The CSIRO Astronomy and Space Science Phased Array Feed Development Program

Mark Bowen
CSIRO – Technologies for Radio Astronomy and The SKA PAF AIP
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Outline

- Current CSIRO PAF Development
  - ASKAP
  - Parkes 64m – Bonn PAF (MPIfR)
  - Rocket PAF

- CSIRO PAF Development – The Future

- SKA PAF Development – SKA Survey

- PAF – Dish Consortium Engagement

- PAF Advanced Instrumentation Program (AIP)

- SKA Observatory Development Program (ODP)

- Questions for the Future
# ASKAP – Australian SKA Pathfinder

## A Wide Field-of-View Radio Telescope

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of dishes</td>
<td>36</td>
</tr>
<tr>
<td>Dish diameter</td>
<td>12 m</td>
</tr>
<tr>
<td>Max baseline</td>
<td>6km</td>
</tr>
<tr>
<td>Resolution</td>
<td>10” (6km array), 30” (2km core)</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>70 m²/K</td>
</tr>
<tr>
<td>Field of View</td>
<td>30 deg²</td>
</tr>
<tr>
<td>Speed</td>
<td>$1.5 \times 10^5$ m$^4$/K$^2$.deg$^2$</td>
</tr>
<tr>
<td>Observing frequency</td>
<td>700 – 1800 MHz</td>
</tr>
<tr>
<td>Processed Bandwidth</td>
<td>300 MHz</td>
</tr>
<tr>
<td>Spectral Channels</td>
<td>16,000</td>
</tr>
<tr>
<td>Phased Array Feeds</td>
<td>188 elements (94 dual polarisation)</td>
</tr>
</tbody>
</table>
ASKAP – Australian SKA Pathfinder

• **Boolardy Engineering Test Array (BETA)**
  - Decommissioned February 2016
  - 6 antennas fitted with Mk. I Chequerboard PAFs
  - Conversion and baseband sampling at antenna

• **ASKAP Design Enhancement (ADE)**
  - 12 antennas currently operational
  - Mk. II Chequerboard PAFs
  - Direct sampling at central site
Parkes 64m – Bonn PAF (MPI)

- ASKAP PAF (Mk. II) built by CSIRO for MPIfR
  - ASKAP Digitiser and Beamformer
  - GPU Correlator
  - Modified RF signal chain – Additional filters (RFI)

- Commissioning on Parkes 64m antenna
  - Replaces Parkes multibeam receiver (13 beam)
  - Installed – February 2016
  - Commissioning and software development
  - Removal – September/October 2016
Rocket Array – CSIRO

Originated in CSIRO SKA PAF Program

- Initially focussed on 650 – 1670 MHz
- Common RF signal chain (SKA Bands 1, 2, 3)
- Reduced system temperature ($T_{\text{LNA}}$)
- Concept demonstrator – Signal distribution
- Ongoing evolution of ASKAP feed package (Mk. II → Mk. III → Mk. IV)
Element and LNA Design

- Element based on a conical solid of revolution
- Edge elements designed to reduce the effect of the edge discontinuity
- Feed line loss minimised
- Balanced LNA – Differential impedance 180Ω
- Commercial HEMT LNA – TriQuint TQP3M939 & TQP3M9040
- 5 x 4 array constructed as proof-of-concept
RF Signal Chain

- Leverage off other developments – SKA
- Common RF system architecture – SKA bands (1, 2, 3)
  - RF over Fibre (RFoF) for signal transport (ASKAP)
  - Integrated 8 channel assembly completed and tested
  - Allows direct interfacing with ASKAP digital backend

Simplified System Block Diagram

(Y. Chung 2015)
Array Testing - Parkes
CSIRO PAF Development – The Future

- Enhance existing Australia Telescope National Facility (ATNF) Instruments
- Collaboration and engagement with radio astronomy PAF community
- GPU based correlator development – MPIfR PAF
- Reduction in PAF Tsys achieved incorporated into ASKAP
- Incorporate development from other projects
  - Next generation beamformer
  - High speed digitisation
- Continue rocket PAF development
- Cryogenically cooled PAF for Parkes
  - Rocket array element geometry
  - RFI/EMI considerations
  - Sampling at the focus
- Participate in SKA PAF AIP
SKA PAF Development – SKA Survey

CSIRO PAF Design

- Chequerboard array
- Australian SKA Pathfinder (ASKAP) Mk. II
- RF over Fibre signal transport
- 650 – 1670MHz band (SKA - Band 2)

NRC PAF Design

- Thick Vivaldi Array
- Advanced Focal Array Demonstrator (AFAD)
- Cryogenic cooling (CryoPAF)
- 1.5 – 4.0Hz band (SKA - Band 3)
SKA Measurement Program
Measurements “calibrated’ using ASKAP (Mk. II) reference array.

Gaps in the measurements are caused by RFI.
PAF – Dish Consortium Engagement

- SKA Dish common optical configuration defined and dish design well developed (SKA SA, EMSS, NRC, CSIRO).
  - 15m Offset Gregorian
  - 5m sub-reflector (oversized)
  - Shaped reflector with 58° opening angle

- Ensure PAFs are not built out in SKA1_MID antenna design
  - SKA Feed Indexer design and structure interfaces
  - SKA_Survey Band 2 PAF replaces – SKA SPF Band 1
  - SKA_Survey Band 3 PAF (CryoPAF) replaces – SKA SPF Band 3, 4, 5.

- Basic system architecture defined
- Draft PAF ICD under development – Compatibility with SKA_Mid antennas
SKA PAF Advanced Instrumentation Program

- SKA Organisation agreed to set up a PAF AIP
  - Initial AIP Plan to SKA Board – November 2016
  - AIP runs for the remainder of SKA Preconstruction – Late 2018
  - System Requirements Review (SRR) and Conceptual Design Review (CoDR)
  - Precursor to PAF development program during SKA Construction (ODP)

- PAF AIP Consortium “founding” members
  - CSIRO – Australia (Lead)
  - NRC – Canada
  - ASTRON – The Netherlands
  - INAF – Italy
  - JBCO – UK

- Additional members
  - JLRAT – China
  - MPIfR – Germany
SKA Observatory Development Program

• Role of the ODP – To ensure ongoing instrumentation development
  ➢ Concept agreed but shape of program yet to be defined
  ➢ Cover ALL areas of development – PAF, WBSPF, AAMID, Software, …
  ➢ Managed centrally by SKA Organisation
  ➢ Funding model not decided (Fully funded or co-funded)

• ODP Proposals put to SKA Organisation on possible ODP Programs

• General agreement that PAFs are one of the key future technologies for radio astronomy and should be part of the ODP

• Key role of AIP program(s) is to do the ground work for the ODP
Questions for the Future

Radio Astronomy in General

• Which niche/niches do PAFs fill in radio astronomy? What science will PAFs do better than anything else?
  
  **Remember** – Scientists can be an impatient bunch; although they can see the potential; they will not wait forever – Promising early science results

• What is the role of PAFs in the SKA?

Key Areas of Technical Development

• Understanding on-dish performance

• Beamforming – Algorithm, calibration, RFI mitigation, de-rotation

• Improving sensitivity – Room temperature, cooled and cryogenic

• Bandwidth – Observed and processed

• Manufacturability and cost – Appropriate for the application
We acknowledge the Wajarri Yamatji people as the traditional owners of the Murchison Radio Observatory site.

CSIRO Astronomy and Space Science
Mark Bowen
Group Leader – Front End Technologies
+61 2 9372 4356
Mark.Bowen@csiro.au
www.csiro.au