



International
Centre for
Radio
Astronomy
Research

Expected and unexpected RFI in the VHF band at the Murchison Radio-astronomy Observatory

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THE UNIVERSITY OF
**WESTERN
AUSTRALIA**



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Office of Science



Outline

History & background.

- A brief introduction to the MRO & VHF-band instruments at the MRO
- Historical RFI monitoring

Introduction to current radio telescopes and their capabilities

- Murchison Widefield Array (MWA)
- SKA-Low prototypes

Results from all-sky imaging campaigns



Murchison Shire Boundary

Murchison Radio-astronomy
Observatory (MRO - operated by CSIRO)

Population Density: 0.002 km^{-2}

Geraldton

Perth

~200 km





Murchison
Widefield
Array (MWA)
mwatelescope.org

256 antenna tiles

~5km diameter

70-300 MHz



VHF band instruments @ MRO

BIGHORNS (<https://ui.adsabs.harvard.edu/abs/2015PASA...32....4S>)

Single antenna EoR/CD
global signal project

Calibrated total power
radiometer

Conical log-spiral
antenna

- 50-300 MHz
- 117 kHz freq res
- ~1s time res





SKA-Low Prototypes – 2nd generation



SKA1-Low specs:

- 512 stations
- 256 antennas / station
- 50-350 MHz
- Full digital beamforming
- 300 MHz instantaneous bandwidth
- **Current prototypes:**
 - EDA2
 - AAVS2

Engineering Development Array 2 – Completed June 2019

EDA2 facing north-east
Wayth et al, 2021. SPIE JATIS.



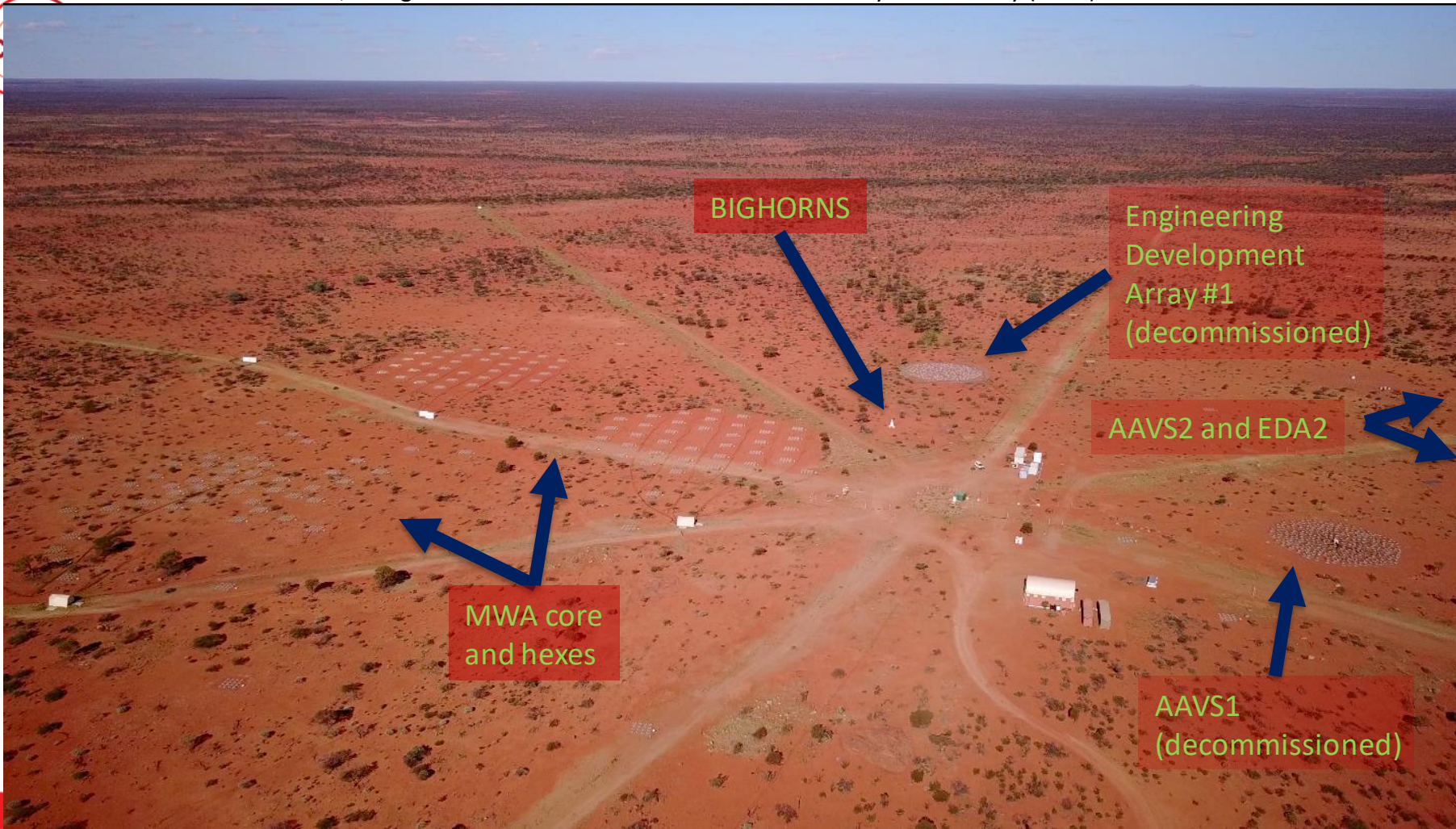


VHF band instruments @ MRO

EDGES (<http://loco.lab.asu.edu/edges/>)

Single antenna EoR/CD global signal project





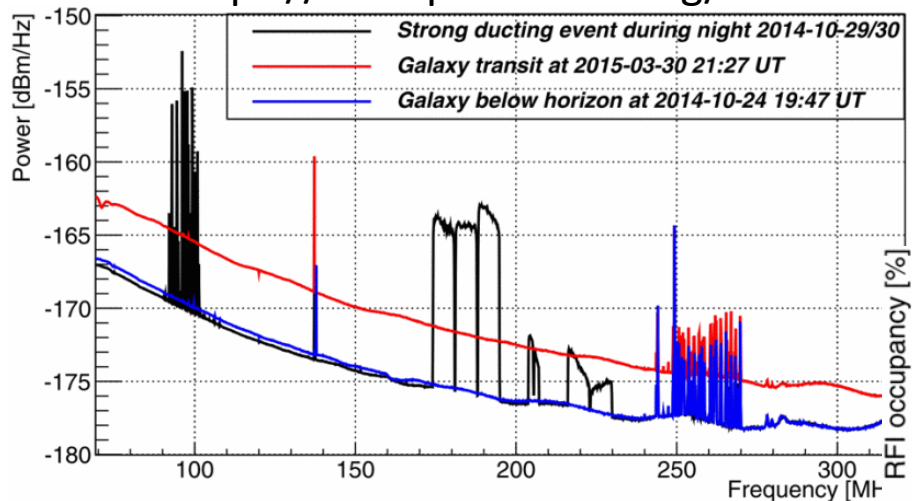


BIGHORNS long-term sky monitoring

Sokolowski et al., 2015

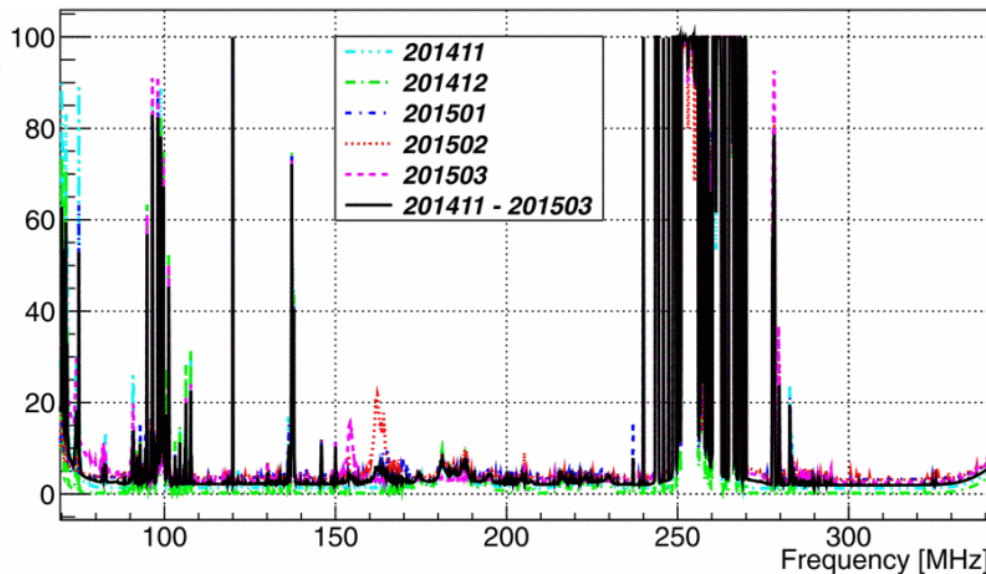
<https://ieeexplore.ieee.org/document/7386856>

- 50-350 MHz
- 117.2 kHz resolution
- < 1s time resolution
- Archival data available on request



Example spectra for typical data and extreme ducting events

Statistics of channels flagged as having RFI



- MWA has been used as sensitive imaging instrument for passive radar and to collect statistics of interference in various bands

RFI stats:

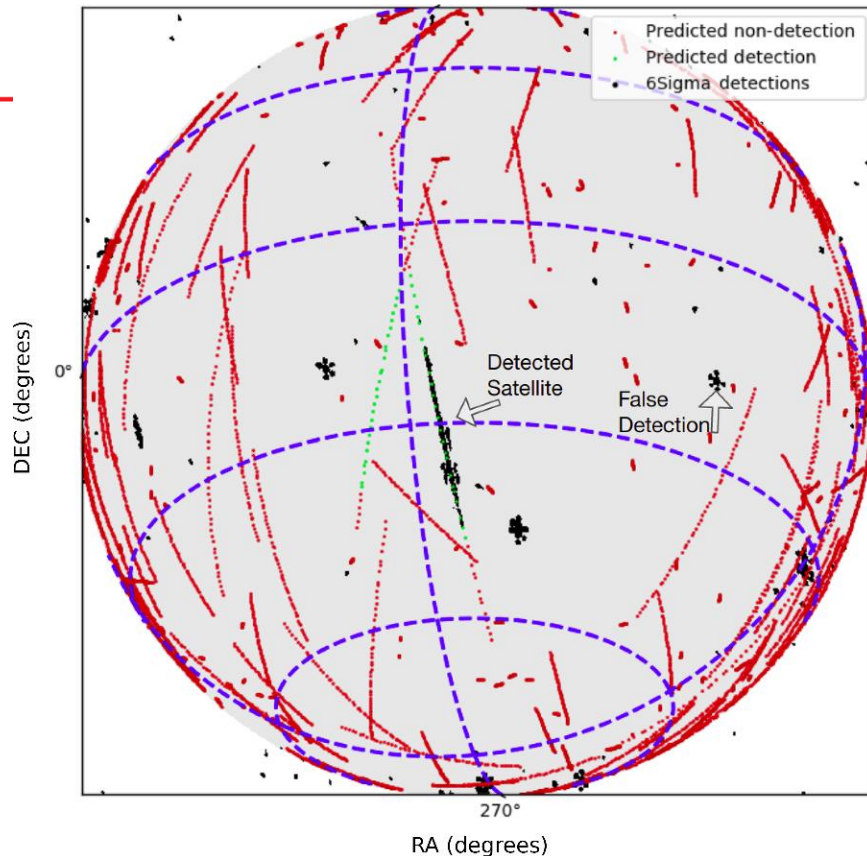
<https://ui.adsabs.harvard.edu/abs/2015PASA...32....80>

Coherent passive radar with range/doppler:

<https://ieeexplore.ieee.org/document/8835821>

Low-level RFI in DTV bands:

<https://ui.adsabs.harvard.edu/abs/2020MNRAS.498..265W>



Prabu et al., 2020

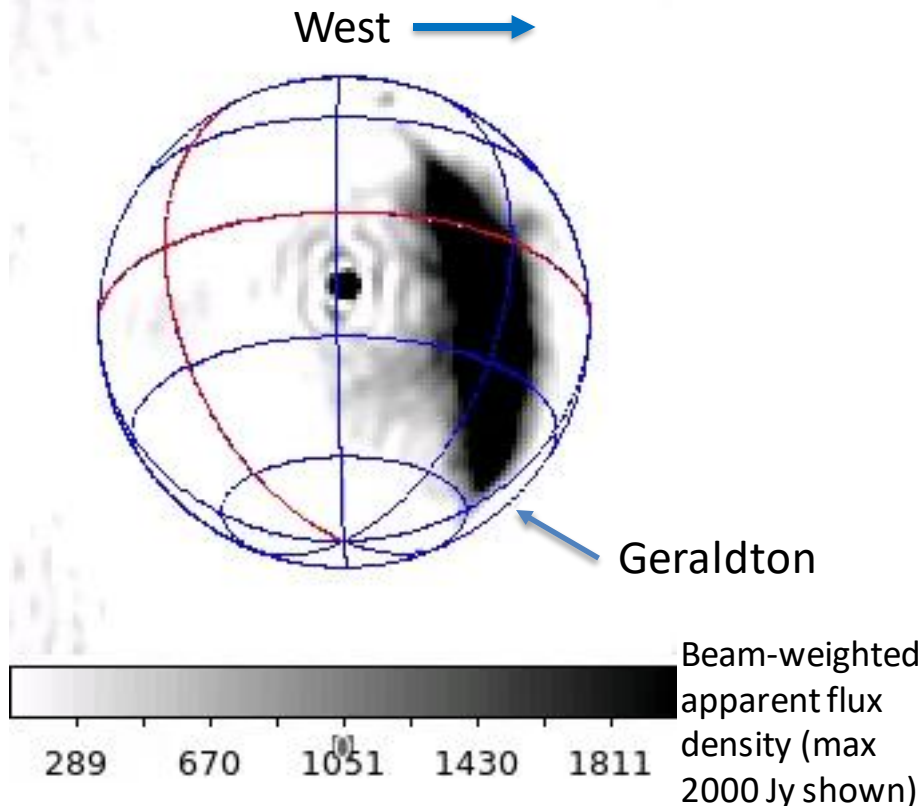
<https://ui.adsabs.harvard.edu/abs/2020PASA...37...52P>

EDA2 all-sky observations in FM band

Tingay et al, 2020. PASA.

DOI: <https://doi.org/10.1017/pasa.2020.32>

See also Sokolowski et al: All-sky transient monitor
<https://ui.adsabs.harvard.edu/abs/2021PASA...38...23S>

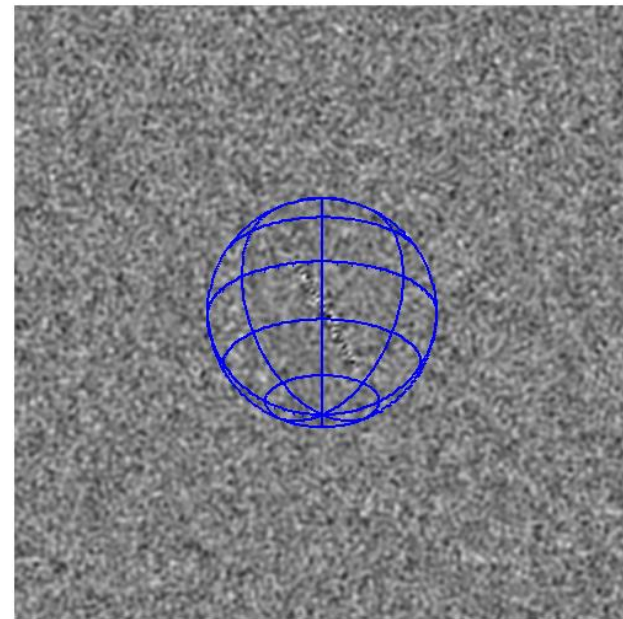
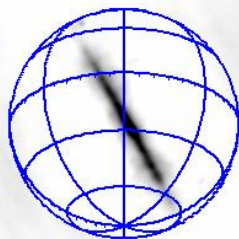
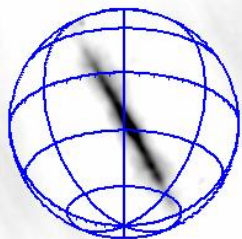


- FM band observations (centred on 98.4375 MHz, 0.9 MHz BW)
- Freq chosen to include known radio stations in Geraldton 98.1 & 98.9
- ~8s time resolution
- 33 994 individual images generated over 3-day period from 2020-01-31 to 2020-02-03

Methods: difference imaging

- Snapshots are confusion limited, but difference images are noise-like
- All sources that are constant on timescales $>$ snapshots subtract

Consecutive snapshots separated by a few seconds



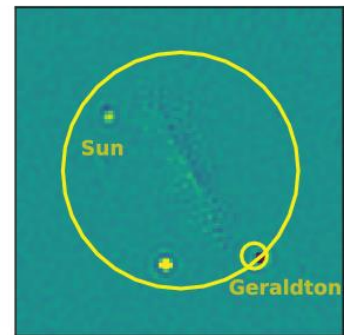
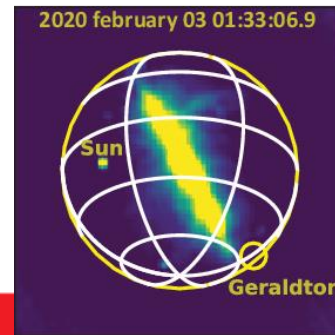
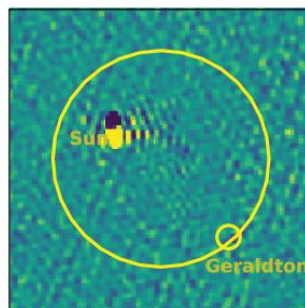
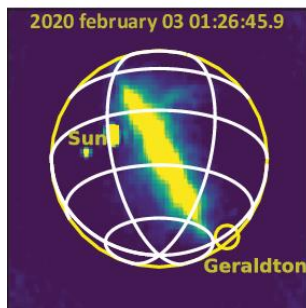
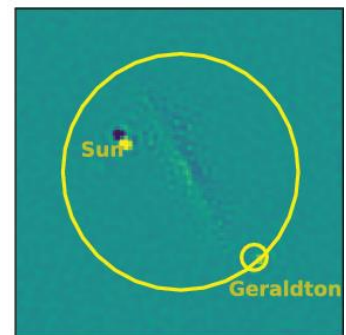
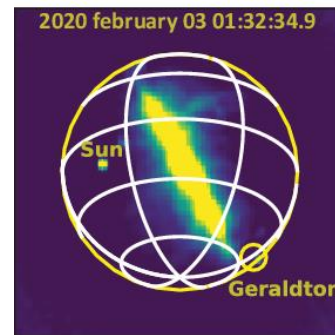
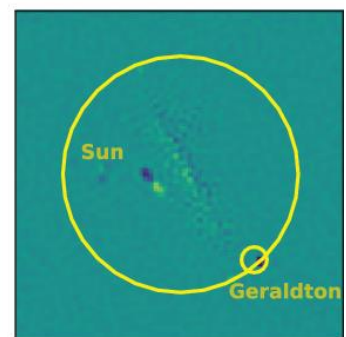
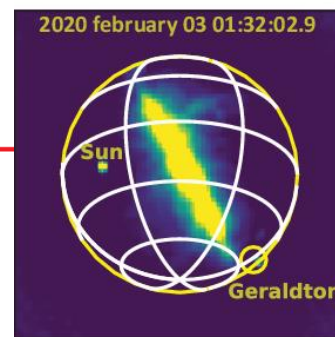
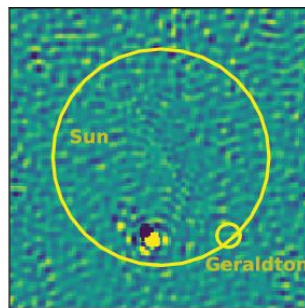
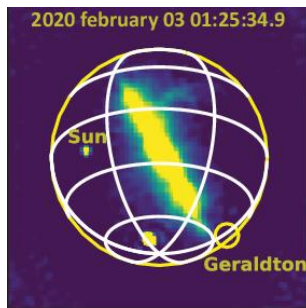
1015 2010 3015 4010 5015 6011 7006 8011 9006

1015 2010 3015 4010 5015 6011 7006 8011 9006

-2e+02 -1e+02 0.24 1e+02 2e+02

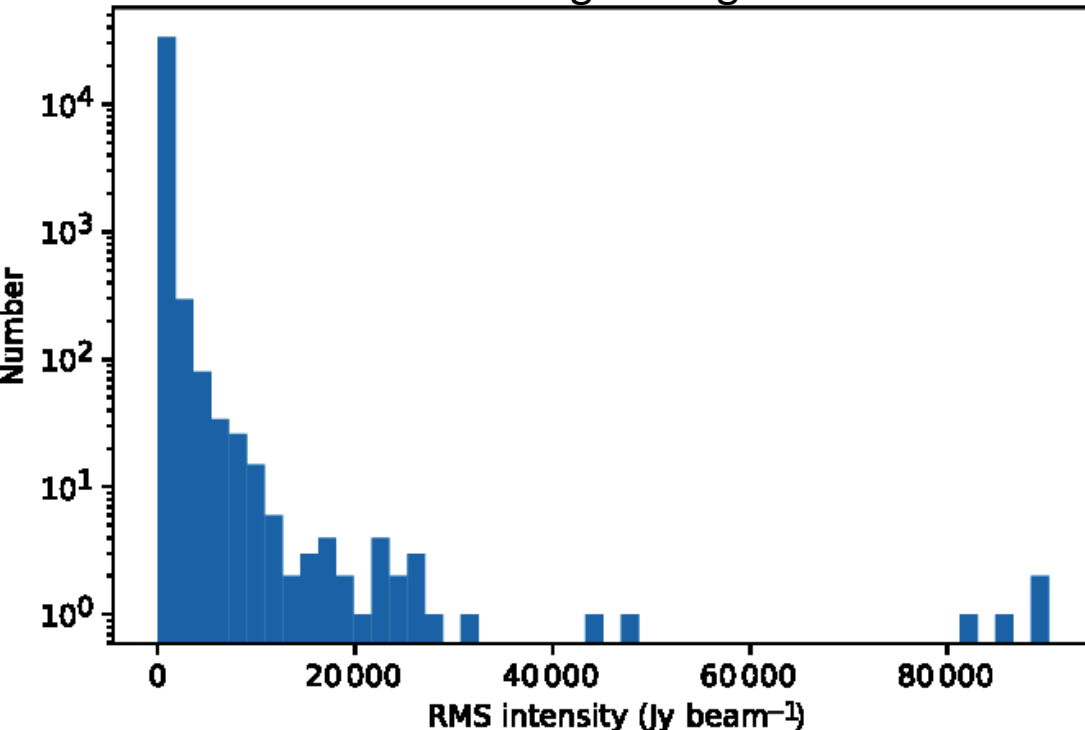


- Sources > 10 sigma detected in difference images
- Background RMS changes, can be affected by very bright sources (or RFI!)
- Difference imaging can detect objects that are not obvious in the raw images



Event/background statistics

Difference image background statistics



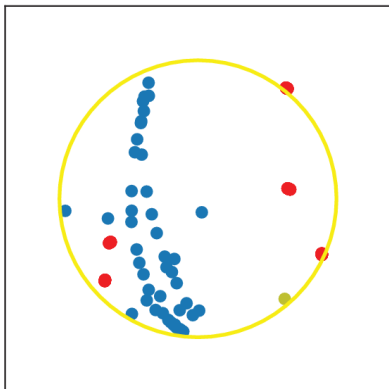
RMS background is generally low and noise-dominated.
Occasionally strong events

Categories of events:

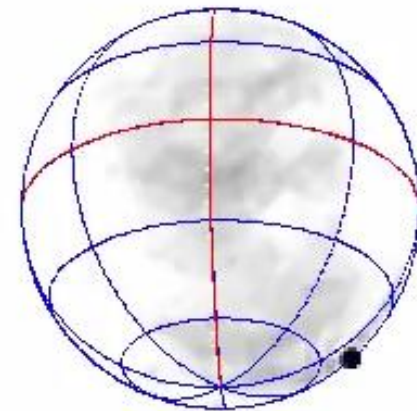
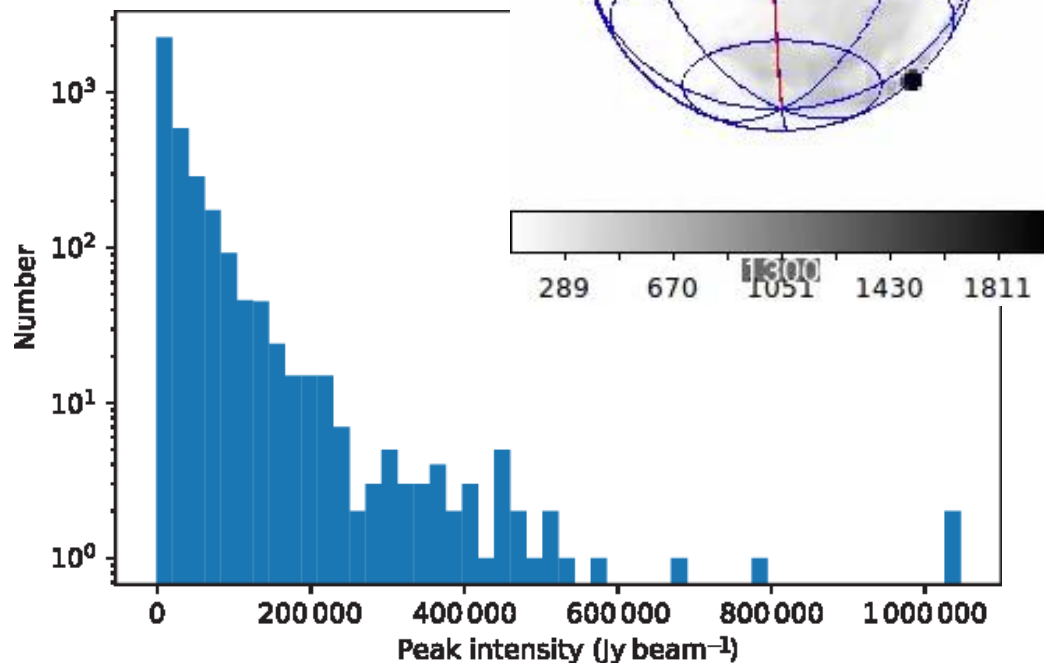
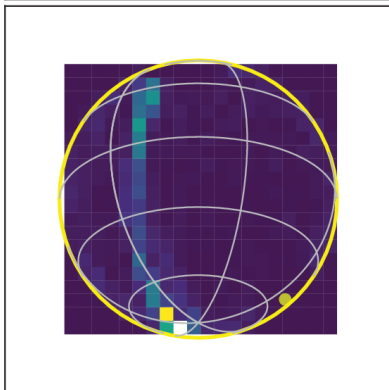
1. Single events, e.g. meteor reflections
2. Reflections from aircraft
3. Candidate reflections from satellites
4. Persistent, time-variable (e.g. signal from Geraldton on horizon)
5. Events at locations of brightest astronomical sources

Aircraft backscatter

Example
events



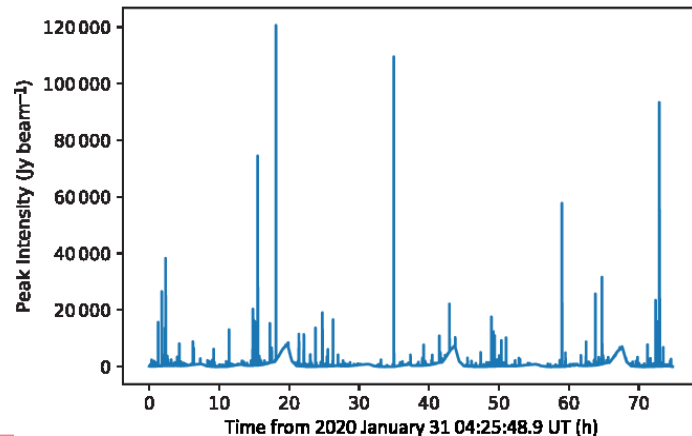
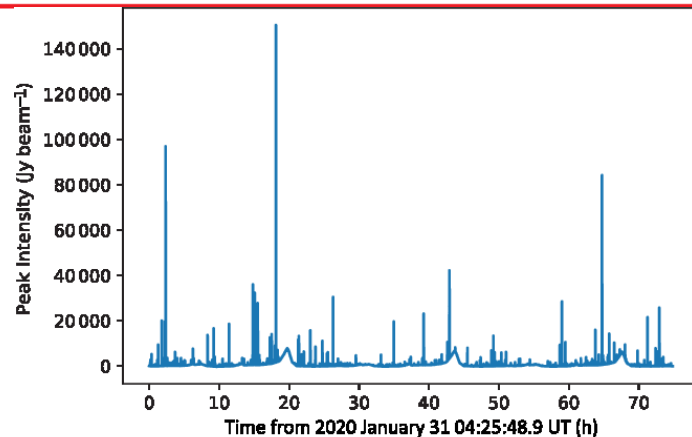
Long term
occupancy





FM radio from Geraldton

- FM radio from Geraldton arrives mostly via tropospheric scattering, at relatively low signal levels
- Occasional very strong bursts occur
- It is naturally attenuated by antenna radiation patterns that have nulls towards the horizon

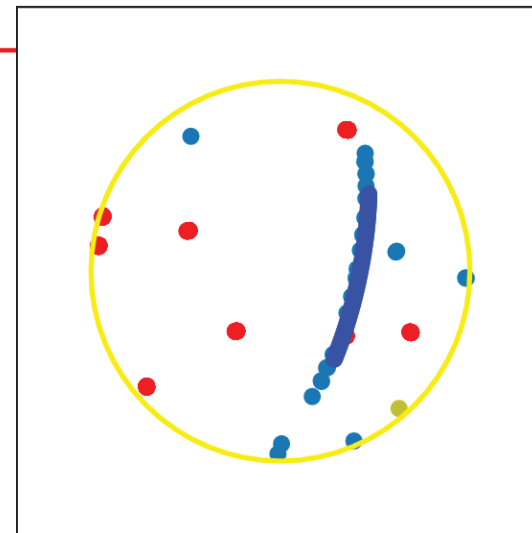




Satellites

Example detections and orbit for BGUSAT

- Larger satellites (e.g. ISS) are detected in FM backscatter.
- Smaller satellites are unexpected
- These and some other cubestats have previously been detected in and near to the FM band
- Hypothesis is these transmissions are unintentional spillover from downlinks at 145 MHz



Satellite ^a name	NORAD ID #	Start time (UT)	End time (UT)	Mean intensity (Jy beam ⁻¹)	RCS ^b (m ²)
BGUSAT	41999	2020-01-31 14:40:09.9	2020-01-31 14:43:11.9	1 060	<0.1
ISS (ZARYA)	25544	2020-01-31 17:17:41.9	2020-01-31 17:19:00.9	440	>1.0
MAX VALIER SAT	42778	2020-02-03 01:18:16.9	2020-02-03 01:20:09.9	650	0.1–1.0
ISS (ZARYA)	22554	2020-02-03 01:31:07.9	2020-02-03 01:33:14.9	930	>1.0
FLOCK 3P 71	42024	2020-02-01 14:16:22.9	2020-02-01 14:18:05.9	330	<0.1
ISS (ZARYA)	25544	2020-02-02 02:18:17.9	2020-02-02 02:20:16.9	740	>1.0
BGUSAT	41999	2020-02-02 02:18:17.9	2020-02-02 02:20:16.9	1 010	<0.1

Zhanget al, 2018

<https://ui.adsabs.harvard.edu/abs/2018MNRAS.477.5167Z>

Prabu et al., 2020

<https://ui.adsabs.harvard.edu/abs/2020PASA...37...10P>



Unexpected satellite RFI - continued

How bad is it?

- A 1000 Jy radio source would be in the **top 10 brightest objects** in the radio sky
 - RFI at this level would corrupt data from virtually all astronomical sources
 - The signal is not narrowband (see Prabu et al, 2020)
- $1 \text{ Jy} = 10^{-26} \text{ W/Hz/m}^2 = 10^{-20} \text{ W/m}^2$ in a 1 MHz band.
- At a nominal distance of 500 km, the EIRP for 10^{-20} W/m^2 is $3.1 \times 10^{-8} \text{ W}$.

A small amount of out-of-band transmission (by engineering standards) can still be a huge source of RFI at LEO distances.



Summary

- Sensitive radio astronomy instruments have also been used as RFI monitors at the MRO for many years
- Using the recently deployed SKA-Low prototype station EDA2 as an imaging interferometer, the entire sky can be monitored on ~2s timescales
- The system provides direction and apparent flux density statistics of sources:
- Known
 - Meteor scatter
 - Aircraft backscatter and from the largest satellites
 - Long distance tropospheric propagation
- Unexpected
 - Some cubesats (apparently out-of-band transmissions)