RIT

6G Midband Technology and Spectrum

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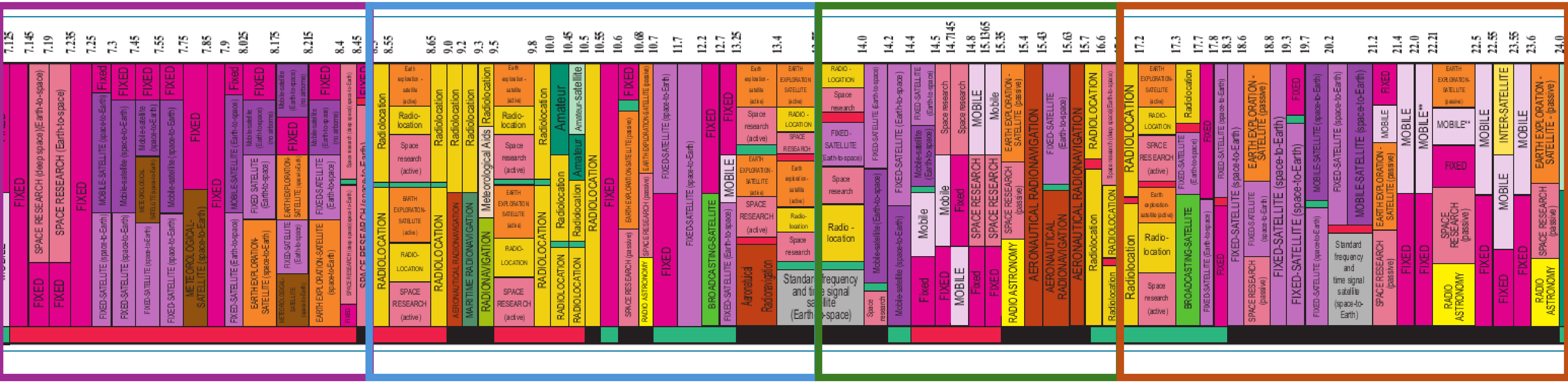
Jan 2025

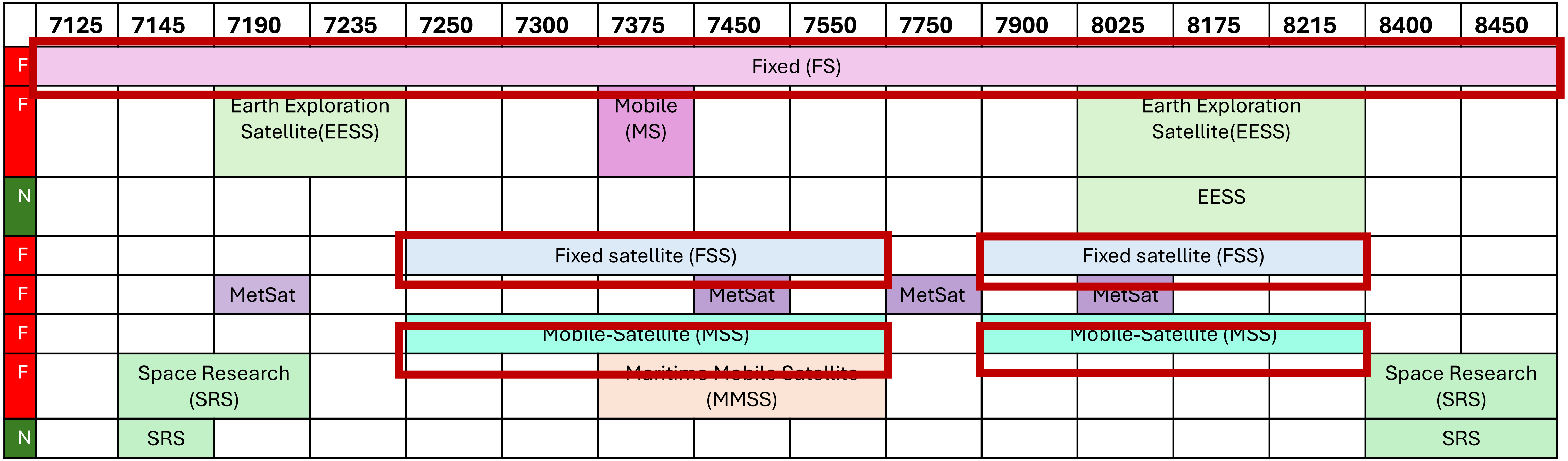
Current allocations and uses in 7.125 - 24 GHz in the U.S.

- 7.125 - 24 GHz band is split into four sub-categories for ease of presentation and analysis

7.125 - 8.5 GHz   8.5-13.75 GHz   13.75-17.1 GHz   17.1 - 24 GHz



7.125 - 8.5 GHz



- FS, FSS and MSS are the largest current allocations
- Approximately 20% of FS use is by the Department of Defense (DoD),
- The 8400 – 8500 MHz band is allocated for SRS (DL).
- Other uses may not be ubiquitous and hence perhaps more amenable to sharing.

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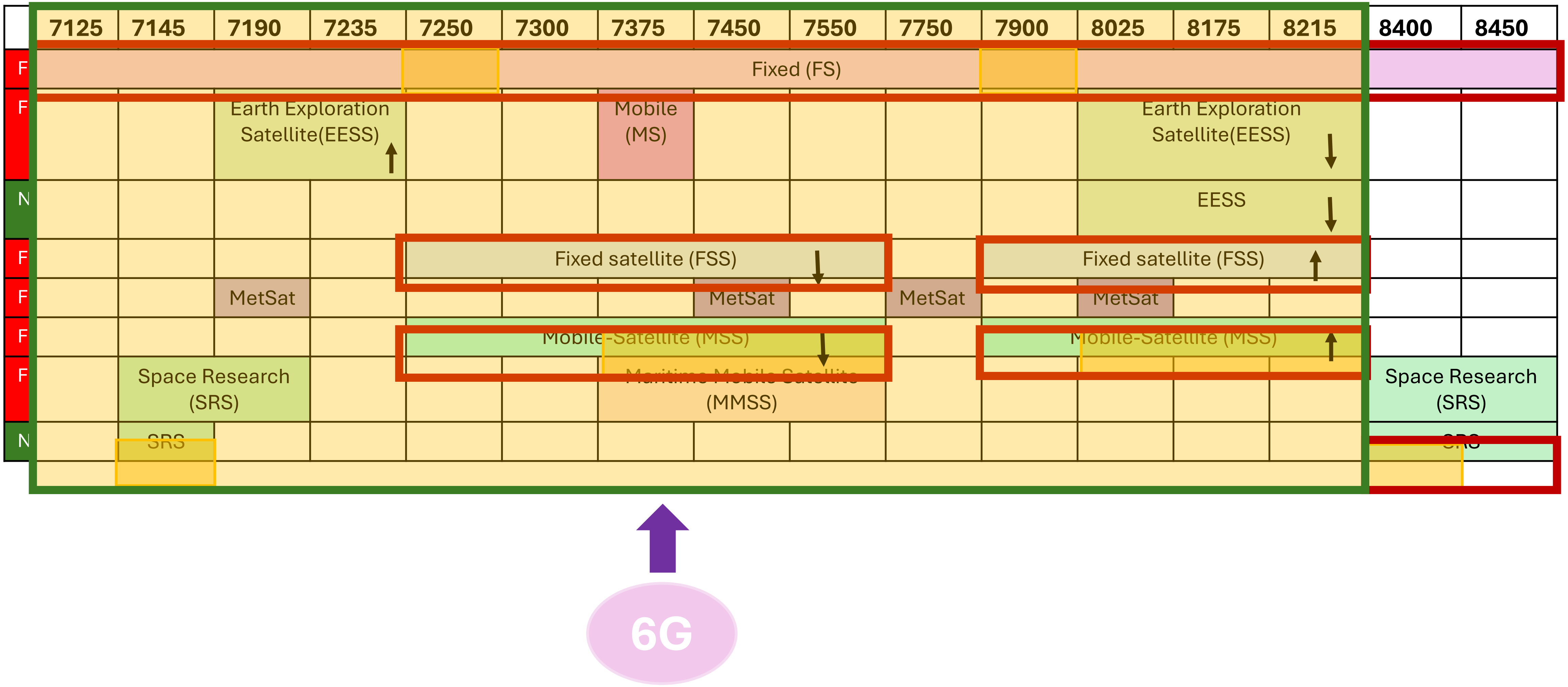
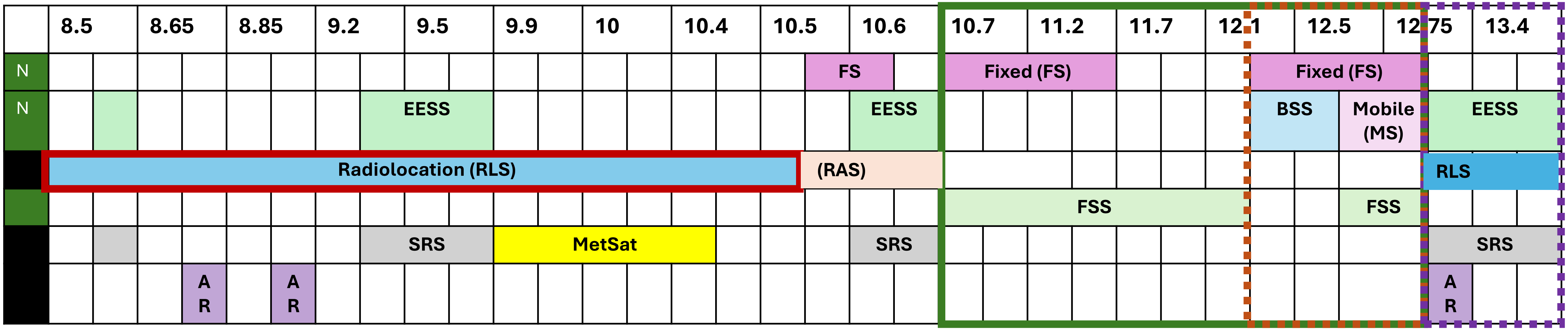
7.125 - 8.5 GHz

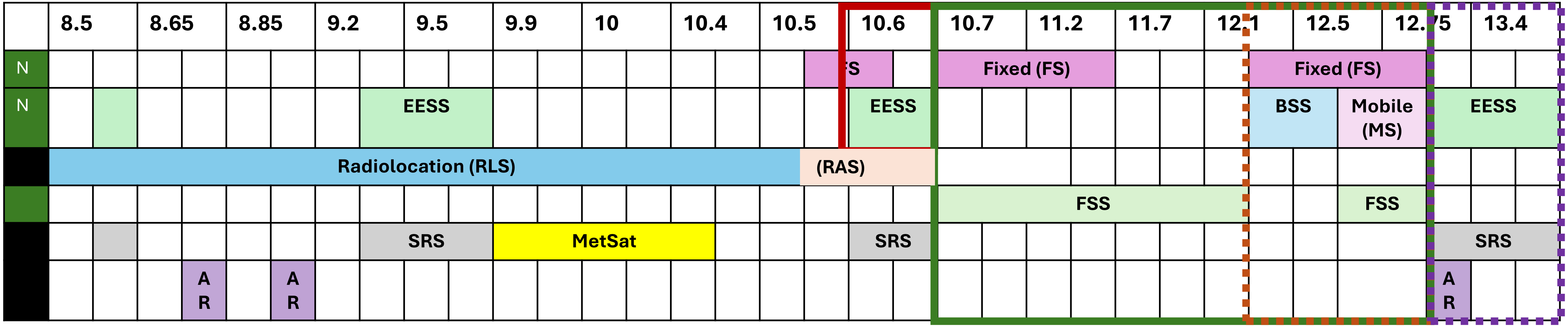


8.5-13.75 GHz



- RLS is the single largest allocation.
- ~2500 MHz in 10.7 – 13.25 GHz is allocated for non-federal use, of which 12.2 - 13.25 GHz is already under consideration by the FCC for sharing with other services.
- 13.25 - 13.75 may also be available for sharing with limited restrictions.

8.5-1375 GHz



- Passive EESS in the nearby 10.6–10.7 GHz band

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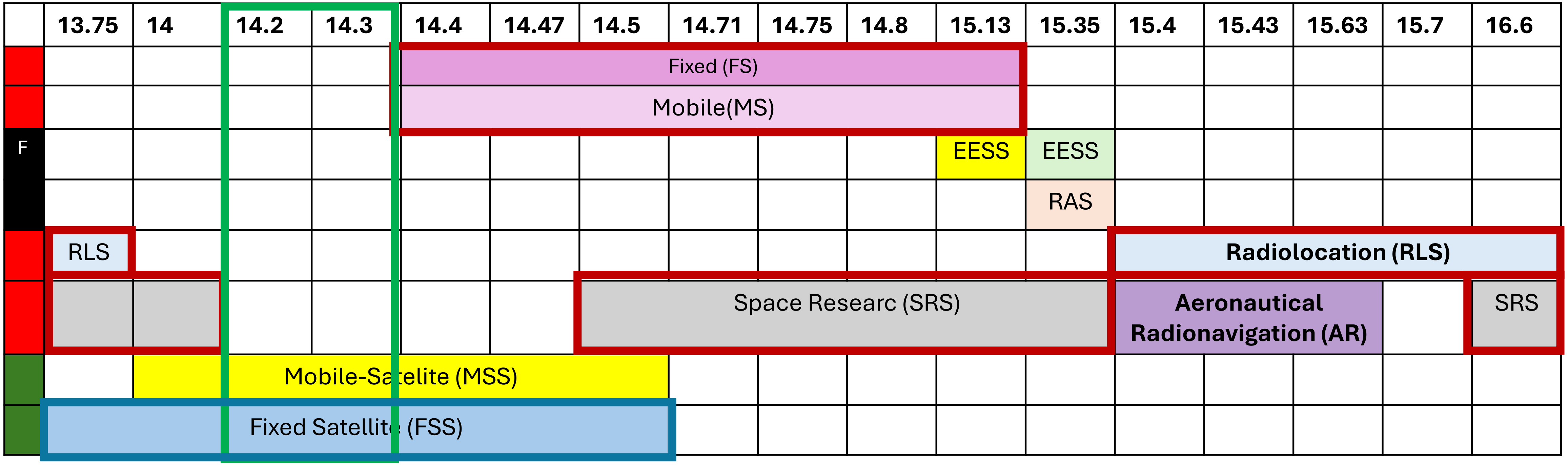
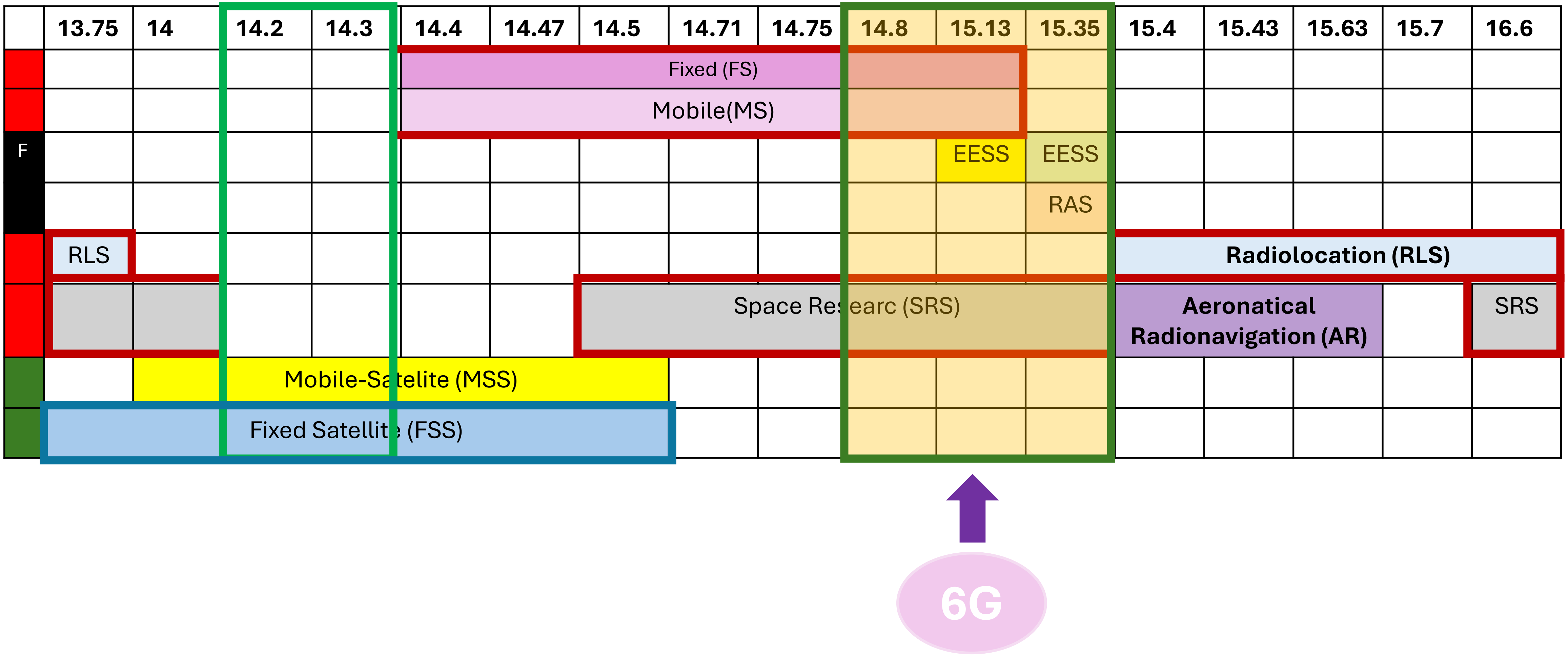
13.75-17.1 GHz



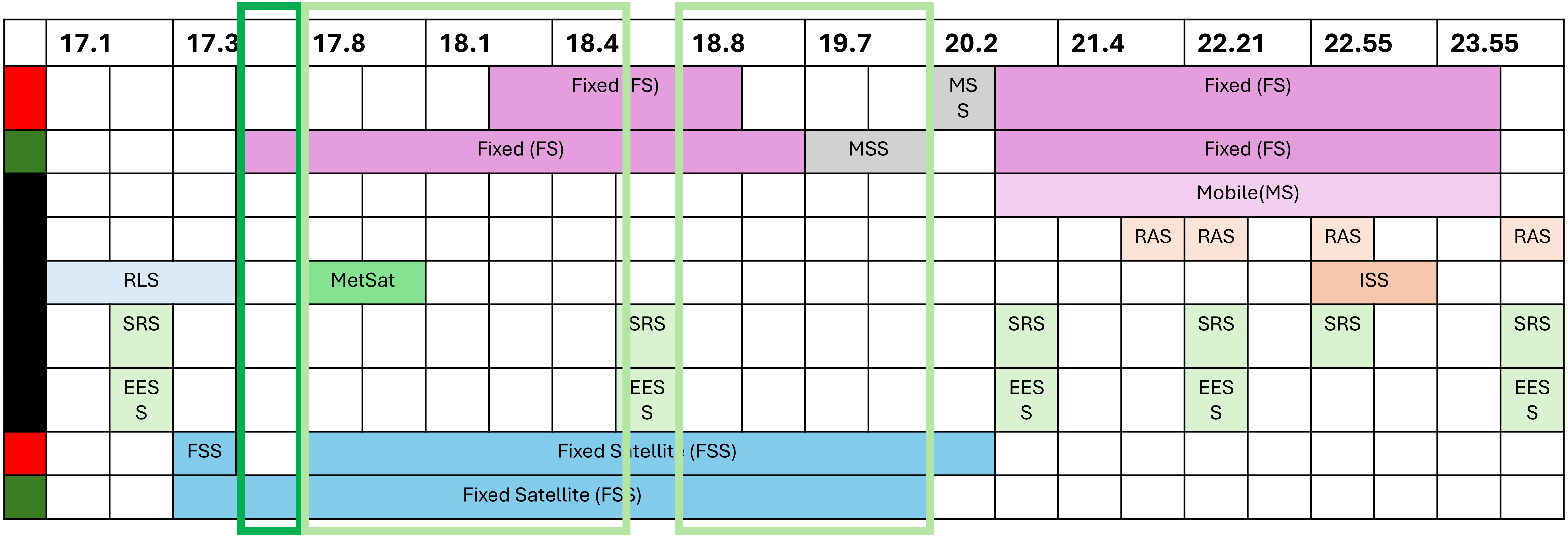
- RLS, SRS, FS and MS are the largest allocations in this part of the spectrum.
- 200 MHz between 14.2 – 14.4 GHz is not allocated for federal use.

13.75-17.1 GHz


13.75
14
14.2
14.3
14.4
14.47
14.5
14.71
14.75
14.8
15.13
15.35
15.4
15.43
15.63
15.7
16.6
F
Fixed (FS)
Mobile(MS)
EESS
EESS
RAS
RLS
Radiolocation (RLS)
Space Researc (SRS)
Aeronatical Radionavigation (AR)
SRS
Mobile-Satelite (MSS)
Fixed Satellite (FSS)
6G

RIT

17.1-24 GHz



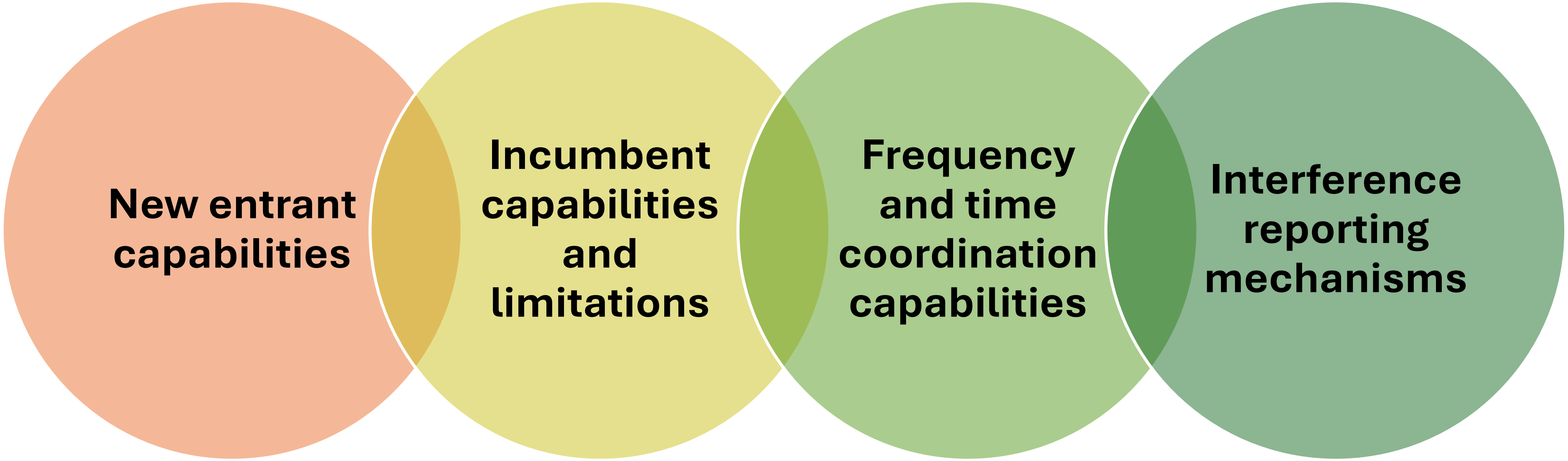
- 100 MHz spectrum in 17.7 – 17.8 GHz is not allocated for federal use.
- 2,200 MHz of spectrum in 17.8 – 18.6 GHz and 18.8 – 20.2 GHz may be practical for coexistence if used for earth stations rather than user devices.

Potential Shared Spectrum Bands

7.125-8.5 GHz	10.7-13.25 GHz	14.0-14.2 GHz	17.8-18.6 GHz and 18.8-20.2 GHz
• Federal Fixed • Federal Fixed satellite • Federal Mobile Satellite	• Non-Federal Satellite Services	• Space Research	• Federal Satellite • Additional analysis need to be done with regard to commercial satellite

Fundamental sharing framework

Success of spectrum sharing depends upon a few basic components:



They have to work in harmony with each other for the overall benefit

6G Spectrum

6G demand : **Peak data rate** 200 Gbit/s

$$c = Bandwidth \,.\, Layer \,.\, \log_2(1 + SNR)$$

More Bandwidth?

5G

Current 5G candidates:

- 3.3-3.8 GHz (400 MHz)
- 6.4-7.1 GHz (700 MHz)

6G

Upper Mid

WRC-23 candidates:

- 4.4-4.8 GHz (400 MHz)
- 7.1-8.4 GHz (600-1275 MHz)
- 14.8-15.35 GHz (550 MHz)

6G will only have slightly more bandwidth than 5G

Björnson E, Kara F, Kolomvakis N, Kosasih A, Ramezani P, Salman MB. Enabling 6G performance in the upper mid-band through gigantic MIMO. arXiv preprint arXiv:2407.05630. 2024 Jul.

The need for 6G

6G demand : **Peak data rate** 200 Gbit/s

6G will only have slightly more bandwidth than 5G

$$c = Bandwidth\,.\,Layer\,.\log_2(1 + SNR)$$

~~**More Bandwidth?**~~

Bigger MIMO

Increase the Frequency and number of the antenna

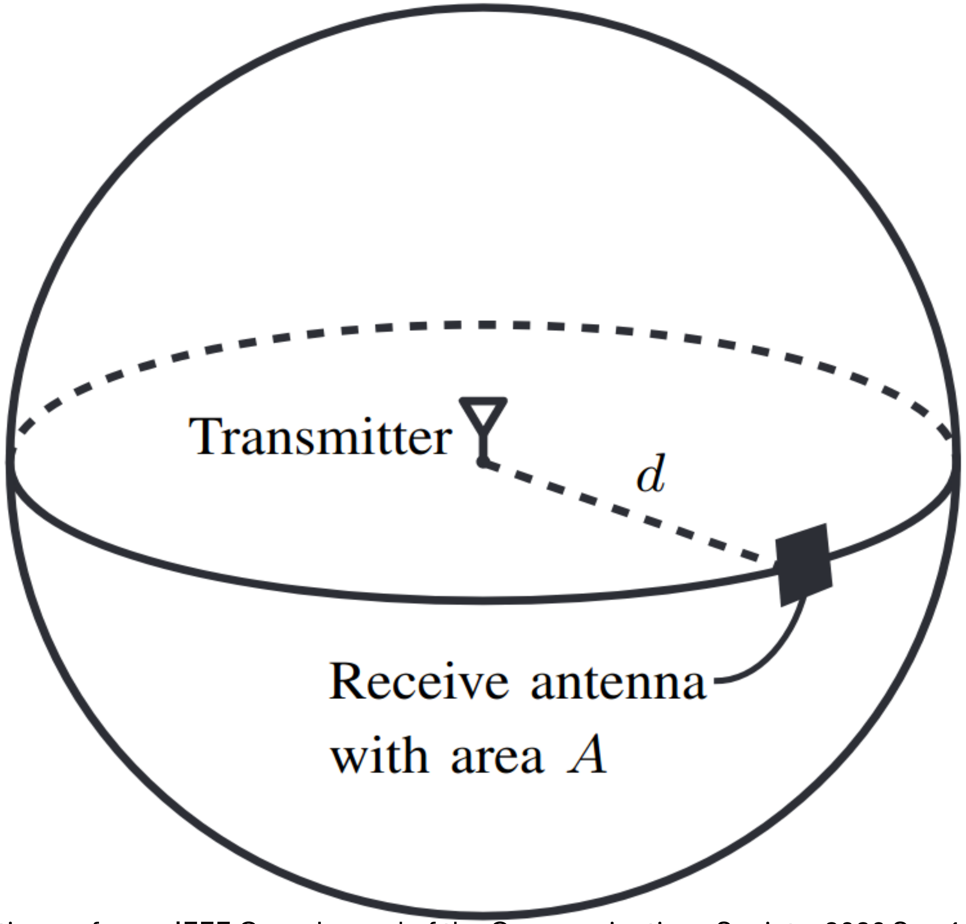
What Happens to Path Loss at High Frequencies?

- Friis' formula: the received power from an isotropic transmitter antenna

$$P_{\mathrm{rx}} = \frac{A}{4\pi d^2} P_{\mathrm{tx}} \qquad A = \frac{\lambda^2}{4\pi}$$

$$\boxed{p_r = \frac{\lambda^2}{(4\pi d)^2} \cdot p_t}$$

- Higher frequency Less power

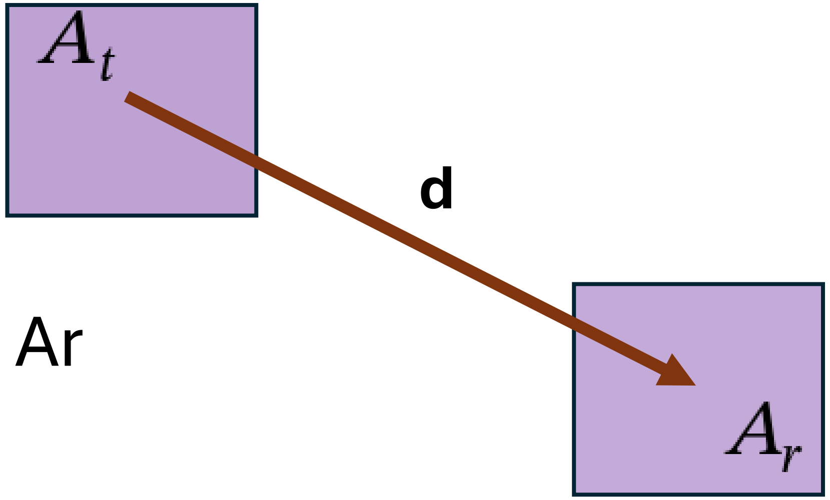


Björnson E, Sanguinetti L. Power scaling laws and near-field behaviors of massive MIMO and intelligent reflecting surfaces. IEEE Open Journal of the Communications Society. 2020 Sep 1;1:1306-24.

What Happens to Path Loss at High Frequencies?

- A reasonable design goal is to keep the free-space path-loss constant when frequency increased

$$P_{\mathrm{rx}} = \frac{A}{4\pi d^2} P_{\mathrm{tx}}$$



- Received power with array areas At and Ar

$$\boxed{p_r = \frac{A_r A_t}{d^2 \lambda^2} \cdot p_t}$$

- Higher frequency More power!!

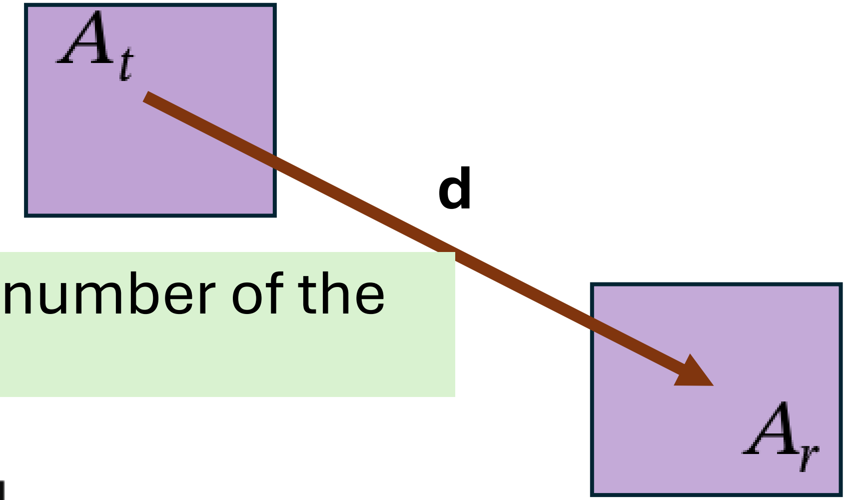
- We need more antenna to fill the area

Björnson E, Kara F, Kolomvakis N, Kosasih A, Ramezani P, Salman MB. Enabling 6G performance in the upper mid-band through gigantic MIMO. arXiv preprint arXiv:2407.05630. 2024 Jul.
6G in the Upper Mid-Band: The Rise of Gigantic MIMO - YouTube

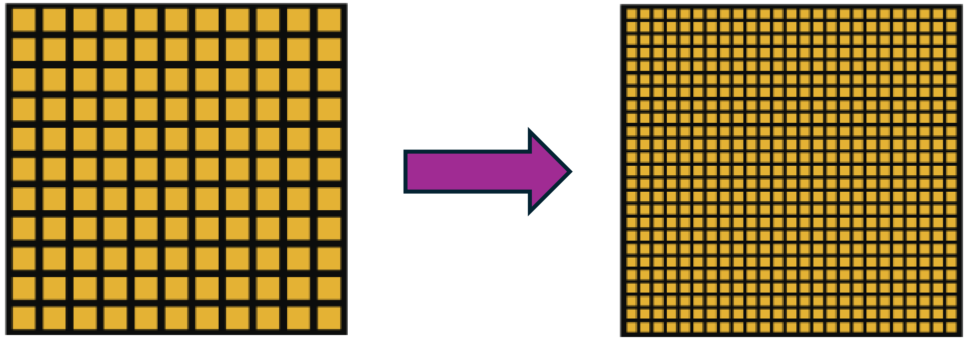
What happen to pathloss in high frequency?

$$p_r = \frac{A_r A_t}{d^2 \lambda^2} \cdot p_t$$

- Higher frequency More power!!



- Improve the free space pathloss by increasing the number of the antenna but the same aperture area



- So what is the problem with mmWave?

6G in the Upper Mid-Band: The Rise of Gigantic MIMO - YouTube

What happen if we increase the number of the antennas?

- Just more links between the transmitter and receiver?
- Just a bigger channel matrix?
- Just more complexity?

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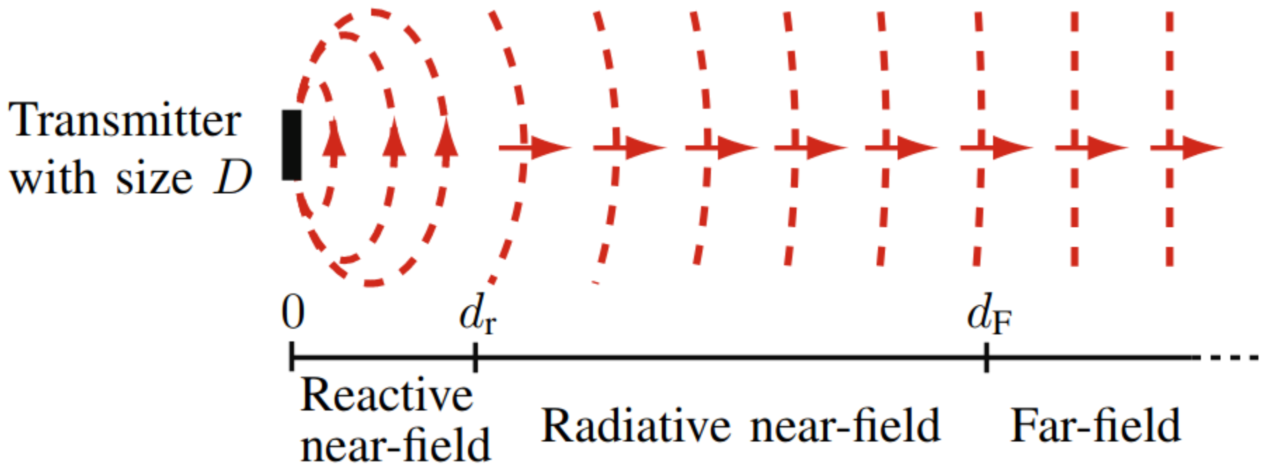


Nearfield Communication

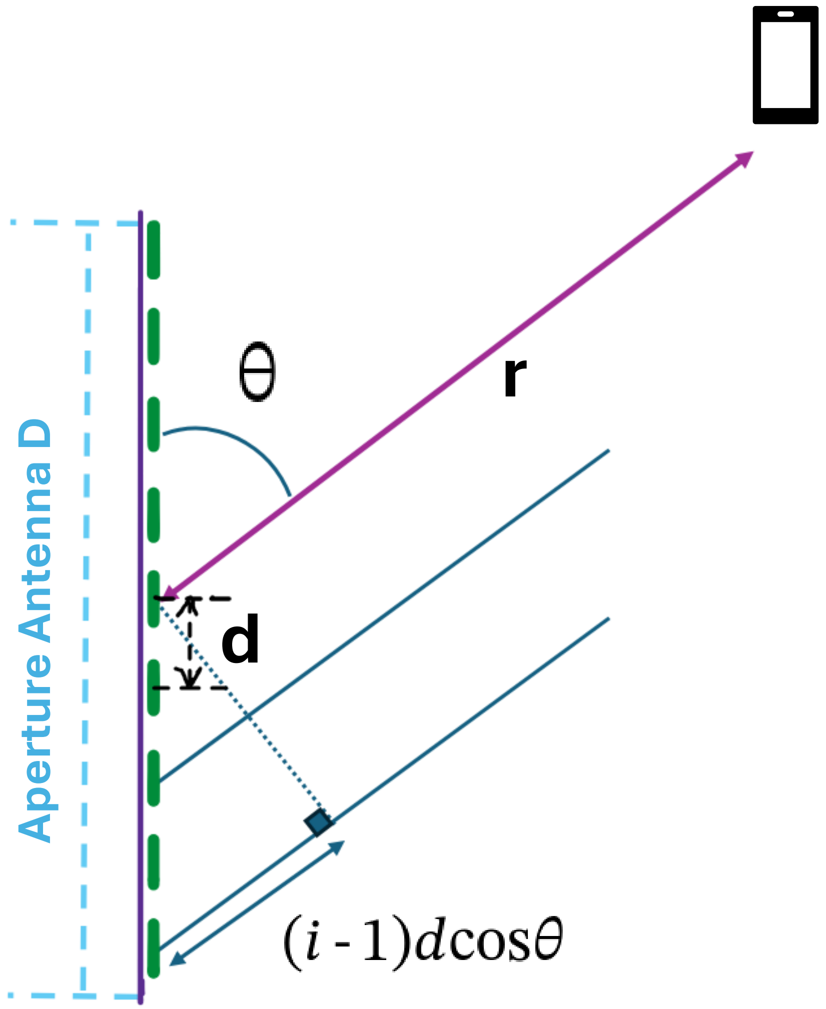
SIMO Channel Model

- Considering a simple SIMO channel with LOS

$$h_1 = \frac{\lambda\sqrt{G}}{4\pi r} e^{\left(-j\frac{2\pi}{\lambda} r\right)}$$

$$h_i = \frac{\lambda\sqrt{G}}{4\pi r} e^{-\left(j\frac{2\pi}{\lambda}\left(r + (i-1)d\cos\theta\right)\right)}$$

$$H = h_1\left[1, e^{-j\frac{2\pi}{\lambda} d\cos(\theta)}, \ldots, e^{-j\frac{2\pi}{\lambda}(N-1)d\cos\theta}\right]^T$$



SIMO Channel Model in Near-field

- Considering a simple SIMO channel with LOS

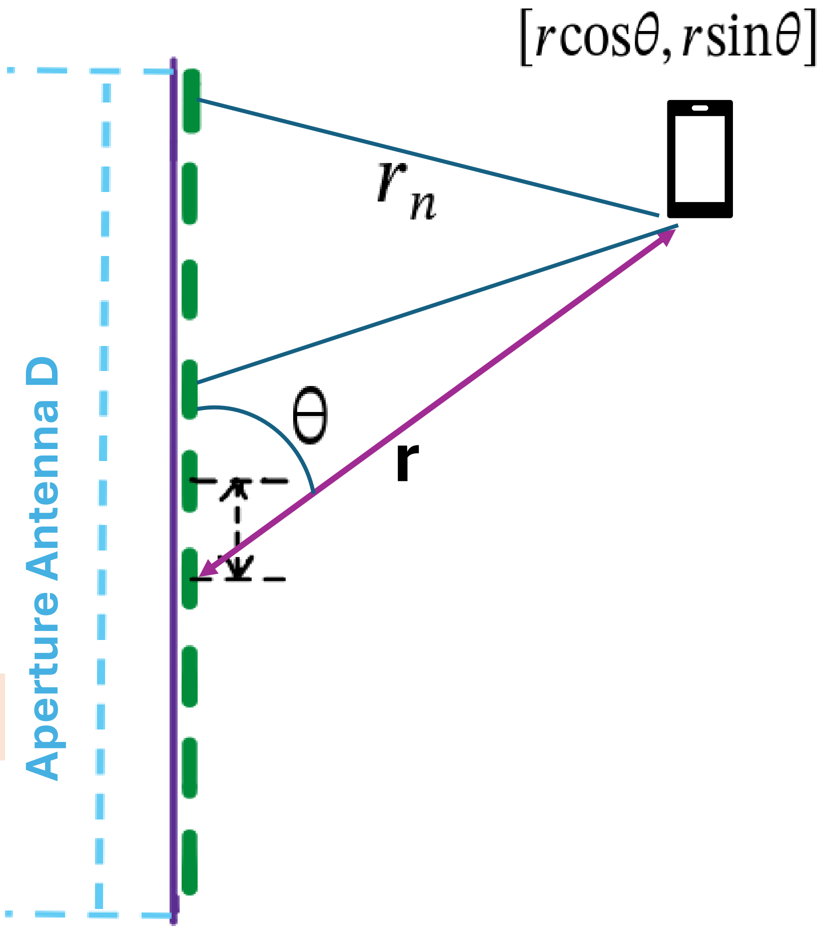
$$h_1 = \frac{\lambda\sqrt{G}}{4\pi r} e^{(-j\frac{2\pi}{\lambda}r)}$$

$$h_n = \frac{\lambda\sqrt{G}}{4\pi r_n} e^{-j\frac{2\pi}{\lambda}r_n}$$

$$r_n = \sqrt{r^2 + n^2 d^2 - 2rnd\cos\theta}$$

$$r_n = r(1 + \frac{n^2 d^2}{2r^2} - \frac{nd\cos\theta}{r})$$

- Taylor approximation



Wang Z, Mu X, Liu Y. Near-field integrated sensing and communications. IEEE Communications Letters. 2023 May 25;27(8):2048-52.

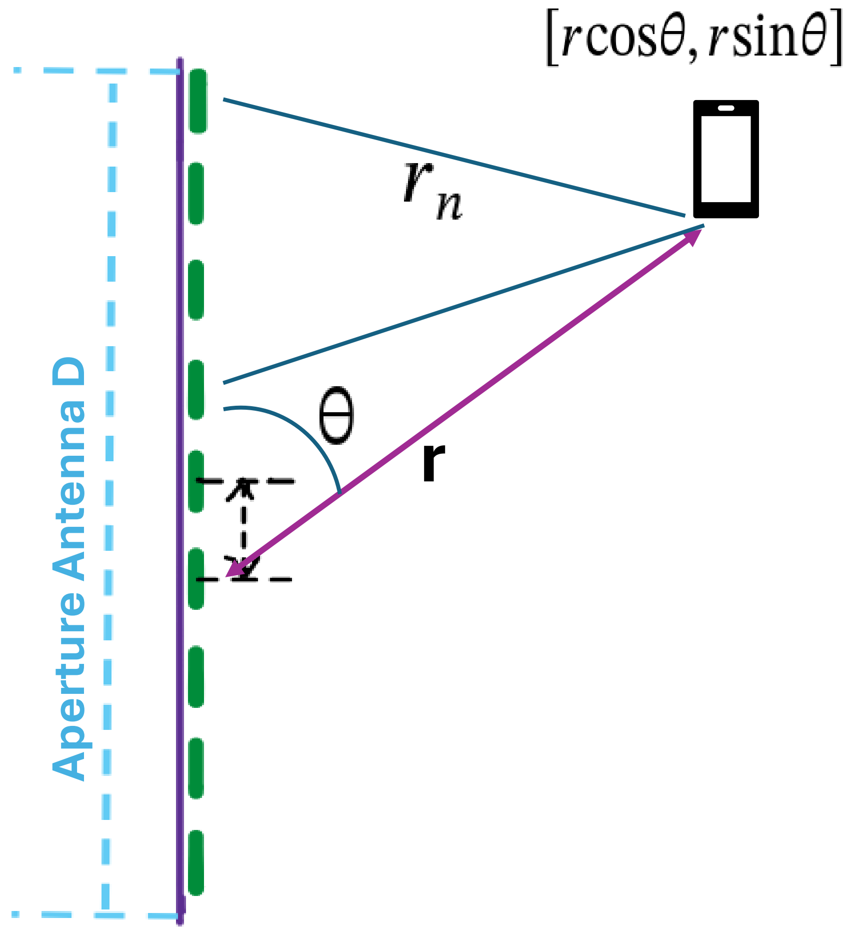
SIMO Channel Model in Near-field

$$r_n = r(1 + \frac{n^2 d^2}{2r^2} - \frac{nd\cos\theta}{r})$$

$$\boxed{h_n = h_1 e^{-j\frac{2\pi}{\lambda}(\frac{n^2 d^2}{2r} - nd\cos\theta)}}$$

$$\frac{2\pi}{\lambda}(\frac{n^2 d^2}{2r})$$

For the enough large **r** (far-field) equal to **0**



SIMO Channel Model in Nearfield

$$r_n = r(1 + \frac{n^2 d^2}{2r^2} - \frac{nd\cos\theta}{r})$$

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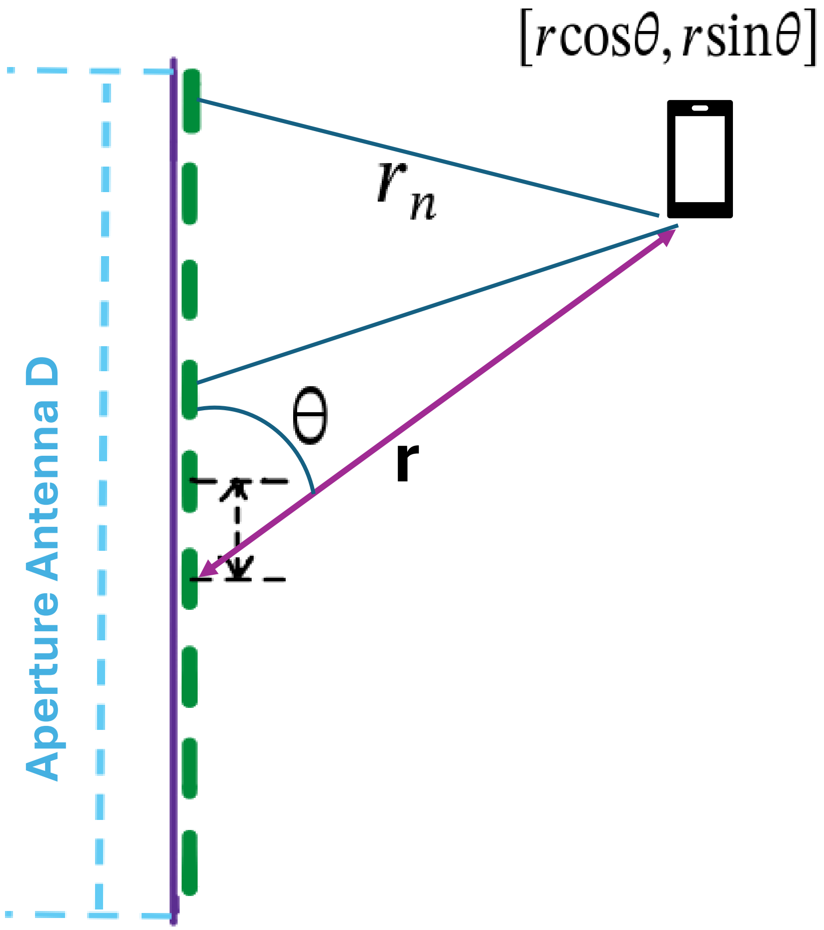
$$\frac{2\pi}{\lambda}(\frac{n^2 d^2}{2r})$$

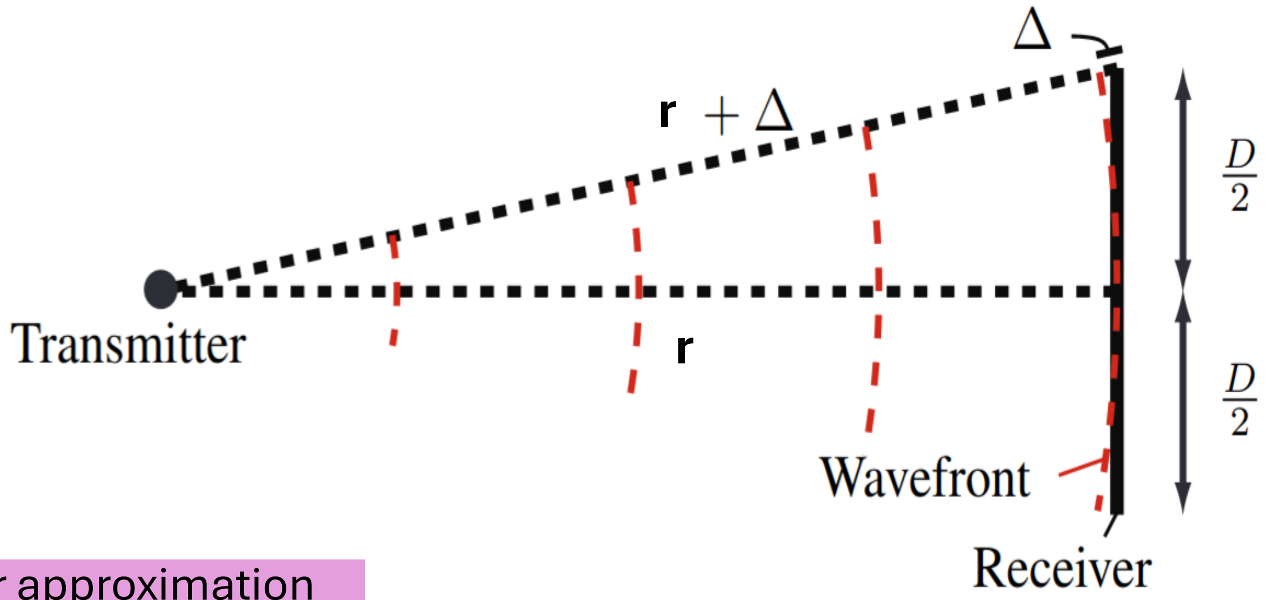
For the enough large **r** (far-field) equal to **0**

But how much large?



Phase Variation in the Nearfield of the Antenna Array

$$\frac{2\pi}{\lambda}\left(\frac{n^2 d^2}{2r}\right)$$



What is the largest phase shift for a given r?

- Taylor approximation

$$\Delta = \sqrt{r^2 + \frac{D^2}{4}} - r = r\sqrt{1 + \frac{D^2}{4r^2}} - r \approx \frac{D^2}{8r}$$

$$\boxed{\frac{2\pi}{\lambda}\frac{D^2}{8r} = \frac{\pi}{8}}$$

$$\boxed{\cos\left(\frac{\pi}{8}\right) \approx .92 \approx 1}$$

$$d_F = \frac{2D^2}{\lambda}$$

Fraunhofer array distance

Björnson E, Demir ÖT, Sanguinetti L. A primer on near-field beamforming for arrays and reconfigurable intelligent surfaces. In2021 55th Asilomar Conference on Signals, Systems, and Computers 2021 Oct 31 (pp. 105-112). IEEE.

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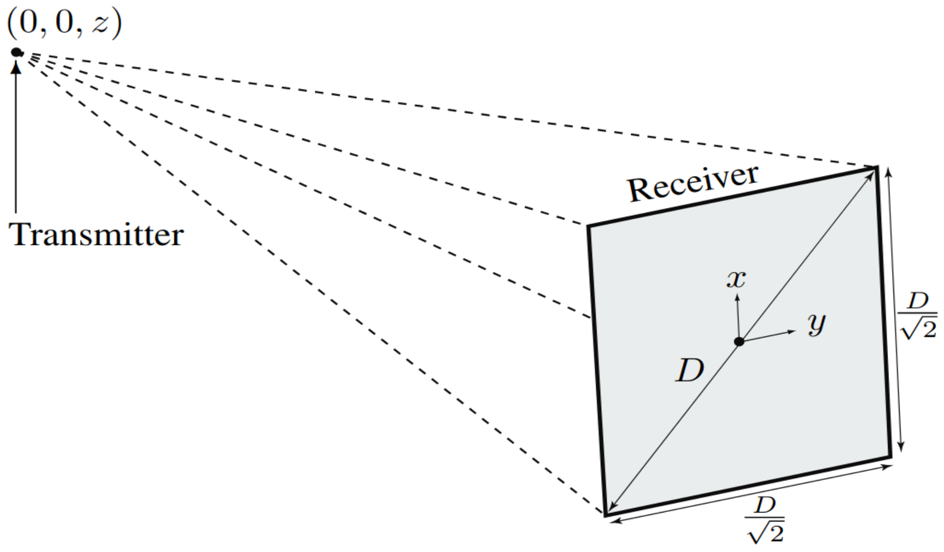


Planar wavefront

phase variation depends on **the incident angle.**

→ **Far-field**

Curved wavefront

phase variation depends on **the incident angle and distance.**

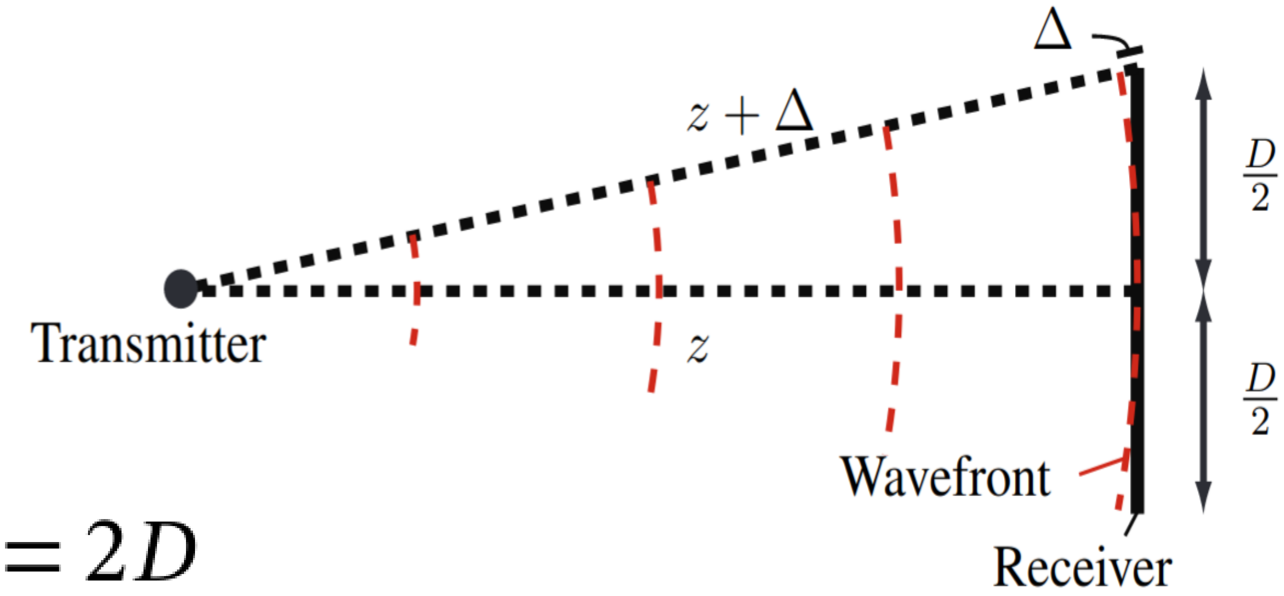
→ **Nearfield**

Power Variation in Nearfield of the Antenna Array

- The spherical curvature also gives rise to power variations over the receive antenna.

The power differences

$$\frac{r^2}{(r+\Delta)^2} \approx \frac{r^2}{\left(r+\frac{D^2}{8r}\right)^2}$$



Bjönson distance

$$r = d_B = 2D$$

$$d_F = d_B \frac{D}{\lambda}$$

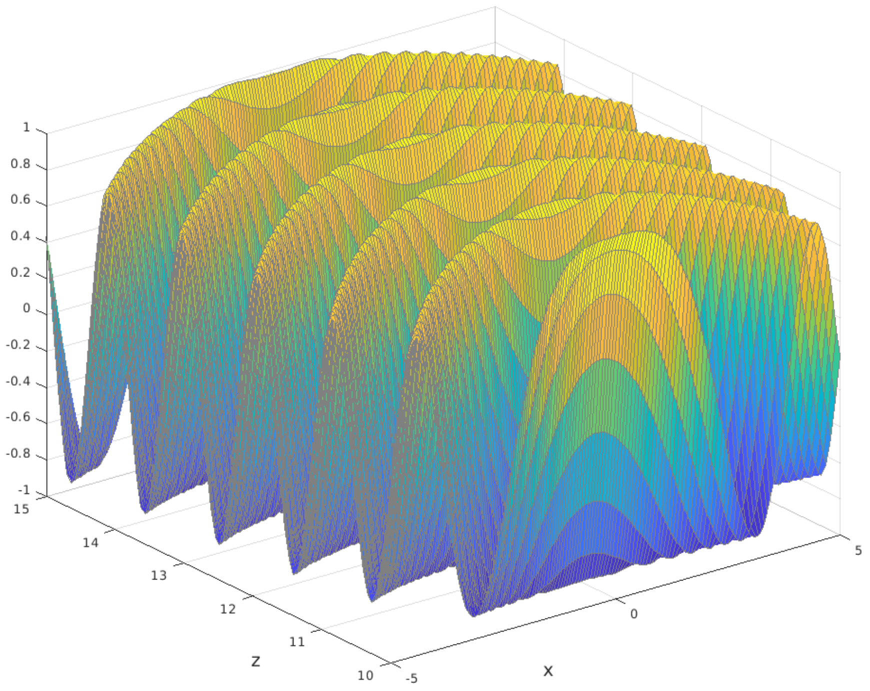
Phase variations are more prevalent

Björnson E, Demir ÖT, Sanguinetti L. A primer on near-field beamforming for arrays and reconfigurable intelligent surfaces. In2021 55th Asilomar Conference on Signals, Systems, and Computers 2021 Oct 31 (pp. 105-112). IEEE.

Nearfield of the Antenna Array

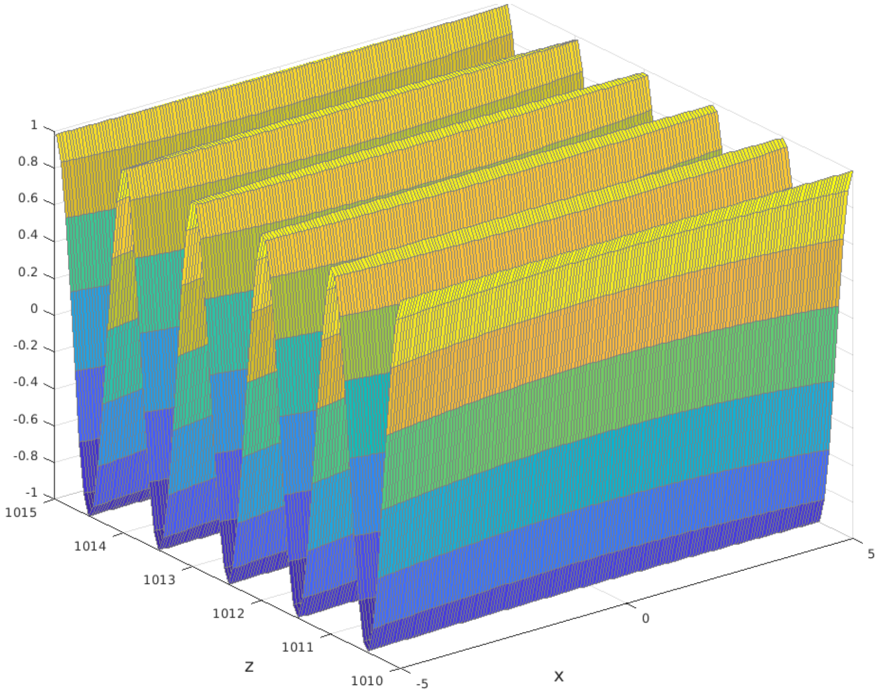
- Fresnel region and is characterized by the fact that the amplitude variations can be neglected, but not the phase variations.

$$\boxed{d_B < r < d_F}$$



Example : Fraunhofer distance

0.5×0.5, 3 GHz = 10 m
1×1 m, 15 GHz = 200m
1×1 m, 30 GHz = 400 m



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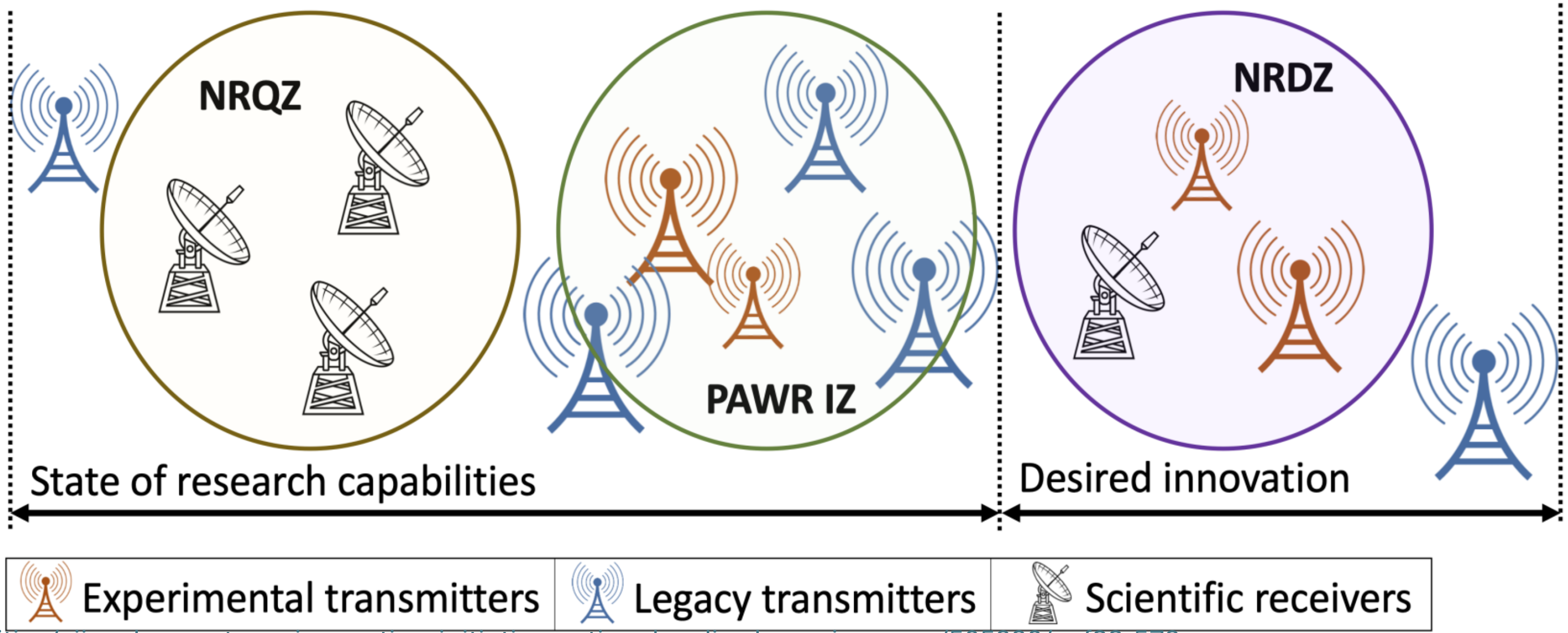
National Radio Dynamic Zones (SII-NRDZ)

- **What is the Dynamic Zone?**
  - Allows radio waves to transmit freely.
  - Advanced technologies for **spectrum sharing** and coexistence.
- **Why It Matters**
  - Spectrum is a limited resource.
  - Traditional methods are insufficient.



https://www.cs.albany.edu/nrdz-ra/

https://new.nsf.gov/funding/opportunities/sii-nrdz-spectrum-innovation-initiative-national-radio-dynamic-zones/505990/nsf22-579

How to detect aliens' signals?

NASA's **Project Cyclops** in 1971

Detect signals traveling up to **1000** light-years

Absorbtion
Noise
Distinguishable from natural sources

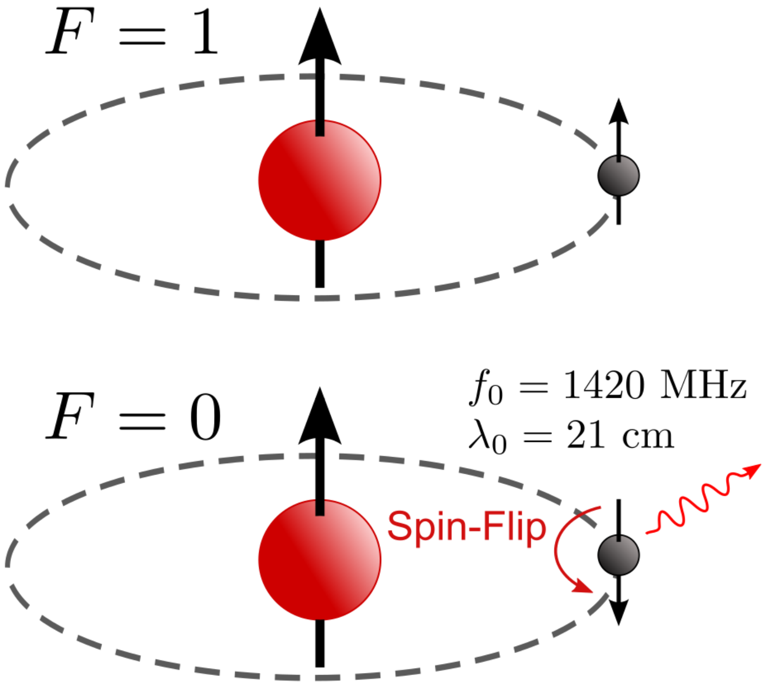
Microwaves
1 mm – 1 m

https://en.wikipedia.org/wiki/Water_hole_(radio)
https://en.wikipedia.org/wiki/Project_Cyclops

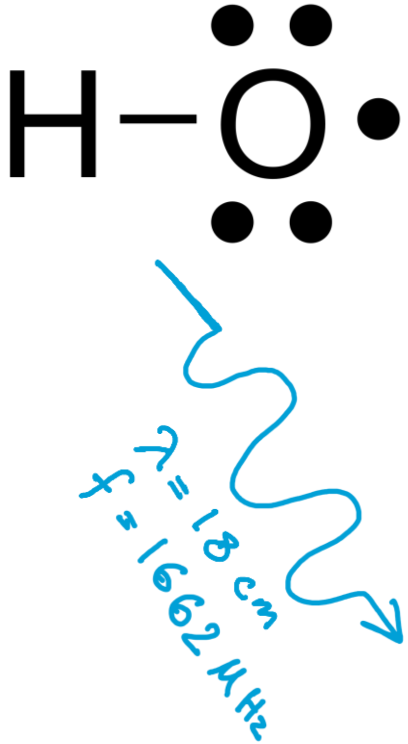
Waterhole

There is a magical narrow gate in Microwaves

https://en.wikipedia.org/wiki/Hydrogen_line



https://en.wikipedia.org/wiki/Hydroxyl_radical

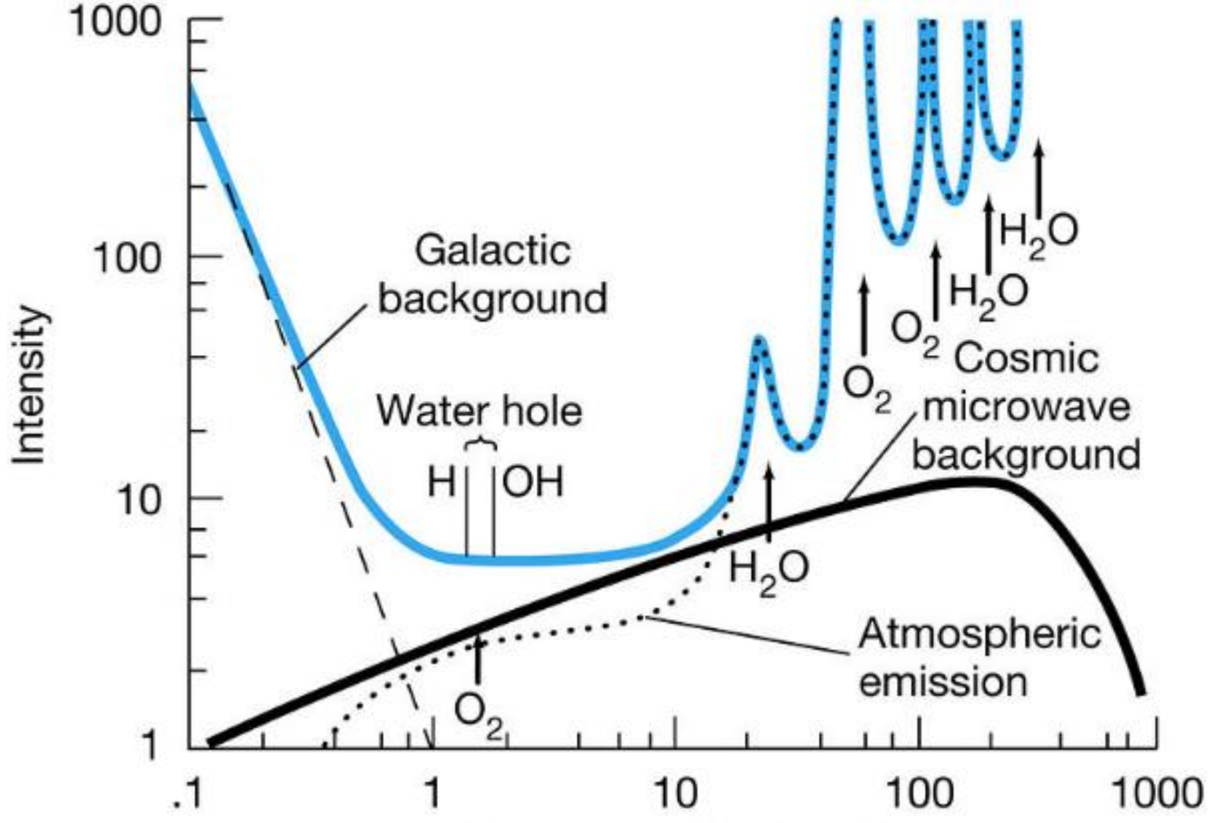


Water hole
18cm-21cm

The 242 MHz area, between the hydrogen line (1420 MHz) and the hydroxyl lines (1662MHz), are the quietest part of the spectrum

https://en.wikipedia.org/wiki/Water_hole_(radio)
https://en.wikipedia.org/wiki/Project_Cyclops

Waterhole



Waterhole 18cm-21cm

1420-1662 MHz

Oliver:
“What more **poetic** place could there be for **water-based life** to seek its kind than the age-old meeting place for all species: the water hole”

https://www.seti.net/indepth/waterhole/waterhole.php