Satellite Constellations:
Regulatory Considerations

Rubin Community Workshop
August 10, 2023

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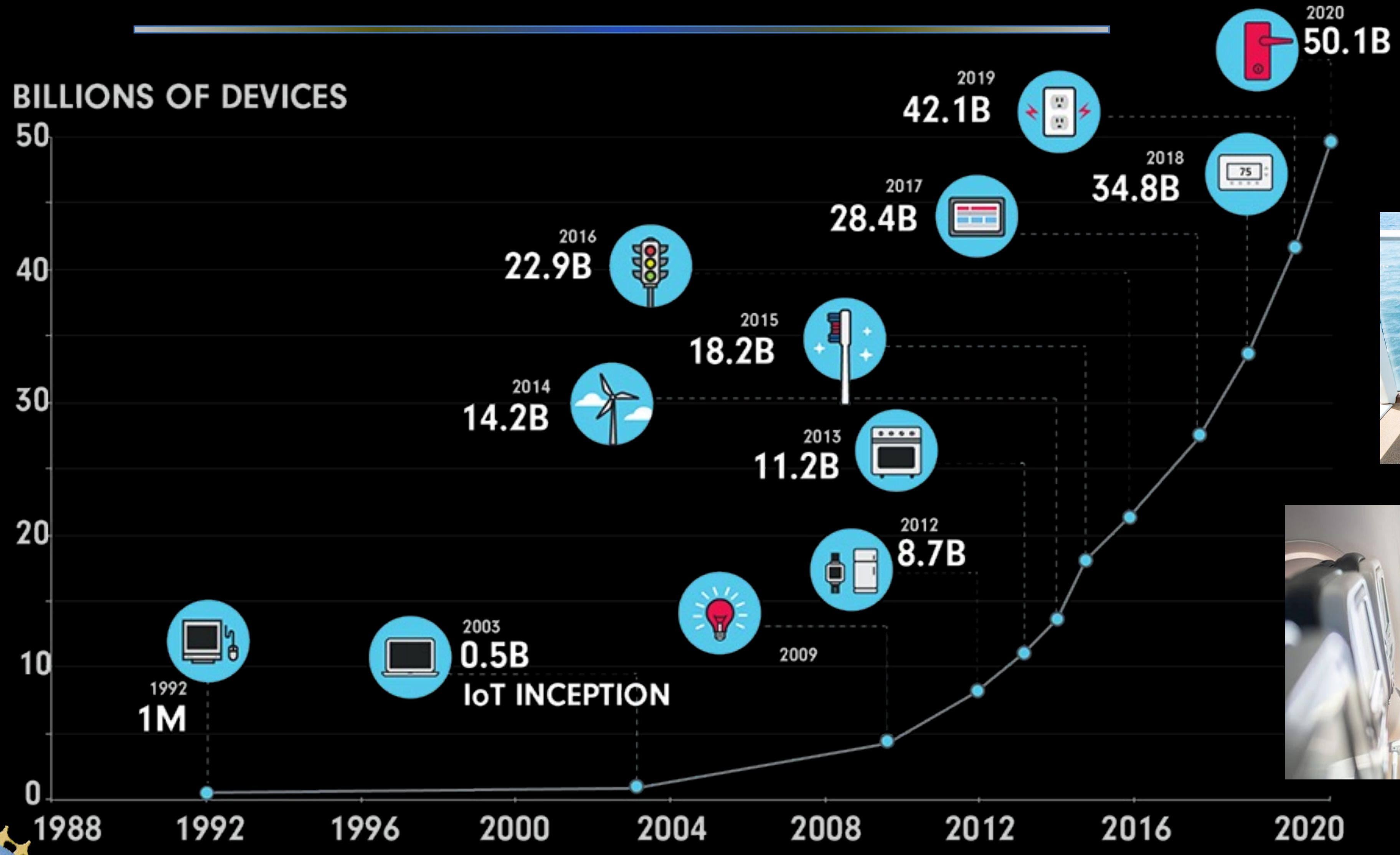
When are satellite streaks…

- ***ruining an observation*** (saturation)?

- ***causing a nuisance*** (that may be challenging to remove – non-linear)?

- ***easily mitigated?***

Demand for radio spectrum is unrelenting



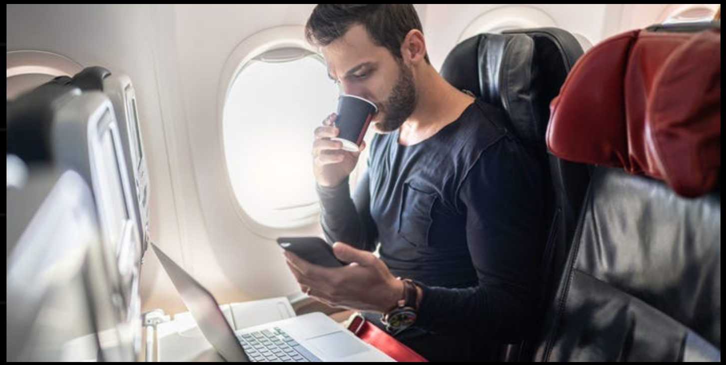


Image credits: Cisco, onestepthenanother.com, Norwegian Cruise Line, FG Trade/Getty Images

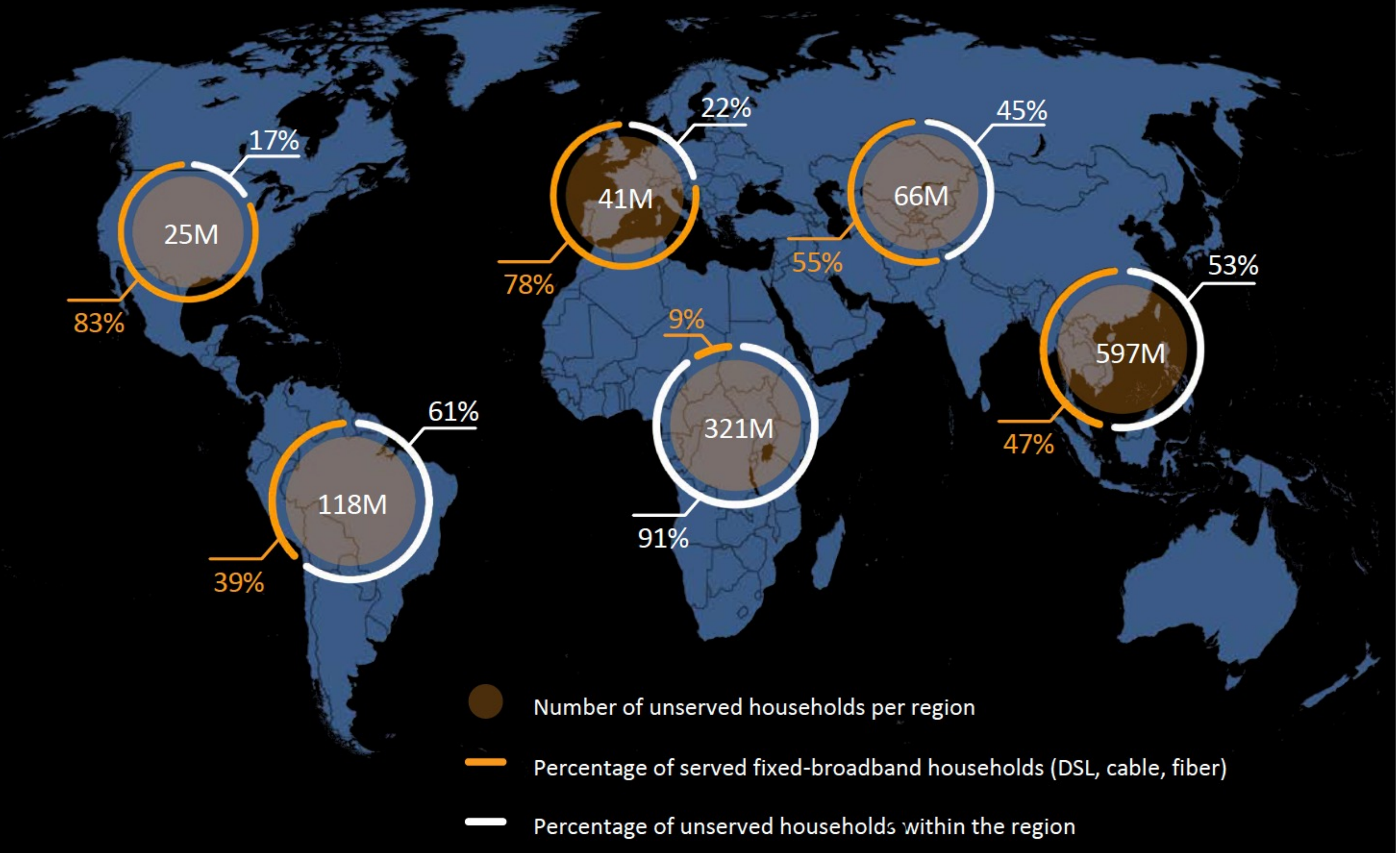
Bridging the digital divide

There are billions of people on Earth without reliable broadband. NGSOs will bridge the gap in places where service is unreliable or expensive, or where it doesn't exist at all.

1 billion
unserved households across the globe have no fixed broadband today (50% of the global total).

300 million
underserved households are on legacy technologies.

100 million
business, enterprise, and public sector endpoints lack reliable connectivity.



Source: S&P Market Intelligence

What is coming?

Constellations of thousands of NGSO satellites (10-50+ GHz transmitters) such that from any location you would always "see" at least one and up to 3 or 4 satellites or more!

Credit: University of Southampton

Also:

- Mobile telecommunications

NSF's response to ***new*** spectrum challenges

1-2 full-time spectrum managers (1970s)

Focus on radio astronomy -> broaden to consider all NSF interests and optical/IR impacts

Spectrum research: "Advanced Wireless" (1997)

Individual research programs -> platforms -> external partnerships

NSF-wide ESM Coordination Group formed (2018)

NSF-wide collaboration


RESEARCH AND DEVELOPMENT PRIORITIES FOR AMERICAN LEADERSHIP IN WIRELESS COMMUNICATIONS

May 2019

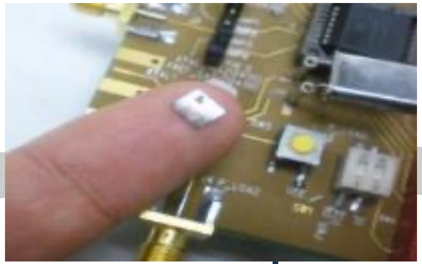
Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future

Spectrum Innovation Initiative (2020)

funding

Spectrum Connections Across NSF

MPS
Astronomy



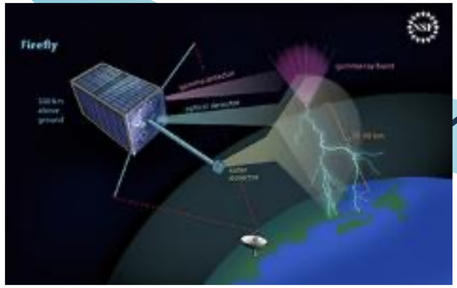
ENG
Wireless
Devices/
Circuits

SBE
Spectrum Auctions/
Game Theory

BIO
NEON/
Biosphere
Monitoring

NSF-wide ESM Coordination Group

EHR
Workforce
Development



GEO
Cubesats/
Earth Sensing

CISE
Wireless
Technology/
Networking/Theory/
Algorithms/Software

TIP
Advanced
Wireless/Technology
Outreach/Partnerships

NSF activities related to satellite constellations

Optical and Infrared

- 2 NSF-funded workshops: NOIRLab + AAS
  - SATCON1 – July 2020
  - SATCON2 – July 2021
- NSF's Rubin Observatory working closely with satellite operators
- NSF/Satellite Industry Association joint technical presentation for the USA to UN Committee on the Peaceful Uses of Outer Space (COPUOS), SME for COPUOS STSC
- NSF's NOIRLab jointly runs IAU Centre for the Protection of Dark and Quiet Skies with SKAO (launch date 1 April 2022)

Radio Frequency

- Spectrum coordination agreements
  - SpaceX (signed 2019, updated 2022)
  - OneWeb (signed 2023)
  - Other US-licensed operators to come
- R&D on satellite interference mitigation/coexistence
  - Spectrum Innovation Initiative
    - SpectrumX: An NSF Spectrum Innovation Center
  - SWIFT program: includes a stream for satellite and astronomy impacts
- Active engagement in "traditional" satellite spectrum management (domestic and international)

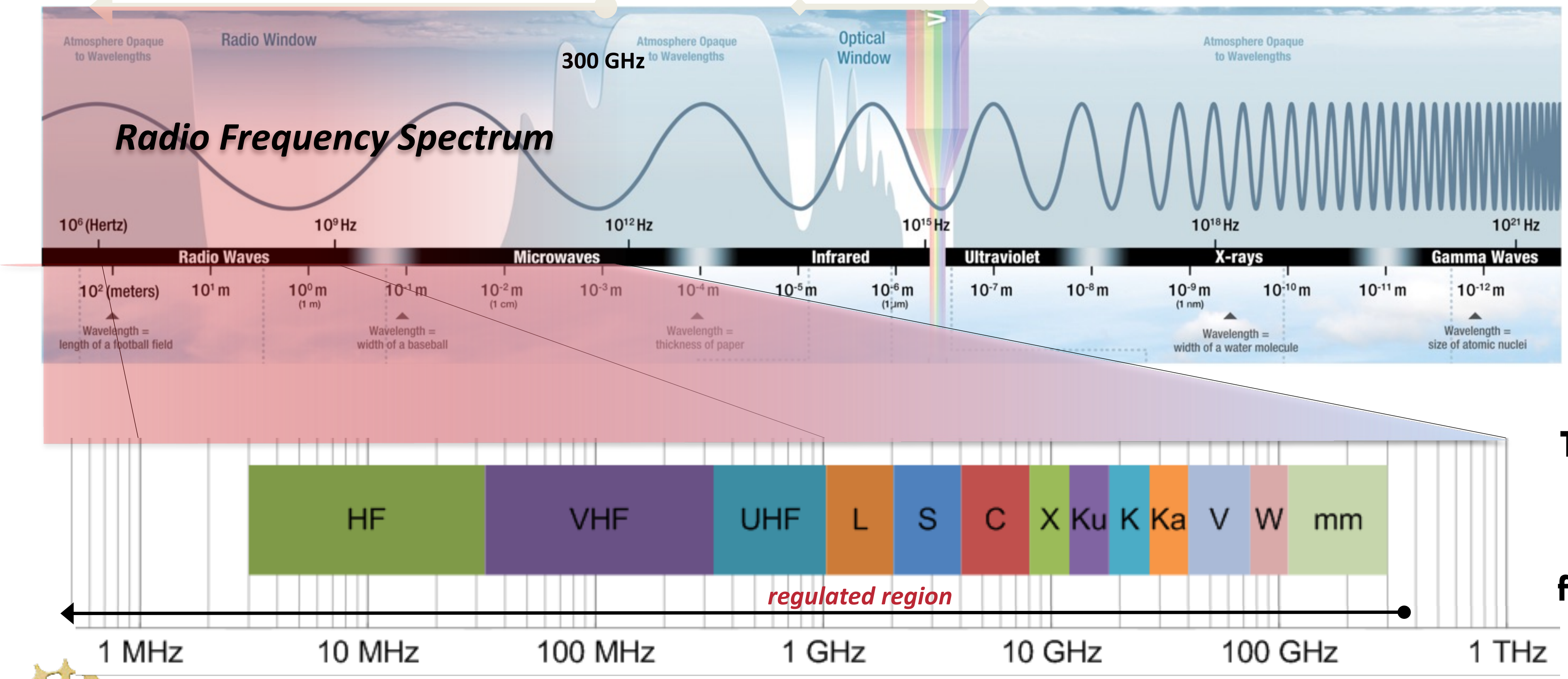
- NSF-supported JASON study (July 2021)
  - Optical impacts on NSF/Rubin Observatory
  - Mitigation opportunities
  - Good practices for satellite vendors
- Analytic study of radio interference, including
  - Single-dish telescopes
  - Interferometers
  - Cosmic Microwave Background-Stage 4

SATCON1: https://aas.org/satellite-constellations-1-workshop-report SATCON2: https://aas.org/satellite-constellations-2-workshop
NSF/SIA briefing to UN COPUOS: https://www.unoosa.org/oosa/en/ourwork/copuos/technical-presentations.html
JASON study: https://www.nsf.gov/news/special_reports/jasonreportconstellations/

Scientists and Engineers use the entire spectrum of which only 8.3 kHz to 275 GHz is regulated:

- ***Radio Frequency Spectrum*:** frequency region of the EM Spectrum that is managed via international and national laws and regulations

- Limited regulations in the near-infrared and optical region (e.g., laser coordination & safety standards)



Terminology used with portions of the radio frequency domain

Slide Credit: NASA

International Bodies

International Telecommunications Union
Specialized agency of the UN

ITU-R (Radiocommunication sector)
Handles up to 275 GHz with allocations
Up to 3 THz with "identifications"

ITU-D (development sector), ITU-T (standards sector)

Mostly focused on radiocommunication services and "transmissions"

There is an official liaison between ITU and COPUOS: currently Véronique Glaude

UN Office of Outer Space Affairs (UNOOSA)

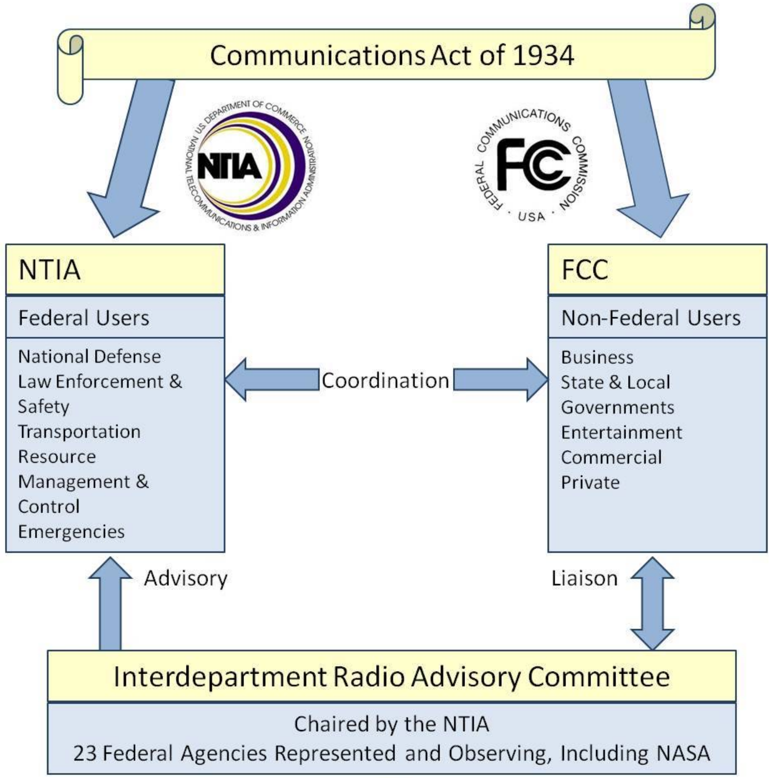
UN Committee on the Peaceful Uses of Outer Space (COPUOS)

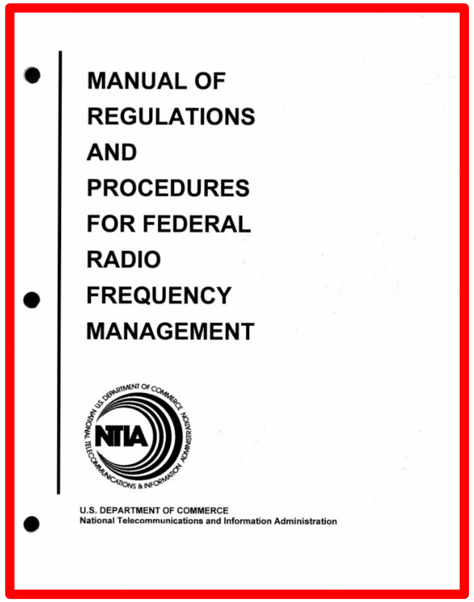
Subcommittees
-currently STSC most relevant, LSC may also be..

Handling optical reflections (from space); space debris in the Long Term Sustainability Working Group

Allocations and Coordination

- Radio Regulations:
  - (1) International (ITU-R Radio Regulations; www.itu.int)
    - (2) Regional
  - (3) National (USA: NTIA - www.ntia.doc.gov; FCC - www.fcc.gov)




MANUAL OF REGULATIONS AND PROCEDURES FOR FEDERAL RADIO FREQUENCY MANAGEMENT

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration

International Table

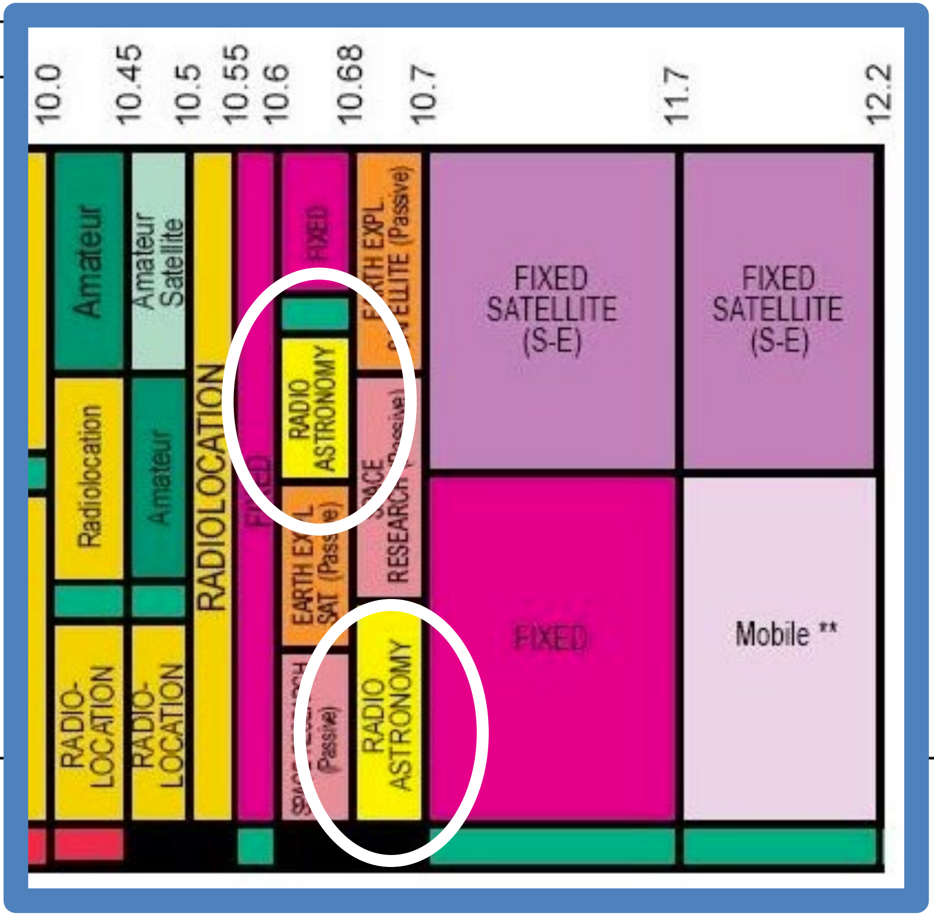
US Domestic Table

10-10.45 FIXED MOBILE RADIOLOCATION Amateur 5.479	10-10.45 RADIOLOCATION Amateur 5.479 5.480	10-10.45 FIXED MOBILE RADIOLOCATION Amateur 5.479	10-10.5 RADIOLOCATION US108 G32 5.479 US128	10-10.45 Amateur Radiolocation US108 5.479 US128 NG50	Private Land Mobile (90) Amateur Radio (97)
10.45-10.5 RADIOLOCATION Amateur Amateur-satellite 5.481				10.45-10.5 Amateur Amateur-satellite Radiolocation US108 US128 NG50	
10.5-10.55 FIXED MOBILE Radiolocation	10.5-10.55 FIXED MOBILE RADIOLOCATION		10.5-10.55 RADIOLOCATION US59		Private Land Mobile (90)
10.55-10.6 FIXED MOBILE except aeronautical mobile Radiolocation			10.55-10.6	10.55-10.6 FIXED	Fixed Microwave (101)
10.6-10.68 EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY SPACE RESEARCH (passive) Radiolocation 5.149 5.482 5.482A			10.6-10.68 EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive) US130 US131 US482	10.6-10.68 EARTH EXPLORATION-SATELLITE (passive) FIXED US482 SPACE RESEARCH (passive) US130 US131	
10.68-10.7 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.483			10.68-10.7 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) US131 US246		
10.7-11.7 FIXED FIXED-SATELLITE (space-to-Earth) 5.441 5.484A (Earth-to-space) 5.484 MOBILE except aeronautical mobile	10.7-11.7 FIXED FIXED-SATELLITE (space-to-Earth) 5.441 5.484A MOBILE except aeronautical mobile		10.7-11.7 US131 US211	10.7-11.7 FIXED FIXED-SATELLITE (space-to-Earth) 5.441 US131 US211 NG52	Satellite Communications (25) Fixed Microwave (101)

Radio Astronomy protections at 10.6 GHz

US131 In the band 10.7-11.7 GHz, non-geostationary satellite orbit licensees in the fixed-satellite service (space-to-Earth), prior to commencing operations, shall coordinate with the following radio astronomy observatories to achieve a mutually acceptable agreement regarding the protection of the radio telescope facilities operating in the band 10.6-10.7 GHz:

Observatory
Arecibo Observatory, PR.……….........
Green Bank Telescope (GBT), WV…..…....
Very Large Array (VLA), Socorro, NM…..….
Very Long Baseline Array (VLBA) Stations:
Brewster, WA………………………..…
Fort Davis, TX………………………….
Hancock, NH…………………….........
Kitt Peak, AZ……………………...........
Los Alamos, NM…………………...........
Mauna Kea, HI…………………….…......
North Liberty, IA………………………....
Owens Valley, CA…………………….........



United States (US) Footnotes

International protection standards

- *Interference levels from ITU-R RA.769-2 (esp. Section 2.2)*
- *2% data loss*
- *Assumes 2,000 second integrations*
- *Divides sky into uniform cells of 9 square degrees*
- *Utilizes simplifying models in appropriate ITU-R Reports and Recommendations for beam patterns, etc.*

Image Credit: Tesmanian.com

2.2 Interference from non-GSO satellites

In the case of non-GSO satellites, and in particular for low-Earth orbit satellites, the systems usually involve constellations of many individual satellites. Thus determination of interference levels requires analysis of the combined effect of many signals, most of which are received through far side lobes of the radio astronomy antenna. A more detailed side-lobe model than that of Recommendation ITU-R SA.509 is therefore desirable, and it is proposed that the model in Recommendation ITU-R S.1428 be used until such time as a more representative model for radio astronomy antennas is obtained. In using this proposed model the case for antennas with diameter greater than 100 λ is generally appropriate for radio astronomy applications. It should be noted that Note 1 of Recommendation ITU-R S.1428, which allows cross-polarized components to be ignored, cannot be applied since radio astronomy antennas generally receive signals in two orthogonal polarizations simultaneously. The motion of non-GSO satellites across the sky during a 2 000 s integration period requires that the interference level be averaged over this period, that is, the response to each satellite must be integrated as the satellite moves through the side-lobe pattern. One system of analysis that includes these requirements is the epfd method described in RR No. 22.5C. Values of epfd represent the pfd of a signal entering the antenna through the centre of the main beam that would produce an equivalent level of interference power. Since the threshold levels of detrimental interference in Tables 1 and 2 correspond to pfd received with an antenna gain of 0 dBi, it is necessary to compare them with values of ($epfd + G_{mb}$), where G_{mb} is the main beam gain, to determine whether the interference exceeds the detrimental level. Making use of the epfd method, Recommendation ITU-R S.1586 has recently been developed for interference calculations between radio astronomy telescopes and FSS non-GSO satellite systems. A similar Recommendation, Recommendation ITU-R M.1583 was developed for interference calculations between radio astronomy telescopes and MSS and radionavigation-satellite service non-GSO satellite systems. The applicability of the protection criteria given in Tables 1 and 2 is described in Recommendation ITU-R RA.1513.

Data loss is expected even in protected band

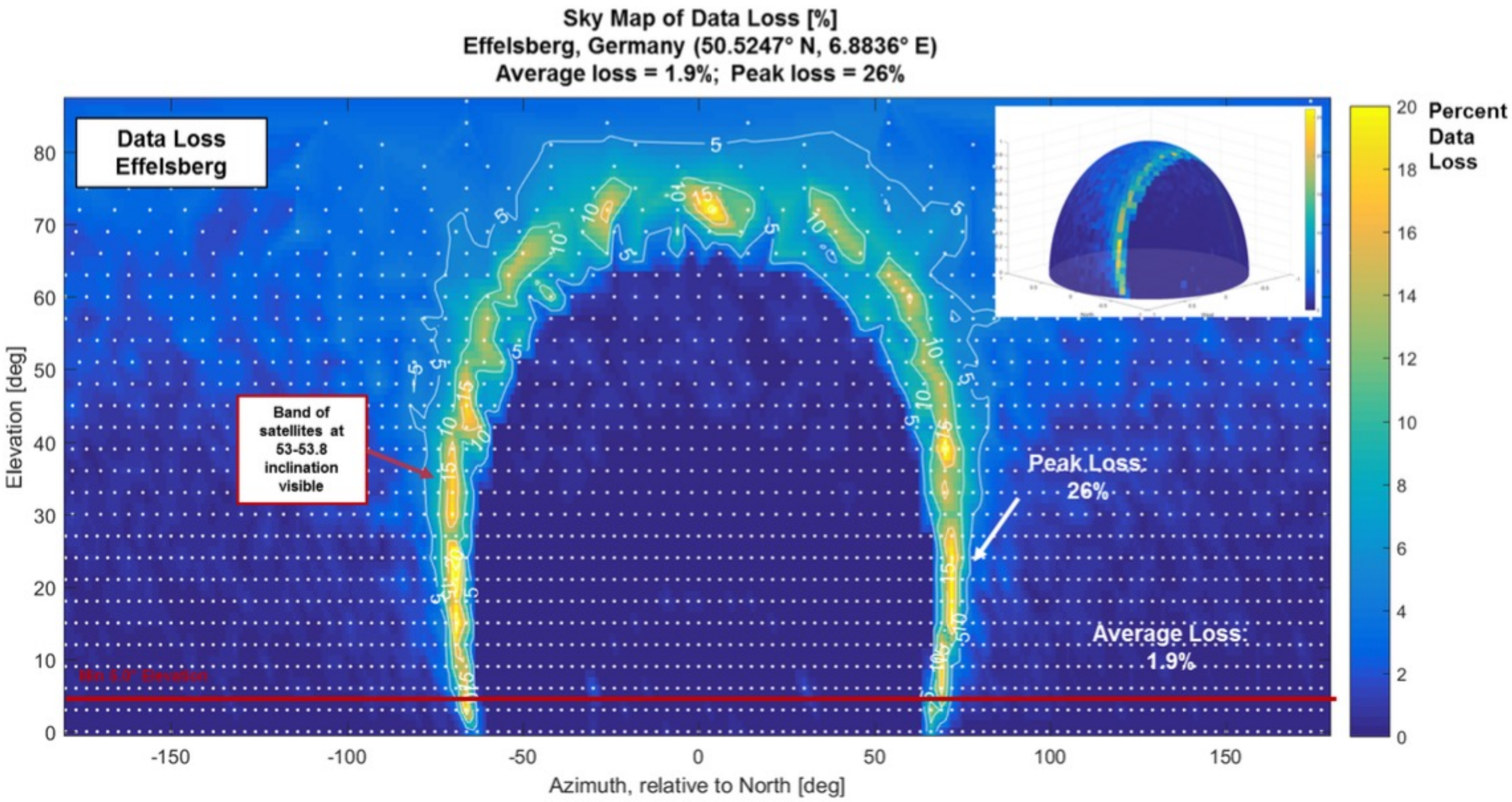


Figure 64: Effelsberg – Sky Map of Percent Data Loss

Statement on NSF and SpaceX Radio Spectrum Coordination Agreement

June 4, 2019

In late May, SpaceX launched its first 60 Starlink satellites into orbit. SpaceX plans to launch a much larger satellite constellation into low-Earth orbit with the goal of providing terrestrial internet service. The operation of these satellites will utilize frequencies that neighbor some radio astronomy assets in the 10.6 - 10.7 GHz band. SpaceX coordinated with NSF and its radio astronomy observatories regarding potential interference from their use of the radio spectrum. After working closely with SpaceX, NSF has finalized a coordination agreement to ensure the company's Starlink satellite network plans will meet international radio astronomy protection standards, limiting interference in this radio astronomy band. Additionally, NSF and SpaceX will continue to explore methods to further protect radio astronomy. Together we are setting the stage for a successful partnership between commercial and public endeavors that allows important science research to flourish alongside satellite communication.

-NSF-

2022 Updated Agreement: Optical

NSF and SpaceX agreed to cooperate to the extent practicable to mitigate the impact on optical and infrared ground-based astronomical facilities. SpaceX committed to continue work towards recommendations that came from NSF's NOIRLab, the American Astronomical Society's SATCON workshops and the International Astronomical Union's Dark and Quiet Skies best practices guidance. ***These recommendations include continuing to work to reduce the optical brightness of their satellites to 7th visual magnitude or fainter by physical design changes, attitude maneuvering, or other ideas to be developed; maintaining orbital elevations at ~700 km or lower; and providing orbital information publicly that astronomers can use for scheduling observations around satellite locations.***

See talk by David Goldstein, SpaceX

https://beta.nsf.gov/news/statement-nsf-astronomy-coordination-agreement

Many factors contribute to overall scientific impact

Satellite Operator:

- Orbital altitude / dwell time of satellite in field of view (FOV)
- Constellation total number
- Size of individual satellites
- Reflectivity properties of material
- Geometry of reflected light
- Orbit/De-orbit plans

Astronomers:

- Telescope
  - Camera detector properties
  - Scheduling
  - Field of View
  - Image sensitivity
- Post-processing algorithms
- Observational requirements

Coordination now required in FCC authorizations

- **For example, February 8, 2023 FCC Amazon Kuiper authorization (see No. 27 on page 9)**

"Given the similar issues raised by both agencies here and in the SpaceX Gen2 Starlink Order,66 we find that it is in the public interest to condition this authorization similar to the SpaceX Gen2 Starlink Order, and require Kuiper to continue to coordinate and collaborate with NASA to promote a mutually beneficial space environment that would minimize impacts to NASA's science missions involving astronomy **and to coordinate with NSF to achieve a mutually acceptable coordination agreement to mitigate the impact of its satellites on optical ground based astronomy.** We also condition this authorization to require Kuiper to submit an annual report to the Commission, by January 1st each year, covering the preceding year and containing the following information: (1) whether it has reached a coordination agreement with NSF addressing optical astronomy; and (2) any steps Kuiper has taken to reduce the impact of its satellites on optical astronomy, including but not limited to darkening, deflecting light away from the Earth, attitude maneuvering, and provision of orbital information to astronomers for scheduling observations around satellites' locations."

Summary

- Work by the Rubin team has been critical to establish technical limits for us to put in coordination agreements (e.g., 7th magnitude, provision of telemetry, preferential choice of lower orbits)
  - *Continued technical assessment of these targets is helpful*
  - *What will be the scientific impact with X satellites, size Y, with given distribution in orbital slots?*

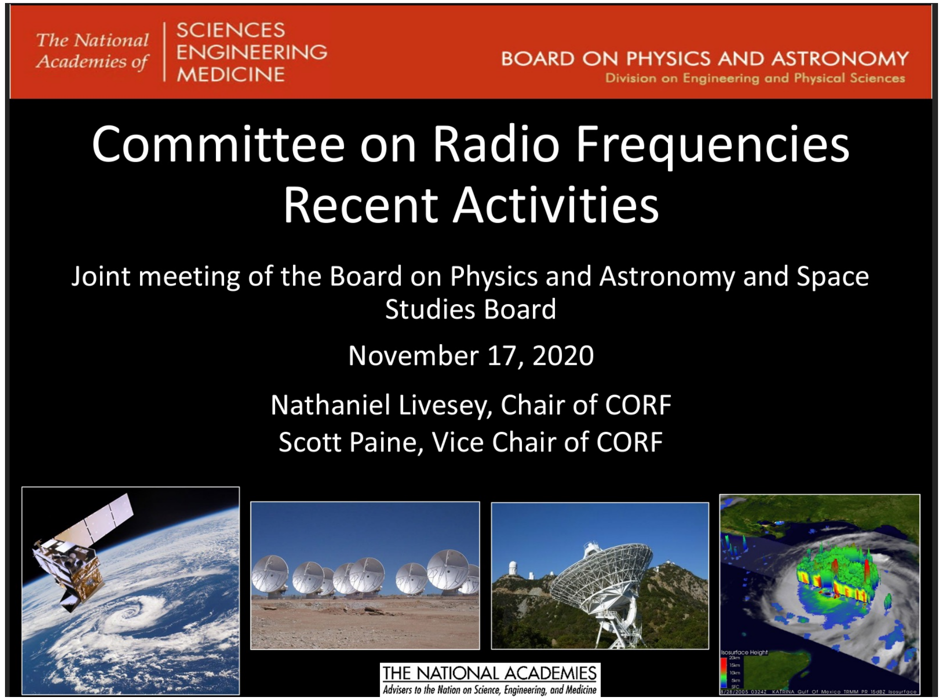
- FCC has done an excellent job taking expressed concerns into account in authorizations, requiring coordination agreements

- Large satellite companies have been working to mitigate:
  - *Amazon Kuiper: co-chair of the IAU CPS Industry Hub*
  - *SpaceX: demonstrated improvements (lower orbital elevations, telemetry, design changes)*
  - *OneWeb: Signed coordination agreement*

- U.S. support of international agenda item and expert group at U.N. COPUOS for establishing voluntary "best practice guidance"
  - *Gaining international support is critical as satellites are international, cross-border*

What can you do?

Volunteer/serve – technical studies / raise awareness

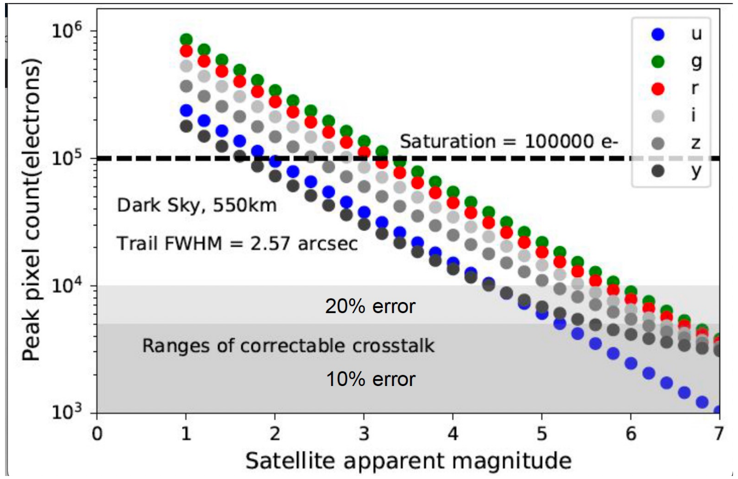


IAU

CPS

Committees

Committee for the Protection of Astronomy and the Space Environment (COMPASSE)



Tyson et al. 2020

Questions and Comments

esm@nsf.gov

Thank you!

Credit: Sophia Dagnello, NRAO/AUI/NSF; NASA, STScI