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ON EXTRA-ATMOSPHERIC RADIOASTRONOMICAL INVESTIGATIONS

by

G. G. Getmantsev
A. E. Salomonovich
and V. I. Slysh

(USSR)

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ABSTRACT

This review paper considers the initial limitations of radioastronomy due to atmosphere transparency window and the new strides it has taken since the launchings of A.E.S., giving way to a new program of extra-atmospheric satellite radioastronomy. Both the advantages and sortcomings of long-wave and shortwave radioastronomy are discussed, with millimeter and sub-millimeter one emerging as the most promising.

For comparison, some results of AES ALOUETTE-1 and -2 and also of Elektron-2 and -4 are brought forth. Special attention is given to solar type-III radiobursts and the results of AES ZOND-3 are compared with ground observation data.

Appropriate antenna systems with proper angular resolution are recommended for further research, the first problem being the creation of high-quality, properly equipped mirror antennas in the submillimeter range. The second problem consists in cooling the receiving devices to liquid helium temperatures in cosmic conditions. In this regard the experiments conducted at the Lebedev Physical Institute of the USSR Academy of Sciences are of unquestionable interest. Further development of submillimeter radioastronomy will be dependent upon their success.

Finally, the exceptionally promising direction of extra-atmospheric radioastronomy is in investigations with cosmic interferometers, in which either one or both shoulders utilize antennas on board spacecrafts. This is of particular importance for the study of quasars, pulsars and other sources of the so called "mysterium".

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(*) VNEATMOSFERNYYE RADIOASTRONOMICHESKIYE ISSLEDOVANIYA

As is well known, the possibilities of ground radioastronomy are limited by the transparency windows of terrestrial atmosphere. The shortwave transparency threshold, conditioned by the absorption of atmospheric water vapor and oxygen, as well as the absorption and scattering on hydrometeors, extends for only a few millimeters. The longwave ground radioastronomical investigations are bounded by the ionosphere (it is referred to the waves of a few tens of meters).

The beginning of the era in the mastery of space, initiated by the launching of the first Soviet Artificial Earth Satellite in 1957, was the dawn of radioastronomy emergence beyond the limits of the mentioned window. An extensive and well-founded program of extra-atmospheric satellite radioastronomical investigations have already been accumulated. As usu path of the new direction was beset with unexpected technical difficuities and at the same time some phenomena were revealed which were difficult to foresee.

Let us point to one essential feature. Naturally, wishing to overstep beyond the framework of the atmospheric window, radioastronomers could have turned to longer waves as well as to the millimeter and submillimeter waves. Here arose a traditional situation: ten years ago, just as with the emergence of ground radioastronomy, it was considered that the basic decisive interest is offered by the longwave radioastronomy. Besides, to realize experiments in the frequencies below 2-3 MHz is technically easier than in the millimeter and submillimeter regions. The shortwave extra-atmospheric radioastronomy was found to be little attractive. Such an approach was very rational in many respects, but, in reality, the longwave direction was precisely being developed, in which quite interesting results have already been obtained.

However, lately the rigorous attitude of astrophysists toward the shortwaves has somewhat relented. More than that, some prominent scientists now assert that the key investigations are precisely the submillimeter and the millimeter waves. To such a reversal of views obviously contributed the fundamental discoveries of the latest years, namely the detection of quasars and other radioemitting objects with anomalous spectra and background radiation with spectrum close to the blackbody emission spectrum at quite low temperature, i.e. with maximum in submillimeter waves.

In this paper we shall attempt to bring to light the state and certain perspectives of the already long established longwave extra-atmospheric radioastronomy, having passed the first decade, as well as that of the almost immature, but, to be more precise, embryonic shortwave radioastronomy.

For the past 6-7 years, considerable amounts of various extra-atmospheric radioastronomical investigations were conducted in the frequencies lower than 10 MHz (wavelength > 30 m) with the aid of instrumentation installed on board A.E.S. and rockets, whose trajectories pass above the ionosphere's F-layer maximum.

Presented in Fig.1, are the results of all the so far accomplished measurements of the effective temperature of the distributed cosmic radio-emission (for the sake of comparison and completeness we also brought out here the results of ground investigations). The bulk of measurements were

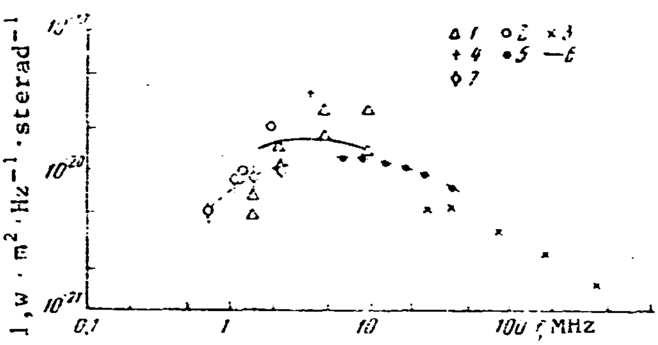

Fig.1.

Spectrum of cosmic radiation in the region 0.7-700 MHz

1) Ground measurements by G. Ellis (Australia), 2) rocket measurements of the University of Michigan (USA), 3) ground measurements of the Mallard Observatory (England), 4) data of the satellite "Transit" (USA), 5) ground measurements by Yu.S. Korobkov (Radiophysical Institute of Scientific Research), 6) data of satellite "Alouette-1"), 7) data of satellite "Elektron-2 and 4".

conducted at separate fixed frequencies in the 0.7-5 MHz range The investigations on AES "Ariel-II" and "Alouette-I and II" were conducted with the aid of radic receivers with smooth reconversion by frequency. Inasmuch as in all measurements the reception of radioemission was carried out on simplest dipole antennas with a wide radiation pattern, the variations of cosmic radioemission level linked with the irregularity of distribution of effective radioemission temperature in the firmament, were not great and, as a rule, did not exceed the measurement error of average radioemission level (approximately ± 30%). If according to data of Fig.1 we construct the frequency spectrum of radioemission intensity I(f), it is possible to detect that the curve I(f) has a maximum in the frequency f ≃ 3 MHz. Contrary to the relatively high frequency band for f < 3 MHz, the intensity of radioemission drops with frequency decrease.

The presence of radioemission intensity maximum in the frequency f ≃ 3 MHz and the intensity drop with frequency decrease for f < MHz, may, in principle, be interpreted in different ways. Apparently, the explanation of the effect consists in that the low frequency distortion of the intensity spectrum (effective temperature) of the received radioemission is conditiond by its absorption in the interstellar ionized gas of the plane subsystem of the Galaxy.

From the point of view of perspectives of future investigations of distributed cosmic radioemission intensity in low frequencies, the most imporant, in our opinion, should be the attempts of reliable measurement of the superficial brightness distribution about the sky. Measurements of angular variations of radioemission intensity will allow us to contribute some clarity to the estimate of the role of interstellar absorption of cosmic radioemission. Besides, angular intensity variations of synchrotron radioemission of the Galaxy, linked with the emission of relatavistic electrons in a well regulated magnetic field of local spiral arm, will possibly be detected. For the solution of this problem the basic technical task is the improvement of the on-board antennas' radiation pattern.

The most complete data on sporadic radioemission of the Sun, from measurements on cosmic objects were obtained on AES "Alouette-I and II". Basically, it is referred to type-III radiobursts, as the identification of other events was beset with a series of difficulties due to the specific type of measurements.

Two type-III radiobursts were registered in August 1964, in the frequencies of 1.1 and 2.3 MHz in the process of measurements on the Soviet AES "Elektron-4". The intensity of the bursts in both frequencies was of the order of $2 \cdot 10^{-20}$ watt/m^2·hertz.

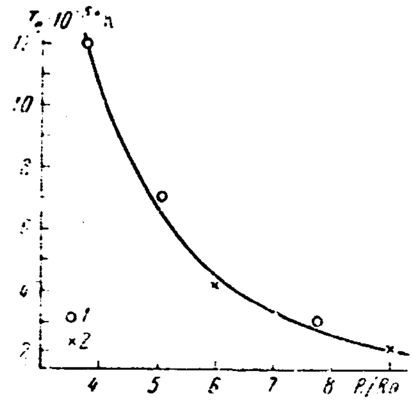

Fig.2

Temperature of solar corona according to the measurements of the type-III bursts.

1) Data of AES "Alouette-I" (T. Hartz)
2) Data of AES "Elektron-4" (E.A. Benediktov et al)

According to data of measurements of the type-III bursts, T. Hartz (USA), determined the temperature of solar corona as a function of the distance above the photosphere by starting from a preassigned model distribution of electrons. At the same time it was assumed that the burst attenuation is linked in time with electron-ion collisions in the coronal plasma.

Analogous estimates for the observed type-III bursts were made by E.A. Benediktov, G.G. Getmantsev, N.A. Mityakov, V.O. Rappoport, and A.F. Tarasov (Radiophysical Institute of Scientific Research). The resultant dependence $T_e(R/R_\odot)$ is plotted in Fig.2. As may be seen from it, the results agree well among themselves. The electron temperature in the outer corona decreases monotonically as a function of $R/R_\odot$ with the increase of distance from the Sun.

A large amount of bursts of sporadic radioemission of the Sun were registered in the frequencies of 2 MHz, 0.21 MHz and 0.02 MHz during the five months of flight in 1965 of AIS "Zond-3". In spite of the fact that readings of the received radioemission were taken down only once in four hours, V.I. Slysh of State Astronomical Institute in the name of P.K. Shternberg succeeded to identify a series of registered events with the bursts of solar radioemission by way of comparison of data of AIS "Zond-3" with ground measurements.

The first results of localization of radioemission type-III radio bursts in kilometer waves were obtained with the aid of artificial satellites of the Moon. These results were rather unexpected: the radioemission sources are located much farther than suggested by the solar corona model and plasma mechanism of radioemission. Thus in the frequency 1 MHz the source of the type-III radioemission is located at a distance of (20-30)$R_\odot$ from the Sun instead of the assumed 8 $R_\odot$; and in the frequency 0.2 MHz it is at the distance of 200 $R_\odot$, i.e. of one astronomical unit instead of the assumed 25 $R_\odot$. It was also found that the motion velocity of the source remains constant and about one half of the speed of light over the entire path from the inner corona to the Earth's orbit. These data concern only two bursts and cannot be considered as final.

The basic problem of further investigations lies in the attempts of observing solar radioemission bursts and other types with compulsory localization; this requires antenna systems with sufficient angular resolution. It is also important to widen the frequency spectrum toward the low frequencies with the purpose of determining the lower critical frequencies for bursts of various types.

During the flights of AES and rockets in the Earth's ionosphere, the radio receivers registered in rather low frequencies (from tenth fractions of MHz to several MHz) radiosignals, exceeding in intensity the level of the distributed cosmic radioemission at corresponding frequencies. Most characteristic are the relatively narrow maxima, substantial in intensity and responding to plasma resonances. These resonances are accompanied by substantial increase of refraction indices of ordinary or extraordinary waves passing at specific frequencies into the so called "plasma waves". The presence of radiosignals in the respective resonance frequencies correlates well with the presence of fast charged particle fluxes in the inner radiation belt. Moreover, the signal induced in the antenna by plasma waves, could be quite big as long as for plasma waves the "radiation resistance" of satellite antenna is great, while the intensity itself of plasma waves could be determined by the temperature of high-energy particles of Earth's radiation belts.

The great radionoise level of ionospheric origin may also be observed even in a case when the satellite is located higher and even considerably above the basic ionospheric layers. Similar radioemission, of which the level correlates well with the presence in radiation belts of relatively soft electron fluxes with energy > 100 ev were most probably, registered on AES "Elektron-2 and 4" in the frequencies of 0.75, 1.1, 1.5 and 2.3 MHz. It is quite possible that analogous radioemission was also observed on AES "Alouette-II".

During the satellite flight in ionospheric or interplanetary plasma, intensive radionoises can be induced in its antenna at the expense of "fractional" effect linked with the flight past the antenna of electrons and ions with thermal velocities.

In the process of cosmic radiation measurements in several fixed frequencies of average wave range, still another interesting effect was noticed on the AES "Elektron-4":the slow variations of the receiver signal's minimal level, with characteristic time of the order of one month, usually identified with the level of cosmic radioemission.

From the quantitative standpoint the most probable reason of the long-period variations of the level of received radioemission could be the bremmstrahlung radioemission of fast electrons trapped by the Earth's magnetic field.

Measurements of radionoises originating in the ionosphere and interplanetary plasma with the aid of receivers installed on AES and rockets, are of paramount value for the investigation of physical processes in the ionosphere, magnetosphere and Earth's radiation belts. Owing to these measurements, it is possible to study the interaction of charged particle fluxes inducing in it plasma waves with magnetoactive plasma, and also various local mechanisms of plasma interaction with the satellite, etc., Such measurements are also essential since the increased radioemission of ground origin conceals in a series of cases its proper cosmic radioemission, the radioemission of the Sun, etc.,

Let us turn now to another matter, namely to the submillimeter trend of the extra-atmospheric radioastronomy. As was already indicated, the Earth's atmosphere is practically opaque for the ground submillimeter radiation. Even in the relative transparency window the absorption factors in ~ 2 mm waves exceed 1 db/km. This is why the astronomical measurements are possible mainly beyond the atmosphere. It should be noted that there are series of specific problems, which require for their solution the conducting of observations precisely in the submillimeter band. This is precisely the fact that attracts attention to investigations in the indicated region.

One of such problems is the study of characteristics of primary pre-stellar state of matter by way of measurements of the so called background relict radiation. The maximum of this radiation corresponds to a wave of about 1 mm in length. Of greatest interest here are the precise measurements of the intensity of spectral density in wavelengths shorter than 1 mm, inasmuch as such measurements allow us to clarify whether or not the spectrum of background radiation is Planck's. Of substantial significance is also the ascertaining of the degree of radiation isotropy.

No less important is the study of the state of chemical and isotropic composition of interstellar and intergalactic media. For example, investigations of the millimeter and sumbillimeter spectrum emission will, apparently, permit to establish the presence in Galaxy of different molecules and dust.

Lately, previously unknown sources of electromagnetic radiation, in particular the class of "infrared stars" have been discovered. The spectral density maximum of their emission is in the 3-20 μ range, which corresponds to black-body radiation at temperature of only 700°K. Quite probable is also the detection of analogous objects in longer and sumbillimeter bands. The observations in submillimeter and infrared bands may have a decisive significance for the development of the nature of the quasar-type sources of radioemission.

The spectral investigations in millimeter and submillimeter waves are extremely important for the explanation of chemical composition of planetary atmospheres of the solar system, and the distribution of pressure and temperature in the atmosphere. Data on these atmospheric characteristics of the majority of planets are quite scarce.

The submillimeter radiation of the Sun is the source of information on the deepest layers of the chromosphere. Quite promising apparently are the submillimeter spectral investigations of highly ionized heavy atoms in the atmosphere of the Sun.

The basic difficulty in the development of the extra-atmospheric submillimeter astronomy techniques, stems from the necessity of carrying the receiving apparatus beyond the limits of terrestrial atmosphere, or, at least, in partly eliminating its influence.

Naturally, one of the methods of receiving cosmic submillimeter radiation is the lifting of the receivers (radiometers) to the mountains, where moisture content is for the most part of the year less than 1 g/m^3. Such attempts were realized by several groups of investigators, including the group of Queen Mary College (England) which conducted the observations in the Swiss Alps at the altitude of about 2000 m in 1-4 mm wave lengths, as well as the group of the Radiophysical Institute of Scientific Reasearch working in Elbrus, Aragatze (Caucasus) and in Eastern Pamirs. On the whole, investigations of atmospheric absorption in 1-4 mm were conducted and at the same time the radioemission of the Sun and the Moon was observed.

Another relatively simple method is the lifting of apparatus on aircrafts and aerostats. The first published results of such measurements in submillimeter region are quite promising. The aerostat measurements were recently done by N. Wulf and F. Law et al, formerly of NASA Goddard Space Flight Center (USA). Quite interesting are the works begun about two years ago at the Meudon Observatory (France). Emplcying oxygen aerostats with gondola, stabilized with a precision to 10-20 sec arc by the Sun, this group began the study of the Sun's spectrum with the 0.3 cm^{-1} resolution in the 0.05-2.5 mm band.

For a series of enumerated problems the apparatus lifting by aerostats, still being insufficient, it is necessary to place it on geophysical rockets or orbital satellites. There are two problems in this field and from their successful solution the tempo of submillimeter astronomy development will depend. The first problem consists in the creation of high quality mirror antennas of submillimeter range, equipped with corresponding observation mechanisms. The second is the cooling of the receiver apparatus to the temperature of liquid helium in the cosmic flight conditions. In this connection the experiments performed at the Physical Institute in the name of P N. Lebedev of the USSR Academy of Sciences, by the L.B. Kurnosova and A.B Fradkova groups for the verification of various methods of keeping helium temperature below 10°K on board of the cosmic devices, are of unquestionable interest.

In conclusion we would like to point out another exceptionally promising direction of the extra-atmospheric astronomy which consists in the radioastronomical investigations with the aid of cosmic interferometers, of which one or both shoulders would use antennas installed on board of cosmic devices. The construction of such interferometers is necessary, because the bases even of global ground interferometers are not sufficiently long to allow the study of some quite interesting objects such as quasars, the radiation regions of the so called "mysterium" and, apparently, pulsars.

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Volt Information Sciences, Inc.,
1145 - 19th Street, N.W.
Washington, D.C. 20036
Telephone: [202] 223-6700 X 36 & 37

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Ludmilla D. Fedine
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Dr. Andre L. Brichant
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