Unintended EM radiation of large satellite constellations

Federico Di Vruno (SKAO, ESF-CRAF)

Benjamin Winkel (MPIfR, ESF-CRAF)

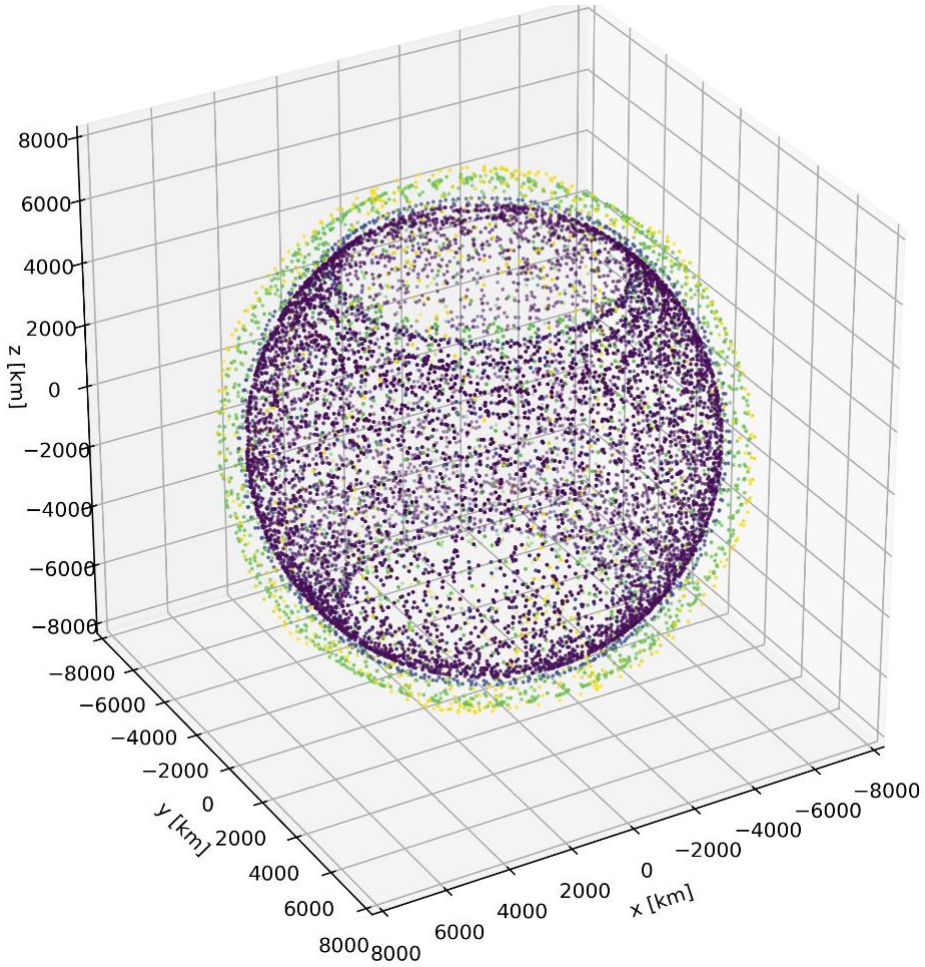
Cees Bassa (ASTRON)

Michiel Brentjens (ASTRON)

Gyula I. G. Józsa (MPIfR, ESF-CRAF)

Axel Jessner (MPIfR)

Simon Garrington (JBO, Uni Manchester)



Max-Planck-Institut für Radioastronomie

SKAO

MANCHESTER 1824 The University of Manchester

CRAF

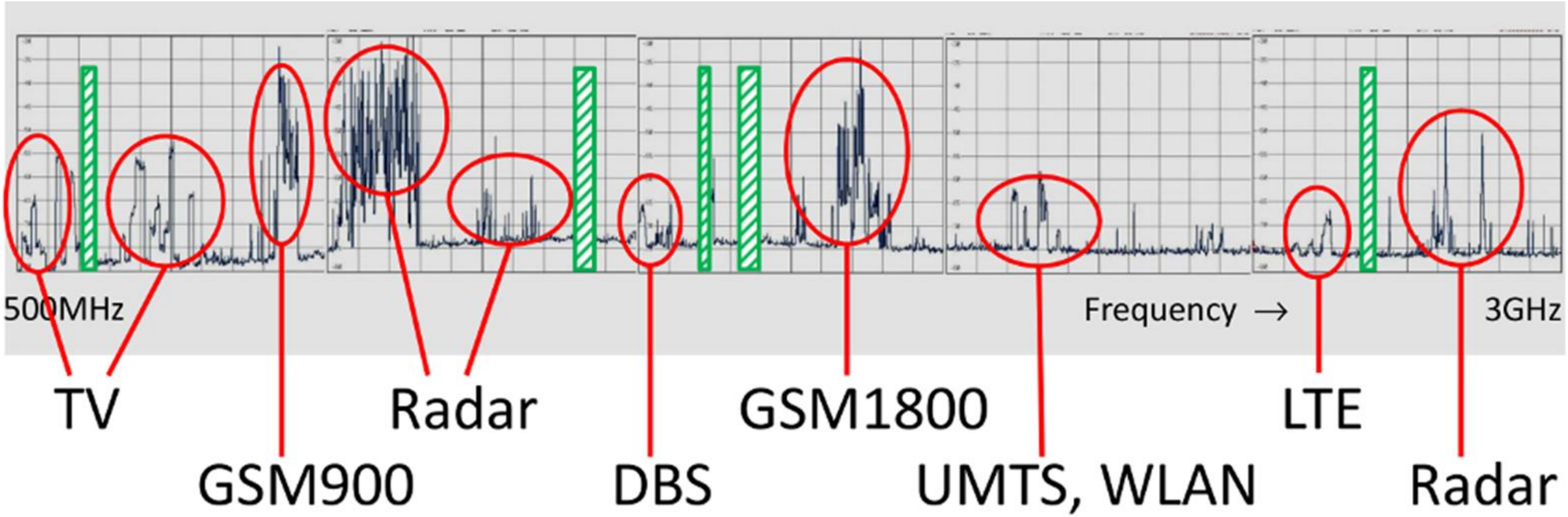
ASTRON

Overview

- Introduction
  - Intended vs. unintended radiation
  - Existing spectrum regulation and standards
  - What about satellites?
- Satellite constellation simulations
  - Ephemerides
  - Compatibility calculations (vs. radio astronomy)
  - Results and analyses
- Conclusions

Intro: Intended vs. unintended radiation

Image: R. Keller et al., MPIfR



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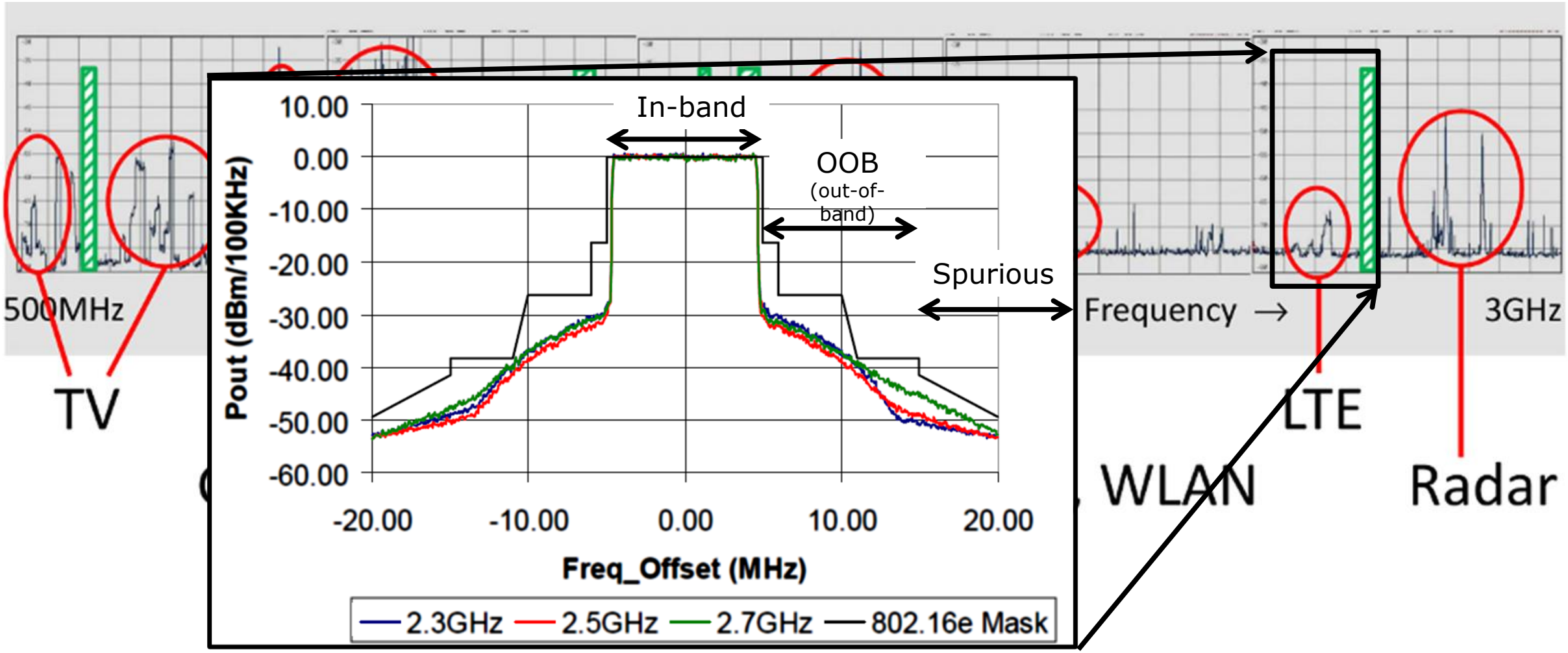

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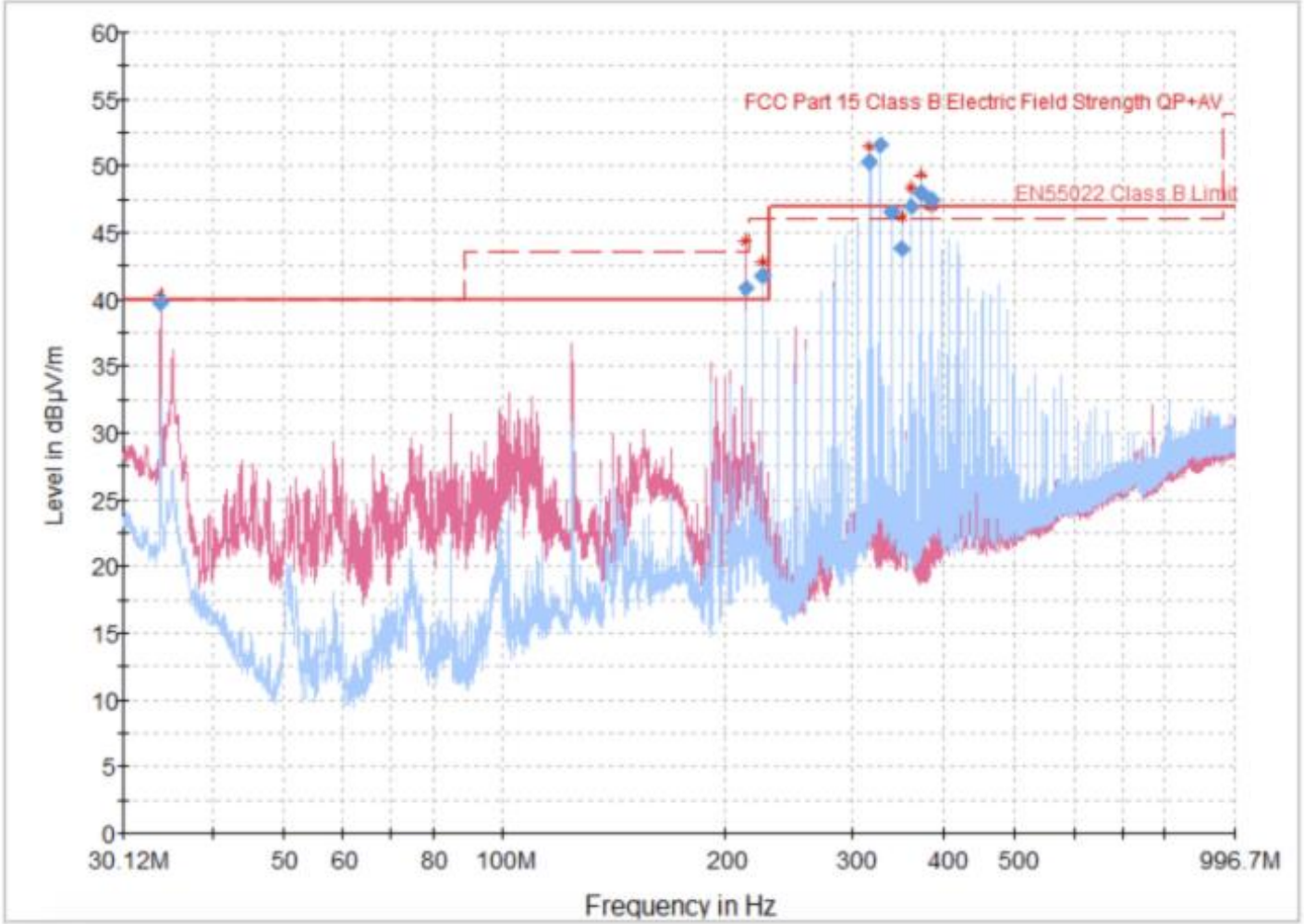


Generic example of a radiated emissions test
https://cushychicken.github.io/radiated-emissions-debug/

Possible sources

- Consumer electronics (High clock rates + PCB acting as antenna…)
- High-power electrics (transmission lines)
- Electrostatic discharge (electric fences)
- Unterminated circuits

Intro: Intended vs. unintended radiation

Intended radiation

- Up to few 100 GHz
- Attached to a radio communication service; regulated by ITU-R
- Transmission via an antenna
- Wanted vs. unwanted emissions (In-band, Out-of-band, Spurious)

Unintended radiation

- Mainly below 1 GHz
- “Power leakage” (not via an antenna)
- IEC/EMC standards, e.g. CISPR, MIL-STD
- Can be narrow- or broadband, continuous or pulse-like

Intro: What about satellites?

Intended radiation

- Subject to ITU-R regulation
  - Fixed-satellite service (FSS)
  - Inter-satellite service (ISS)
  - Space operation service (SOS)
  - Mobile-satellite service (MSS)
  - Radiodetermination sat service (RDSS)
  - Radionavigation sat service (RNSS)
  - Earth exploration sat service (EESS)
- Protection of radio astronomy bands

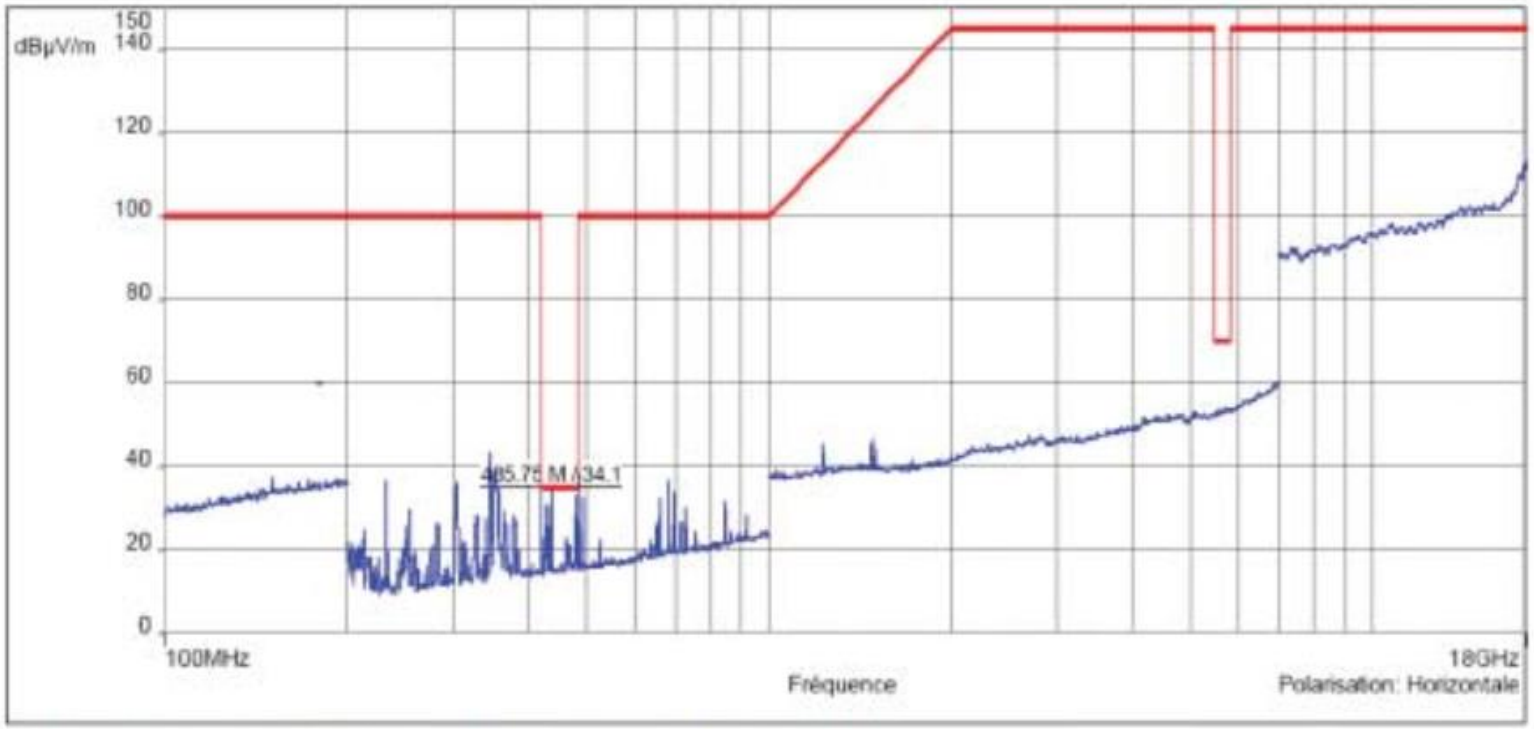
Unintended radiation

- Standards apply to component level, e.g., MIL-STD, ECSS, NASA; often tailored to a specific mission
- Radiated power tests are limited to self- and launcher compatibility
- Measurements rarely made public
- For existing satellites, no problem reported so far (for radio astronomy)

Intro: What about satellites?

Unintended radiation

- Varies with frequency
- Can be much lower than standard
- But also very close to standard



Source: G. Yavaş and S. Akgül, "GÖKTÜRK-1 Satellite System Level Radiated Emission and Radiated Susceptibility Tests"

Intro: What about satellites?

Unintended radiation

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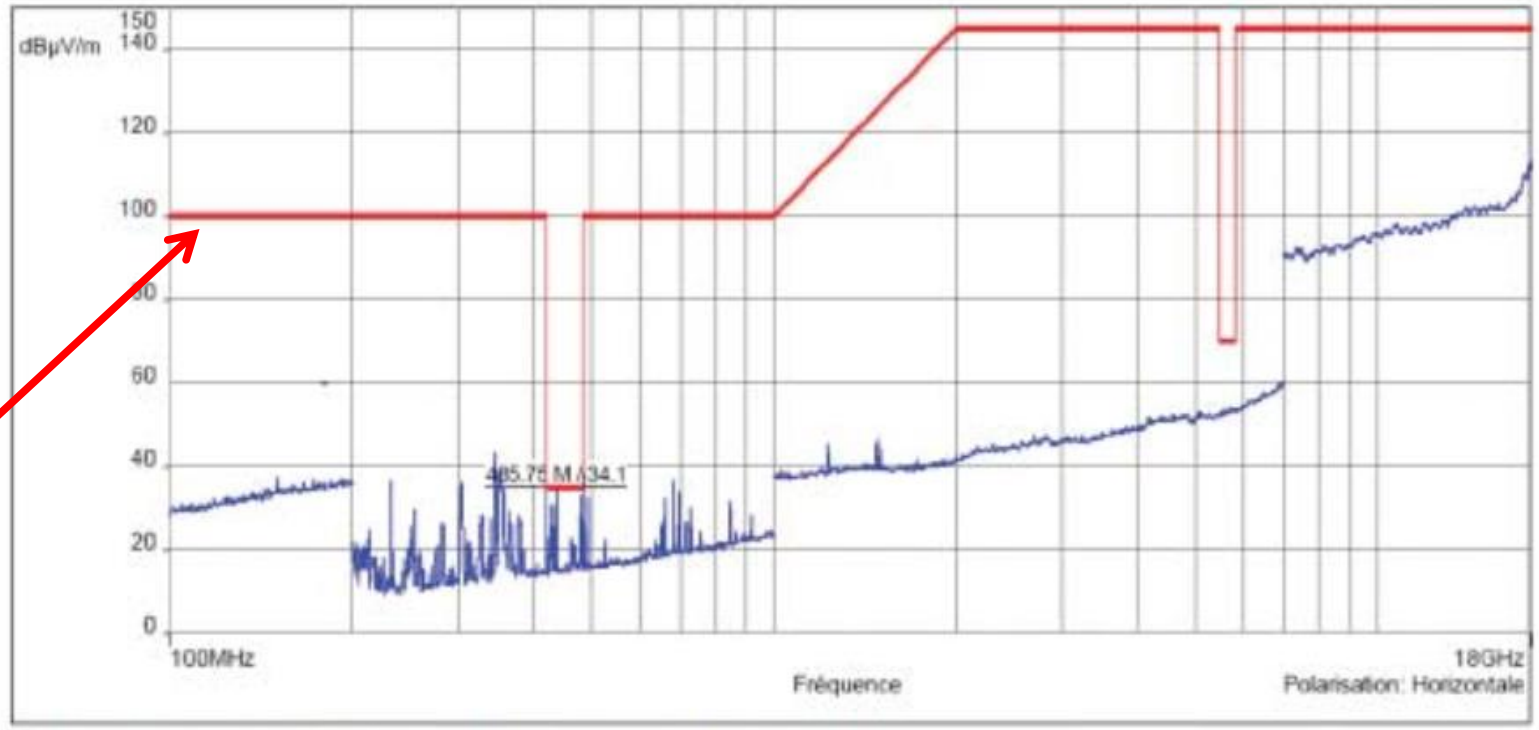
Much less stringent than consumer electronics! (30 dB[μV/m], CISPR-32)



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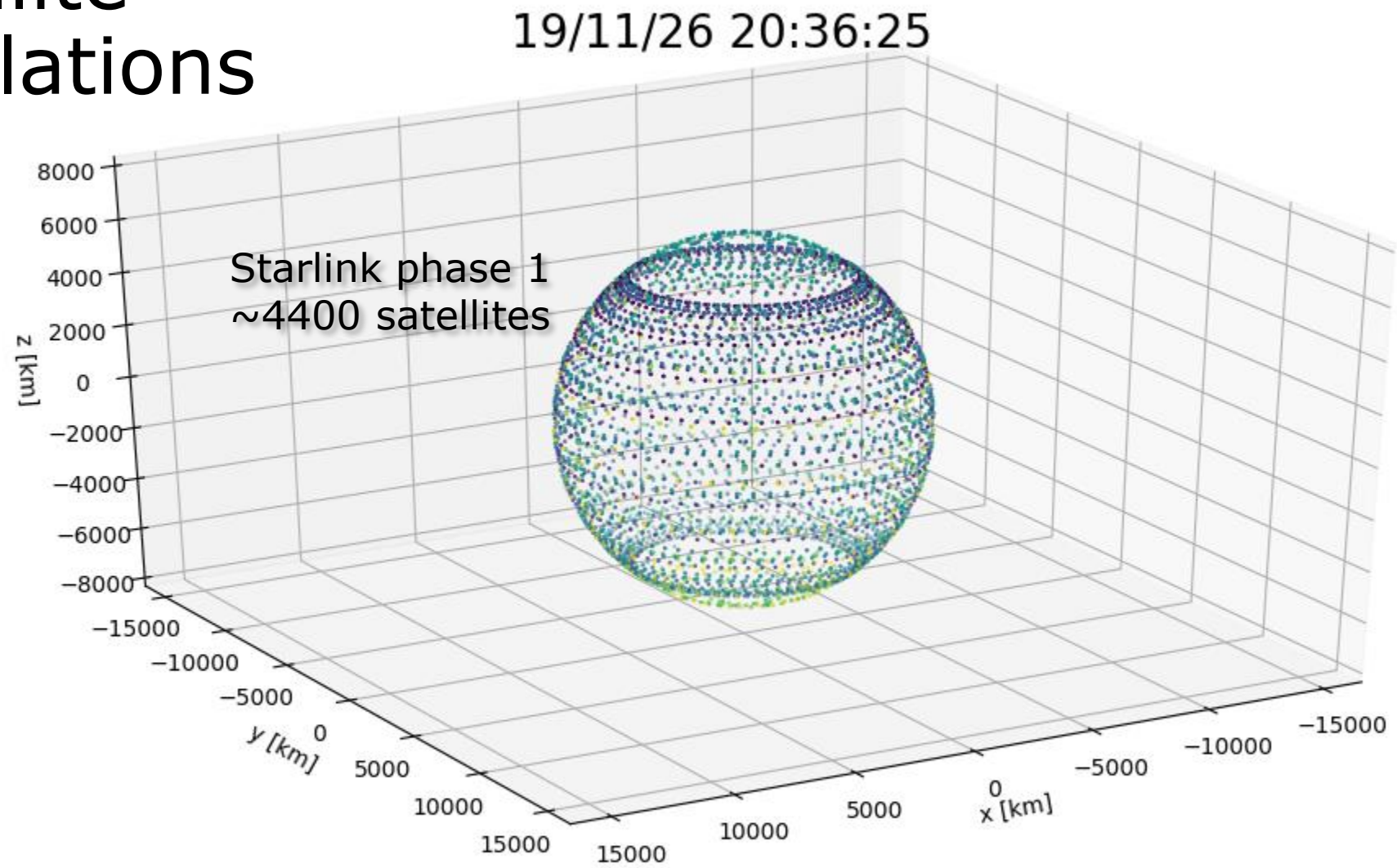
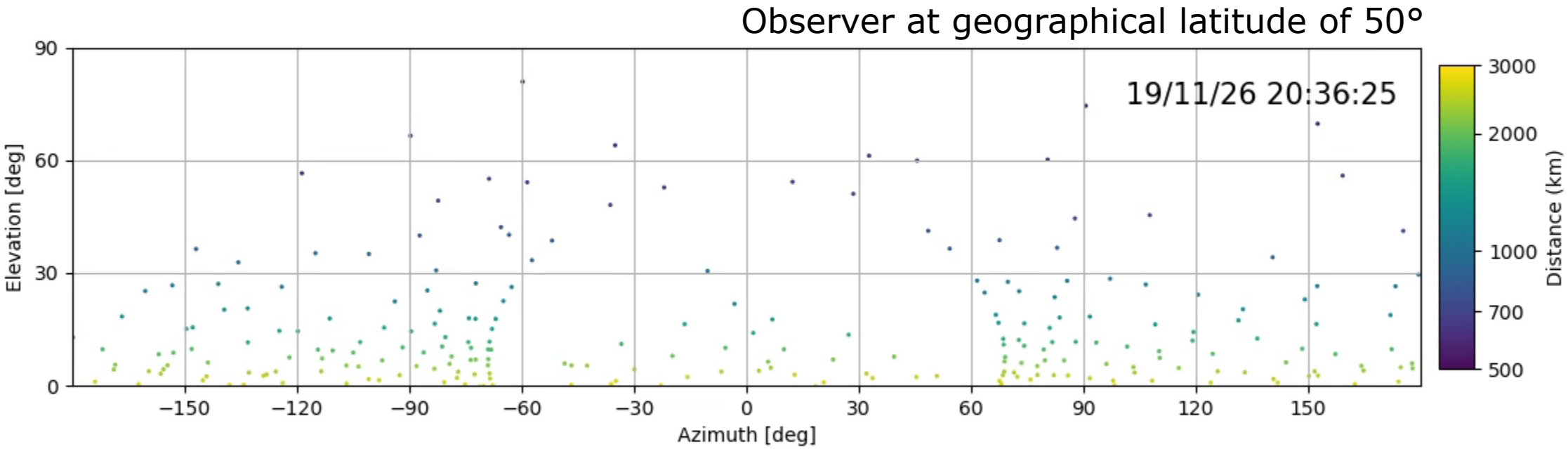
Satellite simulations



Orbit calculations powered by cysgp4: https://github.com/bwinkel/cysgp4

Satellite simulations



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Intermezzo: Emission of a satellite?

Unintended radiation

- For simplicity: assume CISPR standards for consumer electronics
  - 30 dB[μV/m] (measured at 10-m, 120 kHz detector)
  - = −46 dB[mW/MHz] (transmitted spectral power)
  - ≈ 600 mJy (at 600 km distance)
- Assume isotropical emission
- What happens to a radio astronomy receiver?
  - Example RAS band: 151±1.5 MHz
    (assume full RAS band is affected)
  - Antenna size: 25-m
  - Limit on received power: P_{rx} = −199 dB[W] after 2000 s

Intermezzo: RAS threshold levels

Recommendation
ITU-R RA.769

TABLE 1

Threshold levels of interference detrimental to radio astronomy continuum observations

Centre frequency (1) f_c (MHz)	Assumed bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity (2) (noise fluctuations)		Threshold interference levels (2) (3)		
				Temperature ΔT (mK)	Power spectral density ΔP (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13.385	0.05	50 000	60	5 000	–222	–185	–201	–248
25.610	0.12	15 000	60	972	–229	–188	–199	–249
73.8	1.6	750	60	14.3	–247	–195	–196	–258
151.525	2.95	150	60	2.73	–254	–199	–194	–259
325.3	6.6	40	60	0.87	–259	–201	–189	–258
408.05	3.9	25	60	0.96	–259	–203	–189	–255
611	6.0	20	60	0.73	–260	–202	–185	–253
1 413.5	27	12	10	0.095	–269	–205	–180	–255

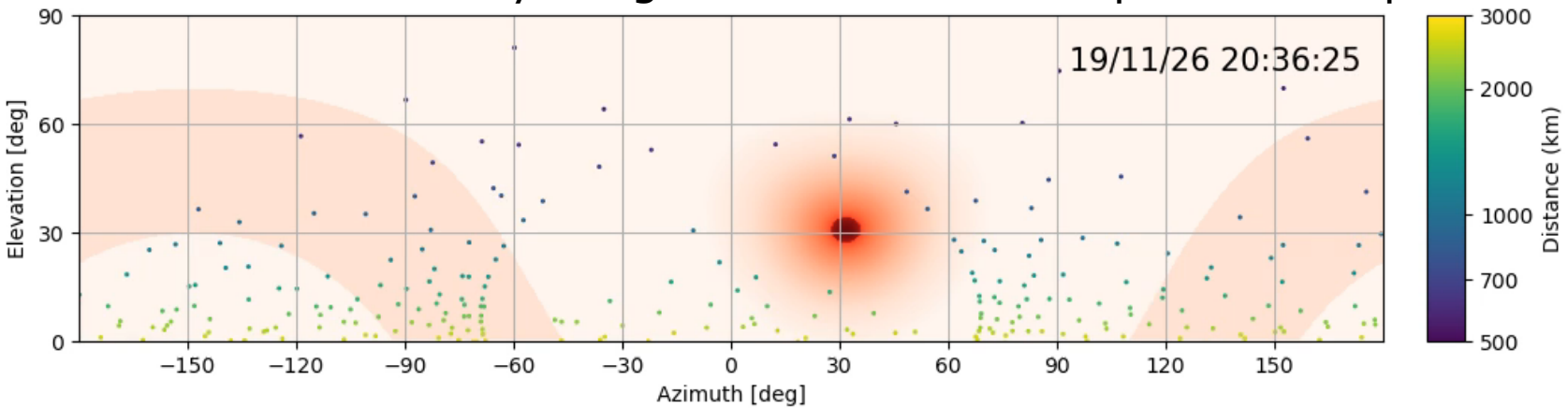
= P_{rx} threshold

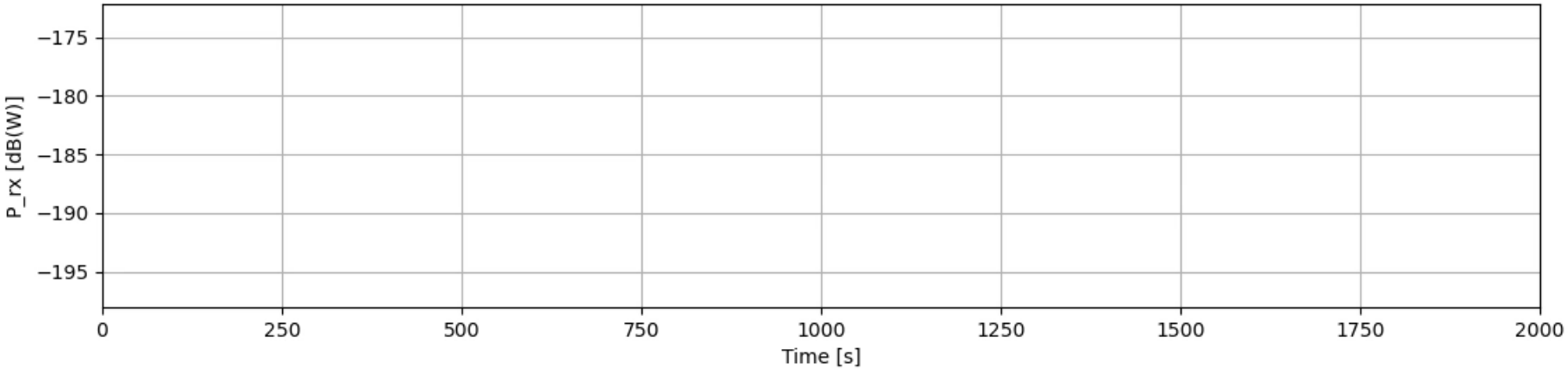
RAS thresholds

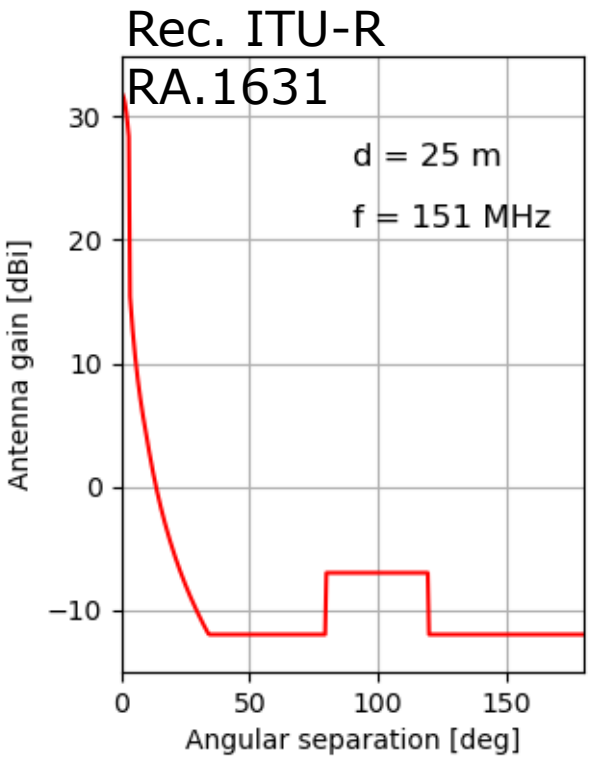
- 10% of radiometric noise (rms) after a given integration time
- Usually: 2000 s integration time

Satellite simulations: received power

Convolution of sky "brightness" with telescope antenna pattern

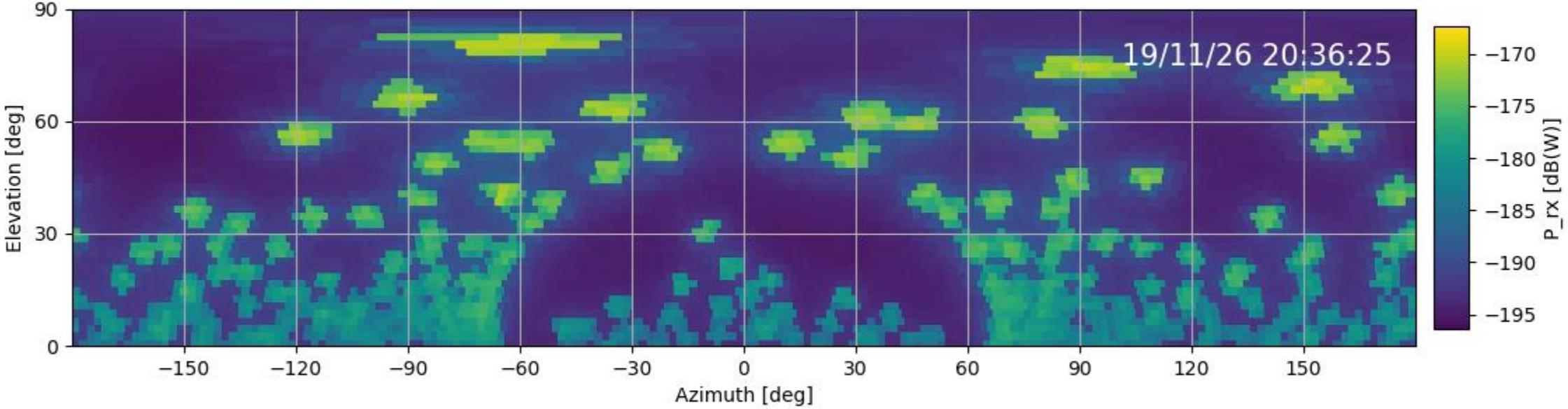






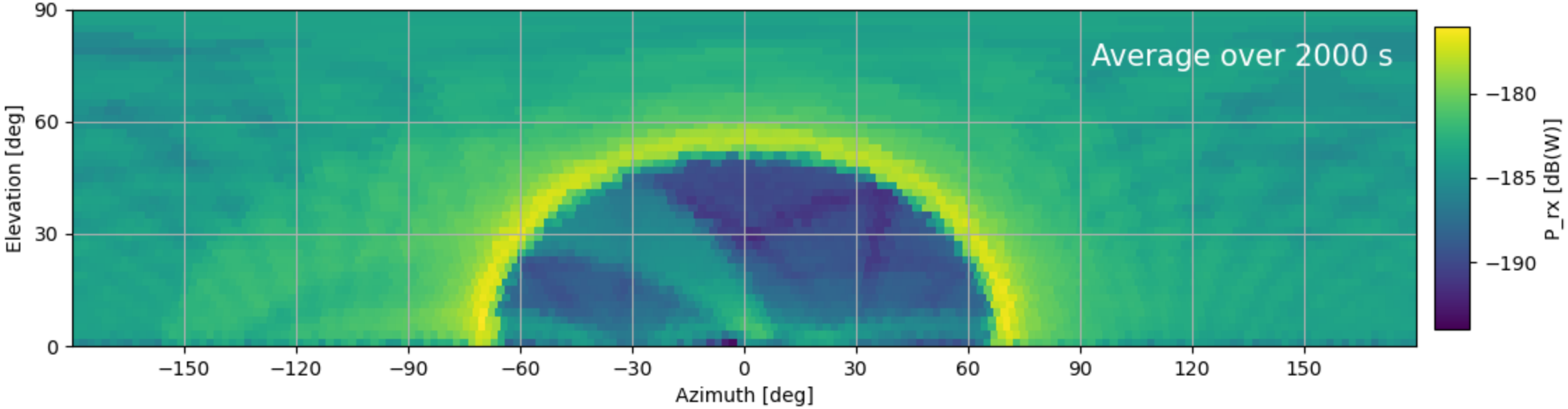
Satellite simulations: received power

Repeat for all positions on the sky



Satellite simulations: received power

Average over 2000 s → Compare with threshold level: −199 dB[W]



Satellite simulations: anything else?

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Yes

- RAS has to accept “data loss” of 2% (per system)
  According to Rec. ITU-R RA.1531-2

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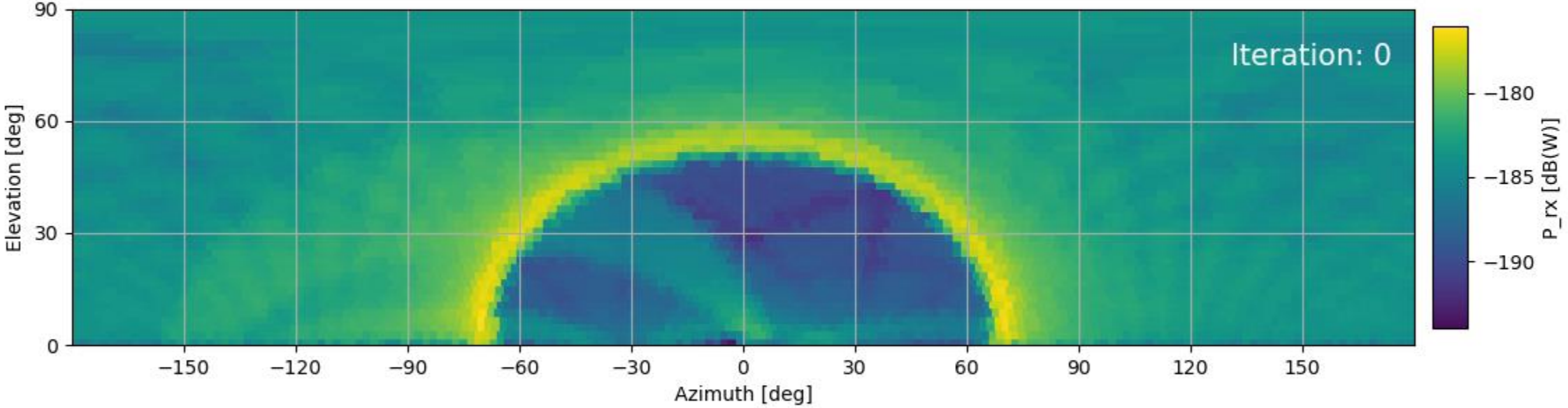
Also:

- Statistical scatter?
- Can we assess other useful parameters (as figures-of-merit)?
  - Actual data loss?
  - Margin with respect to RAS threshold?

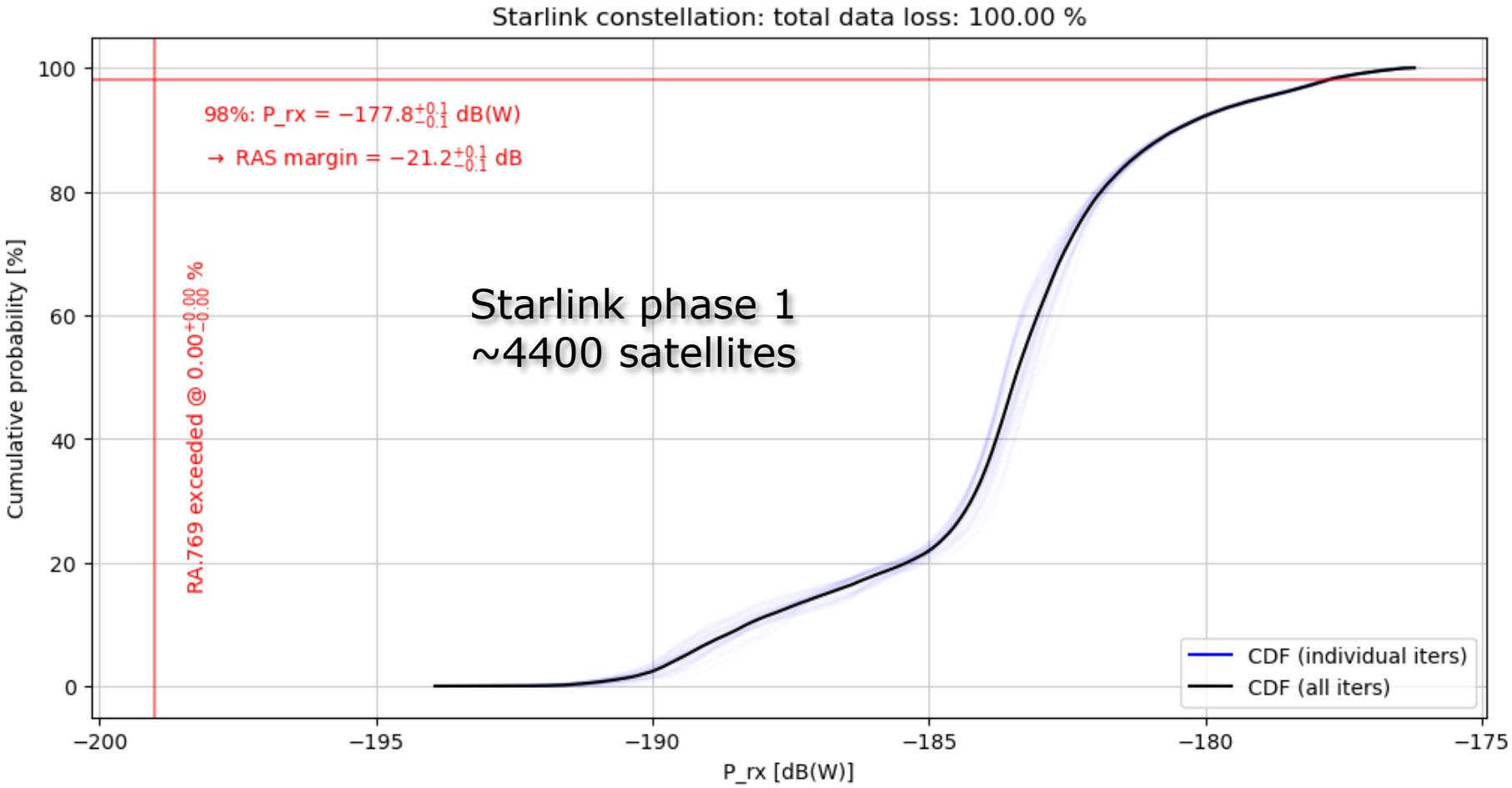
Satellite simulations: statistics

Rinse and repeat: assess statistical scatter etc.



Satellite simulations: statistics

Cumulative distribution: how many samples are below a given P_rx value?



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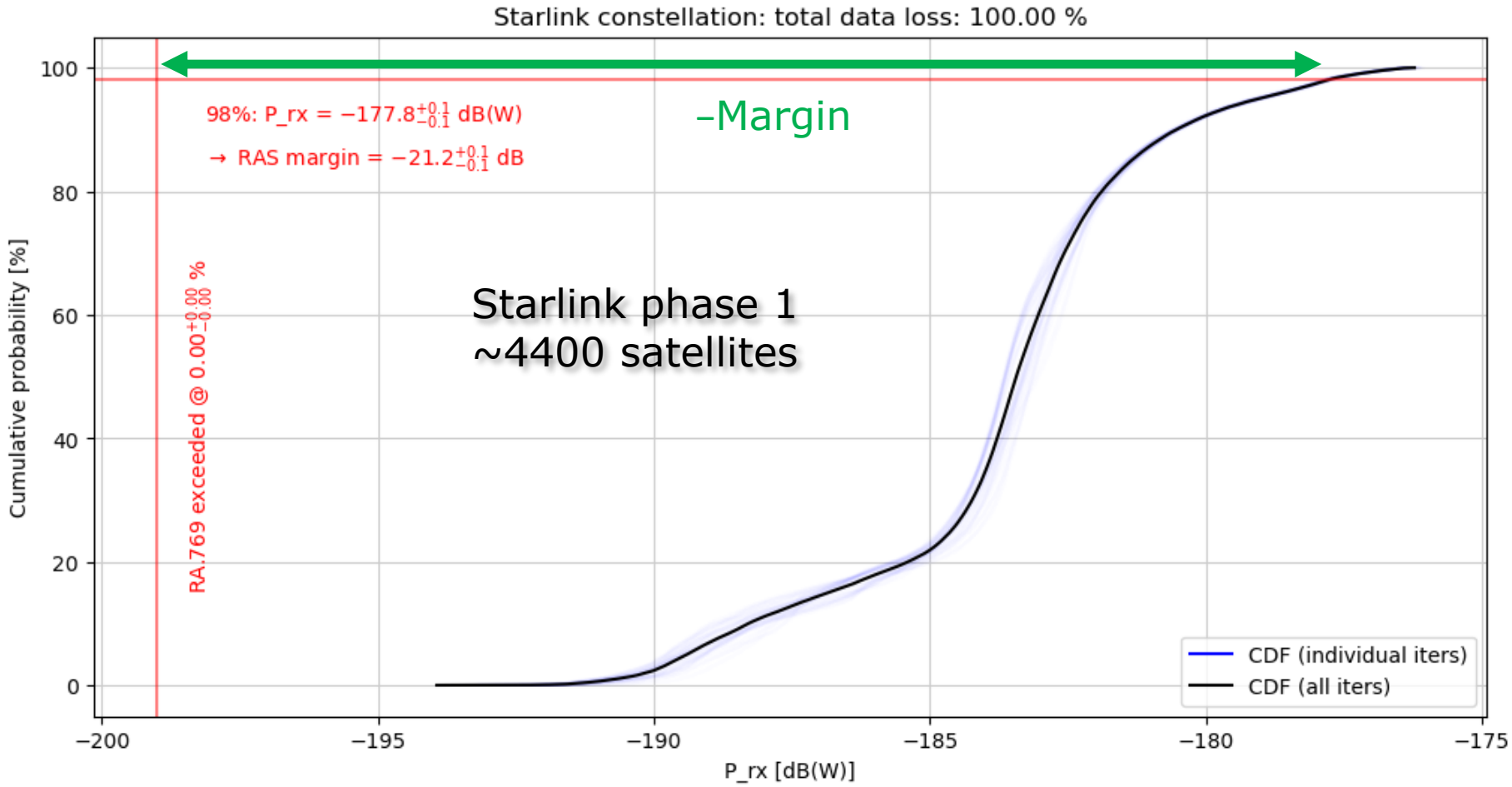

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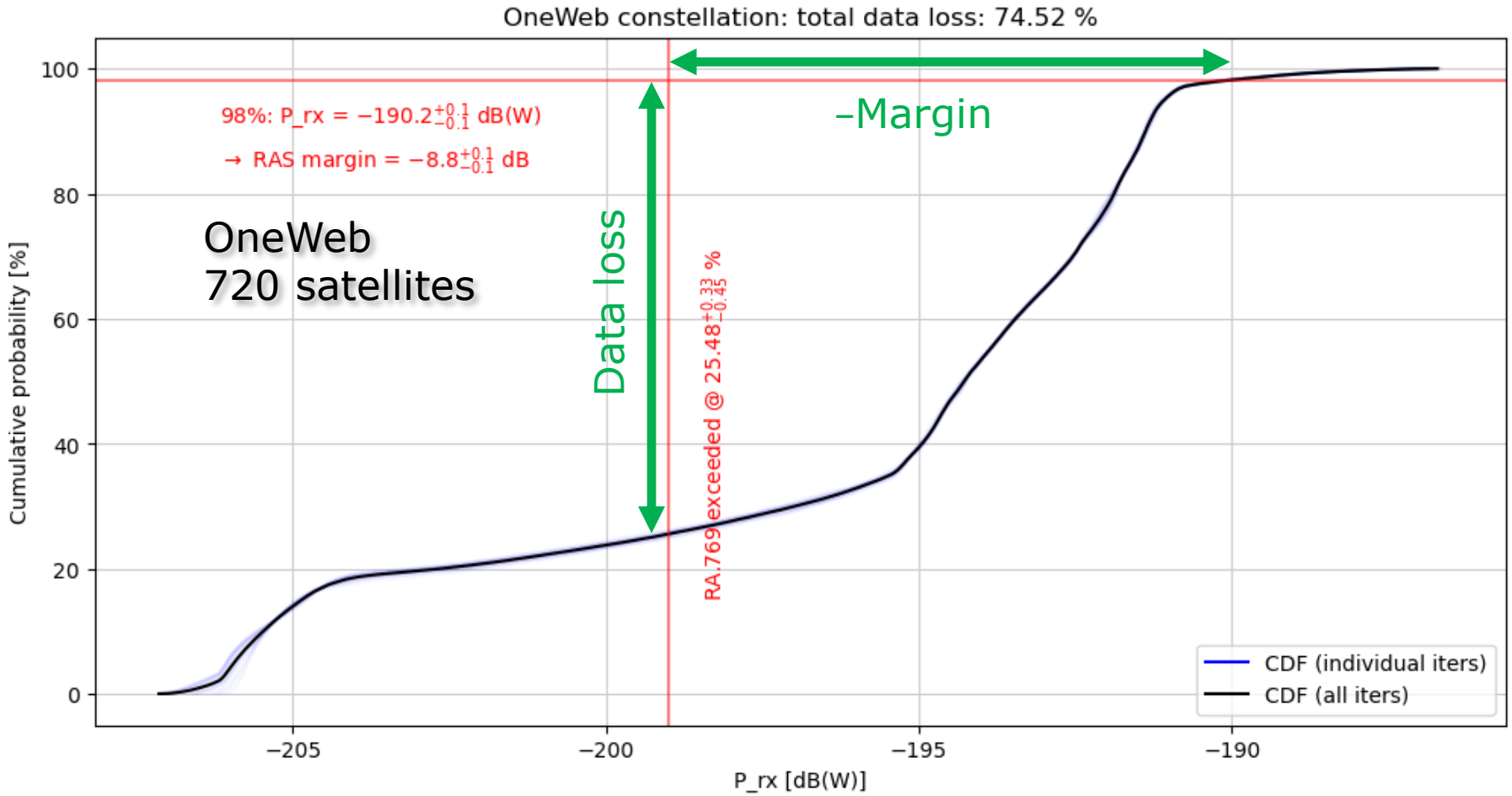
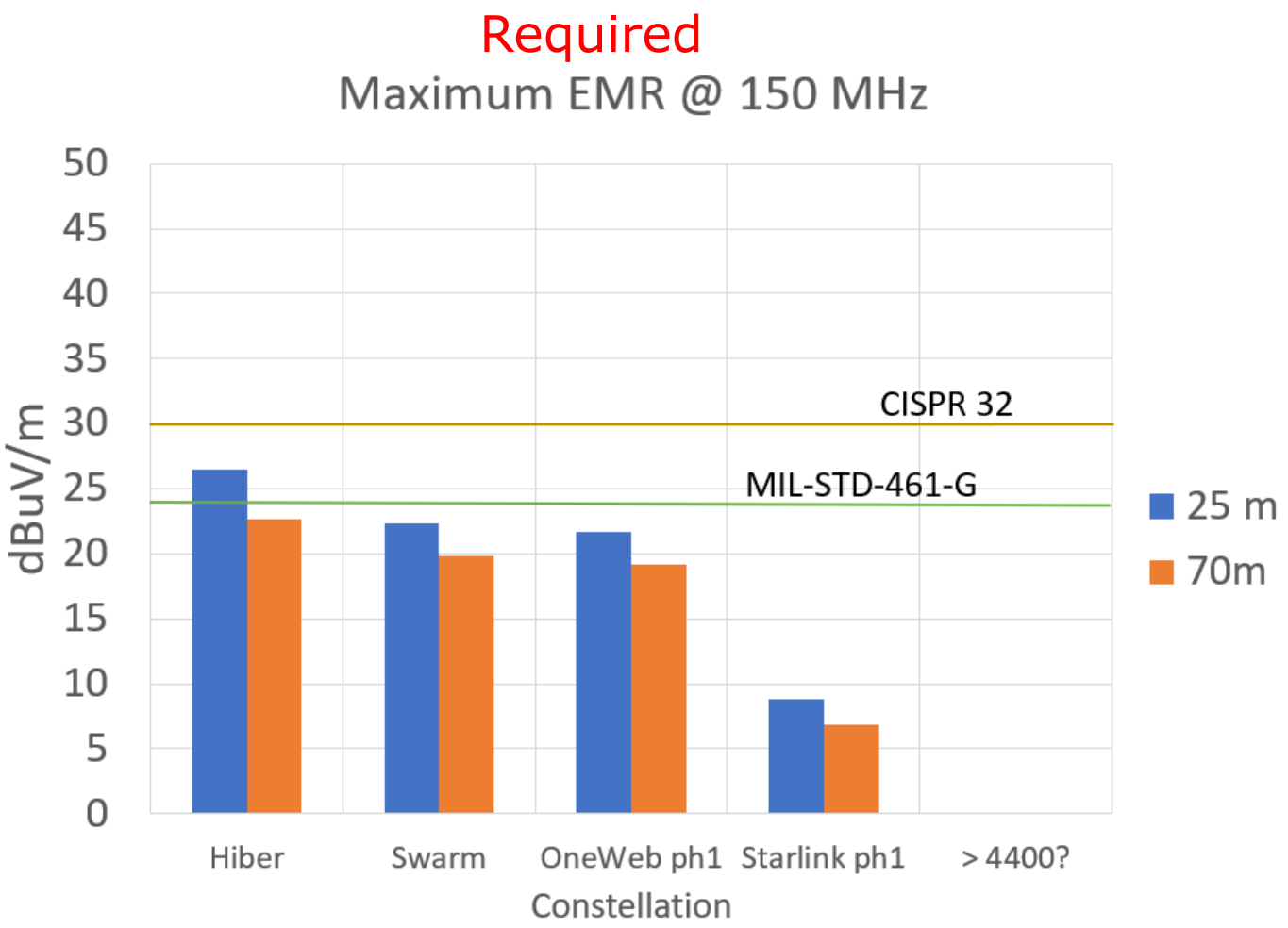


Conclusions

- Unintended radiation from large satellite constellations may cause problems for RAS
- Stricter emission standards necessary
- Lab measurements should be mandatory
- Consider RAS bands (not only for applications/services regulated by ITU-R)



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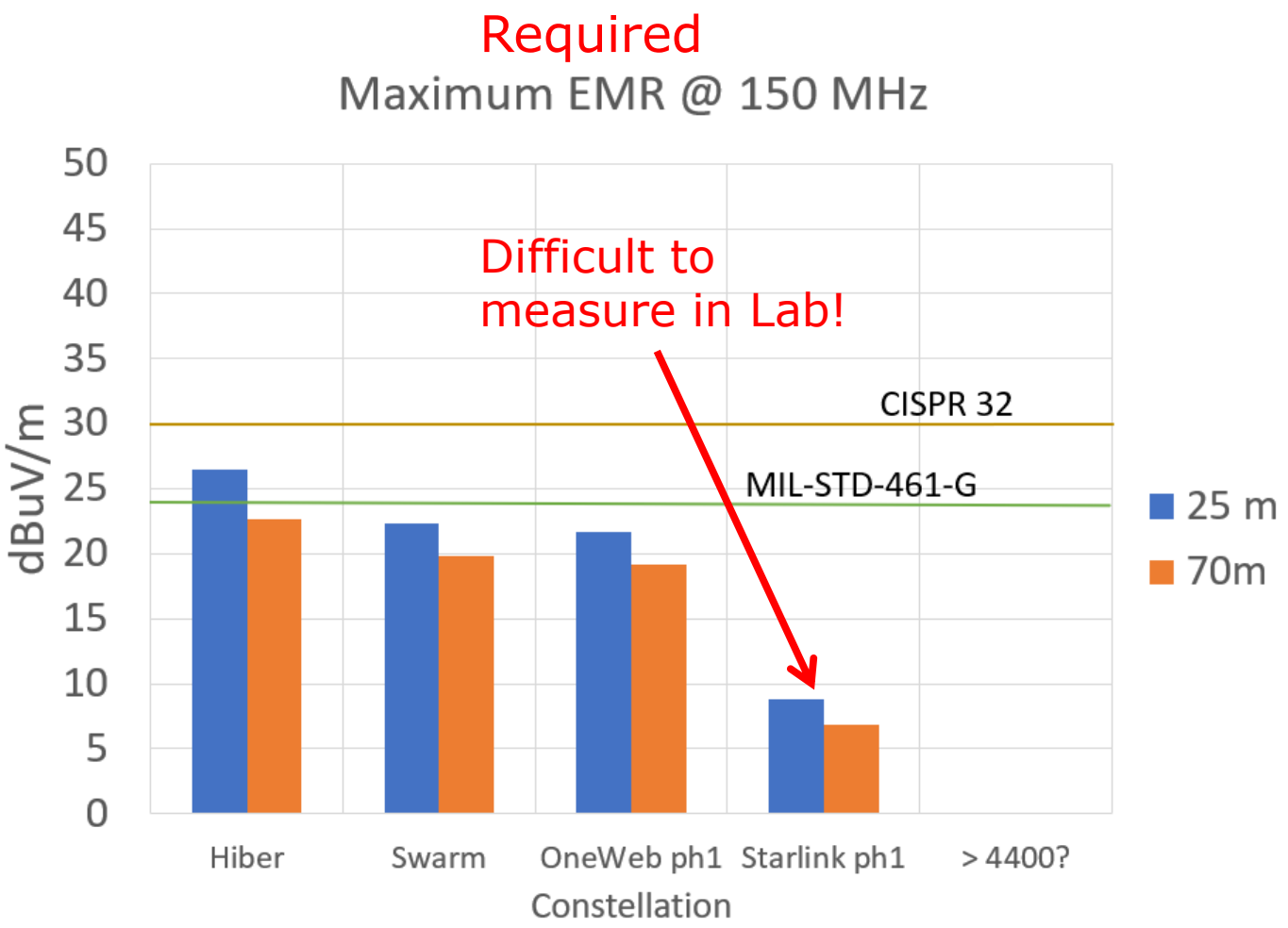

Thank you!