ATUC Open Day Session 4

From now to the future

A low energy beamformer and its potential use for ATNF

Paul Roberts

Low energy beamforming

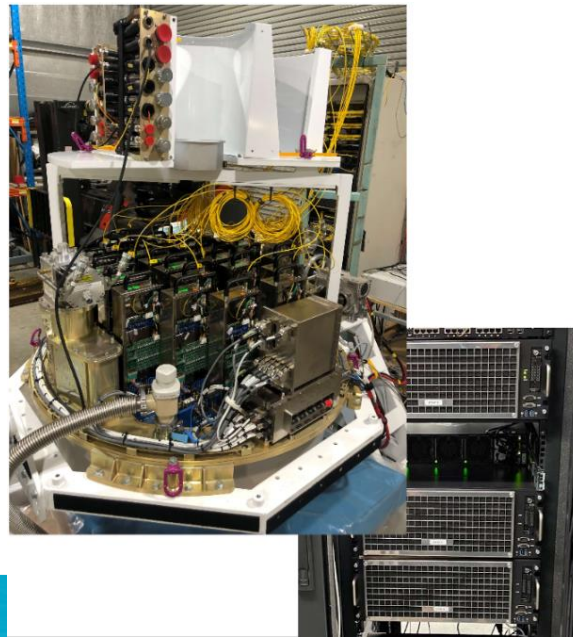
Multiple simultaneous beam beamforming is a computationally expensive process
-> High power

High physical complexity (signal processing or routing) as elements/beams -> large

Problem especially for lunar or space use , remote inaccessible locations and increasingly for low power terrestrial deployment

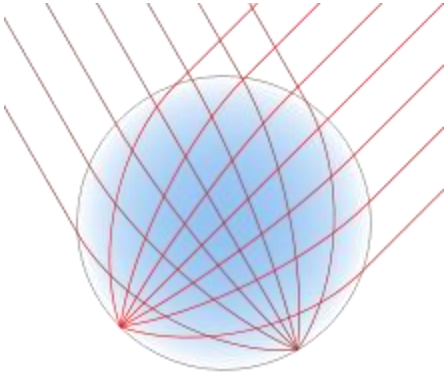
Current ASKAP, CryoPAF - fully digital beamforming multiple simultaneous beams

- Digitise every element with an ADC
- Perform all beamforming operations fully digitally in FPGAs and CPU/GPU
- Ultimate flexibility in beam steering, beam control, calibration and novel signal processing
- Comes at a cost of high power and complexity
  - CryoPAF - > ~ 10kW for PAF receiver and beamformer (c.f. LunaPAF ~100W)
  - Complexity – 10s of man-years effort in dev

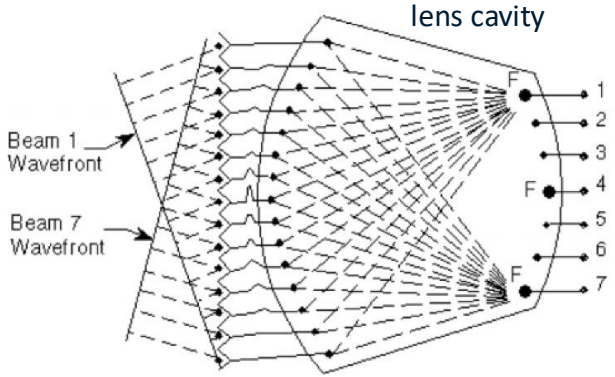


An alternative to fully digital beamforming - lens based beamformer (Analogue)

- Relies on path length compensation for multiple steer angles using material and / or geometric properties of device
- Passive
- TTD wide band device
- Fixed beams and beam pointing

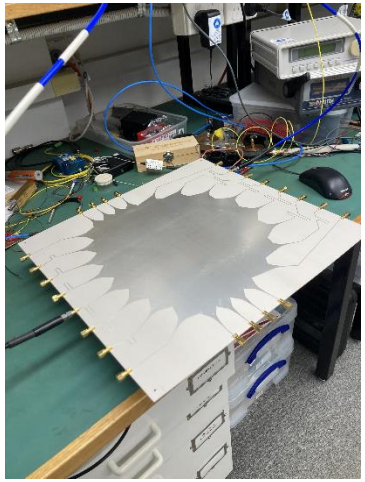


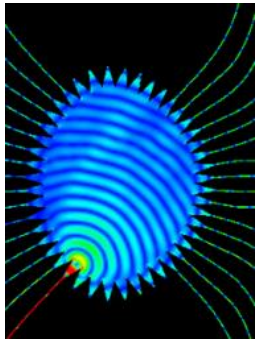
Luneburg lens



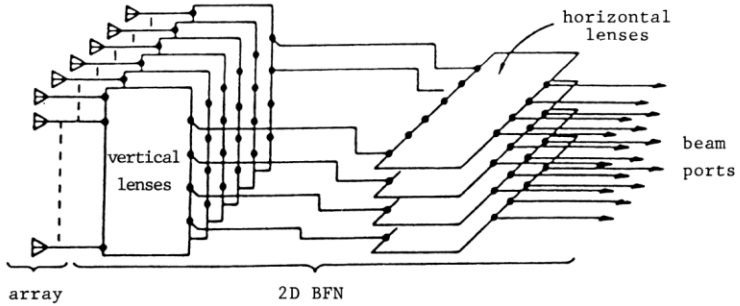
Microwave (Rotman) lens

Planar Rotman microwave lens

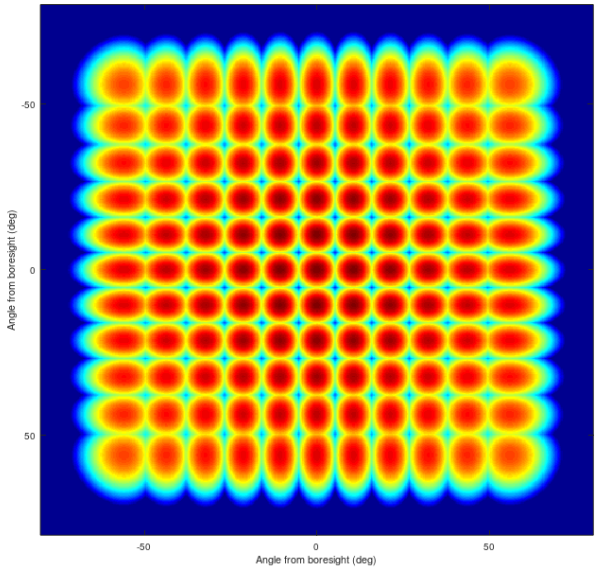




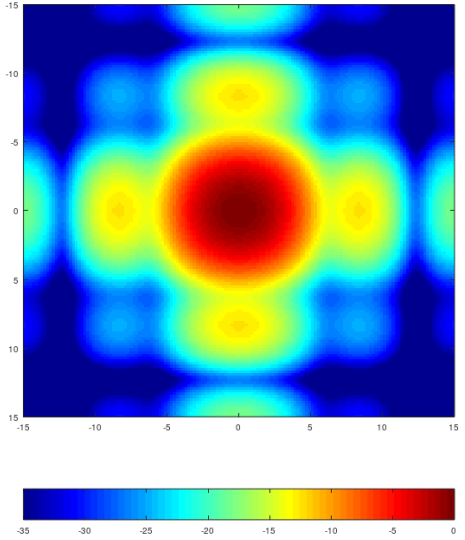
- Simple low cost planar microstrip construction
- Provides set of fan beams
- Couples to any type of feed element
- LNA and compensating gain prior to lens so no impact on NF
- TTD wide band device
- Is a unit cell that can be replicated 2xNb in two dimensions times to provide 2D pencil beams



Example beam response on sky for 10x2 lenses



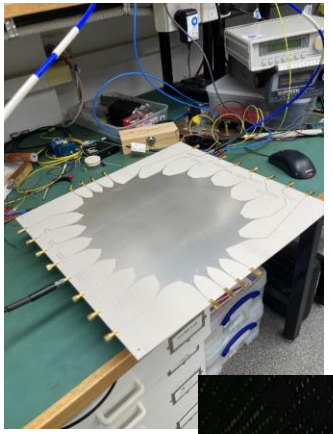
On sky beam pattern

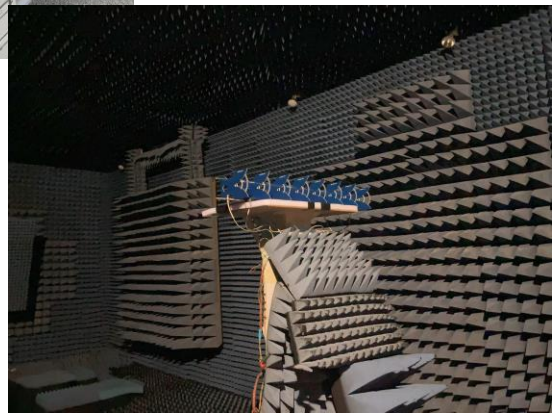


Beam shape

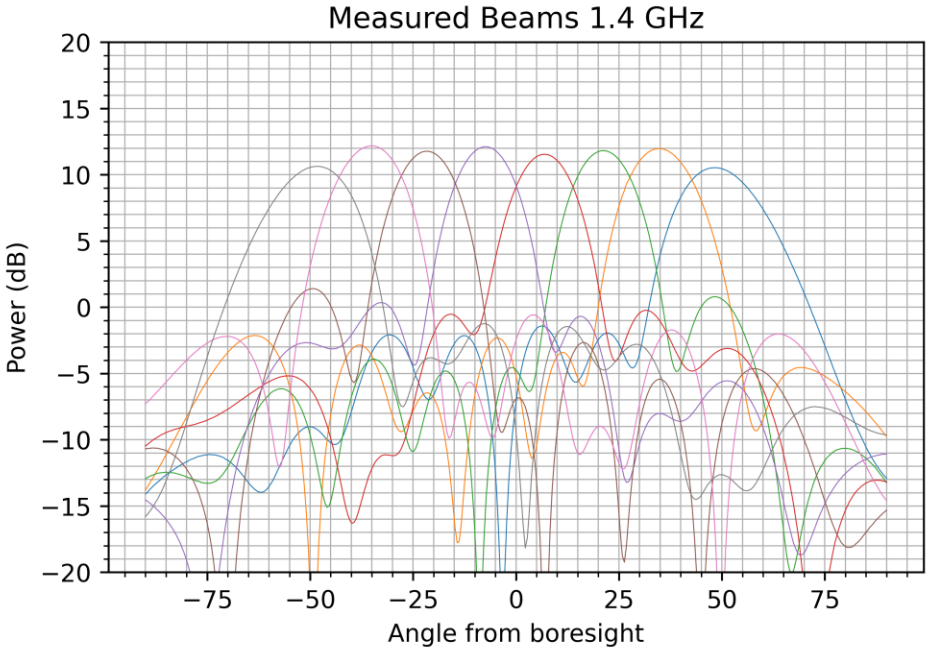
Current progress – 8 element lens

- unit cell for 64 element array

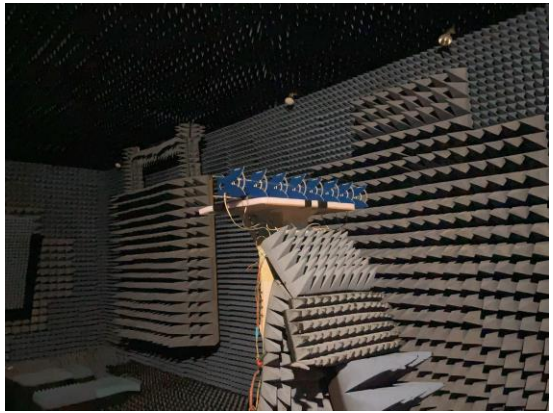


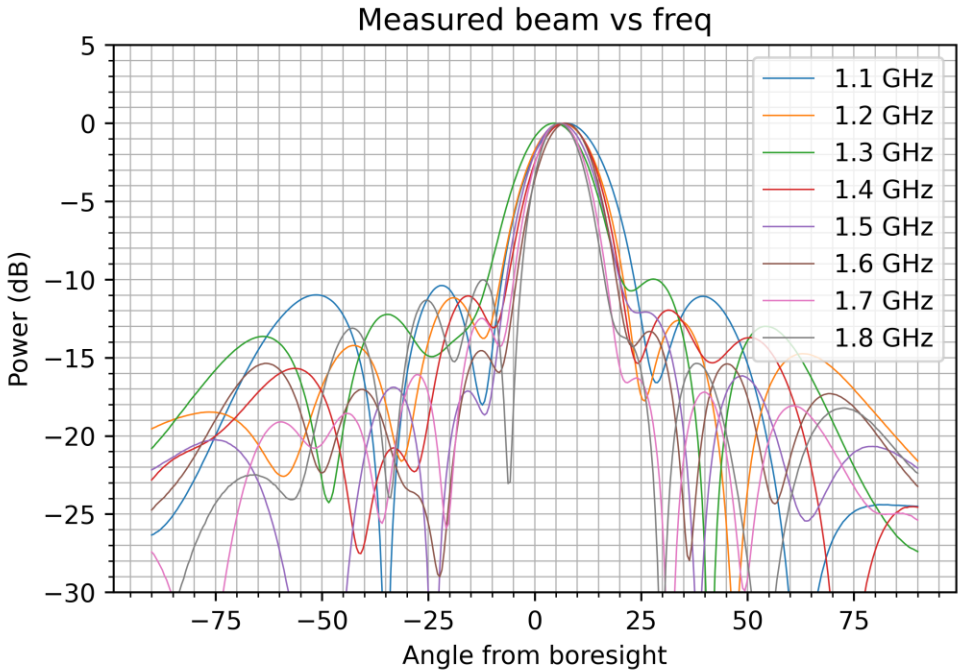


Beam response of 8 element linear array of tapered slot antennas + LNA + lens measured in test range



Measured beam frequency response (beam 3)





Conclusion

Lens based low-energy beamformer is an attractive option for situations with

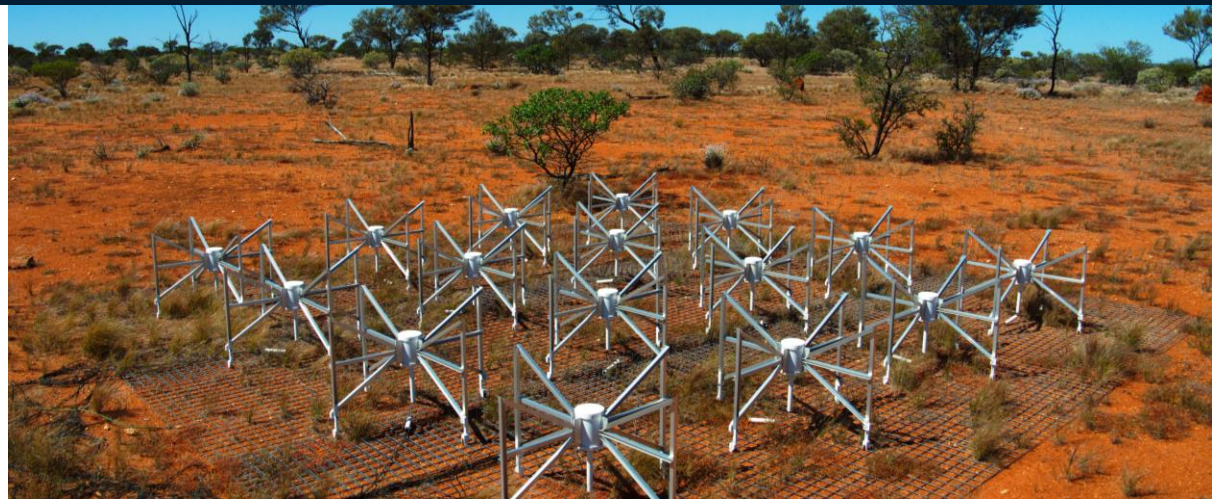
- Fixed beams
- Fixed element weights
- Moderately selective beams
- Significant power constraints

For example: All Sky Surveys (ASS) for transients or techno-signatures or high-energy particle and related phenomena. Especially for lunar or remote locations.

Pursing a practical prototype system targeting ASS use for transient phenomena

A nexus of surveys:

compact sources across multiple wide-field instruments

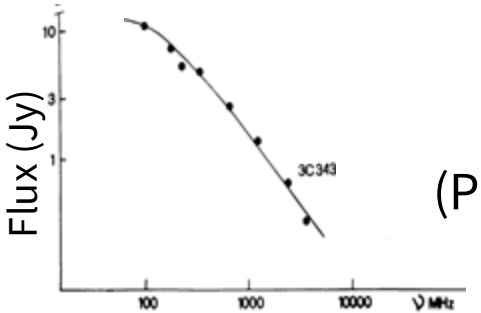


Emily F. Kerrison

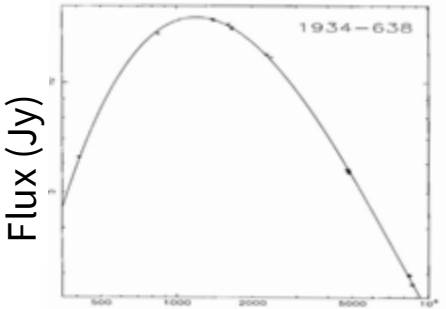
Elaine M. Sadler & Vanessa A. Moss

Peaked Spectrum (PS) sources

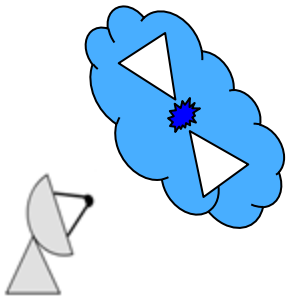
CSS
(3C 343)



GPS
(PKS 1934-638)



“Peaked Spectrum” (O’Dea & Saikia 2021)



Linear size $\lesssim$1kpc

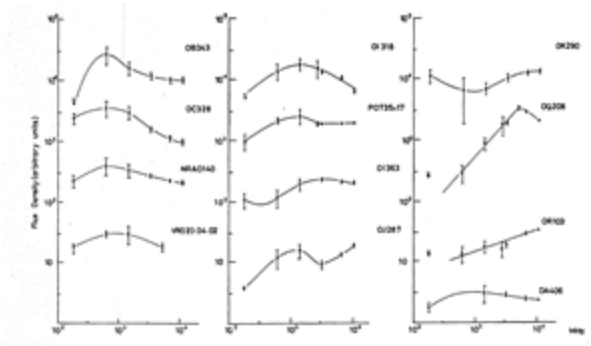
Spectral turnover due to either (Kellerman 1966):

Previous samples of PS sources

Original samples (1960s - 70s)

< 5 flux measurements

<< 100 sources (e.g. Kraus 1970, Blake 1970)

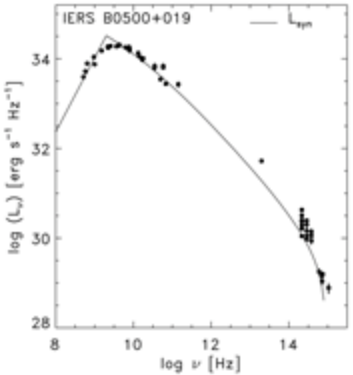


Blake 1970

Growing interest (80s - 2000s)

targeted observations (e.g. Snellen+2003, Ostorero+2010)

larger samples (e.g. Hancock 2009 with 656 sources)



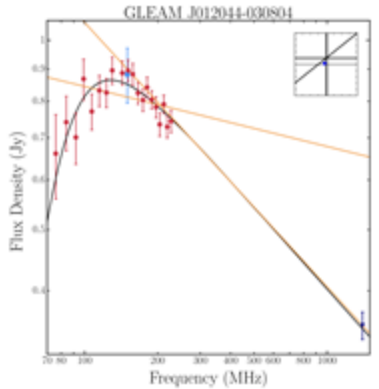
Ostorero+2010

'New Era' of untargeted surveys

Callingham+2017 **(1483 sources)**

also Coppejans+2015, Ross+2021

more **standardised modelling**



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‘New Era’ of
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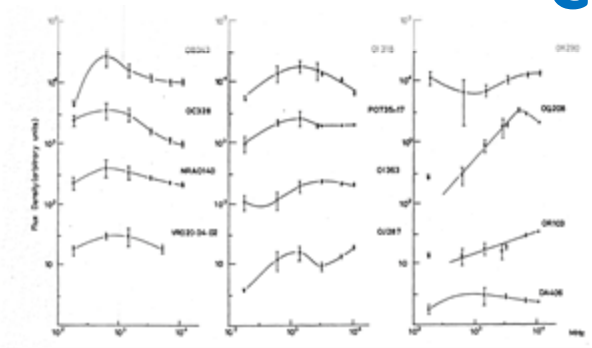
more **standardised modelling**

Can we do even better?



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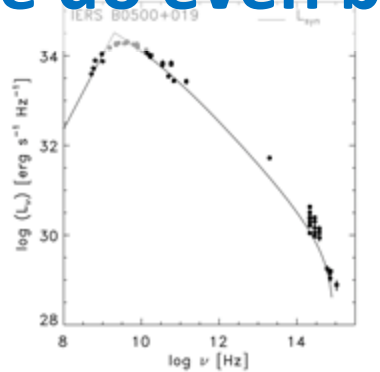
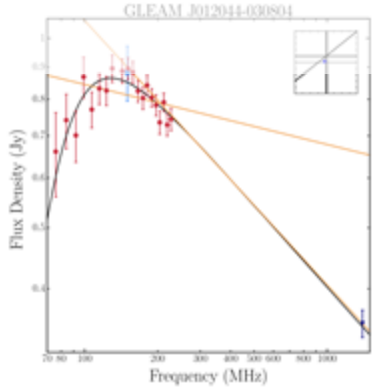


Ostorero+2010

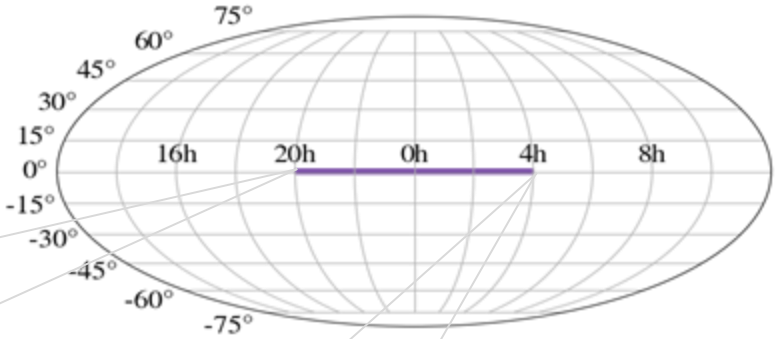


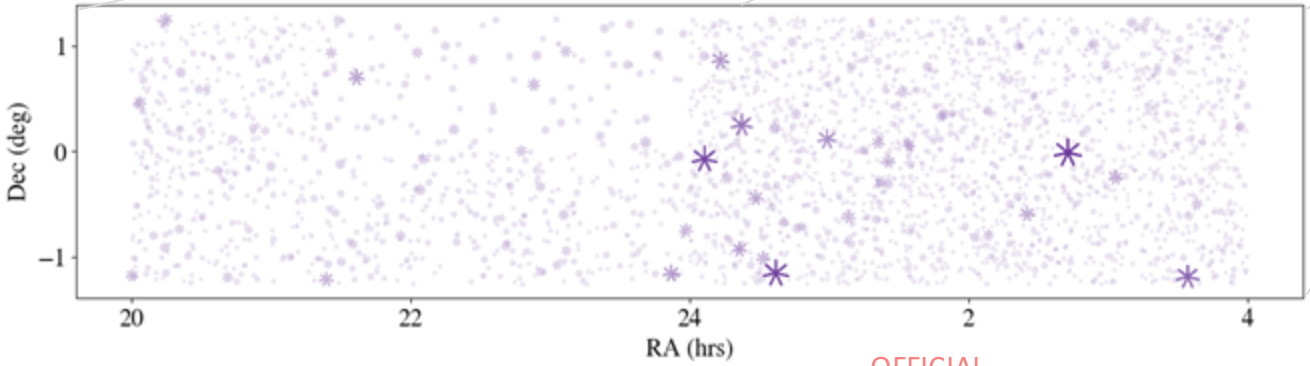
Callingham+2017

Stripe 82 – a test case (Kerrison+ submitted)

Stripe 82 with RadioSED (Kerrison+2024a)

~300 deg^2 equatorial field (20h-4h)





Radio sources (2,760)

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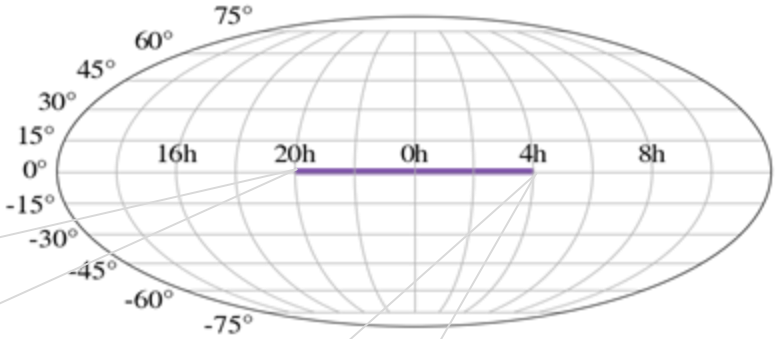

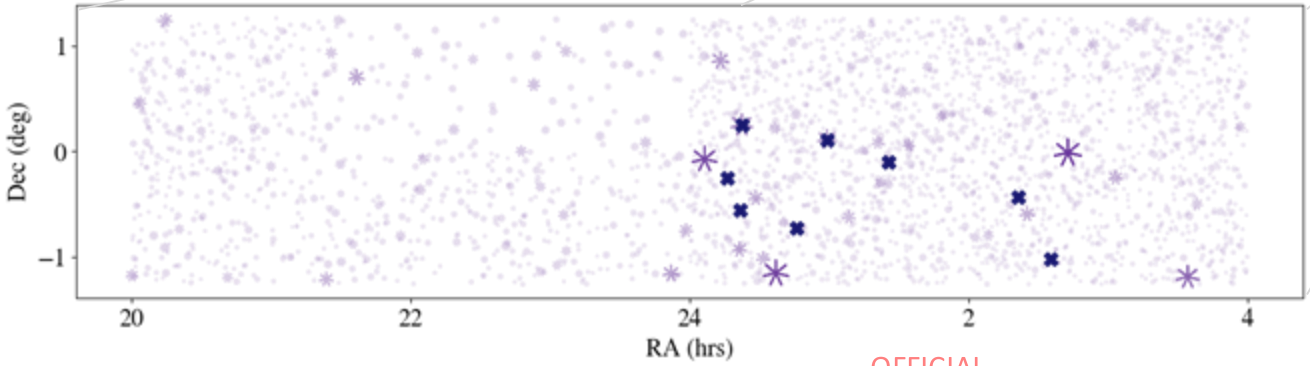

Radio sources (2,760)

Known PS sources (12)

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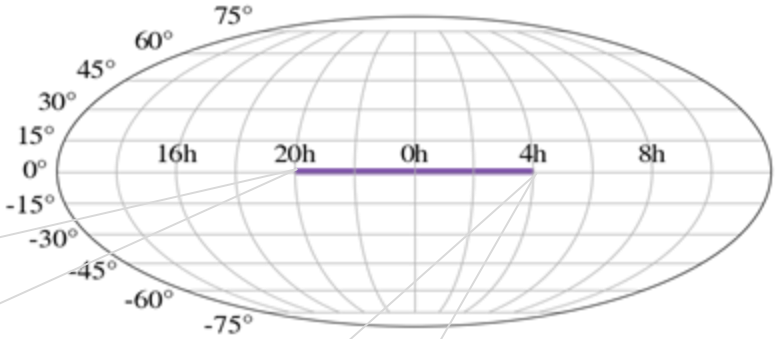
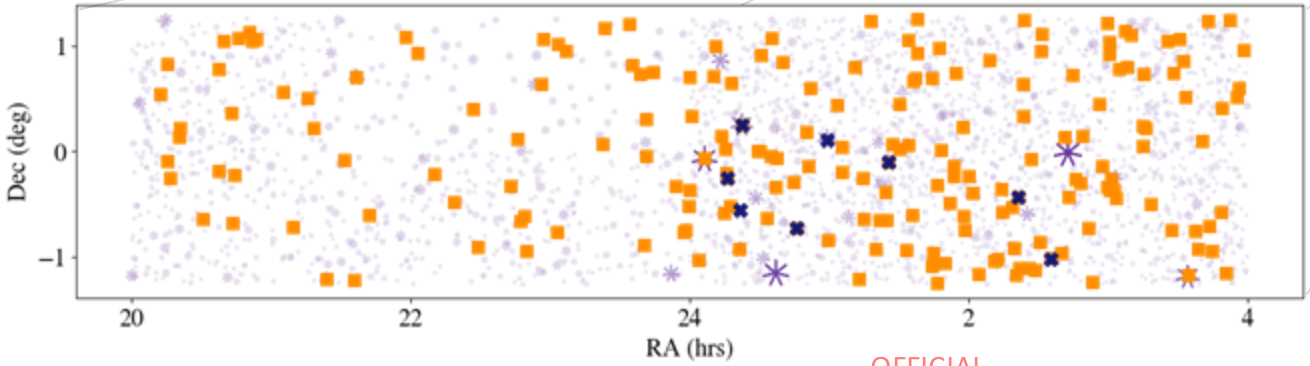
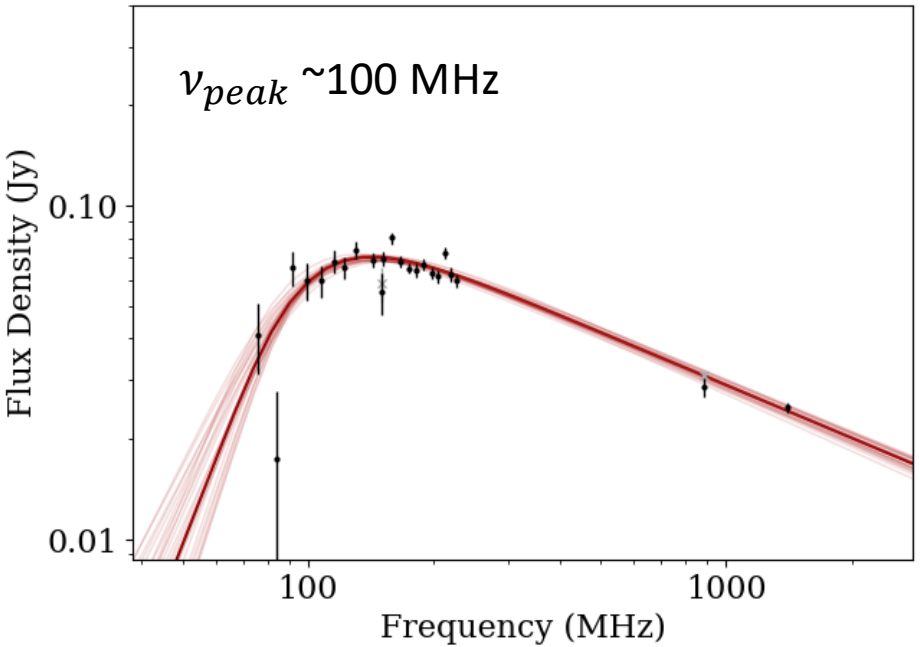
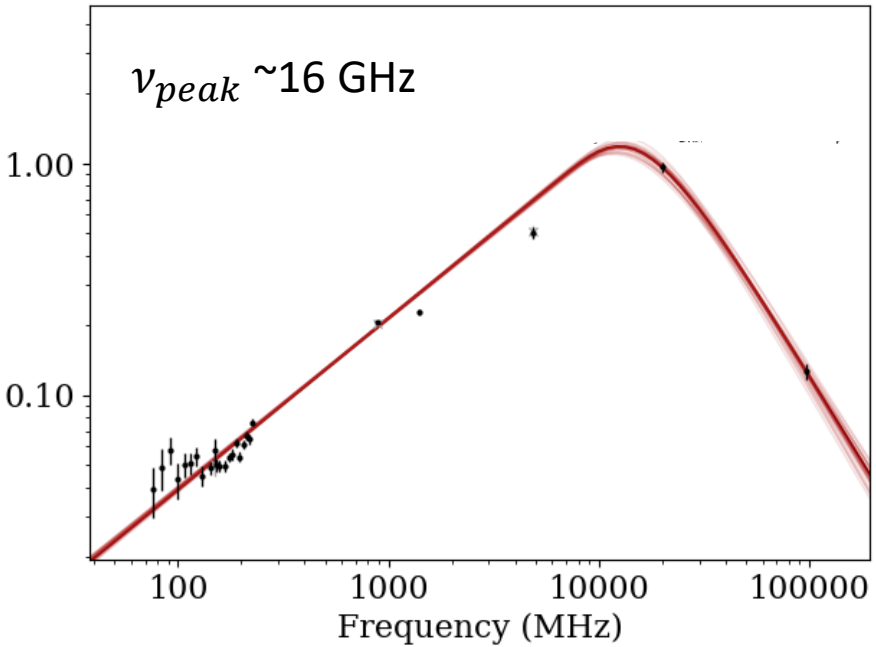




Radio sources (2,760)
Known PS sources (12)
New PS sources (359)

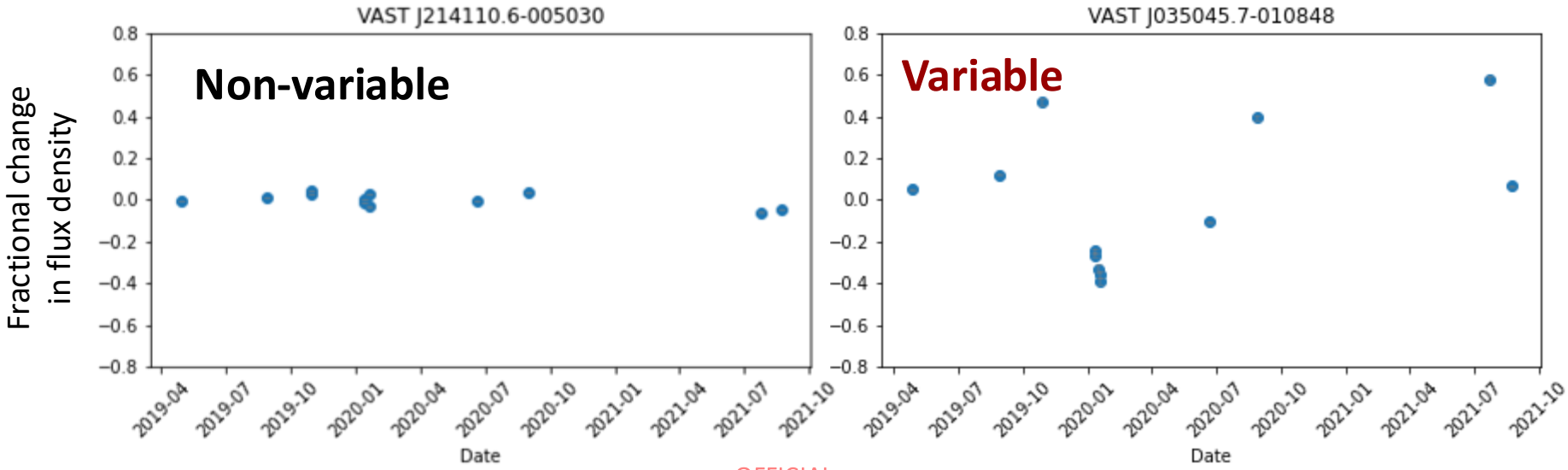
Stripe 82 – a test case (Kerrison+ submitted)



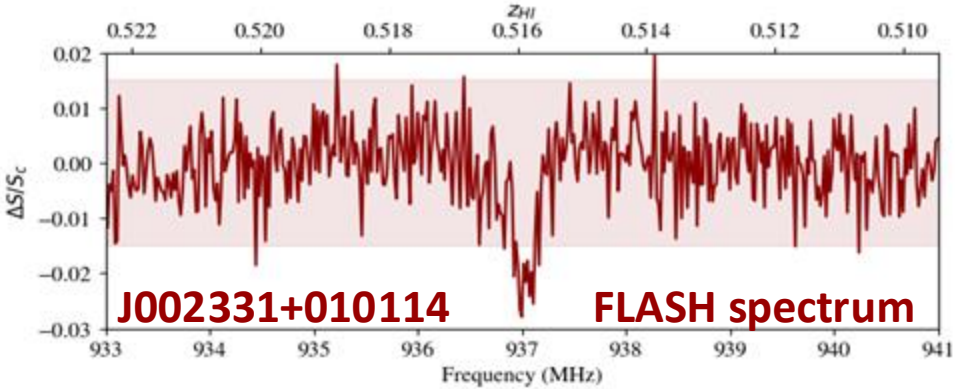


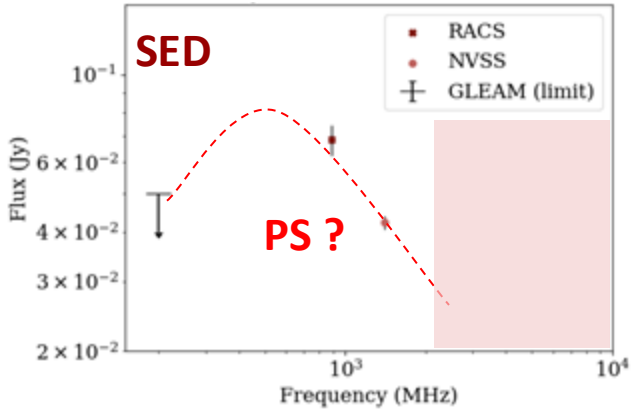
Widefield synergies I : long-term variability

With ASKAP-VAST (Murphy+2021)



Widefield synergies II : spectral line





With ASKAP-FLASH (Yoon+2025)

1 ASKAP-FLASH field (#525)

1 detection! (z = 0.516)

Peaked spectrum?

Widefield synergies III : IPS

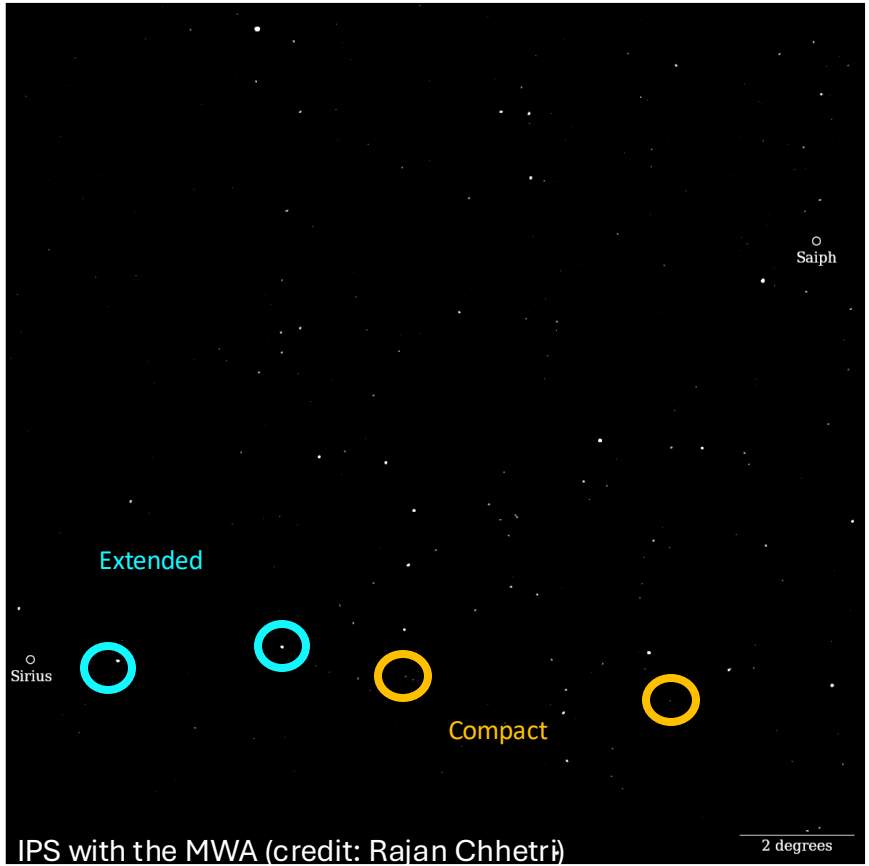
With MWA (Morgan+2022)

200MHz = **0.3” structure**

And ASKAP (Chhetri+*in prep.*)

1GHz = **0.1” structure**

Look out for *Gordon Hall et al. (in prep) !*



IPS with the MWA (credit: Rajan Chhetri)

Well-chosen follow-up

With ATCA (6 hours)

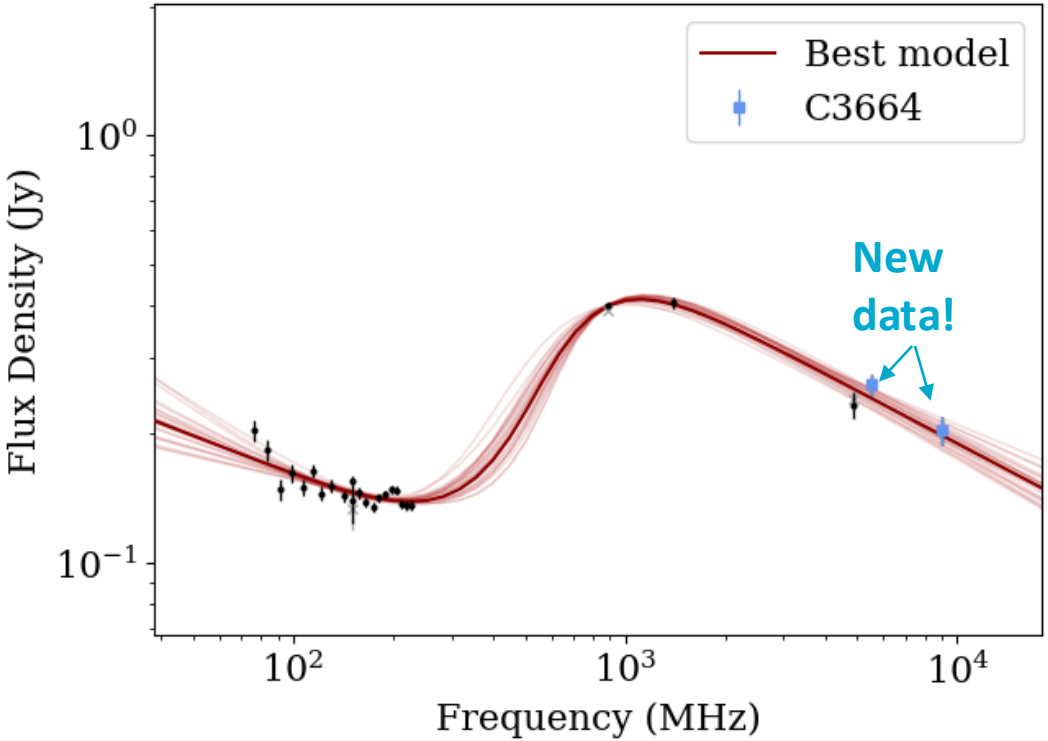
(C3664 PI: Kerrison) to obtain 5/9GHz fluxes for 44 sources

J213847.4-184931

~extended (200MHz)

80% compact (1GHz)

Extension at low frequencies → multiple epochs of radio emission



A nexus of surveys

What we need

- ☆ data in an accessible place! Vizier is ideal – easy API, distributed access
- ☆ survey limits in a machine-readable format

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What we can do

- ☆ Multi-band continuum identification
- ☆ Long-term variability (VAST)
- ☆ Multi-phase gas (FLASH)
- ☆ Short-term variability (IPS - a ‘commensal’ use case)

VLBI, by Vanessa Kelly

VLBI with ASKAP

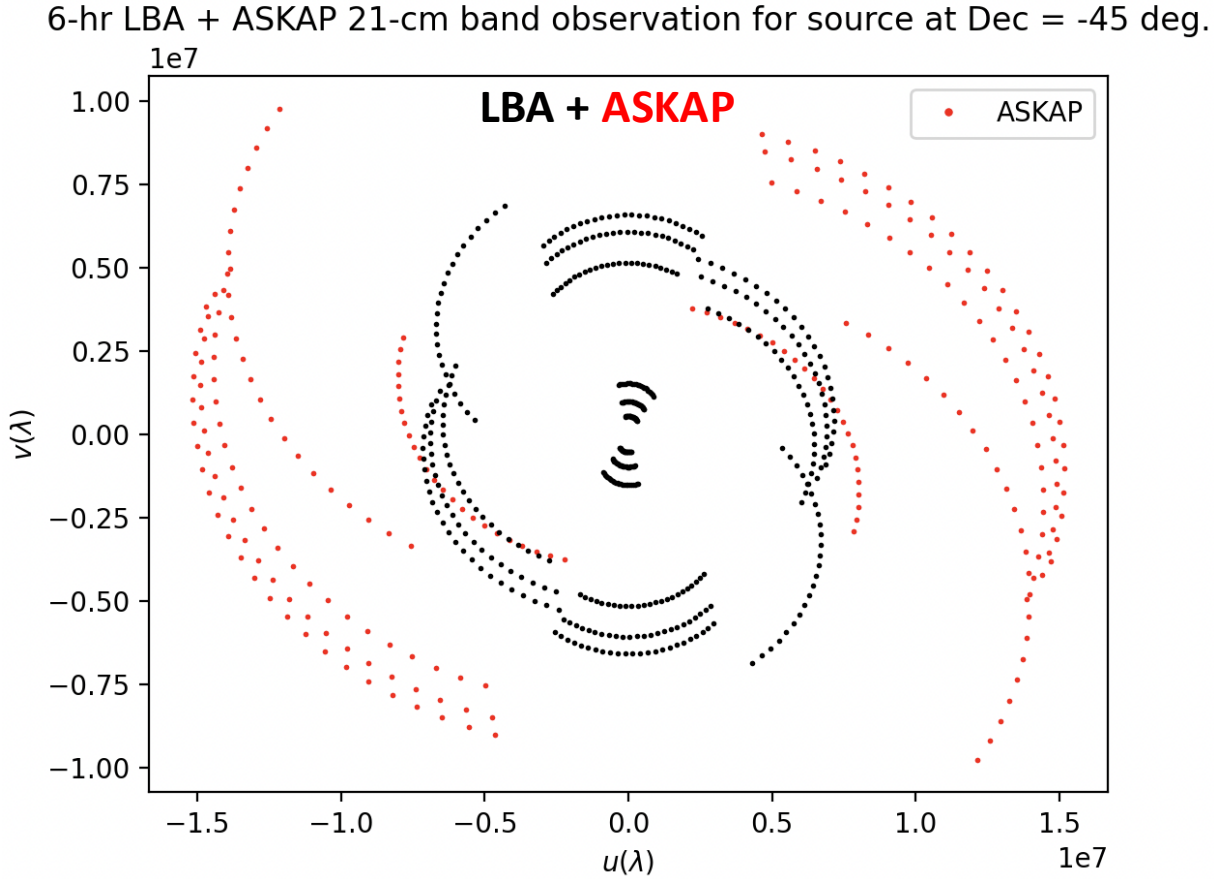
Dr. Kelly Gourdji

Bolton Fellow based in Marsfield

ASKAP-VLBI gains: *uv*-coverage

Typical 1.4-GHz LBA beam:
~30 x 25 (mas)
(1700 km baseline)

A 3300-km ASKAP baseline would *double* this resolution.



ASKAP-VLBI gains: **sensitivity**

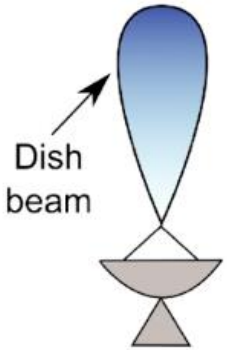
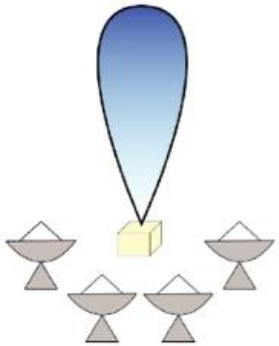
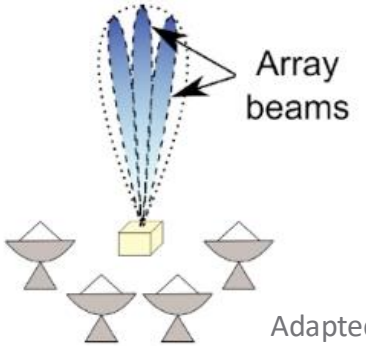
SEFD (Jy) at 21 cm

	Existing PAF	PAF upgrade
Single antenna	1850	850
Phased ASKAP	**50**	25

A phased ASKAP today would increase LBA sensitivity by 35%

Astrometric precision $\propto \frac{beam}{S/N}$ → **2.5x increase in LBA precision**

ASKAP-VLBI gains: **tied-array beams**

Single dish	Phased array	Multiple beams
		

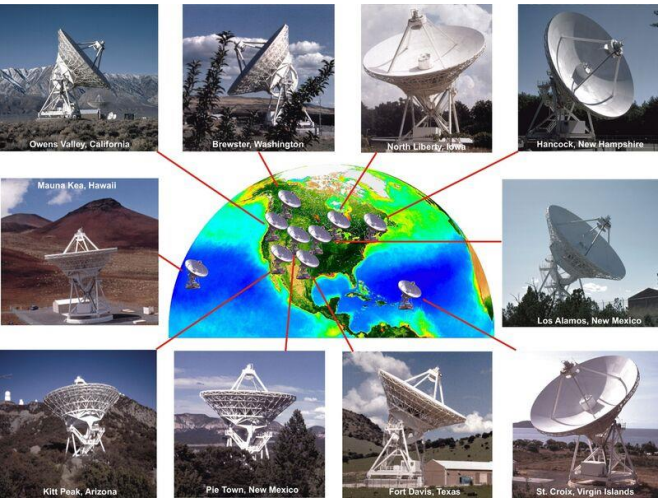
Adapted from T. Colegate

FoV capabilities

ASKAP:	~1°	arcseconds	Possible!
ATCA:	~0.5°	arcseconds	Thanks to BIGCAT
Murriyang:	~0.2 degrees	N/A	CryoPAF: 8 PAF beams → 1.5°

LBA + ASKAP c.f. northern networks

VLBA



EVN

LBA

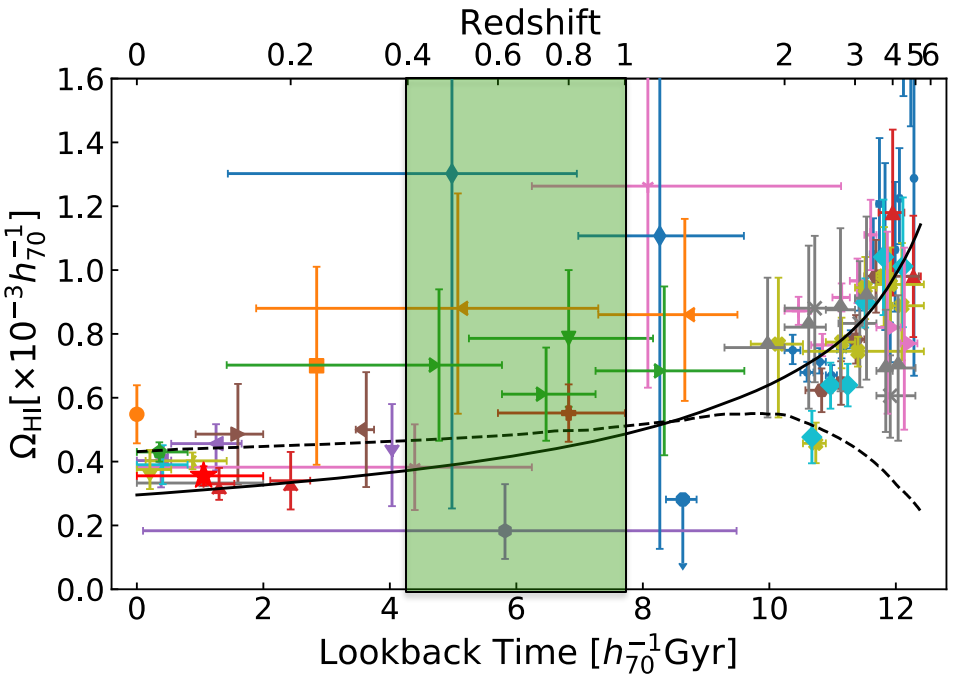
NB: Theoretical thermal limits for 6-hr obs.

		(With ASKAP)	(no ASKAP)
10 µJy	6 µJy	11 µJy	17 µJy
6 x 4 mas	5 x 4 mas	15 x 12 mas	30 x 25 mas
FoV: 0.5°	FoV: 0.1°	FoV ≥ 0.2°	

Under-served VLBI frequency range

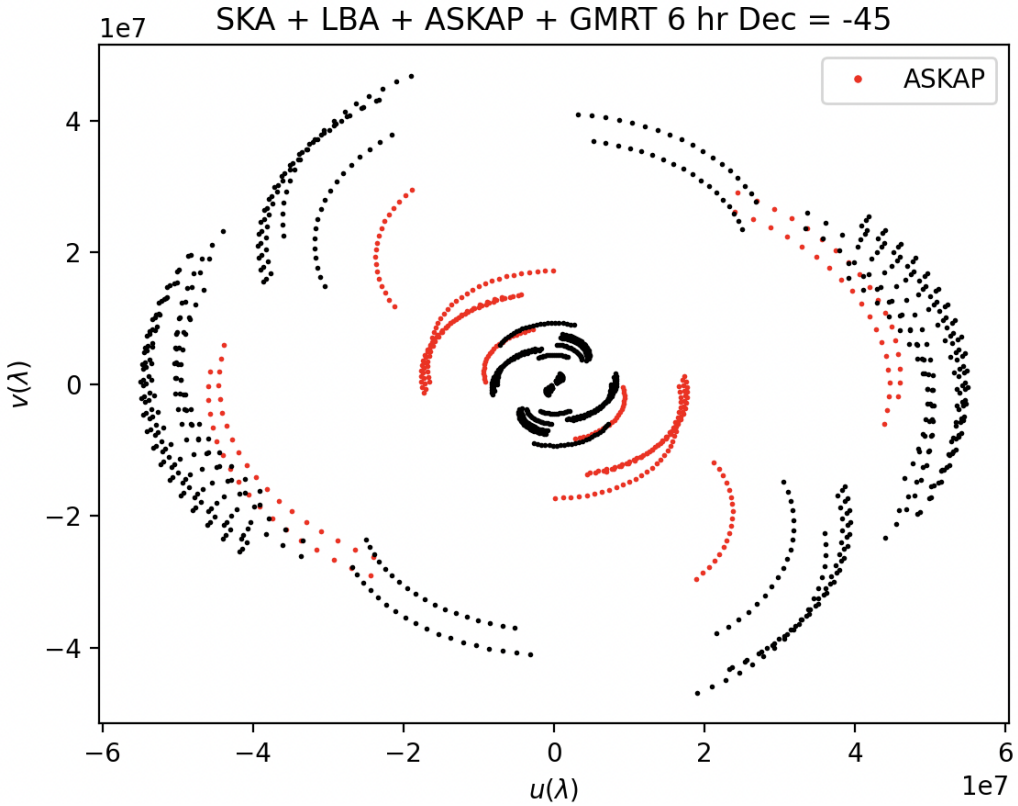
- Follow-up transients closer to their detection frequency
- Pulsar astrometry
- HI science

  (absorption between z=0.4-1.0)



Global-VLBI opportunities

Possible ASKAP baseline



Theoretical values for 6-hr obs

SKA-mid + ASKAP VLBI

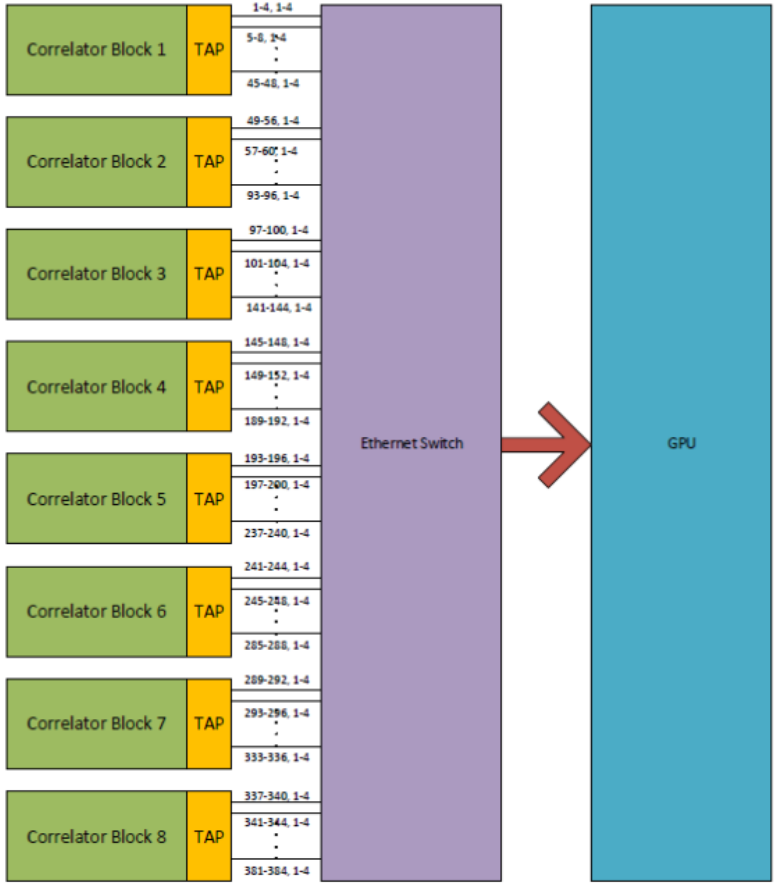
Thermal limited precision: ~10 µas

Some key science cases:

- Pulsar astrometry – tests of gravity
- Magnetar, LPT astrometry – birth sites
- TDE ejecta
- OH masers
- Gravitational wave ejecta proper motion – precise H_0 measurement

	SKA-LBA + ASKAP	SKA-LBA	SKA-EVN	SKA-VLBA
Sensitivity (1σ, µJy)	2.8	3.4	2.3	4.1
Beam (mas)	5.3 x 3.8	5.3 x 3.8	4.4 x 3.5	3 x 3

What will it take?

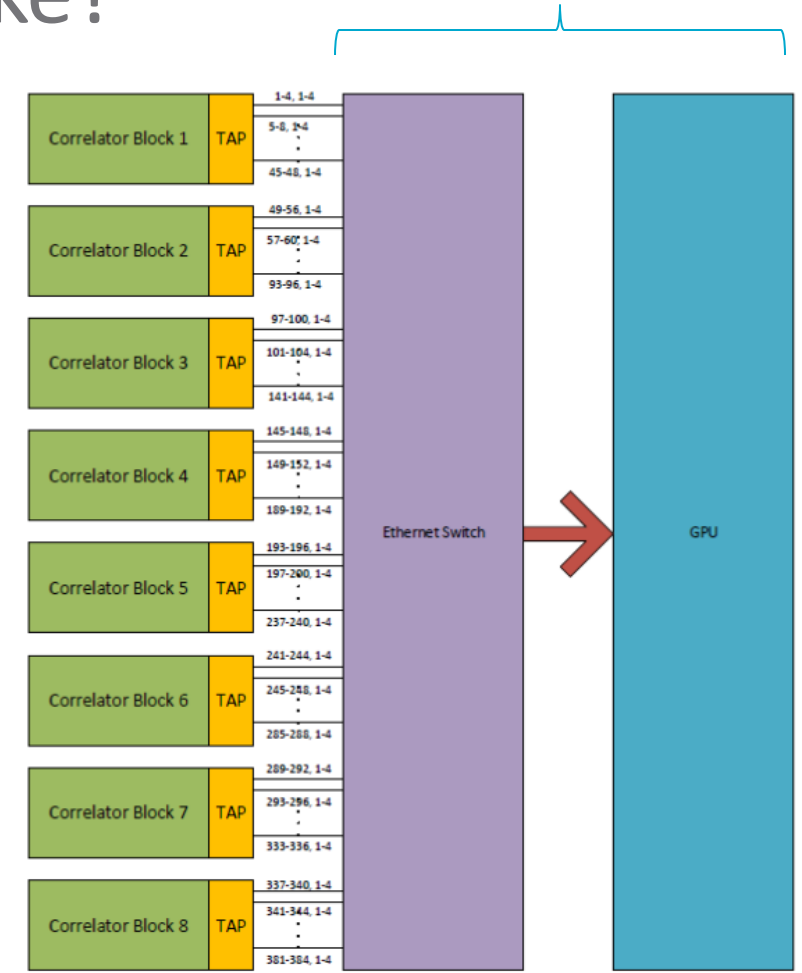


Proposed design from 2016 memo on ASKAP *Tied array processing.*

Diagram by John Tuthill

What will it take?

- Tied array firmware (‘TAP’ block)
- VLBI CPU/GPU software (e.g. inverse PFB)
- co-existence with regular ASKAP observations & operations

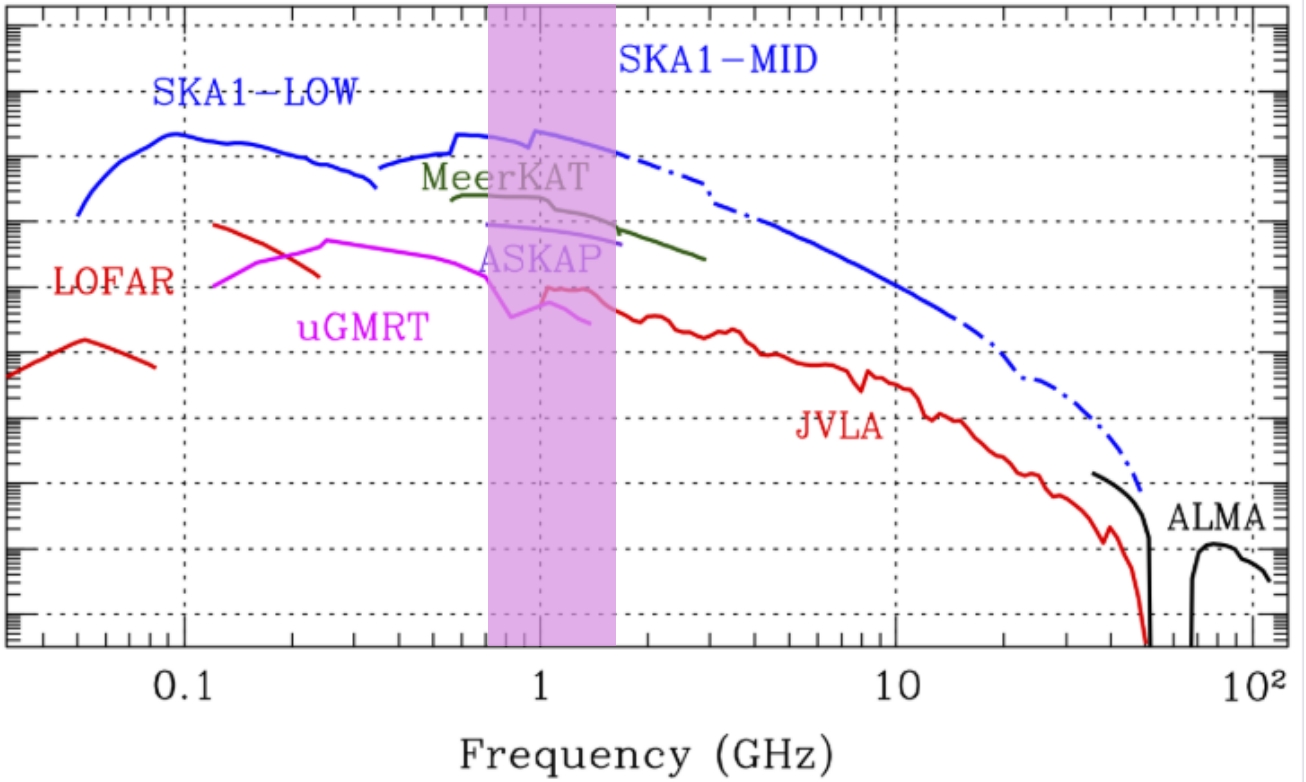


Proposed design from 2016 memo on ASKAP *Tied array processing.*

Diagram by John Tuthill

Why stop at L-band?

How about 5 to 10 SKA-mid-like dishes in WA?



ASKAP VLBI: summary & outlook

- **An LBA boost -** ASKAP VLBI would help to close the LBA's gap in capabilities c.f. Northern VLBI networks

- **Unique frequency range –** ASKAP would enable high frequency and spatial resolution VLBI at 0.7-1 GHz to deliver e.g. novel HI science

- **An important SKA baseline –** ASKAP plugs crucial gaps in the uv-plane and opportunities to participate in other global-VLBI observations

What's next?

- how can ASKAP-VLBI serve your science?
- Does the user community want this?
- Deep technical and operational feasability assessment

The LOw Time Resolution Universe Survey (LOTRUN)

and CRACO as a National Facility Instrument

Andrew Zic
Bolton Research Scientist, ATNF

2025-09-16

https://www.atnf.csiro.au/projects/science/wide-area-surveys/lotrun/

ATUC, September2025

Australia's National Science Agency

What is the LOTRUN survey?

Roughly half of all ASKAP GSPs request CRACO, showing community demand

The LOTRUN survey is an Observatory-led survey

Primary aim is to robustly test and validate CRACO as a National-Facility instrument

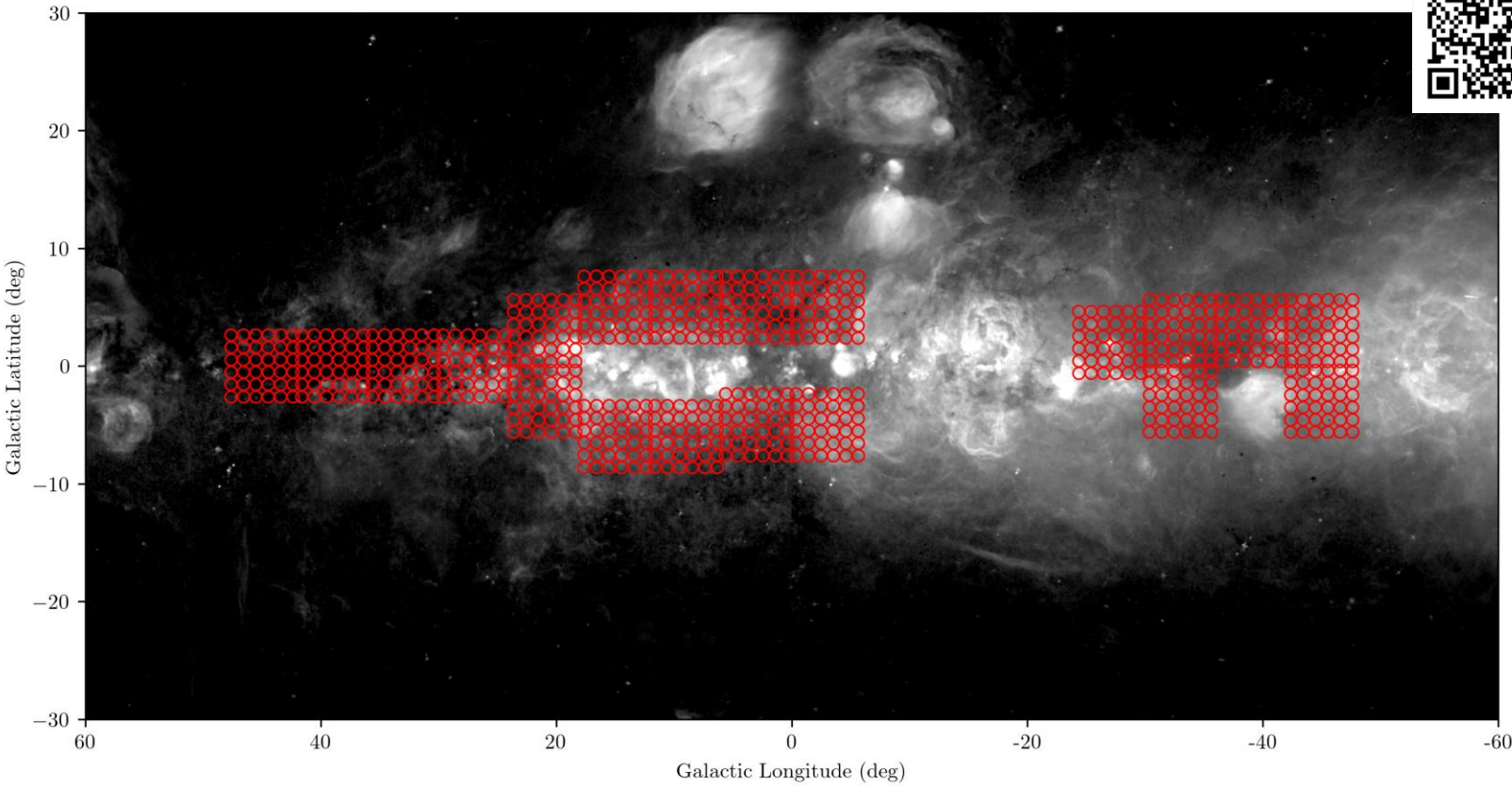
The **secondary aim** is to enable high-impact science by enabling access to parameter space non necessarily well-covered by existing SSPs.

The survey will take 200h of observing time, spanning 20 fields across 5 epochs

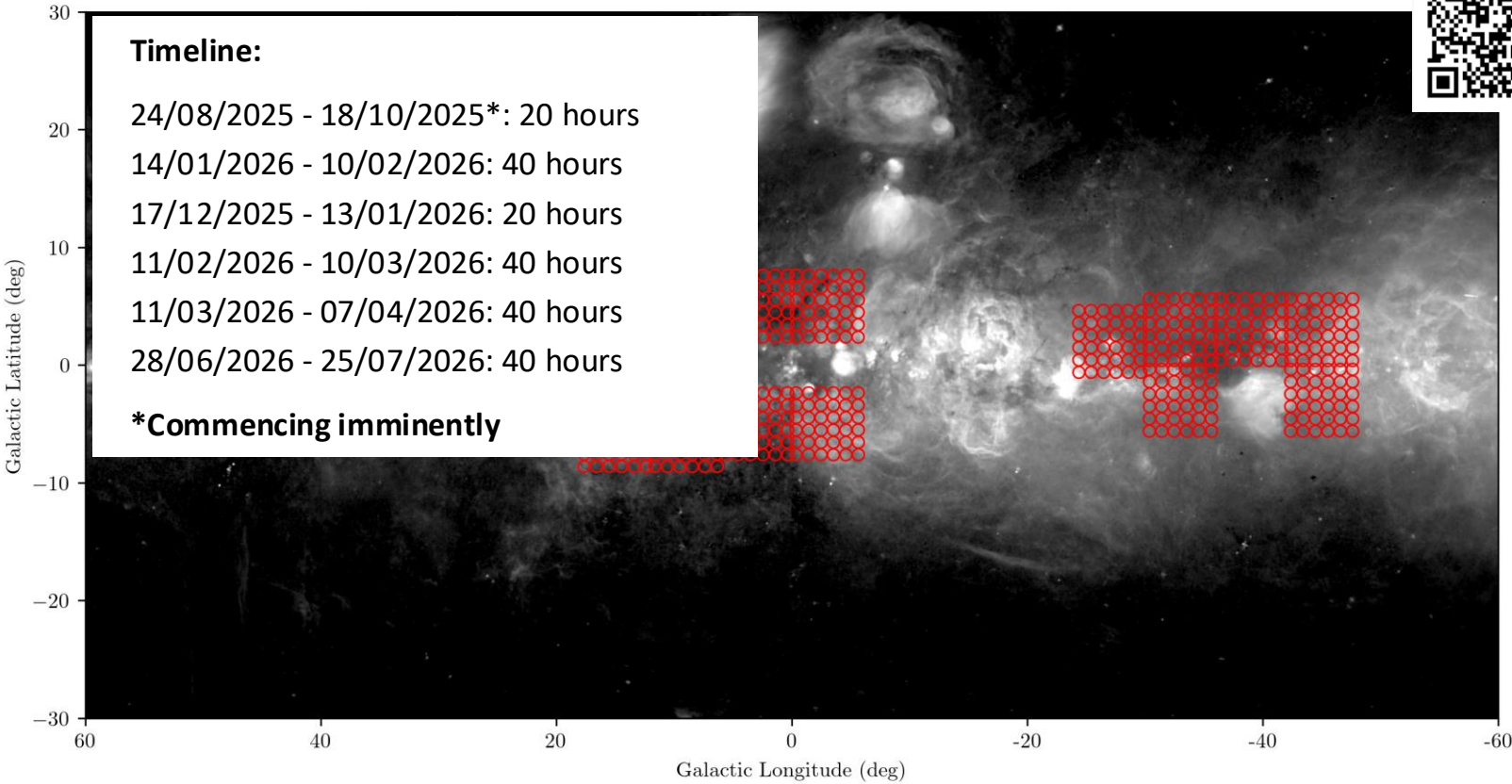
The MWA will shadow LOTRUN observations, providing a low-frequency complement

All data (ASKAP and MWA) will be promptly made publicly available

What is the LOTRUN survey?



What is the LOTRUN survey?

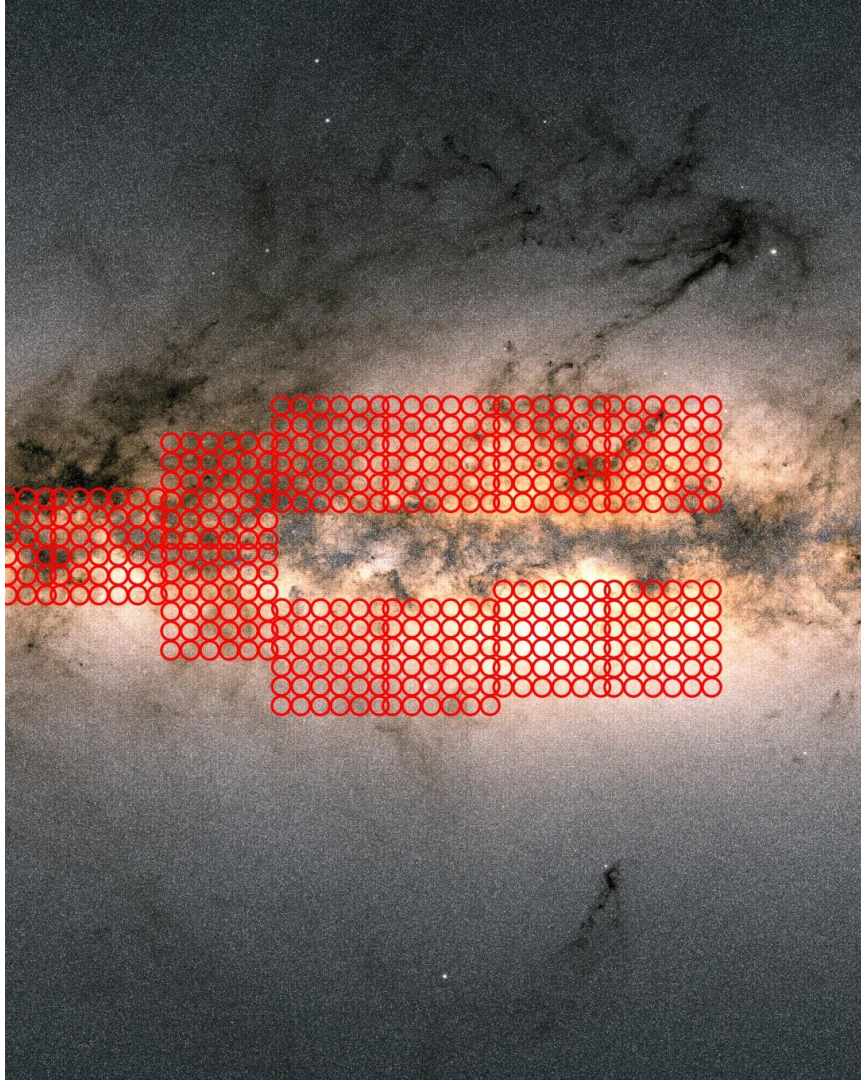


Science with LOTRUN

The survey will probe the Galactic radio transient sky at 110ms and 10s resolution

Primary science targets:

- Long-period transients
- Neutron star related transients and variability (RRATs, intermittent pulsars)
- Stellar activity
- Interplanetary and interstellar scintillation
- Interferometric pulsar/periodicity searches
- Longer-timescales: IDV, XRBs, eclipsing binaries
- Optimised transient search technique development



LOTRUN data products

CRACO Data Products

- Total-intensity visibilities at 110 millisecond time resolution and 1 MHz spectral resolution.
- Relevant calibration data files, and metadata associated with the CRACO observations
- Candidate lists and other outputs from high time resolution searches

ASKAP correlator data products

- Full polarimetric visibilities at standard 10s, 1 MHz resolution, mosaicked images, selavy catalogues, and other standard continuum data products
- Individual per-beam continuum images in Stokes I, Q, U, V, and per-beam CLEAN model images for continuum subtraction in low latency fast imaging processing

CRACO data rate: 27.2 GB /hour/beam ⟶ 980 GB / hour across all 36 beams. Total survey volume ~200 TB.

CRACO visibilities to be segmented into 15-minute scans, each stored in a separate uvfits file approximately 244 GB in size which will be provided on CASDA.

LOTRUN data access: principles and policies

Principle: an openly-collaborative community time-domain survey

Data is collected for the benefit of the SSTs and broader community

LOTRUN data will be made **fully public on CASDA** as soon as the data quality is assessed and ensured

The LOTRUN team will have access to the data prior to public release for the purpose of initial processing and validation of the data products.

Should any discoveries be made by the processing team prior to public release, publications from the pre-release processing teams are possible under the proviso that publications follow ASKAP & ATNF guidelines, **including that all publications must only use publicly-released data,** and more – see survey policy document

LOTRUN team

ATNF Members

- Andrew Zic
- Aidan Hotan
- Vanessa Moss
- Keith Bannister
- Matthew Whiting

External Members

- Ziteng Wang
- Dougal Dobie
- Yuanming Wang
- Ryan Shannon
- Tara Murphy
- David L. Kaplan

CRACO now and in the future

The LOTRUN survey has driven improvements to the stability and accessibility of CRACO to the user community

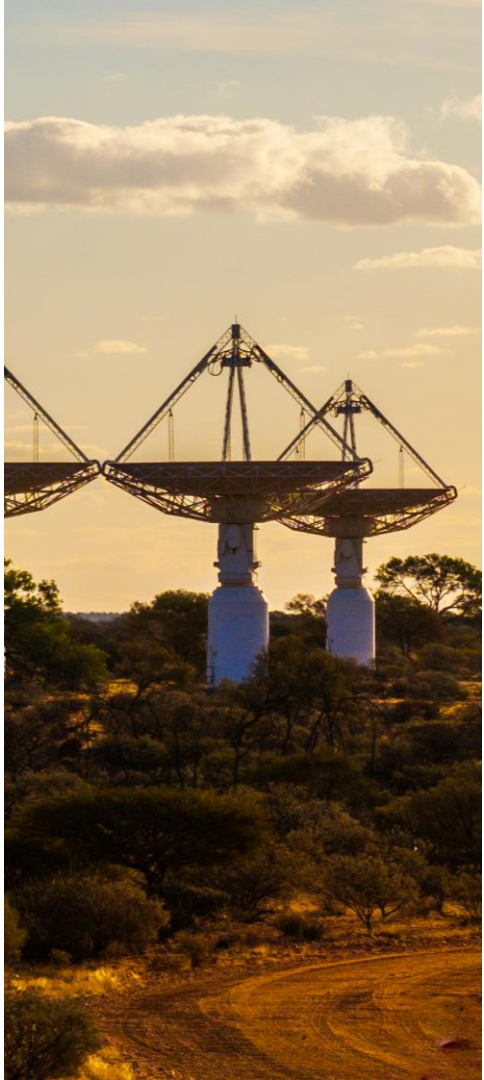
A number of critical improvements to the stability of the system have been made and CRACO data will be archived on CASDA for quality validation and long-term user access

This is subject to data rate limitations: limit of 110ms resolution, can support up to 100h/semester overall

Currently, provision of filtered transient candidates to users requires manual filtering by CRACO/CRAFT expert team member, and automated candidate filtering is not yet commissioned.

Future possibilities may include:

- Transient candidate "snippets" at higher time resolution archived to CASDA
  - Including automated candidate filtering
- Ability to request fewer beams at higher time resolution (subject to same overall data rate limitations)



Questions?

https://www.atnf.csiro.au/projects/science/wide-area-surveys/lotrun/

LOTRUN ATNF team
Andrew Zic
Aidan Hotan
Vanessa Moss
Keith Bannister
Matt Whiting

Postgraduate student program update

- Change to CSIRO Affiliate access (includes students)
- We are now charged $100 per month per affiliate for network access by IM&T. Potential ~$45k pa for all our students!
- Default is now no network access- students no longer have CSIRO email address but do not need to complete mandatory training modules.
- Provide paid access if required for eg HPC access.

Observatory visit funding

Funding has been allocated to support student visits to observatory sites.

Should allow students at least one visit

Initially looking at Narrabri and Parkes, extension to WA sites later

Mode/s for operating this will be discussed with students and the committee.

CSIRO Supervisor survey

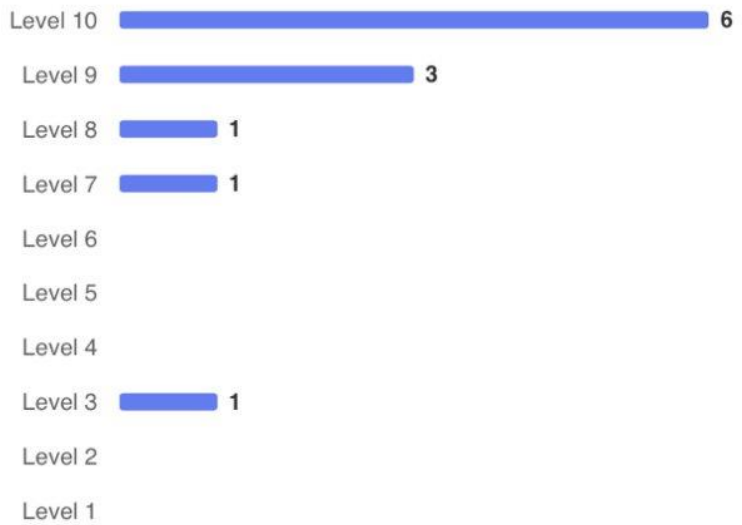
- Survey of CSIRO supervisors conducted recently
- 60% respondents interact with students daily or weekly
- ~80% interact with University supervisor weekly or monthly
- Useful feedback and ideas for improvement
- Awareness of diversity of student needs, locations and research

8. On a scale of 1 to 10 with one being lowest, how likely are you to co-supervise a student in the future?

More details

8.75

Average Rating

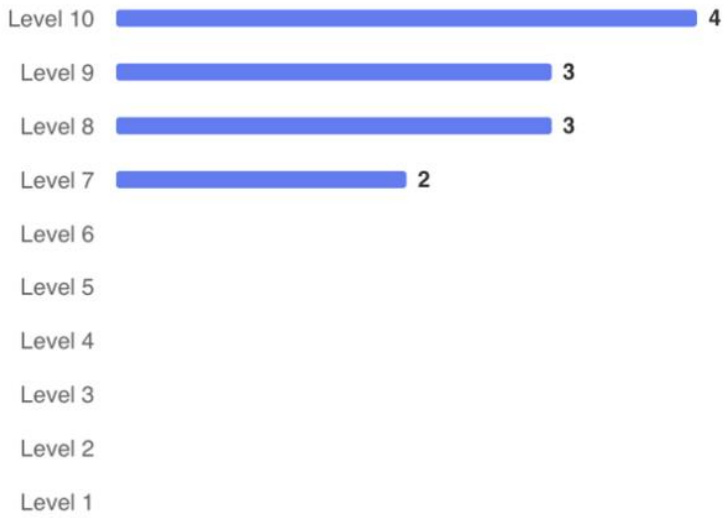


9. On a scale of 1 to 10 with one being the lowest how successful do you think our co-supervised postgraduate student program is?

More details

8.75

Average Rating



Student committee update

- Kelly Gourdji is Postdoc/ECR representative for student committee
- Met with students to discuss wants/needs of student committee
- Ongoing discussion re structure of student committee
- Running monthly postgrad catch-up meetings
- Student involvement in observatory visit funding
- Student symposium to be an annual event around April ATUC meeting.

Undergraduate Studentships

- 18 projects for 2025/2026 - Perth, Sydney, Adelaide, Parkes, Tidbinbilla
- 355 applications!
- ~50:50 gender split
- Observatory trip to Narrabri and Parkes in January 2026
- Student symposium 4-5 Feb 26