BIGCAT GPU Correlator

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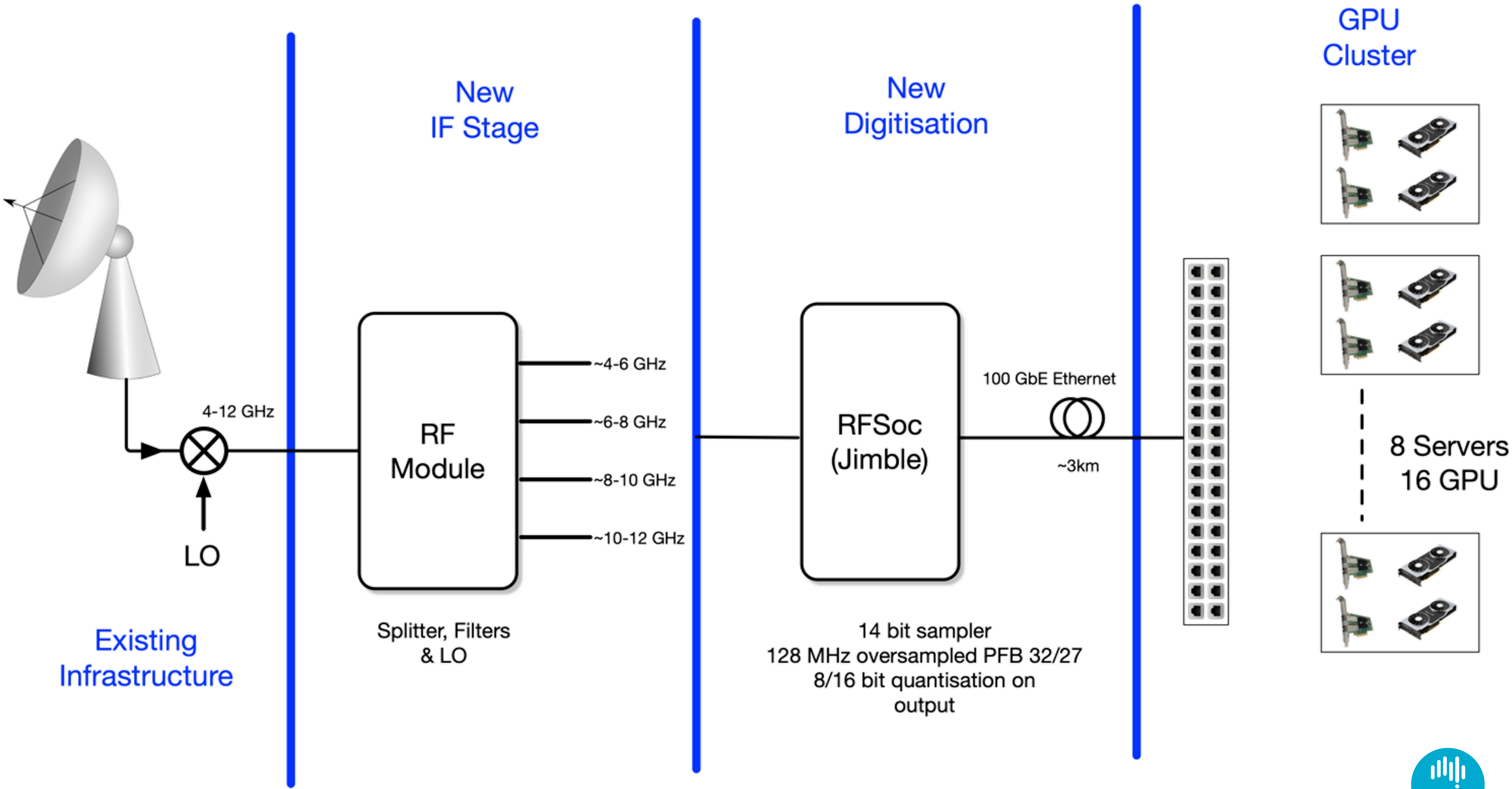
Australia Telescope Compact Array (ATCA)

- Array of six 22-m Cassegrain antennas spread over 6 km
  - 3km east-west track with 214m northern spur, 6th antenna “fixed”
  - ~425 km northwest of Sydney, ~21 km west from Narrabri
  - Officially opened 2 September 1988
- 1.1-105 GHz frequency coverage
- 4 GHz bandwidth backend (CABB)
  - 2x2 GHz tunable over 8 GHz
  - Only 2x64 MHz for VLBI

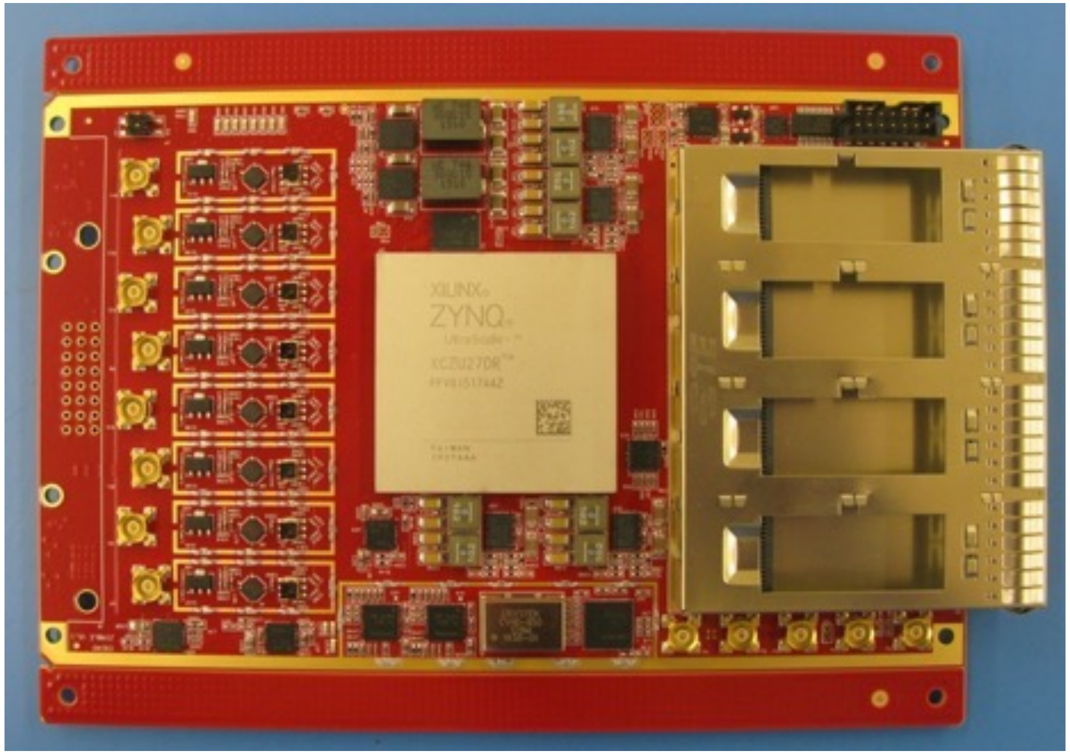
ATCA-BIGCAT upgrade

- BIGCAT: Broadband Integrated Gpu Correlator for ATca
  - Replacement of CABB digitisers and correlator with a hybrid FPGA+GPU backend
- (Partially) Government funded, led by WSU (PI Ray Norris)
- Key aspects of BIGCAT:
  - Double instantaneous bandwidth to ~8 GHz
  - Flexible spectral resolution
  - Improved reliability
  - More flexibility:
    - Many more options wrt. frequency resolution and integration times
    - Ability to change quickly between different observing modes
  - More adaptable to automated observing (e.g. rapid ToO follow-up)
  - Retain standard CABB features (e.g. mosaicing)
  - Installed Q4 2024 till Q1 2025



GPU
Cluster
New
IF Stage
New
Digitisation
4-12 GHz
LO
RF
Module
~4-6 GHz
~6-8 GHz
~8-10 GHz
~10-12 GHz
RFSoc
(Jimble)
100 GbE Ethernet
~3km
8 Servers
16 GPU
Existing
Infrastructure
Splitter, Filters
& LO
14 bit sampler
128 MHz oversampled PFB 32/27
8/16 bit quantisation on
output

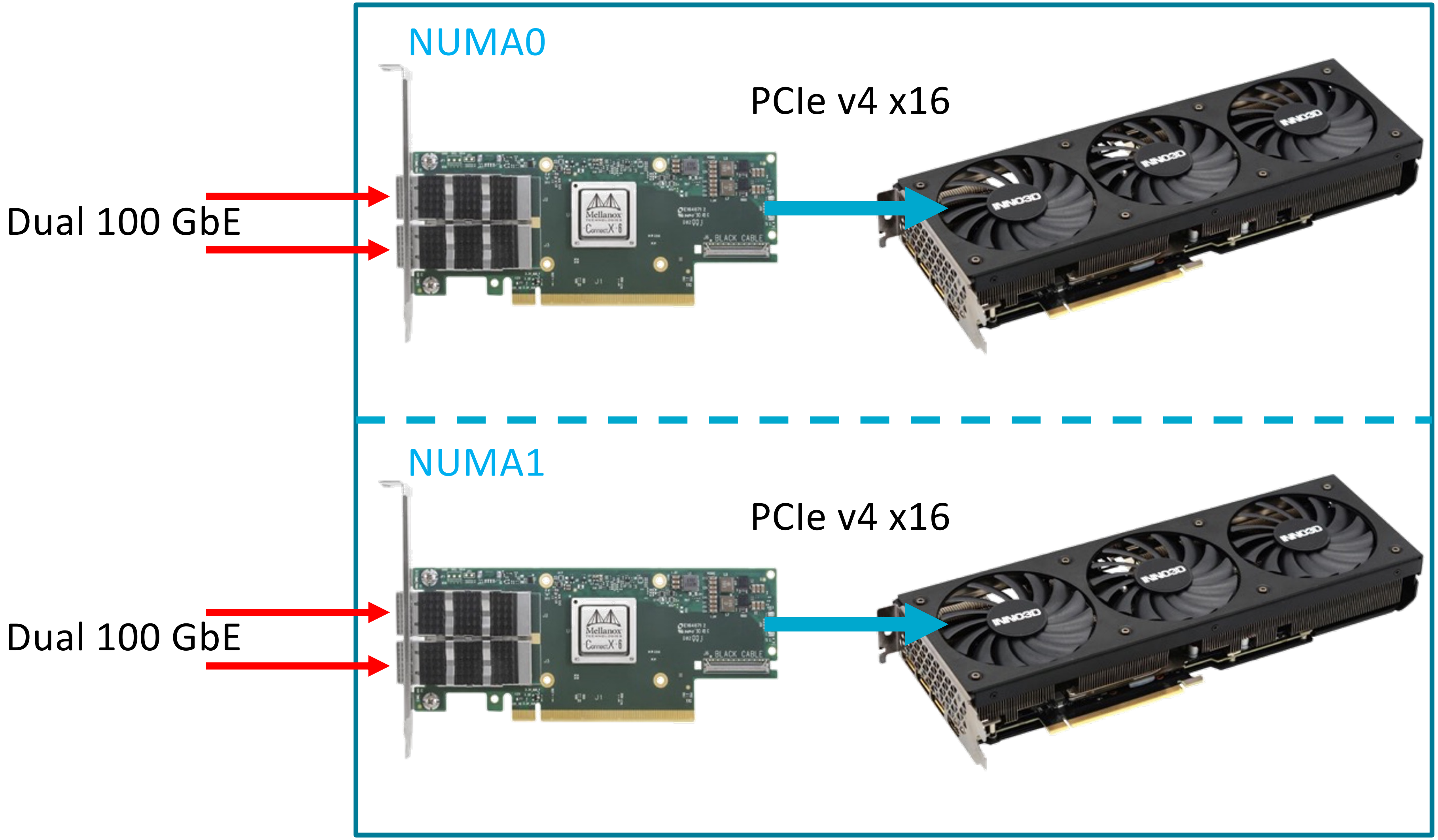
Jimble Digitisers

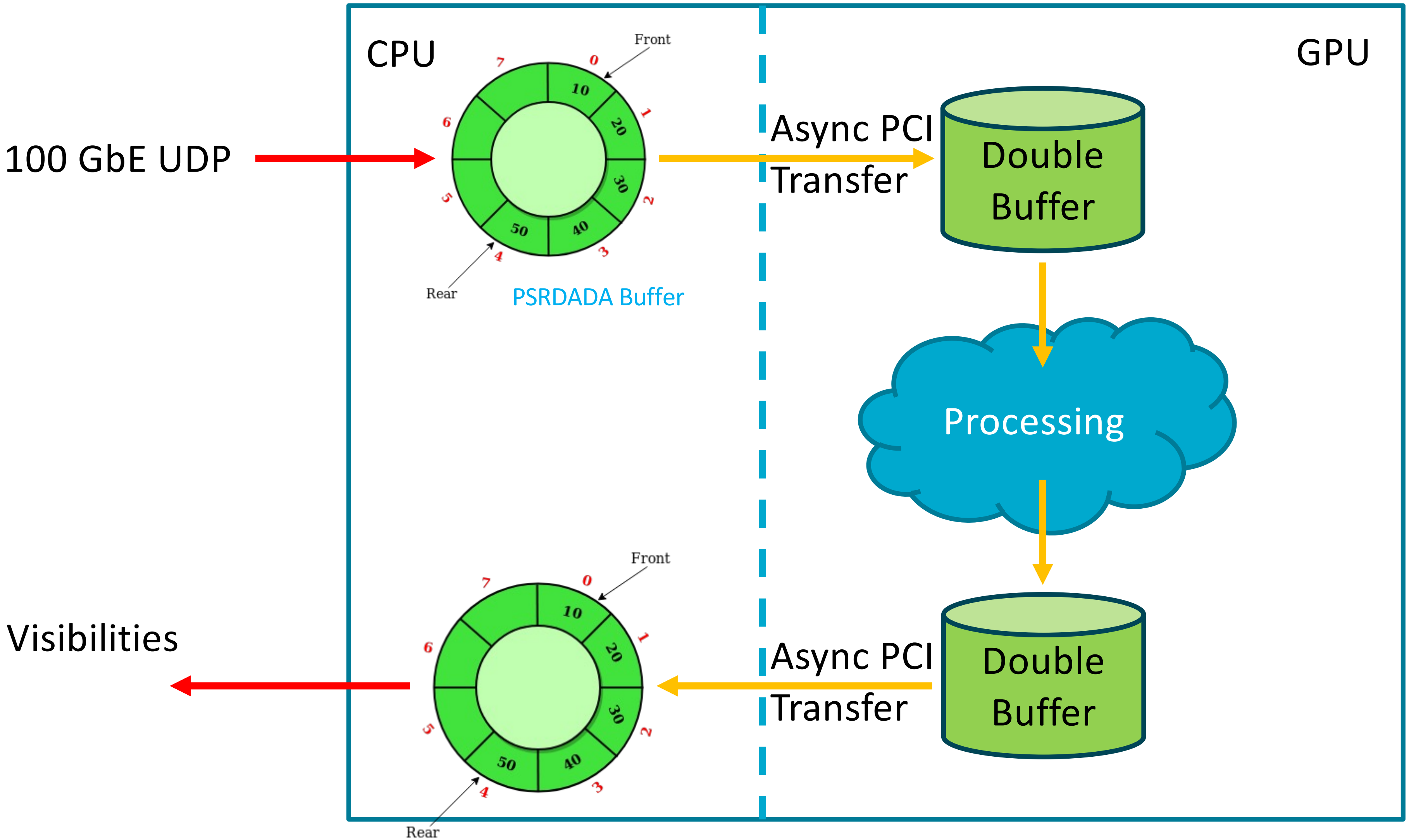


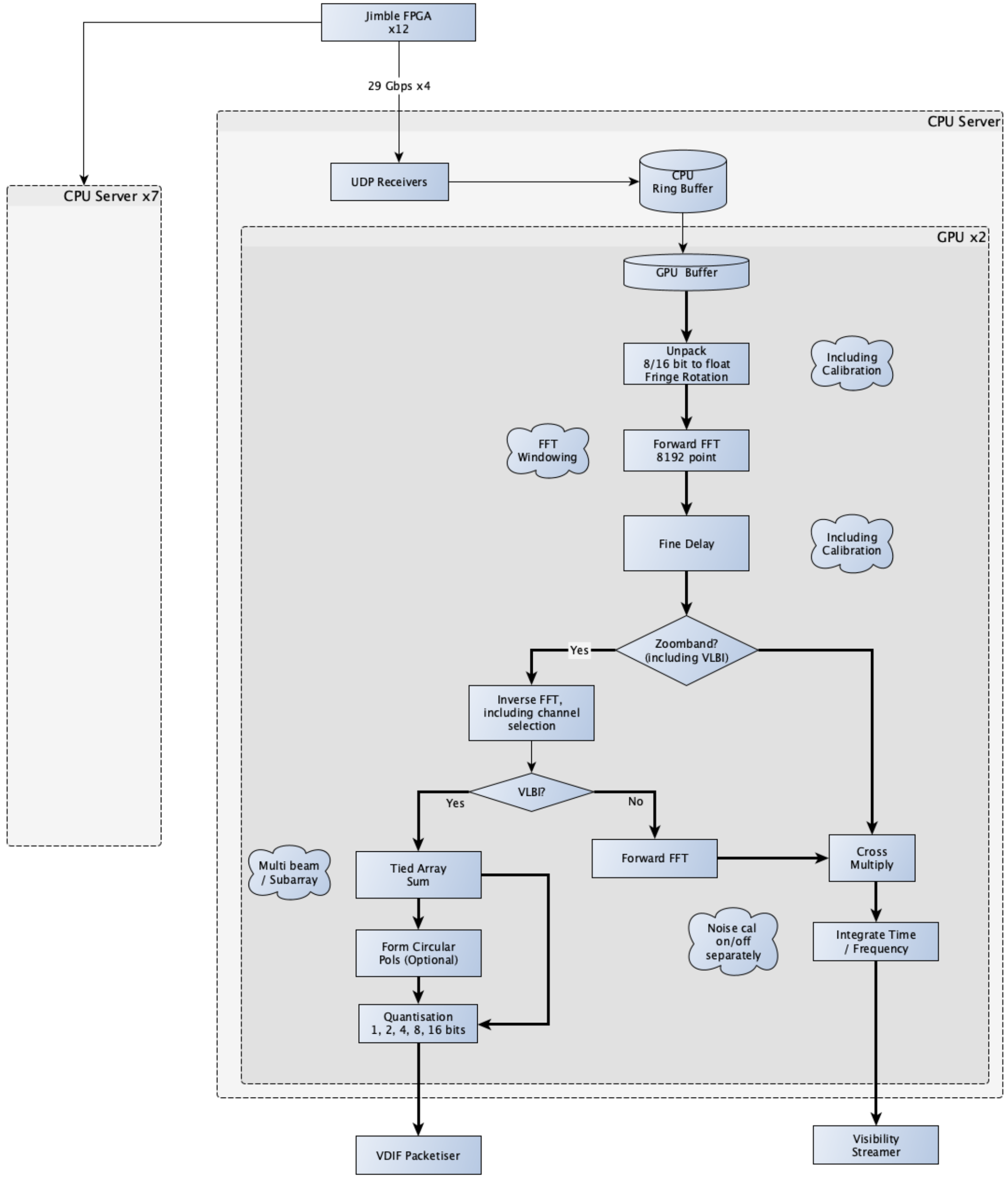
- 2 GHz IFs sampled using Xilinx RFSoC ADC
  - 8 samplers and FPGA fabric on single chip
  - 14 bits/sample
- Built into CSIRO “Jimble board”
  - 4x 2 GHz per board
  - 2x 100 GbE output
  - 128 MHz PFB, oversampled (151 MHz)
  - 8/16 bit streamed to GPU
  - Packetise into Ethernet UDP formatted as CODIF
- Jimble common to CryoPAF project
  - Plan to upgrade for Parkes UWB systems using same firmware as BIGCAT

GPU Backend

- GPU backend 8+1 servers, with 2 GPU and 2x100 GbE dual port
  - Nvidia L40 (same Ada Lovelace architecture as RTX 4080)
  - 116 Gbps/GPU
- Each 128 MHz coarse frequency channel processed independently
  - Same frequencies from all telescopes to single GPU
    - No GPU cross connect planned
    - 4 coarse channels/GPU
- 291 Gbps/antenna
- 1.7 Tbps total
- Initially GPU code written by Xinping Deng – currently developed by Ian Morrison

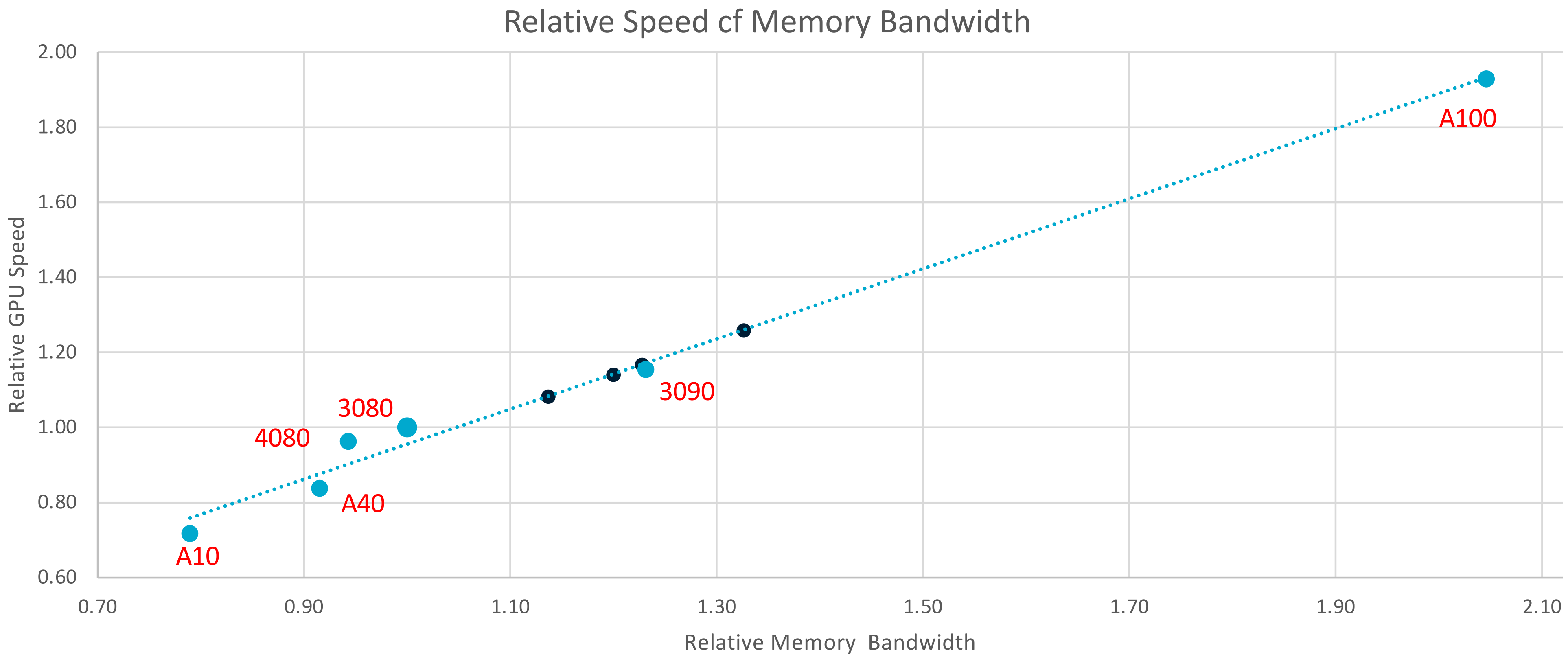

NUMA0
PCIe v4 x16
Dual 100 GbE
Mellanox
ConnectX-6
BLACK CABLE
INNO3D
NUMA1
PCIe v4 x16
Dual 100 GbE


CPU
GPU
100 GbE UDP
Front
Rear
PSRDADA Buffer
Async PCI
Transfer
Double
Buffer
Processing
Double
Buffer
Async PCI
Transfer
Front
Rear
Visibilities



Jimble FPGA
x12
29 Gbps x4
CPU Server
CPU Server x7
UDP Receivers
CPU
Ring Buffer
GPU x2
GPU Buffer
Unpack
8/16 bit to float
Fringe Rotation
Including
Calibration
FFT
Windowing
Forward FFT
8192 point
Fine Delay
Including
Calibration
Zoomband?
(including VLBI)
Yes
Inverse FFT,
including channel
selection
VLBI?
Yes
No
Multi beam
/ Subarray
Tied Array
Sum
Forward FFT
Cross
Multiply
Form Circular
Pols (Optional)
Noise cal
on/off
separately
Integrate Time
/ Frequency
Quantisation
1, 2, 4, 8, 16 bits
VDIF Packetiser
Visibility
Streamer

Benchmarking – Memory Dependency



Zoombands vs Spectral Windows

- Huge FFTs possible on GPU
  - Modest spectral resolution does not require “Zoombands”
  - Process entire band at high spectral resolution
    - Average channels across whole band to continuum resolution (e.g. 1 MHz)
    - Define “Spectral Window” over regions of interest
      - Select channels range and less (or no) averaging to form band of higher spectral resolution
    - Don’t keep entire band at high resolution to reduce size of data sets
  - < 1 kHz spectral resolution demonstrated over entire band
- Zoombands needed for very high spectral resolution and potentially reduce overall compute load

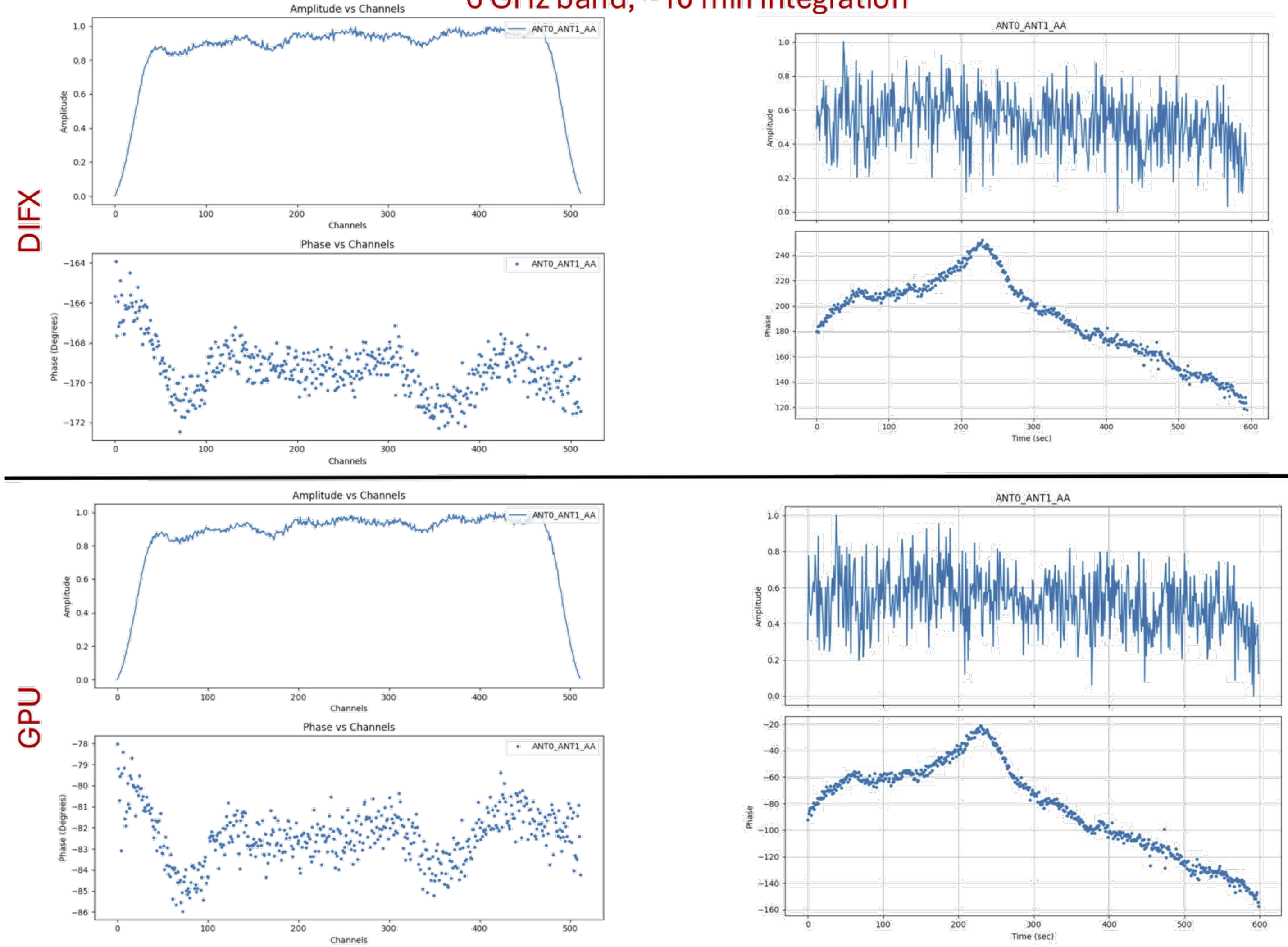
Spectral Flexibility – *Indicative numbers only*

- Up to 18.5 kHz over entire 1-3 GHz band (4 km/s)
- Up to 74 kHz over 8 GHz at > 4 GHz (5.5 km/s @ 4 GHz)
  - “Spectral window” selectable to reduce data rate
- Up to 0.01 km/s over limited bandwidth (zoom bands)
  - Up to 8 zoombands per 128 MHz
  - Maximum 262144 spectral channels over ALL spectral windows and zoombands
- Specific spectral resolutions will be ”pre-canned” modes, but new modes easily created then tested before being offered to astronomers
  - E.g. 4 zoom bands (per 128 MHz) of 16 MHz, each with 4096 spectral points
  - Constrained by GPU resources and visibility data rate
  - Zoombands and spectral windows “tunable” by observer

DIFX Comparison

- Prototype digitizer modules
- 2 km baseline
- Recorded voltages
- 2,6,22,55 GHz

6 GHz band, ~10 min integration



VLBI

- CABB limits VLBI to 2x 64 MHz (dual pol)
  - 1 Gbps maximum rate, no frequency flexibility for astrometry/geodesy
- BIGCAT will give access to full IF bandwidth
  - 2 GHz for 1-3 GHz
  - ~8 GHz higher frequencies
- Initially 8-16 Gbps maximum rate
  - Limited by disk recorders. Much higher rates possible with faster or multiple recorders
- Flexible selection of subbands over full bandwidth
  - However, limited by 128 MHz first stage coarse filters
    - Currently no plans to generate VLBI bands straddling coarse channels

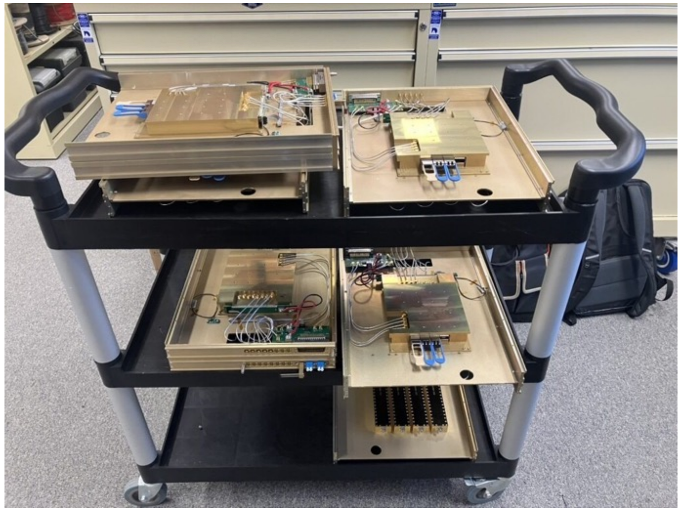
Advanced VLBI*

- Multi-bit option
  - 2,4,8,16-bit quantization
- Multiple phased array beams
  - Limited by available recording capacity/speeds
- Phasing on “near field” objects (ie satellites)
- Subarray option
  - “Fly’s eye” VLBI?
  - Frequency subarray – e.g. S/X using separate antenna?
- Record antennas separately (ie no phasing, fringe rotation etc)

** Not promised on day 1!*

Timelines

- Digitizer modules built
- 2 stage upgrade:
  - Replace CABB with BIGCAT digitisers/GPU
  - Upgrade IF to full 8 GHz
- Phase 1 ~Feb 2025
  - Integration of GPU with C&M
  - Outstanding Firmware bugs
- Phase 2 Q3-Q4 2025
  - Large manufacturing effort
  - Maybe combine with infrastructure updates



GPU Software

- All processing code written in CUDA
  - All algorithms VLBI “compliant” – no short baseline assumptions
  - All testing so far on VLBI baselines
- Main kernels written in independent library
- When tested/documented will make available as GPLv3 software license via git
  - Hope long term to have general purpose interferometry processing library which can be used by other telescopes
- Initial kernels will be very specific to ATCA requirements

Thank you

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