An overview of the impact of RFI on radio astronomy

RFI 2025

Dr Vanessa Moss | 21 October 2025

Head of ASKAP Science Operations, CSIRO

Image: CSIRO

I would like to begin by acknowledging the **Dharug people** as the Traditional Owners of the land that I'm meeting from today, and pay my respect to their Elders past and present.

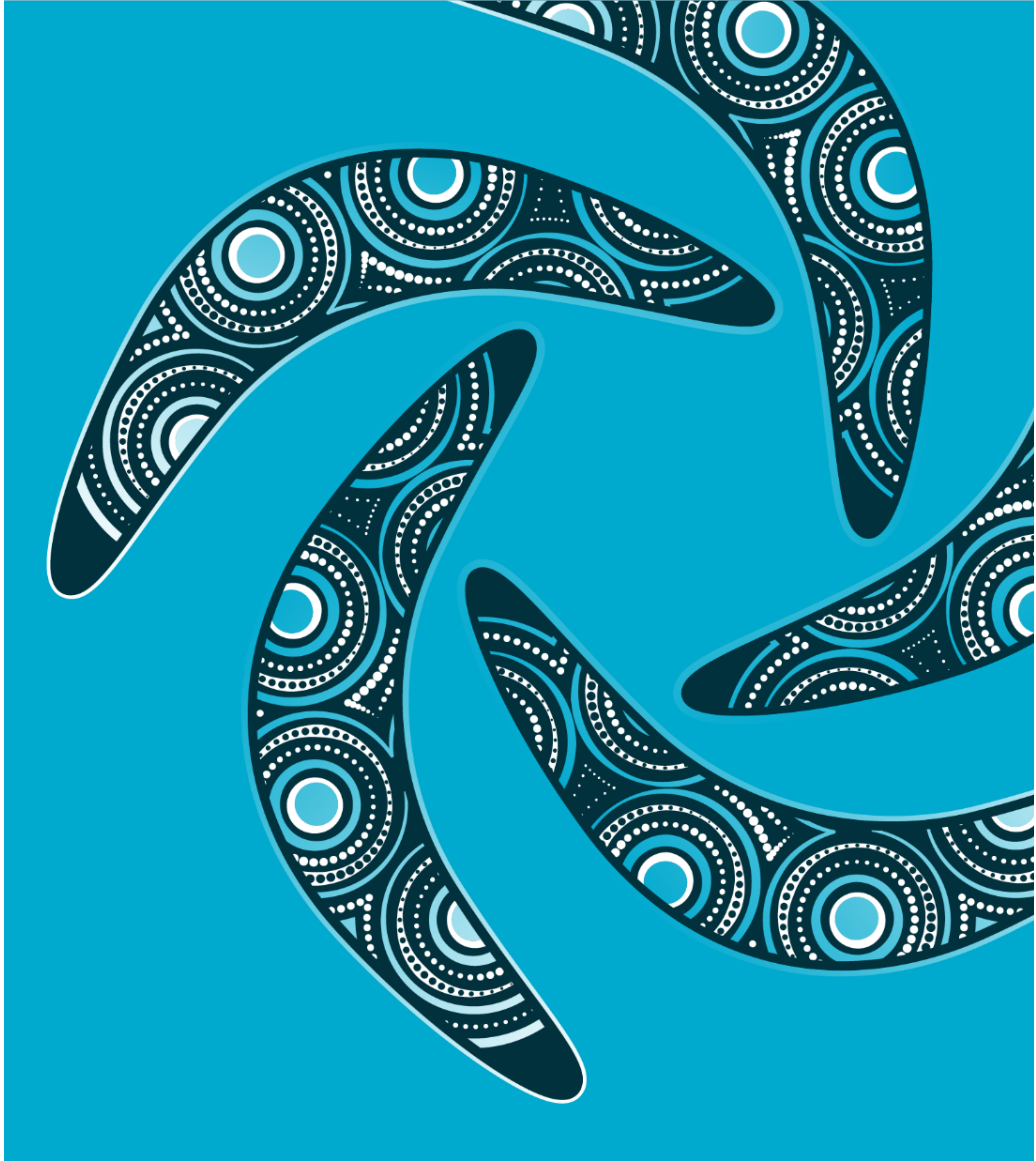

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Image: AIATSIS

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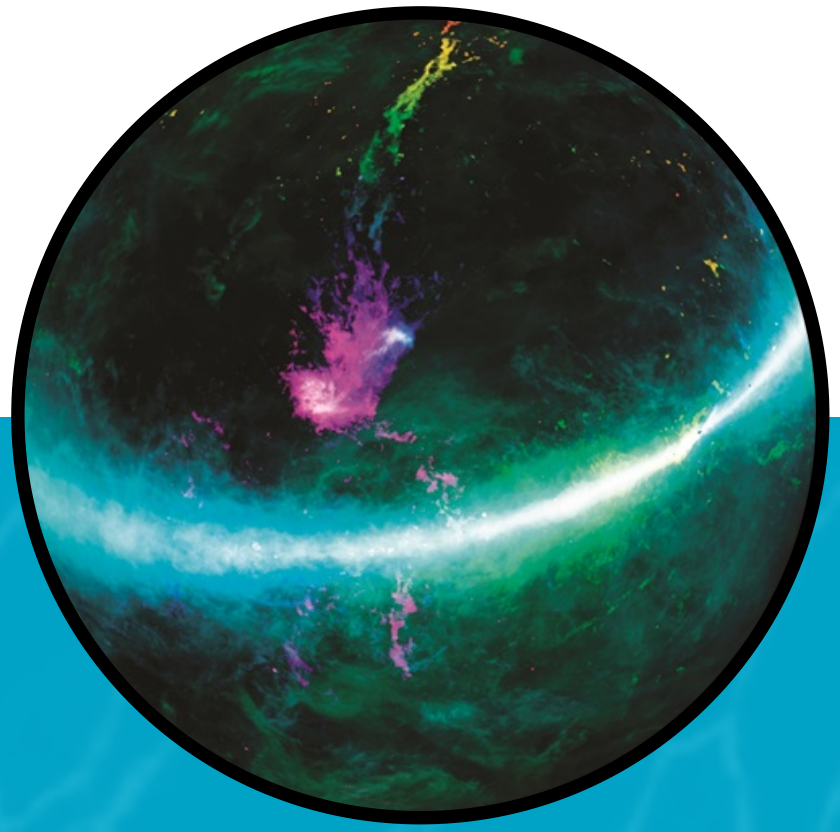
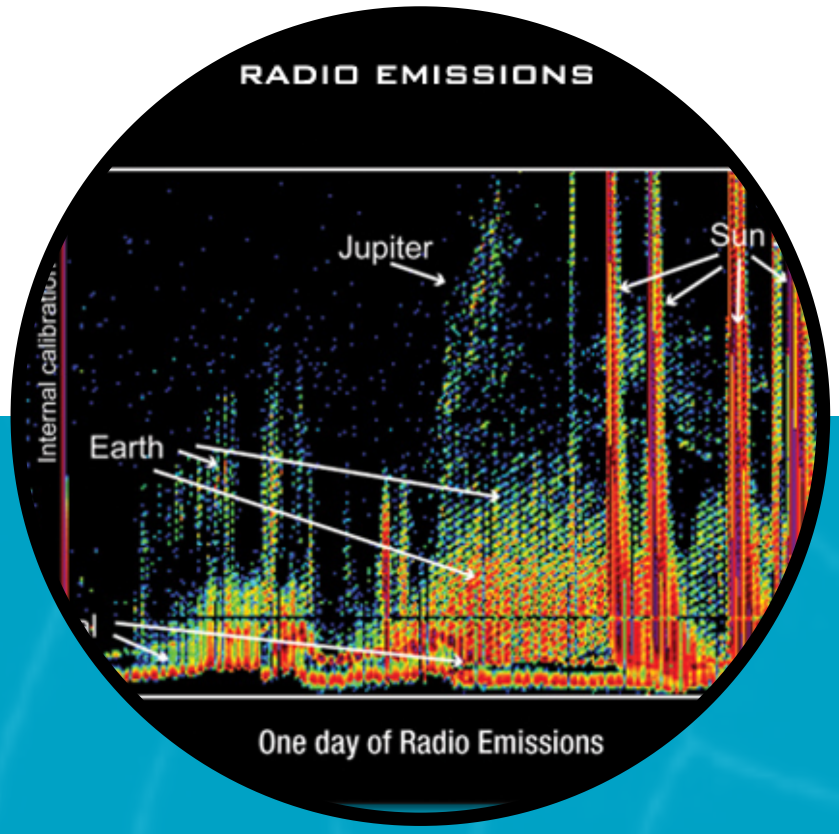
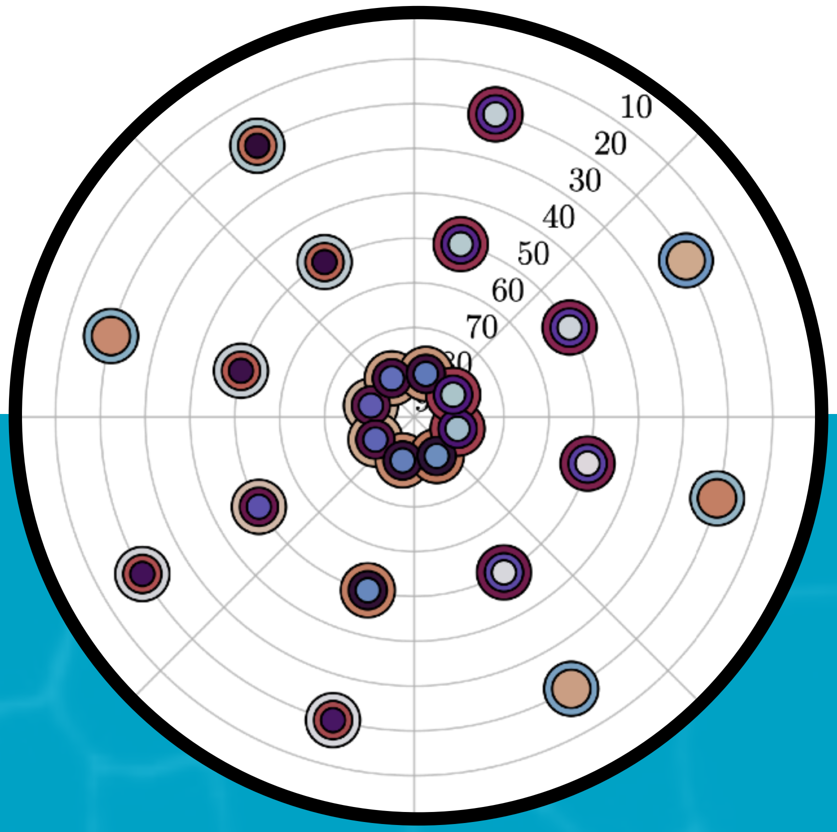


Introduction to radio astronomy



The impact and significance of RFI



Case studies in RFI

Considering the future

An overview of the impact of RFI on radio astronomy

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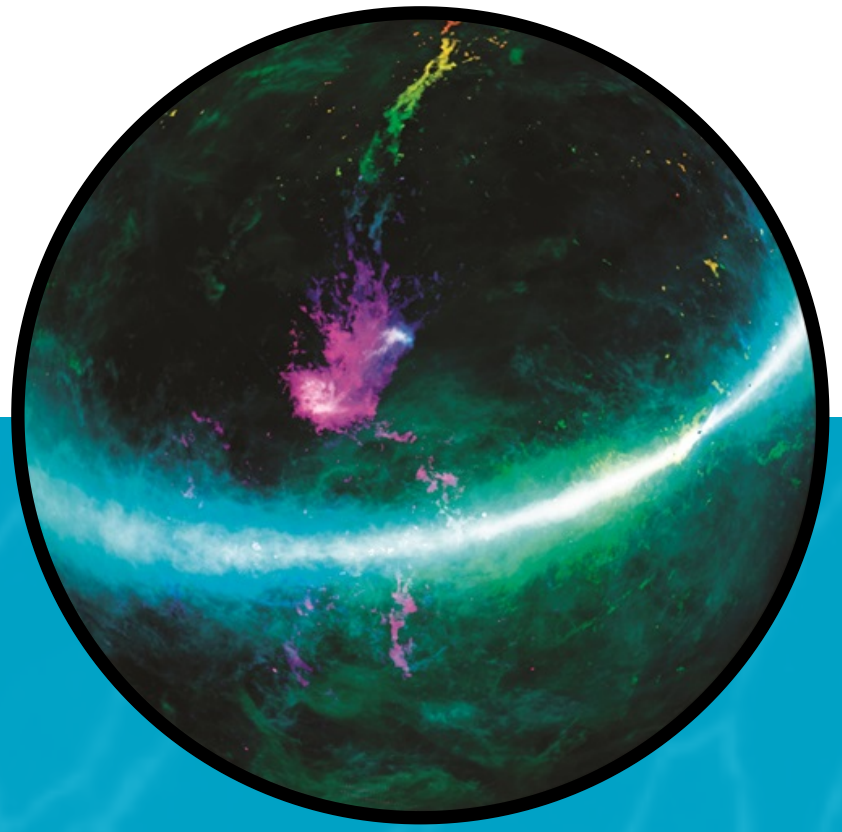

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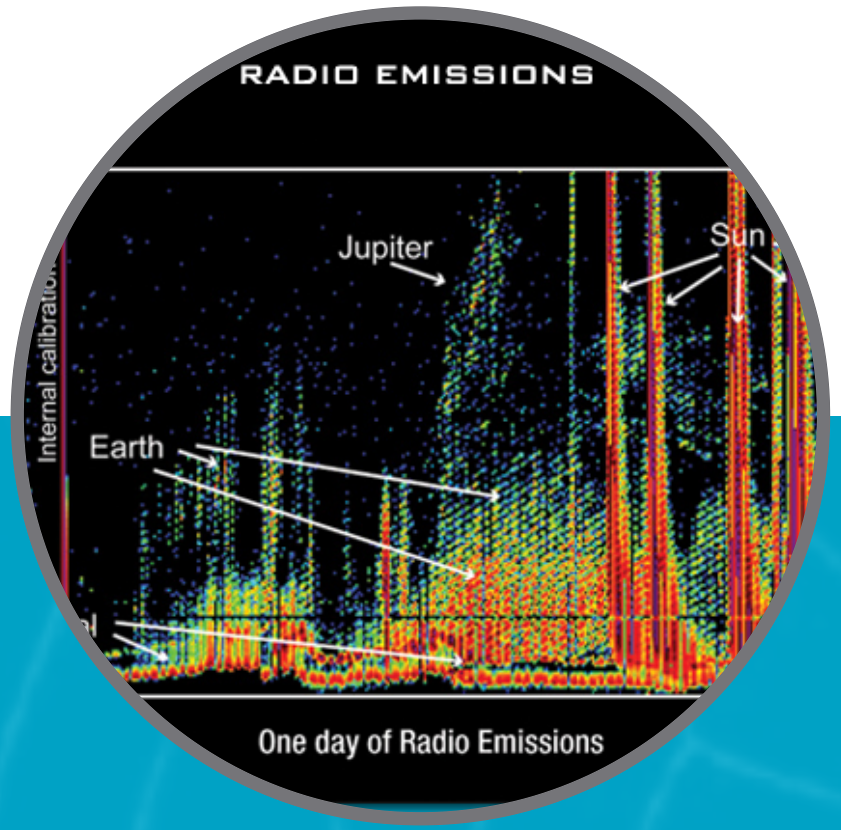

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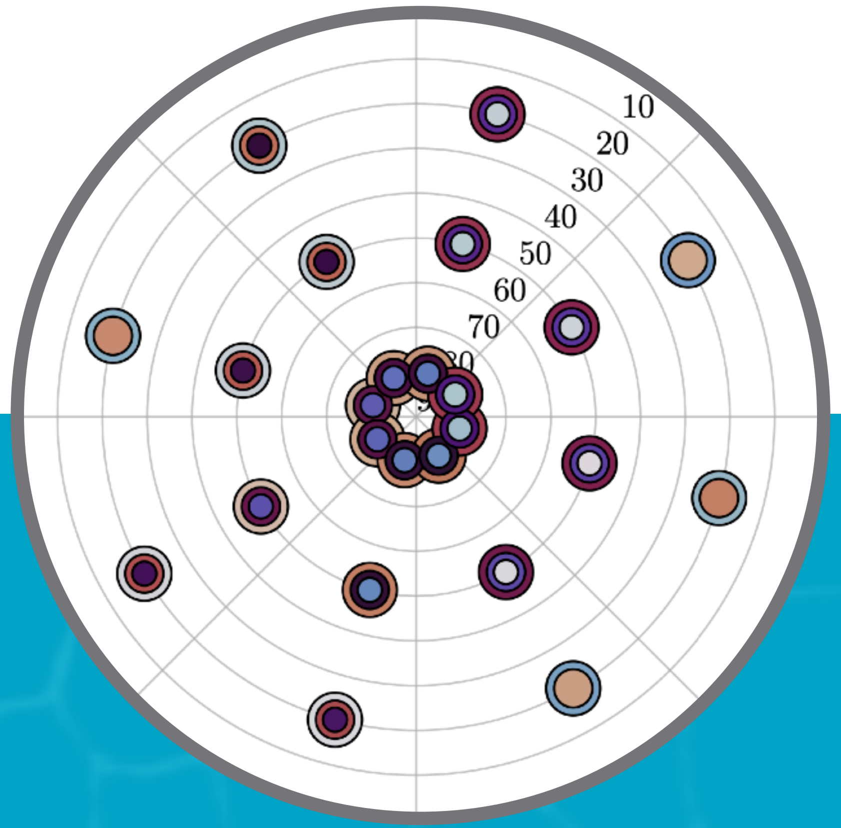


Case studies in RFI

Considering the future

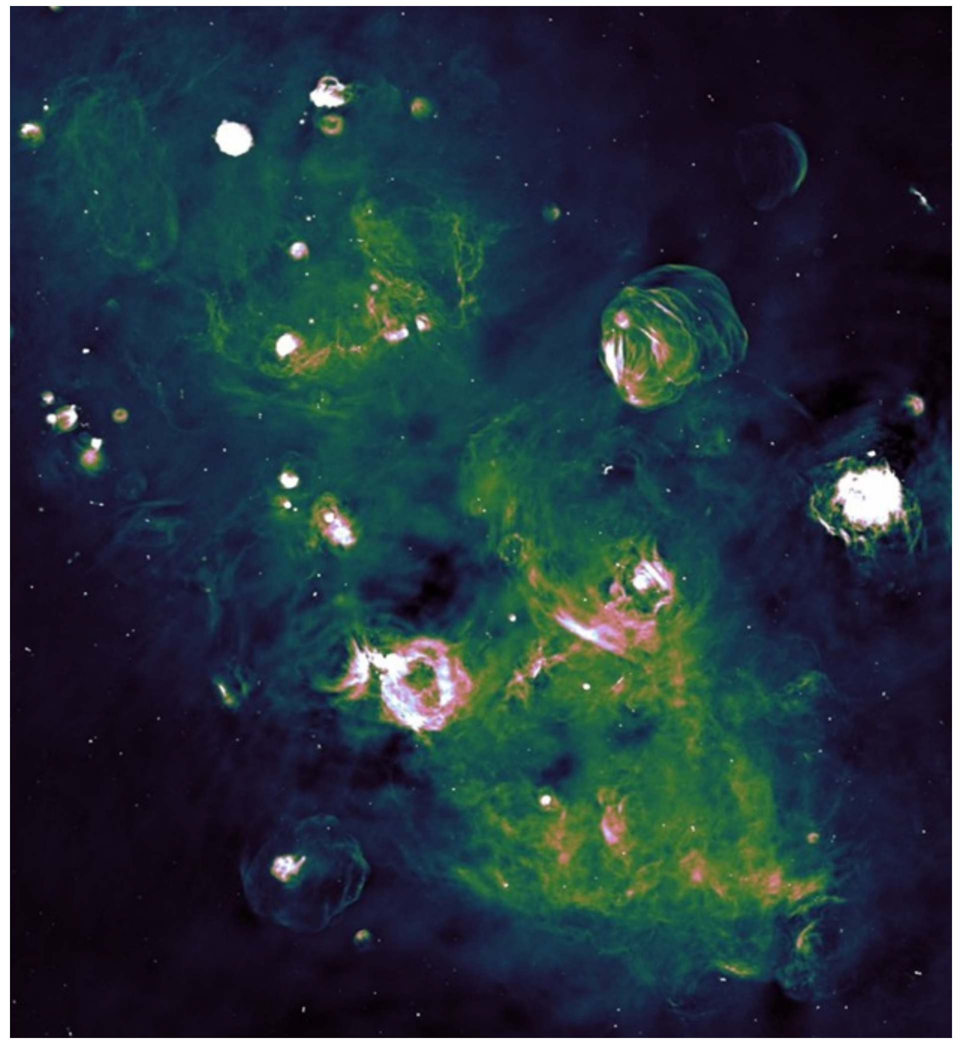

Image: A. Lopez-Sanchez

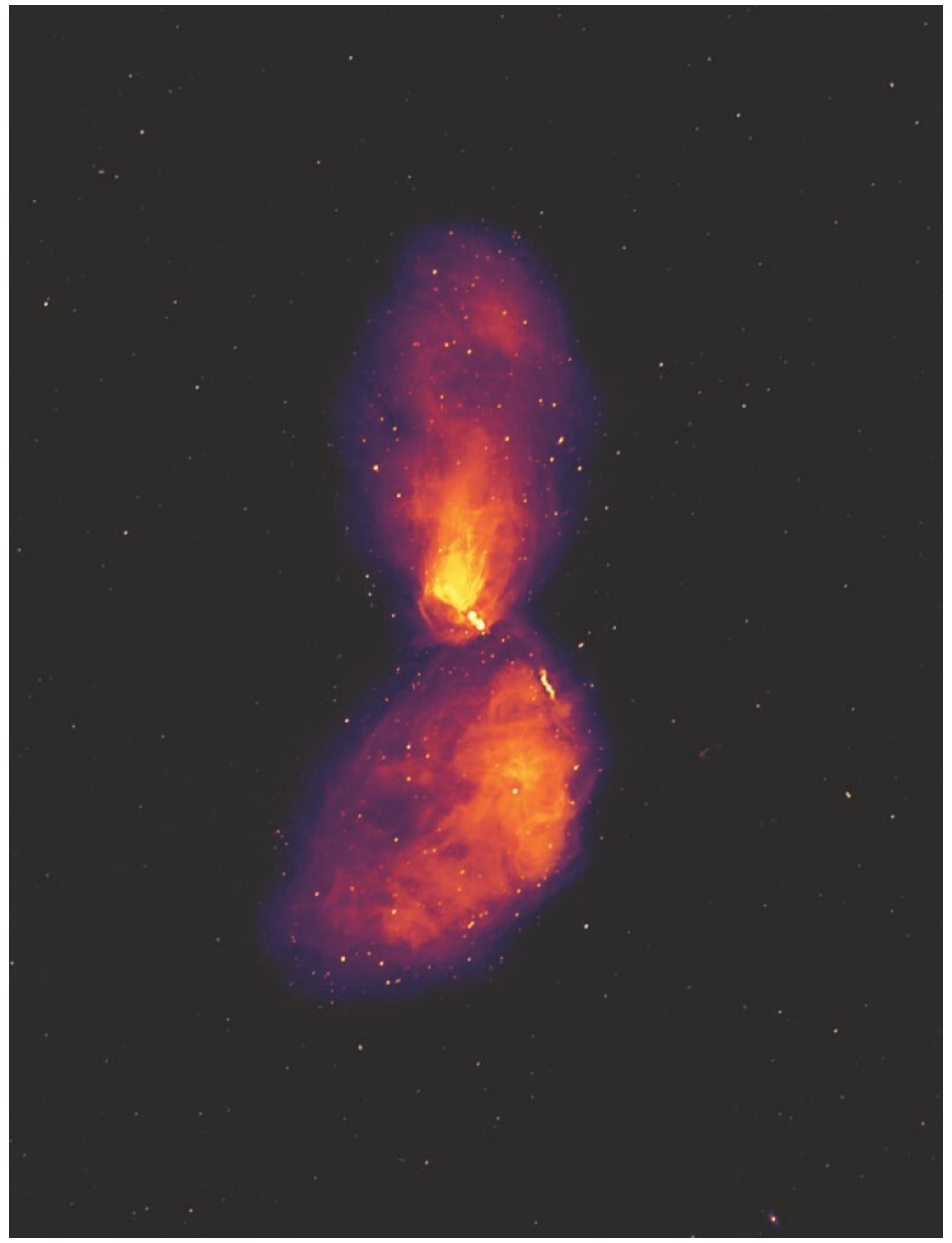
Image: NRAO/AUI

Image: I. Feain/CSIRO

A brief intro to radio astronomy

- Radio astronomy: surveying, studying and understanding the Universe at **radio frequencies**
- Essentially: **up to 100 GHz** is usually considered radio, although it blurs into millimetre astronomy
- **Critical pieces** of the astrophysics puzzle from the solar system to the edge of the visible Universe





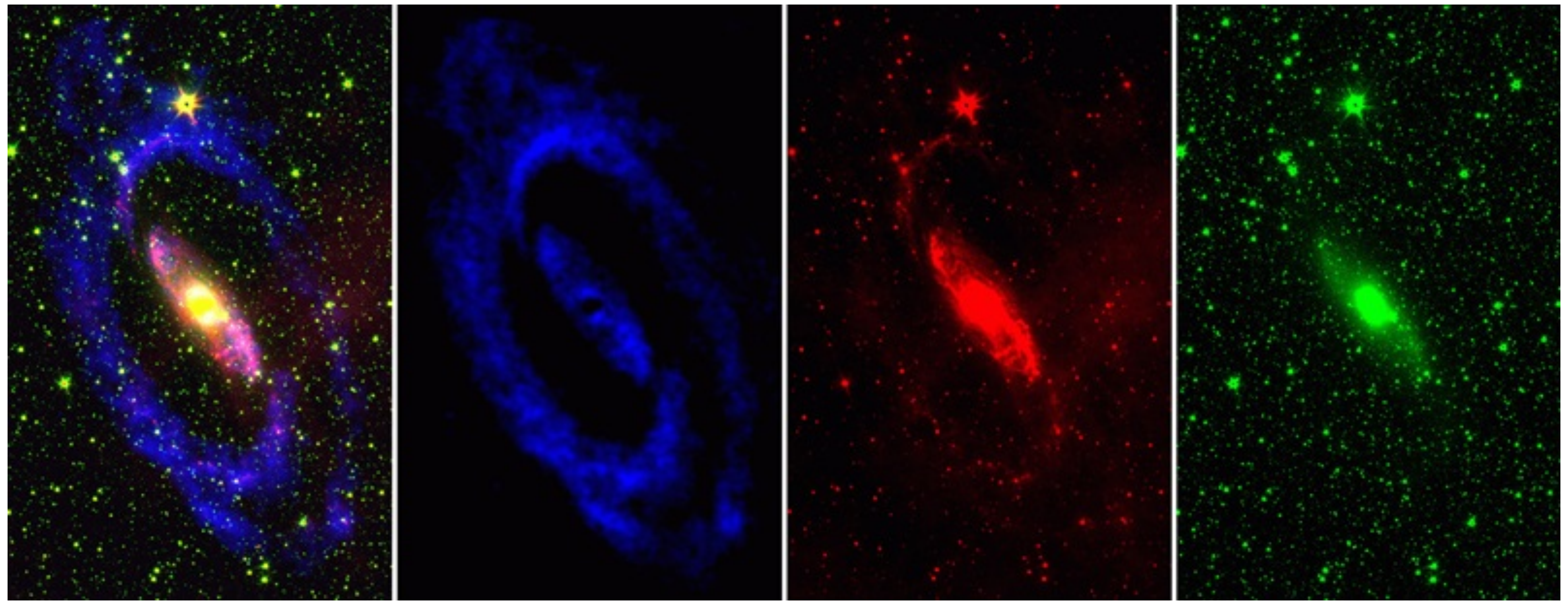


Image: R. Kothes/PEGASUS, B. McKinley/ICRAR, RAS/CSIRO


THE ELECTROMAGNETIC SPECTRUM
Atmosphere Opaque to Wavelengths
Radio Window
Atmosphere Opaque to Wavelengths
Optical Window
visible light
Atmosphere Opaque to Wavelengths
10^6 (Hertz)
10^9 Hz
10^12 Hz
10^15 Hz
10^18 Hz
10^21 Hz
Radio Waves
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Waves
10^2 (meters)
10^1 m
10^0 m (1 m)
10^-1 m
10^-2 m (1 cm)
10^-3 m
10^-4 m
10^-5 m
10^-6 m (1µm)
10^-7 m
10^-8 m
10^-9 m (1 nm)
10^-10 m
10^-11 m
10^-12 m
AM radio
FM Radio
Cell Phone and Wi-Fi
Microwave Oven
Human bodies radiate heat
Remotes
Visible Light
Sunburn
Sunblock
Medical X-rays
Nuclear Power
Image: NASA


THE ELECTROMAGNETIC SPECTRUM
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Image: NASA


Radio Continuum (408 MHz)
Atomic Hydrogen
Radio Continuum (2.4 - 2.7 GHz)
Molecular Hydrogen
Mid Infrared
Mid Infrared
Near Infrared
Visible
X-Ray
Gamma Ray
Image: NASA


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Atomic Hydrogen
Radio Continuum (2.4 - 2.7 GHz)
Molecular Hydrogen
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Image: NASA

Radio emission mechanisms

- **Thermal emission**: also known as free-free or bremsstrahlung emission
- **Synchrotron emission**: electrons spiralling along magnetic field lines
- **Spectral lines**: atomic and molecular lines in emission and absorption, will be **redshifted** depending on distance
- **Transient science** (micro to milliseconds) is rapidly growing (e.g. GRBs, FRBs)

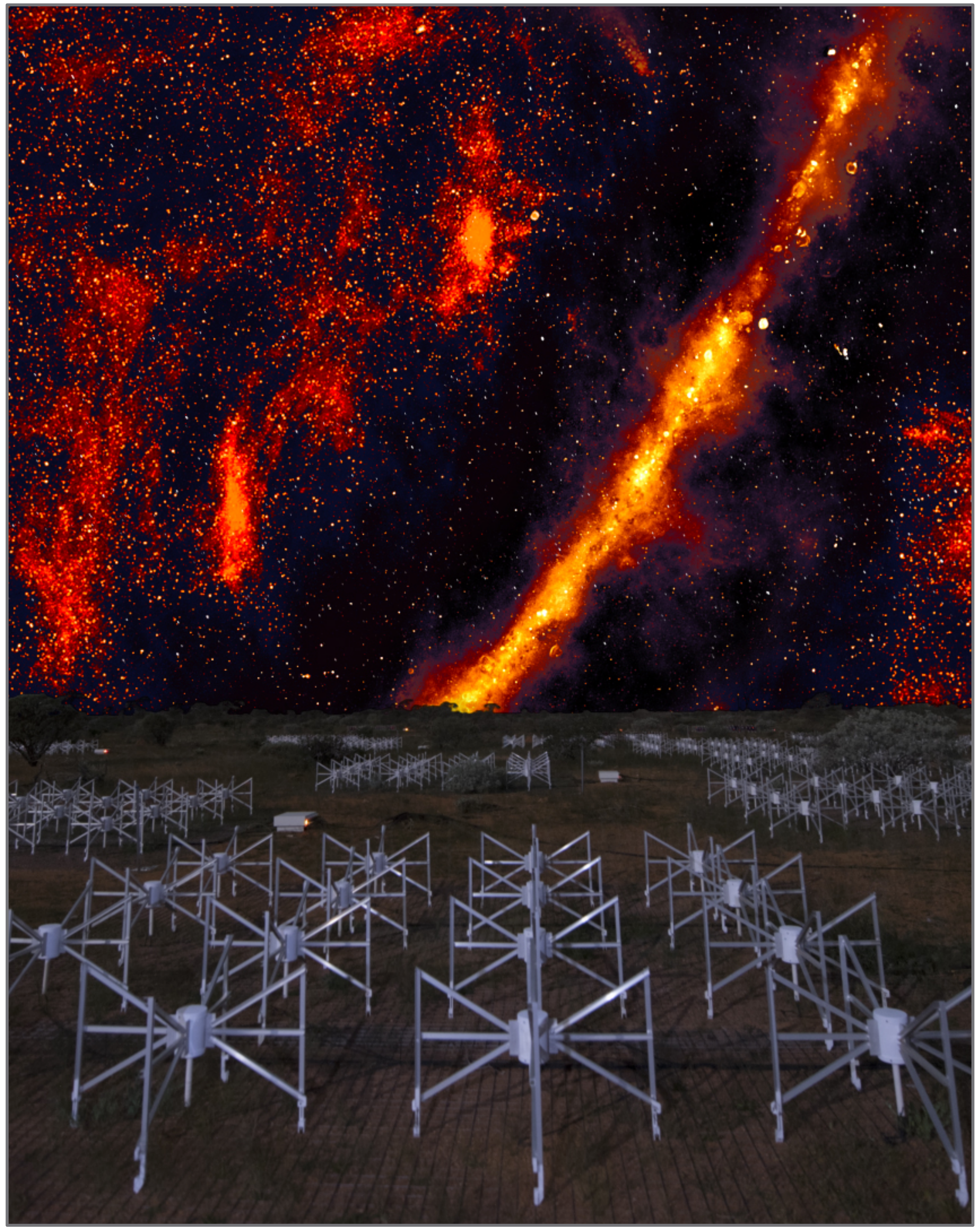

Image: MWA/CAASTRO

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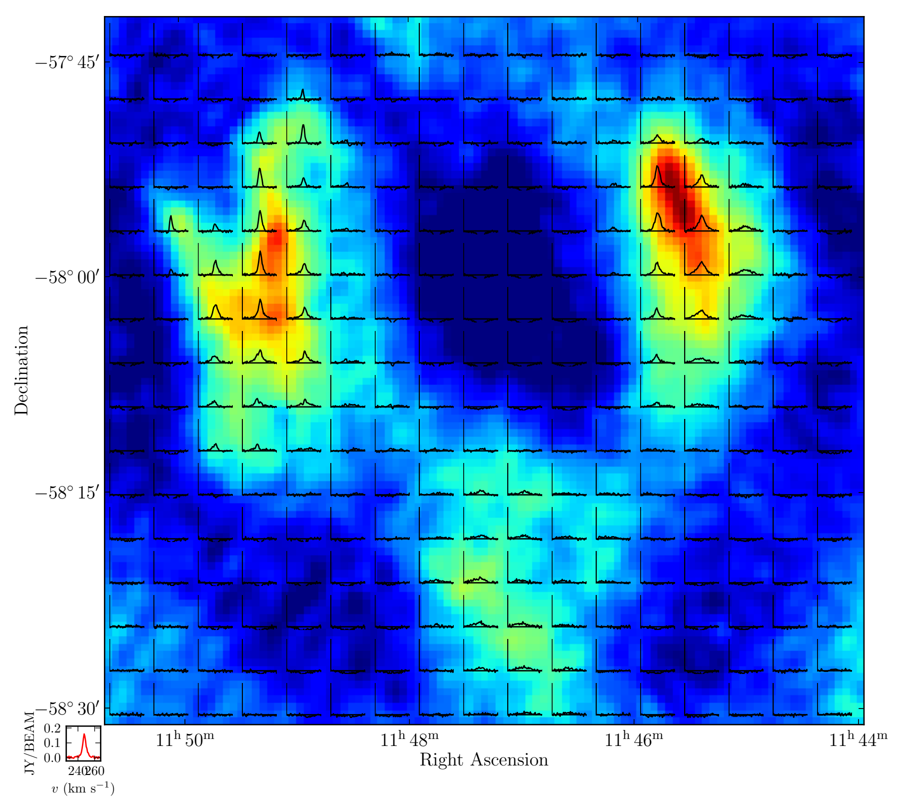
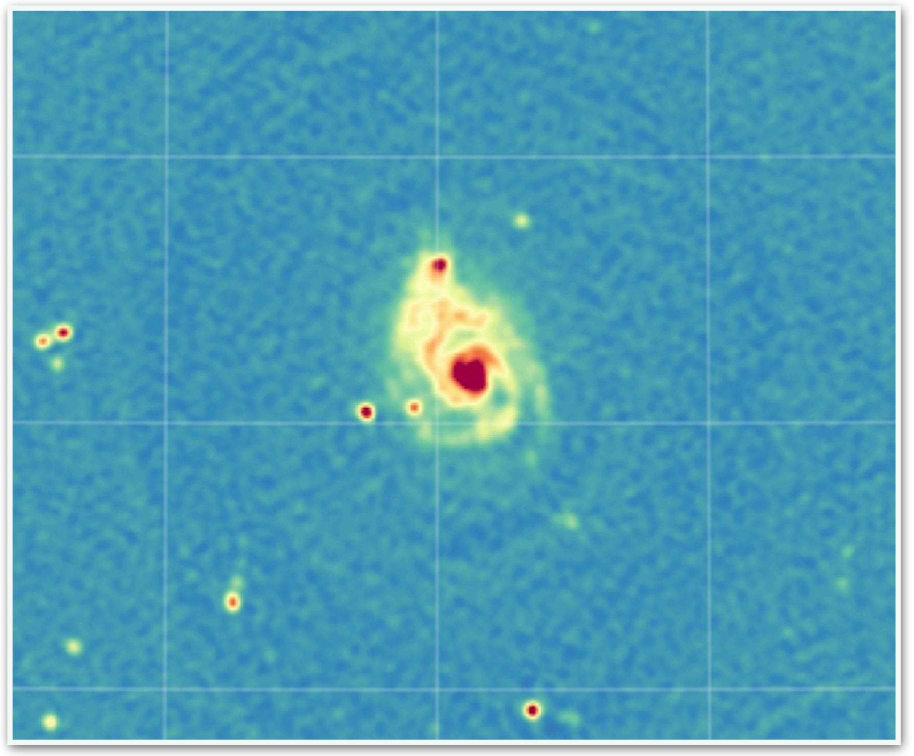




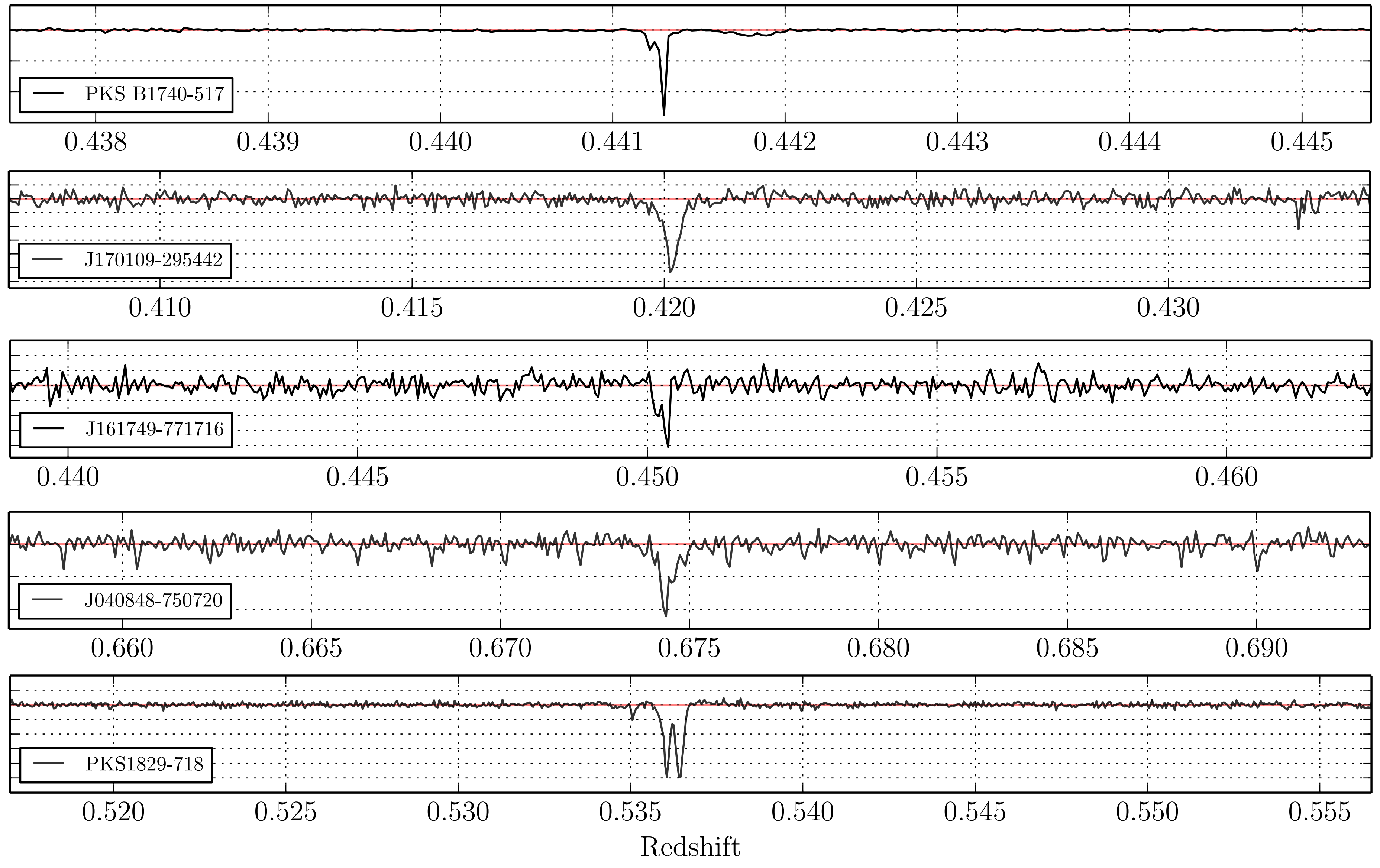
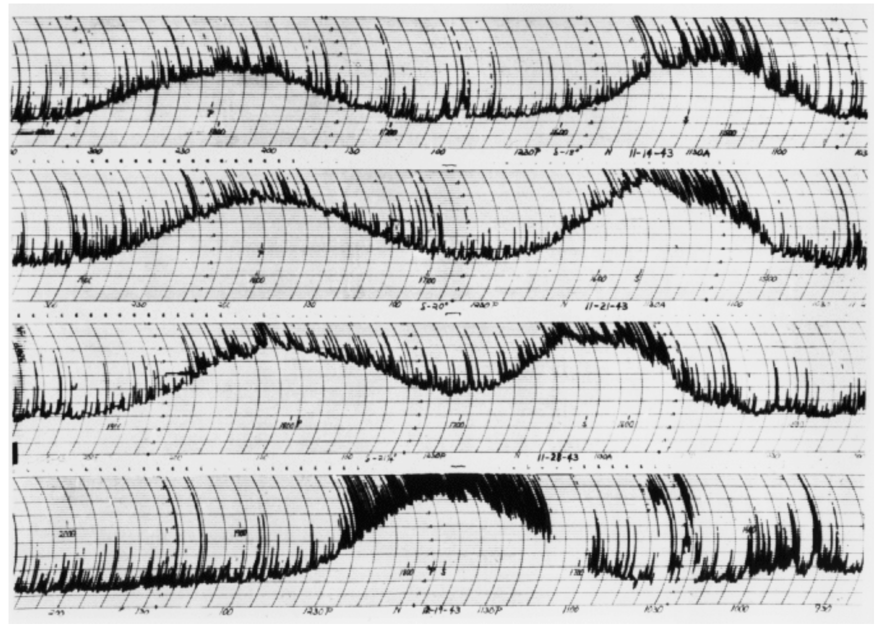
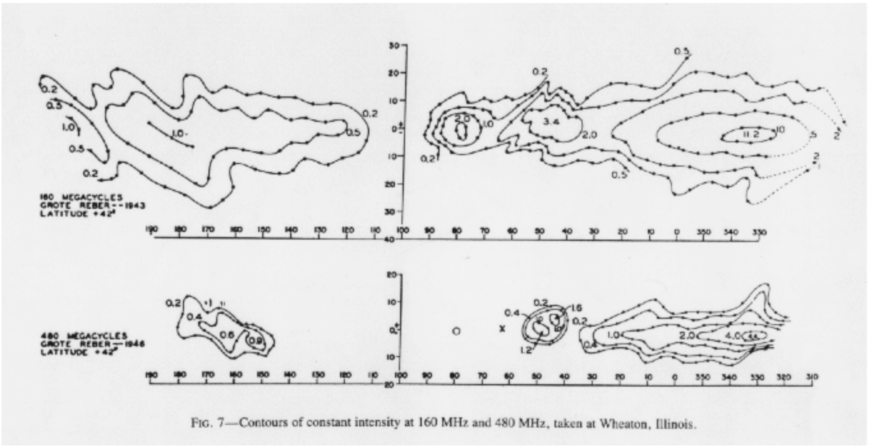


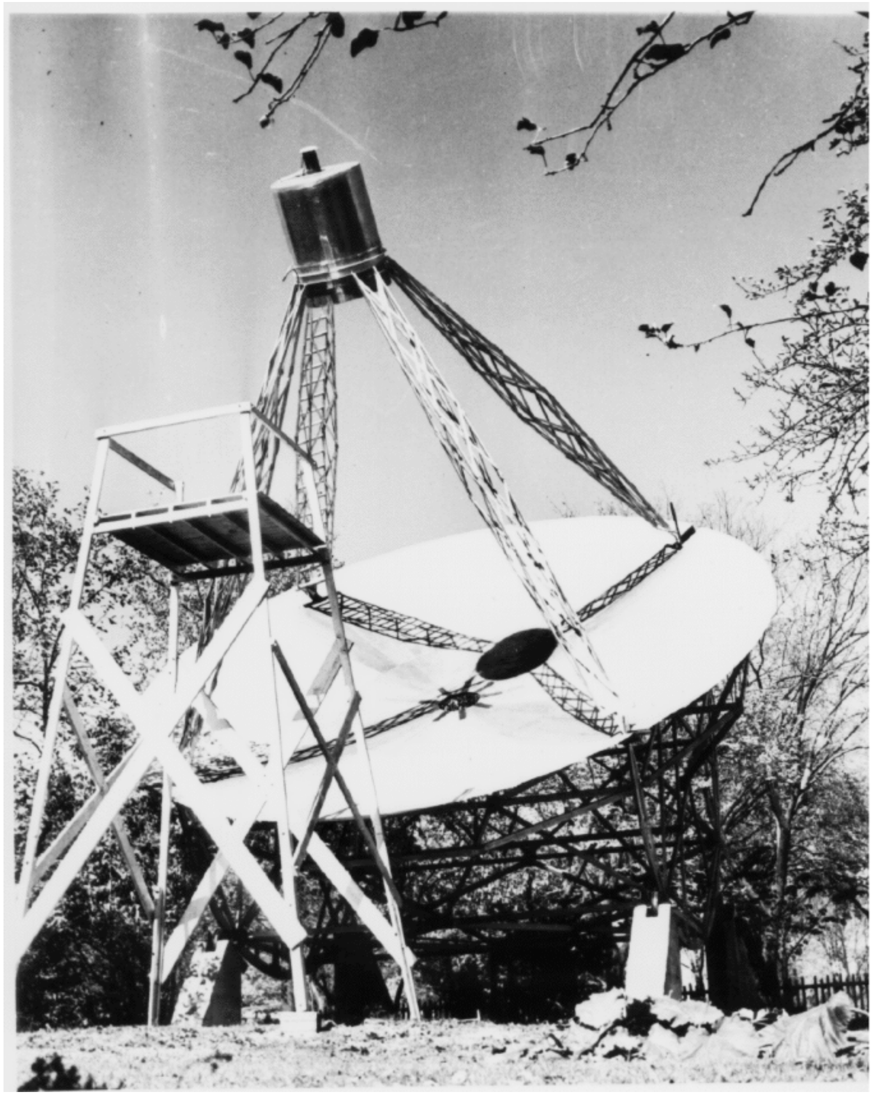
Image: V. Moss

Less than a century old!

- Original detection of **extraterrestrial radio waves** dates to 1930s (Jansky/ Reber), met with initial **scepticism**
- **Contribution highlights**: Galactic HI (1951), solar radio bursts (1950s), planetary radio emission (1955), quasars (1960s), CMB (1964), pulsars (1967), FRBs (2007), black hole direct imaging (2019)







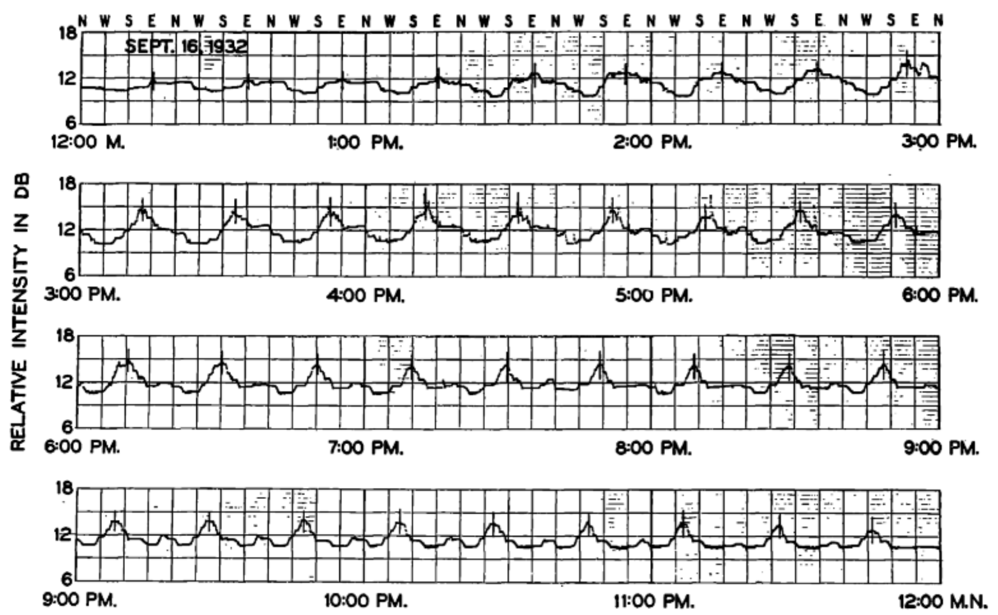


Figure 1.
Sample Record of Waves of Interstellar Origin.

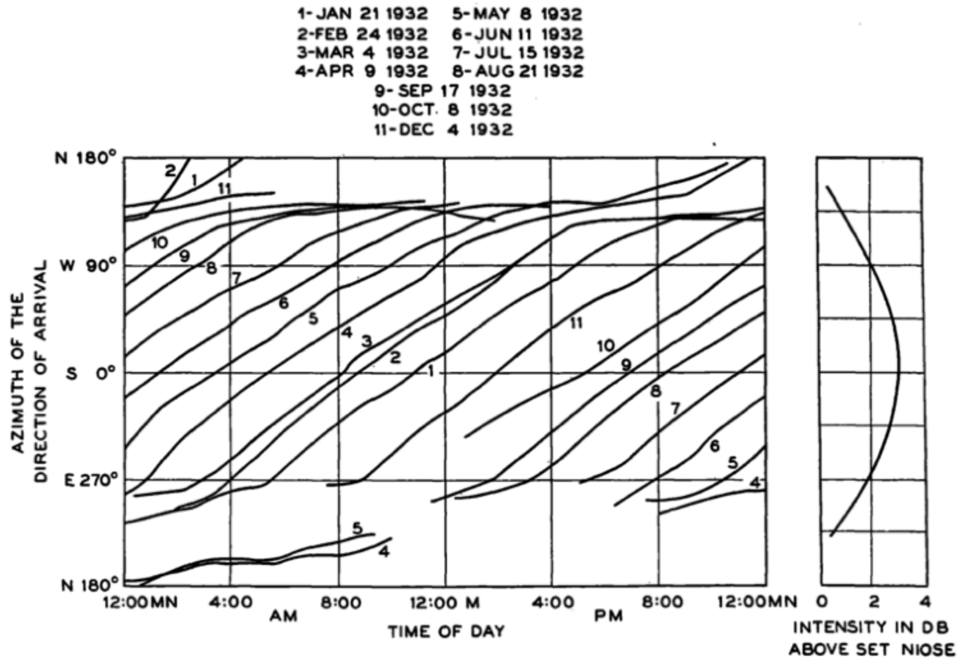


Figure 2.
Azimuth of the Direction of Arrival of Waves of Interstellar Origin
Plotted Against Time of Day.

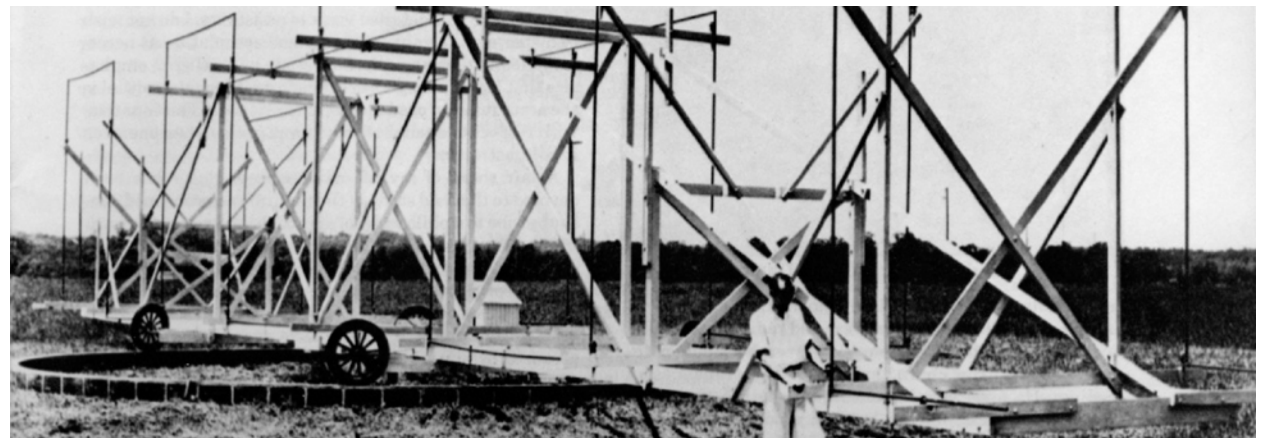
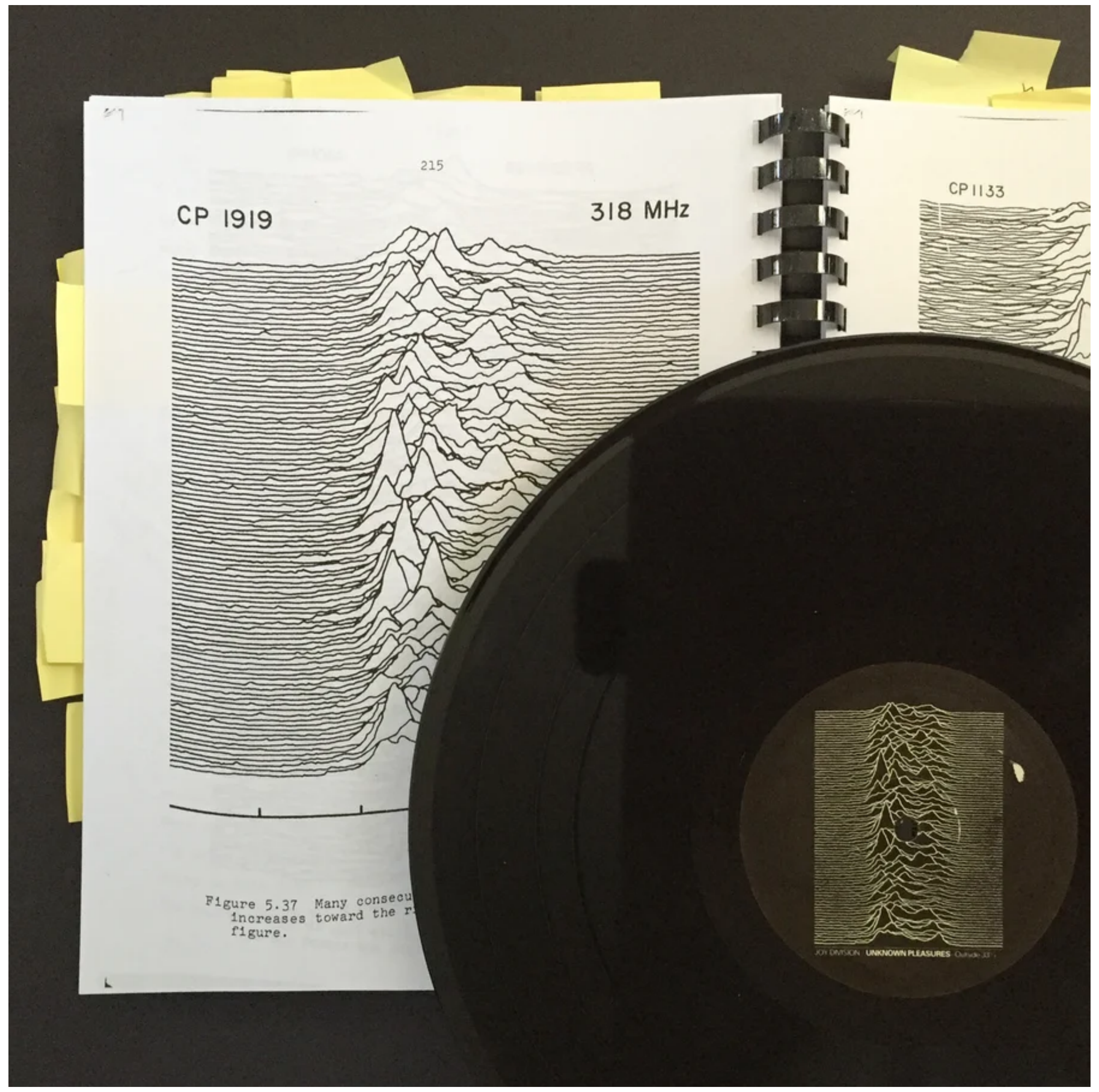
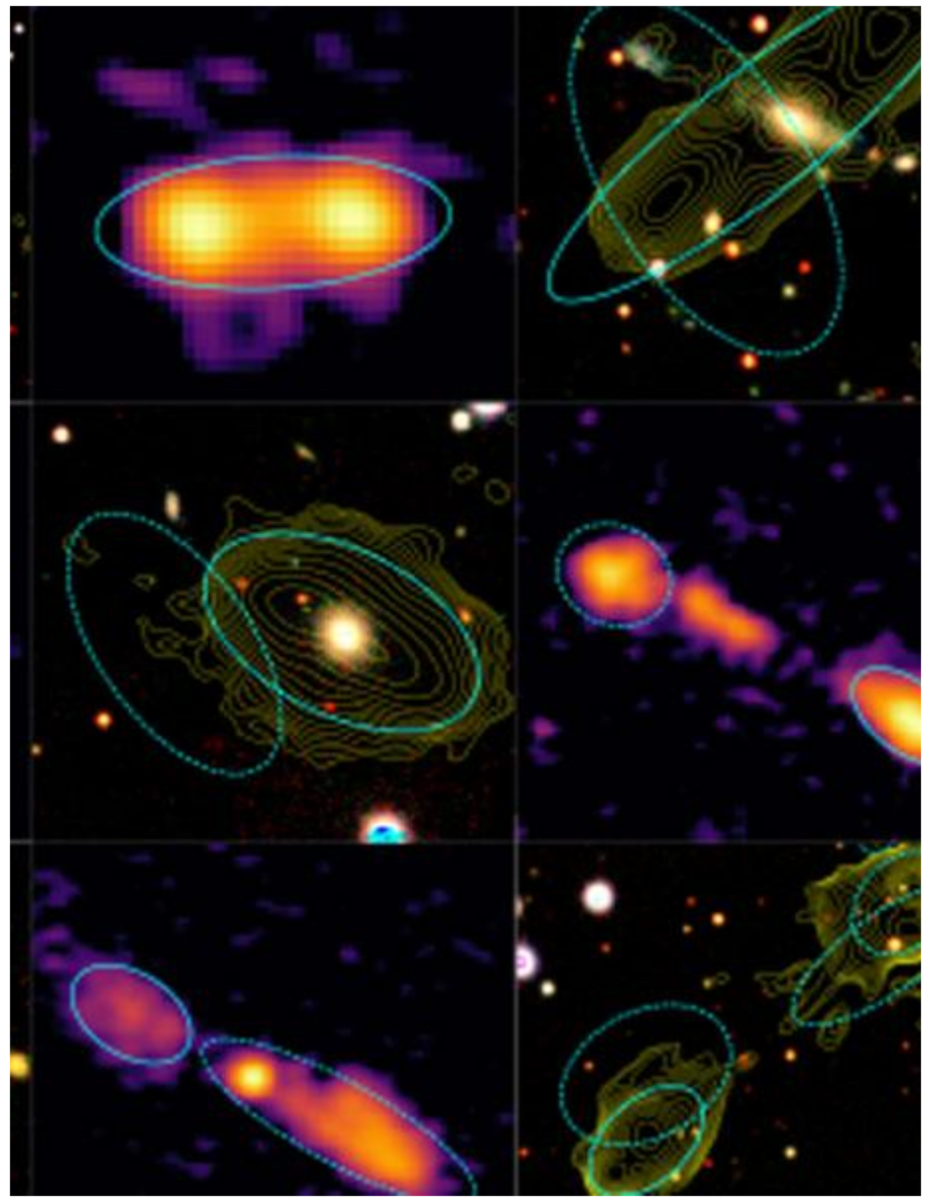
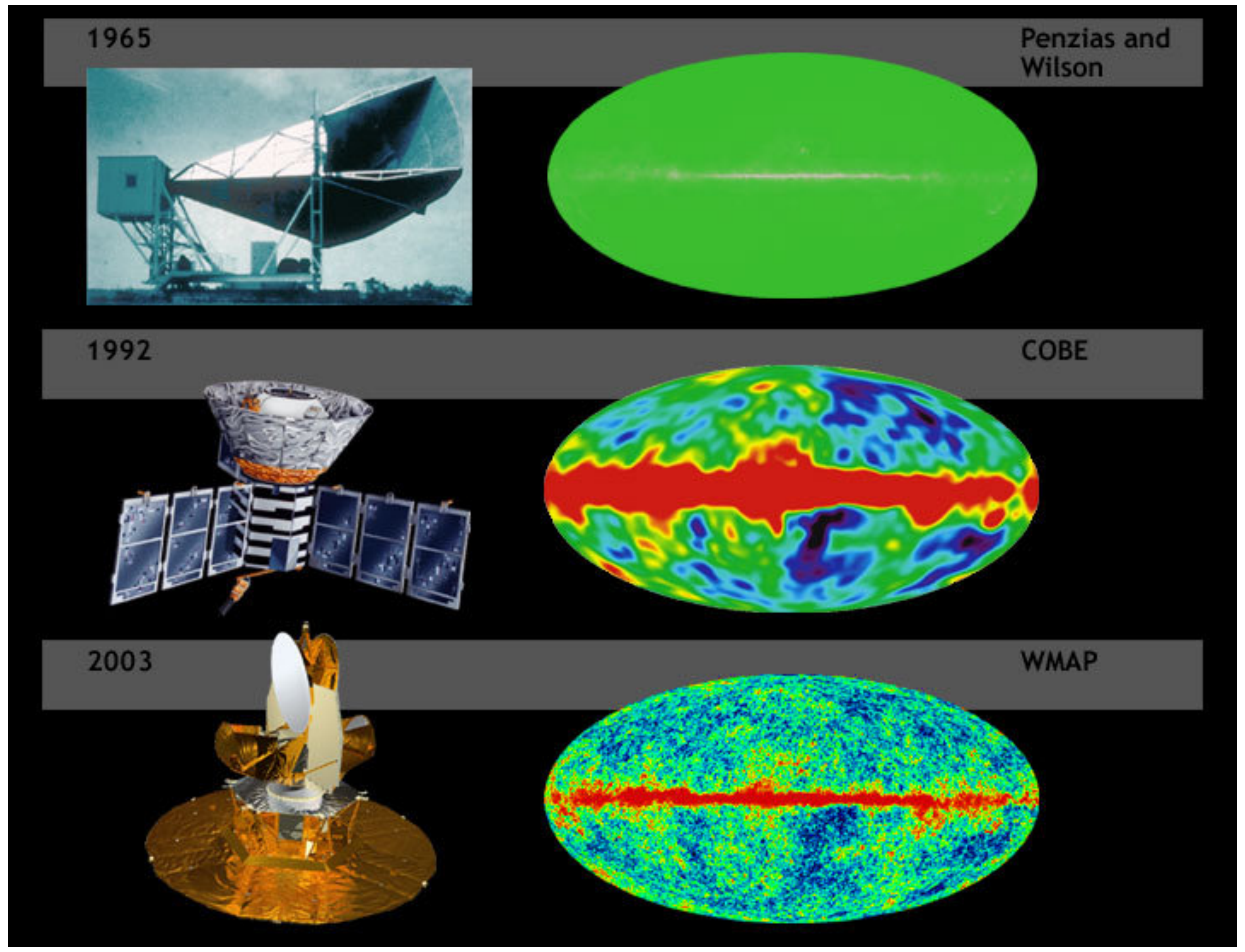
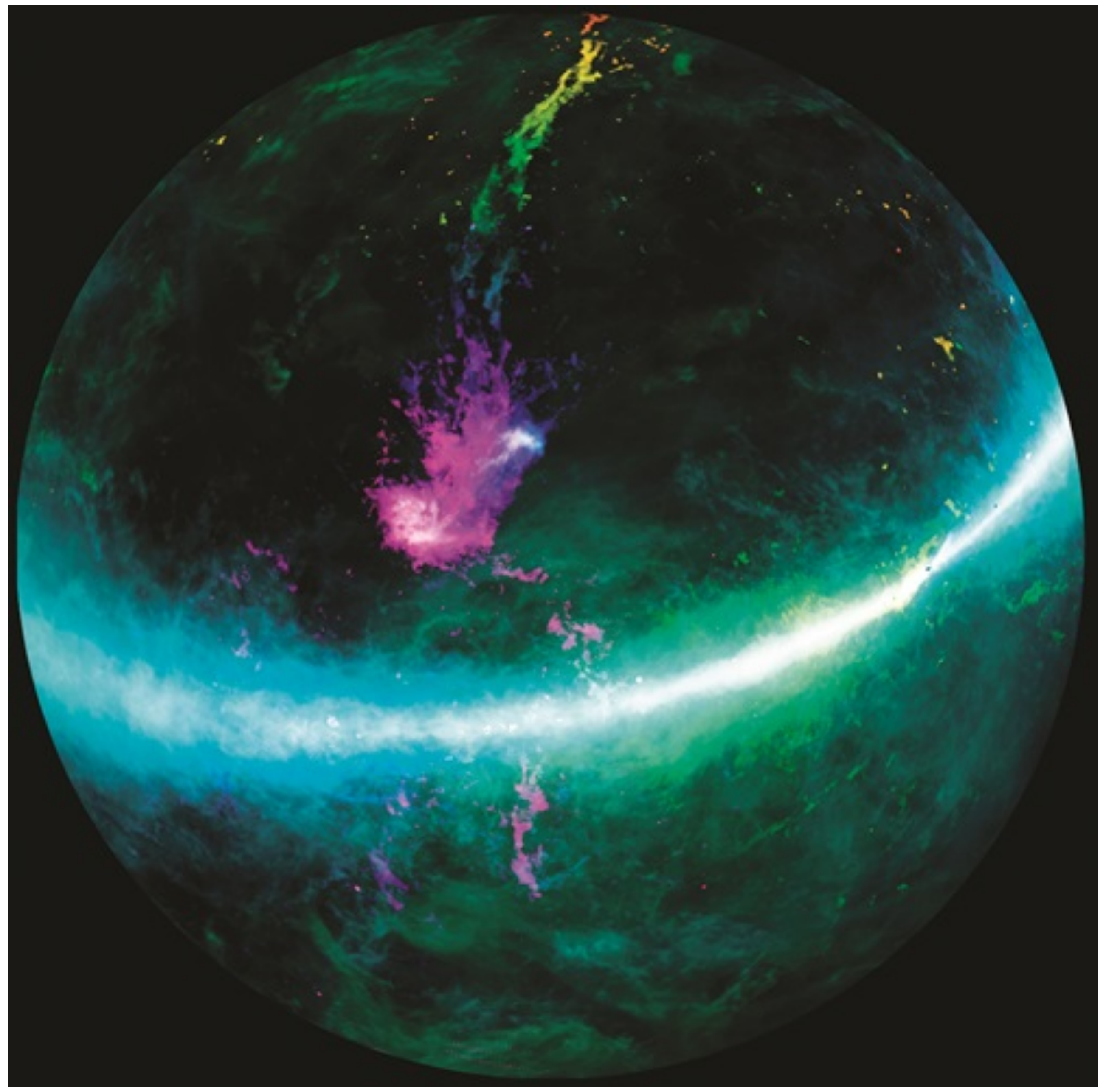


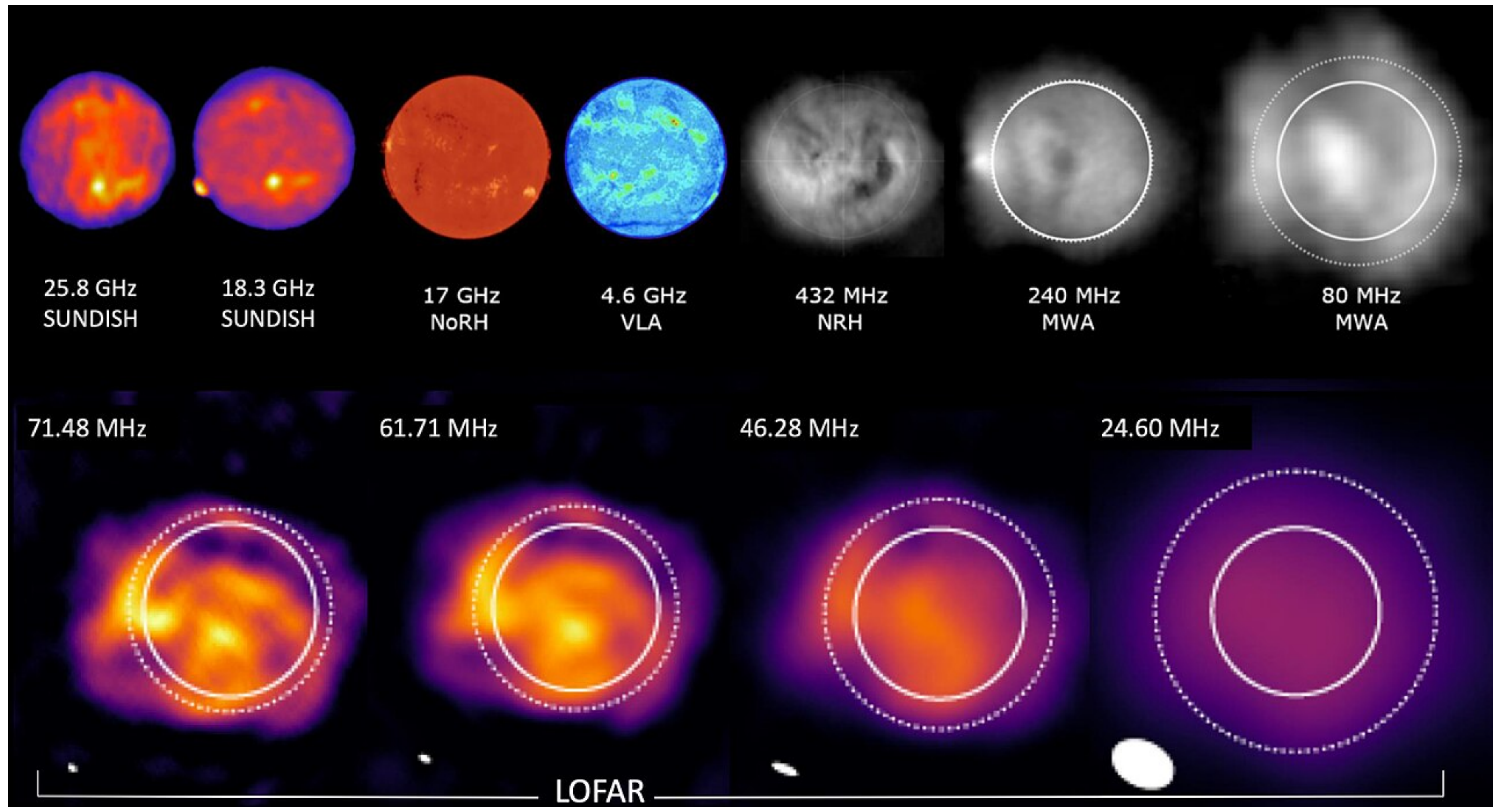
Image: http://www.nrao.edu/whatisra/hist_reber.shtml, http://www.bigear.org/CSMO/HTML/CS04/cs04p12.htm











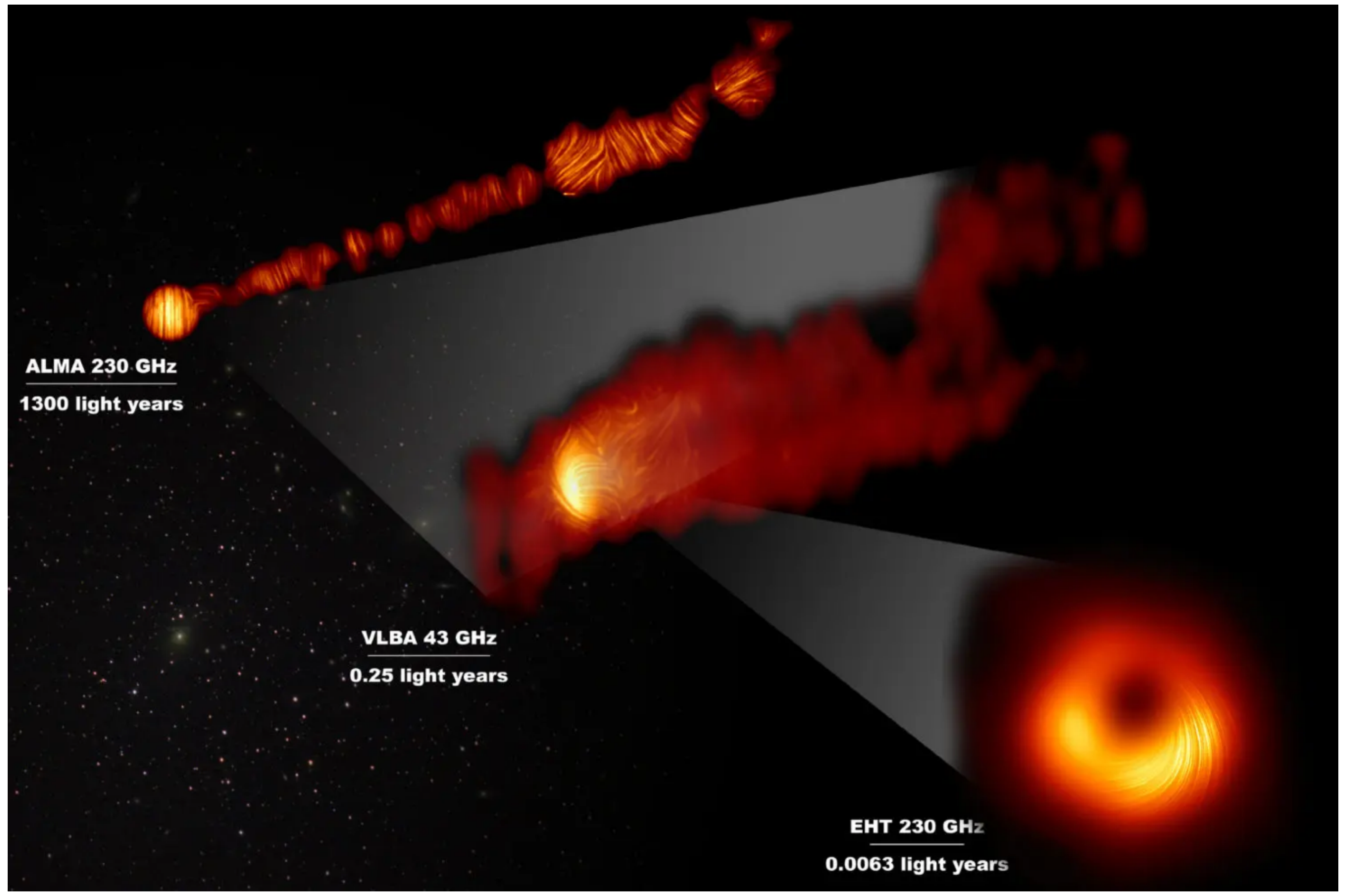


Image: H. Craft Jr/J. Christiansen, S.Janowiecki/GASS, OzGrav/Swinburne, P. Zhang, Project ESCAPE, NASA, EHT Collaboration

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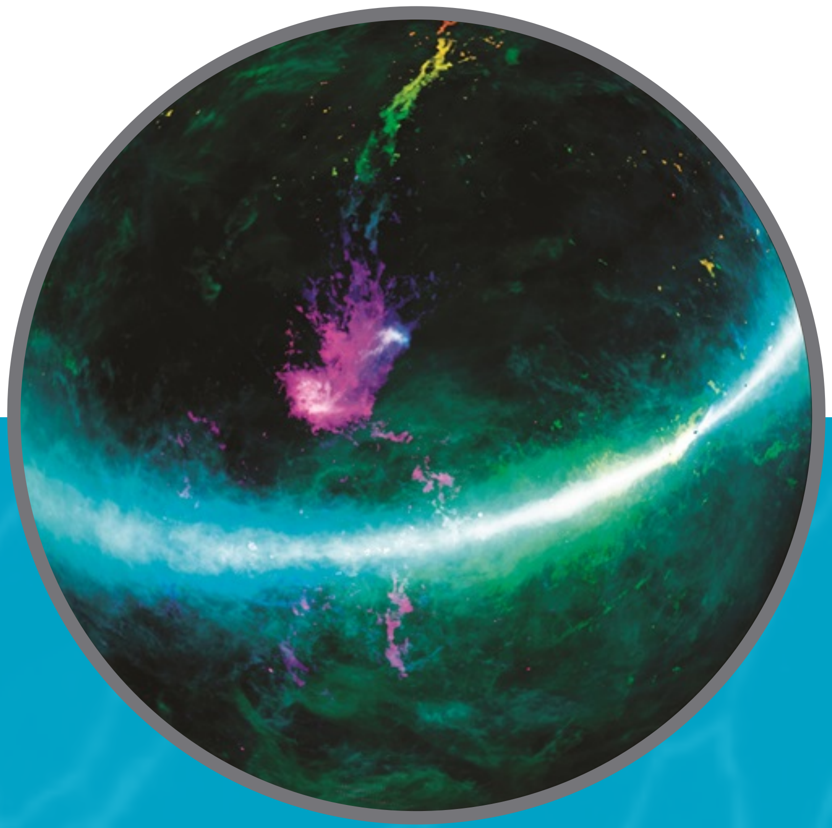

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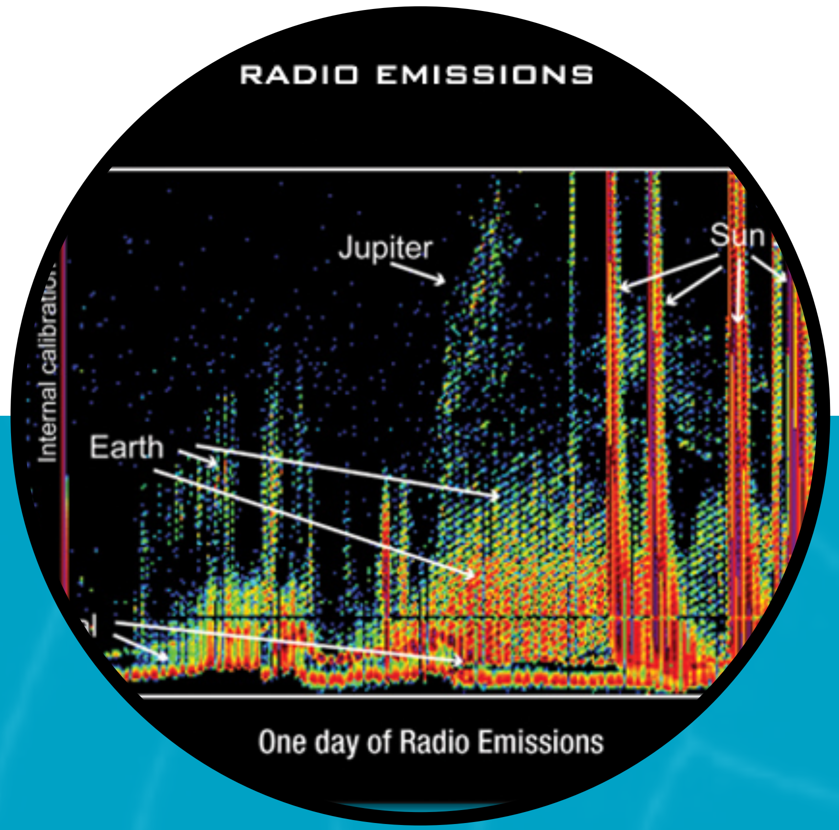

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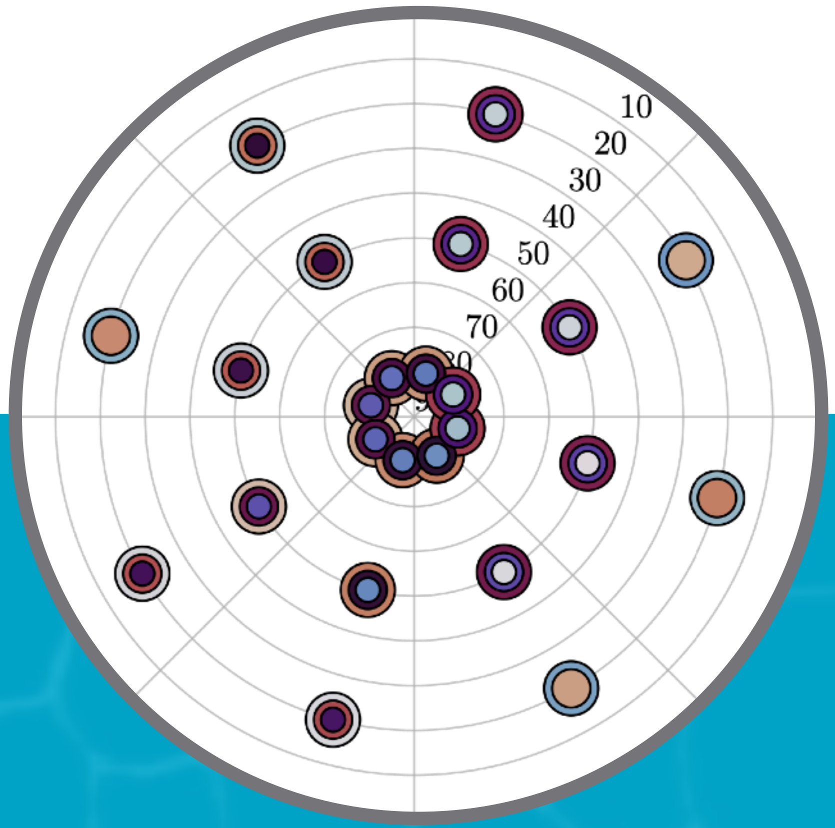
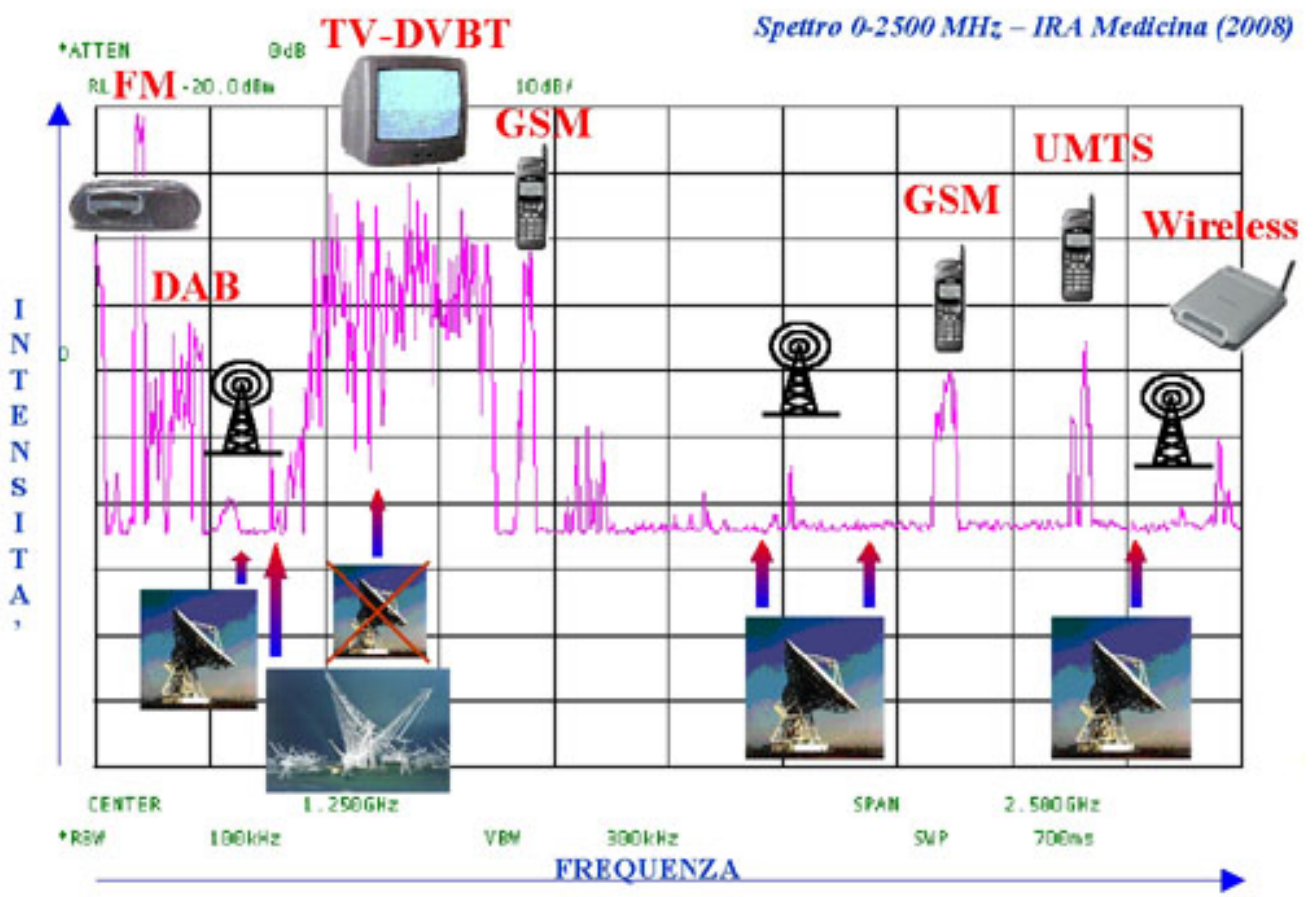


Case studies in RFI

Considering the future

Most signals are very faint

- Units of **Jansky** are used: ~1 Jy sources being the very brightest radio galaxies
- Comparison: 1 Watt mobile phone on the Moon at 1.8 GHz estimated to emit **1.45 Jy** (Astroquizzical/Jillian Scudder)
- Many signal detections are in the **noise**, swamped by other sources of interference
- Radio astronomy depends on detecting **fainter** signals with **larger** telescopes



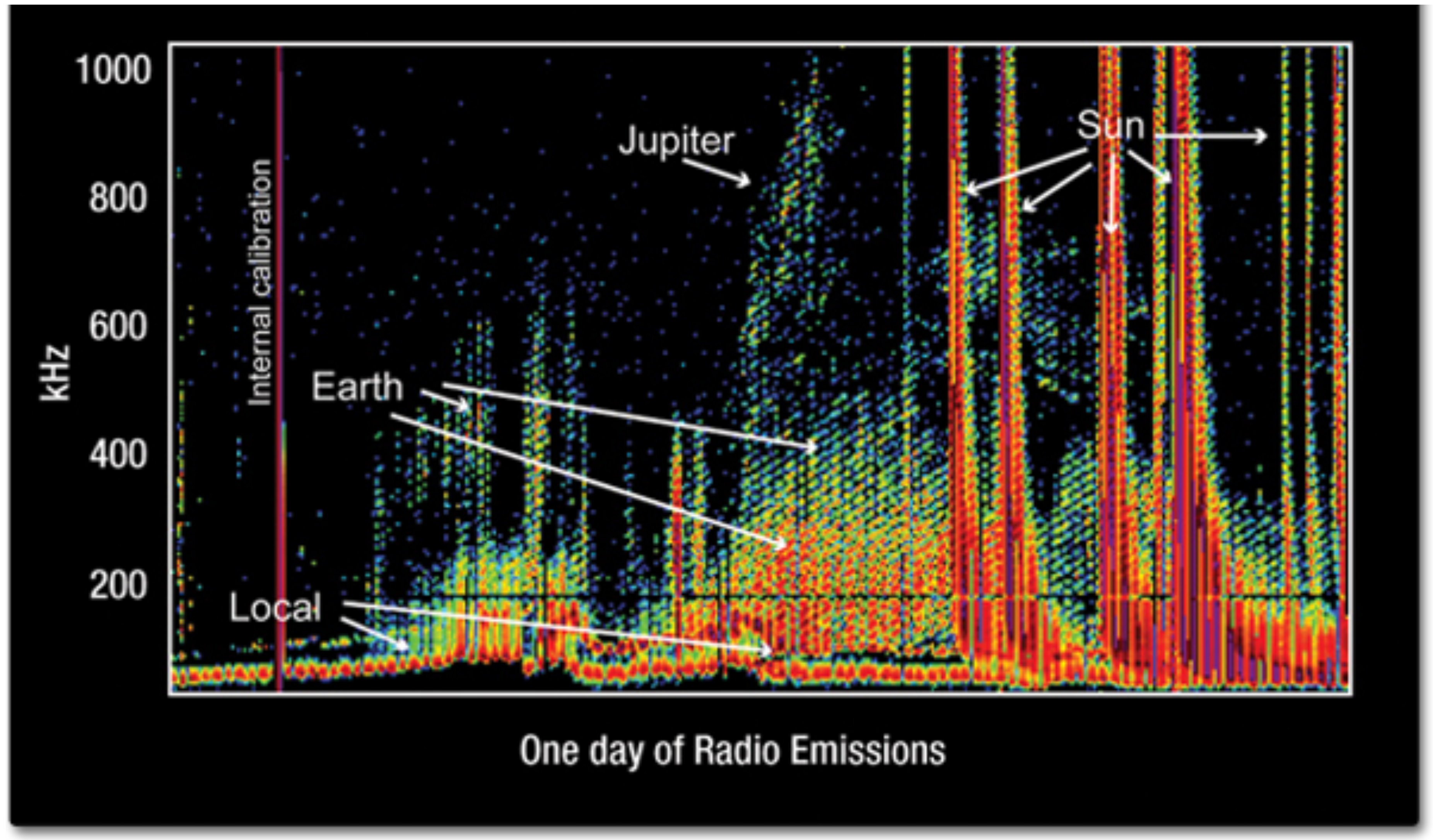
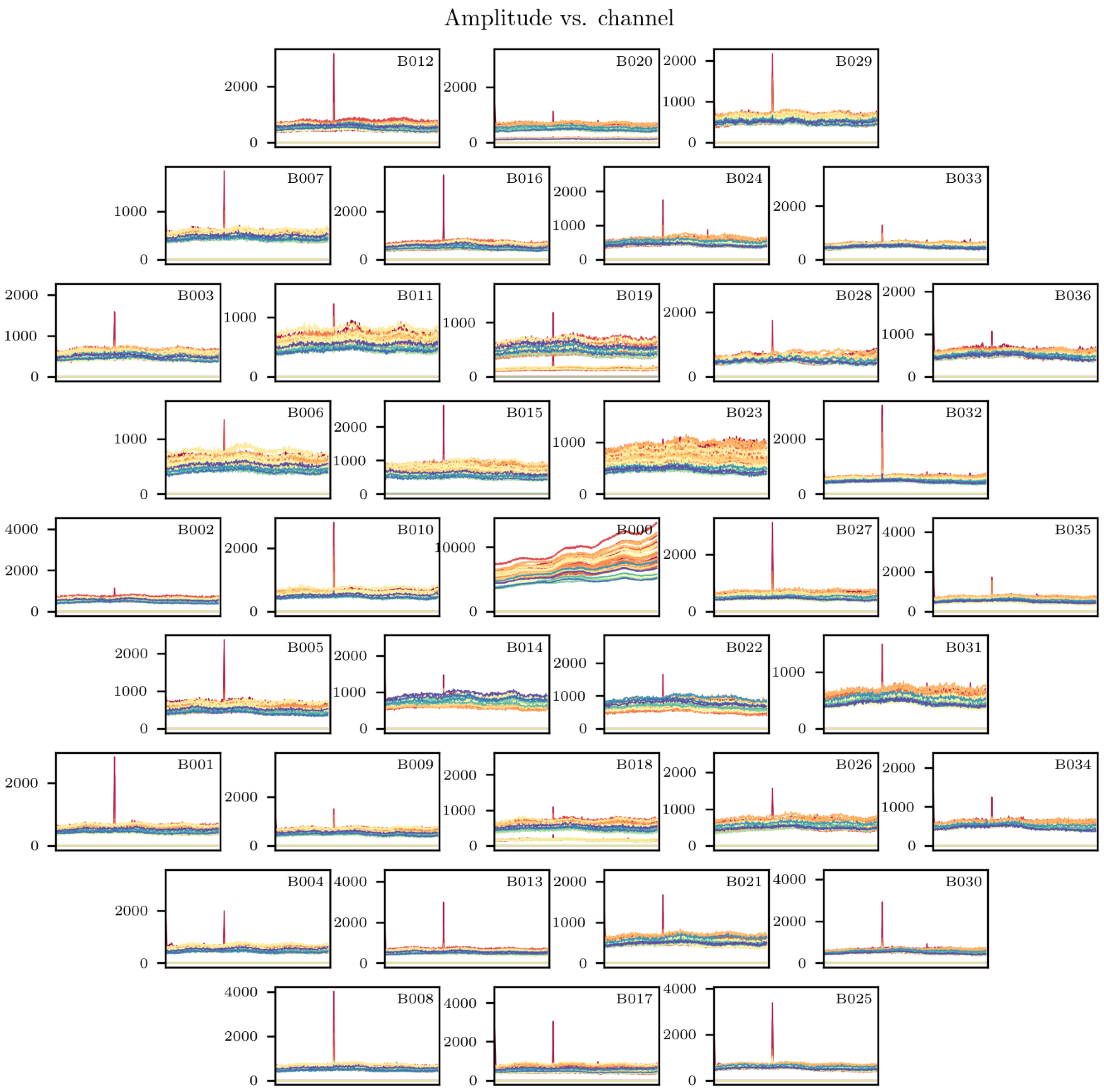


Image: IRA Medicina, NASA/GSFC

Normal observation (WSRT-Apertif)



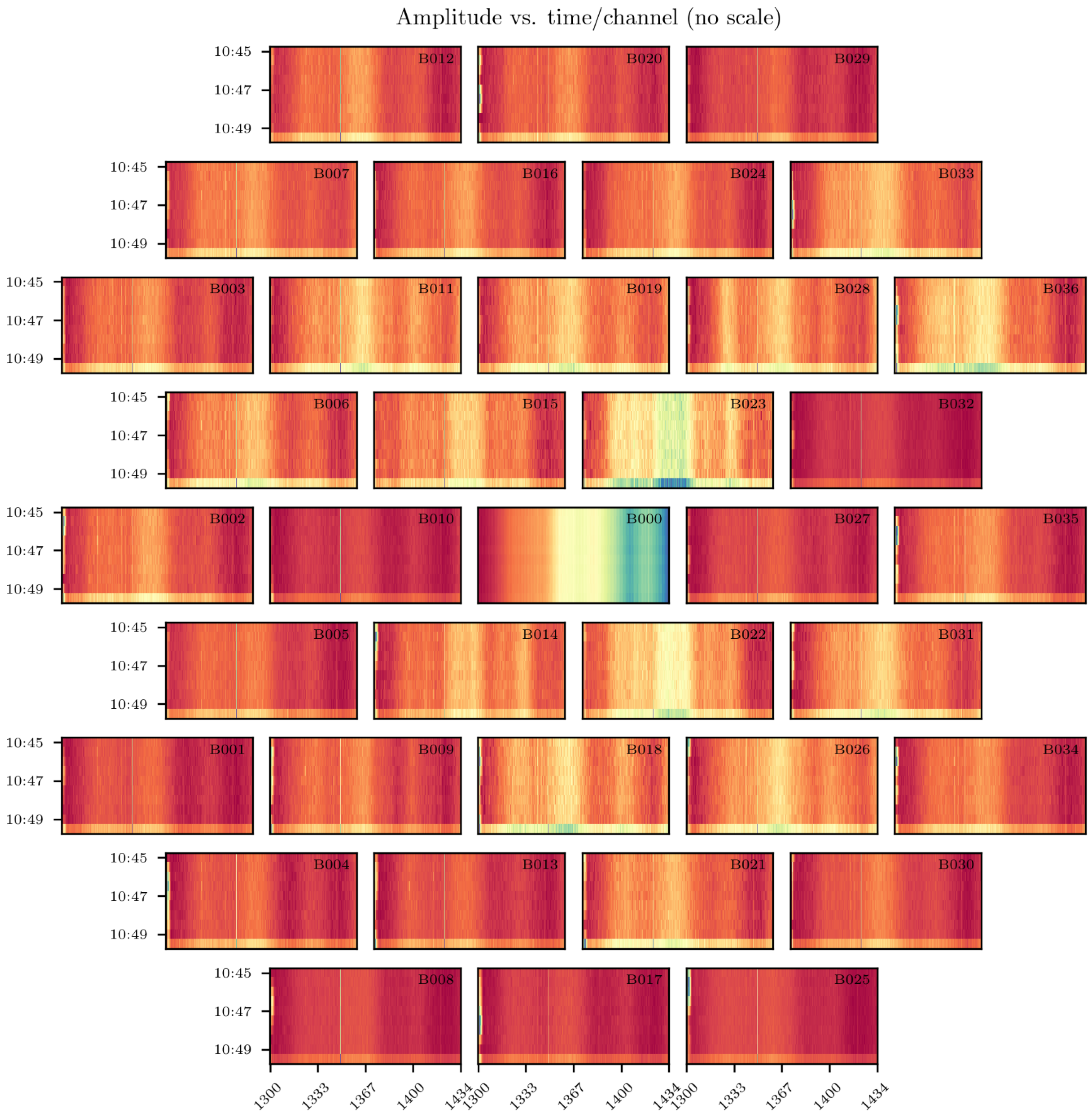
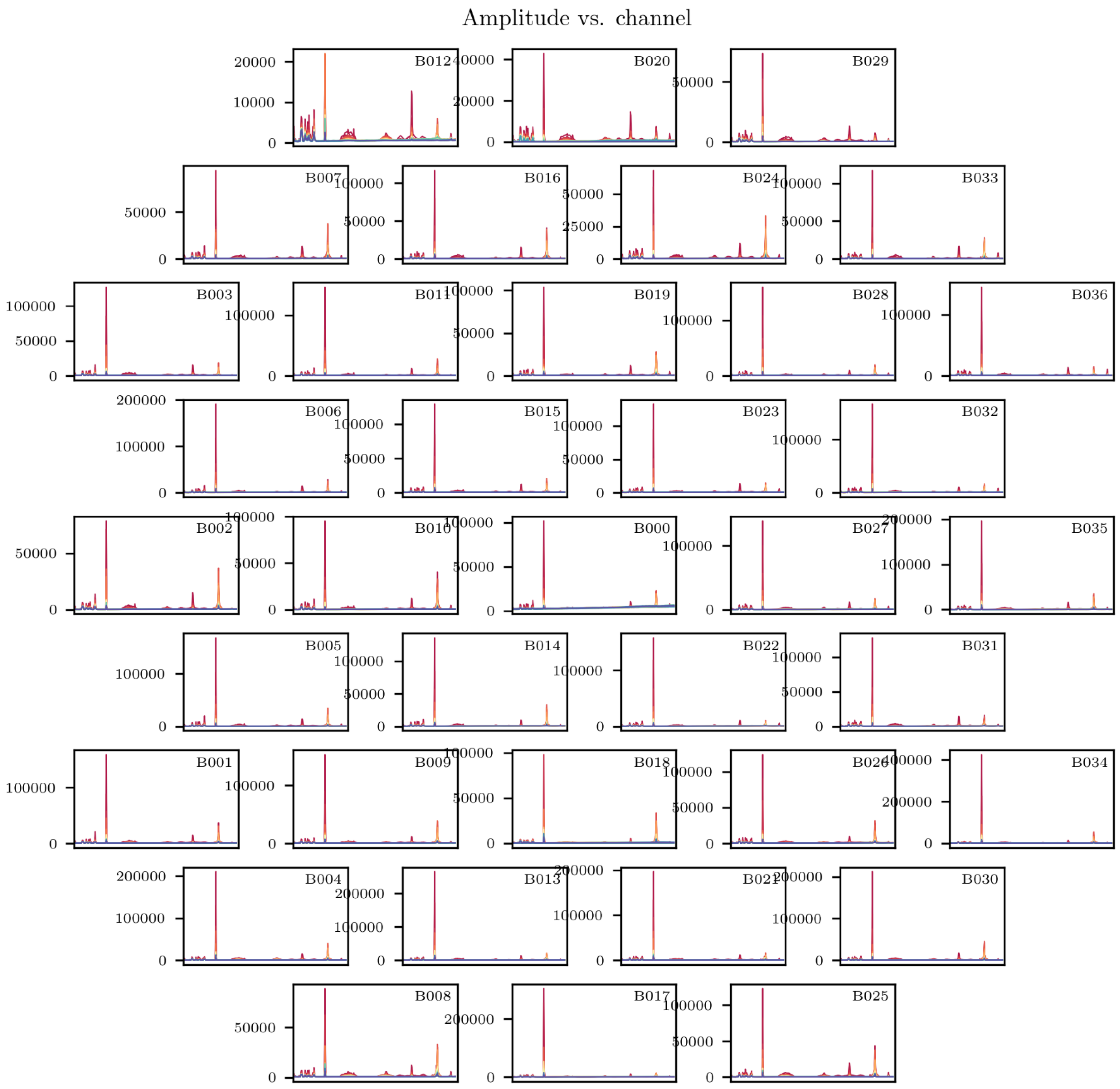


Image: V. Moss/Apertif

RFI-affected observation (WSRT-Apertif)



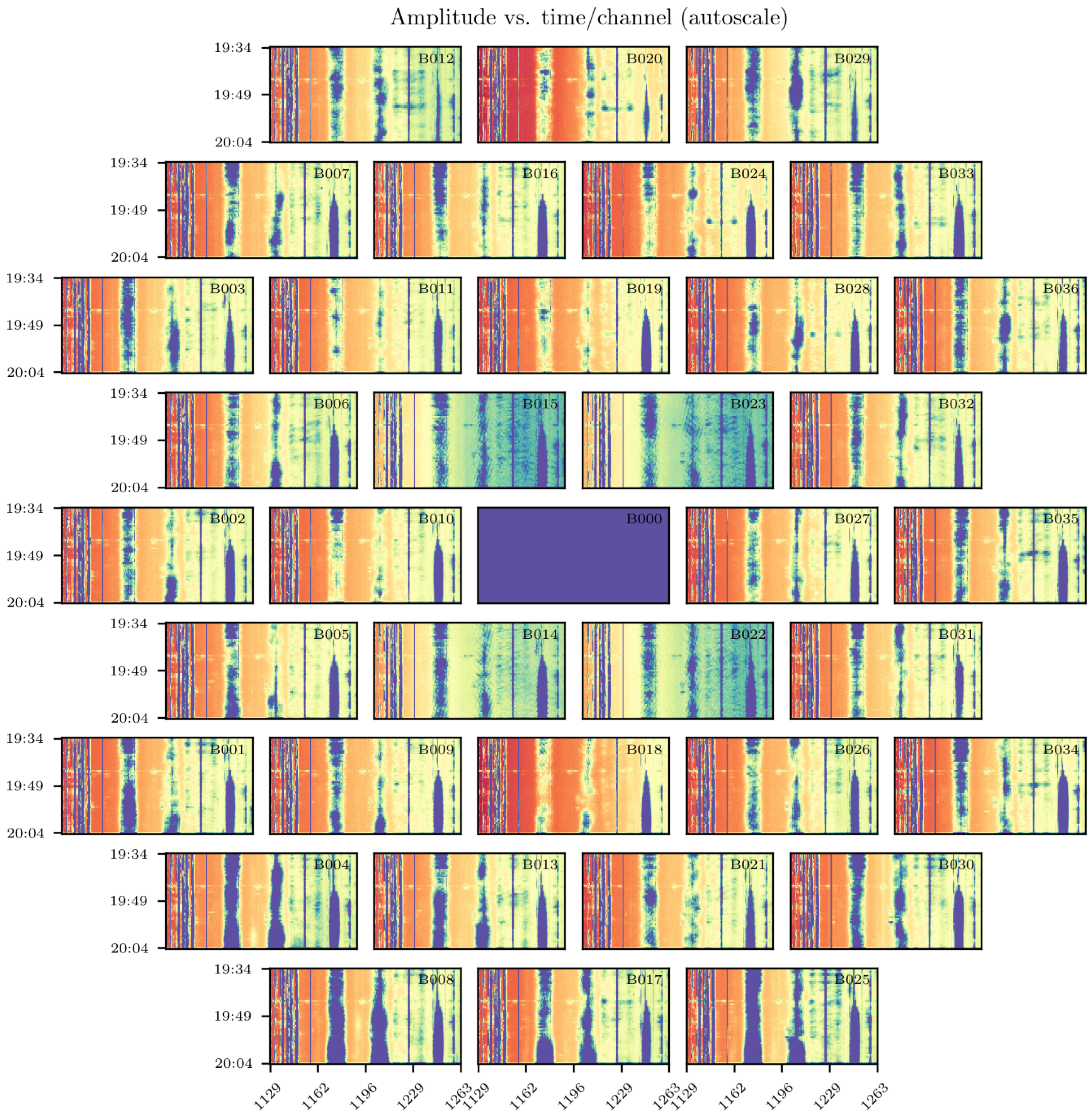
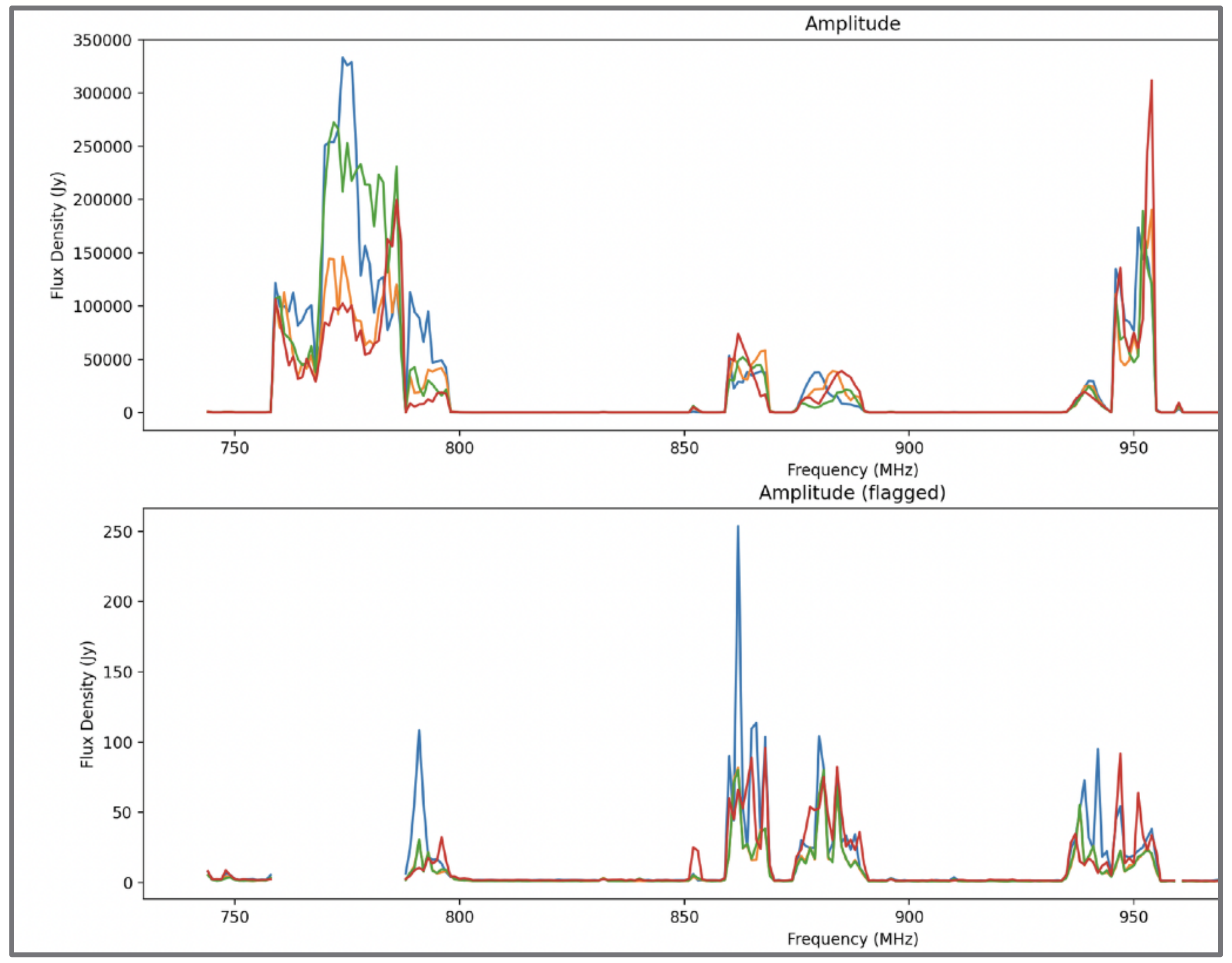
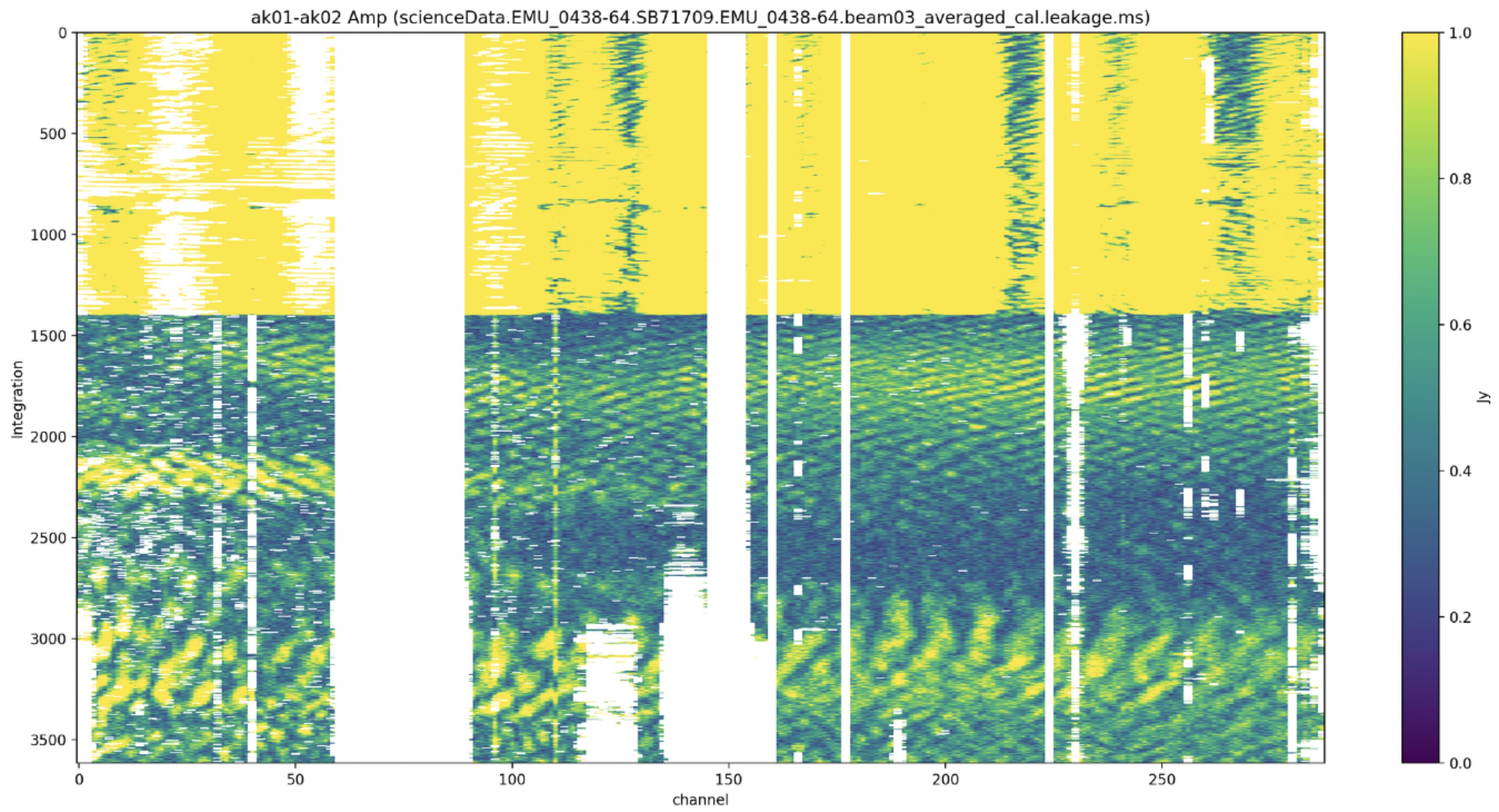
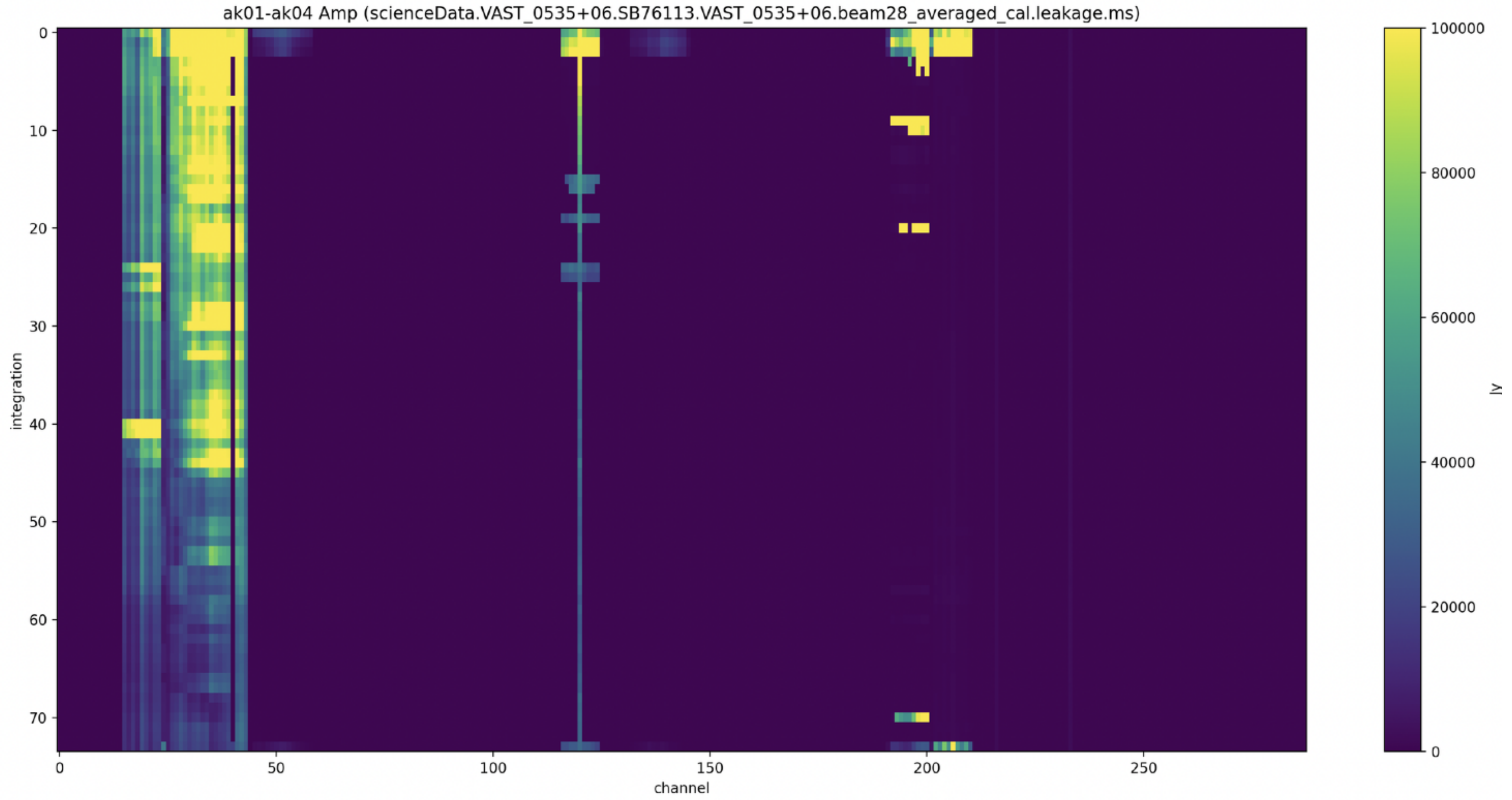


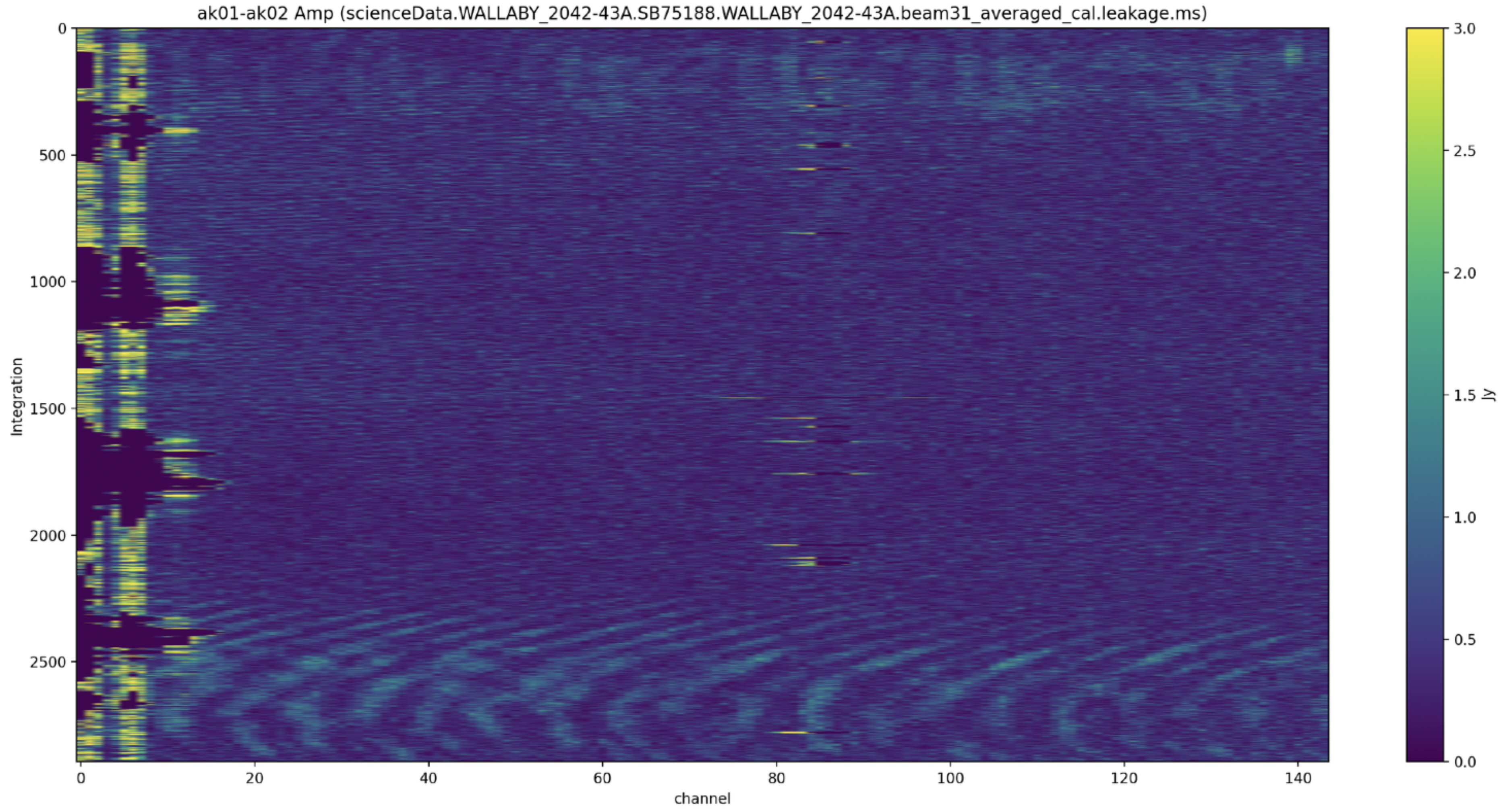
Image: V. Moss/Apertif

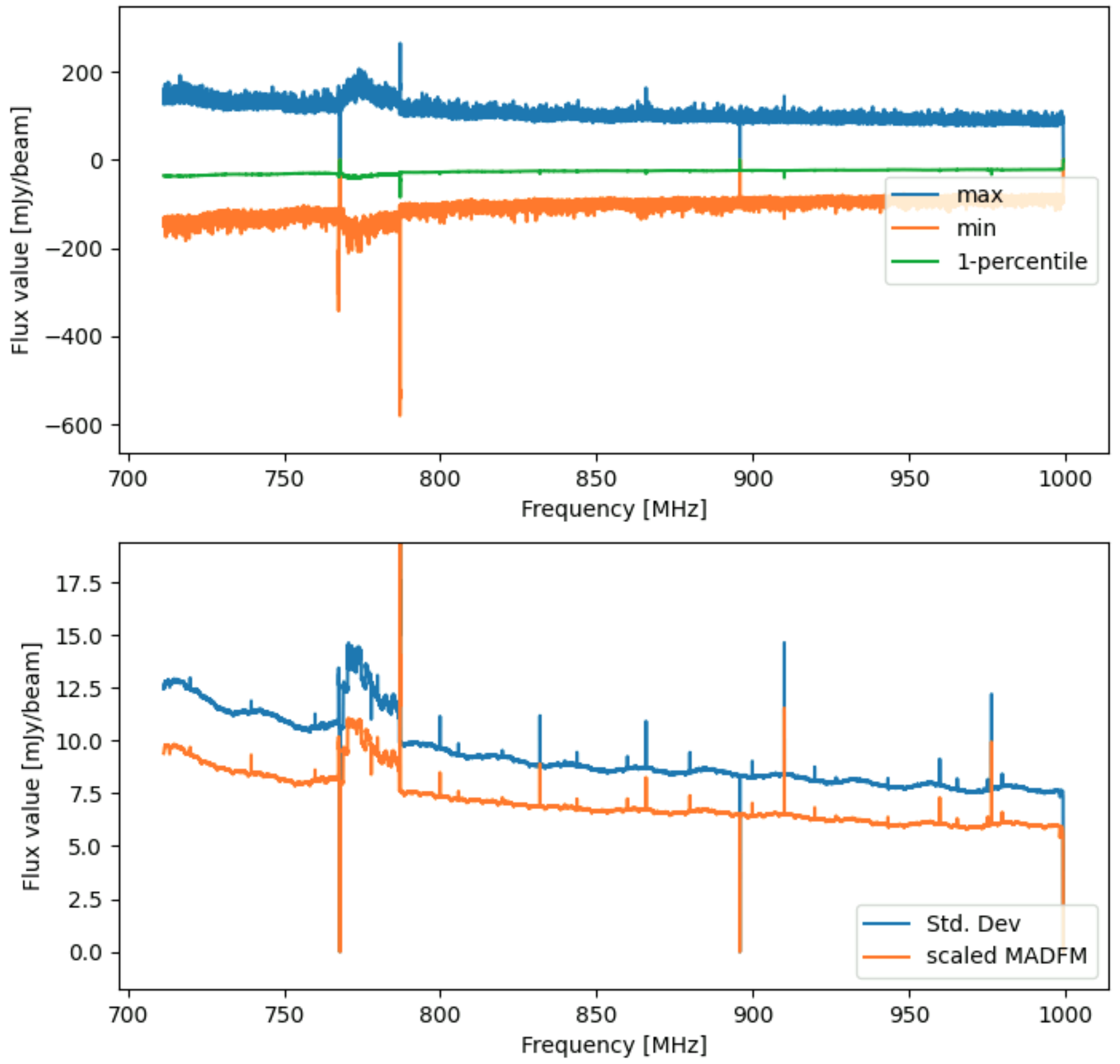
Examples of RFI impacts (ASKAP)











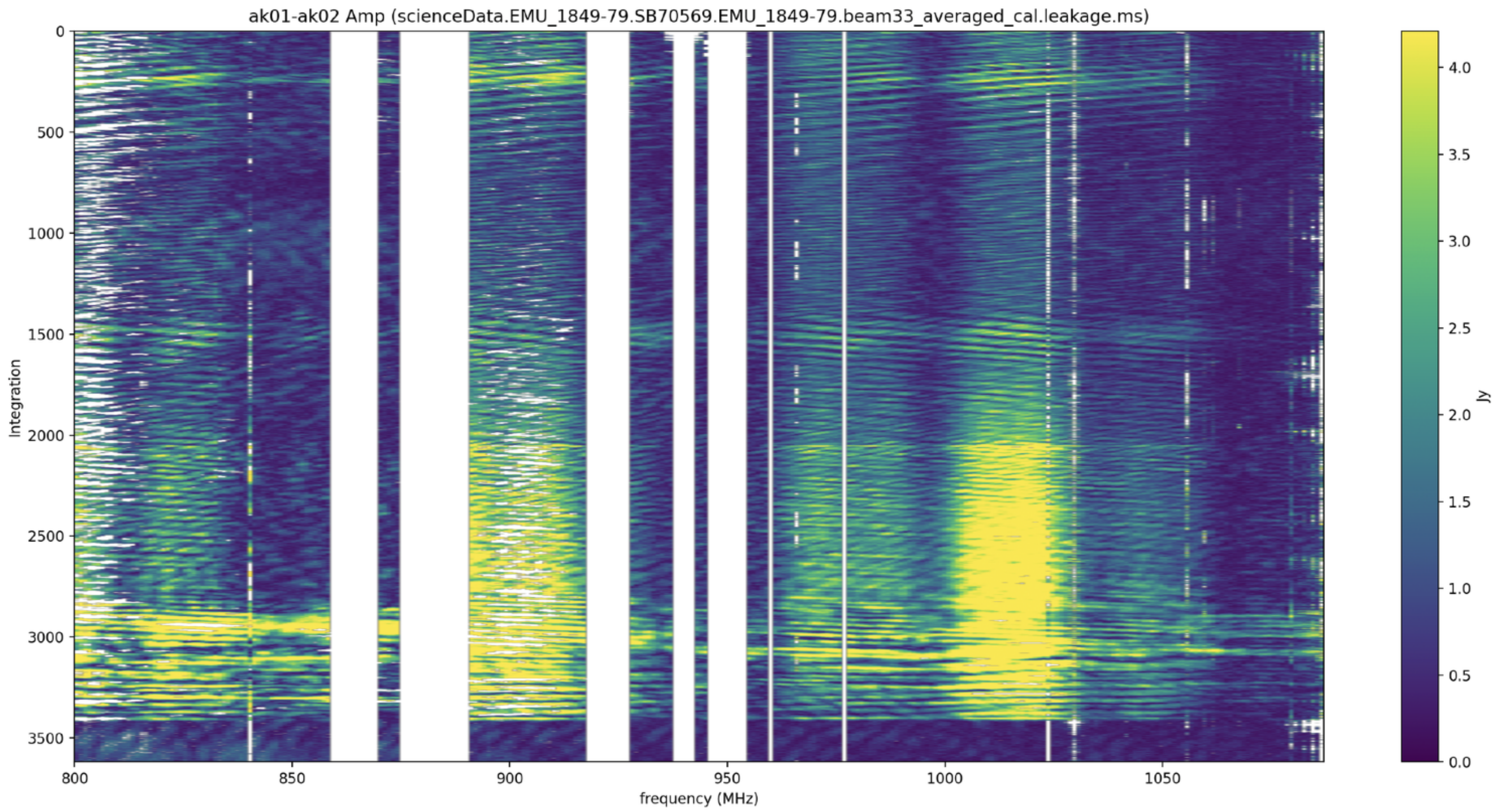


Image: E. Lenc, M. Whiting

Humans rely heavily on radio technologies

- Technology at **radio frequencies** is an important part of our daily lives!
- (… radio astronomy played a key role in the practical implementation of **WiFi**)
- The quest for **ubiquitous connectivity** leads to new allocations, filling spectral holes and maximising efficient usage
- More and more **powerful transmitters** in all directions impacts radio astronomy

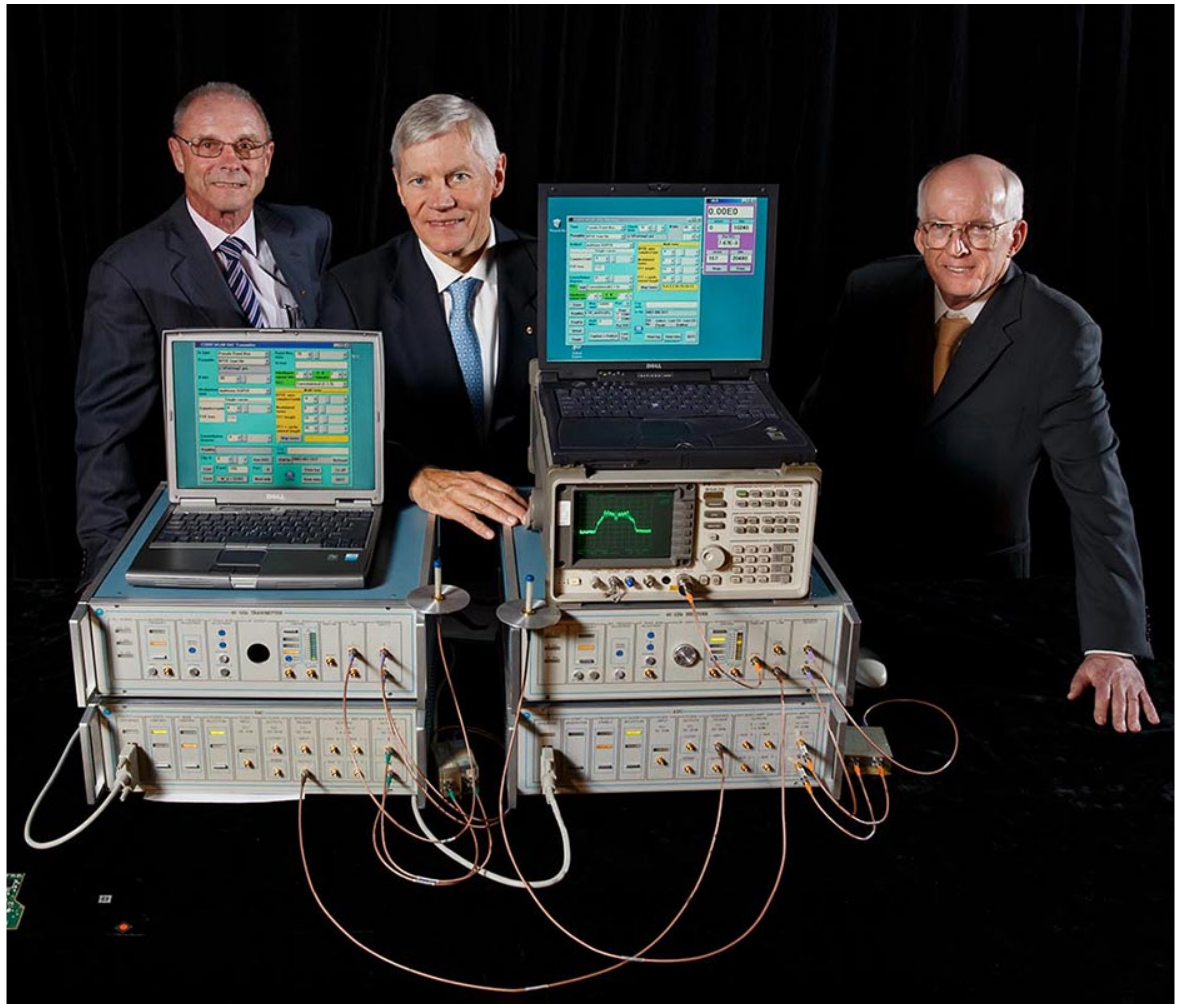
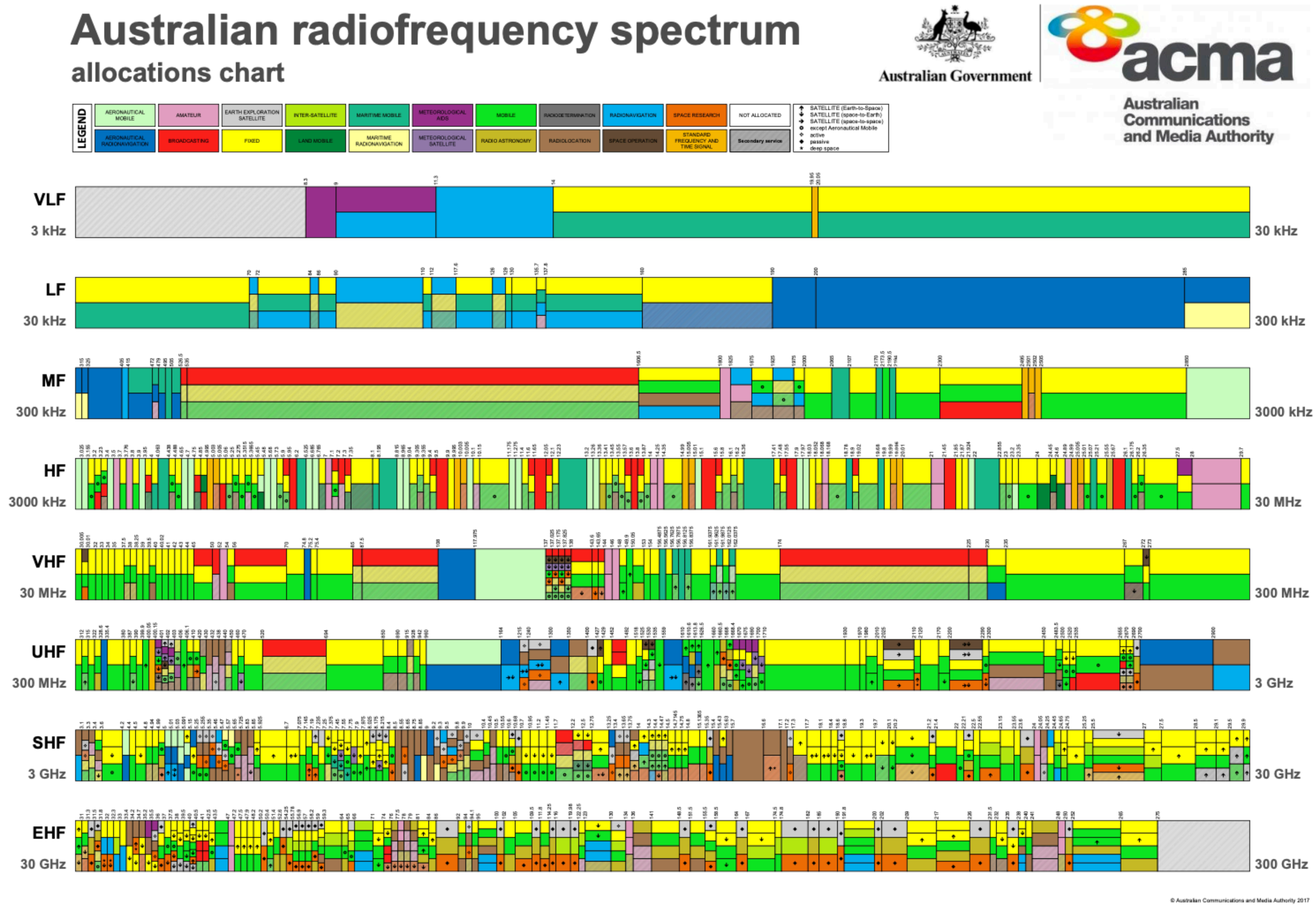


Image: National Museum of Australia

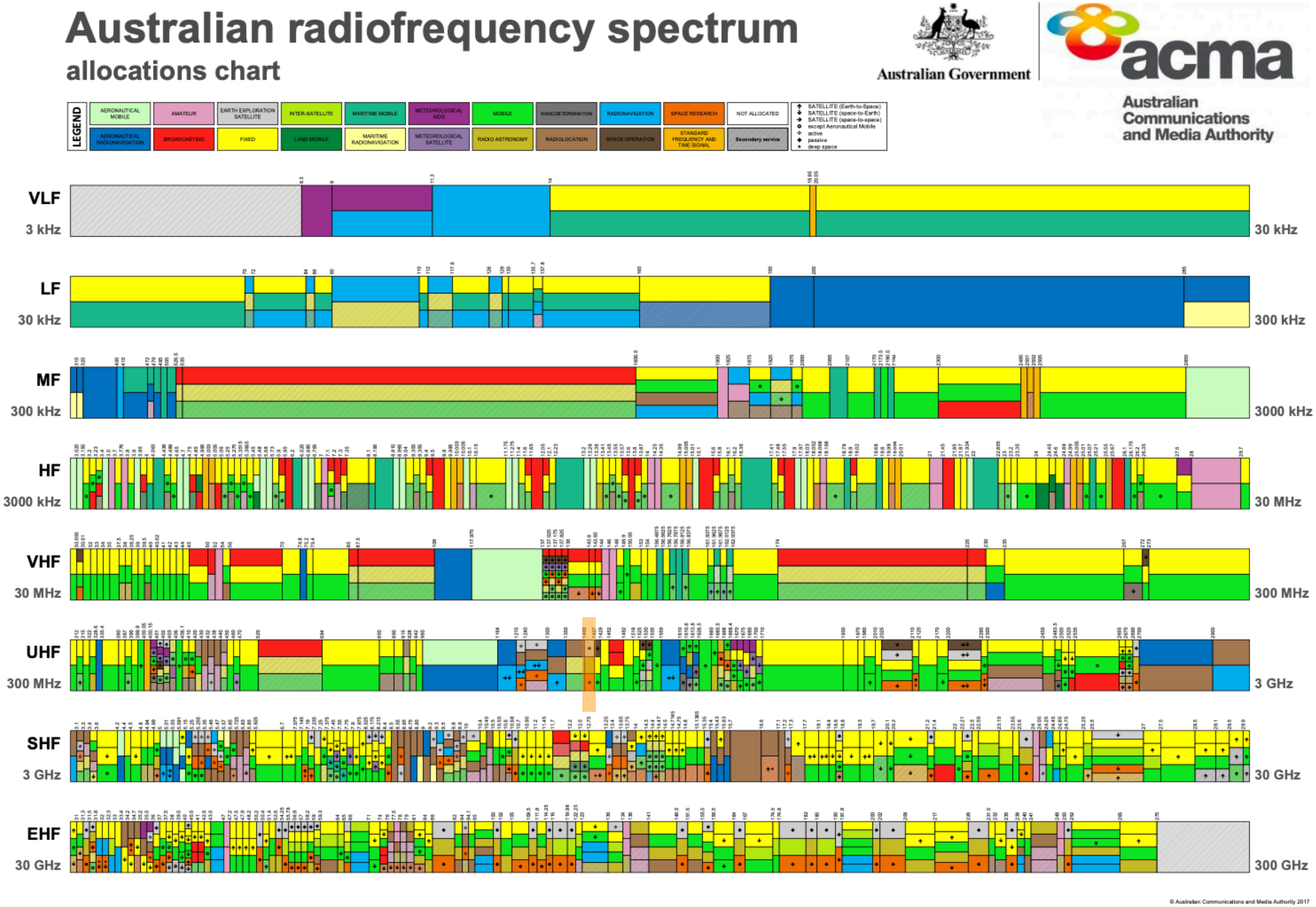


RADIO ASTRONOMY

EARTH EXPLORATION SATELLITE

SPACE RESEARCH

Image: ACMA



RADIO ASTRONOMY

EARTH EXPLORATION SATELLITE

SPACE RESEARCH

Image: ACMA

The rise of wide bandwidth astronomy

- Protected bands are **insufficient** on their own - limited, small bandwidth, redshift
- Technology allows for wider bands, with **great scientific gain** via parameter space
- Wider bands help improve **sensitivity** (in the absence of RFI), and are **required** to observe redshifted spectral lines that are "pushed" outside the protected bands
- **Impacted** by increased spectrum usage

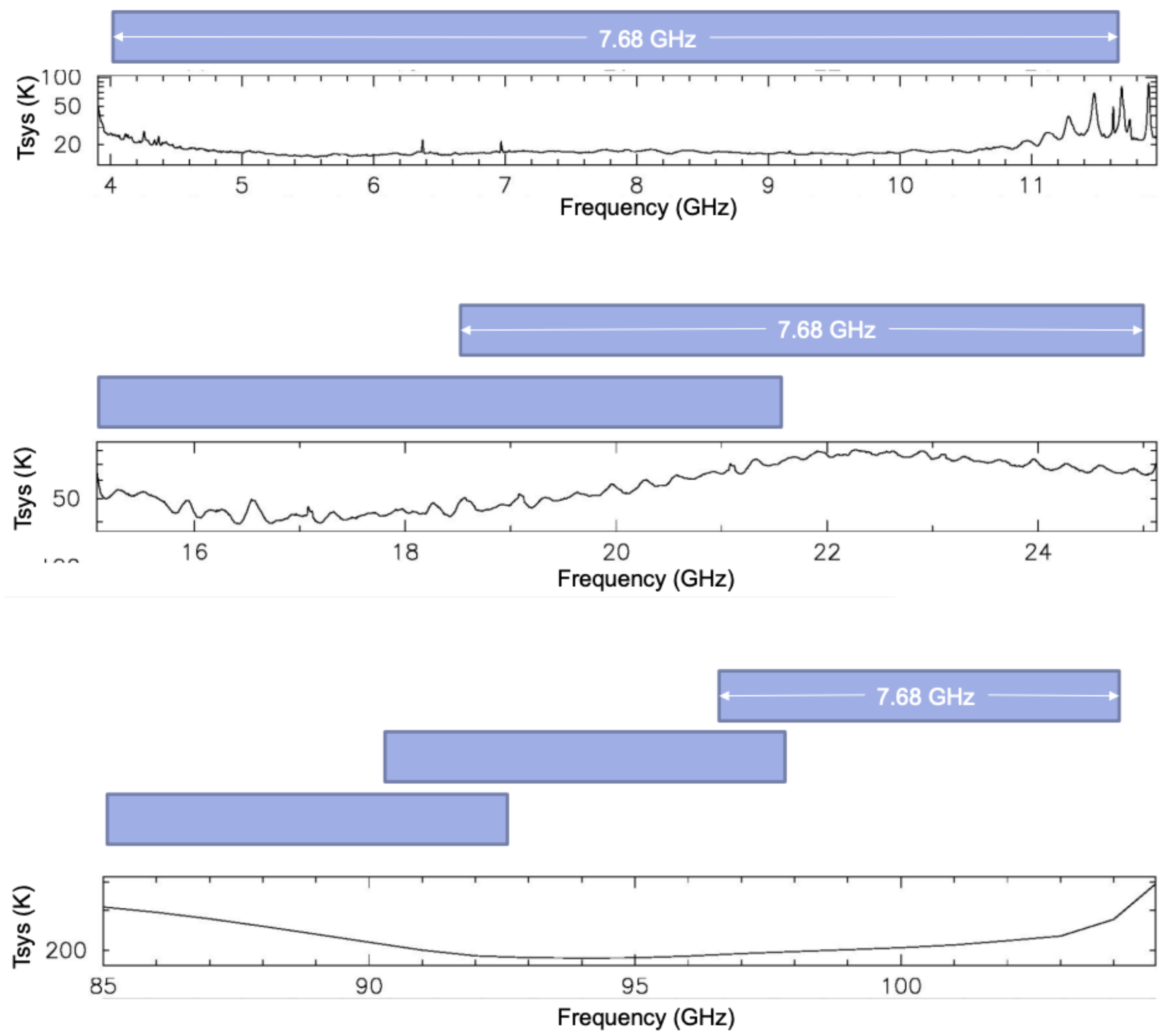


Image: BIGCAT/CSIRO

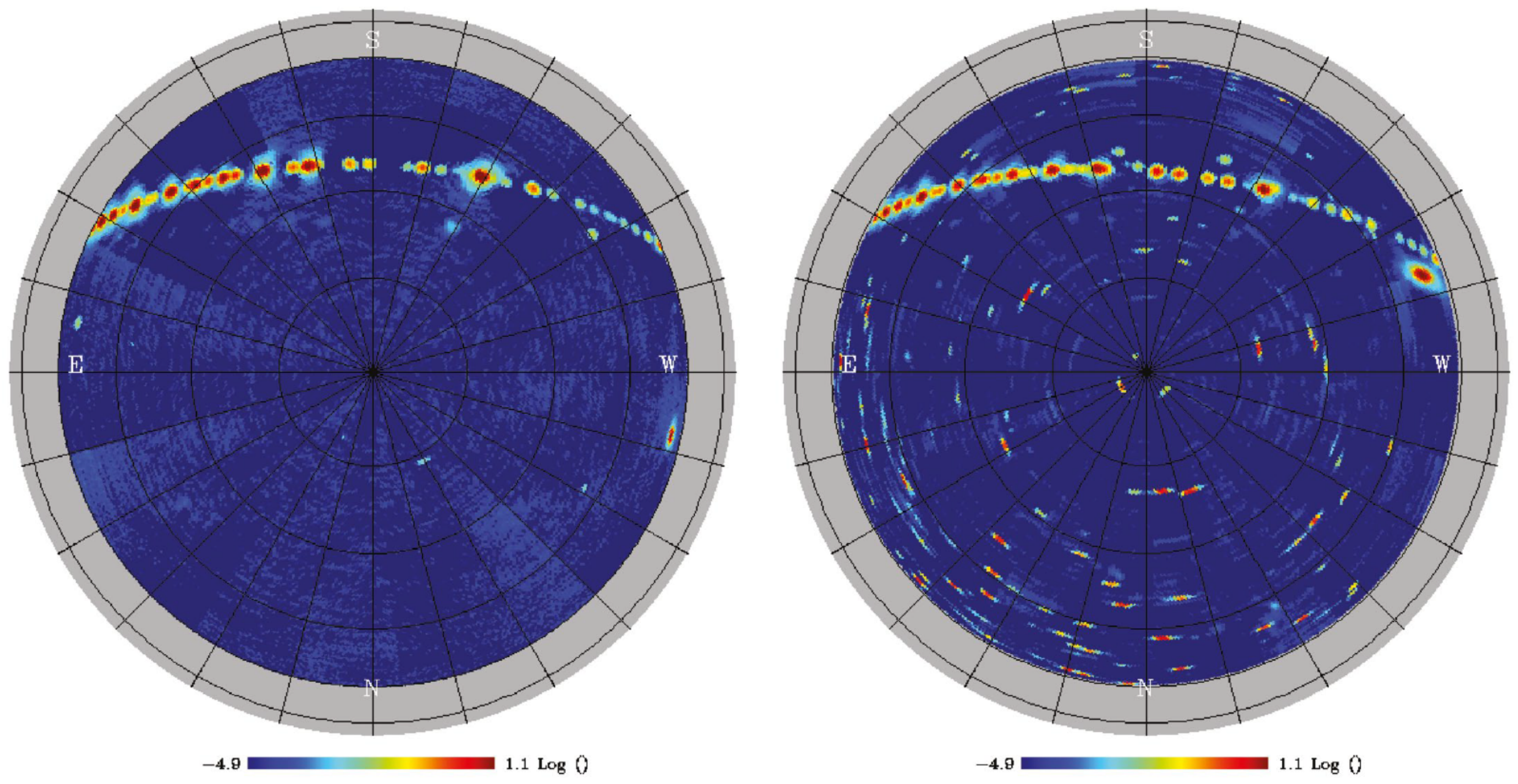
The role of radio quiet zones

- Radio quiet zones are highly valuable to preserve **clean spectrum** environments for astronomy
- Not an **infinitely scalable** approach *(the Moon*)*
- Land legislation is more established than the sky - big impacts from **growing satellite interference**

Image: CSIRO, ASKAP vs. Parkes Murriyang spectrum (B. Indermuehle)

Impact from satellites

- Certain frequency ranges are **already lost** for radio astronomy (e.g. ASKAP mid-band reduced by half to 144 MHz)
- **Massive growth** in satellite launches, sky is increasingly **crowded**
- Avoidance has **limited effect**, e.g. in long tracks and wide fields of view
- Direct, indirect, **surprise*** emissions



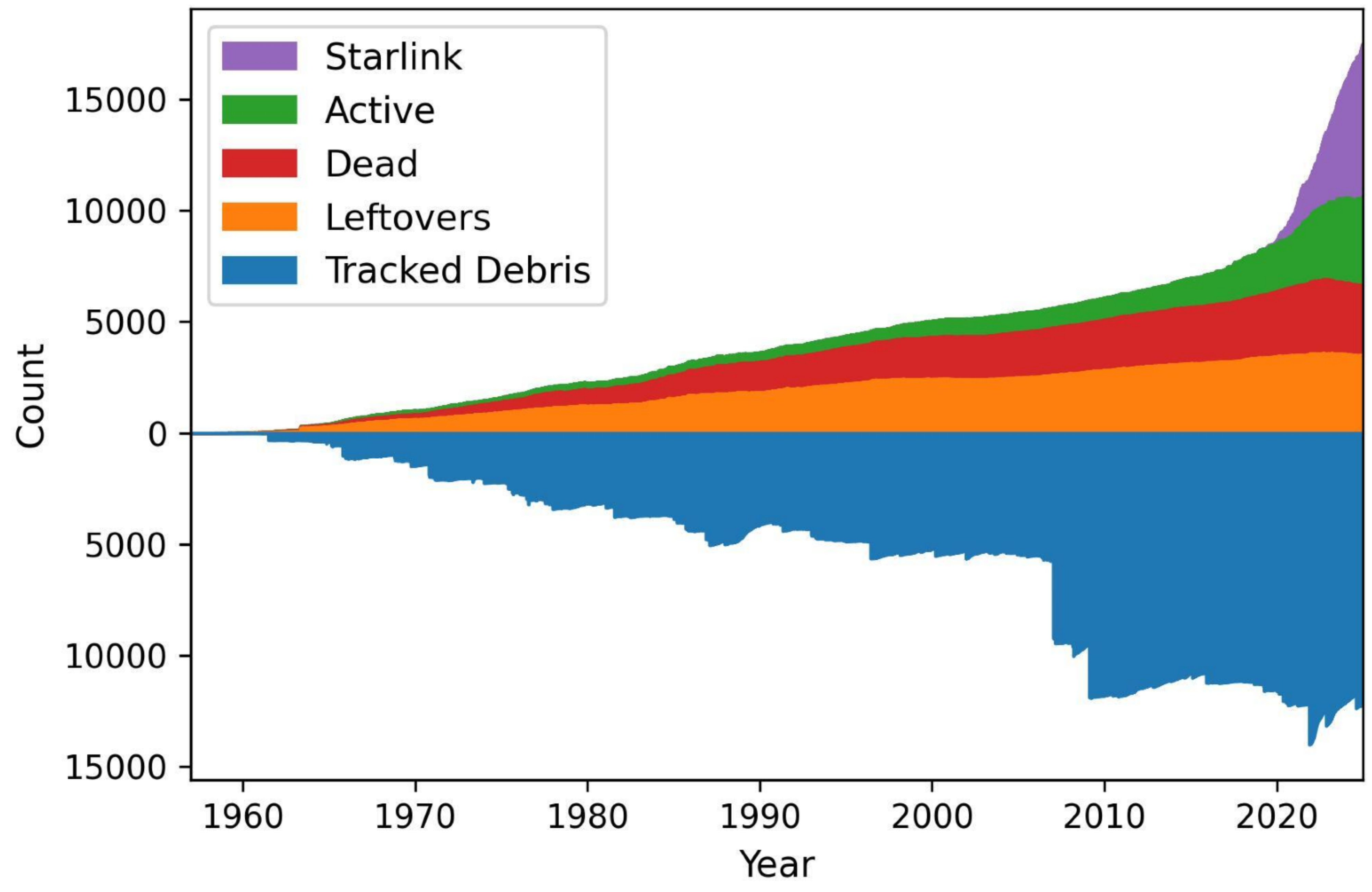
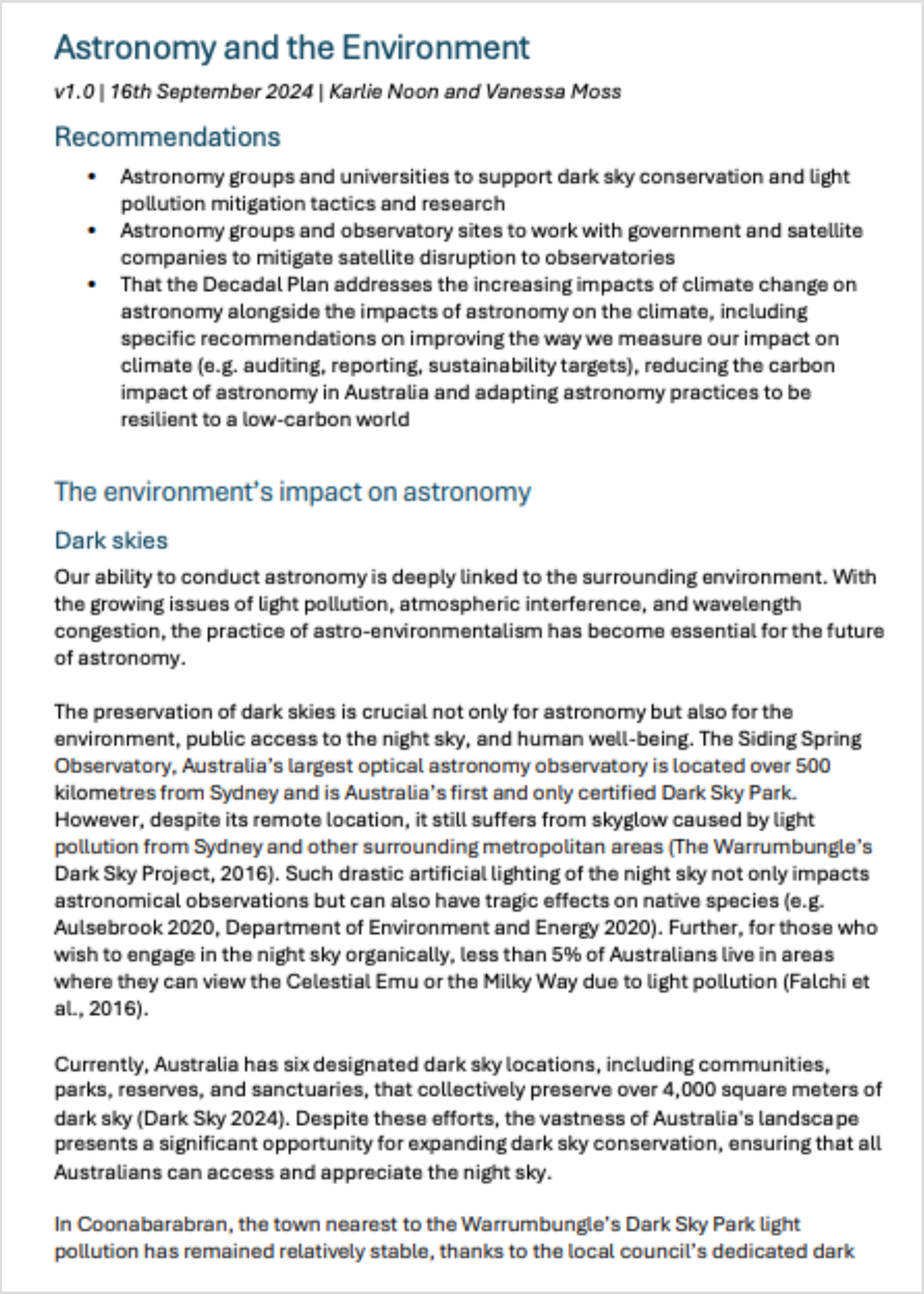


Image: QUIJOTE Collaboration, M. Peel/J. McDowell

Dark skies for radio astronomy

- Radio astronomy requires "**dark skies**" in the same way as optical astronomy, e.g. far away from population centres, **remote locations** and **high altitudes** for high frequencies (atmosphere)
- **Population displacement** for various reasons can change the spectrum landscape, impacting telescope sites
- Climate change as **highly disruptive**



Astronomy and the Environment

v1.0 | 16th September 2024 | Karlie Noon and Vanessa Moss

Recommendations

- Astronomy groups and universities to support dark sky conservation and light pollution mitigation tactics and research
- Astronomy groups and observatory sites to work with government and satellite companies to mitigate satellite disruption to observatories
- That the Decadal Plan addresses the increasing impacts of climate change on astronomy alongside the impacts of astronomy on the climate, including specific recommendations on improving the way we measure our impact on climate (e.g. auditing, reporting, sustainability targets), reducing the carbon impact of astronomy in Australia and adapting astronomy practices to be resilient to a low-carbon world

The environment's impact on astronomy

Dark skies

Our ability to conduct astronomy is deeply linked to the surrounding environment. With the growing issues of light pollution, atmospheric interference, and wavelength congestion, the practice of astro-environmentalism has become essential for the future of astronomy.

The preservation of dark skies is crucial not only for astronomy but also for the environment, public access to the night sky, and human well-being. The Siding Spring Observatory, Australia's largest optical astronomy observatory is located over 500 kilometres from Sydney and is Australia's first and only certified Dark Sky Park. However, despite its remote location, it still suffers from skyglow caused by light pollution from Sydney and other surrounding metropolitan areas (The Warrumbungle's Dark Sky Project, 2016). Such drastic artificial lighting of the night sky not only impacts astronomical observations but can also have tragic effects on native species (e.g. Aulsebrook 2020, Department of Environment and Energy 2020). Further, for those who wish to engage in the night sky organically, less than 5% of Australians live in areas where they can view the Celestial Emu or the Milky Way due to light pollution (Falchi et al., 2016).

Currently, Australia has six designated dark sky locations, including communities, parks, reserves, and sanctuaries, that collectively preserve over 4,000 square meters of dark sky (Dark Sky 2024). Despite these efforts, the vastness of Australia's landscape presents a significant opportunity for expanding dark sky conservation, ensuring that all Australians can access and appreciate the night sky.

In Coonabarabran, the town nearest to the Warrumbungle's Dark Sky Park light pollution has remained relatively stable, thanks to the local council's dedicated dark

Image: "Astronomy and the Environment" requested white paper for Australian Decadal Plan

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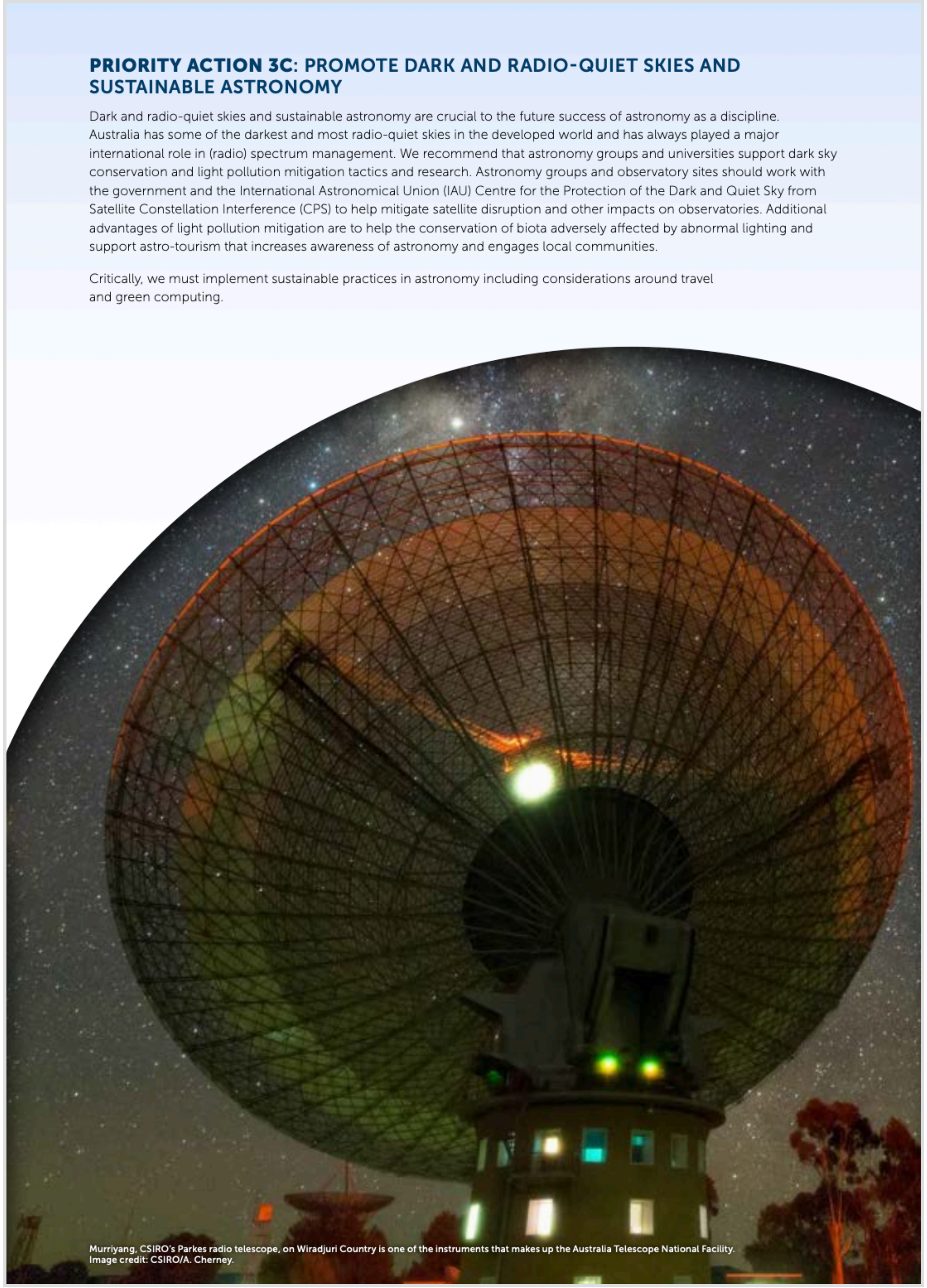

PRIORITY ACTION 3C: PROMOTE DARK AND RADIO-QUIET SKIES AND SUSTAINABLE ASTRONOMY

Dark and radio-quiet skies and sustainable astronomy are crucial to the future success of astronomy as a discipline. Australia has some of the darkest and most radio-quiet skies in the developed world and has always played a major international role in (radio) spectrum management. We recommend that astronomy groups and universities support dark sky conservation and light pollution mitigation tactics and research. Astronomy groups and observatory sites should work with the government and the International Astronomical Union (IAU) Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS) to help mitigate satellite disruption and other impacts on observatories. Additional advantages of light pollution mitigation are to help the conservation of biota adversely affected by abnormal lighting and support astro-tourism that increases awareness of astronomy and engages local communities.

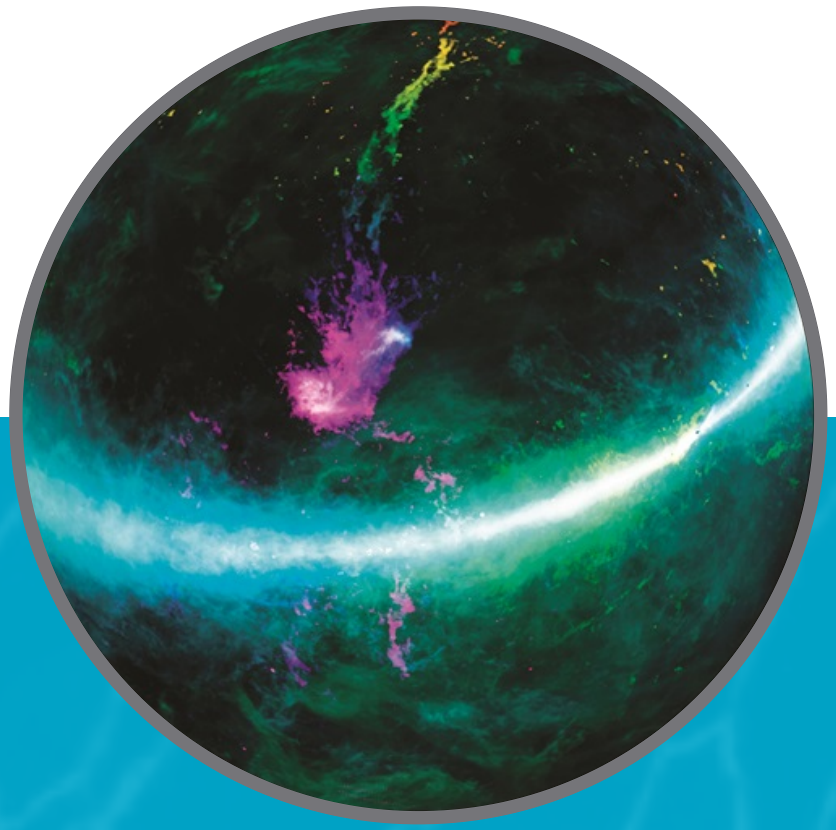
Critically, we must implement sustainable practices in astronomy including considerations around travel and green computing.

Murriyang, CSIRO’s Parkes radio telescope, on Wiradjuri Country is one of the instruments that makes up the Australia Telescope National Facility.
Image credit: CSIRO/A. Cherney.

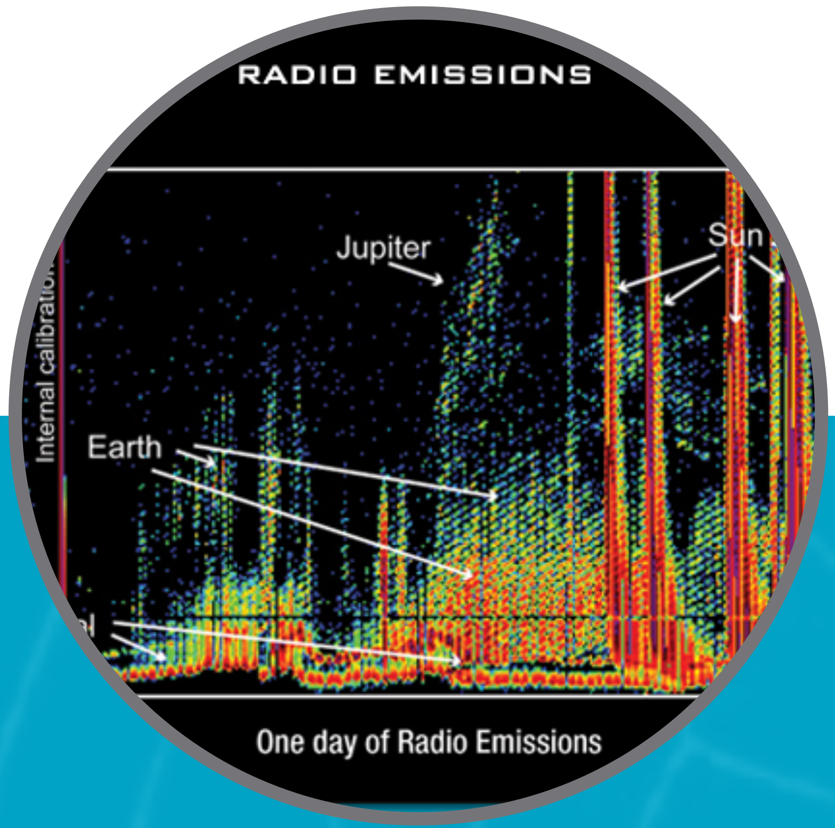
Image: Priority Action 3C from the Australian Decadal Plan for Astronomy 2026-2035

An overview of the impact of RFI on radio astronomy

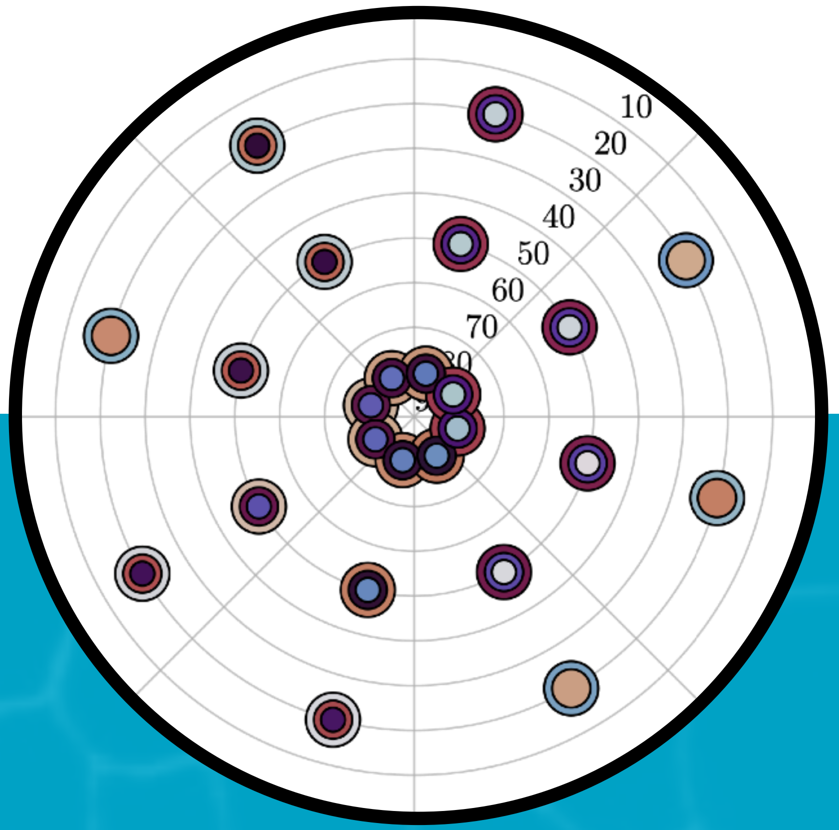
Contents of this talk



Introduction to radio astronomy



The impact and significance of RFI

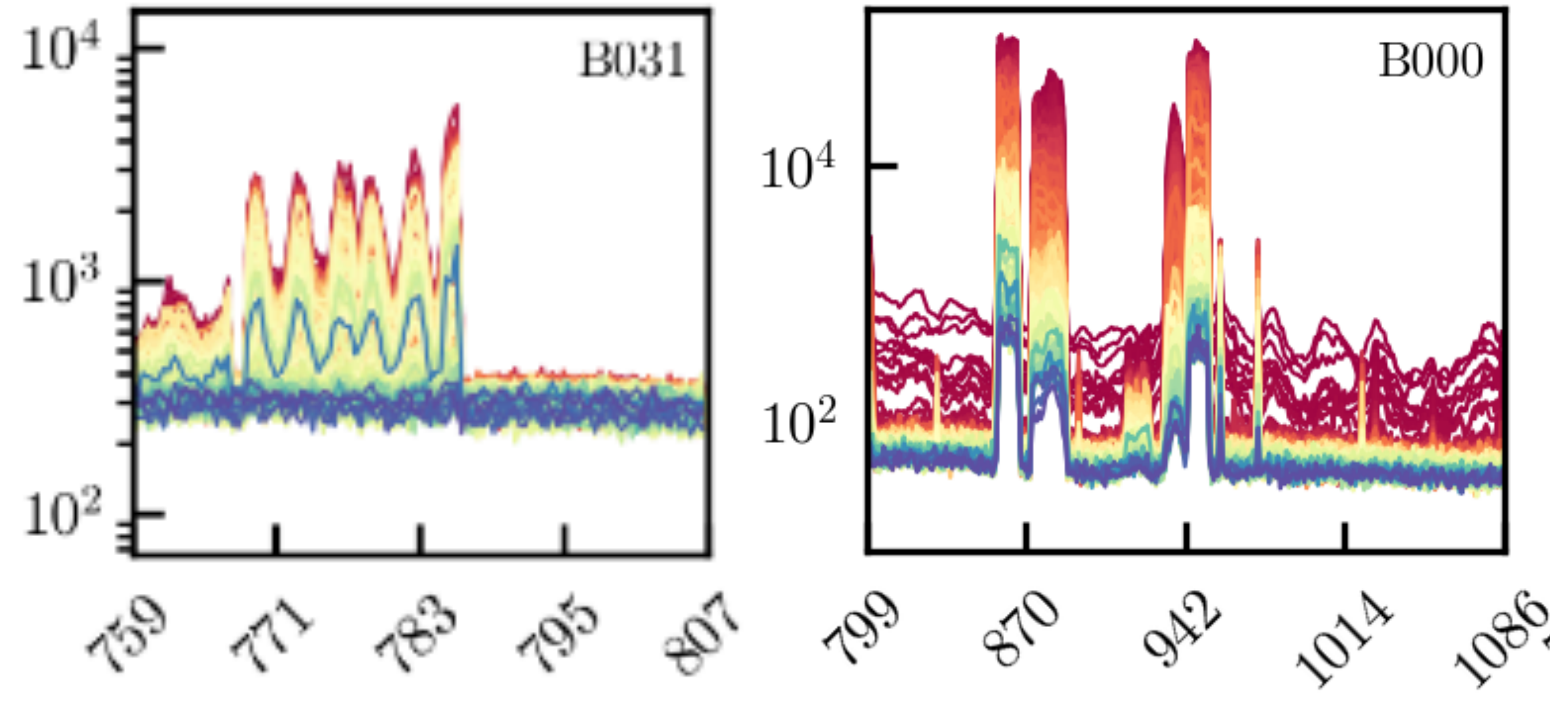


Case studies in RFI

Considering the future

Impact of tropospheric ducting on ASKAP

- Combination of **environmental** effect with increased RFI impact on data
- Can lose **entire sections** of bandwidth (Universe), as well as greatly reducing sensitivity and quality of the data
- RFI monitor **not as sensitive** - difficulty with using dynamic alerts (*prediction)
- Currently: observe within **specific UTC window** that minimises ducting chance



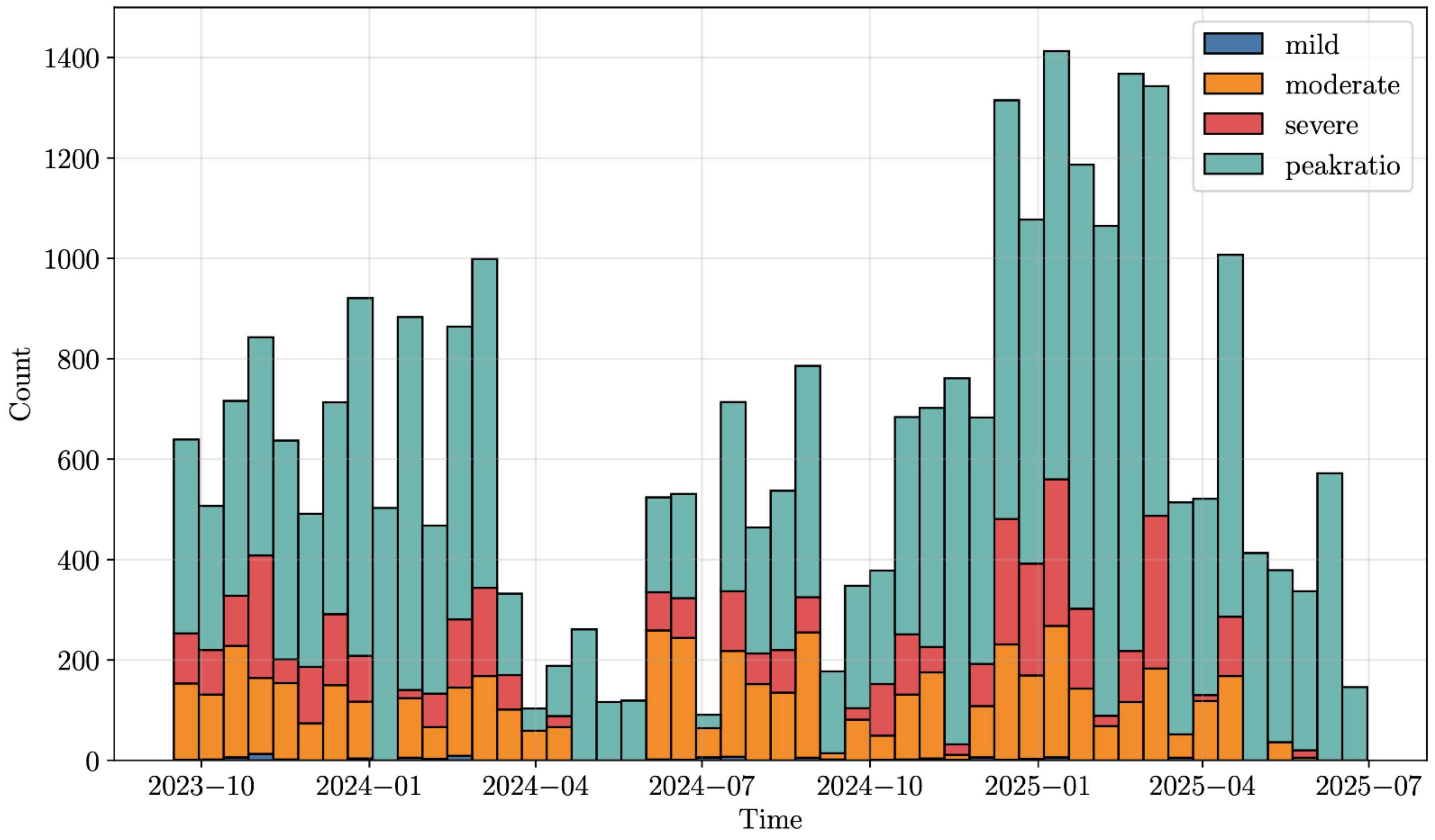


Image: ARWEN, V. Moss

SMART: RFI surveying for ASKAP

- **SMART**: Survey and Monitoring of ASKAP's RFI environment and Trends (PI: Liroy Lourenco, see also **Lourenco et al. 2023**)
- Five footprints chosen to cover the full ASKAP frequency range from **700-1800 MHz**, recording data in full-resolution mode
- Positions consist of **8 directions, 3 elevations (20, 50, 80 degrees)** to cover the whole sky, with the strategy to revisit each position three times across different UTCs during a 24 hour period
- Initial trial epoch conducted at 843 MHz

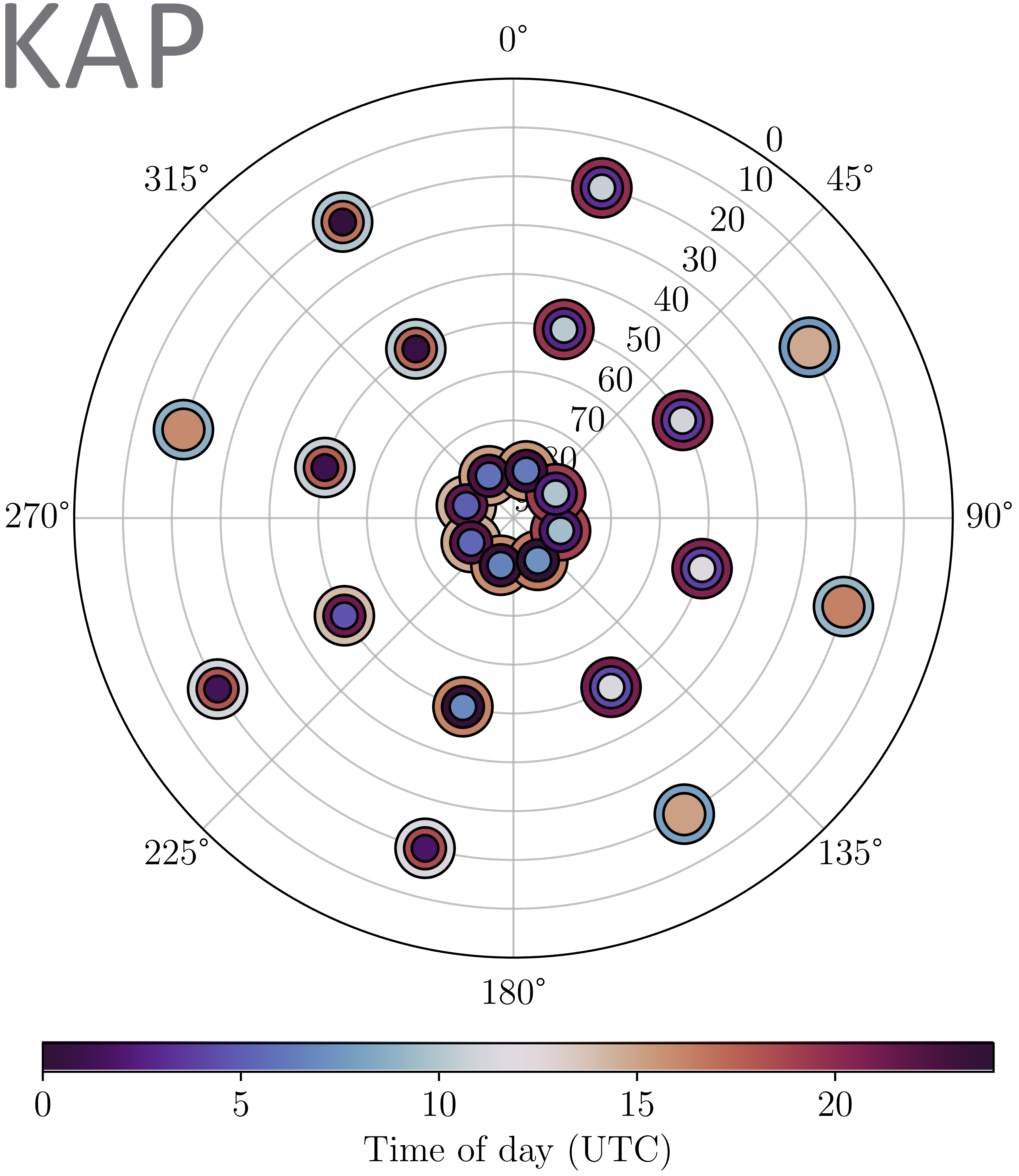


Image: V. Moss

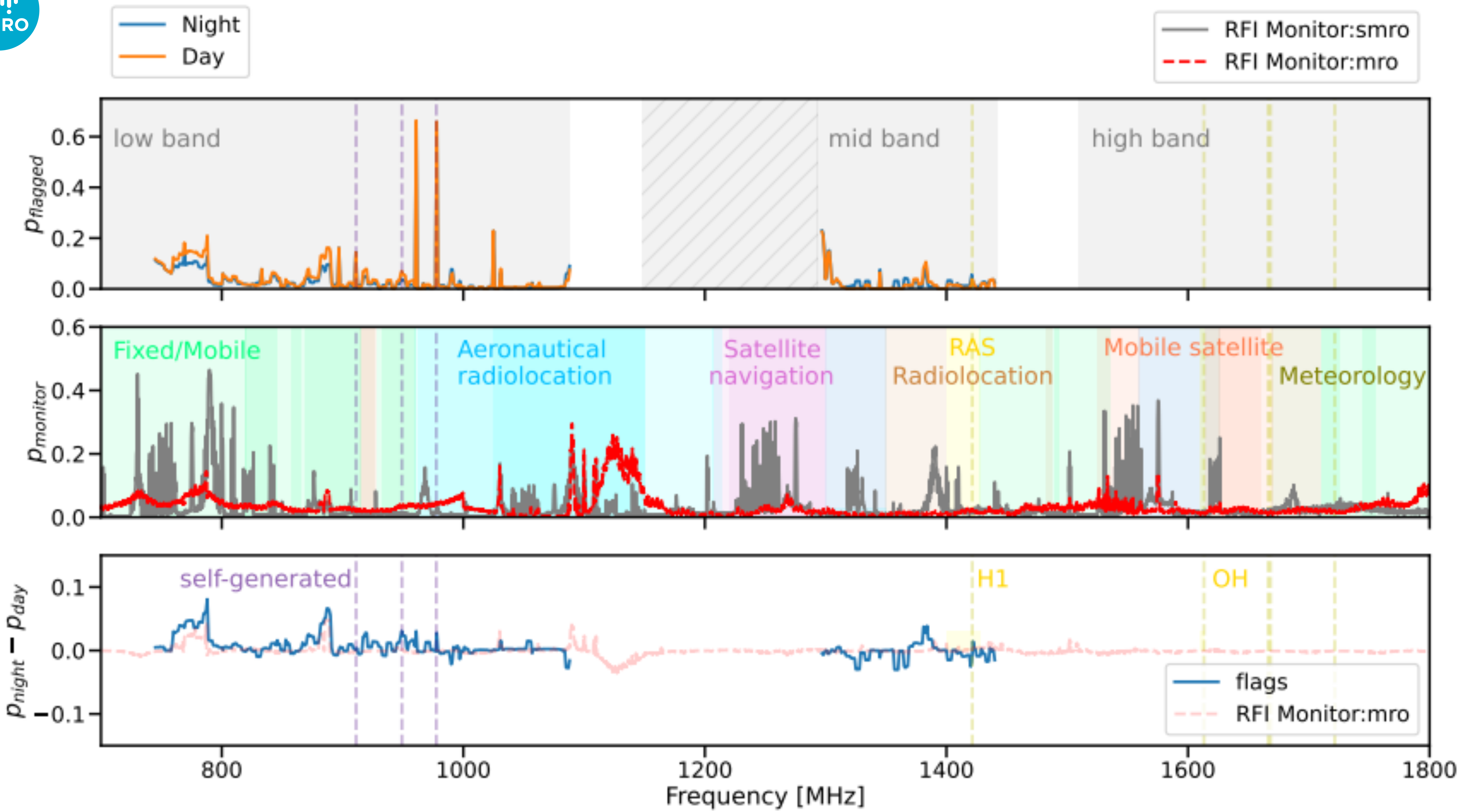


Image: L. Lourenco

LOFAR RFI identification

- LOFAR Low Band Antennas (LBA) work at **10-90 MHz**, capable of **all-sky** view
- Can make use of individual station data to study the **local RFI** environment
- Instead of imaging the sky, you can image the **ground plane** (M. Brentjens)
- Used by the observatory to **investigate and localise** new sources of RFI

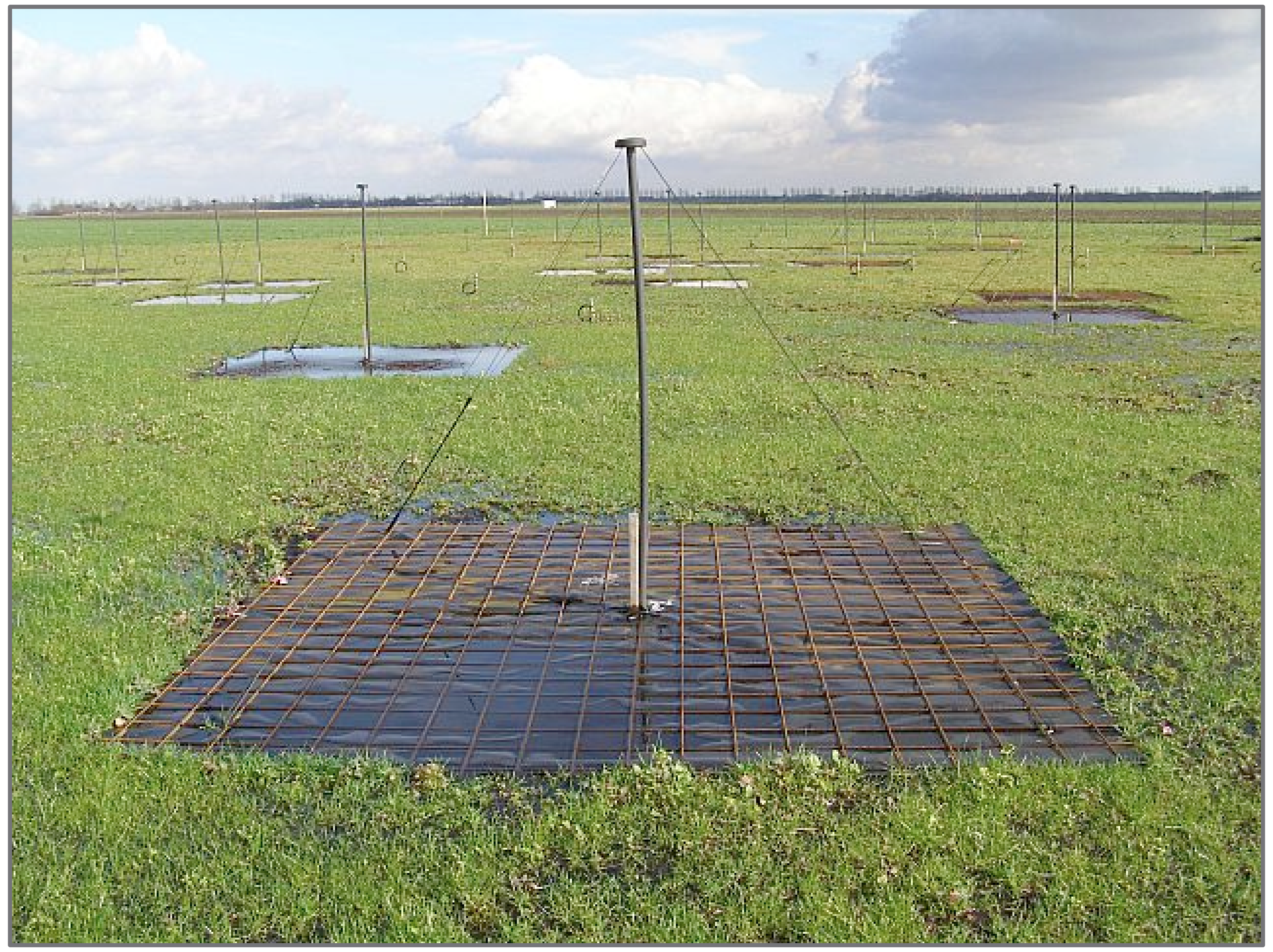
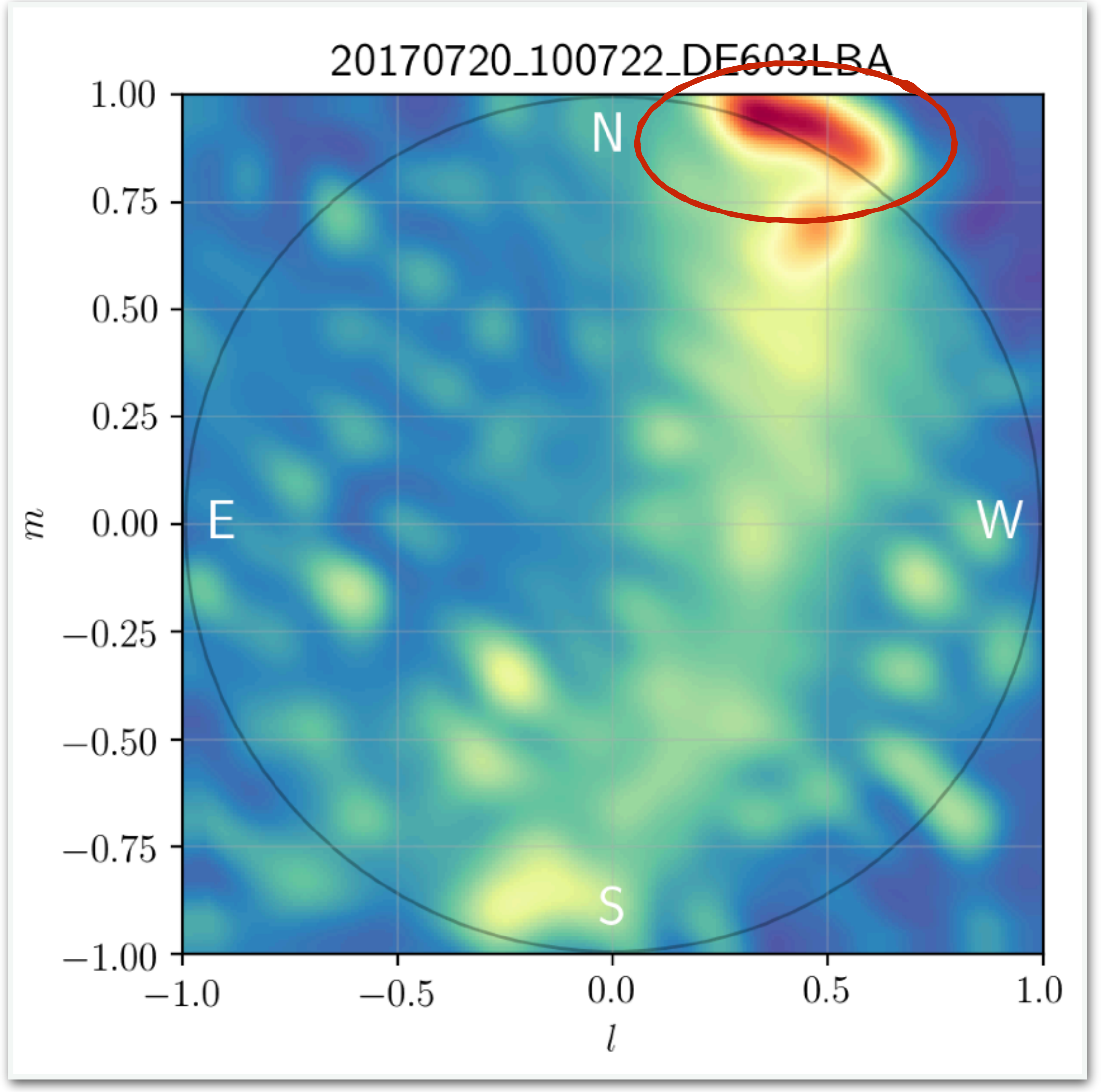


Image: ASTRON

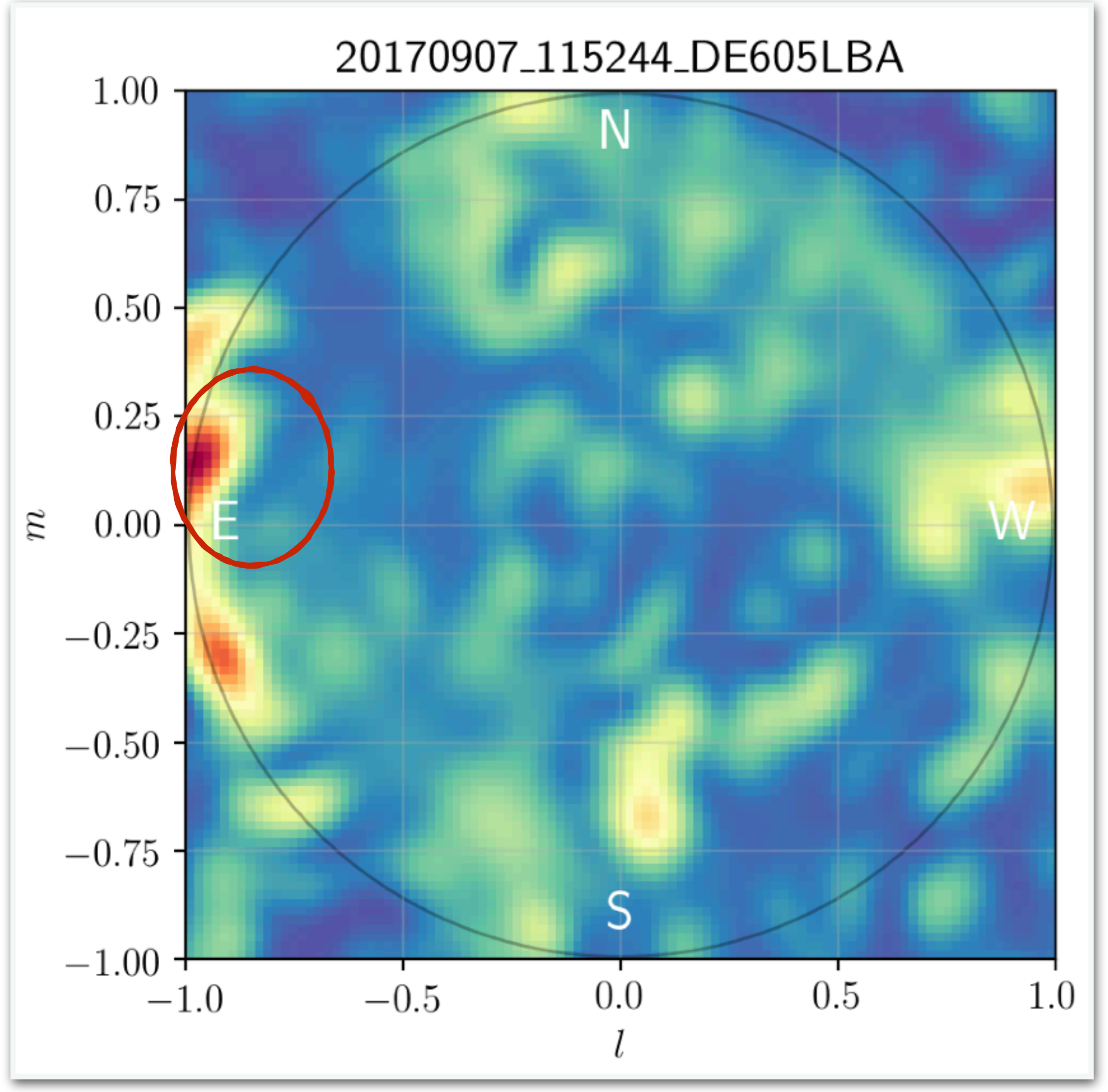
LOFAR RFI identification

DE603: 20th July 2017

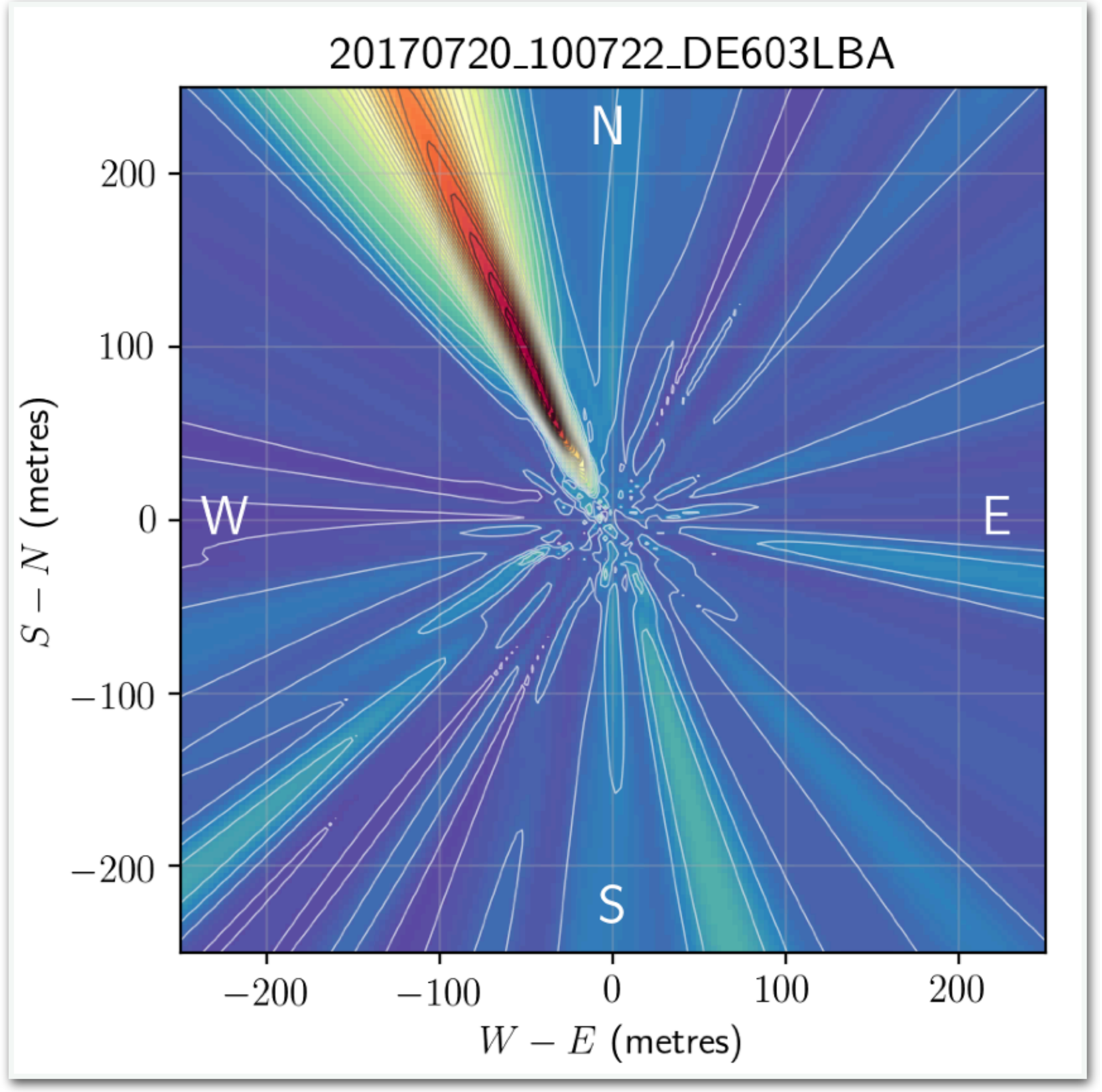


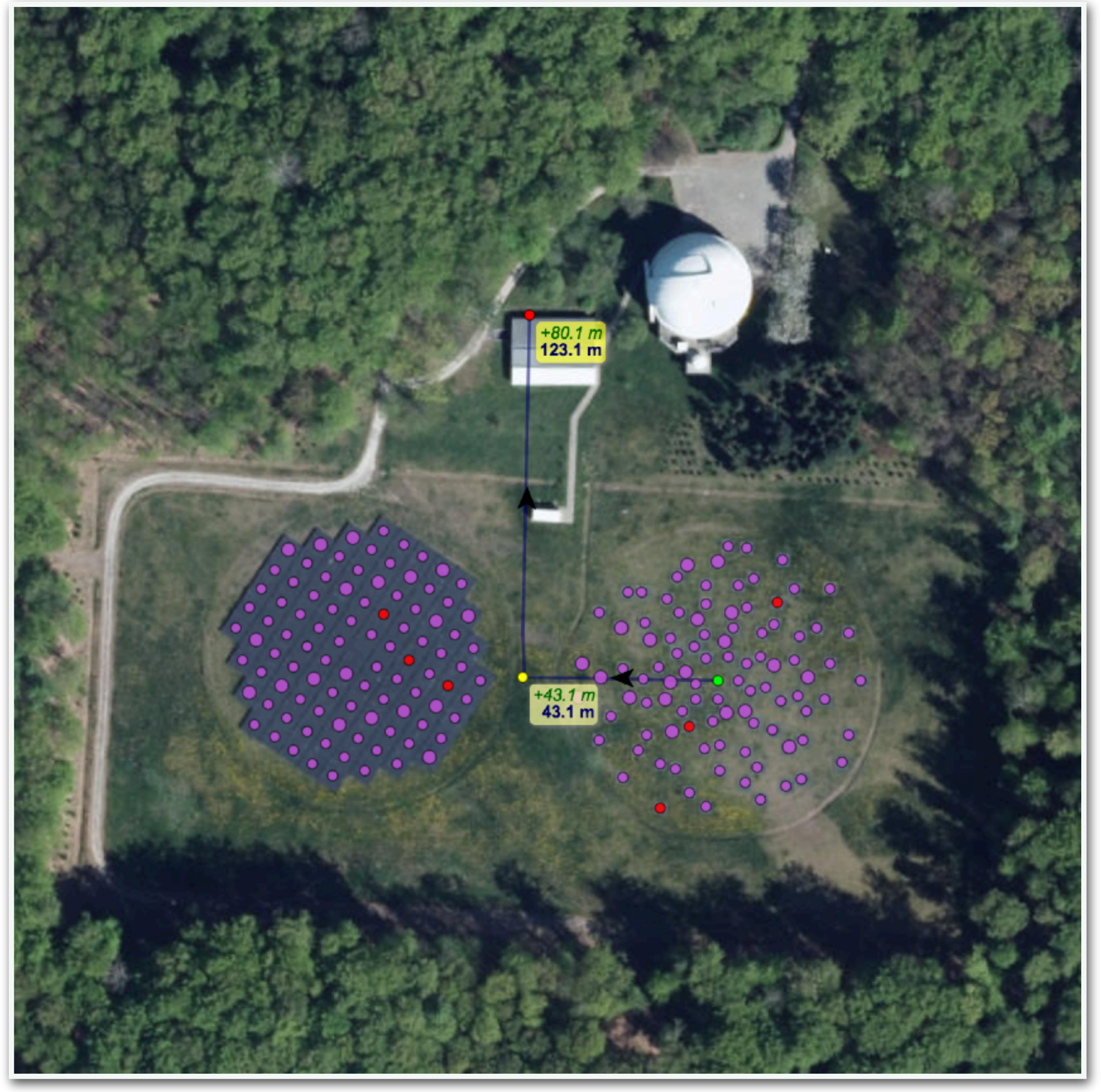
RFI visible in north-west

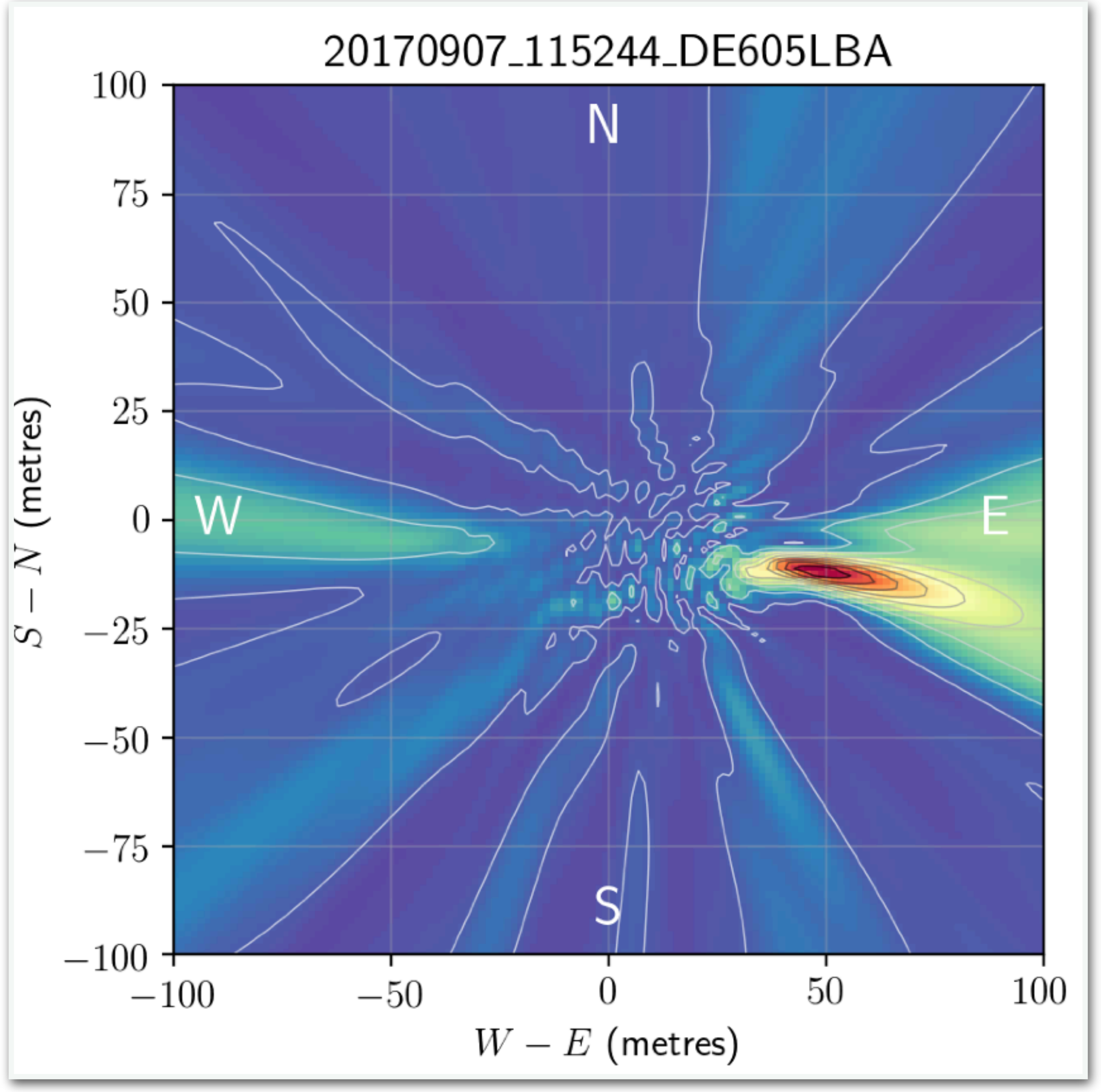
DE605: 7th September 2017

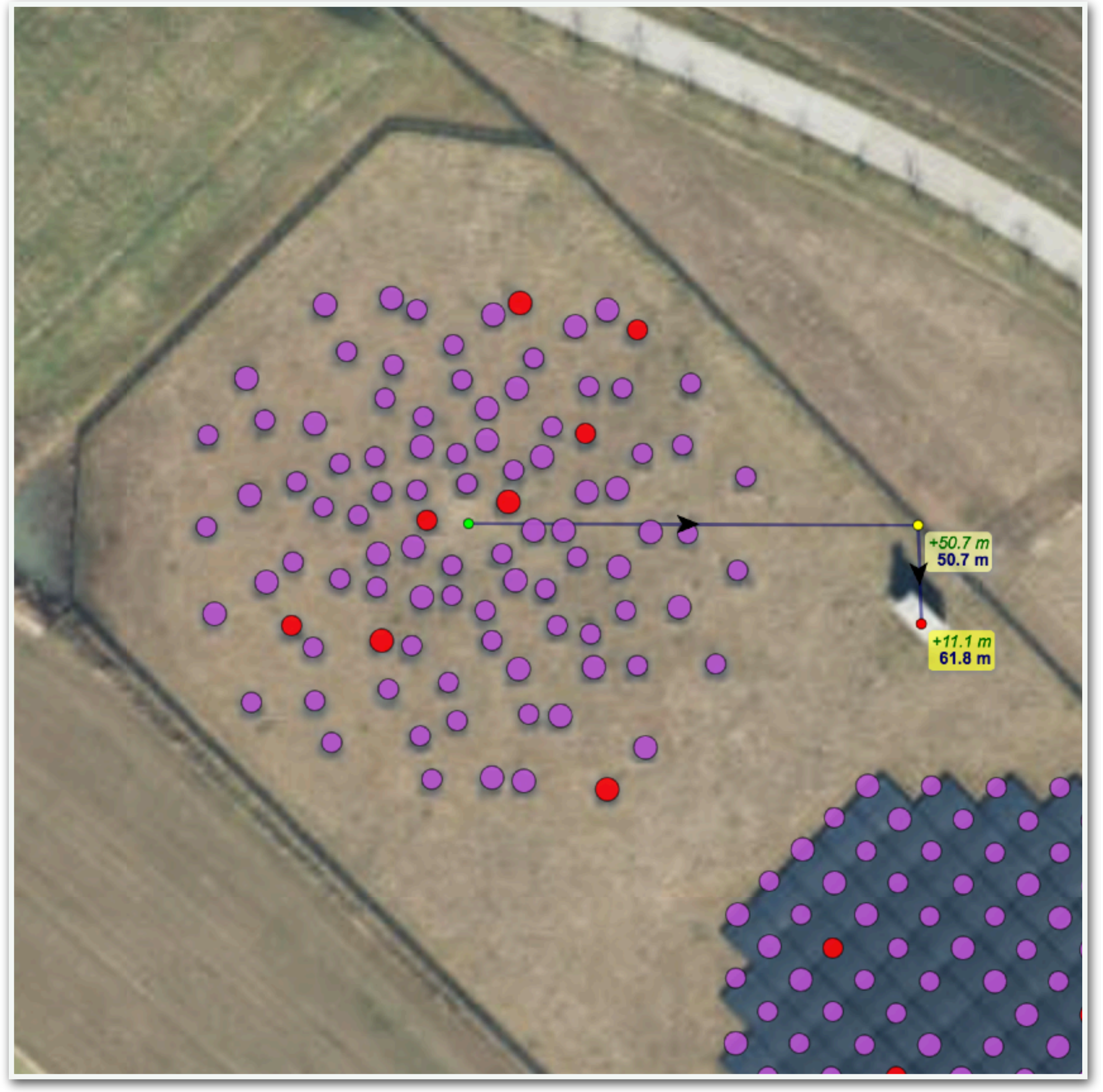


RFI visible in east





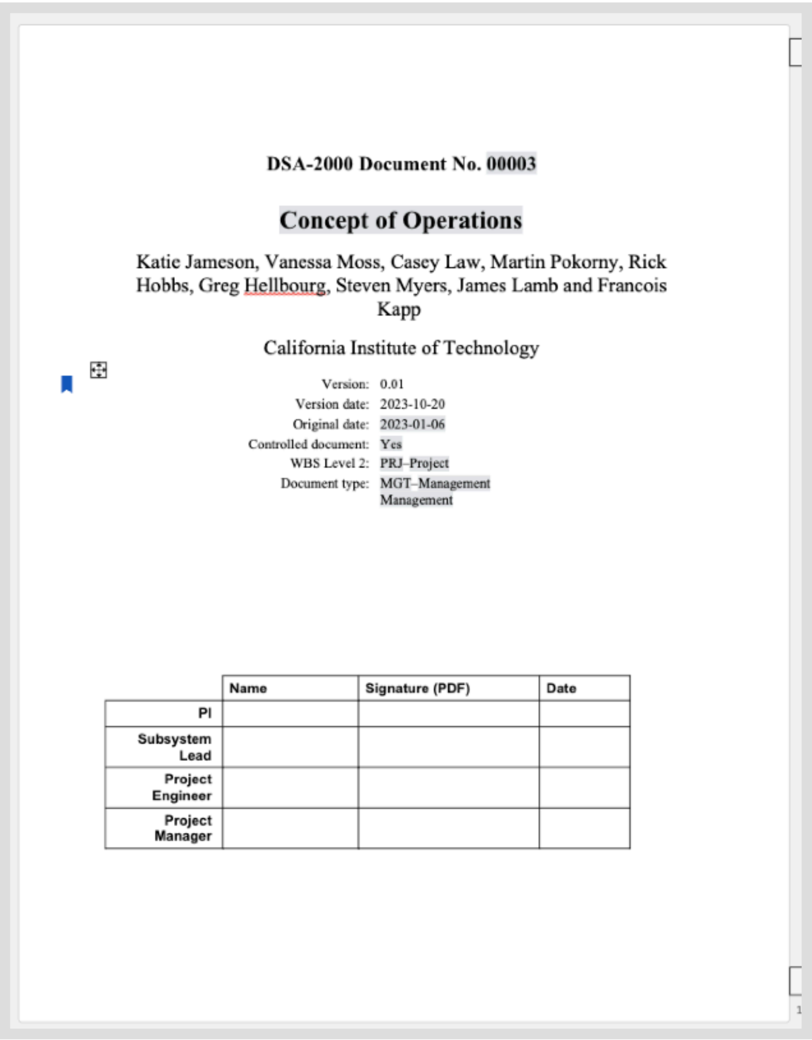




Similar technique used for ATCA (C. James thesis), but best/easier to apply to all-sky instruments (e.g. MWA, LWA, SKA-Low)

Considering RFI for DSA-2000

- Chat to **Greg** for all your RFI questions!
- RFI considerations for the Observation Planner (OPL) subsystem will include **weak and strong avoidance** depending on the associated consequences
- Committing to scheduling decisions with **minimum lead-time** (e.g. 30 min) in order to publish/share the pointings
- Balance vs. other **constraints/weightings**


DSA-2000 Document No. 00003

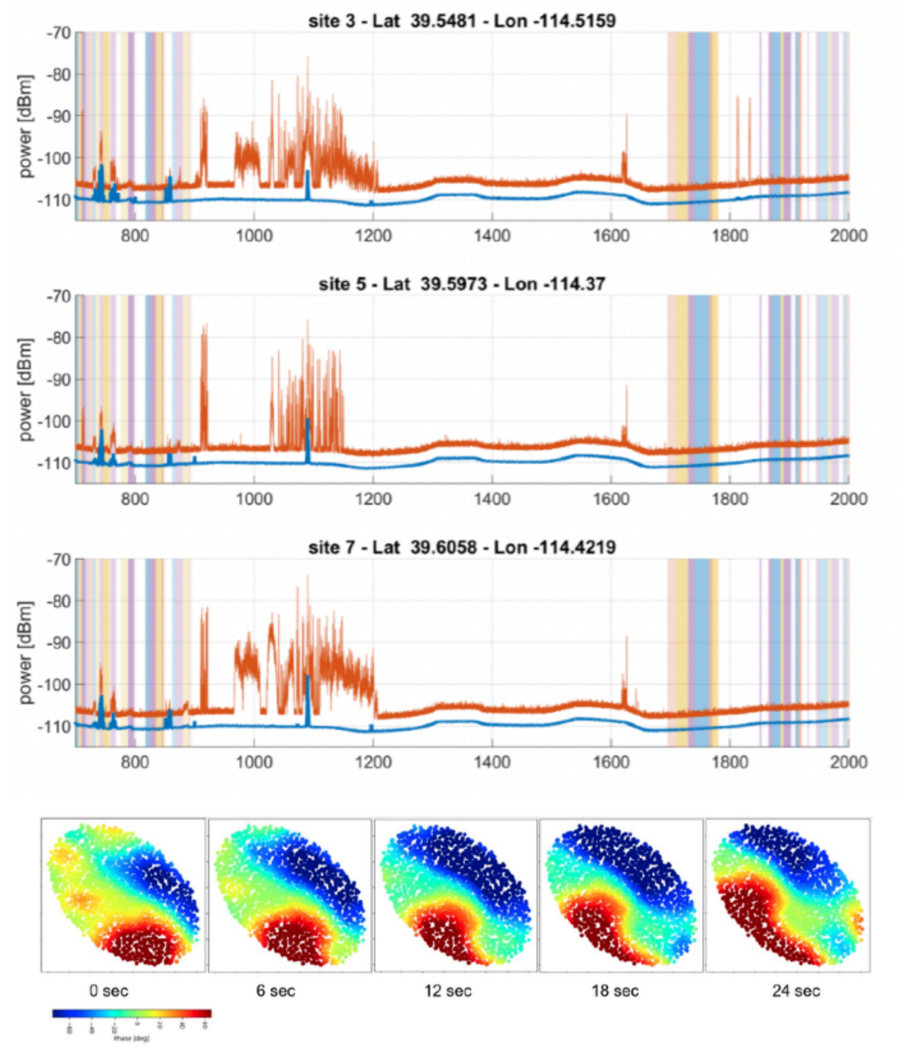
Concept of Operations

Katie Jameson, Vanessa Moss, Casey Law, Martin Pokorny, Rick Hobbs, Greg Hellbourg, Steven Myers, James Lamb and Francois Kapp

California Institute of Technology

Version: 0.01
Version date: 2023-10-20
Original date: 2023-01-06
Controlled document: Yes
WBS Level 2: PRJ–Project
Document type: MGT–Management Management

	Name	Signature (PDF)	Date
PI			
Subsystem Lead			
Project Engineer			
Project Manager			



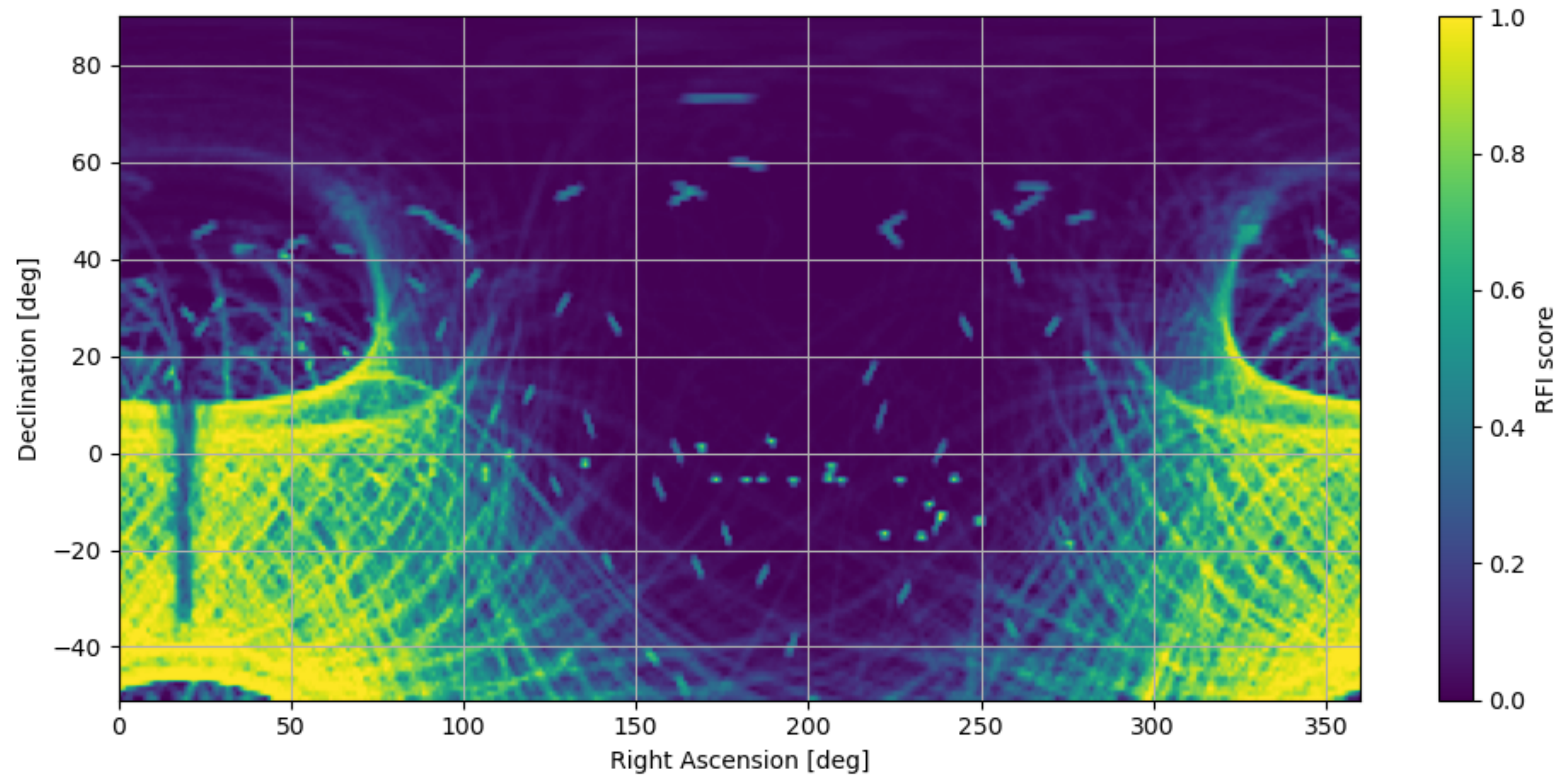
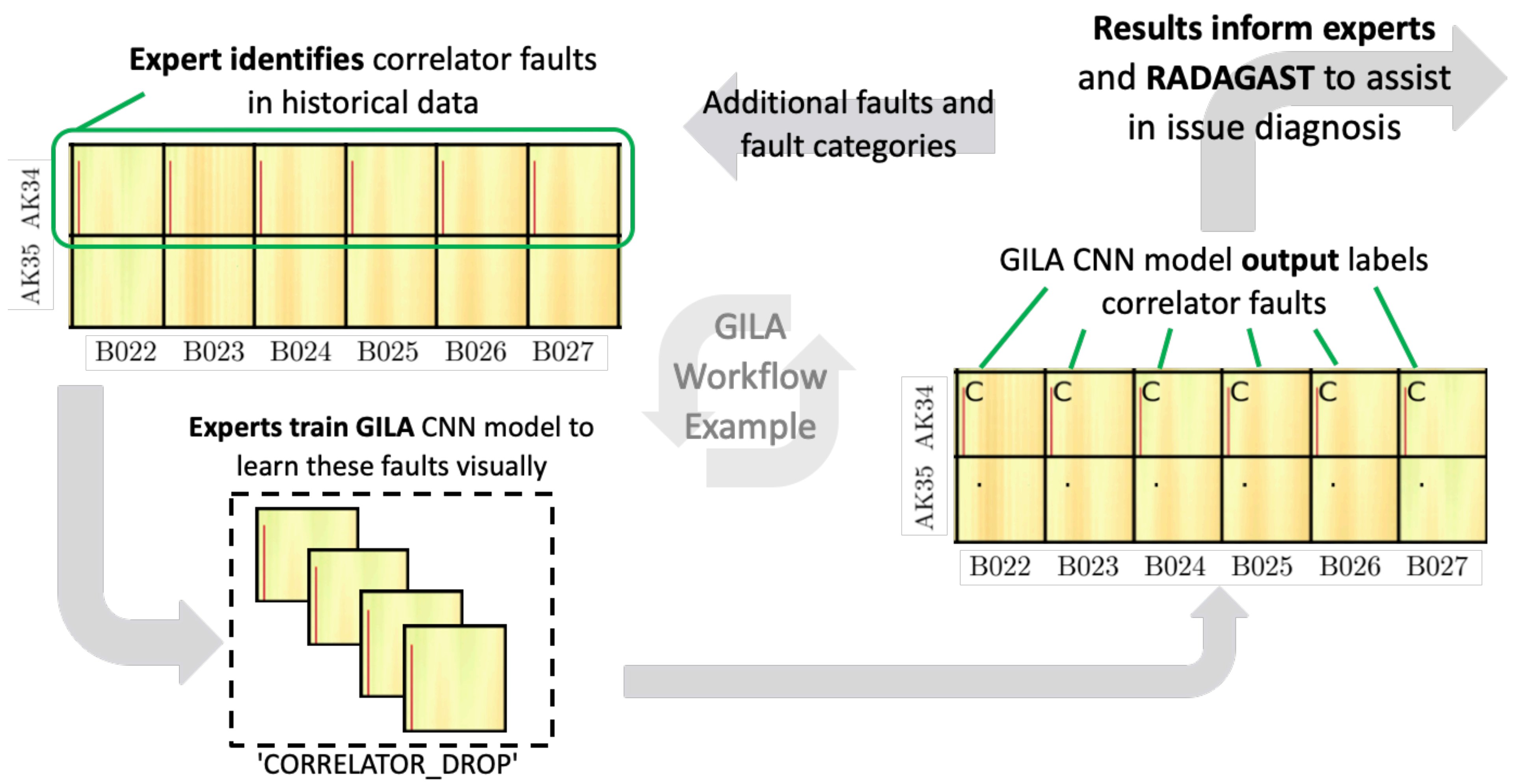


Image: G. Hellbourg, J. Albert

Outlier detection with GILA

- ASKAP raw data plots are visualised as part of the **ARWEN** workflow
- e.g. https://diagnostics.askap.tools
- GILA is a trained **CNN-based outlier detection** algorithm which runs on every dataset to categorise issues
- **[R]FI** is one of the categories - confused (not surprisingly) with **[D]ucting**



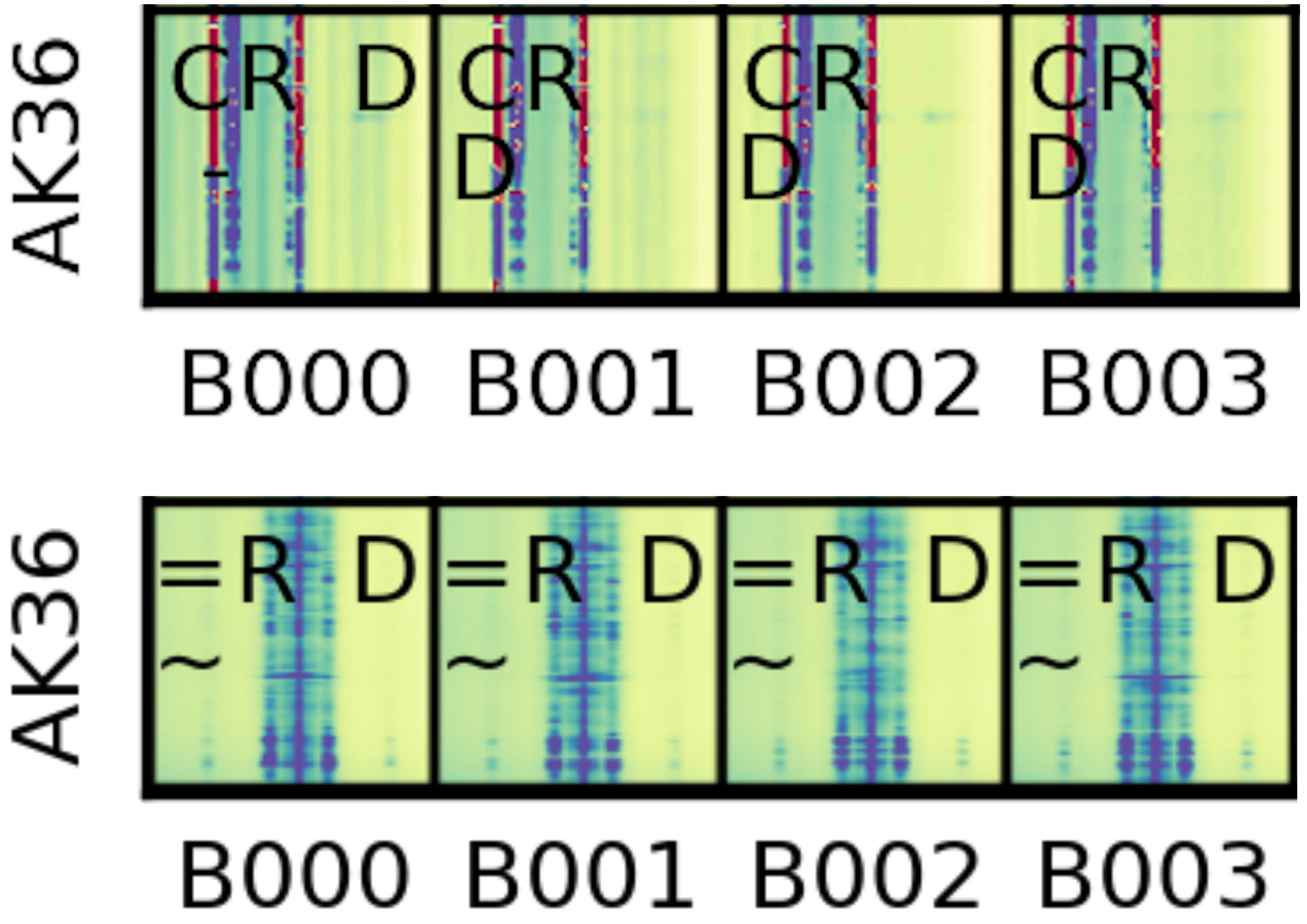
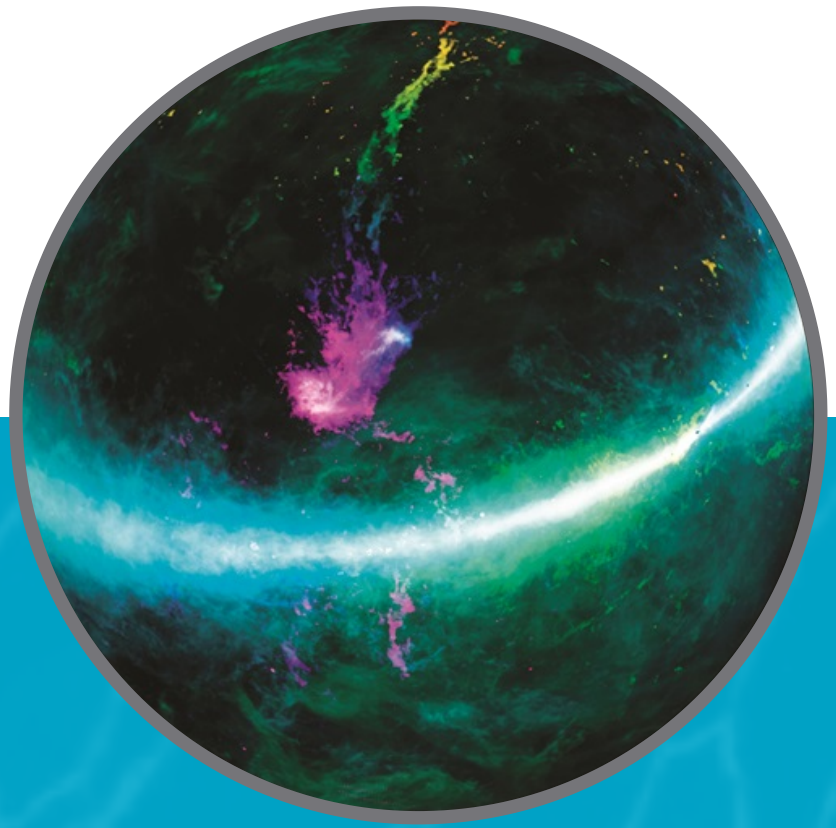


Image: M. Hudson/GILA

An overview of the impact of RFI on radio astronomy

Contents of this talk



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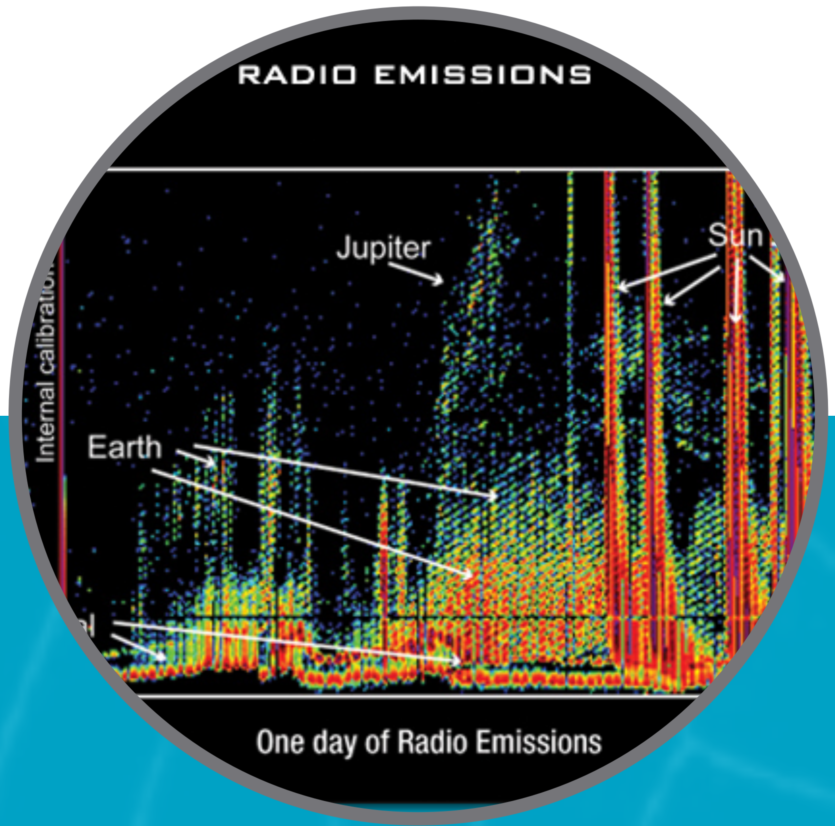

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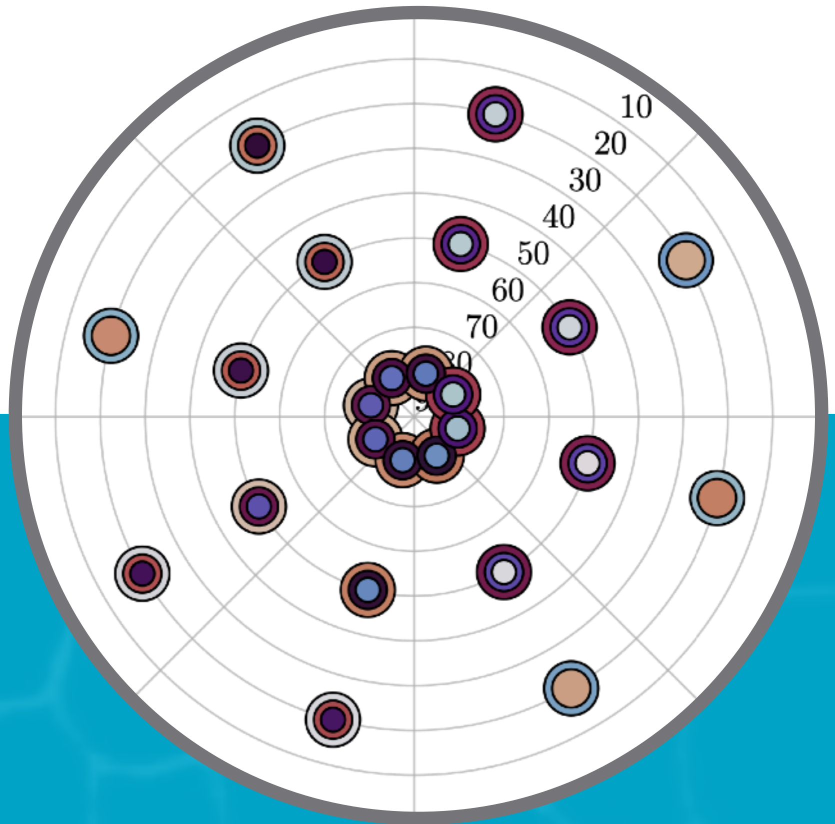


Case studies in RFI

Considering the future

The future of RFI in radio astronomy and beyond…

…to be explored and discussed as part of this **RFI 2025** meeting!

Purpose

This workshop aims to:

- Keep the radio astronomy and Earth observation communities connected
- Raise awareness about the impact of RFI on passive scientific services
- Provide updates on spectrum management developments and interference threats
- Share recent innovations and best practices in RFI detection and mitigation

DSA-2000: Deep Synoptic Array

https://www.deepsynoptic.org

Image: DSA/Caltech/C.Carter

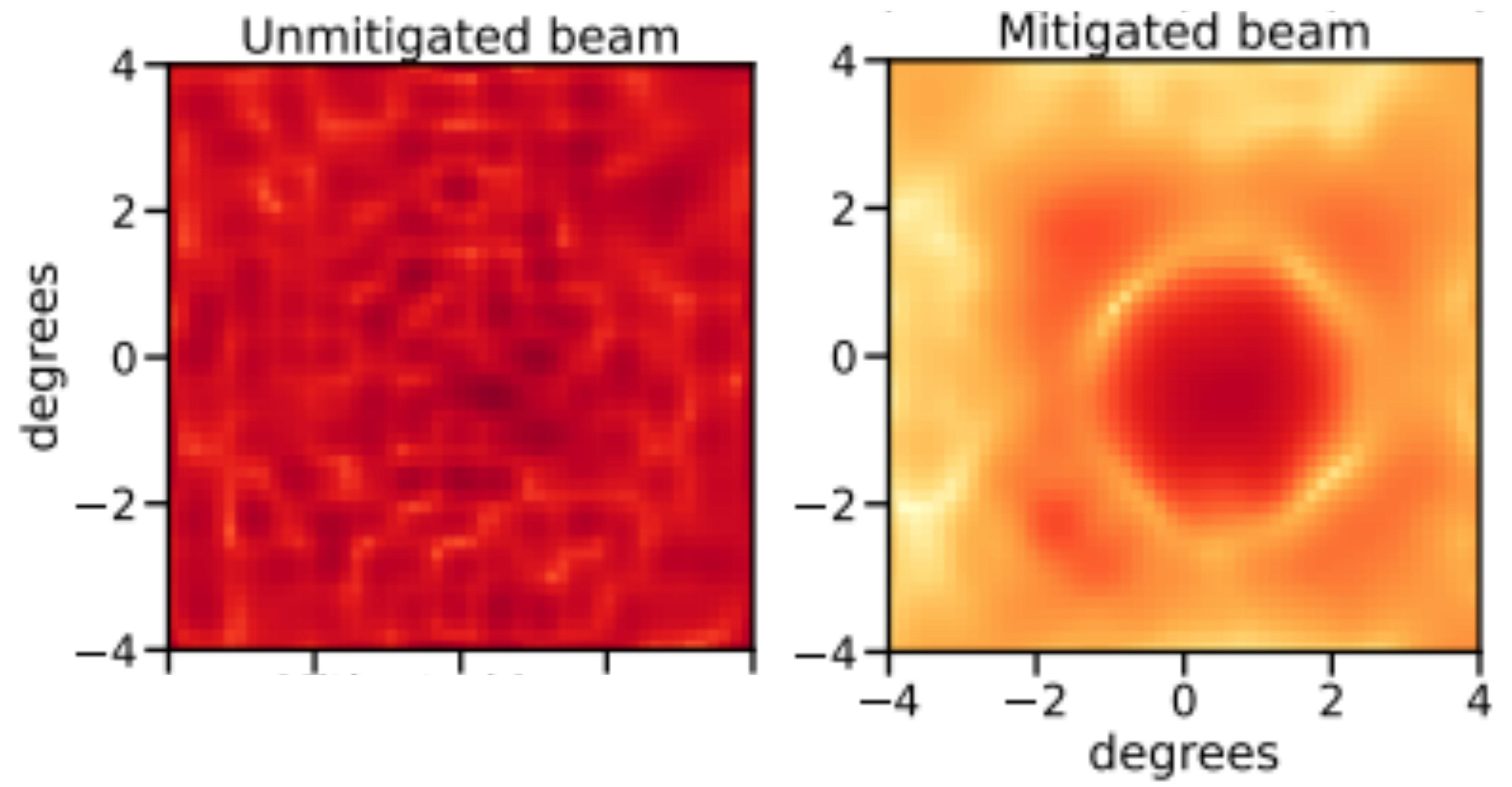
The SKA telescopes: Mid and Low

https://www.skao.int

Image: SKAO

RFI nulling in radio receivers

- Phased array feed receivers offer the potential for **active nulling** of signals
- Demonstrated to work in a number of **prototype/experimental** approaches, but not yet at the production stage
- Astronomers typically concerned about the impact on **beams/data quality**
- Maximum opportunity in **lost data**? e.g. lower 144 MHz of the ASKAP mid-band



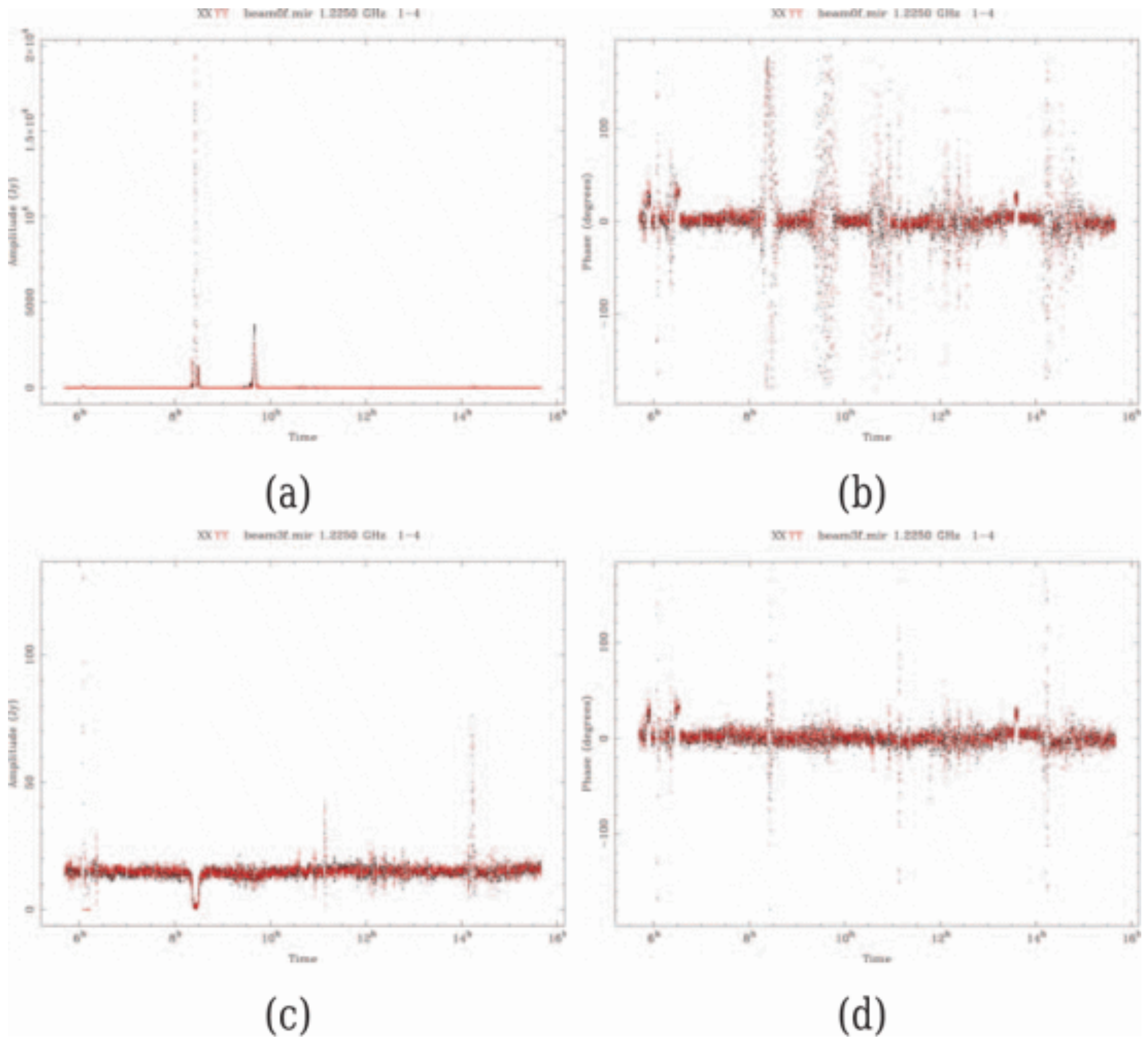
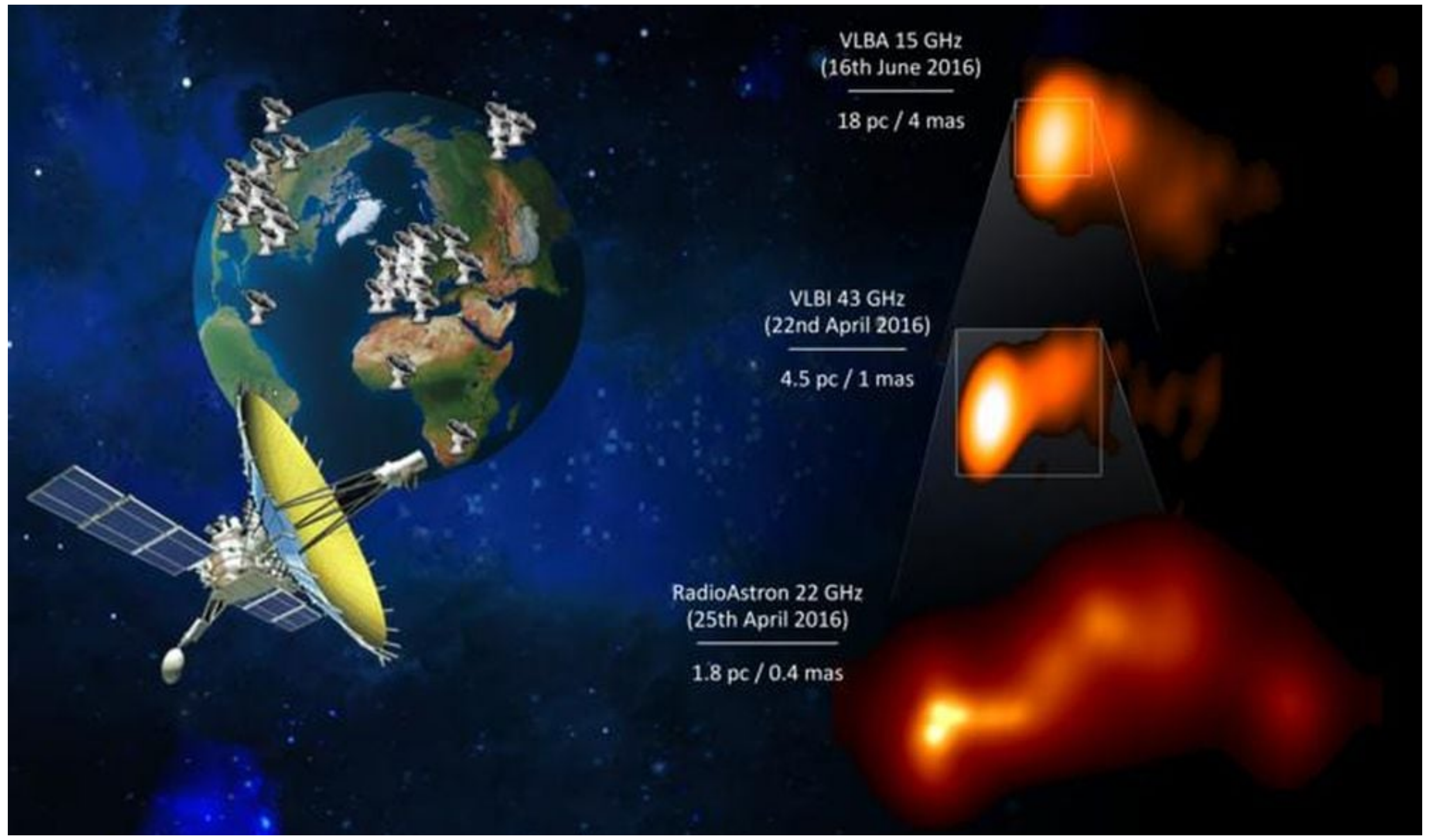


Image: Lourenco & Chippendale 2024, Hellbourg et al. 2016

On the role of space

- Space-based radio astronomy offers a unique view of the Universe, with potential to **complement** ground-based systems
- **Cannot replace** ground-based due to amount of data (TB, PB!), launch and maintenance costs, physical limitations, synchronisation challenges, etc
- Ground-based systems offer opportunities for **hands-on education** of next generation



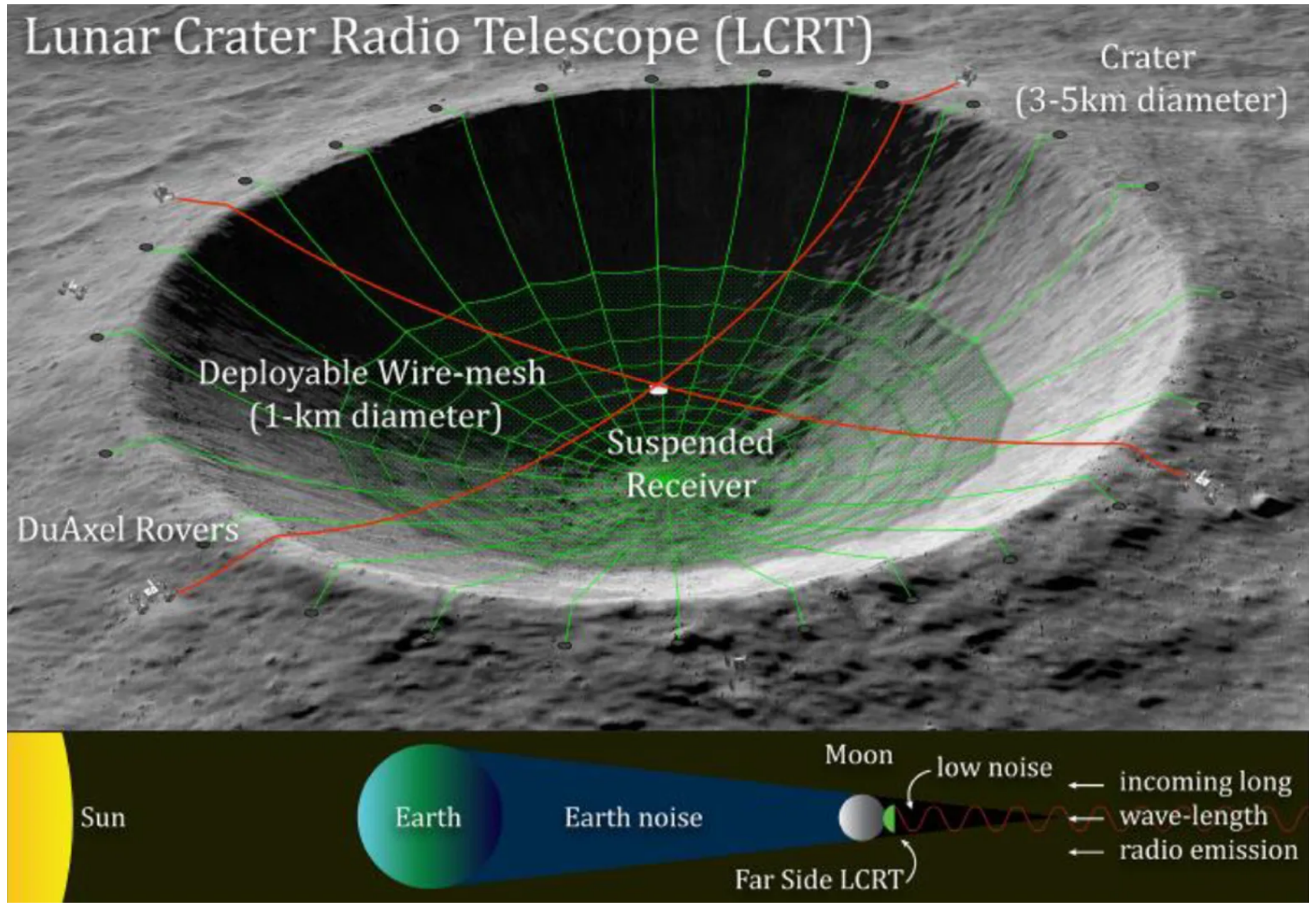


Image: J. Carlos Algaba, S. Bandyopadhyay

Automation, autonomy and… AI?

- A topic very close to my heart and my primary area of work, c.f. **SAURON/OPL**
- Somewhat tangentially related to RFI, but there is **much scope for growth** in these areas (e.g. DSA, GILA, LOFAR, etc)
- Potential for **global data sharing** via centralised APIs, e.g. SatChecker satchecker.readthedocs.io
- **Widely applicable** across the RFI context

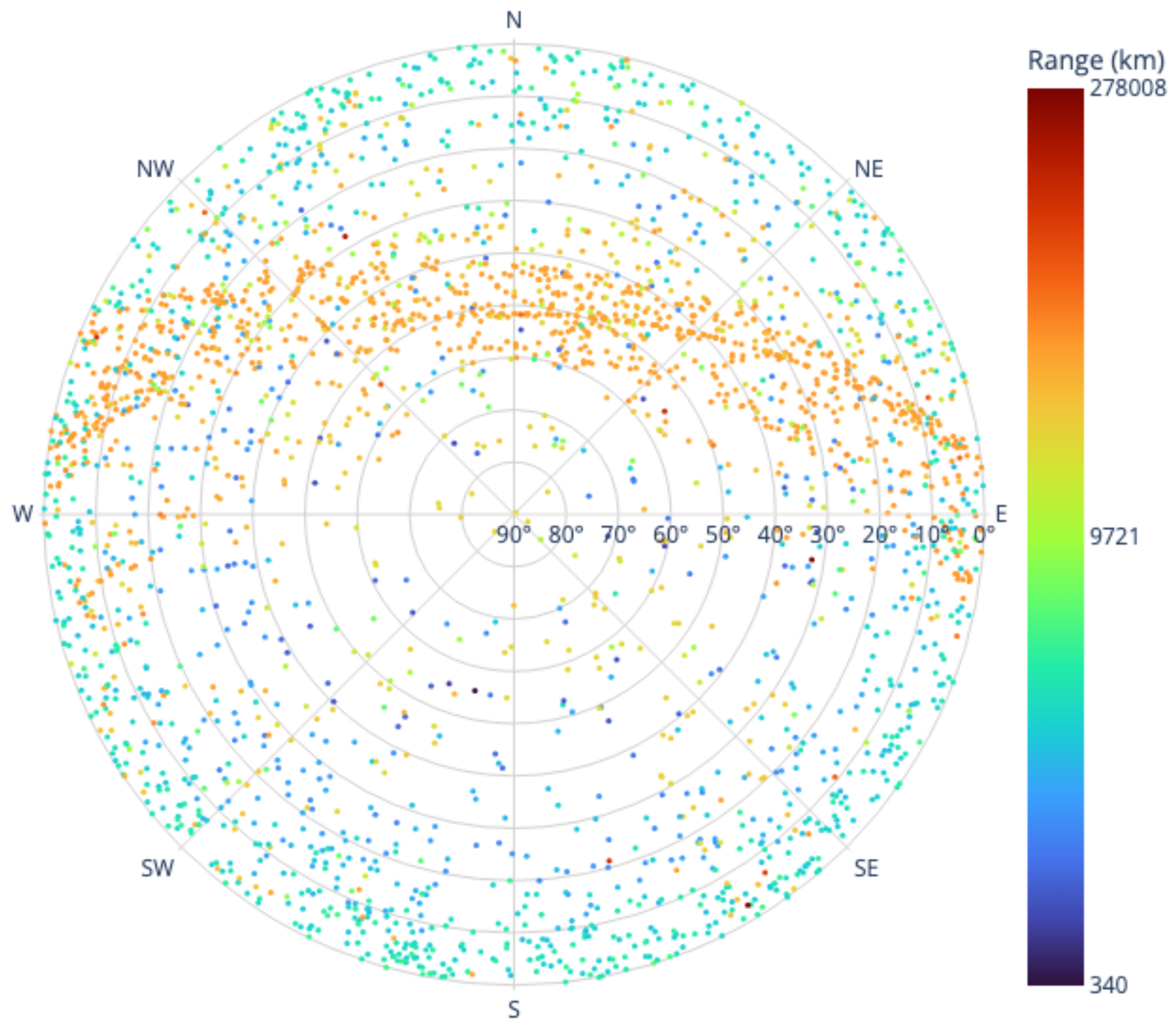


Image: SatChecker

Summary

Radio astronomy is a **relatively young** field of astronomy with many scientific contributions over the past century, locally to the edge of the Universe!

RFI has a **huge impact** on the ability to study the radio sky, and this impact is **growing** with the rapidly evolving radio environment globally.

Close **coordination**, **collaboration** and **evolution** of approaches are essential to future-proof radio astronomy!

Key active strategies

Coordination/knowledge sharing*
Flagging/removal from data
RFI-quiet locations
Avoidance where feasible
Satellite-side mitigations
Direct cooperation

Future opportunities

RFI signal nulling
Global data sharing/networks
Autonomous monitoring/detection
Advanced avoidance strategies
Generalised approaches
Things we haven’t thought of yet!