

# The EVLA: Prospects for HI

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**Abstract.** To continue the unparalleled success of the Very Large Array (VLA) for radio astronomy, the facility is currently being converted to become the ‘Expanded VLA’ (EVLA). The EVLA will radically improve the VLA in order to cover the full 0.93 – 50 GHz radio wavelength range without gaps, provide up to an order of magnitude better sensitivity, and to allow observations at much larger bandwidths and spectral resolution as currently possible. For observations of the 21 cm line of atomic neutral hydrogen (HI), the EVLA offers thousands of  $\text{km s}^{-1}$  velocity coverage at sub- $\text{km s}^{-1}$  resolution for targeted observations as well as an improved spectral baseline stability. In addition, every L-band (21 cm) continuum or targeted HI observation can be set-up to simultaneously observe a full  $z = 0 - 0.53$  HI redshift survey at a velocity resolution of a few  $\text{km s}^{-1}$ . In turn, every HI observation will also yield deep radio continuum images of the field. These synergies will deliver a wealth of data which opens up a wide ‘discovery space’ to study the details of galaxy evolution and cosmology.

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## INTRODUCTION

The Very Large Array (VLA) has played a key role in exploring the radio Universe for almost three decades. To continue the unparalleled success of this facility, the VLA is currently undergoing a drastic rejuvenation process to become the ‘Expanded VLA’ or EVLA. The conversion is very comprehensive and comprises additional and upgraded receivers, new broad-band fiber optics, new online control systems, new digital electronics, and a state-of-the-art correlator called WIDAR (Wideband Interferometric Digital Architecture). The upgrades will not only improve the continuum sensitivity by about an order of magnitude largely due to a substantial increase of instantaneous receiver and correlator bandwidth, but they will also provide extreme spectral resolution and a wide coverage of the radio spectrum – for the first time it will be possible to observe at any chosen frequency in the entire 1 – 50 GHz radio window.

The EVLA specifications and its current status is described on its webpage<sup>2</sup> [see also 1]. With its unparalleled sensitivity the EVLA is a true pathfinder for the Square Kilometer Array (SKA). Even the EVLA’s mapping speed matches that of special-

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<sup>2</sup> <http://www.aoc.nrao.edu/evla>

purpose, ultra-wide field but lower sensitivity and narrow band SKA pathfinders like ASKAP, ATA, or MEERKAT in their early incarnations.

One of the fields of astronomy that the VLA pioneered is the observation of atomic, neutral hydrogen (HI) in our Milky Way, in nearby galaxies and the intragroup medium, as well as at higher redshifts. Those observations revealed the complex properties of the neutral ISM, its importance on star formation and the physics of the interface between a galaxy's disk, its halo and the intergalactic medium. The abundance of HI and its 21 cm line properties also proved to be indispensable tools to derive the complex dynamics of galaxies in the form of, for example, density waves, rotation curves (and thus the dark matter distribution), tidal interactions, and mergers of galaxies. In this article we like to summarize what EVLA offers for future HI observations.

## EVLA RECEIVERS FOR HI OBSERVATIONS

The HI hyperfine line rest frequency of  $\sim 1.420$  GHz falls into the radio L-band. The VLA L-band receivers cover a frequency range of 1.25 – 1.8 GHz. The EVLA receivers will widen this to 0.93 – 2.1 GHz. At the lower end this will increase the HI redshift coverage from a current upper limit of  $z \sim 0.14$  to  $z \sim 0.53$ . This is an improvement of almost  $\Delta z \sim 0.4$  or an additional  $\sim 3.5$  Gyr of look-back time (in a WMAP  $\Lambda$ CDM cosmology). The system temperature over telescope efficiency  $T_{\text{sys}}/\epsilon$  of the EVLA is expected to decrease from  $\sim 75$  K to about 60 K or less ( $T_{\text{sys}}$  of the EVLA is designed to hover around  $\sim 26$  K), saving about 30% of integration time to reach the same sensitivity.

The old VLA L-band feedhorn design featured a microwave lens in the optical path. With the redesigned EVLA receivers, this lens is not required anymore. Thus, ground radiation scattered by the lens (and other structural dish elements) into the feedhorn is largely reduced and the EVLA L-band system temperature improves substantially over the VLA at lower elevations; at an elevation of  $\sim 20^\circ$  the EVLA system temperature is about half that of the VLA which corresponds to a four fold increase in sensitivity.

As part of the EVLA conversion, the L-band receivers will be equipped with new orthomode transducers. Until they become available for all antennas in 2012, an interim L-band system is currently being installed (with a slightly lower sensitivity and a minimum frequency of 1 GHz, corresponding to  $z \sim 0.42$ ). For more information on the performance of the EVLA L-band system upgrade and performance, we would like to refer to the EVLA webpages and also to Emmanuel Momjian's contribution [2].

At lower frequencies the EVLA offers a P-band receiver which covers frequencies of 300 – 340 MHz equaling an HI  $z \sim 3.2 - 3.7$  redshift range. This band remains unchanged in the VLA to EVLA conversion. The system is not sensitive enough to observe typical, gas rich galaxies at the available redshift in HI emission. However, searches for HI absorption in P-band have been conducted in the past [e.g. 3] and are still an option for the EVLA.

## THE WIDAR CORRELATOR

Since the installation of the VLA correlator, Moore's law pushed processing speeds of computers by  $\sim 5$  orders of magnitude. Taking advantage of this, a new correlator, WIDAR, will be commissioned in 2008/2009. However, one should keep in mind that the current VLA correlator was designed to be very suitable for HI observations toward nearby galaxies. The bandwidth and resolution almost perfectly matches what is needed for such observations (bandwidth of  $\sim 200 \text{ km s}^{-1}$  at a resolution of  $\sim 5 \text{ km s}^{-1}$ ). But the VLA correlator design severely limits the amount of 'discovery space', e.g., very wide and shallow lines [for an example, see 4] would not be discovered with the VLA without prior knowledge of these features. The narrow bandwidth typically used for galaxies of  $\sim 1.5 \text{ MHz}$  has only few, supposedly line-free channels at the band edges. Any wide lines extending across these channels would not be discovered because they would be removed in the process of continuum subtraction. Another case of limited discovery space is that other HI sources in the field, e.g., companion galaxies, remain undetected with the VLA if they are at a slightly different velocity than the main target. At the other extreme, very narrow line features, e.g., caused by HI self-absorption are smeared out and would be missed in a typical extragalactic HI setup with its velocity resolution of a few  $\text{km s}^{-1}$ . To open up new discovery space, wide bands at high spectral resolution are desired. Such capabilities are provided by the new WIDAR correlator (for a description of the technology, see [5]). WIDAR will have a spectral resolution of down to Hz ranges and a bandwidth of up to 8 GHz. The full bandwidth is split up into four 2 GHz baseband pairs and in each baseband pair up to 16 independent sub-band pairs can be selected with bandwidths between 31.25 kHz and 128 MHz. The full 8 GHz baseband pairs have a *minimum* of 16384 channels which will always be available. Recirculation trades bandwidth for more channels and the maximum number of channels are of order 4 million. Such a flexible design will cover virtually any need for setups to observe HI in single targets with thousands of  $\text{km s}^{-1}$  bandwidth and sub- $\text{km s}^{-1}$  velocity resolution.

But the EVLA will be able to do more. The L-band receivers and WIDAR will cover the entire HI redshift range of  $z = 0 - 0.53$  at a resolution of  $3.2 \text{ km s}^{-1}$  when observed with two polarization products, and at  $6.4 \text{ km s}^{-1}$  when observed at full Stokes. Other configurations will be able to, e.g., stack multiple radio recombination lines in order to improve the signal-to-noise of Zeeman splitting experiments in a single observation.

## PIGGY-BACKING

The velocity resolution of a few  $\text{km s}^{-1}$  over the full 0.93 – 2.1 GHz L-band range enables new, unique synergies with other observations. Every EVLA L-band continuum observation will also be an HI redshift survey and vice versa. Also, virtually every targeted HI observation leaves enough computing power in WIDAR to once more perform a simultaneous HI survey over the entire  $z = 0 - 0.53$  range at good velocity resolution. As if this would not be enough, the minimum data dumping time for 1 GHz bandwidth L-band data is  $\sim 100 \text{ ms}$  which allows monitoring of and searches for transient sources in the field while simultaneously observing HI or radio continuum projects (but note that current data output limitations imposed by archiving are  $\sim 25 \text{ MB s}^{-1}$ , equaling to

dumping times of  $\sim 20$  s, when the maximum number of channels and baselines is read out). These are exciting new opportunities that will pave the way toward SKA HI surveys. For example, without spending any dedicated survey time, the  $z = 0 - 0.53$  redshift volume around a VLA standard calibrator will accumulate hundreds of hours prior to the commissioning of the SKA. This will provide very deep HI and radio continuum images essentially for free. The up to 8 bit quantization of WIDAR also delivers improved high dynamic range imaging capabilities which reduce current sensitivity limitations due to the inevitable presence of strong sources in any field. The new digital transmission system also removes the infamous “3 MHz ripple” and related spectral baseline instabilities. This reduces the systematic uncertainties of deep HI observations dramatically.

## SUMMARY

Over the VLA, the EVLA will improve HI observations in terms of a wider L-band frequency range (down to  $\sim 930$  MHz), a better  $T_{\text{sys}}/\epsilon$  sensitivity (in particular at off-zenith elevations), much improved spectral baseline stability, and, most importantly, spectral bandwidth and resolution. The L-band receiver improvement guarantee that the EVLA will still remain the most sensitive interferometer for HI in the world for at least a decade, until SKA pathfinders will be expanded far beyond the currently planned prototypes. The new WIDAR correlator is flexible enough to allow observations of virtually any galaxy at sub- $\text{km s}^{-1}$  resolution with thousands of  $\text{km s}^{-1}$  bandwidth. At the same time, every L-band continuum or targeted HI observation will also yield a blind  $z = 0 - 0.53$  redshift HI survey at a velocity resolution of a few  $\text{km s}^{-1}$ , and vice versa. It is clear that these new possibilities have their price in a very large data rate and that data reduction will challenge today’s computing capabilities. The opportunities, however, are tremendous and it is up to the community to develop new strategies on how to take advantage of the wealth of EVLA data in order to answer the open questions of galaxy evolution and cosmology.

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