An international telescope for radio astronomy

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The successful design of 45-m diameter dishes for the Giant Metrewave Radio Telescope (GMRT) at a relatively modest cost using the SMART concept, which incorporates stretched mesh attached to rope trusses to form the reflecting surface, gives us sufficient confidence to project the possibility of a much larger International Telescope for Radio Astronomy (ITRA), consisting of about 160 dishes of about 75 m diameter each, for investigating a variety of outstanding astrophysical problems. Some of these problems can only be studied in the decimetre- and metre-wavelength region of the electromagnetic spectrum. ITRA could be located at a suitable site that has low winds, no snow and low man-made radio-frequency interference, in South America, Africa or Australia.

Over the last few decades, many dramatic improvements have been made in the capabilities of radio telescopes, which have increased our knowledge about the Universe a great deal. However, while the angular resolutions of the radio telescopes have increased a million-fold, there has hardly been any significant increase in their collecting area.

Any major breakthrough in the development of a new scientific instrument takes place generally due to a pressing scientific need, e.g. desire to solve important astronomical issues. We believe that this is the case now: a radio telescope operating in the decimetre- and metre-wave region with a sensitivity about 30 to 50 times higher than GMRT (see page 95 this issue), Arecibo[1] or VLA[2] will provide vital clues concerning the origin of the Universe, and the growth of density perturbations in the Universe that give rise to the formation of galaxies. Such a powerful telescope is also likely to result in many unforeseen discoveries.

In this paper, I discuss the scientific objectives, design considerations and estimated cost of a radio telescope with a collecting area about 15 times that of GMRT. Its system temperature can be about 1.5 and 3 times lower than that of GMRT at frequencies of 600 and 1420 MHz respectively, owing to higher efficiencies of the antennas and the use of cooled receivers. A multifrequency feed system could provide a near continuous frequency coverage, from about 25 to 1700 MHz, with additional feeds operating in the 2.2- and 2.7-GHz bands. The 2.7-GHz band could be the upper limit of the operation of the telescope at $\sim$30% efficiency. We may call the proposed instrument 'The International Telescope for Radio Astronomy' (ITRA) (*itra* means perfume or essence in Hindustani, and is derived from *attar* in Persian).

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Scientific objectives

Two of the most important astrophysical objectives of GMRT are (i) the detection of the 21-cm radiation of the neutral hydrogen in the early stages of the Universe before the formation of galaxies, and (ii) the detection of primordial gravitational radiation through accurate timing measurements of rapidly rotating pulsars. Even if GMRT succeeds in finding answers to these questions, a much more sensitive instrument would be required to unravel the mysteries of the Universe in greater detail. For this reason, and also to search for extraterrestrial intelligence (SETI), I proposed, in 1988, the possible construction of 1000 numbers of GMRT-type 45-m-diameter dishes[3]. Recently Wilkinson[4] has proposed the 'hydrogen array' consisting of 100 antennas of 113-m diameter to get a collecting area of 1 km^2 for a detailed study of neutral hydrogen clouds in nearby galaxies as well as in distant parts of the Universe. As noted by him, the 'encyclopedia of the Universe is written in the small (weak) 21-cm typescript, to read which one requires a very sensitive telescope'. Such a telescope will allow detailed mapping of both continuum and line radiations from galaxies located up to a redshift of about one. Studies of the intergalactic clouds, interacting galaxies, radio galaxies, quasars, deuterium line and recombination line emission, pulsars, stellar radio emission, supernova remnants, HII regions and our solar system are also likely to yield many new and exciting results.

Array configuration and antenna system

To satisfy the requirement of some of the major scientific objectives of ITRA, e.g. study of diffuse features in our galaxy and in radio galaxies, studies of HI emission or absorption lines in galaxies and search for protoclusters and protogalaxies, we need to achieve quite a high sensitivity but a relatively modest resolution, say a few arcmin at 327 MHz or ~20 arcsec at 1420 MHz. For many other programmes resolutions of up to 0.1 arcsec are required. Therefore it may be preferable to place 60, 15, 15 and 10% of the antennas within about 2, 10, 25 and 200 km respectively. The central 2-km array may be chosen to be a random circular array in order to provide nearly uniform coverage of spatial frequencies. The outer array may consist of 3 arms in the form of a 'Y'. A Y-shaped array provides a reasonably good spatial frequency coverage and, further, the optical-fibre links can be used economically to interconnect all the antennas. However, the arms need not lie along straight lines and can deviate appreciably to suit existing terrain and approach roads.

Since the maximum frequency of ITRA will be about 2 GHz, it will be sufficient to use wire mesh for the reflector surface of the antenna, which will minimize wind loads on the antenna. For the 45-m dishes of GMRT, the SMART (*s*tretched *m*esh *a*ttached to *r*ope *t*russes) concept has been adopted to minimize the cost of the antennas. The dish is placed on a 3.6-m-diameter slew ring bearing, which is mounted on a reinforced-concrete tower. The reflecting surface consists of 960 plain facets. The expected weighted r.m.s. error of the surface is about 1 cm. The basic concept of this design seems to be well suited for the antennas of the proposed ITRA. However, for improving the efficiency of the antennas at 21 cm and for the sake of economy, the design could be further optimized in several respects, such as (i) by adopting the homologous principle for the back-up structure and also optimization of its shape and design; (ii) a more elaborate rope-truss system to allow a better approximation to the curved surface; (iii) using a wire mesh made of half-hard stainless steel wires instead of the annealed wires used for the GMRT wire mesh, so that a smaller spacing of wire mesh can be used to cut down the leakage of the radio waves through the wire mesh; and (iv) using a wheel-and-track mount which would be economical.

What it will cost

Since the cost of a parabolic dish of diameter d is proportional to d^k, where k is 2.5 to 2.7, its cost increases rapidly with the diameter. But a larger antenna has a narrower field of view, which is of considerable advantage at the longer wavelengths, since the ionospheric variations are smaller across the field of view of the antenna. On the other hand, smaller antennas will require more complex electronics. Hence the number and diameter of the dishes must be optimized suitably. We may estimate the cost of n dishes of ITRA of diameter d, including the associated electronics, by extrapolating the cost of 30 numbers of 45-m-diameter dishes of GMRT as follows:

$$\text{Cost} = K_1 (n/30)(d/45)^{2.5} (v/v_0)^2 + K_2 (n/30) + K_3 (n/30)^2 + K_4 + K_5 + K_6$$

where $K_1 \ldots K_6$ are the cost of 30 parabolic dishes, associated electronics system including FFT engines of a FX-correlator, cross-multipliers and integrators, computer system, array operation centre, and salaries of technical and administrative staff including overheads, respectively. For GMRT $K_1=14$, $K_2 \simeq 3$, $K_3 \simeq 0.2$, $K_4=2$, $K_5=2.5$ and $K_6=2.3$ million US dollars at the prevalent (1990) cost in India. The design wind velocity v_0 for a wind of 50-year return period at the GMRT site is 140 kmph at 10-m height. We assume $v=v_0$ for the ITRA site. For ITRA, we assume $(K_4+K_5+K_6)$ to be about 20% of the cost of n antennas and associated electronics, which will be of the order of \$70 to \$80 million and seems to be a fair estimate taking into account the higher labour cost in the Western countries than in India. An exponent $k=2.5$ is used because of the likely improvements in the design of the ITRA antennas. In Table 1 are given the estimated cost of ITRA at 1990 prices for several choices of dish diameters, assuming the total collecting area of ITRA antennas to be 15 times that of GMRT. It is seen that cost is nearly the same for dishes with diameter d in the range of about 50 to 75 m. Considering various factors, about 160 numbers of 75-m-diameter dishes may be a reasonable choice for ITRA. The detailed design would entail many trade-offs, e.g. the steerability of the dish may be restricted, particularly because wind speeds are appreciably higher at a height of 100 m than at 50 m. In any case, it seems desirable to achieve a steerability of at least ± 60°, preferably ± 75°, from the zenith.

Table 1. Approximate cost estimate of ITRA with total collecting area of about 700,000 m².

d(m)	45	60	75	90	105
Number of dishes	450	253	162	113	83
Cost (US\$, millions)	360	338	352	373	397

Conclusion

The proposed ITRA will be an extremely valuable instrument for investigating a variety of outstanding astrophysical problems. It is likely to yield many exciting discoveries. A suitable site, with low radio-frequency interference, low winds and no snow, is likely to exist in South America, Africa or Australia. The estimated cost of ITRA is about \$350 million at 1990 prices, which is relatively modest considering its tremendous scientific potential. I hope that the project can be initiated as an international collaborative effort, particularly by the European nations, starting from 1992, which has been declared as the International Space Year, the 500th year since the great voyage of Columbus. It will be a fitting tribute to the fraternity of the new European federation and its international outlook.

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Finding the finance

In 1963 four Indian astronomers then in the USA wrote to Bhabha, D S Kothari (Chairman of UGC) and Husain Zaheer enquiring whether any opportunity existed for beginning construction of some experimental facilities Only Bhabha replied Later two of the group actually arrived due to his encouragement (after Bhabha had 'ascertained that the members of the group had considerable original work and were of sufficient maturity to be able to work on their own in India) The group began with a small field station at Kalyan, utilizing a gift of 32 parabolic dishes from CSIRO of Australia lying unpacked for several years at NPL, New Delhi A site for a big telescope was then chosen in 1965, at Ootacumund, where TIFR had long maintained a laboratory for studies of extensive air showers at 6000 feet altitude. Bhabha hopefully predicted the telescope would be operating in 1968, but it was ready only in 1970 after overcoming engineering problems of great difficulty Bhabha had been advised by Swarup (the group leader) to expect a cost of approximately Rs 3 million However, Bhabha discovered that such an expenditure could be included only in the Fourth Five-Year Plan of the Government of India 'Until I arrived in Bombay, and until we had done something with the Kalyani dish, I didn t know what I'd do But I was sitting in the library, saw an interesting paper, began thinking of Arecibo and Greenbank, and then I began to get concrete technical ideas.' Bhabha solved this problem by searching in the provisions of the Third Plan for possible loopholes He found an adequate yet untouched sum under the heading 'inter-university centres' The ultimate cost of the telescope was about ten times the amount suggested as a memorial to Saha in 1957. That was not only the solution to financial problems (to avoid waiting) but also the beginning of the idea of a facility which would be shared among surrounding universities, as would be done in Calcutta with the VEC accelerator

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