Compatibility between Radioastronomical Observations and Wind Turbines

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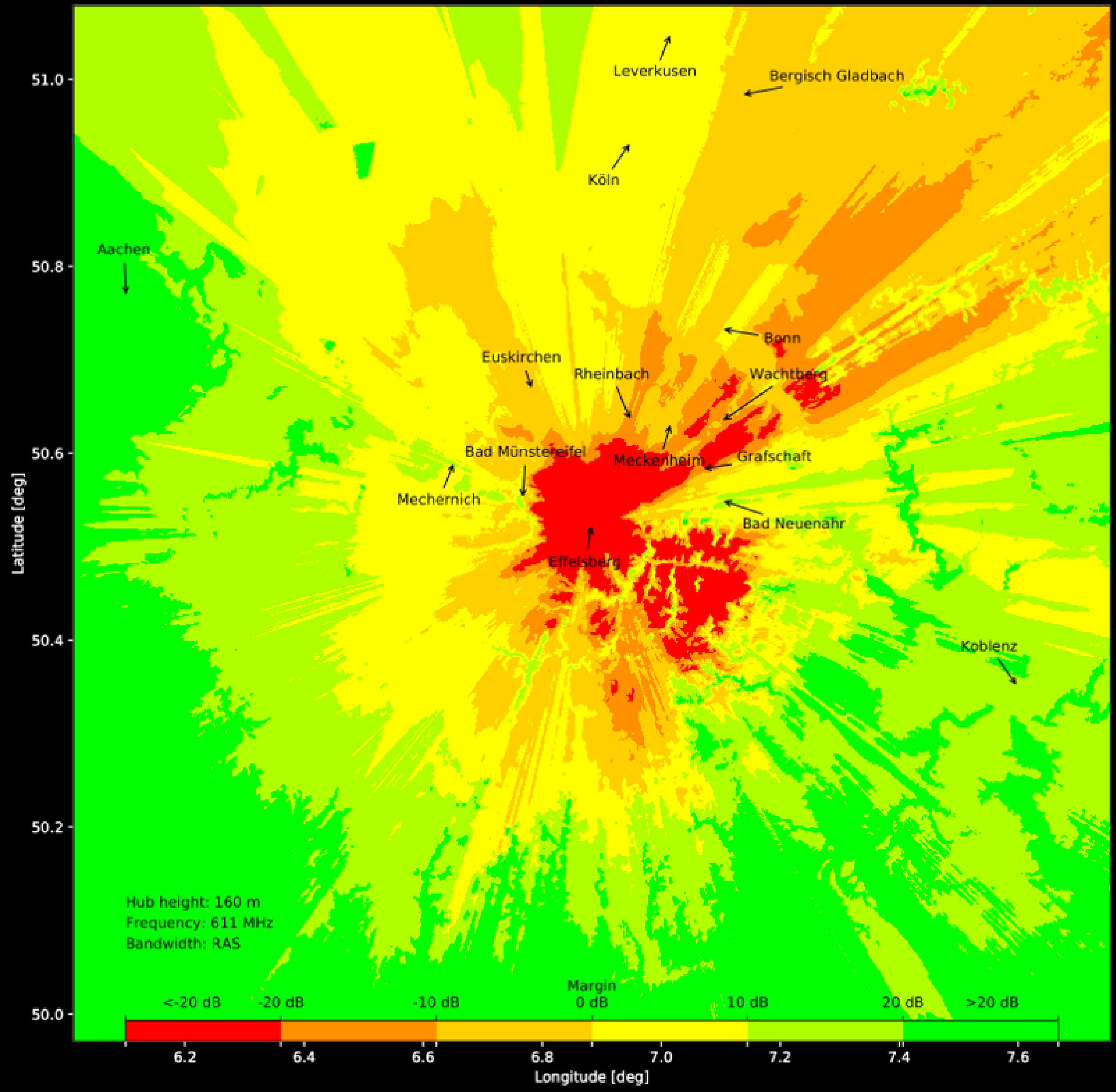
Axel Jessner



Max-Planck-Institut für Radioastronomie

Overview

- Introduction: radio astronomy
- Wind turbines and the 100-m telescope
  - Spectrum management
  - Compatibility calculations
- Conclusions

Introduction – Radio astronomy

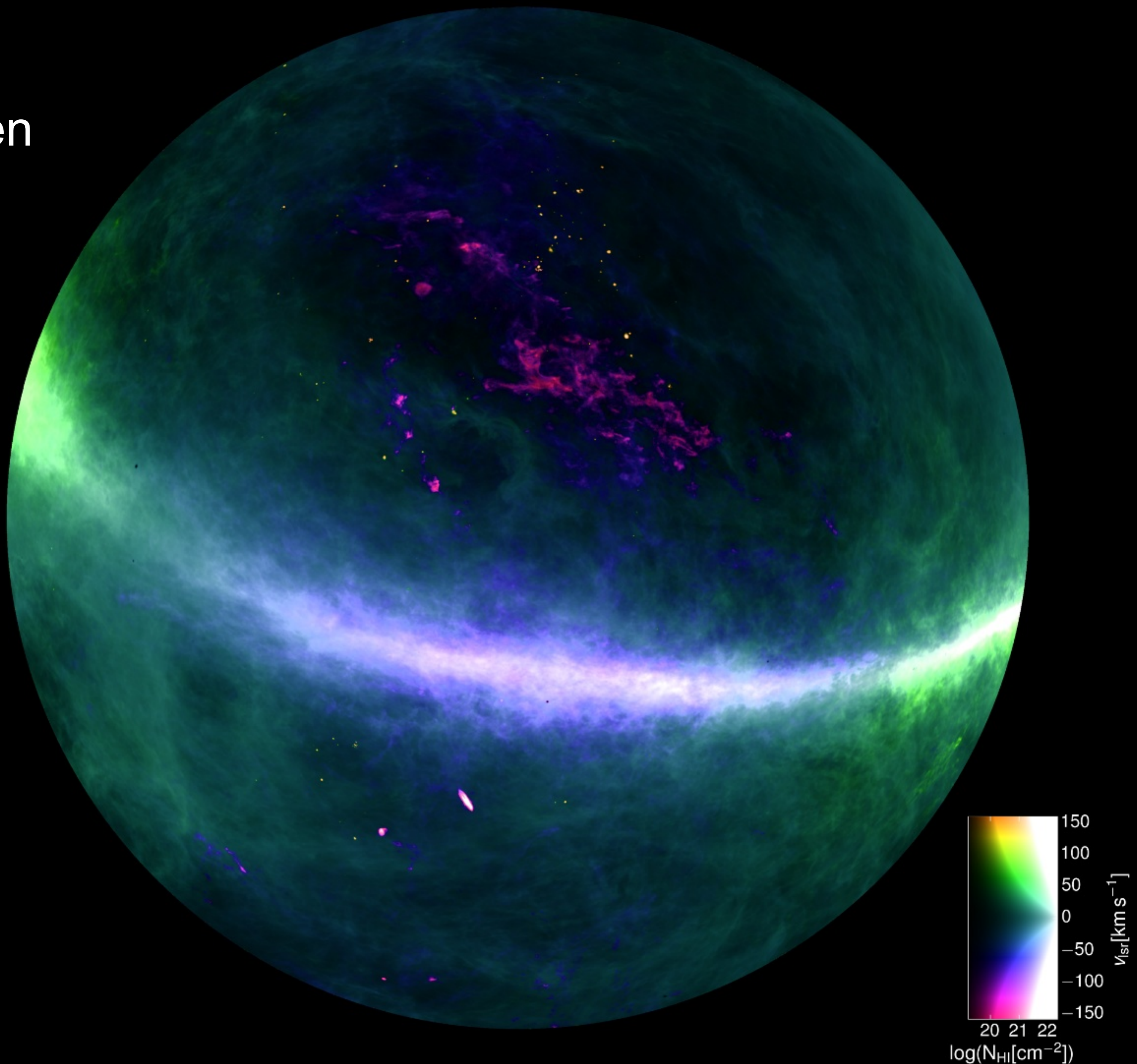
Effelsberg 100-m telescope

- Antenna gain: ~80 dBi
- Receivers:
  - 0.3 – 90 GHz
  - cooled to 20 K
  - T_{sys}: 15 – 100 K
- Long integrations to decrease noise; up to days
- Sensitivity: $<10^{-29}$ W/m^2/Hz

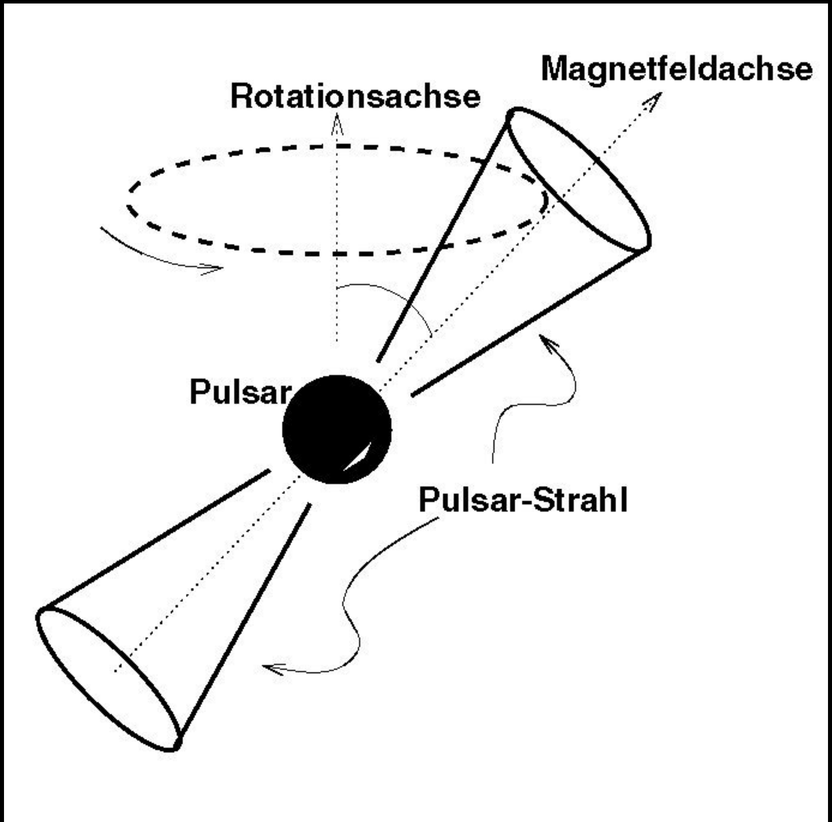
Introduction – Radio astronomy

EBHIS:

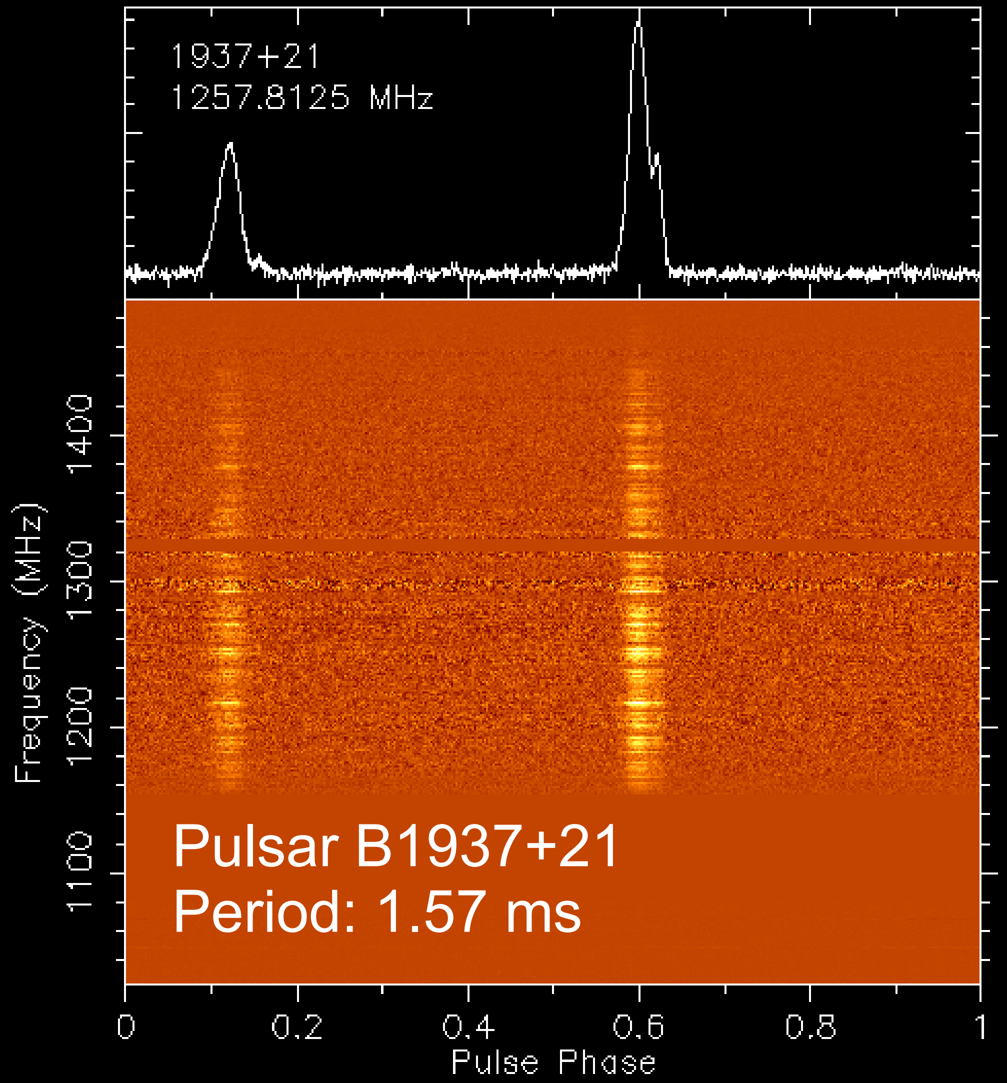
Neutral hydrogen spectroscopy @ 1.4 GHz



Introduction – Radio astronomy



Magnetic field ~ 10^{15} G

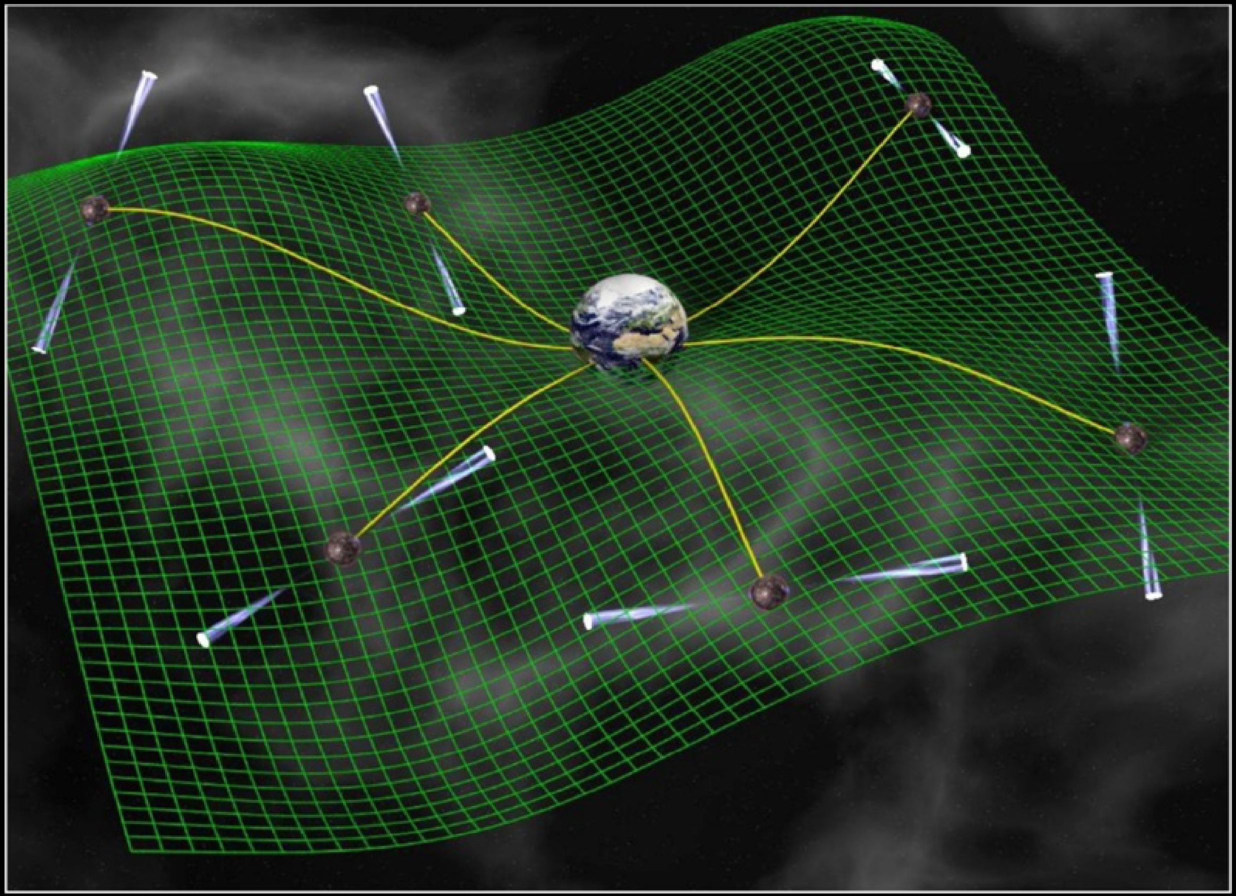


Introduction – Radio astronomy

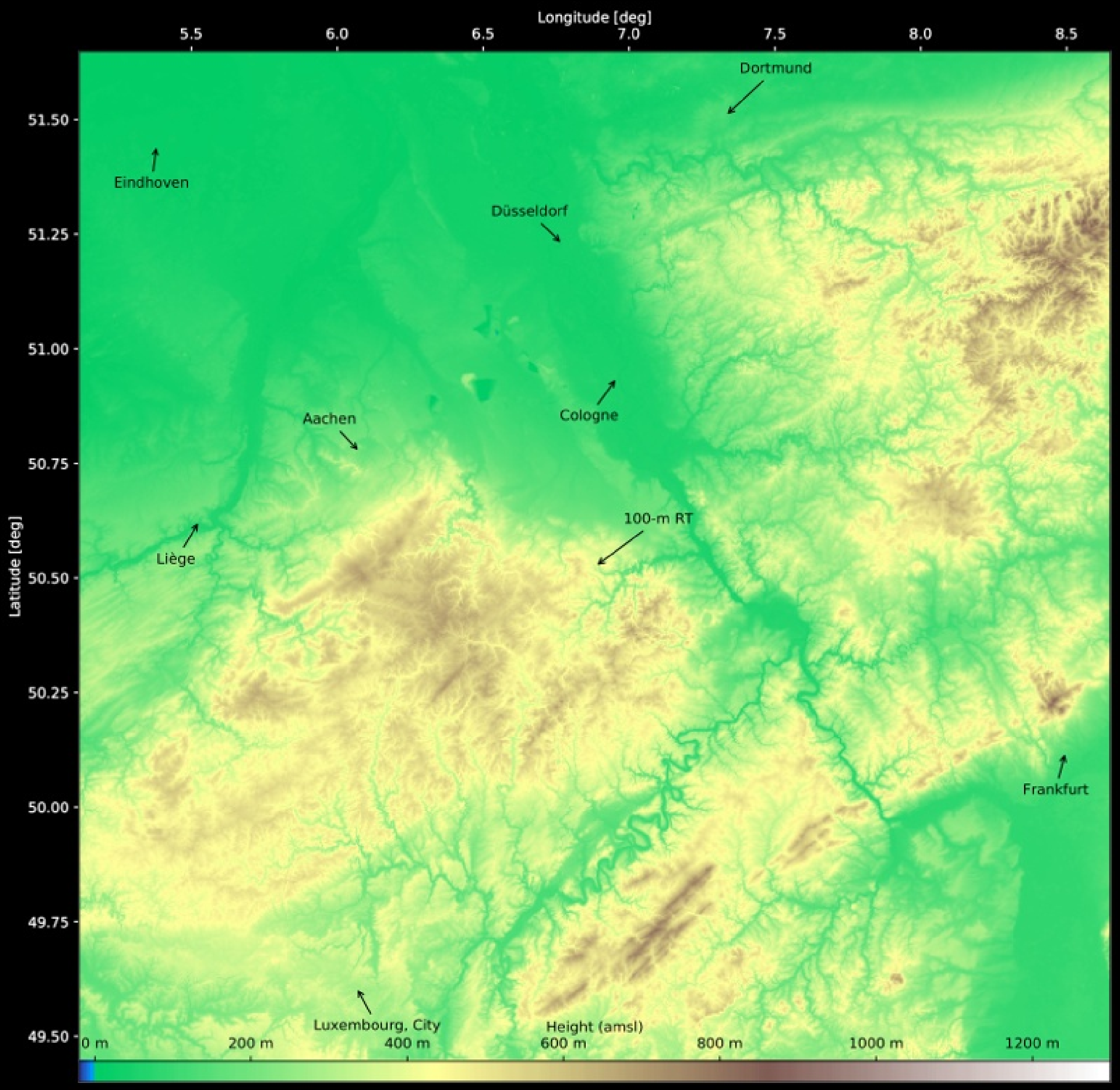
Some Pulsars have extremely regular periods:

PSR J0437-4715
Period: 5.757451924362137(2) ms

→ Detect gravitational waves?



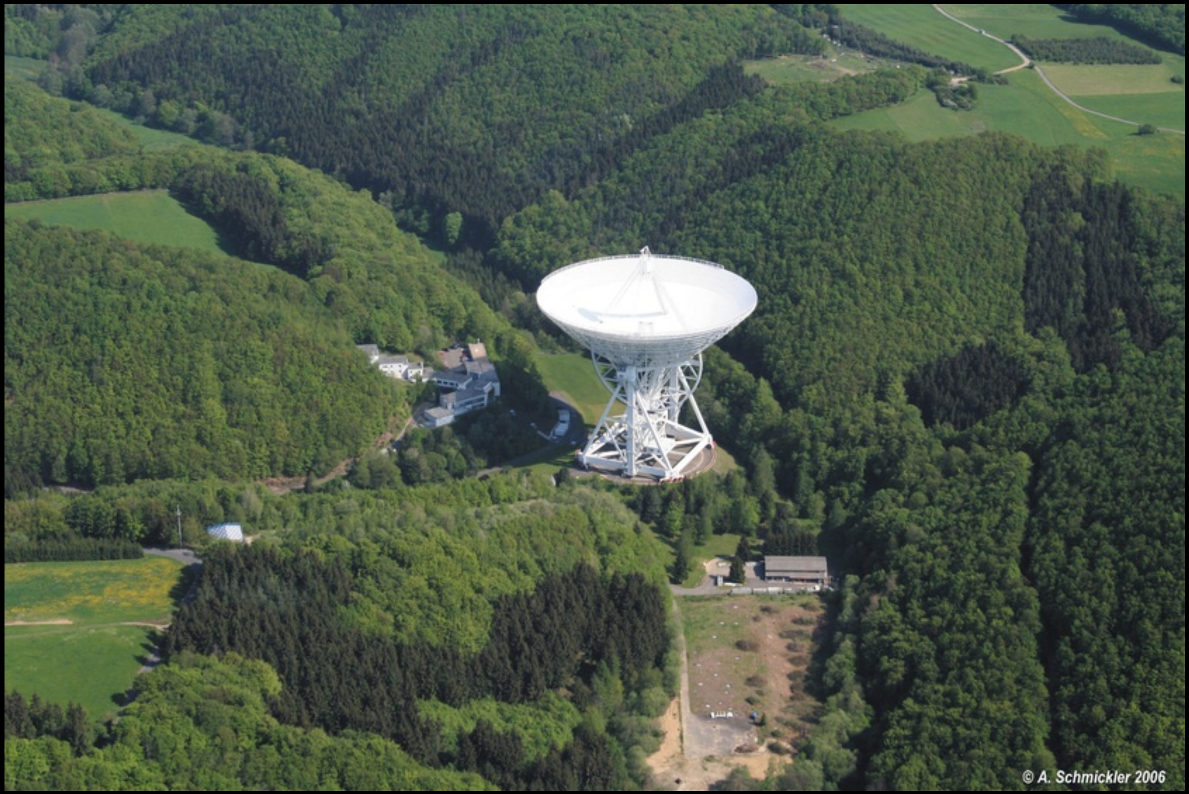
Introduction – Radio astronomy



100-m telescope

- Located in the northern Eifel region

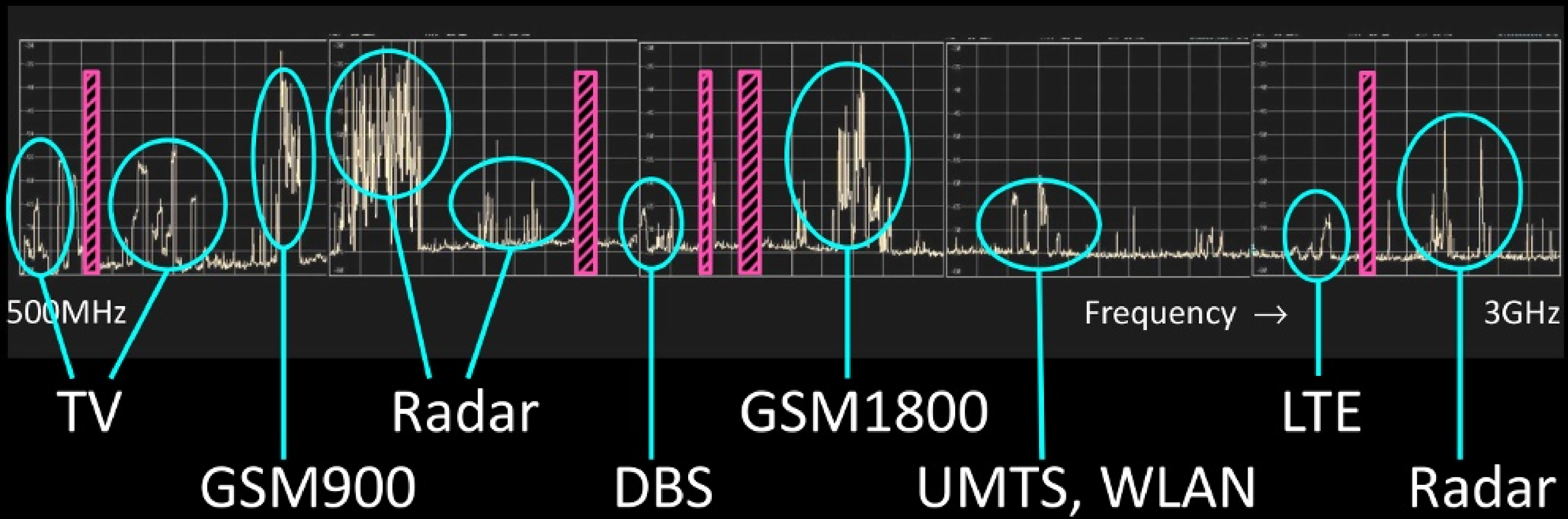
Introduction – Radio astronomy



100-m telescope

- Located in the northern Eifel region
- Inside a valley
  → natural shielding
- Spectrum coordination (via BNetzA)

Introduction – Radio astronomy



- Still a lot of radio frequency interference

Sources of RFI

Radiocommunication services

- Mobile service
- RADAR (civil, military)
  - Weather radar
  - Parking assistant
  - Earth sensing
- Broadcasting (radio, DVB-T)
- Navigation
- WiFi, Bluetooth, etc.
- Amateur radio
- Fixed links

Unwanted emission (EMI)

- Out-of-band emission of radiocomm. services
- Digital electronics
- Industrial devices
  → Wind turbines
- Electrical devices

Introduction – Radio astronomy

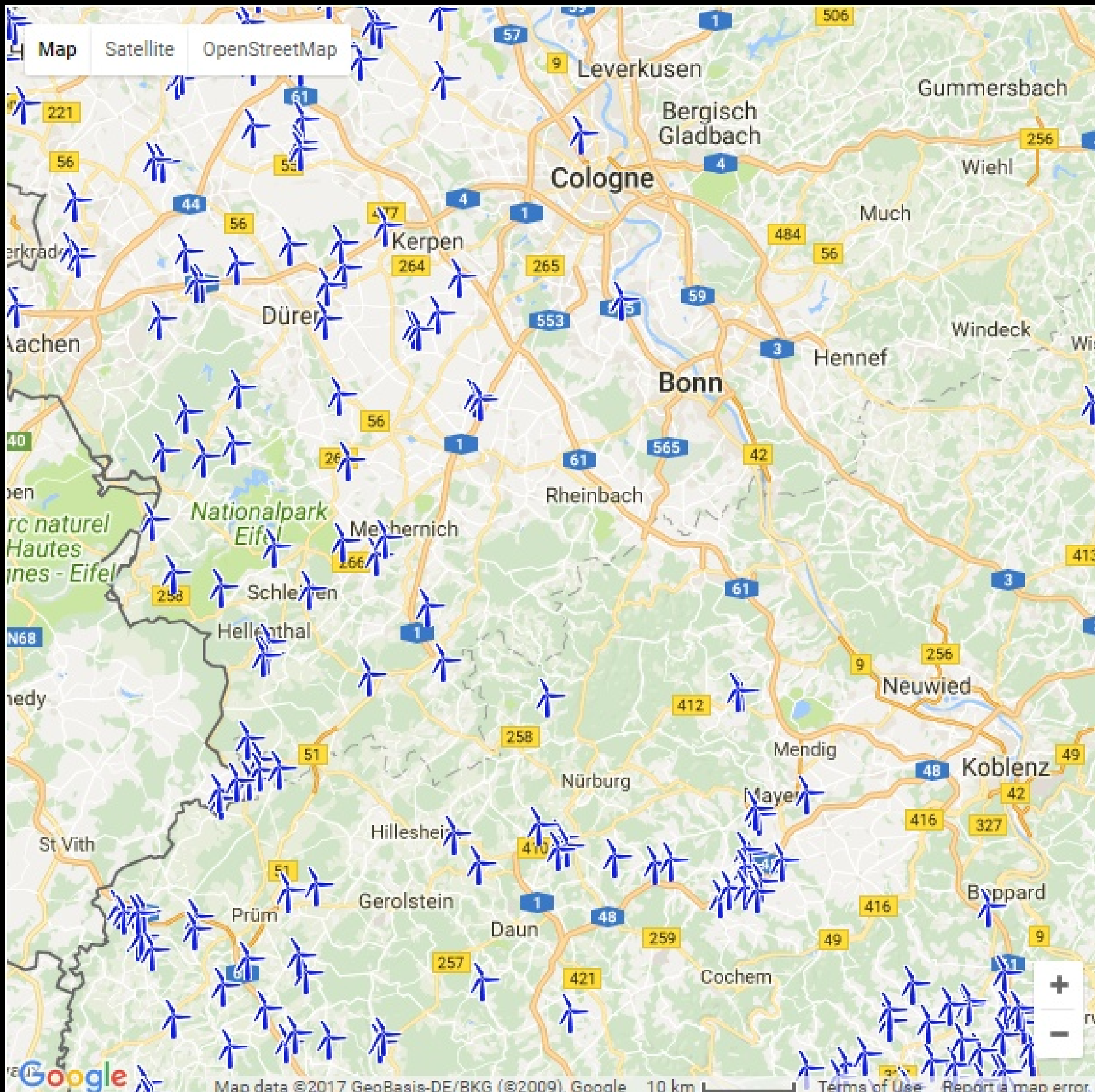
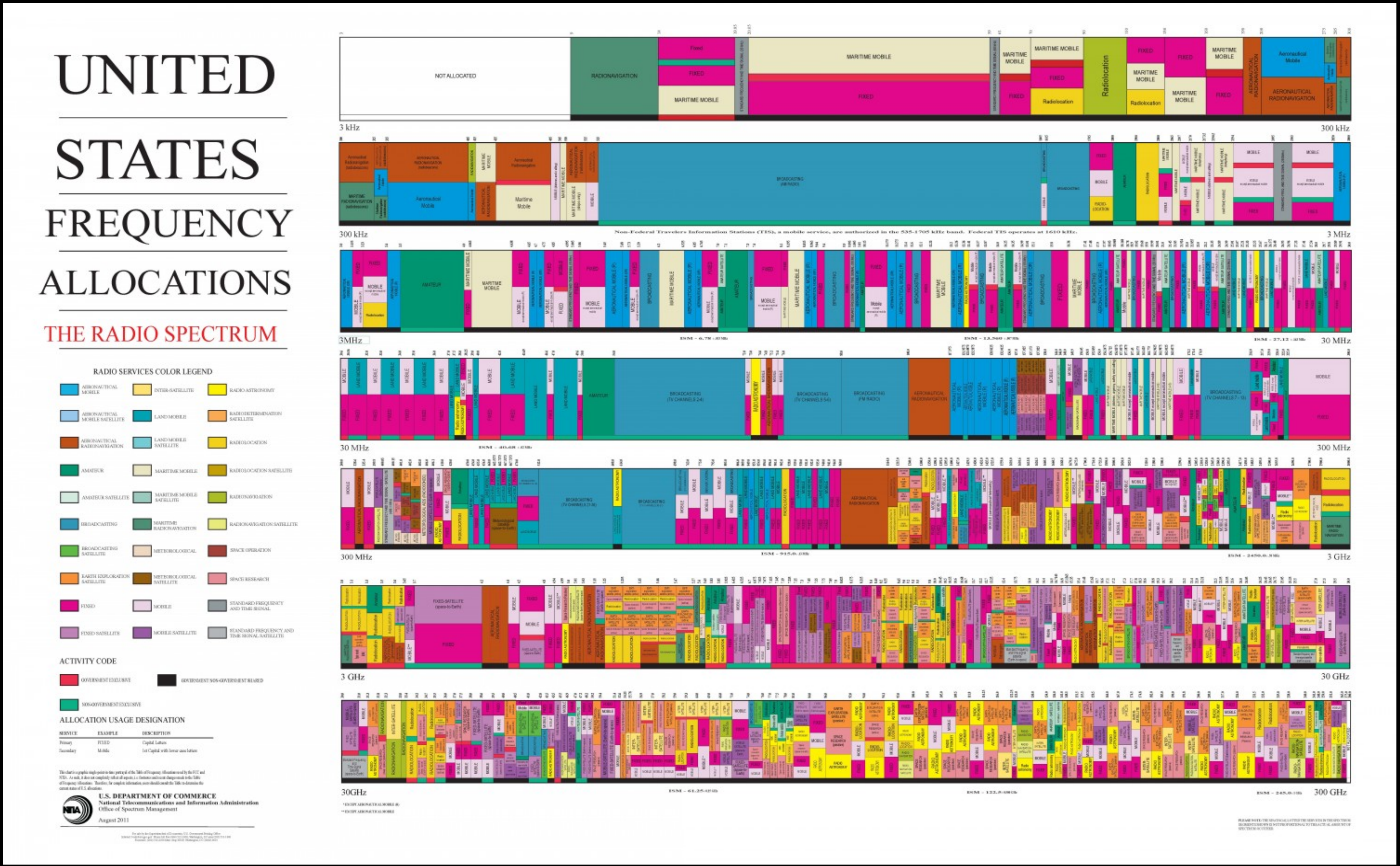


Image: www.proplanta.de

100-m telescope

- Located in the northern Eifel region
- Inside a valley → natural shielding
- Spectrum coordination (via BNetzA)
- Still a lot of radio frequency interference
- Many wind turbines beyond ~30 km

Spectrum management



Spectrum management

Wind turbines are no radiocomm. services

- Not subject to coordination by administration (BNetzA)
- EMI rules apply:
  - EN 55011 (CISPR-11), Group 1, Class A
    f < 230 MHz: 30 $dB_{\mu V/m}$
    f ≥ 230 MHz: 37 $dB_{\mu V/m}$
    (@ 30m, QP detector)

Spectrum management

RECOMMENDATION ITU-R RA.769-2

Protection criteria used for radio astronomical measurements

(Question ITU-R 145/7)

(1992-1995-2003)

The ITU Radiocommunication Assembly,

considering

a) that many of the most fundamental astronomical advances made in the past five decades, (e.g. the discovery of radio galaxies, quasars, and pulsars, the direct measurement of neutral hydrogen, the direct measurement of distances of certain external galaxies, and establishment of a positional reference frame accurate to ~20 arc μs) have been made through radio astronomy, and that radio astronomical observations are expected to continue making fundamental contributions to our understanding of the Universe, and that they provide the only way to investigate some cosmic phenomena;

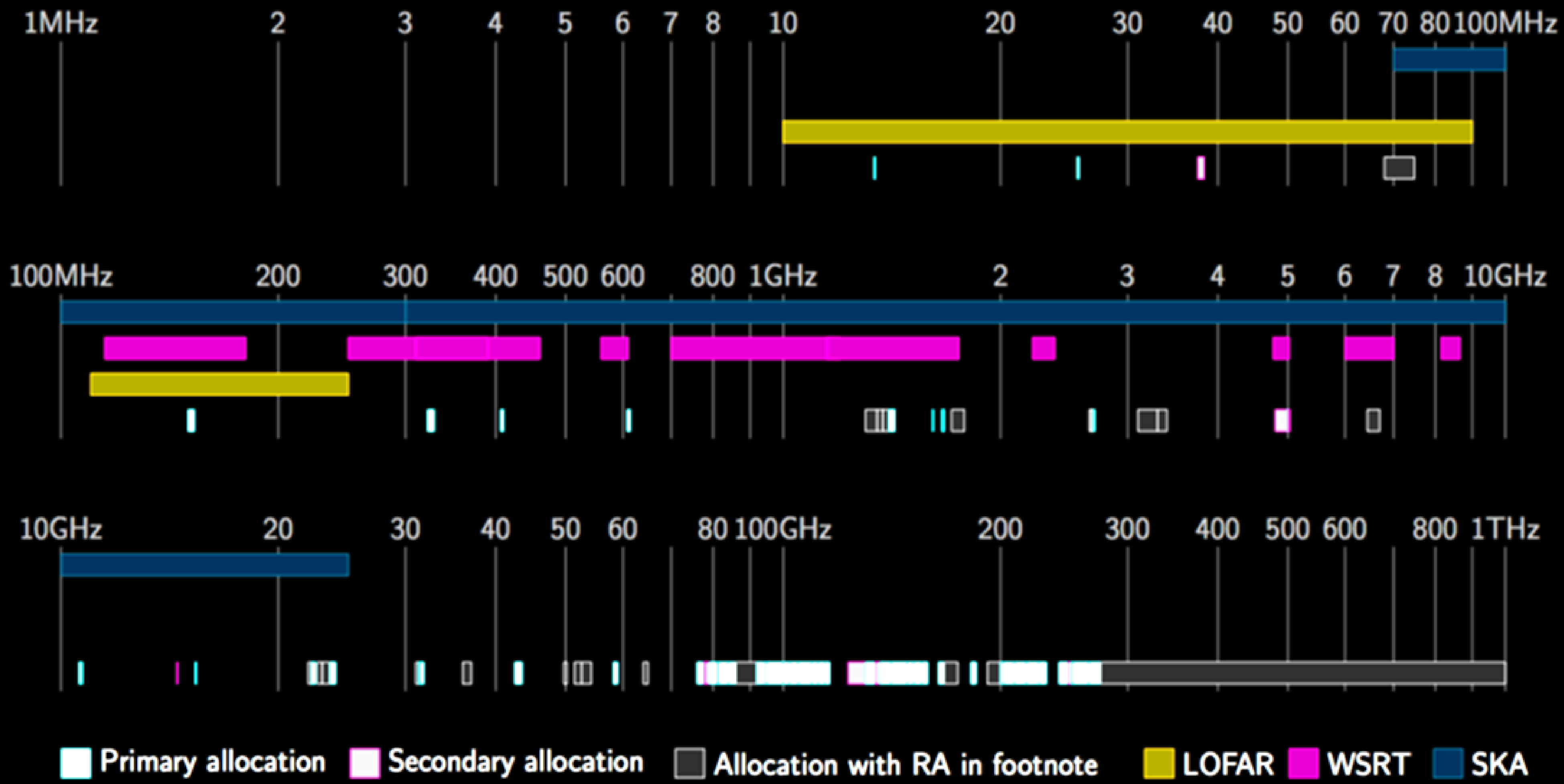
Spectrum management

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/m²))	Spectral pfd S_H (dB(W/(m² · 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
1 665	10	12	10	0.16	–267	–207	–181	–251
2 695	10	12	10	0.16	–267	–207	–177	–247
4 995	10	12	10	0.16	–267	–207	–171	–241
10 650	100	12	10	0.049	–272	–202	–160	–240
15 375	50	15	15	0.095	–269	–202	–156	–233
22 355	290	35	30	0.085	–269	–195	–146	–231
23 800	400	15	30	0.050	–271	–195	–147	–233
31 550	500	18	65	0.083	–269	–192	–141	–228
43 000	1 000	25	65	0.064	–271	–191	–137	–227
89 000	8 000	12	30	0.011	–278	–189	–129	–228
150 000	8 000	14	30	0.011	–278	–189	–124	–223
224 000	8 000	20	43	0.016	–277	–188	–119	–218
270 000	8 000	25	50	0.019	–276	–187	–117	–216

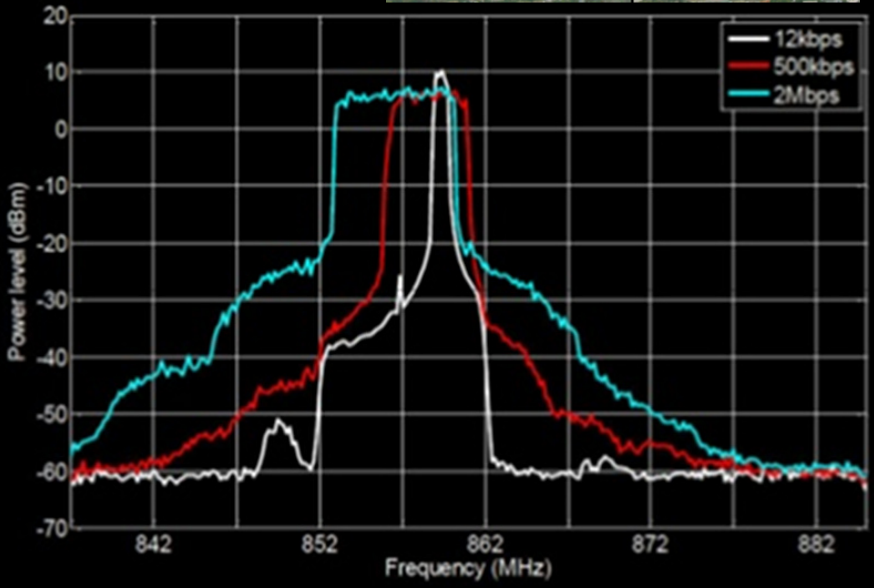
Spectrum management



Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer



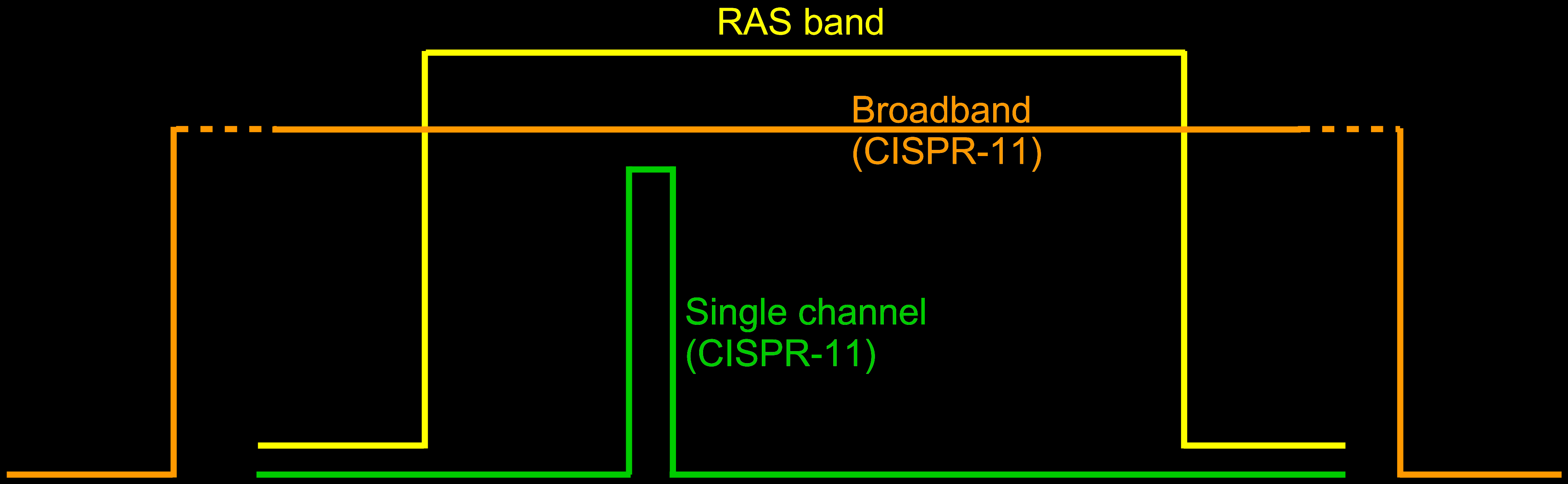
Source: Ofcom (August 2012)

Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer

Wind turbine spectrum not well known
→ make assumptions:



Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer
- Generate topographic maps (height profiles) from SRTM data

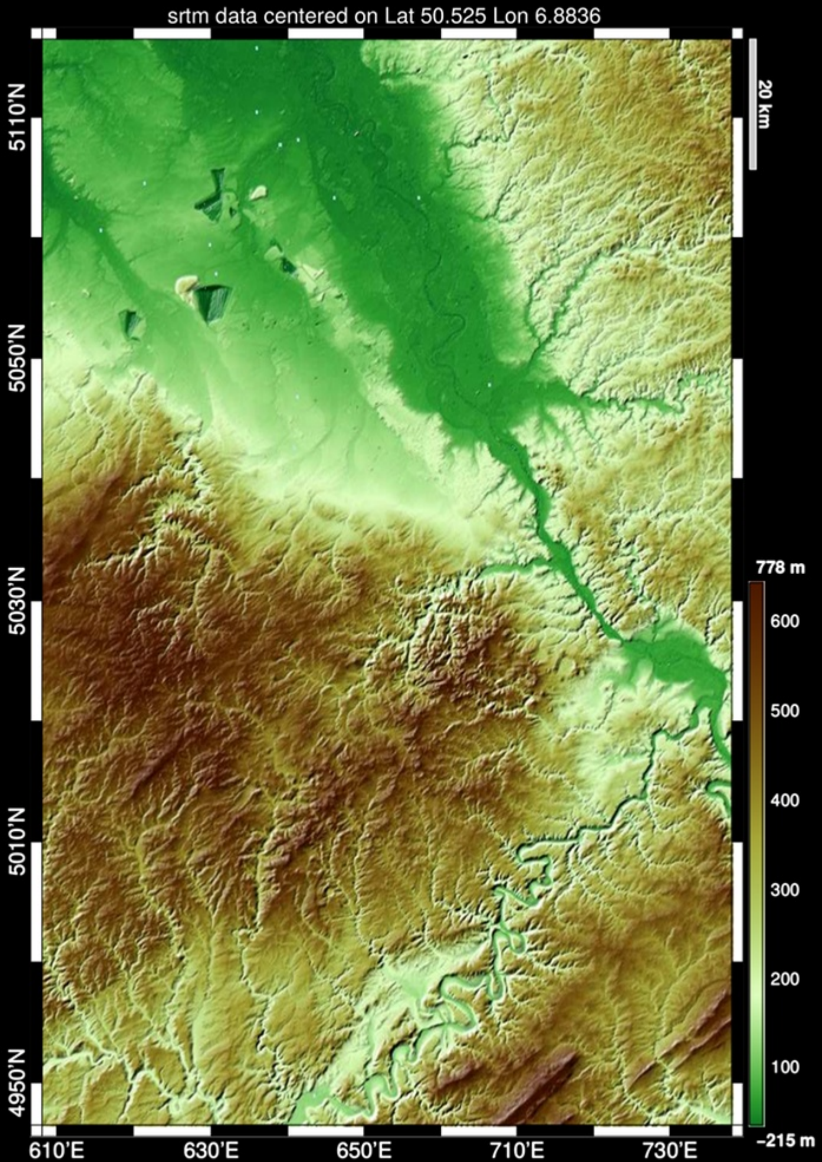
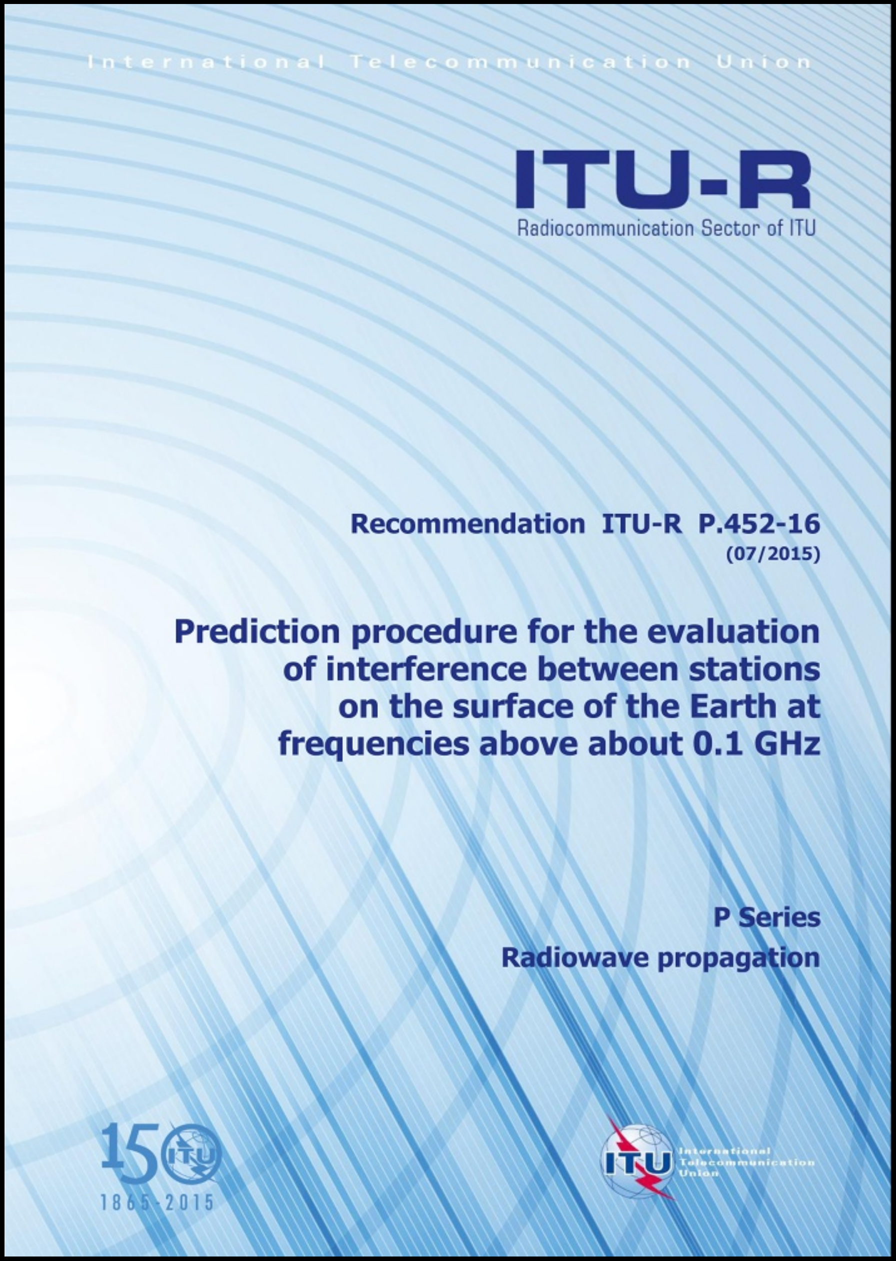


Image based on NASA/SRTM data

Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer
- Generate topographic maps (height profiles) from SRTM data
- Path propagation: implement ITU-R Recommendations



Compatibility: path propagation

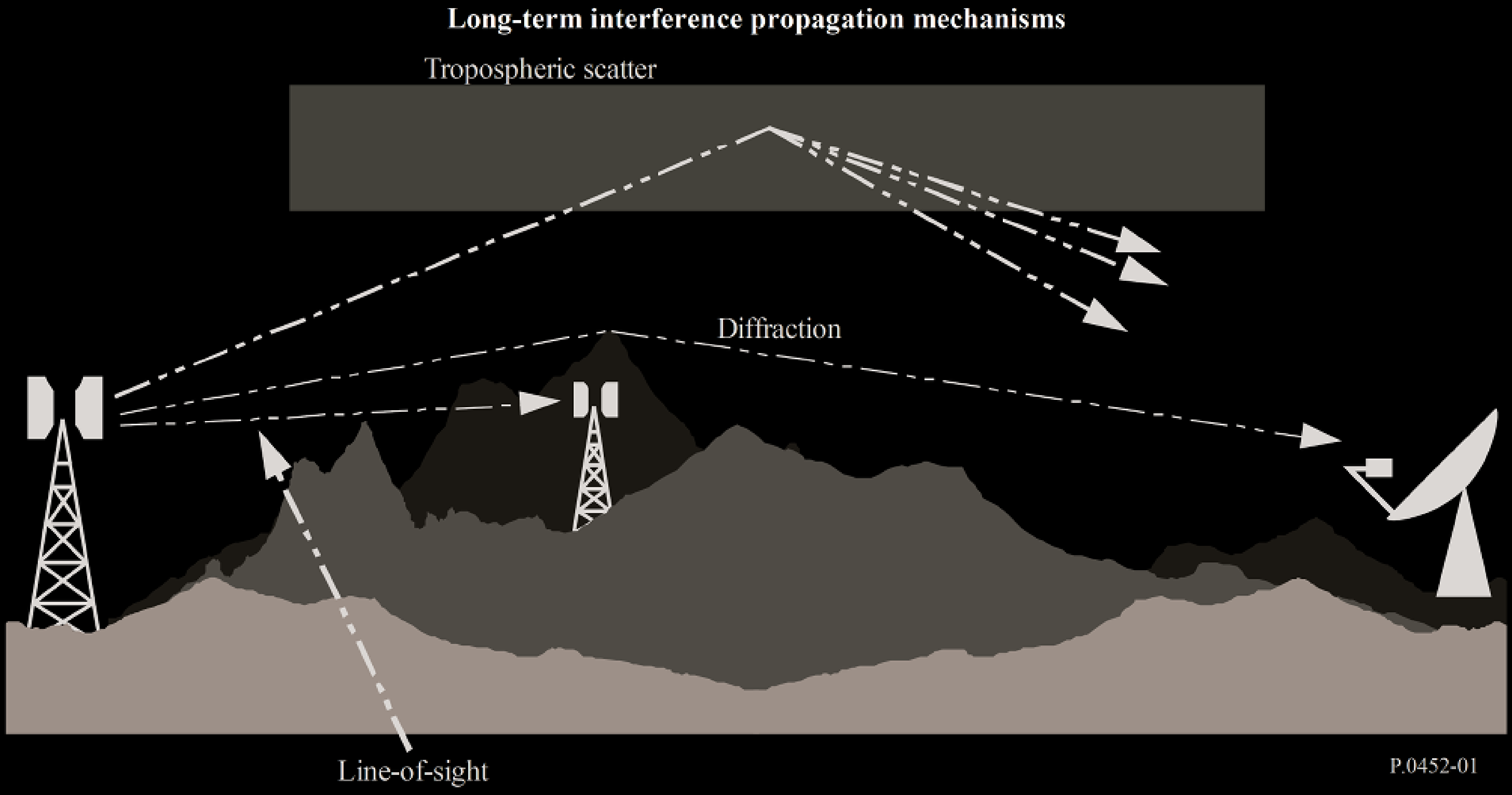


Image: ITU-R Rec. P.452-16

Compatibility: path propagation

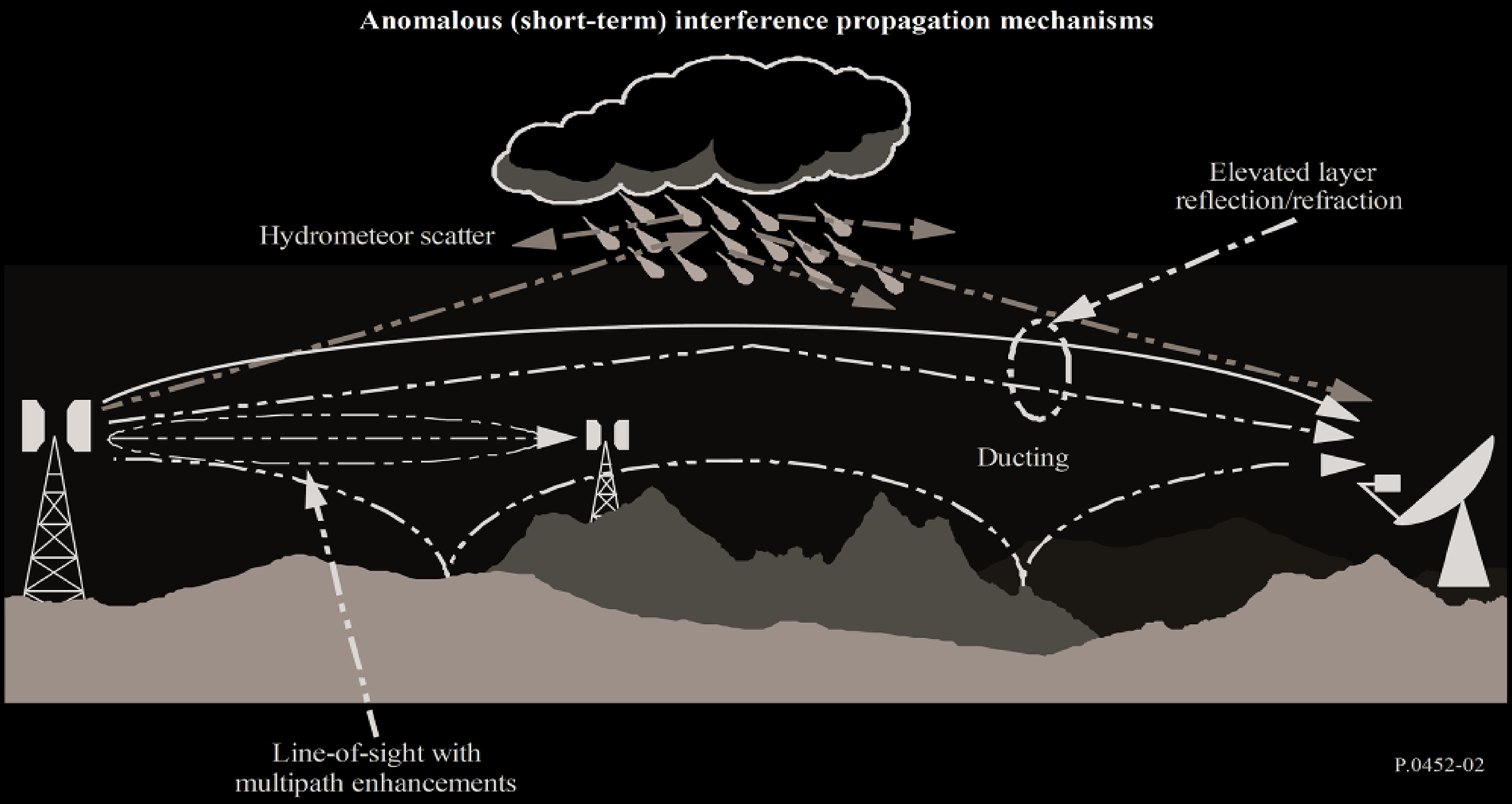
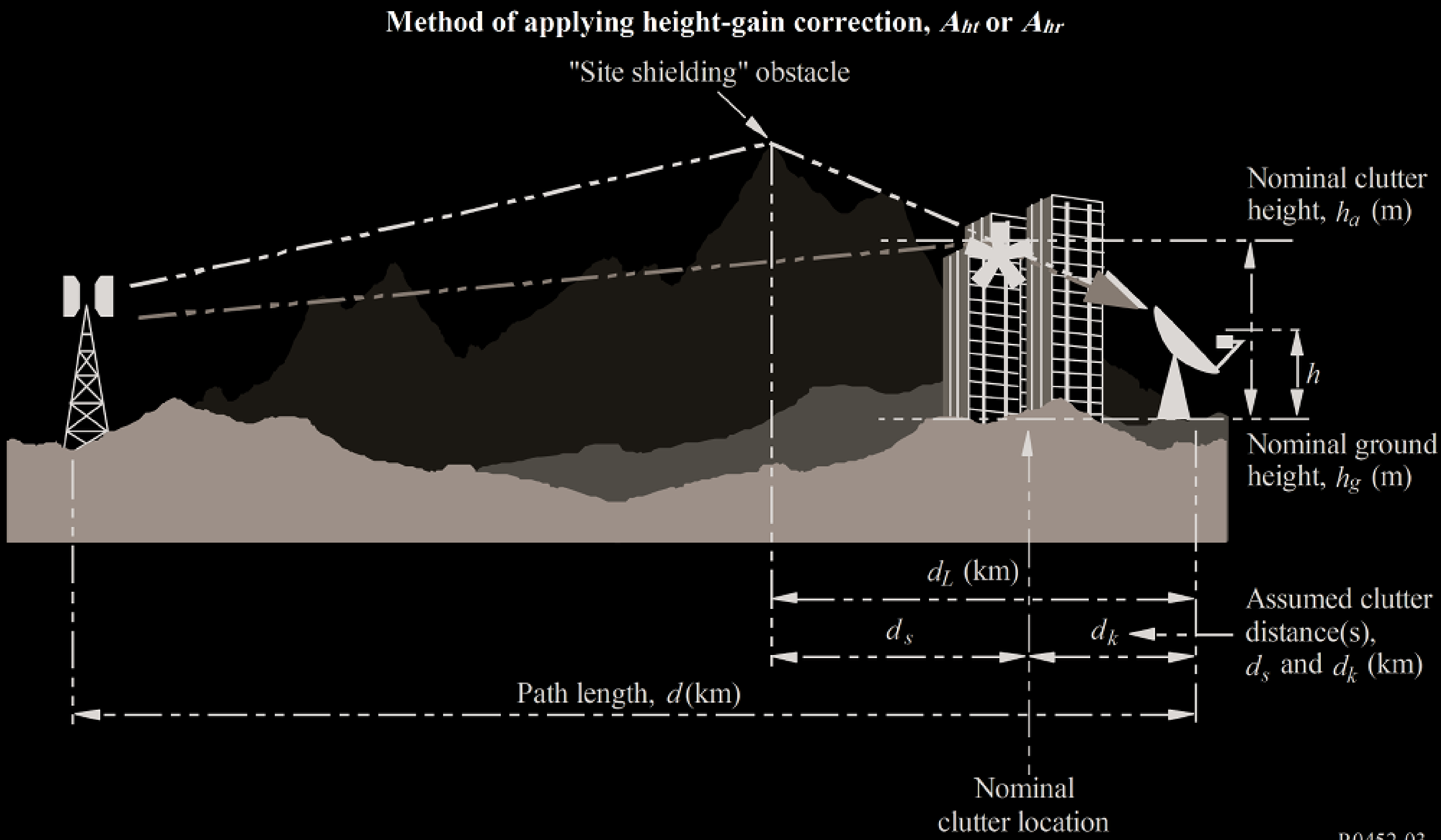


Image: ITU-R Rec. P.452-16

Compatibility: path propagation



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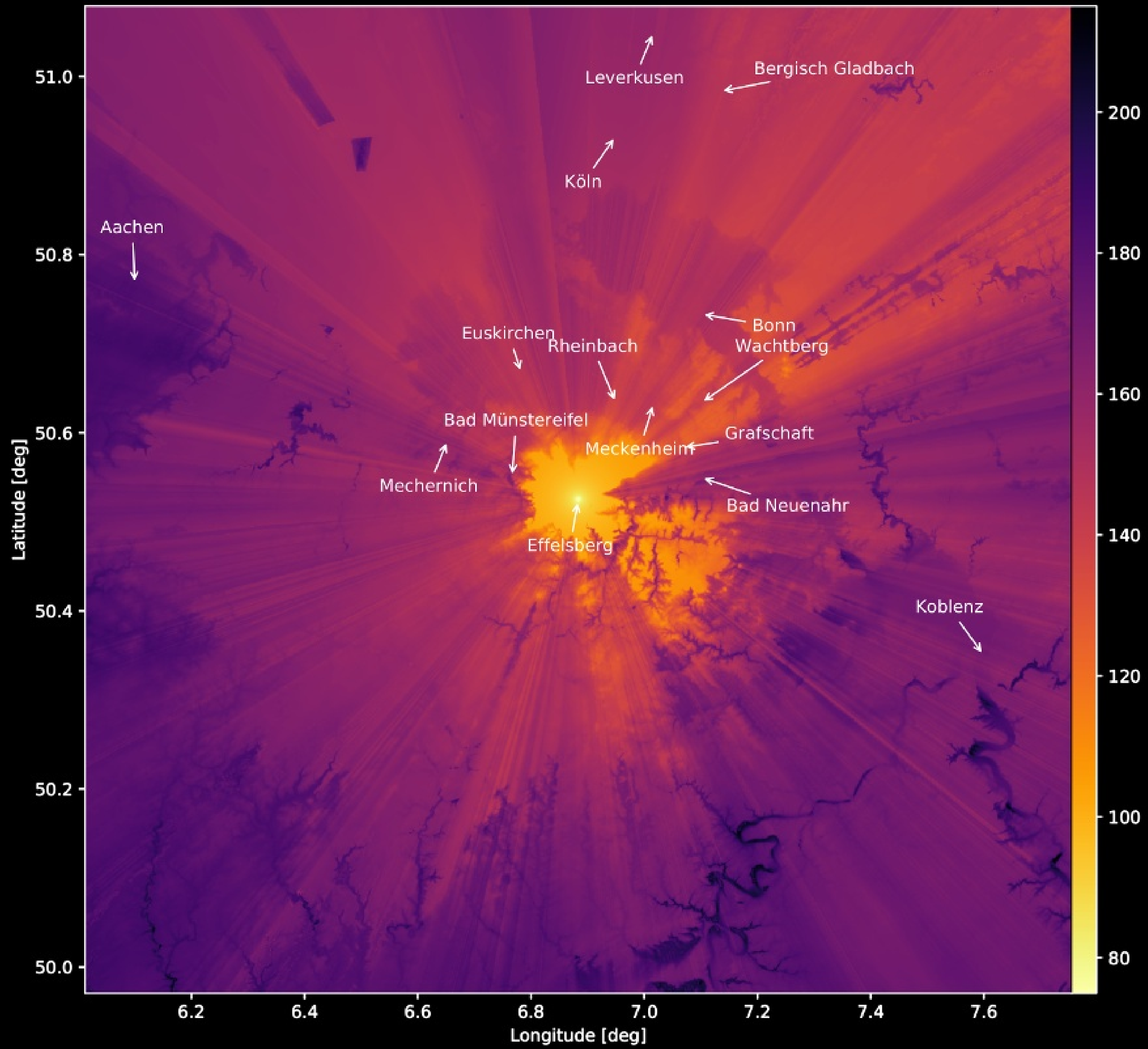
Compatibility calculations



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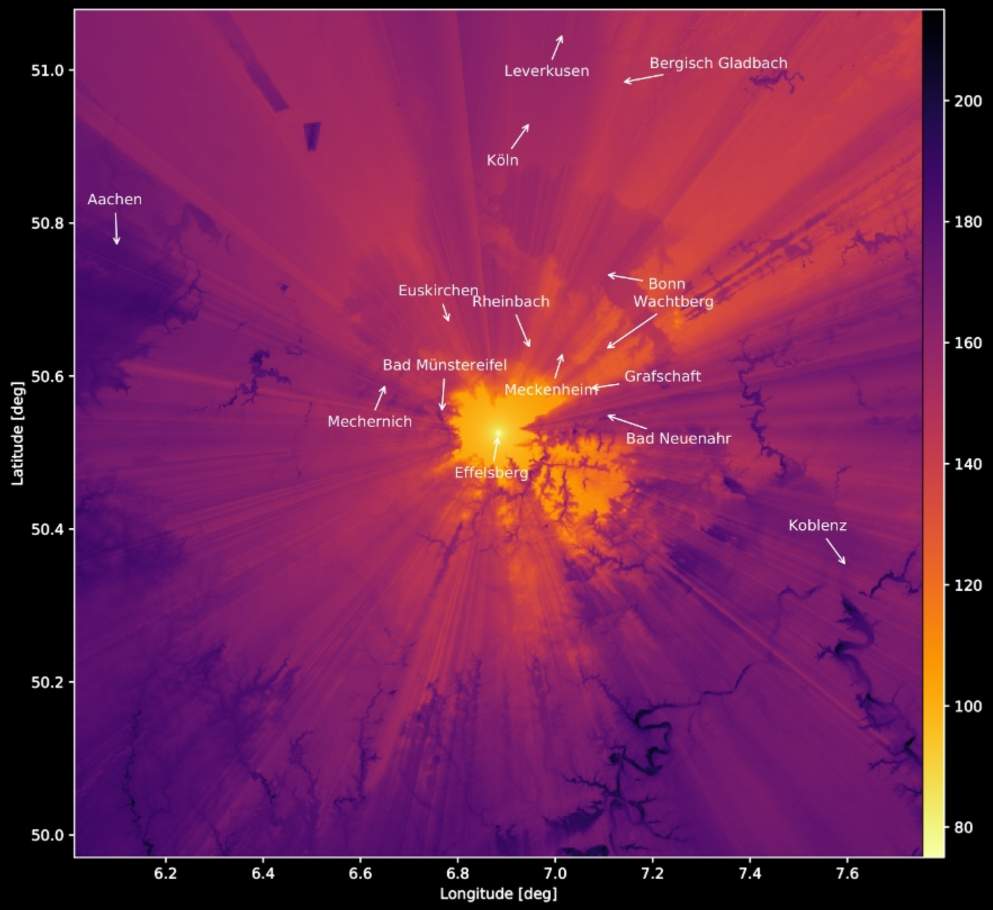
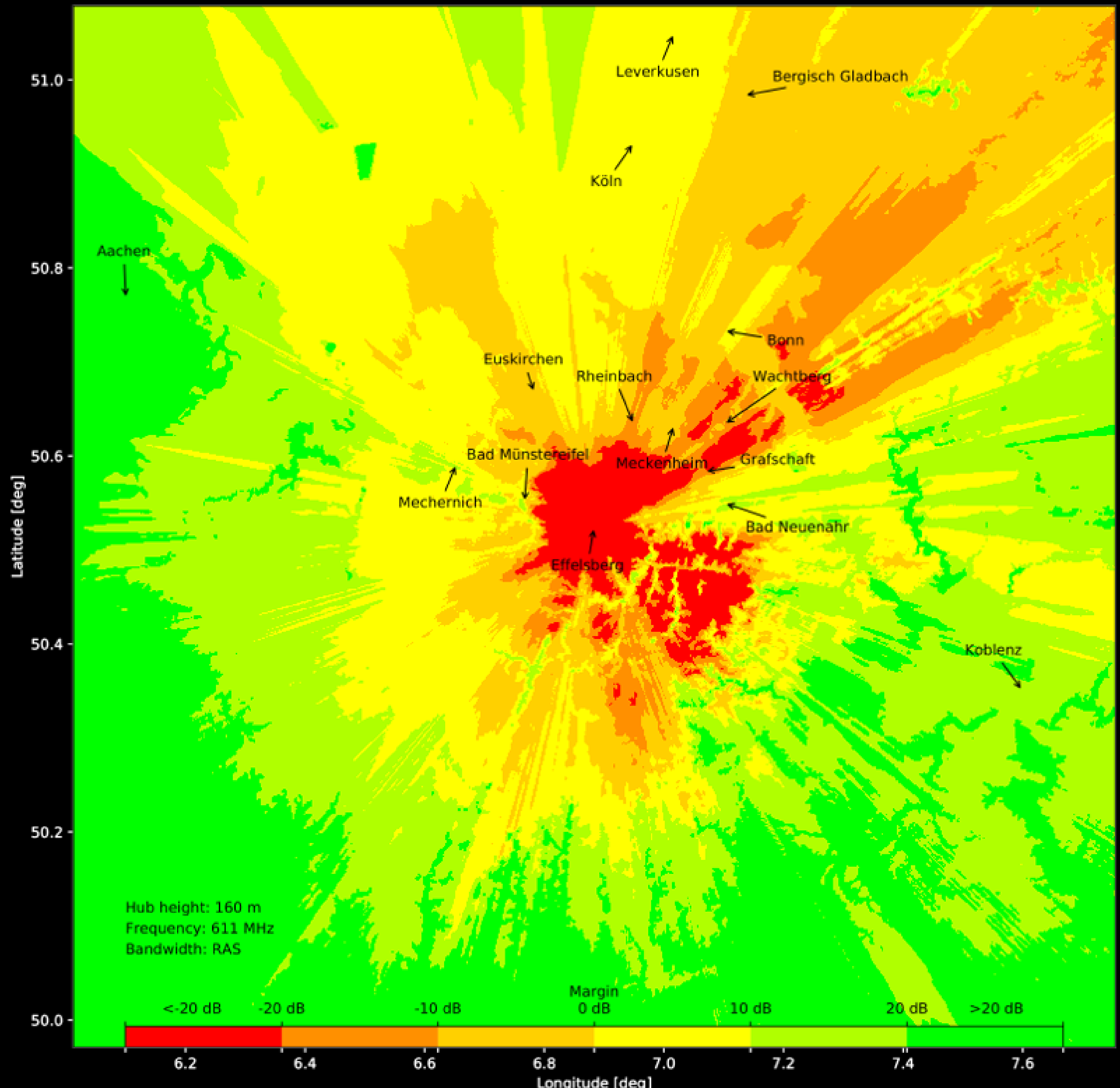


Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer
- Generate topographic maps (height profiles) from SRTM data
- Path propagation: implement ITU-R Recommendations
- Infer received power flux densities / E-field strengths at victim receiver
- Compare with permitted limits


Leverkusen
Bergisch Gladbach
Köln
Aachen
Bonn
Euskirchen
Rheinbach
Wachtberg
Bad Münstereifel
Meckenheim
Grafschaft
Mechernich
Bad Neuenahr
Effelsberg
Koblenz
Hub height: 160 m
Frequency: 611 MHz
Bandwidth: RAS
Margin
<-20 dB
-20 dB
-10 dB
0 dB
10 dB
20 dB
>20 dB
51.0
50.8
50.6
50.4
50.2
50.0
Latitude [deg]
6.2
6.4
6.6
6.8
7.0
7.2
7.4
7.6
Longitude [deg]

Compatibility calculations

Compatibility studies

- Calculate un-/wanted emission levels of interferer
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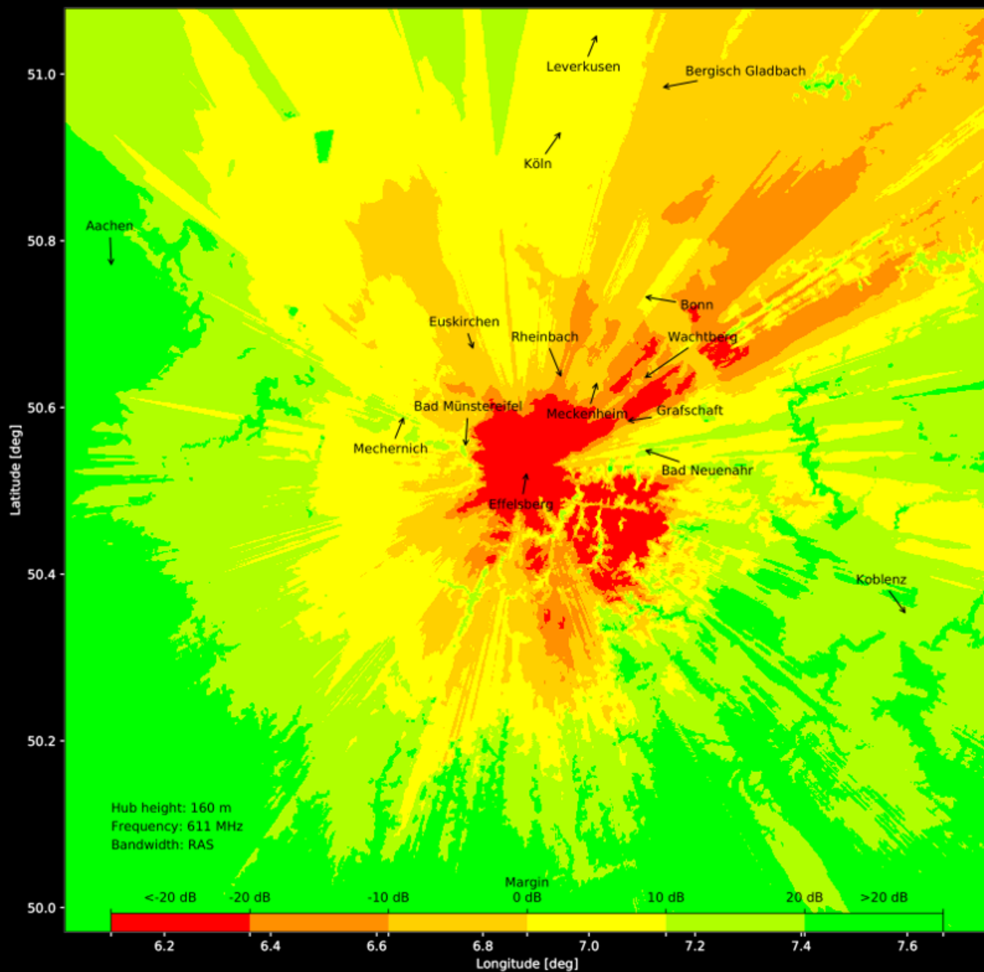

Measurements (by BNetzA)

Images: Hasenpusch/Fleckenstein
(BnetzA, 2017)

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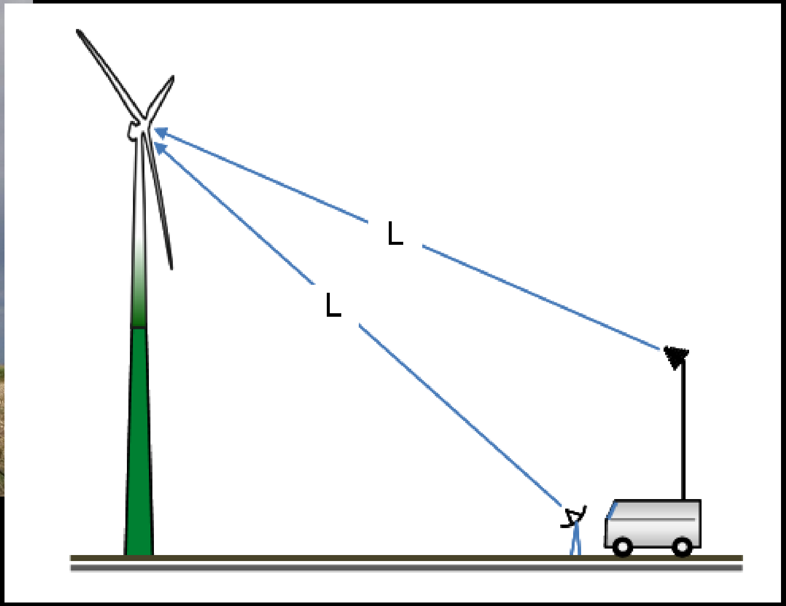

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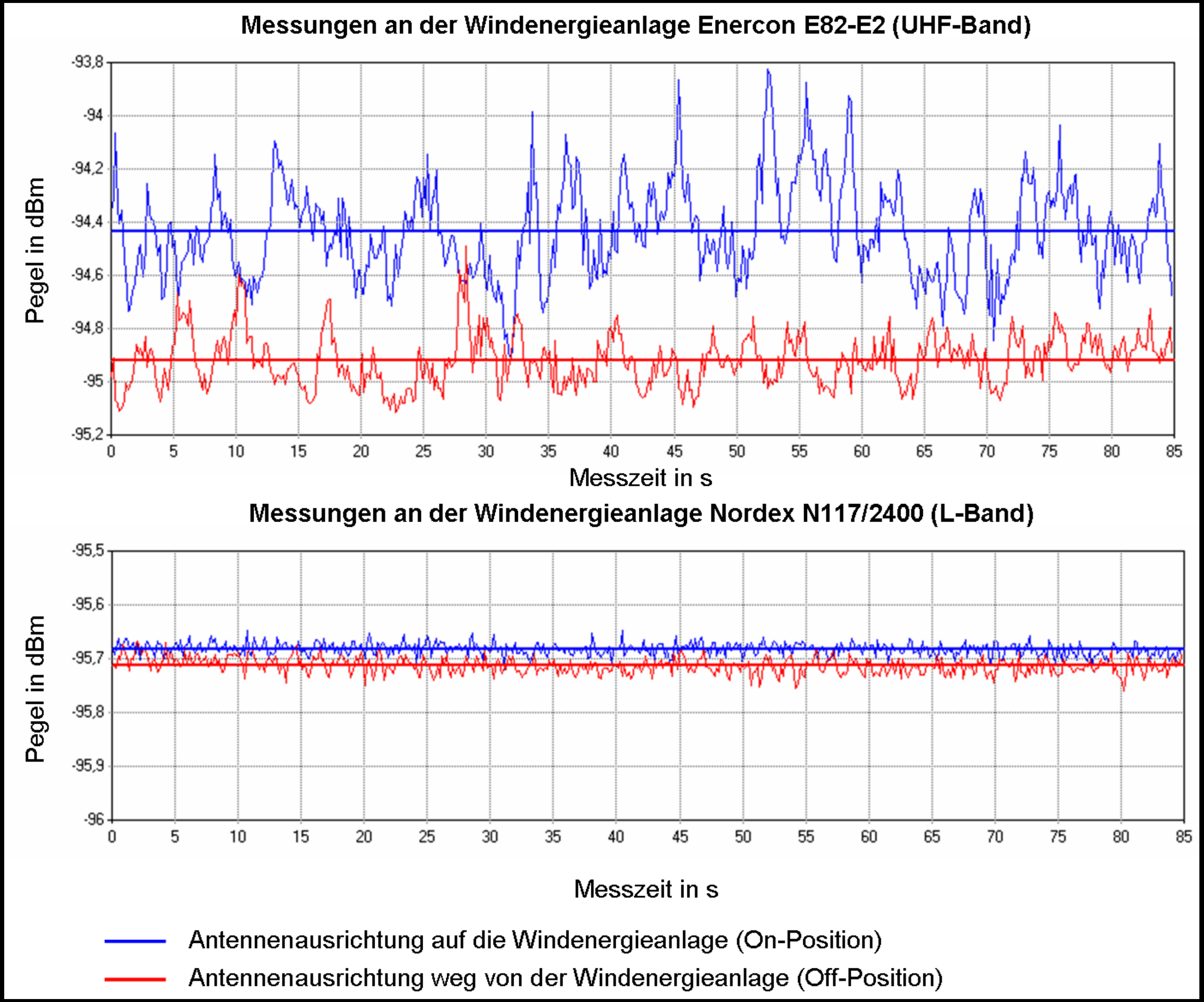
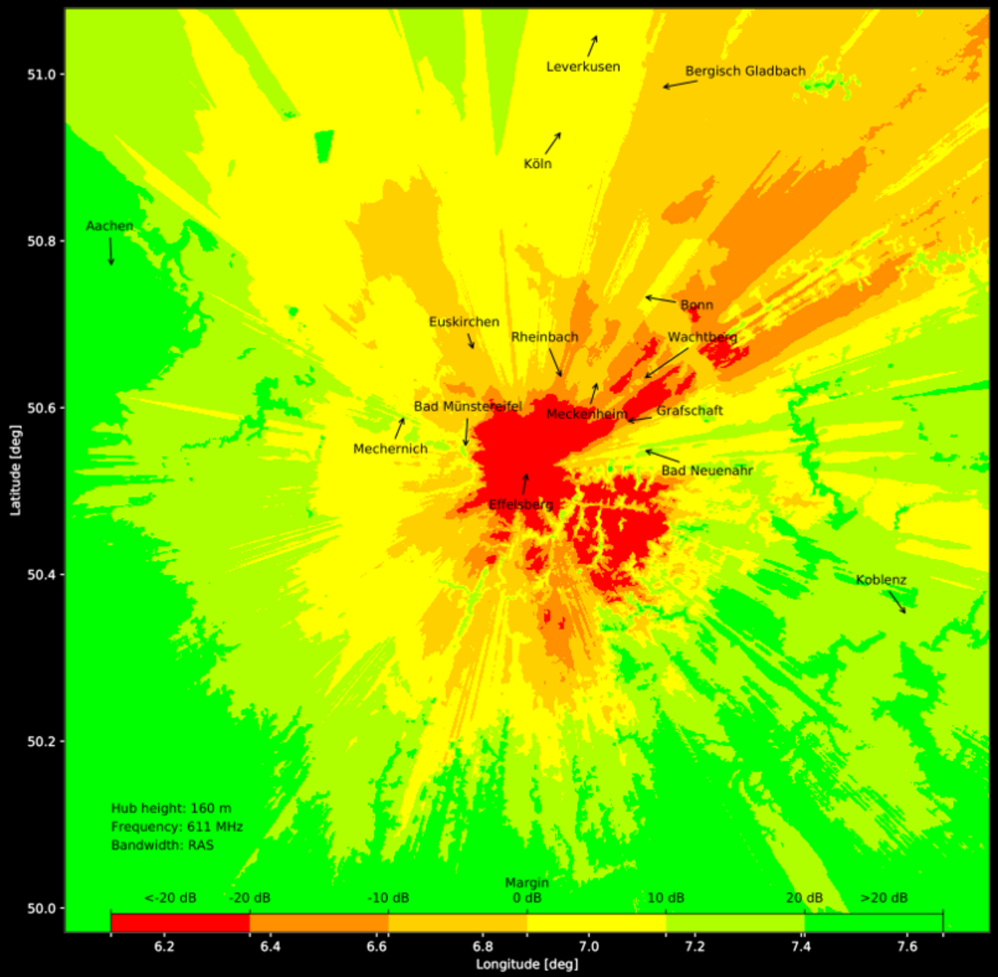


Images: Hasenpusch/Fleckenstein
(BnetzA, 2017)

Measurements (by BNetzA)

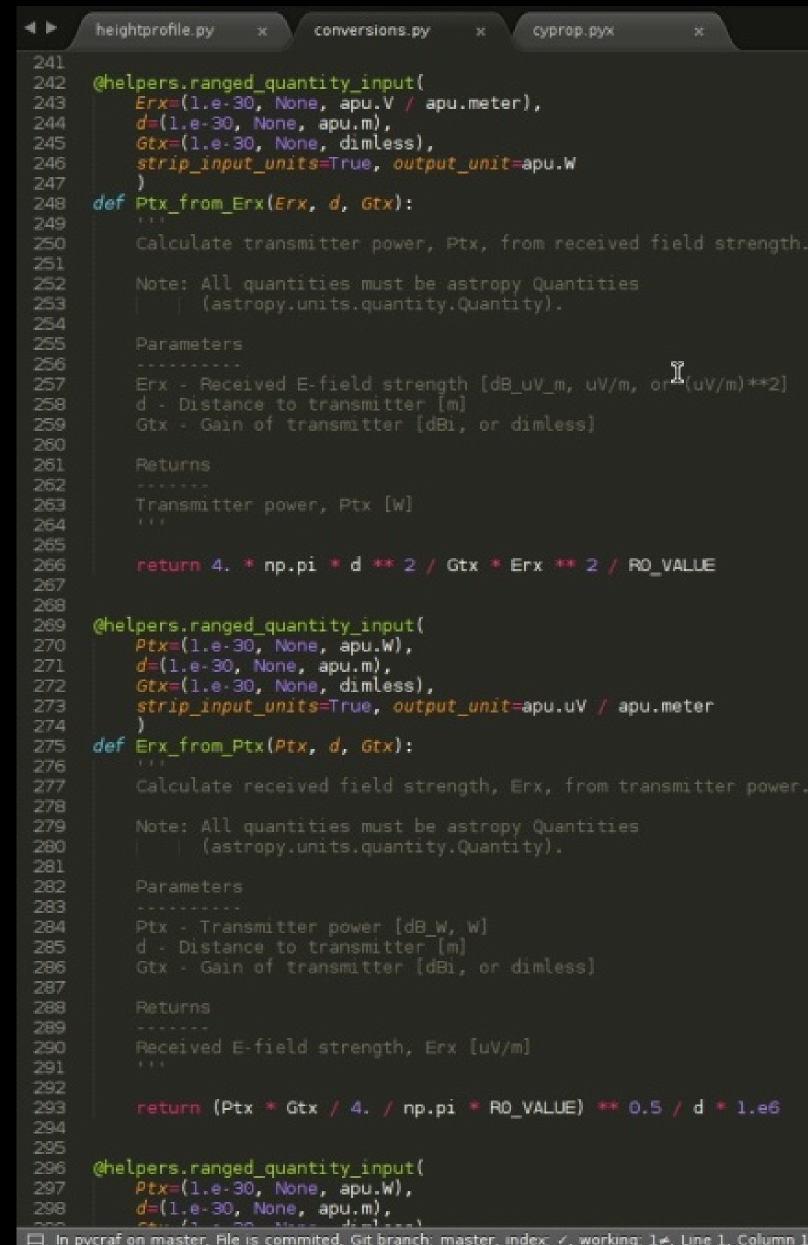
- Typically wind turbines stay 20+ dB below CISPR-11 → necessary distances smaller
- “Broken“ equipment can lead to much larger EMI



pycraf

Python library pycraf

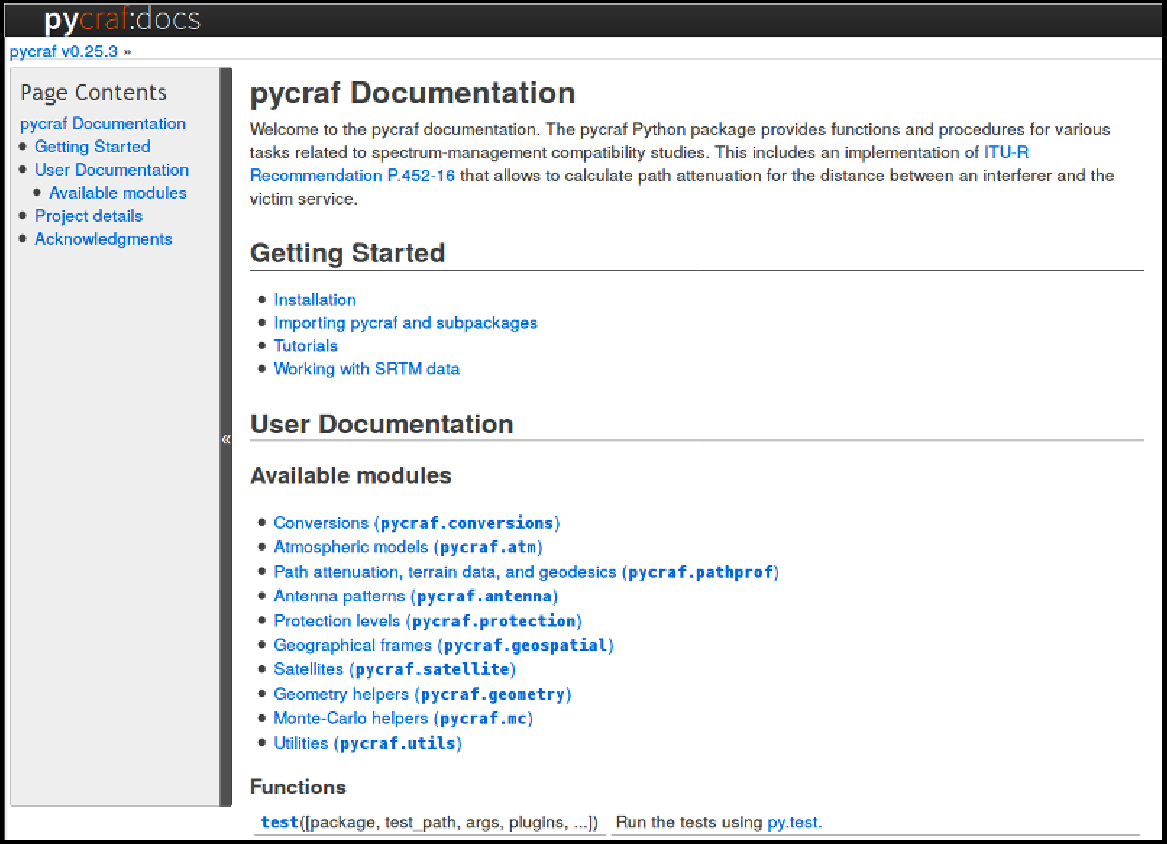
- Aid with compatibility studies
- Implements ITU-R Rec. algorithms
- Features:
  - Conversion formulas
  - Query SRTM data
  - Path propagation (P.452)
  - Atmospheric attenuation (P.676)
  - Geographical coordinates/frames
  - Some antenna models
  - Satellites (two-line elements)



pycraf

Python library pycraf

- Open-Source
  (Hosted on GitHub)
- Well-documented
- Many examples
- Contributions welcome


pycraf:docs
pycraf v0.25.3 »

Page Contents

- pycraf Documentation
  - Getting Started
  - User Documentation
    - Available modules
  - Project details
  - Acknowledgments

pycraf Documentation

Welcome to the pycraf documentation. The pycraf Python package provides functions and procedures for various tasks related to spectrum-management compatibility studies. This includes an implementation of ITU-R Recommendation P.452-16 that allows to calculate path attenuation for the distance between an interferer and the victim service.

Getting Started

- Installation
- Importing pycraf and subpackages
- Tutorials
- Working with SRTM data

User Documentation

Available modules

- Conversions (`pycraf.conversions`)
- Atmospheric models (`pycraf.atm`)
- Path attenuation, terrain data, and geodesics (`pycraf.pathprof`)
- Antenna patterns (`pycraf.antenna`)
- Protection levels (`pycraf.protection`)
- Geographical frames (`pycraf.geospatial`)
- Satellites (`pycraf.satellite`)
- Geometry helpers (`pycraf.geometry`)
- Monte-Carlo helpers (`pycraf.mc`)
- Utilities (`pycraf.utils`)

Functions

`test`([package, test_path, args, plugins, ...])	Run the tests using py.test.

https://github.com/bwinkel/pycraf

Conclusions

Necessary separation distances: 10-30 km
→ Established procedure:

- Local administrations contact us if within 30 km
- We provide site analysis,
- Which is then considered during approval procedure

Thank you!