Autumn school "Interaction of hadrons at above-accelerator energies" (Nor-Amberd, ArmSSR, 25 September–2 October 1988)

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The Autumn schools on the physics of the interaction of hadrons at above-accelerator energies that have been organized by the Erevan Physical Institute at Nor-Amberd (ErFI) are becoming traditional. They began as an extension of the well-known Nor-Amberd schools of A. I. Alikhan'yan in the 1960's and in connection with the construction at the high altitude station Aragats of the ANI complex for the study of cosmic rays of ultrahigh energies being developed jointly by ErFi and FIAN SSSR (Physics Institute of the Academy of Sciences of the USSR). By the time of the opening of the school the installation "ANI model" of 220 m^2 area was on the verge of operation, the part of the installation of 120 m^2 area for recording underground shower muons was close to completion, a surface ionization calorimeter of 1600 m^2 was under construction. The participants in the school could see all this in the course of an excursion to the high altitude station Aragats.

The organizers of the present school decided to devote it to problems of gamma-astronomy. The school brought together more than 70 lecturers and auditors. In opening it the director of the Erevan Physics Institute A. Ts. Amatuni pointed to the prominent place gamma-astronomy occupies within ANI and expressed the hope that, in spite of the tense situation in Erevan which was witnessed by many of the participants in the school that have come from elsewhere, the work of the school would proceed normally. In anticipating the output it must be said that these hopes were fulfilled.

Several review lectures were given at the school. The lecture by B. I. Luchkov (MIFI—Moscow Engineering Physics Institute) which opened the scientific programme of the school was devoted to gamma astronomy in the energy range of 10^8–10^{10} eV. This range is at present the most important sector of observational gamma-astronomy with a well-developed methodology, important astrophysical results and promise of future experiments. Here one uses flight apparatus installed on high altitude balloons and satellites, and the technique of spark chambers is being successfully applied. Among the results of the study of the diffuse gamma radiation information was noted on the ratio between atomic and molecular hydrogen in different parts of the galaxy, on the composition of the cold gaseous clouds in the constellations of Orion and Ophiuchus. The first data were obtained on the gradient of cosmic rays in the galaxy. It turned out that the intensity of cosmic rays varies relatively weakly along the radius R in the galactic disk diminishing by not more than a factor of 2 in going from $R \approx 5$ kpc to ≈ 15 kpc. *Of no less interest is the study of discrete sources of gamma-*quanta. Among the twenty-five sources discovered on the satellite COS-B only four have been identified. The nature of the remaining sources is not clear. In order to make a more precise determination of the position of these sources and to search for new ones, experiments are being prepared on the orbital stations: the Soviet-French experiment "Gamma" (1989) and the American experiment GRO (1990–1991).

In his review lecture S. I. Nikol'skiĭ (FIAN SSSR) expressed the point of view that it is too early to speak of gamma-astronomy of ultrahigh energies. At present, searches are still in progress for methods of making reliable distinction between gamma and hadron showers. What such a distinction can bring is demonstrated by the recent result obtained by T. Weeks *et al.* using the mirror telescope of the Whipple observatory. Making the distinction between gamma and hadron showers by using the shape of their Cherenkov flash they have reliably separated the variable gamma-component coming from the Crab pulsar from the constant one coming from its cloud.

The known and postulated intensities of the fluxes of gamma-quanta of ultrahigh energies apparently exclude the use of mirror telescopes for the investigation of sources with energies above 10^{13} eV and also for searching for unknown sources. All-season and all-weather installations with wide angle of observation and effective suppression of background from cosmic rays are needed. Examining the perspectives of using scintillation detectors in such installations S. I. Nikol'skiĭ based his conclusions to a large extent on the results of investigations of gamma-showers in the Tien-Shan mountains. The question was raised of the desirability of detecting in the showers in the mountains both muons and hadrons of relatively low energies $\gtrsim 1$ GeV for reliable identification of gamma-showers. Scintillators under an absorber of thickness 200–300 g/cm^2 would serve as such a detector. For successful work in ultrahigh-energy gamma-astronomy installations are needed with an area of more than 10^5 m^2 at altitudes of 3–5 km above sea level, with an angular resolution not less than 1° and suppression of background due to hadron showers of not less than a factor of ~ 100.

In the review given by F. A. Agaronyan (ErFI) the problems of gamma- and neutrino ultrahigh-energy astronomy were examined jointly. This unification is natural in connection with the identity of sources, and of mechanisms of formation and with the closeness of the methods of recording gamma and neutrino radiation. Possible sources were discussed—cosmic accelerators of protons and nuclei, and also mechanisms of acceleration of particles up to ultra high energies. Mechanisms were examined of generation and *propagation of neutrinos and gamma-quanta that arise in* the interaction of accelerated protons and nuclei with the surrounding thermal plasma and photon field. The importance was pointed out of the generation of electron-photon showers, initiated by gamma-quanta in the radiation-dominated plasma from the point of view of forming photon spectra of ultrahigh energies. The γ/P-ratio in the region of the black-body cut off of the cosmic ray spectra ($E > 5\cdot 10^{19}$ eV) was discussed and it was pointed out that under certain assumptions concerning the energy density of the ratio background and of the magnetic field in the intergalactic medium the contribution of the gamma-quanta can become dominant. Then one could explain the discrepancy between the data on the wide atmospheric showers of very high energies ("Fly's Eye" and "Havera-Park").

The review by V. A. Dogal' (FIAN) was devoted to the diffuse gamma-radiation. Results of observations indicate that the radiation from the galactic disk is due to the interaction of cosmic rays with gas and provide evidence supporting the galactic origin of cosmic rays with energy $\sim 10^9$ eV. The weak intensity gradient of cosmic rays in the galaxy and the absence of correlation of this intensity with the density of sources is satisfactorily explained in the model with the galactic halo which provides for effective "mixing" of cosmic rays.

Of interest for gamma-astronomy is the problem of explaining the nature of non-identified gamma-sources discovered by the satellite COS-B. Models were discussed in which these sources are associated with clouds of interstellar gas. Different models of acceleration of cosmic rays in clouds are examined, and this may also explain the relatively high intensity of cosmic antiprotons and the observed increase in the fraction of positrons in the electron-positron component of cosmic rays.

The report of S. I. Grigor'eva (IYaI AN SSSR—Institute of Nuclear Research of the Academy of Sciences of the USSR) gave a review of the experimental and theoretical papers related to the energy range of $\geqslant 10^{17}$ eV. Particular attention was devoted to papers dealing with the differential energy spectra of cosmic rays. It was shown that the interaction of protons with the relict radiation leads to the appearance of special features in the spectrum in the form of a "hump", due to the creation of e^+e^--pairs, and then of a "dip" due to the same e^+e^--pairs, a photoion "hump" and a black-body cutoff following each other as the energy increases.

The phenomena accompanying the passage of high energy gamma-radiation through the photon field were examined in the report by V. V. Sizov (NIIYaF MGU—Scientific Research Institute of Nuclear Physics at the Moscow State University). The processes of photoproduction of electron-positron pairs and the inverse Compton-effect lead to the appearance of electron-photon cascades which increase by many factors the depth of penetration of gamma-radiation compared with the process of "pure" absorption.

The cascade process of passage of gamma-quanta with energies $E \gtrsim 10^{19}$ eV in the geomagnetic field of the earth is examined in the report by B. L. Kanevskiĭ (NIIYaF-MGU). The spectrum of particles in the cascade at the boundary of the atmosphere is calculated. The interaction of electrons and photons with ultrahigh energies with the magnetic field of the earth leads to the cascade process and to the distribution of the energy of the primary gamma-quantum between particles with an energy of the order of 10^{16}–10^{19} eV, and this strongly diminishes the Landau-Pomeranchuk effect in the development of the cascade in the atmosphere.

The discovery of showers with an energy of $\sim 10^{20}$ eV in the primary cosmic radiation at the Havera-Park installation can serve as an indication of the presence of gamma-quanta in the primary cosmic radiation in the region of the black-body cutoff.

The possible role of the photonuclear mechanism of generation of cosmic gamma-quanta of ultrahigh energies were discussed in the report by V. V. Balashov (NIIYaF–MGU). An analysis was given of the relative contribution of the photonuclear, photomeson and other known mechanisms of generation of cosmic gamma-quanta as applied to the diffuse intergalactic background and to certain of the known discrete sources, including the taking into account of the fraction of iron nuclei in primary cosmic rays. It was shown that the most significant effect of the photonuclear mechanism on the spectrum of cosmic gamma-quanta is expected: for diffuse gamma-radiation in the range 10^{16}–10^{18} eV, for gamma-radiation from discrete sources of the type of Cygnus X-3–in the range of 10^{12}–10^{14} eV.

As previously, attention is attracted to the muon anomalies in showers from point sources of the type of Cygnus X-3 indications regarding which were obtained in certain experiments. In the report by A. Yu. Khodzhamiryan (ErFI) the problem is examined of what new particles might have initiated the showers. A class of models of particles is proposed which could describe the experimental data on these anomalies.

The formation of diffuse gamma-radiation in the intergalactic medium was discussed in the report by V. V. Vardanyan (ErFI). A solution has been obtained of the kinetic equation for cosmic rays interacting with the relict radiation. It was shown that the spectrum of superhigh energy photons formed by these gamma-quanta might turn out to be significant in the energy region of the "blackbody cutoff" of the cosmic ray spectrum. This is realized in the case when the energy density of radiophotons in the universe does not exceed the value of $\sim 10^{-13}$ eV/cm^3. Within the framework of this model one can explain the discrepancy between the data of the "Fly's Eye" and "Havera-Park" installations on the subject of wide atmospheric showers (WAS) of very high energies.

Experimental possibilities for investigating the interactions of ultrahigh energy photons both of diffuse origin, and also from discrete sources of the type of Cygnus X-3 were examined in the report by V. V. Saakyan (ErFI). Experimental possibilities of studying high-energy hadrons and muons in gamma-showers with the aid of installations of the type of AMI and "DUMAND" were discussed.

In the report of A. M. Atoyan (ErFI) a model was proposed according to which the high energy positrons ($E \gtrsim 10$ GeV) observed in cosmic rays are due to the interaction of gamma-quanta with optical and ultraviolet radiation directly in the vicinity of the local sources responsible for the diffuse cosmic gamma-radiation with $E_\gamma \gtrsim 10^{15}$ eV.

Great interest on the part of the participants of the school was evoked by reports in which results of the latest experiments on gamma-astronomy and the physics of high-energy cosmic rays were presented.

G. B. Khristiansen (NIIYaF MGU) examined the results of studying binary systems by the methods of wide atmospheric showers at energies above 10^{14} eV. Investigations of the source Cygnus X-3 carried out in the course of the last several years in many countries apparently showed the essential variability of this source. The scatter of data on intensity reaching a factor of 3–5 is associated not only with the variation of the intensity itself at different periods of observation, but also with the different methods of determining the primary energy of the cosmic rays at the different installations. At the installation ShAL MGU (Wide Atmospheric Showers, Moscow State University) from 1984 to 1988 along with Cygnus X-3 other binary systems in that constellation were also studied: Cygnus X-1 and Cygnus X-2. It was noted that Cygnus X-1 showed increased activity in the period 1985–1986. The report noted the high density, from the point of view of the gamma-nature of the registration being recorded, of the muon accompaniment of the wide atmospheric showers, which enter the cell of the Cygnus X-1.

The results of measurements on the MGU installation were examined in greater detail in the report by G. V. Kulikov. During the entire period of observation the excess flux of showers with $s \geqslant 1.3$ from the sources Cygnus X-1, Cygnus X-3 and Hercules X-1 turned out to be at the level of $\sim 2.5\sigma$. Along with this, periods of increased activity of the sources Cygnus X-1, Cygnus X-3 and Cygnus X-2 were observed. For Cygnus X-1 and for old showers an excess flux was observed both in the direct flux (4.2σ), and also in the phase analysis with a period of 5, 6 days ($\sim 6\sigma$) during the period of observations 16.10.85–9.9.86. As regards the sources Cygnus X-3 and Cygnus X-2, the excess flux for them in showers with $s \geqslant 1.3$ was observed only in phase analysis: with a period of 34 days for the source Cygnus X-3 at a level of 3.8σ (time of observation 1.11.84–23.6.85), and with a period of 9.8 days for the source Cygnus X-2 at a level of 4.4σ (time of observation 18.1.86–8.6.86). In this case the phase of the maximum of radiation from the source Cygnus X-2 corresponds to the periastron of this binary system.

In the report of G. S. Martirosyan (ErFI) results are given of the search for hadron groups in the direction of the Cygnus X-3 source according to the data of the PION installation for 1984–1985. The 1985 data indicate a statistically significant excess in the cell of dimensions $30° \times 30°$ which encompasses the coordinates of Cygnus X-3. The observed effect becomes stronger as the number of hadrons in the group increases. A phase analysis with the period $P_0 = 4.8$ h indicates the presence of a statistically significant peak in the phase interval 0.20–0.25.

Two reports by G. V. Lupenko (NIIYaF MGU) and A. I. Rutkovskiĭ (NIIYaF MGU) were devoted to the results of a search for gamma-radiation from the supernova (SN) 1987A in experiments carried out on orbital complexes "Kosmos-1870", and "Salyut-1686" in 1987–1988. Crystalline scintillators of NaI (T1) and CsI, surrounded by an active anticoincidence shield made of plastic were used as detectors. The gamma-spectrometer on the "Kosmos-1870" complex recorded gamma-quanta in the energy range $E = 0.4$–7 MeV, and on "Salyut-7" and "Kosmos-1686" in the energy range of 1.5–64 MeV. As is well known, until recently there was no unambiguous answer to the question of the charge composition of the primary cosmic radiation at energies $\gtrsim 1$ TeV. This is associated with the methodological difficulties of measurements in this energy range. The question provoking the greatest amount of discussion is one of reducing the fraction of protons in this energy region, which was posed already in the 1960's by experiments on the satellites of the "Proton" series.

In order to study this problem in 1984–1986 two experiments were carried out in NIIYaF MGU to study the primary cosmic radiation of energy 10^{12}–10^{14} eV with the aid of the apparatus "Sokol" installed aboard the satellites ISZ "Kosmos-1543" and "Kosmos-1713". The results of these measurements were communicated in the report by L. A. Khein (NIIYaF MGU). The experimental material consisted of approximately $2 \cdot 10^4$ events including $\sim 2 \times 10^3$ events utilized for subsequent analysis which showed that the charge composition of the primary cosmic radiation does not undergo any sharp changes, at least, up to energies of ~ 20 TeV. In this situation the fraction of protons amounts to 35–40%. In a statistically assured energy range of 2–20 TeV the exponents of the spectra of all the charged components are within the limits of 1.7 ± 0.1.

The results of the UA7 experiment on the CERN collider on measurements of inclusive spectra of photons in $p\bar{p}$-collisions at $s^{1/2} = 630$ GeV and of its consequence for particle interaction physics and for astrophysics were analyzed in the report of A. D. Erlykin (FIAN). Attention was drawn to the considerable (by a factor of ~ 1.5) growth of the average transverse momentum of the fragmentation photons in the energy range $s^{1/2} = 53$–630 GeV. Contrary to the conclusions of the authors of UA7 it is asserted that the data of this experiment taking into account the region of low $p_T < 0.1$ GeV/c testify in favor of violation of scaling. The partial inelasticity coefficient $K_\gamma^{p\bar{p}}$ ($s^{1/2} = 630$ GeV) is equal to 0.193 ± 0.004. An estimate was obtained of the amount of matter z traversed by cosmic rays in the galaxy at an energy of $\sim 5 \cdot 10^{14}$ eV on the assumption that the electromagnetic showers recorded at Tien-Shan originate from diffuse gamma-radiation: 1.87 ± 0.78 gcm^{-2}. The large value of z, and also a number of other arguments testify in favor of the fact that the electromagnetic showers observed at Tien-Shan are not the product of diffuse gamma-radiation, but originate in unidentified discrete sources.

A large amount of attention at the school was devoted to the methodological questions of gamma-astronomy; separation of electromagnetic from nuclear showers, new constructions of detectors, and installations both under design and under construction.

As was noted in the report by V. G. Sinitsina (FIAN) at present a transition is taking place from unconnected experiments in the field of ultrahigh energy gamma-astronomy to systematic investigations of the celestial medium. The search and an investigation of local sources of gamma-quanta of energies 10^{12}–10^{14} eV by recording electron-photon showers in the atmosphere is carried out under conditions of a much greater in terms of flux and practically isotropic background of primary protons and nuclei.

The mirror telescopic system "Gamma" was constructed in 1987 at the Tien-Shan high altitude scientific station of FIAN as a full-scale model of the "Shalon" installation (the latter shall have a system of automatic "tracking" of sources).

The report by V. I. Galkin (NIIYaF MGU) examined the problems of separating electromagnetic and nuclear showers according to their temporal characteristics with the aid of wide-angle and rapid detectors or by angular characteristics using matrices of narrow angle and slow detectors. Calculations were carried out by the method of mathematical modeling as applied to installations of the ANI type situation at mountain altitudes. It was shown that the use of multidimensional selection criteria makes it possible to enrich by a factor of 4–5 the initial set of events by gamma-showers if the energy of the primary particles is known. However, this result also has been obtained so far without taking into account possible experimental errors.

Similar questions of selecting gamma-showers according to the angular characteristics of Cherenkov radiation as applied to the mirror detectors of KrAO (Crimean Astrophysical Observatory) and the Whipple Observatory were discussed in the report by A. K. Konopel'ko (AGU—Azerbaidzhan State University). The effectiveness of the parameters of orientation and shape of the spot was analyzed.

In the report of R. A. Antonov (NIIYaF MGU) the idea was proposed of an installation to search for sources of gamma-quanta in the range of $(1–3)\cdot 10^{12}$ eV with an angular aperture of ~ 1 sr and with an accuracy of determining the direction towards the source of 0.2–0.3°. Such an installation could combine the investigations of preselected sources with a good signal-background ratio with the search for unknown objects over a wide region of the sky. The proposed methodology is based on the widely used determination of the direction of a shower by measuring the relative delays of pulses at several ($\gtrsim 3$) widely separated (~ 150 m) detectors. But in contrast to the usual scintillation detectors of charged particles it was proposed to utilize detectors of Cherenkov light.

In the discussion that arose after this report S. I. Nikol'skiĭ remarked that good angular accuracy on installations of such type could be obtained only if the axis of the shower could be located with an accuracy of $\lesssim 20$ m, and for this three detectors separated by 150 m are clearly insufficient. As a minimum 19 mirrors are necessary on this area, and in terms of complexity and cost this is already comparable with scintillation installations. The higher threshold of the latter to a large extent is compensated by round-the-clock nature of their operation.

In recent years the attention of space scientists is turning ever more in the directions of water detectors with the aim of utilizing them in gamma-astronomy. The possibilities offered in this direction by the DUMAND installation were discussed, and the project GRAND is under development. At the school the report by A. A. Petrukhin (MIFI) was devoted to these questions. A typical water detector for gamma-astronomy consists of a three-dimensional lattice of photomultipliers placed in water at a depth of several tens of meters. Such a lattice can record separately electrons, hadrons, and muons of a wide atmospheric shower. This fact, and also the smaller depth of submersion is its essential advantage over DUMAND which records only muons. With respect to surface installations its advantages consist of the identity of all the detectors, the independence of the conditions of recording of the place of incidence of the shower axis, the possibility of measuring the total energy of the components of the wide atmospheric shower. A. A. Petrukhin described the prototype of such a water detector called NEVOD constructed at MIFI.

In his report V. A. Tsarev (FIAN) proposed a light focusing system for underwater Cherenkov muon detectors—a reflector of the parabolic type (RPT). A Cherenkov detector consisting of an RPT and a photomultiplier placed at its focus has a number of useful features: the light-gathering capability is increased for a muon beam moving in water parallel to the axis of the RPT, and the signal/background ratio is improved.

In his report D. I. Minasyan (FIAN) told about the technology of manufacturing such RPT and about the result of checking the properties of the proposed detector in the beam of the FIAN electron accelerator. This check confirmed the suitability of using the RPT in such water Cherenkov detectors.

The report by O. I. Savun (NIIYaF MGU) presented data on the construction and characteristics of the scintillation detector for the wide atmospheric shower installation at the "Baksan" station. In the reports of V. M. Katkov and A. B. Nomerotskiĭ (IYaF SOAN—Institute of Nuclear Physics of the Siberian Branch of the Academy of Sciences) it was proposed to use the properties of single crystals for detecting ultrahard photons from local sources and an account was given of the use of streamer tubes in large-area coordinate detectors. One more project of a flight-type device called GAMMA-400 was proposed in the report by M. I. Fradkin (FIAN). This gamma-telescope is aimed to work in the as yet uninvestigated energy range of 1–400 GeV which brings together the regions of extra-atmospheric and surface investigations.

Attention was paid in the previously mentioned report by G. B. Khristiansen to the projects of large surface gamma-astronomical installations being constructed abroad and in our country to work in the energy range of 10^{14}–10^{15} eV. The main characteristic features were noted of the installations of Chicago (USA) and Heidelberg (FRG) universities, of La Palma and Karlsruhe (FRG), and of the installations THEMISTOCLE in France, and ShAL-1000 in the USSR. The common features of them all are: the great density of surface detectors for charged particles, high relative apertures, large area of muon detectors, improved angular accuracy.

R. M. Martirosov (ErFI) told about the gamma-astronomical installation GAMMA being constructed within the overall ANI complex. Its special feature is the large area of underground muon detectors (300 m^2 at the first stage), high accuracies of determining parameters of showers, the high altitude (3250 m above sea level) and correspondingly the possibility of working at lower primary energies.

The realization of all the projects planned in our country is a first-priority problem, since in the development of gamma-astronomy, as well as in high energy physics, one feels the lagging of the experimental basis in our country. This was also felt in the lack of new experimental results reported at the school, and in the predominance of theoretical papers.

In conclusion E. A. Mamidzhanyan summarized the work of the school and touched upon the problems of organization of future schools. The organizing committee decided to schedule the next school for 1990 with invitations to be extended to leading specialists from abroad on the subject of new physics in cosmic rays at teraelectron-volt energies.

Translated by G. M. Volkoff