CHAPTER FIVE

Future Large Telescope Projects: SKA and FAST

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ON POST-SKA RADIO ASTRONOMY *

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Abstract. It is suggested that the development of the SKA will drastically change the face of radio astronomy in the 21st Century. A FAST-style SKA would admit observations of low contrast features, and would be the best design for studying the 'dark ages' of the Universe ($x \gg 1$) where sub-arcmin total power instruments can usefully be employed. To date there have been no proposals for post-SKA, billion square-metra instruments; we speculate that mobile communication systems can be used. In the very distant future, SKA multi-beam systems could be used to collect signals reflected by Solar system bodies such as the asteroid belt.

Keywords: SKA, VLBI, radio astronomy, Internet

1. Historical Perspective

When looking ahead to the next 50 years of radio astronomy, it is interesting to look back in time and see what kind of trends in the motivations and strategy, connected with new instrumentation, we have had in the last 50 years.

In the 1950s there were searches for the best *all purpose* instrument, and the parabolic dish was one of the most popular approaches. The Pulkovo group first proposed a reflector system as big as modern SKA projects -5×10^6 m^2, with arcsecond resolution at decimetre wavelengths. A smaller version was suggested for the Russian Space Tracking Center (0.5×10^6 m^2) near our observatory site, but only a very small version of these giant projects was realized: the RATAN-600 transit 600 m ring system, with a geometric collecting area of about 10^4 m^2 in the 'zenith mode' of observations (Khaikin *et al.*, 1967).

At the end of the 1950s, the efficiency of aperture synthesis arrays was demonstrated, and this type of instrument was suggested as the *all purpose* solution. The advent of VLBI techniques changed the emphasis once more, and looking back we can state that radio astronomers *failed* to find an *all purpose* telescope design. For example, high angular resolution and good surface-brightness sensitivity need very different approaches. To make further progess, it is much easier to discuss *special purpose* instrumentation.

With the advent of aperture synthesis telescopes, rapid progress was made in shifting from natural image formation processes (as in dishes) to 'man-made' (syn-

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thesis) images, with full ability to regulate the amplitudes and phases of all Fourier components of the incident coherence function.

Finally we note that, in many cases, the limitations of our data will be connected not just with the technology we use, but with natural 'screens' of all kinds (this is true for space-based observations as well).

All types of *special purpose* instruments also have their own problems. Even all SKA-type projects, with the same collecting area, can have very different properties. The various published proposals do not compete, but are complementary. Collecting area is a very important instrumental parameter. It may be shown that, for given area of sky, observed with the same resolution and for the same time, with the same receiver, the collecting area is the dominant factor for all types of instruments – single dish, aperture synthesis, or RATAN-600 type – to a first approximation, with the same collecting area we shall have the same flux density limit!

All SKA-type projects, with a large collecting area, can help global and space radio astronomy greatly in several respects:

- No problem with objects now – all standard VLBI sources with $T_b \sim 10^{12}$ K can be mapped with any resolution up to the limit dictated by the longest available baselines.
- 'Snapshot' images can be realized with very simple space arrays (just equipped with communication dishes or even dipoles).
- Three-dimensional synthesis may be realized using much bigger space arrays, and post-SKA radio astronomy may look very unusual.

2. Advantages of the FAST Approach

The FAST project has several specific features which should prove very useful, and which we should make efforts to exploit. In a single-beam mode, a reflector-type solution is practically unlimited in bandwidth, so that multi-frequency observations and spectroscopy in the entire radio-frequency 'window' may be performed with state-of-the-art technology.

Filled aperture is the only way to have high beam efficiency and high surface brightness sensitivity, which is one of the most slowly improving parameters in the history of radio astronomy.

High accuracy in low flux-density measurements can be obtained before attempting VLBI (ground-based or space-based), for selection of IDV sources, pulsars etc. It is well known that source variability (whether intrinsic or due to scintillation) can give much finer resolution than any suggested VLBI project.

Even in a simple beam-switching mode, atmospheric noise can be filtered out practically completely, and very deep, broad-band bolometric observations are possible up to the shortest wavelengths. In interferometry, there are no common atmospheric emitters in the elements' beams and so the atmospheric noise is incoherent.

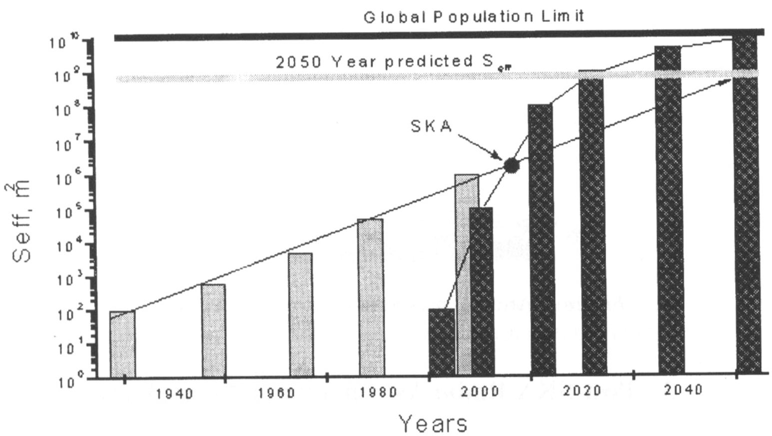

Figure 1. 'Dedicated' versus 'private' global collecting area. Gray: 'dedicated' dark: 'private'; S_{eff} – effective area in m^2.

In single-dish mode, closely-spaced beam switching can use another near-field zone method, where practically the same emitters are visible in both feeds. We demonstrated that, when used in combination with RATAN-600, FAST may be as sensitive as *space-based* radio telescopes (at the same observing frequency) for all targets with sizes smaller than several arcmin (Parijskij, 2000; Esepkina *et al.*, 1973).

There is a big box of unsolved problems, connected with arcminute, and sub-arcminute stales. On these angular stales Silk damping should suppress noise from Cosmic Microwave Background (CMB) anisotropies, and we can escape from the radio source confusion limit by using a beam size comparable to the median source size (say, 10–20 arcsec). As was originally pointed out by Ken Kellermann, though, at the micro-Jy level most of the sky may be covered by sources, and in this limit the situation does not improve with resolution (only AGN-type objects may be separated with higher resolution).

In this scale range it is possible to check many predictions connected with secondary CMB anisotropies and Sunyaev-Zel'dovich-effects, as well as studying various types of proto-objects and spectral features of the early Universe. All predictions are much below the level of CMB anisotropies visible at larger scales, and only filled apertures can help here: aperture synthesis observations would be too time-consuming.

If a phased array is used as a feed, telescope aberrations can be corrected, and multi-beaming is possible. This option has been investigated for the RATAN-600 (Pinchuk *et al.*, 1995). Multi-beaming is the only way to increase the information capture rate of a dish when sensitivity is limited by external noise, and may be important in reducing the necessary observing time for the next-generation astronomy programmes which are aiming at micro-Kelvin or micro-Jansky levels.

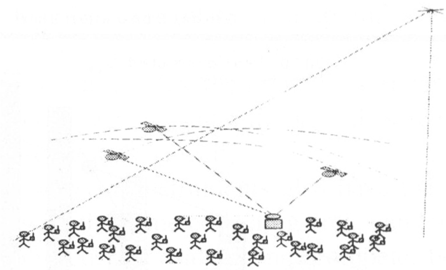

Figure 2. Array of personal communication devices.

3. Post-SKA Radio Astronomy: 50 Years Ahead

Let us attempt to extrapolate from present-day radio astronomy to the middle of the next century by examining the general trends. How big might future instruments be? As has been noted by many radio astronomers, all the main parameters of the instruments improve exponentially with time, and nano-arcsecond resolution with 10^9 m^2 telescopes are projected (see Figure 2). In the microwave band, this resolution may require an 'ecliptic array' (see later). It is not clear, though, how to get a billion square metres of collecting area – it would cost quite a substantial fraction of the 'civilization budget' (i.e. the global wealth). It would be impossible even to ask for so much money solely for a scientific project. It *is* possible to ask for this funding if the very existence of civilization depends on a project of this type (e.g. to avert invasion from other civilizations, asteroid hazards etc.), but we shall not consider these cases. At present there are no proposed projects in this class, with 10^9 m^2 of collecting area. We suggest that two approaches may be used: (i) private facilities of our civilization (ii) natural bodies, lenses etc. Let us explain what we mean. At present radio astronomers exclusively use facilities which have been constructed specifically for radio astronomy. Let us call these 'dedicated facilities'. TV-sets and communication facilities we shall call 'private facilities'. We are currently witnessing life-style and technological revolutions in these fields. Leading companies in the new industries predict that the number of personal communication devices, interconnected with each other and integrated with the global computer network, will expand so quickly that it will soon approach the global population figure. The latter is predicted by the same companies, and will amount to about 20×10^9 in the year 2020. With a dipole antenna in each device, the global potential may be as great as 10^9 m^2.

What should be done to combine all of these devices in a coherent array? One simple and attractive idea is to use an array of personal communications devices with GPS (Global Positioning System) and low-noise embedded receivers. Such a system would be completed by data recording hardware – a few GigaBytes in a flash memory chip might be sufficient – and access to data could be facilitated via embedded Internet servers. Many individuals will want such a device for personal,

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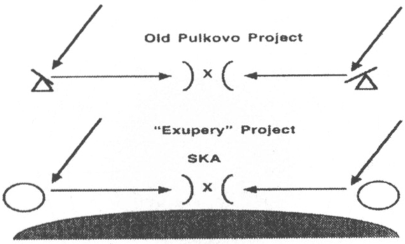

Figure 3. SKA and 'asteroid interferometry'. Collection of the signal from first Fresnel zones, formed on two asteroids by a distant source, with multi-beam SKA instrument. Upper sketch – ground-based analog.

portable network access and storage. Communication rates of a few megabits per second will be available via low Earth orbit satellites (aimed primarily at TV and multimedia applications but nevertheless useful for astronomy).

A central processing station could acquire data from all antennas accessible over the network, and combine these signals (making use of the GPS-derived position information), to generate an image of the radio sky. Thus it may well be that the bulk of the hardware necessary for radio astronomy in the future will be available as a matter of course, driven by the desire for powerful personal communication systems. In combination with dedicated radio telescopes, such as FAST and SKA, private facilities with dipole antennas (all sky field of view!) can be used to create a high resolution, high sensitivity, high dynamic-range global observing system, just by introducing the proper phase lags and amplitude weighting in the correlations. Standard reference-source methods can be used. It is possible that China, with FAST and with a well-organized society of around 1.5 billion people in the next decade, could be a pioneer of this very promising technique.

With SKA-type instrumentation, we can consider expanding the facilities by incorporating other solar system bodies into a phased array. Two particular suggestions are offered here. The first of these is connected with last year's Russian 'Asteroid Hazard' project, where it was suggested that several tons of dipole communication devices could be boosted into the solar system to cover the surfaces of asteroids with active point emitters (about 10 per object). VLBI monitoring would then allow extremely accurate prediction of the asteroid orbits. Here we just transform this suggestion and propose to use the same kind of dipole devices to sample cosmic signals and transmit them to Earth. With SKA-type multi-beam systems we can collect all this information and have all-sky monitoring of cosmic events.

A second way of utilizing the solar system geometry is to use the first Fresnel zones of the solar system bodies as dishes in space and, again with SKA, employ them in a phased array. Let us remind you that the United States' intelligente services proposed to use the first Fresnel zone of the Moon to detect secret conver-

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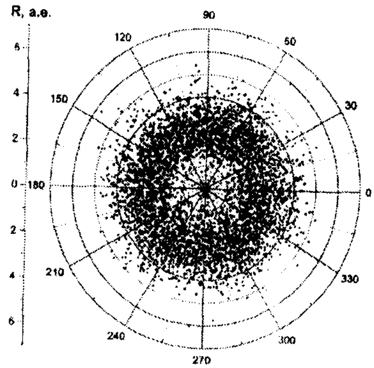

Figure 4. Ecliptic 'Fresnel zones' array of all known asteroids. For such an array, the nearfield zone, i.e. distances less than D^2/λ, may be greater than the size of the Universe (c/H_o), and three-dimensional imaging of the cosmic emission is possible.

sations in the USSR, during the cold war (Figure 3). Now we propose to listen to the Universe as a whole! There are more than 5000 asteroids in the solar system, and they are distributed very nicely across an aperture of order 10 AU. If this technique were used, then high resolution, high dynamic-range, *three-dimensional* mapping of cosmic sources could be undertaken (Figure 4).

With this system, the entire Universe is in the near-field zone at centimetre wavelengths, and two new effects are anticipated:

1. Direct trigonometric distances may be found for all point sources up to the Hubble distance (c/H_o) (Parijskij, 1969; Parijskij and Stotskij, 1972).
2. Scattering effects have to be considered because the aperture may be larger than the 'Fried scale' (i.e. the field coherente scale). Standard VLBI techniques work in this regime, because the site of the individual mirrors is smaller than the atmospheric Fried scale, and simple reference wavefront techniques can restore the image (Parijskij, 1991). For this technique to work, at least one antenna has to be large, and in our case it is the Earth-based SKA.

References

Esepkina, N., Korolkov, D. and Parijskij, Y.: 1973, Radio Telescopes and Radiometers, *Nauka* **368**, Moscow.

Khaikin, S., Kaidanovsky, N., Esepkina, N., Korolkov, D., Parijskij, Y., Stotsky, S., Shakhbazian, Y., and Shivris, O.: 1967, *Izvestia GAO* **N182**, 235.

Parijskij, Y.: 1969, *Ph.D Thesis*, Leningrad,

Parijskij, Y.: 1991, *Frontiers of VLBI*, Universal Academy Press, pp. 221–223.

Parijskij, Y. and Stotskij, A.: 1972, *Izvestia GAO* **188**, 195.

Parijskij, Y. and Tsiboulev, P.: 2000, *Astron. Astroph. Tr.* **19**, 287.

Pinchuk, G., Majorova, E. and Berlisev, I.: 1995, *ASP Conf. Series* **75**, 163.