2022 CRD report
Main achievements, directions of research, plans.
List of publications and conference reports

The high-altitude research stations at Aragats and Nor Amberd of the A. Alikhanyan National Lab, with its unique equipment for monitoring particle fluxes, electric fields, environmental parameters, lightning location, and atmospheric discharges provide possibilities for advanced multisensory research in the following areas of Astroparticle physics:

- Cosmic ray origin and acceleration mechanisms.
- Solar-terrestrial connections; solar modulation of galactic CRs.
- Space weather.
- Operation of particle accelerators on the Sun.
- High-energy physics in the Atmosphere (HEPA).
- Thunderstorm Ground Enhancements (TGEs).
- Monitoring of the radiation environment.
- Research of the vertical and horizontal profiles of the atmospheric electric field;
- Influence of the atmospheric electric field on the operation of the Atmospheric Cherenkov Telescopes and particle arrays registering extensive air showers.
- Lightning physics.
- Measuring and storing datasets of geophysical parameters for the global change monitoring.
- Scientific instrumentation.
- Multivariate data analysis, including Bayesian and neural network models.

The newly emerging field of HEPA (with most efforts in the last decade) comprises various physical processes extended to many cubic kilometers in thunderclouds and many hundred cubic kilometers in space. CRD scientists have discovered mechanisms and characteristics of short particle bursts and long-lasting particle multiplication and acceleration produced within thunderstorms and for the first time have measured the energy spectra of electrons and gamma rays of particle avalanches of atmospheric origin that reach the Earth surface. Also, for the first time, we observed the light glows emitted during the development of electron-gamma ray cascades in the atmosphere, which were well correlated with the high-energy electron flux registered by surface particle detectors. Thus, first, we specified TGE phenomena by detecting simultaneous fluxes of high energy electrons, gamma rays and neutrons; then we observe relativistic runaway electron avalanches (RREA) by detecting particle showers coming from the clouds (extensive cloud showers), next we proved the existence of the lower dipole that accelerated electrons downward. Afterward, we performed simulations of the electron propagation in the strong atmospheric electric fields, and estimate maximum potential drop (voltage) in the thunderous atmosphere, proving the origination of the runaway phenomena; and only then do we present a comprehensive model of TGE and evidence of RREA origination in the thunderous atmosphere.Germany, Slovakia, Czech Republic, Bulgaria, and Croatia, all using

detectors of the SEVAN type (made by CRD), contribute to a better understanding of the variations of secondary cosmic rays, as well as for the study of vertical profile in electron-positron and gamma components produced during thunderstorms. The SEVAN detector is a unique device that can observe modulation of particle fluxes due to violent bursts on the Sun, forecast dangerous consequences of the Space weather, and perform wide research program in the fundamental aspects of the atmospheric physics.
During the last decade, the research in high-energy physics in the atmosphere was mostly concentrated on measuring the particle fluxes from the electrified atmosphere (thunderstorm ground enhancements, TGEs, and Terrestrial gamma flashes, TGFs) and revealing their origin. In 2021 we started the research of the atmospheric electric fields with particle fluxes traversing thunderstorms and being registered on the Earth surface with particle spectrometers. We use particle fluxes for screening of a thunderous atmosphere (like X-ray screening). This new approach gives very interesting results, sometimes contradicting the commonly held views on the vertical profile of atmospheric electric field, but supported by the exact methods of particle physics and well-established theories of electromagnetic interactions.
Proceeding from developed methodology, we establish a model of electron acceleration in strong atmospheric electric fields. Comparison of measured and simulated fluxes of electrons and gamma rays on Aragats (with simplified models of the vertical electric field profile) demonstrates that RREAs developing in the atmosphere are resulting in the TGEs with a rather broad range of parameters. Then, using the largest TGEs observed on Aragats and Lomnicky Stit, we estimated the maximum achievable potential drop (voltage) on these summits to be 300 and 500 MV, respectively. Afterward, we use the modulation of the "muon beams" by strong atmospheric electric fields to disclose the "muon stopping effect" and deduce from it the disturbances of the atmospheric electric field. Finally, with the 24/7 operation of the Solar neutron spectrometer (ASNT), we derive a simple equation for estimating the height of the strong electric field above the earth's surface. The correlation analysis of the TGEs and the distances to the lightning showed that the TGE particle flux is much higher than was anticipated. The particle flux in the thunderous atmosphere, most of which reach the Earth surface comprises $\approx 10^{18}$ particles per second with energies above 100 keV. Such abundant radiation can affect terrestrial climate and global climate change.
The synergy of cosmic ray and atmospheric physics can become a leading direction in atmospheric physics research explaining all types of particle bursts in one framework, i.e., as consequences of extensive air shower fluxes. Spectra measured in 2019-2021, indicate very large electric fields (of up to 200 kV/m) near the Earth surface (50-150 m), which can affect the safety of rockets launches and aircraft operation during thunderstorms. The operation of the SEVAN network in 2021-2022 reveal new exciting results. On September 12, 2021 the SEVAN detector on Lomnicky Štít (Slovakia) measured a 500% enhancement of low-energy thunderstorm ground enhancements (TGE). The world-largest TGE, with particle fluxes exceeding the normal rates by 100-times, also was measured by the Slovak SEVAN detector in 2017. The Croatian SEVAN detector was used in the study of a relationship between the heliospheric magnetic field, atmospheric electric field, lightning activity, and secondary cosmic rays flux measured on Lomnický Štít.

In 2022 CRD physicists continue the research program approved by the international advisory board of the ASEC collaboration (chair: Dr. Johannes Knapp from DESY). See the main points of the program below. Fluxes of electrons, photons, and muons and also weather parameters are continuously monitored at all sites (different latitudes, longitudes, altitudes) and entered into the CRD databases. Physicists from all participating countries can use the multivariate visualization and correlation analyses (provided on the ADEI platform at the CRD servers) for their own and for collaborative work. Now besides CRD data bases, the multiyear data from the Aragats detectors is exposed in the publicly available Mendeley datasets, now contained also databases on TGE electron spectra and coincident images of light glows registered by panoramic cameras on Aragats. The Mendeley databases of optical emissions in the lower atmosphere, and short particle bursts registered by Aragats neutron monitor. These datasets contain long writeups, and links to databases, allowing the HEPA community to use measurements from Aragats for the investigation of a wide variety of atmospheric physics problems. In 2022 we published a series of papers in the CERN-based Instrumentation journal (JINST) with a detailed description of the networks of particle detectors and field meters used in the last decade for measurements of the enhanced particle fluxes during thunderstorms. Special attention was given to demonstrating how we measure energy spectra of TGE electrons with the ASNT scintillation spectrometer, a crucial measurement for HEPA.

Publications 2022

1. Chilingarian, G. Hovsepyan, T. Karapetyan, B. Sarsyan, and S. Chilingaryan, Measurements of energy spectra of relativistic electrons and gamma-rays avalanches developed in the thunderous atmosphere with Aragats Solar Neutron Telescope, Journal of Instrumentation, 17 P03002 (2022), https://doi.org/10.1088/1748-0221/17/03/P03002.
2. A.Chilingarian, G. Hovsepyan, The synergy of the cosmic ray and high energy atmospheric physics: Particle bursts observed by arrays of particle detectors, New Astronomy, 97 (2022) 101871, https://doi.org/10.1016/j.newast.2022.101871
3. A.Chilingarian, G. Hovsepyan, T. Karapetyan, Y. Khanykyanc, D. Pokhsraryan, B. Sargsyan, S. Chilingaryan and S. Soghomonyan, Multi-messenger observations of thunderstorm-related bursts of cosmic rays, 2022 JINST 17 P07022
4. A.Chilingarian, G.Hovsepyan, T.Karapetyan, B.Sargsyan, and M.Zazyan, Development of the relativistic runaway avalanches in the lower atmosphere above mountain altitudes, EPL, 139 (2022) 50001, https://doi.org/10.1209/0295-5075/ac8763
5. Ashot Chilingarian Gagik, Hovsepyan, Tigran Karapetyan, Balabek Sargsyan, and Ekaterina Svechnikova, Transient Luminous Events in the Lower Part of the Atmosphere originated in the Peripheral Regions of a Thunderstorm, Universe, 2022, 8, 412. https://doi.org/10.3390/universe8080412
6. 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, Phys. Rev. D, 2022, in press
7. A.Chilingarian, G. Hovsepyan, T. Karapetyan, L. Kozliner, S. Chilingaryan. D. Pokhsraryan and B. Sargsyan, The horizontal profile of the atmospheric electric fields as measured during thunderstorms by the network of NaI spectrometers located on the slopes of Mt. Aragats, 2022, *JINST* **17** P10011.

8. A.Chilingarian, Ashot, Hovsepyan, Gagik (2022), Dataset for 16 parameters of ten thunderstorm ground enhancements (TGEs) allowing recovery of electron energy spectra and estimation the structure of the electric field above earth’s surface, Mendeley Data, V1, doi: 10.17632/tvbn6wdf85.2
9. Soghomonyan, Suren; Chilingarian, Ashot; Pokhsraryan, David (2021), “Extensive Air Shower (EAS) registration by the measurements of the multiplicity of neutron monitor signal”, Mendeley Data, V1, doi: 10.17632/43ndcktj3z.1
10. Chilingarian, G. Hovsepyan, T. Karapetyan, B. Sargsyan, D.Aslanyan, and M.Zazyan (2022) TGE electron energy spectra: Comment on “Radar Diagnosis of the Thundercloud Electron Accelerator” by E. Williams et al. (2022), submitted to JGR
11. A Chilingarian, G Hovsepyan, M Zazyan, Sinergy of extra-terrestrial particle accelerators and accelerators operated in the terrestrial atmosphere, Journal of Physics Conference Series, in press.
12. A Chilingarian, G Hovsepyan, T Karapetyan, and B Sargsyan and M Zazyan, On the vertical and horizontal profiles of the atmospheric electric field during thunderstorms, Journal of Physics Conference Series, in press.
13. Зазян М.З, Овсепян Г.Г., Чилингарян А.А, Взаимовлияние внеземных ускорителей и ускорителей, работающих в земной, Известия РАН, сер. Физическая, в печати
14. Овсепян Г.Г., Чилингарян А.А, Энергетические спектры легких частиц первичных космических лучей в диапазоне энергий от 10 ТэВ до 100 ПэВ, Известия РАН, сер. Физическая, в печати

Conferences 2022

1. T.Karapetyan, B.Sargsyan, A.Chilingaryan, SEVAN network report -2022, Annual meeting of the International Space Weather Initiative (ISWI) of the United Nations Committee on the Peaceful Uses of Outer Space, 11 February 2022, Vienna UN headquarters, https://www.unoosa.org/oosa/en/ourwork/psa/bssi/iswi.html
2. A.Chilingarian, How Energy spectra of TGE electrons help to reveal the atmospheric electric field in the lower atmosphere, Workshop on Thunderstorm Radiation, Prague, April 1, 2022.
3. A.Chilingarian, Ground-based facilities for the correlated study of particle bursts, lightning occurrences, and light glows, NASA Workshop on Lightning-Related Research Beyond the Troposphere • May 2-3, 2022
4. A.Chilingarian, G.Hovsepyan, Energy spectra of the TGE electrons and estimation of the structure of the electric field in the lower atmosphere, General Assembly of the European Geophysical Union, Vienna, 23-27 May 2022.
5. A.Chilingarian, S.Soghomonyan Atmospheric Electricity, Thunderstorms, Lightning and their effects, General Assembly of the European Geophysical Union, Vienna, 23-27 May 2022.
6. A.Chilingarian, G.Hovsepyan, On the strength of atmospheric electric field during thunderstorm ground enhancements (TGEs), 17th International Conference on Atmospheric Electricity (ICAE 2022), June 19-24, Tel Aviv.

7. A.Chilingarian, G. Hovsepyan, L.Kozliner, Charge distribution in the thundercloud, electron acceleration, and lightning initiation, 17th International Conference on Atmospheric Electricity (ICAE 2022), June 19-24, Tel Aviv.
8. A.Chilingarian, B.Sargsyan, On the nature of the optical emission during intense electron fluxes in the low atmosphere, 17th International Conference on Atmospheric Electricity (ICAE 2022), June 19-24, Tel Aviv.
9. Чилингарян А., Овсепян Г., Энергетические спектры легких и тяжелых первичных космических лучей в диапазоне энергий от 10 ТэВ до 100 ПэВ, 37 Всероссийской конференции по космическим лучам (Москва, 27.06 – 1.07.2022).
10. Зазян М.З., Овсепян Г.Г., Чилингарян А.А., Интерференция внеземных ускорителей частиц и ускорителей, работающих в земной атмосфере, 37 Всероссийской конференции по космическим лучам (Москва, 27.06 – 1.07.2022).
11. Чилингарян А., Овсепян Г., Карапетян Т., Саркисян Б., Свечникова Е., Переходные световые события в нижней части атмосферы, возникающие в периферийных областях грозы, 37 Всероссийской конференции по космическим лучам (Москва, 27.06 – 1.07.2022).
12. Саргасян Б., Циркуляция продуктов радона в земной атмосфере во время гроз, 37 Всероссийской конференции по космическим лучам (Москва, 27.06 – 1.07.2022).
13. Чилингарян А., Модуляция космических лучей электрическими полями грозовых облаков, 37 Всероссийской конференции по космическим лучам (Москва, 27.06 – 1.07.2022).
14. A Chilingarian, G Hovsepyan, M Zazyan, Sinergy of extra-terrestrial particle accelerators and accelerators operated in the terrestrial atmosphere, ATmospheric MOnitoring for High Energy Astroparticle Detectors (AtmoHEAD 2022), Island of Capri (NA) – Italy, July 13th - 15th, 2022
15. A Chilingarian, G Hovsepyan, T Karapetyan, and B Sargsyan and M Zazyan, On the vertical and horizontal profiles of the atmospheric electric field during thunderstorms, ATmospheric MOnitoring for High Energy Astroparticle Detectors (AtmoHEAD 2022), Island of Capri (NA) – Italy, July 13th - 15th , 2022.
16. A.Chilingarian, G.Hovsepyan, M.Zazyan, The synergy between High-energy Physics in Atmosphere and Cosmic Ray Physics, The 27th European Cosmic Ray Symposium (ECRS 2022) Nijmegen, the Netherlands, July 25th to 29th, 2022.
17. G.Hovsepyan, A.Chilingarian, Energy spectra of light and heavy primary cosmic rays in the energy range from 10 TeV to 100 PeV, The 27th European Cosmic Ray Symposium (ECRS 2022) Nijmegen, the Netherlands, July 25th to 29th, 2022.
18. A.Chilingarian, Neutron monitors detecting EAS cores, Hybrid symposium on cosmic ray studies with neutron detectors, Athens, 26 – 30 September 2022.
19. D.Aslanyan, The catalogof GLEs registered on Aragats, Hybrid symposium on cosmic ray studies with neutron detectors, Athens, 26 – 30 September 2022.
20. H.Martoyan, Forbush decrease observed by nodes of SEVAN East European particle detector network in November 2021, Hybrid symposium on cosmic ray studies with neutron detectors, Athens, 26 – 30 September 2022.
21. A.Chilingarian, Modulation effects posed by strong atmospheric electric fields of the fluxes of secondary cosmic rays, International conference on Thunderstorms & elementary particle acceleration, Prague, October 17-2.

22. T.Karapetyan, Status of the East-European SEVAN network and planned modernizations, International conference on Thunderstorms & elementary particle acceleration, Prague, October 17-2.

23. B. Sargsyan, Modulation effects posed by strong atmospheric electric fields of the fluxes of secondary cosmic rays, International conference on Thunderstorms & elementary particle acceleration, Prague, October 17-2.
24. *T.Karapetyan,* SEVAN East-European particle detector network for the solar and space weather studies, International conference on Thunderstorms & elementary particle acceleration, Prague, October 17-2.

Scientific and technical infrastructure (modernization, repairs, commissioning of new networking equipment) developed (or started) in 2022.

- Repairs in Nor Amberd (office rooms, 1 floor)
- New powerful diesel generator on Aragats for winter operations;
- Modern UPSs for the uninterruptable data stream from Aragats and Nor Amberd experimental facilities;
- Modernization of the networking equipment - for establishing reliable radio-internet connections with Aragats and Nor Amberd research stations;
- New hardware and software for the SEVAN module to be installed on Zugspitze in Germany.
- New laboratory in Nor Amberd for measuring particle fluxes, electric fields, and weather parameters;
- Modernization of the node of world-wide lightning location network in Yerevan;
- Installing new servers in Nor Amberd and Burakan for data storage, backup and data analysis;
- New small lab on Aragats for measuring optical emission in the lower atmosphere.

Fulfilled in 2022

1. 24/7 operation of experimental facilities at slopes of Mt. Aragats and in Nor-Amberd;
2. Start a new experiment for research of the horizontal profile of the atmospheric electric field during thunderstorms.
3. Start experiment with 3 panoramic cameras for monitoring skies above Aragats and making photos of enigmatic lights coinciding with strong electric fields and electron fluxes in the atmosphere.
4. Develop methodology and estimate the vertical profile of the atmospheric electric field at thunderstorms.
5. Establish a fully supported server center in Nor Amberd for storing and rescuing databases.
6. Repair offices in the Nor Amberd main building.
7. Establish a new experimental facility in Burakan, including SEVAN detector, NaI detectors, and electric field sensor.

8. Commission two boards of the new 4-channel logarithmic ADC for SEVAN detector to be installed on Zugspitze, and 1-channel in Nor Amberd, both allowing measurement of energy spectra of atmospheric particle fluxes in the energy range 0.3 -50 MeV.
9. Preparing a new lab on Aragats for detecting optical emission in the lower atmosphere.
10. Purchase and install new more powerful diesel generators and UPSs on Aragats and in Nor Amberd.

Plans for 2023

Our main projects in 2023-2025 will be connected with all aspects of observation of the cosmic ray flux on the Earth's surface. Cosmic rays are messengers from the most distance regions of Universe, from our Galaxy, from the Sun and from the terrestrial atmosphere. Having modern facilities to detect almost all species of cosmic rays and developed methodologies of data analysis, CRD physicists will continue the research on cosmic ray origin, solar and atmospheric particle accelerators, atmospheric electric field and lightning phenomena. The brief description of research program follows:

Continuous monitoring of species of secondary cosmic rays on Aragats and with the Space Environment Viewing and Analysis Network (SEVAN) East-European network of particle detectors.

Research of the thunderstorm ground enhancements, exploring relations between relativistic runaway process and enhanced particle fluxes measured on the earth's surface.

Developing methodology and perform measurements of the vertical and horizontal profile of the atmospheric electric field with extending network of particle detectors and the slopes of Mt. Aragats and with mobile measuring facility.

Measurements of the modulation of the cosmic-ray flux traversing the electrified atmosphere. Remote sensing of electric fields in the lower atmosphere by measuring the energy spectra of electrons and gamma rays.

Installation of new panoramic cameras and registration of optical emissions in the lower atmosphere. Development of a model of this emission.

Use the SEVAN network for the Solar physics and Space weather research in the coming maximum of 24^{th} solar cycle.

Maintaining and modernizing experimental facilities and technical infrastructure on research stations and for the SEVAN network.

Modernizing networking infrastructure, data transfer, storage and providing access to users worldwide.

Modernization of ADEI knowledge platform, update WiKi site, perform visual tutorials, add new data analysis features, develop a mirror site in Germany.

Several details of the program

- Install modernized SEVAN detector with possibility of measuring energy spectra on Zugspitze in Bavarian Alps
- Repair, re-calibrate and cross-calibrate SEVAN detectors of the European network (if political situation allows).
- Using a fast synchronized data acquisition system (FSDAQ), which correlates pulses from particle detectors, and electromagnetic emission from the atmospheric discharges on the nanosecond time scale disclose the space-time structure of the TGE.
- Investigate origination of “snow” and “graupel” dipoles in the thundercloud.
- Perform simulations of SEVAN detectors’ responses to particle fluxes (incl. solar and space weather events).
- Investigate enhancement of positron peak (511 keV) during negative near-surface electric field (electrons accelerated upward in direction to open space).
- Change the main CRD data analysis tool, ADEI multivariate visualization and statistical analysis platform for modern LINUX versions.
- Establish Mendeley datasets for presenting 580 TGE’s in the most user-friendly way.
- Establish a mobile lab on the basis of a Toyota car for remote measurements of TGEs and near-surface electric fields.