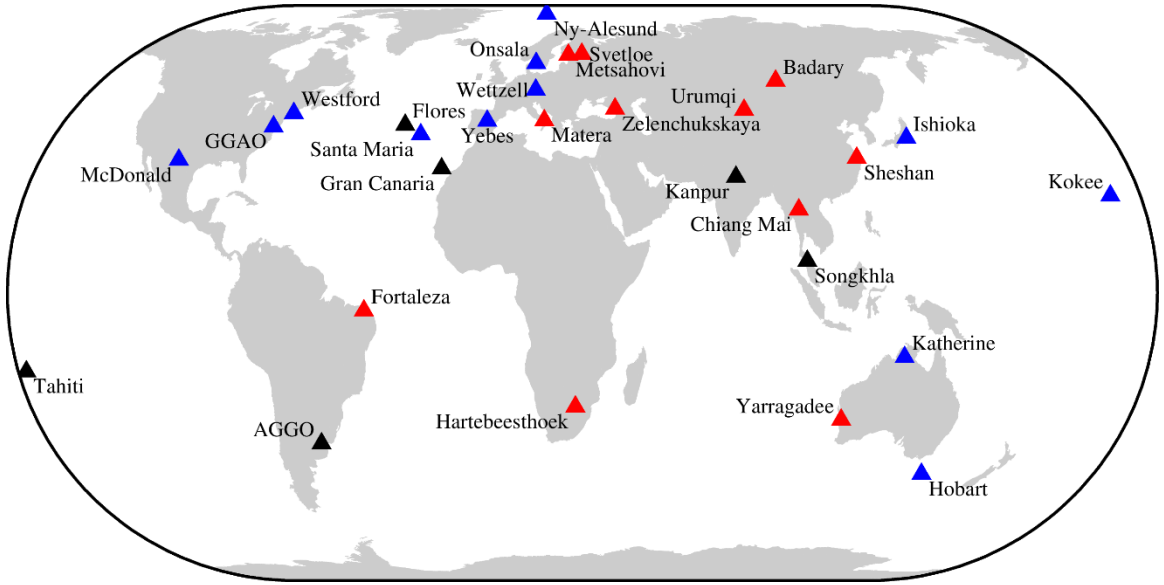
Federal Agency for Cartography and Geodesy

BKG
Wir geben Orientierung.

On the efforts to prepare VLBI for the next decade

Hayo Hase, BKG
Marta Bautista, IGN
Jose Antonio Lopéz Pérez, IGN

Current situation of geodetic VLBI



Global VGOS network as of 2024. The network will be expanded in future.
(operational, signal-chain, planning stage)

- In general the VGOS stations are registered as RAS stations at ITU-R.
- VLBI Global Observing System (VGOS) operates in the frequency range of 2-14 GHz.

- The same spectrum is targeted by telecommunications (ground, space).
- The VGOS broadband receiver catches all emissions, wanted cosmic radiation as well as unwanted manmade emissions.
- This is an increasing problem.

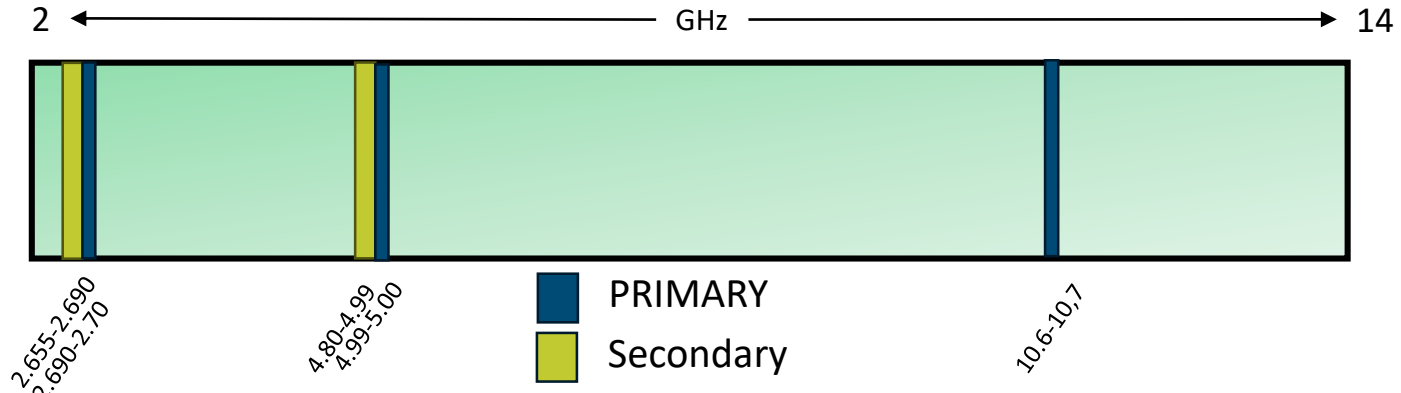
- **Geodetic VLBI does not operate in allocated bands!**

The quasi non-existence of Geodetic VLBI in spectrum management

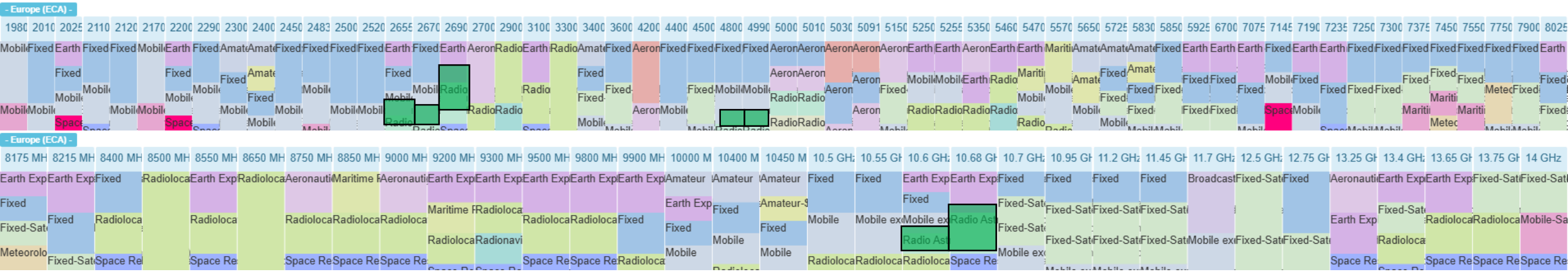
Geodetic VLBI receives “cosmic radiation” and is assigned to Radio Astronomy Service (RAS).

RAS: Only 2.4% of any allocation
-> just **0.8%** of the spectrum is **primary** allocation.

- “Radio Frequency Interference (RFI)” only in allocated RAS bands.
- “Unwanted electromagnetic emissions” in bands not allocated to RAS.



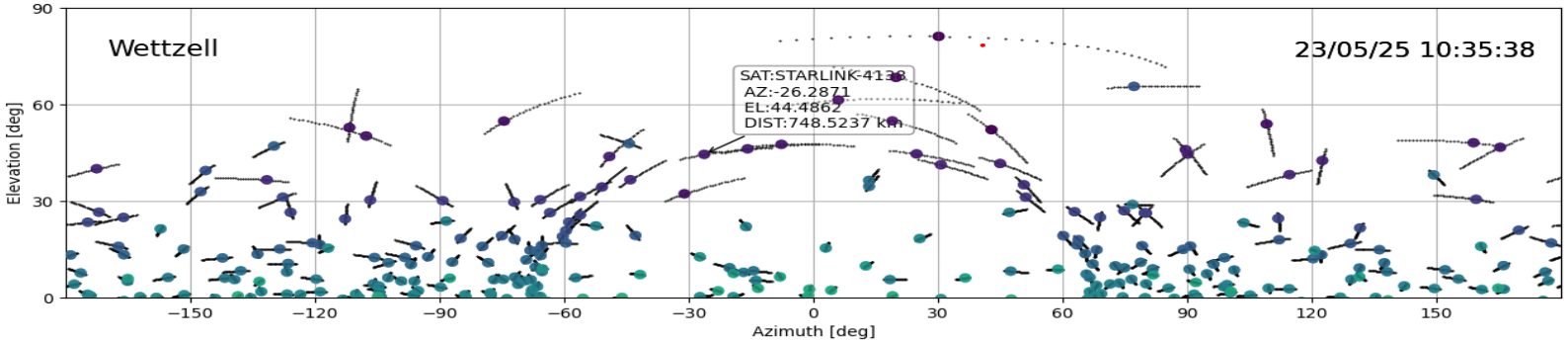
Geodetic VLBI with 32 channels of 32 MHz bandwidth each exceeds the bandwidth of allocated RAS bands.



ECA table

Problem 1: Existing and upcoming large satellite constellations

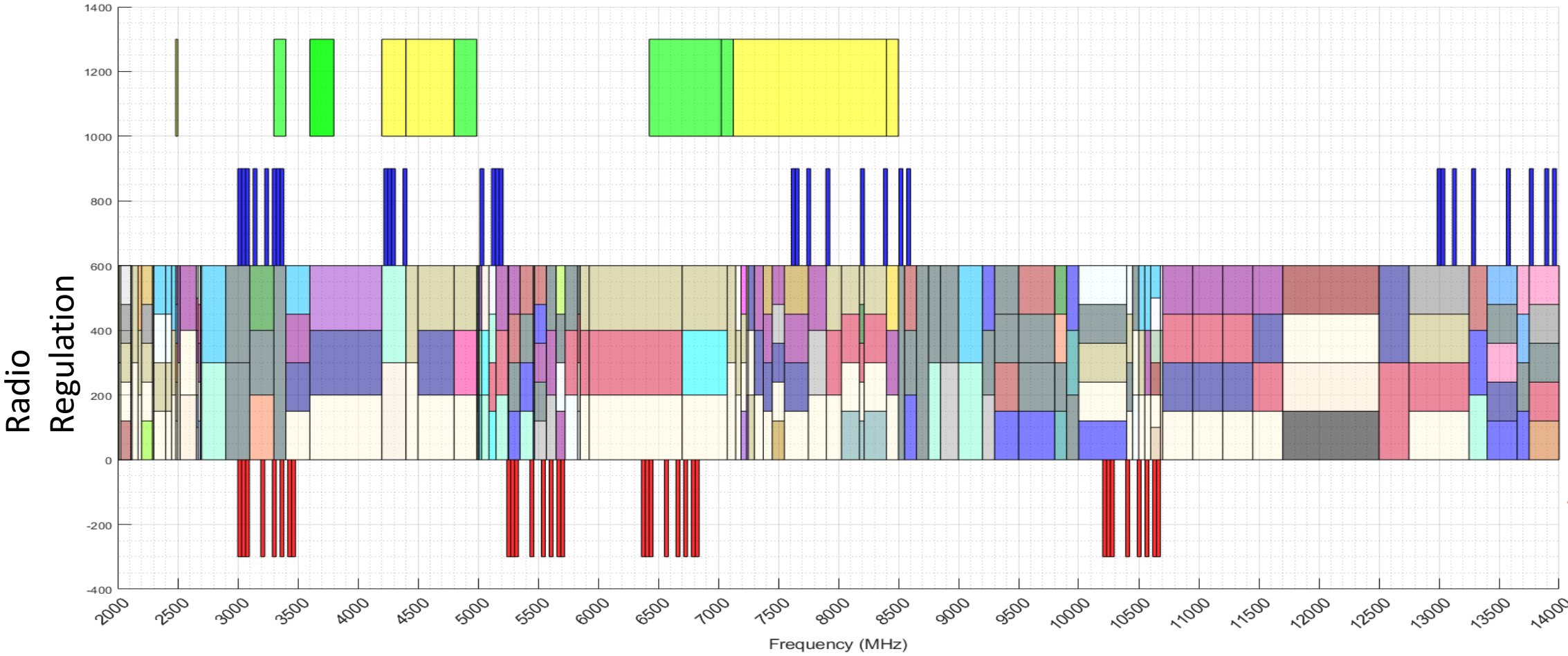
Constellation	Number of satellites	Downlink Frequencies	Altitude [km]
Starlink Phase 1	4400	Ku, Ka	550
OneWeb Phase 1	648	Ku, Ka	1200
Amazon Phase 1	3200	Ka	~600
Guo Wang (GW)	13000	Ku, Ka	590 – 1145
Starlink VLEO	7600	V	340
Telesat	1700	Ka	
Starlink Phase 2	30000	Ku, Ka, E	328 – 614
OneWeb Phase 2	6372	Ku, Ka, V	1200
Boeing	5789		
Astra	13620		
Amazon Phase 2	7774		
Cinnamon-937	300000	???	???



- Satellite downlinks are made at **10.7-12.7 GHz** (Ku-band).
- This spectrum is also used for SAT-TV (Region 1).
- One transmitter per each square degree will be reached by Starlink and OneWeb after phase 2.
- At which altitude stops national regulation?

Snapshot of existing Starlink and One Web satellites over Wettzell at May 25, 2023. Starlink uses beamforming and could avoid Wettzell, OneWeb does not.

Problem 2: Expansion of International Mobile Telecommunication (IMT)



WRC-23
WRC-27

VGOS_perf

allocated bands to services

VGOS_00

From pico-second to milli-meter

Uncertainty of delay τ:

$$\sigma_\tau = \frac{2.65}{2 \cdot \pi \cdot RMS_{bandwidth} \cdot SNR} \; [ns]$$

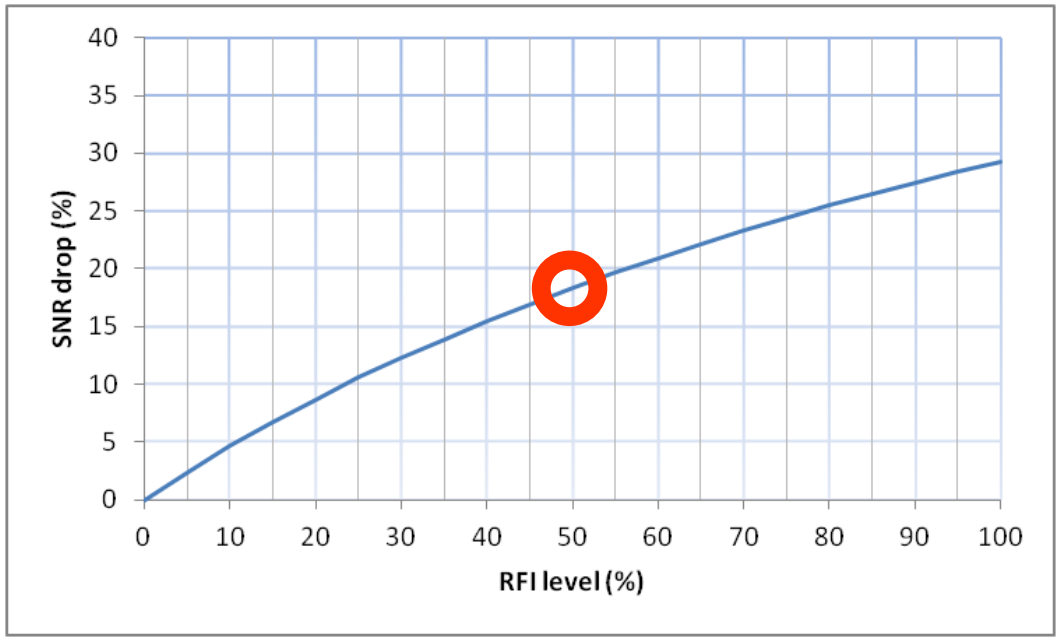
$$RMS_{bandwidth} = 2.93 \; (\text{for mode}_{00})$$

$$\sigma_\tau = 7.2 \; ps \text{ for } SNR = 20$$
$$\sigma_\tau = 4.8 \; ps \text{ for } SNR = 30$$
$$\sigma_\tau = 3.6 \; ps \text{ for } SNR = 40$$

$$3.3 \; ps = 1 \; mm$$

8.8 ps
5.9 ps
4.4 ps

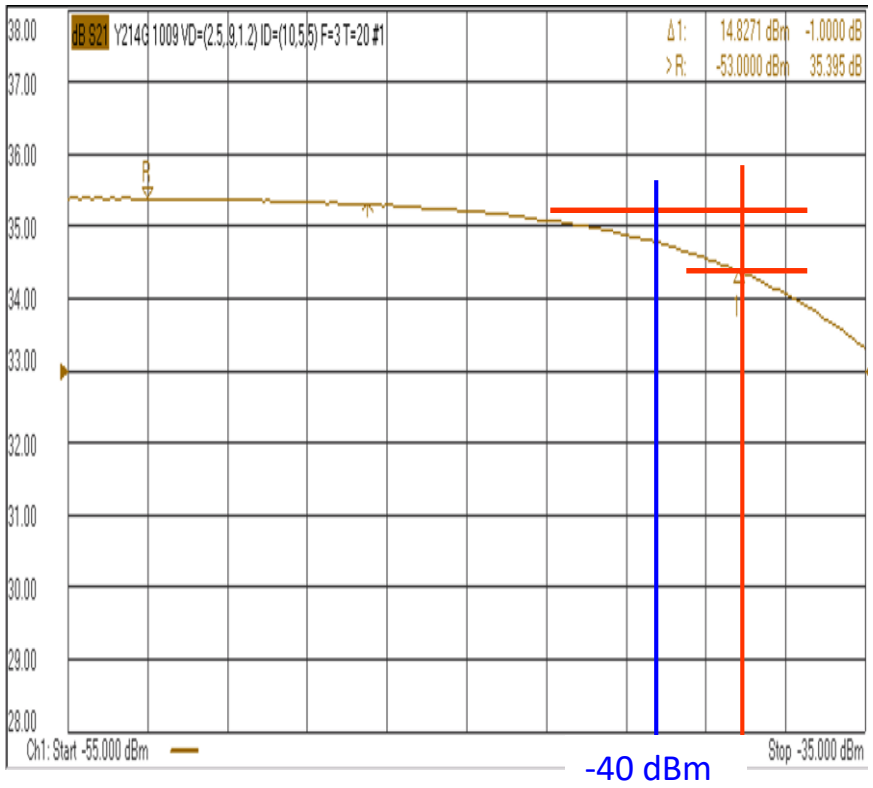
Unwanted electromagnetic emissions increase the system noise over the cosmic signal.



We can reach the “1 mm” only by optimized channel configuration and schedules.

If the system noise increases by 50% the SNR drops by 18%.

Affect of man-made emissions to the receiver hardware chain



Rx input: -55 dBm ... -35 dBm

Linear and non-linear behaviour of a typical VGOS-LNA.

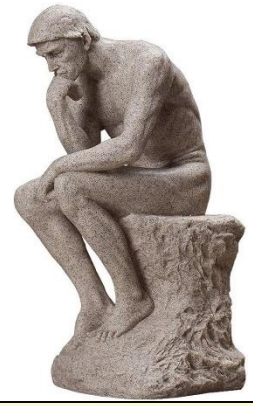
- **LNA damage** !!!
  - First amplifier is the most sensitive part in the Rx-chain. Typical damage level is 15 mW (12 dBm)
    => power flux density threshold = -38 dB (W/m²) for VGOS
  - Typical compression point Pi1dB = -30 dBm
    => max. input power < -40 dBm (= 0.000 000 1 W)
    to guarantee operation in linear regime

- **Gain compression** at some point of the receiver´s chain:
  - Intermodulation + harmonics => spurious signals
  - System temperature increase => less sensitivity
  - Lack of linearity in the receiver

Unwanted emissions can be destructive.
Dynamic range of amplifiers is limited.

Mitigation of unwanted electromagnetic emissions in Geodetic VLBI

1. Use “unused” frequency bands for observation.
   - Only short term solution, spectrum tends to be sold out, services sharing bands
2. Development of new feed tailored to the lower and upper frequency range.
   - Does not address unwanted emissions between upper and lower limit
3. Implementation of superconducting filters at front end.
   - Number of filters is limited, lowers overall sensitivity
4. Development of digital filtering methods at back end.
   - Does not protect from overloading amplifiers at front end
5. Install VGOS in Radio Quiet Zones (coordination zones).
   - Are not immune against radiation from satellites.
6. Communicate observation schedules to satellite operators.
   - No obligation to be followed by all services
7. Adapt observation schedule, avoid low elevations
   - Loss of very long baselines and atmosphere sampling



All approaches to **mitigation** of unwanted electromagnetic emissions lead to a **decrease of performance** of Geodetic VLBI.

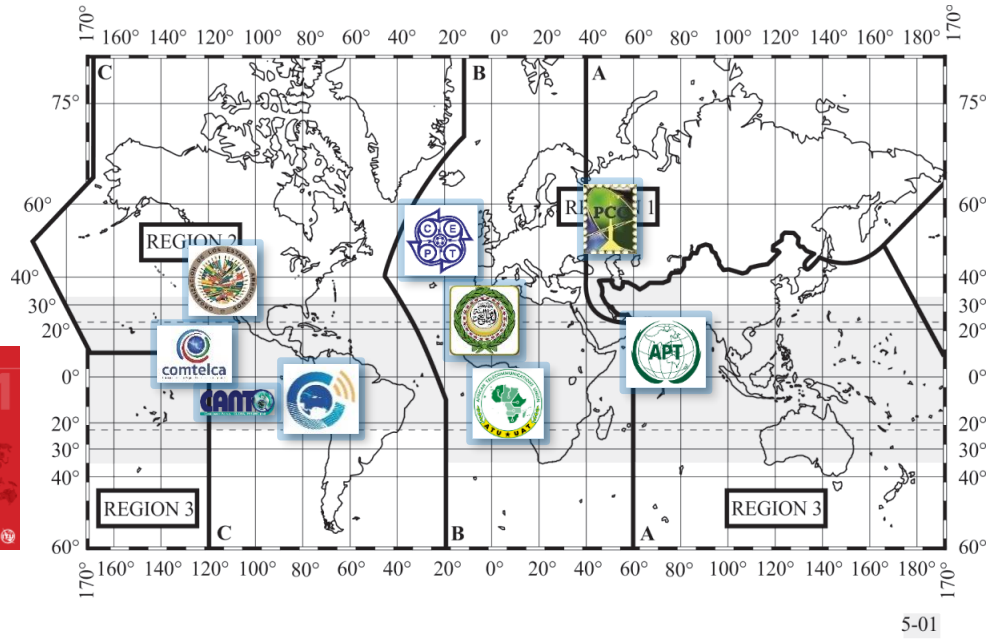
Spectrum Management – administrative mitigation?!

The **regulation** of frequency spectrum resources is the sovereign right of **national** governments

→

But radio waves do not respect national borders
→ **International regulations** are required!

- International Telecomunication Union (ITU)
  - Responsible of the **harmonization** of the radio-frequency spectrum at international level.
  - Elaborate rules, definitions,..
  - Elaborate ITU-Reports, ITU-Recommendations (based on compatibility studies).
  - WRC-[year] meetings every 3-4 years -> Radio Regulations
- ITU separates the world into 3 regions
  - Different regional organizations
    - CEPT (Europe, Region 1)



European Conference of Postal and Telecommunications Administrations
– 46 European countries cooperating to regulate posts, radio spectrum and communications networks

International Telecommunication Union – Radiocommunication Sector (ITU-R)

- Radio services in ITU (~40):

ITU RR radiocommunication services		
N°	Description	Short
1.19	**Radiocommunication service**	
1.20	Fixed service	fixed
	obsolete ~~Aeronautical fixed service~~	
1.21	Fixed-satellite service	FSS
1.22	Inter-satellite service	ISS
1.23	Space operation service	SOS
1.24	Mobile service	mobile
1.25	Mobile-satellite service	MSS
⋮		
1.55	Space research service	SRS
1.56	Amateur service	Amateur
1.57	Amateur-satellite service	Amateur-satellite
1.58	Radio astronomy service	RAS
1.59	Safety service	
1.60	Special radio service	

Study Groups

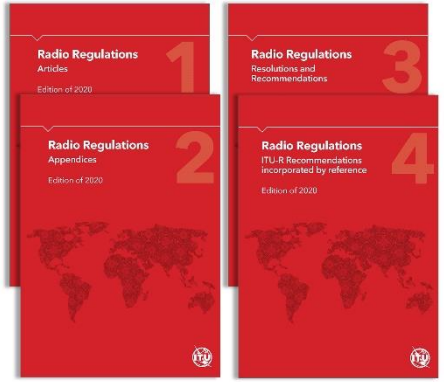
- **Study Group 1 (SG 1) Spectrum management**
- **Study Group 3 (SG 3) Radiowave propagation**
- **Study Group 4 (SG 4) Satellite services**
- **Study Group 5 (SG 5) Terrestrial services**
- **Study Group 6 (SG 6) Broadcasting service**
- **Study Group 7 (SG 7) Science services** ← Working Party 7D Radio Astronomy Service
- **Coordination Committee for Vocabulary (CCV)**

Related Groups

- **Conference Preparatory Meeting (CPM)**
- **Chairs and Vice-Chairs Meeting (CVC)**
- ***Disbanded Groups***

Spectrum Management for Geodetic VLBI

- **The goal:**
  - **Achieve an Agenda Item at WRC31**
    - Get frequency allocations for geodetic VLBI / achieve protection for geodetic observatories
- **What is needed:**
  - Support from several/many(!) national spectrum administrations
  - Exact frequency bands used in VGOS-operation (“fixed frequencies” to be defined by IVS)
- **The process:**
  - Convince several administrations to apply for an Agenda Item on Geodetic VLBI in WRC31 before WRC27
  - Enter into the study cycle 2027-2031 on the implication of Geodetic VLBI to existent services
  - Proposal of study to be decided on WRC31
- **What has been done:**
  - 1. Questions regarding the technical characteristics of Geodetic VLBI (2020)
  - 2. ITU-R Technical Report, ITU-R RA.2507, (2022)
  - 3. ITU-R Recommendation (2025?)



Radio Regulations

Report RA.2507

To do

- IVS to fix frequencies
  - Update the ITU-R Technical Report RA.2507
- VGOS stations to maintain good relation to their national spectrum authorities
  - Communicate your station contact together with point of contact at national spectrum authority to CRAF-VGOS group
  - Convince national spectrum authorities to support a Geodetic VLBI AI
- Stimulate the formation of a group of nations with VGOS infrastructure for a joint input by their spectrum authorities to WRC27 about Geodetic VLBI as AI in WRC31
- Continue work on ITU-R Recommendation on Geodetic VLBI
- Execute studies on the impact of Geodetic VLBI to other services during 2027-2031
- Be present and missionary at relevant conferences on the national, regional and international level (best effort – or professional?)

Federal Agency for
Cartography and Geodesy

BKG
Wir geben Orientierung.

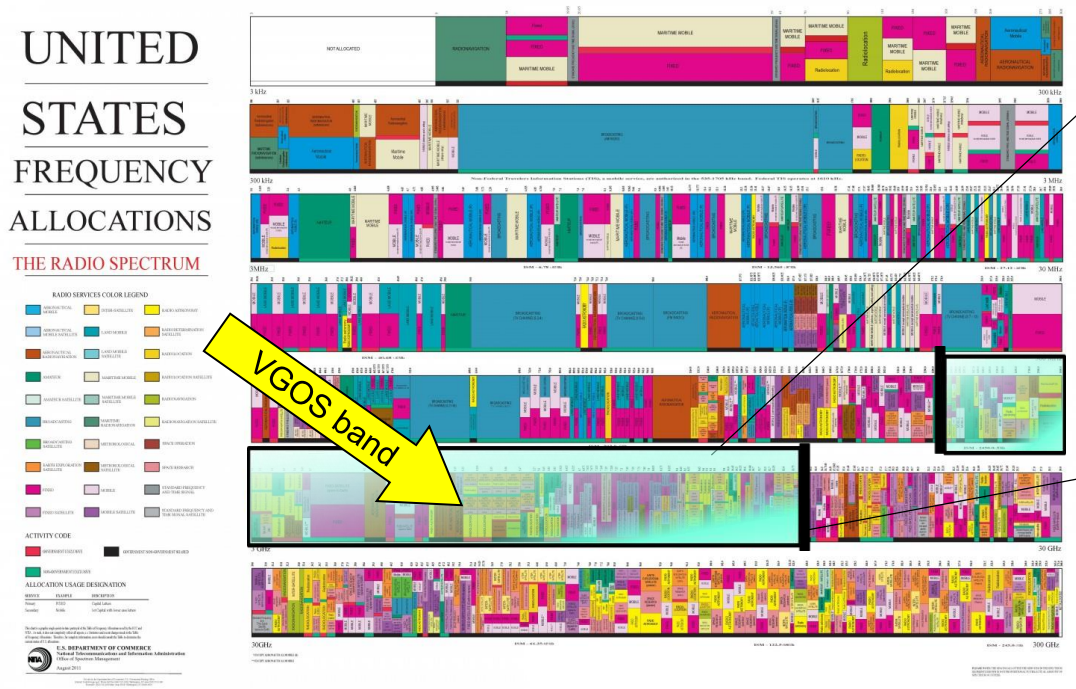
Thank you for your kind attention!

Bundesamt für Kartographie und Geodäsie
Organisationseinheit
Richard-Strauss-Allee 11
60598 Frankfurt am Main

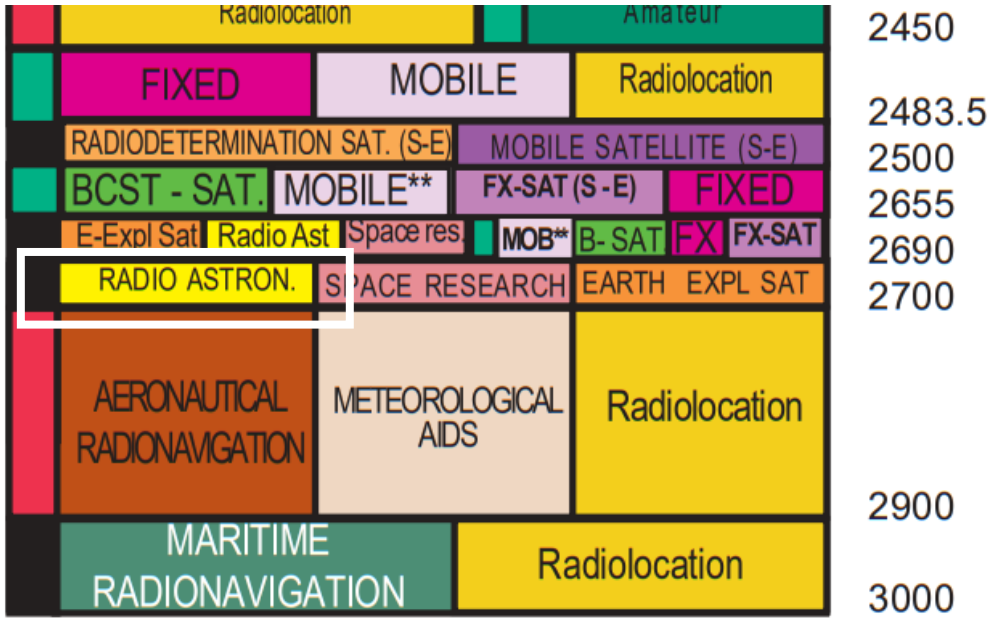
Vortragende(r)
vorname.name@bkg.bund.de
www.bkg.bund.de
Phone +49 69 6333 – 1

How spectrum administrators see the electromagnetic spectrum

Geodetic VLBI is not recognized within the Radio Regulations of ITU-R, but Radio Astronomy Service (RAS) is for “cosmic“ radiation.



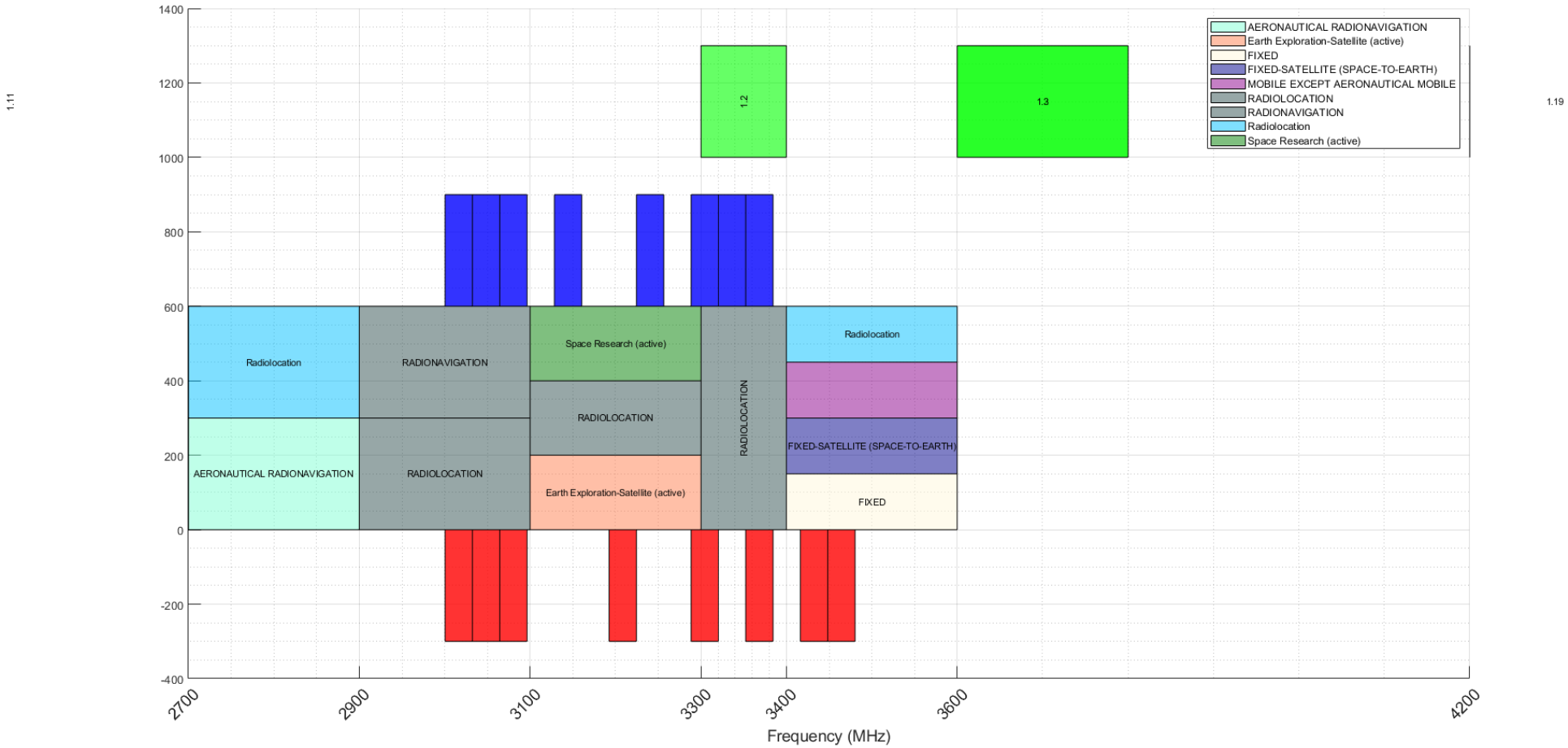
Example of co-spectrum users to Geodetic VLBI



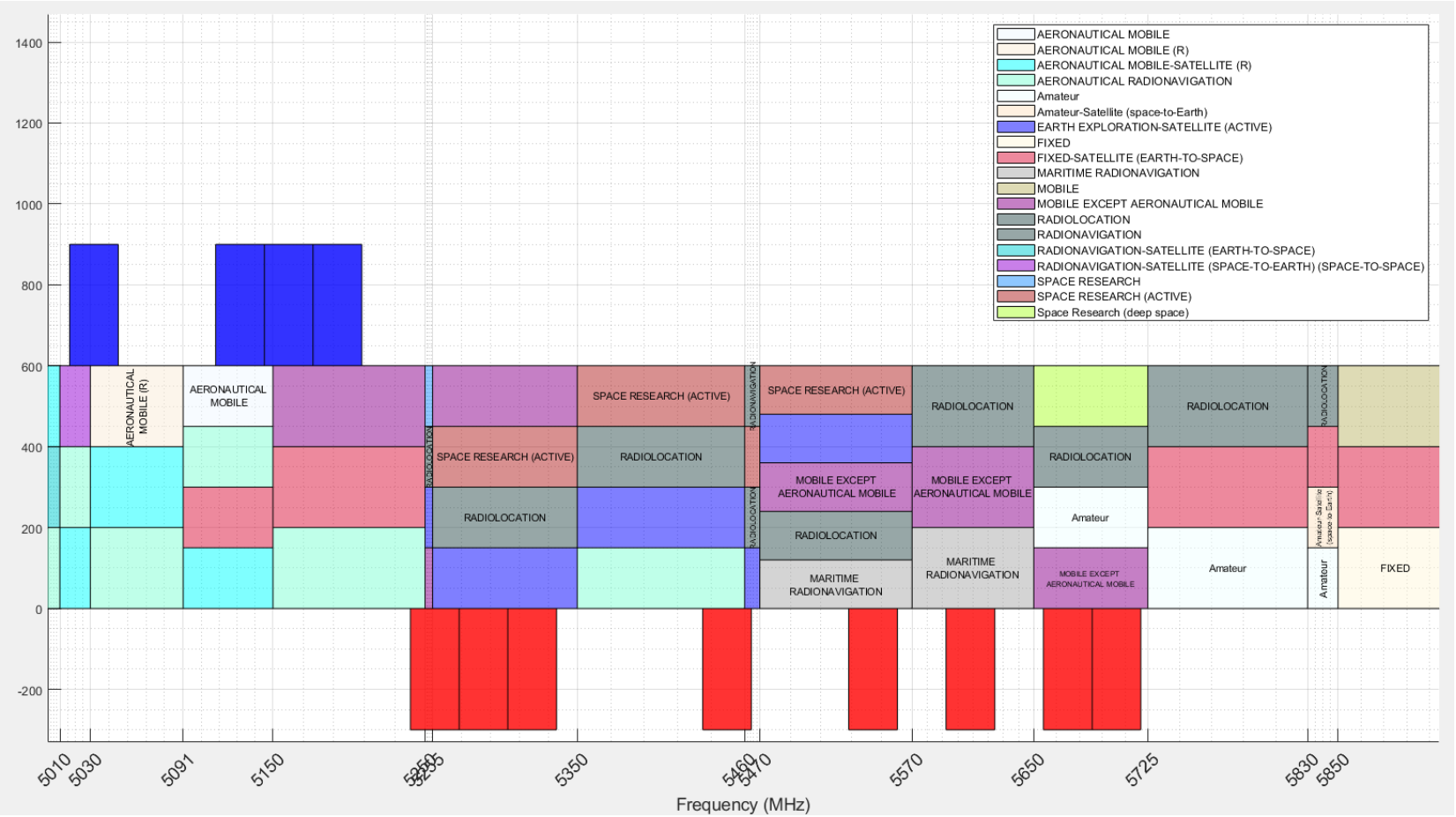
Example of 10 MHz RAS band

PRIMARY and **Secondary** allocations

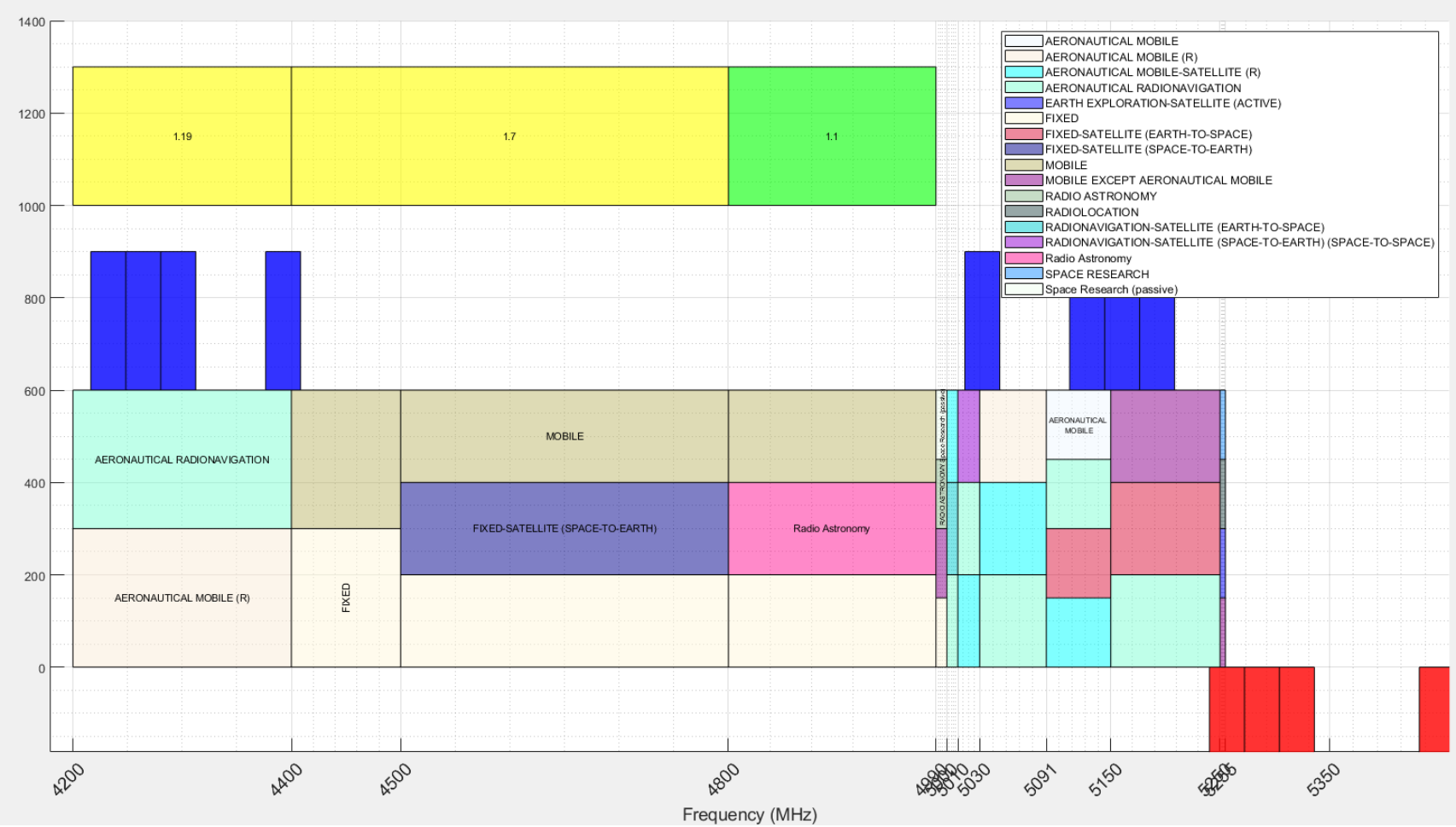
Band A_00 and Band A_perf vs. allocations and WRC27/31 agenda items



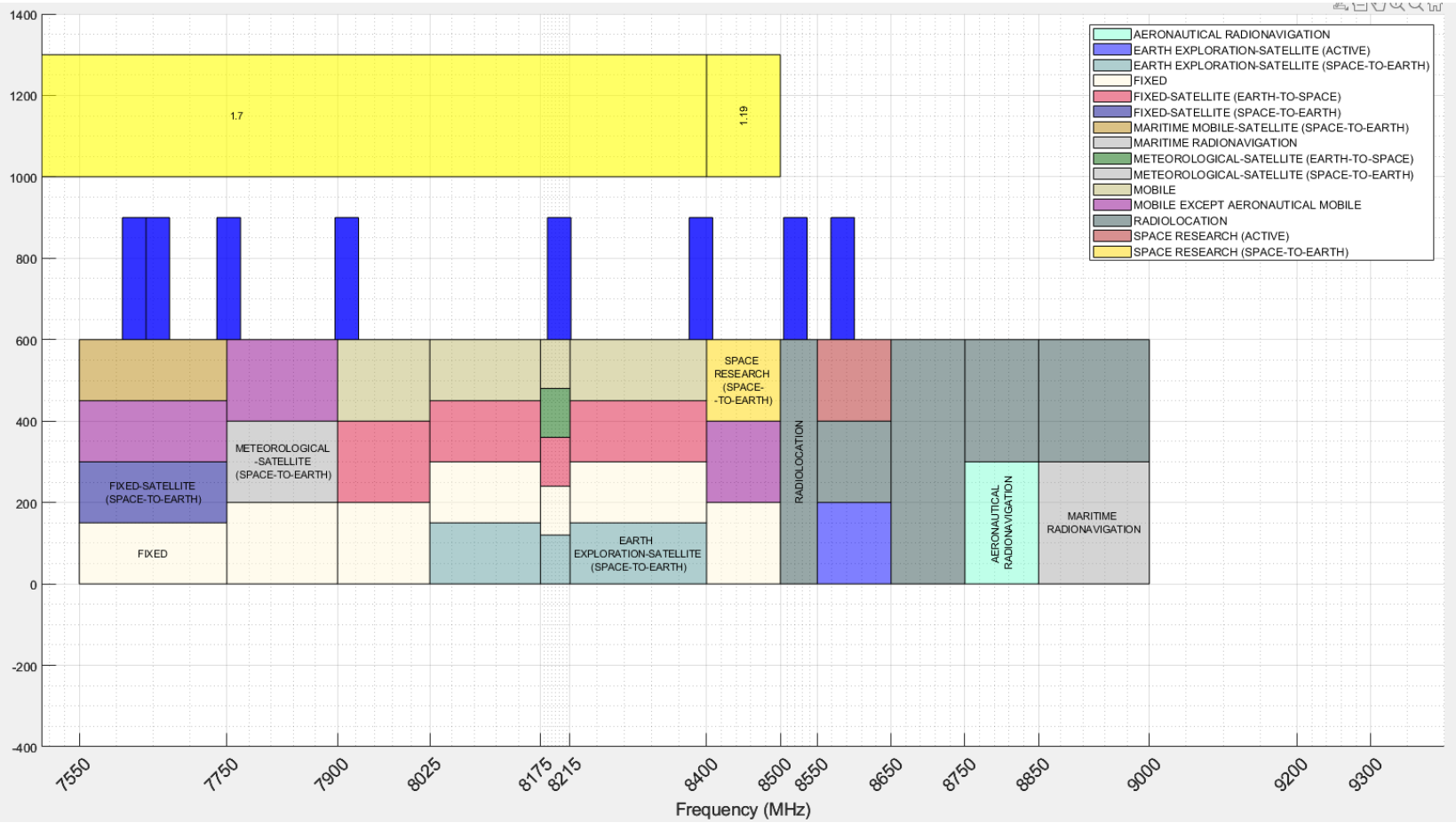
Band B_00 and Band B_perf (partly) vs. allocations and WRC27/31 agenda items



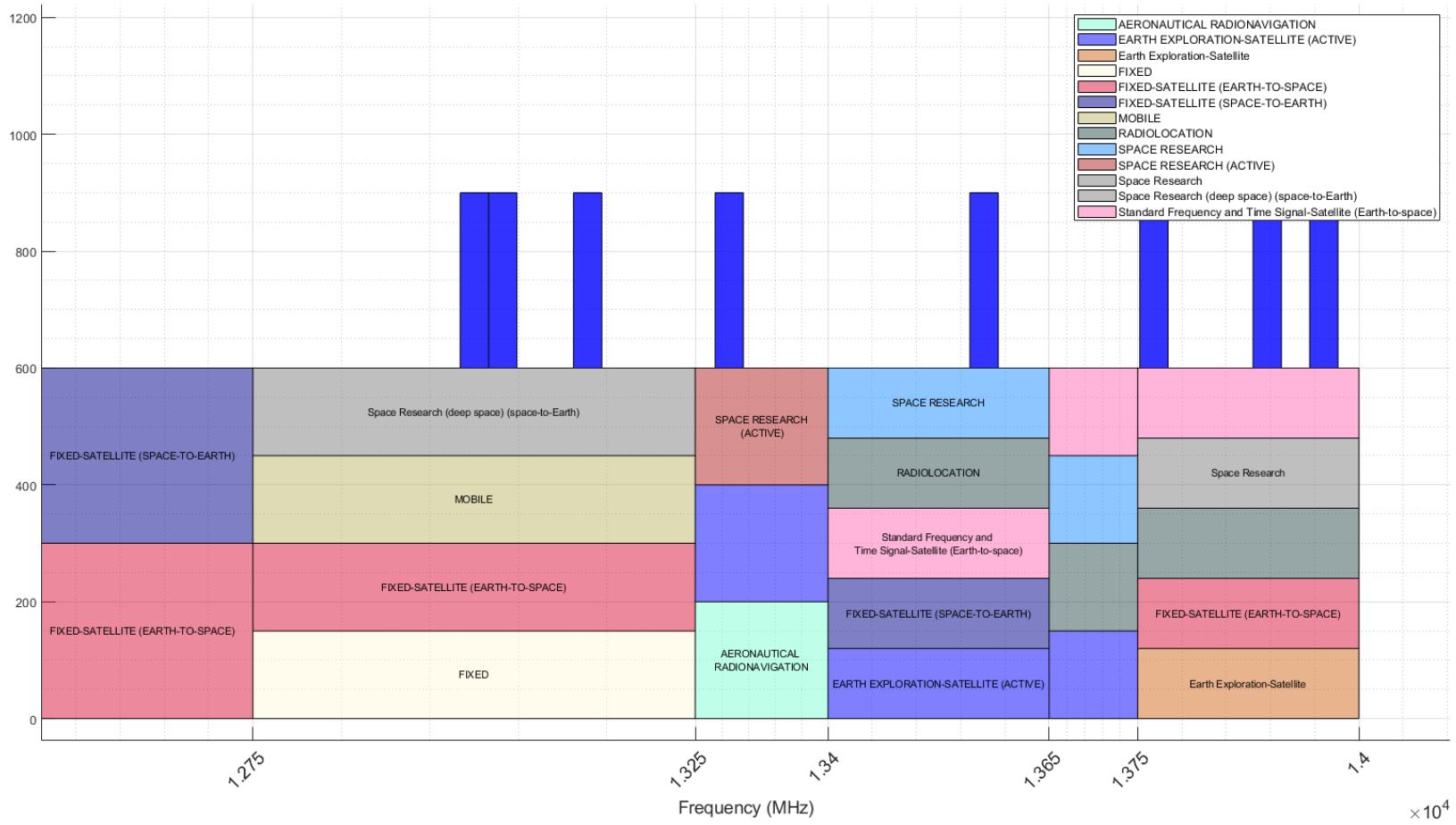
Band B_00 (partly) and Band B_perf vs. allocations and WRC27/31 agenda items



Band C_perf vs. allocations and WRC27/31 agenda items



Band D_perf vs. allocations and WRC27/31 agenda items



Band D_00 vs. allocations