VLBI:

The very high resolution component of ASKAP

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LBA

- LBA VLBI array operated by CSIRO
  - University of Tasmania, Auckland University of Auckland and Hartebeesthoek Radio Observatory
- Five core telescopes
  - Parkes (64m), ATCA (5x22m), Mopra (22m), Hobart (26m), Ceduna (30m)

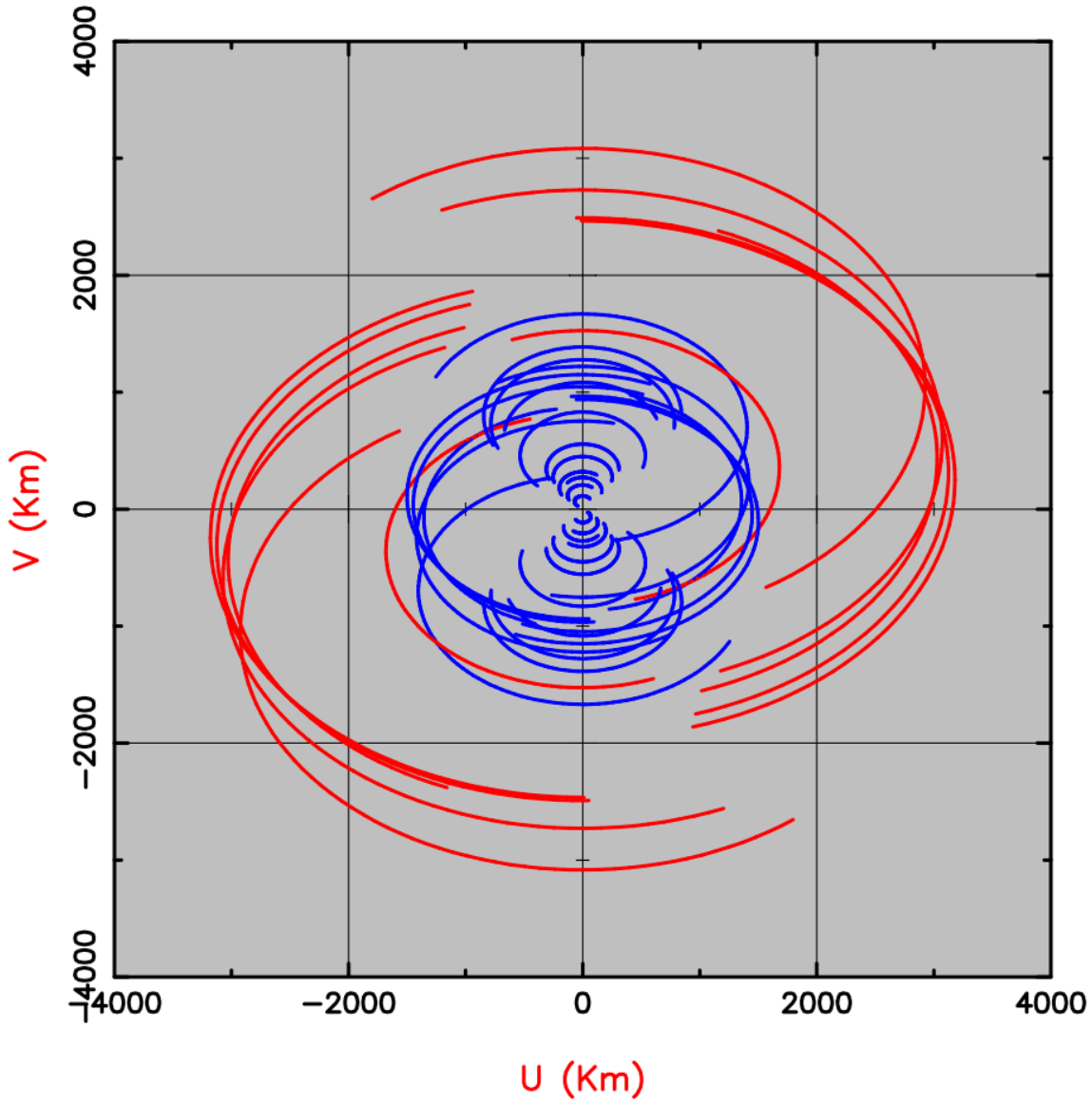
- Warkworth (14m/30m), Hartebeesthoek (26m/15m), Tidbinbilla (70m/34m), Auscope (12m)
- Some Asian & EVN involvement
- 1-100 GHz frequency range
- ~30 days/year observing

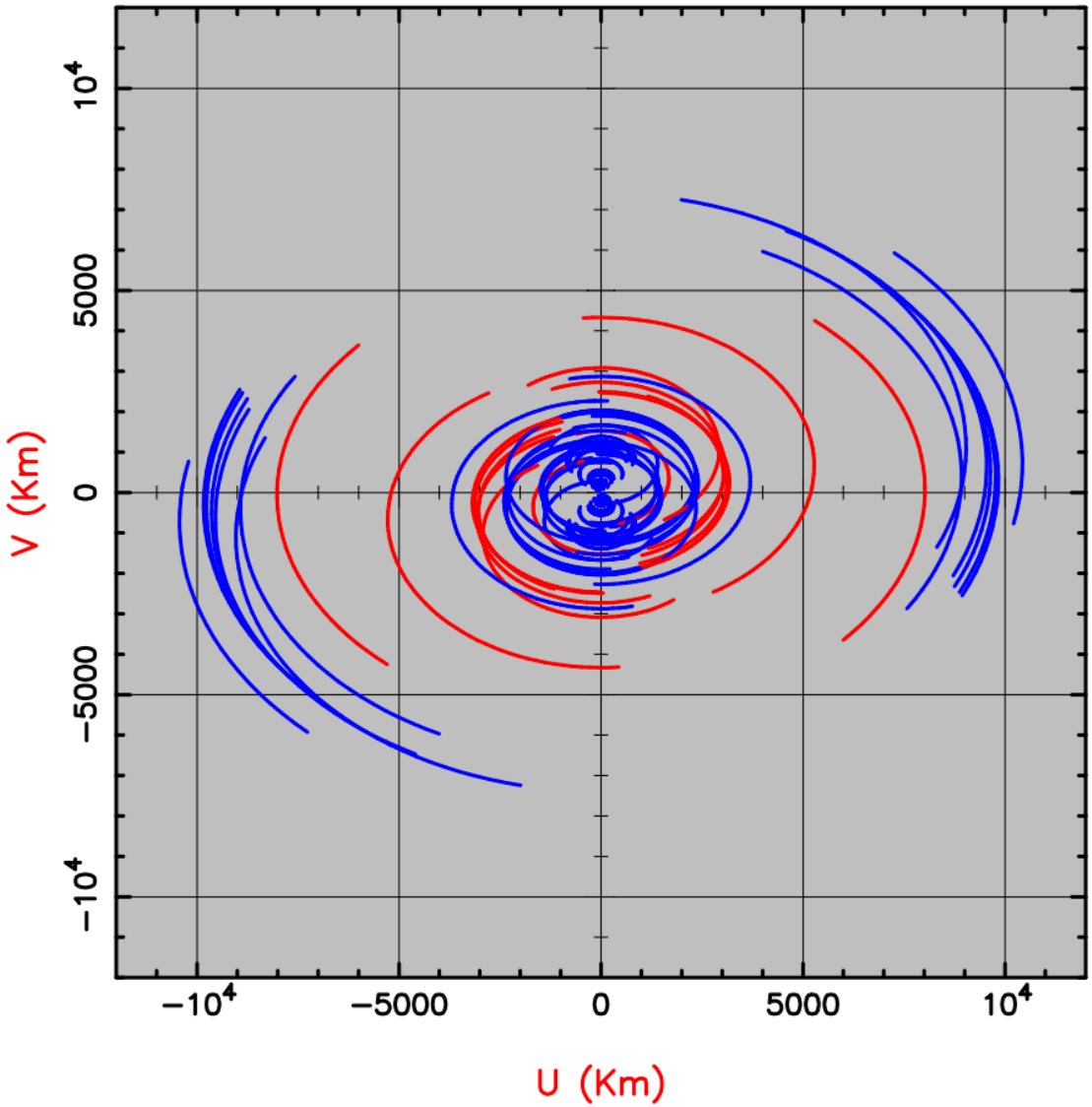
Frequency (GHz)	Baseline (km)		Resolution (mas)	
	Aus LBA	Full LBA	Aus LBA	Full LBA
1.6	1702	9847	22.7	3.93
2.4	1702	10480	15.1	2.46
6.7	1702	10480	5.4	0.88
8.4	1702	10480	4.3	0.70
22.2	1702	9847	1.6	0.28
35	566		3.1	
85	114		6.4	

Aus LBA: Parkes, ATCA, Mopra, Hobart & Ceduna
Full LBA: Also Warkworth, Hartebeesthoek

The High Resolution Components of ASKAP: Meeting the Long Baseline Specifications for the SKA (VLBI)

- Use ASKAP as an element of the LBA
- Accepted as "technology demonstrator" rather than full on survey
- Main requirement ASKAP tied array
  - ~35m equivalent single dish
- Doubles maximum Australia only baseline
  - 1.5x longer which including New Zealand
- Fills in uv coverage to South Africa
- Explore "multi-view" VLBI
  - Multibeam VLBI


4000
2000
0
−2000
−4000
V (Km)
−4000
−2000
0
2000
4000
U (Km)


V (Km)
U (Km)
10^4
5000
0
−5000
-10^4
-10^4
−5000
0
5000
10^4

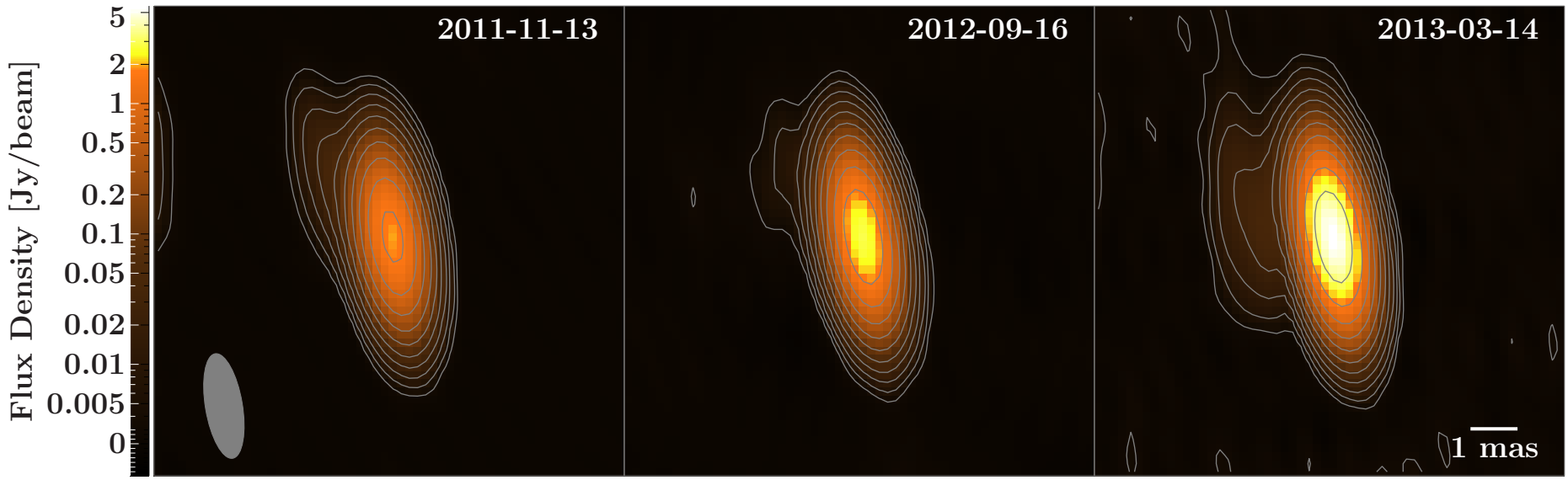
Frequency (GHz)	Baseline (km)		Resolution (mas)	
	Aus LBA	Full LBA	Aus LBA	Full LBA
1.6	**3273**	9847	**11.8**	3.93
2.4	1702	10480	15.1	2.46
6.7	1702	10480	5.4	0.88
8.4	**3273**	10480	**2.3**	0.70
22.2	1702	9847	1.6	0.28
35	566		3.1	
85	114		6.4	

Project Update

- Installed single pixel feeds at 1.6 and 8.4 GHz on two antenna
- Supplied Hydrogen maser for observatory
- Installed own VLBI backend
  - First ASKAP fringes 22 April 2010
  - First eVLBI fringes 27 June 2011
  - Determined absolute position for AK29
    - Original survey position 17m off
  - Demonstrated PAF VLBI with single dish beta system
- No tied array developed for beta
- Tied array for full ASKAP spun off as separate project
- Exploring ASKAP PAF-PARKES PAF VLBI

ASKAP VLBI Science

- Regular inclusion in regular LBA observations since
  - 69 user experiments
  - 1000 hours observing (including June 2016 session)
- First science - 1934-638 - Tzioumis *et. al.* 2010
  - Higher resolution low frequency observations reinterpreted evolution changes as optical depth effect
- Pulsar astrometry (Miller Jones *et. al.*)
- PKS B1424−418
  - Possible radio association with extraterrestrial very-high-energy neutrinos discovered by IceCube
  - Kadler et al. Nature Physics 2016


Flux Density [Jy/beam]
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0
2011-11-13
2012-09-16
2013-03-14
1 mas

VLBI with ASKAP/VLBI for ASKAP

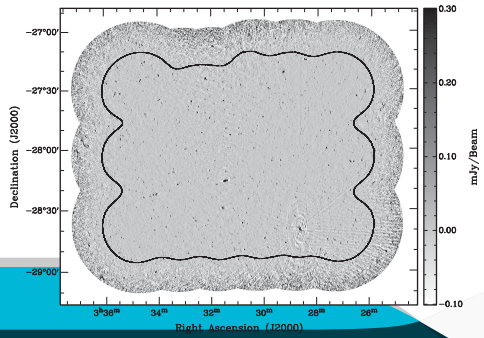
- ASKAP will enhance all low frequency LBA observations
  - Better resolution matching for higher frequency observations
  - Benefits a range of science
- ASKAP SSPs need VLBI for follow up
  - LBA is only Southern Hemisphere LBA array
  - ASKAP has unique frequency coverage
- Call for 1 GHz LBA observations will increase

Pulsar Astrometry

- Accurate astrometry give parallax and proper motion independent of timing
  - Good to break some degeneracies in timing model
  - Improved GR tests
- Independent parallax measurement anchors electron density distribution of Milky Way
  - Improved distance estimate for other pulsars, Galactic formation models
- Calibrate pulsar 2D velocity distribution – kick physics
- Pulsar timing arrays have underestimated errors on parallax and pm (Deller *et al*, 2016, ApJ submitted)

EMU

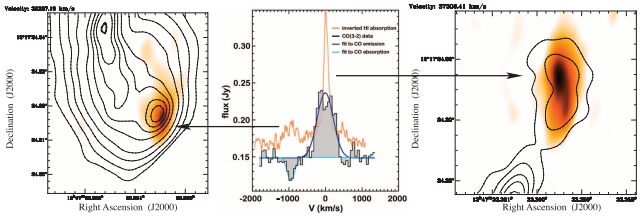
- EMU is a deep (10 µJy/beam rms) radio continuum survey of 75% of the sky
- Will detect 70 million radio galaxies
- Need VLBI to distinguish between AGN and Star forming galaxy
  - Ideally VLBI on all sources….
- High quality VLBI on a sample of sources, high resolution
- Widefield VLBI of 1000 square degrees
- Single baseline survey of large fraction of EMU sources
  - Parkes-ATCA. Would include ASKAP if practical but resolve out some sources
- Want 1 GHz VLBI



FLASH

ASKAP-FLASH

- A blind HI absorption-line survey using background radio continuum sources to identify and characterize foreground neutral hydrogen
- Want VLBI to interpret results based on shape of background radio source



- Also VLBI follow up of actual HI detections
  - 700-1000 MHz (need ASKAP & Parkes PAF)
  - Estimate size of absorbing clouds
  - Figure out where absorption is coming from
  - E.g. fast jet-driven outflows of neutral gas in nearby radio galaxies

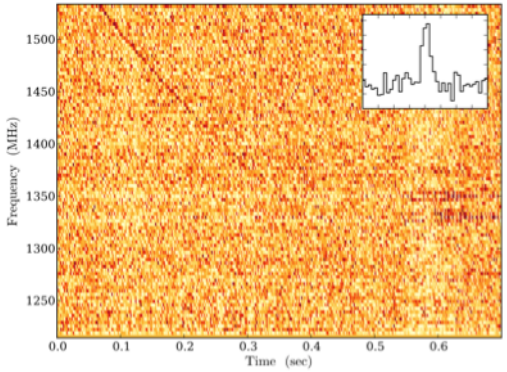
CSIRO

GASKAP

- High spectral resolution survey of HI and OH lines in the Milky Way and Magellanic Systems
- VLBI follow up of OH masers:
  - Structure and dynamics of individual sources
  - Astrometry – distance and Galactic dynamics
  - Zeeman pair polarisation
    - Need high resolution to match pairs and overcome spatial depolarisation
- Required VLBI at 1.6 GHz

Transients

- VAST and CRAFT investigate the radio sky looking for transients at a range of timescales
- Fast transients must be small
  - Need VLBI to resolve
- VLBI crucial for interpreting many of the detections
  - ESE (Extreme Scattering Events)
    - Image while on progress – infer geometry of the lens
  - FRBs (Fast Radio Bursts)
    - Location of afterglow associated with blackhole core or elsewhere
  - Gamma-ray bursts and supernova
    - Measure expansion rate and discriminate between difference sources for the radio emission

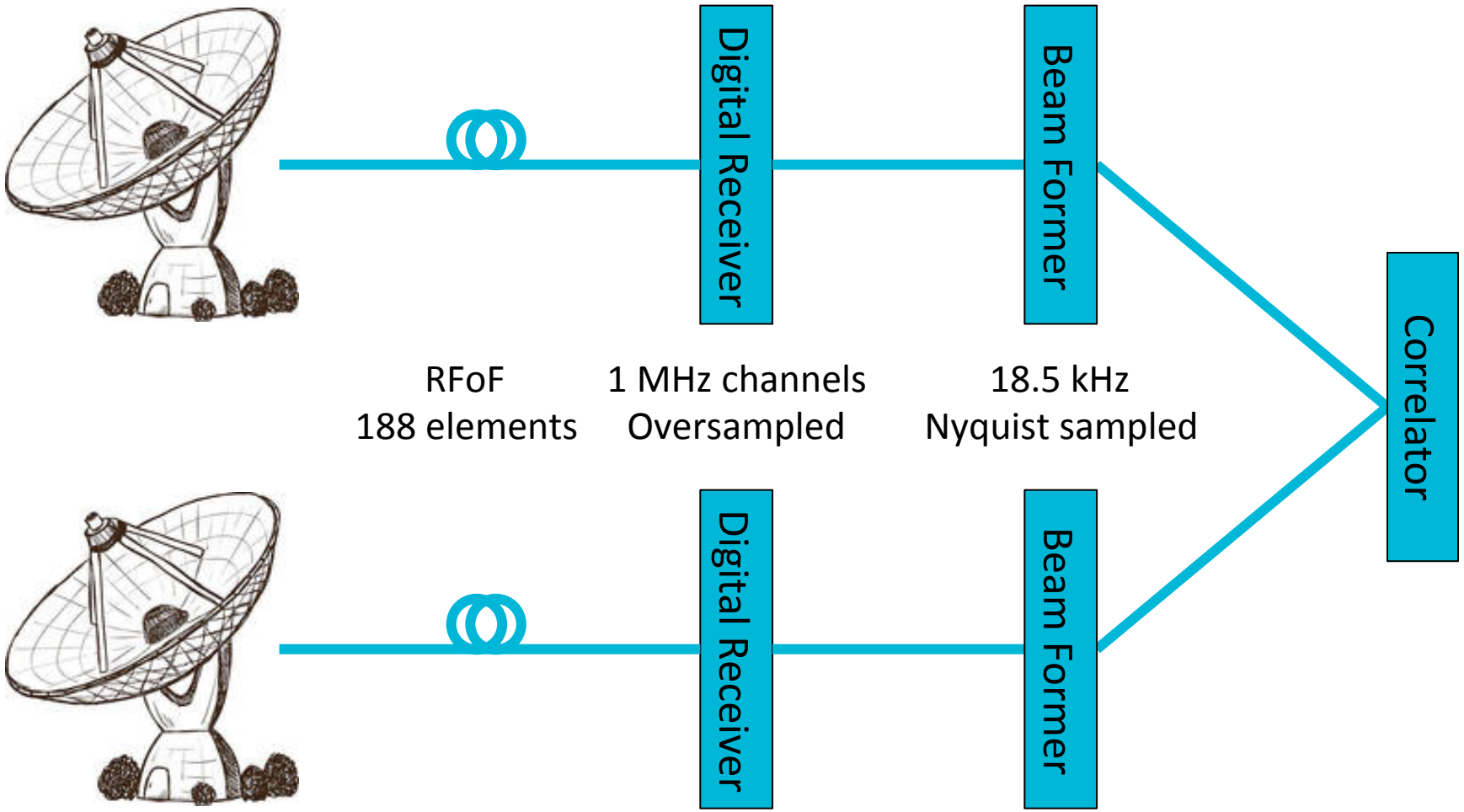


POSSUM

- Measure the Faraday rotation of three million extragalactic radio sources
- Significant population of de- (or un-) polarized compact steep spectrum sources, as well as a smaller population of higher polarization compact sources
- VLBI to see if they are structurally different, are embedded in different types of media, etc
  - Including polarimetry
  - 1 GHz LBA plus at a higher frequency (with ~matched resolution) to get rough spectral indices for the resolved components (to help distinguish between CSOs and blazars).

SETI

- SETI with ASKAP would require tied array
  - Untargeted search would require prohibitive compute
- Multiple tied array beams with dedicated SETI backend per beam
  - Presumably would want many tied array beams


Digital Receiver
Beam Former
Correlator
RFoF
188 elements
1 MHz channels
Oversampled
18.5 kHz
Nyquist sampled
Digital Receiver
Beam Former

Tied Array Strawman

- Develop oversampled fine filterbank
  - Beamformer ➔ Correlator link at capacity
- Add tied array functionality in correlator
  - Maybe linear ➔ circular conversion
- Add Ethernet packetisor
- Purchase "large" switch and add *lots* of Ethernet cables
- Develop GPU based synthesis (inverse) filterbank
  - GPU server with 4 GPUs can probably handle 4 beams
  - Purchase 1 or 2 GPU servers initially
- Feedback for array calibration

Conclusion

- ASKAP tied array functionality would be a major benefit for a range of science using the LBA
- VLBI is critical for the follow up of a lot of ASKAP science
  - Much of this needs to be at ASKAP frequencies
- The tied array project is still being planned

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Thank you

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