ANNUAL REPORT

of Artem Alikhanyan National Lab
Cosmic Ray Division

A. ALIKHANYAN National Laboratory

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CONTENT

Annual Report, Cosmic Ray Division of Artem Alikhanyan National Lab (AANL) 2023

THE 2023 ANNUAL REPORT

SHORT DESCRIPTION OF PAST ASEC RESEARCH PROGRAM

One of the world's largest high-altitude cosmic-ray research stations is located on the slopes of Mt. Aragats, 3200 m and 2000 m above sea level. Since 1942, physicists of the Cosmic Ray Division (CRD) of YerPhI have been studying Cosmic Ray fluxes on Mt. Aragats with various particle detectors: mass spectrometers, calorimeters, transition radiation detectors, and huge particle detector arrays detecting particle cascades initiated by protons and nuclei accelerated in most energetic explosions in the Galaxy. The latest research at Mt. Aragats adds to traditional fields of Space Weather, Solar accelerators, and high-energy physics in the atmosphere. From 2008 to 2022, particle detectors at Aragats continuously registered fluxes of charged and neutral particles using various particle detectors. ASEC detectors measure particle fluxes with different energy thresholds and Extensive air showers (EASs) initiated by primary protons and nuclei with energies above 50–100 TeV. Thunderstorm activity on Aragats is extreme in May - June. Long-lasting light flashes sometimes occur near the station, and lightning activity lasts an hour or more. Thunderclouds are usually below the southern peak (i.e., not higher than 500 m above ground level) and sometimes only 25–50 m above the station. Therefore, most energetic Thunderstorm ground Enhancements (TGEs) contain many avalanche electrons, like the one that occurred on 19 September 2009, which triggered the MAKET surface array 100 times, proving that avalanche electrons are distributed over areas of thousands of square meters.

Most of the particle detectors are located in the MAKET experimental hall. First, the Aragats Solar Neutron Telescope (ASNT) remains the main detector in high-energy atmospheric physics, measuring the flux of electrons and gamma rays in the 10-100 MeV energy range. In the same hall are the Aragats Neutron Monitor (ArNM), type 18HM64, and the space environment viewing and analysis network (SEVAN) particle detector, which records charged and neutral particle fluxes. Sixteen plastic scintillators of the MAKET-ANI surface array record EASs and avalanches unleashed by runaway electrons originating in the thunderclouds above.

After the first years of TGE research, the experimental complex at Aragats was significantly expanded. Numerous new particle detectors were installed at an altitude of 3200 m. A network of 7 spectrometers (based on NaI crystals of 12 x 12 x 24 cm^3 size was established in the SKL experimental hall. The low energy threshold (~ 300 keV) provides extensive statistics (~ 50,000 counts per minute) for reconstructing gamma ray differential energy spectra from 0.3 to 50 MeV. A network of 3 STAND1 detectors (three stacked scintillators with a thickness of 1 cm and an area of 1 m^2 and one stand-alone with a thickness of 3 cm) is located at Aragats station premises with a spacing of ≈250 m. The network is connected to the fast data synchronization system that can capture time series with a sampling time of 50 ms, which allows one to study the relation of the TGE development to atmospheric discharges.

The largest TGEs registered by SEVAN network units at Mt. Musala (Bulgaria) and Mt. Lomnicky Stit (Slovakia), as well as the results obtained by the Japanese group and recent measurements at Zugspitze, prove that TGE isn't only a specific Aragats feature but – a universal characteristic of thunderstorms over high altitude experiments. The measured energy spectra allow us to get insight into the charge structure of the thundercloud and clarify the role of the lower positively charged region (LPCR) in the development of the TGE.

Data from local and international networks are transferred to the MySQL database at the CRD headquarters in Yerevan and is available through the ADEI multidimensional visualization and statistical analysis platform. ADEI allows users to analyze data quickly, prepare figures and slides, perform joint data analysis with remote groups, test hypotheses, and draw physical inferences. Alerts and forewarnings sent by e-mail to service subscribers make it possible to follow the progress of thunderstorm events in real-time. ADEI database contains a time series of neutral and charged particle count rates together with data on disturbances of the NSEF measured by a network of Boltek EFM-100 electric field mills and meteorological conditions from automatic weather stations from Davis Instruments. Placing these data in one database allows the visualization and multivariate correlation analysis of particle fluxes and numerous environmental parameters.

The simulation of the Relativistic runaway electron avalanches (RREA) development supported measurements of TGEs in the atmospheric electric field above detectors with GEANT4 and CORSIKA codes and spectrometric measurements of Radon progeny gamma radiation. By making multiple simulations with different electric field strengths and elongation, we outline plausible parameters of the electric field that give rise to TGEs and define the main charge structures supporting the origination of TGE.

Among other discoveries made on Aragats are the registration of the atmospheric neutrons observed during thunderstorms, which proved to originate from the photonuclear reactions of the RREA gamma rays, the discovery of the Radon circulation effect, uncovering of muon stopping effect and positron modulation, estimation of the largest electric voltage (potential difference) at mountain peaks, and observation of transient luminous events (TLEs) in the lower atmosphere.

In the following sections, we will present the methodology of TGE selection and highlight the most important results of TGE physics.

MAIN ACHIEVEMENTS OF LAST FIVE YEARS

- Continuous measurements of particle fluxes, near-surface electric field, and geomagnetic field, as well as meteorological parameters and lightning location by facilities of Aragats research stations.
- Proving the origin of TGE by measuring for the first time the electron energy spectrum.
- Providing data to the community by open-access databases and putting data in the Mendeley dataset repository.
- Measurements of TGs sharing the same characteristics with the SEVAN network on Aragats, Lomnicky Stit, Musala, Zugspitze, and Mileshovka.
- Measurement of the TGE particle arrival times on the nanosecond time scale proves the Poisson nature of TGE.
- Model of the electron acceleration in atmospheric electric fields;
- Radon circulation effect,
- Muon stopping effect;

- Measurement of energy spectra of the magnetospheric effect of 5 November 2023 by Zugspitze and Aragats spectrometers.
- Positron modulation and role of the lowest dipole of cloud charge structure;
- Measurement of the largest electric voltage (potential difference) at mountain peaks;
- Observation of transient luminous events (TLEs) in the lower atmosphere.

2023 ACHIEVEMENTS AND 2024 PLANS

The instrumental complex for the synchronous detection of electric fields, atmospheric discharges, and various species of elementary particles arriving at the earth's surface, which operated on the slopes of Aragats in 2023, continuously worked and detected the world's largest TGE on May 23, with a record intensity of 3.2 million particles per minute per m^2 with energies above 300 keV. 2023 was very fruitful for large TGEs, providing 5 TGEs with enhancement of larger than 100% (by STAND3 1000 coincidence). 4 of them allow electron spectrum recovery because a strong electric field prolongs to 50-100 m above the surface. A new SEVAN node was installed on the highest mountain in Germany, Zugspitze. First, TGE was already registered, and the energy spectrum of gamma rays was recovered.

The experimental complex on Aragats was enlarged in 2023 by 4 new experimental facilities:

1. For the first time, a new experimental facility in SKL hall allows measuring the space-time distribution of the TGE particles on nanosecond time scales, proving the Poisson-type distribution of particle arrival.
2. The response function of a new precise spectrometer was determined, allowing recovery of electron gamma spectra on Aragats and, for the first time, recovery of gamma and neutron energy spectra at Zugspitze.
3. Two panoramic cameras were installed on Aragats to research enigmatic lights, which coincide with intense electron flux and the high strength of the near-surface electric field; 2 TGEs were recorded.
4. We finish the experiment to investigate the enhancement of the positron peak (511 keV) and its dependence on the near-surface electric field;
5. In Nor–Amberd—Burakan, we install new particle detectors and perform experiments to investigate the lateral extent of thunderstorm ground enhancements (TGEs) to understand the horizontal profile of the atmospheric electric field at strong thunderstorms.

The main infrastructure repairs: MAKET experimental hall and power station walls were repaired. The first floor of the Nor Amberd research station was rebuilt.

Details of the 2024 research program:

In 2024, in Nor-Amberd and Aragats research stations, we plan to continue 24/7 monitoring of:

1. Particle fluxes of different species of cosmic rays with a variety of particle detectors and spectrometers located on high-altitude research stations;
2. Atmospheric discharges with fast antennas;

3. The near-surface electric field with a network of electric mills;
4. Meteorological conditions with DAVIS weather station;
5. Geomagnetic field;
6. Particle fluxes on the mountain peaks of Eastern Europe and Germany with SEVAN European network;
7. Skies above Aragats research stations with a system of AllSky cameras.
8. Store all data, make bookkeeping backups, and establish a mirror site in Germany, make all data available for users worldwide online via MySql databases and ADEI multivariate visualization and statistical analysis platform;
9. Install on Aragats 4 new facilities according to results of international competition: “Install your detector on Aragats”;
10. Research conditions supporting the acceleration of the electrons in the atmosphere up to 50 MeV; investigate the origination of “snow” and “graupel” dipoles in the thundercloud;
11. Investigate the MOS process by GEANT4 simulations and data from Aragats particle spectrometers;
12. Investigation of a new type of atmospheric glows related to the development of electron-gamma ray avalanches in the atmosphere;
13. Investigation of types and conditions of atmospheric flashes that abruptly terminated particle flux;
14. Recover differential energy spectra with 4 particle spectrometers (ASNT, SEVAN, CUBE, NaI) in the broad energy interval from 300 KeV to 100 MeV;
15. Simulation of the RREA process in the strong atmospheric electric fields with CORSIKA code;
16. Perform GEANT4 calculations of the response function of Aragats spectrometers and particle detectors. Estimate the count rates of the SEVAN, STAND1, and STAND3 detectors by the energy spectra measured by the ASNT and NaI networks.
17. Estimate the neutron flux during TGEs by SEVAN 010 combination. Estimate the contribution of atmospheric neutrons to overall neutron flux (neutrons born in the lead filter);
18. Reoperate muon detector in MAKET hall and restart measurement of the horizontal muon flux;
19. Recover the “white house” station, launching 2 SEVAN modules;
20. Prepare in Nor-Amberd STAND4 detector for testing detectors and electronics;
21. Modernize the software and fabricate boards for the new modes of SEVAN module operation, including the registration of the coincidences and measurements of energy releases by 20-25 cm thick plastic scintillators;

We plan to publish 20 research papers (mainly in APS, Elsevier, and AGU journals) in 2023 and 2024. In 2024, we plan to accept a new student and a young software engineer and present a Ph.D. thesis for defense (Balabek Sargsyan).

STAFF AND FINANCE.

The total number of CRDs at the beginning of 2024 was 30, including One professor, 5 PhDs, 2 Ph.D. students, 5 engineers, 7 technicians, 3 electrical technicians, 2 drivers, 4 cocks, a WEB designer, an accountant, a secretary, and an assistant. We have 3 vacations: 1 Ph.D. student, who works primarily at UCLA, USA, and 1 data analysis consultant, who works at KIT, Karlsruhe, Germany.

During the past five years, ASEC's staff and finances have been more or less stable (see Fig. 1).

The budget in 2024 was ≈400,000 USD, including base funding from the Armenian government covering salaries, electricity, gas, and fuel (250,000 USD), a DESY grant (48,000 USD), a US diaspora grant (24,000 USD), and an Armenian government grant (76,000 USD). Grants are spent on equipment purchases, business travel, additional salaries, repairs, and other urgent purchases.

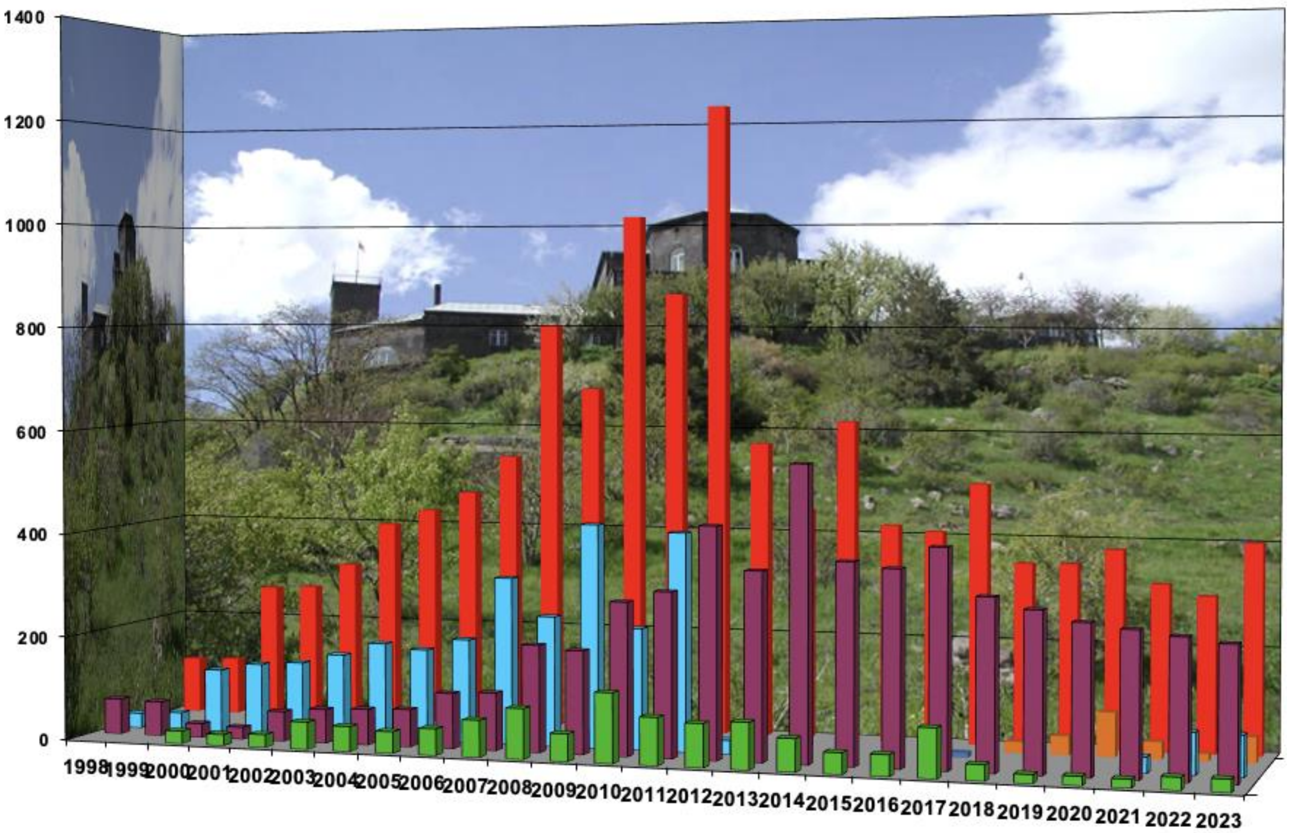

Figure 1. CRD budget of last 26 years. Red total, magenta – Armenian government base funding, green – diaspora grant, blue – international and Armenian grants.

PUBLICATIONS

Astronomy and Computing 44 (2023) 100714

Proving ‘‘new physics’’ by measuring cosmic ray fluxes

A. Chilingarian *, G. Hovsepyan
Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, 0036, Armenia

Radiation on Earth’s surface has been measured for more than a century using different particle detectors. These detectors have evolved from electroscopes to sophisticated, thousands-ton LHC detectors. Recently, with the availability of cheap particle detectors and simple data acquisition systems, publications have attempted to link changes in detector count rate to various astrophysical phenomena. However, measurement errors, meteorological conditions, and disturbances of electrical and geomagnetic fields can significantly impact cosmic ray fluxes. Some authors overlook these factors and publish ‘‘unique’’ correlations between their detector count rates and events such as solar and lunar eclipses, lightning strokes, Venus’s transit over the Sun, and others. When searching for the causes of cosmic ray enhancements, carefully distinguishing the atmospheric, instrumental, and astrophysical effects is essential. This paper aims to demonstrate how analyzing different species of cosmic ray flux can provide valuable insights into the underlying physical processes. We will explain how to verify that measurements are not due to abrupt changes in atmospheric conditions or equipment malfunctions but rather evidence of a novel physical phenomenon. Our goal is to provide a clear path from measurement to physical inference.

PHYSICAL REVIEW D 107, 102003 (2023)

Genesis of thunderstorm ground enhancements

A. Chilingarian , G. Hovsepyan, T. Karapetyan, D. Aslanyan , S. Chilingaryan, and B. Sargsyan
Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia, 0036

Proceeding from a stormy day on 22 September 2022, when seven thunderstorm ground enhancements occurred (TGEs, three of them very large), we analyze the TGEs’ energy spectra and conditions supporting the unleashing of the intense particle flux. For the first time, we present a detailed analysis of the shape of the TGE energy spectra in the energy range from 0.3 to 50 MeV and discuss the conditions of TGE origination. The cross calibration of different detectors is possible thanks to the 24/7 monitoring of particle fluxes with numerous detectors and spectrometers operated on Aragats cosmic ray observatory. Despite the difficulties of measuring energy spectra from an electron accelerator with a beam size of several km^2, which can change the electron energy in seconds, we reliably recover energy spectra of electrons and gamma rays. We estimate the intensity of the most significant particle flux to be ≈1.25 million TGE particles with energies greater than 0.3 MeV hitting each square meter of surface on Aragats, 3200 asl. We analyze the charged structure of the thundercloud giving birth to the operation of the lower dipole, which accelerates electrons, and discuss the precursors of the lighting flashes.

Journal of Geophysical Research: Atmospheres, 128, e2022JD037309 (2023)

TGE Electron Energy Spectra: Comment on "Radar Diagnosis of the Thundercloud Electron Accelerator" by E. Williams et al. (2022)

A.Chilingarian, G. Hovsepyan, D. Aslanyan, T. Karapetyan, B. Sargsyan, and M. Zazyan
Alikhanyan National Lab, Yerevan Physics Institute, Yerevan, Armenia

E. Williams et al. (2022, commented paper) questioned electron energy spectra derived from thunderstorm ground enhancements (TGEs) measured on Aragats; they concluded that "A more likely origin for any detected electrons at 3.2 km above sea level is Compton scattering and pair production activated by longer-range bremsstrahlung gamma rays, themselves produced by runaway electron encounters with nuclei in the breakeven field at higher altitude." This comment shows that the selection criteria of "electron" TGEs unambiguously reject the assumption of the origination of TGE electrons measured on Aragats from the Compton and pair production processes. Thus, the strong accelerating electric field above the earth's surface can be significantly lower (25–150 m) than derived in the commented paper 500 m altitude. Electron accelerators operate in the thunderous atmosphere, sending copious particles to the Earth's surface. To get inside the models of electron acceleration and multiplication by strong atmospheric fields, the critical problem is the measurement of electrons and their energies as they arrive at the earth's surface. It is rather tricky because electrons are fast attenuated in the air, and the flux of accompanied gamma rays is attenuated much less and reaches the ground in overwhelming amounts. We developed special hardware and software methods to prove electrons' existence in the vast particle fluxes reaching the ground and to measure their energies. Simulations and careful examination of the registered particle fluxes check these methods.

Atmosphere 2023, 14,300. https://doi.org/10.3390/

Thunderstorm Ground Enhancements Measured on Aragats and Progress of High-Energy Physics in the Atmosphere

Ashot Chilingarian

High-energy physics in the atmosphere (HEPA) has undergone an intense reformation in the last decade. Correlated measurements of particle fluxes modulated by strong atmospheric electric fields, simultaneous measurements of the disturbances of the near-surface electric fields and lightning location, and registration of various meteorological parameters on the Earth have led to a better understanding of the complex processes in the terrestrial atmosphere. The cooperation of cosmic rays and atmospheric physics has led to the development of models for the origin of particle bursts recorded on the Earth's surface, estimation of vertical and horizontal profiles of electric fields in the lower atmosphere, recovery of electron and gamma-ray energy spectra, the muon deceleration effect, etc. The main goal of this review is to demonstrate how the measurements performed at the Aragats cosmic ray observatory led to new results in atmospheric physics. We monitored particle fluxes around the clock using synchronized networks of advanced sensors that recorded and stored multidimensional data in databases with open, fast, and reliable access. Visualization and statistical analysis of particle data from hundreds of measurement channels disclosed the structure and strength

of the atmospheric electric fields and explained observed particle bursts. Consequent solving of direct and inverse problems of cosmic rays revealed the modulation effects that the atmospheric electric field has on cosmic ray fluxes.

EPL, 143 (2023) 59002 doi: 10.1209/0295-5075/acf340

Thunderstorm ground enhancements observed on Aragats mountain in Armenia in the wintertime

A. Chilingarian[1] , G. Hovsepyan[1], D. Aslanyan[1], T. Karapetyan[1], B. Sargsyan[1] and E. Svechnikova[2]

[1] *A. Alikhanyan National Lab (Yerevan Physics Institute) - Yerevan 0036, Armenia*

[2] *Institute of Applied Physics of RAS - 46 Ul'yanov Str., Nizhny Novgorod 603950, Russia*

Thunderstorm ground enhancements (TGEs) occur in the spring-autumn seasons at Aragats due to warm air updrafts that cause hydrometeor charging. However, particle detectors recorded three TGEs within 10 hours on February 7, 2023, despite the temperature being −10 °C. Upon analyzing the energy spectra of TGE electrons and gamma rays, it was discovered that the atmospheric electric-field strength above Aragats, at heights 3300–5300 m, could be around 2.1 kV/cm even in winter. We provide details on the fluxes and energy spectra of TGE electrons and gamma rays, as well as discuss models of cloud electrification in winter.

PHYSICAL REVIEW D 109, 062003 (2024)

Atmospheric positron flux modulation during thunderstorms

A. Chilingarian and B. Sargsyan
A I Alikhanyan National Lab (Yerevan Physics Institute), Yerevan 0036, Armenia

We have discovered a new phenomenon in high-energy atmospheric physics involving an increased fraction of ground-level positrons during a thunderstorm. This increase is linked to developing a lower positively charged region (LPCR) at the thundercloud bottom. When the electric field strength in the lower atmosphere exceeds a critical value, seed electrons from cosmic rays accelerate and multiply, creating relativistic runaway avalanches of millions of electrons and gamma rays with energies up to 50 MeV. The emerging LPCR changes the polarity of the electric field nearly to the Earth's surface, causing electrons to decelerate and positrons to accelerate, increasing the flux of 511 keV "annihilation" gamma rays. By measuring these gamma rays, we can reveal the formation of the LPCR and follow the dynamics of the charge structure in the lower part of the thundercloud. Our previous measurements demonstrate that the atmospheric electric field during thunderstorms modulates fluxes of cosmic ray electrons and gamma rays, muons, and neutrons. This research shows that the emerging charged structures in the thundercloud also modulate positron flux.

Advances in Space Research in the press, doi.org/10.1016/j.asr.2024.02.041
https://www.sciencedirect.com/science/article/abs/pii/S0265931X24000419?via%3Dihub

Enormous impulsive enhancement of particle fluxes observed on Aragats on May 23, 2023

A.Chilingarian, G. Hovsepyan, B. Sargsyan, T. Karapetyan, D. Aslanyan, L. Kozliner
Alikhanyan National Lab (Yerevan Physics Institute), Yerevan 0036, Armenia

An unprecedented thunderstorm ground enhancement (TGE) event was recorded on May 23, 2023, at Aragats Mountain, the highest peak in Armenia. This event showcased a maximum flux intensity surpassing 3 million particles per minute per square meter for energies above 0.4 MeV. Distinctly, the fluence of the event was measured at approximately ≈700 particles/cm^2. The comprehensive instrumentation at the Aragats research station, including a suite of spectrometers and detectors, enabled precise cross-correlation of measurements. The electron flux at energies exceeding 10 MeV was observed at roughly ≈55,000 particles per minute per square meter. Additional measurements, including cloud base heights and corona discharge detections, validated the intensity of the electric field, reaching approximately 2.1 kV/cm at elevations 50–100 m above ground level. Our observations confirm that TGE is a universal and significant atmospheric event, contributing a substantial flux of high-energy electrons to the global electrical circuit. Integrating such TGE phenomena into Earth's numerical models is imperative, considering their impact on aviation and aerospace operation safety.

Advances in Space Research in the press, doi.org/10.1016/j.asr.2024.03.013

Extensive air showers and atmospheric electric fields. Synergy of Space and atmospheric particle accelerators.

A. Chilingarian
A I Alikhanyan National Laboratory (Yerevan Physics Institute), Alikhanyan Brothers 2, Yerevan, Armenia, 0036

Various particle accelerators operate in the space plasmas, filling the Galaxy with high-energy particles (primary cosmic rays). Reaching the Earth's atmosphere, these particles originate extensive air showers (EASs) consisting of millions of elementary particles (secondary cosmic rays), covering several km^2 on the ground. During thunderstorms, strong electric fields modulate the energy spectra of EAS secondary particles, changing the shower size (number of EAS electrons) and altering the primary particle's estimated energy and frequency of the surface array triggers. Impulse amplifications of particle fluxes (the so-called thunderstorm ground enhancements, TGEs) manifest themselves as large peaks in the time series of count rates of particle detectors located on the Earth's surface. Free electrons are abundant at any altitude in the atmosphere, from small to large EASs. These electrons serve as seeds for electron accelerators, which operate in the thunderous atmosphere and send particle avalanches in the direction of Earth's surface and into space (terrestrial gamma flashes, TGFs). EAS cores randomly hitting arrays of particle detectors also generate short bursts of relativistic particles. For years, particle detectors, electric field sensors, and lightning locators have

gathered information about the complex interactions of secondary particle fluxes, electric fields, and lightning flashes. This information is crucial for establishing a field of high-energy physics in the atmosphere.

Journal of Environmental Radioactivity 274 (2024) 107409
https://doi.org/10.1016/j.jenvrad.2024.107409

The causes of the abrupt enhancement of the natural gamma radiation in the thunderous atmosphere on the mountain tops

A.Chilingarian, B. Sargsyan
A I Alikhanyan National Laboratory (Yerevan Physics Institute), Yerevan, 0036, Armenia

The study presented the relationship between sudden Natural Gamma Radiation (NGR) increases related to enhanced atmospheric electric fields. We pinpoint Thunderstorm Ground Enhancements (TGEs) as the primary source of abrupt and significant NGR spikes. These TGEs, which are transient, several-minute-long increases in elementary particle fluxes, originate from natural electron accelerators within thunderclouds. The more pro- longed, yet less pronounced, increases in NGR, persisting for several hours, are attributed to the gamma radiation from radon progeny and enhanced positron fluxes. This radon, emanating from terrestrial materials, is carried aloft by the Near-Surface Electric Field (NSEF). To measure NGR at Aragats Mountain, we use an ORTEC detector and custom-built large NaI (Tl) spectrometers, employing lead filters to discriminate between cosmic ray fluxes and radon progeny radiation. Our analysis differentiates between radiation enhancements during positive and negative NSEF episodes. The resultant data provide a comprehensive measurement of the intensities of principal isotopes and positron flux during thunderstorms compared to fair weather conditions.

The global emergence of strong electric fields within the Earth’s atmosphere during thunderstorms implies that the observed NGR enhancements are widespread phenomena. Due to their significant planetary i2mpact, these effects warrant inclusion in the numerical models of Earth’s atmospheric processes.

EPL- A letter Journal Exploring Frontiers of Physics 146 (2024) 24001
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Increase in the count rates of ground-based cosmic-ray detectors caused by the heliomagnetic disturbance on 5 November 2023

A. Chilingarian[1], T. Karapetyan[1], B. Sargsyan[1], M. Zazyan[1], J. Knapp[2], M. Walter[2] and T. Rehm[3]
[1]*A I Alikhanyan National Lab (Yerevan Physics Institute), Yerevan 0036, Armenia*
[2]*Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany*
[3]*Environmental Research Station Schneefernerhaus (UFS), Germany*

The unexpected surge in solar activity in fall 2023 following a period of the calm sun during the previous relatively small 24th solar activity cycle indicates the approach of the solar maximum of the 25th cycle expected in 2024. The nonlinear interplay between disturbed interplanetary magnetic and geomagnetic fields yields diverse effects, from damage to satellite electronics to fascinating Auroras.

In these circumstances, it is increasingly important to understand the effects of large magnetized clouds ejected from the Sun on near-Earth environments. Cosmic rays are direct messengers, conveying crucial information about these intricate processes. Networks of particle detectors continuously monitoring cosmic ray flux on the Earth's surface provide valuable insights complementary to spaceborne detectors operated by NOAA, NASA, and ESA. Our letter unveils a rare Magnetospheric Effect observed by particle detector networks at middle latitudes on mountaintops. Additionally, we present, for the first time, the energy spectrum of the particles causing the observed count rate enhancement, shedding light on the solar-magnetospheric interaction.

Physics Open 18 (2024) 100202, https://doi.org/10.1016/j.physo.2023.100202

Space-temporal structure of the thunderstorm ground enhancements (TGEs)

A.Chilingarian, D. Pokhsraryan, F. Zagumennov, M. Zazyan
A I Alikhanyan National Laboratory, Yerevan, 0036, Armenia

We analyzed the structure of the Thunderstorm Ground Enhancement (TGE) using a particle detector network on Aragats. We performed a statistical analysis of the particle arrival time series on a nanosecond time scale using the largest TGE event on record, which occurred on May 23, 2023. Our findings confirm that the TGE is a mixture of multiple runaway electron avalanches that arrive independently and provide stable particle flux. The electron accelerator, operated by the dipole that emerges in the lower part of the thundercloud, sends copious electrons and gamma rays toward the Earth's surface that sustains for minutes. The experimental results are supported by simulations of electron multiplication and acceleration in strong atmospheric electric fields. We compare TGEs and Terrestrial Gamma Flashes (TGFs), which are brief bursts observed by gamma-ray detectors in orbit and are thought to be associated with atmospheric discharges.

On 23 May 2023, the RREA in the thundercloud above Aragats produced a stable ten times higher particle flux than the ambient cosmic ray flux during fair weather. The count rate of TGEs shows a smaller relative error compared to the flux of the ambient population of cosmic rays during fair weather. TGE particles arrive uniformly and randomly, according to the Poisson process.

*Astroparticle Physics 156 (2024) 102924,
https://doi.org/10.1016/j.astropartphys.2024.102924*

Energy spectra of the first TGE observed on Zugspitze by the SEVAN light detector compared with the energetic TGE observed on Aragats

A. Chilingarian [a, *], T. Karapetyan [a], B. Sargsyan [a], J. Knapp [b], M. Walter [b], T. Rehm [c]
[a] Alikhanyan National Lab (Yerevan Physics Institute), Yerevan 0036, Armenia [b] Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
[c] Environmental Research Station Schneefernerhaus (UFS), Germany

The energy spectra of Thunderstorm ground enhancement (TGE) electrons and gamma rays are the key evidence for proving the origin of enhanced particle fluxes from thunderclouds. Till now, the electron energy spectrum was measured only by the Aragats large scintillation spectrometer ASNT. We changed the electronics board of the SEVAN detector installed at the Umwelt-Forschungs-Station (UFS, Schneefernerhaus, 2650 m asl) to allow these vital measurements near the top of the Zugspitze.

The new electronics of the SEVAN detector, supplied with logarithmic ADC, for the energy release measurements up to 50 MeV (the thickness of the spectrometric skintiller is 25 cm). Thus, by measuring energy releases well above 3 MeV, we unambiguously separate Radon progeny gamma radiation from the electrons and gamma-ray relativistic runaway avalanches. Using the different energy release histograms allows for separating charged and neutral particles, enabling the disentangling of electron and gamma-ray energy spectra. On May 23, 2023, the first TGE was registered on Zugspitze by the SEVAN detector. The gamma-ray flux enhancement was 44%, corresponding to the observed count rate peak enhancement of 44σ. The gamma-ray energy spectrum was recovered, maximum energy is 60 MeV. On the same day, a large TGE was observed on Aragats. The TGE maximum flux overpasses the fair-weather flux by 207%, equivalent to a 1-minute peak significance of 400σ. Maximum energy of electrons is 50 MeV, gamma rays – 45 MeV. In this context, we will explore and explain the new capabilities of the SEVAN detector installed on Zugspitze and the rearranged similar detector on Aragats. We also present and compare electron and gamma-ray energy spectra from Aragats TGE and gamma-ray energy spectrum from Zugspitze.

The new possibilities offered by SEVAN detectors give a unique opportunity for high-energy atmospheric physics and solar physics research. The recovered spectra, coupled with the ability to estimate the height and strength of intracloud electric fields, significantly advance high-energy atmospheric physics research.

Mendeley Data, V1, (2024) doi: 10.17632/z4ry54hccb.1https://data.mendeley.com/datasets/z4ry54hccb/1

“Extreme thunderstorm ground enhancements registered on Aragats in 2023

Chilingarian, Ashot; Karapetyan, Tigran; Aslanyan, Davit; Sargsyan, Balabek (2024),

We present the catalog of thunderstorm ground enhancements (TGEs) collected by 24/7 monitoring of various particle fluxes, environmental parameters, and near-surface electric fields on the slopes of Mt. Aragats in Armenia in 2023. Previously, we published the catalog of TGE events registered in Mendeley in 2013-2022. The posted dataset shows 12 parameters of 55 TGEs observed in 2023. All multivariate measurements from the hundreds of registration channels are available from the links to each TGE event. We present our measurements on a user-friendly site, allowing further correlation analysis by colleagues worldwide. The users are provided with multivariate data to continue the research and come to new interesting physical results. The survey of TGE physics and TGE selection procedure users can be found in the paper attached to the dataset, the details of Aragats station facilities, and data analysis methods in the WiKI section of ADEI, accessible from links in the dataset.

Atmospheric Research, in press, 107403, https://doi.org/10.1016/j.atmosres.2024.107403

Corrigendum to “Termination of thunderstorm-related bursts of energetic radiation and particles by inverted intracloud and hybrid lightning discharges”, Atmospheric Research, 233 (2020), 104713-104720.

A. Chilingarian, Y. Khanikyants[1], V. Rakov

The authors would like to apologize for any inconvenience caused by our conclusion on the frequency of lightning flashes of different types terminated by Thunderstorm Ground Enhancements (TGEs) and that TGEs associated with inverted IC flashes and hybrid flashes caused relatively small particle flux drops (Chilingarian et al., 2020). We recently analyzed different types of lightning flashes that terminate TGEs using a significantly enlarged data sample (163 TGE events instead of 49) observed from 2012 to 2021 (Soghomonyan et al., 2021). Our analysis of this three times larger dataset has led to results that do not support some of our previous conclusions based on smaller statistics. Therefore, we present a new analysis of the expanded database and compare our previous and current findings on the relationship between particle fluxes and lightning discharges.

Pure and Applied Geophysics, Springer Nature Switzerland AG https://doi.org/10.1007/s00024-024-03481-5

Measurements of Particle Fluxes, Electric Fields, and Lightning Occurrences at the Aragats Space-Environmental Center (ASEC)

A. Chilingarian,[1] T. Karapetyan,[1] B. Sargsyan,[1] Y. Khanikyanc,[1] and S. Chilingaryan[1,2]

[1]*Alikhanyan National Laboratory (Yerevan Physics Institute), 0036 Yerevan, Armenia*

[2] *Karlsruhe Institute of Technology, Hermann-Von-Helm- holtz-Platz, 176344 Eggenstein-Leopoldshafen, Germany.*

To catalyze transformative advancements in High- energy Physics in the Atmosphere (HEPA), a comprehensive understanding of particle fluxes, electric fields, and lightning occurrences across atmospheric layers is imperative. This paper elucidates the instrumentation and capabilities of the Aragats Space-Environmental Center (ASEC), which encompasses measurement tools for various cosmic ray species, near-surface electric fields, and lightning events integrated across high-mountain research stations at slopes of Mt. Aragats and the highest mountains of Eastern Europe and Germany. Through these measurements, we aim to elucidate models of particle acceleration mechanisms and the charge distribution within the lower atmosphere. We introduce an Advanced Data Extraction Infrastructure (ADEI) integrated with sophisticated statistical analysis tools to facilitate rapid access to this wealth of data. Despite the significance of these atmospheric processes, the intricate interplay between thundercloud electrification, lightning activity, wideband radio emissions, and particle fluxes remains poorly understood. A particularly compelling avenue of inquiry lies in exploring the relationship between high-energy atmospheric phenomena, intracloud electric fields, and lightning initiation. Furthermore, investigations into accelerated structures within geospace plasmas hold promise for shedding light on particle acceleration processes, potentially extending to higher energies within analogous structures in cosmic plasmas. This paper also examines practical methodologies for extracting meaningful physical insights from temporal datasets, such as correlating surges in particle flux intensity with variations in near-surface electric field strength and precipitation patterns. Additionally, we explore the utility of wideband field and interferometer antenna signals in this context, offering valuable avenues for further research and analysis. Through these endeavors, we aim to deepen our understanding of high-energy atmospheric processes and their broader implications for terrestrial and cosmic phenomena.

MOST CITED CRD PAPERS (17 April 2024)

KASCADE experiment

KASCADE measurements of energy spectra for elemental groups of cosmic rays: Results and open problems

T Antoni, WD Apel, AF Badea, K Bekk, A Bercuci, J Blümer, H Bozdog, ...
Astroparticle physics 24 (1-2), 1-25

865 citations

A non-parametric approach to infer the energy spectrum and the mass composition of cosmic rays

T Antoni, WD Apel, F Badea, K Bekk, K Bernlöhr, H Blümer, E Bollmann, ...
Astroparticle Physics 16 (3), 245-263

110 citations

MAGIC experiment

Variable very high energy γ-ray emission from Markarian 501

J Albert, E Aliu, H Anderhub, P Antoranz, A Armada, C Baixeras, JA Barrio, ...
The Astrophysical Journal 669 (2), 862

760 citations

Aragats experiments and data analysis papers

Methods for multidimensional event classification: a case study using images from a Cherenkov gamma-ray telescope

R.K. Bock, A. Chilingarian, M..Gaug, F. Hakl, T. Hengstebeck, M. Jiřina, ...
Nuclear Instruments and Methods in Physics Research Section A: Accelerators ...

327 citations

Ground-based observations of thunderstorm-correlated fluxes of high-energy electrons, gamma rays, and neutrons

A Chilingarian, A Daryan, K Arakelyan, A Hovhannisyan, B Mailyan, ...
Physical Review D 82 (4), 043009

279 citations

Particle bursts from thunderclouds: Natural particle accelerators above our heads

A Chilingarian, G Hovsepyan, A Hovhannisyan
Physical review D 83 (6), 062001

155 citations

Correlated measurements of secondary cosmic ray fluxes by the Aragats Space-Environmental Center monitors

A Chilingarian, K Arakelyan, K Avakyan, V Babayan, N Bostanjyan, ...
Nuclear Instruments and Methods in Physics Research Section A: Accelerators …

99 citations

Recovering of the energy spectra of electrons and gamma rays coming from the thunderclouds

A Chilingarian, B Mailyan, L Vanyan
Atmospheric research 114, 1-16

93 citations

Neutron bursts associated with thunderstorms

A Chilingarian, N Bostanjyan, L Vanyan
Physical review D 85 (8), 085017

77 citations

Thunderstorm ground enhancements—Model and relation to lightning flashes

A Chilingarian
Journal of Atmospheric and Solar-Terrestrial Physics 107, 68-76

68 citations

Statistical decisions under nonparametric a priory information

A.A. Chilingarian
Computer Physics Communications 54 (2-3), 381-390

66 citations

Aragats Space-Environmental Centre: status and SEP forecasting possibilities

A Chilingarian, K Avakyan, V Babayan, N Bostanjyan, S Chilingarian, ...
Journal of Physics G: Nuclear and Particle Physics 29 (5), 939

64 citations

Role of the lower positive charge region (LPCR) in initiation of the thunderstorm ground enhancements (TGEs)

A Chilingarian, H Mkrtchyan
Physical Review D 86 (7), 07200

59 citations

Multivariate approach for selecting sets of differentially expressed genes

A Chilingaryan, N Gevorgyan, A Vardanyan, D Jones, A Szabo
Mathematical Biosciences 176 (1), 59-69

58 citations

Types of lightning discharges that abruptly terminate enhanced fluxes of energetic radiation and particles observed at ground level

A Chilingarian, Y Khanikyants, E Mareev, D Pokhsraryan, VA Rakov, ...
Journal of Geophysical Research: Atmospheres 122 (14), 7582-7599

48 citations

On the initiation of lightning in thunderclouds

A Chilingarian, S Chilingaryan, T Karapetyan, L Kozliner, Y Khanikyants, ...
Scientific reports 7 (1), 1371

46 citations

Study of extensive air showers and primary energy spectra by MAKET-ANI detector on mountain Aragats

A Chilingarian, G Gharagyozyan, S Ghazaryan, G Hovsepyan, ...
Astroparticle Physics 28 (1), 58-71

46 citations

Structures of the intracloud electric field supporting origin of long-lasting thunderstorm ground enhancements

A Chilingarian, G Hovsepyan, S Soghomonyan, M Zazyan, M Zelenyy
Physical Review D 98 (8), 082001

41 citation

Thunderstorm ground enhancements: Gamma ray differential energy spectra

A Chilingarian, G Hovsepyan, L Kozliner
Physical Review D 88 (7), 073001

41 citations

Lightning origination and thunderstorm ground enhancements terminated by the lightning flash

A Chilingarian, G Hovsepyan, G Khanikyanc, A Reymers, ...
Europhysics Letters 110 (4), 49001

39 citations

Remarks on recent results on neutron production during thunderstorms

A Chilingarian, N Bostanjyan, T Karapetyan, L Vanyan

Physical Review D 86 (9), 093017

34 citations

Structure of thunderstorm ground enhancements

A Chilingarian, G Hovsepyan, T Karapetyan, G Karapetyan, L Kozliner, ...
Physical Review D 101 (12), 122004

33 citations

Investigations of the response of hybrid particle detectors for the Space Environmental Viewing and Analysis Network (SEVAN)

A Chilingarian, A Reymers

31 citations

On the production of highest energy solar protons at 20 January 2005

NK Bostanjyan, AA Chilingarian, VS Eganov, GG Karapetyan
Advances in Space Research 39 (9), 1454-1457

31 citations

Termination of thunderstorm-related bursts of energetic radiation and particles by inverted intracloud and hybrid lightning discharges

A Chilingarian, Y Khanikyants, VA Rakov, S Soghomonyan
Atmospheric Research 233, 104713

31 citations

GOOGLE Citation summary

(https://scholar.google.de/citations?user=_hOAVu4AAAAJ&hl=de&oi=ao)

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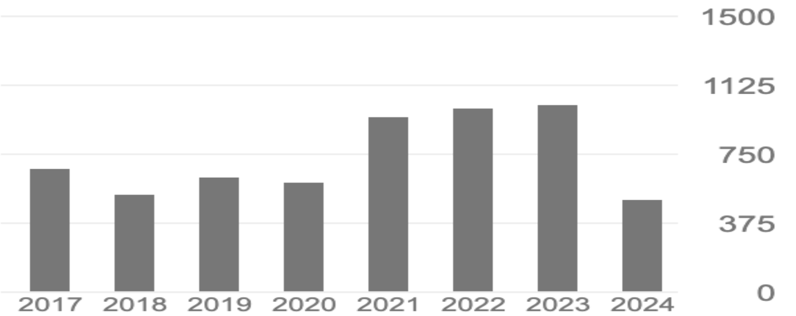


PRESS RELEASES

A.I. Alikhanyan National Science Laboratory Foundation (Yerevan Physics Institute)

PR №43 **03.01.2023**

New Discoveries of Aragats Physicists

The first years of Armenia's independence were very difficult for the staff at Yerevan Physics Institute’s Cosmic Ray Division (CRD). With funding suddenly stopped from the largest soviet ministry, there was no fuel, electricity, or food. Monthly salaries were the equivalent of five U.S. dollars. The construction of the world’s largest cosmic ray experiment, ANI, remained noncompleted. Work on the detectors ceased, and a question arose: “Is it really necessary to continue this research on Aragats? Will it be possible?” How could our research stations keep working on Mt. Aragats’ severe high-mountain winter conditions?

After a year of shock, CRD physicists adopted a realistic program for future research. They would continue measurements of high-energy cosmic rays and establish new research directions where CRD could be a world leader. They would conduct research that would not require abundant funds for constructing expensive, gigantic experiments. The key part of this program was CRD’s participation in international projects, submitting proposals for international funding, and establishing close ties with the Armenian diaspora in the USA.

These hard efforts produced positive results during the initial five years. In collaboration with Russia’s Lebedev Institute, two arrays of particle detectors were completed to measure extensive air showers of cosmic ray particles. These detectors, named “GAMMA” and “MAKET ANI,” consisted of more than three hundred scintillation detectors that measured fluxes of almost all species of cosmic rays and gigantic particle showers initiated by ultra-high-energy particles accelerated in our Galaxy and beyond.

CRD collaborated world-wide with Japan’s Nagoya University, the German nuclear centers at Karlsruhe, and the Max Plank Institute Fur Physics in Munich. CRD physicists won grants totaling $2.5 million. New particle detectors and advanced electronics were designed, fabricated, and commissioned. Modern software for data storage and for making physical inferences was created. Neutron monitors were reoperated with modern electronics at Nor Amberd and Aragats research stations at 2.0 km and 3.2 km altitudes, respectively.

In the new scientific field of solar physics and space weather research, CRD physicists produced rapid results, making important measurements, publishing their initial scientific papers, and joining the International Heliophysical Year (IHY) – managed by the UN’s Agency of Outer Space Research. CRD participated as a leading group in developing networked particle detectors to be installed in developing countries. This was one of the most successful IHY programs and is continuing, with

SEVAN[2] nodes located in Armenia, Bulgaria, the Czech Republic, Croatia, Germany, and Slovakia with a total of 10 detectors.

In 2009 CRD scientists revealed electron accelerators operated in the thunderclouds above Aragats, registering intense particle bursts from electron-photon avalanches developing in thunderous atmosphere. This physical phenomenon was called Thunderstorm Ground Enhancement – TGE, and now tens of groups around the world are registering TGE. Aragats physicists were the first to measure the energy spectra of electrons and gamma rays from particle avalanches of atmospheric origin that reach the Earth's surface.

Figure 1. Mt. Aragats, MAKET-ANI detector researching physics around the "knee", the first observation of the light and heavy Galactic nuclei energy spectra was done on Aragats.

Figure 2. ***Gagik Hovsepyan examined data from the Aragats Solar Neutron Telescope (ASNT) designed to detect neutrons from solar flares in collaboration with Professor Yasushi Muraki (Nagoya University).***

Also, for the first time, CRD scientists observed the light glows emitted during the development of electron-gamma cascades in the atmosphere, which was well correlated with the high-energy electron flux registered by surface particle detectors. Thus, they first discovered TGE phenomena by detecting simultaneous fluxes of high energy electrons, gamma rays, and neutrons; then, they observed Relativistic Runaway Electron Avalanches (RREA) by detecting particle showers coming from the clouds. Subsequently, they proved the existence of the lower dipole that accelerated electrons toward the Earth's surface. Simulations of electron propagation in the strong atmospheric electric fields and estimation of the maximum voltage in the charged atmosphere reveal the origin of this phenomenon. Then, CRD presents a comprehensive model of TGEs and evidence of RREA's origination in the atmosphere. Simultaneously, Bulgaria, Croatia, Czech Republic, Germany, and Slovakia, all using SEVAN detectors, contributed to a better understanding of the high-energy physics in the atmosphere. They also contributed to studying vertical profiles of the strong electric fields in thunderclouds and modulation of the different species of cosmic rays into these fields.

Figure 3: Bagrat Mailyan, Gagik Hovsepyan, Levon Vanyan, Ashot Chilingarian, Nikolaj Bostanjyan (CRD physicists), the group that received Armenia president prize for achievements in establishing high-energy atmospheric physics, 2012.

CRD's SEVAN detectors are unique devices that can observe the modulation of particle fluxes due to violent outbursts from the Sun, forecast dangerous consequences of space weather, and perform wide research programs in the fundamental aspects of atmospheric physics.

The operation of the SEVAN network in 2021-2022 revealed new exciting results. Electron energy spectra indicate very large electric fields (of up to 200 kV/m) near the Earth's surface (50-150 m), which can affect the safety of rocket launches and aircraft operations during thunderstorms. On September 12, 2021, the SEVAN detector on Lomnicky Štít (Slovakia) measured a 500% enhancement of particle fluxes. The largest TGE, with particle fluxes exceeding the normal rates by 100 times, was also measured by the Slovakian SEVAN detector in 2017. With installing SEVAN light detectors on Zugspitze, the highest peak in Germany, in April, SEVAN detectors will occupy the highest peaks in Eastern Europe. They will monitor the consequences of violent space and atmospheric storms. SEVAN light will have the possibility to measure the energy spectra of neutral particles. Thus it will be the second destination to access the energy spectra of TGEs and solar neutrons!

Now, research on Aragats encompasses the most interesting aspects of fast-developing atmospheric, solar, and high-energy physics. This includes cosmic ray origin, solar-terrestrial connections, solar modulation of galactic cosmic rays, space weather, acceleration of particles on the sun, high-energy physics in the atmosphere, lightning physics, and multivariate data analysis. Particle fluxes measured by spatially scattered networks and information from satellites provide experimental data on the Sun's most energetic processes and the Earth's atmosphere. This will become an important element of global space weather monitoring and forecasting services

PR №44. ***6.02.2023***

Climb to Aragats (Duty shift change in February)

The Aragats Cosmic Ray observatory, used for studying particle acceleration in outer space and the terrestrial atmosphere (see attachment), is located at an elevation of 3200 m. asl (above sea level) on the shore of Kare Lake (Kari Lij). Strong winds, predominantly from west to northwest, relocate large amounts of unconsolidated winter snow, accumulating on the sheltered sides of sharp edges in the terrain. There, snow is deposited in cornices that may reach 10 m. in thickness. Thus, special vehicles are needed to rotate the staff each month. Although the machinery is new and well maintained, the weather conditions make the staff change difficult. Sometimes this takes several days. Due to abundant snow, the climb on 1 February 2023 took 14 hours, and only in the evening, with the help of a tractor (see Fig.1), did the new duty staff reach Aragats Station. The next day, snowfall was so intense that the drivers decided to wait until the snow stopped before returning. Meanwhile, drivers and technicians changed the oil and cabling for a new diesel generator, a reserve energy source for emergencies (see Fig. 2). Only on the next day did the old duty shift, with great difficulty, reach the Nor Amberd station at 2000 m. asl (see Fig. 3). They were transported to their homes the same day.

Figure 1. Tractor risqué stuck in the snow next to the Ohara all-terrine vehicle

Figure 2. Aragats staff near the new diesel generator, from left to right: technicians: Avagyan Serega, Asatryan Karen, Gabaryan Gurgen, drivers: Karapetyan Ara, and Hunanyan Samvel

Figure 3. Before leaving the Aragats station on February 3

SEVAN detector installed on Zugspitze in Bavarian Alps

Armenian and German SEVAN groups established the SEVAN module at the Environmental research station Scheefernhaus (Zugspitze, 2650 m). A historical site where Johim Kuettner performed seminal experiments on the charge structure of the thundercloud in 1945-1949. The near-surface electric field (NSEF) measurements will support particle flux measurements with the EFM-100 sensor installed nearby. The NSEF measurements will highly improve the research of particle-atmosphere relations, which is on top of atmospheric physics research. The highest mountains in Armenia, Bulgaria, Germany, Slovakia, and Czechia monitor enhanced particle fluxes and atmospheric charging to understand electron acceleration and lightning origination. This information is inevitable for solar physics, space weather, solar-terrestrial connections, and Earth numerical models.

Figure 1. European SEVAN network loins mountain and sea level detectors

Figure 2. On April 18, the weather at Zugspitze was severe

Figure 3. The final location of the SEVAN module in Kugelhime, where ≈10 other neutron detectors are operated

PR№ 46 *18.09.2023*

The visit of delegations of CANDLE SRI and the Joint Institute for Nuclear Research (JINR), Dubna, Russia, to Aragats Research Station of Yerevan Physics Institute

On September 15th, Bagrat Grigoryan, the director of CANDLE, along with Oleg Belov and Ksenya Belokopitova, senior scientists of the applied research department of NICA accelerator, JINR, Dubna, visited the Aragats Research Center. Professor Chilingarian, the head of the Cosmic Ray Division, introduced them to the station's ongoing research. He demonstrated and explained the experimental facilities and answered numerous questions.

During the visit, the group discussed possible mutual cooperation. The main areas of interest are the measurement of natural gamma ray radiation and Thunderstorm ground enhancements (TGE), a new physical phenomenon discovered by CRD scientists. TGE refers to a huge flux of gamma rays and electrons generated by electron accelerators operated in thunderous atmospheres.

From left to right: Oleg Belov, Ashot Chilingarian, Maria Avetisyan, Kseniya Belokopitova, Zaruhi Asaturyan, Bagrat Grigoryan at Aragats Research Center

PR№ 47 *8.10.2023*

Czech Academy of Science in Prague hosted the 9th edition of the TEPA Conferences.

From the 2nd to the 5th of October, the Czech Academy of Science in Prague hosted the 9th edition of the TEPA Conferences: Thunderstorms and Elementary Particle Acceleration. Over the last decade, high-energy physics in the atmosphere (HEPA) has undergone significant transformation. Correlated measurements of particle fluxes modulated by strong atmospheric electric fields, simultaneous measurements of the disturbances of the near-surface electric fields, and registration of various meteorological parameters on the Earth have led to a better understanding of the complex processes in the terrestrial atmosphere.

The conference reports present the largest-ever particle fluxes detected at Lomnicky Stit and Aragats, showing the success of the first TGE research campaign on the mountaintops in Eastern Europe and

Armenia. These extreme events shed light on the entire HEPA scientific field and indicate that thunderstorm ground enhancements (TGEs) are a universal physical phenomenon originating by the natural electron accelerator in the thunderous atmosphere.

Scientists in many countries are monitoring particle fluxes around the clock using synchronized networks of advanced sensors that record and store multidimensional data. Reports from Japanese, Indian, German, Swiss, Czech, and Armenian physicists have shed new light on the terrestrial atmosphere full of radiation. These reports will help establish a comprehensive cloud electrification theory and estimate cloud radiation's possible role on climate change.

The TEPA meeting is an opportunity for scientists to discuss current ideas and exploit synergies between Atmospheric and Cosmic ray physics.

Mileshovka Hill: after climbing on the highest peak in the Bohemian Central Mountains. SEVAN detector 24/7 operates already 5 years, providing valuable data to Czech physicists

Balabek Sargsyan speaks about positron acceleration in thunderclouds and bursts of Natural gamma radiation. Session chair Tigran Karapetyan.

PR №48 ***23.10.2023***

Fifteen years of research in High-energy Physics in the Atmosphere
The number of citations to the first 2 HEPA publications reached 400

Mt. Aragats, located 3200 meters above sea level, near the southern peak on the beach of the large Kari Lake, is home to one of the world's biggest high-altitude cosmic-ray research stations. Physicists have been studying cosmic ray fluxes on Mt. Aragats since 1942 using various particle detectors such as mass spectrometers, calorimeters, transition radiation detectors, and particle detector arrays detecting particle cascades initiated by protons and nuclei accelerated in most explosions in the galaxy. The latest research at Mt. Aragats focuses on the origin and acceleration mechanisms of the galactic cosmic rays, space weather, and solar proton accelerators. In 2008, after finishing experiments with galactic and solar cosmic rays High-energy physics in the atmosphere (HEPA) became the main topic of CRD research. Since 2008, particle detectors of the Aragats Space Environmental Center (ASEC) have continuously registered fluxes of charged and neutral particles using various particle detectors located on the slopes of Aragats. Thunderstorm activity on Aragats is extreme in May - June. Thunderclouds are usually below the southern peak (i.e., not higher than 500 m above ground level) and sometimes only 25–50 m above the station. As a result, the most energetic TGEs can contain many avalanche electrons, allowing recovery of the electron energy spectrum. The primary research goal, TGE research, was established with continuous monitoring of cosmic rays for

15 years, and just the first papers published by CRD scientists in 2010 and 2011 already contain valuable information on new physical phenomena, with a number of citations reaching now 400 (according to Google Scholar). The main results of CRD physicists in HEPA include:

- Registration of more than 600 TGEs minute-long fluxes of electrons, gamma rays, and rarely neutrons [3].
- Measurement of energy spectra of electrons and gamma rays [4,5]
- Discovery of Radon circulation, muon-stopping, and positron acceleration effects.
- This study revealed the thundercloud's charge structure, estimated the maximum potential drop above Aragats and Lomnicky Stit research stations, and clarified the horizontal extent of atmospheric electric fields.
- Revealing the cloud charge structure and the role of lightning discharges on particle fluxes.
- Performing simulations of runaway process, verifying it with recovered energy spectra and count rates of ASEC detectors.
- Clarifying the influence of atmospheric electric fields on estimating the energy of galactic cosmic rays by large surface arrays.
- The first TGE registration campaign was performed on the highest mountain tops of Eastern Europe, Germany, and Armenia by SEVAN detectors network.

These and other results, published in 80 papers, have helped to understand the mechanism of TGE origination in strong atmospheric electric fields establishing the HEPA scientific discipline.

Aragats research station of Yerevan Physics Institute near Kare Lake and South peak of Aragats

REFERENCES

1. Chilingarian, A. Daryan, K. Arakelyan, A. Hovhannisyan, B. Mailyan, L. Melkumyan, G. Hovsepyan, S. Chilingaryan, A. Reymers, and L. Vanyan, Ground-based observations of thunderstorm-correlated fluxes of high-energy electrons, gamma rays, and neutrons, Phys. Rev. D 82, 043009 (2010).
2. Chilingarian A., Hovsepyan G., and Hovhannisyan A., Particle bursts from thunderclouds: Natural particle accelerators above our heads, Physical Review D 83, 062001 (2011).
3. Chilingarian, G. Hovsepyan, D. Aslanyan, T. Karapetyan, Y. Khanikyanc, L.Kozliner, B. Sargsyan, S.Soghomonyan, S.Chilingaryan, D.Pokhsraryan, and M.Zazyan (2022) Thunderstorm Ground Enhancements: Multivariate analysis of 12 years of observations, Physical Review D 106, 082004 (2022).
4. Chilingarian, G. Hovsepyan, T. Karapetyan, D. Aslanyan, S. Chilingaryan, and B. Sargsyan, Genesis of thunderstorm ground enhancements, Physical Review D 107, 102003 (2023).
5. Chilingarian, A., Hovsepyan, G., Aslanyan, D., Karapetyan, T., Sargsyan, B., & Zazyan, M. (2023). TGE electron energy spectra: Comment on “Radar diagnosis of the thundercloud electron accelerator” by E. Williams et al. (2022). Journal of Geophysical Research: Atmospheres, 128, e2022JD037309

PR №49 ***27.10.2023***

The Cosmic Ray Division of the A. I. Alikhanyan National Science Laboratory has been accepted as an associate member of the “Virtual Alpine Observatory (VAO)”

Munich, 26 October: Johannes Knapp, representing the Cosmic Ray Division, receives the VAO accession certificate from the Chair of the VAO board, Prof. Dr. Michael Krautblatter.

With already well-established institutions in the Alpine and Prealpine regions, such as the observatories Sonnblick (Austria), Jungfraujoch/Gornergrat (Switzerland), UFS Schneefernerhaus (Germany), Otlica (Slovenia), EURAC Research (Italy) and OSUG (France) outstanding research infrastructures have joined up to form the VAO. The VAO

aims to give coherence to the research efforts of partner organizations and thus maximize scientific outputs. Laboratories at mountain tops allow a variety of research topics. A SEVAN Network detector has been operating since May 2023 at the UFS Schneefernerhaus on the Zugspitze.

CRD operates its high-altitude research laboratory in Armenia with several research stations on the slopes of the standing-alone Aragats Mountain (4090 m asl, the highest mountain in Armenia) south of the Caucasus Mountains range. In 1943, one of the world's largest high-mountain research stations was established on Mt. Aragats at 3,200 m. elevation. Since then, expeditions on Aragats have continued uninterruptedly. Currently, physicists of the Cosmic Ray Division of the Yerevan Physics Institute, with re-equipped and renewed facilities, continue their research in galactic and solar cosmic rays, solar-terrestrial connections, high-energy atmospheric physics, and space weather.

Within the VAO (https://www.vao.bayern.de), coordinated research and development projects will be executed with other VAO partners in international networks and research programs, data will be exchanged, experiences will be shared, and joint outreach and training projects will be conducted (e.g., for university and high-school students, teachers training, summer schools, training and exchange of young scientists).

PR №50 ***30.11 2023***

The Electric Line Is Repaired on Aragats

The Aragats High Altitude Research Station, located at an altitude of 3200m, is a part of the A. Alikhanyan National Lab. The primary objective of the research conducted here by Cosmic Ray Division (CRD)is to monitor various species of cosmic rays, which helps identify the modulation of flux by solar, atmospheric, and galactic sources. The study also focuses on predicting and alerting about the dangerous consequences of weather in space and on Earth. Therefore, the numerous detectors and field meters must operate 24/7. The winter weather conditions can be quite severe than in Yerevan, with snowstorms often blocking the staff from going outside for several days and strong winds cutting off the 35 kV electricity supply lines.

On November 29th, the staff of the Cosmic Ray Division carried out repairs on the electric lines of the five nearby masts. Tigran Karapetyan, Balabek Sragsyan, Ararat Simonyan, Ara Karapetyan, and Gurgen Jabaryan worked hard and restored the electricity supply to the station.

Figure 1. The highly qualified electrical engineer Ararat Simonyan, who had emigrated from Stepanakert, completed his first day at CRD. The electricity reaches the station!

Figure 2. The sunny day helped us finish the repairs during the day.

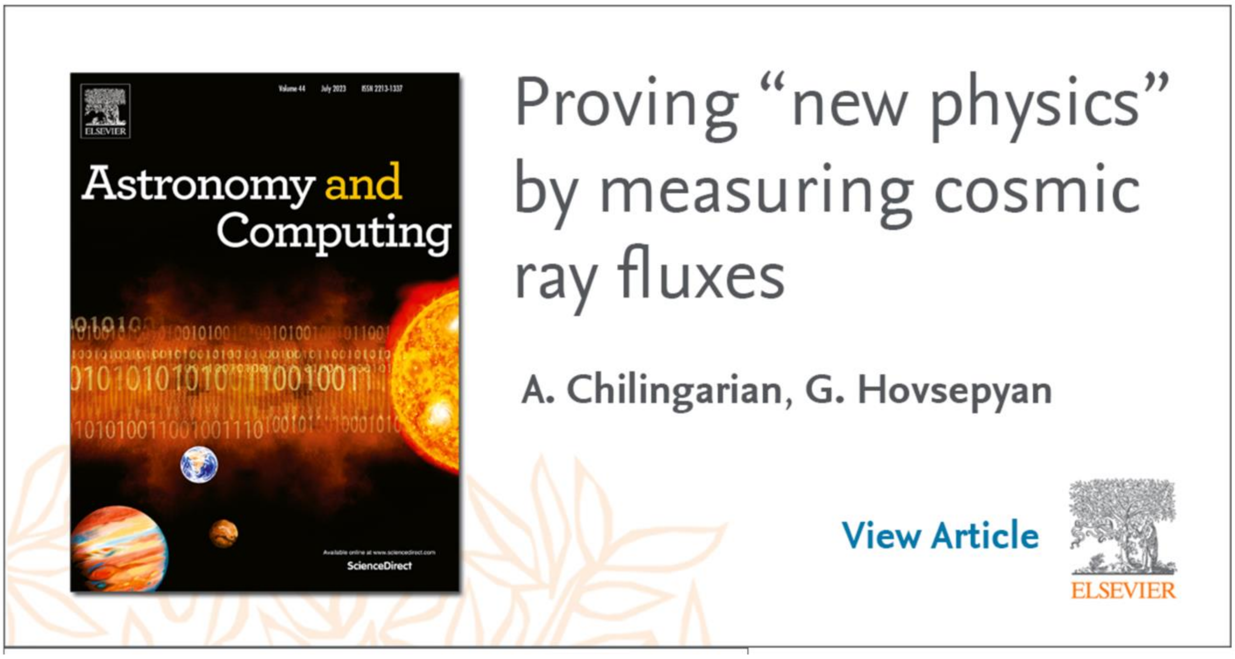
Figure 3. Climbing the mast

Figure 4. Ararat mountain as seen from Aragats

HIGHLIGHTED ARTICLES

20 November 2023

NEW PHYSICS REVEALED BY MEASURING COSMIC RAYS AS THEY BOMBARD EARTH



Credit: Robert Lea

NEW RESEARCH SUGGESTS ANALYSING DIFFERENT SPECIES OF COSMIC RAY FLUX CAN REVEAL UNDERLYING PHYSICAL PROCESSES

Earth is under non-stop bombardment by charged particles from space originating from powerful events such as violent stellar explosions and the merging of ultradense objects like neutron stars; these particles are called cosmic rays.

These cosmic rays consist of particles such as electrons, neutrons, muons, and neutrinos and radiation-like gamma-rays, and have been measured on Earth for around a century using a range of detectors. Even as cosmic ray detectors have improved in sophistication, measurement errors, meteorological conditions, and disturbances of electrical and geomagnetic fields can still significantly impact cosmic ray fluxes. This occasionally leads researchers to correlate their detection rates with events such as violent solar burst, lightning strikes, and even changes in the atmospheric pressure.

Thus, distinguishing deep peaks in the cosmic ray count rates from atmospheric, instrumental, and astrophysical effects is incredibly important for establishing the causes of changes in flux.

In a new paper in Astronomy and Computing, astrophysicists Ashot Chilingarian and Gagik Hovsepyan both of the Yerevan Physics Institute, Armenia, demonstrate how analysing different types of cosmic ray flux can reveal their underlying physical processes. The duo also present a method to verify that measurements are not due to things like changes in atmospheric conditions but are evidence of a novel physical phenomenon.

"We perform all necessary calibrations and simulations to understand the response of detectors to charged and neutral fluxes. We performed simulations of primary particle transport in the atmosphere and the electric field," Chilingarian explained. "Only after

knowing the response function of the detector, all experimental errors and accuracies, and sensitivity to different fluxes is it possible to draw physical inferences and construct the models and theories of cosmic ray flux."

Chilingarian explained that multisensory registration of neutral and charged fluxes, along with electric field and lightning distance from the detector, weather parameters, and pictures of skies above the detector, allowed Hovsepyan and himself to make a comprehensive model of a new physical phenomenon enhancing cosmic ray flux detection-namely electron accelerators operating in thunderclouds.

This surprised Chilingarian, who knows much about misidentifying the cause of particle fluxes. When he first detected a huge enhancement in particle count rates lasting around 10 minutes in September 2009, he first attributed it to something exotic and distant only to find its cause was closer to home. However, when in May 2023 another huge event occurred, it was registered in all detail with numerous new detectors operated on Aragats Cosmic Ray Research Station. Furthermore, due to new advanced facilities, it was possible for the first time to get inside a space-temporal pattern of enhanced particle fluxes on nanosecond time scales.

"I was really surprised and looked for a supernova explosion. However, finally, we found that it was an electron accelerator operated just over our heads in a storm and sending copious electrons and gamma rays to our detectors," Chilingarian said. "We proved the origin of electron acceleration- runaway electron avalanches, the dipole that accelerates electrons, the height of the accelerator in the cloud, and how the electric field influences muon and positron fluxes."

The duo have estimated strong electric fields at altitudes of between 50 metres and 100 metres over Earth but would now like to make direct measurements of electric fields in thunderclouds using drones.

"It will be a ground-breaking result if we succeed in measuring the electric field in the cloud simultaneously with particle flux on the ground," Chilingarian concluded. "New physics comes when you ensure reliable and non-stop operation of your experimental complex for years. Sure, first comes the idea of experiment; you have to understand what and how to measure. However, sometimes discoveries come by accident."

Article details:

A. Chilingarian., G. Hovsepyan., 'Proving "new physics" by measuring cosmic ray fluxes' Astronomy and Computing (2023)

From measurement to knowledge

INSTALL YOUR DETECTOR ON MOUNT ARAGATS

(Open Competition)

The Cosmic Ray Division of A. I. Alikhanyan National Laboratory, the world's biggest high-altitude cosmic ray research station for monitoring cosmic ray fluxes, declares open competition for a project in High-energy Physics in the Atmosphere (HEPA) to be performed on Aragats, see Fig.1. Aragats is a unique place for HEPA research. Each year, in May-June and September-October, tens of intense TGEs (Thunderstorm ground enhancements) covered the particle detectors with millions of electrons and gamma rays (rarely by neutrons). However, proposals for atmospheric and environmental physics experiments will also be considered. We will approach this through a multivariate, multidisciplinary analysis of physical phenomena, measuring all relevant parameters.

The competition mirrors how researchers propose to use the built, especially for this competition laboratory's unique facilities. The laboratory (9 m^2 area) is equipped with an electric field sensor, a weather station, and two all-sky cameras, see Fig. 2. The mentioned facilities will be provided to the winning projects for multivariate research of Atmospheric physics phenomena, including registration of the Thunderstorm ground enhancements (TGEs), air glows, electric fields, lightning occurrences, natural gamma radiation, and other environmental studies. Researchers/students can add particle detectors, photometers, high-speed cameras, and other equipment for their experiments. Standard data-acquisition (DAQ) electronics and online computers are anticipated to be a part of the installed facility. Multiple particle and spectrometers, weather stations, and geomagnetic and near-surface electric field monitoring systems operated on Aragats station can be used to calibrate newly installed facilities. CRD will provide the Internet connection, database, and analysis platform for storing and accessing data.

The unexpected rise of solar activity points to reaching the solar maximum in 2024. After a long period of quiet Sun and a rather small 24^{th} solar activity cycle, research of near-earth environments affected by huge magnetized clouds ejected from the Sun again became relevant. The nonlinear interaction between disturbed interplanetary magnetic and geomagnetic fields causes various effects in geospace, ranging from damage to satellite electronics and some surface industries to the beautiful Aurora Borealis. The cosmic rays are messengers bringing direct information on these complex processes. Networks of particle detectors 24/7 monitoring the intensities of cosmic rays' incidents on the Earth's surface are an important addition to the spaceborne particle detectors operated by NOAA, NASA, ESA, and other space agencies. Recently, we reported observing the very rear Geomagnetic effect measured by particle detector networks operated on middle latitudes on mountain tops. For the first time, we measured the energy spectrum of the Geomagnetic effect, confirming its physical model. Thus, we also welcome proposals related to research in Solar physics and Space weather. Please feel free to submit your proposals.

Proposals will be judged based on motivation and creativity, and the winning team will have the chance to discuss and tune their project ideas with CRD researchers before installing their facilities on Aragats. They will be invited to spend one week at Aragats (in June-August) for their experiment, with the unique opportunity to join the CRD team. The results are supposed to be summarised in a report and presented at the upcoming TEPA conferences. Students will be invited to attend planned summer school.

Projects in free format, including all proposed facility specifications, should be provided to CRD by 1 March 2024. All correspondence should go to Asaturyan Zara, zaraasaturyan.87@gmail.com. The winners will be declared on March 15, 2024.

Links to the CRD site and CRD publications:http://crd.yerphi.am/

http://crd.yerphi.am/crd_publications

Figure 1. All four peaks of Aragats, Kare Lake, and Aragats high altitude research station located at an altitude of 3200 m.

Figure 2. Experimental Laboratory provided to the winner projects