Dark and Quiet Skies for Science and Society

UNITED NATIONS
Office for Outer Space Affairs

IAU International Astronomical Union

INSTITUTO DE ASTROFISICA DE CANARIAS · IAC ·

With the support of NOIR Lab

Dark and Quiet Skies for Science and Society

Opening Remarks

SOC Member

Casiana Muñoz Tuñón

IAC, Spain.

DARK & QUIET SKIES

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Opening Remarks
Special Guest
Pedro Duque
Minister of Science and Innovation. Spanish Government

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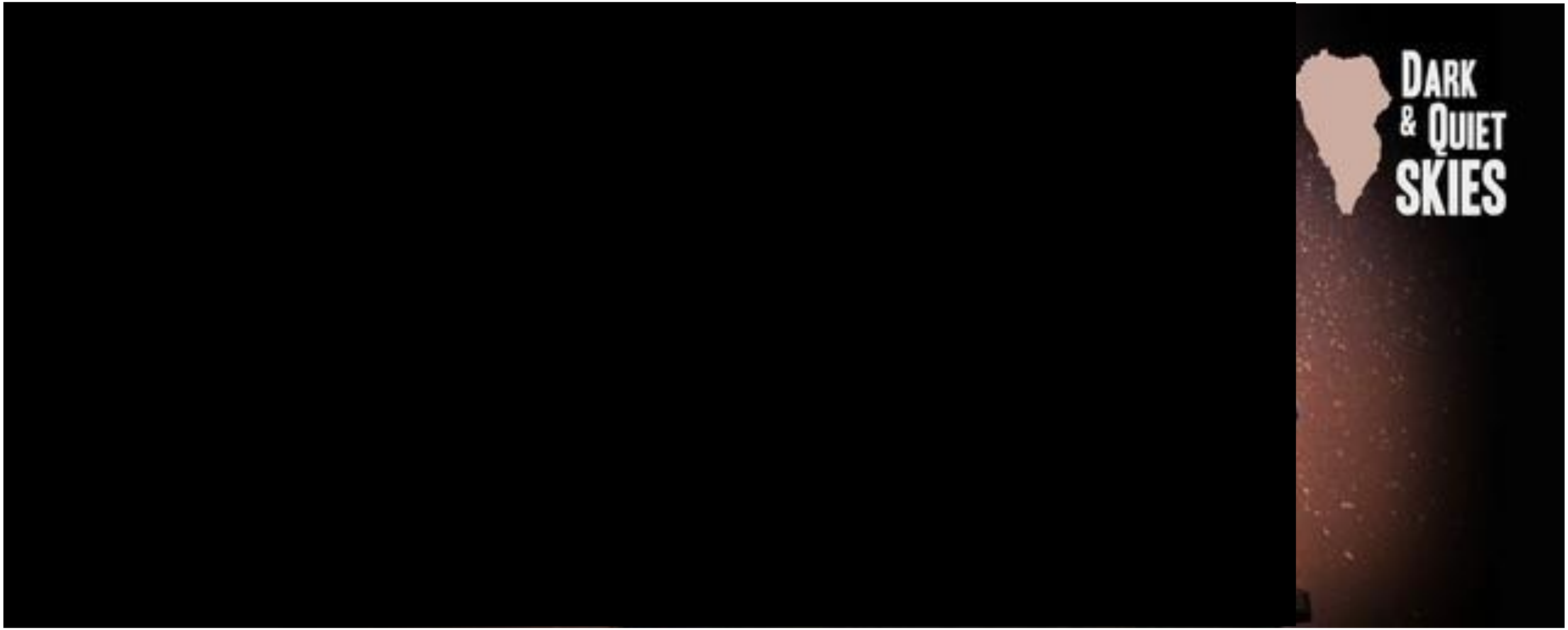

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Dark and Quiet Skies for Science and Society

Radio Astronomy
15:00 – 17:00 UTC

Notes & Introductions
SOC Member/Moderator
Harvey Liszt

DARK & QUIET SKIES

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Dark and quiet skies for space and society: inputs

Five Draft Reports are available and open for comments online until 16 October

- Download them from http://bit.ly/DQS_reports

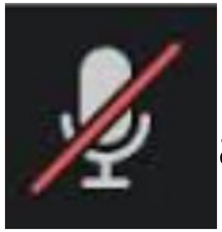
- Comment on the recommendations at http://bit.ly/DQS_comment

If you registered for today's Workshop, you have received these links on Thursday in an email from UNOOSA-Events@un.org and on Friday in an email from DQSkies@iac.es

Not received even though you had registered? Please email UNOOSA-Events@un.org

Zoom Meeting “Housekeeping”

SPEAKERS

Please keep your mic muted  and video off. 

ATTENDEES

You have a Question? Write it in “Chat” 

Preface it with “Q” or “Question” perhaps, please

SPAIN SUPPORTS RADIO ASTRONOMY

THE RADIO ASTRONOMY WORKING GROUP

Harvey Liszt, National Radio Astronomy Observatory, IUCAF Chair (USA)

Federico Di Vruno, SKA Organisation (UK)

Michael Lindqvist, Chalmers, Onsala Space Observatory (Sweden)

Masatoshi Ohishi, National Astronomical Observatory of Japan

Adrian Tiplady, South African Radio Astronomy Observatory

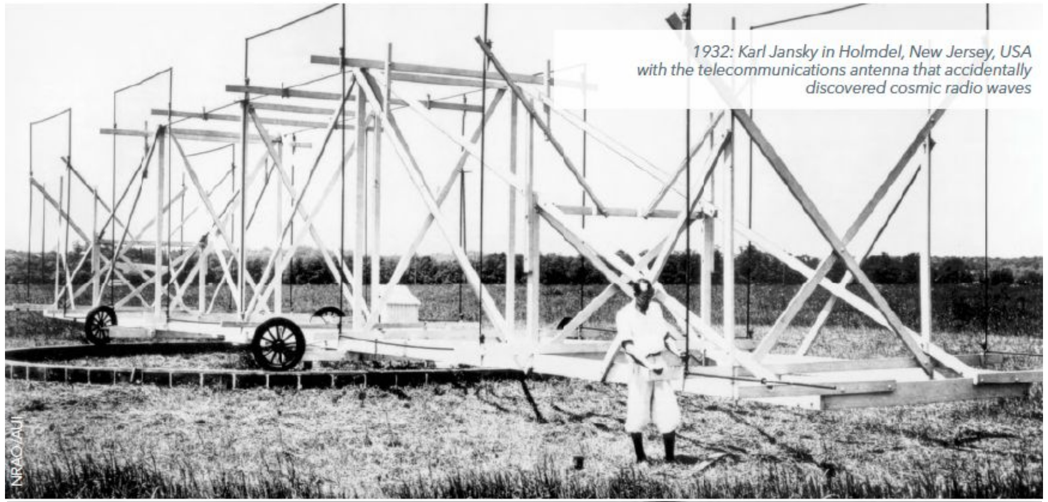
Tasso Tzioumis, CSIRO (Australia)

Bevin Ashley Zauderer, National Science Foundation (USA)

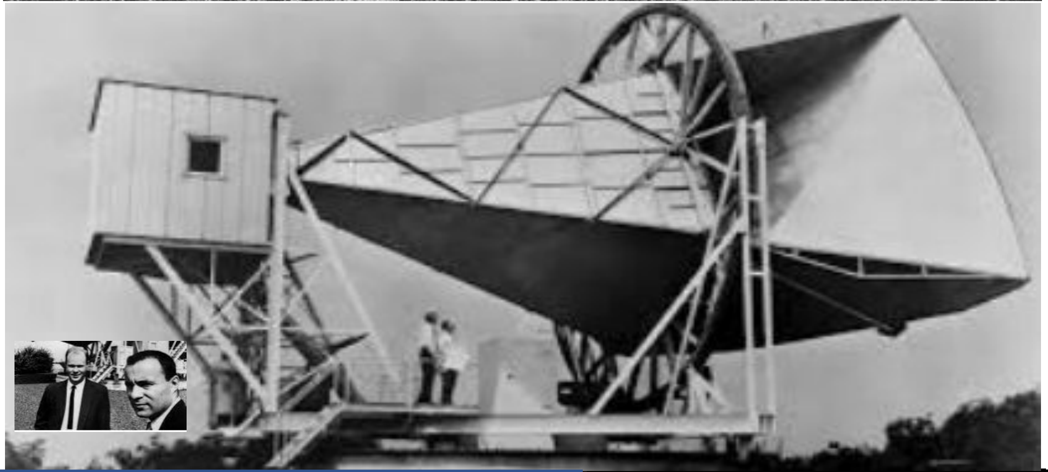
Liese van Zee, Indiana University (USA)

OVERVIEW

1. Radio Astronomy as a Discipline
2. Regulation of Use of Radio Spectrum
3. Spectrum Protection for Radio Astronomy - *Liese*
4. Risks to Radio Astronomy - *Federico*
5. The way forward and two recommendations



1932: Karl Jansky in Holmdel, New Jersey, USA with the telecommunications antenna that accidentally discovered cosmic radio waves



RADIO ASTRONOMY AS A DISCIPLINE

HARVEY LISZT

RADIO ASTRONOMY AS A DISCIPLINE

- Radio waves are the electromagnetic radiation at wavelengths >100microns, < 3THz

The dumping ground at the long wavelength end of the electromagnetic spectrum

- Radio waves can penetrate opaque dust that shrouds the Universe in visible light
  - Dust that might coagulate around a new star to form another rocky planet like Earth
- Cosmic radio waves are a very very very very … very faint noise at some frequency, in some direction, perhaps only at that moment, with no carrier to lock on
- The frequency of the radiation tells you its origin in some cases
- But expansion of the Universe displaces signals across the entire radio spectrum

Whither they go we must follow

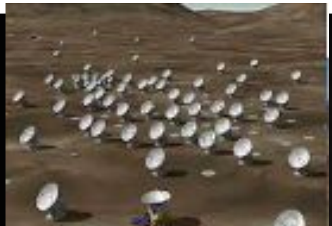
- The entire history of the Universe back to the Big Bang is encoded in the radiation at every frequency

RADIO ASTRONOMY AS A DISCIPLINE

- Angular resolution ~wavelength/diameter: long wavelength =>large diameter, separation
- Noise on the sky while observing ~ (system noise)/(Bandwidth * time)$^{1/2}$
  - Radio astronomy system noise levels are the lowest possible and must be kept steady for long times
  - Radio astronomy detects cosmic radio waves that are billions of times below the system noise
  - Radiocommunication signals are billions of times stronger than cosmic radio waves, *may be toxic*
- The net gain of every radio antenna is the same as that of an isotropic antenna with no gain and no resolving power whatsoever
  - All-sky integral of Area * antenna response*d(solid angle) = $\lambda^2/4\pi$ = wavelength^2/4*pi
- Antennas have sidelobes where they less strongly “see” away where they are pointed
  - Comm signals are so strong, they create strong RFI in even very weak, very distant sidelobes
  - Sidelobes within 20^{o} will **boost** signals, so transmitters should be kept at least that far away
  - Antennas have no ability to accept good cosmic waves and reject bad extraneous ones

RADIO ASTRONOMY AS A DISCIPLINE

- Radio astronomy is a remarkable engine of discovery and invention of great practical use
- Radio astronomy works internationally, of necessity
- Radio astronomy needs and builds big antennas and antenna arrays, even globally
- Even the biggest radio telescope is blind without adequate access to spectrum
- No radio antenna is entirely insensitive to radiation arising in directions away from where it is pointed, even behind it, owing to its “sidelobes”
- Radio telescopes are sited misanthropically to escape as much interference as possible
- Radio telescopes must point upward to see the cosmos
- Radiocommunication signals are billions of times stronger than cosmic waves

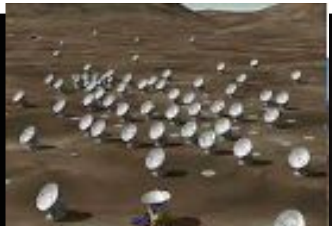


Some of The Facts of Life

- Billions of public $/Euro/Rand/whatevers are invested in terrestrial radio astronomy

Private investment in radio astronomy facilities is rare, less than optical

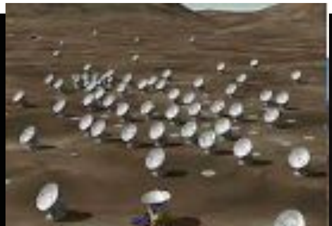
- *Any* of *several* spectacular satellite industry bankruptcies would have funded terrestrial radio astronomy practically forever



REGULATION OF USE OF THE RADIO SPECTRUM

REGULATION OF USE OF THE RADIO SPECTRUM

- Transmission and reception imply common frequency use, necessitate protection
- Communication historically used narrow bands, spectrum rights were finely sliced
  - Radio spectrum is proportionally wider than optical, regulated 3 kHz - 275 GHz (factor 10^8)
- Mechanisms were created to define rights to use spectrum slices (bands)
  - Rights are apportioned among radiocommunication services, not companies or, usually, nations
  - The practice of these mechanisms is called **"spectrum management"**
  - *Spectrum regulators* work internationally at ITU-R to revise the Radio Regulations every 4 years
  - National regulators (FCC,OFCOM) implement ITU-R decisions but also influence ITU-R work
  - The entire hierarchical structure of ITU-R is mirrored in individual administrations to prepare
- Mechanisms require more/more servicing as spectrum use innovates/diversifies
- Radio astronomers long ago had to learn to swim in treacherous waters
  - Radio astronomy use is so different that ITU-R rules for protecting it are still evolving



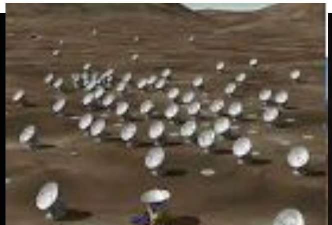
WHAT RADIO ASTRONOMERS DID TO ORGANIZE

- 1960: URSI, IAU and COSPAR organized ICSU-chartered IUCAF
  - Radio astronomers and engineers went to the WRC-equivalent in 1959-1960
  - Radio astronomy service was defined as receiving radio waves of cosmic origin
  - Got a sole allocation at 1 400 - 1 427 MHz to the radio astronomy service
- Subsequent effort developed protection criteria and acquired other frequency allocations
- Astronomy spectrum managers were hired at national science agencies (NSF, CSIRO)
- Created bodies to practice radio astronomy spectrum management locally and at ITU-R
  - CRAF Committee on Radio Astronomy Frequencies in CEPT countries
  - CORF Committee on Radio Astronomy Frequencies in US
  - RAFCAP Committee in Asia-Pacific region
- Appointed spectrum managers at observatories large enough to spare manpower
  - Most of them divide their time with other activities

WE GO WHERE THE ACTION IS

WRC-19 28/10 - 22/11 2019

DARK & QUIET SKIES



5th International IUCAF Spectrum Management School for Radio Astronomy
Stellenbosch, South Africa 2 – 6 March 2020

SCIENTIFIC COMMITTEE ON FREQUENCY ALLOCATIONS FOR RADIO ASTRONOMY AND SPACE SCIENCE
IUCAF

- Supported by IUCAF, SARAO, RadioNet http://www.iucaf.org/sms2020/
- No registration or banquet fee!
- Previous schools 2002 (USA), 2005 (Italy), 2010 (Japan), 2014 (Chile)

SPECTRUM PROTECTION FOR RADIO ASTRONOMY

Table of Frequency Allocations			1400-1626.5 MHz (UHF)	
International Table			United States Table	
Region 1 Table	Region 2 Table	Region 3 Table	Federal Table	Non-Federal Table
1400-1427 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341			1400-1427 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) 5.341 US246	

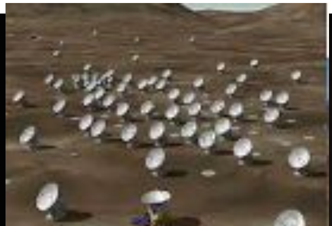
Liese van Zee

Spectrum Management and Policy

- Radio spectrum shared between commercial, governmental, and scientific uses.
- Currently, radio regulations cover frequencies from 8.3 kHz to 275 GHz and are both international (ITU) and domestic (e.g., FCC).
  - Radio spectrum defined as 0 – 3000 GHz.
  - IAU identified preferred bands for science below 3 THz.
- Increasing commercial demand/usage for radio frequencies due to recent advances in telecommunications technology.
- Increased need for spectral sharing and coordination.
  - However, issues with implementation of coordination agreements.
  - It is difficult to reverse regulations and recover spectrum when passive services are negatively impacted.

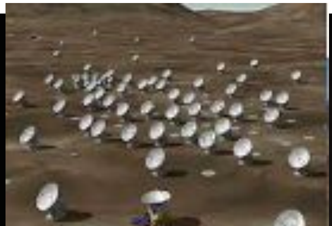
RAS Allocations – Part 1

- International Table of Frequency Allocations
  - Primary Allocations: entitled to protection from harmful interference from any other service.
  - Secondary Allocations: cannot claim protection from harmful interference from stations of a primary service to which frequencies are already assigned, but can claim protection from harmful interference of other secondary services.
  - Footnotes
    - RR 5.340: “All emissions are prohibited in the following bands:”
    - RR 5.149: “…administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service…”



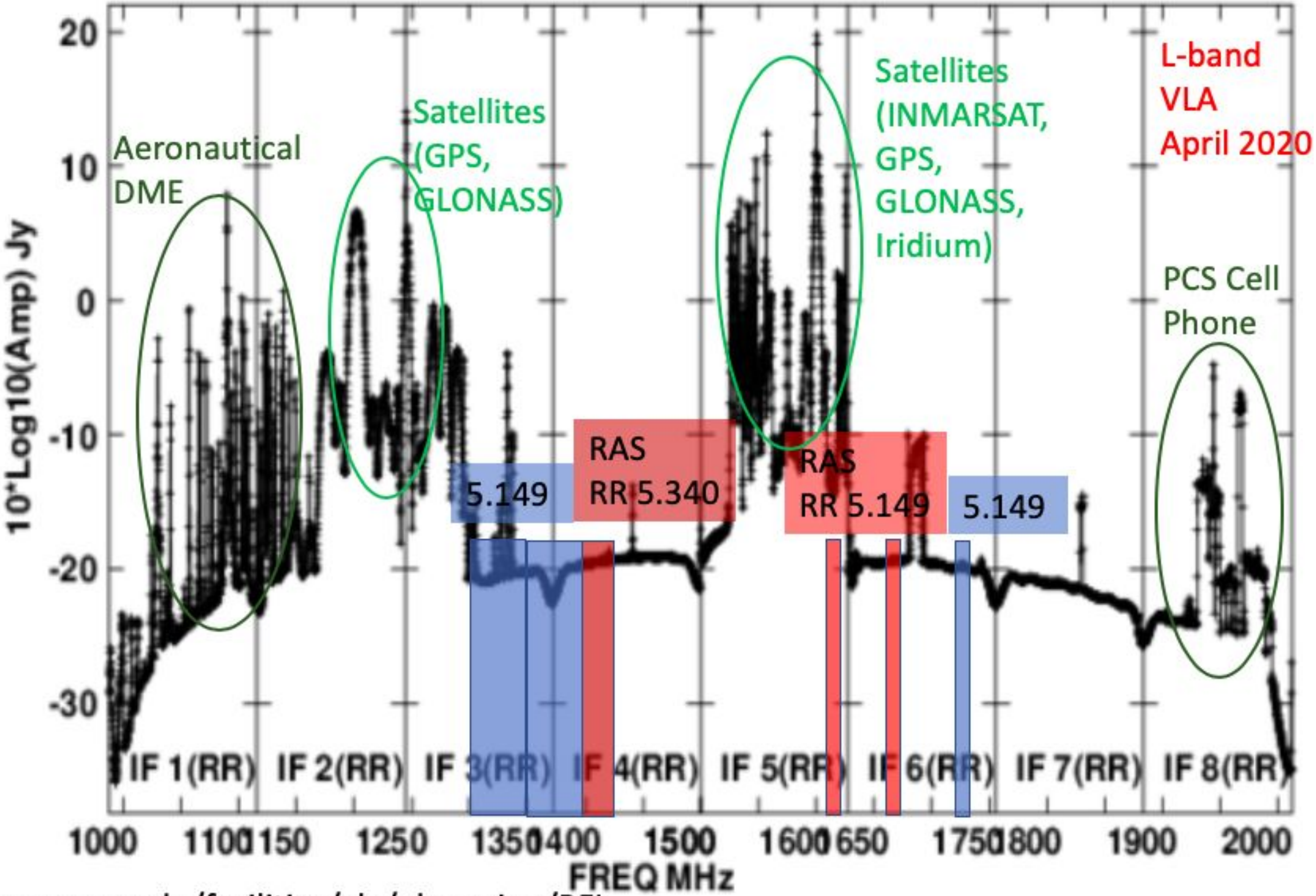
RAS Allocations – Part 2

- Radio Astronomy is allocated less than 1.5% of the radio spectrum below 5 GHz
  - 1.25% is RR 5.340
  - 5.43% includes above plus RR 5.149 bands.
- Radio Astronomy is allocated 29% below 94 GHz
  - 9.6% is RR 5.340
- Radio Astronomy is allocated more than 65% of radio spectrum between 95 – 275 GHz
  - 18.43% of 95 – 275 GHz is RR 5.340
- No allocations above 275 GHz
  - RAS interests in 58.2% of 275 – 1000 GHz are noted in RR 5.565.



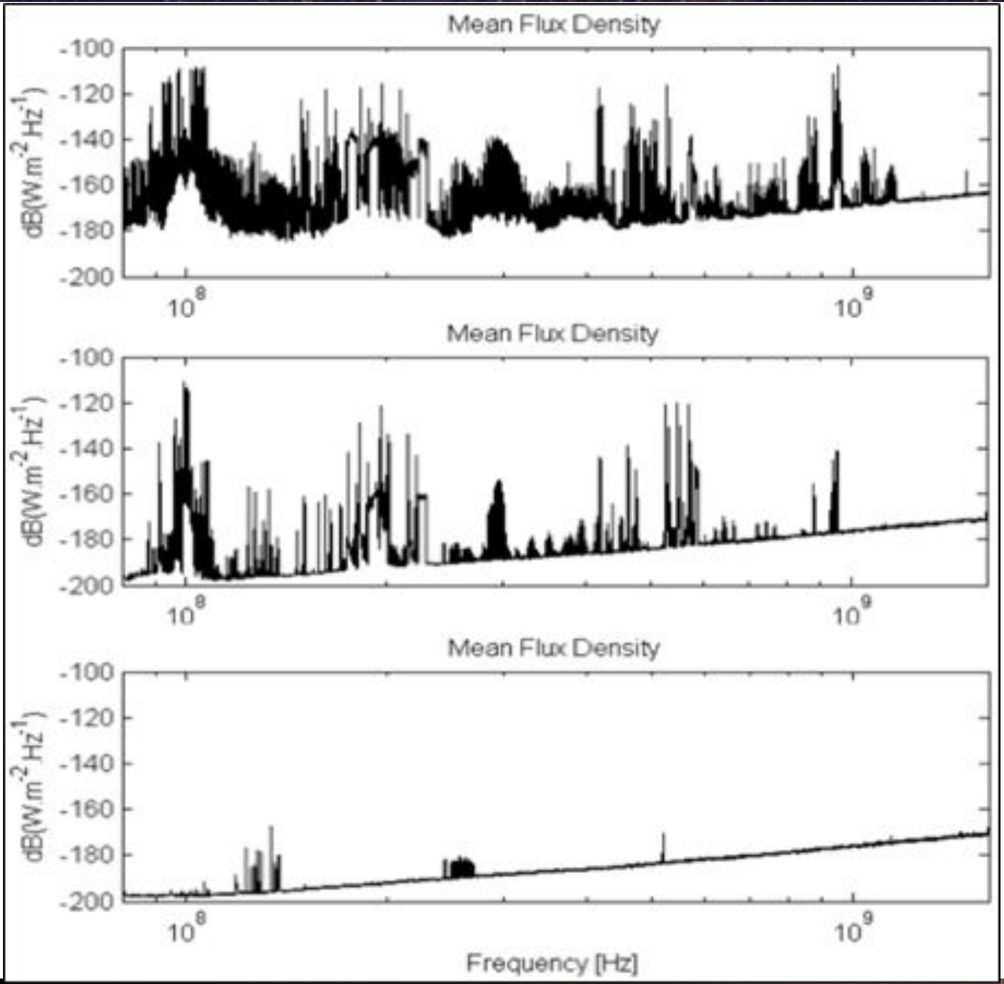

Liese van Zee

SAMPLE RAS ALLOCATIONS - L band



science.nrao.edu/facilities/vla/observing/RFI

RADIO ASTRONOMY SPECTRUM USE



Sydney, Australia
(~6 million people)

Narrabri, Australia
(~6000 people)

Murchison, Australia
(<10 people)

RADIO QUIET ZONES

- National Radio Quiet Zone (NRQZ) in WV
  - Established in 1958; 13,000 square miles.
  - Typically, applicants coordinate with the GBO prior to FCC filing
- West Virginia Radio Astronomy Zone
  - Established by WV Legislature.
  - 315 square miles (10 mile radius).
  - Applies to any electrical equipment that causes RFI.
- Puerto Rico Coordination Zone (PRCZ)
  - For new or modified stations below 15 GHz at permanent locations
  - Notification at least 20 days in advance of planned operation.
  - Requires *reasonable* efforts to protect Arecibo Observatory

SATELLITES AND HIGH ALTITUDE PLATFORMS (HAPS)

- Airborne and satellite services have always been problematic for radio astronomy
  - Geostationary satellites block access to the sky in a belt centered on geostationary orbit.
  - Non-geostationary satellite (NGSO) systems are now being deployed with tens of thousands of satellites in mega-constellations with multiple satellites above the radio horizon at all times.
  - High Altitude Platforms will also have several stations visible at all times.
- Coordination Agreements
  - Dedicated transmission-free times for geographical areas around radio observatories. In the US, negotiated via the NSF electromagnetic spectrum management group.
  - These will be particularly challenging in the era of mega-satellite constellations.

RISKS TO RADIO ASTRONOMY

Federico DiVruno

Risks to Radio Astronomy

- RAS Observations are orders of magnitude more sensitive than typical communication systems

- RAS antennas can't distinguish the intended signals from the interference (sidelobes)

- RAS requires access to large portions of spectrum (due to red-shifted spectral lines, continuum observations, transients) that can be assigned to other users

- Risks to RAS can go from damage of a receiver to lost of data in a frequency range for a period of time.

Federico DiVruno

Risks to Radio Astronomy

1. Increased interference on bands allocated to the RAS
2. Increased use of the radio spectrum outside of the RAS bands
3. The radio sky
4. Spaceborne and mobile high-power radars
5. GSO and existing NGSO satellites
6. New large NGSO constellations

Federico DiVruno

Increased interference on bands allocated to the RAS

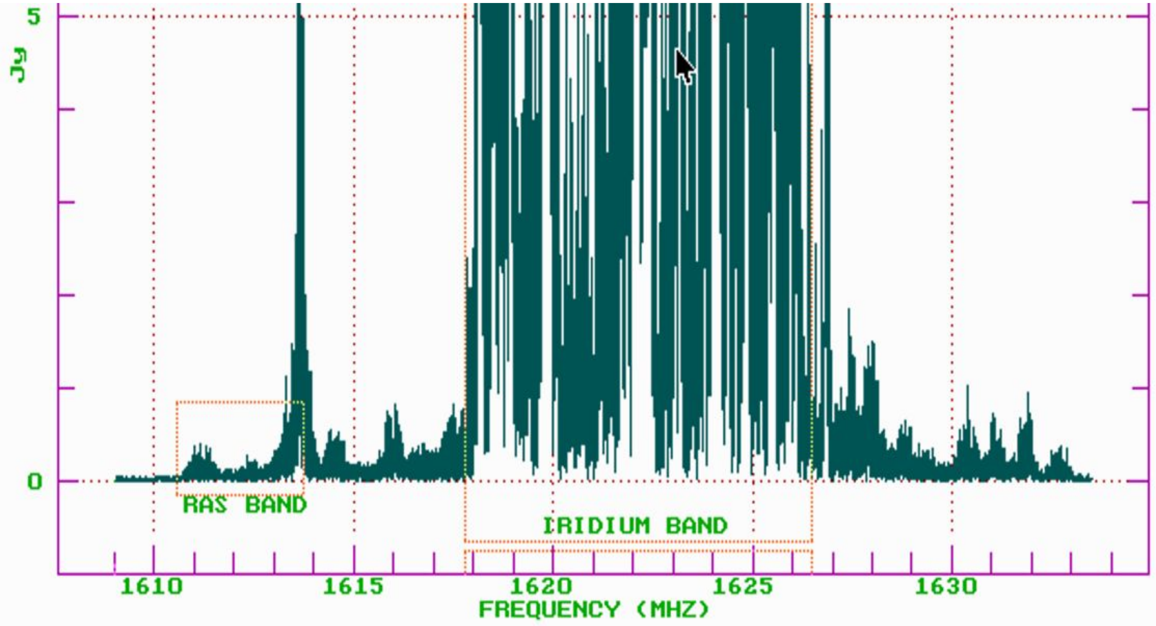
- The protection of the RAS bands is not absolute, permitted levels of radio interference are defined based on typical observation parameters (ITU-R RA.769).

- The protected RAS bands are constantly under pressure by active services, RAS receivers are not only sensitive to in-band and adjacent-band transmissions but also to signals with further frequency separation (Out of band emissions) and harmonically related frequencies.

- Radio astronomy must accept a data loss of 2% from one system and up to 5% for the aggregation of many systems.

- In some cases, theoretical studies may show compliance, but the real system can behave differently than expected. For satellite systems this is a very important issue because the detection and report of interference does not translate in automatic remediation.

- Example: OH molecule in 1610.6 - 1613.8 MHz

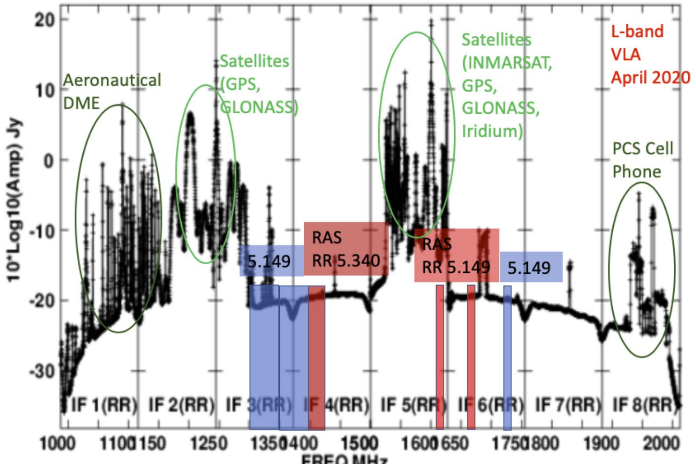


Federico DiVruno

Increased use of the radio spectrum outside of the RAS bands

- Very often, observations need to be conducted outside of the protected bands due to the characteristics of the signals under observation. Most modern RAS receivers are very wideband.
- The advancement of wireless technology keeps increasing the spectrum occupancy all around the protected RAS bands, especially near populated areas.
- Cosmic signals can be easily buried by relatively high-power transmissions from terrestrial, maritime, aerial or space borne transmitters.
- This not only generates data loss, very strong RFI signals can completely saturate a receiver. Sometimes even outside of the receiver's band!

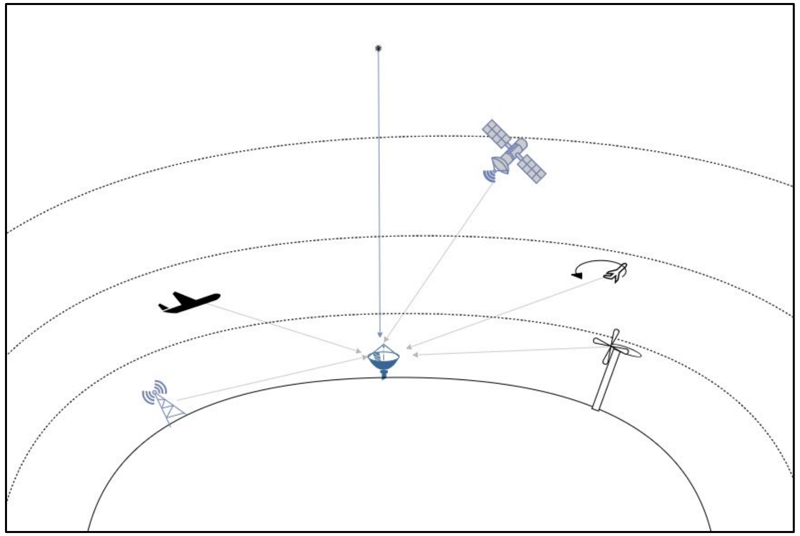
SAMPLE RAS ALLOCATIONS - L band



science.nrao.edu/facilities/vla/observing/RFI

The radio skies

- The sky is full of radio sources, most of them beaming radio waves towards the Earth. RAS tries to observe toward and past those transmissions.

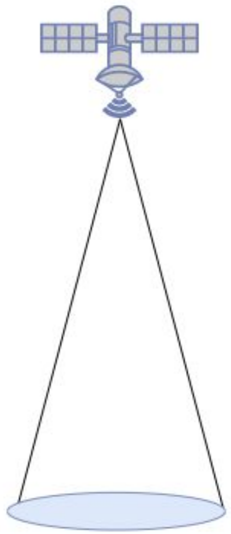


- Terrain shielding is not effective to protect RAS observatories from overhead transmissions.
- Line of Sight distances* for air and space born transmitters can be extremely large:
  - Airplanes at 10km altitude: 350km
  - High Altitude Platform Systems at 20km altitude: 500 km
  - Satellite in LEO orbit at 500km altitude: LoS = 2600 km
  - Satellite in LEO orbit at 1200km altitude: LoS = 4000 km

* LoS: Direct line from transmitter to receiver without an obstacle

Spaceborne and mobile high-power radars

- Synthetic aperture radar (SAR) systems use high power transmitters to generate signals that are as much as 17 dB (50 times) stronger than the power level that can burn out the first stage of a radio astronomy receiver.
- SAR satellites are no longer limited to national space agencies, private companies are now using small satellite technology to deploy SAR constellations.
- Radio telescopes **<u>must at all costs</u>** avoid pointing near such satellites when they are mapping the area close to the telescope site. The ITU-R has the Recommendation RS.2066 to mitigate the risk of direct beam-to-beam coupling from SARs at 9.4GHz.
- A cloud profiling radar at 94 GHz can briefly saturate every RAS receiver over which it passes no matter where it is pointing at.
- Car radars in 76-81 GHz are also powerful enough to destroy a receiver at close range, close encounters with a car radar is possible in mountainous terrain observatories.

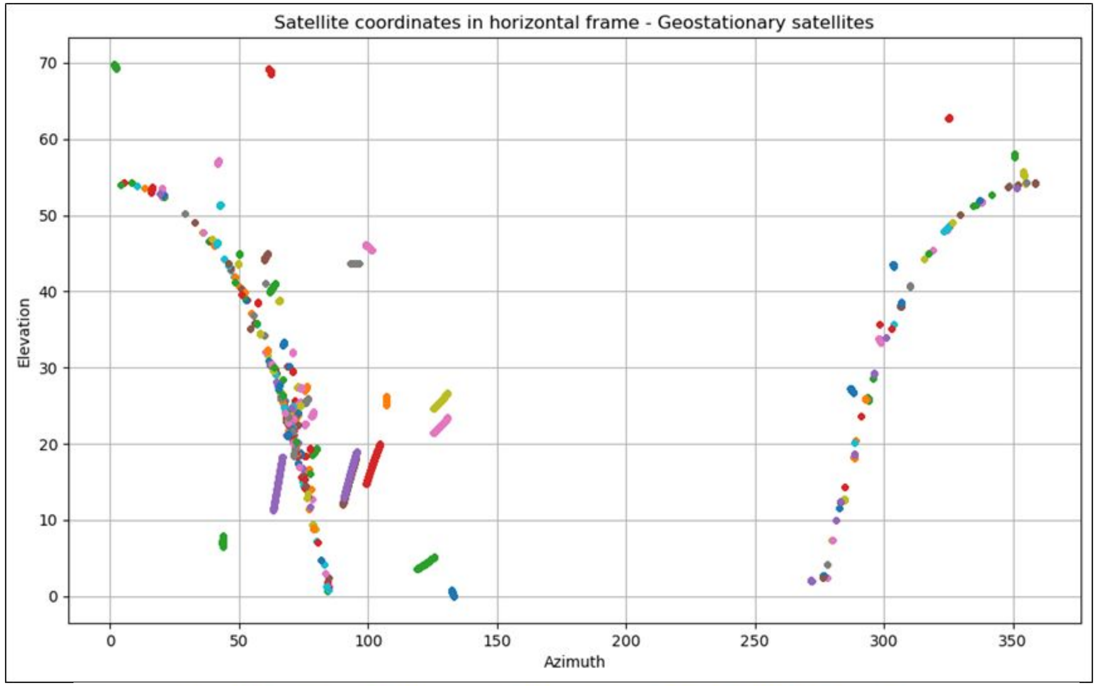


GSO and existing NGSO satellites

- Overhead transmissions present a very challenging interference situation for radio astronomy.

- Slow moving or fixed satellites can be avoided by radio telescopes, or their effect mitigated by post processing techniques, this is the case for Geostationary Orbit (GSO) satellites.

- For the case of existing MEO and LEO satellite constellations, their transmissions are seen almost 100% of the time through the sidelobes of the RAS antennas due to their low densities.



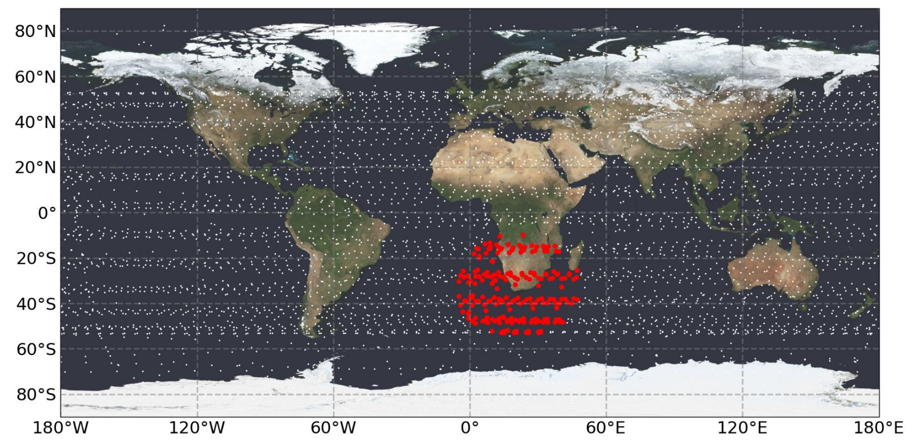
Sky distribution of the existing GSO satellites as seen from the SKA-Mid site in South Africa

NGSO “mega-constellations” in RAS bands

- New NGSO “mega-constellations”, with immediate deployment of constellations having 1000-4000 satellites and with prospects to deploy more than 100,000.

- The spectrum used by these constellations is located adjacent or close to some important protected RAS bands, and the operators are committed to protect them in accordance to the ITU-R Radio Regulations*.

- The protection of the RAS bands near the downlinks is subjected to a total data loss of 2%. This data loss is computed across all the sky, resulting in areas with larger data loss values.



Snapshot of 4400 satellites in Starlink phase1 constellation

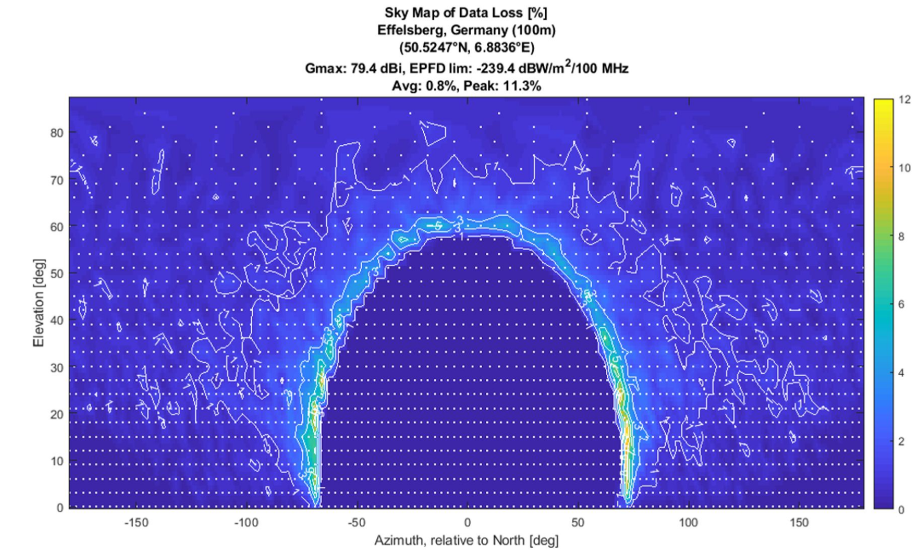


Figure 5.4.4: Sky Map of Data Loss at 10.6-10.7 GHz from ECC report 271

* See ECC report 271

DARK & QUIET SKIES

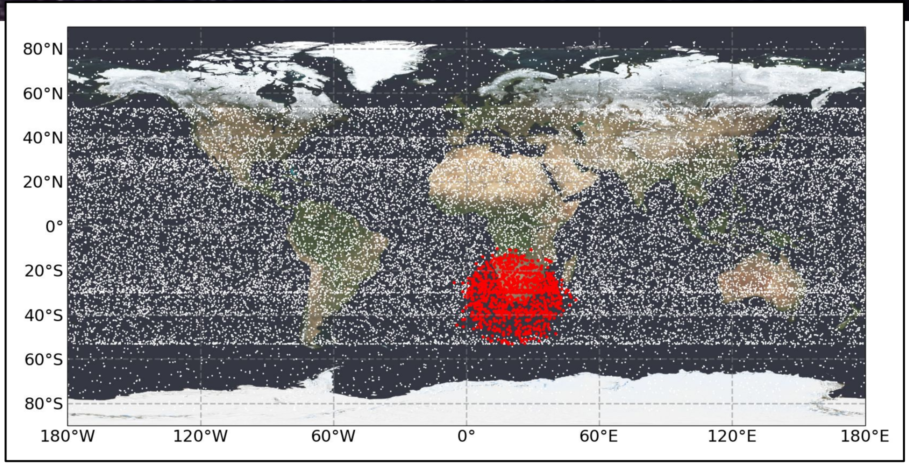
NGSO “mega-constellations” outside of RAS bands

- RAS receivers are broader than the protected radio astronomy bands, downlinks from satellites will be received by many RAS receivers

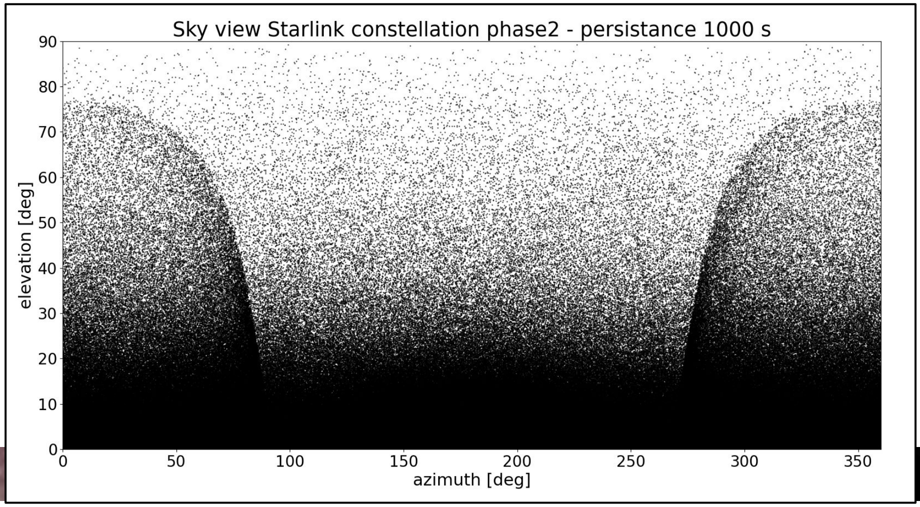
- 1000’s of satellites will always be above the horizon, contributing to the received power through the sidelobes of the radio telescope but also increasing the probability of strong interference through main-beam coupling.

- The level of radio interference received is directly related with the Power Flux Density (footprint) that a satellite places over the RAS site

- Radio observations in some frequencies will experience a significant challenge, with thousands of rapidly moving bright radio sources in the sky.



Snapshot of Starlink phase2 satellites with visible satellites from the SKA-Mid site in red



Horizontal view of Starlink phase2 satellites with 1000 s persistence from the SKA-Mid site

THE WAY FORWARD - WHAT WE WILL DO FOR OURSELVES

Radio astronomy will continue to operate as much as possible in remote locations using the terrain to shield it from direct line of sight contact with populated areas. It will operate inside radio quiet and coordination zones whenever possible, to avoid interference from terrestrial systems. But it will be increasingly necessary to observe in the presence of strong radiocommunication signals arising overhead from spaceborne transmitters that cannot be avoided geographically. Interferometry techniques mitigate interference that has different arrival times at different antennas, especially VLBI, but this technique loses its effectiveness for short baselines and distant interference sources such as satellites.

THE WAY FORWARD - TOWARD RECOMMENDATIONS

The first step in protecting RAS systems electronically is to ensure linearity in the operation of RAS receivers. If the receiver system goes non-linear (saturates), the resulting intermodulation products can wipe out the whole observing band. Hence, the need for "robust" receivers i.e.

- Design the RF system's Low Noise Amplifiers (LNA) to tolerate higher input radiation power over a wide band. As RFI is often impulsive and narrow band, the total power over a wide band is not large and the system can be designed to remain linear. In extreme cases, some form of notch filtering could be considered but it is not an ideal solution because the addition of any element before the first amplifier will increase the noise temperature of the system.
- Design the digital part of the receiver to a high dynamic range to cope with the RFI spikes. This mostly necessitates digitizing with many bit levels, with 12-bit systems used in current cm-wave receiver designs. Of course this results in an avalanche of data (often Tbps), extremely wideband networking and large computer clusters to cope with the analysis of the data.
- Design RF and digital transport systems to the highest possible dynamic range and headroom.

THE WAY FORWARD - TOWARD RECOMMENDATIONS

Radio astronomy will always advocate for and defend its interests in the spectrum regulatory arena. But despite this, despite its broader public advocacy and outreach in support of scientific knowledge, and despite the public's inherent interest in preserving the value of its investment in radio astronomy, access to the spectrum is being eroded in the radio spectrum along with other wavebands. Radio astronomy defends its allocations in small portions of the spectrum, often with concessions from services transmitting in nearby bands, but faces grave problems as commercial exploitation of radio spectrum expands.

This situation has taken a perverse turn as indifferent radio spectrum regulators authorize the launch of mega-constellations in non-geostationary orbit that degrade the appearance of the night sky and hinder optical astronomy with unforeseen optical reflections. But these same constellations present the gravest threat to radio astronomy. If launched in the quantity now foreseen, it will be impossible to point anywhere in the sky without having one or more within a few degrees of the telescope beam. Satellite signals, already inherently at least 10^{10} times stronger than radio astronomy sources, will be collected and boosted by the radio astronomy antennas and amplified by receiver electronics.

TWO RECOMMENDATIONS

How to accomplish the needed modification of current practice that sees spectrum merely as a resource from which to extract commercial value? Science must also be minded. As we discussed in Section 5.2, spectrum is a shared resource for everyone.

The following two recommendations distill the discussion and the experience of radio astronomers and radio astronomy spectrum managers into two practical tools that are needed to allow radio astronomy to continue to operate:

- RAS1: Non-GSO satellites should be required to be able to avoid direct illumination of radio telescopes and radio quiet zones, especially the radar and other high-power satellite applications that are capable of burning out radio astronomy's receivers;
- RAS2: Non-GSO satellites should be required to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio quiet zones do not interfere, individually or in the aggregate.

Recommendations to be applicable to radio astronomy

1. RAS1: Non-GSO satellites should be required to be able to avoid direct illumination of radio telescopes and radio quiet zones, especially the radar and other high-power satellite applications that are capable of burning out radio astronomy's receivers;
2. RAS2: Non-GSO satellites should be required to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio quiet zones do not interfere, individually or in the aggregate

Dark and Quiet Skies for Science and Society

Discussion Session:

To ask questions, please use the chat

DARK & QUIET SKIES

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Dark and Quiet Skies for Science and Society

Closing Remarks

SOC Member

Casiana Muñoz Tuñón

IAC, Spain.

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Dark and quiet skies for space and society: inputs

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DARK & QUIET SKIES

Dark and Quiet Skies for Science and Society

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