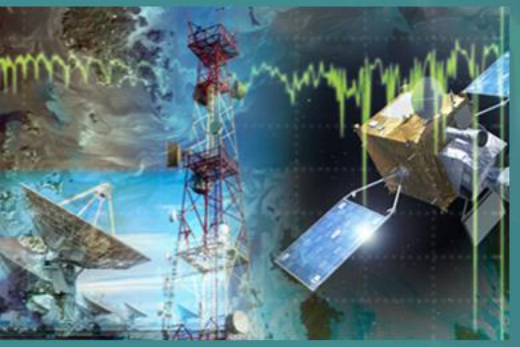

RFI 2022
14–18 FEBRUARY 2022
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Spectrum Allocations and Interference in Scientific Services: Outlook and Challenges

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ITU-R Study Group 7
Chairman

ECMWF

Overview

- Spectrum Allocations for Science Services
- Radio Frequency Interference
- Challenges to RFI Protection of Science Services
- ITU-R Study Group 7
- WRC-23 Agenda Items

Spectrum Allocations for Science Services

Science Services in ITU-R

Earth Exploration-Satellite Service (EESS)

- Command and Control of Satellites and Data transmission
- Active remote sensing
- Passive remote sensing

Space Research Service (SRS)

- Command and Control of Satellites and Data Transmission
- Active remote sensing
- Passive remote sensing

Radio Astronomy Service (RAS)

What is a passive sensor?

RR 1.183 - *passive sensor:* A measuring instrument in the *earth exploration-satellite service* or in the *space research service* by means of which information is obtained by reception of *radio waves* of natural origin.

- ***Passive sensors*** **measure the electromagnetic energy emitted and scattered by the Earth and the constituents of its atmosphere.**
- ***Spaceborne passive microwave sensors*** **provide the ability to obtain all-weather, day and night, global observations of the Earth and its atmosphere.**

EESS (passive) allocations in exclusive passive bands (RR No. 5.340)

1400-1427 MHz	50.2-50.4 GHz	164-167 GHz
2690-2700 MHz	52.6-54.25 GHz	182-185 GHz
10.68-10.7 GHz	86-92 GHz	190-191.8 GHz
15.35-15.4 GHz	100-102 GHz	200-209 GHz
23.6-24 GHz	109.5-111.8 GHz	226-231.5 GHz
31.3-31.5 GHz	114.25-116 GHz	250-252 GHz
31.5-31.8 GHz*	148.5-151.5 GHz	

* in Region 2 only

EESS (passive) allocations shared with active services

2655-2690 MHz*	36-37 GHz
4200-4400 MHz**	54.25-59.3 GHz
10.6-10.68 GHz	116-122.25 GHz
18.6-18.8 GHz	155.5-158.5 GHz
21.2-21.4 GHz	174.8-182 GHz
22.21-22.5 GHz	185-190 GHz
31.5-31.8 GHz#	235-238 GHz

* Secondary allocation

** Secondary allocation in RR 5.437

\# in Regions 1 & 3 only

EESS (passive) Use of Unallocated Bands

5.458 In the band 6425-7075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7075-7250 MHz, passive microwave sensor measurements are carried out. Administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the bands 6425-7075 MHz and 7075-7250 MHz.

Note: RR No. **5.458** is **NOT** an allocation!

What is radio astronomy?

RR 1.13 – *radio astronomy:* Astronomy based on the reception of *radio waves* of cosmic origin.

RR 1.58 – *radio astronomy service:* A service involving the use of *radio astronomy.*

RR 22.22-22.24 – Radio astronomy in the shielded zone of the Moon

ARTICLE 29 – Radio astronomy service

Radio astronomy allocations shared with active services

13.36-13.4 MHz	1610.6-1613.8 MHz	22.21-22.5 GHz	94-94.1 GHz*	151.5-158.5 GHz
25.55-25.67 MHz	1660-1670 MHz	31.5-31.8 GHz[3]	94.1-100 GHz	209-226 GHz
37.5-38.25 MHz*	1718.8-1722.2 MHz*	42.5-43.5 GHz	102-109.5 GHz	241-248 GHz
73-74.6 MHz	2655-2690 MHz	48.94-49.04 GHz	111.8-114.25 GHz	248-250 GHz*
150.05-153 MHz[1]	4800-4990 MHz*	76-77.5 GHz	123-130 GHz*	252-275 GHz
322-335.4 MHz	4990-5000 MHz	77.5-79 GHz*	130-134 GHz	
406.1-410 MHz	10.6-10.68 GHz	79-86 GHz	134-136 GHz*	
608-614 MHz[2]	14.47-14.5 GHz*	92-94 GHz	136-148.5 GHz	

* Secondary allocation

[1] Region 1, Australia, India

[2] Region 2, China, India

[3] Shared in Region 1 & 3

Radio Astronomy and footnote 5.149

5.149 In making assignments to stations of other services to which the bands:

13 360-13 410 kHz,	1660-1670 MHz,	10.6-10.68 GHz,	48.94-49.04 GHz,	151.5-158.5 GHz,
25 550-25 670 kHz,	1718.8-1722.2 MHz,	14.47-14.5 GHz,	76-86 GHz,	168.59-168.93 GHz,
37.5-38.25 MHz,	2655-2690 MHz,	22.01-22.21 GHz,	92-94 GHz,	171.11-171.45 GHz,
73-74.6 MHz in Regions 1 & 3,	3260-3267 MHz,	22.21-22.5 GHz,	94.1-100 GHz,	172.31-172.65 GHz,
150.05-153 MHz in Region 1,	3332-3339 MHz,	22.81-22.86 GHz,	102-109.5 GHz,	173.52-173.85 GHz,
322-328.6 MHz,	3345.8-3352.5 MHz,	23.07-23.12 GHz,	111.8-114.25 GHz,	195.75-196.15 GHz,
406.1-410 MHz,	4825-4835 MHz,	31.2-31.3 GHz,	128.33-128.59 GHz,	209-226 GHz,
608-614 MHz in Regions 1 & 3,	4950-4990 MHz,	31.5-31.8 GHz in Regions 1 & 3,	129.23-129.49 GHz,	241-250 GHz,
1330-1400 MHz,	4990-5000 MHz	36.43-36.5 GHz,	130-134 GHz,	252-275 GHz
1610.6-1613.8 MHz,	6650-6675.2 MHz,	42.5-43.5 GHz,	136-148.5 GHz,	

are allocated, 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 (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

What is an active sensor?

RR 1.182 *active sensor*: A measuring instrument in the *earth exploration-satellite service* or in the *space research service* by means of which information is obtained by transmission and reception of radio waves.

- ***Active sensors*** **illuminate the object under observation and respond to the reflected energy.**
- ***Spaceborne active microwave sensors*** **comprise five basic types:**
  - **Scatterometers**
  - **Altimeters**
  - **Imagers (Synthetic Aperture Radars)**
  - **Precipitation Radars**
  - **Cloud Profile Radars**

EESS (active) allocations

432-438 MHz*	13.25-13.75 GHz
1215-1300 MHz	17.2-17.3 GHz
3100-3300 MHz*	24.05-24.25 GHz*
5250-5570 MHz	35.5-36 GHz
8550-8650 MHz	78-79 GHz**
9.5-9.8 GHz	94-94.1 GHz
9.8-9.9 GHz*	133.5-134 GHz
9.9-10.4 GHz	237.9-238 GHz***

* Secondary allocation

** Allocated by RR 5.560

*** Limited to Cloud Profile Radars by RR 5.563B

Radio Frequency Interference (RFI)

RFI to EESS Passive Sensors in Exclusive Passive Bands

- **Many frequency bands allocated to EESS passive sensors are in the exclusive passive bands listed in RR 5.340 where all emissions are prohibited**
  - **While this sounds wonderful on paper, in practice even passive sensors operating in exclusive passive bands can and do experience RFI**
    - **Most commonly RFI in exclusive passive bands is from out-of-band emissions from adjacent or nearby frequency bands where active radio services operate**
    - **Sometimes the RFI is from illegally operating transmitters**
    - **Sometimes the RFI is from malfunctioning radio equipment unknown to the equipment operator**

RFI to EESS Passive Sensors in Shared Bands

- **Unfortunately, many other frequency bands allocated to EESS passive sensors are shared with active radio services and will receive varying degrees of interference**
  - **Some interference is intermittent and/or not widespread; in these cases, some observations can still be made.**
  - **In other cases, interference is widespread and cannot be ignored or mitigated to a large extent**
  - **RFI environment for EESS passive sensing may only get worse due to increasing use of the radio spectrum**
- **In retrospect, allocations to EESS passive sensors in bands shared with active radio services causes inevitable RFI**

RFI Mitigation for Passive Sensors

- Passive spaceborne sensors are very sensitive instruments based on radio astronomy receivers
- Passive sensors have fields of view that are usually 100s – 1000s of square kilometers
  - Main source of RFI is from the aggregation of interference sources
- Mitigation of RFI to passive sensors is difficult to impossible
  - RFI above a certain level is easily recognizable as interference and data can be discarded; however, loss of data is not really mitigation of RFI
  - RFI above the sensor's measurement threshold but below the level of obvious RFI is more nefarious as the corrupted data is not recognized leading to erroneous results from its use

Passive Sensor RFI Mitigation Techniques

- To date, some passive sensing RFI mitigation techniques have been used in 1400-1427 MHz observations:
  - to identify a particular type of RFI (i.e., pulsed RFI from adjacent band radars) in NASA's SMAP mission
  - to geolocate RFI sources for reporting to regulatory authorities for enforcement actions by NASA's SMAP and ESA's SMOS missions
- Time-sharing of passive sensing bands has been postulated
  - In theory, if all transmitters were turned off when the passive sensor was in view and taking measurements, RFI would be mitigated
  - In practice, this concept would require a global database of all passive sensors in orbit at any time and real-time access by smart electronics controlling ALL of these transmitters.

RFI to Active Sensors

- Bands allocated to EESS active sensors are largely shared with terrestrial radar (i.e., pulsed) systems
- In most cases, the EESS (active) allocations operate on a non-interference basis with the terrestrial radars (i.e., the radars have priority over the EESS (active) systems)
- In general, EESS (active) systems, which are spaceborne pulsed radars operating in low Earth orbit, can share allocations with terrestrial pulsed radars
- While EESS (active) systems can experience RFI from very high-power terrestrial radars, this is not usually a major concern

RFI to Radio Astronomy

- Radio astronomy observatories are placed in isolated areas and/or Radio Quiet Zones in order to be able to make observations across the radio spectrum
- While some radio astronomy allocations are in the RR 5.340 bands, radio astronomers require access to far more spectrum than could ever be protected via allocation status
- Normal ground-based transmitters can generally be kept away from radio astronomy sites
- However, radio astronomy sites are most susceptible to RFI from airborne and spaceborne transmitters, including out-of-band emissions from these transmitters

Challenges to RFI Protection of Science Services

Regulatory Protection

- **Outside of RR 5.340, it is very difficult to provide regulatory protection for EESS passive sensors or the radio astronomy service and even RR 5.340 is not universally accepted**
  - **Meaning of "All emissions are prohibited" in RR 5.340 is debated by some regulators**
  - **Some countries permit low-power/non-licensed devices to operate in RR 5.340 bands**
- **Sharing of frequency bands is increasing at each World Radiocommunication Conference (WRC) and pressure on bands included in RR 5.340 is also increasing**

Challenges to Protection

- Telecommunications engineers and regulators do not understand the operations and sensitivity of EESS passive sensors or radio astronomy receivers and constantly question the protection criteria used
- Protection criteria for these passive services is often labeled as “overly protective”
- As the growth in mobile broadband has accelerated in the last decade, the insatiable desire for more spectrum has grown as well
- Areas of the radio spectrum that were previously used predominantly by the science services (i.e., ~20-100 GHz) are now of increasing interest to mobile broadband and satellite communications

Challenges to Protection (continued)

- **Millimeter-wave spectrum (~> 100 GHz) is also seeing growing interest including the possibility of operating in RR 5.340 bands**
- **Radio spectrum is now valued as a commodity and is being auctioned to telecommunication companies for their exclusive use**

USA Auction	Net Winning Bids (US$)
Advanced Wireless Services (AWS-3)	41.33 Billion
Spectrum Frontiers (24 GHz)	2.02 Billion
Spectrum Frontiers (37 GHz, 39 GHz, 47 GHz)	7.56 Billion
3.5 GHz band	4.54 Billion
3.7 GHz band	81.11 Billion
600 MHz band	19.32 Billion

Reporting RFI

- Historically, space systems have not reported RFI to the ITU-R very often
  - This led to erroneous assertions that the space services, including EESS and SRS, do not experience any significant RFI
- In response to this problem, the ITU-R has developed the Satellite Interference Reporting and Resolution System (SIRRS) which is an online tool for reporting RFI to satellite systems
- Through important work on passive sensor RFI that began in the Space Frequency Coordination Group and in ITU-R Study Group 7, it is now possible to report RFI to EESS passive sensors

ITU-R Study Group 7

Study Group 7
"Science Services"

Working Party 7A (WP 7A) - Time signals and frequency standard emissions

- Chairman: Joseph Achkar
- TF Series of documentation

Working Party 7B (WP 7B) - Space radiocommunication applications

- Chairman: Catherine Sham
- SA Series of documentation

Working Party 7C (WP 7C) - Remote sensing systems

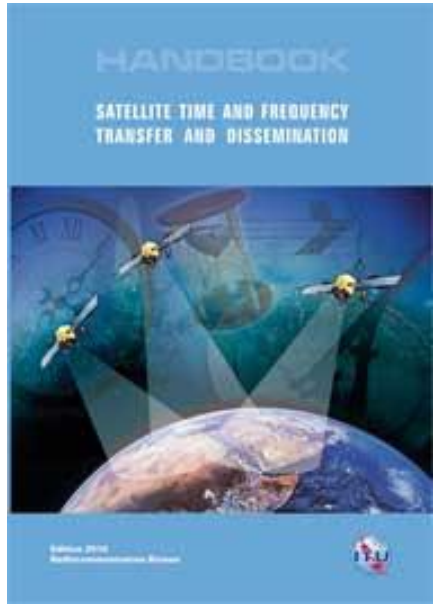
- Chairman: Markus Dreis
- RS Series of documentation

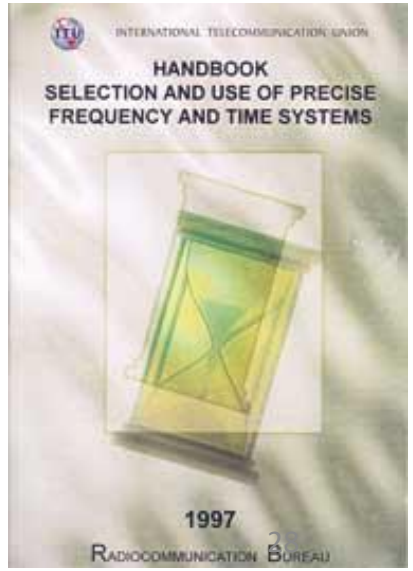
Working Party 7D (WP 7D) - Radio astronomy

- Chairman: Tasso Tzioumis
- RA Series of documentation

WP 7A Topics

- Work continues on a Report concerning the "Content and structure of time signals…" in response to Resolution 655 (Rev. WRC-15) which deals with Coordinated Universal Time (UTC) and the "leap second"
- A Memorandum of Understanding (MOU) between ITU-R and the International Bureau of Weights and Measures (BIPM) completed 30-June-2020
- Two Handbooks
  - A new revision to the Handbook on "Selection and use of precise frequency and time systems", previously published in 1997.
  - "Satellite Time and Frequency Transfer and Dissemination" (2010)





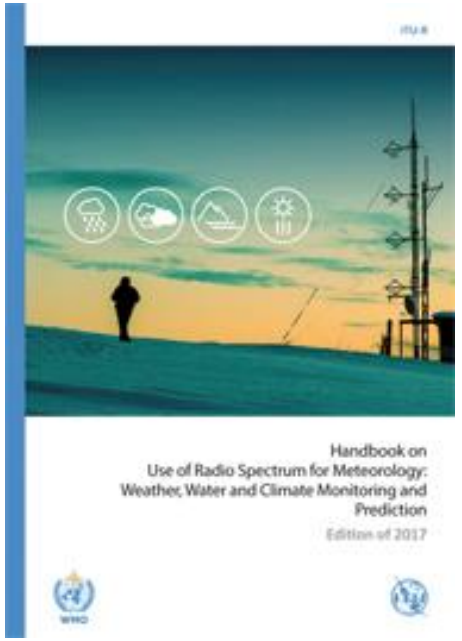
WP 7B Topics

- Protection of space operation, space research, Earth exploration-satellite, and meteorological-satellite services for both the spacecraft and the earth stations which support them.
- Two current Handbooks
  - Space Research Communications (rev 2014)
  - Earth Exploration-Satellite Service (2011)

    (Jointly with WP 7C)

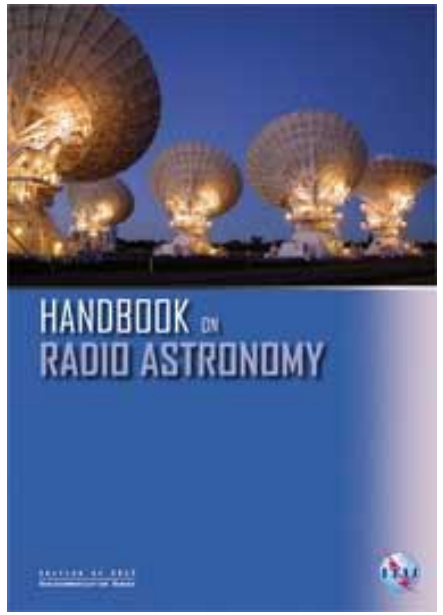
WP 7C Topics

- **Protection of active and passive remote sensors operating in the Earth exploration-satellite service and systems of the meterological-aids (MetAids) service, as well as sensors operating in the space research service, including planetary sensors**
- **Two current Handbooks**
  - **Earth Exploration-Satellite Service (2011)**
    (Jointly with WP 7B)
  - **Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction (2017)**
    (Joint publication of ITU and WMO)



WP 7D Topics

- Protection of radio astronomy and radar astronomy sensors, both Earth-based and space-based, including space very long baseline interferometry (VLBI)
- As radio astronomers observe the entire radio spectrum, WP 7D has an interest in a large number of WRC-23 Agenda items
- New work on the VLBI Global Observing System (VGOS)
- Continuing work on Radio Quiet Zones (RQZ)
- Current Handbook
  - Radio Astronomy (rev 2013)



WRC-23 Agenda Items and Science Services

WRC-23 Agenda Items where Study Group 7 is Responsible

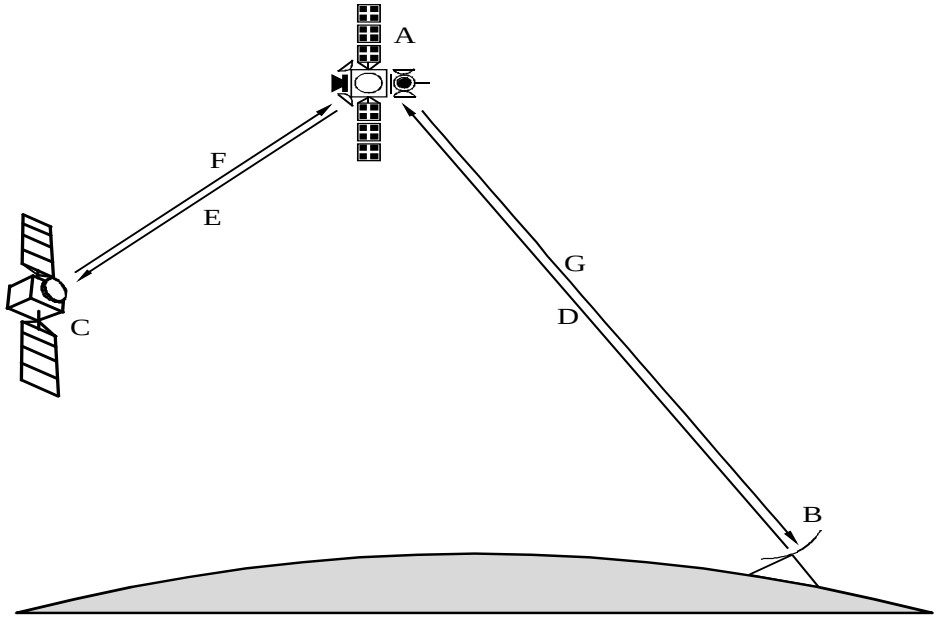
WRC-23 Agenda Item	Area of Interest	Responsibility
1.12 Radar Sounders around 45 MHz	• Space based active sensing to detect water tables below ground and ice thickness in polar regions	WP 7C
1.13 Possible primary upgrade of the space research service in 14.8-15.35 GHz	• Current space research links to data relay satellites are on a secondary basis and future systems also require use of this band	WP 7B (WP 7C & 7D to contribute)
1.14 Adjustments to EESS (passive) allocations in 231.5-252 GHz	• Envisioned Earth remote sensing operations are not properly aligned with scientific needs	WP 7C (WP 7D to contribute)
9.1 a) Space weather	• Obtaining regulatory recognition of space weather sensors	WP 7C
9.1 d) Protection of EESS (passive) in the frequency band 36-37 GHz	• Protection of EESS (passive) in the frequency band 36-37 GHz from OOB emissions from NGSO FSS	WP 7C

Select WRC-23 Agenda Items where Study Group 7 is Contributing

WRC-23 Agenda Item	Contributor	WRC-23 Agenda Item	Contributor
1.2 International Mobile Telecommunications in 3300-3400 MHz, 3600 3800 MHz, 6425-7025 MHz, 7025-7125 MHz and 10.0-10.5 GHz	WP 7B, 7C, 7D	**1.16** Earth Stations in Motion (ESIMS) in 17.7-18.6 GHz and 18.8-19.3 GHz and 19.7-20.2 GHz (space-to-Earth) and 27.5-29.1 GHz and 29.5-30 GHz (Earth-to-space) for NGSO Fixed-Satellite Service (FSS)	WP 7B, 7C
1.4 Use of High Altitude Platforms (HAPS) in bands below 2.7 GHz identified for IMT	WP 7B, 7C, 7D	**1.17** Satellite-to-satellite links in the frequency bands 11.7-12.7 GHz, 18.1-18.6 GHz, 18.8-20.2 GHz and 27.5-30 GHz	WP 7B, 7C
1.6 Radiocommunications for sub-orbital vehicles	WP 7B, 7D	**1.18** Mobile-Satellite Service (MSS) in 1695-1710 MHz, 2010-2025 MHz, 3300-3315 MHz and 3385-3400 MHz	WP 7B, 7C
1.10 Non-safety aeronautical mobile in 15.4-15.7 GHz and 22-22.21 GHz	WP 7C, 7D	**1.19** FSS (space-to-Earth) in 17.3-17.7 GHz in Region 2	WP 7C

WP 7B Agenda Item

- **WRC-23 Agenda Item 1.13 considers a possible upgrade of the secondary allocation to the space research service (SRS) in the frequency band 14.8-15.35 GHz**
- **Systems under consideration in the space research service may include:**
  - **Direct data downlinks from spacecraft to earth stations**
  - **Earth-to-space links to data relay satellites (DRS)**
  - **Space-to-space links from spacecraft to DRS**

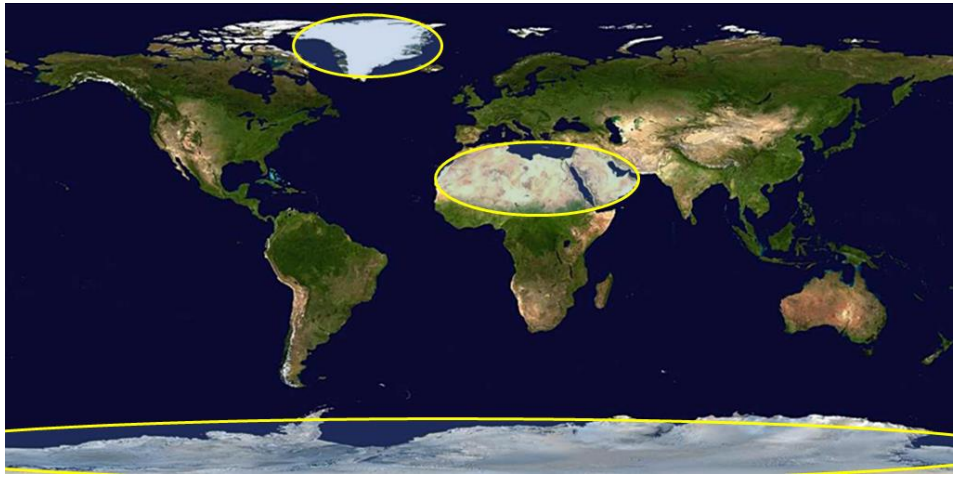


A: DRS
B: DRS earth station
C: DRS user spacecraft
D: forward feeder link
E: forward inter-orbit link (IOL)
F: return IOL
G: return feeder link

SA 1626-0

WP 7C Agenda Item

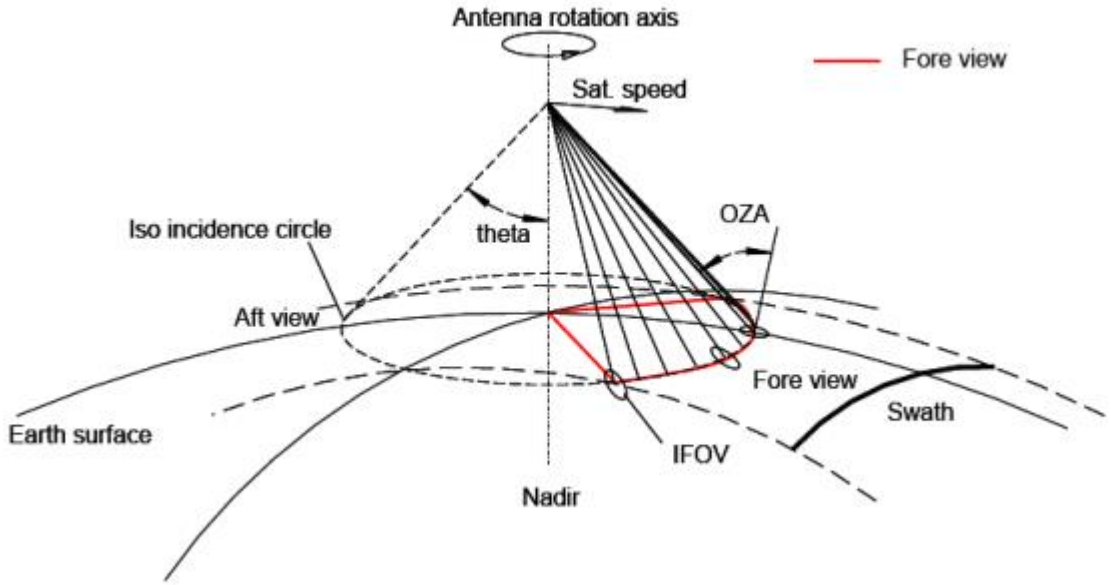
- **WRC-23 Agenda Item 1.12 considers a possible new secondary allocation to the Earth exploration-satellite (active) service for spaceborne radar sounders around 45 MHz**
- **Space based active remote sensing to detect water tables below ground and ice thickness in polar regions**
- **Propagation of radio waves at these frequencies is very complex**



Radar Sounder Possible Coverage Areas

WP 7C Agenda Item

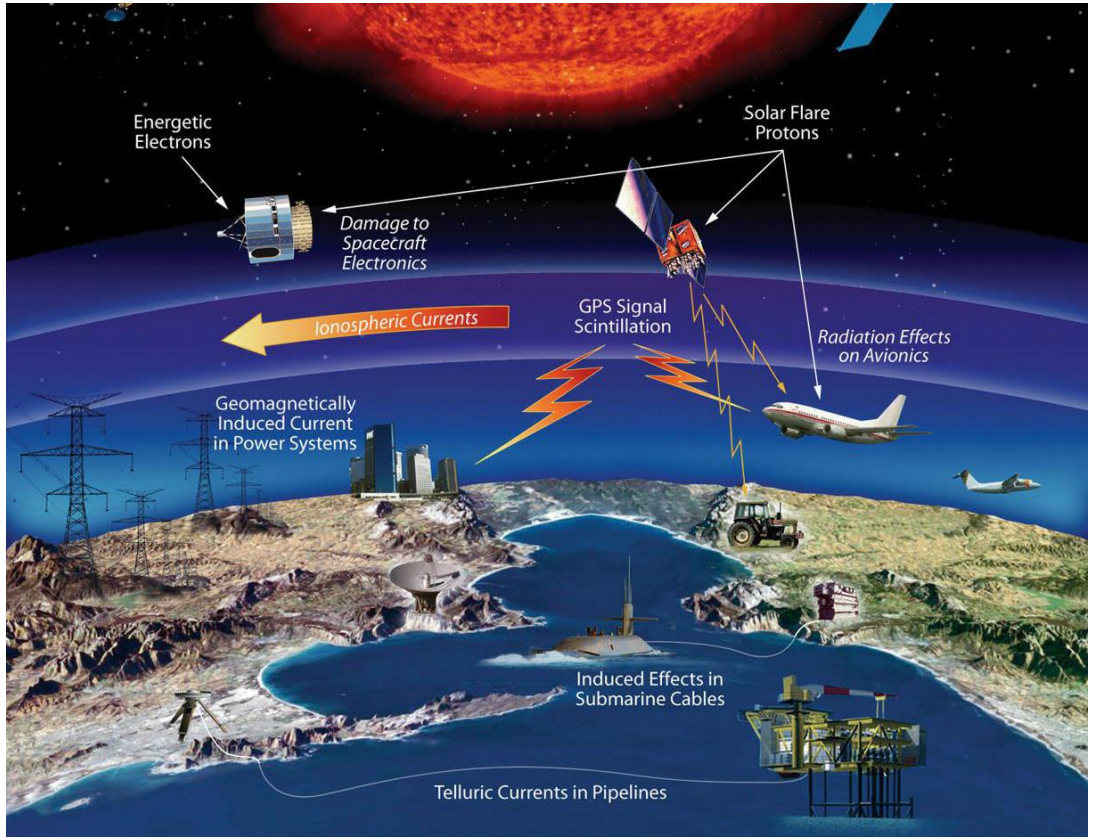
- **WRC-23 Agenda Item 1.14 considers reviewing and adjusting, if necessary, the allocations to EESS (passive) in the range 231.5-252 GHz**
- **Allocations were previously adjusted at WRC-2000 when not as much was known about the remote sensing observation requirements in this range**
- **New observation requirements for study of cloud ice have been the impetus for this work**



Geometry of Ice Cloud Imager instrument

WP 7C Agenda Item

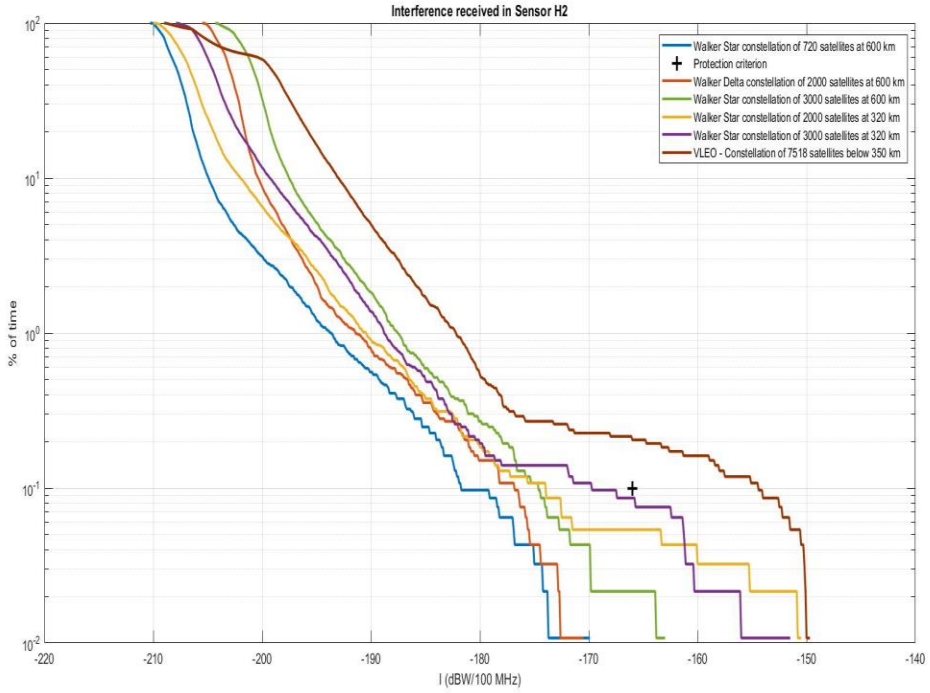
- **WRC-23 Agenda Item 9.1 topic a) considers the protection and possible recognition of radio spectrum-reliant space weather sensors used for global prediction and warnings**
- **Systems used for observations**
  - **Solar activity such as coronal mass ejections (CME)**
  - **Geomagnetic storms**
  - **Solar radiation**
  - **Solar winds**



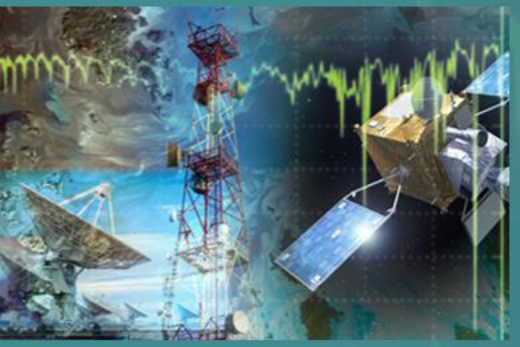
Possible Effects of Space Weather

WP 7C Agenda Item

- **WRC-23 Agenda Item 9.1 topic d) considers the protection of EESS (passive) sensors from out-of-band emissions of non-geostationary satellites operating in the adjacent FSS allocation**
- **Preliminary study indicated an OOB e.i.r.p. would be necessary**
- **In addition, interference into the cold calibration channel of the EESS (passive) sensor operating in the frequency band 36 37 GHz has not been studied**



Preliminary Study Results for Sensor H2



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Thank you!

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