Radio Frequency Interference and Mitigation

Dr. Aaron Chippendale

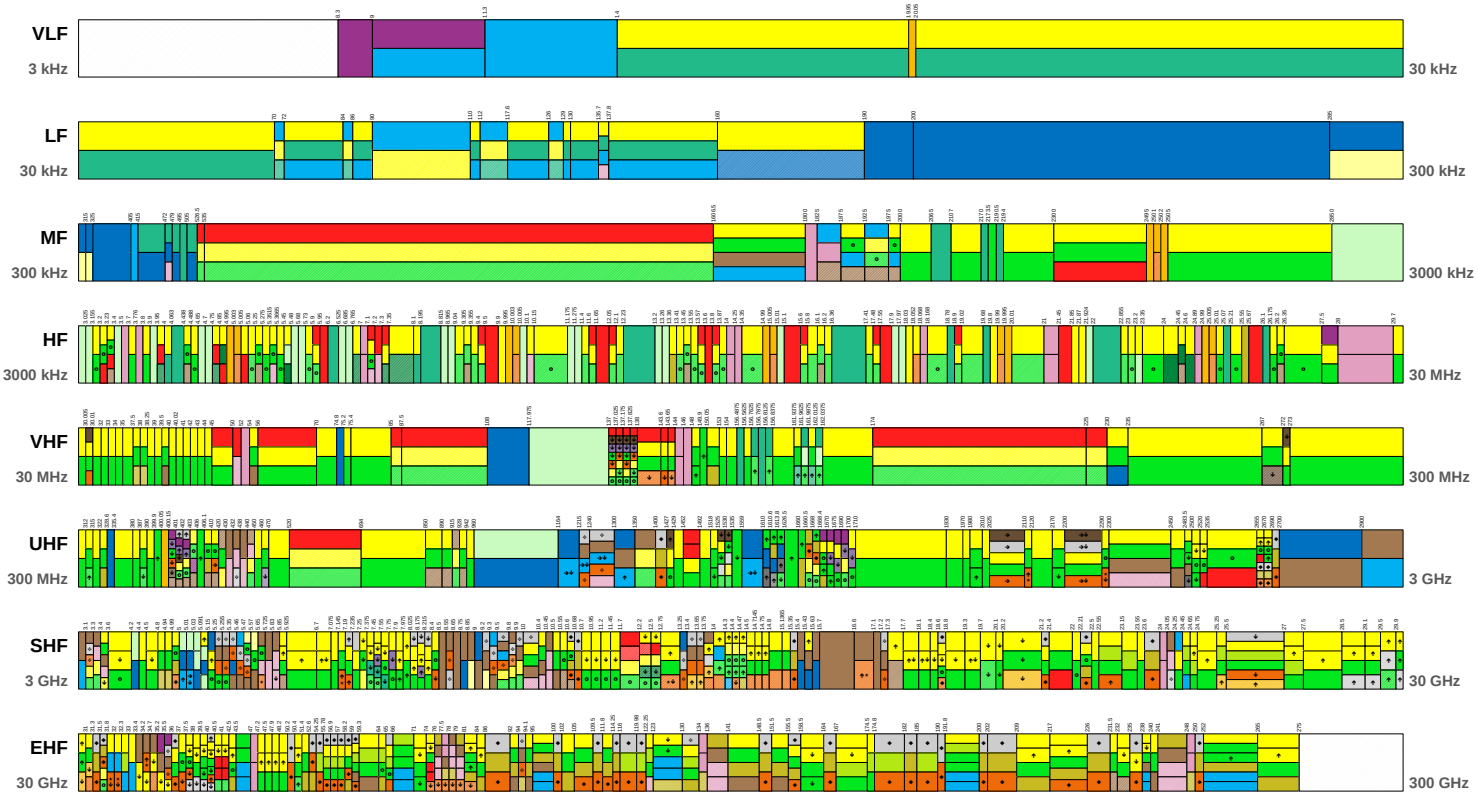
CASS Radio School 2017

Australian radiofrequency spectrum

allocations chart

Australian Government

acma
Australian Communications and Media Authority

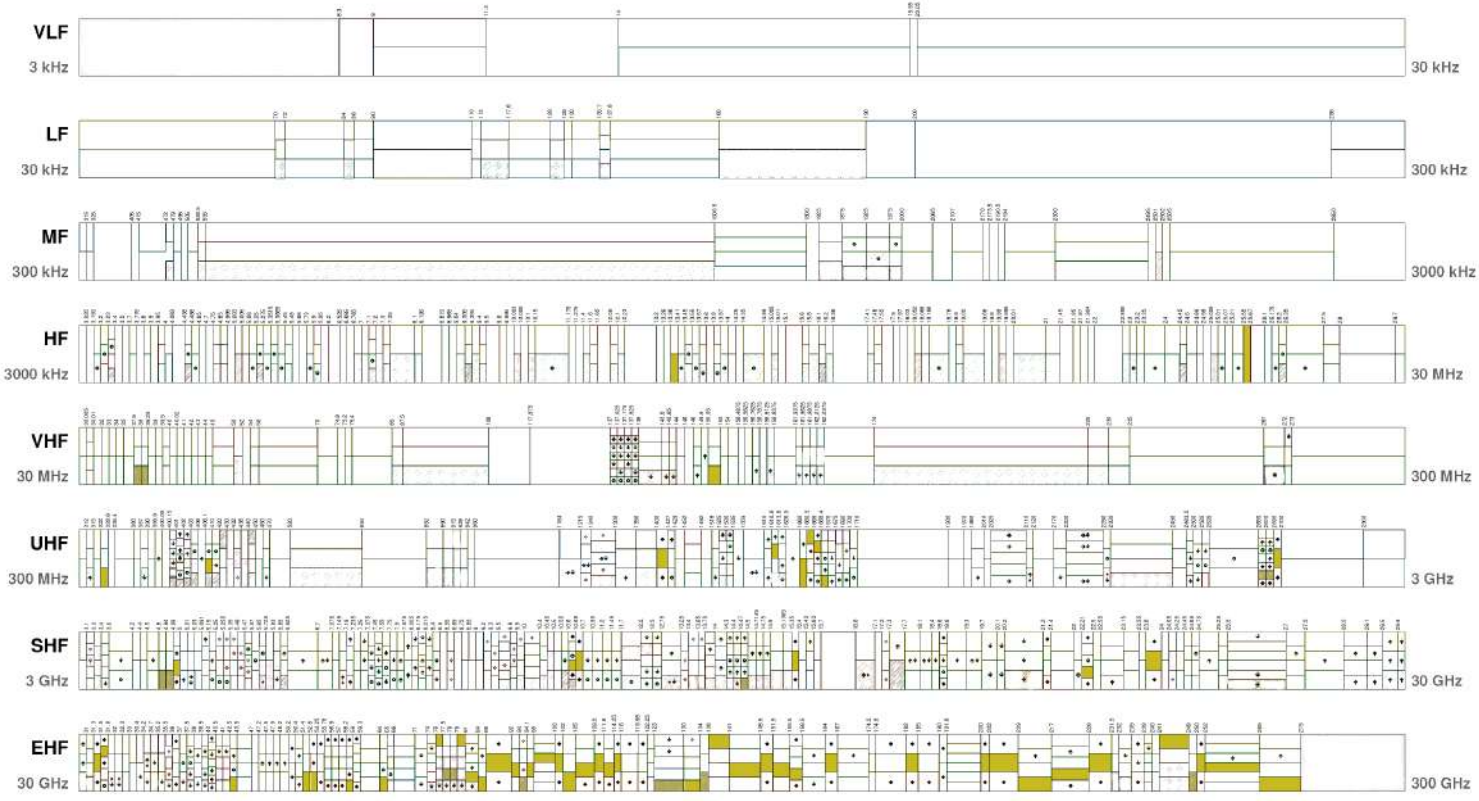


Australian radiofrequency spectrum

allocations chart

Australian Government

acma
Australian Communications and Media Authority



Can’t we get away from it all?

Propagation can bring it to you

Proliferating satellites

Populous sites

Outline

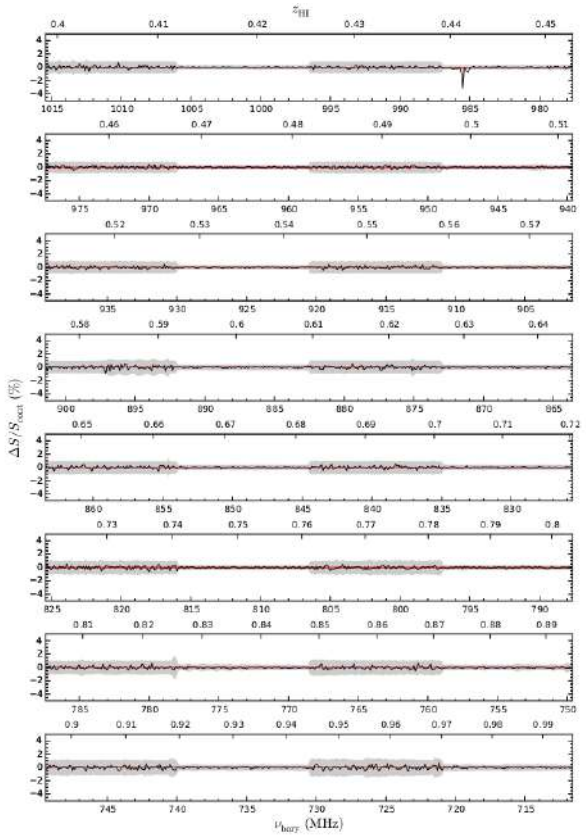
1. Radio-frequency interference
   (a) Understand, measure and calculate impact on astronomy
   (b) Categories of mitigation techniques
2. Spatial nulling with phased array feeds
   (a) Subspace projection method
   (b) Demonstrations on ASKAP and Parkes
   Hellbourg et al., RFI2016; Bannister et al., ACES Memo 12
   Chippendale & Hellbourg, ICEAA 2017

Murchison Radio-astronomy Observatory: Pristine

Population 113

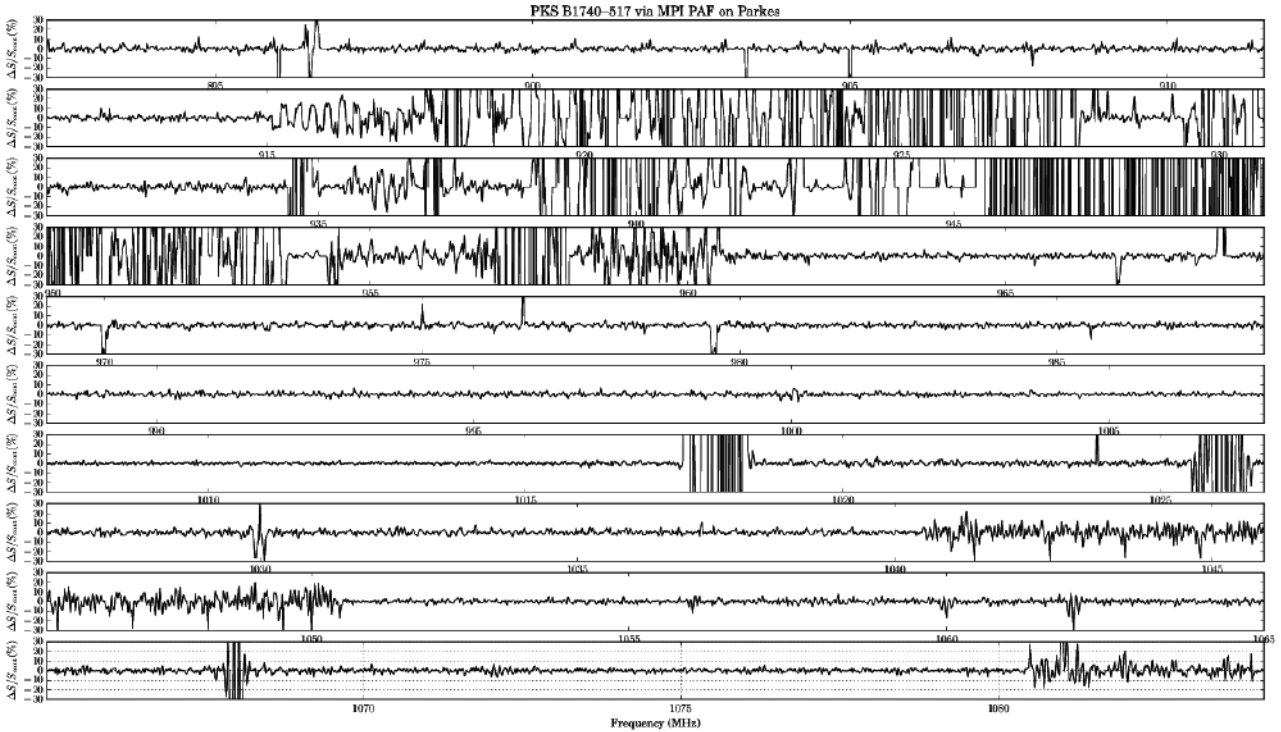
Allison et al., PASA 2015
Discovery of neutral hydrogen gas in a young radio galaxy

PKS B1740–517

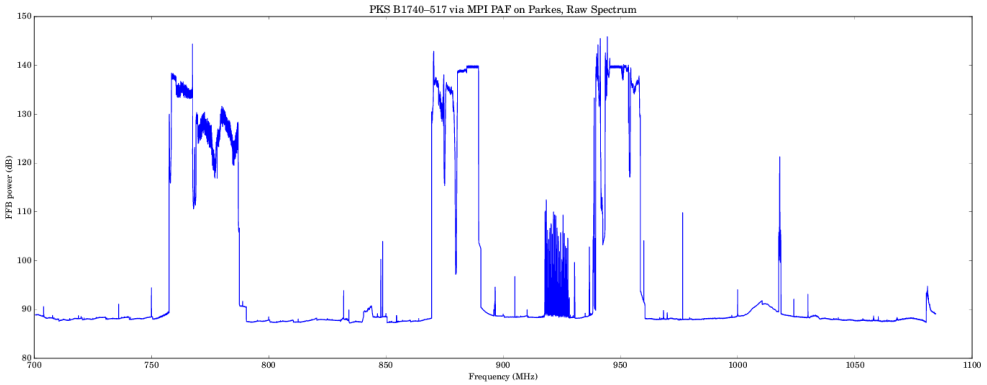


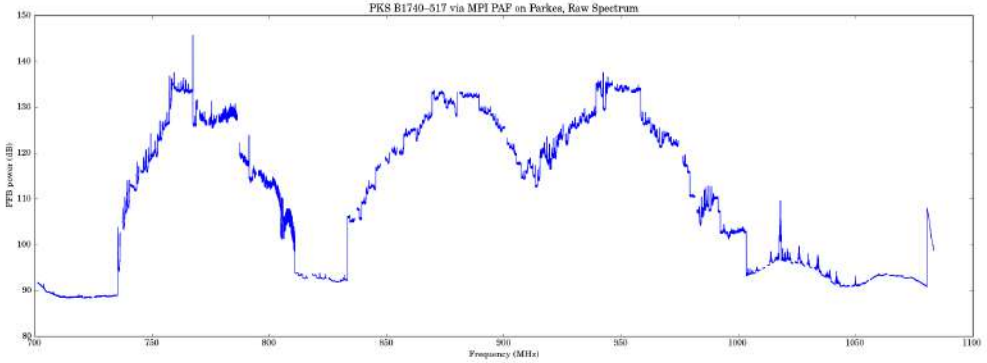
MPIfR PAF on Parkes: Highly Occupied

Population 15,000



MPIfR PAF on Parkes: Nonlinear





How do we assess the impact of RFI on astronomy?

Chippendale & Wormnes, APEMC 2013

Viability of telescope hardware

1. Total RFI Power
2. Interference-to-Noise Power Ratio

Availability of spectrum for sensitive astronomy

3. Time-Frequency Occupancy

RFI survey composition

Low-sensitivity spectrograms

Short integration ($<$1 s), peak detection, rapid scan, high headroom

High-sensitivity spectrograms

Long integration ($>$1 hr), large instantaneous bandwidth

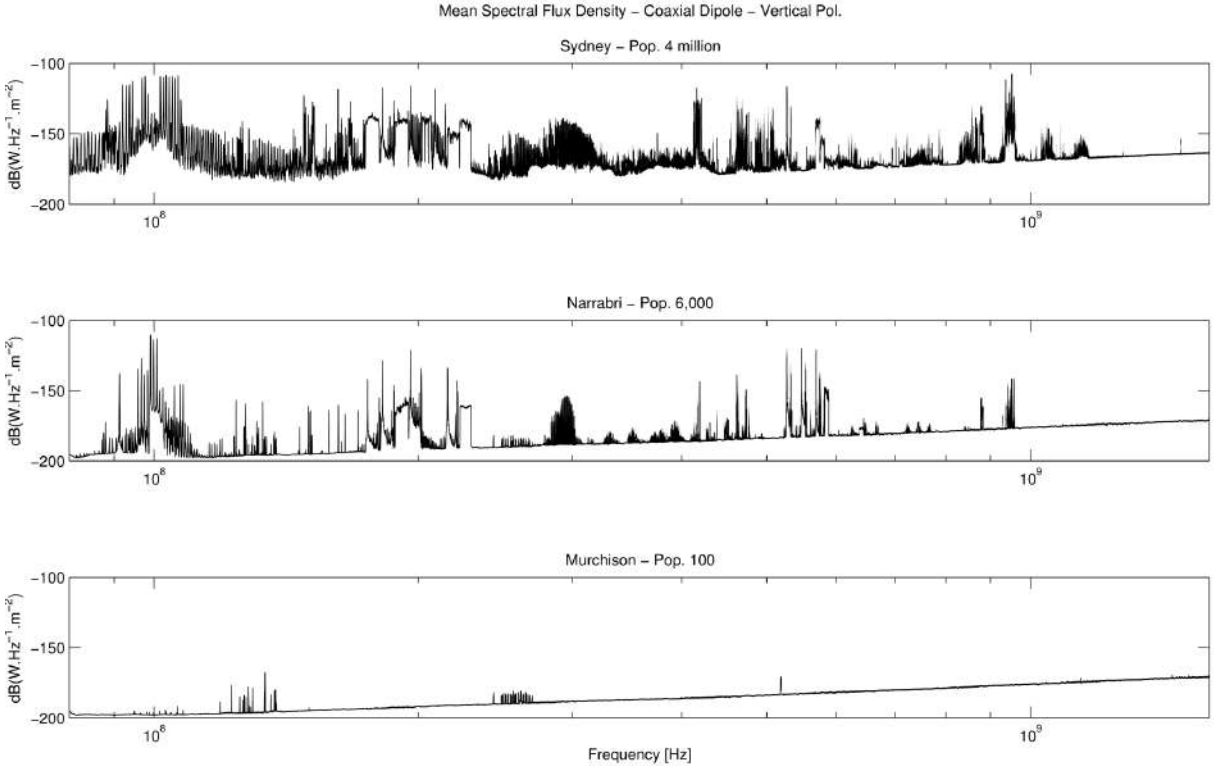
Raw-voltage recordings

Nyquist rate ($<$0.5 ns), large instantaneous bandwidth, triggered

What are the impacts of discarding data and undetected RFI?

Low sensitivity spectra

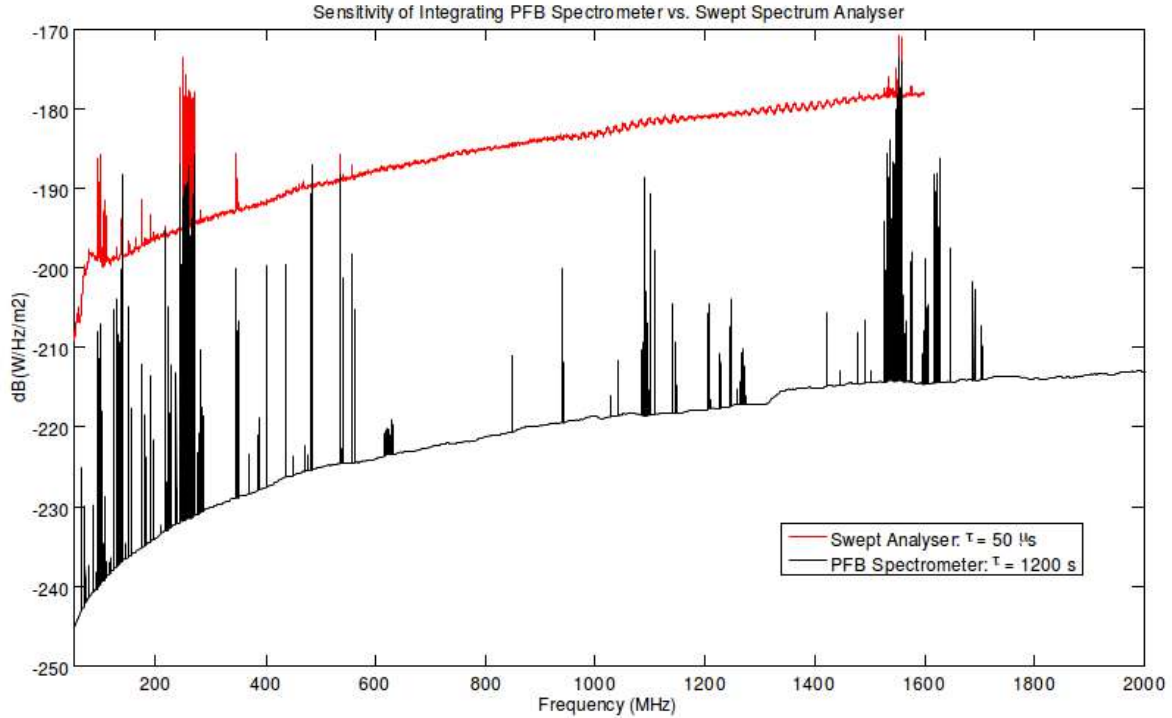
Swept-tuned spectrum analyser



Credit: R. Beresford & A. Chippendale

High sensitivity spectra

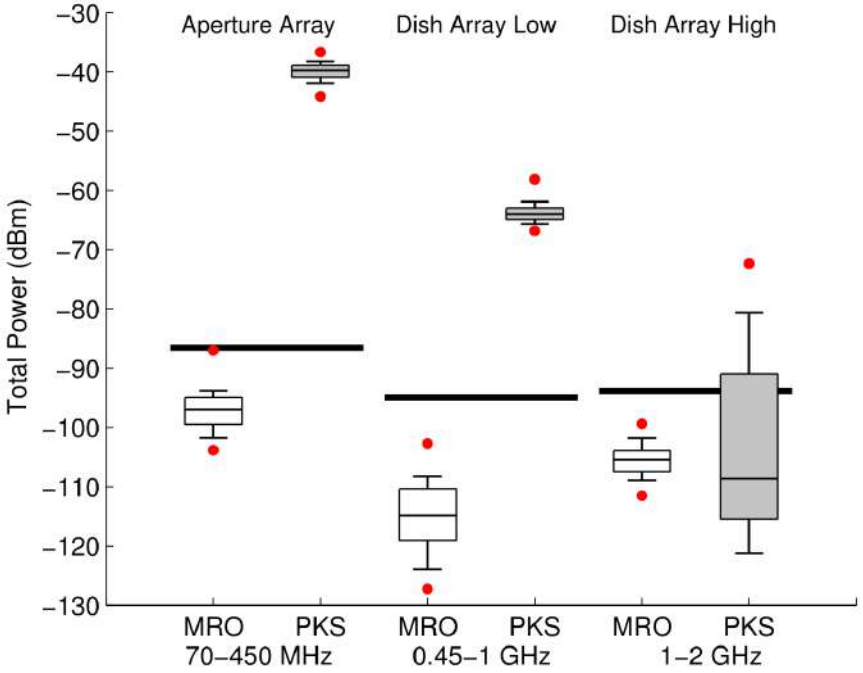
Digital receiver with firmware FFT



Credit – SKA Site Survey Team: R. Beresford, A. Boonstra, W. Cheng, A. Chippendale, R. Millenar, L. Sofeya, A. Tiplady & K. Wormnes.

Comparing total RFI power at MRO and Parkes

12 hr duration, Δf=10 kHz, τ=0.5 s



Chippendale & Wormnes, APEMC 2013

Parkes Data: R. Beresford, A. Chippendale, A. Hotan, A. Chippendale, R. Manchester & P. Roberts

Resources for assessing impact on astronomy

Observatory Websites RFI notes, monitoring and reporting

https://www.narrabri.atnf.csiro.au/observing/

https://www.parkes.atnf.csiro.au/observing/

Australian Radiofrequency Spectrum Plan

https://www.acma.gov.au/theacma/australian-radiofrequency-spectrum-plan-spectrum-planning-acma

ACMA Register of Radiocommunicaitons Licenses

https://web.acma.gov.au/rrl

ITU Recommendations

ITU-R P.372-13: Radio noise

ITU-R P.526: Propagation by diffraction

ITU-R P.676-11: Attenuation by atmospheric gasses

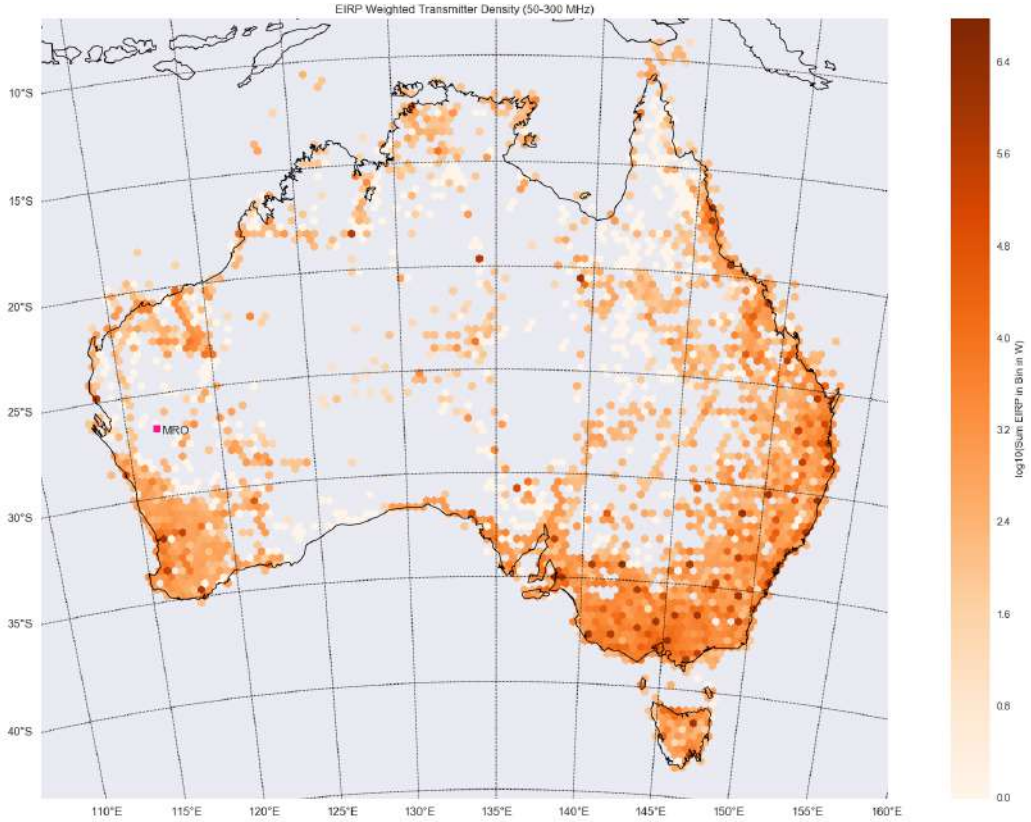
ITU-R RA.769-2: Protection criteria used for radio astronomical measurements

Thompson 1982: Response of a Radio-Astronomy Synthesis Array to Interfering Signals

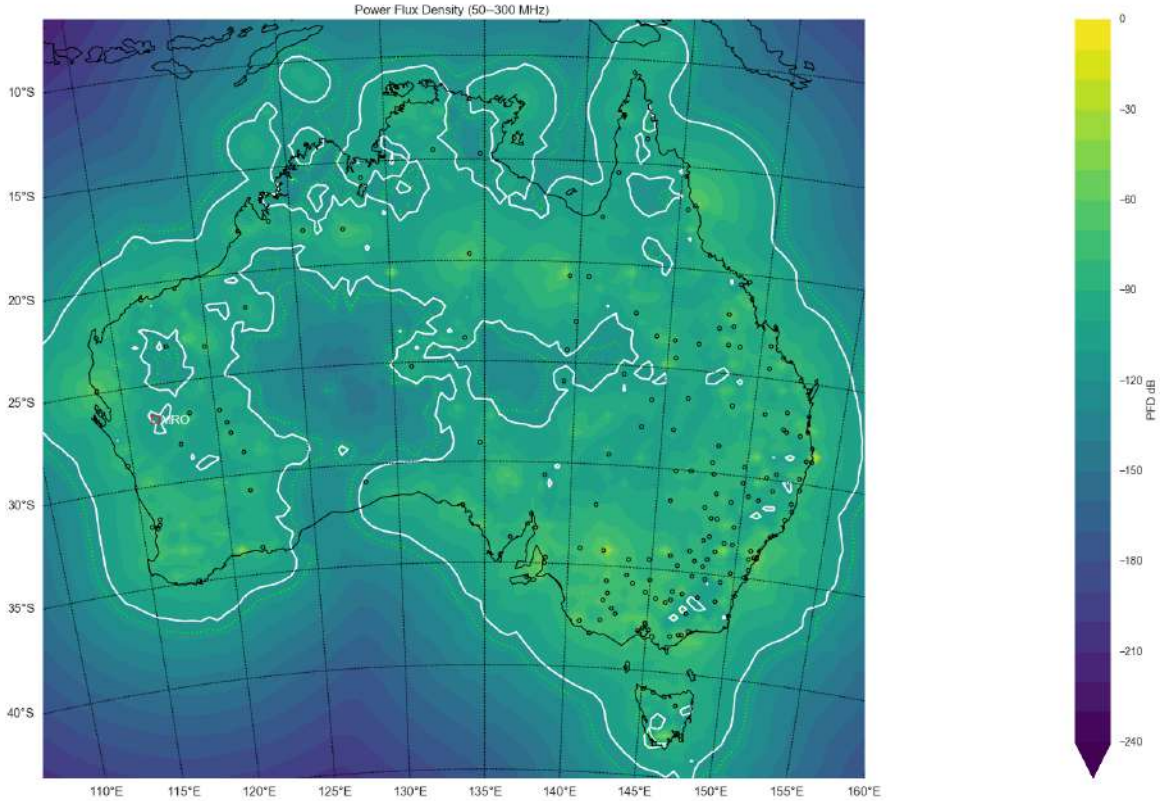
doi:10.1109/TAP.1982.1142799

RFI conference proceedings 2001, 2004, 2010, 2016

EIRP-weighted transmitter density 50–300 MHz, 44 km scale



Received flux density 50–300 MHz, 44 km scale



Mitigating RFI in radio astronomy

Categories of RFI mitigation (ITU-R RA.2126-1)

1. Pro-active: turn it off, run away, put it in a box, change band, legislate
2. Spatial nulling: beamforming of array antennas to direct nulls at RFI
3. Waveform subtraction: estimate parameters, synthesise and subtract
4. Anti-coincidence: multiple antennas, identical astronomy, different RFI
5. Excision in time & frequency domain: notching, blanking & flagging

Techniques to improve RFI estimates

- direct copies
- reference antennas
- demodulation
- cyclostationarity
- subspace tracking
- polarisation and more . . .

Spatial nulling with phased array feeds

Successful live interference mitigation with ASKAP's PAF system

- Suppressed RFI by up to 20 dB in real time
  - will improve with faster mitigation cycles
- Immediately useful on narrow-band, stationary self-interference
- Recovered beam weights at interference-affected channels
  - prevents freezing RFI into beam weights
  - required to suppress RFI and not the desired signal

Viable now on all CSIRO PAF systems: Effelsberg, Lovell, Parkes & ASKAP

Black et al., SP/SPE 2015 ASKAP simulations with 5 s update period

Hellbourg et al., RFI 2016 ASKAP BETA 6-antenna imaging experiment

Chippendale & Hellbourg, ICEAA 2017 MPIfR PAF on Parkes experiment

Spatial nulling

Subspace projection method

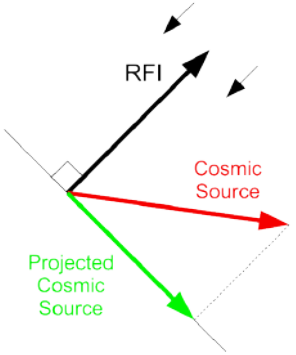
Covariance decomposision

$$\mathbf{R} = \left\langle \mathbf{x}\mathbf{x}^H \right\rangle = \mathbf{U}\Lambda\mathbf{U}^H$$

$$\begin{aligned}\mathbf{U} &= [\mathbf{U}_{\text{RFI}}|\mathbf{U}_{\text{S+N}}] \\ &= [\mathbf{u}_1 \dots \mathbf{u}_d|\mathbf{u}_{d+1} \dots \mathbf{u}_{\text{M}}]\end{aligned}$$

Orthogonal projector

$$\mathbf{P} = \mathbf{I} - \mathbf{U}_{\text{RFI}}\mathbf{U}_{\text{RFI}}^H$$



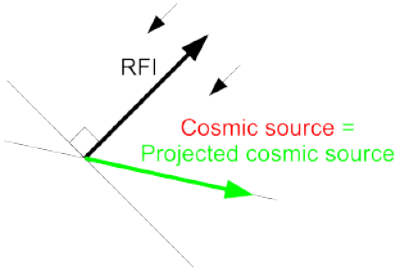
Oblique projector

$$\mathbf{P} = \mathbf{w}_0\mathbf{w}_0^H\left(\mathbf{I} - \mathbf{U}_{\text{RFI}}\mathbf{U}_{\text{RFI}}^H\right)$$

Projection operation

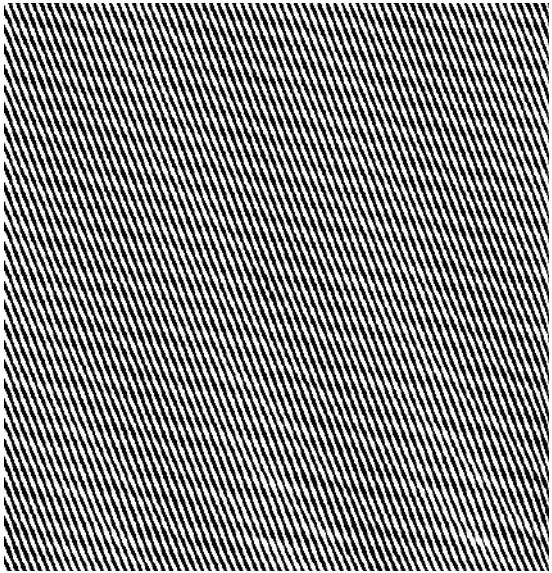
$$\mathbf{R}_{\text{proj}} = \mathbf{PRP}$$

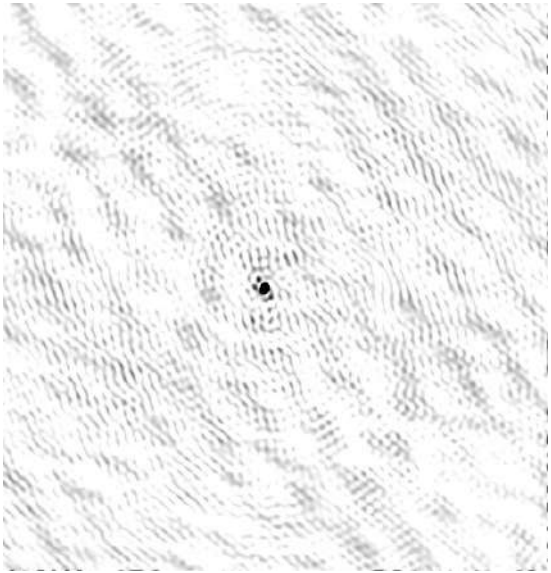
$$\mathbf{w}_{\text{proj}} = \mathbf{P}\mathbf{w}_0$$



Mitigation on versus off (ASKAP BETA)

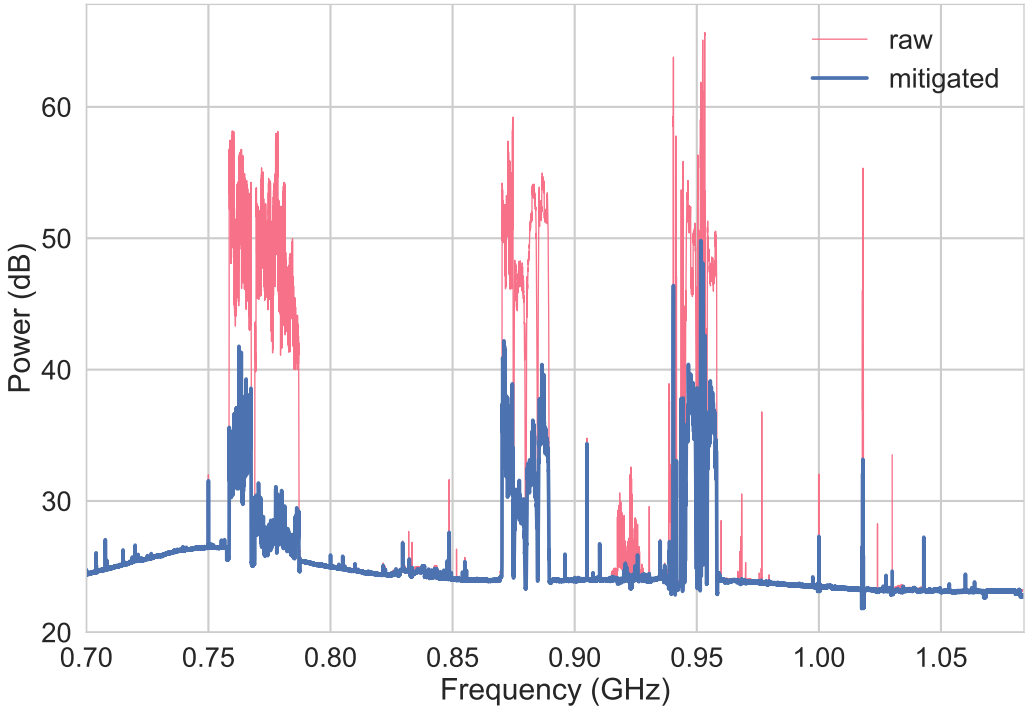
PKS B1934-638 and GPS L2 at 1225 MHz (1 MHz BW)



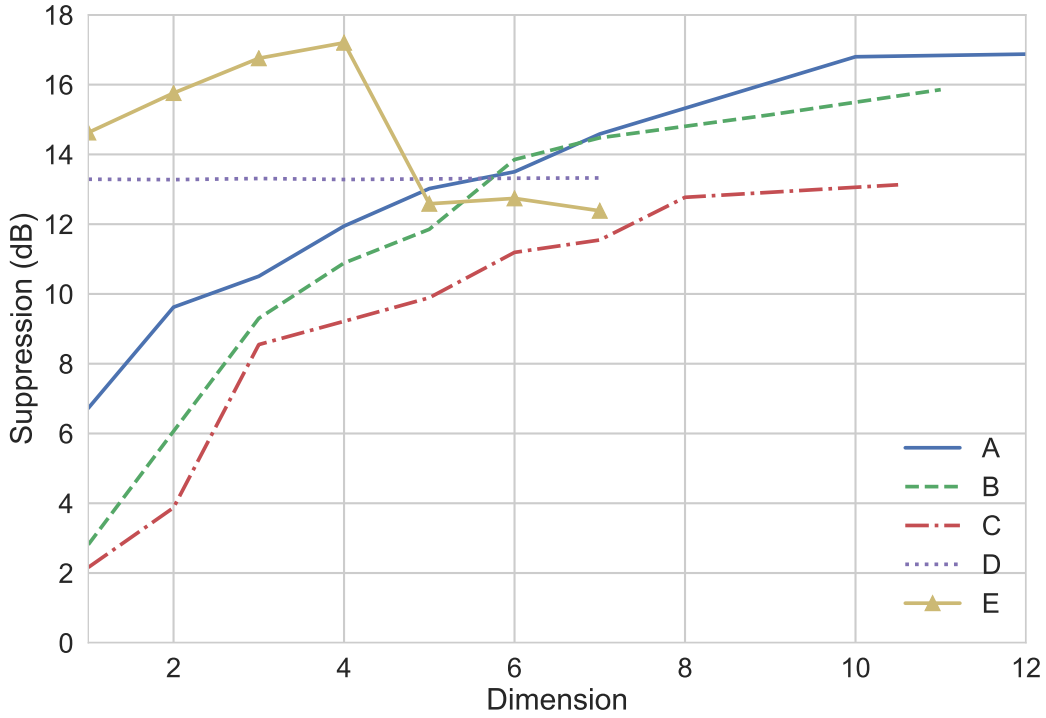


Hellbourg et al., RFI2016; Bannister et al., ACES Memo 12

Mitigation on versus off (MPIfR PAF on Parkes)

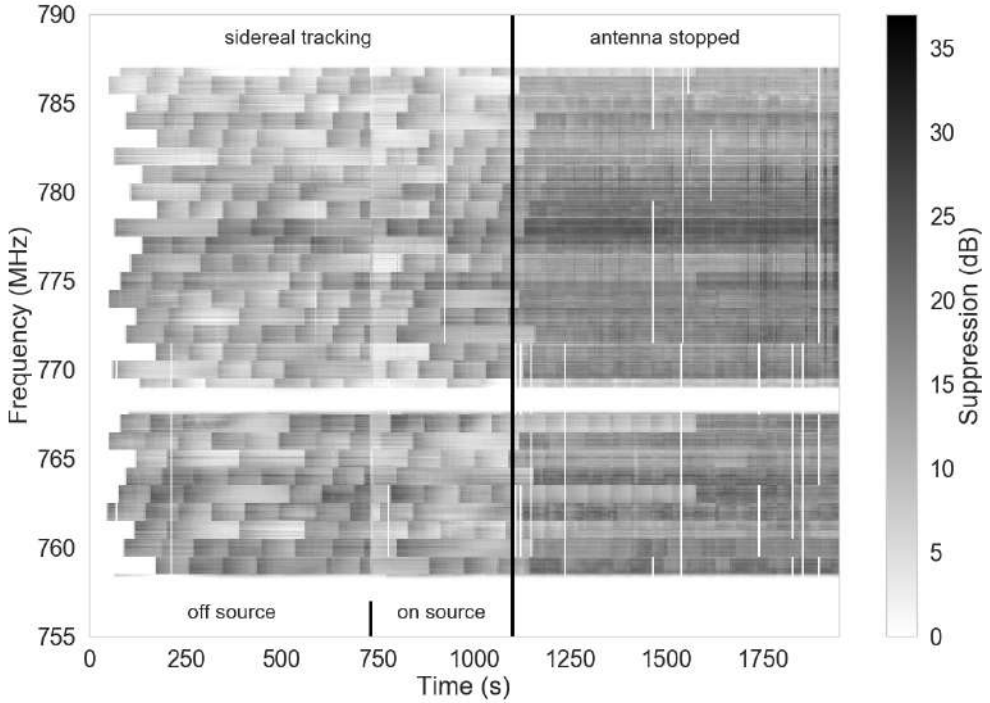


Suppression versus dimension (MPIfR PAF at Parkes)

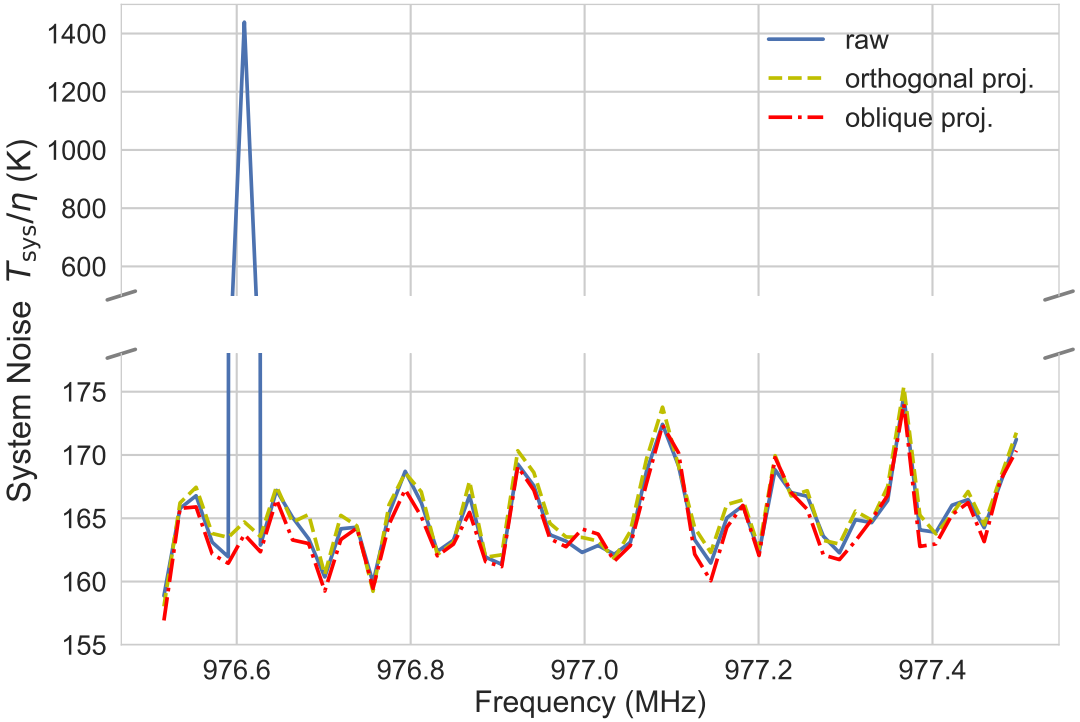


Suppression versus antenna motion (MPIfR PAF on Parkes)

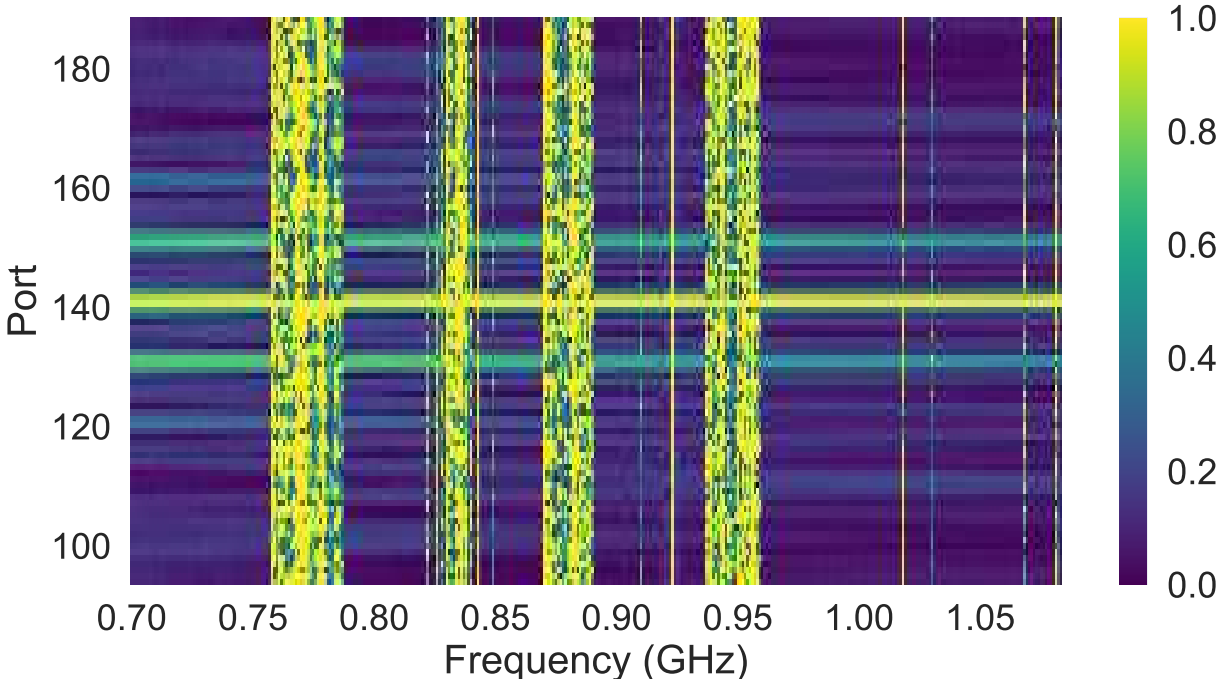
120 s update period



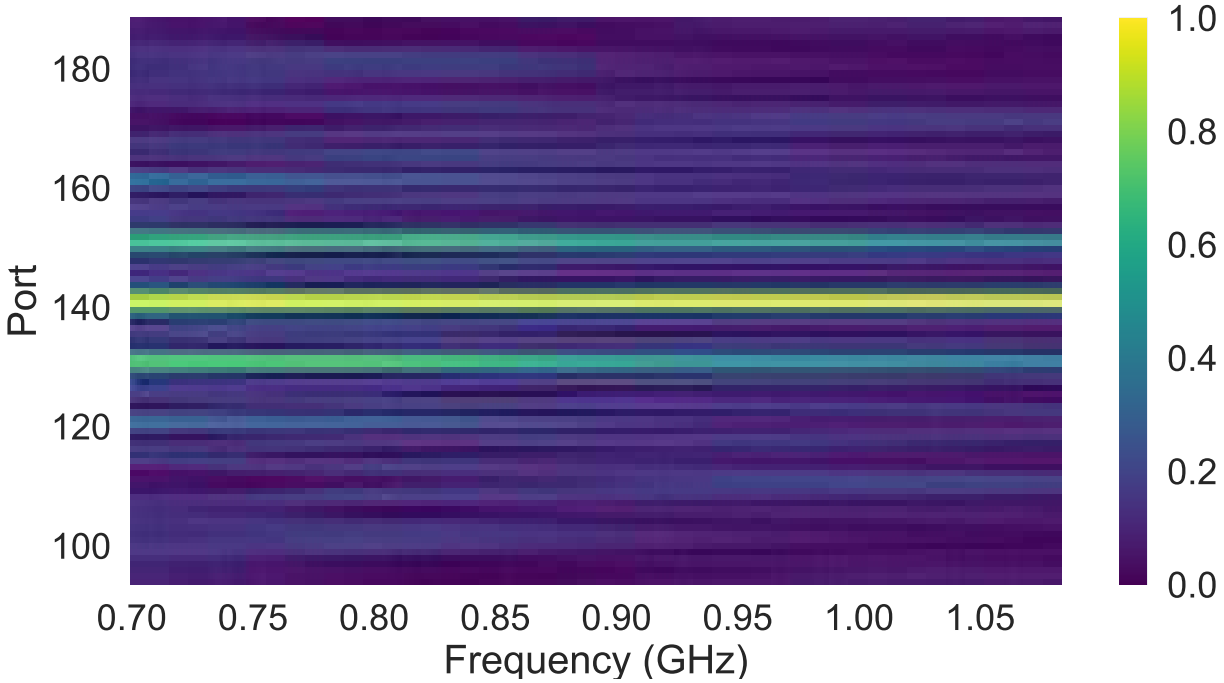
Removing interference from DSP clock (MPIfR PAF on Parkes)



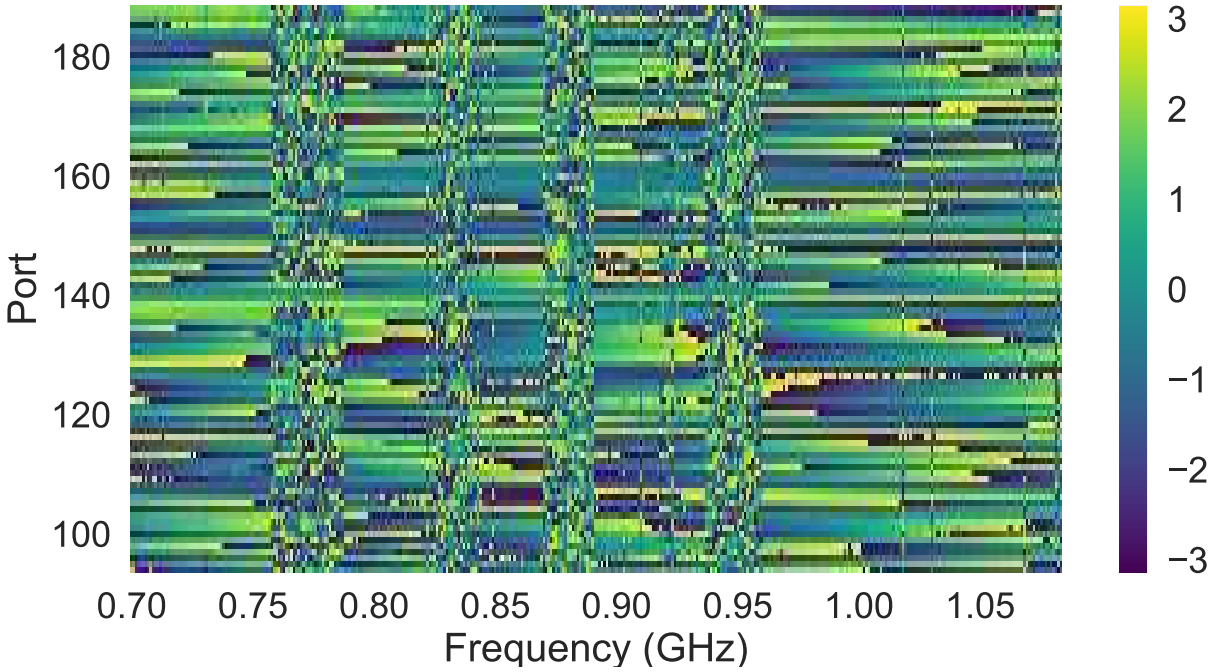
Interpolating weights corrupted by RFI (MPIfR PAF on Parkes)



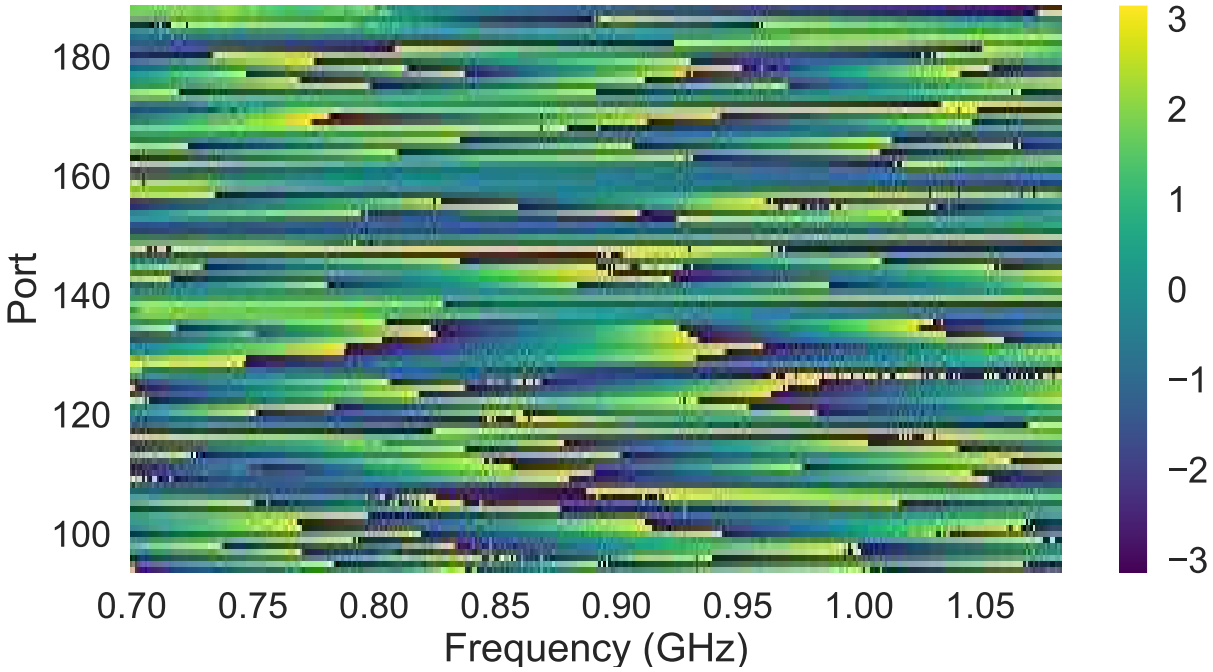
Interpolating weights corrupted by RFI (MPIfR PAF on Parkes)



Interpolating weights corrupted by RFI (MPIfR PAF on Parkes)

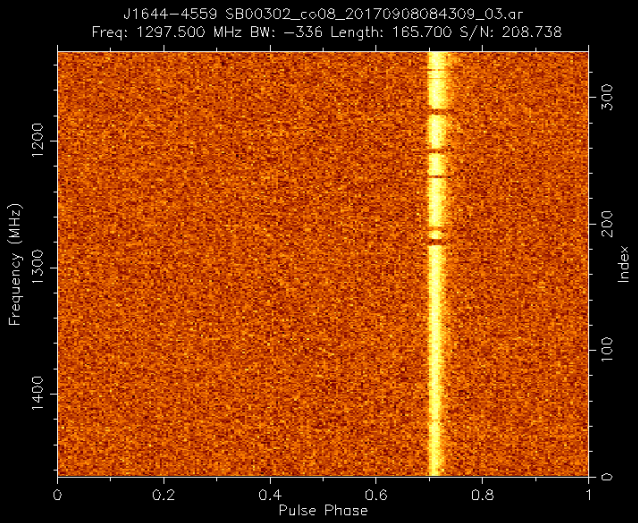


Interpolating weights corrupted by RFI (MPIfR PAF on Parkes)

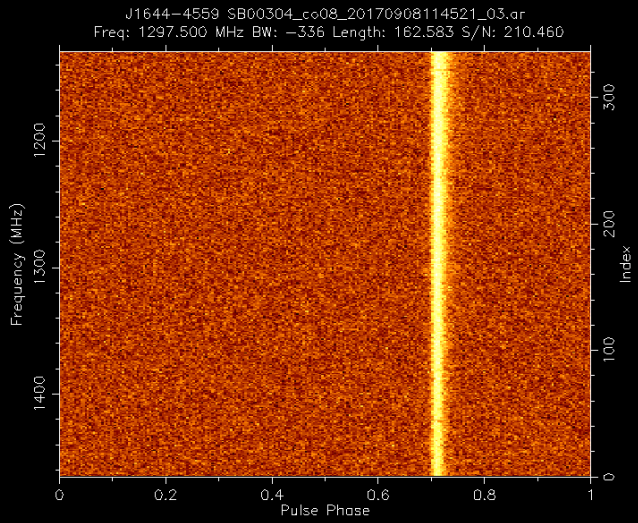


ASKAP pulsar observation

Original weights



Interpolated weights



Measurement by Dr. R. Shannon

~~Conclusion~~ Challenge

1. Learn to live with RFI because humanity relies on it.
2. Be vigilant and proactive.
3. Collaborate to make RFI-affected data useful.

Thank You

CSIRO Astronomy and Space Science

Dr. Aaron Chippendale

t +61 2 9372 4296

e Aaron.Chippendale@csiro.au

w www.atnf.csiro.au

We acknowledge the Wajarri Yamatji people as the traditional owners of the Murchison Radio-astronomy Observatory site.