2022 CRD report
Main achievements, directions of research, and 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 locations, and atmospheric discharges, provides 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.
- Vertical and horizontal profiling of atmospheric electric fields.
- Influence of atmospheric electric fields on data of the Atmospheric Cherenkov Telescopes and particle arrays registering extensive air showers.
- Lightning physics.
- Measuring and storing datasets of geophysical and meteorological parameters for monitoring long-term global change.
- Scientific instrumentation.
- Multivariate data analysis methods.

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 occurring within thunderstorms. They have measured, for the first time, the energy spectra of electrons and gamma rays of particle avalanches of atmospheric origin that reach the Earth's surface. Also, for the first time, we observed light glows emitted during the development of electron-gamma ray cascades in the atmosphere, which correlated well with the high-energy electron flux registered by surface particle detectors. We observed TGE phenomena by detecting simultaneous fluxes of high-energy electrons, gamma rays, and neutrons. We proved the existence of the lower electric dipole that accelerates electrons downward. We performed simulations of the electron propagation in strong atmospheric electric fields and estimated the maximum potential drop (voltage) in the thunderous atmosphere. Eventually, we presented a comprehensive model of TGE and evidence of RREA origination in the thunderous atmosphere.
Meanwhile, CRD-made SEVAN detectors are used in Germany, Slovakia, the Czech Republic, Bulgaria, and Croatia, and, in combination with the SEVAN Network, contribute to a better

understanding of the variations of secondary cosmic rays and the vertical profile in electron positron and gamma components produced during thunderstorms at various altitudes. SEVAN detectors are unique devices that can observe variations of particle fluxes due to violent bursts of the Sun, forecast dangerous Space weather events, and contribute to a wide research program on fundamental aspects of atmospheric physics.

During the last decade, the research in high-energy physics in the atmosphere was mostly concentrated on measuring 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 atmospheric electric fields with particle fluxes traversing thunderstorms and being registered on the Earth's surface with particle spectrometers. We use particle fluxes for screening the 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.
A 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 “cosmic 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 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 showers. Spectra measured in 2019-2021, 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. The operation of the SEVAN network in 2021-2022 revealed new exciting results. On September 12, 2021, the SEVAN detector on Lomnicky Štít (Slovakia) measured a 500% enhancement of TGE particles compared with fair-weather fluxThe 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 continued 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, and 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. Besides the CRD data bases, the multiyear data from the Aragats detectors is made publicly available on the Mendeley datasets (links are provided in references 8-10):

data on TGE electron spectra and coincident images of light glow registered by panoramic cameras on Aragats, optical emissions in the lower atmosphere, and short particle bursts registered by Aragats neutron monitor. These datasets contain long writeups and links to other databases, allowing the HEPA community to use measurements from Aragats to investigate a wide variety of atmospheric physics problems. 2022 was a very productive year (see the list of publications below). 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 the energy spectra of TGE electrons with the ASNT scintillation spectrometer, a crucial measurement for HEPA.

In October 2022, after two years of COVID pause, we held a TEPA symposium in Prague. Although the audience was not very large, the meeting was a real success giving the possibility to discuss in deep the TGE physics and SEVAN networks operation in Slovakia, Bulgaria, Germany, Czech Republic, and Armenia.

Publications 2022 (CRD publications are available in http://crd.yerphi.am/crd_publications)

1. A. 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. A. 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, 106, 082004 (2022).

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, Ashot; Hovsepyan, Gagik; Aslanyan, Davit; Aslanyan, Balabek; Karapetyan, Tigran (2022), "Catalog of Thunderstorm Ground Enhancements (TGEs) observed at Aragats in 2013- 2021", Mendeley Data, V1, doi: 10.17632/8gtdbch59z.1
11. A. 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), JGR, in press.
12. 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.
13. 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.

14. Зазян М.З, Овсепян Г.Г., Чилингарян А.А, Взаимовлияние внеземных ускорителей и ускорителей, работающих в земной, Известия РАН, сер. Физическая, в печати 15. 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.

16. A. Chilingarian, Neutron Monitors detecting cores of Extensive Air Showers, Series on Cosmic ray studies with neutron detectors, Kiel University, in press.
17. A. Chilingarian, D. Aslanyan, T. Karapetyan et al., The database of the secondary cosmic ray fluxes registered on Mt. Aragats, Series on Cosmic ray studies with neutron detectors, Kiel University, in press.
18. A. Chilingarian, T. Karapetyan, H. Martoyan, et.al., Forbush decrease observed by SEVAN particle detector network on November 4, 2021, Series on Cosmic ray studies with neutron detectors, Kiel University, in press.

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 added in 2022
(Modernization, repairs, commissioning of new networking equipment)

• Installing 2 new powerful Diesel generators on Aragats for winter operations; • 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;
• Commission of the two boards of the 4-channel logarithmic ADC for SEVAN detector to be installed on Zugspitze, and in Nor Amberd, both allowing measurement of energy spectra of atmospheric particle fluxes in the energy range 0.3 -50 MeV.
• New laboratory in Burakan for measuring particle fluxes, electric fields, and weather parameters;

- Modernization of the node of the worldwide lightning location network (WWLLN) 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, particle fluxes, and electric fields.