The SKA, RFI and ITU Regulations

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1. How do radio astronomers interact with the ITU?

The Square Kilometer Array (SKA) is expected to cover the frequency range 60 MHz to 35 GHz, approximately (SKA Memo 45). The International Telecommunication Union (ITU), a specialized agency within the United Nation system, provides the regulatory framework that governs international usage of the radio spectrum in this range. It is therefore of interest to consider what regulatory mechanisms exist within the ITU to minimize the impact of radio frequency interference (RFI) on the telescope.

The ITU is divided into the Radiocommunication, Telecommunication Standardization and Telecommunication Development Sectors, referred to as the ITU-R, ITU-T and ITU-

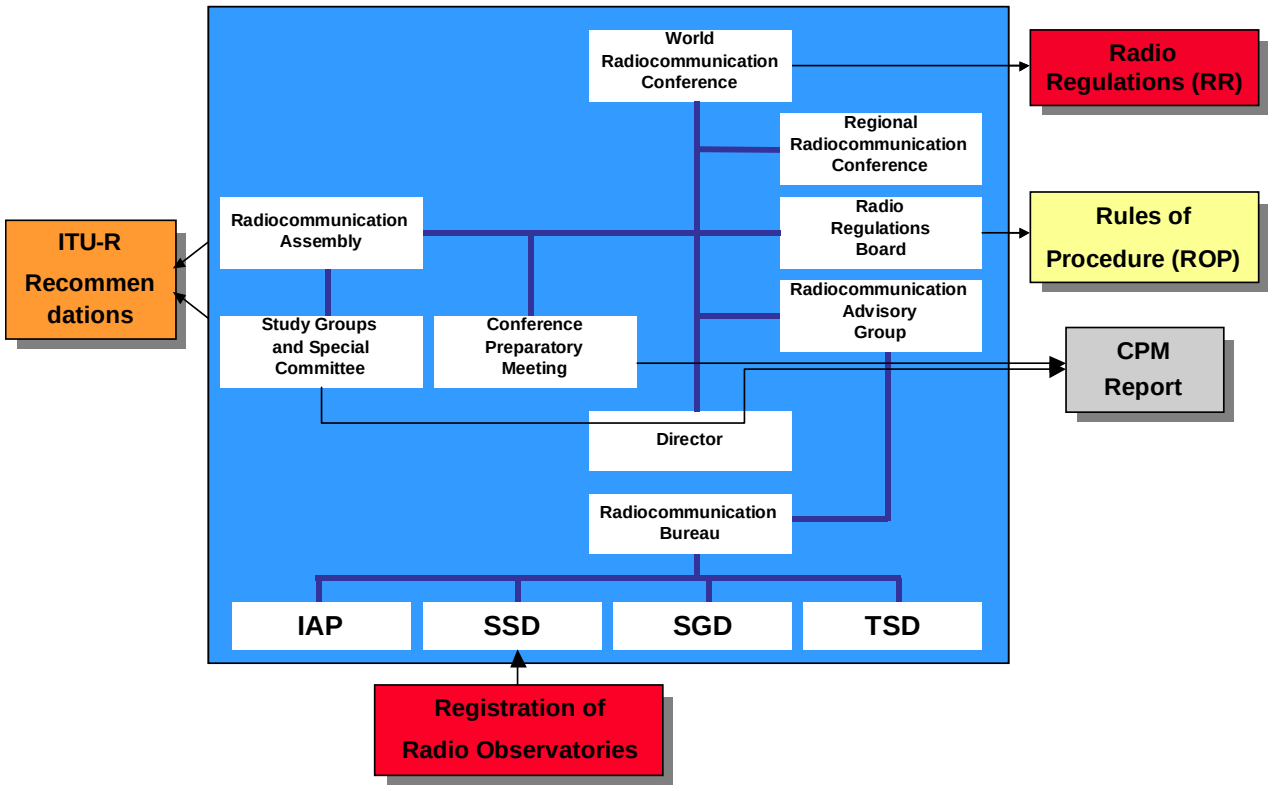


Figure 1. Radio Astronomers' Interaction with the ITU-R

D, respectively. Only the ITU-R, the stated aim of which is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum and the geostationary satellite orbit, is relevant to the activities of the SKA. The ways that radio astronomers may interact with the ITU-R are summarized in Fig. 1.

The Radiocommunication Bureau (RB) carries out the day-to-day work of the ITU-R. It is responsible for the registration of frequencies in the Master International Frequency Register (MIFR), the international coordination of satellite systems, and for providing technical and administrative support and assistance to ITU-R meetings, to mention just a few areas. The Space Services Department (SSD), one of four BR departments, is responsible for the registration of radio astronomy observatories.

World Radiocommunication Conferences (WRCs) are held periodically, about every three years. Their task is to review, and, if necessary, to revise the Radio Regulations (RR), the international treaty governing the use of the radio frequency spectrum. Revisions are made on the basis of an agenda determined by the ITU Council, which takes into account recommendations made by previous world radiocommunication conferences and input from Administrations. The Radiocommunication Assembly, a joint meeting of the ITU-R Study Groups (SGs) is held one week before the WRC. Its task is to approve recommendations and discuss problems that may affect more than one Study Group. The SGs consist of experts in the various radio services “involved with developing the technical, operational and procedural bases for efficient use of the radio spectrum and the geostationary-satellite orbit”. Seven are in existence at present; of which SG 7 (Science Services) deals with topics of importance to the science community, including radio astronomy. Issues under the purview of SG 7 range from the level of protection required for protection of radio astronomy or meteorological observations to efficient communications with satellites. The objective of SGs is to elaborate recommendations, and to provide input towards the Report of the Conference Preparatory Meeting (CPM). The CPM is held some six months before a WRC, with the objective of compiling a Report that is supposed to provide considerations on technical, operational and regulatory basis for all agenda items, in order to facilitate decisions at the WRC. SGs are divided into Working Parties (WPs) that deal with specific services or fields. WP 7D, one of four within SG 7, concerns itself with radio astronomy issues. WPs progress their work at meetings held twice a year.

Finally, the Radio Regulations Board (RRB), an elected body of 12 members, elaborates and approves the Rules of Procedure (RoPs) used by the BR in applying the provisions of the RR and registering frequency assignments by Member States. It also addresses matters referred to it by the BR that cannot be resolved through application of the RR, considers reports of unresolved interference investigations carried out by the BR at the request of administrations, and formulates recommendations and provides advice to WRCs. RRB members perform their duties on a part-time basis, normally meeting up to four times a year.

The Radio Regulations, as revised by successive WRCs constitute an international treaty and, once ratified by an Administration, they become binding. There are mechanisms,

however, by which Administrations may, and often do except themselves from specific provisions of the RR. CPM reports guide preparations for a WRC, and once the WRC is over have no further validity. Below the RR in hierarchy are the set of ITU-R Recommendations that, while not mandatory, are followed by most Administrations, most of the time. For radio astronomy, the most important of these is **Recommendation ITU-R RA.769**, which lists the thresholds levels of interference harmful (or, in ITU-speak, detrimental) to observations in various radio astronomy bands. Finally, RoPs, an interpretation of the RR, are highly changeable. They are internal rules, intended to facilitate and guide the work of the BR, but are not necessarily followed by others. Administrations sometimes disagree with RoPs and (on occasions successfully) exert pressure to change them. The hierarchy of the output of the various ITU-R bodies is illustrated in Fig. 2.

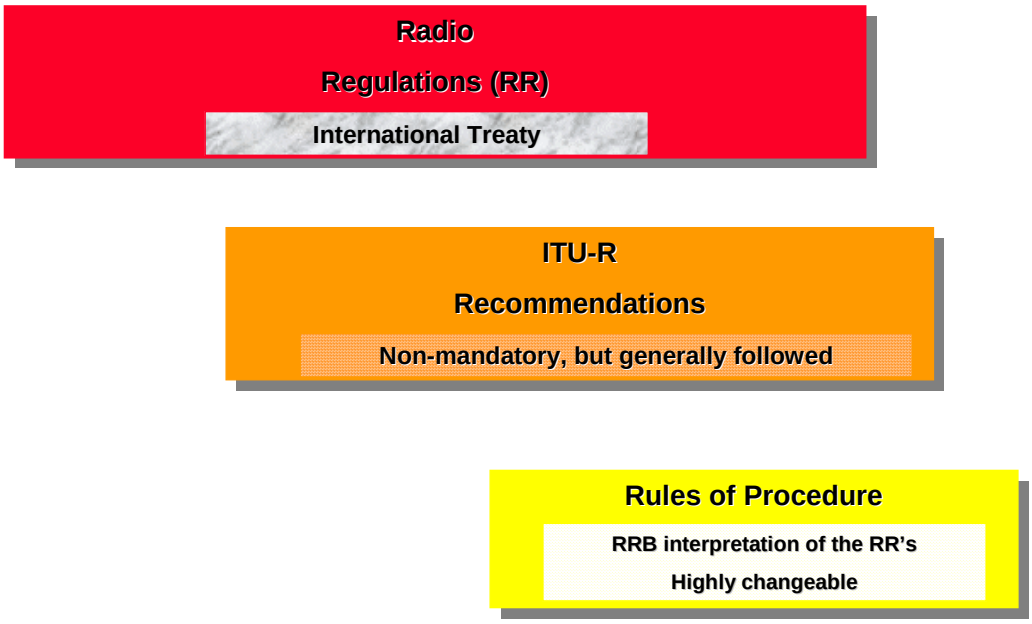


Fig. 2. Hierarchy of the output of various ITU-R bodies

In the rest of this paper, I discuss briefly the provisions of the RR that cover radio astronomy, and how they may apply to the SKA.

2. The Radio Regulations.

The Radio Regulations are the primary instrument by which the ITU manages the radio spectrum. **Figure 3** summarizes the provisions of the RR that reference radio astronomy directly.

The principle that underlies most national and international spectrum regulatory activities is that the various radio services are due protection only in the bands allocated to them,

according to their status. For the radio astronomy service, this is specifically spelled out in Article 29 of the RRs:

> **29.8** The status of the radio astronomy service in the various frequency bands is specified in the Table of Frequency Allocations (Article **5**). Administrations shall provide protection from interference to stations in the radio astronomy service in accordance with the status of this service in those bands (see also Nos. **4.6**, **22.22** to **22.24** and **22.25**).

Given the desire to observe over a broad range of the spectrum, could any of the provisions be applicable to the SKA? Possibly only **RR 11.12** that states that any frequency used by a radio telescope may be notified and recorded in the MIFR, but that the data will be recorded for information only, and without providing protection from interference. The RR treat radio astronomy as they would any other service, insofar as **RR 4.4** states that while a station can be assigned any frequency, it should neither cause nor claim protection from harmful interference. Nevertheless, registering the SKA once a site has been selected should be useful in providing protection from harmful interference in allocated bands, and possibly in non-allocated bands, by alerting potential transmitters to the presence of the telescope. Since many provisions of the RR apply on a first come, first served basis between services with equal rights, the data should be submitted as soon as a site is chosen! Registration will have to be carried out by the host Administration; the parameters required are found in **App. 4, Annex 2B** of the RR (Table of characteristics to be submitted for space and radio astronomy services). The parameters include the geographical coordinates of the telescope; the process does not contemplate registration of an instrument distributed over large areas. Outlying portions of the SKA may be registered separately (as are the various component dishes of the VLBA), but it is likely that some changes will be required to App. 4 to register the distributed inner core, that is still likely to be too extended to be registered as a single geographical location. Some thought should be given to this issue, since changes to the RR, including **App. 4**, can be made at WRCs only, and so a 2-3 year lead time may be required even before the site is chosen.

Radio Astronomy in the Radio Regulations

- **Art. 1 (Definitions): 1.7,1.13, 1.16, 1.58, 1.61 and 1.97**
  - Defines radio astronomy, radio astronomy service and radio astronomy station
    - Radio astronomy is defined as a *service*, but not a communication service, thus setting it apart from all other services
- **Art. 4 (Assignment and use of frequencies) 4.6**
    - For the purpose of resolving cases of harmful interference, the radio astronomy service shall be treated as a radiocommunication service. However, protection from services in other bands shall be afforded the radio astronomy service only to the extent that such services are afforded protection from each other
- **Art. 5 (Frequency allocations) 5.149, 5.208A, 5.225, 5.304, 5.305, 5.306, 5.307, 5.372, 5.376A, 5.379A, 5.385, 5.402, 5.413, 5.443, 5.443B, 5.458A, 5.511A, 5.551G, 5.555, 5.556, 5.562A, 5.562B, 5.562D, 5.565**
    - Spells out the status of the radio astronomy service in the various frequency bands allocated to it and specified in the Table of Frequency Allocations
- **Art. 11 (Notification and recording of frequency assignments) 11.12, 11.31.3**
    - RR 11.12 states that any frequency used by a radio astronomy station can be registered, but that in non-allocated bands the registration is only for information
- **Art. 20 (Service documents) 20.13**
    - Instructs the RB to publish the list of (registered) radio astronomy stations
- **Art. 22 (Space services) 22.22 - 22.25**
    - Prohibits emissions causing harmful interference to radio astronomy in the shielded Zone of the Moon, except for certain transmissions. It leaves the determination of what constitutes harmful inference to agreements between Administrations
- **Art. 29 (Radio Astronomy Service) 29.1 – 29.13**
    - Instructs Administrations to cooperate in protecting the radio astronomy service
    - Lists measures to be taken by radio astronomy stations to minimize their susceptibility to interference, and
    - Urges protection of the radio astronomy service in accordance with the RR and applicable recommendations
- **App. 3 (Table of maximum spurious emission power levels)**
- **App. 4, Annex 2A (Characteristics of satellite networks ‘ earth stations or radio astronomy stations)**
    - Lists the characteristics of radio astronomy stations required for registration and the compliance of satellite systems operating in some bands with pfd limits protecting radio astronomy in adjacent/nearby bands
- **App. 4, Annex 2B (Table of characteristics to be submitted for space and radio astronomy services)**

Figure 3. Radio Astronomy in the Radio Regulations

3. ITU-R Recommendations.

ITU-R Study Groups maintain their own set of recommendations; those in the Radio Astronomy series, maintained by WP 7D are listed in **Table 1**. It is obvious that only a few are in any way relevant to the SKA. Other study groups also have recommendations on sharing with radio astronomy or that may be relevant to radio astronomy, e.g. SG 1, that deals with general spectrum management issues that affect various services, maintains **ITU-R Recommendation SM.1542** on Protection of Passive Services from Unwanted Emissions.

Number	Title
Rec. ITU-R RA.314	Preferred Frequency Bands for Radioastronomical Measurements
Rec. ITU-R RA.1031	Protection of the Radioastronomy Service in Frequency Bands Shared with Other Services
Rec. ITU-R RA.517	Protection of the Radioastronomy Service from Transmitters in Adjacent Bands
Rec. ITU-R RA.611	Protection of the Radioastronomy Service from Spurious Emissions
Rec. ITU-R RA.1237	Protection of the Radioastronomy Service from Unwanted Emissions Resulting from Applications of Wideband Digital Modulation
Rec. ITU-R RA.769	Protection Criteria Used for Radioastronomical Measurements
Rec. ITU-R RA.1272	Protection of Radioastronomy Measurements Above 60 GHz from Ground Based Interference
Rec. ITU-R RA.479	Protection of Frequencies for Radioastronomical Measurements in the Shielded Zone of the Moon.
Rec. ITU-R RA.1417	A Radio-quiet Zone in the Vicinity of the L2 sun-Earth Lagrange Point
Rec. ITU-R RA.1513	Levels of Data Loss Acceptable to Radio Astronomy Observations and Percentage-of-Time Criteria Resulting from Degradation by Interference for Frequency Bands Allocated to the Radio Astronomy Service on a Primary Basis
Rec. ITU-R RA.	Technical and Operational Characteristics of Ground-based Astronomy Systems for Use in Sharing Studies with Active Services Between 10 THz and 1 000 THz

Table 1.
Recommendations in the ITU-R RA Series

The principle that radio services are due protection only according to their allocation status also underlies the system of ITU-R recommendations. For example c*onsidering b)* of **ITU-R Recommendation RA.314,** that lists the preferred frequency bands for radioastronomical measurements, (that follows the list compiled by the Working Group on Radioastronomical Frequencies of Commission 40 of the IAU, revised at each IAU General Assembly) states that: “protection from interference on certain frequencies is essential to the advancement of radio astronomy and the associated measurements:” A similar considering is found in a number of other radio astronomy recommendations. For this reason, ITU-R recommendations are generally not directly applicable to the SKA and

its protection. Nevertheless, *considering*s d) and e) of **ITU-R Rec. RA.314-10** that state that:

> "astronomers also study spectral lines outside bands allocated to radioastronomy, as far as spectrum usage by other services allows" and
>
> "that account should be taken of the Doppler shifts of the lines, resulting of the motion of the sources"

provide some opening for consideration of observations outside allocated bands. Even more to the point, the same Recommendation also
recommends

> "3. that administrations be asked to provide assistance in the coordination of experimental observations of spectral lines in bands not allocated to radioastronomy."

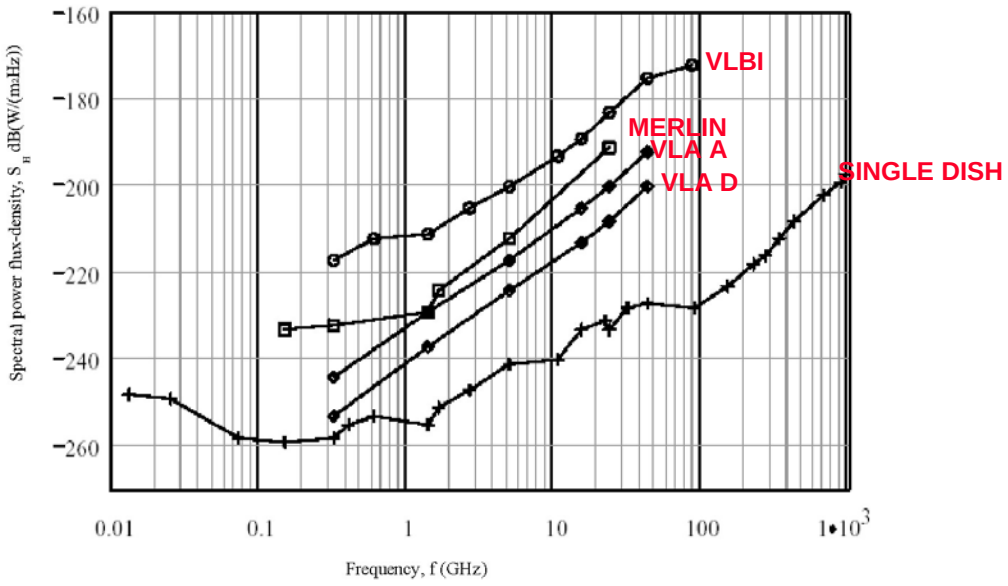
Conceivably, this recommendation could be invoked for protection of the SKA outside allocated radio astronomy bands.

The most basic and fundamental radio astronomy recommendation is **ITU-Rec. RA.769-2** that gives the protection criteria for radio astronomy observations. Tables 1 and 2 give the detrimental interference levels for continuum and spectral line observations for single dish telescopes, under certain assumptions, Table 3 gives the detrimental levels for VLBI observations. It has been assumed that the detrimental levels in Table 1 in **ITU-Rec. RA.769-2** are applicable directly to the SKA, and e.g. that they should be used as a criterion for site selection (e.g. SKA Memo 37) It is sometimes also said that since the SKA is expected to be several orders of magnitude more sensitive than current radio telescopes, it will require more stringent levels of protection as well.

The sensitivity of a radio telescope (see, e.g. Eq. 3 in **Recommendation ITU-R RA.769-2)** depends on the system temperature and the bandwidth and integration time of the observation, but not on its collecting area. Moreover, the detrimental interference levels in Tables 1 and 2 of Rec**.** RA.769 were computed for a single dish telescope, under the assumption that interference is received from a stationary interferor in 0 dBi sidelobes. For a closely spaced array the interference caused by such a source is reduced, due to the frequency of the fringe oscillations that are observed when the outputs of two antennas are combined. This effect may reduce an interferometers' susceptibility to interference by over 20 dB. Decorrelation of broadband signals may further reduce interfering signals, depending on the declination of the source observed. A detailed discussion of both of these effects is given in Thompson et al. (1986). Antennas within VLBI arrays will see interfering signals as totally decorrelated unless they originate in satellite transmissions. Consequently, detrimental interference levels for VLBI observations are over 40 dB less stringent than those for single dish telescopes. **Figure 3,** taken from the ITU Handbook on Radio Astronomy, shows the detrimental interference levels for a single dish, total power telescope, the A and D configurations of the VLA, the MERLIN array, and VLBI. Most of the SKA configurations currently envisioned consist of a relatively compact core

and an outer component of thousands of kilometers radius. SKA Memo 45, (SKA Science Requirements: Version 2) states that 20 % of the collecting area should be within a 1 km diameter radius, 50% within a 5 km diameter radius, and 75% within a 150 km diameter radius. One could therefore expect the detrimental interference levels for the SKA core to fall within the area between the curves for the A configuration of the VLA and MERLIN for the core on **Fig. 3,** while outlying stations may be protected at the VLBI levels. Thus, in spite of its much greater sensitivity the SKA may be expected to be ~ 15- 20 dB less sensitive to interference than, say the Arecibo or Green Bank telescopes. The precise levels required for protection of the SKA will depend on the configuration that is selected. Once a configuration has been selected, it would be desirable to compute precise protection criteria for it, and incorporate the results into an ITU-R Recommendation specific to the SKA.

Detrimental thresholds of interference for continuum observations with several types of radio telescope systems



Threshold values of power flux density for continuum observations. Crosses are for total-power observations. Diamonds are for the VLA, lower curve for configuration D (longest antenna spacing 1 km) and upper curve for configuration A (longest antenna spacing 36 km). Squares are for the MERLIN array and open circles for VLBI.

Figure 3

4. Radio Quiet Zones

There are no International Radio Quiet Zones in existence, and some countries are adamantly opposed to establishing one. National radio quiet zones protect some observatories, e.g the US National Radio Quiet Zone (NRQZ) that protects the GBT in

West Viginia and Virginia is possibly the most extensive such zone in existence, covering some 34,000 square kilometers. Even so, it is nowhere close to the extension that would be required to protect the outlying stations of the SKA, at some 3000 km from the core. Fortunately, a quiet zone is not needed to protect these outlying components. Even for a national quiet zone that would protect the SKA, thought must be given to how it would be set up. Existing quiet zones, e.g the US NRQZ protect single dish telescopes not distributed arrays such as the SKA. At the NRQZ, the power density (due to fixed transmitters within the zone) is required to stay below a certain threshold level at the focal point of the GBT. To establish a quiet zone for the benefit of a distributed array, with a criterion appropriate to cover a 1/5/150 km diameter area could be far more challenging and vastly more complicated, even if only fixed terrestrial transmitters, the only ones covered by the US NRQZ are included. To include mobile transmitters presents much more difficulty (how does one account for them, since by their nature they could be anywhere in a country, continent, etc). Transmitters on aircraft would further complicate the picture, as they would need to be restricted over larger areas than fixed transmitters. Finally, satellites would need to be restricted over the horizon (and possibly beyond it). These difficulties are only hinted at here, detailed consideration should be given to what would kind of a quiet zone would be desired for the benefit of the SKA, and how could it be set up.

5. Summary

- Few of the existing ITU Regulations cover the SKA

- Once the site and a configuration have been selected, it will be advantageous to register the SKA with the ITU, as soon as possible. Even this relatively modest step may require changes in the RR and these should be thought about as soon as possible

-A specific ITU-R Recommendation along the lines of Recommendation ITU-R RA.769 should be drafted to cover the SKA once a configuration is selected, taking into account the characteristics of the telescope

- Consideration should be given to the kind of Quiet Zone that may be needed for the SKA, and to how it might be set up. It is difficult to do so before the telescope is defined

-By virtue of being a distributed array, the SKA may be considerably more resistant to interference than total power telescopes, in spite of its high sensitivity

References:

-SKA Science Requirements: Version 2, Jones, D. L., Memo 45, SKA Memo Series
-RFI Measurement Protocol for Candidate SKA Sites. Ambrosini, R., Beresford, R., Boonstra, A. -J.Ellingson, S. Tapping, K , Memo 35, SKA Memo Series
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