A Case for Development of the UWL Receiver for Parkes

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The Parkes UWL Receiver – Design Goals

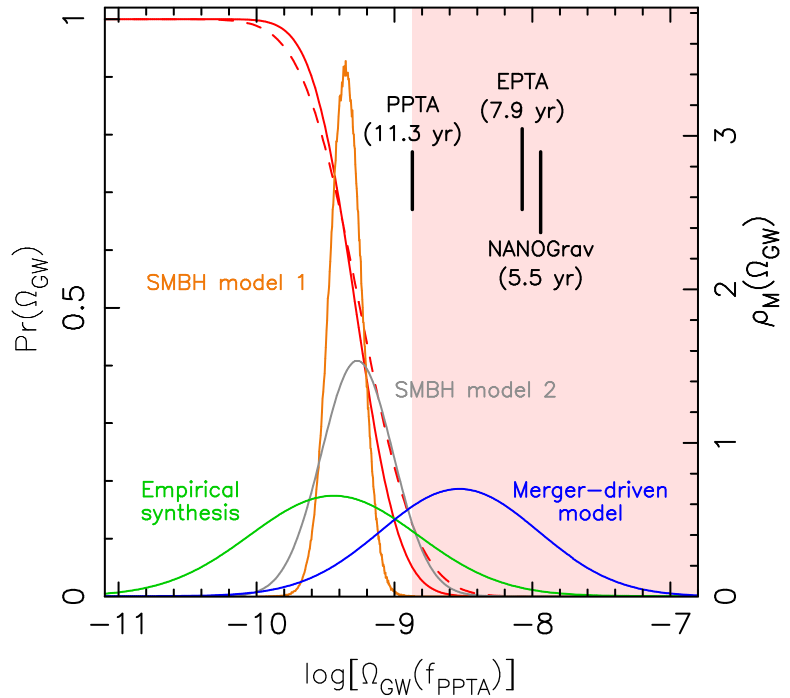
- Received band: 0.7 – 4.0 GHz
- Wideband single-pixel feed, dual linear polarisation
- Feed cross-polar below -20 db over whole band
- Tsys ~20 K over most of band, dynamic range >30 db
- Aperture efficiency >65% over whole band
- Noise calibration injection from vertex radiator and/or couplers after first RF amplifier
- Digitisation of entire band in focus cabin, >8 bits/sample
- Optical fibre transmission to Tower receiver room
- FPGA preprocessor: time tagging, RFI rejection, signal distribution
- Versatile GPU-based signal processing system
- Digital signal processor used for all Parkes single-beam systems

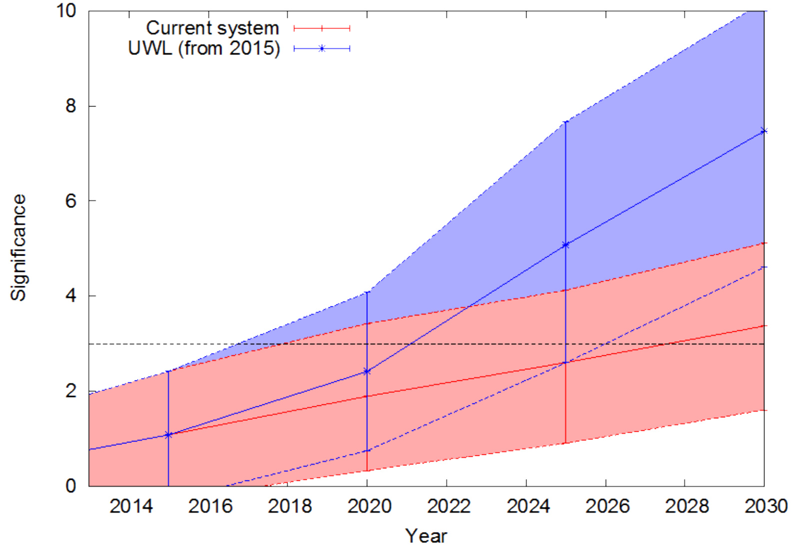
Main Science Goals for the UWL Receiver

- Pulsar timing – PPTA, relativistic binaries, Fermi, magnetars
- Pulsar emission mechanism studies, intermittent pulsars, etc
- Interstellar medium – Faraday rotation, dispersion, scattering
- Spectral lines – HI, OH, CH (methyladyne)
- Continuum background polarisation, RM synthesis
- VLBI – “L-band” (20cm, 18cm) and “S-band” (13cm)
- Low spatial-frequency data for ASKAP imaging
- The PAI – a real-time interferometer between Parkes and ASKAP

Pulsar Timing – the PPTA

- Long-term precision timing of MSPs to detect correlated signals
- Main aims: gravitational-wave detection, pulsar timescale
- Highest possible precision for pulse arrival times needed
- Currently limited by dispersion-delay uncertainties - correction for ISM effects essential
- Current PPTA results lead the world – seriously constraining models for galaxy and super-massive black-hole evolution in early Universe
- Present datasets vital to SKA PTA

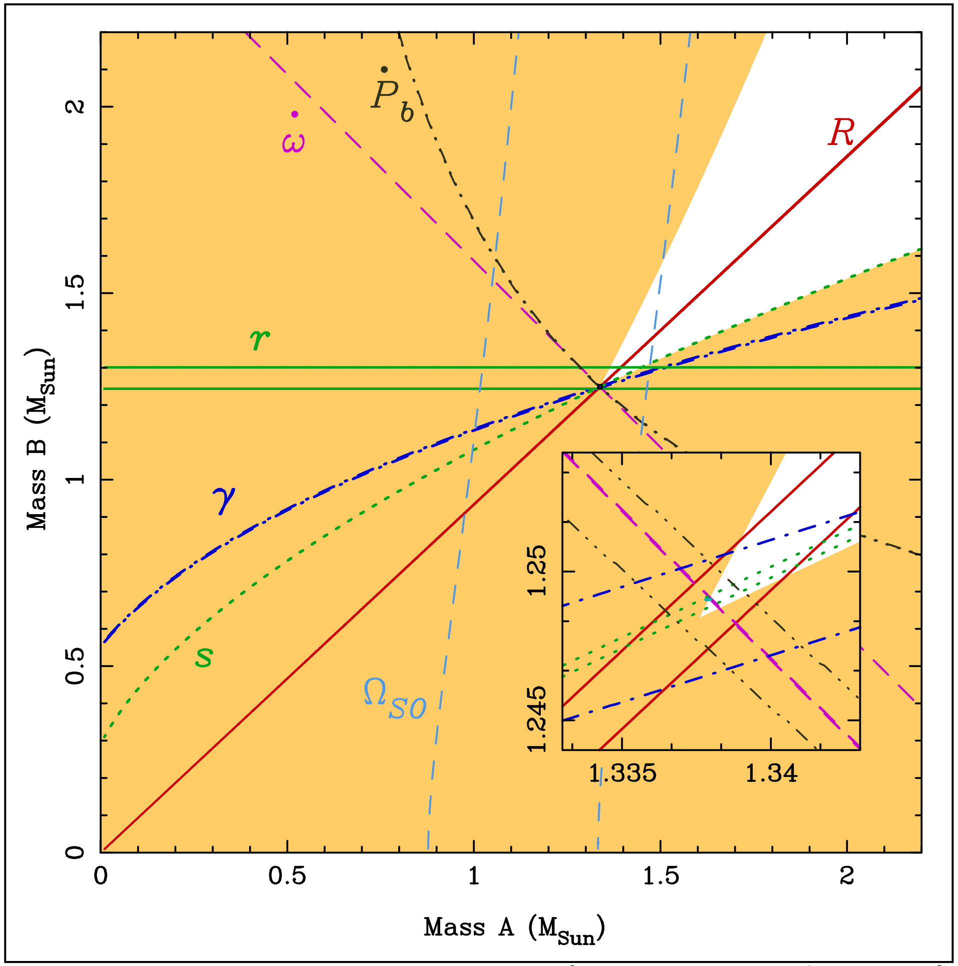




Pulsar Timing – Relativistic Binaries

- Double neutron-star systems provide the most stringent tests of gravitational theories in strong-field conditions
- UWL receiver will give improved timing precision – especially important for Shapiro delay measurements
- Key Science Project for the SKA
- Long time baseline important for SKA project

Relativistic Effects in the Double Pulsar

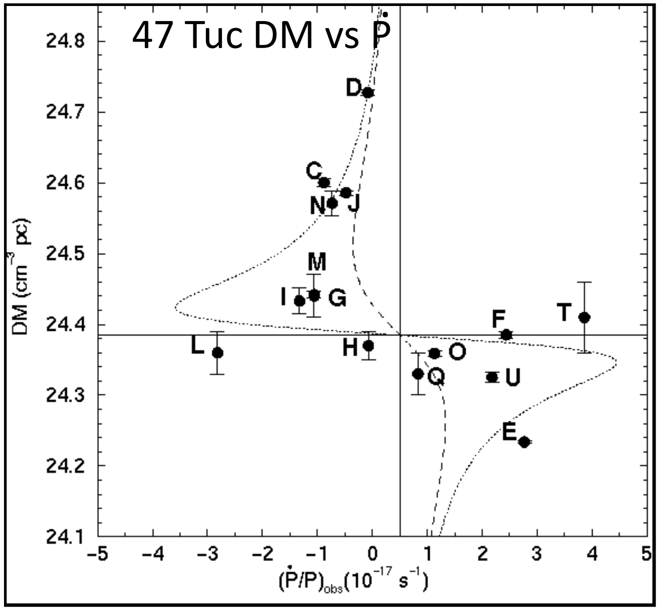


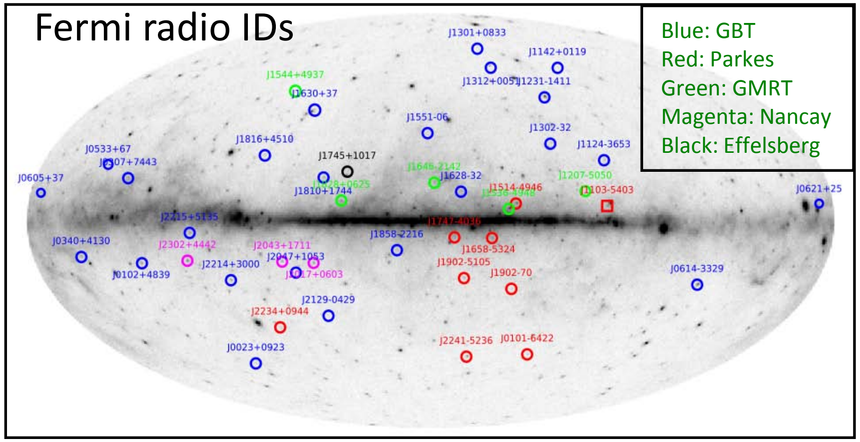
(Kramer et al. 2013)

CSIRO

Other Pulsar Timing Projects

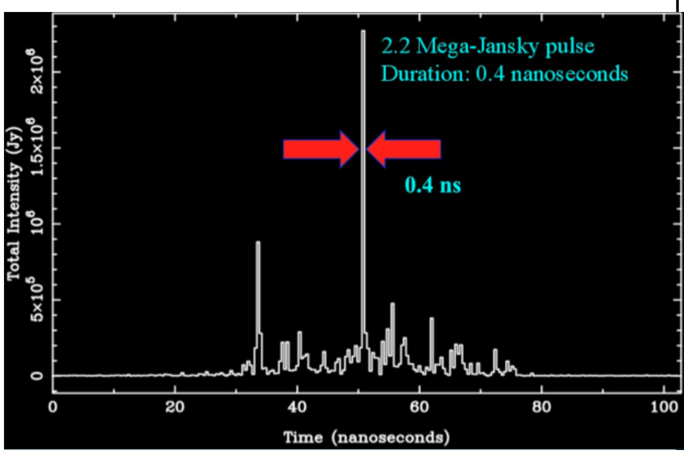
- Globular cluster pulsars
  - o Cluster and binary-system evolution
  - o Intra-cluster gas
  - o Gravitational potential field in clusters – central black holes
- Magnetar studies
  - o Magnetic field structure and evolution
- Fermi and other high-energy collaborations
  - o High-energy studies of known pulsars
  - o Searches for pulsed radio emission from high-energy pulsars
- Intermittent and irregular pulsars
  - o RRATs, nulling pulsars, glitches etc



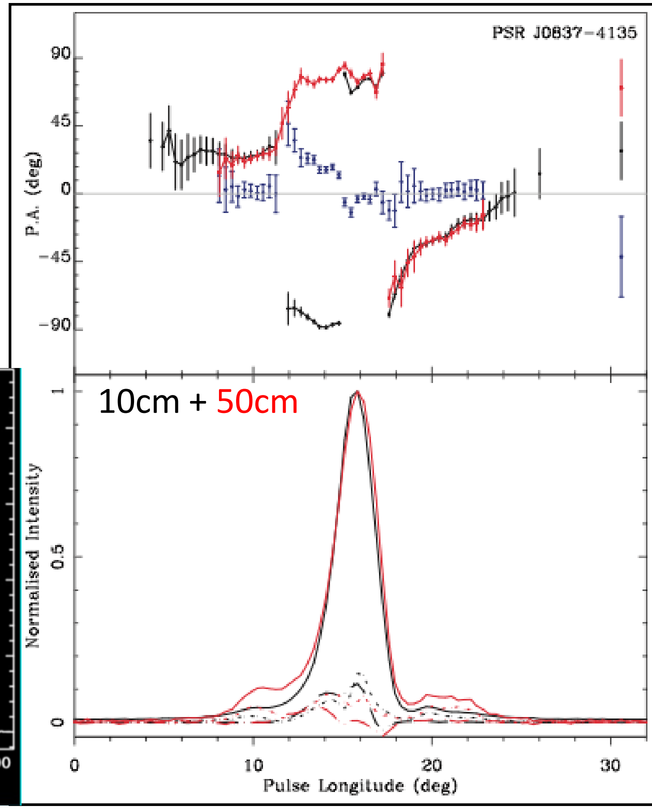


Pulsar emission mechanisms

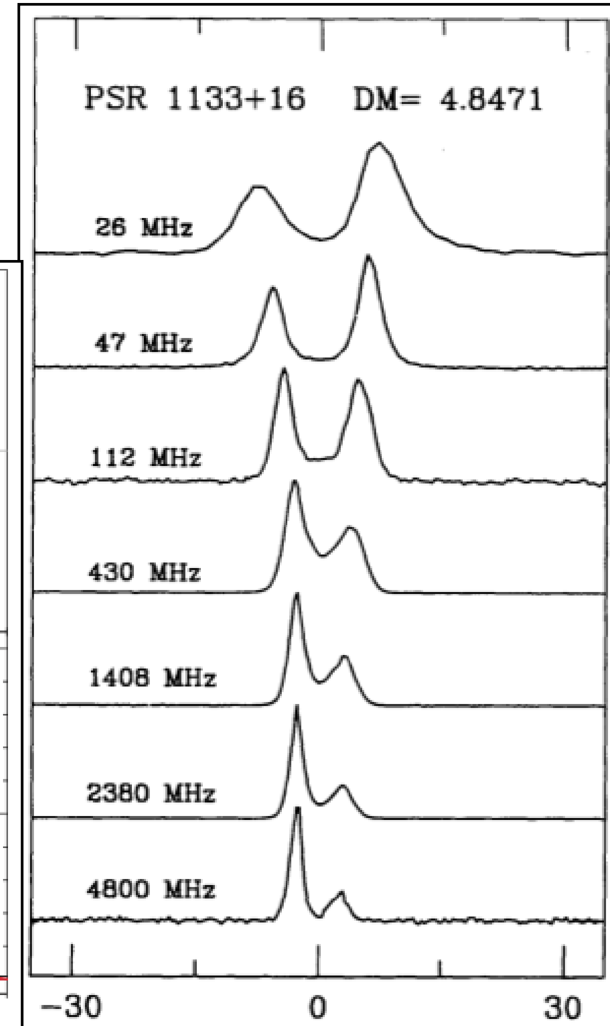
- Frequency dependence of pulsar parameters
- Multi-frequency polarisation studies
- Single-pulse studies, e.g. subpulse drifting
- Pulse microstructure and nanostructure



(Hankins 2012)



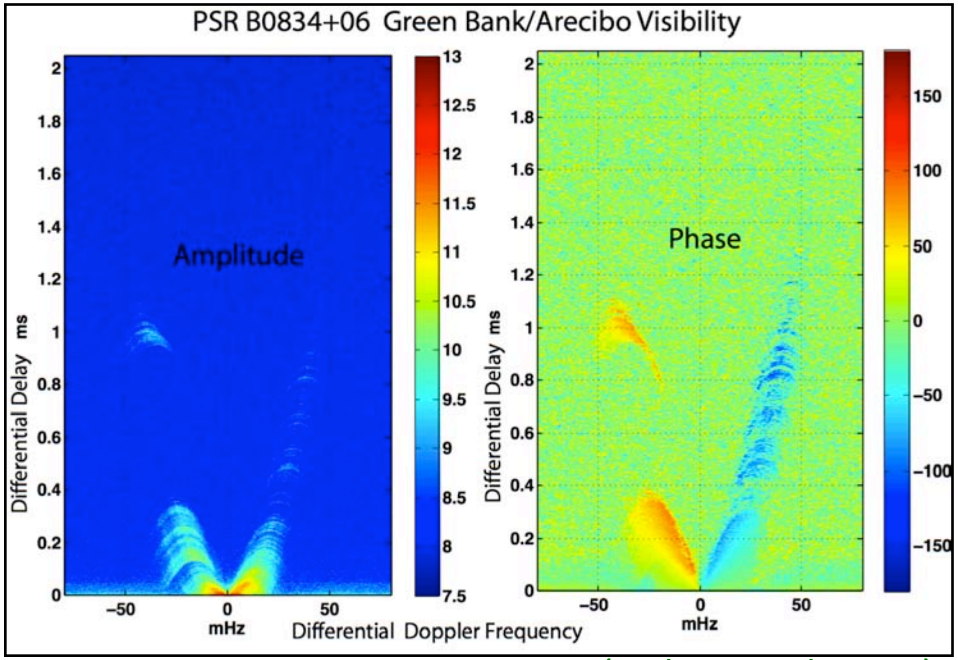
(Karastergiou & Johnston 2006)



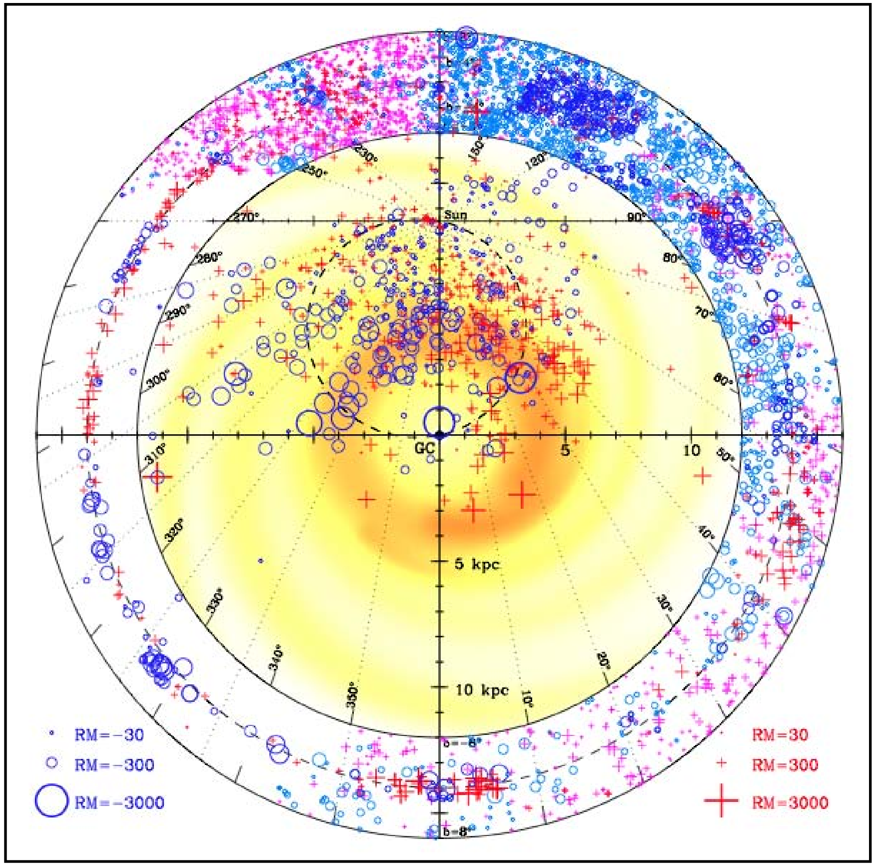
(Phillips & Wolszczan 1992)

Interstellar Medium Studies

- Pulsar Faraday rotation – 3D tomography of the Galactic magnetic field
- Dispersion-measure variations – pc-scale structure
- Scintillation and scattering – AU-scale structure



(Rickett et al. 2012)

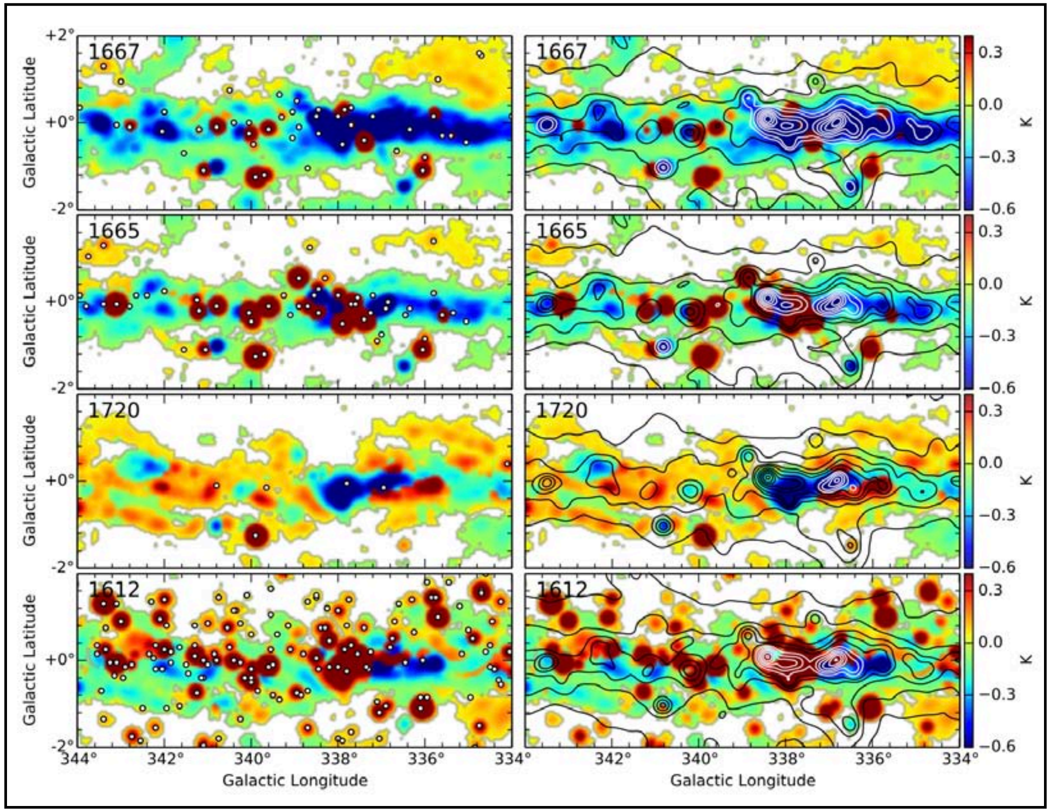


(Han et al. 2013)

Spectral-line Observations

- Studies of extended Galactic/extra-galactic spectral-line emission, e.g., SPLASH OH survey, Magellanic Stream HI, etc.
- Red-shifted HI (to z ~ 1) and OH (to z ~ 1.3), e.g. Zeeman splitting
- Recombination lines of H, He, C etc.
- CH emission in molecular clouds – 3 ground-state transitions near 3.3 GHz – very little work since 1980s

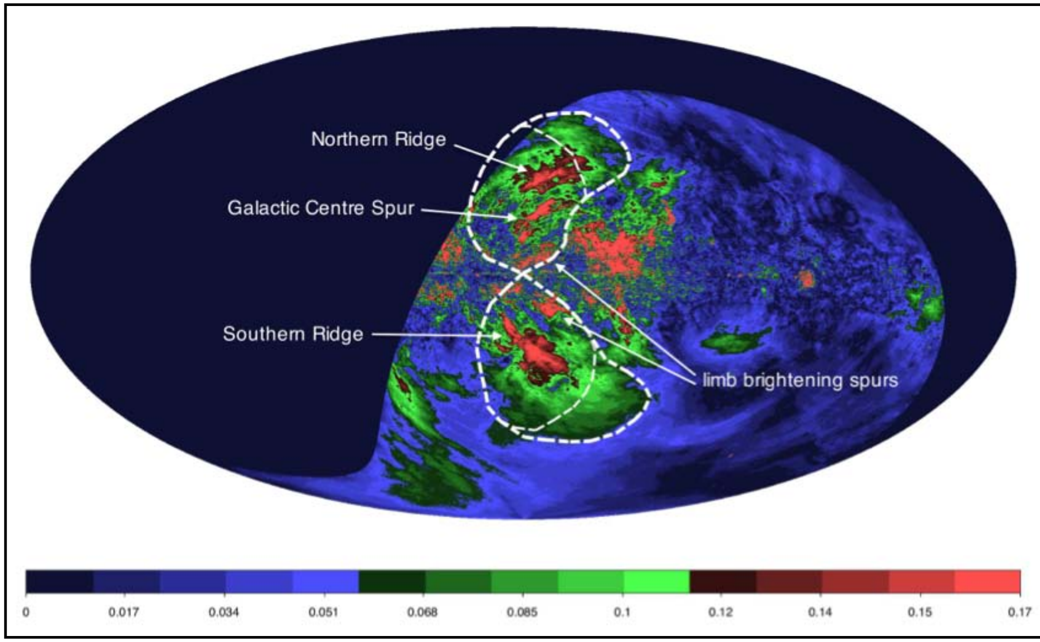
SPLASH OH Emission and Absorption



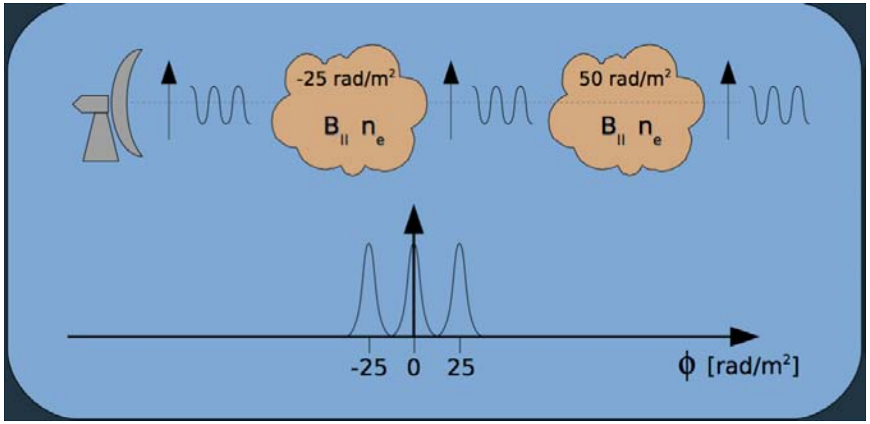
(Jo Dawson 2013)

Continuum Polarisation and RM Synthesis

- Diffuse Galactic emission
- Lower frequencies good for high Galactic latitudes, and vice versa
- Off-axis cross-polar response of feed is critical



(Carretti et al. 2013)

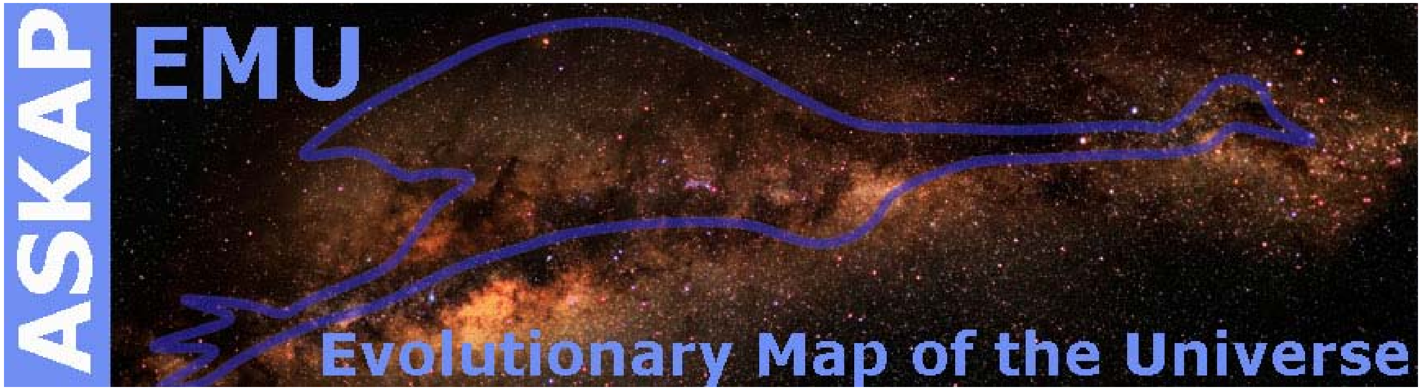


(Wolleben 2012)

- RM synthesis allows investigation of mixed emission and rotation regions
- Needs wide bandwidth

VLBI and ASKAP

- Will provide a sensitive element for VLBI arrays operating in the 20cm, 18cm and 13cm bands, also red-shifted HI, OH
- Signal-processor system can interface directly with e-VLBI systems
- Can be used to provide low spatial-frequency data for ASKAP imaging over whole ASKAP band
- GASKAP, WALLABY, EMU and POSSUM projects all need or would benefit from these data
- Potential to set up a real-time interferometer – the "PAI" – for follow-up of ASKAP detections, e.g., selecting AGN cores from EMU sample



Parkes Science is High-Impact Science!

- Of the 20 most highly cited papers using CASS facilities since 2000 (not including catalogues):

16 were based on Parkes observations!

- Most highly cited paper:

Discovery of the Double Pulsar, Lyne et al. 2004 – 370 citations!

Continuation of Parkes observations is vital to the continued high profile of CASS:

- within CSIRO
- within the national and international astronomy community
- with the general public

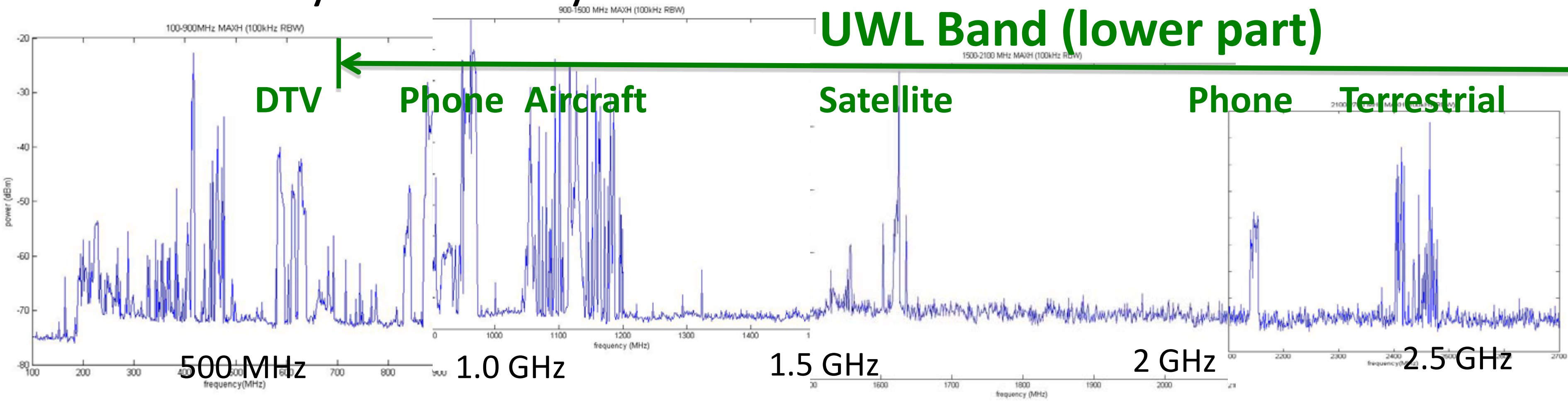
Radio-Frequency Interference Issues

- Very wide band and relatively low frequency of the UWL receiver means that RFI is a significant issue
- RFI comes in two main classes:
  - Narrow-band quasi-steady transmissions
  - Broad-band transient signals
- Different mitigation strategies:
  - Narrow-band emissions:
    - Analogue filters in RF amplifier chain – band excision
    - Digital filters in FPGA preprocessor – band excision
    - Real-time adaptive filtering – removal of RFI only
  - Transient emissions:
    - Digital excision in time domain – e.g., kurtosis filtering of baseband data

Essential that amplifier chain and digitiser remain linear in presence of RFI

Parkes RFI Spectrum

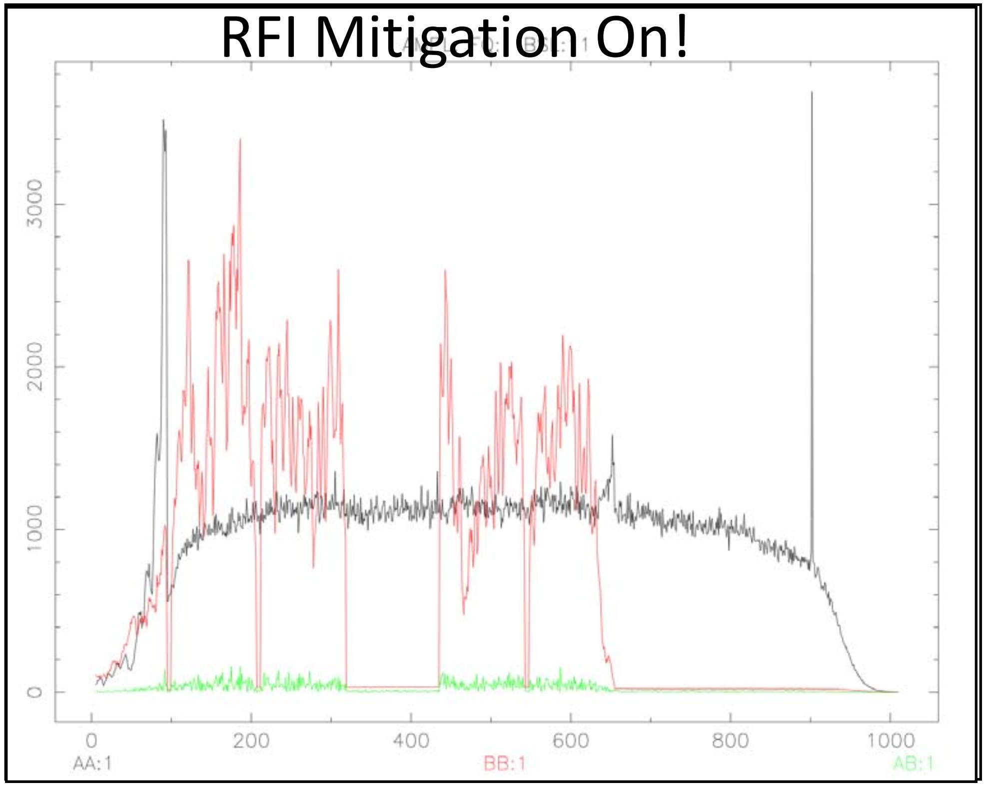
- 0-6 GHz RFI survey led by Paul Roberts, Aidan Hotan, Ron Beresford
- Preliminary results only so far



- Peak-hold spectra – worst case! Upper spectrum basically clear
- Aircraft signals are strong but very low-duty-cycle transients – reject in time domain
- Exploring adaptive filtering of all strong quasi-continuous RFI using isotropic reference antenna

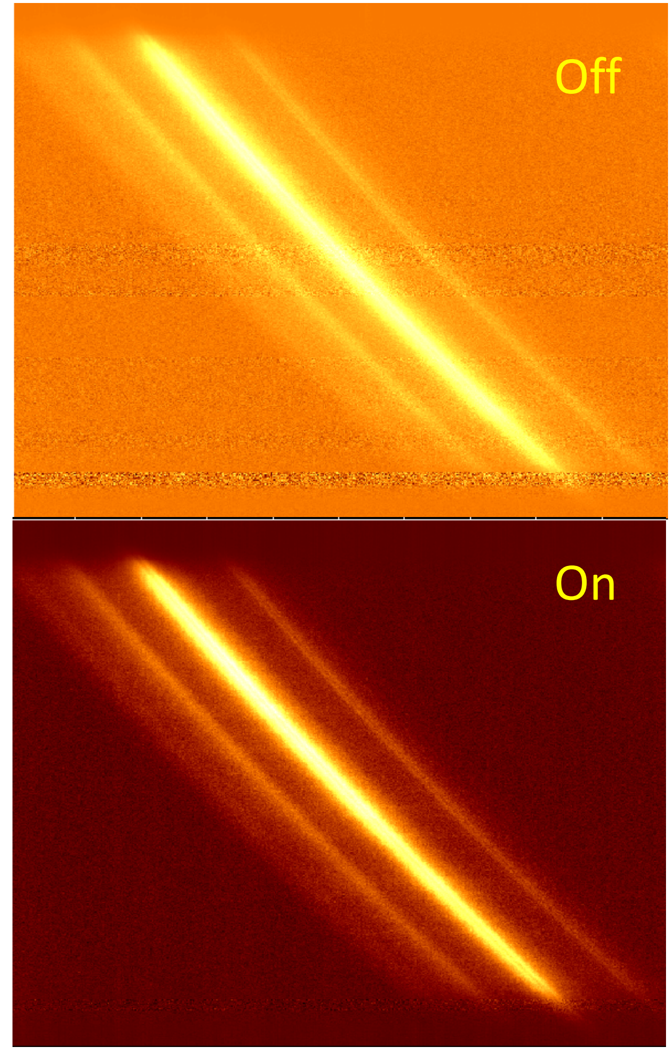
A Real-time Adaptive RFI Filter

- Parkes – original 50cm band
- PDFB3 signal processor



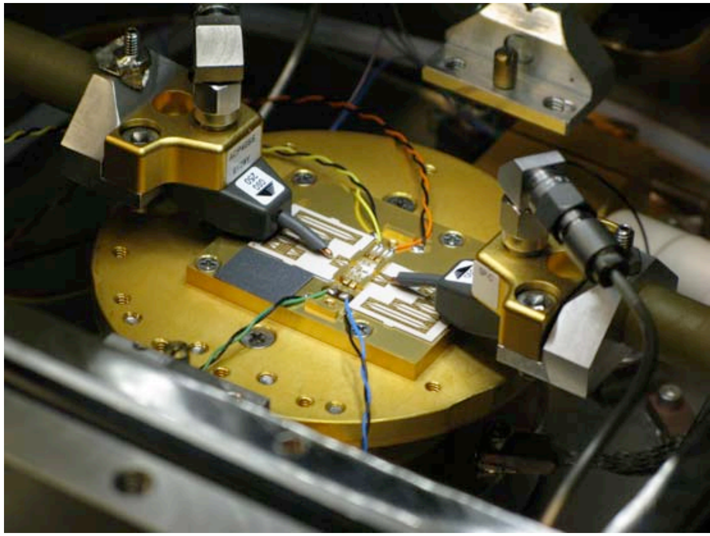
System devised by Mike Kesteven, implemented by Andrew Brown and Grant Hampson

PSR J0437-4715: Freq - Phase



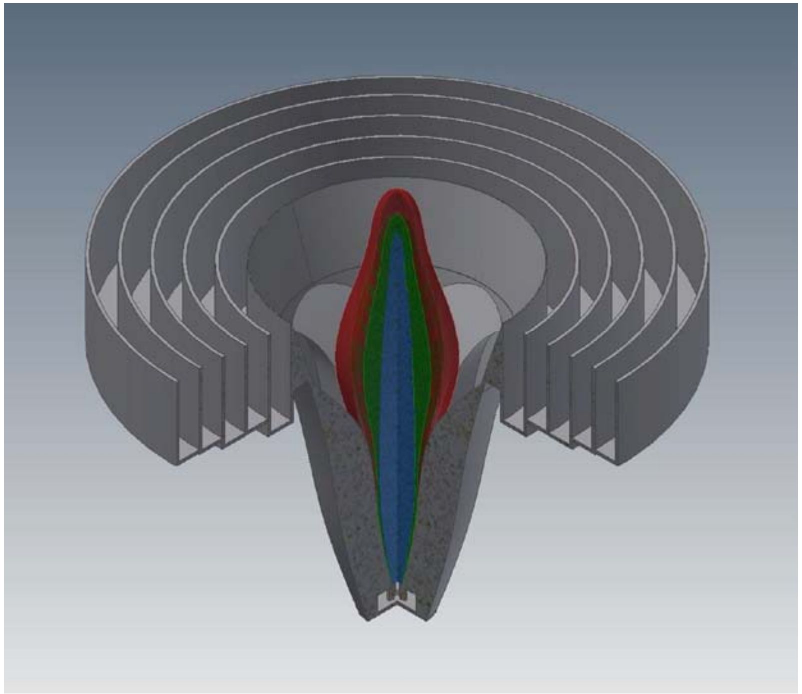
Engineering Benefits

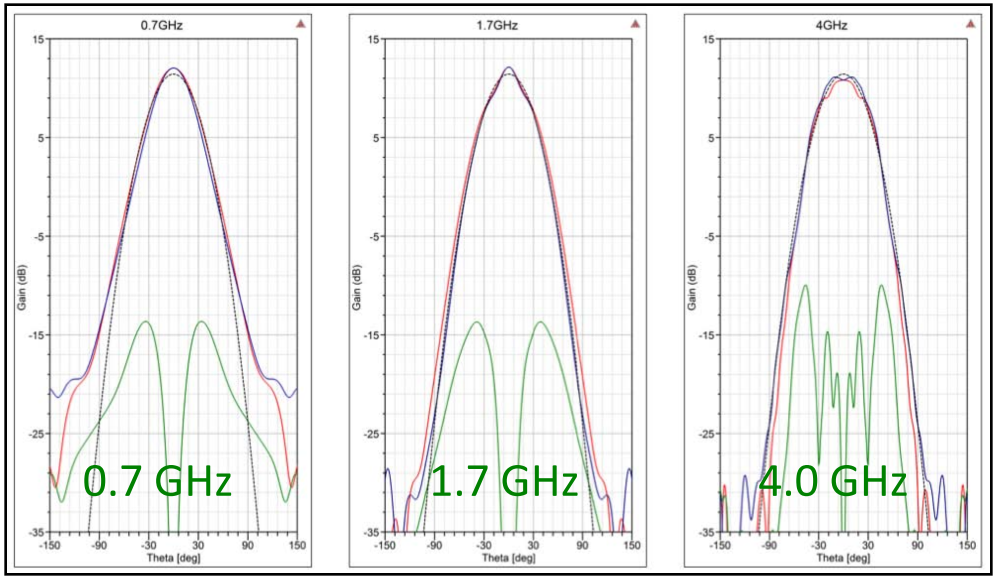
- CASS currently has world-leading engineering teams for radio astronomy receivers and signal-processing systems
- Need continuing development projects that are at the cutting edge of technological innovation to maintain this
- Ultra-Broad-Band receivers with fully digital signal-processing systems are the way of the future for radio astronomy, including SKA applications
- These include wideband feeds, high-dynamic-range cryogenic preamplifiers, high-speed digitisers and FPGA signal conditioners, high-data-rate optical fibres and GPU-based signal processors
- Opens up scope for national and international collaborations for the mutual benefit of both parties



CASS UWL Feed Design

- 0.7 – 4.0 GHz, dielectrically-loaded quad-ridge horn
- Aperture efficiency 0.70 +/- 0.05 across whole band
- Beam cross-polar less than -20 db across whole band
- Feed/OMT to ring slots cooled to 70 K – feed/OMT loss 1-3 K in Tsys

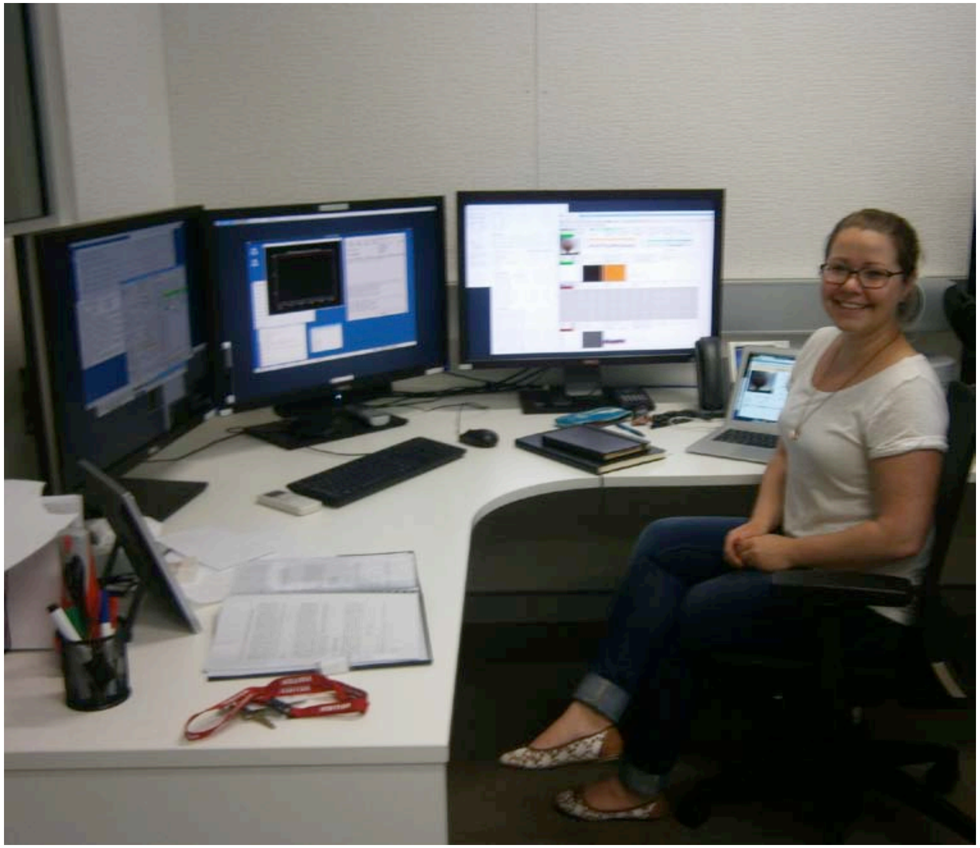




Design by Alex Dunning

Operational Issues

- Need to reduce operating cost of CASS facilities
- Facilitate remote observing
- Minimise manual changes required for different projects
- Development of ultra-wide-band receivers – few or no receiver changes necessary
- Development of versatile signal processing system minimises maintenance issues
- Currently Parkes observations are dominated by observations in the UWL band



Observing at the Marsfield SOC

Parkes Usage: April + October Semesters 2013

- Total of 36 proposals, 7279 hours scheduled
- Topics

  - Other: 1 proposal, 67 hours

The UWL Receiver could satisfy:
26+ proposals – 72+% of total
4277+ hours – 58+% of total

The HI MB + UWL Receivers could satisfy:
32+ proposals – 88+% of total
6511+ hours – 89+% of total

Development Path

- UWL Receiver + High-frequency receivers (4 – 26 GHz) on one side of translator
- Existing 20cm/HI Multibeam on other side until a PAF with better performance is available
- Strong national and international support for development of UWL receiver and signal processing system
  - MPI für Radioastronomie, Bonn, has committed €100K plus collaborative development
  - NAOC Beijing has committed $A100K plus two engineer person-years for signal processing system development
  - Swinburne University has committed at least 0.5 FTE/year of engineer/scientist time for 3 years on GPU system development
- ARC LIEF application for signal processing system being explored
- Two-year timescale for development of UWL system

With these developments Parkes has at least another decade of world-leading science in front of it!

Thank you

Dick Manchester