LARGE GROUND BASED ARRAY ANTENNAS
FOR VERY LOW FREQUENCY RADIO ASTRONOMY

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Very low frequency radio astronomy has considerable astrophysical importance. But its development comes up with significant methodological and instrumental difficulties. It is evident that many of them can be overcome by creating low frequency radio telescopes outside of the Earth ionosphere. However the giant size of the effective area needed for many astrophysical tasks - especially below 30 MHz -, shows the topicality of building new generation concept of large ground based radio telescopes. Exciting world potential confirms the reality of such an approach.

1 Introduction

A great number of physical processes and phenomena in the Universe are displayed very uniquely at lowest radio frequencies – in decameter and hectometer wavelength bands. We can mention first the effective interaction of matter with radio emission (such as free-free absorption, dispersion, scattering and refraction in plasma), synchrotron emission spectra formation (especially at lower frequencies), significant variations of spectral indexes (with increases due to synchrotron losses and decreases due to reabsorption and other causes), intensive impulsive and sporadic radio emissions by particle beams moving through magneto-active plasmas, coherent emissions, fine atomic effects and many others. In spite of beautiful examples of detections of those phenomena, it is very important to carry out their full and detailed study at all the Universe scales and at new quantitative and quality levels. This is the reason why, during last years, the interest for the very low frequency radio astronomy has grown considerably. The hectometer/decameter band remains a largely unexplored wavelength range and, certainly, has as much interest as other frequency ranges in modern all wave astronomy from the viewpoint of astrophysical significance and perspectives.

However radio astronomy, high quality investigations at extremely low frequencies meet a great number of difficulties. It is a problem to reach high angular resolution at so long wavelengths while the aperture or interferometer baselines are fixed. A lot of natural and artificial interferences are concentrated with intensities many times higher than those of radio emissions from space. The influence of the wave propagation through various media (ionosphere, interplanetary and interstellar medium) is very strong leading to absorption, refraction/diffraction and scattering of radio waves. Decameter range brightness temperature of the galactic background is quite high. It determines the noise temperature of receiving systems but, of course, cannot be decreased.

It is evident that two of those main difficulties (interferences and ionosphere effects) can be completely removed if the low frequency instruments can be operated outside of the Earth ionosphere. Now such space borne projects are actively discussed and prepared around the world. They plan to install decameter/hectometer sensitive antenna elements in open space or on the far side of the Moon. Corresponding concepts are described, for example, in works [1, 2] as well as in various proceedings of past, high level scientific conferences. Such projects will likely be realized during the incoming century and they will open new possibilities for the Universe study.
2 Why giant, ground based arrays are needed for very low frequency radio astronomy?

In spite of favorable perspectives of future, space borne very low frequency radio astronomy, one
should not forget the development of ground based decameter radio astronomy. Indeed, a number
of difficulties and restrictions often come with space projects. There are economical and reliability prob-
lems, project lifetime as well as astrophysical restrictions. The latter are the most important. Realize
giant effective area (several square kilometers) in space is a problem. So far planned space projects
(they all have very poorly aperture filling) involve a number of antenna elements not larger than a few
hundred, with corresponding total effective not exceeding a few thousand square meters. Due to the
possibility of very long lasting observing sessions and, correspondingly, high integration time, one
could reach very good uv-plane coverage at relatively high spatial frequencies, high angular resolution
and sensitivity, in the case of mapping of stationary continuum radio sources. But due to low “instant”
filling factor and small effective area size, a great amount of interesting astrophysical tasks and short-
term phenomena (at first with low contrast) will be practically not accessible. They include large scale
galactic and extragalactic structures; spectral lines; pulsars (especially, individual pulse studies); as well
as all the short time scale phenomena, which greatly fill the decameter range, such as Sun-like stars,
flare stars, planets, exoplanets; weak events on the Sun and Jupiter, unknown exotic phenomena; vari-
ability of galactic and extragalactic sources; interplanetary and interstellar scattering, moon occultation
effects; radar experiments, etc.... According to theoretical estimations and existing world experience,
the effective area must not be less than $10^6$ m$^2$ if we want to carry out all the mentioned objectives at a
new level. This effective area is even much more than that of the largest existing decameter radio tele-
scope UTR-2 (see below). Some of the mentioned phenomena were already detected with the help of
this telescope.

Thus, the idea of new generation, giant, ground based, low frequency radio telescope is very actual.
Such approach has received support in world radio astronomy community. It does not exclude realiza-
tion of space projects but, on the contrary, is a necessary step before to go into space, and naturally sup-
plements them. It offers a more immediate possibility of carrying out the interesting, fore mentioned
studies, because they will not be with any space instruments in visible future. New astrophysical results
obtained with ground instruments will allow to optimize and to strengthen the scientific programme of
space projects. Furthermore, it will be possible to probe new technical ideas and methods, which are
interesting for space missions too. Finally, joint operations of ground and space instruments are impor-
tant for mutual support, verification, increasing of experiments reliability and effectiveness.

3 Pre feasibility study discussion

New concept of giant ground based low frequency radio telescope must be based on a number of facts
which come from astrophysical, methodological and instrumental features of radio astronomy at very
low frequency. For example, since the brightness background temperature is high and correspondingly
governs the system noise temperature, it is not necessary to have highly effective antenna elements and
supersensitive receiving devices. The need for huge dimension and electrodynamic features at so long
waves provide the only criteria for a large instrument design: it must be built as electrically scanning (or
with synthesis) multi-element array made of simple dipoles and having optimum configuration match-
ing the angular resolution and sensitivity. For an array, consisting of low directivity elements and with a
given effective area, the required number of element scale approximately as $1/\lambda^2$. The cost of the radio
telescope will roughly follow the same law. Therefore, it is easier to reach the giant effective area at the
lowest frequencies. Moreover, some fundamental constraints on spatial, time, and frequency resolutions
determine the requirements for antenna, equipment and methods at the determined and realized level.
On the other hand, the modern electronics and technologies provide simpler and more effective ways to
build radio astronomy instrumentation in particular at decameter wavelength. They are: integrated anal-
og down converter followed by digital devices such as high speed ADC, real time spectral processors,
correlometers; high power computers and data archiving means; wide band video recorders; new data
processing methods; telecommunication and frequency-timing systems.

It should be emphasized that the decameter range is the only part of the radio spectrum in which any
considerable growth of its pollution is not foreseen. 30-years experience of operations shows that the
level of pollution by RF interference remained practically constant. More significant variations of RF interference level are determined by terrestrial ionosphere and solar activity, by seasons, by day of week and time of day.

Excellent proposals and concepts of new generation, giant, low frequency radio telescope are now actively discussed and developed [3-7]. There is a great interest for this problem in many world countries. Of course, successful preparation and realization of such projects are only possible in close international collaboration.

We propose to discuss and to investigate the following aspects in a preliminary stage.

- Development of scientific motivation, taking into account interdisciplinary interests, ground and space projects coordination as well as principal requirement formulation to the new generation instruments.
- The choice of the used frequency range, restricted to 8-30 MHz or covering up to 200 – 300 MHz. There is a need to take into account the technical difficulties of very broad range overlap (antenna elements, optimum matching of element numbers with large effective area) as well as the existence of effective instruments near 100 MHz and higher (such as VLA at 74 MHz, GMRT, MRT, SKA project with lowest frequencies near 200 – 300 MHz and so on). According to existing experience we can propose the following quality estimation of the 8 – 30 MHz range from viewpoint of interference and ionosphere effects
  - 20 – 30 MHz – the situation is satisfactory, the work is possible at every time for all programmes;
  - 16 – 20 MHz – the situation is ordinary, the work is possible for significant part of time for many programmes;
  - 12 – 16 MHz – the situation is complicated, the work is possible for only some time and programmes;
  - 8 – 12 MHz – the situation is very complicated, the work is possible only for a few selected programmes;
  - less than 8 MHz – ground based observations is practically not possible;
  - more than 30 MHz – the situation is rather favorable, but the number of specific astrophysical topics is decreasing.
- New approaches and methods must improve the described situation for all the frequency ranges.
- The choice of simple cross dipole basic element type (active or passive with low efficiency but with excess of galactic background temperature over preamplifier noise not less than 10 dB for whole range). Because the number of elements must be more than 10 thousand, the cost of one element simply determines the whole antenna cost.
- The choice of antenna type, i.e. receiving-transmitting of only receiving. Low efficiency element is not usable for transmission regime. We prefer receiving antenna from an economical viewpoint and because the number of scientific objectives is higher. It is possible to use other kind of antenna for transmission.
- The choice of preamplifiers type (it should be on each element in any case) as well as of other analog semiconductor devices from viewpoint of high dynamic range and sensitivity.
- The choice of the optimum antenna configuration (configured as a few rather compact big arrays or distributed up to few hundred kilometers system), taking into account confusion effect and high-resolution requirements. It should be emphasized that high-resolution mapping will be more qualitative with space instruments. High resolution and confusion effects are of secondary importance when large instant effective area is very needed (see above). Of course, it is not possible to exclude the creation of a rather compact array if it would give significant economical advantage.
- Determination of optimal combination of analog and digital systems in antenna architecture, hierarchy of time delay phase system and aperture synthesis principles (probably, taking into account cheap optical fiber lines).
- Evaluation of expediency of using adaptive antenna methods (beam forming). Spatial interference distribution is quite isotropic at frequencies less than 30 MHz due to radio waves propagation features. Side lobes level minimization can be preferable.
- Interference study with struggle methods at the post-recording processing level and by real time waveform adaptive rejection methods.
- Ionosphere effects and methods for reducing its influence, taking into account antenna structure, frequency range and angular resolution.
- Choice of geographical specific locations for building the instrument, taking into account ionospheric situations as well as existing infrastructures.
- Development of absolute measurement methods, calibration and self-calibration ones, system parameters checking and measurements.
- Substantiation of back-end facilities and archiving systems structure taking into account various astrophysical tasks requirements and other ones, as quick-looks or automated recording.
- Project cost estimation taking into account current status of electronics and development perspectives.
- The aspects mentioned above should be investigated by theoretical and experimental methods on the base of worldwide working experience in the decameter range and adjacent ones.

4 UTR-2, URAN and NANCAY arrays as probes for the development of new generation decameter radio telescopes.

There are many good decameter radio telescopes in the world. A big amount of interesting astrophysical results was obtained by operating them. We will consider briefly in this review a few of them, which are now operated, in non-stop regime. The decameter wave band UTR-2 radio telescope (Kharkov, Ukraine) [8], Fig. 1, was developed about 30 years ago. Its principal parameters are the following.

- Frequency range is 8 – 32 MHz.
- Angular resolution for zenith orientation is 25' at 25 MHz.
- Beam steering interval is ± 70º from zenith in N-S and E-W directions.
- Maximum effective area is 150,000 m².
- Sensitivity is ~10 Jy.

The large effective area of the radio telescope ensures the mentioned sensitivity even for very narrow analysis band and small time constant which are corresponding to 10 kHz and 60 s respectively. During past years of UTR-2 operation a large amount of new astrophysical information was obtained practically for all Universe object types [9, 10]. Fig. 2 illustrates some possibilities of UTR-2 radio telescope (high sensitivity and directivity, electronic steering, interference immunity). The radio emission of 3C338 radio source was registered in computer by consecutive scans with the duration of 20 min for each. The measurements were carried out during the evening time on June 1999 at the frequencies 25, 20 and 16 MHz (from the top to the bottom). Analysis band was ~20 kHz, time constant was ~30 s. The records of calibration signals are in the left part of each frequency image. As we can see from them, the noise fluctuations are practically absent. The fluctuations on the scans are determined by well-known side lobes, some interference and ionosphere influences and by confusion effects at the level of about 10 Jy.

Ukrainian decameter VLBI system URAN includes, in addition of UTR-2, four radio telescopes of 5 – 10 times less in size [11]. The system provides baselines from 40 km to 900 km and angular resolution down to 1". At present time, URAN measurements consist in determination of visibility function modules for different bases and hour angles [12].

The use of effective UTR-2 and URAN instruments confirms high informativeness of decameter radio astronomy. However, the possibilities of improvement of these instruments have not reached limits yet. Furthermore, it is evident that future progress requires effective area even considerably larger than the one of UTR-2.

The Decameter Array in Nançay (France), which is mainly used for daily monitoring of Jupiter and Solar Corona activities at decameter wavelength, is an example of a large, low-cost, planetary dedicated radio telescope. [13], Fig.3. It is made of 144 helix spiral, wide band elementary antennas filling an aperture of about 10⁴ m². The antennas are arranged in two sub-arrays in opposite senses of circular polarization. The measured effective area of each sub-array is 4000 m² at 20 MHz. This lead to the possibility of polarimetric measurements. The total bandwidth of the instrument goes from 10 to 85 MHz. The instantaneous bandwidth is one octave and the useful tracking time is 8 hours per day for δ=0°. Several specialized, digitized spectrographs (with broadband frequency coverage, high time and spectral resolu-
tion capabilities) can be simultaneously operated, including new generation receiver – real-time high
dynamic range digital spectral analyzer [14,15]. The Nançay Decameter array adapts optimally for con-
tinuous, fully automated Sun and Jupiter sporadic radio emission monitoring [16,17] and for some other
astrophysical tasks, compatible with its relatively small antenna aperture. Specific capabilities of the
 telescope (broad frequency range, two polarizations, electronic beam steering, immunity to RF inter-
ference) are illustrated by Fig. 4

The instruments mentioned above are proposed for the investigations and approbation of new ideas,
means and methods which need for perspective development of decameter radio astronomy and corre-
sponding instrumentation. For example, coordinated operations of these different decameter antennas,
besides of VLBI investigations, can be achieved, in order to enhance reliability and quality of the meas-
urements, since the antennas are in different conditions of ionosphere and interference influences.

5 Conclusions

Very low frequency radio astronomy has considerable significance for many fields of Universe sci-
ences. It can give the answers for fundamental questions not resolved yet. Great international interest,
existing expertise and broad experimental basis, modern electronics, close international collaboration
shows the reality of a new project of ground based very low frequency giant radio telescope. The future
of the next century low frequency radio astronomy will be determined by combining high effective area,
space and ground-based radio telescope

Acknowledgements

The authors are thankful to their friends and colleagues taking part in the development and operation of
UTR-2, URAN and Nançay arrays. We thank world specialists in the field of low frequency radio astron-
omy for mutual understanding and fruitful discussions. Current activity of the authors is supported
in part by grants INTAS 97-1964, INTAS-CNES 97-1450.

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Figure 1 View of the North-South arm of the UTR-2 radio telescope.
Figure 2  UTR-2 observations of 3C338 radio source.

Figure 3  View of the Nançay Decameter Array.
Figure 4. Example of Jovian polarization dynamic spectrum recorded in Nançay. The recorded antenna temperature from the LHC and RHC arrays are greyshade coded, from white to black. In spite of the high level of interference, the Jovian emission can be easily followed down to 10 MHz. A pass band filter was suppressed at about 22:13 UT. Periodical, vertical streaks are calibrations.