ICRAR

International Centre for Radio Astronomy Research

Tardis-MWA:

A fast transients detection system for the Murchison Widefield Array

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Curtin University

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Fast Radio Bursts (FRBs), aka Fast Transients

- Several FRBs detected to date at Parkes
  (McLaughlin et al., 2006; Lorimer et al., 2007; Keane et al., 2011, 2012; Bannister et al., 2012; Thornton et al., 2013)
- We aim to:
  - Detect FRBs with other telescopes and at different frequencies, and
  - Localize detections with interferometry
- Expect MWA to be able to detect from a few FRBs per week to as many as tens of FRBs per day – Trott et al., 2013
- MWA Voltage Capture System (VCS) will be capable of recording tile voltages
  - Continuous recording (limited to several hours), or
  - Record snippets in time on receiving triggers from other instruments/telescopes
- Tardis-MWA will de-disperse and detect FRBs in real time, and trigger voltage capture

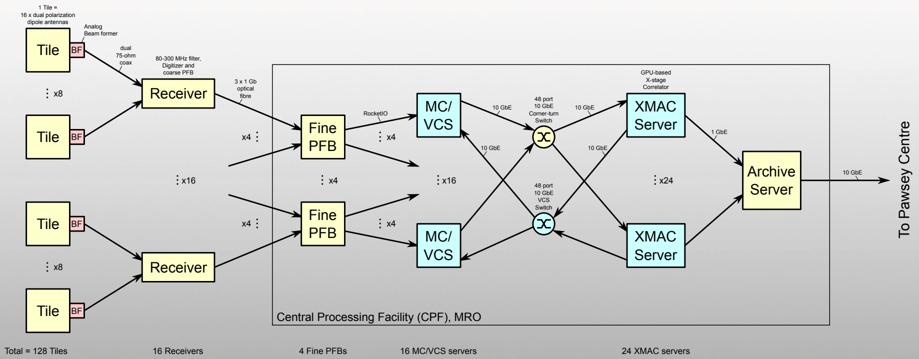
MWA high-time resolution instrumentation

Correlator (24 XMAC servers)

- Delivers fully corner-turned voltages to VCS for recording

Voltage Capture System (VCS) (16 servers)

- Circular capture buffer (of order several minutes)
- Triggered snap-shots to disk
- Records up to 16 coarse channels (2/3rds bandwidth $\Rightarrow$ 82% sensitivity)



MWA high-time resolution instrumentation

Correlator (24 XMAC servers)

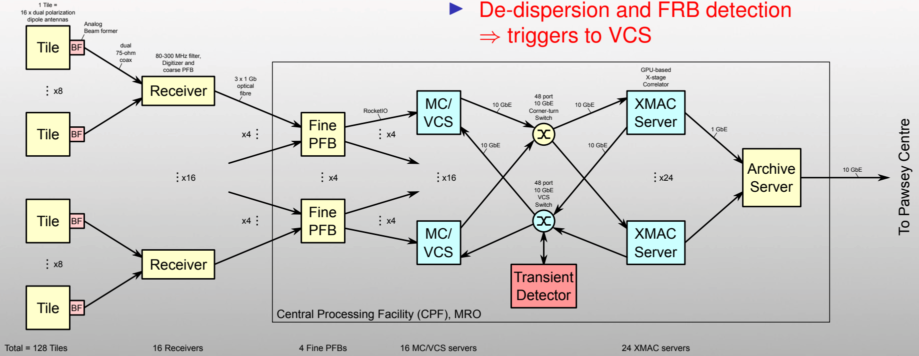
- Delivers fully corner-turned voltages to VCS for recording
- Combines tile signals (incoherent sum and/or beam-form)
- Detects signal power

Voltage Capture System (VCS) (16 servers)

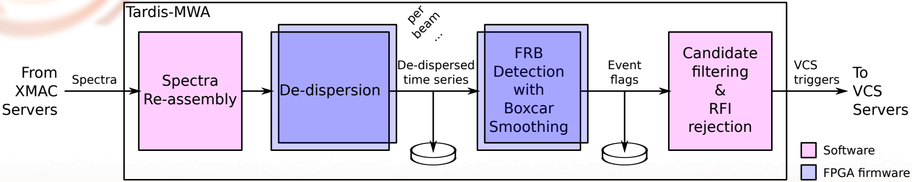
- Circular capture buffer (of order several minutes)
- Triggered snap-shots to disk
- Records up to 16 coarse channels (2/3rds bandwidth $\Rightarrow$ 82% sensitivity)

Tardis-MWA (1 node)

- De-dispersion and FRB detection $\Rightarrow$ triggers to VCS



Tardis-MWA Pipeline



Bandwidth:	30.72 MHz
No. Chans:	3,072 (24 coarse channels of 128 fine channels)
Freq. res.:	10 kHz
Time res.:	2 ms, with boxcar smoothing up to 128 ms
De-disp. trials:	1,024
Max. disp. delay:	131 s (2 min, 11 s)
Max. DM:	423–1,700–11,800 pc/cm^3 (freq. dependent)
No. Beams:	2 currently, possible future expansions to 6 or 12

Tardis-MWA hardware

Host computer

- Two Xeon 8-core processors (8GB RAM each)
- 120GB SSD system disk + 4 x 3TB data HDDs

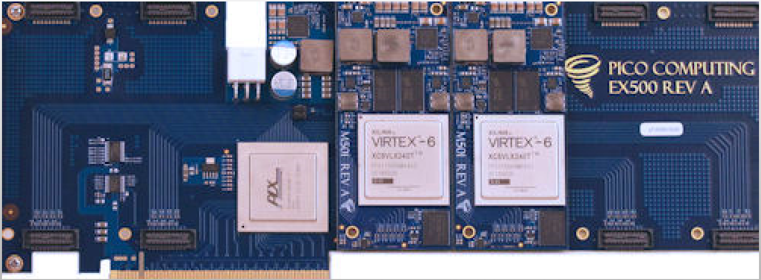
10-GbE NIC

- Receives spectra from XMAC servers, and
- Transmits triggers to VCS servers

Field Programmable Gate Array

COTS PCIe card with plug-in FPGA modules

- Pico Computing EX-500 backplane and up to 6 M-501 FPGA modules
- Each module has one Virtex-6 LX240T-2 and 512 MB DDR3 memory
- One M-501 FPGA module for each beam (2 currently installed)
- Backplane has x16 Gen2 PCIe to host, 8 GB/s bandwidth



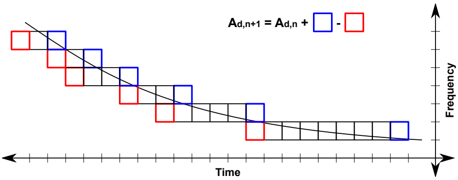
EX-500 backplane with two M-501 FPGA modules installed

Tardis-MWA De-disperser

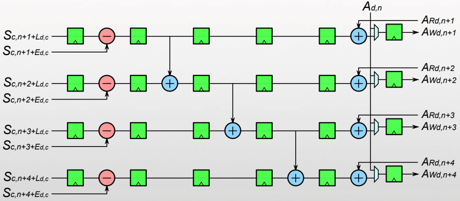
- Unique algorithm that sums across both time and frequency:

$$A_{d,n} = \sum_{c=0}^{C-1} \sum_{\Delta n = E_{d,c}}^{L_{d,c}} S_{c,n+\Delta n}$$

- $E_{d,c}$, $L_{d,c}$ parameters define the dispersion profiles of the trials — software programmable
- Sums are computed by successively differencing the Early and Late samples of each channel
- Processing performed in blocks of $J = 64$ samples (128 ms)
- Less than $3CD$ numeric ops. per sample period (per beam)



Sketch of how Tardis sums spectra across frequency and time.



Example of the Tardis de-dispersion circuit ($J = 4$).

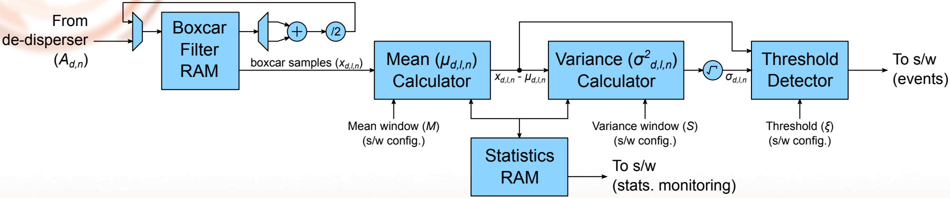
Definitions:

C: Number of spectral channels
D: Number of trials
$S_{c,n}$: n^{th} sample of spectral channel c
$A_{d,n}$: n^{th} de-dispersed sample of trial d
$E_{d,c}$: Ealiest chan. c sample containing signal for trial d
$L_{d,c}$: Latest chan. c sample containing signal for trial d

Algorithm details in:

Clarke, N., et al., JAI submitted, 2013

Tardis-MWA Transient detector



- De-disperser delivers 64 samples of each trial in turn
- Boxcar filter sums sample pairs ⇒ 8 boxcar levels (2, 4, 8, ..., 128 ms)
- Mean and variance are computed and stored in statistics RAM

$$\mu_{d,l,n} = \mu_{d,l,n-1} + \frac{x_{d,l,n} - \mu_{d,l,n-1}}{M}$$

$$\sigma^2_{d,l,n} = \frac{(S-1)\,\sigma^2_{d,l,n-1} + (x_{d,l,n} - \mu_{d,l,n})(x_{d,l,n} - \mu_{d,l,n-1})}{S}$$

- 64-KB Statistics RAM stores latest mean and variance per boxcar level per trial
- Threshold Detector flags excursions above a programmable threshold:

$x_{d,l,n} - \mu_{d,l,n} > \xi\,\sigma_{d,l,n}$ ⇒ Flag detection event to S/W

Comparison with other systems

Why use FPGA technology?

- Tardis system already designed – looking for a telescope
- Demonstrate the use of FPGA technology for time-domain radio astronomy

How does it compare?

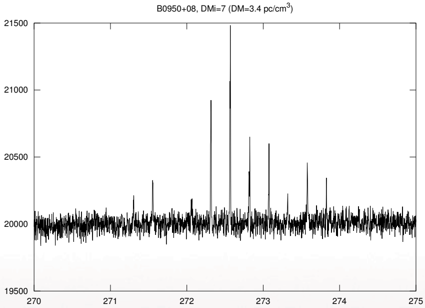
- We define a Figure of Merit (FoM) for comparison:

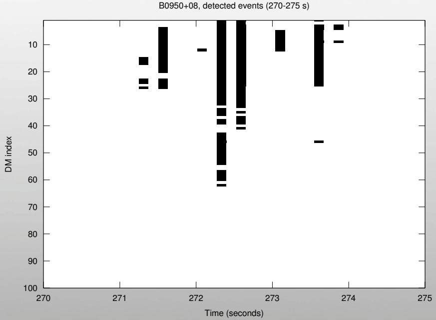
	GPU-based system[a,b]	Tardis-MWA M-501[c]
Real-time processing factor (R)	$\sim$3	2.58
Maximum dispersion delay (T)	1.31 s	77 s
Number of bits/sample (S)	2	16
Number of beams (B)	1	1
Number of freq. channels (C)	1,024	3,072
Number of trials (D)	1,196	1,024
Time resolution (Δt)	64 μs	2,000 μs
Power (P)	250 W (max)	40 W (max)
FoM $= R \cdot T \cdot S \cdot B \cdot C \cdot D / \Delta t^2 / P$	9.4	62.5

[a] Direct algorithm without time scrunching on a GTX-480 GPU (Barsdell et al., 2012).
[b] Calculated for DMs up to 1000 pc/cm^3 @ 1181.8–1581.8 MHz (400 MHz).
[c] Calculated for DMs up to 1000 pc/cm^3 @ 134.64–165.36 MHz (30.72 MHz).

Early test results

- Processed ∼14 minutes of MWA recorded data of B0950+08 (J0953+0755)
- Spectra summed across all 128 tiles
- Only one coarse channel (128 fine chans) at 151.8 MHz, i.e., ∼1/5th sensitivity
- Strongest pulses observed in trial 7, 3.4 pc/cm^3
- Trial 6 was closest to the published DM, 2.958 pc/cm^3
- Test was performed prior to completing the boxcar filter
  ⇒ Detector is now more sensitive to these pulses (W_{50} = 9.5 ms @ 408 MHz)





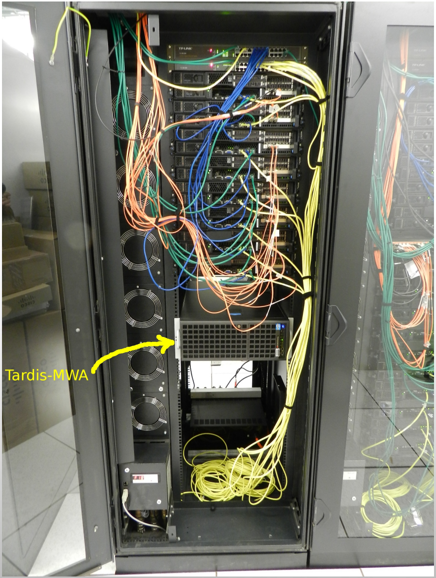
Current status

Now:

- Tardis-MWA is installed at the MRO and ready to receive data
- New XMAC GPU code is available to perform incoherent sums across tiles — soon to be installed
- Our aim is to get transmissions of summed spectra from XMACs to Tardis-MWA before end of this year

Going forward:

- Some work needed to filter candidate events and issue triggers to the VCS
- Form and search tied-array beams — How many can we do?
- Investigate inclusion of a real-time periodicity search engine



Tardis-MWA server installed at MRO, July 2013

Conclusion

Tardis-MWA will:

- Extend MWA capabilities to support commensal and directed searches for FRBs at milli-second timescales
- Increase MWA profile as an instrument for high-time-resolution observations at low frequencies
- Provide experimental results for framing SKA1-low time-domain signal processing requirements
- Demonstrate the capabilities of FPGA technology in time-domain radio astronomy
- Provide a useful source of on-site impulsive RFI statistics

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What do we think we might see?

— Kermit the Frog, Rainbow Connection

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FRBs, that's what!