Window to the Very Early Universe and some problems of "μK Astrophysics"

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Abstract

A few years ago it was demonstrated by several groups that we can see predicted by theory small scale CMB anisotropy at the recombination epoch, $z = 1000$. It means, that:

1. We can check the history of evolution of the primordial disturbancies up to the recombination time.

2. There was an extended epoch of "neutral" Universe when gravitation formed proto-objects from very small relative disturbancies, say, 10^{-5}, up to more than 10^5 ("DARK AGE", $10 < z < 1000$).

3. The size of the "Luminous Universe" is limited by some redshift, say, $z = 10$.

There are many projects connected with item 1 (PLANCK mission - the most ambitious one), and with item 3, (NGST - the most ambitious in optics from Space, and $100m - 5000m$ in diameter - the most ambitious ground-based optical-IR telescopes, SKA - in Radio).

The situation with facilities for the "DARK AGE" Universe is not so clear [1], and we shall discuss here this item. Neutral epoch of the Universe cannot be observed by optical tools because of strong absorption beyond Layman limit, and radio tools are the first and may be the only possibility. As in the early history of Radio (first half of the 20th century), when there where many researches connected with propagation effects in the Earth atmosphere before optimal band for the "people-to-people" communication was found, at the end of the last century hundreds of papers appeared in attempts to find the best widow to the Early Universe and "DARK AGE" of its history ("people-to-Big Bang" window). Here we present a recent data, collected by different groups, including new data from RATAN-600 multi-frequency focal field array [2]. New data on the "polarization noise" from the Galaxy will be discussed, and a large difference with predicted values from lower frequencies and greater scales will be explained by "Faraday cleaning" process. A new upper limit on the "spinning dust" emission, more stringent, than before, simplifies the situation in the low frequency part of the Galaxy window [3].

Most groups agree that in the frequency domain the best window is in the $1cm - 1mm$ region. In the angular scale domain (or on the "l-axis") the lower l is limited by "recombination noise" by l=3000, above which "Silk Damping" process

acts strongly. High l boundary for small telescopes is instrument-depending and was computed individually for all projects.

Appearance of the "Redshift cutoff" effect suggests that there are no instrumental boundary now, if the number of antenna beams on the sky is greater than the number of galaxies in the Universe. Even existing instruments are close to this situation (e.g. VLA at short wavelengths).

In this paper we estimate how deep the window on the frequency-scale plane is and how close we can be to the expected secondary anisotropy effects suggested in literature (e.g., [4, 5, 6]).

We show that there is small window to the "DARK AGE" epoch where experiments with sensitivity below 1 μK in brightness temperature are possible if adequate instrumentation will be invented. One way of the solution connected with very big receivers focal array in big reflectors will be discussed in much more detail. Present day status of this direction at RATAN-600, the biggest reflector type instrument, will be shown. A possible role of the next generation bolometers in Space [7] will be mentioned as well.

1 Introduction

New millennium changed drastically the accents in observational astronomy and as a result the requirements to the instrumentation.

1. It is now clear from direct observations in the selected regions of the sky, that at least several famous populations in the Universe have so cold "redshift cutoff" phenomena (that is, no objects beyond some redshift, say $z > 7 - 20$), and ALL UNIVERSE projects now under discussion. In Radio domain, powerful Radio Galaxies were the first in this list, and even GB87 catalog included practically all most powerful RG in the Universe. New SKA project began from simple target to catch most of the galaxies in the Universe, which emit strong 21cm line.

2. Direct observation of the recombination (z=1100) epoch demonstrated, that medium between recombination epoch and observer has small Thomson optical depth, and there was extended period of neutral hydrogen epoch. It means, that the Universe is transparent for radio waves, but not for optical one.

3. A Great hope to use "Big-Bang" as a Giant Accelerator up to GUT energies, say, 10^{19} Gev, which are absolutely out of the laboratory range, and existence of a great gap in our knowledge about formation of the all kinds of objects visible in the local Universe, raised urgent request to optimize the facilities to new targets.

The higher sensitivity of new millennium facilities will be, the greater number of questions may be answered. We shall touch in the following sections two problems: Natural "screens" effects and some unsolved instrumental problems, connected with new scientific goals.

2 News about "Screens" and "Window" on the scale- frequency plane

There are many "screens" between observer and distant Universe — Atmosphere, Galaxy (Synchrotron , Free-Free, Dust emissions), Metagalaxy (Point Sources), recombination and secondary ionization noises. In the middle of the last century the main interest was connected with the window for very deep SETI programs, and only mean temperature and quantum noise limit were considered. It was found, that 1GHz- 30GHz frequency range is one of the best solutions. This conclusion had not changed drastically as far as point radio sources in this range we are interested in. The situation is absolutely different, if extended objects are under consideration. The present day understanding of the formation of all objects in the Universe in the all theories ("bottom -Up", "Up-Down"; Inflation or M-theories) suggests the phase with very small density (temperature) contrast, and not mean screen temperature, but "roughness" of the screen at the scales of interest is the most important parameter. There were many attempts to clarify the situation, most of them in connection with CMB anisotropy at the recombination epoch ("Sakharov oscillations", e.g., [14]). Here we are looking for the POST-PLANCK astronomy, where Sakharov Oscillations should be regarded as a noise, but not as the target. We used RATAN-600 facilities, which happened to be very useful for exploration of all screens with negative spectral indexes (Synchrotron, Free-Free Galaxy emissions). These screens have the noise strongly increasing to the low frequencies, and even 1mK temperature resolution at few GHz frequency corresponds to 1 μK temperature resolution at 100GHz. RATAN-600 now has new multi-frequencies focal field array, which is shown at the Fig.1.

At the left — 1cm (30GHz) small receivers array under the testing as a prototype of the very big array of the simple hot HEMT MMIC receivers. At the right — new multi-frequency feed system for all decimetric channels with single phase centre. In between — all criogenic receivers at 1.38cm, 2.7cm,

Figure 1: New 23-channel receivers array at the focal line of the RATAN-600 radio telescope.

3.9cm, 7,6cm.

We have reached level below 1mK at the scales not studied yet directly, beyond l=1000 (0.1degree scale). At these scales Synchrotron and Free-Free components have r.m.s. noise below 1 μK even at 30GHz, and much smaller at PLANCK central frequencies, 100-300 GHz. First RATAN-600 results were published earlier ([1]), as well as the summary on the Atmospheric noise([3]).

In some regions of the Galaxy the synchrotron and free noise was less than 50 μK even at 3.8 GHz (not 0.5mK, suggested by "All sky" Galaxy model, [10]), that is much below 1 μK at PLANCK LFI band).

After Drain, Lazarian ([9]) suggestion on the possible great role of the Macro-molecules and "spinning dust)" at 20-30 GHz range, we accumulated few months of observation in the 0h<R.A.<24h, at declination of 3C84 and found no emission greater than 10 μK at 21GHz (just at the predicted frequency for the spinning dust) in the $b > 20$ regions of the Galaxy of this strip ([3]).

In the same strip we tried to estimate the small scale polarization of the Galaxy at high galactic latitudes at 8.8GHz, again at small scales, $l =$

2000. No sign of the small scales polarization was found at the level much below 1mK in Q parameter, close to Q_2 level.This level is by factor 10 less, than in "All sky" recent model, ([10]). It is interesting, that this level is also below extrapolated from new generation 1.4GHz data and used for all sky predictions at PLANCK frequencies and scales. We suggest, that small structure "Faraday noise" dominates above the synchrotron noise due to small structure of the Galaxy magnetic field. The scales of magnetic fields may be greater, than the scales of the HII patches, responsible for Faraday effect. In that case, the frequency dependence of the r.m.s. fluctuations of the polarized Galaxy noise may be as strong as ν^{-5} at the scales small enough. In any case, at frequencies above 30GHz we expect, that polarized synchrotron noise should be below 1 μK at $l > 1000$.

It is known, that quadruple moment of the atmospheric oxygen gives some polarization effect. We have checked this effect at 8.8GHz and at 21GHz and found, that it is small at the scales of interest for Early Universe experiments. Oxygen type inhomogeneities are much greater in size, than water vapor one. It makes ground based experiments in polarization comparable in the sensitivity with space based one.

Some new information appeared on the confusion noise due to background radio sources from RATAN-600 deep 23-frequencies cut of the same region of the sky. We realized, that, up to about 10GHz, the main energy from Point Sources are connected with "NVSS sky" converted to high frequencies with standard spectral indexes. Number of objects with inverted spectrum is no more than few percent (see also [11]). We found, that $Log(N) - Log(S)$ relation at 30GHz does not differ greatly from that, recently obtained by CBI group ([13]), about 1-3 objects per 1 sq. degree for $S > 10mJy$. The situation is less clear for higher frequencies, but many new results should appear soon. More over, the redshift cutoff effect suggests, that with high enough resolution the number of the antenna beams on the sky may be greater, than number of galaxies on the sky! It may be realized even with existing facilities.

There was suggestion from Ken Kellermann group, that finite angular size of the radio sources may result in the full coverage of the sky at sub-μJy level. We estimated this effect at PLANCK frequencies and realized, that r.m.s. temperature noise should be below 1 μK even at the sub-arcmin scales.

We used RATAN-600 DATA to construct the shape of the "window" on the "frequency-scale" plane. Recombination noise was suggested has black body spectrum and the Cl values were taken from the Lambda- CDM theory.

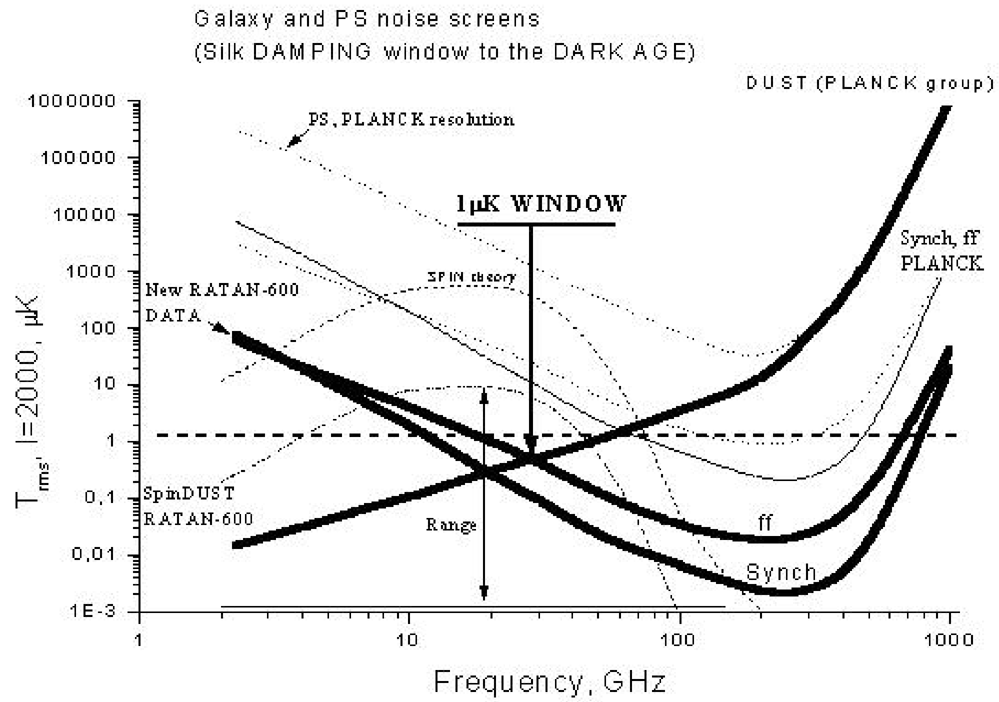

Figure 2: Comparison of the RATAN-600 new DATA on the Galaxy screens with PLANCK MISSION "Pessimistic" variant.

At l=3000 we obtained the window shown in Fig.2.

Upper curves — PLANCK estimation, 1998. Lower curves — RATAN-600 high resolution data at cm. waves. Result on the "Spinning dust" is shown also (prediction- upper curve, RATAN-600 data — lower curve, with the shape from theory but normalised to the RATAN-600 upper limit at the predicted frequency of maximum emission.

The main result — it is possible to find window with screens noise below 1 μK at the angular scales less than few arcmin. and in the frequency range 20GHz–200GHz. As was demonstrated by many groups, it is possible to go deeper, say, even below 0.1 μK, if accurate multi-frequencies observations will be in our hand (see PLANCK Survey Mission documents).

3 Instrumentation problems

There are no instrument (and even projects!) with these (0.1μK) specification yet. All last century history of the development of radio facilities was connected with the construction of the facilities very sensitive to the point sources, later — for extremely high resolution, then — for high quality imaging of local population type objects (but distant and weak). New targets, connected with very early Universe, with absolutely different populations of small contrast (proto) objects are uncommon for standard engineering groups.

We are living in the exponentially evolving society, and standard parameters are improving exponentially also. More that 10 orders of magnitudes improving occurred in flux density sensitivity and resolution, but only 3 orders in the temperature resolution of extended sources. Even next generation instruments in all bands from Gamma-XRAY to very low frequencies bands will have bad brightness temperature sensitivity. VLBI (ground based, space based) projects have no better than 10^6K limit, SKA — about 1K, but not μK. The same problem even with so called "OWL" (Over-Whelming Large) telescopes, which under discussion in the literature. For high temperature resolution filled apertures (or filled arrays) should be used, with best receivers and clever enough in the struggle against all screens. Only last few years, stimulated by CMB problems, new solutions of this type appearing, and PLANCK Mission sensitivity will be exceeded soon by several new solutions (e.g., see Smooth, this issue). But even in these new projects it is not easy to attain sub-μK sensitivity in brightness temperature, permitted by Nature in the 'Window" to the Early Universe. Even for filled telescope or array the brightness temperature sensitivity is not better then

$$dT_b = T_{sys}/(df \times t)^{1/2}$$

where df, t – bandwidth and integration time.

But T_{sys}, system temperature, can not be smaller than CMB temperature, $df/f < 1$, and t should be unacceptable large. With $200\mu\text{K/sec}^{1/2}$ bolometers we should spend several years per each pixel. Multi-pixels arrays, up to 1000 can help in imaging of very small part of the sky (see SZ instrumentation, Smooth, this issue).

We may suggest the following variants of moving ahead:

1. Multi-telescopes system operating in the total power mode and looking

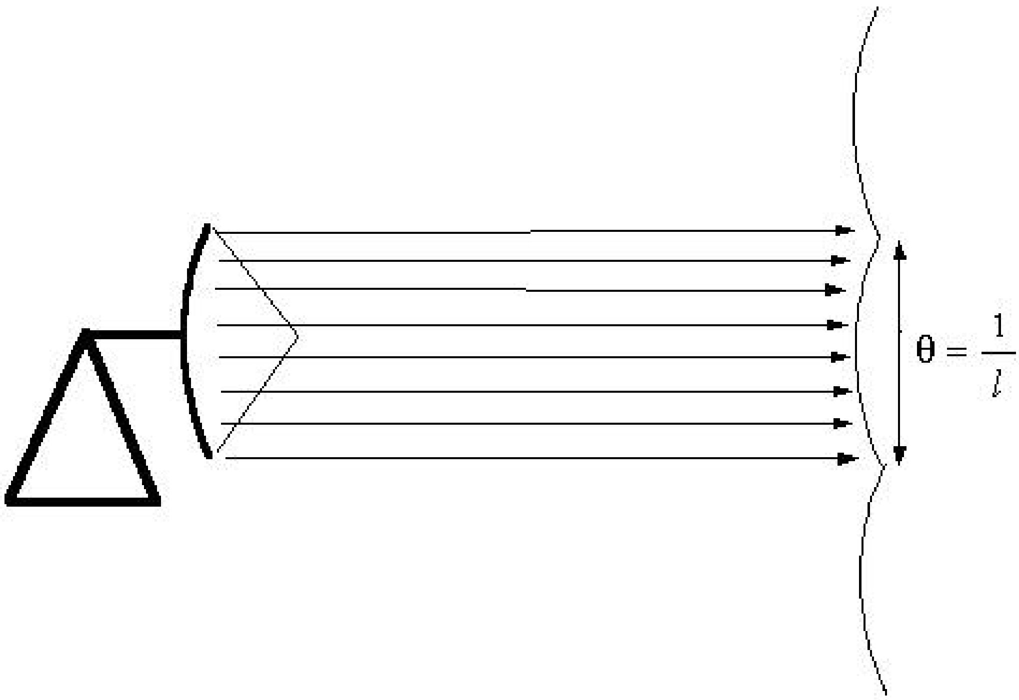

Figure 3: The case when all receivers are looking at the same Sky pixel.

at the same pixel.

2. Filled aperture or filled arrays are preferable.

3. New generation receivers with noise temperature below 3K should be used.

4. Next step may be connected with many receivers array looking into the same pixel.

We demonstrate this approach by Fig.3.

The best pixel sizes are about $1/l, l = 3000-10000$, and the receivers array size d is limited by the $F/d = l$, where F — focal length of the telescope. It means, that telescope diameter D should be big enough to realize full receivers array capability, if we want to look at the same pixel with all receivers. For $l > 3000$, telescope with $D > 100m$ should be used even for only 100 receivers array at 100GHz.

RATAN-600, the world biggest reflector, 600m in diameter, can operate at the low frequency side of the "window" , at 20-30GHz, and it has very small aberrations at small zenith angles. With few arcsec resolution $\times 1$ arcmin we can look into the same pixel with about 100 receivers.

4 Conclusion

We have demonstrated, that at least in some regions of the Sky, there is very deep window in the screens between observer and $Z >> 1$ Universe on the Frequency-Scale plane. In the 20GHz-500GHz, and $3000 < l < 30000$ bands it is possible to check all predicted "secondary" anisotropy effects down to the fraction of μK level. In the Early PLANCK group work, even the primary anisotropy measurements were under question ([10]) at any frequencies without separation of all types of screens. Many polarization projects, based on the 30GHz band, were questionable as well (e.g., [10]). Here we suggest much more optimistic picture. It seems, that this picture confirmed by direct polarization experiments published Sept. 19, 2002 ([12])

As for the life on the Earth, where Nature adjusted properly the SUN radiation spectrum, atmospheric window, and receiving system of all creatures on the Earth, we, living in the third millennium, are civilized enough to adjust our receiving system to the prepared by Nature window to the dominating source of energy in Universe, CMB.

5 Acknowledgements

Many groups of Special Astrophysical observatory were connected with RATAN-600 experiments, resulted in Fig.2 values. A.Berlin, N.Nizhelski, A.Bogdantsov, P.Tsibulev were responsible for modernisation and support of the unique multi-frequency receivers array, N.Bursov was the guiding person in observations, and M.Mingaliev realized observing program.
Investigations are partially supported by grants RFBR 02-02-17819, "Astronomy" and "INTEGRATION".

References

[1] Y.Parijskij (2001) The High Redshift Radio Universe, in N.G.Sanchez (ed.), *Current Topics in Astrofundamental Physics: The Cosmic*

Microwave Background, Kluwer Academic Publishers, Netherlands, 219–239.

[2] A.B.Berlin, G.M.Timopheeva, N.A.Nizhelsky, A.V.Bogdantsov, A.M.Pillipenko, V.M.Chmil, Yu.N.Meshkov and A.N.Zdor (2000) MARS (Matrix Radiometric System) Project, *Astronomical and Astrophysical Transactions*, **19(3–4)**, 559–565.

[3] Yu.Parijskij, A.B.Berlin, A.V.Bogdantsov, N.N.Bursov, N.A.Nizhelskij, P.Tsibulev, I.D.Novikov, P.D.Naselskij (2002) Small Scale I,U,Q Galaxy Noise at sm.Waves, in S.Cecchini et al. (eds.), *Astrophysical Polarized Backgrounds* AIP, New York, 51.

[4] P.Tozzi, P.Madau, A.Meiskin, M.Rees (2000) Radio Signatures of Hi at High Redshift:Mapping the End of the "Dark Ages", *Ap.J.* **528**, 597–606.

[5] N.Yu.Gnedin, A.Jaffe (2001) Secondary Cosmic Microwave Background anisotropies from cosmological reionozation, *Ap.J.* **551**, 3–14.

[6] V.Dubrovich and B.Partridge (2000) Line and Continuum Emission from High Redshift Objects and Proto-Objects, *Astr.&Astrophys.Trans.*, **19(3–4)**, 233–251.

[7] V.D.Gromov, L.S.Kuzmin, D.Chouvaev, L.A.Gorshkov, N.S.Kardashev, V.I.Slysh, S.F.Stoilo, M.A.Tarasov, A.G.Trubnikov, A.N.Vystavkin (2001) Submillimeter Telescope for the Russian Segment of the ISS: Submillimetron project, *astro-ph/0108491.*

[8] Y.N.Parijsky, P.Tsibulev (2000) Limit on the Ground based CMBA Experiments , *Astro. and Astroph. Transactions*, **9**, issue 3-4, 287.

[9] T.Drain, A.Lazarian (1998); *Ap.J.* **494**, L19

[10] G.Giardino, A.Banday, K.Gorski, K.Bennet, J.Jonas, J.Tauber (2002), Toward a model of full-sky Galactic synchrotron intensity and linear polaririsation: a reanalysis of the Parkes data, *Astro-ph/0202520*, subm. to A&A.

[11] N.S.Soboleva, A.V.Temirova (2001) Spectral Characteristics of Faint Radio Sources of the Kholod Survey, *Astron.Journal* (Russian), **78**, N12, 1066

[12] DASI WEB-site *http://astro.chicago.edu/dasi*, Sept. 19, 2002 news.

[13] T.Pearson, B.Mason, A.C.Readhead, M.Sheherd, J.Silvers, P.Udomprasert, J.Cartwright A.Farmer, S.Padin (2002) The Anisotropy of Microwave Background to l=3500: Mosaik Observations with the Cosmic Microwave Imager, *Astro-ph/0205339*

[14] M.Tegmark, D.Eisenstein, W.Hu, A. de Oliveira-Costa (2000) Foregrounds for the Cosmic Microwaves Backgrounds, *Ap.J.*, **530**, 133