Bull.Spec.Astrophys. Obs., 1994, 37, 178-186.

THE SEARCH FOR OPTICAL SIGNALS OF COSMIC CIVILIZATIONS

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ABSTRACT. *The necessity of search for extraterrestrial civilizations in the optical range is stated. The ideas and methods of the MANIA experiment in the search for the brightness variations of astronomical objects with a time resolution of* $5\cdot10^{-7}$ *s are described. The results of observations with the 6 m telescope of 50 objects interesting within the framework of SETI problem, ROCOSes, DC-dwarfs and sunlike stars, are presented. In none of the objects brightness variations are detected within the range* $5\cdot10^{-7}-10^{2}$ *s. The upper limits onto the power of hypothetic lazers of the extra-terrestrial civilizations localized in the vicinity of DC-dwarfs and sunlike stars are estimated.*

I. SOME WORDS AGAINST RADIOSHOVINISM IN SETI

According to the theorem of Shennon the informational effect of transmissions in the optical range can be 10^5-10^6 times more efficient than that in the radio range. But, the energy expenditures in the optical range are as much as in the radio one.

Nevertheless, the difference in velocities of transmissions (the amount of information sent at one and the same time) is the difference between the ABC book context and context of all encyclopaedias existing on Earth (10^6 and 10^{11} bits accordingly).

Thus, the optical range is likely to be the most suitable for the rapid transmission of more developed civilizations than ours (of II & III types by Kardashov).

As known, shortly after Cocconi and Morrison (1959) had proposed to look for the ignals of artificial origin, in the radio range Townes and Shwarts (1961) noted the erspectives of optical range for communications between stars. They proposed to give lazer signal a form of a supernarrow line ($\Delta\lambda/\lambda \simeq 10^{-9}$), located at an unusual requency. The signal spectral coding of that kind leads to photon correlations (that s intensity fluctuations) on short time scales $\tau_s \sim 1/\Delta\nu = (\lambda/\Delta\lambda)\cdot 1/\nu \sim 10^{-6}$ s, excepting the pure coherent radiation of a single-mode lazer, when $\tau_s \sim 1/\nu \sim 10^{-15}$ s).

One of the versions of signal time coding was analysed by Shvartsman (1977). Namely, the pulse modulation of lazer radiation, its duration, filling factor, and form are the elements of the code.

It is necessary to emphasize that the photon statistics of signals in both kinds should deviate from the Poisson's one, which is typical of "ordinary" astronomical objects. So the task in searching for artificial signals in the optical range is to search for radiation variability of peculiar objects in the wide range of time 10^{-7}-10^{2} s. The deviation statistics of the photon from the Poisson's one is the criterion for the detection of a variable signal.

I. EQUIPMENTS AND PROGRAMMES FOR THE MANIA EXPERIMENT

The search for variability of peculiar objects was started in the Special Astrophysical Observatory of the Russian AS in 1972. Since 1978 the observations have been carried out with the 6 m telescope. This is MANIA experiment (MANIA = Multi-channel Analysis of Nanosecond Intensity Alterations). The specialized mathematical methods as well as the special complex of soft- and hard-ware have been projected and built under the guidance of Victorij Shvartsman (Shvartsman, 1977; Beskin et al., 1982). The aim of the experiment is the search and investigation of relativistic and fast variable objects with a superhigh time resolution of about 10^{-7} s. The observational method is based on measurements of each photon detection time and analysis of statistical properties of this time sequence.

The complex of equipment consists of:

a) a photometer - to count photons with a set of diaphragms (4"-20"), and filters (U,B,V,R) which gives the standard pulses of < 100 ns duration corresponding to every registered photon;

b) a "time-code" converter "Quantochron" which measures the moment of detection of every photon with an accuracy of ±20 ns, then generates a 16 bit digital time code and 16 bit flag of the channel number and sends these 32 bit digital code into a computer;

c) a computer with an applied tape recorder which records the final observational data on magnetic tape or flexible disks;

d) a counter system and a recoder which allow us to control the process of information acquisition.

The quantum efficiency of the complex determined by the type and quality of the photomultiplier is a few percent. Its dead time is 100 ns; the maximum intensity of photocounts flux, which is registered without distortions (< 1%), depends on the speed of computers and is about 30 000 photocounts per second.

The sequence of the moments of photon registration, recorded on a magnetic tape, is the final result of acquisition. As a rule 1-10 million photocounts are registered during one run of observations.

From the view point of mathematics the problem to find a signal, coded both "spectrally" and "temporally", reduces to the studying of the detected photon statistics. Namely, these are the searches and investigations of deviations of the time sequence statistic characteristics from similar characteristics of standard sequence (Poisson's, Gauss', sequences of photocounts from the comparison star, luminophor, etc.). These deviations, of course, are connected with the parameters of variable signals which are expected to be obtained.

We use the methods for statistical analysis of the time sequence, which can be divided into those which "work" on short times and those which are used to investigate "slow" brightness variations. The value of the average time interval between the photocounts $\langle\tau\rangle = 1/\langle\lambda(t)\rangle$ ($\lambda(t)$ - intensity of the photocount flux) is the natural boundary of the applied methods. Actually the dependence of the number of counts in a certain fixed time window upon the time (in case $\tau_v > \langle\tau\rangle$) is quite an informative one, being the light curve. In case $\tau_v < \langle\tau\rangle$ this standard approach is not quite an optimum one. In observations on the 6 m telescope (BTA) objects of 17^m-18^m have $\langle\tau\rangle \sim 10^{-3}$ s. As we are interested in time $\sim 10^{-6}$ s, so the light curve in most cases would consist of zero counts.

In this connection a special method of y_2-functions was proposed by Shvartsman (1977). The basis of the method is statistical analysis of time intervals between photocounts (in contrast to analysis of the photocount amount in fixed time intervals). The indicator of variability, y_2-function, is the relative difference between fractions of intervals of definite duration in fluxes of photocounts of investigated and standard objects.

$$y_{2i}(\tau_i,\tau_{i+1}) = [p_0(\tau_i,\tau_{i+1}) - p_s(\tau_i,\tau_{i+1})]/p_s(\tau_i,\tau_{i+1}),$$

where $p_0(\tau_i,\tau_{i+1})$ is the fraction of intervals of duration from τ_i to τ_{i+1}, and $p_s(\tau_i,\tau_{i+1})$ - is the same for the standard one.

We can take as standard both the Poisson flux, with the mean intensity consistent with the intensity of the photocounts flux from the investigated object ("normalization to the theory"), and the photocounts flux of the same intensity from a comparison star ("normalization to the comparison star"). In the second case one manages to get rid of the apparatus noise and atmospheric variability.

The asymptotic value of y_2-function is connected with the parameters of variable signal (Plokhotnichenko, 1983). When the variability is absent, its upper limits are defined by the scatter of y_2-function for the comparison star.

On times more than $\langle\tau\rangle \sim 10^{-3}$ s the light curve is built and its analysis is carried out with the help of several "classical" methods. Namely:

1) investigations of light curves on various time scales;
2) search for narrow pulses;
3) spectral analysis;
4) search for pure periodical components.

III. THE RESULTS OF SEARCH FOR ETI SIGNALS

Thus, the MANIA soft- and hard-ware complex experiment allows us to discover and investigate brightness variations of celestial objects in the time range from 10^{-7} to 10^{-3} s and accordingly narrow emission lines with the width from 10^{-3} to 10^{-7} Hz. For 13 years of observations on the 6 m telescope we have investigated more than 100 different objects. MANIA objects are candidates in the single black holes - DC-dwarfs and ROCOSes, X-ray binaries, pulsars, flare stars, sunlike stars, etc.

We have obtained a light curve of the Crab pulsar with the best time resolution, 6 microseconds (Shvartsman et al., 1988a). We finally found out that its main pulse had a flat top of nearly 100 µs duration. We have made a search for the fine time structure in the bursts of UV Ceti-type M-dwarfs (Shvartsman et al., 1988b) and shown that they have a thermal nature. We have detected 4 supershort bursts (with duration nearly 0.1 ms - 1 ms) from the X-ray binary A0620-00 (Shvartsman et al., 1989a), which is the argument for probable realization of nonthermal processes at the accretion onto a black hole in this system.

During the experiment we have also observed objects which are interesting from the view point of SETI problem. These are starlike radio objects (Shvartsman et al., 1989b) with purely continuous optical spectra (ROCOSes), DC-dwarfs are stars with measured proper motion and continuous spectra (Shvartsman et al., 1989c), and near sunlike stars of G0V-G5V spectral classes (Shvartsman and Shtivelman, 1988).

It's necessary to emphasize that among many hundred of thousands of starlike objects only about two hundred have spectra in which neither emission nor absorption lines are found. Few of them belong to the known types. These are optical pulsars (Crab and Vela), which generate nonthermal radiation, and some X-ray binaries, where absorption of normal component cannot be detected against the background of the continuous radiation of the accretion gas around the compact component.

Yet still the nature of a great number of objects with continuous spectra at least up to the beginning of our observations remained unknown. Three hypotheses could be formed.

1. The objects belong to the well-known types of sources (ROCOSes - to the QSO or BL Lac-type, DC-dwarfs to DA- or DB-dwarfs), but have weak lines for that (or other

causes exist).

2. We see the halos of accreted interstellar gas around the isolated stellar mass black holes. Shvartsman has shown that their optical spectra must be featureless and their brightness must be variable on times nearly $\tau_v \sim r_g/c \sim 10^{-4} - 10^{-5}$ s (Shvartsman, 1971).

3. Lastly, the absence of lines means that their radiation is of artificial origin.

Actually, as the continuous spectrum phenomenon is quite a rare one, so the high level civilizations could use it to draw attention to their laser transmitters.

Hypotheses 2 and 3 have identical proofs - the detection of superrapid brightness variations, on time scales from 10^{-7} to 10^{-3} s. We have certainly been searching for black holes in MANIA experiment, but blunting the razor of Okkam we did not give up hypothesis about artificial origin of the objects with continuous optical spectra.

Now about the results of observations of ROCOSes. The search for superrapid brightness variations was carried out for 20 ROCOSes in the time range from 500 nanoseconds to 40 seconds (see Table I). All the data have been analysed, and for none of them brightness variation, in the whole time range, with a confidence probability of $p > 0.99$, has been detected.

Typical upper limits on the relative power of fast variable component of radiation on times from 10^{-6} s to 10^{-2} s are from 20% to 5%, for the flashes with a filling factor of 0.2 (for the rare flashes with the filling factor 10^{-3} the limits are 10 times better). Thus, among ROCOSes there are probably no single black holes with masses of few solar masses and transmitters of cosmic civilizations.

DC-dwarfs are close objects with measured proper motions (0.02″- 1.8″ per year), their distances from the Sun are from 5 to 50 pc.

Our list of DC-dwarfs, which contains more than 100 objects, helped us to choose 17 most interesting nontypical white dwarfs. The criteria of the choice are the following: 1) the high accuracy of the line absence; 2) the colour difference from the thermal ones; 3) the variations on time scale months / years. The search for variability was carried out for 17 DC-dwarfs (see Table II) in the time range from 500 ns to 40 s. The statistical analysis showed that with a confidence probability of more than 99% the brightness variations are absent.

On the same level we have estimated the upper limit for the relative power of the flashes with duration of 1 microsecond, and with an interval between them of 1 second (lazer's pulses). They were $S \sim 7 \cdot 10^{-4}$ for the fraction of luminosity of the object. These results allow us to put the upper limit on the power P of hypothetical lazers, which could transmit flares to the Sun from the vicinity of DC-dwarfs. Since $P = S(\varphi^2/4\pi)L_{DC}$, ($\varphi \sim 10^{-6}$ is the angle of lazer beam, L_{DC} - the typical luminosity of the DC-dwarfs), then $P < 7 \cdot 10^6$ W. This value is approximately one million times less than the energy production on the Earth. While studying ROCOSes and DC-dwarfs we detected the signals of transmitters specially built by high level civilizations of the II and III types and situated far from their creators. Observing sunlike stars we expected to detect transmission sent towards us right from the area of the I type civilization inhabitation. We have observed 13 sunlike stars (see Table III) with the superhigh time resolution at the 6 m telescope.

Table I. ROCOSes studied in the experiment MANIA

Name	Date of observation	Magnitude, m_v	Volume, 10^6 counts
01.09+224	22.12.79	15.36	1.4
OC+215.7	31.12.81	15.6	1.8
0300+47	11.10.78	17.3	2.3
OE+400	21.12.79	17.5:	1.4
0346-163	21.12.79	15.76	2.7
OE-177.2			
0422+004	22.12 79	15.74	1.4
OF+038			
0716+714	24.12.82	16.02	2.5
0754+100	28.02.79	16.0	1.4
01+090.4	25.12.82	14.76	2.4
	25.12.82	14.76	2.4
0818-128	28.02.79	17.13	1.8
OJ-131			
0823-223	31.12.81	16.75	1.8
OJ-240			
0829+046	22.12.79	16.9	1.4
OJ+049	22.12.79	16.9	
	24.12.82	15.83	0.8
0912+297	25.12.82	15.78	2.5
OK+222			
1057+100	02.03.79	17.68	1.5
1147+245	25.12.82	16.24	2.5
OM+280			
1155+169	20.12.84	18:	2.5
1215+303	27.02.79	16.0:	1.7
ON+325	02.03.79	15.58	1.5
1402+042	30.04.86	16.6	2.5
1418+546	27.02.79	15.30	1.5
OQ+530			
1424+240	25.12.82	15.92	1.8
OQ+240	23.03.83	16.09	1.2
1514+197	02.03.79	19.3:	1.4
1538+149	28.02.79	17.3:	0.6
OR+165	28.02.79	17.3:	0.6
1749+096	13.06.83	18.5:	2.4
OT+0.80			

Table II. DC-dwarfs studied in the experiment MANIA

Name	Date of observation	Magnitude, m_v	Volume, 10^s counts
EG 1	31.08.86	16.85	2.5
Gr 459	30.08.86	16.61	2.5
	08.09.86		2.5
EG 246	11.12.79	15.1	1.8
GD 674	04 09.86	16.80	2.5
Gr 517	04.09.86		2.5
	08.09.86	16.57	6.2
EG 12	21.12.79	16.8	2.1
	29.08.86	17.62	2.5
Gr 471	07.09.86	15.86	2.5
EG 169	30.08.86	15.40	2.5
EG 259	01.05.86	18.7	2.5
EG 329	28.04.86	16.5	2.5
EG 124	01.05.86	15.89	2.5
Gr 288	06.08.86	14.58	1.2
Gr 375	28.04.86	17.20	2.5
Gr 202	06.08.86	16.57	2.5
Gr 379	01.09.86	16.29	2.5
Gr 335	31.08.86	15.10	2.5
Gr 380	30.08.86	17.07	2.5

Table III. Sunlike stars studied in the experiment MANIA

Name	Spectral type	Magnitude, m_v	Date of observation	Duration of observation s
Cl 504	G0 V	5.9	28.04.86	193
Gl 547	G1 V	7.0	28.04.86	392
Gl 606.2	G0 V	6.1	28.04.86	200
Gl 672	G2 V	6.1	28.04.86	210
Gl 679	G5 V	7.3	28.04.86	116
Gl 794.3	G2 V	7.5	28.04.86	96
SAO136176	G0 V	7.2	1.05.86	185
SAO139590	G0 V	8.1	1.05.86	202
W 652	G8 IV-V	6.57	18.06.91	685
MK 146233	G1 V	6.36	18.06.91	783
MK 160269	G0 V	5.92	18.06.91	693
MK 186408	G2 V	6.79	18.06.91	687
W 9678	G0 V	5.88	19.06.91	664

Two objects are in the "Zodiak" programme which investigates ecliptical stars (Filipova, 1990), and 11 are taken from the catalogs of Gliese, SAO and MK with the spectrum classes from G0V to G8V and magnitudes from 6^m to 9^m. The search for brightness variations have been carried out in the time range from 100 nanoseconds to 100 seconds. For none of them brightness variations have been detected in all the time ranges with a confidence probability of $p > 0.99$. For the relative power of rare (one per second) flashes with the duration of 1 microsecond the upper limits were about (2-6)$\cdot 10^{-2}$%. For the power of hypothetic lazers of cosmic civilizations we get an upper limit of approximately 10^{9} W.

Note, that the total power of lazers in the SDI-programme is of the order of 10^{11} W. This type of lazer could be detected. Thus, having made observations with the superhigh time resolution of 50 peculiar objects and sunlike stars we did not find signals of extra-terrestrial civilizations.

But the search for them will be continued.

1. We shall observe old sunlike stars in the spectrum range from G0V to G5V.

2. We shall include some stars with IR-excesses (Vega in particular) into our investigations.

3. Currently a second set of MANIA equipment is installed on the 2.2-m telescope of the Leonsito Observatory in Argentina. It will give us a chance to observe southern sunlike stars. In particular, some stars within the programme "Zodiak".

We are improving the equipment: we are starting work with a multichannel detecting system for two-dimensional, spectral, polarizational observations with superhigh time resolutions (see Table IV).

Table IV. Dynamic of the MANIA experiment equipments

MANIA	yesterday '78-'90yrs	today '94y	tomorrow '95-'96yrs
·time resolution	$5\cdot 10^{-7}$s	10^{-7}s	10^{-7}s
·channel number	1	2^{8}	2^{24}
·detector	photometer	2-channel photometer	spectrometer spectropolarimeter 2-dimensional photometer
·telescope	6 m	6 m 2 m	6 m 2 m

The MANIA experiment is going on. It means that the search for ETI in the optical range is also going on also! MANIAcs hope for the best.

This work was supported by the Scientific and Educational Center "Cosmion".

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