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.

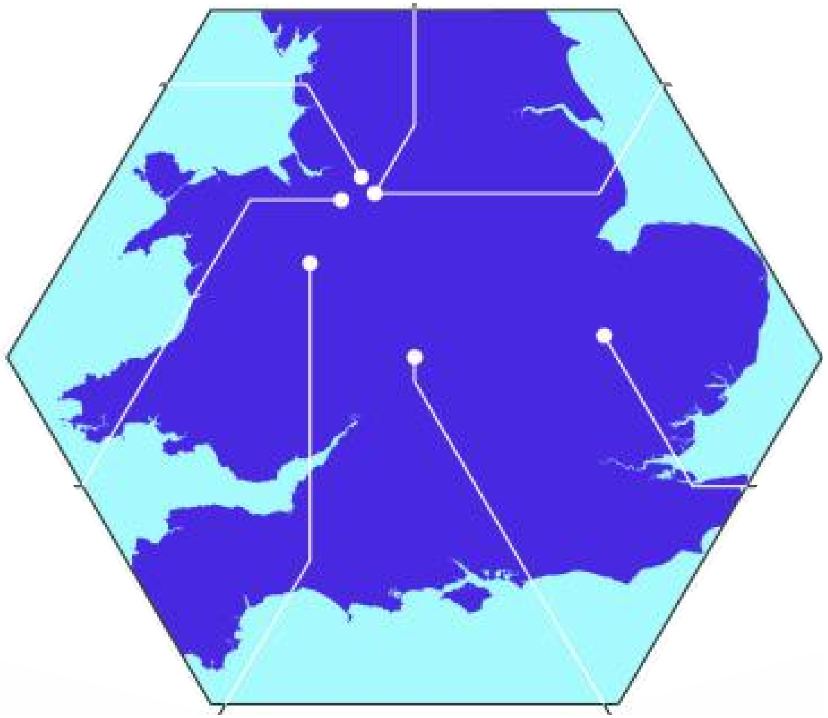
1) Our facility: e-MERLIN

2) Our upgrade: Localisation Of Fast Transients with e-MERLIN (LOFT-e)

3) Our results

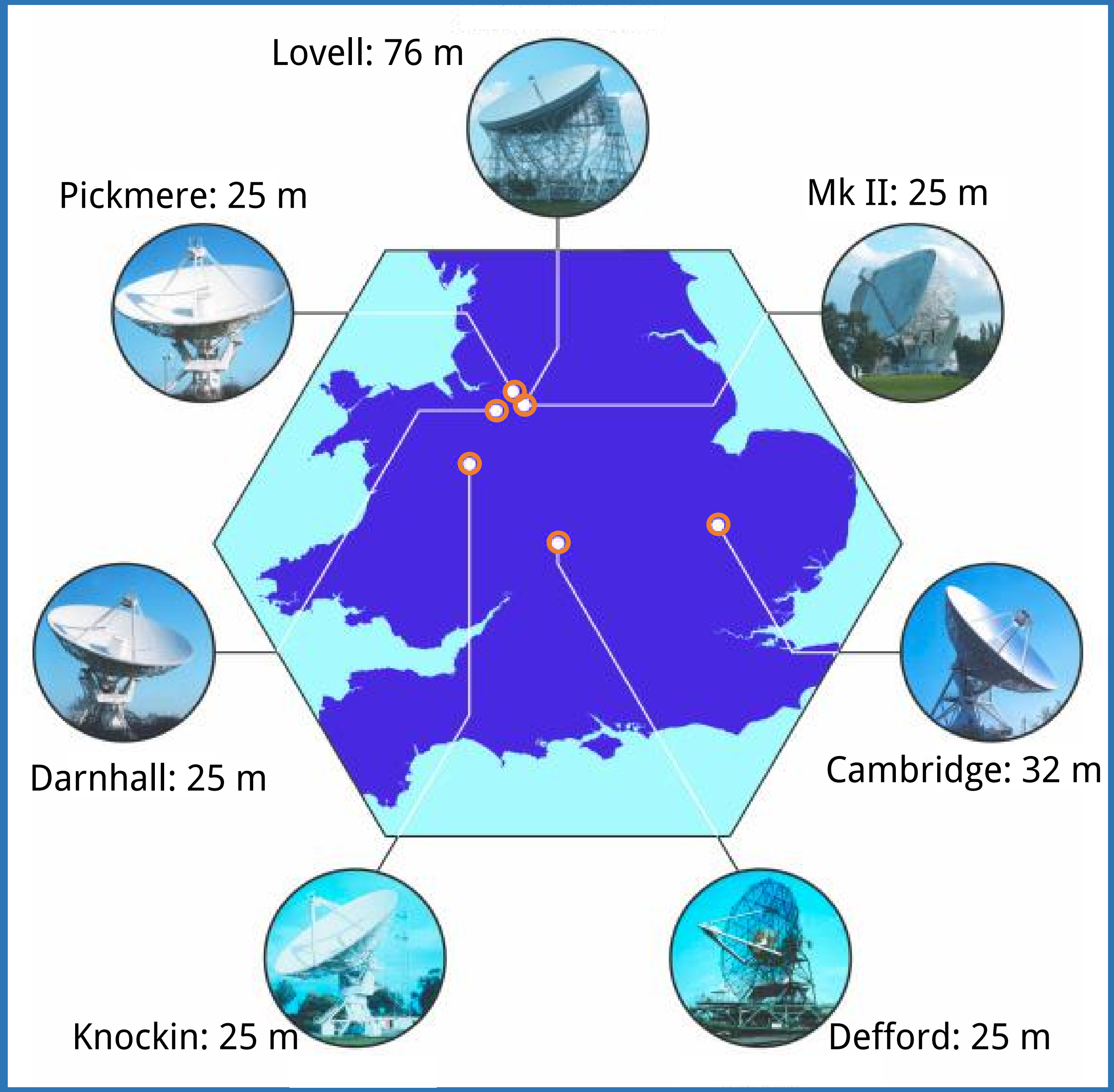
e-MERLIN

- UK-based interferometer



e-MERLIN

- UK-based interferometer
- 7 telescopes:
  - Longest baseline: 217 km



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- UK-based interferometer
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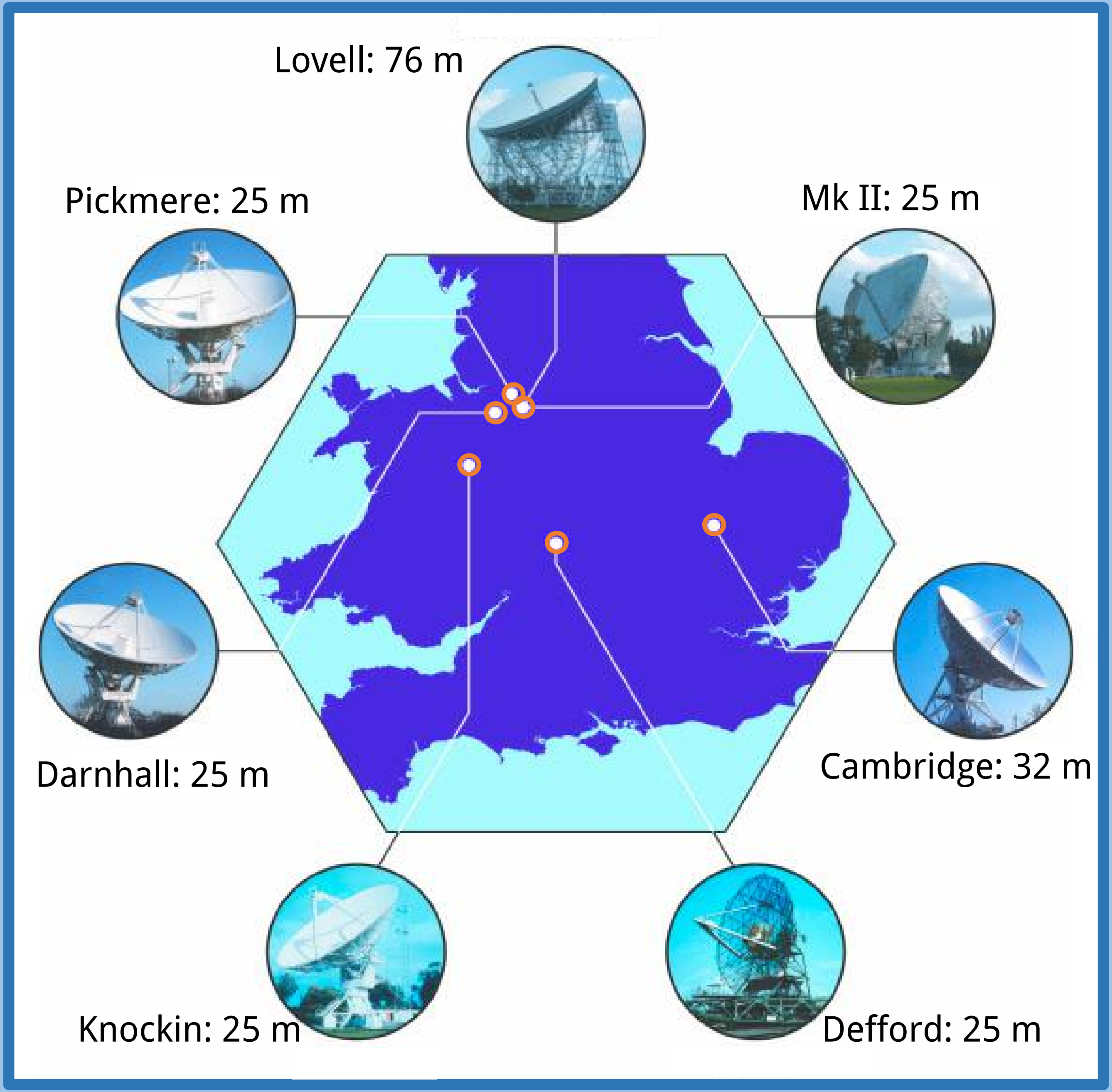
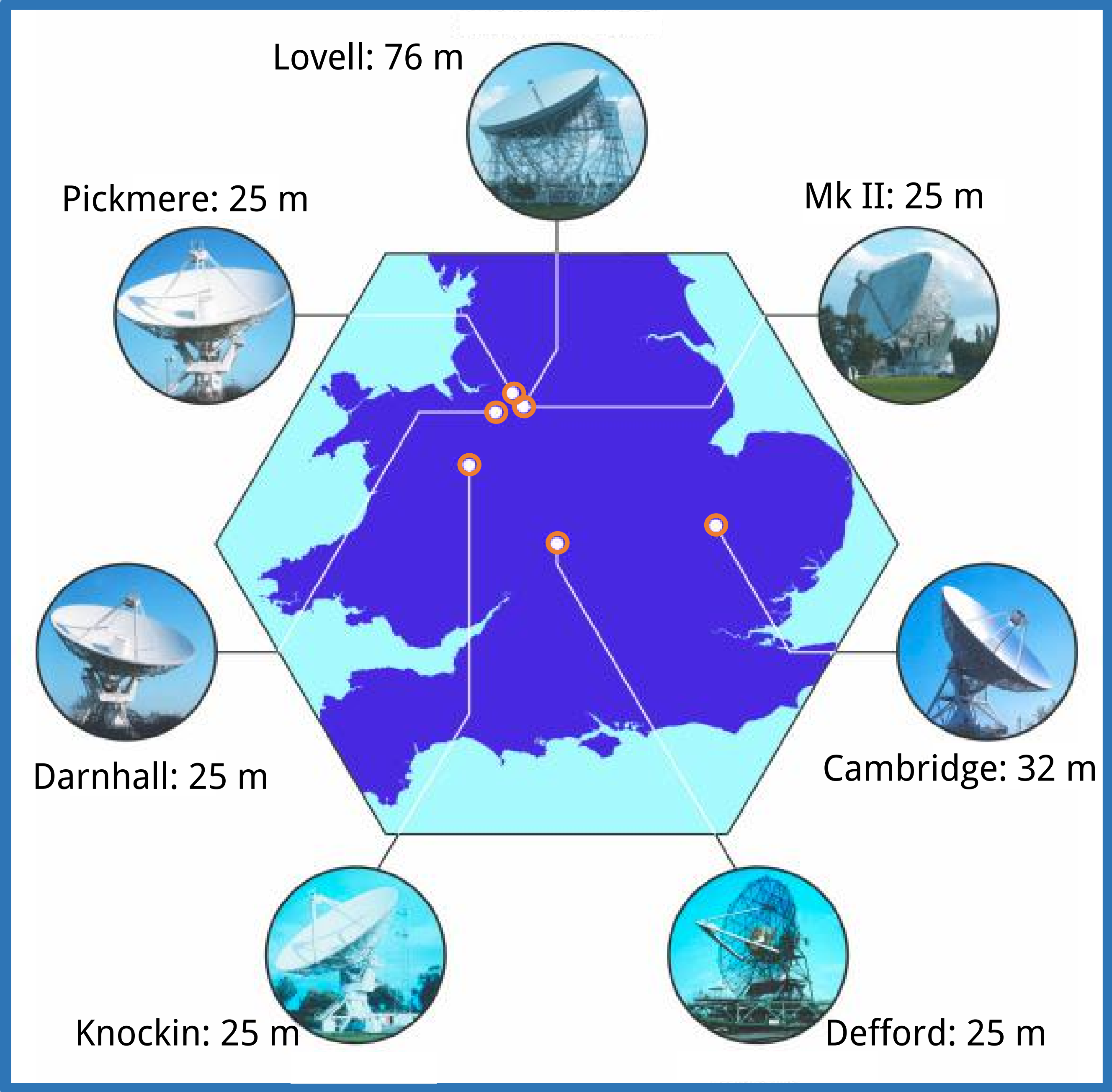
- 3 receivers:
  - L-band (1.4 GHz), C-band (5 GHz), K-band (22 GHz)



e-MERLIN

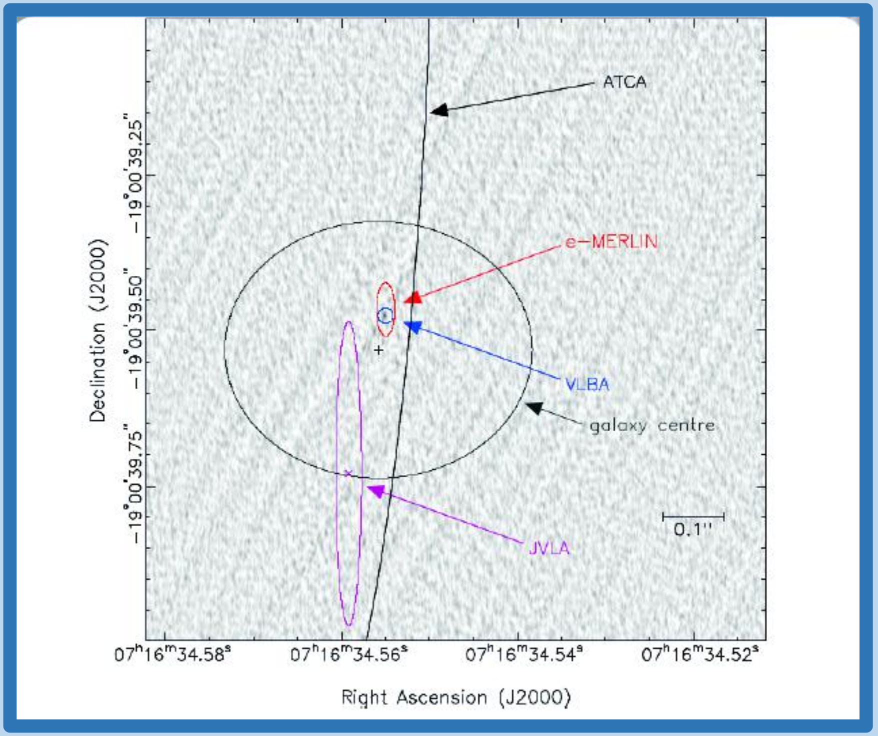
- UK-based interferometer
- 7 telescopes:
  - Longest baseline: 217 km
- 3 receivers:
  - L-band (1.4 GHz), C-band (5 GHz), K-band (22 GHz)
- L-band:
  - Angular resolution: 150 mas
  - Bandwidth: 512 MHz
  - Hours on sky: 1700 hrs/yr



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)

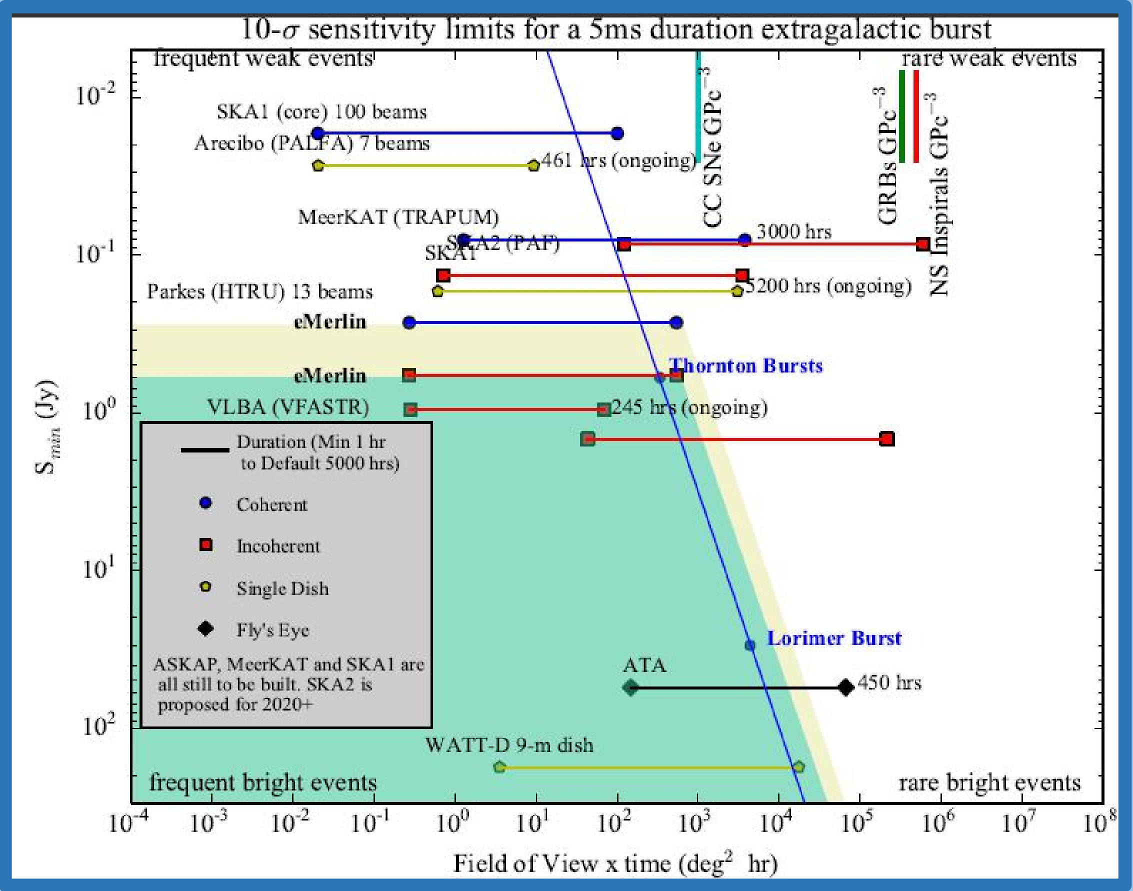
(credit: Bassa et al., MNRAS 2016)

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)



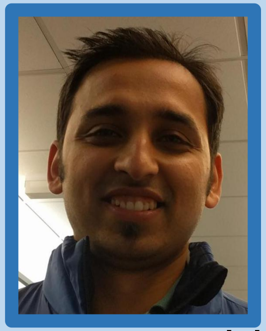
(credit: Stappers)

...Detect and localise 0.3 - 1 FRBs per 1700 hrs

Localisation of Fast Transients with e-MERLIN

Prof. Ben Stappers

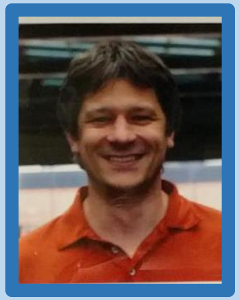
Dr. Ant Holloway



Dr. Kaustubh Rajwade

Dr. Mike Keith

Dr. Paul Harrison

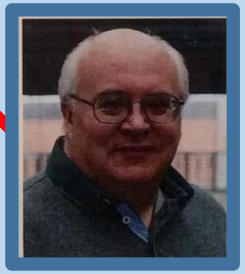


Dr. Rene Breton

Mat Malenta (PhD)

Dr. Jayanta Roy

Dr. Mitch Mickaliger



Tom Scragg (PhD)

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!

IN PROGRESS

Mat Malenta (PhD)

LOFT-e: Modes

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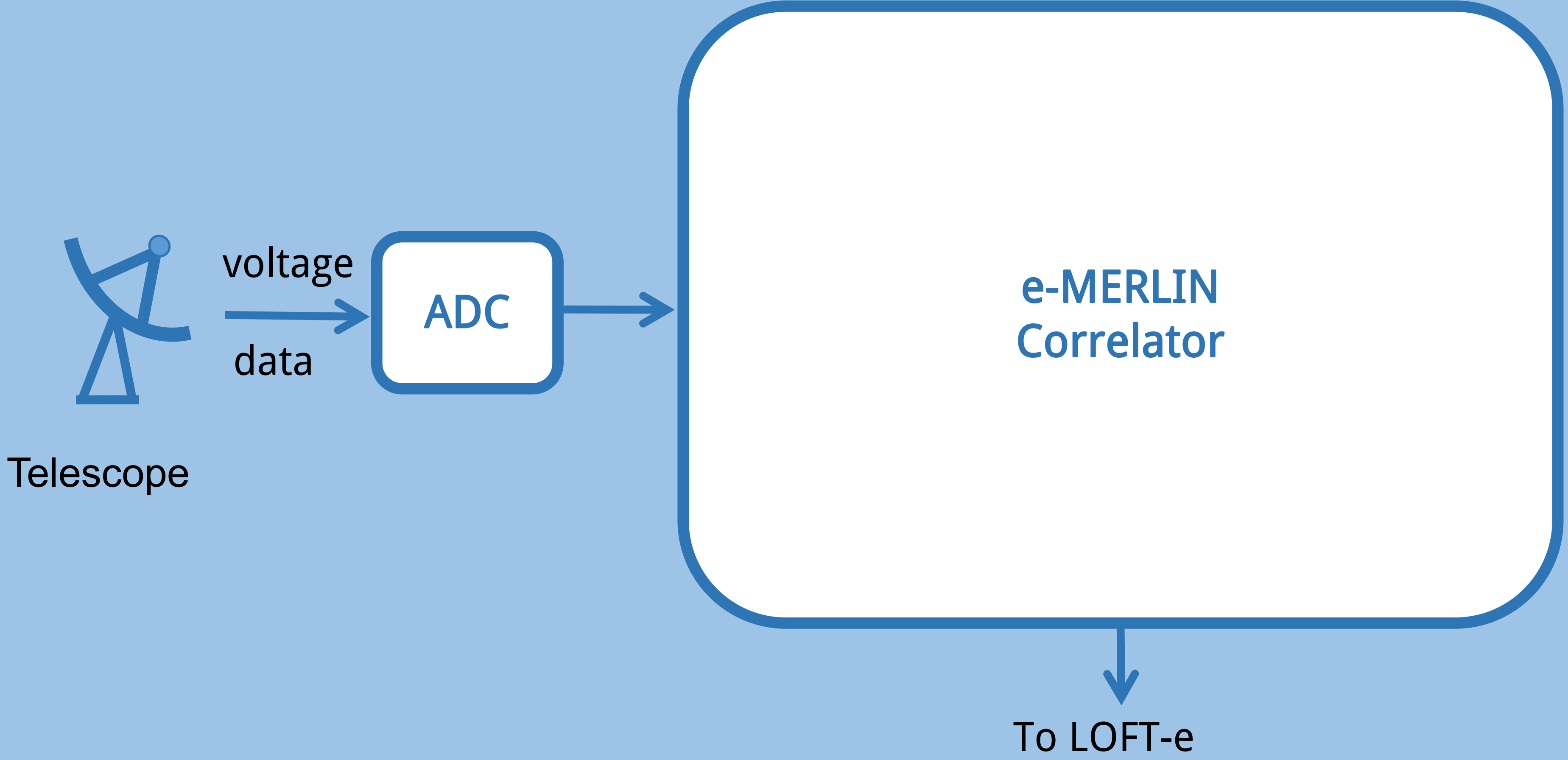
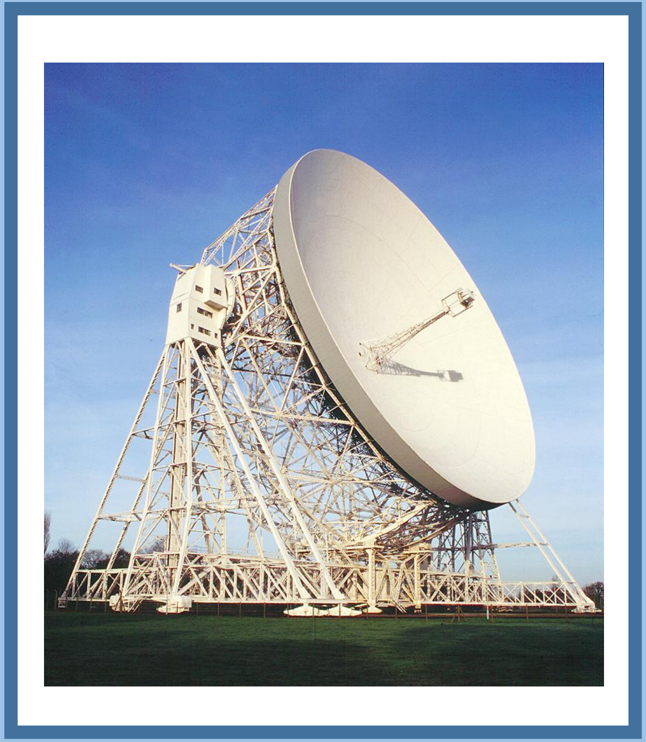
     - Likely candidate? Store raw voltages offline:
       - Correlation, LOCALISATION!
  2) Offline
     - The non-commensal high time-resolution e-MERLIN mode
     - Testbed for real-time strategy:
       - Data capture, filterbanking, RFI mitigation, telescope combination via:
       - Observing pulsars, 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

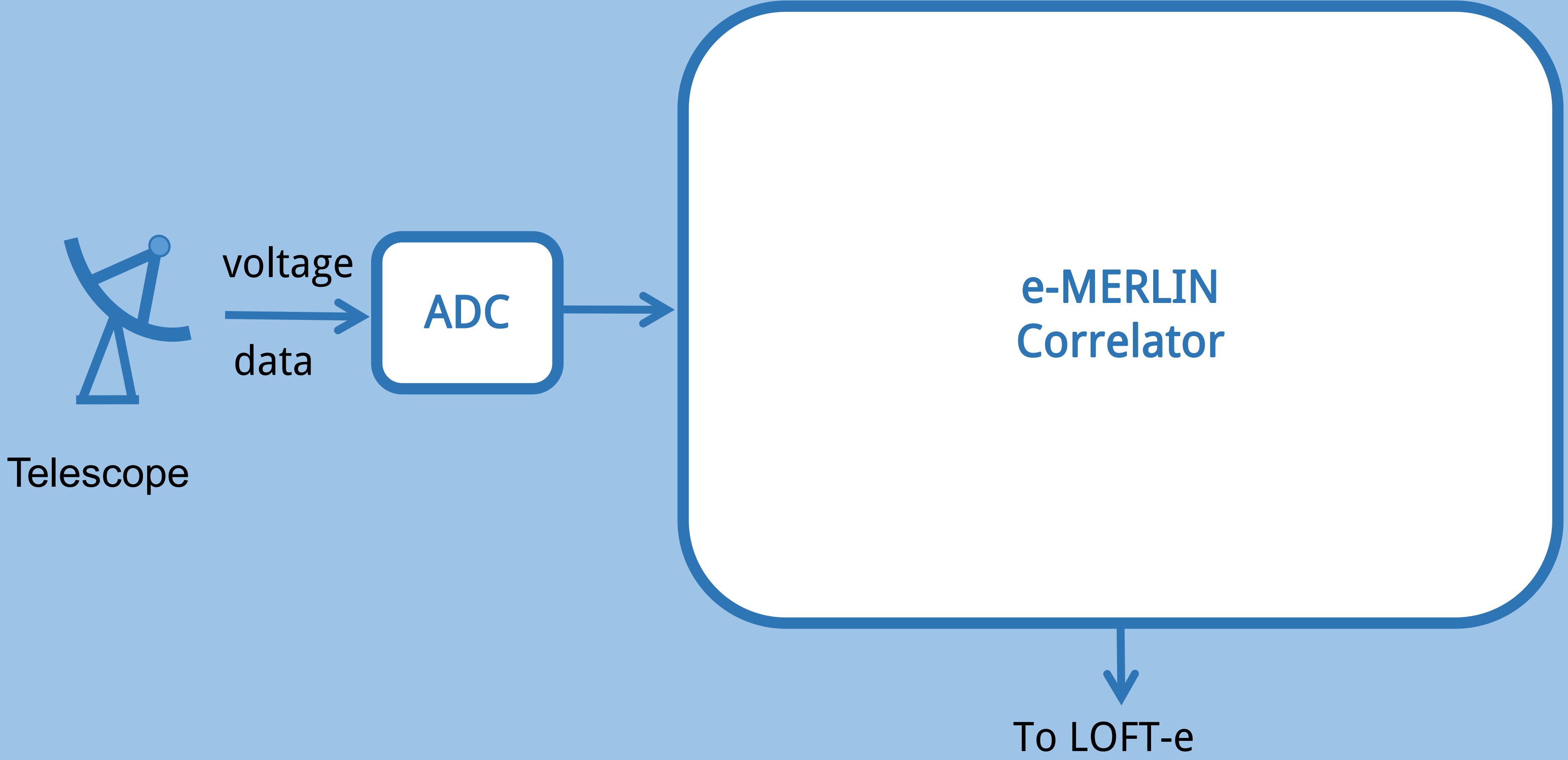


Telescope



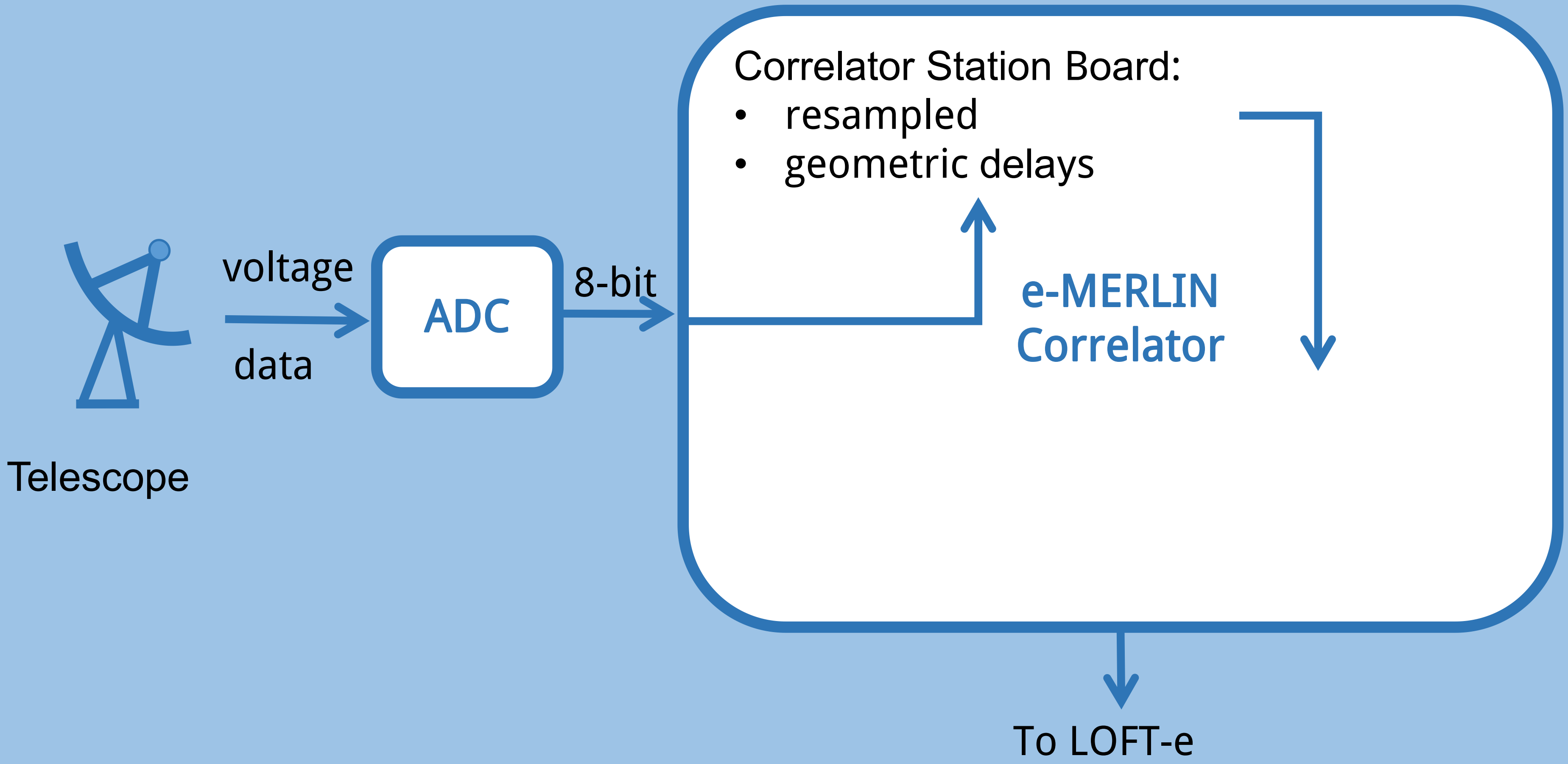
LOFT-e: A high time-resolution backend

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

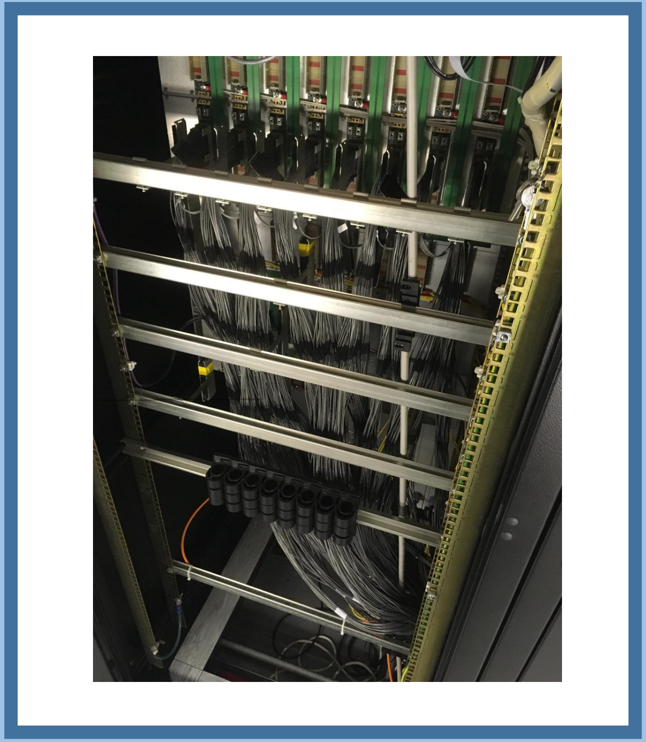


LOFT-e: Signal Path

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



Station Board



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Telescope

voltage

data

ADC

8-bit

e-MERLIN Correlator

Correlator Station Board:
- resampled
- geometric delays

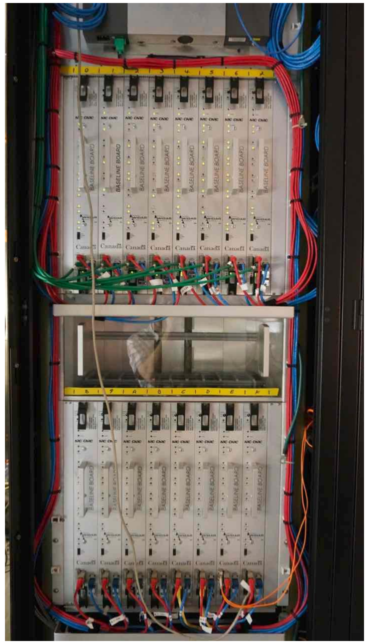
4-bit

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

2-bit

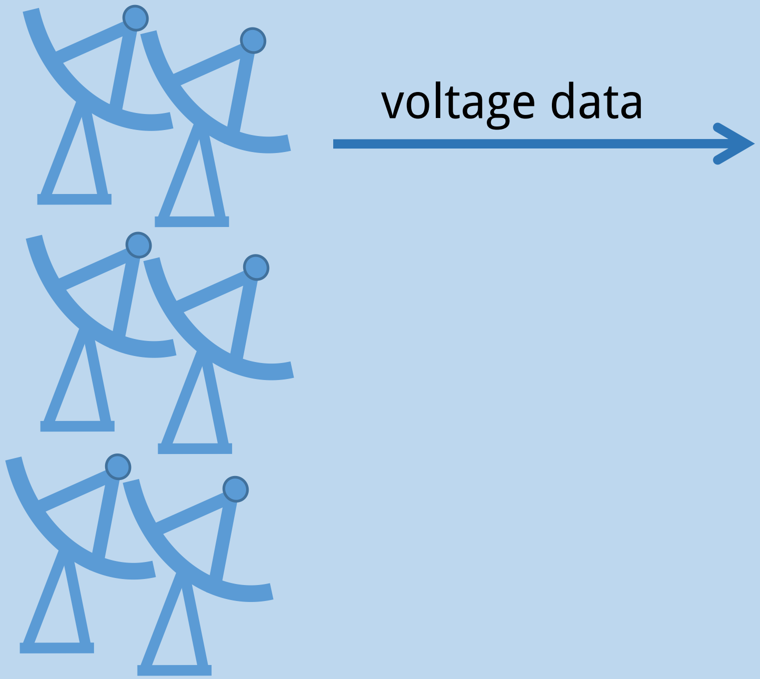
To LOFT-e

Baseline Board



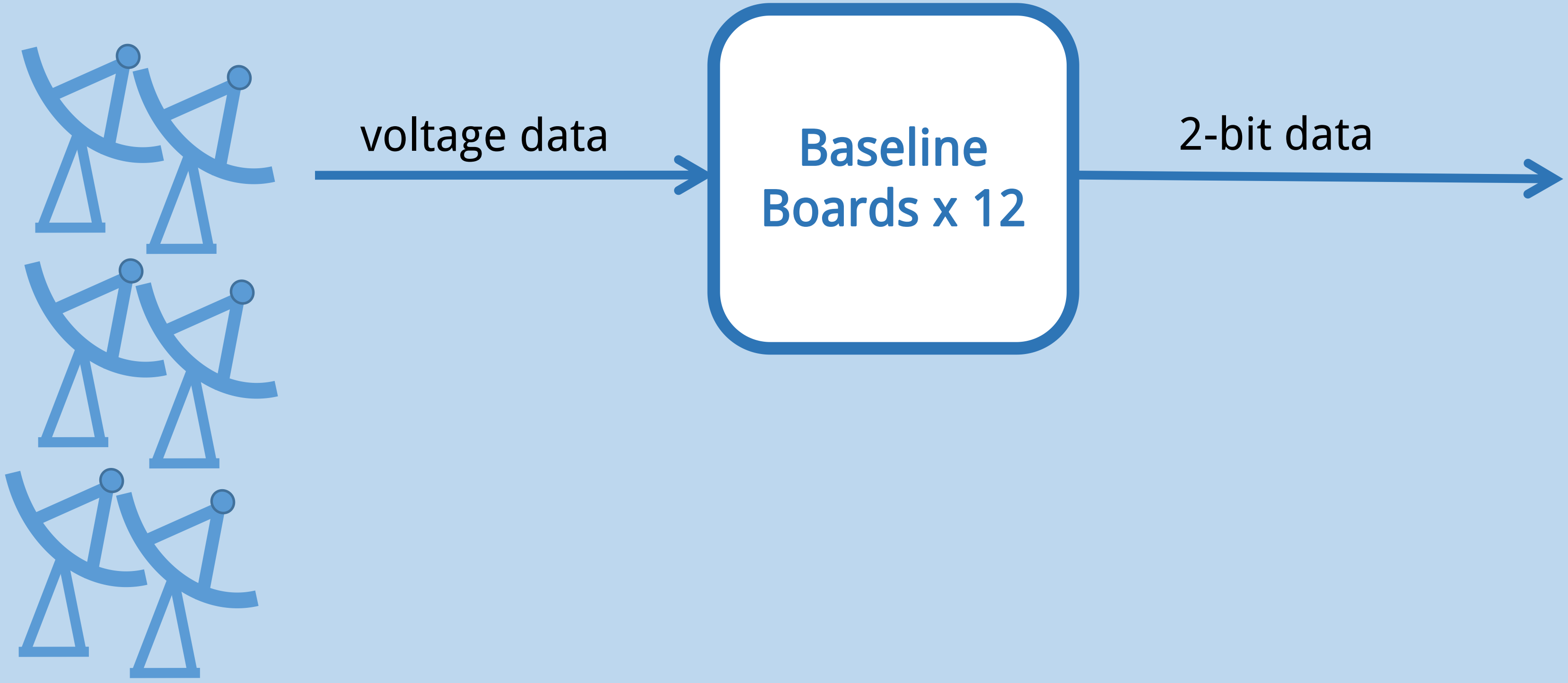
Technical Setup

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



Technical Setup

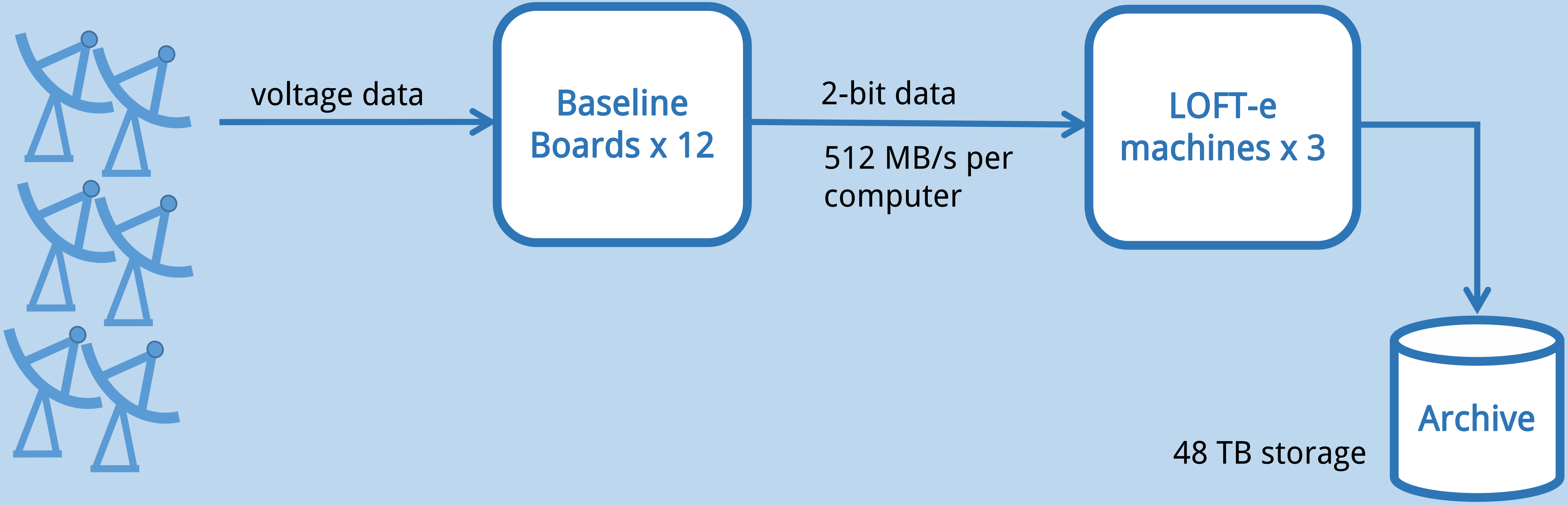
- 12 available baseline boards
  - Modified EVLA design
  - 1 board: 64 MHz dual-polarisation VDIF data,128 MB/second



Technical Setup

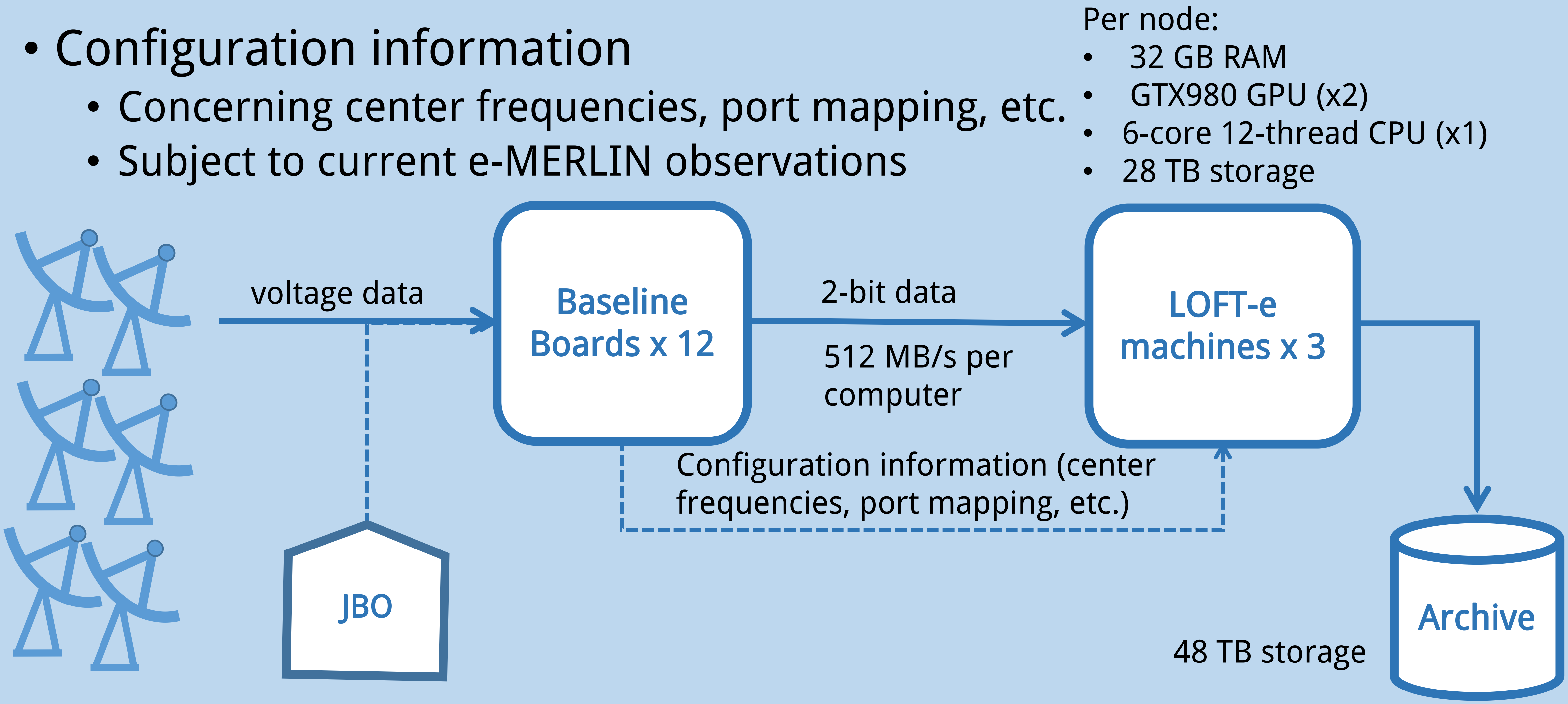
- 3 LOFT-e nodes
  - Data capture software written in c, python

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



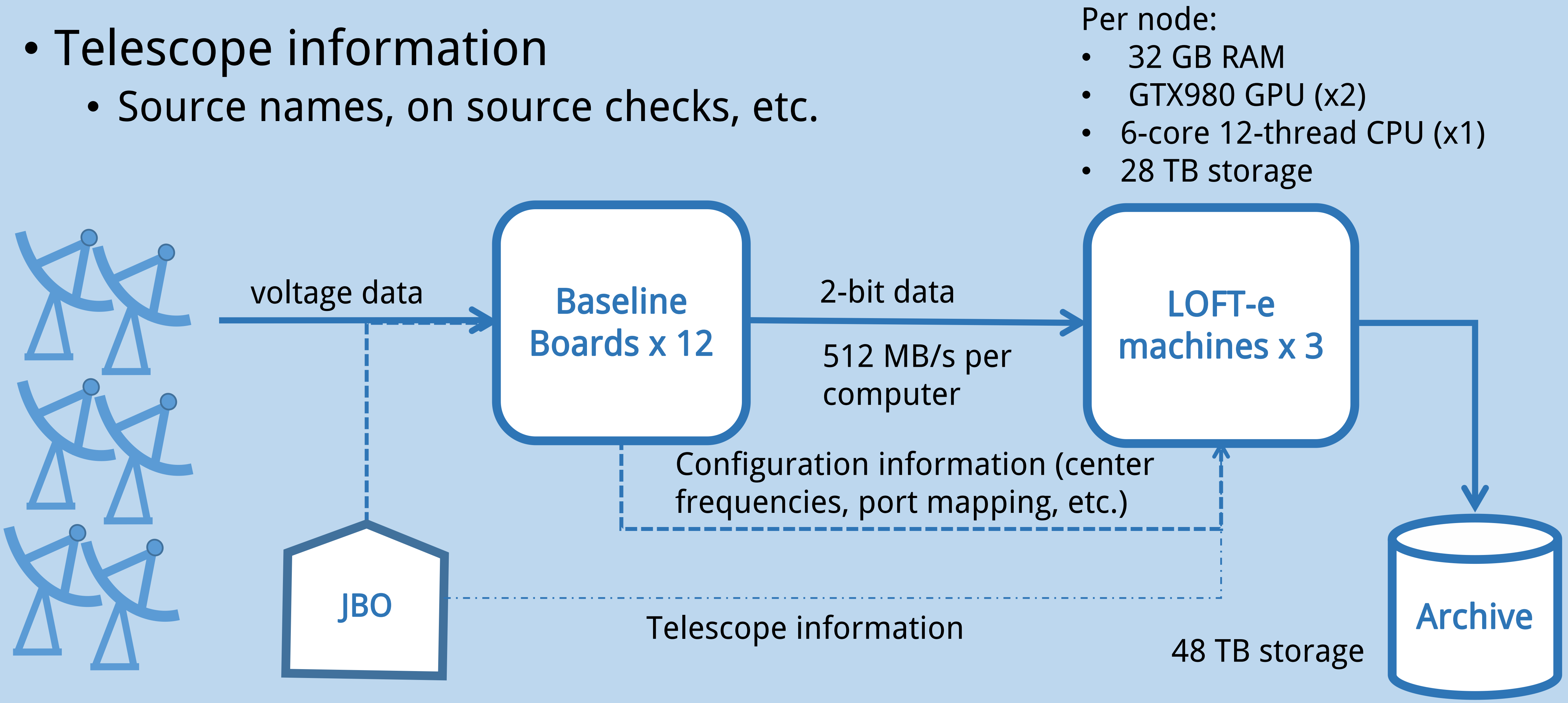
Technical Setup

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



Technical Setup

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



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

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   - Can increase sensitivity further by coherently combining data
     - Began modifying GMRT pipeline
     - Too hardwired for GMRT
       - Potentially looking for help with beamforming

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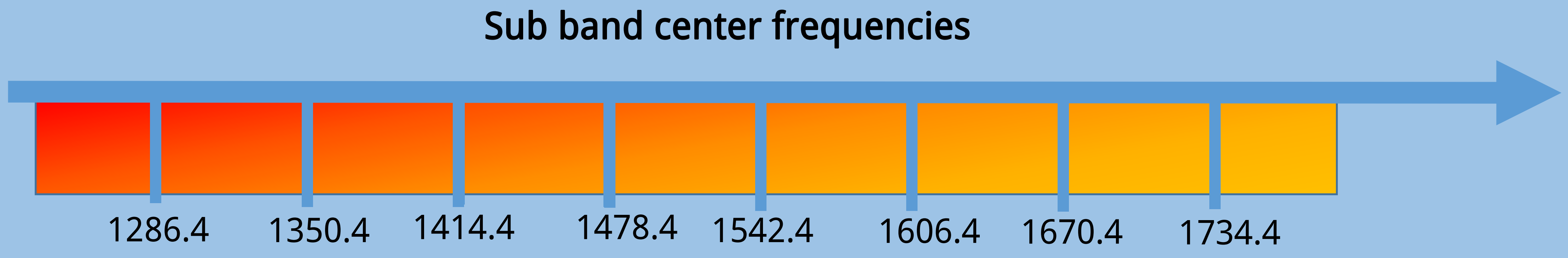
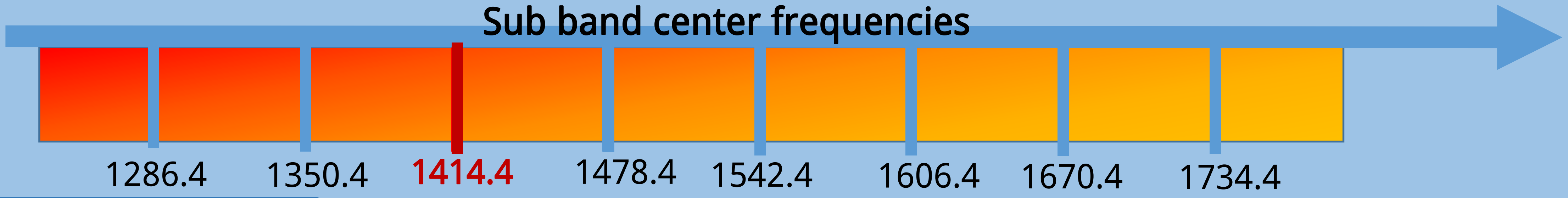
3) RFI (see next slides)

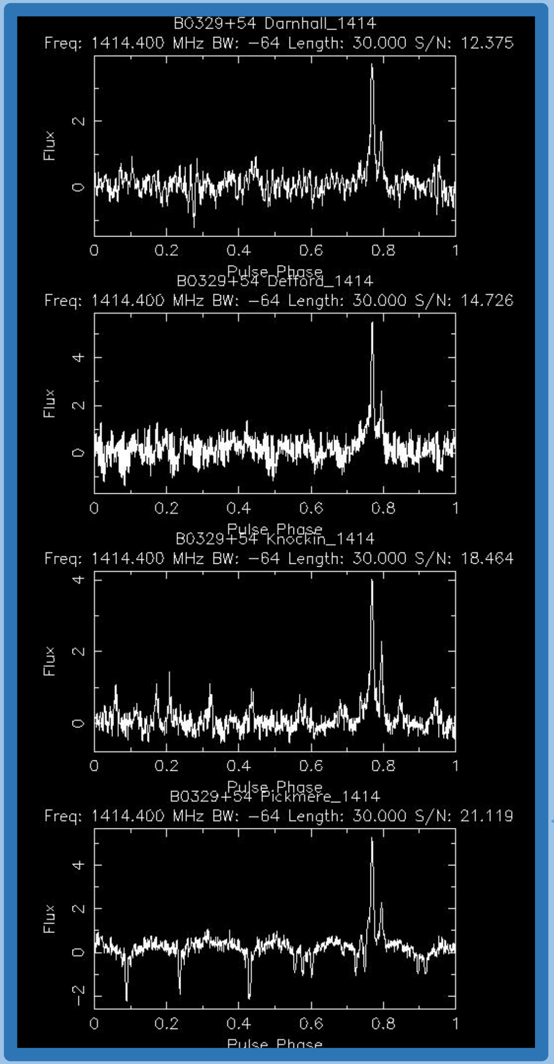
e-MERLIN at 1.4 GHz

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



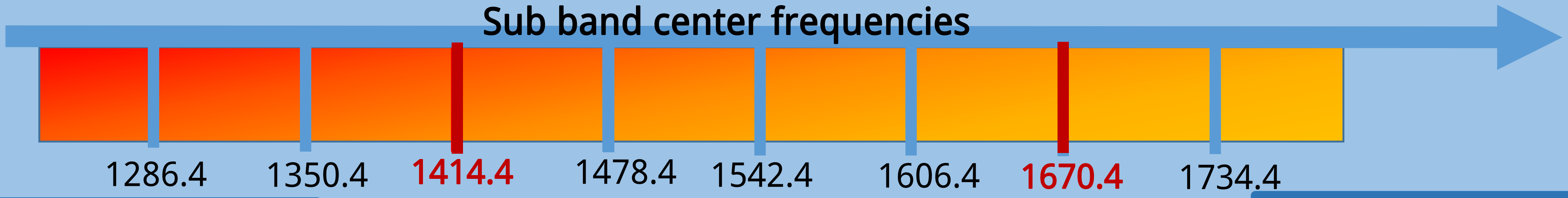


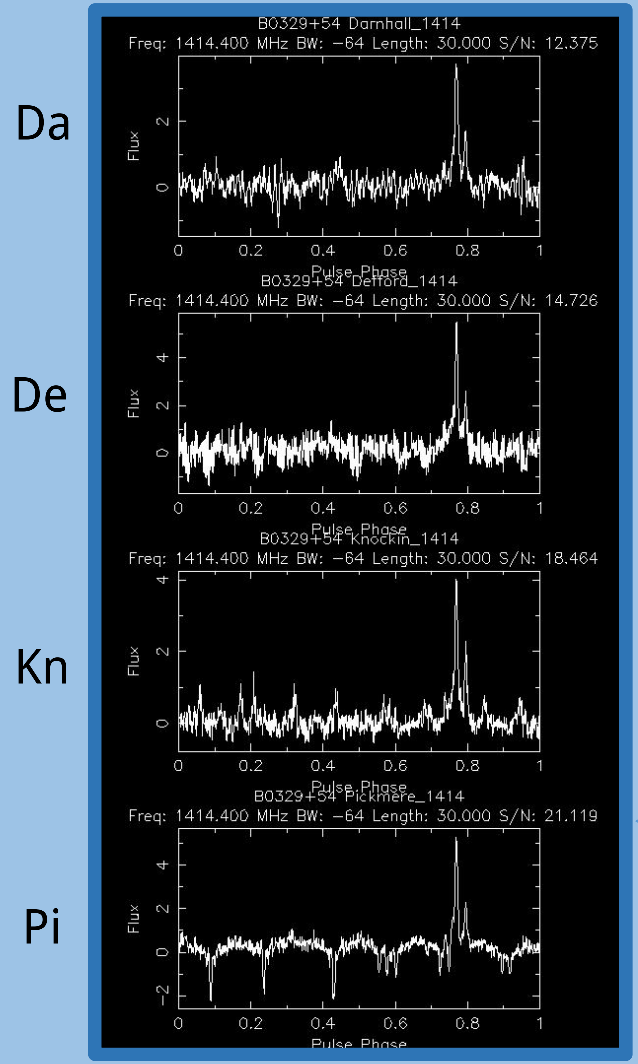
Da
De
Kn
Pi



- RFI is time, position, and sub band dependent
  - Some sub bands are consistently quite clean...

PSR B0329+54: 30 s observation





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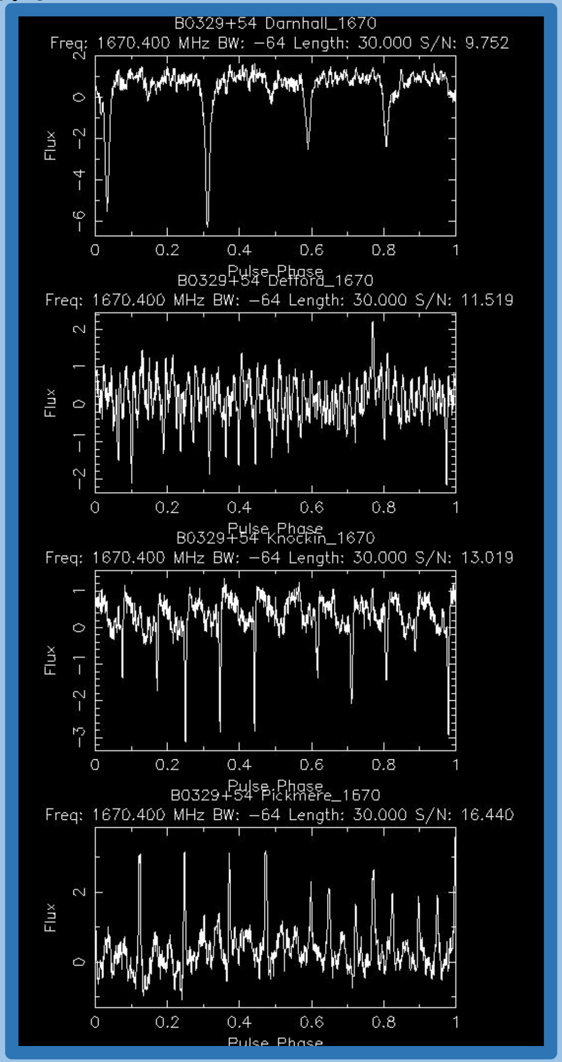

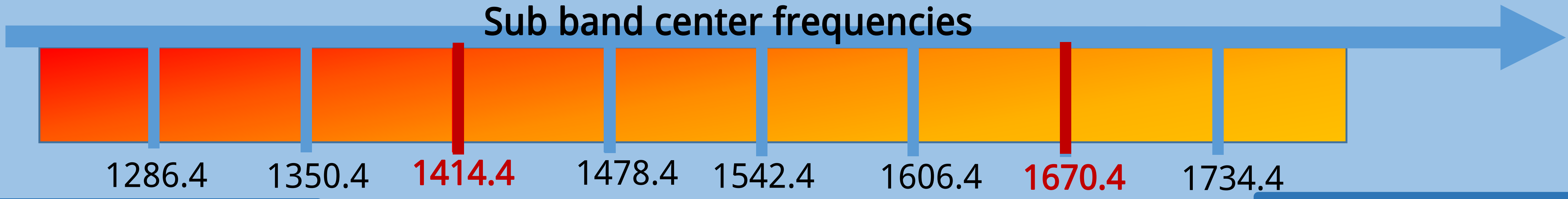

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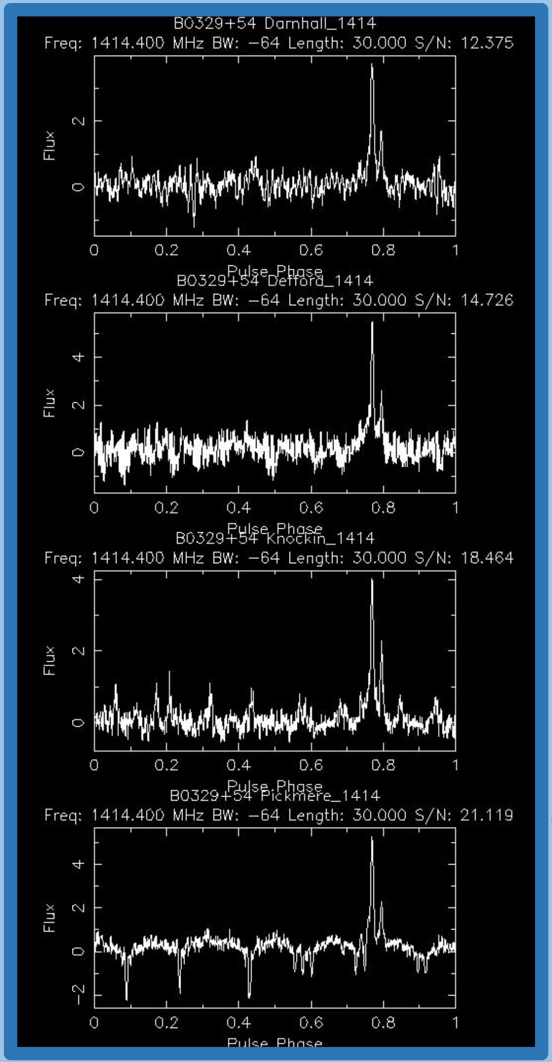

- RFI is time, position, and sub band dependent
  - Some sub bands are consistently quite clean...
    - ...Others are not...
    - ...But can be improved!
      - Median clipping, MAD

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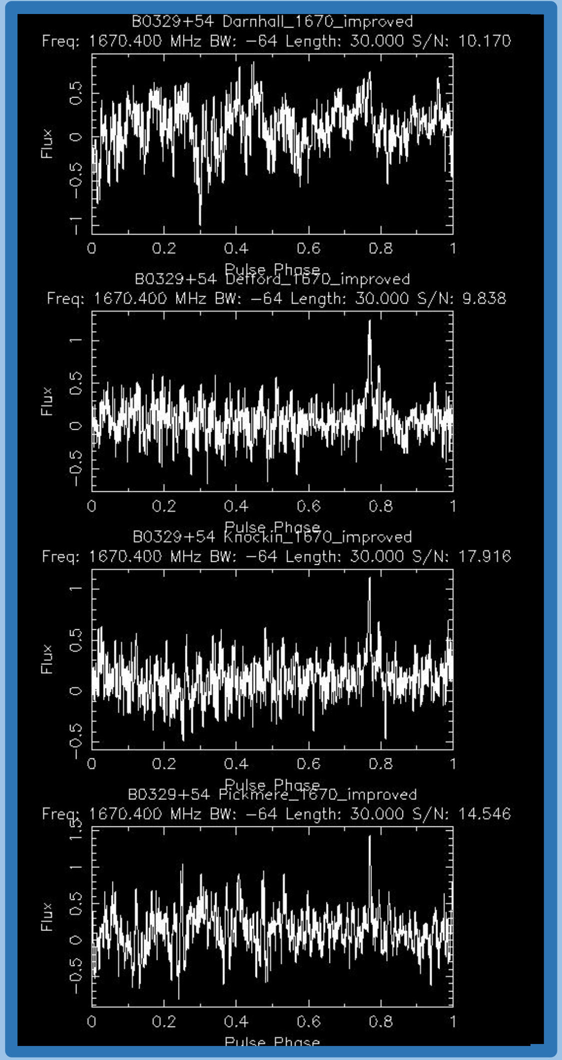
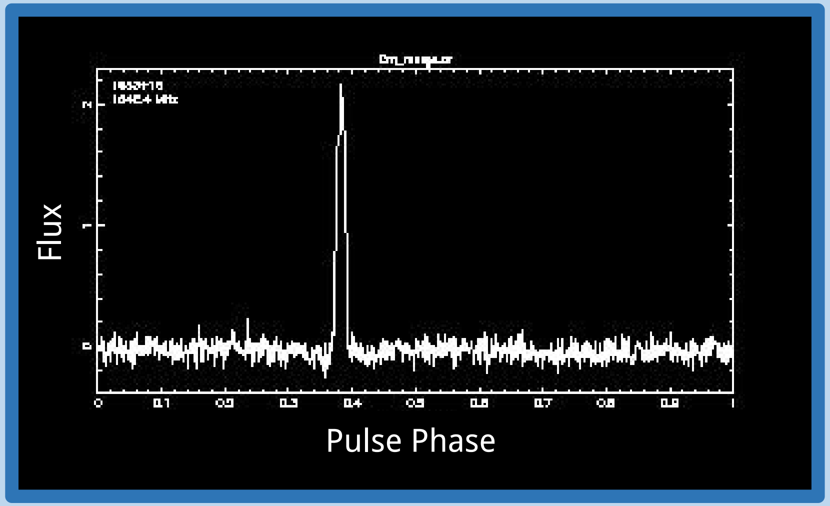


Results: Combining bands

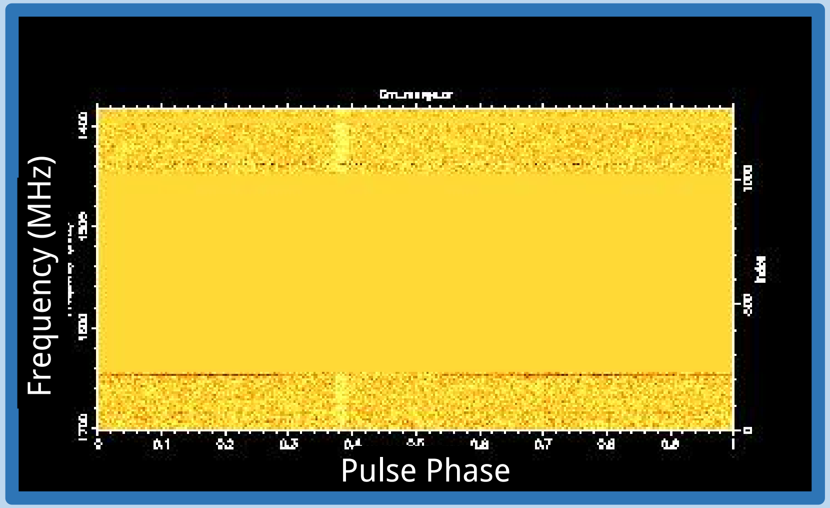
We can combine data from separate baseline boards:

Details:

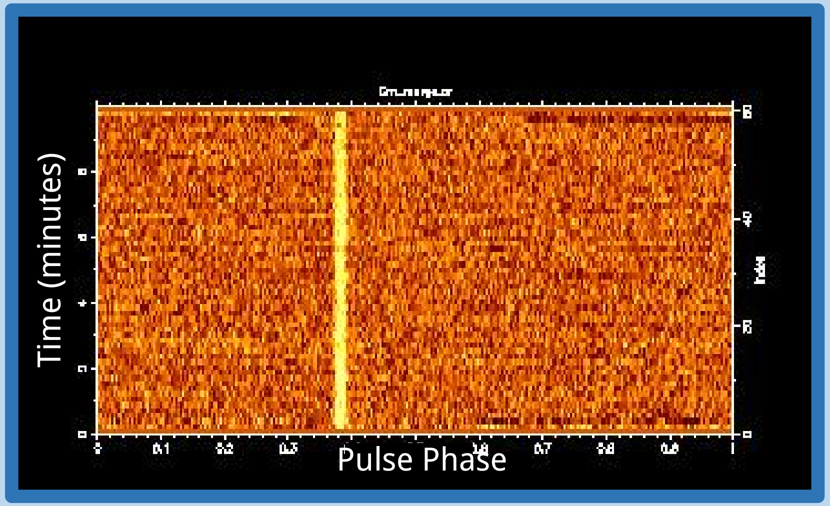
- Source: PSR B1933+16
- Sub bands: 1414.4, 1670.4 MHz
- Antenna: Cambridge
- Observation length: 10 minutes



Pulse Profile



Phase vs Frequency



Phase vs Time

Results: Combining beams

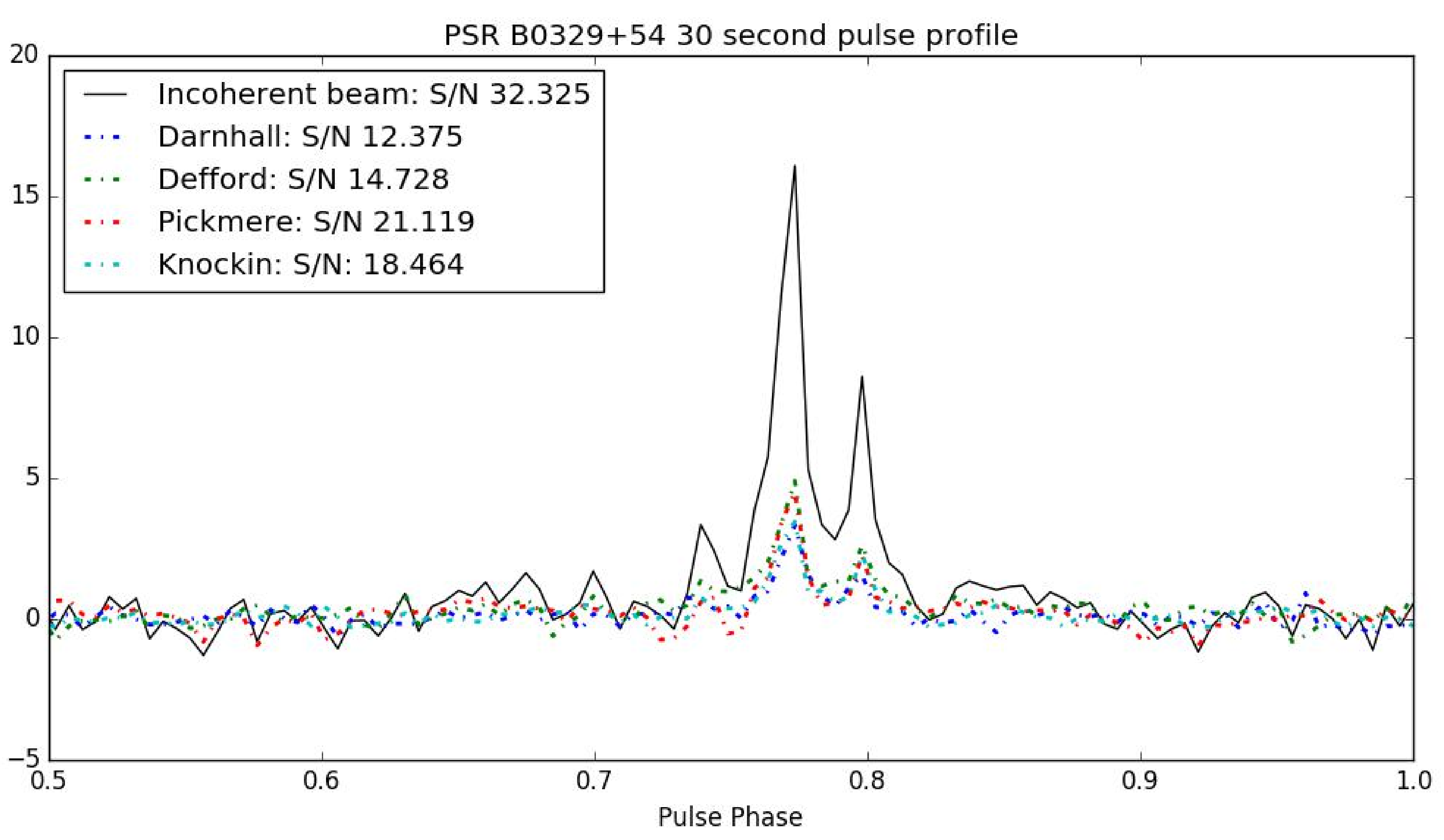
We can combine individual dishes for increased sensitivity:

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:

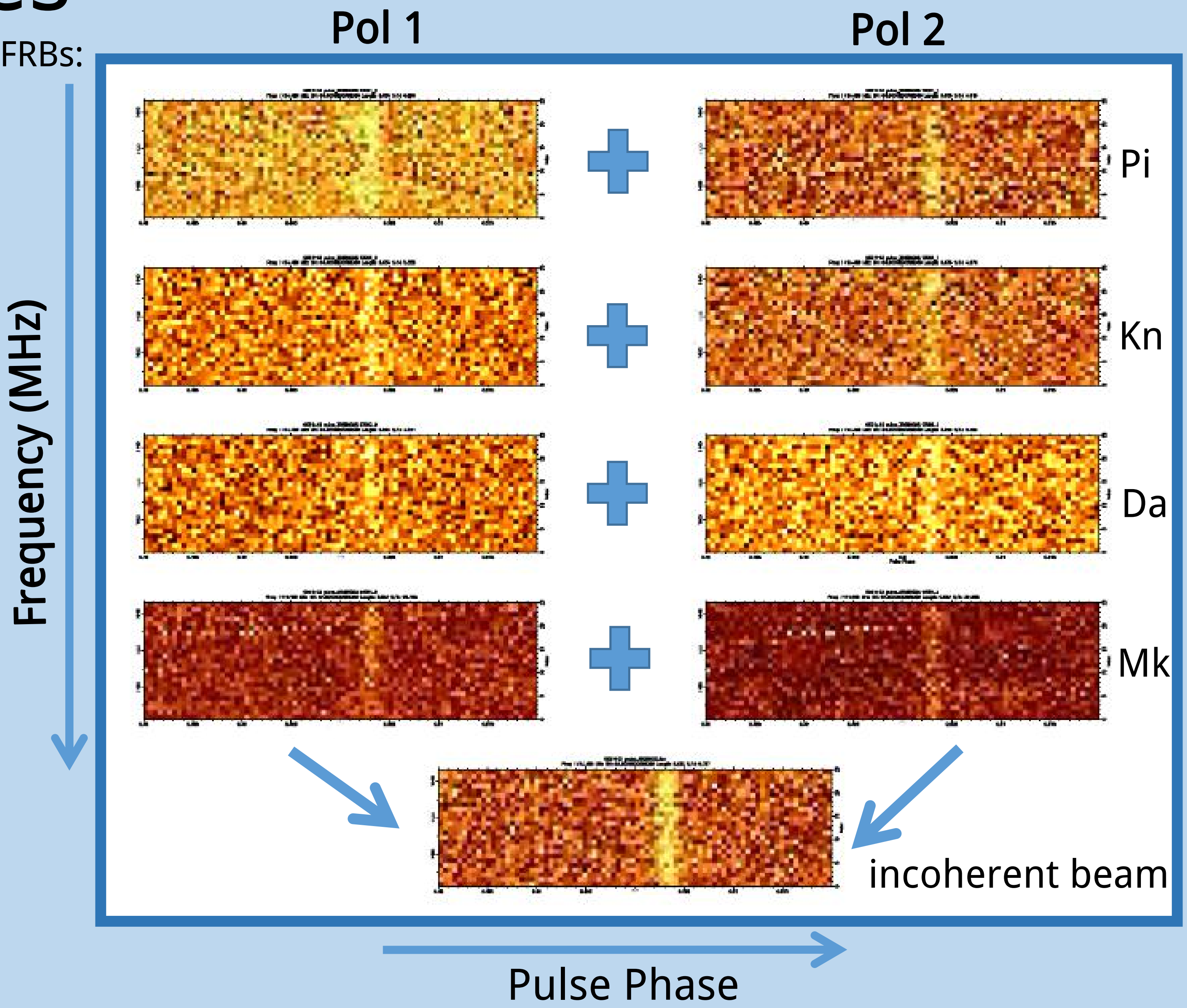
Details:

- 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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