THE HYDROGEN ARRAY

P.N. WILKINSON
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell
Bank, Macclesfield, Cheshire, SK11 9DL, United Kingdom

ABSTRACT   The time is ripe for planning an array with a collecting
area of 1 km² (14 times larger than Arecibo and 75 times larger than
the VLA). In view of its major astronomical target I have dubbed this
concept 'The Hydrogen Array', although 1μJy continuum sources will
also be reliably detected. I present some initial thoughts about the issues
involved.

INTRODUCTION

Since the late 1960s radioastronomers have increased the capability of their
instruments many fold. The maximum resolution achieved with interferometry
has increased from $\sim$ 50 milliarcsec to $\sim$ 50 microarcsec; the highest frequency
in use has gone from $\sim$ 10 GHz to > 350 GHz and the aperture plane coverage
has improved from that of the One–Mile Telescope to that of the multi-
configuration VLA. However, in terms of raw sensitivity the improvement has
been less dramatic. The Arecibo telescope remains the world's largest and
the improvements to system noise temperatures at decimetric and centimetric
wavelengths have been relatively small ($\leq$ 5). Despite its limitations in sky
and frequency coverage, the scientific output of the Arecibo telescope amply
demonstrates the advantage of a collecting area 5–10 times larger than that of
the largest steerable parabaloids.

Swarup and colleagues have been stressing the advantages of large collecting
areas at low frequencies for over twenty years. They are now constructing
the Giant Metrewave Radio Telescope (GMRT – Swarup, this volume) which
is essentially a 'pointable Arecibo' working up to L–band. Pariskii (this
volume) discusses the trend of collecting area with time and points out that
an instrument with an area of 10^6 m² is now required if we are to keep up with
the progress made by the pioneers. I arrived at a similar conclusion in 1985
from the following argument: the VLA and the WSRT can only image in HI
with a resolution of $\sim$ 10 arcsec; to allow imaging at the much more useful
resolution of 1 arcsec requires a telescope with $\sim$ 100 times the collecting area.
The reaction of colleagues at this conference to this idea convinced me that we
should begin to think in earnest about a telescope with a collecting area of 1
km².

The first task is to establish a clear set of scientific goals. To my mind one goal stands out – a volume of the 'Encyclopaedia of the Universe' is written in 21cm typescript. Unfortunately the printing is rather faint and we need a large 'lens' to read the text! Hence the reason for dubbing the proposed instrument, 'The Hydrogen Array' or HIA for short.

SCIENTIFIC GOALS

Neutral Hydrogen Observations at z=0 to z=10:   With a collecting area of 1km^2 the HIA could image nearby galaxies with a resolution of 1 arcsec. The detailed measurements of the HI distribution at this resolution would provide exciting new information on star formation, density waves and the amount and location of dark matter in individual galaxies. Some rotation curves are still flat where the surface brightness limit of current telescopes is reached. The HIA could detect galaxies > 4 times further away than Arecibo i.e. out to z=0.1–0.2 (500–1000 Mpc). Integrated HI observations of these galaxies will better constrain the value of H$_o$ via the Fisher–Tully technique. Deep HI redshift surveys would then measure the departures from the local Hubble flow and hence constrain the matter distribution on large scales (the 'Great Attractor' debate). Studying the kinematics of many more clusters and groups of galaxies will also constrain the total (visible+dark) matter content of the Universe. HI can be studied in absorption against background quasars out to z>4 with the HIA. Several quasars show Lyα spectra which indicate column densities $\geq 10^{20}$ cm^{-2} which should readily be detectable. Observations in the redshifted HI line will provide information on the structure and kinematics of the absorber which cannot be obtained in any other way. Finally a search for redshifted HI in emission at z=3–10 will confront theories of galaxy formation following the era when the ionised gas combined to form HI. Observations with the HIA will be able to detect HI masses in the range 10^{12} M$_\odot$ to 10^{13} M$_\odot$.

Pulsar searches and timing: The HIA would be an exciting instrument for finding and studying pulsars, particularly millisecond ones, many of which have been found in globular clusters. The current searches with 70m class telescopes have found up to 7 pulsars in a cluster, a telescope > 100 times more sensitive would likely find an enormously larger number. Such a survey would place useful limits on the number of neutron stars in a cluster – a valuable constraint on the end–point of stellar evolution. The HIA will not only be able to find more pulsars it will also enable them to be studied in much greater detail. The accuracy of pulse timing on millisecond pulsars is limited by the achievable signal–to–noise ratio, even with Arecibo. Nevertheless timing of a few rapid pulsars in binary systems has yielded evidence for gravitational radiation and measured the absolute masses of the binary components. The periods of some isolated millisecond pulsars are extraordinarily stable. As well as producing a flood of new pulsars to study individually, an ensemble of millisecond pulsars could provide the most stable clock known to mankind. And a comparison of their periods could reveal the passage of long-wavelength gravitational radiation. Finally pulsars have already been detected in the Magellanic Clouds; with the > 100 times greater sensitivity of the HIA it will be possible to detect pulsars in Local Group galaxies.

<u>Continuum Sources</u>: If T_{sys} = 25 K at ~ 1400 MHz and the total bandwidth is 2 × 50 = 100 MHz then the 1σ noise level of the HIA after a four hour integration will be just over 0.1μJy; 1μJy sources will therefore be reliably detected. With this sensitivity many observing programmes suggest themselves. For example: i) The extension of the radio luminosity function to very faint sources; do new populations of source exist? ii) How many normal galaxies have compact sources in their nuclei? VLBI between HIA and a 70m class telescope would pin–point those galaxies with milliarcsec nuclear structures; the results would constrain the frequency of occurence of black holes in galactic nuclei. iii) Extragalactic supernovae could be detected ~ 10 times further away than is currently possible in the radio. VLBI observations with the HIA would enable radio 'hypernovae', such as 41.9+58 in M82 and SN1986j in NGC891, to be studied out to > 500 Mpc iv) A large number of stellar systems would be detectable with the HIA; almost certainly new types of stellar radio source would be found. Note, for example, that the quiescent flux density of the Sun at L–band would be ~ 1μJy at a distance of 5 pc; the flaring Sun could be detected ten times further away.

<u>Other Targets</u>: HIA could extend the study of OH mega–masing, in those galaxies currently undergoing the greatest amount of star formation, out to z=0.2–0.3. HIA would have about one tenth the area eventually envisaged for project Cyclops. It would have obvious interest for the SETI community.

TECHNICAL CONSIDERATIONS

Array designs need to trade off cost, collecting area, primary field–of–view, complexity of electronics and imaging speed. In view of the frequency flexibility required for the scientific programme outlined above, dish antennas are preferred despite their relatively high unit cost compared with cylindrical antennas. The GMRT designers opted for parabaloids for this reason, and because of the additional data processing problems associated with cylindical elements (e.g. Gray, this volume).

<u>Antenna Specification</u> With an antenna diameter of 50 m (similar to GMRT) over 500 antennas would be required for a collecting area of 1 km². With a diameter of 113 m only 100 antennas are needed; this would reduce the amount and complexity of the electronics. In order to keep the overall cost to within reasonable bounds (which I arbitrarily set at around $300M – comparable with the cost of the ESO VLT optical array) the unit cost of a 113m antenna must therefore be around $2–2.5M. The unit cost of the fully-steerable 45m antennas of the GMRT is $0.5M; applying a (diameter)$^{2.7}$ law leads to an estimated cost of $6M for a 113m antenna, even with the low labour costs in India. Some reduction in capability over the 45m design may have to be accepted, even allowing for the greater economy of scale inherent in the HIA. The obvious parameter to relax is sky coverage but a range of ±30° in zenith angle is the minimum acceptable. On the other hand the design must provide full aperture efficiency at L–band, whereas the GMRT design has reduced efficiency above ~ 1 GHz. Innovative thinking is clearly needed here. A start might be made with the SMART concept pioneered by Swarup and

colleagues, with the parabaloid mounted on (or in) a rotatable frame, low to the ground to minimise wind loads.

Array Configuration   The HIA will operate at long wavelengths (for highly redshifted HI), where the rfi environment is likely to be hostile; it should therefore be capable of producing images quickly. Circular arrays, pioneered by Wild and studied in detail by Cornwell for the mm-wave array, seem attractive for this reason. The antenna locations must be fixed to minimise cost and the overall dimension of the array must be $\sim$ 40km to give 1 arcsec resolution at 1420 MHz. A few more distant outriggers would extend the capability of the array for continuum work; for the latter work the array should be designed to make maximum use of multi–frequency synthesis (Conway – this volume). For pulsar observations, a central compact array containing a significant fraction of the collecting area would be needed. With an overall dimension of 1km the compact array would have $\sim$ 100 synthesised beam areas within the primary beam. For pulse searching each beam would need to be treated as an output from a separate telescope. The estimated data rate is not excessive for the computers of the 1990s.

Location: One of the prime considerations when deciding where to build the HIA will be the rfi environment. There is much science to be accomplished outside the protected bands, most obviously for observing neutral hydrogen at $z > 0.015$. This seems to rule out Europe and the USA; snow militates against remote Canadian sites. For pulsar work one needs a good view of the galactic plane. A site in India would have the advantage of low labour costs for construction, but the rfi environment will be degraded as Indian industrialisation proceeds. The Australian outback sounds promising (pulsar searches at Parkes routinely use a bandwidth of $\sim$ 300 MHz at L–band) but then there are not as many telescopes with which the HIA could do VLBI.

WHAT NEXT?

I have sketched in a few ideas. I propose that interested parties contact me and we will try to take these, and many other, issues further. In the first instance I am prepared to act as a clearing house for an email discussion about the HIA. My email addresses are: SPAN 19739::PNW; BITNET PNW@UK.AC.MAN.JB.STAR.

ACKNOWLEDGEMENTS

G. Swarup: (comment) The major question is to identify some outstanding science objectives - or the "science - drivers" as suggested by you. The antenna design aspects would depend on the above, whether it should be a one square kilometer array or a 100 kilometer long array. Antenna cost can be kept low by identifying sites with low wind etc.

Peter Wilkinson: I couldn't agree more - we must first address the science and the rest will follow!