Radio Astronomy Technologies at CSIRO

Tasso Tzioumis | 13 April 2021

ATNF Technologies Capabilities

- **Antennas & Receivers (Front-end) (~15):** RF technologies (Feeds; OMTs; LNAs; RF Electronics; Cryogenic systems; Mechanical design; …)
  - **Workshop (~5):** Mechanical systems (Machining; Fitting; Production;…)
- **Signal processing (Back-end) (~19):** 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; …

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

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

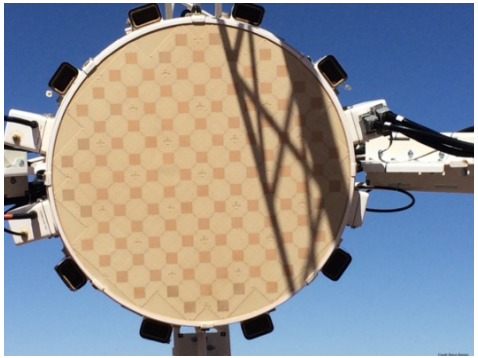
Directions for ATNF Engineering

- ** **Broad directions largely unchanged**
- **ASKAP** & **SKA**: Priorities for the Engineering Program.
  - Significant number of people and effort at present.
- Development projects for all ATNF facilities.
  - Budgetary constraints ☾ Priorities
- Strategic developments – develop capabilities.
- External contracts – maintain capabilities.
- ** **Critical capabilities in maintaining and developing radio astronomy observatories** **

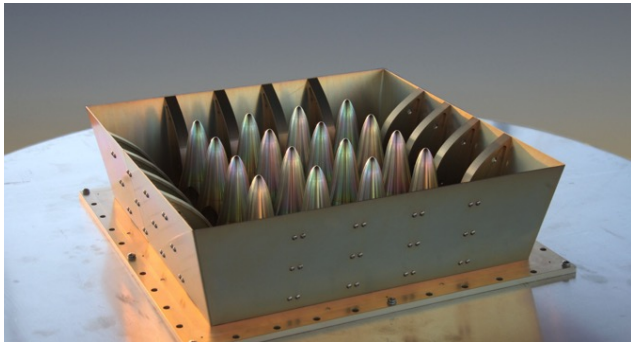
Next generation
Radio Astronomy Technologies

- **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 for satellite tracking with PAFs (April 2021)
    - Leveraging cryoPAF technologies.
  - Balance Impact on ATNF & New resources

Phased Array Feeds –Large Field-of-View (FoV)



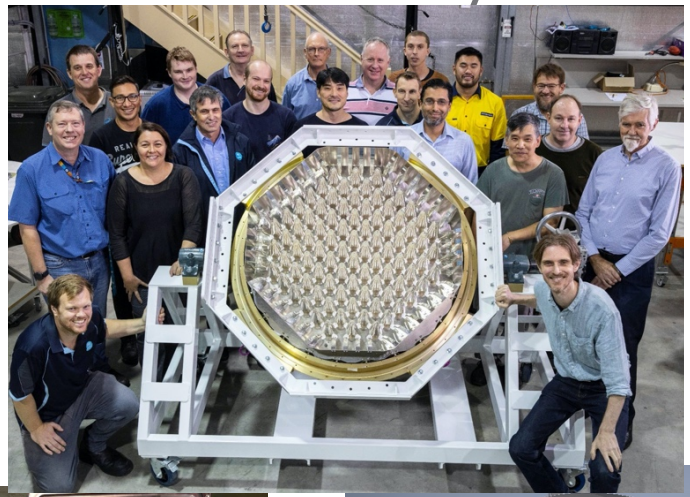
- Surveys
- Imaging
- FRB searches & localisation

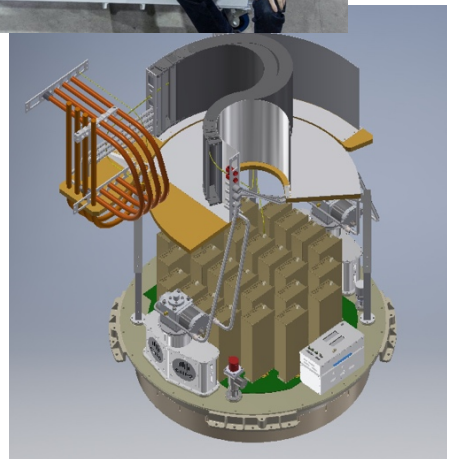


- ASKAP – Chequerboard PAF
  - 36 x 12m antennas
  - 94 x 2 pols PAF
  - 36 x 2 pols beams
  - 30 deg^2 FoV
  - 700-1800 MHz; 300 MHz BW
  - Tsys ~60-70K (uncooled)

- Next generation “Rocket” PAF
  - “rocket” elements; “edge” elements
  - Superb LNA matching
  - Wider BW (~3:1)
  - Cryo-Cooled for Tsys <20K

Parkes cryo-Cooled Phased Array Feed



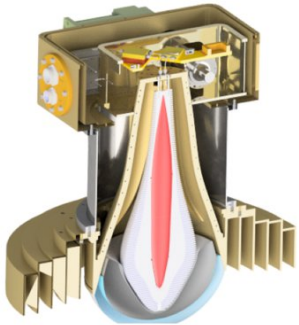


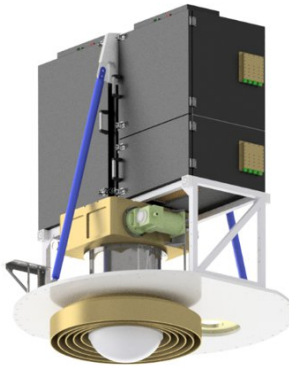
Funded and construction underway

- 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 tested. (Rev2)
  - 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
- Timelines in Jimi's talk.

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

- Arecibo failed – no UWL
- 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

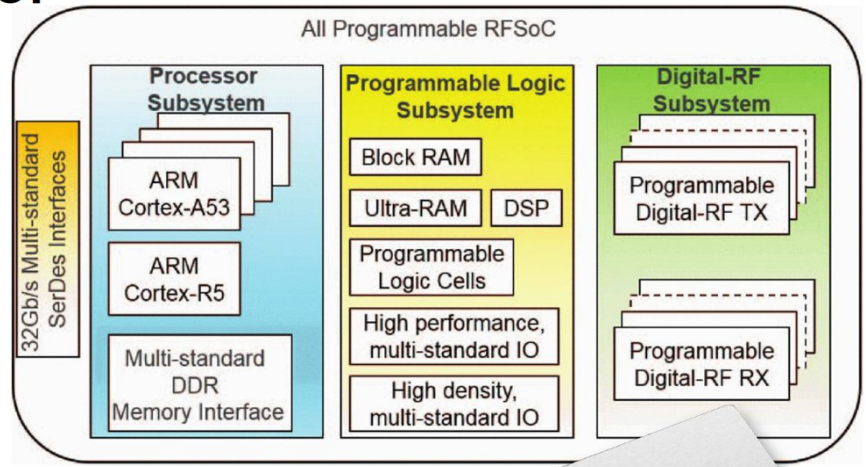
- ARC LIEF proposal submitted!!
  - See Jimi’s presentation

RFSOC based digital back-ends

RFSoC - more than an FPGA

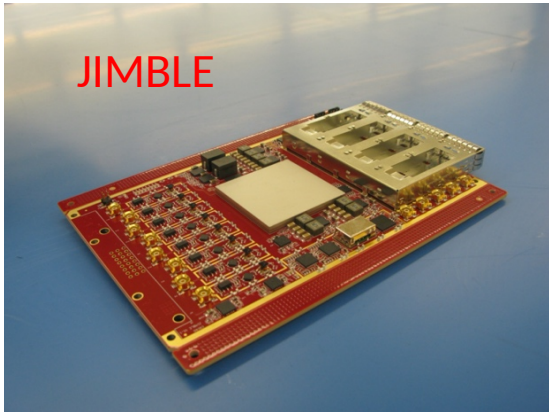
Four major parts to RFSOC:

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

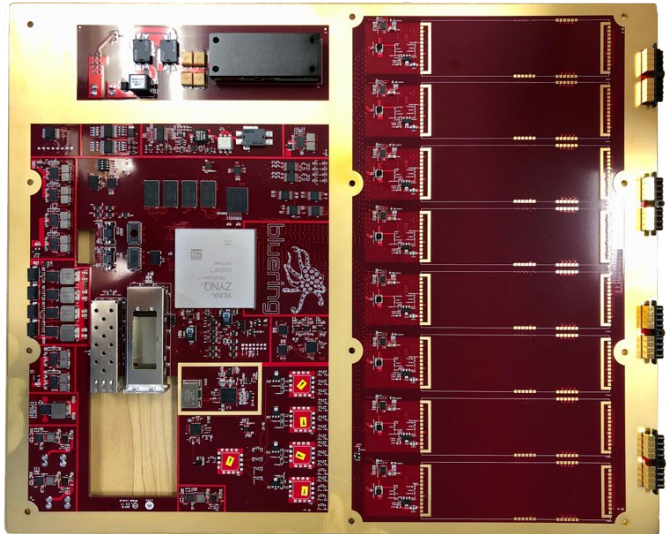
CSIRO RFSoC boards



- 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 – Rev2
- CryoPAF; BIGCAT; UWBs; (Sat tracking)

IRUKANDJI
Synchronisation board
In Construction

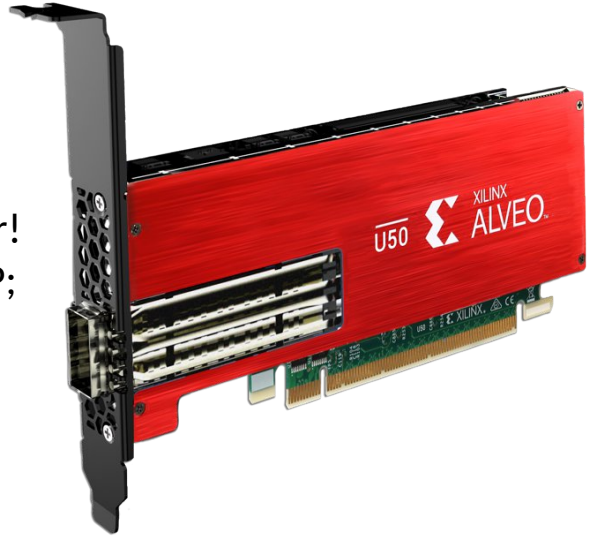
BLUERING



- 16 x 1 GHz inputs; 12-bit outputs
- Optical outputs
- Option for daughter RF input boards
- Great for low-freq arrays – **LBA-Low?**
  - See G. Heald's talk
- 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.

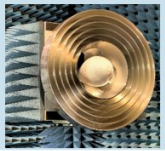
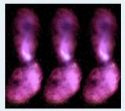
ATCA

- **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 - (contact: Chris Phillips)

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)

Roadmap and future

Technology	2020	2021	2022	2023	2024	2025	2026 +
 **Ultra Wide Band Feed Systems**	0.7 – 5.0 GHz systems AO PKS			4.0 – 30 GHz feeds (dual reflector) SKA			
			4.0 – 30 GHz systems PKS				
				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				Cryogenic Phased Array Feeds* (20GHz and above) ATCA		
			Cryogenic Rocket Phased Array Systems* (4.0 – 20.0 GHz) ATCA				
 **Digital Signal Processing**	RF System on a Chip Technologies (low frequency – large volume)						
		RF System on a Chip Technologies - scalable and fully digitized systems* (high frequency, high bandwidth – low volume) PKS ATCA ASKAP AO					
			COTS Technologies (FPGA, GPU, Switch) – beamforming and signal processing PKS SKA ASKAP				
 **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						

*To accommodate the proposed commercialisation program inside CASS, the technologies program must resource dedicated training and knowledge translation across to the team recruited into the proposed venture

Possible Future ATNF developments?

- **Consistent with Roadmap!!**
- **RFI mitigation for all ATNF observatories**
  - Coordination and enhancement of effort. Underway.
  - R&D difficult. New Ph.D. with Syd Uni just started.
- **Future possible LIEF projects (next 2-3 years)**
  - **LBA-Low: (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.
  - **Suggestions** from Community??
    - ATNF can do technical evaluation.

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

- **FAST Array** (China) – proposal under development
  - 6 x FAST dishes ☾ Full Square Kilometre sensitivity!!
  - PAF receivers – Collaboration with CASS in R&D?

Thank you

Astronomy and Space Science
Tasso Tzioumis
Program Director, Technologies for Radio Astronomy
P: +61 2 9372 4350
E: tasso.Tzioumis@csiro.au