A.E. Chudakov: His Life in Science

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Abstract

A brief scientific biography of an outstanding Russian scientist is presented, and a review of his main contributions to science is given.

1. Introduction

Professor A.E. Chudakov, who was a pioneer in many branches of cosmic ray physics, gamma ray astronomy, and underground physics, passed away three months ago. He was not particularly regular visitor of the Baksan Particles and Cosmology schools. However, these schools would unlikely be organized at this place, if not for the close proximity of the Baksan Neutrino Observatory. Since A.E. Chudakov was one of the founders of this Observatory, it was a unanimous decision of the Organizing Committee of the present school to dedicate it to the memory of this outstanding scientist. This paper is a brief review of his versatile scientific activity.

2. Biography

Aleksandr Evgenievich Chudakov was born on June 16, 1921 into the family of Evgenii A. Chudakov who was a prominent scientist in the field of mechanics and much later became the vice president of the Academy of Sciences of the USSR. Aleksandr entered the Physics faculty of the Moscow State University in 1940 and was graduated from it only in 1948 (due to an interruption caused by the World War II). However, he started his research activity under the supervision of S.N. Vernov in 1946, while still a student. His further biography is extremely simple if one considers the mere facts: for twenty three years (from 1948 to 1971) he was a researcher in the Lebedev Physical Institute of the USSR Academy of Sciences, and for thirty years (1971-2001) he was the head of a laboratory in the Institute for Nuclear Research of the USSR (since 1991, Russian) Academy of Sciences.

The principal dates of his scientific career are as follows: PhD degree (1953), Doctor of Science (1959), Corresponding member of the USSR Academy of Sciences (1966), Professor (1969), full member of the Academy (1987), and a member of the Presidium of RAS (1990). From 1983 until the end of his life he was a head of the Council on Cosmic Rays in the Academy of Sciences.

As far as his international activity is concerned, one should notice that he was a member of the International Academy of Astronautics (elected in 1963). Starting from 1975 he was a member of the Cosmic Ray Commission of the International Union of Pure and Applied Physics (IUPAP). Later, he became a secretary (1981-1984) and chairman (1984-1987) of this Commission. However, not his degrees and awards is the subject matter of this paper, but his contributions to science.

3. The beginning. Studying cosmic rays with rockets

In 1946 young Aleksandr Chudakov joined a group in the Lebedev Physical Institute, which was involved in experiments with rockets. The most interesting fact about Chudakov's investigations in this period is that their results were never published. The experiments were carried out in parallel with RD works for rocket design that were top secret. Accordingly, no open publications were permitted for the results of cosmic ray studies either, and they were presented only in the form of closed reports. Now it is known what was done in these experiments.

(i) The intensity and composition of cosmic rays were measured beyond the atmosphere (up to 100 km), and first upper limits on the flux of cosmic gamma rays with energies of 1 MeV and 100 MeV were obtained.

(ii) New methods of coding the experimental data were invented (in particular, the conversion amplitude-time-code, now in common usage, was applied for the first time by Chudakov).

(iii) By the method of observation of the so-called transition effect in thin lead layers, the generation of the electron-photon component by primary protons was discovered. Analyzing these data, Chudakov roughly estimated the lifetime of a meson responsible for the soft component generation to be less than 10^{-9} s (this was done two years prior to the discovery of neutral pion at accelerators).

4. The Chudakov effect

In 1949, Chudakov predicted the effect of the reduced total ionization of a high-energy electron-positron pair near the point of its origin due to the mutual screening of particle fields. The results of his calculations are shown in Fig. 1, where the reduction of ionization losses in comparison to $2I_0$ is clearly seen. Since this effect depends on the energy of a pair (which determines the angle of divergence) the effect was used in some experiments with nuclear emulsions for measurements of the energy of gamma rays.

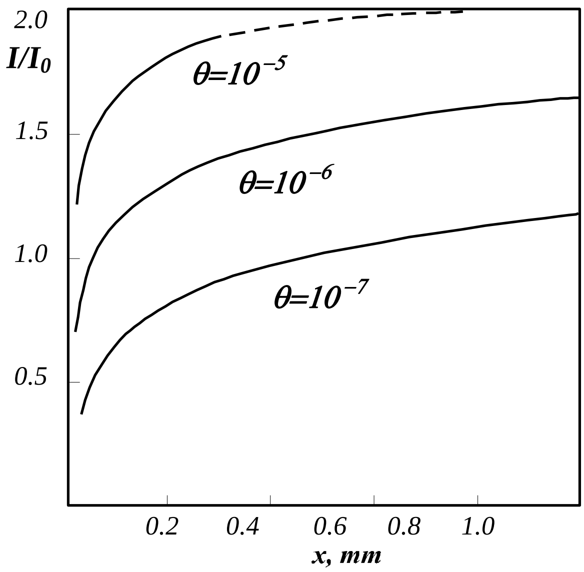

Fig. 1. Ionization of an electron-positron pair as a function of the path length from the point of origin for three values of the angle of divergence.

This effect was referred to by many scientists as the Chudakov effect, but it was not particularly popular. However, much later it became clear that the effect is, in fact, universal. Now the effects of the screening of color fields for narrow pairs of quarks and gluons are widely discussed in

QCD, and this is an obvious manifestation of the Chudakov effect.

It is interesting to note that the paper on this effect was published only in 1955 [1]. There is a story that this was done only upon insistence of one of his colleagues (I.M. Frank, future Nobel prize winner). Was it a result of first unpublished investigations or not, but this was typical for Chudakov throughout his entire life: he was not prolific publicator, and some of his results even remained unpublished.

5. Ionization Glow and Transition Radiation

As a preparatory stage for future experiments with Cherenkov radiation of extensive air showers (see later), in 1953 Chudakov began to study the luminiscence of air and other gases irradiated by relativistic electrons. The experiment was made at various pressures, and, reducing pressure to zero, Chudakov discovered that some signal still existed at zero pressure. Putting additional metal foils into the beam of electrons he proved this signal to be the result of transition radiation predicted by V.L. Ginzburg and I.M. Frank in 1945. This was the first experimental observation of the transition radiation.

As for the ionization glow, it turned out to be sufficiently weak so that it could be neglected in Cherenkov observations. But Chudakov immediately understood that the isotropy of this radiation could be used in experiments of another type in order to observe extensive air showers from a large distance. This idea was realized much later in the Fly's Eye detector, and now the detectors of this type are being developed both for ground-based (the Auger project) and for satellite (EUSO) experiments.

However, as was usual for him, Chudakov published nothing again. The following citation is a present-day comment of a live witness (J. Linsley) on the situation [2]. "I tried … to get clarification from Chudakov himself in his later years about an idea that *apparently came to him before it came to others*: to observe EAS by means of atmospheric scintillation. In a well-known remark of his at the 1962 Interamerican Symposium in La Paz, Bolivia, published in the Proceedings, he described his idea in some detail, dating it to 1955-57, the time he made pioneering measurements on atmospheric Cherenkov radiation from EAS." How strange it sounds now: *a well-known remark* as a reference! Indeed, it was a remark to the talk presented by K. Suga [3].

6. Cherenkov Radiation of EAS: Pamirs Experiments

In these experiments, carried out in the Pamirs Mountains Chudakov has realized the idea of calorimetric measurements of the energy of air shower cascades and measured the energy spectrum of primary cosmic rays in a wide range applying the technique of fast oscillography in eight channels simultaneously. After the first experimental detection of EAS Cherenkov radiation by Galbraith and Jelley, it was the first experiment where this radiation was studied in great detail, and it is quite true that in the above citation of J. Linsley these experiments are referred to as pioneering. (In actual fact, this can be said about almost all works performed by Chudakov throughout his entire life.) The results of these experiments were world-best at least for two decades, and many interesting experimental methods were suggested by him in this Pamirs period, like the use of a small spark as a light source for calibration of photomultipliers.

7. Discovery of the Outer Radiation Belt

With the advent of satellite era, the new possibilities to study cosmic rays beyond the atmosphere have opened up. The first experiments on the first Soviet satellites were carried out by S.N. Vernov and A.E. Chudakov. The first satellite (Sputnik) launched in 1956 had no instruments for this purpose, but the second Sputnik in 1957 recorded cosmic ray intensity with a Geiger counter. The lost possibility of discovering the inner radiation belt is well described by the following narration by J.F. Lemaire, a modern investigator of the problem.

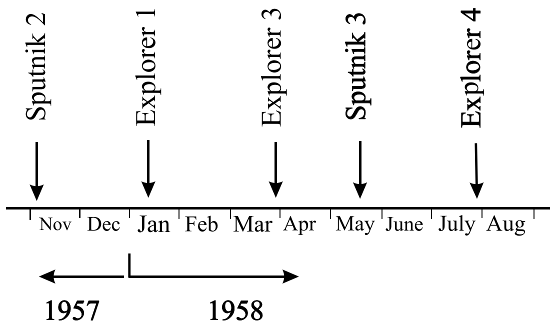

Fig. 2. Launching time of the first satellites that measured CR intensity. The inner radiation belt was observed by Sputnik 2 and Explorer 1 (confirmed by Explorer 3), the outer radiation belt by Sputnik 3. Explorer 4 observed both.

"The Geiger counters of Sputnik 2 … had detected the trapped radiation near apogee over Australia with KS-5, the first orbiting instruments for cosmic ray studies. But since S.N. Vernov and A.E. Chudakov did not receive the data from the Australian receiving station they did not see the rapid rise in intensity with altitude until much later. At Sydney, Australia, the scientists with Professor H. Messel, a noted cosmic ray researcher and head of the School of Physics at the University of Sydney, recorded the telemetry signals from Sputnik 2. But they did not have the telemetry code. Asked about this during the Cosmic Ray Congress in 1959, Messel said to Singer '*They would not send us the code and we were not about to send them data*' (Hess, 1968). This is why in the November 23, 1984, issue of Science, Alex Dessler published an editorial titled '*The Vernov*[1] *Radiation Belt (Almost)*' [3].

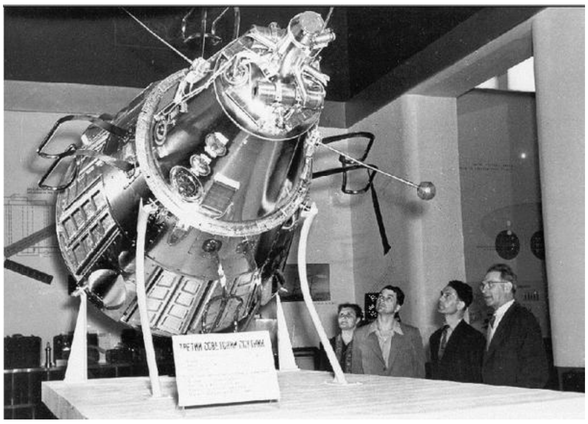

Fig. 3. The model of Sputnik 3 in a museum.

The possibility lost by Sputnik 2 was fully used by the Explorer 1 American satellite. The launching times of the first satellites that measured the intensity of cosmic rays are given in Fig. 2. As was said above, the Sputnik 2 and Explorer 1 satellites observed the inner radiation belt. The outer radiation belt was first observed by the Sputnik 3 satellite (see Fig. 3), which was the first heavily instrumented spacecraft, the laboratory in space. Explorer 4 also observed the outer radiation belt, but two months

[1] One certainly should read Vernov-Chudakov. In this very successful tandem S.N. Vernov was a leader and organizer, while A.E. Chudakov was a principal investigator and experimentalist.

later. To summarize the instructive story of discovering the Earth's radiation belts, let us again give a word to J.F. Lemaire.

"This piece of History re-opens the issue of who, in scientific races, are remembered as the key actor and discoverer: the pioneer who had the idea first, who designed an experiment to check this idea and prove it to be correct, or the author(s) whose paper passed the refereeing process and who, luckily, first published the results in open literature. In Geophysics it is the latter who wins this 'Guinness Book of Records' competition."

8. Large Water Cherenkov Detector

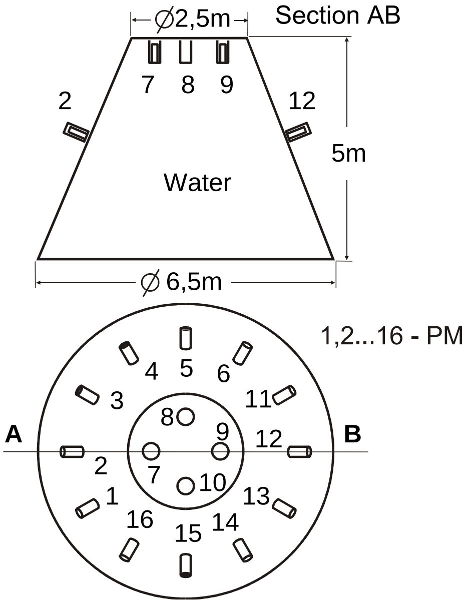

Fig. 4. The design of the Large Water Cherenkov Detector

This detector was constructed by Chudakov in 1959. This facility in the form of a truncated cone contained nearly 85 t of cleared water and 16 large PM tubes (the diameter of photo-cathode 15 cm). This detector was but a short episode in the Chudakov's activity, and, as usual, he did not published anything about it. Figure 3 presents the top view and cross section of the Large Water Cherenkov detector, so to say, just for fun, because for me it turned out to be very difficult to find any details about its design.

However, it is very interesting to notice on this occasion that the destiny of practically all his initiatives was a long life or fruitful development. From the modern standpoint, this detectror looks like a very small prototype of Superkamiokande, less than 0.2% of it, but constructed 40 years earlier, though essentially in the same design scheme.

The detector was used only in a single experiment studying muon groups near the EAS axis [4], while Chudakov was already involved in quite different experiment, which made him the founding father of gamma ray astronomy.

9. First Gamma Ray Telescope in Crimea.

The paper by A.E. Chudakov and G.T. Zatsepin [6] suggesting a new method of searching for high-energy gamma rays of cosmic origin was published in 1961. And at the moment of publication the first gamma ray telescope was nearly completed at Catsively, Crimea (Fig. 4). It was designed by Chudakov with a very small group of people. This was not only the beginning of the air Cherenkov method in gamma ray astronomy. This Cherenkov telescope was the first instrument ever specially made for observations in gamma ray astronomy.

Generally, the result of this first experiment was totally negative: no celestial sources of TeV gamma rays were discovered. One should take into account how far ahead of time was this experiment. The objects that are known now to be gamma ray emitters in this energy range (pulsars and blazars) had not yet been discovered. Radio galaxies were considered to be most promising as potential sources, and they were

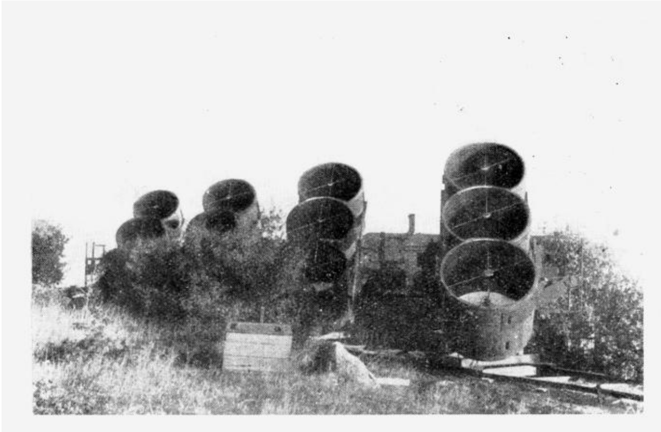
Рис. 1. Общий вид установки

Fig. 5. First gamma ray telescope in Crimea.

mainly observed by Chudakov and his team. Due to some bad luck, one of them (Cygnus A) showed statistically significant excess in one of the first runs. So, a lot of time was spent observing this object, in a hope to confirm the signal that finally disappeared.

However, one gamma ray emitter was known at that time, and at least one result of fundamental importance was obtained by Chudakov from the upper limit on the flux of high energy gamma rays derived from observations of this object. This is the famous Crab Nebula source. It was generally believed at that time that the synchrotron radiation in the Crab Nebula was produced by electrons of secondary origin (produced by pions generated in proton-proton collisions via $\pi \rightarrow \mu \rightarrow e$ decay). If so, one would expect a significant gamma ray flux from decays of neutral pions. The upper limit obtained by Chudakov was a proof of direct acceleration of electrons in the Crab Nebula (and hence in other similar objects).

10. Baksan: Underground Physics and Cosmic Rays

In 1963, the idea to construct the Neutrino Observatory was approved by the Soviet academic and government authorities, and soon after that Chudakov started designing the Baksan Underground Scintillation Telescope (BUST). At that time, two underground facilities to detect atmospheric neutrinos (in India and South Africa) already existed, both located at large depths and detecting the horizontal neutrino-induced muons. The choice of Chudakov was to place the new neutrino telescope at a rather shallow depth so that investigations of cosmic ray muons would become possible. Thus, the BUST was planned as a multipurpose instrument, and as such it actually became the first detector of so called underground physics. The small depth of the BUST was a big problem, since the neutrino signal should be detected against the background of 10^7 times more intense flux of muons (this problem was successfully solved). The scale of this detector required semi-industrial methods of construction, new technological solutions, and enormous efforts on organization work. New very cheap liquid scintillator was specially developed in the Chudakov's laboratory (the BUST contains 330 t of this

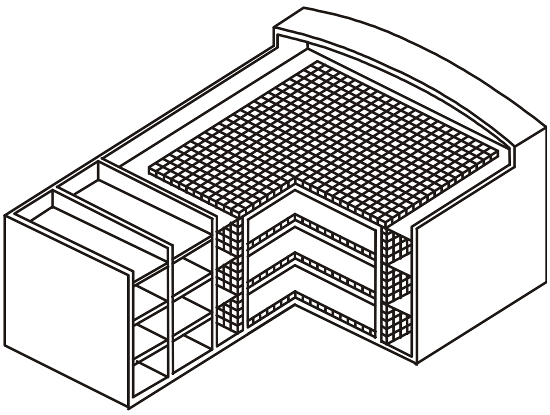

Fig. 6. Schematic view of the Baksan Underground Scintillation Telescope (BUST).

scintillator), all electronics for data acquisition in several channels from more than 3000 PM tubes was self-made. The BUST was put into operation in 1978. Thus, the process of construction took fifteen years, a very long period especially for such a dynamic area as experimental nuclear physics. Nevertheless, when the BUST became operative, it turned out to be at the level of contemporary problems, and more than that: it appeared to be the best instrument in the world for the problems which were totally unknown at the time of its design (the monopole search is a very good example of such a problem). So universal, perfect, and flexible was the original scheme of this detector!

But before the BUST, the Carpet air shower array was constructed at Baksan (1974). This facility represents one plane of the underground detector, and it was designed as an auxiliary instrument for adjustment of the method and staff education. But it was found to be very useful for cosmic ray studies. Another air shower array, "Andyrchi" was constructed on the mountain slope 300 m above the BUST in 1991. With these three large facilities, Baksan is a unique place for cosmic ray research.

All works carried out by Chudakov and his team using this experimental base hardly can be listed in this paper. I would like to recall only the most important issues, making comments on the time when a particular result was obtained (published), and for how long it was among the best results in the world. The selected results are as follows.

- Vertical intensity of upward-going neutrino-induced muons is measured for the first time (1980). The limits for parameters of neutrino oscillations are obtained (1985-1990).
- The lower limit for nucleon lifetime is estimated as 10^{30} years for neutrinoless modes of decay (world-best result for half a year only, 1981).
- The upper limit for the magnetic monopole flux was world-best for many years. Recently, the MACRO collaboration has reached the level of Baksan, but failed to improve it. One should also notice that Chudakov himself was the first who calculated the flux limit for monopoles from astrophysical considerations, and it would be appropriate to change the commonly used term "Parker limit" for more correct "Chudakov-Parker" limit.
- Muon bundles are extensively studied, and the composition of cosmic rays is estimated on this basis. Multiplicities of multimuons and their lateral distribution are measured at various depths. The data on extremely large multiplicities (more than 1500 muons) are still unique.
- A new phenomenon of short-term cosmic ray variations during thunderstorms is discovered (the Carpet, 1984).
- From the analysis of multicore showers (the Carpet) the cross section of generation of high P_t jets at $\sqrt{S} \sim 500$ GeV is estimated and demonstrated to be in agreement with the QCD predictions (1981, at least one year before the similar results of UA1 and UA2 collaborations at the CERN SPS-collider).
- Anisotropy of cosmic rays is measured at 1 TeV (the BUST, 1985) and 10 TeV (the Carpet, small-size EAS, 1982).
- The positive temperature coefficient for the intensity of muons with $E > 220$ GeV is measured (1987). Based on these data, the diurnal temperature wave in the stratosphere is derived.
- The upper limit for the density of cold dark matter (neutralino) is derived searching for neutrino flux from the Sun and the Earth's center (1995).

- Continuous monitoring of possible neutrino bursts from collapsing stars is being executed for a long time (over two decades).

Though this list is far from being complete, one can easily see how versatile was the research activity of Chudakov at Baksan. At the same time, he put forward some new ideas related to other experimental facilities. For example, in the middle of 1970s, when the DUMAND project was under discussion, and the Pacific Ocean was suggested as a place for the future detector, Chudakov was the first who paid attention to the fact that the lake Baikal would be a suitable place for a deep underwater neutrino telescope, because of the possibility to sink strings with PM tubes in winter time from ice. As is known, the DUMAND project failed, and the first underwater neutrino telescope NT-200 was successfully constructed at Baikal by the collaboration headed by G.V. Domogatsky.

An interesting story is connected with another Chudakov's idea. In 1972 he suggested a new method to measure the spectrum of giant air showers by recording their air Cherenkov radiation reflected from snow. The idea was to use an optical detector mounted at the airplane flying over snowy territories, presumably during the polar night. Though some attempts were made, this idea still waits for proper experimental realization. Chudakov published this suggestion [7], but he was greatly confused when he presented a report on this matter at a certain conference. After the presentation he was asked: "Are you going to make this experiment?" He had to answer: "No", and many years later he still used to recall how ashamed he was answering in this way. Though it was may be the only case, when he was not going to realize his idea, he really was very much ashamed! Chudakov was a professor of Moscow University and educated many young scientists. But it is precisely this attitude of "honest experimentalist" to the results of his research that served as an example to all the people around him and educated them better than his lectures. In this respect, he really was a knight of science. At the same time, A.E. Chudakov was unquestionably one of the leading persons in cosmic ray science of the second half of the past century, and his name belongs to its history. Summarizing all, that was made by this man in his life, with a sort of surprise one can list the following.

- He predicted a new physical effect (Chudakov effect), which turned out to be of universal nature;
- He was the first who observed an interesting physical effect predicted by other people (transition radiation);
- He discovered the outer radiation belt, a new physical object (area in space) of fundamental importance for space exploration, environment and physical studies;
- He was a founding father for several branches of modern science, like gamma ray astronomy and underground physics, where his ideas predetermined the future development in both direction and methods of investigations.
- And last but not least, he was a leader of the scientific school, which still exists.

Let us hope that it will exist for a long time. Because this is the best thing we can do in order that the memory of our teacher would continue to live.

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References

1. A.E. Chudakov, One ionization effect related to observation of electron-positron pairs at very high energies, Bulletin USSR Acad. Sci., Phys. Ser., vol. 19, (1955), p. 651 (In Russian).
2. J. Linsley, Private communication, 2001.
3. K. Suga, Methods for Observing Extremely Large Extensive Air Showers, Proc. of the Fifth Interamerican Seminar on Cosmic Rays, La Paz, 1962, vol. II, p. XLIX-1.
4. Yu.N. Vavilov, G.I. Pugacheva, V.M. Fedorov, On muon groups near to the axis of extensive air showers, J. Exp. Theo. Phys., vol. 44 (1963), p. 487 (In Russian).
5. J.F. Lemaire, From the discovery of Radiation Belts to Space Weather perspectives, , Proc. "Space Storms and Space Weather Hazards", Crete, Greece, 19-29 June, 2000, NATO ASI to be published by Kluwer.
6. G.T. Zatsepin and A.E. Chudakov, On the methods of searching for local sources of high energy photons, J. Exp. Theor. Phys., vol. 41 (1961), p. 655 (In Russian).
7. A.E. Chudakov, A possible method to detect EAS by the Cherenkov radiation reflected from the snowy ground surface, in “Experimental methods of studying cosmic rays of superhigh energies”, Proc. All-Union Symposium, Yakutsk, 1972, p. 69 (In Russian).