V-FASTR: TRANSIENT DETECTION AT THE VLBA, AND IMPLICATIONS FOR THE SQUARE KILOMETRE ARRAY

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WHAT ARE FAST TRANSIENTS?

• Short, non-periodic pulses
  – Excellent probes of ISM, IGM via dispersion measure (DM) and rotation measure (RM)

• Known sources
  – Intermittent pulsars (RRATs)
  – Giant pulses

• Exotic sources
  – Black hole evaporation
  – ETI

• Largely unexplored space. New discoveries await!

\[ \Delta t = 4.15\text{ms DM} \left( v_L^{-2} - v_H^{-2} \right) \]
Freq in GHz, DM in pc·cm\(^{-3}\). Detection requires “dedispersion”
TRANSIENT DETECTION CHALLENGES

• Validation
  – Atmospheric or terrestrial events may mimic dispersion profiles [Burke-Spolaor et al. 2011]

• RFI
  – Any momentary or time-variant change looks like an anomaly

• Localization
  – Important for interpreting a detected pulse
  – Challenging for single-dish studies

• High data volumes
  – Millisecond-resolution data streams

“Peryton” event - likely of terrestrial origin

Momentary RFI in Parkes Pulsar Survey
**Solution: Continent-scale radio telescope**

- Good spatial resolution
- Geographic scale identifies local RFI
- General strategy
  - Incoherent dedispersion of data streams in real-time
  - Real-time adaptive RFI excision, detection of candidate events
  - Copy snippets of raw data for candidates for post-processing
V-FASTR OVERVIEW

- **Real-time fast transient detector** on the Very Long Baseline Array (VLBA) using DiFX software correlator
- **Trailblazer for ASKAP CRAFT project**
- **Operates commensally on all VLBA Observations**
- **New technologies:**
  1. **Geographically-dispersed stations** exclude local interference
  2. **Adaptive self-calibration** of detection parameters
  3. **Automatic imaging** to validate and localize pulses
DATA QUALITY IS A PERENNIAL CHALLENGE

- VLBA not designed for high time resolution
- Receiver performance varies over time
  - Tsys changes based on station, sky position
  - Local RFI conditions are dynamic
  - One bad station can ruin an entire observation
  - Left: three pulses from B0329+54
MULTI-STATION DETECTION ALGORITHMS

Sum:
$$\max_{DM} \frac{1}{A} \sum_{a=1}^{A} S_a(DM)$$

Robust:
$$\max_{DM} \frac{1}{A} \sum_{a=1}^{A-1} S_a(DM)$$

ECDF:
$$\max_{DM} \frac{1}{A} \sum_{a=1}^{A} P(X \leq S_a(DM))$$

[Thompson et al., Apj 2011]
PULSAR B0329+54 OBSERVATION
ADAPTIVE REAL TIME SELF-CALIBRATION

• Many parameters must be tuned per observation
• Example: how many stations to excise?
  • Too many loses sensitivity
  • Too few risks RFI
• Test in real-time on a parallel data stream
  – Inject synthetic transient pulses at known intervals
  – Optimize parameters to retrieve them
EXAMPLE

- L-band observation correlated on June 26, 2011
- Some stations exhibit channelized RFI (filterbank power data shown here for 7 stations)

Result of real-time self-calibration
2. (High level) Imaging followup pipeline

2a. Create a FITS file

- Baseband data
- mpifxcorr (higher time res; read from file not UDP)
- Correlated data (.dix)
- estimate_dm_and_range.py
- generate_candidate_fitsfile.py
- dedisperse_dix (read from file)
- snipDix
- dix2fits

2b. Determine delays and localise

- prepare_localisation.py
  Set up output dirs, config.yaml
- localise_transient.py
  Generate solveddelays.yaml and posoffsets.yaml
- setup_imaging_correlation.py
  Set up input files for recorrelation

2c. Generate sky image (with correct position)

- Baseband data
- mpifxcorr
- generate_candidate_fitsfile.py
- Better FITS file
- AIPS fringe-fit, calibration, image
- PNG image + ASCII summary
SINGLE-PULSE IMAGING

- Imaging of B0329+54 from a single pulse, no external calibration

Post-correlation dedispersed

Cleaned image from ~5ms data
INITIAL V-FASTR RESULTS

• Single pulse detections of B0329+54 and the Crab
**INITIAL V-FASTR RESULTS**

- Single pulse detections of B0329+54 and the Crab
SUMMARY

• Continent-scale arrays hold special advantages for transient detection
• Adaptive and automatic systems will be important for commensal operation on large arrays

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SENSITIVITY ANALYSIS FOR MULTIPLE-STATION CONFIGURATIONS
**DETECTION PERFORMANCE ROC CURVE FOR PULSAR B0329+54 OBSERVATION**

“Area under the curve” is a good performance heuristic.