A.E. Chudakov as a scientist and one of the founding fathers of underground physics

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Abstract Professor A.E. Chudakov was one of the founders of the Baksan Neutrino Observatory, and it is quite appropriate on the day of its half-centenary to commemorate him and his many-sided research activity. A short review of his scientific achievements is given, with a special emphasis on their pioneer character.

Keywords:, Cosmic Rays, Muons and Neutrinos, Underground Physics, Gamma Ray Astronomy

1. Introduction

Alexander Chudakov started his research career under the supervision of S.N. Vernov in 1946, while still a student. His further biography is extremely simple: 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, I would like rather to consider his contributions to science and him as a scientist type.

2. Pioneer of gamma-ray astronomy and fluorescence method

It was said about one English medieval king that he was “every inch a king”. Alexander Chudakov was “every inch a scientist”, and of a rather special type: he was pioneer par excellence. ***Fig1*** shows the view of the first gamma-ray telescope constructed by Chudakov in Crimea. This was the first instrument specially designed for observations of very high energy gamma rays of cosmic origin, and because of it the Cherenkov astronomy started earlier than satellite astronomy. To confirm the recognition of this fact ***Fig1***

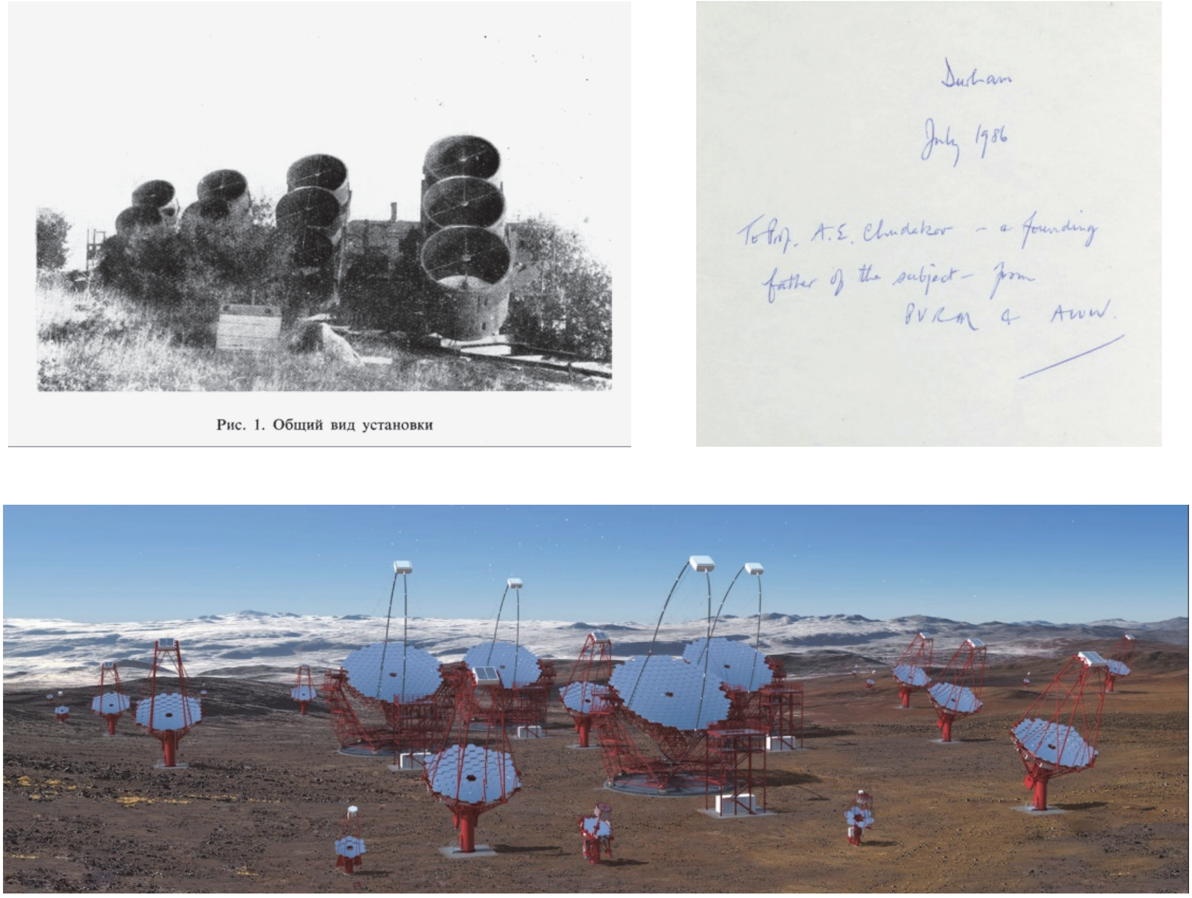

Fig1. The first Cherenkov gamma-ray telescope constructed by Chudakov in Crimea (upper left), the inscription made by Prof. Sir Arnold Wolfendale on the copy of his monograph "Gamma ray astronomy"[1] presented to Chudakov (upper right panel), and (bottom panel) the future look of the CTA system (Southern Hemisphere site).

demonstrate also the presentation inscription made by Prof. Sir Arnold Wolfendale, former Astronomer Royal for Britain, on his monograph [1] written together with Indian scientist P.V. Ramana Murthy: "To Prof. A.E. Chudakov – a founding father of the subject – from PVRM and AWW. Durham, July 1986". Also shown in ***Fig1*** (bottom panel) is the general view of the future CTA (Cherenkov Telescope Array) observatory, most promising and advanced project which is under construction at the moment. More exactly, ***Fig1*** presents only one part (southern) of the CTA system that is designed as two arrays constructed simultaneously in both hemispheres of the globe. CTA is planned as a first Cherenkov detector of the fourth generation, and it is not the only project of this type. The very high energy (VHE) gamma ray astronomy (or Cherenkov astronomy) is thriving branch of science, whose foundations were laid by Chudakov. He not only constructed the very first instrument of VHE gamma ray astronomy. He also (together with G.T. Zatsepin) had suggested the very idea of the method in paper [2]. When this paper was published (1961), the first stage of the air Cherenkov telescope (four mirrors), had been in operation for the season of 1960. But even before this Crimea gamma ray astronomy experiment Chudakov studied Cherenkov radiation of extensive air showers in Pamir mountains.

As a preparatory stage for future experiments with Cherenkov radiation of extensive air showers in 1953 Chudakov began to study the luminescence 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 and for satellite experiments.

The priority of Chudakov can be supported by another famous scientist Prof. John Linsley from University of New Mexico who wrote to the author after Chudakov's departure [3]: "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

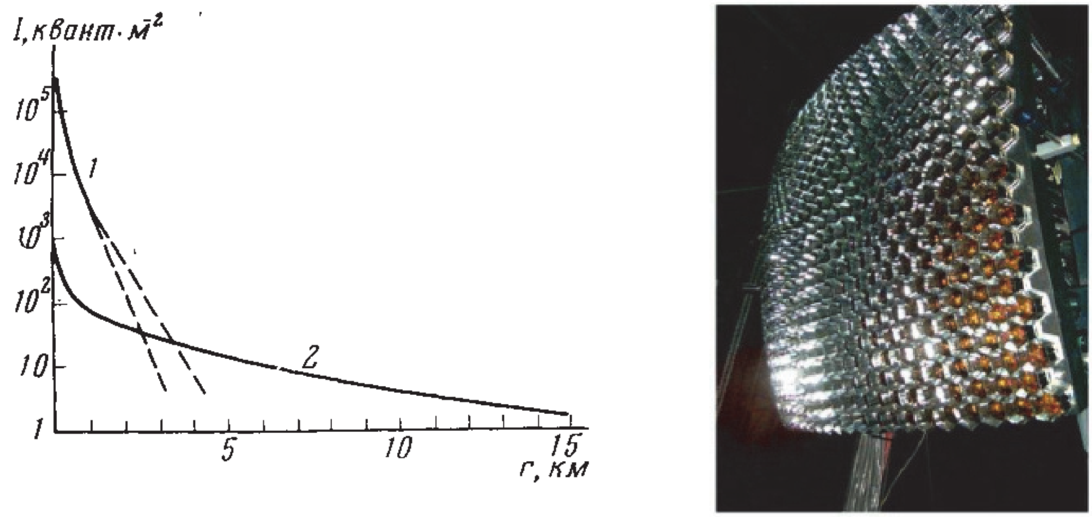

Fig2. *The lateral distribution of Cherenkov radiation and ionization glow of an EAS from paper [3], where the idea of fluorescence detection was put forward (left) and a camera of such a detector (PAO) completely assembled with all PMTs and light collectors in place.*

1955-57, the time he made pioneering measurements on atmospheric Cherenkov radiation from EAS." Several years later Chudakov with his student published this idea in a Russian journal [5]. But his *well-known remark* (to the talk presented by K. Suga [4]) was made much earlier, and still earlier (according to J. Linsley) he had understood this possibility. The left panel of ***Fig3*** presents the plot from paper [5] demonstrating lateral distributions of Cherenkov light and ionization glow. On the basis of these distributions, it was formulated in [5]: "Ionization glow… definitely dominates at distances of 5 km from the axis and more…Using pulse shape analysis at several points located at distances 5-10 km from the axis one can in principle determine not only spatial position of the axis, but the cascade curve form as well, and accordingly, the energy released in the atmosphere. It is possible to detect inclined and even almost horizontal showers". It is this suggestion that was later implemented in many detectors. As an example, the right panel of ***Fig2*** shows the camera of one modern fluorescence detector (that of the Pierre Auger Observatory).

To finish with the topic of Chudakov and Cherenkov radiation one should recall another ingenious idea put forward by Chudakov. In 1972 he suggested a new method to measure the spectrum of giant air showers by recording their air Cherenkov radiation reflected from snow [6]. The idea was to use an optical detector mounted at the airplane flying over snowy territories, presumably during the polar night. There were some attempts to realize this idea in different modifications (to use mountain glaciers as reflectors, and balloons, tethered or in stratospheric flights, as detector carriers). However, up to the present time this idea was not properly implemented, and it waits for more successful realization.

3. Chudakov effect and the Earth's radiation belts

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 interference (mutual screening) of particle wave functions (as usual, he published this result much later, only in 1955 [7]. The results of his calculations are shown in ***Fig3***, where the reduction of ionization losses in

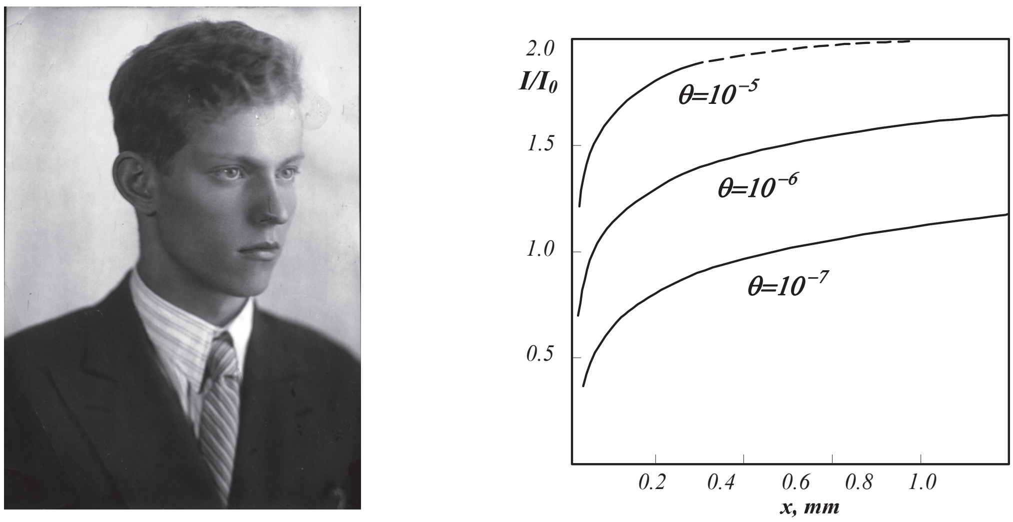

Fig3. *Young Alexander Chudakov (1946) and his calculation of ionization of an electron-positron pair as a function of the path length from the point of its origin for three values of the angle of divergence (the plot from paper [7]).*

comparison to $2I_0$ is clearly seen. ***Fig3*** present also a photo of young Alexander Chudakov. So he looked when calculating quantitatively the Chudakov effect manifestation. 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.

This effect was referred to by many scientists as the Chudakov effect (see for example, [8]), 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 taken into account in QCD, and this is an obvious manifestation of the

Chudakov effect.

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 1957 had no instruments for this purpose, but the second Sputnik recorded cosmic ray intensity with a Geiger counter. The lost possibility of discovering the inner radiation belt is well described in [9] by J.F. Lemaire.

"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*' [9].

The possibility lost by Sputnik 2 was fully used by the Explorer 1 American satellite. However, both Sputnik 2 and Explorer 1 satellites observed the inner radiation belt. The outer radiation belt was first observed by the Sputnik 3 satellite, which was the first heavily instrumented spacecraft, the laboratory in space. Explorer 4 also observed the outer radiation belt, but two months later. To summarize the instructive story of discovering the Earth's radiation belts, let us again give the floor 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."

It is worthwhile to notice that, notwithstanding the discovery, Chudakov was again a pioneer in this case: "the first orbiting instruments for cosmic ray studies."

4. Large volume 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. ***Fig4*** presents the top view and cross section of the Chudakov's Large Water Cherenkov detector. 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 detector looks like a very small prototype of Superkamiokande, less than 0.2% of it, constructed 40 years earlier, though essentially in the same design scheme. The right part of ***Fig4*** demonstrates the interior views of two largest water-Cherenkov detectors used so far by underground physics experiments: the IMB (Irwine-Michigan-Brookhaven) in the US and the Superkamiokande in Japan. The original detector was used only in a single experiment studying muon groups near the EAS axis [10], while Chudakov was already involved in quite different experiment, which made him the founding father of gamma ray astronomy.

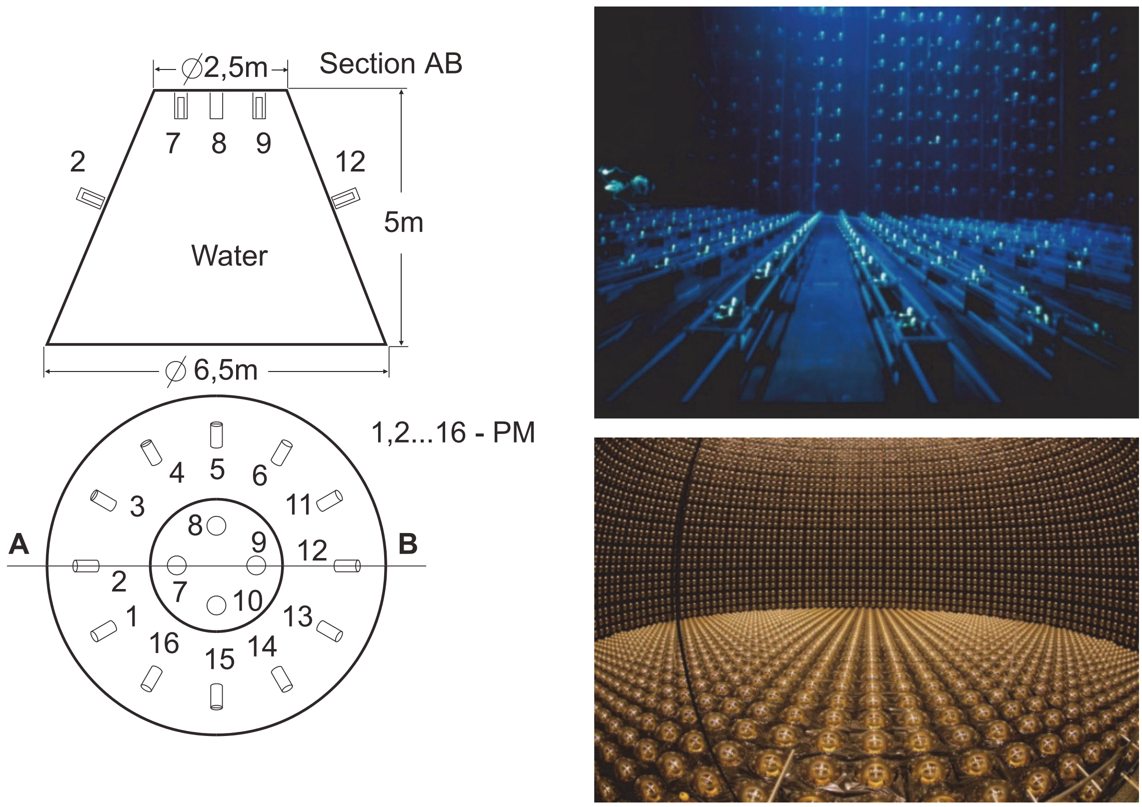

Fig4. *The first large-volume water Cherenkov detector constructed by A.E. Chudakov in 1959 (left), and two giant modern underground water Cherenkov neutrino detectors IMB (top right) and Super-Kamiokande (bottom right).*

5. Underground physics and Baksan

The very large water Cherenkov detectors (whose first prototype had been constructed by Chudakov), demonstrated in ***Fig4***, much later become instruments of the so called underground physics. But Chudakov also can be considered to be the founding father for this science due to his ideas and approach when constructing the Baksan Underground Scintillation Telescope [11]. The primary goal of this instrument, as it was planned by initiators of the project of a neutrino observatory in the governing body of USSR Academy of Sciences (academicians M.A. Markov and B.M. Pontecorvo), was to study the neutrinos generated by cosmic rays in the atmosphere. At that time only two experiments were performed to detect such neutrinos: one in India and another in South Africa. Both were located at very large depths (to suppress the muon background) in mines of conditionally natural (industrial) origin. The BNO facilities were the world-first for which special underground tunnels and cavities were constructed. Next, both previous neutrino experiments were carried with instruments recording the horizontal neutrino flux. The BUST was the first instrument aimed at detecting the vertical upward-going neutrinos having crossed the entire globe. At the same time it was placed at such a depth, where the muon background was higher than the expected neutrino signal by a factor of 10^7. This circumstance made the task of extracting the sought signal from the background extremely difficult. But on the other hand this made it possible to investigate simultaneously many problems of muon physics (to measure the flux of muons and its variations, to study interactions of high-energy muons, their spectra, muon bundles, etc.). This multi-purpose character of the BUST allows us to call it the first instrument of underground physics. The task of detection of upward-going neutrinos was successfully solved using the time-of-flight technique, and the first neutrino from ‘antipodes’ was recorded by the BUST on December 14, 1978 at 08:31:10 LT. Some other important results that were obtained at Baksan by Chudakov and his team are reviewed in brief in paper [12]. More information about this outstanding scientist and his selected papers can be found on memorial web page [13].

Acknowledgments

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