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Wide Field of View Imaging with a VHF Phased Array

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Introduction: The Long Wavelength Array (LWA; http://lwa.unm.edu/) is an ONR-funded project to design and construct a large, next-generation facility focusing on both ionospheric and astronomical research and operating in the high frequency (HF) and very high frequency (VHF) bands (20–80 MHz). The baseline design for the LWA consists of approximately 50 dipole-based phased-array stations, with each station consisting of 256 dual-polarization dipoles, distributed over approximately 400 km in the state of New Mexico. In operation, the stations themselves would be phased together to form a radio interferometer.

The Long Wavelength Demonstrator Array (LWDA) was funded by NRL and developed jointly by NRL and the Applied Research Laboratories of the University of Texas at Austin (ARL:UT), with assistance from the University of New Mexico. The LWDA serves as a technology and scientific testbed for the LWA project by fielding prototype hardware and by providing experience with site preparation, radio frequency interference monitoring and mitigation, software development, environmental concerns, and initial science capability. The LWDA consists of 16 dual linear polarization dipoles, tunable in the frequency range of 60 to 80 MHz with an instantaneous received bandwidth of 1.6 MHz. The dipoles have an intrinsically large field of view (field of regard) and images of the entire sky are now being produced routinely. As part of the scientific prototyping work with the LWDA, these images are being used to search for transient celestial radio emitters at higher sensitivity levels than previously accessible. The LWDA also has obtained data, currently under study, containing passive radar observations of meteor scatter, anomalous propagation phenomena, and aircraft.

Technical Approach: Figure 4 shows the LWDA, which is located on the Plains of San Agustin in central New Mexico. The locations for the 16 LWDA antennas were chosen as a subset of those planned for a much larger LWA station. The baseline LWA station consists of 256 dual-polarization dipoles distributed in a pseudo-random array over a circular area 50 m in radius and optimized for reduction of sidelobes from its phased-array operation mode. The 16 antennas of the LWDA are located in what would be the northeast quadrant of a full LWA station.

An LWDA antenna is a "droopy dipole," standing approximately 1.5 meters tall and with the dipole arms inclined at 45° to the horizontal. Each polarization of a dipole is mated with an NRL-developed, low-noise "balun" for impedance matching and improved frequency dynamic range. Signals from the antennas are transmitted to a shelter, heavily shielded against electromagnetic interference (EMI), where FPGA-based digital receivers and signal combiners are located. Significant EMI shielding (100 dB) is required both to prevent the LWDA electronics from corrupting the extremely faint celestial signals of interest and to avoid producing interference in the operation of the nearby astronomical radio interferometer, the National Radio Astronomy Observatory's Very Large Array.

Two operational modes of the LWDA are possible. In the first, digital delay beamforming of the signals from the dipoles generates two fully independent beams of 1.6 MHz bandwidth. In the second, signals from the 120 unique pairs of dipoles are cross-correlated (multiplied and integrated) producing estimates of the visibility function, which is the Fourier transform of the sky brightness under the van Cittert-Zernike theorem. The field of view of the individual dipoles effectively encompasses the entire sky, so an inverse Fourier transform of the measured visibility function produces an image of the entire sky.

In the second data acquisition mode, the estimated visibility function from successive pairs of dipoles is acquired cyclically. The measurement of the visibility function for a pair of dipoles requires 50 ms, so that the measurement of the visibility function from the full array (120 unique pairs = $16 \times 15/2$) requires a total of 6 s. In addition, relatively constant phase and gain calibrations, as determined during the array installation, are applied to each of the visibilities.

Results: Figure 5 shows an LWDA all-sky image. Clearly visible are a number of strong astronomical radio emitters. To date, approximately 80 hr of data have been acquired in late 2006 and early 2007, allowing dynamic all-sky movies to be constructed.

One of the key scientific drivers for the LWA is to search for transient radio emitters, particularly celestial emitters. Traditional radio astronomical imaging assumes that the sky is constant in time, but a variety of recent results is beginning to suggest that numerous celestial emitters can have significant variability in time. In extreme cases, these transient events can have quite low duty cycles and limited emission durations (< 1 s). We are using the LWDA movies to develop the software to search for transient celestial emitters, a precursor to the studies eventually possible with the full LWA.

FIGURE 4
The 16 antennas of the LWDA on the Plains of San Agustin in central New Mexico. In the background is the shielded electronics hut and 25-m-diameter antennas that are part of the National Radio Astronomy Observatory's Very Large Array.

While the initial data analysis is ongoing, we already can begin to place limits on the event rate of celestial transients. Our current limit is that we find no celestial transients above a rate of 0.01 events/year/deg^2 for pulses stronger than –136 dB(J/m^2) at 74 MHz over the 1.6 MHz bandwidth. Even this initial limit is comparable to results obtained at higher frequencies and is significantly better than what has been obtained previously for celestial transients in the low VHF band. As more observations are analyzed, we expect to be able to improve these results significantly, either by finding celestial transients or by improving the upper limits on the pulse strength and event rate.

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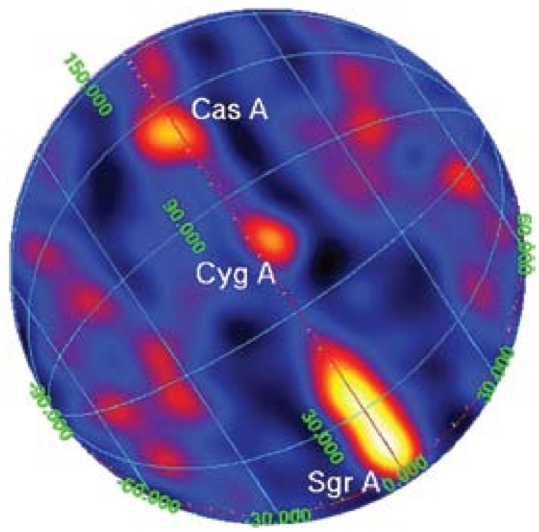

FIGURE 5
An all-sky image from the LWDA. Three of the strongest (temporally constant) celestial sources are indicated: Cas A, the remnant of a massive stellar explosion in the constellation Cassiopeia; Cyg A, an active galaxy in the constellation Cygnus; and Sgr A, the nuclear region of the Milky Way Galaxy in the constellation Sagittarius. Grid lines indicate the Galactic coordinate system, defined by the spiral disk of the Milky Way Galaxy. Approximately 80 hr of data have been acquired, allowing movies to be constructed, and the images are being used to search for transient celestial radio emitters. (See http://www.phys.unm.edu/~lwa/progress_photos.shtml for examples of movies.)