 1 AU one after another with several hour delay.

- The orientation of the “frozen” magnetic field of the first ICME was anti-southward; the orientation of the second was southward.

- 2 events were triggered by the colliding ICMEs reaching 1 AU simultaneously as a composite space structure preserving initial magnetic field orientation. Again the orientation of the “frozen” magnetic field of the first part of the composite ICME was anti-southward; the orientation of the second part was southward.

- The rest 3 events are hard to analyze due to the absence of the observations.

In addition we can conclude that analyzed events support the hypothesis that colliding ICMEs form a composite structure moving with the same speed, but keeping own magnetic structures.

6. CRD Space Education Center

Artem Alikhanyan, whose 100-th anniversary was celebrated on July 9, 2008 at Nor Amberd station, was not only a brilliant scientist, but also an experienced educator. In early 60's when 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. Seasoned prominent and young new 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 the 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 annually organizes international symposia devoted to the 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. Participants got 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 *Fo*recasting 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

7.1 International Networks of particle detectors

Currently Aragats is a modern scientific center, equipped with key scientific equipment and necessary supporting infrastructure, which is constantly updated. Information on changing fluxes of secondary cosmic rays is distributed worldwide 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 Europian countries decided to form joint data base for 1-minute 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. The operation of all ASEC monitors will continue during the next five years, we plan to establish new experimental facilities at 1000 m a.s.l. at Yerevan campus of YerPhI and locate their new type of particle detectors now under construction. Establishing uninterruptable monitoring of almost all species of secondary cosmic ray will put ASEC on the first roles in the research of Solar physics, Space Weather and Solar –terrestrial connections.

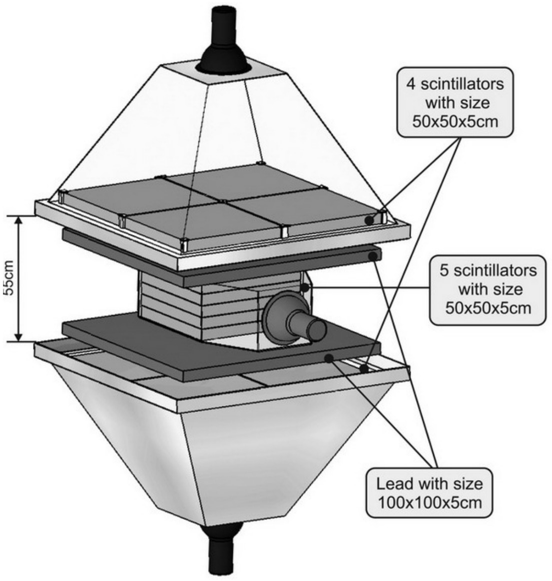

Figure 12 Layout of the basic model of SEVAN network

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) activities. SEVAN

Network aims to improve the fundamental research on particle acceleration in the vicinity of the sun and 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 operate 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 Figure 12) is assembled from standard slabs of 50x50x5cm^3 plastic scintillators. Between two identical assemblies of 100 x 100 x 5 cm^3 scintillators (four standard slabs) are located two 100 x 100 x 5 cm^3 lead absorbers and thick 50 x 50 x 25 cm^3 scintillator assembly (5 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 25cm plastic scintillator and produce protons and other charged particles. In the upper 5cm thick scintillator charged particles are registered very effectively; however for the nuclear interactions of neutral particles there is not enough substance. When a neutral particle traverses the top thin (5cm) 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 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 the existing neutron monitor and muon telescope world-wide networks.

7.2 Research of the Galactic cosmic Rays

A new trend in astrophysics research is the observation of celestial objects in several wavelengths simultaneously (e.g. in radio, optical, X-ray, and gamma rays). The 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} eV to 10^{17} eV has been well explored during the 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-Sough observatory started to present valuable data, to be confirmed in the next decade by an expected large volume of data.

This picture contains 2 obvious gaps in satisfactorily well established spectra: 10^{13} - 10^{14} eV; and 10^{17} - 10^{19} eV. If the first gap can be filled with planned long-duration balloon flight and experiments on the Space Station, the second can be filled by the several square kilometre size particle arrays.

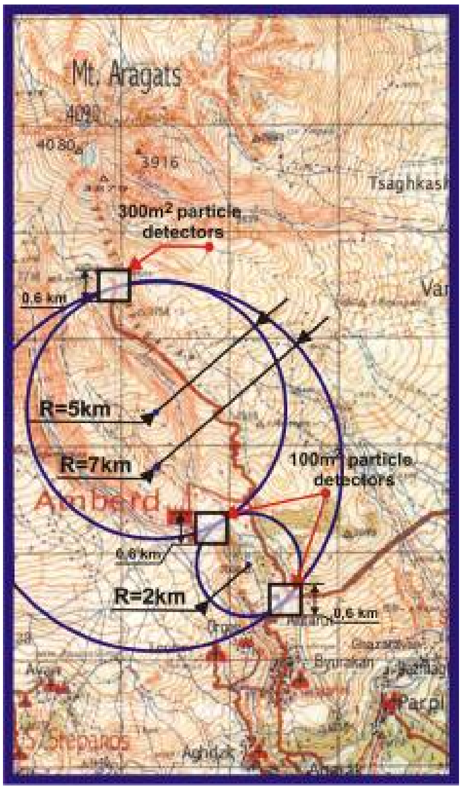

Figure 13 New ANI EAS array is planned to be installed on the slopes of Mt. Aragats

Recently CRD physicist started to prepare a 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 the investigation of the mentioned energy region, using the 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 problem is the 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 10^{18} eV energy will produce $6 \cdot 10^{8}$ 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 Figure 13).

Project objectives include:

- *Development of a new-generation particle detector for measuring neutral and charged CR fluxes and their directions;*
- *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;*
- *Correlating obtained results with data from X-ray and γ-ray observatories, as well as from optical telescopes.*

Two networks of particle detectors will be formed around the central part of ~ 20 m^2 hybrid particle detectors (see figure 8). Each array will be populated 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 3 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 km^2 and 75 km^2 correspondingly for 2 and 5 km radii circles.

Basic detectors tests and deployments will start in 2008; with appropriate funding in 2011 new EAS detector will be equipped with sufficient 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 located. No operating or planned surface array is intended to cover this very important and large energy domain: the KASCADE energy limit is ~10^{18} eV, the energy range of HighRes and Auger are started from $5 \cdot 10^{18}$ eV. Therefore the proposed detector will provide unique information extending the already well investigated low energy domain with the enigmatic highest energy domain.

Before constructing the ANI-NEW detector the GAMMA array remains the basic facility for the galactic cosmic ray research. GAMMA will continue operation investigating fine structure of the partial energy spectra after the "proton knee". GAMMA also will search the showers initiated by primary gammas (so called muon poor showers) to measure diffuse flux and maybe explore point sources of high energy gamma quanta.

7.3 Magnetometric measurements on Aragats.

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 in the ground the best instrument is the magnetotelluric station LEMI-417, produced by the Lviv Space research center, which was specially developed for the long-term monitoring of these signals with reasonable error.

Our observations of the GMS occurred during the 23rd Solar activity cycle demonstrate that Cosmic Ray increase during GMS occurs coherently (or ~ 1 hour in advance) with abrupt changes of the geomagnetic field, sized up by Dst index.

To test geomagnetic disturbances models and provide a valuable user-oriented forecast, it is not sufficient to have only global geomagnetic indices. Several studies demonstrate that local geomagnetic indices are better correlated with consequences of severe GMS. Unfortunately, in the radius of 1000 km. there are no permanently operating geomagnetic observatories or magneto-telluric stations on mt. Aragats. Therefore, to develope our studies of solar transient events and to establish reliable alert services we need to equip ASEC with modern facilities allowing precise measurements of geomagnetic and electric fields at ASEC monitors location. The installation of the magnetometric center at Aragats is planned in Summer 2009, first measurements are planned in fall of 2009.

7.4 Radio bursts monitoring

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 register radio signals from the sun to warn that it is generating a radiation storm which will hit us soon. In collaboration with Hartmut Gemmeke from research center Karlsruhe, we started measurements of radio-noise on slopes of Aragats to select the best place to install a network of radio antennas for solar burst monitoring.

7.5 Research of the atmospheric electricity

The short-and long-term cosmic ray influences on terrestrial weather are a commonly accepted idea currently tested for the several meteorological phenomena. However, physical links that connected CR intensity and frequency of rains have not been yet put on firm basis. An interesting example is the bombardment of the terrestrial atmosphere by solar cosmic rays. The cosmic rays and the secondary particles ionize enough of the atmosphere to disturb the entire planetary current ring systems; seem there are correlations between cosmic rays and thunderstorm activities. A mechanism proposed in (Gurevich et al., 1992) suggests that large showers of energetic particles produced by high-energy cosmic rays in the terrestrial atmosphere might provide a conductive path that initiates lightning. Alike a spark chamber, a very large voltage is applied across a small gap filled with gas to cause discharge following the path of elementary particle. On the other hand, the cases of thunderstorms and lightning are slightly different. Unlike the spark chamber, the electric fields inside the thunderstorm do not appear to be big enough to initiate a spark, so in order to operate Gurevich's mechanism, he had to suppose that there were many charged particles passing through the storm at once. As cosmic-ray air showers do not produce enough particles alone, Gurevich postulated that the thunderstorm gave the cosmic-ray shower a boost by increasing the number of energetic electrons through an exotic process called "runaway breakdown."

"Runaway breakdown"— is a theoretical process in which the liberated electron ionizes nearby air molecules. These molecules become accelerated in the very high electric fields inside a thundercloud, which can reach up to ten million volts in strength. A group of fast electrons is then formed, which can emit gamma rays as they are gradually slowed down by contact with surrounding air molecules. In such cases, the electrons will "run away," gaining very large amounts of energy. As the runaway electrons collide with air molecules, they generate other runaway electrons plus x-rays and gamma rays, resulting in an avalanche of high-energy particles. According to the Gurevich model, this conductive path is what causes lightning (see details in Dwyer, 2005).

Runaway breakdown can create large amounts of high-energy electrons, as well as x-rays and gamma rays. Interestingly, we know that runaway breakdown works for the low electric fields already seen inside thunderstorms. We also know that sometimes does happen right before lightning, because we can see big bursts of x-rays and gamma rays shooting out of thunderstorms. In fact, these gamma rays are so energetic and so bright that they have been observed from outer space, 600 kilometers above the Earth's surface.

The Monte Carlo transport calculations of the cosmic-ray muons and associated particles (e.g. knock-on electrons and bremsstrahlung photons) in thunderstorm electric fields, using GEANT4 code indicate that the production of energetic electrons by cosmic ray muons play an important role in the enhancement of electron and photon fluxes in thunderstorm electric fields. Muons form a large part of the secondary cosmic-rays directly reach the regions of strong electric fields owing to their high penetrability in the atmosphere. Therefore, they can serve as the source of a considerable amount of runaway electrons, through their ionization process with air molecules, and their decay into energetic electrons. The electron and photon fluxes show notable increases in the strong electric field, while the muon flux does not fluctuate significantly. From the calculation results, authors of (Torii et al., 2004) estimate that the irradiation of muon beams rapidly increases energy deposition in the region of strong electric fields, and produce numerous electron - ion pairs. These productions may induce the lightning discharge by the runaway breakdown process (Gurevich et al., 1992).

It is very important to find correlations between runaway breakdown and lightning; thunderclouds may be a natural particle accelerator and could provide a nearby hidden prototype for other energetic cosmic accelerators.

In experiments at Baksan cosmic ray station of the Institute of Nuclear Physics of Russian academy of sciences the spectrum of cosmic rays measure continuously along with precise measurements of the electric field and monitoring of thunderstorms. Characteristic enhancements of soft cosmic rays (below 30 MeV) and hard cosmic rays (30-90 MeV) were studied. The detected enhancements of the soft component of cosmic rays are interpreted as runaway electrons. Events with fast exponential increase of intensity are interpreted as a feedback effect for runaway particles. It was shown that the critical field and particle energy for this process are 300 kV/m and 10 MeV, respectively (Khaerdinov et al., 2005).

In the time series of the ASEC monitor count rates in May – June 2008 were detected few count rate enhancements possibly connected with thunderstorm activity. The most significant one was recorded on May 4, 2008. The count rate enhancement was observed by all ASEC detectors measuring low energy charged particles of secondary cosmic rays. The shape of the enhancement was the same for ASNT (a colorimetric device measuring charged particle energy in the interval 5-120 MeV with accuracy ~5 MeV) and for particle detectors of Aragats Multichannel Muon Monitor (low energy particles; detectors on the surface), located on 700 m. distance from ASNT.

After locating the enhancement and proving that it is not an artifact due to failure of one detector we examine this event in more details. The 4% constant enhancement last ~10 minutes followed by the abrupt peak and recovery lasting another 15 minutes. The peak enhancement was ~12%; the accuracy of ASNT is ~0.6%, therefore the peak enhancement corresponds to 20 standard deviations!
The energy spectra of enhancement (runaway electrons & photons) fit rather well by the exponential function. In this way we prove that ASNT has a unique possibility to measure not only the enhancement due to thunderstorm activities, but also energy spectra of the additional particles. This advanced possibilities to detect thunderstorm-cosmic ray correlations provide a possibility to quantitatively compare predictions of Gurevich’s theory and experimental data. However, additional work is needed to confirm our findings:

- Detect thunderstorms with detailed time history;
- Install a precise detector to measure electrical field on the Earth's surface to locate in time the exact thunderstorm discharge time.
- Perform monitoring in different radio frequencies for multivariate evidence of thunderstorm evolution.

7.6 Scientific instrumentation

Several new particle detectors for ASEC were designed and now are under testing in experimental physics labs of CRD. A scintillation electromagnetic calorimeter is a universal detector for measuring energy of horizontal muons by the counting of the energy release (energy of electron-positron pairs born in lead filter). The accessed primary energies range will be enormously large, of course for a price of very weak flux at highest energies. It Table 1 we post the intensities and count rates of the near-horizontal muon flux and correspondent energy deposit in the ten-layer detector (Ivanov, 2008). As we can see in Table 1 the expected count rate of > 5 GeV muons (this energy is definitely higher than the threshold energy of detector) for 1-hour (~$1.3 \bullet 10^4$), is rather large and we can perform time-series analysis both for diurnal variation research and for observing precursors of upcoming geomagnetic storms. Furthermore, we can establish the upper threshold of the solar cosmic Ray (SCR) spectra for strongest radiation storms.

Table 2: Expected intensities of the horizontal muon flux and corresponding medians of energy releases in the calorimeter layers (zenith angles range 45° - 90°)

E_μ	$I_\mu (m^2 \cdot h \cdot sr)^{-1}$	**Median of the energy deposits in scint. layers**
≥ 550 MeV	**$1.77\ 10^4$**	**1.9 MeV**
≥ 5.0 GeV	**$1.3\ 10^4$**	**2.4 MeV**
≥ 50 GeV	**$2.16\ 10^3$**	**2.7 MeV**
≥ 500 GeV	**$1.08\ 10^2$**	**4.2 MeV**
≥ 1.0 TeV	**14.4**	**5.6 MeV**
≥ 2.0 TeV	**2.52**	**8.2 MeV**
≥ 5.0 TeV	**0.36**	**17 MeV**
≥ 10 TeV	**$7.2\ 10^{-2}$**	**30 MeV**

Horizontal Electromagnetic Calorimeter (HEC, Figure 14) consists of ten 1 m^2 area and 1cm thick plastic scintillators with fiber readout. Scintillators are interlayer by 1.5 cm. thick lead filters; with total thickness of 170 g/cm^2. The minimal ionizing particle (mip) energy to generate signal in 1 cm. scintillator is 2.1 MeV (Reymers, 2008) and minimal muon energy to traverse whole detector is 210 MeV.

HEC acceptance corresponds to zenith angle range of 45°- 90°, to reduce acceptance of detector down to 80°- 90°, we put additional scintillaor at distance of 8 m. from HEC. This additional scintillator also can select unidirectional muons by applying time-of-flight technique. To suppress shower event we use as VETO (rejecting trigger) signal from the same type detector placed horizontally above HEC. The PM signals are digitized by the LeCroy ADC2249 with discrimination of 1 mV.

Figure 14. Setup of Horizontal Electromagnetic Calorimeter (HEC)

For HEC we use *molded polystyrene* scintillation detectors designed and fabricated in the Institute for High Energy Physics (IHEP) in Protvino, Russian Federation (Britvich, 2002, Chubenko, 2007). As an active medium are used molded polystyrene scintillation plates of the SC-301 type produced in IHEP; lateral sizes 20x20 cm^2, thickness 0.5 cm^2, light output about 60% of that of anthracene, maximum of luminescent spectrum around the wavelength 420 nm and the mean emission time t=2.3 ns (Britvich,2002). Producer guarantees registration efficiency of a relativistic charged particle of 95% or better; high homogeneity of light collection (in the limits of +-12%) independent of the position of particle's trajectory (Ampilogov et al., 2007); stability for long time operation. RMSE of the mode of energy deposit distribution from single charged particles should be no worse than 2%.

To improve the efficiency of neutron detection and reduce γ-quanta contamination new module of SEVAN world-wide network of hybrid particle detectors (Chilingarian &

Reymers, 2008, Chilingarian et al, 2009) is under testing at CRD.The prototype detector consists of 4 plastic scintillators interlayered by three 1.5 thick lead filters stacked vertically; total thickness of lead is 51 g/cm^2. MIP energy to be detected in one scintillator is 2.1 MeV and particles with energies greater than 65 MeV can intersect the detector. In Figure 15 we present the picture of the detector.

Figure 15 ***4-fold scintillator Detector assembly***

Signals from 2 middle scintillators were used as a trigger of detector, the coincidence of which opens the gate for pulse analyzer. The PM pulses within gate are converted to code and stored. Due to high level of noise, we cannot trigger detector by the signal from one scintillator only. Therefore, we cannot use 1 cm. thick detectors as standalone devices; instead of testing all 16 possible detector states (all 15 combinations of signal and absence of signal in 4 scintillators; sure, we did not consider 0000 combination), the given trigger allows only three combinations: 1111; 1110 and 0111.

Test operation of the Horizontal Electromagnetic Calorimeter (HEC) with new type of scintillators allows to investigate its operational characteristics. The hourly count rates are rather stable, thus providing possibility to investigate transient solar events and overall solar-terrestrial connections in the energy range much higher comparing with the ones available at the existent networks of particle detectors measuring neutrons and muons of the secondary cosmic rays.

In the 4-fold vertically stacked detector setup due to high level of noise, only 2-fold coincidence trigger is implemented and corresponding possible configurations of signals from 4-layeres were studied. Further work is needed to determine characteristics of 4-fold scintillator setup, to investigate efficiency of detection of electrons, muons, gammas and neutrons and contaminations of selected events. A new order to High Energy Physics (IHEP) in Protvino, Russian Federation is prepared for 3 cm. thick scintillators with improved signal-to-noise characteristics, allowing operation of the detector in the single detector triggering mode.

7.7 Measuring high energy muon flux in the Low-background laboratory of YerPhI

The Laboratory is located at the depth of 660 m w.e. in Yerevan salt mine. The natural background in salt mines is exceptionally low (in harder rock the background is higher by several order of magnitude). The natural conditions in the mine (the humidity is about 35%, temperature 20-21 C) are very convenient both for people and electronic devices.
In parallel of ongoing research performed by Experimental physics division we suggest to start measurements of the flux of high energy muons by scintillator detectors. It will not only add valuable information to ASEC monitors accessing highest primary energies, but additionally give information on the temperature in the troposphere and other interesting atmospheric and magnetospheric phenomena.

7.8 Monitoring of the radiation doze on the spacecrafts

The method of the controlled nuclear emulsions (Akopova, 2005) developed by Aida Akopova and YerPhI colleges found wide recognition in space science. Numerous spacecrafts carry tiny containers with emulsion, that precisely measure neutron and ion flux incident the spacecraft. Several ongoing international projects expose the emulsion on orbit and the emulsion development and treating is carried out in YerPhI.

7.9 Reestablishment of the Cherenkov Atmospheric Telescope group

YerPhI played a leading role in introducing Atmospheric Cherennkov Telescope in Europe. First HEGRA system, HESS telescope system, then MAGIC (now stereoscopic) are the most fruitful European collaborations. Armenian physicists actively participate in the construction of all ACTs, and are employees of several European institutions where they keep leading positions in analysis and physical inference. Unfortunately, after scientists and engineers of F.Aharonian's group leaved YerPhI, the activity of the institute significantly diminished. YerPhI participated in electronics design and commissionings for MAGIC, in mirror fabrication for HESS, and simulations. However, YerPhI physicists did not participate in the shifts and in analysis of the new crucial observations of both ACTs. To prevent final fading of YerPhI activity in ACT field the institute (Cosmic Ray and Experimental Physics Divisions) should reestablish the ACT group, having in mind also participation in the starting Cherenkov Telescope Array (CTA) European project.

8. *Cosmic Ray Division of the Yerevan Physics Institute*

History, status and development 2009-2014; Summary:

In 1942 Alikhanyan brothers initiated the first expedition to Aragats. Since then, expeditions on Aragats have continued uninterruptedly, despite the World War II, insufficient funding, and electricity and fuel shortages during the recent history of Armenia. The most important dates and achievements of Cosmic Ray research at Aragats can be itemized as follows:

- 1942 – The first expedition to Aragats
- 1943 – Establishment of the Physical-mathematical Institute of Yerevan State University; now Yerevan Physics Institute after Artem Alikanyan;
- 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: measuring 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);
- 1989-1992 – 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 the intensive solar modulation effects in September – November in the low energy charged particle, neutron and high energy muon fluxes;
- 2004 – First publishing 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>20GeV);
- 2007 - Starting of SEVAN (Space Environmental Viewing and Analysis Network - a new type of world-wide network of particle detectors for monitoring of geophysical parameters
- 2008 - Multivariate analysis and classification of the solar transient events (Ground level enhancements, Geomagnetic effects, Forbush decreases) detected by ASEC monitors during 23rd solar activity cycle.

Now the Cosmic Ray Division of Yerevan Physics Institute 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 in search for new methods and new frontiers as the Armenian physicists do their best in the quest of solving the mysteries of the Universe.

CRD funding comprises from international scientific foundations; funding of Republic of Armenia and support from the US diaspora (NFSAT project). The annual budget rose 3 times during the last 10 years and in 2008 approached K600$. Broad scientific collaborations, winning of international grants and current achievements of the CRD scientists make hopeful that this rise will continue in coming years.

CRD is now world leader in the surface monitoring of the secondary cosmic rays. Numerous particle detectors measuring charged and neutral fluxes are operating on 3 levels (100, 222 and 3200 above sea level) and provide scientific community with unique data.

Measuring as many as possible of secondary fluxes with various energy thresholds, CRD physicists access wide spectrum of primary energies incident on the Earth's atmosphere and can research the solar modulation effects with unprecedented accuracy. Among scientific topics to be addressed in coming years, coinciding with rise of solar activity of the 24th cycle are:

1. Detection of the highest energy solar cosmic rays; research of the acceleration mechanisms and propagation in the interplanetary space;

2. Measurements of the geomagnetic effects; research of the interaction of Interplanetary Coronal Mass Ejections with magnetosphere; investigation of geomagnetic storms and interplanetary magnetic field.
3. Multiple correlation analysis of the flare, CME, geo-parameters; identification and explanation of the nontrivial correlations; forming of the model of violent solar event in progress.
4. Establishment of reliable and timely forewarning services of space storms.
5. Research of atmospheric electricity and mechanisms of the thunderstorms.

Above goals will be reached by 24 hour, all year operation of the ASEC monitors, by actively participating in the international measuring networks, by enlarging SEVAN network to new countries, by establishing on Aragats a magnetometric center, by designing and assembling new particle detectors and new data analysis methods.

New detectors and new experimental labs for secondary flux monitoring will be established in the campus of Yerevan Physics Institute in Yerevan to measure and compare changing particle fluxes on 3 altitudes.

Research of the Galactic Cosmic Rays after the “knee” will be continued with GAMMA detector to research fine structure of spectra and to investigate possibility to detect and resolve showers from gamma-quanta.

If appropriate international funding will be available we’ll start preparation for the ANI-new experiment in the energy ranges $10^{16} – 10^{19}$ eV: perform detailed simulation of the shower propagation in the atmosphere and detector response. The design of detectors will be finalized, orders assigned and prototype array commissioned.

In the Low-background laboratory of YerPhI jointly with Experimental Physics Division we plan to start monitoring the flux of the high energy muons.

CRD will continue international collaboration in measuring radiation doze on the Space station and other spacecrafts using the methodology of controlled emulsion developed in Yerevan Physics Institute.

The YerPhI ACT group will be re-established to actively participate in construction of the new large telescope of HESS collaboration, in MAGIC, and in the new established CTA project (jointly with Experimental Physics Division).

We plan to repair offices and teaching labs in 2009; purchase detectors, measuring devices, networking and computer equipment.

The Space Education center will operate for the Yerevan State University undergraduate students; in 2009 we plan a Summer school at Aragts with ~10 participants and an international conference in Nor Amberd with ~35 participants.

In 2009 we also plan to continue education of 2 PhD students, 2 master students and 3 undergraduate students.

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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