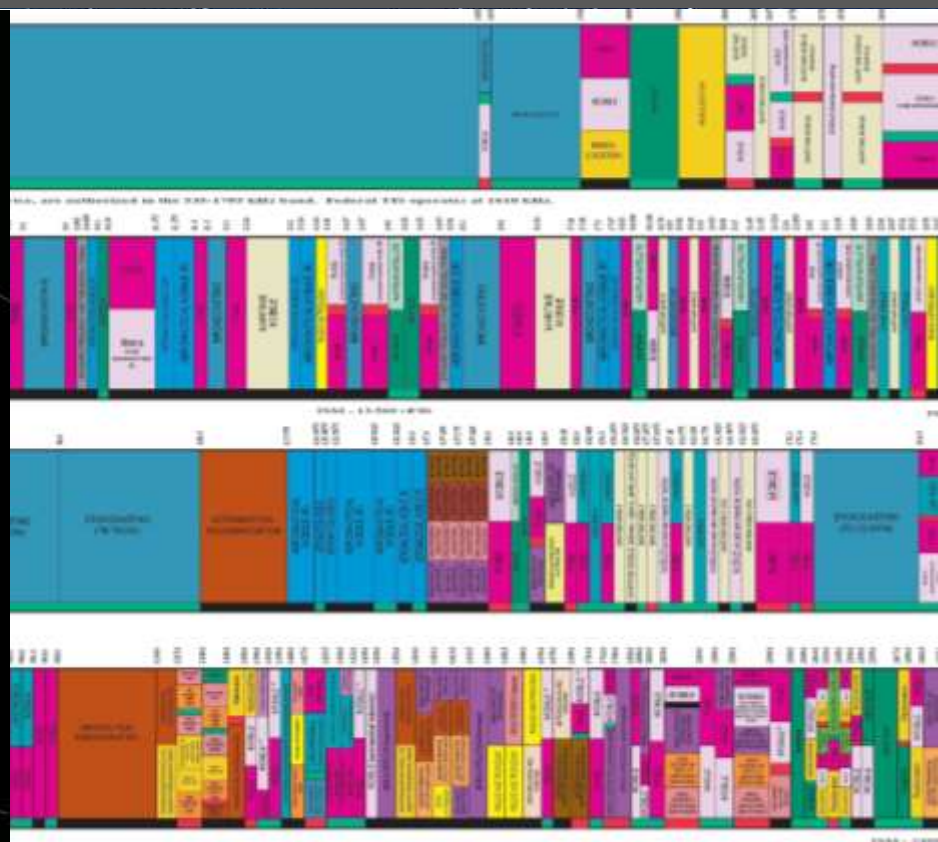
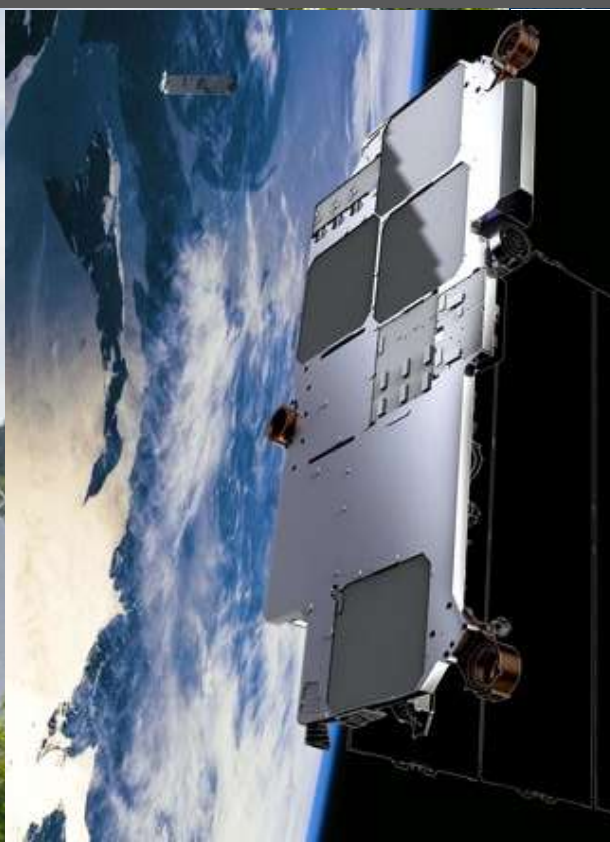




Radio frequency interference and the international harmonization process

Gyula I. G. Józsa (MPIfR, ESF-CRAF, ORP)





Sutherland night sky

(Credit: Sterland Stargazing)



Inanna (Sumerian goddess of love and fertility. Credit: Marie-Lan Nguyen)



Zodiac, Catalanian manuscript (1200-1500)



Willem van Herp: Fourth day of creation (1626-1677)



El Caracol, Chichén Itzá (900)



Star disc of Nebra (2100 – 1700 v. Chr.)

Background image: Sternpark Eifel (Credit: Maximilian Kaiser)



Nicolaus Copernicus
(1473-1543)



Tycho Brahe
(1546-1601)



Johannes Kepler
(1571-1630)



Galileo Galilei
(1564-1641)

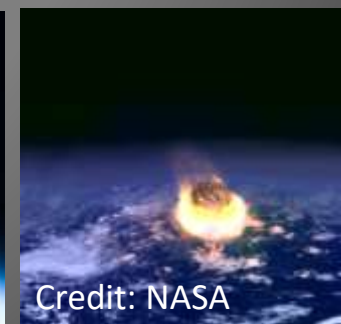
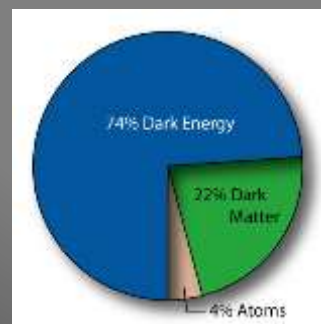
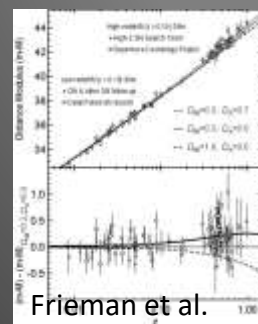
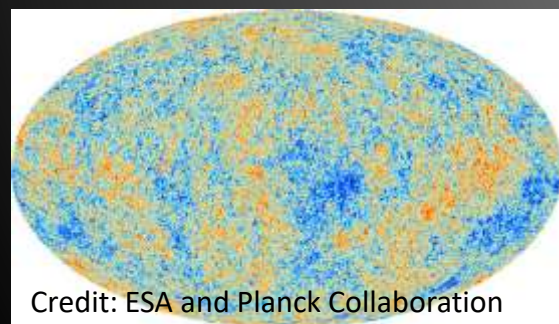


Isaac Newton
(1642-1726)



Albert Einstein
(1879-1955)

- 13+2 Nobel prices in the past 20 years





Nicolaus Copernikus
(1473-1543)



Tycho Brahe
(1546-1601)



Johannes Kepler
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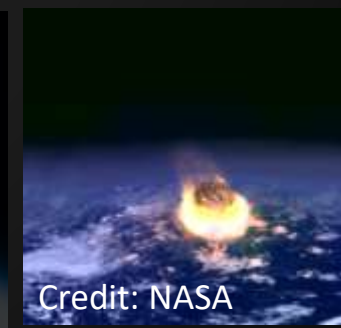
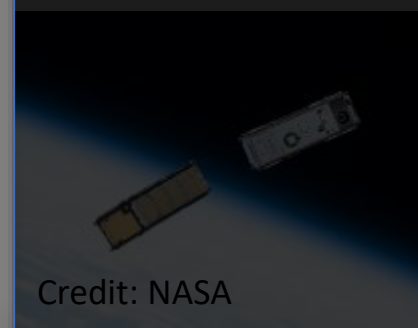
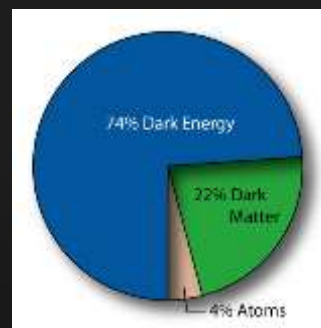
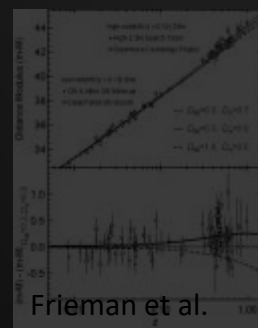
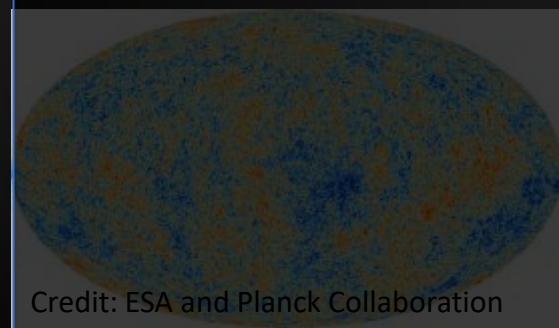
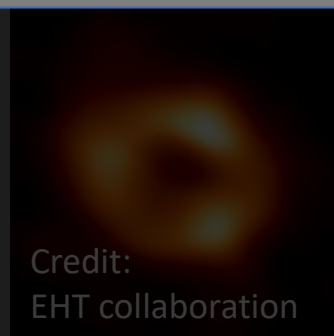
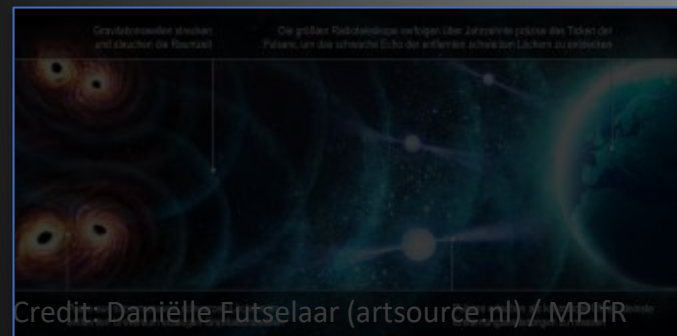


Isaac Newton
(1642-1726)

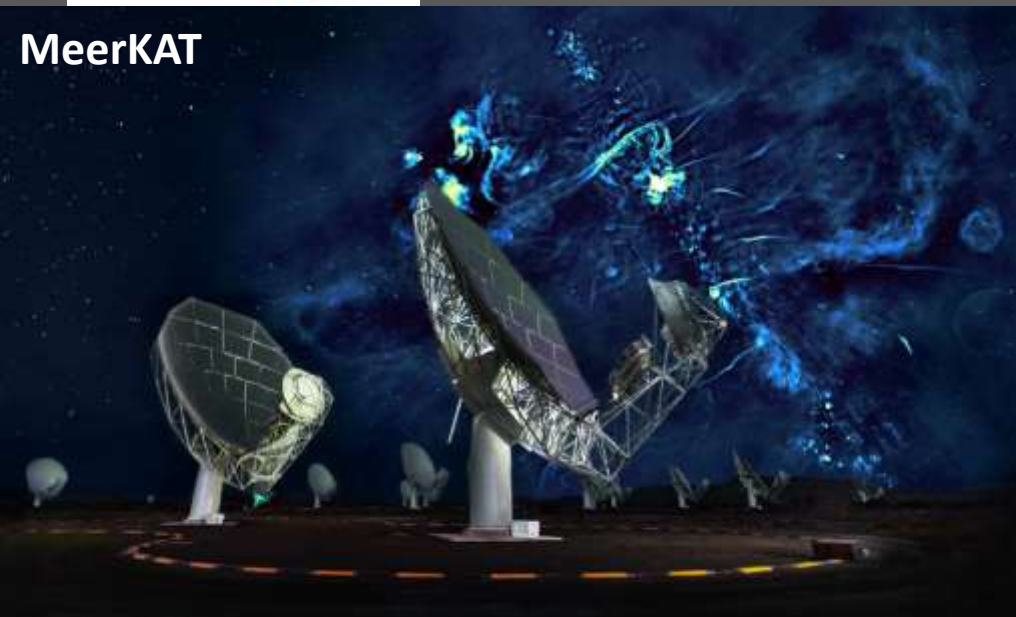


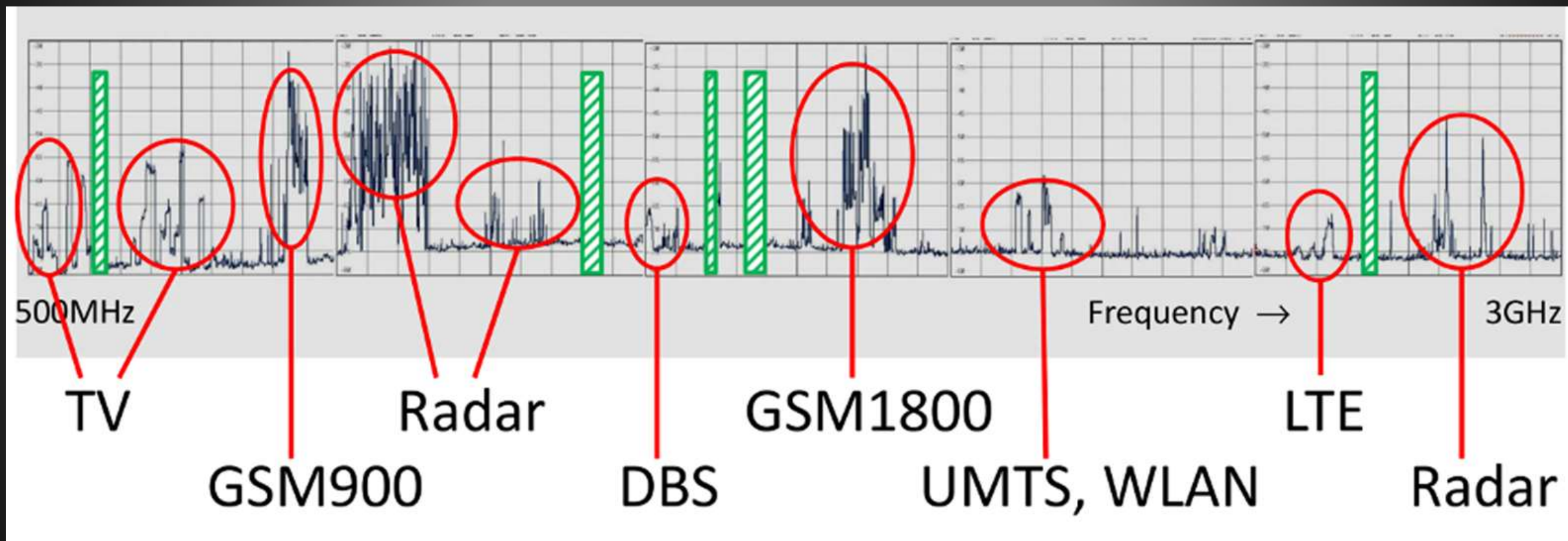
Albert Einstein
(1879-1955)

- 13+2 Nobel prices in the past 20 years



MeerKAT





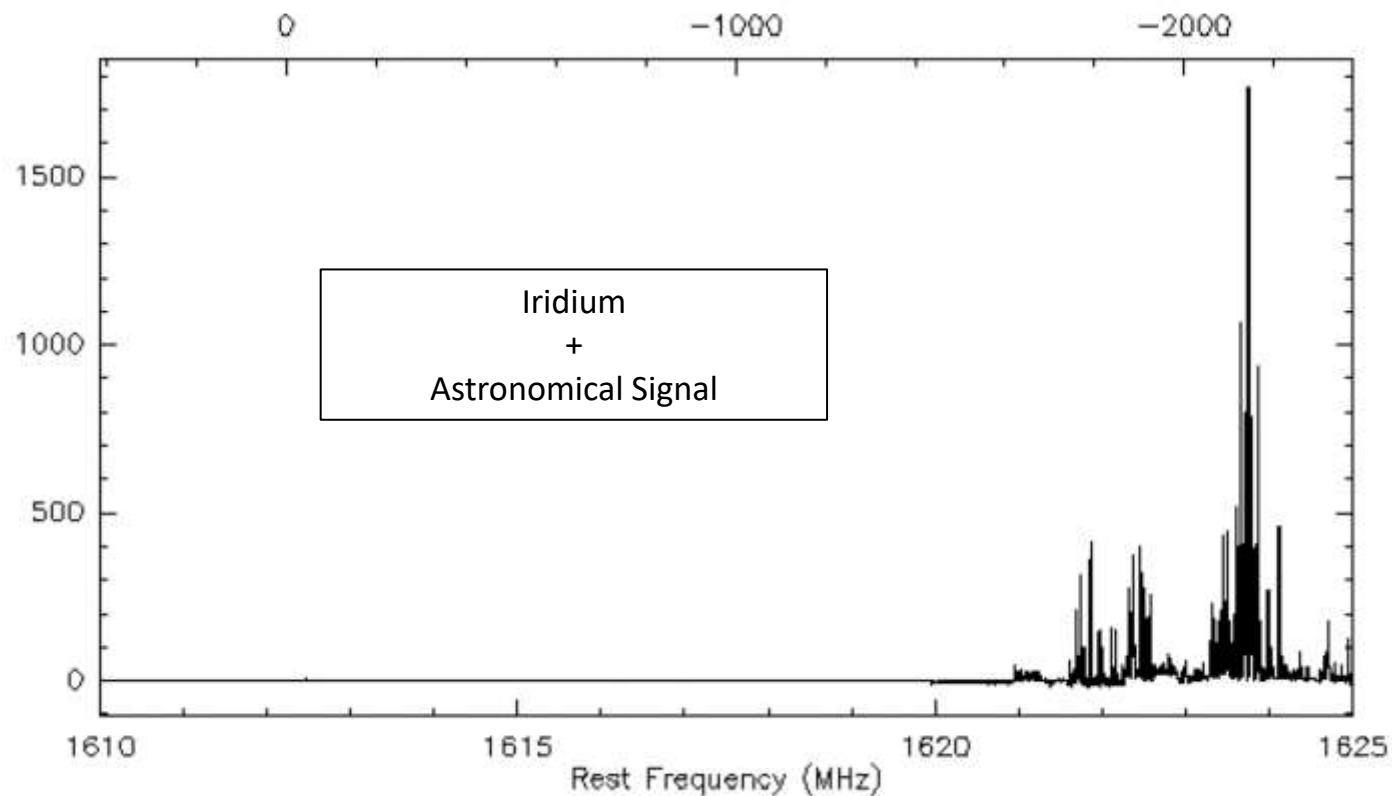
Sensitivity: $< 10^{-32} \text{ W m}^{-2} \text{ Hz}^{-1}$ (1 μJy)



Credit: B. Winkel

Q;0 W3OH NONE P180-XFF1-1- 0:27-JUN-2022 R:04-JUL-2022
RA: 02:23:16.45 DEC: 61:38:58.0 Eq 1950.0 None 0.0° Offs: -1.8 +0.7
Unknown tau: ***** Tsys: 15. Time: 3.9min El 33.7
N: 65536 I0: 44414.7 V0: 0.000 Dv: 0.2837 LSR
F0: 1612.23000 Df: -1.5259E-03 Fi: -1357.23000
Scan: 7726 Subscan: 2

Credit: A. Kraus, MPIfR



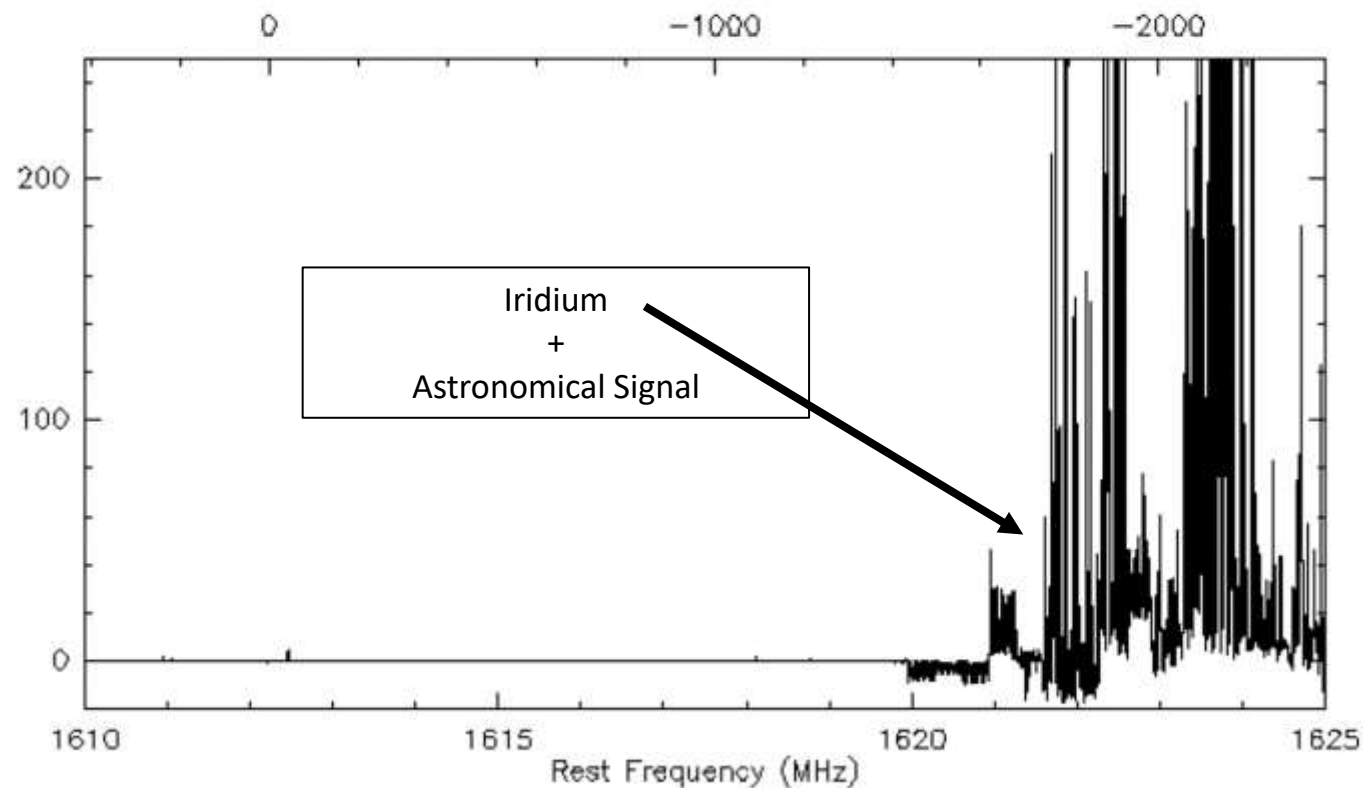
Sensitivity: $< 10^{-32} \text{ W m}^{-2} \text{ Hz}^{-1}$ (1 μJy)



Credit: B. Winkel

O₃ W3OH NONE P180-XFF1-1- 0:27-JUN-2022 R:04-JUL-2022
 RA: 02:23:16.45 DEC: 61:38:58.0 Eq 1950.0 None 0.0° Offs: -1.8 +0.7
 Unknown tau: ***** Tsys: 15. Time: 3.9min El 33.7
 N: 65536 I0: 44414.7 V0: 0.000 Dv: 0.2837 LSR
 F0: 1612.23000 Df: -1.5259E-03 Fi: -1357.23000
 Scan: 7726 Subscan: 2

Credit: A. Kraus, MPIfR



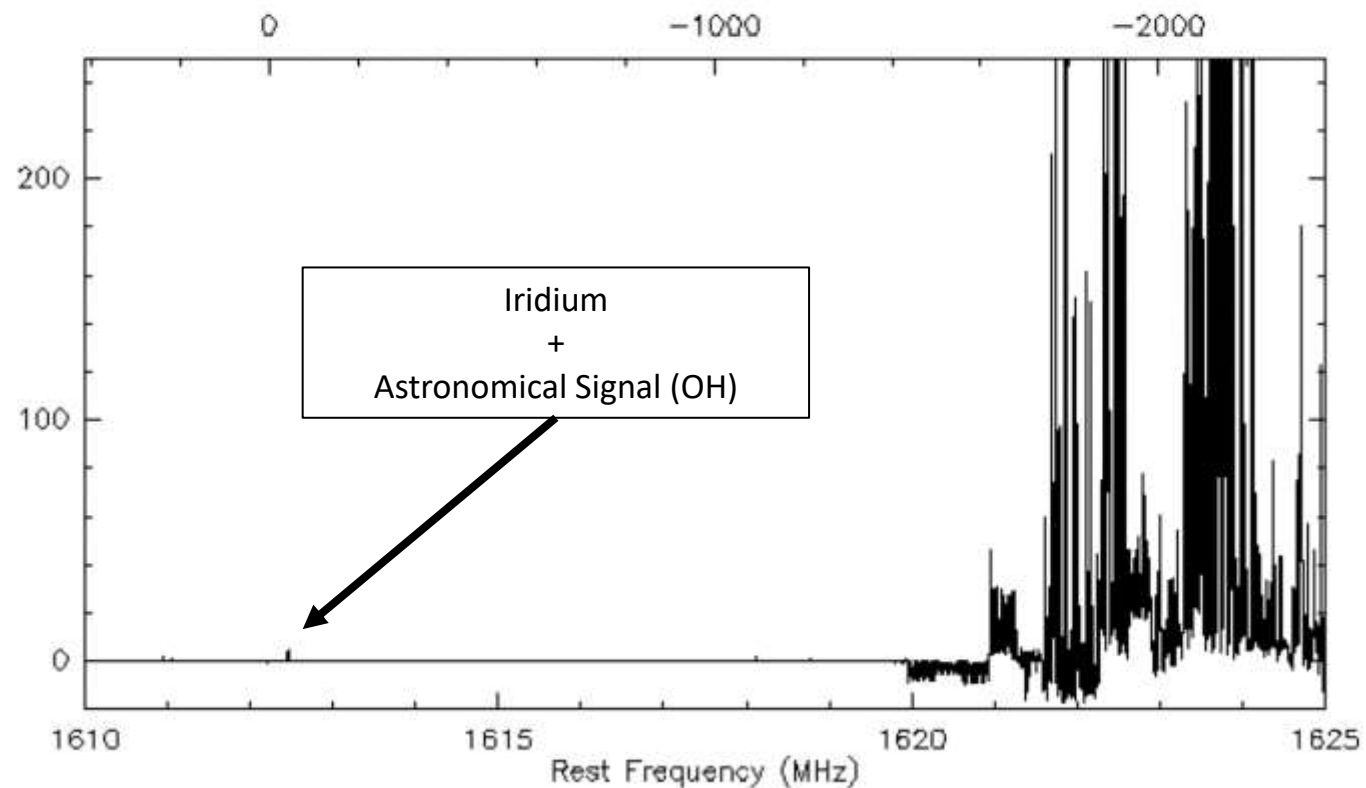
Sensitivity: $< 10^{-32} \text{ W m}^{-2} \text{ Hz}^{-1}$ ($1 \mu\text{Jy}$)



Credit: B. Winkel

O₃OH NONE P180-XFF1-1- 0:27-JUN-2022 R:04-JUL-2022
RA: 02:23:16.45 DEC: 61:38:58.0 Eq 1950.0 None 0.0° Offs: -1.8 +0.7
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Scan: 7726 Subscan: 2

Credit: A. Kraus, MPIfR



- International Telecommunication Union (UN Agency)
- Radio Regulations (international treaty)
 - Definitions/Principles/Rules
 - Services including Radio Astronomy Service (RAS)
 - Frequency allocation table
 - Updated every 3-4 years → Agenda Items
- ITU-R Reports
- ITU-R Recommendations
- Work in Study/Working Groups (Meeting here in Almaty)
 - Compatibility calculations for coordination
 - Regulatory studies
- Regional organisations prepare international meetings
- National administrations are responsible for
 - Operation permits and licensing (Assignment)
 - Filing of radio stations (if relevant)
 - Coordination (also bilaterally)
 - Handling interference reports





UNITED
STATES
FREQUENCY
ALLOCATIONS

THE RADIO SPECTRUM



Vollzugsordnung für den Funkdienst

Radio Regulations

Edition of 2016



UNITED
STATES
FREQUENCY
ALLOCATIONS

THE RADIO SPECTRUM

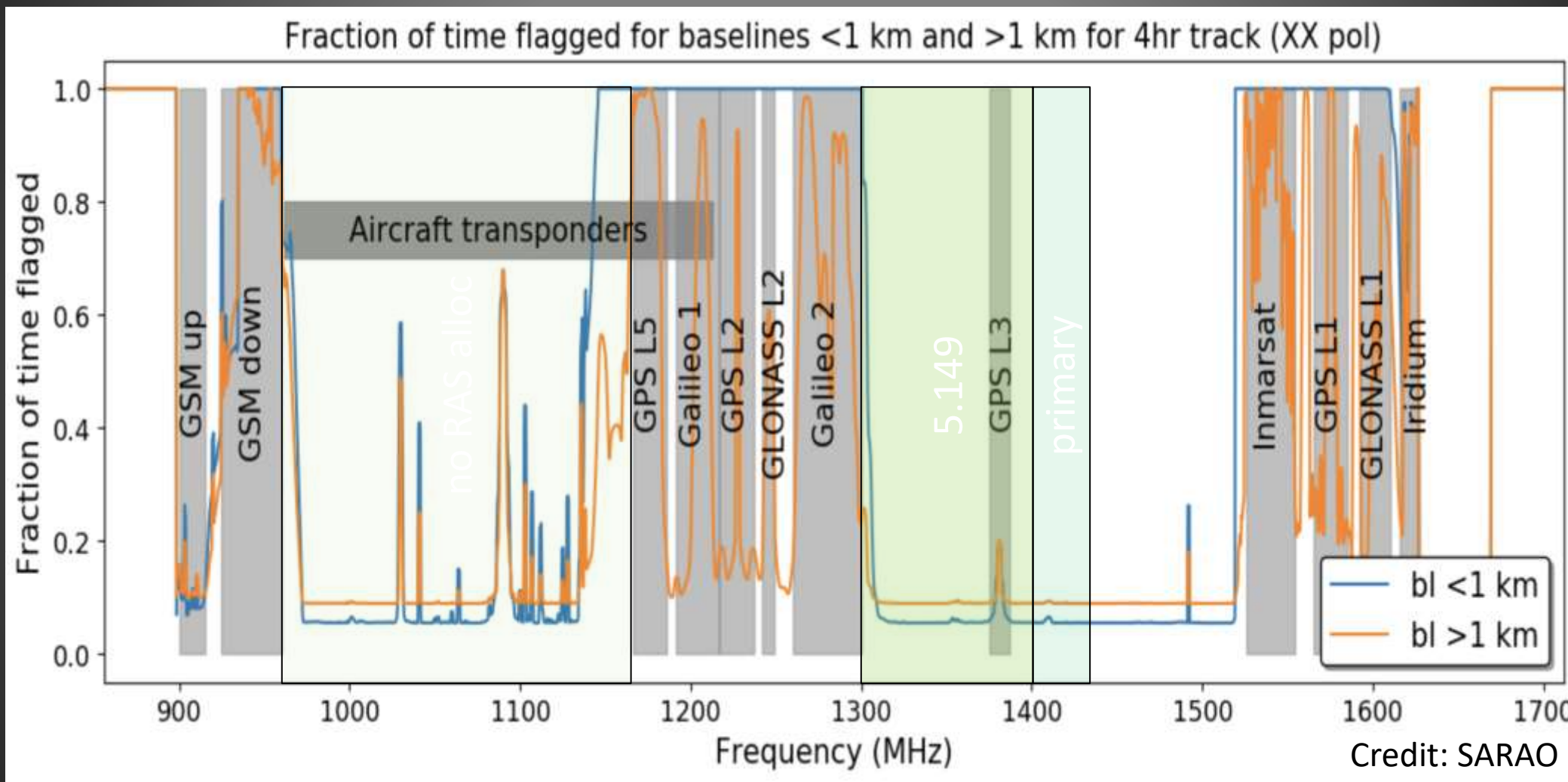


Vollzugsordnung für den Funkdienst

Radio Regulations

Articles

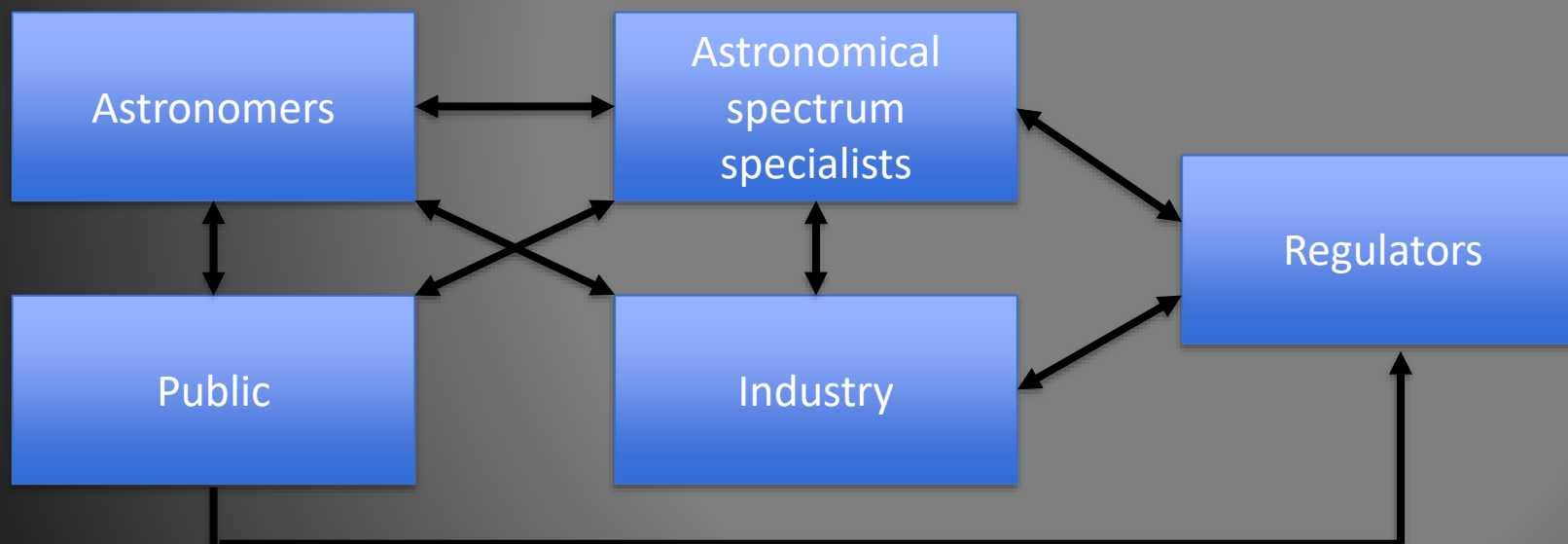




MeerKAT L-band RFI occupancy

Credit: SARAO

- Increasing pressure on spectrum puts pressure on radio astronomy
- Most radio astronomical observations are opportunistic
- **Active incorporation of radio astronomy in harmonization process essential**



IUCAF

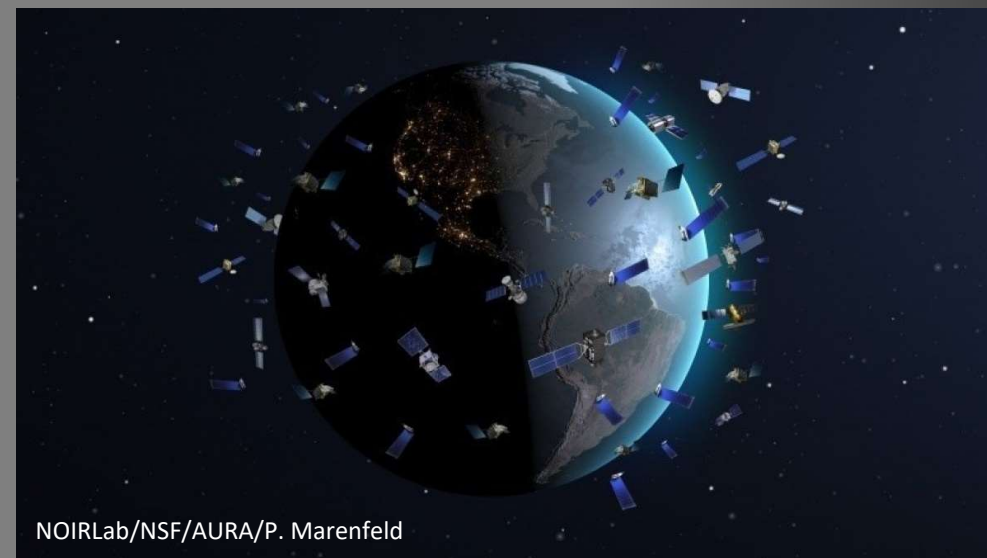


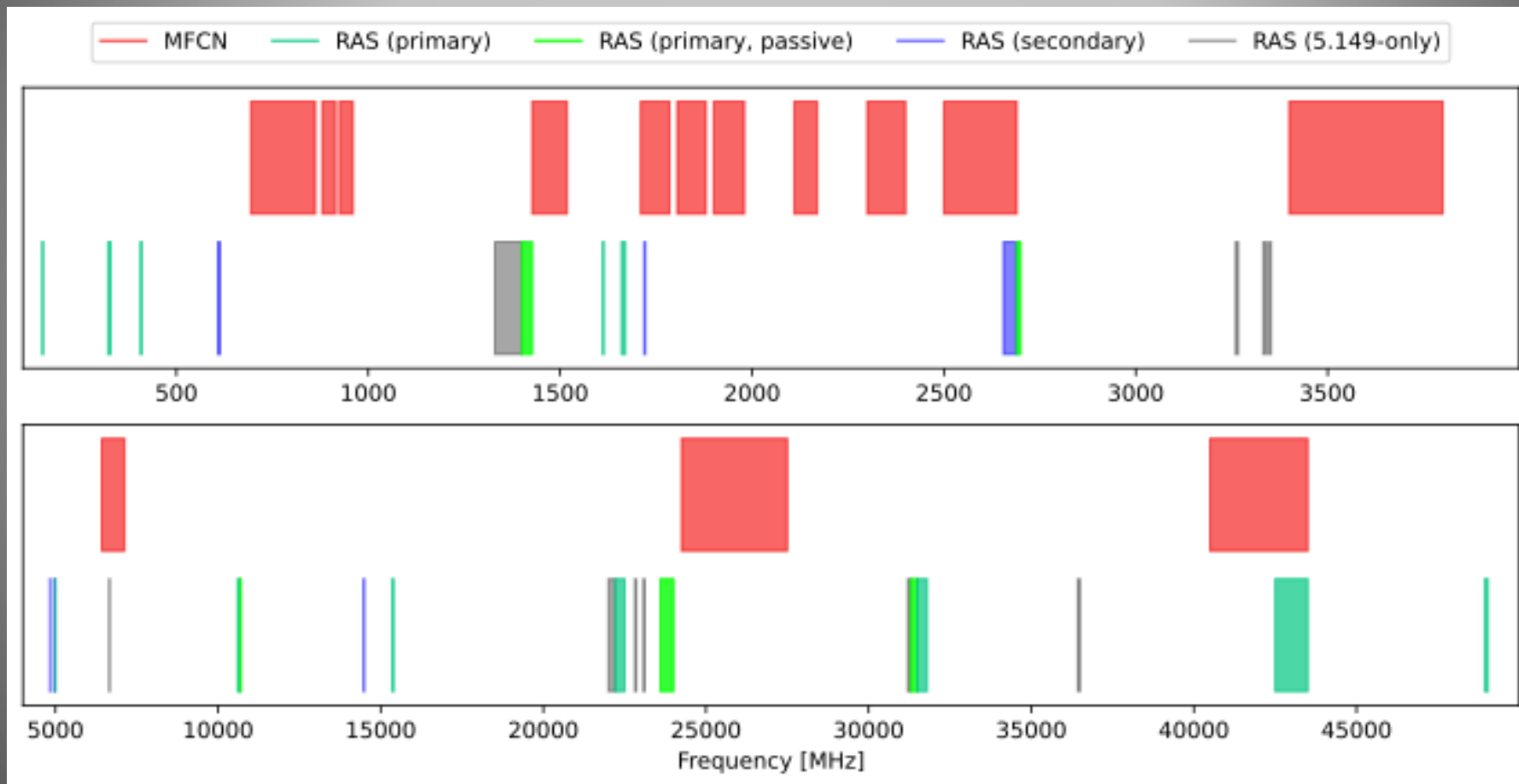
RAFCAP

- Regulation
 - Primary allocation → Secondary allocation → recommendations to protect
- Radioastronomy as passive service
 - Primary and secondary allocations exist, but only small total bandwidth
 - Primary allocations in only 1.7 % below 10 GHz
 - Footnote RR 5.149
 - Recommended protection of radio astronomy
 - Only relevant in national allocation processes
 - Limited protection
 - Footnote RR 5.340
 - No emissions allowed
 - Radio Quiet Zone (RQZ)
 - Zone around a radio telescope in which transmissions are not allowed or limited
 - Only in national context (not extending into space or beyond national borders)
 - Might change

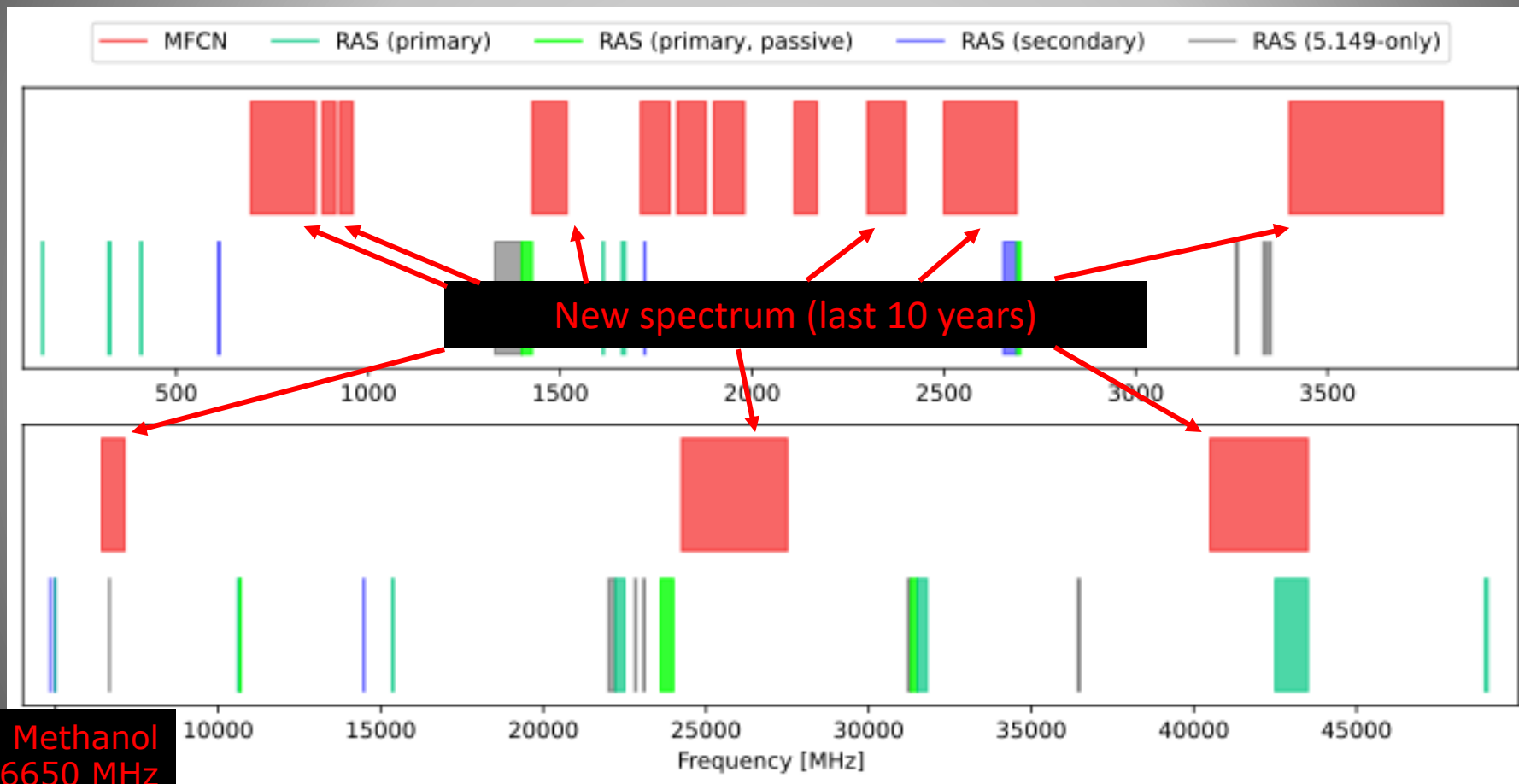


- Further allocations to International Mobile Telecommunication (GHz-range)
- Non-Geostationary Orbit (NGSO) Satellites (Megaconstellations)
 - Risks: Unintended radiation
 - optical
 - radio





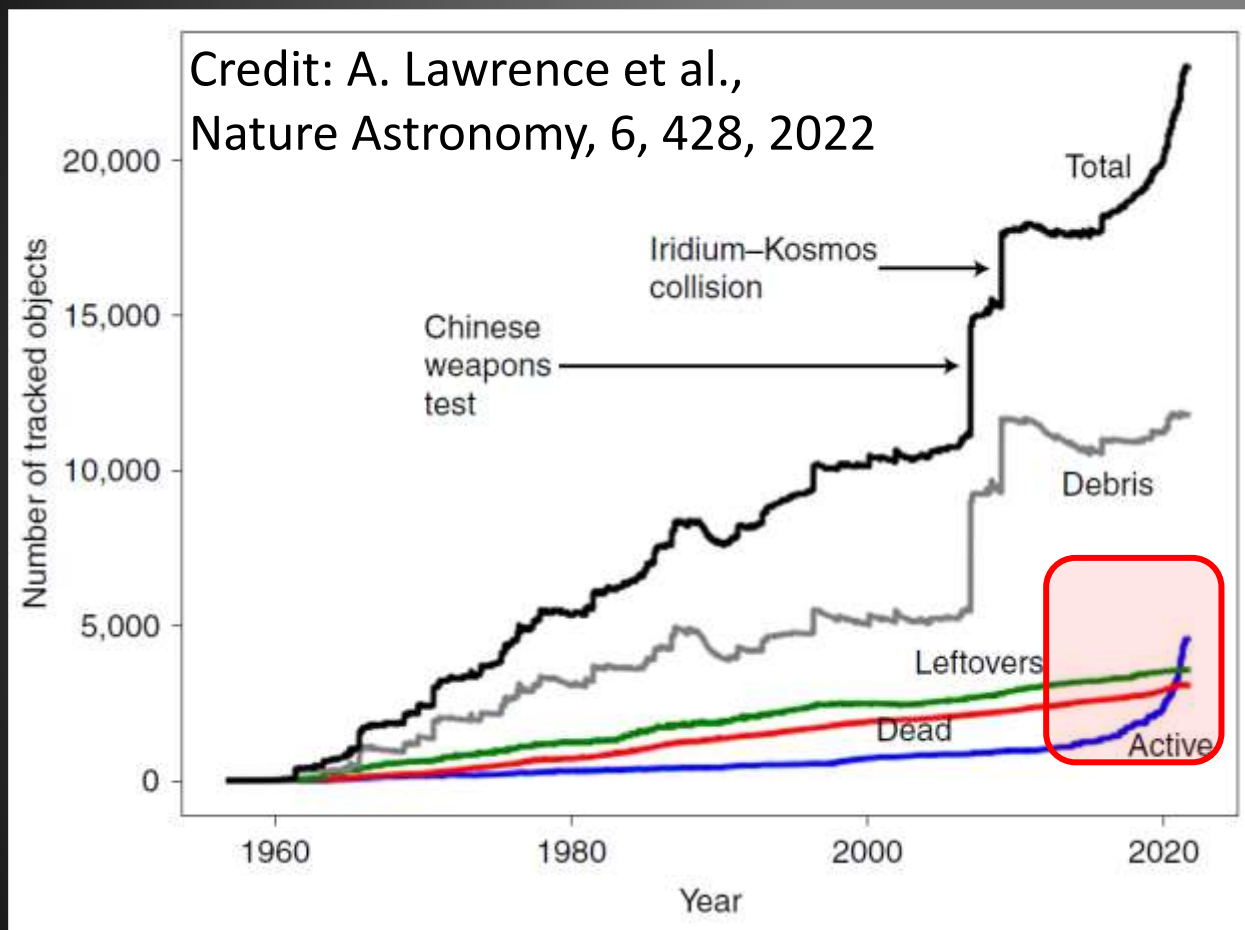
Credit: B. Winkel



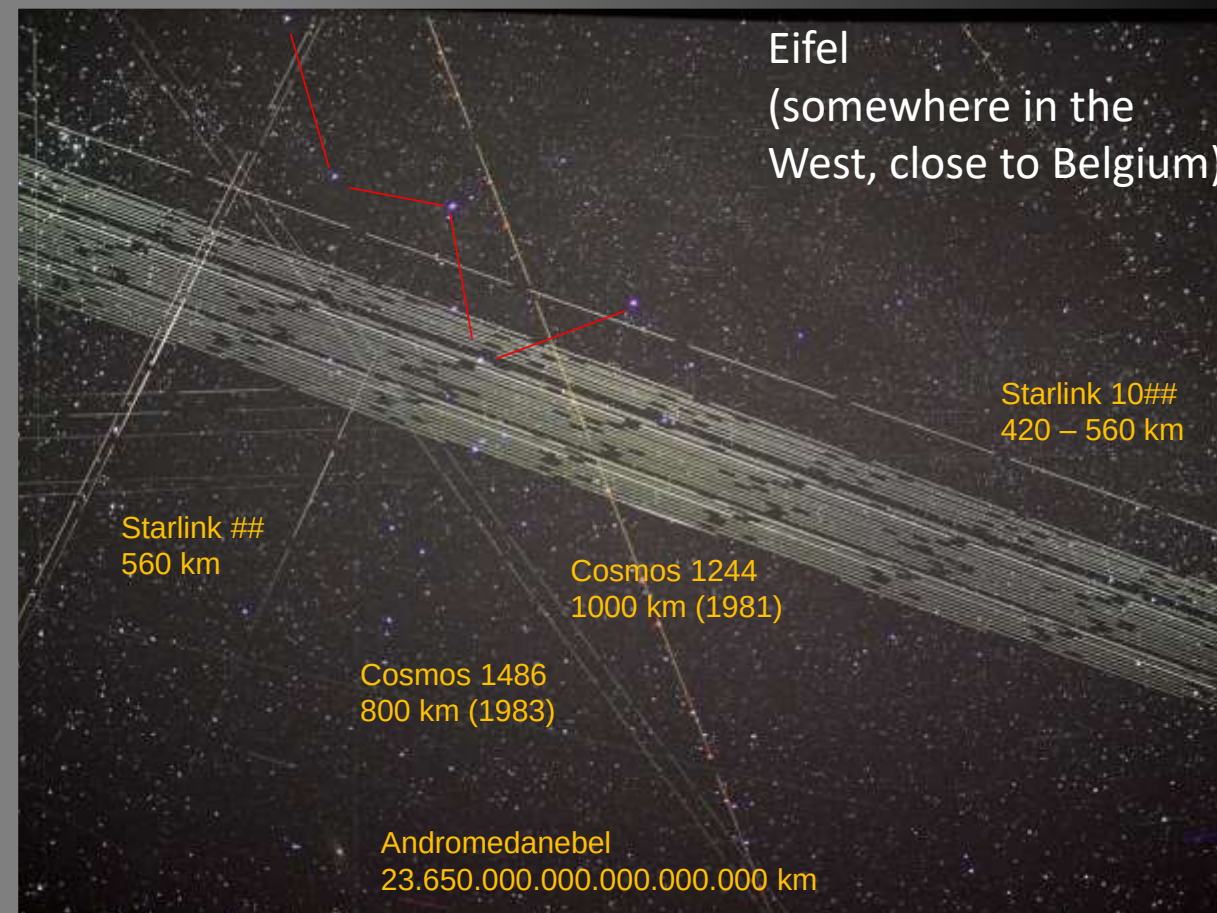
Credit: B. Winkel



Credit: NOIRLab/NSF/AURA/P. Marenfeld



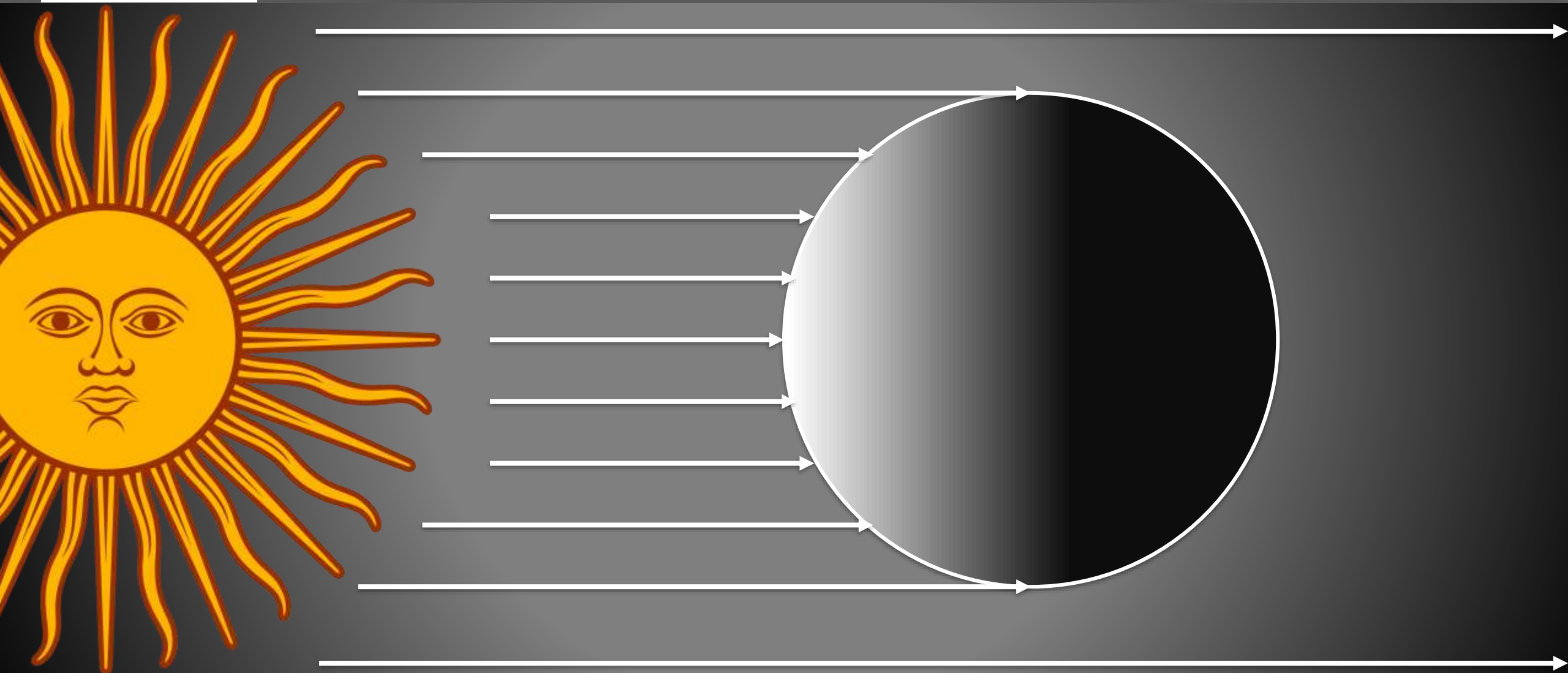
**Registered in BR IFIC
Register of the
International
Telekommunikation
Union (ITU):
> 1 000 000 Satellites
(B. Winkel et al.)**

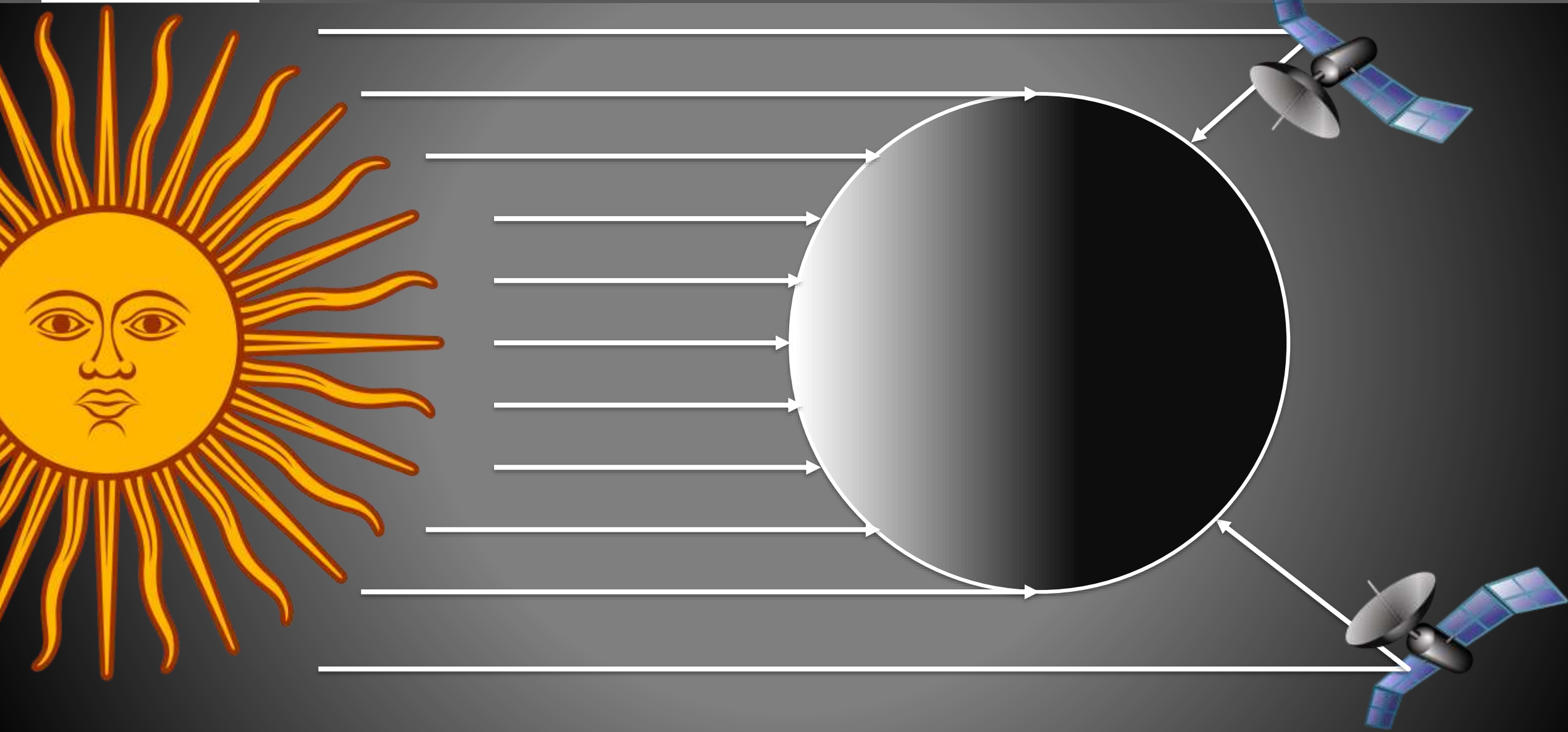


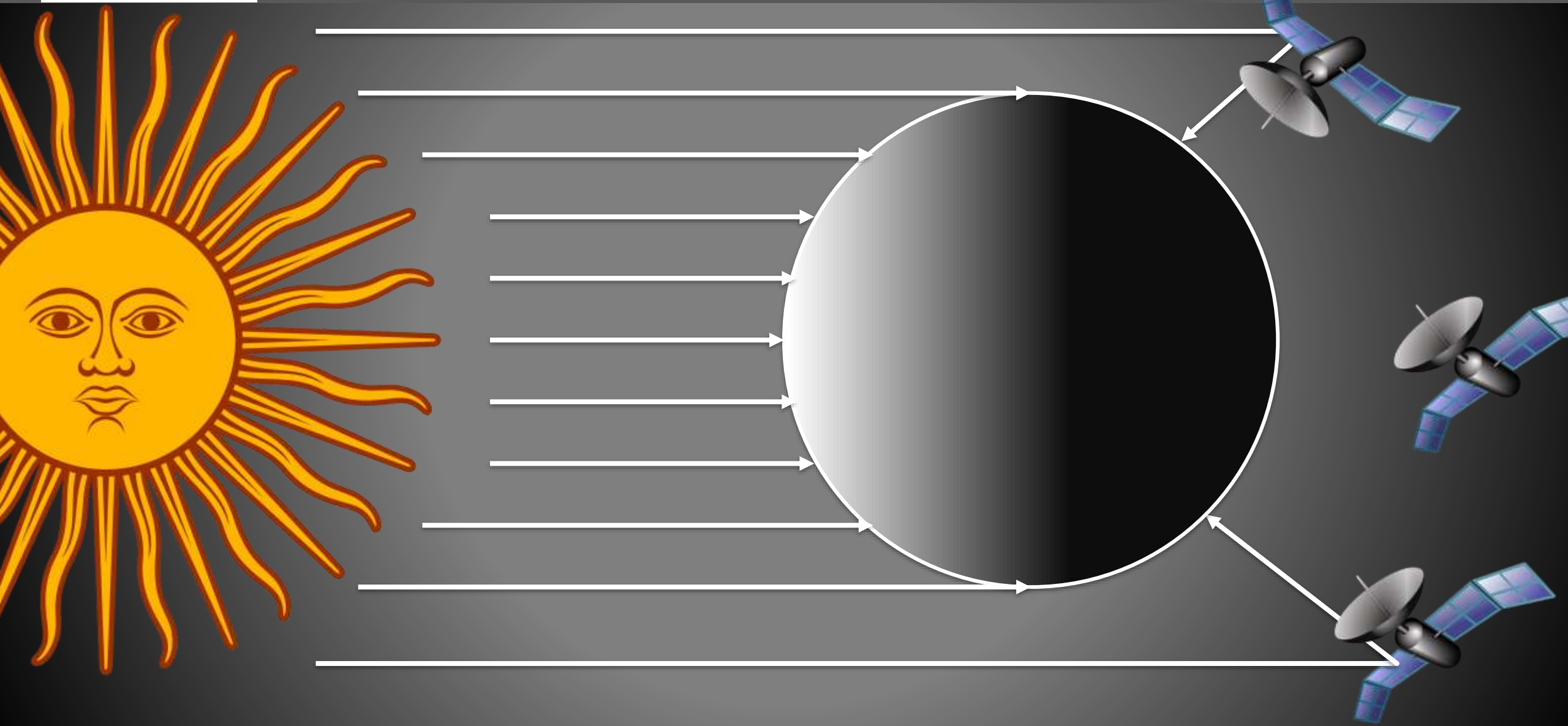
Starlink Satellites in Germany

Credit: Andreas Hänel

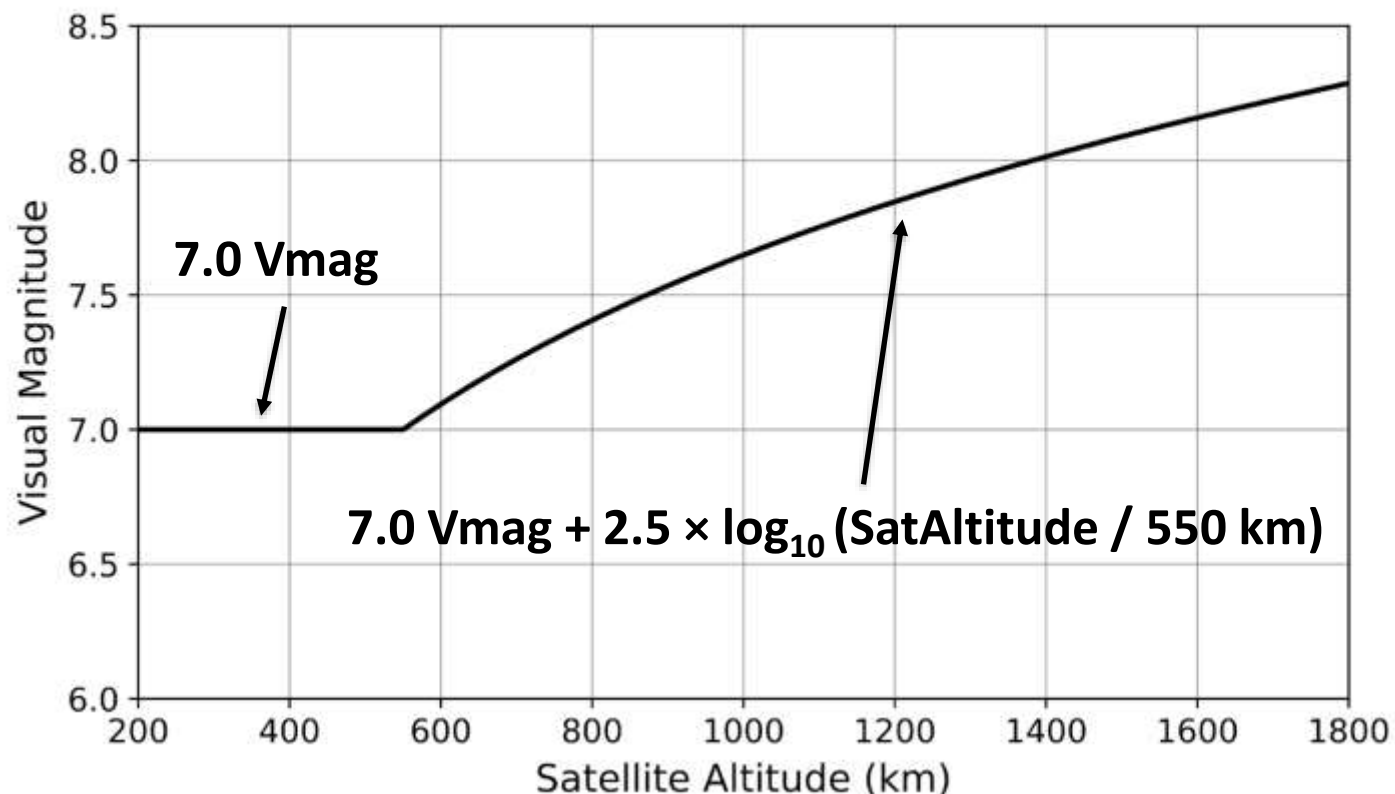








Acceptable brightness limit of LEO satellites as formulated by the IAU CPS



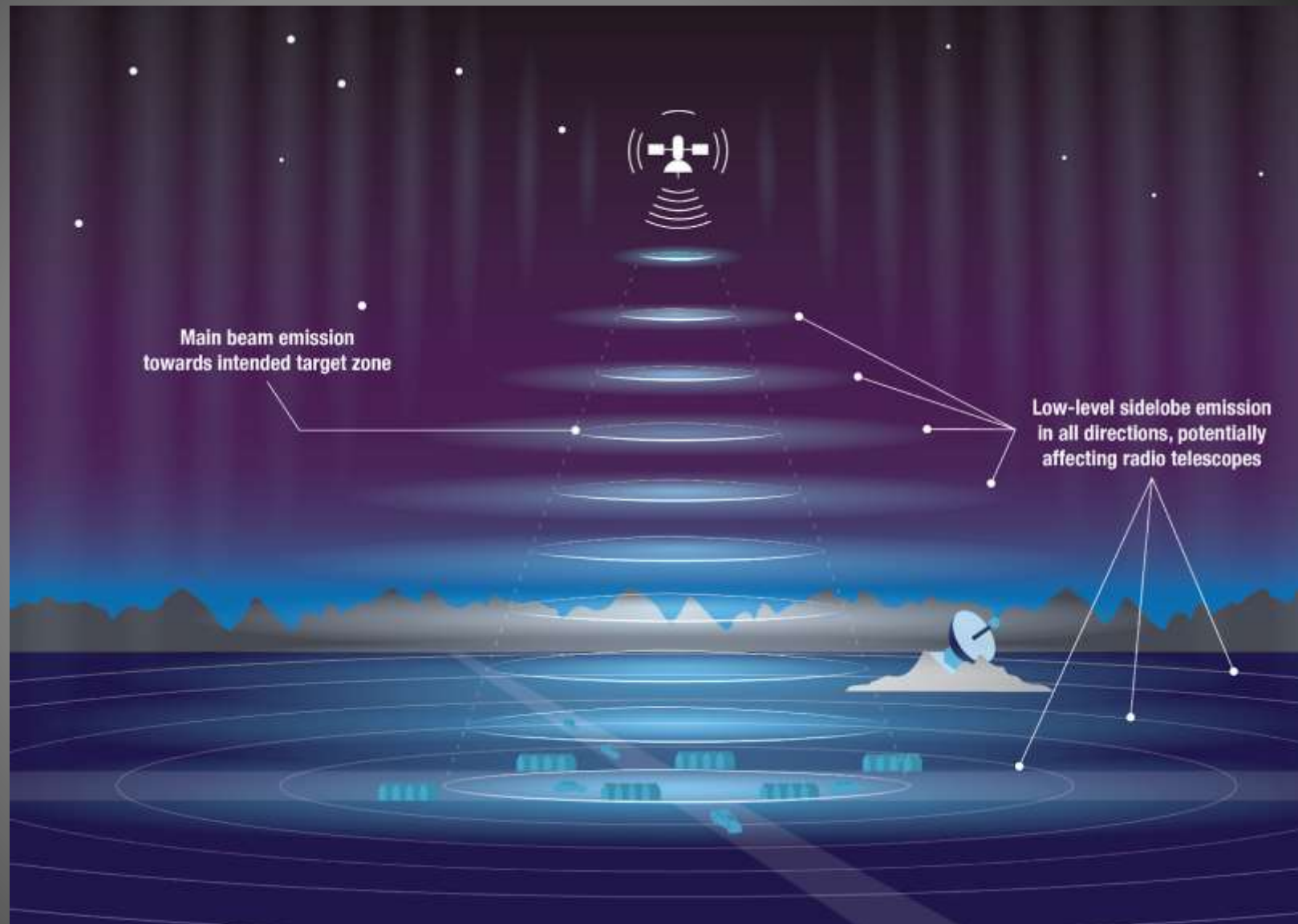
- Orbital height below 600 km above surface
- Dark enough to never be seen by eye
- Measures
 - Reflecting Surface (Bragg-Coating)
 - Absorbing surface
 - Industry is collaborating (SpaceX)



- Regulation
 - Allocations of bands to Radio Astronomy Services at several protection levels
- Radio astronomy as passive Service (Radio Astronomy Service, RAS)
 - Allocation is only a small portion of the spectrum, most important bands
 - Below 10 GHz only 1.6%
 - Most observations are opportunistic, observing in unallocated bands
 - RAS sites are built in remote places, as recommended in the RR (29.6)
 - used to work in the past
 - Radio Quiet Zone (RQZ)
 - Protection zones around radio telescopes
 - Only nationally applied (no protection from satellites)



- Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (FN RR 5.149)



Credit:
IAU CPS
NOIRLab
SKAO

Map of the extragalactic source 3C84 in the 10.6-10.7 GHz band with the Effelsberg 100 m radio telescope

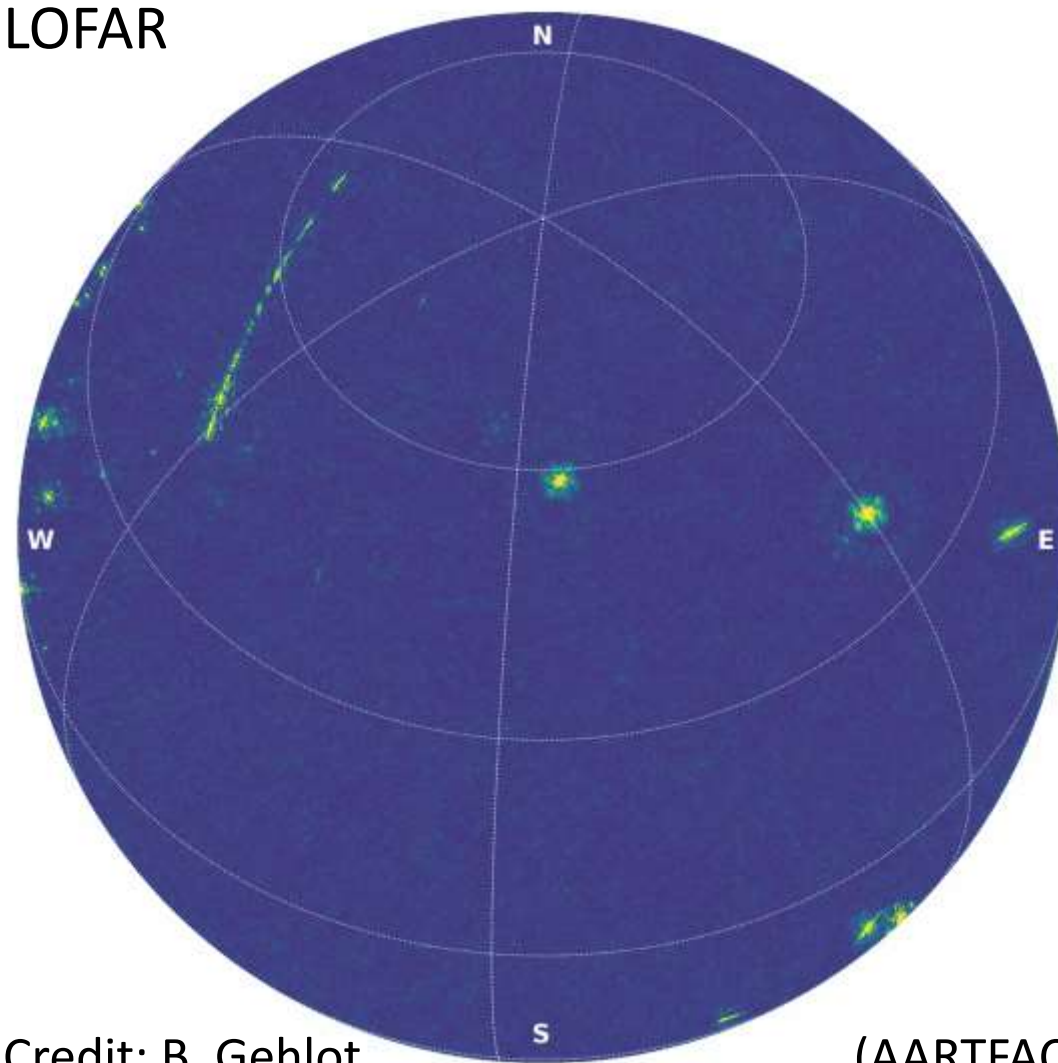


FIGURE 6.4

Map of the same sky field as in Fig. 6.3, but with interference received at Effelsberg radio telescope



LOFAR

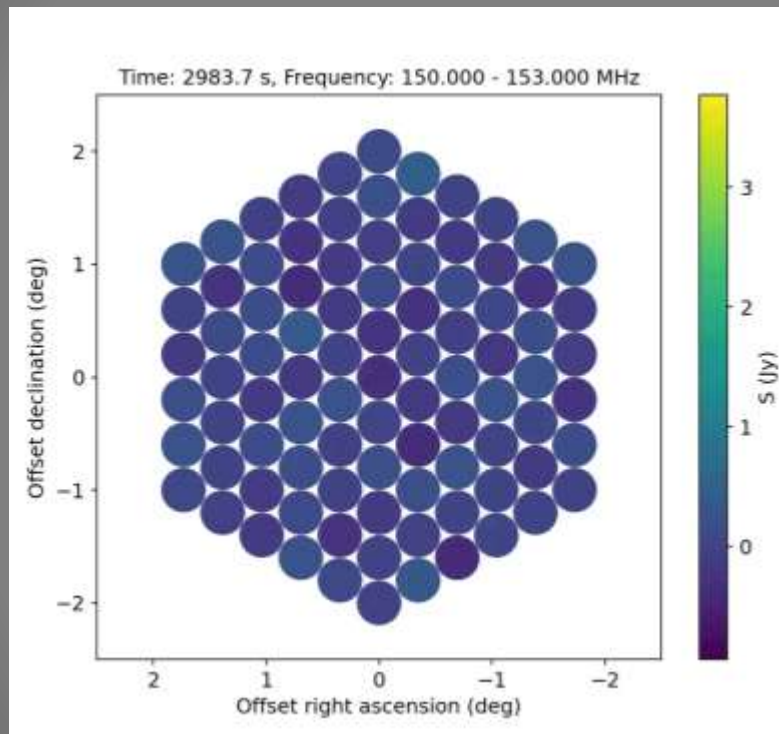


Credit: B. Gehlot

(AARTFAC)

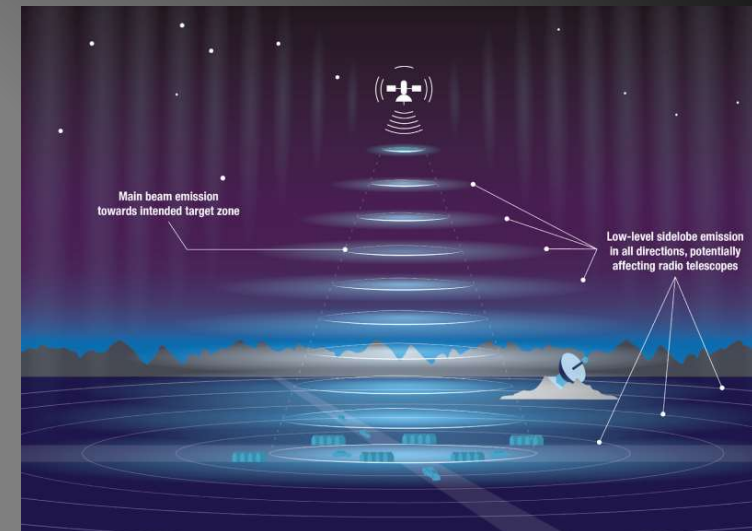
- Negative impact on radio astronomy by satellites is long known
- Huge increase in number of satellites is new
- Broadband internet
- No escape in radio quiet zones for opportunistic observations
- Leakage radiation

Credit: IAU CPS



Credit:
Daniëlle Futselaar

- Radio observatories are using bands allocated to other services
 - geographic shielding (RR 29.6)
 - Intended use of spectrum
- Satellite industry aims at reaching any point on Earth
 - Number of satellites growing fast
 - RQZs require further attention
- Industry aims at Device-to-device (D2D) solutions, connecting mobile phones with satellites at mobile phone (IMT) frequencies
 - Application of RR 4.4 for D2D joint ventures suggested
 - Unintended electromagnetic radiation (UEMR)
 - Regulation for satellites unclear (ITU, CISPR, States?)
 - Question ITU-R 243/1



Credit:
IAU CPS, NOIRLab, SKAO

- Regulation of satellites
 - Registration of constellations through national regulators
 - Can be tied to conditions
 - States are responsible for registered constellations
 - ITU checks compatibility
 - But not with RAS
 - Other States may comment
- ITU-R is not (?) responsible for
 - Electromagnetic compatibility issues
 - Radio Quiet Zones -> no international protection of RAS
- Exceptions from RR possible:
 - RR Article 4.4: “No harm no protection”

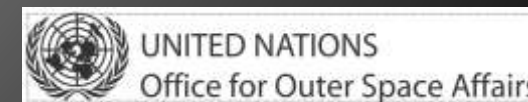


4.4 Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.

- Radio observatories are using bands allocated to other services (geographic shielding)
 - Intended use of spectrum
 - Satellite industry aims at reaching any point on Earth
 - Number of satellites growing fast
 - RQZs require further attention, potentially at ITU level
 - Industry aims at Device-to-device (D2D) solutions, connecting mobile phones with satellites at mobile phone (IMT) frequencies
 - Application of RR 4.4 for D2D joint ventures suggested
 - Unintended electromagnetic radiation (UEMR)
 - Regulation for satellites unclear (ITU, CISPR, States?)
- Measurement campaigns and simulations
- Collaboration with satellite operators
- Work with national regulators, politics
- Agenda Item 1.16 for WRC 27 (Res. 681 WRC-23)
- Agenda Item 1.18 for WRC 27 (Res. 712 WRC-23)

**The traditional system
to protect radio
astronomy is less
effective**

**Astronomers, politics,
regulators, and
industry to find a
solution**



- AI 1.16 (WP 7D/PTA): Aggregate interference from non-GSO satellite constellations into RAS
 - Regulatory provisions in certain primary RAS bands
 - Radio Quiet Zones

1.16 to consider studies on the technical and regulatory provisions necessary to protect radio astronomy operating in specific Radio Quiet Zones, and in frequency bands allocated to the radio astronomy service on a primary basis globally, from aggregate radio-frequency interference caused by non-geostationary-satellite orbit systems, in accordance with Resolution **681 (WRC-23)**;



- AI 1.18 (WP 7D/PTA): RAS and EESS protection from satellite interference above 76 GHz
 - RAS and EESS protection from satellite interference above 76 GHz
 - Update of Res. 739 w.r.t. new allocations to satellite services

1.18 to consider, based on the results of ITU Radiocommunication Sector studies, possible regulatory measures regarding the protection of the Earth exploration-satellite service (passive) and the radio astronomy service in certain frequency bands above 76 GHz from unwanted emissions of active services, in accordance with Resolution **712 (WRC-23)**;



Selected Agenda Items at WRC-27

- AI 1.15 (WP 7D/PTA)
 - Lunar communication
 - Highly important for coming generations
 - Interpretation of RR 22.22-24 Radio Astronomy in the Shielded Zone of the Moon

1.15 to consider studies on frequency-related matters, including possible new or modified space research service (space-to-space) allocations, for future development of communications on the lunar surface and between lunar orbit and the lunar surface, in accordance with Resolution **680 (WRC-23)**;

- AI 1.13 (WP 4C/PTC/PT1)
 - Direct-to-cell allocations
 - Special care required to prevent RAS to be ignored (considerings not relevant)
 - Pushback on harmonics at ITU

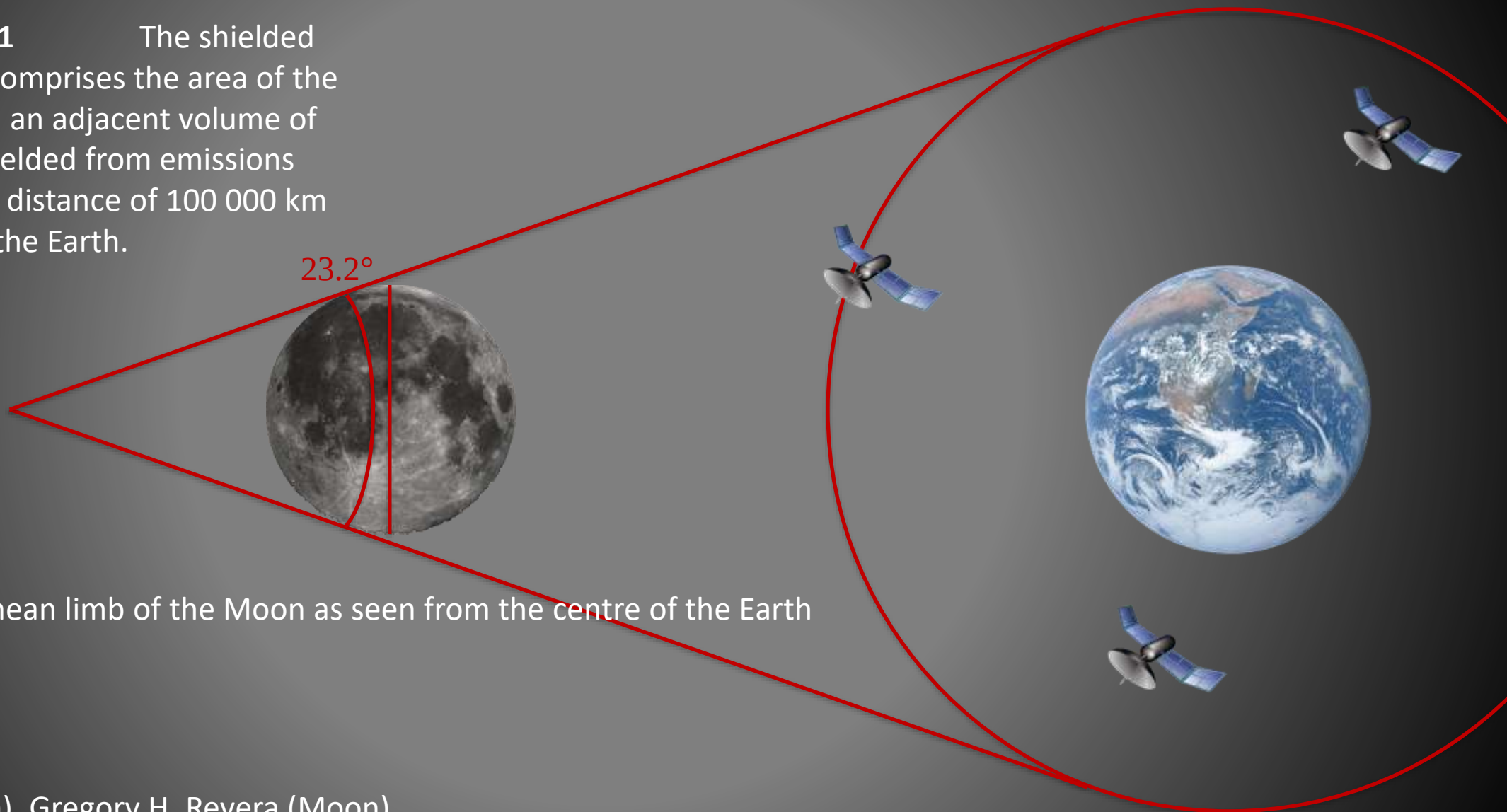
1.13 to consider studies on possible new allocations to the mobile-satellite service for direct connectivity between space stations and International Mobile Telecommunications (IMT) user equipment to complement terrestrial IMT network coverage, in accordance with Resolution **253 (WRC-23)**;



- ITU-R Radio Regulations 22.22 – 22.25
- No radio emission allowed
- Exceptions:
 - Space research service (SRS, research using spacecraft) using active sensors
 - In the context of supporting space research, communications, and operation
 - Space operation service (SOS, operation of spacecraft)
 - Earth exploration-satellite service using active sensors (EESS)
 - Radiolocation service using stations on spaceborne platforms (RLS)
 - Some room for interpretation, but clear emphasis on recognized services in space research
- Administrations may agree to protect radio astronomy from **harmful interference** also in exempted bands



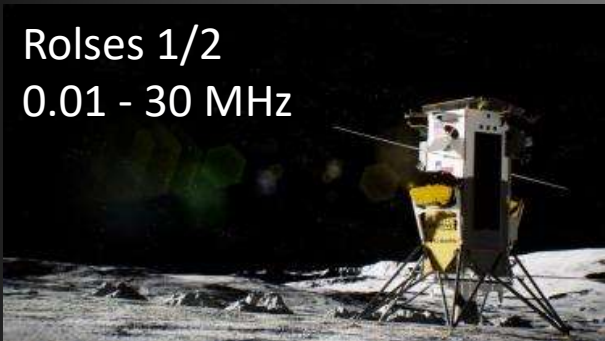
Footnote RR 22.22.1 The shielded zone of the Moon comprises the area of the Moon's surface and an adjacent volume of space which are shielded from emissions originating within a distance of 100 000 km from the centre of the Earth.



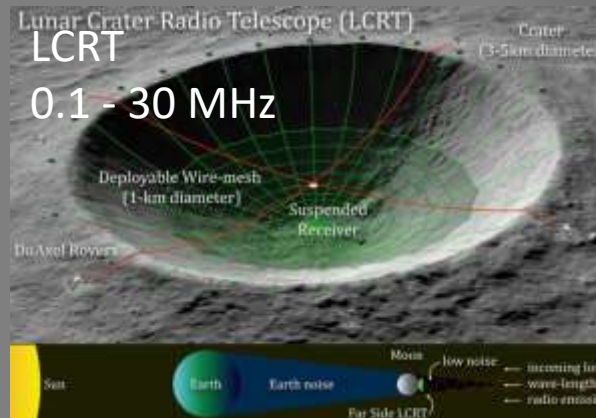
Credits: NASA (Earth), Gregory H. Revera (Moon)

- Current and near-future missions at low frequencies (low hanging fruit)
- Rec. ITU-R RA.479 emphasizes protection at frequencies below 2 GHz

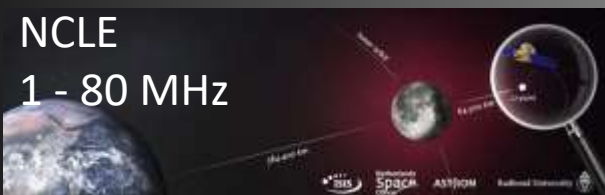
Rolses 1/2
0.01 - 30 MHz



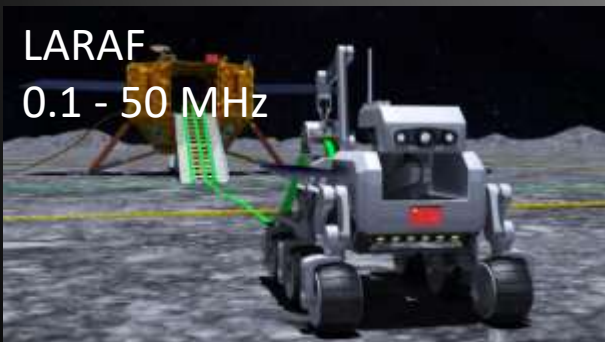
LuSEE-Night
0 - 51.2 MHz



NCLE
1 - 80 MHz



LARAF
0.1 - 50 MHz



DEX
30 - 50 MHz



- All electric/electronic devices produce unintended radiation
 - Inevitable by-product of electromagnetism
- Examples
 - Badly shielded cables
 - Power transmission lines; electric fence
 - Strong electric fields can lead to spark discharge
 - Traces on a printed circuit board can act as antennas
 - Micro-wave ovens (purpose full radiation, must not leak from casing)
- EM leakage can be used to steal device secrets (e.g., crypto-keys)
- Standardised on ground, but limited standardisation in space



Image: PCB of a DVD player
© CC BY-SA 4.0, R. Spekking

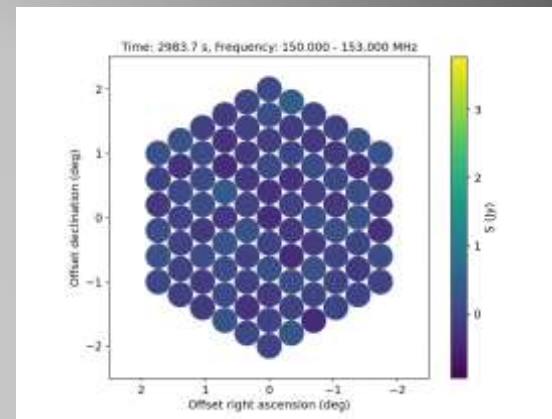


Image: Plug-in power adapter
© CC BY-SA 4.0, R. Spekking

Credit: creative commons



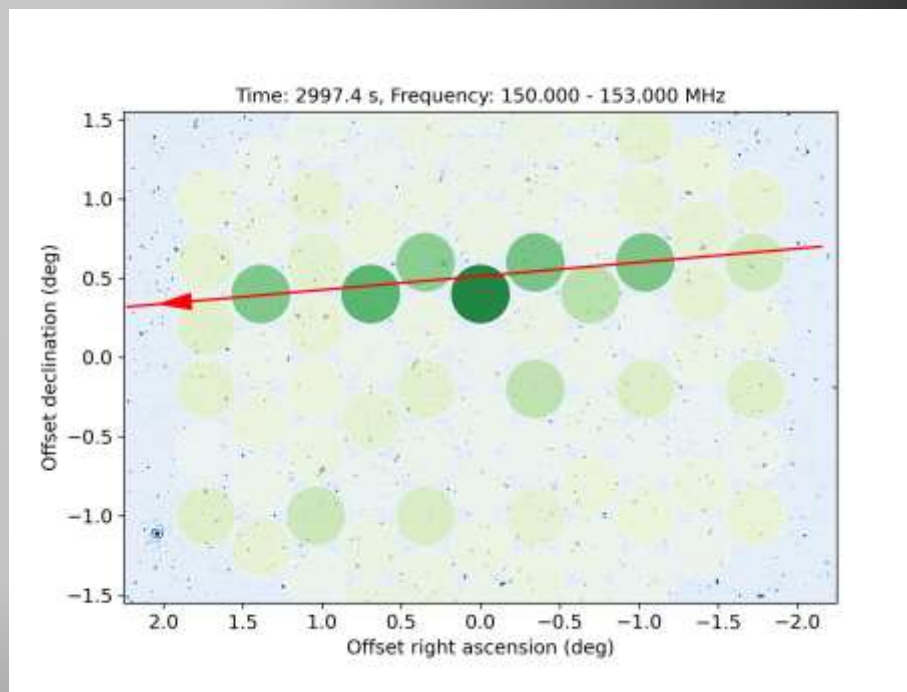
Credit: Daniëlle Futselaar



Credit: IAU/CPS

- Leakage radiation not regulated by ITU-R (but see Question ITU-R 243/1)
- International electromagnetic compatibility standards exist, but only for terrestrial devices, not in space
- Some space agencies apply standards for carriers and spacecraft aimed at protection of spacecraft
- Exploding number of space craft may become problem for radio astronomy
- Example: Di Vruno et al. 2023

Credit: IAU/CPS



- Radio astronomy requires harmonisation
 - Growth of broadband mobile telecommunication
 - Satellites
 - Combination of the two
 - Leakage radiation
- Opportunistic observations (in remote places) become very difficult
- Radio spectrum is harmonized in the International Telecommunication Union
- Engagement at national, regional, and international level
- Collaboration with industry and regulators
- Proposed new Agenda Items for WRC 27 to harmonize satellite and radio astronomy services



Credit: B. Winkel