Quiet, please -
protecting radio astronomy from interference

Michael Lindqvist
Onsala Space Observatory, Chalmers
TOW, May 2023

Starlink satellite trains: Is this the future of the night sky? Alaska
The Washington Post, 2023, January 6

Content

- Introduction
- What is the problem?
- How do we solve it? Can we?

Some slides from:

IUCAF 5th School on Spectrum Management for Radio Astronomy

South African Radio Astronomy Observatory (SARAO)

2-6 March 2020

and other CRAF presentations

Radio astronomy : a new science

FIG. 1—Karl Guthe Jansky, about 1933.

The first dete...

fr...

...radio

...e strength

...power flux density) of radio sources is the Jansky: 10^{-26} $Wm^{-2}Hz^{-1}$.

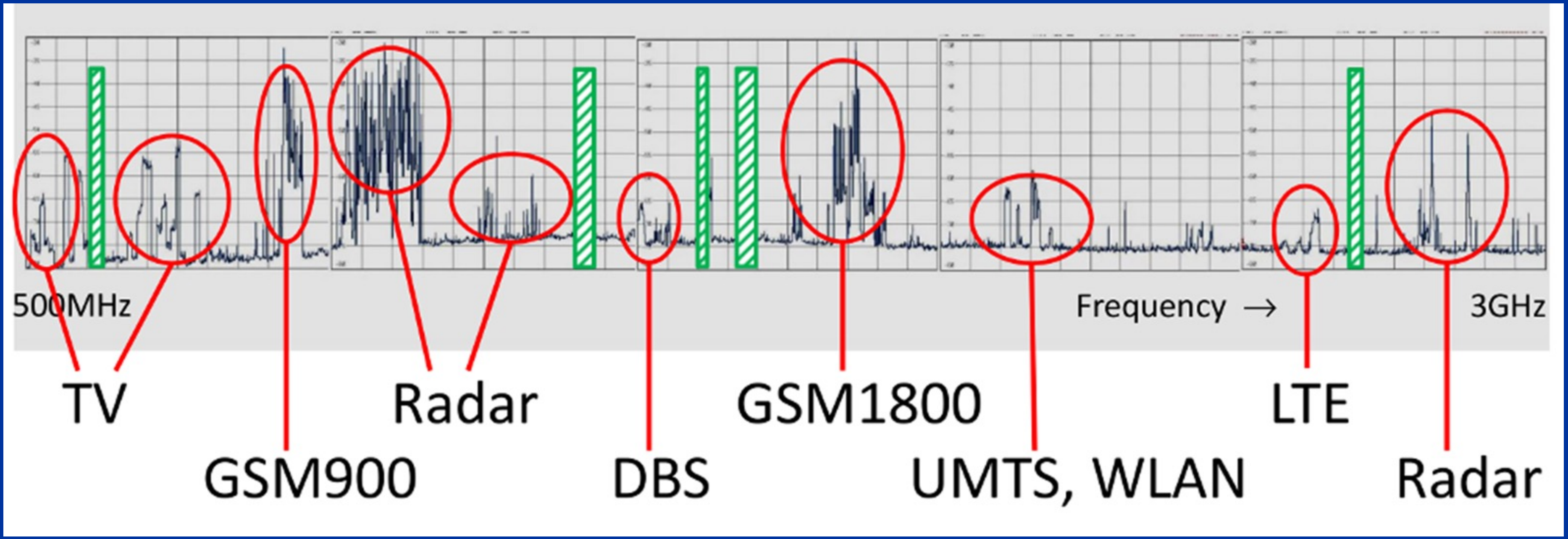
Mobile Phone on the Moon (assume 500 mW across a 30 kHz channel)

Power at Earth is ~900 Jy, which is almost that of Cassiopeia A

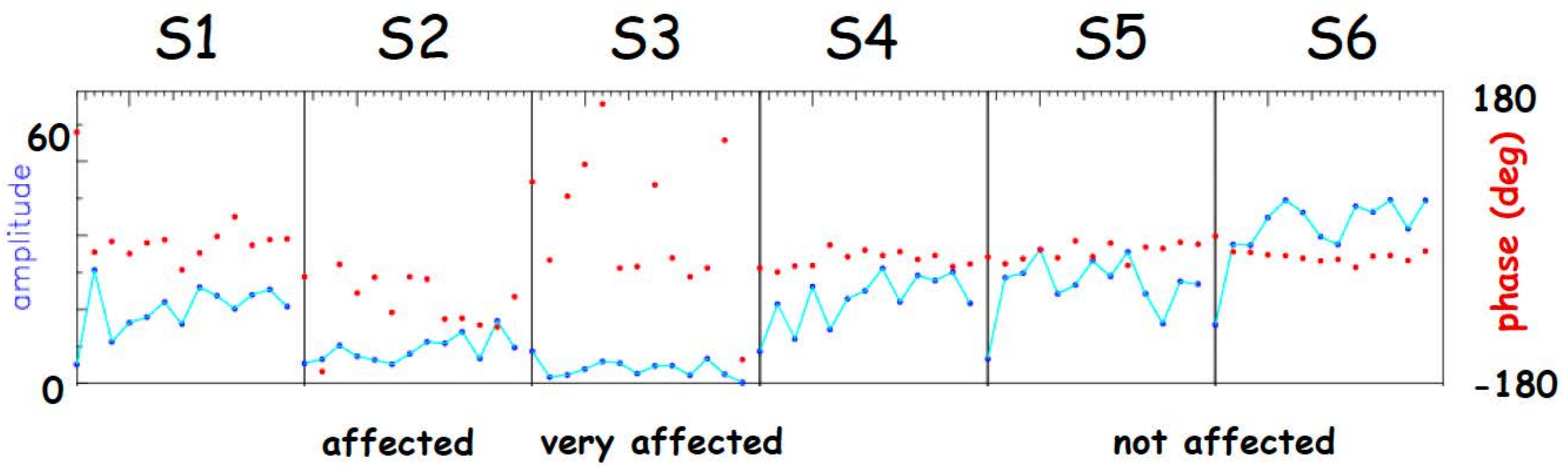
Today we measure signals at levels of mJy or even μJy.

The Electromagnetic Jungle

Image: R. Keller et al., MPIfR



Amplitude & Phase vs Time: RFI



Broadband RFI in S-band.

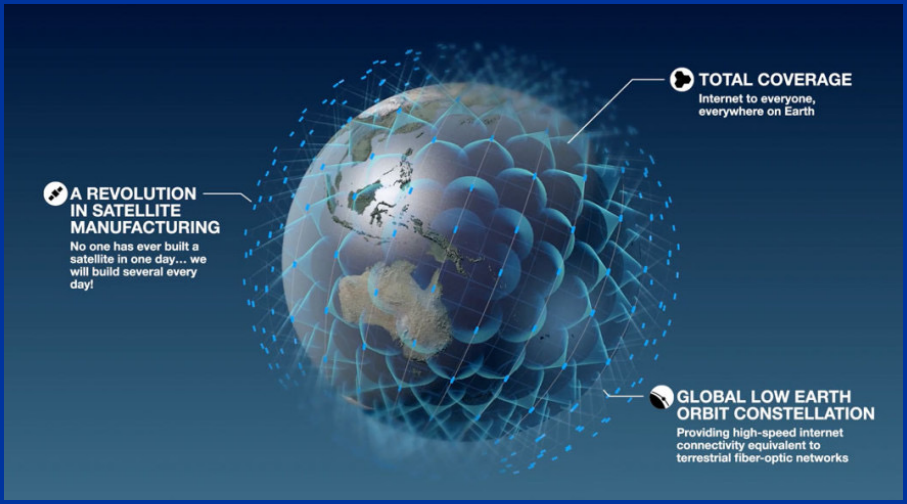
The amplitude is low (almost zero in S3) and the phase is noisy.

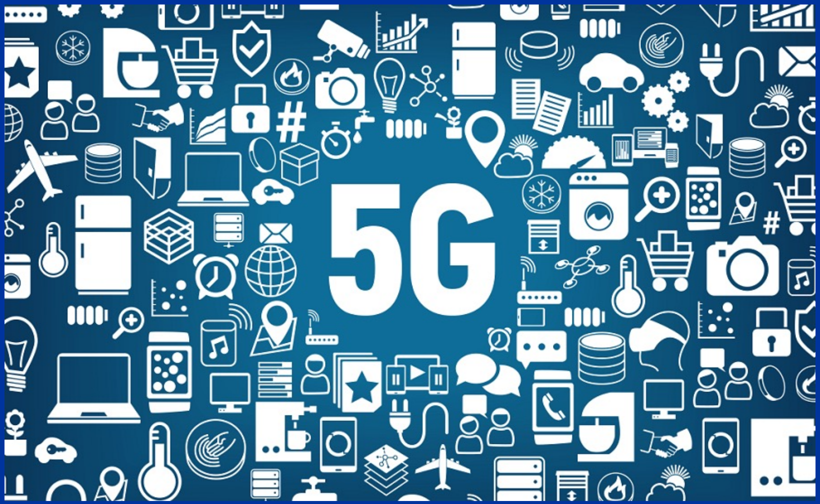
Channels S2 and S3 need flagging.

Slide: A. Bertarini et al., TOW 2015

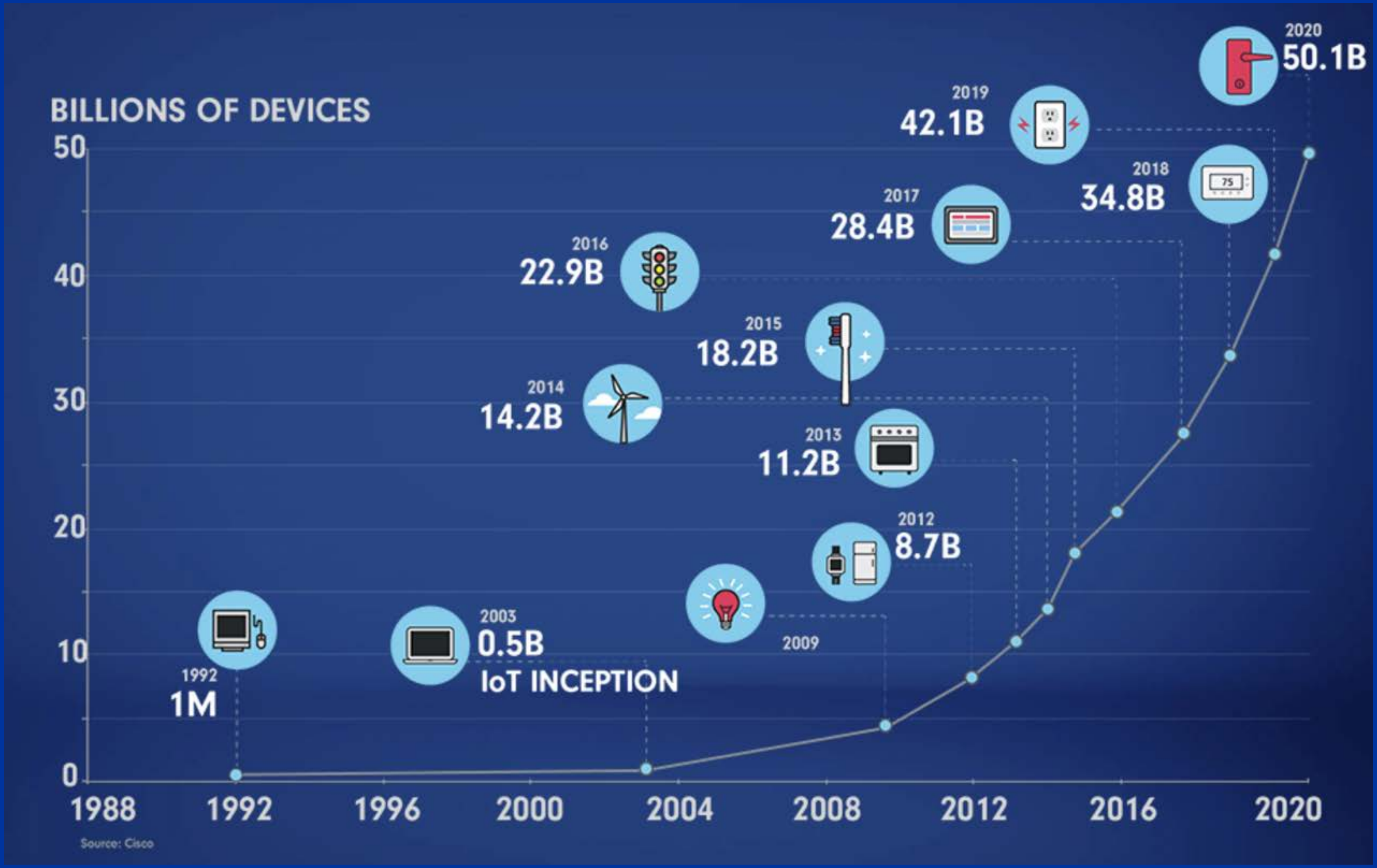

Onsala Space Observatory, Sweden

Satellites, 5G, IoT





Satellites, 5G, IoT



How do we solve it? Can we?

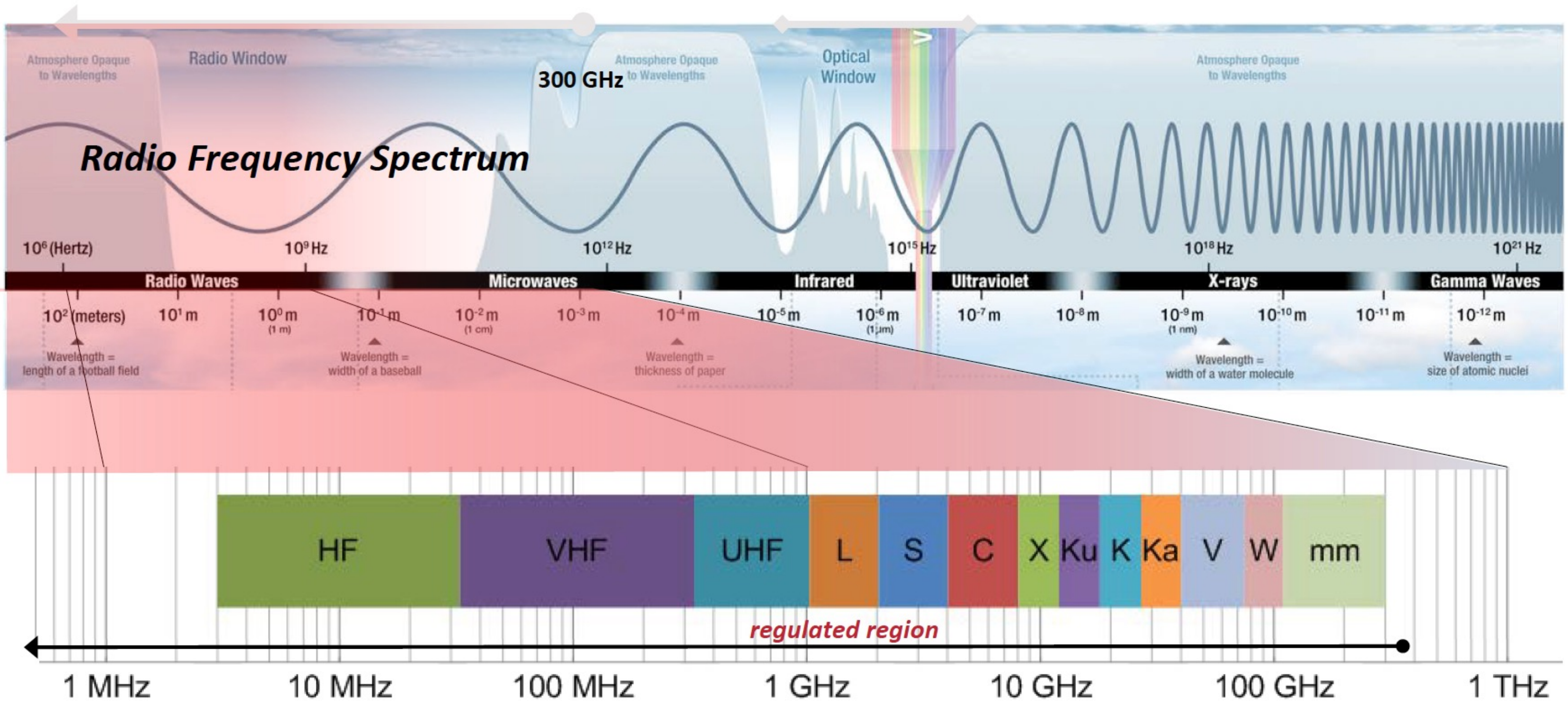
- Remote locations of telescopes
- Robust designs – receivers and filters
- RFI mitigation, machine learning
- Spectrum management

The importance of International Bodies

- The radio spectrum is a limited natural resource equally available in every country.
- Radio waves do not respect national borders - international regulations are required!
- An efficient use of the radio spectrum can only be obtained by rules agreed on a worldwide basis.
- Making the regulations work/making new regulations is called “spectrum management” .

Scientists use *the entire spectrum* but only *8.3 kHz to 275 GHz is regulated*:

- ***Radio Frequency Spectrum***: frequency region of the EM Spectrum that is managed via international and national laws and regulations
- Limited regulations in the near-infrared and optical region (e.g., laser coordination & safety standards)



Terminology used with portions of the radio frequency domain

Slide Credit: NASA

Spectrum is money …

FCC's largest spectrum auction nets $4.47 billion for 5G mmWave bands

Jeremy Horwitz @horwitz March 12, 2020 9:09 AM Mobile

Image Credit: Dong Wenjie/Getty Images

Leaders | Internet from the sky

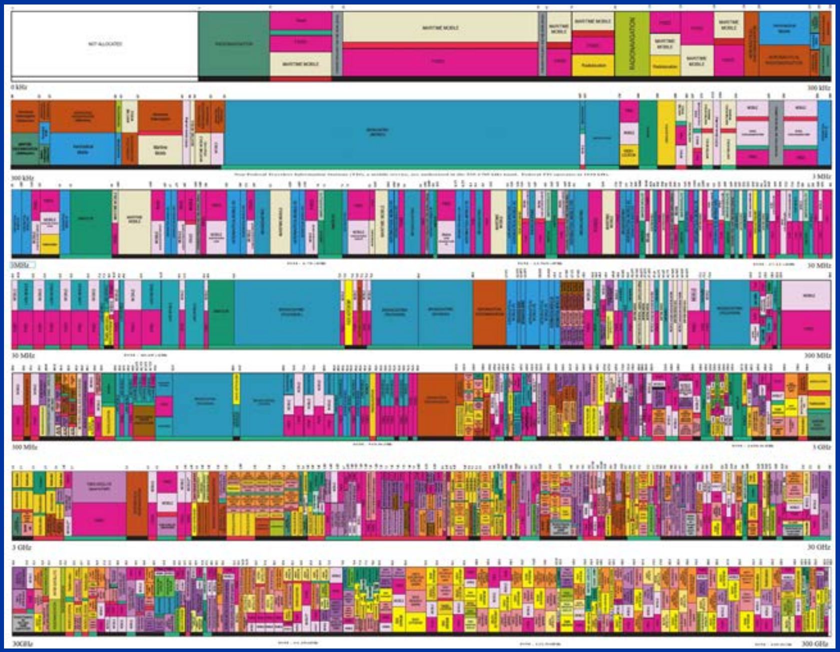
Starlink's performance in Ukraine has ignited a new space race

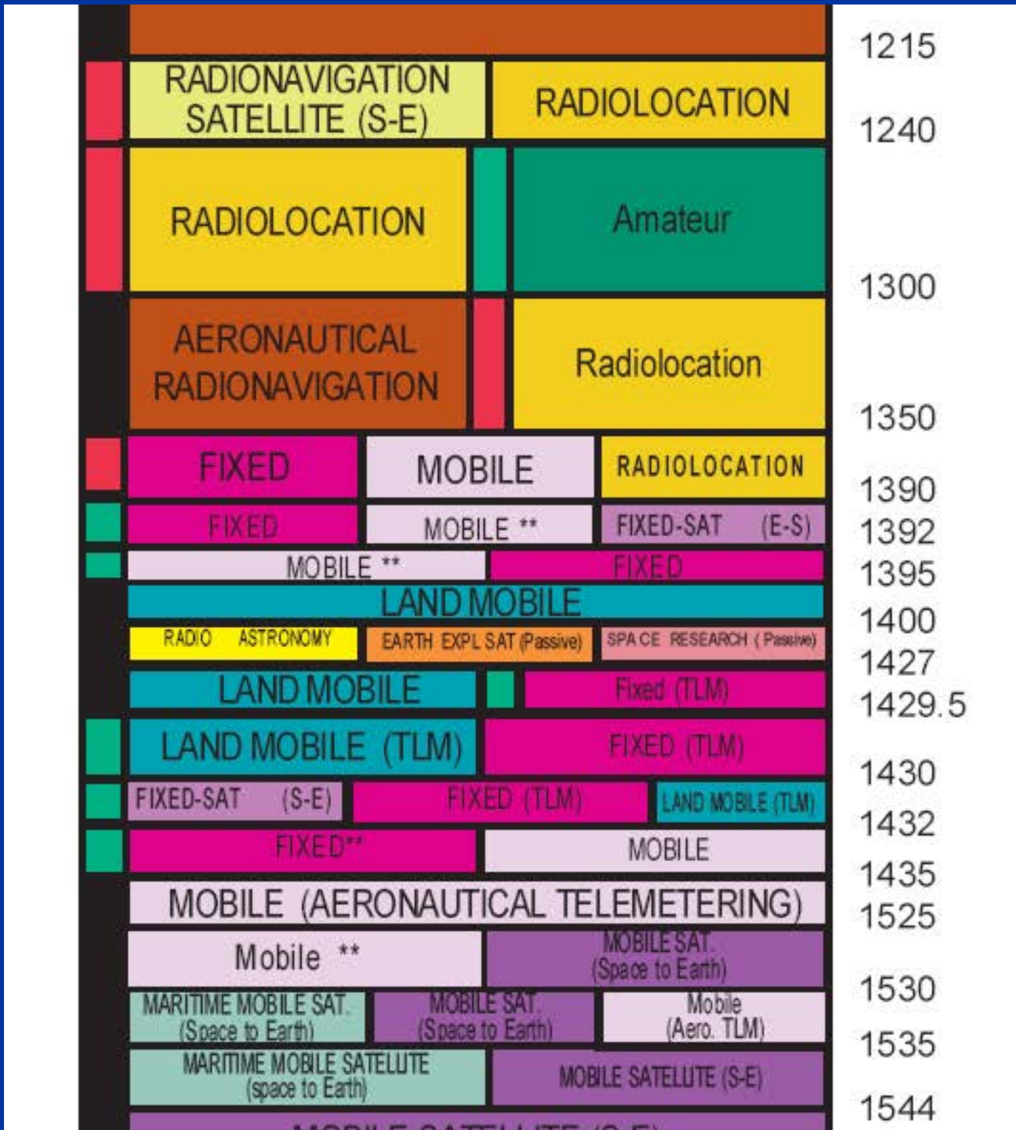
Never mind the moon; look to low-Earth orbit

And politics…

Sweden bans Huawei and ZTE from 5G telecoms networks

Spectrum allocation

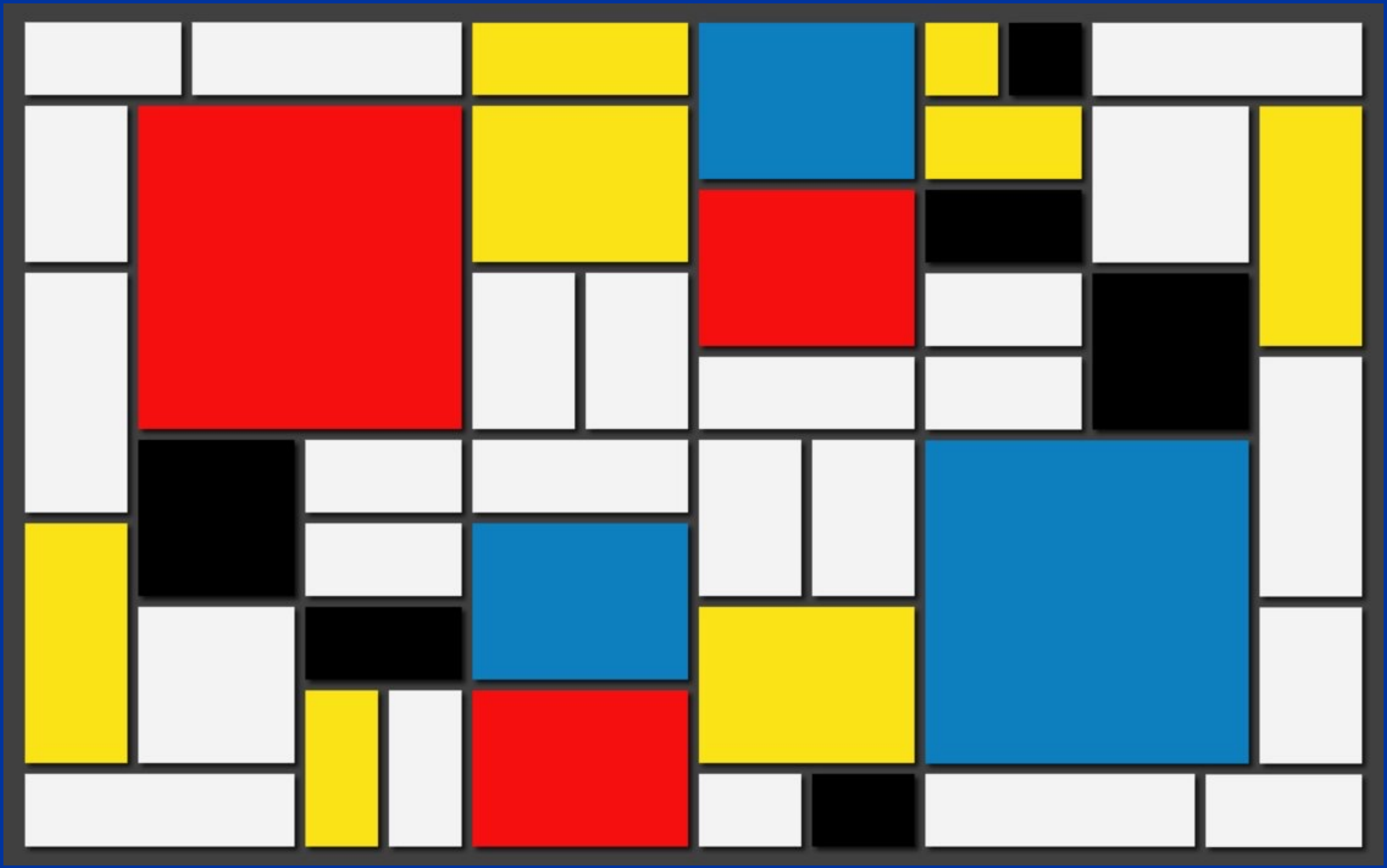




Spectrum bands are allocated to 'services'

- Service = purpose or application
- Most services are 'active' – they transmit
- PRIMARY and secondary allocations
- Radio astronomy service (RAS) is 'passive'
- Fragmented

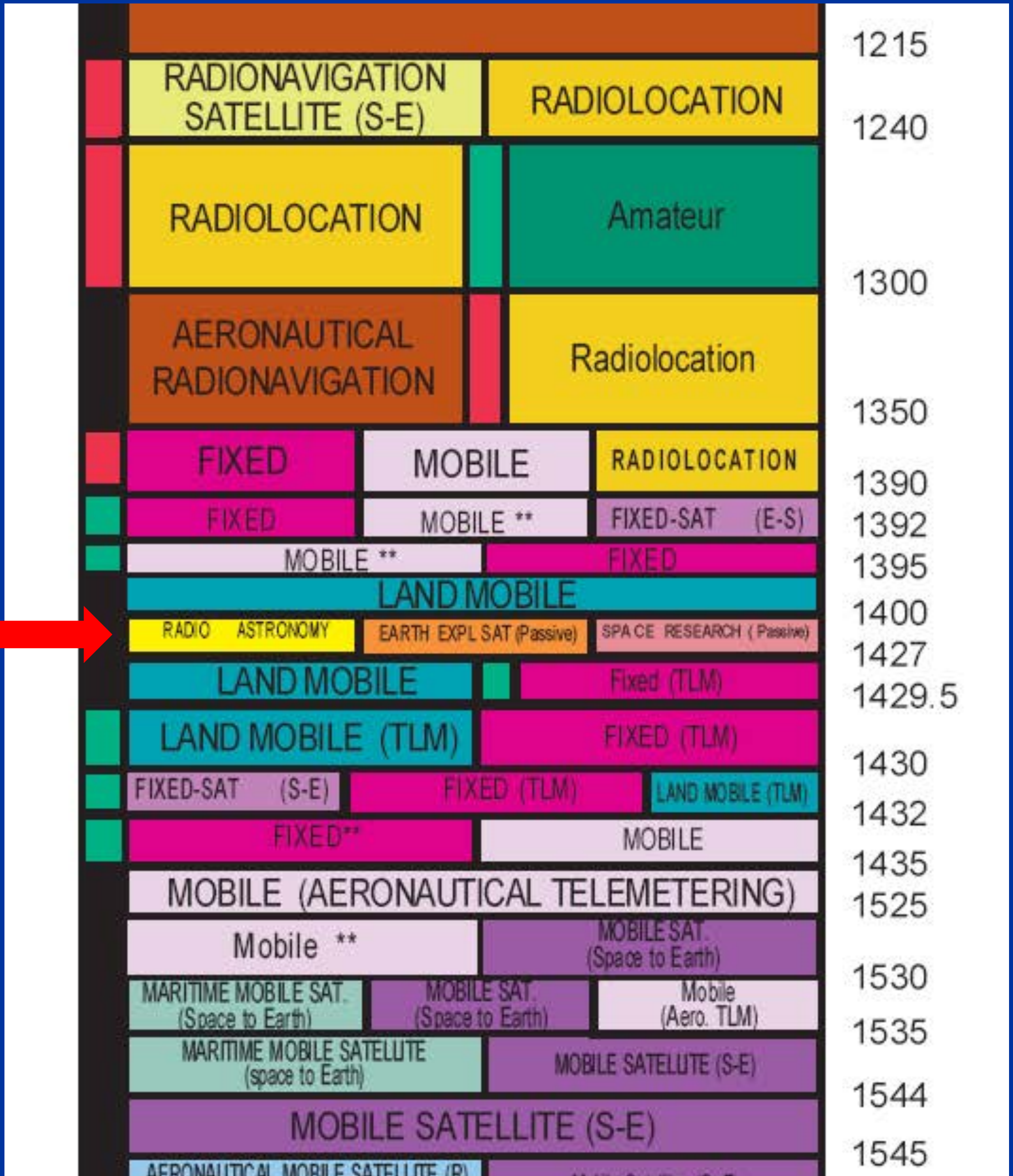
Spectrum art



Piet Mondrian

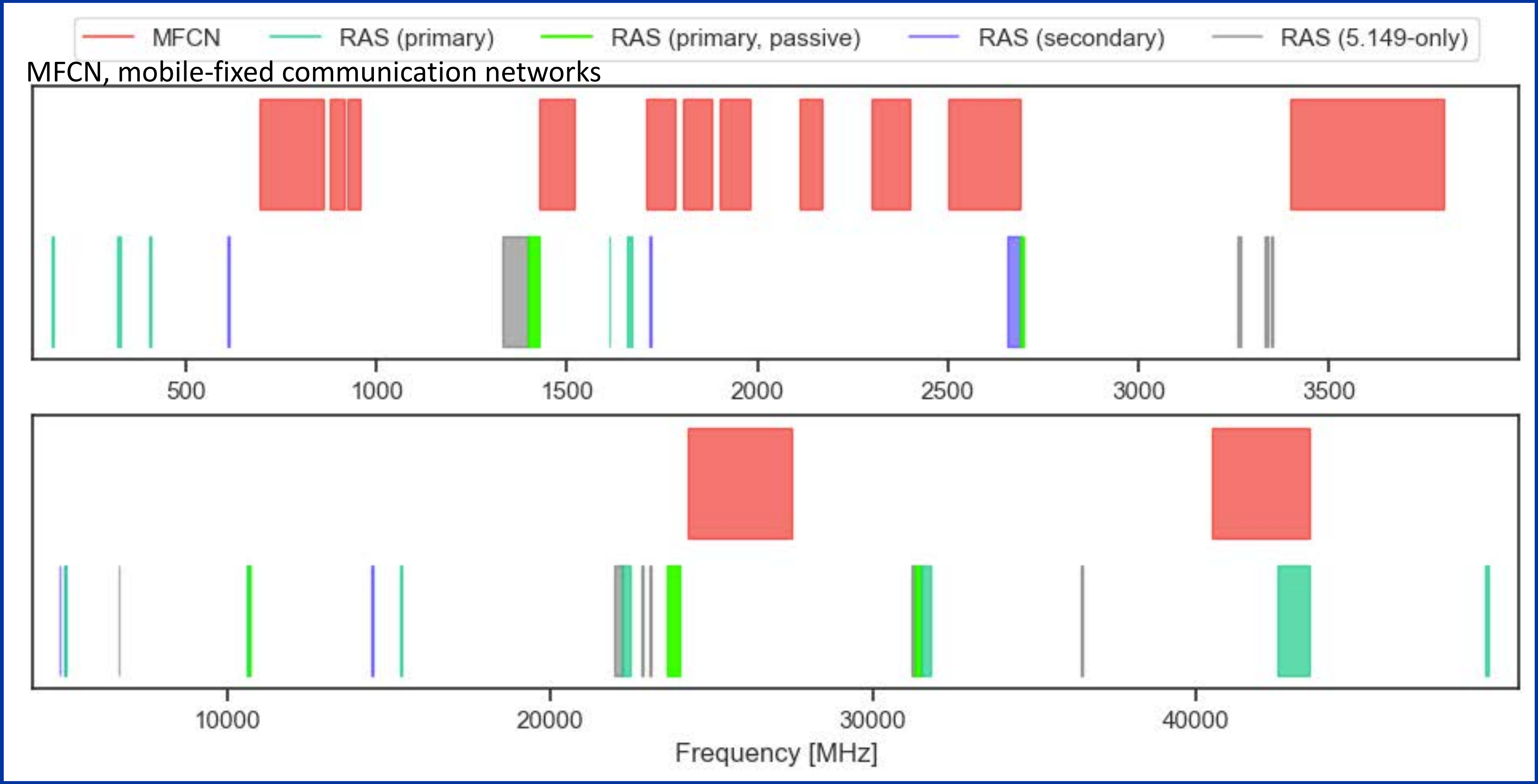
Observing outside allocated bands

Contact PTS...



Observe here

Radio astronomy vs 'mobile phones'



Below 4 GHz, a huge portion (one third) of the spectrum is assigned to IMT/MFCN networks, whereas RAS has only 5 %. If one only counts primary bands, as little as 1.5 % is allocated to the RAS.

What is interference?

- **Interference** is an unwanted signal occurring in a band which has been **allocated** to other services
- When you observe outside the bands allocated to radio astronomy you may see *intentional* radiation which is someone else's *signal*
- RAS also uses spectrum outside its own allocated bands…. 'opportunistic observing'
- Interference is what happens when spectrum management FAILS

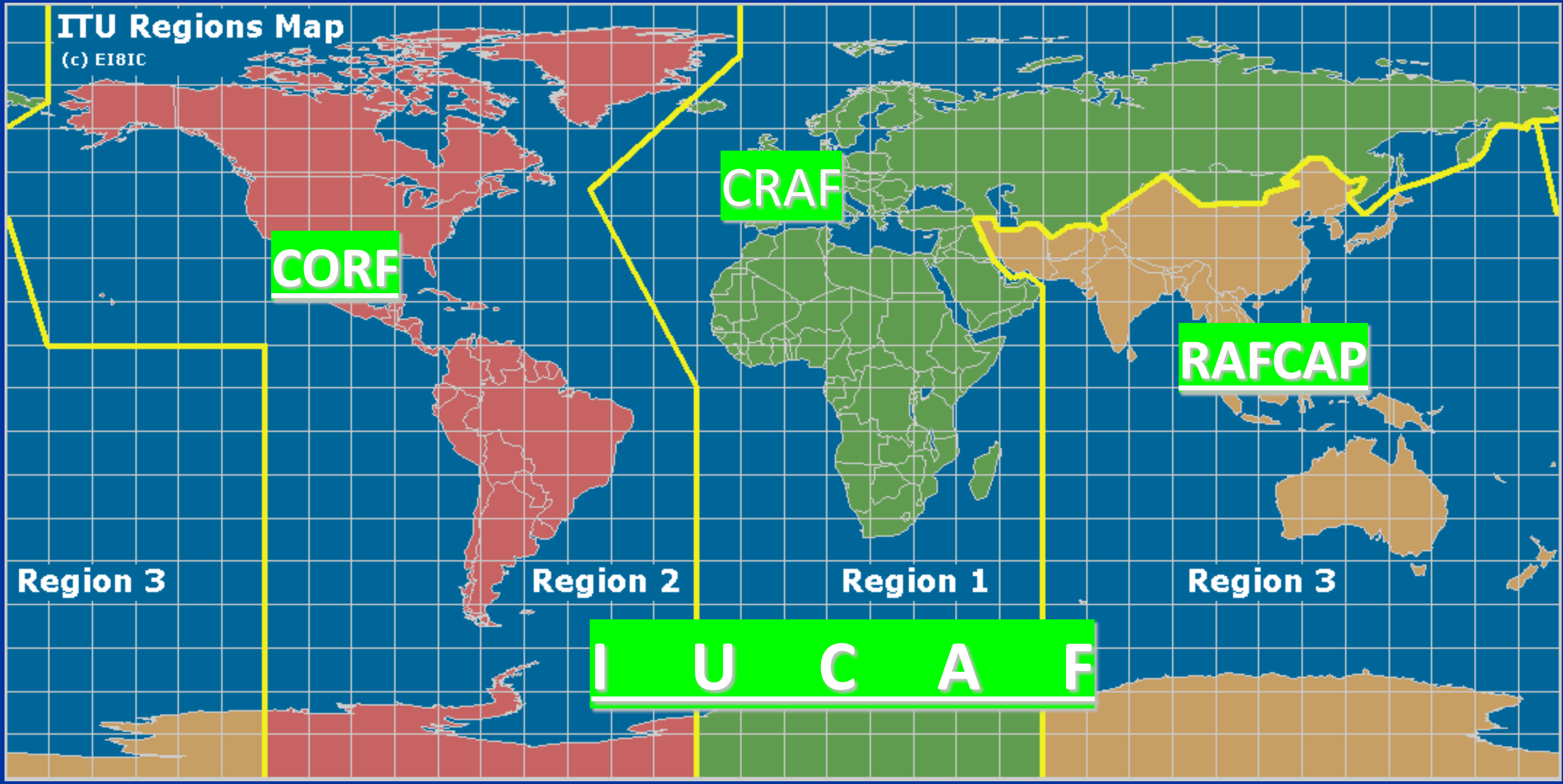
The importance of International Bodies

The rules are established by International Bodies tasked to promote the harmonisation of Radio Spectrum according to a top-down approach:

- ITU-R (International Telecommunication Union, Sector Radiocommunications), an agency of the United Nations

- The European Conference of Postal and Tele-communications Administrations (CEPT) of 46 European regulatory administrations (~~Russia~~, ~~Belarus~~) administers radio spectrum in Europe. *In Sweden, PTS, Post- och telestyrelsen*
- ***Administrations DECIDES!***

ITU regions

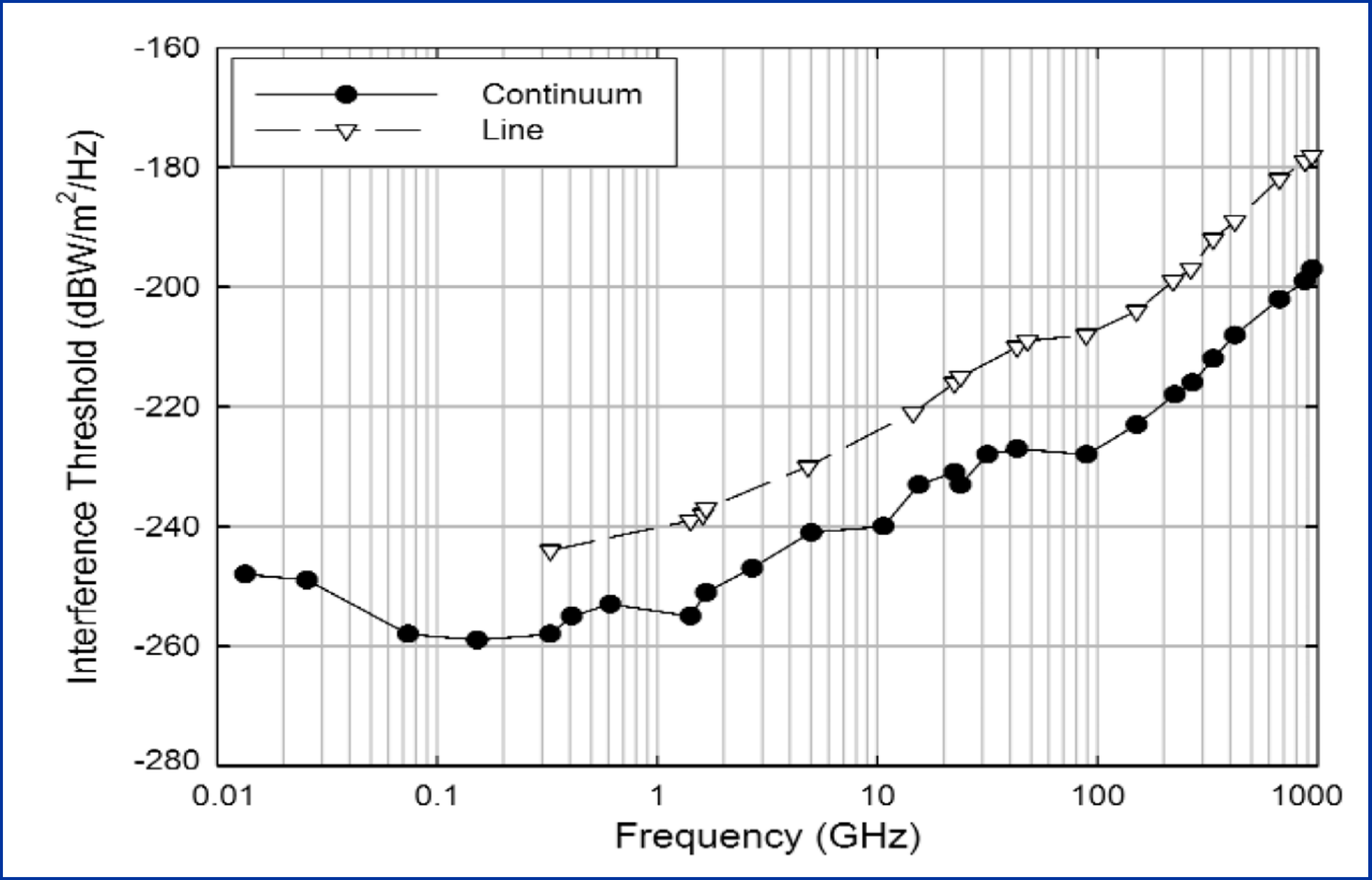


ITU Regions Map
(c) EI8IC
CRAF
CORF
RAFCAP
Region 3
Region 2
Region 1
Region 3
I U C A F

The importance of International Bodies
Most important deliverables

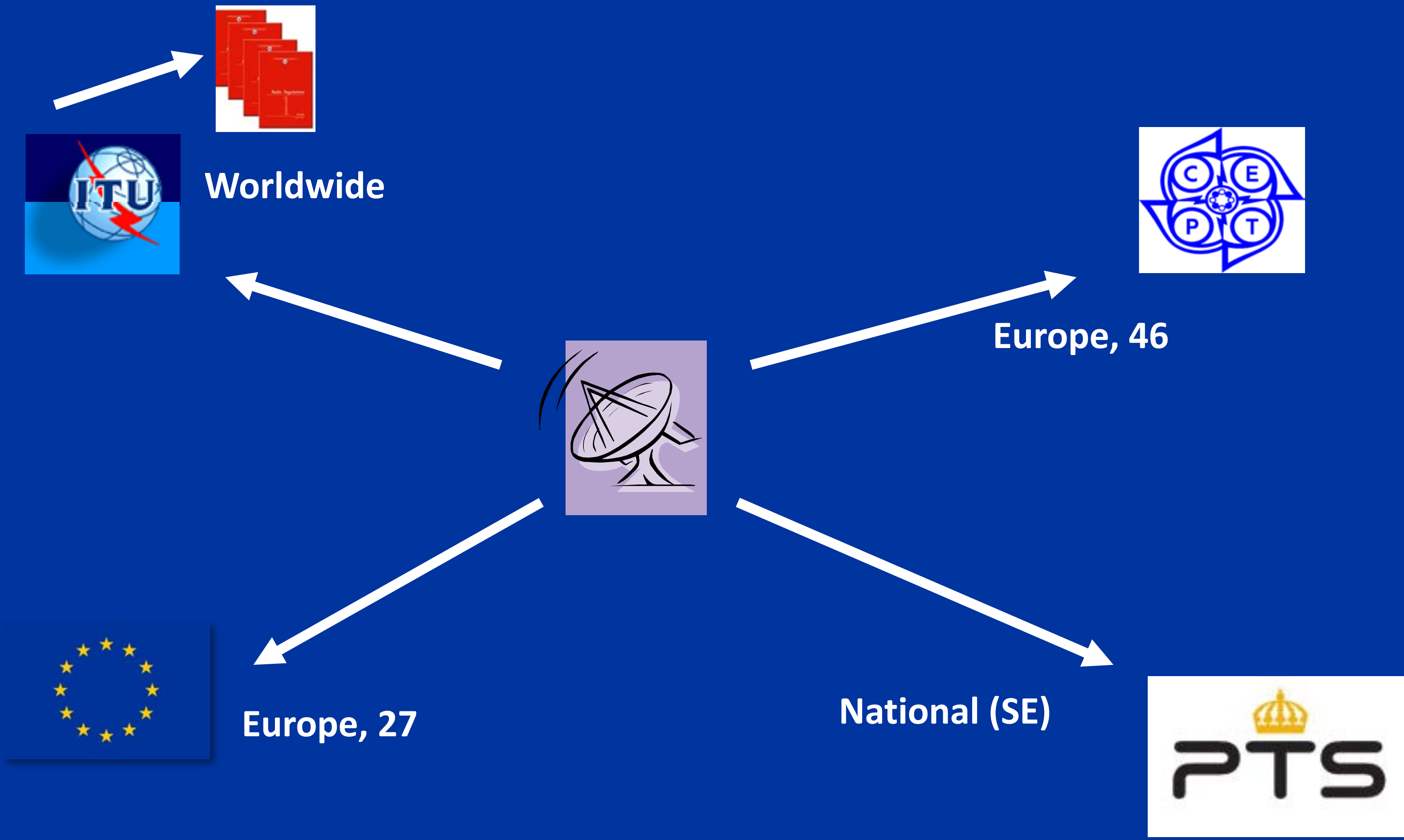
- **ITU-R -** *Radio Regulations*
  - ✓ *WRC, World Radiocommunication Conference*
  - ✓ *United Arab Emirates, 20 November - 15 December 2023*
- **CEPT -** *ECA (European Common Allocation) Table, Decisions,…*
- **EU –** *Directives, Decisions and Opinions*

Thresholds of interference versus frequency



Thresholds of interference versus frequency for radio astronomy spectral line and continuum observations. From ITU-R Recommendation RA.769.

Spectrum management

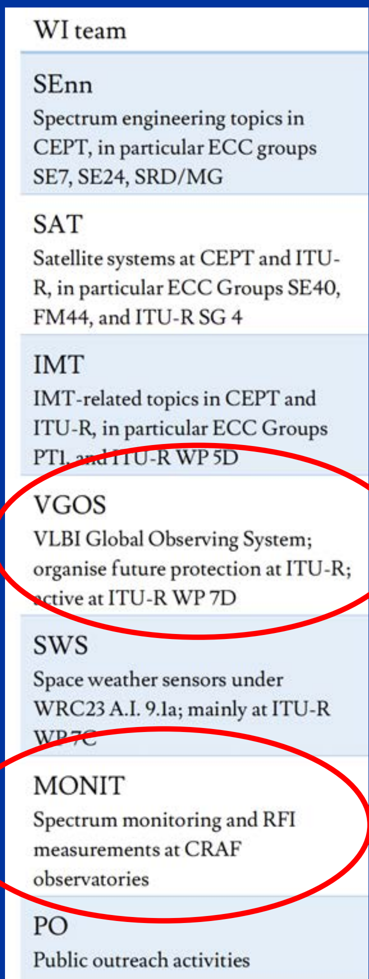


CRAF –
The Committee on Radio Astronomy Frequencies

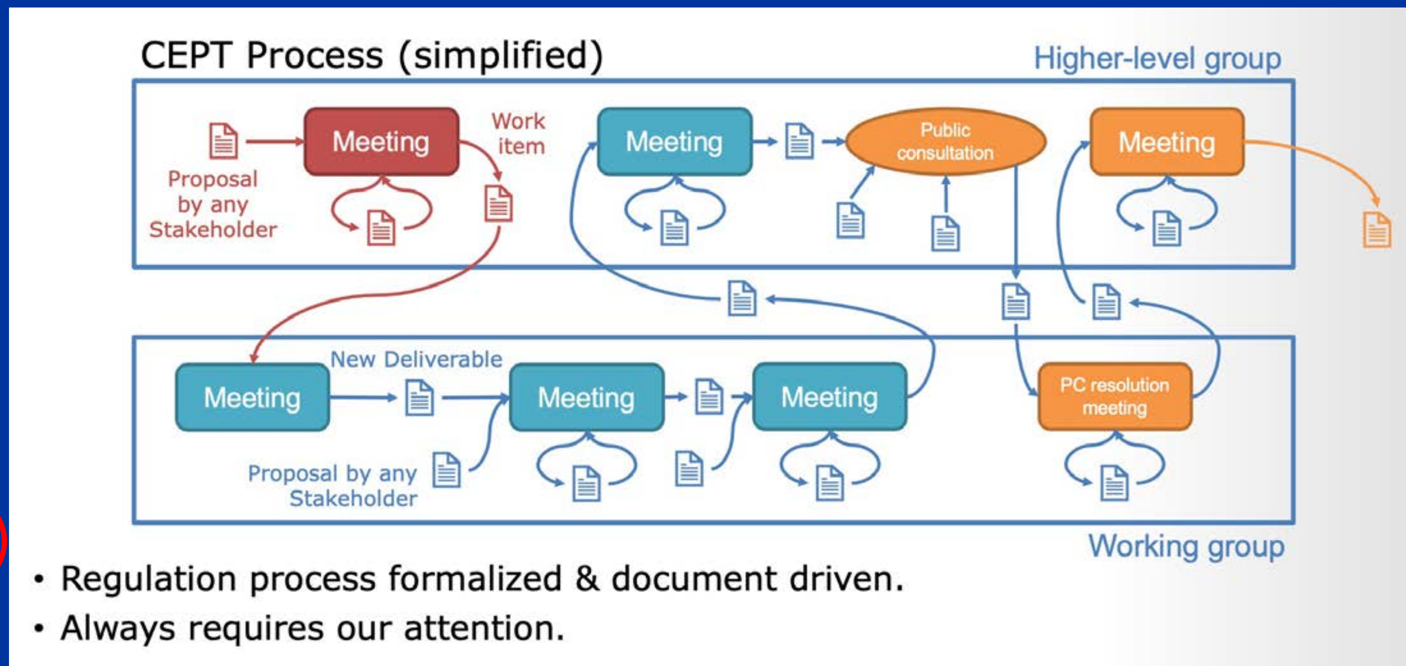
- Complicated landscape – radio astronomy needs to coordinate
- CRAF is the expert committee on radio astronomy frequencies of the European Science Foundation (ESF).
- CRAF represents all European radio observatories at the European and global level.
- CRAF has member institutes (radio observatories, national academies or funding agencies, including IVS) in 22 countries + observers (e.g. SKA).
- Full-time frequency manager, Waleed Madkour, JIVE. Paid by (some of) the member institutes.
- ITU-R sector member & observer status in CEPT.

CRAF

- CRAF, Work Item (WI) teams, take care of all the topics in a particular field of spectrum management.



WI team
SEnn Spectrum engineering topics in CEPT, in particular ECC groups SE7, SE24, SRD/MG
SAT Satellite systems at CEPT and ITU-R, in particular ECC Groups SE40, FM44, and ITU-R SG 4
IMT IMT-related topics in CEPT and ITU-R, in particular ECC Groups PT1, and ITU-R WP 5D
VGOS VLBI Global Observing System; organise future protection at ITU-R; active at ITU-R WP 7D
SWS Space weather sensors under WRC23 A.I. 9.1a; mainly at ITU-R WP7C
MONIT Spectrum monitoring and RFI measurements at CRAF observatories
PO Public outreach activities



- CRAF submit input documents (usually on compatibility studies for new proposed frequency allocations for active spectrum use)

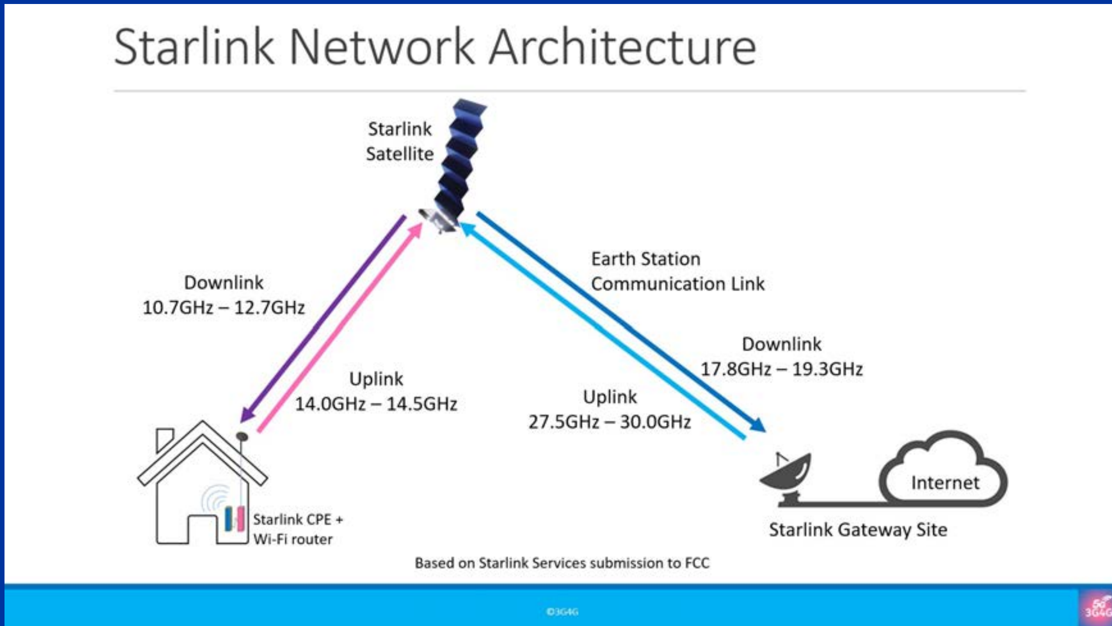
CRAF - VGOS

- CRAF – VGOS WI team is led by Hayo Hase
- ITU-R Report RA.2507 "Technical and operational characteristics of the existing and planned Geodetic Very Long Baseline Interferometry".

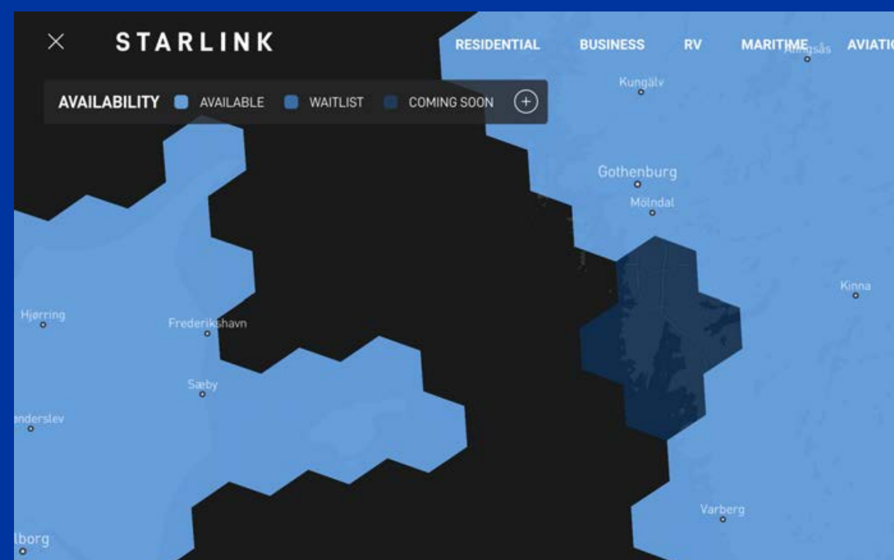

Report ITU-R RA.2507-0
(10/2022)
Technical and operational characteristics of the existing and planned Geodetic Very Long Baseline Interferometry

- The VGOS WI team has also been successful in establishing the IAU Resolution B1-20212, the group is now preparing a draft resolution for the IUGG General Assembly 2023.
- The VGOS team is finalising a study on the compatibility of the DORIS-System with VGOS radio telescopes, because a co-location of both systems is desirable for aligning global geodetic reference frames using different systems.

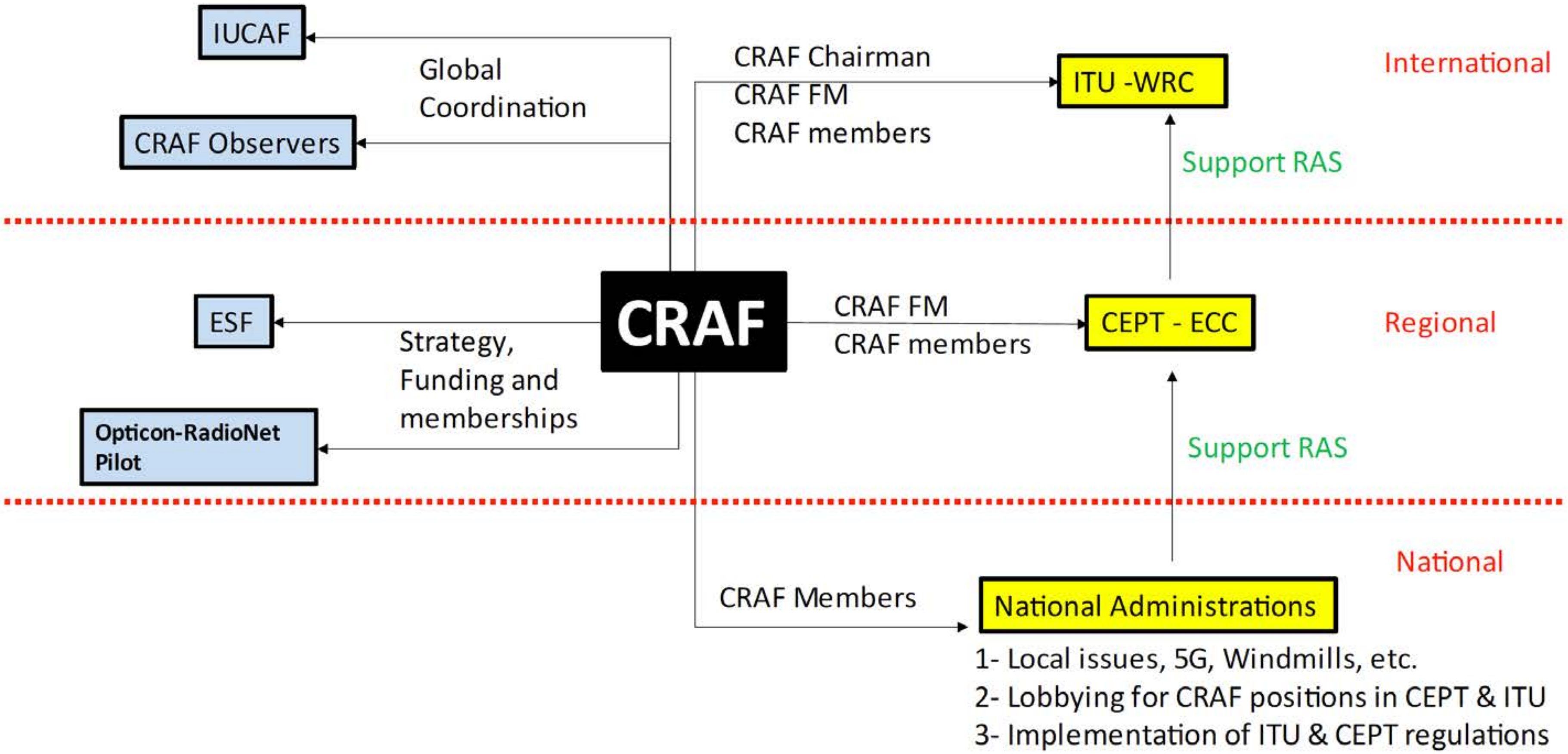
Non-geostationary satellite systems



- Starlink is only one...
- SKA, VGOS, ...



CRAF activities



Dark & Quiet Skies

On-line Workshop

Dark and Quiet Skies for Science and Society

Report and recommendations

UNITED NATIONS
Office for Outer Space Affairs

IAU

Astronomers and public stargazing joins forces

IAU centre for the protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS)

CPS

IAU NOIRLab SKAO

The case for space environmentalism

Andy Lawrence[1]✉, Meredith L. Rawls[2], Moriba Jah[3,4], Aaron Boley[5], Federico Di Vruno[6], Simon Garrington[7], Michael Kramer[8,9], Samantha Lawler[10], James Lowenthal[11], Jonathan McDowell[12] and Mark McCaughrean[13]

The shell bound by the Karman line at a height of ~80–100 km above the Earth's surface and geosynchronous orbit at ~36,000 km is defined as the orbital space surrounding the Earth. It is within this region, and especially in low Earth orbit, where environmental issues are becoming urgent because of the rapid growth of the anthropogenic space object population, including satellite 'mega-constellations'. In this Perspective, we summarize the case for considering the orbital space around the Earth as an additional ecosystem, subject to the same care and concerns, and the same broad regulations as the oceans and the atmosphere, for example. We rely on the orbital space environment by looking through it, as well as by working within it. Hence, we should consider damage to professional astronomy, public stargazing, and the cultural importance of the sky, as well as the sustainability of commercial, civic, and military activity in space. Damage to the orbital space environment has problematic features in common with other types of environmental issue. First, the observed and predicted damage is incremental and complex, with many contributors. Second, whether or not space is formally and legally seen as a global commons, the growing commercial exploitation of what may seem to be a 'free' resource is in fact externalizing the true costs.

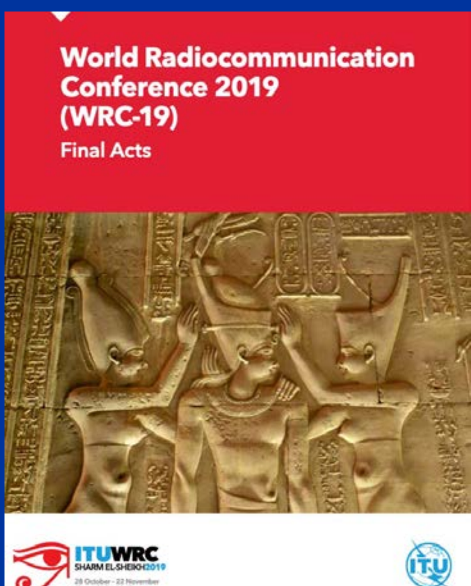
nature astronomy

Radio quiet zones

- Most of the established radio quiet zones regulate only fixed terrestrial transmitters, not emissions from airborne (most of them) or space-borne (all) transmitters
- Footprints from GPS satellites in the 1-2 GHz band are thousands of kilometres on the ground, making it impossible for them to avoid radio quiet zones
- The concept of radio quiet/coordination zones for airborne and spaceborne transmitters will require international cooperation

World Radiocommunication Conference

- The output of a WRC is contained in the Final Acts, a Treaty Document.
- An international treaty – enforceable
- Allocations to services
- Rules on sharing and protection
- Agenda items for the next WRC



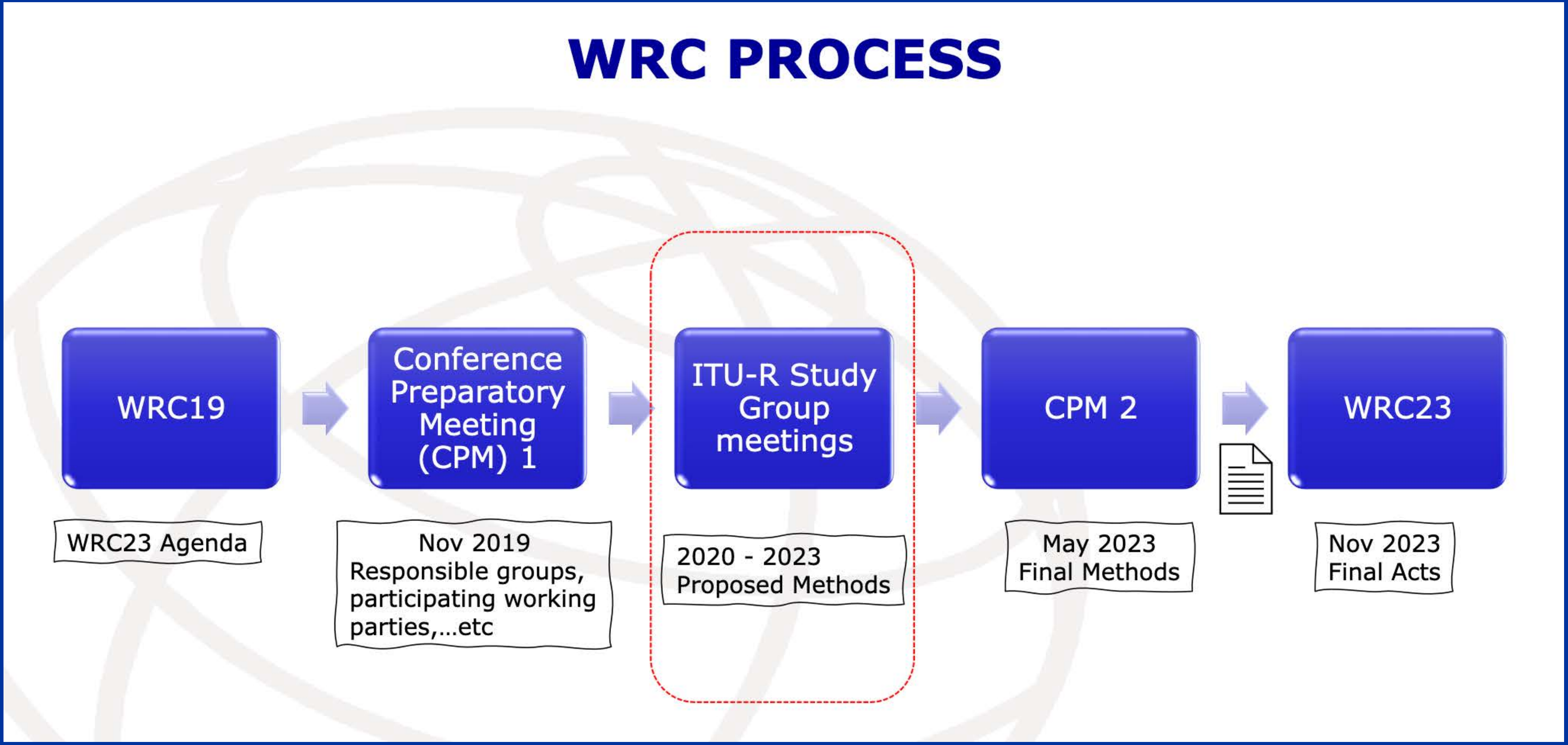
WRC -19

2019 World Radiocommunication Conference
28 October 2019 – 22 November 2019

2019 World Radiocommunication Conference

Same place as the Climate Change Conference, COP27

Study Cycle (~4 years)



WRC-23

306 d | 20 h | 50 m | 29 s

ITU World Radiocommunication Conference 2023 (WRC-23)
Dubai, United Arab Emirates, 20 November to 15 December 2023

World Radiocommunication Conferences (WRC) are held every three to four years to review, and, if necessary, revise the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made on the basis of an agenda determined by the ITU Council, which takes into account recommendations made by previous world radiocommunication conferences.

WRC-23

WRC23 Agenda Items

Mobile communications, etc.

- IMT (3.3-10.5 GHz): 1.1, 1.2, 1.3
- High-altitude IMT (HIBS)(0.694-2.7 GHz): 1.4
- MS, BS (470-960 MHz): 1.5

Transports

- Sub-orbital vehicles: 1.6
- AMS(R)S in VHF: 1.7
- Unmanned Aircraft Systems (UAS): 1.8
- Aviation safety-of-life: 1.9
- AMS for non-safety (15.5/22 GHz): 1.10
- GMDSS & e-navigation: 1.11

General

- Recommendations: 2
- Res/Rec: 4
- Country footnotes: 8
- Director's report: 9.1, 9.2
- Resolution 80: 9.3
- WRC-27 agenda: 10

Scientific

- EESS(a) for radar sounders (45 MHz): 1.12
- SRS (14.8-15.35 GHz): 1.13
- EESS(p) remote sensing (231.5-252 GHz): 1.14

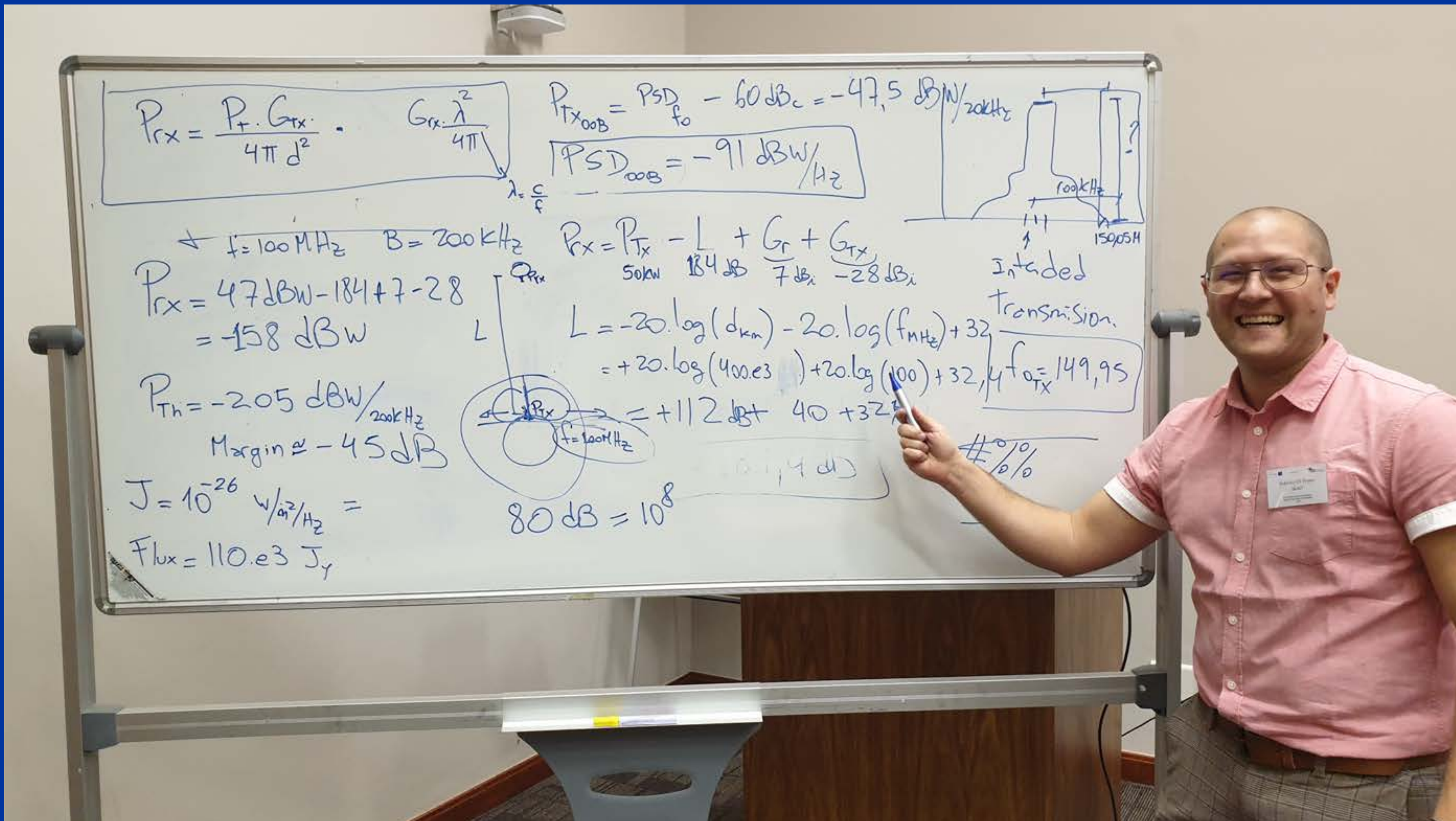
Satellites

- Aero & Maritime-ESIM (12.75-13.25 GHz): 1.15
- NGSO ESIM (Ka-band): 1.16
- Inter-satellite links: 1.17
- Narrowband MSS for IoT: 1.18
- Ka-band FSS (R2): 1.19
- Regulatory issues: 7

Follow the outcome – impact on non-protected bands

CRAF

I've just touched the surface…



Federico Di Vruno from the UK SKA office gives a tutorial on the noble art of compatibility studies at the 5th IUCAF School on Spectrum Management for Radio Astronomy

The way forward

What radio astronomy can and will do, by and for itself

- Operate as much as possible in remote locations using the terrain to shield it from direct line of sight contact with populated areas (but this may the place where internet via satellites is needed…)
- Build “robust” receivers
- Radio astronomy has engaged with the radio spectrum regulatory regime since 1958 and has succeeded in securing exclusive rights to small fractions of the spectrum, make sure we keep them - care for the protected bands
- Radio quiet zones around radio telescopes are important for continued radio astronomical exploration
- Keep good contact with the administrations – they decide

Summary

Why are we gathered here?

- To protect scientific use of the radio spectrum
- This should be an intrinsic part of frequency allocation
- Allocation now is more like an uncontrolled land grab or gold rush or Mad Max in the Thunderdome
- Probably doesn't matter, we have to learn to live in the real world
- Spectrum management is the first line of defense
- Spectrum management is complicated, hard, tedious, distracting
- Spectrum management is necessary
- Let's use this week to help ourselves figure it out

Harvey Liszt, summer school, Stellenbosch

Thank you for your attention

CRAF