Bull. Spec. Astrophys. Obs., 1998, 45, 63-65

To the history of the RATAN-600 radiotelescope

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RATAN–600 is one of the achievement of Academician L. E. Mandelshtam and his students.

The Big Pulkovo Radiotelescope (BPR) with manually controlled reflecting elements was the prototype of RATAN–600. In the first stage of use the RATAN–600 operated in a semiautomatic mode, but provision was made for full automation. These intentions were gradually fulfilled. At the present time the multielement reflecting surface of the radiotelescope and its reflector operate automatically. Readjustment of the surface for observations at different elevations is homologically compensated by focus displacement. Possible slow variations of the wave front are corrected by the method of holography in a semi-real time.

The RATAN–600 operates in the optimum wave bands from mm to m. Having a multibeam radiation pattern, it allows us to simultaneously observe several sources in both transit and tracking modes.

Advantages of the radiotelescope rank it among the constructions of new technology based on the application of modern automatic and computing techniques. Many of the principles of modern telescope construction were first tested and implemented at the RATAN–600. The idea of variable profile antenna (VPA), on the basis of which the BPR and RATAN–600 were built, emerged more than forty years ago (1954) when modern means of automation and calculating techniques did not exist. However, possibilities for such antennas were envisaged, though in long-term perspective. Therefore, it might be of interest to recall the history of the early principles of constructing radio telescopes with VPA. Here both systematic and incidental factors played a role. To the systematic ones we may refer the fact that the authors of a new idea S. Eh. Khajkin and N. L. Kaidanovsky studied as physicists under the leadership of the academician L. E. Mandelshtam, an expert in the field of solving physical paradoxes and the author of some exceptionally bold and original prepositions, though contradictory from the first point of view. It is from him that the authors of the VPA learned the art of experiment and search for hidden opportunities. In lectures and seminars L. E. Mandelshtam created an atmosphere of logical clearness and simplicity, based on the correct idealization of physical phenomena, allowing to simplify their mathematical interpretations. Complicated and intricate physical phenomena often became clear in the course of discussions with L. I. Mandelshtam and his students. Their profound ideas have led later to unexpected discoveries. At that time a suggestion was made to the chief of the radioastronomy sector at the Institute of Physics of USSR AS (PhIAS) S. Eh. Khajkin to organize the Radioastronomy Department at the Pulkovo Observatory. It was a direct stimulus to the eventual evolution of the VPA.

In 1952 S. Eh. Khajkin, completing a large program of investigation of radiowave propagation through the whole depth of the Earth's atmosphere, which proved to be the basis for the development of Russian radioastronomy, and turning to astrophysical subject matter considered it expedient to develop radioastronomy not in PhIAS but in the astrophysical observatories.

Until 1954 the largest Russian Observatory at Pulkovo, in contrast to Byurakan and the Crimean Observatories, had no Department of Radioastronomy. S. Eh. Khajkin took it upon himself to organize it on the basis of the PhIAS staff. However, with the exception of N. L. Kaidanovsky, N. F. Ryzhkov and T. M. Egorova, the scientific staff in the radioastronomy sector of PhIAS were against this decision and turned down the move to Pulkovo. I agreed with the move, thinking it would be interesting to work with S. Eh. Khajkin, a man so full of ideas. Actually, he proposed I work on developing for the Pulkovo observatory a new radiotelescope which would have both large receiving area and resolution. Since such systems did not exist, it was necessary to invent a new one. This fascinated me. Having proposed this to me, S. Eh. Khajkin said: "I still don't know how the Directors at the Observatory view our nomination".

To clear up everything I went to the Pulkovo Observatory and reported to Scientific Council on plans for observing radio emission of the Sun using the polarization apparatures elaborated together with the post–graduate student Mirzabekyan, and on the supposed astrophysical results. My report was discussed and approved. The Director A. A. Mikhailov invited me into his study and in the presence of his deputy, M. S. Zverev, asked me about my family and previous activities. I was offered the post of senior researcher, and they promised to send a petition to Moscow on my transference and a guarantee on lodging.

In Moscow I started work on the new radiotelescope project. Since it was destined for the cm range it could only be a reflector. High resolving power meant the radiotelescope's diameter be of the order of 100 m. Such a large reflector radiotelescope of traditional construction with a rigid reflector would be very expensive. Such a telescope did not meet the main demand — low cost of production — since the means were not allotted for this. Therefore, the radiotelescope had to be reflective, have large dimensions and small height. I looked through a few variants of construction, but none were suitable.

The solution to this problem came by accident. My colleague A. E. Salomonovich, who worked with the mm range, acquired a glass paraboloid from a small searchlight and placed it on my table. Gazing at this mirror, I remembered the words of my university teacher M. A. Leontovich (one of Mandelshtam's finest students and later an academician): "Every element of the reflector behaves the same way as the whole mirror". These words had stuck in my memory since my student days. It became clear to me that while we could not build a paraboloid reflector (too expensive), we could construct a strip of some imaginary mirror and lay it out near the ground level. Since it is advantageously to place the focus (with the receiving horn and amplifier) near the ground level, then the reflecting strip of the mirror must be formed by section of the imaginary paraboloid, directed to an object, and the horizontal plain, passing through the focus. Of course, these sections will differ in form, depending on height, which the imaginary paraboloid is directed to, and they will be at different distantces from the focus. If the paraboloid is directed to zenith the sections will be circular, and if to horizon — paraboloidal. In all intermediate directions the sections will be elliptical. Just from this inference I decided to examine what the curves in the horizontal sections of the paraboloid look like within the angle of illumination 120°. For this purpose I drew up a series of parabolic sections on a large sheet of paper. To my surprise I saw that they all had a shape resembling the circumference of the equal radius, but are at different distances from the focus. This fact made me happy because it seemed to me possible to combine all the sections on one circular strip of constant radius, using individual flat elements. In such a case the pointing of a strip radiotelescope can be done by the focus displacement along the circular arc axis, and by such turn of the reflecting elements that the reflected rays be horizontal and intersect at the focus. Such a radiotelescope would be cheaper, have a large horizontal dimension and area, and a high resolution (however only in horizontal directions).

The beam pattern of such strip radiotelescope would have the form of a knife but not of a pencil. It would enable us to study a detailed brightness distribution of the vertical strips of the extended source. Here, however the fact that an object when moving rotates relative to vertical line can be of great help. Therefore at observations in different azimuths one can find brightness distribution of the other strips and while processing the data one can find detailed brightness distribution as if the observation was carried out not with the strip but circular mirror. For observations in different asimuths a reflective surface of exclusive circumference is required, but the focus must be easily transferred along the area of the radiotelescope. And with several receiving devices it would be possible to simultaneously observe several objects, since the central angle of the reflector receiving strip is less than 90°. Such a radiotelescope is consequently an equivalent of three/four simultaneously operating instruments.

All these aforementioned arguments, which take so long to describe, occured to me in less than twenty minutes. I reported on them at the next seminar of the laboratory of oscillations. My speech provoked amazement, and S. M. Rytov ridiculed me for the primitiveness of my graphic calculations. He was right. With the help of such a crude tool as beam compasses one cannot to make an inference on the curvature equality of different sections of paraboloid. A detailed analytical computation, that I made after a few days, showed that elipses in horizontal sections of the imaginary paraboloid were greatly dissimilar from the circumference, and in order to displace reflective elements from the initial circumference onto the ellipse it was necessary to shift them radially by 3% of the radius, i.e. when the radius is 100 metres it is necessary to shift it by 3 metres. This conclusion nearly killed off the idea of a big strip radiotelescope, since the cost of large and precise mechanisms of radial displacement would greately rise in price their construction.

However, I have found a way to get out of this difficult situation. There was one free parameter at our disposal, namely the dimension of this imaginary paraboloid. It turned out that a small alteration of this parameter, subject to the height of the observing object, permitted the maximum radial displacement of the reflecting elements to be reduced 10 times, i.e. with a radius of 100 m, a shift reduces up to 30 cm. This fact changed greatly the situation since mechanisms with such small displacements wouldn't be expensive. Consequently, building of the Pulkovo radiotelescope became reality. So, the initial coarse graphic computation of paraboloid sections has been fully justified, since it led to the possibility of creating reflecting surfaces in the form of circular strips. (Much later I showed the reality of the "circular periscope" antenna, if a special form feed is employed for compensating aberrations. The construction advantage of such a telescope is that it consists of equal elements, allowing mass production and gradual implementation.

It is now time to acknowledge the important role played by my mentor S. Eh. Khajkin in the cultivation and especially implementation of the new antenna. When he gave me the task to design the antenna he said, "The whole antenna must be on the ground, something like a fence". There were no other, clearer instructions. And in calculations and designing I always received his support which inspired me to go ahead. He also understood the main idea, that a reflected wave will come not at one point, but along the vertical line where it must be registered by a vertical linear antenna.

I made the calculation for phase variation on the linear feed. It fully corroborated the considerations of S. Eh. Khajkin. After the principles stated above had been arranged, I reported them at our department's seminar, where one of the leading antenna specialists, professor Ya. N. Fel'd was present. The speech was thoroughly discussed. Professor Ya. N. Fel'd pointed out impending difficulties in measuring the characteristics of such a large antenna. Problems with directing the radiotelescope onto the source were also discussed. With the exception of a bad–tempered negative speech of V. V. Vitkevich, the overall attitude of the seminar to our report was favourable.

After the report at the Institute of Physics I went to Pulkovo and at a session of the Scientific Council explained the principles of the new telescope. Such famous specialists in telescope production as Corr. mems of the USSR AS, D. D. Maksutov and N. N. Mikhelson, were present at this Council. My report was approved. After this the question on building the Big Pulkovo Radiotelescope passed from word to deed.

For a subsequent history of development of variable profile antennae see the account in the book "Essays of the History of Radioastronomy in the USSR" (Kiev, Naukova Dumka, 1985).

The report by S. Eh. Khajkin and N. L. Kaidanovsky "New high resolution radiotelescope", presented at a Session of the Department of Physics and Mathematics of the USSR AS, dedicated to the memory of N. D. Papaleksi, the closest associate of L. I. Mandelshtam, is a clear evidence that the invention of the VPA can be considered Mandelshtam's school achievement.