# Technologies for Radio Astronomy

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# ATNF Technologies Capabilities

- **Antennas & Receivers (Front-end) (~15):** RF technologies (Feeds; OMTs; LNAs; RF Electronics; Cryogenic systems; Mechanical design; …)
  - **Workshop (~4):** Mechanical systems (Machining; Fitting; Production;…)
- **Signal processing (Back-end) (~15):** 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). (*Operations Program*).
- **Engineering Generalists (~4):** System Scientists/Engineers; System integrators; New Ideas; …
- (**Program support (4):** Systems engineering; Program & Project support)

***1: Small groups ☾ Single subject experts ☾ (Risk: Single-point failures?)**

***2: Critical mass issues ☾ Could not lose ≥ 1-2 people/group**

- ***People:*** ***No significant changes.***

# Directions for ATNF Engineering

** **Broad directions largely unchanged**

- **ASKAP-X & SKA**: Core business of the Engineering Program.
  - Much of the program's people and effort at present.
- Development projects for all ATNF facilities.
  - Budgetary constraints ☾ Priorities
- Strategic developments – develop capabilities.
- External contracts – maintain capabilities.

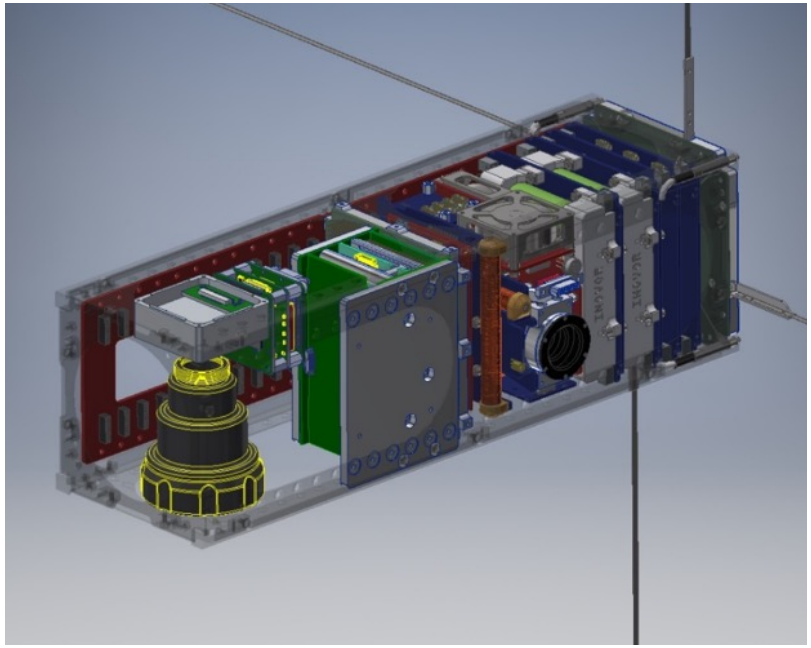
** **Critical capabilities in maintaining and developing radio astronomy observatories** **

# Current Technologies Projects (FY 2019-20)

1. **ASKAP-X:** Highest Priority; ~6 FTE (Engineering)
   - Enhanced modes – bug-fixes a priority
   - Coherent FRB searching – R&D and LIEF proposal
   - (ADE PAFs for **Effelsberg** & **Jodrell Bank** (External contracts)
     - Effelsberg operational ; Jodrell Bank – digital installation and testing. )
2. **SKA:** International commitment. ~8 FTE (Engineering)
   - Bridging activities (CSP; AIV; SDP; SaDT…)
   - AIP/ODP **technology developments** – PAF & Single Pixel consortia
3. **UWB:** System for Parkes ~2-3? FTE (Engineering)
   - 700-4000 MHz; novel technology
   - Operational at Parkes. Great results!!
   - Some development still necessary…
4. **Rocket PAF ☾ CryoPAF LIEF proposal Successful!**
   - Extensive R&D continuing in CASS. Cryo prototype.
   - Design for new Digital back-end (RFSoC) & Beamformer (Gemini)
   - Construction (~7 FTE) funded via LIEF proposal.

# Space Technologies

- **CSIROSat-1: 3U CubeSat. (~3 FTE)**
  - Hyperspectral IR Earth imaging
  - On-board FPGA and SoC image processing
    - Strong CASS technical involvement
  - In-orbit re-programming
  - S-Band down-link
  - Technology demonstrator
  - Capability building



- **Future Science Platform (FSP) - (~2-3 FTE)**
  - CASS involvement already in small projects
  - Space Situational Awareness; Satellite ground station; …
- **Space - Exciting new R&D**
  - **Impact on ATNF?? ☾ New resources needed!**
  - **Space research Group??**

# Future Projects

# Priorities and Funding proposals

- Any future project requires large CASS contributions
  - e.g LIEF proposals ~50% from CASS (mainly labour)
  - Limited CASS annual budgets – Labour + CAPEX
- ☾ Need to prioritise what proposals go forward each year
  - Implications for future years; Strategic considerations.
- **ATUC** link to community input in **prioritisation**.
  - LIEF proposals are university led.
  - Strong science case and support from community essential.

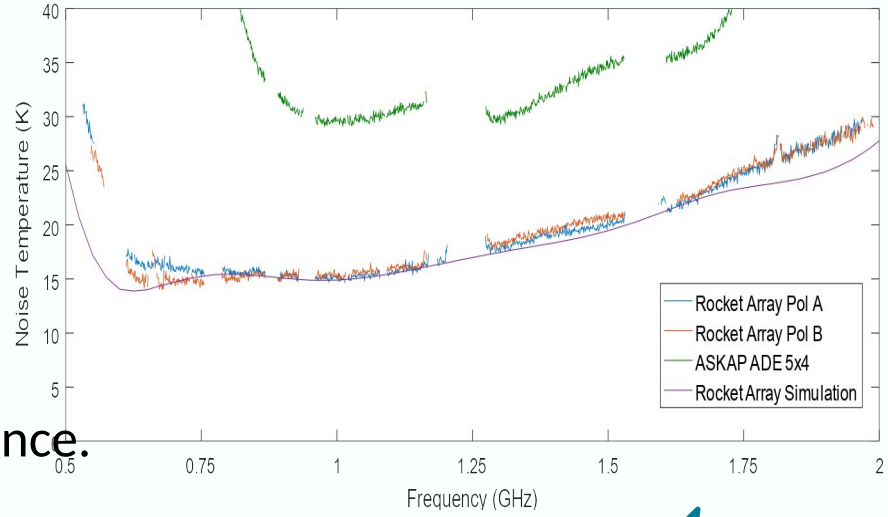
à **Expression of Interest (EoI)**

à EoI call – October 2019; CASS Exec review (Nov); ATSC comments (Dec)

- Possible candidates: BIGCAT(?); ASKAP Coherent detector; UWB-H @ Parkes
- LIEF proposals deadline (Feb-Mar 2020) – extended
- CRAFT COherent detector (**CRACO**) LIEF proposal submitted!!
- UWB-M/H @ Parkes – LIEF proposal in 2021??
- EoI call again in Sept-Oct.

# "Rocket" PAF ☾ CryoPAF

- Next generation PAF - "rocket" elements
- Superb matching with LNA ☾ improved performance
  - Noise Temp due to uncooled LNAs
- 4x5 prototype constructed & tested on Parkes
  - ~15K better than equivalent ADE tests
- Design better suited to cooling ☾ **cryoPAF**
  - ☾ **CryoPAF for Parkes** – Tsys ~20K !?
  - Cost: ~$3.5M (incl >7 FTE from CASS)
- LIEF led by UWA – Decision Jan 2020!
  - **Successful** after 3rd attempt…
  - ***Agreement underway for signature.***
- R & D underway – Construction to commence.
  - Prototyping – EM design; cooler; LNA
  - RFSoC based backend; SKA Gemini board for Beamforming.
- **Strategic priority – (Possible external contracts)**
  - **Continuing commitment by CASS**




**Parkes Talk by Jimi**

# GPU upgrade of ATCA - BIGCAT

- Update CABB and double BW (sensitivity increase) *(ATUC Jun 2017)*
  - Versatile; flexible; fast transients; maintainability; unattended observing; support
  - Full proposal ~$2.5M - Capital ~$1M; Labour ~$1.5M (mainly from CASS)
  - **CABB Update: ~**$1M. Possible within ~6 month period
    - **Fallback** if major CABB failure
  - ** ☾ **LIEF proposal;** Led by WSU ☾ **Successful!!**

  - CASS has continued R&D;
    - RFSoC design underway – Board in production **
    - GPU tests underway
    - Software Correlator design (GPU "hackathon" @ Pawsey) – April 2018
      - Initial effort underway

  - Full Construction over 2 years
    - Agreement underway for signature
    - Detailed Project Planning underway (Chris Phillips)
      - Contact Chris – involvement in developing Scientific Requirements?

# ASKAP coherent FRB detector

- **ASKAP coherent FRB detector** (+ tied-array VLBI)
  - GPU cluster needed (~$1M); Commensal; 1” localization
  - x 5-10 than best current systems on ASKAP
  - Comments:
    - Very high science return!! But competition means time critical.
    - Find alternative funding in community and start immediately!!?
    - R & D has continued – alternative funding not yet secured.

- Discussions on collaborative effort/funding ongoing
  - Requires ASKAP array fully operational
  - Highest priority for “ASKAP enhancements”
  - Concept Design finalized – **LIEF Proposal submitted** (Apr 2020)
    - CRAFT COherent FRB detection **(CRACO)**
  - **Pilot** project at MRO started by ATNF
    - Install h/w (June); Prototyping firmware/software (Sept); Testing (Dec)

# Digital systems R&D

- ADC: Faster designs
  - Current: 4 Gsps; New: 6 Gsps avail; Future: 8 Gsps & 16 Gsps!
- **Xilinx RFSOC: Integrated ADC + FPGA**
  - 8 x 4 Gsps ADCs or 16 x 2 Gsps ADCs. Sampling at 12-bits!
  - Chips now available; Eval Boards tested.
- **"Jimble"** RFSoC board (4 Gsps)
  - Boards designed and prototype construction
  - BIGCAT & UWB systems
  - CryoPAF back-end re-designed using RFSoC (Jimble)
- **"Bluering"** RFSoC prototype (2 Gsps)
  - Modular, scalable to 512 RF inputs
  - Direct RF sampling (12-bits)
  - Array-based DSP
  - Optical data transport
  - Prototype board in construction
- **RFSoC systems: ☾ game-changer**
  - UWB; CABB; cryoPAF; SKA; Space?, …


# Parkes UWB Mid/High

Based around UWBL and compact array CX system

**Utilising much of the UWBL system; i.e. Samplers; Back-end; GPUs; Software**

Current Bands are

- 4.0-15.4GHz
- 15.4-26.9GHz

Using 12 UWBL digitizers (6 per polarisation)

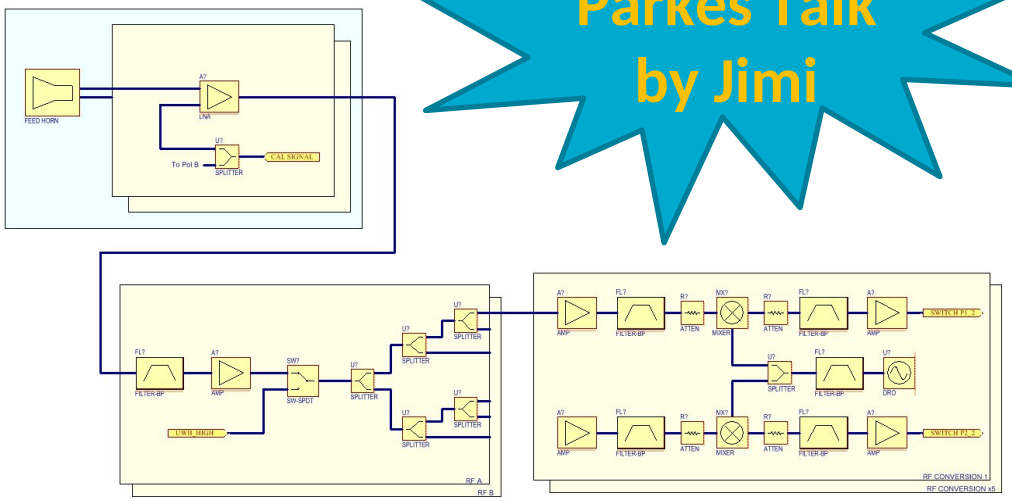
4-15 GHz band is sampled using 6 digitizers at 4096MSPS

15-27 GHz band is converted down to 4-15 GHz band

4-24 GHz system may be possible but is problematic as effective area changes; would be very attractive for other telescopes

- Suggestion for system up to 32 GHz!?
  - RA (31.3-31.8 GHz); Space (31.8-32-3 GHz) NASA/ESA

Parkes Talk by Jimi




UWB Mid preliminary circuit diagram

- **Discussed at ATUC 2014; Chose UWL first**
- **Cost: ~$0.5M h/w; + 5 FTE Labour.**
- **Needs funding. LIEF?? -2021?**
- **Priority?**

**NOT currently funded**

# Low-Frequency Long-Baseline Interferometer

- Science/utilisation
  - (sub)arcsecond imaging at LF in the Southern hemisphere.
  - Leveraging MWA and SKA1-LOW
  - High-quality imaging follow-up for MWA, ASKAP, and SKA;
  - Radio galaxy evolution, exoplanets, pulsars, and the ISM
  - Platform for ATNF low-frequency technical developments,
  - Increase capabilities in the domain of space surveillance.
- Engineering components available i.e.
  - MWA or LFAA antennas & LNAs. (“tiles”)
  - “Bluering “ digital beamformers; FPGA (“Gemini”) for DSP
  - VLBI expertise & correlator (LBA)
- Basic R&D development underway
  - Small test array  with MWA tiles.
    - Some MWA dipoles purchased for testing
  - Bluering prototype board to be tested with prototype array
  - **Demonstrator** (4x4?) planning underway. At ATCA site.

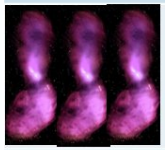
# External Projects

- ngVLA UWB feed (3.5-12.3 GHz) – invited design study
  - Feasibility study completed and report submitted.
- Effelsberg UWB feed (1.2-5 GHz)
  - Contract with MPIfR signed
  - Design completed
  - Construction and testing underway or planned
- UWL for Arecibo Observatory?
  - In **discussion** to provide system similar to UWL@Parkes
  - Complete “end-to-end” system
  - Quotation provided
  - Potential upgrade of UWL to RFSoC based digital back-end
- Commercialisation?
  - Use PAF technologies to track multiple satellites simultaneously
  - Could utilise many of the radio astronomy technologies (PAF; Digital)
    - Extensive developments Synergies…
  - Also for RFI mitigation?

# Current world-leading R&D areas

- **Phased Array Feeds (PAF) and receivers**
  - Demonstrated with ASKAP and provided for MPIfR & Jodrell Bank.
  - New **"rocket PAF"** feed and **cryoPAF** system for Parkes
  - **Wide-band** (3.4:1) & **Scalable** designs for ~0.5-30 GHz.
- **Ultra-Wide Band (UWB) feeds and receivers:**
  - Cover 6:1 BW with constant beams. UWB-L system (0.7-4 GHz) at Parkes.
  - **Scalable** designs that can be adapted to cover frequencies from ~0.5-30 GHz.
  - **High dynamic range** systems (>60 dB) with high RFI tolerance
- **State-of-the-art Digital Systems** for PAF & UWB systems
  - **Demonstrated** for PAF (ASKAP) and UWB-L (Parkes)
  - **R&D systems: Gemini FPGA** (SKA) & **RFSoC** (ADC+FPGA)
- **GPU back-end systems:** Emerging R&D.
  - Parkes UWB-L collaboration with Swinburne
  - Planned for future ATCA correlator and PAF systems.

# Technologies for Radio Astronomy Roadmap

| Technology | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 + |
|---|---|---|---|---|---|---|---|
|  **Ultra Wide Band Feed Systems** | 0.7 – 5.0 GHz systems (prime focus) PKS | 4.0 – 30 GHz systems (prime focus) PKS | | | | | |
| | 4.0 – 12.0 GHz feed (dual reflector) | | | 4.0 – 30 GHz feeds (dual reflector) SKA | | | |
|  **Phased Array Feed Systems** | | | | Cooled/room temp Rocket Phased Array Systems (0.7 – 2.0 GHz) ASKAP | | | |
| | Cryogenic Rocket Phased Array Systems* (0.7 – 2.0 GHz) PKS | | | | Cryogenic Phased Array Feeds* (20 GHz and above) ATCA | | |
| | | | Cryogenic Rocket Phased Array Systems* (4.0 – 20.0 GHz) ATCA | | | | |
|  **Digital Signal Processing** | RF System on a Chip Technologies - scalable and fully digitised systems (low frequency – large volume) SKA | | | | | | |
| | | | RF System on a Chip Technologies - scalable and fully digitised systems* (high frequency, high bandwidth – low volume) PKS ATCA 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 for Radio Astronomy Program must resource dedicated training and knowledge translation across to the team recruited into the proposed venture

Working Document, Version 2, Monday 29nd October 2019.

# Summary & Questions

- ATNF Technologies capabilities & world leading R&D
  - PAFs & UWB
  - FPGAs & RFSoC
  - GPUS
- Current, planned & future projects
  - ASKAP; SKA; UWB-L
  - CryoPAF; BIGCAT
  - ASKAP coherent FRB detector - collaboration
  - UWB-High?; LF VLBI?;
  - ?? Suggestions ??
- EoI process again
  - Feedback & Prioritisation process…
  - Open to suggestions & collaborations

**** Need community support, collaboration and endorsement for current & future radio astronomy systems ****

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