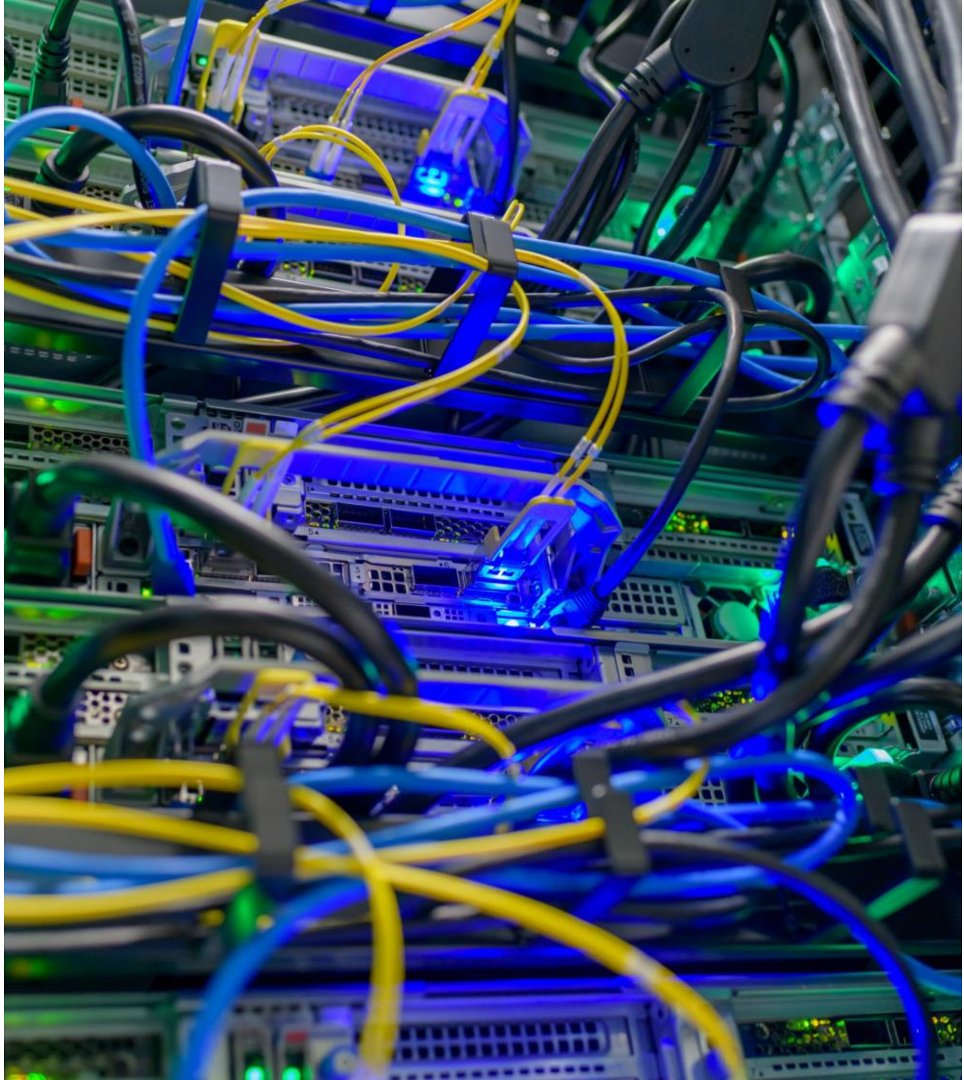
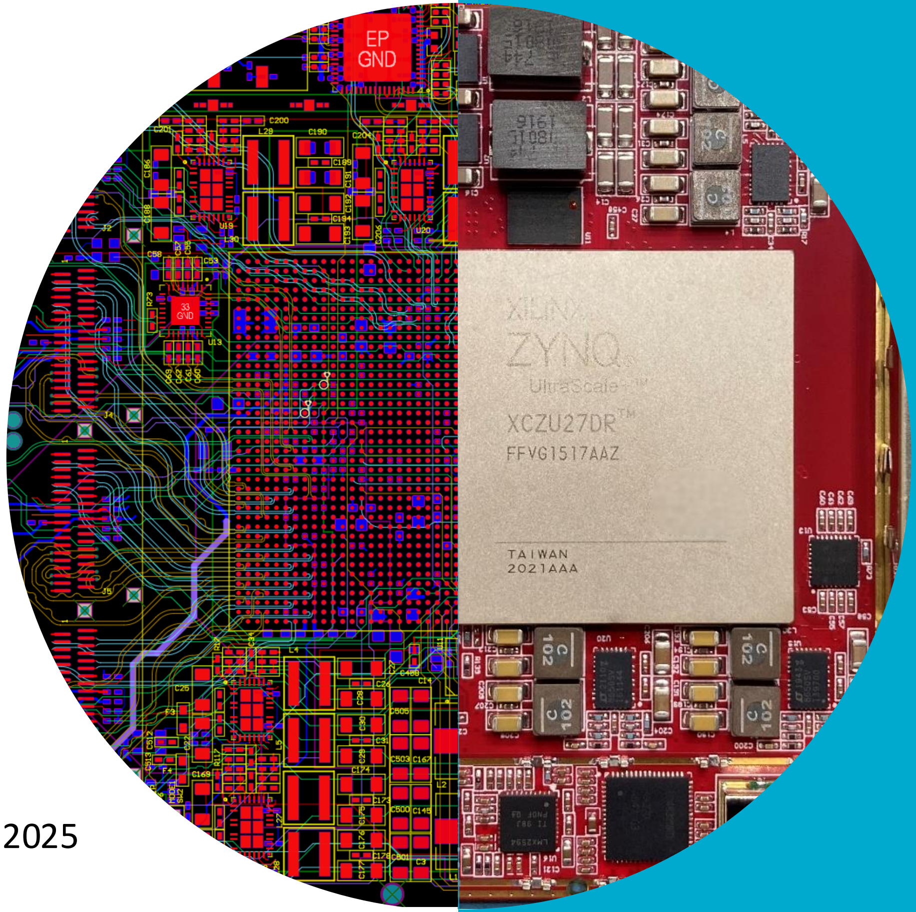
ATUC Open Day Session 3

Getting the most from our data



Australia's National Science Agency

Digital Systems



John Tuthill | 16 September 2025

Australia's National Science Agency

ATUC

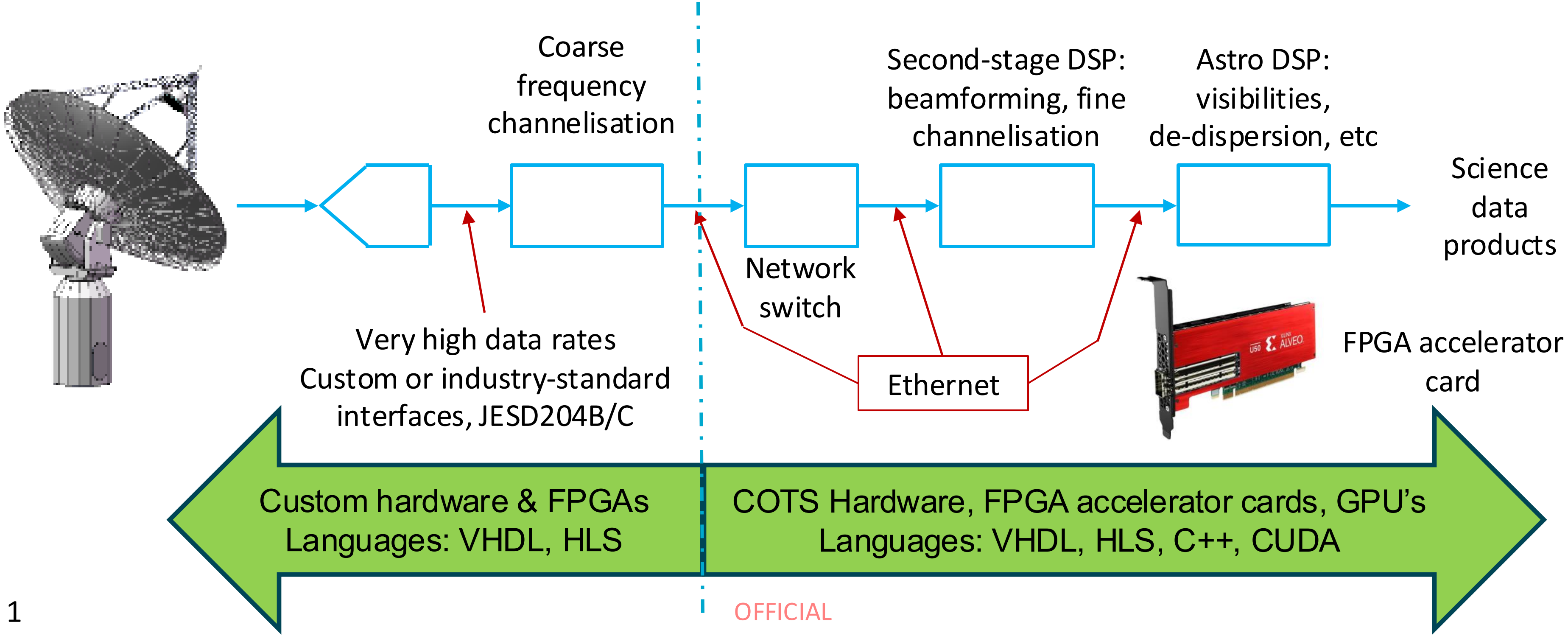
“Our backend systems for Murriyang, ATCA and ASKAP (update on the JIMBLEs)”

Some general notes…

Despite significant advances in:

- ADCs: ultra-wideband, high resolution
- FPGAs: Versal, SoCs, NoC, AI Engines
- GPUs: ??

the general architecture hasn't really changed



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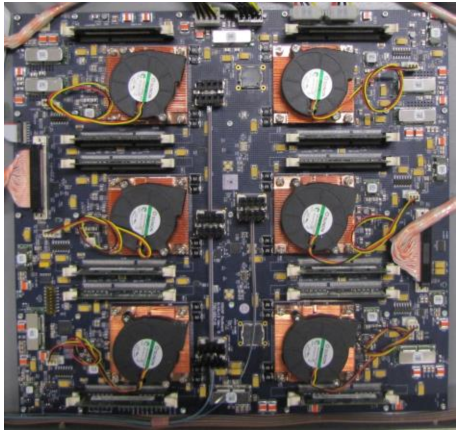
ASKAP

Image: John Tuthill

ASKAP Correlator
room aisle



"Redback" DSP card
Xilinx series-7 FPGAs
(2012)
768 custom FPGA boards
in ASKAP

ASKAP

Custom digital system:

- Raw data ingest: 130Tbits/s
- Raw processing power: 2.3PMAC's/s

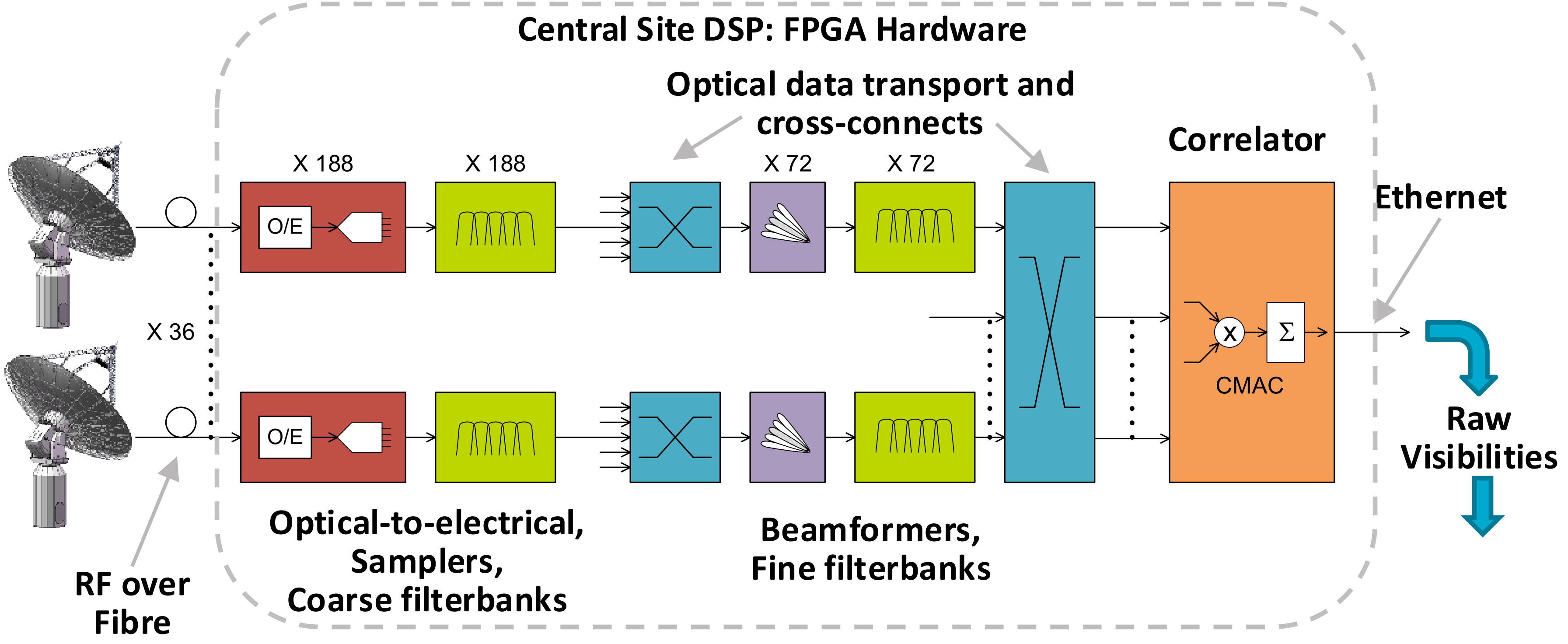
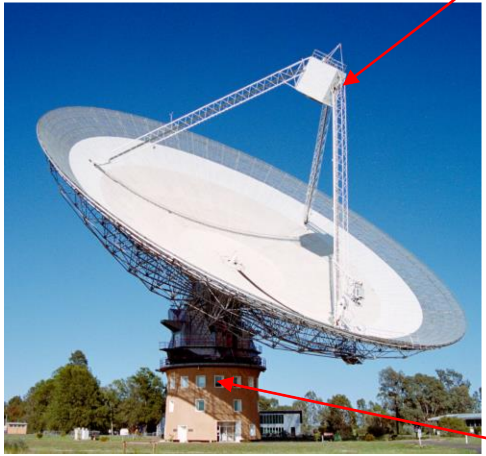


Image: Shaun Amy

Murriyang : Ultra-Wide Band (Low) current

ADC's, 12-bits @ 2,560MSps/4,096MSps



SMF : JESD204B

Focus

Tower

GPU cluster

MMF : 40GbE

COTS FPGA cards

Murriyang : UW-Mid/High upgrade

Jimble Digital Receivers
14-bits @ 4,096MSps
+ channeliser, packetiser & 100GE

Adds two extra single pixel receivers:
- 4-16 GHz
- 16-27 GHz

+ tuneable extension for spacecraft tracking up to ~33 GHz.

SMF : 100GbE

Focus

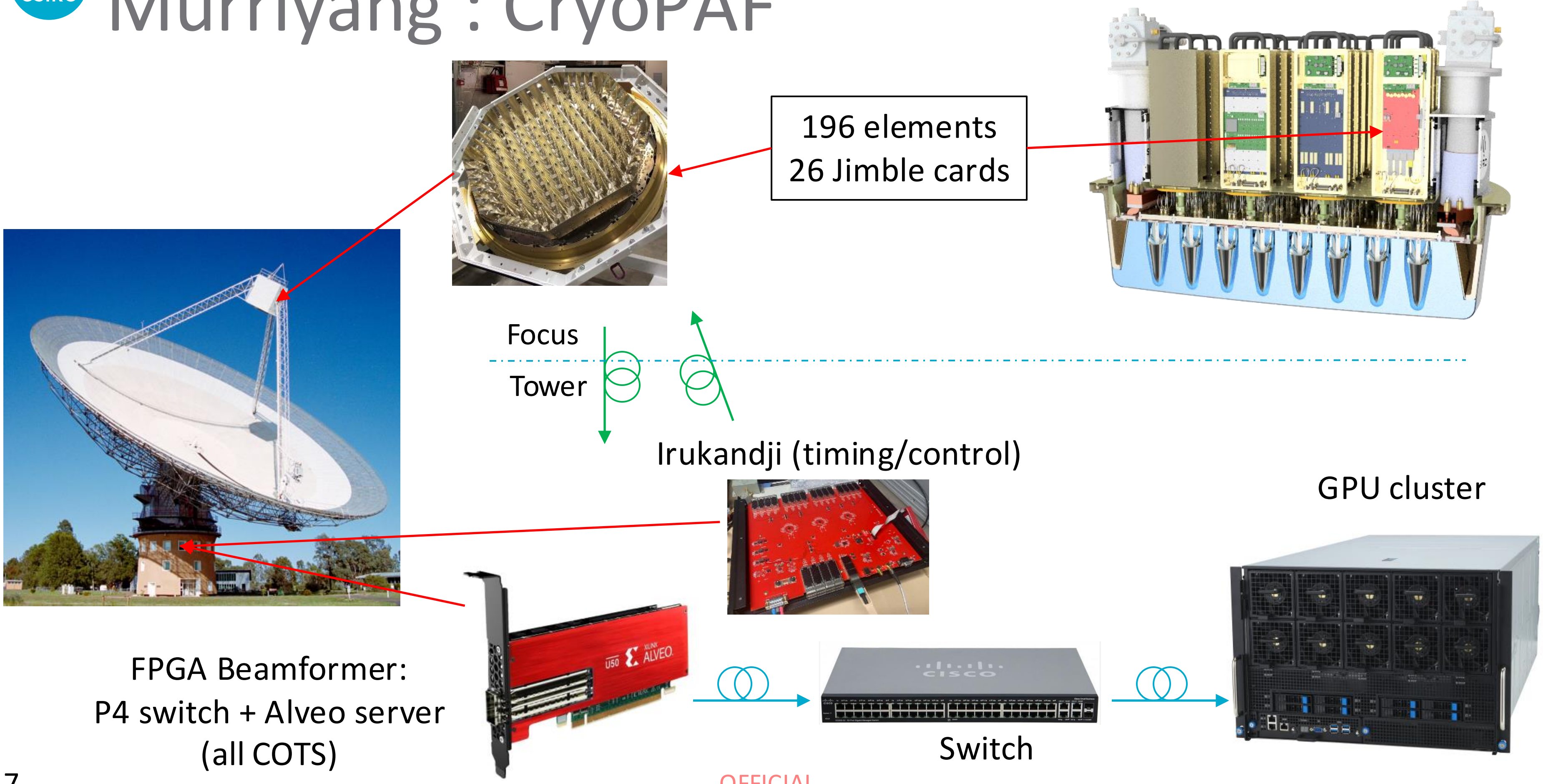
Tower

GPU cluster

Switch

MMF : 100GbE

Murriyang : CryoPAF

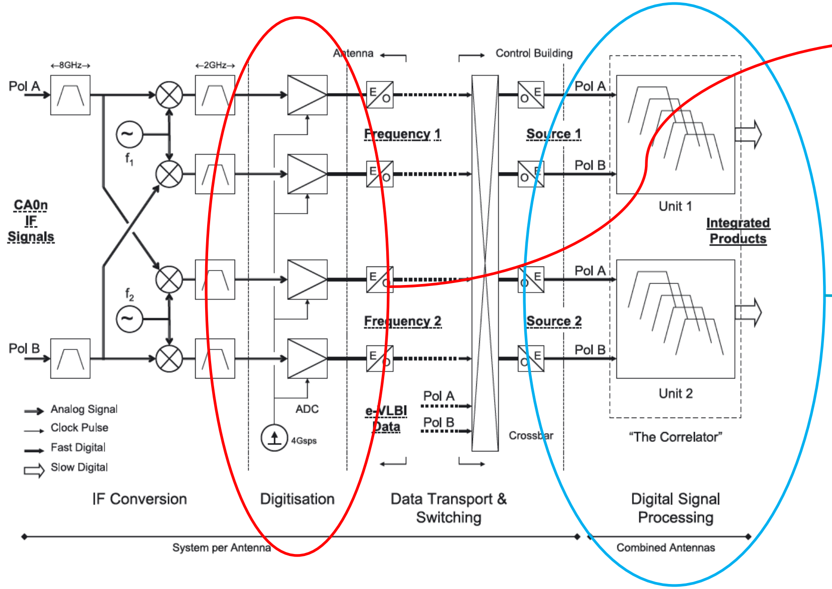


ATCA

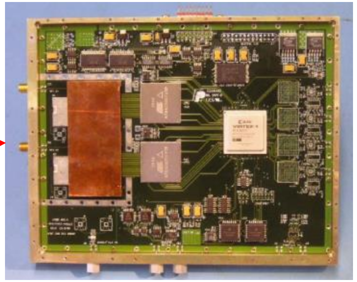
Image: ?

ATCA

CABB Compact Array Broadband Backend



CABB Digitisers:
4,096 MSamp/sec, 10-bit custom-designed interleaved converters

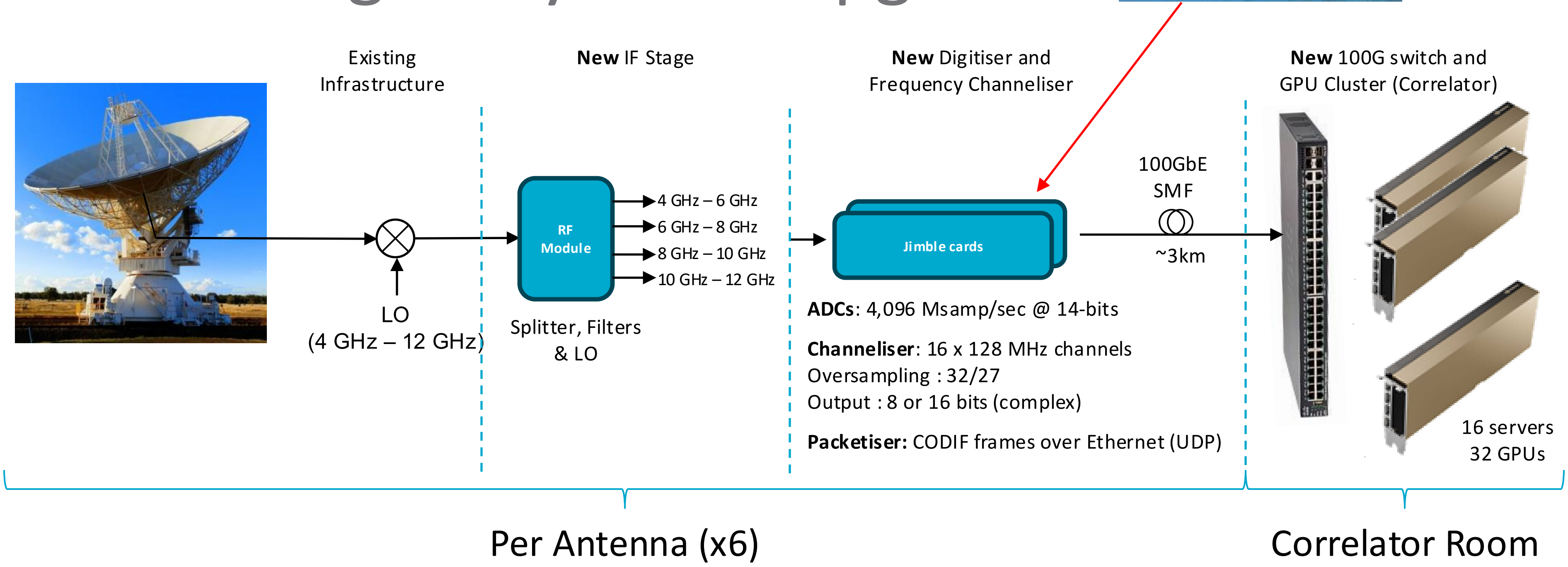


CABB FPGA Channeliser and Correlator card:
Xilinx Series-4 FPGAs
(Virtex-4 discontinued 2015)

CABB FPGA Correlator cabinet

Images: W. E. Wilson, et. al., The Australia Telescope Compact Array Broad-band Backend: description and first results, Monthly Notices of the Royal Astronomical Society, Volume 416, Issue 2, September 2011, Pages 832–856, https://doi.org/10.1111/j.1365-2966.2011.19054.x

BIGCAT Digital Systems Upgrade

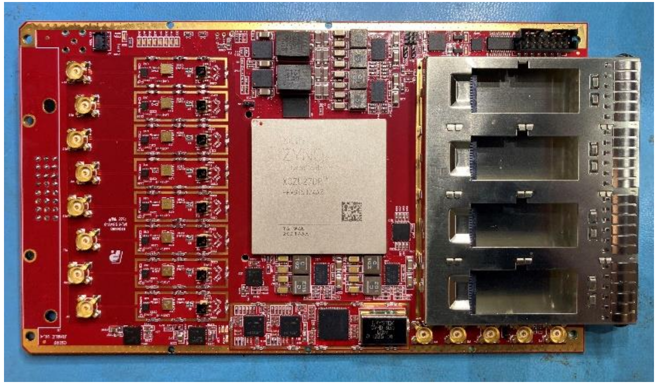


Jellyfish Themed Hardware

Jimble

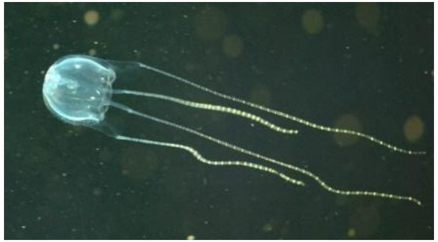
(AMD/Xilinx Zynq Ultrascale+ RFSoC device)

Jimble jellyfish,
Carybdea rastoni

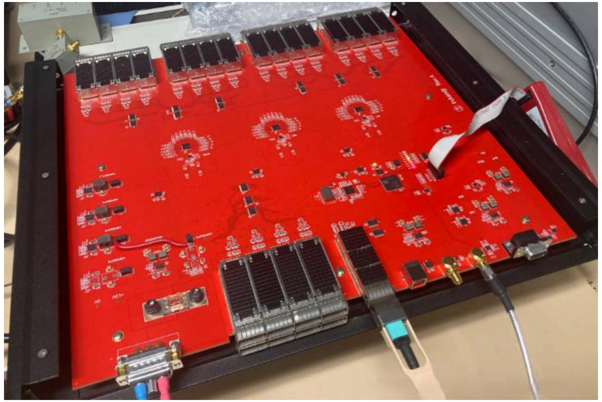


Irukandji

(Timing and M&C network distribution)



Irukandji jellyfish,
Carukia barnesi



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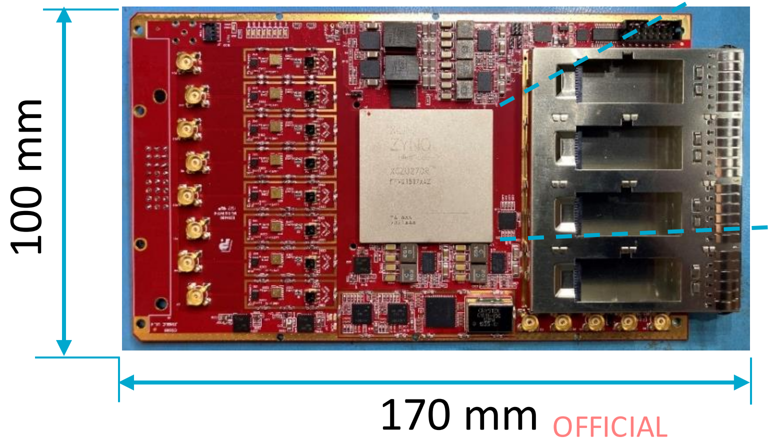
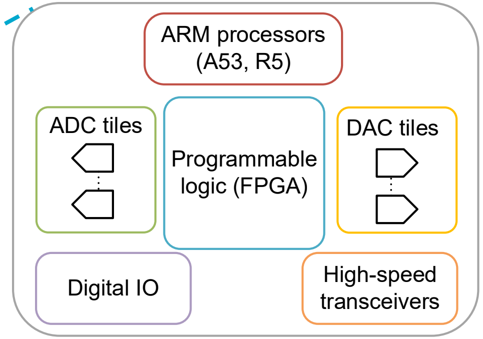
"Jimble" Digital Receiver Hardware

- Analogue BW = 6 GHz, processed BW = 2 GHz in 2 Nyquist zones
- 8 x RF inputs, simultaneous sampling @ 4096 MHz and 14-bits
- 3 x 100GbE QSFP+ outputs for BIGCAT
- Eurocard form factor @ ~70W per card





AMD/Xilinx Zynq Ultrascale+ RF System on Chip (RFSoC) device

Two Jimble firmware variants

- CryoPAF
  - 8 processed ADC inputs
  - 2,560 channel polyphase filterbank (1.6 MHz output channels, 32/27 OS)
  - 16-bit streaming output
  - Routed BW : 921.6 MHz per ADC
- BIGCAT, UWM/H, JPL/DSN
  - 4 processed ADC inputs
  - 32 channel polyphase filterbank (128 MHz output channels, 32/27 OS)
  - 8-bit or 16-bit streaming output
  - Routed BW : 2,048 MHz per ADC

OFFICIAL

Streaming Data Interface

- CODIF encapsulation in Ethernet UDP
  - CODIF: CSIRO Oversampled Data Interchange Format
  - Originally an extension of the VDIF standard to support fractionally oversampled data streams
  - 8 x 64-bit word header: timing, source and data payload details
  - Data array payload: user-defined length typically constrained by network factors such as MTU size.

Software Monitoring and Control

- Python and Rust framework using the open source ZeroMQ messaging lib.
- Controls:
  - initialisation and synchronisation process
  - Dynamic range in the streaming output
  - Configuration, starting and stopping of the 100GE streams
  - Precisely timed event-based system functions
- Monitors:
  - Jimble hardware status – power supplies, temperatures, reference oscillator status
  - Signal chain – ADC histograms, subband statistics, integrated power spectra
  - Output stream status

Towards operational realtime RFI mitigation (Tommy Marshman)

R.F.I.

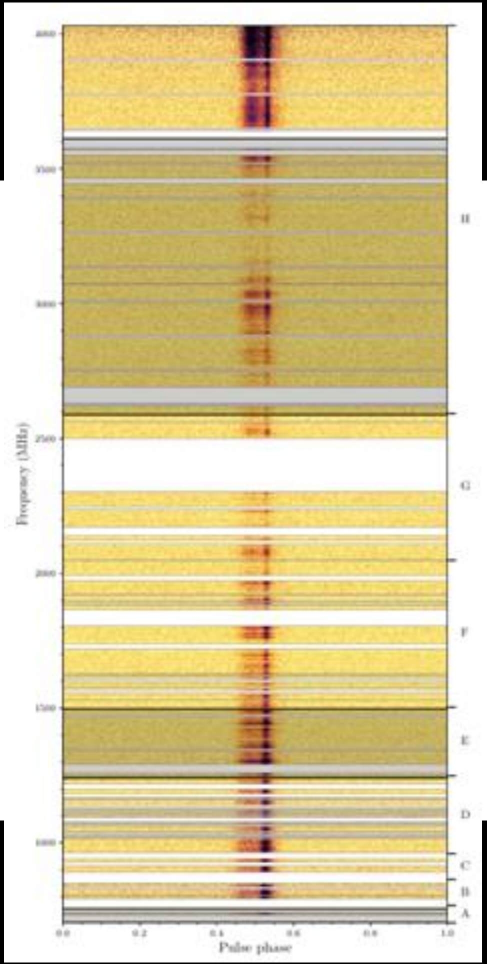
"Towards operational real-time RFI mitigation"

Outline

- The RFI Problem
- Introduction to the RFI we studied - Bluetooth and WiFi
- General Characteristics of RFI
- Mitigation Methods we tried
- State of Play
- Conclusion

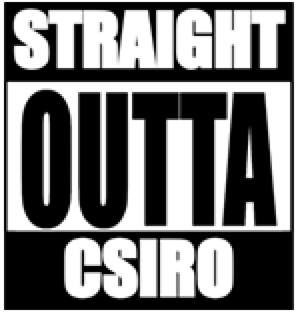
The Problem

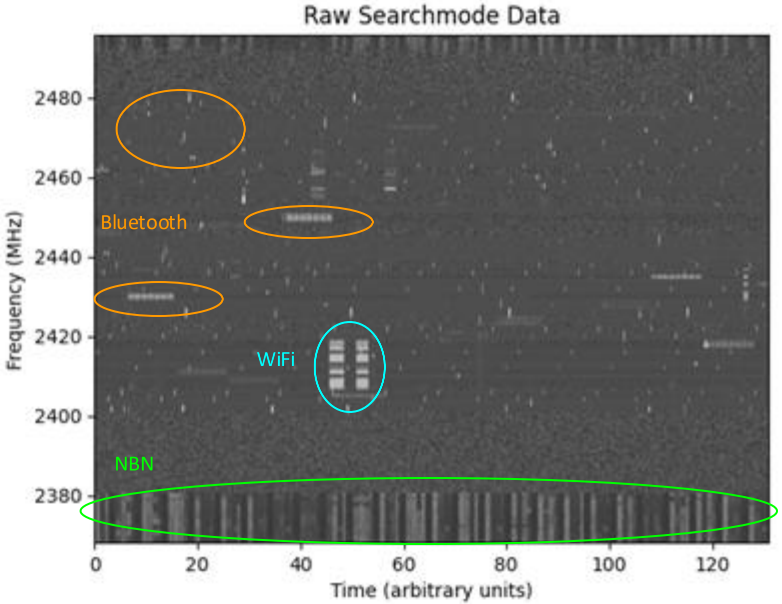
- RFI is ubiquitous
- Only small bands are protected for Radio Astronomy
- RFI is increasing as technology increases
- Varied sources - phones, watches, microwaves, satellites, NBN, etc..



Bluetooth and WiFi

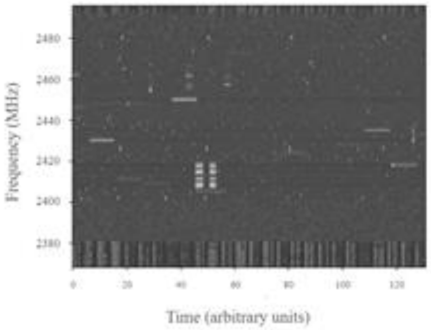
- 2400-2480 MHz
- UWL sub-band 13/26
- Well characterised due to specifications

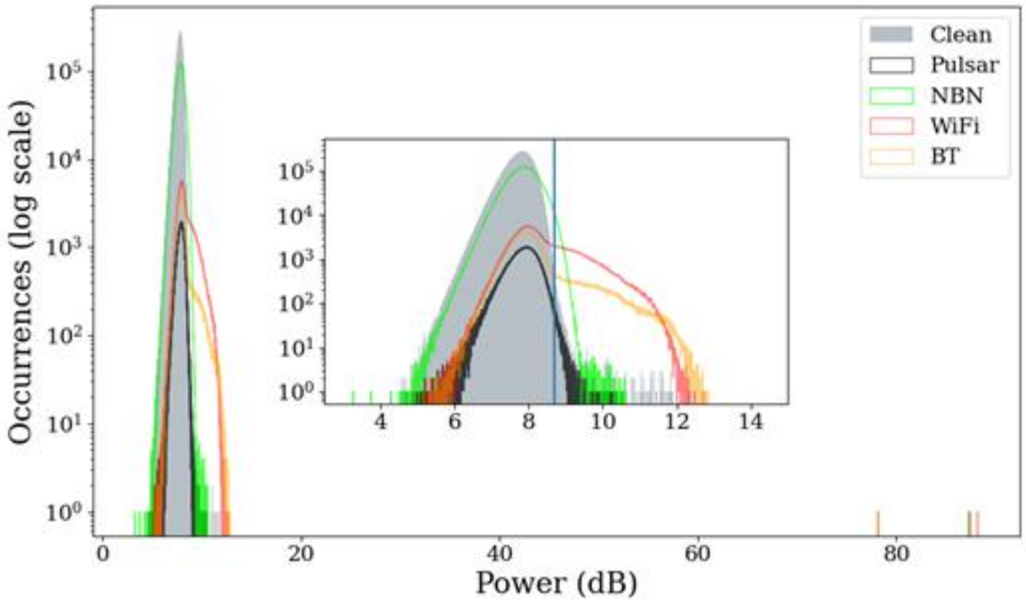




Characteristics of RFI

- Powerful
- Kurtotic
- Well characterised in frequency and time





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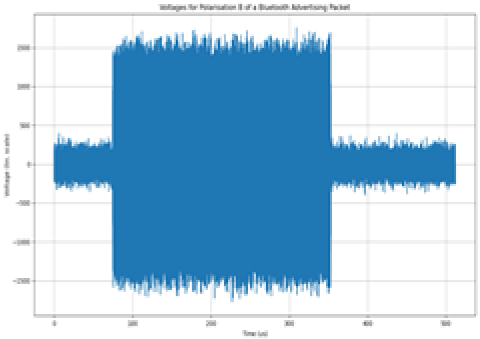
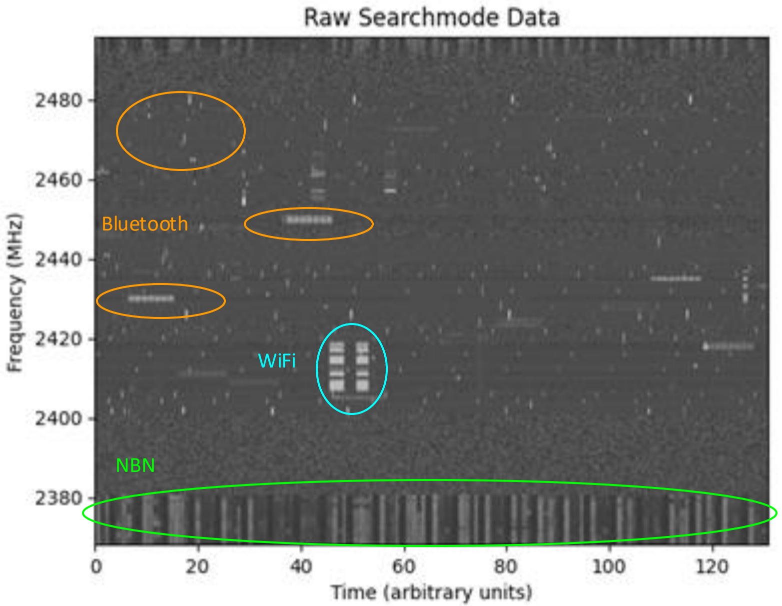




Mitigation Methods

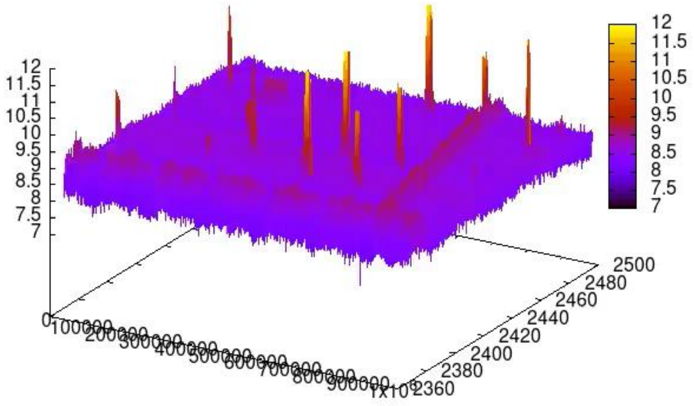
- Simple Voltage Threshold
- Spectral Kurtosis
- Threshold on Demodulated Signals

Mitigation Methods

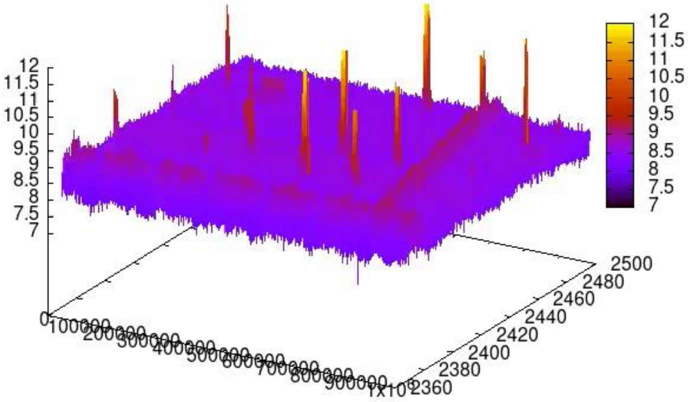
- Simple Voltage Threshold (Powerful)
- Spectral Kurtosis (Kurtotic)
- Threshold on Demodulated Signals (Well Characterised)

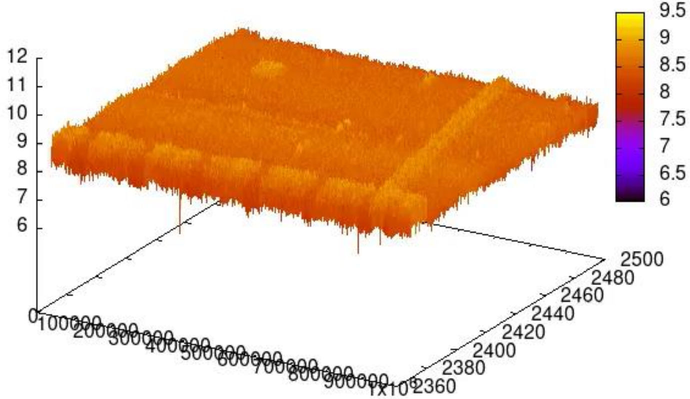
Simple Voltage Threshold

- RFI is regularly orders of magnitude more powerful than astronomical signals
- Log. scale
- Pulse is Vela (brightest known pulsar)



Simple Voltage Threshold

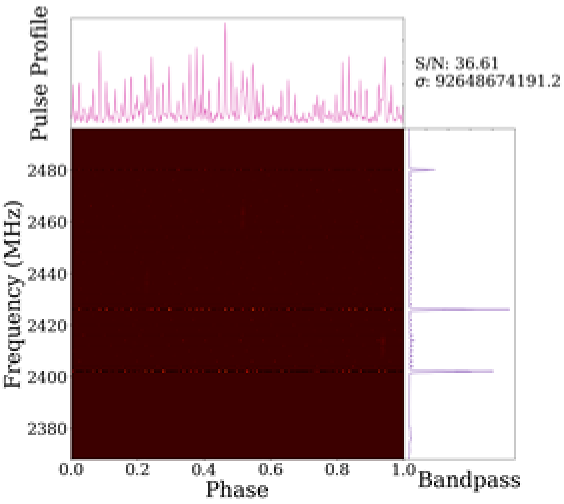




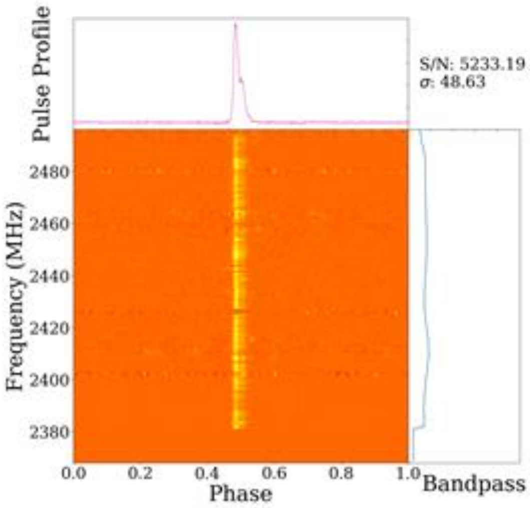
Spectral Kurtosis

- Takes a block of samples and calculates the non-gaussianity of the sample.
- Improves S/N ~36 to >5000

No Mitigation



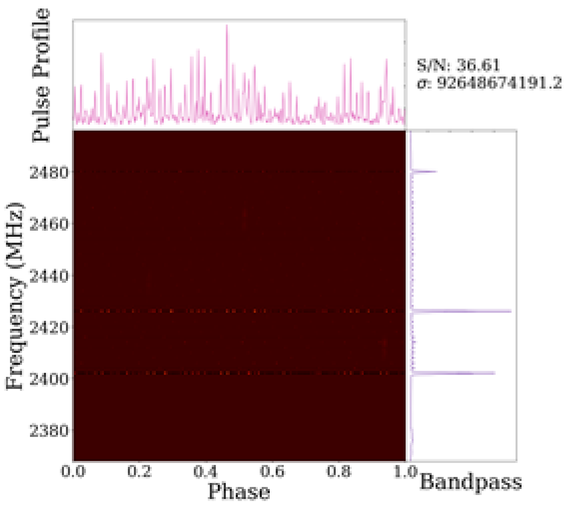
Spectral Kurtosis



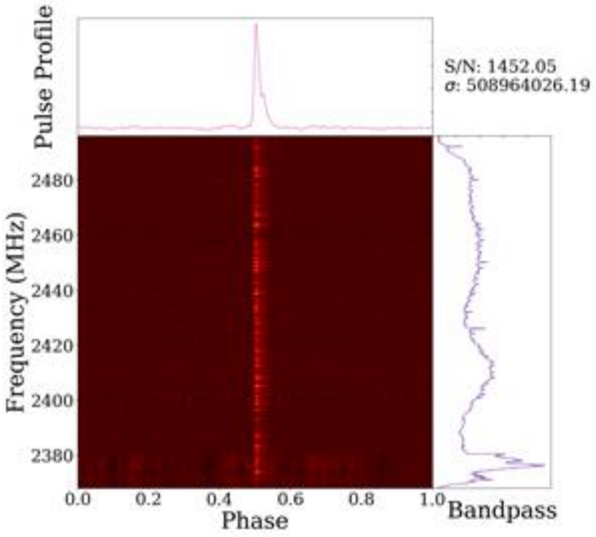
Threshold on Demodulated Signals

- RFI is well characterised by industry specifications
- Identify protocol specific signatures in the signal

No Mitigation



Demod. Threshold



State of Play

- The features required for effective kurtosis mitigation are not currently available online with DSPSR
- Don’t have any thresholding methods despite being simple and effective

Conclusion

- All methods require channelisation
- A voltage threshold is simple, but needs to be specific to the science case
- Spectral kurtosis is already available in DSPSR for fold mode but will require different settings for different bands/RFI
- Demodulating signals may make it easier to identify specific sources of RFI
- These methods may not be effective on all telescopes
- This needs to be implemented by a GPU programmer which I am not

Reprocessing EMU and more with FLINT (Tim Galvin)

Reprocessing EMU with *Flint*

Tim Galvin | ATUC 16 Sep 2025
Slide credits: A. Thomson, S. Duchesne

Australia’s National Science Agency

What is Flint?

Flint *is*:

- Python module(s) to process ASKAP data
- Built on Prefect and Dask frameworks
- Containerised native code
- Pirate themed

Some important bits

Flint *can*:

- Process
    - Raw visibilities, or
    - CASDA deposited MSs

Flint *does*:

- Rely on community software
- Use Prefect and Dask
- Use WSClean
- Provide CLI entry points

Flint is easily deployable

- Used successfully on different HPCs

Join the flint crew!

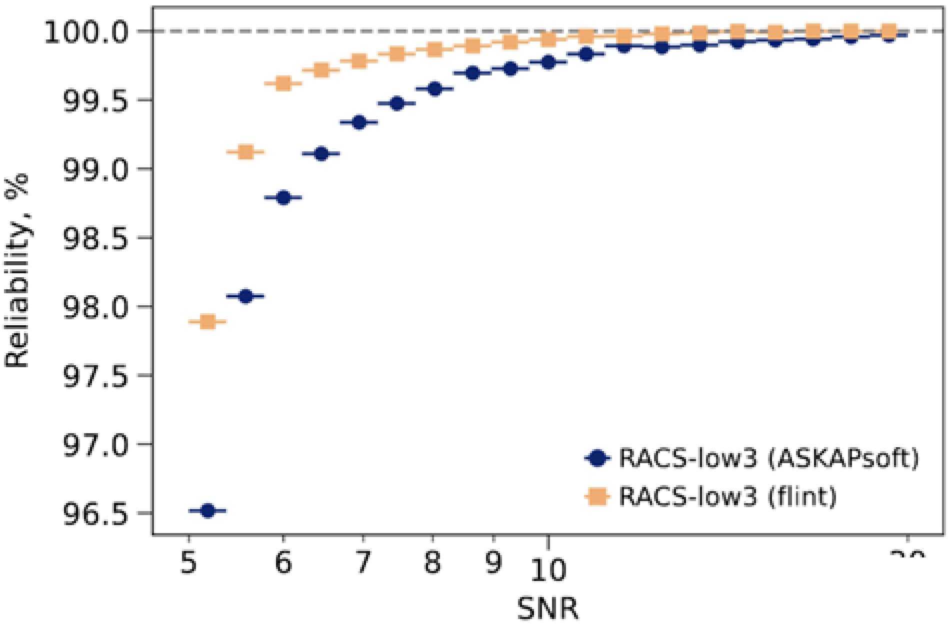
Code is available on GitHub

Lots of dev tools to assist with contributions

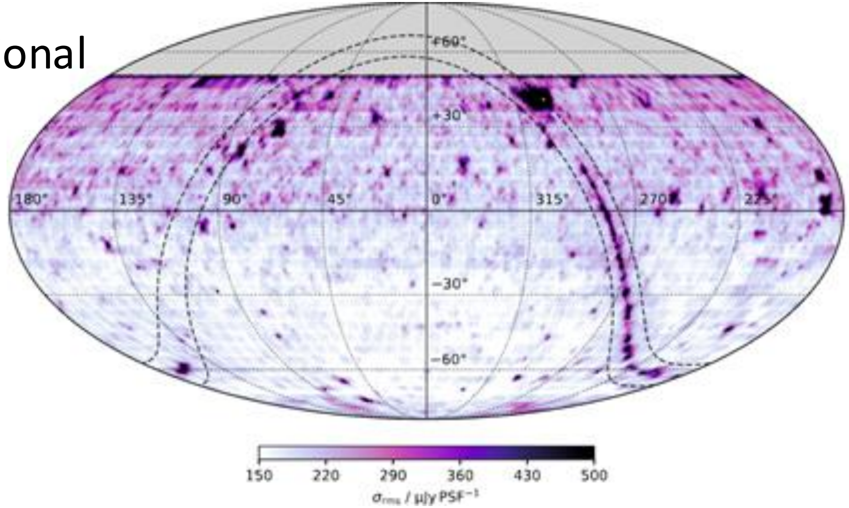
RACS-Low3 Results

Analysis by Stefan Duchesne:

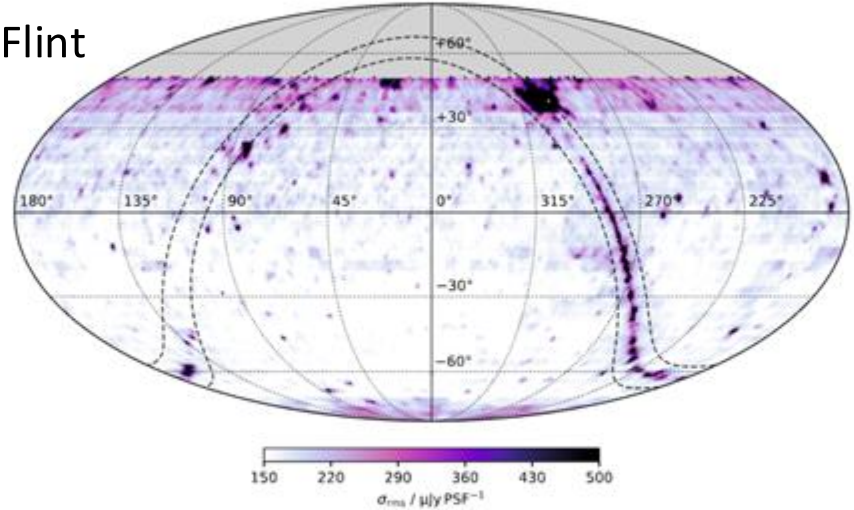
- Flux scale 1 to 1
- 3.9M to 4.4M detected islands
- 6% improvement in reliability at 5σ



Operational



Flint



Key workflow differences

Robust clean mask

- Minimum absolute clip
- Reverse flood fill
- Erosion of islands based on restoring beam shape

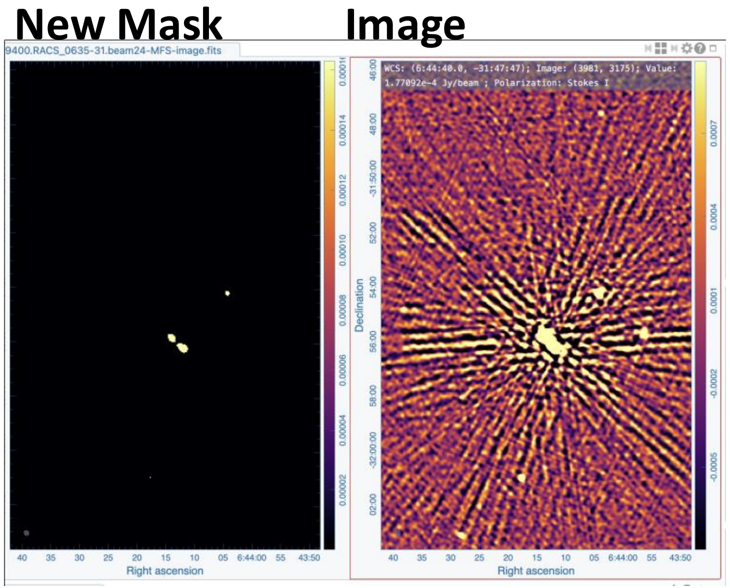
Robust cleaning critical for optimal self-calibration

Self-Calibration strategy

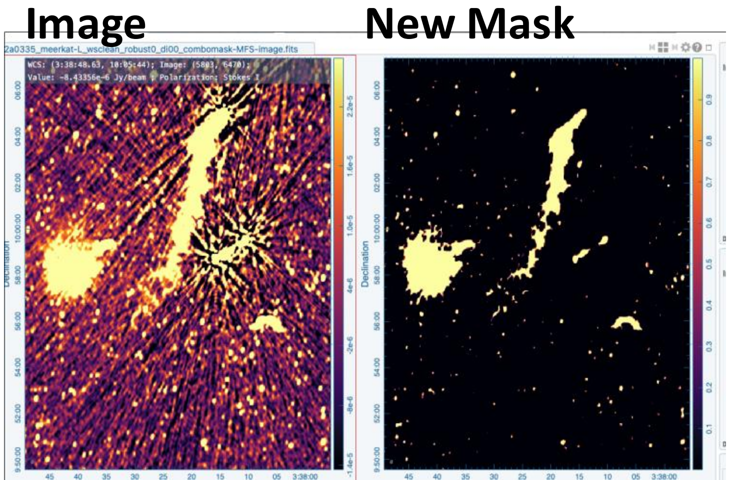
- Two rounds of phase only
- Two rounds of amplitude
    - 7-minute solution intervals

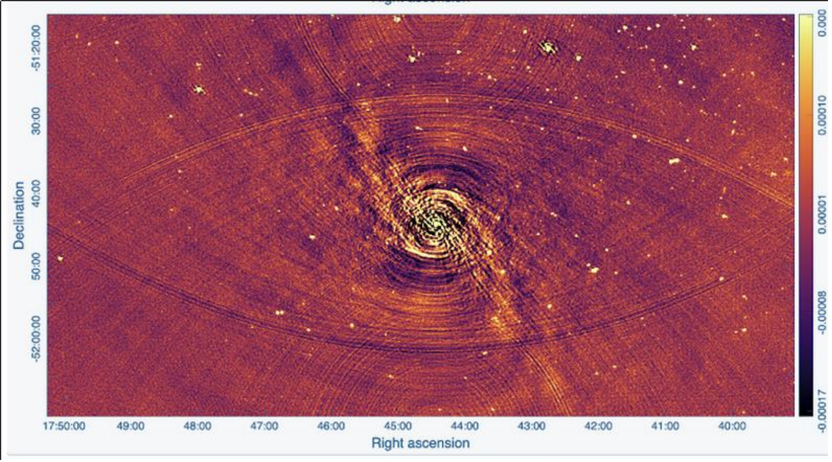
RACS data after application of bandpass.

Colour image is after initial image, left is clean mask formed from it.

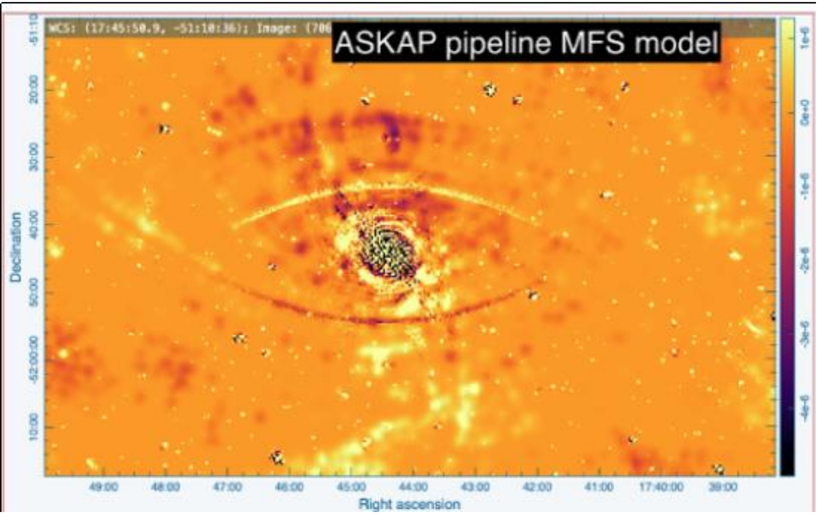


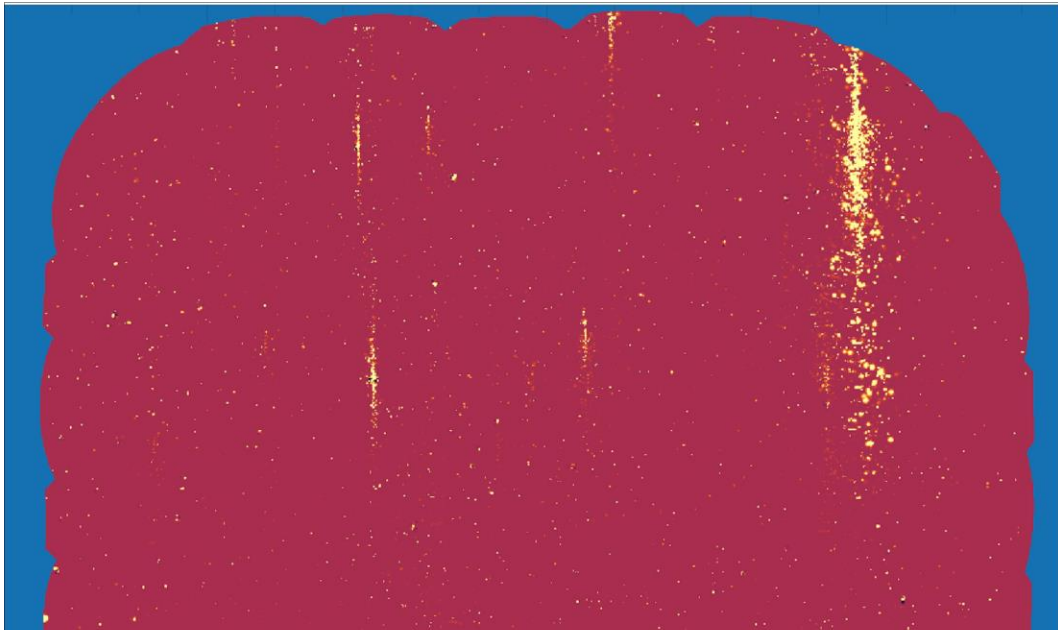
MeerKAT data





Top: EMU observation beam 20 w. additional w-planes, *Bottom:* MFS model





Above: PI clean model of channel 1 in POSSUM cube towards an equatorial field

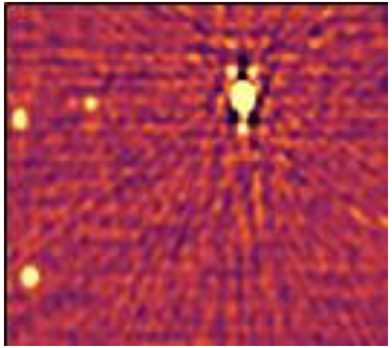
As an example

Bottom is restored, top is residual

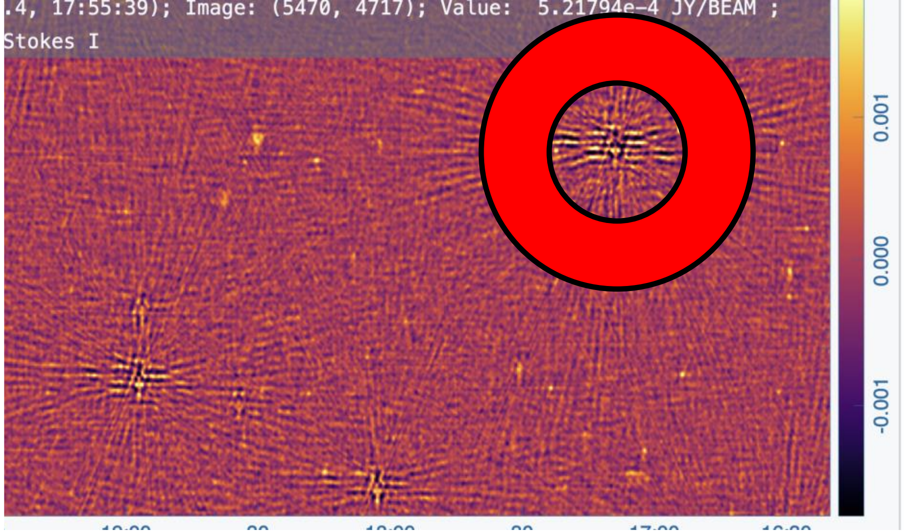
Wsclean used as imager

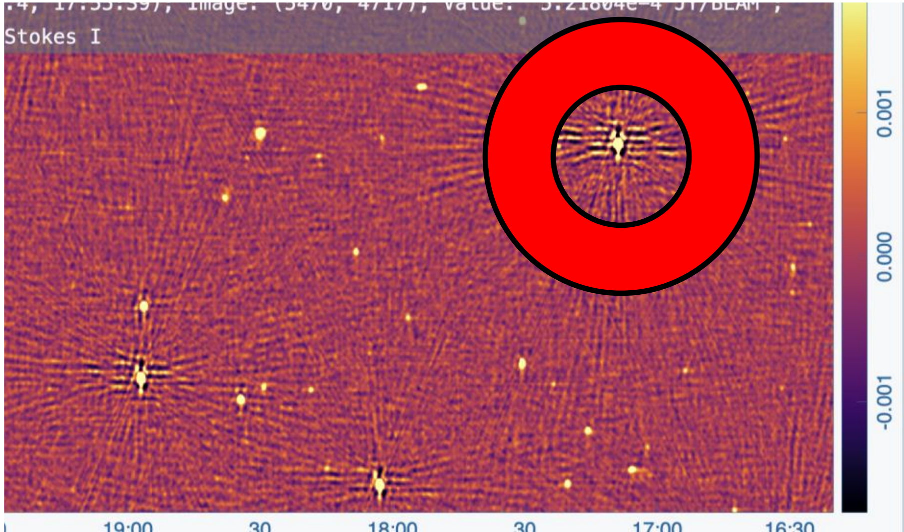
- position dependent noise estimation
- cleaning to ~15 sigma (deep lower)

The phase errors have been cleaned into the model – *phase only self-cal makes them look nice*



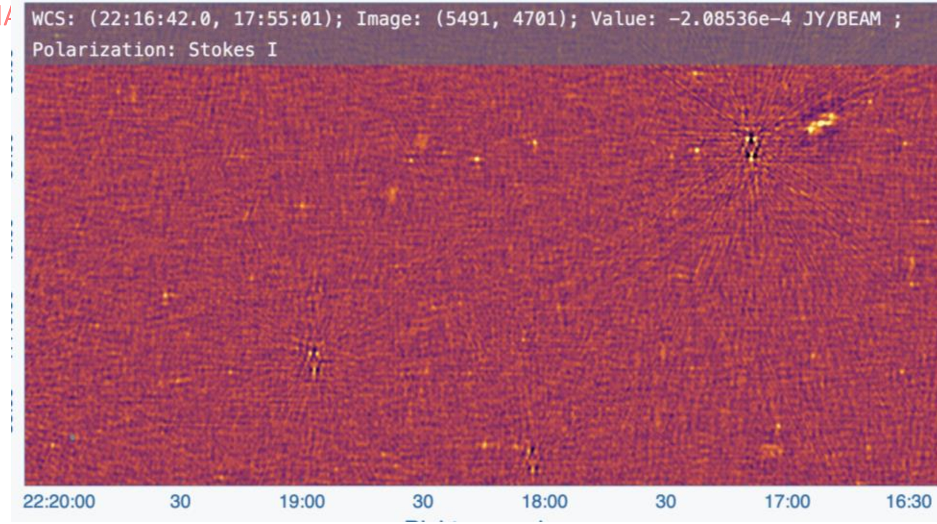
Left: Phase only self-calibration applied

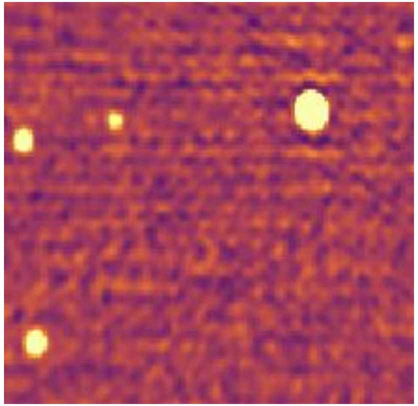




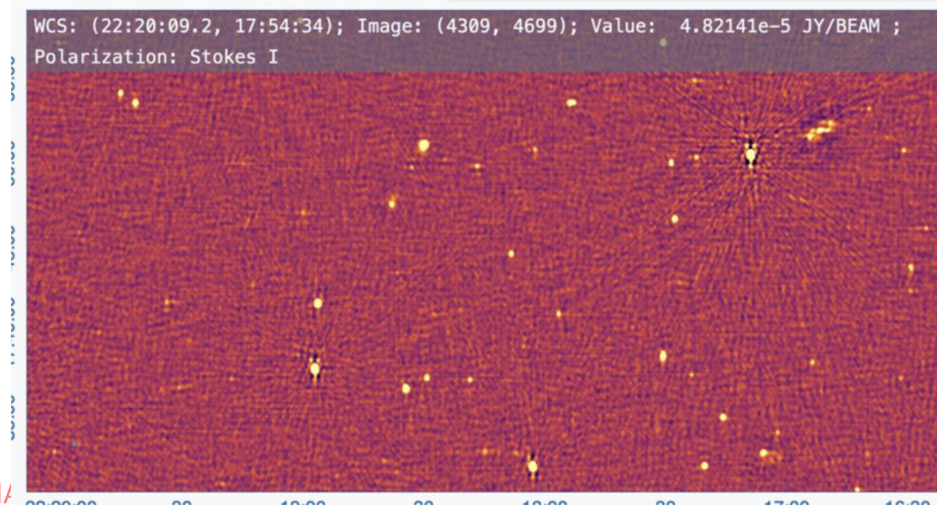
As an example

Robust clean masking to avoid cleaning artefact





Left: Phase only self-calibration applied with robust clean mask



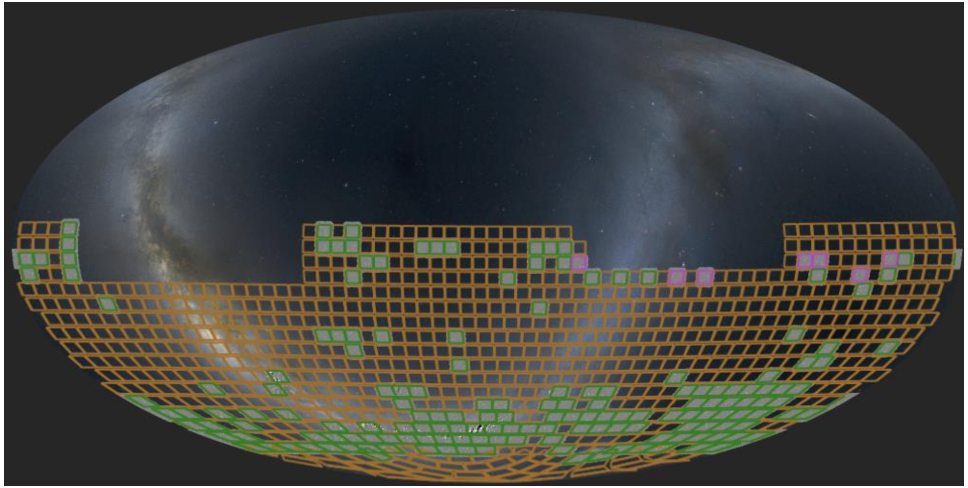
Evolutionary Map of the Universe

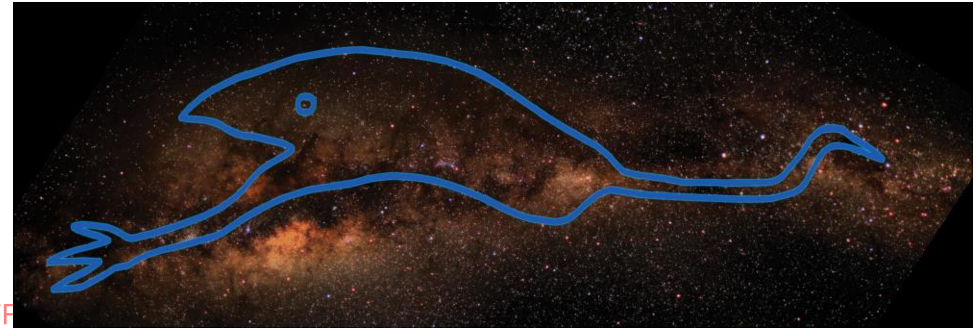
EMU a key SSP for ASKAP

Near all-sky radio-continuum survey

- ~900MHz
- 20-30uJy/beam rms

https://www.emu-survey.org



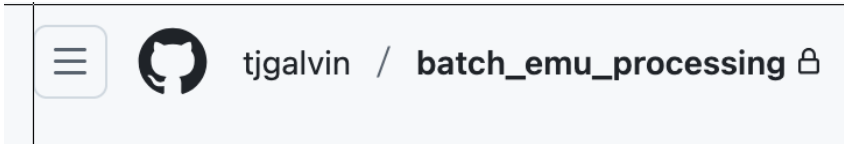


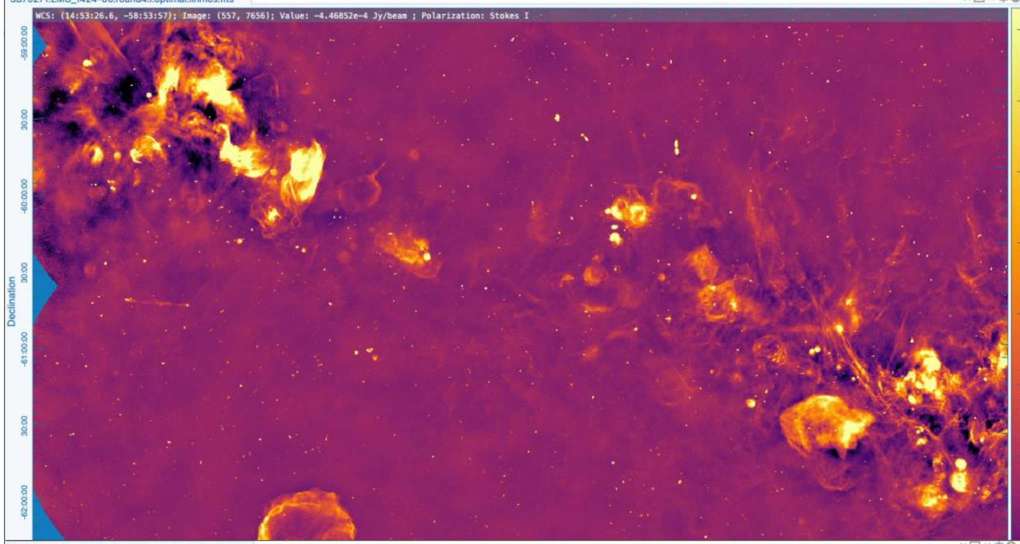
Flint on EMU?

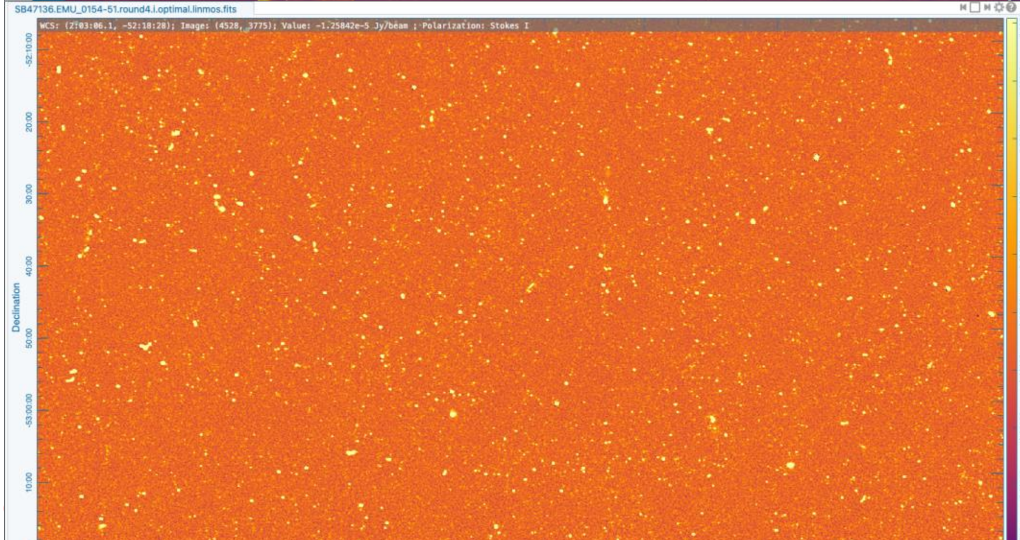
- Yes – either CASDA deposited MS or raw MS
- Routinely processing EMU datasets from CASDA
- Working towards automated workflow

Top: SBID 70271 towards GP

Bottom: SBID 47136







Processing to-date?

Diffuse stacking experiment: improvements seen towards GAMA equatorial fields

- Credit to Sai Wagh, PhD student at UWA

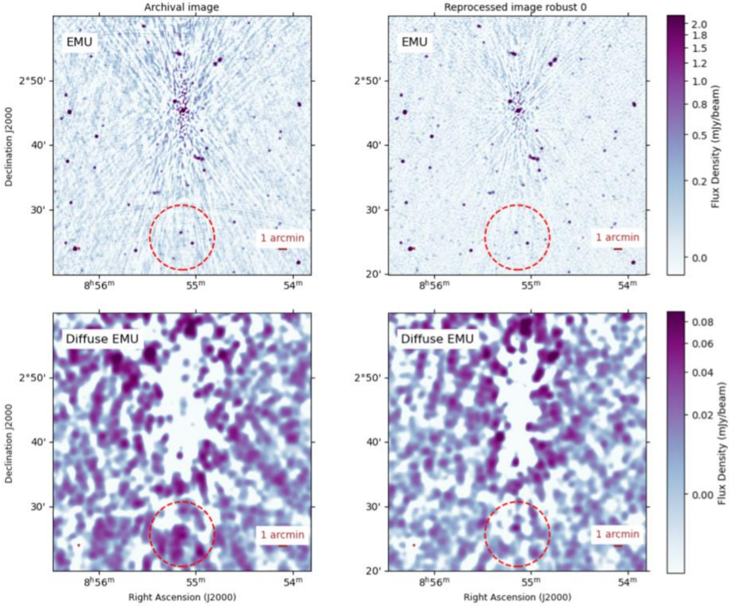
ONE-YEAR MILESTONE - 28 AUGUST 2025

Reprocessing of EMU data

Flint pipeline for self-calibration
minimum start-to-finish calibration and imaging workflow

Number of tiles reprocessed	23
Self-calibration rounds	2-phase only and 1-amplitude-phase
Robust weighting	0
Multiscale cleaning scales	0, 4, 8, 16, 24, 32, 48, 64, 92, 128, 196, 512, 796, 1025
UV range	> 400m

RMS improvement
37 μJy/beam to 30 μJy/beam

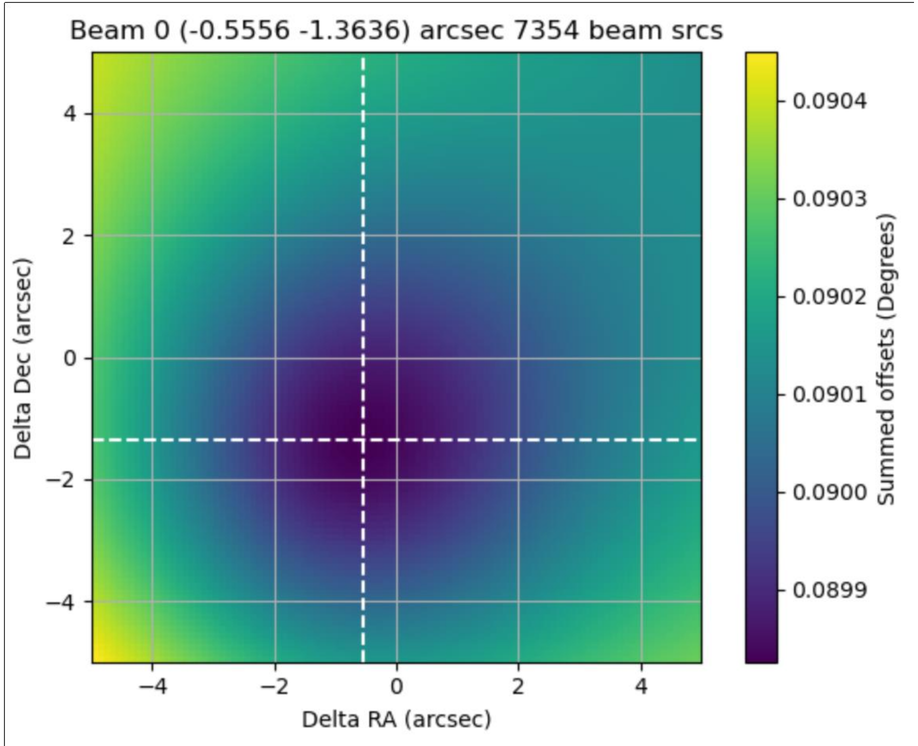


Reprocessing of EMU data done by Tim Galvin

Next steps

Perfection is my enemy, but

1. Incorporate astrometrically correct RACS-Low3
   - Contribution from Erik Osinga
2. Verify imaging characteristics with EMU team

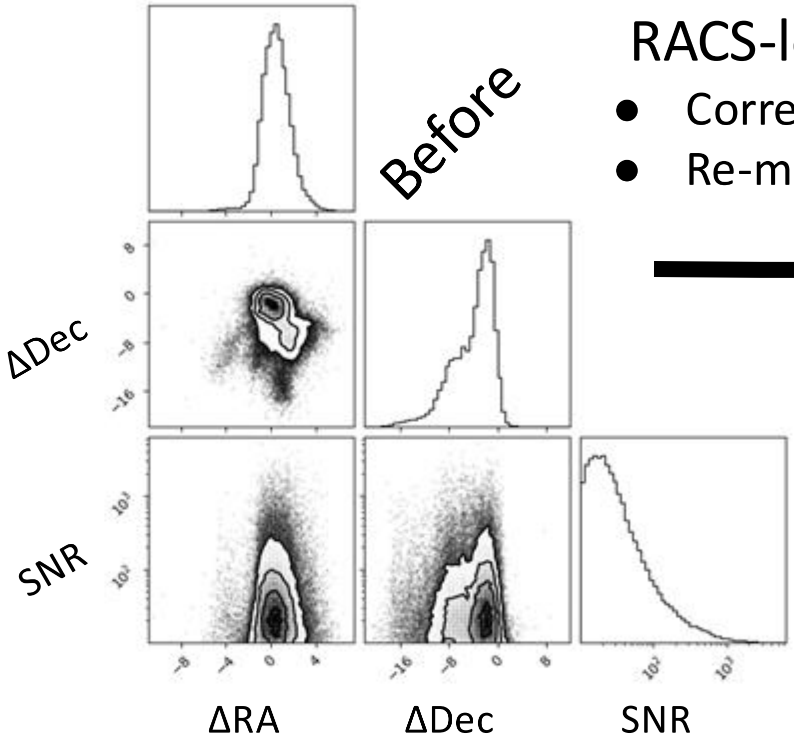


https://github.com/flint-crew/cross-bones

On point 1:

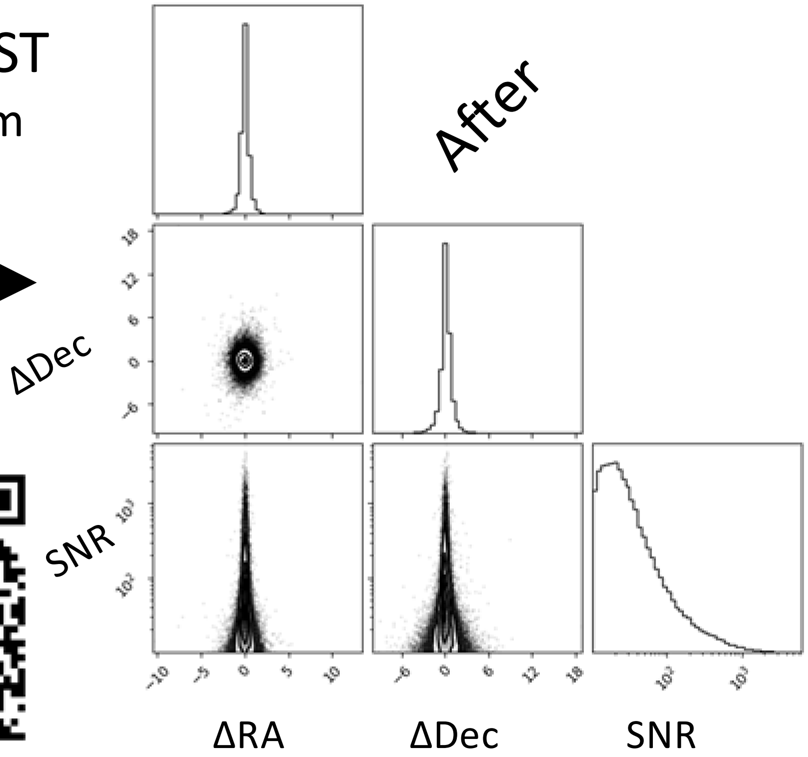
- Acquire per-beam catalogues
- Filter for isolated and compact sources
- Add offsets, cross-match to unwise, sum
- Repeat across a grid

Astrometry Correction for Global Sky Model



RACS-low3 ⨉ FIRST

- Corrected per beam
- Re-mosaicked



(Credit S. Duchesne)

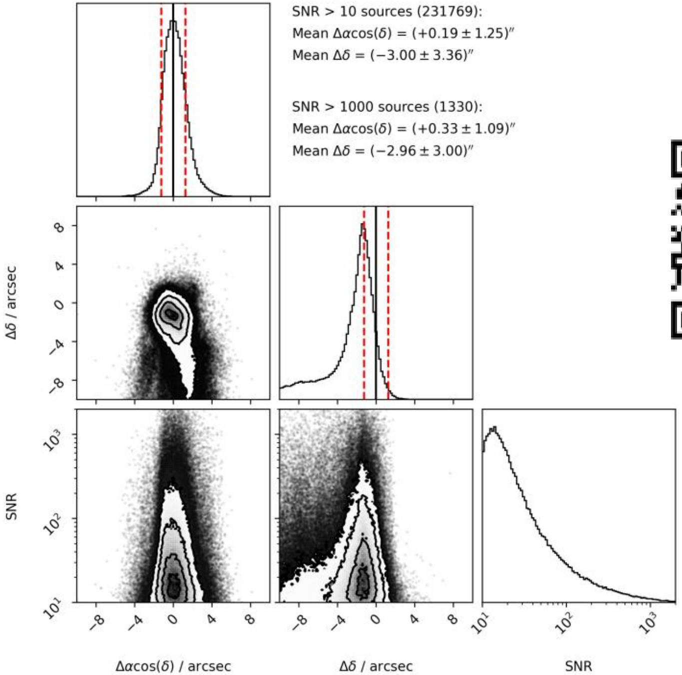
https://github.com/flint-crew/cross-bones/

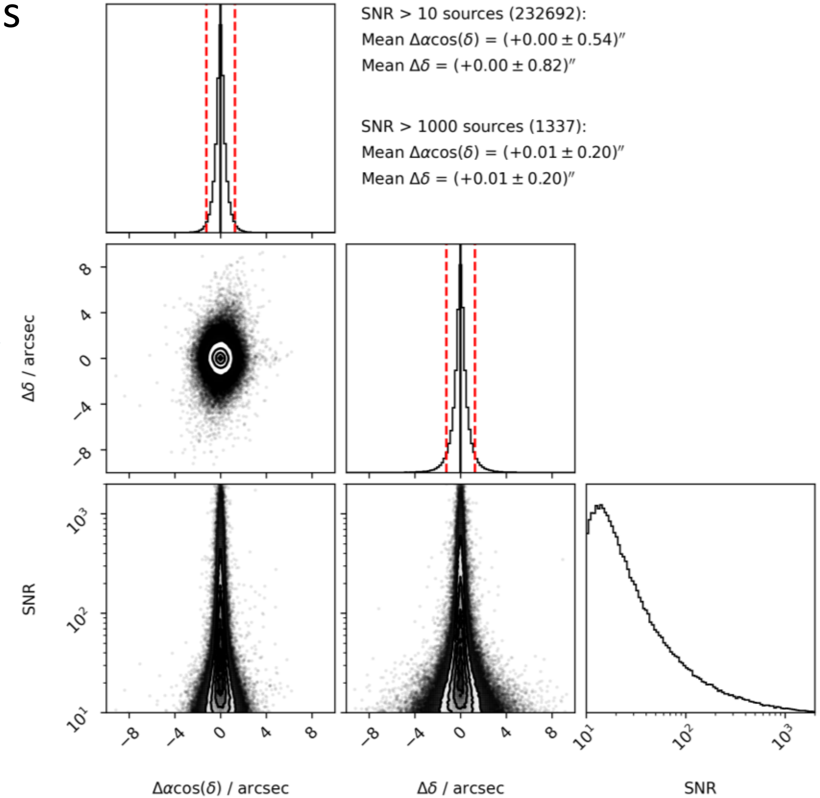
Final RACS Low3 Sky Model

A huge thanks to both Stefan Duchesne and Emil Lenc

Inputs:

- Per beam catalogues
- Per beam images





Summary

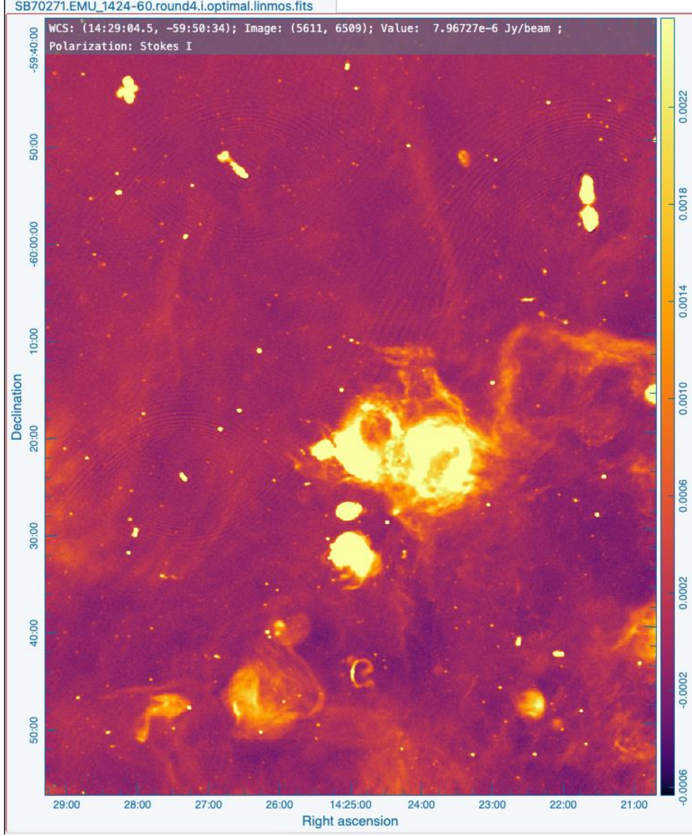
Flint is open source ASKAP pipeline framework

Contributions are welcome

Aim to re-process EMU data

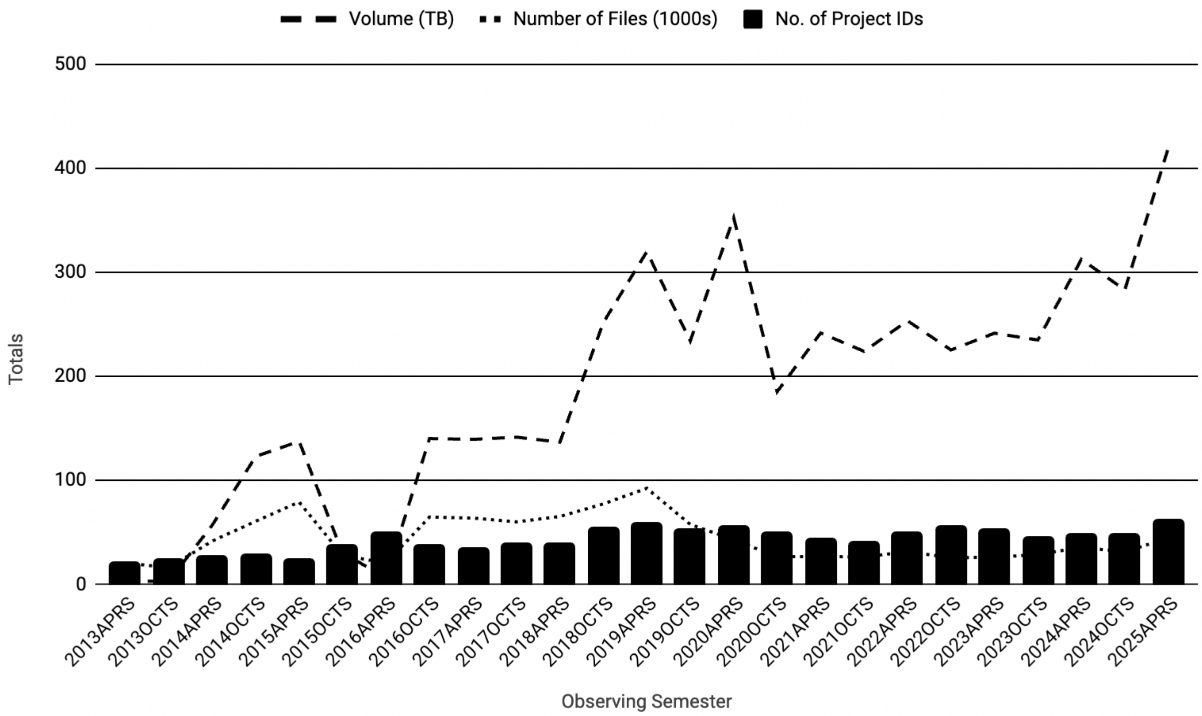
Close to ‘pushing the button’
- Calibrate against RACS Low3 catalogue
- Verify imaging settings

Big thanks to:
- Alec Thomson, Stefan Duchesne, Emil Lenc, Erik Osinga and Sai Wagh
- Larger ASKAP team for queries around the data



Data (Lawrence Toomey)

Steady growth in data on DAP



Current status

New archival data in DAP

- P512 (A Methanol Multibeam Pulsar Survey)
- P630 (HITRUN: High latitude, 25% complete)
- ~40TB archival data added per year
- Total available data in DAP is **~4.6PB**

Improvements

- Faster publishing: **~2 days** from end of observation
- Faster downloads with rclone/aria ~100MB/s to Europe/USA
- PX collections (ToOs and Green Time) now more identifiable

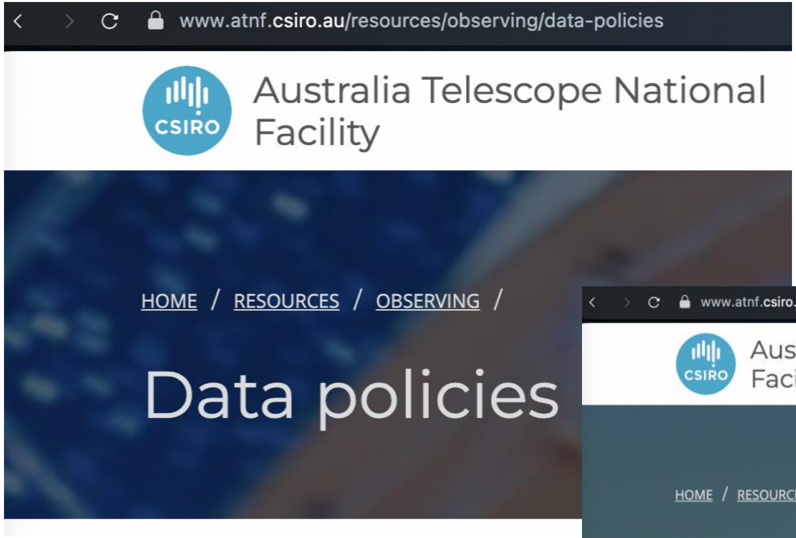
Command-line DAP query and access

- dap-query.sh
- get-dap-psr-collection.sh
- get-dap-psr-data.sh

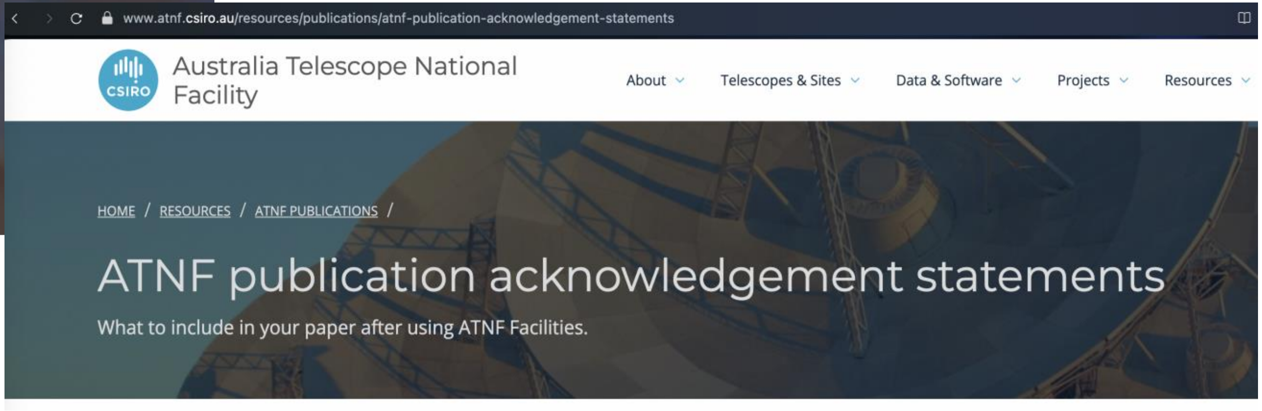
```
hydra-103% dap-query.sh

 Usage:
 dap-query.sh [OPTION] [ARG]...

 Available options:
              [-h]           This help
              [--fields]     Fields to return ['id', 'filename', 'filesize', 'doi' and URL are enabled
by default]
              [--conditions] Query conditions
              [--order]      Order to return [optional, default is 'id DESC']
              [--format]     Output format [optional, topcat|csv, default is csv]

 This program queries CSIRO's Data Access Portal (DAP)
 Table Access Protocol (TAP) service, and either writes result sets
 to CSV file or loads them in the TopCat GUI.
 By default, it will provide the total volume of data returned by the query.
```

```
hydra-104% get-dap-psr-collection.sh

 Usage:
 get-dap-psr-collection.sh [OPTION] [ARG]...

 Available options:
                          [-h]      This help
                          [--dir]   Path to an existing directory for your data

 Example:
 get-dap-psr-collection.sh
                          --dir /path/to/download/data/to

 This program retrieves a pulsar collection from CSIRO's
 Data Access Portal (DAP) and optionally allows you to
 specify the files to download.

 Requires the following packages to be installed locally:
        rclone
```

A reminder to acknowledge DAP and cite data



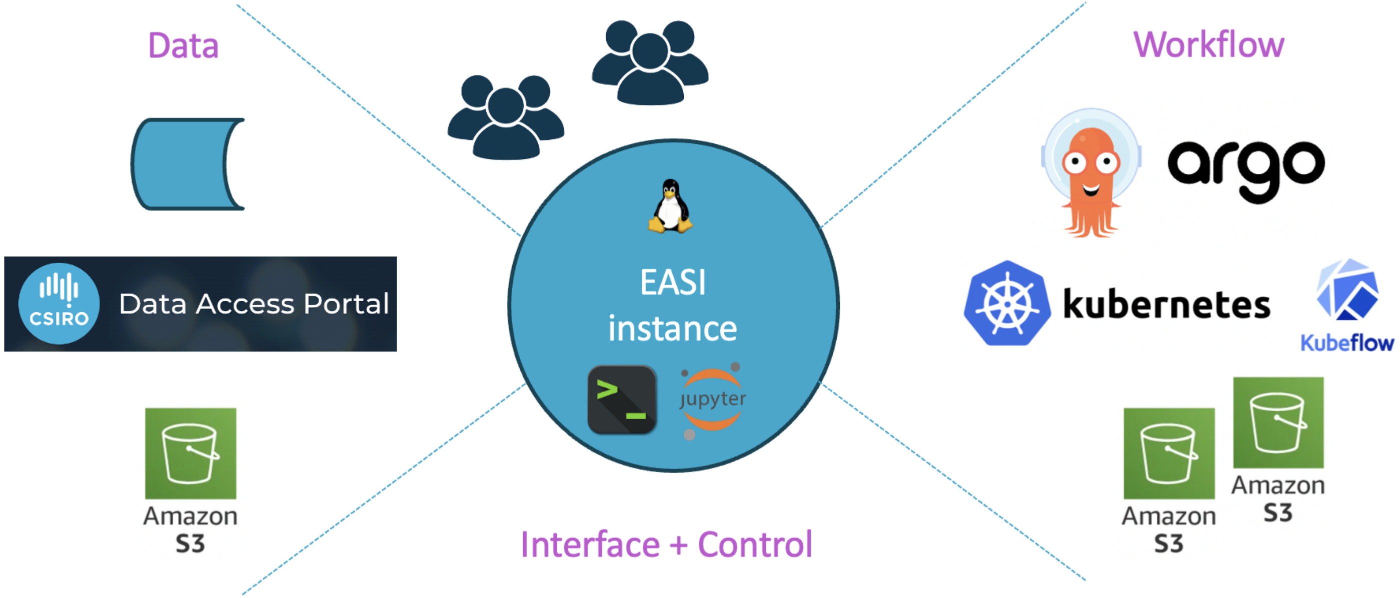

```
@ELECTRONIC{csiro:P456-2019APRS_50,
  author = {Hobbs, G AND Manchester, R AND...},
  year = {2019},
  title = {Parkes observations for project P456 semester 2019APRS_50},
  language = {English},
  howpublished = {\url https://doi.org/10.25919/5d93cd5f35b31},
  doi = {10.25919/5d93cd5f35b31},
  owner = {CSIRO}
}
```



research.csiro.au/easi

Earth Analytics Science & Innovation Platform

Work in progress I: 'EASI-Pulsar'



Work in progress II: PSRCAT

- Ongoing development of the SQLite backend (but with limited resources)
- Hobbs et al. (in prep.)

How you can help :)

- Ensure all parameters are published in tables
- Use Digital Object Identifiers (DOIs) instead of online links to the data – links can be short-lived!
- If possible, provide DOIs to machine-readable files containing parameters

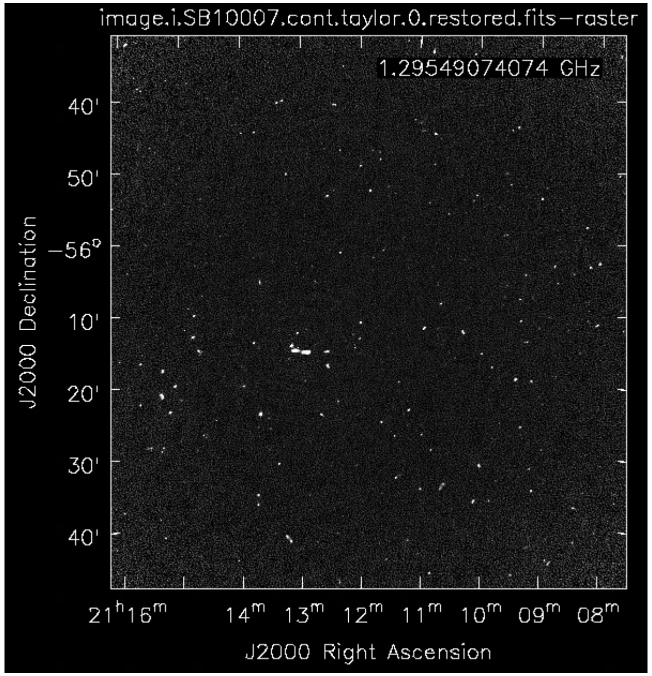
Spectrum management update (Balthasar Indermuehle)

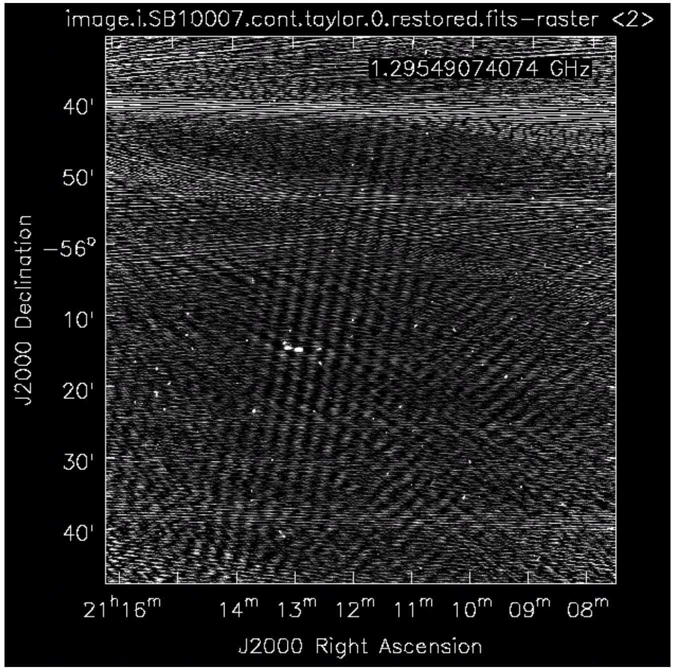
Update on ATNF Spectrum Management

Dr Balthasar Indermuehle | ATUC Sep 16 2025
Chair ITU-R WP 7D, Chair RAFCAP

Australia's National Science Agency

Starting with the Problem: What is RFI?





Near field boundary at 1.295 GHz:

- 30 m baseline: 3.8 km
- 2 km baseline: 17,266 km
- 3 km baseline: 38,850 km
- 6 km baseline: 155,400 km

GNSS satellites ~ 20,000km away

Credit: Wasim Raja, CSIRO

Starting with the Problem: What is RFI?

For a radio astronomer:

Any radio emission that is not of cosmological origin

For a spectrum manager: Defined in Radio Regulations (RRs) 1.166:

1.166 *interference:* The effect of unwanted energy due to one or a combination of *emissions*, *radiations*, or inductions upon reception in a *radiocommunication* system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

Radio astronomy for the purposes of the RRs is a service, the Radio Astronomy Service (RAS)

What is Spectrum Management then?

To some astronomers, surprising information:

- Radio astronomy does not own the full radio frequency spectrum.
- Less than 2% of radio spectrum is allocated to RAS
- Many RAS allocations are shared with other services
- Only a small number of allocations are providing hard protections for RAS ("all emissions prohibited" as per footnote 5.340):
  - 1400 – 1427, 2690 – 2700 MHz
  - 10.68 – 10.7, 15.35 – 15.4, 23.6 – 24, 31.3 – 31.8, 48.94 – 49.04 GHz
  - 86 – 92 GHz, 100 – 102 GHz
  - 9 more allocations > 100 GHz up to 275 GHz (where the table of allocations currently ends)
- SM is radio spectrum husbandry!

Protection from RFI only as good as the regulatory framework

(to a first approximation)

Regulatory Framework

National Regulator: ACMA in Australia

- Enforces national regulations harmonised with international rules, the ITU-R Radio Regulations
- Makes national legislation that governs sovereign use of the radio spectrum, e.g.
  - RALI MS31 (Coordination zones around our telescopes)
  - RALI MS32 (ARQZWA)

Regulatory Framework

International Telecommunications Union ITU, Radiocommunication Sector – ITU-R

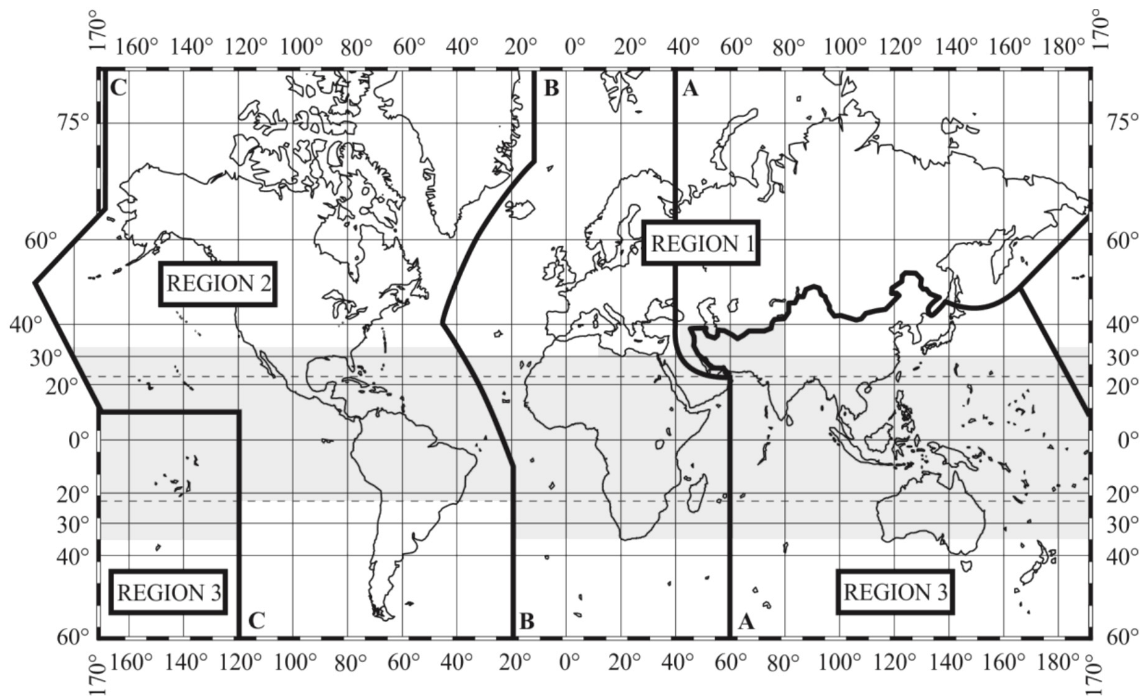
- Specialised Agency of the UN with 196 signatory nations
- Consensus and input driven organisation
- Members can provide inputs and participate in meetings
  - Administrations (the only membership with a vote – should it ever come to it)
  - Sector Members (e.g. SKAO, regional advocacy groups like CRAF)
  - Other UN agencies (e.g. IMO, WMO, ICAO…)
  - Industry (random examples: Eutelsat, Nokia, Ericsson, Airbus, Boeing)
  - Academia
- But: Most impactful to participate as an administration. Hence most industry and research participate on the delegations of national administrations.

Regulatory Framework

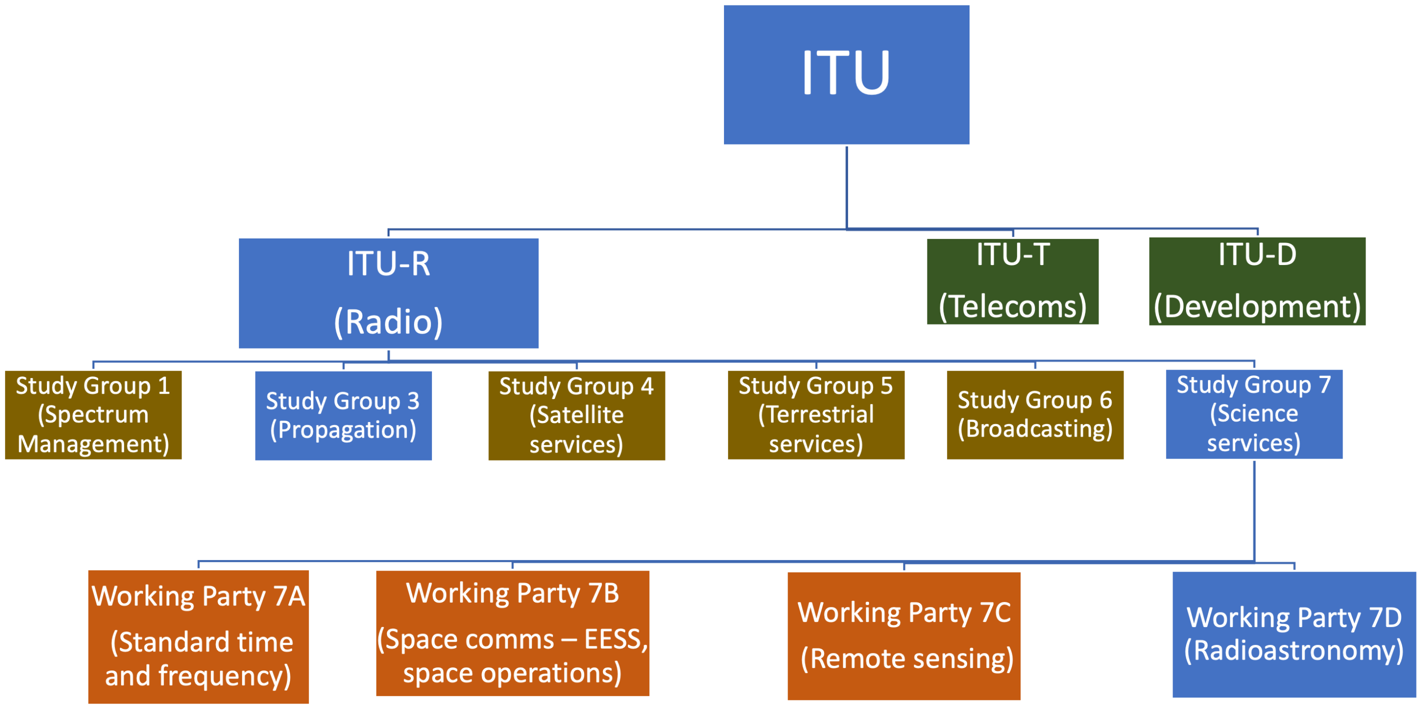
- ITU-R allocates spectrum in the Table of Frequency allocations.
- RAS:
  - < 2% of radio spectrum allocated to RAS
  - RRs are a legal framework written in legalese with engineering terminology, catering to protection of huge commercial and national interests.
- Radio Regulations (RRs), updated every 4 years. Next WRC is in 2027

Regulatory Frame

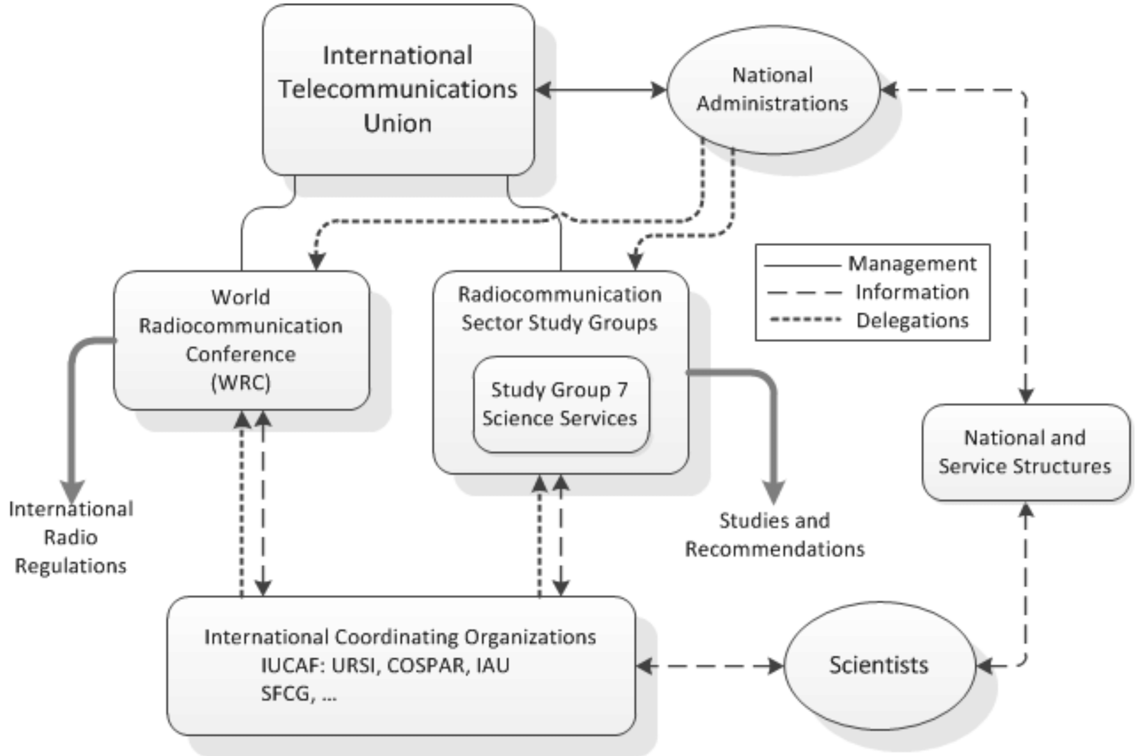
- 3 Regions
- Regional Radio Astronomy advocacy groups
  - CRAF
  - CORF
  - RAFCAP



Regulatory Framework



Regulatory Framework



Credit: Sandra Cruz-Pol

ATNF engagement in SM

- ATNF plays a very active role in ITU-R since the 1970s:
  - SG7/WP7D (Radio Astronomy)
    - John Whiteoak chaired WP7D from the 1970s – 2000
    - Tasso Tzioumis chaired WP7D from 2011 – 2024
    - Balthasar Indermuehle chairs WP7D since 2025
    - Kevin Knights chairs WP7B-2, vice-chairs SG7 and WP7B
    - Liroy Lourenço currently being onboarded for support
  - SG3/WP3K (Propagation)
    - Carol Wilson chaired SG3 from 2015 – 2023
    - Hajime Suzuki chairs WP3K since 2024

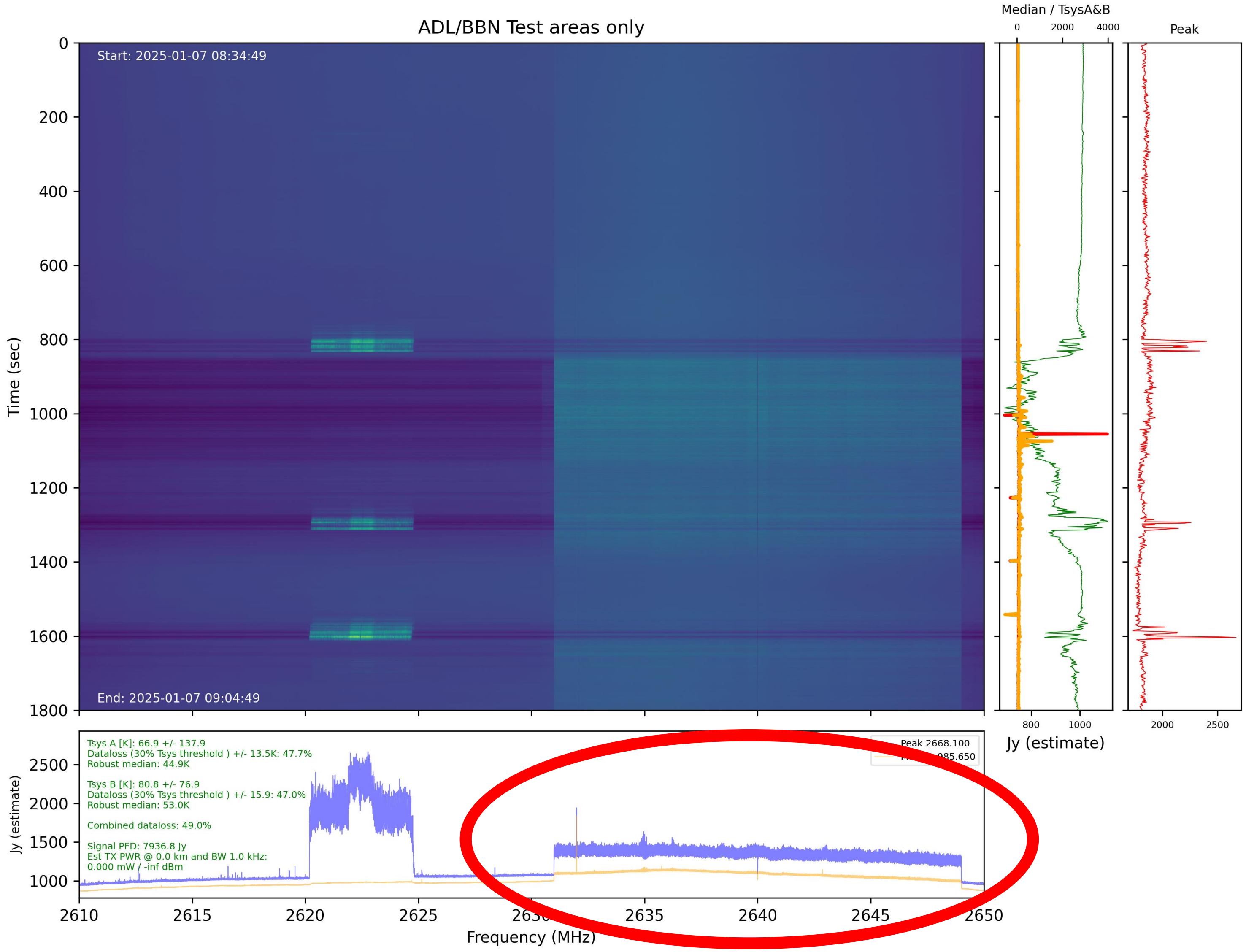
Eminently important to have a seat at the table and help shape the future use and accessibility of radio spectrum!

Current challenges...

- New large satellite constellations are posing new challenges:
    - D2D (using IMT spectrum from space, or MSS allocation)
    - Satellite internet (Starlink, Kuiper, Guowang, 10's of thousands of satellites)
    - UEMR
    - Until 2021: worst impact from Iridium (66 satellites, 2-3 in view at any time). **Going forward 100s of satellites above the horizon at any given time!**
- IMT transmissions from space are extremely powerful, low frequency = large beams
- Any part of the RAS receiver band that is exposed and saturated is lost for science
- In addition, because they are so powerful, up the 4^{th} harmonic is wiped out:
    - Transmission at 2620-2630 MHz (10 MHz bandwidth) disables 5240-5260, 7860-7890, 10480-10520 MHz at the minimum – a total of 100 MHz, 200 MHz with OOBE
    - And that is just a single provider with only 10 MHz bandwidth
    - 3 providers with 20 MHz each could wipe out 1.2 GHz of spectrum for RAS!
- UEMR an additional issue predominantly at low frequencies (30-350 MHz), but also at L/S/C/X bands – which becomes a problem with future satellite density
- Immediate problem for LOFAR, MWA, Nenufar, SKAO!

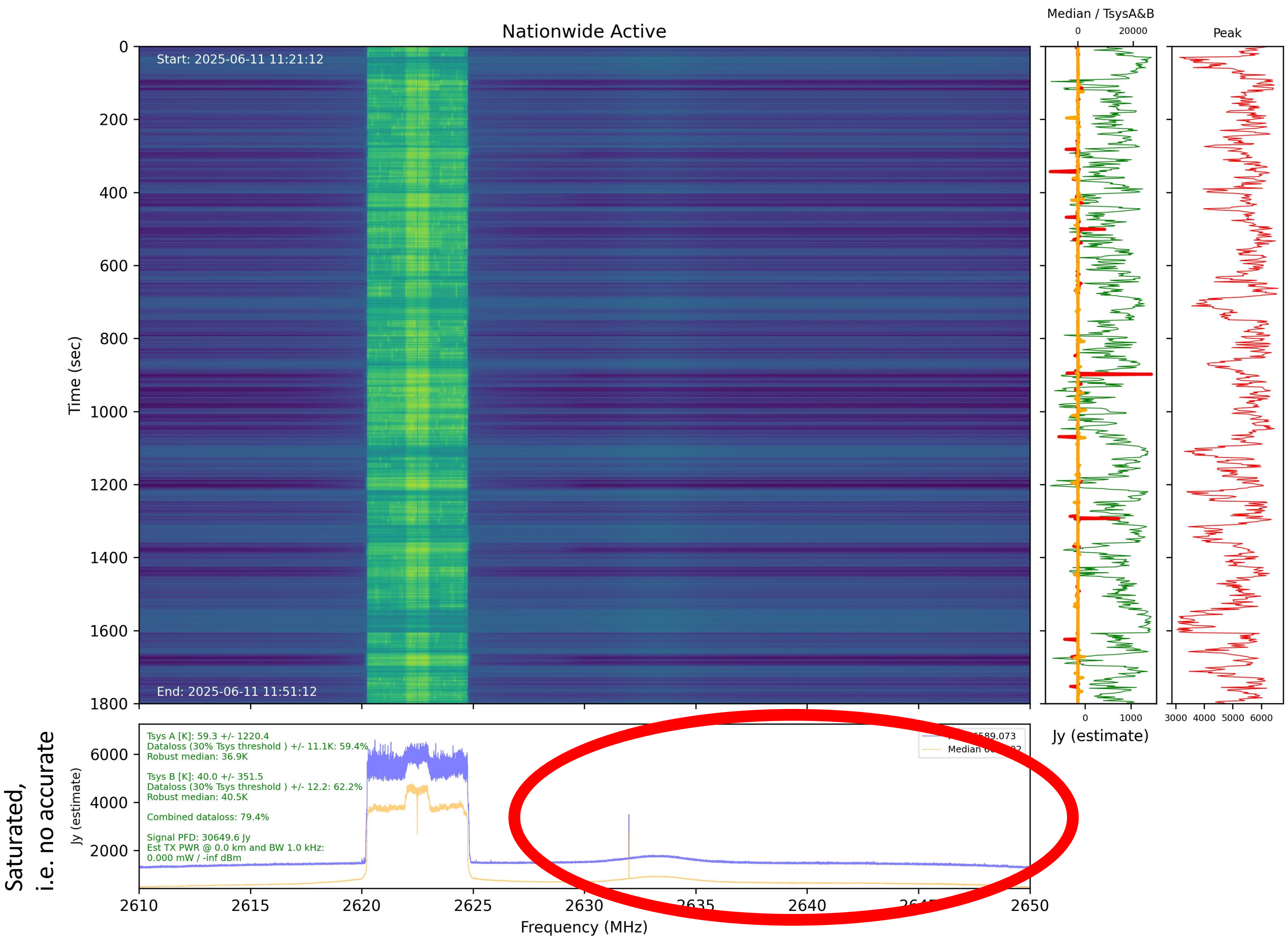
D2D Ex.

- January 2025
- Zenith observation (not looking at the satellites)
- Only 2 footprints illuminated:
  - Adelaide (1200km away)
  - Brisbane (1000km away)
- > 6 times stronger emission than nearby terrestrial base station



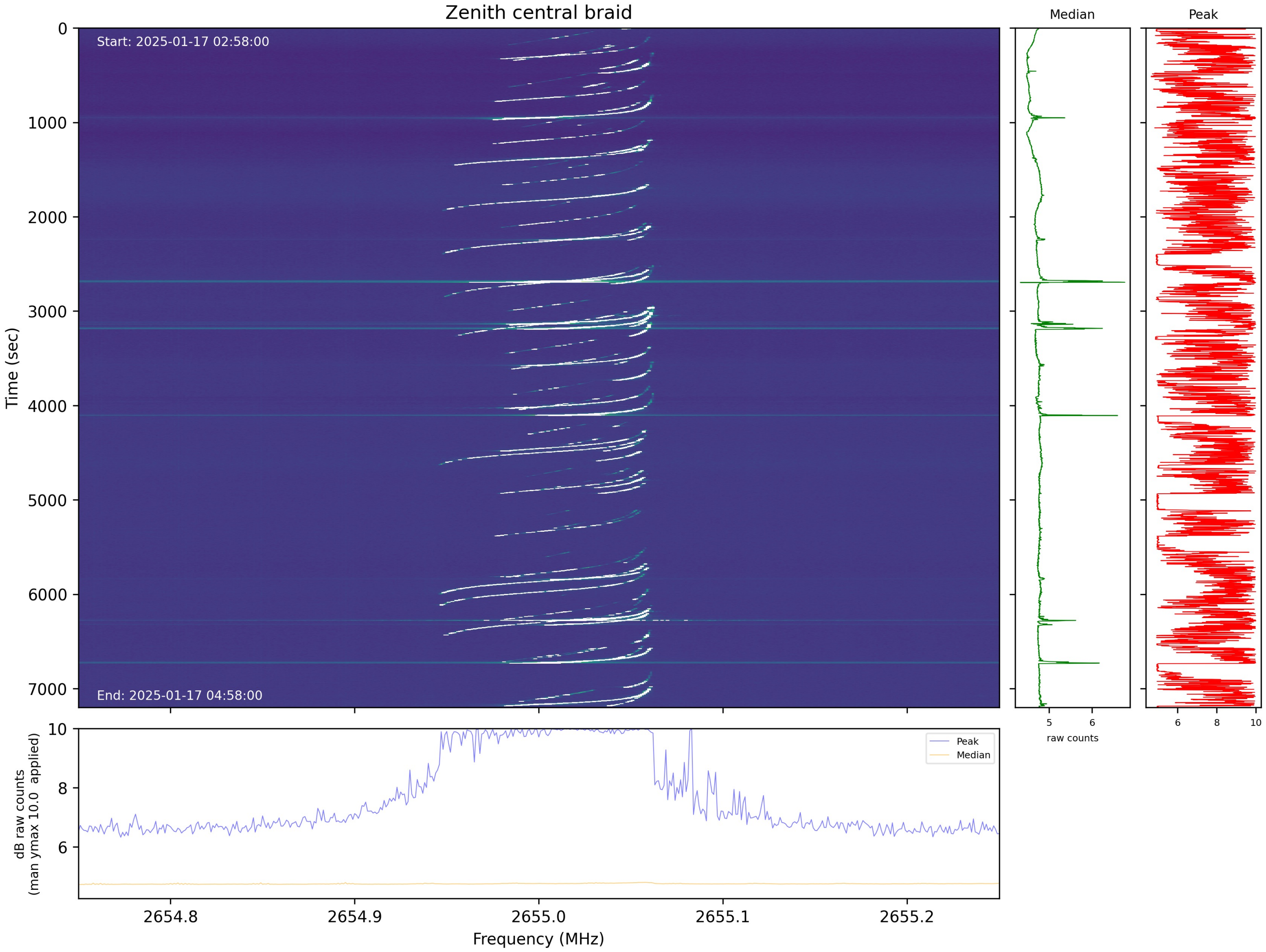
D2D Ex.

- June 2025
- Zenith observation (not looking at the satellites)
- Nationwide coverage for Telstra active
- Permanent receiver saturation
- Local terrestrial station not even visible anymore



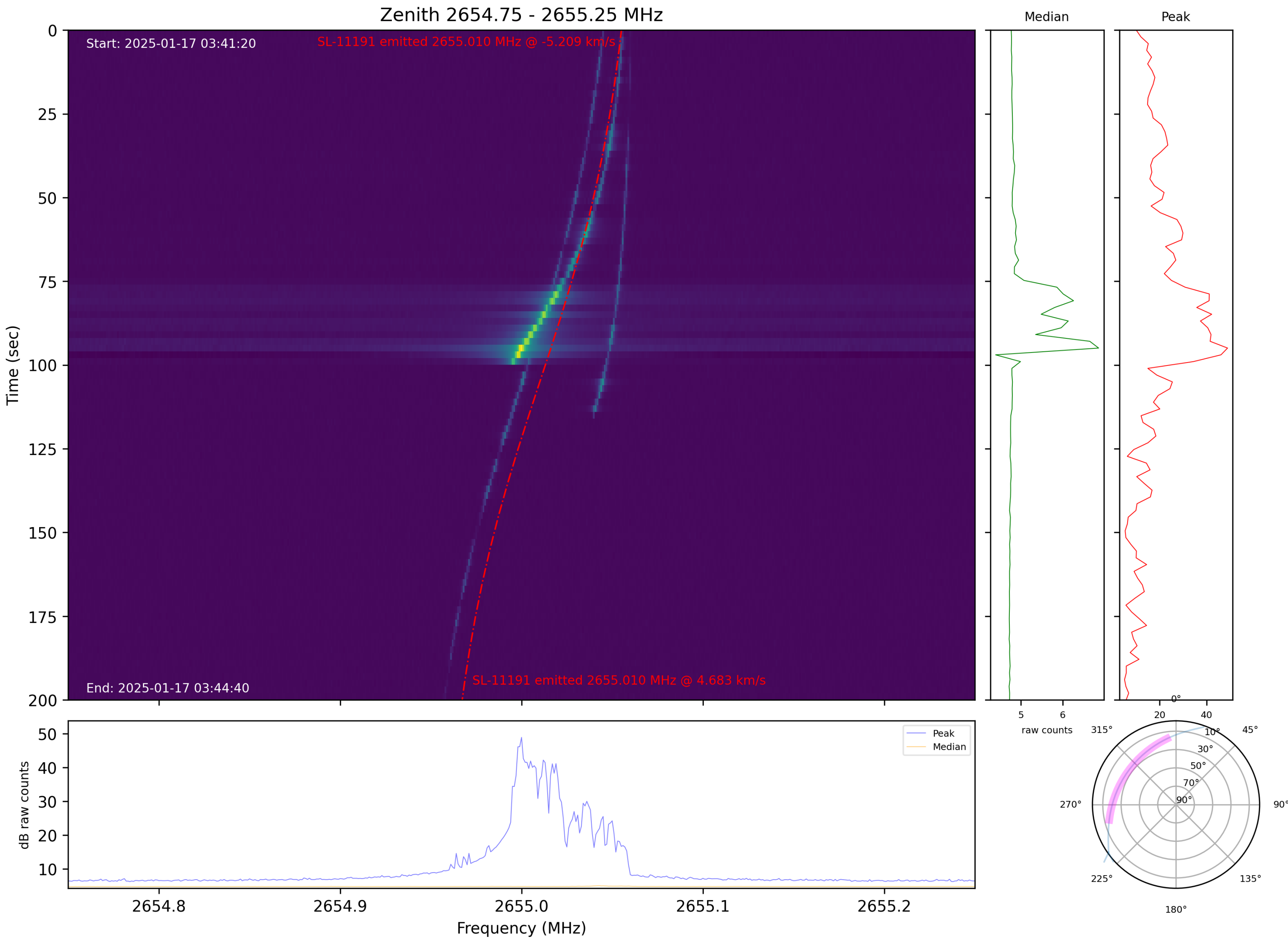
UEMR Ex.

- Zoomed into 2654.75 – 2655.25 MHz
- Looks like every satellite is emitting
- Visible regardless of antenna pointing



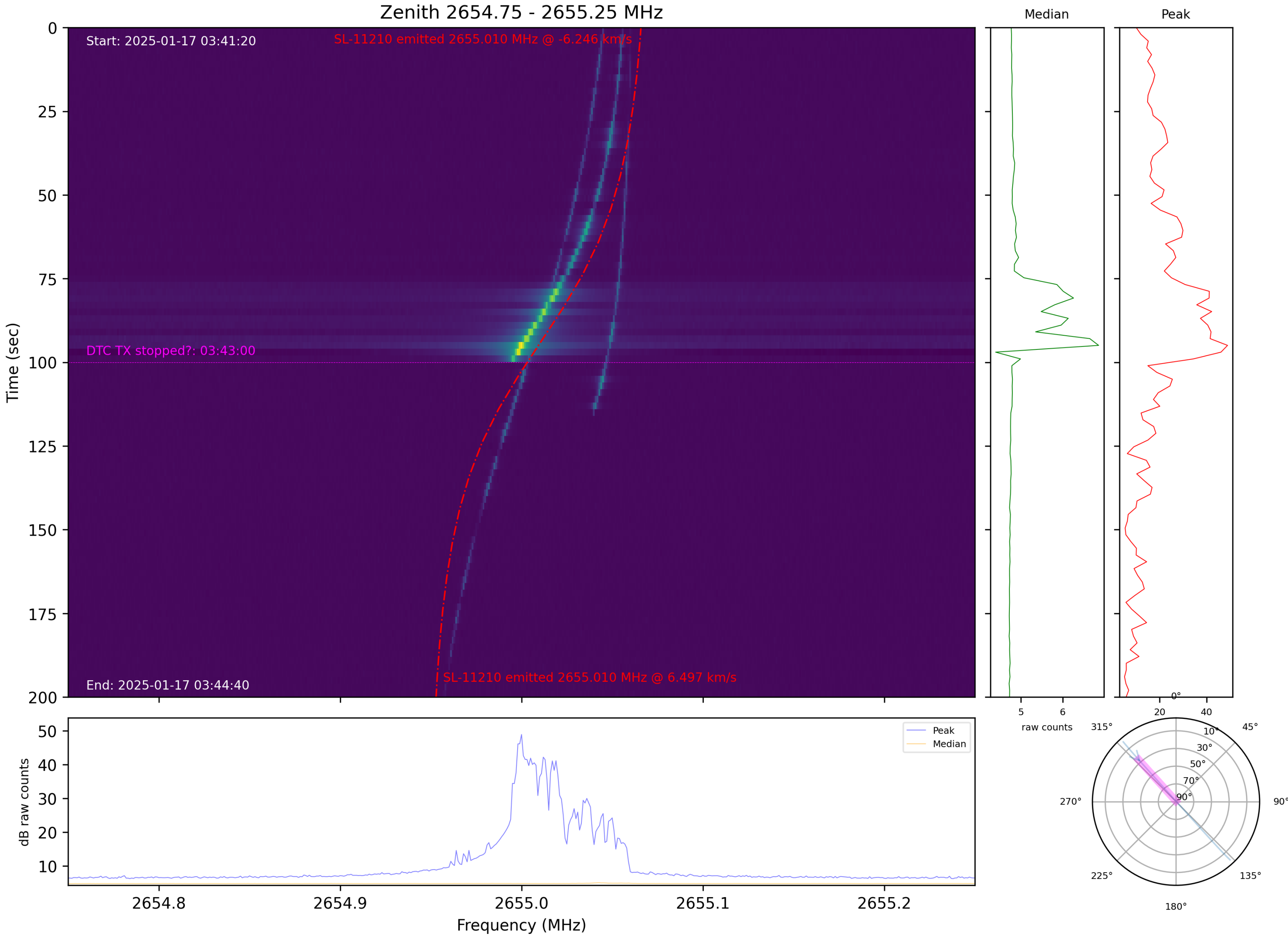
UEMR Ex.

- Doppler for SL-11191 overlaid (at fiducial emit f=2655.01 MHz)
- UEMR at 2655 MHz



UEMR Ex.

- Doppler for SL-11210 overlaid (at fiducial emit f=2655.01 MHz)
- UEMR at 2655 MHz



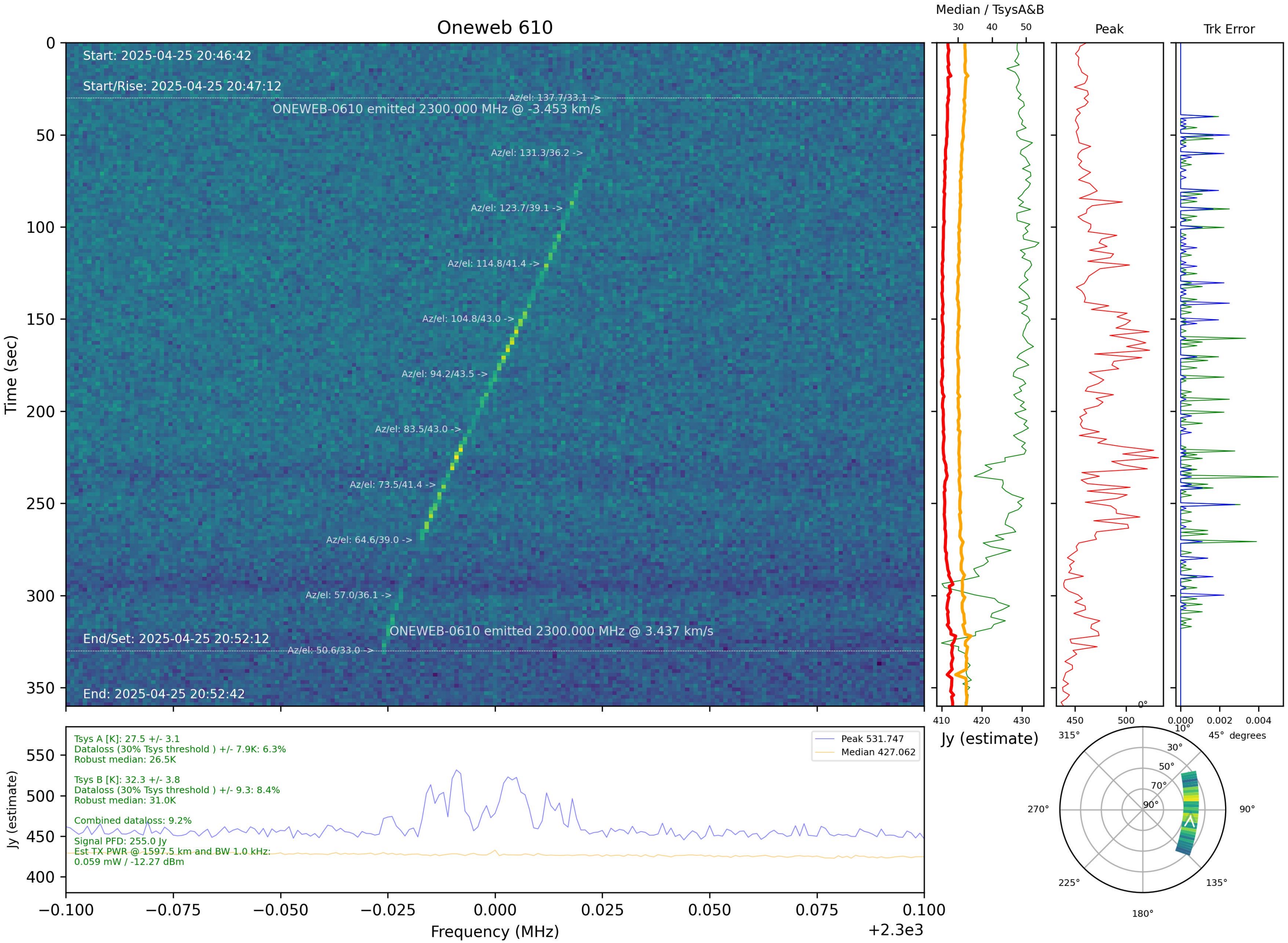
UEMR Ex.

Radiation :
2300 MHz

TOFA:
2290 – 2300 MHz
FS, MS, SRS (active)
AUS87

2300 – 2450 MHz
FS, MS, RLS, AS
AUS87

Incidence: 100%
7/7 observations



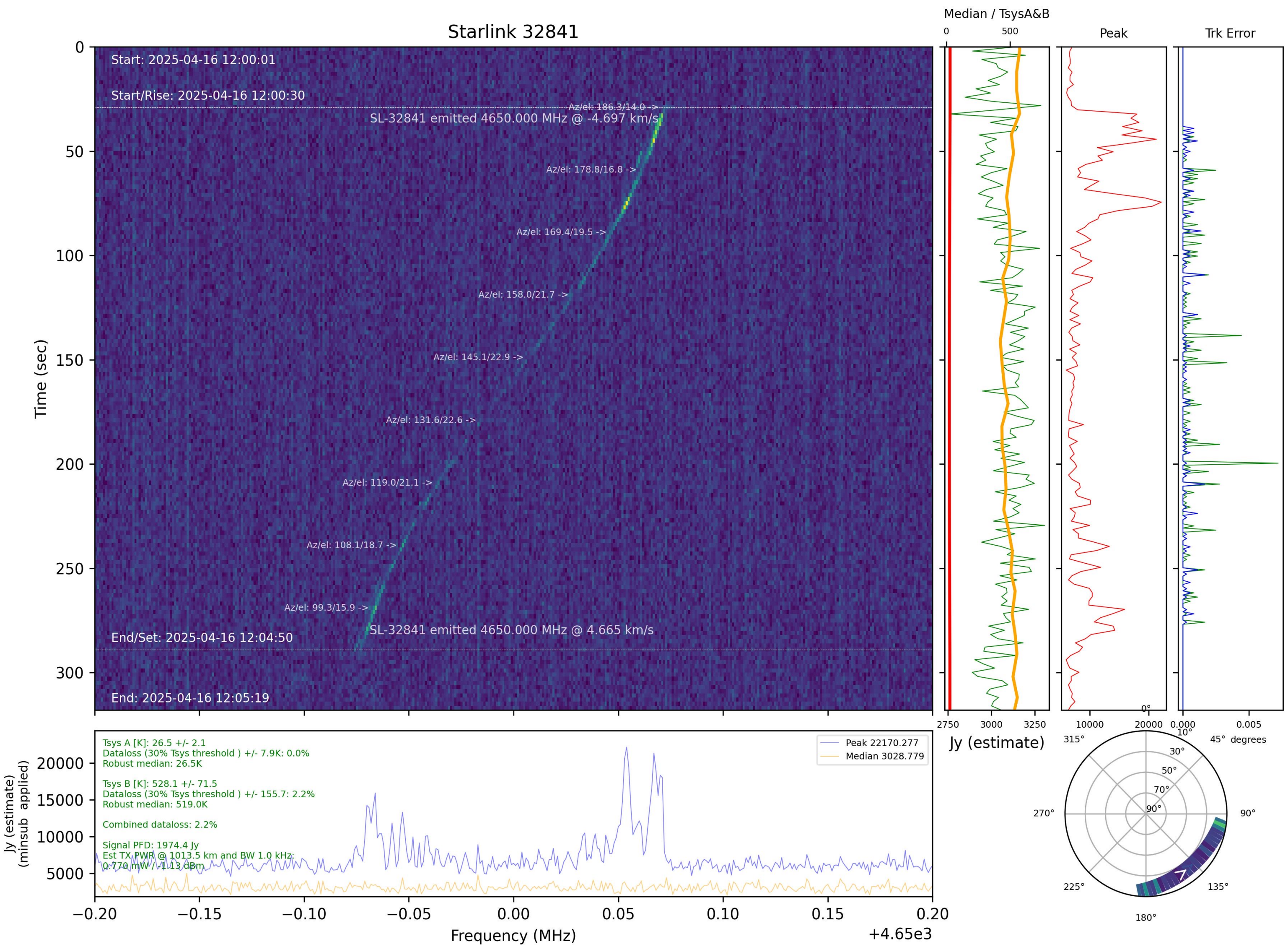
UEMR Ex.

Radiation :
4650 MHz

TOFA:
4500 – 4800 MHz
FS, FSS (s-E)
AUS87

Disregard scale (corrupt Tsys)

Incidence: 100%
1/1 observations

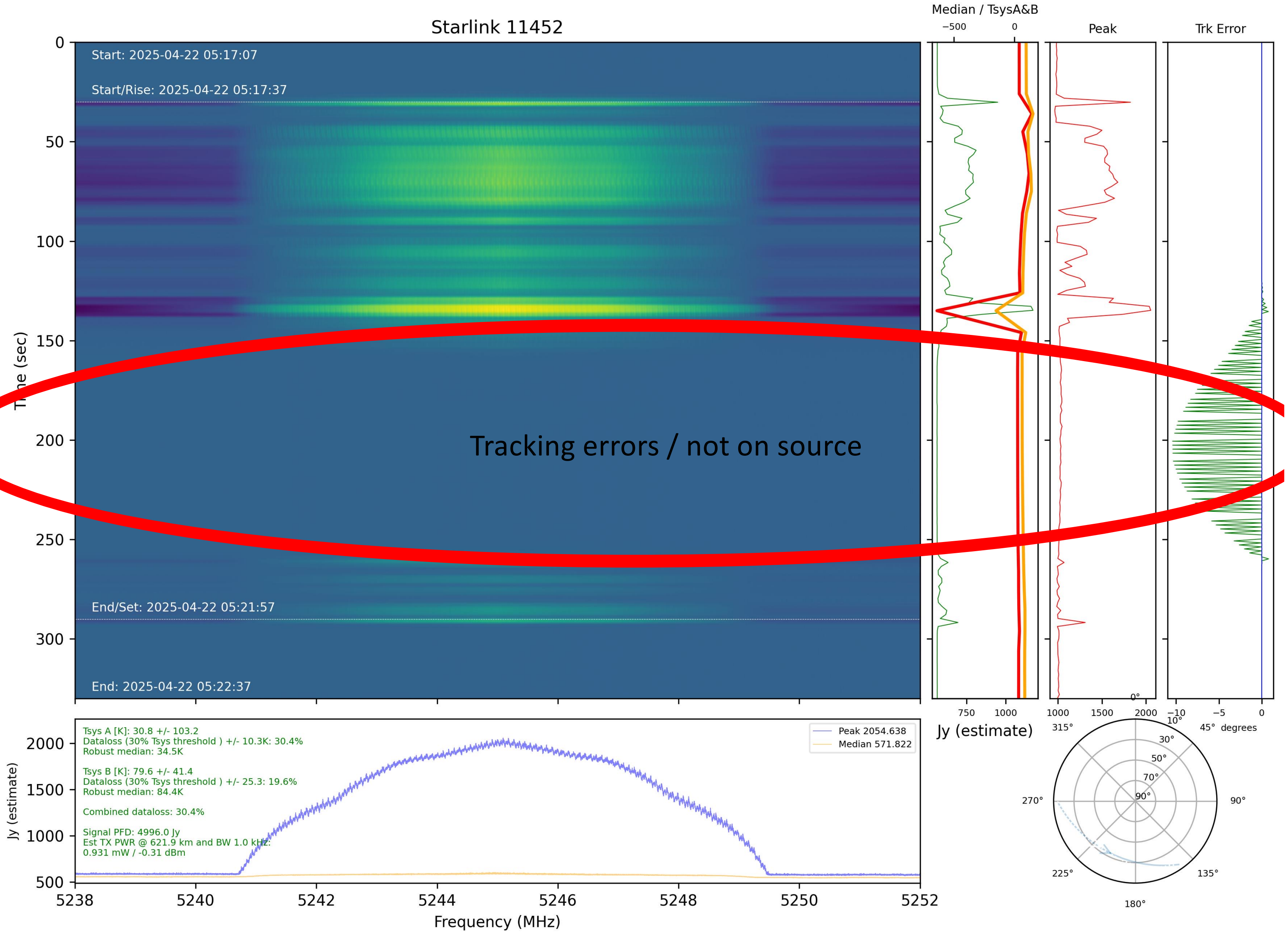


UEMR Ex.

Emission:
5240 MHz
2nd DTC harmonic

TOFA:
5150 – 5250 MHz
ARNS, FSS (E-s), MS
AUS87

Incidence: 89%
16/18 observations

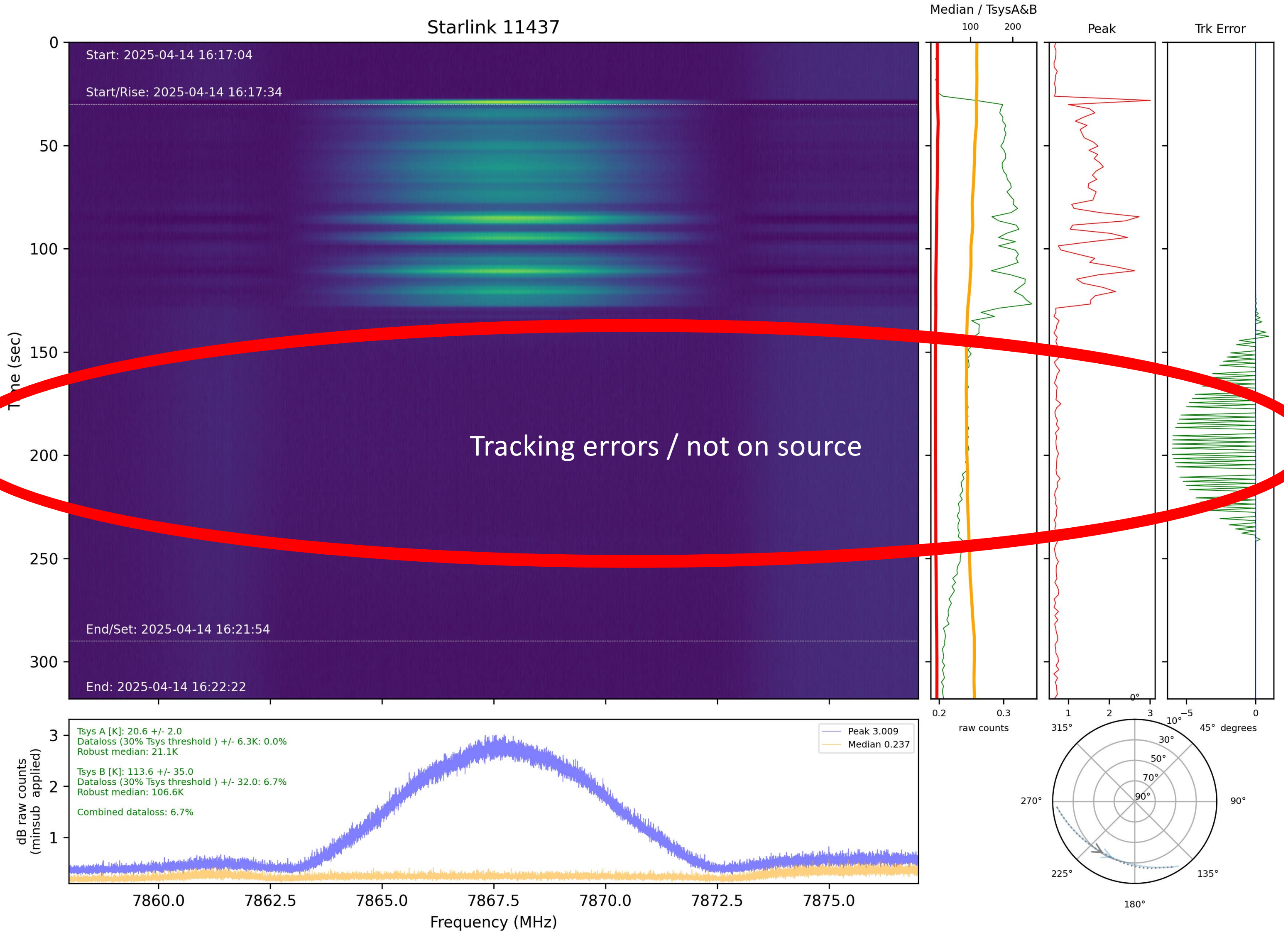


UEMR Ex.

Emission:
7860 MHz
3rd DTC harmonic

TOFA:
7750 – 7900 MHz
FS, METSAT (s-E), MS

Incidence: 77%
10/13 observations

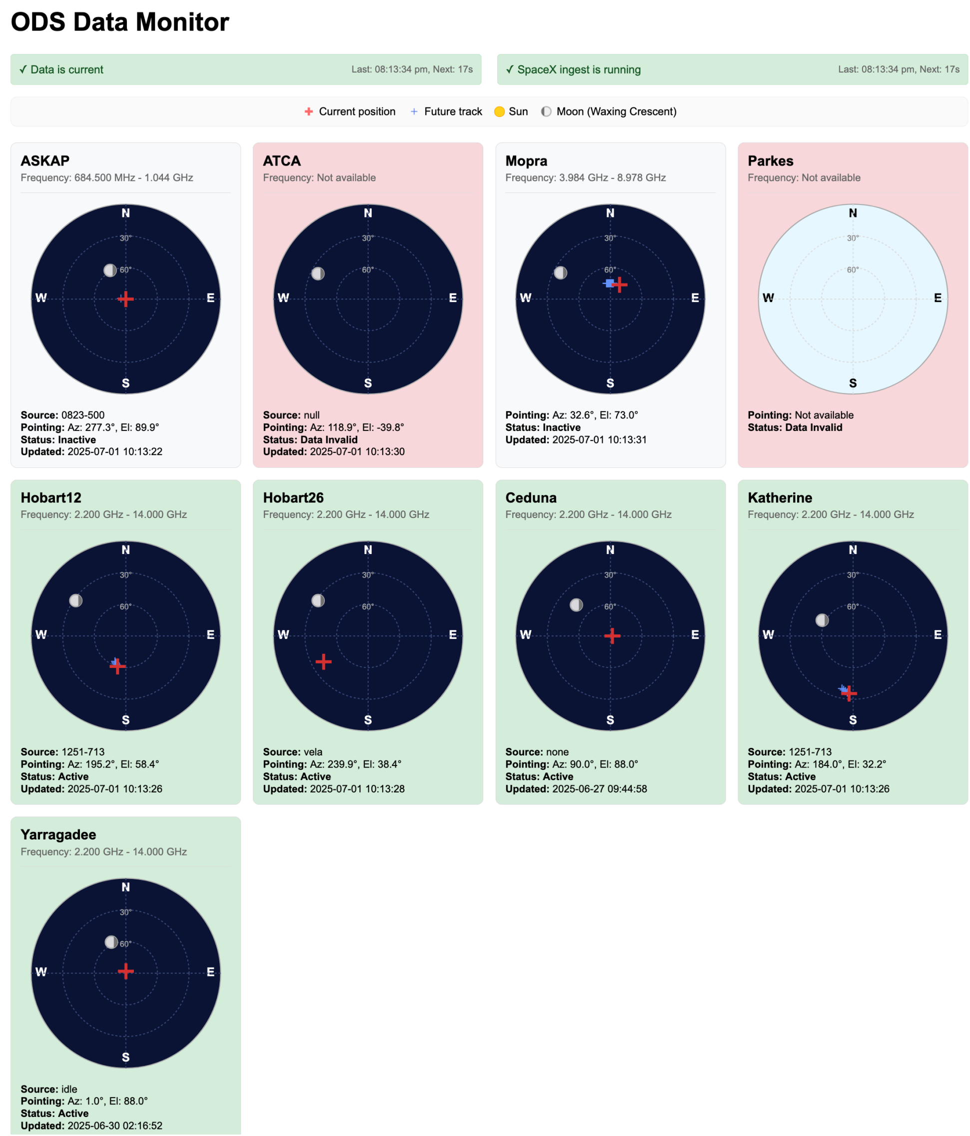


...and what we are doing about it

- Engaging at ITU-R and working closely with ACMA and Satellite Operators
  - Implement novel mitigation methods such as boresight avoidance, site exclusion from illumination
  - Avoid using low band for D2D (700 – 1000 MHz)
  - TPG and Optus both intend to use 870-890 MHz and 935-955 MHz in the short term due to AST SpaceMobile only supporting low band. Envisaged to be in use from 2026.
  - Telstra currently using 2620-2630 on SpaceX satellites for D2D.
  - **Long term project to move all IMT transmissions from space into 1800 MHz band. Little RAS use of this band due to existing RFI landscape.**
- LIPD band use from satellites 915-928 MHz
  - Band lost in Europe, satellite transmissions allowed
  - CSIRO agreed to find a spectrum sharing solution. Aided by the fact the IoT satellite operators only need about 2h every 2 days of transmit time (used to send satellite ephemerides to IoT devices so they don't transmit when no satellites are overhead)
  - We built an LIPD transmit coordination facility into ODS.
  - C.f. talks at IAC by myself and Martin von der Ohe

ODS

- Observational Data Sharing (ODS) platform is active
- Boresight avoidance (BA) proves effective to mitigate the highest in-band impacts. No panacea (about 10% band-loss improvement @ D2D frequencies, much better at Starlink DL 11.25-12.5 GHz – quantitative measurements soon with BIGCAT)
  - SpaceX implemented for both Starlink and D2D
  - Kuiper in discussions
- LIPD Band coordination (915-928 MHz)
  - Lacuna and Plan-S coordination agreement in progress
- www.narrabri.atnf.csiro.au/ods



The last slide – Take home Messages

- Unprecedented challenges lying ahead
- We're working hard on mitigating what's coming (and what's already here)
- Active mitigation work is under development in the technologies group
- Astronomers tend to not report RFI. Please do! **Reach out to me**. We can't defend against what we don't know is there!