N. D. Papaleksi and Soviet radioastronomy

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Usp. Fiz. Nauk 134, 541–550 (July 1981)

PACS numbers: 01.60. + q, 01.30.Cc, 95.85.Dj, 96.60.Tf

In opening the memorial meeting devoted to the memory of N. D. Papaleksi on Apr. 21, 1947, the president of the Academy of Sciences of the USSR, Academician S. I. Vavilov said: "The last years of N. D.'s life conveyed a special impression of heightened interest in geophysical and astronomical applications of radio— in studies of the ionosphere at normal times and in periods of solar eclipses, in radio location of the Moon, and in studies of the intrinsic radio emission of the Sun. Death overtook N. D. in preparation for an expedition to Brazil, for which he and his students had thoroughly prepared themselves, as always, and which he was to direct. He was not destined to survive until the date of the expedition, and now his orphaned students are sailing on a Soviet steamship to the shores of Brazil without their teacher... ".[1]

In his report at the same meeting, S. M. Rytov bore witness: "... Another, quite new problem with which N. D. was especially occupied in the last months of his life was the radio emission of the Sun and of outer space. In these phenomena N. D. saw the foundation for a new science— radioastronomy... ".[2]

At the present session devoted to the centennial of N. D.'s birth, it is natural to take up in somewhat greater detail the radioastronomical facet of his many-sided activity.

N. D.'s interest in employing radio to expand and deepen astronomical studies was not fortuitous nor episodic. It stemmed from the organic features of N. D.'s personality as a scientist. Perhaps G. S. Gorelik spoke best of all about this at the time of meeting now memorable to many in April 1947 at the building of the Division of Technical Sciences in Malyĭ Khariton'evskiĭ Pereulok. I still remember this extremely brilliant presentation. Gabriel' Semenovich said then: "In his experiments and theoretical studies, in his many-sided interests, N. D. was seriously interested in meteorology, in physical problems in biology, and even, one time in Strasburg, somewhat in medicine—in all his activity N. D. was primarily, if one can so express it, a conqueror scientist, an opener of new lands, or what is very precisely expressed in French by the word "explorateur". This feature of his creativity fully harmonized with his love for the ocean, for travel, and for sports. And when I try to understand the fine structure of the brilliant radiophysical doublet of Mandel'shtam-Papaleksi, and to estimate its spacing, and to say of either of them what cannot be said of the other, a childhood memory comes into my head of the Jules Verne novels, of the heroes of science, full of daring, of physical endurance, and youthful enthusiasm, who cross the seas and continents and fly off into outer space. If we throw out all the extravagances of these

N. D. Papaleksi (1880-1947)

heroes, with which N. D. was never saddled, their images are definitely in tune with his creativity.

I have collected reprints of the last articles and reports of N. D. How much they contain of geographical names, geophysics, astronomy, and expeditions! And is not the expedition of the Institute of Physics of the Academy of Sciences organized at N. D.'s initiative, which is sailing at this instant to the shores of Brazil to observe a solar eclipse, an embodiment of how N. D. Papaleksi always lived so intensively?"[3]

N. D.'s studies in the field of location of the Moon, development of radiointerference ranging methods, and study of the ionosphere have already been mentioned today. Many of these approaches have naturally led to the problem of studying the intrinsic radio emission of the Sun and of the Galaxy.

As we know, in thinking out the potentialities of an experiment on radio location of the Sun, N. D. requested the young theoretician, Dr. V. L. Ginzburg to examine the problem of the conditions for reflection from the solar atmosphere of radio waves of different wavelengths. The calculations, which were published in 1946 in *Doklady Akademii Nauk SSSR* upon being submitted by N. D.,[4] showed that reflection from the Sun is apparently impossible throughout the range of wavelengths of interest. Radio waves in the meter range will be absorbed in the solar corona, and the shorter ones in the chromosphere, and will not reach regions of reflection.

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But this implied that the source of the thermal radio emission of the Sun must not be the photosphere, but the chromosphere and (for meter waves) the corona. V. L. Ginzburg's contemporary, I. S. Shklovskiĭ, arrived at analogous conclusions independently and practically simultaneously. These results were published in the same year 1946.[5] N. D. attentively followed all the foreign publications and knew of the first observations outside an eclipse of the radio emission of the Sun, and of course, of the pioneer studies of Jansky and Rieber. N. D. arrived at the idea of observing the radio emission of the Sun at the time of the forthcoming prolonged total eclipse of the Sun on May 20, 1947, whose track was to pass through Brazil. The significance of this idea is in the fact that one could "compare" successively different regions of the solar atmosphere by means that were relatively simple for that time during the changes of phase of the eclipse. Thus one could confirm experimentally the validity of the hypothesis of the coronal origin of the radio emission of the Sun in the meter range. Moreover, the opportunity was presented here of revealing the role of active structures on the Sun in producing an increase in radio emission. Information on radio emission of this type had begun at that time to permeate the scientific literature from English and American wartime reports.

N. D. undertook the preparation of the radio observations. This was not the first expedition to observe a solar eclipse in which he had participated. However, while previously the topic was radio observations of the ionosphere during an eclipse, now the program was to include also observation of the intrinsic radio emission of the Sun.

A radio specialist was needed to perform the radio observations, sufficiently experienced to deal with problems highly complex for that time, and an enthusiast in this new topic to boot. Such a person was found—he proved to be B. M. Chikhachev—a scion of the Leningrad Polytechnic Institute, a student and associate of N. D. Papaleksi at the Leningrad Central Radio Laboratory, and then one of the pioneers of our domestic radio tube industry, who after the war exchanged his position of chief technologist of the radio plant for the meagerly paid post of a graduate student at the Institute of Physics of the Academy of Sciences. However, in the midst of preparation for the Brazilian expedition, in February 1947 its director, the head of the oscillation laboratory at the Institute of Physics of the Academy of Sciences, N. D. Papaleksi suddenly passed away.

The fate of the projected experiment, and to some extent the entire expedition, hung in the air. However (and apparently this constitutes the viability of a scientific school), the successor of N. D. Papaleksi was found within the resources of the same laboratory. He proved to be Professor S. É. Khaĭkin, who after the war had gathered at the Institute of Physics of the Academy of Sciences a group of his students, having continued his prewar investigations on the physical properties of solids and liquids by radio methods. In 1981, 80 years will have passed since the birth of S. É. Khaĭkin, who left us prematurely in 1968. It is difficult now for many to imagine that S. É. at one time was not occupied with radio astronomy. However, we can point out exactly when he began to occupy himself with it: February 1947. Apparently the fruitful work on designing phase radiolocation stations performed by S. É. during World War II did serve as the launching pad from which S. É.'s involvement in radio astronomy took off. From the very first days under Khaĭkin's direction, the preparation for the expedition resumed with renewed vigor. An important role in this was played by the president of the Academy of Sciences of the USSR, Academician S. I. Vavilov, and the chairman of the Astrosoviet, Academician A. A. Mikhaĭlov, who headed the expedition. In the expedition, which was planned to conduct also radio and ionospheric observations, as well as optical observations, a whole constellation of physicists participated—V. L. Ginzburg, I. S. Shklovskiĭ, and others. The legendary polar explorer G. A. Ushakov was invited as the deputy director. As it turned out this was his last major expedition.

The steamship "Griboedov" arrived at the bay of Bahia in the middle of May. Only a few days remained for preparation for the eclipse. The observations of the eclipse on May 20 were performed at a wavelength of 1.5 m with a cophased antenna fixed immovably to the deck of the steamship. The angle of elevation, which was close to the zenith, was fixed. How can one track the Sun in azimuth during an eclipse? S. E. Khaĭkin solved the problem with his characteristic ingenuity. The rotation mechanism became the steamship itself. For the first time in the history of the fleet, the crew loosened and drew in the anchor chains at the orders of a professor of physics, and the steamship obediently rotated on the anchors. There were no reliable recorders. Observers were installed in the various cabins, and independently wrote down the readings from the pointer devices.

The results of the observations, which were published in October 1947[6] and in greater detail in the following year,[7] have become classical: the radio emission of the solar corona predicted by the theoreticians was detected experimentally. A certificate was awarded a quarter century after this discovery. Today not one of the authors of this discovery—N. D. Papaleksi, S. É. Khaĭkin, and B. M. Chikhachev—the only one who saw this certificate with his own eyes—is among us.

Before proceeding to list briefly the stages of development of radioastronomical research in the Soviet Union, whose pioneer was N. D. Papaleksi, I should like to make two remarks.

1. The above-mentioned publication in the *Doklady Akademii Nauk*, which was presented by N. D., indicated the addresses at the end of the article: "P. N. Lebedev Institute of Physics, Gor'kiĭ State University". This was not fortuitous. At that time V. L. Ginzburg and also S. M. Rytov were also collaborating at Gor'kiĭ University, where a Gor'kiĭ branch of the Mandel'shtam-Papaleksi school was developing, and where a very strong school of radiophysicists was being created rapidly around A. A. Andronov, G. S. Gorelik, and M. T. Grekhova. Thus not only Moscow, i.e., the In-

FIG. 1. The group of participants in the Soviet expedition on the steamship "Griboedov". The first from the right in the first row is S. É. Khaĭkin, the fourth is G. A. Ushakov, the fourth from the left in the second row is V. L. Ginzburg, the ninth is B. M. Chikhachev, the second from the right in the third row is I. S. Shklovskiĭ.

stitute of Physics of the Academy of Sciences and Moscow State University, but also Gor'kiĭ were sites where Soviet radioastronomy developed.

2. In his remarkable lecture read at the Moscow House of Scientists a month before his death, N. D., in speaking of the promising problems of radiophysics, made his main emphasis on extending it into the microwave region. He took this term to mean waves in the centimeter, millimeter, and shorter-wavelength ranges. In formulating the scientific problems of further development of radio, N. D. said, "As we have seen, the present stage of development of radio reveals a certain tendency to go to ever shorter wavelengths." He stressed that "microwaves (centimeter, millimeter, and shorter) can be focussed into very narrow beams of enormous power, e.g., with parabolic mirrors such as are used in optics, or by specific radiotechnical methods involving the possibility of creating coherent-radiation systems... ".[8]

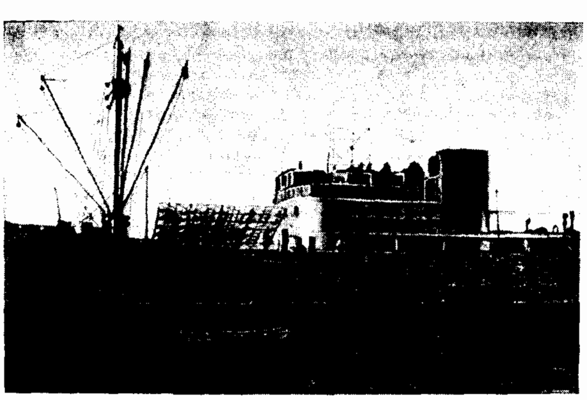


FIG. 2. The steamship "Griboedov" in the bay of Bahia (Brazil). On the deck is the cophased antenna with which the Soviet scientists first observed a radioeclipse of the Sun.

Throughout the lecture the idea ran like a red thread that the main problems in the future will be those of generation, channelling, emission, propagation, and reception of millimeter and shorter radio waves, as far as the optical region. In particular, N. D. stressed the importance of radio waves of this range, not only for radio communications, geodes, and astrophysics, but also for meteorology, since a close relation is observed between the conditions of propagation of radio waves of the centimeter, millimeter and shorter-wavelength ranges and the meteorological parameters of the atmosphere.

Having been the initiator of the development of radioastronomy in the Soviet Union, N. D. left us at the very instant when the conditions had ripened for a broad study of solar and cosmic radio emission. The great service of S. É. Khaĭkin was that he not only brought to a brilliant conclusion the Brazilian experiment conceived and prepared by N. D., but he raised the banner of observational radioastronomy in the Soviet Union and carried it forward. He knew how to link the first steps in Soviet radioastronomy with the solution of an applied problem important to the government. This enabled him to formulate and solve the problems of creating the needed material basis for subsequent astrophysical studies.

There is no opportunity here to take up all the stages of development of Soviet radioastronomy. A collective volume is being prepared on the history of radioastronomy in our country (see also Refs. 9 and 10). We hope that all of its important advances will find a place there. Among other things, this depends on the radioastronomers themselves, who like all people are unfortunately mortal. In recent years, after the untimely death of V. V. Vitkevich in 1972 and B. M. Chikhachev in 1971, we have lost S. B. Pikel'ner, S. A. Kaplan, G. G. Getmantsev, É. G. Mirzabekyan... .

So as to keep closer to the theme of today's session, I shall restrict the treatment only to a very short list of what was subsequently accomplished in our country in

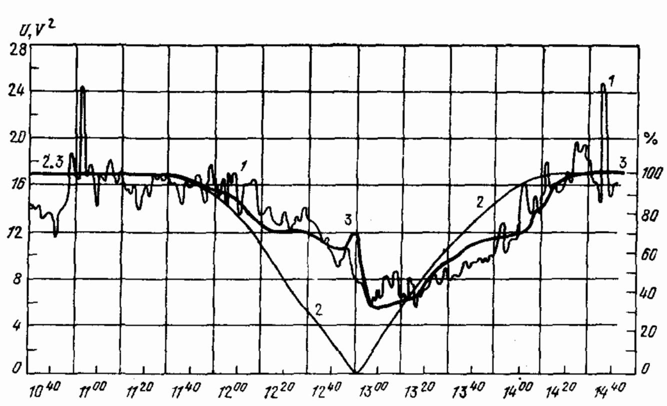
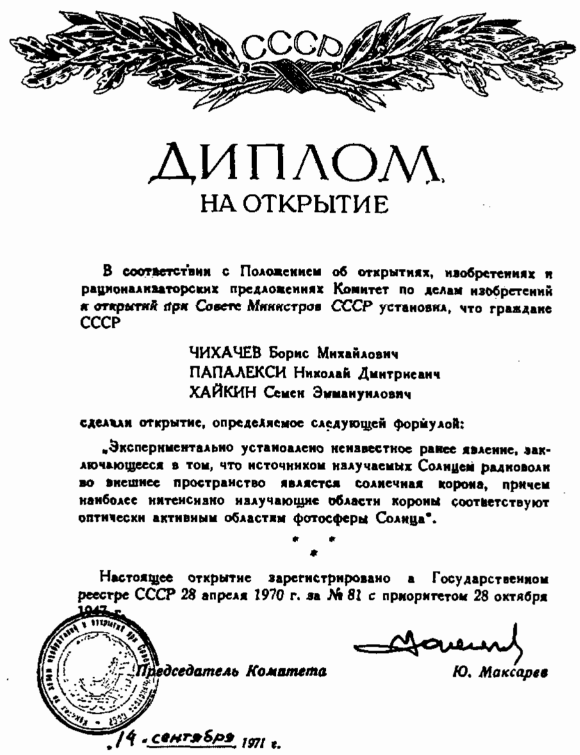


FIG. 3. Recordings obtained by the Soviet radioastronomers at the time of the solar eclipse on May 20, 1947. 1—variation of the intensity of radio emission of the Sun at the wavelength of 1.5 m, 2—variation of the visible area of the solar disk, 3—course of the "eclipse" of the hydrogen prominences and filaments [Dokl. Akad. Nauk SSSR **58**, 1923 (1947)].

the field of solar radioastronomy. I must say that at the outset an especially rapid advance was made precisely in this field.

The very interesting studies of the active regions on the Sun performed in the meter range by B. M. Chikhachev at the Crimean Radioastronomical Station were


СССР

ДИПЛОМ
НА ОТКРЫТИЕ

В соответствии с Положением об открытиях, изобретениях и рационализаторских предложениях Комитет по делам изобретений и открытий при Совете Министров СССР установил, что граждане СССР

ЧИХАЧЕВ Борис Михайлович
ПАПАЛЕКСИ Николай Дмитриевич
ХАЙКИН Семен Эммануилович

сделали открытие, определяемое следующей формулой:

„Экспериментально установлено неизвестное ранее явление, заключающееся в том, что источником излучаемых Солнцем радиоволн во внешнее пространство является солнечная корона, причем наиболее интенсивно излучающие области короны соответствуют оптически активным областям фотосферы Солнца".

* * *

Настоящее открытие зарегистрировано в Государственном реестре СССР 28 апреля 1970 г. за № 81 с приоритетом 28 октября 1947 г.

Председатель Комитета Ю. Максарев

„14" сентября 1971 г.

FIG. 4. Photograph of the certificate* for the discovery of the solar radiocorona. The copy is from B. M. Chikhachev's specimen, which explains the order of listing of the authors.

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*Translation of certificate:

USSR
Certificate of discovery

In accordance with the statute on discoveries, inventions, and rationalizers' suggestions the Committee on Inventions and Discoveries of the Council of Ministers of the USSR has determined that the citizens of the USSR

CHIKHACHEV, Boris Mikhailovich
PAPALEKSI, Nikolaĭ Dmitrievich
KHAĬKIN, Semen Émmanuilovich

have made the discovery defined by the following formulation:

"An experimental demonstration has been made of a previously unknown phenomenon consisting of the fact that the source of radiowaves emitted by the Sun into space is the solar corona with the most intensely emitting regions of the corona corresponding to the optically active regions of the photosphere of the Sun."

* * *

The discovery is recorded in the State Registry of the USSR on 28 April 1970 under No. 81 with the priority date of 28 October 1947.

Chairman of the Committee Yu. Maksarev
19 September 1971

followed by the series of brilliant studies of V. V. Vitkevich on the radio emission of the quiet and the weakly perturbed Sun. The Crimean station was organized as early as 1948 by S. É. Khaĭkin, initially based on buildings existing there, which were restored by N. D. after the war in connection with radiointerferometric studies that he had planned. Thus, even in this act, already posthumous, N. D. enabled an acceleration of the development of radioastronomy in our country.

In 1951 V. V. Vitkevich put forward the idea of the method of "transilluminating" the outer corona (supercorona) of the Sun with the radiation of a discrete source. This idea was then realized with V. V.'s characteristic flourish. This brought to Soviet radioastronomy world renown, and V. V. was awarded a State Prize, the first received in radioastronomy.

The discovery of the supercorona gave rise to a "chain reaction" of studies performed by V. V. and his students. They studed the inhomogeneities of the outer corona, its polarization characteristics, the features of the corpuscular radiation of the Sun, and subsequently the phenomena of scintillation and of the solar wind. These studies, including the building of the unique DKR-1000 and BSA radiotelescopes, continued right up to V. V.'s death.

As I mentioned above, N. D. perspicaciously paid attention to the role of microwaves as early as the late forties. S. É. Khaĭkin with all ardor persisted in a global push of radioastronomical observations into the centimeter and millimeter ranges. The advances, in particular, in solar radioastronomy in the Soviet Union are directly associated with the creation, initially of relatively small mirror radiotelescopes, and then of others for the stated ranges that were record-setting in area and in precision of the parabolic and other, original constructions.

A 31-meter stationary mirror was built in the Crimea that enabled the radioastronomers of the Institute of Physics of the Academy of Sciences in 1957 for the first time in our country to obtain a two-dimensional radio image of the Sun at the wavelength of 3.2 cm. Earlier, at the Main Astronomical Observatory, where S. É. had completely moved his activity after 1954, having founded a radioastronomical section there, an original mirror radiotelescope, the BPA, was built for the centimeter range following an idea of his and of N. L. Kaĭdanovskiĭ. This instrument was put into service in 1956. From the outset it was used to conduct an extensive cycle of studies on the radio emission of the Sun including the discovery of the radio emission of coronal condensations, the investigation of the polarization of the slowly varying component, and then of the bursts of radio emission from the Sun.

In 1959 at a newly created radioastronomical station of the Institute of Physics of the Academy of Sciences at Pushchino, a full-rotation radio telescope of diameter 22 m for millimeter waves was put into service. This allowed one to obtain a radio image of the Sun in the millimeter range and to localize the bursts of radio emission in this range. Of course, many other programs were also carried out on it. Later an improved variant RT-22 was built at the Crimean observatory, in Goluboĭ Zaliv. This enriched the studies even more, primarily the solar studies, by extending them into the shortwave part of the millimeter range.

The BPA radiotelescope served as a prototype for a most impressive instrument built in the Soviet Union in the past decade—the RATAN-600 radiotelescope. Within an extensive program, extremely interesting studies of the radio emission of the Sun are also being conducted with this instrument. I should note here that, from the very birth of Soviet observational radioastronomy, the most stable observations have been and yet continue to be those performed in the Division of Solar Studies of the Institute of Terrestrial Magnetism, the Ionosphere, and Propagation of Radiowaves. It is precisely here, after a temporary diversion into quantum radiophysics, where he obtained outstanding results, that B. M. Chikhachev returned, alas, not long before his death.

I have no opportunity to discuss the radioastronomy that had developed during all these years at Gor'kiĭ, nor the research at Leningrad University, where pioneer studies were started on solar observations. A few words on the radio observations of solar eclipses. I should mention this topic if for no other reason, then because observational radioastronomy began in our country with observations of this type. Up to recent years, the Soviet radioastronomers in groups or individually have continued this tradition. Radioastronomers have participated in almost all the expeditions to observe each sequential total, annular, or even partial eclipse. Whether at Ashkhabad, Novo-Moskovsk, Mali, or on the Cook Islands, on the islands of Hainan (People's Republic of China), or in Cuba, our national radiotelescopes received the radio emission of the Sun and yielded new, sometimes unique, information at highly different wavelengths.

A separate theme might be the lunar and planetary radio investigations of the Scientific Research Institute of Radiophysics, the Institute of Physics of the Academy of Sciences, and the Main Astronomical Observatory, and also the radiolocation studies of the planets of the solar system performed at the Institute of Radio Engineering and Electronics of the Academy of Sciences of the USSR.

A separate subject might be a presentation of the history of development in the USSR of dekameter radioastronomy, which was started at Khar'kov in 1961. Undoubtedly the cultivation of phase methods, which was being developed even in prewar time by the school of L. I. Mandel'shtam and N. D. Papaleksi, facilitated and accelerated the mastery of the promising method of radiointerferometric studies.

From the simplest radiointerferometers—the "marine" and two-antenna types, through the multiantenna gratings and variable-baseline interferometers to interferometers with independent recording on very long baselines, the antennas of which are linked only by a common atomic time standard, including the international ones—of the Pushchino-Crimea-Bonn-USA type with the participation of our RT-22 radiotelescope, and finally, to the space radiointerferometers, one of the mirrors of which has already been taken to the orbiting station "Salyut-6"—this is the path of this branch of Soviet radioastronomy. Spectroscopic radioastronomy has acquired great importance in our country, and with it important, sometimes unique, results have been obtained.

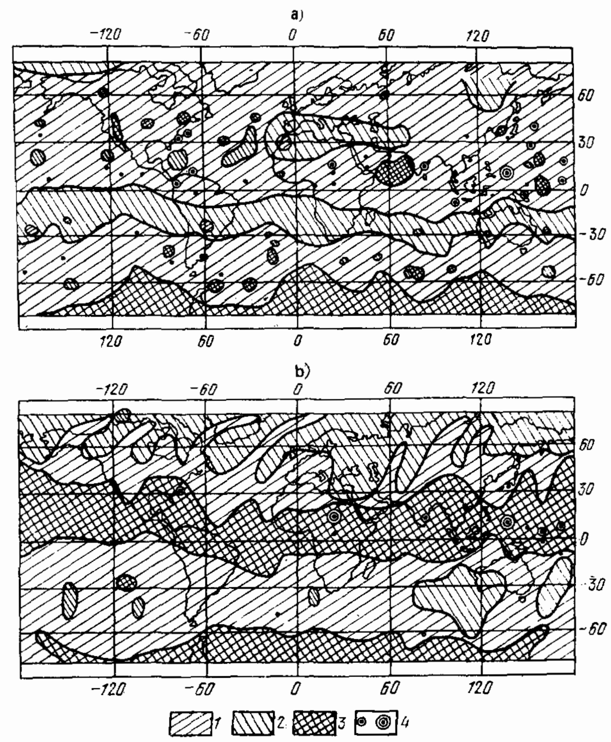

FIG. 5. Brightness distribution of the submillimeter emission of the Earth as obtained from the satellite "Cosmos-669" on July 30, 1974. a) The 350–650 μm channel; b) the 60–130 μm channel. Brightness gradations: 1—above average, 2—average, 3—below average, 4—compact cold regions [Dokl. Akad. Nauk 223, 853 (1975)].

Yet the advance toward waves "shorter than millimeter" (we now call them submillimeter), of which N. D. spoke in 1947, and the connection between microwaves and meteorology, of which he also spoke—this is also a subject for a separate report. Let me merely illustrate the potentiality of extraatmospheric submillimeter radiometeorology with the demonstration of the "radio imaging" of our planet, the Earth, at wavelengths of 0.5 and 0.1 mm obtained in 1974 from on board the spaceship "Cosmos-669", where a cryogenic radiometer built at the P. N. Lebedev Institute of Physics had been installed.

I would like to close this presentation with the words of N. D., which he spoke in the above-mentioned lecture given a month before his death:

"This new field of studies, which is now still in its infancy, is indisputably of extreme interest for the physics of the Sun. There is every ground for thinking that the application of radio methods for astronomy opens a new era, which we can compare in its significance with the discovery of the Fraunhofer lines and the application of spectroscopy in astrophysics, and which will aid in penetrating even deeper into the secrets of the Universe."

[1]S. I. Vavilov, Izv. Akad. Nauk SSSR, Ser. Fiz. **12**, 5 (1948).
[2]S. M. Rytov, *ibid.*, p. 20.
[3]G. S. Gorelik, *ibid.*, p. 22.
[4]V. L. Ginzburg, Dokl. Akad. Nauk SSSR **57**, 491 (1946).
[5]I. S. Shklovskiĭ, Usp. Fiz. Nauk **30**, 63 (1946).
[6]S. É. Khaĭkin and B. M. Chikhachev, Dokl. Akad. Nauk SSSR **58**, 1923 (1947).
[7]S. É. Khaĭkin and B. M. Chikhachev, Izv. Akad. Nauk SSSR, Ser. Fiz. **12**, 38 (1948).
[8]N. D. Papaleksi, Usp. Fiz. Nauk **21**, 297 (1947).
[9]V. A. Kotel'nikov and A. D. Kuz'min, in: Oktyabr' i nauchnyĭ progress (October and Scientific Progress), Nauka, M., 1967.
[10]A. E. Salomonovich, Vestn. Akad. Nauk SSSR, No. 3, 122 (1973).

Translated by M. V. King