# New Particle Detector Network for Solar Physics and Space Weather research

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***Abstract*. A network of particle detectors located at middle to low latitudes, SEVAN (Space Environmental Viewing and Analysis Network), aims to improve fundamental research of the particle acceleration in the vicinity of the sun and the space environment. 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 used for exploration of solar modulation effects. The first SEVAN modules are under test operation at Aragats Space Environmental Center in Armenia, in Bulgaria and Croatia. We present the first results of SEVAN operation, as well as some characteristics of the detector setup.**

***Keywords*: Cosmic rays, Particle detectors**

## I. Introduction

Ground based particle detectors measure time series of secondary particles born in cascades originating in the atmosphere caused by primary ions and solar neutrons. The networks of particle detectors can predict upcoming geomagnetic and radiation storms hours before the arrival of Interplanetary Coronal Mass Ejections (ICMEs) at the ACE and SOHO spacecraft. The less than one hour lead time (the time it takes for the ICME to travel from the spacecraft to the magnetosphere) provided by particle detectors located at ACE and SOHO at the libration point 1,5 million kilometers from the Earth is too brief to take effective mitigating actions to protect satellites and surface industries from the harm of major geomagnetic storms.

To establish a reliable and timely forecasting service, we need to measure, model and compare:

- the time series of neutrons and high energy muons;
- the correlations between changing fluxes of secondary particles; and
- the direction of the detected secondary cosmic rays.

Using our experience (see [1], [2], [3], [4], [5], [6], [7]) with data analysis of multivariate time-series from Aragats Space Environmental Center (ASEC) monitors, we designed and fabricated a 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. The price of a fully autonomous basic detector, with facility to send data to the internet will not exceed $ 20,000 US. For this reason the network of countries involved in space research can be significantly expanded, which will facilitate their part in International Heliophysical Year (IHY).

At any time one can add additional similar units to achieve improved functionality; for example, several new observational directions can be added to enhance the accuracy of particle flux measurements. As a world-wide network of neutron monitors ([8]), the new monitors will measure neutron fluxes and, additionally, charged particle fluxes with different energy thresholds, thus allowing investigation of the additional populations of primary ions. These units will be deployed at universities and research centers of developing countries to perform survey and monitoring of the most dangerous space storms and to involve new generations of students and scientists in space research.

The network is planned to be installed at middle and low latitudes. It will be compatible with the currently operating high-latitude neutron monitor networks Spaceship Earth ([9]), coordinated by the Bartol Research Center, the Solar Neutron Telescopes network coordinated by Nagoya University ([10]), the Muon network coordinated by the group from Shinshu University ([11]) and the Athens Neutron Monitor Data Processing Center ([12], [13]).

Particle detectors are and will be installed in Armenia, Croatia, Slovakia, Costa Rica, Bulgaria, Indonesia, and India (see Fig. 1 and Table I). When fully deployed the SEVAN network will provide reliable monitoring of the Sun by at least one detector 22 hours and by two detectors 18 hours every day. We assume that particle fluxes measured by the new network at medium to low

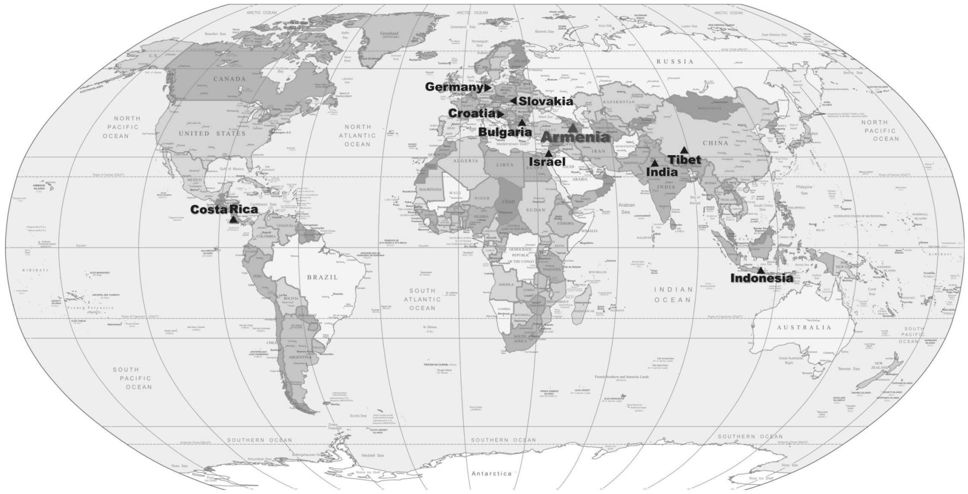


Fig. 1. Possible locations of the Space Environment Viewing and Analysis Network (SEVAN).

TABLE I
GEOPHYSICAL CHARACTERISTICS OF POSSIBLE SEVAN SITES.

| Country | Station | Latitude | Longitude | Altitude [m] | $R_c$ [GV] |
|---|---|---|---|---|---|
| Germany | (Greifswald) | 54.5N | 13.23E | 6 | 2.34 |
| Slovakia | (Lomnicky Stit) | 49.2N | 20.22E | 2634 | 3.88 |
| Croatia | (Zagreb) | 45.82N | 15.97E | 120 | 4.89 |
| Bulgaria | (Musala) | 42.1N | 23.35E | 2930 | 6.19 |
| Armenia | (Aragats1) | 40.25N | 44.15E | 3200 | 7.1 |
| Armenia | (Aragats2) | 40.25N | 44.15E | 2000 | 7.1 |
| Israel | (Hermon) | 33.18N | 35.47E | 2025 | 10.39 |
| Costa Rica | (San Jose) | 10.0N | 84.0W | 1.2 | 10.99 |
| China | (Tibet) | 30.11N | 90.53E | 4300 | 13.86 |
| India | (Delhi) | 28.61N | 77.23E | 239 | 14.14 |
| Indonesia | (Jakarta) | 6.11S | 106.45E | 8 | 16.03 |

latitudes, combined with information from satellites and particle detector networks at high latitudes, will provide experimental evidence on the most energetic processes in the solar system and will constitute an important element of the global space weather monitoring and forecasting service. In the paper we present first results of the SEVAN modules operation in Armenia, Bulgaria and Croatia and comparisons with simulations reported in ([14]).

## II. CONSTRUCTION OF SEVAN PARTICLE DETECTORS

The basic detecting unit of the SEVAN network (see Fig. 2) is assembled from standard slabs of 50x50x5cm$^3$ plastic scintillators. Between two identical assemblies of 100x100x5cm$^3$ scintillators (four standard slabs) are located two 100x100x5cm$^3$ lead absorbers and thick 50x50x25cm$^3$ scintillator assembly (5 standard slabs). A scintillator light capture cone and Photo Multiplier Tube (PMT) are located on the top, bottom and the intermediate layers of detector. The detailed detector charts with all sizes are available from http://sevan.aragats.am/.

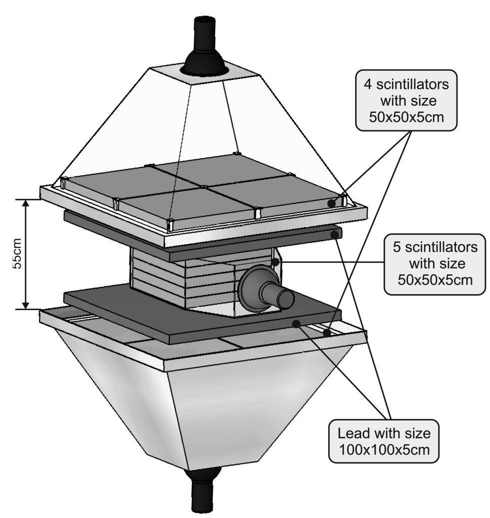


Fig. 2. Basic detecting unit of the SEVAN network.

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 improve the efficiency of the neutral flux detection and filtered low energy charged particles. If we denote by 1 the signal from a scintillator and by 0 the absence of a signal, then the following combinations of the 3-layered detector output are possible:

- 111 and 101 traversal of high energy muon;
- 010 traversal of a neutral particle;
- 100 traversal of a low energy charged partice stopped in the scintillator or in the first lead absorber (energy less than ∼100 MeV);
- 110 traversal of a higher energy charged particle stopped in the second lead absorber;
- 001 registration of inclined charged particles;

Microcontroller-based Data Acquisition (DAQ) electronics and an Advanced Data Analysis System (ADAS) ([15], [16])provide registration and storage of all logical combinations of the detector signals for further off-line analysis and for on-line alerts issuing. The slow control system of the ADAS subsystem allows providing the remote control of the PMT high voltage and important parameters of the DAQ electronics.

## III. Comparison of modeled and measured SEVAN count rates

At the Nor Amberd research station of ASEC we are starting tests of the operation of the SEVAN detector prototype with reduced sizes: area of upper and lower 5-cm this scintillators are 0.55 m2, instead of 1 m2, and thickness of middle detector is 20 cm, instead of 25. In 2008 the standard SEVAN unit (see detailed charts in http://sevan.aragats.am/) was launched in CRD headquarters in Yerevan and at slopes of Aragats mountain. The simulation of the detector response was made in the same way as described in (Chilinarian and Reimers, 2008). The comparison of simulated and measured count rates are presented in Table II.

Each layer of SEVAN module is registering a combination of charged and neutral particles, to purify detected fluxes we have to use coincidences of signals also registered by SEVAN. The different combinations of the signals and absence of signals in three layers of the SEVAN detector make it possible to select events enriched by low energy charged secondary particles, neutral particles and high energy muons ([14]). The following combinations are of upmost interest:

- The combination 100 (signal only in upper scintillator) represents the flux of low energy charged particles (mostly electrons and muons) filtered by 5cm of lead below the upper scintillator; energy not greater than 100 MeV;
- The combination 010 represents the neutral component of secondary cosmic ray fluxes, detected by nuclear interaction in thick scintillator, accompanied by generation of charged particles;
- Combinations 111 and 101 represents the traversal of a high energy muon with minimal energy 200 MeV;
- There exists also exotic channels, for example, trapping of muon in lead and creation of a mesoatom combination 110, but obviously the signal of this effect is hidden by more frequent cases of filtering of a muon by the lower lead filter or by the traversing of a high energy electron through the first lead filter or nuclear interaction of a neutral particle in the upper scintillator with consequent birth of a charged particle cascade reaching the middle scintillator. For revealing the mesoatom cases, we need more precise calculation of the detector response.

The purity of selected events and efficiency of registration were investigated in detail by [14]. As we can see in Table II the SEVAN module can detect the low energy charged component, neutral component and high energy muons. Low energy charged particles, as well as neutrons and gammas, are attenuated very fast as they penetrate deep in atmosphere. High energy muons did not attenuate so fast as one can see in Table II.

With the SEVAN nodule it is possible to detect modulation effects solar activity pose on galactic cosmic rays and magnetosphere, i.e., Forbush decreases and post-Forbush increases of count rate due to coupling of frozen magnetic fields in Interplanetary Coronal Mass Ejections (ICMEs). Also it will be possible to detect changes in count rates during the travel of ICMEs from the sun to Earth lasting 17- 50 hours. Time series of different species of cosmic rays can be used for forecasting of the severity of upcoming Geomagnetic storm. For reliable detection of Ground Level Enhancements (GLEs) additional SEVAN modules will also be needed, because at middle and low altitudes GLEs usually do not exceed 2%. However for extreme events like in 1956, 1989 when the counts can increase by 50% and more even at middle latitudes, GLEs will be reliably detected with one SEVAN module only.

## IV. Conclusion

Reliable forecasts of major geomagnetic and radiation storms are of great importance because of associated Space Weather conditions leading to failures of space and earth surface based technologies as well as posing radiation hazards on crew and passengers of satellites and aircraft.

Measured solar and interplanetary parameters do not allow for reliable warning on the severity of upcoming radiation and geomagnetic storms ([17]). Measurements of Solar Wind parameters performed at spacecraft located at L1 provide too short a time span for mitigation actions to be taken. Another piece of valuable information on major storms is provided by networks of particle detectors located at the Earths surface.

Networks of particle detectors on Earths surface will provide timely information and will be an important element of planetary Space Weather warning services. The big advantage of ground based particle detectors is their consistency, 24 hour coverage, and multi-year

TABLE II
EXPERIMENTAL AND SIMULATED ONE-MINUTE COUNT RATES OF DIFFERENT SPECIES OF SECONDARY PARTICLES MEASURED BY SEVAN MODULE.

| | YerPhI (1000m) | | NorAmberd (2000m) | | Aragats (3200m) | | Zagreb, Croatia, (130m) | Moussala, Bulgaria, (2925 m) |
|---|---|---|---|---|---|---|---|---|
| Type of secondary particle | Measured count rate | Simulated count rate | Measured count rate | Simulated count rate | Measured count rate | Simulated count rate | Measured count rate | Measured count rate |
| Low energy charged particles (100) | 8862±108 | 7202 | 11593±161 | 10220 | 16010±130 | 17330 | 6415±84 | 17479±14 |
| Neutral particles (010) | 363±19 | 359 | 690±27 | 795 | 2007±46 | 1680 | 316±18 | 1115±38 |
| High energy muon (111 & 101) | 4337±67 | 5477 | 4473±99 | 5548 | 4056±64 | 8051 | 3824±64 | 6315±78 |

operation. In contrast the planned life of the satellites and spacecraft is only a few years, they are affected by the same solar blast that they should alert, and space-born facilities instead of sending warnings are usually set in the stand-by mode.

The multi-particle detectors proposed in the present paper will probe different populations of primary cosmic rays. The basic detector of the SEVAN network is designed to measure fluxes of neutrons and gammas, of low energy charged particless and high energy muons. The rich information obtained from the SEVAN network located mostly at low and middle latitudes will allow estimating the energy spectra of the highest energy SCR. The SEVAN network will be sensitive to very weak fluxes of SCR above 10 GeV, a very poorly explored region of the highest energy. To understand the sensitivity of the new type of particle detectors to high energy solar ions we investigate the response of SEVAN basic units to galactic and solar protons. The hard spectra of solar ions at highest energies ( $\sim$ -4 to -5 at rigidities $\geq 5$ GV) indicate the upcoming very intense solar ion flux with rigidities $> 50$ MV, very dangerous for satellite electronics and astronauts. The SEVAN network detectors will also allow distinguishing very rare and very important GLEs initiated by primary neutrons.

Summarizing, the 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 regidities from 3 GV up to 20-30 GV;
- Reconstruct SCR spectra and determine position of the spectral knees;
- Classify GLEs in neutron or proton initiated events;
- Estimate and analyze correlation matrices among different fluxes;
- Significantly enlarge the reliability of Space Weather alerts due to detection of 3 particle fluxes instead of only one in existing neutron monitor and muon telescope world-wide networks.

## V. ACKNOWLEDGEMENT

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## REFERENCES

[1] A. Chilingarian, K. Arakelya, K. Avakyan, et al., *Correlated measurements of secondary cosmic ray fluxes by the Aragats Space - Environmental Center monitors*, Nucl. Instrum. Methods Phys. Res., Sect. A, 483-496, 2005.

[2] N. Gevorgyan, V. Babayan, A. Chilingarian and H. Martirosyan, *Test alert service against very large SEP events*, Advances in Space Research (ASR), Vol. 36, Issue 12, 2351-2356, 2005.

[3] A. Chilingarian, K. Avakyan, V. Babayan, et al., *Aragats Space - Environmental Center: status and SEP forecasting possibilities*, J. Phys. G: Nucl. Part. Phys., Vol. 29, 939 952, 2003a.

[4] A. Chilingarian, V. Babayan, N. Bostanjyan, et al., *Monitoring and forecasting of the geomagnetic and radiation storms during the 23rd solar cycle: Aragats Regional Space Weather Center*, Advances in Space Research, Vol. 31, 861-865, 2003b.

[5] A. Chilingarian, L. Melkumyan, G. Hovsepyan, et al., *The Response Function of the Aragats Solar Neutron Telescope*, Nucl. Instr. and Meth. A 574, 255-263, 2007.

[6] A.A. Chilingarian, A.E. Reymers, *Particle detectors in solar physics and space weather research*, Astropart. Phys., Astropart. Phys., 27, 465-472, 2007.

[7] N.Kh. Bostanjyan, A.A. Chilingarian, V.S. Eganov, et. al.: *On the production of highest energy solar protons at 20 January 2005*, Advances in Space Research 39, 14561459, 2007.

[8] H. Moraal, A. Belov, J.M. Clem, *Design and co-Ordination of Multi-Station International Neutron Monitor Networks*, Space Science Reviews 93, 285-303, 2000.

[9] T. Kuwabara, J.W. Bieber, J. Clem, P. Evenson and R. Pyle, *Development of a ground level enhancement alarm system based upon neutron monitors*, SPACE WEATHER, VOL. 4, S10001, doi:10.1029/2006SW000223, 2006.

[10] H. Tsuchiya, Y. Muraki, K. Masuda, et al., *Detection efficiency of a new type of solar neutron detector calibrated by an accelerator neutron beam*, Nucl. Instrum. Methods Phys. Res., Sect. A 463, 183 193, 2001.

[11] K. Munakata, J.W. Bieber, S. Yasue, et al., *Precursors of geomagnetic storms observed by the muon detector network*, J. Geophys. Res. 105, 27457-27468, 2000.

[12] H. Mavromichalaki, G. Souvatzoglou, C. Sarlanis, et al., *The new Athens center on data processing from the neutron monitor network in real time*, Annales Geophysicae, 23, 31033110, 2005.

[13] H. Mavromichalaki, G. Souvatzoglou, C. Sarlanis, et al., *Space weather prediction by cosmic rays*, Advances in Space Research, Volume 37, Issue 6, 1141-114, 2006.

[14] A. Chilingarian, A. Reymers, *Investigations of the response of hybrid particle detectors for the Space Environmental Viewing and Analysis Network (SEVAN)*, Ann. Geophys., 26, 249-257, 2008.

[15] S. Chilingaryan, *Universal Data Exchange Solution for Modern Distributed Data Acquisition Systems and its Implementation for Cosmic Ray Monitor Networks*, National Academy of Science, Armenia, Ph.D. thesis, 2006.

[16] A.R. Yeghikyan, A.A. Chilingarian, *Data visualization interactive network for Aragats Space Environmental Center*, $2^{nd}$ International Symposium SEE-2005, Nor-Amberd, Armenia, 245-251, 2005.

[17] R.P. Kane, *How good is the relationship of solar and interplanetary plasma parameters with geomagnetic storms?* (2005), JGR, 110, A02213.

[18] United Nations, *Comprehensive overview on the worldwide organization of the International Heliophysical Year 2007*, Office for Outer Space affairs, UN office at Vienna, p.44, 2006.