# RFI from the sky

## *Unintended electro-magnetic radiation from satellite constellations*

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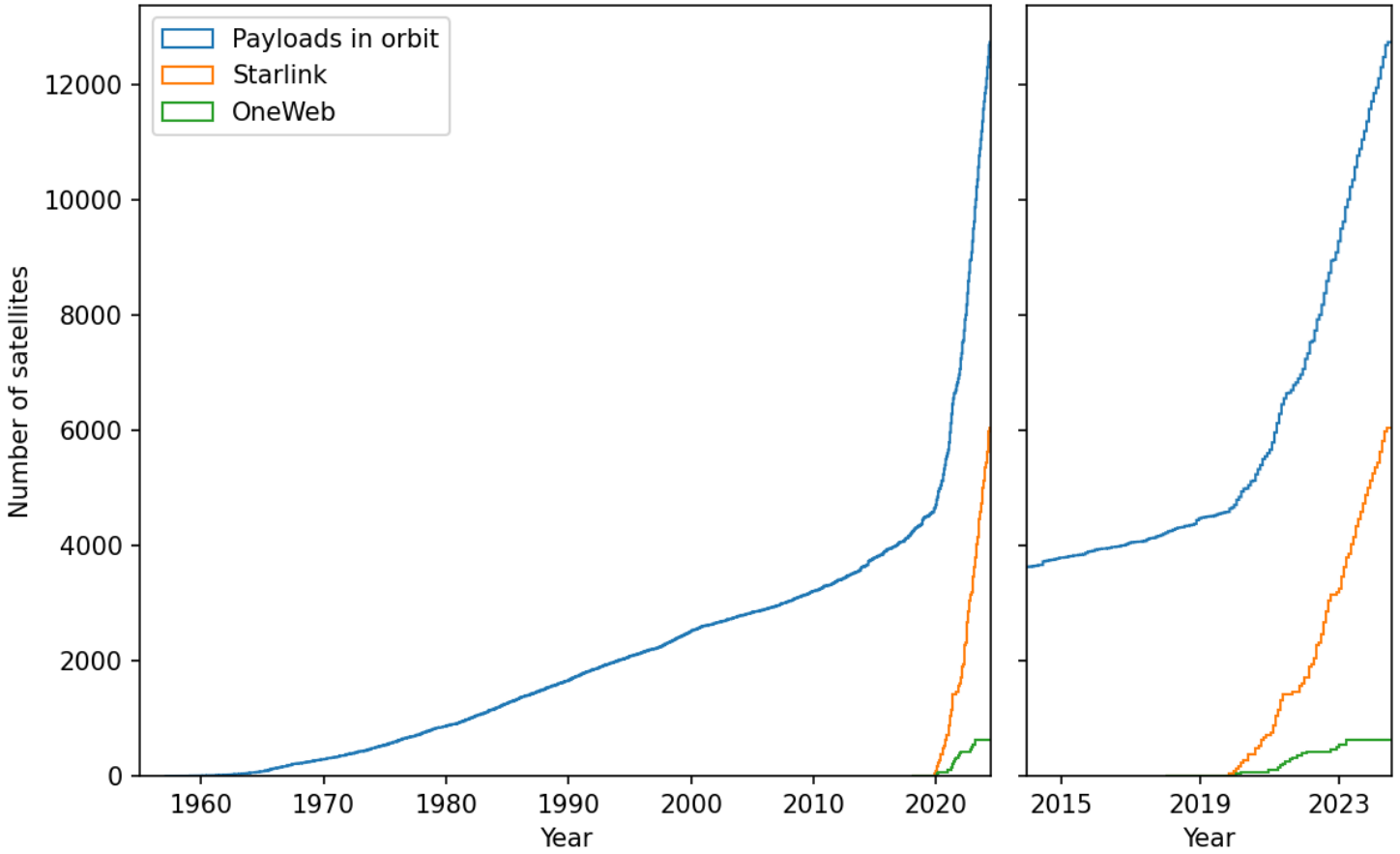
*Di Vruno et al. 2023, A&A 676, A75*

2024 LOFAR Family Meeting

Netherlands Institute for Radio Astronomy

# Commercialization of low Earth orbit




1166 satellites launched since January 1st, 2024!

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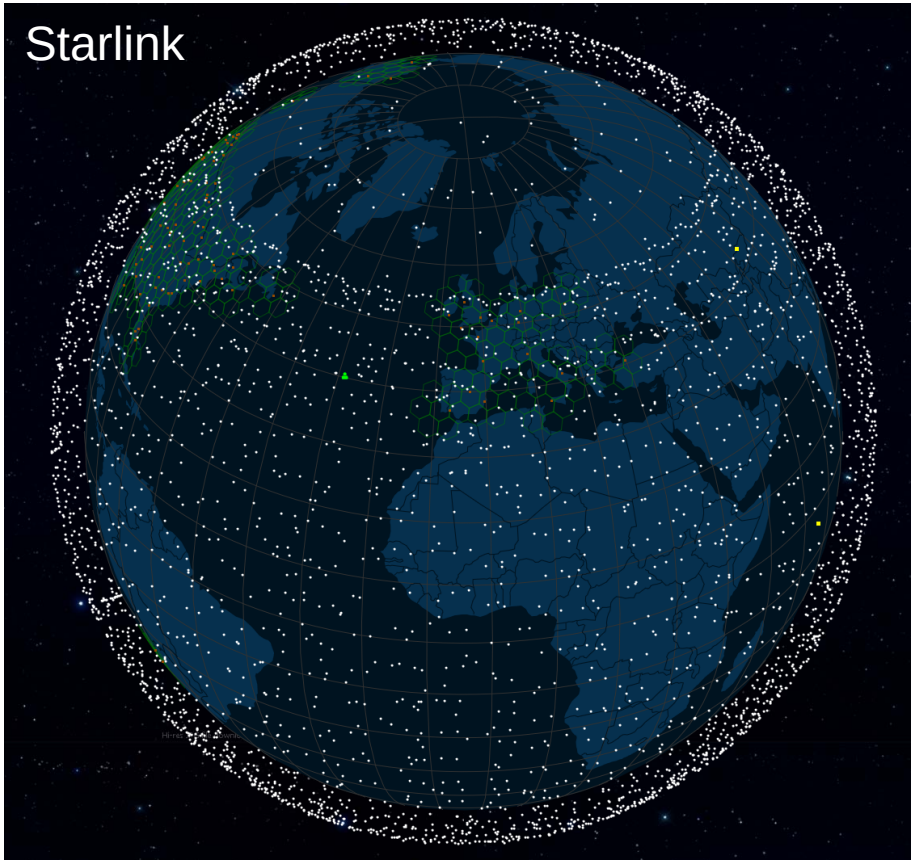
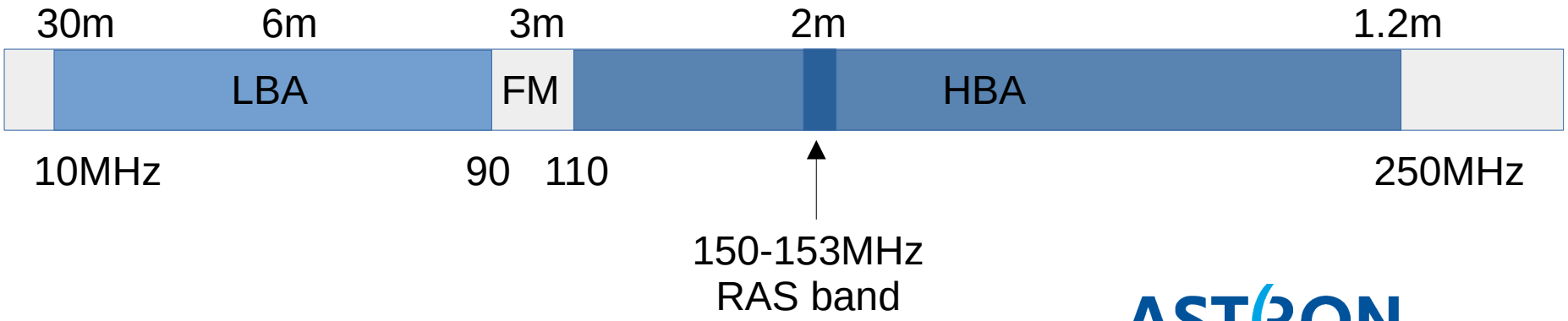
# Broadband internet from space





satellitemap.space

# LOFAR – Low-Frequency Array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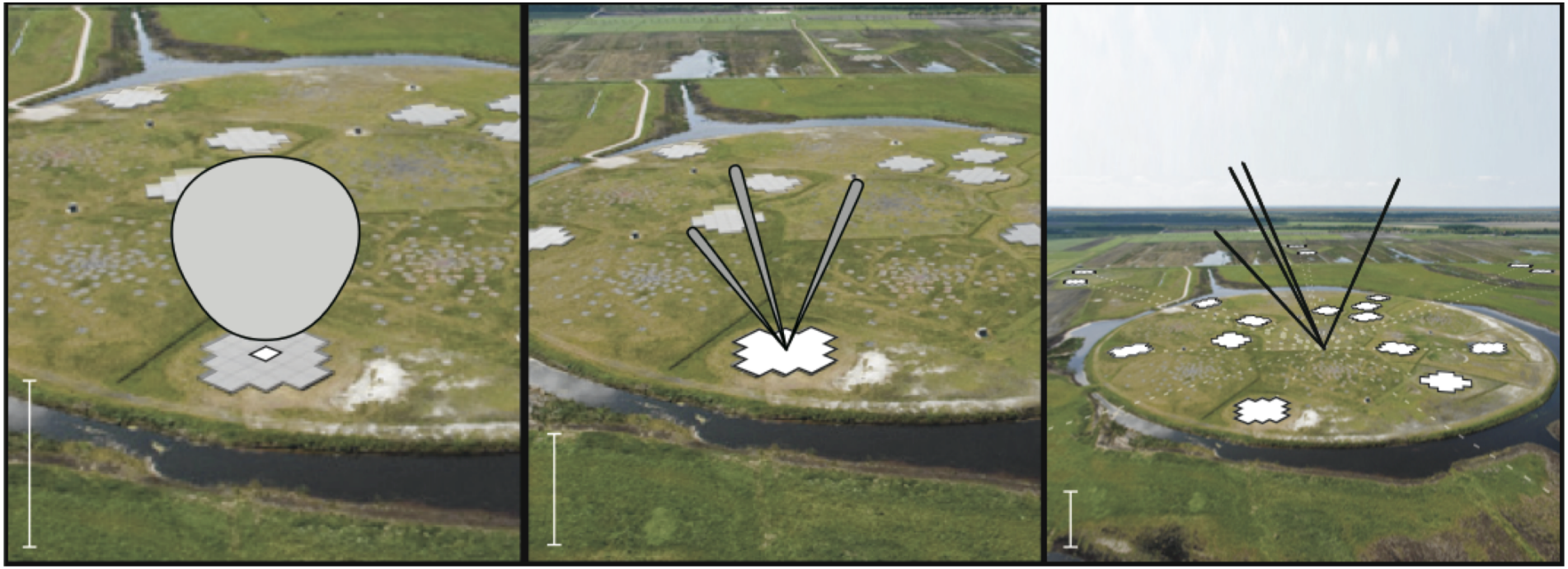
# Beamforming with LOFAR



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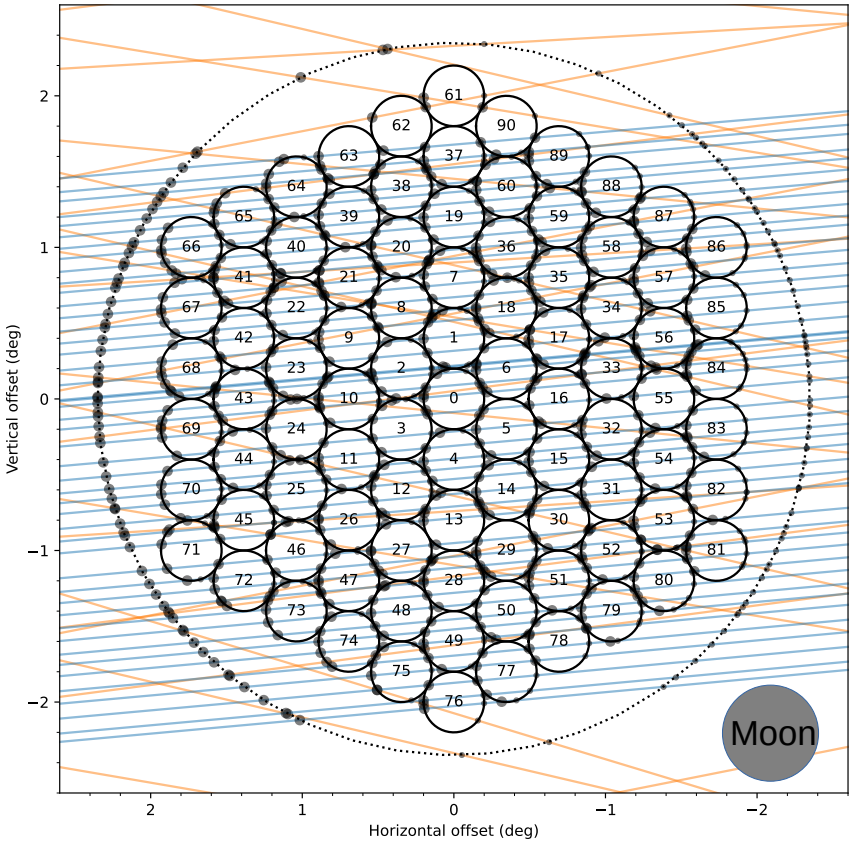
# LOFAR beamformed observations

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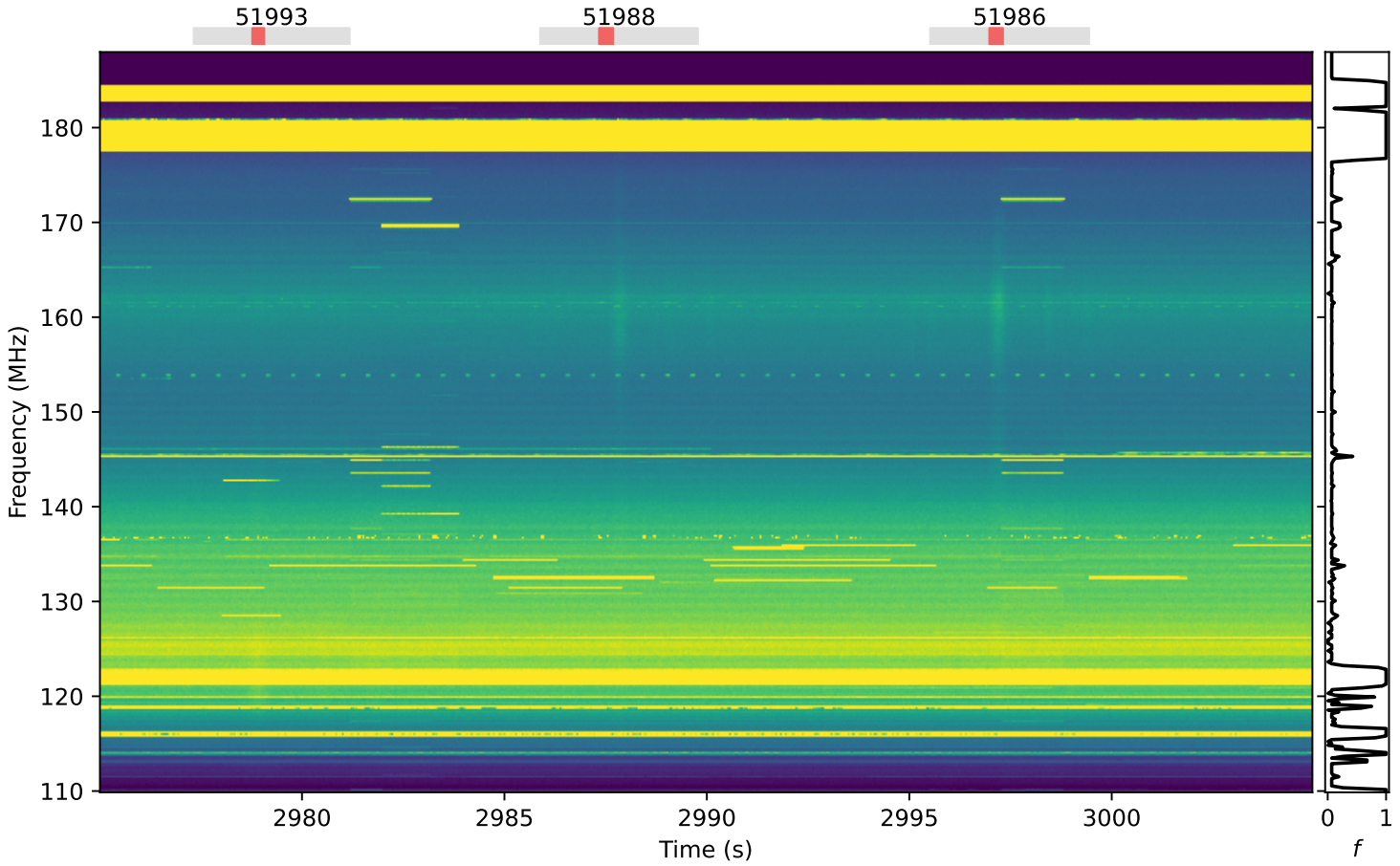
# Unintended electro-magnetic radiation (UEMR)

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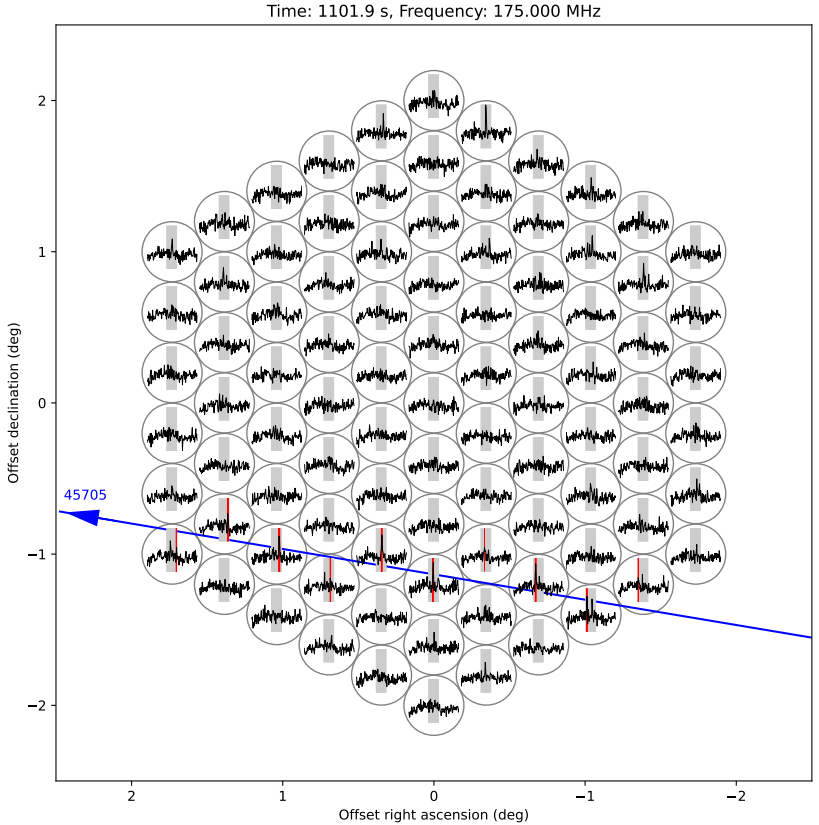
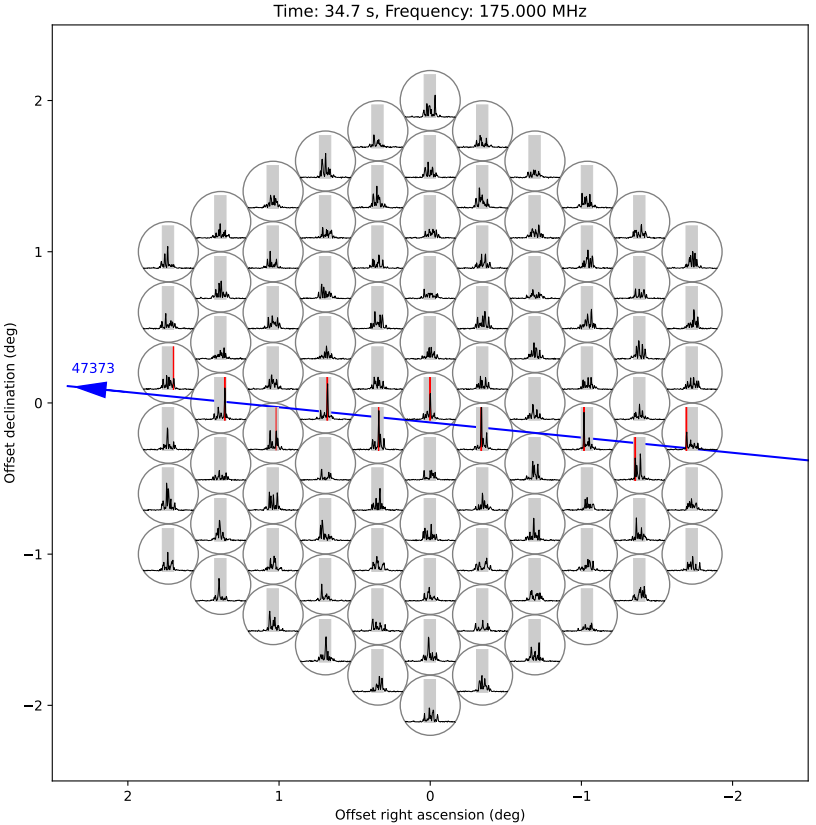
# Beam passages

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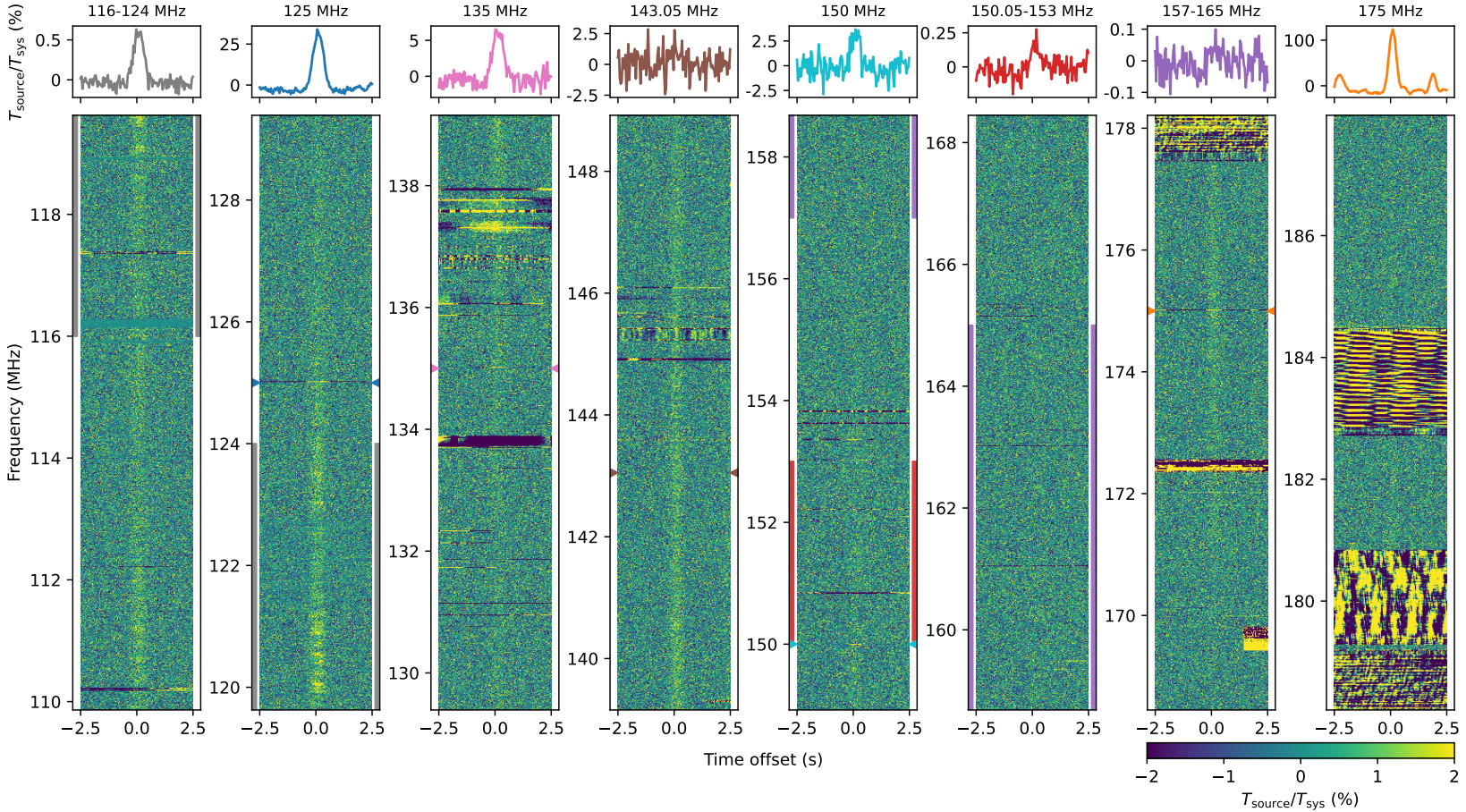
# Tied-array beam averages

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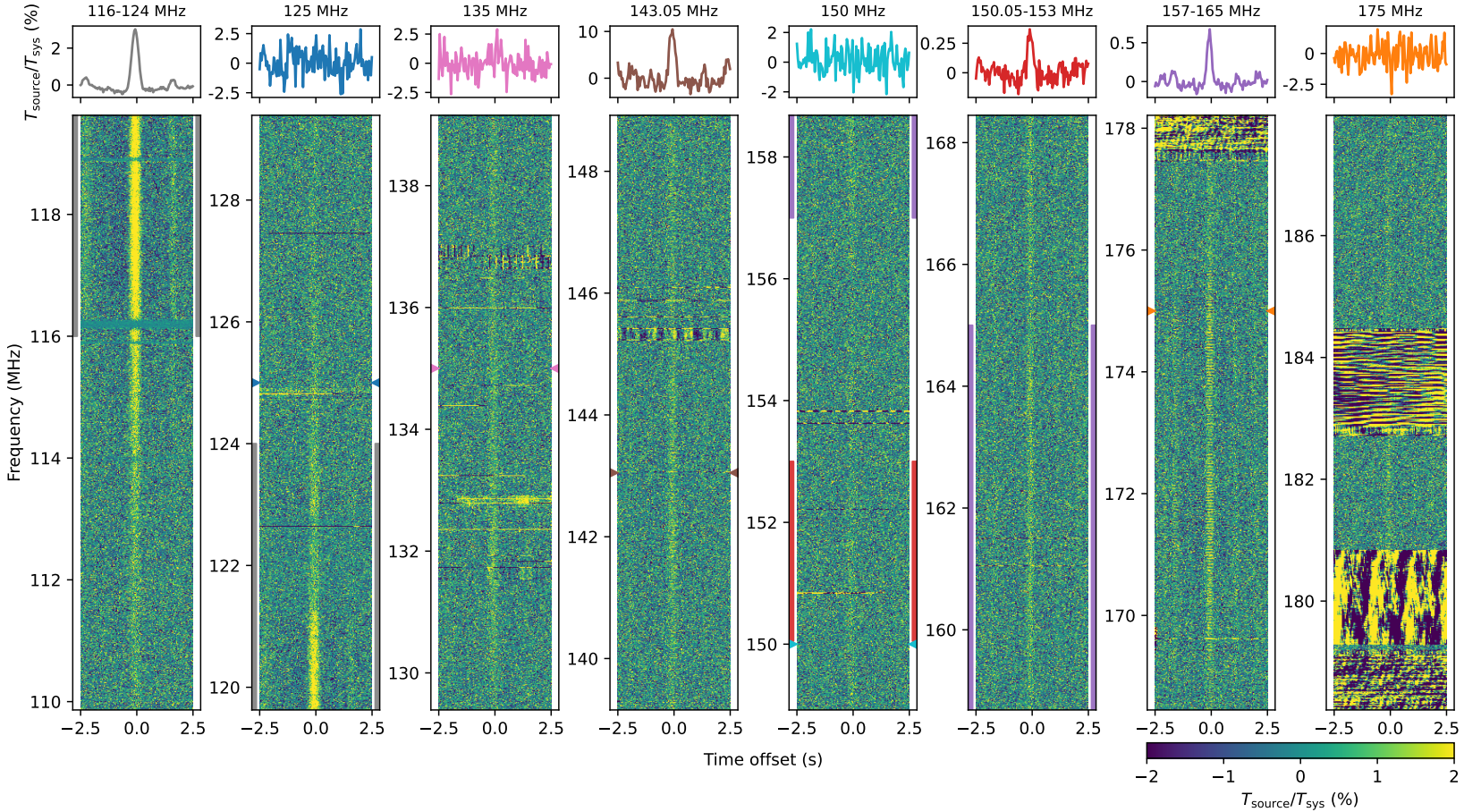
# Tied-array beam averages

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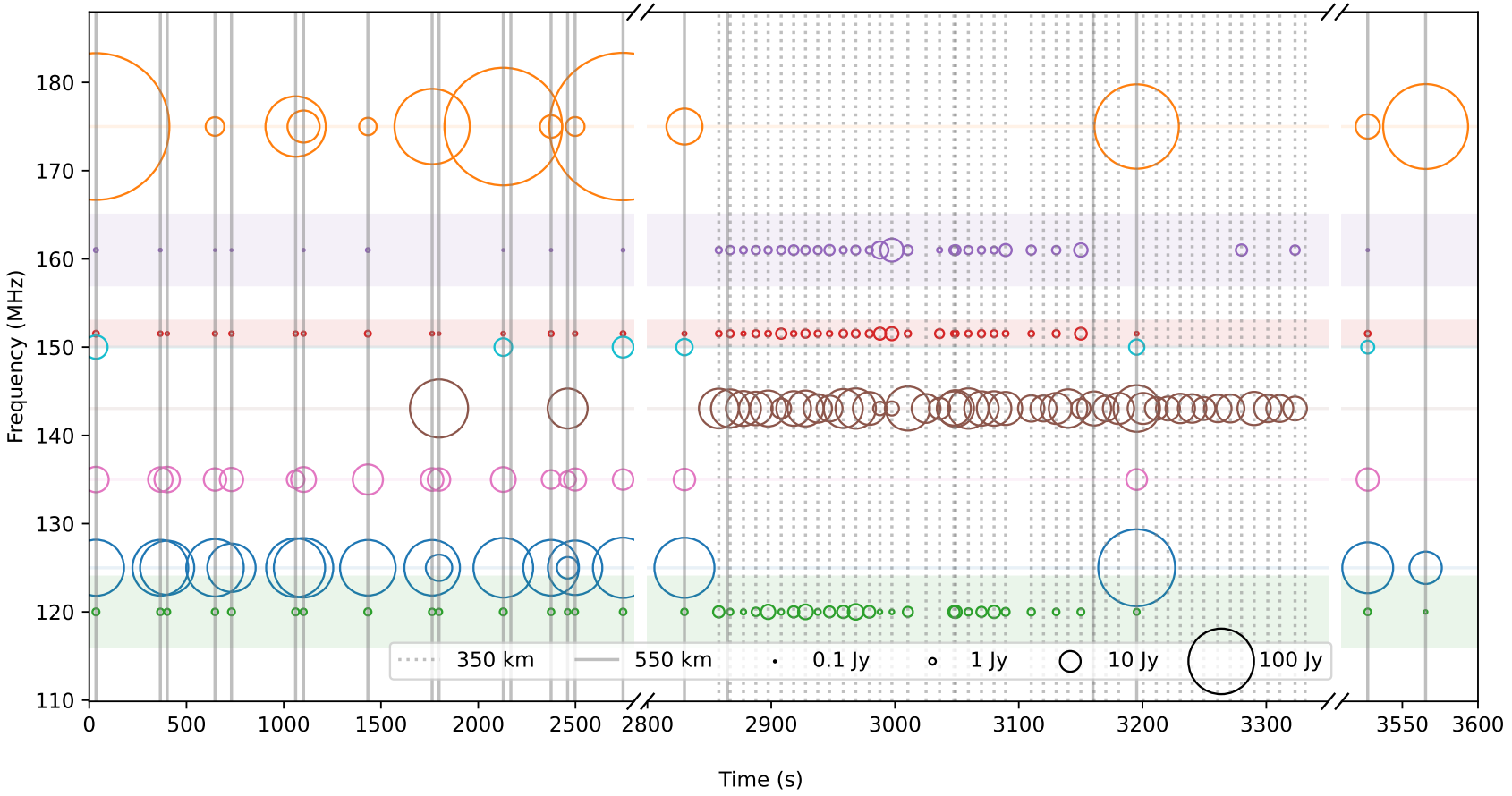
# All detections

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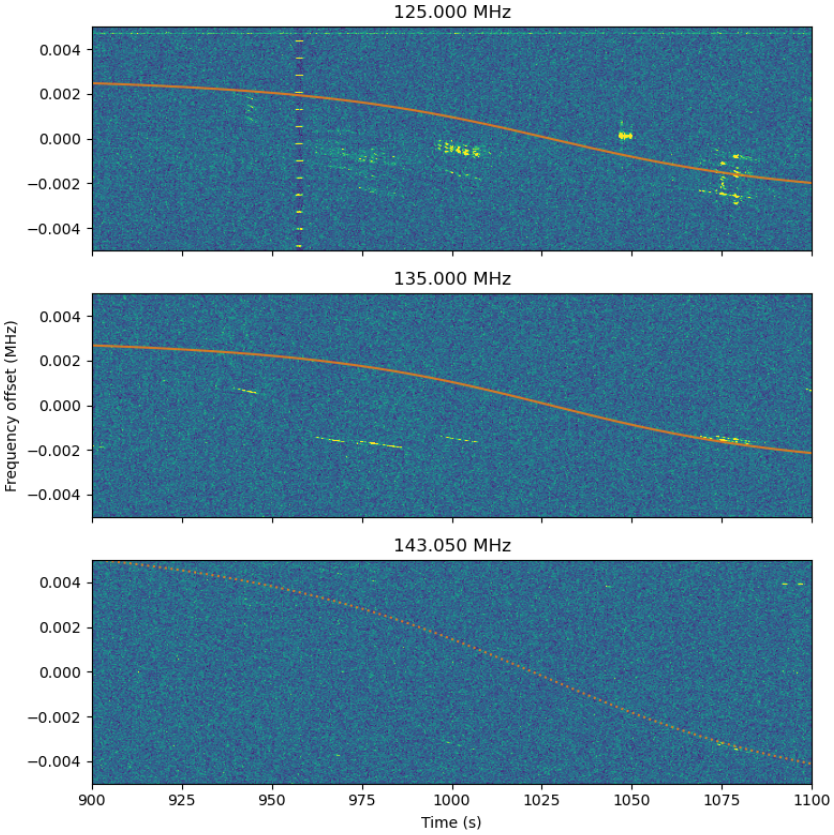
# Signal properties

**Narrowband signals:**

- Bright! ~500Jy at 175MHz
- Harmonically related (clock signal?)
- Absent on low altitude signals (satellites not in operation?)
- 143.050MHz due to GRAVES radar

**Broadband signals:**

- Fainter, few Jy
- Seen at both altitudes (always present?)
- Scales with distance
- Strength with frequency varies between satellites
- 50kHz comb around 150-180MHz (DC-DC converter?)
- Signals confirmed from AU SKA site (Grigg et al. 2023)

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# New results

**24h Starlink monitoring**

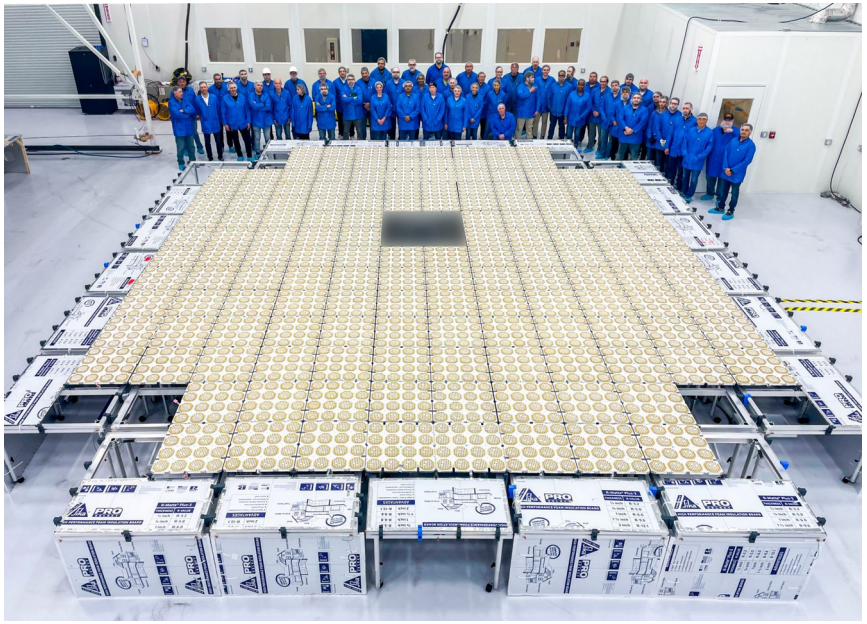
- 1766 satellites observed near zenith
- ~550 km distance
- Around 90% detected

**BlueWalker-3 detected**

- Mobile telecom from space with 64m$^2$ antenna at 500km altitude
- Licensed for 243 satellites at 725km

**Non-detections of other constellations**

- OneWeb at 1190km distance (66 out of 634)
- Iridium NEXT at 780km distance (12 out of 80)
- PlanetLABS Flock at ~500km distance (4 out of 170)



AST SpaceMobile

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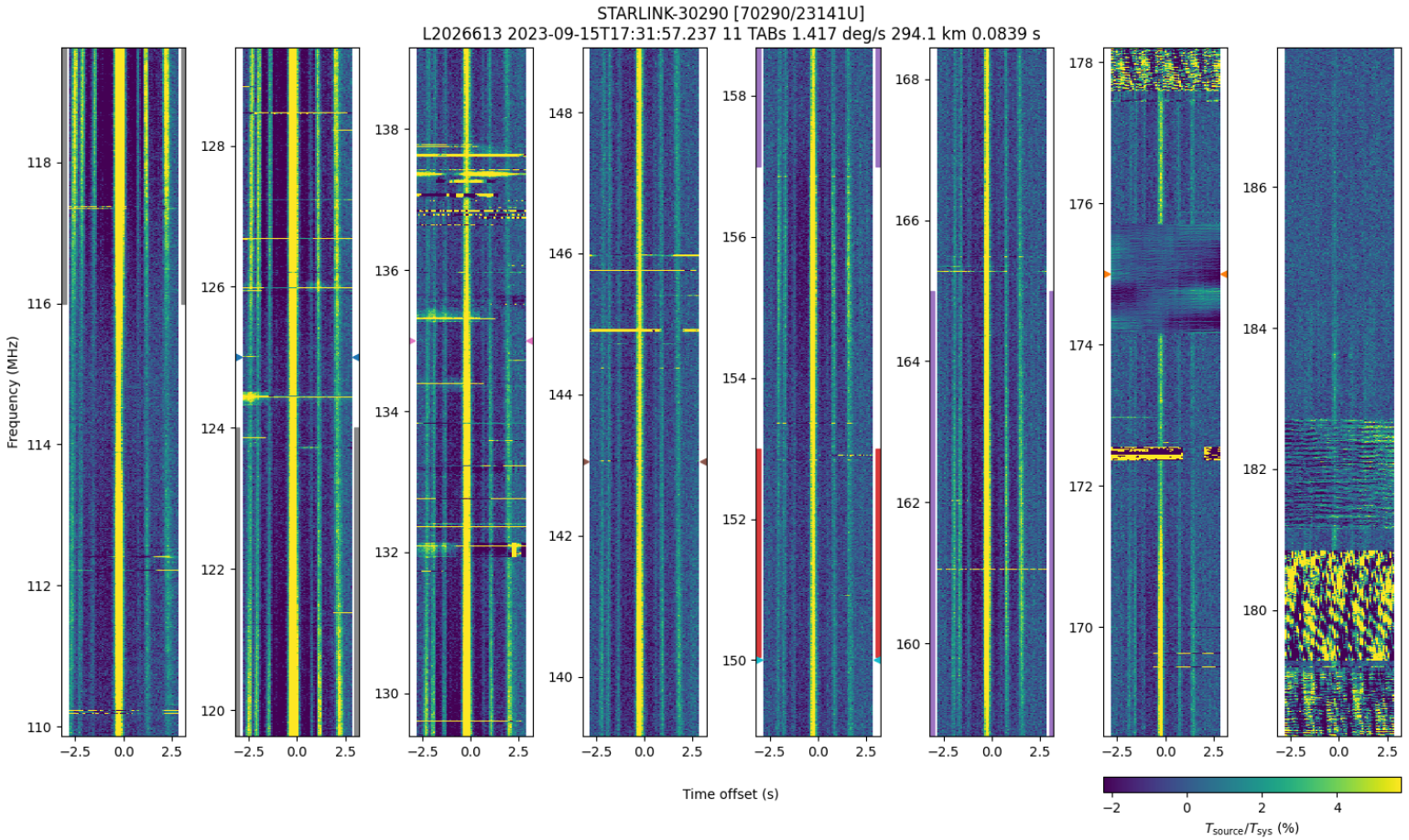
# Orbit raising Starlinks are bright!

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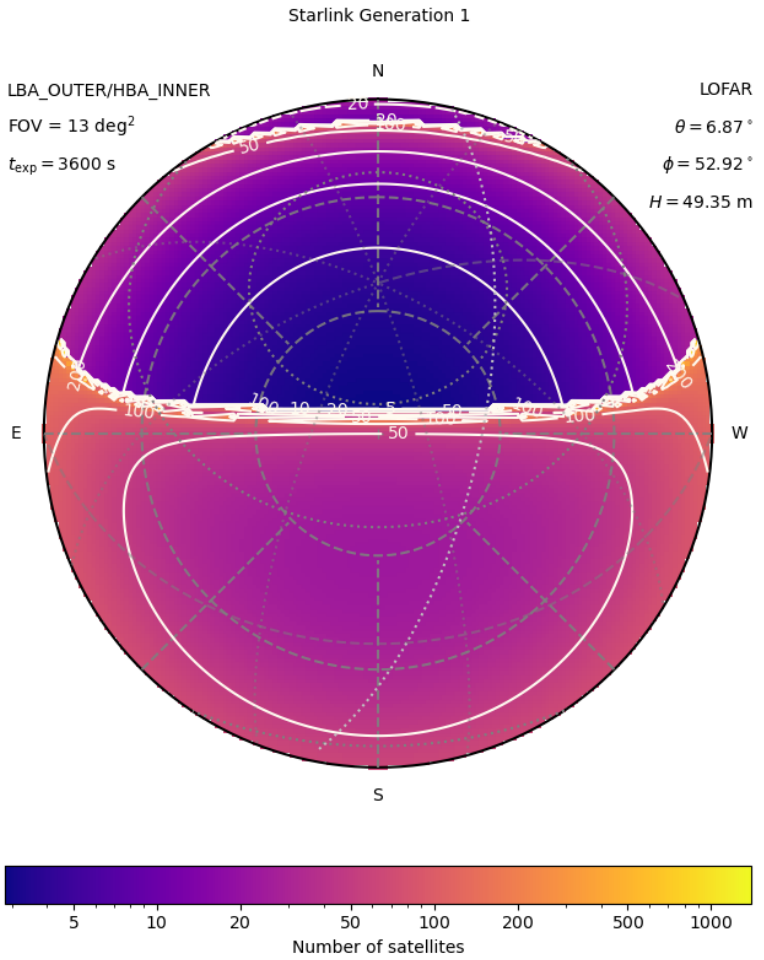
# Impact and outlook

- Increased noise in all observations
- Temporal variations due to motion
- No decorrelation on short baselines
- Spectral structure due to combs
- Impact depends on observatory latitude
- UEMR expected above 190MHz

- ITU-R regulations specific to transmissions, unlikely to apply to UEMR
- Need to rely on goodwill of satellite operators, collaboration with SpaceX
- *Many* more satellites/constellations planned (Amazon Kuiper, EU/Chinese)

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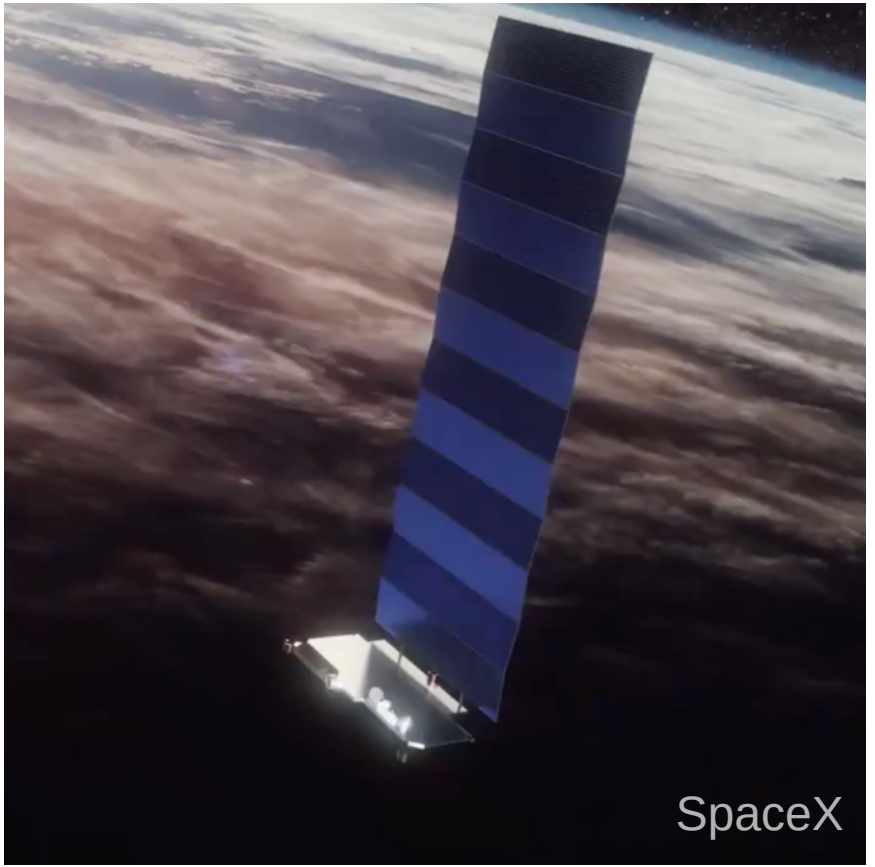
# Take home message

- Satellites leak radiation (UEMR) which can be detected by our radio telescopes
- Likely detectable at other frequencies
- Signals ~~may~~ **will** already be in your data...
- … may impact your science case
- Many many satellites will be launched in the future
- UEMR possibly not covered by regulations
- Problem will likely get worse before it get better (if it gets better)

- Bring this issue to the attention of your national radio spectrum managers
- Report detections to IAU CPS

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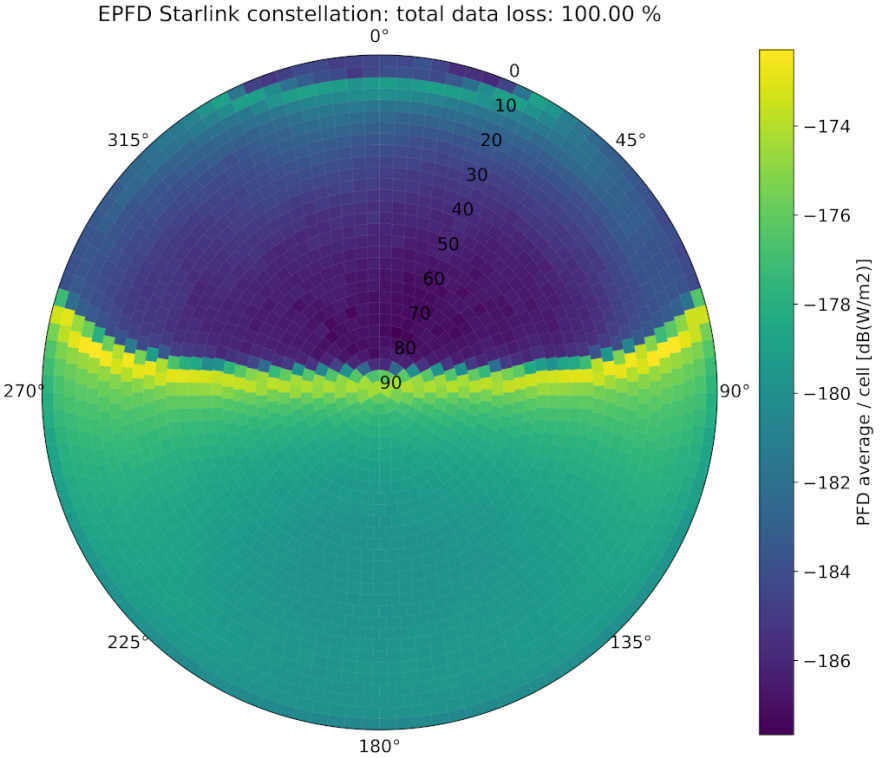
# Data loss simulations

- Equivalent power flux density (EPFD) method
- 2000 s integrations, 70 m equivalent antenna (e.g. ILT station) at 53 deg North
- 150-153 MHz ITU assigned radio astronomy band
- Assumed commercial standard of -45.6dB [mW/MHz] isotropic radiated power (30dB [uV/m] field strength)
- Interference threshold of -194dB [W/m$^2$] (ITU-R Ra.769-2)
- Data loss <2% (ITU-R RA.1513-2)

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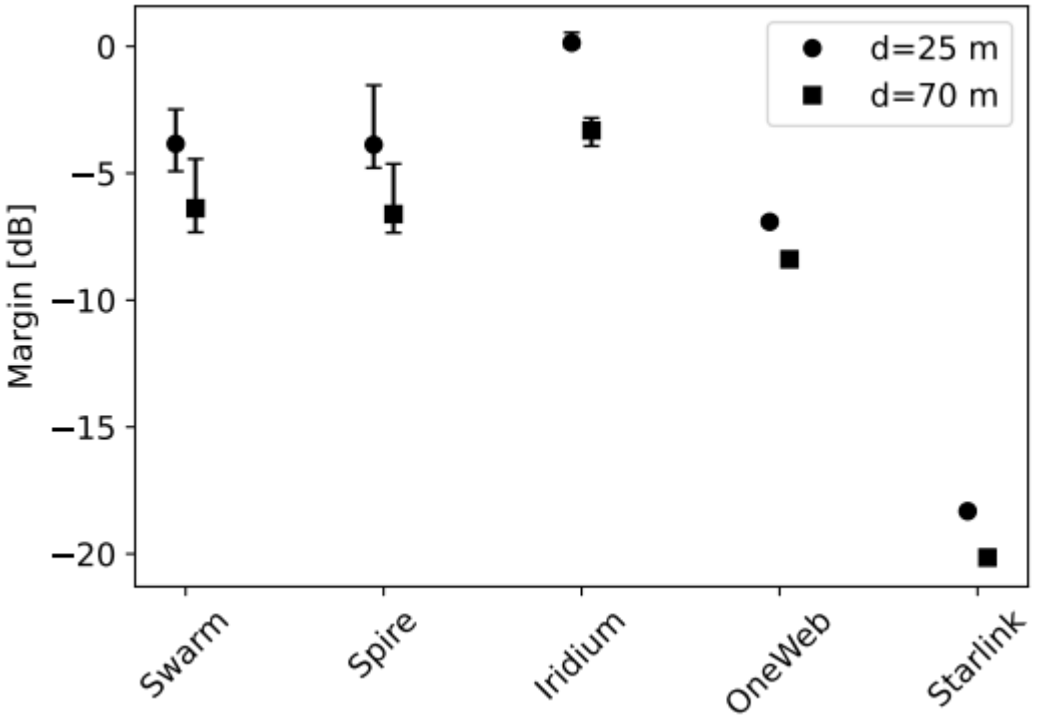
# Simulation results

**Table 1.** Results of the EPFD simulations: to avoid exceeding the RAS threshold levels in the band 150.05−153 MHz, the electric field values produced by satellites (measured with a 120 kHz detector at 10 m distance) should be lower than the stated E-fields. This assumes that the UEMR has broad-band type, or more precisely that the signal is constant over the full RAS band, 150.05−153 MHz. With a measurement bandwidth of 2.95 MHz the electric field limits are (2950/120) = 13.9 dB higher.

| Satellite System | # Sats | Avg. alt. km | Max. E-field dB $[\mu V\ m^{-1}]$ | |
|---|---|---|---|---|
| | | | $d$ = 25 m | $d$ = 70 m |
| Spire | 118 | 500 | $26.1^{+2.3}_{-0.9}$ | $23.4^{+2.0}_{-0.7}$ |
| Iridium NEXT | 66 | 780 | $30.1^{+0.4}_{-0.2}$ | $26.7^{+0.5}_{-0.6}$ |
| OneWeb | 720 | 1200 | $23.1^{+0.2}_{-0.1}$ | $21.6^{+0.2}_{-0.2}$ |
| SpaceX/Starlink | 4408 | 560 | $11.7^{+0.1}_{-0.1}$ | $9.9^{+0.1}_{-0.1}$ |
| SpaceX/Swarm | 150 | 500 | $26.2^{+1.4}_{-1.1}$ | $23.6^{+1.9}_{-0.9}$ |




Simulations assume 30dB [uV/m], 175MHz reaches 49 dB [uV/m], 100x higher!

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# LOFAR – Low-Frequency Array


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