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Science with the Long Wavelength Array

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Abstract. The first station of the Long Wavelength Array, called "LWA1", is working as a beamforming and imaging array, and has begun scientific operations as a stand-alone instrument with collecting area roughly equivalent to a 100m dish. The LWA1 images the sky in realtime using the transient buffer - narrowband (TBN) system which is operational with 260 dipoles, and a bandwidth of 70 kHz. The LWA1 can also form up to 4 beams on the sky simultaneously with 16 MHz bandwidth in each of two tunings and full polarization. Early results include observations of pulsars, the Sun, Jupiter, meteors and ionospheric phenomena. Over 50 projects are in progress, including investigations into the "dark ages" using redshifted hydrogen. The LWA1 is supported by NSF as a University Radio Observatory and as such is open for use by the international community.

`http://lwa.unm.edu/`

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1. Introduction

The Long Wavelength Array (LWA) will be a new multi-purpose radio telescope operating in the frequency range 10-88 MHz. The first of these stations (LWA1) has been in operation since November 2011 (Taylor et al. 2012; Ellingson et al. 2013a). The LWA1 Radio Observatory is shown in Fig. 1. It is located on NRAO land within the central square mile of the Very Large Array, which offers numerous advantages, such as shared communications infrastructure. The project to design and build LWA1 was led by UNM, who also developed analog receivers and the shelter and site infrastructure systems. The system architecture was developed by VT, who also developed LWA1's monitor & control and data recording systems. Key elements of LWA1's design were guided by experience gained from a prototype stub system project known as

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Figure 1. Aerial view of the LWA1 radio observatory. The antenna assembly building and some of the VLA dishes can be seen in the background.

the Long Wavelength Demonstrator Array, developed by NRL and the University of Texas at Austin; and by VT's Eight-meter wavelength Transient Array (ETA). NRL developed LWA1's active antennas, and JPL developed LWA1's digital processing subsystem. Caltech has funded and deployed an LWA station at Owens Valley (LWA-OVRO). LWA1 is operated as a University Radio Observatory by NSF and as such offers observing time to the astronomical community.

The instrument consists of 260 dual-polarization dipoles, which are digitized and combined into beams. Four independently-steerable dual-polarization beams are available, each with two tunings of 16 MHz bandwidth that can be independently tuned to any center frequency between 10 MHz and 88 MHz. The system equivalent flux density for zenith pointing is ~7 kJy (dual polarization) and is approximately independent of frequency; this corresponds to a sensitivity of ~12 Jy/beam (5σ, 1 s); making it one of the most sensitive meter-wavelength radio telescopes. LWA1 also has two "transient buffer" modes which allow coherent recording from all dipoles simultaneously, providing instantaneous all-sky field of view. LWA1 provides versatile and unique new capabilities for Galactic science, pulsar science, solar and planetary science, space weather, cosmology, and searches for astrophysical transients. A software package for data analysis - the LWA Software Library (Dowell et al. 2012) is available from the LWA web pages. In these proceedings we briefly summarize some of the recent science being accomplished with the LWA1 facility.

2. Science

With the ability to point in several directions at once, wide fractional bandwidths, high spectral and temporal resolution, and large collecting area, the LWA1 is a versatile instrument. A collection of recent results using LWA1 are shown in Fig. 2.

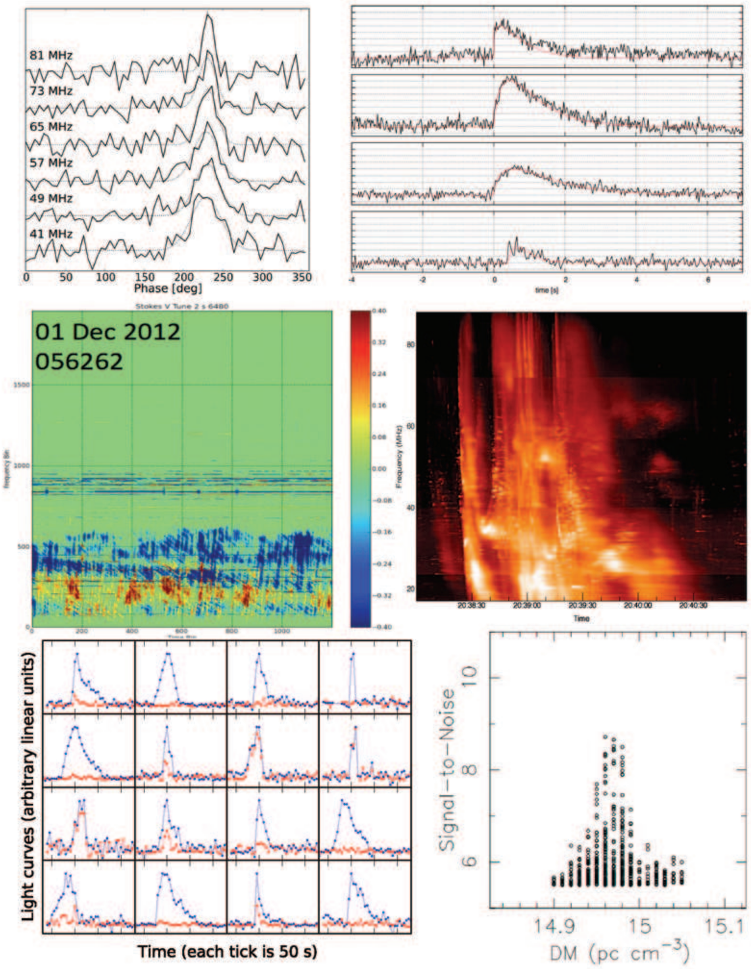

Figure 2. Clockwise from top left: pulse profiles of the millisecond pulsar J2145–0750; a giant pulse from the Crab observed with the LWA1 at 76, 60, 44, and 28 MHz passbands from top to bottom, respectively; a solar burst on May 24, 2013 showing fine structure in time and frequency; a detection of 35 pulses above 7σ from an RRAT; a sampling of light curves for transients seen by the LWA1 where the blue points indicate total intensity, while circularly polarized intensity (Stokes V) is shown in red; and a Stokes V spectrogram of Jupiter during a burst showing modulation lanes (narrow features that sweep down in frequency with time).

2.1 Pulsars

The LWA1 has been used to study some 30 known pulsars to date (Stovall et al. 2013, in prep.), including giant pulses from the Crab (Ellingson et al. 2013b), and the lowest frequency observations of a millisecond pulsar, J2145-0750 at 41 MHz (Dowell et al. (2013); and see Fig. 2 top left). An all sky survey for pulsars and fast radio transients is currently underway with LWA1 as well as attempts to detect newly discovered pulsars from surveys being conducted at other telescopes, and monitoring of giant pulses from the Crab. Effects caused by the interstellar medium (ISM) such as dispersion and scattering are particularly strong at frequencies detectable by the LWA (Cordes et al. 2002). Dowell et al. (2013) measured the DM of PSR J2145-0750 to an accuracy of $10^{-3}\mathrm{pc\,cm}^{-3}$, which is comparable to fluctuations in dispersion measure detected in pulsar timing array experiments (see for example Demorest et al. (2013)). This is of particular interest because this DM fluctuation can mask the signal of a prospective gravitational wave, if it is not measured independently such as can be done with LWA1. With recent improvements the measurement of the error in DM, divided by DM, has improved to 10^{-5}.

Rotating radio transients (RRATs) are a recently discovered astrophysical source (McLaughlin et al. 2006), which are thought to be related to neutron stars, possibly old pulsars that are sputtering out. The LWA1 is being used to observe known RRATs (see Fig. 2 bottom right) and the data from the all-sky pulsar survey mentioned above is being searched for new RRATs. The spectral properties of RRATs is still unknown, however there is some indication that they may have steeper spectral indices than is typical for pulsars, making them ideal sources for study at frequencies below 100 MHz.

2.2 Space Physics

Low frequency observations are useful for studies of the ionosphere and upper atmosphere, planetary, solar, and space science, including space-weather prediction. Observations of solar flares (see middle-right panel of Fig. 2) show detailed structure that challenge accepted emission models. In addition, the LWA1 can see 10 000 meteors/hour under average conditions. This exceptional sensitivity allows us to map out the wind speeds in the upper atmosphere (Helmboldt et al. 2014), and even to identify new meteor showers which show up as an arc of excess events due to specular reflection (see Fig. 3). The LWA1 is undertaking a survey of the debris in the Earth's orbit that should help to constrain models of solar system formation.

2.3 Gamma Ray Bursts and Radio Transients

Using TBN observations of the entire sky over the past 2 years we have placed stringent limits on prompt low frequency emission from Gamma Ray Bursts (GRBs) (Obenberger et al. 2014). While our limits depend on the zenith angle of the observed GRB, we estimate a 1σ RMS sensitivity of 68, 65 and 70 Jy for 5 second integrations at 37.9, 52.0, and 74.0 MHz at zenith. These limits are relevant for pulses

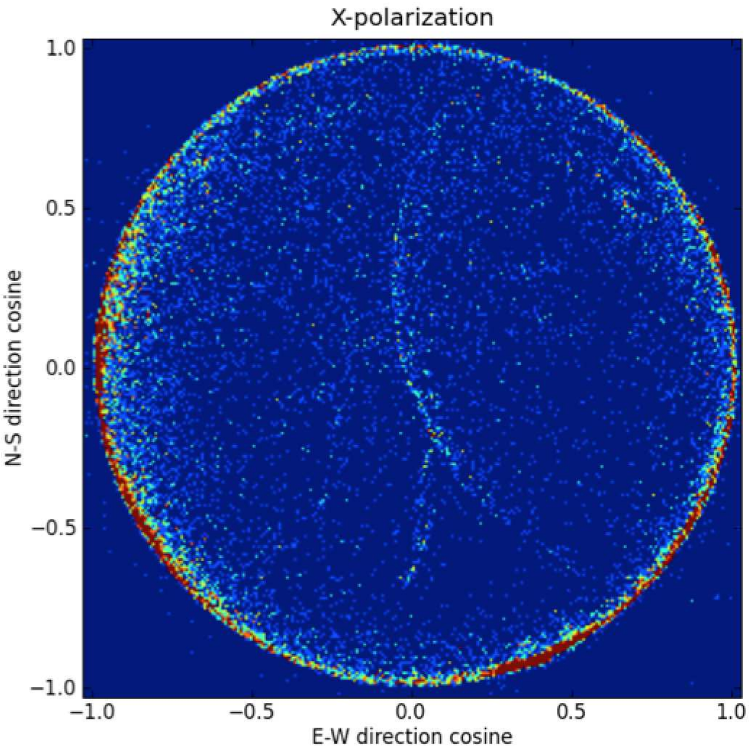

Figure 3. A plot of meteors observed with LWA1 over the visible hemisphere during 1 hour illuminated by a 55.25 MHz narrowband TV signal (analog TV channel 2 XPMS from Juarez and other locations). Each point represents a detection of a meteor. The large arc of higher density may be the result of specular reflection from an unnamed meteor shower coming from a fixed radiant (Helmboldt et al. 2014).

≥ 5 s and are limited by dispersion smearing. For pulses of length 5 s we are limited to dispersion measures (DMs) ≤ 220, 570, and 1,600 pc cm^3 for the frequencies above. We also report two interesting transients, which are, as of yet, of unknown origin, and are not coincident with any known GRBs. In Fig. 2 (bottom left) we show lightcurves for several of these transients. Typical peak flux densities are around 1000 Jy at 38 MHz.

2.4 Dark Ages

A very interesting epoch in the history of the Universe is that when the first stars and galaxies begin forming at a redshift of ~30. This occurs during the so-called “dark ages” before the onset of luminous sources. Low frequency arrays offer the possibility of detecting highly redshifted 21cm emission from hydrogen Greenhill & Bernardi (2012) and using it to trace the thermal history. As part of the Large-Aperture Experiment to Detect the Dark Ages (LEDA), we have outfitted the LWA1 and LWA-

OVRO with 5 outriggers equipped with noise-switching front ends, and will measure the spectrum of the sky between 30 and 80 MHz.

3. Summary

The LWA1 provides a window on the Universe between 10-88 MHz, a region not accessible by any other telescope in the US. As of February 15, 2014 there were 60 observing projects underway with the LWA1. The LWA1 continues to have open calls for proposals every 9 months, and accept target-of-opportunity proposals at any time. LWA1 data are archived at UNM and available to anyone after a 12 month proprietary period.

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