At the Karl G. Jansky Very Large Array (VLA)

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Realfast: Real-time fast transients on the VLA.
Localization

Need ~arcsecond resolution for repeater-like hosts!

Eftekhari & Berger (2017)
Galaxies in 6dF redshift survey

DM $\iff$ Redshift cut

Redshift of galaxy

[Color scale: 0 - 0.20]
Localization

At DM \(<\sim200 \text{ pc/cc}, \text{ up to 10 arcsec can work!}

*note: gets even better with less conservative DM(z) model

Eftekhari & Berger (2017)
Since last year…

- 2017 “Axes of awesome”:
  - Sensitivity.
  - Localization.
- Now add:
  - Polarization calibration.
  - Voltages for resolving structure.
- Field of view vs. SEFD trade-off: probe FRB evolution
Our FRB science playing field.

FRB params:
100\mu s < w_{int} < 3\text{ms}
0 < \tau_{\text{scat}} (1\text{GHz}) < 3\text{ms}
<DM_x> = 400-800 \text{pc/cc}
-1.5 < \gamma < -0.5
-1.0 < \alpha < 2.0
Our FRB science playing field.

FRB params:
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\gamma = -1.5
\alpha = +2.0
The Very Large Array

On-target time per year

- 500 h
- 600 h
- 1000 h
- 800 h

Recently upgraded!
Continuous bandwidth coverage!
Super-fancy!

12-50 GHz:
~1000 h/year but tiny field of view
Signal chain

Standard Operation:
~MHz channels
~>1s samples

Correlator Back-End (CBE)

- CPU1
- CPU2
- CPU3
- (…)

Public Archive

u,v data to staging disk

Live calibration

Observing info
Operation:
\[ f_{\text{center}} = 1.5, 3, 6 \text{ GHz} \]
256 channels
\(~5\text{ms samples}~

Processing speed limit:
2-6 h per day of observing to keep up!

Write speed limit!
L-band (1GHz):
244 MHz bandwidth
(1/4 of available)

S-band (3GHz):
1000 MHz bandwidth
(1/2 of available)

Each node:
Flag, calibrate.
Dedisperse the VISIBILITIES.
2D FFT to make IMAGES.
Search image.
Save significant time segments.

Public Archive

Live calibration
Observing info
Signal chain

- **Correlator Back-End (CBE)**
  - CPU1
  - CPU2
  - CPU3
  - (…)

- **Data manager**
  - GPU1
  - GPU2
  - GPU3
  - (…)

- **Manage data buffer**
  - Farm out data
  - Contextual decisions on candidates

- **Public Archive**
  - slow u,v data
  - fast u,v snippet

- **Live calibration**

- **Observing info**

Flow:
- Fast visibilities...
- Correlator Back-End (CBE) to Data manager
- Data manager to GPU1
- GPU1 to GPU2
- GPU2 to GPU3
- GPU3 to (…)
- (…) to EXTERNAL CLUSTER
- EXTERNAL CLUSTER
- Contextual decisions on candidates
- Manage data buffer
- Farm out data
More time: 150h/year —> ~3000h/year!

More sensitivity: larger bandwidth/shorter sampling

Required:

- Changes to VLA CBE pipeline (visibility “spigot”).
- GPU pipeline (currently benchmarking).
- GPUs and infiniband (Installation in March).
- Commissioning L, S, C, X; pushing faster.
Realfast Perks

❖ Thousands of hours/year, large frequency range.

❖ Calibration well-understood.

❖ Correlation: minimal RFI filtering required!

❖ Slow sampled data for free.

❖ Connection to nearby multi-λ facilities (and shared CHIME sky!).

❖ Instant localization.
<table>
<thead>
<tr>
<th>Image peak</th>
<th>Spectral Std. dev</th>
<th>Spectral Skew</th>
<th>Spectral Kurtosis</th>
<th>Image Skew</th>
<th>Image Kurtosis</th>
<th>DM</th>
<th>Pulse bins</th>
</tr>
</thead>
</table>

All $\lvert S/N \rvert > 6$ realfast candidates to date!

Kshitij Aggarwal
Slow-sampled data for free
Demonstration of the “VLA Dispatcher,” which automatically triggered co-observing with Realfast, RAPTOR (optical), and VLITE (350 MHz VLA; single-antenna) for an observation of the Crab pulsar. The red circle on the RAPTOR image indicates the pulse localization by Realfast, while the left panel shows the VLITE light curve for the selfsame Realfast 1 GHz pulse.

3.3 Anticipated FRB Detection Rates

As a commensal system, the yearly Realfast FRB yield depends on the distribution of continuum-mode VLA observations and the progress of Realfast GPU commissioning. Here, we use these to estimate FRB detection rates based on a range of possible FRB properties. We project detection rates based on the formulation of Burke-Spolaor & Bannister (2014), which accounts for instrumental sensitivity losses in rate calculations. For FRB rate input, we use the all-southern-sky survey of Champion et al. (2016), in which a total of 10 FRBs were discovered in a search covering 1441 deg² h.

For a comparison of rates from the VLA and other instruments using this same formulation, see Figure 3.

The typical FRB duration, scattering, dispersion measure, luminosity index, and spectrum all affect projected detection rates, but are only roughly constrained by observations. Here, we use representative ranges to estimate best- and worst-case FRB detection rates. On average, non-scattered FRBs show durations of \( \sim 3 \) ms and dispersion measures of \( 770 \) pc cm\(^{-3} \) (e.g. Law et al. 2015). We use a 1 GHz scattering timescale range of 0 to 3 ms and project to the radio frequency using an index \( \mu = 4.0 \) (this is typical of a pulsar \( \mu \), and matches that of the scattered FRB in Thornton et al. 2013). For spectral index we adopt a conservative, physically motivated range \( 1.0 < \alpha < 2.0 \), which is roughly consistent with crude spectral index limits (Karastergiou et al. 2015, Burke-Spolaor et al. 2016). We use luminosity indices between -0.5 and -1.5; the latter represents a Euclidean distribution and the former represents the indices inferred by Vedantham et al. (2016).

We anticipate commensal Realfast observing at all frequencies \( \sim 12 \) GHz, L to X band, to be commissioned over the course of year 1 of our program (09/2017–09/2018) with 5 ms sampling time on all but the most extended A-configuration. We inspected VLA usage through the past two full VLA configuration cycles to determine typical on-sky science time spent observing in continuum modes, not including overheads lost to slewing and set-up scans. We find a total of \( \sim 3650 \) searchable hours are expected in an average year, distributed as 800, 500, 1500, and 850 h per year in L, S, C, and X bands, respectively. Given the above range of FRB parameters, average sensitivity loss to radio interference, and a conservative 10

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**Also involved, not shown:**

Realfast: 1.5 GHz
VLITE: 350 MHz

Long Wavelength Array (\(~100\) MHz)
Experiment vs. Facility

- Typical continuum observations:
  - AGN, supermassive and intermediate-mass black holes
  - Star formation
  - HII regions
  - Molecular clouds
  - Pulsar timing (sometimes!)

- Open for targeted proposals!!!
Realfast prototype commissioning, Aug 23 2016

Peak (arcmin): (-1.324, 1.856)
Peak (RA, Dec): (5:31:58.6, 33:8:52.3)
Source: FRB121102-off
scan: 13
segment: 47
integration: 184
DM = 560.0 (index 3)
dt = 5.0 ms (index 0)
disp delay = 186.4 ms
SNR: 16.3

Here is the dedispersed pulse

Zoomed view of 5ms image

5 ms image!
Why haven’t we found anything (blind)?

Realfast prototype campaigns (500 hours)

95% confidence

50% confidence

Champion et al. (2017)

rate: \( \gamma = -1.5 \)

Standardised fluence limit (Jy ms)
What do non-detections tell us?

Assumptions:
- Distance limit < 200 Mpc (Wasserman & Cordes 2016)
- Parkes observed large sky areas (Champion et al. 2017)
Pitfall(s)...

(Lessons from a desperate interferometry crew?)
VLA error (D config)

Optimized S/N: $8.1\sigma$

SDSS Optical Image

$z = 0.6$
“Normal Quantile” Plots

e.g. Law et al. (2015)
Blizzards hide the faintest snowflakes.

Number of samples = Integration rate \times \text{Resample factor} \times N_{\text{DMs}} \times N_{\text{pixels}}

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Independent samples per hour</th>
<th>Average time between &gt;8\sigma \text{thermal noise} events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single dish</td>
<td>$10^{11}$</td>
<td>8000 hours</td>
</tr>
<tr>
<td>Realfast D config</td>
<td>$10^{14}$</td>
<td>8 hours</td>
</tr>
<tr>
<td>Realfast A config</td>
<td>$&gt;10^{15}$</td>
<td>20 minutes</td>
</tr>
</tbody>
</table>
Lessons

❖ S/N alone is not necessarily a good measure of significance. Where do we draw the line?

❖ Where is YOUR noise floor?

❖ Patience…

❖ (Possibly?) wider FOV would improve bright, rare detections.
Realfast Commensal: The Book

arXiv:1802.03084

REALFAST: REAL-TIME, COMMENSAL FAST TRANSIENT SURVEYS WITH THE VERY LARGE ARRAY


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(under review at ApJ Supplements)
Ultimate goals

❖ Commensal.

❖ Real-time detection.
DATA RATES, SELF-TRIGGERING, PROMPT EMISSION.

❖ Localization of every FRB detected.
  ❖ At least 10 by early/mid-2020.

❖ Public triggers and open data availability.

❖ (Eventually, hopefully) An open VLA capability supported by NRAO.