ITU-R Working Party 7D

Radio Astronomy

Presenter: Dr Balthasar Indermühle, Chair ITU-R Working Party 7D

Seminar on Science Services in relation to ITU RR and WRC-27

9-10 December 2025
MCMC Centre of Excellence,
Cyberjaya, Selangor, Malaysia

ITU

Scope

Working Party 7D covers the radio astronomy service. Its scope includes radio astronomy and radar astronomy sensors, both Earth-based and space-based, including space very long baseline interferometry (VLBI).

The goals of WP 7D activities are to develop and maintain the RA Series ITU-R Recommendations and Reports and Handbook

Radio Astronomy observations involve the detection of extremely faint radio signals from the cosmos over the whole radio spectrum, and therefore require the most sensitive radio telescope systems. Careful management of the radio spectrum is of extreme importance to radio astronomy.

The radio astronomy service uses very diverse instruments ranging from very large single-dish telescopes such as the new 500m diameter FAST telescope in China, to large distributed arrays such as the new Square Kilometre Array (SKA) now under construction in Australia and South Africa.

Structure

- Chair: Dr. Balthasar Indermuehle (Australia)
- Vice Chairs:
  - Dr. Ashley Vanderley (USA)
  - Mr. Federico Di Vruno (SKAO)
- Standing Working Groups:
  - 7D-1 AI 1.16: Mr Jonathan Williams (USA)
  - 7D-2 AI 1.18 (resolves 2): Mr Ivan Thomas (France) & Dr Ashley Vanderley (USA)
  - 7D-3 WRC-23 Resolutions, ITU-R Questions & AOB: Dr Balthasar Indermuehle (Australia)

Importance

- Radio astronomy plays an important role in modern society:
  - **Satellite navigation and positioning** - Radio astronomy techniques like Very Long Baseline Interferometry (VLBI) are defining the International Celestial Reference Frame, which is fundamental for GPS/GNSS accuracy and Earth orientation parameters essential for precise navigation
  - **Deep space communications** - Radio astronomy facilities and expertise support spacecraft tracking and communications for space missions, with techniques developed for weak signal detection directly applicable to deep space exploration
  - **Timekeeping and fundamental constants** - Pulsar timing arrays contribute to international atomic time standards and test fundamental physics, with implications for everything from financial transactions to testing theories of gravity
  - **Technology development spillovers** - Innovations driven by radio astronomy's extreme data processing needs have contributed to advances in signal processing, high-speed networking, cryogenic receivers, and data compression algorithms used in telecommunications and computing

A (very) quick radio astronomy overview

Why Do Humans Explore the Universe?

Fundamental Human Drive

- Curiosity is core to human nature - we've always looked up at the stars! Earliest documented history may be as old as 60'000 years: The Emu in the sky from Australian indigenous culture
- Quest to understand our place in the cosmos
- Drive to push boundaries of knowledge and technology

Practical Benefits

- Technology spillover enables and benefits society (GPS, WiFi, medical imaging)
- Understanding Earth's place in space helps predict threats (asteroids, solar storms)
- Resource exploration for future generations

Philosophical Significance

- Addressing humanity's biggest questions: Are we alone? How did it all begin?
- Unifying perspective - seeing Earth as one small planet
- Inspiring next generations of scientists and innovators

A (very) quick radio astronomy overview

Eora nation Emu in the sky. Image credit: ABC News Australia, 2017

A (very) quick radio astronomy overview

What Questions Are We Answering?

Origins and Evolution
- How did the Universe begin and evolve after the Big Bang?
- How do galaxies form and change over billions of years?
- What triggered the first stars to ignite?

Structure and Composition
- What is dark matter and dark energy?
- How much of the Universe can we actually see?
- What exotic objects exist beyond our current understanding?

Life and Habitability
- Are the conditions for life common or rare?
- What chemical building blocks exist in space?
- Could we detect signs of other civilizations?

A (very) quick radio astronomy overview

Radio Astronomy's Unique Role

Seeing the Invisible
- Penetrates cosmic dust clouds that block visible light
- Reveals cold matter invisible to optical telescopes
- Detects objects billions of light-years away

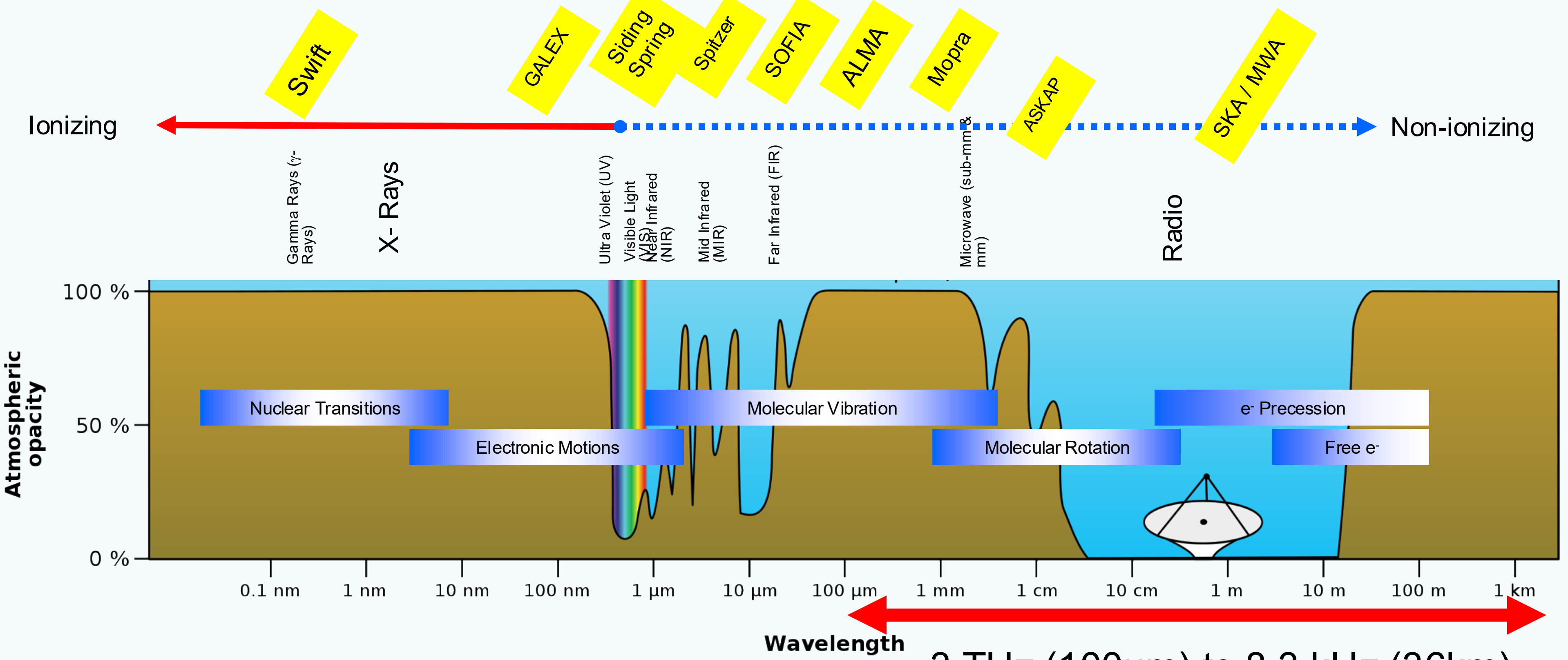
Unique Phenomena Only Visible in Radio
- Pulsars - cosmic lighthouses spinning hundreds of times per second
- Black hole jets extending millions of light-years
- Molecular clouds where stars are born
- Cosmic Microwave Background - echo of the Big Bang

Scientific Breakthroughs
- Discovery of quasars and active galactic nuclei
- Mapping hydrogen distribution across the Universe
- Detecting complex organic molecules in space
- Precision tests of Einstein's theory of relativity using pulsars

A (very) quick radio astronomy overview

The Electromagnetic Spectrum

All physical processes emit energy in the Electromagnetic Spectrum
All matter absorbs selected wavelengths from the EM Spectrum



3 THz (100µm) to 8.3 kHz (36km)
within ITU mandate

A (very) quick radio astronomy overview

The importance of multi spectral imagery

F090W
F187N
F200W
F335M
F444W
F444W-F470N

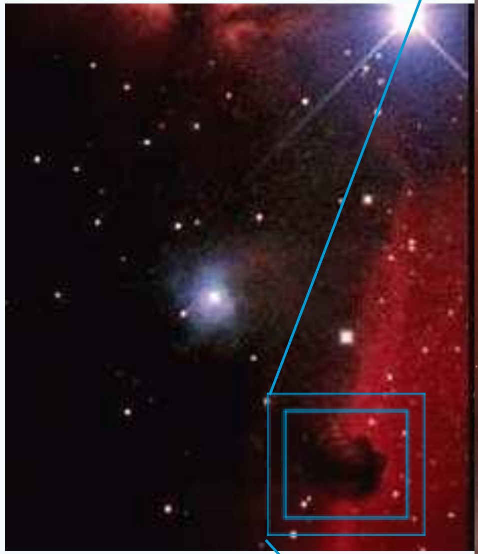
JWST data composite processed by Dr Balthasar Indermuehle

A (very) quick radio astronomy overview

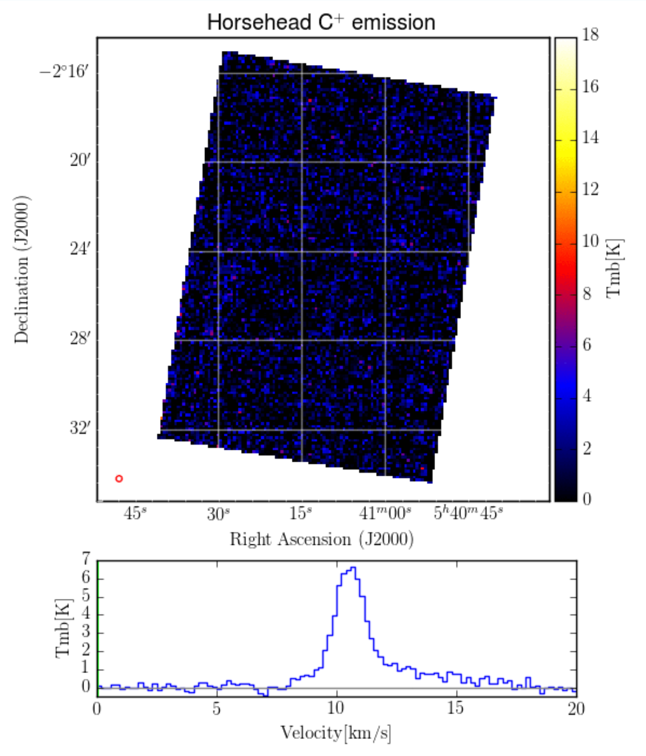
The importance of multi spectral imagery – a radio example

A rest frequency emitted at different velocities translates to shift in frequency!

The Horsehead N



VIS



Velocity resolved map of Horsehead Nebula GREAT/SOFIA at (157µm / 1.9 THz) to image CII and $CO_{11\text{-}10}$

Bally, John, et al., 2018, AJ, 155, 80

Image courtesy 2MASS, IPAC (Caltech), Hubble Heritage Archive

A (very) quick radio astronomy overview

The doppler shifted universe

- The universe is expanding at H_0 ~ 70 km/s/mpc.
- The farther away a radio signal comes from, the faster it recedes from us the more the frequency is doppler shifted to longer wavelengths / lower frequencies. This is called cosmological red-shift, because in reference to visible light, the wavelengths are shifted towards red (longer wavelengths)
- The edge of the observable universe (13.8 billion light years away) is at present receding at 3.2x the speed of light – light it emits today will never reach us!
- Light emitted from about 380'000 years after the big bang is still reaching us: The Cosmological Microwave Background (CMB). This was emitted as visible light at the time of photon decoupling – but cosmological redshift has shifted it to microwave frequencies!

Cosmological doppler shift has profound implications for radio astronomy

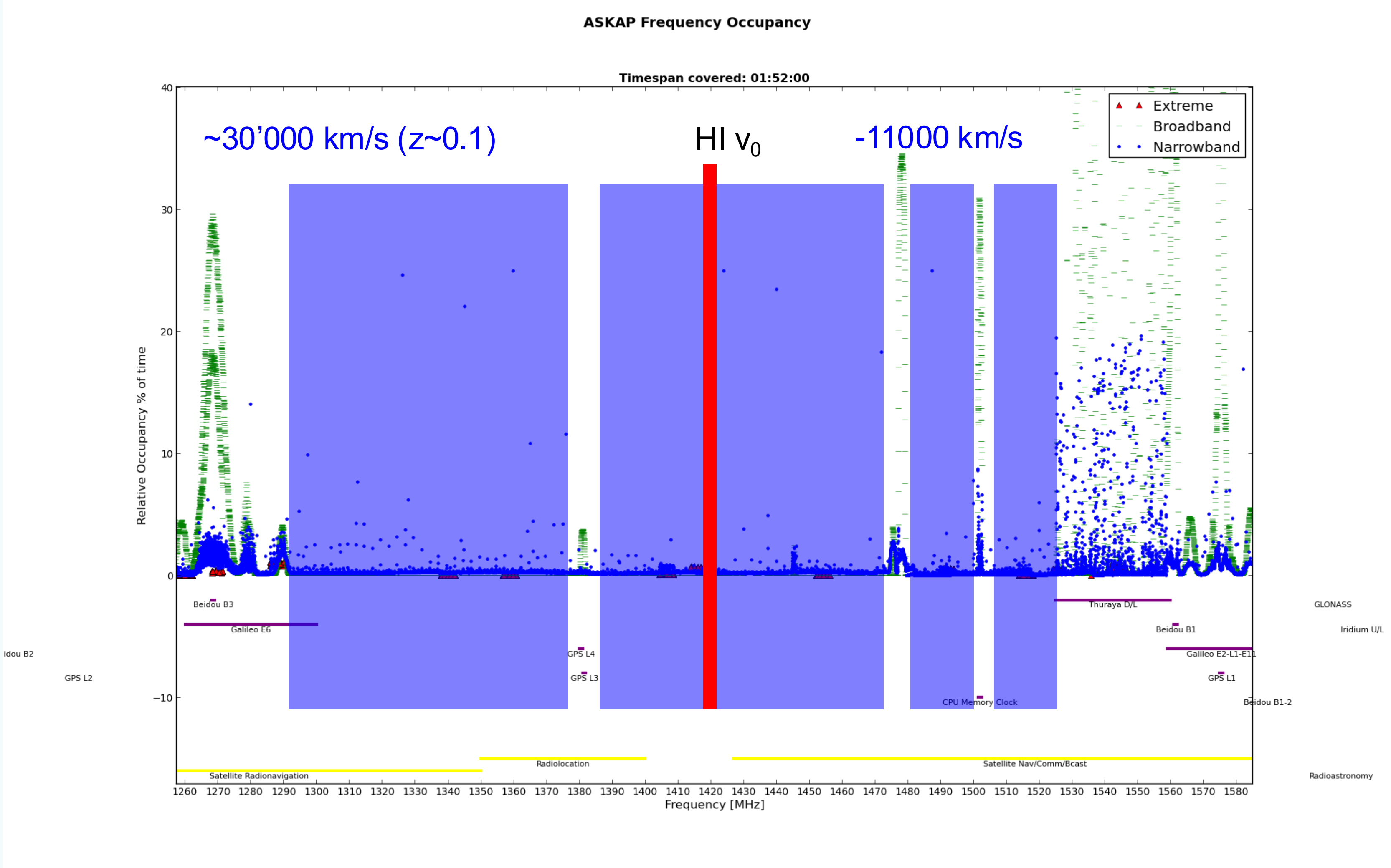
A (very) quick radio astronomy overview

The doppler shifted universe

- Hydrogen is the most abundant element in the universe.
- It emits at a rest frequency of 1420 MHz
- Emissions from radio services create blind spots in the cosmological evolution of the universe
- Example of the ASKAP telescope operating from 700 – 1800 MHz

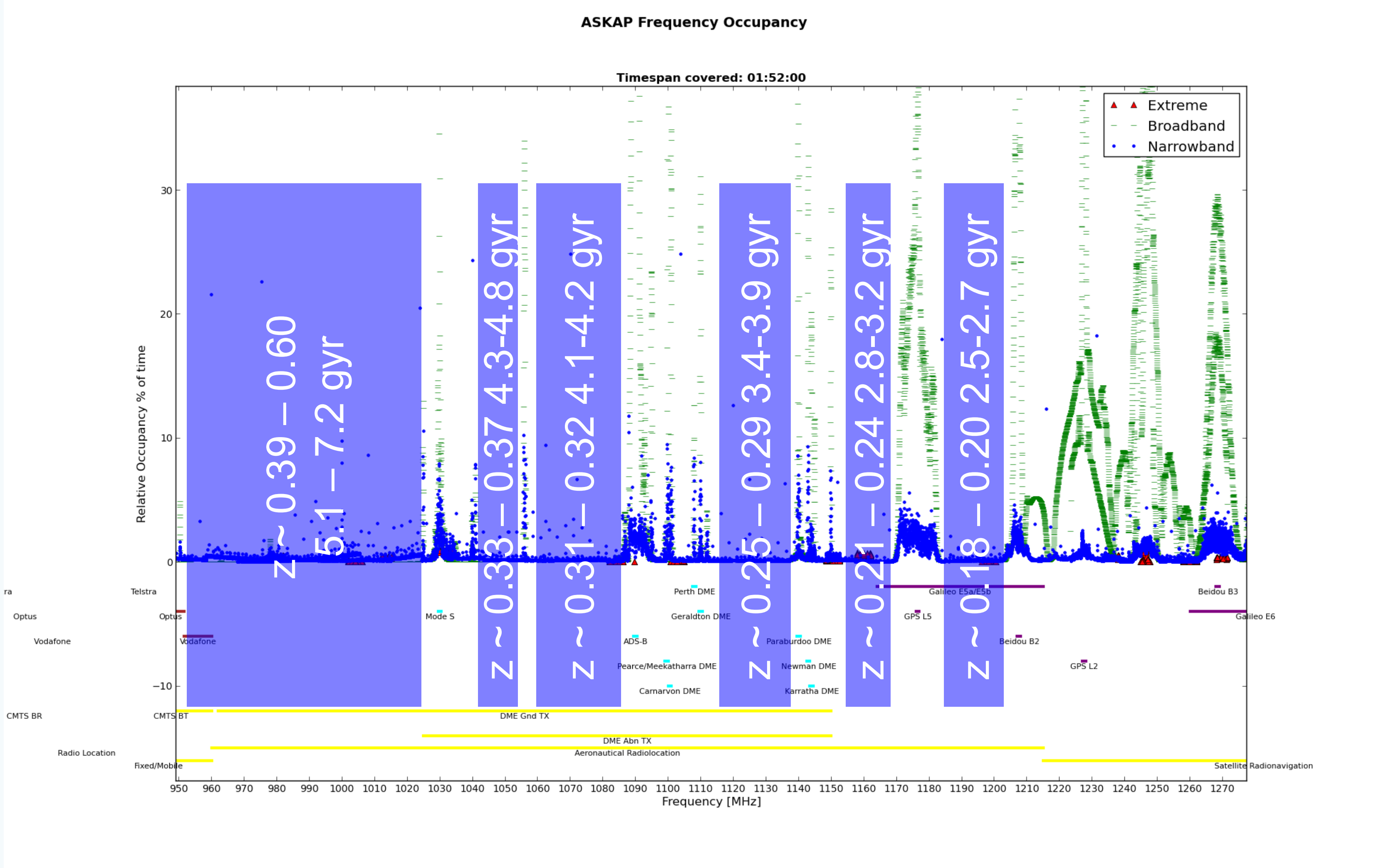
A (very) quick radio astronomy overview

The doppler shifted universe – ASKAP HI survey telescope 1260 – 1580 MHz



A (very) quick radio astronomy overview

The doppler shifted universe – ASKAP HI survey telescope
950 – 1270 MHz



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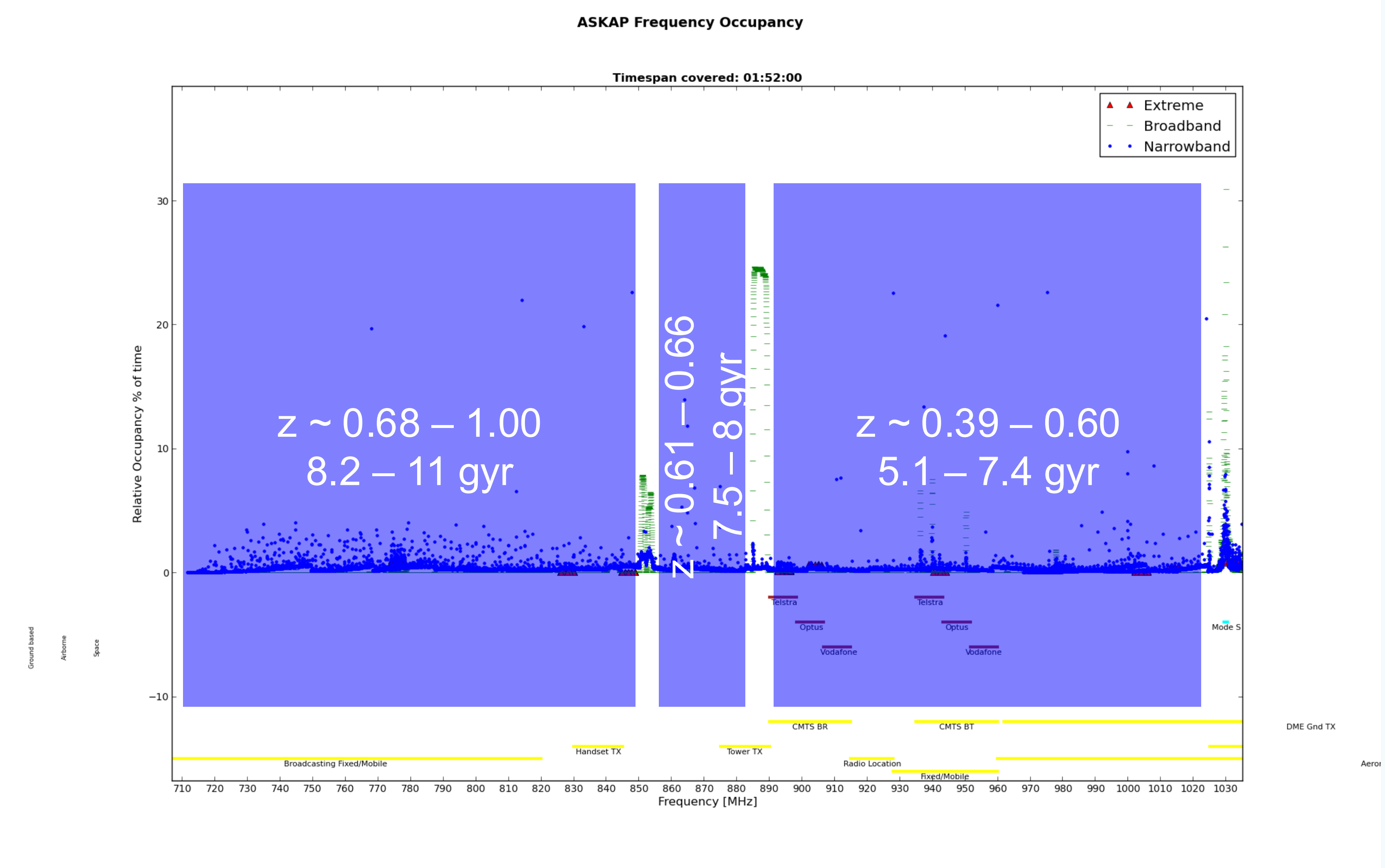
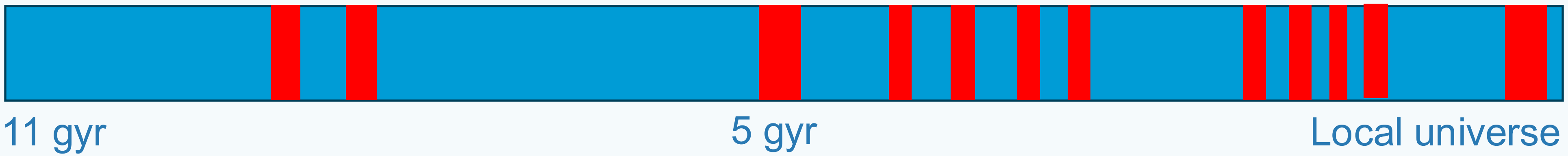
The doppler shifted universe – ASKAP HI survey telescope
700 – 1030 MHz



A (very) quick radio astronomy overview

The doppler shifted universe

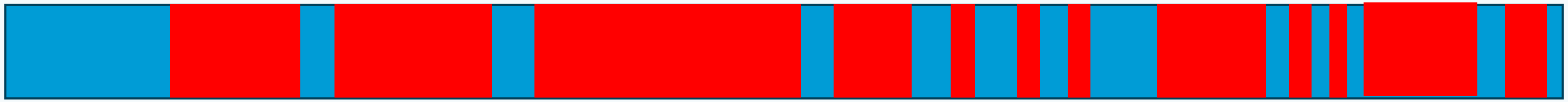
HI observing band with ASKAP has gaps due to "RFI":



- 8.0 – 8.2 gyr
- 7.4 – 7.5 gyr
- 4.8 – 5.1 gyr
- 4.2 – 4.3 gyr
- 3.9 – 4.1 gyr
- 3.2 – 3.4 gyr
- 2.7 – 2.8 gyr

We will never know what's happening in those gaps because we can't see past the noise

- The future?



Note that ASKAP is at one of the world's most radio quiet sites inside the ARQZWA. There is no escape from satellites.

This translates to other cosmological gas tracers, not just HI. Many thousands of emission lines are present throughout the radio spectrum and beyond

A (very) quick radio astronomy overview

Sensitivity to RFI

3G/4G/5G Smartphone
Sensitivity: -170 dBW/m²Hz

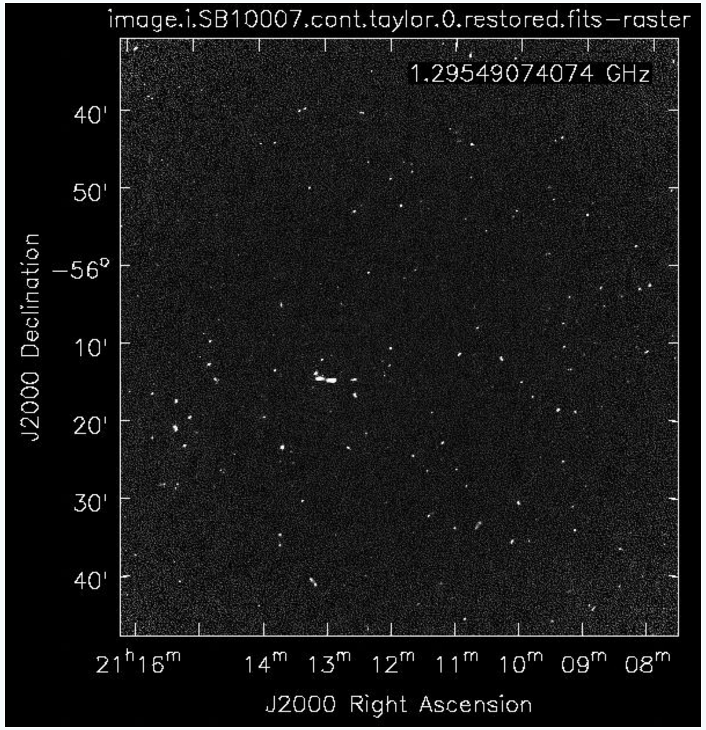
Radiotelescope
Sensitivity: -320 dBW/m²Hz

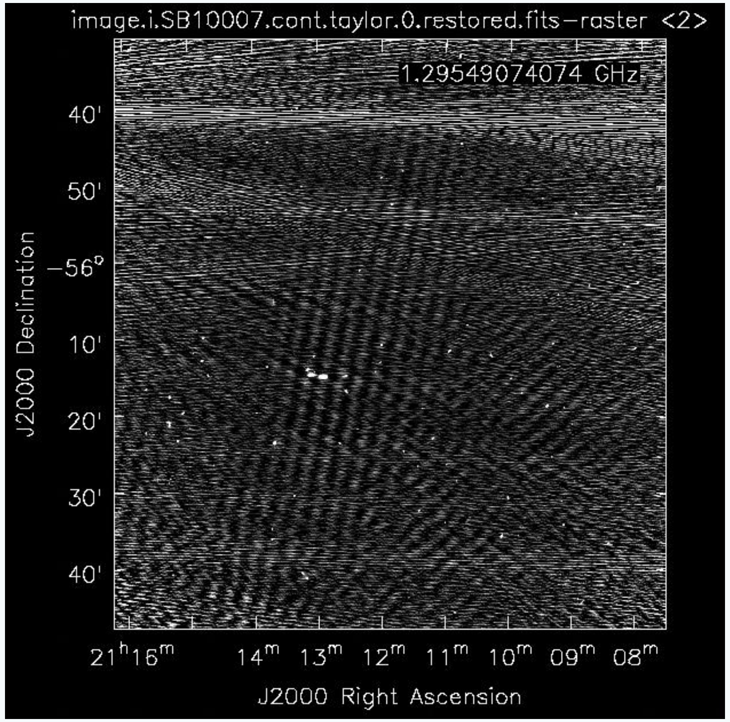
A radiotelescope is ~150 dB (1,000,000,000,000,000 times – a quadrillion) times more sensitive than a mobile phone!

If you think of it in computer storage terms:
1 byte = phone, 1 petabyte / 1,000 terabytes = telescope

A (very) quick radio astronomy overview

Sensitivity to 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

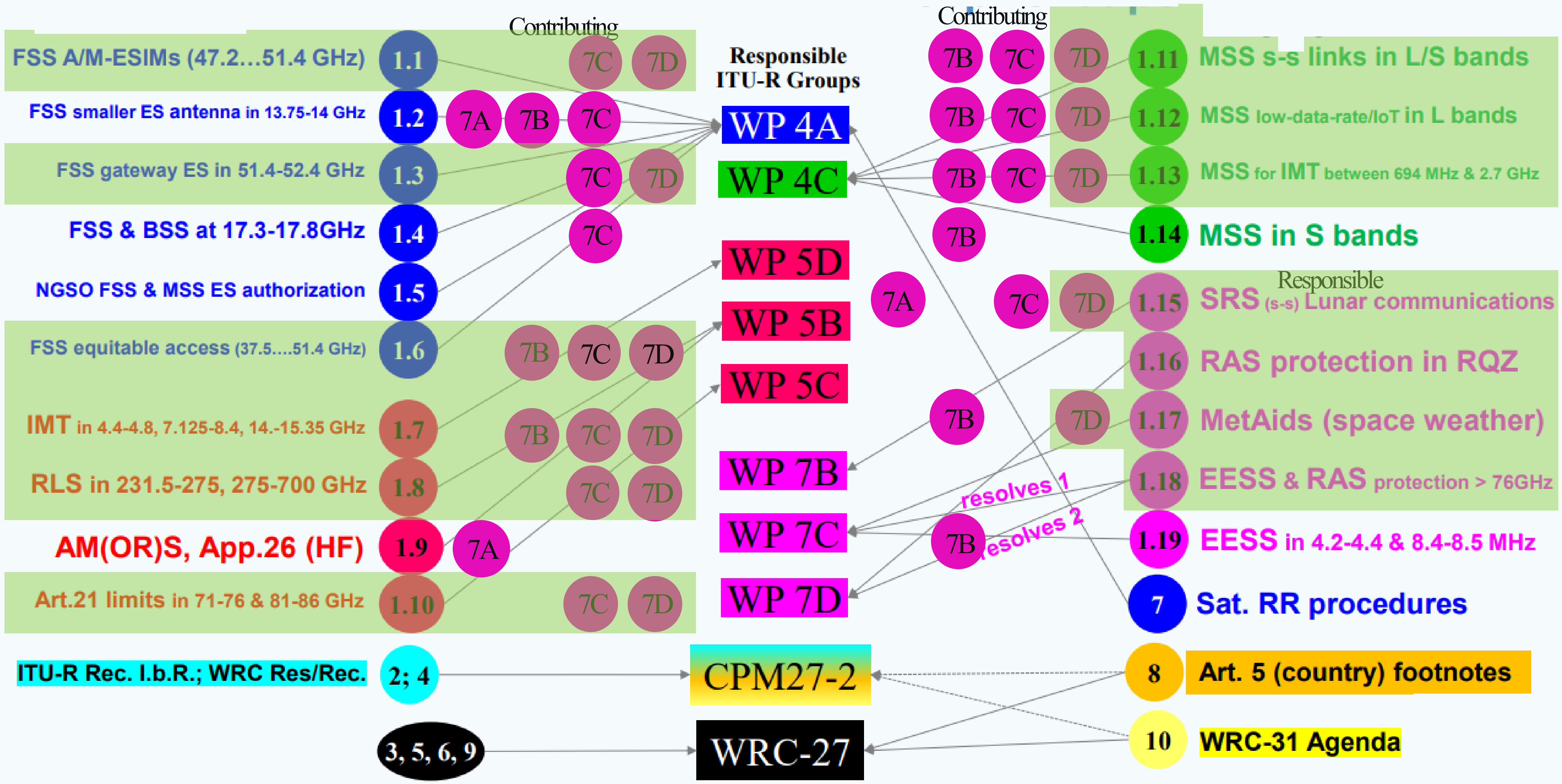
A (very) quick radio astronomy overview

Summary

Radio astronomy has…

- significant societal benefits
- provides the foundation for critical infrastructure (geodetic VLBI to derive EOPs, vulnerable between 3 – 14 GHz specifically)
- is extremely susceptible to interference (from both intended and unwanted emissions)
- is critically dependent on the judicious use of radio transmitters and associated radiations from space

WRC-27 Agenda Items under WP7D lead/contribution



WRC-27 Agenda Items under WP 7D lead/contribution

Allocation of ITU-R preparatory work for WRC-27			
WRC-27 agenda item	WRC Resolution	Responsible Group	Contributing Group
1.1	176 (Rev.WRC-23)	WP 4A	WP 7C/D
1.3	130 (WRC-23)	WP 4A	WP 7C/D
1.6	131 (WRC-23)	WP 4A	WP 7B/C/D
1.7	256 (WRC-23)	WP 5D	WP 7B/C/D
1.8	663 (Rev.WRC-23)	WP 5B	WP 7C/D
1.10	775 (Rev.WRC-23)	WP 5C	WP 7C/D
1.11	249 (Rev.WRC-23)	WP 4C	WP 7B/C/D
1.12	252 (WRC-23)	WP 4C	WP 7B/C/D
1.13	253 (WRC-23)	WP 4C	WP 7B/C/D
1.15	680 (WRC-23)	WP 7B	WP 7A/C/D
1.16	681 (WRC-23)	WP 7D	
1.17	682 (WRC-23)	WP 7C	WP 7B/D
1.18	712 (WRC-23)	WP 7C (resolves 1) WP 7D (resolves 2)	

WRC-27 Agenda Item preparations under WP7D lead

WRC-27 Agenda Item	Responsibility
1.16 Protection of radio astronomy operating in specific Radio Quiet Zones and, in frequency bands allocated to the radio astronomy service on a primary basis globally, from aggregate radio-frequency interference caused by non-geostationary satellite orbit systems, in accordance with Resolution 681 (WRC-23)	**WP 7D**
1.18 Possible regulatory measures regarding the protection of the Earth exploration-satellite service (passive) and the radio astronomy service in certain frequency bands above 76 GHz from unwanted emissions of active services, in accordance with Resolution 712 (WRC-23)	**WP 7C** (resolves 1) **WP 7D** (resolves 2)

WRC-27 Agenda Item preparations with WP7D contributing

WRC-27 Agenda Item	Contributor
1.1 Technical and operational conditions for the use of the frequency bands 47.2-50.2 GHz and 50.4-51.4 GHz (Earth-to-space), or parts thereof, by aeronautical and maritime earth stations in motion communicating with space stations in the fixed-satellite service and develop regulatory measures, as appropriate, to facilitate the use of the frequency bands 47.2-50.2 GHz and 50.4-51.4 GHz (Earth-to-space)	WP 7C, 7D
1.3 Use of the frequency band 51.4-52.4 GHz to enable use by gateway earth stations transmitting to non-geostationary-satellite orbit systems in the fixed-satellite service (Earth-to-space)	WP 7C, 7D
1.6 Technical and regulatory measures for fixed-satellite service satellite networks/systems in the frequency bands 37.5-42.5 GHz (space-to-Earth), 42.5-43.5 GHz (Earth-to-space), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space) for equitable access to these frequency band	WP 7B, 7C, 7D
1.7 Use of International Mobile Telecommunications (IMT) in the frequency bands 4 400-4 800 MHz, 7 125-8 400 MHz (or parts thereof), and 14.8-15.35 GHz taking into account existing primary services operating in these, and adjacent, frequency bands	WP 7B, 7C, 7D
1.8 Possible additional spectrum allocations to the radiolocation service on a primary basis in the frequency range 231.5-275 GHz and possible new identifications for radiolocation service applications in the frequency bands within the frequency range 275-700 GHz for millimetric and sub-millimetric wave imaging systems	WP 7C, 7D
1.10 Developing power flux-density and equivalent isotropically radiated power limits for inclusion in Article 21 of the Radio Regulations for the fixed-satellite, mobile-satellite and broadcasting-satellite services to protect the fixed and mobile services in the frequency bands 71-76 GHz and 81-86 GHz	WP 7C, 7D
1.11 Technical and operational issues, and regulatory provisions, for space-to-space links among non-geostationary and geostationary satellites in the frequency bands 1 518-1 544 MHz, 1 545-1 559 MHz, 1 610-1 645.5 MHz, 1 646.5-1 660 MHz, 1 670-1 675 MHz and 2 483.5-2 500 MHz allocated to the mobile-satellite service	WP 7B, 7C, 7D
1.12 Possible allocations to the mobile-satellite service in the bands 1 427-1 432 MHz (space-to-Earth), 1 645.5-1 646.5 MHz (space-to-Earth) (Earth-to-space), 1 880-1 920 MHz (space-to-Earth) (Earth-to-space) and 2 010-2 025 MHz (space-to-Earth) (Earth-to-space) for low-data-rate non-geostationary mobile-satellite systems	WP 7B, 7C, 7D
1.13 Possible new allocations to the mobile-satellite service for direct connectivity between space stations and International Mobile Telecommunications (IMT) user equipment to complement terrestrial IMT network coverage	WP 7B, 7C, 7D

WP 7D topics (1/2)

Leading group for WRC-27 agenda item 1.16 (Radio Quit Zones & aggregate interference):

- Working document towards a preliminary draft new Report ITU-R RA.[NGSO-RAS-RQZ] - [Mitigation techniques that could be taken by the concerned administration in their bilateral and multilateral negotiations to improve data collection quality at Radioastronomy Observatory in the Radio Quiet Zones supporting the Square Kilometre Array (SKA) and the Atacama Large Millimeter/submillimeter Array (ALMA) in presence of non-GSO satellite systems (Doc 7D/235, Annex 1);
- Working document towards draft CPM text for WRC-27 agenda item 1.16 (Doc 7D/235, Annex 25);
- Elements document regarding WRC-27 agenda item 1.16 with the EPFD calculation method and a compatibility study between non-GSO FSS systems and RAS Earth stations at 10.7 GHz (Doc 7D/235, Annex 3);

- Leading group for WRC-27 agenda item 1.18, resolves 2 (RAS protection > 76 GHz):
  - Working document towards a preliminary draft new Report ITU-R RA.[RAS-SAT 71-235 GHZ] - Compatibility between RAS operating in the 76-81, 130-134, 164-167 and 226-231.5 GHz and adjacent active satellite services (Doc 7D/235, Annex 7);
  - Considerations on draft CPM text for WRC-27 agenda item 1.18 (Doc 7D/235, Annex 8);
  - Draft revision of Tables 1 and 2 of the Annex to Resolution 739 (WRC-19) - WRC-27 agenda item 1.18 (Doc 7D/235, Annex 6);

WP 7D topics (2/2)

- Shielded zone of the Moon (several Working documents towards preliminary draft new Reports (Doc 7D/235, Annexes 9 to 13);
- RAS receiver resilience,
- RAS vs. IMT at 6-7 GHz and 43 GHz,
- Geodetic Very Long Baseline Interferometry (GEOVLBI),
- **Unintended electromagnetic radiation (UEMR) from space systems,**
- Revisions to Recommendation ITU-R RA.1513 and Reports ITU-R RA.2188-1 and ITU-R RA.2126.
- Contributing to WRC-27 AIs 1.1, 1.3, 1.6, 1.7, 1.8, 1.10, 1.11, 1.12, 1.13, 1.15 and 1.17.

WP 7D important documentation

- Characteristics:
  - Report ITU-R RA.2259 - Characteristics of radio quiet zones
  - Report ITU-R RA.2507 - Technical and operational characteristics of the existing and planned Geodetic Very Long Baseline Interferometry
  - Report ITU-R RA.2509 - Technical and operational characteristics of radio astronomy systems operating below 350 MHz (85 cm)
  - Report ITU-R RA.2510 - Technical and operational characteristics of radio astronomy systems in the 67-116 GHz (3-4 mm) range
  - Report ITU-R RA.2512 - Technical and operational characteristics of broadband, background-limited detectors operating in the millimetre-wave regime
  - Recommendation ITU-R RA.314 - Preferred frequency bands for radio astronomical measurements below 1 THz
- Sharing/Performance/Protection Criteria:
  - Recommendation ITU-R RA.769 - Protection criteria used for radio astronomical measurements
  - Recommendation ITU-R RA.1031 - Protection of the radio astronomy service in frequency bands shared with active services
  - Recommendation ITU-R RA.1513 - Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis
- Handbooks:
  - Radio Astronomy Handbook (revision in next cycle)

Summary of topics of concern to WP7D

- Large constellations of non-geostationary satellite systems and in general the unprecedented proliferation of NGSO systems today and in the coming years bring significant challenges and RFI
- Expansion of use and applications of satellite services within existing satellite allocations require appropriate regulations to avoid RFI (WRC-27 AIs 1.1 and 1.3)
- General trend by active services to also use higher frequency bands require appropriate regulation to avoid RFI (WRC-27 AIs 1.8 and 1.18, WRC-31 AIs 2.1 (275-325 GHz allocations) and 2.6 (IMT >102 GHz)).
- New Mobile Satellite Service (MSS) allocations/applications, particularly direct connectivity between space stations and IMT User Equipment in the frequency range 694-2700 MHz (WRC-27 Agenda Item 1.13), will have a major impact on radio astronomy.
- Increase in lunar missions requires the development of the appropriate regulatory environment to ensure the protection of RAS in the SZM (WRC-27 Agenda Item 1.15), but also harbours potential impacts on terrestrial RAS from the lunar near side
- Unintended electromagnetic radiation from space systems (UEMR)

Large constellations of non-geostationary satellite systems

- Unprecedented proliferation of filings for large constellations of non-geostationary satellite systems
  - Recent Space Sustainability Forum (7-8 Oct, Geneva) talked about 1.8 million satellites in ITU filings by 2030
  - Both intended emissions and unwanted emissions and unintended electromagnetic radiation from satellite platforms (UEMR) are significant challenges for RAS
- RAS is affected throughout the radio spectrum, not just in those currently allocated to the RAS
  - WRC-27 Agenda Item 1.16 attempts finding mechanisms to protect RAS
  - There is no recognition of RAS being critically dependent on observing throughout the radio spectrum
  - Assessing the single-entry and aggregate impact of NGSO FSS in the several bands listed in Annex 1 to Resolution 681 (WRC-23)
  - Recognition of Radio Quiet Zones (RQZ)
    - Discussion: Recognition/protection strictly within the bands allocated to RAS vs. larger bandwidths RAS is critically dependent on;
    - Res 681 explicitly only mentions two RAS facilities in considering k) for a possible RQZ recognition in the RR, leaving no room for extending the scope to other sites.

Expansion of use & applications within existing satellite allocations

- WRC-27 Agenda Items 1.1 (FSS aeronautical and maritime ESIMs in the 47.2-50.2 GHz and 50.4-51.4 GHz bands) & 1.3 (FSS gateways in the 51.4-52.4 GHz band transmitting to non-GSO systems;
  - Are the already established unwanted emission limits in the RR Resolution 750 still appropriate to protect the 50.3 GHz and 52.7 GHz passive sensing bands from these additional applications?

General trend by active service to also use higher bands (> 71 GHz)

- Opportunity: WRC-27 Agenda Item 1.18 attempts at implementing relevant unwanted emission limits to protect RAS and EESS (passive) in a number of bands subject to RR footnote 5.340 (all emissions are prohibited) or subject to RR footnote 5.149 (RAS) (76-81 GHz, 130-134 GHz), ahead of the deployment by allocated active services;
    - First temporary licenses for a satellite constellation using the bands 71-76 GHz and 81-86 GHz for NGSO gateway earth stations already issued in individual countries, requiring the establishment of appropriate unwanted emission limits in the RR Res 750 to protect the RR footnote 5.340 band 86-92 GHz and also measures to protect RAS in the bands 76-86 GHz and 92-94 GHz, both subject to RR footnote 5.149.
- Preliminary WRC-31 agenda item 2.1 (Extension of the frequency allocation table from 275 GHz to 325 GHz) and agenda item 2.6 (IMT (6G) in bands between 102 and 275 GHz).

Additional spectrum identification for IMT (WRC-27 Agenda Item 1.7)

- The band 15.35-15.4 GHz is subject to RR footnote 5.340 (all emissions are prohibited) and thus used by RAS worldwide.
  - Mechanism: Unwanted emissions to be limited to comply with RAS protection requirements (Rec. ITU-R RA.769).

New Mobile Satellite Service (MSS) allocations/applications

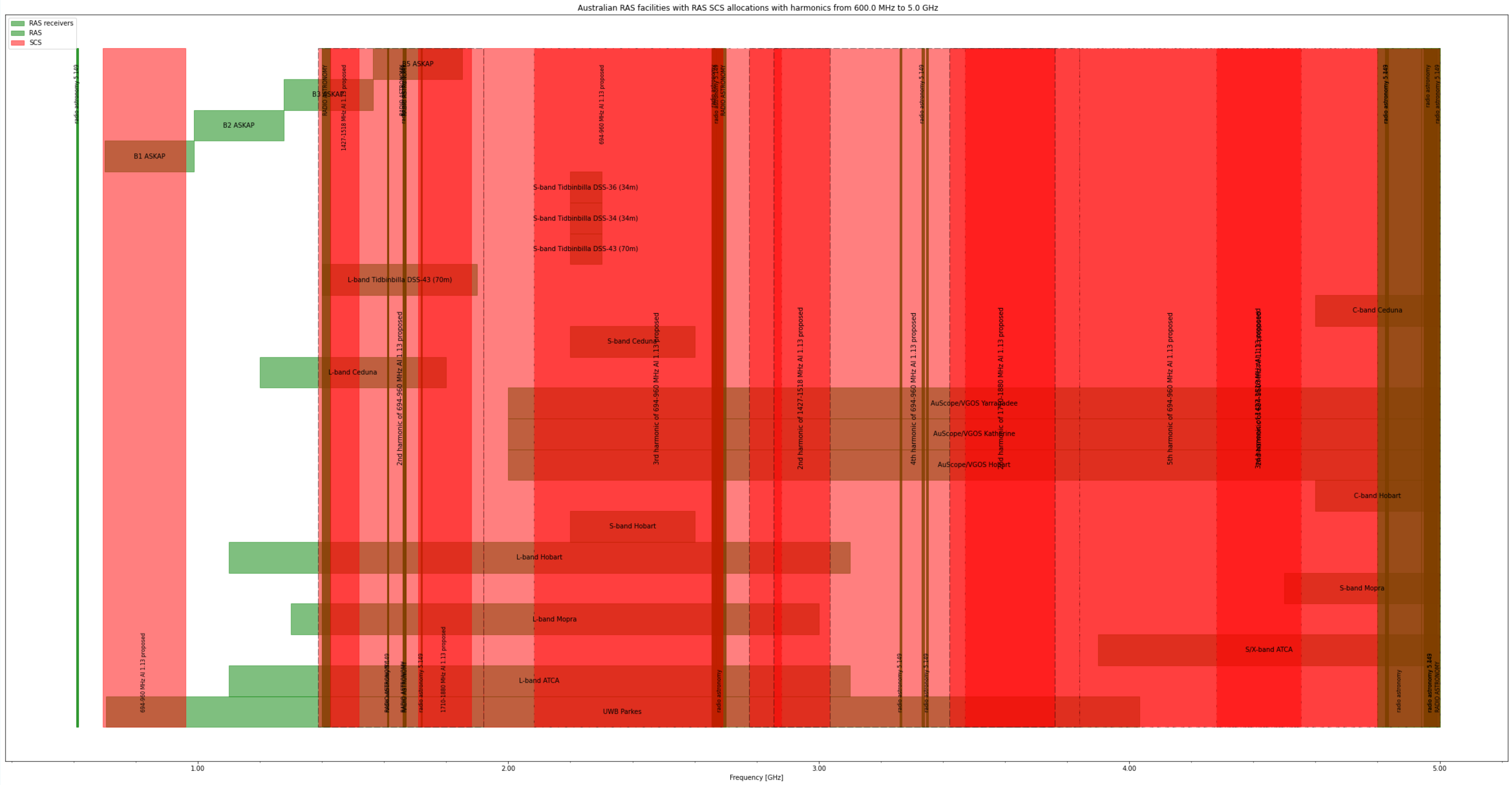
- Direct connectivity between space stations and IMT User Equipment (UE) in the frequency range 694-2700 MHz (WRC-27 Agenda Item 1.13)
  - Identification of a list of 15 frequency band pairs in the uplink and downlink for MSS direct communication with IMT UE
  - 5 bands in overlap with other WRC-27 agenda items on MSS (1.12 and 1.14) adding complexity;
  - Severe impact from direct to cell transmissions on RAS up to 4th and 5th harmonics;
  - One uplink frequency under consideration is at 1427-1470 MHz which is adjacent to the band 1400-1427 MHz, subject to RR footnote 5.340 (all emissions prohibited). The same applies to agenda item 1.12.
    - Mechanism: Protection to be ensured through mandatory unwanted emission limits in Res. 739.
- MSS in the 1427-1432 MHz, 1645.5-1646.5 MHz, 1880-1920 MHz and 2010-2025 MHz bands for low data rate non-GSO systems (WRC-27 Agenda Item 1.12).
- MSS in the bands 2 010-2 025 MHz, 2120-2160 MHz and 2 160-2 170 MHz (WRC-27 Agenda Item 1.14).

New Mobile Satellite Service (MSS) allocations/applications

AI 1.13 prop'd allocs: 600 MHz - 5 GHz (red). RAS allocations (green, vertical), AUS RAS facilities (green, horizontal)

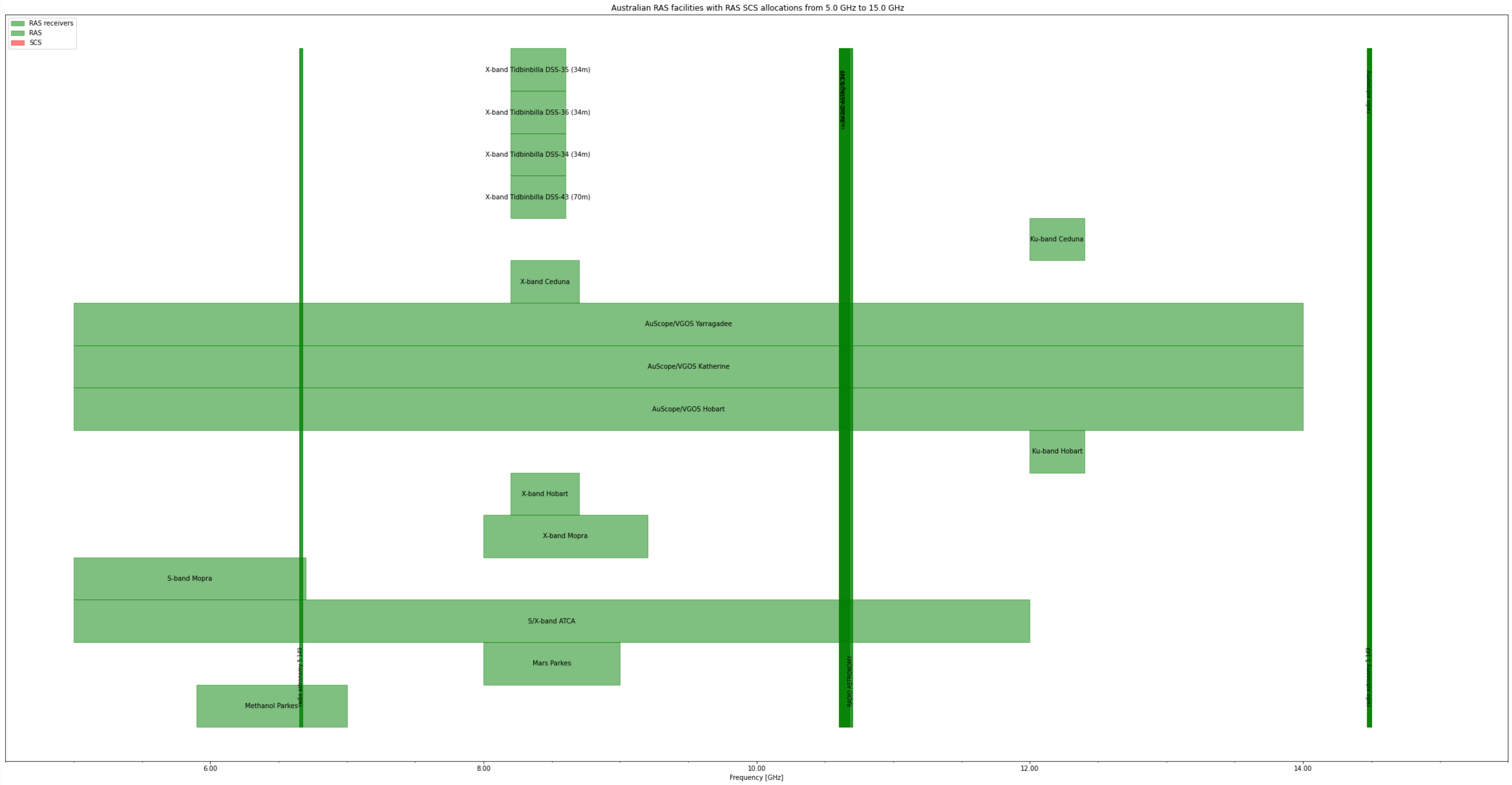
New Mobile Satellite Service (MSS) allocations/applications

- 1.13 proposed allocations: 600 MHz - 5 GHz – including up to 5th order harmonic



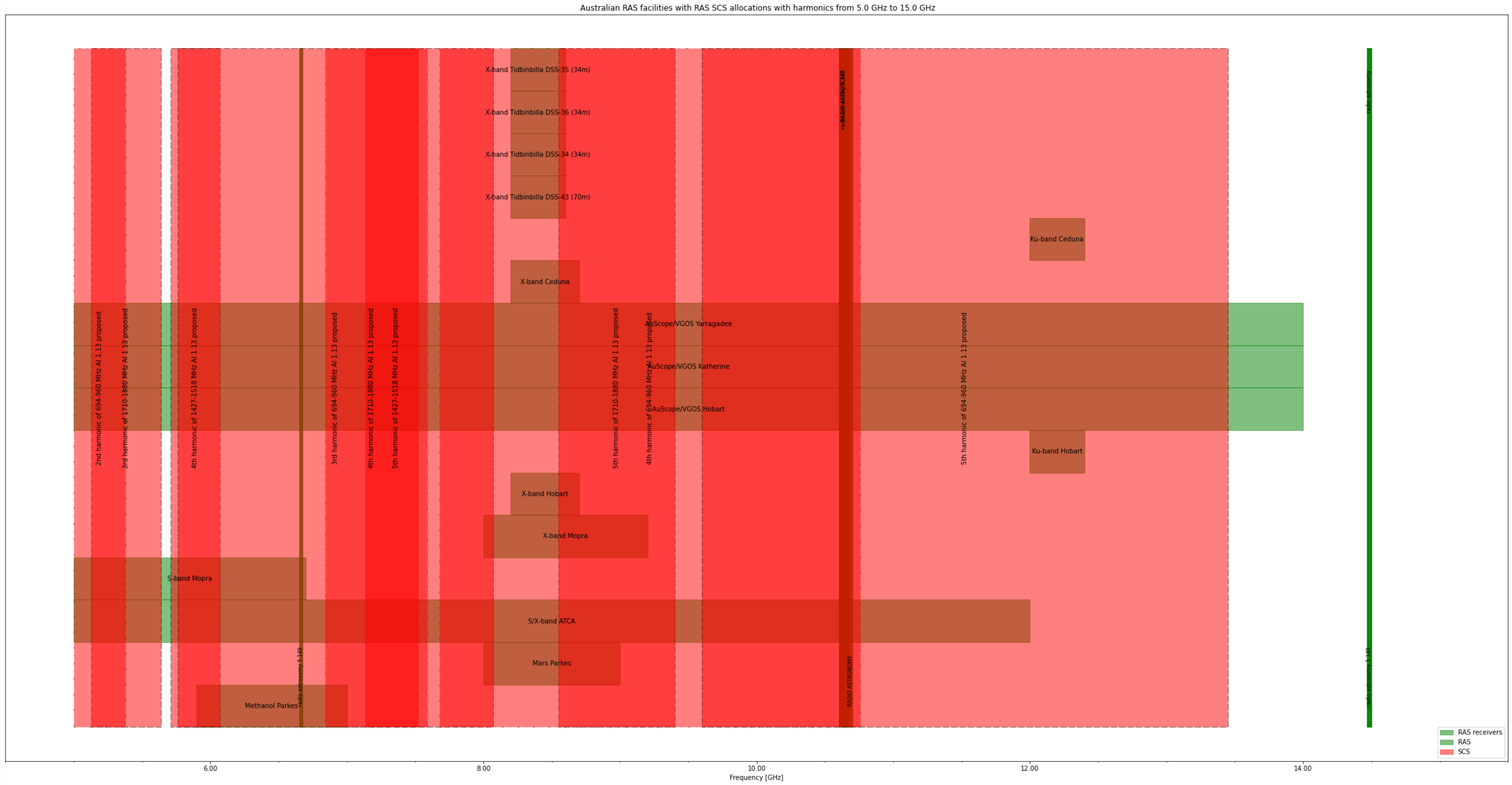
New Mobile Satellite Service (MSS) allocations/applications

1.13 proposed allocations: 5 GHz - 15 GHz. RAS allocations (green, vertical), AUS RAS facilities (green, horizontal)



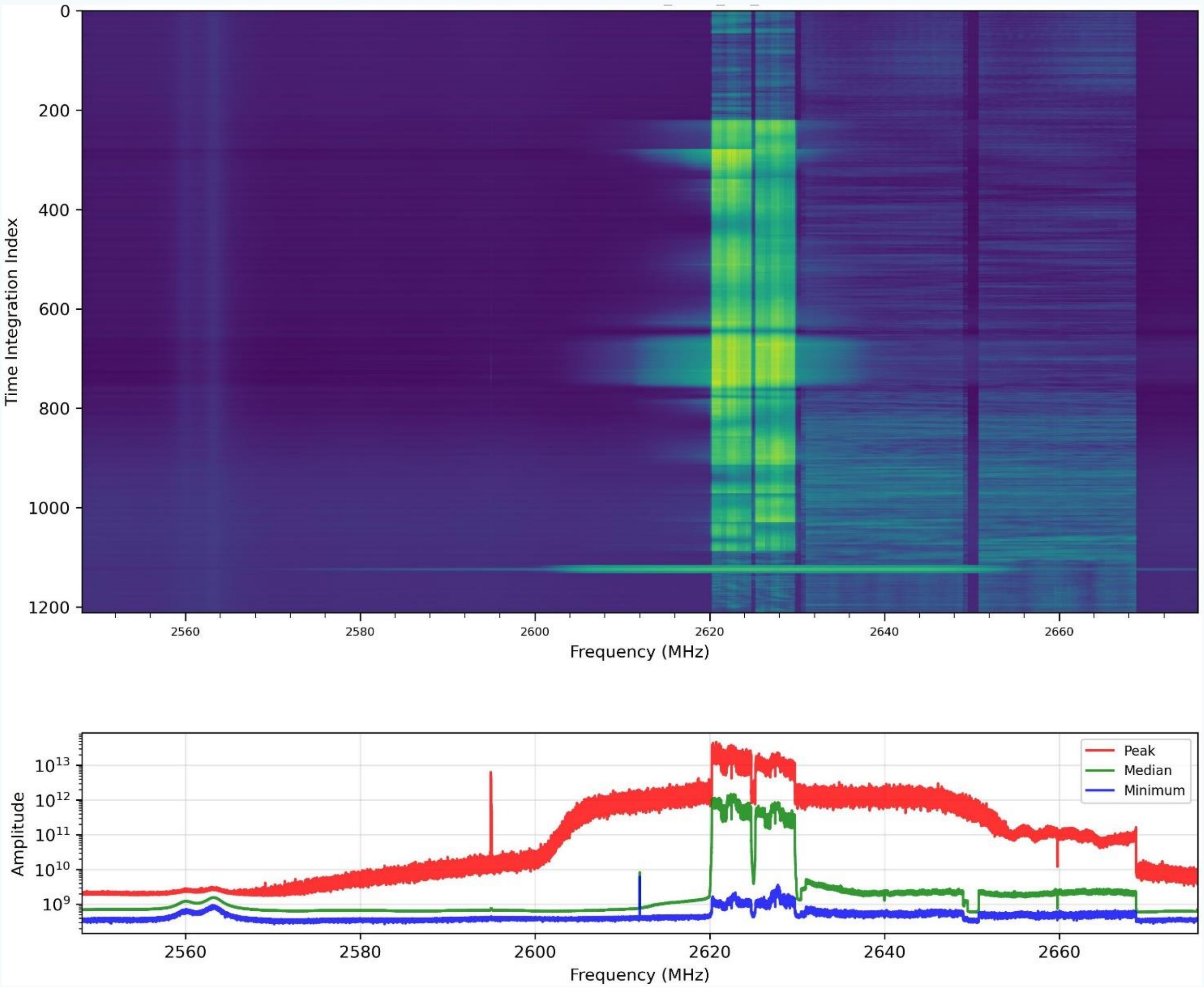
New Mobile Satellite Service (MSS) allocations/applications

AI 1.13 proposed allocations: 5 GHz - 15 GHz – including up to 5th order harmonic (red)



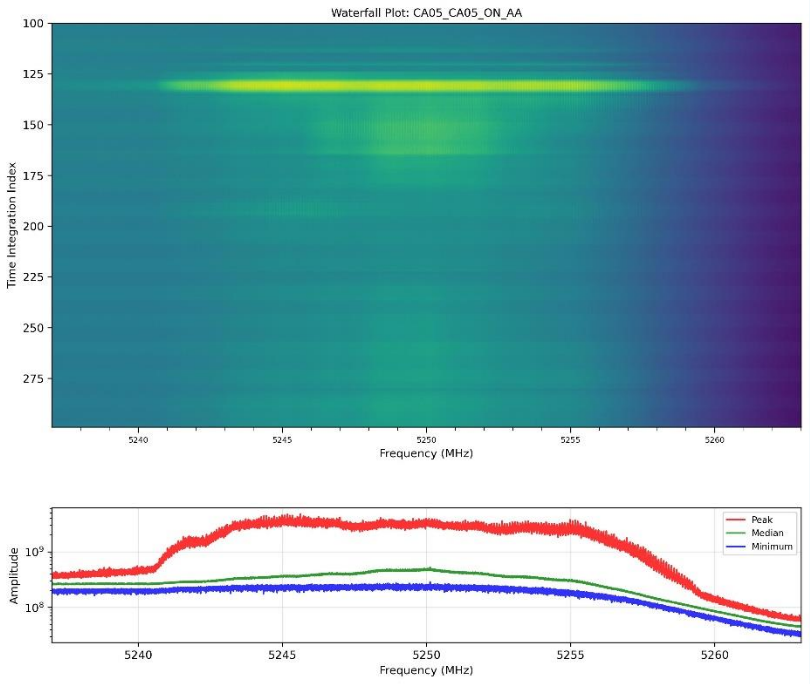
New Mobile Satellite Service (MSS) allocations/applications

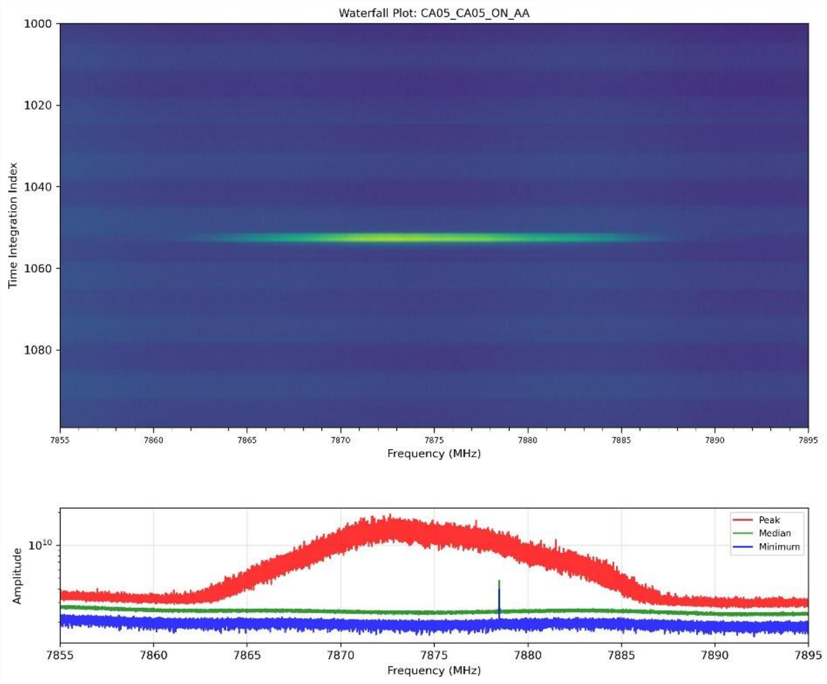
- Harmonics are real
- 5 minute RAS observation of the sky that includes the DTC band 2620-2630 MHz.
- Enormous powers compared to terrestrial interferers 2630-2670 MHZ
- 4+ magnitudes above terrestrial
- Enormous shoulder emissions
- Drives LNAs and/or (16-bit!) sampler non-linear

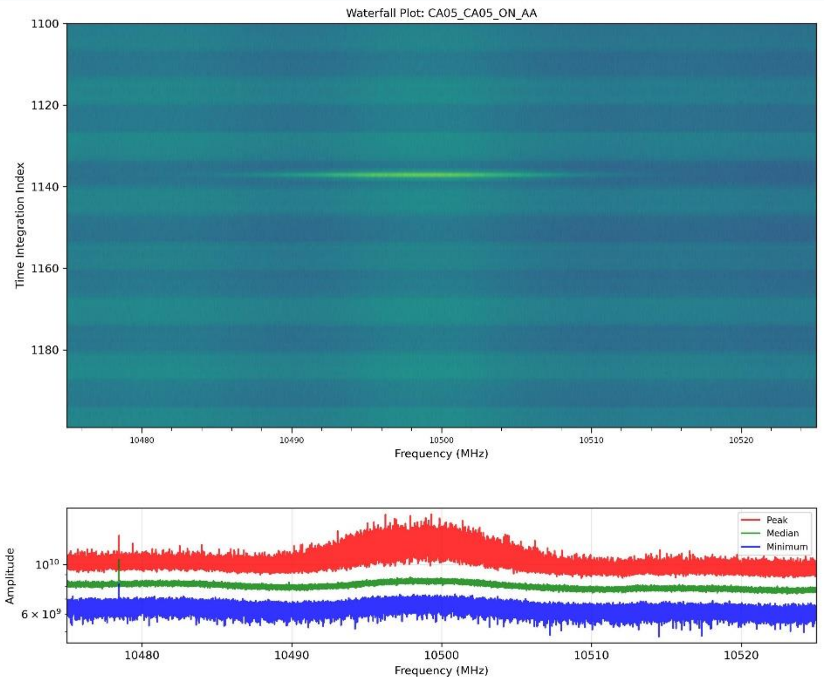


New Mobile Satellite Service (MSS) allocations/applications

- 2nd, 3rd, and 4th order harmonics of the same DTC emission, spurious domain!
- ATCA/BIGCAT data taken in Oct 2025
- 0.256s integration times (ITU-R RA.769 assumed integration time: 2000s!)





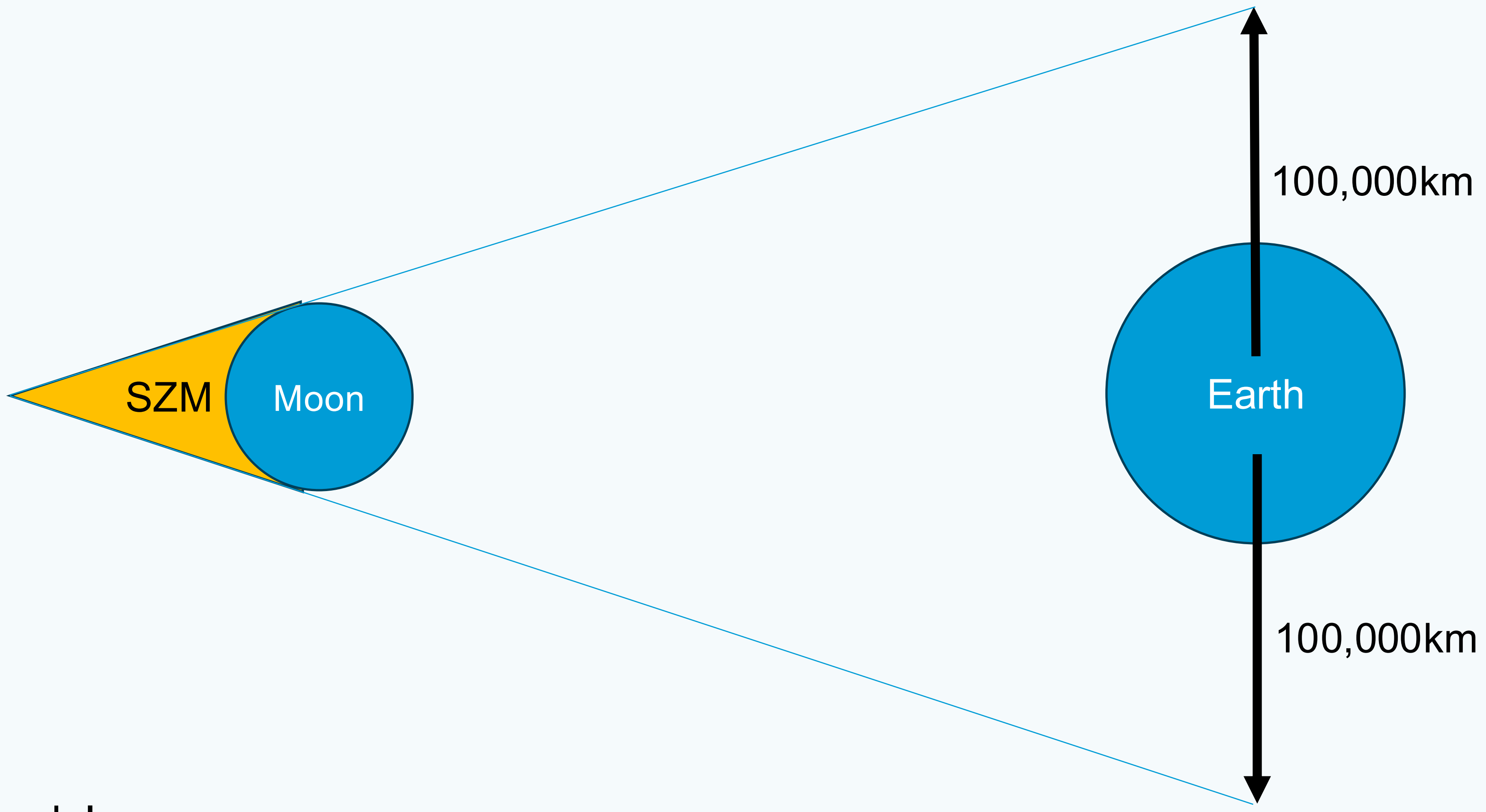


Lunar exploration requires dedicated spectrum

- Lunar surface communications and with lunar orbits (WRC-27 Agenda Item 1.15);
  - Resolution 680 (WRC-23) calls for studies on systems in the Space Research Service (SRS) which may operate on the lunar surface, or systems in lunar orbit communicating with systems on the lunar surface, in the following frequency ranges or portions thereof:
    - 390-406.1 MHz, 420-430 MHz and 440-450 MHz, limited to outside the shielded zone of the Moon;
    - 2400-2690 MHz, 3500-3800 MHz, 5150-5570 MHz, 5570-5725 MHz, 5775-5925 MHz, 7190-7235 MHz, 8450-8500 MHz and 25.25-28.35 GHz.
  - The Shielded Zone of the Moon (SZM) is a unique radio quiet environment for radioastronomical research and other passive applications, subject to RR No. 22.22-22.25 (Do these provisions leave room for interpretation?);
    - In particular, the frequency range below 2 GHz has to be kept free from interference into the RAS. Of interest to the RAS in the short term are frequency bands below 50 MHz, since many planned space missions concentrate on that frequency range;
    - Protection of RAS in the Shielded Zone of the Moon (SZM);
      - Mechanism: Appropriate thresholds for harmful interference to protect RAS operating in the SZM remain to be determined.

Lunar exploration requires dedicated spectrum

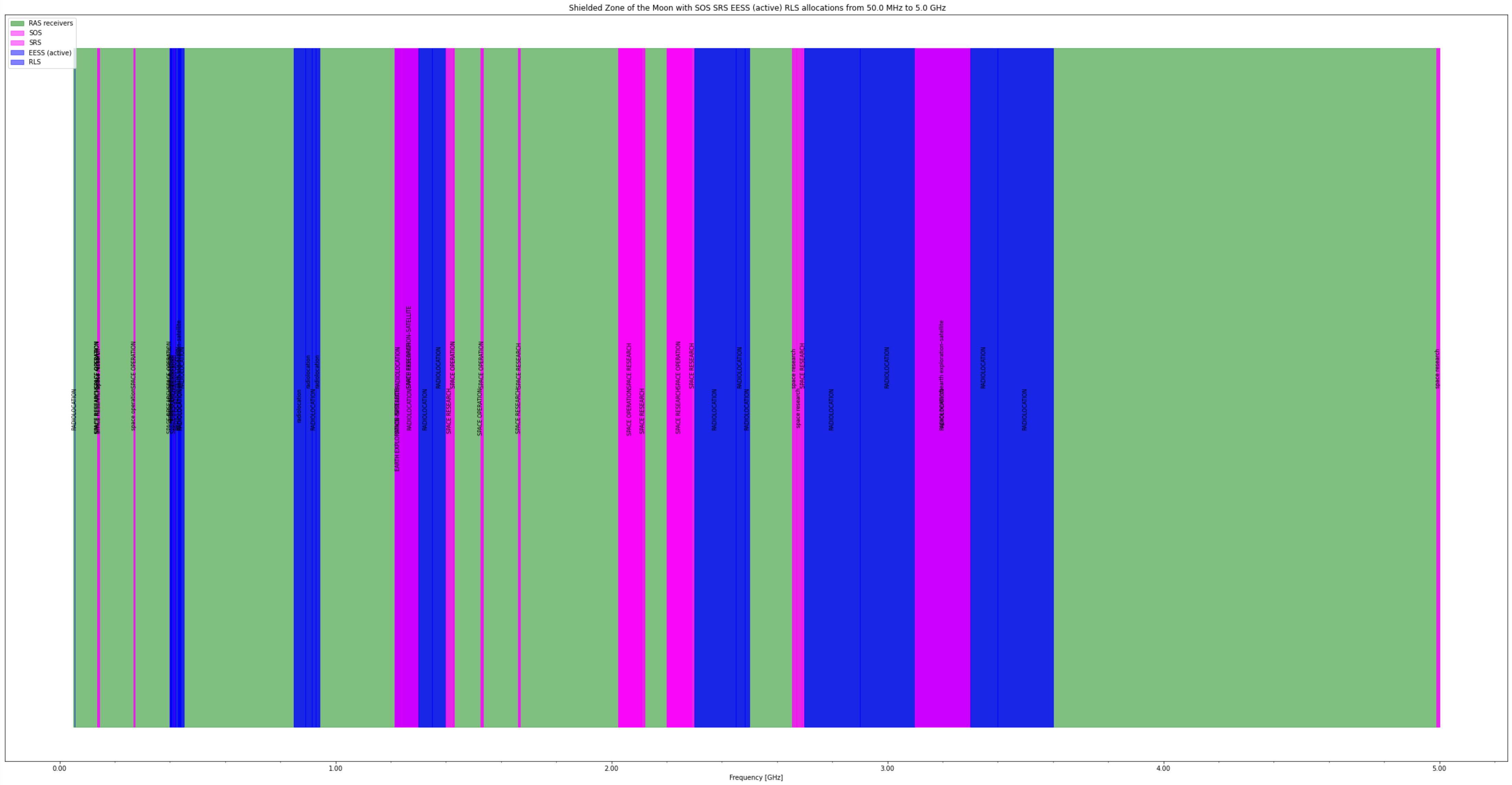
- The SZM is the conic volume of space at the lunar far side subtended by the angles illustrated below
- It features ~2 weeks of day / ~2 weeks of night, allowing for about 2 million seconds of integration time without solar RFI



Not to scale!

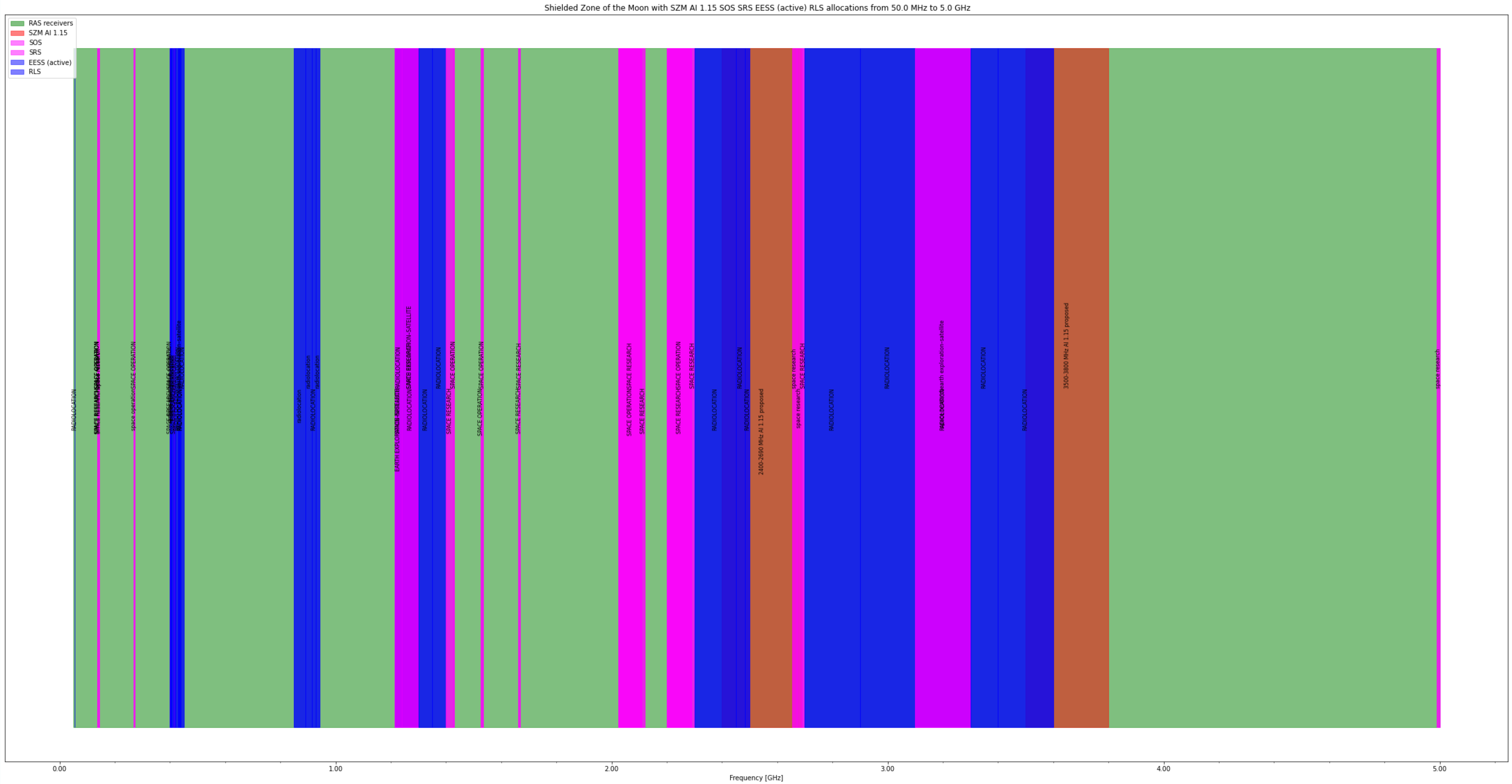
Lunar exploration requires dedicated spectrum

- SZM allocations today 50 MHz – 5 GHz: SRS/SOS/RLS/EESS (active). ~50% RAS



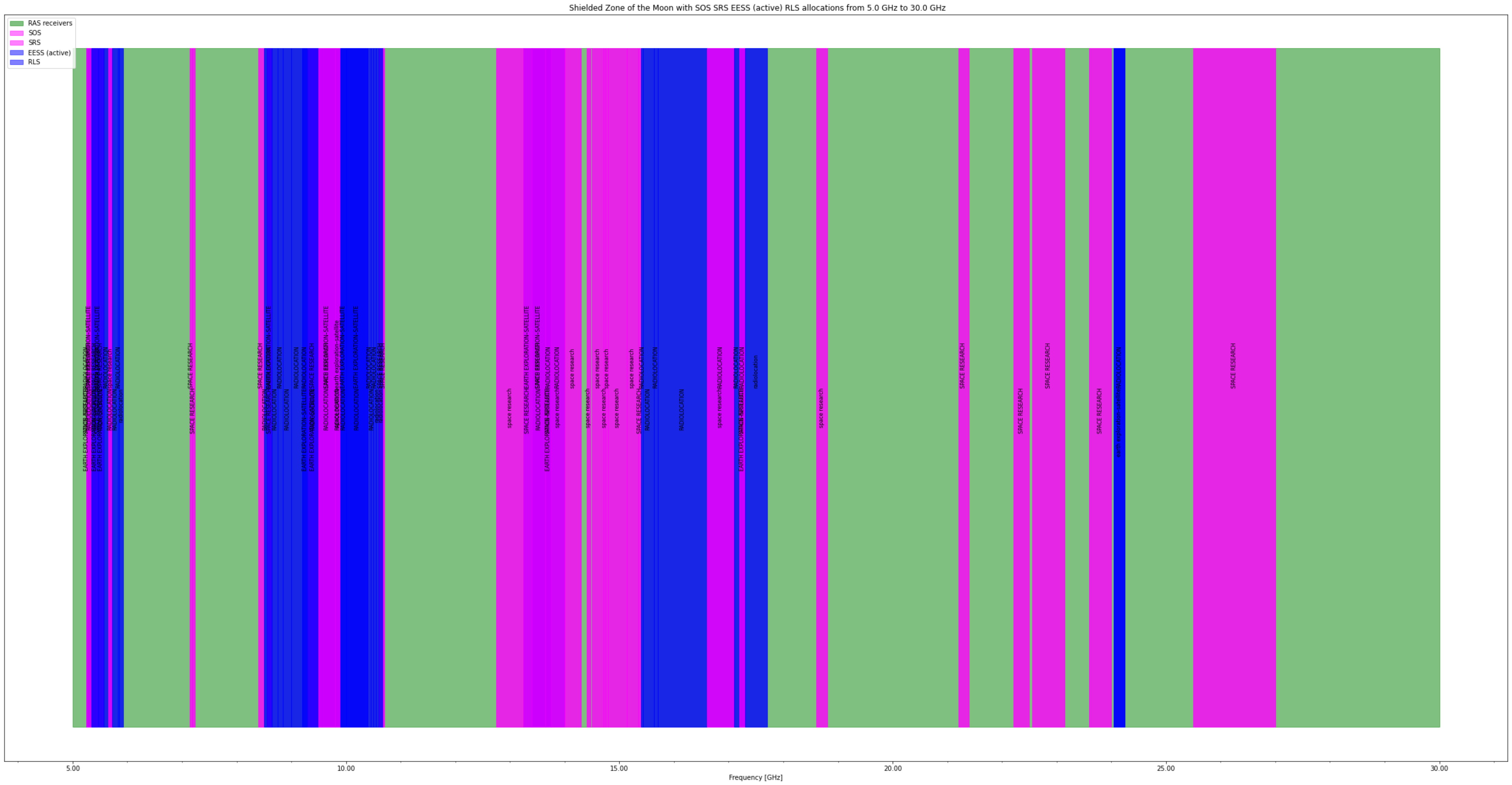
Lunar exploration requires dedicated spectrum

- SZM allocations today 50 MHz – 5 GHz: SRS/SOS/RLS/EESS (active) + AI 1.15 proposed (red): RAS ~46%



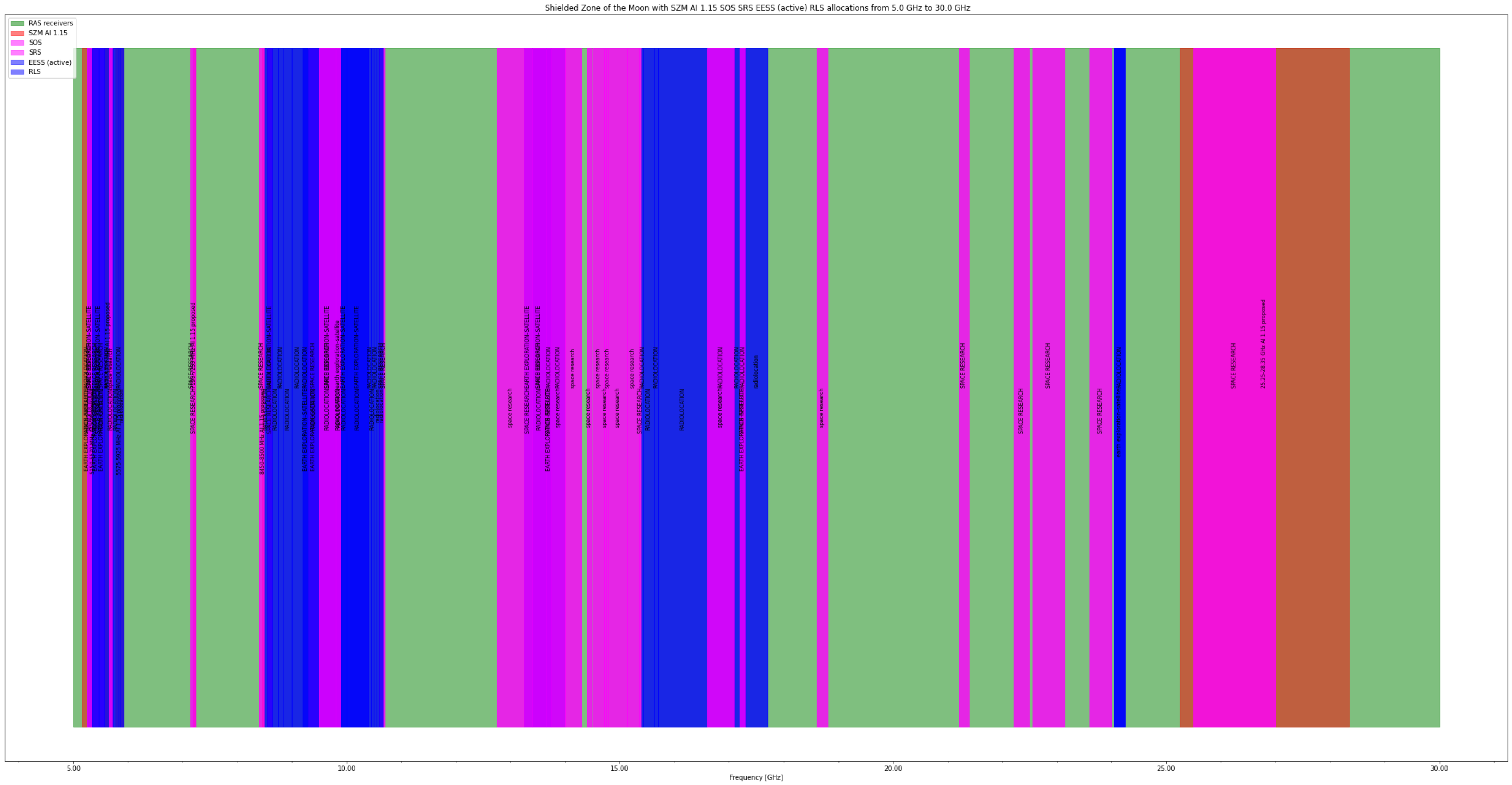
Lunar exploration requires dedicated spectrum

- SZM allocations today 5 GHz – 30 GHz: SRS/SOS/RLS/EESS (active)



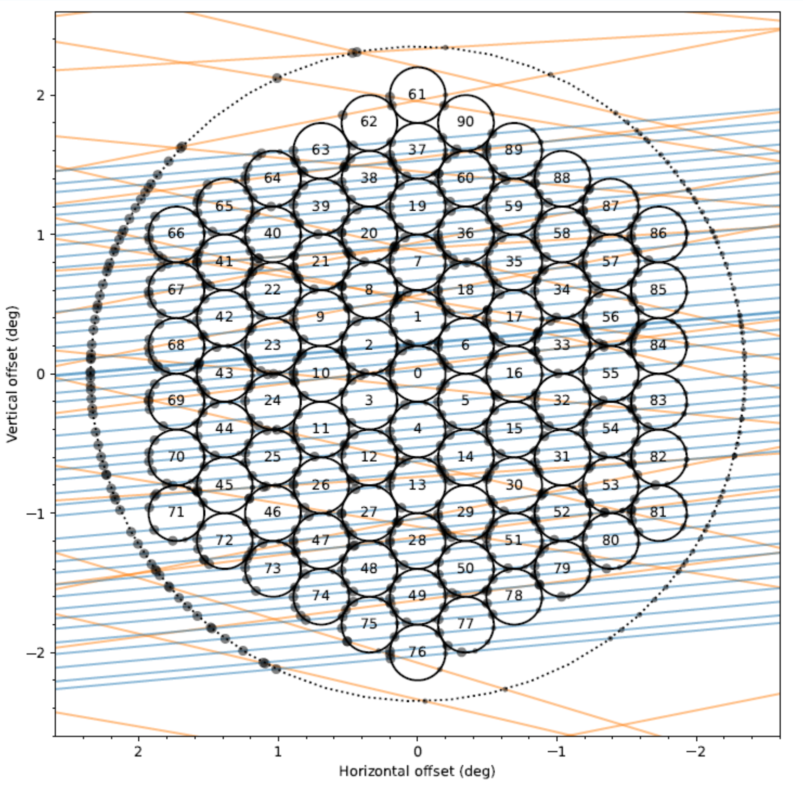
Lunar exploration requires dedicated spectrum

- SZM allocations today 5 GHz – 30 GHz: SRS/SOS/RLS/EESS (active) + AI 1.15 proposed (red)

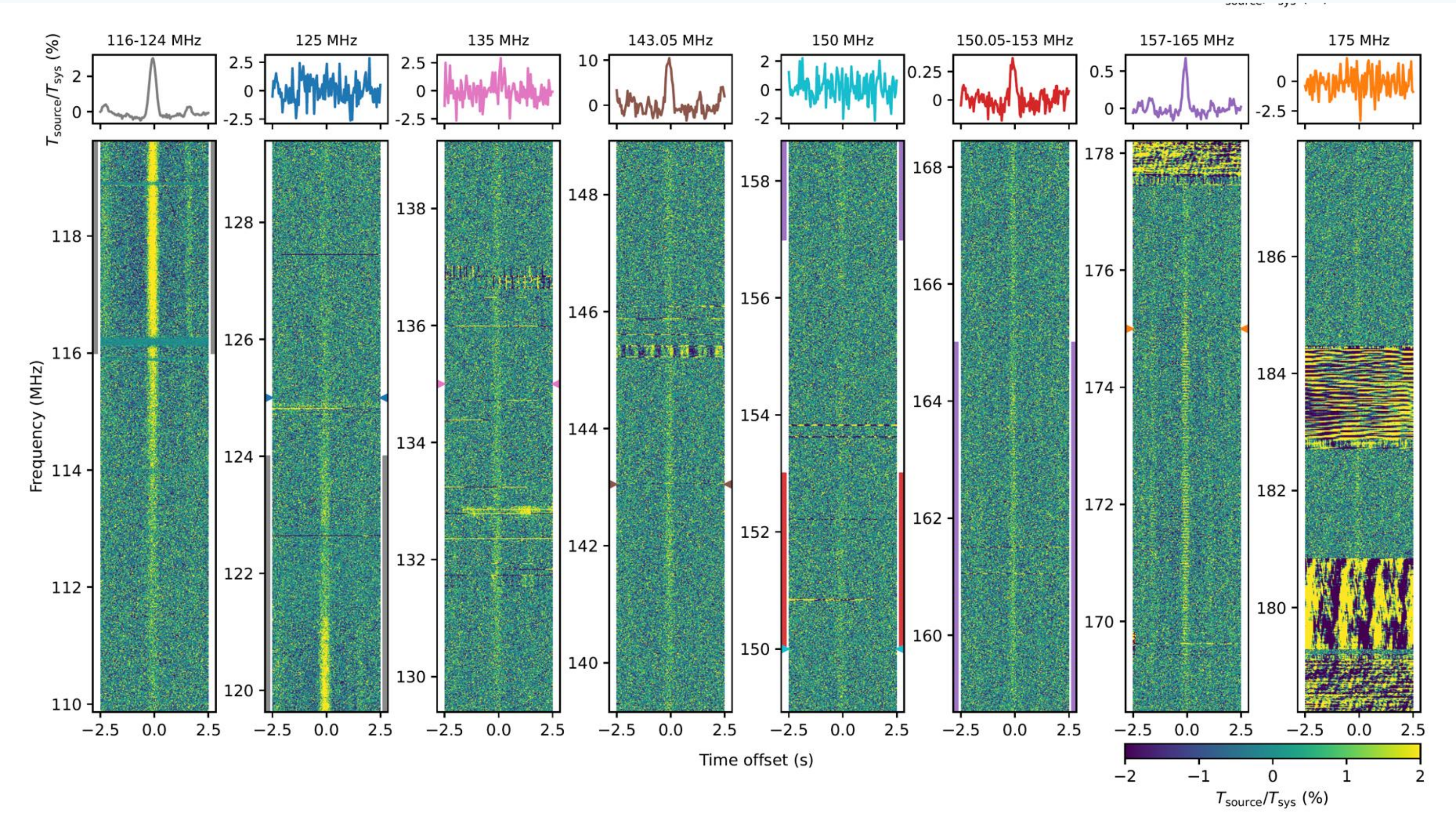


Unintended Electromagnetic Radiation (UEMR) from Space Systems

- New problem since large constellations launched. At low frequencies (50 – 350 MHz)



91-beam arrangement in the sky with satellite transits



Detection of broadband EM radiation in 110-180 MHz
Di Vruno, F., et al.: A&A Volume 676, id.A75 2023

Unintended Electromagnetic Radiation (UEMR) from Space Systems

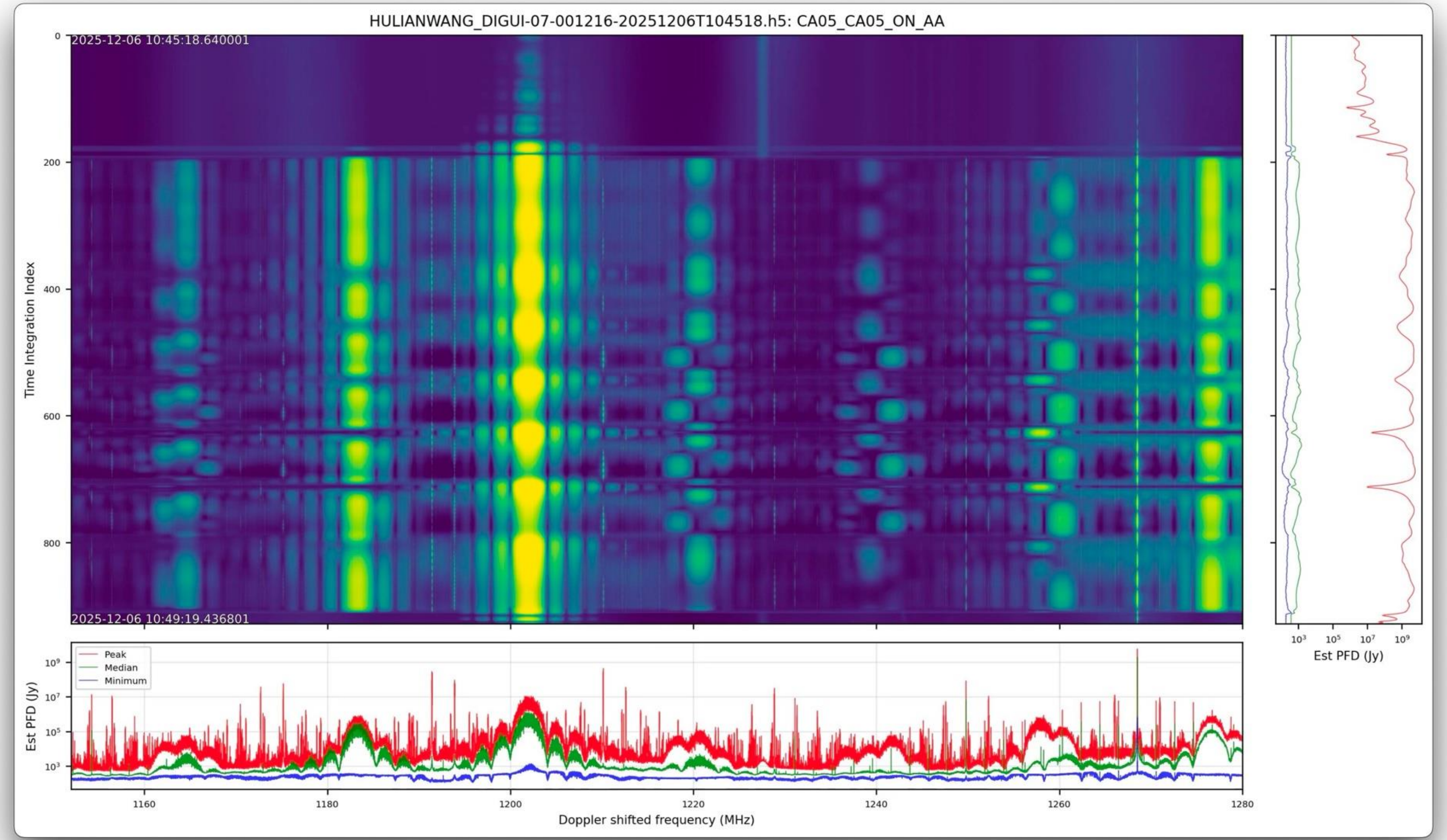
- But also at high frequencies - L/S/C/X/K bands. BIGCAT measurements (8 x 128 MHz wide windows) 1150 – 2170 MHz at 1.1 kHz resolution

1150 – 1280 MHz
Peak PFD ~ 10 GJy!

Radiation:
Broadband

New detection (Dec 2025)

Note absence prior/after satellite entering the beam



Unintended Electromagnetic Radiation (UEMR) from Space Systems

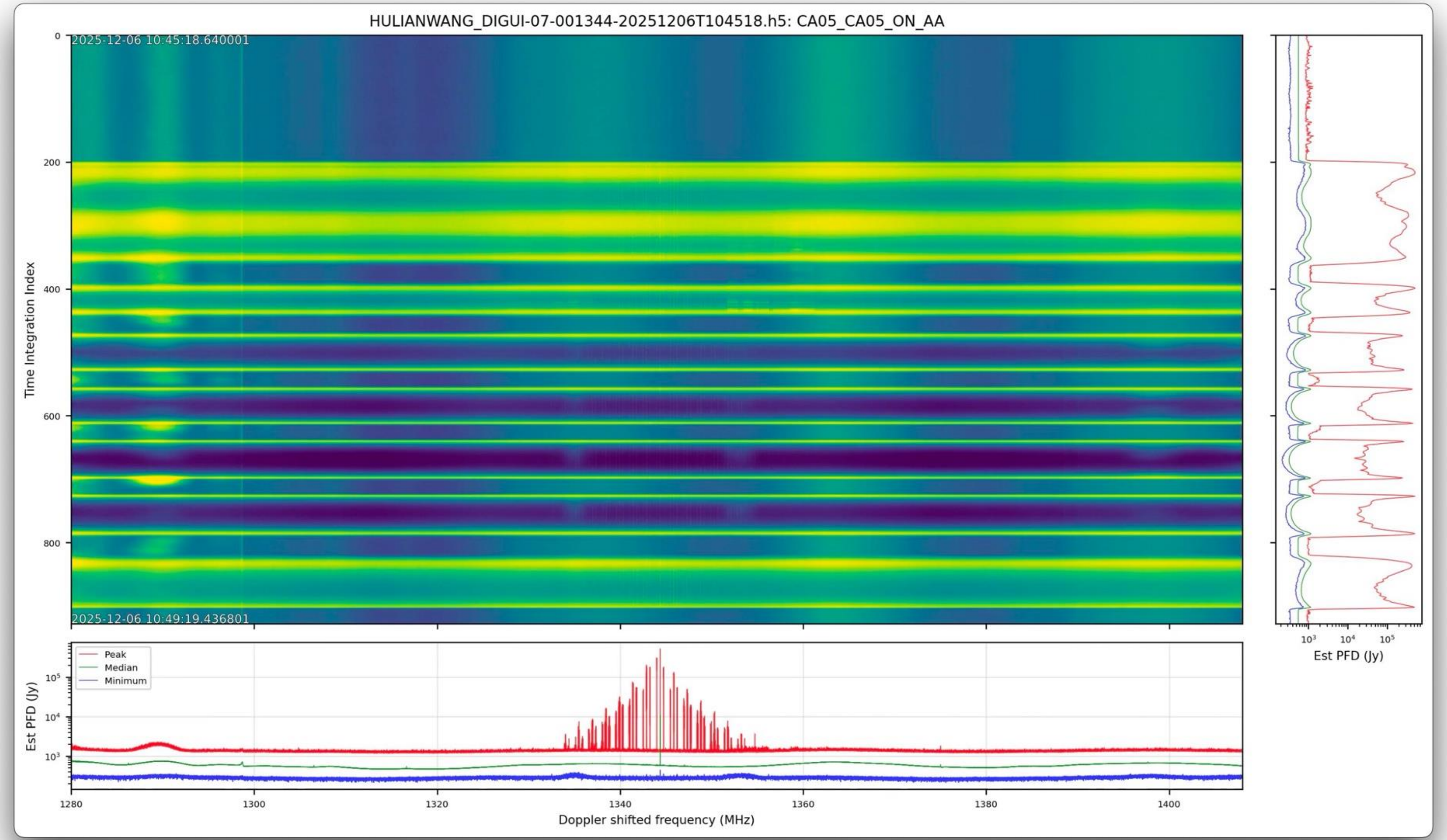
- New problem since large constellations launched. BIGCAT measurements (8 x 128 MHz wide windows) 1150 – 2170 MHz at 1.1 kHz resolution

1280 – 1410 MHz
Peak PFD ~ 10 MJy!

Radiation: Broadband

New detection (Dec 2025)

Note absence prior/after satellite entering the beam



Unintended Electromagnetic Radiation (UEMR) from Space Systems

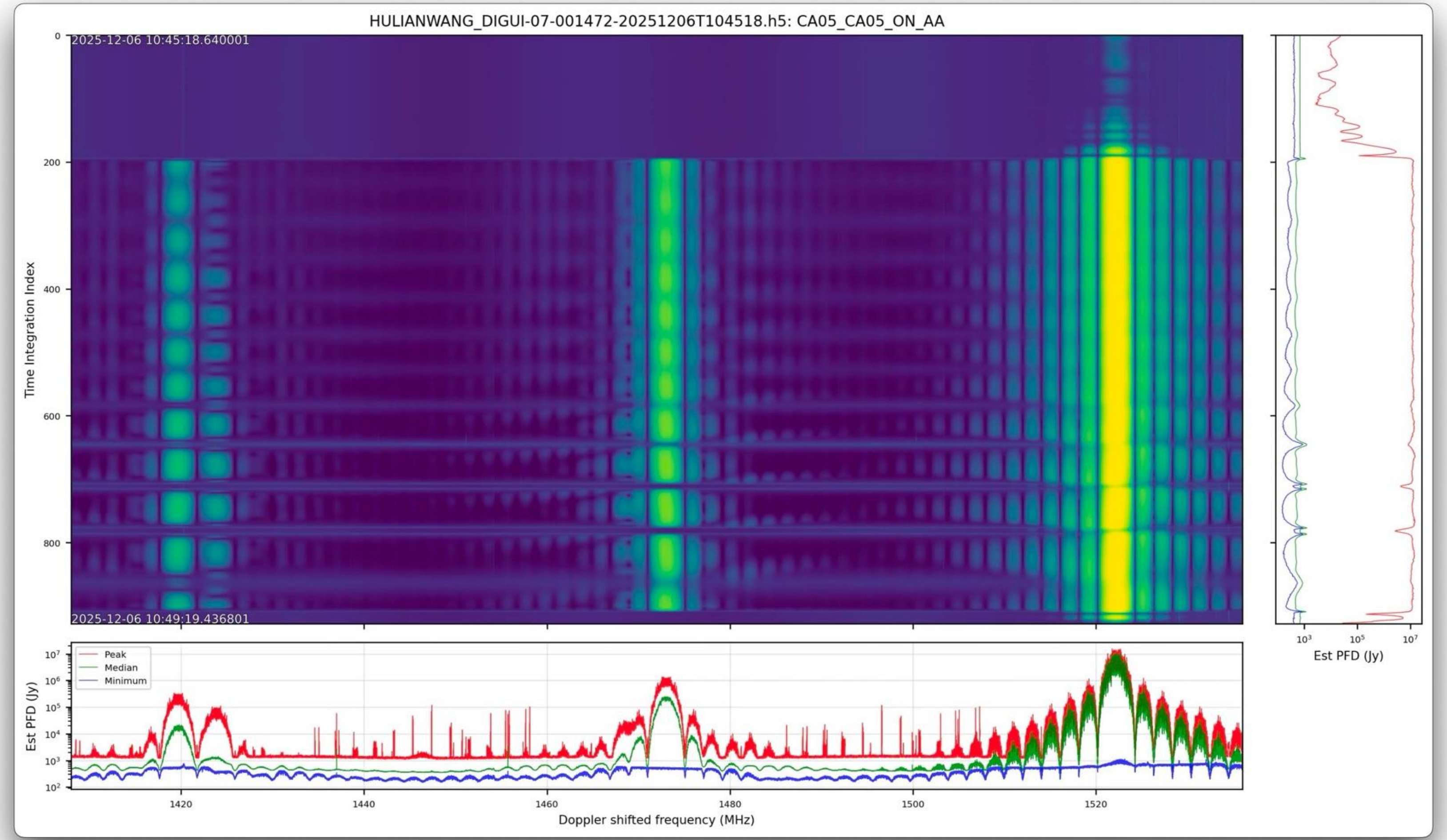
- New problem since large constellations launched. BIGCAT measurements (8 x 128 MHz wide windows) 1150 – 2170 MHz at 1.1 kHz resolution

1410 – 1530 MHz
Peak PFD ~ 10's MJy!

Radiation:
Broadband

New detection (Dec 2025)

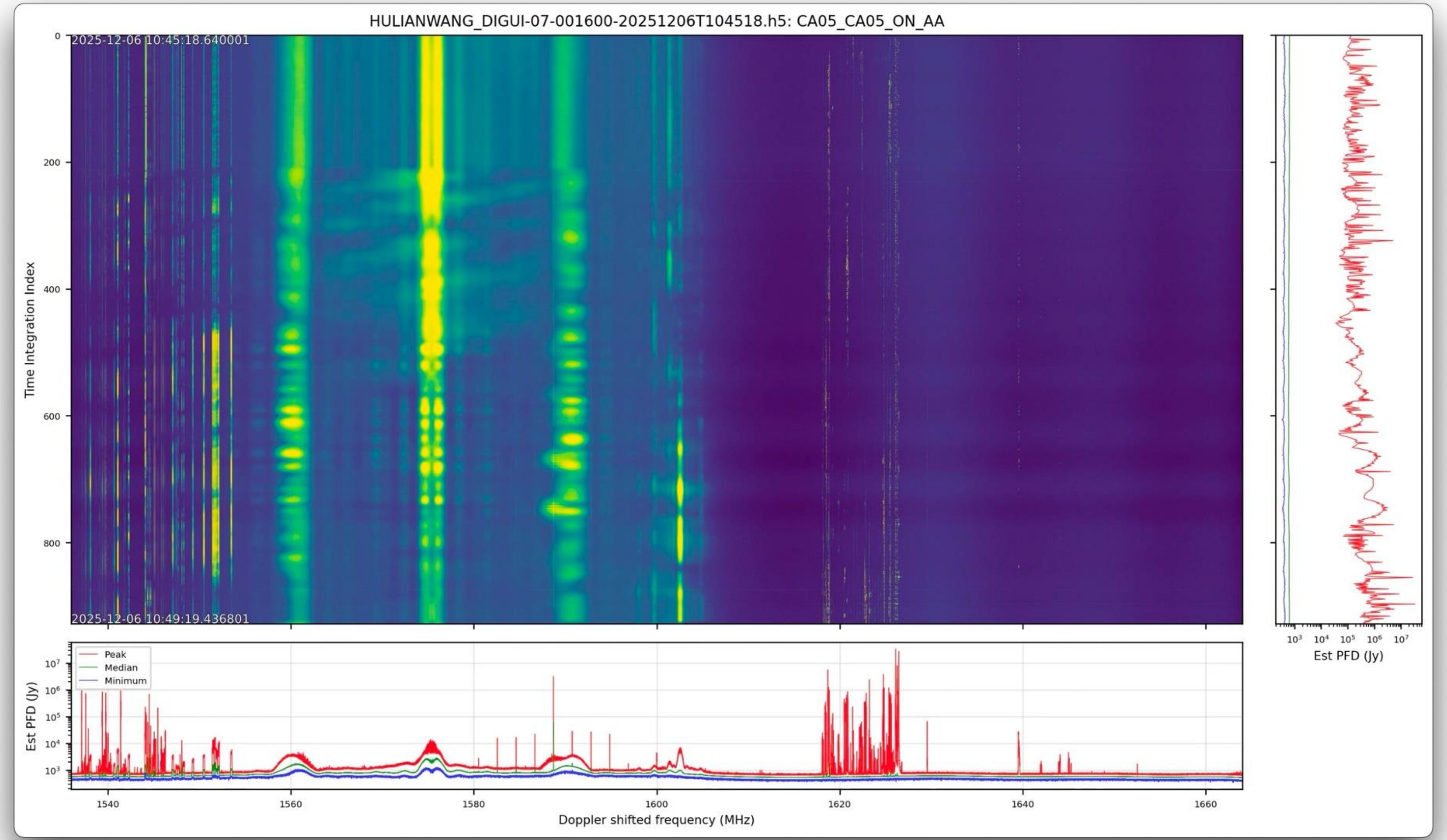
Note absence prior/after satellite entering the beam



Unintended Electromagnetic Radiation (UEMR) from Space Systems

- New problem since large constellations launched. BIGCAT measurements (8 x 128 MHz wide windows) 1150 – 2170 MHz at 1.1 kHz resolution

1530 – 1665 MHz



Radiation:
None (all known terrestrial emitters + Iridium at ~ 10^7 Jy (normal)

New detection (Dec 2025)

Note all emissions relatively constant, including prior/after satellite entering the beam = no emission from this satellite

Unintended Electromagnetic Radiation (UEMR) from Space Systems

- New problem since large constellations launched. At L/S/C/X/K bands

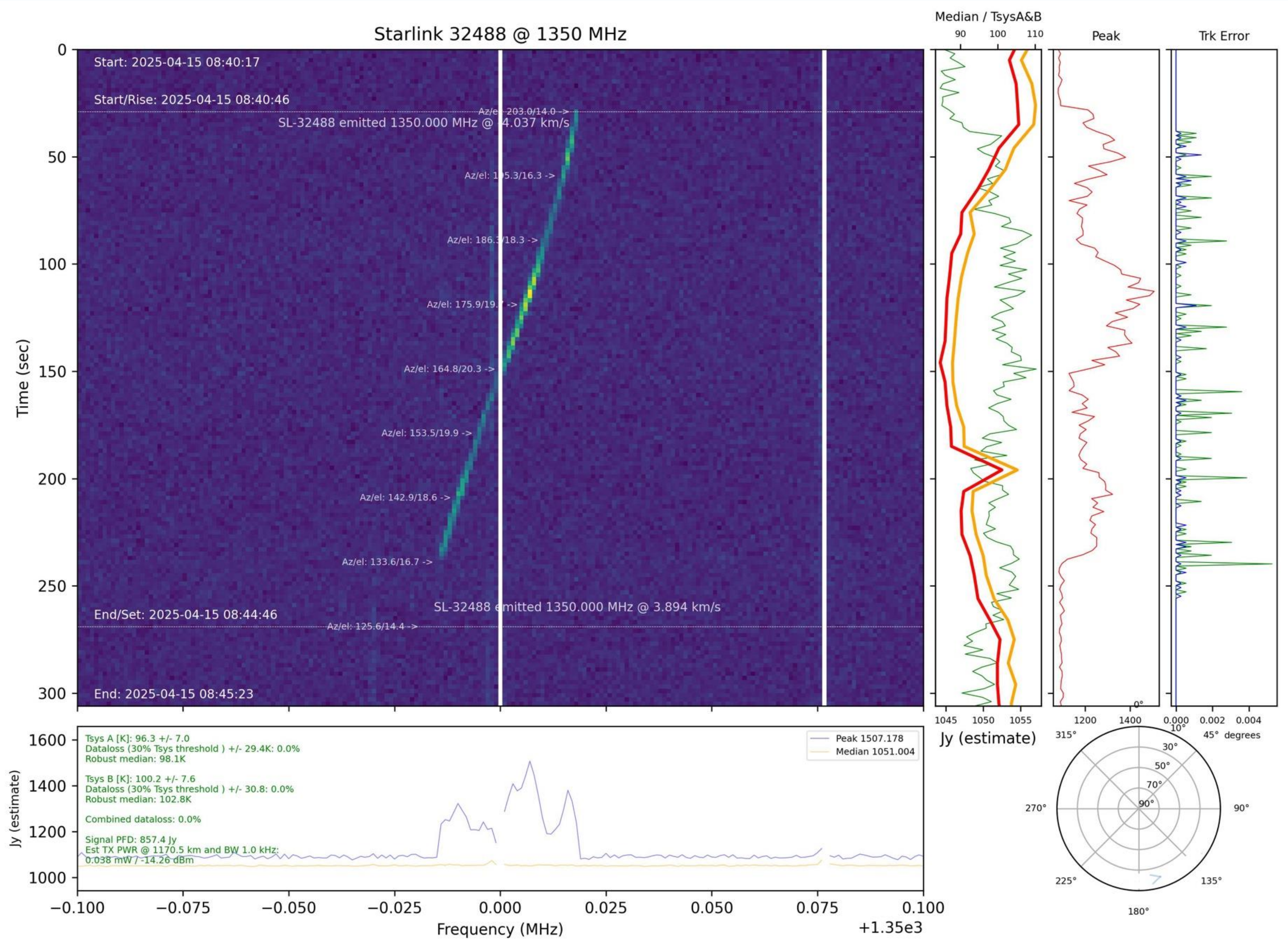
Selected results: L-band

Radiation:
1350 MHz

TOFA:
1300 – 1350 MHz
RLS, ARNS, RNSS (E-s)
5.149 AUS87 AUS103

1350 – 1400 MHz
RLS
5.149 AUS87 AUS103

Incidence: 33%
1/3 observations



Unintended Electromagnetic Radiation (UEMR) from Space Systems

- New problem since large constellations launched. At L/S/C/X/K bands

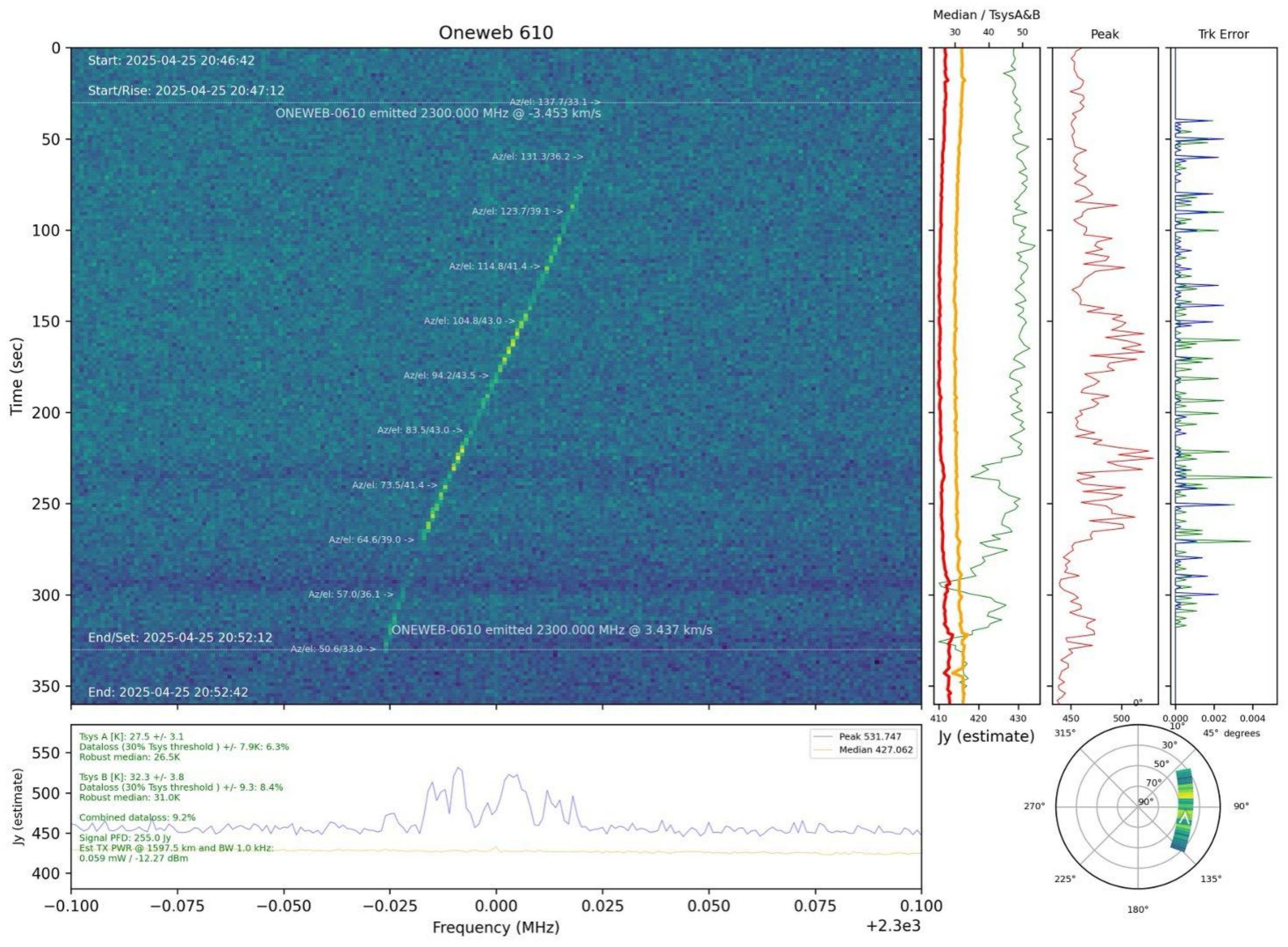
Selected results: S-band

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



Unintended Electromagnetic Radiation (UEMR) from Space Systems

- New problem since large constellations launched. At L/S/C/X/K bands

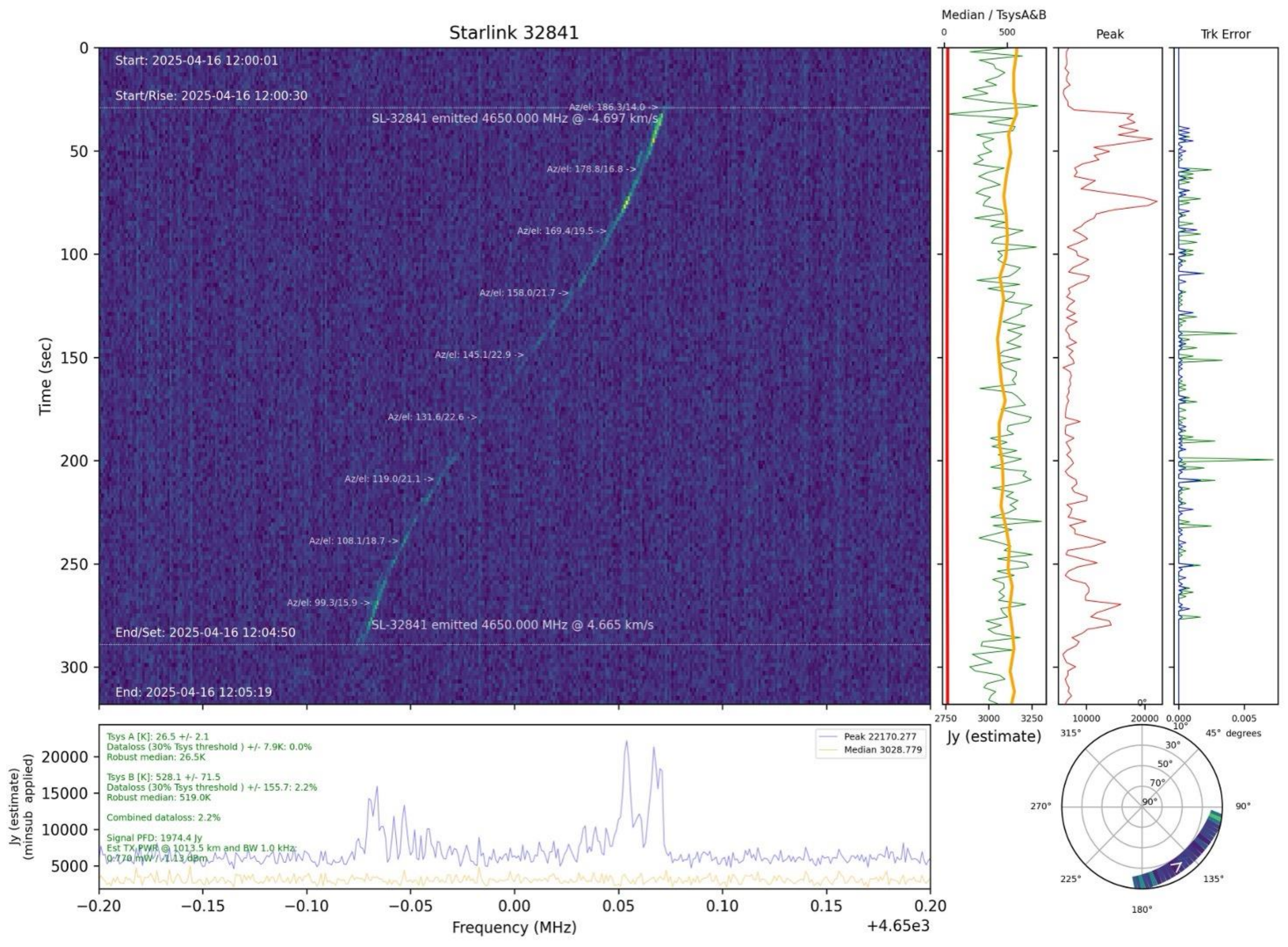
Selected results: C-band

Radiation :
4650 MHz

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

Disregard scale (corrupt Tsys)

Incidence: 100%
1/1 observations



Unintended Electromagnetic Radiation (UEMR) from Space Systems

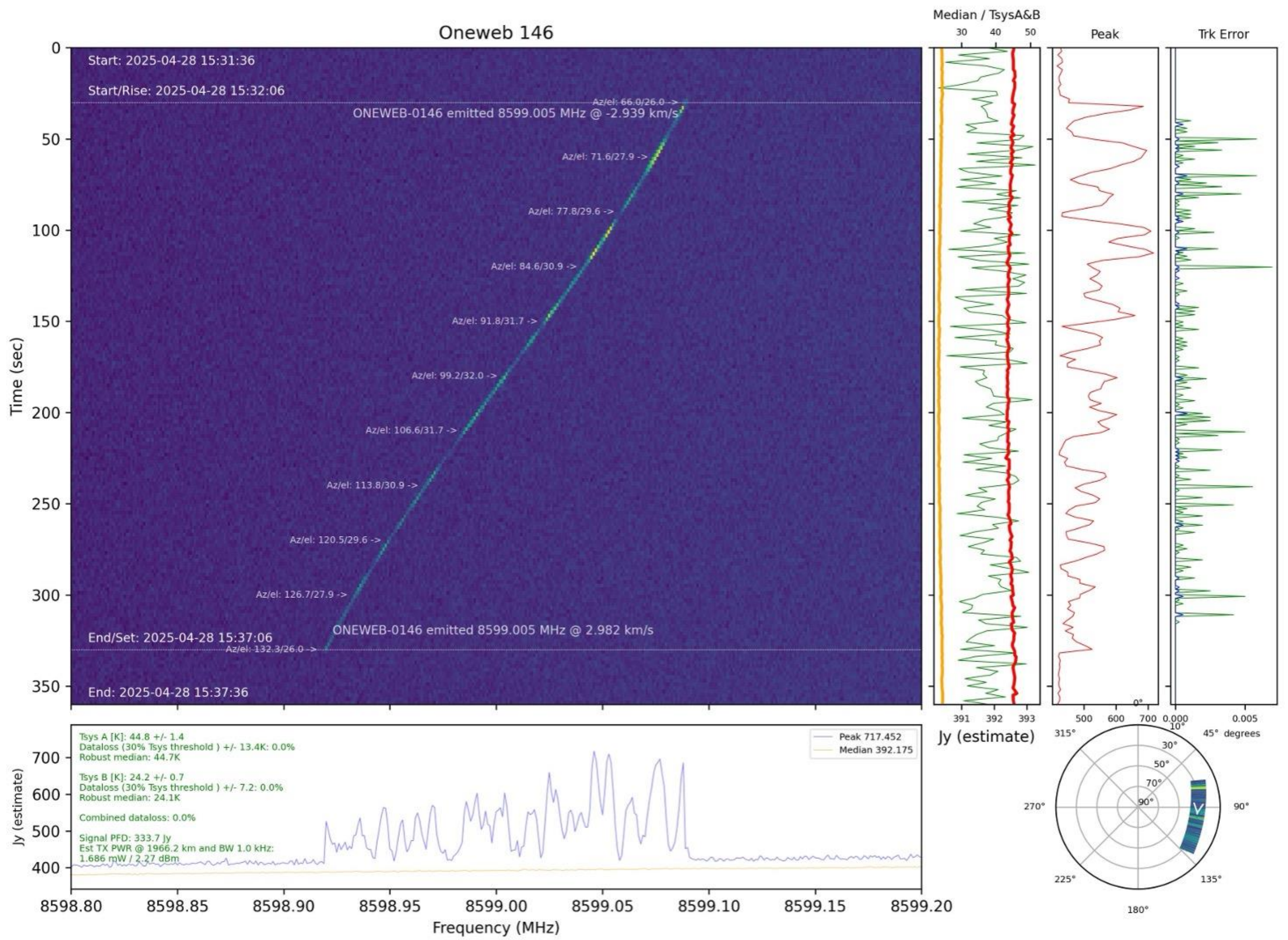
- New problem since large constellations launched. At L/S/C/X/K bands

Selected results: X-band

Radiation :
8599 MHz

TOFA:
8560 – 8650 MHz
EESS (active)
RLS
SRS (active)
AUS87

Incidence: 100%
3/3 observations



Unintended Electromagnetic Radiation (UEMR) from Space Systems

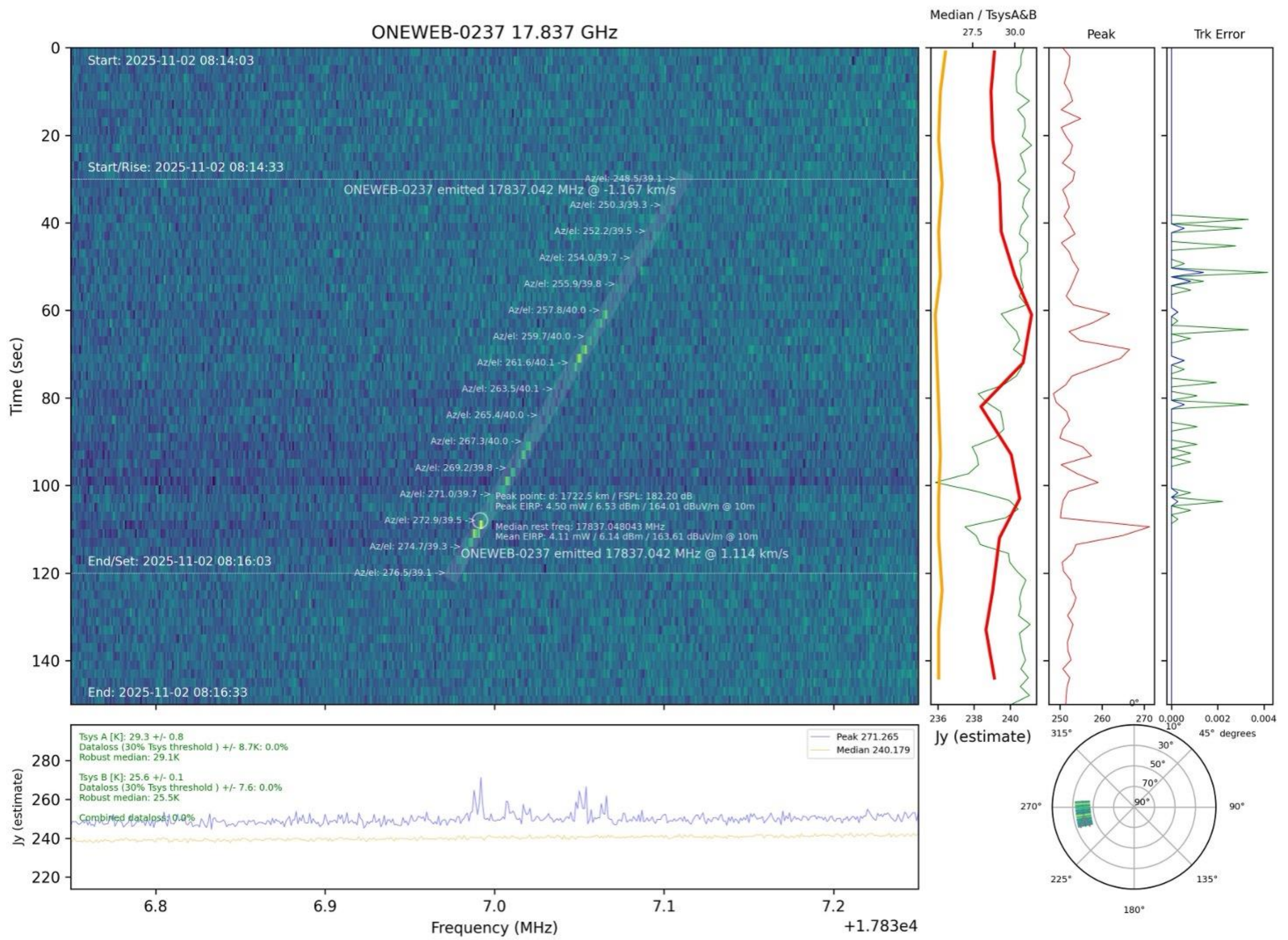
- New problem since large constellations launched. At L/S/C/X/K bands

Selected results: K-band

Radiation (?)
17.837 GHz

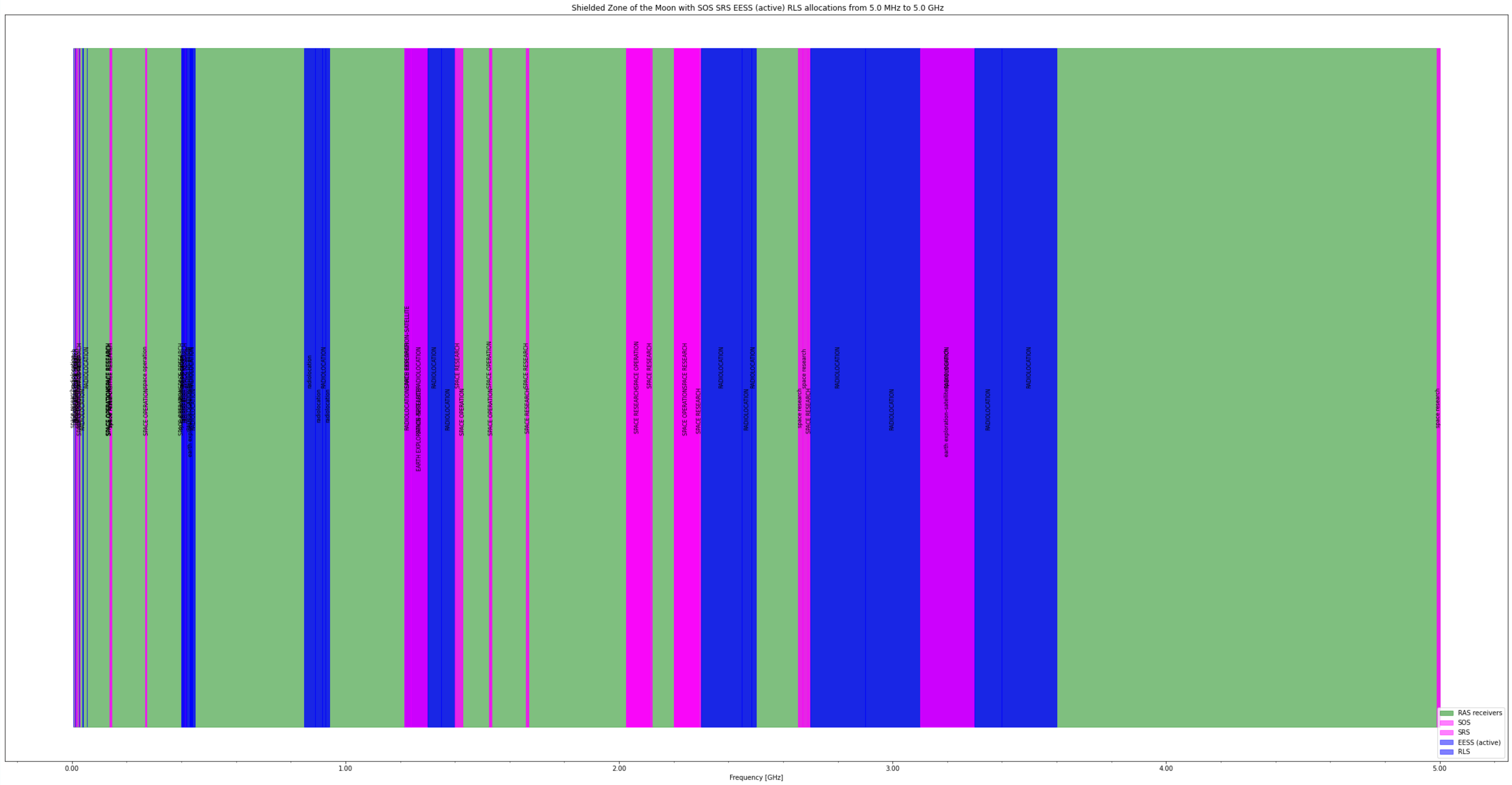
TOFA:
17.7 – 18.1 GHz
FS
FSS (s-E, E-s)
MS
AUS87

Incidence: 80%
4/5 observations



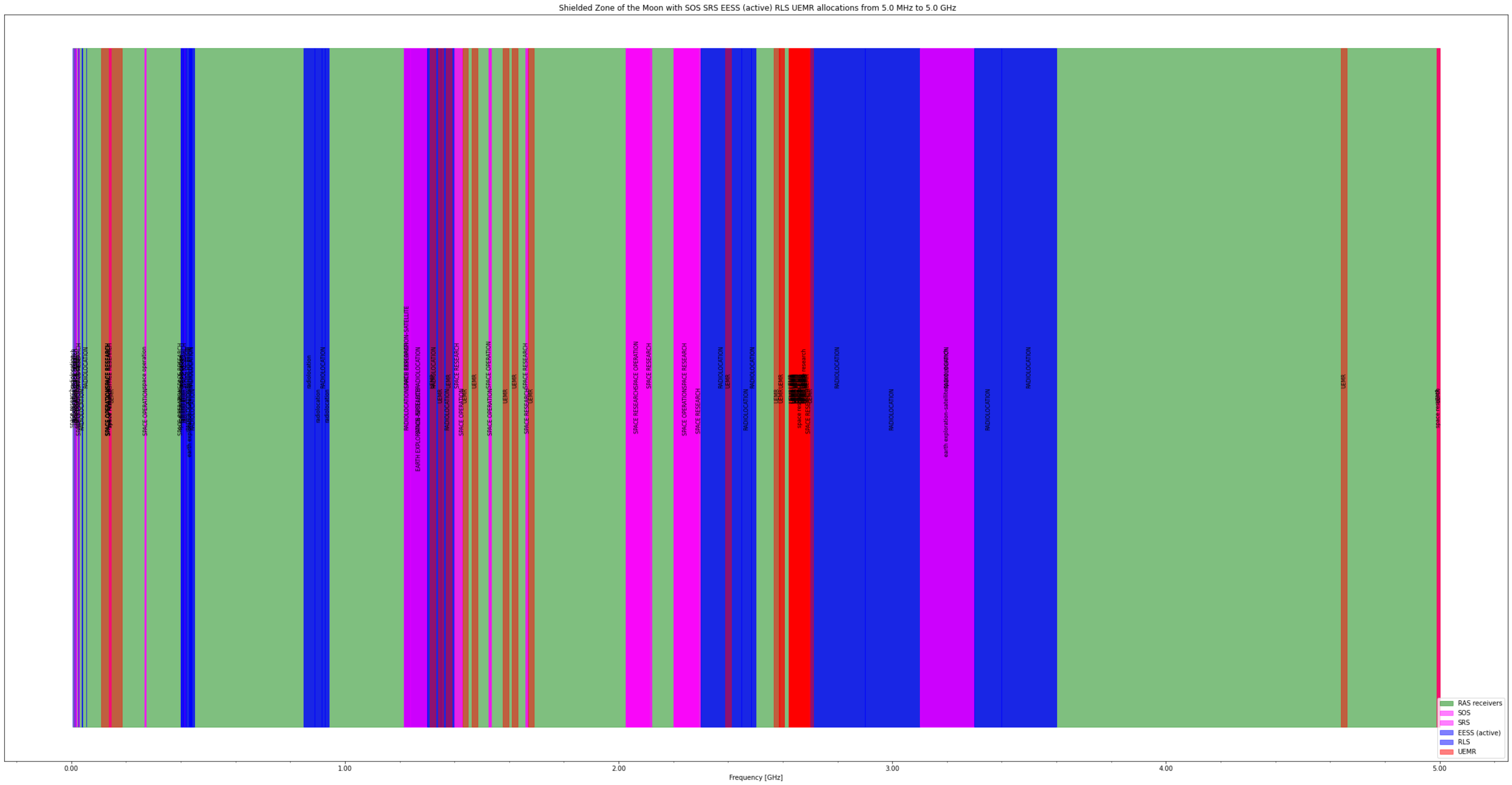
Unintended Electromagnetic Radiation (UEMR) from Space Systems

UEMR in the SZM: 50 MHz – 5 GHz with allocations. Consider LLO altitudes ~100km (30% of VLEO!)



Unintended Electromagnetic Radiation (UEMR) from Space Systems

UEMR in the SZM? 50 MHz – 5 GHz, Red = Currently detected UEMR on terrestrial NGSOs

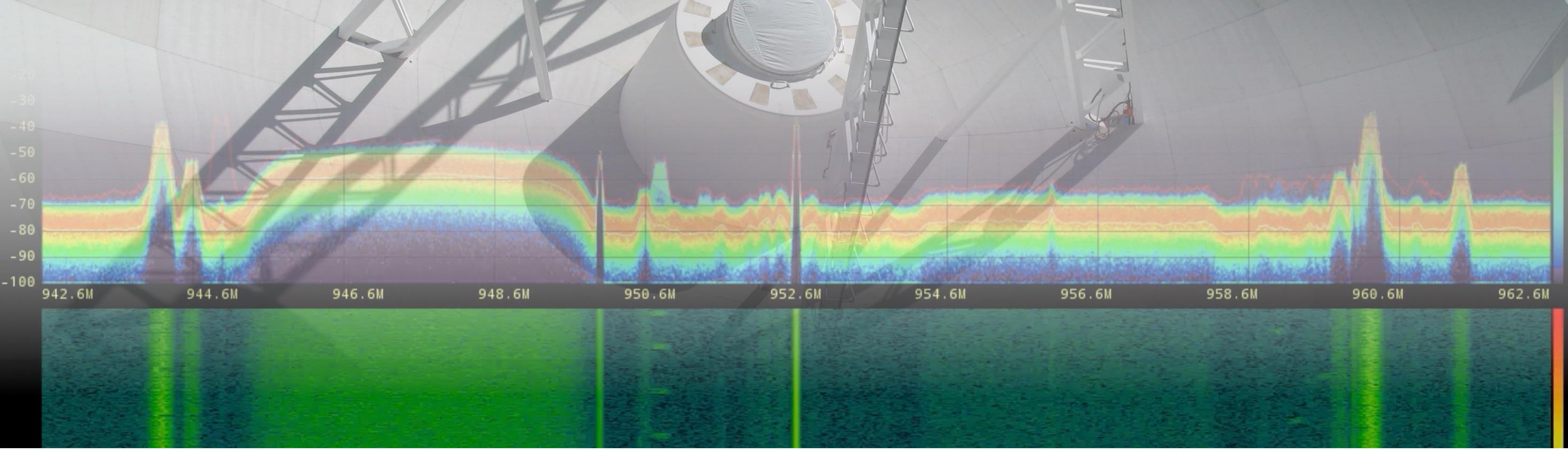


Unintended Electromagnetic Radiation (UEMR) from Space Systems

- EMI standards for terrestrial equipment have adequately addressed interference to RAS – but there are no mandatory EMI standards in space
- The standards embraced by the satellite industry are not sufficient to protect RAS, they are meant to **protect against self-interference**: MIL-STD-461, ECSS-E-ST-20-07C, NASA Standards (SSP Series – for ISS equipment)
- Contentious topic, with some administrations opposing recognition of this new problem. **But:**
- ITU-R RRs show regulatory intent to address all unintended radiation:
    - **The definition of "space station" encompasses the entire satellite platform**, not just its radio equipment.
    - **The fundamental obligation to prevent harmful interference** (Preamble 0.4) applies to "all stations" without qualification.
    - **Protection requirements for passive services** demonstrate ITU-R's concern with all sources of electromagnetic interference.
    - **The inclusion of "parasitic emissions" and broad equipment requirements** shows regulatory intent to address all unintended radiation.
    - **Article 15.12 explicitly includes electrical apparatus or installations of any kind.**

- WP7D is currently working on a WD PDNRep RA.[UEMR]

- Work ongoing also with standards bodies (ISO/CISPR)



Thank you

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