LWA Project Summary

- 10-88 MHz aperture synthesis radio telescope

- First station “LWA-1” collocated with EVLA; partially operational

- Leases obtained for LWA-2 and LWA-3 sites (baseline lengths 19 km, 35 km, 43 km)

- (Unfunded) goal is 53 stations with baselines up to 400 km for resolution [8,2]” @ [20,80] MHz with mJy-class sensitivity
- 10-88 MHz usable; Galactic noise-dominated (>4:1) 24-87 MHz
- 4 independent beams x 2 pol. x 2 center frequencies x up to 19.6 MSPS
- SEFD ~ 3 kJy (zenith) (~ frequency independent)
  - $S_{\text{min}}$ ~ 5 Jy ($5\sigma$, 1 s, 13 MHz, zenith)
- “All sky” (all dipoles) modes:
  - “TBN”: 67 kHz-bandwidth, continuous for up to 10 hours
  - “TBW”: 78 MHz-bandwidth, 61 or 183 ms burst, 0.1% duty cycle
- LWA-1 science emphasis: transients, pulsars, Sun, Jupiter, & ionosphere
LWA-1 Status

- 228 of 258 stands (456 of 516 dipoles) installed
- 10 stands (20 dipoles) operational using first-run ARX and DP1 boards
- TBW & TBN modes (but not beamforming) are available for these dipoles
LWA Collaborators

- Antennas
- Analog Receivers
- System Engineer
- Project Office
- Digital Processing
- Data Recorders
- Monitoring & Control System
- Site Host

Distributed:
- Software
- Commissioning
- Science
RF Signal Path

258 dual-pol antenna “stands”

“Front End Electronics” boards

RF cables to shelter (buried, in conduit)

33 x 16 = 528 analog receivers

4 x 16 = 64 ARXs installed

(32 stands, or 64 dipoles)

Reconfigurable bandpass:

(1) 10-88 MHz “full RF” mode

(2) 41 MHz “shelf filter” mode

(3) 28-54 MHz “fallback” mode
Digital Processor (DP)

- **12-bit x 196 MSPS Digitization**
  - “Direct sampling” architecture
  - Sample rate selected to alias FM broadcast band onto itself

- **Output Data Modes**
  - **DRX:** 4 beams x 2 pol x 2 tunings x 19.6 MSPS (~13 MHz BW), with 4096 channels/beam. Sample rates down to 250 kSPS (~167 kHz BW) supported, always with 4096 channels/beam.
  - **TBW:** Full RF from all antennas in a 61 ms (12b) or 183 ms (4b) burst
  - **TBN:** Up to 67 kHz BW from all antennas, continuously; Can be tuned anywhere in the digital bandpass
Data Recording System

- Data must be recorded on site
- Using new PC-based data recorders; installed/operational now
- Each PC streams up to 115 MB/s continuously for at least 10 h onto a 5 TB “DRSU” hard drive array
- Two DRSUs per PC (so, at least 20 h before manual intervention)
- PCs are $2K/ea; DRSUs $875/ea
TBW Output

\( \tau = 10 \text{ s}, \Delta \nu = 6 \text{ kHz} \)

Early afternoon

Galactic noise-dominated by at least 4:1 over this range

Antenna replaced with matched load
Interim DP – “S60” System

Time Delay Analog Beamformer
Up to 30 dipoles
Switch-selectable 0.5 ns delay resolution

Digitizers / Digital Receivers / Data Acquisition
4 ea. 12-bit x 120-MSPS A/Ds on
2 Altera Stratix II FPGA evaluation boards
– Each FPGA (eval board) handles 2 RF inputs
  at the same center frequency
– Ethernet output to PC
Python acquisition code; up to 11.4 h continuous

$S_{\text{min}} < 200 \text{ Jy (5}\sigma, 1 \text{ s, 1.86 MHz, } Z=12^\circ)$
Accumulated time-on-sky: 366 h continuous
+ 506 h low duty cycle
Deep Integration

Data collected from S60 beam between 2-3 AM local time.

Center freq $\sim 72.25$ MHz
$B \sim 2.379$ MHz
$\Delta\nu \sim 915$ Hz

RFI Mitigation:
Freq channel blanking;
Discarded worst 20% of channels (unnecessarily aggressive)

Necessarily removed diurnal sky noise variation; estimated from a fit to 1 s total power measurements.

1 hour of noise-limited integration, and still going!
1.86 MHz x 103 s integrations ($S_{\text{min}} \sim 20\ Jy$)
No RFI mitigation (!)
Further confirmation of sky noise domination
Useful diagnostic: e.g., antenna orientation

Hours past 2010 Aug 04 00:00 LWA1 Local Time

Dipole from LWA Stand 258, 38 MHz (S60-2 Dataset 100804_k2)
Dipole from LWA Stand 258, 74.56 MHz (S60-2 Dataset 100804_k1)

Same experiment at 74 MHz

Sys. Temp. ($\epsilon T_A + T_R$) [K]

Hours past 2010 Aug 04 00:00 LWA1 Local Time

Regional afternoon thunderstorms
First Glimpses of Crab Giant Pulses

- 74.56 MHz; ~16 h with the Crab pulsar within S60 (26-dipole) beam FWHM
- Manual inspection of 103-s spectrograms for RFI; ~40% rejected
  No other RFI mitigation applied
- Incoherent dedispersion, $0.03 < DM < 60.00$, $\Delta DM = 0.03$ pc cm$^{-3}$
- 57 ms pulse-matched filter; detections sorted into 1 pc cm$^{-3}$ bins

Incoherent dedispersion, $0.03 < DM < 60.00$, $\Delta DM = 0.03$ pc cm$^{-3}$

Becomes $\sim 100\sigma$ for completed LWA-1

$\sim 1$ kJy ($5\sigma$, 57 ms, 1.86 MHz)

Becomes $\sim 100\sigma$ for completed LWA-1

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Concluding Remarks

- LWA-1 planned to be fully operational ~ Spring 2011
  - For more dipoles, awaiting ARX and DP1 manufacturing runs
  - For beamforming, awaiting “DP2” board development & firmware
- RFI situation is surprisingly good (See J. Craig talk, this workshop)
- Science is underway
  - Dispersed single pulse search using archived S60 data
  - PASI (TBN-based transient search; J. Dowell talk; this workshop)
  - 20-dipole TBW/TBN datasets being examined by science teams

This spectrogram:
74.56 MHz, Tau A, 26 dipoles
1.86 MHz (W) x 102.7 s (H)
Pixels are 57 ms x 1.22 kHz
RMS Noise < 190 Jy / pixel
~ 09:00 local time, weekday
For More Information:


Henning et al. (2010), “The First Station of the Long Wavelength Array” [LWA Memo 170]


Ellingstion, Liu, & Craig, “The LWA-1 S60 System” [LWA Memo 176]

Project Web Site:
http://lwa.unm.edu

Memo Series:
http://www.phys.unm.edu/~lwa/memos
http://www.ece.vt.edu/swe/lwavt

The LWA is on Facebook
Backup Slides / Additional Information
# Scheduled LWA-1 Observing Programs

## Galactic Astronomy
- **Hartman**: Continuing Measurements of the Cas A / Cyg A Flux Ratio
- **Pihlstrom**: Carbon Radio Recombination Lines in the Cygnus Arm
- **Polisensky**: Multi-Frequency Large Scale Sky Surveys with LWA-1

## Pulsars
- **Ellingson**: Crab Giant Pulses
- **Ray**: Low Frequency Studies of Radio Pulsars

## Transients
- **Ellingson**: A GCN-Triggered Search for GRB Prompt Emission
- **Simonetti**: Single Dispersed Pulses
- **Taylor**: Observing the Transient Universe ... (PASI)

## Solar System
- **White**: Solar Radio Bursts at High Temporal and Spectral Resolution
- **Clarke**: Tracking the Dynamic Spectrum of Jupiter

## Ionosphere
- **Crane**: Ionospheric Scintillation
- **Rickard**: Ionospheric Absorption Measurements ... Imaging Riometer

Much of the data collected will have multiple uses.
LWA-1 Antenna Array

Stations are arrays of dual-pol dipole-like elements (“stands”) in ~100 m diameter aperture for beam FOV ~ [8,2]°

• Every element is digitized to allow independent pointing of beams and all-sky snapshot Imaging

• Using 256 dual-pol antennas results in spacings 3 x Nyquist at 80 MHz

• Irregular spacings mitigate against aliasing

• Minimum separation 5 m for maintainability; also reduces beam desensitization due to sky noise correlation

• “Outrigger” Stands 257 & 258 also available/instrumented.

• Station electronics will support at least 2 additional stands (259 & 260).
Simulation accounting for mutual coupling and degradation due to sky noise correlation. *Upper curves:* “Simple” beamforming; *Lower curves:* Max-SNR beamforming (astro-ph/1005.4232, LWA memo 166)
Noise-limited integrations in excess of 1 hour have been achieved.
TBW ("Transient Buffer Wideband")

196 MSPS x 12 bits from A/Ds

Per Trigger:
- 12,000,000 12-bit samples (61.2 ms) → Δν ~ 16 Hz
- 36,000,000 4-bit samples (183.7 ms) → Δν ~ 5 Hz

~60 s between triggers (~0.1% duty cycle)

12-bit STATUS
10 stands

4-bit STATUS
10 stands, firmware gain adjustment required

Engineering Uses
- Diagnostics/Status
- Station Level Cal
- Panoramic RFI assessment
- Impulsive RFI assessment

Science Uses
- Long duration "total power" transients
- Solar Riometry

* Could also be done with beams, but doing it with TBW frees up beams for other uses.
TBN ("Transient Buffer Narrowband")

Can run continuously (100% duty cycle)  
Center frequency selectable in 10-88 MHz  
Rate selectable 1 - 100 kSPS (3-dB bandwidth ~ 2/3 rate)  
Output samples are 8-bit I + 8-bit Q

This mode sets the data recorder throughput requirement (~115 MB/s for all stands @ max BW)  
Can do this up to ~10 hours (5TB) without gaps; ~20 hours (10TB) without physical intervention

Engineering Uses  
Station-Level Cal  
Narrowband RFI assessment  
High-sensitivity RFI assessment

Science Uses  
All-sky transient search (PASI)  
Radio recombination lines, maybe  
(Post-observation customization of beam shape, Positioning of RFI-suppressing nulls, etc.)
Beamformer

196 MSPS x 12 bits from A/Ds

Coarse delay
FIFO
Fine delay
FIR
Polarization adjust

2 x 2 Matrix Mult.

To DRXs
196 MSPS x 12 bits

Stand 1

Coarse delay
FIFO
Fine delay
FIR
Polarization adjust

2 x 2 Matrix Mult.

Subsample delay + Cable dedispersion

0-15 steps of 5.1 ns

LWA-1 will have 4 of these, each independently-pointable

Course delay, fine delay, and the 4 polarization coeffs can be user-specified if desired

STATUS
In development, expected Jan 2011
From BF$n$
$n = 1..4$

DRX ("Digital Receiver")

Each beam gets two "tunings" (10-88 MHz)

Output samples are I4+Q4

250 kSPS -- 19.6 MSPS; Bandwidth will probably be ~2/3 of rate

Note output is channelized:
$\Delta v \sim 61 \text{ Hz} - 4.8 \text{ kHz}$ (Rate / 4096)

STATUS
In development, expected Jan 2011