Science with the xNTD

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1 Introduction

This document assumes the following parameters for the xNTD telescope. A total 20 dishes making up 4000 m^2 of collecting area. A system temperature of 50 K, and a field of view (FoV) on the sky of 50 square degrees at 1.4 GHz. The operating frequency range will be 0.7 - 1.7 GHz, possibly extending up to 2.4 GHz. The instantaneous bandwidth will be 256 MHz with up to 16000 frequency channels across the band. This document should be considered as a draft science case which will undergo modifications as the technical specifications become better known.

The large FoV makes the xNTD primarily a survey telescope. Although it has a slightly larger collecting area than Parkes, its uncooled receivers reduces its raw sensitivity. In terms of surveys however, it gains by a factor of 3 in line sensitivity and a factor of 8 for continuum surveys compared to the multibeam surveys.

As an interferometer it also provides low frequency imaging not otherwise available at the ATCA. It also exceeds the ATCA sensitivity at 1400 MHz on baselines shorter than 1 km. It is therefore ideal for moderate angular resolution imaging of large galactic structures (e.g. supernova remnants). There are several issues as regards the configuration and maximum baseline length. The detection of H I from galaxies requires a resolution no less than 15 arcsec (baselines less than 3 km). Galactic H I requires good surface brightness sensitivity, and, given the collecting area the optimum baseline length is around 750 m yielding a 45 arcsec beam. Finally, the all-sky continuum survey ideally requires long baselines to avoid confusion but not too long that sources get resolved. The NVSS and SUMMS both have a 45 arcsec beam at their respective frequencies (see the arguments in Condon et al. 1998).

A further important application of the xNTD is for Very Long Baseline Interferometry (VLBI), especially if it is located in Western Australia. The xNTD would then provide significant collecting area on east-west baselines of $\sim$3000 km.

As detailed below, the xNTD is a very powerful telescope in its own right. It is highly flexible and can be upgraded to larger collecting areas relatively easily.

2 Extra-galactic H I surveys

A 2-yr survey for H I galaxies over the whole sky with the xNTD would be complete to z=0.07, 3

times the distance of the Parkes survey. A deep survey would yield several hundred galaxies at z=0.3.

An extra-galactic survey of the entire sky contains valuable information on the distribution of galaxies, the H I mass function, the dynamics of groups and the frequency of dwarf galaxies. Such a survey is unbiased in terms of tracing large-scale structure, especially as it can detect galaxies optically hidden behind the plane of our own Galaxy.

The recently completed Parkes Multibeam (HIPASS) survey detected 4500 galaxies in H I over the entire southern sky with a median velocity of 4500 km s^{-1} (Koribalski et al. 2004; Meyer et al. 2004). The large beam of the Parkes telescope meant that many sources are confused, and identification with optical galaxies was difficult. This resulted in substantial follow-up time using the ATCA to obtain high resolution images and hence accurate positions. A survey with the xNTD would need to go significantly deeper than HIPASS to make a scientific impact. The xNTD survey would have arcmin resolution, obviating the need for follow-up observations.

The relative sensitivity of the xNTD is 3.3 times better than that of the Parkes MB (HIPASS) survey and roughly equal with the Arecibo MB survey. The HIPASS survey nominally covered the entire southern sky in 150 days of telescope time. As the xNTD survey needs to go substantially deeper than HIPASS, it is envisaged that a survey would require 2 years of telescope time. Extrapolating from the HIPASS completeness limit (which is a factor 2 higher than the nominal sensitivity), the xNTD survey would be complete out to z=0.07, and 25% complete to z=0.1. However, many of the problems associated with the single dish HIPASS survey would be reduced by using the xNTD as an interferometer which should increase the completeness to faint galaxies. Scaling from Briggs (1999) we might expect 1 galaxy per square degree at z=0.1, yielding a total of several thousand such galaxies in an all-sky survey.

As noted by several authors, going to high redshifts really requires very large collecting areas and/or very long exposures. Briggs (1998) estimates a detection rate of 1 galaxy per square degree per 20 MHz of bandwidth at z=0.3 for a survey which can attain 0.2 mJy detection thresholds. This limit requires 35 days of integration time with the xNTD! However, a 100 day survey would cover 150 square degrees of sky and then yield a few hundred galaxies near z=0.3, providing that the sensitivity continues to decrease with time over such a long exposure.

3 Survey for OH megamasers at z=1

The xNTD would detect 1000 OH megamasers at z=1 in a 100 day survey.

OH megamasers are found in galaxies with the highest far-infrared (FIR) luminosities. In turn, these highly luminous FIR galaxies likely originate from strongly interacting or merging galaxy systems. Was the merger rate greater in the past than it is today, and if so, how does the merger rate change as a function of z? One way to answer this question is to search for OH megamasers in high z objects; the preponderance of the masers then potentially yields information on the merger rates of galaxies.

The xNTD makes an ideal instrument to survey for OH megamasers around z=1 in a blind survey. Darling & Giovanelli (2002) argue that with a 3 σ sensitivity of 0.25 mJy one should expect to find a few OH megamasers per square degree per 50 MHz bandwidth interval. To achieve this sort of sensitivity requires 5 days of xNTD time. A 100 day survey would cover 1000 square degrees and could potentially discover more than 1000 OH megamasers at z=1.

4 Continuum imaging and monitoring

The xNTD can achieve NVSS sensitivity over the whole sky every day. It will provide huge advances in understanding the variable sky.

The xNTD can see 30,000 square degrees of sky. In 1 day, the xNTD would have an effective integration time of 75 seconds on each sky pixel (assuming a hexagonal grid pattern to achieve uniform sensitivity), with a 5-sigma detection limit of 2.0 mJy. This is almost identical to the NVSS survey which detected more than 10^6 objects in a survey which took 75 days of VLA time (Condon et al. 1998). Repeated observations would reduce the sensitivity limit in total intensity down to the confusion limit of 0.08 mJy (assuming a beam size of 45 arcsec). However, the polarization confusion limit is significantly lower than this making searches for polarization variability viable.

For searching for fast variable sources (either Intra-Day Variables (IDV) or X-ray transients) one could envisage observing the entire sky every day and searching for variability. With a 5σ rms of 1.0 mJy and this would yield variability at the 1% level for 100 mJy sources and at the 10% level for 10 mJy sources on a daily basis. This is similar to the levels recently achieved in the (targetted) MASIV survey (Lovell et al. 2003) which has now found more than 150 variable sources out of 700. However, with 17 sources per square degree above 10 mJy in the sky (Blake et al. 2004), the xNTD variability survey would revolutionise our knowledge in this domain.

The most interesting sources show variability on timescale of hours or less. Follow-up of these sources ideally requires dedicated time on an instrument capable of observing up to 10 GHz.

5 Galactic H I surveys

A high resolution, high sensitivity survey of the galactic H I could be completed in only 40 days. Deep imaging of mid-latitudes to search for high velocity clouds would also be possible.

The recently completed southern galactic plane survey (SGPS) used the ATCA to image the galactic plane with 2.6 K rms (in the line) at a spatial resolution of 2 arcmin and a velocity resolution of 0.8 km s^{-1} (McClure-Griffiths et al. 2001). The survey covered 100 degrees of galactic longtude and 3 degrees of latitude and took 40 days of observing time.

It would be extremely useful to repeat this survey with a factor of 3 better resolution. This would be ideal for applications like HI absorption, tracing the small scale turbulence, and studying the interaction of SNRs and HII regions with the gas. The mapping speed of the xNTD at this resolution is about 3 times better than achieved with the ATCA for the SGPS survey and hence a survey with twice the sensitivity and 3 times the resolution could be completed in the same length of time as the orginal SGPS.

At high galactic latitudes, a deep survey is necessary to unveil the structure of the interstellar medium, with an rms of at least 100 mK required. The impetus for such a survey would be to determine whether the halo is made up of discrete structures (clouds) or whether it is generally smooth. Also, high latitude surveys would likely detect many high velocity clouds, whose nature still remains unclear. Currently, an all-sky survey with the Parkes multibeam is being carried out to this depth but at low angular resolution. Follow-up work of interesting regions of the sky at higher angular resolution would be an ideal project for the xNTD. The xNTD can cover the sky at 2.0 square degrees per hour to a sensitivity of 100 mK and a survey which lasts for $\sim$ 40 days could therefore cover 2000 square degrees at a resolution of 2 arcmin.

6 Pulsar surveys

In a 120 day survey, the xNTD could detect 5000 pulsars and 500 millisecond pulsars.

Large-scale pulsar surveys are required to find exotic and rare objects, as witnessed by the discovery of a binary pulsar-pulsar system in late 2003 (Burgay et al. 2003; Lyne et al. 2004). Timing of pulsars in binary systems provide stringent test of gravity in the strong field limit, and timing of millisecond pulsars aims to detect gravitational waves from merging black holes in the distance universe. The current shopping list for pulsar searchers includes a pulsar-black hole binary system, pulsars in the Galactic Centre, millisecond pulsars and sub-millisecond pulsars.

We have used simulation codes to predict the number of pulsars which we detect in a survey of duration 120 days, covering 30,000 square degrees. This yields a sensitivity a factor of 2 better than the Parkes MB survey of the galactic plane and a factor 7.5 better than any all-sky survey yet undertaken. We estimate a total detection of 5000 pulsars of which 500 would be millisecond pulsars.

However, all the above is predicated on being able to coherently add the collecting area and pixelise the primary beam. This implies enormous data rates from the back end, about two orders of magnitude larger than we can cope with today. It is not clear if or how this problem can be overcome in the short term.

7 Polarization and Cosmic Magnetism

The origin of magnetic fields in galaxies and galaxy clusters remains an open question and a key science driver for the SKA. The xNTD can make a start on determining rotation measures for a large number of extragalactic sources, and provide tomographic imaging of small scale structure in the Milky Way.

The large instantaneous bandwidth of the xNTD enables the rotation measure and position angle of polarized radiation to be measured relatively easily (although ionospheric effects will be important below 1 GHz). Both the all-sky continuum survey and any spectral line surveys would provide polarization information as a natural by-product.

Small scale structure and turbulence in the Milky Way can be probed using Faraday tomography in which foreground gas produces complicated frequency dependent polarization features when viewed against the diffuse background emission. Observations in slices of say 100 MHz from 800 - 1800 MHz would then provide a complete 3-D imaging of the small scale structure in our local neighbourhood. The mapping speed superiority over the ATCA means that most of the southern galactic plane could be imaged in this way.

8 VLBI

The Australian VLBI network will be upgraded with the move to 1 Gbit/s links between the telescopes in the near future. This will enable bandwidths of up to 128 MHz to be used rather than the 20 MHz in use today. A large collecting area telescope in WA would provide a further significant upgrade to the Australian VLBI network. This drives the top end of the frequency range of the xNTD to 2.4 GHz. Although the resolution provided by the long baselines to the xNTD is significantly better than that obtainable currently at 2.4 GHz, it is roughly equivalent to the current resolution available with the Ceduna baselines at 4.8 GHz.

There are two science cases to be made at frequencies near 2.4 GHz. The first is pulsar proper motions. Because pulsar spectral indicies are generally steep, low frequencies are best if good resolution can be obtained. Brisken et al. (2000) using the VLBA, has developed techniques for dealing with ionospheric effects at low frequency and has successfully measured a dozen or so pulsar proper motions with up to 100 pulsars planned for the near future. Using the east coast telescopes plus the xNTD could result in proper motions being obtained for several tens of pulsars in the southern hemisphere (cf only 6 now).

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