RFI Sources, Identification and Mitigation

Part 1: Spectrum Management

José A. López-Pérez

Yebes Observatory, Instituto Geográfico Nacional, Spain

13th TOW meeting, May 4-8, 2025

Class Overview

Part 1: Spectrum Management

José A. López-Pérez

Part 2: RFI detection and measurement

John Swoboda

Part 3: RFI effects and examples

Samuel Thé

Presentation Overview

RFI Fundamentals

Definition, sources, and signal properties

Spectrum Management

International regulations and coordination frameworks

VGOS and the Regulations

Actions to protect VGOS from interferences

What is RFI?

ITU Definition (RR Art. 1.166)

Unwanted energy causing performance degradation, misinterpretation, or information loss in radiocommunication systems.

Interference Types

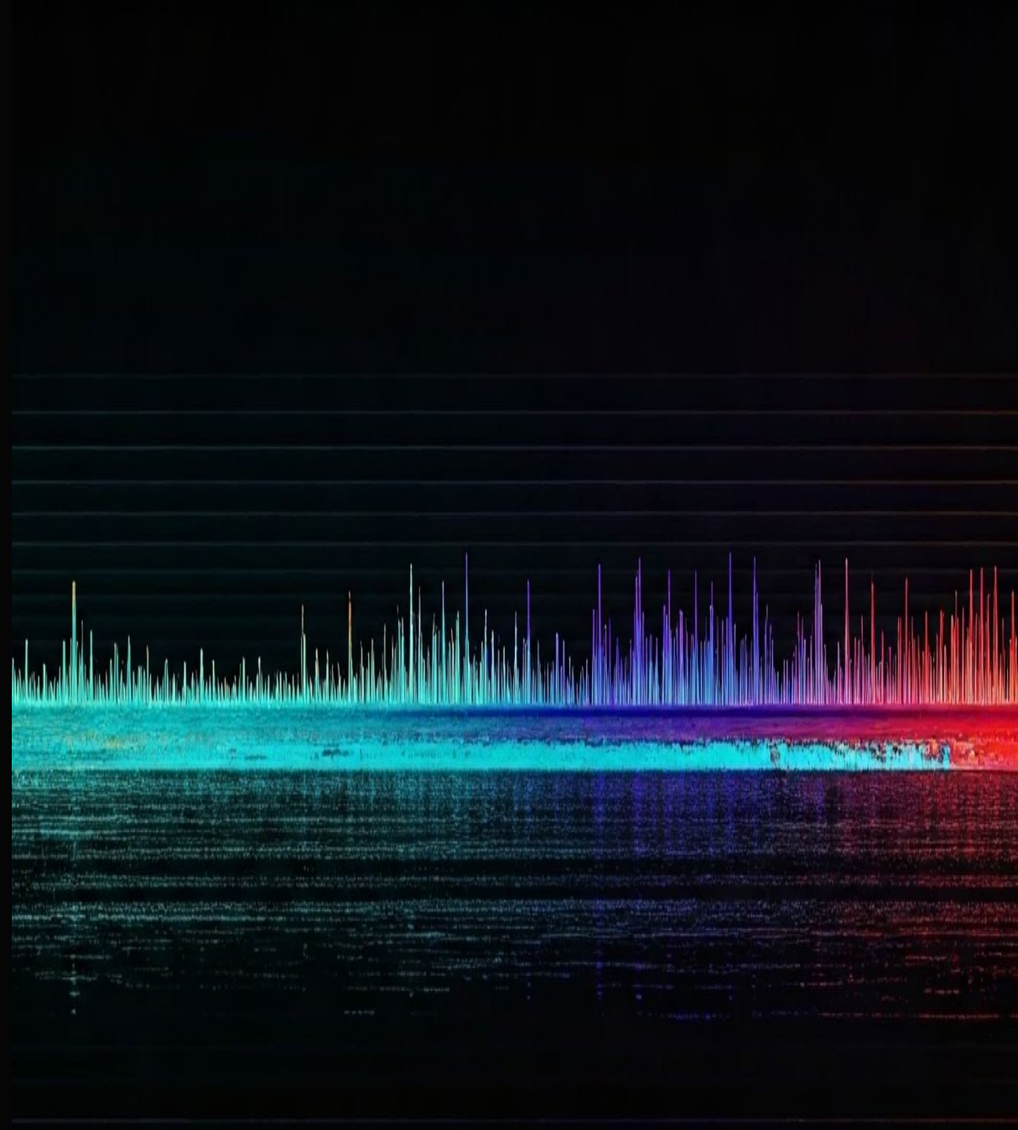
Permissible interference: Within defined limits.

Accepted interference: Greater than permissible but agreed upon.

Harmful interference: Endangers services' functioning.

Key Characteristics

Can originate from emissions, radiations, or inductions
From ground or space equipments
Measurable by quantifiable degradation of signal quality.



RFI Environment

Astronomical Signals

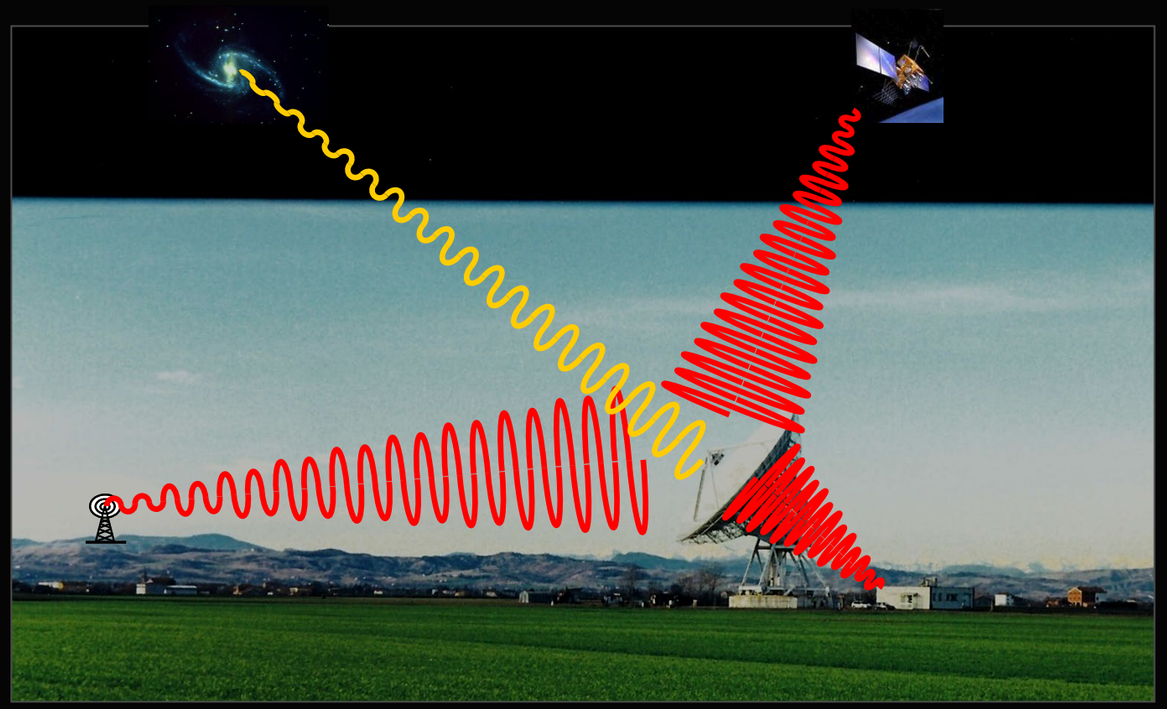
Several light-years (1 ly = 9.5×10^{12} km)

Extremely weak compared to RFI

Space Sources

400-40,000 km range

Satellite communications dominate this region



Terrestrial Sources

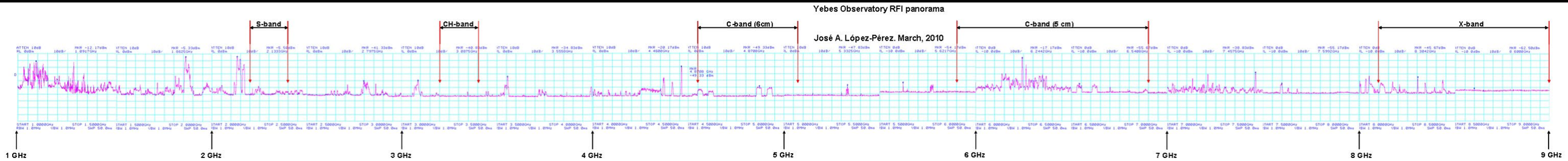
2-100 km range

Cellular networks,
radio/TV,
radar systems,
Radiolinks, …

Local Sources

Immediate vicinity

Observatory equipment
Windmills, solar power plants, …



RFI Signal Properties

Temporal Characteristics

RFI varies in time. It can be persistent, intermittent, or burst-like.

Astronomical observations require long integration times.

Spatial Distribution

RFI can be stationary or mobile. Source location affects mitigation strategies.

Moving sources present additional challenges.

Spectral Characteristics

Narrowband or broadband signals affect different observing modes.

Polarization variations (H, V, RCP, LCP) impact specific measurements.

RFI signals are non-thermal in origin and many orders of magnitude stronger than cosmic signals.

RFI Sources

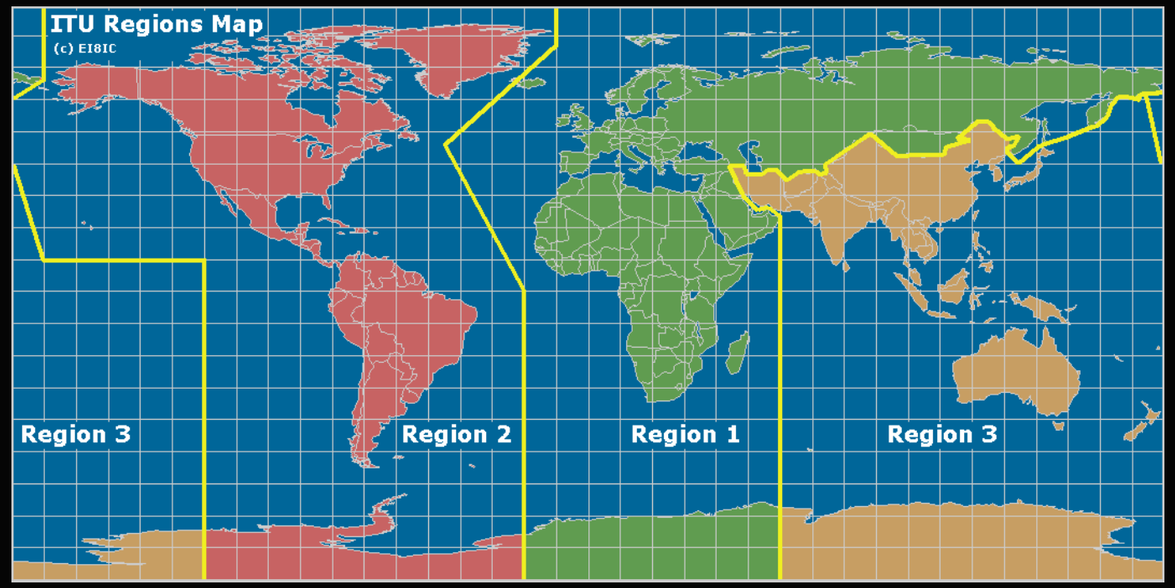
External Sources	Self-generated Sources
Satellite downlinks	Leaky connectors & cables
Cellular networks	Amplifier oscillation/instability
Radio & TV transmissions	Digital back-ends
Radar systems	Control buses (Profibus, CANbus)
Wind turbines	LAN/Ethernet equipment
Electric fences	Computers & auxiliary equipment
LED light drivers	Servo electronics

International Spectrum Management: ITU

The International Telecommunication Union (ITU) is an agency of the UN whose responsibility is the coordination of the vast and growing range of radiocommunication services and the harmonization at international level of the radio-frequency spectrum

The allocation of frequency spectrum resources is the sovereign right of national governments

But radio waves do not respect national borders, so international regulations are required



International Telecommunication Union

Asia-Pacific Telecommunity (APT)

Arab Spectrum Management Group (ASMG)

African Telecommunications Union (ATU)

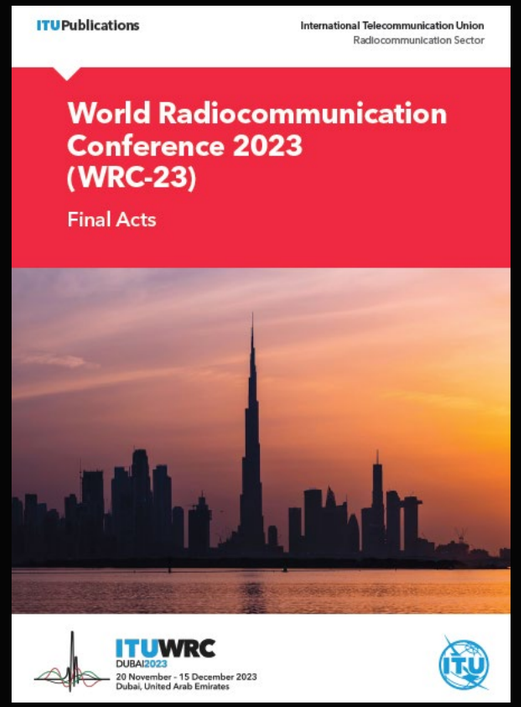
European Conference of Postal and Telecommunications Administrations (CEPT)

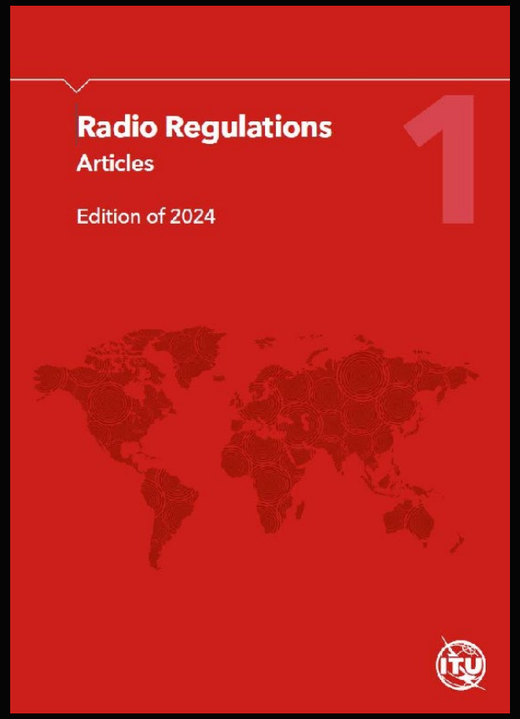
Inter-American Telecommunication Commission (CITEL)

Regional Commonwealth in the Field of Communications (RCC)

ITU World Radio Conference (WRC)

- ITU meets at WRC every 4 years
- The output of the WRC is an international treaty
- Defines allocations to radio services
- Defines rules of sharing and protection of bands
- Defines agenda items for next WRC





- Free download from ITU web
- Updated after each WRC.

Frequency Allocation Chart

Primary Allocations

Services with highest protection status

Shared Bands

Multiple services coexist with defined rules

Congested Regions

VGOS band overlaps with licensed services

The VGOS (VLBI Global Observing System) band spans 2-14 GHz. This range overlaps with numerous licensed radio services.

The Value of Radio Spectrum

€198M

Vodafone Spain

Cost for 90 MHz in 3.7 GHz band

€107M

Telefonica Spain

Cost for 50 MHz in 3.6-3.8 GHz band

€2.4B

Vodafone Italy

For multi-band spectrum package

€2-6M

Price Per MHz

Spectrum valuation range

~1MHz

VGOS Antenna

Equivalent spectrum footprint

Telecommunications companies invest billions in spectrum licenses lasting 15-20 years. This economic reality drives increased spectrum congestion.

5G Networks & Space-Based Internet

Region	5G Frequency Allocations
USA	3.1 – 3.55 GHz, 3.7 – 4.2 GHz
Europe	3.4 – 3.8 GHz
Japan	3.6 – 4.2 GHz, 4.4 – 4.9 GHz
China	3.3 – 3.6 GHz, 4.4 – 4.5 GHz, 4.8 – 4.99 GHz

Constellation	Satellites in Orbit (Apr 2025)	Total Planned Satellites	Source
Starlink (SpaceX)	Over 8,000	Up to 42,000	(apnews.com)
OneWeb (Eutelsat)	633	648	(es.wikipedia.org)
Kuiper (Amazon)	27	3,236	(apnews.com)
Qianfan / Thousand Sails (China)	90	Over 15,000	(en.wikipedia.org)
IRIS² (EU)	0	Up to 170	(es.wikipedia.org)

These 5G and satellite allocations directly overlap with VGOS observing bands, creating significant RFI challenges.

RAS: ITU Terms and Definitions

ITU RR Art. 1.13: Radio Astronomy

Astronomy based on the reception of radio waves of cosmic origin.

ITU RR Art. 1.58: Radio Astronomy Service (RAS)

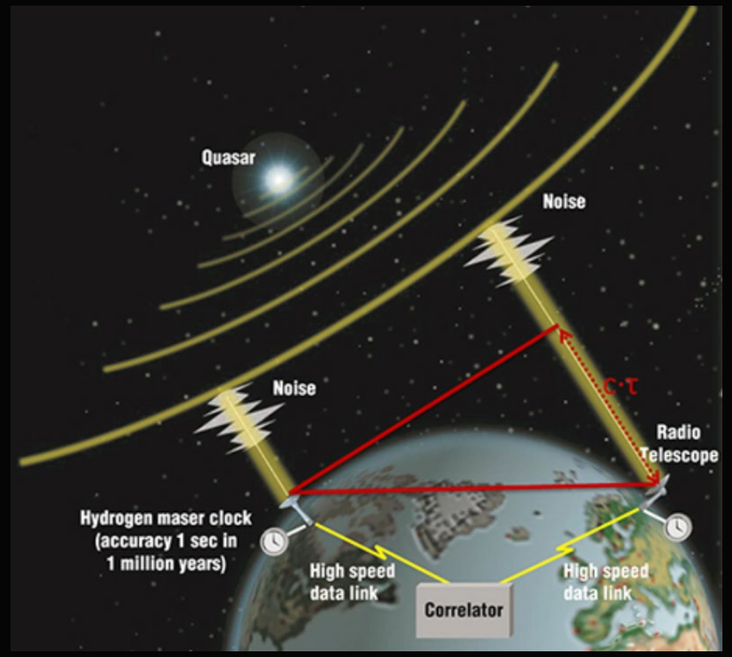
A radio service involving the use of radio astronomy.

ITU RR Art. 1.61: Station

One or more transmitters or receivers or a combination of them, including accessory equipment, necessary at one location for carrying on a radiocommunication service, or the radio astronomy service.

ITU RR Art. 1.97: Radio Astronomy Station

A station in the Radio Astronomy Service.

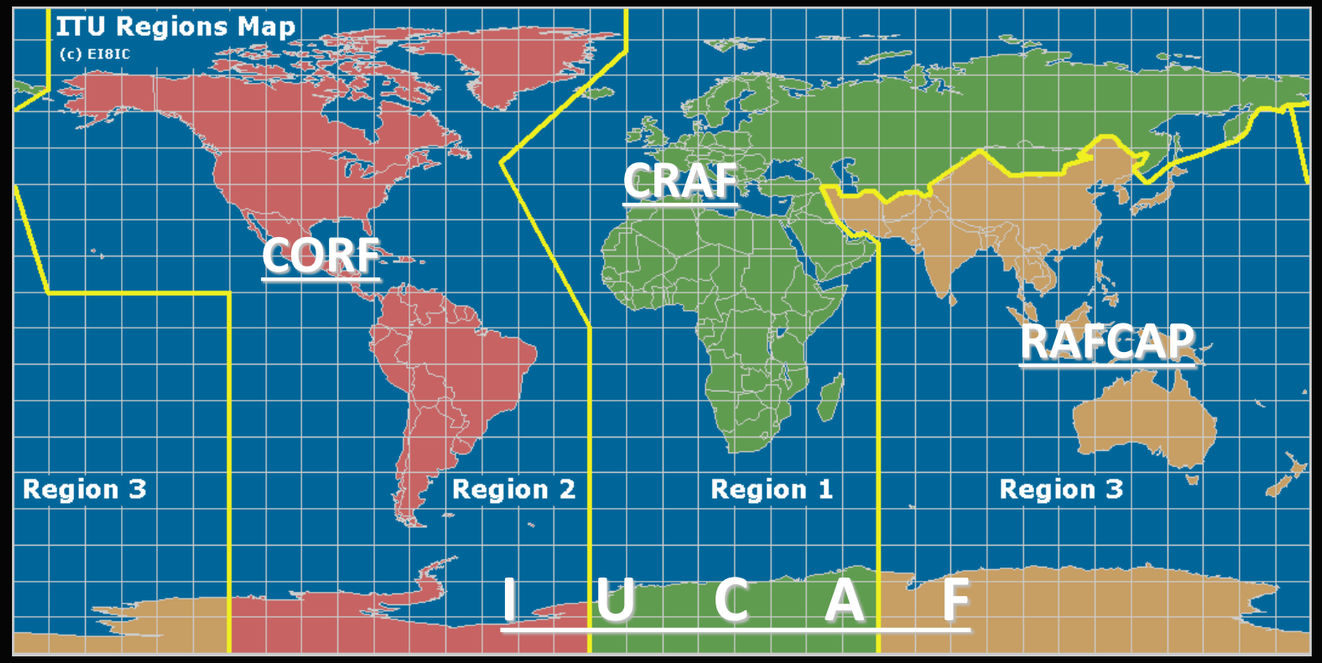


Geodetic VLBI can be included in the Radio Astronomy Service

The Radio Astronomy Service

Since 1959, RAS is recognized as ITU service, creating the legal basis to seek protection against harmful interference.

RAS is represented by regional committees: CORF, CRAF and RAFCAP and globally by IUCAF (auspiced by URSI, IAU and COSPAR to work for passive services, not only RAS).

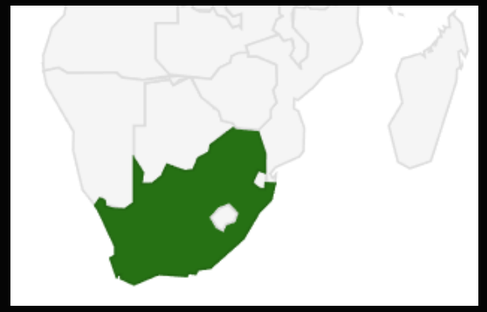


6th IUCAF School on Spectrum Management
Sept. 29th – Oct. 3rd 2025
Alcalá de Henares, Spain.

Hosted by IGN-Spain

http://www.iucaf.org/sms2025

The Committee for Radio Astronomy Frequencies (CRAF)



https://www.craf.eu/

- CRAF was established in 1988 and it acts as an ESF Expert Committee
- CRAF: ITU sector member & observer status in CEPT
- 22 countries (incl. Ukraine, Turkey and South Africa) + International organizations (observers: ESA, IRAM, IVS and SKA).
- Missions:
    - to keep the frequency bands used for radio astronomical observations free from interference;
    - to argue the scientific needs of the European research community for continued access to and availability of the radio spectrum for radio astronomy;
    - to support related science communities in their needs concerning interference-free radio frequency bands for passive use.
- Funding by MoU ≈ 150 k€
- CRAF employes one full-time Frequency Manager
- CRAF working groups: Outreach, IMT, SAT, WI-MONIT, VGOS, ...

VLBI station registration

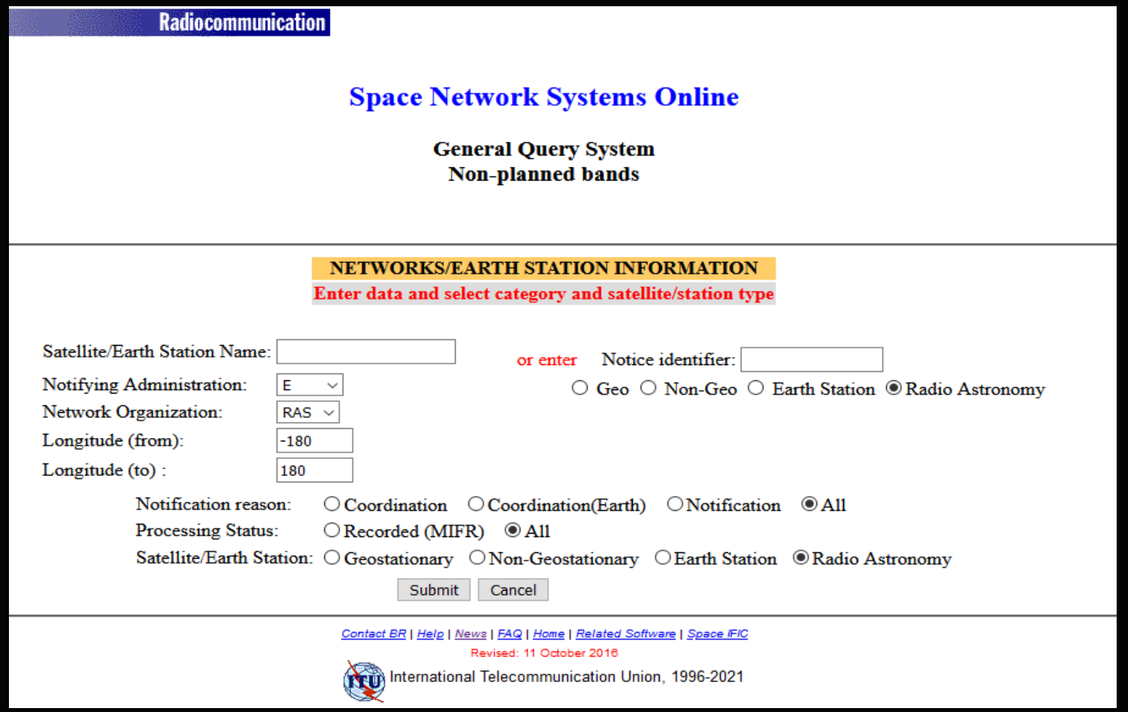
Why should I register my station at ITU database:

- To obtain administrative protection
- To avoid direct illumination from strong transmitters
- To be taken into accout by space agencies
- To claim losses due to RFI
- To complain to the responsible of RFI

See H. Hase, V. Tornatore, B. Corey: “How to register a VGOS radio telescope at ITU and why it is important”. IVS 2016 GM Proc.

Watch TOW-2021 video “Radiotelescope Registration at ITU-R” by Marta Bautista

https://www.itu.int/sns/database.html



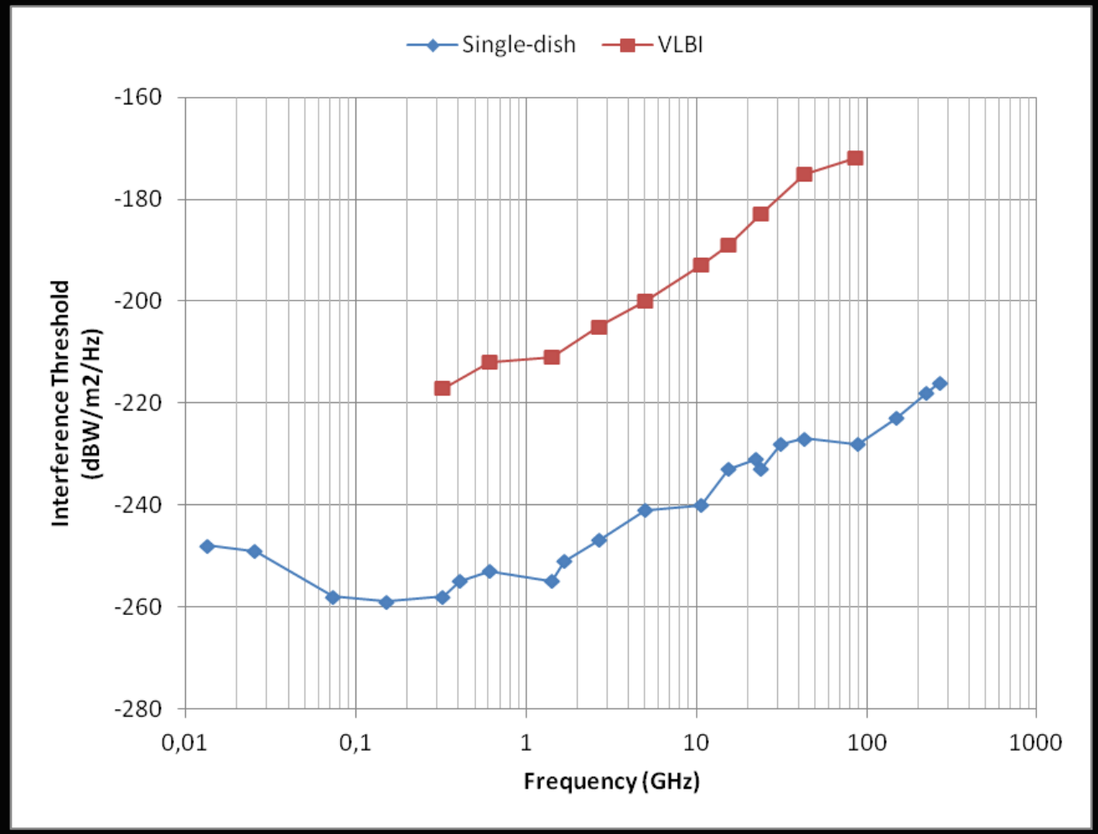
ITU regulations to protect RAS

- Thresholds for detrimental interference in RAS bands are given in ITU-R RA.769.
- Percentage of acceptable data loss ITU-R RA.1513.
- In exclusive passive bands (RR footnote No. 5.340), all emissions are prohibited.
- Other bands: administrations are urged to take all practical steps to protect RAS from interference.

However, ITU regulations only consider RFI received through telescope sidelobes (0 dBi gain)

If RFI were received through the main beam (50 dBi typical main beam gain), the ITU limit for spectral line observations would be exceeded for any RFI with a flux larger than 10 Jy.

For VLBI, ITU-R criterion is that RFI should add no more than 1% to the receiver noise (ITU-R RA.769), which is the typical uncertainty of "well-calibrated" VLBI data.



VLBI is more inmune to uncorrelated RFI that single-dish

Example: GSM Mobile phone on the Moon

Speed of light	3,00E+08	m/s
Signal frequency	0,9	GHz
Signal wavelength	333,3	mm
Tx power	27	dBm
Tx antenna gain	0	dBi
TX EIRP	-3	dBW
Tx channel bandwidth	30	KHz
Distance	385000	Km
Power flux density at Rx site	-186	dB(W/m2)
Spectral power flux density at Rx site	-230	dB(W/m2·Hz)
	897	**Jy**
Rx antenna diameter	13,2	m
Rx antenna aperture efficiency	0,70	70% typ.
Rx antenna gain	40,3	dBi
Rx antenna effective area	95,8	m2
RFI power at LNA input	-166	dBW
	-136	**dBm**

At 900 MHz, fluxes are:

- GSM mobile phone 900 Jy
- Cassiopeia A: 3,364 Jy
- Cygnus A: 2,422 Jy
- Taurus A: 1,000 Jy
- Virgo A: 301 Jy

The phone is brighter than Virgo A or as bright as Taurus A

VGOS Band Challenges

Broadband Advantage

VGOS covers larger spectral range (2-14 GHz), enabling more observation channels and more accurate delay measurements

RFI Vulnerability

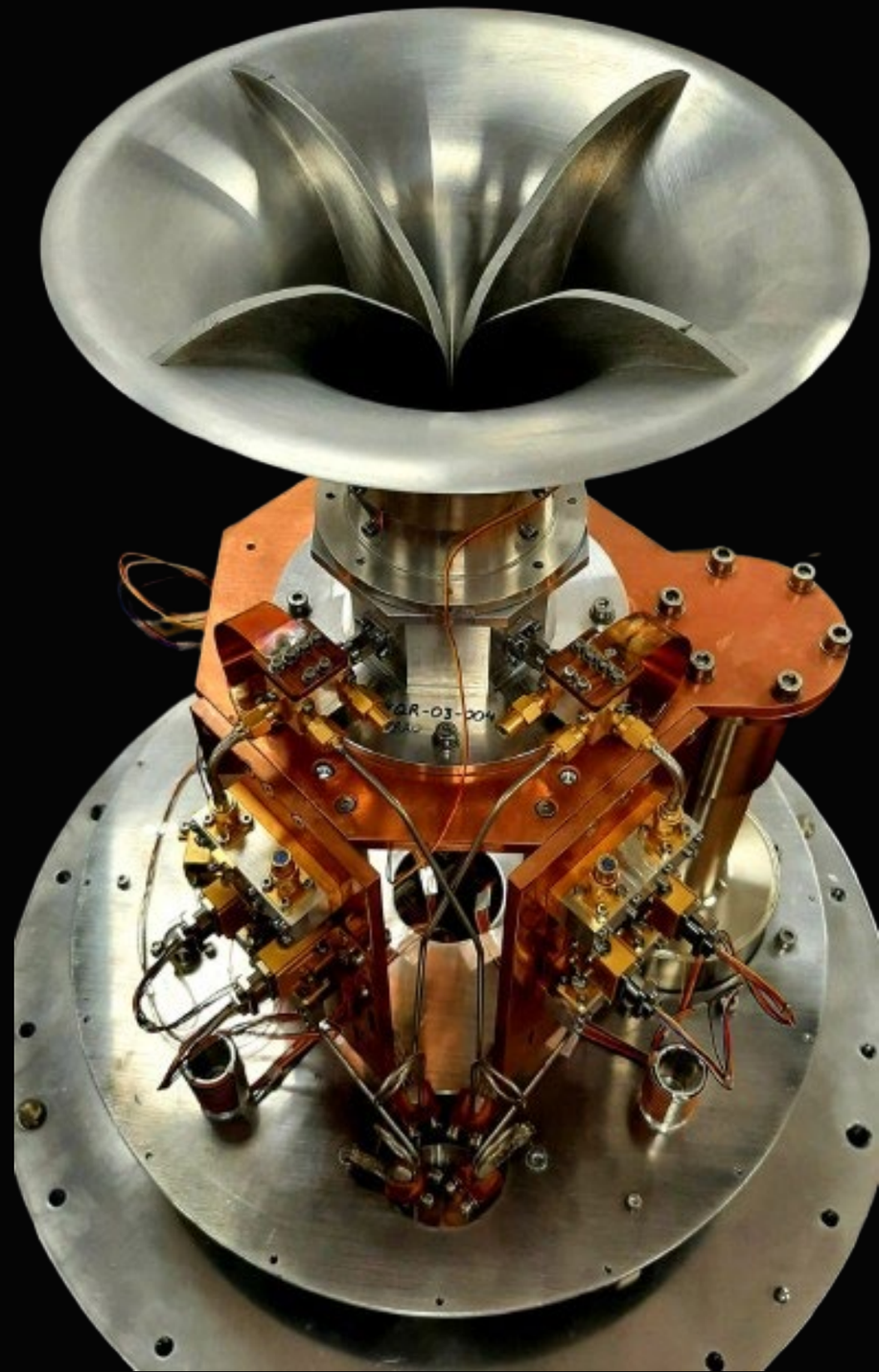
Broadband receivers catch all signals within range, including interferences.

System Complexity

Receivers are complex systems as they involved varios sub-systems (cryogenics, vacuum, microwave electronics, ...) which are expensive investments

Equipment Considerations

Receiver components need enhanced RFI mitigation.



Example of RFI mitigation

RAEGE Santa Maria VGOS Rx

Sept-2022: It was blinded by a space debris radar emitting 50 kW at 1.75 km

High Temperature Superconducting Filters

HTS notch filters were developed at Yebes Observatory to reject the radar signal

VGOS operations resumed

Sept-2023: successful installation of HTS in the receiver

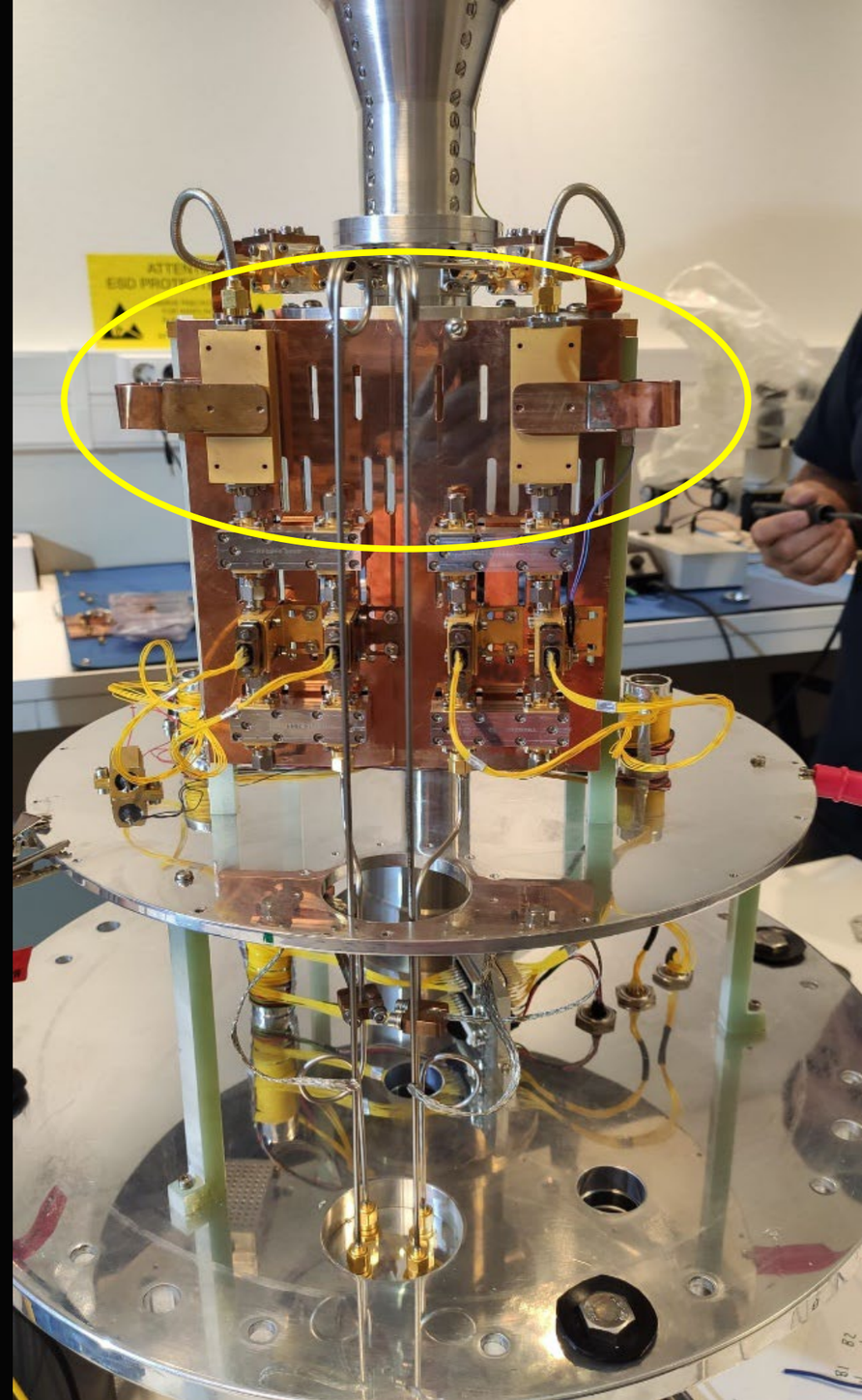
Oct-2023: good performance confirmed from correlator

Drawbacks

Sensitivity degradation of 1-2 Kelvin

Expensive technology

Customized design



The path to protect VGOS in RRs

1. Question to ITU-R SG7 on the “technical and operational characteristics of geodetic VLBI“.

2. Answer to the question is ITU-R Report RA.2507 on the Technical and operational characteristics of the existing and planned Geodetic Very Long Baseline Interferometry (10/2022)

3. In preparation ITU-R Recommendation on “Guidance to administrations regarding geodetic very long baseline interferometry networks”

4. Preparing an Agenda Item on Geodetic VLBI at the World Radio Conference (WRC) by spreading awareness for action to be taken:

5. (2025) IVS to determine “fixed frequencies“ to enter the RR (New freq. tests)

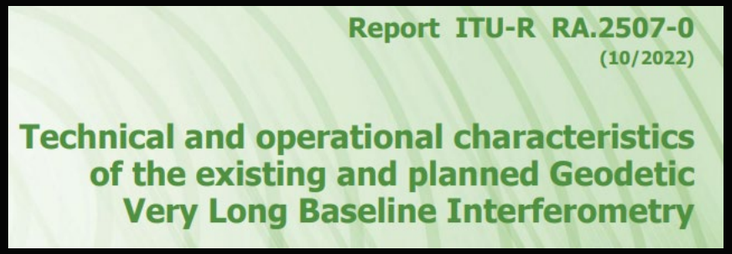
6. (2025+) Update of ITU-R Report RA.2507

7. (2025-2026) Convince national administrations for a joint proposal of a WRC-2031 Agenda Item on Geodetic VLBI

8. (2027) Defend AI-proposal duringWRC-2027

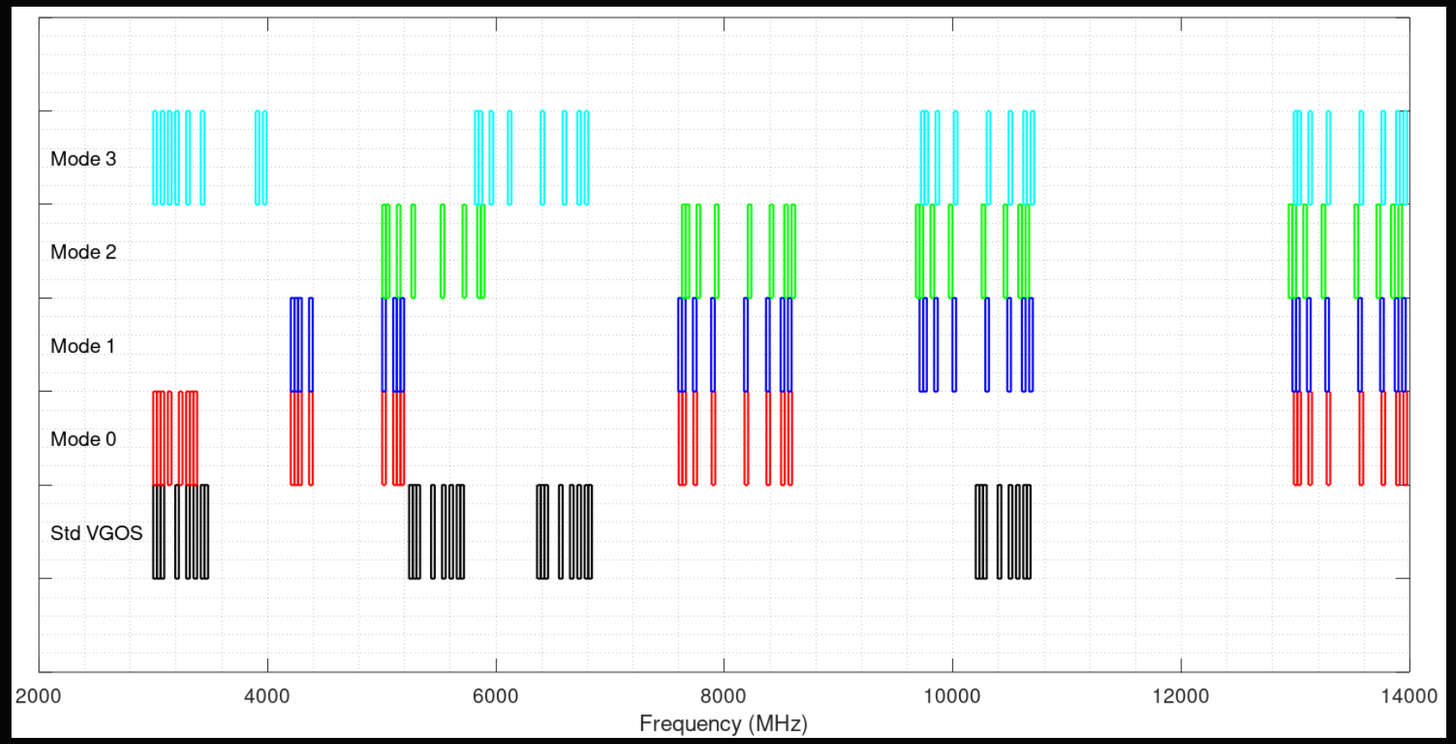
9. (2027-2031) Conduct studies on the impact of including the needs for protection of geodetic VLBI to other services in the RR

10. (2031) Decision on studies at WRC-2031



- IAU Resolution B1 (2021) “in support of the protection of geodetic radio astronomy against radio frequency interference”
- IUGG Resolution 1 (2023) “Improving Protection of Geodetic Observatories from Active Radio Services”
- IVS-Flyer (2025) “Protect Geodetic VLBI“
- UN-GGCE Policy Brief (2025) “Safeguarding VLBI Radio-Frequencies“

Tests of new VGOS frequencies

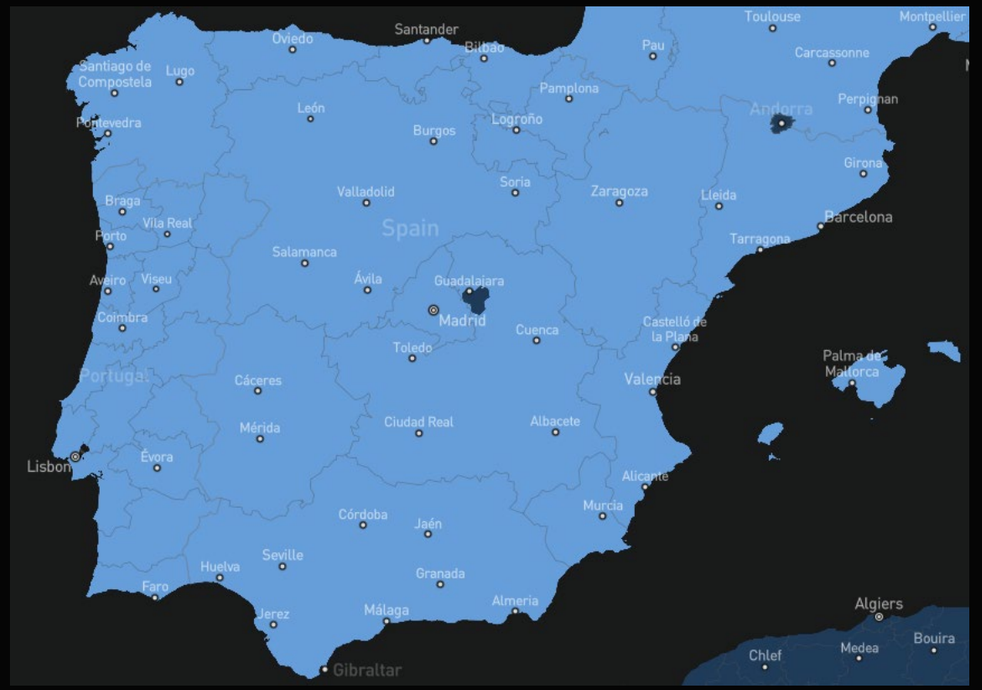


S. Bernhart et al. “A Report on new VGOS Frequency Sequences Test Observations”. 27th EVGA meeting, 6-11 April 2025, Matera, Italy.

Conclusions

- Select remote locations for your VGOS
- Build resiliant receivers
- Register your radio telescope in ITU database (contact your national authority to do it)
- Support your regional committee (CORF, CRAF or RAFCAP)
- Help our efforts to protect VGOS in the RRs.
- Install an RFI measurement system and claim for protection in RAS bands if you are interfered.
- Keep good relations with your spectrum administration

Starlink coverage of Iberian peninsula



References

- ITU-R RA.2188: Power flux-density and EIRP levels potentially damaging to radio astronomy receivers.
- ITU-R RA.2428-0: Parameters for the registration of distributed radio astronomy systems
- ITU-R RA.RA-769: Protection criteria used for radioastronomical measurements
- ITU-R RA-314: Preferred frequency bands for radioastronomical measurements
- ITU-R RA-1513: Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis
- ITU-R RA-2126: Techniques for mitigation of radio frequency interference in radio astronomy
- B. Corey: RFI Measurement Techniques. IVS 2000 GM Proceedings P.397-401
- D. Shaffer: RFI Effects on Bandwidth Synthesis. IVS 2000 GM Proceedings P.402-406
- PyCRAF software from Benjamin Winkel: https://github.com/bwinkel/pycraf
- J. A. López-Pérez, P. García-Carreño: “Recommendations on RFI frequencies to be filtered in BRAND prototype receiver for the 100-m Effelsberg radio telescope”. Report, H2020-INFRAIA-2016-2017/H2020-INFRAIA-2016-1. 2017-06-22.
- *Frederick Huang, Pietro Bolli, Luca Cresci, Sergio Mariotti, Dario Panella, Jose A. Lopez-Perez, Pablo García-Carreño:* Superconducting spiral bandpass filter designed by a pseudo-Fourier technique. *IET Microw. Antennas Propag., 2018, Vol. 12 Iss. 8, pp. 1293-1301*
- H. Hase, V. Tornatore, B. Corey: “How to register a VGOS radio telescope at ITU and why it is important”. IVS 2016 GM Proc.
- SFCG-31 SF31-9/D R1 NASA: Potential Damage to RAS site by EESS (active). 7-15 June 2011.
- TOW-2021 video “Radiotelescope Registration at ITU-R” by Marta Bautista

Thanks for your attention !

How to protect VGOS in RRs?

VGOS uses broadband 2-14 GHz receivers for accurate delay measurements, but this range has allocations from many other radio services