ANNEX I

Work Plan

I. Summary Project Information

1. Project Title

Full title of the project: Space Weather Research and Forecasting by Networks of Hybrid Particle Detectors measuring neutral and charged fluxes

2. Project Manager

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3. Participating Institutions

3.1. Leading Institution

Short reference: YerPhI	
Full name: Yerevan Physics Institute after A.I.Alikhanyan	
Street address: Alikhanyan Brothers 2	
City: Yerevan	**Region:**
ZIP: 000036	**Country:** Armenia
Name of Signature Authority: Sargis Taroian	
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Tel.: 3741-341500	**Fax:** 3741-350030
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Governmental Agency: Ministry of Trade and Economical Development	

4. Foreign Collaborators/Partners

4.1. Collaborators

Institution: Forschungszentrum Karlsruhe, Institute for Data Processing and Electronics	
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4.3. Collaborators

Institution: Space Environmental Center, NOAA, USA.	
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4.4. Collaborators

Institution: School of Physics and Astronomy, University of Leeds, UK	
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5. Project Duration

36 months

6. Project Location and Equipment

Institution	Location, Facilities and Equipment
Leading Institution	Yerevan Physics Institute, 2 Alikhanian Brothers, Yerevan, Armenia, Administrative building, offices 101, 102, 116,117,118,119,205,206,207,302, 303,307,311, 312a, 312b,313,31,315,316,317,320 and 2 small buildings nearby. Aragats and Nor-Amberd research stations with all buildings and infrastructure, Aragazotn district, Armenia Particle detectors of the Aragats Space-Environmental Center, Computer Center of the CRD, YerPhI
Participant Institution 1	

II. Specific information

1. Introduction and Overview

European COST-724 action participants agree on the following definition of the newly emerging scientific topic: *"Space Weather (SW) is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modeling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and now-casting the possible impacts on biological and technological systems".* Enlarging human Space activities through scientific research in space and through developing space based technologies is acknowledged as strategic to the scientific and industrial development. Space platforms play a leading role in Earth, Universe, Environmental, Physical and Life sciences as a privileged observation points for our planet and objects of the universe in synergy with ground observations, data analysis and modeling tools and research in laboratories (EU FP 7 programme, 2006).

Space based facilities record the topography, movement of the oceans and atmosphere, and distribution of life on planet. The satellites are indispensable for tracking the Earth's environment, uncovering meteorological phenomena, predicting disasters, improving medical/welfare services and education and traffic systems (JAXA vision, 2007)

The infrastructure and the activities of our modern, technology-based society can be adversely affected by rapid magnetic field variations driven by the dynamic processes in the near-Earth space environment. This is particularly true during so-called 'geomagnetic storms', when radio communication can be difficult or impossible, global-positioning systems (GPS) can be affected, satellite electronics can be damaged, satellite drag can be enhanced, astronaut and high-altitude pilots can be subjected to increased levels of radiation, pipe-line corrosion can be enhanced, and electric-power grids can experience voltage surges which cause blackouts (Canadian National Geomagnetism program).

It is a well-recognized need to improve *the forecast and prediction of dangerous consequences of Space Weather (SW)* by facilities on board of satellites and space stations and networks of the surface based measuring system. Many risks could be mitigated or avoided if reliable space weather forecasts were operational and reliable, quantitative models were available to system designers. We now have the scientific knowledge and the technical skills to move forward to improve space weather understanding, forecasts, and services dramatically and to meet customer needs (USA National Space Weather Strategic Plan).

In line with planned planetary manned missions and further technological expansion of humanity in Space and as novel particle detectors and scientific methods are reaching technical maturity (see for example Chilingarian & Reymers, 2007c), new SW service capabilities become feasible. Therefore, the *main project goal is to create an operational and reliable Space Weather forecasting service* by integrating surface and space-borne data and by developing better models of the Space Weather drivers.

A comprehensive interplanetary cosmic ray monitoring network, using space-borne and surface particle detectors is needed for the delivery and sustainability of Space Weather services. Although satellite spectrometers provide precise and globally available data on low energy particle fluxes, information from the surface particle detectors on highest energy cosmic rays is an unique and necessary element of Space Weather forecast service.

Established in 2000, the Aragats Space Environmental Center (ASEC) (Chilingarian et al., 2003a, 2005) is the world's largest center for monitoring of the secondary particle fluxes. ASEC facilities measure and estimate intensities and important parameters of the following particle fluxes:

- neutral and charged particle fluxes at 1000, 2000 and 3200 m a.s.l., from a large solid angle ;
- highest energy solar primaries incident on earth atmosphere;
- correlations of different particle fluxes;
- energy deposits in particle detectors, allowing estimates of particle energies;
- special physical events, selected by programmable software triggers.

ASEC is a unique combination of large area of particle detectors providing real-time data from many measuring channels, from different directions with good temporal resolution and, thanks to the high altitude, also with high statistical accuracy. ASEC already returned results on relation of the changing intensities of the cosmic ray fluxes with Space Weather effects. ASEC launched a test service of alerts for violent radiation storms, recorded by abrupt enhancements of count rates in ASEC monitors (Gevorgyan et al., 2006). Several scientific centers are now operating Space Weather portals based on surface particle detector data (Kuwabara et al., 2006, Mavromichalaki et al., 2005, 2006), some of them include ASEC data in the surveys.

Pre-operational information on Space weather products from ASEC was gained from a large variety of Space storms which occurred in the 23rd solar activity cycle (1996 – 2007). ASEC monitors registered almost all severe events of the 23rd solar cycle and report them widely to the scientific community (Proceedings of ICRC, Puna, India, 2005, Proceedings of Solar Extreme Events (SEE) -2005, Nor Amberd, 2005, Proceedings of COSPAR congress, China 2006).

In the frameworks of the new ISTC project new facilities will be installed at 1000 m a.s.l. at the location of the Alikhanian Physics Institute (API). The network of hybrid particle detectors will be expanded in Armenia and worldwide; via new electronics and advanced data analysis systems we will achieve integration of terrestrial and space systems on one Space Weather portal. The last, but not least goal of the project will be the validation of Space Weather services and products.

During the last 10 years at CRD brand new scientific and technical infrastructure was developed, including new particle detectors, modern electronics, powerful computers and networking, advanced data acquisition (DAQ) and data integrating systems, uninterruptable power supply, teaching laboratories and others. More than 50 scientific papers have been published in referred journals and ~100 reports were presented at International scientific forums and on meetings of the managing committee of the COST 724 action.

CRD experts have provided teaching and education for undergraduate, master and PhD students of the Yerevan State University (YSU), including courses on High Energy Astrophysics, Cosmic Rays, Modeling of Physical process and modern Electronics. 3 PhD theses and more than 50 undergraduate and graduated theses were defended. CRD has now adopted the western scheme of employing undergraduate and graduate students in research. Scientific cooperation with European, Japanese and American scientists is organized via joint research projects, scientific visits and participation in conferences.

2. Expected Results and Their Application

In accordance with the stages of development the expected results are as follows:

2.1.1. Results to be promoted

Scientific results on particle acceleration in solar flares and by shock waves in solar corona, and on Space Weather drivers.

Operational Space Weather forecasting services to provide following certified information products :

- 1 minute time series of fluxes of different species of secondary cosmic rays with different energy thresholds and directions of incidence;
- Ground Level Enhancement (GLE) Alerts;
- Estimate of the SCR energy spectra;
- Estimate of the total fluency of Solar Energetic Particle (SEP) events;
- Estimate of the expected strength of the upcoming Gemagnetic Storm (GMS) (in units of K_p and DST);
- Estimate of start time of the GMS.

2.1.2. Uniqueness of results

To establish reliable and timely forecasting service at the *Aragats Space Environmental Center (ASEC)* we need to measure, simulate and compare:

- time series of neutrons, the low energy charged component (mostly electrons and muons) and the high energy muons;
- the correlations between changing fluxes of various secondary particles; and
- the direction of the detected solar cosmic rays.

Only ASEC surface monitors located at the ASEC at 2000 and 3200 m altitudes (40˚25′N, 44˚15′E; Vertical cut-off rigidity in 2007: 7.1 GV) can provide the required information. ASEC monitors detect the charged and neutral components of the secondary cosmic rays with different energy thresholds and various angles of incidence. ASEC monitors reliably detect the highest-energy CRs due to its unique geographical location and variety of operating particle detectors. Space Weather information products delivered by Aragats Space Environmental Center (ASEC) will complement the plans for new NASA satellites for SW research. NASA/NOAA plan to use the 24^{th} solar activity cycle (2008-2017) for developing and tuning of highly-accurate SW forecasting services (comparable with accuracy of the meteorology). ASEC's products will provide complementary information and will be an important element of planetary SW services.

A huge advantage of ASEC is its long-term stability, 24 hours coverage and multi-year operation. In contrast the planned life of the satellites and space stations is a few years only (STEREO – 2 years), they are affected by the same solar blast that they should alert, and space-born facilities instead of sending warning are put into the stand-by mode.

2.1.3. Demand for results

Total losses due to major radiation and geomagnetic storms could reach multibillion dollar levels. National programs on the Space Weather forecasting (USA, Canadian, Japanese, EU) are aimed to improve *the forecast and prediction of dangerous consequences of Space Weather* by facilities on board of a fleet of satellites and space stations and networks of the surface based measuring systems. Many risks could be mitigated or avoided if reliable space weather forecasts were available. Results and services to be developed within the proposed project along with services planned with data from space-borne facilities will significantly improve reliability and timeliness of Space Weather forecasting.

2.1.4. Expected income

Subscription fee for SW services, consulting and other benefits may reach 200,000 USD annually

2.1.5. IPR situation

Intellectual property rights on results to be developed in the framework of the proposed project will belong to the project team and will follow ISTC rules and regulations.

2.1.6. Additional developments

We plan to develop world-wide network of particle detectors of new type to be installed in Croatia, Bulgaria, Costa Rica and India.

2.1.7. Plan of implementation

The business scheme will be tuned according to activity of the "major national players" in the field: NASA, NOAA, JAXA, ESA. Products and services developed in the project will form an essential part of the planetary space weather forecasting service to be established in coming years. All services will share same marketing scheme and will be offered to user in one package.

2.1.8. Additional licenses or permits

Not needed

2.1.9. Business network

We are part of the world-wide networks of particle detectors aimed to prepare SW forecasting,. We establish working relations with agencies and institutions providing space weather forecasting. Collaborators of project are key persons of Space Weather services world-wide.

3. Meeting ISTC Goals and Objectives

- Supporting the applied, fundamental research and theoretical elaboration for their future usage in the national economy;
- Integrating of the scientists previously working for the military into international scientific association;
- Creating new possibilities for active scientific and business contacts with foreign specialists;
- Assisting in solution of the international problem of Space Operation safety.

4. Scope of Activities

Task 1

Develop and maintain Space Weather monitoring scientific and technical infrastructure.

Task description and main milestones	Participating Institutions
Task 1.1 Detailed measurements of the main parameters of particle detectors. 24 hour, whole year monitoring of the secondary cosmic rays by networks of particle detectors. Providing data to world-wide networks and partners in real time. Calculate and deliver of the Space Weather products. Task 1.2 Maintain and modernize scientific and technical infrastructure of the particle detector networks and sites at Aragats mountain and in Yerevan. Develop and install new networking and data analysis software. Establish new file-servers and precise timing servers for local DAQ computer networks .Purchase and install new more reliable radio-modems and antennas. Task 1.3 Develop Space Weather portal and its mirrors for presenting information Space Weather products as well as outreach and education information. Register and classify the Space Weather events. Compare ASEC observations with data from world-wide networks and space-born facilities.	1-YerPhI 2- 3-

Description of deliverables	
1	Space Weather products. Space Weather portal.
2	Reports and journal publications.

Task 2

Building particle detectors network

Task description and main milestones	Participating Institutions
Task 2.1 Purchase, develop and test new advanced particle detectors. Purchase and install precise devices for magnetic and electric field measurements. Organize magnetotelluric station at Aragats. Task 2.2 Installing and test advanced electronics developed in the previous ISTC project. Design and commission of new modernized Data Acquisition (DAQ) electronics for systems of particle detectors. Build particle detectors network in Nor Amberd and in Yerevan. Establish nodes of SEVAN network worldwide. Task 2.3 Prepare proposal of particle detector surface array at Nor Amberd for detecting galactic cosmic rays in the energy range 10^{17} - 10^{19} eV. Design, commission and test new particle detectors, fast timing system and networks of microwave antennas.	1-YerPhI 2- 3-

Description of deliverables	
1	Particle detector networks, DAQ and network electronics.
2	Reports, proposals, journal publications.

Task 3

Development of Neural Network models for forecasting and estimating the severity of Space Storms

Task description and main milestones	Participating Institutions
Task 3.1 Prepare integrated data base of solar events, including parameters of flare, coronal mass ejection (CME), Solar Wind, Interplanetary Magnetic Field (IMF) and geophysical parameters. Select of the best combination of variables for prognosis of severity of upcoming space storms. Task 3.2 Develop Bayesian statistical models and Neural Net models for the forecasting and estimating severity of Space Storms. Train the Neural Network models on data bases including all relevant data on solar events. Task 3.3 Develop and test Space Weather forecasting methods. Design and implement automatic systems of issuing alerts and warnings. Design and install new integrated data transfer, storage and analysis software.	1-YerPhI 2- 3-

Description of deliverables	
1	Data bases, Algorithms for issuing Space Weather alerts. Networking software.
2	Publications, reports

5. Role of Foreign Collaborators/Partners

- Providing of the comments to the technical reports and SW design;
- Support in development of technical equipment;
- Joint publications in field of Solar Physics and Particle Physics Instrumentation;
- Crosschecks of developed methods and their implementation to the data from solar neutron telescopes, neutron monitors and RHESSI spectrometers;
- Providing contacts with NOAA, ESA and NASA.

6. Technical Approach and Methodology

Hybrid particle detectors measuring neutral and charged particle fluxes

The changes of the intensities of high energy particles in vicinity of earth can provide highly cost-effective information on the key characteristics of the interplanetary disturbances (ICMEs). Because cosmic rays are fast and have large scattering mean free paths in the solar wind, this information travels rapidly and may prove useful for space weather forecasting (Leerungnavarat et al., 2003). Size and occurrence of southward B_z in an ICME are correlated with the modulation effects ICME poses on the ambient population of the galactic cosmic rays during its propagation up to 1 AU. In a statistical study (Kudela & Storini, 2006) the relation of CR variability/anisotropy with the geospace disturbances was investigated. It was demonstrated that the parameters of changing CR time series are potentially useful for the geomagnetic activity forecasts. Of course, the direct detection of the Energetic Storm Particles (ESP) by the EPAM instrument on board the ACE space station (Gold, 1998) also alerts hours prior to the approaching interplanetary shock and plasma cloud (ACE news, 2003).

The information about primary ion type and energy is mostly smeared during successive interactions of the primary particle with atmospheric nuclei. *Thus, only coherent measurement of all secondary fluxes (neutrons, muons, and electrons), along with their correlations, can help to make unambiguous forecasts and estimates of the energy spectra of the dangerous flux that follows.* Based on the analysis of multivariate time-series from the ASEC monitors (see Chilingarian, et al., 2005; Gevorgyan, et al., 2005; Chilingarian et al., 2003a and 2003b), we designed and fabricated new-type of particle detector to meet the above goals. In order to keep the instruments inexpensive the options are kept flexible by using modular designs. *Like the world network of neutron monitors, the new monitors will measure the neutron fluxes and in addition they will measure charged particle fluxes with different energy thresholds, thus allowing the investigation of additional populations of primary ions.* These units plan to be deployed at universities and research centers of the developing countries to perform survey and monitoring of most dangerous space storms and to introduce the space research to new generations of students and researchers (for more details see UN/A/AC.105/856 and Chilingarian et al, 2007a).

The basic detecting unit of the SEVAN network is assembled from standard slabs of 50x50x5 cm^3 plastic scintillators. Between 2 identical assemblies of scintillators of size 100 x 100 x 5 cm^3 (four standard slabs) are located two lead absorbers of size 100 x 100 x 5 cm^3 and thick scintillator assembly of size 50 x 50 x 25 cm^3 (5 standard slabs). A scintillator light capture cone and Photo Multiplier Tube (PMT) are located on the bottom, top and on the intermediate layers of detector as is shown in Figure 1, detailed charts of detector with all sizes are available from http://crdlx5.yerphi.am/. The Data Acquisition (DAQ) system developed for the SEVAN basic units allows cascading to achieve greater detecting surfaces and additional possibilities of measuring particle incoming directions. Examples of operation of the 4-fold SEVAN-type detector – Aragats Solar Neutron Telescope (ASNT) see in (Chilingarian et al., 2007a).

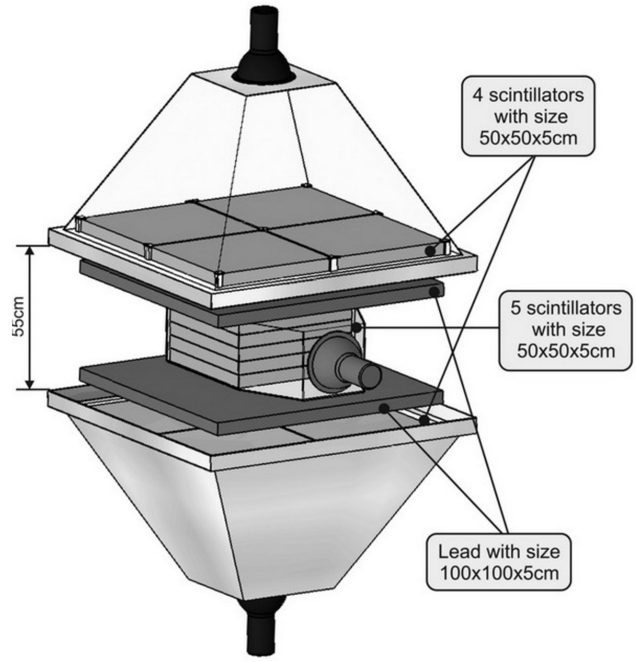

Figure 1 **The basic detecting unit of the SEVAN network**

Incoming neutral particles undergo nuclear reactions in the 25 cm thick plastic scintillator and produce protons and other charged particles. In the upper 5 cm of the scintillator charged particles are registered very effectively; for the nuclear interactions of neutral particles it is not enough material. When a neutral particle traverses the top thin (5cm) scintillator, typically no signal is produced. The absence of signal in the upper scintillators, coinciding with signal in the middle scintillator, points to neutral particle detection. The coincidence of signals from the top and bottom scintillators indicates traversal of high energy muons. Lead absorbers improve efficiency of the neutral flux detection and filtered low energy charged particles. If we denote by the sign "1" signal from scintillator, and by sign "0" absence of signal, following combinations of the 3-layered detector output are possible:

111 – traversal of high-energy muon;
011 and 010 – traversal of the neutral particle;
100 – traversal of low energy charged particle stopped in scintillator or in first lead absorber.
110 – traversal of higher energy charged particle stopped in the second lead absorber.
001 – registration of the inclined charged particles.

Microcontroller based Data Acquisition (DAQ) electronics and 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 issuing of the alerts. Slow control system subsystem provides possibilities of remote control of the PMT high voltage and other important parameters of the DAQ electronics. To improve neutron registration purity we plan to add to detector setup (Figure 1) additional layer of 1 cm thick scintillator. Additional scintillator under 1 cm of lead will effectively detect γ-quanta by electron-positron pairs generated in lead. In turn neutrons will not undergo nuclear interaction in 1 cm of lead and will escape from detection. In this way the scintillator below 1 cm lead will reject both charged particles and gammas.

In the following sections we will illustrate possibilities of multivariate detection of secondary cosmic ray fluxes by examples of most violent solar events of 23rd solar activity cycle detected by ASEC monitors.

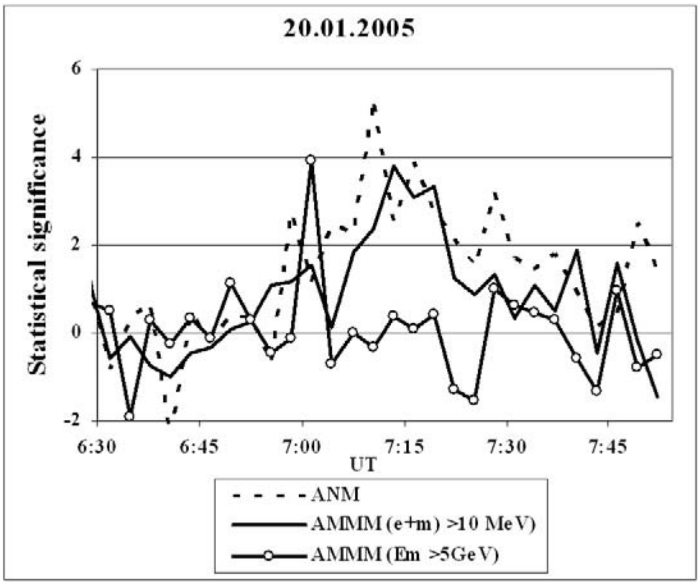

Figure 2 Detection of the GLE from 20 January 2005 by ASEC monitors

On 20 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 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) SEP/GLE event of the 23-cycle was detected by space-borne 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 the NM at the South Pole is the largest increase ever recorded by neutron monitors. The event was highly anisotropic (see Belov et al., 2006, Vashenuk et al., 2005a and 2005b) and the hardest of the 23rd solar cycle.

As we can see in the Figure 2 on 20 January 2005, ASEC monitors detected significant excess of count rates at 7:00 – 8:00 UT. From 7:02 to 7:04 UT, AMMM detected a peak with significance *~4σ*. It was the first time that we detected a significant enhancement of the >5 GeV muon flux coinciding with the GLE detected by the world-wide networks of Neutron Monitors. Detailed statistical analysis of the peak (Bostannjyan et al, 2006, 2007) proves the non-random nature of the detected enhancement. This short enhancement (denoted in Figure 2 by the solid curve with open circles) at 7:02-7:05 exactly coincides in time with peaks from Tibet NM (Miyasaka et al., 2005), Tibet SNT (Zhu et. al., 2005) and Baksan array (Karpov et al., 2005). The solid line in Figure 2 denotes the time series of the low energy charged component and the dashed line indicates the Aragats neutron monitor time series.

Although peak signals from the other ASEC monitors do not coincide in time with the maximal intensity of the 5 GeV muons flux, they also demonstrate enhancement at 7:02-7:05, thus providing possibility to extend the energy spectrum measured by the proton channels of GOES 11 satellite up to 20 GeV (presented in Figure 3). The energy spectra of the SCR protons at 7:02 – 7:05 UT measured by the space-borne spectrometers and surface particle detectors covers more than 3 orders of magnitude from 10 MeV to 20 GeV and demonstrates very sharp knee ("turn-over") at 500-800 MeV.

The energy spectrum remains very hard up to knee (with power index ~ -1) and prolongs till tens of GeV with power index ~ -4 to -5.

It is consistent with most spectra estimates reported at the 29th ICRC at Puna, India (Miysaka et al., 2005, Vashenuyok et.al., 2005a). The uncertainty in the spectral index reflects the methodical difficulties of estimation of differential spectrum at such high energies. The estimated energy spectra index of γ = -4 - -5 at highest energies is a very good indicator of upcoming abundant SCR protons and ions with energies 50 - 100 MeV, extremely dangerous for the astronauts and high over-polar flights, as well as for satellite electronics.

Another way to estimate the index of power law exploits the different attenuation of the secondary fluxes depending on altitude or the particular species of detected secondary particles. Estimation of the energy spectra index using data from NM located at same latitude, but different altitudes was suggested by (Lockwood et al., 2002). Recently same methodology was used for the determinations of the radiation doses received on-board of airplanes during solar particle events (Lantos, 2006). We use this technique for estimation of the spectral index of the 20 January GLE from the data of the Aragats and Nor Amberd NM (Zazyan & Chilingarian, 2005). Proceeding from detected fluxes at Aragats, we check if using the ratio of the enhancements of the flux of different secondary particles (for example neutrons and low energy charged particles) it is possible to estimate the power law index. As one can see from Figure 4, indeed the ratio of the neutral-to-charge flux is more sensitive to the power index value compared with neutron flux ratio measured at different altitudes.

The estimate of the spectral index obtained by the proposed parameter R^{3200}, as one can see in Figure 4, coincides within statistical error bars, with the most probable value of the index obtained by the direct method (see Figure 3).

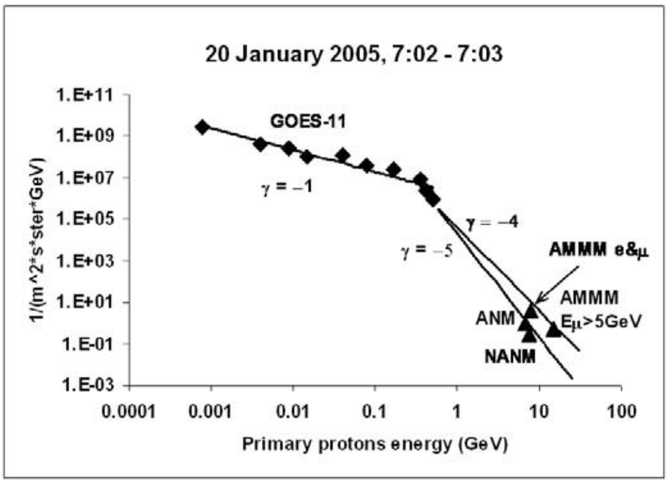

Figure 3 Differential energy spectra of the SCR protons 20 January 2005

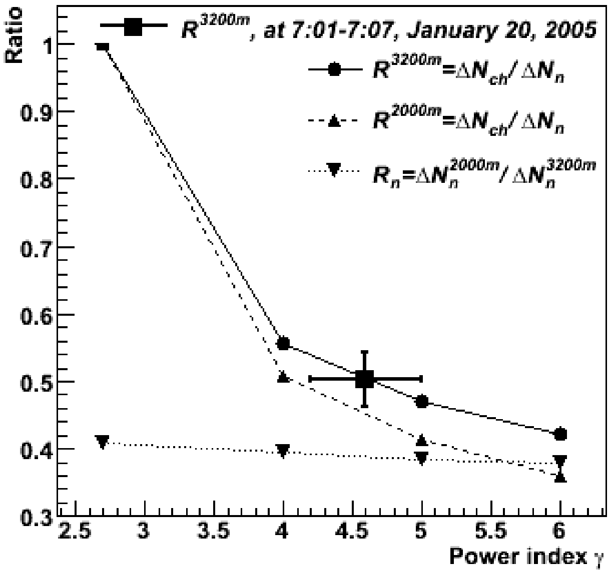

Figure 4 Estimation of the energy spectral index by comparing different secondary fluxes measured at same the location

On the Possibility of forecasting the upcoming radiation storm by GLE detection

In (Chilingarian et al, 2003a, see also ACE news, 2005) based on the GLE events from of 23rd cycle we claimed that relativistic solar ions with energies above Neutron Monitor (NM) cutoff rigidity arrive well before 50 MeV protons, thus providing possibility of alerting on upcoming radiation storm. As we can see from Table 1 (updated from Gevorgyan et al., 2005), where arrival times of GLE events of 23rd cycle are compared, GeV particles are usually coming well before abundant fluxes of middle energy particles reach earth and pose danger to human in space and satellites. In column 5 the time of the first large peak is depicted. Relative standard deviation of the ANM equals: $\sigma \sim 0.7\%$; NAMM ~ 0.9%. For all 3 events the significance of the peak is greater than 4.5σ, thus the probability that the peak is due to random fluctuation only is very small. The last column shows the time of onset of the S2 type radiation storm according to the **NOAA** Space Weather Scales.

Table 1 GLE of 23rd cycle detected by the ASEC detectors

Date	Monitors	X-Ray Flare	Onset	First Max	σ	Second Max	σ	I(E>10Mev) >100/cm^2 * s*ster
4/15/2001	ArNM	X14.4	13:55	14:05	4.5	14:30	3.0	14:25
GLE 60	NaNM		13:55	14:05	5.9	14:30	5.9	
10/28/2003	ArNM	X17	11:25	11:45	6.7	12:10	6.5	12:35
GLE 65	NaNM		11:30	11:35	5.0	12:10	5.2	
1/20/2005	ArNM	X7	6:55	7:10	4.4			6:55
GLE 69	NaNM		6:55	7:00	4.5			

With the exception of the event on 20 January, when due to very good magnetic connection of the flare site with earth, all relativistic particles seem to come simultaneously, the enhancements of GeV SCR detected by the Neutron Monitors can alert on upcoming severe radiation storm. The alerts from middle and low latitude monitors are even more important compared to high latitude networks, because of lower probability of false alarms. If an enhancement occurs at monitors with large cutoff rigidity it indicates that spectral knee occurs at large enough energy and energy spectra index is not too small. Enhancements in the ASEC detectors count rates indicate higher solar ion energies, and, consequently hard spectra of the GLE in progress. Of course, not all GLEs will have ions with energies of tens of GeV, but ones having such energies are of utmost hazard and should be reported as soon as possible to satellite operators. *ASEC monitors can provide just such alerts.* To detect very weak fluxes of highest energy solar ions we plan to enlarge the surface of 5 GeV muon detector at Aragats up to 120 m^2, to achieve the relative accuracy of signal detection of 0.16% (for 1 minute time series).

On 2003 October 28 one of the biggest solar flares of the 23rd cycle occurs (X17.2 according to the NOAA scale, X-ray flux maximum at 11:10). It was a remarkable event not only because of its strength, but for many associated physical phenomena. Large flux of relativistic particles from the sun unleash Soar Energetic Particle event (SEP) and Ground level enhancement (GLE), registered by space born facilities and networks of particle detectors at earth surface (Panasyuk et al. 2004). Among these particles were solar neutrons observed by the ground-based neutron monitor (Bieber et al., 2005) and satellite detectors (K. Watanabe et al., 2006). The record cosmic ray depletion (Forbush decrease) was detected by the middle-latitude particle detectors (Chilingarian et al., 2005). The radiation storm (S4, according to the NOAA scale) was 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 satellites. 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. Sever over-polar flights were rescheduled. The Geomagnetic Storm (GMS) triggered by the interplanetary coronal mass ejection reached earth 19 hours after flare. GMS also interfere with satellite communications; power grids in the northern United States and Canada are feeling the effects of the extreme geomagnetic storm and are experiencing power surges, voltage control problems and protective system problems. Event influence on the Earth's Atmosphere, the Ionospheric and Magnetospheric responses (see details in Gopalswamy et al., 2005) make this event unique in terms of the free energy available at the Sun and the geospace and heliospheric consequences. Therefore, it is of special interest compare the forecasts issued by the National Oceanic and Atmospheric Administration's (NOAA's) Space Environment Center (SEC) in Boulder with possible alerts from the Aragats Space Environmental Center (ASEC, Chilingarian et al., 2005). Of course, ASEC provides only post-event analysis, because in 2003 there was not operational Space Weather service established at ASEC.

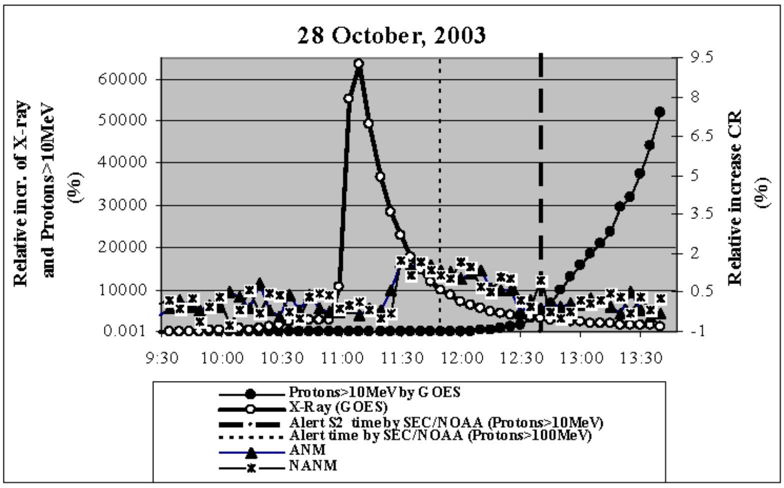

Figure 5 Radiation from 28 October 2003 X17.2 flare. X-ray count rate is multiply by 2 (flux maximum at 11:10). SEC/NOAA alerts enhancement of 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.7% and reaches maximum at ~11:30.

In Figure 5 we can see that ASEC could alert at least 20 minutes earlier than 100 MeV protons alert and more than 1 hour earlier than S2 alert, both issued by SEC. The significance of ASEC alerts is determined not only by the “peak” size at 11:30, by also by the correlated increase of counts on both stations related to the increase of the X-ray flux measured by facilities of GOES satellite.

Correlation information along with information on the GLE makes the false alarm probability extremely small. Information only on the GLE 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 monthly.

The “correlated” alert can be organized 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.

This example demonstrates power of combining information from space born spectrometers and surface particle detectors in constructing reliable and timely Space Weather forecasting services.

On the Possibility of forecasting of the upcoming geomagnetic storm by surface particle detectors

Density and velocity distributions of the ambient population of the Galactic Cosmic Rays (initially uniform and isotropic) are influenced by the global phenomena as propagated ICME. In turn, the intensities of the secondary cosmic rays reproduce these changes. There are different types of modulation effects which change the count rate of surface particle detectors.

Retrospective analysis of the joint occurrence of the “precursors” (significant variations of the particle flux in the vicinity of Earth) and following severe GMS pointed on rather high efficiency (70-80%) of the precursors registered by neutron monitor (Belov et al., 2001) and muon detectors (Munakata et al., 2000). Several groups (Kuwabara et al., 2006, Mavromichalaki et al., 2006) developed real time monitoring systems for Space Weather predictions. The characteristics of the proposed warning systems (efficiency vs. false alarm probability) will be estimated during the 24-th solar cycle starting in 2006.

However, in other statistical study (Kudela & Storini, 2006) it was mentioned that CR variability “seems to be more adequate as a measure of interplanetary disturbances appearing in a large volume of the heliosphere than just as an indicator for the expected geoeffective event only”. The interaction of the ICME with disturbed interplanetary magnetic field and the magnetosphere can produce various modulation effects reflected in the changing count rates of surface particle detectors. And it is not obvious which of these modulation effects are correlated with the severity of the expected GMS.

Therefore, for the reliable forecast of the geomagnetic storms, we need fundamental research of the moving ICME on its journey from the Sun to Earth. New missions like STEREO will provide valuable information on propagated ICME and its modulation effects including changing particle fluxes. To emphasize the importance of the ICME interactions and to illustrate the possibility of the early forecast based on particle detector data, we present here precursors of the great GMS from 20 November 2003. During recovering phase of the Fd on 20 November 2003, the most intense GMS ever detected was registered, DST reached value of -422. Several fast CMEs were unleashed at 18 November 2003 from active regions 501 and 508; the characteristics of these CMEs are posted in the Table 2.

Table 2 Characteristics of the CME of November 18, 2003

Date	Time UT	Heliocoordinates	Angular depth (^{0})	CME velocity км/sec	Kinetic Energy erg
18-10-2003	11:30	S16E08	360	2459	$1.3 \cdot 10^{33}$
18-11-2003	**8:06**	**N01E19**	**>104**	**1223**	$\mathbf{1.3 \cdot 10^{32}}$
18-11-2003	**8:50**	**N02E18**	**360**	**1660**	$\mathbf{3.3 \cdot 10^{32}}$
18-11-2003	9:50	S13E89	>197	1824	$3.6 \cdot 10^{32}$

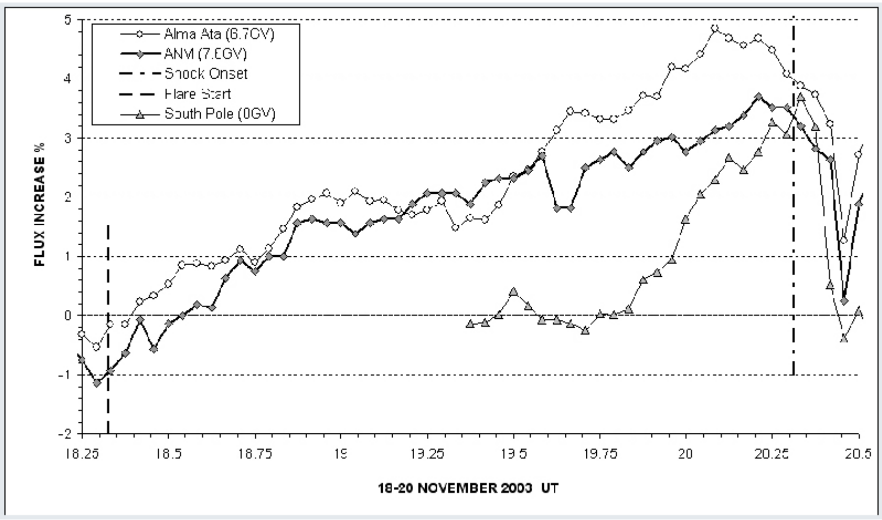

Figure 6 Time history of count rate enhancements of high and middle latitude Neutron Monitors

In Table 2 we can see that the first CME (out of two CMEs coming from the center of the solar disc, denoted by bold sumbols) was started at 8:06 with initial speed of 1223 km/sec; second CME launched after 44 minutes with initial speed of 1660 km/sec. Both CMEs have approximately the same heliocoordinates; the other 2 CMEs were from the eastern limb and could not interact with the central CMEs.

The faster CME overtakes the first one 5.5 hours after start of the flare at a distance of ~ 48 R_{sun} (0.22 AU) from the Sun (details on the interacting CMEs see in Gopalsvami et al., 2002). At the same time, as can be seen from Figure 5, the precursor at middle altitude was observed. Therefore, we can assume that CME interaction forms a "magnet-bottle" type structure "sending" (by reflecting particles from the approaching shock) additional flux of GeV particles in the Earth's direction.

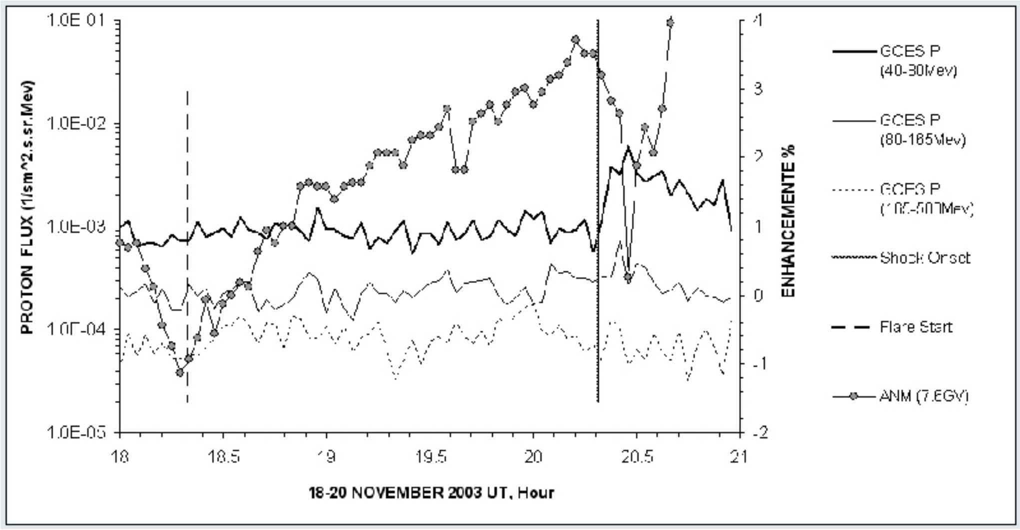

Figure 7 Time history of count rate enhancements ANM and GOES proton detector channels.

Gradual increasing of NM count rates, as we can see in Figure 6, already started on 19 November 2003 ~ 20 hours before the sudden commencement of the Geomagnetic storm. Particle detectors located at high latitudes (as an example the South Pole monitor time series are also plotted in Figure 6) did not demonstrate early precursor feature. Therefore, continuous monitoring of the particle detectors located at middle latitude is necessary to provide timely alert. Of course, the presented results were obtained during post-event analysis. Nonetheless, the pattern of the steady enhancements of count rates of all middle latitude monitors, provides firm basis for the on-line warning service (Martirosyan, 2006).

In Figure 7 we demonstrate comparison of the near-linear rise of the count rate enhancement detected by the ANM with cont rates of MeV particles registered by the facilities of the GOES satellite. No enhancement was detected in MeV particle flux prior to the shock arrival, thus, MeV fluxes directly measured by space-born facilities were not sensitive to this all-time largest GMS.

As we can see, recent results of the detection of the extreme solar events (2003, 2005) by the ASEC monitors illustrate the range of possibilities opening up with the introduction of new particle detectors measuring neutron, electron and muon fluxes with inherent correlations. One of the major advantages of multi-particle detectors is the probing of the different populations of the primary cosmic rays, initiated particle cascades in terrestrial atmosphere. With the basic detector of the SEVAN network we are measuring fluxes of neutrons and gammas, low-energy charged component and high-energy muons. This diversity of information obtained from hybrid detectors network located mostly at low and middle latitudes will give the possibility to estimate the energy spectra of the highest energy SCR. The SEVAN network will be sensitive to very weak fluxes of SCR above 10 GeV, coming very fast and bringing valuable information on upcoming radiation and geomagnetic storms.

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