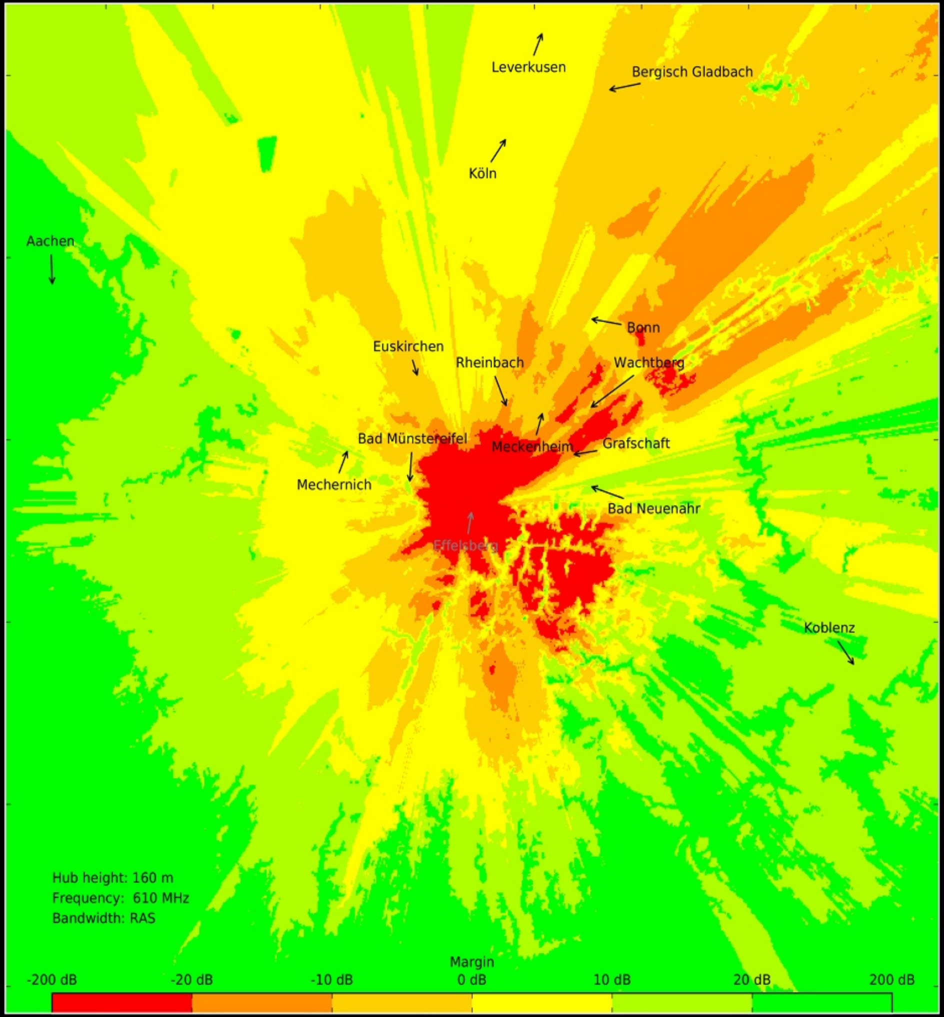
# Oneweb, Starlink and 5G

## A new dark age for radio astronomy?


Benjamin Winkel

@HIprocessor

Max-Planck-Institut für Radioastronomie

# Launch of the first 60 of 12000 SpaceX/Starlink satellites

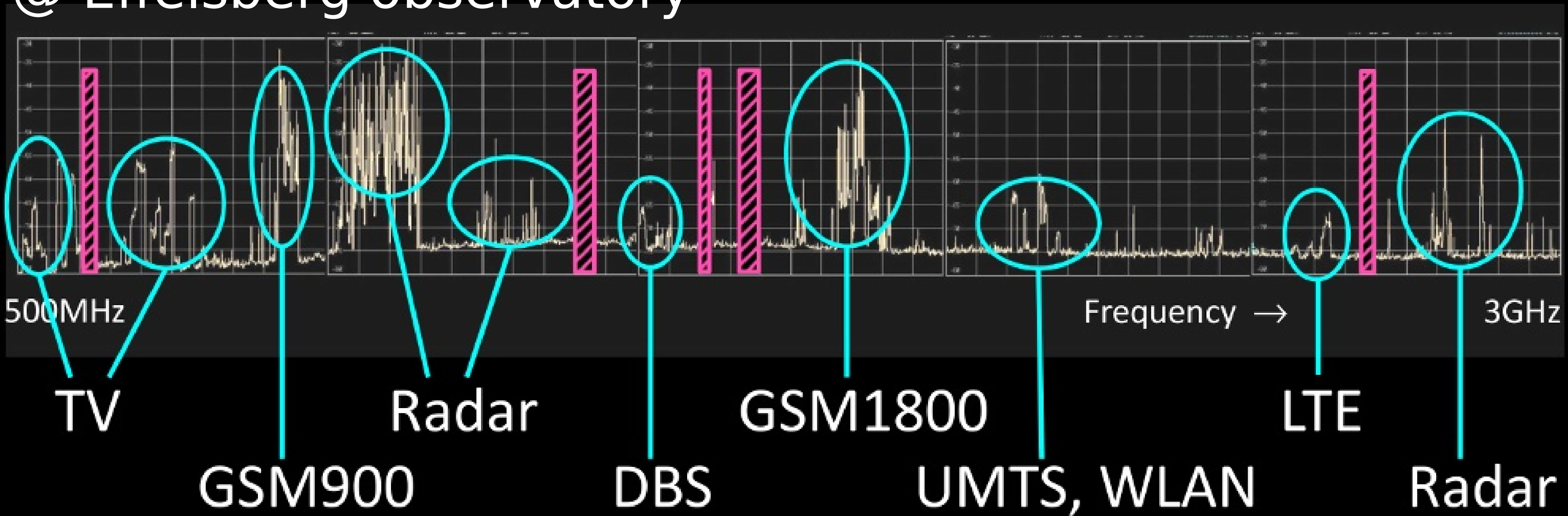
Image: Marco Langbroek; May 24, 2019


Light pollution
Image: NASA, 2016

# Radio frequency interference (RFI)

@ Effelsberg observatory

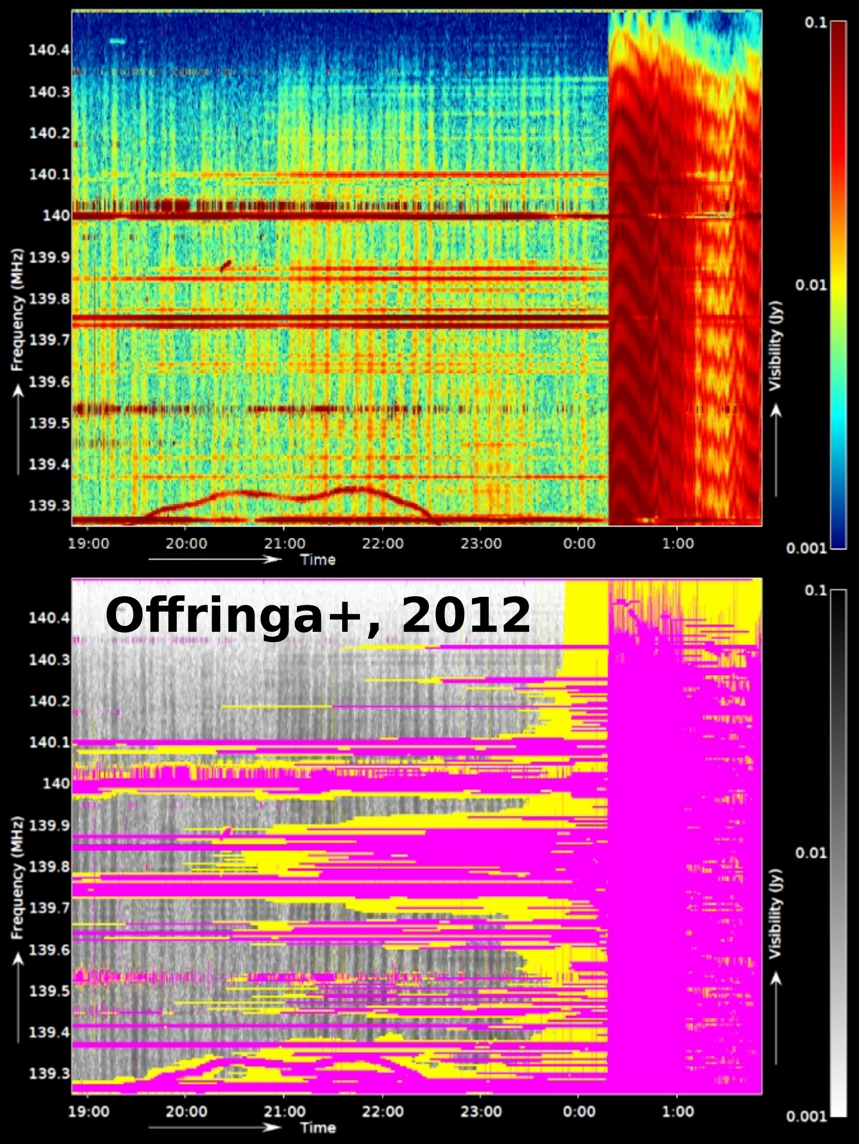
Image: MPIfR



# RFI flagging or mitigation

Many tools available, e.g.

- Adaptive filtering
- Peak thresholding
- Higher order statistics
- Deep neural networks



# Limits of RFI mitigation / detection

- Often highly adapted to:
  - One or few types of RFI
  - Particular observing modes
- High incident power can
  - Cause intermodulation products
  - Completely saturate receiver (blocking)
    → any kind of (digital) post-processing will fail

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  - Completely saturate receiver (blocking)

Must limit transmit power or distance
→ Spectrum management

# Spectrum management

- Lobbying :-(
- Convince administrations and companies to protect radio observatories
- Compatibility calculations
  If you want protection, you need to proof that you are affected!

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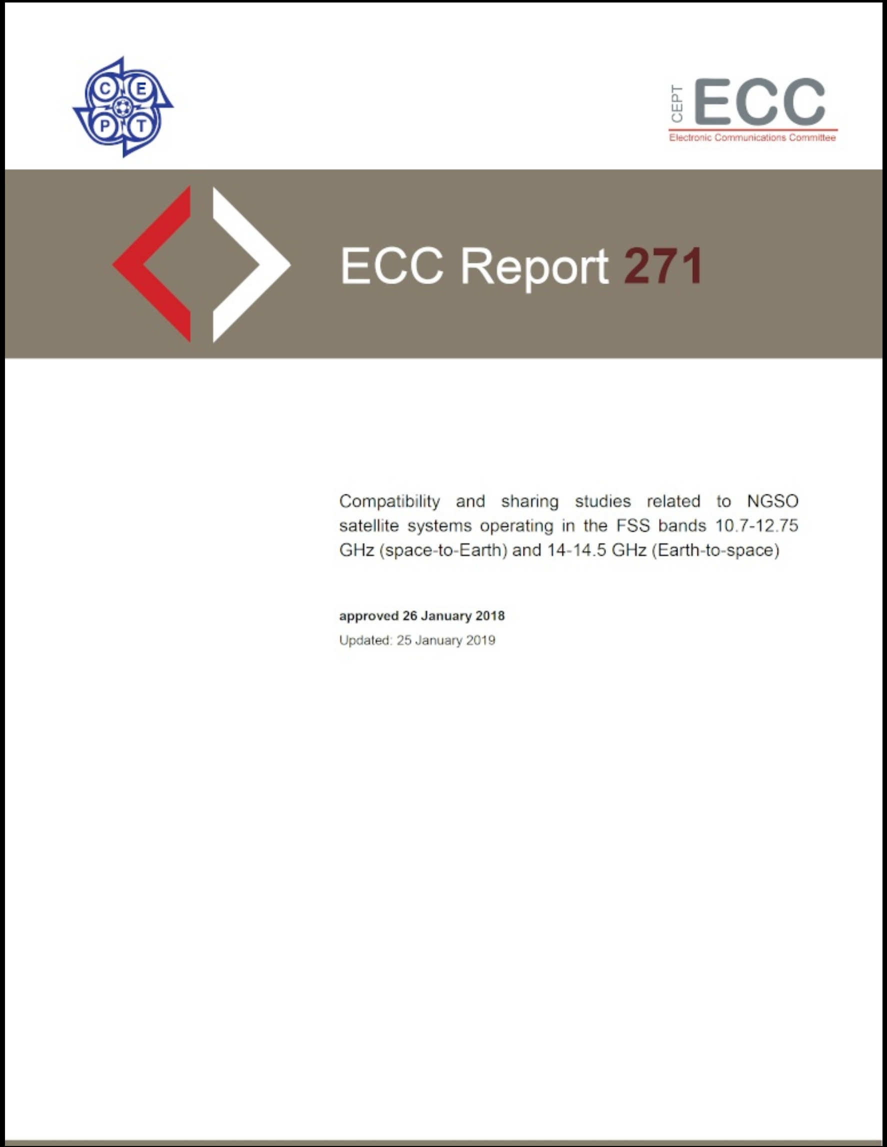

CEPT ECC
Electronic Communications Committee

ECC Report 271

Compatibility and sharing studies related to NGSO satellite systems operating in the FSS bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space)

approved 26 January 2018
Updated: 25 January 2019

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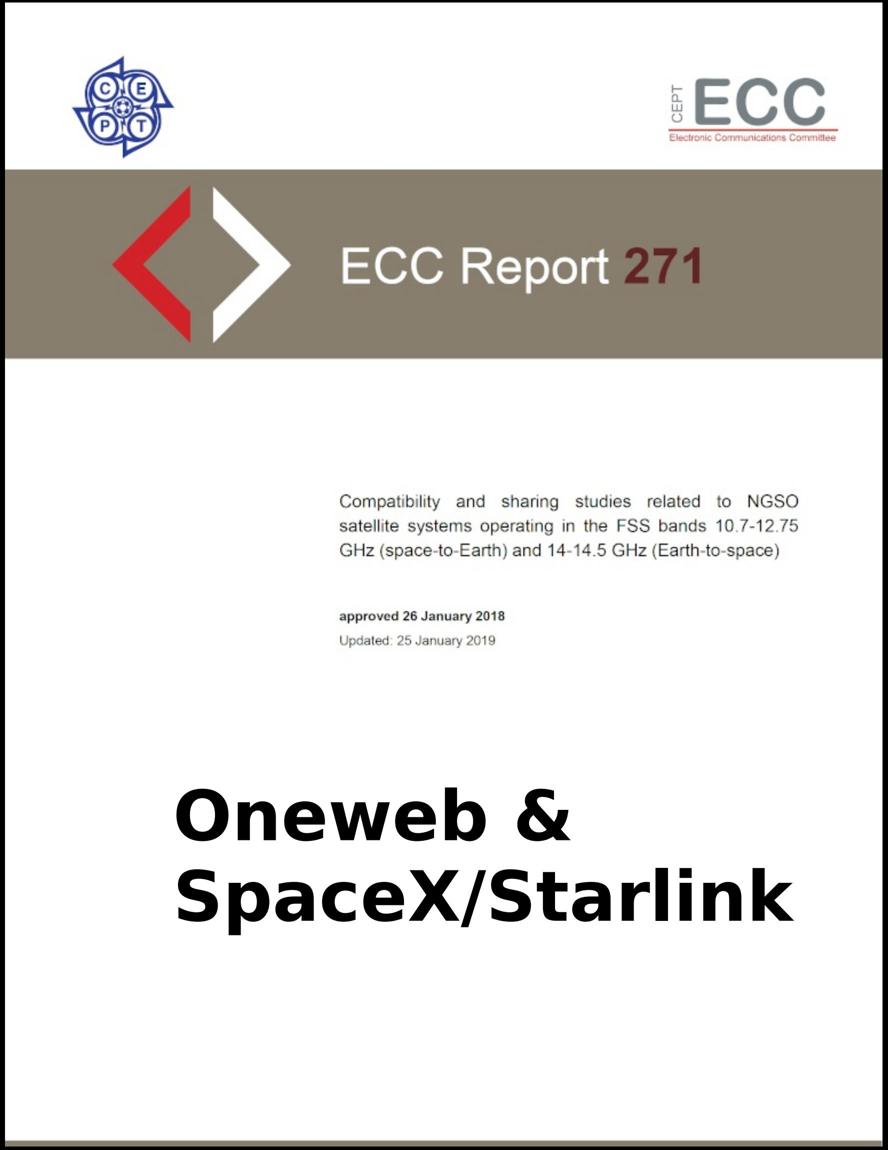
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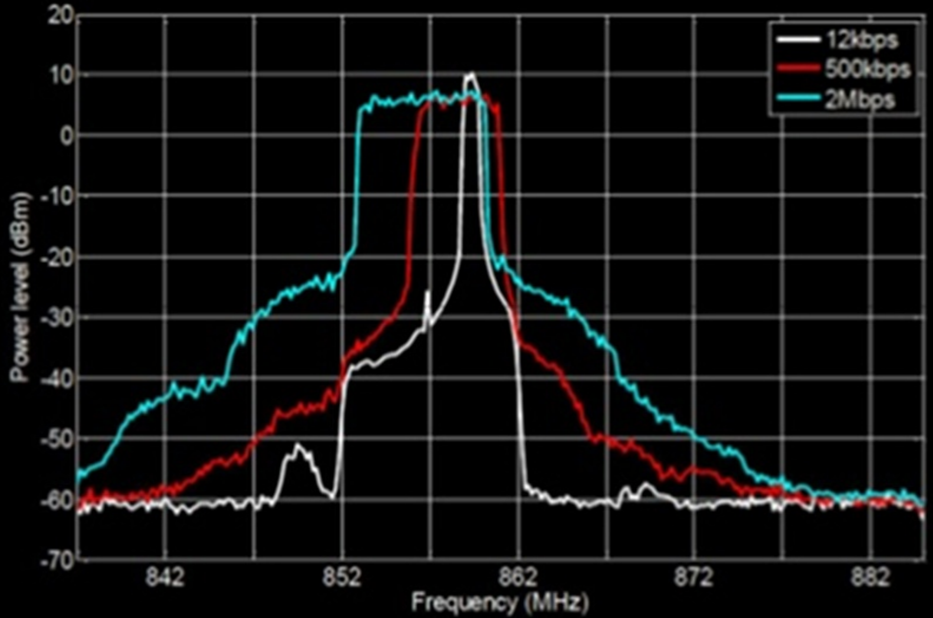
**Oneweb & SpaceX/Starlink**

# Compatibility calculations

Recipe

- Calculate un-/wanted emission levels of interferer
- Path propagation loss between Tx and Rx
- Infer power flux densities at victim receiver
- Compare with permitted limits




Source: Ofcom (August 2012)

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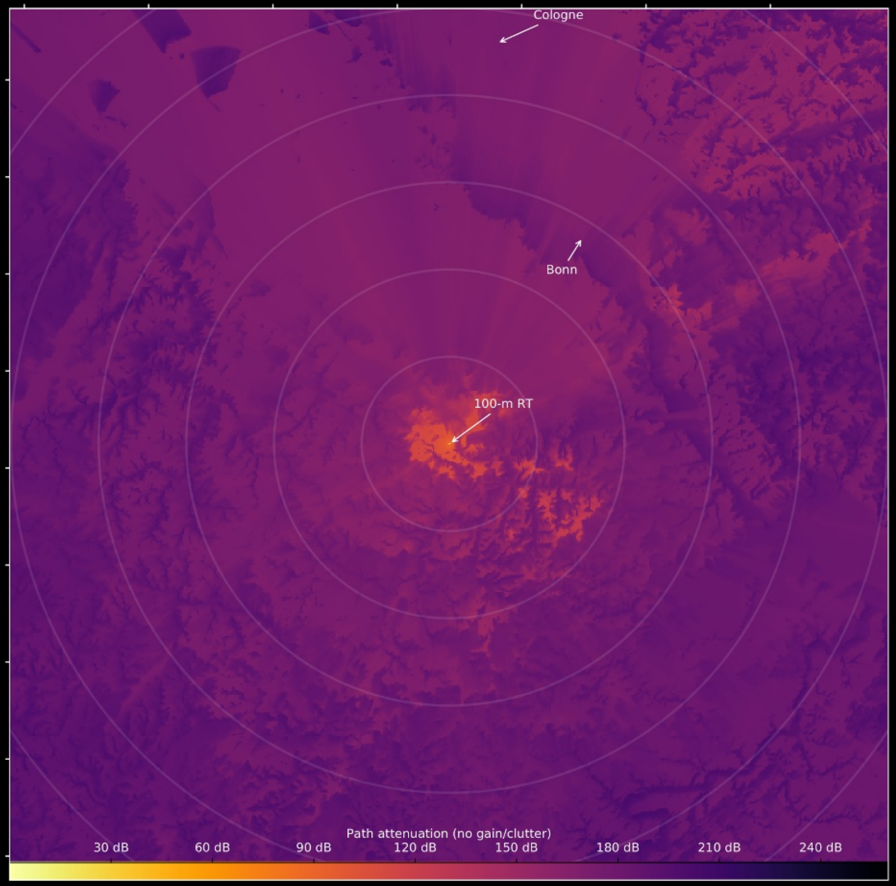

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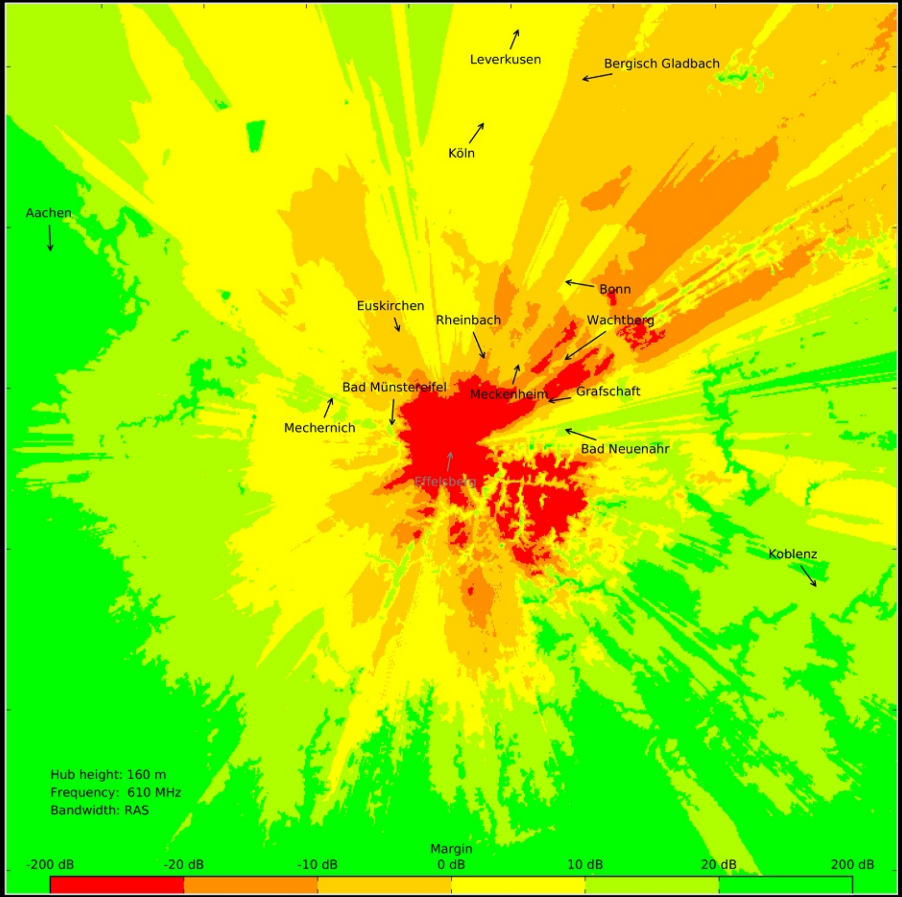
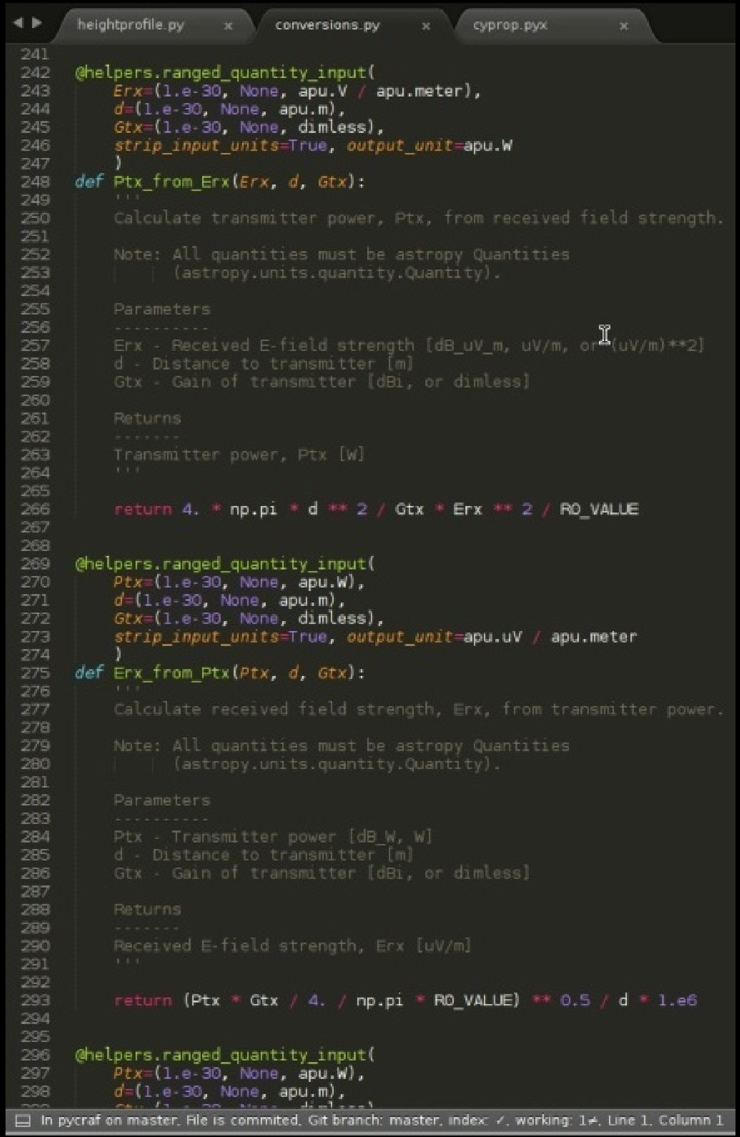


# pycraf

- Python package for compatibility studies
- Winkel & Jessner 2018, 2019
- Features:
  - Path propagation loss (P.452)
  - Atmospheric attenuation (P.676)
  - Query topographical data
  - Antenna patterns
  - Geographical coordinates
  - Satellite visibility



# pycraf

- Free & OSS
- Hosted on GitHub
- Powered by Astropy package template
- Well documented
- Many examples
- Contributions welcome!
- `pip install pycraf`
- `conda install pycraf` (conda-forge channel)

https://github.com/bwinkel/pycraf

## pycraf

- *Version:* 0.25
- *Author:* Benjamin Winkel
- *User manual:* stable | developer

pypi v0.25.8 | license GPL | DOI 10.5281/zenodo.1244192

The pycraf Python package provides functions and procedures for various tasks in spectrum-management compatibility studies. A typical example would be to calculate the interference levels at a radio telescope produced from a radio broadcasting tower.

Releases are registered on PyPI, and development is occurring at the project's github page.

### Project Status

build passing | build passing | coverage 92%

pycraf is still in the early-development stage. While much of the functionality is already working as intended, the API is not yet stable. Nevertheless, we kindly invite you to use and test the library and we are grateful for feedback. Note, that work on the documentation is still ongoing.

### Features

- Full implementation of ITU-R Rec. P.452-16 that allows to calculate path attenuation for the distance between interferer and victim service. Supports to load NASA's Shuttle Radar Topography Mission (SRTM) data for height-profile generation.
- Full implementation of ITU-R Rec. P.676-10, which provides two atmospheric models to calculate the attenuation for paths through Earth's atmosphere.
- Provides various antenna patterns necessary for compatibility studies (e.g., RAS, IMT, fixed-service links).
- Functions to convert power flux densities, field strengths, transmitted and received powers at certain distances and frequencies into each other.

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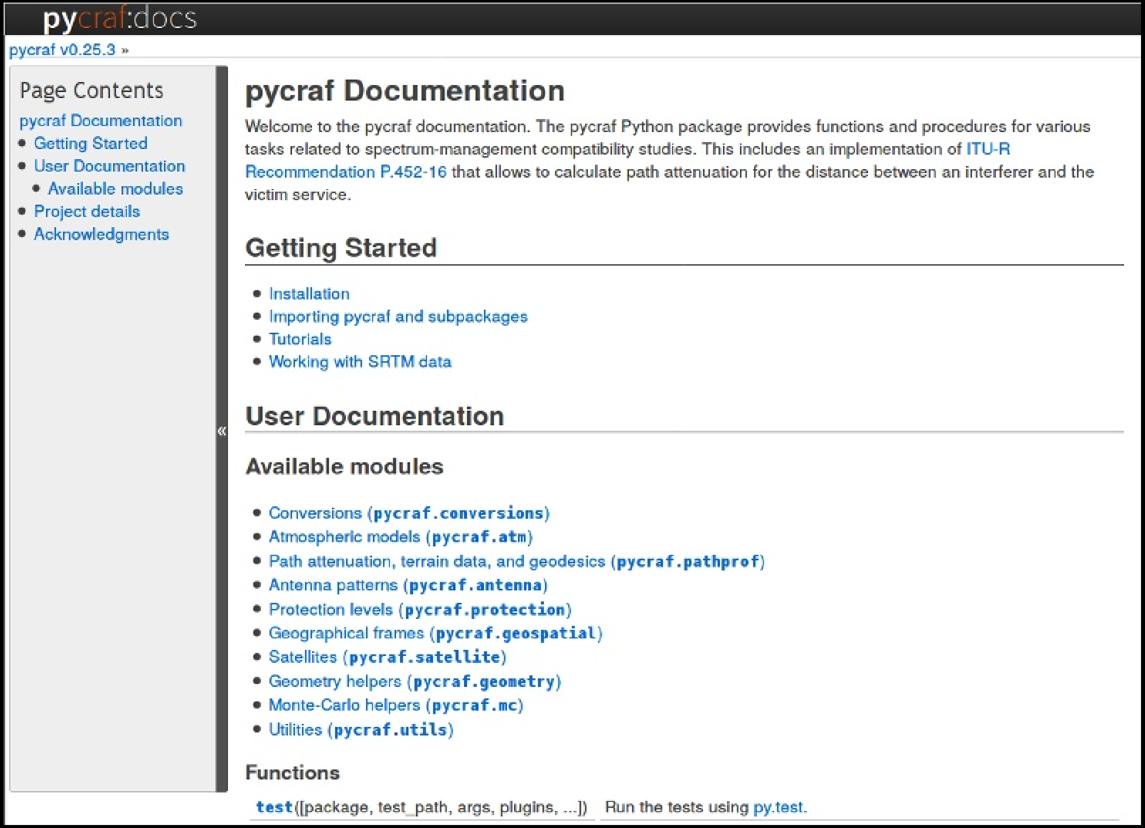
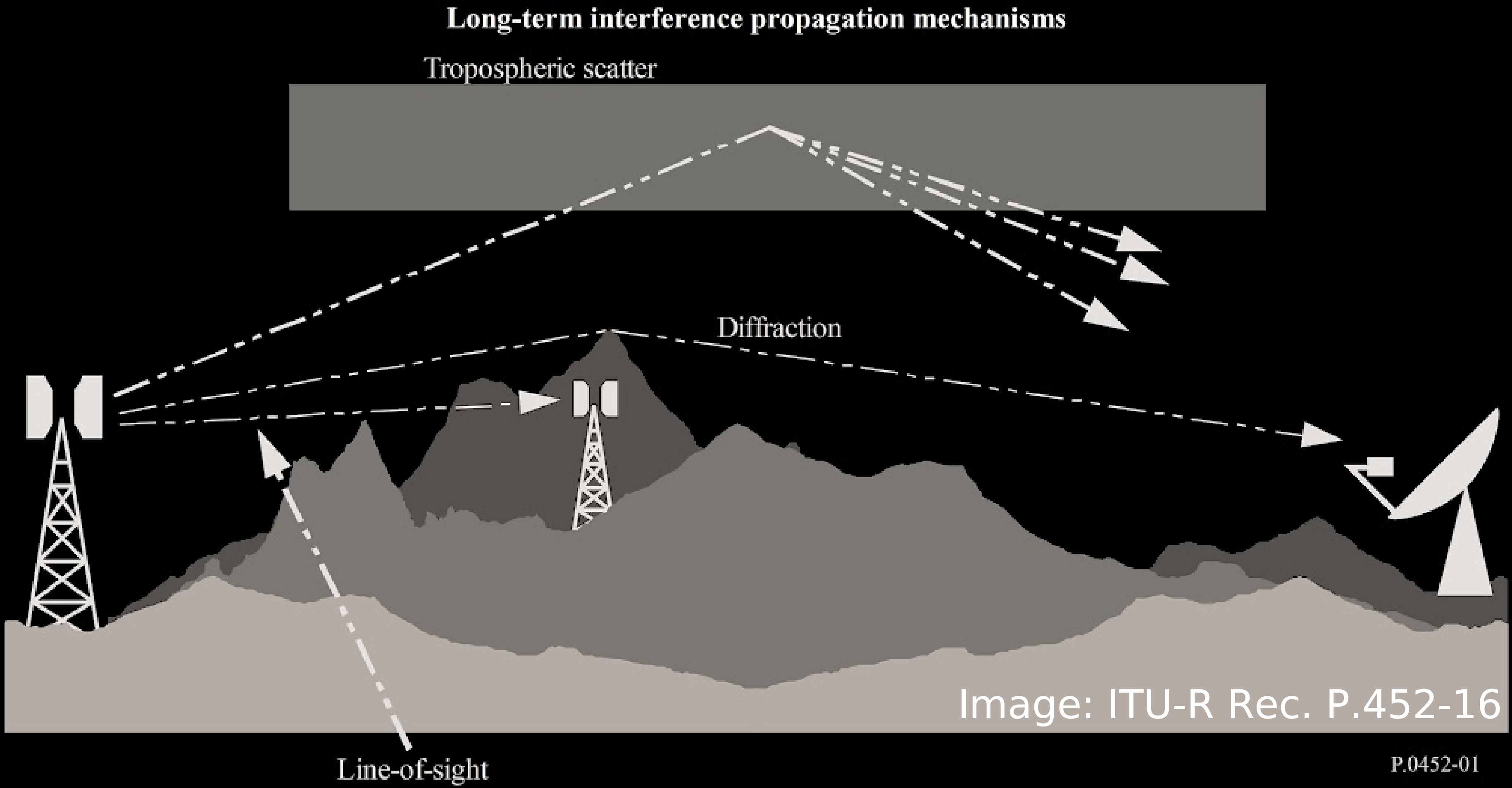


# Path propagation loss



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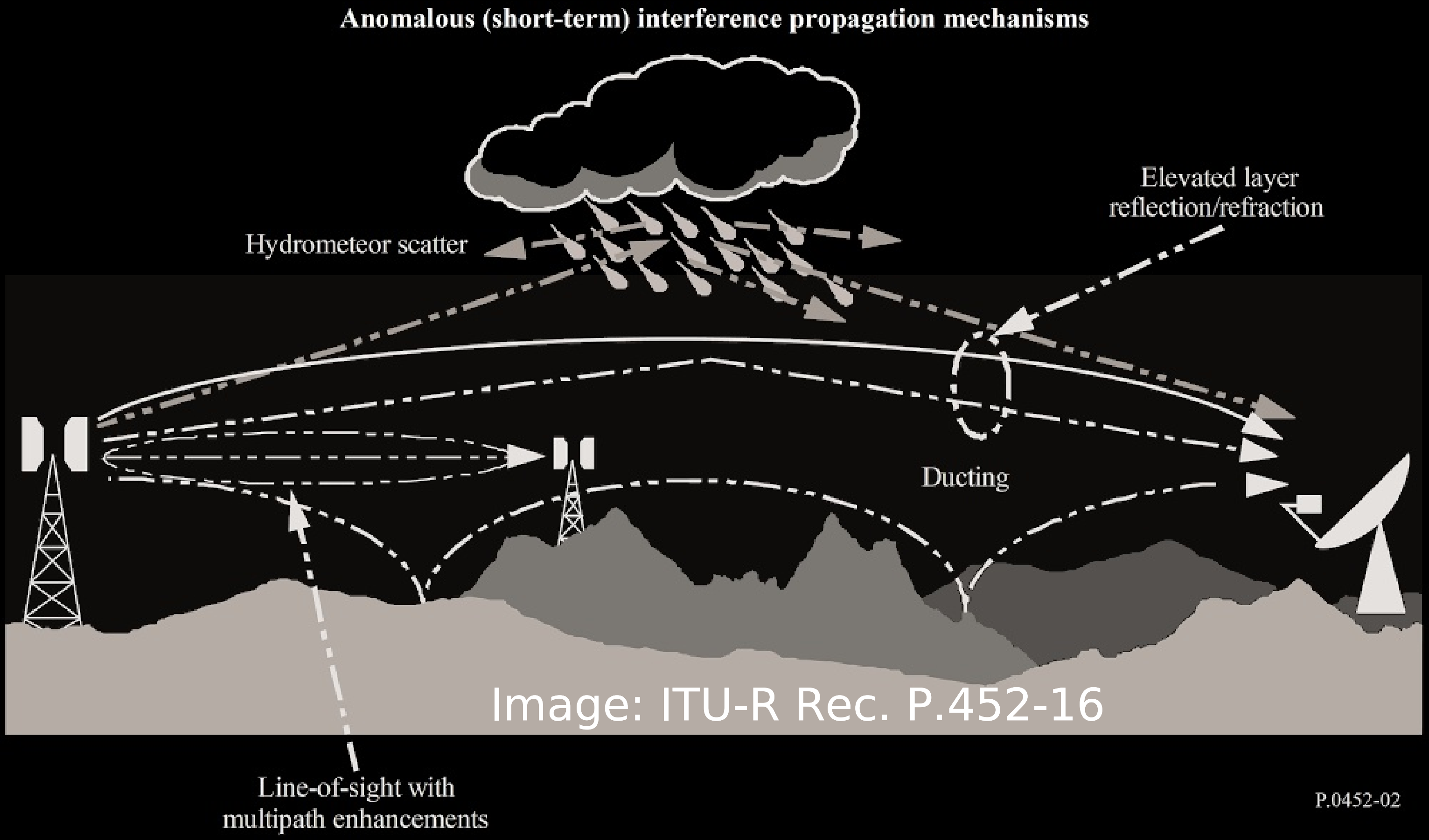
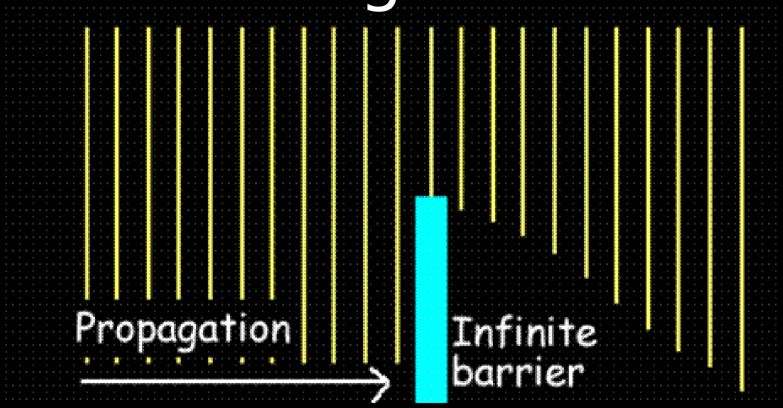
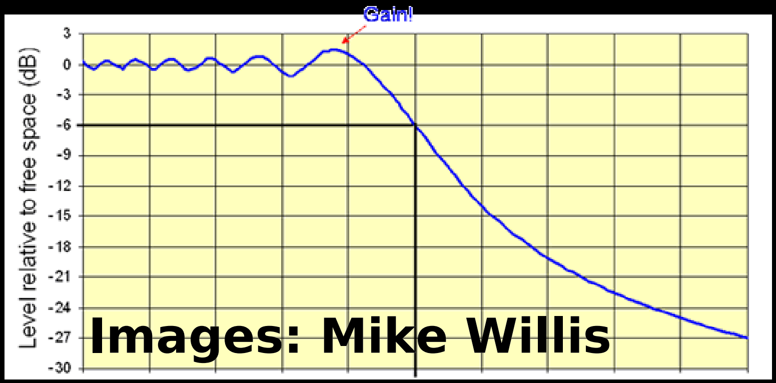


# Path propagation loss

## Knife edge diffraction




**Images: Mike Willis**

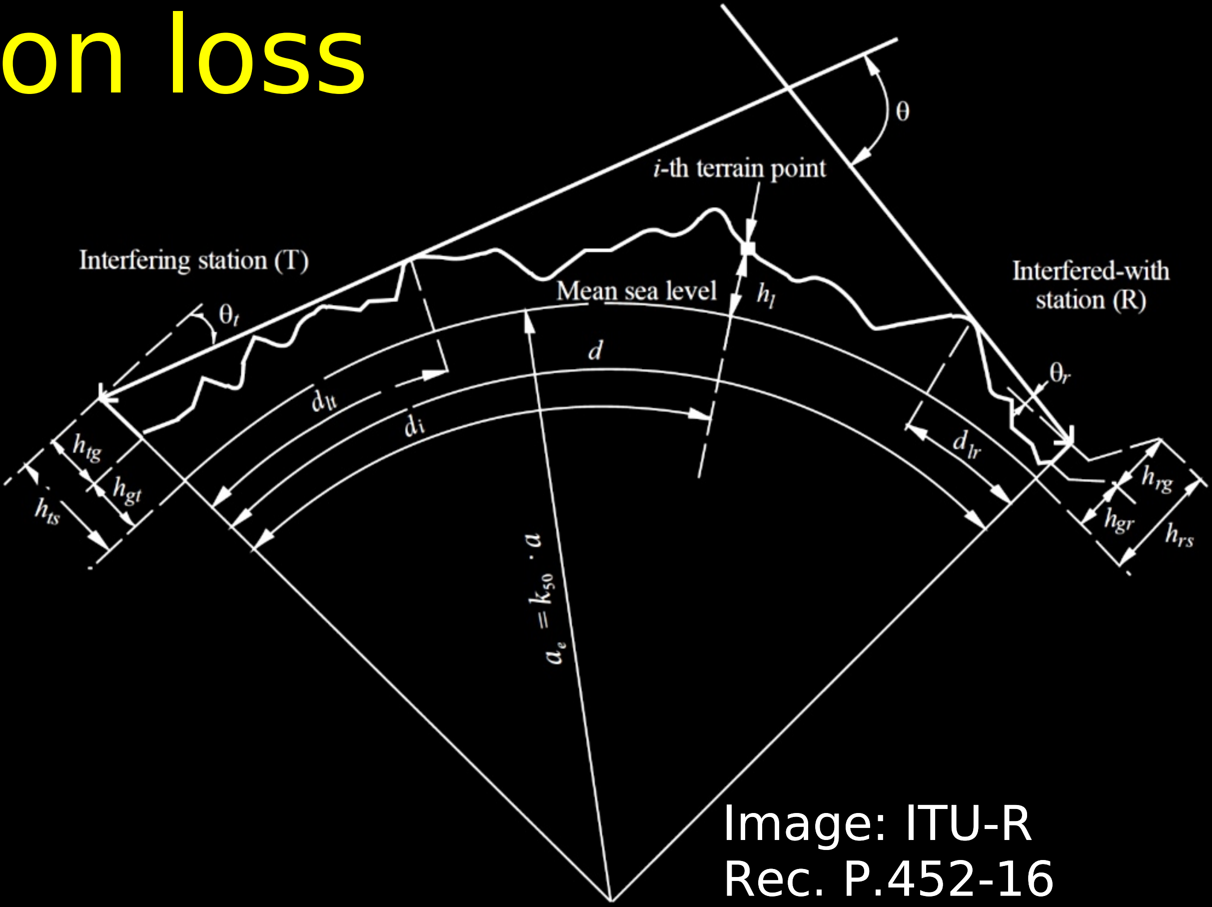
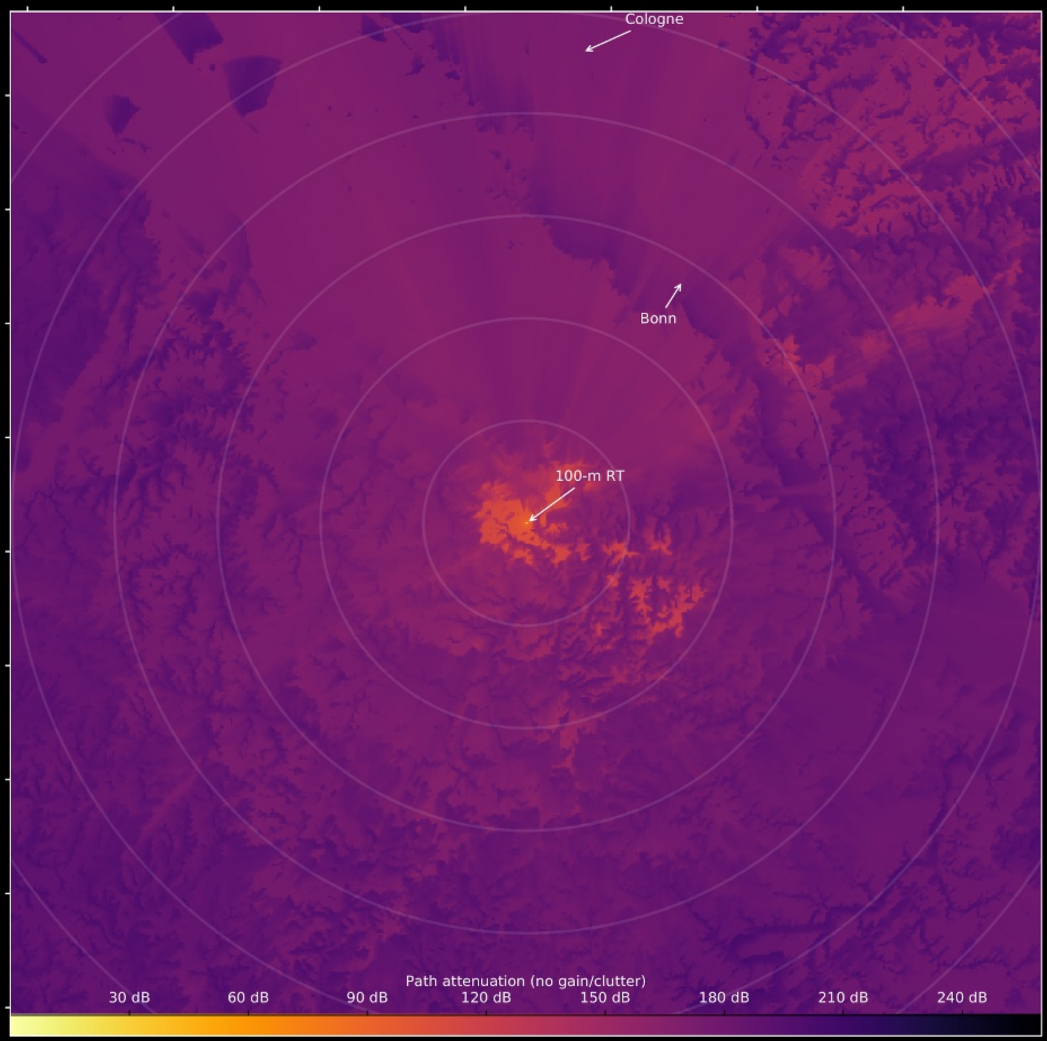


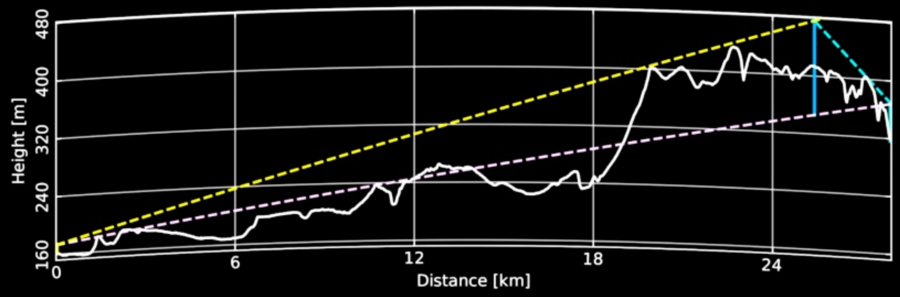

Image: ITU-R Rec. P.452-16

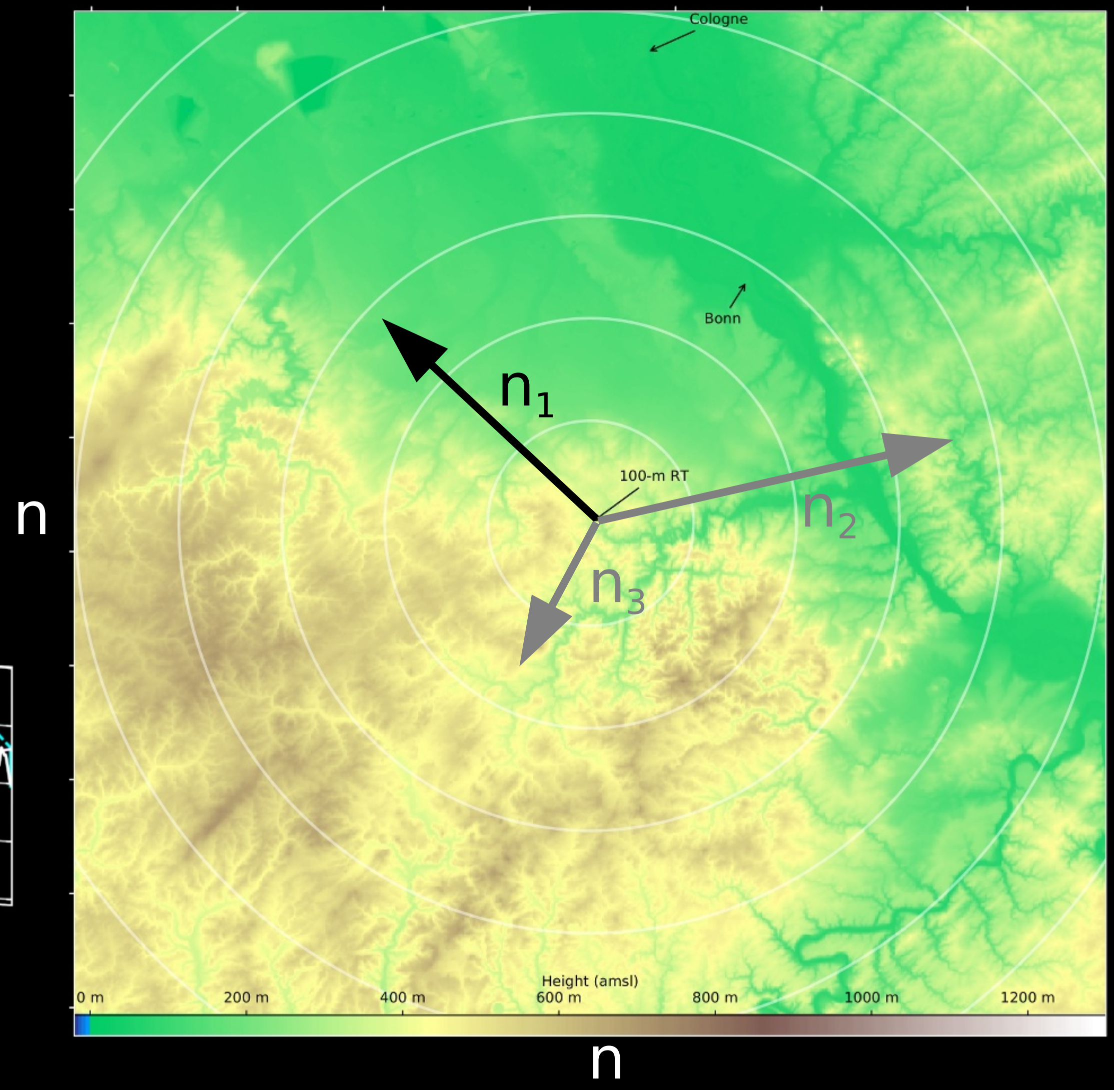
# Propagation loss maps



# Propagation loss maps

- Query height profiles
- $O(n^3)$ problem



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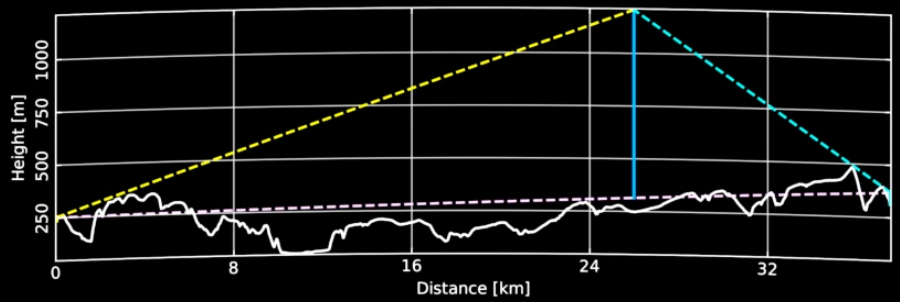


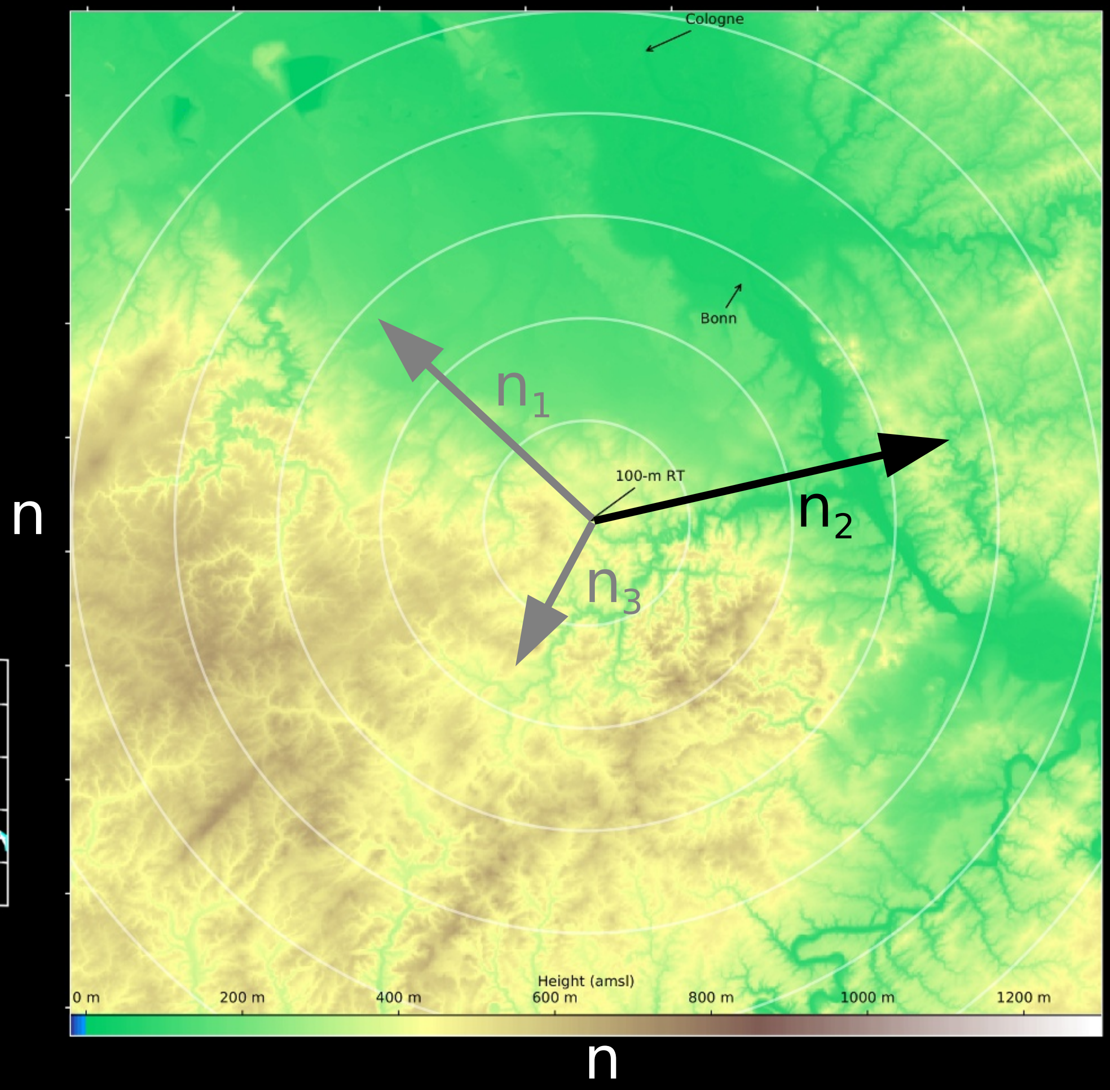

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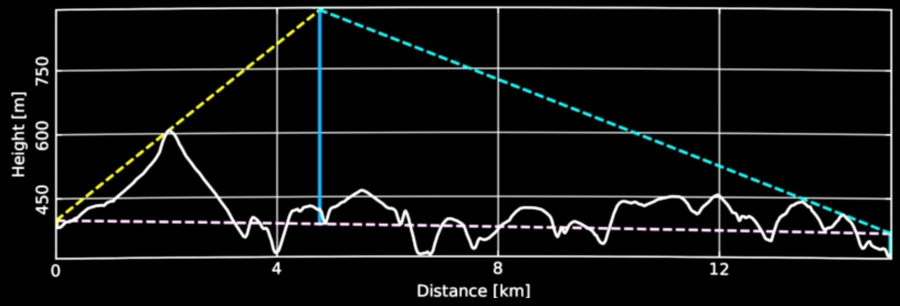
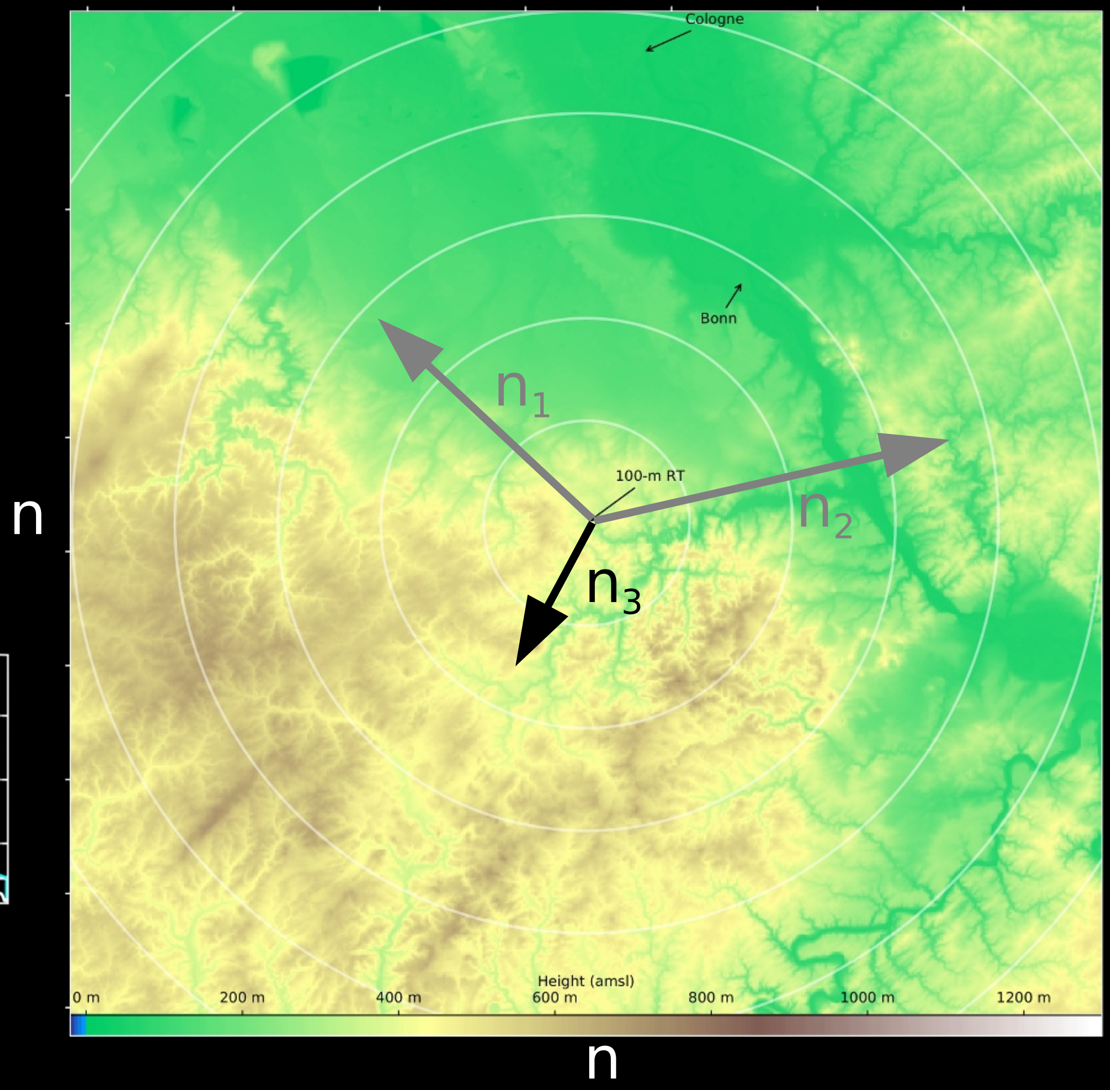
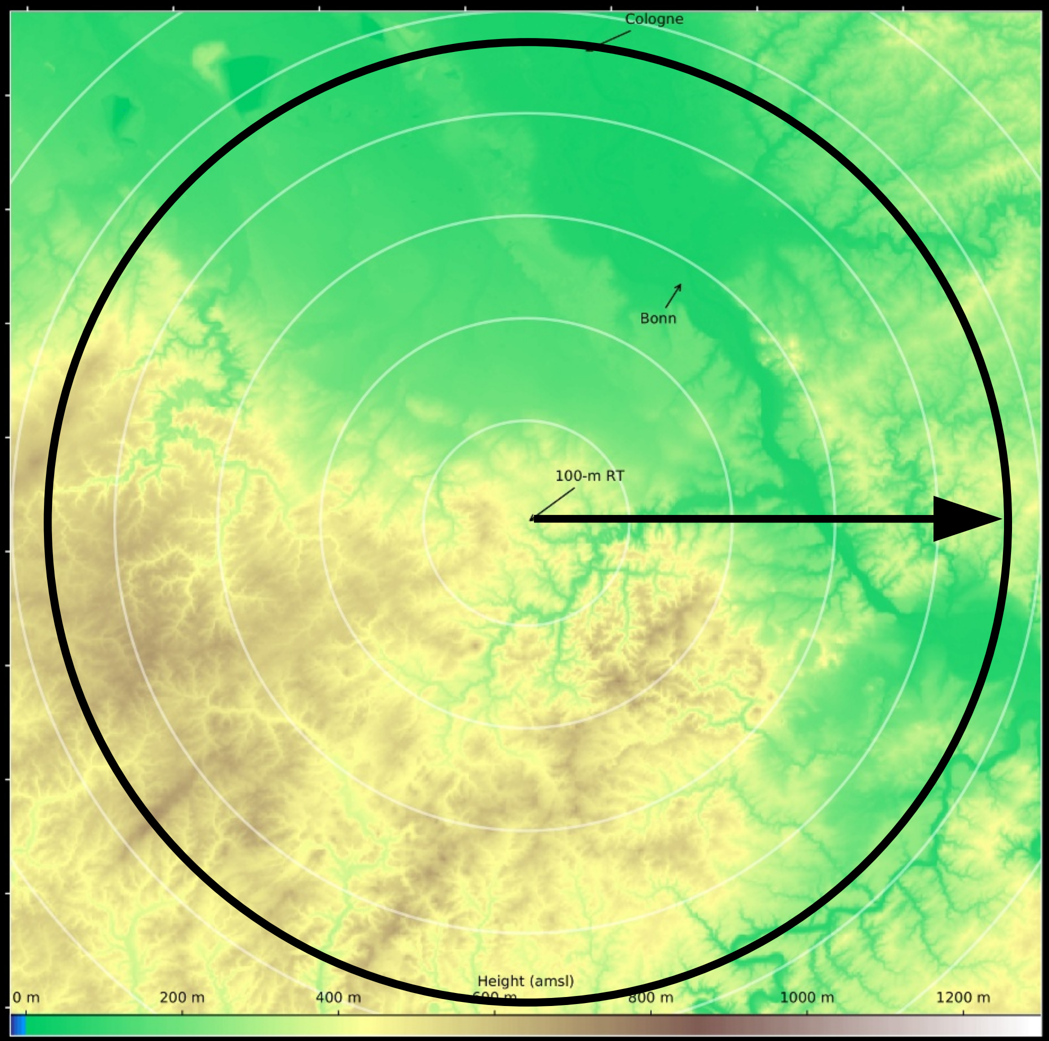


# Propagation loss maps

- Query height profiles
- $O(n^3)$ problem
- Memoization



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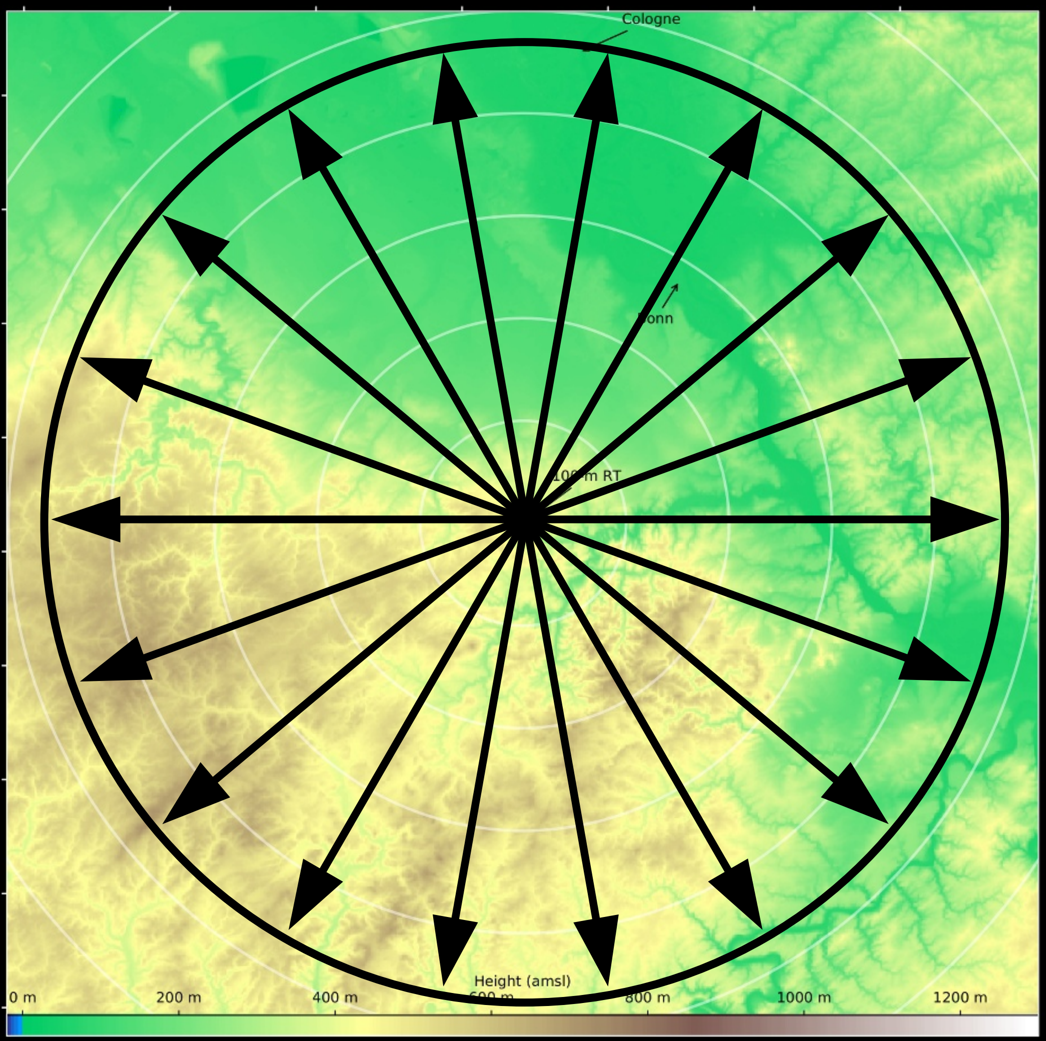
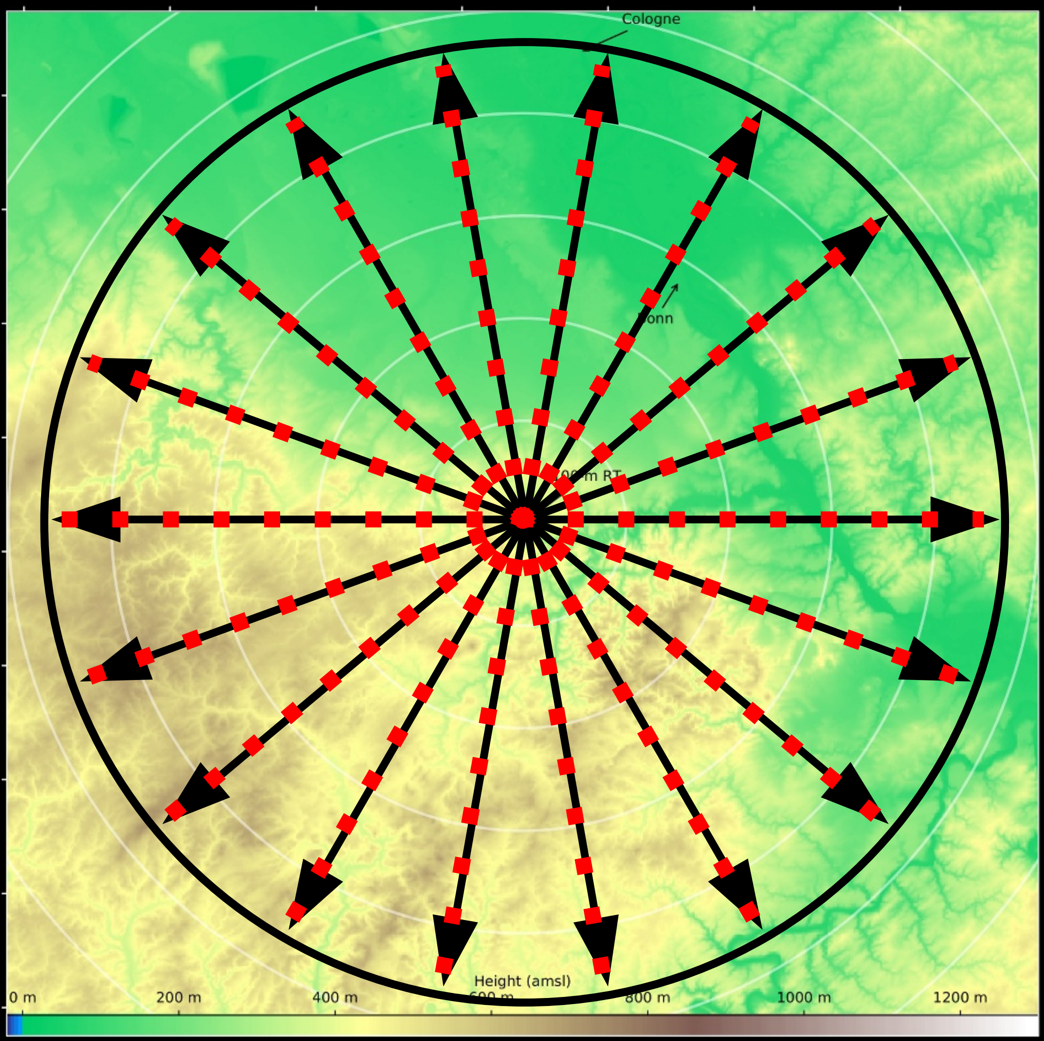


# Propagation loss maps

- Query height profiles
- $O(n^3) \rightarrow O(n^2)$ problem
- Memoization
  → Look-up table
  (can be stored on disk)



# Propagation loss maps

- Query height profiles
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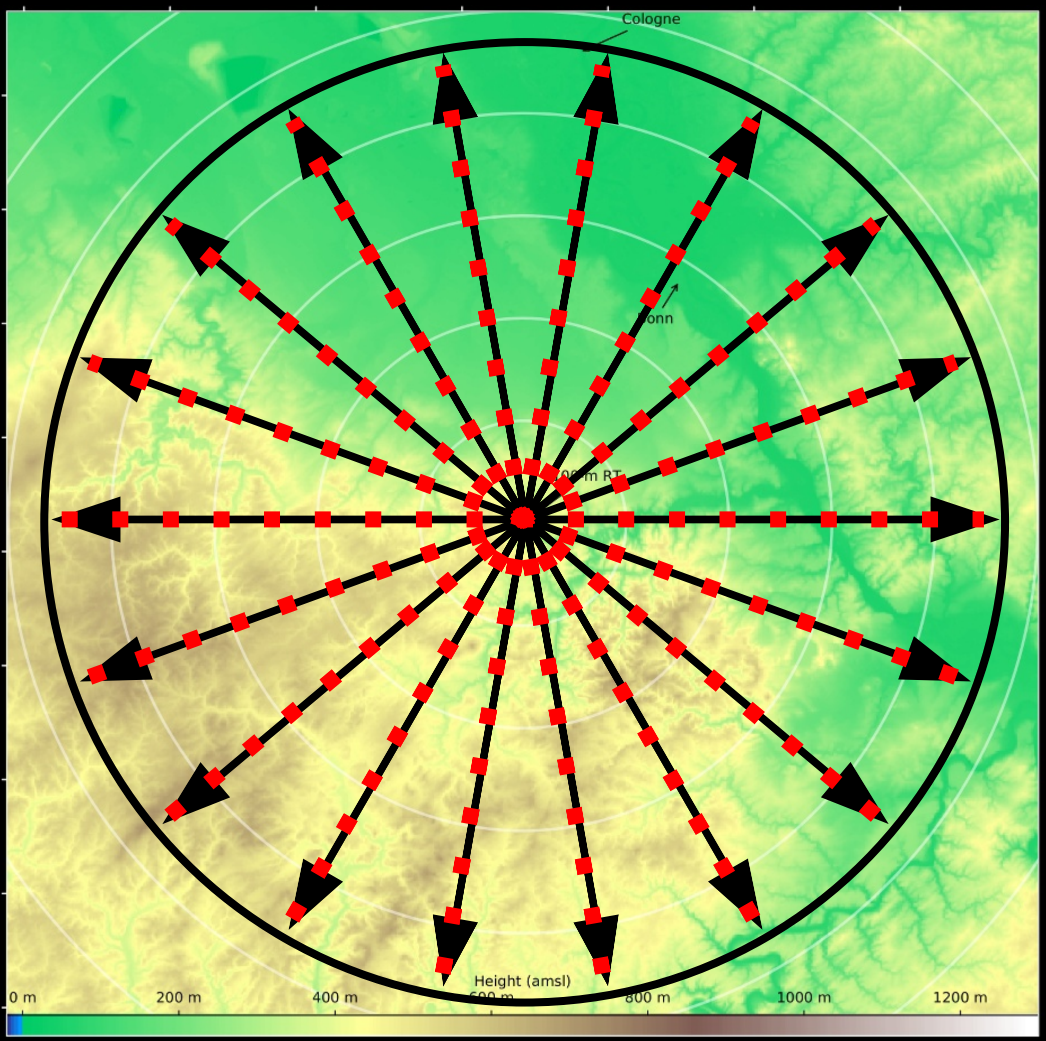
- Memoization
- Parallelization

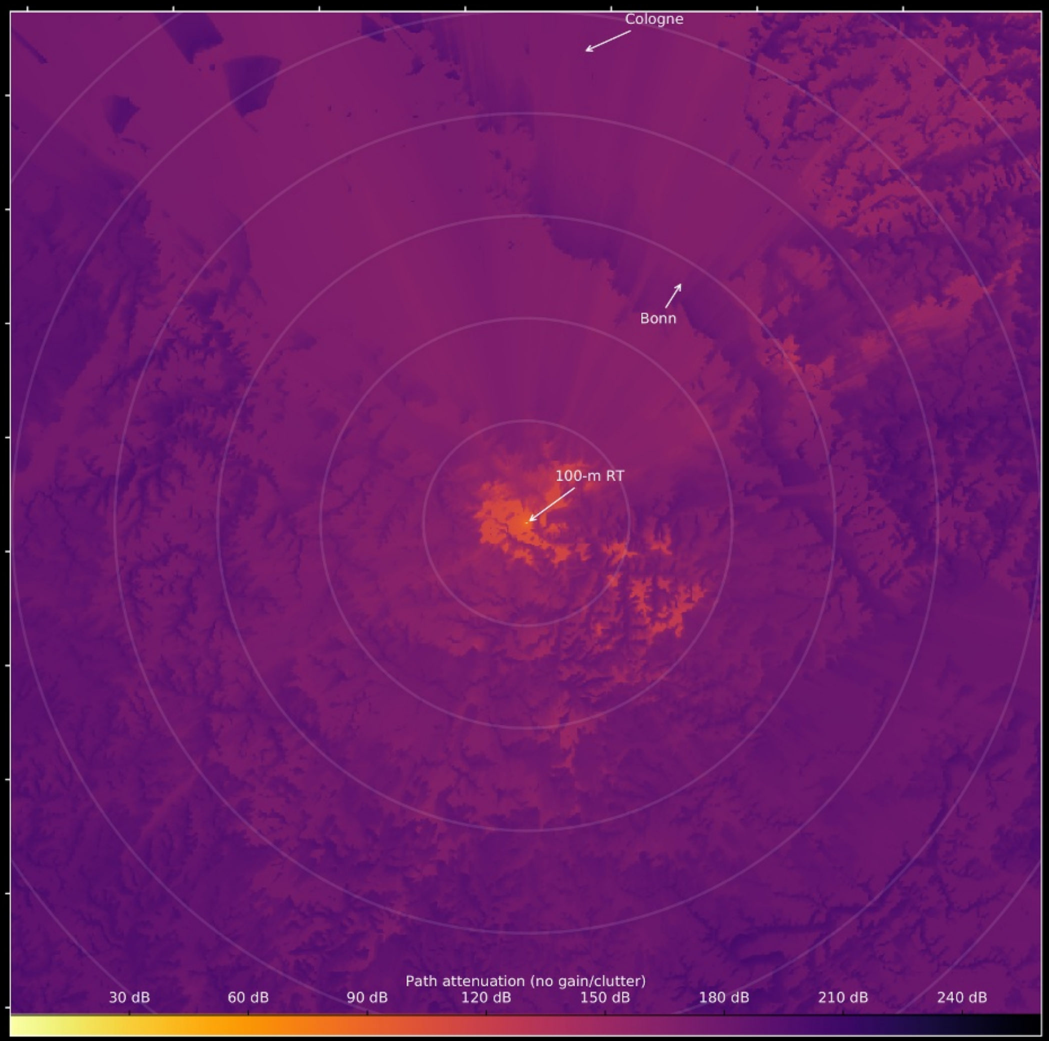
  → Cython



# Propagation loss maps

- Query height profiles
- $O(n^3) \rightarrow O(n^2)$ problem
- Memoization
- Parallelization
- Cython

1−2 dex faster than other implementations



# Conclusions

- Spectrum management is vital for radio astronomy
- Python package, “pycraf”, for compatibility studies
- First optimize algorithms, then code

# Backup slides

# World Radiocomm. Conference

- Updates radio regulations
  - Frequency table
  - Footnotes
  - Procedures
- Meets every 3−4 yrs
- Decides on “Agenda Items” (for next WRC)
  - AIs are studied in working groups
  - Changing RRs needs ≳5 years

# Allocation tables

**10.7-11.7 GHz**

| Allocation to services | | |
|---|---|---|
| **Region 1** | **Region 2** | **Region 3** |
| **10.7-10.95**<br>FIXED<br>FIXED-SATELLITE<br>(space-to-Earth) 5.441<br>(Earth-to-space) 5.484<br>MOBILE except aeronautical mobile | **10.7-10.95**<br>FIXED<br>FIXED-SATELLITE (space-to-Earth) 5.441<br>MOBILE except aeronautical mobile | |
| **10.95-11.2**<br>FIXED<br>FIXED-SATELLITE<br>(space-to-Earth) 5.484A 5.484B<br>(Earth-to-space) 5.484<br>MOBILE except aeronautical mobile | **10.95-11.2**<br>FIXED<br>FIXED-SATELLITE (space-to-Earth) 5.484A 5.484B<br>MOBILE except aeronautical mobile | |
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ITU-R Radio Regulations 2016

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ITU-R Radio Regulations 2016

# IMT2020 / 5G

New spectrum requested (WRC-19 cycle; AI 1.13)

- 24.25–27.50
- 31.80–33.40
- 37.00–40.50
- 40.50–42.50
- 42.50–43.50
- 45.50–47.00
- 47.00–47.20
- 47.20–50.20
- 50.40–52.60
- 66.00–76.00
- 81.00–86.00

GHz

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GHz

*Potentially affecting RAS*

$\boxed{\phantom{xx}}$ *Favored by Europe*

# 5G base stations: beam-forming

28 GHz, 8x8

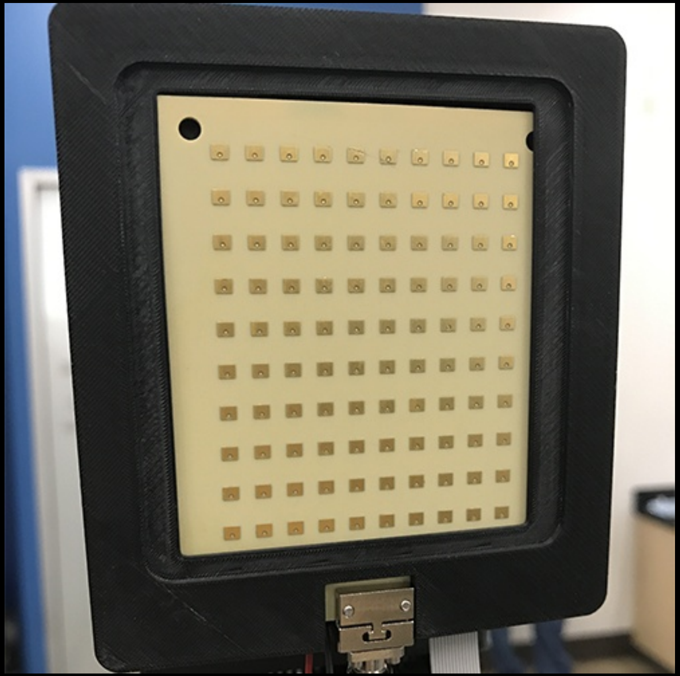
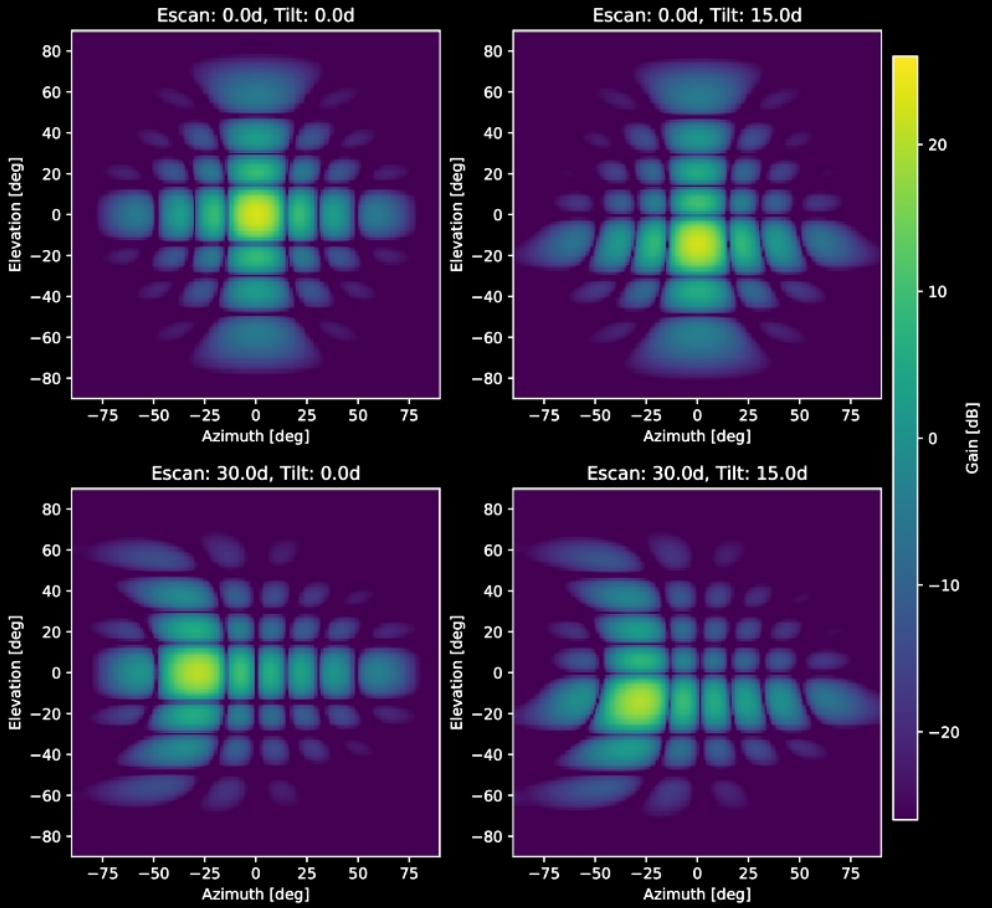
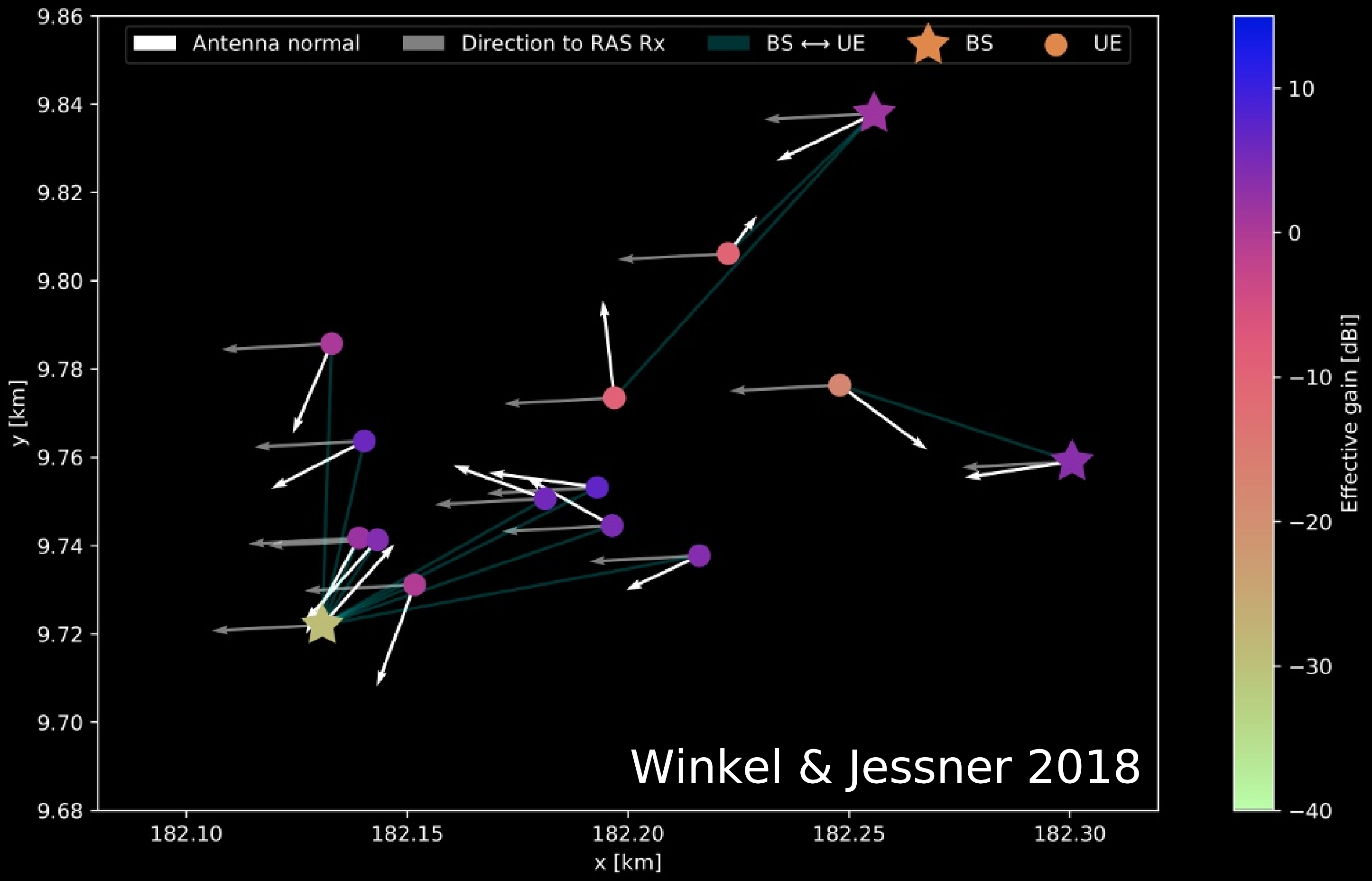


Image: UCSD

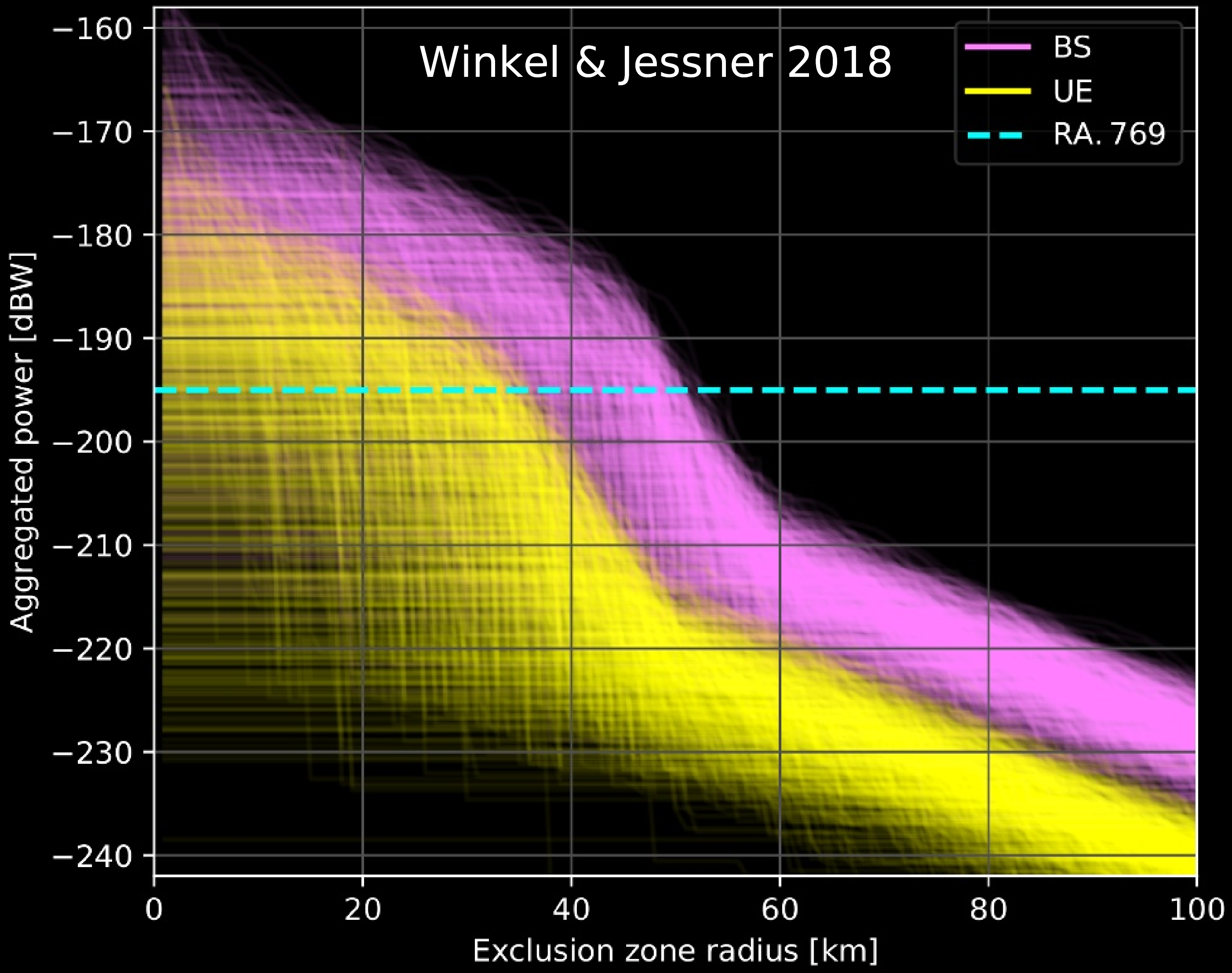



Winkel & Jessner 2018

# Aggregation: simulating a network



# 5G: results



Winkel & Jessner 2018
BS
UE
RA. 769
Aggregated power [dBW]
−160
−170
−180
−190
−200
−210
−220
−230
−240
0
20
40
60
80
100
Exclusion zone radius [km]