Chapter 6
Radio Astronomy at the Byurakan Astrophysical Observatory, the Institute of Radio Physics and Electronics of the Academy of Sciences of the Armenian SSR and Other Armenian Organisations

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Abstract The establishment and development of radio astronomy in Armenia is described in detail. Information about the radio telescopes of the Byurakan Astrophysical Observatory (BAO) is summarised. The main results of radio-astronomy studies carried out by BAO staff are described, including a number that used large Soviet and foreign radio telescopes, primarily studies of active galaxies.

6.1 Formation and Development of the Department of Radio Astronomy of the Byurakan Astrophysical Observatory, and Its Role in the Development of Radio Physics and Electronics in Armenia

Radio astronomers from the Byurakan Astrophysical Observatory (BAO) of the Academy of Sciences of the Armenian SSR occupy an important position among Soviet radio astronomers.

The Radio Astronomy Laboratory headed by V. A. Sanamian was formed in May 1950, at the initiative of Academician V. A. Ambartsumian. Subsequently, in 1955, it was reorganised into the Department of Radio Astronomy, which is still in existence today. The Department is primarily occupied with research in Galactic and extragalactic radio astronomy and the development of radio astronomy methods.

At the end of 1958, the Very-High-Frequency (VHF) Radio Astronomy Group of the BAO was transformed into the Department of Radio Physics Research Methods, headed by E. G. Mirzabekian. At the initiative of Ambartsumian, the Armenian Institute of Radio Physics and Electronics (IRFE), based on this Department, was established in the city of Ashtarak under Mirzabekian.

In 1968, again at the initiative of Ambartsumian, the VHF Laboratory of IRFE became the Armenian Division of Radio Physics Measurements of the All-Union Research Institute for Physical–Technical and Radio Physical Measurements. In turn, the All-Union Research Institute for Radio Physical Measurements was organised based on this institute, with P. M. Geruni at its head.

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As early as 1950, the Mechanical Laboratory was organised in the BAO, which became in 1957 the Optical Mechanical Laboratory, under the supervision of G. S. Minasian. It is this laboratory that was responsible for realising the design and construction of the antennas and antenna-feeder devices for all the radio telescopes of the BAO.

A Department of Radio Physics and Electronics headed by R. A. Kazarian was organised at Erevan State University in 1954 at the initiative of the BAO. Further, in 1975, a Department of Radio Physics was formed at the initiative of Mirzabekian, which prepared specialists in radio physics, including those working in radio astronomy.

Thus, interest in radio astronomy at the BAO and the requirements for its further development was stimulated by the progress of radio electronics and very-high-frequency techniques in Armenia. Each of the organisations indicated above played a large role in the development of science and technology in the Armenian SSR.

6.2 Radio Telescopes of the BAO

Beginning from the first days of the BAO, its director Academician Ambartsumian directed the main efforts of his group into observational astronomy, and radio astronomy was no exception. The BAO Department of Radio Astronomy worked on establishing its own observational base, as well as making use of observational facilities of other observatories. The main focus was constructing radio interferometers, since they provided good resolution and could be comprised of relatively small antennas.

During the first two to three years of the existence of the BAO Department of Radio Astronomy, one radio interferometer after another came into use; these operated at wavelengths of 0.5, 1.5 and 4.2 m, and applied methods for amplitude and phase modulation. By modern standards, they were tiny radio telescopes, but their construction represented a certain accomplishment at the time. They required the development of multi-element, fully-steerable, synchronous-phase antennas, sensitive high-frequency radiometers and acquaintance with new methods for receiving and recording small noise powers.

As we will see below, interesting scientific data were acquired using these radio telescopes. The most effective of them was the two-antenna radio interferometer operating at a wavelength of 4.2 m (Fig. 6.1). It was relocated and rebuilt several times, and was used under both fixed and field conditions. It is still in operation today. The method of phase switching and photographic and resonance methods for integrating weak noise signals were first applied in the USSR on this radio interferometer (see also Essay 1). Data obtained on this radio telescope were used to confirm the presence of secular variations in the radio flux of the supernova remnant Cassiopeia A predicted by I. S. Shklovskii, and to draw the conclusion that the physical mechanisms giving rise to the radio emission of the two brightest radio sources—the Galactic source Cassiopeia A and the extragalactic source Cygnus A—were the

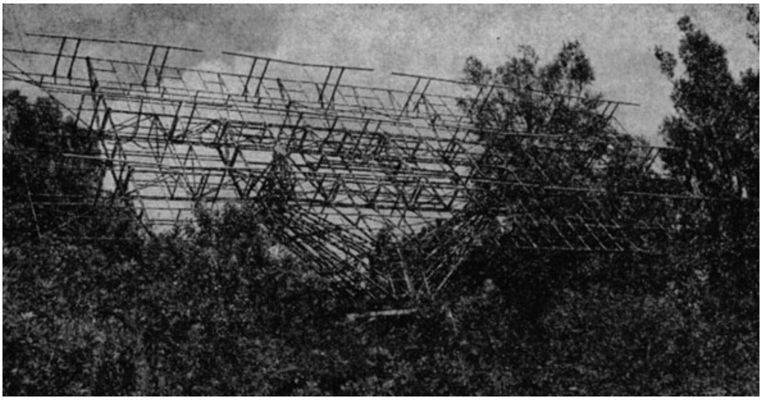

Fig. 6.1 One of the antennas of the first BAO radio interferometer (4.2 m wavelength)

same. This instrument was used to observe partial solar eclipses, to study the propagation of radio waves from cosmic sources through the perturbed ionosphere of the Earth and to acquire interesting data on the absorption and refraction of radio waves in the ionosphere.

In 1967–1968, the BAO radio telescope operating at 1.5 m wavelength was successfully used for systematic observations of the total radio emission of the Sun as part of the programme of the International Geophysical Year.

In 1956, work began on the planning (and, in 1968, on the construction) of a large T-shaped radio interferometer comprised of four antennas whose reflectors had the form of parabolic cylinders, with a total area of 4400 m^2 (Fig. 6.2). This instrument was intended for observations at wavelengths from 0.5 to 4 m, with the change between wavelengths realised by changing the feed system used. The first feed system was designed to operate at 2.5–3.5 m, and was brought into use at the end of 1960. However, strong, regular radio interference appeared in this range in the early 1960's, bringing about the need to move to a new feed system operating at a wavelength of 75 cm. Simultaneous with the change to this new feed system, work was also carried out to increase the area of the radio-interferometer antennas and improve their characteristics. The total collecting area was nearly doubled, to 7800 m^2, and the antennas were equipped with sensitive pre-amplifiers, a system for the calibration of individual sections directly from the pre-amplifier inputs and other devices. All this work was completed at the end of the 1960's. Work on automating the rotation of the radio-interferometer antennas was carried out at the beginning of the 1970's. Note that this instrument has a resolution of $5'$ in right ascension and a total effective area of no less than 2500 m^2, which can provide for the mean characteristics of the radiometer a flux sensitivity of 1 Jy for a signal to noise ratio of about five. This radio telescope was successfully used for Very Long Baseline Interferometry (VLBI) observations on the baseline between Byurakan and Simeiz, and, from early 1981, on the baseline between Byurakan and Ootakamoond (India).

The radio telescope is currently undergoing a new stage of reconstruction. One of its antennas with a length of 144 m is being re-outfitted for observations at 327 MHz

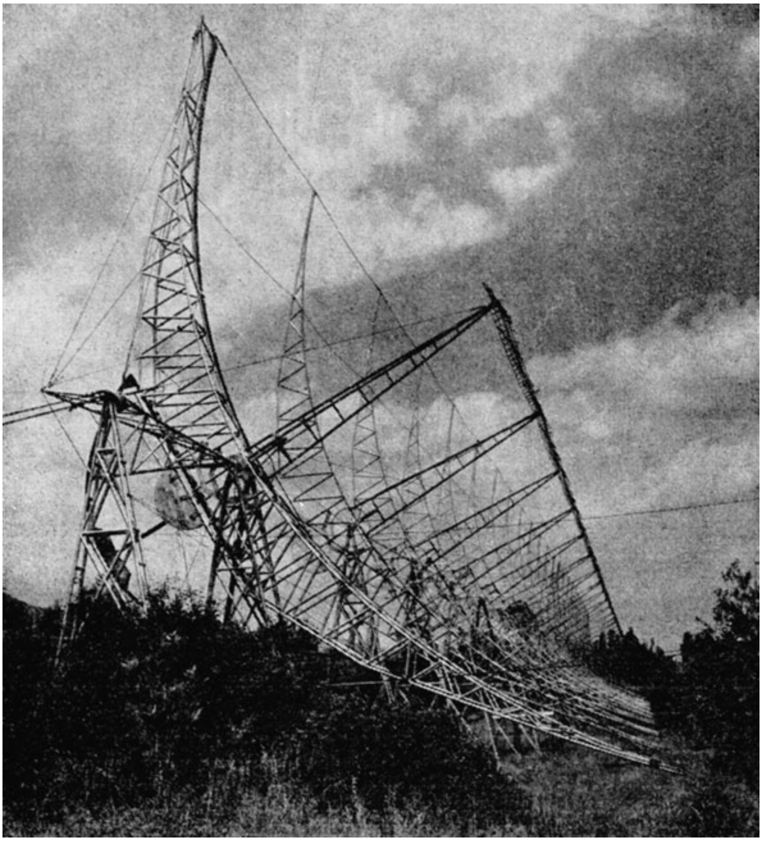

Fig. 6.2 Antenna of the large BAO radio interferometer, 216 × 18 m in size (75 cm wavelength)

with circularly polarised receivers, with the goal of using it in a VLBI programme between Byurakan and Ootakamoond, India. A preliminary analysis of the possibilities provided by building a new northern arm to the radio interferometer with a baseline of about 10 km is simultaneously being made. The realisation of such a programme could correct the main deficiency of the radio interferometer—its low resolution in declination. This would appreciably improve the efficiency of the radio telescope, giving rise to new possibilities for using the telescope in various interesting scientific research.

6.3 VLBI Programme

The technique of VLBI opens new possibilities for enhancing the effectiveness of small instruments, which individually are not very sensitive, but can prove to be very useful when they observe jointly with other larger radio telescopes.

Radio astronomers at the Byurakan Astrophysical Observatory were well aware of this circumstance. When at the end of the 1960s the Scientific Council of the USSR Academy of Sciences on Radio Astronomy called for radio astronomy institutions in the USSR to participate in an all-Soviet-Union VLBI programme, radio astronomers at the BAO were among the first to respond to this challenge and to take specific measures to develop this programme at the observatory.

In 1970, jointly with the Gorkii Radio Physical Research Institute (NIRFI), work began on a VLBI system operating at 408 MHz to be used on the Byurakan–Simeiz baseline. The elements of this interferometer were the large BAO radio interferometer and the 22-m radio telescope of the Crimean Astrophysical Observatory (CrAO). A *Razdan-3* computer of the Computational Centre of the Academy of Sciences of the Armenian SSR and a Ch1-48 Soviet frequency standard were used in the system.

As a result of combining the efforts of radio astronomers and engineers at the BAO and NIRFI, as well as staff at the CrAO and the Computational Centre, it was possible to put together a VLBI system for a short time and to conduct observations of a number of quasars. This was essentially the first VLB interferometer in the Soviet Union that was constructed entirely based on Soviet technology. This project was awarded a prize at the Exhibition of National Economic Achievement of the USSR.

In 1972, through the joint efforts of NIRFI, BAO, the Lebedev Physical Institute (FIAN), the CrAO, and IRFE together with other organisations, a new correlator for spectral observations was created, based on the correlator used for the above experiment on the Byurakan–Simeiz baseline. This new correlator was successfully used in VLBI observations of the interstellar water-vapour line at 1.35 cm on the Simeiz–Pushchino baseline.

Unfortunately, however, these collaborative works were not continued after the first successful experiment.

In the last 5–6 years, new steps in developing VLBI have been undertaken at the BAO. At the initiative of the Observatory and jointly with its constant scientific parter, NIRFI, an agreement was reached between the Academies of Sciences of the USSR and India to carry out joint projects on the Byurakan–Ootakamoond baseline ($\sim$4000 km). The elements of this interferometer are the Large Ooty Radio Telescope, which has an effective area of about 7000 m^2 at 327 MHz (India) and one antenna of the Byurakan radio interferometer outfitted with a circularly polarised feed and a correlation radiometer based on an ES-1030 computer. This interferometer has already passed the first stage of operational tests on the Byurakan–Ootakamoond baseline.

Participation in VLBI is one of the main and most promising research areas in observational radio astronomy within the BAO Department of Radio Astronomy.

6.4 BAO Participation in Work on the RATAN-600

In addition to observing on the radio telescopes of the Observatory, radio astronomers at the BAO have also successfully used other major Soviet and foreign radio telescopes for observations that are of interest for the general scientific programme of the Observatory. In this regard, a special place is occupied by the largest radio telescope in the Soviet Union, the RATAN-600 of the Special Astrophysical Observatory.

When at the end of the 1970s the Scientific Council on Radio Astronomy called for radio astronomy institutions to participate in the construction of the RATAN-600 telescope in whatever way they could, the BAO was able to make a modest contribution to this project (see Essay 5).

In particular, the BAO and the Armenian IRFE ordered the manufacture of low-noise radiometers with parametric quantum paramagnetic input amplifiers, which were included in the suite of RATAN-600 radiometers and were successfully used for a number of observational programmes, including those initiated by the BAO.

6.5 Development of Radio Astronomy Methods and Instrumentation in the IRFE

Work on high-frequency receivers operating at centimetre wavelengths was carried out in the BAO Department of Radio Physics Research Methods, and then IRFE. A new method for the polarisation modulation of a VHF signal was developed by the then PhD student Mirzabekian under the supervision of S. E. Khaikin and N. L. Kaidanovskii. This method made it possible to distinguish a weakly polarised component of a signal in the presence of a strongly polarised background. The VHF waveguide devices required to realise this method were also constructed: a polarisation modulator, ring feed, balance transformer, broadband phasometer etc. (see Essay 1).

A series of unique VHF radiometers were designed and manufactured at IRFE, and found wide application in studies carried out on space radio telescopes, as well as for space communications and other applied tasks.

The development at the IRFE of quantum paramagnetic amplifiers under the supervision of R. M. Martirosian laid the basis for research in quantum radio physics in Armenia. Efficient quantum paramagnetic amplifiers operating at decimetre, centimetre and millimetre wavelengths were constructed. New methods were proposed for expanding the transmission bandwidth and increasing the inversion bandwidth, based on frequency-modulated pumping. The 21-cm maser developed by Martirosian was the first in the world to be used on the 22-m telescope of the LPI for spectral studies of interstellar neutral hydrogen. The 1.35-cm maser constructed at IRFE is currently included in a suite of radiometers for the RATAN-600 radio telescope, and is being successfully used for spectral observations of interstellar water.

A number of parametric amplifiers in both integrated and band form with fairly good characteristics were developed at IRFE. Radiometers operating at 13 and 30 cm outfitted with parametric amplifiers designed by K. S. Mosoian and R. Kirakosian have been successfully used for many years on the RATAN-600 telescope. F. A. Grigorian was the first in the world to construct a parametric amplifier operating at 4 mm for radio astronomy use.

6.6 Antenna Measurements at VNIIRI

Work on the design and construction of unique antennas for radio telescopes and on antenna measurements was begun in 1968 at the All-Union Research Institute for Radio Physical Measurements (VNIIRI), which had separated from IRFE. A method for engineering calculations of multi-mirror antennas was developed, and applied to radio physical calculations of large radio telescopes in the new system. An original system for the automated control of large antennas that corrects the phase distribution of the field on their apertures was developed. Models of antennas with spherical primary mirrors designed for operation at millimetre and sub-millimetre wavelengths were constructed. A new method was developed for determining the parameters of antennas based on measurements of the field on their apertures, with subsequent machine and optical reconstruction of the field in the far zone. This method is still widely applied both in the Soviet Union and abroad. The construction of a unique two-mirror antenna system with a half-spherical primary mirror with a diameter of 54 m intended for operation at wavelengths from 5 mm to 1 m is ongoing.

6.7 Beginning of Radio Astronomy Observations at the BAO

The first cosmic radio signal at 50 cm wavelength (from the Sun) was detected in May 1951 at the BAO. This was a huge event for the BAO. The still relatively small collective assembled by the modest 3-m radio telescope (adapted from a "Small Wurzburg" radar system), which had been set up right next to the veranda of the laboratory building. Everyone awaited the passage of the Sun through the antenna beam. The spectators were not disappointed—the galvanometer arrow firmly followed the motion of the Sun.

The next step was the reception of signals from the radio sources Cassiopeia A and Cygnus A in Autumn 1951, when one of the antennas of the radio interferometer set up for observations at 4.2 m was ready for operation. A year later, the second antenna of the interferometer was ready, and the first interference signals from cosmic radio sources were received. Regular interferometer observations of roughly the 20 strongest cosmic radio sources began at the beginning of 1953, when a mirror-galvanometer oscillograph was acquired to record the received signals.

Observations of cosmic radio sources were of special interest to Ambartsumian. One antenna with its apparatus cabin was located close to his home at that time, and he very often, usually at night-time, came to the radio telescope to inquire how things were going. One warm autumn night, when Ambartsumian was told that he could see the signal from Cassiopeia A, he immediately came to the radio telescope and requested that the antenna be pointed at and then away from the source several times. He himself turned the antenna, carefully directing it at the source, then ran to the apparatus cabin to see the readout from the instruments. Cassiopeia A is always above the horizon at Byurakan, and this procedure for obtaining the signal went on for several hours. When Ambartsumian was convinced that the signal was real and the readout from the instruments was repeatable again and again, he joyously said, "Now this is happiness!" Note that Ambartsumian was generally very attentive with regard to any observational data.

Another important event was the first observation of a partial solar eclipse, in 1954. The radio astronomers prepared painstakingly for this. At that time, three people worked in the Radio Astronomy Laboratory, which was clearly an insufficient number to carry out observations on three radio telescopes, and it was necessary to mobilise other astronomers and workers for these observations. The efforts were not in vain—good flux-variation curves were obtained on two of the telescopes (operating at 1.5 m and 4.2 m wavelength).

A group of BAO radio astronomers took part in an expedition of the USSR Academy of Sciences to the People's Republic of China, in order to observe the total solar eclipse of 1958. In a short time, a new two-antenna radio interferometer operating at 50 cm was constructed and sent to the site of the expedition. The observations, which were conducted by Mirzabekian, Geruni and G. A. Erzn'kanian, were successful, and yielded interesting data on the radio emission of the Sun, including its polarisation characteristics.

Subsequently, radio observations of cosmic radio sources became commonplace, although, in principle, there are no uninteresting observations.

6.8 Scientific Results

The radio astronomy research programme in the BAO Department of Radio Astronomy as a whole emerged from the general scientific programme of the Observatory. In brief, it consists of studies of non-stationary processes in the Universe, in both our own and in other galaxies. Since the radio emission of cosmic sources can be an important indicator of activity, Galactic and extra-galactic radio astronomy have always been one of the main research directions at the BAO.

In stands to reason that it is not possible in a short survey of the history of radio astronomy to list all the scientific results obtained in the course of three decades of research. We will aim to focus on those that, in our view, are the most important, following a primarily chronological approach.

The first fundamental word on the nature of the radio emission of galaxies was expressed by Ambartsumian. At the Fifth All-Union Conference on Cosmogony in 1955, which was essentially the first radio-astronomy conference in the USSR, A. G. Masevich read a letter written by Ambartsumian, in which he briefly argued against the then popular hypothesis of W. Baade and R. Minkowski that the radio emission of Cygnus A was due to a "head-on" collision of galaxies. Ambartsumian showed that the radio emission of this source, like that of Centaurus A, Perseus A and others, was not a consequence of a collision, but indeed just the opposite—it was the result of processes occurring in the nucleus of the galaxy that were accompanied by the ejection of a huge amount of matter from the nucleus. This conclusion, which formed the basis for a new understanding of radio galaxies, was then laid out in more detail at the Sol'veev Conference (1958), and, in subsequent years, was confirmed by new observational data and became the basis for the theory of the role of activity in the galactic nucleus in the formation and evolution of these galaxies. This theory is currently widely accepted among both Soviet and foreign scientists. Today, it is rare to find anyone who doubts in the presence of active processes in the nuclei of galaxies and quasars, one manifestation of which is their radio emission.

Since we are concerned here with the history of radio astronomy, I think it is appropriate to point out that, at the Fifth All-Union Conference on Cosmogony (1955), Shklovskii, who was then a proponent of the colliding-galaxy theory and presented a talk on the origin of the radio emission in Cygnus A in the collision process, spoke sharply against the comments of Ambartsumian. But a year later, at the following radio-astronomy conference, Shklovskii had clearly moved away from his former position.

One important scientific result of the BAO Department of Radio Astronomy was the experimental confirmation of the secular, monotonic decrease in the intensity of the radio flux from Cassiopeia A, identified with a supernova remnant. Monitoring observations of this source at wavelengths of 1.5, 3.6 and 4.2 m over many years showed, as had been predicted by Shklovskii, that the radio flux of this source over a wide range of wavelengths was decaying almost before our eyes as a result of the expansion of the electron gas in the source and scattering by magnetic fields.

Interesting results were also yielded by observations of the radio emission of the Galactic-centre region (Sagittarius A) obtained at 30 cm and 3.6 m on the Pulkovo and Byurakan telescopes, respectively. These observations showed the presence of fine structure of the radio emission of the Galactic centre, and indicated that the source spectrum was non-thermal, and probably a synchrotron spectrum. The 3.6-m data demonstrated strong absorption of the radio emission at metre wavelengths in regions of ionised hydrogen.

In 1967–1968, members of the BAO Department of Radio Astronomy jointly with radio astronomers of FIAN conducted a series of observations of about 150 radio sources from the 3C catalogue at a frequency of 60 MHz on the East–West arm of the FIAN DKR-1000 telescope using a radiometer specially constructed for this purpose at the BAO (see Essay 1). The low-frequency spectra of these sources were analysed in detail using these data together with data obtained in other studies. These were the first 60-MHz observations for many of these sources, and this frequency is also located near the region where the spectra of many of the sources turn over. For these reasons, these data proved to be very valuable. In particular, analysis of the spectra showed that the spectra of about 60 display low-frequency turn-overs in their spectra, with the curvature of the spectra usually being positive. Low-frequency spectra with negative curvature were more often encountered among double or multiple radio sources.

Interesting studies concerning searches for slow variations in the radio fluxes of a number of quasars and galactic nuclei were carried out at metre wavelengths. Long-term series of measurements of the relative fluxes of the radio sources 3C48, 3C84, 3C273 and others at 408 MHz were carried out over many years at the BAO; the source 3C120 was monitored at 327 MHz on the Indian radio telescope. A number of sources displayed variability at 408 MHz. It was concluded that the observed flux increases were the result of some explosive process. The flux of 3C273 decreased by 25 percent over 10 months, searches for variability in the radio emission of quasars and galactic nuclei are ongoing.

After the role of active galactic nuclei in giving rise to the radio emission of radio galaxies (and then quasars) was understood, a natural question occurred to Ambartsumian: is nuclear activity a general property of all galaxies, including normal, "quiet" galaxies, from the point of view of their radio emission? He presented the scientific staff of the Observatory the challenge of carrying out multi-faceted investigations of normal galaxies, especially those with bluer colours, in order to search for signs of activity in their nuclei.

The very first such searches led B. E. Markarian to the discovery of a class of galaxies with an intense ultraviolet continuum spectrum. Analysing the brightest of these galaxies to investigate the origin of their excess blue radiation, he very early expressed the opinion that this excess radiation was non-thermal in nature. About 1500 such objects were discovered by Markarian and his students over the following 15–20 years, indicating that they form a fairly widespread class among normal galaxies, now known as Markarian galaxies.

Spectroscopic research conducted by E. A. Khachikian and D. B. Vidman revealed a new property of these galaxies. It was found that the vast majority of galaxies with "ultraviolet excesses" in their spectra also have emission lines, and, more interestingly, many display the properties of Seyfert galaxies. This enhanced interest in Makarian galaxies among the radio astronomers of the BAO, as well as among many other radio astronomers both in the Soviet Union and around the world. Since one of the most accessible means to reveal active processes occurring in galactic nuclei is to study their radio emission, radio astronomers, especially those at the BAO, could hardly be uninterested in this class of object.

Over the subsequent 15 years, BAO radio astronomers carried out numerous observations of galaxies with ultraviolet continuum spectra ("ultraviolet continuum galaxies") on various major radio telescopes of the USSR and other countries. For example, G. M. Tovmasian obtained observations of 18 very bright ultraviolet continuum galaxies in 1965 on the 64-m Parkes telescope and the large cross telescope in Australia. The very first set of these observations showed that 80% of these galaxies possess radio emission exceeding 0.1 Jy having a non-thermal spectrum. As we will see below, this large fraction came about due to the selection effect that, as became clear later, this sample included a large number of Seyfert galaxies, whose radio emission is, on average, greater than that of normal galaxies.

In 1970, V. Malumian studied the radio emission of about 30 ultraviolet continuum galaxies by analysing observational data obtained on the Cambridge radio telescope in England. These data showed that the radio emission of these galaxies at 408 MHz did not exceed the sensitivity threshold of this telescope, $\sim$0.5 Jy.

In 1973, Sanamian used the unique Ooty radio telescope in India to observe about 80 selected ultraviolet continuum galaxies. About 10% of these displayed radio emission exceeding 0.6 Jy at 327 MHz. However, due to the large degree of "confusion," this result must be considered uncertain. Some of the firmest results were yielded by lunar occultation data for three ultraviolet continuum galaxies (Mrk384, Mrk369, Mrk370). In particular, it was found that two of these galaxies (Mrk369 and Mrk384) possess appreciable radio emission at 327 MHz. Based on this result, it was proposed that many galaxies of this class should display radio emission at metre wavelengths exceeding 0.2 Jy if they could be observed with the same resolution and sensitivity as for the lunar-occultation observations with the Ooty telescope. About 100 new ultraviolet continuum galaxies, most of them Seyfert galaxies, were observed on this same telescope by Sanamian and R. A. Kandalian in collaboration with Indian radio astronomers in 1981.

A joint preliminary analysis of the data from these two series of observations confirmed the previous result: of 180 ultraviolet continuum galaxies, 30 displayed radio emission at 327 MHz exceeding 0.8 Jy, with most of them being Seyfert galaxies.

About 500 galaxies from the first five lists compiled by Markarian were observed by Tovmasian and R. A. Sramek on large American radio telescopes in 1973. They obtained a large amount of observational data, enabling a statistical analysis of the question of how the radio emission of these galaxies depends on their morphological type and other characteristics.

When the northern sector of the RATAN-600 radio telescope became fully operational, Sanamian and Kandalian began systematic observations of ultraviolet continuum galaxies over a wide frequency range, from 2.3 to 14.4 GHz. Guided by previous results, they concentrated on those galaxies that also displayed properties of Seyfert galaxies. The number of galaxies observed thus far is 150, with a substantial fraction being Seyfert galaxies. These data appreciably supplemented those obtained by Tovmasian, Sramek and others. Measurements of the radio spectra of a number of galaxies at long wavelengths were continued, and the variability of Mrk348 was confirmed. Some of the most interesting data concern the radio emission of Seyfert galaxies. It was shown that, although the relative number of radio-emitting galaxies is higher for SyII galaxies than for SyI galaxies, the mean radio luminosity of SyI galaxies is appreciably higher (by more than a factor of two to three) than that for Sy2 galaxies. Tovmasian and Sramek had arrived at the opposite conclusion.

Starting in early 1980, radio astronomers from the BAO (Sanamian, Kandalian, G. A. Oganesian) and the radio astronomy station of the Lebedev Physical Institute in Pushchino (V. S. Artyukh and others) began studies of ultraviolet continuum galaxies at 102 MHz using the FIAN Large Scanning Antenna to observe the scintillation of these objects on inhomogeneities in the interplanetary plasma (see Essay 2).

The various results of BAO radio astronomers led to increased interest in ultraviolet continuum galaxies among foreign colleagues, particularly many radio astronomers in the USA.

Malumian obtained systematic observations of about 60 galaxies with high surface brightnesses on the RATAN-600 telescope. He also observed about 140 of these galaxies at 1412 MHz on the Westerbork Synthesis Radio Telescope. These galaxies are also currently being studied at 102 MHz using the Pushchino Large Scanning Antenna (FIAN).

V. G. Panadzhian studied the fine structure of a number of radio sources using observations of their scintillation on inhomogeneities in the interplanetary plasma using the FIAN DKR-1000 radio telescope at 40, 60 and 86 MHz and the BAO radio interferometer at 408 MHz. The characteristics of the scintillation (quasi-period, scintillation index, etc.) were determined as a function of the elongation of the radio source. He demonstrated that the frequency dependence of the maximum scintillation index could be used to estimate the structure of the source. Joint scintillation observations of radio sources at several different frequencies were also used to estimate a number of characteristics of the interplanetary plasma.

6.9 Scientific Connections Between the BAO and Both Other Soviet and Foreign Radio Astronomy Institutions

From the first days of the Department of Radio Astronomy, BAO radio astronomers have been greatly helped by prominent colleagues at the Lebedev Physical Institute, and then the Pulkovo Observatory. BAO radio astronomers carried out their first practical work at the Crimean Station of FIAN in November–December 1950. The first radio astronomer to visit Byurakan for consultation and to offer assistance was V. V. Vitkevich (Spring 1952). With his characteristic enthusiasm, he approved the decision of BAO radio astronomers to concentrate on interferometric methods and recommended that the Observatory work more intensely to develop these methods. Vitkevich remained a great friend and helper of BAO radio astronomers in subsequent years, right to the end of this life.

S. E. Khaikin also greatly aided BAO astronomers. Nearly all the leading BAO radio astronomers (Sanamian, Tovmasian, Mirzabekian, Malumian) did their PhD research under the supervision of Khaikin, with co-supervision by N. L. Kaidanovskii. Khaikin jokingly referred to himself as the "enlightener of Armenian radio astronomers," which was not far from the truth. During a visit to Byurakan in Autumn 1955, Khaikin and Kaidanovskii made a number of important suggestions concerning the subsequent work of the BAO Department of Radio Astronomy.

The positive attitude of these heads of two major radio astronomy centres in the USSR toward the BAO radio astronomers was also maintained by their research groups. The BAO Department of Radio Astronomy has often and effectively collaborated with radio astronomers of FIAN and the Pulkovo Observatory, and there are now collaborations with the Special Astrophysical Observatory as well (Yu. N. Pariiskii, N. F. Rykhkov, A. D. Kuz'min and many others). The collaboration with Leningrad radio astronomers became especially strong after the construction of the RATAN-600 radio telescope began. Currently, nearly all prominent radio astronomers at the BAO carry out systematic observations on the RATAN-600, and have felt the support of the entire staff of the SAO Department of Radio Astronomy, in particular, of its head—Corresponding Member of the USSR Academy of Sciences Yu. N. Pariiskii.

Corresponding Member of the USSR Academy of Sciences V. S. Troitskii first came to Byurakan to organise solar radio observations as part of the programme of the International Geophysical Year in 1976, and a close scientific relationship between the radio astronomers of the BAO and NIRFI in Gorkii has been established since that time. Collaborative work on VLBI has been especially effective.

The scientific relationship between radio astronomers of the BAO and Crimean Astrophysical Observatory (CrAO) is likewise close. In particular, the 22-m radio telescope of the CrAO served as one element in the Byurakan–Simeiz and Simeiz–Pushchino radio interferometers, and CrAO radio astronomers (I. G. Moiseev, V. A. Efanov and others) contributed in many ways to the success of this programme. Moiseev and Tovmasian have also collaborated on studies of radio-source variability at millimetre wavelengths on the 22-m CrAO radio telescope.

The scientific links between BAO radio astronomers and foreign colleagues that were referred to above were not one-sided. Many foreign radio astronomers visited the Byurakan Astrophysical Observatory for extended periods of time and carried out collaborative research with our own researchers (R. A. Sramek and G. Kojoian of the USA; G. Swarup, V. R. Venugopal and M. Joshi of India; M. Kaftan of Iraq and many others). In addition, several dozen foreign radio astronomers have made shorter visits to the Radio Astronomy Department in order to become better acquainted with research at the BAO.

In a number of cases, scientific relations with foreign researchers have developed into ongoing scientific collaborations. A good example is the VLBI programme between the BAO and the Radio Astronomy Centre of the Tata Institute in India, which is carried out as a scientific collaboration in radio astronomy between the USSR Academy of Sciences and the Indian National Academy.