LOFT-e (Localisation of Fast Transients with e-MERLIN)

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Talk Motivation

- Understanding FRBs and their hosts, requiring:
- **Real-time detection and localisation with interferometers**, via:
- Synergies between current facilities and/or identifying opportunities for existing facility upgrades.

1) Our facility: e-MERLIN
2) Our upgrade: Localisation Of Fast Transients with e-MERLIN (LOFT-e)
3) Our results
• UK-based interferometer
e-MERLIN

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- 7 telescopes:
  - Longest baseline: 217 km
e-MERLIN

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- 3 receivers:
  - L-band (1.4 GHz), C-band (5 GHz), K-band (22 GHz)
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- UK-based interferometer
- 7 telescopes:
  - Longest baseline: 217 km
- 3 receivers:
  - L-band (1.4 GHz), C-band (5 GHz), K-band (22 GHz)
- L-band:
  - Angular resolution: 150 mas
  - Bandwidth: 512 MHz
  - Hours on sky: 1700 hrs/yr
JBO + e-MERLIN: Transients

Lovell: Apollo

- Piggybacks pulsar observations (real-time)
- 400 MHz (1.4 GHz)
- 3.5 years of data processed
- No localisation

e-MERLIN: Follow-up contributions:

- FRB150418 follow-up (Bassa et al., 2015; Giroletti et al., 2016)
- GW170817 follow-up (Abbott et al., 2017)
- Ongoing time to follow up FRBs (Beswick et al., 2017)

(credit: Bassa et al., MNRAS 2016)
But e-MERLIN could do more...

• Equipment* at our disposal:
  *L-band, 25 m dishes
  • Good resolution:
    • 215 km baseline: 150 mas resolution
  • Decent FoV:
    • FWHM: 30 arcminutes
  • 6 dishes
    • Combine for increased sensitivity
  • 0.004 - 0.012 FRBs per day
    • (Parkes rate scaled to e-MERLIN fluence limit, incoherent beam sensitivity, logN-logS slope of -1)

...Detect and localise 0.3 - 1 FRBs per 1700 hrs
LOFT-e: Modes

• Currently working on two different modes for e-MERLIN:
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  1) Real-time
     • Filterbank incoming data (8-bit, 256 channels, 64 microsecond sampling)
     • Mitigate RFI
     • Combine/search for transients
     • Likely candidate? Store raw voltages offline:
       • Correlation, LOCALISATION!

Mat Malenta (PhD)
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       • Correlation, LOCALISATION!
  2) Offline
     • The non-commensal high time-resolution e-MERLIN mode
     • Testbed for real-time strategy:
       • Data capture, filterbanking, RFI mitigation, telescope combination via:
       • Observing pulsars, giant pulses, RRATS
LOFT-e: A high time-resolution backend

- Goal: Piggyback standard operations
  - Stream voltage data to machines
    - Filterbank, dedisperse, RFI mitigate, search for transients
LOFT-e: A high time-resolution backend

- First steps (2015 e-MERLIN cycle):
  - Establish "always-on" data stream from e-MERLIN correlator:
    - Develop software for data capture/processing

![Diagram of LOFT-e system](image-url)
LOFT-e: Signal Path

- e-MERLIN was not originally designed for high time-resolution studies
  - We are working within intrinsic hardware limitations
    - Using VLBI capability to extract data

### Diagram Details

- **Telescope** → **ADC**
  - 8-bit output

- **Correlator Station Board**
  - Resampled
  - Geometric delays

- **e-MERLIN Correlator**

- **Station Board**

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Correlator Station Board:
- resampled
- geometric delays

Correlator Baseline Board:
- Fine delay correction (phasing up)

ADC

Telescope (voltage data) → ADC (8-bit) → e-MERLIN Correlator → Correlator Baseline Board (4-bit) → 2-bit → To LOFT-e

Baseline Board
Technical Setup

• Currently excluding Lovell telescope
  • Form incoherent sum from similar telescopes
  • Maximum of 6 dishes

![Diagram showing multiple telescopes with voltage data flow]
Technical Setup

• 12 available baseline boards
  • Modified EVLA design
  • 1 board: 64 MHz dual-polarisation VDIF data, 128 MB/second
Technical Setup

- 3 LOFT-e nodes
  - Data capture software written in c, python

Baseline Boards x 12

2-bit data
512 MB/s per computer

Per node:
- 32 GB RAM
- GTX980 GPU (x2)
- 6-core 12-thread CPU (x1)
- 28 TB storage

LOFT-e machines x 3

Archive

48 TB storage
Technical Setup

- Configuration information
  - Concerning center frequencies, port mapping, etc.
  - Subject to current e-MERLIN observations

Baseline Boards x 12

LOFT-e machines x 3

Per node:
- 32 GB RAM
- GTX980 GPU (x2)
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48 TB storage

JBO

Voltage data

2-bit data

512 MB/s per computer

Configuration information (center frequencies, port mapping, etc.)
Technical Setup

- Telescope information
  - Source names, on source checks, etc.

Baseline Boards x 12

2-bit data

Configuration information (center frequencies, port mapping, etc.)

Telescope information

LOFT-e machines x 3

512 MB/s per computer

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JBO

voltage data
Challenges along the way

1) Working with pre-existing technology
   • Example: Correlator Auto-Gain Control
     • Automatically rescales data based on current signal
     • If RFI-dominated: 2-bit output data concentrated into a single level - **BAD**
       • We've turned this off now
Challenges along the way

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2) Coherent combination
   • Can increase sensitivity further by coherently combining data
     • Began modifying GMRT pipeline
     • Too hardwired for GMRT
       • Potentially looking for help with beamforming
Challenges along the way

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3) RFI (see next slides)
e-MERLIN at 1.4 GHz

- L-band: 1254.4 MHz - 1766.4 MHz
  - Split into 8 available 64 MHz sub bands:

Sub band center frequencies

- 1286.4
- 1350.4
- 1414.4
- 1478.4
- 1542.4
- 1606.4
- 1670.4
- 1734.4
• RFI is time, position, and sub band dependent
  • Some sub bands are consistently quite clean...

PSR B0329+54: 30 s observation
RFI is time, position, and sub band dependent

- Some sub bands are consistently quite clean...
- Others are not...

PSR B0329+54: 30 s observation
• RFI is time, position, and sub band dependent
  • Some sub bands are consistently quite clean...
    • ...Others are not...
    • ...But can be improved!
      • Median clipping, MAD

PSR B0329+54: 30 s observation
Results: Combining bands
We can combine data from separate baseline boards:

Details:

- Source: PSR B1933+16
- Sub bands: 1414.4, 1670.4 MHz
- Antenna: Cambridge
- Observation length: 10 minutes
Results: Combining beams

We can combine individual dishes for increased sensitivity:

Details:

- Source: PSR B0329+54
- Sub bands: 1414.4, 1670.4 MHz
- Antennae: Da, De, Kn, Pi
- Observation length: 30 s

Testing various incoherent beam techniques:

1) Straight sum
2) Median filtering
3) Median clipping
Results: Single pulses

Single pulse detection provides proof-of-concept for FRBs:

Details:

- Source: Crab Pulsar giant pulse
- Sub band: 1414.4 MHz
- Antennae: Pickmere, Knockin, Darnhall, MkII

Plots:

- Incoherent beam (bottom)
- Individual dishes (2 pols: left, right) (top)

Current method:

- AstroAccelerate
  - GPU-based searching
Next Result: RRATs

• Granted e-MERLIN time for RRAT observations to test single-pulse pipeline

• Observed: RRAT 1819-1458
  • Time: ~ 6 hours
    • Antennae: Cambridge, Darnhall, Defford, Knockin, Pickmere

• To come:
  • 36 hours of dedicated observing time for other RRATs
Summary

• LOFT-e:
  • A new high time-resolution backend for an existing interferometer
  • Offline mode for development, pulsar science
  • End goal: real-time commensal FRB detections + localisation

• Demonstrated:
  1) Combining sub bands - increased bandwidth
  2) Combining dishes - increased sensitivity
  3) RFI mitigation
  4) Pulsars, giant pulses observed

• Next steps:
  • RRAT observations - proposal accepted
  • Fully-fledged FRB pipeline
  • Investigating software correlation
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Thank you!

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