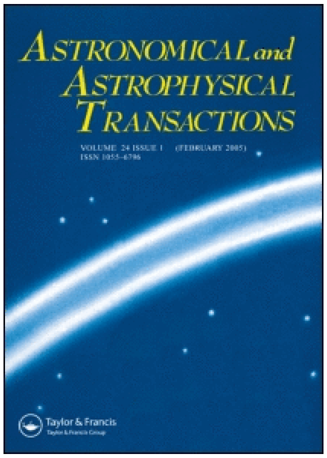

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 January 2000
To cite this Article: Parijskij, Yu. N. (2000) 'Ratan-600 'cosmological gene' project', Astronomical & Astrophysical Transactions, 19:3, 265 - 276
To link to this article: DOI: 10.1080/10556790008238576
URL: http://dx.doi.org/10.1080/10556790008238576

Astronomical and Astrophysical Transactions, 2000, Vol. 19, pp. 265–276
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RATAN-600 'COSMOLOGICAL GENE' PROJECT

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(Received June 13, 2000)

We present some details of the new generation RATAN-600 CMBA project and estimate an efficiency of the 'near field zone' mode of ground based experiments in atmospheric noise filtration as well as in instrumental polarization effects. It is shown that with big enough aperture the sensitivity of the ground-based and space based CMBA experiments can be close to each other. Ground based experiments are not limited in resolution even at low frequencies boundary of the 'Galaxy window', and we suggest using RATAN-600 as a pre-PLANCK probe of possible Galaxy contamination for future mission, and as a post-PLANCK facility for very deep CMBA polarization experiments. This project may help to interpret deeply PLANCK mission results.

KEY WORDS CMBA experiments, RATAN-600 'Cosmological Gene' project

1 INTRODUCTION

This project is part of Zeldovich–Sakharov's COSMO-PARTICLE initiative, the Project 1990 was suggested by the SAO group in cooperation with: St. Petersburg groups (St. Petersburg State Technical University, St. Petersburg State University, Main Pulkovo Observatory, Ioffe Physical-Technical Institute, Institute of Applied Astronomy, SPb branch of SAO RAS); Moscow groups (Lebedev Physical Institute RAS and Astro-Space Centre RAS, Institute of Theoretical Physics RAS, Institute of the Cosmic Research RAS, Moscow University, COSMION Astro-Particle Centre); Rostov Group (Rostov University); Spain Group (Canarian University); Danish Group (Theoretical Astrophysical Centre, TAC)

Partners, connected with receivers: SAO RAS and 'Saturn', Ukraine (MAtrix Radiometric System, 'MARS', Project Leader A. Berlin), SAO RAS and AO 'Svetlana' and 'Ascor', St. Petersburg (Multi-beam Integral Patch ARray, 'MIPAR', Project Leader V. Khaikin); SAO RAS and STU and Real Time Devices Scandinavia OY (Remote Controlled Data Acquisition System, Project 'RC-DAS'); Gurley Precision Instruments and SKBIS and SAO RAS, Project; New encoder for RATAN-600, Project Leader B. Mintseris; 'Polytechnic-DEC' Centre and SAO RAS, RATAN-600–'Polytechnic DEC' Centre; Communication Project (Project 'RP-COM', Project Leader A. Glebovsky).

Table 1. The list of 'Project Team' CMBA experiments, 1968–1998.

Year	*Motivation*	*Results*
1968	J.Silk predictions for protogalaxies	Anisotropy by factor 10 less than predicted
1969	M. Rees prediction for polarization of CMB	At small scales polarization less than 0.001%
1973	Ya. Zeldovich pancakes and Daucourt	Grav. noise predictions less than predicted
1975	3 Russian approaches: adiabatic, vector and tensor type perturbations	Anisotropy by factor 3–5 less than all the predictions
1980	Neutrino Universe prediction based on Moscow University neutrino mass estimates	Better agreement, but less than predicted by factor 2 even for very late epoch of the galaxies formation
1981–1995	Check of Inflation predictions	Discovery of strong extra noise at horizon scales but difficult to interpret (Parijskij and Korol'kov, 1986); all references may be found there connected with CMBA experiments made by the PROJECT group in 1968–1986)
1997	Spectrum of the CMBA	First strong confirmation of the Black Body spectrum of CMBA at sub-degrees scales by comparison of the RATAN-600 longest wavelengths (7.6 cm) measurements with SK and MSAM results at MM waves (Parijskij *et al.*, 1998)
1997–	Development of the 'Sakharov oscillations' ('Cosmological Gene') project at RATAN-600 using the near-field zone atmosphere filtration theory	New information on the small-scale Galactic noise which extends the Galactic Window to 30 GHz. The beginning of the next generation RATAN-600 CMBA project

It is now generally accepted that the features in the Radio Sky predicted by A. Sakharov (1965) are the most powerful tools of exploration of the early Universe. COBE 4-year Sky map has brightly demonstrated a large-scale CMBA. Using a resolution much higher than in RELICT1 and COBE missions, it is possible to:

1. Select right High Energy Physics, because CMBA is a result of the Big Bang which is equivalent to the 10^{19} Gev accelerator, i.e. by many orders of magnitudes higher than that available on Earth and at just the right level to check variants of the New Physics (like 'Theory Of Everything').

2. Select the right COSMOLOGY in which we live.

3. Determine all parameters of the working Cosmology with an accuracy about

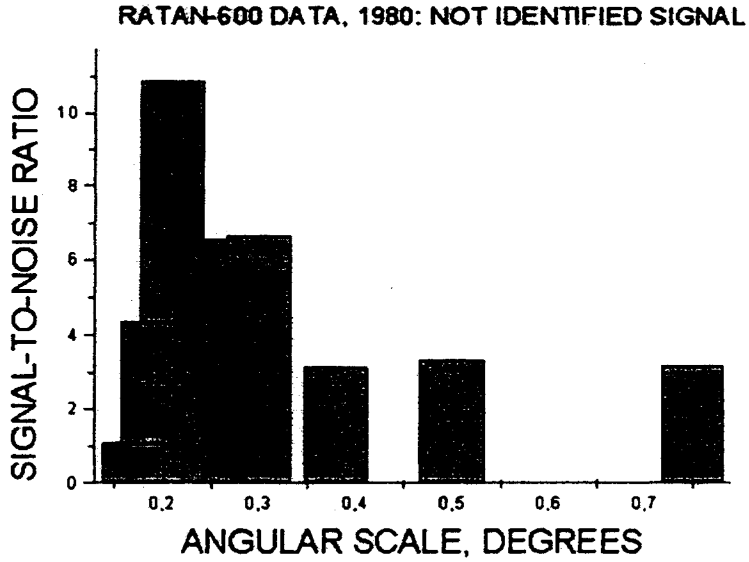

Figure 1 Extra noise observed at RATAN-600 at 7.6 cm in 1980 on the subdegree scale with amplitude about 100 micro-K. 'Signal' – all 22 Days data, 'noise' – difference between two subgroups of the same data. $S/N > 10$ was found only on subdegree scales, (see Parijskij and Korol'kov, 1986).

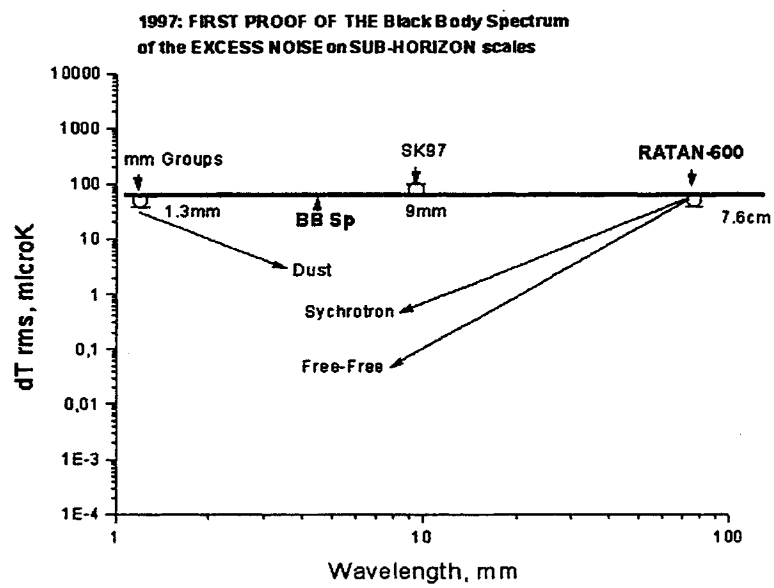

Figure 2 Confirmation of the 'Black Body' spectrum of the extra noise on a sub-degree scale (Parijskij *et al.*, 1998). All published data were grouped in three frequency domains: mm, 1 cm, 7.6 cm.

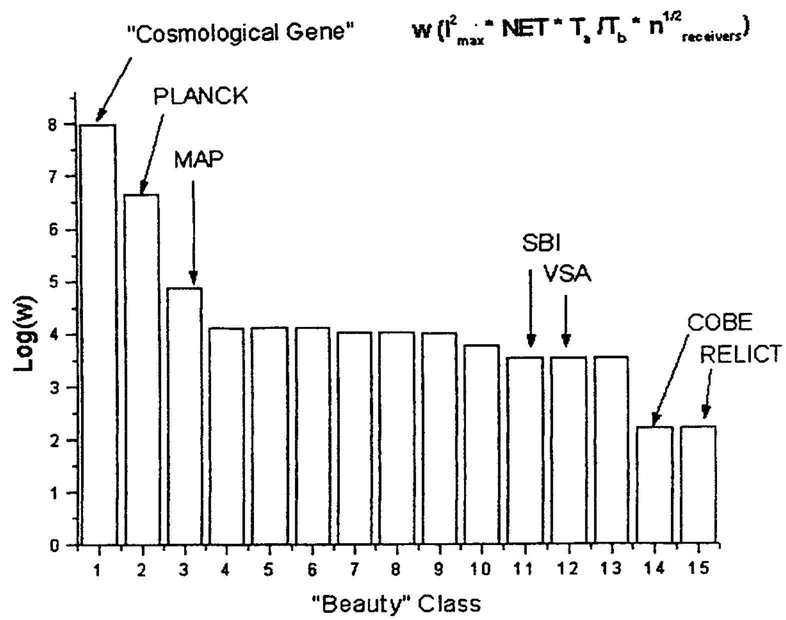

Figure 3 Limiting ability of RATAN-600 facility with a full use of resolution, l_{max}, PLANCK-type receivers sensitivity, NET, and a full unaberration field of view, $n_{receivers}$.

1%, i.e. by an order of magnitude better than it was done by all XX Century Astronomy.

4. Construct a complete theory of the origin of barionic matter and all visible and dark structure of the Universe and predict the Future of the Universe.

We started experiments in this field in 1968 (see Table 1). The most intensive one – 'Experiment Cold' (Parijskij and Korol'kov, 1986).

After 30 years of attempts, in 1997 it was realized by the world community that predicted features really exist and are equivalent to the GENE in Biology – new terminology, 'COSMOLOGY GENE', 'GOD FACE' etc., appear now in Science, because this very early Universe structure fully determines the evolution and structure of all visible objects in the nearby Universe. In 1997 it was demonstrated that the discovered extra noise has a black body spectrum 1, 2 (Parijskij *et al.*, 1998).

New generation of Giant projects immediately appeared in the US, Europe, the most powerful one – PLANCK SURVEY Space Based mission in 2007 (500 million USD).

2 PROJECT

Here we propose to use the world biggest reflector-type 600 m-radio telescope, which is the most efficient ground based world facility in this field, with which several

Table 2. Project parameters

	PLANCK	*RATAN-600*
Central frequency, GHz	100	32
Accompanied frequencies, GHz	31–857	21.7; 7.7; 11.2; 4.8; 3.9; 2.3; 0.96; 0.61
Receiver temperature, K	20	17–30
Bandwidth, GHz	4.7	4.7–10
Number of receivers	4	16–1800
Angular resolution, min of arc	30	0.08×1
Pixel integration time in a single observation, ms	90	100 000
Number of pixels	165012	199298
System temperature, K	30	30–300
Next Table – pixel sensitivity which may be achieved after 14 months of observations		
Integration time per pixel, s	223	477
Temperature sensitivity, mK in 1 s	0.311	0.3–0.010
T rms, micro K	20.8	3.6–0.1
Relative sensitivity, $(\mathrm{d}T/T) \times 10^{-6}$	7.8	1.3–0.05
Flux density sensitivity, MJy	37.8	0.03–0.01

CMBA experiments were performed at the 10–5 level earlier than results abroad. It is only with very big size reflectors that atmospheric problems may be fully solved efficiently, and sensitivity of the ground based observations of CMBA will be equivalent to the spaced based ones (but by factor 100 cheaper).

We can begin the experiment immediately after the installation of the best present-day receiver system of the same quality as are under construction for the PLANCK mission. Even with the same receivers we can reach better results due to much higher (by factor 500) resolution, which is also important in this experiment.

Scientific areas addressed by CMBA projects, see PLANCK argumentation, ESA D/SCI(96) February 1996. A full potential of the RATAN-600 in the CMBA experiments was never used yet, and we show now that, using proper mode of observation, all main parameters which determine an efficiency of CMBA experiments ($l_{\max}$, NET, N receivers, T_b/T_a), can be the same or even better than in the specified best next generation projects. Indeed, the resolution, $1/l_{\max}$ of RATAN-600 ($\lambda^2/S_{\mathrm{eff}}$) is much higher than in all projects, receivers may be used with the same sensitivity as for PLANCK mission (30 GHz and lower), a large field of view of RATAN-600 permits one to use hundreds and even thousands independent receivers pixels in matrix solution, the total power mode in reflectors suggest the brightness temperature-to-antenna temperature ratio, T_b/T_a, close to 1 (but not $\ll 1$ as in the aperture synthesis mode). We demonstrate the potential ability of RATAN-600 in Figure 3.

Table 3. Project parameters errors: RATAN-600 versus other best projects.

	BOOM/MAX	*MAP*	*PLANCK*	*RATAN-600*
Total density	6%	18%	1%	<0.5%
Barion density	30%	10%	0.7%	<0.5%
Dark matter part	36%	28%	1.7%	1%
Lambda term	10%	20%	2%	1%
Neutrino role	25%	8%	3%	2%
Hubble constant	10%	20%	2%	0.5%
Spectrum slope	30%	5%	1%	<1%
Universe transparency	50%	20%	15%	5%
H_e/H_{ratio}	10%	10%	7%	<5%
Tensor/Scalar ratio	160%	38%	9%	<5%

We can compare the RATAN-600 technical parameters with some well-known projects below (see Table 2).

Now we can calculate an efficiency of RATAN-600 in determining the main cosmological parameters, using the same route as the PLANCK group used, just taking RATAN-600 numbers from Table 2 (see Table 3).

First steps accents.

In Figure 3 we have shown a limit of the RATAN-600 potential in CMBA experiments, and it is a long way to get it. Many great projects are in progress in this field, and we decided to move step by step, selecting them with first priority goals, which seems real for RATAN-600 but most difficult for PLANCK mission. Observations of the low frequency part of the Galaxy window with resolution adequated to the problem (comparable with the highest resolution at highest PLANCK mission HFI) can help in the interpretation of the PLANCK mission results. We began this step and some results are shown in Figure 4. We used multi-frequency array (Berlin *et al.*, 1999).

Second group of the first priority experiments – polarization at the very high l values. Polarization is a very important CMBA parameter. Scales above the horizon scale can be used in reconstruction of the shape of the scalar field in the vacuum stage of the Universe, small scales are very sensitive to recombination processes and to the physics of acoustics waves at $100000 < z < 1000$. It is now clear that complete I, U, Q, CMBA data can only give the information needed to correct the comparison of the theory with observations. We can show here how polarization can improve the errors budget considered in Table 4 (see Figure 5).

Two points of interest can be mentioned here.

- Atmospheric noise is unpolarized, and ground based experiments may be performed easily.

- The last year activity demonstrated that small scales polarization must dominate, and minute-of-arc resolution have to be used. Even in the best space-

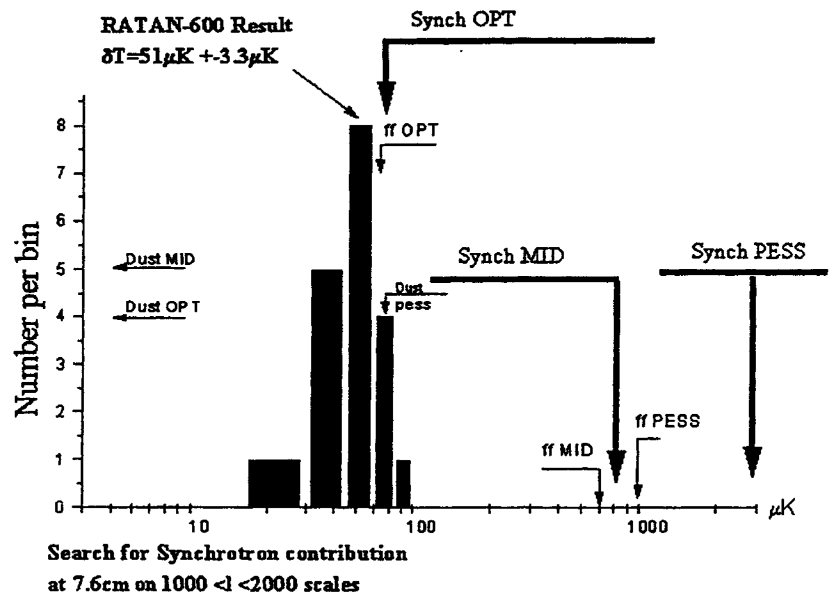

Figure 4 Demonstration of the efficiency of the RATAN-600 in estimation of possible synchrotron Galaxy contamination at the central frequency of the PLANCK mission and at the unexplored earlier scales, $l \gg 100$. Conversion to the PLANCK 140 GHz, much less than 1 μK is expected at $l > 1000$. Present-day estimations are shown following PLANCK group, suggested for pessimistic, median and optimistic cases.

based CMBA experiments this resolution may be achieved at a sub-mm domain only, where the strongly polarized dust screen component can limit an accuracy of observations.

Both factors strongly suggest a preference of ground-based high resolution observations. 'Cosmological Gene' project belongs to this class of CMBA experiments. First sensitive (at the 1 mK level) CMBA polarization measurements of small scale were made by the PROJECT group in 1969, using prototype of the RATAN-600 – 130 m strip radio telescope at the Pulkovo Observatory with 1 minute-of-arc resolution and with the best receiver (T_n = 100 K, 1 GHz bandwidth) and several attempts were made later with RATAN-600 with about 0.1 mK sensitivity and higher resolution in a 'free scale' mode of observations. Below we present (see Table 4) the collection of all CMBA polarization measurements.

All references connected with PROJECT's group experiments may be found in Parijskij and Korol'kov (1986), others – in SPOrt or POLAR projects (Eisenshtein *et al.*, 1998).

We have used standard approach in evaluation, of this Table of errors, see COBRAS/SAMBA ESA Project, and the same receiver sensitivity (There are changes in the number of receivers, dT and dT/T in recent publications on the Planck project (Bersanelli and Mandolesi, 1998) which are not reflected in our table yet).

Table 4. Our collection of CMBA polarization measurements.

Reference	*Wavelength (cm)*	*Scales (min of arc)*	dT_{pol}/T_{limit}
Penzias *et al.*, 1965	7.35	900	0.1
Parijskij *et al.*, 1968	3.95	1–10	3×10^{-4}
Pyatunina, 1970	3.95	1–10	1.3×10^{-4}
Caderni *et al.*, 1978	0.05–0.3	90–2400	3×10^{-4}
Nanos, 1979	3.2	900	6×10^{-6}
Lubin *et al.*, 1981	0.9	900	6×10^{-5}
Parijskij *et al.*, 1984	7.6–3.95	1–100	2×10^{-5}
Parijskij *et al.*, 1986	7.6–3.95	1–100	2×10^{-5}
Partridge *et al.*, 1988	6	0.3–2.5	1.4×10^{-4}
Wollack *et al.*, 1993	1.2–0.83	72	2.5×10^{-6}
COSMOLOGICAL GENE PROJECT, 1999–2006	1	1–100	3×10^{-7}
CBI Project, 1999–2001	1	10	3×10^{-7}
POLAR Project, 2001–2004	0.3	100	3×10^{-7}
SPOrt Project, 2001–2004	1.5–0.5	420	1×10^{-6}
MAP Project, 2001–2004	0.3–1	6–30	1×10^{-6}
PLANCK Project, 2006	0.3–1	6–30	3×10^{-7}

As was stressed by many groups, the final accuracy depends strongly on a resolution limit of the facilities, and we have calculated RATAN-600 errors budget using predictions made by Jungman *et al.* (1996). We see from Table 3 that, indeed, most of the physical parameters may be estimated better with RATAN-600 resolution than with 1 m Space telescope with equal receiver sensitivity.

In the PROJECT we are using the following peculiar features of RATAN-600 radio telescope:

1. Very effective 'near field zone' atmospheric noise filtration. Using the aperture averaging effective dual-beam and dual (multi-) frequency filtration, we demonstrated a full filtration of the atmosphere noise down to the receiver noise at all scales of acoustics peaks (Parijskij and Tsibulev, 2000).

2. Low 'confusion' limit due to resolution much greater than that of the simple dish with the same collecting surface.

3. The world largest reflector type and the only 'total power aperture synthesis' system gives the brightness temperature sensitivity equal to the antenna temperature sensitivity,
$$dT_a = dT_b$$
not but
$$dT_a = \frac{S_{\text{eff}}}{S_{\text{synth}}} T_b, \quad S_{\text{synth}} = D^2$$

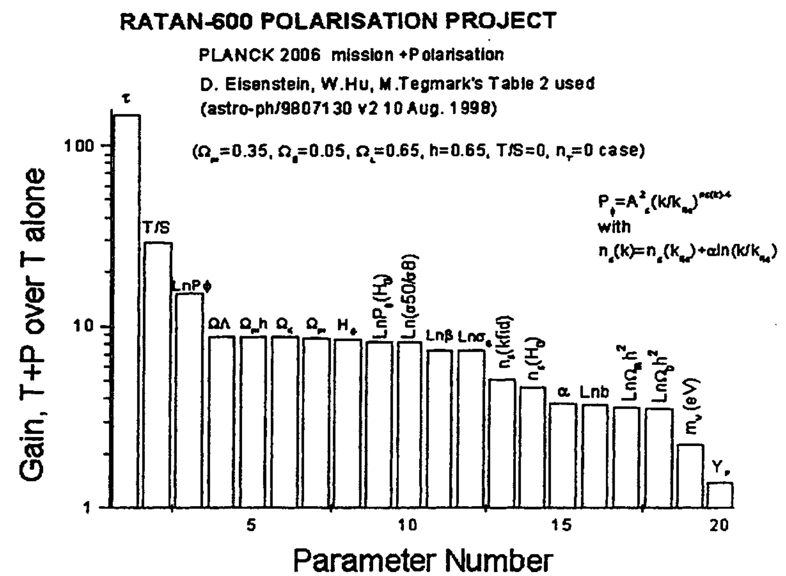

Figure 5 'Gain', i.e. improvement of the error budget, expected by theory, if not only I, but also Q, U Stokes parameters of CMBA will be measured. Errors may suppressed by a factor about 10 for many cosmological parameters (Eisenshtein *et al.*, 1998).

as for all interferometric arrays. It is possible to reach the same brightness temperature resolution with aperture synthesis but using much longer integration time, again by a factor about square of the ratio of physical to synthesized apertures.

4. In practice, no aberrations at high elevation angles and multi-frequencies and matrix receiver modes of operation can be done easily.

RATAN-600 has a collecting surface by a factor 1000 greater than any other space and balloon radio telescopes used for the CMBA measurements. It means that all kind of the discrete objects may be observed very efficiently. Two types of the accompanying programmes may be realized:

a Sunyaev–Zeldovich effect at $z \gg 1$ may be discovered in many directions. This effect was originally observed in St. Petersburg in 1970 and now it is clear that the density of such objects in the early Universe may be very high, up to 100000 str^{-1}, (new Cambridge – NRAO estimation). Amplitude of this effect does not depend on the redshift in a radio domain and may be the only indication of a cluster hot gas at $z \gg 1$ (see $6 < Z < 1000$ objects).

b LBO, Lyman Break Objects with $z \gg 1$ with no emission in optics, as well as dusty primeval galaxies (PG) due to positive K – correction may be observed with RATAN-600 at 1 cm better than at sub mm waves with 1 m Space dish.

Structure of the Universe at $2 < z < 5$ may be traced using HZ USS RG approach, because the mean red shift of a few mJy population of FRII USS RG should be close to 3, and even radio photometric red shifts will be accurate enough to check the observable LSS with numerous predictions.

3 FREQUENCY SELECTION

Using high sensitive RATAN-600 COLD strip survey at 7 frequencies with a high resolution, we improved limit on the Galactic synchrotron and free–free emission just on the scales of the Sakharov Oscillations, 1–0.1 degrees. Much smaller effect from free–free components than expected earlier was found (by factor 10). It moves the optimal frequency from 100 GHz to 30 GHz. We select this frequency as the central one in our project.

4 RECEIVER SYSTEM

Three variant of the receiving 30 GHz system was discussed: 1–2 world best deeply cooled in PHEMT receivers, small array (8–16) of the best receivers of the type we are using at RATAN-600, and the very dense array of the MMIC broad-band room temperature in PHEMT receivers with about 300 K system temperature. At present, we are close to the last variant. Up to 300 receivers of this type can be installed along the 3.8 m focal line of the secondary mirror (parabolic cylinder) without any aberration in the 1 steradian field at a high elevation angle. Even at a much lower elevation angle all aberrations will be inside the scales under investigation. 2–3 lines of the one-dimensional matrix receivers are also under consideration, they can help to reach a sensitivity level above the expected one in all next generation projects of this type.

5 ANTENNA CONFIGURATION AND SKY COVERAGE

RATAN-600 is a multi-mode instrument and can use 1 quarter of the whole ring absolutely independently. In ZENITH mode only we use all the ring in the single mode. An utmost importance of the problems to be solved by CMBA experiments has brought us to the following solution: one quarter of the ring will be used with an absolute priority of the CMBA programme as long as we need to get the desirable level of sensitivity. Five year (COBE-type) programme does not seem to be too much.

83% of the whole sphere are visible from RATAN-600 site. Cosmic variance noise may be suppressed by a number of independent pixels only, but for a given total time of experiment, and for a given receiver noise there is an optimum sky coverage, which we have calculated for all 5 first peaks, l = 200, 500, 800, 1100,

1400. It occurred that only for $l = 200$ receiver noise permits us to observe almost whole sky, but for the higher l we need receivers much better than that of PLANCK SURVEY to be close to the Cosmic variance limit. At the same time the Cosmic variance is not of utmost importance for $l > 1000$, and we can have 1% accuracy with small sky coverage. At present, we have made a full computer model of the experiment and limit ourselves by 1 steradian.

6 PRESENT STATUS OF THE PROJECT

Antenna surface. RATAN-600 panel surface was being improved during last three years, and it significantly reduced the antenna scattering background at 1 cm and shorter wavelengths. The RMS panel surface error is now about 0.2 mm, instead of about 1 mm before resurfacing.

Ground radiation. We installed recently about 8000 m^2 screens below and above the working surface of each 900 2×7.4 m^2 panels. Now the ground radiation part of the system temperature is less than a few degrees K.

Multi-wavelengths focal array. New version of broad-band multi-wavelengths focal plane receiver array was build with sensitivity below 10 mK at all wavelengths (1.38, 2.7, 3.9, 7.6, 13, 31 cm). Now this array we use to get information on the role of the Galaxy synchrotron, free–free and dust emission in realization of next generation CMBA experiments (Berlin *et al.*, 2000).

A new secondary mirror was constructed (open parabolic cylinder) with a very long focal line, were hundreds (up to 3500 (Khaikin, 2000)) receivers can be installed, and greater in size to decrease instrumental scattering.

New highly stable rail-tracks were constructed for realization of the accuracy of the main surface.

New generation experiments connected with a non-standard new method of atmosphere noise filtration were performed, and a better understanding of the sensitivity limitation for RATAN-600 now available (Parijskij and Tsibulev, 2000).

New data on the small scale structure of the synchrotron and free–free emission were obtained, and these will be used to improve Galaxy screens model.

Limits for the CMBA polarization observations with RATAN-600 were established, and it helped in the selection of the best mode of U, Q CMBA RATAN-600 measurements.

A full computer modelling of the RATAN-600 experiment now available, with demonstration of the reality of separation of all types of 'screens' (including radio sources) from CMBA signals.

7 COST ESTIMATES

It is not easy to make very accurate estimates due to quick changes in the market. As far as most of the experiment components are available except the new receiver system, we hope that about 1 mln USD can solve the financial problem. It is a small fraction of the cost of the Space-based missions.

8 CONCLUSION

RATAN-600 can (and should) be used for CMBA experiments, which are one of the key experiments in the present-day Science, connected with understanding of Nature, formation of the Universe, light, matter, structure and with formation of Physical Laws.

RATAN-600 Russian PROJECT may be started immediately after installation of the receivers with MAP or PLANCK type LFI, it is complimentary to next generation mm and sub mm experiments and can help in refining the scientific goals of these future projects. Updated information may be found at the project WEB-site: http://www.sao.ru and http://brown.nord.

Aknowledgements

This work was supported by INTAS 97-1192, RGBR 99-02-17114, COSMION and VUZ-RAS grants.

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