Radio Astronomy Technologies at CSIRO

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ATNF Technologies Capabilities

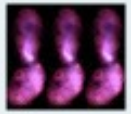
- **Antennas & Receivers (Front-end) (~15→18):** RF technologies (Feeds; OMTs; LNAs; RF Electronics; Cryogenic systems; Mechanical design; …)
  - **Workshop (~5→6):** Mechanical systems (Machining; Fitting; Production;…)
- **Signal processing (Back-end) (~19→22):** Digital technologies (RFoF; Samplers/Digitisers; Timing systems; Beamformers; Correlators;…) - Digital Signal Processing & FPGAs
- **Scientific Computing (~13):** Control and monitoring systems; calibration strategies and algorithms; data processing (e.g ASKAPsoft).
- **Engineering Generalists (~5):** System Scientists/Engineers; System integrators; New Ideas; …
- (**SKA Construction Group** – Manage SKA1-LOW construction contracts.
  - Contact negotiations in progress.)

**** Produce fully integrated radio telescope systems!**

- **Concept; design; construction; testing; commissioning; operation; science.**

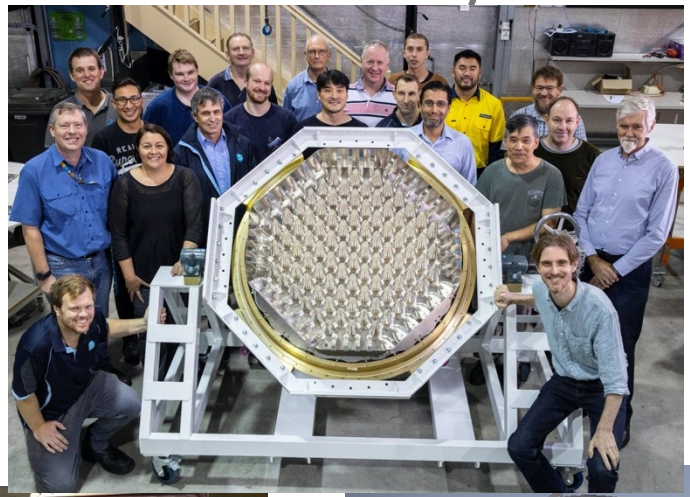
Next generation Radio Astronomy Technologies

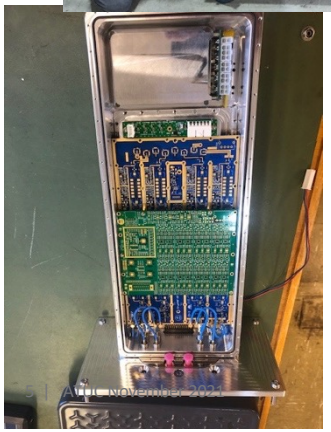
- **CSIRO Astronomy Research and Development:**
  - Phased Array Feed systems (**PAF**s)
  - Ultra Wide Band systems (**UWB**s)
  - FPGA-based Digital Signal Processing (**DSP** systems)
  - COTS-based back-end systems – (GPU, ALVEO-FPGA, Switch)
- **Complementary R&D activities**
  - Space systems?
    - CSIROSat-1 (Cubesat)
  - (Commercialisation)
    - New spin-out company QUASAR for satellite tracking with PAFs (April 2021)
    - Leveraging cryoPAF technologies.
  - Balance Impact on ATNF & New resources
- **R&D effort:** Sustain at about 25-30% of engineering effort
  - In-project R&D – most of our projects are novel and unique
  - Focused R&D – new ideas & exploiting new disruptive technologies

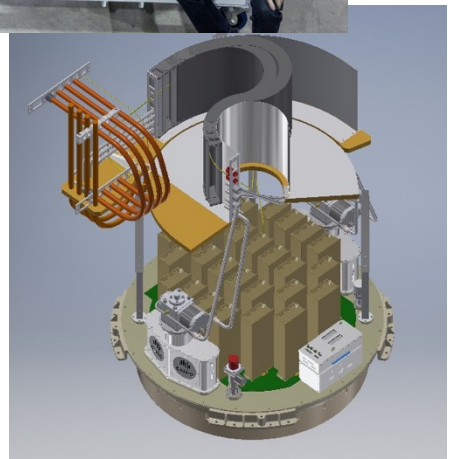
Technology	2020	2021	2022	2023	2024	2025	2026 +
 Ultra Wide Band Feed Systems	0.7 – 5.0 GHz systems PKS MPI						
			4.0 – 30 GHz systems PKS ngVLA				
					Cooled/room temp Rocket Phased Array Systems (0.7 – 2.0 GHz) ASKAP		
 Phased Array Feed Systems	Cryogenic Rocket Phased Array Systems* (0.7 – 2.0 GHz) PKS FAST				Cryogenic Phased Array Feeds (20GHz and above) ATCA Quasar		
			Cryogenic Rocket Phased Array Systems (4.0 – 20.0 GHz) ATCA Quasar				
 Digital Signal Processing	RFSoC Technologies (low frequency, large volume) VLBI-Low MWA SETI Commercial						
		RF System on a Chip Technologies - scalable and fully digitized systems* (high frequency, high bandwidth – low volume) PKS ATCA TID					
			COTS Technologies (FPGA; GPU; P4 switches) – beamforming and signal processing* PKS ASKAP ATCA SKA				
 Image and Data Processing	RFI mitigation, real time processing, big data analytics, archiving and end user curation All ATNF facilities						
 Underpinning Technology Development	Antennas, feeds and RF design and EM modelling, cryogenic systems, ultra-low noise amplifiers (LNA) and electronics design, precision machining and manufacture (including exotic materials), power supply systems and thermal design All ATNF facilities						
	Embedded software and computing, networking, high precision timing, fibre optic systems All ATNF facilitie						

*To accommodate the commercialisation project inside CASS, the Technologies Program will resource dedicated training and knowledge translation across to the team recruited into Quasar.
Shaded boxes indicate technologies feeding into Quasar.

Parkes cryo-Cooled Phased Array Feed



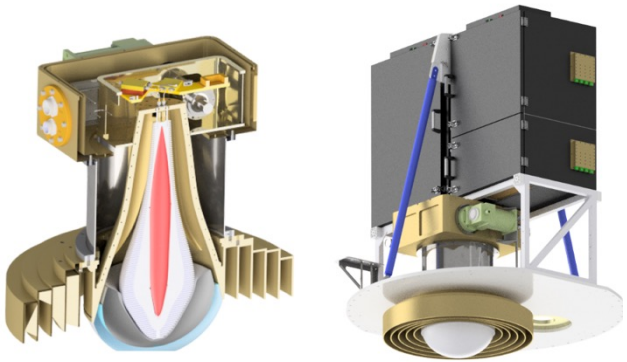




Funded and construction underway

- 700 MHz - 1950 MHz
- ~20-25 K System Temperature
- ~3 x Multibeam footprint with Nyquist sampling
- Combined 10-30 fold survey speed increase
- ~1.5 deg^2 FoV
- Up to 70 x 2 pol beams
  - Less beams needed at low frequencies
  - Multiple modes – many commensal
- Construction underway
  - Structural Thermal Model complete
  - Dewar under vacuum and cold
  - RF electronics boards – screened
- RFSoC board for digitisation at front-end (screened)
  - "Jimble" board under testing. (Rev3)
  - Output of up to ~920 MHz BW available
- COTS beamformer – designed and under testing
  - using ALVEO technologies & P4 Tofino switches
- Processed BW depends on digital and GPU cluster sizes
  - Funded 600 MHz. Seeking extra ~$200k to full 920 MHz
- Extensive Parkes infrastructure upgrades
  - He-lines; Optical fibres; Co-axial cables; GPU cluster update.
- Production underway. On telescope in 2022.
- Operational 2023

Parkes Ultra-Wideband - Low ‘UWL’



- 700MHz - 4 GHz, ~20 K System Temperature, Linear polarization feeds, Digitisation at focus
- Installed in 2018 – main low-freq system at Parkes
- Publications flowing

- Observational Developments:
  - Commensal observing modes
  - Scanning
  - New observing modes (e.g., fold multiple pulsars simultaneously)

- Technical Developments:
  - RFI mitigation tools (adaptive RFI mitigation, impulsive RFI mitigation, flag tables)
  - Calibration schemes (pseudo-random noise etc.)

- Update digitisation with RFSoC board (Jimble)
  - Oversampled filterbanks

- UWB-L feed (1-5 GHz) for MPIfR – in construction
- UWB-L RF and Digital system for Tid – under discussion

Parkes Ultra-Wideband-Mid/High ‘UWM/H’

Seeking funding

- 4 GHz - ~25 GHz
- ~20 K System Temperature
- Linear polarization feeds
- Digitisation at focus – shares digitisers and backend infrastructure with UWL
- Essentially ‘just’ the frontend – frontend, RF electronics and conversion required
- Single feed for entire range would have sub-optimal feed illumination – engineering preference is for 2 feeds, 4-15GHz, ~15-27 GHz, or ~4-18GHz, ~18-32 GHz

- Will replace most high-freq feeds at Parkes
  - → **All systems available on the antenna**

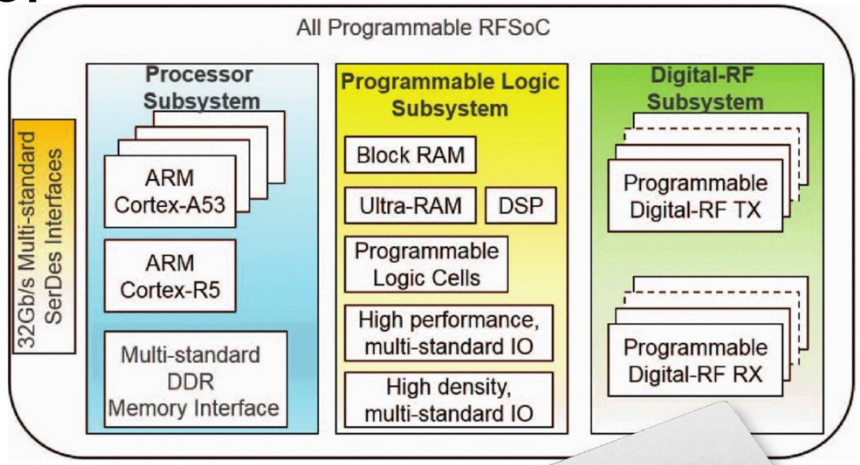
- ARC LIEF proposal submitted!! Result in Jan’22?
  - Critical future development @ Parkes.

RFSOC based digital back-ends

RFSoC - more than an FPGA

Four major parts to RFSOC:

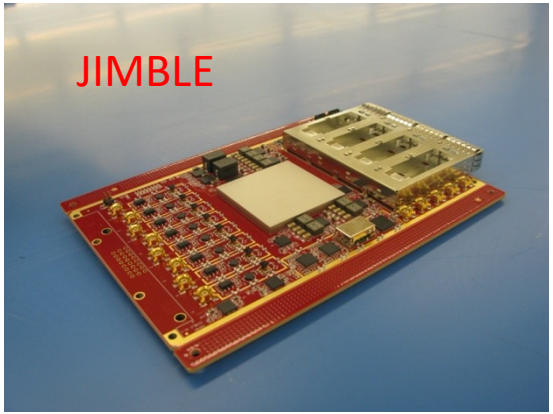
1. **Digital-RF subsystem (ADC/DAC)**
2. **Programmable logic (FPGA core fabric)**
3. **Processor System (ARM Cortex + DDR)**
4. **SerDes interfaces (high speed serial IO)**



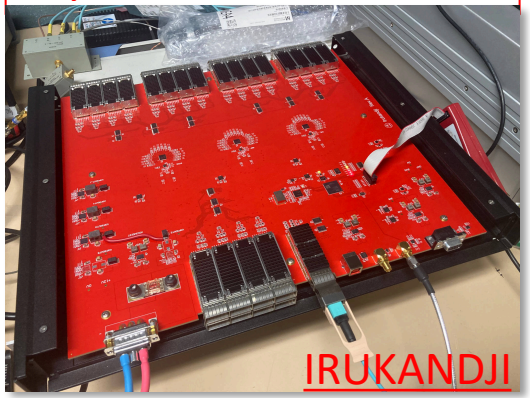
Powerful combination of four technologies in one - all four are utilised by astronomy

CSIRO RFSoC boards

JIMBLE



Synchronisation board



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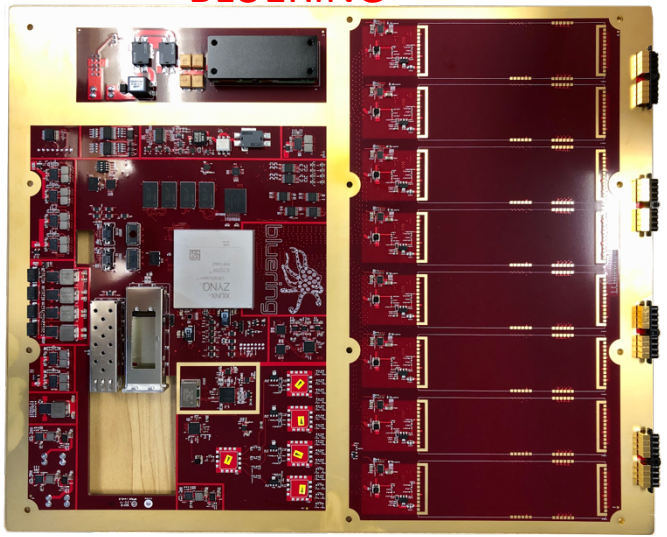
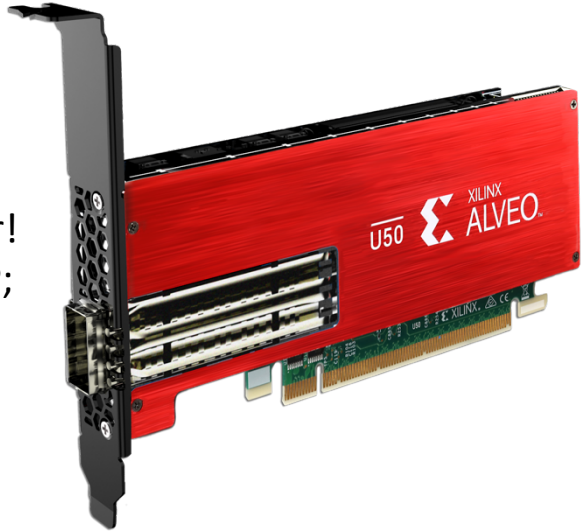


- 8 x 2 GHz inputs; 12 bit outputs
- Optical outputs only (100 Gbps channels)
- Designed to be screened - install near feed.
- Adopted for cryoPAF, UWL, BIGCAT
- Versatile and programmable
- JIMBLE testing – Rev3
- CryoPAF; BIGCAT; UWBs; (Quasar)

- 16 x 1 GHz inputs; 12-bit outputs
- Optical outputs
- Option for daughter RF input boards
- Great for low-freq arrays – **LBA-Low?**
- Protype built and tested – going to Rev3
- Test R&D array under development
  - MWA tile(s) @ Narrabri - Proof of Concept
- LBA-Low & (MWA; SETI) – under discussion

COTS digital back-ends (ALVEO & P4 Switch)

- **Xilinx Alveo** U50 HBM Board.
- Very small & low power – 20 in server!
- 8GB HBM; 5952 DSP; 1x100GbE
- FPGA-based accelerator boards



- Bare metal h/w switch
- Fully user programmable
- P4 Tofino
- Versatile for one-way traffic
- System under testing in CSIRO.

- Faster and cheaper than own FPGA boards
- Many variants and prices cheaper than FPGA chip!
- Adopted and under testing for cryoPAF
- Adopted for SKA1-LOW BF-Cor
- U280 version for ASKAP coherent FRB detector (CRACO)

GPU & ALVEO - BIGCAT & CRACO

PARKES

- **GPU** computer clusters at Parkes – collaboration with Swinburne
- The UWL uses the "Medusa" cluster & Breakthrough Listen a cluster for SETI
- The cryoPAF ALVEO beamformer will also feed into an updated Medusa GPU cluster.

ATCA

- **BIGCAT** (Broadband Integrated GPU Correlator for the Australia Telescope)
  - 8 GHz of BW (x2 current capability)
  - Use "Jimble" RFSoC digitizer board (8 x 2GHz) and 12-bit.
  - Aging CABB correlator to be replaced with GPU cluster
    - Flexible and versatile - new modes → New science
  - Funded via ARC LIEF proposal and construction underway

ASKAP

- **CRACO** – Coherent FRB detection @ ASKAP – Funded ARC LIEF!!
  - Sub-arcsecond localization & many more FRBs
  - Using ALVEO technology – utilises ASKAP correlator and all beams
  - Pilot/prototype R&D – small cluster + firmware/software development
  - Construction & Commissioning within 1 year. (Contact: Keith Bannister)

Possible Future ATNF developments?

- **Consistent with Roadmap!!**
- **RFI mitigation for all ATNF observatories**
  - Coordination and enhancement of effort. Underway. (George Hobbs talk)
  - R&D difficult. New Ph.D. student just started.
- **Future possible LIEF projects (next 2-3 years) –** (~$1-3m)
  - **LBA-Low:** (MWA; SKA) - **(George Heald talk)**
    - Prototype and test technologies with stations at Parkes and ATCA.
    - First science with MWA and also GMRT and FAST.
    - High sensitivity VLBI at Low Frequencies
  - **ASKAP tied array** – always part of ASKAP plans but not funded
    - High sensitivity VLBI station. Greatly enhance LBA.

Ideas for Longer term ATNF developments

- **Full LBA-Low implementation**
  - Work with MWA & SKA1-Low

- **Upgrade of ASKAP** beyond current surveys
  - Rocket PAF upgrade to improve sensitivity??
  - Different PAFs at higher frequencies?
  - Need to start thinking where to go - Science case

- **New ideas!!? – MUST be driven by Science cases**
  - Exploration follows by Ron Ekers.

Thank you

Astronomy and Space Science
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