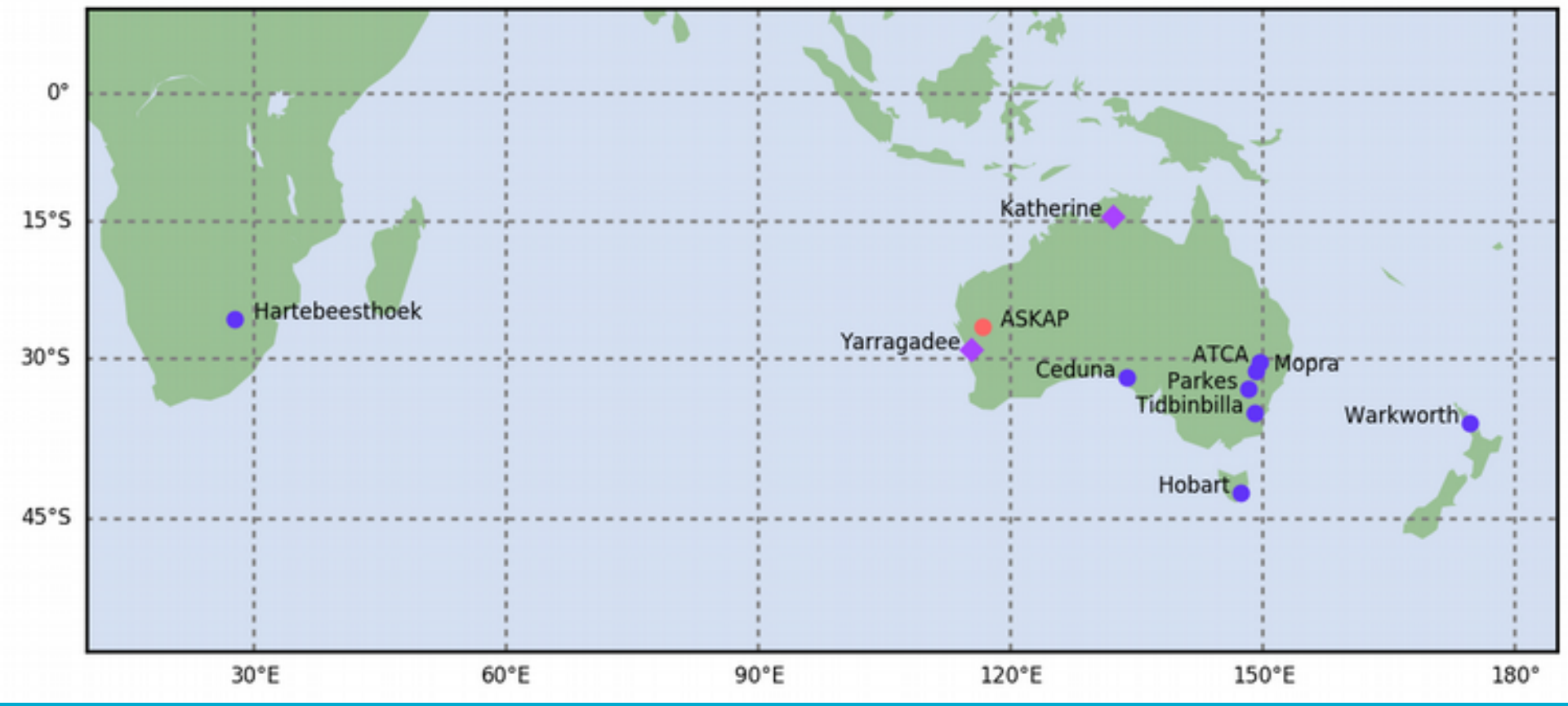


VLBI Developments in Australia

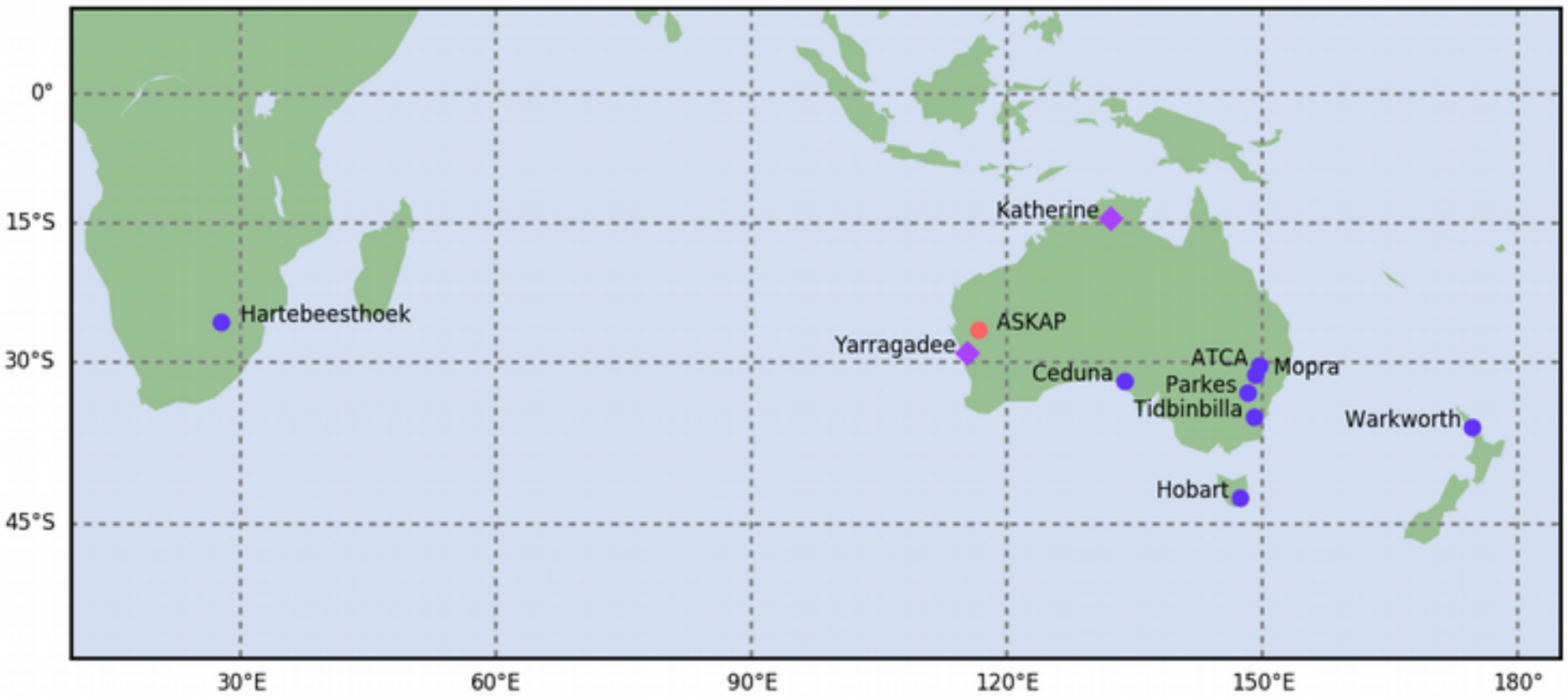
Cormac Reynolds, Chris Phillips + LBA & Parkes Teams

14 November 2018

LBA

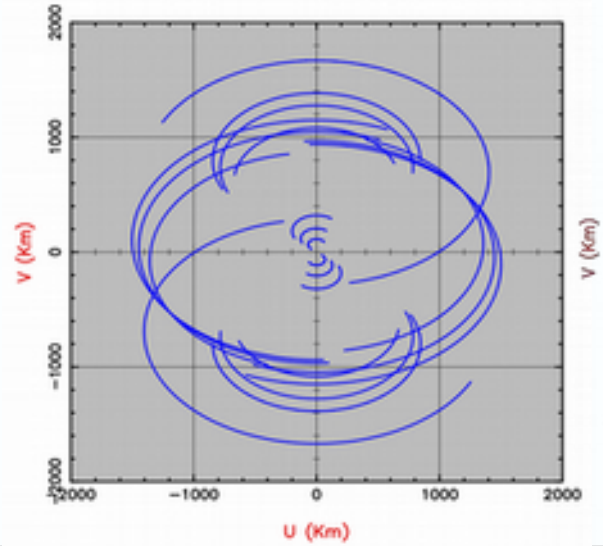
- LBA VLBI array operated by CSIRO
  - UTAS, AUT and SARAO (Hart)
- Parkes (64m), ATCA (5x22m), Mopra (22m), Hobart (26m), Ceduna (30m)
- Warkworth (12m/30m), Hartebeesthoek (26m/15m), Tidbinbilla (70m/34m), Auscope (12m)

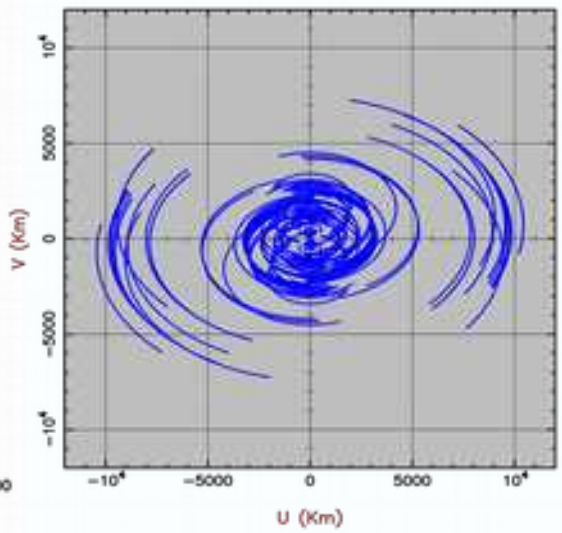
Long Baseline Array



Imaging Performance

Frequency/MHz	Sensitivity/(microJy/beam) 1hr [+ Tid]
1400	45 [25]
2300	40 [20]
4800	65
8400	50 [25]
22000	230 [90]
43000	[220]





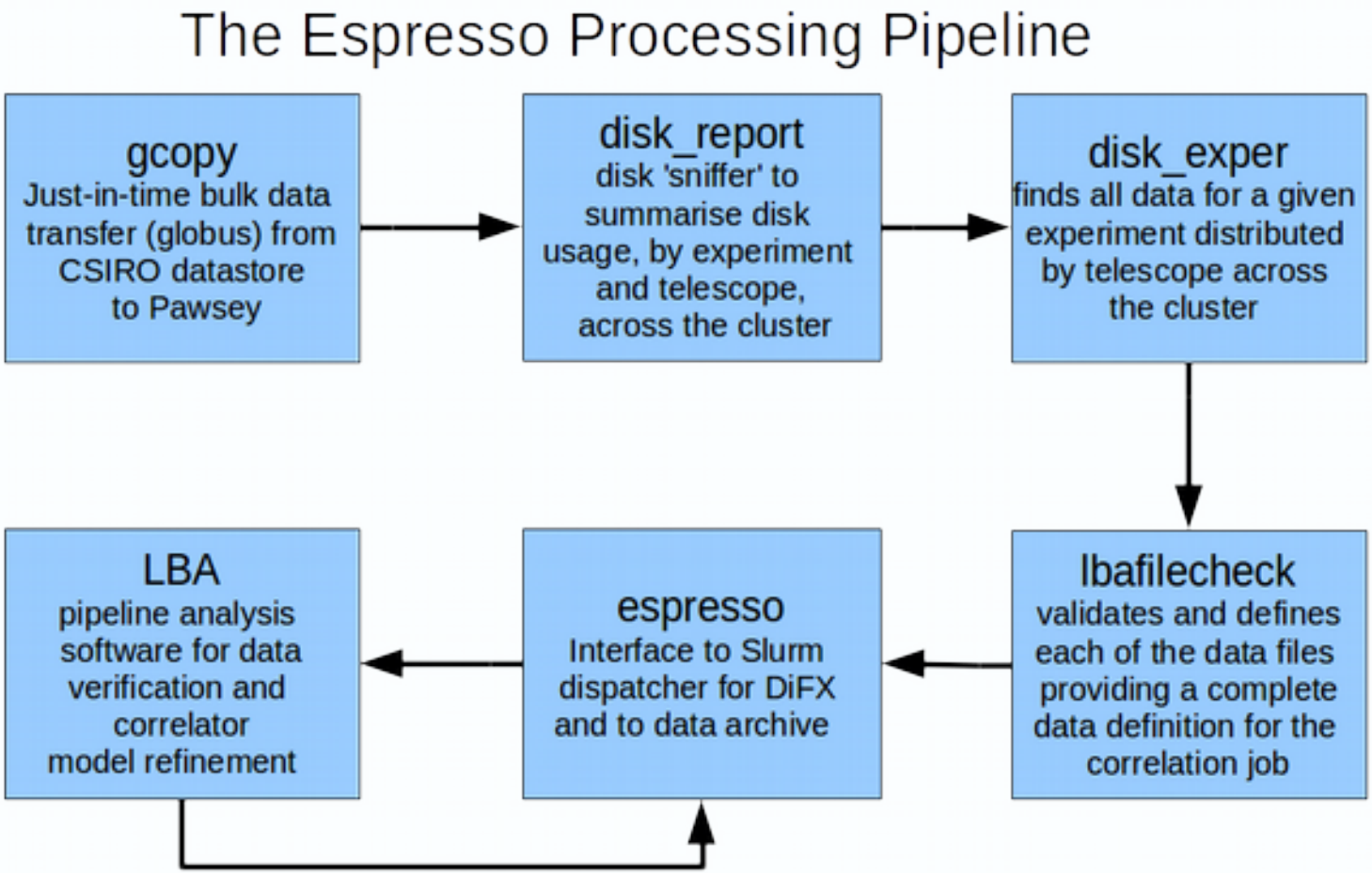
The Long Baseline Array (LBA)

- Regular observations in 20, 13, 6, 3, 1cm bands
  - Session-based but flexible for ToO, Parallax, etc.
  - Also 7mm and 3mm on ATCA, Mopra, Tid
- Disk-based recorders with e-shipping
  - or/and eVLBI on a subset of the array
  - Real-time fringe checks
- LBADR, DBBC+Mk5 systems
- Max. bit-rate 1 Gbps
- Data correlated on DiFX software correlator
- Correlation at Pawsey Centre for SKA Computing
- **Open VLBI network -** proposals 15 June & December
  - Joint application with EVN

LBA Correlator – Pawsey Centre for SKA Supercomputing

- **Magnus Specs**
  - 1488 x 24 core nodes
    - 1097 Teraflops
  - Cray Aries interconnect
    - 72 Gbps per node
  - 64 GB memory per node
  - 3 PB storage (~200 TB for VLBI)
    - Lustre FS: Aggregate read/write speed 70 GB/s
      - 2 Gbps per rank (inferred)
  - #41 on Global Top500 list of supercomputers (2014/11)
- 250,000 CPU hours for VLBI through merit allocation in 2018
- $70m Upgrade Funded (end 2019?)

Espresso (DiFX Interface)



The LBA – Past 12 months

- 27 days observing
  -
  - 4 ATNF Antennas (Parkes, ATCA, Mopra, ASKAP)
  - 5 UTAS antennas (Hobart x2, Ceduna, Yarragadee, Katherine)
  - Warkworth x2 antennas (AUT, NZ)
  - Tidbinbilla, Hartebeesthoek
  - RadioAstron (50+ hours)
- Joint observations
  - EVN/Global
  - KVN+ATCA
  - CVN: Shanghai, Kunming, Tianma65
  - Quasar: Zelenchukskaya, Svetloe, Badary
- Median data rate 512 Mbps (Max 1 Gbps)
  - (Almost) all data e-transferred
- Fully fledged remote obs

ATNF Telescope Status - Mopra

- Mopra: 1.3-3, 4.5-6.7, 9-9.2, 16-27, 30-50, 76-117 GHz
- Collaboration funding (UNSW et al.) has provided operations for last few years
- Future remains uncertain – KVN plan for mm upgrade (see Hodgson talk)

ATNF Telescope Status - ATCA

- ATCA: 1.1-3.1, 3.9-11, 16-25, 30-50, 83-105 GHz
- LBA DAS connected to 5x22m Tied Array
  - No **broadband** VLBI capability currently
  - Plans to replace CABB with GPU-based system to provide this
- ATCA split array capability: 7mm/3mm obs with KVN
- Reliable 32 GHz fringes ATCA/Mopra/Tid-34m

BIGCAT:
Broadband Integrated-GPU Correlator for ATca

- Based on Parkes UWB hardware and design
  - 2 GHz bandwidth sampler, FPGA coarse filter, GPU based processing
  - 128 MHz initial filtering
- 4 (8?) GHz total bandwidth
- Flexible processing, lots of possible options…
- 12 bit initial sampling, 8 bit after coarse filterband (16 bit for 1-3 GHz band).

BIGCAT - Design Priorities

- Reliability
- Simplify control (hands off reconfiguration)
- “Unlimited” spectral resolution (0.1 kHz over 8 GHz?)
- RFI mitigation (Blanking, adaptive filtering)
- Advanced modes
  - Multiple tied array beams
  - Short integration visibilities (piggyback FRB searches?)
  - Sub-arraying

ATNF Telescope Status

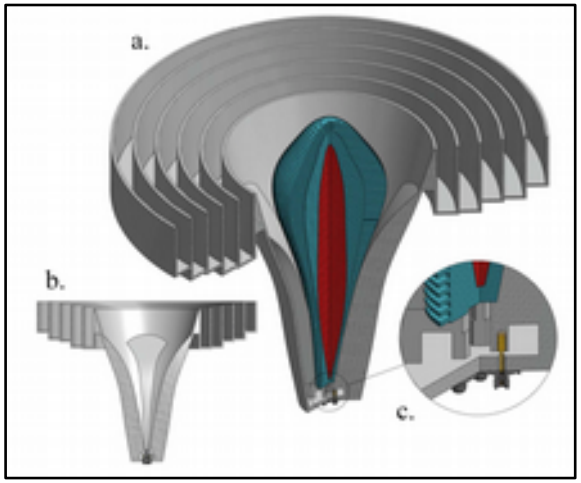
- Parkes: Large Receiver fleet
  - 700-764, 2600-3600, 1230-1530 (Multibeam), 1200-1800, 2150-2500, 5900-6800, 8100-8500, 12000-15000, 16000-26000 MHz, S/X
  - Commissioning 700-4000 MHz UWB-Low Rx
    - Planning for 4-25 GHz UWB-High
    - Planning PAF 0.7-1.7 GHz (Multi-view demonstrator)
    - All systems to share common GPU backend
    - No more receiver changes!
  - LBA DAS and Mark4/Mark5b backends

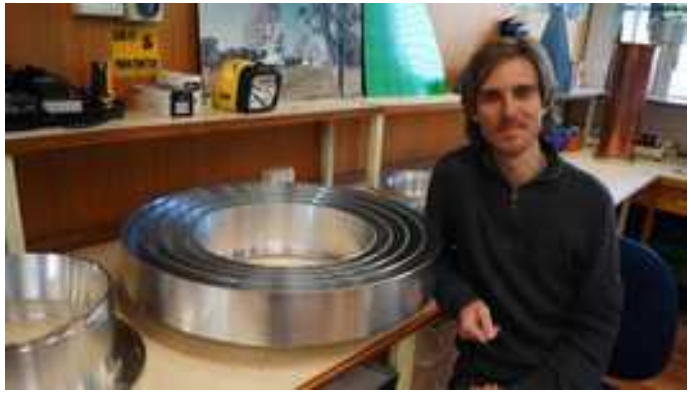
Parkes UWB-L Receiver

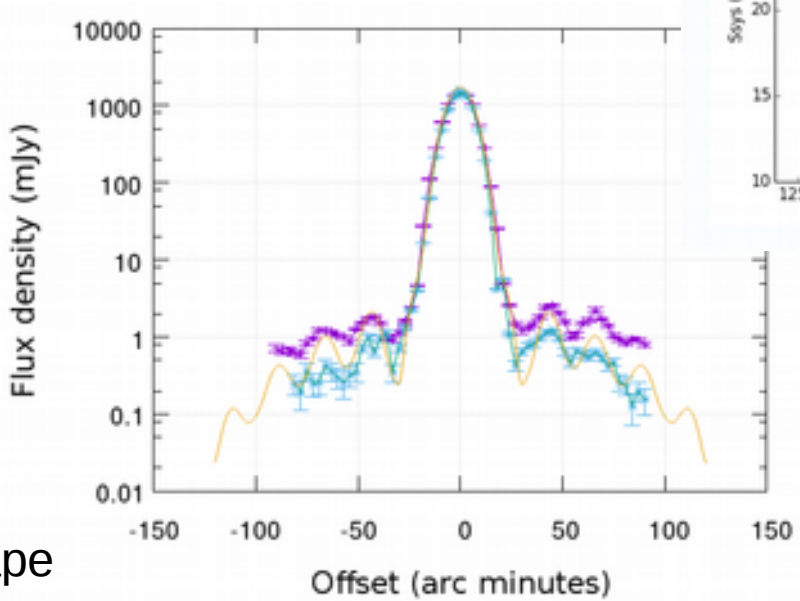
- Drivers:
  - Improve operational efficiency of Parkes
  - Pulsar, FRB and HI surveys
  - Precision pulsar timing
  - ISM studies: scattering, magnetic fields
  - SETI
  - VLBI
- Generic Backend
  - 2 x Xeon E5-2630 v3 CPUs (8-core, 2.4 GHz)
  - 128 GB DDR4-2133 RAM (8 x 16GB)
  - 4 x Titan X GPUs
  - 2 x Single-port Mellanox Connect-X 3 40Gb NICs (QSFP)
  - 9 servers total
- Full ~4 GHz available simultaneously for VLBI

UWB-L Feed

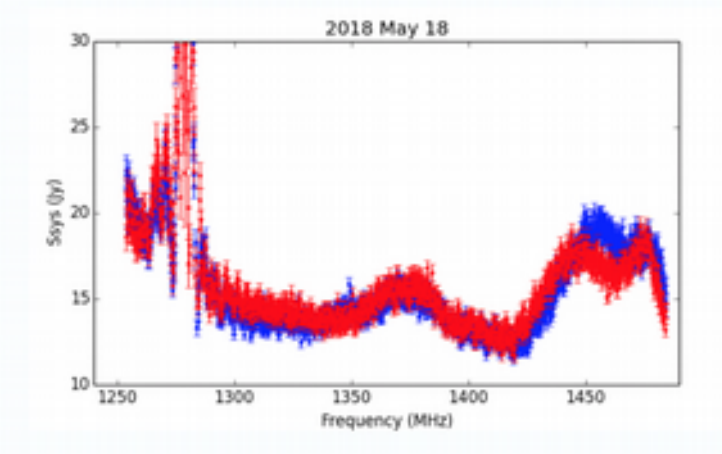
- Design by Alex Dunning
- Bandwidth 0.7 – 4.5 GHz
- Quad-ridge horn with outer rings and graded dielectric insert
- Exceptional polarisation performance
- Commissioning Tests at Advanced Stage
- VLBI spigot expected in Q.1 2019







Beam Shape



System Noise

General system use

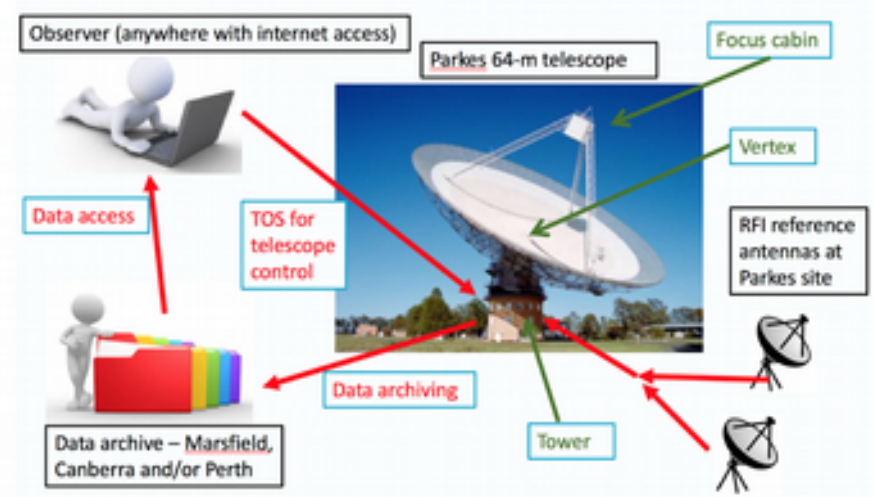
The UWL signal is digitised in the focus cabin. The signal processing is carried out in the telescope tower.

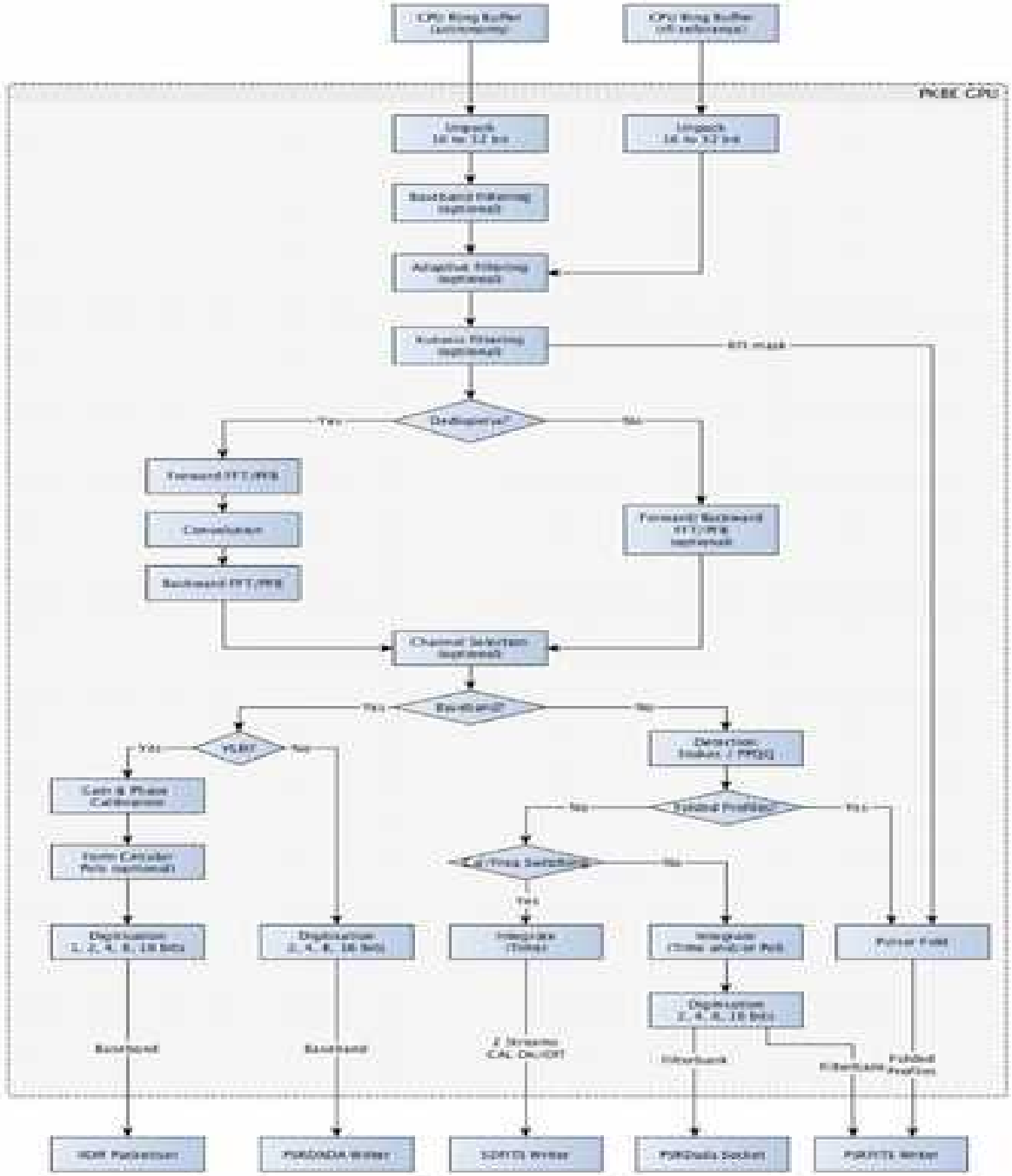
The observer will use a web-based system to control the observations.

Reference antennas will be used to mitigate RFI in real time.

Various calibration methods will become available including transmitting signals from the telescope vertex

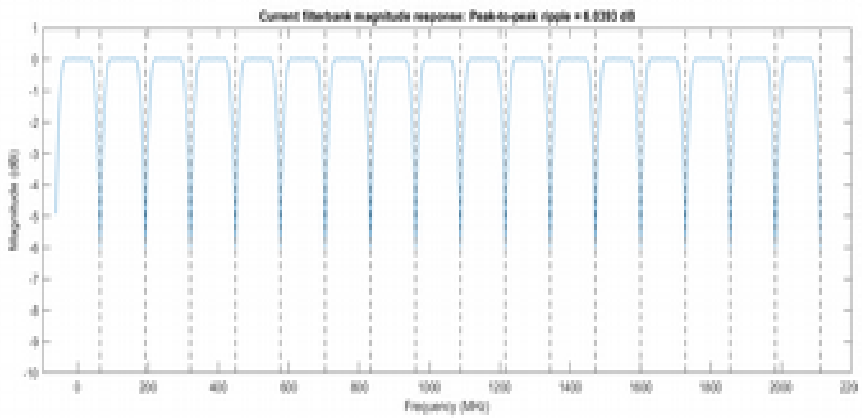
The observer will access data from the data archives.

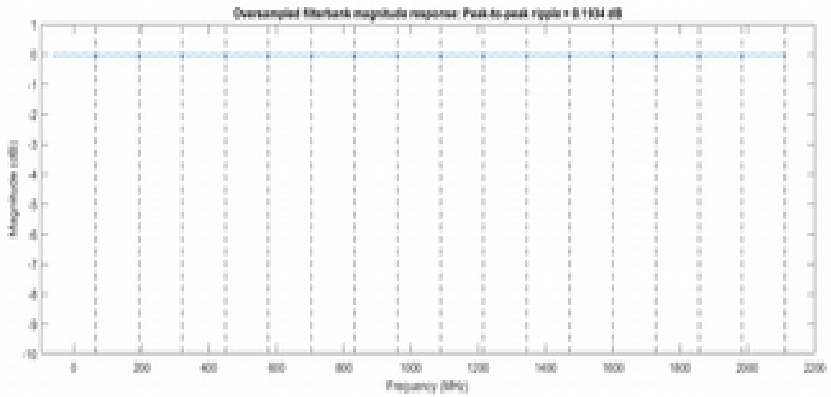



PKBE CPU
Yes
No
Yes
No
Yes
No
No
Yes
No
Yes
Baseband
Baseband
2 Streams
CAL On/Off
Filterbank
Filterbank
Folded
Profiles

UWB-L Channelisation

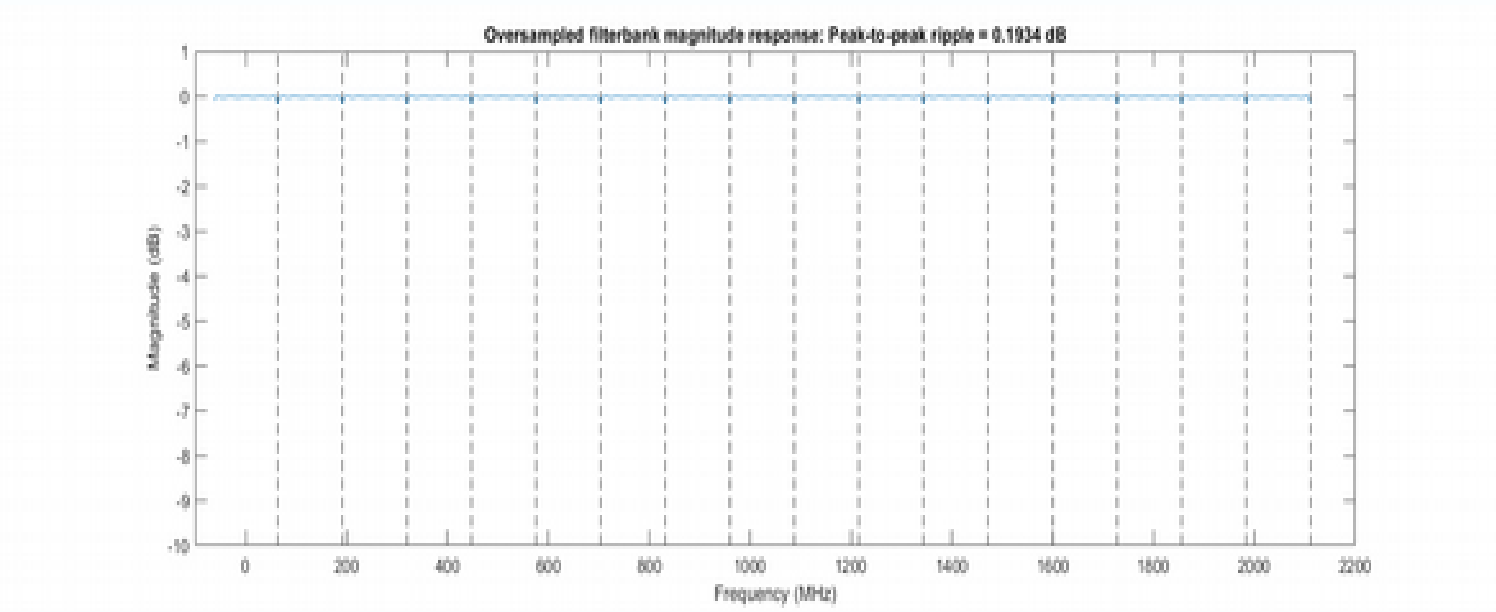
- Current critically sampled filterbank magnitude response
  - Peak-to-peak amplitude ripple = 6.04 dB
- Same filterbank order as the current critically sampled filterbank
  - Oversampling ratio = 4/3 (TBC for Data Rate).
  - Output sample rate of each sub-band = 128 x 4/3 = 170.67MSps
  - Peak-to-peak amplitude ripple = 0.1934 dB





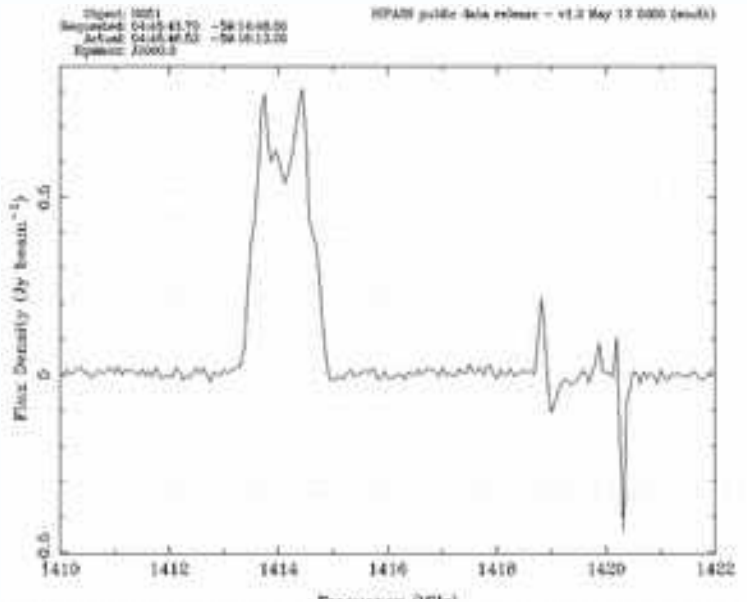
Oversampled filterbanks

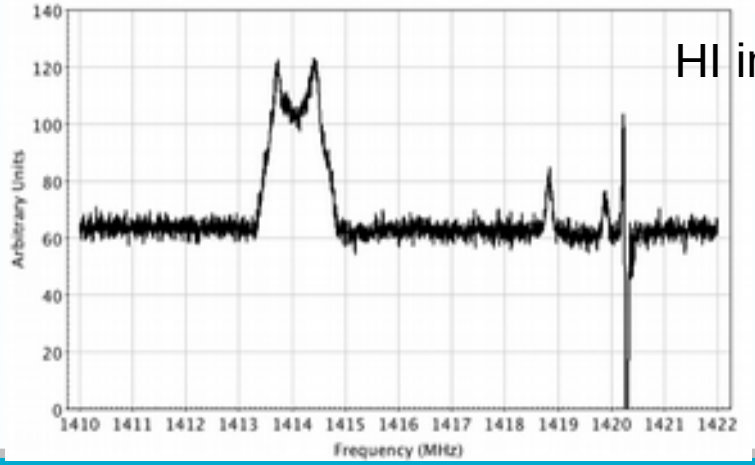
- Same filterbank order as the current critically sampled filterbank
- Oversampling ratio = 4/3 (this needs to be confirmed for compatibility with the max. output data rate for streaming interfaces).
- Output sample rate of each sub-band = 128 x 4/3 = 170.67MSps
- Peak-to-peak amplitude ripple = 0.1934 dB



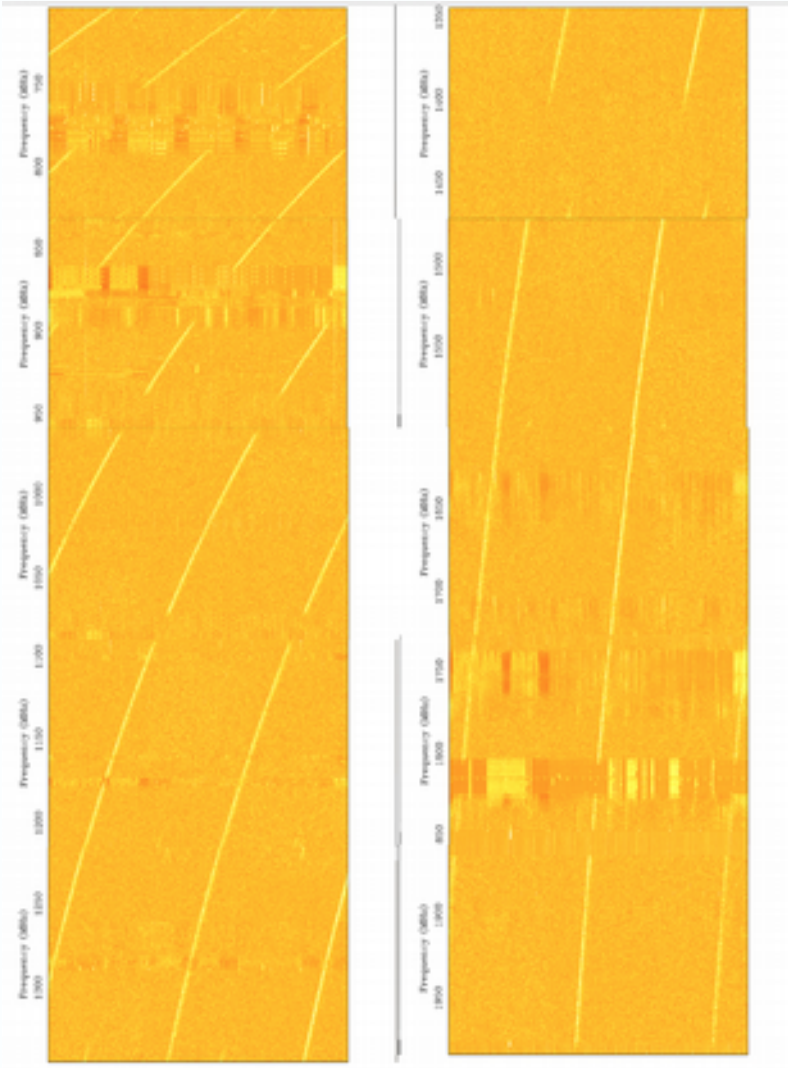
UWB-L in Action

Courtesy George Hobbs, Jane Kaczmarek





HI in NGC1672



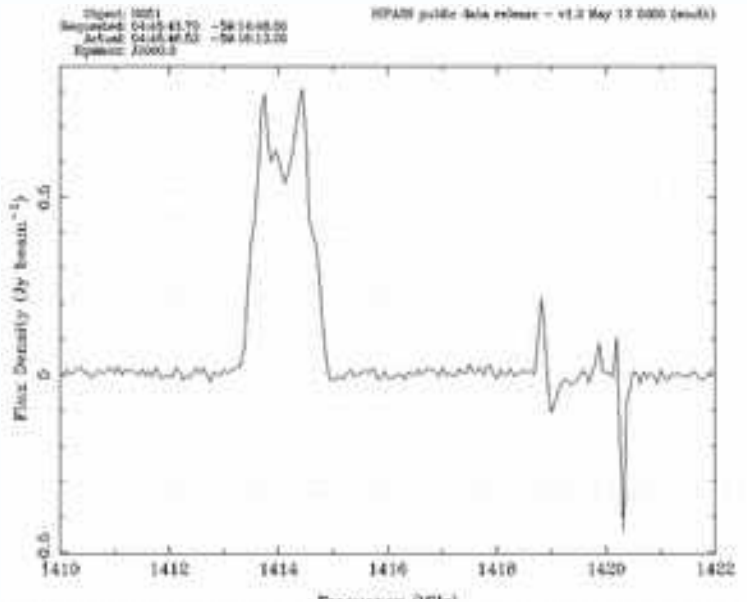
Single pules in Vela

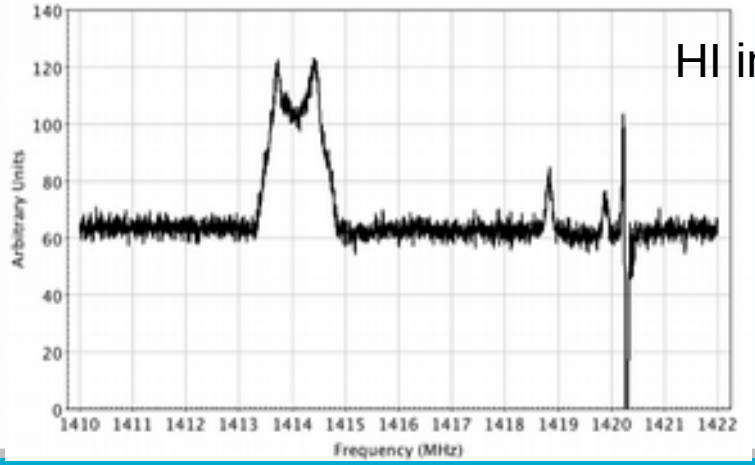
UWB-L VLBI Plans

- UWB-Low 700-4000 MHz, full band sampled
- Coarse channelisation on FPGA to 128 MHz - 16bit complex VDIF
- Legacy receivers can also be processed with UWB GPU backend
- VLBI will process a selection of each 128 MHz independently
- Re-Channelisation and re-quantisation to VLBI standards on GPU
  - VDIF output
  - Probably linear polarizations
- Will decommission LBA DAS and Mark5B+ at end of 2019.
- Move to oversampled Filterbank planned for end 2019 (needed to get continuous spectral coverage).

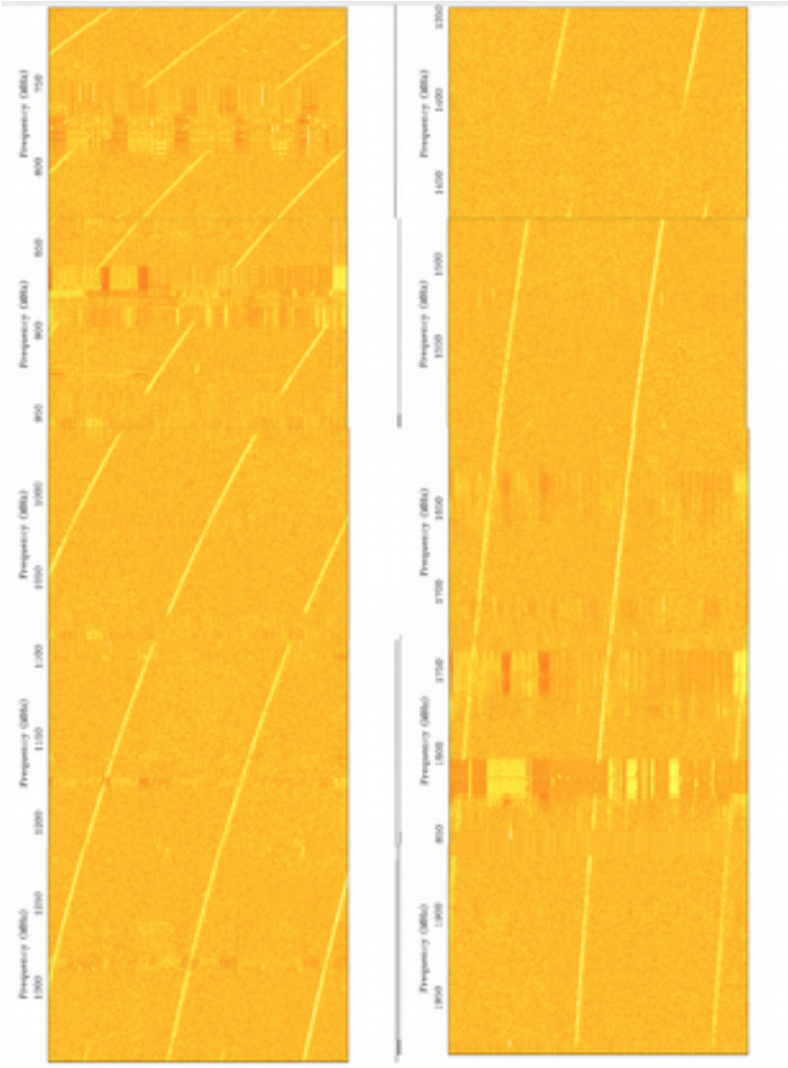
UWB-L in Action

Courtesy George Hobbs, Jane Kaczmarek





HI in NGC1672



Single pules in Vela

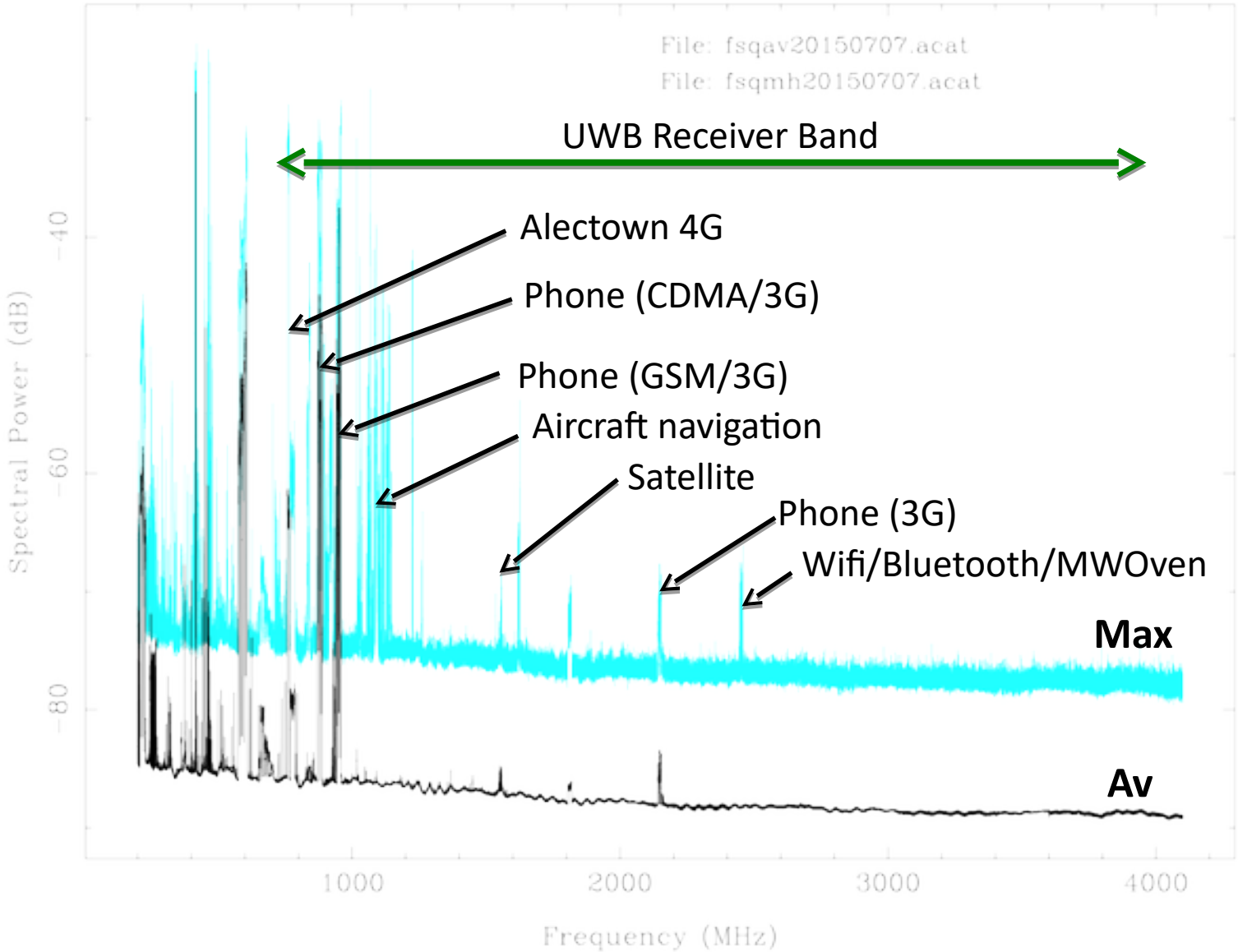
Parkes UWB-High Receiver

- Currently planned, but not yet funded
- Shares backend with UWB-L
- 4-25 GHz split between two bands
  - 4-16 GHz, 16-25 GHz (primarily for illumination)
- ~4 GHz available simultaneously for VLBI recording
- No more receiver changes!

Radio-Frequency Interference Issues

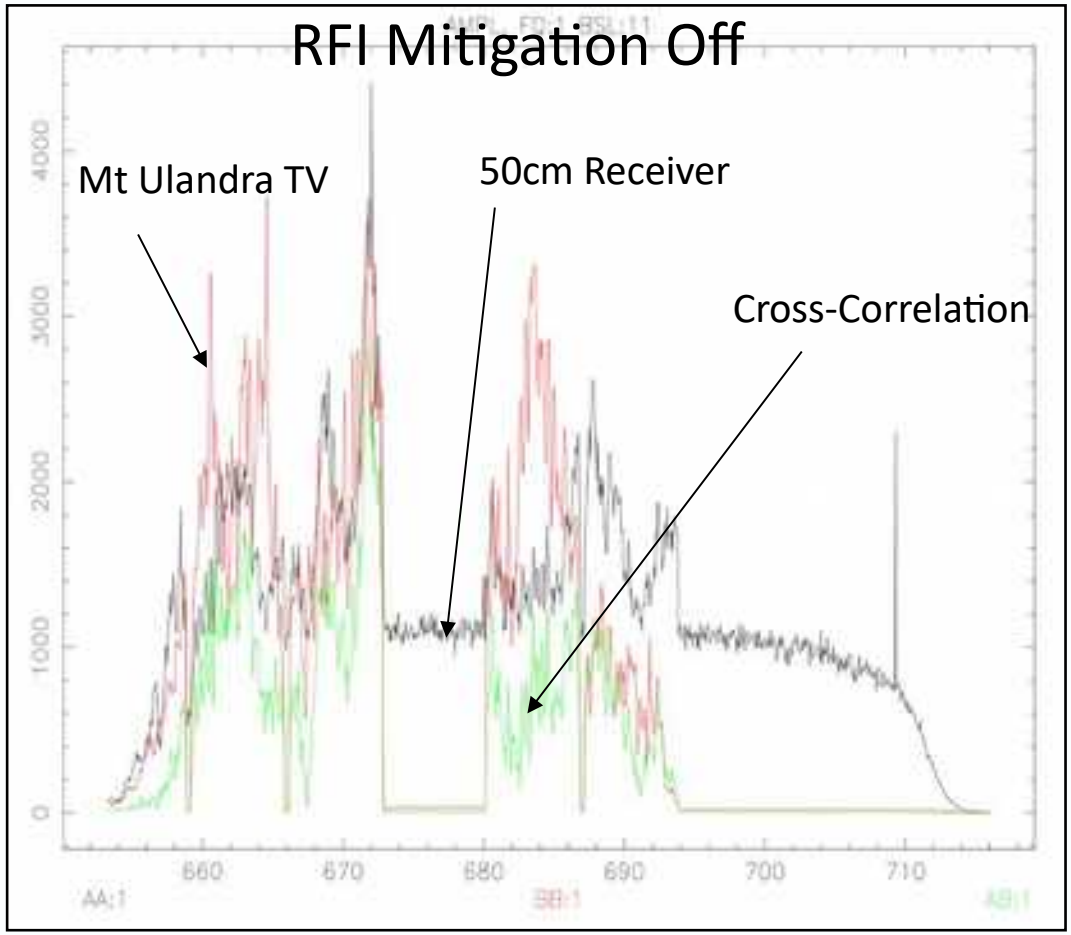
- Very wide band and relatively low frequency of the UWL receiver means that RFI is a significant issue
- RFI comes in two main classes:
  - Band-limited quasi-steady transmissions
  - Broad-band and band-limited transient signals
- Different mitigation strategies:
  - Quasi-steady transmissions:
  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

Parkes RFI Spectrum (July 2015)



Real-time Adaptive Filtering of RFI

- Parkes – original 50cm band, PDFB3 processor
- Single reference signal used for both polarisations of astronomy signal
- Any signal not in the reference channel is unaffected
- Provided receiver remains linear, bands with strong and near-continuous RFI can be zapped in digital data without major penalty
- Envisage a multi-antenna reference signals



System devised by Mike Kesteven, implemented by Andrew Brown and Grant Hampson (Kesteven et al. 2010)

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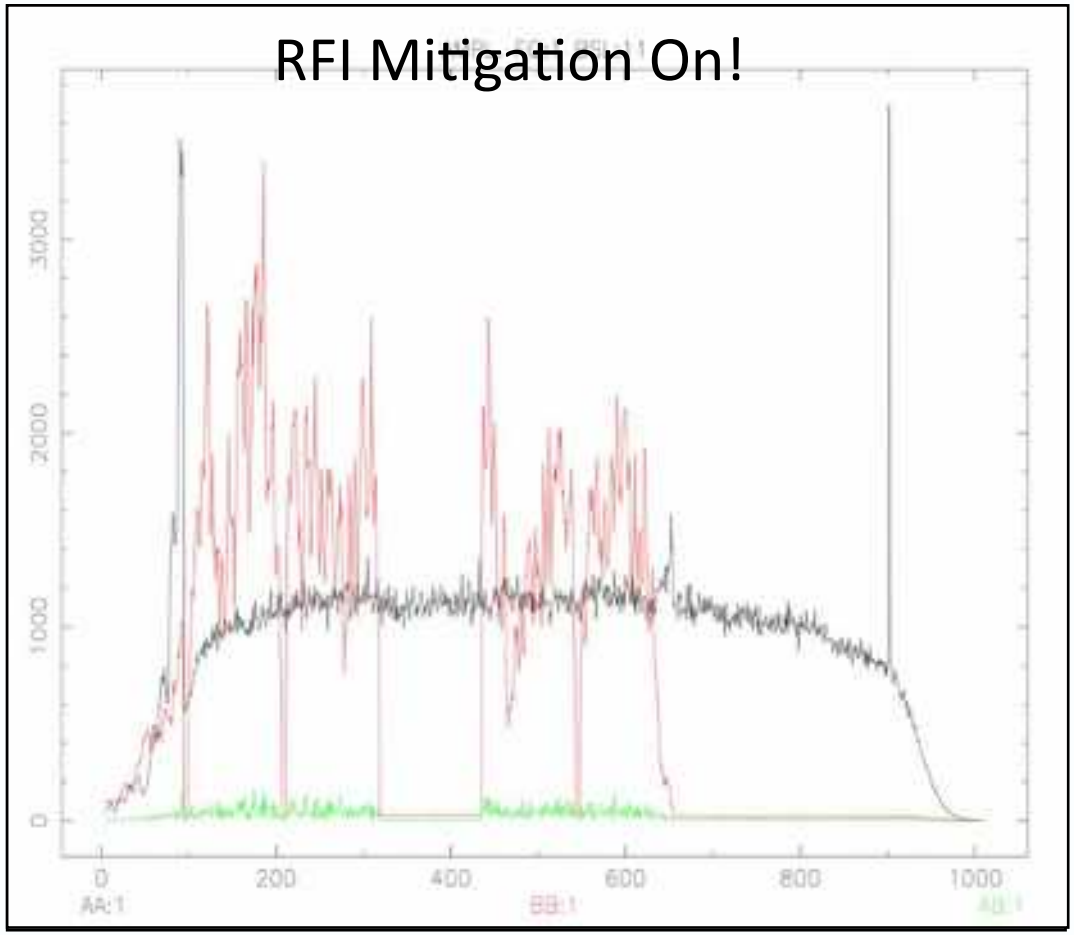
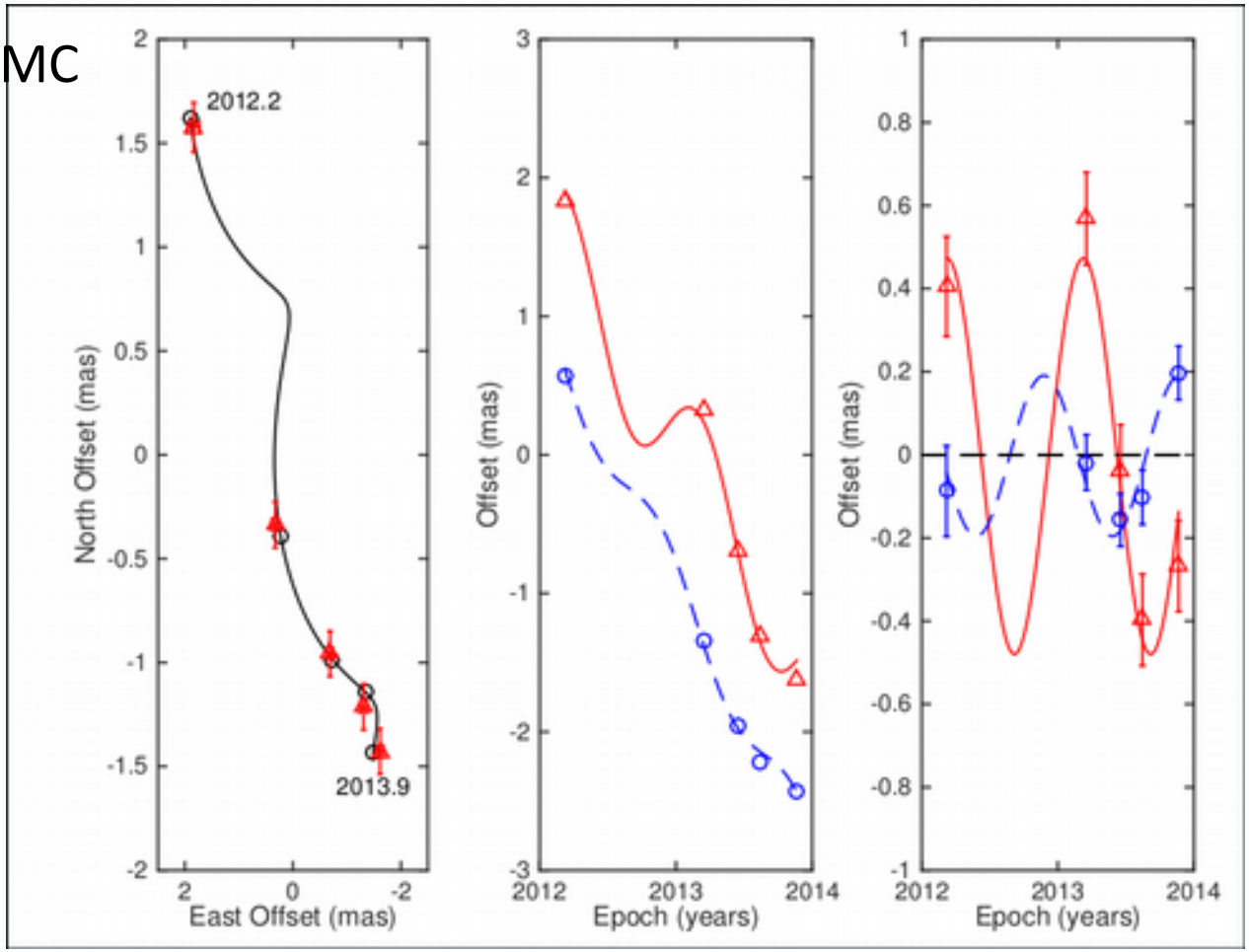


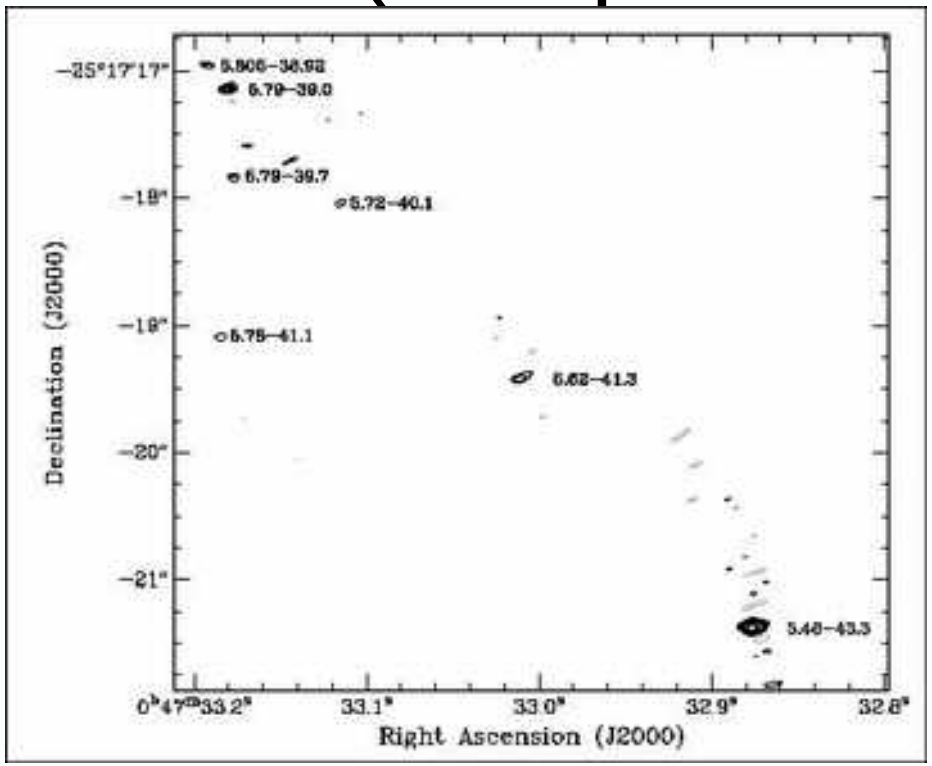
System devised by Mike Kesteven, implemented by Andrew Brown and Grant Hampson

MASER Astrometry (Krishnan et al.)

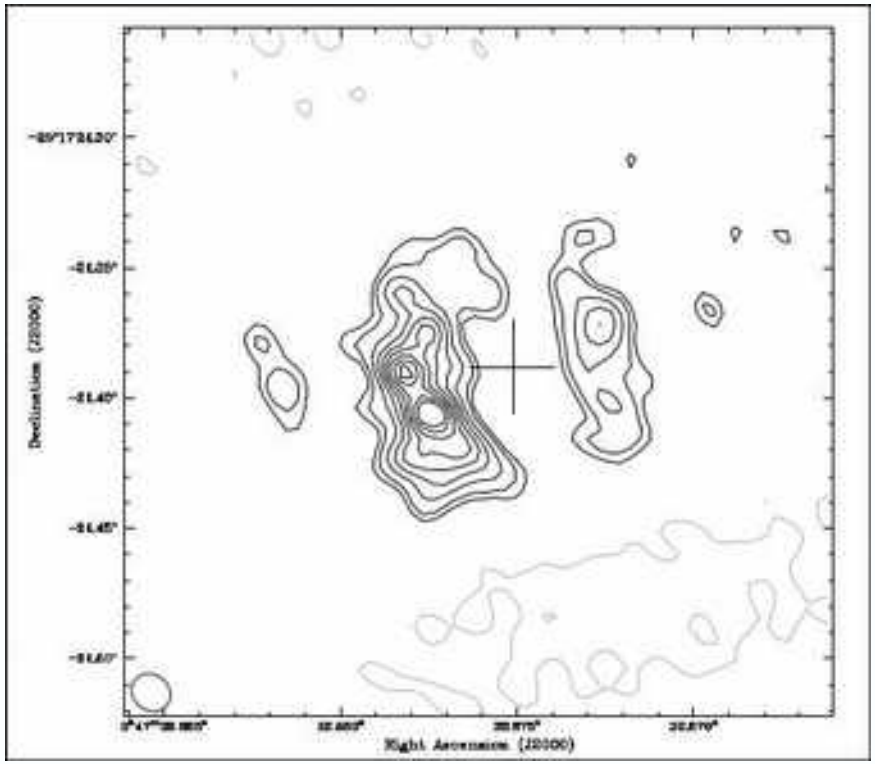
- Structure of spiral arms
- Proper motion of SMC/LMC



Wide Field Supernova Remnants (Rampadarath et al.)

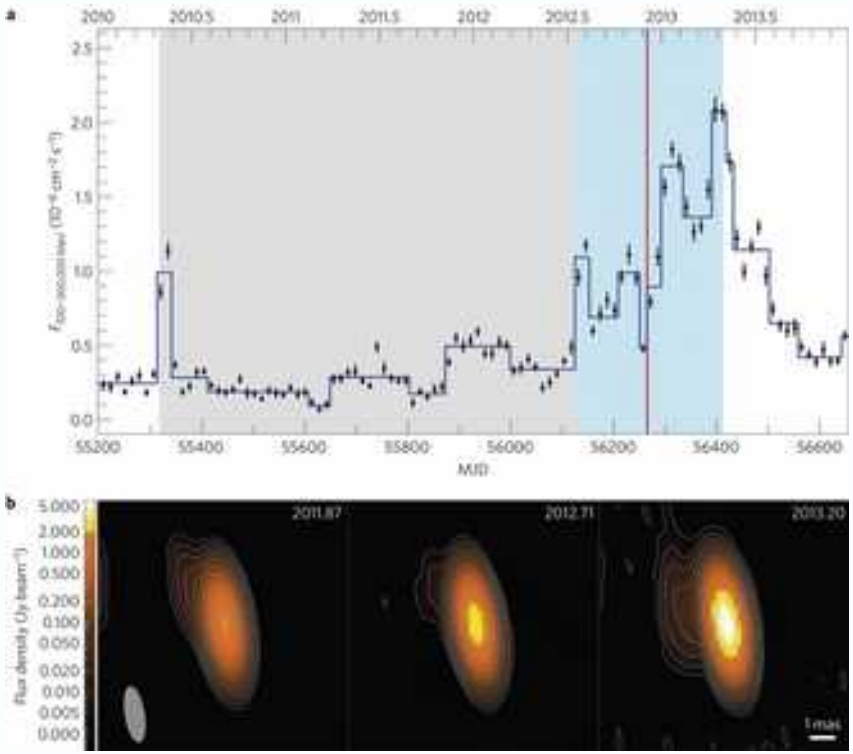


NGC 253



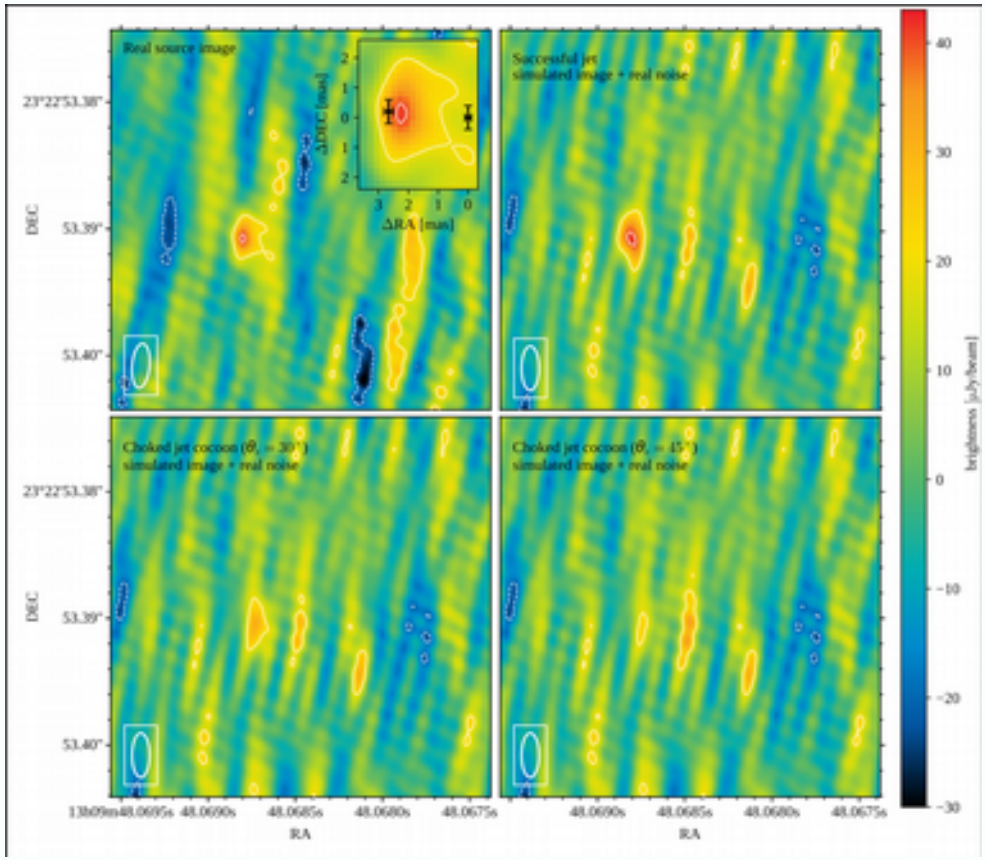
Jet Properties (Kadler et al. 2016)

- Coincidence of blazar outburst with a PeV-energy neutrino event



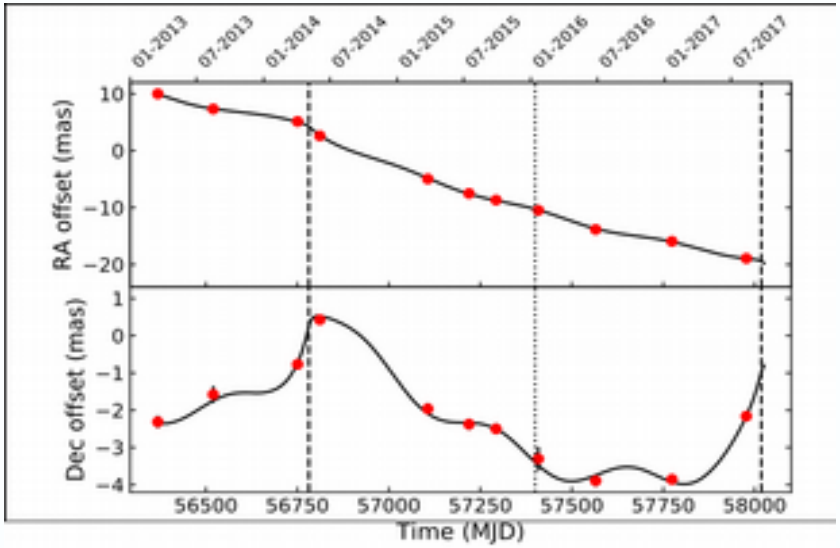
Gravitational Wave EM Counterpart

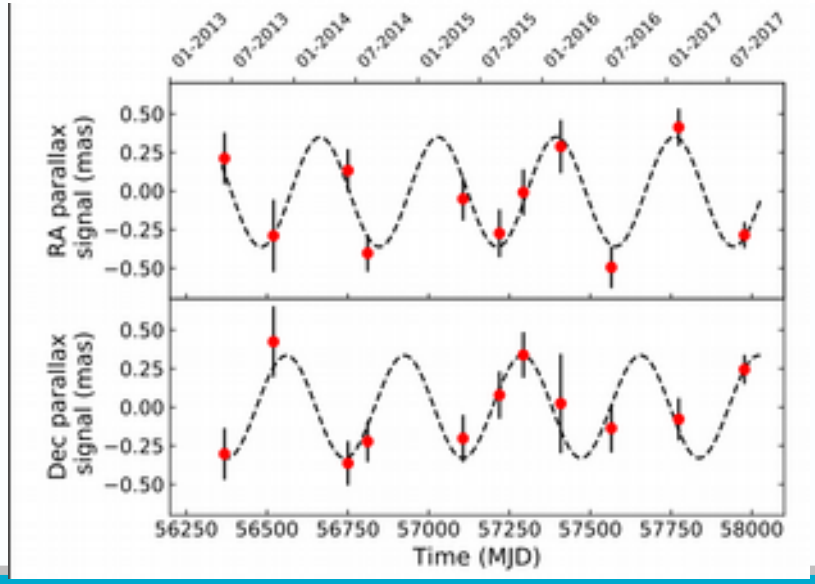
- Global VLBI follow-up of GW170817
  - LBA+EVN+VLBA
- Size constraint supports Mooley et al. Successful jet interpretation

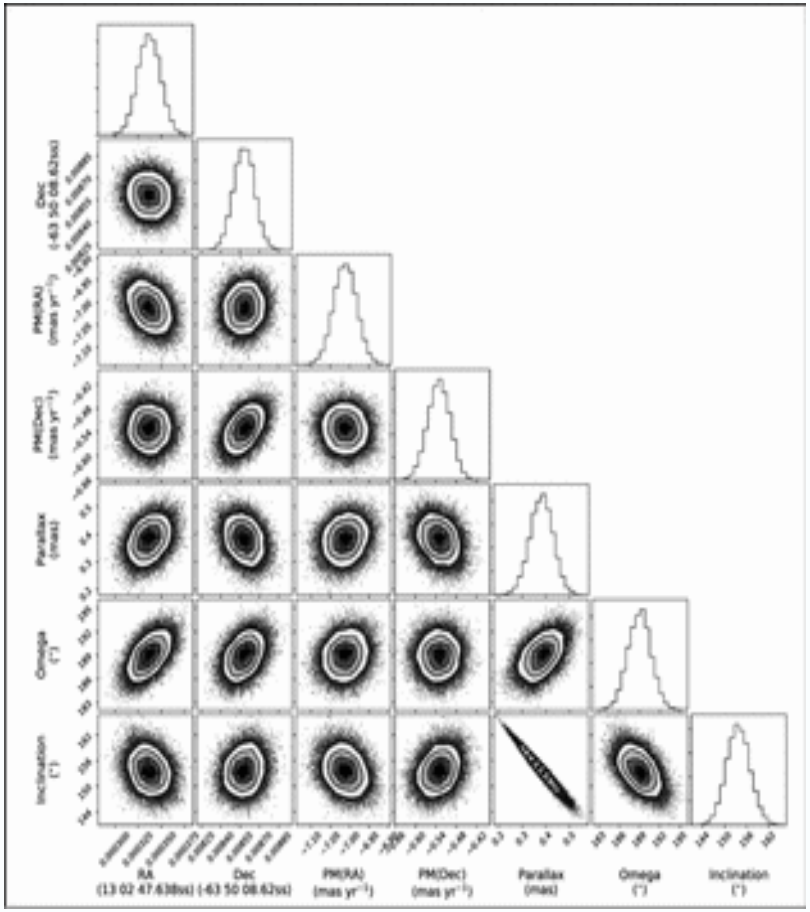


Distance to PSR B1259-63

Miller-Jones et al. 2018

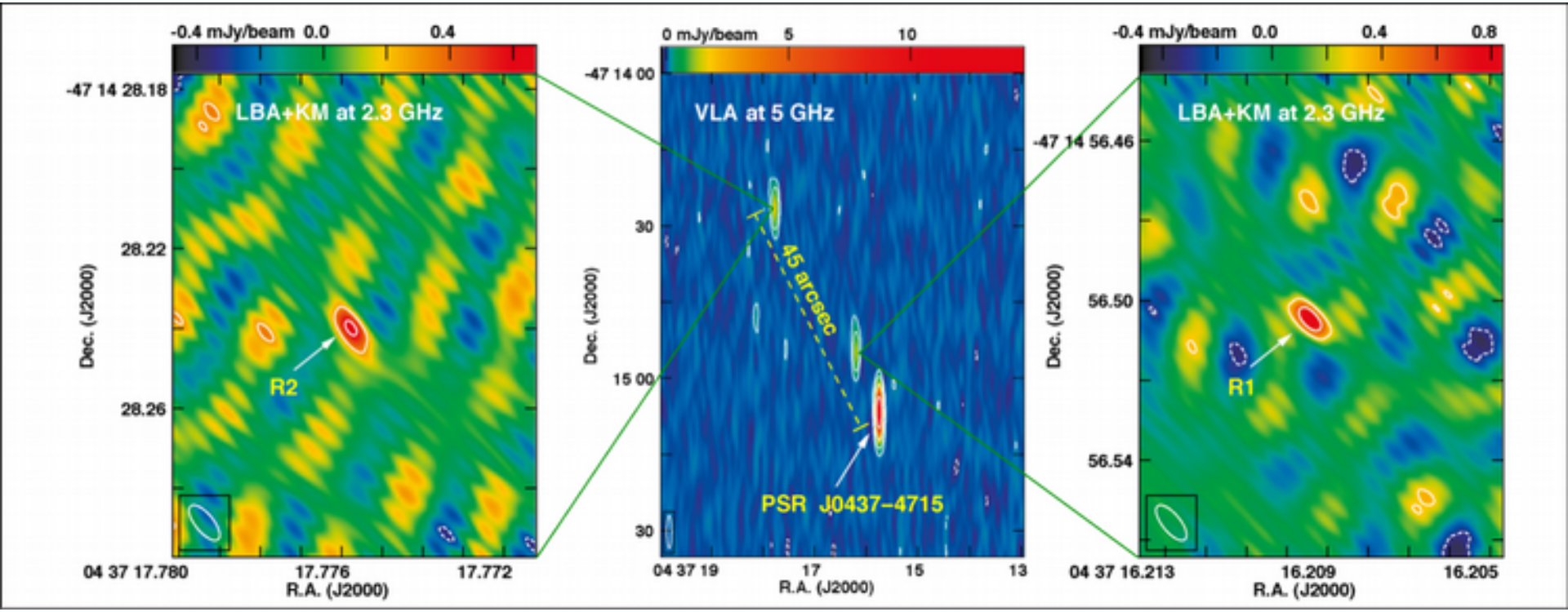






Extreme Astrometry of PSR J0437−4715

- Li et al. 2018 (see talk by J. Yang)
  - Comparison of parallax and timing distance constrains $\dot{G}$



Thank you

CASS/ATNF
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w www.atnf.csiro.au