Spectrum Management for the VGOS

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Abstract Spectrum management for the VLBI Global Observing System (VGOS) is an important task to keep radio frequency interference as absent as possible from observation sites. Protection can only be granted, if national and international authorities are made aware of the activities and operations at VLBI observing sites. To begin with spectrum management for the VGOS, it means two things: to be registered at the ITU-R as a Radio Astronomy Service site and try to get the requirements of VGOS into an official ITU-R document, so that further regulation actions can refer to an official document, e.g. for compatibility studies.

Keywords VGOS, geodetic VLBI, ITU-R, WP7D, RAS, RFI, ITU registration

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1 International Telecommunication Union - Radiocommunication Sector (ITU-R)

The need for coordination of international communication dates back to the 19th century when the precessor of the ITU, the International Telegraph Union was founded in 1865. Today, one of the three ITU-divisions covers radio communication, ITU-R. Its main mission is to facilitate seamless and interference free operation of radio communication services between member states. The coordination started among service providers with active transmitters.

Radio astronomy, as a passive receiver of cosmic noise, was recognized with its needs only later (during the 1930s, when historically radio astronomy was born). The Radio Regulations (RR) are the main references in spectrum management. In RR Article 4.6 it is recognized that *'the Radio Astronomy Service (RAS) can be regarded as a radio communication service within the ITU-R for the purpose of protecting its operation from harmful interference'*. This means, that Radio Astronomy is equally considered with its requirements as any other (active) service. This is very important for spectrum management for VLBI as a radio astronomy technique.

Fig. 1 The Radio Regulations are binding in international law and are the 'bible' in spectrum management. `https://www.itu.int/pub/R-REG-RR`

It is important to note, that the RR have the status of an international treaty among member states, binding in international law. Consequently, most national spectrum authorities practise national spectral use in a way adherent to the international RR. The RR are constantly updated by decisions at the World Radio Conferences, every four years (next in 2023).

The Radiocommunications Bureau is hosted within the ITU-R (ITU-R BR). It holds the *'Master International Frequency Register'* - or in short *'Master Register'* - which contains *frequency assignments* and a database of the *radiocommunication stations*. With the recognition of radio astronomy as a service, radiotelescope sites count as 'radiocommunication station' and can be registered. The RR Article 11.12 reads: *Any frequency to be used for reception by a particular radio astronomy station may be notified if it is desired that such data be included in the Master Register.*

2 The process of registration of a radio telescope at ITU-R

The registration of a radio telescope site is done in 3 steps (Fig. 2).

1. The radio telescope station owner notifies its national spectrum authority about its (passive) use of radio spectrum as a RAS site. The national spectrum authority cannot know on its own, that a new radio telescope had been built. Only the owner knows about it and has to take the first step.
2. The national spectrum authority is the only entity which can request to the international entity a recording of the notification from the RAS site on its territory. As this registration procedures does not happen very frequently, it might take time to push the issue forward.
3. Once the completed forms have reached the ITU-R BR in the correct format, the request from the country will be evaluated, the location and the spectral use (the receiver capabilities) will be verified. Upon approval, the RAS site is registered.

There are benefits of a registration. In the coordination of spectrum a *chronological priority* is applied. It counts the date of registration, not the date of radio telescope construction. Therefore, the earlier the telescope is registered the better for the site protection.

A registered RAS station has to be considered by compatibility studies by those planning new transmitters in its vicinity or in space. Missions installing new transmitters in space have to follow special procedures at ITU-R in order to get permission for spectral use. For the avoidance of harmful interference the Master Register is an important resource for the mission planning.

The international registration is also important for RAS sites located near borders which then require bilateral coordination.

If the RAS station employs a new receiver with previously uncovered (and therefore unregistered) spectral bands, the Master Register should be updated following the same 3 steps mentioned earlier.

As it can be seen in Table 1 the registration process has been mainly initiated by ITU-Region 1 stations (Europe-Africa), but not in Region 2 (Americas) and 3 (Asia-Australia). For the global network of VGOS stations it would be an advantage to argue on the international level with the global network instead of individual national stations. The authors recognize actions already taken to improve the registration situation and are aware that the process is slow and needs to be triggered by questioning for the actual status.

Fig. 2 Registration process. The initiative must come from the VLBI station.

Table 1 Registration of VGOS sites at ITU-R, status March 2021. The status *'completed'* means that the registration process has finished successfully; *'in progress'* means that the request for registration has been received, evaluation did not finish yet; *'empty space'* means that it is unclear whether any action had been taken or if the file got stuck at the national spectrum authority or at ITU-R BR; '–' no action taken yet (due to project planning phase).

ITU-Region	Country	Station	N-Latitude	E-Longitude	Reflector	ITU-Status
R1	Finland	Metsähovi	60°13'04.8"	24°23'38.4"	13.2	in progress
R1	France	Tahiti	-17°31'04.8"	-149°26'13.2"	project	–
R1	Germany	Wettzell North	49°08'38.4"	12°52'40.8"	13.2	in progress
R1	Germany	Wettzell South	49°08'34.8"	12°52'40.8"	13.2	completed
R1	Italy	Matera	40°38'56.4"	16°42'18.0"	project	–
R1	Norway	Ny Alesund North	78°56'34.8"	11°51'18.0"	13.2	
R1	Norway	Ny Alesund South	78°56'34.8"	11°51'18.0"	13.2	
R1	Portugal	Flores	39°28'01.2"	-31°13'37.2"	project	–
R1	Portugal	Santa Maria	36°59'07.2"	-25°07'33.4"	13.2	in progress
R1	Russia	Badary	51°46'12.0"	102°14'02.4"	13.2	in progress
R1	Russia	Svetloe	60°31'48.0"	29°46'48.0"	13.2	in progress
R1	Russia	Zelenchukskaya	43°47'16.8"	41°33'54.0"	13.2	in progress
R1	South Africa	Hartebeesthoek	-25°53'16.8"	27°41'09.6"	13.2	completed
R1	Spain	Gran Canaria	28°01'33.6"	-15°40'15.6"	project	–
R1	Spain	Yebes	40°31'22.8"	-03°05'16.8"	13.2	in progress
R1	Sweden	Onsala NE	57°23'38.4"	11°55'12.0"	13.2	completed
R1	Sweden	Onsala SW	57°23'34.8"	11°55'08.4"	13.2	completed
R2	Brazil	Fortaleza			project	–
R2	USA	GGAO	39°01'19.2"	-76°49'37.2"	12.0	
R2	USA	Kokee	22°07'33.6"	-159°39'54.0"	12.0	
R2	USA	McDonald	30°40'48.0"	-104°01'26.4"	12.0	
R2	USA	Westford	42°36'46.8"	-71°29'38.4"	12.0	
R3	Australia	Hobart	-42°48'21.6"	147°26'16.8"	12.0	
R3	Australia	Katherine	-14°22'30.0"	132°09'07.2"	12.0	
R3	Australia	Yarragadee	-29°02'49.2"	115°20'45.6"	12.0	
R3	China	Seshan13	31°05'56.4"	121°11'56.4"	13.0	
R3	China	Tianma13	31°05'27.6"	121°08'13.2"	13.0	
R3	China	Urumqi13	43°28'16.0"	87°10'40.0"	13.2	
R3	Japan	Ishioka	36°06'10.8"	140°05'20.4"	13.2	
R3	Thailand	Chiang Mai	18°51'56.0"	99°13'03.4"	project	–

3 Protection by Regulation

How does the ITU-R regulate the spectrum? The Master File contains all spectral bands and lists the allocated services to a given band, defined by a start and a stop frequency, e.g. 4990-5000 MHz. The RR distinguishes two categories and restrictions to the spectral bands by footnotes.

- **PRIMARY allocations** give legal protection from interference, but they are not necessarily exclusive if more than one service shares the same primary allocation. Services allocated to a band are written in capital letters.

- **Secondary allocations** do not provide protection from primary users in the same band. Secondary users shall not cause interference to primary users of that band, nor can they claim protection against detrimental interference from primary users of that band.
- **Footnotes** regulate special attention to specific bands used e.g. by RAS. Two footnotes are of major importance to RAS:
  - **Footnote 5.149** urges administrations to take all practical steps to protect RAS from harmful interference. It notes that emissions from spaceborne and airborne stations can be particularly serious sources of interference to RAS.
  - **Footnote 5.340** lists frequency bands in which *'all emissions are prohibited'*. This gives the maximum protection for the passive RAS.

The current RAS-spectra in the 2-14 GHz VGOS range are shown in Table 2. It can be seen in the table, that the entire RAS spectrum covers only 220.9 MHz, whereas VGOS observes in 32 bands of 32 MHz bandwidth each, resulting in a demand of a total 1024 MHz bandwidth. The allocated bandwidth for RAS is insufficient and its distribution is not optimized for geodetic VLBI. However, when arguing for more spectrum to be protected for VGOS some of the RAS-bands could be covered in order to have a stronger argument.

At this point, where the actual RAS spectrum is insufficient, one might ask, whether geodetic VLBI might fit better to other services which might own more spectrum. The answer is that most services are active and when using the targeted VGOS spectrum of 2-14 GHz interfering to the observation. The RR Article 1 Nos. 13 and 58 defines *radio astronomy* and *radio astronomy service* as being astronomy based on the **reception of cosmic radio waves**. Geodetic VLBI receives cosmic radio waves. Therefore, geodetic VLBI might trigger more spectrum to be made available to RAS at the VGOS sites. The advantage to treat geodetic VLBI as RAS is that the ITU-R Recommendation RA.769 on the *'Protection criteria used for radio astronomical measurements'* which contains the protection levels also for VLBI measurements apply and can be used immediately (instead of pushing something similar for geodetic VLBI through the World Radio Conference cycle).

4 How to achieve protection?

The European Committee on Radio Astronomy Frequencies (CRAF) has been tasked with RAS spectrum management in Europe resp. ITU-Region 1. A VGOS-Working Group has formed in which strategies and actions are being discussed. In 2020 this group started an initiative to raise *'Questions on VGOS'* within the Working Party 7D (Radio Astronomy) of the ITU-R. These questions had been supported by the following countries: Finland, France, Germany, Norway, Spain, Switzerland; and CRAF as an European entity. Recently, this document had been accepted by the representatives in WP7D and

1. What are the technical and operational characteristics of geodetic VLBI?
2. How does geodetic VLBI use radio spectrum to achieve the accuracy needed to fulfil its mission?

needs to be approved by the Study Group 7 (Science). If agreed, a study on these question will be drafted and may result in a Report or a Recommendation, which shall be finished within 2021/22. If of particular importance, the subject might enter as an Agenda Item (AI) to the World Radio Conference 2027. The US-delegation at WP7D provided a *'Working document towards a preliminary draft new Report ond Geodetic VLBI'* which is a base for the answers to the questions. Input to answer these questions is welcome!

5 Difficulties of Spectrum Management for VGOS

The task of spectrum management for RAS is not easy. If successful, nobody will recognize that RFI is missing! In addition to that, it is a permanent task because the modern world is wireless and spectrum is a limited resource. To satisfy the demand, models of bandwidth sharing in time and in space are already in practice. Just as the telecommunication industry increases its demands for a better service, the geodetic VLBI also requires more bandwidth to provide the accuracy required for geodetic tasks.

Several difficulties have been encountered with spectrum management for the VGOS:

Table 2 RAS Spectra in the VGOS-spectrum range of 2-14 GHz. The demand for bandwidth VGOS is about 5-times higher than what is allocated to RAS.

Frequency band	Bandwidth	Allocated	Footnotes
2655-2670 MHz	25 MHz	secondary	5.149, 5.208B
2670-2690 MHz	20 MHz	secondary	5.149, 5.208B
2690-2700 MHz	10 MHz	PRIMARY	5.340, 5.413, 5.208B
3260-3267 MHz	7 MHz		5.149
3332-3339 MHz	7 MHz		5.149
3345.8-3352.5 MHz	6.7 MHz		5.149
4825-4835 MHz	10 MHz	secondary	5.149
4990-5000 MHz	10 MHz	PRIMARY	5.149, 5.402, 5.443B
6650-6675.2 MHz	25.2 MHz		5.149, 5.458A
10600-10680 MHz	80 MHz	PRIMARY	
10680-10700 MHz	20 MHz	PRIMARY	5.340
Σ= 220.9 MHz			
VGOS is using 32-times 32 MHz bandwidth/channel, Σ= 1024 MHz.			

- The increased bandwidth of VGOS shall lead to the global 1 mm accuracy in the global geodetic reference frame. The first VGOS observations demonstrate its potential. However, the observed VGOS frequency bands are not yet fixed, but kept flexible. For spectrum management it will be essential that sooner rather than later the different configurations of the system are fixed. Each 32MHz channel has a start and stop frequency, which is the base for the RR. We might argue for footnotes for each 32 MHz subband at globally distributed VGOS sites. But then they should be fixed, not flexible.
- VGOS does not make use of the allocated RAS spectrum, but it is asking for more bands.
- If regulation provided a coordination zone around an observatory site for a given spectral band, then the spectral band must be used by the observatory.
- Existing VGOS infrastructure cannot be moved to more radio quiet zones (e.g. ALMA, SKA). For new VGOS stations it might be an option, however a certain infrastructure is necessary to comply with the timeliness of processing the results and finding experts to run the observatory.
- Commercialization of space will probably have an impact on VGOS through new missions (Starlink, OneWeb, SAR).
- Geodetic VLBI for Earth monitoring as a RAS method is widely unknown and in the spectrum world should not be confused with methods used by Earth Exploring Satellite Service (EESS).
- The lack of professional spectrum management for VGOS compared to companies who present their issues using dedicated staff (engineers and lawyers).

6 Conclusion

During the decade 2020-2030 the electro-magnetic spectrum will be exploited in a way, which was difficult to foresee when the first ideas of VGOS had been discussed and at a time when the smartphone was not yet invented. In addition to the widespread wireless communication, the commercialization of space will lead to thousands of transmitting satellites in the sky. Geodetic VLBI needs access to the cold sky to catch the cosmic rays from far and faint radio sources. The perspective of loosing observable spectrum for geodetic VLBI demands action.

The VGOS radio telescope stations should all be registered at ITU-R with their receiver capabilities, so that potential interferers could know in advance where the VGOS sites are.

Geodetic VLBI is essential to the Global Geodetic Reference Frame and is covered by UN-General Assembly Resolution 69/266. The consequence of the resolution has to be reflected in the spectrum management. The first steps are undertaken with Questions to ITU-R. The geodetic community has to focus on this issue in order to enable geodetic VLBI also in the future.

References

CRAF-Handbook for Radio Astronomy, 2005
https://craf.eu/wp-content/uploads/2015/02/CRAFhandbook3.pdf